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Task 7.1 LCA/LCC

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OUTLINE

- LCA/LCC goal and scope
- Life cycle inventory
- LCA/LCC methodology
- LCA/LCC results and discussions
- Conclusions

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LCA Goal and Scope

- **Goal**
  - understand the environmental performance of the BLAZE system, under optimal operating mode
  - Compare BLAZE system to competing technologies (PEM)
  - To be communicated within the consortium to guide early design decisions and understand the impact of choices
  - Potential for scientific publication or contribution to LCA database

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LCA Goal and Scope

- **Scope**
  - System life-cycle excluding use of outputs
  - Primary data from pilot system and models
  - Secondary data using Ecoinvent database v3.6
  - Impact assessment methods: IPCC2013, ImpactWorld+
  - Align with FC-Hy guide, ISO14044 for fuel cell LCA

- **Functional unit**
  - producing 1 kWh electricity in IT in 2023

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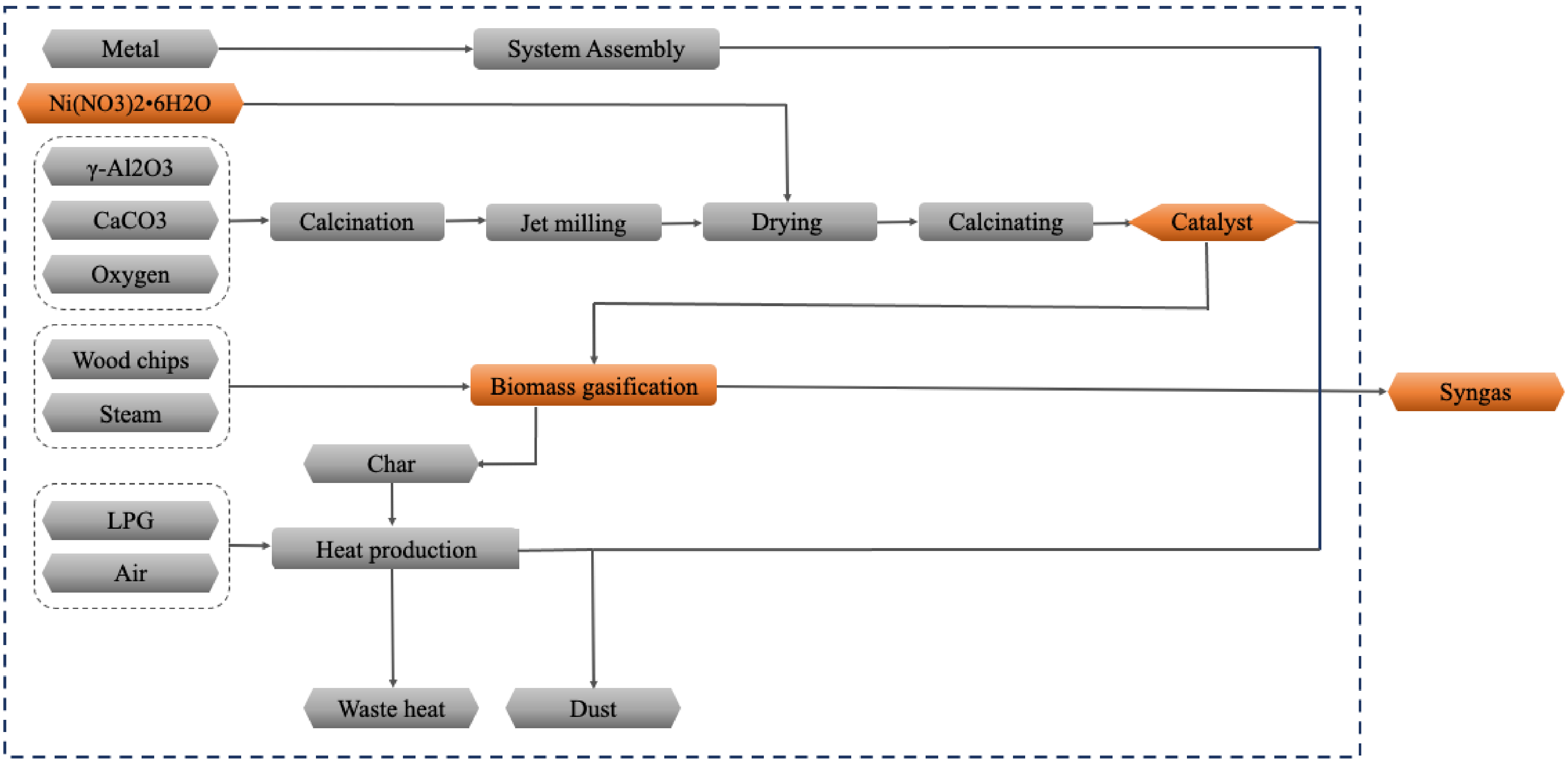
Biomass Gasification Process Tree



