Electrodes

Alkaline Water Electrolysis Solutions

DE NORA

Founded in **1923, De Nora** is an Italian multinational company listed on the Euronext Milan stock exchange, specializing in electrochemistry, a leader in **sustainable technologies**, and has a vital role in the **industrial green hydrogen production chain.** The Company has a portfolio of products and systems to optimize the energy efficiency of critical industrial electrochemical processes and a range of products and solutions for water treatment.

De Nora has 25 operating companies in 10 countries and 5 R&D centers in Italy, the United States, and Japan, which ensure the **continuous improvement** and enlargement of its proprietary technologies covered by over 260 patent families with more than 2.800 territorial extensions. With its widespread presence and broad product portfolio, the Company can effectively serve customers in 100 countries, employing more than 1.900 people worldwide.

De Nora everywhere

Globally, **De Nora** is the **world's largest supplier of activated electrodes**, serving a broad portfolio of customers operating in chlorine & caustic soda production, components for electronics, and non-ferrous metal refining. De Nora is among the world's leading suppliers of **water filtration and disinfection** technologies (for the industrial, municipal, and marine sectors) and swimming pool disinfection components. Leveraging its well-established electrochemical knowledge, proven manufacturing capability, and a supply chain established over the years, the Company has developed and qualified a portfolio of electrodes and components to **produce hydrogen** through the electrolysis of water, which is **critical for the energy transition.**

Energy Transition

Energy transition applications are the natural extension of the Electrode Technologies business. De Nora's solutions are used to **generate green hydrogen** through water splitting and convert hydrogen into electricity. Hydrogen is crucial for **decarbonizing** many industrial processes; green hydrogen is key to achieving **"carbon neutrality"** and **"net-zero emissions"**.

Sustainability in DNA

De Nora aims to provide new solutions that can contribute to achieving the **United Nations 2030 Agenda** and the **Sustainable Development Goals (SDGs)**.

Alkaline Water Electrolysis

De Nora has a solid **Alkaline Water Electrolysis** (AWE) background. More than 100 years of expertise in electrochemistry and significant efforts applied in new R&D projects have made De Nora's AWE the state-of-the-art technology for green hydrogen generation, ready to contribute to reducing the global carbon footprint in several industrial sectors.

ENERGY STORAGE

FUEL CELLS

TRANSPORT & HEAT AND POWER

INDUSTRIAL APPLICATIONS

FOOD & BEVERAGE

AGRICULTURE AND FERTILIZER

Hydrogen & Electrolysis

To reach the ambitious goal of net zero carbon emission by 2050 (NZE), the penetration of renewable energy sources will dramatically increase to reach the largest share in the next decades. The intermittency of these energy sources (such as Photovoltaic and Wind Turbines) highlights the necessity to integrate storage systems to balance the energy grid.

In the Energy transition process, **Green hydrogen** is widely recognized not only as a promising option for storing large quantities of renewable electricity over long periods of Power to Power **(P2P)** and as an energy vector for more sustainable **Mobility** (through Fuel Cell Electric Vehicle), but also as a renewable feedstock for a variety of **Chemical Production Power to Chemical (P2C)** (ammonia, methanol, green fuels, ...) and as unique alternative **energy source** for those sectors defined as **"Hard to Abate"** where electrification cannot substitute carbon-based power sources.

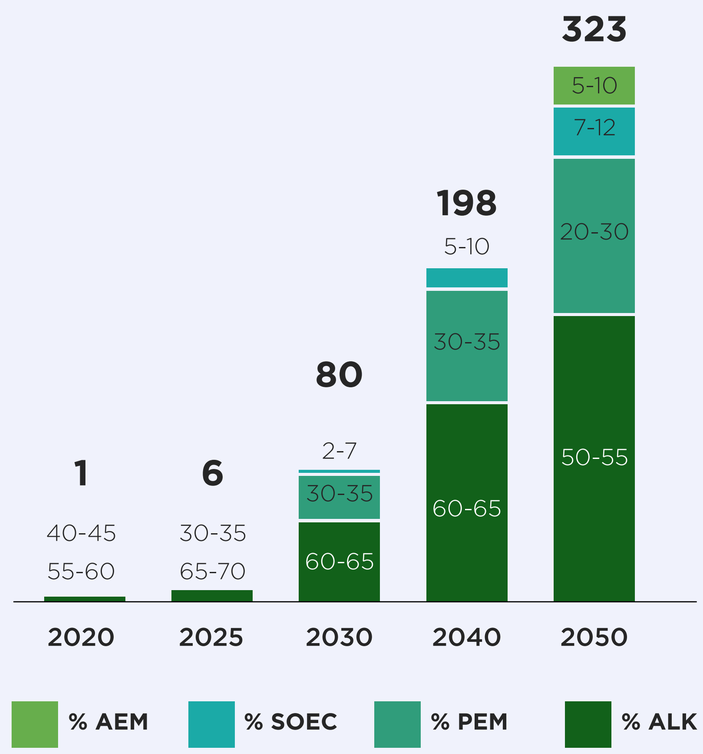
Today, the most established technology option for producing Green Hydrogen from electrical power sources is water electrolysis.

