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

LCA and LCC of existing and novel EoL technologies of target FHC products targeting critical materials

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www.best4hy-project.eu

Clean Hydrogen Partnership

Co-funded by the European Union

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) under Grant Agreement No 101007216. This Joint Undertaking receives support from the European Union's Horizon 2020 Research and Innovation program, Hydrogen Europe and Hydrogen Europe Research.

Objectives, tasks, milestones of WP5

- **to conduct LCA and LCC** for **existing and novel EoL technologies** of target FCH technologies (PEMFC, SOFC)
- **Target: critical materials**
- **Partners ALL**

T5.1: Calculate the environmental profile of FCH products and the existing EoL technologies

T5.2: Calculate the environmental profile of the novel EoL technologies

T5.3: LCC of existing and novel EoL technologies

T5.3: Ecolabelling certification for Fuel cell technology

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Status at the Best4Hy start

- Basic knowledge from **HyTechCycling** regarding recycling approch
- Start collaboration with **JRC** for inventory integration in JRC databases

HyTechCycling EU funded project

Inventories of PEMWE, AWE and basic SOFC manufacturing technologies

Simple approach for End of Life of PEMWE and AWE

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What was the objective of WP5

- new **inventory of PEMFC technology**
- novel **inventory of SOFC technology** for EoL technologies
- conduct e-LCA from cradle to grave for PEMFC, SOFC for **existing EoL technologies** for target materials
- make e-LCA for cradle to grave for PEMFC, SOFC for **novel EoL technologies** for target materials
- **life cycle costing (LCC)** of the existing and novel EoL concepts
- Guidelines **eco-labelling** of FCH products

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Key outcomes and objectives

KO4: LCA and LCC of the processes for sustainability benchmarking proving an **overall GHG reduction of -20%** in the overall production LC including innovative EOL/recycling approaches → contributes to OBJ5 and it is achieved through WP5.

KO5: overall cost of **recycled materials comparable (±10%) to market cost of virgin material** in a scenario of industrialised recycling processes → contributes to OBJ5 and it is achieved through WP5

OBJ5.	
FCH 4.4.2020	A comprehensive environmental-economic analysis of the considered strategy should be undertaken.
Best4Hy proposal	Environmental (LCA) analysis and cost (LCC) analysis will be performed for all considered technologies and all current and novel EoL approaches. The analysis will be done for the whole life cycle with emphasis on EoL with possible open or closed loop recycling. Benchmarking will serve to pick the best EoL scenario for each technology including also recovery rate of recycled material and quality of recovered material. →**Key Outcomes 4,5,6&10**

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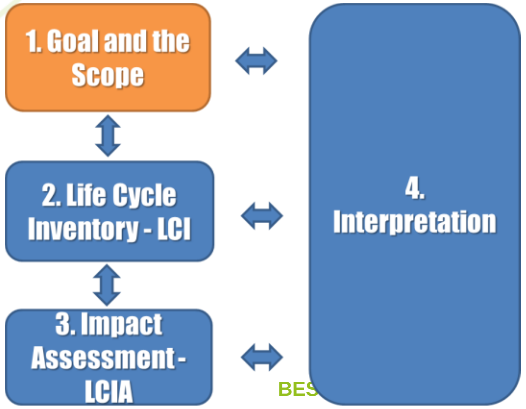
Methodology used: LCA and LCC

- **Scope**: cradle to grave (CRMs, rare earth), gate to cradle (no use phase included)
- **Functional unit**: mass of recycled CRMs (rare earth) material
- **Life Cycle Inventory**: BoM from industry partners
- **Software**: LCA for experts
- **Databases**: Sphera, Sphera extension, Ecoinvent, Data on demand
- **Life cycle impact assessment**: EF3.0



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Life cycle inventories for EoL processes

6 x New Life cycle inventories for FCH EoL!

PEMFC

- **Existent (TRL 5):** hydrometallurgical process → **Pt recovery (Pt/C)**
- **Novel (TRL 5):** Pt electrochemical process → **Pt recovery (Pt metal on GDL)**
- **Novel (TRL 5):** Alcohol dissolution (AD) process → **Pt salt + ionomer dissolution**

SOFC (anode):

- **Novel (TRL 5):** YSZ + NiO

SOFC (cathode):

- **Novel (TRL 3):** nitric acid root → **La oxide and Co oxide**
- **Novel (TRL 2):** sulfuric acid root → **La oxide and Co oxide**
- **Novel (TRL 2):** citric acid root → **La oxide, Co oxide and Sr oxide**

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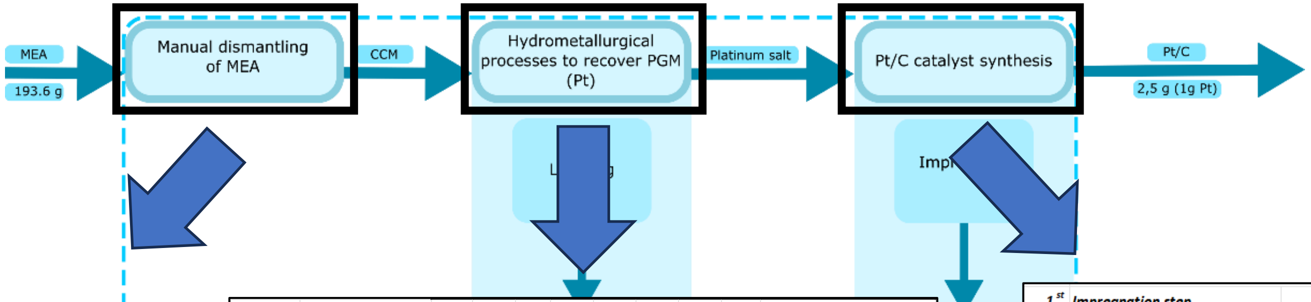
EoL phase (Pt REC) - LCI analysis and LCA modelling



