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H2Cork

3DOM Ceria Ecoceramics from Sustainable Cork Templates for Solar Thermochemical CO_2 Splitting

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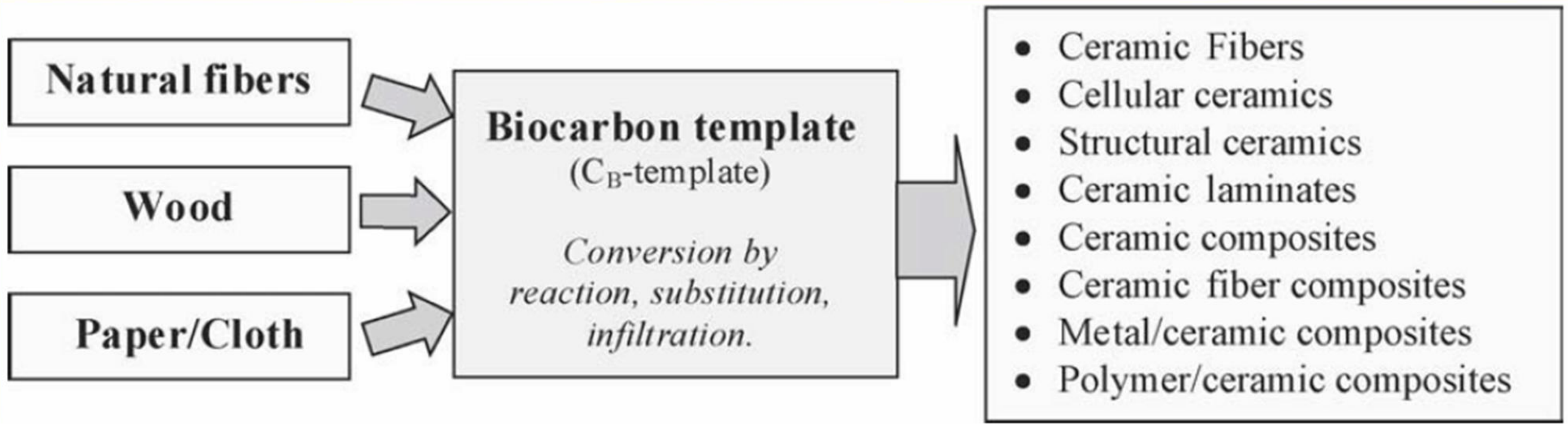
What are Ecoceramics?

- The name "Ecoceramics" - environmentally conscious ceramics – was invented by M. Singh at NASA in 2003
- A new class of Materials which can be fabricated from sustainable sources such as wood and wood wastes
- Aim is to create ceramics with the cellular microstructure of wood - "biomimetic" or "biomorphic" material (copying nature)

