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Parametric comparative analysis of lifetime energy demand and CO_2-eq savings of a SOFC m-CHP unit

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Overall purpose of the present analysis:

➔ to utilise the results of the Life Cycle Assessment of the fuel cell m-CHP unit developed within project FlameSOFC (FlameSOFC unit) in order to **estimate a critical threshold of operational parameters**, over which:

- the **lifetime energy demand** (overall and fossil oriented) and
- the **lifetime CO_2-eq emissions**

are lower than two competitive cases:

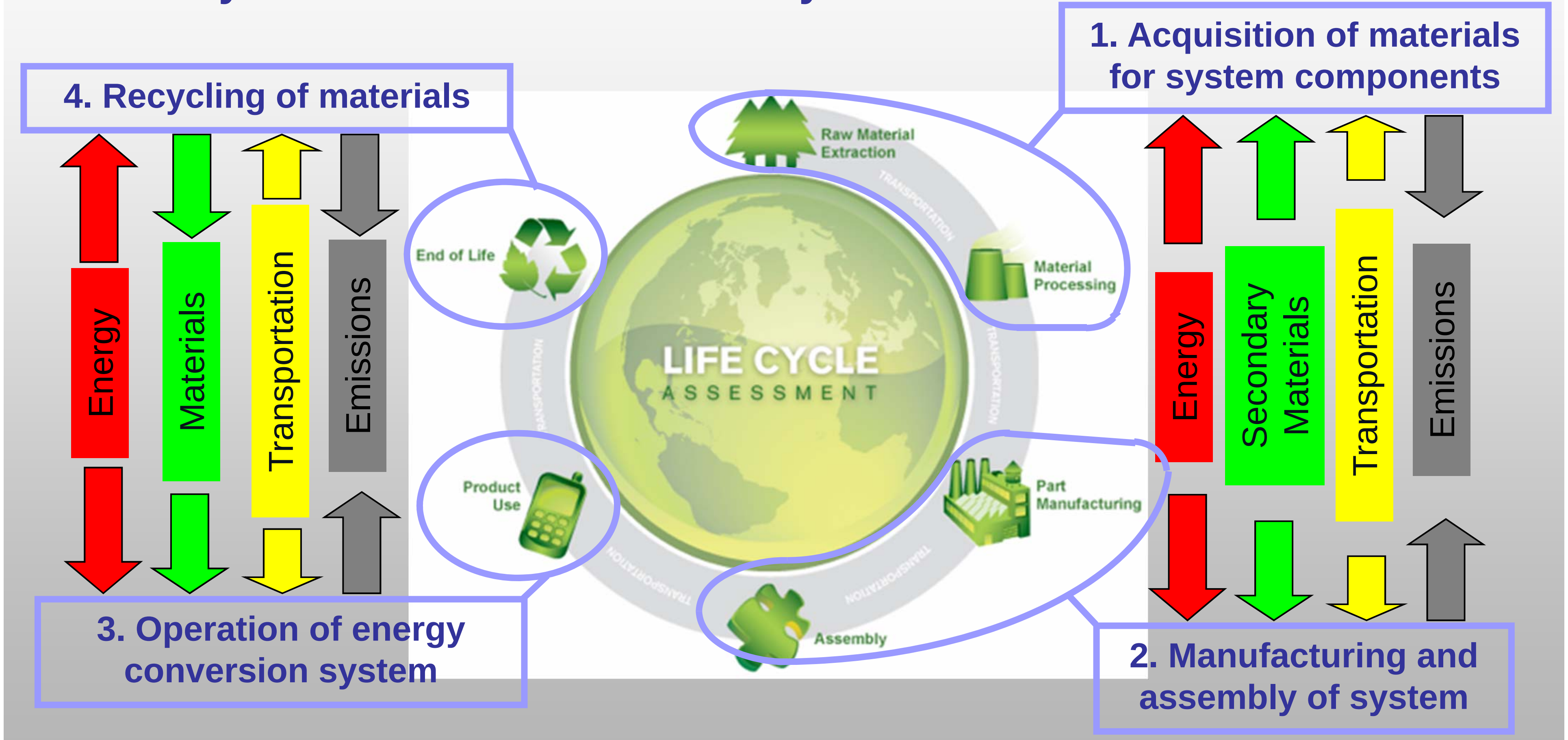
A) A Standard case (**grid electricity and gas boiler**) and

B) A m-CHP case (**Internal Combustion Engine** – ICE of similar power scale).

for a single family dwelling in Central European electric and thermal loads.

