

Industrial Solutions

Chlor-Alkali Electrolysis

Three Best-in-Class
Technologies



thyssenkrupp



Six centers of excellence, global reach



■ Houston

Headquarters

Dortmund

Milan

“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.”

Denis Krude, CEO, thyssenkrupp Uhde Chlorine Engineers

Why we are best in class

At thyssenkrupp Uhde Chlorine Engineers we supply leading technologies and comprehensive solutions for high-efficiency electrolysis plants. Headquartered in Dortmund, Germany, we are represented around the world with additional centers of excellence in Okayama, Tokyo, Shanghai, Milan and Houston. Thanks to our global presence we are always close to our customers and capable of providing fast and comprehensive technology services. Some indication of our size is given by the annual output of 39 million metric tons (mt) of chlorine from chlor-alkali electrolysis plants for which we were awarded contracts.

We are not just world-leading experts for electrochemical technologies but also part of the thyssenkrupp Industrial Solutions business area. This business area – a world-leading planning, engineering, construction and service company in the field of industrial plants and systems – develops top-quality solutions that deliver efficiency, reliability, and sustainability over the entire life cycle of a plant. With a global network of some 19,000 employees at 70 locations, thyssenkrupp Industrial Solutions delivers turnkey plants worldwide that set standards in terms of value added and resource-saving technologies. At thyssenkrupp Uhde Chlorine Engineers we profit from thyssenkrupp Industrial Solutions as a powerful parent, sturdy backbone and source of expanded global reach as well as additional technological know-how. And our customers benefit from synergies within the Group.

Content

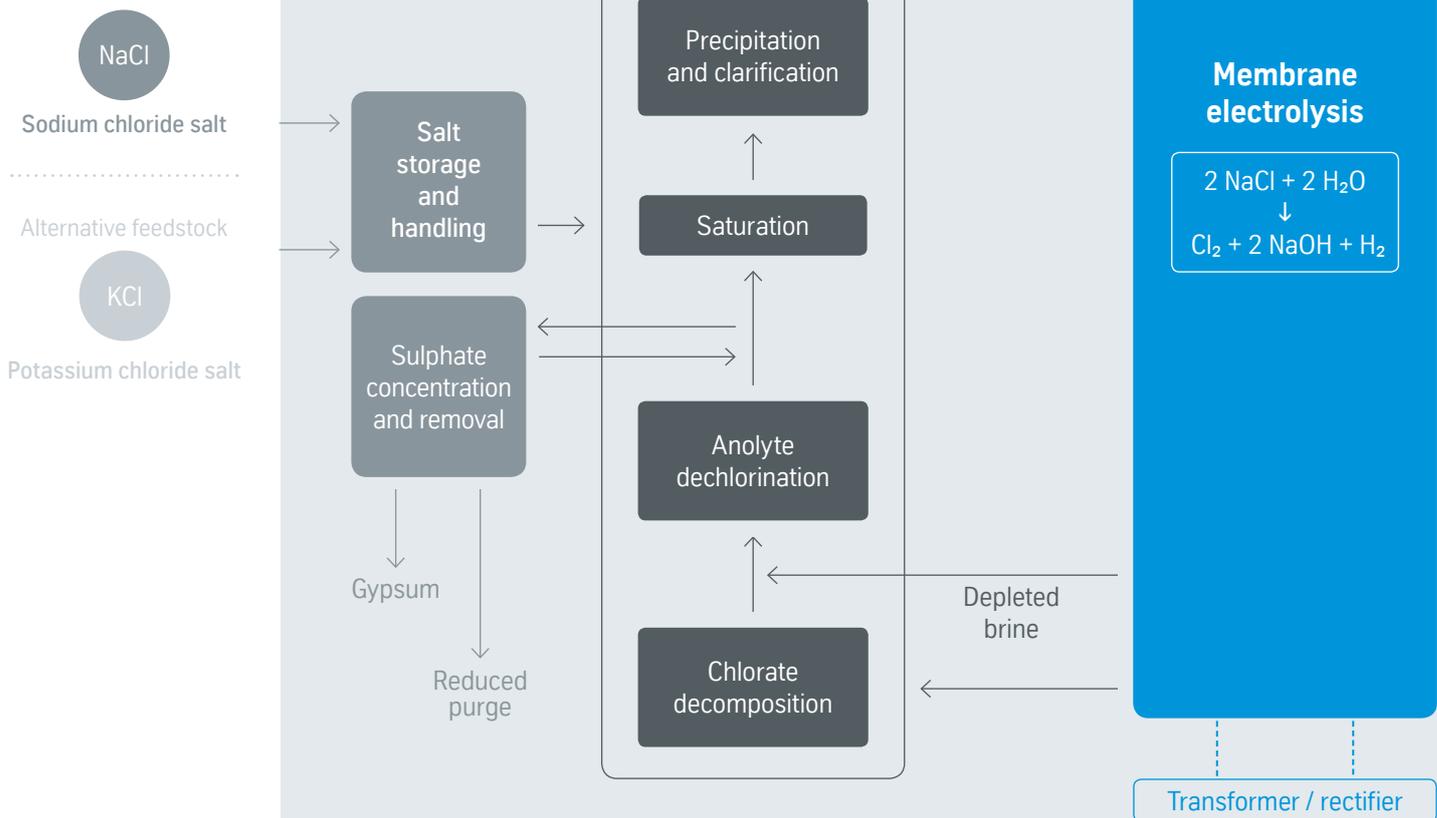
04	Technology expertise & EPC competence Three best-in-class technologies:
06	- BiTAC family (filter press)
10	- BM2.7 series (single-element)
14	- ODC technology
16	Cost-effective solutions
18	Service portfolio

