MATERIAL PASSPORTS

Circular Economy in the Wind Sector – Example

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CONTENTS

NOMENCLATURE

CEAP	Circular Economy Action Plan
CEWS	Circular Economy for the Wind Sector
LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment
NREL	National Renewable Energy Laboratory
ORE Catapult	Offshore Renewable Energy Catapult
PMSG	Permanent Magnet Synchronous Generator

1 INTRODUCTION

The offshore wind sector is fast approaching the point where the earliest wind farms in the UK and across Europe will be decommissioned. With this major milestone there are several key considerations around the supply chain readiness to handle the materials arising in the most environmentally sustainable manner. ORE Catapult developed the Circular Economy in the Wind Sector joint industry programme (CEWS) as an industry-wide initiative to investigate the barriers and opportunities for a sustainable approach to decommissioning. As part of this, the use of material passports within the offshore renewables sector were considered. Existing applications within various sectors - such as construction, battery production and textiles - were reviewed to highlight current developments within industry. Based on current applications and industry recommendations, an example material passport was produced for an offshore wind component.

Material Passports or Digital Product Passports are a tool for collecting and transferring information related to sustainability, circularity and value retention along the entire product lifecycle. This can be used at end of life for reuse or recycling. As products move from the supply chain to consumers and then to end of life, material passports can be continually updated with details such as raw material use, manufacturing processes and product repairs. This creates a traceable and more transparent product lifecycle, enabling stakeholders to make informed decisions about reuse, recycling, or proper disposal.

Material passports can promote more sustainable decision making, such as choosing lower emission manufacturing, transport, and the use of recycled or raw material options, due to increased transparency and tracking of products throughout the value chain. The energy required, emissions released, and carbon footprint of most recycled materials is considerably less than for the manufacture of virgin materials, and reusing components can reduce their lifetime impact even further. Political and social pressure is growing for companies to have higher sustainability goals, with new policy, legislation and international standards being developed.

2 MATERIAL PASSPORTS

2.1 Example of application

Material passports are part of the Ecodesign for Sustainable Products Regulation - Ecodesign Directive 2009/125/EC – which focusses on sustainable and energy efficient products and was proposed at the start of 2022 [1]. This falls under the broader Circular Economy Action Plan (CEAP), which details the main sustainability goals within Europe [2]. CEAP has proposed key industries to introduce digital passports as a requirement, based on waste levels and climate impact. Projects to develop passport proof of concepts and industry specific best practices have been implemented or proposed across construction (Buildings as Material Banks [3]), textiles (Trace4Value [4]) and battery production (Global Battery Alliance [5]).

2.1.1 Recovery and reuse of shipping steel.

Maersk Line has been exploring the use of a Cradle-to-Cradle Passport to allow consideration of quality recycling right from the design phase of their vessels [6]. When a cargo ship is decommissioned, the separation and identification of different material types and grades is challenging. When the quality and property information of the materials is lost, steel of all grades is combined and becomes a low-grade recycled steel. By applying a materials passport to components at the point of recycling, material quality can be maintained for recovery and reuse.

2.1.2 Materials passport in construction

Madaster is a Dutch initiative that functions as a digital platform for creating, managing, and sharing materials passports for buildings [7]. It was founded with the goal of promoting transparency and circularity in the construction sector. Madaster allows users to document detailed information about the materials used in a building, including their composition, origin, and location within the structure.

2.2 Use in Offshore Wind

Adoption of material passports within the offshore wind industry is more likely to be driven by supply chain procedures and sustainability criteria in leasing and consenting decisions than direct regulation. Material passports will streamline reprocessing and increase the value of the end of life materials. Proactive steps by the offshore wind industry to gather and present the necessary data in advance of physical decommissioning will result in a greater proportion of materials being reclaimed or recycled at end of life.

Blade material passports have been created as part of the DecomBlades innovation project aiming to produce a sustainable value chain for end of life wind turbine blades. The passports, supported by LM Wind Power, Vestas, and Siemens Gamesa, provided standardised blade disposal details, to assist with the material handling, separation, and recycling.