EKPO FUEL CELL TECHNOLOGIES

1st MEA disassembling

	Input (materials)	g	Process	g	output (Wastes, energy..)
Description					
Main input	MEA (with gaskets)	14,40	*Manual disassembling + Cutting machine + Delamination*	9,90	Gaskets, subgasket
				3,40	GDL
				0,00	.....
				0,00	
	Energy			0,00	
	Electricity (kWh) (cutting machine)	0,16			Main output
	Electricity (kWh) (shredder)	0,125		1,10	CCM
	Heat (kWh)	0,00			

1st Leaching

	Input (materials)	g	Process	g	output (Wastes, energy..)
Main input	CCM	34,38	*Leaching process*	0,00	Material A
	HCl (36% con. 200 mL)	352,34		0,00	Material B
	HNO_3 (63% conc., 50mL)	137,48		0,00	.....
				0,00	
				0,00	
	Energy				Main output
	Electricity (kWh)	0,63		524,20	$[PtCl_6]^{-2}$ dissolved in aqua regia
	Heat (kWh)	0,00			Hexachloroplatinate

2nd Filtration

Description: After leaching, a filtration stage removes the carbon particles from the PGM-containing solution.

	Input (materials)	g	Process	g	output (Wastes, energy..)
	[PtCl6]-2 dissolved in aqua regia	524,20	*Solid/liquid separation+ ICP-OES*	521,12	Carbon powder
neglectable	NaCl (buffer)	?		0,00	Polimer membrane (Nafion, PEEK)
neglectable	Argon	?		0,00	5 ml waste for analyiss
neglectable	Scandium	?		0,00	
	Ribbon filter paper	?		0,00	
	Energy				Main output
	Electricity (kWh)	0,65		3,08	Pt in $[PtCl_6]^{-2}$ clear solution
	Heat (kWh)	0,00			Hexachloroplatinate

3rd and 4th Precipitation + Filtration

Description: In this case, the Pt-rich stream coming from the separation process is treated with e.g. **ammonium chloride (NH4Cl) in order to precipitate platinum as**

	Input (materials)	g	Process	g	output (Wastes, energy..)
	Pt in [PtCl6]-2 clear solution	3,08	*Precipitation + Filtration*	305,24	Pt (filtrate), waste?
	NH_4Cl (saturated - 250g/L) 1000mL	250,00		0,00	Co ?
	HCl (63% conc., 50mL)	58,72		0,00	Material A.....
	cellulose filter paper 2µm			0,00	
				0,00	
	Energy				Main output
	Electricity (kWh)	1,04		6,56	$(NH_4)_2PtCl_6$
	Heat (kWh)	0,00			Ammonium-hexachloroplatinate - Pt salt

1st Impregnation step

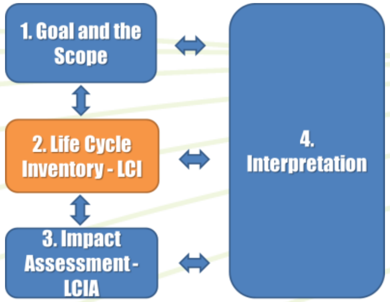
Input (materials)	g	Process	g	output (Wastes, energy...)
(NH4)2PtCl6 (Pt salt)	0,377	*Impregnation (with magnetic agitator)*	0,000	no lossess
Carbon Vulcan XC-72	0,200			
Ethylene Glycol	45,20			
Energy				Main output
Electricity (Wh)	4,50		45,777	Solution Pt salt/Vulcan/EG (liquid)
Heat (Wh)	0,00			

2nd Reduction polyol synthesis

Input (materials)	g	Process	g	output (Wastes, energy...)
Solution Pt salt/Vulcan/EG (liquid)	45,78	*Reduction polyol synthesis (90 °C, 5h)*	0,000	No losses
NaOH (1M in water)	3,00			
HNO3 (1 M in water)	3,00			
Energy				Main output
Electricity (kWh) - Heating plate	0,95		51,777	Heated and mixed solution (Pt/XC/EG)
Electricity (kWh) - Magnetic Agitator	0,18			

3rd Filtration step

Input (materials)	g	Process	g	output (Wastes, energy...)
Heated and mixed solution (Pt/XC/EG)	51,78	*Filtration (3x)*	51,20	EG - drying
3x Filtration paper	1,47		0,030	loss of Pt (from Pt salt) not used during the reduction polyol synthesis found in the filtrate
H20	300,00		0,000	loss of C not used during the synthesis, found in the filtrate + on filtration paper
			300,00	H2O - removed after filtration
			0,003	Pt loss (from Pt/C weight) during filtration step (2w.% on filtration paper) (g)
Energy			0,004	C loss (from Pt/C weight) during filtration step (2w.% on filtration paper) (g)
Electricity (kWh) - Oven	6,600		1,47	3x filtration paper
Electricity (kWh) - Vacuum pump	0,105		0,334	Pt/C (Catalyst powder)



