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Sustainable SoluTions FOR recycling of end-of-life Hydrogen technologies

Deliverable D5.3

Guidelines for the setup Ecolabelling qualification

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Abbreviations

AHWG	Ad-Hoc Working Group
AWE	Alkaline Water Electrolyser
BOP	Balance of plant
DMFC	Direct methanol fuel cell
EN	Euronorm
EoL	End-of-life
EPD	Environmental Product Declaration
EUEB	European Union Ecolabelling Board
FC	Fuel Cell
FCH	Fuel Cell Hydrogen
GHG	Greenhouse Gases
GPI	General Programme Instructions
ISO	International Organization for Standardization
MCFC	Molten carbonate fuel cell
MND	Module not declared
PEF	Product Environmental Footprint
PEFCR	Product Environmental Footprint Category Rules
PGMs	Platinum Group Metals
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LSC	Lanthanum Strontium Cobaltite
PAFC	Phosphoric acid fuel cell
PEMFC	Polymer electrolyte fuel cell
PCR	Product Category Rules
SOFC	Solid oxide fuel cell
YSZ	Yttrium Stabilized Zirconium

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Executive Summary

This document aims at investigating how the ecolabeling certifications are setup and how they could be adapted to FCH technologies.

Within this document, different types of environmental labels are described, with special focus on Type I – Environmental labelling (ISO 14024:2018) and Type III – Environmental product declaration (ISO 14025:2006) labels.

Moreover, some guidelines are presented, with the aim to customize the existing labels and schemes to the fuel cell sector.

1 Introduction

The BEST4Hy Project focuses on the development and validation of existing and novel recycling processes for two key Fuel Cell and Hydrogen technologies (FCH): Polymer Electrolyte Membrane Fuel Cell (PEMFC) and Solid Oxide Fuel Cell (SOFC) to ensure the maximization of recycling of the critical raw materials (CRMs) including Platinum Group Metals (PGMs), rare earth elements (REE), cobalt and nickel.

The End of Life (EoL) strategy supported is accompanied by Life Cycle Cost (LCC) and Life Cycle Assessment (LCA) evaluations to ensure it delivers the best (cost effective and more sustainable) material for closed loop and open loop recycling.

In this framework, Task 5.4 'Ecolabelling certification for Fuel cell technology' aims at investigating how the ecolabeling certifications are setup and how they could be adapted to FCH technologies.

This deliverable represents the main outcome of the task 5.4, and mainly addresses the following objectives: analysis of existing certification for fuel cell technology, identification of main criteria used for the evaluation of the environmental performance and drafting of guidelines to assess the sustainability of FC.

The report is structured in the following Chapters:

- **Chapter 1** gives an overview of the project and the aim of the task.
- **Chapter 2** describes what "Ecolabelling" is and the types of ecolabels.
- **Chapter 3** identifies the main ecolabelling options for FCH products.
- **Chapter 4** focuses on proposal for new Ecolabel product group, including the procedure and criteria.
- **Chapter 5** provides a proposal for new EPD PCR, exploring the procedure to obtain the certification, screening of previous studies and criteria.
- **Chapter 6** ~~summaries~~ summarises the conclusions and findings of the task.

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2 Ecolabelling

Ecolabelling is a voluntary method for certifying and labelling the environmental performance of products or services.

The environmental labels are defined within the **ISO series 14020** (ISO 14020, *Environmental labels and declarations – General principles)*, which establishes the guiding principles for the development and use of environmental labels and declarations.

Different types of labels are then described in dedicated standards:

- Type I – Environmental labelling (ISO 14024:2018) [1]
- Type II – Self-declared environmental claims (ISO 14021:2016) [2]
- Type III – Environmental product declaration (ISO 14025: 2006) [3]

The main objectives of ecolabelling are to encourage the use of products or services that generate less environmental impacts and to provide consumers with reliable and verified information on the sustainability performance of product or service.

In the table below, the main differences among the different labels are summarized. Additional details are provided in the following chapters, per each type.

Table 1: Environmental Label Types and main characteristics

Label Type		Main characteristics
I	**Environmental labelling (ISO 14024:2018)**	✓ Voluntary systems, with third party verification ✓ Multiple-criteria-based ✓ The rules to be followed for a given product category are defined within specific Product Groups ✓ Criteria include minimum or threshold values
II	**Self-declared environmental claims (ISO 14021:2016)**	✓ Voluntary. Third party verification is optional ✓ Generally single-criteria-based (e.g. recyclable/ compostable, etc)
III	**Environmental product declaration, EPDs (ISO 14025:2006)**	✓ Voluntary systems, with third party verification ✓ Multiple-criteria-based (LCA based) ✓ The rules to be followed are defined within specific Product Category Rules (PCR) ✓ No threshold values

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2.1 Environmental labelling

Type 1 Ecolabels are established based on the guidelines specified in ISO 14024 [1], outlining principles and procedures for the selection of product categories, product-environmental criteria, function characteristics, and compliance assessment.

These labels are voluntary systems that certify products or services with reduced environmental impact throughout their entire life cycle.

Ecolabels are based on **scientifically defined criteria**, set to minimise the main environmental impacts of products over their entire life cycle.

Ecolabel criteria cover various aspects:

- Use of resources (energy, water, chemicals),
- Waste generation and emissions,
- Product functionality and performance,
- Social aspects.

The criteria favour the replacement of hazardous substances with safer alternatives and promote product durability, reusability, recyclability, and use of recycled materials. They also encompass fitness for use requirements and guarantee compliance with existing EU legislation.

The criteria and the rules to be followed for a given product category are defined within specific **Product Groups**. Such Product groups must be developed in an open process where stakeholders can influence the development through continuous improvements through regular evaluation and review of the requirements. Since each product group has different function and characteristics, the criteria are customized to effectively address its specific features.

The compliance with the criteria is **verified by an independent third-party body**. Furthermore, the criteria are periodically revised in order to take into account technical innovations and market changes, ensuring that they are up to date, robust and reliable.

There is a wide variety of ecolabelling programmes. The main examples of Type 1 Ecolabels are reported in Table 2.

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Table 2: Ecolabel examples

Logo	Scheme	Origin/ Geographic scope	Sector
	EU Ecolabel	EU	Generic
	Blauer Engel	Germany	Generic
	Nordic Swan	Nordic countries: Denmark, Iceland, Finland, Sweden, Norway	Generic

Figure 1 reports instead the numbers of certified products per each scheme. They correspond to almost 90,000 certified products per the EU Ecolabel scheme, more than 40,000 for Nordic Swan and more than 30,000 for Blauer Engel.

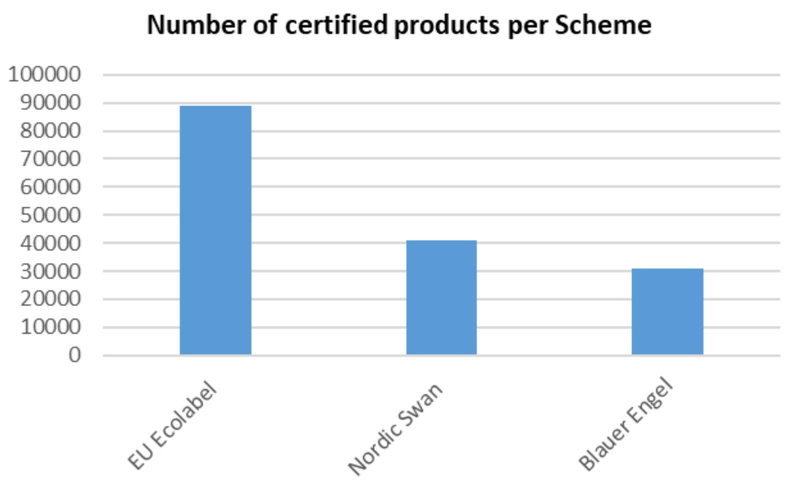

Figure 1: Number of certified products per Scheme (Status October 2023) [4] [5] [6]

2.2 Self-declared environmental claims

Type 2 labels are ~~S~~self-declared environmental claims developed by producer according to the main rules and requirements defined within the ISO 14021.This standard lists some commonly used terms reported in claims and it indicates some evaluation methods for each term, to help ensure they are quantified and communicated in an objective way. This type

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of label is voluntary and third-party verification is not mandatory but can be optionally conducted in order to make the claim more reliable.