Four main electrolyzer technologies are used or being developed:

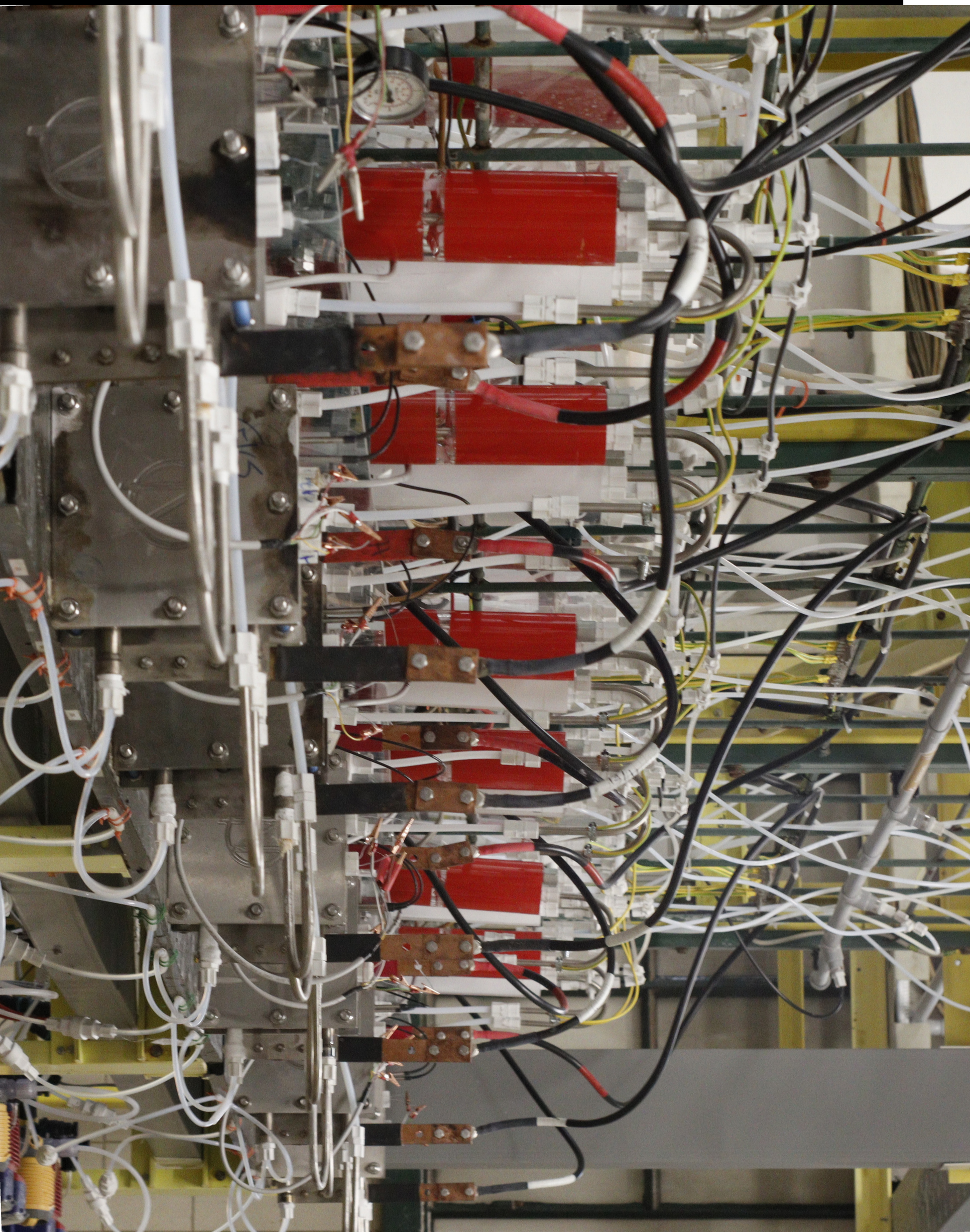
- **Alkaline (AWE)** is well established and has been used by industry for nearly a century
- Proton exchange membrane (PEMWE) is commercially available today
- Solid Oxide (SOWE) is still in the development phase.
- Anion Exchange Membrane electrolysis (AEM) is still in the development phase.

De Nora, in recent years, spent substantial R&D efforts on AWE to maximize its operating current density (CD) and reduce the overall power consumption, pushing this technology toward PEMWE performances but guaranteeing the lower CAPEX investment.
The result of this effort is a wide electrode coatings portfolio both for the anodic and cathodic compartments.

Hydrogen Production by technology in Mtons*



* Roland Berger - Project Demetra Report. December 13th 2021



AWE Electrodes Coatings

De Nora, leveraging its expertise in electrode coatings for the chlor alkali industry, developed a wide and up-performing product portfolio for Alkaline Water Electrolysis (AWE) enabling:

- **Reduction of Stack dimensions and CAPEX** by Increasing operating current density (CD)
- **Improvement of the cell efficiency and OPEX** by reducing cell voltage (CV)
- **Improvement of the direct coupling with RE sources** by developing shutdown and reversal current-resistant coating and enlarging the stack operational range

Anode and Cathode coatings can be applied on different substrates. All electrode combinations have been designed to adapt to the different electrolyzer operating conditions and to satisfy the different customer needs in terms of overall cell performance, initial CAPEX expenditure, and OPEX.

