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

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D6.1 Cost model description including first assessment of material cost

WP6 Cost model, evaluation and LCA

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Executive Summary

This document, D6.1 Description of the cost model, including the first material cost evaluation, is the first deliverable of WP6 Cost model, evaluation and LCA.

It provides the background information on which the Cost Model, including Life Cycle Costing (LCC) and Techno-Economic Analysis (TEA) will be developed in the next WP6 deliverables.

A methodology for the LCC and TEA calculation is presented by selecting parameters that lead to the selected evaluation and calculation method. The LCC will focus on the stack, aligned with the objectives of the Life Cycle Analysis, LCA, to be presented in D6.2, to obtain the most accurate information possible on the stack developed in the frame of the PROMETH2 project. The TEA analysis will consider the complete system, including the operation of the electrolyser.

Additionally, an evaluation of the materials of a commercial PEM electrolyser is presented, pointing out three possible points of cost reduction: the materials used in the catalysts, reduce the thickness of Nafion™ membranes and the replacement of titanium by stainless steel.

These results are the first step for the economic and environmental evaluation of the future PEM electrolyser developed in the frame of the PROMET-H2 project.

1 Introduction

Nowadays the biggest challenge for most organizations is a real and substantial application of sustainability through the measurement and comparability of results to satisfy the principles of sustainability of all the stakeholders. It is necessary to pursue sustainability through the measurements of specific indicators and control the variables that influence the state of the economic and environmental issues. WP 6 covers the evaluation of costs and environmental impact of the technology developed in the PROMET-H2 project. These calculations will provide a comprehensive picture on the main advantages of the innovative technology and will prove its potential for future industrial implementation. Furthermore, the analyses will point out the main challenges and pain points for future developments and research.

The aim of deliverable D6.1 Description of the cost model, including the first assessment of material costs, is to provide the base information on which the Life Cycle Costing (LCC) and Tecno-Economic Analysis (TEA) will be developed in PROMET-H2. Therefore, the cost model is composed of two studies: LCC and TEA.

LCC is an assessment of all costs associated with the life cycle of a product that are directly covered by one or more actors in the product life cycle. In PROMET-H2 the main results of the LCC are associated with the determination of the life cycle cost of the PROMET-H2 stack, in €/kW. The analysis will focus on the production cost of the stack also including the end-of-life costs related to the recycling process. The size of the electrolyser stack studied is 25kW. The data used as a basis will refer to the real system developed.

On the other hand, Techno-Economic Analysis (TEA) is a method of analyzing the economic performance of an industrial process, product, or service. The objective of this analysis is estimate capital cost, operating cost, and revenue based on technical and financial input parameters. The TEA will include not only a focus on the 25 kW real stack developed in the framework of the project but also also a focus on a potential up-scaling MW stack. Both assessments will focus on the whole electrolyser (stack + BoP) including potential operational scenarios considering inputs from other WPs. The main result expected are the cost of hydrogen (€/kg H2) and methanol (€/ton) production in both cases.

The reason for this cost model splitting is to analyse the direct cost information, which will be provided by the PROMET-H2 partners that manufacture and recycle the stack and will result in a LCC with accurate and reliable results. Moreover, the boundary conditions of the LCC are expected to be the same as those of the Life Cycle Analysis, LCA, which will also be developed in WP6. On the other hand, the TEA will optimise the operating scenarios based on the LCC results and provide economic values for hydrogen and methanol prices from the PROMET-H2 stack electrolyser.

Thus, to complete the WP6 a LCA will be develop. LCA is a technique to assess the environmental aspects and potential impacts associated with a product, by compiling an inventory of relevant energy, material inputs and environmental releases, evaluating the potential environmental impacts associated with identified inputs and releases. In PROMET-H2, the main results associated to LCA is the environmental impact of the 25 kW PEMWE stack developed in the project throughout its life cycle. The analysis will include not only manufacturing and transportation of the materials but also the end-of-life stage, which will be modelized with the data provided by Monolithos. The main information on the planned LCC, TEA and LCA is shown in the 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 Cost 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.

As described above, the results of both LCC and LCA analysis depend on the experimental results of the project, specifically, on the materials chosen by the to develop the PROMET-H2 electrolyser, as well as the prices of these materials. Collaboration between WPs will be crucial for accurate and real results. Therefore, the results of LCC and LCA will be published in the next deliverables of the project, D6.2, D6.3 and D6.4. The present D6.1 will define the conditions, assumptions, and the way in which the studies will be developed.

2 Calculation methodology

The model is based on the Activity Based Costing (ABC) methodology[1] that decomposes a process into elementary process steps. Thus, the main steps have been defined as: PCS, OS and EOL, defined previously in the introduction of this document.

