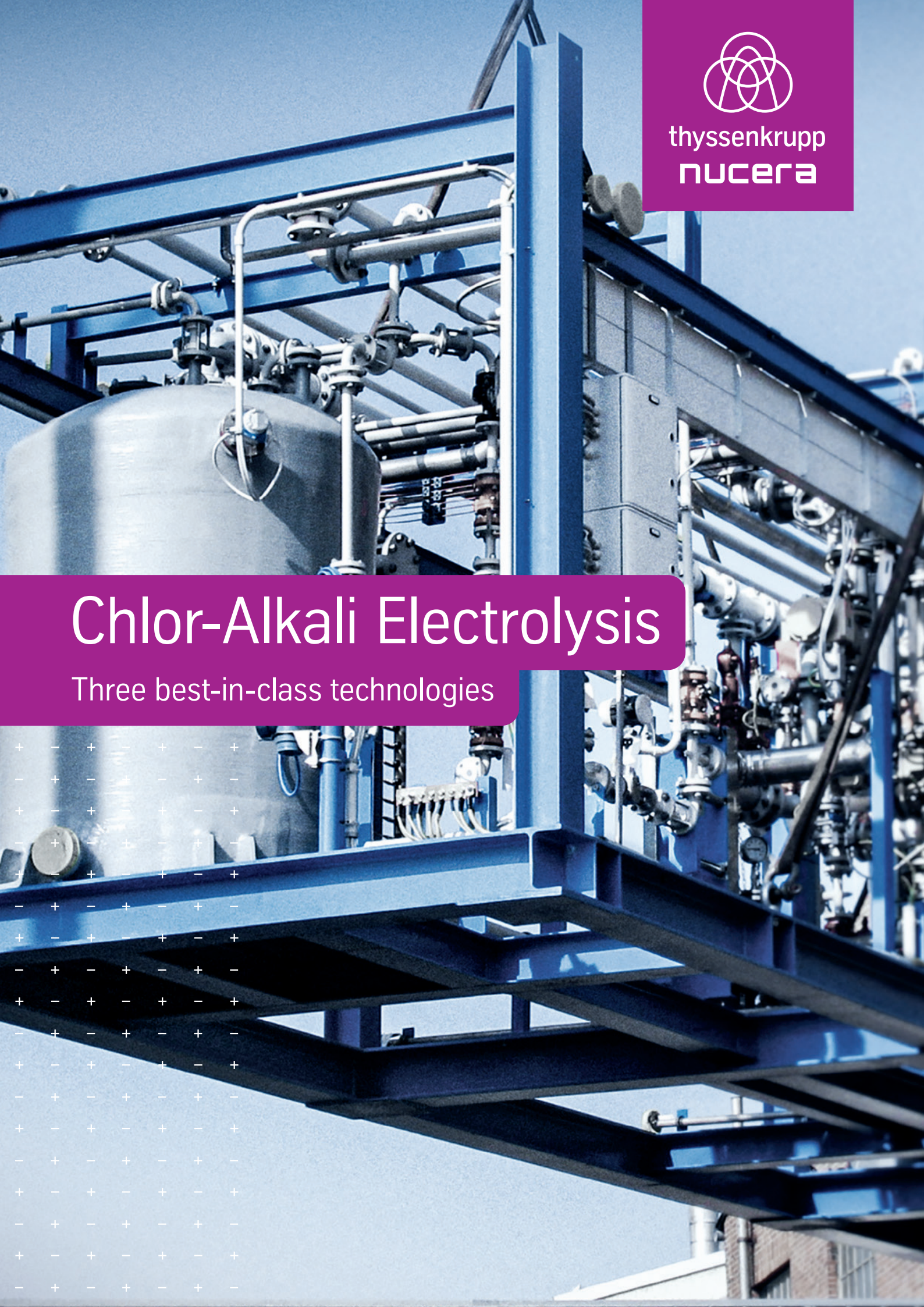


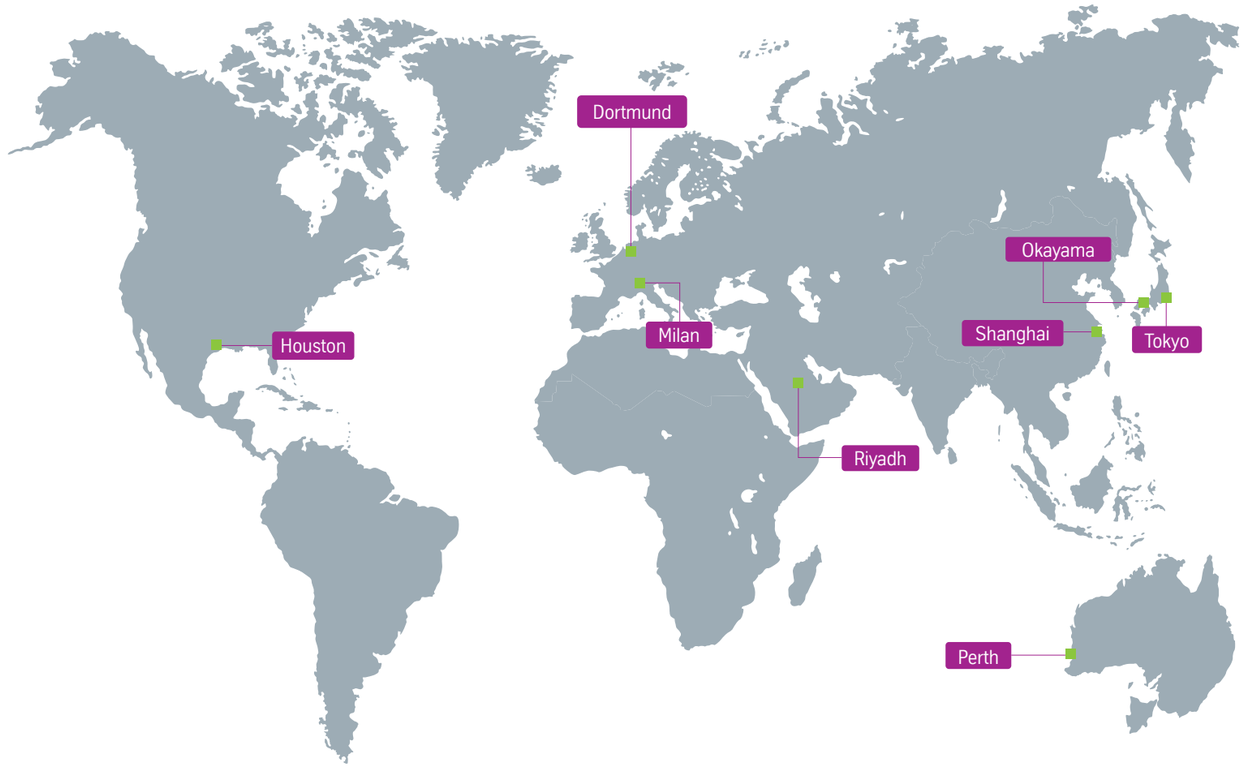
thyssenkrupp nucera

Chlor-Alkali Electrolysis

Three best-in-class technologies

Eight centers of excellence, global reach

Content

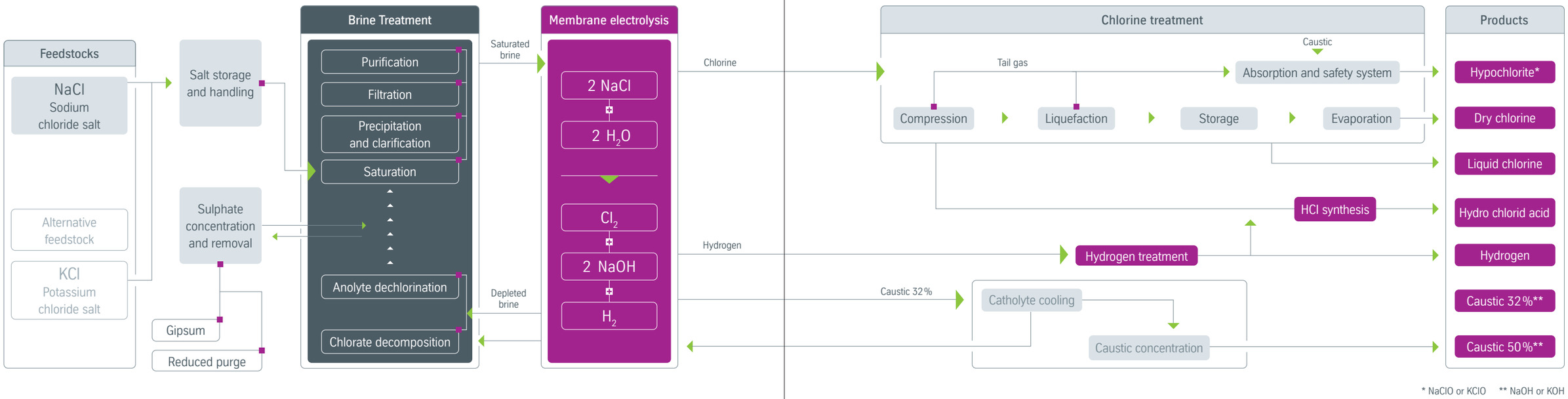


> We not only offer you the three market-leading technologies for chlor-alkali electrolysis, we also offer an all-round package as a one-stop-shop supplier.

Why we are best in class

thyssenkrupp nucera offers world-leading technologies for high-efficiency electrolysis plants. The company, a Joint Venture with Industrie De Nora, has extensive in-depth knowledge in the engineering, procurement, and construction of electrochemical plants and a strong track record of more than 600 projects with a total rating of over 10 gigawatts already successfully installed. With its water electrolysis technology to produce green hydrogen, the company offers an innovative solution on an industrial scale for green value chains and an industry fueled by clean energy – a major step towards a climate-neutrality.

Technology expertise and EPC competence from your one-stop shop



* NaClO or KClO ** NaOH or KOH

Worldwide, we have planned and implemented some 600 electrochemical projects, over 40 of them as turnkey engineering, procurement and construction (EPC) plants.

In all these projects, we have worked side by side with customers and extensively proven our expertise in implementing projects from small facilities to huge chlor-alkali plants with capacities of over 800,000 mt/year of NaOH. From the licensing business through engineering and procurement projects to very complex, turnkey projects we have demonstrated our ability to implement projects on time, to the highest standards of quality, and to our customers' complete satisfaction.

Proven quality
At thyssenkrupp nucera we offer state-of-the-art products that feature engineering of the highest quality while taking economic, ecological and safety considerations into account. The expertise we have gained in the field of electrochemical plants is partly the fruit of long-lasting collaboration with important industrial partners and customers.

Added value and complete process chains
Our proven EPC competence in turnkey projects is enhanced by the know-how, resources and global experience of thyssenkrupp Industrial Solutions. Our business area also offers EDC, VCM and PVC plants which can use the chlorine directly for EDC production.

