Electrode Package

The heart of Electrolyzer

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-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.

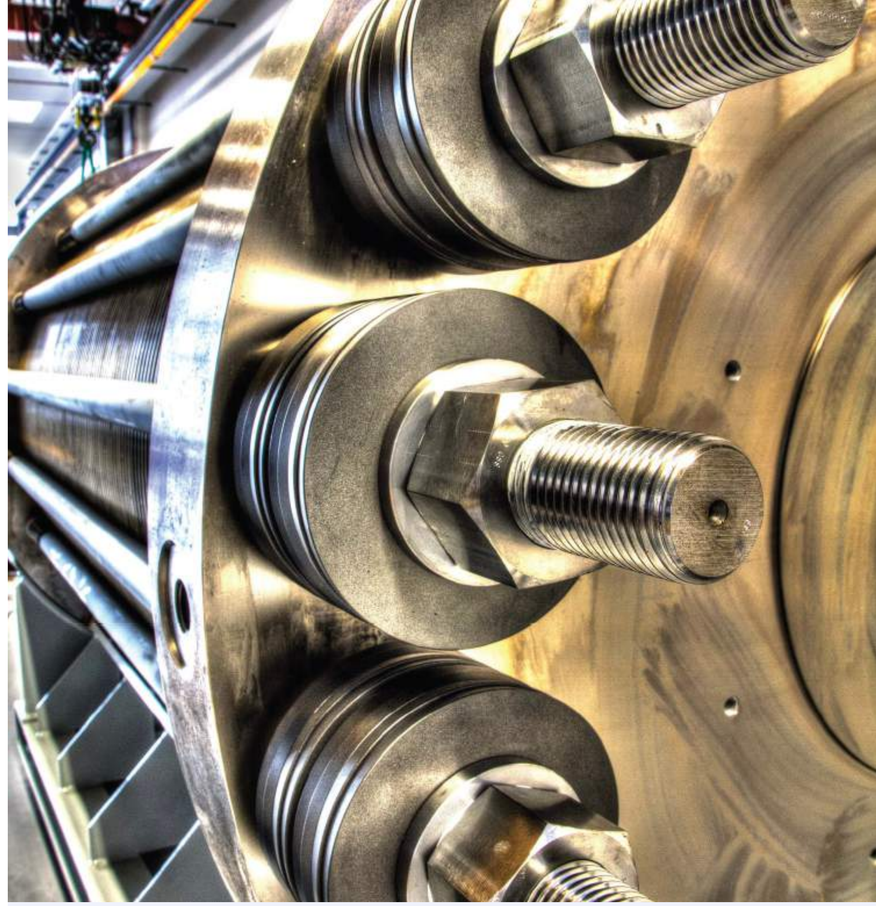
In the Energy transition process, **Green hydrogen** is widely recognized not only as a promising option for storing large quantities of renewable electricity over long periods of Power to Power **(P2P)** and as an energy vector for more sustainable **Mobility** (through Fuel Cell Electric Vehicle), 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.

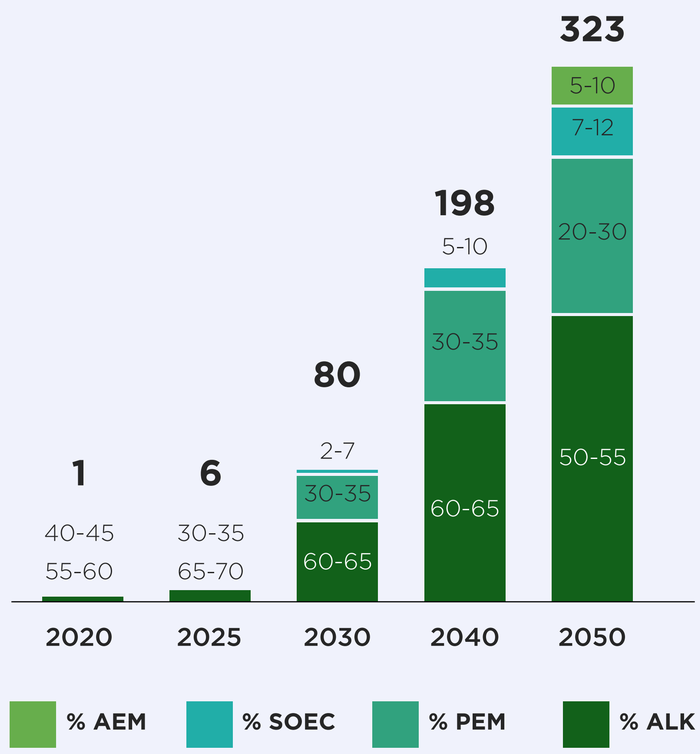
Four main electrolyzer technologies are used or being developed:

- **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 the **"De Nora electrode Package".**



Hydrogen Production by technology in Mtons*



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

Electrode Package
The Heart of the Electrolyzer

De Nora provides customers different combinations of anode and cathode coatings as a function of the electrolyzer operating conditions, the overall required performance in terms of cell voltage and the availability of a higher CAPEX expenditure for obtaining the lower possible OPEX.

De Nora offers, embedded into the "package", in addition to the electrodes, other cell internals such as the cell bipolar plates, the anode/cathode separator (membrane or diaphragm) and the related gasketing system (between the separator and the cell frames).

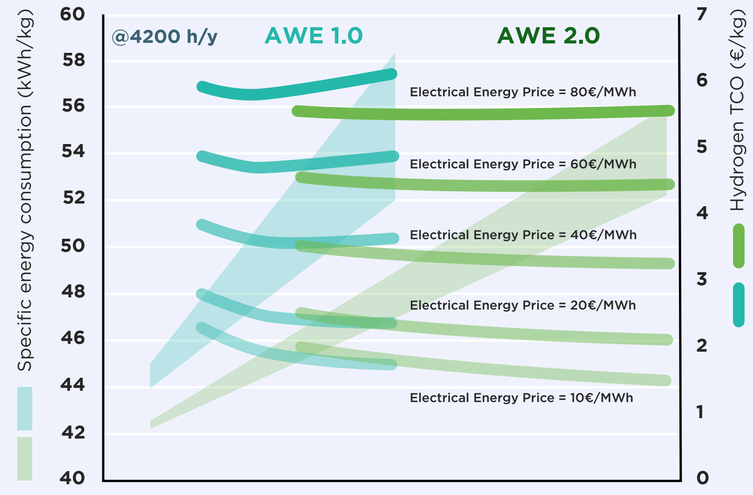
De Nora could supply, as an alternative to the "package", the active electrodes only, realized following customers' proprietary drawings and therefore easy to install inside the existing electrolysis cells/stacks.

De Nora's R&D efforts were focalized on pursuing the **lower Total Cost of Hydrogen (TCO)** through a reduction of the overall AWE plant footprint (maximizing the operating current density) and the optimization of the overall power consumption (increasing efficiency and operating pressure), while maintaining a low manufacturing cost of the electrolyzer.

The electrodic package design started from the necessity of guaranteeing a perfect and "live" ZERO GAP configuration, able to ensure anode and cathode contact to the diaphragm in any operating conditions and along the overall life of the package.
In the electrodic package, the cathode is always activated to reduce the hydrogen evolving over potential, while the anode can be activated or not, depending on the requested performances.

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 lower TCO.

Installation of De Nora package into an existing AWE cell architecture can increase the operating CD by more than two times, maintaining or even reducing the cell voltage



Electrodes coating life time: > 5 years (#, ##)
Electrodes coating performances drift:

Cathode performance drift: **< 0,5 % / Year**
Anode performance drift: **< 0,5 % /Year**
Parameters affecting the electrodes coating performances decay are:

- Operating current density (CD);
- Pollutants concentration in the electrolyte loop;
- Number of starts / stop in unprotected (no polarized) conditions.