Generally, self-declared environmental claims are based on single criterions such as recyclable, compostable, etc.

Some examples of possible ~~S~~self-declared environmental claims are reported in Table 3.

Table 3 Examples of Self-declared environmental claims

Example of claims
✓ Compostable ✓ Degradable ✓ Designed for disassembly ✓ Extended life product ✓ Recovered energy ✓ Recyclable ✓ Recycled content ✓ Reduced energy consumption ✓ Reduced resource consumption ✓ Reduced water consumption ✓ Reusable and refillable ✓ Waste reduction ✓ Renewable material ✓ Claims relating to greenhouse gases emissions

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2.3 Environmental Product Declaration

Environmental Product Declarations (EPD) are voluntary systems with third-party verification, grounded in LCA principles. The EPD process involves identifying and assessing environmental impacts throughout the product's life cycle.

EPDs offer a comprehensive and transparent representation of the environmental performance of products, favouring communication with stakeholders.

The EPDs are based on the **Product Category Rules (PCR**), which provide requirements and guidelines for developing EPDs for specific product categories. They are used as complements to the general rules defined by the scheme and add specific requirements for the specific product, ensure comparability between different EPDs dealing with the same product.

The PCR must specify all the information that needs to be included in the LCA:

- ✓ Functional unit
- ✓ System boundaries
- ✓ Cut-off criteria
- ✓ Allocation rules
- ✓ Data quality requirements
- ✓ Environmental indicators
- ✓ etc...

The EPDs cover different aspects:

- Potential environmental impacts
- Use of resources (non-renewable and renewable)
- Waste generation and emissions
- Other indicators (e.g., content of recycled materials).

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There are several EPD system program operators, who have the role of leading, administering and supervising the development of EPD. Usually, each country has its own program operator and thus their own EPD system.

The main European EPD systems are listed in Table 4, including the country of origin, the geographical scope and sector of application.

Table 4 EPD examples

Logo	Scheme	Origin	Geographic scope	Sector
	The International EPD® System	Sweden	International	Generic
	Institut Bauen und Umwelt e.V.(IBU)	Germany	National	Building and Construction
	Inies FDES	France	International	Building and Construction
	EPD Italy	Italy	International	Generic (mainly building and construction)
	EPD Danmark	Danmark	International	Building and Construction
	EPD Norway	Norway	International	Generic
	BRE Global	United Kingdom.	International	Building and Construction
	Global EPD	Spain	International	Generic
	ITB-EPD	Poland	International	Building and Construction
	Bau EPD	Austria	International	Building and Construction
	DAPHabitat	Portugal	National	Building and Construction
	ZAG EPD	Slovenia	National	Building and Construction
	EPD Ireland	Ireland	National	Building and Construction
	MRPI	Netherlands	National	Building and Construction
	PEP Eco passport	France	International	Electric and electronic

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Figure 2 shows in a chart the number of EPDs published by each Scheme. The more established EPD Scheme are those with more than 1.000 EPD publications, such as the International EPD® System, IBU, Inies FDES, EPD Norge and PEP eco passport.

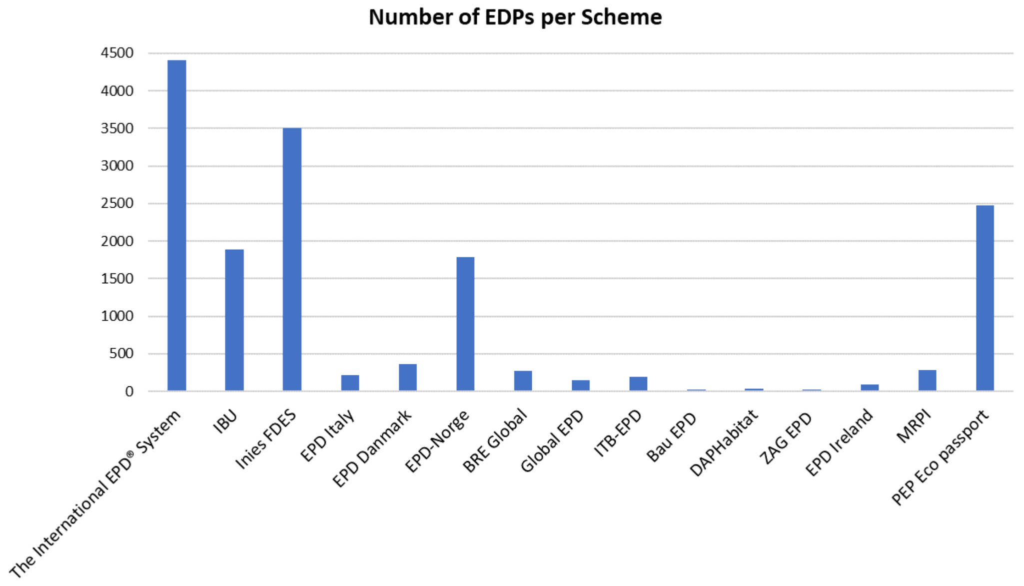

Figure 2: Number of EPDs published per scheme (Status 1.7.2023) [7]

Another framework which is in line with the main requirements of ISO 14025 is the Product Environmental Footprint (PEF). The PEF is a methodology developed by the European Commission that is grounded in LCA. The PEF establishes a common framework encompassing all necessary steps and specific rules, i.e., Product Environmental Footprint Category rules (PEFCR), required for conducting a reliable and comparable LCA. Currently, the PEF methodology is in a development phase and is being tested in various pilot stages to assess its effectiveness and applicability.

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3 Identification of the ecolabelling options for FC

Based on the screening of the existing ecolabelling certifications, the most relevant options for the for the fuel cell product were identified, considering several factors:

1) **Reliability:** A crucial factor in the selection process was reliability. This led to the consideration of **Environmental labels Type I** and **Type III** as possible candidate schemes. These options follow specific and well-defined product rules established on scientific criteria and LCA, and they are third-party verified. They offer an effective communication of the environmental performance of product, ensuring credibility and accuracy.
2) **Sector of application**: The selected ecolabel option must be applicable to **FCH sector.**
3) **Geographical scope**: The focus of the project is **Europe**, so the ecolabel's geographical scope was a key consideration for this initial analysis. However, the ecolabelling certification should be recognized also outside Europe and be applicable also for other international producers.
4) **Relevance of the scheme**: Relevance was determined by examining the number of certifications published.

Based these considerations, the following options were selected to be analysed in the present guidelines:

✓ **EU Ecolabel**
- Reliability: Type I – Environmental labelling (third-party verification)
- Sector: Generic
- Geographical scope: Europe*
- Relevance: 88.045 certified products

✓ **The international EPD® System**
- Reliability: Type III – Environmental Product Declaration (third-party verification)
- Sector: Generic
- Geographical scope: International
- Relevance: 4.410 EPDs published

* The geographical scope of the EU Ecolabel is primarily within the European Union member states. However, it's worth noting that the EU Ecolabel can also be awarded to products and services from non-EU countries.

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4 Existing specific rules

As mentioned in the previous chapter, the selected ecolabelling options adhere to specific product rules. This ensures reliability and comparability among different products within the same product group, as the studies must be carried out following a common methodological approach and choices defined in the product rules.

In the following chapters, the existing specific product rules (Product groups or Product category rules) for the two ecolabelling options will be investigated.

4.1 Existing EU Ecolabel Product groups

Table 5 provides an overview of all the existing EU Ecolabel product groups. A new product group related to financial products is under development. The European Commission started the development process in 2018 and is proceeding with continuous consultation with experts and different stakeholders.

Table 5 EU Ecolabel product groups

Current product groups	Products groups under development
✓ Cleaning	✓ Financial products
✓ Clothing and textiles	
✓ Coverings	
✓ Do it yourself	
✓ **Electronic equipment [8]**	
✓ Furniture and mattresses	
✓ Gardening	
✓ Holiday accommodation	
✓ Lubricants	
✓ Paper	
✓ Personal and animal care products	

Among the current product groups, the “Electronic equipment” group (which refers to electronic displays) is the most closely aligned with the BEST4Hy case, and it can be a useful example for the definition of criteria for a new ecolabel product group for FC.

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4.2 Existing Product category rules

Table 2 provides a list of the current Product Category Rules available on The International EPD® System.