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SOFC System Process Tree

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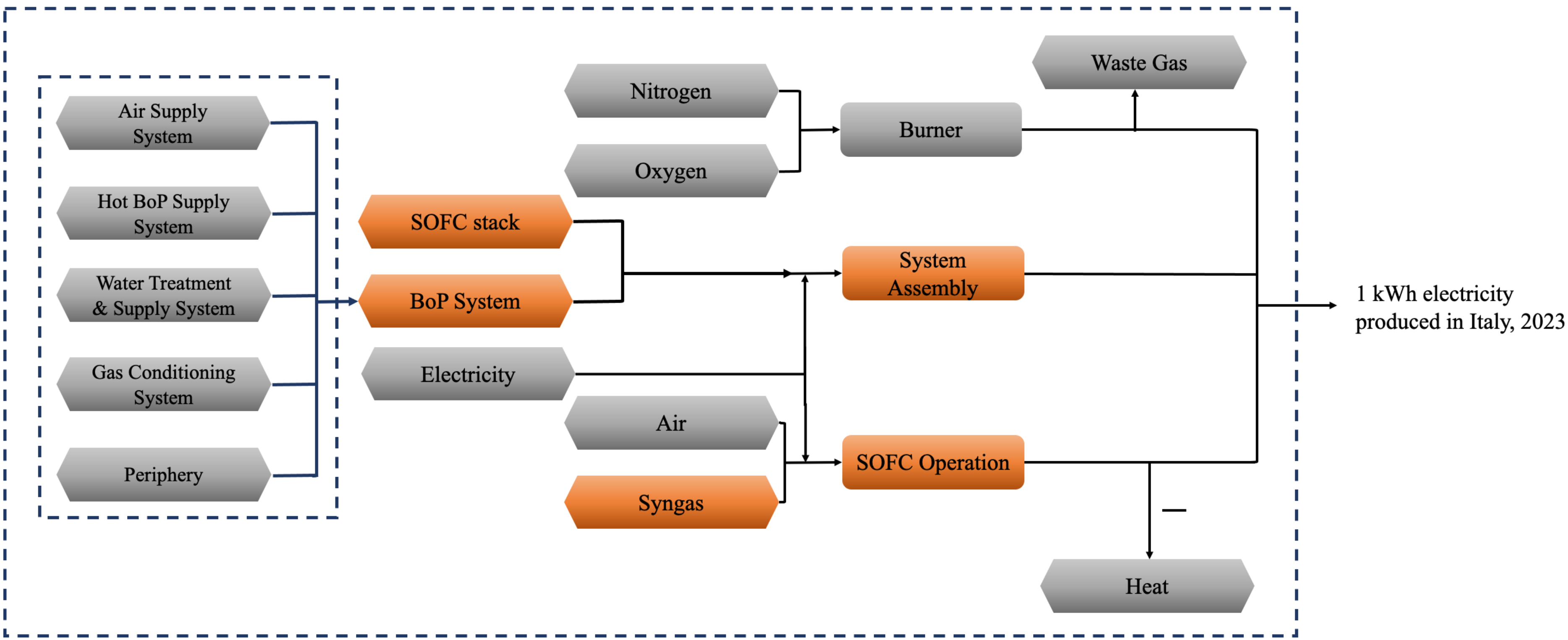

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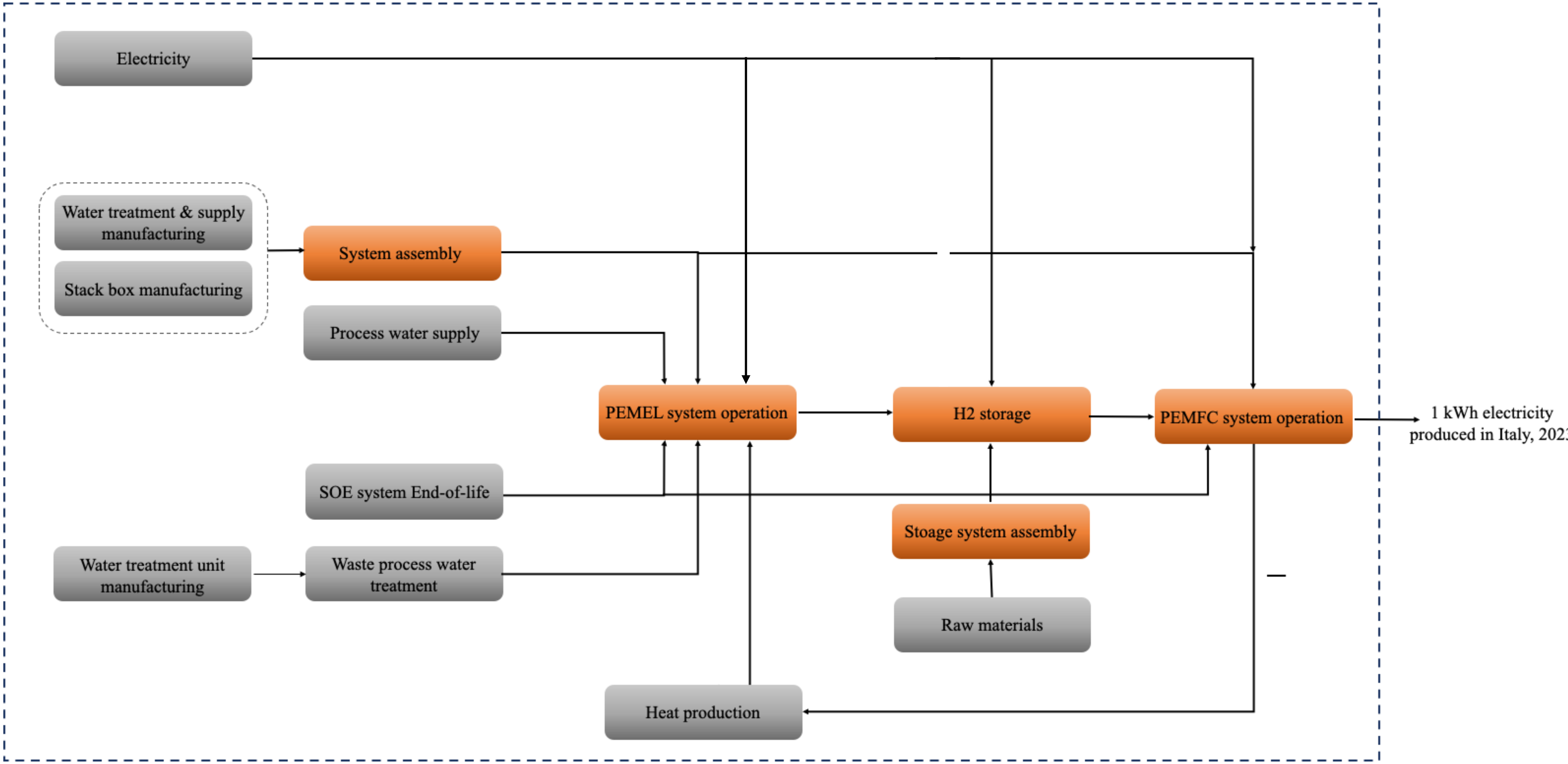
PEM System Process Tree



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Life Cycle Inventory

- Biomass gasification (lab testing data)

