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eco-design
Guidelines for Hydrogen
Systems and Technologies

eGHOST Spring School (20-24 May 2024)

Eco-design of hydrogen systems, the eGHOST approach

Emmanuelle Cor (CEA)

Co-funded by the European Union

Clean Hydrogen Partnership

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) under Grant Agreement No 101007166.
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CONTENT – 2 HOURS

1. ECO-DESIGN PRINCIPLES METHODS AND TOOLS

2. ECO-DESIGN CHALLENGES FOR HYDROGEN SYSTEMS

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3. PRESENTATION OF THE eGHOST APPROACH FOR ECO-DESIGNED HYDROGEN SYSTEMS

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ECO-DESIGN PRINCIPLES METHODS AND TOOLS

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ECO-DESIGN : OBJECTIVES

During the design phase, 80% of the environmental impacts of the system are determined

80% OF THE IMPACTS DEFINED

20% OF THE IMPACT

DESIGN → PRODUCTION → TRANSPORT → USE → END OF LIFE

90% OF THE COSTS FIXED

10% OF EXPENSES

Eco-design objectives : Reduce the environmental impacts (and social and economical) on the entire life cycle, while keeping the same function on the system

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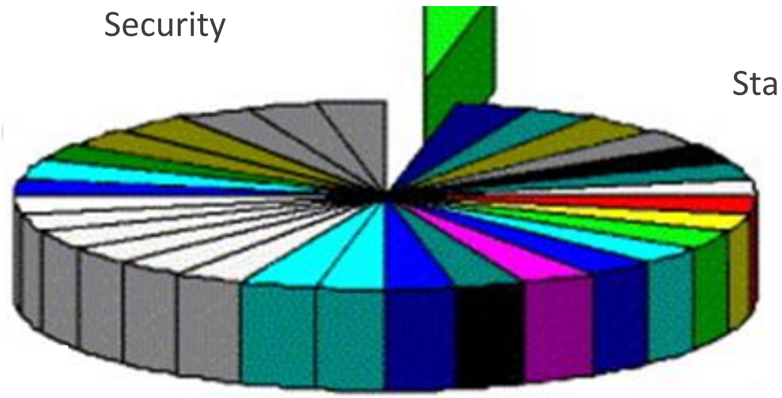
What is eco-design ?

Do you have examples in mind ?

ECO-DESIGN DEFINITION



"Eco-design is both a principle and an approach. It consists of integrating environmental protection criteria over a service or a product's lifecycle. The main goal of eco design is to anticipate and minimize negative environmental impacts (of manufacturing, using and disposing of products). Simultaneously, eco design also keeps a product's quality level according to its ideal usage"(Standard ISO14006:2020)

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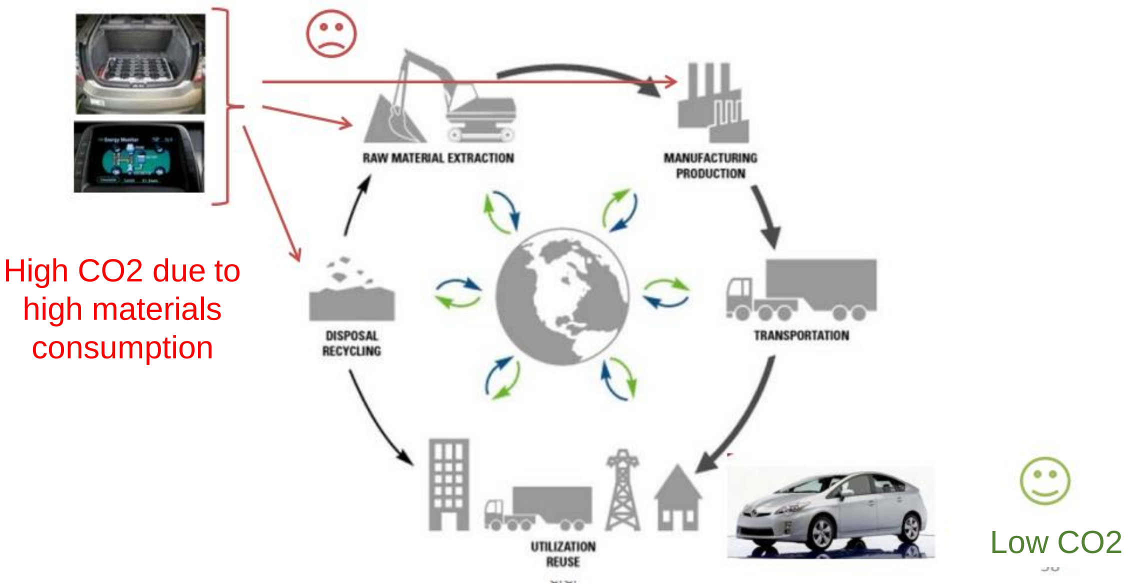
ECO-DESIGN : 6 KEY PRINCIPLES

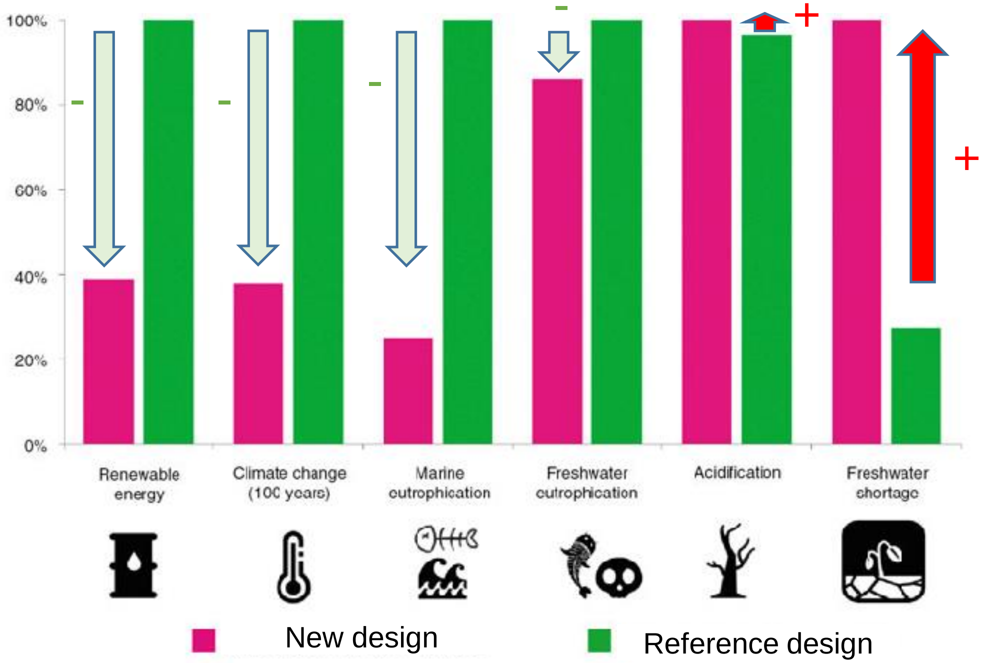
1 – ADOPT A LIFE-CYLE THINKING

- Consider all life cycle phases of the system
- Avoid impact transfer from one life cycle step to another



2 – MULTICRITERIA THINKING

- Consider several impact indicators
- Avoid impact transfer from one indicator to another



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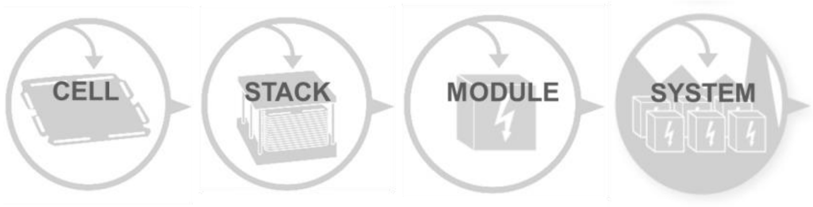
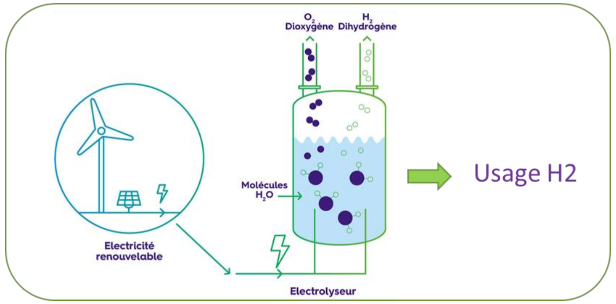
ECO-DESIGN : 6 KEY PRINCIPLES

