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Comparative Life Cycle Assessment of electroceramic material manufacturing methods

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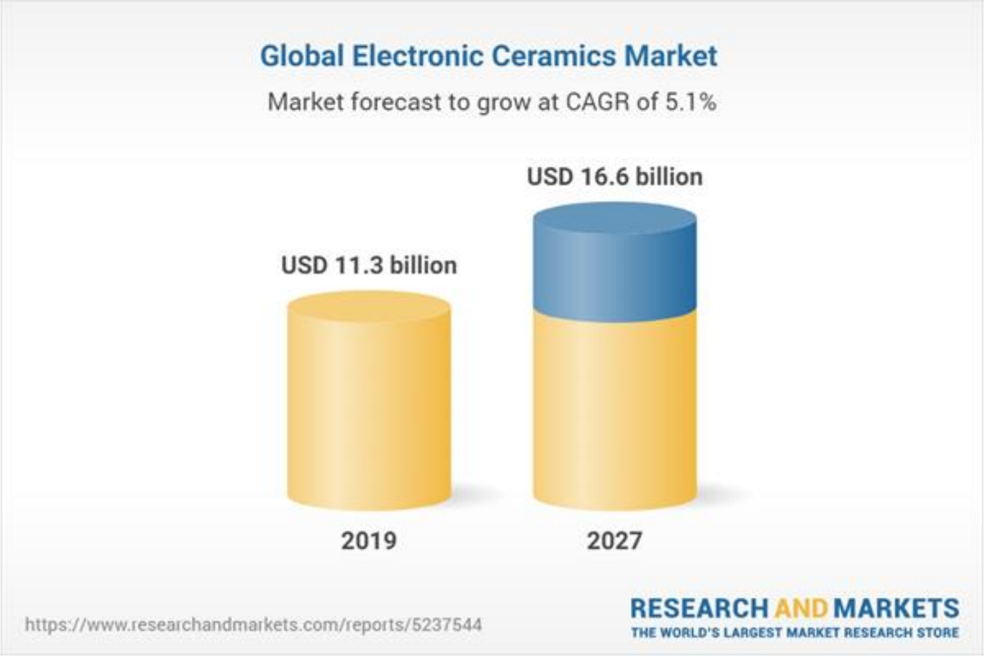
Electroceramics are key materials in all electronics

$2-trillion global electronics industry would not exist without electroceramics

The share of electroceramic materials of this market is over 11 billion euros



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Electroceramics manufacturing

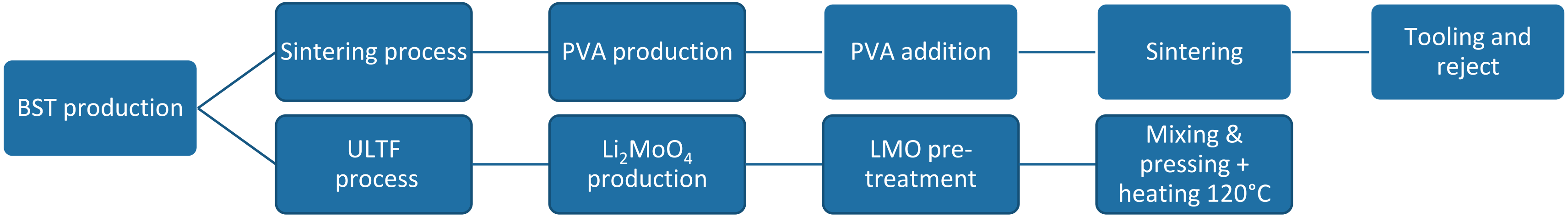
- The traditional sintering method requires temperatures of ~1300 °C
  - *Significant energy consumption and carbon emissions*
- Several lower temperature ("cold-sintering") methods have been developed
  - *However, they also require temperatures of a couple of hundreds degrees*
- An alternative, ultra-low temperature fabrication (ULTF) method of ceramics has been developed at the University of Oulu (4 patents to date)
  - *Operates at room temperature*
- The objective of this work was to illustrate with the use of LCA that the alternative manufacturing method is environmentally preferable to the traditional method
  - *Modelling is based on assumptions, using materials, processes, machinery, etc. typically used in industry, as well as based on laboratory scale measurements*
    - *Part of a Business Finland 'Research to Business' project* ***InnoPro***

Comparison of methods

	Material preparation	Forming component	Sintering	Post treatment
TRADITIONAL METHOD	Ceramic powder mix	High pressure moulding	High temperature sintering 1000-1450 °C	Cutting, size tuning
COLD SINTERING PROCESS	Ceramic powder mix -nanoscale particles; Solvent	Medium pressure moulding with heating (300-500°C)	Medium temperature sintering during moulding (300-500°C)	Post treatment/ sintering with post heating 120-200°C (preferred 700-900°C)
ULTRA LOW TEMP FABICATION (ULTF)	Ceramic, multi-modal powder mix Distribution in size (>50um); LiMbX + Solvent Saturated; LiMbX Ceramic powder <50um	Medium pressure moulding	No sintering needed	Drying at room temperature (or accelerated <120 °C)

