GRAEBENER

Made in Germany

Your Production Technology for Electrolyzer and Fuel Cell Components

From engineering and production laboratory up to the individual production line.

Our Declared Goal:

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

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 family-owned company in its fourth generation, we develop and manufacture customized special machines worldwide for the core markets of hydrogen, automotive, hydroforming, pipes, wind towers and vessels as well as shipbuilding.

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. We know that what we create must also work for our customers in the future.

With regard to the stability of our customer relationships, it is therefore 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.

Our view:
Focused on the future.

We have long been convinced that the future belongs to hydrogen - and that both the fuel cell and the electrolyzer are key technologies for an ecologically and economically sensible energy generation in future.

This is why we are one of the first companies to have been involved in research and development of production processes and machines of electrolyzer and fuel cell components, such as metallic (bipolar) plates, for more than 20 years.

Our goal:

Developing the quality standard for future-oriented processes and machines which help you to produce components for hydrogen-based energy generation, precisely tailored, integrable, scalable and thus economically efficient.

Our Solutions:

For an Economical and Sustainable Production of Electrolysis and Fuel Cell Components

From the individual single machine up to the scalable production line - with the decisive plus of our engineering and production laboratory

Our Graebener® machines for the production of fuel cell and electrolysis components are ideally suited for manufacturing projects with clearly defined goals.
Do you have a more complex project instead? We would be pleased to develop a customized and scalable production line for your serial production.

Thanks to the production parameters determined in our production laboratory, you will receive solutions perfectly tailored to your needs including the necessary tools for the production of high-quality components.

You have a plate design and are not sure whether it can be produced? No problem. Together with you, we will analyze and optimize it regarding manufacturability. Subsequently, we are even able to manufacture it in our production laboratory.

SINGLE MACHINES

Stack Presses
Forming Presses
Laser Cutting Machines
Laser Welding Machines
Straightening Machines

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PRODUCTION LINES

Production Lines for Metallic Single or Bipolar Plates

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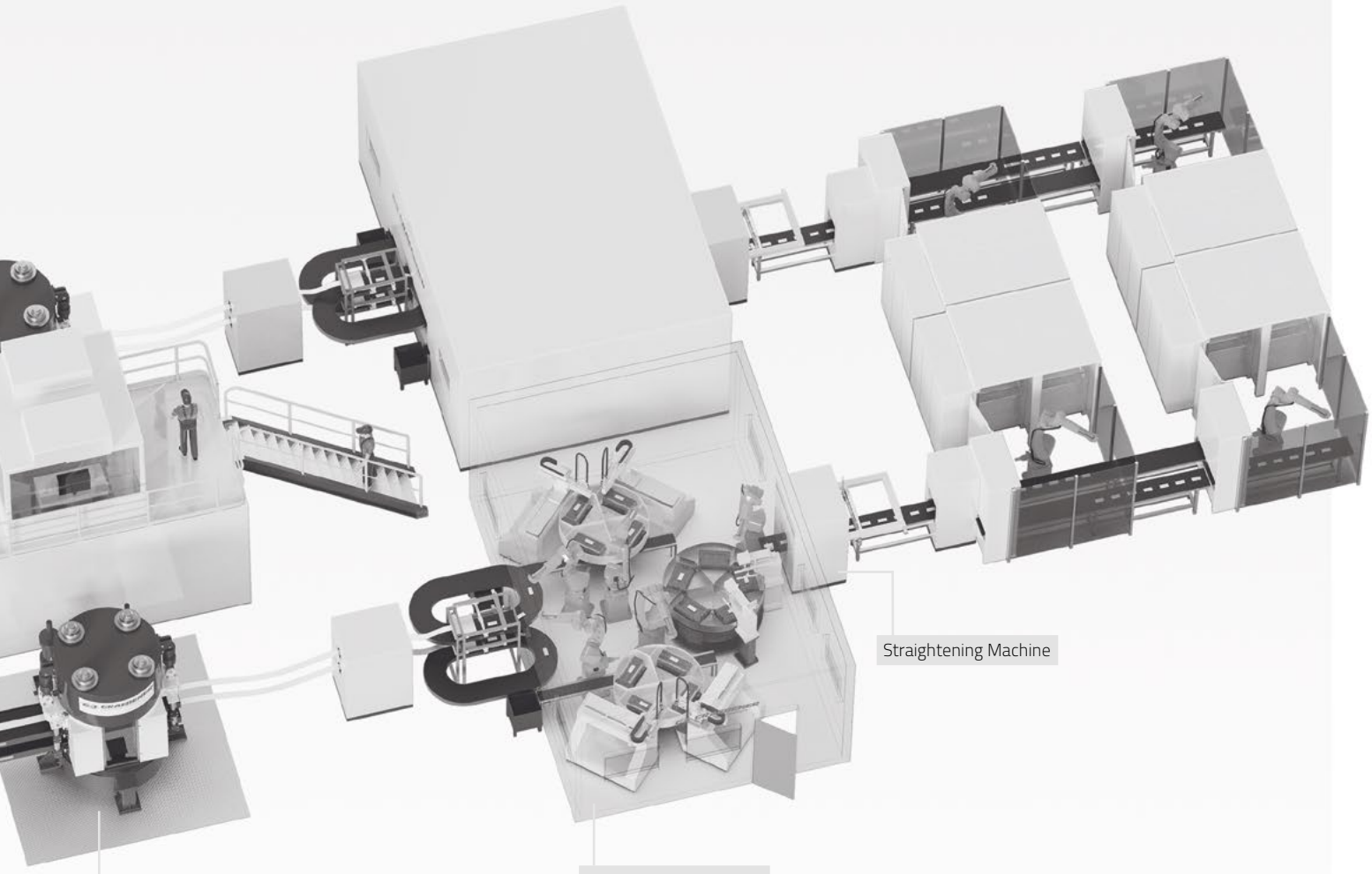
MORE THAN 20 YEARS OF EXPERIENCE