Within the CEWS decommissioning case study, batch level passports have been considered, where specific data for smaller components is included within a larger main component. Production of more detailed small component-specific passports would require additional material data and transparency from turbine manufacturers and owners.

The format proposed for offshore wind material passports is based on examples from the following projects and research:

- DecomBlades – Blade specific material passport examples [8].
- The anatomy of a passport for the circular economy – Literature review of material passport specific research [9].
- WBCSD: Introducing the EU Digital Product Passport – An overview of current material passport requirements [10].

Table 1 shows the most common key requirements for material passports and was used to generate the offshore wind specific example in.

Table 1 - Material passport specifications overview

Key Requirements for a Material Passport			
Technical	**Operational**	**Environmental**	**Additional Documents**
Mass and Dimensions	Intended Use	Consumption Data	Life Cycle Assessment
Material Breakdown	Maintenance and Repairs Record	Component Modularity	Environmental Product Declaration
Assembly and Decommissioning Guidelines	Service History	Material Separability	Material Safety Data Sheet
Maintenance Schedule and Guidelines	Operational Hours	Component Quality	Bill of Materials
Design Specifications	Operating and Environmental Conditions	Recyclability and Re-Use Options	Technical Data Sheet
Manufacturing Process	Estimated Lifetime		

Other relevant industry standards include:

- Ecodesign Directive 2009/125/EC – established October 21, 2009, serving as a framework for defining eco-design requirements related to environmental parameters. These requirements apply to energy-related products sold within the European Union and aim to promote the design and production of energy-efficient and environmentally friendly products and contribute to a more sustainable approach to manufacturing and consumption [1].
- ISO 14040:2006 – describes the principles and framework for life cycle assessment (LCA) including: definition of the goal and scope of the LCA, the life cycle inventory analysis phase, the life cycle impact assessment (LCIA) phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, the relationship between the LCA phases, and conditions for use of value choices and optional elements [11].
- ISO 14021:2016 – specifies requirements for self-declared environmental claims, including statements, symbols, and graphics, regarding products. It further describes selected terms commonly used in environmental claims and gives qualifications for their use [12].
- ISO 14024:2018 – establishes the principles and procedures for ecolabels and certifications that include independent verification, ensuring that consumers and professional purchasers are given accurate, comparable information [13].
- ISO 14025:2006 – provides guidelines for environmental declaration programmes for business-to-business communication [14].

3 EXAMPLE MATERIAL PASSPORT

GENERATOR (DIRECT DRIVE)

MATERIAL PASSPORT

3.1 Introduction

This document outlines an example material passport for a generic 2MW direct-drive generator. The template would be used to capture and display data related to the sustainability, circularity, and value retention of the components along the value chain. This would then be used at the end of life stage for more effective re-use or recycling. The information displayed is estimated based on the most relevant available data.

3.2 Technical data

3.2.1 Component Specification

This section summarises the high-level component information relevant to the end of life and re-use process. The majority of information should be provided at an early stage by the manufacturer. This should also be available in more detail within documentation such as the bill of materials and technical data sheet.

Table 2 - Example of high-level component specification

Component Characteristic	Value
Unique ID	CEWSDDGEN1
Generator Type	Permanent Magnet Synchronous Generator (PMSG)
Subcomponents	See Section 3.2.3
Estimated Lifetime (hours)	180,000
Rated Power (MW)	2
Wind Class	IEC IIIA

Figure 1 shows further component information that could be provided by a manufacturer to be stored in the material passport.

Standard	IEC60034, IEC61400
Power	up to 5MW or higher available with segmented stator
Shaft heights	710, 1120, 1400, 1600, 2500 (larger with segmented stator)
Number of poles	8-24 and multipole
Voltages	up to 3.3kV or higher on request
Frequency	VFD, 50Hz or 60Hz
Ambient	-30 up to 50 °C
Cooling	Air to air, Air to water, Open air cooled
Protection	IP54
Enclosure material	Welded steel
Bearings	Antifriction

Figure 1 – Generator manufacturer component specification [15]