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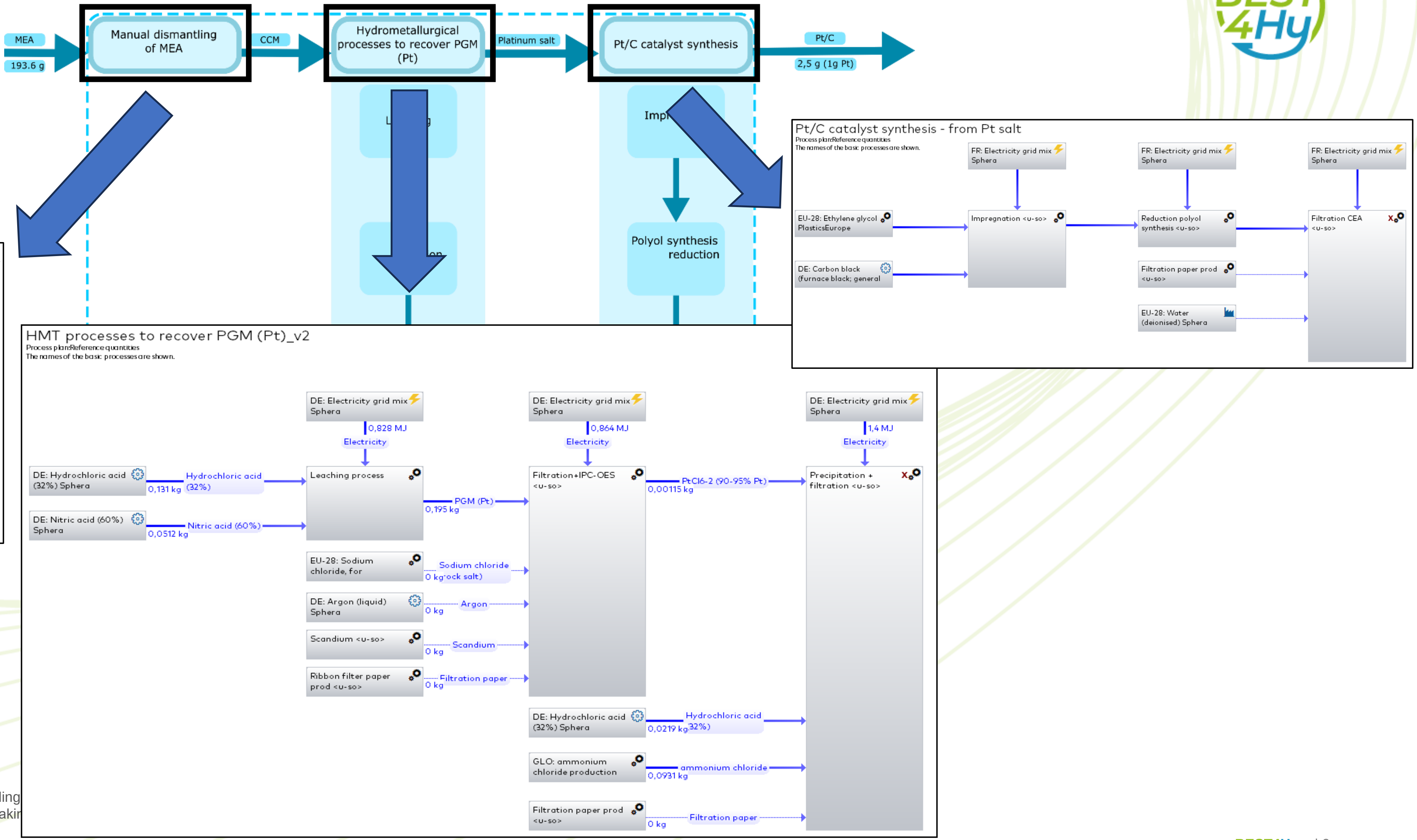
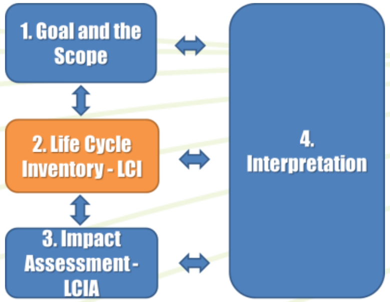
EoL phase (Pt REC) - LCI analysis and LCA modelling





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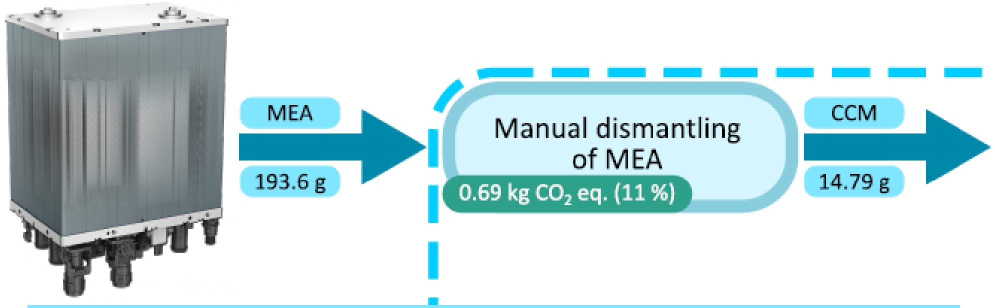
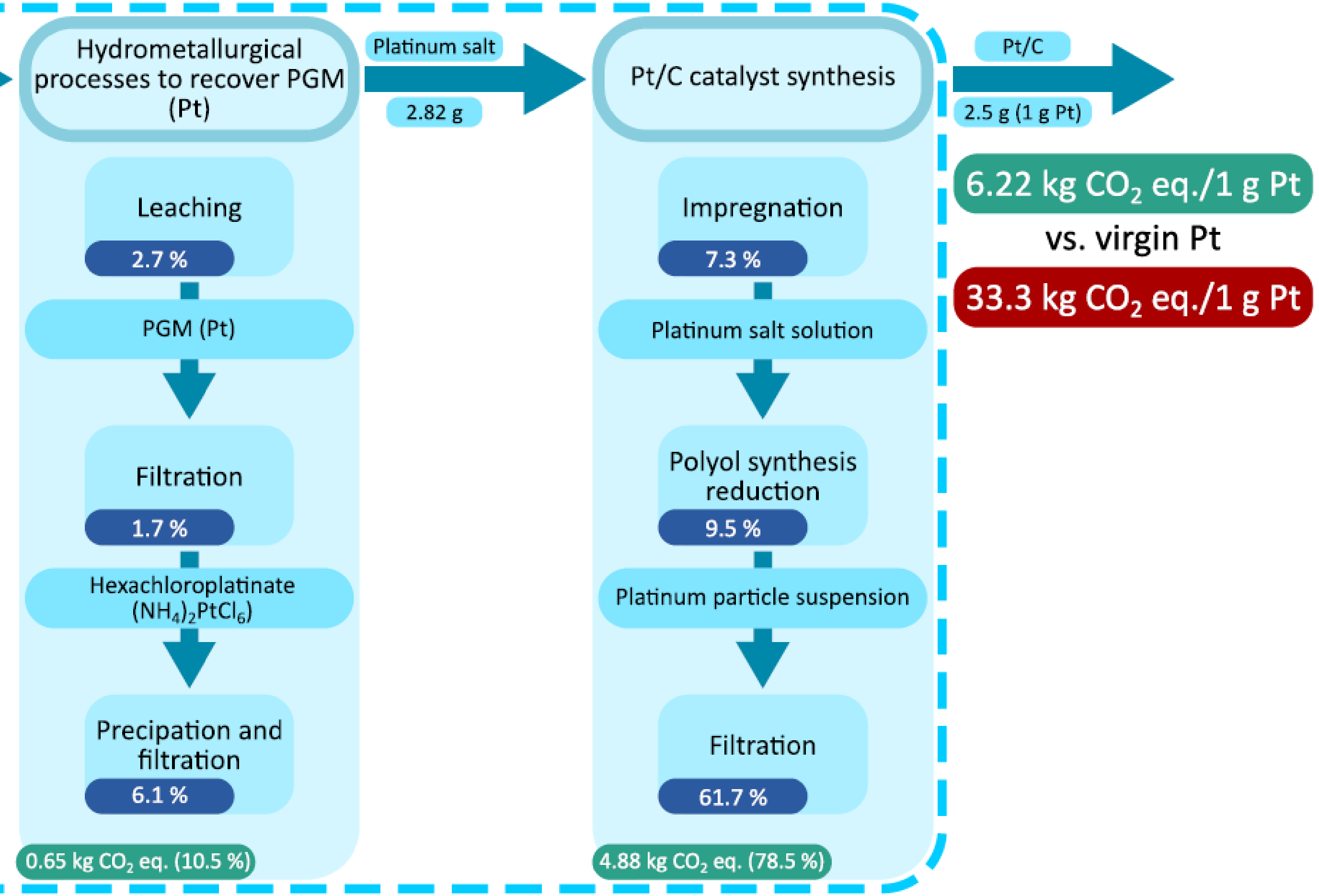
EoL phase (Pt REC) – Climate change [$CO_{2eq.}$] Results