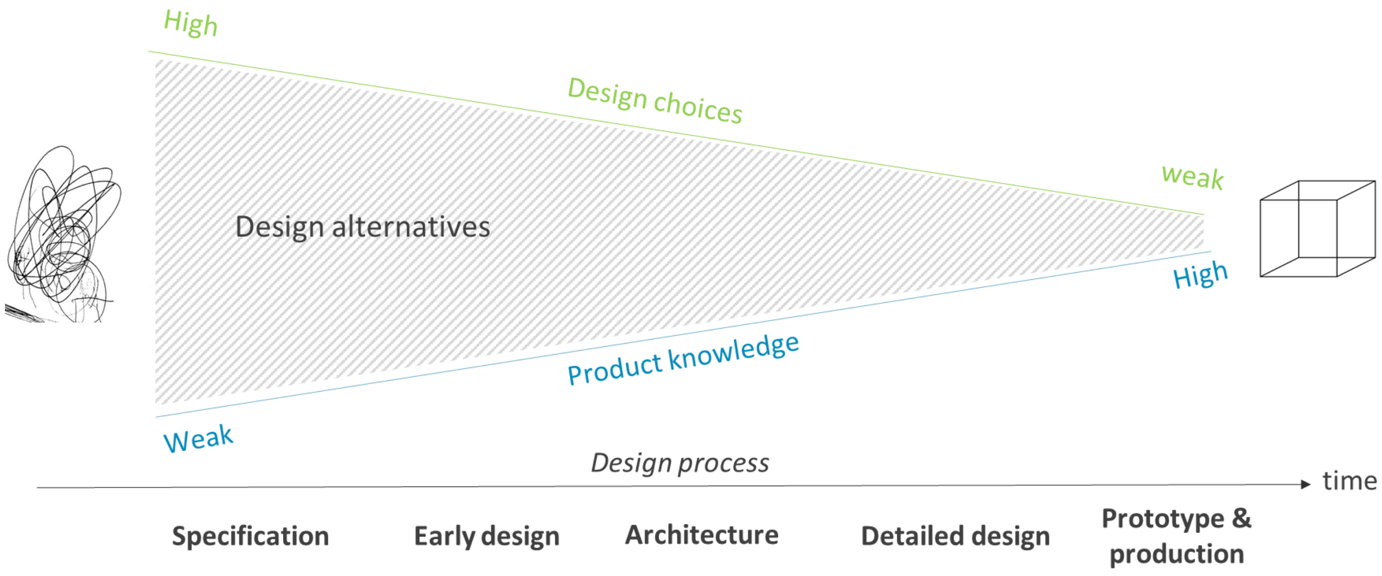
3 – THINK ABOUT ALL THE SYSTEM

Explore the entire system in which your material/component will be integrated





4 – INTEGRATION AT THE EARLIEST IN THE DESIGN PROCESS



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ECO-DESIGN : 6 KEY PRINCIPLES

5 – INVOLVE ALL DESIGN AND VALUE CHAIN ACTORS

Users

HSE

Suppliers

Buyers

Industrialization

Strategy

Design and R&D team

Recyclers

6 – DEFINE YOUR SYSTEM ACCORDING TO ITS FUNCTION (FUNCTIONNAL UNIT)

Ex : « Transport 1 person on 30 km every days »

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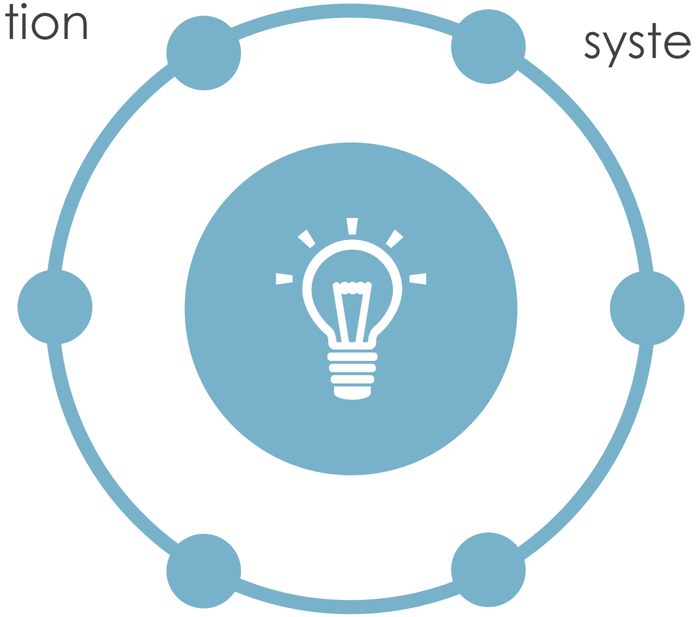
ECO-DESIGN : AN ITERATIVE PROCESS



1 - Identification of the system and its functional unit

2- Environmental evaluation (quali or quanti) of a reference situation

3 – Identification of eco-design actions

4- Choice and deployment of design solutions

5- Comparative environmental evaluation

6- Communication / Information

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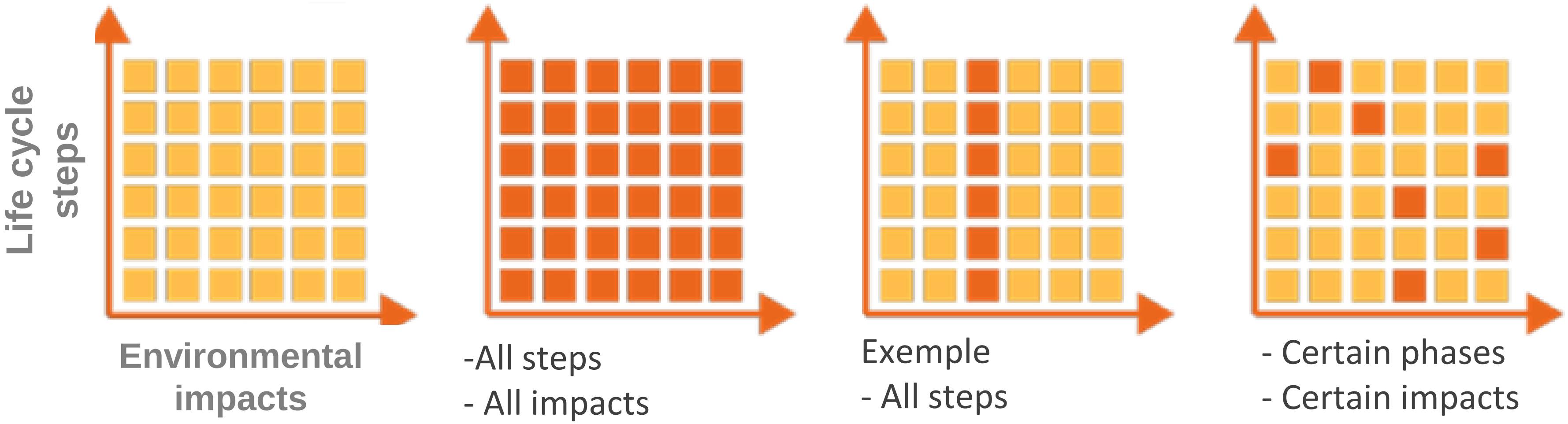
ECO-DESIGN TOOLS : SEVERAL APPROACHES

Exhaustive vs Selective

Qualitative vs Quantitative

General methodology	LCA	Monocriteria approaches	Qualitative evaluation



-All steps
- All impacts

Exemple
- All steps
- One impact
ex : Carbon footprint

- Certain phases
- Certain impacts

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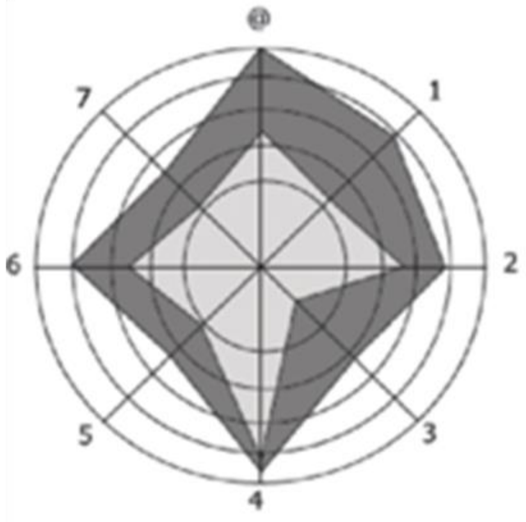
ECO-DESIGN TOOLS : THE ECODESIGN STRATEGY WHEEL

1 – Selection of low-impact material

- Cleaner materials
- Renewable materials
- Lower energy contents materials
- Recyclable Materials



2 – Reduction of material usage

- Reduction in weight
- Reduction in (transport) volume

3 – Optimisation of production techniques

- Alternative production techniques
- Fewer production steps
- Low cleaner energy consumption
- Less production waste
- Fewer/cleaner production consumables

4 – Optimisation of distribution systems

- Optimisation of distribution system
- Less/cleaner/reusable packaging
- Energy-efficient transport mode
- Energy-efficient logistics

Adpated from: Brezet, H., Van Hemel, C., Brezet, Han, Rathenau Instituut (Eds.), 1997. Ecodesign: a promising approach to sustainable production and consumption, 1. ed. ed, United Nations publication. UNEP, Paris

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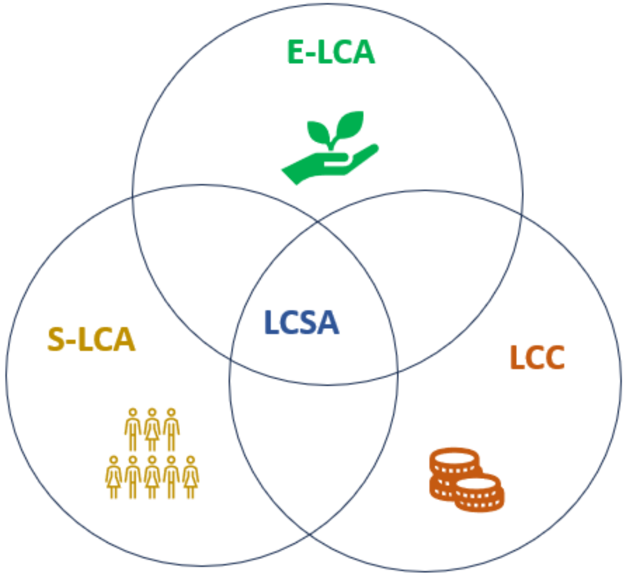
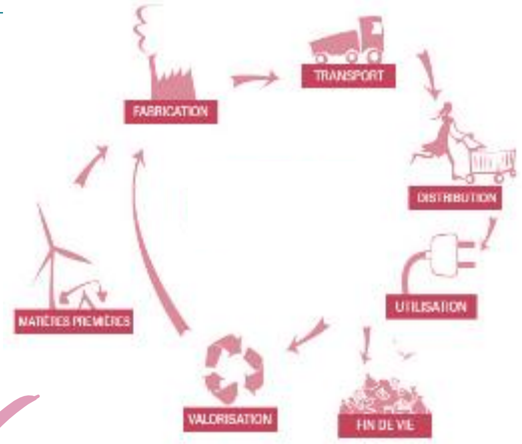
ECO-DESIGN TOOLS : LCSA