Table 6 Current Product Categories on The International EPD® System

Current Product Categories on The International EPD® System
✓ Chemical products
✓ Construction products
✓ **Electricity, steam and fuels**
✓ Food and beverages
✓ Furniture and other goods
✓ Infrastructure and buildings
✓ **Machinery and equipment**
✓ Metals, mineral, plastic and glass products
✓ Paper and plastic products
✓ Services
✓ Textiles, footwear and apparel
✓ Vehicles and transport equipment

Among this list, the Product Categories that can be considered more similar to the fuel cells, are "Electricity, steam and fuels" and "Machinery and equipment". For these Product Categories, the PCRs included are reported below, in Table 7 and Table 8, respectively.

Even if there is no specific PCR for fuel cell, the PCRs belonging to similar sectors can be taken as reference for the development of the PCR related to the Fuel cells.

Table 7 PCRs included in the Product Group Electricity, steam and fuels

PCRs included in the Product Group Electricity, steam and fuels
✓ **Electricity, steam and hot/cold water generation and distribution [9] – undergoing updating**
✓ Electrical cables and wires (for construction sector)

Table 8 PCRs included in the Product Group and Machinery and equipment

PCRs included in the Product Group and Machinery and equipment
✓ Air-conditioning machines
✓ Bearings, bearings units and parts thereof
✓ **AC and DC gear motors for automation systems [10] - undergoing updating**
✓ Liquid immersed power transformers (>25 MVA) - undergoing updating
✓ Machine-tools for drilling, boring or milling metal - undergoing updating
✓ c-PCR-026 Concrete batching plants (c-PCR under PCR 2019:14)
✓ **Electrical motors and generators and parts thereof [11]**
✓ Home and SOHO Gateway
✓ Industrial furnaces and ovens
✓ Lifts (elevators) (expired 2020-10-14)
✓ Machines for filling and packaging of liquid food

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PCRs included in the Product Group and Machinery and equipment
✓ Machine-tools for material working by removal of material ✓ Other special- and general-purpose machinery and parts thereof ✓ Parts and accessories of computing machines (e.g. laser printer cartridges) ✓ Presses for working metal ✓ **Batteries and parts thereof (c-PCR) - Under development** ✓ **Electronic and electric equipment and electronic components (non-construction) (main PCR to be complemented by c-PCRs) - Under development -** ✓ Industrial dehumidifiers (c-PCR to PCR 2019:14) - Under development ✓ Respiratory protection devices (RPD) - Under development

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5 Proposal for new Ecolabel product group

This chapter is intended to provide all the information required for proposing a new Ecolabel product group for the Fuel Cell and draft preliminary criteria in order to pave the way for the creation of EU Ecolabel for FC.

5.1 Procedure

A new EU Ecolabel product group can be proposed by the Commission, Member States, competent bodies and any other interested stakeholder. Where such stakeholders are in charge of leading the criteria development, they must demonstrate expertise in the product area, as well as the ability to lead the process impartially, aligning with the aims of the EU Ecolabel Regulation.

The first step for proposing a new product group in EU Ecolabel scheme is to fill out the **dedicated form** available on the European Commission portal [12] and send it to the specific channel EU Ecolabel Helpdesk: helpdesk-eu-ecolabel@adelphi.de.

The European Commission will collect and consider the proposal based on the priorities identified in the Strategic EU Ecolabel Work Plan 2020-2024 [13].

The **EU Ecolabel Criteria Development form** must be completed including all the information required on the proposed new category:

- Product group designation: definition of the new product group and product group targeting;
- Reasons for choice and scope of the product group;
- Significant potential for effecting environmental improvements;
- Market description;
- Environmental awareness;
- Complementary information and references.

According to **Regulation (EC) No 66/2010** [14], the procedure for developing the criteria is as follows, as schematized in Figure 3.

- The Joint Research Centre (JRC) is responsible for development and review of requirements for product groups. Additionally, the JRC invites stakeholders to participate in an ad hoc working group (AHWP). This working group comprises various stakeholders, including non-governmental organization (NGOs), consumer interest associations, industry organizations, and businesses.
- The working group meets about twice per year to provide feedback on the criteria based on the findings of various studies. These studies encompass feasibility assessment, environmental impact analysis, market research, improvement analyses, and review of existing LCA analysis.
- During the development process, the board of European Union Ecolabelling Board (EUEB) discusses the draft criteria.
- The draft criteria are presented to the respective agencies of the European Commission and subsequently shared with the EUEB.

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- The criteria are then voted on by a legislative committee of national authorities.
- The European Commission ultimately lays down the final criteria.
- The decision of the European Commission is announced in the official journal.

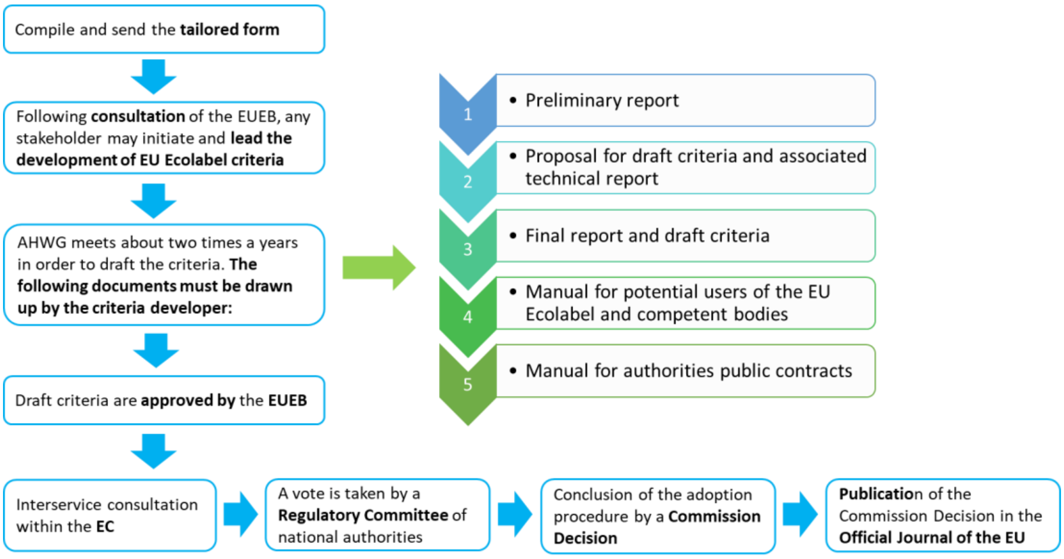

Figure 3: Procedure for the development of EU Ecolabel criteria [15]

In particular, the procedure requires the drafting of the following documentation:

1. Preliminary report
2. Proposal for draft criteria and associated technical report
3. Final report and draft criteria
4. Manual for potential users of the EU Ecolabel and competent bodies
5. Manual for authorities awarding public contracts.

Annex I of Regulation (EC) No 66/2010 provides the guidelines for the drafting of the documents, indicating all the elements to be included.

In particular, the **Preliminary Report** should include the following key points:

- Quantitative indications of potential environmental benefits related to the product group;
- Reasoning for choosing and defining the scope of the product group;
- Possible trade issues;
- Analysis of other environmental labels' criteria;
- Current laws and legislative initiatives related to the product group sector;
- Possibilities of substituting hazardous substances with safer ones;
- Market data for the sector;
- Evaluation of the extent and overall relevance of environmental impacts associated with the product group, based on LCA studies and scientific evidence.

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The preliminary report is made available on the Commission's EU Ecolabel website for public comment and reference during criteria development.

After the preliminary report, a **proposal for draft criteria and a technical report** supporting the proposal are developed. The criteria should be defined as follows:

- The criteria must promote the most environmentally friendly products and provide consumer choice.
- They must represent the best 10-20% of products in terms of environmental performance on the market at the time of adoption.
- In addition to environmental impacts, they must also consider health and safety aspects as well as social and ethical aspects.
- The proposed criteria should be based on reliable Life cycle data and representative of the entire Community market.
- They must align existing legislation applicable to the product group and take into account relevant Community policies and work on related product groups.

The technical report is developed considering all interested parties during the consultation process. It should include scientific explanation of each criterion and highlight key environmental characteristics.

Both the proposal and technical report are subject to public consultation on the Commission's EU Ecolabel website, with at least two open working group meetings involving various stakeholders. Any changes to the criteria in subsequent drafts should be fully explained and documented, considering feedback from the open working group meetings and public comments.

All the comments shall be taken into account to produce the **final report**, including the definitive criteria.