Biogasification Process Data		
Input Data		
	Unit	Scaled Value per FU
Catalyst	kg	0.0002
Almond/Hazelnut Shells	kg	0.6027
Steam	kg	0.3616
Heat from Heat Production	kWh	Utilized in the System
Output Data		
Syngas	kg	0.9644
Dust	kg	0.0022
Waste Heat	kWh	0.0030
Char	kg	0.0603

Catalyst Production Process Data		
Input Data		
	Unit	Scaled Value per FU
Ni(NO3)2•6H2O	kg	0.0004
γ-Al2O3	kg	0.0009
CaCO3	kg	0.0016
Oxygen Flow	kg	0.0000
Output Data		
Catalyst	kg	0.0002
CO2	kg	0.0001
Nitrogen Oxides	kg	0.0000
H2O	kg	0.0000

- SOFC operation

SOFC System Operation Data			
Input Data			
		Unit	Scaled Value per FU
Sysgas		kg	0.9644
Air		kg	7.3771
Steel		kg	0.0059
Electricity		kWh	0.0128
Burner	O2	kg	0.4025
	N2	kg	1.3255
Output Data			
Electricity		kWh	1.0000
O2		kg	1.3640
N2		kg	6.9847
H2O		kg	0.8048
CO2		kg	0.9600
Heat		kW	0.0250

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LCA Methodology

- Functional Unit (FU): 1 kWh electricity production.
- System expansion is used in dealing with system multifunctionality.
- Avoided system for heat production: *market for heat, central or small-scale, natural gas, IT.*
- Climate change (CC), ecosystem quality (EQ), human health (HH) impacts have been used in LCIA.

➢ Assumptions

- SOFC stack lifetime = 5 years.
- BoP lifetime = 10 years.

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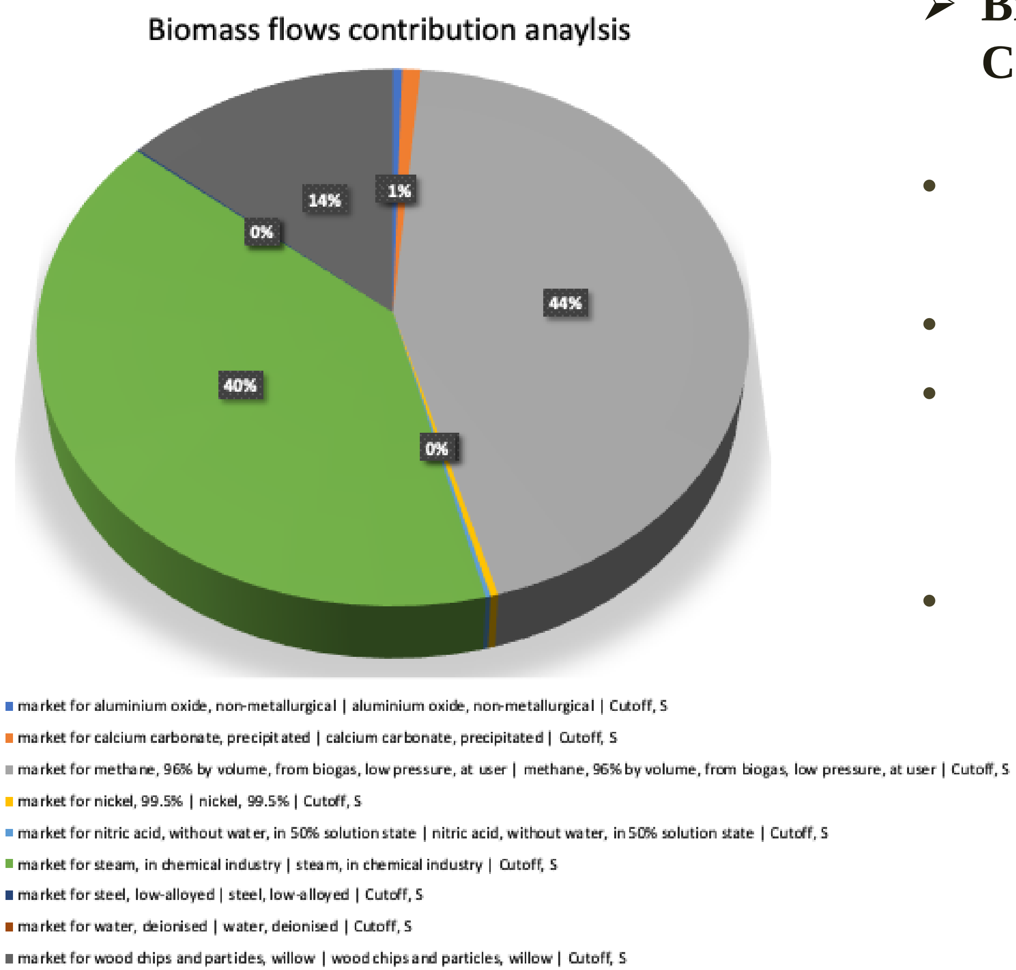
Results and Discussion



➢ **Biomass Gasification CC Impact Contribution Analysis**

- Biomethane is used to supply heat required and it contributes 44%.
- Steam used in gasifier, contributes 40%.
- Wood as input, contribute 14%, which is relatively low compared with catalyst production.
- Catalyst lifetime is assumed as 6 months, if it can be improved in future, it can improve environment performance.