EKPO FUEL CELL TECHNOLOGIES





- Scope: existing EoL for PEMFC (gate to gate/grave)
- Functional unit: 2.5 g Pt/C (1 g recycled Pt)
- LCI: MEA input based on 48 kW waste PEMFC stack (EKPO) and TRL5 EoL process (Hensel recycling Deutschland)
  Input: mass of membrane electrode assembly (MEA): 193.6 g
- Output: mass of platinum on carbon support (Pt/C): 2.5 g
- LCIA: Environmental footprint 3.0 impact assessment methodology with target impact indicators: climate change, acidification, eutrophication, and resource use
- Results:
  - Virgin Pt production (IPA): 33.3 kg CO_2 eq./1 g Pt
  - Recycled Pt/C production: 6.22 CO_2 eq./1 g Pt
  - In the case of recycled Pt the reduction of CO2 eq. is 81 % per gPt
- At TRL 5 65.3 % of Pt could be recycled from waste PEMFC stack

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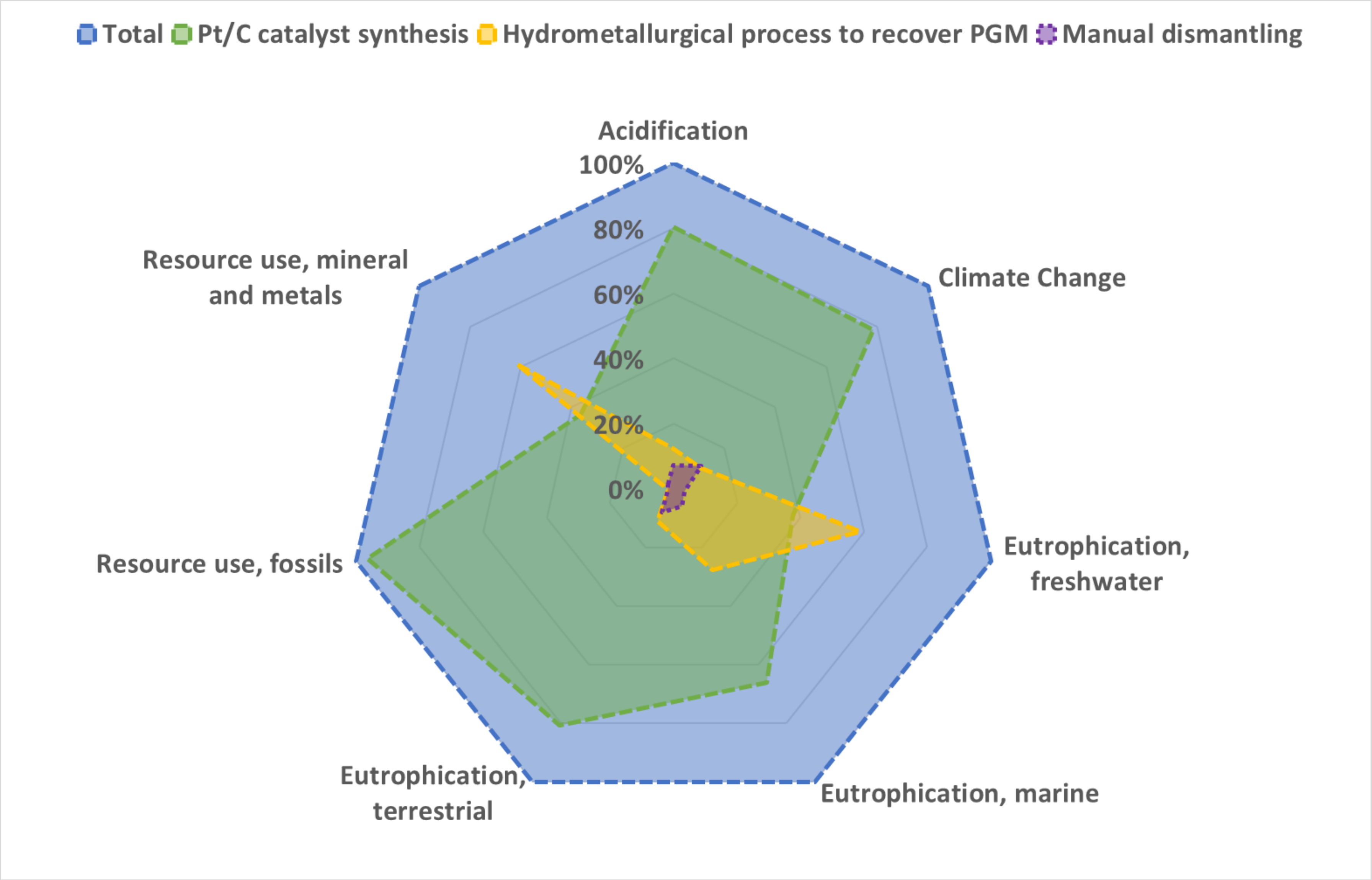
EoL phase (Pt REC) – share of processes in total en. impacts