These three main stages (PCS, OS and EOL) are further divided into 6 categories, as shown in Figure 1. In addition, the transport is represented in Figure 1 by the "T". A schematic of these three main stages is represent in Figure 1, noting the categories defined within them.

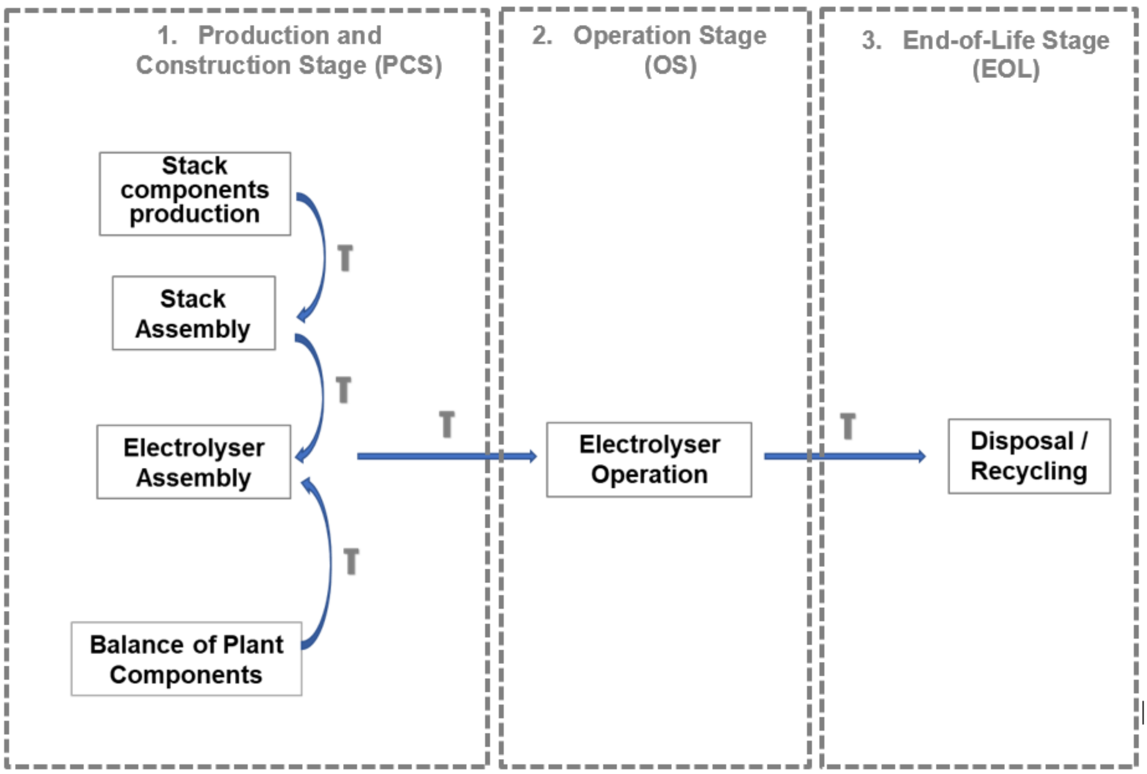

Figure 1. Diagram summarising the main blocks considered for the Cost Model. T: Transport stage.

[1] D2.3 Definition and evaluation of base case studies. eGHOST Project EU funded under Grant Agreement No 101007166.

The PCS includes the relevant information on the production phase of the stack components, the assembly of the stack, the assembly of the electrolyser and the cost of the balance of plant. In addition, all transports of the main components necessary to realise these stages will be included. The OS includes information on the operation of the electrolyser, and finally EOL includes information on the transport of the electrolyser to its recycling or disposal point.

The current document aims to have a first detailed collection of data list and the approach that will be used in the cost calculations. Once the work proceeds, these first assumptions and approach will be revised to confirm their validity or to adapt it to new requirements.

2.1 Scope of the PROMET-H2 TEA

The scope of the TEA is defined in three distinct stages of its life cycle: Production and Construction Stage (PCS), Operation Stage (OS) and End-of-Life Stage (EOL). Therefore, this study is an evaluation of the sum of the main three stages as shown in Equation 1.

$$TEA = PCS + OS + EOL \qquad \text{(Equation 1)}$$

The calculation methodology for each of these three main stages is presented below.

2.1.1 Production and construction stage

The objective will be to determine the cost of the system manufactured in the PROMET-H2 project.

For this purpose, the manufacturing process of the electrolyser is broken down into elementary steps, from the manufacturing of the basic elements of the electrolyser, to the stack assembly and materials, energy, and labour, are quantified.