Lifetime energy demand – CO_2-eq savings of a SOFC m-CHP unit

Life Cycle Assessment of mCHP systems



1. Acquisition of materials for system components

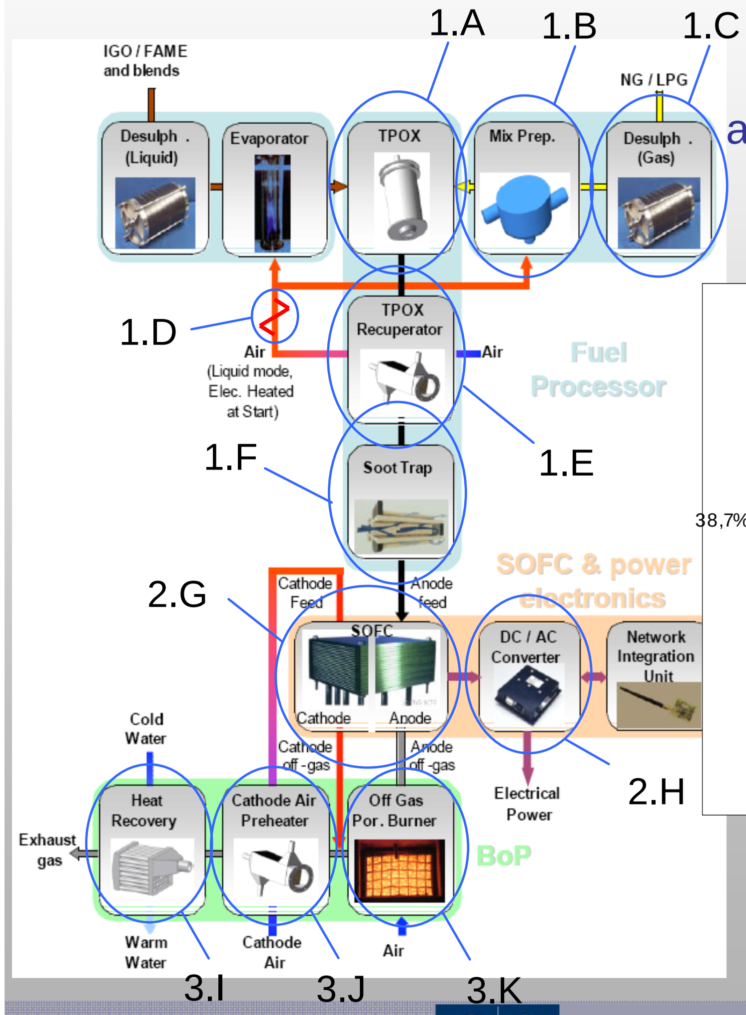
2. Manufacturing and assembly of system

3. Operation of energy conversion system

4. Recycling of materials

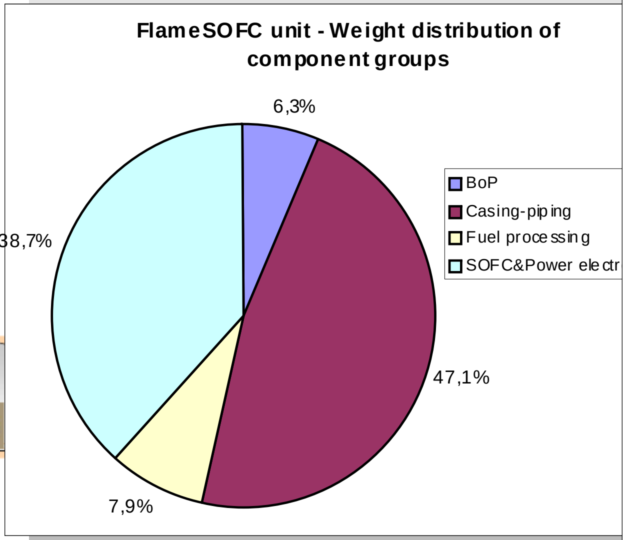
Functional unit: 1 kWh of electricity (exergetic allocation of emissions)

