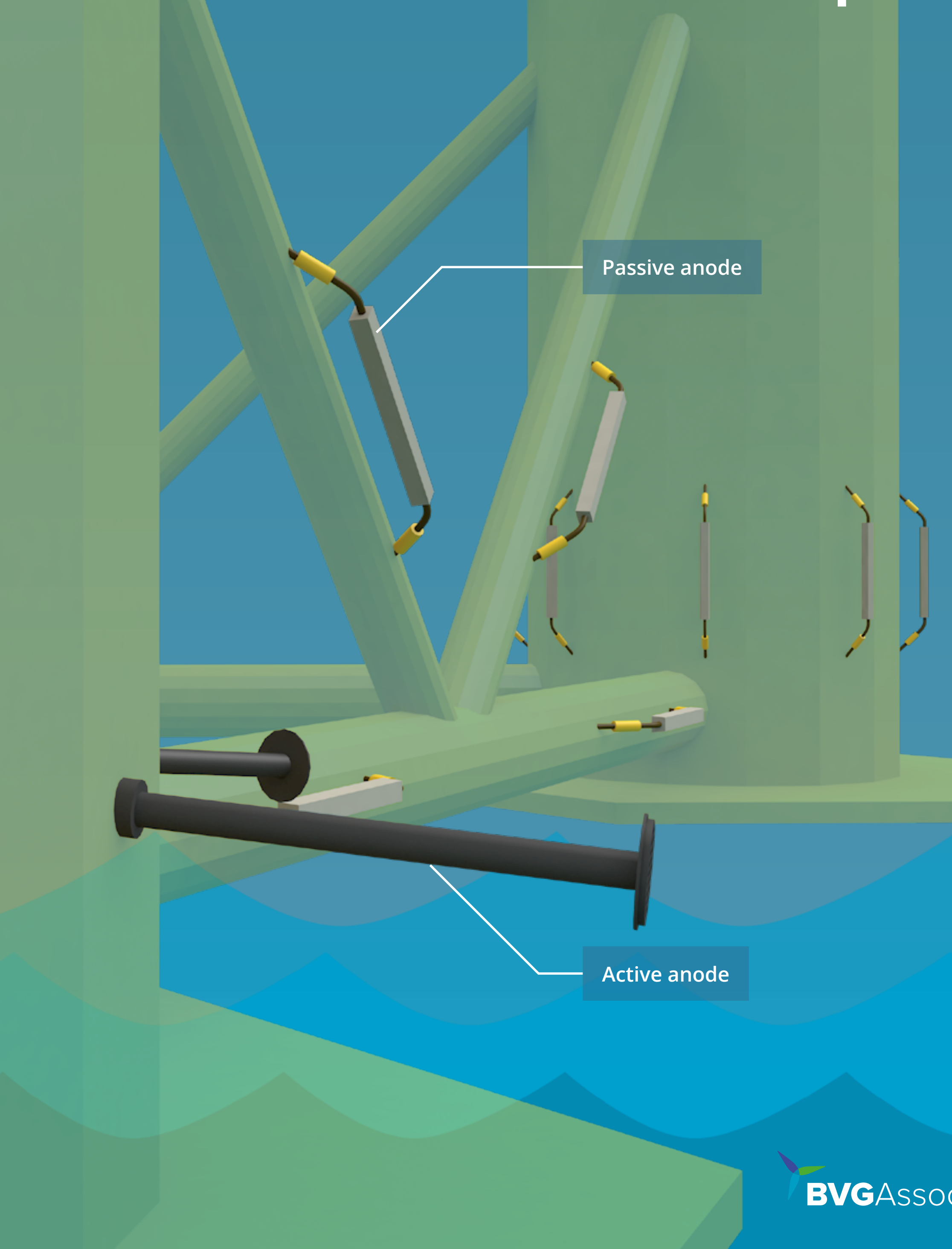
Fact sheet 5: **Corrosion protection**



What are corrosion protection systems?

Corrosion protection systems protect equipment above and below the water line from corrosion. One or more forms of corrosion protection can be used to protect the substructure to the extent that is required, such as a paint barrier with cathodic protection.

Overall description

Corrosion predominantly occurs when sea water interacts with metallic surfaces. This can lead to oxidation (or rusting) of metallic surfaces. Corrosion can also occur from microbiological activity.

Corrosion can compromise the strength and performance by general and localised wall loss in steel substructures such as monopile, jackets, or floating foundations. This can lead to failure of the structure as it is less able to withstand fatigue loads.