LCA of the two process methods

- The raw material in both processes is $Ba_{0.55}Sr_{0.45}TiO_3$ (BST)
  - In the traditional production, Polyvinyl alcohol (PVA) is used as organic additional material
  - In the ULTF process, water-soluble Li2MoO4 (LMO) is added to BST
    - Dried at room temperature for two days, or
    - At 120 °C for two hours
- The processes were built in SimaPro as presented in diagram below



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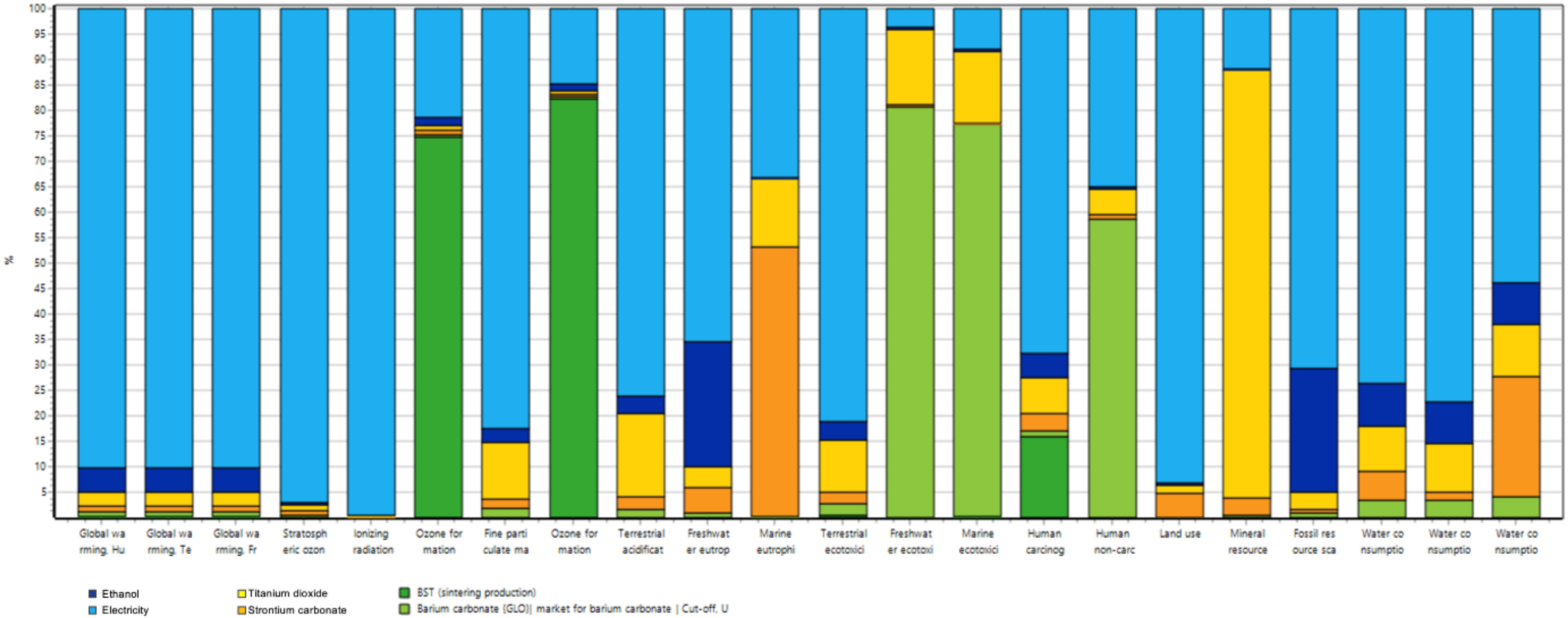
Assumptions made

- Raw material: 100g BST for both processes
    - There is shrinkage in the traditional process, requiring tooling, assumed 5%
- All combustions are complete, emissions are mainly CO_2
    - PVA combustion: all intermediate products are expected to react to CO_2
- The quantities of materials and energy consumptions are all calculated and/or estimated
    - Energy consumption of ovens measure in laboratory conditions
- Components that had to be created in SimaPro (based on scientific articles):
    - Li_2MoO_4 are produced by ($LiOH + H_2O$) + MoO_3
        - Reactions happen in room temperature during 1 h, no energy consumption
    - PVA is prepared by polymerization of vinyl acetate
        - PVA is an auxiliary in the sintering step, mixed into BST and then burnt off in the sintering furnace

BST –characterization



Method: ReCiPe 2016 Endpoint (H) V1.06 / World (2010) H/A / Characterization / Excluding infrastructure processes / Excluding long-term emissions
Analyzing 105 g 'BST (sintering production)';