We have been involved in various research projects over the years and have implemented a variety of customer projects.
That we are good at what we do is not only proven by our renowned references, network and research partners, but also - quite pragmatically - by more than 100 bipolar plate designs implemented and over 125.000 plates manufactured on our machines.



Your plus - for certainty from the very beginning

Expansion into new markets always bears certain risks and uncertainties. In mechanical and plant engineering in general, as investments only pay off through capacity utilization and running time, and in the hydrogen industry in particular.

For exactly this reason, we have decided not only to develop production lines, but also to support our customers from the very beginning with both a holistic engineering and services of our production laboratory.

ENGINEERING & PRODUCTION LABORATORY

Plate Design Analysis
Process Development
Prototyping

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The Technology to Support Stack Testing:

Stack Presses

Our Graebener® stack presses support the technical testing of pre-assembled stacks.

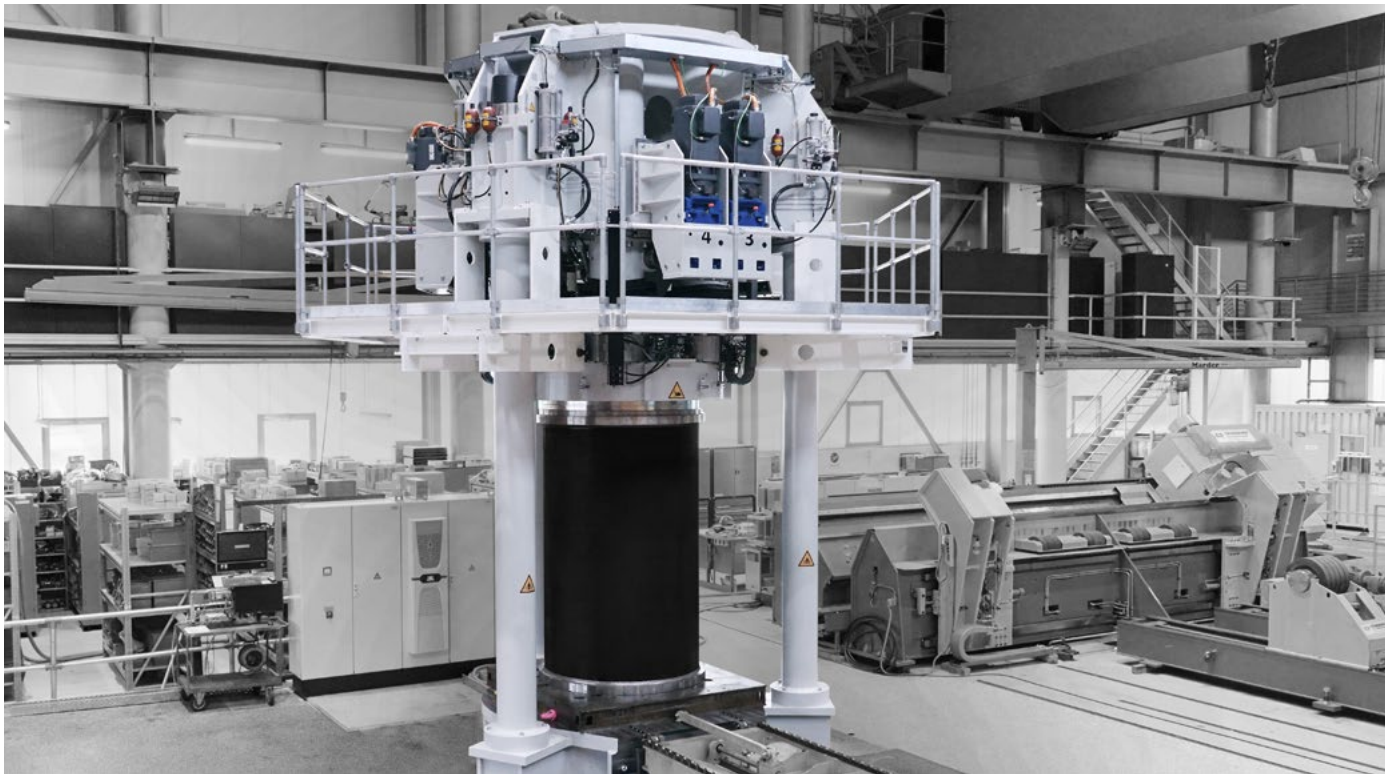
The pre-assembled stack, which consists of a large number of plates, is first moved into the machine and then compressed to a defined height until a certain pressure is reached within the stack. This pressure must then be maintained