Corrosion protection mitigates against corrosion and methods include:

- Protective coatings
- Passive cathodic protection utilises sacrificial galvanic anodes to positively charge the main structure, reducing corrosion risk. However, this process leads to the oxidation and corrosion of the sacrificial anode. Galvanising also works this way, however molten zinc is used to coat steel, rather than using a separate unit.
- Active cathodic protection is where the main structure is positively charged using an external power source causing reduction, therefore protecting it from corrosion.

Both passive and active cathodic protection only work below the water line. Corrosion protection design will allow for in-built corrosion resistance of the material and the overall design may include additional material thickness to allow for some corrosion.

Corrosion protection: Subcomponents

Passive cathodic

Description: Galvanic anode cathodic protection (GACP) systems are comprised of several sacrificial anodes made of aluminium or zinc-based alloys that are fixed to the steel structure below the waterline. These can be designed to be replaced periodically to extend the lifetime of the corrosion protection. The lifetime of a sacrificial cathode will vary based on environmental conditions, and the level of corrosion protection needed. Typically, sacrificial anodes may last anywhere from a few months to several years.

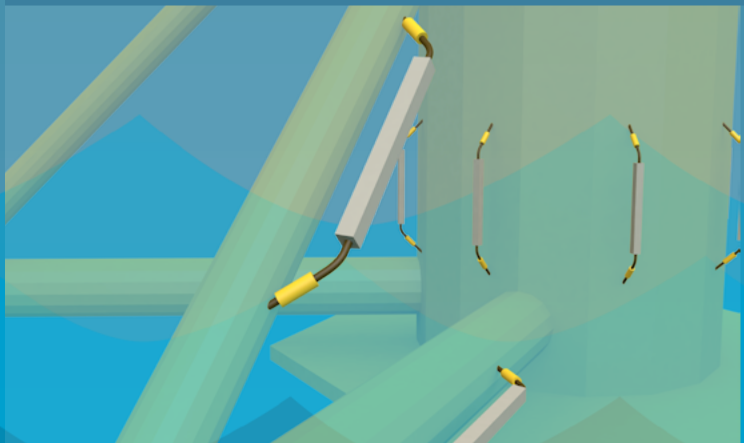
Sub-components: Anodes, anode supports

Applicable standards: DNV-RP-B401, ISO 24656

Typical weights: 100 kg – 500 kg depending on size

Typical dimensions: Anodes are typically 4 m – 6 m in length, 100 mm – 200 mm in height and 150 mm to 300 mm in width.

Anode support dimensions will vary greatly depending on design, see the Secondary Steel factsheet for detailed information.



Active cathodic

Description: Impressed current cathodic protection (ICCP) systems use an external DC power source and rectifier to supply a negative current to the steel structure and a corresponding positive current to non-consumed anodes mounted internally and adjacent to the structure. An ICCP is substantially lighter and causes less drag in the water than GACP but requires a reliable power supply and additional instrumentation. They are attached to the foundations below the waterline using bolts and a flange. Their exact position must be selected to minimise potential impacts with access or maintenance vessels.

Sub-components: Anodes, bolts, cables, casing, flange, power cabinet, protection cap

Applicable standards: DNV-RP-B401, ISO 15257, ISO 12473, ISO 24656

Typical weights: Approximately 100 kg – 150 kg per anode and 150 kg per power cabinet

Typical dimensions: Anode OD typically 12.5 mm – 250 mm, lengths of 750 mm to 2,000 mm

Example of an ICCP anode.
Image courtesy of CORROSION. All rights reserved.

Protective coatings

Description: Coatings form a non-permeable barrier between the surfaces prone to corrosion and the outside environment, both seawater and air. All foundations must be yellow above the water line so they can be easily seen by vessels.

Composition: Generally, epoxy resin-based coatings are used. These can either be zinc or non-zinc (typically aluminium) based epoxies. Traditionally, thermal sprayed aluminium (TSA) coatings were used, however this is being phased out with Non-Zinc-Based epoxy resin the preferred solution due to its requirement for fewer coats and integrity.

Applicable standards: NORSOK M501, ISO 12944

Typical weights: Approx. 1 kg/l - 2 kg/l

Typical dimensions: A typical litre of coating can cover 1 m^2 - 2 m^2

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Corrosion protection: Manufacture

Typical manufacturing process

- Passive anodic protection systems are typically made of cast aluminium alloy. Aluminium is melted in a furnace and poured into moulds. Anode supports can be placed directly into the cast aluminium during pouring, creating an integrated unit without having to connect supports to the anode.
- Active anodic protection systems are assembled in a workshop from sourced components.
- Protective coatings are manufactured from input chemicals, usually epoxy resin, polyurethane, polyester and pigments. Chemicals are dispersed to ensure even mixing, mixed, filtered and packaged. If the coatings are sensitive to large temperature variations, heat exchangers can be used to control the temperature of the process.