The BiTAC family: Setting standards in low power consumption

Sample reference:
Ningxia Risheng, China (commissioned in 2018 and 2019)
> **NaOH capacity:** 320,000 mt/year

Two different BiTAC generations in a single cell room, nx-BiTAC and nx-BiTAC plus, each with 160,000 mt/ year. An extensive reference list is available on request.

The latest BiTAC generation in our portfolio is based on more than two decades of expertise and experience in filter press technology.

First marketed in 1994, the pioneering filter press bipolar ion-exchange membrane process electrolyzer, BiTAC, set a new power consumption benchmark of 2,200kWh/t at 6kA/m^2. Such a high current density had also never before been achieved by a zero-gap cell. Moreover, BiTAC minimized damage to the ionexchange membranes, which tend to be more vulnerable in a zero-gap environment. These BiTAC design features have been maintained in each subsequent generation, with each one having the same active area of 3.27m^2.

The n-BiTAC introduced in 2005 further reduced power consumption to 2,060kWh/t and featured a 0.15mm fine cathode mesh. In 2013 the launch of the nx-BiTAC marked another milestone in energy savings with a consumption of 2,010–2,025kWh/t. It was also the first ever cell to include a fine anode mesh. Within three years of first being marketed, nx-BiTAC had achieved record sales of 20 projects worldwide. Then, in 2019 e-BiTAC v7 started commercial operation, pushing energy consumption to a new record low of 1,960-1,979kWh/t NaOH at 6kA/m^2.

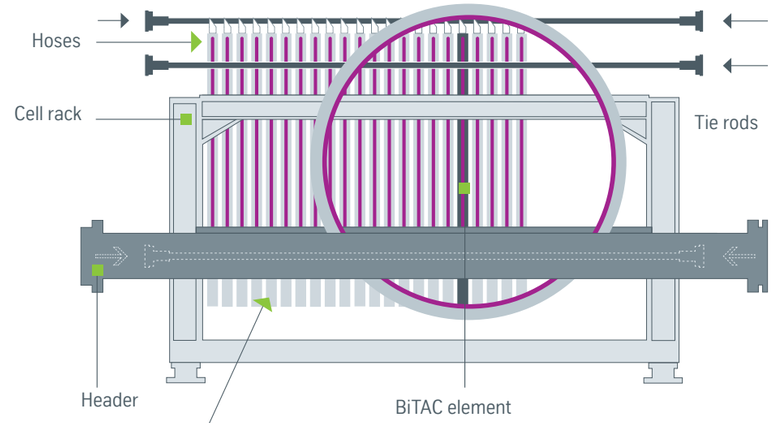
e-BiTAC v7 benefits

- Fine anode mesh reduces cell voltage (minimized gas stagnation)
- Smooth anode surface with no dents thanks to unique spot-welding tip
- Superior separation of gas and liquid
- Single piece of cathode mesh to fill gap losses and maximize active surface
- Elastic MWX spring with a large number of contact points to decrease IR drop and make homogeneous distribution of current density possible
- Superior inner circulation to ensure uniform concentration and brine supply

The design of the e-BiTAC v7 elements brings the following benefits:

The filter press technology utilized in the BiTAC series has specific advantages

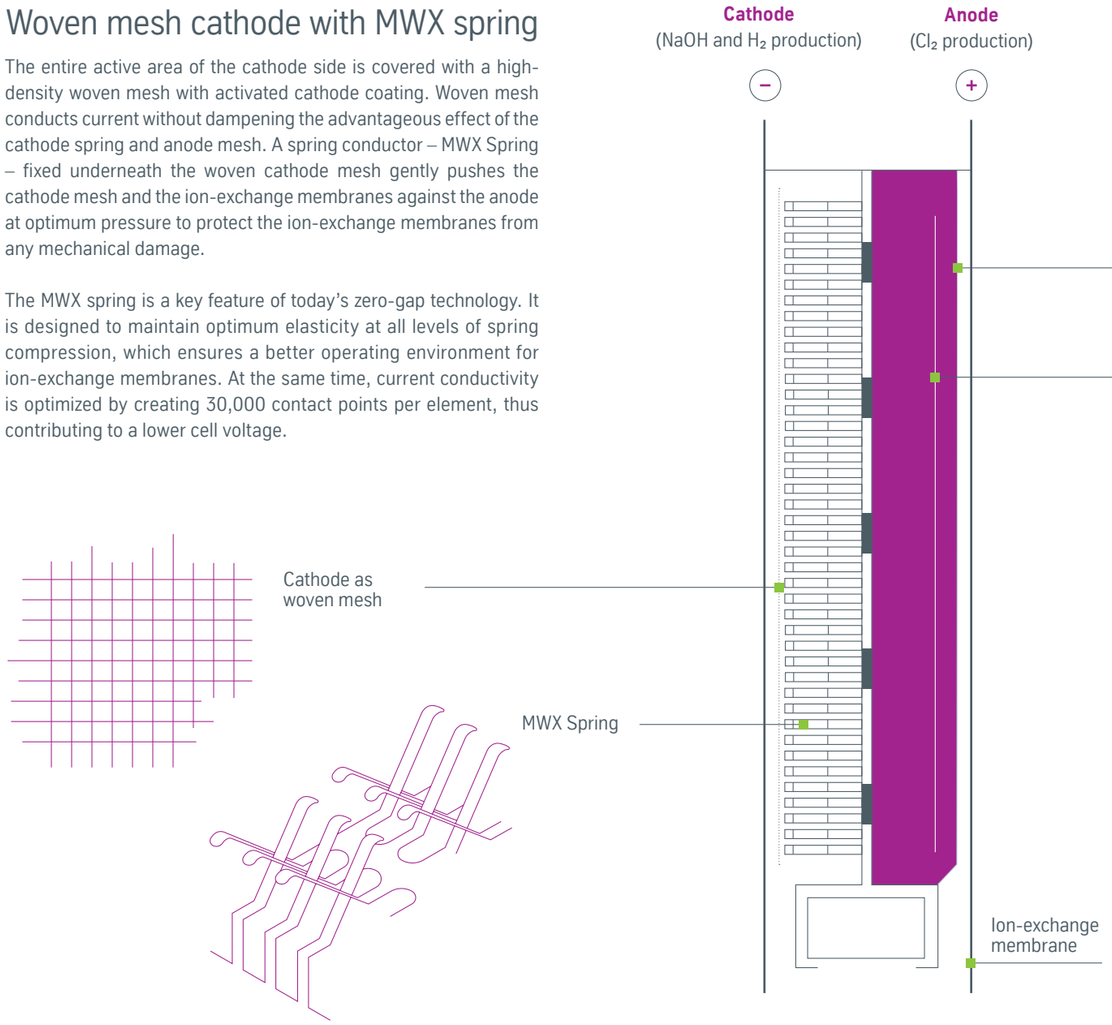
- Low sealing force required for gaskets, no bolts needed
- Fast remembraning of complete electrolyzer
- Smaller maintenance area required
- Lower power consumption through joining anode and cathode compartments by explosion bonding