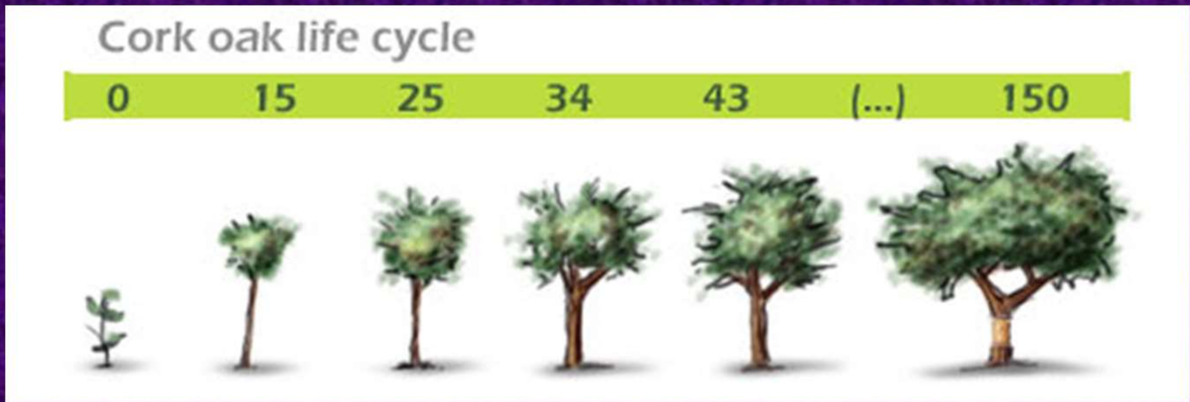


The transformation is typically carried out by infiltration and then pyrolysis

- We are the first to make Ecoceramics from cork templates

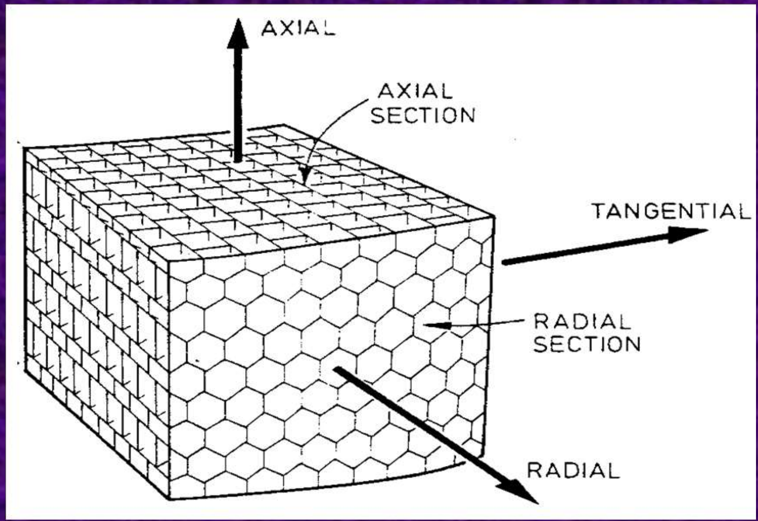
Cork is the Bark of a Slow Growing Oak (Quercus Suber) from the Mediterranean

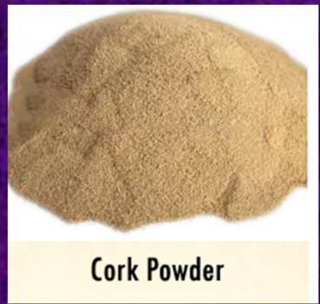
50% of all cork comes from Portugal



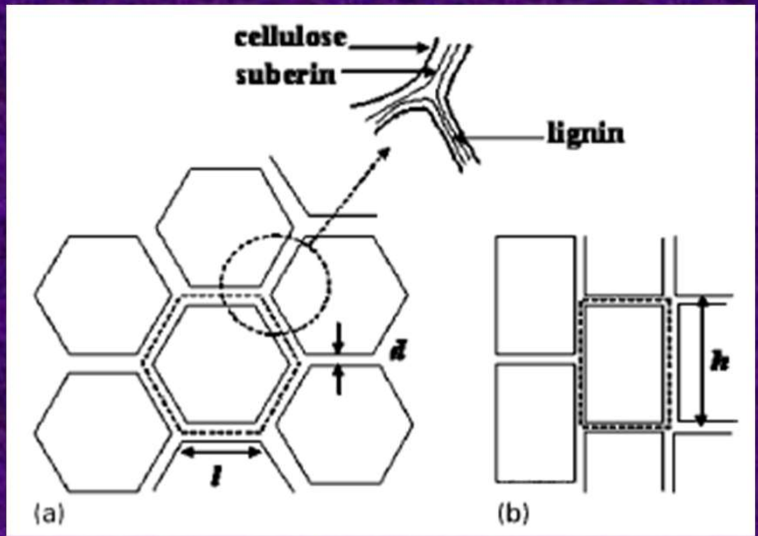
Bark is harvested every 9-13 years, but tree lives on unharmed as carbon sink for >200 years