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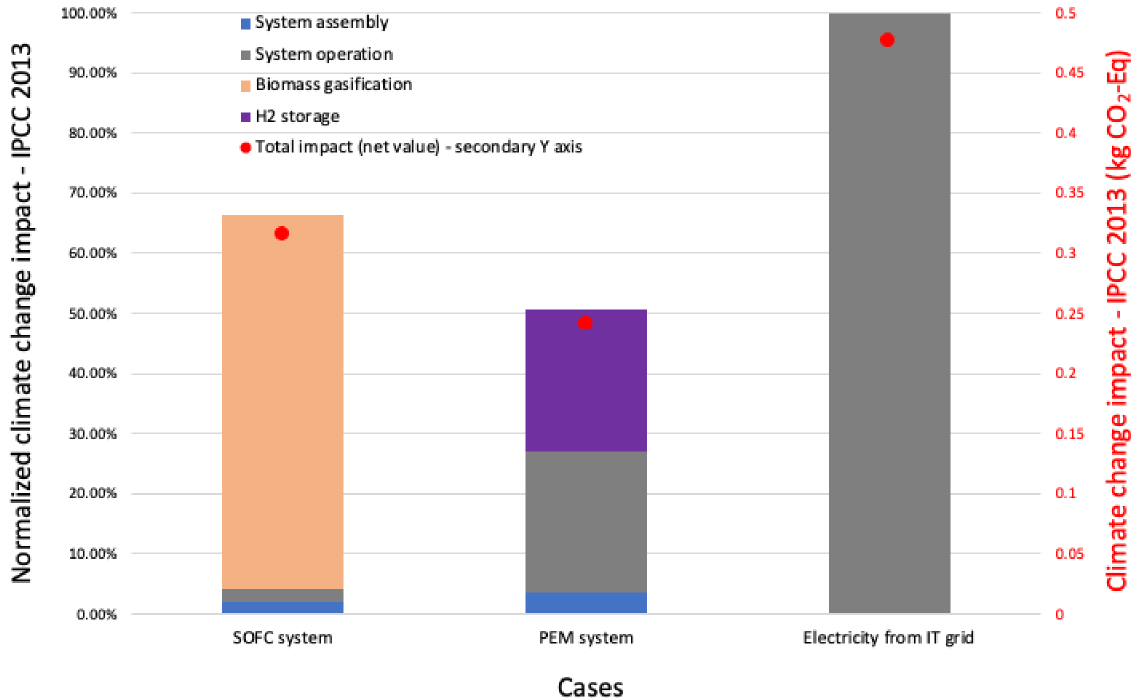
Results and Discussion

➢ **Three Technologies CC Impact Analysis**



- Gasification-SOFC, PEM, and electricity from IT grid have been chosen to study.
- PEM shows the best performance in CC assessment, which is around 0.25 kg CO2-eq.
- SOFC system is slightly higher than PEM (0.31 kg CO2-eq), but much better than electricity from grid.
- Within Gasification-SOFC system, biomass contributes most, due to catalyst production. In case of PEM system, H2 storage contributes the most.

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Results and Discussion

➢ Potential LCA impact of BLAZE system

- Steam can be generated from BLAZE plant internally, instead of purchasing it.
- BLAZE biomass gasification system can reach below 0.1 kg CO2-eq/FU
- SOFC operation and SOFC system assembly will become key unit processes

✓ SOFC stack manufacture detailed LCA

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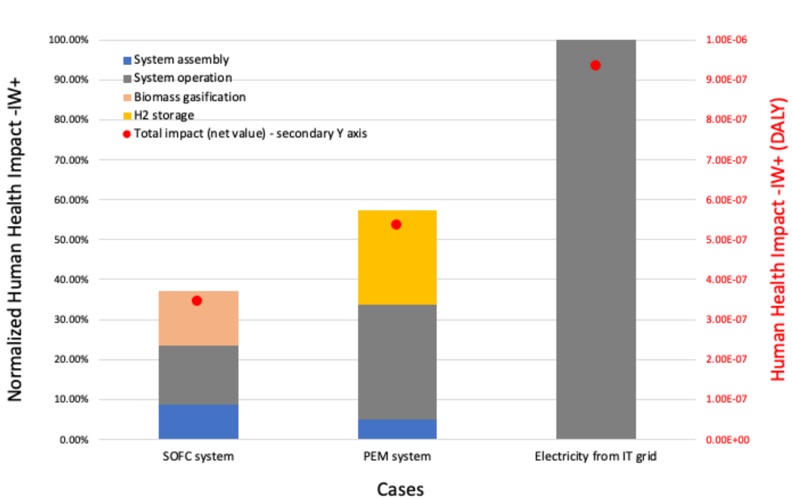
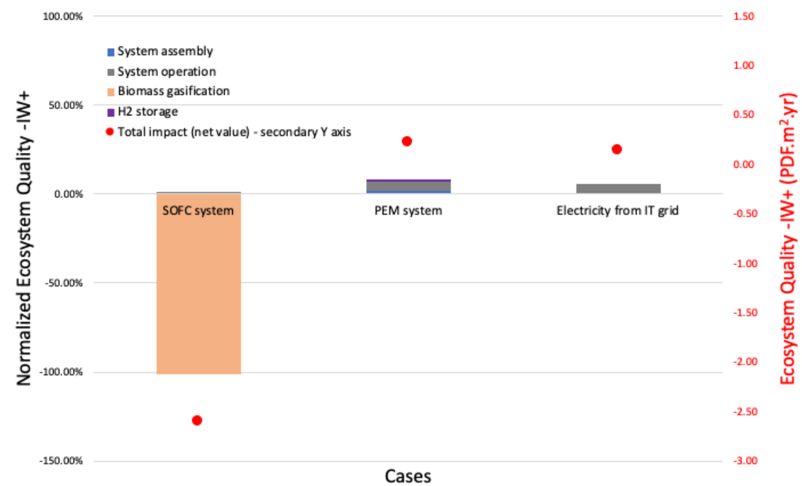
Results and Discussion

➢ Three Technologies HH & EQ Impact Analysis





- HH and EQ show that Gasification-SOFC system is much better than other two technologies, due to the usage of nature resource – wood.
- Similarly, catalyst production, H2 storage and system operation contribute most to system in HH, whereas in EQ, wood application shows negative value, indicating the benefit in improving environment.