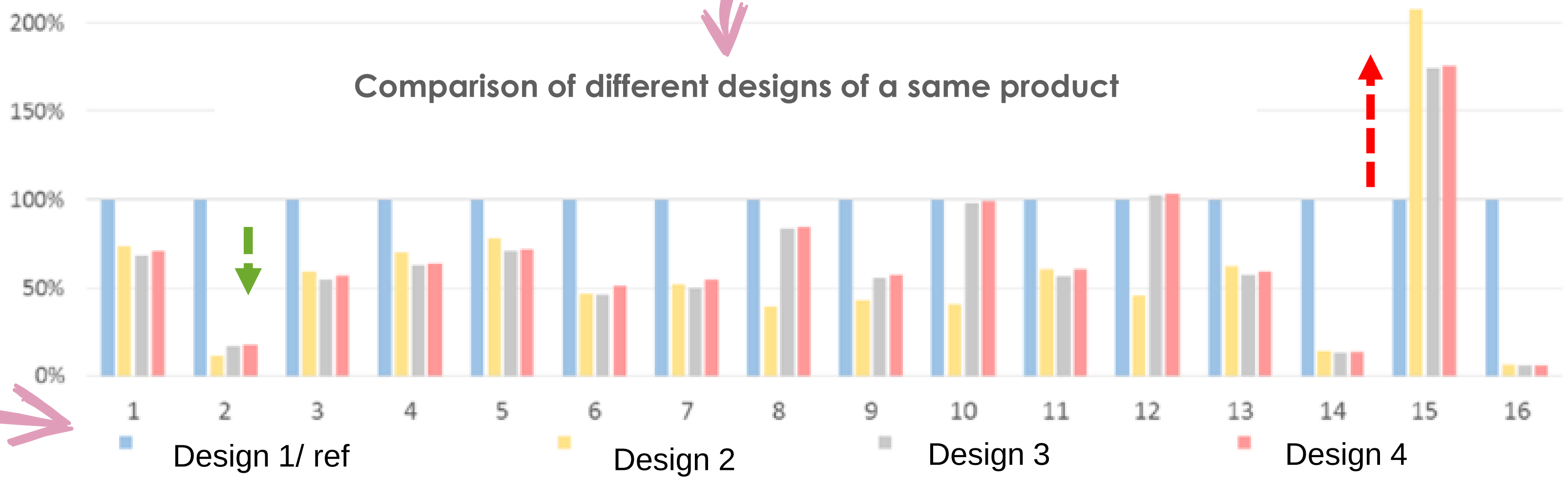


Inputs
Energy
Materials
Water
…



Outputs
Emissions
Wastes
Product
…

Sustainability indicators (climate change, toxicity, child labor, material consumption, costs etc...)



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ECO-DESIGN REGULATION CONTEXT

EU ecodesign framework aims to make green products the 'new norm'

The European Parliament and the Council have reached a provisional agreement on the Ecodesign for Sustainable Products Regulation which promises to redefine product standards and make sustainable products the "new norm" in the EU.

Isatou Ndure | December 7, 2023

Share

The Ecodesign for Sustainable Products Regulation aims to reverse detrimental trends, making sustainable products the norm in the EU market and diminishing overall environmental and climate impacts. Credit: Shutterstock

https://www.just-style.com/news/eu-ecodesign-framework-aims-to-make-green-products-the-new-norm/

ESPR or Eco-design Requirements for Sustainable Products

Key aspects include:

- Product durability, reusability, upgradability, and reparability.
- Presence of chemical substances inhibiting reuse and recycling.
- Energy and resource efficiency.
- Recycled content.
- Carbon and environmental footprints.
- Availability of product information, including the introduction of a Digital Product Passport.

Evolution of the current Eco-design directive

https://commission.europa.eu/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/sustainable-products/ecodesign-sustainable-products-regulation_en

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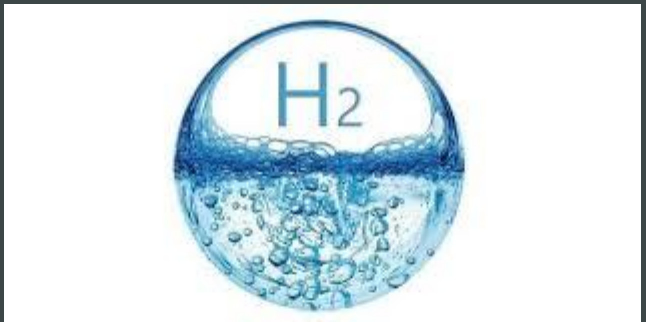

ECO-DESIGN CHALLENGES FOR H2 SYSTEMS

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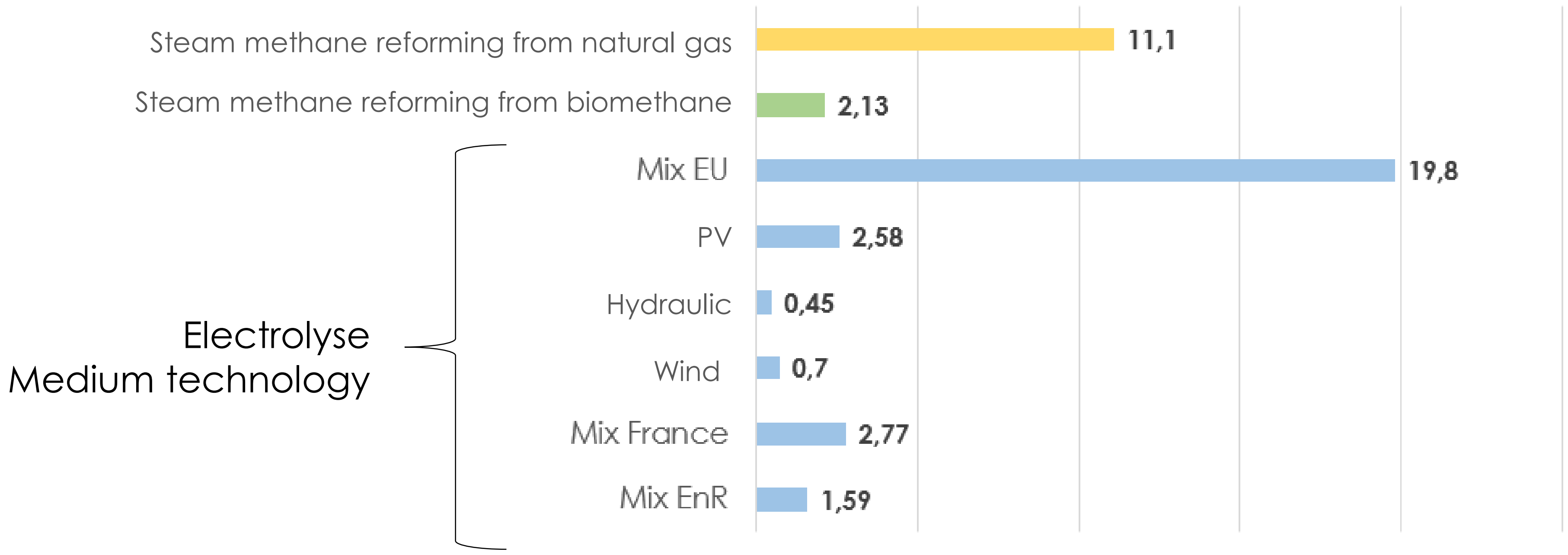
Do you know the carbon footprint of 1 kg of H_2 ?

CONTRIBUTION TO CLIMATE CHANGE FOR HYDROGEN TECHNOLOGIES

Carbon footprint of the production of hydrogen (kg CO_2 eq. / kg H_2)

