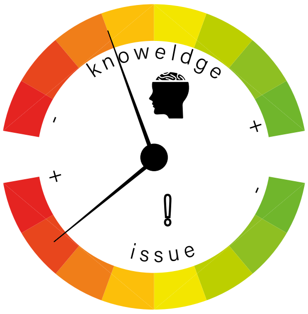
Do the metals released by galvanic anodes used in offshore wind farms pose a risk to the marine environment?


© Pichitstocker/AdobeStock

Bulletin n°8
June 2023

The **COME3T label** aims to promote research projects designed to enhance knowledge of the environmental and socio-economic issues arising from the development of offshore renewable energies.

It comes under the COME3T initiative, a committee of experts for environmental issues related to offshore renewable energies, which brings together neutral, independent experts to provide scientific knowledge and recommendations in response to these issues.



Question deemed by the experts to be "a major issue with regard to the concerns of civil society and the current state of knowledge, which is considered low due to the difficulty in establishing robust (reliable) thresholds (PNECs) for certain substances"

Scientific experts

Isabelle Amouroux - Analysis of chemical risks and contamination in the marine environment (Ifremer)

Emmanuel Aragon - Ageing of materials and corrosion in a marine environment (Université de Toulon)

Christelle Caplat - Study of the toxicity of metals on marine organisms (Université de Caen-Normandie)

Jean-Louis Gonzalez - Passive sampling, chemical contaminant concentration measurements (Ifremer)

Nicolas Michelet - Seabed modelling and dynamics (France Energies Marines)

Georges Safi - Ecosystem approach, ecosystem interactions and ORE (France Energies Marines)

*With the participation of **Rui Duarte** (France Energies Marines) and **Thierry Burgeot** (Ifremer), scientific coordinators of the ANODE project (Quantitative evaluation of metals released into the marine environment from the galvanic anodes of ORE structures).*

Coordination, compilation and drafting

Sybill Henry - France Energies Marines

Introduction

The use of cathodic corrosion protection systems in the marine environment is not a new phenomenon. Such systems are commonly used to protect ships, maritime and port infrastructures, etc. However, with the development of offshore wind farms, environmental concerns over this issue are rising among public authorities and the general public, particularly in relation to the risks of metal pollution and its potential impacts on water quality and the functioning of marine ecosystems.

In order to gain a better understanding of the risks for the marine environment posed by the installation of these corrosion protection systems, the ANODE project[1], conducted between 2019 and 2020, had two main objectives:

- To assess the chemical compounds released by anodes associated with offshore wind farms
- To quantify the risks associated with the dispersal of these chemical compounds in the marine environment for living organisms in the water column.

This bulletin, produced in collaboration with the experts involved, presents the main results of this project.

Galvanic anodes on the jacket foundation of a wind turbine

© France Energies Marines

---

[1] ANODE project, Quantitative evaluation of metals released into the marine environment from the galvanic anodes of ORE structures.

Definitions

Ion

An ion is an electrically charged atom or group of atoms (molecule) that has gained or lost one or more **electrons** (negatively charged elementary particles). There are two categories of ions: cations, which are positively charged, and anions, which are negatively charged.

Anode and cathode

An **anode** is an electrode at which a chemical reaction known as oxidation takes place, releasing electrons. An oxidation reaction is always associated with a reduction reaction. This reaction takes place at the surface of a **cathode**, which is an electrode that gains the electrons produced at the anode. The difference in electrical potential between the anode and cathode induces an electric current that flows in the reverse direction, from the anode to the cathode, in a medium rich in **electrolytes**, i.e. minerals (such as sodium, potassium or calcium) capable of carrying an electric charge when dissolved in a liquid such as seawater.

Polarisation

Polarisation refers to the separation of the electric charges of a material or a solution, resulting in a difference in **electric potential** between two electrodes. Due to this difference in potential, the anode and cathode are polarised surfaces.

Conductivity

Capacity of a medium (electronic or ionic conductor) to carry an electric current, expressed in Siemens (S) as a function of distance (S/m). The opposite of conductivity is **resistivity**, i.e. the ability to resist the flow of an electric current, expressed in Ohms (Ω) as a function of distance (Ω.m).

Speciation

The **speciation** of a contaminant refers to the identification of all the different "forms" (dissolved and particulate) in which the compound is present in a given environment. Speciation will depend on the physico-chemical properties of the compound and the environment (pH, concentration of suspended matter, nature of the particles, etc.).

Corrosion potential

The **corrosion potential** is used to distinguish between metals according to their resistance to

Galvanic anodes on the jacket foundation of a wind turbine

© France Energies Marines

corrosion. For a given medium, the higher the corrosion potential of a metal, the more "noble" the metal is considered to be (Fig. 1). The most noble metals (i.e. those most resistant to corrosion) include gold, silver and platinum.

Chemical risk

The probability of occurrence of an undesirable or harmful effect on a species or group of species when exposed to a chemical substance. The chemical **risk** is dependent on two distinct concepts: the **hazard** and the **exposure**. A reduction in exposure and/or hazard can reduce the risk.

Hazard

The intrinsic capacity of a substance to cause undesirable or harmful effects on a species or group of species.

Exposure

The level to which individuals of one or more species are exposed to a chemical substance.

Sensitivity

The sensitivity of a biological compartment or species is defined by its capacity to tolerate changes to the environment (resistance) and the time required for it to recover following these changes (resilience)[2].

Ecotoxicity

The harmful effect of one or more chemical substances on living organisms and on the ecosystem as a whole.