Cork is a Renewable Portuguese Resource, with a Natural 3-DOM Microstructure



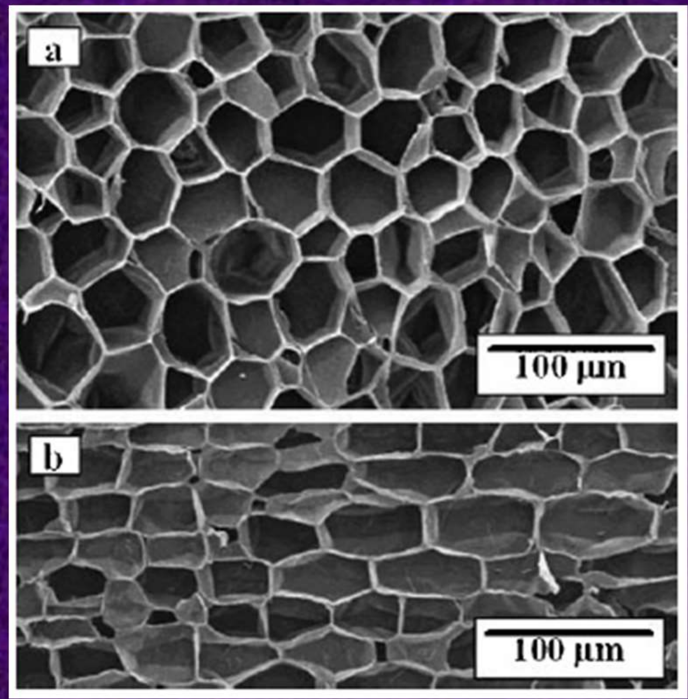


~50,000 t per year of waste cork powder & granules are generated by the cork industry – currently most is burnt to generate energy



a) Hexagonal Radial section

b) Rectangular Tangential or Axial section



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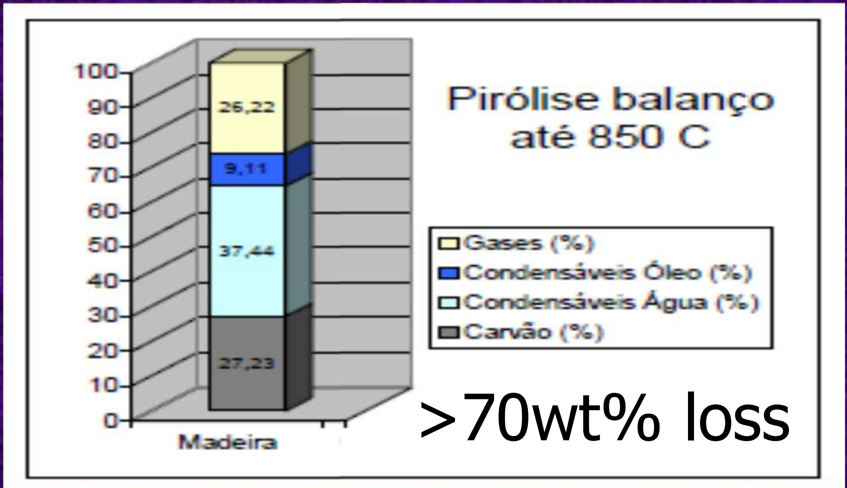
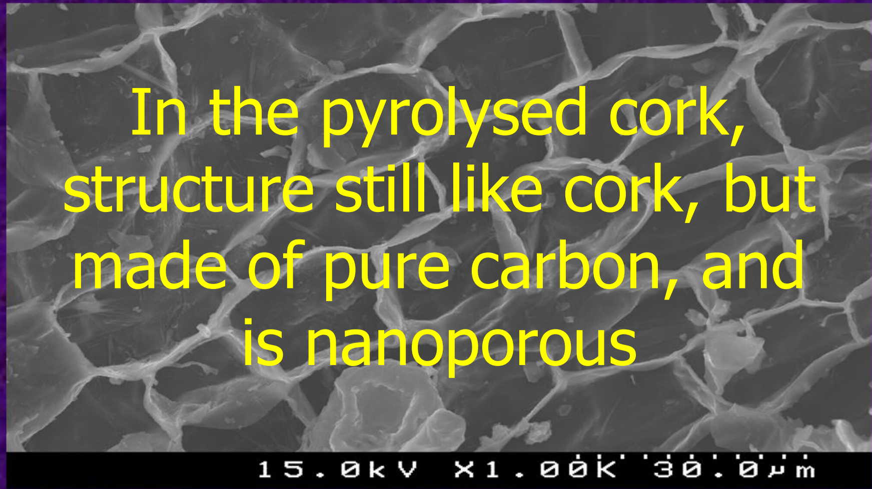
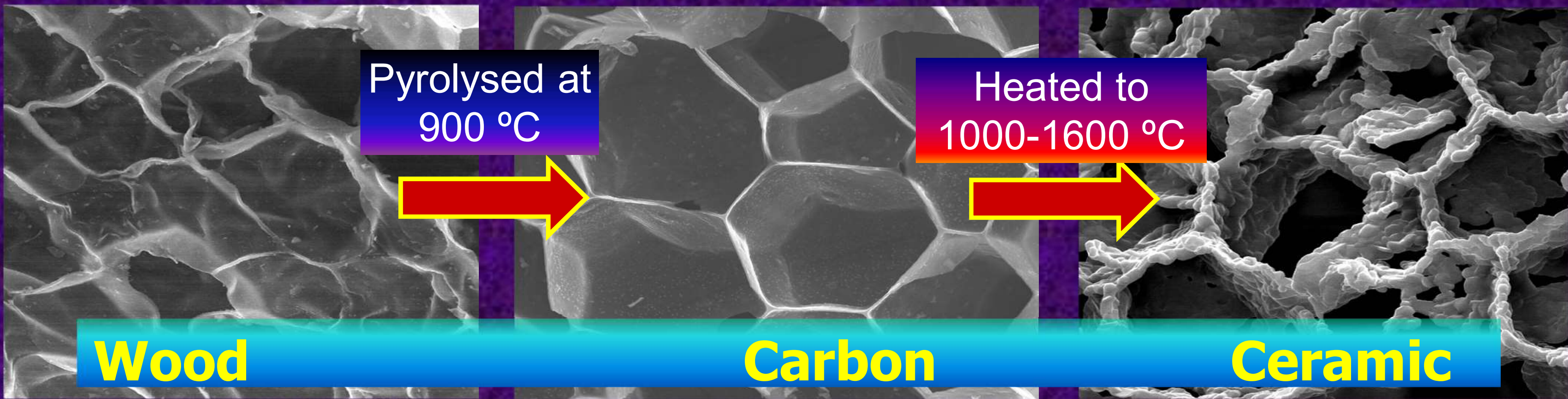
Pyrolysed Cork → Carbon → Ceramic