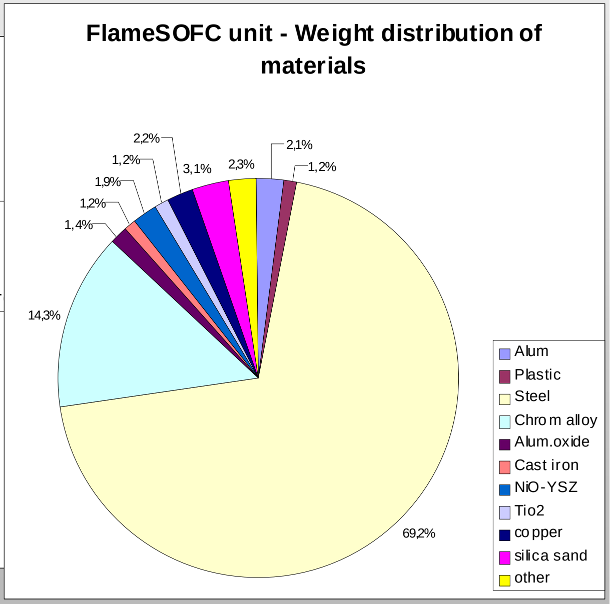
Lifetime energy demand – CO_2-eq savings of a SOFC m-CHP unit



Modelling objective:

A network of raw materials supply (for each subassembly), alongside with the relevant information on energy consumption, material use and emissions/wastes of every process.





Approximately 85% of the total estimated unit weight (254 kg) originates from the SOFC assembly and the casing.

Lifetime energy demand – CO_2-eq savings of a SOFC m-CHP unit

Lack of energy consumptions, emissions and material loss data for all the components → data and assumptions documented in published literature and reliable LCA databases

Major assumptions:

- Manufacturing process energy input: 5% of energy for the production of materials. Material loss during manufacturing: 15% of corresponding material weight in the unit components.
- Regarding the Power Conditioning Unit, manufacturing process energy input and material loss acquired from the Ecoinvent 2.0 LCA database
- Regarding the SOFC module, data adapted from:
  - Ecoinvent 2.0 LCA database
  - Karakoussis et al., “Environmental Emissions of SOFC and SPFC system manufacture and disposal”
  - Little, A.D. Assessment of Planar Solid Oxide Fuel Cell Technology
  - Zapp, P. Environmental analysis of solid oxide fuel cells. J of Power sources

Lifetime energy demand – CO_2-eq savings of a SOFC m-CHP unit

Introduction | Methodology | **Inventory Analysis** | Results | Conclusions

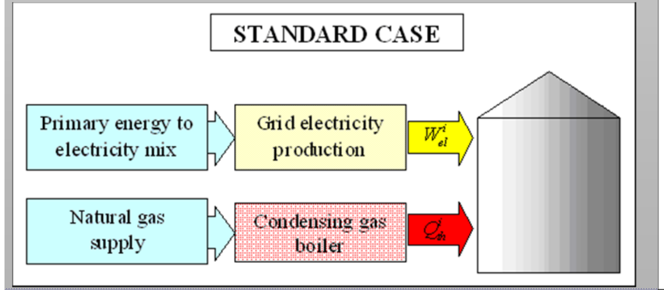
Materials | Manufacturing | **Operation** | End of life

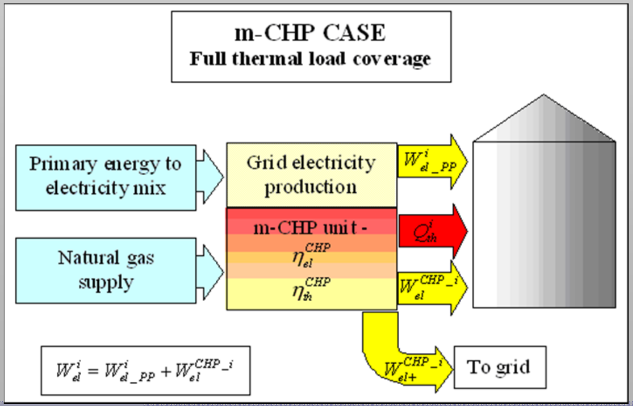
Application: Single family dwelling, Central Europe

Annual loads: W_{el}=5 MWh_{el} , Q_{th}=20 MWh_{th}

	SOFC unit				Gas Boiler
	Scenario 1		Scenario 2		
Annual electric eff.	25%		35%		-
	Scenario 1a	Scenario 1b	Scenario 2a	Scenario 2b	
Operational target	Full coverage of annual thermal load	Half coverage of annual thermal load	Full coverage of annual thermal load	Half coverage of annual thermal load	-
Annual thermal eff.	66%		56%		95%
Max. electric output	2.0 kWel				-
Max. thermal output	5.3 kWth		3.2 kWth		8 kWth