Pelagic

A **pelagic** organism is an organism that spends all or part of its life cycle swimming (case of many fish) or floating (case of plankton and many larvae of marine species) in the water column.

Benthic

A **benthic** organism is an organism that spendsthe majority of its life cycle (or even its entire life cycle) on or near the bottom or in the sediment.

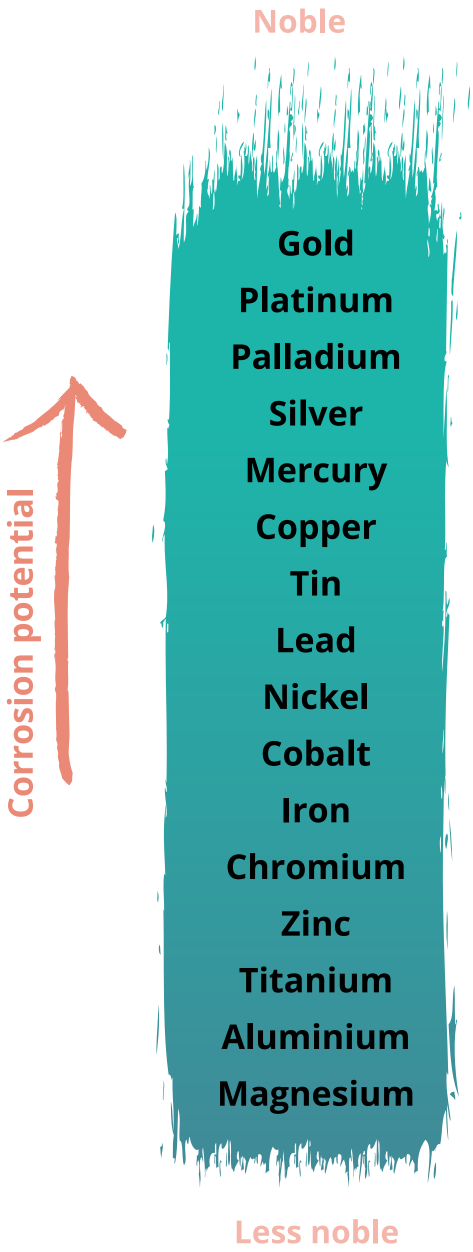


Fig. 1 *Diagram showing the classification of different metals according to their corrosion potential in a seawater environment. Based on the definition of corrosion given by AFICPAR*[3].

Biota

The biota corresponds to all the living organisms (flora and fauna) in a given environment or habitat.

---

[2] Definition taken from the work of the working group on cumulated effects under the French Ministry in charge of the environment and derived from the French order of 17 December 2012 relating to the definition of good ecological status.

[3] AFICPAR: The French-speaking Society of Certified Inspectors in Anticorrosive Protective Coatings

Basic principles

Corrosion on a metal surface

© Andrew Martin / Pixabay

What is corrosion?

Derived from the Latin *corrodere* which means "to gnaw, to attack", corrosion is a natural phenomenon resulting from the interaction between a metal and its environment. This interaction deteriorates the metal, altering its properties. The durability of metals in an environment will depend on their mechanical resistance (fatigue, erosion, etc.) and their corrosion resistance. This is an important factor to consider when designing an infrastructure. Corrosion can lead to additional costs for the replacement or repair of corroded materials and for protective measures (coatings, etc.) or preventive measures (oversizing of structures, maintenance, etc.). Knowledge of the corrosion of metals by seawater dates back to the 15th century, when it was observed that when wooden-framed ships took on water, the diameter of the nails in contact with seawater decreased over the years due to corrosion. In seawater, metal corrosion is said to be **electrochemical**, i.e. it causes a chemical reaction resulting in electron transfer. This is known as a **redox (or oxidation-reduction) reaction**. This irreversible reaction occurs between a metal and an "oxidising" agent in the environment:

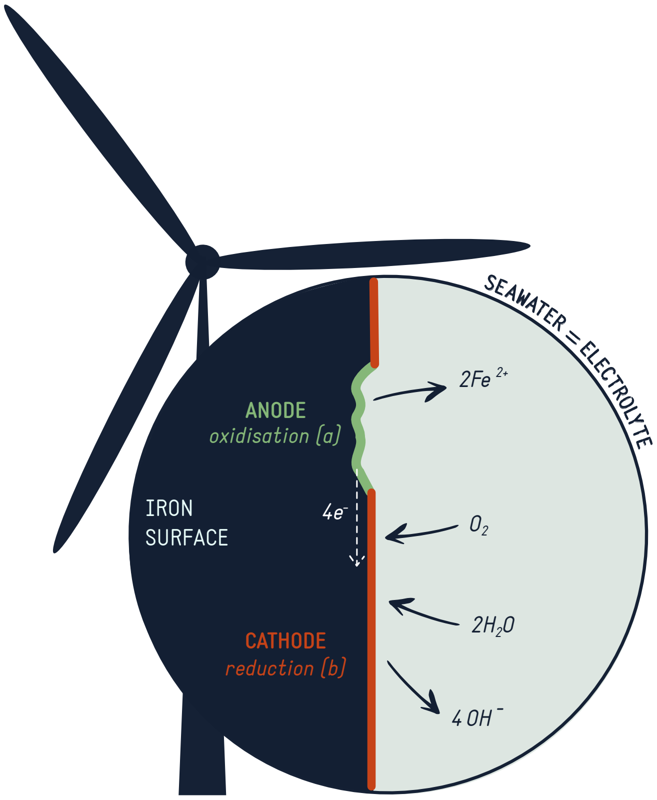
metal + oxidising agent > oxidised metal + reducing agent

In this reaction, the chemical element that gains the electron is called the **oxidant** and the element that donates it is called the **reductant**. In the marine environment, the main oxidising agent is dissolved oxygen.