Component materials

- For protective coatings, epoxy resin, polyurethane, polyester and zinc or glass flake are required.
- Passive anodic protection manufacture requires steel and aluminium alloy, the composition of which is outlined in DNV-RP-B401.
- Active anodic protection requires titanium/mixed metal oxide, zinc, steel, and cable components (see *Fact Sheet 4: Cables and accessories* for more detail).
- Power cabinet manufacture requires power electronics, user interface equipment and display screen equipment.

Assembly of a power cabinet.
Image courtesy of CORROSION.

International Paint and Coating's Interzone 9545 product applied to transition pieces.
Image courtesy of International Paint and Coatings.

Manufacture facility requirements

Passive cathodic protection manufacture facilities requires:

- Metal casting equipment
- Furnaces
- Lifting and handling equipment, and
- Steel fabrication equipment (see Fact Sheet 1: Secondary Steel for more detail).

Active cathodic protection manufacture requires equipment typically found in an electrical workshop, as well as:

- Lifting and handling equipment
- Torque tools to tighten bolts
- Type testing equipment, and
- If in-house cable manufacture is desired, cable manufacture equipment (see Fact Sheet 4: Cables and accessories for more detail).

Protective coating manufacture requires typical chemical process equipment such as:

- Dispersing equipment and mixing vessels
- Pumps and filtration equipment
- Filling and packaging equipment
- Lifting and handling equipment, and
- If temperature must be controlled, heat exchangers.

Corrosion protection: Design data

Component/Sub-component	Cost range	Material	Typical mass	Typical dimensions	Design considerations
Active cathodic	**Approximately £15,000 to £25,000 per turbine, depending on project requirements**	**See below**	**-**	**-**	**To be designed to DNV-RP-B401, ISO 15257 and ISO 12473 and meet the operational requirements of the foundations, site, and O&M philosophy**
Anodes	£300 to £1,500 per anode depending on size	Titanium/Mixed metal oxide anode Zinc reference cell	Approximately 0.1 kg per unit - 30 kg per unit	OD of approximately 12.5 mm - 250 mm Length of approximately 150 mm	Anodes should be designed to comply with DNV-RP-B401, ISO 15257 and ISO 12473. Dimensions and weight will depend on if the anode is internal or external
Bolts	Will vary based on size, material and number required	Stainless steel	Approximately 0.5 kg per bolt	M20 bolt	Bolts are used to fix the anode structure to the turbine via the flange
Cables	Exact cost will depend on the functional requirements of the system and power requirements	Aluminium core. Cross-linked polyethylene or ethylene propylene rubber insulation. Kevlar Polypropylene casing. Steel wire armouring	Approximately 5 kg per m	OD of 2 mm – 5 mm Length will depend on project requirements, but typically 20 m or more	Cables should be suited for offshore use and be reinforced, typically with Kevlar. See *Fact sheet 4: Cables and accessories* for more details
Casing	Approximately £200 to £4,000 per unit	S355 steel	Approximately 100 kg	OD of 100 mm – 250 mm Length of 750 – 1,500 mm	Tubular casing that houses and protects the anode
Flange	Approximately £50 to £100 per unit	S355 steel	Approximately 20 kg	OD of approximately 350 mm Thickness of approximately 30 mm	The flange provides the interface between the anode and turbine structure
Power cabinet	Exact cost will depend on the functional requirements of the system and power requirements	-	Approximately 150 kg	Approximately 500 mm x 500 mm x 1,500 mm	Power cabinets contain the various electronic equipment needed for the anode to function, including rectifiers, electrical control devices and user interfaces
Protective cap	Will vary based on size required and quantity purchased	High-density polyethylene (HDPE)	Approximately 120 g	OD of approximately 400 mm Thickness of approximately 30 mm	End-cap provides protection to the anode