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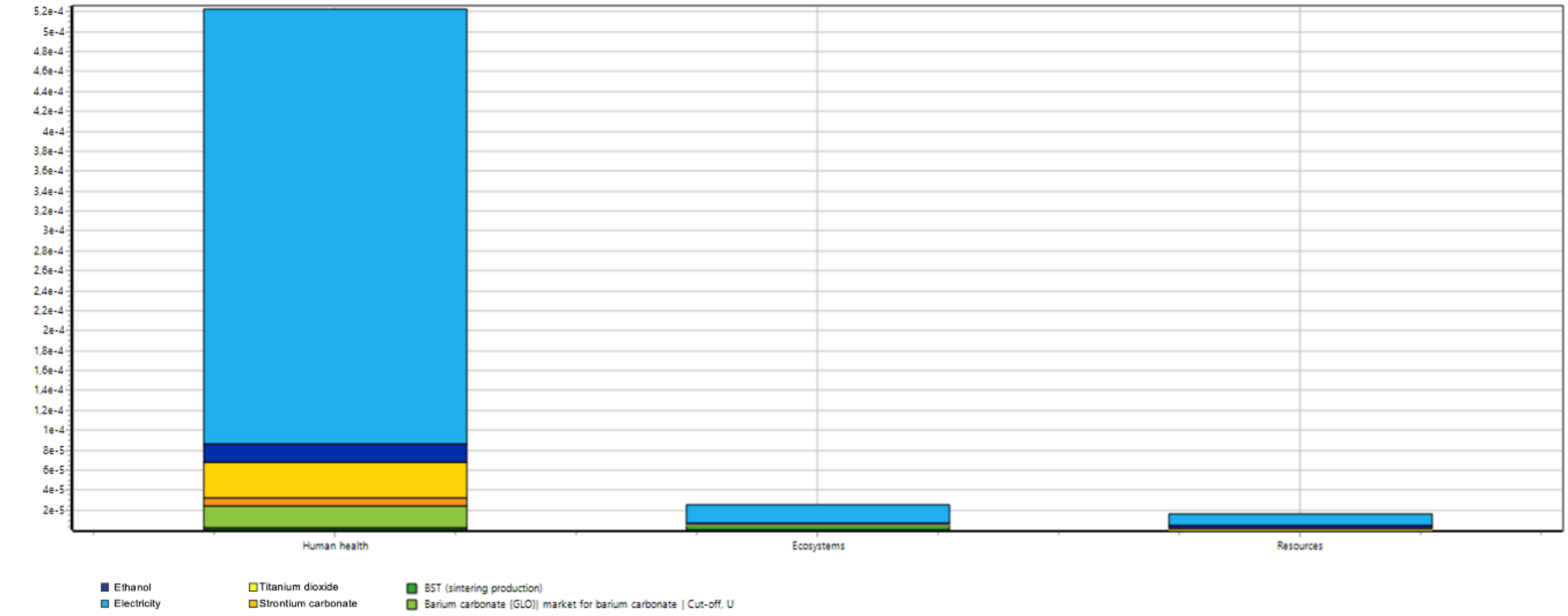
BST – normalization



Method: ReCiPe 2016 Endpoint (H) V1.06 / World (2010) H/A / Normalization / Excluding infrastructure processes / Excluding long-term emissions
Analyzing 105 g 'BST (sintering production)';

Se	Damage category	Unit	Total	BST (sintering production)	Barium carbonate	Strontium carbonate	Titanium dioxide {RER}|	Ethanol, without water, in 99.7%	Electricity, low voltage {FI}|
☑	Human health		0,000523	2,46E-6	2,21E-5	8,04E-6	3,48E-5	1,88E-5	0,000436
☑	Ecosystems		2,49E-5	4,65E-6	2,16E-7	4,08E-7	9,71E-7	8,64E-7	1,78E-5
☑	Resources		1,56E-5	x	1,24E-7	1,42E-7	8,27E-7	3,72E-6	1,08E-5

