eGHOST

eco-design
Guidelines for Hydrogen
Systems and Technologies

eGHOST Spring School (20-24 May 2024)

eGHOST ECO-DESIGN GUIDELINES

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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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eGHOST ECO-DESIGN GUIDELINES

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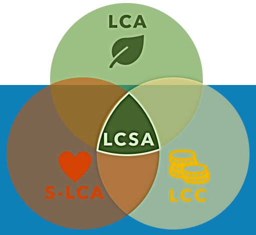
ECO-DESIGN GUIDELINES DEFINITION METHODOLOGY

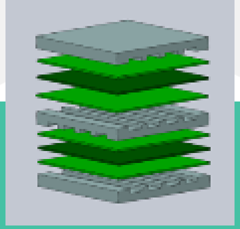


1

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

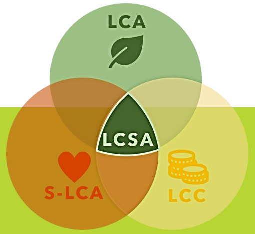
2

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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LCSA OF THE CASE-STUDY

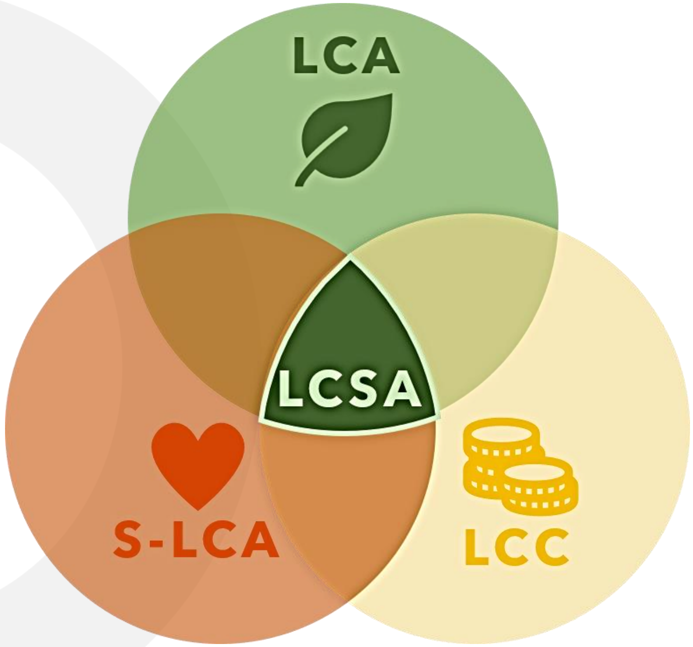
- PEMFC case-study definition
- SOEC case-study definition

LCSA PEMFC case-study

- PEMFC case-study E-LCA results
- PEMFC case-study LCC results
- PEMFC case-study S-LCA results

LIFE CYCLE SUSTAINABILITY ASSESSMENT

- **E-LCA**
  - Scope: **Manufacturing** and **EoL** phase
  - Functional unit: **one 48 kWel PEMFC stack** without BoM
  - LCI provided by industry partner SYMBIO France
  - LCIA: **Environmental Footprint 3.1** (EF3.1)
- **LCC**
  - Scope: **Manufacturing** phase
  - 4 production rates (100, 1000, 10,000 and 50,000 stacks per year)
  - Same inventory as for E-LCA
- **S-LCA**
  - Scope: **Manufacturing** phase
  - Same inventory as for E-LCA and LCC
  - Economic data related to the **production rate 10,000** stacks per year
  - PSILCA database used



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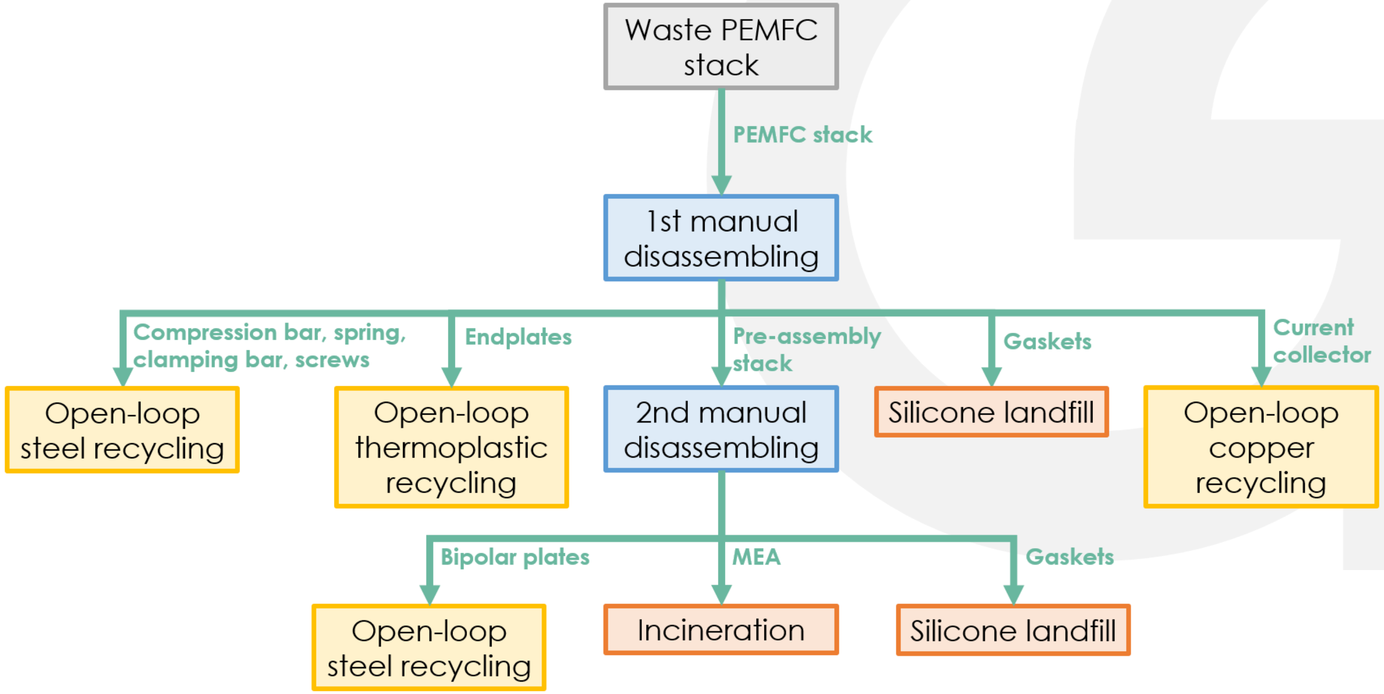
PEMFC CASE-STUDY DEFINITION – INVENTORIES

- **Manufacturing** phase provided by **industry partner** SYMBIO France
- **EoL** treatment defined based on **current state processes** of EoL technologies



Component	Material	Value	Unit	Share
Pt/C	Platinum nanoparticles	26	g	0.08%
	Carbon black	39	g	0.11%
Ionomer	PFSA (Nafion®)	144	g	0.42%
/	Water[1]	490	g	/
/	Alcohol[1]	220	g	/
Subgasket	PEN/PET film with thermo active glue	1820	g	5.26%
Gas diffusion layer	Carbon cloths fibres	1249	g	3.61%
Bipolar plates	Stainless steel	21623	g	62.52%

Component	Material	EoL process	Value	Unit
Compression bar	Chromium steel	Open loop recycling	825	g
Current collector	Copper	Open loop recycling	950	g
Spring	Steel	Open loop recycling	750	g
Clamping bar	Steel	Open loop recycling	2070	g
Gasket	Silicone	Landfill	5	g
Screws	Chromium steel	Open loop recycling	27	g
Endplates	Glass reinforced thermoplastic	Open loop recycling	3800	g
Gaskets	Silicone	Landfill	1260	g
Bipolar plates	Stainless steel	Open loop recycling	21623	g
MEA	/	Landfill & incineration	3278	g

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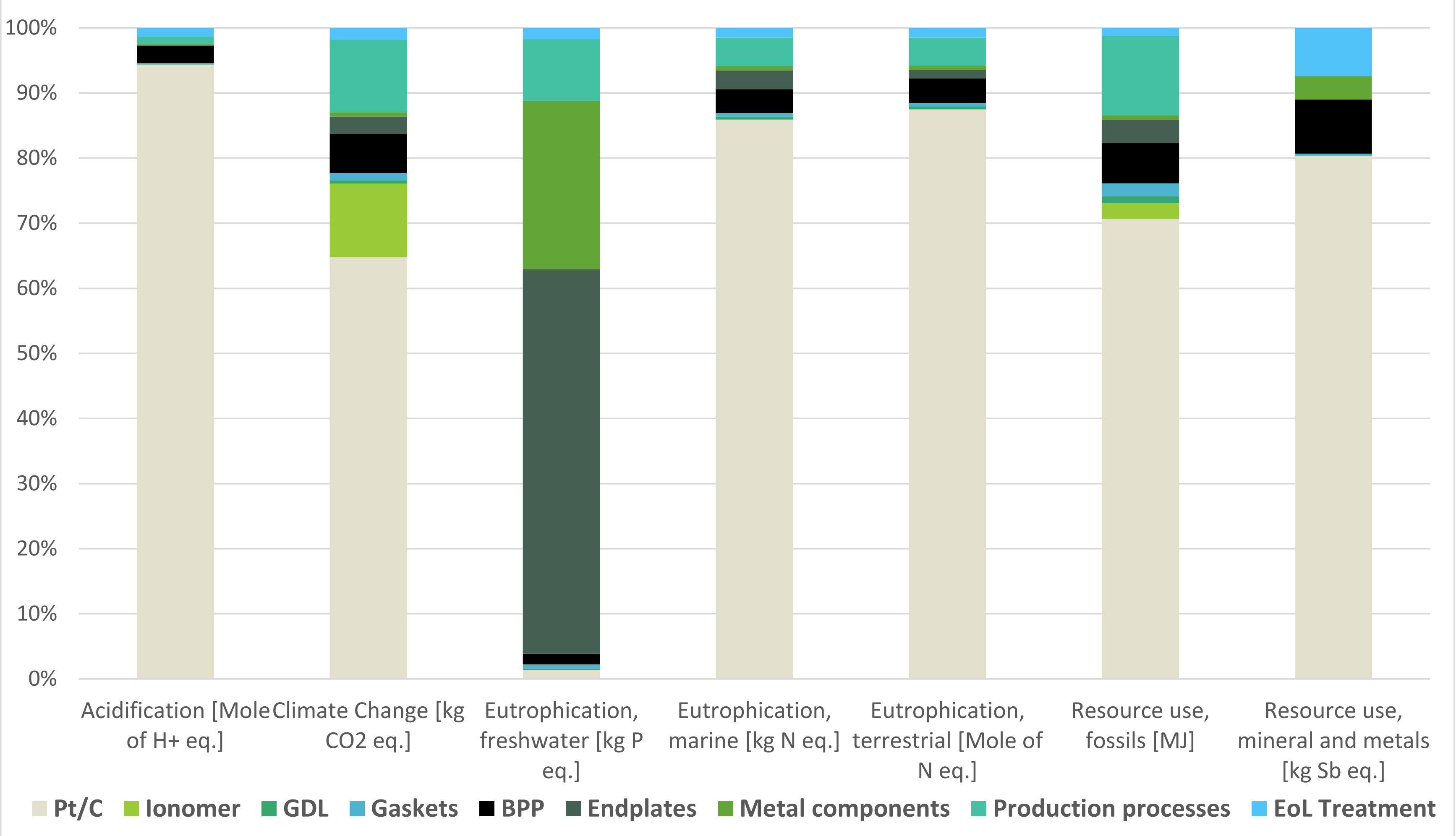
PEMFC CASE-STUDY DEFINITION – E-LCA RESULTS

- **Platinum** is the main environmental **hotspot** (6 out of 7 indicators)
- Carbon support have negligable environmeltal impact
- The total **mass share** of **platinum** in the PEMFC is only **0.1%**
- The **production processes** (electricity (EU mix) and water consumption) is the second highest contributor to the **climate change**, marine eutrophication and terrestrial eutrophication



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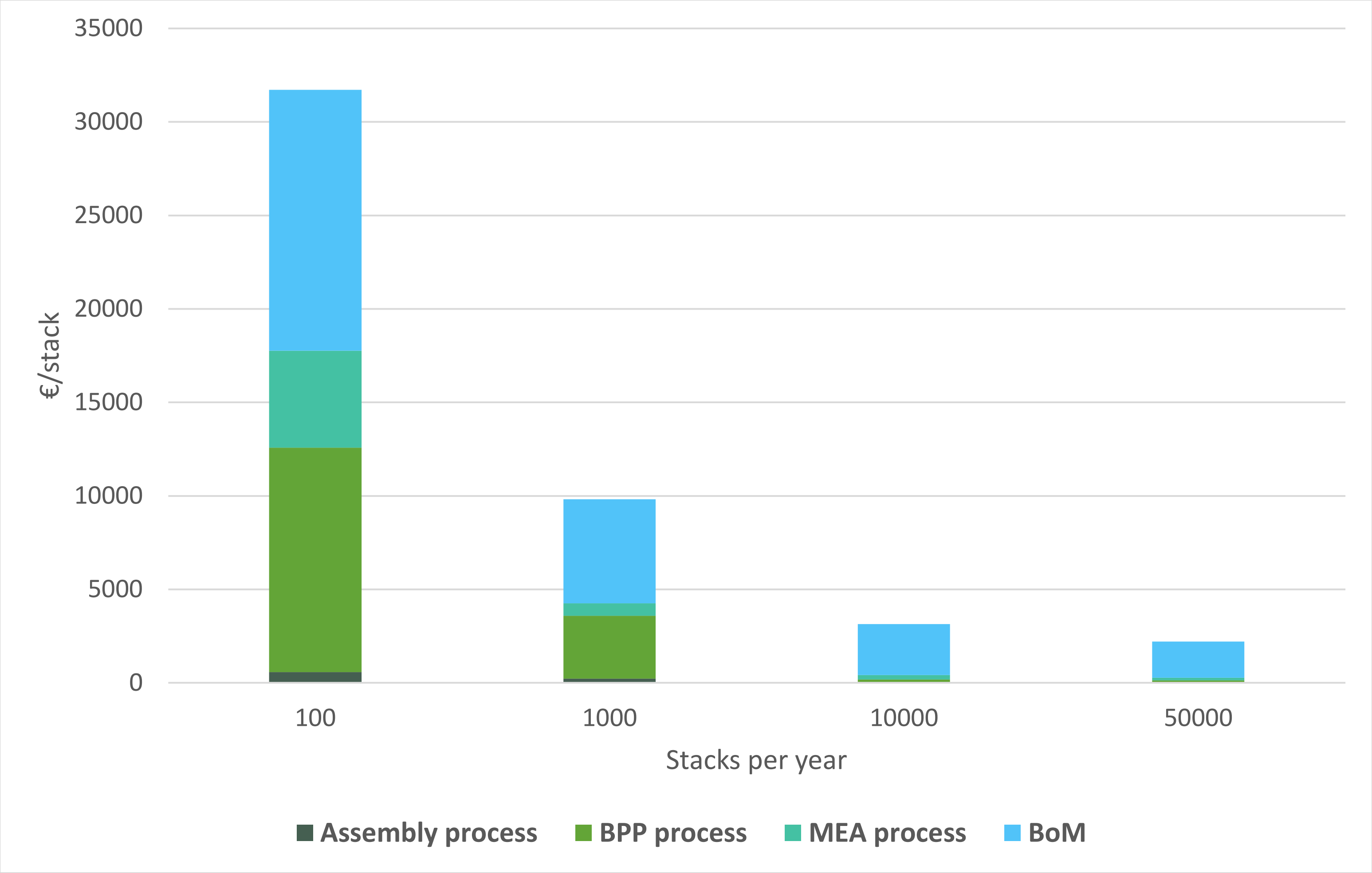
PEMFC CASE-STUDY DEFINITION – LCC RESULTS

- **Production rate** highly influence the cost of the PEMFC stack
- Higher production rate **reduce cost** of PEMFC stack for up to 93%
- Cost of **materials** more influential with **higher production rates**
- At **low production rates**, the **manufacturing processes** significantly contribute to total cost (56% for 100 stacks/year and 43% for 1000 stacks/year)



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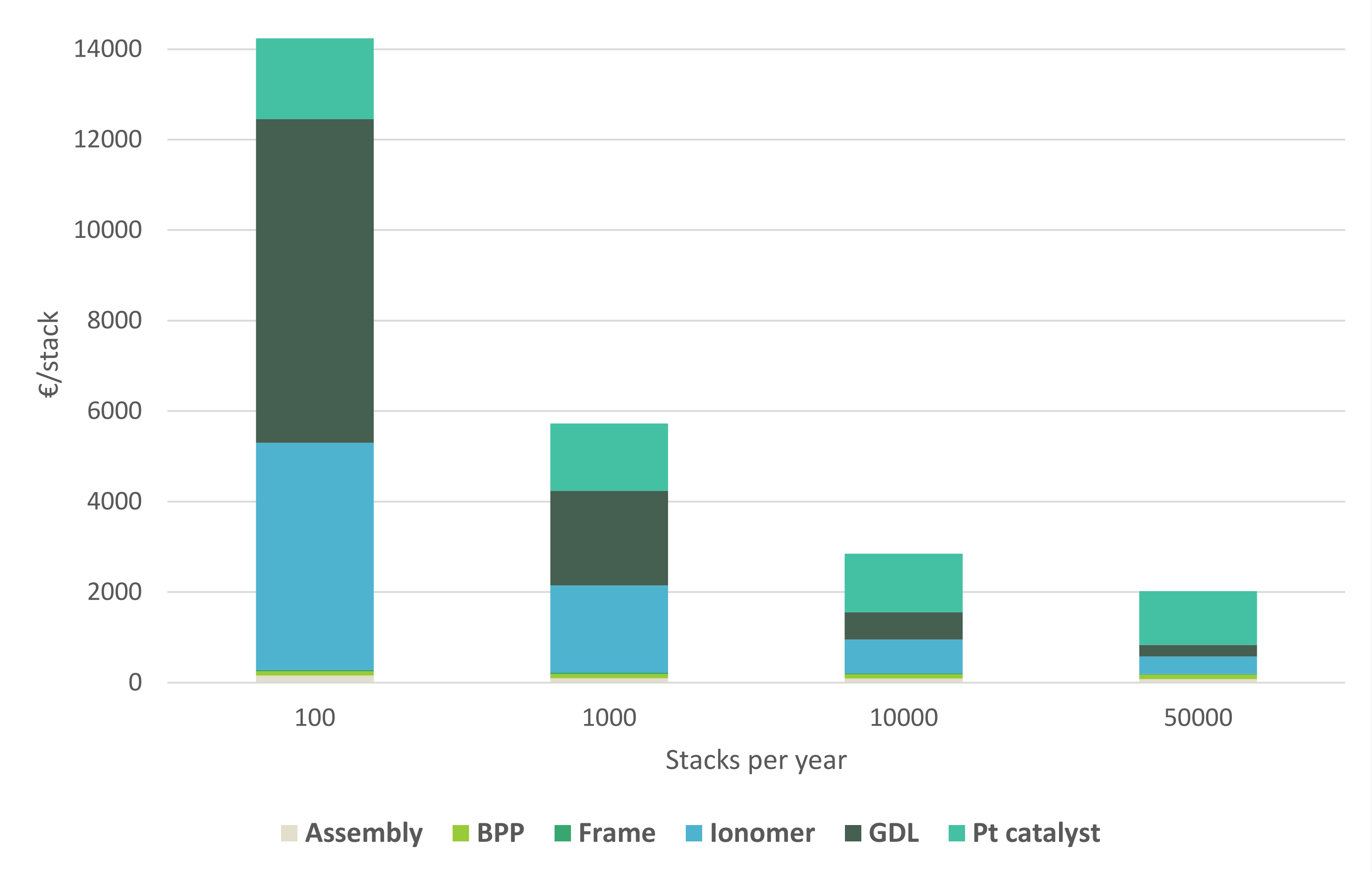
PEMFC CASE-STUDY DEFINITION – LCC RESULTS

- Contribution of costs of **materials**
- Ionomer, Gas Difussion Layer (GDL) and Platinum have the highest cost
- With **higher** production rates the cost of **ionomer** and **GDL reduces significantly** (92% and 96%), while the cost of platinum reduces only for 34%
- **Platinum** becomes the **costly material** in the PEMFC stack with production rate of **10,000** stacks/year
- All costs **depend on** the **market**, meaning they change without good prediction all the time, especially **platinum**



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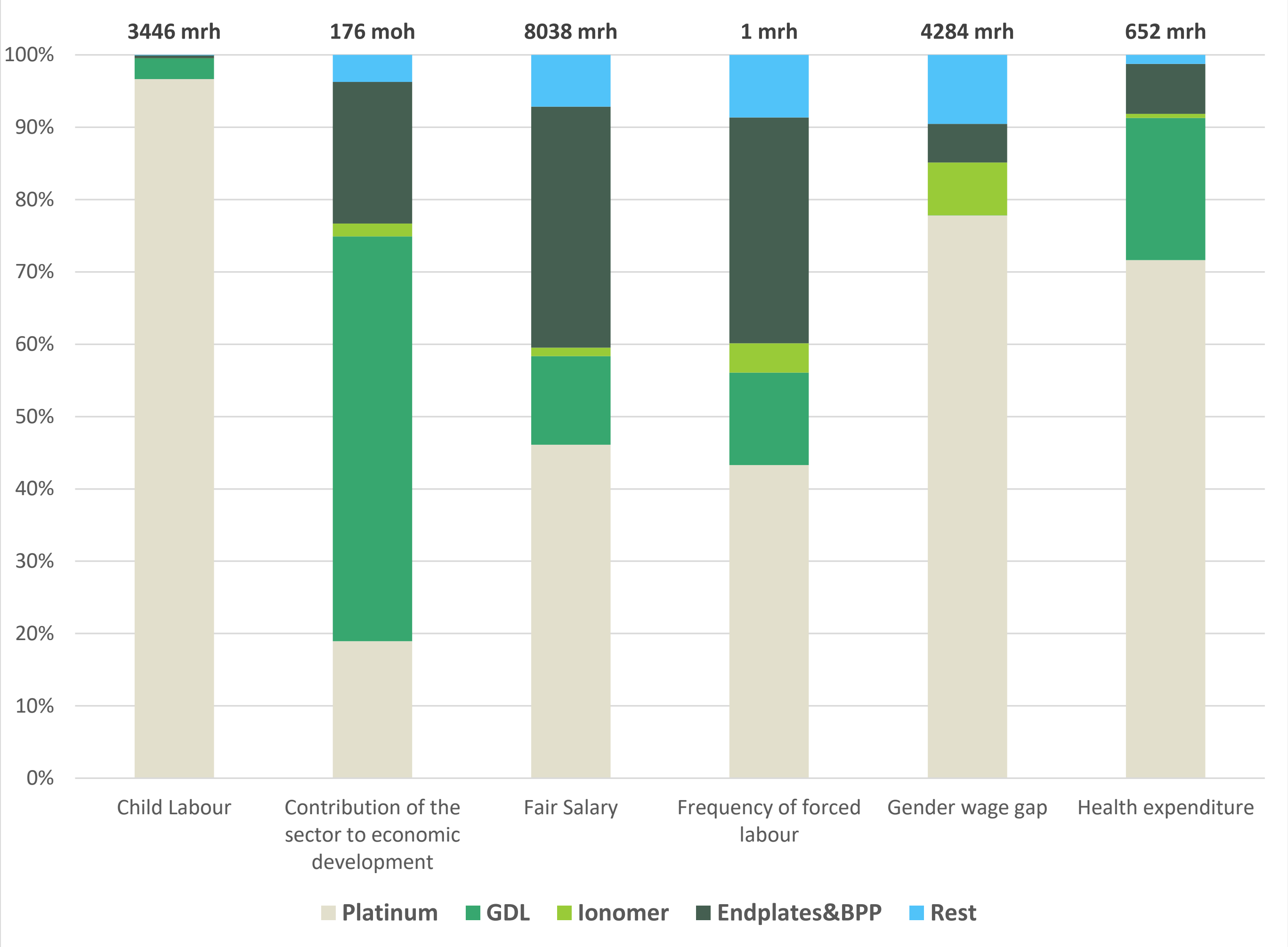
PEMFC CASE-STUDY DEFINITION – S-LCA RESULTS

- Once again is **platinum** (from South Africa) the **main hotspot**, especially for child labour
- **GDL** production contributes the most to the only **possitive indicator** – contribution to economic development
- Significant impact have also endplates & BPP (both of them are produced in Europe) especially for **fair salary and forced labour**
- **Fair salary** has the **highest potential risk** between evaluated social indicators



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LCSA SOEC case-study

- SOEC case-study E-LCA results
- SOEC case-study LCC results
- SOEC case-study S-LCA results

SOEC CASE-STUDY DEFINITION

- **Prospective E-LCA**
  - Scope: **Manufacturing** and **EoL** phase
  - For case-study screening only manufacturing phase is considered
  - Functional unit: **one 5 kWel SOEC stack** without BoM
  - LCI based on literature data and partners expertise
  - LCIA: **Environmental Footprint 3.1** (EF3.1)
- **LCC**
  - Scope: **Manufacturing** phase
  - 1 production rate – 10,000 stacks per year
  - Same inventory as for E-LCA
- **S-LCA**
  - Scope: **Manufacturing** phase
  - Same inventory as for E-LCA and LCC
  - **PSILCA** database used

Component	**Material**	**Mass**
Electrolyte	8% mol YSZ [g]	8.7
	Binder Dow B-1000 [g]	3.8
	Ammonium polyacrylate[1] [g]	1.5
	Water[1] [g]	2.1
Cathode	8% mol YSZ [g]	258
	Nickel oxide [g]	368
	Binder Dow B-1000[1] [g]	239
	Ammonium polyacrylate [g]	10
	Water [g]	119
Anode	LSCF [g]	86
	YSZ/LSM [g]	21
	YSZ/LSM [g]	10
Interconnects/Frames	Stainless steel [g]	11864
	Perovskite coating [g]	33
Anode and cathode mesh	Stainless steel [g]	4572
Sealant	Lanthanum oxide [g]	14
	Boron-silicate glass [g]	4.7
End plates/Tie rods	Stainless steel [g]	12468
SOEC stack [g]		**29709**

1 - Binder Dow B-1000, ammonium polyacrylate, and water are not included in the stack and therefore, do not contribute to the total SOEC stack mass. They are included in the LCI because they are needed in the manufacturing phase of the stack.