3.2.2 Mass and Material Breakdown

Table 3 - Example generator mass and material breakdown

Component	Mass (kg)	Material	Density (kg/m^3)	Percentage of Total (%)
Stator Structural Steel	6,435	S 355 Steel	7,580	19
Rotor Structural Steel	7,802	S 355 Steel	7,580	23
Generator iron mass	16,377	SG Iron (EN-GJS-400-18U-LT)	7,100	49
Winding	815	Copper	8,940	2
Magnet	2,190	N40-grade sintered neodymium (NdFeB)	7,500	7
Total Generator	**33,619**			

3.2.3 Dimensions

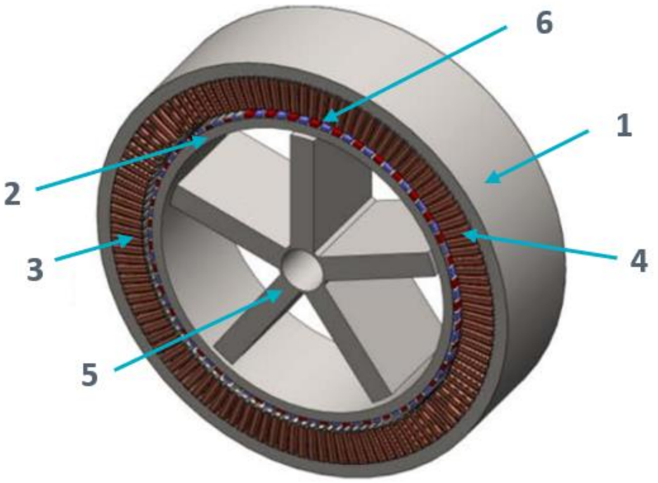

Table 4 - Example 2MW generator component breakdown [16].

Part Number	Component	Known Dimensions
1	Stator Yoke	Length (m) – 0.93 Thickness (mm) – 50.51
2	Rotor Yoke	Length (m) – 0.93 Thickness (mm) – 62.43
3	Stator Teeth	Height (mm) - 58.32 Width (mm) – 14.34
4	Winding	Length (m) – 11.4
5	Rotor Wheel	Diameter (m) – 3.92 Length (m) - 0.93
6	Magnets	Width (mm) – 54.7 Height (mm) - 5

The dimensions and component breakdown in the above table is based on data in the NREL GeneratorSE report [16].

3.2.4 Manufacturing Process and Testing

To assist in evaluating the quality of material and subcomponents at end of life, it is useful to understand the manufacturing processes and raw materials used. Any information is likely to be provided by the manufacturer and for a generator might include:

- Specific material processes such as basic oxygen/electric arc furnace steel production, carbon content reduction etc.
- Stator winding process, stator core production
- Magnet production and coating
- Component performance testing
- Use of recycled materials

3.3 Operational Data

The operational lifetime of the component will have a significant impact on the reusability and quality at the end of life stage. The manufacturer would be responsible for providing guidance on required maintenance while the end users/operators should record any repair and service activities. Captured data could include:

- Assembly and Decommissioning Guidance
- Maintenance Schedule and Repairs Record
- Service History
- Operational Hours
- Intended Use
- Operating and Environmental Conditions

Figure 2 outlines a potential maintenance schedule for a direct drive generator.

Maintenance level	**Level 1 (L1)**	**Level 2 (L2)**	**Level 3 (L3)**	**Level 4 (L4)**
Interval	Max. 10,000 to 20,000 equivalent hours[1] of operation	Max. 20,000 to 40,000 equivalent hours[1] of operation, or max. 3 years	Max. 50,000 to 70,000 equivalent hours[1] of operation, or max. 6 years	Max. 80,000 to 102,000 equivalent hours[1] of operation, or max. 12 years
Main customer preparations prior to maintenance	• Disconnect motor/ generator electrically • Connect outgoing lines to the earth	• L1 • Give access to terminal connections	• L2 • Block cooling and oil system • Disconnect piping from motor/generator • Drain water coolers and bearing house	• L3 • Split shaft couplings • Prepare for rotor removal
Measurements, tools and special instruments		• IR/PI[2] of stator. Stator diagnostic measurement[3] • IR of rotor	• IR/PI[2] of stator. Stator diagnostic measurement[3] • IR of rotor. Impedance measurement of rotor coils • Bearing and exciter removal tools • Optional: ABB Air Gap Inspector or video borescope • Rectifier test equipment	• IR/PI[2] of stator. Stator diagnostic measurement[3] • IR of rotor. Impedance measurement of rotor coils • Rotor, bearing, exciter removal tools • Rectifier test equipment
Maintenance parts	• L1 Preventive maintenance kit	• L2 Preventive maintenance kit • Parts recommended in previous preventive maintenance	• L3 Preventive maintenance kit • Parts recommended in previous preventive maintenance	• L4 Preventive maintenance kit • Parts recommended in previous preventive maintenance
Expected duration	**Approx. 1 working day**	**Approx. 2 working days**	**Approx. 5 working days[4]**	**Approx. 10 working day[4]**