Subsequently, a **manual** shall be established to **assist potential users of the EU Ecolabel** and competent bodies in assessing the compliance of products with the criteria. Additionally, a **manual** providing guidance **for the use of EU Ecolabel criteria by authorities** awarding public contracts shall be established.

5.1.1 Format

As mentioned above, the first step for proposing the new category is to compile the dedicated form (Figure 4), providing some general information and showing the benefits and impacts that can be achieved. Therefore, it is important to include all the possible information giving an exhaustive picture of the product group and highlight the significance that it could have in the context of the Ecolabel scheme.

In this chapter, contents for drafting the preliminary form are suggested.

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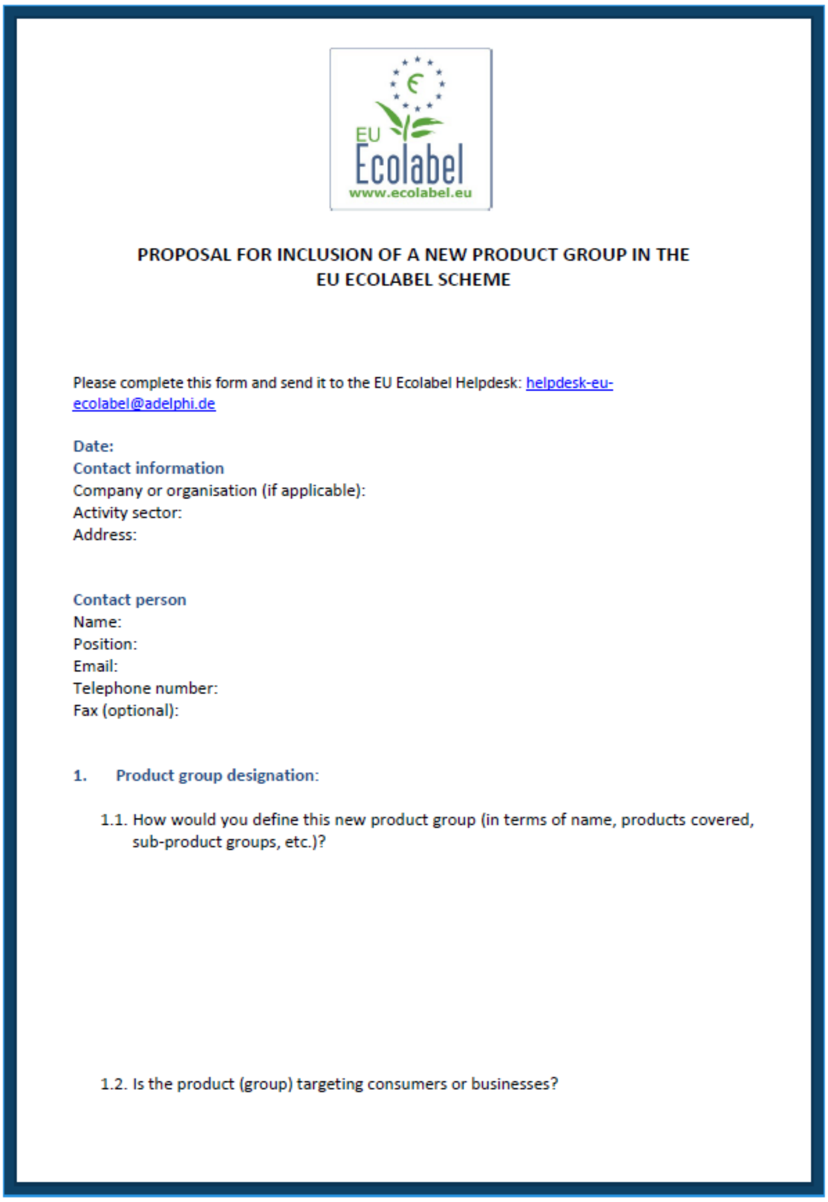

EU Ecolabel
www.ecolabel.eu

PROPOSAL FOR INCLUSION OF A NEW PRODUCT GROUP IN THE EU ECOLABEL SCHEME

Please complete this form and send it to the EU Ecolabel Helpdesk: helpdesk-eu-ecolabel@adelphi.de

Date:
Contact information
Company or organisation (if applicable):
Activity sector:
Address:

Contact person
Name:
Position:
Email:
Telephone number:
Fax (optional):

1. **Product group designation:**

1.1. How would you define this new product group (in terms of name, products covered, sub-product groups, etc.)?

1.2. Is the product (group) targeting consumers or businesses?

Figure 4: EU Ecolabel Criteria Development form [12]

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1. Product group designation
1.1 How would you define this new product group (in terms of name, products covered, sub-product groups, etc.)?
Fuel Cell products The product group is presented by Fuel cell products (fuel cell stack, which represent the core of the fuel cell, and BoP components). **Considered sub-groups:** • Solid oxide fuel cell (SOFC) • Polymer electrolyte membrane fuel cell (PEMFC) • *Additional technologies might also be added*
1.2 Is the product (group) targeting consumers or businesses?
Both businesses and individual customers can be buyers of fuel cells, depending on the context and application, so the product (group) targets both consumers and businesses.

2. Reasoning for choice and scope of the product group
2.1 What are the advantages and limitations of the product(s) compared to competing products and/or other products produced by the same company (if applicable)?
Fuel cells offer a cleaner and more efficient solution compared to conventional combustion engines and power plants, especially when "renewable" or "low-carbon" hydrogen is used as fuel. They can be utilized in stationary applications as well as in mobile applications to provide power for vehicles and mobile power packs. The main benefits of the fuel cells are: reduced greenhouse emissions, high reliability and energy efficien**cy**, flexibility in installation and operation, reduced noise pollution, development of renewable energy resources, improved environmental quality and reduced demand for foreign oil.

3. Significant potential for effecting environmental improvements
3.1 Please provide information on environmental impacts of the product group (preferably using life cycle assessment data/studies). Please indicate critical and controversial issues related to these claims on environmental impact if any.
Life cycle assessments indicate that, when evaluating the entire life cycle of a fuel cell, the operation phase can have the most significant impact, contingent on the type of fuel utilized. The contribution of certain fuels, such as natural gas, may substantially exceed that of the manufacturing and end-of-life phases.

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Conversely, the use of hydrogen can result in reduced impacts during the usage phase when compared to other fuels. However, the source of hydrogen (e.g., "renewable", "low-carbon", "fossil-based" hydrogen) can also play a significant role in further reducing environmental impacts.

When examining the manufacturing phase in more detail (over which the producers have more control), the analysed LCA studies indicate that for PEMFC the stack is the dominant contributor to the environmental impact associated with manufacturing, while the remaining balance-of-plant (BOP) components account for a limit share of the total environmental impact.

In addition, the studies report that the platinum group metals (PGMs) are extremely high in terms of criticality and have very large environmental impacts (despite the total mass share of Pt in the whole stack is less than 1%).

Consequently, it is considered of utmost importance the maximisation of the recovery of the key critical materials (PGMs, ionomer, BPP, …), ensuring high amount of recycled materials (considering the manufacturing phase) and also efficient technologies for the recycling of this critical materials at the EoL. Taking into account also the scarcity of materials and increasing prices, it is evident that they are of major importance in FCH technologies.

In reference to the SOFC, attention should be given to manufacturing the stack using a high proportion of recycled materials, which should include a combination of Ni, YSZ, and LSC. Also, concerning these critical raw materials, the utilization of efficient technologies for their recovery at the end of the product's life phase can contribute to achieving effective environmental improvements.

3.2 *Please provide information on potential environmental benefits that the establishment of the EU Ecolabel product group may bring.*

In the current market, there is a pressing need for companies to demonstrate the sustainability of their products. With an increasing demand from consumers for more eco-friendly options, businesses are now tasked with providing tangible evidence that their offerings are indeed sustainable. This rising market demand for sustainability is pushing companies to consider obtaining ecolabels that validate a product's environmental claims. In some sectors, ecolabels are already required. The FC sector, recognizing this trend, is also inclined to align itself with these provisions.

For FC manufacturers, the ecolabel can act as a driving force, pushing them to enhance their products' performance to meet the stringent criteria of these labels. Moreover, the requirements of the ecolabel can incentivize them to minimize the use of critical raw materials and rare earth elements, also by using recovered critical raw materials and rare earth elements, wherever feasible. Consequently, this commitment to improving product performance not only ensures ecolabel certification but also leads to a significant reduction in the environmental impact of their offerings.