(#) Electrodic package life time indicated above refers to a current density of 9 kA/m2;
In case of a higher current density (up to 10 kA/m2) and/or a required lifetime period beyond 5 years, the subject should be discussed in detail with De Nora specialists;

(##) The acceptable number of unprotected shut-downs (complete system shut down, no load fluctuation) per day should be discussed and agreed between the customer and De Nora because impacting on the coating solution choice;

Electrode Package

The Heart of the Electrolyzer

Bipolar plates
If requested

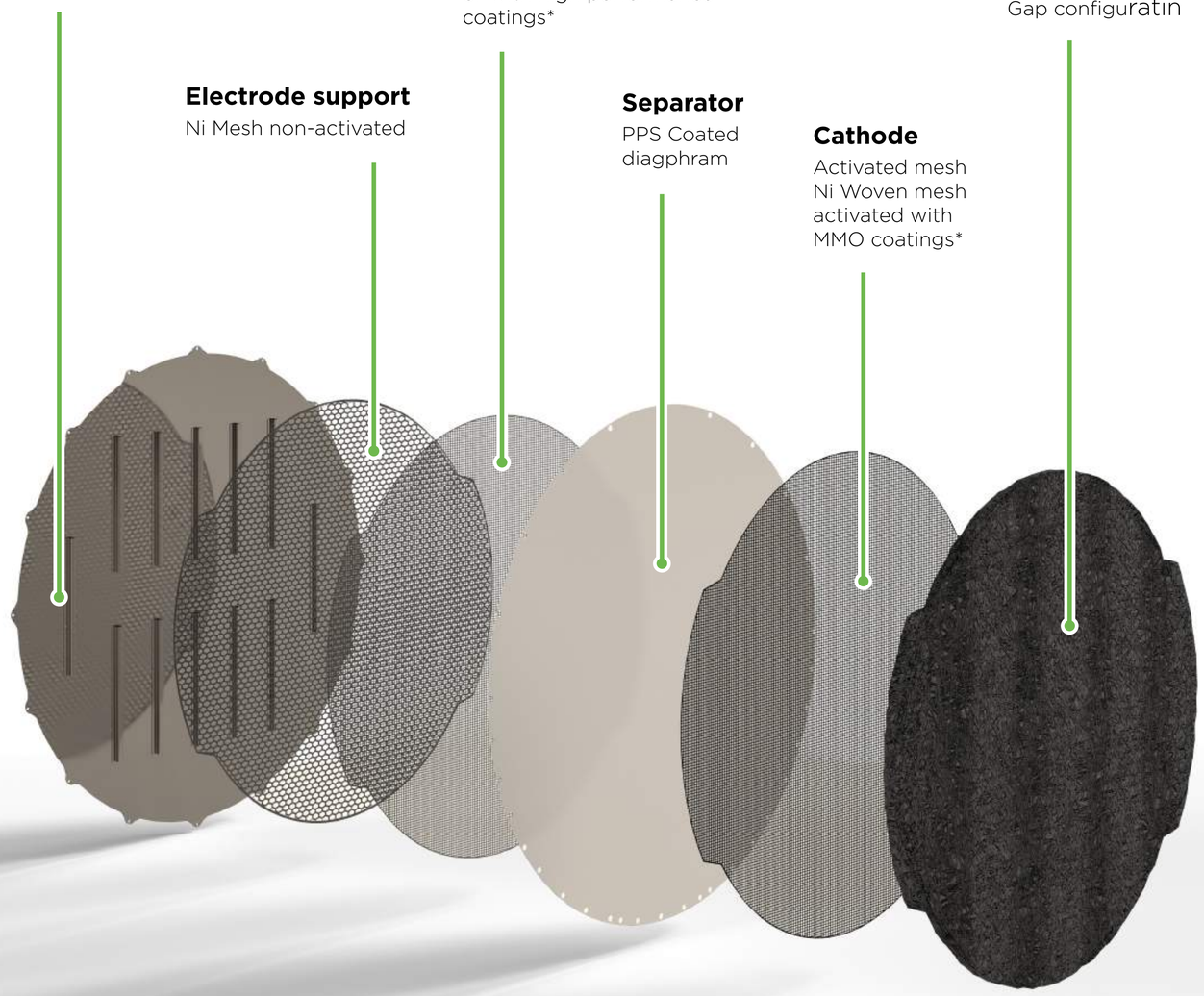
Electrode support
Ni Mesh non-activated

Anode
Nickel substrate
Ni woven mesh non-activated or with high performance coatings*

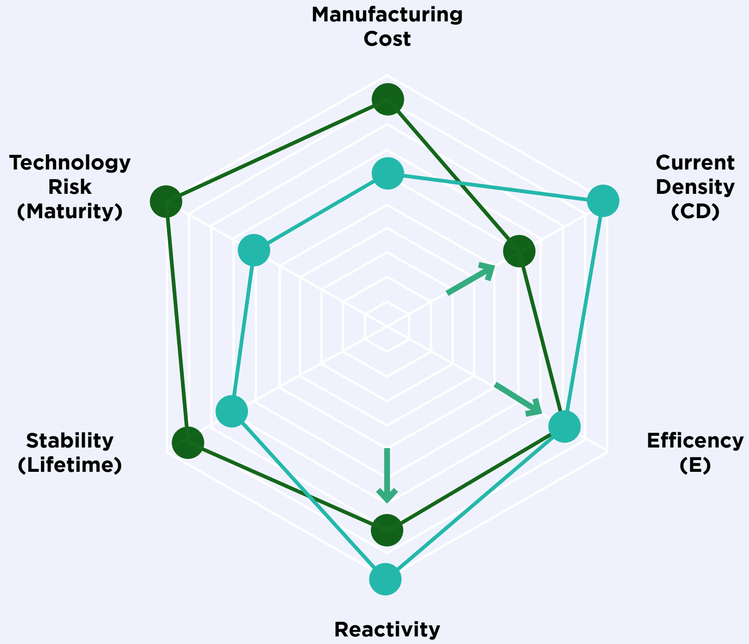
Separator
PPS Coated diagphram

Cathode
Activated mesh
Ni Woven mesh activated with MMO coatings*

Flow Fields
Ni mattress for Zero Gap configuratin



De Nora's electrodic package pushes Alkaline Water Electrolysis toward PEM Water Electrolysis performances, allowing the best TCH (Total Cost of Hydrogen)



High current density (CD) allows a reduction of stack footprint, increasing the electrode's specific hydrogen production (Kg/h/m2) and reducing CAPEX investment.

Efficiency (therefore, the cell voltage-CV at a certain load-CD) is increased, reducing the specific energy consumption (kWh/Kg) impacting CAPEX.

Furthermore, the system is very reactive, allowing the stack to follow the power output from Renewable Energy at best.

*Our experts will help you to find the best coating for your application.

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 package:

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, Package's performace can be impacted, this should be discussed with De Nora Sales and/or Business Development.