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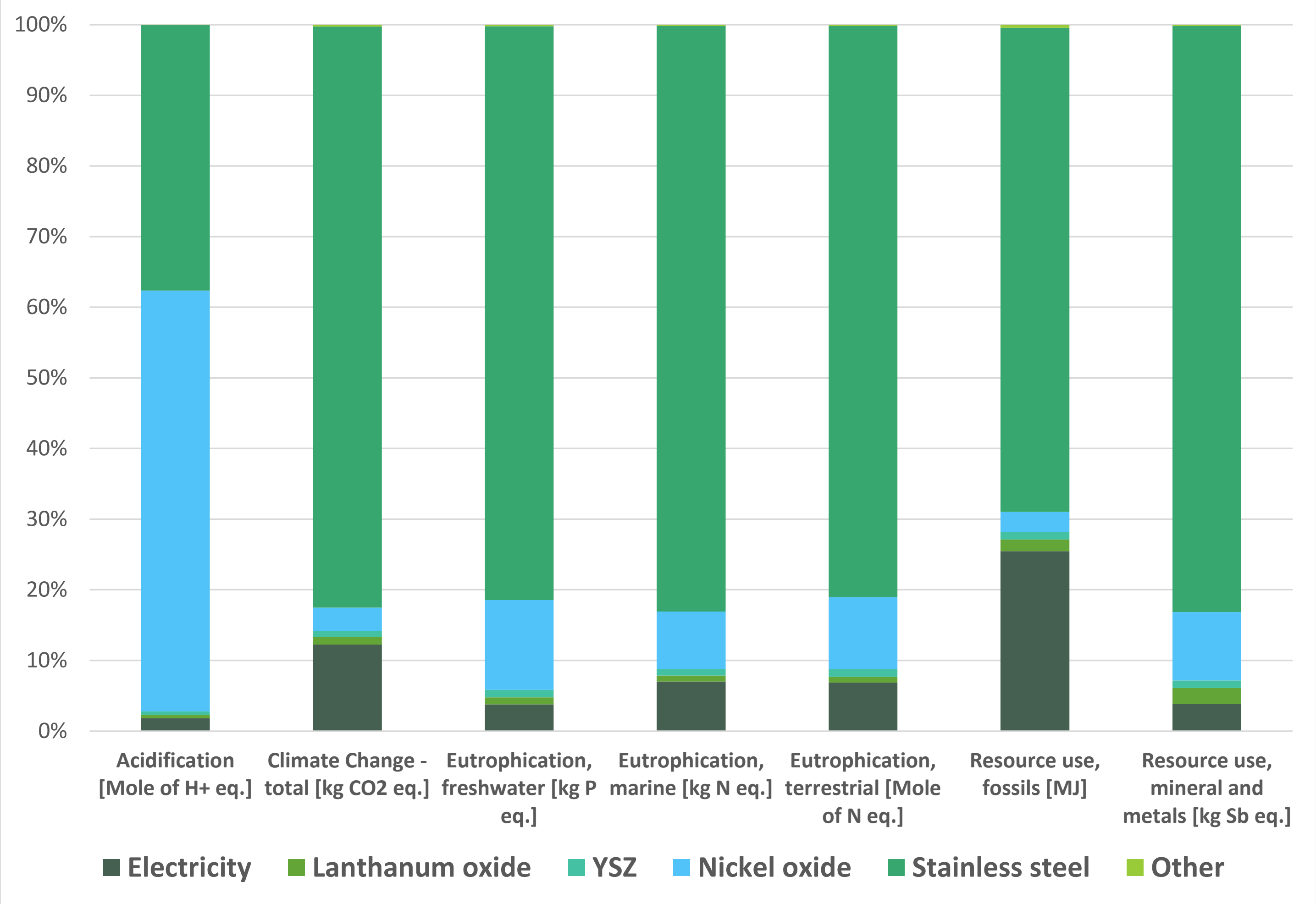
SOEC CASE-STUDY DEFINITION – E-LCA RESULTS

- The main **hotspot** is **stainless steel** (6 out of 7 indicators)
- **Stainless steel** has also the **highest mass rate** within the SOEC stack
- Nickel oxide contributes the most to the acidification (60%)
- Significant impact has also electricity used in manufacturing process
- **Prospective 2030** electricity mix for Spain is used (81% RES)



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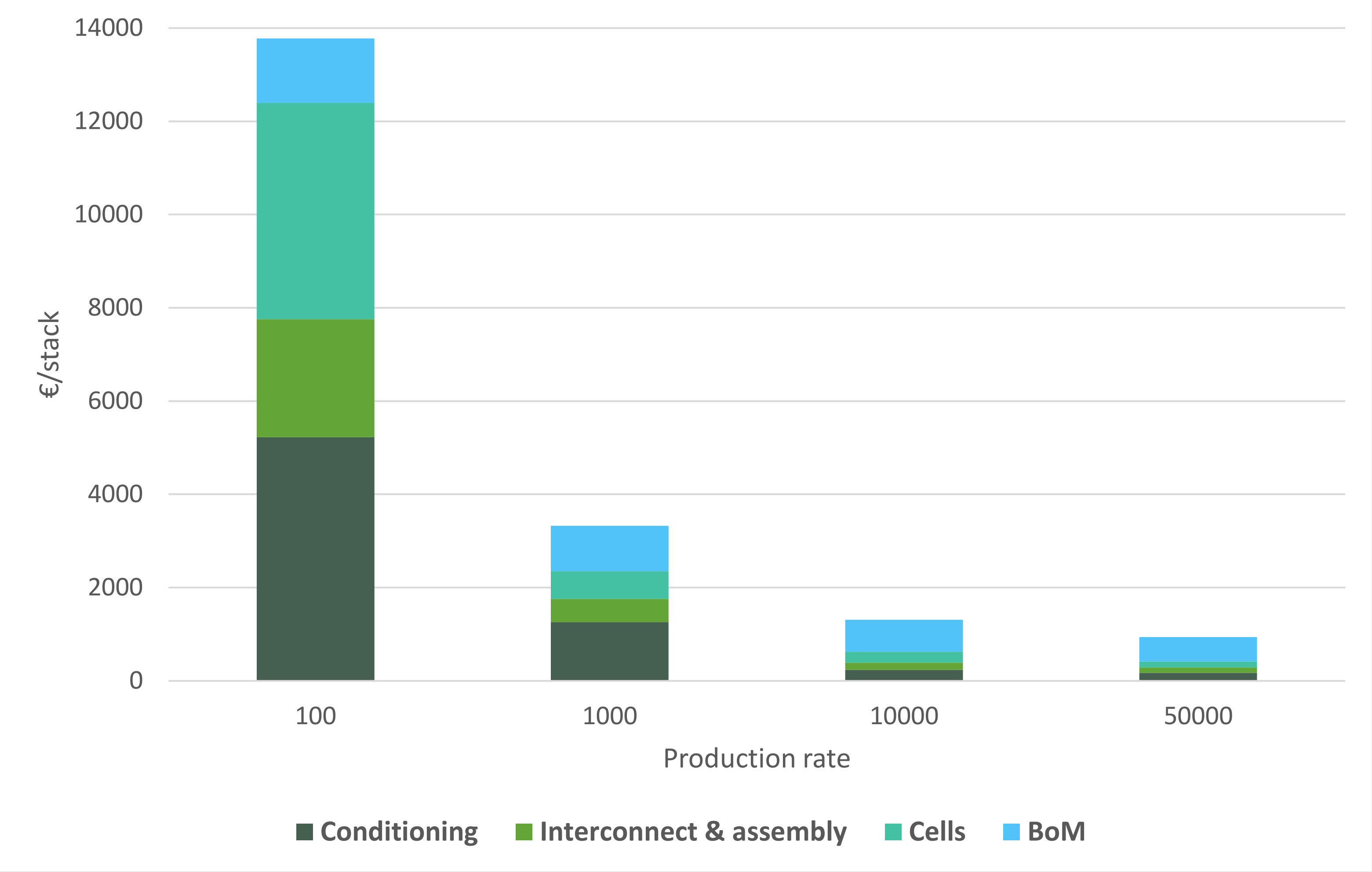
SOEC CASE-STUDY DEFINITION – LCC RESULTS

- SOEC stack strongly **dependent** on the **production scale** (from 14k€ at lab scale to the 940€ at industrial scale)
- The share of cost of **materials** increases with **higher production rate** (from 9% to 56%)
- At the production rate 10,000 stack per year **materials** represent **52%** of the cost



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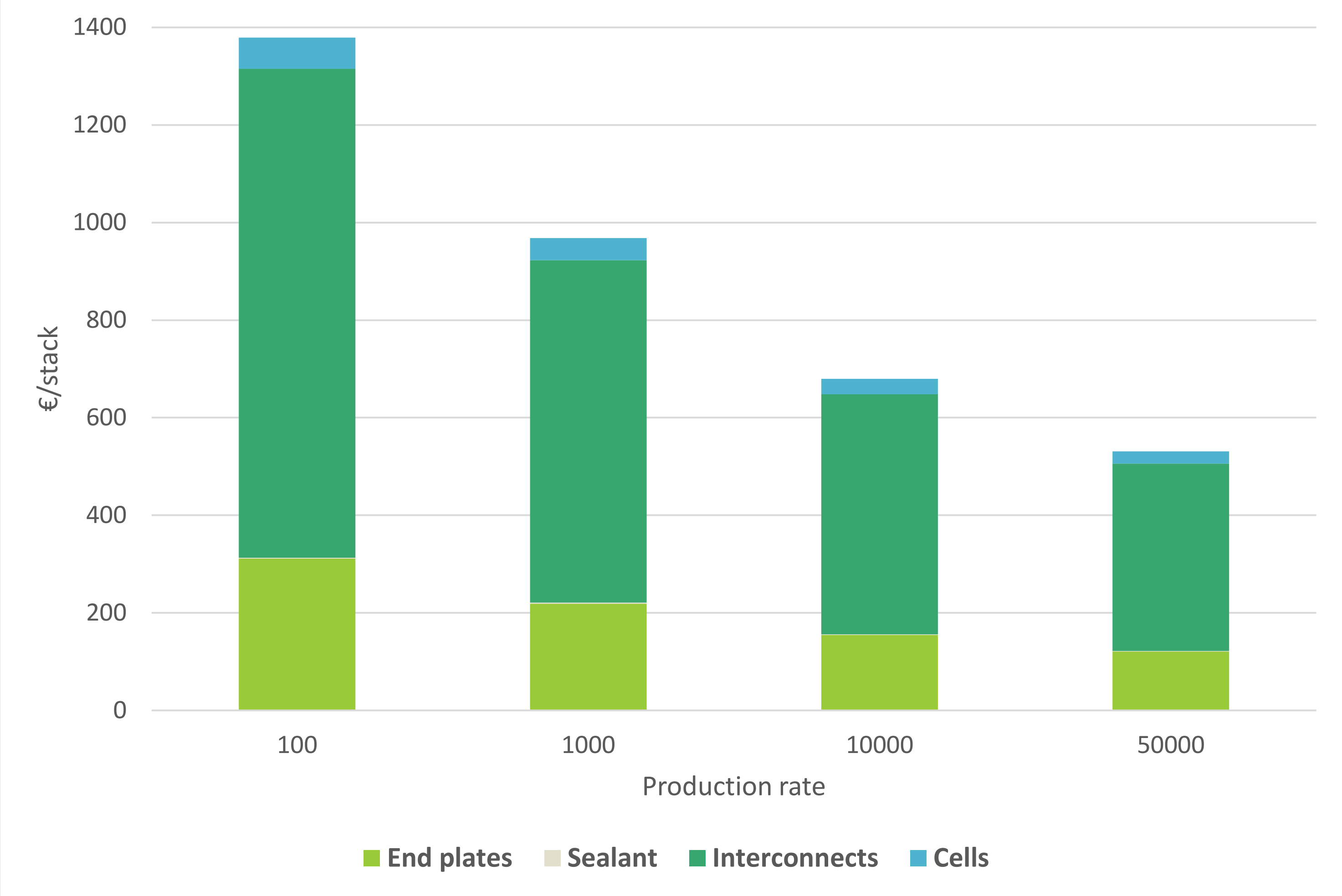
SOEC CASE-STUDY DEFINITION – LCC RESULTS

- Contribution of costs of **materials**
- The shares of materials **stays the same** with production rate increase:
  - Endplates: 23%
  - Sealant: 0,2%
  - Interconnects: 72%
  - Cells: 5%
- Interconnects and endplates (stainless steel) have also the **highest mass rate** in the SOEC stack
- With **higher production rate** the cost of materials lowers for 62%



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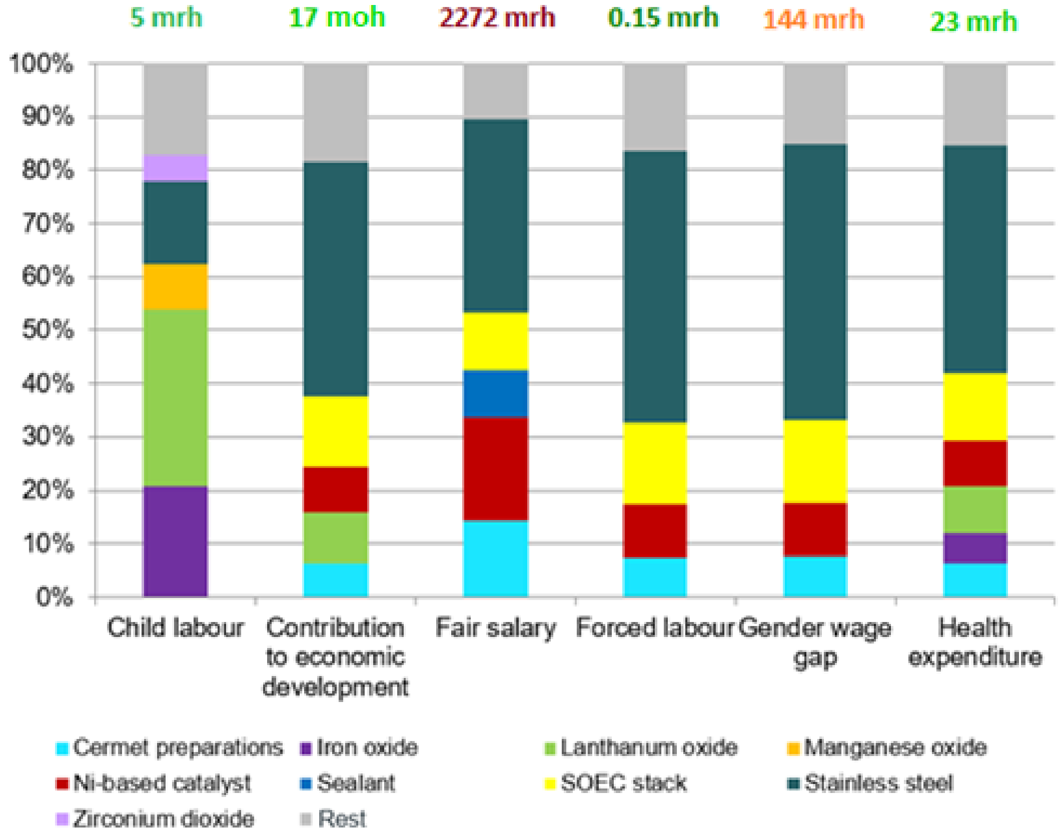
SOEC CASE-STUDY DEFINITION – S-LCA RESULTS

- Once again is **stainless steel** the main **hotspot**
- Contribution more **even** than in PEMFC
- Significant impacts have also: Ni-based catalyst, Lanthanum oxide, SOEC stack, and Cermet preparations
- **Absolute values** of impact **lower** than in PEMFC, again is the **fair salary** the most critical



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eco-design Guidelines for Hydrogen Systems and Technologies

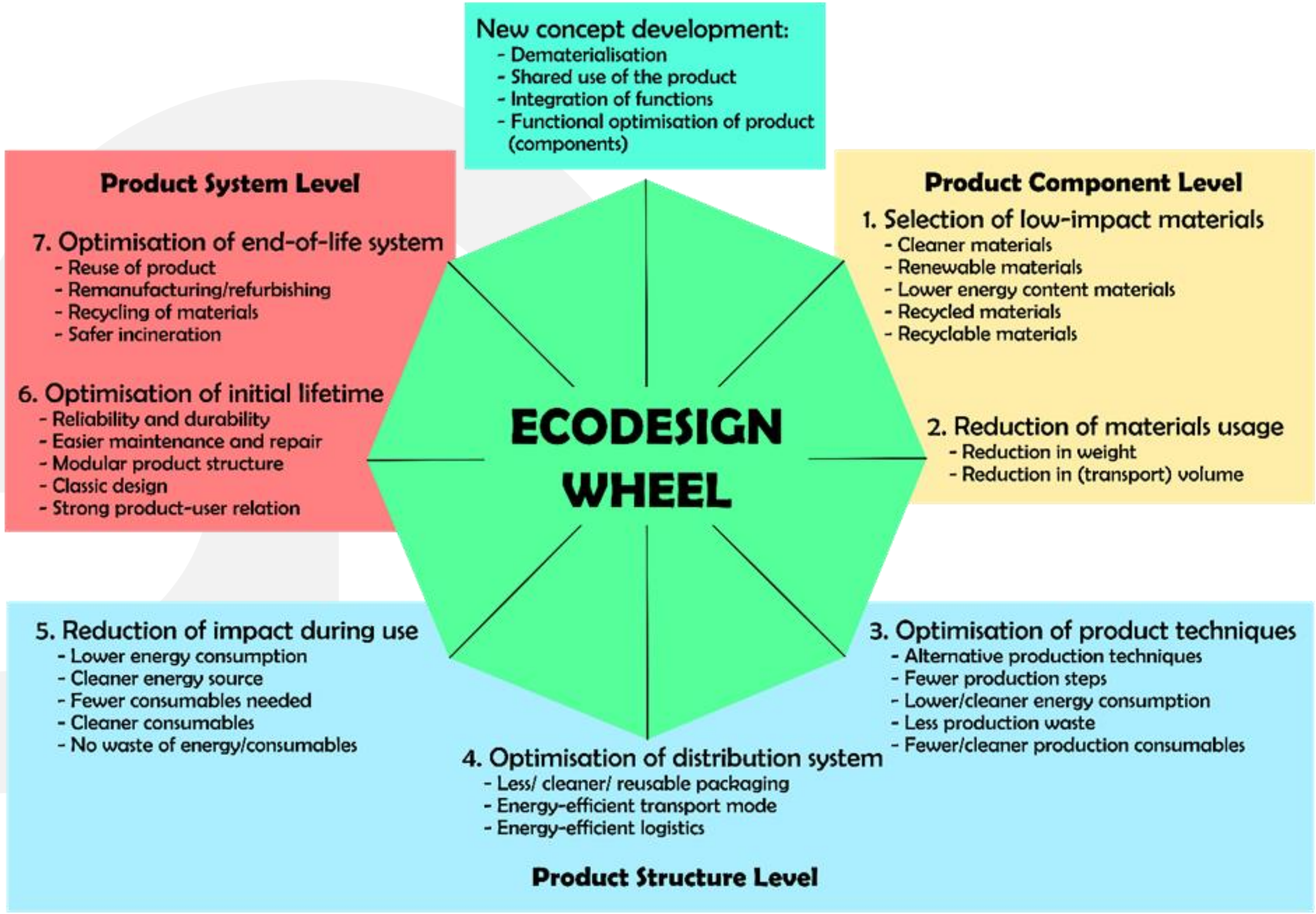
(20-24 May 2024)

ECO-DESIGN ACTIONS & PRODUCT CONCEPTS

- PEMFC eco-design actions & product concepts
- SOEC eco-design actions & product concepts

ECO-DESIGN ACTIONS

- **Anticipate** and **minimise** negative environmental impacts **without compromising** the quality and functionality of the product
- **2 brainstorming** sessions for each technology
- Ideas **based** on LCSA of the study-case and **aligned** with eco-design wheel
- The defined actions are divided into:
  - Short-term actions (within 3 years)
  - Medium term-actions (3-10 years)
  - Long-term actions (>10 years)



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PEMFC eco-design actions & product concepts

ECO-DESIGN ACTIONS – PEMFC

- **Short-term actions**

Action number	Action	Material/Component	Description of action
2.1	Reduce the catalyst loading		Reduce the amount of platinum loading. Targets: lower than 0.41-0.52 mg/cm². Current best-case scenario is 0.22-0.25 mg/cm² for the new Toyota Mirai [4]. ... or EU KPIs [5].
			particle optimization size, shape, surface increase the specific
			due to interaction of Pt decrease the amount particle Pt is partially terial, which further
			support and achieve

rial/Component	Description of action
um (MEA)	Reduce the use of virgin platinum with recycled platinum that is already available on the market and meets technical requirements (low amounts expected).
	Reduce energy consumption and/or use of renewable energy with EU investments (e.g. offsetting programs for carbon footprint).
ess steel rnal case)	Reduce the stack weight. The current external case is made of aluminum with stainless steel covers.
	e overall stack impacts (i.e. end plates
	o be reused; it

Action number	Action	Material/ Component	Description of action
3.1	Low-impact impregnation/different coating technologies	MEA	Optimized, low-impact, and low-waste manufacturing processes (e.g. replace the decal process with CCM direct coating processes).
3.2	Integration of RES for the production processes	Stack	The manufacturing company should use renewable
3.3	Ready-to-recycle assembly technologies		
3.4	Reduce rejection rate		

Action number	Action	Advantages and notes
7.1	Improve the recycling of materials, especially platinum	Potential recovery of platinum and membrane. Recovery of copper in current collectors. **Note**: To include the results from the BEST4Hy project.

		influence the energy minimize the dynamic
	hybridization strategy	conditions of the stack). **Note**: recommendation for manufacturers.

Action number	Action	Description of action
4.1	Minimize the packaging	Keep the wooden packaging. Reduce the mass of packi **Note**: No technical specifications of the packaging avail
4.2	Use reusable and low-impact packaging	Keep the wooden packaging with reusable strategy. U corrugated cardboard box material.

		tack energy drop-control, power hybrid
	system	structure in the control strategy, etc.). **Note**: recommendation for manufacturers.
5.2	Supply the fuel cell with green hydrogen	The use of green (renewable) hydrogen is recommended in the use phase. **Note**: recommendation for consumers.
5.3	Ease the stack dismantling and replacement within the system	More efficient maintenance – i.e. place the stack in the vehicles in very reachable places, simplify the fastening. **Note**: recommendation for manufacturers.

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ECO-DESIGN ACTIONS – PEMFC

- **Medium-to-long-term actions**

Axis	Action nr.	Action	Component	Description of action
6 – Prolonged lifetime	6.2	Reduce nitrogen crossover	Stack	Increases the stack durability and efficiency (by optimizing the anode purging cycles and recirculation).
	6.3	Alternative catalyst support	MEA	Replacing carbon support with another material to improve cell durability.
7 – EoL optimization	7.2	Establish a secondary raw materials market specific to FCH systems	Overall system	Involve manufacturers in EoL phase of their products and establish market where all entities would participate.
	7.3	Promote the creation of industrialized processes and recycling centers to collect/recycle the stacks		

Axis	Action nr.	Action	Component	Description of action
3 – production optimization	3.6	Optimize upstream manufacturing	Component level	Especially in platinum extraction/supply chain.
	3.7	Improve the stack and system modularity	Stack / overall system	Simplifies maintenance, repairs, refurbishing, and dismantling in EoL.
	3.8	Reduce the distance between component manufacturers and system assembly site	Overall system	Find the strategy (within EU) where the distances between manufacturers of components will be optimized.
	3.9	Low-activation stack	Stack/BoP	Increases the stack durability and efficiency (by optimizing the thermal management system). Decrease of hydrogen and energy consumption during activation phase using optimized catalyst.
				Product specifications might lead to specific packaging with dedicated cleaning & washing logistics, logistic loops plus optimization [10]. **Note:** No data currently available due to lack of logistical details and established infrastructure. ***Recommendation level***
				Logistics: Use of renewable fuels and sustainable transport for delivery of products. *Storage:* Reduce the frequency of distribution / balanced production and optimization of costs. ***Recommendation level***
				Avoid long distances by local (EU-based) manufacturing and recycling sites. ***Recommendation level***
5 – low impact during use phase	5.4	efficient stacks to the system	Overall system	At lower load the efficiency of FC is higher, and lifetime is prolonged. New stacks provide additional power at higher efficiency due to technological improvements.
	5.5	Develop refurbishing technologies for FC systems failing within low-to-medium lifetime	Overall system	Especially in the case of BoP components. Within the stack, refurbishing (or even reusing) the bipolar plates could be feasible.
	5.6	Optimize the design of flow channels	Bipolar plates	Optimize fuel consumption, oxygen distribution and water balance (humidification) systems.