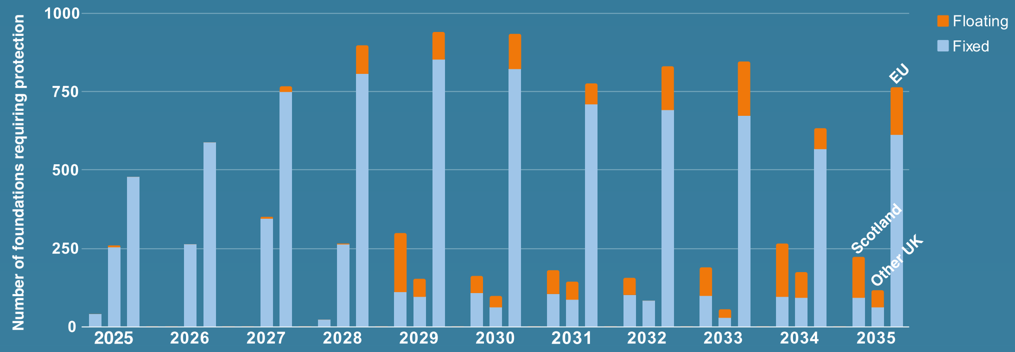
Corrosion protection: Design data

Component/Sub-component	Cost range	Material	Typical mass	Typical dimensions	Design considerations
Passive cathodic	**Approximately £400 to £5000 per unit**	**See below**	**-**	**-**	**Must be designed to meet corrosion protections requirements and O&M philosophy**
Anodes	£300 to £1,500 per anode depending on size.	Aluminium or zinc alloy	100 kg – 500 kg depending on size.	Length approximately 4 m – 6 m Height of approximately 100 mm – 200 mm Width of approximately 150 mm to 300 mm	Alloy composition should align with specifications outlined in DNV-RP-B401
Anode supports	Approximately £150 to £3,000 per unit.	S355 steel	Approximately 50 kg – 1 tonne depending on design.	Approximately 50 cm to 4 m in length depending on design	Different mounting designs can be used, including anode cages, flush mount or stand-off designs. The mount will typically be attached to the anode during casting. See Secondary Steel sheet for more detail
Coatings	**£25 - £100 per litre**	**Epoxy resin Polyurethane Polyester Zinc or glass flake for pigmentation**	**-**	**-**	**Coatings should comply with NORSOK M501 and ISO 12944**

Corrosion protection: Market

Available market

Corrosion protection will be required on all foundations, fixed and floating. The exact methods of protection will vary significantly between designs and maintenance philosophies. The chart below shows the number of foundations (fixed and floating) which will need corrosion protection between 2025 and 2035.



The table below shows forecast values for ScotWind and INTOG projects, based on an 18 MW turbine capacity. Designs of corrosion protection systems for these projects are not confirmed, therefore we have assumed 50% of turbines will use passive protection, 50% will use active and all will use coatings of some sort. The exact choice of components is unknown. The exact number of anodes required will vary significantly based on foundation size and maintenance philosophy so cannot be specifically forecast so only the number of foundations requiring protection is given.

Component	Assumption	Forecast for ScotWind / INTOG*	
		ScotWind	INTOG
Passive cathodic units	50% of turbines, assuming 55 per fixed foundation and 130 per floating foundation	86,000 units	20,000 units
Active cathodic units	50% of turbines, assuming 5 per foundation	4,175 units	765 units
Coating systems	All turbines	1,700 foundations	300 foundations

**this forecast is based on the entire ScotWind/INTOG capacity being installed. This number may decrease if projects are not taken forwards, or increase if projects increase their capacity.*

Route to market

- Corrosion protection systems make up a portion of the balance of plant expenditure of a development.
- Aluminium for melting, steel for fabrication, epoxy resin, polyurethane, polyester and pigments must be sourced.
- Power electronics, user interfaces and display screen equipment can be sourced from external suppliers.
- Passive anodic systems are typically sourced by the T1 and T2 fabricator.
- There is no typical buyer of active anodic protection. Developers, EPC(I) contractors, fabricators and owners all purchase these systems. In this case the buyer will depend on the contract.
- Developers and EPC(I) contractors are reluctant to obtain specific paint and coating contracts. Typically, T1 and T2 fabricators and paint applicators will contract for protective coatings.
- Incumbent suppliers include CORROSION, Imenco, Impalloy, Metec Group, Hempel, Hutchinson Engineering, International Paint and Coatings and Jotun.

Accreditation / regulatory landscape

To achieve accreditation, accrediting bodies will request ISO management documentation, QHSE documentation and qualifications of employees. They will also inspect manufacturing facilities.

For active anodic protection, products must be type tested to give a statement regarding product lifespan.

Standards applying to corrosion protection systems include but are not limited to:

- DNV-RP-B401
- NORSOK M501
- ISO 12473
- ISO 15257
- ISO 12944
- ISO 24656

Corrosion protection: Costs

Typical costs / CAPEX requirements

- Corrosion protection systems cost approximately £22 million for a 450 MW floating offshore wind farm.
- This equates to 48,000 £/MW or approximately £720,000 for a 15 MW turbine's substructure.
- This is approximately 0.8 % of the total project cost.
- This cost is for the corrosion protection work package for a typical floating offshore windfarm as outlined in the cost assumptions. This will include the components described above.
- This cost will vary significantly depending on what is included in the design and the maintenance philosophy, environmental conditions, and the foundation design used.
- Costs are sourced from **The Guide to a Floating Offshore Wind Farm**. See for more information and detail of all cost assumptions.