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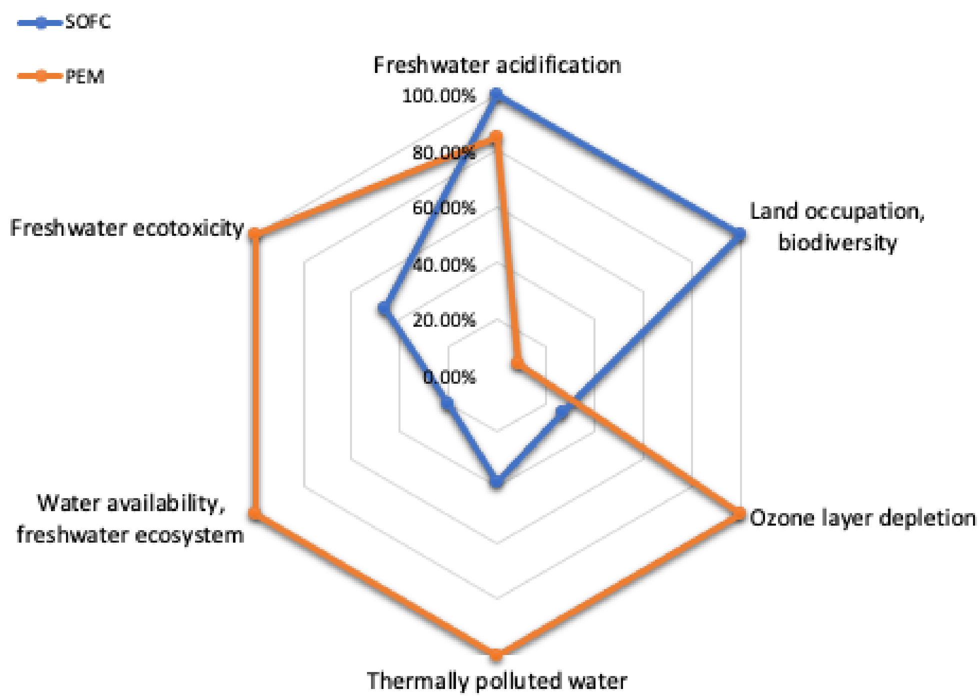
Results and Discussion

➢ **Other Impact Analysis**

- ✓ PEM shows better performance in freshwater acidification and land occupation.
- ✓ Gasification-SOFC system is much better in other indicators compared with PEM.
- ✓ Climate change is critical, but other impact assessments are important to include.
- ✓ Gasification-SOFC can still be improved by optimized catalyst production.



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LCC Goal and Scope

- **Goal**

–Understand the system overall capital (CAPEX) and operational costs (OPEX)

–Understand CAPEX/FU, OPEX/FU (1 KWh electricity)

–Perform Life Cycle Cost analysis (LCC) together with a cost benefit analysis

–Perform case studies to make it possible to compare the proposed hydrogen/electricity production system of fuel cells with currently used technologies

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LCC inventory

–Equipment cost data from project partners

–Operational data from database: ERUOSTAT, IEA

–LCC method: Net present value calculation with a fixed discount rate

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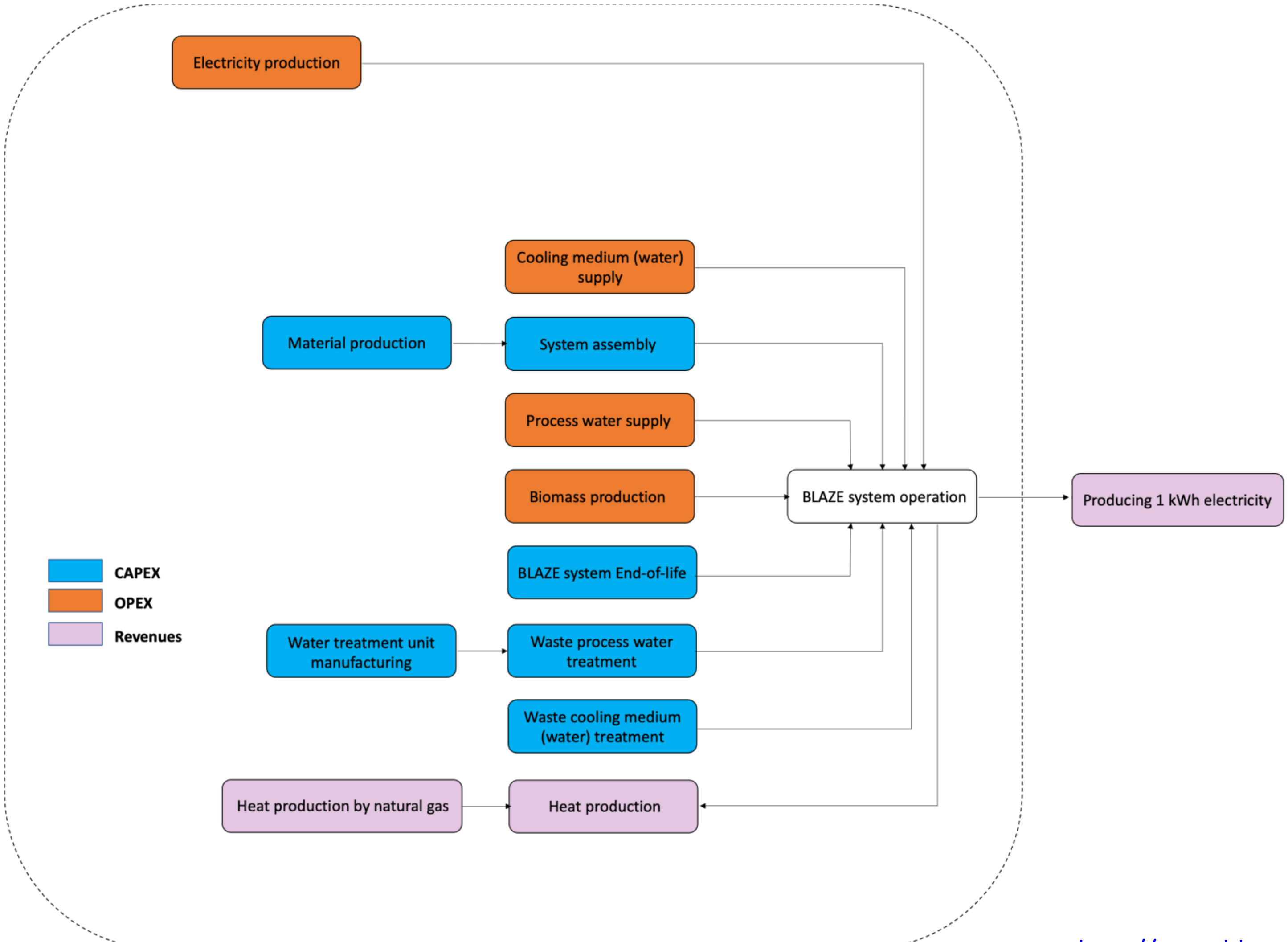
LCC Process Tree