Source : Base Carbone Ademe - https://bilans-ges.ademe.fr/



200 bars
Purity according to ISO 14687:2019

► Hydrogen production all scenarios : **0,45 - 19,8 kg CO_2 eq. / kg H_2**

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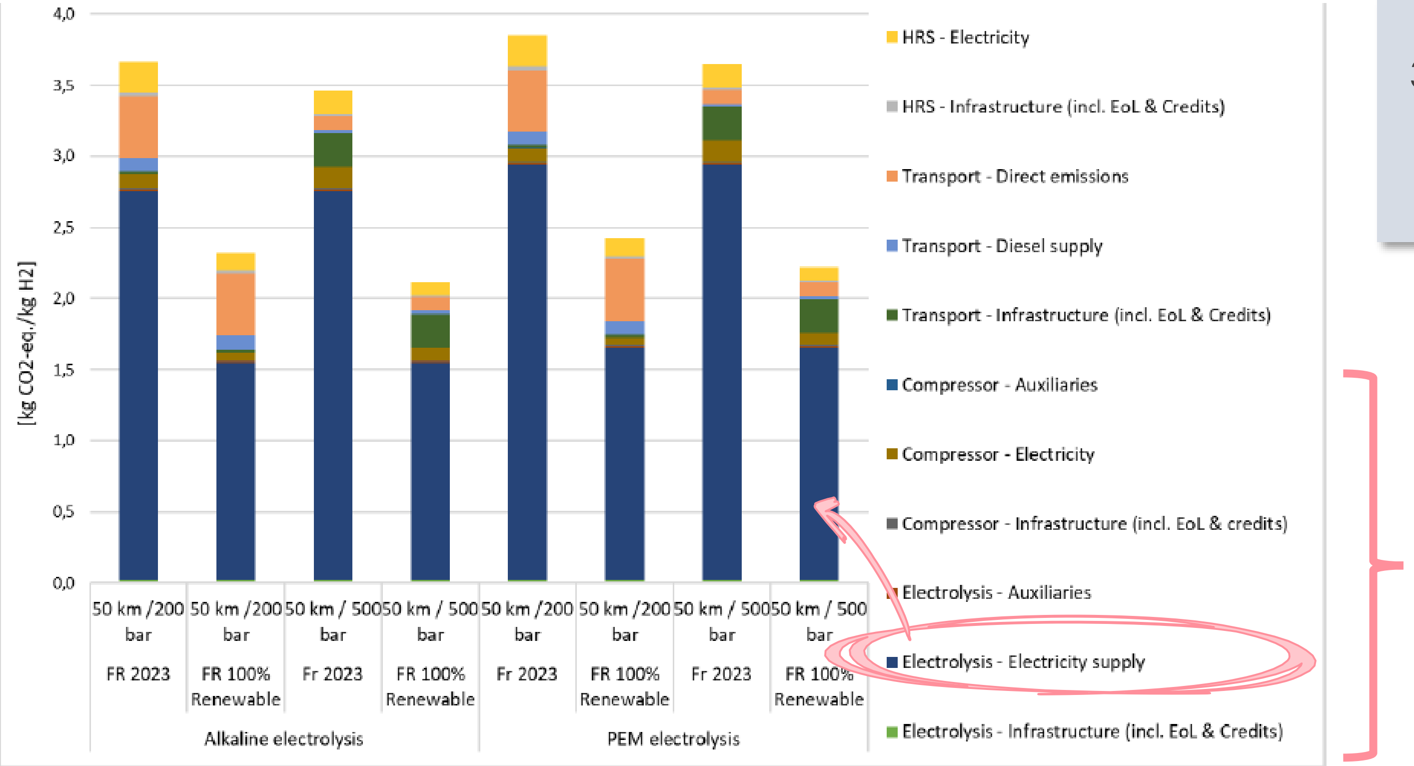
CONTRIBUTION TO CLIMATE CHANGE FOR HYDROGEN TECHNOLOGIES

Contribution to climate change for H2 production and distribution with electrolysis technologies
ADEME Study - 2020

ADEME
AGENCE DE LA TRANSITION ÉCOLOGIQUE

The electricity needs for H2 production in use is the principal contributors to the impacts (btw 66% & 79% according to the scénarios)



Mix FR ➔ btw 2,1 & 3,8 kg eq. CO2/kg H_2

Mix EU ➔ 21 kg eq. CO2/kg H_2

https://librairie.ademe.fr/changement-climatique-et-energie/4213-analyse-de-cycle-de-vie-relative-a-l-hydrogene.html

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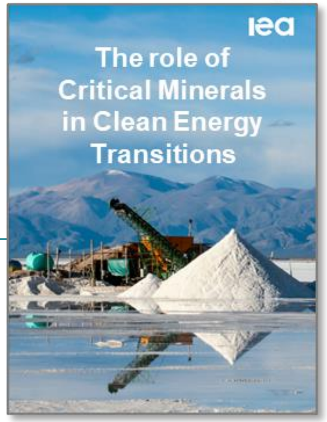
What about material criticality ?

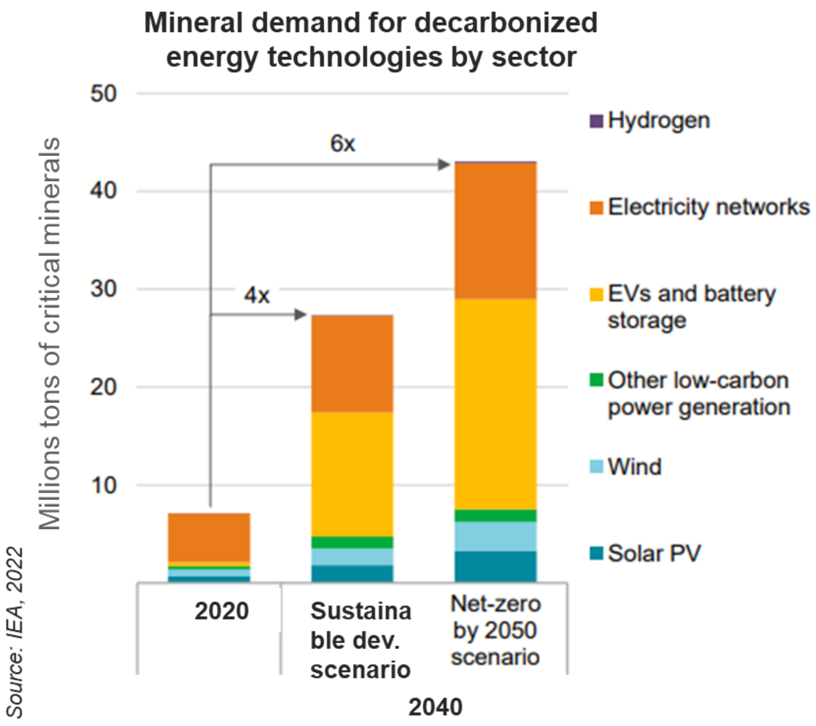
RESOURCES CHALLENGES FOR CLEAN ENERGY TRANSITION



Critical mineral needs for clean energy technologies

	Copper	Cobalt	Nickel	Lithium	REEs	Chromium	Zinc	PGMs	Aluminium*
Solar PV	●	○	○	○	○	○	○	○	●
Wind	●	○	◍	○	●	◍	●	○	◍
Hydro	◍	○	○	○	○	◍	◍	○	◍
CSP	◍	○	◍	○	○	●	◍	○	●
Bioenergy	●	○	○	○	○	○	◍	○	◍
Geothermal	○	○	●	○	○	●	○	○	○
Nuclear	◍	○	◍	○	○	◍	○	○	○
Electricity networks	●	○	○	○	○	○	○	○	●
EVs and battery storage	●	●	●	●	●	○	○	○	●
Hydrogen	○	○	●	○	◍	○	○	●	◍

Notes: Shading indicates the relative importance of minerals for a particular clean energy technology (● = high; ◍ = moderate; ○ = low), which are discussed in their respective sections in this chapter. CSP = concentrating solar power; PGM = platinum group metals.
* In this report, aluminium demand is assessed for electricity networks only and is not included in the aggregate demand projections.



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MATERIALS NEEDS FOR HYDROGEN TECHNOLOGIES

Notes: PEM = proton exchange membrane; SOEC = solid oxide electrolysis cells; SOFC = solid oxide fuel cell. Normalisation by output accounts for varying efficiencies of different electrolysis technologies. Full load hours of electrolysers assumed to be 5 000 hours per year.

Sources: Bareiß et al.(2019); Fuel Cells and Hydrogen Joint Undertaking (2018); James et al. (2018); Kiemel et al. (2021); Koj et al. (2017); Lundberg (2019); NEDO (2008); Smolinka et al. (2018); US Department of Energy (2014; 2015).

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RECYCLING CHALLENGES FOR HYDROGEN TECHNOLOGIES

- The rapid growth of hydrogen use in the sustainable development scenarios underpins major growth in demand for nickel and zirconium for use in electrolysers, and for copper and platinum-group metals for use in fuel cell electric vehicles (FCEVs)

Challenges linked to the recycling of hydrogen technologies

1- Increase in the demand of critical materials

2- Necessity to create adataped recycling paths

3- Economic and environmental optimisation necessary compared to virgin material

4- Maximize the value of material after recycling

Source : Recycling strategies for Solid Oxid Cells, 2022, Sarner et al

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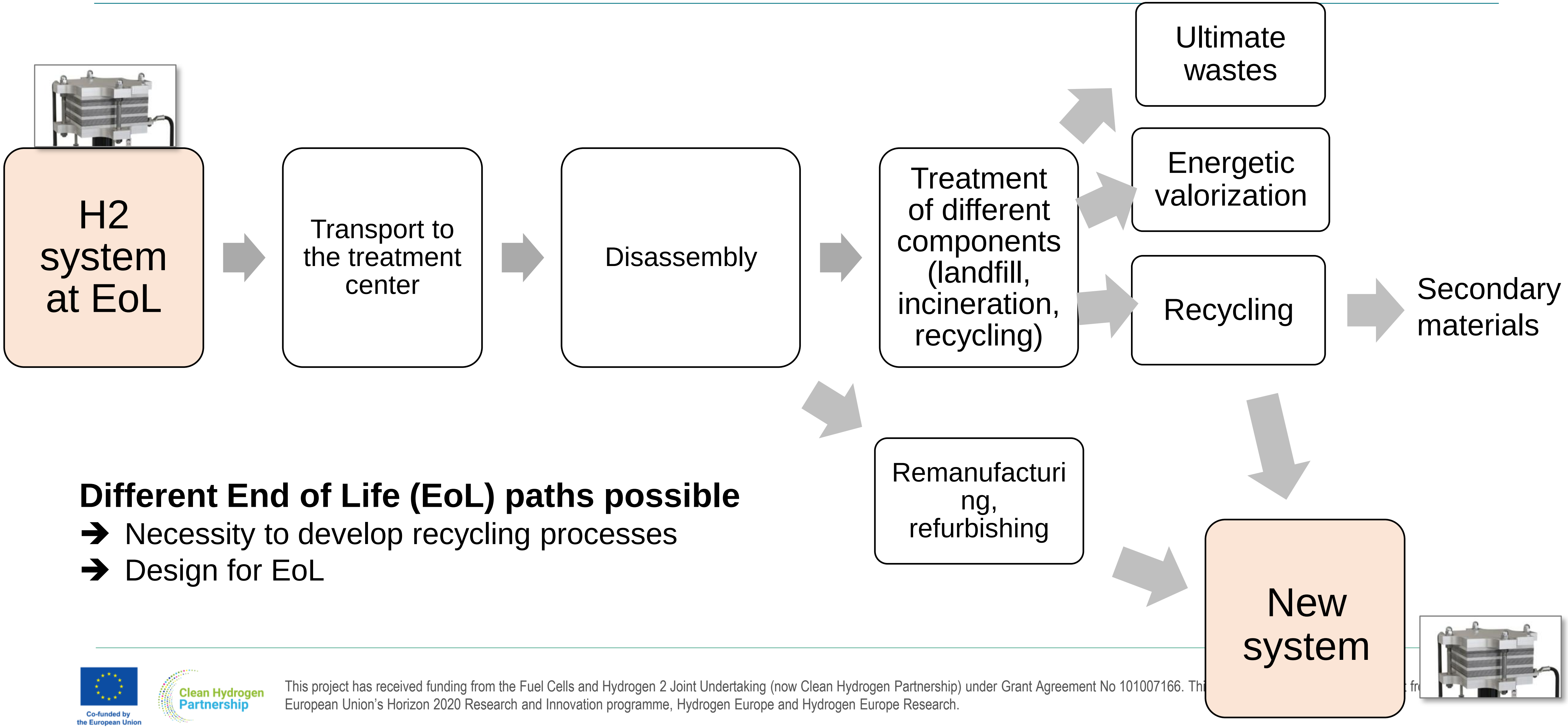
RECYCLING CHALLENGES FOR HYDROGEN TECHNOLOGIES