unchanged for several hours. At this time, the stack is subjected to all the necessary technical tests carried out by the customer and with the help of further procedures. These are necessary to confirm its full operability. As soon as the tests are completed, the stack is finally assembled with tie rods or tension straps and the finished stack is removed.

All our stack presses are customized and designed for specific applications. Therefore, our machines can be used **for fuel cell stacks as well as for electrolysis stacks**.

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

Graebener® stack press for electrolyzers



The Technology for Forming Metallic (Bipolar) Plates:

Forming Presses

Our customized Graebener® forming presses can be used for serial production of metal (bipolar) plates for a wide range of fuel cell and electrolysis applications - in various sizes and material thicknesses and from a variety of materials (e.g. stainless steel, nickel, titanium; also pre-coated).

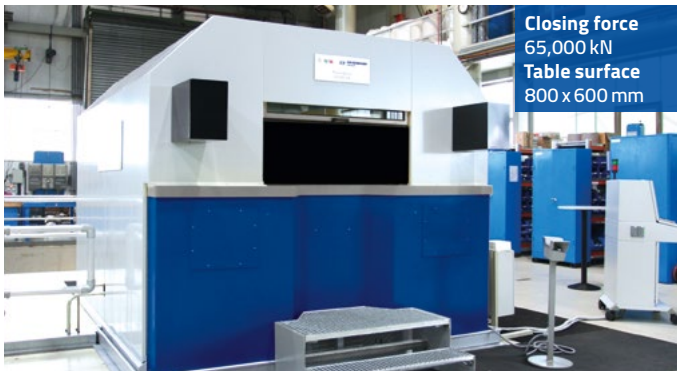
Special features

- **Hydraulic and hydroforming presses**
- Forming of thinnest **foils from 25 µm**
- Flexible adjustment of production parameters
- **Several plates per stroke** with Graebener® sandwich or multi-cavity tools
- Prototyping and small series production in our **in-house production laboratory** (closing forces 1,500 - 10,000 tons, table surfaces up to 6 x 2.2 m)