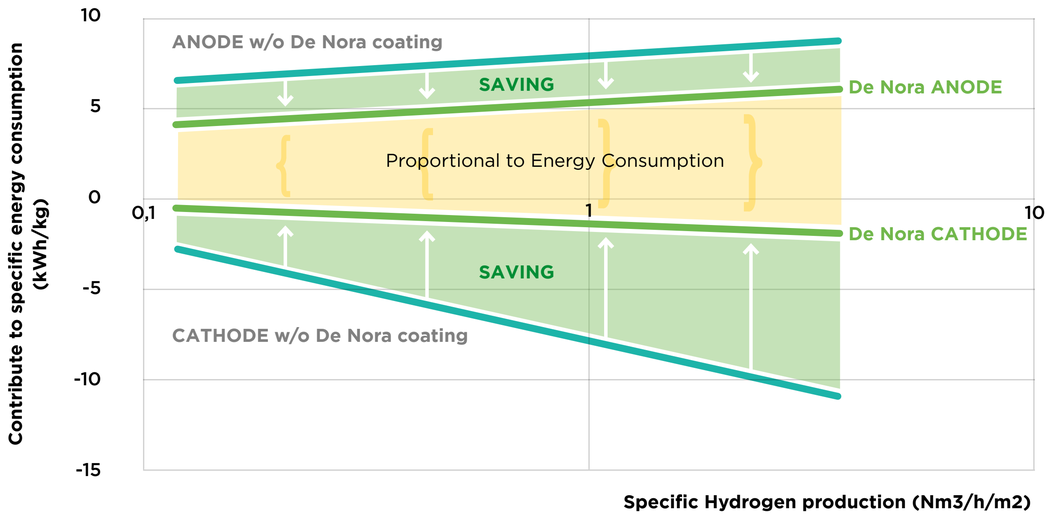
De Nora's R&D efforts are therefore focused on pursuing the lowest Total Cost of Hydrogen (TCO) through the reduction of the overall AWE plant footprint and the optimization of the power consumption while maintaining a low manufacturing cost of the electrolyzer.

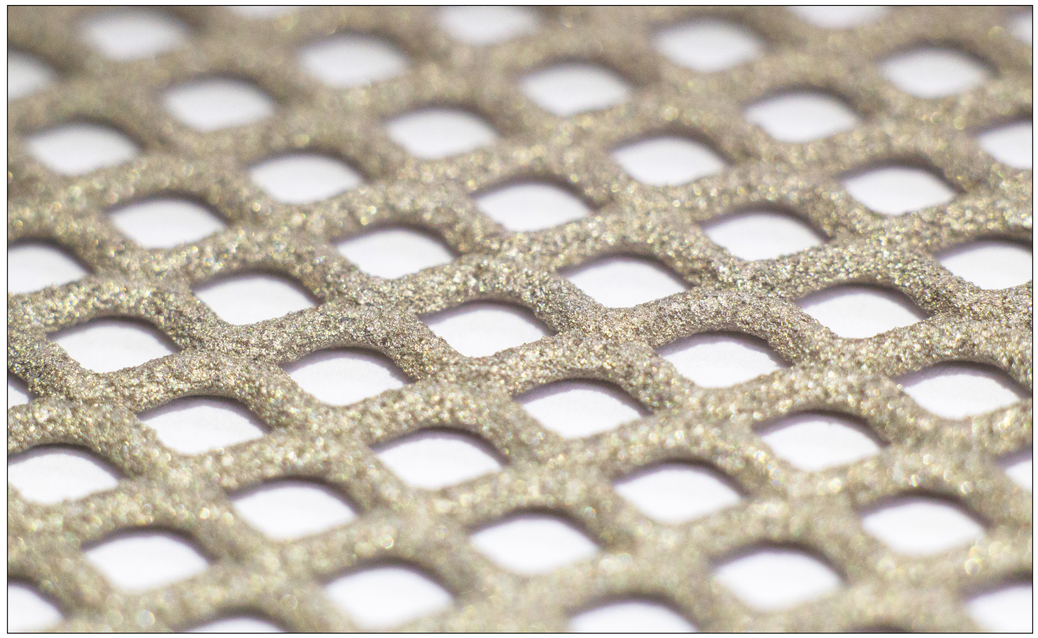
De Nora has developed during the years Electrode solutions applicable to all the current AWE electrolyzer architectures:

- Pressurized or Atmospheric
- With or without reversal of current protection

Case by case De Nora SALES and BUSINESS DEVELOPMENT could assist customers in finding the electrode combination capable of providing, given the specific boundary conditions, the lowest TCO.