Different End of Life (EoL) paths possible

➔ Necessity to develop recycling processes

➔ Design for EoL

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SYNTHESIS ON ECO-DESIGN & SUSTAINABILITY CHALLENGES FOR H2 SYSTEMS

- Optimize carbon footprint of the technology
- Care of impact transfers when decarbonizing
- Increase efficiency in use for electrolysis
- Reduce dependency on critical materials
- Design for recycling / disassemblability

…

- Be cautious of the value chains associated to the hydrogen sector
- Acceptability of technologies
- Material criticality
- Geopolitical issues
- Mining conditions issues

…

- Optimization of the cost of H2 production / use
- Efficiency in use
- Maturity of the technology and industrialization costs
- Cost of recycled H2 systems materials

…

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THE EGHOST APPROACH FOR ECODESIGNED H2 SYSTEMS

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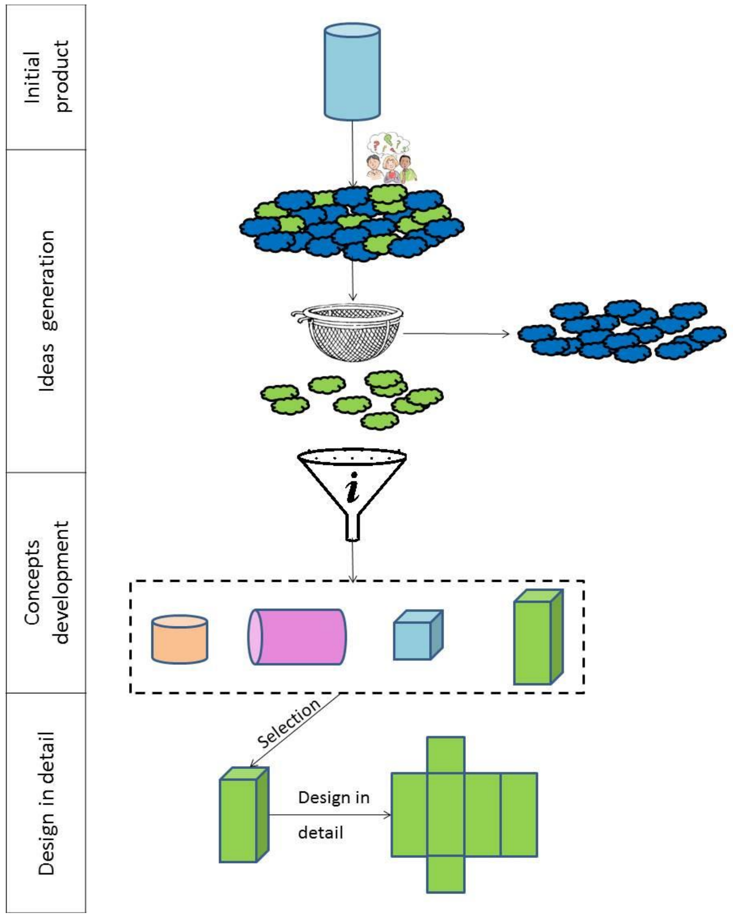
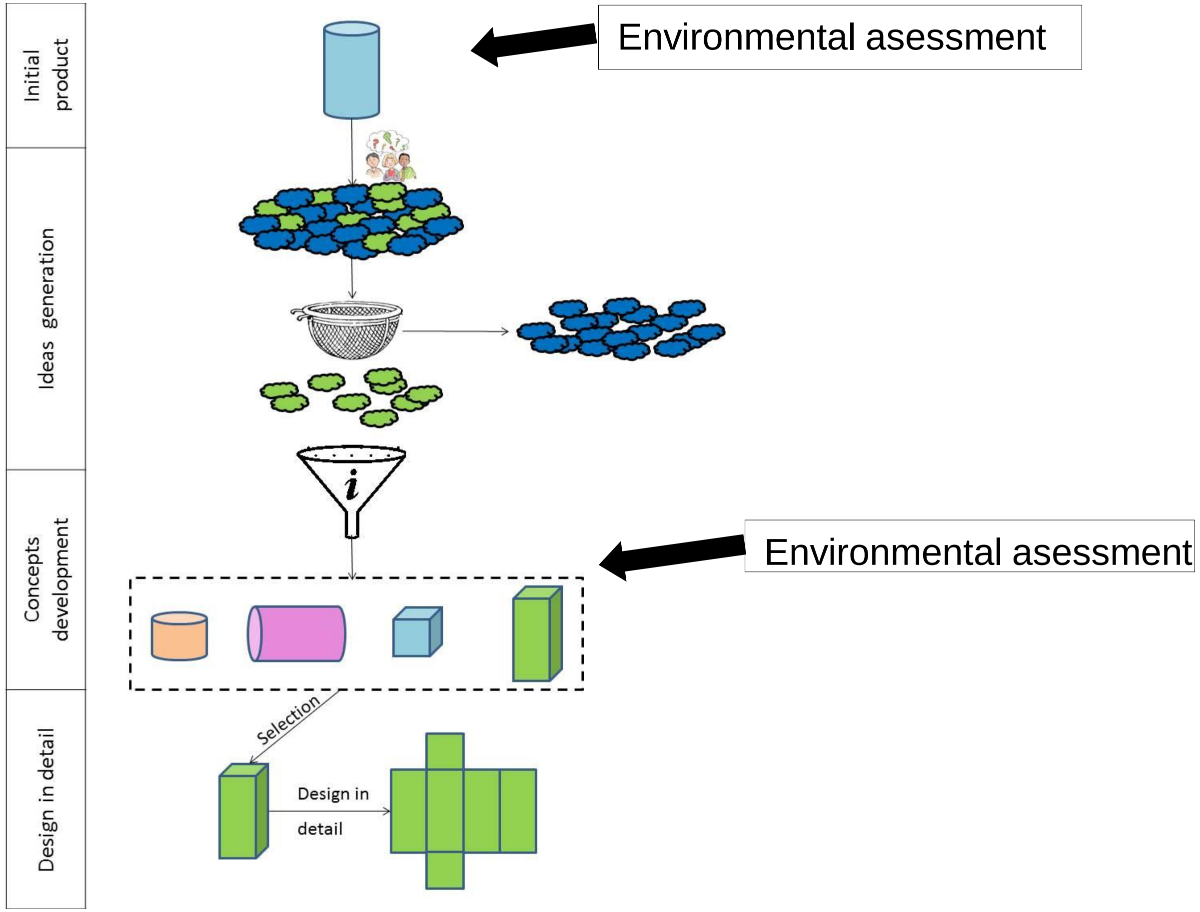
Conventional product development



Eco-design methodology



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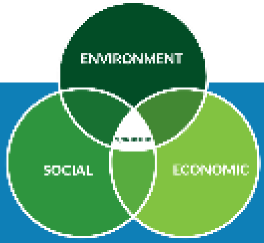
eGHOST eco-design methodology – GENERAL APPROACH

Methodology for eco-design guidelines definition

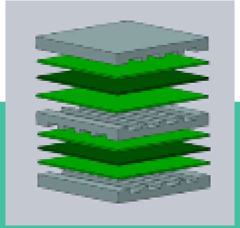


1

First sustainability evaluation of case-studies (PEMFC & SOEC)

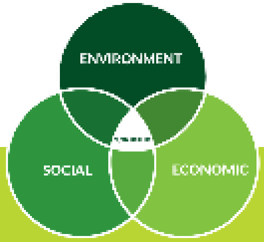
2

Development of first eco-design guidelines based on sustainability hotspots



3

Definition of new stacks product concepts integrating eco-design aspects



4

Sustainability evaluation of eco-designed product concepts for final guidelines validation

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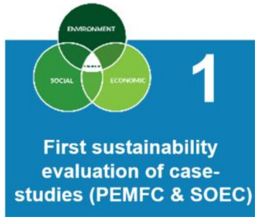
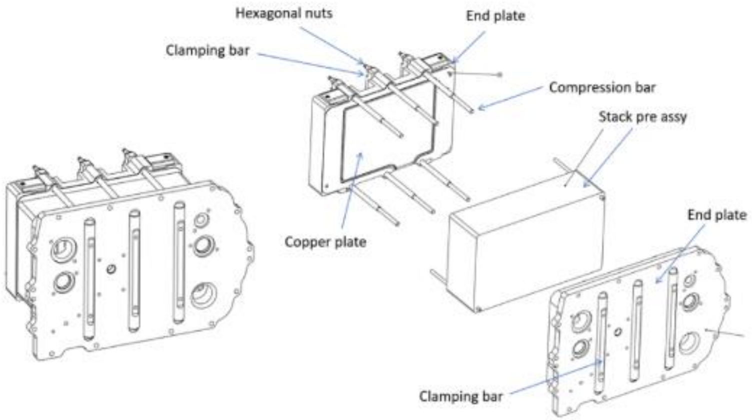
eGHOST eco-design methodology – STEP 1