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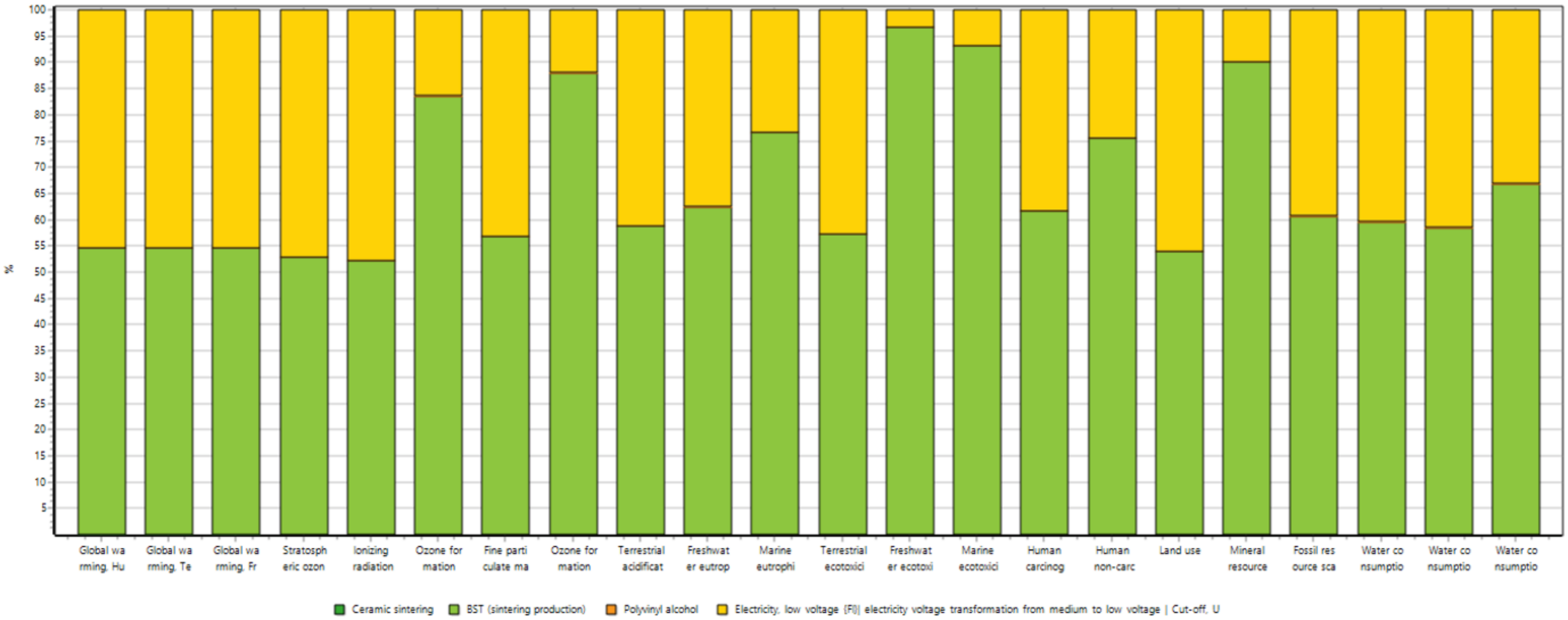
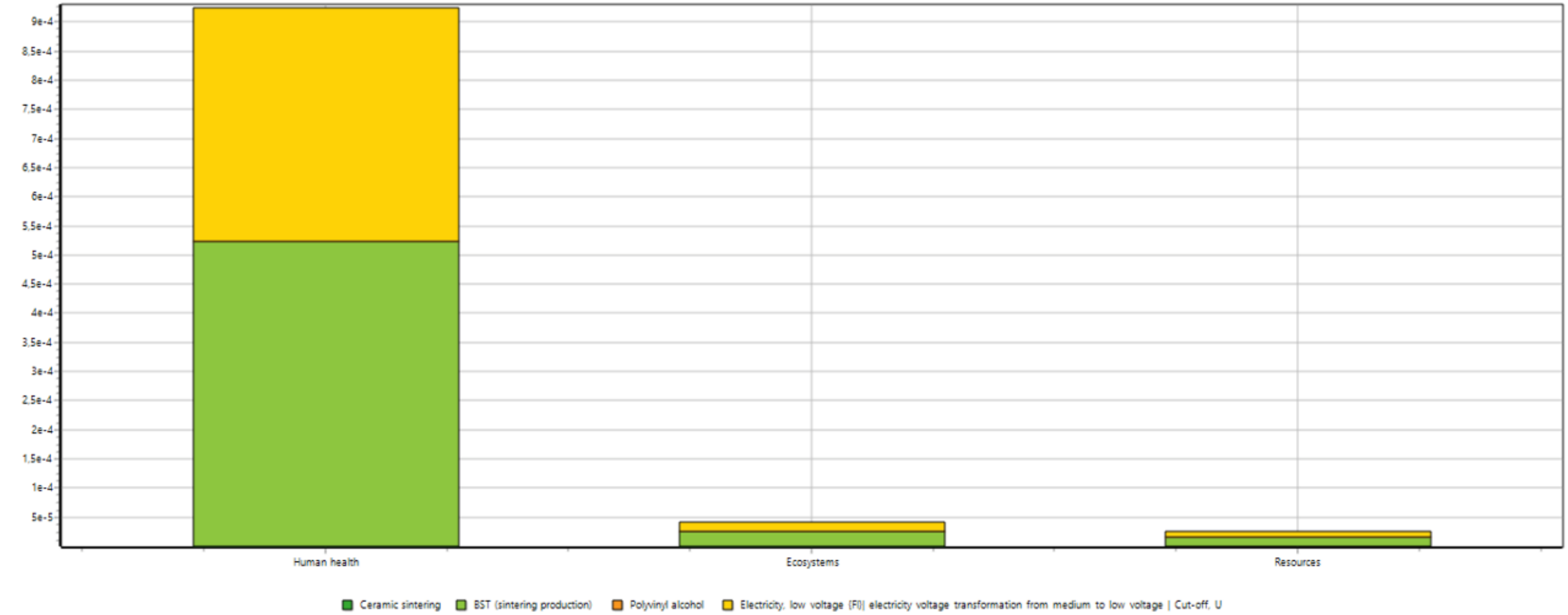
Sintering (traditional process), characterization



Method: ReCiPe 2016 Endpoint (H) V1.06 / World (2010) H/A / Characterization / Excluding infrastructure processes / Excluding long-term emissions
Analyzing 105 g 'Ceramic sintering';

