Modelling CO_2 Emissions from SOFC micro-CHP

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Fuel cells are expected to offer stationary power with lower CO_2 emissions and fuel consumption. However, their whole life cycle emissions *(including manufacture and disposal)* are poorly understood: previous life cycle analyses ignore or simplify fuel cell operation in individual houses, and their results are only applicable to the particular country being studied. All life cycle stages must be considered to verify that a new product is actually beneficial to society: as seen with bio-ethanol, rainforests and world food supplies..

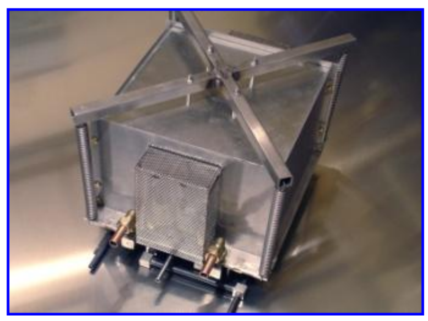
An LCA of a prototype SOFC CHP system was performed, with a focus on modelling the usage phase. The LCA results were calculated for several national electricity mixes, showing the geographical variation in environmental performance.

SOFC Stacking Technology

An SOFC stack has been developed by Fuel Cells Scotland, capable of producing 1kW of electrical power from a compact unit. The design uses unsealed planar cells stacked with novel stainless steel interconnects. Its performance has been verified experimentally under static conditions, and further tests under domestic load-cycling conditions are planned.

Dimensions	21 x 21 x 16 cm
Weight	15kg
Capacity*	$1.3kW_{el} + 1.5kW_{th}$
Efficiency* (HHV)	$31\%_{el} + 42\%_{th}$
Durability	3000 hrs / 100 cycles
Warm up time*	12-24 hours

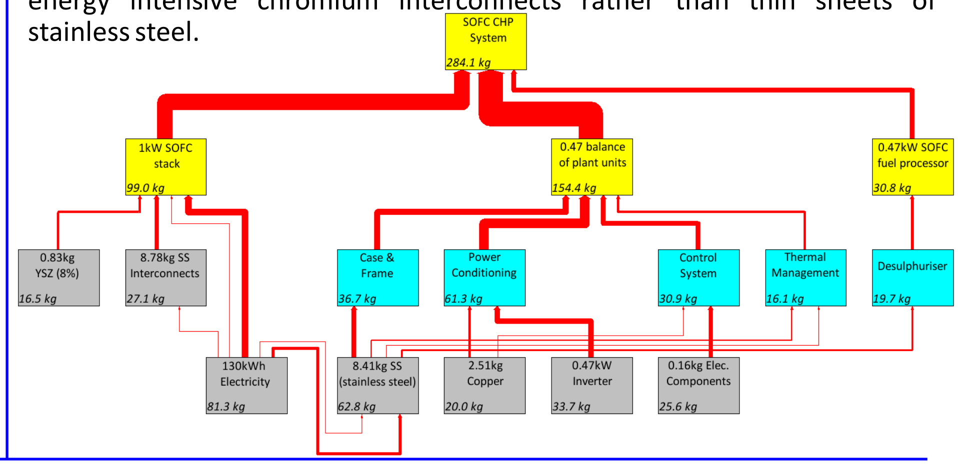
* Using InDEC electrolyte supported cells fuelled by hydrogen, with AC output.



Estimating CO_2 from manufacture

The CO_2 emissions from manufacturing and recycling this SOFC system were estimated with a life cycle analysis. LCA technique involves breaking these processes down into their materials and energy requirements and any direct emissions. Primary data on the stack construction was collected while working with Fuel Cells Scotland, and additional data on the fuel processor and other components was taken from previous LCAs and other literature. SimaPro and its EcoInvent databases were used.

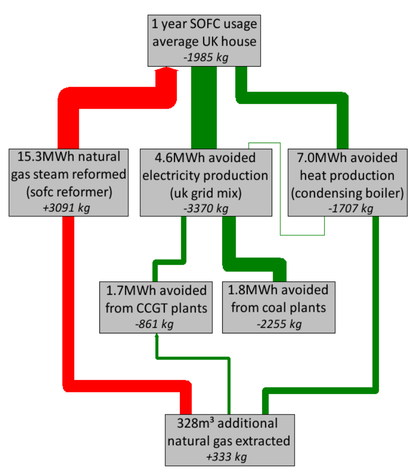
It was estimated that 200-375kg of CO_2 would be emitted in manufacture and disposal of a complete SOFC CHP system – compared with estimates of 450kg and 600kg from previous studies.[1,2] These however considered energy intensive chromium interconnects rather than thin sheets of stainless steel.



Estimating CO_2 from energy production

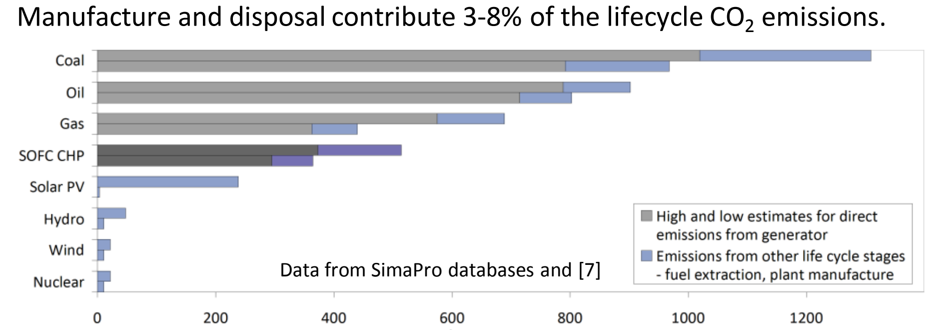
The performance of the FCS unit was fed into a model of domestic fuel cell CHP operation developed previously.[3] This estimated the amount of natural gas and electricity required to heat and power UK homes with a traditional setup *(condensing boiler + national grid)*, and with a hypothetical CHP system based around the FCS stack and a standard fuel processor.