The case of steel

Composed of 99% iron, steel is the most widely used material in the maritime industry. Corrosion of steel involves two simultaneous reactions:

- an **oxidation reaction (a)** in which the iron (Fe) is transformed to iron(II) ions (Fe^{2+}) and releases two electrons ($2e^-$);
- a **reduction reaction (b)** in which the two electrons ($2e^-$) are used by water (H_2O) and oxygen (O_2) molecules dissolved in seawater to form hydroxide ions (OH^-). These two reactions take place simultaneously on the surface of the metal in contact with the seawater. The release of electrons creates an electric current through the electrolyte, from the area where the Fe^{2+} ions are released, known as the **anode**, to the area where these electrons are captured, known as the **cathode**.



© Siegrid Design

Fig. 2 *Diagram of the redox reaction of iron (the main component of steel) in the marine environment*

Seawater, which is rich in ionic content, carries the current and causes iron(II) ions (Fe^{2+}) and hydroxide ions (OH^-) to dissolve. These ions lead to the formation of iron hydroxide ($Fe(OH)_3$) and iron oxide (Fe_2O_3), and are responsible for the solid, visible product of corrosion: **rust** (Fig 2).

The degree of corrosion of metals varies depending on whether the structure is immersed permanently, periodically (for instance in a tidal area) or, in the case of aerial parts, exposed to splashes or condensation.

Protection against corrosion

What corrosion protection methods exist?

To reduce the risk of corrosion in offshore structures, various protection and prevention systems are used, often in combination. They have long been used in different maritime sectors (shipping, maritime safety, port management) and can be divided into the following categories:

- Protective **coatings** include so-called "organic" coatings, such as anti-corrosion paints and metallic coatings (generally composed of a less noble metal than steel, such as zinc). These coatings can be applied in the factory prior to assembly of the structure or on site, particularly during maintenance operations to protect submerged or emerged structures;
- Improving structure **design** to reduce the risk of corrosion by minimising areas where seawater can stagnate and enhancing water flow;
- **Oversizing** structural members to allow for corrosion-induced material losses throughout the structure's lifetime. This strategy is often used to compensate for the corrosion of port structures without resorting to specific protection systems but rather to periodic checks and maintenance operations where necessary;
- **Cathodic protection**, which aims to reduce the corrosion potential of submerged structures by installing anodes, which may be sacrificial or associated with an external current source (impressed current). Widely used in the maritime sector (merchant ships, freight transport, port structures, oil rigs, etc.), these two protection systems are presented in detail later in this document.

What protection systems are used in offshore wind farms?

As for any human activity involving the installation of offshore structures, the development of wind farms must take account of corrosion risks when designing structures, particularly those that will be in permanent contact with seawater.

Offshore wind farm

© Thomas / Pixabay

The different types of foundations used for bottom-fixed wind turbines (monopiles, jacket foundations, gravity foundations – reinforced concrete structures containing steel) and floating wind turbines (barges made of steel or reinforced concrete containing steel) are mainly made of **steel**, for technical and cost-related reasons. Steel is an easy material to work with, and its high mechanical strength means it can withstand considerable stress. It is therefore the ideal choice for use in a marine environment exposed to natural forces (waves, wind, tide) that can be particularly strong (winter storms, etc.). It is strong enough to carry heavy weights and is abundantly available. Steel is also reusable (it can be remelted without affecting its properties) and durable; it is therefore attractive for long-term investments, given the expected lifetime of offshore wind farms (25 to 30 years, on average).

While it offers many advantages, steel is nevertheless a metal that, when in constant contact with seawater (foundations and submerged parts of floats), is subject to **corrosion**. To mitigate this risk, corrosion protection systems are installed on offshore wind farms. **Cathodic protection systems**, possibly together with anti-corrosion paint, are the most common solutions.

Impressed current cathodic protection systems

Impressed current cathodic protection (ICCP) systems require an electrical power supply. A **direct current** runs between the structure to be protected and an auxiliary anode. This anode is made of a noble metal (that is wear- and corrosion-resistant) with a high electrochemical potential. It is connected to the positive terminal of a generator, while the structure to be protected is connected to the negative terminal (Fig. 3).

This electric current will **artificially polarise** the surface of the structure to be protected by imposing a potential in order to suppress natural oxidation. The structure will be protected to a varying extent according to the intensity of the current (in the case of insufficient current, corrosion will be slower but still present and the structure will therefore only be partially protected). The generator is usually installed on the structure to be protected which has the advantage of being able to adjust the power supply according to the resistivity of the environment.