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LCC literature review

- **Discount rate, Time horizon**

i	0.06	Investor's interest rate
r^n	0.06	Discount rate (for depreciation)
n	10	Time horizon
r^r	0.06	Real discount rate

–Time horizon is same as equipment lifetime
–25 years' time horizon has also been tested in further analysis

- **Findings**

Location	Discount rate	Note
Poland SDR	5%	SDR value based on the EU recommendation for CEE countries, 4.72% is from research
Panama	5.60%	Assuming time consistent exponential discounting. The exponential discount rate (rE) is estimated to be 5.6%.20 The positive discount rate suggests that people discount future payment streams in land use contracts and prefer receiving payments sooner rather than later. This estimated discount rate is close to comparable market interest rates for loans in Panama. For example, Banco General offers financing at 7.25% for land purchases on fixed 10-year terms and personal loans at rates of 6.5 – 17%.21 Across the banking sector, the interest rate on livestock and agricultural loans averaged 5.56% and 6.25%, respectively, during the months when our survey work was conducted.22 The estimated 5.6% discount rate is also close to the social discount rate for Panama of 6.0% estimated by Addicott et al. (2020) using an age-dependent Ramsey rule.
OMB	7%	For residential photovoltaic (PV) power systems
German	9.20%	There is +/-50% uncertain
Europe	9%, power generation industry	The discount rate range for an EU member is suggested to be between 3% and 6%

–For Europe, discount rate is between 3% - 6%, depending on location, and industry properties
–OPEX data is based on 2022 S1 Europe database
–In LCC, OPEX, CAPEX all varied in different year, to represent inflation

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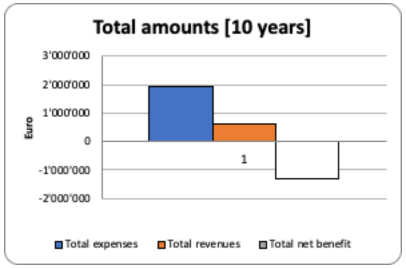
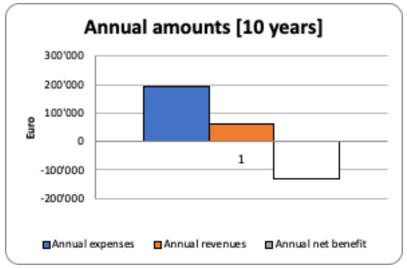
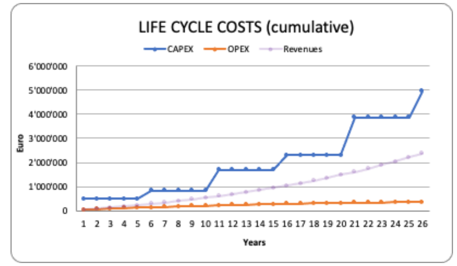
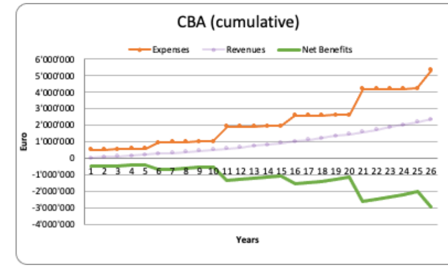
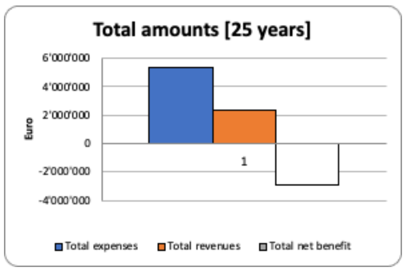
LCC General Results

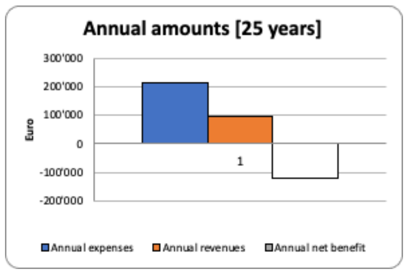


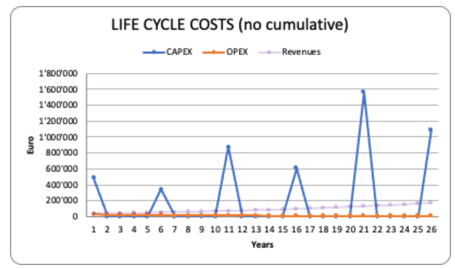


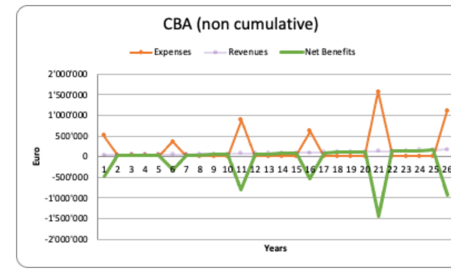












- Assumed CAPEX based on literature review and other EU projects
- Inflation is considered
- Expenses represent the summation of OPEX and CAPEX
- Revenues constitute the earnings from electricity and heat produced
- Net benefit illustrates the profit of the project – always shows negative value

- CBA mainly provides a general analysis of project profit, and the variation within the life time.
- LCC shows detail information such as CAPEX and OPEX contribution.