100% individuality

Our Graebener® machines 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.

Exemplary Graebener® forming presses for fuel cells and electrolyzers



Closing force
65,000 kN
Table surface
800 x 600 mm

Closing force
25,000 kN
Table surface
3,100 x 2,100 mm

Closing force
32,000 kN
Table surface
2 x 620 x 920 mm

Excursus: Hydroforming

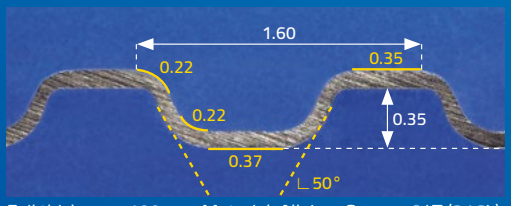
Complex geometries - highly precise and gentle

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. Since 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.

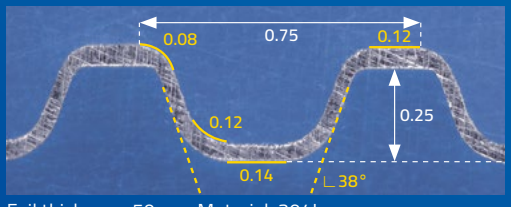
With so-called **external high-pressure forming**, extremely filigree structures can be realized in series using extremely thin **materials from 25 µm**. Since plate production for fuel cells and electrolyzers is all about **repeatable precision, attention to detail and high value**, hydroforming is the optimal process - and one of the quality features that make Graebener® your sustainable competitive edge.

Criteria	Graebener® hydroforming
Repeat accuracy in the process	Very high
Elasticity after forming	Highly elastic through gentle forming with integrated cooling
Wall thickness variation	Very homogeneous over the entire duct cross-section
Suitability for pre-coated materials	Ideal: no friction on the water side
Contact areas	Almost ideal shaping of the flat contact surfaces
Use of different material thicknesses in one tool	Flexible: different material thicknesses can be used per tool
Adaptation of the manufacturing parameters in the forming process	Flexible
Tool costs	Low: less wear and fewer tools
Number of tool stages	One

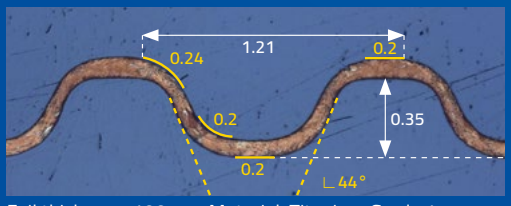
Exemplary Graebener® hydroforming plates



Foil thickness: 100 µm, Material: Alleima Sanergy® LT (316L)



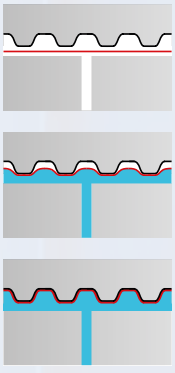
Foil thickness: 50 µm, Material: 304L



Foil thickness: 100 µm, Material: Titanium Grade 1

Technology by Graebener®

We have developed our Graebener® hydroforming press especially for the economic production of metallic plates for fuel cells and electrolyzers 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.



What is hydroforming?

Hydroforming resp. 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 — Metal foil — Active medium —

The Technology for More Precision:

Laser Cutting Machines

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. Further, the quality of the cutting edge has a significant influence on the quality of the final product. Therefore, special precision is required when cutting the plates.