For the balance of plant, the costs considered are those of the plant elements themselves, as well as their transport to the final location of the electrolysis plant.

This detailed analysis has the advantage of providing the cost structure by process steps or cost components. The calculation of the manufacturing cost of the system is then done by Equation 2-4.

$$PCS= SC+ BoPC \qquad \text{(Equation 2)}$$

$$SC= MatC+MC+LC+TC \qquad \text{(Equation 3)}$$

$$BoPC = \sum PCC \qquad \text{(Equation 4)}$$

Where:

- PCS: Production and Construction Stage
- SC: Stack Cost
- BoPC: Balance of Plant Cost
- MatC: Material Cost
- MC: Machinery Cost
- LC: Laboral Cost
- TC: Transport Cost
- PCC: Purchase Component Cost

2.1.2 Operational stage

The operational stage cost of the PROMET-H2 system will depend on the use scenario. The definition of the scenario will be based on the contributions of Task 5.4 for 25 kW TEA and Tasks 7.2 and 7.3 for up-scaling MW TEA.

Thus, one of the parameters that will have a major contribution to the cost will be the operating regime to which the electrolyser will be subjected. The calculation of the operational cost of the electrolyser is then done by Equation 5.

$$OC= EOC + MRC \qquad \text{(Equation 5)}$$

Where:

- OC: Operational Cost
- EOC: Electrolyser Operation Cost. The scenario details will be defined with the support of the WP5 (T5.4) and WP7 (T7.2 and 7.3)
- MRC: Maintenance and Rehabilitation Cost

2.1.3 End of Life stage

The final stage includes cost of material, with electricity included machinery and labour. The financial benefit of the recycling process could be assessed considering the recycling rate on the most valuable components of system and the entire cost of the recycling process.

$$EOLS = MatC + MC + LC + TC \qquad \text{(Equation 6)}$$

Where:

- EOLS: End-of-Life Stage
- MatC: Material Cost
- MC: Machinery Cost
- LC: Labour Cost
- TC: Transport Cost

2.1.4 Levelized Cost of Hydrogen

In the TEA, Levelised Cost of Hydrogen (LCOH2) will be analysed as:

$$LCOH2\ (€/kgH_2\ ) = \frac{PCS + \sum \frac{(EOC + MRC + EOLS - RR)}{(1+\tau)^t}}{kgH_2} \qquad \text{(Equation 7)}$$

When:

- PCS: Product and Construction Stage
- EOC: Electrolyser Operational Cost

- MRC: Maintenance and Rehabilitation Cost
- EOLS: End of Life Stage
- RR: Recycling Revenue
- τ: Discount rate
- t: System lifetime

All these costs are discounted to present value using a discounted cash flow methodology. Discount rate τ and year of operation t is a method of valuing a project, which gives a present value to all future cash flows, incoming and outgoing. These parameters will be defined in the progress of this project according to similar study cases. For methanol case, similar parameter will be defined.

2.2 Scope of Life Cycle Cost of PROMET-H2 Stack

The life cycle cost includes exclusively the stack over its lifetime. As previously introduced, the objective of limiting the system to this element is to know exactly the costs associated with the main development of the project and thus be able to provide valuable information for possible future developments. The equation that captures this information is as follows. With this equation, we can obtain the cost associated with the stack per kW of the stack.

$$LCC\left(\frac{€}{kW}\right) = \frac{SC + \sum \frac{(\mathrm{MRC} + MatRC + EOLS - RR)}{(1+\tau)^t}}{25\ kW} \qquad \text{(Equation 8)}$$

Where:

- SC: Stack Cost
- MRC: Maintenance and Rehabilitation Cost
- MatRC: Material Replacement Cost
- EOLS: End of Life Stage
- RR: Recycling Revenue
- τ: Discount rate
- t: System lifetime

These variables for the LCC shall be calculated in the same way as TEA, as mentioned in section 2.1.

In a first approach, R&D and testing costs will not be included, although they could be considered.

It is worth mentioning that, following the approach outlined for this study, this is a first approximation made to develop the LCC, which are usually carried out in an iterative manner. After defining the scope of the analysis, the technology is analysed, and the data are collected. Depending on the quality and amount of available data, it may be needed to re-think the initial assumptions. For example, new important aspects of the technology are discovered and need to be included; or some data that were expected from the partners are not available, thus new assumptions need to be made to obviate the problem.

3 Collection of information for cost modelling

3.1 Data base and inventory data

With the aim of developing a cost database and an inventory compiling the data to feed into both LCC and TEA studies, a list of tables has been developed with the aim of being completed by the partners associated with each stage of the process, i.e., with the different technical work-packages of the project.
The following sections contain the different tables mentioned above.