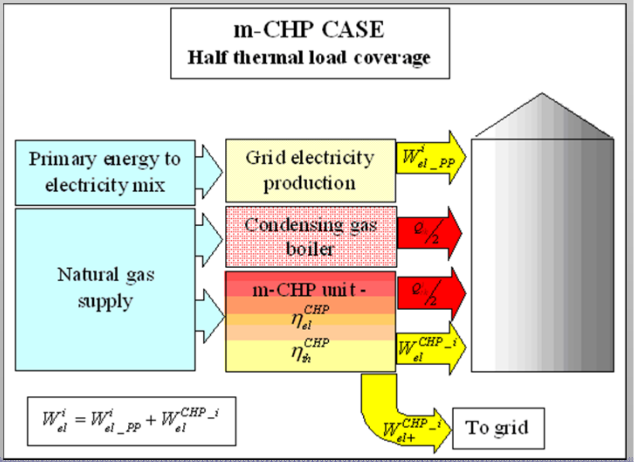
Assessment Case A: SOFC unit vs Standard Case





	Scenario 1		Scenario 2	
Annual electric eff.	SOFC: 25% ICE:25%		SOFC: 35%, ICE:25%	
	Scenario 1a	Scenario 1b	Scenario 2a	Scenario 2b
Operational target	Full coverage of annual thermal load	Half coverage of annual thermal load	Full coverage of annual thermal load	Half coverage of annual thermal load
Annual thermal eff.	SOFC: 66% ICE:65%		SOFC: 56%, ICE:65%	
Max. electric output	SOFC: 2.0 kWel, ICE: 3.0 kWel			
Max. thermal output	SOFC: 5.3 kWth, ICE: 8.0 kWth		SOFC: 3.2 kWth, ICE: 8.0 kWth	

Assessment Case B: SOFC unit vs ICE



Lifetime energy demand – CO_2-eq savings of a SOFC m-CHP unit

- **Overview of operational cases / parameters examined:**
  - 2 competitive systems Life Cycles: A Standard Case (domestic loads covered by grid electricity and a gas boiler) and a competitive mCHP system (an IC Engine – reference product: Ecopower e3.0)
  - 2 mCHP energy products (Electric and Thermal kWh) – Allocation of emissions according to exergy.
  - 2 cases of FlameSOFC electric efficiency (Scenario 1: 25%; Scenario 2: 35%).
  - 2 cases of annual thermal load coverage by mCHP (Scenario a: 100%, Scenario b: 50%+peak boiler).
  - 2 cases of considering the environmental benefit of mCHP surplus electricity exported to grid (full benefit; zero benefit).
  - 3 environmental impact factors: Cumulative & Fossil Energy Demand (CED & FED); Global Warming Potential (GWP)

Lifetime energy demand – CO_2-eq savings of a SOFC m-CHP unit

- An optimistic recycling rate of 90% of the most widely used materials is assumed, standing for approximately 90% of total FlameSOFC unit weight.

- All the assumed manufacturing losses are considered recycled.

- An **open-loop recycling scheme** has been followed, where end-of-life products are recycled into raw material, without decreasing the level of material use at manufacturing.

- The remaining material is assumed to be disposed in an inert material landfill.

Amount of FlameSOFC unit materials for recycling

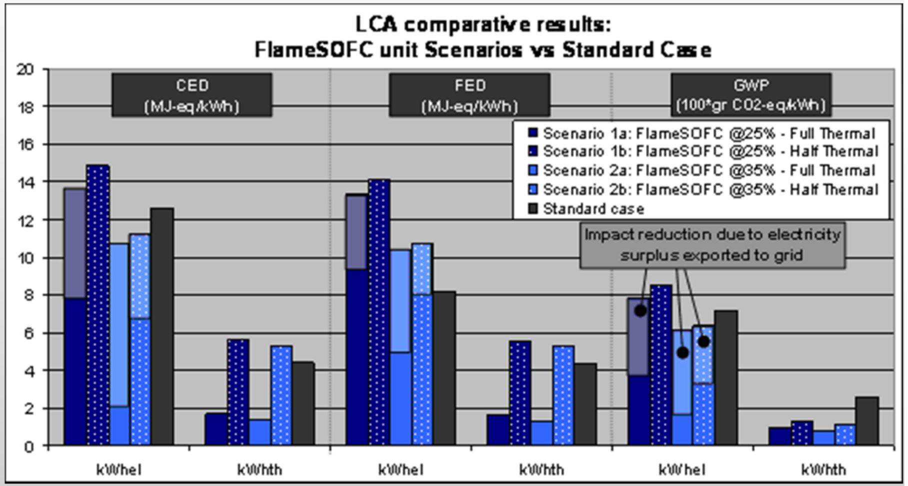
Material	Recycled (kg)	Manufacturing loss (kg)	Total (kg)	Reference for data on energy demand and emissions of recycling
Stainless Steel	158.5	25.0	183.5	SimaPRO 7 LCA Databases
Cast Iron	2.7	0.5	3.2	
Chrome Alloy	32.9	5.5	38.4	
Copper	5.0	0[1]	5.0	
Aluminum	4.9	0.6	5.5	
Plastic	2.7	0.5	3.2	
Scenario C **(90% recovery of selected materials)**		Total recycled weight (kg)	238.6	
		% of used material	93.7%	