The profile of electricity and heat demands was taken from studies of hundreds of UK houses.[4,5] The SOFC stack was assumed to follow the maximum of thermal and electrical load of the building to maximise economic potential.[6] In ordinary operation it was constrained to run at a minimum of 20% load to minimise damaging thermal cycles.

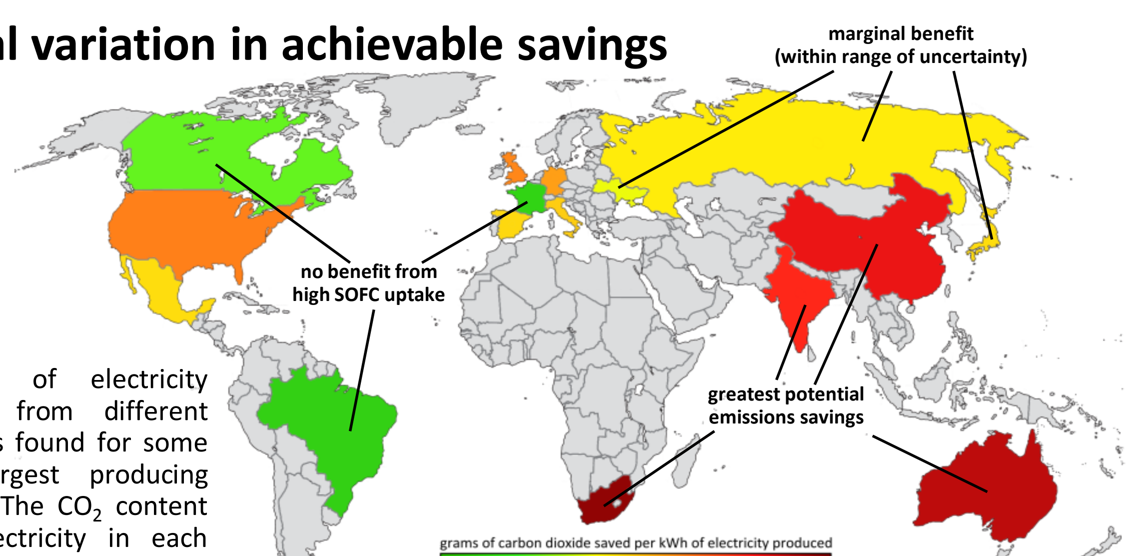


Over the course of a year, the SOFC system is estimated to save 1250-2350kg of CO_2 in UK houses, depending on their size and occupancy. These savings are due to avoiding generation by a boiler *(225g/kWh)* and power stations *(610g/kWh)*. The largest influence was the displacement of coal fired plants.

The carbon content of electricity from the fuel cell was therefore estimated to be 365-515g per kWh generated – when heat is credited by avoided production from an 86% efficient condensing boiler. Of this, 10-40g/kWh are from the system itself, and 60-100g/kWh from sourcing the natural gas. Manufacture and disposal contribute 3-8% of the lifecycle CO_2 emissions.



Global variation in achievable savings



The share of electricity generation from different sources was found for some of the largest producing countries. The CO_2 content of grid electricity in each country was estimated, and the potential savings from SOFC CHP calculated. The average grid mix of each country was displaced by the fuel cell, if significant penetration was assumed.

Three of the sixteen countries would increase their CO_2 emissions with CHP uptake rates over 10-25%, as the majority of their power comes from renewables and nuclear. The potential of savings are unclear in six more *(including Japan)*, and of the remaining seven, savings range from ~150 to 600g/kWh of electricity produced *(30-60%)*.

Conclusions

There is significant uncertainty in the CO_2 emissions from system manufacture. Different stack designs and assumptions about the energy consumed in sintering cells must be reconciled. Similarly, the CO_2 savings during operation show a large range, due to different operating profiles and sizes of dwellings.

When run in place of a condensing boiler, an SOFC system produces 365-515g/kWh of electricity. It is cleaner than any fossil plant, but cannot compete with renewables or nuclear in this sense. Interestingly, efficiency improvements have little effect on these results: the 45% efficient Kyocera/Rinnai system produces only 30g/kWh less, due to lower thermal efficiency and lower utilisation in a house.

Promisingly, some of the rapidly developing nations stand to gain the greatest benefit from fuel cell CHP, so aggressive subsidies and technology transfer would have the greatest effect on reducing global CO_2 emissions and mitigating climate alterations.

[1] An LCA of a Sulzer Hexis stack by Karakoussis et al. in *J. Power Sources 101 p10*
[2] An LCA of a Siemens stack by Pehnt - Ganzheitliche Bilanzierung von Brennstoffzellen in der Energie- und Verkehrstechnik (PhD Thesis)
[3] I. Staffell, *J. Power Sources 181 p339*
[4] Data from 288 houses collected from 2002-2006. Available from the Carbon Trust in the UK.
[5] Data from 130 low energy homes built in the 1980s. Available from The Bartlett, University College London
[6] Hawkes & Leach show that maximum load following approaches the most economical dispatch mode. *Energy 32 p711*
[7] Spadaro, J. et al. Assessing the Difference: Greenhouse Gas Emissions of Electricity Generation Chains. *The IAEA Bulletin 42:2*