Potential user costs

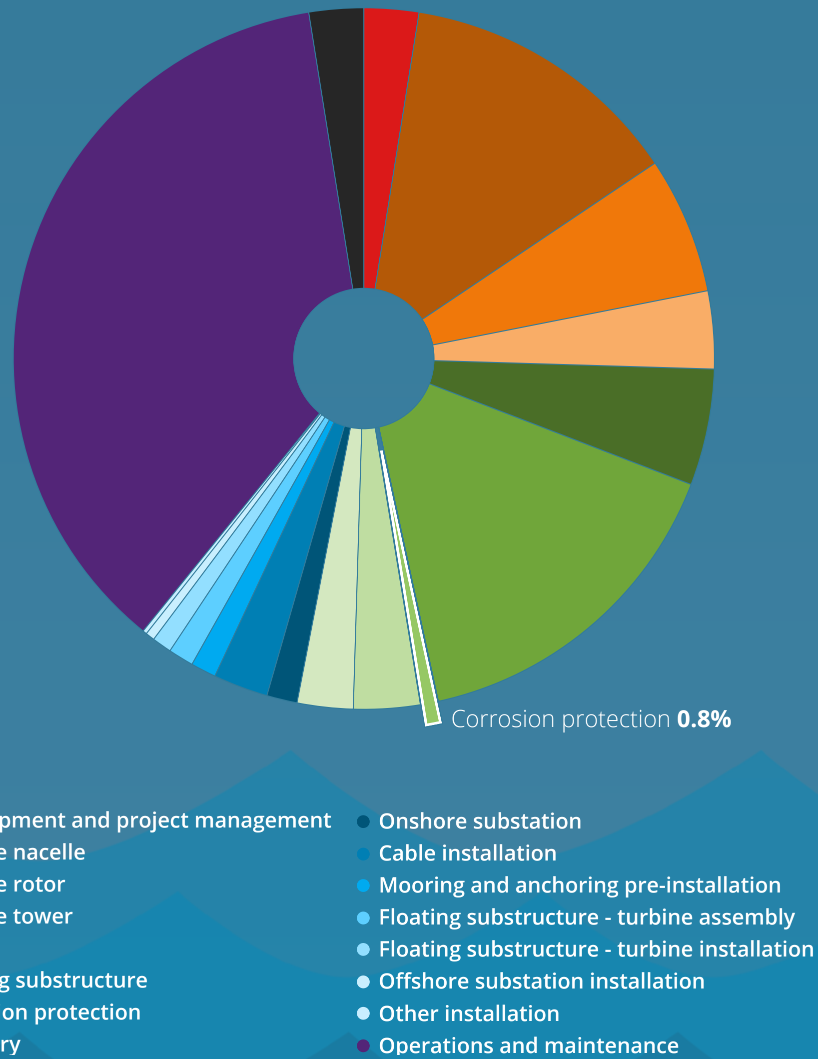
- Where used, Galvanic anodes will need to be regularly monitored and replaced once depleted.
- Active cathodic systems will need to be monitored to ensure they are working.
- Protective coatings will need to be inspected and reapplied on any areas where the protection has worn away.

Support available

For further details on offshore wind supply chain assistance, information, and support programmes available, please contact Scottish Enterprise: offshorewind@scotent.co.uk

450 MW floating offshore wind farm lifetime costs

Lifetime 450 MW windfarm cost approximately £2,600 million.



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Acknowledgements

Scottish Enterprise, Highlands and Islands Enterprise and South of Scotland Enterprise commissioned BVG Associates to produce a number of fact sheets on different aspects of floating offshore wind projects. They are intended to provide background information for companies wishing to enter the offshore wind supply chain. Other fact sheets are available including:

Fact sheet 1: Secondary steel

Fact sheet 2: Anchors and moorings

Fact sheet 3: Cable protection systems, and

Fact sheet 4: Cables and accessories

Thanks to CORROSION and International Paint and Coatings for providing information used in this fact sheet.

Further reading:

Guide to a Floating Offshore Wind Farm

The Guide to a Floating Offshore Windfarm provides more information on supply element of floating offshore wind projects. It has an overview of the important physical elements, lifecycle processes and costs of a floating offshore wind farm.

guidetofloatingoffshorewind.com

guidetofloatingoffshorewind.com/b-2-4-corrosion-protection

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