Cost-effective PROton Exchange MEmbrane WaTer Electrolyser for Efficient and Sustainable Power-to-H2 Technology

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D6.2 LCA first report: definition of scope and information interfaces

WP6 Cost model, evaluation and LCA

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3	28/01/2022	D. Cortés (FHA)	Recommendations included

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Executive Summary

This document, D6.2 LCA first report: definition of scope and information interfaces, is the second Deliverable of WP6 Cost model, evaluation and LCA.

It will present the initial stages of the development of the LCA to be carried out in the framework of the project. These stages are decisive for the subsequent stages as they mark the results to be obtained from the project.

To this end, a brief introduction to the LCA methodology is given, the standards followed are reported, the main stages are described, information is provided on the objective and scope of the study and a section is included on the way in which the information will be collected from the partners responsible for each of the stages of the product life cycle.

This document will be completed by D6.4 Final LCC and LCA analysis.

1 Introduction

Today, one of the challenges for most organisations is a real and substantial implementation of environmental sustainability through measurement and comparability of results to satisfy the sustainability principles of all stakeholders. Sustainability needs to be pursued through the measurement of specific indicators and the monitoring of variables that influence the status of not only economic but also environmental issues. Work Package 6 covers the assessment of the costs and environmental impact of the technology developed in the PROMET-H2 project. These calculations will provide a complete picture of the main advantages of the innovative technology and demonstrate its potential for future industrial application and further developments. In addition, the analyses will point out the main challenges and weaknesses for future developments and research.

The objective of deliverable D6.2 LCA first report: definition of scope and information interfaces is to provide the basis for the development of the Life Cycle Assessment to be developed within the framework of the project. The main steps to be addressed in this document are the Goal and Scope and how the necessary information to carry out this study will be obtained, which will be provided by the project partners who are responsible for each specific part of the element to be studied.

Throughout this document the system boundaries, the functional unit, the data type and source, as well as the impact categories will be defined.

LCA is a harmonised and implemented technique to assess the environmental aspects and potential impacts associated with a product, process, or service by compiling an inventory of relevant energy and material inputs, and environmental releases, evaluating the potential environmental impacts associated with these processes. In PROMET-H2, the main results associated with the LCA will be defined as the environmental impact of the 25 kW PEMWE stack developed in the project throughout its life cycle. The analysis will include not only the manufacturing and transport of the materials, but also the end-of-life phase, which will be modelled with the data provided by Monolithos.

In order to frame this action and to see the possible relation they have with the rest of the activities developed within this WP, the main information on the expected LCC, TEA and LCA is shown in Table 1.

Table 1. WP6 analyses to be carried out, main results expected, stages included in the analysis, system under study and targeted level of details considered.

Name of the analysis	LCC life cycle cost	TEA techno-economic analysis	LCA life cycle assessment
Main result	- Life cycle cost of PROMET-H2 stack (in €/kW)	- Production cost of H_2 (in €/kg) (kW and MW scale) - Production cost of MeOH (in €/ton) (kW and MW scale)	- Environmental impact of PROMET-H2 stack
Stages included in the analysis	1) Production and Construction Stage 2) Maintenance and Rehabilitation Cost 3) End of life	The same as the LCC but will also be included: - BoP - Electrolyser Operation Cost	1) Production and Construction Stage 2) Maintenance and Rehabilitation 3) End of life
System under study	25 kW stack developed in the project frame	- 25 kW electrolyser developed in the project frame - 1MW (scaling-up from the 25kW developed in the project frame)	25 kW developed in the project frame
Targeted level of detail	The data used as a basis will refer to the real system developed in the project aiming for the highest possible precision and accuracy.	The TEA will consist of information obtained directly from the LCC and: - Purchase prices of the BoP elements. - Agreed cost approaches to be performed on the operating scenarios provided by WP 5 and WP7.	The data used as a basis will refer to the real system developed in the project aiming for the highest possible precision and accuracy.