Lifetime energy demand – CO_2-eq savings of a SOFC m-CHP unit

Comparison of impacts - both cases

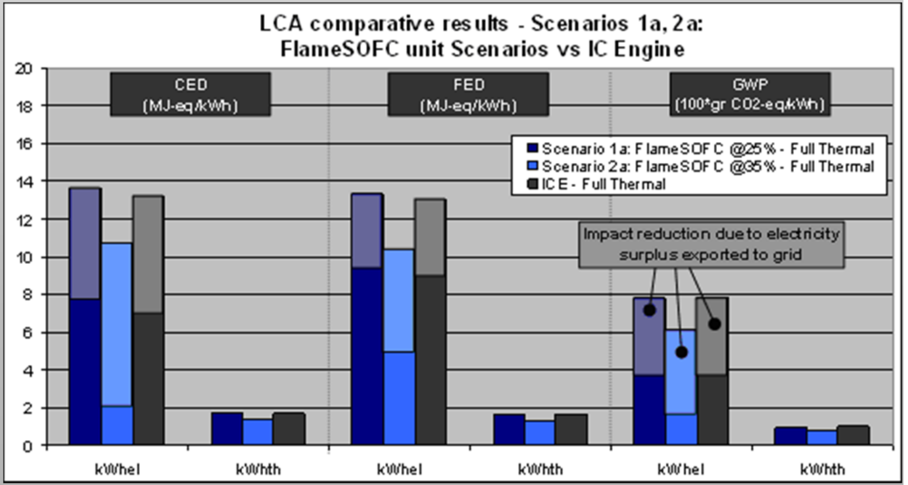
Assessment case A – SOFC unit vs SC

- Covering half of the annual thermal load leads to worse environmental indices than full coverage.
- Improving the electric efficiency (scenarios 2a, b) can provide a **definite environmental advantage over the Standard Case (CED, GWP)**
- The fossil fuelled SOFC unit provides worse FED index.


LCA comparative results:
FlameSOFC unit Scenarios vs Standard Case

Assessment case A – SOFC unit vs ICE

- Straightforward comparison of two mCHP systems.
- Major influential parameter: **SOFC unit potential for higher electric efficiency ➔** less primary and fossil energy demand, less greenhouse emissions.


LCA comparative results - Scenarios 1a, 2a:
FlameSOFC unit Scenarios vs IC Engine