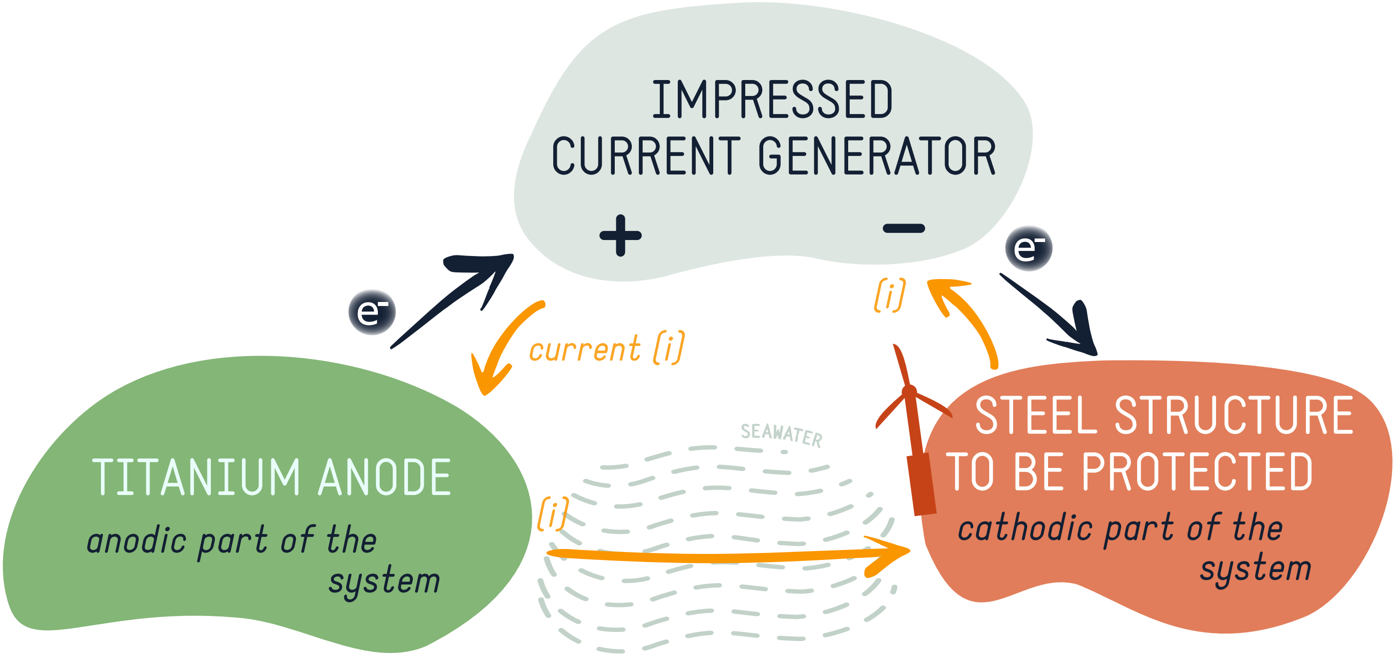


Fig. 3 *Diagram illustrating how impressed current cathodic protection (ICCP) systems work.*

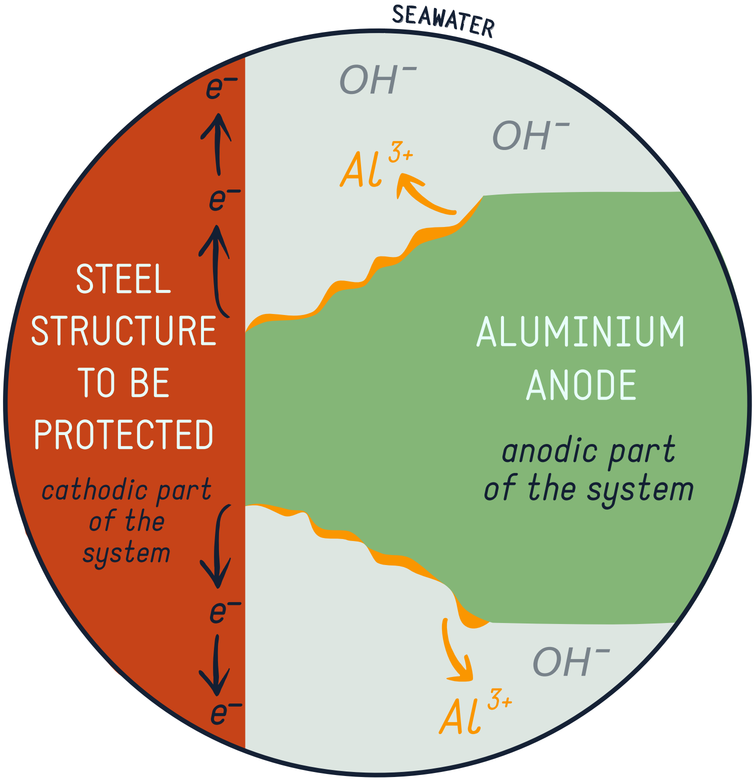
ICCPs therefore offer long-term protection and can cover large submerged surfaces. However, they require a constant power supply and closer monitoring due to the risk of reduced efficiency in the event of system failure or malfunction.

Sacrificial or galvanic anodes

The use of galvanic anode cathodic protection (GACP) systems involves installing **galvanic anodes**, made of a less noble metal than steel (usually zinc or an aluminium alloy) with a lower electrochemical potential, on the structure to be protected. In a conductive medium, the oxidation reaction will therefore take place on the metal with the most electronegative potential and will induce **cathodic polarisation** of the structure to be protected. The anode will therefore be corroded instead of the structure itself. This explains why the term **sacrificial anode** is used for this type of protection system (Fig. 4).


Galvanic anodes on a ship's hull

© Mark Sølvgren / Pixabay



© Siegrid Design

Fig. 4 *Diagram illustrating how galvanic anode cathodic protection (GACP) systems work.*

At sea, GACP systems are used to prevent the corrosion of port facilities, offshore structures and ships' hulls using aluminium or zinc anodes. For offshore structures, aluminium anodes are mostly used because of their electrochemical capacity. These anodes must comply with certain **standards[5] that define the required quality and composition.**

Once the design (geometry and surface area) of the structures to be protected is known, the number of anodes required can be estimated. The fraction of galvanic anodes that will be consumed over the lifetime of the project can then be calculated and the mass percentage that will be "sacrificed" estimated. For optimal protection, these anodes should (i) be positioned far enough apart from each other to adequately protect the entire surface of the structure and to avoid interaction effects that could reduce the polarisation capacity and (ii) not be installed near to a weld or an area exposed to high stress. The principle and design of such protection systems are fairly simple and they do not need constant monitoring. However, they require a large number of anodes and can increase the weight of structures.