Technology expertise and EPC

competence from your one-stop shop

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

Feedstocks



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.

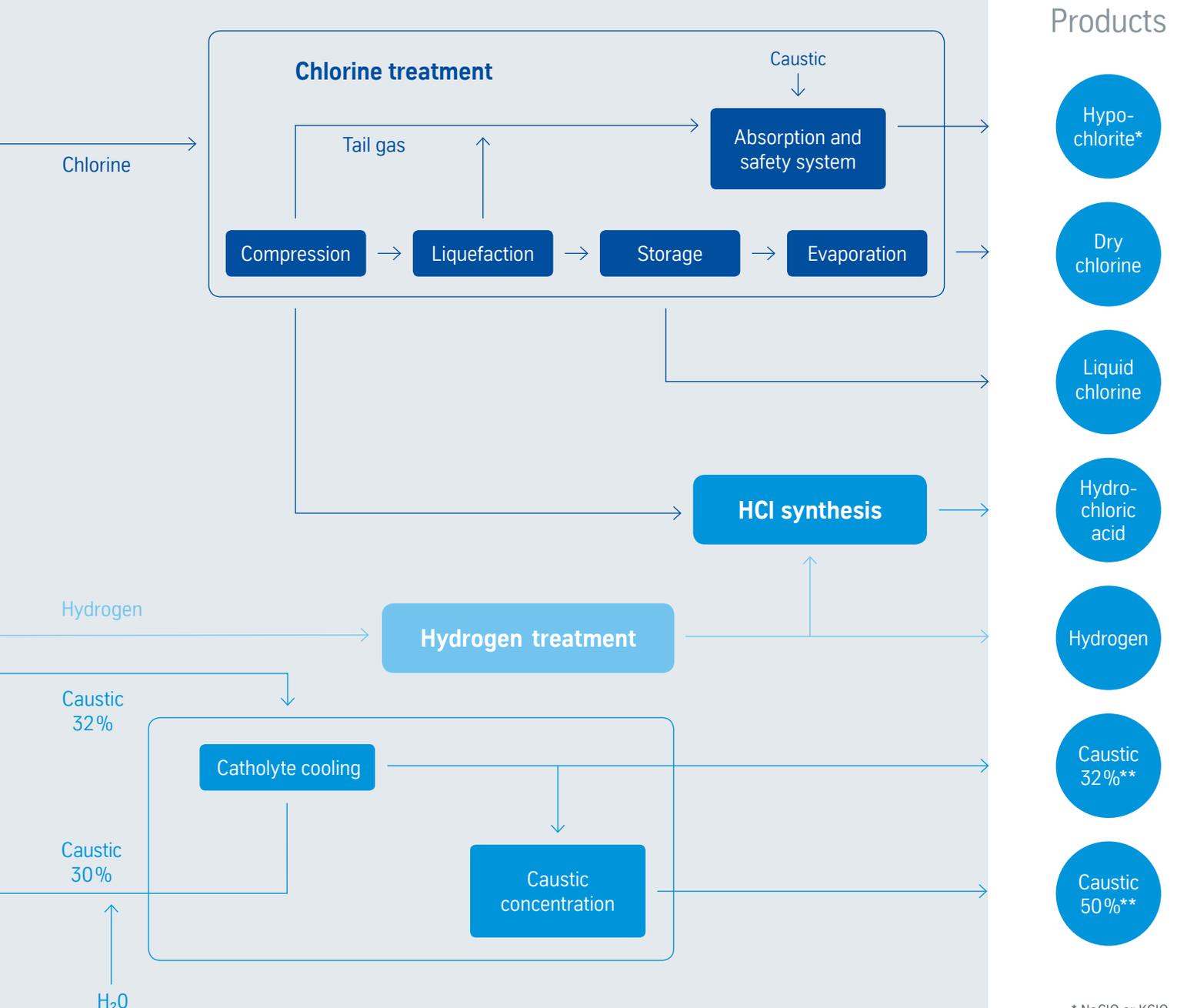
Proven quality

At thyssenkrupp Uhde Chlorine Engineers 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.



* NaClO or KClO
 ** NaOH or KOH



Sample reference:
BorsodChem, Hungary (commissioned in 2005, 2006 and 2012)
NaOH capacity: 200,000mt/year

Two different generations of BiTACs in a single cell room; first-generation BiTACs replaced by the latest nx-BiTAC in autumn 2015. An extensive reference list is available on request.



The BiTAC family: Setting standards in low power consumption

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 benchmark in low power consumption at 2,200 kWh/t at 6 kA/m². It was also the world's first zero-gap cell to achieve a high current density of 6 kA/m². Moreover, BiTAC minimized damage to the ion-exchange membranes, which tend to be more vulnerable in a zero-gap environment. These BiTAC design principles have been maintained in each subsequent generation, with each

one featuring the same active area of 3.27 m². The n-BiTAC introduced in 2005 further reduced power consumption to 2,060 kWh/t and featured a 0.15 mm fine cathode mesh. Then, in 2013 the launch of the nx-BiTAC marked another milestone in energy savings at 2,010–2,025 kWh/t, and was also the first ever cell to include fine anode mesh. Within three years of being first marketed, nx-BiTAC has achieved record sales of 20 projects worldwide.

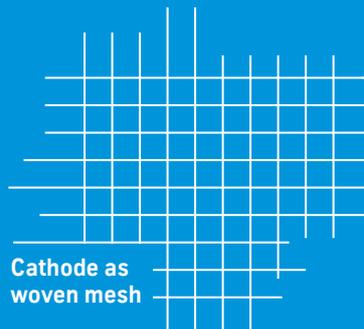
nx-BiTAC benefits

- 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 cushion with 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

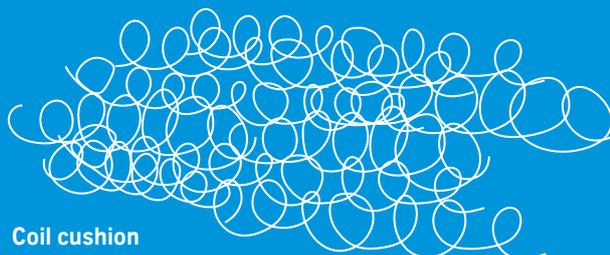
The design of the nx-BiTAC elements brings the following benefits:

Woven mesh cathode with coil cushion

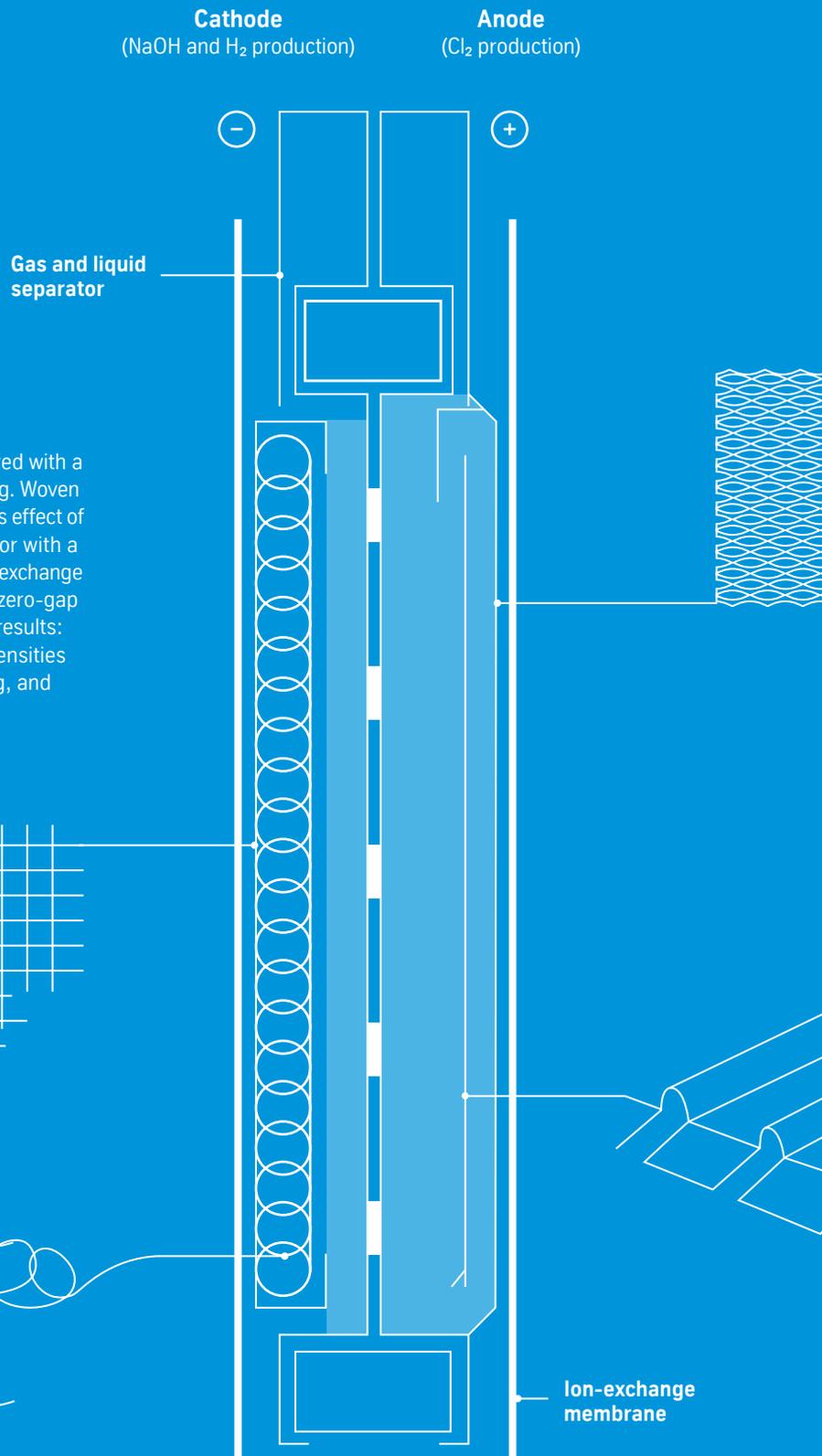
The cathode face on the nx-BiTAC element is entirely covered with a high-density woven mesh with an activated cathode coating. Woven mesh conducts current without dampening the advantageous effect of the cathode cushion and anode mesh. A cushion conductor with a flexible spring function presses the woven mesh and the ion-exchange membrane against the anode at optimum pressure. This “zero-gap technology” drastically improves current distribution. The results: remarkably low power consumption even at high current densities due to low structural voltage drop, better electrolyte mixing, and smoother gas separation.