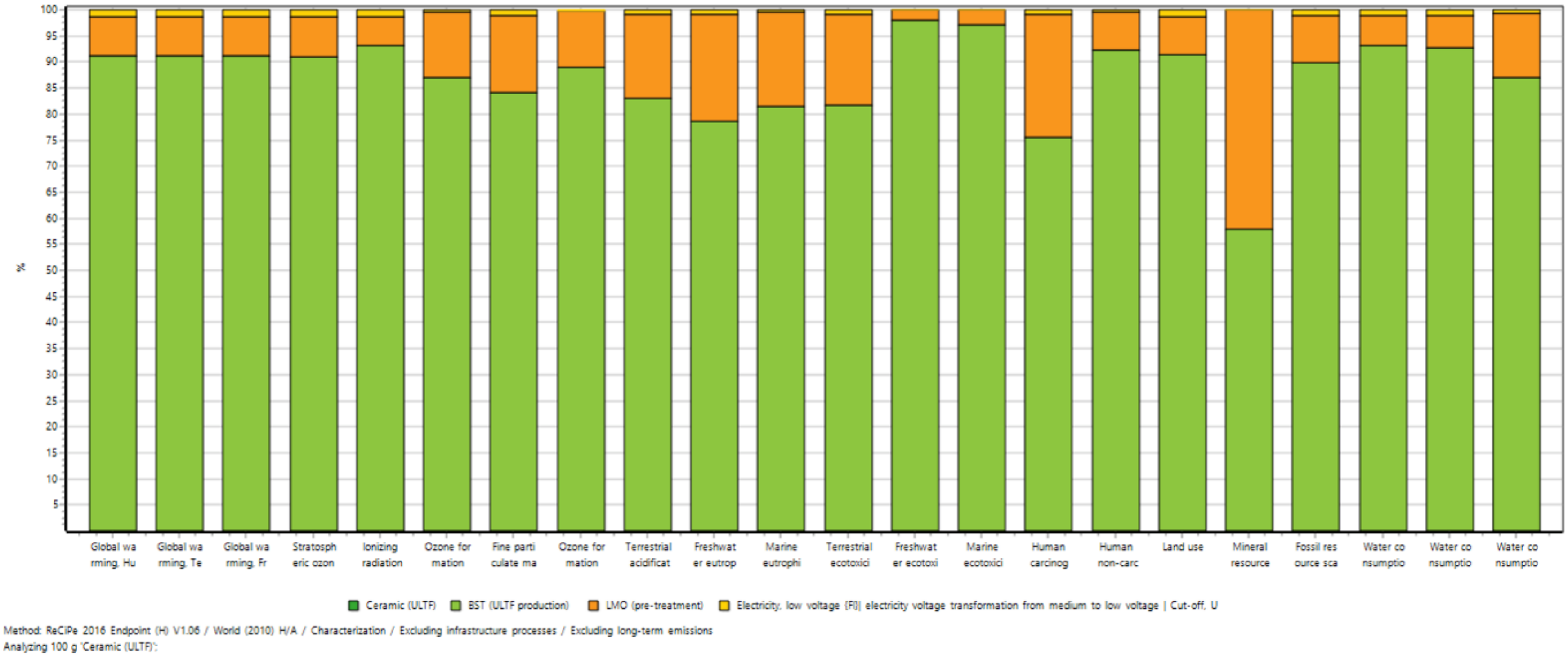
Sintering (traditional process), normalization