Demi water quality

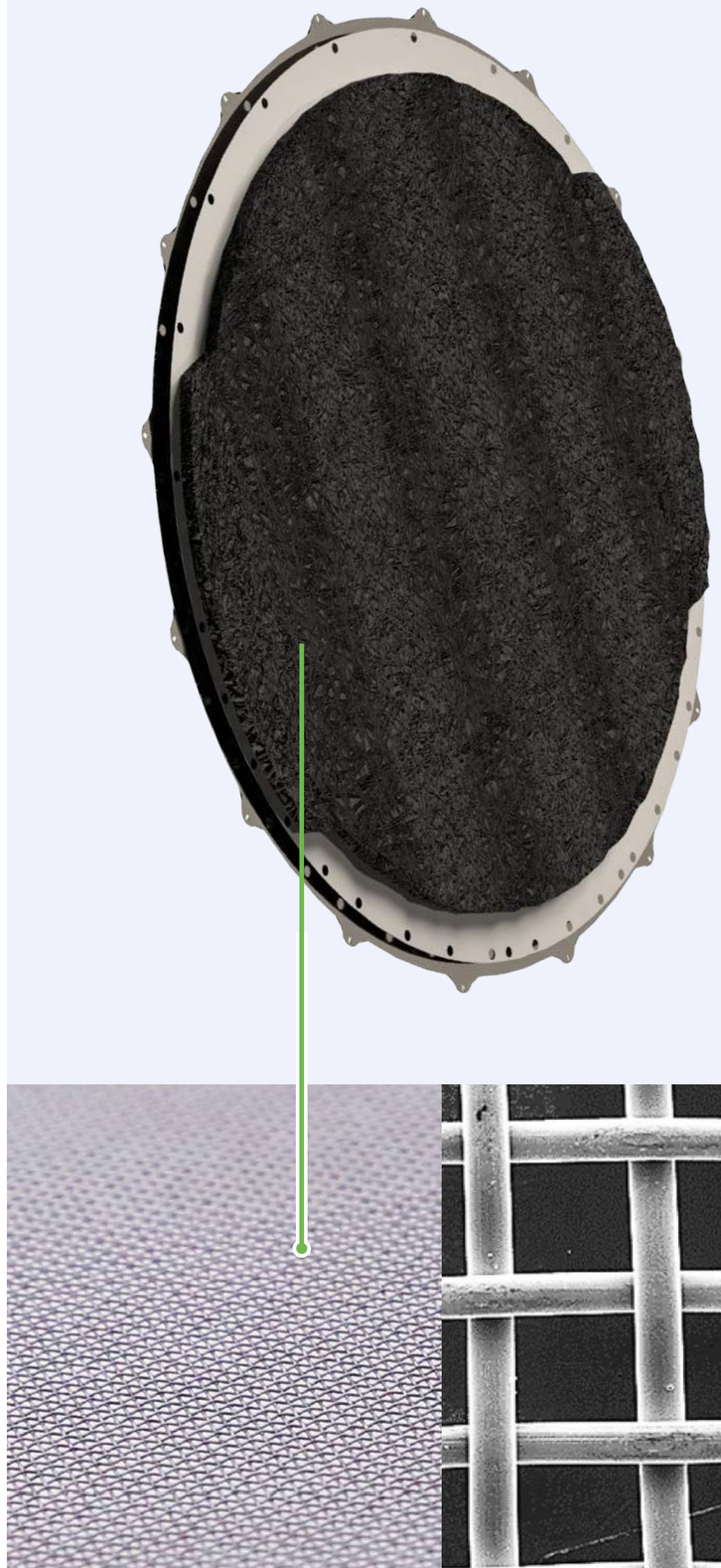
The table above indirectly determines the feed demi water quality. A simple material balance of the system, considering the initial KOH purity, the BOP material corrosion rate and the demi water feed quality, should close (at the end of expected electrodes life) on the pollutants concentrations value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

More details on feed water quality and maximum allowable pollutant 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 on the STACK / BOP (balance of plant) design temperature;
Pressure	**Up to 60 bar(g)** (design) depending on the STACK/BOP design pressure;
Delta Pressure	0.2 bar (design) max differential pressure between anodic and cathodic chambers;
Circulation	**Forced or natural** (gas lifting), depending on 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 $^{\Delta}$T (delta temperature) through the cell;
Current Density	**Up to 12 kA/m²**