At our Graebener® cutting machines with laser fusion cutting we use a process that achieves this level of accuracy and quality. And this is achieved without significant maintenance costs or tolerance problems due to tool wear.

Special features

- Combination of a **cartesian axis system and fiber laser** with the latest cutting optics
- **High cutting speeds** of up to 2 m/s
- **Extremely high cutting quality** with minimal burr formation and roughness
- Suitable for **2D and 3D cuts** (e.g. for the most filigree geometries in the port area of the plate)
- **Foil thickness from 25 µm up to massive plates** (for high-pressure electrolysis applications)
- **Highest positioning accuracy and repeatability**

- **Modular system**
  - Manual operation, partially automated or fully automated
  - including distance and collision monitoring
  - including scrap handling
  - including data monitoring and status monitoring
- **Customized process and clamping technology**

Laser cutting

100 µm plate, cut

The Technology for Shorter Cycle Times:

Laser Welding Machines

Not only do we form your plate for fuel cells or 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 for our Graebener® welding machines. Benefit from our many years of practical experience.

Special features

- Combination of the **the latest fiber laser and laser scanner technology**
- Achievement of **high speeds** (e.g. up to 0.8 m/s with stainless steel foils of 100 µm)
- Reliable welding in the channel structures thanks to **smallest focus diameters**
- Suitable for a **wide range of materials from 25 µm** (from stainless steels and titanium to pre-coated materials)
- **Highest positioning accuracy and repeatability**

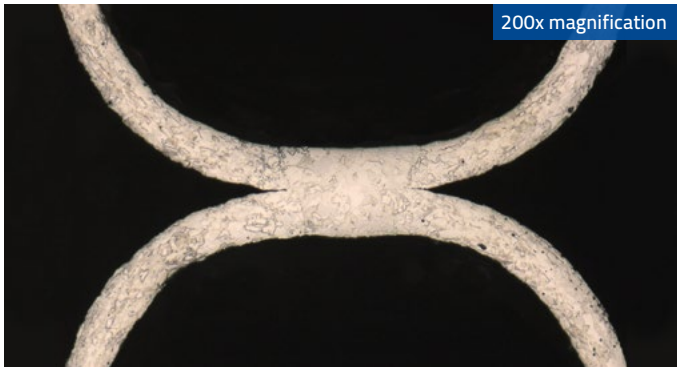
- **Modular system**
  - Manual operation, partially automated or fully automated
  - including process sensors
  - including inline process monitoring via camera
  - including multi-field system for large components
- **Customized process and clamping technology**
- **Ideal control of all process gases**

Prepared for the future

Take advantage of our production laboratory and our longstanding expertise to find solutions for your complex challenges. The generated process parameters can be directly transferred to your own series production systems.

Laser welding

50 µm bipolar plate, welded



The Technology for Shorter Cycle Times:

Straightening Machines

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

For the first time, our Graebener® straightening machines enable you to produce flat plates - a necessary requirement for both economical stack production as well as high performance and durability of the stacks.

Special features

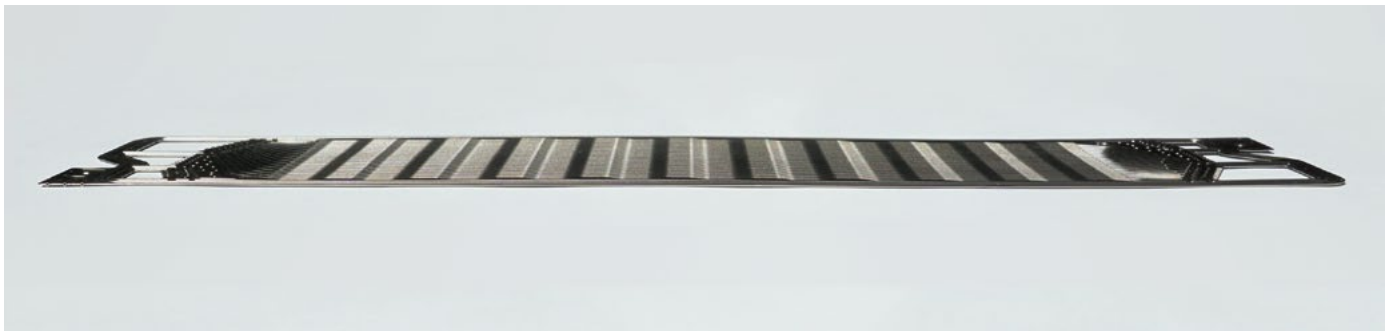
- **Contactless straightening**
  - no influence on the surface or a possible coating
  - no influence on the moulded geometry
- Suitable for **metallic single and bipolar plates, without geometrical restriction**