4. Market description

4.1 How is this product's market segmented? Please provide information on the corresponding market shares.

Fuel cells market can be segmented by type, by application and by region.

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By type, they can be divided into different technologies. The Polymer Electrolyte Membrane Fuel Cells (PEMFC) accounts for the largest share, followed by Solid Oxide Fuel Cells (SOFC) and **Direct Methanol Fuel Cells (DMFC). The remaining fuel cells**, Molten Carbonate Fuel Cells (MCFC), and Phosphoric Acid Fuel Cells (PAFC) and Alkaline Fuel Cell (AFC) **, collectively constitute less than 1% of the total shipments**. **[16]** With reference to the application, the market has been segmented into transport, stationary and portable. Since the request for clean transport is growing, the transport segment is expected to grow rapidly in the near future. In terms of geographical coverage, the market encompasses North America, Asia Pacific, Europe, and the rest of the world. It is worth noting that Asia Pacific currently commands the dominant share of the global fuel cell market **[17]**.
4.2 *Please provide intra-community market data for the sector, including volumes, turnover and main actors.*
The global fuel cell market size was valued at €4.38 billion in 2021 & is projected to grow from €5.60 billion in 2022 to €34.59 billion by 2029. The leading players in this market are Ballard Power Systems, Bosch, Hydrogenics, Ceres Power, Mitsubishi Hitachi Power Systems, Plug Power and Bloom Energy **[17]**.
4.3 *Could you describe any possible trade issues (for instance, in terms of access to the market, intellectual property, etc.)?*
NA
4.4 What is the current and future potential for market penetration of the product(s) bearing the EU Ecolabel? Please provide relevant market estimates.
The rising demand for clean sources of energy to reduce carbon emissions is likely to boost the market growth of fuel cells.

5. The environmental awareness
5.1 Has this product(s) already been awarded a certification or ecolabel under another scheme?
Currently, there are no certifications available for these products.

6. Complementary information
6.1 Are you/your organisation interested in initiating and participating in the development of EU Ecolabel criteria for the proposed product group? If yes, please describe how you propose to do so.
RINA-C can leverage the experience gained within the BEST4Hy project to contribute to the development of criteria for evaluating the sustainability of fuel cell technologies.
6.2 *Please suggest stakeholders who should be involved in criteria development.*
FC manufacturers, adopters and recyclers.

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5.1.2 Preliminary report

The contents for the form compilation, listed in the previous chapter, may also be functional for the subsequent drafting of the preliminary report by the JRC, which will further investigate and estimate the aspects presented in the form. Indeed, the preliminary report is intended to provide background information for the proposed product group. To support the development process, it should include an analysis of the scope, definitions and description of the legal framework, an exhaustive market analysis as well as an environmental assessment.

5.1.3 Proposal for draft criteria and associated technical report

Following the publication of the preliminary report, the next step is to propose a draft of the criteria and drafting the related technical report. This work is carried out by the JRC with the involvement of the AHWG (Ad-Hoc Working Group).

The next section focuses on the draft criteria. The main purpose is to provide a list of possible criteria to support and facilitate the development of the criteria for FC products.

5.1.3.1 Proposal for draft Criteria

The EU Ecolabel addresses different key environmental hotspots. The proposed criteria address environmental impact of toxic substances, inefficient use of resources, waste generation as well as social aspects. The criteria aim to act on these specific hotspots by setting requirements to minimize and restrict the hazardous substances, increase the product reparability and recyclability, thus significantly reducing the use of new resources and waste generation. The criteria also set up relevant social criteria about working conditions and responsible sourcing of the so-called 'conflict minerals'. These requirements are necessary to support sustainable development from a social point of view, by increasing corporate social responsibility. The criteria reported below represent just a preliminary draft/proposal, that should be further discussed/ refined, in cooperation with the relevant stakeholders. Among the relevant stakeholder, for example, it would be beneficial to involve the partners of the sister project eGhost, which aims at establishing a first milestone in the eco-design criteria in the European hydrogen sector [18].

Table 9 Proposed Ecolabel criteria for Fuel cells

Hot issues	EU ecolabel criteria
Environmental impact of toxic substances	**Restricted hazardous substances: :** ✓ substances included in the candidate list of substances of very high concern for authorisation shall not be intentionally added to the product ✓ the use of classified hazardous substances is restricted ✓ the use of all per-and polyfluorinated alkyl substances (PFAS) except those that are essential. [19]
Use of sustainable fuel	**Source of fuel:** ✓ Fuels with reduced GHG emissions shall be used (e.g. "renewable", "low-carbon"hydrogen)

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Hot issues	EU ecolabel criteria
	✓ Informative documentation should be made available to customers to highlight the influence of the type of fuel an of its source on environmental performances of the fuel cell.
Inefficient use of resources	**Product reparability:** ✓ a proper design of the product is requested, avoiding non-detachable material connections between different materials ✓ components should be easy to dismantle, also for the purpose of repair ✓ spare parts must be available for at least 10 years after the devices are launched on the market.
Waste generation	**Recyclability and recycled content:** ✓ products shall contain a minimum amount of recycled materials, with special focus on the critical raw materials: o PEMFC: utilization of high amount of of recycled Pt in the manufacturing phase (and also efficient technologies for the recycling of the Pt at the end of life). o SOFC: manufacturing the stack using a high proportion of recycled materials, which should include a combination of Ni, YSZ, and LSC ✓ proper end-of-life management is requested including the provision of information to improve recyclability, limiting the material selection and promoting an easy-to-dismantle design
Social aspects	**Corporate social responsibility (CSR):** ✓ labour conditions at assembly plants respect ILO conventions and supplementary provisions ✓ responsible sourcing of critical raw materials from conflict-affected and high-risk areas is supported

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6 Proposal for new EPD PCR

This section aims to describe the procedure for the creation of a new EPD Product Category rule for FC products and to propose criteria and requirements to lay the foundations for the PCR development.

6.1 Procedure

The process of developing a new PCR can be started by any interested stakeholders, following the ISO/TS 14027 '*Environmental labels and declarations – Development of product category rules*' [20]. The ISO/TS 14027 describes the internationally agreed set of principles, requirements, and guidelines for developing a PCR. Besides the ISO/TS 14027, the main reference for PCR development is the General Programme Instructions (GPI) [21], which clearly list the rules of the International EPD® System in accordance with ISO 14025 for type III Environmental Product Declarations.

PCRs shall be based on one or more LCAs representing the full product life cycle conducted in accordance with ISO 14044 and other relevant LCA-based footprint studies, including any supporting studies performed in parallel to the PCR development.

The steps to follow to create a new PCR are the schematized in Figure 5:

Figure 5: Procedure for EFD PCR creation

1. **Initiation phase**

The first phase involves the appointment of a **PCR Moderator** and **defining the PCR scope**. The PCR Moderator is appointed by the Program Operator and is responsible for creating a time plan and coordinating the PCR development.

Once the decision is taken to start the work developing a PCR document, the PCR shall be announced by the Secretariat together with relevant information, including:

- preliminary name and scope of the PCR
- name, organization, and contact details of the PCR Moderator
- list of members of the PCR Committee, and
- preliminary time plan of PCR development

To become a PCR Moderator and initiating PCR development, the first step is to submit the **PCR Development Checklist** to the Secretariat at the following channel pcr@environdec.com. The checklist document can be downloaded from the EPD® site [22].

If accepted, the PCR development is announced on the site www.environdec.com and the preparation phase can start.

2. Preparation

In this step, the PCR is development starting from the **PCR template** (available on the site [22]) and in accordance with the GPI. It must also include further methodological guidance adapted for the specific product category. Then, the checklist (part related to phase 2) and the PCR document should be sent to Secretariat for checking before the open consultation.

3. Consultation

The third phase consists in the formation of a PCR stakeholder consultation group, covering expertise related to the PRC under development. Subsequently, the consultation group participates in an open consultation process, which is conducted online. The PCR Moderation is responsible for notifying the Secretariat about any planned public meetings or webinars for announcement on www.environdec.com. During the open consultation period, the PCR moderator guides stakeholders through the process and collects their input and comments.

4. Approval and publication

The PCR Moderator and PCR Committee prepare the final draft of the PCR, incorporating feedback from the open consultation. The technical Committee review it and then once approved, the Secretariat assigns a registration number and publishes the PCR on the website along with relevant information.