3.1.1 Production and Construction Stage

a) Stack components production

Table 2 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. For each of these component-materials, information on the costs of materials, machinery costs and associated personnel costs are requested.

The stacks to be developed and assembled in PROMET-H2 are based on one of the project partners[2,3,4], describing a novel stack technology with hydraulic cell compression which is modular and scalable on cell level enabling the prospective development of large-scale stacks by optimization on single cells or short stacks. The stacks with the most promising MEAs, PTLs and BPPs, will be operated for periods between 1000- 5000 hours, under accelerated stress tests (AST) protocols.

[2] Brodmann M, Greda M, Mutascu C, Roth J. Energy Conversion Apparatus, in particular Fuel Cell Stack or Electrolyser 2011, WO002011069625A1 (patented in USA, PRC, Canada, Japan, and EU).
[3] Brodmann M, Greda M, Mutascu C, Neumann J, Rost U, Roth J, Wildometz A, Method and System for Operating an Electrolyser 2014, WO 2014040746A1 (patent pending).
[4] Brodmann M, Mutascu C, Podleschny P, Rost U, Roth J, Sagewka C, Wirkert F. Vorrichtung zur Energieumwandlung, insbesondere Brennstoffzelle oder Elektrolyseur (patente pending).

Table 2. Stack components production.

	Material				Machinery					Labour		Lifetime
Component	**Material**	**Quantity per unit (g/unit)**	**Scrap per unit (g/unit)**	**Cost material (€/g)**	**Electrical energy (kWh)**	**Other associated costs (€)**	**Total Cost of equipment (€)**	**Lifetime of machinery (h)**	**Machinery hours required (h)**	**Personnel hours require (h)**	**Cost of personnel hours (€/h)**	**Lifetime (h)**
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 components to stack assembly

Table 3 is used to collect information on the transport of the individual stack components to the stack assembly site.

Table 3. Transport components to stack assembly.

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

c) Stack assembly

The parameters shown in Table 4 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.

Subsequently, information is required on possible auxiliary materials needed in the assembly process and finally costs associated with the operation and the total installed cost (TIC) of the assembly plant itself. Furthermore, the labour cost will also be requested, since it is expected to have a large share of the overall cost.

Table 4. Stack assembly.

	Components and assembly material				Machinery Cost					Labour Cost	
Stages of the Stack Assembly Process	**Components involved (Anode Electrode, Cathode Electrode, Membrane, PTL, BP or extra components e.g current collectors or end plates, ect)**	**Assembly material (g/unit)**	**Assembly material cost (€/unit)**	**Scrap assembly material (g/unit)**	**Electrical energy (kWh)**	**Other associated costs (€)**	**Total Cost of equipment (€)**	**Lifetime of machinery (h)**	**Machinery hours required (h)**	**Personnel hours require (h)**	**Cost of personnel hours (€/h)**
1	**a)** **b)** **c)**										
2	**a)** **b)** **c)**										
3	**a)** **b)** **c)**										
4	**a)** **b)** **c)**										
5	**a)** **b)** **c)**										

d) Balance of Plant Components

The electrolyser system comprises the electrolyser stack as the device where actually the reaction takes place (cf. Figure 2, “Electrolysis”) as well as the balance of plant (BOP) needed to build up the whole electrolyser system. Chapter 1.1.1 to 1.1.3 addresses how to access the cost of the stack itself.