Flexibility and safety without compromise

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.

100 µm bipolar plate, not straightened

100 µm bipolar plate, straightened



The Technology for Scalable Series Production of (Bipolar) Plates:

Production Lines

As one of the few companies worldwide, we manufacture not only individual single machines for hydroforming, cutting welding and straightening. **For larger and more complex projects, we also develop tailor-made and scalable lines for your series production - from the coil to the finished single or bipolar plate.**

We know that there is no such thing as "the one" machine and that technologies and processes may change with market requirements. For this reason, we endeavor to respond as flexible as possible to present and future requirements of our customers.

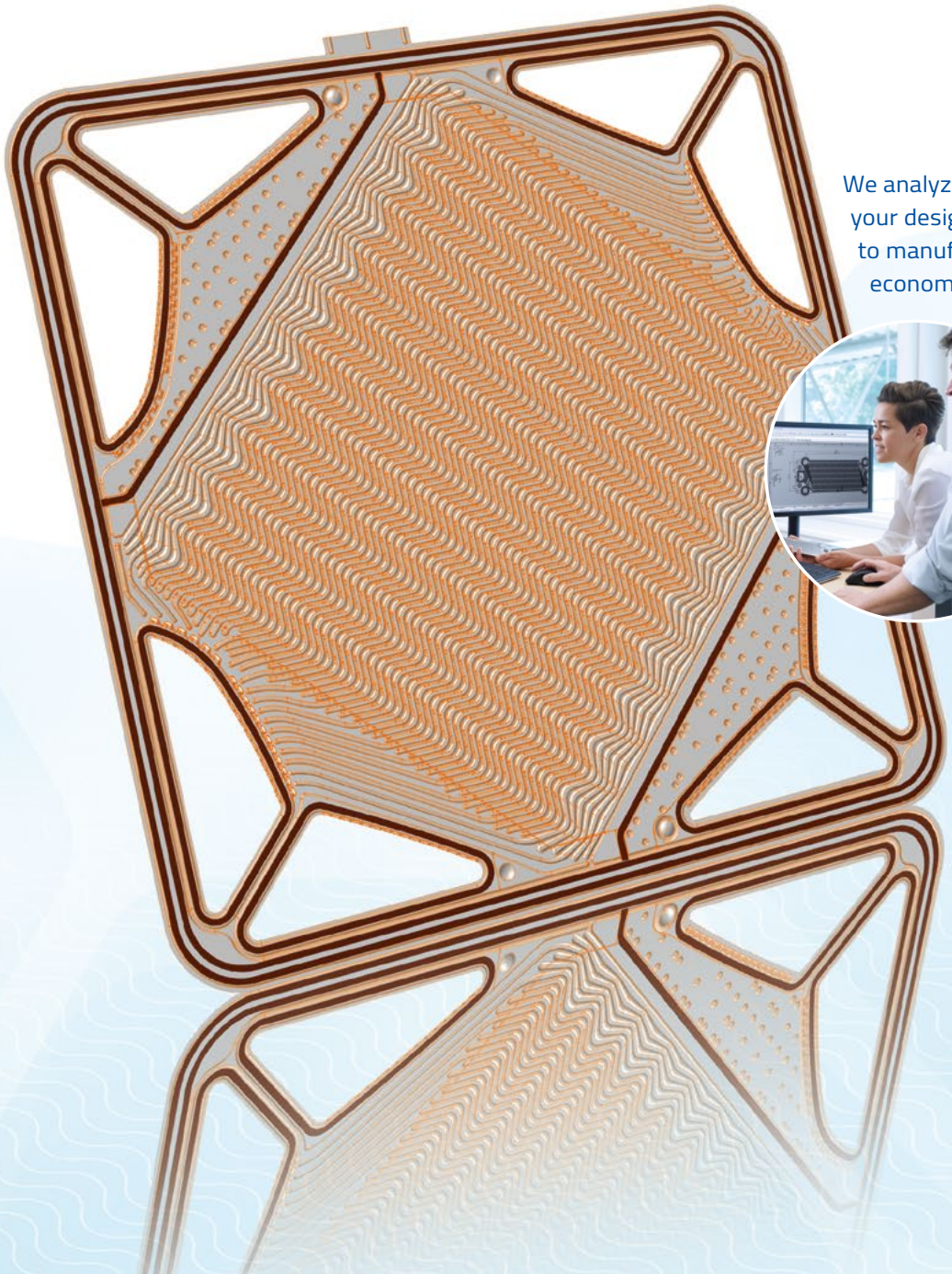
Regardless of whether you are looking at a single machine, a complete production line or an expansion of an existing line. Regardless of whether you want to manufacture fuel cell or electrolysis components. In all these cases, we will provide you with a production solution that is perfectly tailored to your requirements - incl. analysis of your production steps from coil to finished plate, incl. determination of requirements of individual machines as well as necessary handling and automation systems.