The results of all these studies depend directly on the experimental results of the project, not only on the materials chosen by the project to develop the PROMET-H2 stack, but also on the masses used, the production processes and the possible end-of-life strategies at the end of the stack's lifetime. Collaboration between the WPs will be crucial to obtain accurate and realistic results and for this purpose a series of questionnaires have been developed in tabular form to enable the partners to provide this information as accurately and realistically as possible.

2 Life Cycle methodology and stages

The conduct of this study will be guided by the recommendations set out in the commonly followed standards for the development of LCAs: EN ISO 14040:2006[1] and EN ISO 14044:2006[2].

In addition, and as the main novelty, it will try to put into practice the recommendation recently published by the European Commission in December 2021 entitled "Recommendation on the use of Environmental Footprint methods"[3]. As a follow-up to the existing 2013 guide, which provided detailed guidelines on how to model and calculate environmental impacts, this new guide replaces the previous 2013 document on this topic.

As defined in the aforementioned standards, the 4 phases that should make up an LCA are shown in the following figure and explained below:

[1] ISO 14040:2006 Environmental management — Life cycle assessment — Principles and framework

[2] EN ISO 14044:2006 Environmental management - Life cycle assessment - Requirements and guidelines

[3] Environment. 2021. *Recommendation on the use of Environmental Footprint methods*. [online] Available at: <https://ec.europa.eu/environment/publications/recommendation-use-environmental-footprint-methods_en> [Accessed 19 January 2022].

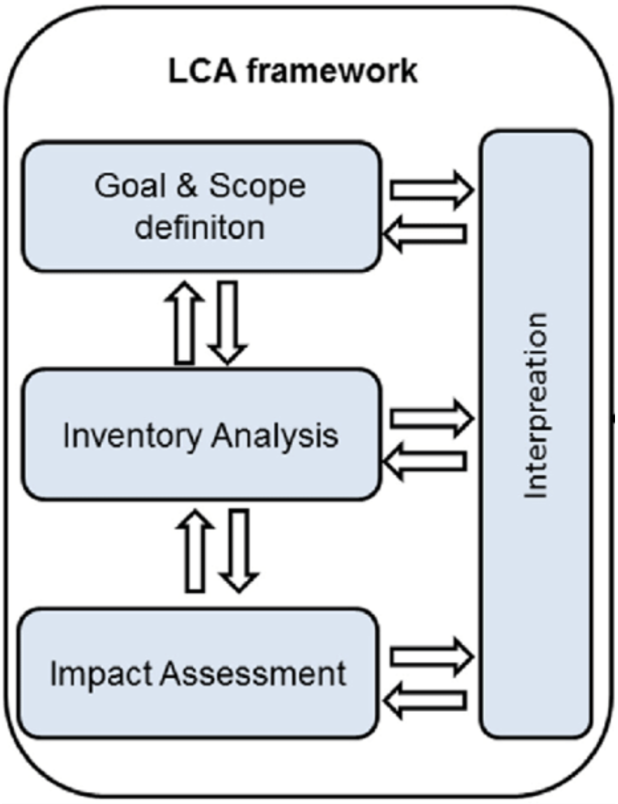

Figure 1. Common four stages of LCA studies according to international standards.

During the **Goal definition phase**, the study objectives are defined, including the intended audience, the reasons for conducting the study, and the intended application.

In the **Scope definition phase** key methodological decisions are made, such as the definition of the functional unit, identifying the system boundaries, selecting additional environmental and technical information, and formulating main assumptions and constraints.

Life Cycle Inventory (LCI) entails collecting data and quantifying inputs and outputs of the system under study. Energy, raw materials, products, by-products, and waste are all inputs and outputs. Air, water, and soil emissions are also inputs and outputs. The data collected relate to foreground and background processes. The data are linked to the process units and the functional unit. The LCI is an iterative process. Indeed, as data is collected and more is learned about the system, new data requirements or constraints may be identified that require a change in the data collection procedures in order to continue to meet the objectives of the study.