[1] Equivalent hours = total hours of operation + number of starts x 20, or 1.2 x actual operating hours for variable-speed motors
[2] IR = Insulation Resistance, PI = Polarization Index
[3] Option: Diagnostic insulation test of the stator winding (ABB Ability™ LEAP)
[4] Depending on the accessibility of the motor/generator and lifting equipment

Figure 2 - Generator manufacturer recommended maintenance schedule [17]

3.4 Environmental and Circularity data

As the component moves through the value chain, various stakeholders are involved. It is important to capture information at each stage related to the sustainability and circularity of the component that may impact any potential re-use or recycling. Relevant information to record would include:

- Consumption data (Energy, water, and other resources) during manufacture, transportation, and operation
- Critical materials and hazardous substances used
- Component modularity and material separability
- Component quality
- Recyclability and re-use options
- Expected waste

The estimated equivalent CO_2 emissions for a 2MW generator are shown in the Table 5.

Table 5 - Estimated 2MW generator equivalent CO2 emissions

Component Material	Tonnes CO_2 Equivalent
Stator Structural Steel	9.344
Rotor Structural Steel	11.329
Generator iron mass	1.412
Winding	0.488
Magnet	60.444
Total Generator	**83.018**

Figure 3 outlines some of the key decisions made at each stage of the value chain and the required data from the material passport.

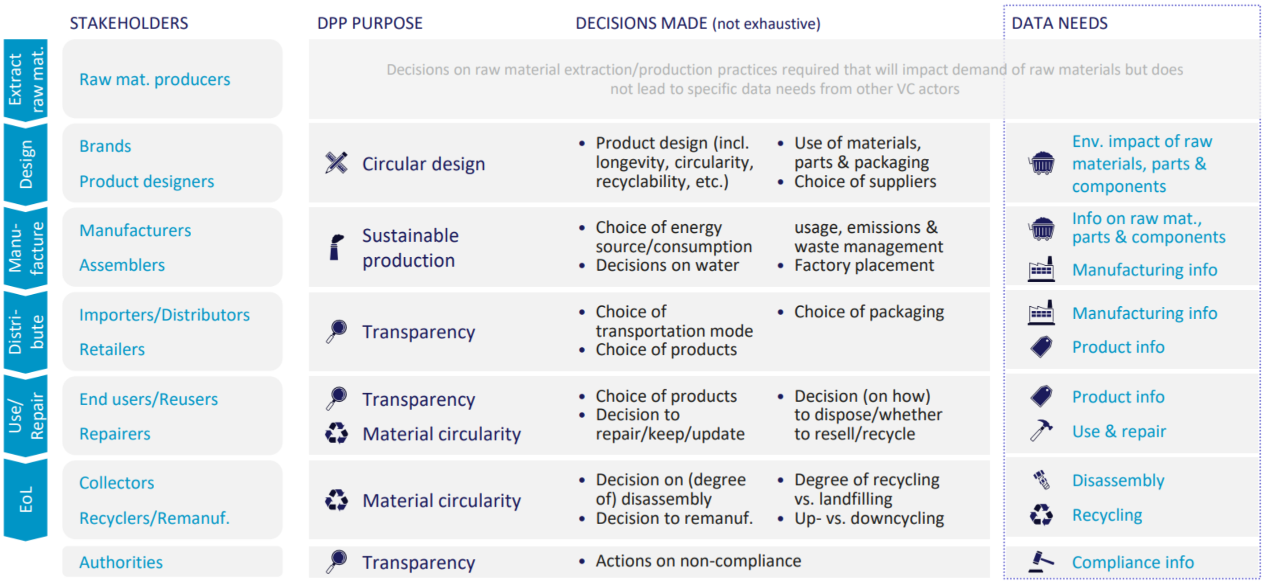

Figure 3 - Data requirements along the component value chain [18]