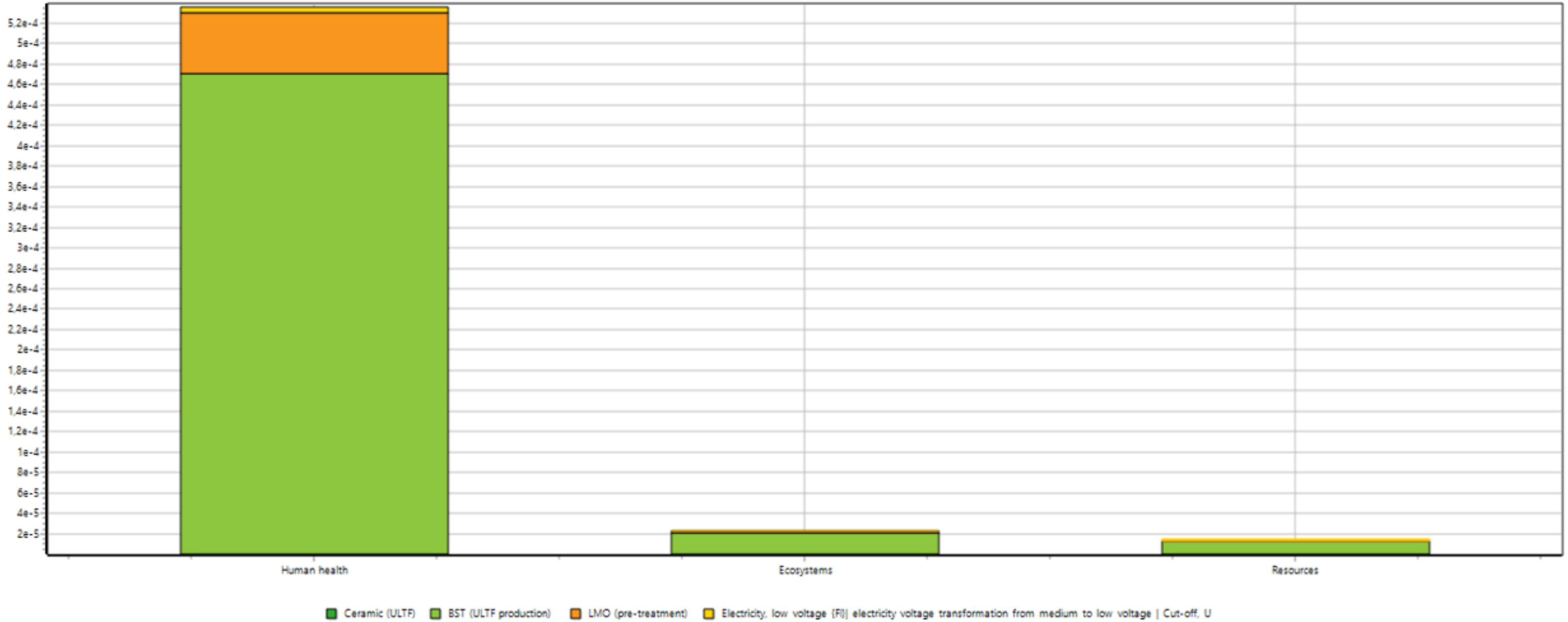
Method: ReCiPe 2016 Endpoint (H) V1.06 / World (2010) H/A / Normalization / Excluding infrastructure processes / Excluding long-term emissions
Analyzing 105 g 'Ceramic sintering';

Se	Damage category	Unit	Total	Ceramic sintering	BST (sintering production)	Polyvinyl alcohol	Electricity, low voltage {FI}|
☑	Human health	%	100	0,00643	56,6	0,065	43,4
☑	Ecosystems	%	100	0,00705	60,3	0,0531	39,6
☑	Resources	%	100	x	61,1	0,199	38,7

Drying – ULTF, characterization



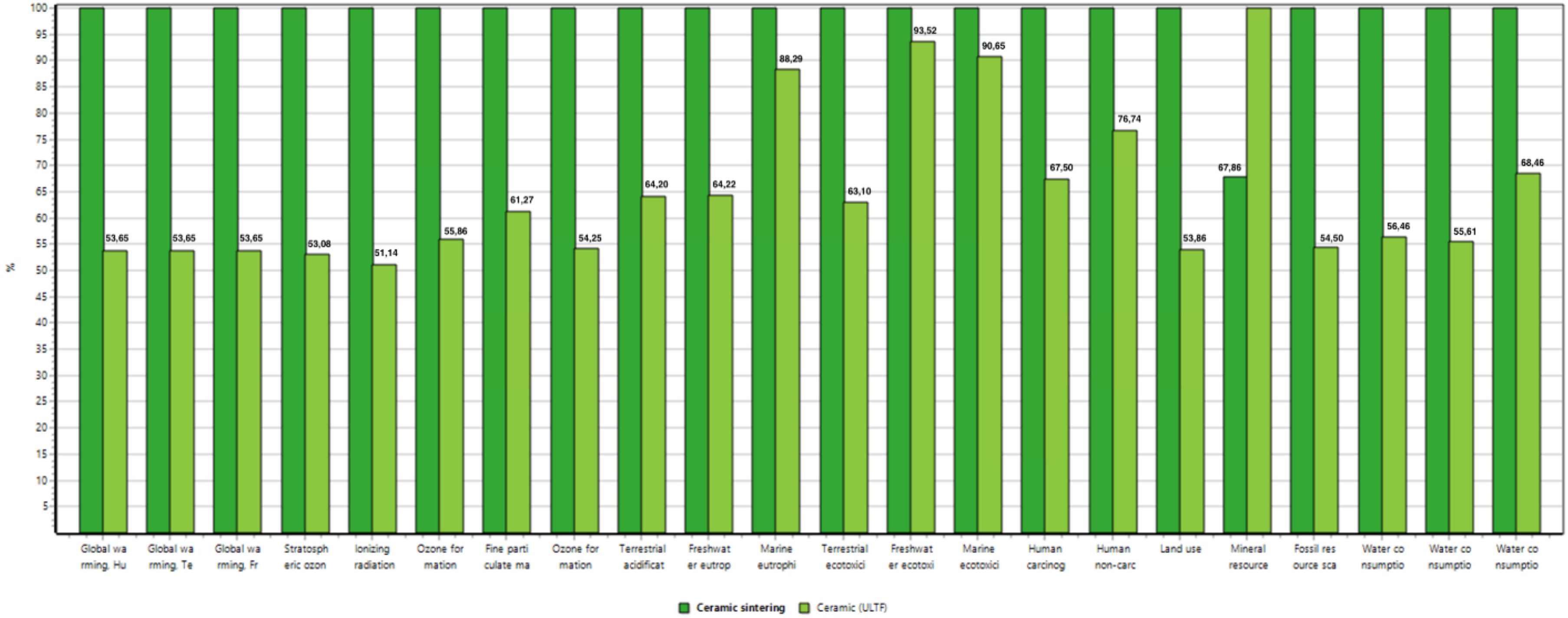
Drying – ULTF, normalization



Method: ReCiPe 2016 Endpoint (H) V1.06 / World (2010) H/A / Normalization / Excluding infrastructure processes / Excluding long-term emissions
Analyzing 100 g 'Ceramic (ULTF)';