In the **Life Cycle Impact Assessment phase (LCIA)**, LCI results are associated with environmental impact categories and indicators. This is done through LCIA methods, which first classify emissions into impact categories and then characterise them as common units.

In the **Interpretation phase**, the results of the LCI and LCIA are interpreted according to the set objective and scope. In this phase, the most relevant impact categories, life cycle stages, processes and elementary flows are identified. From the analytical results, conclusions and recommendations can be drawn. It also includes the reporting phase, designed to summarise the results of the study in the final report.

3 Goal Definition Phase

In the first phase, the study goals are defined, and the general context is established. This allows study participants to have a concise and clear vision of the study. This procedure also helps to ensure that the aims, methods, results and applications of the study will fit together. The objectives should identify the intended applications and the depth and analytical rigor of the study.

The goal definition, following the aforementioned document "Recommendation on the use of Environmental Footprint methods" includes:

1. Intended application(s);

- To obtain the environmental impacts of manufacturing the new stack for a better understanding and implementation of the processes.

- Evaluation of the critical points of the new stack in terms of environmental impacts.

2. Reasons for carrying out the study and decision context;

The reasons for carrying out the study are based on the need to evaluate the environmental sustainability of the new stack developed. The intention of the project is to replace environmentally harmful components and use more environmentally benign ones. The completion of this study will demonstrate clearly and concisely whether the objectives have been achieved and obtained as expected. For this purpose a comparative case will be established, benchmarking the new stack developed with a “standard” PEM stack (the inventory will be provided by the project partners or from the bibliography.) It will also be possible (if information from TEA analyses is available) to perform this benchmarking at the MW scale. Only one benchmarking study will be carried out.

3. Target audience;

The study is aimed at a technical audience in the hydrogen sector, but not at an expert in the field of LCA. It can be used to help decision makers decide on the next development methods to reduce the environmental impact considering the entire life cycle of the product.

4. Commissioner of the study;

The commissioner of the study is PROMET-H2 project which is financed by the European Union's Horizon 2020 research and innovation programme under grant agreement No 862253.

5. Identity of the verifier.

Air Liquide (AL) will follow and supervise the study ensuring that the analysis is carried out accordingly to the project objectives. A verification scheme, strictly in accordance with the PEF procedure, is not foreseen.

4 Scope Definition Phase

The scope of an LCA study provides a precise outline of the product to be evaluated and the technical specifications.

The definition of the scope is in line with the defined goals of the study and includes. Accordingly to the "Recommendation on the use of Environmental Footprint methods" the following information is included:

1. Functional unit and reference flow
2. System boundary
3. EF impact categories
4. Additional information to be included
5. Assumptions/limitations

4.1 Functional unit and reference flow

The functional unit is going to be defined according to the following aspects:

i) The function(s)/service(s) provided: **'what'**; the 25kW PEM stack designed and developed within the PROMET-H2 project.

ii) The extent of the function or service: **'how much'**; a single unit.

iii) The expected level of quality: **'how well'**; meet the needs to be integrated into a 25 kW electrolyser that will produce the hydrogen to be used in a pilot plant to produce methanol from CO_2 in the framework of the project.

iv) The duration/lifetime of the product: **'how long'**; full life time of the stack.

v) In a second stage, the functional unit will be modified to consider the use stage of the electrolyser to have an overview of the impact relative to the stack with hydrogen production. For this purpose, the functional unit will be 1 kg of hydrogen produced with the conditions under which it is produced by the electrolyser, which will be defined in D6.4.

4.2 System boundary

The system boundary defines which parts of the product life cycle and which stages, and associated life cycle processes fall within the system under analysis, except for the processes excluded under the cut-off rule.