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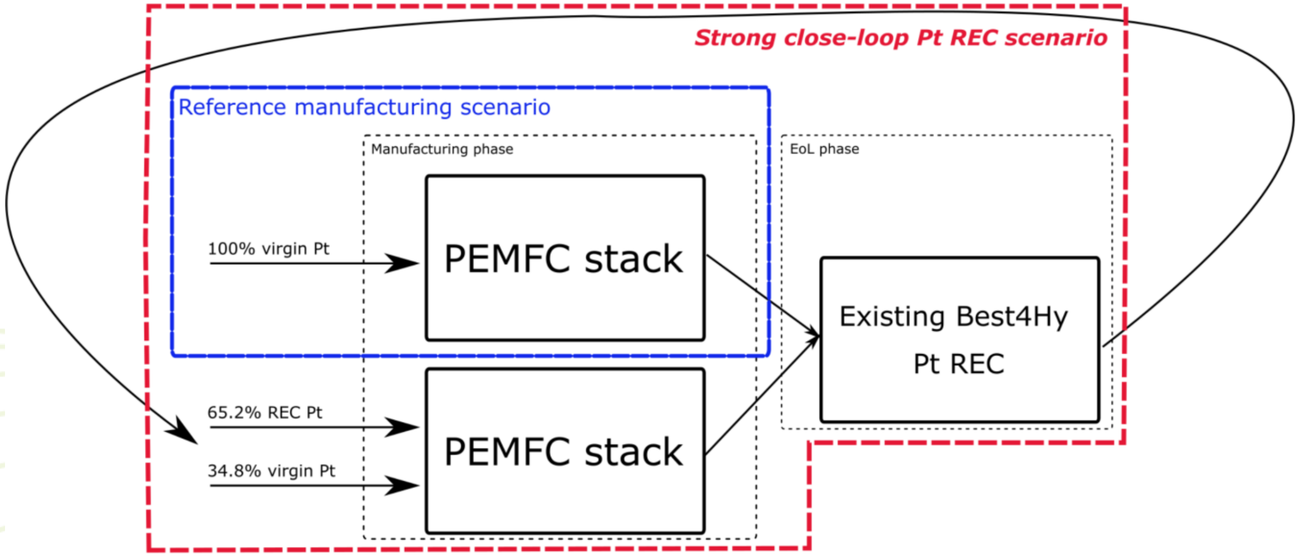
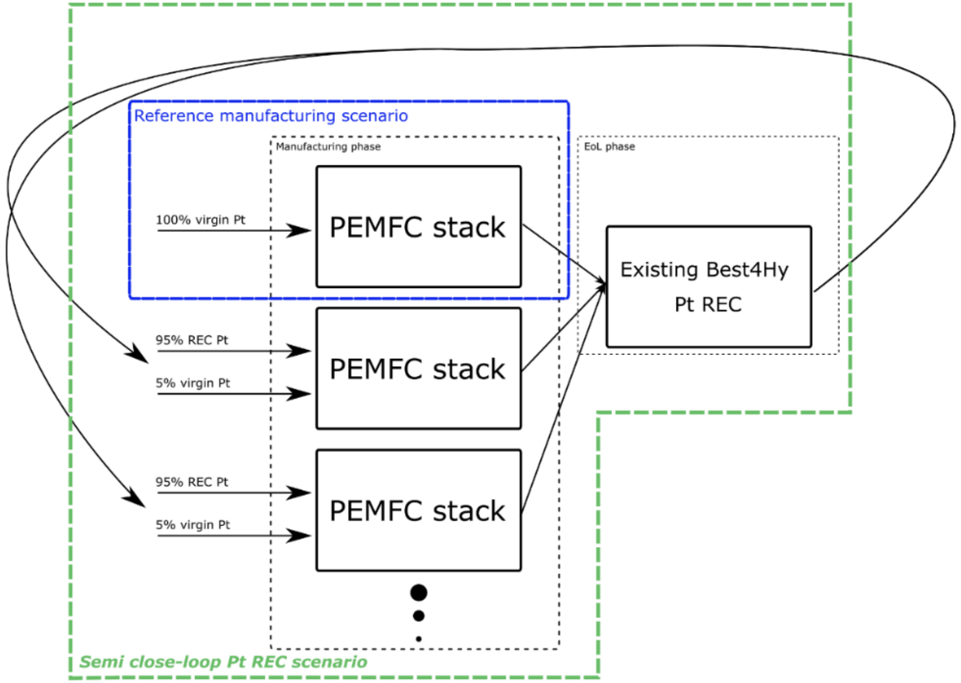
Close loop Pt recycling

1. ***Strong close-loop Pt REC:*** This scenario includes close-loop for Pt recycling according to the Existing Pt REC within BEST4Hy project with **current lab. scale Pt recovering efficiency.**
2. ***Semi close-loop Pt REC:*** This scenario focus on **KPI-2 (Hydrogen innovation agenda) for recycling of Pt (2024 target: 95% of secondary Pt) and goal of BEST4Hy.** For this scenario **95% of recycled Pt** (existing BEST4Hy Pt REC) and **5 % of virgin Pt** is used for manufacturing of the reference 55kW$_{el}$ PEMFC stack.