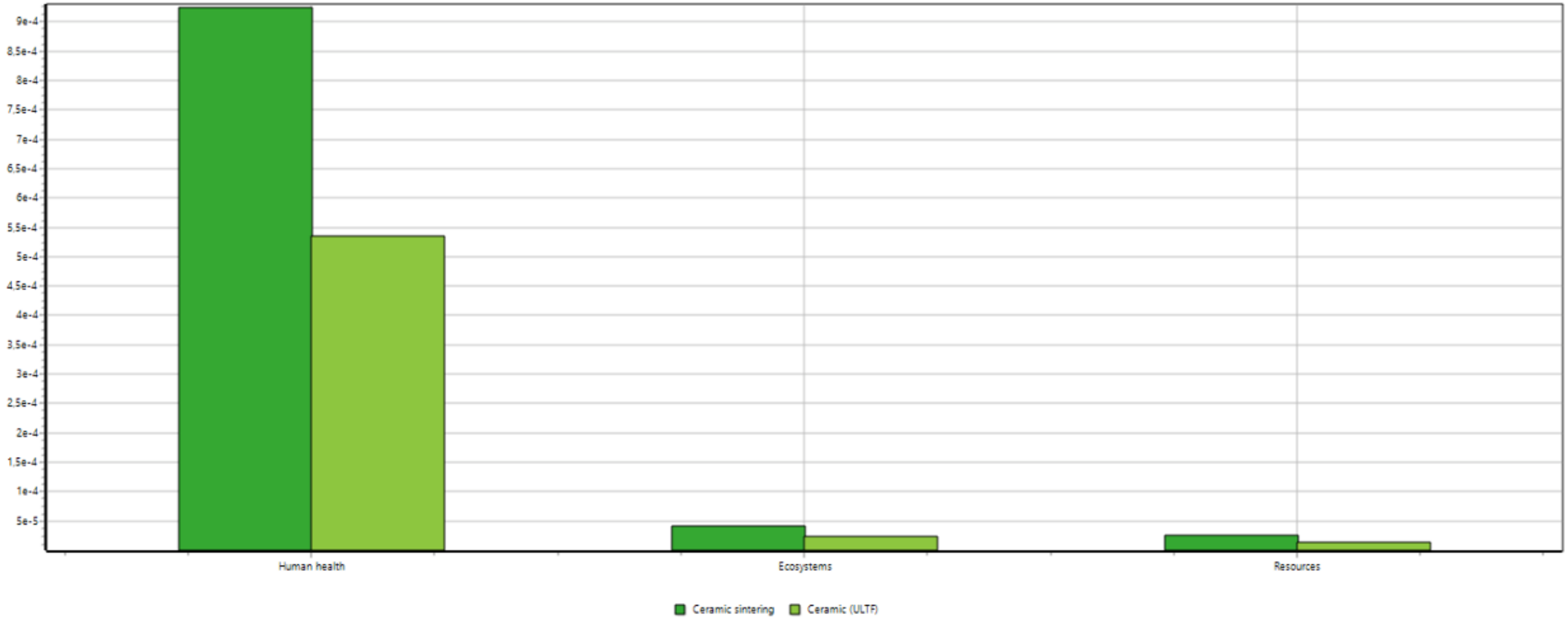
Se	Damage category	Unit	Total	Ceramic (ULTF)	BST (ULTF production)	LMO (pre-treatment)	Electricity, low voltage {FI}|
☑	Human health		0,000536	x	0,000471	5,9E-5	5,84E-6
☑	Ecosystems		2,28E-5	x	2,04E-5	2,1E-6	2,38E-7
☑	Resources		1,43E-5	x	1,26E-5	1,52E-6	1,44E-7

Comparison: Traditional process vs ULTF4



Method: ReCiPe 2016 Endpoint (H) V1.06 / World (2010) H/A / Characterization / Excluding infrastructure processes / Excluding long-term emissions
Comparing 105 g 'Ceramic sintering' with 100 g 'Ceramic (ULTF)';