…on	Component	Description of action
…ycled …inum	Platinum (MEA)	Target is 70-80% of recycled platinum in new products as a closed-loop strategy. To establish the recycling market, a large volume of technology in the market is required.
…-platinum …alysts		Avoid the use of platinum. This is still at laboratory level.
…er proton …hange …erials	Ionomer (MEA)	Avoid/Reduce the use of ionomer (PFSA), improve conductivity (sulfonated PEEK, sulfonated pentablock terpolymers, MOF-polymer hybrid materials, etc.).
…ycled …mer		Reduce the use of virgin ionomer (PFSA).
…bon fiber or …phene/ …xy resin …posites	Stainless steel (Bipolar Plates)	Reduce the stack weight with material substitution that meets technical demands.
…vative …ling system …gn	Balance of plant	Reduce the overall system size/weight with less material use.
…imize the …power …sity	Full stack	Reduce the number of cells, the number of components and the weight (i.e., in the case of a 48 kW stack, from 1.66-2.12 kW/kg to 2.46-4 kW/kg). This is done by increasing the MEA efficiency with different catalyst and ionomer choice: • 2.12 kW/kg stack needs 280 "standard MEA" to reach 48- 50 kW. • 2.46 kW/kg stack need 280 "light weight MEA" or keep 48-50 kW with only 241 MEA. • 4 kW/kg stack needs 280 "light & efficient MEA" or keep 48-50 kW with only 149 MEA.
…of …rnative …mercial …nbranes	Membrane	Lower density and higher durability.

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ECO-DESIGN PRODUCT CONCEPTS – PEMFC

- Based on the eco-design actions **four product concepts** were defined
  - Realistic short-term concept
  - Realistic medium-to-long-term concept
  - Optimistic concept
  - Disruptive concept
- **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
- **Optimistic concept** is the concept already under implementation by some top-end technological companies and/or developed at the laboratory scale
- **Disruptive concept** includes relevant above-mentioned actions plus others that are still under development or in the early research or even conceptual phase

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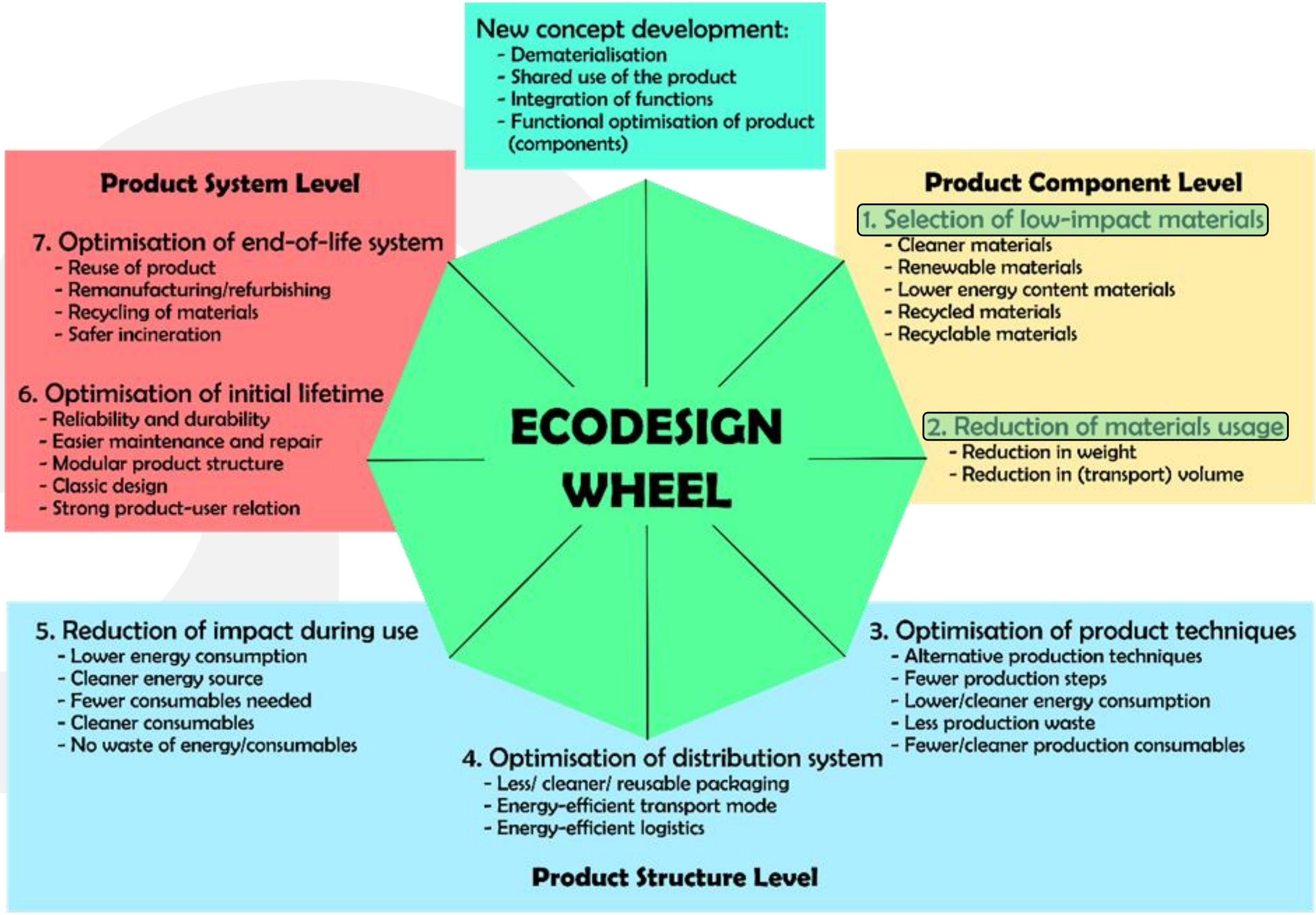
REALISTIC SHORT-TERM PRODUCT CONCEPT

Implemented eco-design actions:

- A1.1 – Use of **recycled platinum**
- A1.4 – **Reuse** of stack housing (GRTP)
- A2.1 – **Reduction** of platinum loading
- A2.2 – Optimised **triple phase** boundary
- A2.3 – **Mass reduction** of GDL, BPP, and ionomer



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REALISTIC SHORT-TERM PRODUCT CONCEPT – MANUFACTURING PHASE

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Implemented eco-design actions:

- A1.1 – Use of **recycled platinum**
- A1.4 – **Reuse** of stack housing (GRTP)
- A2.1 – **Reduction** of platinum loading
- A2.2 – Optimised **triple phase** boundary
- A2.3 – **Mass reduction** of GDL, BPP, and ionomer

Component	Material	Base	Real-short
Pt/C	Platinum nanoparticles – virgin [g]	26	9.1
	Platinum nanoparticles – recycled [g]	/	3.9
	Carbon black [g]	39	37
Ionomer	PFSA (Nafion) – virgin [g]	144	101
	PFSA (Nafion) – recycled [g]	/	/
/	Water [g]	490	467
/	Alcohol [g]	220	210
Subgasket	PEN/PET film with thermo active glue [g]	1820	1733
Gas diffusion layer	Carbon cloths fibres [g]	1249	687
BPP	Stainless steel – virgin [g]	21623	18379
	Stainless steel – reused [g]	/	/
Gaskets	Silicone [g]	1265	1204
Endplate	Glass reinforced thermoplastic – virgin [g]	3800	2533
	Glass reinforced thermoplastic – reused [g]	/	1086
Current collector	Copper – virgin [g]	950	905
	Copper – recycled [g]	/	/
Compression bar	Chromium steel [g]	825	785
Hexagonal screws	Chromium steel [g]	27	26
Spring	Steel [g]	750	714
Clamping bar	Steel [g]	2070	1972
Electricity [kWh]	/	410	391
PEMFC stack		**34588**	**30175**

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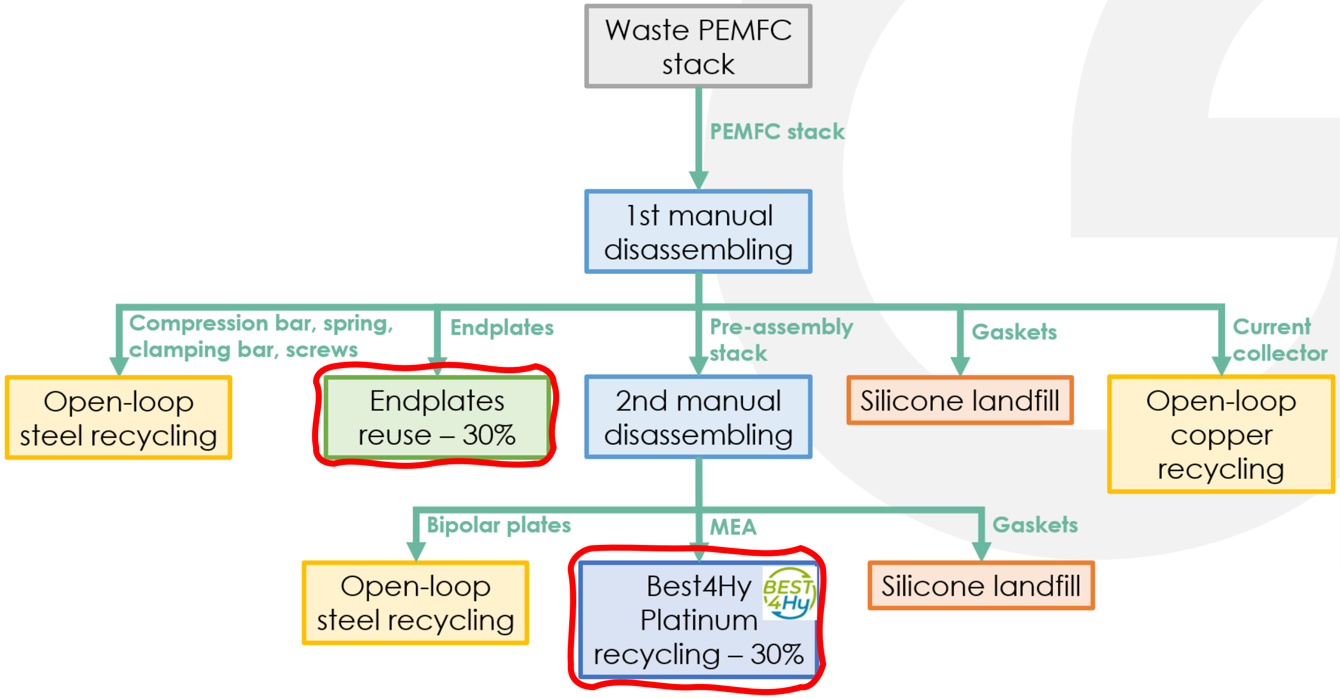
REALISTIC SHORT-TERM PRODUCT CONCEPT – EoL PHASE

Implemented eco-design actions:

- A1.1 – Use of **recycled platinum**
- A1.4 – **Reuse** of stack housing (GRTP)



Component	Material	EoL process	Reference	Real-short
Compression bar	Chromium steel [g]	Open loop recycling	825	785
Current collector	Copper [g]	Open loop recycling	950	905
Spring	Steel [g]	Open loop recycling	750	714
Clamping bar	Steel [g]	Open loop recycling	2070	1972
Screws	Chromium steel [g]	Open loop recycling	27	26
Endplates	Glass reinforced thermoplastic [g]	Open loop recycling	3800	2533
		Reuse	/	1086
Gaskets	Silicone [g]	Landfill	1265	1204
Bipolar plates	Stainless steel [g]	Open loop recycling	21623	18379
MEA [g]		Incineration & landfill	3278	/
		Recycling – BEST4Hy	/	2571

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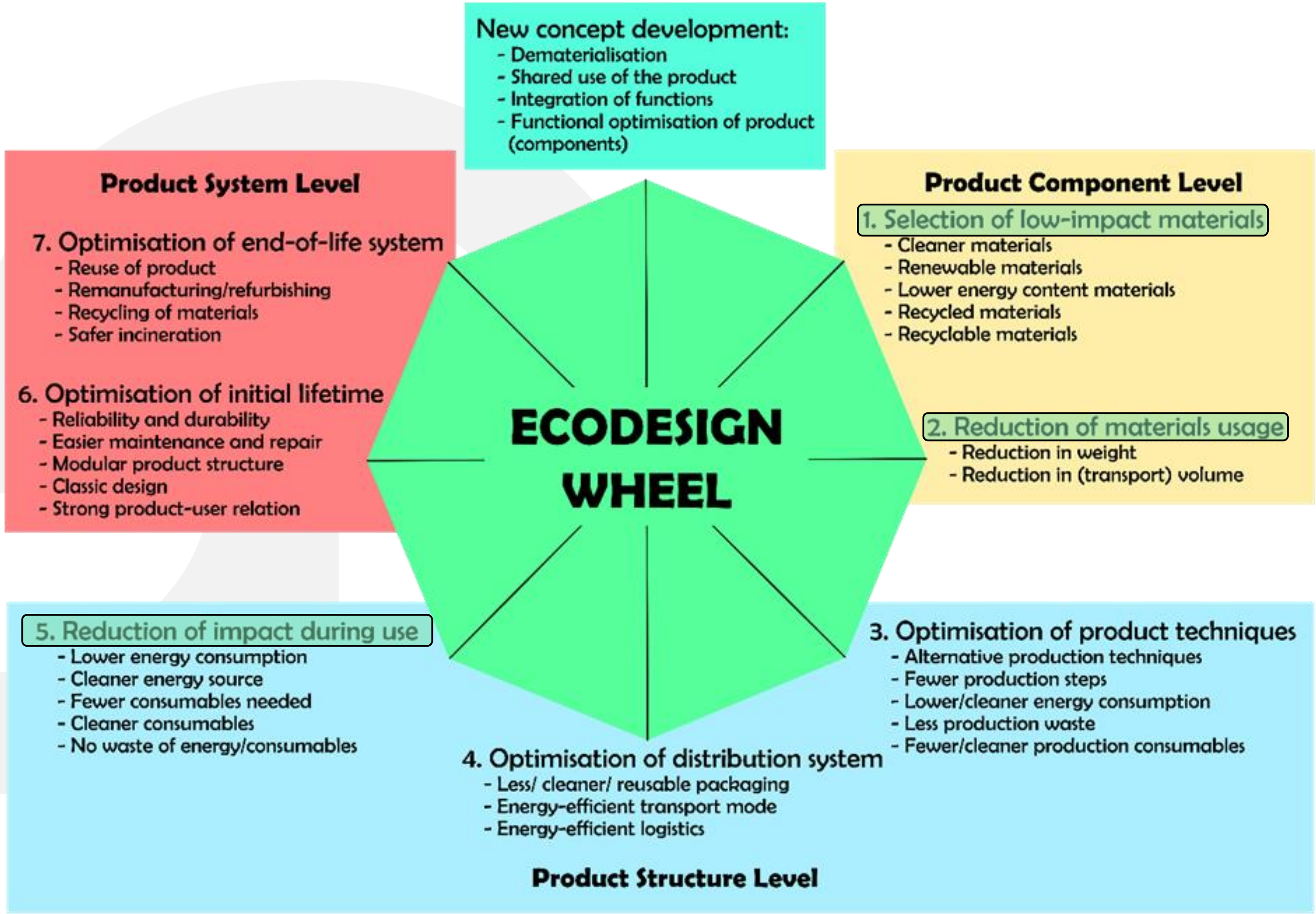
REALISTIC MEDIUM-TO-LONG-TERM PRODUCT CONCEPT

Implemented eco-design actions:

- A1.1 – Use of **recycled platinum**
- A1.4 – **Reuse** of stack housing (GRTP)
- A2.1 – **Reduction** of platinum loading
- A2.2 – **Optimised** triple phase boundary
- A2.3 – **Mass reduction** of GDL, BPP, and ionomer
- A5 – Refurbishment of BPP NEW



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- A2.2 – **Optimised** triple phase boundary
- A2.3 – **Mass reduction** of GDL, BPP, and ionomer
- A5 – Refurbishment of BPP NEW

Component	Material	Base	Real-short	Real-mid/long
Pt/C	Platinum nanoparticles – virgin [g]	26	9.1	8.4
	Platinum nanoparticles – recycled [g]	/	3.9	3.6
	Carbon black [g]	39	37	24
Ionomer	PFSA (Nafion) – virgin [g]	144	101	55
	PFSA (Nafion) – recycled [g]	/	/	/
/	Water [g]	490	467	307
/	Alcohol [g]	220	210	138
Subgasket	PEN/PET film with thermo active glue [g]	1820	1733	1142
Gas diffusion layer	Carbon cloths fibres [g]	1249	687	370
BPP	Stainless steel – virgin [g]	21623	18379	7974
	Stainless steel – reused [g]	/	/	3418
Gaskets	Silicone [g]	1265	1204	793
Endplate	Glass reinforced thermoplastic – virgin [g]	3800	2533	1668
	Glass reinforced thermoplastic – reused [g]	/	1086	715
Current collector	Copper – virgin [g]	950	905	596
	Copper – recycled [g]	/	/	/
Compression bar	Chromium steel [g]	825	785	517
Hexagonal screws	Chromium steel [g]	27	26	17
Spring	Steel [g]	750	714	470
Clamping bar	Steel [g]	2070	1972	1299
Electricity [kWh]	/	410	391	257
PEMFC stack		**34588**	**30175**	**19070**

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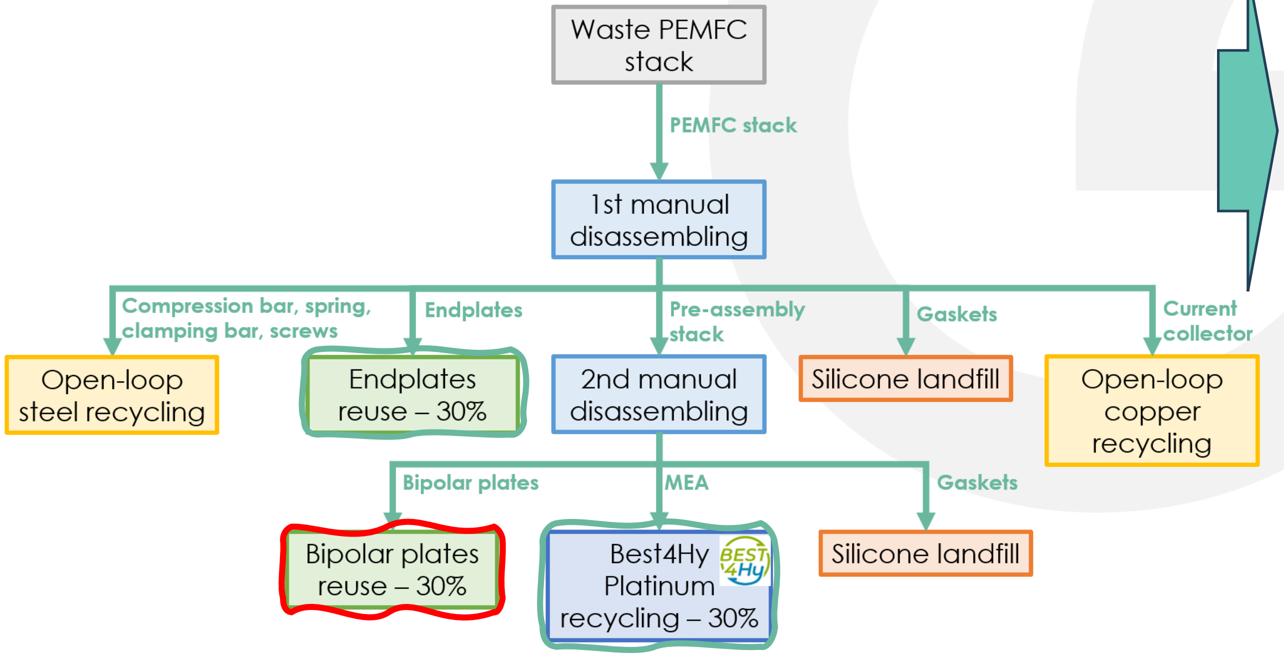

Component	Material	EoL process	Reference	Real-short	Real-mid/long
Compression bar	Chromium steel [g]	Open loop recycling	825	785	517
Current collector	Copper [g]	Open loop recycling	950	905	596
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Endplates	Glass reinforced thermoplastic [g]	Open loop recycling	3800	2533	1668
		Reuse	/	1086	715
Gaskets	Silicone [g]	Landfill	1265	1204	793
Bipolar plates	Stainless steel [g]	Open loop recycling	21623	18379	7974
		Reuse	/	/	3418
MEA [g]		Incineration & landfill	3278	/	/
		Recycling – BEST4Hy	/	2571	1603

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OPTIMISTIC PRODUCT CONCEPT

Implemented eco-design actions:

- A1.1 – Use of **recycled platinum**
- A1.4 – **Reuse** of stack housing (GRTP)
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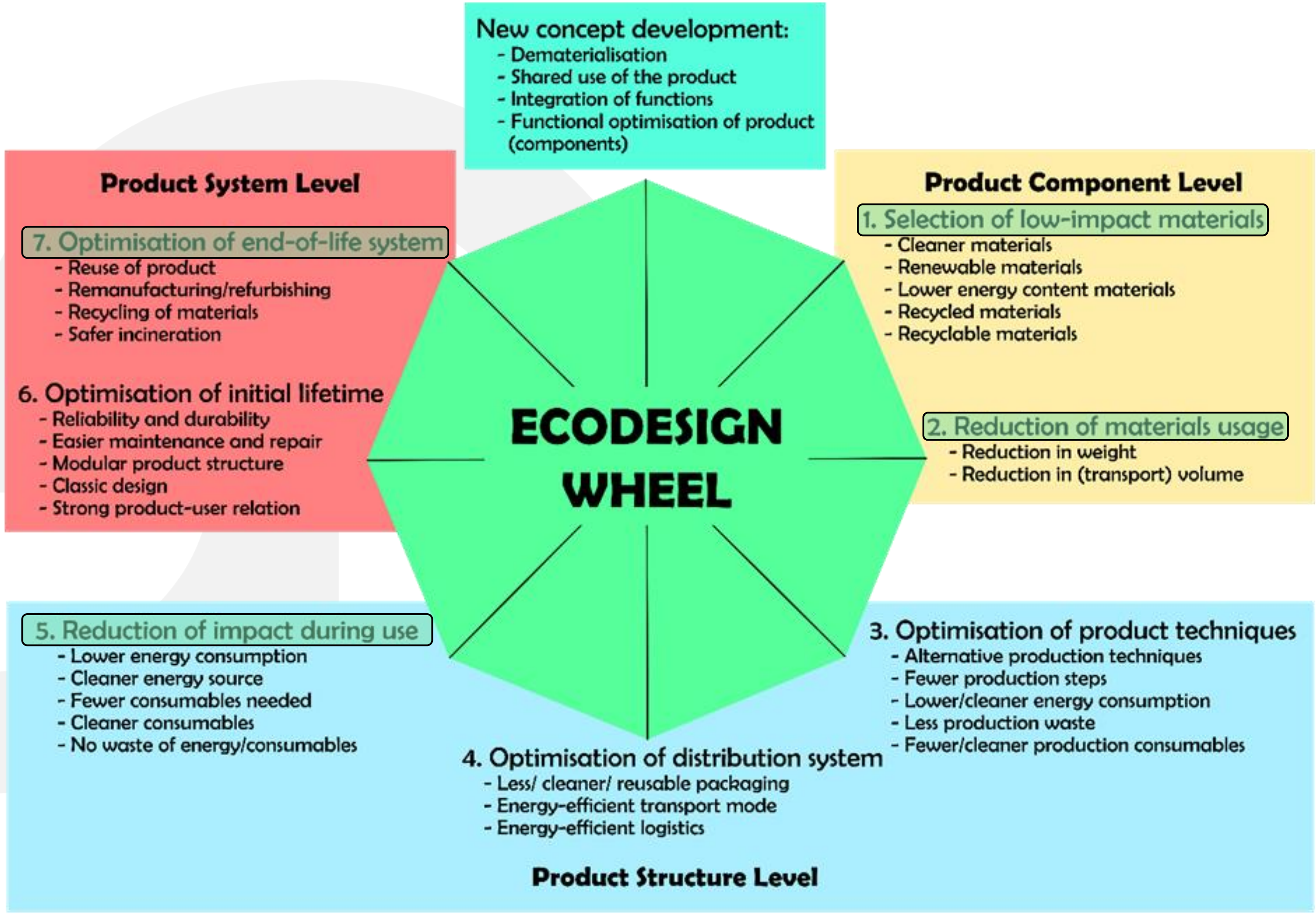
- A2.2 – **Optimised** triple phase boundary
- A2.3 – **Mass reduction** of GDL, BPP, and ionomer
- A5 – Refurbishment of BPP
- A7 – Closed-loop ionomer recycling NEW



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OPTIMISTIC PRODUCT CONCEPT

Implemented eco-design actions:

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

Component	**Material**	**Base**	**Real-short**	**Real-mid/long**	**Optimistic**
Pt/C	Platinum nanoparticles – virgin [g]	26	9.1	8.4	2.1
	Platinum nanoparticles – recycled [g]	/	3.9	3.6	4.9
	Carbon black [g]	39	37	24	23
Ionomer	PFSA (Nafion) – virgin [g]	144	101	55	29
	PFSA (Nafion) – recycled [g]	/	/	/	13
/	Water [g]	490	467	307	293
/	Alcohol [g]	220	210	138	131
Subgasket	PEN/PET film with thermo active glue [g]	1820	1733	1142	1087
Gas diffusion layer	Carbon cloths fibres [g]	1249	687	370	352
BPP	Stainless steel – virgin [g]	21623	18379	7974	3436
	Stainless steel – reused [g]	/	/	3418	6871
Gaskets	Silicone [g]	1265	1204	793	755
Endplate	Glass reinforced thermoplastic – virgin [g]	3800	2533	1668	1589
	Glass reinforced thermoplastic – reused [g]	/	1086	715	681
Current collector	Copper – virgin [g]	950	905	596	567
	Copper – recycled [g]	/	/	/	/
Compression bar	Chromium steel [g]	825	785	517	493
Hexagonal screws	Chromium steel [g]	27	26	17	16
Spring	Steel [g]	750	714	470	448
Clamping bar	Steel [g]	2070	1972	1299	1236
Electricity [kWh]	/	410	391	257	245
PEMFC stack		**34588**	**30175**	**19070**	**17603**

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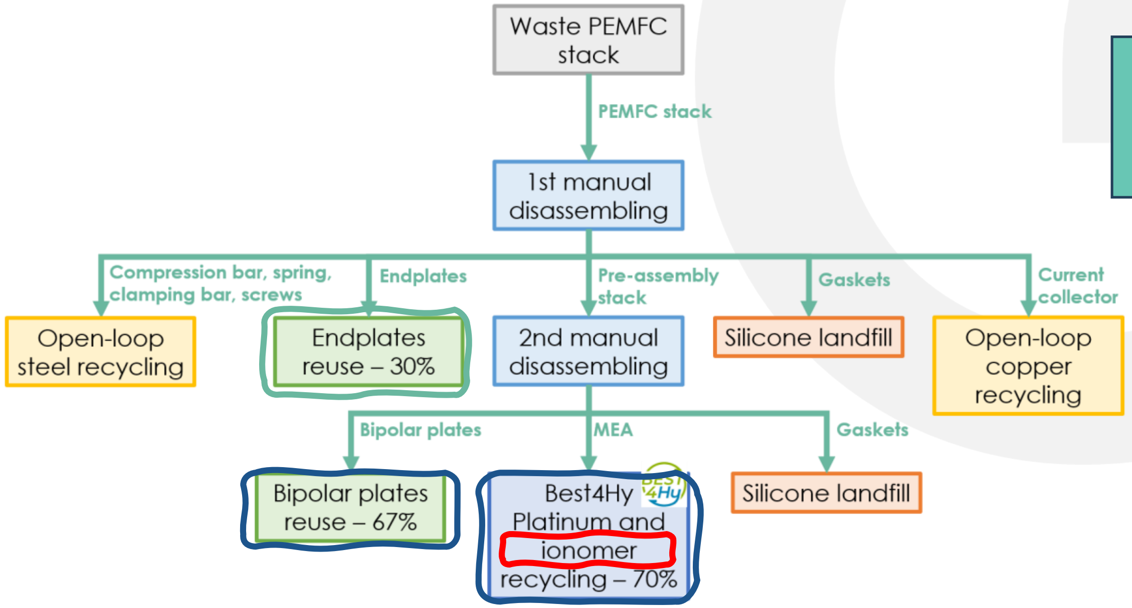
OPTIMISTIC PRODUCT CONCEPT

Implemented eco-design actions:

- A1.1 – Use of **recycled platinum**
- A1.4 – **Reuse** of stack housing (GRTP)
- A5 – Refurbishment of BPP
- A7 – Closed-loop ionomer recycling NEW



Component	Material	EoL process	Reference	Real-short	Real-mid/long	Optimistic
Compression bar	Chromium steel [g]	Open loop recycling	825	785	517	493
Current collector	Copper [g]	Open loop recycling	950	905	596	567
Spring	Steel [g]	Open loop recycling	750	714	470	448
Clamping bar	Steel [g]	Open loop recycling	2070	1972	1299	1236
Screws	Chromium steel [g]	Open loop recycling	27	26	17	16
Endplates	Glass reinforced thermoplastic [g]	Open loop recycling	3800	2533	1668	1589
		Reuse	/	1086	715	681
Gaskets	Silicone [g]	Landfill	1265	1204	793	755
Bipolar plates	Stainless steel [g]	Open loop recycling	21623	18379	7974	3436
		Reuse	/	/	3418	6871
MEA [g]		Incineration & landfill	3278	/	/	/
		Recycling – BEST4Hy	/	2571	1603	1511

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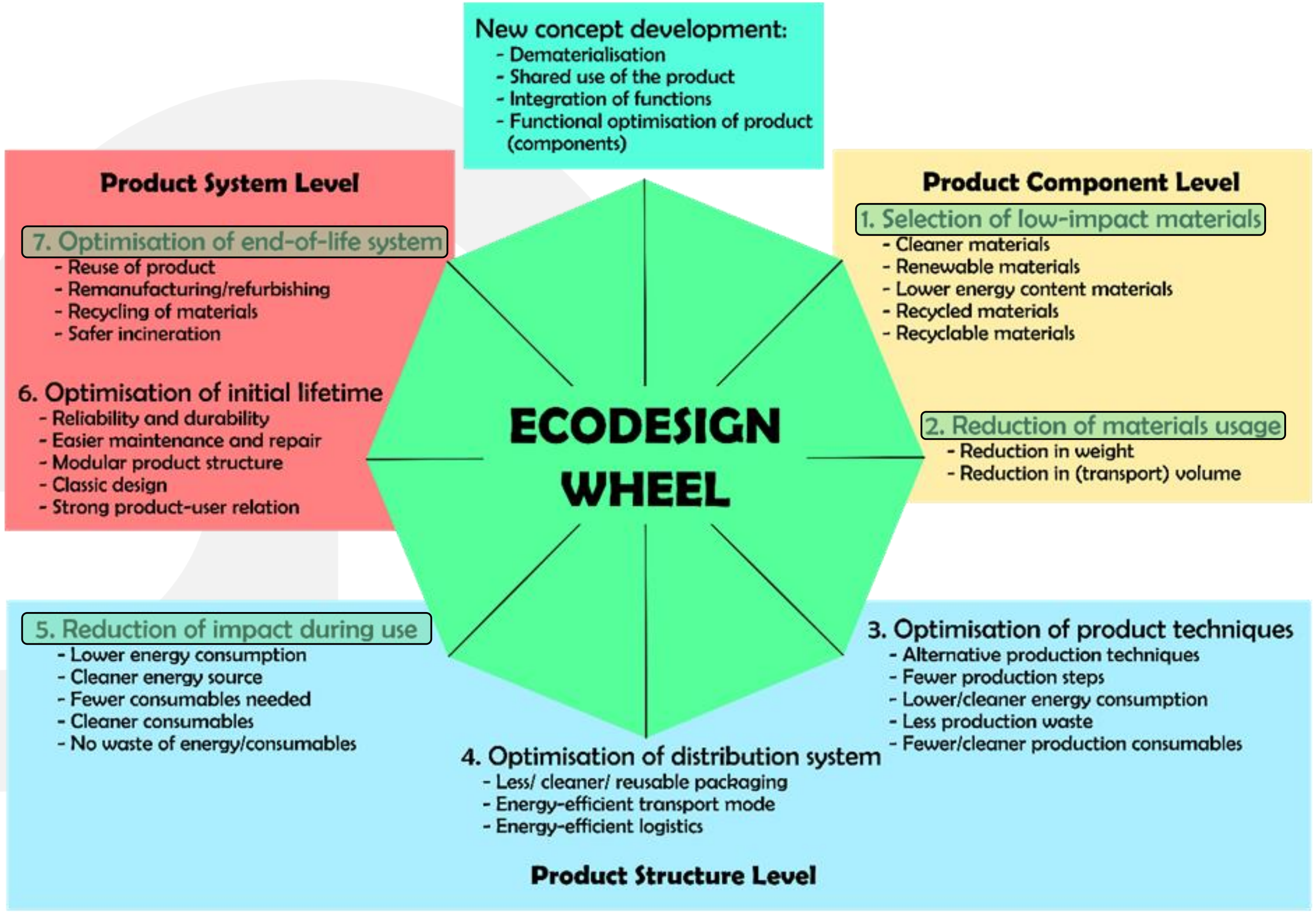
DISRUPTIVE PRODUCT CONCEPT

Implemented eco-design actions:

- A1.1 – Use of **recycled platinum**
- A1.4 – **Reuse** of stack housing (GRTP)
- A2.1 – **Reduction** of platinum loading
- A2.2 – **Optimised** triple phase boundary
- A2.3 – **Mass reduction** of GDL, BPP, and ionomer
- A5 – **Refurbishment** of BPP
- A7 – **Closed-loop ionomer and copper** recycling NEW



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eGHOST

DISRUPTIVE PRODUCT CONCEPT

Implemented eco-design actions:

- A1.1 – Use of **recycled platinum**
- A1.4 – **Reuse** of stack housing (GRTP)
- A2.1 – **Reduction** of platinum loading
- A2.2 – **Optimised** triple phase boundary
- A2.3 – **Mass reduction** of GDL, BPP, and ionomer
- A5 – **Refurbishment** of BPP
- A7 – **Closed-loop ionomer and copper** recycling NEW

Component	Material	Base	Real-short	Real-mid/long	Optimistic	Disruptive
Pt/C	Platinum nanoparticles – virgin [g]	26	9.1	8.4	2.1	0.25
	Platinum nanoparticles – recycled [g]	/	3.9	3.6	4.9	4.75
	Carbon black [g]	39	37	24	23	19
Ionomer	PFSA (Nafion) – virgin [g]	144	101	55	29	1.8
	PFSA (Nafion) – recycled [g]	/	/	/	13	33
/	Water [g]	490	467	307	293	240
/	Alcohol [g]	220	210	138	131	108
Subgasket	PEN/PET film with thermo active glue [g]	1820	1733	1142	1087	891
Gas diffusion layer	Carbon cloths fibres [g]	1249	687	370	352	257
BPP	Stainless steel – virgin [g]	21623	18379	7974	3436	1352
	Stainless steel – reused [g]	/	/	3418	6871	5408
Gaskets	Silicone [g]	1265	1204	793	755	619
Endplate	Glass reinforced thermoplastic – virgin [g]	3800	2533	1668	1589	912
	Glass reinforced thermoplastic – reused [g]	/	1086	715	681	391
Current collector	Copper – virgin [g]	950	905	596	567	93
	Copper – recycled [g]	/	/	/	/	372
Compression bar	Chromium steel [g]	825	785	517	493	404
Hexagonal screws	Chromium steel [g]	27	26	17	16	13
Spring	Steel [g]	750	714	470	448	367
Clamping bar	Steel [g]	2070	1972	1299	1236	1014
Electricity [kWh]	/	410	391	257	245	201
PEMFC stack		**34588**	**30175**	**19070**	**17603**	**12152**

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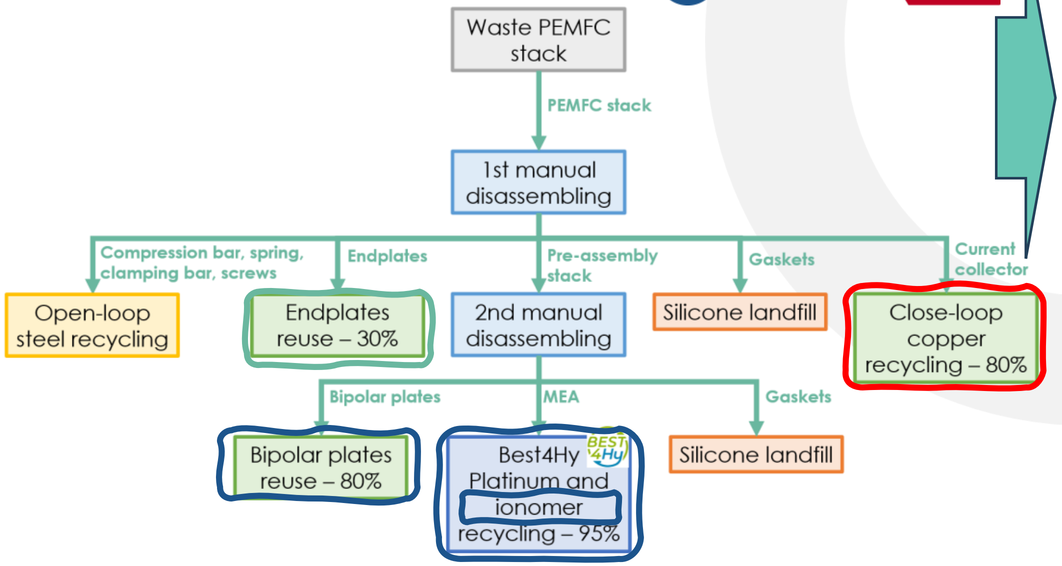
DISRUPTIVE PRODUCT CONCEPT

Implemented eco-design actions:

- A1.1 – Use of **recycled platinum**
- A1.4 – **Reuse** of stack housing (GRTP)
- A5 – **Refurbishment** of BPP
- A7 – **Closed-loop ionomer and copper** recycling

NEW



Component	Material	EoL process	Reference	Real-short	Real-mid/long	Optimistic	Disruptive
Compression bar	Chromium steel [g]	Open loop recycling	825	785	517	493	404
Current collector	Copper [g]	Open loop recycling	950	905	596	567	93
		Close loop recycling	/	/	/	/	372
Spring	Steel [g]	Open loop recycling	750	714	470	448	367
Clamping bar	Steel [g]	Open loop recycling	2070	1972	1299	1236	1014
Screws	Chromium steel [g]	Open loop recycling	27	26	17	16	13
Endplates	Glass reinforced thermoplastic [g]	Open loop recycling	3800	2533	1668	1589	912
		Reuse	/	1086	715	681	391
Gaskets	Silicone [g]	Landfill	1265	1204	793	755	619
Bipolar plates	Stainless steel [g]	Open loop recycling	21623	18379	7974	3436	1352
		Reuse	/	/	3418	6871	5408
MEA [g]		Incineration & landfill	3278	/	/	/	/
		Recycling – BEST4Hy	/	2571	1603	1511	1207

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SOEC eco-design actions

ECO-DESIGN ACTIONS – SOEC

- **Medium-term actions**

Axis	Action number	Action	Material/ Component	Description of action
1	1.1	Different steel alloys	Stainless steel	Reduce the use of virgin stainless steel
	1.2	Recycled steel	Steel	Reduce the use of virgin steel
2	2.1	Optimize the end plates / frames / meshes	End plates, frames, meshes	To reduce the stainless-steel amount
	2.2	Change/optimize the cell shape and size	Cell	To reduce the amount of material employed
	2.3	Change the stack type (electrolyte supported/cathode supported)	Stack	To reduce the amount of REE materials and of nickel
3	3.1	Use less or cleaner energy	All	Especially for cell sintering, which is particularly energy consuming (reduce the time and temperature)
	3.2	Reduce the amount of chemicals/solvents in all production steps	All	E.g., use colloidal processing based on water instead of organic solvents
4	4.1	Keep the current packaging	1*	Wooden boxes with multiple uses, durable packaging. There is room for improvement, but plastic bags are still used to ship stack components. Cardboard is also used.

5	5.1	Supply the system with green electricity	2*	To lower environmental impacts due to RES electricity use
	5.2	Optimize the balance of plant	2*	To reduce the overall energy consumption
	5.3	Produce low-impact steam	2*	To reduce the environmental impacts due to steam production
	5.4	Use steam from steam networks	2*	To reduce the environmental impacts due to steam production. Depends on the location → recommendation level
	5.5	Use water recirculation	2*	To reduce overall water consumption
6	6.1	Have harmonized standards to measure stack degradation	2*	-
	6.2	Create harmonized protocols/recommendations to start/operate the system	2*	-

1* - This recommendation relates to transport/logistics and will not be validated in next steps as transportation is not included in the methodology presented in D2.1 and D2.3.
2* - This recommendation action relates to the use phase of a product's eco-design (not subjected to further Life Cycle Assessment as only manufacturing and EoL phases are included in the methodology presented in D2.1 and D2.3).

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ECO-DESIGN ACTIONS – SOEC

- **Medium-to-long-term actions**

Axis	Action number	Action	Component	Description of action
1	1.3	Different doping strategy for the catalysts	Cell	To reduce the amount of REEs (especially of lanthanum and yttrium) in the stack
	1.4	Ceramic materials	Interconnects D	To reduce the amount of stainless steel in the stack
2	2.4	Reduce material losses	Overall stack	Target: <5%

	2.5	Utilize a different electrolyte	Electrolyte	To reduce the amount of REE materials (e.g. proton conducting electrolyte)
3	3.3	Optimize the surface polishing/cleaning	Cell D	To reduce material losses/impacts
	3.4	Use additive manufacturing instead of subtractive manufacturing	Stack	To reduce material losses
	3.5	Improve the recycling rate	Module/system	Target/base case recycling rate
4	4.2	Optimize logistics	1*	E.g., reduce the distance between producers and consumers
	4.3	Clean way of transportation	1*	RES based electricity vehicles, FCEV trucks
	4.4	Vertical integration	1*	E.g., in-house production. This might reduce the impacts but increase the costs
5	5.6	Reduce the operating temperature	2*	To reduce the overall energy consumption
	5.7	Change from sweep gas to pure oxygen	2*	Unclear whether this could reduce or increase the impacts (using pure oxygen could cause corrosion and safety issues)
6	6.3	Operate the system at lower temperatures	2*	To limit the stack degradation
	6.4	Improve stack modularity	2*	To optimize part load operation and limit degradation
	6.5	Redesign the BoP	BoP components	E.g., to heat up only the active area and not the structural elements such as end plates
7	7.1	Reuse some components after eventual remanufacturing	End plates, tie-rods	It may be possible to design some components to be reused after the first usage (e.g., increase end plates thickness to allow remanufacturing); in this case, thermal and mechanical properties need to be checked
	7.2	Recycle/recover materials	Cathode, anode	BEST4Hy project [9] (e.g., cobalt and lanthanum, through hydrometallurgical processing)

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ECO-DESIGN PRODUCT CONCEPTS – SOEC

- Based on the eco-design actions **two product concepts** were defined
    - Enhanced realistic concept
    - Optimistic concept
- **Enhanced realistic concept** is based on medium-term actions that will be realized and implemented in the FCH industry in the near future (medium-term perspective in next 3 to 10 years)
- **Optimistic concept** includes all relevant above-mentioned medium-term actions with additional view on possible actions still under development or in the early research phase or even conceptual phase

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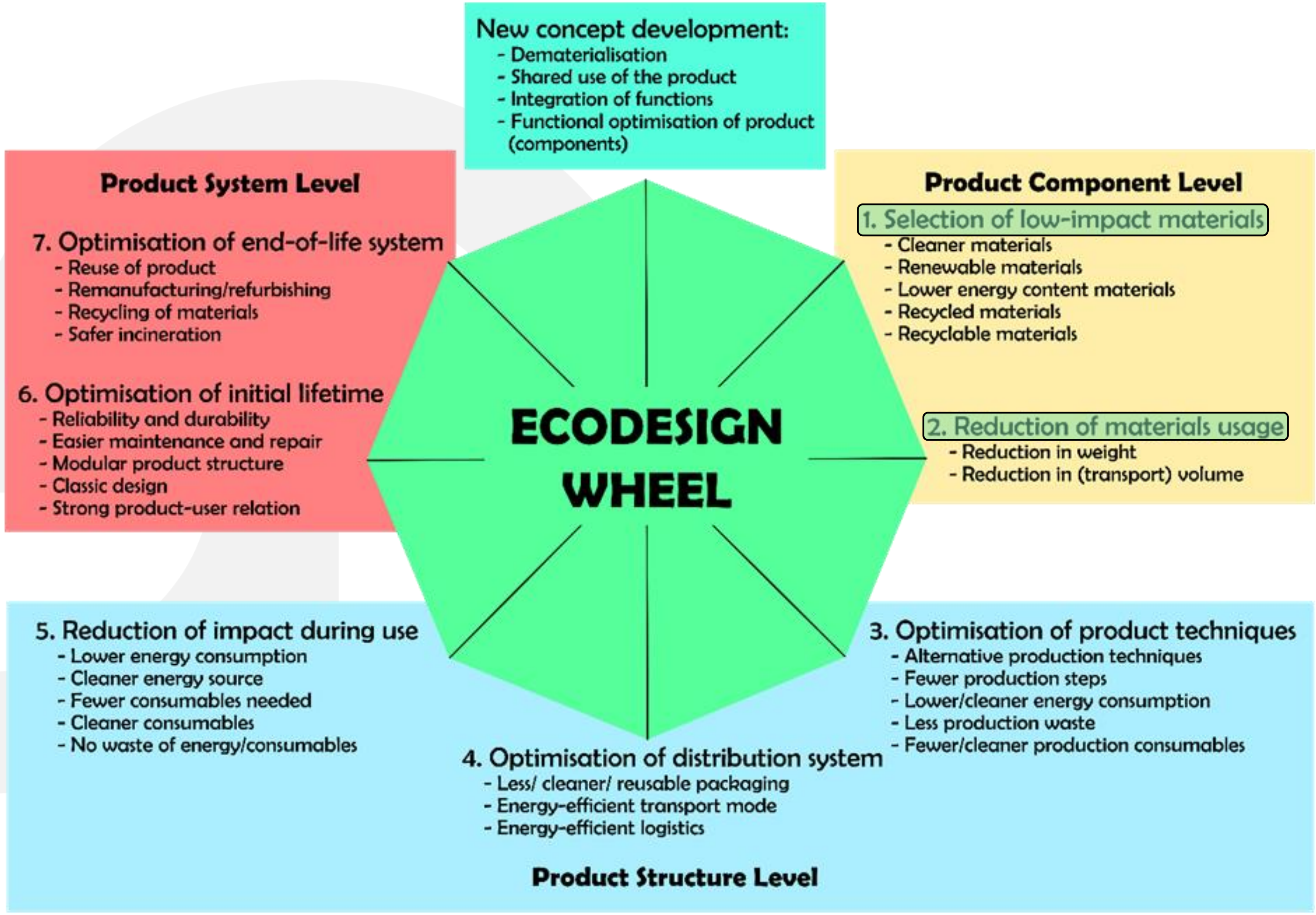
REALISTIC PRODUCT CONCEPT

Implemented eco-design actions:

- A1.1 – **Reduction** of virgin stainless steel
- A1.2 – **Recycled** stainless steel use
- A2.1 – Redesign of endplates (**mass reduction**)
- A2.2 – SOEC cell **shape** and **size optimisation**
- A2.3 – **Mass reduction** of nickel and REE materials

EoL processes:

- **Open-loop recycling:** stainless steel
- **Landfill:** all other materials



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- A2.2 – SOEC cell **shape** and **size optimisation**
- A2.3 – **Mass reduction** of nickel and REE materials

EoL processes:

- **Open-loop recycling:** stainless steel
- **Landfill:** all other materials

Component	Material	Base	Realistic
Electrolyte	8% mol YSZ [g]	8.7	4.0
/	Binder Dow B-1000 [g]	3.8	1.8
/	Ammonium polyacrylate[1] [g]	1.5	0.1
/	Water[1] [g]	2.1	1.0
Cathode	8% mol YSZ [g]	258	119
	Nickel oxide [g]	368	1174
/	Binder Dow B-1000[1] [g]	239	113
/	Ammonium polyacrylate [g]	10	4.7
/	Water [g]	119	56
Anode	LSCF [g]	86	36
	YSZ/LSM [g]	21	8,2
	YSZ/LSM [g]	10	4.1
Interconnects/Frames	Stainless steel [g]	11864	5599
	Perovskite coating [g]	33	16
Anode and cathode mesh	Stainless steel [g]	4572	2158
Sealant	Lanthanum oxide [g]	14	4.8
	Boron-silicate glass [g]	4.7	2.2
End plates/Tie rods	Stainless steel [g]	12468	5239
SOEC stack [g]		**29709**	**13364**

1 - Binder Dow B-1000, ammonium polyacrylate, and water are not included in the stack and therefore, do not contribute to the total SOEC stack mass. They are included in the LCI because they are needed in the manufacturing phase of the stack.