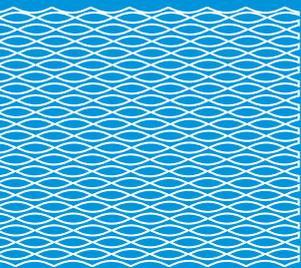
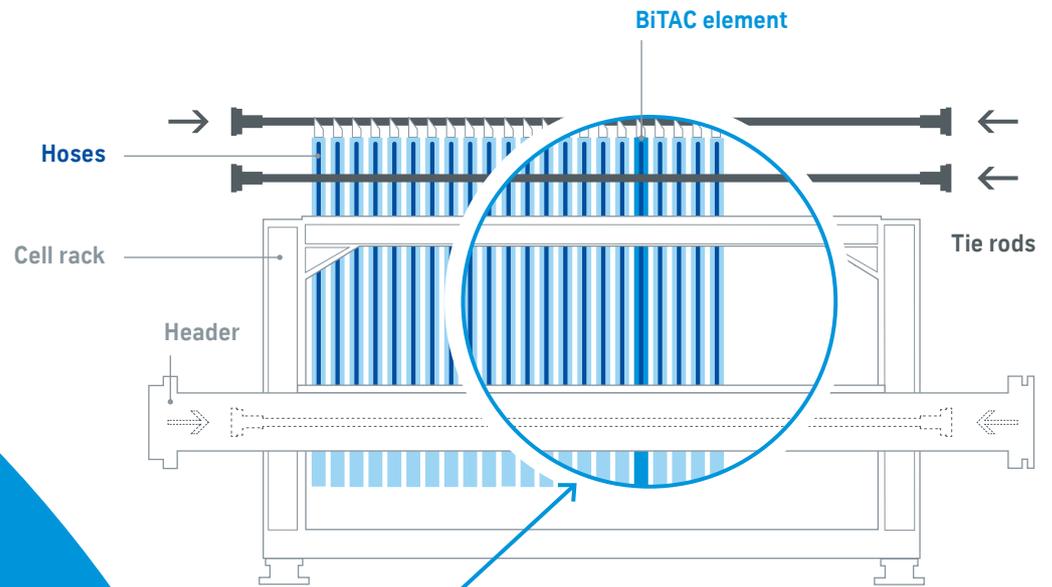


Cathode as woven mesh



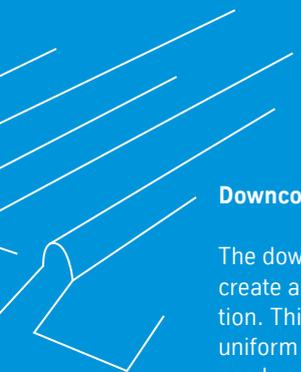
Coil cushion





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 over 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 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.

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

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:





Sample reference:
Vestolit Marl, Germany
(commissioned 2007)

Capacity: 236,900t/year of NaOH;
210,000t/year of Cl₂

An extensive reference list
is available on request.



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

Nearly 30 years after the Uhde® single-element membrane cell was first marketed, the highly successful BM2.7 series is now in its sixth generation. However, cells from every generation are compatible, having an identical active area of 2.72 m².

From the BM2.7v3 in 1997, the first laser-welded cell where internals on the anode side allowed acidified operation, to the BM2.7v6 launched in 2012, the first full zero-gap cell featuring a flexible elastic element in the proven BM2.7 single-element design, the BM2.7 series has set new standards in chlor-alkali electrolysis. The current 6th generation reduces power consumption to 2,020–2,035 kWh per metric ton of NaOH at 6 kA/m².

Single-element + elastic element = zero gap

The defining feature of the BM2.7v6 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.