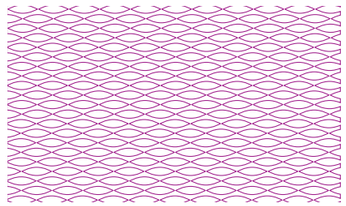


Woven mesh cathode with MWX spring

The entire active area of the cathode side is covered with a high-density woven mesh with activated cathode coating. Woven mesh conducts current without dampening the advantageous effect of the cathode spring and anode mesh. A spring conductor – MWX Spring – fixed underneath the woven cathode mesh gently pushes the cathode mesh and the ion-exchange membranes against the anode at optimum pressure to protect the ion-exchange membranes from any mechanical damage.

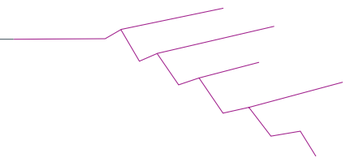
The MWX spring is a key feature of today's zero-gap technology. It is designed to maintain optimum elasticity at all levels of spring compression, which ensures a better operating environment for ion-exchange membranes. At the same time, current conductivity is optimized by creating 30,000 contact points per element, thus contributing to a lower cell voltage.





Fine anode mesh with smooth surface

The semi-fine anode mesh allows smoother gas release from the anode mesh surface and contributes to voltage reduction. A superior current distribution as well as less voltage drop across the metallic structure are the result.
The new "no-dent spot welding" technique ensures a completely flat face over the whole anode mesh surface – for uniform contact with the ion-exchange membrane and an extended membrane lifespan.



Downcomer

The downcomer has a special V-shape and utilizes the gas lift effect to create a high degree of internal brine circulation. This ensures an ideal distribution with uniform density and temperature within the anode compartment. The cathode compartment has no downcomer as caustic soda and hydrogen are easily separated and the difference between the inlet and outlet concentrations of the caustic soda are very small.

By electrolyzing an aqueous solution of sodium chloride, the electrolyzer produces gaseous chlorine and sodium hydroxide as well as hydrogen, the principal by-product. Chlorine is produced at the anodes, sodium hydroxide and hydrogen at the cathodes. The overall reaction is as follows:

$$2\,NaCl + 2\,H_2O \rightarrow Cl_2 + 2\,NaOH + H_2$$

The BM2.7 single-element series: Major energy savings from zero-gap technology

Sample reference: Vestolit Marl, Germany (commissioned 2007)
Capacity: 236,900 t/year of NaOH; 210,000 t/year of Cl_2
An extensive reference list is available on request.

Nearly 30 years after the Uhde single-element membrane cell was first marketed, the highly successful BM2.7 series is now available in generation “6 plus”. However, cells from every generation are compatible, having identical dimensions that fit in the electrolyzer racks.

From the BM2.7v3 in 1997, the first laser welded cell where internals on the anode side allowed acidified operation, to the BM2.7v6plus launched in 2019, a full zero-gap cell featuring a flexible elastic element in the proven BM single-element design, the BM series has set new standards in chlor-alkali electrolysis. The generation 6plus reduced power consumption to below 1,980kWh per metric ton of NaOH at 6kA/m^2.

Single-element + Elastic element = Zero gap

The defining feature of the BM2.7v6plus is a zero gap over the entire active membrane area. This is achieved by combining an Uhde® single-element with an elastic element. With the woven mesh cathode design and a state-of-the-art coating, high resistance to reverse pressure and pressure upsets is also ensured. The combination of the single and elastic elements brings key benefits.

Generation 6 plus & further development
Since 2012 when the first full zero gap cell with Generation 6 was launched, a new high point has been reached as the Generation 6 plus of the BM family was released offering optimized design features and thus breaking the barrier of 1,980kWh per metric ton of NaOH at 6kA/m^2.Highlights are an accessible active area of 2.85m^2 and longer membrane life time under high current density operation beyond 6kA/m^2. And the next generation is already under development.