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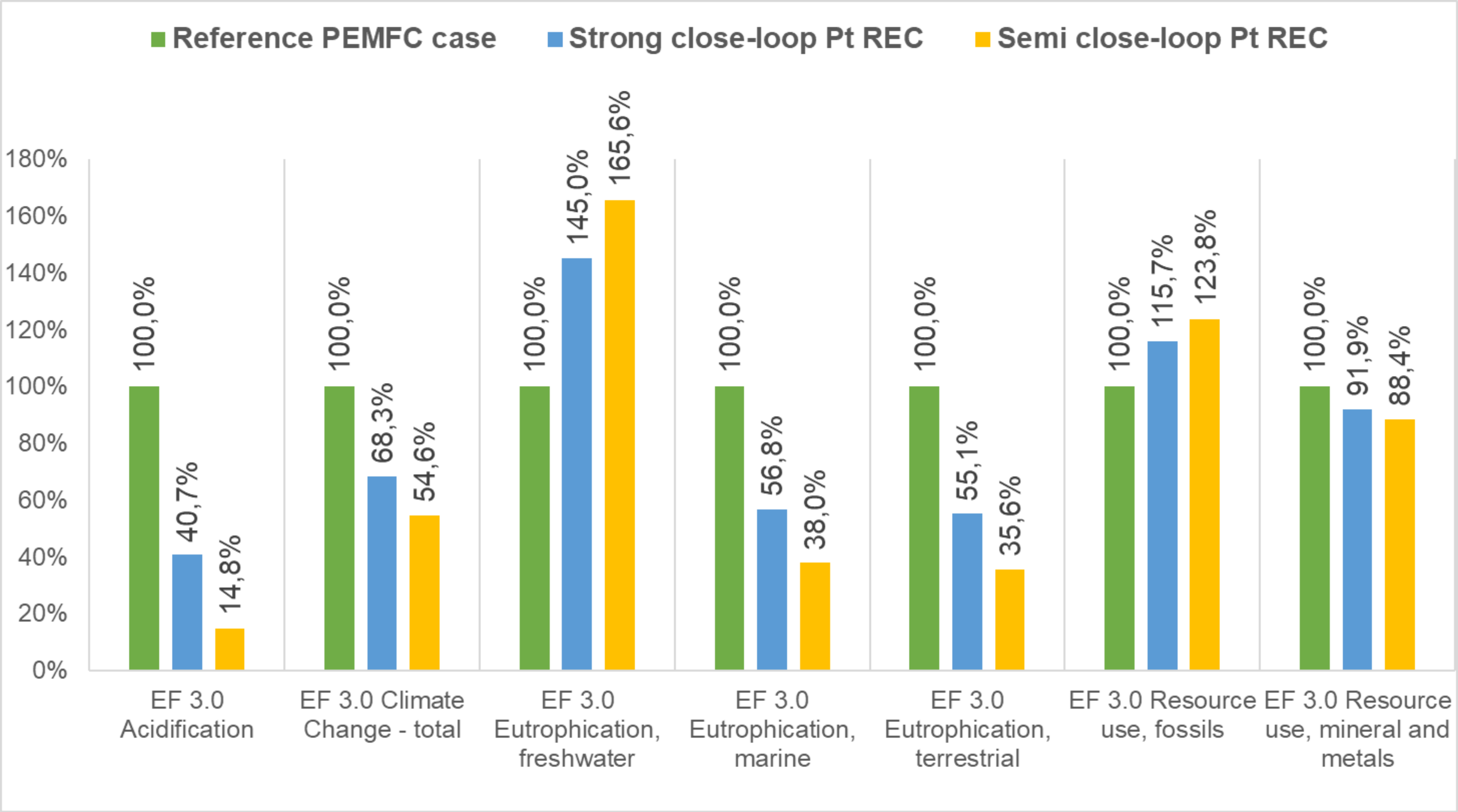