Project will have lower profitable possibility as the lifetime increases, due to the cumulation of the debt

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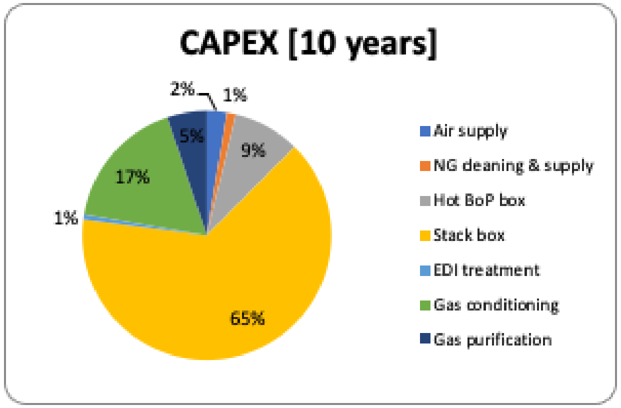
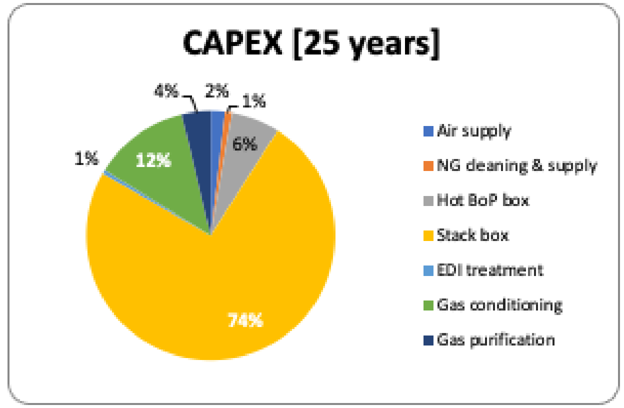
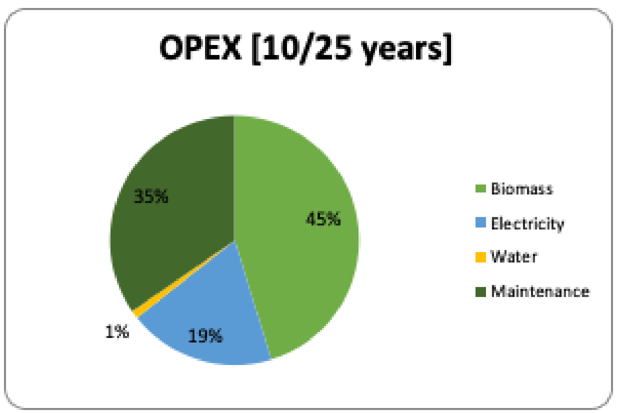
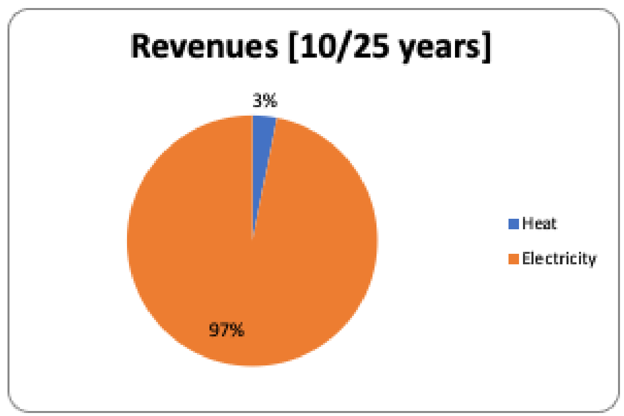
LCC Contribution Analysis





- Stack cost and its lifetime contribute the most in CAPEX
- Longer project lifetime, bigger impact on stack box





- Biomass and maintenance contribute the most in OPEX
- Electricity contributes 96% of overall revenues.

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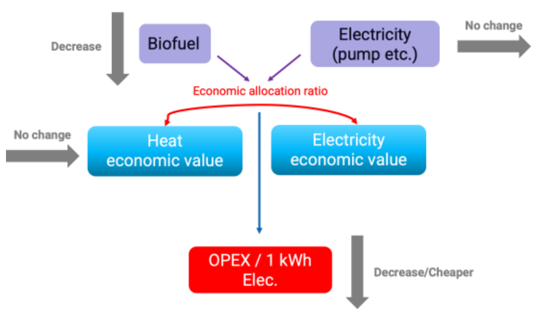
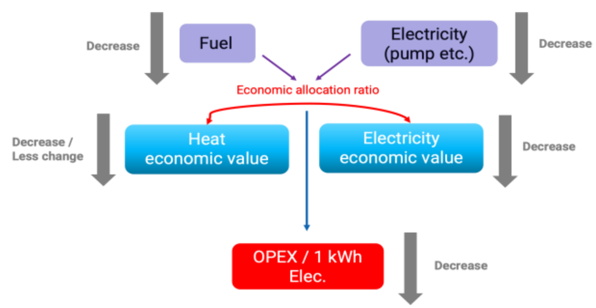
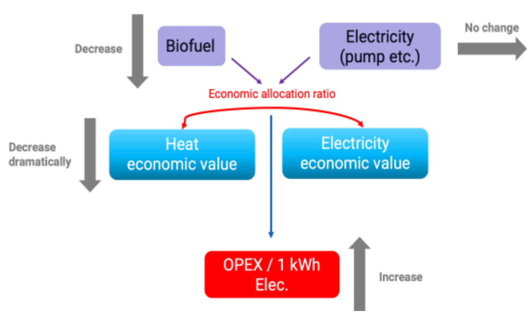
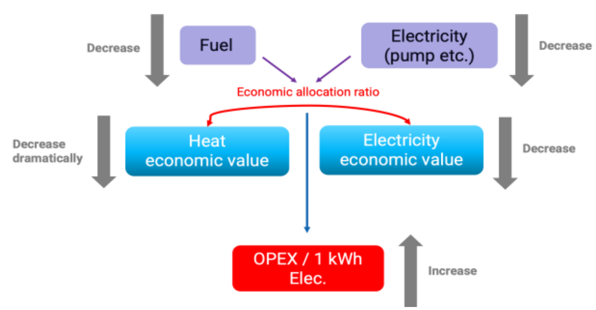
CAPEX/FU, OPEX/FU