Electrode Package



Services

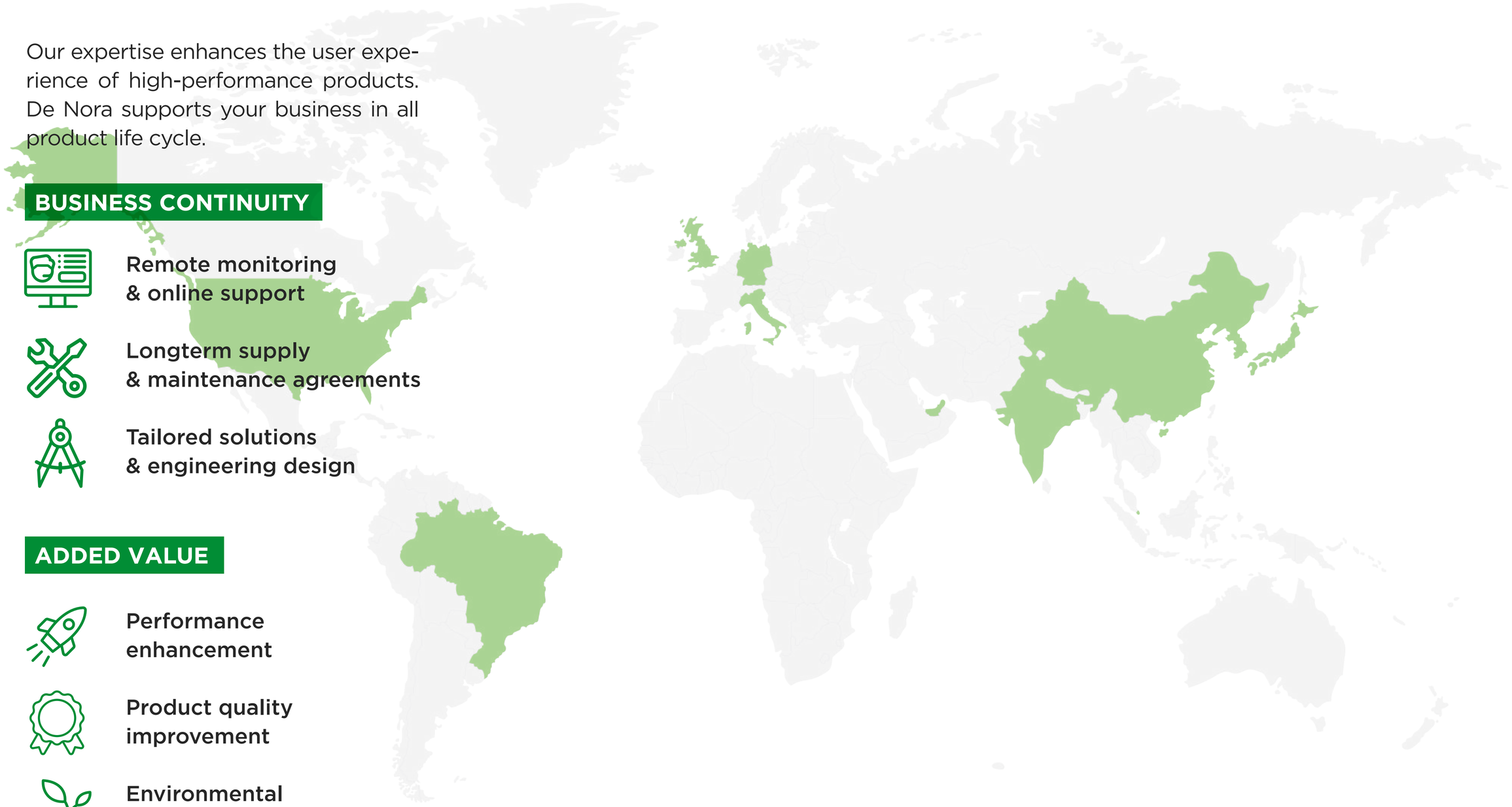
Our expertise enhances the user experience of high-performance products. De Nora supports your business in all product life cycle.

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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Electrode Package Solution Brochure
ETR-EP2405002