Lifetime energy demand – CO_2-eq savings of a SOFC m-CHP unit

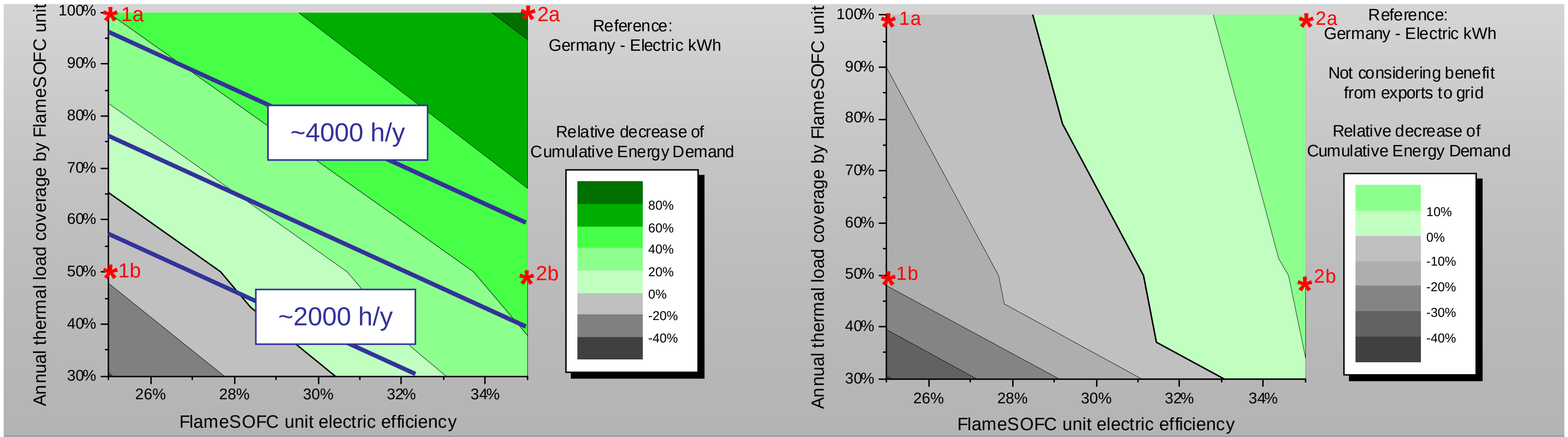
Results

Assessment Case A
CED contours

- Red stars: LCA Iterations for **1 kWh electric**
- Green and grey contours: Linear inter- and extrapolation of results with variables:
  FlameSOFC electric efficiency (25 –35%) and thermal load coverage (30-100%)

- The need for **at least 30% electric efficiency** is shown, enough to provide a marginal reduction of CED, even without the benefit of the grid exports. A **CED reduction of 40-50%** is considered achievable (with grid export benefit).

Relative decrease of CED. FlameSOFC unit vs Standard Case
With and without benefit from exports to grid.



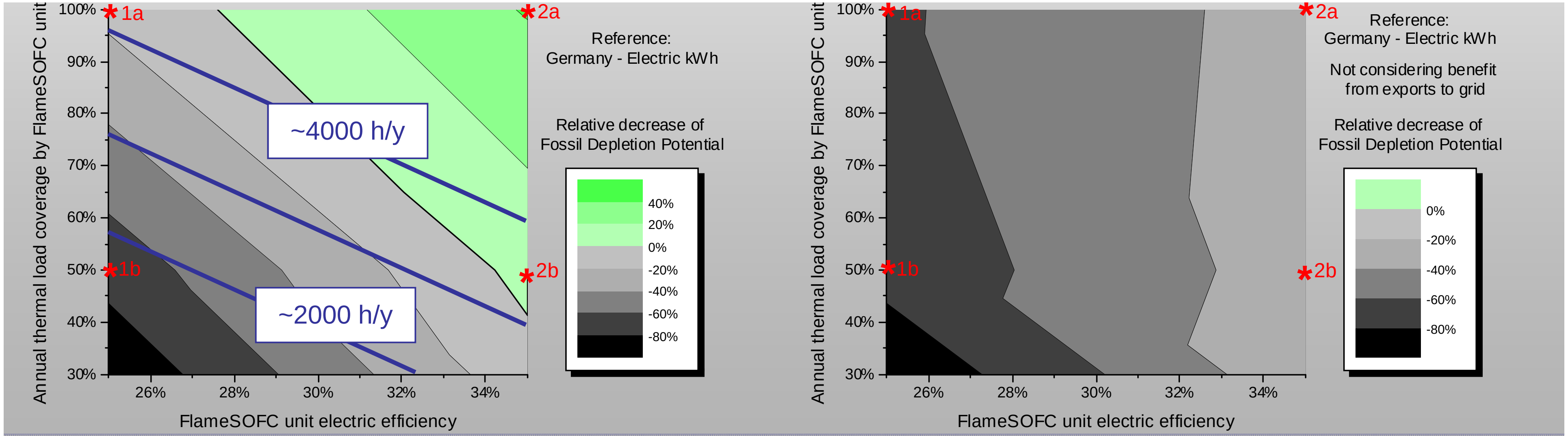
Lifetime energy demand – CO_2-eq savings of a SOFC m-CHP unit

Assessment Case A
FED contours

- Red stars: LCA Iterations for **1 kWh electric**
- Green and grey contours: Linear inter- and extrapolation of results with variables:
  FlameSOFC electric efficiency (25 –35%) and thermal load coverage (30-100%)

- FED potential reduction a challenging task, especially in the near future, where **the renewables contribution in grid generation will rise**. However, some reduction (5-20%) is possible to occur only if the grid export benefit is considered.

Relative decrease of FED. FlameSOFC unit vs Standard Case
With and without benefit from exports to grid.