- CAPEX / FU: 0.38 Euro / 1 kWh electricity
- OPEX / FU: 0.21 Euro / 1 kWh electricity
- Total cost / FU: ***0.59 Euro / 1 kWh electricity***









- The price is not competitive with market mature technology price
- But SOFC with Biomass gasification is a new process; it is not correct if we only consider current price, without thinking future perspective

–OPEX / FU is strongly related by future market
–CAPEX deduction scenarios are reliable

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Sensitivity analysis

- **OPEX future cost**

Category	Unit	Perspective price
Electricity price in 2050	*€/MWh*	60.00
Biomass price in 2050	*€/m3*	110.00

–OPEX / FU is strongly related by future market
–CAPEX deduction scenarios are reliable

- **CAPEX potential cost**

CASE	Unit	CAPEX / 1 kWh electricity
Case 1	*€/kWh*	0.38
Case 2	*€/kWh*	0.22
Case 3	*€/kWh*	0.17
Case 4	*€/kWh*	0.11

Case 1: Stack box 5 years lifespan, 365 days operating times
Case 2: Stack box 10 years lifespan, 365 days operating times
Case 3: Whole system cost has 25% deduction, stack box 10 years lifespan, 365 days operating times
Case 4: Whole system has 50% deduction, stack box 10 years lifespan, 365 days operating times.

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Sensitivity analysis

- **BLAZE system future cost**

Category	Unit	Perspective price
OPEX	*€/1 kWh electricity*	0.10
CAPEX	*€/1 kWh electricity*	0.17
Total cost	*€/1 kWh electricity*	0.27

- BLAZE system is competitive with natural electricity generation technologies
- CAPEX is critical in price deduction:
  - Material improvement
  - Increase of efficiency
  - Increase of stack lifetime
  - Government help
  - More producers
  - International collaboration

How about plant size impact?

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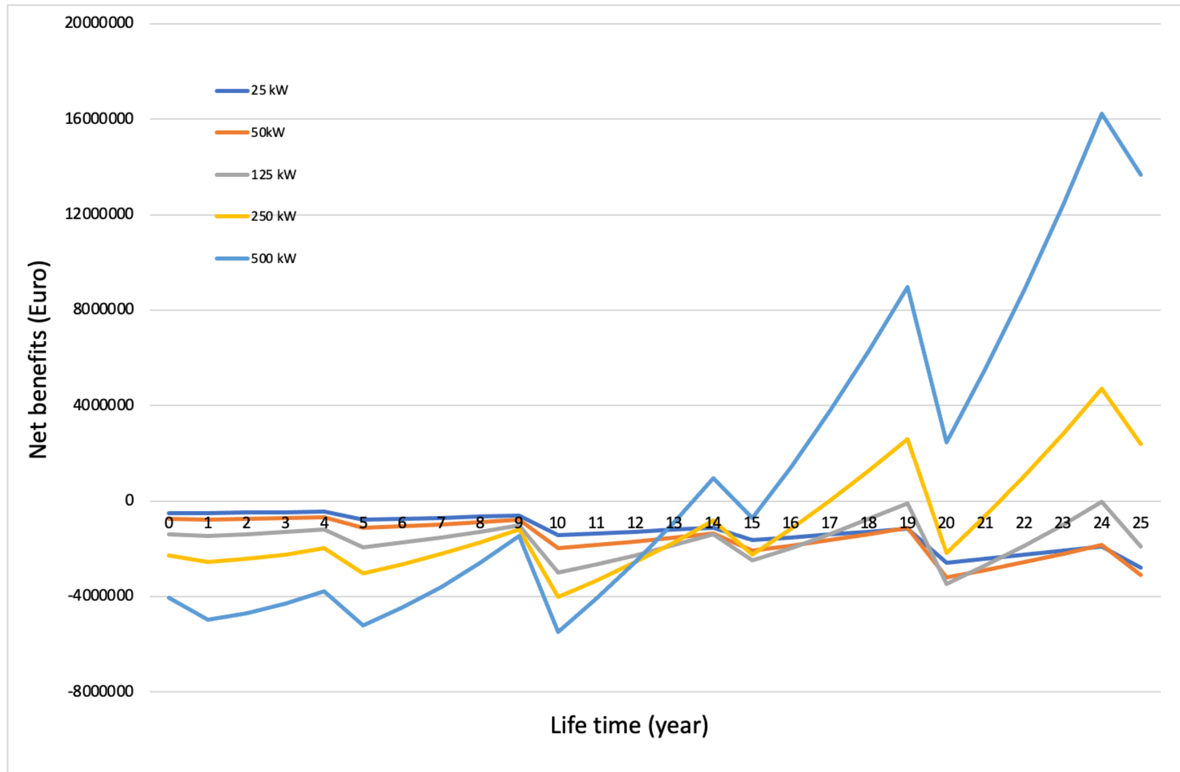
LCC plant size scenarios

- **Cost–to–Capacity Methodology applied**

$$CAPEX_{new} = \left(\frac{f_{scale}}{1}\right)^{0.6} \times CAPEX_{ref} \quad (1)$$

$$OPEX_{new} = \left(\frac{f_{scale}}{1}\right)^{1} \times OPEX_{ref} \quad (2)$$

- Assumed CAPEX based on literature & other EU projects
- Larger scale plant can be profitable within 15 years
- Project has a challenging economic profitability within the first 10 years - expensive CAPEX and short life time of all the components
- SOFC future CAPEX price can use another function



$$C_{BM\_Stack} = 1200 \times 0.9^{\ln(V_{ref} \times J_{ref} \times P_{annual} \times 10^{-5}) \div \ln(2)} \times \frac{CEPCI_{2018}}{CEPCI_{2017}} \times A_{stack} \times f_{istack}$$

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Conclusions

- BLAZE system shows a huge potential in electricity generation technology, with 0.31 kg CO2-eq/ FU emission.
- BLAZE system is better than other technologies in most of impact categories.
- 0.59 Euro / FU can be achieved without considering any future perspective.
- 0.3 Euro / FU can be achieved by applying reasonable assumptions.

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