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OPTIMISTIC PRODUCT CONCEPT

Implemented eco-design actions:

- A1.1 – **Reduction** of virgin stainless steel
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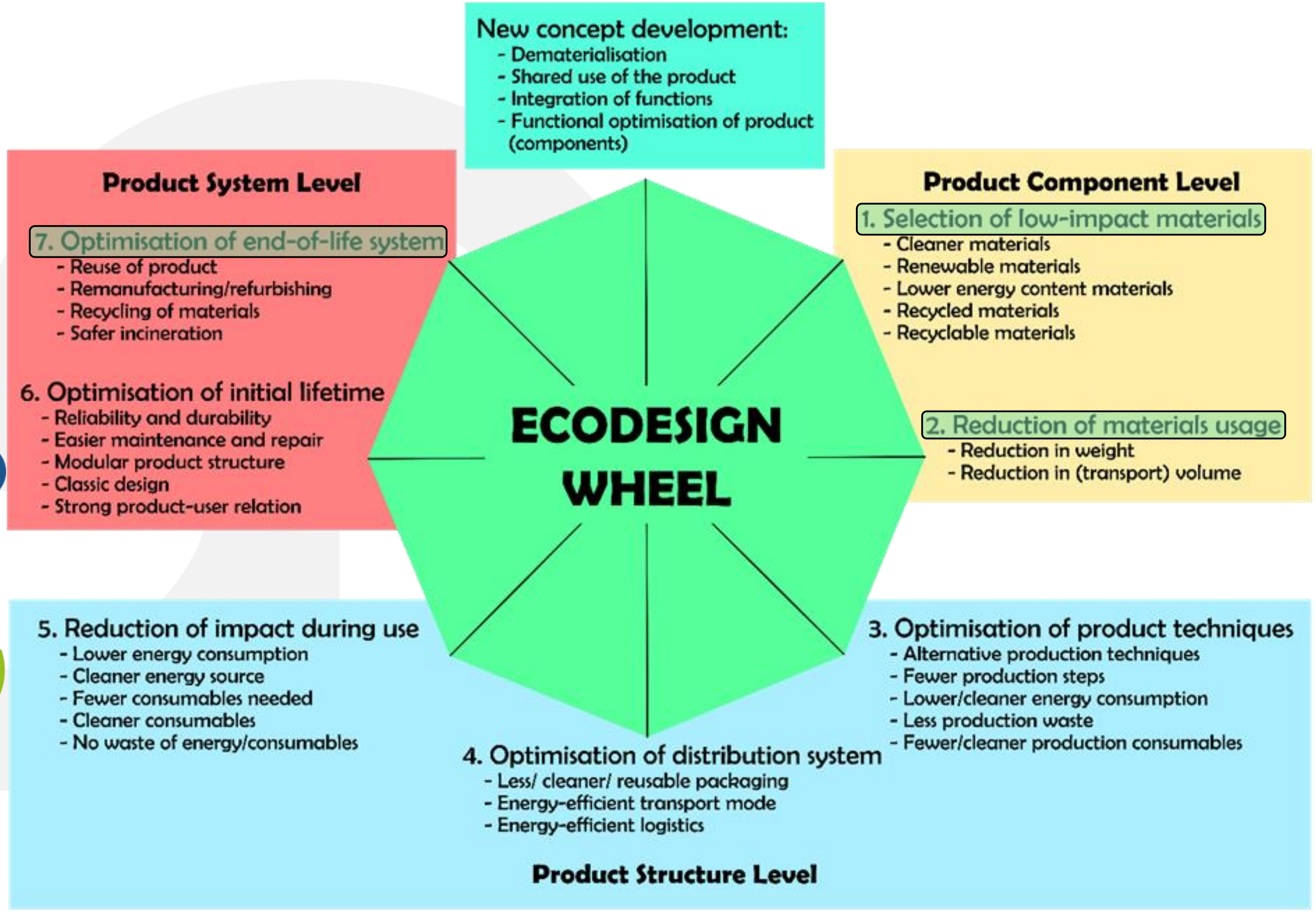
- A2.1 – Redesign of endplates (**mass reduction**)
- A2.2 – SOEC cell **shape** and **size optimisation**
- A2.3 – **Mass reduction** of nickel and REE materials
- A7.2 – **Recycling** of SOEC anode NEW

EoL processes:

- **Closed-loop recycling:** SOEC anode (yttria-stabilised zirconia and nickel oxide)
- **Open-loop recycling:** stainless steel
- **Landfill:** all other materials



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OPTIMISTIC PRODUCT CONCEPT

eGHOST

Implemented eco-design actions:

- A1.1 – **Reduction** of virgin stainless steel
- A1.2 – **Recycled** stainless steel use
- A2.1 – Redesign of endplates (**mass reduction**)
- A2.2 – SOEC cell **shape** and **size optimisation**
- A2.3 – **Mass reduction** of nickel and REE materials
- A7.2 – **Recycling** of SOEC anode NEW

EoL processes:

- **Closed-loop recycling:** SOEC anode (yttria-stabilised zirconia and nickel oxide)
- **Open-loop recycling:** stainless steel
- **Landfill:** all other materials

BEST4Hy

Component	Material	Base	Realistic	Optimistic
Electrolyte	8% mol YSZ [g]	8.7	4.0	2.5
	Binder Dow B-1000 [g]	3.8	1.8	1.1
	Ammonium polyacrylate[1] [g]	1.5	0.1	0.04
	Water[1] [g]	2.1	1.0	0.6
Cathode	8% mol YSZ [g]	258	119	73
	Nickel oxide [g]	368	1174	110
	Binder Dow B-1000[1] [g]	239	113	71
	Ammonium polyacrylate [g]	10	4.7	3.0
	Water [g]	119	56	36
Anode	LSCF [g]	86	36	20
	YSZ/LSM [g]	21	8,2	4
	YSZ/LSM [g]	10	4.1	0.2
Interconnects/Frames	Stainless steel [g]	11864	5599	3535
	Perovskite coating [g]	33	16	10
Anode and cathode mesh	Stainless steel [g]	4572	2158	1362
Sealant	Lanthanum oxide [g]	14	4.8	2.0
	Boron-silicate glass [g]	4.7	2.2	1.4
End plates/Tie rods	Stainless steel [g]	12468	5239	3308
SOEC stack [g]		**29709**	**13364**	**8430**

1 - Binder Dow B-1000, ammonium polyacrylate, and water are not included in the stack and therefore, do not contribute to the total SOEC stack mass. They are included in the LCI because they are needed in the manufacturing phase of the stack.

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LIFE CYCLE SUSTAINABILITY ASSESSMENT

- Environmetal life cycle assesment
- Life cycle costing
- Social life cycle assessment
- Prioritisation of ecodesign actions
- Extented scope with use phase

Environmental life cycle assessment

- PEMFC environmental LCA
- SOEC environmental LCA

ENVIRONMENTAL LIFE CYCLE ASSESSMENT

- **Conventional E-LCA** analysis for **PEMFC** and **prospective E-LCA** analysis for **SOEC**
- Scope: **manufacturing** and **EoL phase**
- Functional unit:
  - PEMFC: **one 48kW$_{el}$ PEMFC stack**
  - SOEC: **one 5kW$_{el}$ SOEC stack**
- Life cycle inventory:
  - PEMFC: provided by **industry partner** SYMBIO France
  - SOEC: **literature** data and **partners expertise**
- LCIA methodology: **Environmental Footprint 3.1**
  - Acidification
  - Climate change
  - Eutropfication – freshwater, marine and terrestrial
  - Resource use – fossils and minerals & metals

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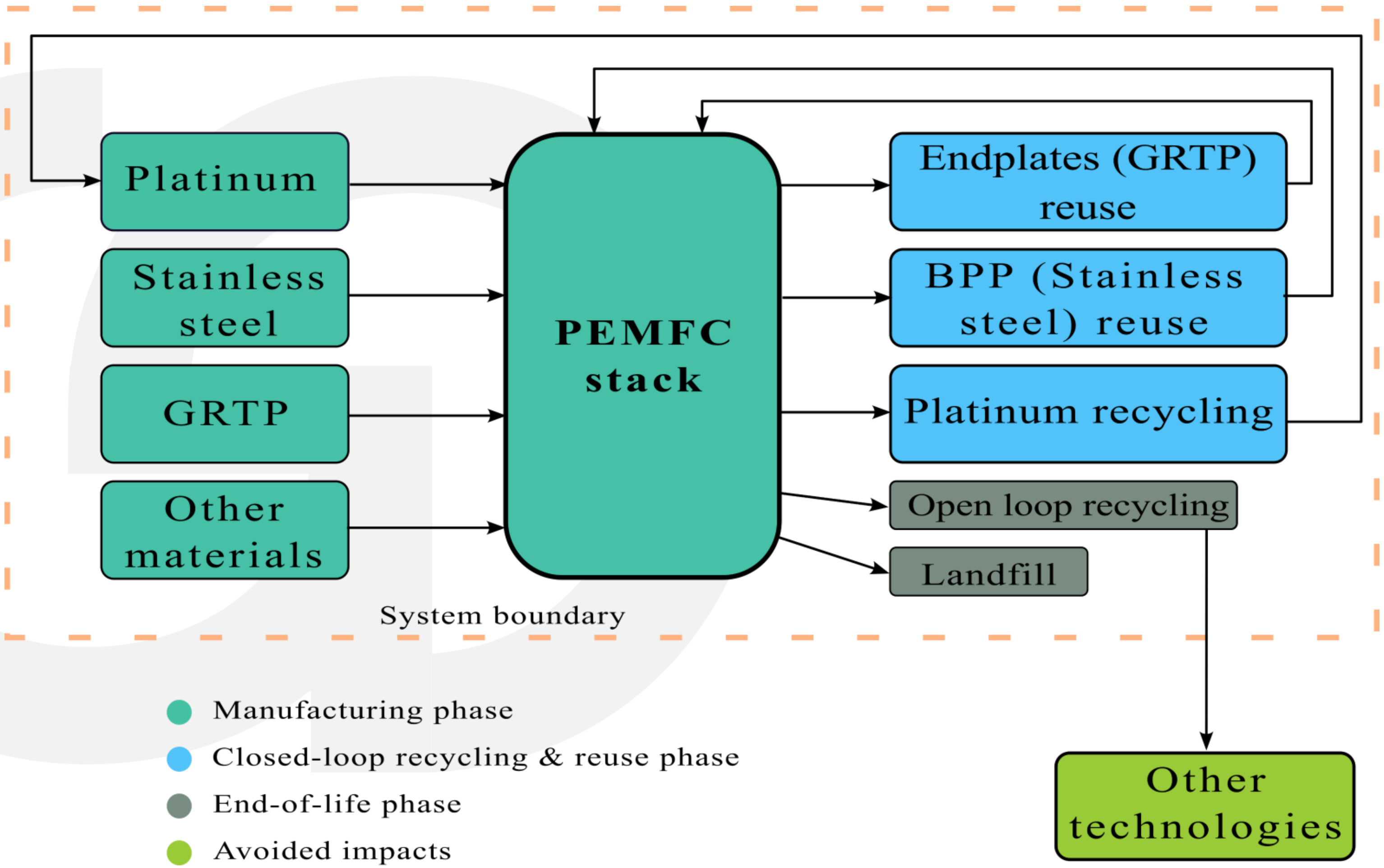
ENVIRONMENTAL LIFE CYCLE ASSESSMENT – LCA model for mid/long-term concept

- Closed-loop recycling & reuse phase:
  - Seperate phase, since it can be included in both manufacturing and EoL phase
- **Avoided impacts**
  - Represent **potential reductions** from open-loop recycling
  - Are **not included** in results



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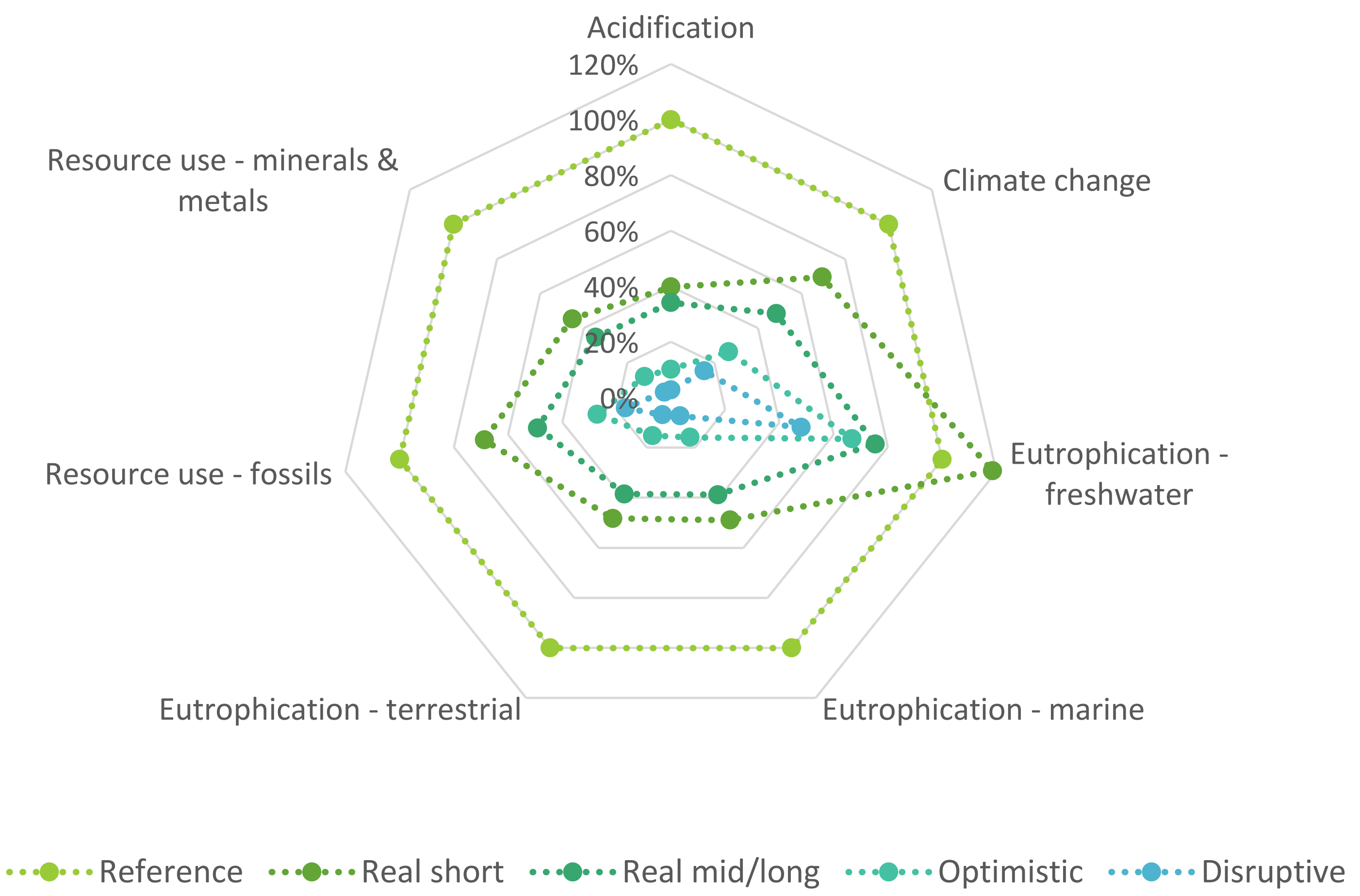
ENVIRONMENTAL LIFE CYCLE ASSESSMENT – PEMFC RESULTS

- Average reductions:
  - Realistic short-term concept: -37%
  - Realistic mid/long-term concept: -54%
  - Optimistic concept: -75%
  - Disruptive concept: -86%
- **Freshwater eutrophication** is the only impact category where **ecodesign actions increase** the **environmental impact** (due to the platinum recycling process – TRL5)
- **Climate change** reductions:
  - Realistic short-term concept: -31%
  - Realistic mid/long-term concept: -52%
  - Optimistic concept: -74%
  - Disruptive concept: -85%



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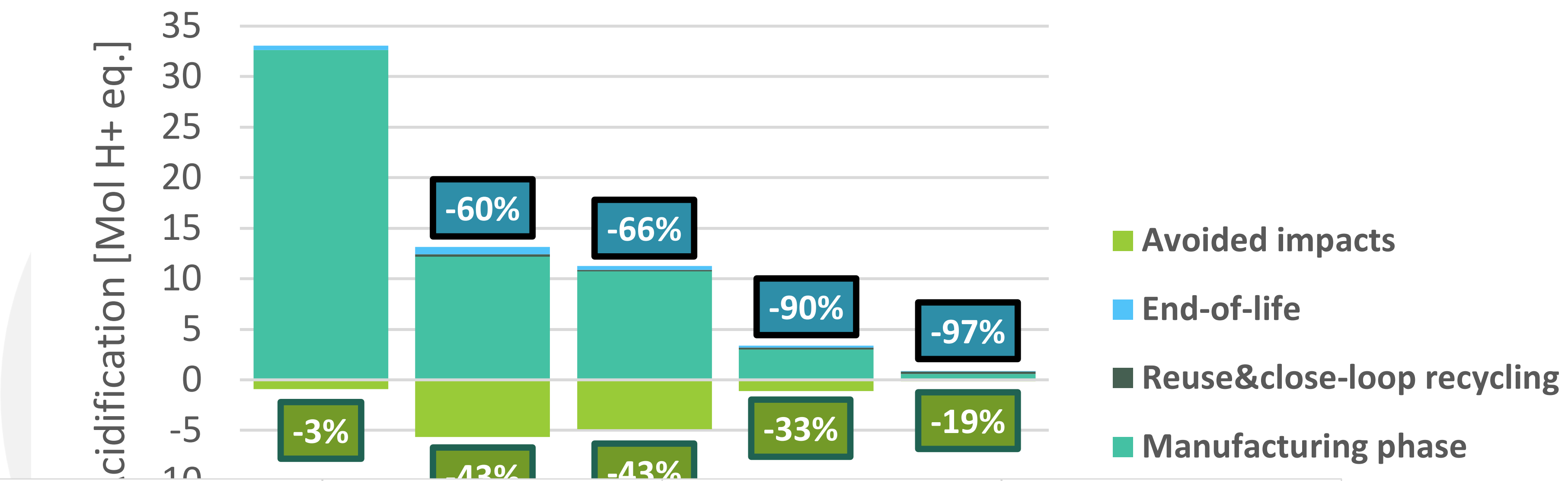
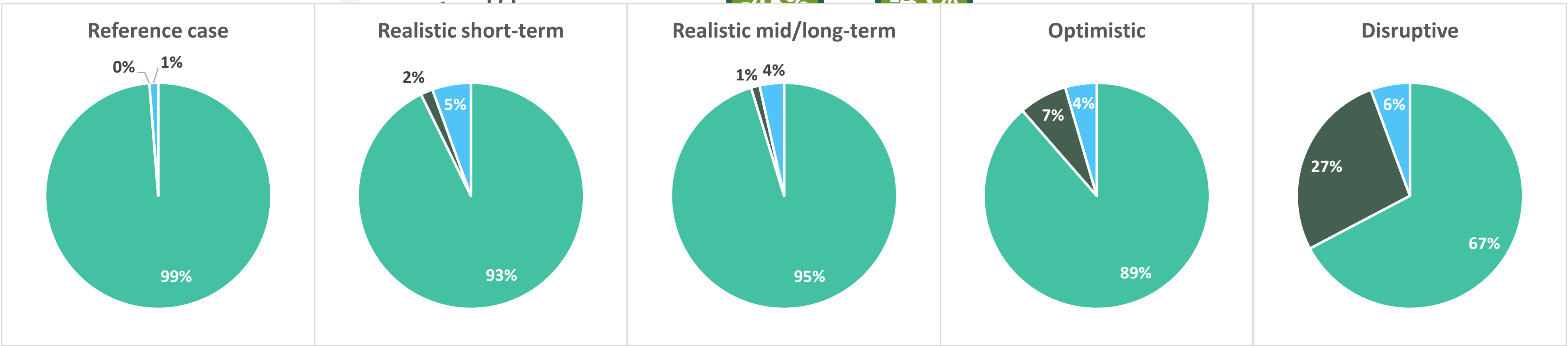
ENVIRONMENTAL LIFE CYCLE ASSESSMENT – PEMFC RESULTS

- Acidification





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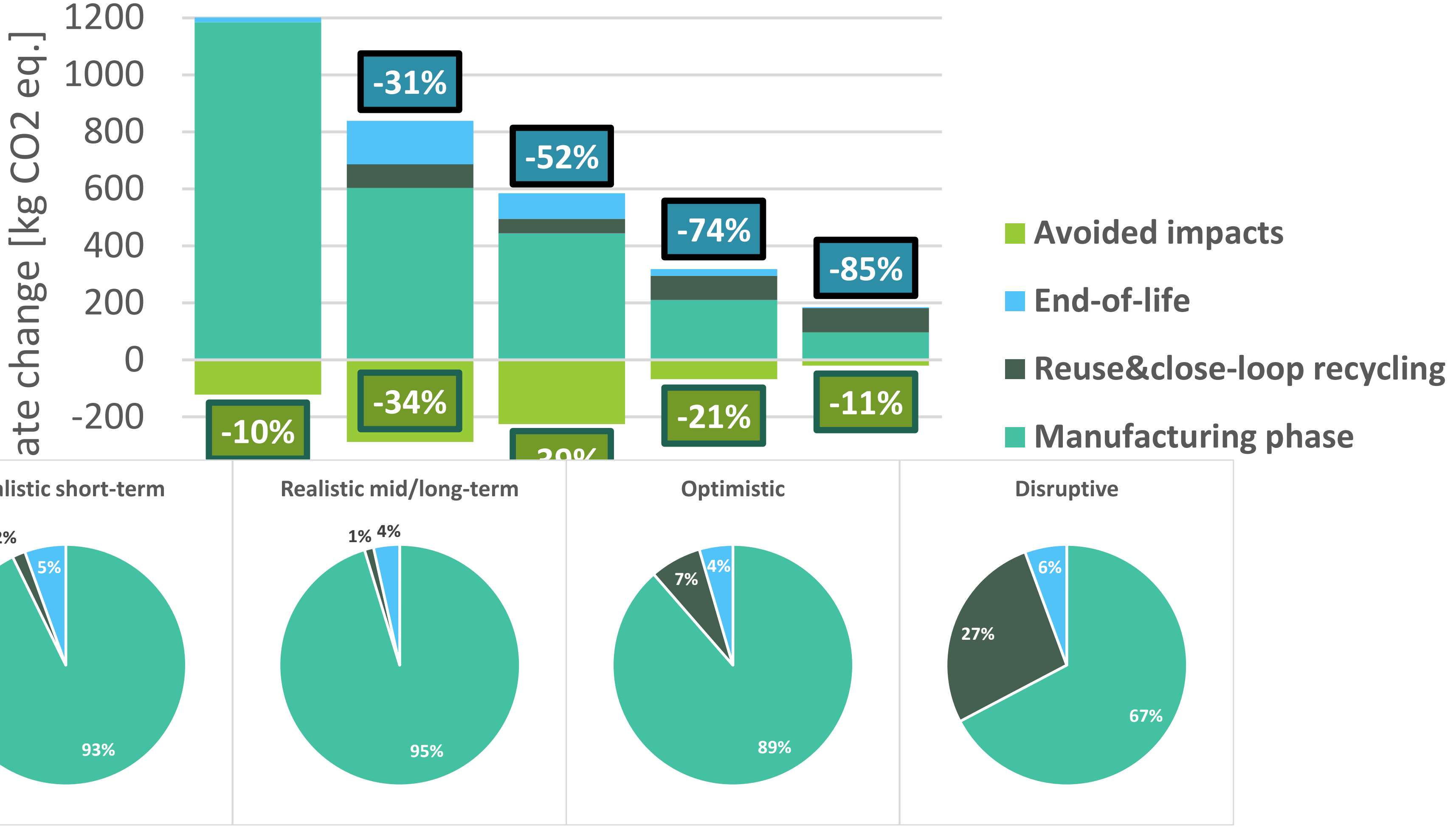
ENVIRONMENTAL LIFE CYCLE ASSESSMENT – PEMFC RESULTS

- Acidification
- **Climate change**



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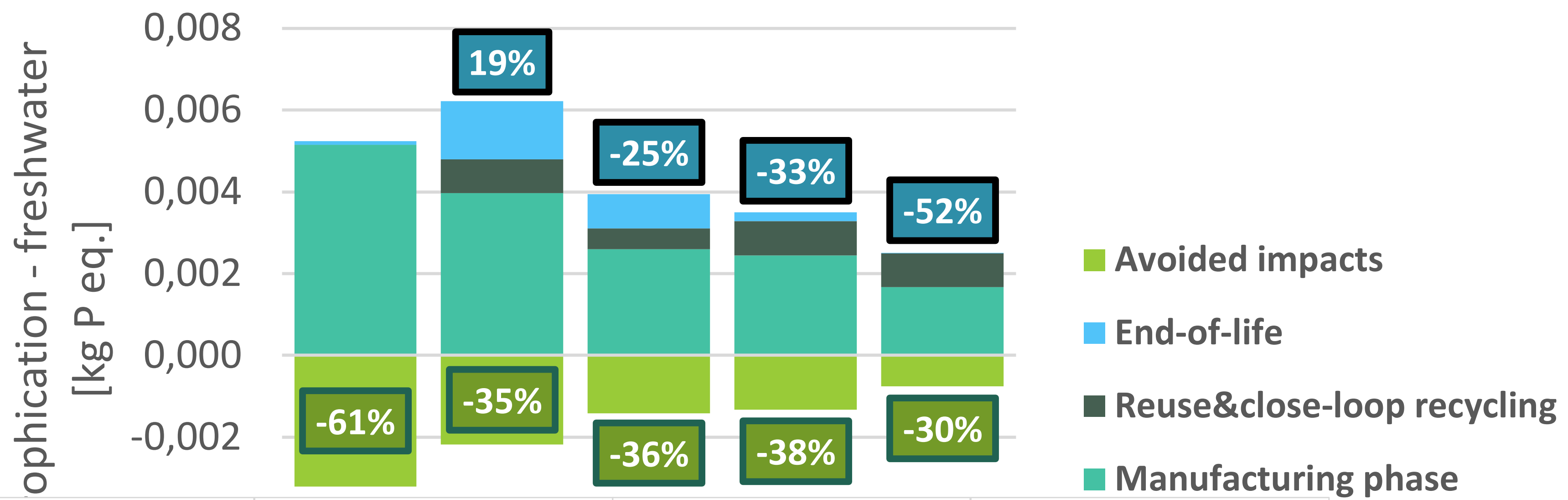
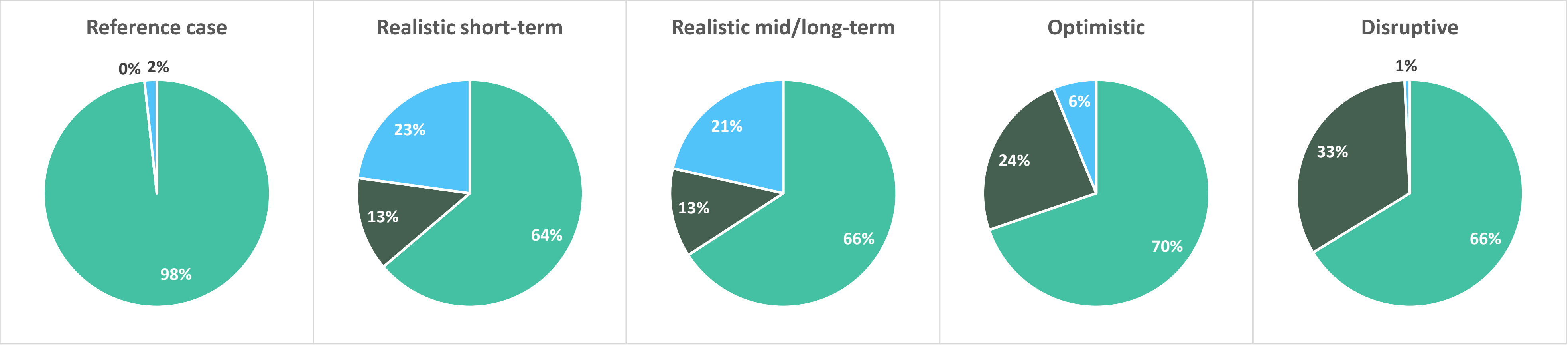
ENVIRONMENTAL LIFE CYCLE ASSESSMENT – PEMFC RESULTS