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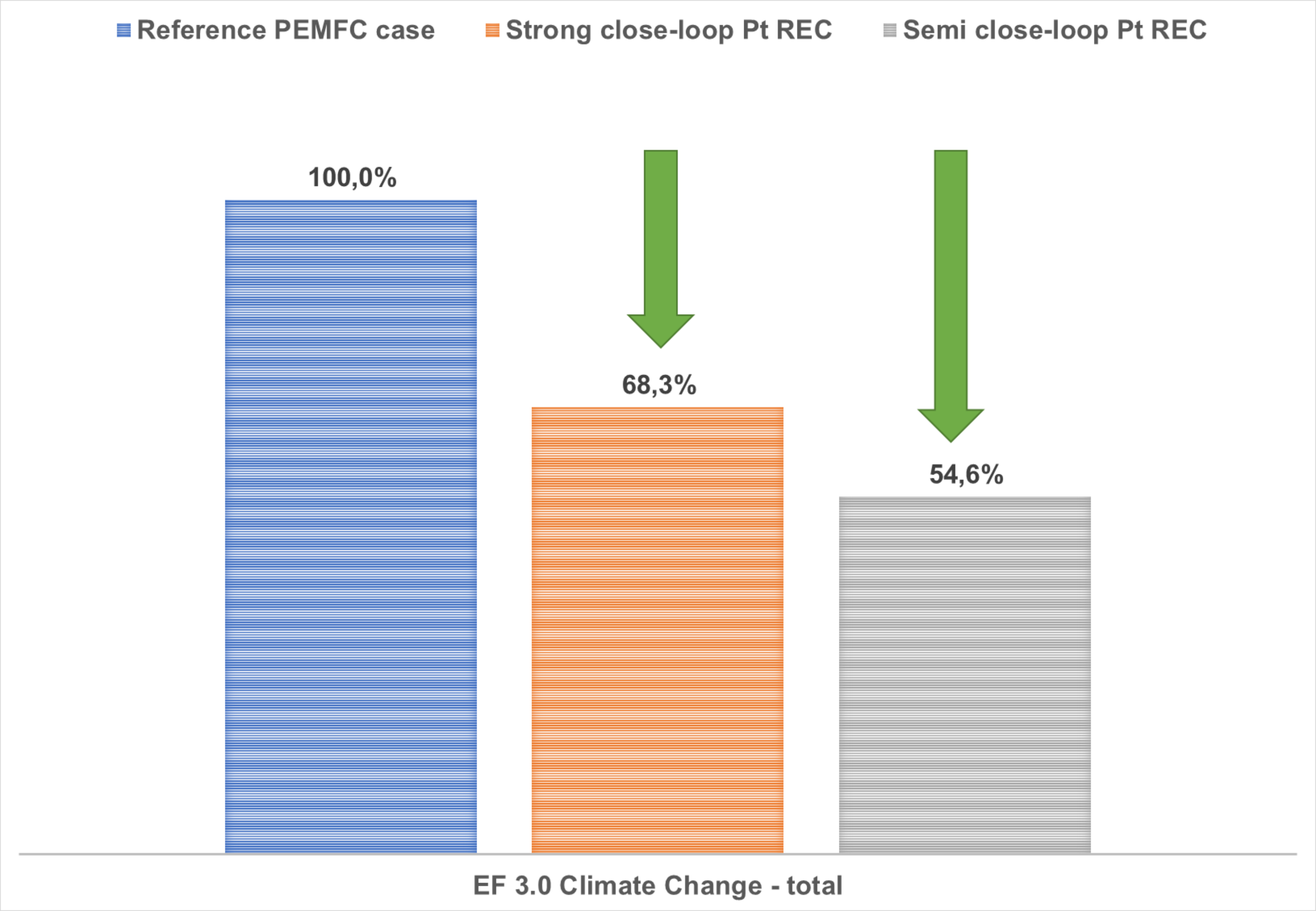

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LCA of existing and novel EoL technologies

- **6 novel inventories** from TRL2 – TRL5 for PEMFC and SOFC technology
- **Step by step process models** with all relevant mass and energy flows
- Hot spot analysis for **further data improvement**
- Environmental impacts **(also in close loops)**
- **3 deliverables (2 Public):**
  - D5.1 - **Environmental profile of existing EoL technologies** and effects in the scope of circular economy in manufacturing phase (PU)
  - D5.2 - **LCA and LCC** impacts of novel EoL technologies and ecolabelling of FCH products (PU)
  - D5.3 - Guidelines for the setup Ecolabelling qualification (CO)
- Horizontal **results sharing**

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Life Cycle Cost

Mathematical model

Validation: Case of HMT route – Pt salt as valuable

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LCC of existing and novel EoL technologies

- LCC methodology according to the guidelines defined in the SH2E project (https://sh2e.eu/)
- Due to the specifics of the EoL industry (some modifications)

Cost breakdown:

- **CAPEX**
  - Land and building construction
  - Engineering, planning & construction
  - Equipment cost
- **OPEX**
  - Salaries
  - Equipment maintenance
  - Insurance, permits, duties
  - Purchased materials and services
  - Waste PEMFC stacks
- **Revenues**
  - Pt salt
  - Other sold materials (Al, SS, Cu)

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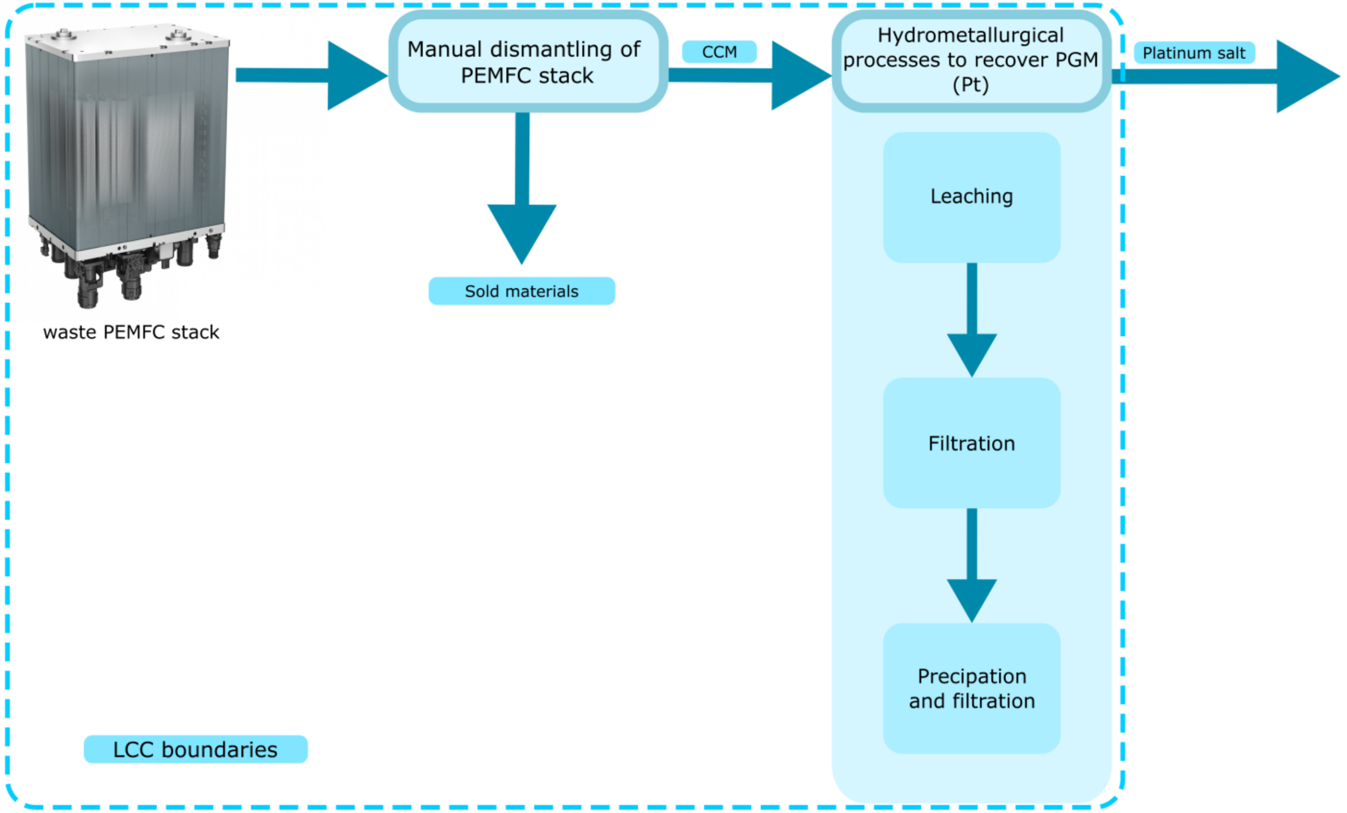
LCC of existing and novel EoL technologies