---

[5] NF EN 12496. French and European standards in force on galvanic anodes for cathodic protection in seawater and saline mud. AFNOR standards (https://www.boutique.afnor.org/en-gb/standard/nf-en-12496/galvanic-anodes-for-cathodic-protection-in-seawater-and-saline-mud/fa150108/41877)

The ANODE project

The main aim of the ANODE project, carried out between 2019 and 2020, was to characterise the risks associated with chemical contaminants liable to be released by galvanic anodes, with a particular focus on aluminium-based anodes. A chemical risk assessment was therefore carried out to determine whether the chemical substances released by galvanic anodes (GACP) could pose a risk to the marine environment. This risk assessment was carried out substance by substance. It was based on a comparison of two criteria for all the relevant environmental compartments (water column, sediment and biota for the marine environment):

- The Predicted Environmental Concentration (PEC);
- The Predicted No-Effect Concentration (PNEC).

This was an iterative process, in which the first stage was based on a worst-case scenario to ensure a high level of protection for the marine environment.

For the ANODE project, the risk assessment focused only on the water column. The information presented below includes the results obtained from (i) modelling of metal dispersal in the marine environment and (ii) the assessment of the associated risks. The case study selected was the site of the Courseulles-sur-Mer offshore wind farm (France, Normandy), an area exposed to tidal currents.

The study focused on the water column as:

- This is the compartment into which metal substances from galvanic anodes are liable to be released and are most readily assimilated by marine organisms;
- Sufficient data (bathymetry, currentology, etc.) is available to conduct modelling scenarios.

How can we assess the risk associated with the release of chemical substances by galvanic anodes on living marine organisms in the water column?

A hydrodynamic model was developed as an initial approach to predicting metal dispersal in the water column. It was used to determine a predicted environmental concentration (PEC) that could be compared with existing PNECs.

The risk assessment method used follows the technical and regulatory framework set out by REACH[6] (derived from the European regulation of the same name). This method characterises the environmental risk as the ratio between: (i) the exposure of a species to a chemical (via the exposure threshold established by the PEC) and (ii) the ecotoxicological effects that this substance will have on an individual, species or group of species (via the hazard threshold defined by the PNEC). This is known as the **risk characterisation ratio**. It is used to assess whether or not a chemical substance poses a risk to the environment (ratio < 1). This method is composed of three key stages, outlined below (Fig. 5):

- Inventory of chemicals (1);
- Definition of hazard and exposure thresholds (2);
- Risk assessment (3).

---

[6] REACH, Regulation (EC) No 1907/2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals, establishing a European Chemicals Agency. Available on the EUR-Lex website (https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:02006R1907-20140410)

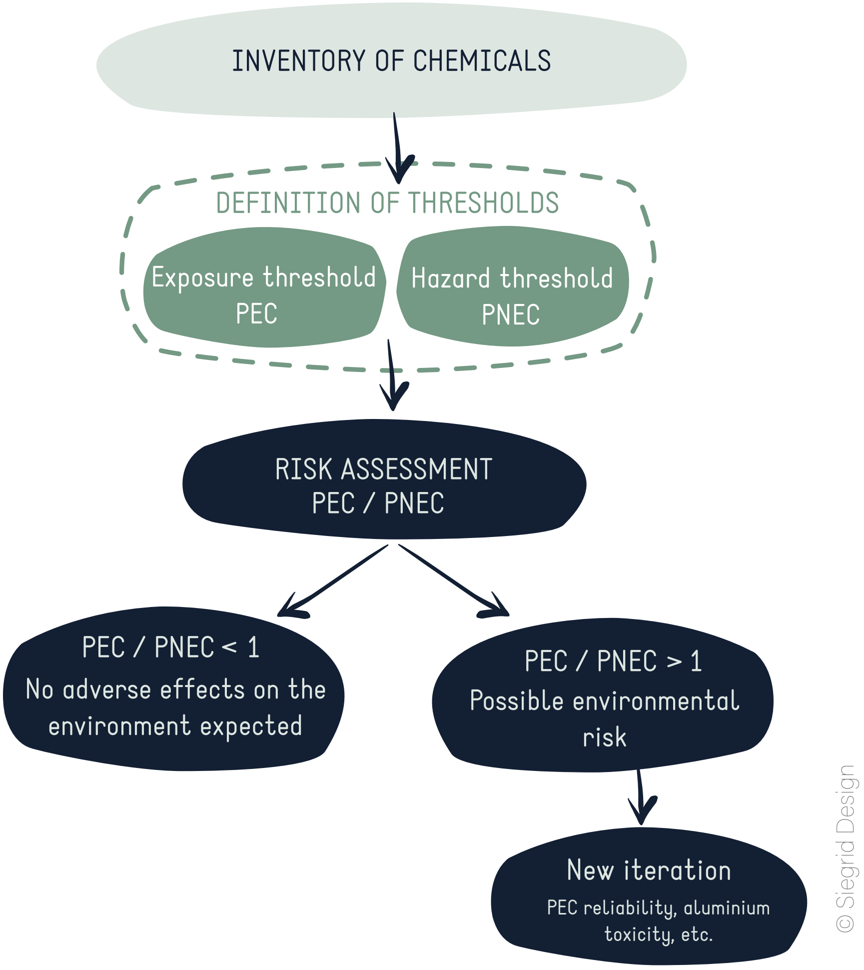


Fig. 5 *Conceptual diagram of the method used to characterise the environmental risk posed by metal elements released by galvanic anodes.*

Which chemical contaminants are liable to be released by GACP anodes?