- Acidification
- Climate change
- **Eutrophication – freshwater**





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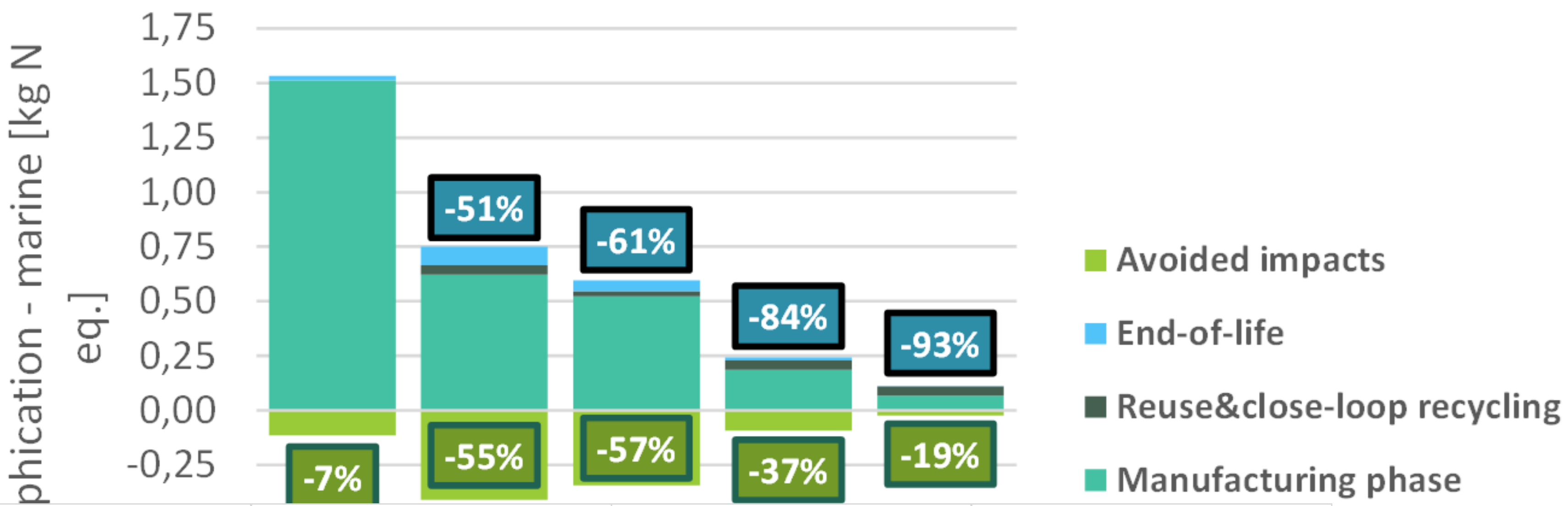
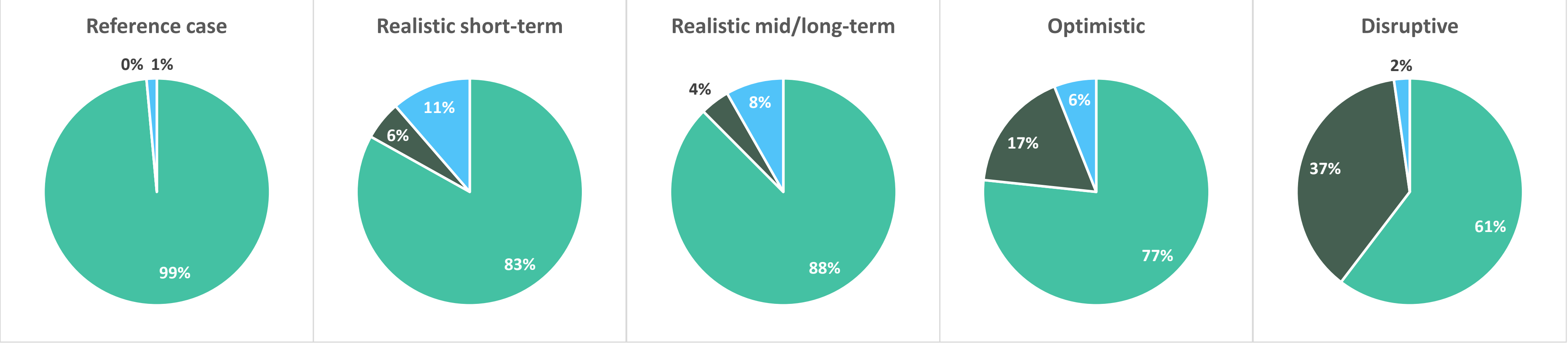
ENVIRONMENTAL LIFE CYCLE ASSESSMENT – PEMFC RESULTS

- Acidification
- Climate change
- Eutrophication – freshwater
- **Eutrophication – marine**





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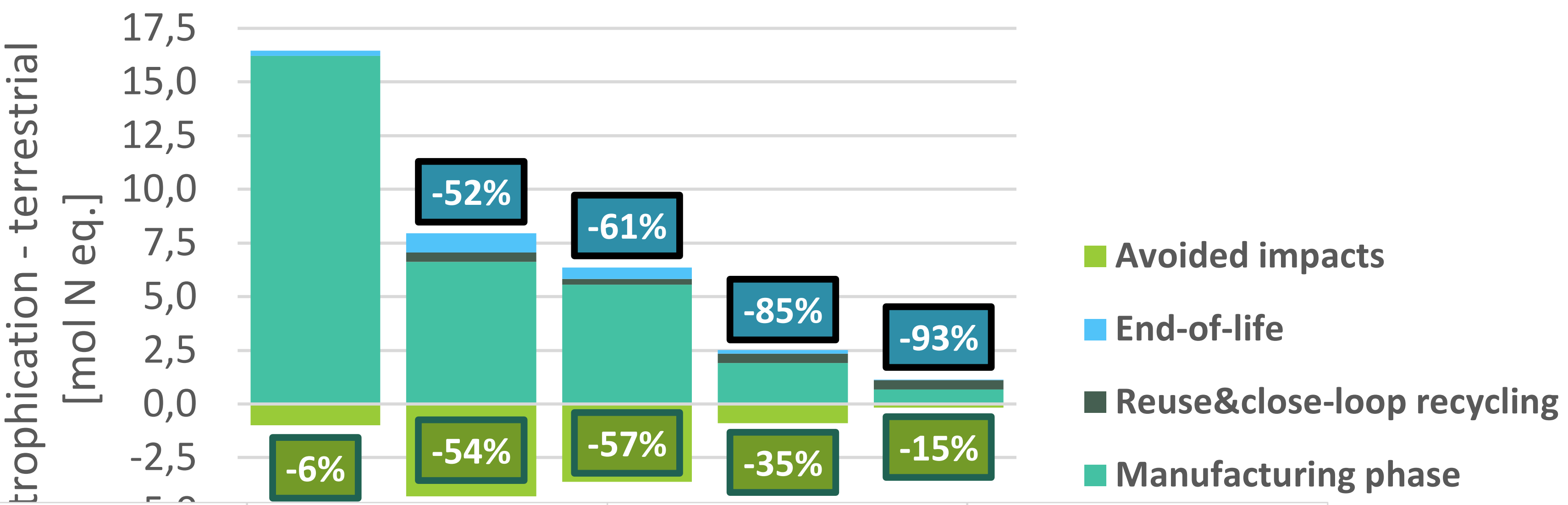
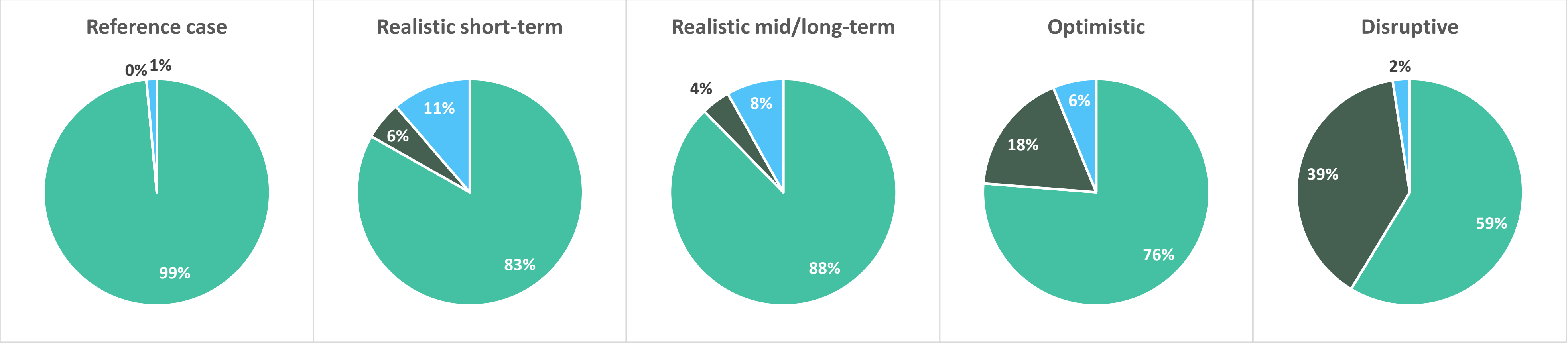
ENVIRONMENTAL LIFE CYCLE ASSESSMENT – PEMFC RESULTS

- Acidification
- Climate change
- Eutrophication – freshwater
- Eutrophication – marine
- **Eutrophication – terrestrial**





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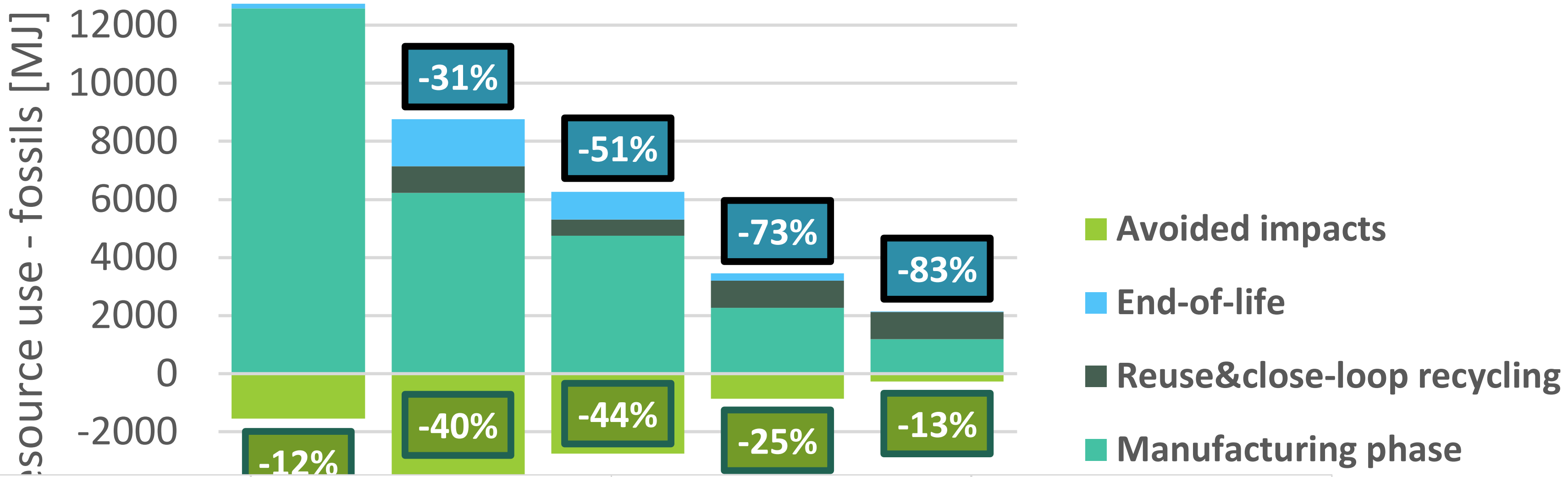
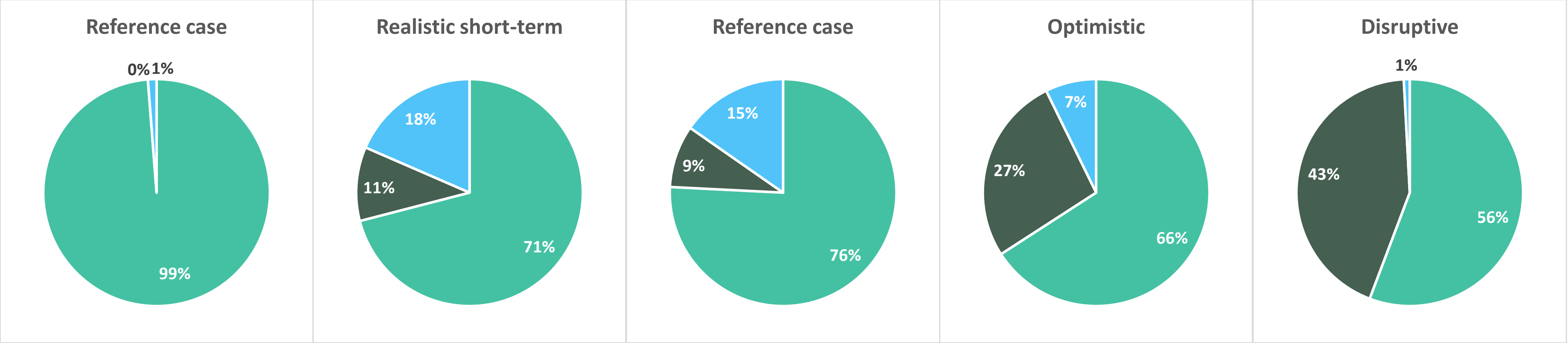
ENVIRONMENTAL LIFE CYCLE ASSESSMENT – PEMFC RESULTS

- Acidification
- Climate change
- Eutrophication – freshwater
- Eutrophication – marine
- Eutrophication – terrestrial
- **Resource use – fossils**





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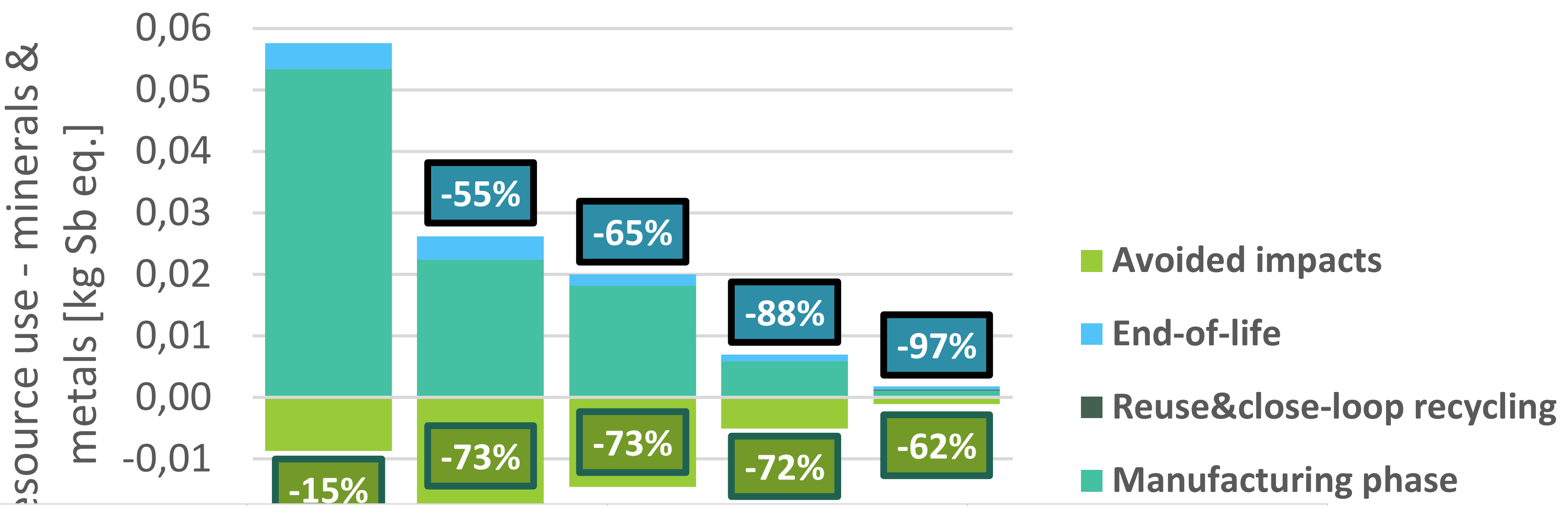
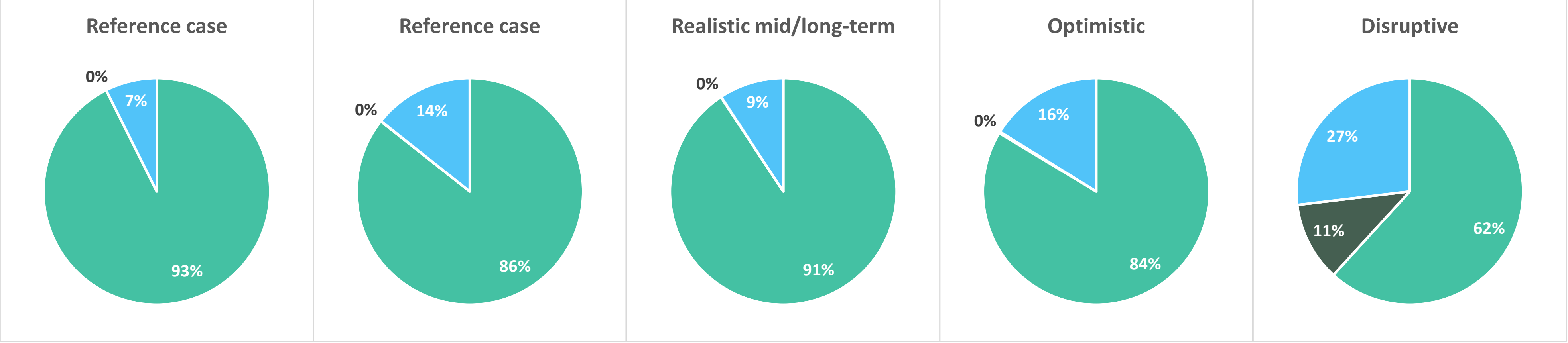
ENVIRONMENTAL LIFE CYCLE ASSESSMENT – PEMFC RESULTS

- Acidification
- Climate change
- Eutrophication – freshwater
- Eutrophication – marine
- Eutrophication – terrestrial
- Resource use – fossils
- **Res & r**





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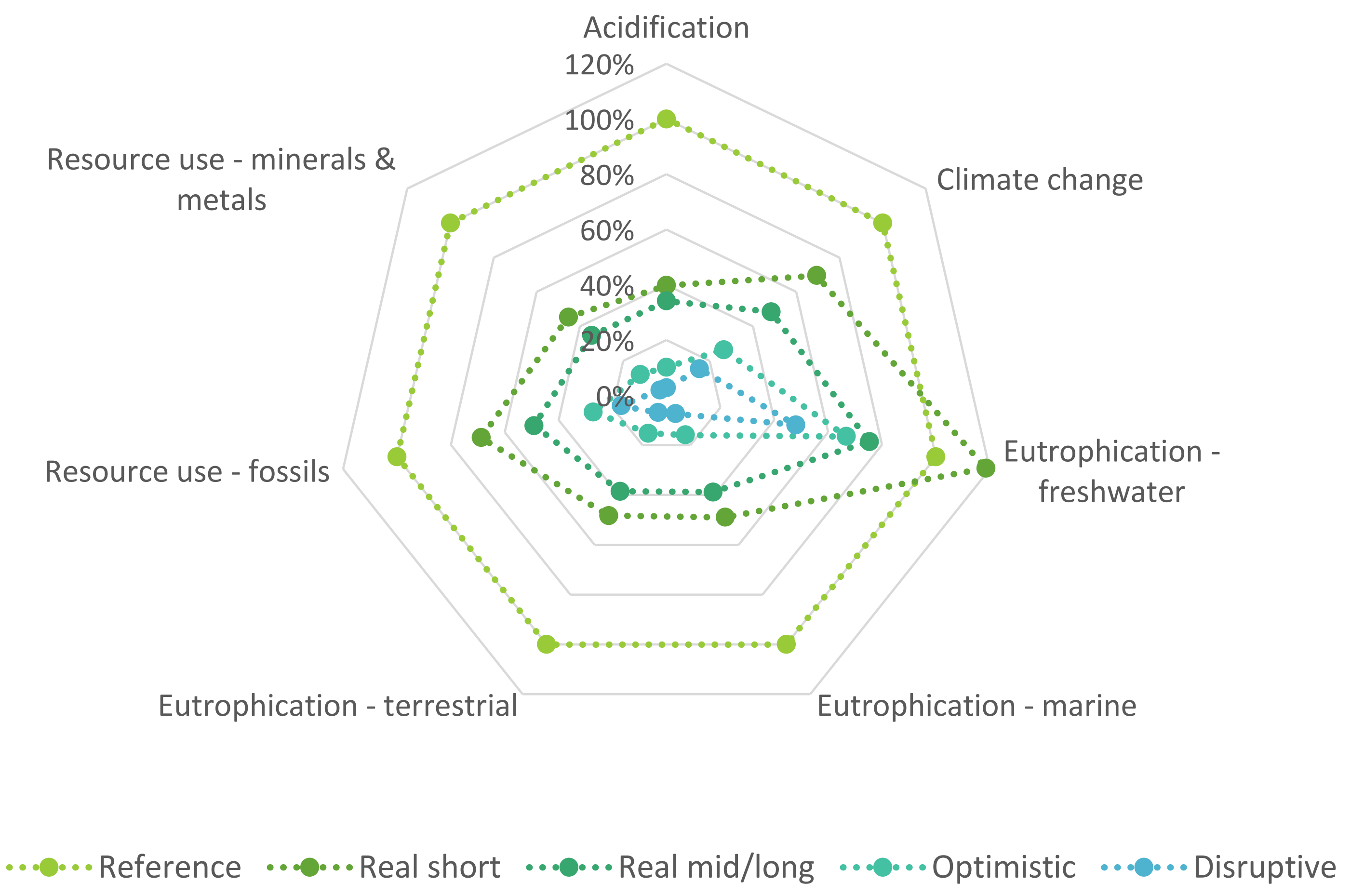
ENVIRONMENTAL LIFE CYCLE ASSESSMENT – SOEC RESULTS

- Average reductions:
  - Realistic concept: -70%
  - Optimistic concept: -84%
- **Eco-design actions** have a **similar effect** on most **impact categories**
- **Climate change** reductions:
  - Realistic concept: -70%
  - Optimistic concept: -83%



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Life cycle costing

- PEMFC life cycle costing
- SOEC life cycle costing

LIFE CYCLE COSTING

- **Conventional LCC** analysis for **PEMFC** and **prospective LCC** analysis for **SOEC**
- Scope: **manufacturing phase**
- Life cycle costing is based on the **same inventory** as environmental LCA
- PEMFC: **4 production rates**
  - 100 stack per year
  - 1000 stacks per year
  - 10000 stacks per year
  - 50000 stacks per year
- SOEC: **1 production rate**
  - 10000 stacks per year
- **Levelized cost** of stack production is calculated
- **Eco-efficiency** based on environmental LCA

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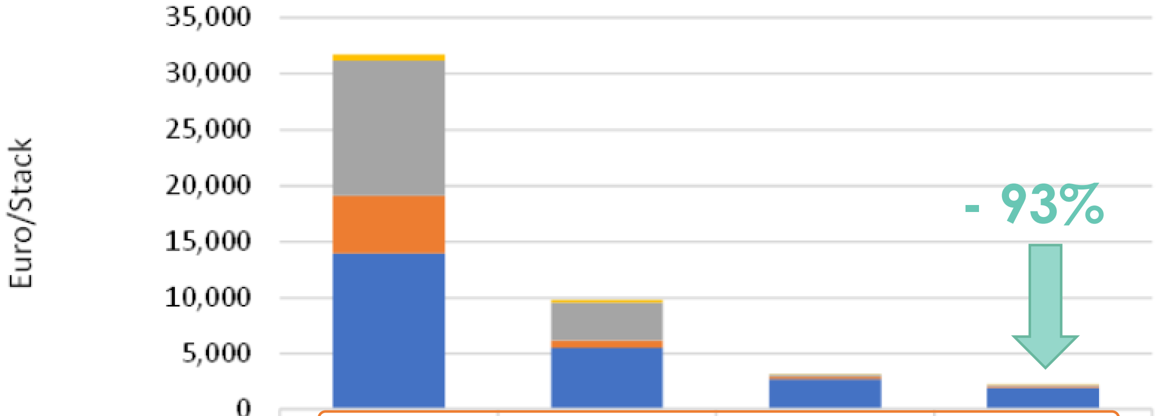
LIFE CYCLE COSTING – PEMFC RESULTS

eGHOST

- **Production rate increase** (from lab to industrial scale) causes **significant cost reductions**
  - From **-93%** (reference case) to **-96%** (disruptive concept)