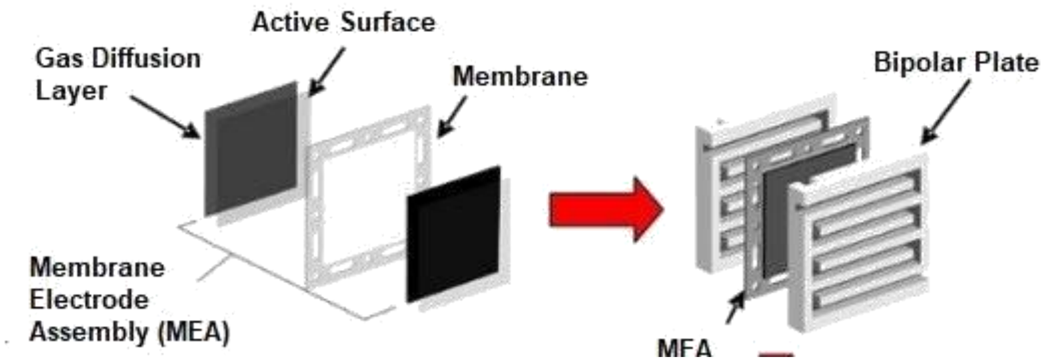


eGHOST case-study 1 definition : PEMFC

PEMFC is mainly used in Vehicles (Van, trucks…)



Hundreds MEA (cells) are stacked



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eGHOST eco-design methodology – STEP 1

First sustainability evaluation of case-studies (PEMFC & SOEC)

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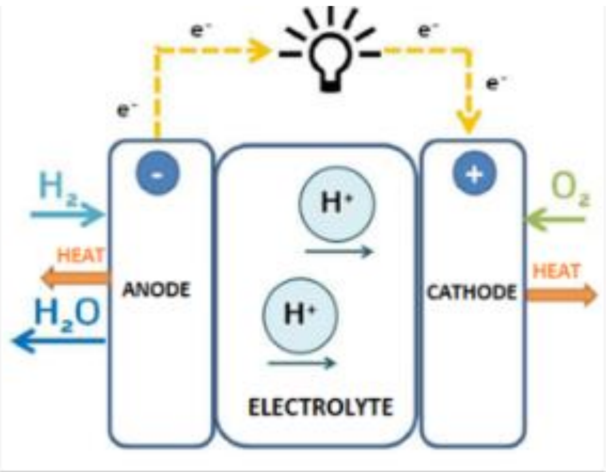
eGHOST case-study 1 definition : PEMFC

Case-study parameters

- *Perimeter :* Stack, *BoP excluded*
- *Size of the system : 48* kWel
- *Technology :* representative stack design
- *Application :* Light Commercial Vehicle
- *Timeline:* current technology
- *Sources of data :* BOM from Symbio's product



Proton Exchange Membrane Fuel Cell principle of operation

In short, the hydrogen (H_2) oxydises with platinum of the anode catalyst to produce hydrogen ions (H^+) and electrons. The H^+ ions go through the electrolyte (membrane) and combine, at the cathode catalyst layers, with electrons and oxygen to produce water.

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eGHOST eco-design methodology – STEP 1

1 First sustainability evaluation of case-studies (PEMFC & SOEC)

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eGHOST case-study 1 definition : PEMFC

PEMFC technology definition and boundary conditions	
Technical Scheme Operation	Membrane Electron Assembly (MEA) structure 
Technical Perimeter	Stack only
Life Cycle Perimeter/scope	"Cradle to gate" (manufacturing phase; EoL planned)
Size of the system	48 kW_{el}
Technology	Representative PEMFC stack design
Application	Light vehicles (FCEV)
Timeline	Current technology
BoM	Finalized by SYMBIO France

Level					Designation	Quantity	Weight		Units	*Material*
1	2	3	4	5			Min	Max		
x					Platinum	/	0.41	0.52	mg/cm^2	Platinum nanoparticles
	x				Platinum on carbon	/	1.03	1.29	mg/cm^2	Platinum nanoparticles on carbon support
	x				Ionomer	/	0.28	0.37	mg/cm^2	Perfluorosulfonic Acid (PFSA) ionomer
	P				Ink mixing	/	/	/	/	
		x			**Catalytic ink**					
		x			Membrane	1	0.4	0.5	g/MEA	Perfluorosulfonic Acid (PFSA) ionomer
		P			Catalyst ink coating	1	0.26	0.33	g/MEA	
			x		**Catalyst Coated Membrane (CCM)**	1				
			x		Sub-gaskets	2	3	3.5	g/MEA	PEN or PET film with thermoactive glue
			x		Gas Diffusion Layer (GDL)	2	1.76	2.7	g/MEA	Carbon fiber fabrics and carbon black with PTFE binders
			P		MEA thermal assembly	/	/	/	/	
				X	**Membrane Electrode Assembly (MEA)**	1				
x					Monopolar plate anode	1	0.03	0.04	kg/part	Stainless steel
x					Monopolar plate cathode	1	0.03	0.04	kg/part	Stainless steel
	P				Polar plate assembly	1				
	X				**Bipolar plate (BPP)**	1				
x					MEA	280	0.010	0.013	kg/part	Assembly
x					Bipolar plate (BPP)	279	0.07	0.085	kg/part	Assembly
x					End Bipolar plate anode	1	0.07	0.085	kg/part	Assembly
x					End Bipolar plate cathode	1	0.07	0.085	kg/part	Assembly
x					Gaskets	560	0.002	0.0025	kg/part	Silicone
P					Stacking					
	x				**Stack pre-Assembly**					
	x				Wet endplate	1	1.5	1.8	kg/part	Glass reinforced thermoplastic
	x				Compression bar M6	6	0.135	0.14	kg/part	Steel
	x				Current collector	2	0.45	0.5	kg/part	Copper
	x				Spring	6	0.125	0.125	kg/part	Steel + polymer coating
	x				Clamping bar	6	0.3	0.39	kg/part	Steel
	x				Gaskets	2	0.002	0.0025	kg/part	Silicone
	x				Hexagonal screws	6	0.004	0.005	kg/part	Steel
	x				Dry endplate	1	1.8	2.5	kg/part	Glass reinforced thermoplastic
		x			**48 kW_{el} PEMFC Stack Assembly**					

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eGHOST eco-design methodology – STEP 1

1

First sustainability evaluation of case-studies (PEMFC & SOEC)

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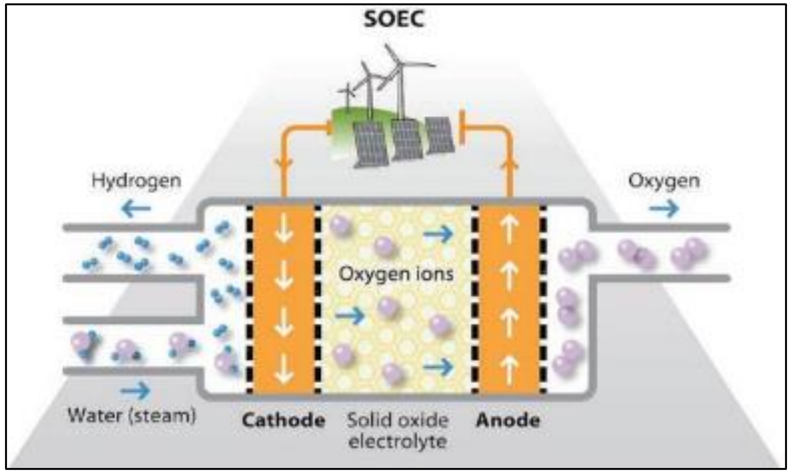
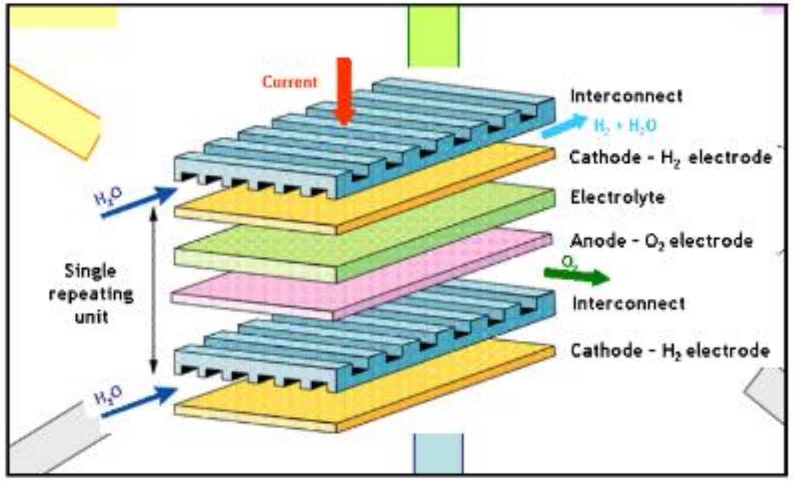
eGHOST case-study 2 definition : SOEC

A Solid Oxide Electrolysis Cell (SOEC) is a Solid Oxide Fuel Cell (SOFC) that runs in reverse mode to achieve the electrolysis of steam (H2O) at high temperatures (~800°C) to produce hydrogen (H2)