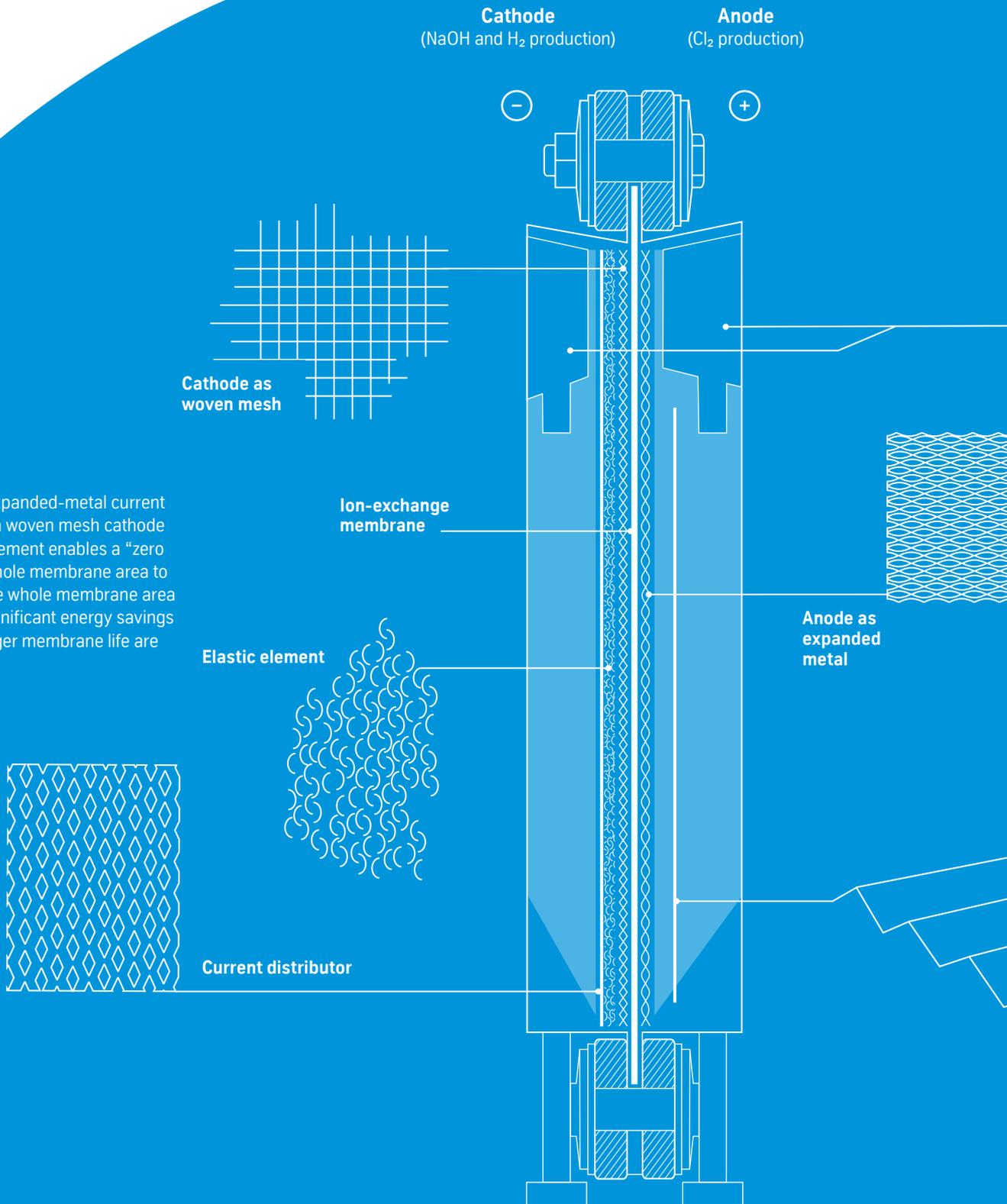
Key benefits of the BM2.7 single-element series

- **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% leakproof 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.



Cathode
(NaOH and H₂ production)

Anode
(Cl₂ production)