To characterise the potential releases from galvanic protection systems into the marine environment, first all the chemical substances liable to be discharged must be identified. By studying the composition of galvanic anodes, an exhaustive inventory of the chemical substances liable to be released into the marine environment can be drawn up. Today, galvanic anodes used to protect large submerged structures are mainly made of aluminium and zinc. Given the "sacrificial" behaviour of galvanic anodes, the list of chemical substances released by the anodes is naturally linked to the list of metals of which they are composed (Tab. 1).

	% of total mass
Aluminum (Al)	94
Zinc (Zn)	5.75
Silicon (Si)	≤ 0.12
Iron (Fe)	≤ 0.09
Indium (In)	≤ 0.040
Copper (Cu)	≤ 0.003
Cadmium (Cd)	≤ 0.002

Tab. 1 *Composition of an aluminium galvanic anode based on the information provided in the recommended practice DNVGL-RP-B401, which defines anode composition standards.*

How do these chemical contaminants interact with living marine organisms in the water column?

© France Energies Marines

A galvanic anode at different stages of degradation

The chemical elements released by the anode can migrate in "dissolved" form into the various compartments of the marine environment (water column, sediment, etc.) or precipitate in the form of oxide deposits that form on the surface of the anodes. The **speciation** of these chemical elements will be controlled by the environment's physico-chemical characteristics. The chemicals may be present in forms of varying stability that can be accumulated by marine organisms if they are "bioavailable", i.e. able to be assimilated by marine organisms.

To characterise the risks, a worst-case scenario approach is taken initially. This scenario assumes that all the metal elements released by the anodes will be present in dissolved form in the environment, and are therefore liable to be assimilated by organisms in the water column.

How can exposure and hazard thresholds be defined?

Having identified the chemicals of interest likely to be released into the environment, information must be gathered on the level of exposure of marine organisms to these substances and the hazard this represents for them.

The level of exposure to a substance is determined by its **predicted environmental concentration** (**PEC**), which can be obtained by measuring concentrations *in situ* or by modelling the different environmental compartments. The $PEC_{seawater}$ characterises the level of exposure of pelagic organisms to a substance. In the case of the ANODE project, the $PEC_{seawater}$ values for each substance were obtained by modelling. Based on these values, the ability of metals to disperse in the water column, according to the hydrodynamic conditions in the area and the influence of rivers and streams (dominated by the Seine at the Courseulles-sur-Mer site), could be studied.

The hazard characterisation for a given substance can be established on the basis of the **predicted no-effect concentration** or **PNEC**. This threshold corresponds to the concentration below which adverse effects are not expected to occur for the environmental compartment under consideration (the water column in this instance). In the case of the $PNEC_{seawater}$, with a view to protecting species living in the water column, it is determined from the results of laboratory-based ecotoxicity tests carried out on different species. Depending on the substance, it is not uncommon for the $PNEC_{seawater}$ to be based on a limited amount of data, or even to be unavailable (in the case of silicon, for example).

How can environmental risks be assessed using PEC and PNEC data?

The risk assessment is based on the PEC/PNEC ratio. The $PEC_{seawater}$/$PNEC_{seawater}$ ratio characterises the environmental risk of a given substance for pelagic species in the water column. When this ratio is below 1, no environmental risk is expected for even the most sensitive individuals. However, if the result is greater than 1, the substance is considered liable to pose a risk to the environment. In this case, a new iteration is performed to refine the risk assessment. The worst-case scenario then evolves towards a more "realistic" scenario, still based on existing data. The aim is to refine the PEC by improving the accuracy of the data and/or the PNEC by assessing the robustness of the values used.

Case study: Courseulles-sur-Mer

In the case study carried out at Courseulles-sur-Mer, **no risks associated with the release of zinc, iron, copper or cadmium from the anodes were identified for pelagic species**. The environmental risk could not be characterised for silicon and indium due to the lack of PEC values for these two elements.

In the case of aluminium, the PEC/PNEC indicator was found to be greater than 1. A second iteration was therefore performed to better characterise the risk. It was thus possible to (1) refine the $PEC_{seawater}$, taking into account dispersal of the plume in the Seine at the Courseulles-sur-Mer site, (2) study the robustness of the $PNEC_{seawater}$ and (3) seek results of ecotoxicity tests to refine this $PNEC_{seawater}$. With this approach, which drew on existing results, the risk associated with aluminium emissions could not be ruled out. A final iteration is required before a conclusion may be drawn. It will involve both (i) a better characterisation of the initial concentration in the environment via *in situ* measurements and (ii) the acquisition of additional data to refine the $PNEC_{seawater}$.