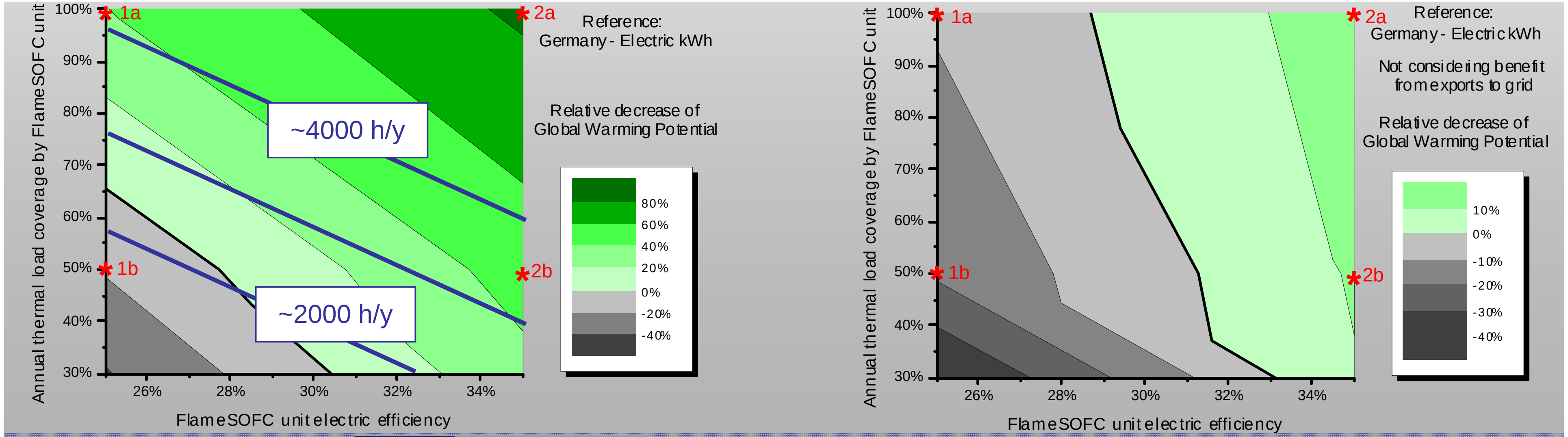


Lifetime energy demand – CO_2-eq savings of a SOFC m-CHP unit

Assessment Case A
GWP contours

- Red stars: LCA Iterations for **1 kWh electric**
- Green and grey contours: Linear inter- and extrapolation of results with variables: FlameSOFC electric efficiency (25 –35%) and thermal load coverage (30-100%)
- The need for **at least 30% electric efficiency** is shown, enough to provide a marginal reduction of GWP, even without the benefit of the grid exports. A **GWP reduction of 40-50%** is considered achievable (with grid export benefit).

Relative decrease of GWP. FlameSOFC unit vs Standard Case
With and without benefit from exports to grid.

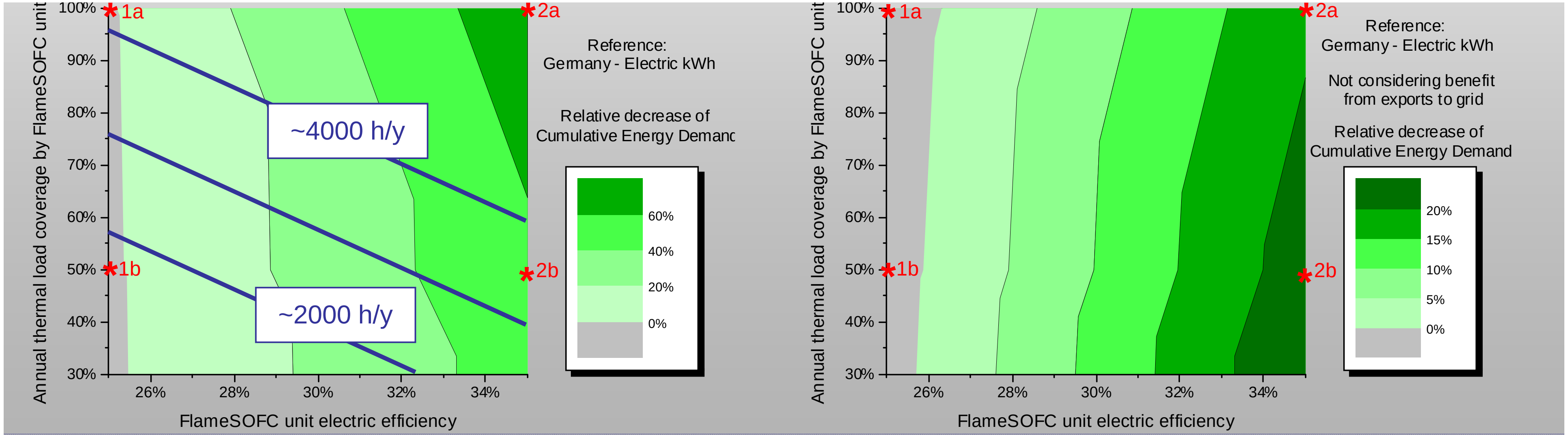


Lifetime energy demand – CO_2-eq savings of a SOFC m-CHP unit

Assessment Case B
CED contours

- The **potentially higher SOFC unit electric efficiency** is enough to provide lower CED.
- The contour lines are much less steeper than the corresponding figures of Assessment Case A, showing the **little influence of the thermal load coverage.**
- Negative contribution of the rising thermal coverage has been identified (at no export benefit), which is intensified at higher SOFC electric efficiencies.
- Little interest in the FED contours, since both mCHP unit are fuelled by fossil fuel.