Special features

- Suitable for the production of single or bipolar plates **for electrolyzers and fuel cells**
- **Modular line concept enables flexible, cost-efficient expansion** (e.g. with increasing quantities or changing component geometries)
- Integration of **Graebener® machines in combination with technologies from our network partners**
- Manual operation, partially automated or fully automated

Engineering

Your Plus -
for an Optimum Bipolar Plate



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. **To ensure that your plate can be successfully manufactured, we analyze your design regarding manufacturability and work with you to develop appropriate optimizations**. At the same time we also consider those features for your plate that are crucial for economical series production.

Alternatively, we may also implement your design idea as a CAD model on request. In this, you will benefit from our many years of expertise in the optimization of single and bipolar plates as well.

Process development:
The best line for your plate

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

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 plate is the basis for our work.

Therefore, we start with a **well-founded analysis of the individual production steps**, always considering the planned output.
In the second step, we 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.
Finally, when implementing your line technology, we take care of the optimal integration into your infrastructure and create the appropriate **installation and assembly plan** for you.

Production Laboratory

Your Plus -
for Certainty from the Very Beginning

We verify the manufacturability of your design using a test geometry

Prototyping:
Safety for your production projects

In our Graebener® 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.

For verification purposes, we work with our own especially developed machine concepts - consisting of Graebener® forming presses, Graebener® cutting machines, Graebener® welding machines and Graebener® straightening machines - which are **ideally suited for a wide range of plate dimensions and materials from a foil thickness of 25 µm** and which can realize the narrowest radii. Our machines are constantly being developed in view of growing market requirements and thus delivers tangible, high-quality results.

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 - from smallest lot sizes to small series with capacities of up to 50,000 parts per year.

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 test geometry to small series:
WHAT we are able to process in the production laboratory and HOW

Material	Diverse, such as stainless steel, titanium, copper, clad materials; also pre-coated
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	Post-Coating as an alternative to pre-coated material, carried out by our partners

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

FVV

www.fvv-net.de

Graebener® is member of the Research Association for Combustion Engines.

NRW.Energy4Climate

www.energy4climate.nrw

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

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 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.

Ziel2.NRW
Regionale Wettbewerbsfähigkeit und Beschäftigung

EUROPEAN UNION
Investing in our Future
European Regional Development Fund

Ministerium für Bauen, Wohnen, Stadtentwicklung und Verkehr des Landes Nordrhein-Westfalen

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.

Made in Germany

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