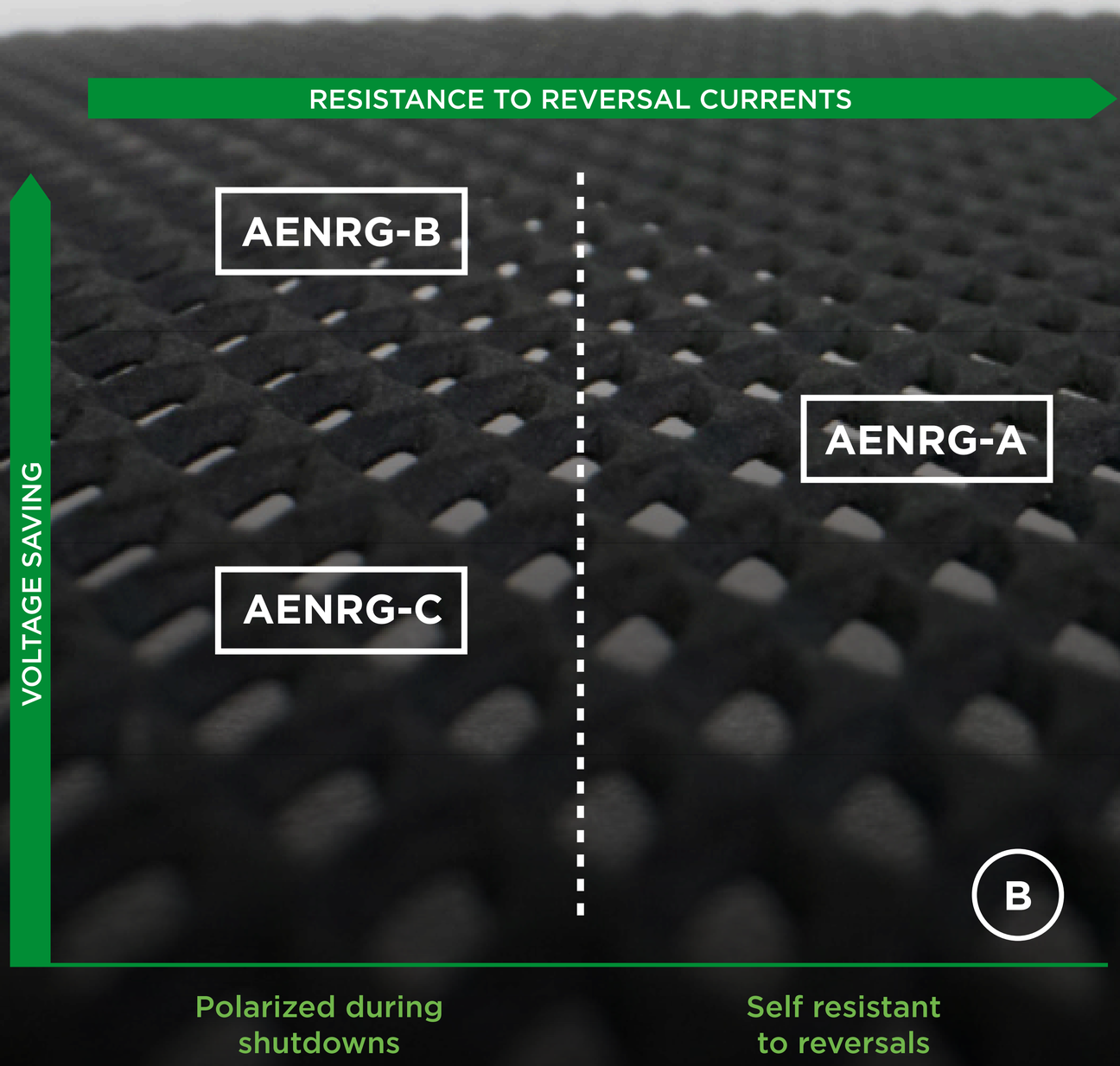
Effect of De Nora coatings on overvoltage specific energy consumption





AWE Electrodes Coatings

AENRG™ Anodes



B — **Bare Nickel**
Not suitable for high current density, adopted by low-performance systems. Reference.

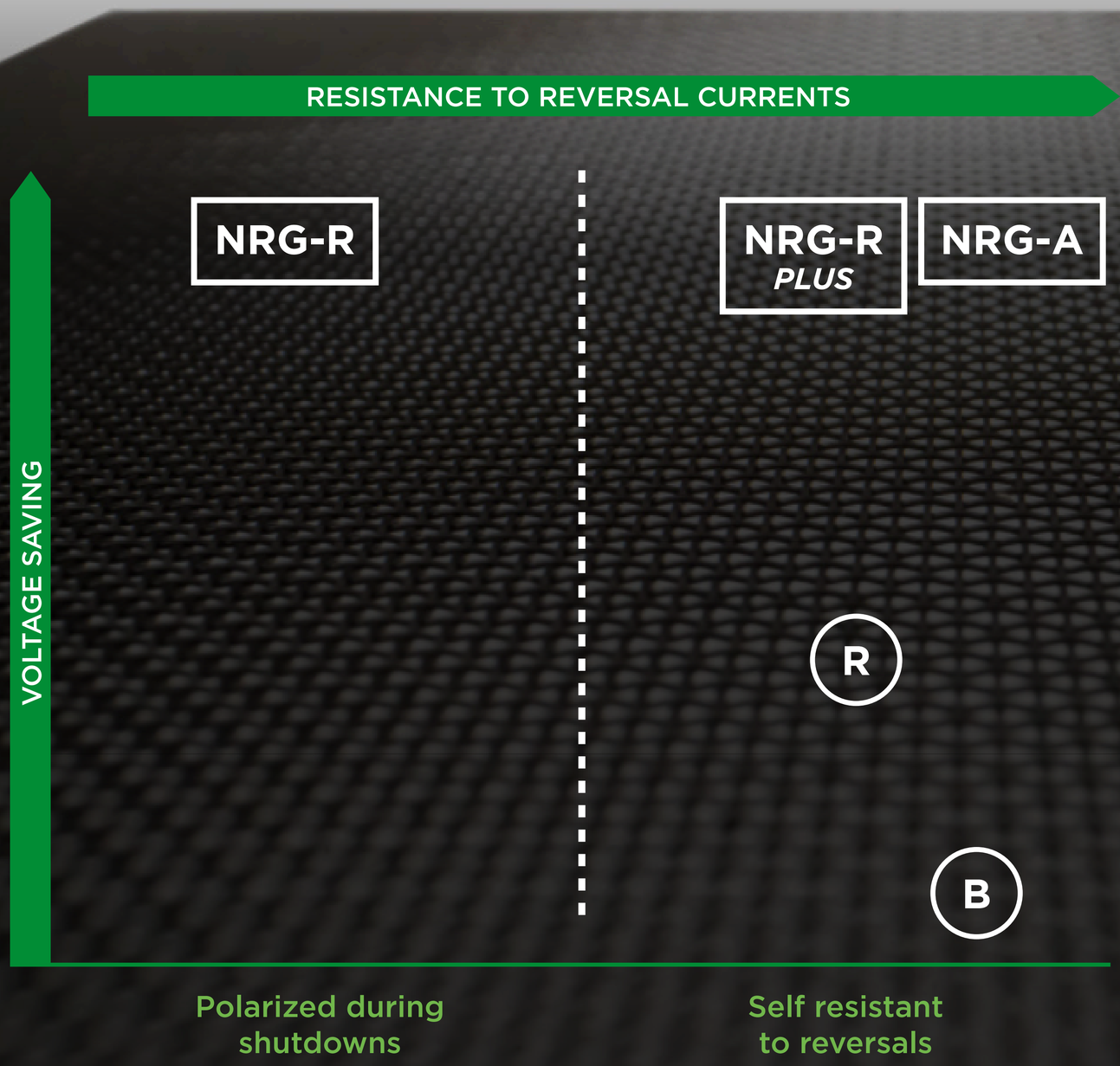
AENRG-A
High-performing and robust coating which combines a good voltage saving with the intrinsic resistance to reversal current and daily shutdown. Adapt for the coupling with RE sources.