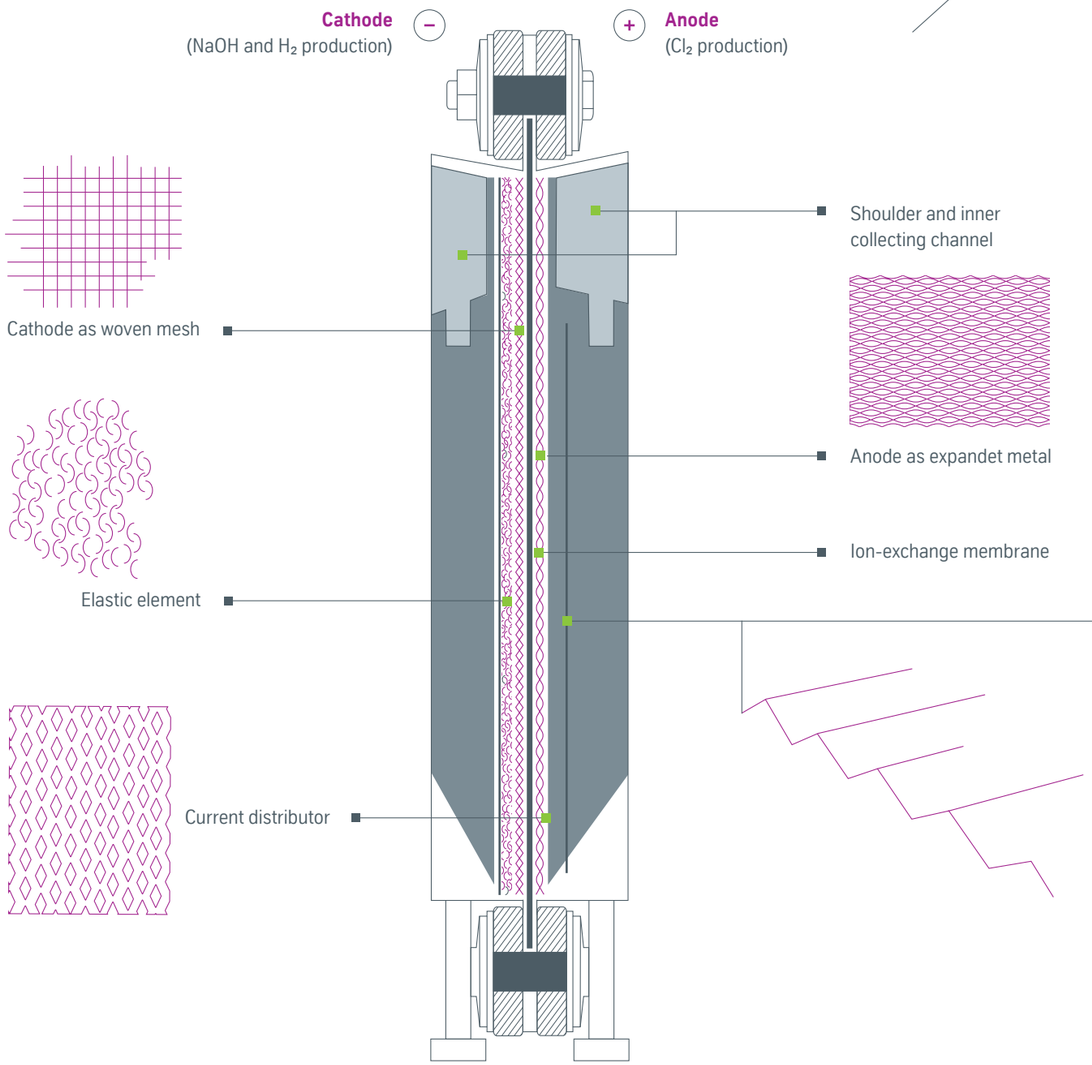
Key benefits of the BM2.7 single-element series

- Energy savings: Much lower energy consumption thanks to increased utilizable area of membrane combined with full zero-gap design
- Enhanced energy efficiency: More uniform current distribution to membrane and better release of gas bubbles to reduce any possible stagnation of gas transport inside cell
- No leaks: 100% leak proof cell throughout service life due to single-element design with unique sealing and hose system
- Contact pressure independently controlled: Direct control of pressure applied to elastic elements and thus to membranes irrespective of torque forces applied on bolts of flanges for the sealing system
- Extended membrane service life: Membranes run in optimal contact window to ensure zero gap across full active area and increase membrane service life

Every BM2.7 “single-element” is fully assembled and tested before inserting it into the electrolyzer stack.

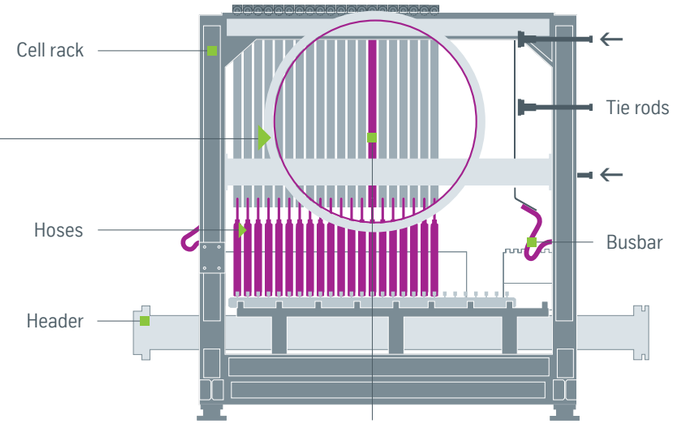
Zero gap

Combining an expanded-metal current distributor with a woven mesh cathode and an elastic element enables a “zero gap” over the whole membrane area to be achieved. The whole membrane area is active, and significant energy savings as well as a longer membrane life are the results.