Case-study parameters

- *Perimeter :* Stack */ Cradle to grave without use phase / BoP excluded*
- *Size of the system :* 5 kWel
- *Technology :* cathode supported planar cell
- *Timeline :* 2030
- *Number of cells :* 26
- *SRU active area :* 100 cm^2
- *SRU total area :* 144.78 cm^2
- *Sources of data* : Literature data and partners expertize



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eGHOST Spring (20-24 May 2024)

eGHOST eco-design methodology – STEP 1

1 First sustainability evaluation of case-studies (PEMFC & SOEC)

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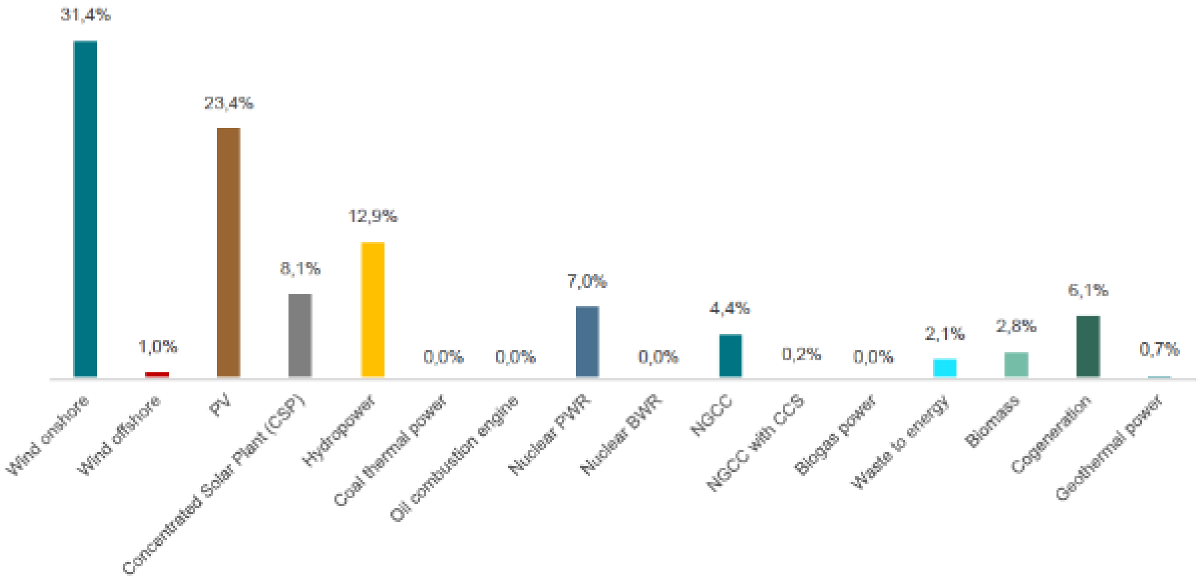
eGHOST case-study 2 definition : SOEC

Summary of materials of the SOEC stack

Part of the stack	Material	Mass with losses (kg)
Electrolyte	8% mol YSZ	0.015
	Binder Dow B-1000/B-1014	
	Ammonium polyacrylate	
	Water	
Cathode	8% mol YSZ	0.12
	Nickel oxide	
	Binder Dow B-1000/B-1014	
	Ammonium polyacrylate	
	Water	
Anode	LSCF	0.99
	YSZ/LSM	
	YSZ/LSM	
Interconnects/Frames	Stainless steel	11.90
	Perovskite coating	
Anode and cathode mesh	Stainless steel	4.57
Sealant	Lanthanum oxide	0.019
	Boron-silicate glass	
End plates/Tie rods	Stainless steel	12.47

Prospective parameters of the SOEC stack

Parameter	Value
Active area per single repeated unit (cm^2/SRU)	100
Current density (A/cm^2)	1.5
Degradation (%/1,000 h)	0.5
Lifetime (h)	80,000



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eGHOST eco-design methodology – STEP 1

1
First sustainability evaluation of case-studies (PEMFC & SOEC)

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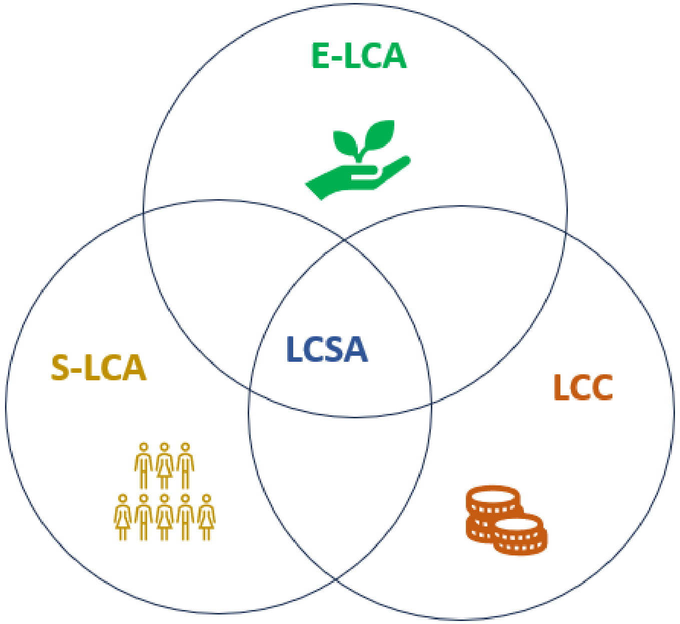
SUSTAINABILITY EVALUATION OF eGHOST PEMFC & SOEC CASE-STUDIES

Identification of main contributors in LCSA :



LCSA Results presented in next session

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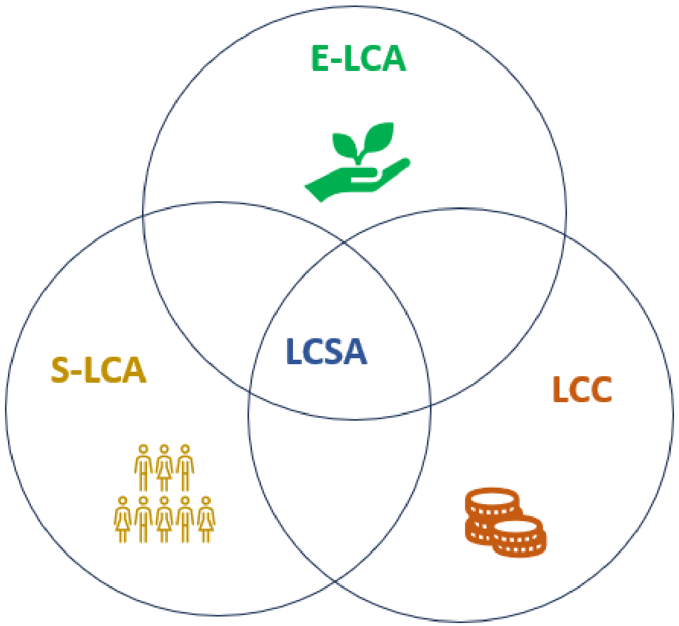
eGHOST eco-design methodology – STEP 2

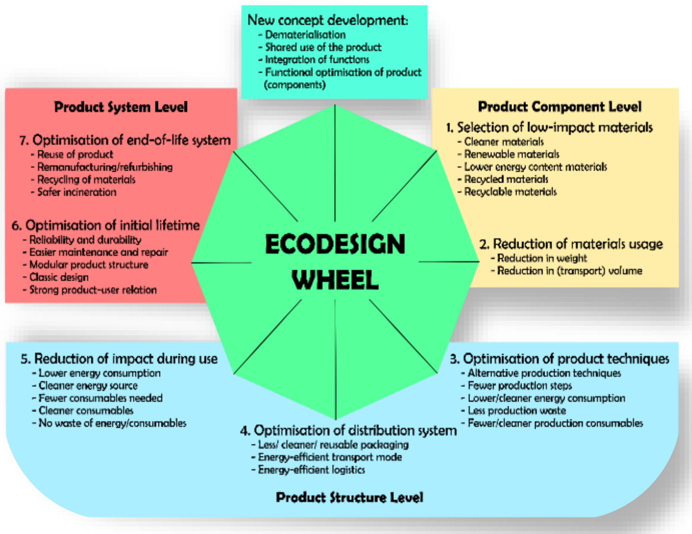
2
Development of first eco-design guidelines based on sustainability hotspots

eGHOST



Identification of environmental, economic and social hotspots for PEMFC & SOEC stacks

Ideas generations



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eGHOST eco-design methodology – STEP 2

2 Development of first eco-design guidelines based on sustainability hotspots

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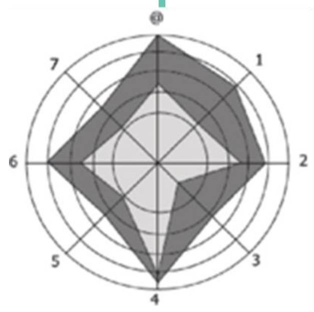
Ideas generations results examples

Selection of low impact materials for PEMFC stack

Action number	Action	Material/ Component	Description of action
1.1	Recycled platinum	Platinum (MEA)	Reduce the use of virgin platinum with recycled platinum that is already available on the market and meets technical requirements (low amounts expected).
1.2	Low/Renewable-energy platinum	Platinum (MEA)	Reduce energy consumption and/or use of renewable energy with EU investments (e.g.: offsetting programs for carbon footprint).
1.3	Aluminum	Stainless steel (external case)	Reduce the stack weight. The current external case is made of aluminum with stainless steel covers.
1.4	Reusable materials/parts	Stack/system	Reduce the overall stack impacts (i.e. end plates and housing). • Bipolar plates are very difficult to be reused; it largely depends on the use phase. • End plates, tie-rods in principle could be reused after some chemical treatment/cleaning. • Housing can be reused, after corrosion evaluation.