AENRG-B
High performing best in class electrode. AENRG-B allows a high voltage saving and is suitable for high current density design. Designed for high performance AWE systems.

AENRG-C
Performing coating with good voltage saving which preserve the electrode during high CD operations.
AENRG-C can be equipped with a proprietary protective element becoming resistant to reversal currents during shutdowns.

AWE Electrodes Coatings

NRG® Cathodes



B — Bare Nickel
Basic technology not resistant to high current density for low performance systems.

R — Nickel Raney
Basic technology with a low voltage saving for low performance systems.

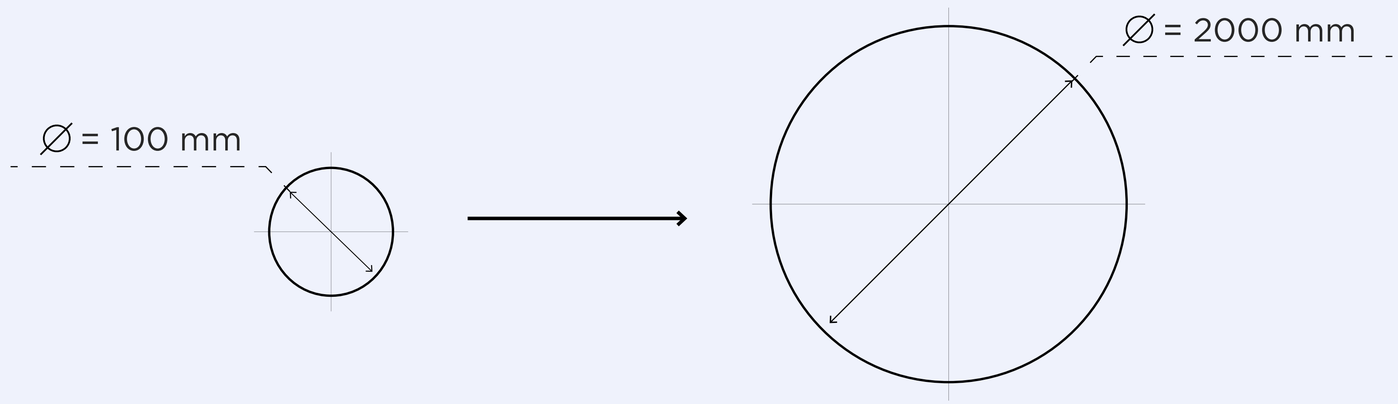
NRG-A
High performing best in class coating, with high voltage saving adapt to high current density design and resistant to reversal current.
Designed for high performance AWE systems coupled with RE sources.

NRG-R *PLUS*
High performing best in class coating, with high voltage saving adapt to high current density design. Designed for high performance AWE systems.