5. Updating

A PCR is valid for a pre-determined period (5 years) to ensure regular updates. Any interested stakeholders can provide feedback on a published PCR via email to the PCR Moderator and Secretariat. Such input can lead to updates during the validity period or be noted for future updates. It is important to note that an expired PCR cannot be used for a new EPDs or to extend the validity of existing EPDs. Before use, an expired PCR must be updated, and its validity extended (new version number or new registration number).

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6.2 Draft of PCR

This section is intended to provide the main contents required for the PCR development, based on the PCR template. Such information may be the basis for the possible PCR working document for the Fuel Cell and Hydrogen products.

6.2.1 Administrative information

Name:	Fuel Cell
Registration number and version:	To be added by the Secretariat
Programme:	EPD® The International EPD® System
Programme operator:	EPD International AB, Box 210 60, SE-100 31 Stockholm, Sweden. Website: www.environdec.com E-mail: info@environdec.com
PCR Moderator:	To be defined
PCR Committee:	To be defined
Date of publication and last revision:	To be added by the Secretariat
Valid until:	To be added by the Secretariat
Schedule for renewal:	A PCR is valid for a pre-determined time period to ensure that it is updated at regular intervals. When the PCR is about to expire, the PCR Moderator shall initiate a discussion with the Secretariat how to proceed with updating the PCR and renewing its validity. A PCR may also be updated without prolonging its period of validity, provided significant and well-justified proposals for changes or amendments are presented. See www.environdec.com for the latest version of the PCR. When there has been an update of the PCR, the new version should be used to develop EPDs. The old version may however be used for 90 days after the publication date of the new version, as long as the old version has not expired.
Standards conformance:	General Programme Instructions of the International EPD® System, version 4.0, based on ISO 14025 and ISO 14040/14044.
PCR language(s):	English

6.2.2 Scope of PCR

6.2.2.1 Product category definition and description

This document suggests Product Category Rules (PCR) for the assessment of the environmental performance of **Fuel Cells** and the declaration of this performance by an

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EPD. The product category can be included under UN CPC 461 Electric motors, generators and transformers, and parts.

This PCR covers different type of fuel cell, e.g:

- Solid oxide fuel cell (SOFC)
- Polymer electrolyte membrane fuel cell (PEMFC)
- Molten carbonate fuel cell (MCFC)
- Direct methanol fuel cell (DMFC)
- Phosphoric acid fuel cell (PAFC)

This list is not exhaustive.

6.2.2.2 Geographical Scope

This PCR may be used globally.

6.2.3 Background information

6.2.3.1 Existing PCRs for the product category

As part of the development of this PCR, existing PCRs were considered in order to avoid overlaps in scope. The existence of such documents was checked in the public PCR listings of the following programmes based on ISO 14025 or similar:

- International EPD® System
- EPD Italy
- EPD Norge
- Global EPD
- Product Environmental Footprint (PEF)

No PCRs covering Fuel Cells were identified, neither PEFCR.

6.2.3.2 Reasoning for development of PCR

This PCR was developed in order to enable publication of Environmental Product Declarations (EPD) for this product category based on ISO 14025, ISO 14040/14044 and other relevant standards to be used in different applications and target audiences.

6.2.3.3 Underlying studies used for PCR development

The methodological choices made during the development of this PCR (functional unit/declared unit, system boundary, allocation methods, impact categories, data quality rules, etc.) in this PCR were primarily based on the following underlying studies:

- Best4Hy D5.1 “Environmental profile of existing EoL technologies and effects in the scope of circular economy in manufacturing phase” [23]
- P. Masoni and A. Zamagni, “Guidance Document for performing LCAs on Fuel Cells and Hydrogen Technologies (FC-HyGuide),” 2011 [24]
- D. Melideo, R. Ortiz Cebolla, and E. Weidner, Life cycle assessment of hydrogen and fuel cell technologies: Inventory of work performed by projects funded under FCH JU, EUR 29986 EN. 2020 [25]

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- EVERYWH2ERE D5.1 – "Preliminary screening of the environmental impacts of the FC genset" [26]

Other studies have been considered as reference. The complete list is reported within Annex A.

6.2.4 Goal and Scope, Life Cycle Inventory and Life Cycle Impact Assessment

The goal of this section is to provide specific rules, requirements and guidelines for developing an EPD for Fuel cells.

6.2.4.1 Functional unit

The functional unit shall be defined as 1 kWh of electricity generated by the fuel cell and/or 1 kWh of thermal energy (if also usable heat is produced).

The functional unit shall be stated in the EPD.

The environmental impact shall be given per functional unit, considering the reference service life of the product.

6.2.4.2 Technical specifications, lifespan and reference service life

The following technical specifications should be provided:

- Type of fuel cell
- Dimension
- Electrical power
- Thermal power (if applicable)
- Efficiency
- Life span (of the fuel cell stack and of the other main components)
- Electricity and/or thermal energy produced during the life span
- Fuel used (specifying its source)

6.2.4.3 System boundary

The International EPD® System uses an approach where all attributional processes from "cradle to grave" should be included using the principle of "limited loss of information at the final product". This is especially important in the case of business-to-consumer communication.

The scope of this PCR and EPDs based on it is cradle-to-grave.

6.2.4.3.1 Life Cycle stages

For the purpose of different data quality rules and for the presentation of results, the life cycle of the product is divided into three life cycle stages:

- Upstream processes (from cradle-to-gate): mainly including the production of material inputs to the core processes (e.g. raw material acquisition and refinement, and the production of intermediate components),

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- Core processes (from gate-to-gate): mainly including the processes managed by the organisation that owns the EPD.
- Downstream processes (from gate-to-grave): including for example further processing of the product, distribution transports, retail, product use and end-of-life management of the product.

In the EPD, the environmental performance associated with each of the three life-cycle stages above shall be reported separately and in aggregated form. The processes included in the scope of the PCR and belonging to each life cycle stage are described in the following Table.

Table 10: Life Cycle stages and unit processes

LIFE-CYCLE STAGES	UNIT PROCESSES
Upstream processes **(from cradle-to-gate)**	• Extraction and production of raw material for all main parts and components. • Transport between raw material extraction and processing of materials shall be identified. • Production of input components (e.g. BOP components). • Energy used in the upstream processes. For example, electricity, steam, fuels and other energy carriers. • Recycling processes of secondary materials from other product life cycles. • Production of packaging.
Core processes **(from gate-to-gate)**	• Transportation of materials and components to manufacturing site of the product under study. • Energy used in manufacturing for the **fuel cell stack**. For example, electricity, steam, fuels and other energy carriers. • Energy used for packaging the product. • End-of-life treatment of production waste, even if carried out by third parties, including transportation.
Downstream processes **(from gate-to-grave)**	• Transportation of product direct to customer or through central stock. • Installation of product at site, including used material and energy. Potential waste generated from installation is also included. • Production and consumption of fuel (e.g. hydrogen) to supply the fuel cell • Maintenance during reference service life, including used materials and components and replacement of spare parts.

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	• End-of-life treatment of studied product and its packaging, including transportation. For example: Disassembly, shredding, material and energy recovery processes and disposal. • Energy used in the downstream processes. For example, electricity, steam, fuels and other energy carriers.

6.2.4.4 System diagram

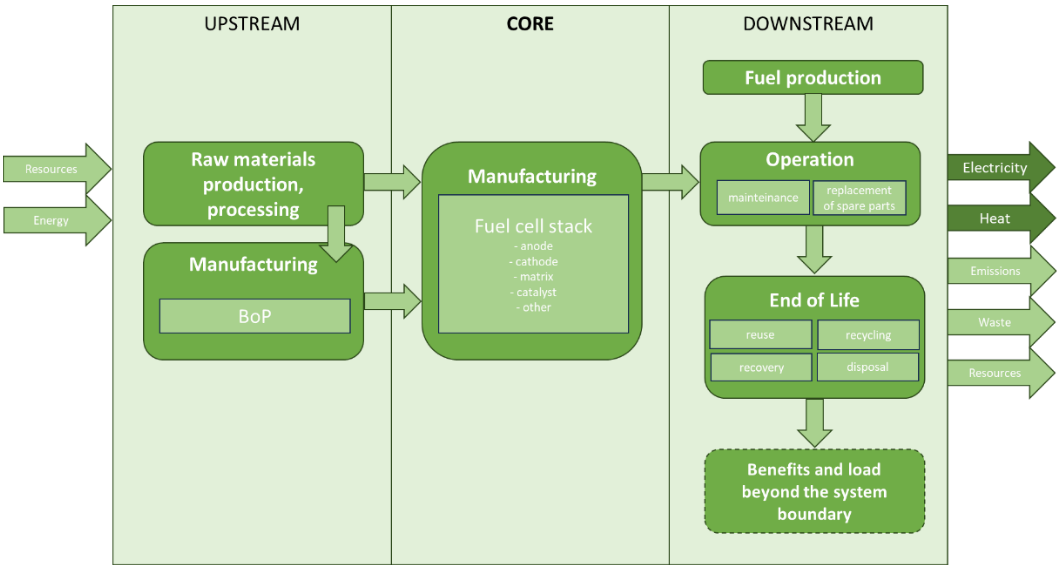

Figure 6: System diagram illustrating the processes that are included in the product system, divided into upstream, core and downstream processes. The illustration of processes is not exhaustive.