BM2.7v6 benefits

- Unique sealing and hose system, 100 % leakproof up to 4.7 barg (operating pressure: below 0.5 barg)
- Roller suspension of each single-element ensures precise adjustment of contact pressure
- Hard, long-wearing PTFE gaskets
- Assembly and testing of elements in clean area outside cell house
- Assembled elements can be stored for many months
- Fast and simple replacement of elements with fully pre-tested elements
- Only one type of element in one electrolyzer (no special end elements required)



Smooth, safe operation

Brine and chlorine (anode side) as well as caustic soda and hydrogen (cathode side) are continuously transported from feed pipes at the bottom to the upper end of the compartments. This ensures that the membrane works optimally. Gas and liquid are separated completely in the collecting channel, ensuring two homogeneous outlet phases and minimizing internal differential pressure fluctuations. This enhances membrane life even further. For maximum safety, both compartments remain flooded even in stand-by mode so hydrogen and chlorine gases cannot meet.

Downcomer

The downcomer has a special V-shape and utilizes the gas lift effect to create a high degree of internal brine circulation. This ensures an ideal distribution with uniform density and temperature within the anode compartment. The cathode compartment has no downcomer as caustic soda and hydrogen are easily separated and the difference between the inlet and outlet concentrations of the caustic soda are very small.

By electrolyzing an aqueous solution of sodium chloride, the electrolyzer produces gaseous chlorine and sodium hydroxide as well as hydrogen, the principal by-product. Chlorine is produced at the anodes, sodium hydroxide and hydrogen at the cathodes. The overall reaction is as follows:

Oxygen-depolarized cathode: Quantum leap in sustainability

In countries where electricity is expensive, the NaCl-ODC electrolysis technology developed in collaboration with Covestro (formerly Bayer Material Science) offers distinct advantages: for example, up to 25% less energy consumption than conventional membrane-based technology.

Hydrogen formation suppressed

NaCl-ODC electrolysis technology is based on oxygen-depolarized cathodes (ODCs) integrated into the single-element electrolysis technology (BM2.7 design). The decisive difference between NaCl-ODC electrolysis and conventional membranebased technology is in the cathode; the anode is no different. The oxygen introduced into the cathode compartment suppresses the formation of hydrogen, which results in a reduction in cell voltage from around 3 V to 2 V. This in turn enables ODC technology to cut power consumption by up to 25%, for example, 1,550 kWH/mt NaOH at 6 kA/m². Alternatively, if power consumption is kept constant, a corresponding power capacity increase is possible. By saving energy, ODC technology indirectly helps customers to improve their carbon footprint and enhance their sustainability image.

Easy upgrades, fully compatible

What's more, a plant running on conventional membrane technology can be partly or entirely converted to NaCl-ODC technology, if required. Since the electrolysis cells and brine cycle are fully compatible, NaCl-ODC and conventional membrane technologies can be easily combined in a single plant.

ODC benefits

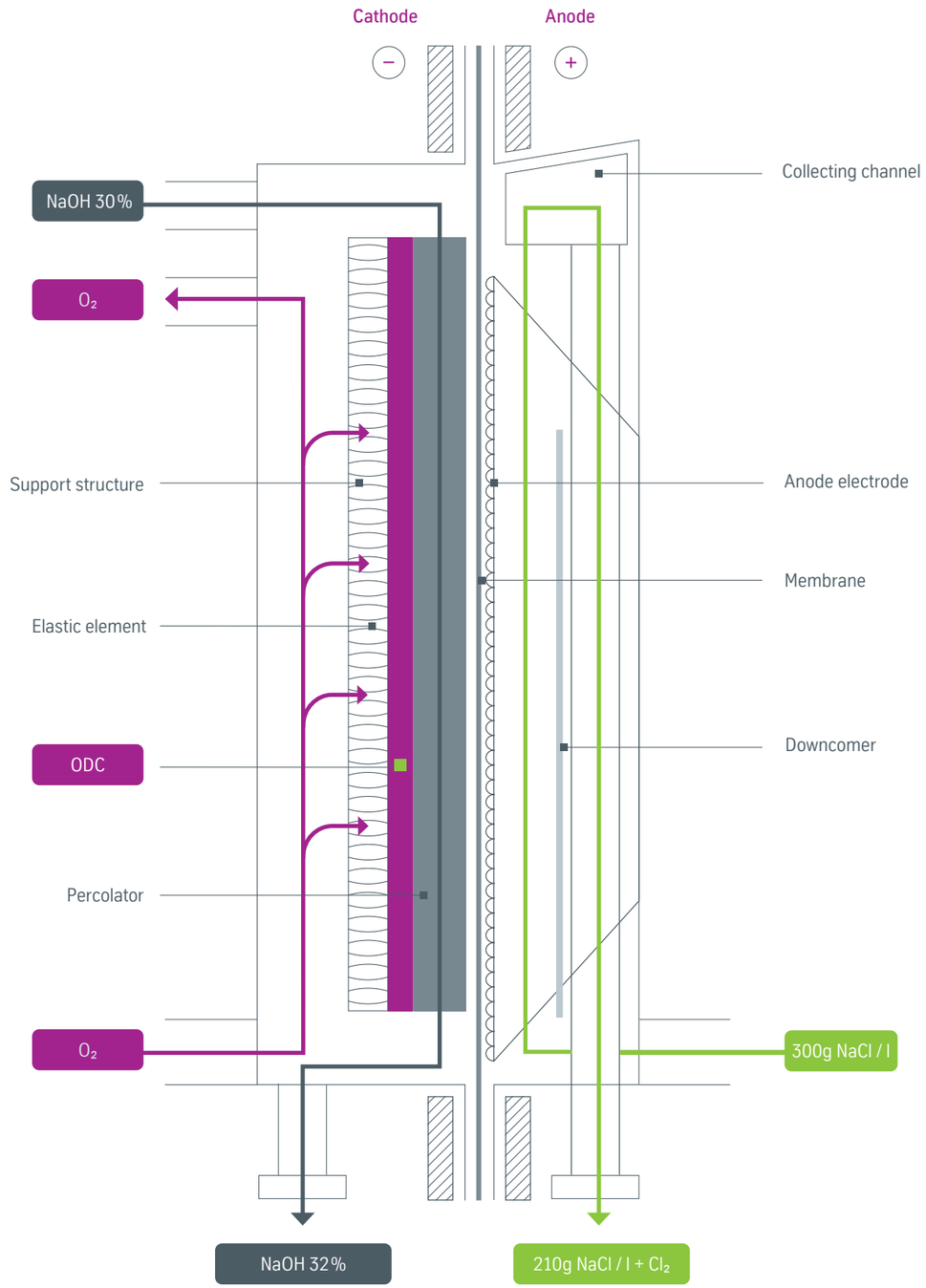
- Up to 25% less energy consumption than conventional membrane-based technology
- Ecologically valuable solution thanks to lower CO2 emissions
- BM2.7 and ODC technologies combinable in a single plant thanks to full compatibility of electrolysis cells and brine cycle
- Reliable, well-proven technology
- Higher degree of site flexibility with regard to electricity and hydrogen supplies