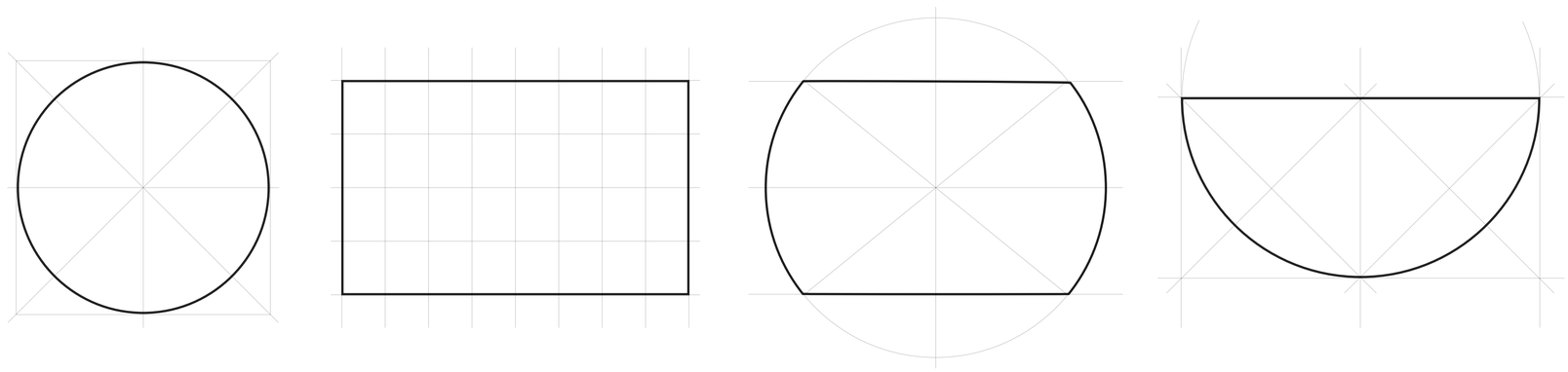
NRG-R
High performing coating with good voltage saving which preserve the electrode during the operation.

Coating capabilities

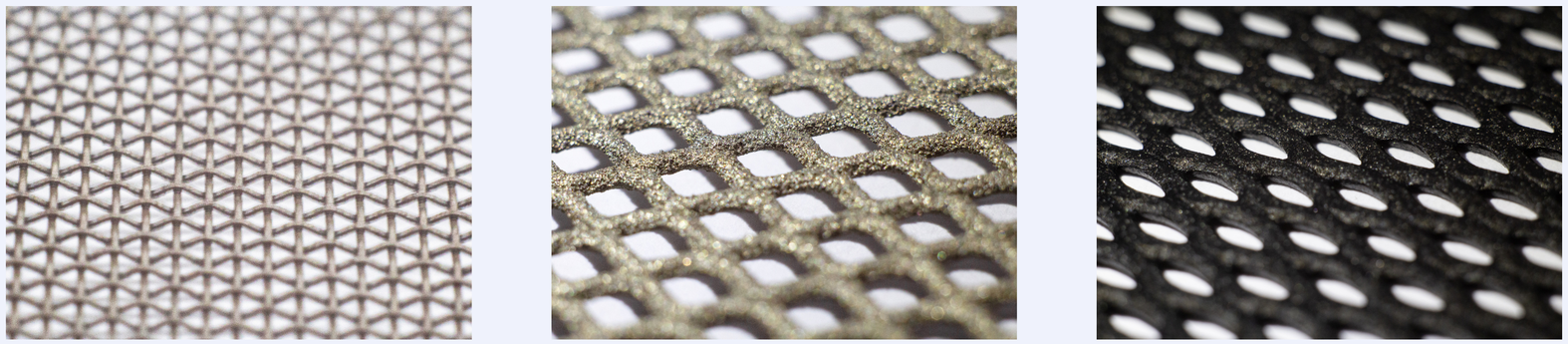
Custom Size



Custom Geometries



Custom Substrates



Electrolyte LOOP quality

The table below shows the maximum allowable concentration of some critical pollutants in the electrolyte loop to reach the higher performance and longer life of the electrodes:

Component (cations)	Conc.	Unit
Iron	1	ppm (w/w)
Chromium	5	ppm (w/w)
Calcium / Magnesium	10	ppm (w/w)
Chloride	100	ppm (w/w)
Carbonate	10.000	ppm (w/w)
Silica	20	ppm (w/w)
Sulphate	1.000	ppm (w/w)

In case of higher pollutant concentrations, electrode's performace can be impacted, this should be discussed with De Nora Sales and/or Business Development.