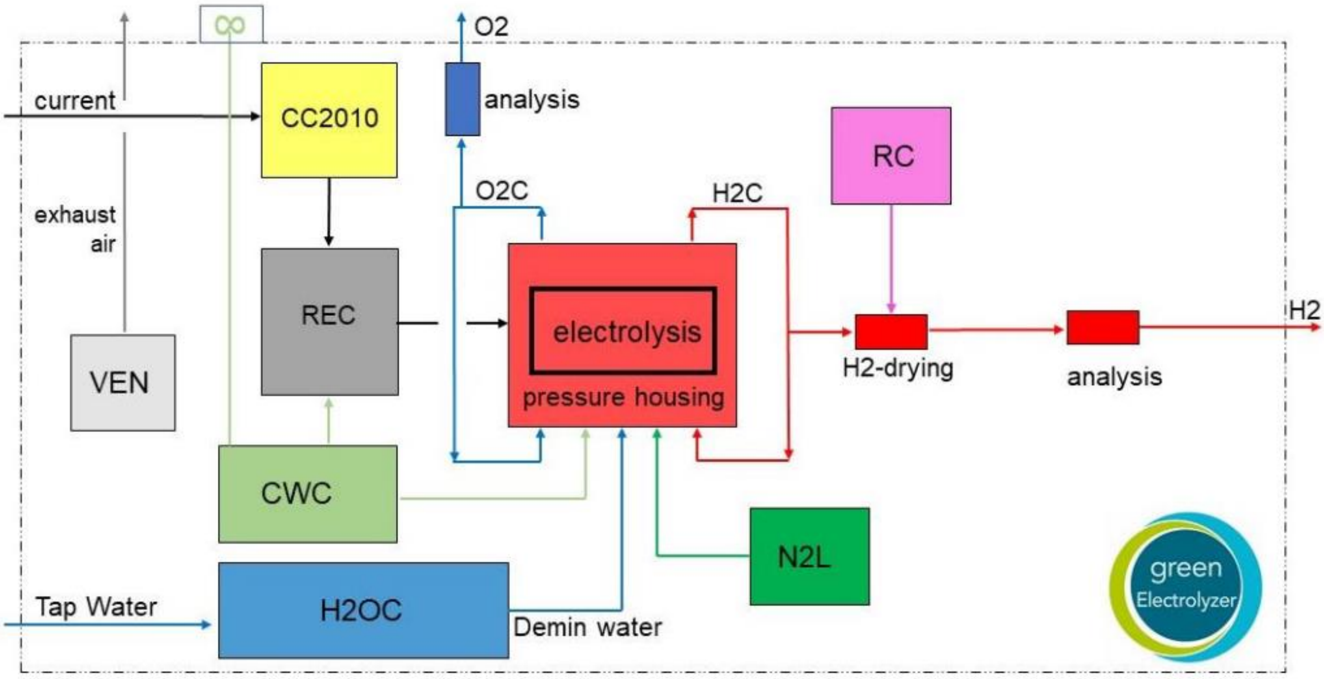

Figure 2. Schematic representation of the functional units of the system.

As can be seen in Figure 2 a couple of other functional units around the stack are needed, which are referred to as BoP, as there are:

- Water purification unit (H2OC)
- Rectifier (Rec)
- Oxygen circuit (O2C)
- Hydrogen circuit (H2C)
- Cooling water circuit (CWC)
- Refrigeration Circuit (RC)
- Nitrogen pipe (N2L)
- Ventilation (VEN)

- Control Center (CC2010)

Finally, the system will be built as a containerized solution, adding the cost for the container itself. The system will be built up by iGas Energy GmbH, who therefore will provide the specification, the material and quantity involved as well as the purchasing cost (Table 5) for each component defined in the equipment list of the green electrolyser product description as input for the TEA and LCC.

Table 5. Input needed for TEA of the BoP Components.

	BoP components				Lifetime
Unit	**Components involved (Main equipment, pumps, heat ex-changer, container etc.)**	**Specification**	**Material and quan-tity (g/equipment)**	**Purchasing cost (€)**	**Lifetime [h]**
H2OC	**a)** **b)** **c)**				
Rec	**a)** **b)** **c)**				
O2C	**a)** **b)** **c)**				
H2C	**a)** **b)** **c)**				
CWC	**a)** **b)** **c)**				
RC	**a)** **b)** **c)**				
N2L	**a)** **b)** **c)**				
VEN	**a)** **b)** **c)**				
CC2010	**a)** **b)** **c)**				
Container Electrical Piping					

e) Transport Balance of Plant components to electrolyser assembly

Table 6 is used to collect information on the transport of the individual balance of plant components to the stack assembly site.

Table 6. Transport components to stack assembly.

BoP Component	Distance (km)	Total transport cost (€)	Mean of transport
1.			
2.			
3.			
4.			
5.			

f) Electrolyser assembly

Table 7 shows the information to be collected according to the assembly of the electrolyser system (i.e., the process including electrolyser stack and the balance of plant).

First, the partner will be asked to provide information on the costs associated with the use of materials. These materials are expected to be related to fasteners, as well as other possible supporting materials. Next, information related to the machinery used are asked and finally the costs associated with personnel.

Table 7. Electrolyser assembly.

Stages of the Electrolyser Assembly Process	Material Cost				Machinery Cost					Labour Cost	
	Components involved (Stack + BoP components + container)	**Assembly material (g/unit)**	**Assembly material cost (€/unit)**	**Scrap assembly material (g/unit)**	**Electrical energy (kWh)**	**Other associated costs (€)**	**Total Cost of equipment (€)**	**Lifetime of machinery (h)**	**Machinery hours required (h)**	**Personnel hours require (h)**	**Cost of personnel hours (€/h)**
1	**a)** **b)** **c)**										
2	**a)** **b)** **c)**										
3	**a)** **b)** **c)**										
4	**a)** **b)** **c)**										
5	**a)** **b)** **c)**										

g) Electrolyser transport to operational site

Table 8 requires the transport costs from the point of assembly of the electrolyser to the operating plant.