ODC process

The ODC process

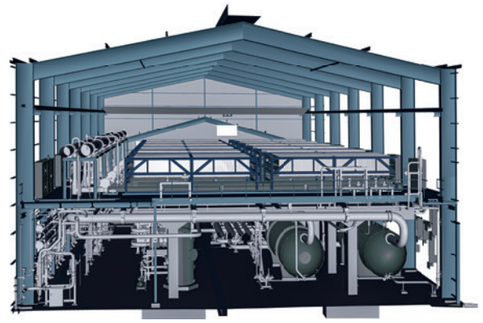
The ODC structure itself consists of a current distributor (woven metal mesh), a catalyst and a binder. The current distributor acts as a support structure for the catalyst and the binder. The reaction proceeds in several steps: It starts with permeation of oxygen into the porous ODC structure followed by a second step, in which oxygen dissolves in the caustic electrolyte and diffuses on the catalyst surface. Oxygen is then chemically reduced and the reaction products are removed by convective transport.

Characteristic for the process is the 3-phase boundary of liquid, gas and solid at the catalyst surface where the reaction occurs. This is essential to bring oxygen, caustic and catalyst in contact for the reaction and it sets our cell design apart from other technologies.



Two solutions for cost-effective chlorine production

Several innovations in our contract-execution concepts are specifically designed to make cost-effective, space-saving chlorine production possible.



Solvay S.A., Tavaux, France (commissioned 2012);
Capacity: 270,000 t/year of NaOH

Compact cell-house design

The largely standardized compact cell-house design has been optimized to deliver low investment costs, minimize space requirements and ensure easy maintenance. By putting special emphasis on equipment and a space-saving construction, this cell-house approach makes lower investment costs possible. It reduces the amount of steel structures needed in the process building and utilizes the space under the electrolyzers in the best possible way, for example, by placing tanks, pumps and heat exchangers there. The cell house has no pits and the catholyte system is an integrated part of the design.

Skid-mounted technology

As the market evolves, the demand for small-capacity chlorine plants is growing: liquid chlorine transportation is becoming more difficult and expensive; chlorine and caustic are the building blocks for industries in remote areas; and securing sustainable supplies of chlorine and caustic is becoming a key objective for chemical companies.

To specifically address the needs of small-scale chlorine producers, we have translated our process and technology expertise in complete plants to our skid-mounted technology. Skid-mounted chlorine plants have a capacity of 5,000 or 15,000 mt/a of Cl_2 and consist of standardized, pre-assembled modules in steel skids, which come in a standard container size for ease of transportation.

We offer, for example, brine filtration, NaCl or HCl electrolyis, chlorine drying/cooling/liquefaction, waste gas dechlorination, and sodium hypochlorite production skids. Moreover, individual skids can be installed in existing plants for modernization or debottlenecking purposes.

Sample reference: Leuna-Harze GmbH Leuna, Germany (commissioned 2012)
Capacity: 15,000 t/year of Cl2
Contract: EPC LSTK

Benefits of skid-mounted plants

- Standardized engineering for optimized costs
- Process simplification to reduce costs
- Fewer civil and erection works on site
- Lower capital expenditure risks
- Much faster project schedule than conventional plants

Worldwide service – everything from a single source

Our ongoing aim is to enter into long-term partnerships with our customers. Therefore, our world-leading technologies and solutions for high-efficiency electrolysis plants are rounded off by a comprehensive service portfolio to meet all your operational needs – wherever in the world your plant may be located.