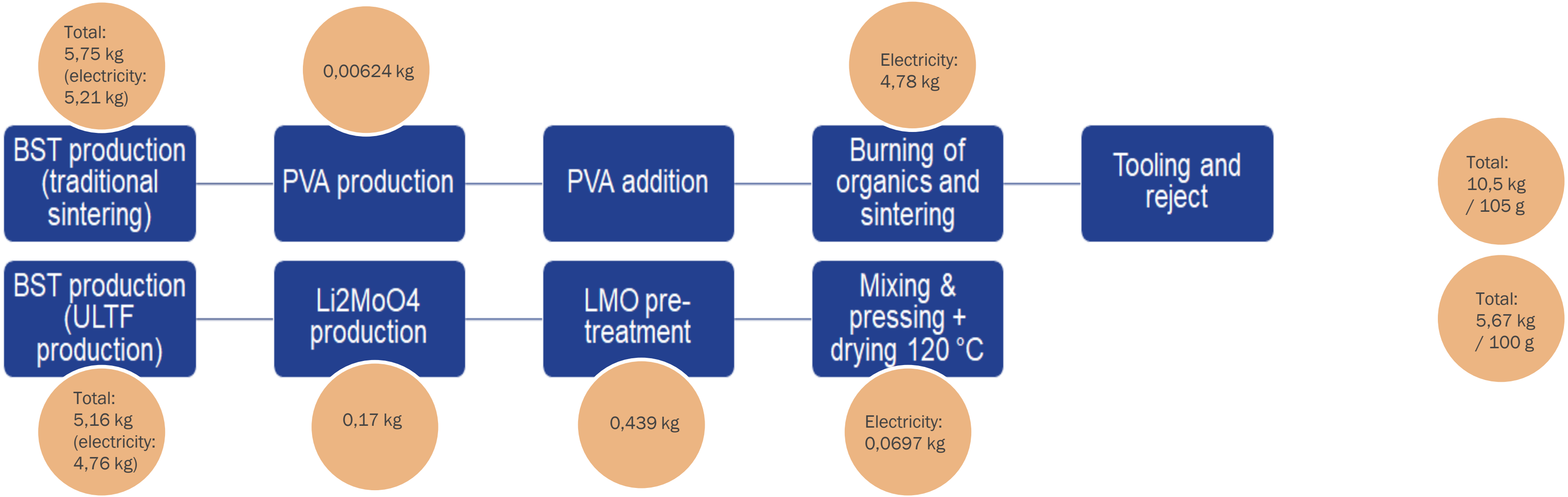
Comparison: Traditional process vs ULTF



Method: ReCiPe 2016 Endpoint (H) V1.06 / World (2010) H/A / Normalization / Excluding infrastructure processes / Excluding long-term emissions
Comparing 105 g 'Ceramic sintering' with 100 g 'Ceramic (ULTF)';

Se	Damage category	Unit	Ceramic sintering	Ceramic (ULTF)
☑	Human health		0,000924	0,000536
☑	Ecosystems		4,12E-5	2,28E-5
☑	Resources		2,55E-5	1,43E-5

Carbon footprint comparison by process stages



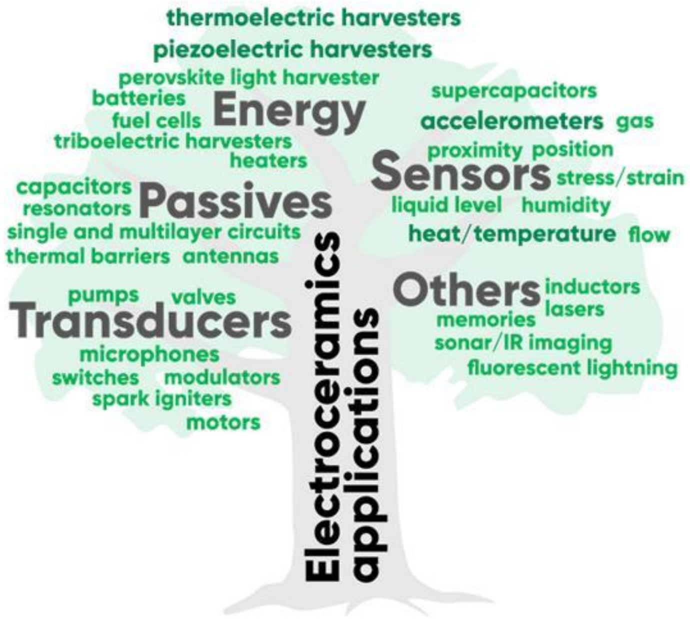
- CO2-eq for 100g ready BST ceramic product, using Finland data: 1kWh=0,248 kg CO2eq
- Note: Calculations are made in laboratory scale; results are not absolute!

Discussion

- The novelty of the research is that we conducted LCA of non-commercial materials, which are still in development process
    - *Some materials had to ”synthesized” in SimaPro*
- The limitation is that e.g. electricity consumption data is based on laboratory-scale measurements
    - *We expect that, while the results are not absolute, relatively they are illustrative*
- While doing LCA on research-based materials is challenging, the benefit was that our research could inform the material development process
    - *For example advising on the environmental impacts of intermediates such as ethanol*

Conclusions

- Reducing energy consumption saves the environment and money to the companies
    - *ULTF method reduces carbon footprint over 40%*
- ULTF has great potential on piezoelectric, dielectric and ferroelectric ceramics (~70% of markets)
    - *The method has potential to obtain 10% share ~ $4,5 billion in the 1-3 years*
- The LCA study helped in material development, as well as providing quantitative evidence on the environmental superiority of the process



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