Demi water quality

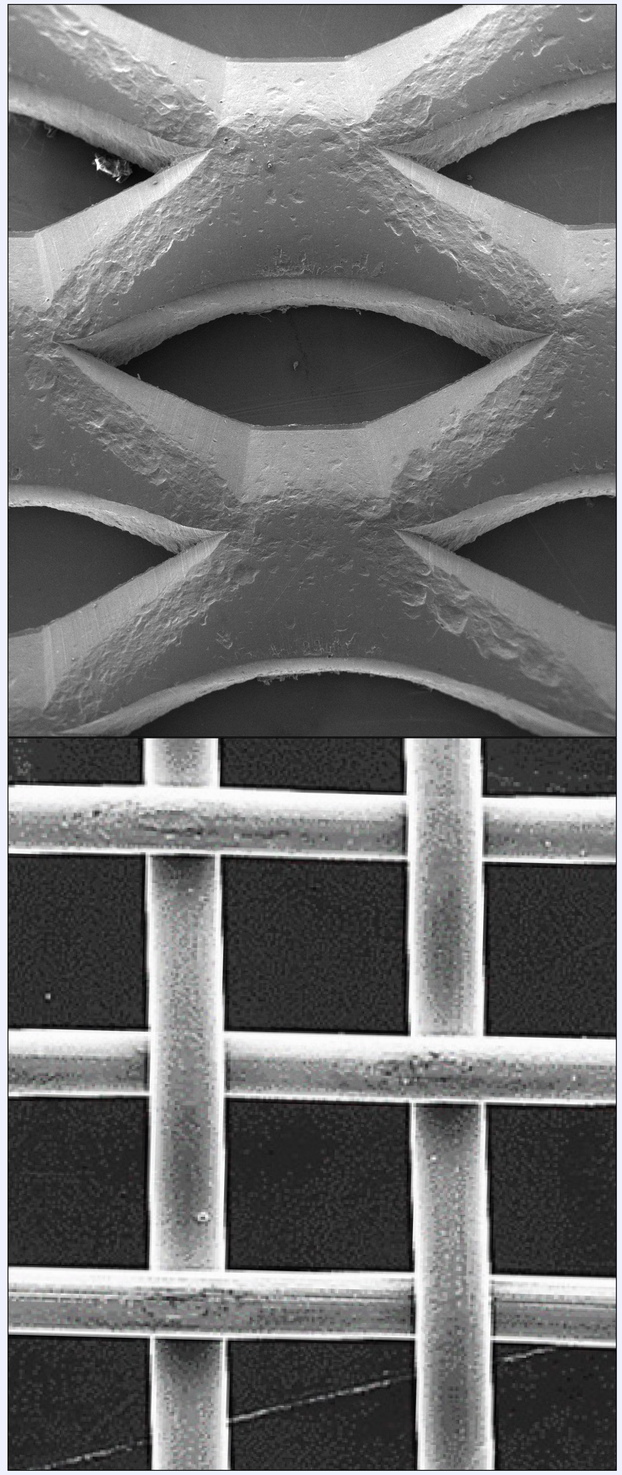
The table above indirectly determine the feed demi water quality. A simple material balance of the system, considering the initial KOH purity, the BOP material corrosion rate and the demi water feed quality, should close (at the end of the expected electrodes life) on the pollutants concentration value reported in the table.

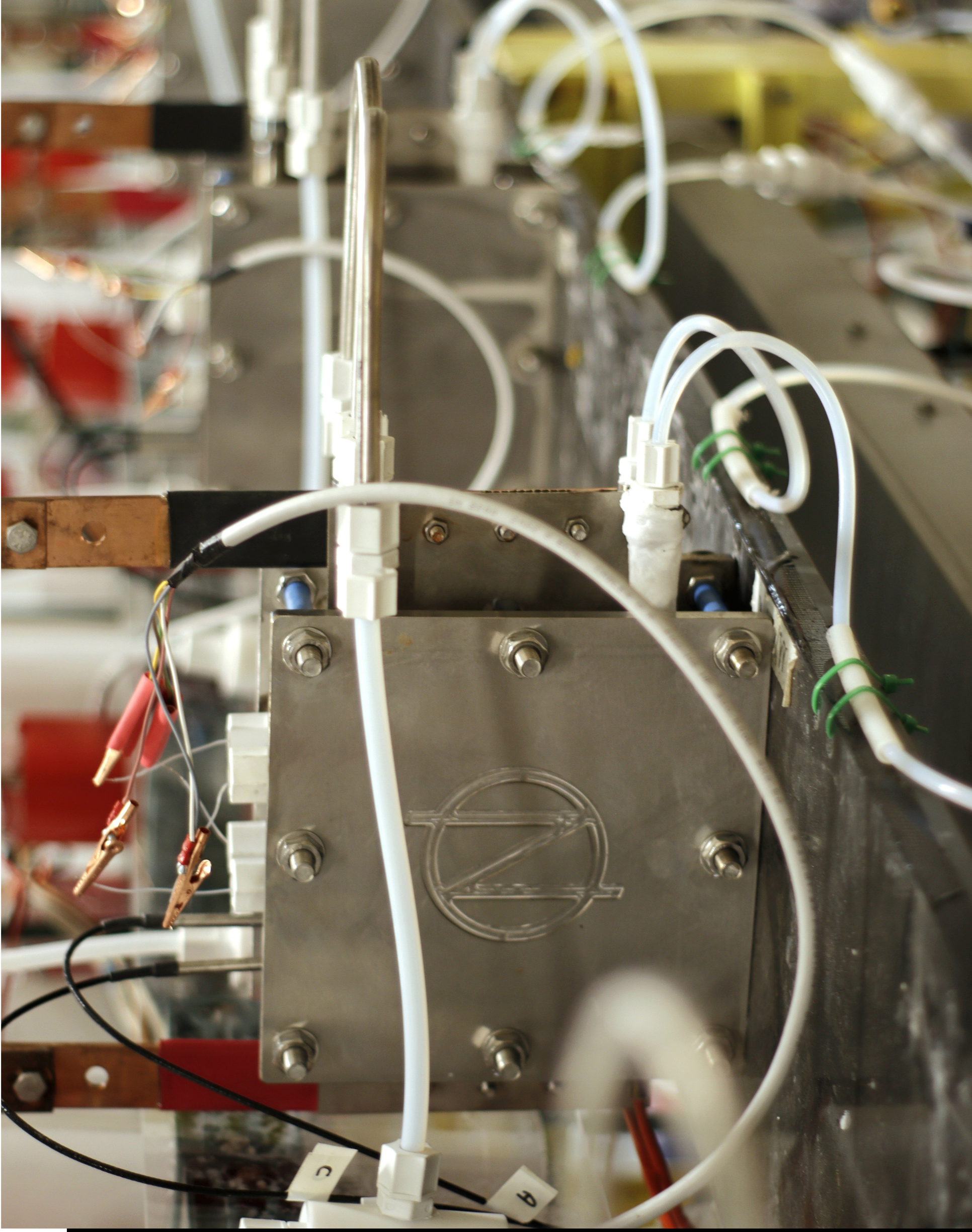
More details on feed water quality and maximum allowable pollutants concentration in the electrolyte loop could be provided by our experts on request.