It is suggested to use this table to clearly indicate the modules (phases) included in the study. For a complete evaluation, all the phases should be included. Any omission should be justified. For example, if end-of-life phase (and associated module D) are not included, it is necessary to clearly state it.

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Table 11: Modules (X indicate included modules; excluded phase can be indicated with MND: 'Module not declared')

UPSTREAM		CORE	DOWNSTREAM			
Raw materials production and processing	**Manufacturing of BOP**	**Manufacturing of fuel cell stack**	**Fuel production**	**Operation**	**End of Life**	**Benefits and load beyond the system boundary**
X	X	X	X	X	X	X

The potential benefit of recycling and waste treatment of the products according to the specified scenarios shall be presented in the EPD as Module D (Benefits and load beyond the system boundary). Module D is a concept taken from the norm EN 15804, which includes the benefits and loads beyond the system boundary through the reuse, recovery or recycling of materials and/or energy, including the processes avoided or substituted due to these practices. In module D, the benefits associated with "open loop" recycling can be quantified. On the contrary, the amount of secondary material output, which is for all practical purposes able to replace one to one the input of secondary material as "closed loop" is allocated to the product system under study and not to module D.

6.2.4.5 Cut-off rules

A cut-off rule of 1% shall be applied. In other words, the included inventory data (not including inventory data of processes that are explicitly outside the system boundary as described in Section 4.3) shall together give rise to at least 99% of the results of any of the environmental impact categories. Also, 99% of the mass of the product content and 99% of the energy use of the product life cycle shall be accounted for. The cut-off of inventory data should, however, be avoided, and all available inventory data shall be used.

The cut-off of inventory data, based on the above cut-off rule, should be an output of a sensitivity analysis, alone or in combination with expert judgment based on experience of similar product systems. Further, the cut-off shall be possible to verify in the verification process, hence the exclusion of inventory data based on the cut-off rule shall be documented in the LCA report, and the EPD developer shall provide the information the verifier considers necessary to verify the cut-off.

6.2.4.6 Allocation rules

6.2.4.6.1 Allocation of co-products

The following hierarchy of allocation methods shall be followed for co-product allocation:

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1.	Allocation shall be avoided, if possible, by dividing the process to be allocated into sub-processes and collecting the inventory data for each sub-process.

2.	If allocation cannot be avoided, the inventory data should be partitioned between the different co-products in a way that reflects the underlying physical relationships between them, i.e. allocation should reflect the way in which the inventory data changes if the quantities of delivered co-products change.

3.	If a physical relationship between the inventory data and the delivery of co-products cannot be established, the inventory data should be allocated between the co-products in a way that reflects other relationships between them. For example, inventory data might be allocated between co-products in proportion to their economic values. If economic allocation is used, a sensitivity analysis exploring the influence of the choice of the economic value shall be included in the LCA report.

Fuel cells can represent multifunction systems, as they can produce electricity and usable heat. In this case, allocation by exergy should be applied.

6.2.4.6.2 Allocation of waste

Allocation of waste shall follow the polluter pays principle and its interpretation in EN 15804: "processes of waste processing shall be assigned to the product system that generates the waste until the end-of-waste state is reached." The end-of-waste state is reached when all the following criteria for the end-of-waste state are fulfilled (adapted from EN 15804):

- the recovered material, component or product is commonly used for specific purposes.
- a market or demand, identified e.g., by a positive economic value, exists for such a recovered material, component or product
- the recovered material, component or product fulfils the technical requirements for the specific purposes and meets the existing
- legislation and standards applicable to products
- the use of the recovered material, product or construction element will not lead to overall adverse environmental or human health impacts.

The above outlined principle means that the generator of the waste shall carry the full environmental impact until the point in the product life cycle in which the end-of-waste criteria are fulfilled. Waste may have a negative economic market value, and then the end-of-waste stage is typically reached after (part of) the waste processing and further refinement, at the point at which the waste no longer has a negative market value. This allocation method is (in most cases) in line with a waste generator's juridical and financial responsibilities. See the GPI for further information and examples.

6.2.4.7 Data quality requirements and selection of data

EPDs may include a declaration of the quality of data used in the LCA calculations.

Life cycle inventory data are classified into specific data and generic data, where the latter can be selected generic data or proxy data. The data categories are defined as follows:

- **specific data** (also referred to as "primary data" or "site-specific data"):

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- data gathered from the actual manufacturing plant where product-specific processes are carried out.
    - actual data from other parts of the life cycle traced to the product under study, for example site-specific data on the production of materials or generation of electricity provided by contracted suppliers, and transportation data on distances, means of transportation, load factor, fuel consumption, etc., of contracted transportation providers; and
    - LCI data from databases on transportation and energy ware that is combined with actual transportation and energy parameters as listed above.
- **generic data** (sometimes referred to as "secondary data"), divided into:
    - selected generic data: data (e.g., commercial databases and free databases) that fulfil prescribed data quality requirements for precision, completeness, and representativeness,
    - proxy data: data (e.g., commercial databases and free databases) that do not fulfil all of the data quality requirements of "selected generic data".

Specific data shall be used for the core processes. Specific data shall be used for upstream and downstream processes, when available, otherwise generic data may be used. Generic data should be used in cases in which they are representative for the purpose of the EPD, e.g., for bulk and raw materials on a spot market, if there is a lack of specific data on the final product or if a product consists of many components. Generic data shall be identified and consistent with the scope of the study in terms of temporal, geographic and technologic coverage.

6.2.4.8 Environmental performance indicators

6.2.4.8.1 Environmental impacts

The EPD shall declare the environmental impact indicators, per functional unit and per life cycle stage and in aggregated form, using the default impact categories, characterisation models and factors available on https://environdec.com/resources/indicators.

The source and version of the characterisation models and the factors used shall be reported in the EPD.

Alternative regional life cycle impact assessment methods and characterisation factors are allowed to be calculated and displayed in addition to the default list. If so, the EPD shall contain an explanation of the difference between the different sets of indicators, as they may appear to the reader to display duplicate information.

6.2.4.8.2 Use of resources

The indicators for resource use based on the life cycle inventory (LCI) listed at www.environdec.com/indicators shall be declared per functional unit or declared unit, and per life cycle stage and in aggregated form.

6.2.4.8.3 Waste production and output flows

Waste generated along the whole life cycle production chains shall be treated following the technical specifications described in the General Programme Instructions. The indicators at www.environdec.com/indicators for the amount of waste or the output flows shall be

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reported per functional unit or declared unit, and per life cycle stage and in aggregated form.

6.2.4.8.4 Additional environmental information

An EPD may declare additional environmentally relevant information not derived from the LCA-based calculations, such as:

- the release of dangerous substances into indoor air, soil, and water during the use stage,
- instructions for proper use of the product, e.g. to minimise energy or water consumption or to improve the durability of the product,
- instructions for proper maintenance and service of the product, e.g. to minimise energy or water consumption or to improve the durability of the product,
- information on key parts of the product that determine its durability,
- information on recycling including, e.g. suitable procedures for recycling the entire product or selected parts and the potential environmental benefits gained,
- information on a suitable method of reuse of the product (or parts of the products) and procedures for disposal as waste at the end of its life cycle,
- information regarding disposal of the product, or inherent materials, and any other information considered necessary to minimise the product's end-of-life impacts, and
- a more detailed description of an organisation's overall environmental work, such as:
  - the existence of any type of organised environmental activity, and
  - information on where interested parties may find more details about the organisation's environmental work.