Table 8. Transport components to stack assembly.

Component	Distance (km)	Total transport cost (€)	Mean of transport
Electrolyser			

3.1.2 Operational Stage

Regarding the operation of the electrolyser, Tables 9 and 10 list the parameters necessary to develop the LCC.

The first table shall be filled with 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 9. Electrolyser Operation.

Electrolyser	Unit	Input
Electricity consumption	**kWh/kgH_2**	
Water consumption	**kgH_2O/kgH_2**	
Maintenance cost	**% Cost installation or $€/kgH_2$**	
Durability	**h**	
Installation cost	**€**	
Electrolyser cost	**€**	

Table 10. Maintenance and Rehabilitation Cost.

Component	**Part to be replaced or repaired**	**Action (replacement / repair)**	**Personnel hours require (h)**	**Cost of personnel hours (€/h)**
Electrolyser				

3.1.3 End-of-life Stage

a) Recycling

In Table 11, the information to be collected according to the recycling is shown.

First, Monolithos will be asked to provide information on the costs associated with the use of materials. This is followed by information related to the machinery used and finally the costs associated with personnel.

In addition, it is expected that Monolithos could provide information on the salvage value to evaluate the potential revenue that could be obtained from the recovery of the salvaged materials at the recycling stage.

Table 11. Recycling.

Stages	Material			Machinery					Labour	
	Components involved (Anode Electrode, Cathode Electrode, Membrane, PTL, BP or extra components e.g current collectors or end plates, etc)	**Material (g/unit)**	**Material cost (€/unit)**	**Electrical energy (kWh)**	**Other associated costs (€)**	**Total Cost of equipment (€)**	**Lifetime of machinery (h)**	**Machinery hours required (h)**	**Personnel hours require (h)**	**Cost of personnel hours (€/h)**
1	**a)** **b)** **c)** **d)** **e)**									
2	**a)** **b)** **c)** **d)** **e)**									
3	**a)** **b)** **c)** **d)** **e)**									

b) Electrolyser transport to recycling

Table 12 requires the transport costs of the electrolyser operating plant to recycling plant.

Table 12. Transport components to stack assembly.

	Distance (km)	Total transport cost (€)	Mean of transport
Electrolyser			

4 First assessment of material costs

A first analysis of the cost of the input materials for the construction of a stack for a 25 kW PEM type electrolyser is given in the third section of this document.

The information provided in this point refers to the Material Cost included in equation 3. Due to the lack of information from SoA PEMWE stacks production on Machinery Costs, Labour Costs and Transport Costs, only the Material Costs are analysed. These sections will be included in forthcoming Deliverables about the system developed within the project.

In this way, it will be analysed which materials have a higher cost and, therefore, present a greater interest for the study of new, less expensive materials that allow their substitution.

Then, an inventory will be obtained, including not only the type of materials used, but also the mass used for the construction of a 25 kW commercial stack with conventional materials. This will allow to know the mass percentage of each material in the stack, the cost per stack of each material and the percentage of the total cost related to each material.

It is important to note that in this first analysis, only the costs of the materials will be used and not the costs associated with the manufacturing processes, which will be studied in future stages of this project.

The list of common materials used in PEMWE has been obtained from the literature.[5,6] The costs of the materials are collected and extrapolated from each of the references listed in the table below.

5 Lotrič, A., Sekavčnik, M., Kuštrin, I. and Mori, M., 2021. Life-cycle assessment of hydrogen technologies with the focus on EU critical raw materials and end-of-life strategies. International Journal of Hydrogen Energy, 46(16), pp.10143-10160.
6 D2.1 Identification of critical materials. Hytechcycling Project EU funded under Grant Agreement No 700190.

Table 13. Typical components and materials of a PEMWE stack with their corresponding costs

	Component	Material	Material Cost (€/kg)	Source
PEMWE	Electrolyte	Perfluorosulphonic acid (Nafion™)	4169	7
		Sulfonated polyether ether ketone	981	8
	Gas Diffusion Layer	Titanium or Ti-alloys	35	9
		Synthetic graphite or graphite composites	55	10
	Catalyst Layer - Cathode	Pt or Pt-alloys	322000	11
	Catalyst layer - Anode	Iridium and Ir-alloys	20800	12
		Ruthenium and Ru-alloys	5700	13
	Interconnect	Titanium or Ti-alloys	35	9
		Stainless steel	3	14
	Sealant	Elastomer	12	15
		Thermoplastic	15	16

From the above table there are three materials commonly used in the manufacture of stacks that are extremely high-priced: Nafion™, platinum and iridium oxide.