Relative decrease of CED. FlameSOFC unit vs ICE
With and without benefit from exports to grid.



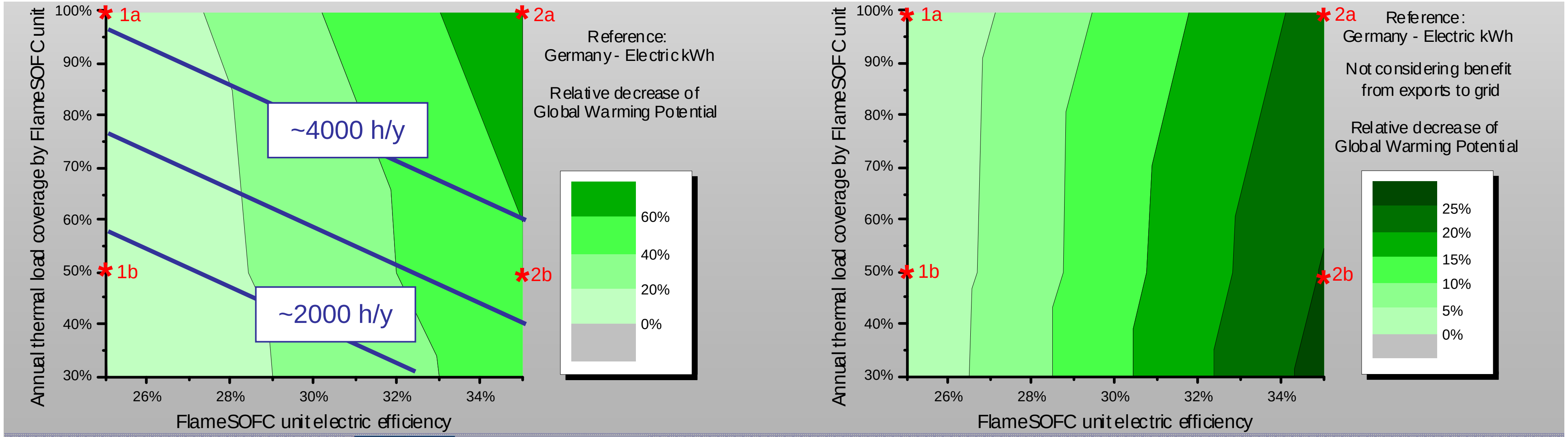
Lifetime energy demand – CO_2-eq savings of a SOFC m-CHP unit

Assessment Case B
GWP contours

- Red stars: LCA Iterations for **1 kWh electric**
- Green contours: Linear inter- and extrapolation of results with variables:
  FlameSOFC electric efficiency (25 –35%) and thermal load coverage (30-100%)

- Indicative GWP results show a feasible reduction potential of 15-40% (depending on whether the export benefit is considered) due to the **higher FlameSOFC electric efficiency.**

Relative decrease of GWP. FlameSOFC unit vs ICE
With and without benefit from exports to grid.



Lifetime energy demand – CO_2-eq savings of a SOFC m-CHP unit

An overall **environmental benefit is feasible** over the Standard Case provided that:

- The **electric efficiency** of the FlameSOFC unit **reaches at least 30%**
- Coverage of **60-70% of the annual thermal load** is achieved **at minimum**.

Weak environmental aspect of FlameSOFC unit:

- Natural gas usage **raises the Fossil Energy Demand index**. However, the FlameSOFC unit **has the potential of fuel flexibility** and the **incorporation of biofuels would act positively** towards reducing this impact.

Exporting electricity back to grid indirectly lowers the impact factors of the SOFC unit. ➔ Uncertain benefit!

Lifetime energy demand – CO_2-eq savings of a SOFC m-CHP unit

A significant environmental advantage to the FlameSOFC unit is identified **over the ICE mCHP option**:

- The influence of the **improved electric efficiency of the FlameSOFC** unit is critical towards **demanding less primary and fossil energy and** emitting **less greenhouse gases**.

Remark:

- Exporting to grid has a similar effect for both the m-CHP systems examined and does not influence the corresponding results significantly.

Lifetime energy demand – CO_2-eq savings of a SOFC m-CHP unit

Thank you for your attention!