	100	1000	10000	50000
Assembly Process	578	223	35	35
BPP Process	12000	3356	149	101
MEA Process	5180	681	223	133
BoM	13,961	5,553	2,742	1,938
Total	31,719	9,813	3,149	2,207

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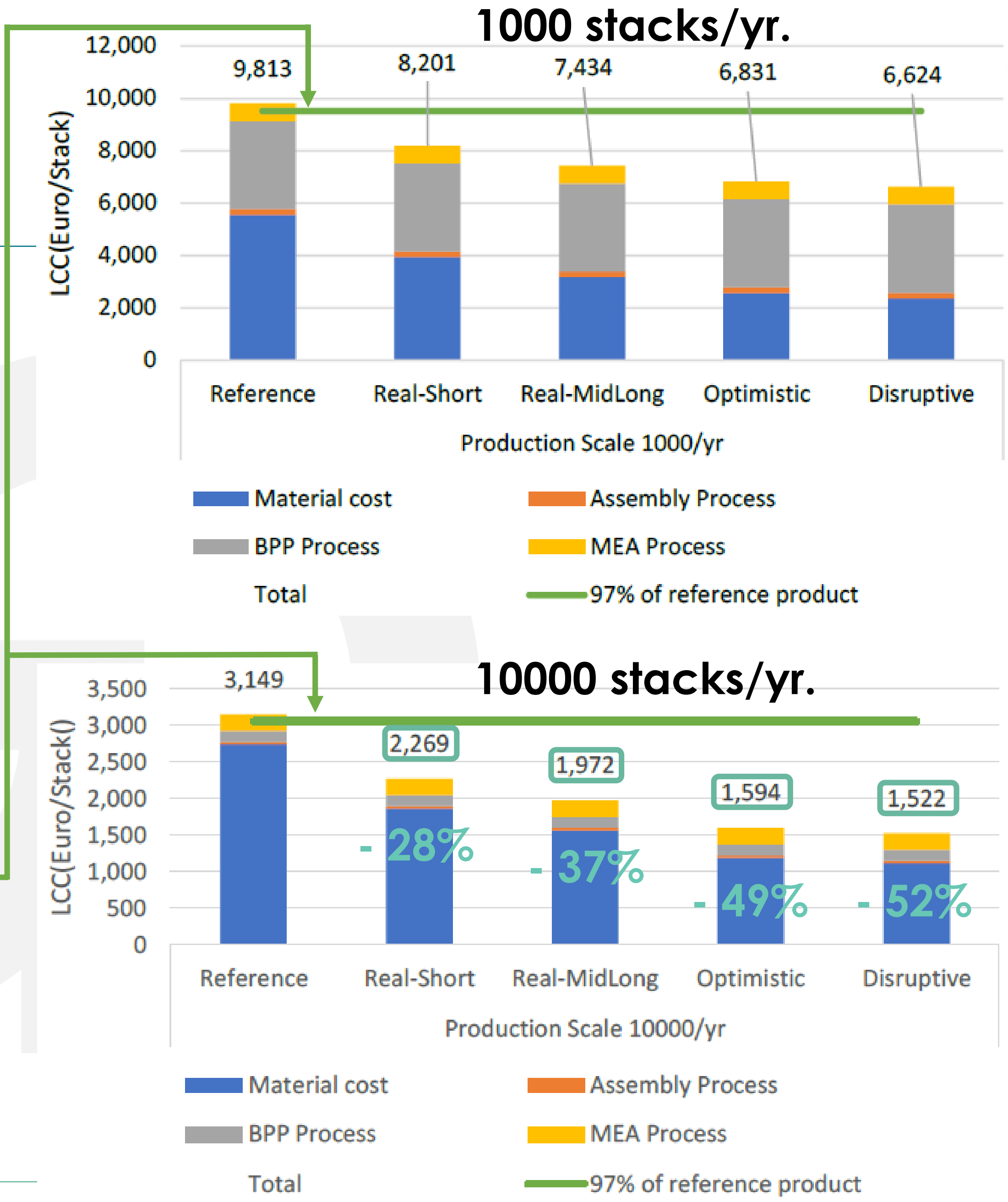
eGHOST Spring (20-24 May 2024)

LIFE CYCLE COSTING – PEMFC RESULTS

- **Production rate increase** (from lab to industrial scale) causes **significant cost reductions**
  - From **-93%** (reference case) to **-96%** (disruptive concept)
- Cost **reduction** due to the **ecodesign** (at 10000 stacks/year)
  - Realistic short-term concept: -28%
  - Realistic mid/long-term concept: -37%
  - Optimistic concept: -49%
  - Disruptive concept: -52%
- **All product concepts** meets the **threshold of -3% LCC reduction** in comparison to the reference case



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LIFE CYCLE COSTING – PEMFC RESULTS

- **Eco-efficiency** and **factor X** presented for production rate 10000 stacks/year
- **Eco-efficiency** – ratio between the products's value and the environmental impact caused by the product
- **Externalities** – costs due to the negative environmental impacts

$$Eco-efficiency_{i,j} = \frac{1/LCC_i}{Carbon\ footprint_i}$$

$$Factor\ X_{i,j} = \frac{Eco-efficiency_{i,j}}{Eco-efficiency_{bc,j}}$$

i – *Product concept*
j – *Carbon footprint*
bc – *Base case*

	Base	Real short	Real mid/long	Optimistic	Disruptive
Externalities [€ / stack]	418	215	165	68	31
Relative reduction of externalities	/	49%	60%	84%	93%
Eco-efficiency [1/€*kg CO_2 eq/stack]	2.63E-07	5.26E-07	8.68E-07	1.97E-06	3.57E-06
Factor X - PEMFC	1.00	2.00	3.30	7.47	13.54

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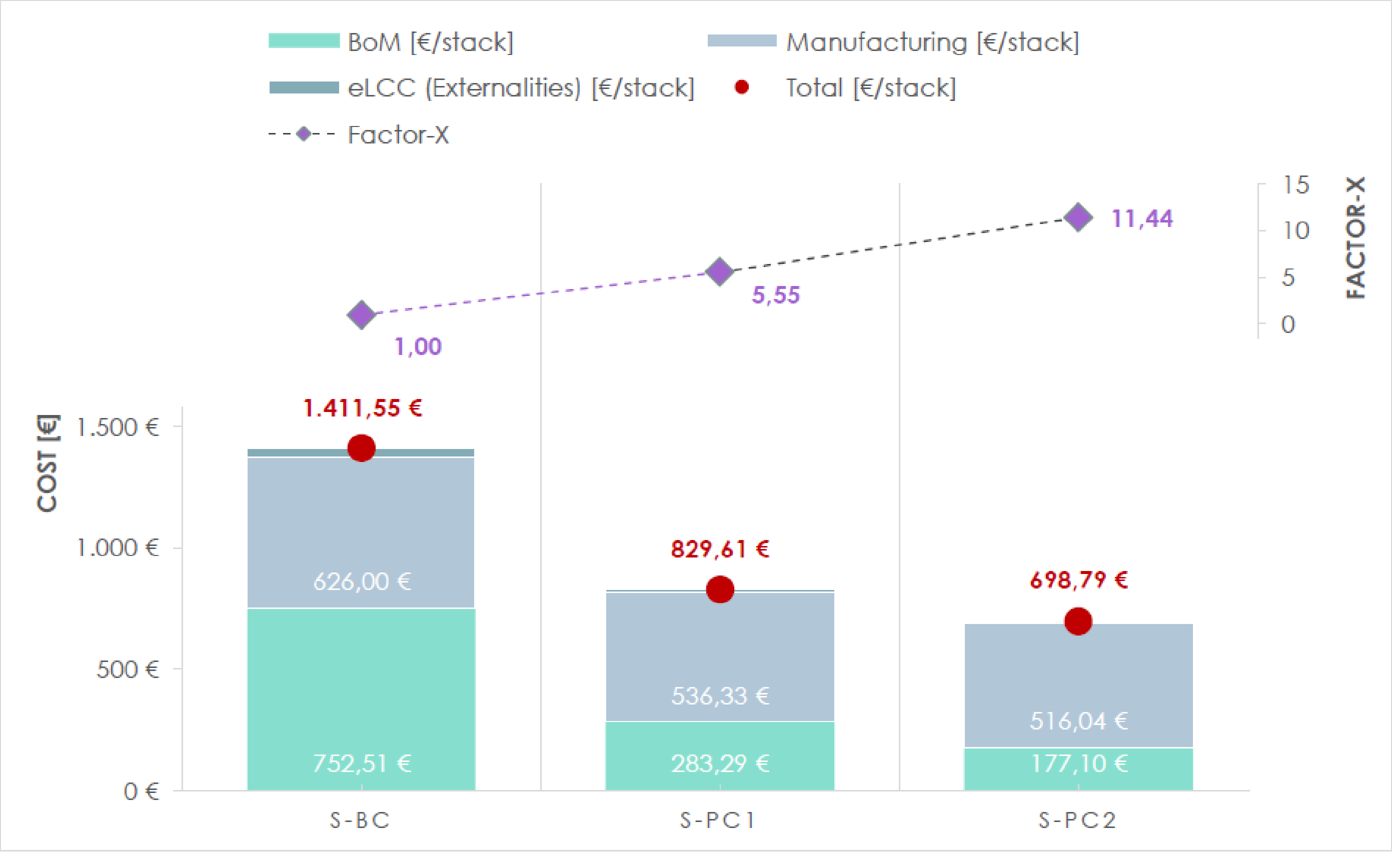
LIFE CYCLE COSTING – SOEC RESULTS

- Cost reduction
  - Realistic concept: -41%
  - Optimistic concept: -50%
- The cost of BoM is reduced by 76% and manufacturing processes by 18% (optimistic concept)
- **All product concepts** meets the **threshold of 3% LCC reduction** in comparison to the reference case
- Externalities reduction:
  - Realistic concept: -70%
  - Optimistic concept: -83%



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Social life cycle assessment

- **PEMFC social LCA**
- **SOEC social LCA**

SOCIAL LIFE CYCLE ASSESSMENT

- Scope: **manufacturing phase**
- Social LCA is based on the **same inventory** as environmental LCA and LCC
- Economic data needed for calculation related to the production rate of 10000 stacks/year
- Three supply tiers were assessed
  - Stack manufacturing
  - Components manufacturing
  - Materials extraction
- **PSILCA** database is used for calculation
- Assessed social impact categories:
  - Forced labour
  - Child labour
  - Health and safety
  - Fair salary
  - Discrimination
  - Contribution to economic development

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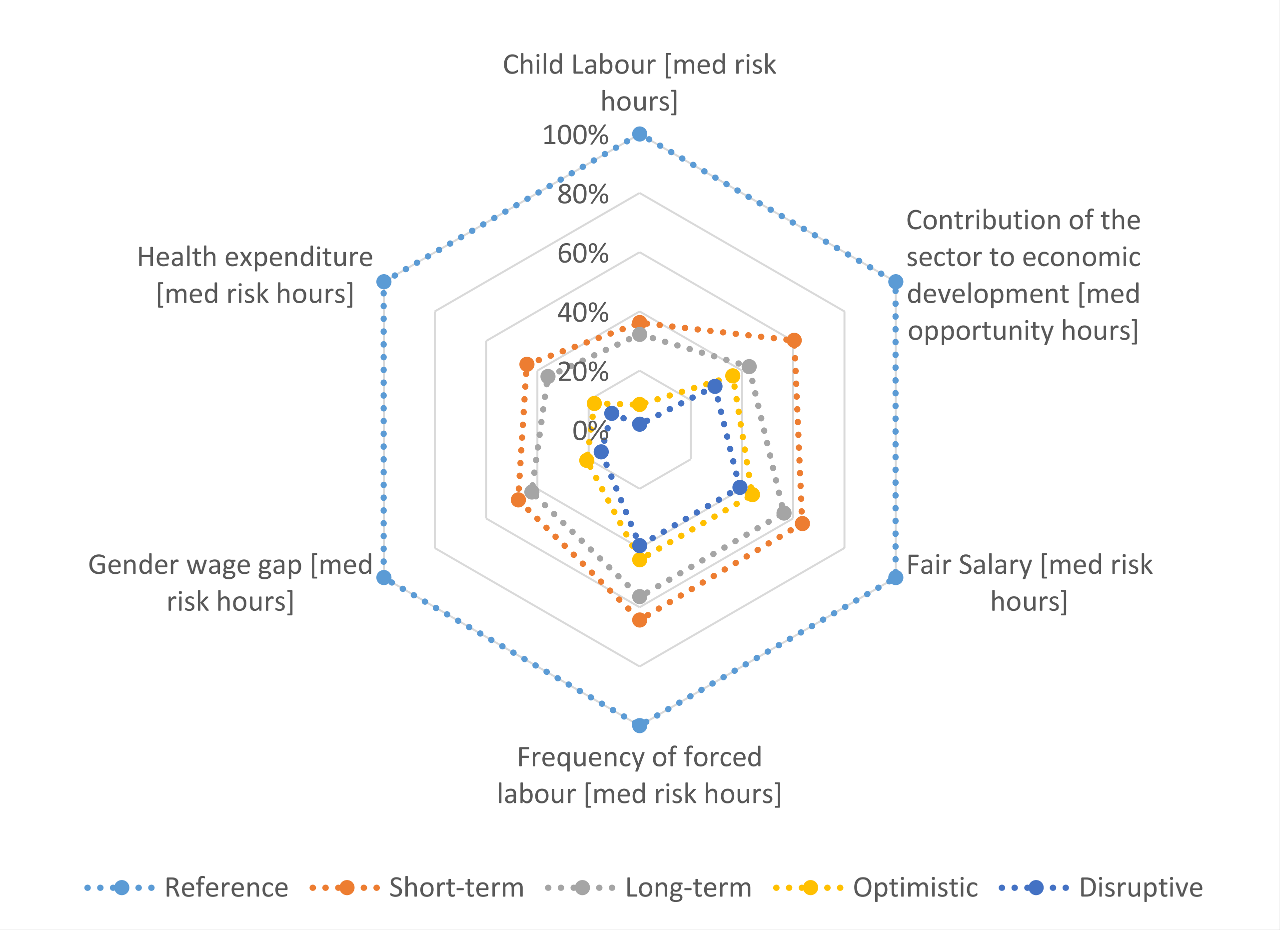
SOCIAL LIFE CYCLE ASSESSMENT – PEMFC RESULTS

- Main hotspot **mining of platinum** in **South Africa**
- With development of product concepts, the hotspot **shifts** to **plate manufacturing** in **Spain**
- Contribution to economical development the **only positive** indicator
- Average **reduction** with ecodesign concept:
  - Realistic short-term concept: -47%
  - Realistic mid/long-term concept: -56%
  - Optimistic concept: -71%
  - Disruptive concept: -77%



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SOCIAL LIFE CYCLE ASSESSMENT – PEMFC RESULTS

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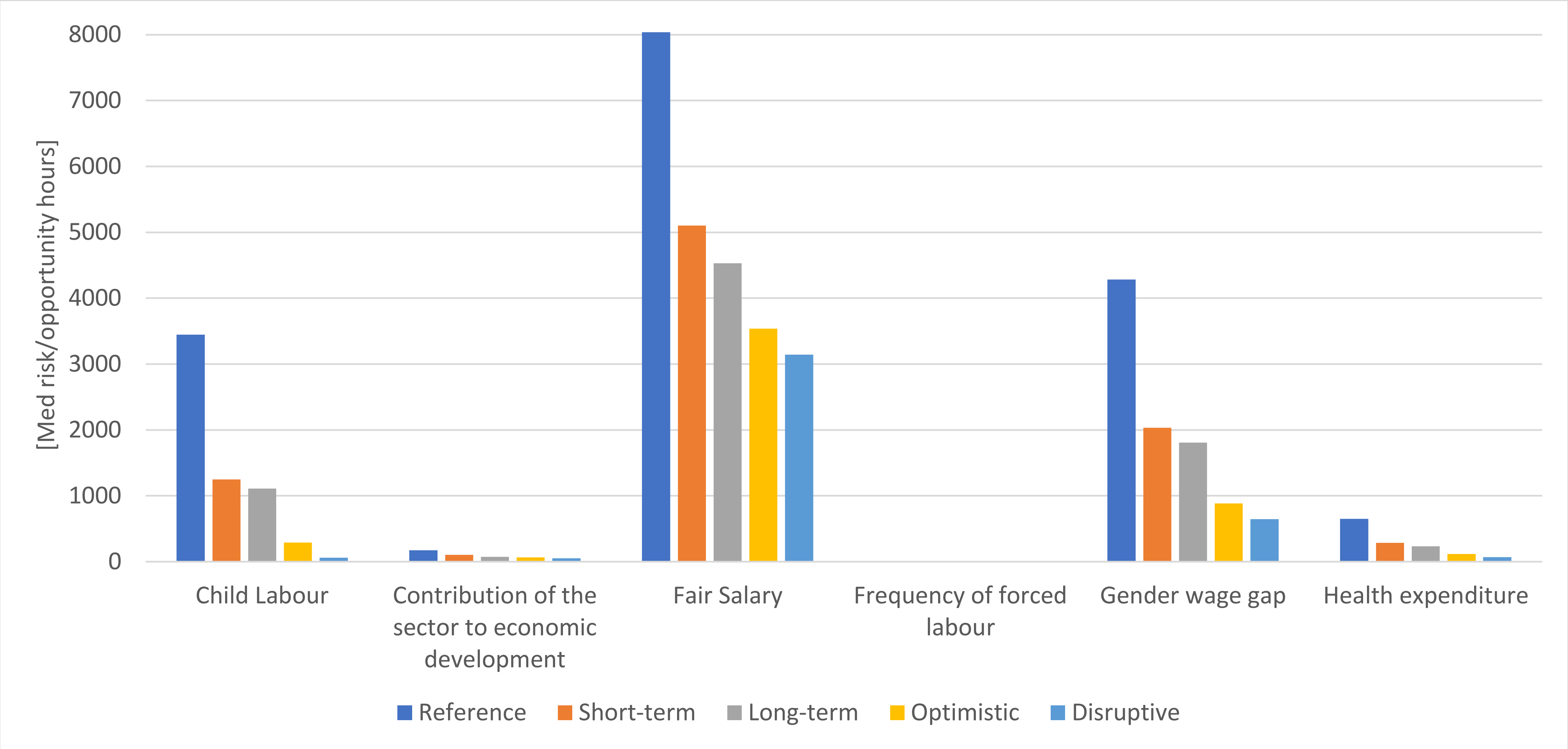

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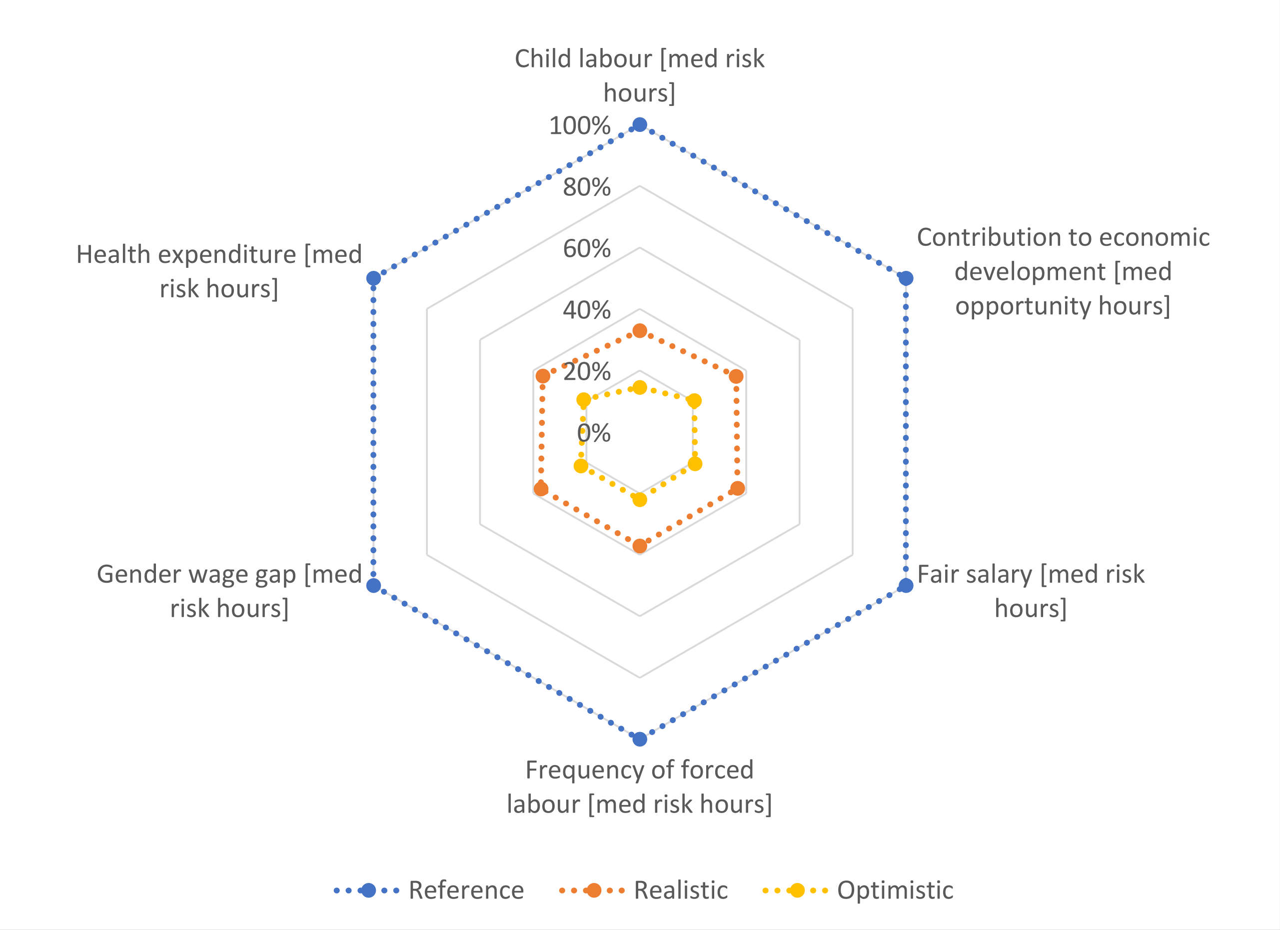
SOCIAL LIFE CYCLE ASSESSMENT – SOEC RESULTS

- **Eco-design actions** have a **relevant impact** on most categories of **social impacts** (as in the case of E-LCA)
- Average reductions:
  - Realistic concept: -64%
  - Optimistic concept: -80%
- The **highest reductions** in both product concepts are achieved for **child labour** indicator



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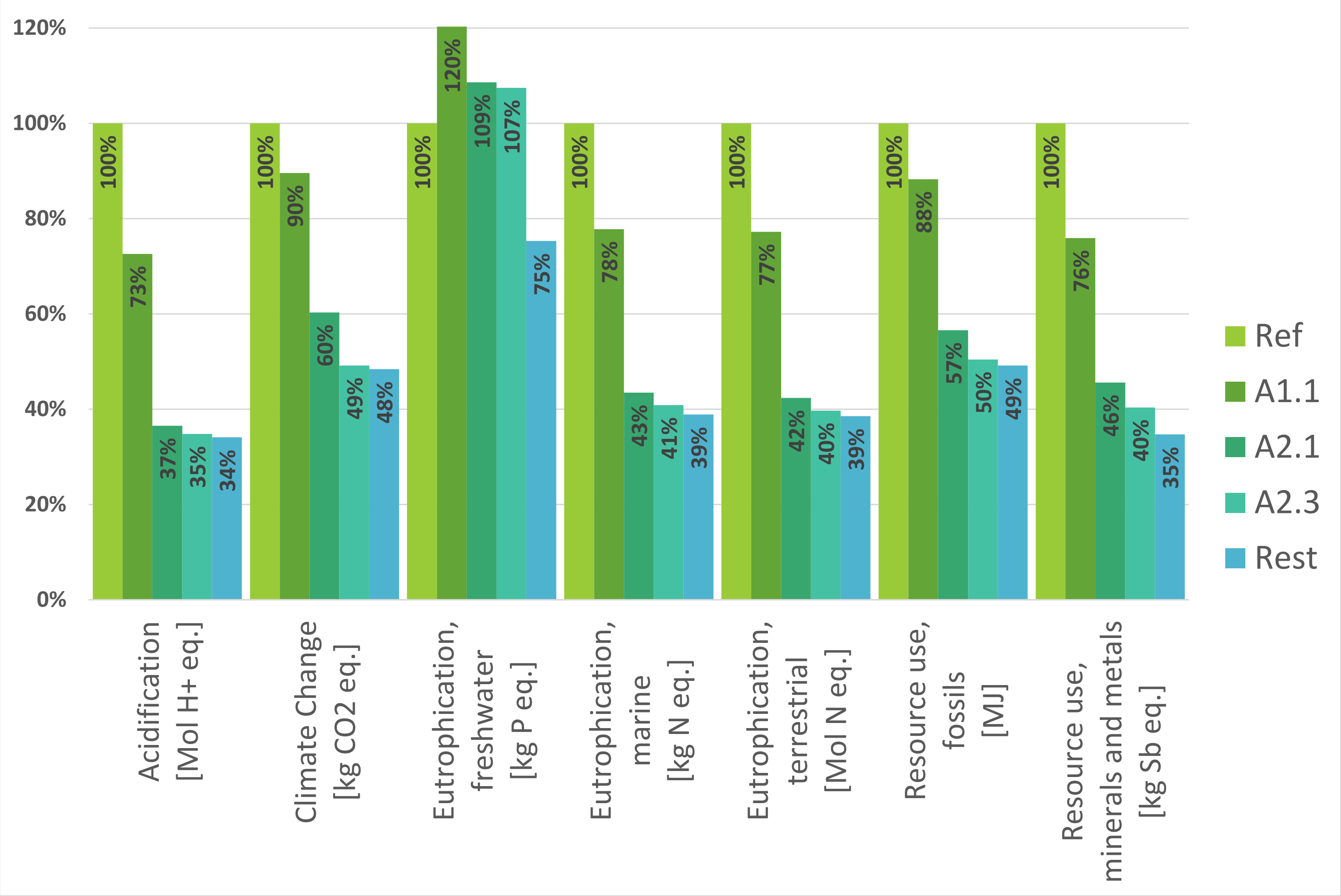
Prioritisation of eco-design actions