Any additional environmental information declared shall be substantiated and verifiable, and be derived using appropriate methods and be specific, accurate, not misleading, and relevant to the specific product. Quantitative information is preferred over qualitative information.

6.2.4.9 Including multiple products in the same EPD

Similar products from a single or several manufacturing sites covered by the same PCR and manufactured by the same company with the same major steps in the core processes may be included in the same EPD if none of the declared environmental performance indicators differ by more than 10% between any of the included products. The results for the environmental performance indicators of one representative product shall be declared according to Chapter 6.2.4.8. The choice of representative product shall be justified in the EPD, using, where applicable, statistical parameters.

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7 Conclusions

The aim of this document is to investigate how the ecolabeling certifications are setup and how they could be adapted to FCH technologies.

First, a list of the existing types of **environmental labels** is presented, including Type I, Type II, and Type III. The main characteristics of each type are then outlined.

Regarding Type I and III, certain schemes are introduced, along with an evaluation of their connection to the fuel cell industry. In particular, EU Ecolabel and the International EPD® System have been identified as the most relevant options for the Fuel Cell product, even though no certification is currently available.

As of now, indeed, there hasn't been a dedicated **Product Group** or **Product Category Rule** established for fuel cells. In response, guidelines have been drafted to facilitate their prospective development. Specifically, the procedures for proposing and developing a Product Group for EU Ecolabel and a Product Category Rule for the International EPD® System are outlined, along with draft criteria for their implementation.

The proposed guidelines are based on the relevant scheme document, but also on the existing LCA studies for fuel cells.

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8 References

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[3] *ISO 14025: 2006 Environmental product declaration - Type III environmental declarations - Principles and procedures.*

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[9] "PCR ELECTRICITY, STEAM AND HOT/COLD WATER GENERATION AND DISTRIBUTION, 2007:08, VERSION 4.2".

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Annex A - Underlying studies used for PCR development

The methodological choices made during the development of this PCR were primarily based on the underlying studies listed in Table 12.

Table 12: LCA studies

Ref	LCA study
[23]	Best4Hy D5.1 “Environmental profile of existing EoL technologies and effects in the scope of circular economy in manufacturing phase”
[24]	P. Masoni and A. Zamagni, “Guidance Document for performing LCAs on Fuel Cells and Hydrogen Technologies (FC-HyGuide),” 2011.
[25]	D. Melideo, R. Ortiz Cebolla, and E. Weidner, Life cycle assessment of hydrogen and fuel cell technologies: Inventory of work performed by projects funded under FCH JU, EUR 29986 EN. 2020.
[26]	EVERYWH2ERE D5.1 – “Preliminary screening of the environmental impacts of the FC genset”
[27]	M. Mori, R. Stropnik, and A. Lotrič, “EU HyTechCycling Grant No. 700190 - WP4 LCA for FCH technologies considering new strategies & technologies in the phase of recycling and dismantling - D4.3 Case studies with new strategies in dismantling and recycling stage,” 2019.
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[30]	K. Al-Khori, S. G. Al-Ghamdi, S. Boulfrad, and M. Koç, “Life cycle assessment for integration of solid oxide fuel cells into gas processing operations,” Energies, vol. 14, no. 15, pp. 1–20, 2021, doi: 10.3390/en14154668.
[31]	Y. D. Lee, K. Y. Ahn, T. Morosuk, and G. Tsatsaronis, “Environmental impact assessment of a solid-oxide fuel-cell-based combined-heat-and-power-generation system,” Energy, vol. 79, no. C, pp. 455–466, Jan. 2015, doi: 10.1016/j.energy.2014.11.035.
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[34]	Mlakar, Nejc, et al. "The influence of degradation effects in proton exchange membrane fuel cells on life cycle assessment modelling and environmental impact indicators." *International Journal of Hydrogen Energy* 47.57 (2022): 24223-24241.

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In this Annex, the main methodological choices behind each of this study are reported.

First, Table 13 list the fuel cell types included in the different studies.

Table 13: Fuel cell type

	[23]	[24]	[25]	[26]	[27]	[28]	[29]	[30]	[31]	[32]	[33]	[34]
PEMFC	X	X		X	X	X	X			X	X	X
SOFC	X	X			X		X	X	X			
PAFC		X										
MCFC		X										
DMFC		X										
AWE										X		

In Table 14, a list of the used functional units is provided.

Table 14: Functional units

Ref	Functional unit
[23]	- one PEMFC stack with 55 kW electrical power output - a Solid Oxide Electrolyte Fuel Cell (SOFC) stack with a rated electrical power of 3 kW
[24]	- the power capacity of the manufactured stack expressed in kW (if a FC stack is considered) - the production of a certain amount of electricity and useful thermal energy in a given number of years (if a whole FC system is considered)
[25]	- [For fuel cell stacks] The functional unit is the power capacity of the manufactured stack expressed in kW (energy if electricity is the only valuable product, exergy if both electricity and heat are valuable products; in this case the share of electricity and heat shall be declared) - [For fuel cell systems] The functional unit is the "production of a certain amount of electricity and useful thermal energy in a given number of years", expressed in MJex. The share of electricity and heat shall be declared. If the thermal output of the FC is not used, the FU is only the production of electricity, expressed in MJel.
[26]	- 1 MWh electricity
[27]	- 1 kWh of exergy
[28]	- manufacturing and recycling one MEA that disposes of 25 cm² of active area - the results can further be easily correlated to the electrical power at a stack scale based on the power density (approximately 0.7 W·cm-2).
[29]	- a mass of 1 g of material used in the assessed FCH technologies

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Ref	Functional unit
[30]	- Integration of 10 MW Solid Oxide Fuel Cells fueled by natural gas in a gas plant
[31]	-the production of one 100 kW-class SOFC cell and stack - 1 year of operation of one 100 kW-class SOFC cell and stack
[32]	- in the case of AWE and PEMWE the functional unit is a 50-kW system, a 5- kW system in the case of the HT PEMFC and a 1-kW system in the case of the LT PEMFC.
[33]	- manufacturing one 48 kWel PEMFC stack used for passenger transportation in a light-duty vehicle, which represents the functional unit (FU), without balance of plant (BoP) components.
[34]	- 1 kWh of electricity generated by the 1 kWel PEMFC system

Table 15 reports the life cycle phases included in the system boundaries of the different studies.

Table 15: System boundaries

	[23]	[24]	[25]	[26]	[27]	[28]	[29]	[30]	[31]	[32]	[33]	[34]
Raw materials production and processing	X	X		X	X	X	X	X	X	X	X	X
Manufacturing - fuel cell stack	X	X		X	X	X	X	-	X	X	X	X
Manufacturing - BoP	-	X		X	(X)	-	X	X	X	X		X
Operation	-	X		X	X	-	-	X	X			X
End of Life	X	X			X	X	-	-		X		X

Table 16 lists the Impact indicators used to express the environmental impacts of the fuel cells, in the different studies.

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Table 16: Impact indicators

	[23]	[24]	[25]	[26]	[27]	[28]	[29]	[30]	[31]	[32]	[33]	[34]
GWP	X	X	X	X	X	X	X	X	X	X	X	X
AP	X	X	X	X	X	X	X			X	X	X
EP	X	X	X	X	X	X	X	X		X	X	X
ADP elem	X	X	X	X	X	X	X			X	X	X
ADP fossil	X		X	X	X	X	X		X	X	X	X
ODP					X	X	X			X		X
POCP			X	X	X	X	X	X		X		X
HTP					X	X	X	X	X	X		X
FAETP					X	X	X			X		X
MAETP					X	X	X			X		X
TETP					X	X	X			X		X
PM								X	X			
SQP									X			

GWP= Global Warming Potential; AP=Acidification Potential; EP=Eutrophication Potential; ADP elem =Abiotic depletion potential, elements; ADP fossil= Abiotic depletion potential, fossil; ODP= Ozone-Layer Depletion Potential; POCP = Photochemical Ozone Creation Potential; HTP = Human Toxicity Potential; FAETP= Freshwater Aquatic Ecotoxicity Potential; MAETP = Marine Aquatic Ecotoxicity Potential; TETP =Terrestrial Ecotoxicity Potential; PM= Particulate matter; SQP = Land use impacts/ Soil quality

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