3.5 Additional Documentation

If available, any additional documentation that may be relevant to the quality, recyclability and disassembly of the component should be included alongside the material passport. These documents could be produced at any stage of the value chain, such as manufacture or operation, and might include:

- Life Cycle Assessment
- Environmental Product Declaration
- Material Safety Data Sheet
- Bill of Materials
- Technical Data Sheet
- Contractual Agreements
- Warranty Periods or Certificates

4 REFERENCES

[1] European Commission, “Ecodesign for Sustainable Products Regulation,” 2022. [Online]. Available: https://commission.europa.eu/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/sustainable-products/ecodesign-sustainable-products-regulation_en. [Accessed 2023].

[2] European Commission, “Circular economy action plan,” 2020. [Online]. Available: https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en. [Accessed 2023].

[3] W. L. Matthias Heinrich, “Material Passports - Best Practice,” 2019.

[4] Trace4Value, “Traceability for sustainable value chains,” 2023. [Online]. Available: https://trace4value.se/.

[5] Global Battery Alliance, “Battery Passport Pilot,” 2022. [Online]. Available: https://www.globalbattery.org/action-platforms-menu/pilot-test/.

[6] European Commission, “Maersk: designing ships that can be dismantled and reused,” [Online]. Available: https://circulareconomy.europa.eu/platform/en/good-practices/maersk-designing-ships-can-be-dismantled-and-reused. [Accessed January 2024].

[7] European Commission, “Madaster: online register and 'material passport',” [Online]. Available: https://circulareconomy.europa.eu/platform/en/dialogue/existing-eu-platforms/madaster-online-register-and-material-passport. [Accessed January 2024].

[8] LM Wind Power, “Blade Material Passport - LM 37.3 P2,” 2022.

[9] G. v. Capelleveen, D. Vegter, M. Olthaarm and J. v. Hillesgersberg, “The anatomy of a passport for the circular economy: a conceptual definition, vision and structured literature review,” *Resources, Conservation & Recycling Advances,* vol. 17, 2023.

[10] World Business Council for Sustainable Development (WBCSD), “Enabling circularity through transparency: Introducing the EU Digital Product Passport,” 2023.

[11] ISO, “ISO 14040:2006,” 2006. [Online]. Available: https://www.iso.org/standard/37456.html.

[12] ISO, “ISO 14021:2016,” 2016. [Online]. Available: https://www.iso.org/standard/66652.html.

[13] ISO, “ISO 14024:2018,” 2018. [Online]. Available: https://www.iso.org/standard/72458.html.

[14] ISO, “ISO 14025:2006,” 2006. [Online]. Available: https://www.iso.org/standard/38131.html.

[15] ABB, “ABB permanent magnet generators,” [Online]. Available: https://new.abb.com/motors-generators/generators/generators-for-renewables/permanent-magnet-generators. [Accessed November 2023].

[16] NREL, “GeneratorSE: A Sizing Tool for Variable-Speed Wind Turbine Generators,” [Online]. Available: https://www.nrel.gov/docs/fy17osti/66462.pdf. [Accessed 2023].

[17] ABB, “Preventive maintenance for synchronous motors and generators,” [Online]. Available: https://library.e.abb.com/public/184fe4cab4204eb7add9d374f7593aea/SM103_Preventive%20maintenance%20for%20synchronous%20motors%20and%20generators%20EN%20RevC_low.pdf. [Accessed November 2023].

[18] WBSCD, “Enabling circularity through transparency: Introducing the EU Digital Product Passport,” [Online]. Available: https://www.wbcsd.org/contentwbc/download/15585/226483/1. [Accessed November 2023].