- **Boundary conditions** – from waste PEMFC stack to Pt salt (HMT)
  - Capacity: **1000 stacks per year** (after 10 years 2000)
  - Operation lifetime: start 2025 (2026)
    - Recycling line equipment – 10y
    - Building – 20y

  - Nominal interest rate: 5 %
  - Inflation rate: 2.08 %
  - Real discount rate: 2.86 %
  - Electricity price: 0.1904 €/kWh
  - Profit tax: 30 %
  - Maintenance increase: 1 %/year
  - Waste PEMFC stack: 490 €/stack
  - Pt salt: 27 €/g



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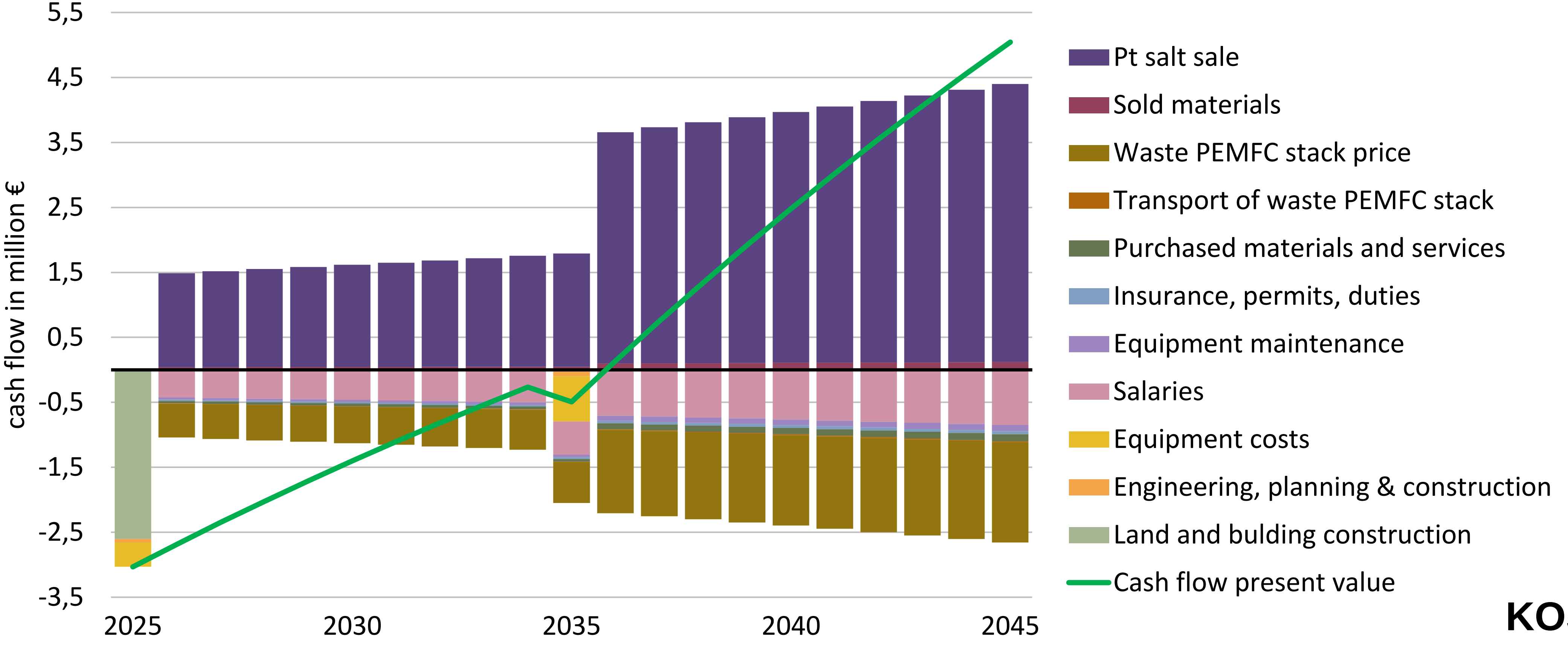
LCC of existing and novel EoL technologies

- **NPV = 5,044,114 €**
- **IRR = 15.62 %** (i=5%)
- **LC of Pt Salt = 17.05 €/gPt salt (**27€/gPt salt (HRD), 40-140 €/g Pt salt market price**)**



KO5

57.4 % - 87.8% reduction to market price

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LCC of existing and novel EoL technologies

- **Mathematical model** adapted from SH2E to the recycling process
- Model **tested for HMT (Pt salt)** recycling process
- **Model applicable** to all recycling processes with needed:
  - Industry data
  - General economic market data
  - Assumptions of future situation in economic markets
- **Improvement** needed to include **dynamic price variations**

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POGANJAMO PRIHODNOST

WE PROPEL THE FUTURE

Univerza v Ljubljani Fakulteta za strojništvo

University of Ljubljana Faculty of Mechanical Engineering

Thank you!

University of Ljubljana, Faculty of Mechanical Engineering, Laboratory for Heat and Power, Slovenia

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