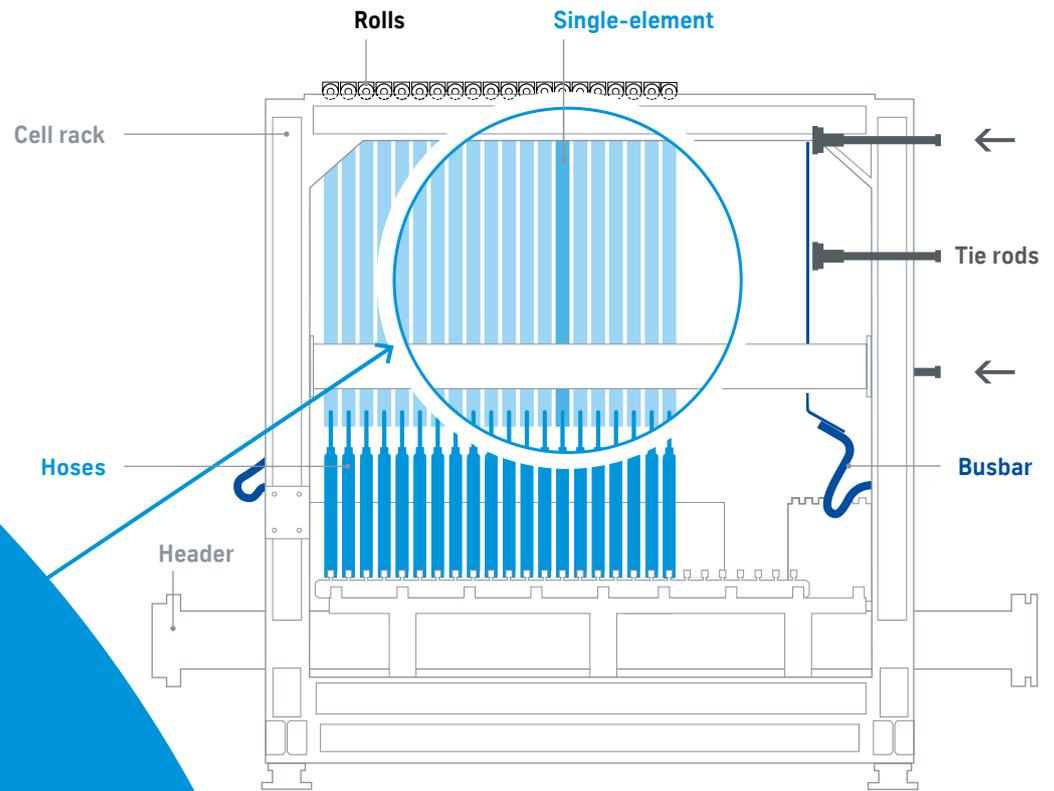
Cathode as woven mesh

Ion-exchange membrane

Elastic element

Anode as expanded metal

Current distributor



Shoulder and inner collecting channel

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.

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)

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 and 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 membrane-based 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 3V to 2V. This