However, this information is not complete and does not allow an assessment of the impact on the total cost of a stack as the amount of materials used in the manufacture of the stack is not known. For this purpose, it is considered that the total mass of the 25 kW PEM type stack is 28 kg and,

[7] Merck KGaA, Darmstadt, Germany, https://www.sigmaaldrich.com/ES/es/product/aldrich/510211?context=product#
[8] Merck KGaA, Darmstadt, Germany, https://www.sigmaa drich.com/ES/es/product/aldrich/gf10188491?gclid=EAIaIQobChMImcCSuYKB8wIVYoFQBh3GOA8_EAMYASAAEgIM6fD_BwE
[9] Mayyas, Ahmad, Mark Ruth, Bryan Pivovar, Guido Bender, and Keith Wipke. 2018. Manufacturing Cost Analysis for Proton Exchange Membrane Water Electrolyzers. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-72740.
[10] Merck KGaA, Darmstadt, Germany, https://www.sigmaaldrich.com/ES/es/product/aldrich/282863?context=product
[11] Merck KGaA, Darmstadt, Germany, https://www.sigmaaldrich.com/ES/es/product/aldrich/204048?context=product
[12] Merck KGaA, Darmstadt, Germany, https://www.sigmaad-rich.com/ES/es/search/iridiumoxide?focus=products&page=1&perPage=30&sort=relevance&term=iridium%20oxide&type=product
[13] Merck KGaA, Darmstadt, Germany, https://www.sigmaaldrich.com/ES/es/product/aldrich/238058?context=product
[14] MetalMiner, https://agmetalminer.com/metal-prices/stainless-steel/
[15] Fenasa Murcia, Spain, https://www.fenasa.es/producto/bidon-de-1kg-de-silicona-rtv-1607
[16] Intratec, San Antonio, US, https://www.intratec.us/chemical-markets/ptfe-price?gclid=EAIaIQobChMIyr-Cnl4mB8wIVC553Ch2HoAqWEAAYAiAAEgJCavD_BwE

All links accesed September 2021

considering the price of the materials in the table above, the total cost of the stack is 1635 euros. This information is checked and approved internally by FHA engineers. With these values, a stack with a cost of 653 euros per kW would be obtained, which, if it represents 40% of the total cost of the system (typical value used in the literature for low power systems), a system of 1631 euros per kW would be obtained, which is within the current cost range.

Therefore, based on and adapting the information provided in the literature, [5,6,17] it is possible to estimate the quantity of each material in the stack. Nafion™ has been selected as the electrolyte and iridium oxide as the anode catalyst as they are the most used.

Table 14. Materials and masses of a single 25 kW stack with common materials

	Material	Mass percen-tage	Mass (kg)	Material Cost (€/kg)	Cost/Stack (€)	% Cost
PEMWE	Perfluorosulphonic acid (Nafion™)	2,3%	0,65	4169	2720	16,7
	Titanium	79,0%	22,12	35	774	4,7
	Synthetic graphite	1,7%	0,47	55	26	0,2
	Platinum	0,1%	0,020	322000	6311	38,7
	Iridium Oxide	0,1%	0,031	208000	6406	39,3
	Silicone	3,6%	1,008	12	12	0,1
	Polytetrafluoroethylene (PTFE)	15,5%	4,35	15	65	0,4

Below it can be found a figure to graphically observe which are the materials with a greater impact on the total cost of the stack after the calculations performed within this document.

[17] D2.3 Definition and evaluation of base case studies. eGHOST Project EU funded under Grant Agreement No 101007166.