- Graphite furnace at 900 ºC in Ar or N_2 cork → carbon
- Then the carbon matrix is infiltrated with precusor solution & heated in air to burn out carbon and form the ceramic







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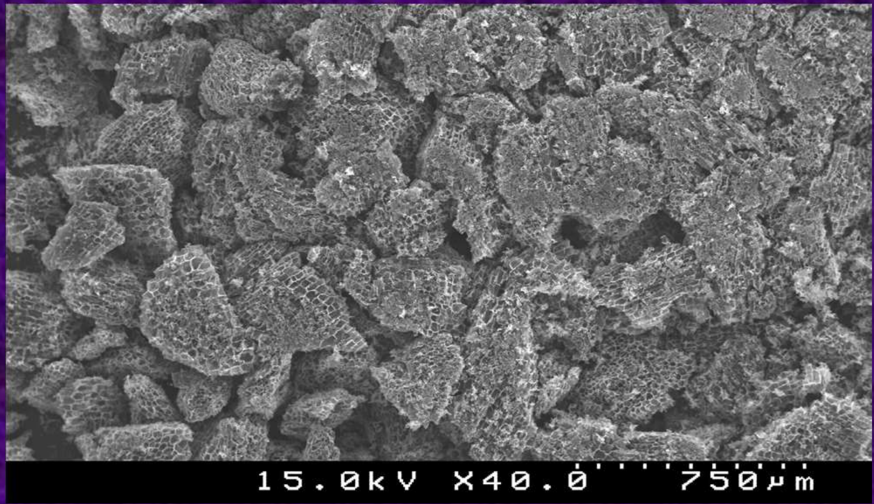
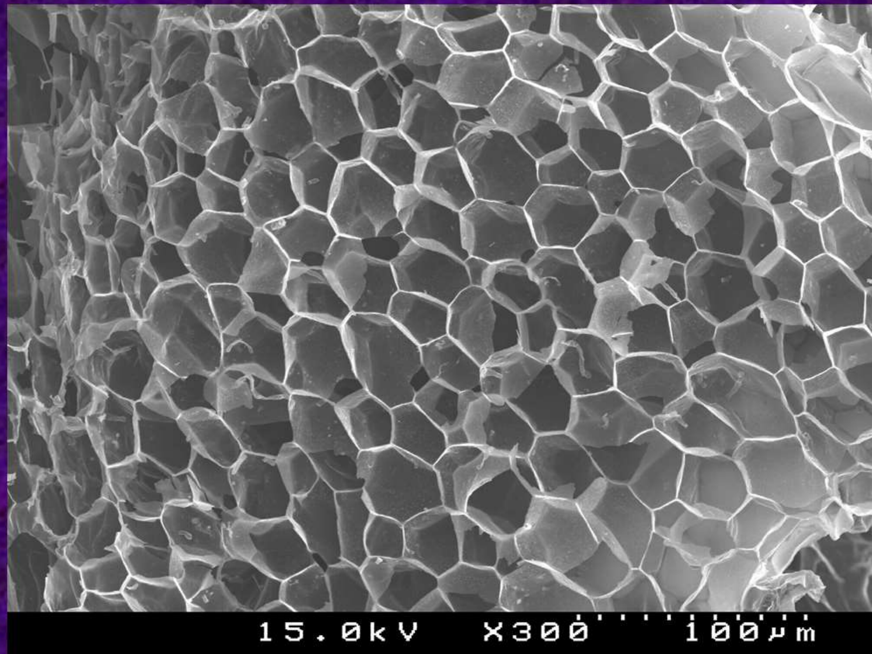
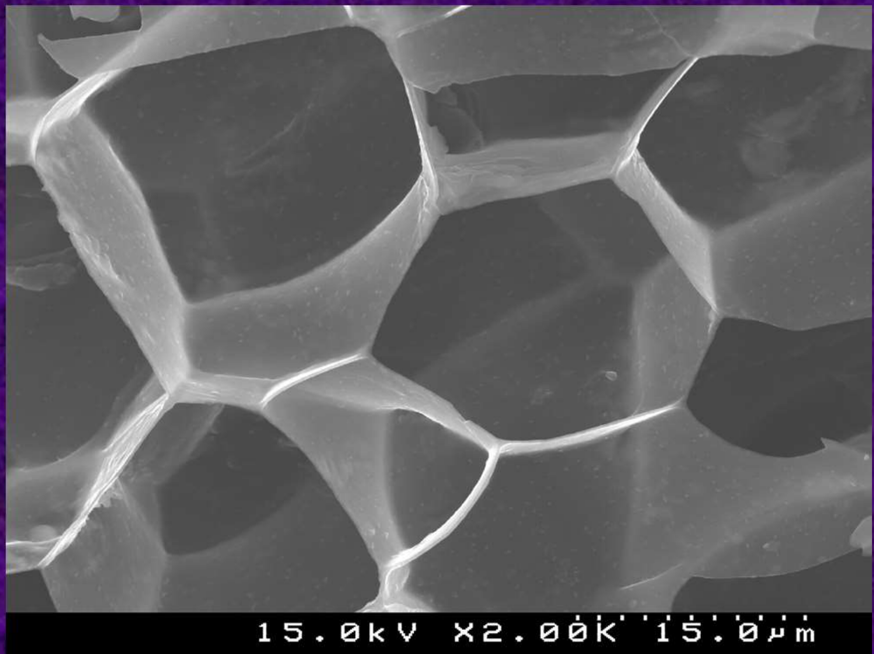
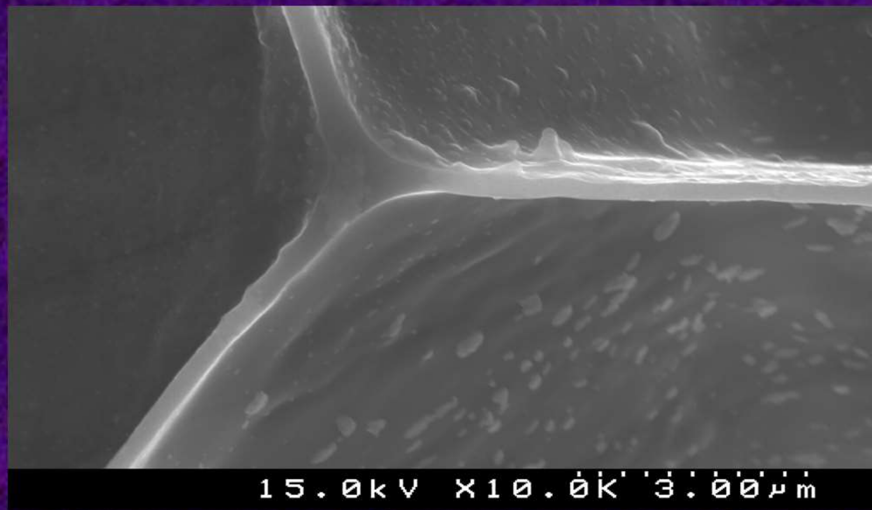
SEM Images of Pyrolysed Waste Cork Powder (now nanoporous carbon)