in turn enables ODC technology to cut power consumption by up to 25%, for example, 1,590kWh/mt NaOH at 6kA/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

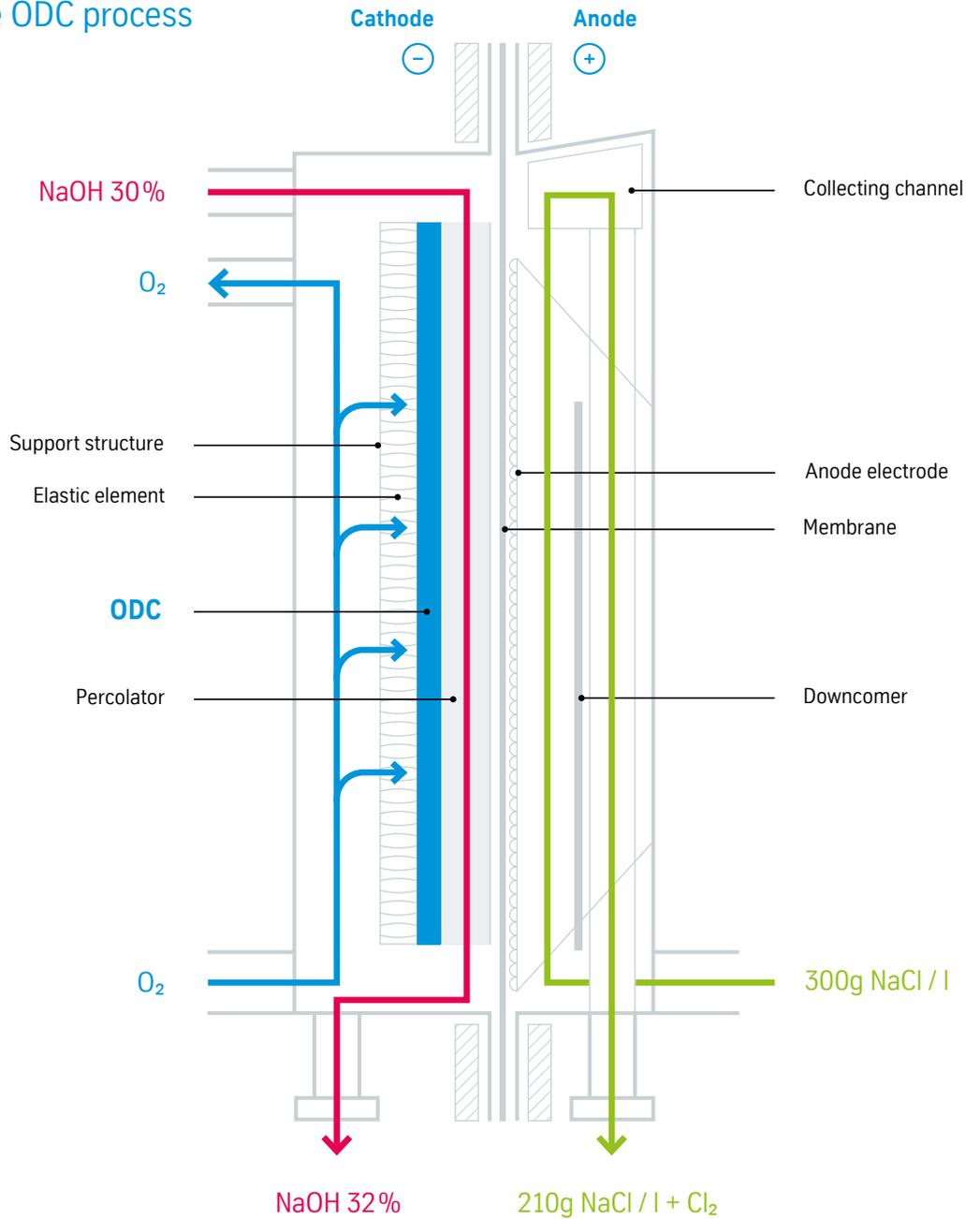
What's more, a plant running on conventional membrane technology can be partly or entirely converted to NaCl-ODC technology, if required. Since the electrolysis cells and brine cycle are fully compatible, NaCl-ODC and conventional membrane technologies can be easily combined in a single plant.