PRIORITISATION OF ECO-DESIGN ACTIONS

- **Which eco-design action** contributes the most to the environmental impact **reductions?**
- Case for **realistic mid/long-term** concept
- Similar impacts of eco-design actions on all impact categories except **freshwater eutrophication**
- **Eco-design action 2.1** (Pt loading reduction) **contributes the most** to the environmental impacts reductions
- **Significant reduction** also from **eco-design action 1.1** (recycled Pt use) and **2.3** (mass reduction of BPP, GDL, and ionomer)



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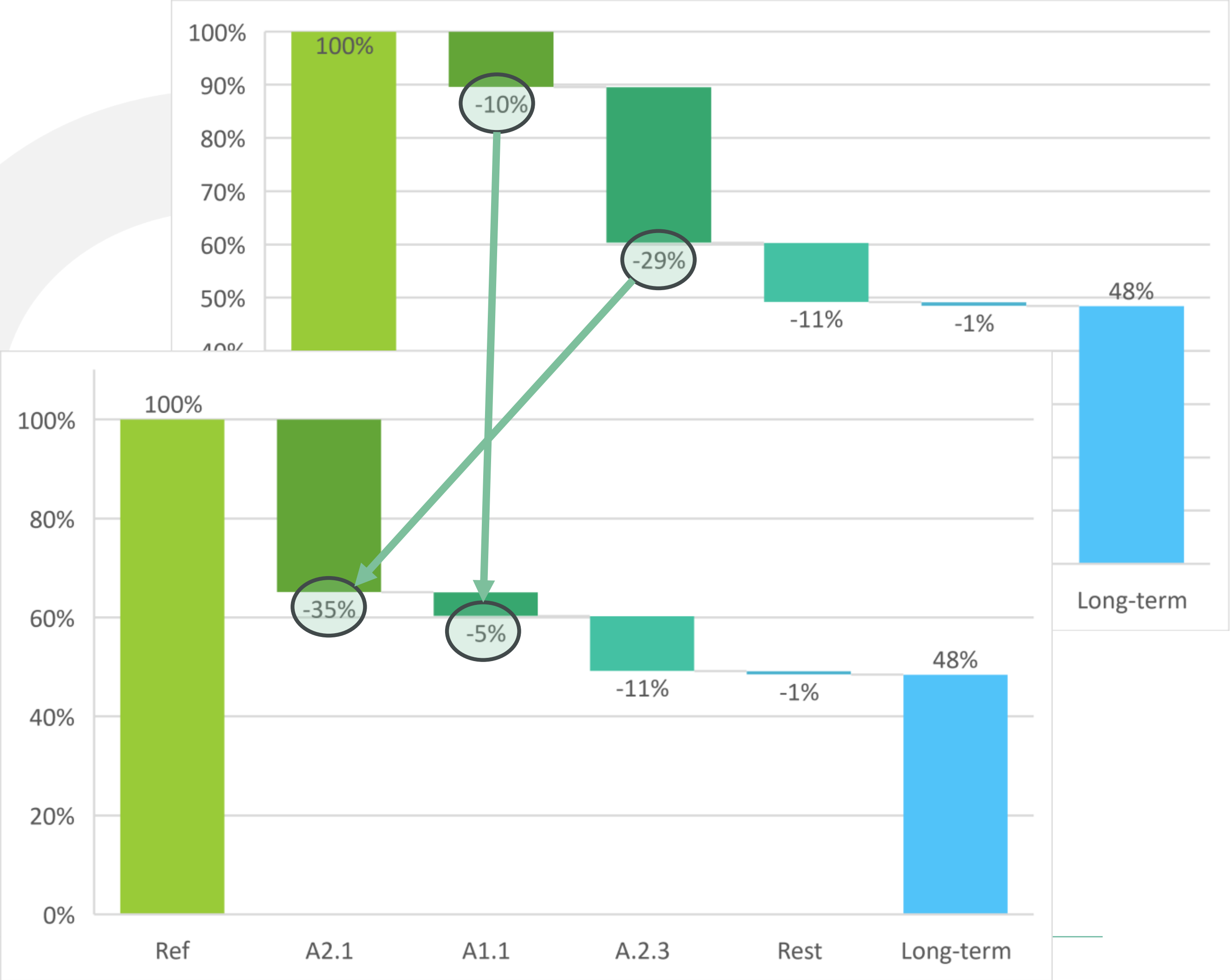
PRIORITISATION OF ECO-DESIGN ACTIONS

- **The order** of eco-design actions implementation **do not** significantly influences the contributions of eco-design actions
- Example for **climate change** indicator



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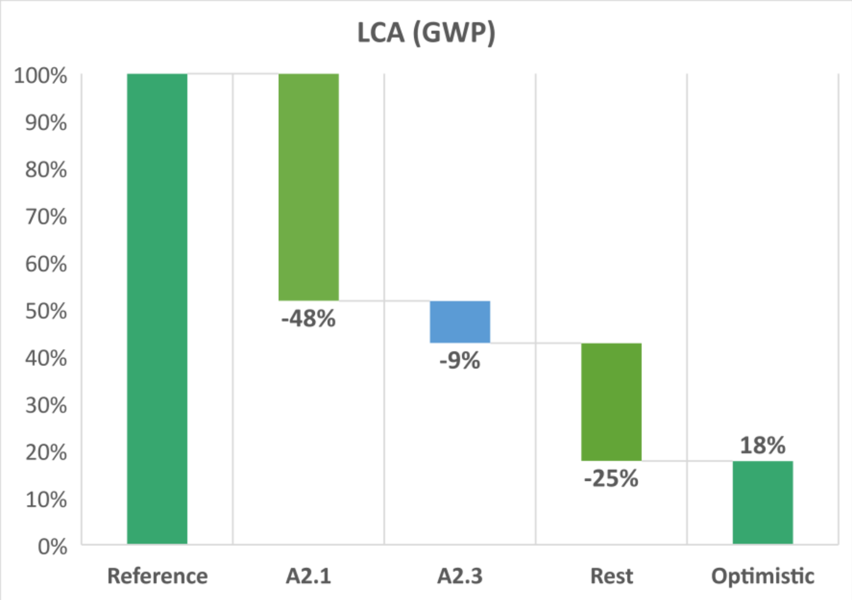
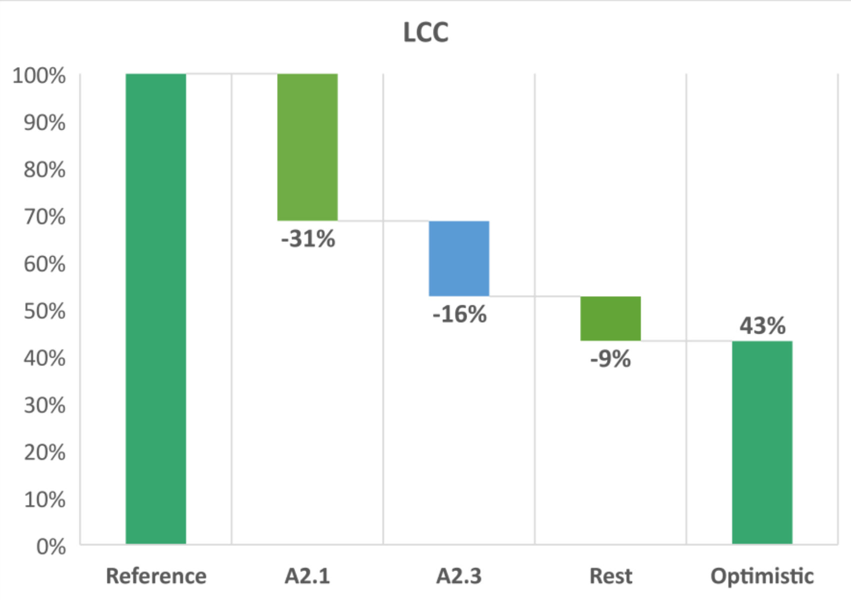
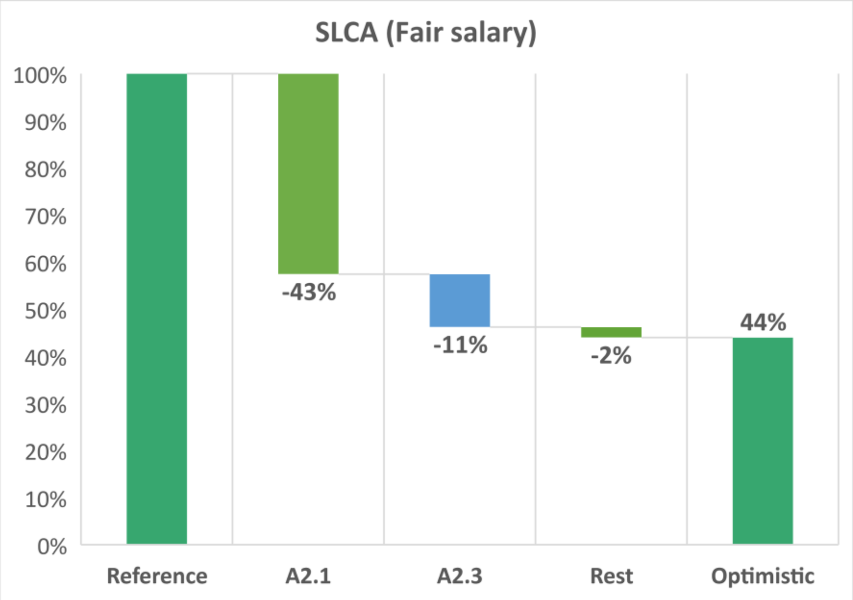
PRIORITISATION OF ECO-DESIGN ACTIONS

- Extended prioritisation of eco-design action also for **economic** and **social aspect** is done for **optimistic concept**
- Eco-design action with the greatest impact:
  - PEMFC: **Action 2.1** (reduction of Pt loading)







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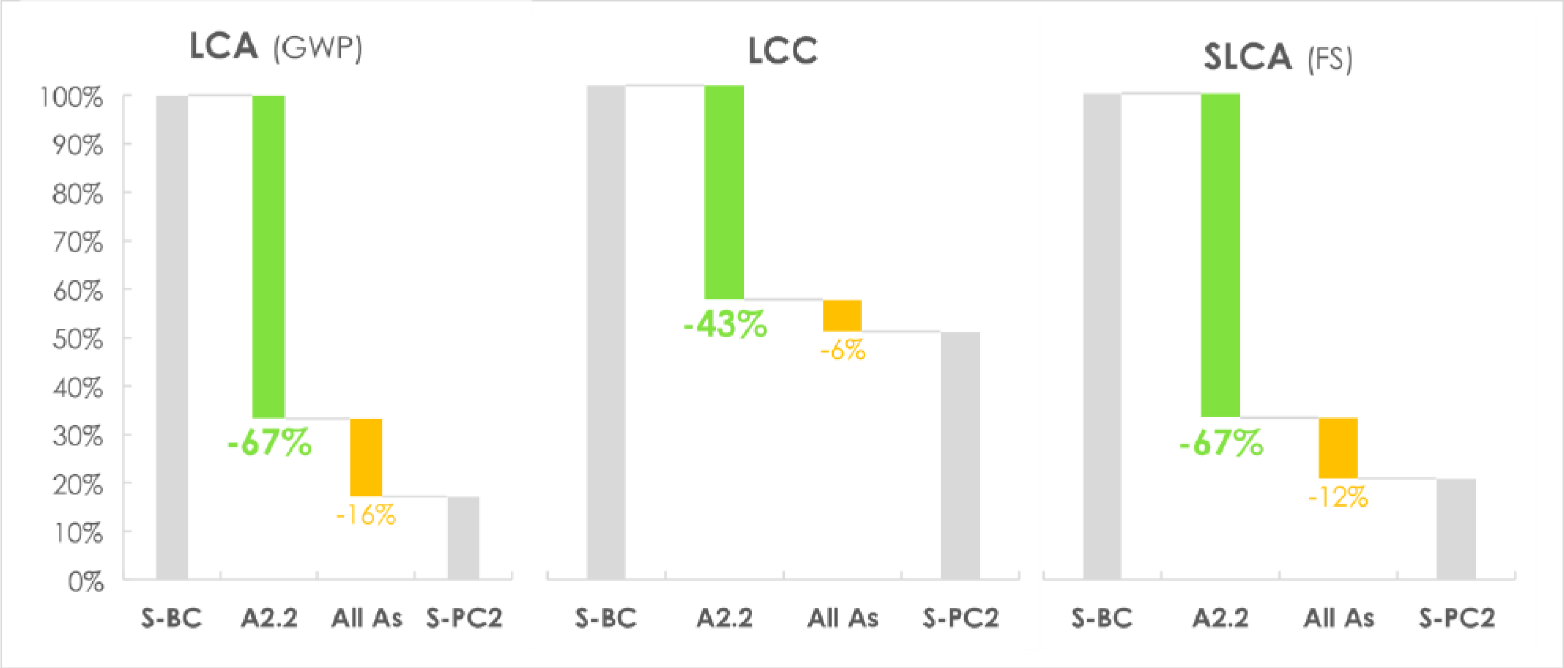
PRIORITISATION OF ECO-DESIGN ACTIONS

- Extended prioritisation of eco-design action also for **economic** and **social aspect** is done for **optimistic concept**
- Eco-design action with the greatest impact:
  - SOEC: **Action 2.2** (SOEC cell shape and size optimisation)



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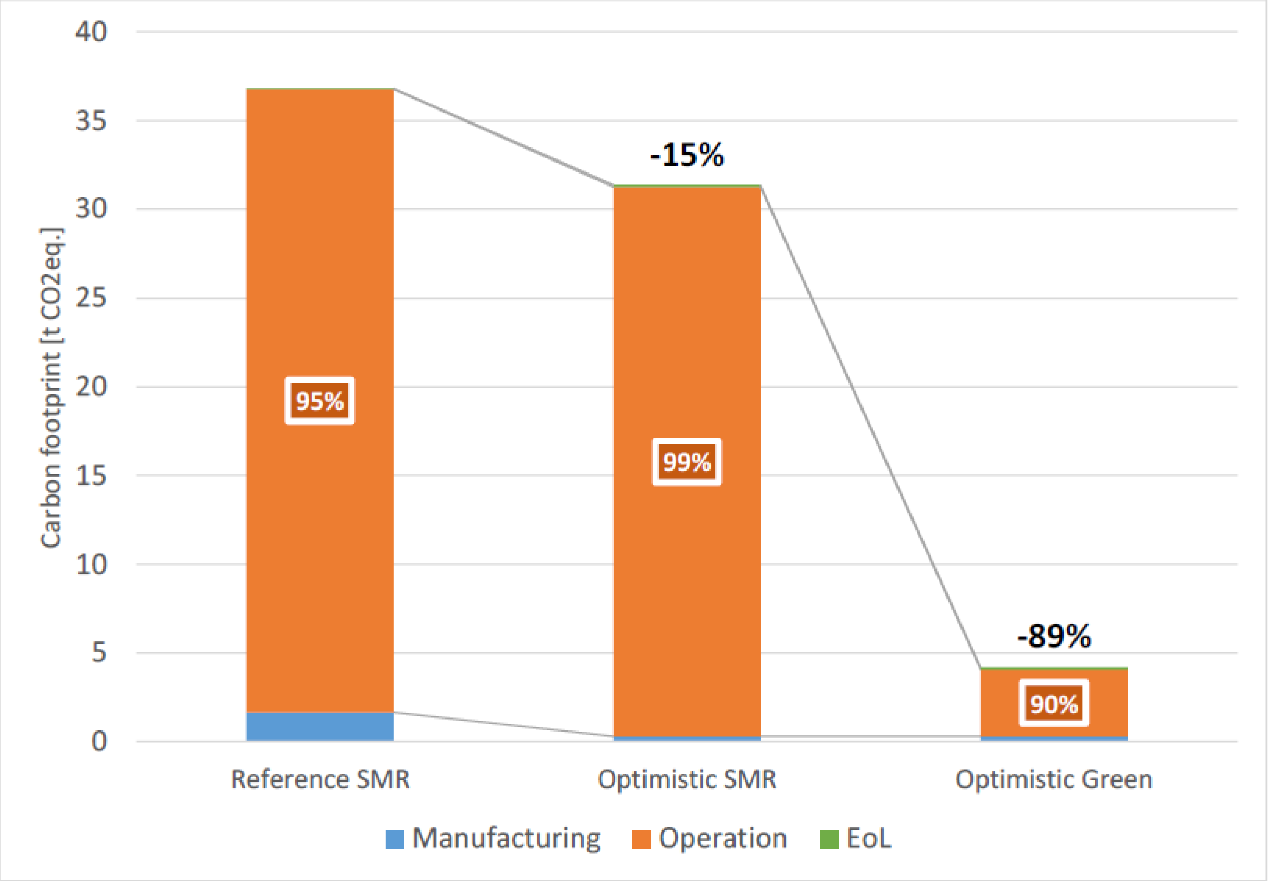
Extended scope with use phase

EXTENDED SCOPE WITH USE PHASE PROSPECTIVE

- Analysis for **optimistic product concept** and **carbon footprint**
- **PEMFC:** Use phase contributes the most of GWP emissions



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EXTENDED SCOPE WITH USE PHASE PROSPECTIVE

- Analysis for **optimistic product concept** and **carbon footprint**
- **PEMFC:** Use phase contributes the most of GWP emissions
- **SOEC:** use phase contributes the vast majority of GWP emissions and costs in the whole life cycle of SOEC

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eco-design
Guidelines for Hydrogen
Systems and Technologies

(20-24 May 2024)

ECO-DESIGN GUIDELINES

ECO-DESIGN GUIDELINES

- Structured in **6 different** life cycle stages
  - Materials selection
  - Manufacturing
  - Transport
  - Operation
  - End of Life
  - Concepts development
- **From generic** eco-design guidelines (eco-design wheel) a **technology specific** guidelines are **defined**
- **Two time frames** of the eco-desing guidelines
  - Medium term (3 – 10 years) - green
  - Medium to long-term (> 10 years) - purple

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ECO-DESIGN GUIDELINES – PEMFC

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Ecodesign topics		Actors

01 – MATERIALS

1.1 Selection of low impact materials

1.2 Reduction of intensity of use of materials

Reducti… diversity	
Reducti… of mate…	
Reducti… volume… materic…	

02 – MANUFACTURING

2.1 Optimization of manufacturing tech…

Reduce the number of production steps	▶ Optimize number …
Reduce the energy consumption in production	▶ Use less energy or … and costs. Reduce… ▶ Use low-carbon or… ▶ Revalorize thermal… ▶ Recover electricity…
Limit and reduce… production…	
Reduce c… in producti… clean cons…	

03 – TRANSPORT

3.1 Optimization of distributio…

Use less packaging and cleaner packaging	▶ Redu… ▶ Use re…
Use transportation mode with high energy efficiency	▶ Use s…
Optimize the logistic for manufacturing, installation and maintenance	▶ Facili… asser… ▶ Redu…

04 – OPERATION

4.1 Reduction of impact during use

Reduce energy consumption in use	▶ Optimize the Balance of Plant (BoP) to reduce the overall energy consumption (e.g. optimize Energy Management System) ▶ Optimize the control strategy to minimize the stack energy consumption. ▶ Reduce operating temperature of the system, to reduce energy consumption	Stack manufacturer
Use clean ene… consumable for operation		
Use less cons… and materi… operation		

4.2 Optimiz…

Improve the … and durability … system		
Ensure easy maintenance and repair	▶ Ease stack maintenance (e.g. access, cell replacement), simplify the fastening	Stack manufacturer
Provide a modular structure for the system	▶ Improve stack modularity to optimize part load operation and limit degradation	Stack manufacturer
Standardize reparation and maintenance procedures	▶ Develop harmonized standards to measure stack degradation	Stack manufacturer

05 - END OF LIFE

Integrate possibility of reuse of components, products	▶ Develop processes and protocols to facilitate the reuse/remanufacturing/refurbishing of valuable components (end plates, BPP, aluminum housing). These processes may include inspection of components to determine if they are suitable for washing and reuse.	*Stack manufacturer*
Possibility for remanufacturing / refurbishing of the components	▶ Develop automated and industrialized processes for efficient stack dismantling (mechanical disassembly techniques) ▶ Design for modularity and disassembly at end of life	*Stack manufacturer*
Possibility of recycling	▶ Improve the recycling of materials, especially platinum and membrane ▶ Develop recycling streams and processes for PEMFC materials (find ways to disassembled the stack, and recycling processes for valuable materials in the stack). Envisage hydrometallurgy processes for critical raw materials recovery. ▶ Use existing recycling streams for aluminum, copper and stainless steel recovery ▶ Improve the total recycling rate of PEMFC systems	*Stack manufacturer and automotive recyclers*
Safe incineration if no possibility for recycling	▶ Ensure safe incineration of the components if recycling is not possible	*Recyclers*

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ECO-DESIGN GUIDELINES – SOEC

01 – MATERIALS

1.1 Selection of low impact materials

Selection of clean materials	▶ Choose materials with low … better performance
Selection of … and sustaina… materials	
Selection of … with low ene…	
Integration … materials	
Integration o… materials	

1.2 Red…

Reduction of … of materials	
Reduction of … materials	
Reduction of … of materials/co…	… amount of nickel employed while maintaining equivalent performances of the cells

02 – MANUFACTURING

2.1 Optimization of manufacturing tech…

Reduce the number of production steps	▶ Optimize nu… ▶ Merge the fi…
Reduce the energy consumption in production	▶ Use less ene… time and te… ▶ Use cleaner … ▶ Revalorize th… ▶ Revalorize H…
Limit and reduce production wastes	▶ Integrate in… reduce envi… ▶ Optimize pr… work with su…
Reduce consumables in production and use clean consumables	▶ Reduce/opti… ▶ Select wate…

03 – TRANSPORT

3.1 Optimization of distribution process

Use transportation mode with high energy efficiency	▶ Use as clean as possible ways of transportation for logistic
Optimize the logistic for manufacturing, installation and maintenance	▶ Facilitate local supply chains for materials and components

04 – OPERATION

4.1 Reduction of impact during use

Reduce energy consumption in use	▶ Optimize the Balance of Plant (BoP) to reduce the overall energy consumption (e.g. to heat up only active materials and not structural elements such as the end plates)
Use clean ener… consumable sou… operation	
Use less cons… and material… operation	

4.2 Optimizati…

Improve the r… and durability … system	
Ensure easy maintenance an…	
Provide a modul… structure for the s…	
Standardize repa… and maintenanc… procedures	

05 - END OF LIFE

Integrate possibility of reuse of components, products	▶ Develop processes and protocols to facilitate the reuse/remanufacturing of steel components (end plates, interconnects, module and BoP components) – in particular offcuts
Possibility for remanufact… refurbishing … component…	▶ Develop automated and industrialized processes for efficient stack dismantling (mechanical disassembly techniques) ▶ Design for modularity and disassembly at end of life
Possibility of recycling	▶ Develop recycling streams and processes for SOEC materials (find ways to disassemble the stack, and recycling processes for valuable materials in the stack). Envisage hydrometallurgy processes for critical raw materials recovery without compromising environmental, social and economic impact compared to the use of virgin materials. ▶ Reuse of terminal plates developed in "material part" ▶ Use existing recycling streams for steel recovery ▶ Improve the recyclability of steels ▶ Improve the total recycling rate of SOEC systems ▶ Find other application for the stack with less stringent requirements than H2 production. Since the stack can be reversible according to its design, Fuel cell mode could offer a second life. This should take into consideration the problems that can encounter stack at end of life like leaks or contacts problems.
Safe incineration if no possibility for recycling	▶ *Ensure safe incineration of the components if recycling is not possible*

06 – NEW CONCEPTS DEVELOPMENTS

	▶ *Add functionalities to end plates like thermal management system, to justify its size and weight*

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FINAL REMARKS

FINAL REMARKS

- In order to define eco-design guidelines, first **LCSA** of the **reference case** has to be made
- **Platinum** (PEMFC) and **stainless steel** (SOEC) have been identified as the **main hotspots**
- Eco-design wheel provides **generic eco-design** actions which were implemented to **specific hydrogen technology**
- **4 product concepts** for PEMFC and **2 product concept** for SOEC technology have been defined
- With eco-design actions **major reductions** in environmetal, social and economic impacts are achieved
- Technology specific guidelines are given to help **hydrogen value chain actors** to understand where environmental, social and economic **challenges** might occur and to **identify potential actions** to tackle those challenges

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eco-design Guidelines for Hydrogen Systems and Technologies

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