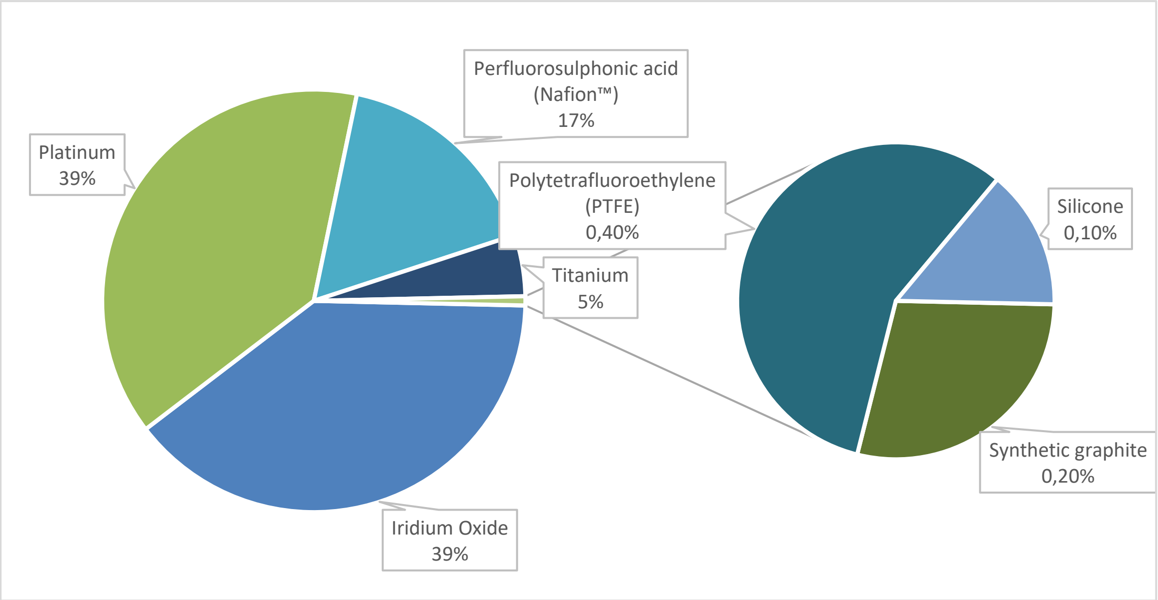

Figure 3. Cost percentage of each of the typical materials in PEMWE stack.

From the above figure, the largest percentage of the stack cost is associated with the use of platinum group metals for both the anode and cathode catalysts. It can also be seen that the use of Nafion^{TM} as an electrolyte has a high associated cost. Finally, the use of titanium in large quantities makes it possible to slightly reduce the total cost of the stack if less expensive materials are used.

With these points as a starting premise, the project seeks to replace these materials with others that have the same characteristics in terms of operability, useful life and performance. For this reason, the following materials, among others, are being studied with the aim of achieving these objectives:

- **Substitution or extreme reduction of the materials used in the catalysts** by others such as iron sulphide and molybdenum sulphide for the cathode and silver and palladium-based ones for the anode. This will allow a significant cost reduction as can be seen in the following table:

Table 15. Sample of some of the materials considered within the project for the replacement of costly materials.

	Component	Material	Material Cost (€/kg)	Source
PEMWE New Materials	Catalyst Layer - Cathode	Iron Sulphide	9060	18
		Molybdenum disulfide	428	19
	Catalyst layer - Anode	Silver	12600	20
		Palladium	20200	21

In addition, by using nanoparticles, the amount of material consumed can be drastically reduced.

- **Creation of thinner Nafion™ membranes**, with a consequent reduction in material consumption and therefore a reduction in material cost. This can have a real impact on the cost of the stack, as it has already been shown to be the third most cost-impacting material.

- **Substitution of titanium by stainless steel**, slightly reducing the total cost of the stack derived from the purchase of materials. For this purpose, Coatings for stainless steel PTLs and BPPs based on non-CRM metals such as Ti, Mo, V, etc will be developed.

[18] Merck KGaA, Darmstadt, Germany, https://www.sigmaaldrich.com/ES/es/product/sigald/343161?context=product
[19] Merck KGaA, Darmstadt, Germany, https://www.sigmaaldrich.com/ES/es/substance/molybdenumivsulfide160071317335?context=product
[20] Merck KGaA, Darmstadt, Germany, https://www.sigmaaldrich.com/ES/es/product/aldrich/265500?context=product
[21] Merck KGaA, Darmstadt, Germany, https://www.sigmaaldrich.com/ES/es/product/aldrich/203939?context=product

All links accesed September 2021

5 Conclusions

In this first WP6 deliverable, the methodologies for calculating the Techno-Economic and Life Cycle Cost Analyses to be developed within the project have been presented.

The main characteristics is that the TEA analysis will consider the complete system, including the operation of the electrolyser. However, the LCC will focus on the stack, aligned with the objectives of the LCA, which will be presented in D6.2, in order to obtain the most accurate information possible, which will allow better planning of possible future improvements in the stack from an economic point of view.

On the other hand, a first approximation has been made to the costs of the materials contained in the stack. This has allowed us to conclude that the substitution or extreme reduction of the materials used in the catalysts, the creation of thinner Nafion™ membranes and the substitution of titanium by stainless steel will significantly reduce the production cost of the PEM type stacks, in line with the project objectives.