The system in the foreground comprises all processes related to the production, assembly, use, end-of-life and related transports of the PEM stack. In this case, the production of components phase in the foreground includes the main production processes of Anode Electrode, Cathode Electrode, Membrane, PTL, BP and Pressure Vessel. The Use Phase will include the Maintenance and Rehabilitation actions. In the foreground all materials and energy flows are evaluated. This information will be provided directly by the project partners.

Figure 2. System boundary diagram.

The background system supports the foreground system and its processes. It handles almost all material and energy flows to and from the foreground system. This secondary information for the background system is obtained from existing high-quality databases (GaBi Professional).

4.3 EF Impact Categories

The LCIA Environmental Footprint 3.0 (EF3.0) method will be used to assess the selected environmental impact categories as it has been proposed by the European Commission as the common method for measuring environmental performance. This method is currently in a transitional phase in the development of EF characterisation and is strongly supported by the JRC. The chosen impact categories homogeneously considers the different end-points of impact such as human health, ecosystems and resource use and are used and recommended in current reference projects in which the authors of this study are involved. It is not possible to reference them because they are not yet available and confidentiality has to be maintained until they are published.

Table 2. Proposed EF impact categories, including indicator, units, and method package.

EF impact category	Impact category indicator	Unit	Characterisation model
Climate change, total	Global warming potential (GWP100)	kg CO2 eq	Bern model - Global warming potentials (GWP) over a 100-year time horizon (based on IPCC 2013)
Acidification	Accumulated exceedance (AE)	mol H+ eq	Accumulated exceedance (Seppälä et al. 2006, Posch et al, 2008)
Eutrophication, terrestrial	Accumulated exceedance (AE)	kg N eq	Accumulated exceedance (Seppälä et al. 2006, Posch et al, 2008)
Eutrophication, freshwater	Fraction of nutrients reaching freshwater end compartment (P)	kg P eq	EUTREND model (Struijs et al, 2009) as applied in ReCiPe
Eutrophication, marine	Fraction of nutrients reaching marine end compartment (N)	Kg N eq	EUTREND model (Struijs et al, 2009) as applied in ReCiPe
Resource use, minerals and metals	Abiotic resource depletion (ADP ultimate reserves)	kg Sb eq	van Oers et al., 2002 as in CML 2002 method, v.4.8
Resource use, fossils	Abiotic resource depletion – fossil fuels (ADP-fossil)	MJ	van Oers et al., 2002 as in CML 2002 method, v.4.8

4.4 Additional information to be included

Additional environmental information that adds value to the rest of the study should be included here. One of the recommendations made by Air Liquide in one of the WP6 meetings included analysing new materials under the focus of Critical Raw Materials (CRMs), which can be defined as those raw materials that are economically and strategically important for the European economy, but which have a high risk associated with their supply. As the inventory compilation has not been carried out, this study will be included in D6.4 Final LCC and LCA analysis.

4.5 Assumptions/limitations

Assumptions and limitations (e.g. data gaps) can not be defined and documented at this stage of the assessment. This will done in D6.4 Final LCC and LCA analysis.

4.6 Data base and inventory data

With the aim of obtaining a complete Life Cycle Inventory, a Bill of Materials has been prepared in order to compile information to develop the LCA studies. A list of following tables should be completed by the partners associated with each stage of the process.

4.6.1 Production and Construction Stage

a) Stack components production

Table 3 aims to compile the information of interest of the PROMET-H2 electrolyser stack component production process. For this purpose, in the first column the elements of the stack are listed. For each component, there are three boxes of possible materials that can compose it. The partners can expand these boxes if the component consists of more than three materials.

Table 3. Stack components production.