Recommendations

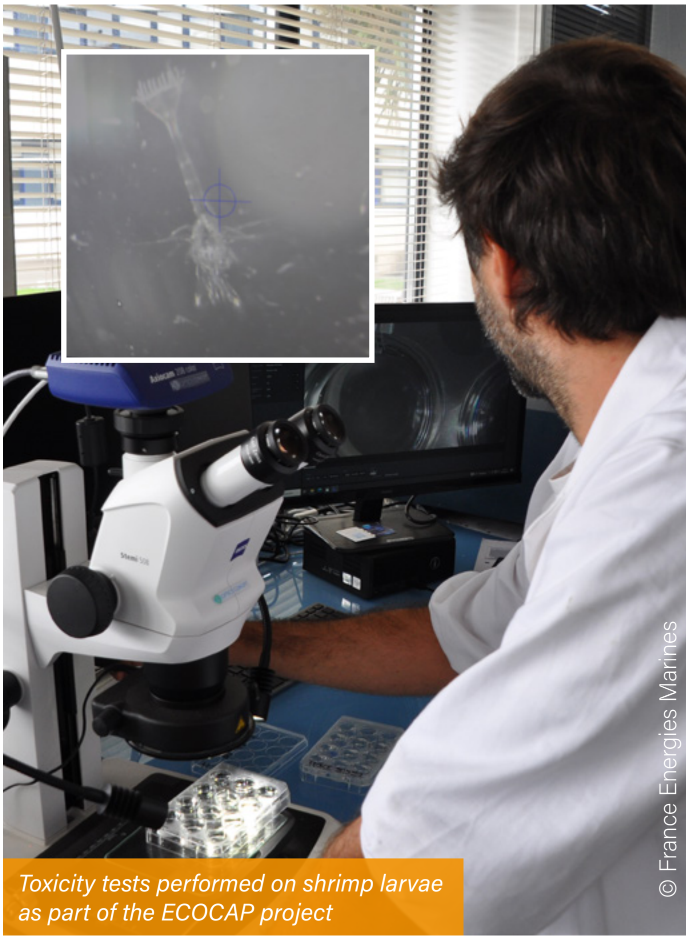
Generally speaking, all the experts involved highlighted the knowledge gaps, in particular in relation to the initial concentrations of metals in the marine environment and the toxicity thresholds for certain substances, especially aluminium. To fill these gaps, a number of recommendations, notably from the ANODE report, are put forward here:

- Define a baseline for each site which sets out (i) the initial concentration levels of metal elements (*in situ* measurements) and (ii) the hydrodynamic conditions in order to establish the dispersal capacity of the substances;
- Improve knowledge of the dissolved and assimilable chemical forms of the metal elements (speciation) released by anodes and conduct ecotoxicological tests on marine species in order to refine the $\mathrm{PNEC}_{\mathrm{seawater}}$ for aluminium;
- Refine the PNEC and PEC values for seawater, ensuring that the two values are comparable (same compartment);
- Conduct an assessment of the sediment compartment to complete the risk assessment process.

The development of offshore wind farms off the French coastline could be combined with the implementation of long-term research and monitoring projects to improve knowledge of the concentrations and environmental risks associated with the use of galvanic anodes.

Outlook

Following on from the work conducted under the ANODE project, the ECOCAP project[7], launched in 2021, aims to gain a better understanding of the potential environmental impacts of corrosion protection systems, focusing on GACP, ICCP and anti-corrosion paints. In accordance with the ANODE project's recommendations, one of the objectives of this project is to refine the aluminium toxicity threshold, in order to come to a conclusion on the risk associated with aluminium in the water column. The POLLUECUME project[8] will develop an initial approach to assessing the chemical risk for the sediment compartment.


Toxicity tests performed on shrimp larvae as part of the ECOCAP project

© France Energies Marines

---

[7] ECOCAP, Ecotoxicology analysis of cathodic protections to assess the chemical risk of elements released from galvanic anode and impressed current on the marine environment and its food webs. 36-month project (2021-2024). Additional information available on the France Energies Marines website: https://www.france-energies-marines.org/en/projects/ecocap/

[8] POLLUECUME, Study of the effects of pollution from compounds released by sacrificial anodes and impressed current protection systems on the seabed. Project led by GT ECUME. Additional information available on the website of the French Ministry in charge of energy transition: https://www.eoliennesenmer.fr/observatoire/ecume

Conclusion

Galvanic anodes have been long used in industry and maritime transport and there is **good knowledge of how they work.** However, environmental concerns over the use of these protection systems are relatively recent and focus especially on the development of wind farms. By combining ecotoxicological expertise and hydrodynamic modelling, **the ANODE project determined that there is no risk associated with most of the elements liable to be released by galvanic anodes, i.e. zinc, iron, copper and cadmium.** However, **additional experiments are required for aluminium**, given the predicted no-effect concentrations (PNECs) currently available, which do not appear to be suited to this type of assessment. These measurements must therefore be refined and data from *in situ* measurements be considered in order to estimate the risks associated with the release of aluminium.

IN SHORT

Corrosion is a well-known natural phenomenon that results from the interaction between a metal and the surrounding environment. The cathodic anode protection systems used in offshore wind farms have long been used in other maritime sectors (shipping, navigation aids, port management, etc.). Two types of anode can be used: impressed current (ICCP) anodes and sacrificial or galvanic (GACP) anodes. The ANODE project, which focused on characterising the risks associated with chemical contaminants liable to be released by aluminium-based galvanic anodes, demonstrated that there is no risk posed by several of their components: zinc, copper, iron and cadmium. No conclusion was able to be reached for aluminium. One of the aims of the ECOCAP project (2021-2024) is to fill this gap by providing answers about the chemical risk associated with the presence of aluminium in the water column.

Find out more

Read the ANODE's recommendation report to learn more about the results of the project:

Further reading

Creus J., Sabot R., Refait P., (2019). Corrosion et protection des métaux en milieu marin. In Techniques de l'ingénieur. COR620 v1, 17 p.

Degraer S., Brabant R., Rumes B., Vigin L., (eds)., (2019). Environmental Impacts of Offshore Wind Farms in the Belgian Part of the North Sea: Marking a Decade of Monitoring, Research and Innovation. Brussels: Royal Belgian Institute of Natural Sciences, OD Natural Environment, Marine Ecology and Management, 134 p.