Operating Conditions

Electrolyte	KOH or NaOH (28%-32% w/w);
Temperature	**70 ÷ 85°C** (design) or higher depending from the STACK / BOP (balance of plant) design temperature;
Pressure	**Up to 60 bar(g)** (design) depending from the STACK/BOP design pressure;
Circulation	**Forced or natural** (gas lifting), depending from the design Current Density (CD), Cell Voltage, (CV) and the operating pressure; Normally the electrolyte circulation configuration and its flow rate are defined in collaboration with our experts to limit the ΔT (delta temperature) through the cell;
Current Density	**Up to 12 kA/m²**

Electrode

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Services

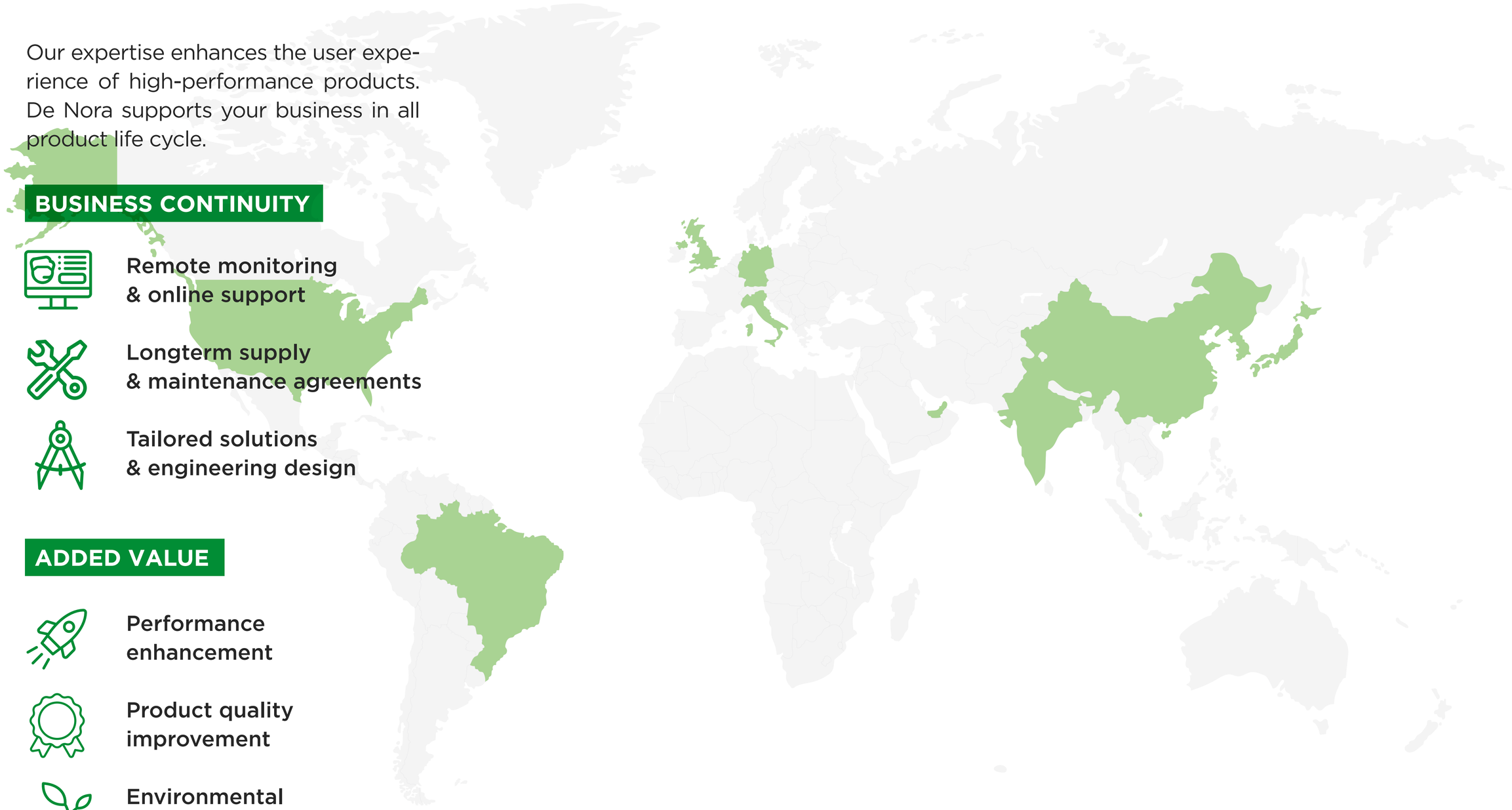
Our expertise enhances the user experience of high-performance products. De Nora supports your business in all product life cycle.

BUSINESS CONTINUITY

- Remote monitoring & online support
- Longterm supply & maintenance agreements
- Tailored solutions & engineering design

ADDED VALUE

- Performance enhancement
- Product quality improvement
- Environmental sustainable solution



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ETR-AWE2405001