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



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.

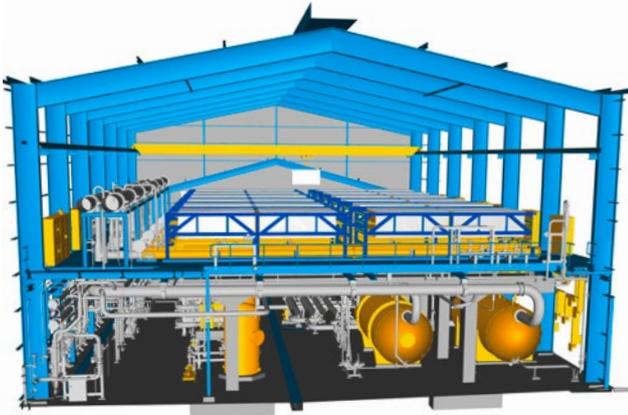
Two solutions for cost-effective chlorine production

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



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

Picture shows skid delivery.



Solvay S.A., Tavaux, France (commissioned 2012);
Capacity: 270,000t/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 Cl₂ 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 electrolysis, 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.



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.

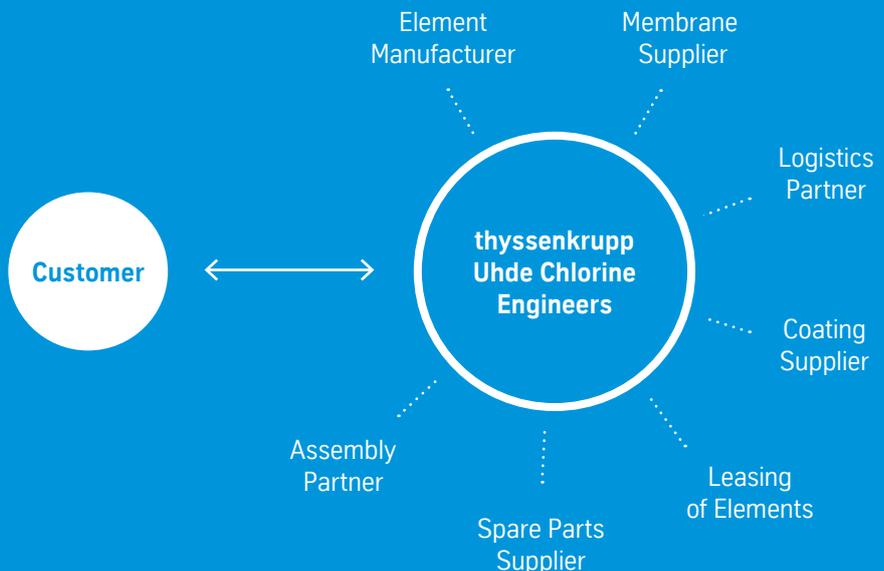
Long-term partnership

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.



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.





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.



Asset Management



Spare Parts Supply & Management



Revamps



Service Center & Field Services

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.

Industrial Solutions

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