Kirchgeog T., Weinberg I., Hörning M., Baier R., Schmid M.J., Brockmeyer B., (2018). Emissions from corrosion protection systems of offshore wind farms: Evaluation of the potential impact on the marine environment. In Marine Pollution Bulletin 136, pp. 257-268. https://doi.org/10.1016/j.marpolbul.2018.08.058

Landolt D., (2003). Corrosion et chimie de surfaces des métaux. In Traité des matériaux. Presses polytechniques et universitaires romandes, pp 1-9

Michelet N., Julian N., Duarte R., Burgeot T., Amouroux I., Dallet M., Caplat C., Gonzalez J.-L., Garreau P., Aragon E., Perrin F.-X., Safi G., (2020). Recommendations for the quantitative assessment of metal inputs in the marine environment from the galvanic anodes of offshore renewable energy structures. France Energies Marines Ed., 34 p.

Parant, L., (2012). La corrosion, un fléau pour les navires. Dossier technologies. In Production maintenance, pp. 25-28

Roche M., (2015). L'essentiel sur la protection cathodique. In CEFRACOR, 14 p

---

Please cite this document as follows:
Henry S., Amouroux I., Aragon E., Caplat C., Gonzalez J.-L., Michelet N. et Safi G.
Do the metals released by galvanic anodes used in offshore wind farms pose a risk to the marine environment?
COME3T Bulletin n°08
Plouzané: France Energies Marines, 2023, 20 pages.
Published: June 2023

Legal deposit upon publication.
Layout: France Energies Marines
Graphic design of figures: Siegrid Design
Translation: Alba traduction

COME3T

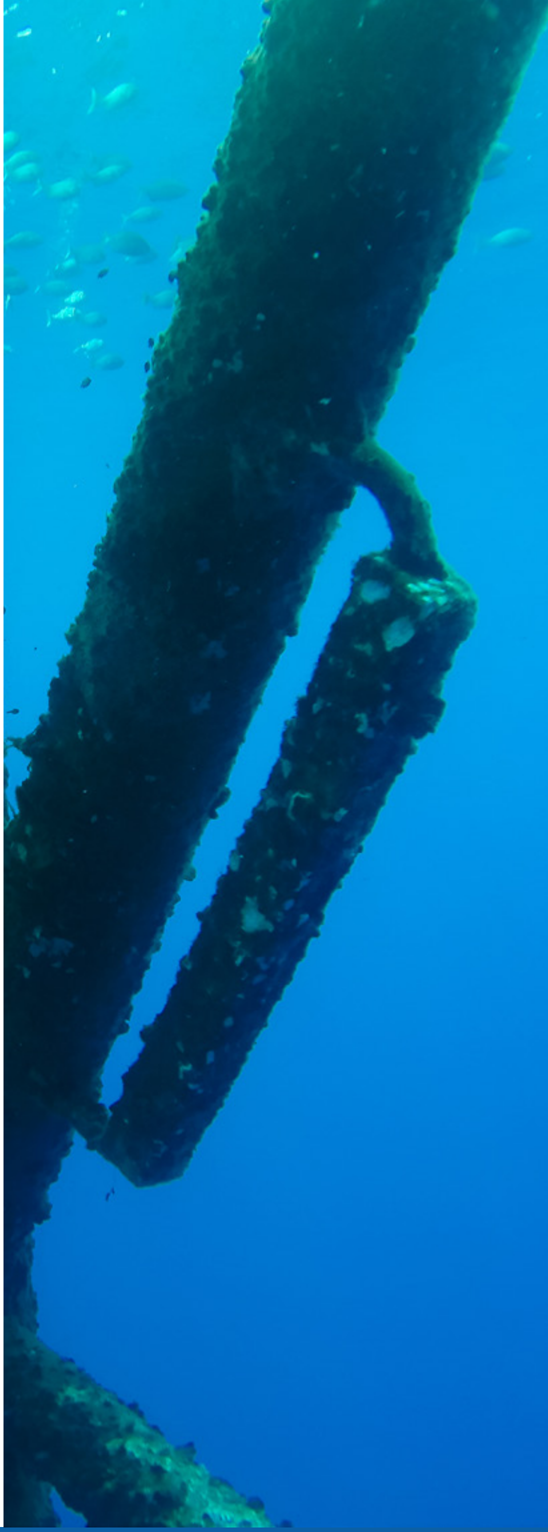
COME3T is an initiative that brings together a panel of national and regional stakeholders (universities, industrial firms, consultants, regions, State services, etc.) within a steering committee that puts forward questions, based on public concerns and key environmental and socio-economic issues identified by the stakeholders, to committees of neutral, independent experts. For each topic, a committee of experts is established following a call for applications and provides information, summaries and recommendations on the environmental and socio-economic issues associated with offshore renewable energy.

https://www.france-energies-marines.org/en/projects/come3t/

An initiative coordinated by France Energies Marines.

FRANCE
ENERGIES
MARINES

France Energies Marines is the Institute for Energy Transition dedicated to offshore renewable energies. Its missions: to define, set up and apply the scientific and technical environment required to overcome the obstacles related to the development of ORE technologies while ensuring optimal environmental integration. Built on a public-private partnership, the Institute is at the interface between institutional (local authorities, regions, etc.), academic, scientific and industrial (project developers and leaders) stakeholders.



Bâtiment Cap Océan
Technopôle Brest Iroise
525, Avenue Alexis De Rochon
29280 Plouzané, France
+33 (0)2 98 49 98 69
www.france-energies-marines.org

ISSN 2743-6942