	Components material			Machinery		Components	
Component	Material	Installed quantity per stack (g/stack)	Scrap per stack (g/stack)	Electrical energy (kWh)	Other associated inputs	Lifetime (h)	Country of manufacture
a) Anode Electrode	1.						
	2.						
	3.						
b) Cathode Electrode	1.						
	2.						
	3.						
c) Membrane	1.						
	2.						
	3.						
d) PTL	1.						
	2.						
	3.						
e) BP	1.						
	2.						
	3.						
f) Pressure Vessel	1.						
	2.						
	3.						

b) Transport of components to stack assembly

Table 4 is used to collect information on the transport of the individual stack components to the stack assembly site.

Table 4. Transport components to stack assembly.

Component	Distance (km)	Mean of transport
a) Anode Electrode b) Cathode Electrode c) Membrane d) PTL e) BP		

c) Stack assembly

The parameters shown in Table 5 are stack assembly process data.

In the first column, the partner must complete the stages of the process, and in the second column the stack components involved in each of them.

Table 5. Stack assembly.

	Assembly material			Machinery Cost		
Stages of the Stack Assembly Process	Components involved	Assembly material	Scrap assembly material	Electrical energy (kWh)	Other associated materials	Country where assembly takes place
	(Anode Electrode, Cathode Electrode, Membrane, PTL, BP or extra components e.g current collectors or end plates, ect)	(g/unit)	(g/unit)			
1	a)					
	b)					
	c)					
2	a)					
	b)					
	c)					
3	a)					
	b)					
	c)					
4	a)					
	b)					
	c)					
5	a)					
	b)					
	c)					

Table 6 requires the transport costs from the point of assembly of the stack to the operating plant.

Table 6. Transport of stack assembly to electrolysis plant.

Component	Distance (km)	Mean of transport
Stack		

4.6.2 Operational Stage

Regarding the operation of the stack, Table 7 lists the necessary parameters.

Table 7. Replacement and reparation Actions.

Component	Part to be re-placed or re-paired	Action (replacement / repair)
Stack		

The next table show experimental data obtained during the system testing in the frame of this project. If the values reported below are not available, some assumptions will be made, also motivating the reasoning for that choice.

Table 8. Electrolyser Operation.

Electrolyser	Unit	Input
Electricity consumption	kWh/kgH_2	
Water consumption	kgH_2O/kgH_2	
Hours of operation	h	
Hydrogen produced	kg	
Hydrogen purity	%	
Hydrogen output pressure	Bar	
Hydrogen output tempera-ture	ºC	

4.6.3 End-of-life Stage

a) Recycling

In Table 9, the information to be collected for the recycling step is shown.

In addition, it is expected that Monolithos could provide information on the recovery of the salvaged materials at the recycling stage.

Table 9. Recycling.

	Recycling materials			Machinery Cost			
Stages of the Stack Assembly Process	Components involved	Input material	Scrap assembly material	Electrical energy (kWh)	Other associated inputs	% of material recovered	Country where recycling takes place
	(Anode Electrode, Cathode Electrode, Membrane, PTL, BP or extra components e.g current collectors or end plates, ect)	(g/unit)	(g/unit)				
1	a)						
	b)						
	c)						
2	a)						
	b)						
	c)						
3	a)						
	b)						
	c)						
4	a)						
	b)						
	c)						
5	a)						
	b)						
	c)						

b) Stack transport to recycling

Table 10 requires the transport costs of the electrolyser operating plant to recycling plant.

Table 10. Transport components to stack recycling process.

	Distance (km)	Mean of transport
Stack		

5 Conclusions

In this document, D6.2 First LCA report: scope and information interfaces, we outline the initial stages of developing the LCA within the context of the project. This stage is crucial to the following ones, as it marks the results of the LCA.

An introduction to the LCA methodology has been provided, along with the ISO standards to be used. As a novelty, a new recommendation of the European Commission will be followed. The stages of the product life cycle have been outlined which includes the production of components, their assembly, the use phase, end of life and the intermediate transport steps. The goal and scope of the study have been explained, and a section has been included on how information will be gathered from the partners of the project responsible for each stage.

This document will be completed with D6.4 Final LCA and LCA analysis.