! More than 150 ideas generated for both case-studies !

Classification and refining of ideas



Realistic short-term concept: based just on short-term actions that will be realized and implemented in the FC industry in the near future;

Realistic medium-to-long-term concept: based on short-term actions and additionally including some medium-to-long-term actions.

Detailed ideas for both case-studies presented in next session

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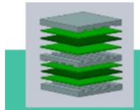
eGHOST eco-design methodology – STEP 3



3
Definition of new stacks product concepts integrating eco-design aspects

eGHOST

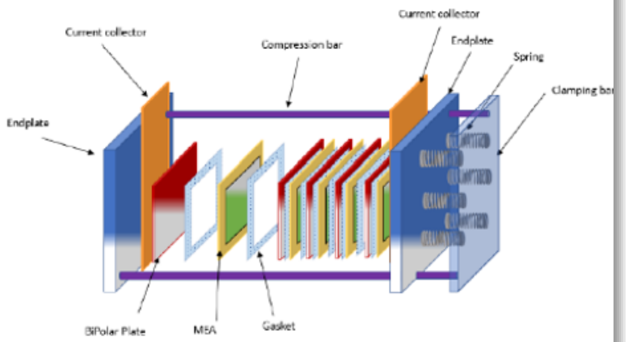
Development of new stacks concepts integrating eco-design ideas

OPTIMISTIC PRODUCT CONCEPT – PEMFC

Implemented eco-design actions: previous one +

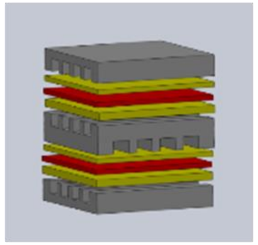
- A1.1 – Use of **recycled platinum**
- A2.1 – **Reduction** of platinum **loading**
- A2.2 – **Optimised** triple-phase boundary
- A2.3 – **Mass reduction** of BPP and ionomer
- A5 – **Refurbishment** of BPP
- A7 – **Closed-loop ionomer** recycling

Optimistic

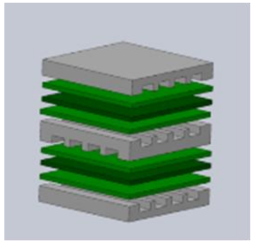


NEW PRODUCT CONCEPTS SOEC

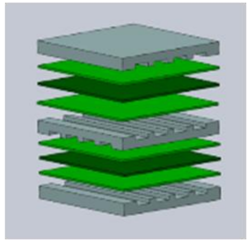
→ Development of life cycle inventories based on guidelines recommendations for realistic and optimistic concepts
→ Concepts based on reduction of the mass of materials used in the different layer of the stacks (thickness reduction) + implementation of recycled materials
→ Reduction of CRM in realistic and optimistic cases (anode & cathode)
→ Virgin steel of the end-plates and interconnectors replaced by recycled steel
→ Sustainability evaluation of the product concepts



Base-case



Realistic case



Optimistic case

Detailed product concepts presented in next session

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eGHOST eco-design methodology – STEP 4

4 Sustainability evaluation of eco-designed product concepts for final guidelines validation

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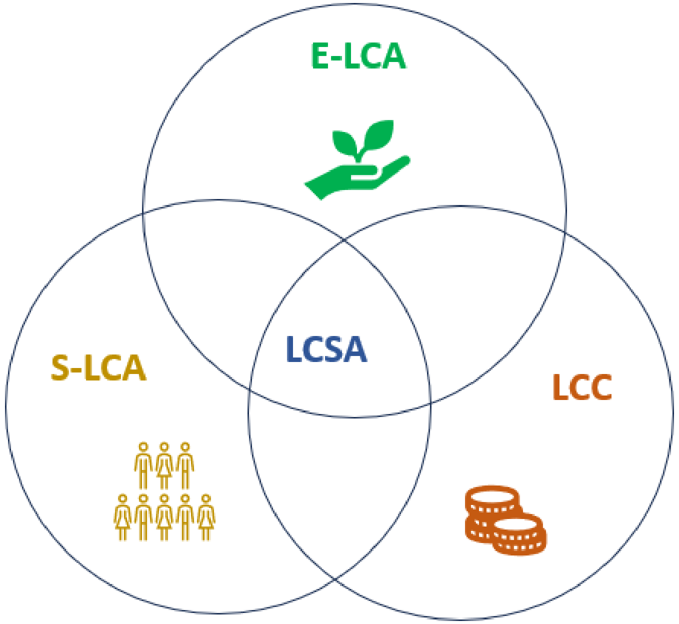
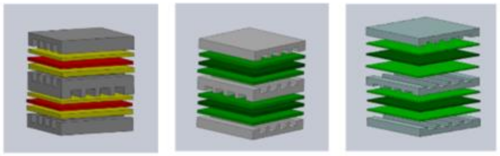
Final life cycle sustainability assessment of new product concepts





Base-case Realistic case Optimistic case

Eco-design guidelines definition for SOEC and PEMFC technology

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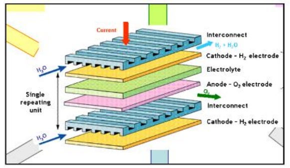
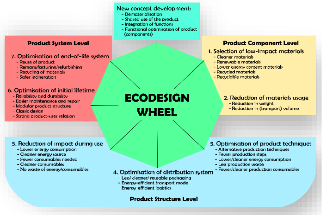
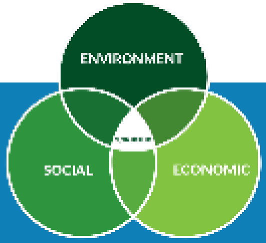
CONCLUSION

An eGHOST eco-design methodology in 4 steps that leads to two eco-design guidelines and new eco-design products concepts for PEMFC 48kW stack and SOEC 5kW stack





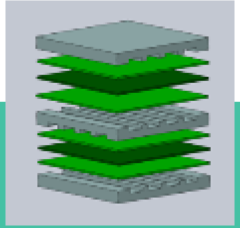


1

First sustainability evaluation of case-studies (PEMFC & SOEC)

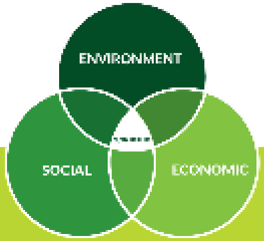
2

Development of first eco-design guidelines based on sustainability hotspots



3

Definition of new stacks product concepts integrating eco-design aspects



4

Sustainability evaluation of eco-designed product concepts for final guidelines validation

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eco-design Guidelines for Hydrogen Systems and Technologies

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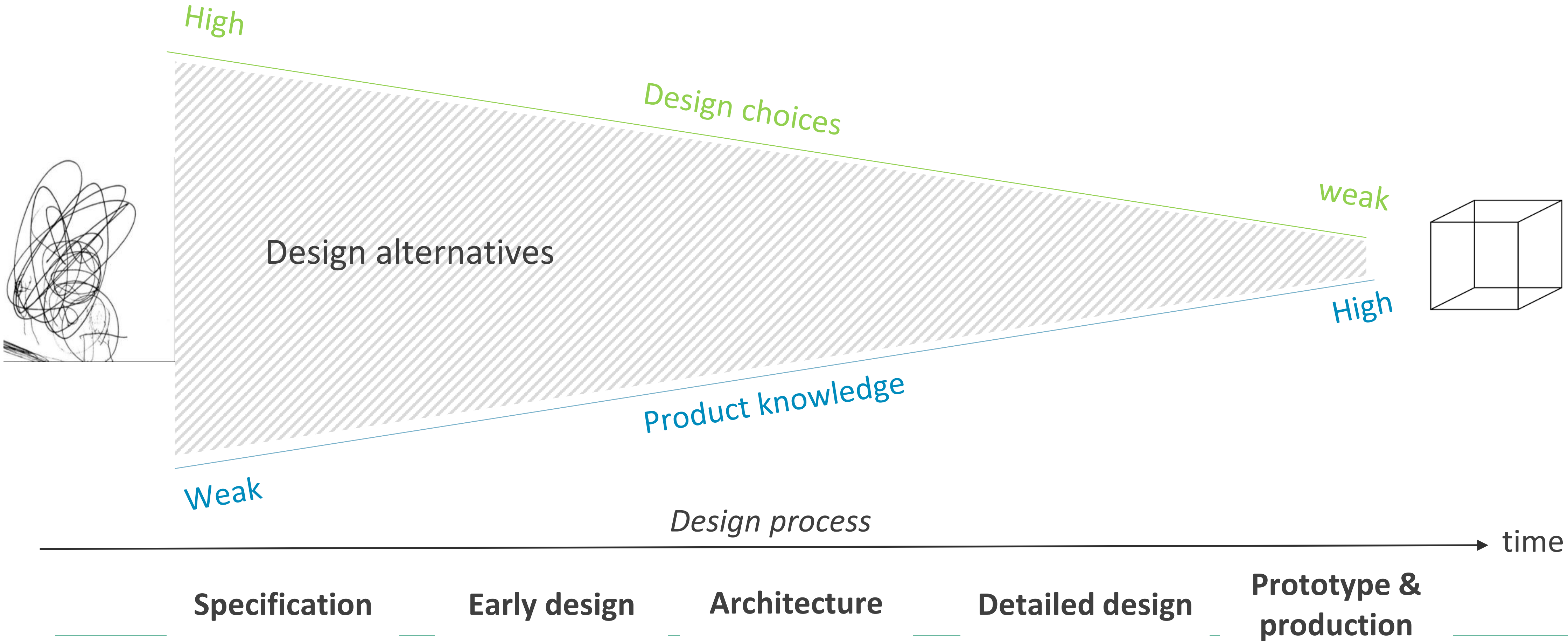

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