Digital plant monitoring and optimization

Uhde® Evaluator
The Uhde® Evaluator measures and analyzes the voltages and operating parameters of the single-elements – 125 times per second with an accuracy of 3 mV to ensure maximum safety levels. It then uses these precise measurements to diagnose the condition of the elements and forecast their future condition. This makes for safer plant operation, on-point maintenance, clear reporting and simplified troubleshooting.

Remote condition monitoring
Plant operating data generated from a variety of sources (e.g. Uhde® Evaluator and Uhde® Administrator) is sent to our Technology Service Center for further analysis. This feedback is then analyzed by our specialists for the purposes of plant optimization and performance improvement. Preventive analysis, as offered by this tool, increases plant availability and makes smart scheduling of targeted maintenance possible.

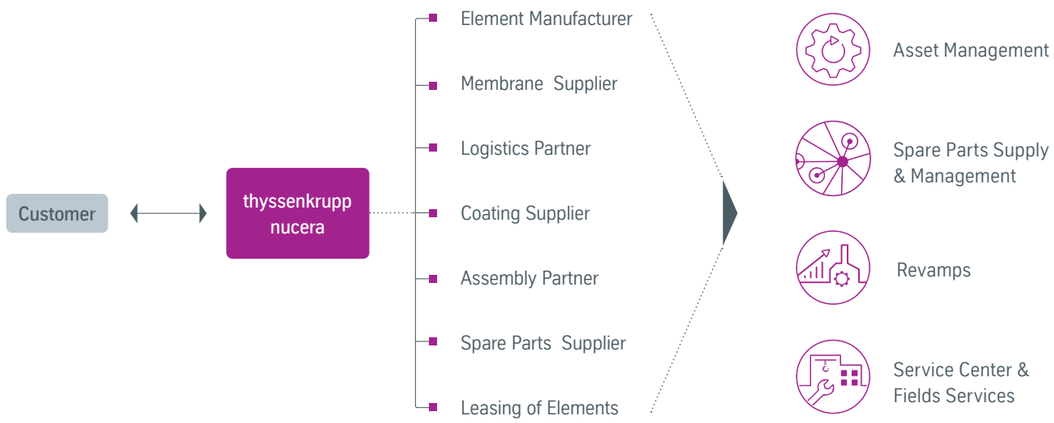
Full service – maximum service, minimal downtime

The challenge in electrolyzer maintenance is to minimize downtime and ensure work undertaken is of the highest quality. This is where our full-service package comes into play. Your main benefits: a single point of responsibility, our comprehensive expertise and experience, and our highly qualified service technicians.

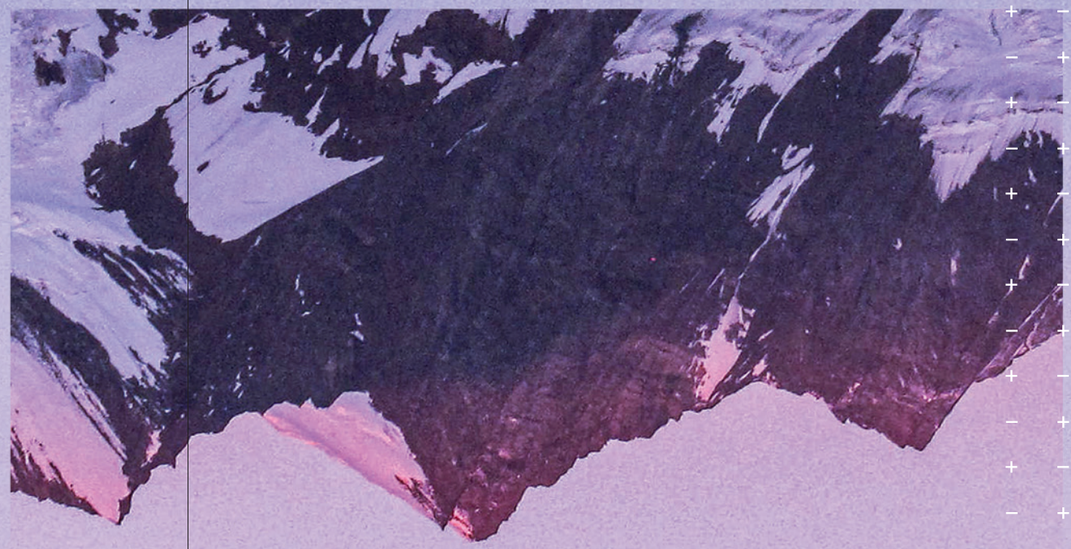
Long-term partnership
If you want a plant that fulfills the highest possible efficiency and safety standards throughout its service life, we are just the partner you need. Our modular service portfolio will provide ongoing support in minimizing power consumption and maximizing plant availability, safety and product quality – so you can achieve your goal of becoming a best-in-class producer.

Spare parts
The innovative design of our electrolyzers ensures any required maintenance activities are kept to a minimum. However, if your plant is to run economically, efficiently and reliably, it is vital to use nothing but our certified and carefully tested spare parts when components need to be replaced. We use proven supply chains to minimize delivery times.

Upgrades & retrofits
To improve the performance of your plant, we offer a range of services which significantly reduce the energy consumed per metric ton of NaOH. These upgrades or retrofits can be carried out for an entire cell room or individual electrolyzers. In the latter case, we make maximum use of the existing equipment in your cell room.



We shape the new era.



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