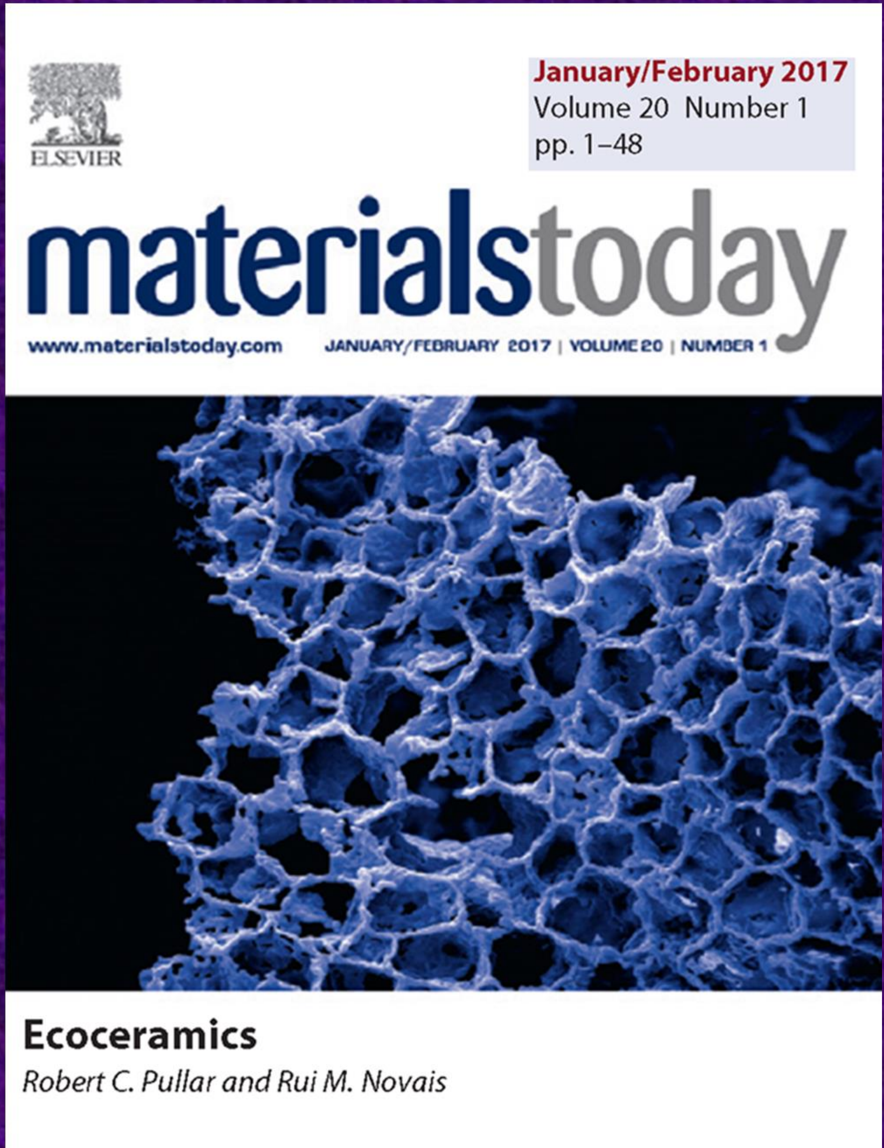


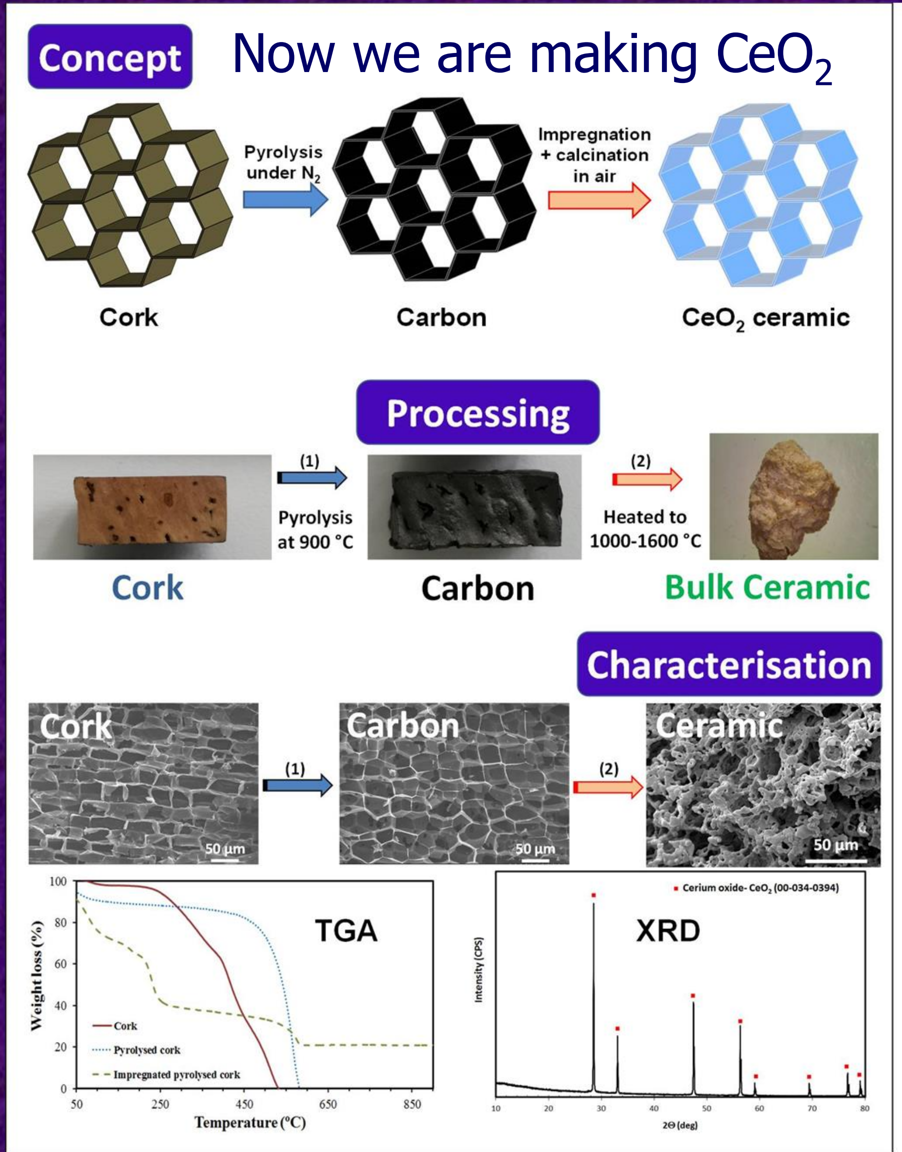






Our Ecoceramics were on the Cover of *Materials Today* (Vol **20**, Jan 2017, p. 45-46)

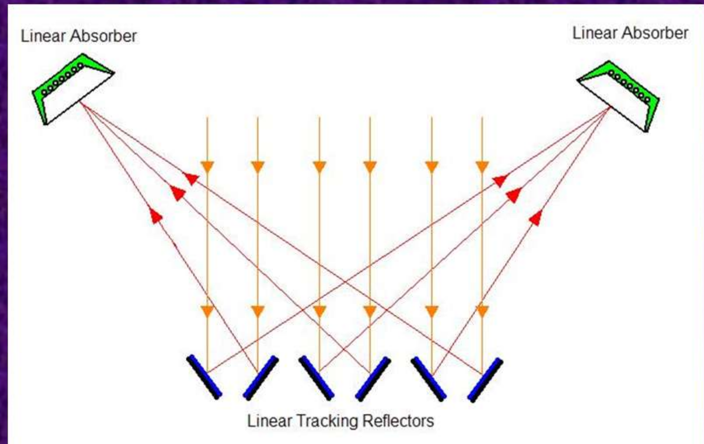


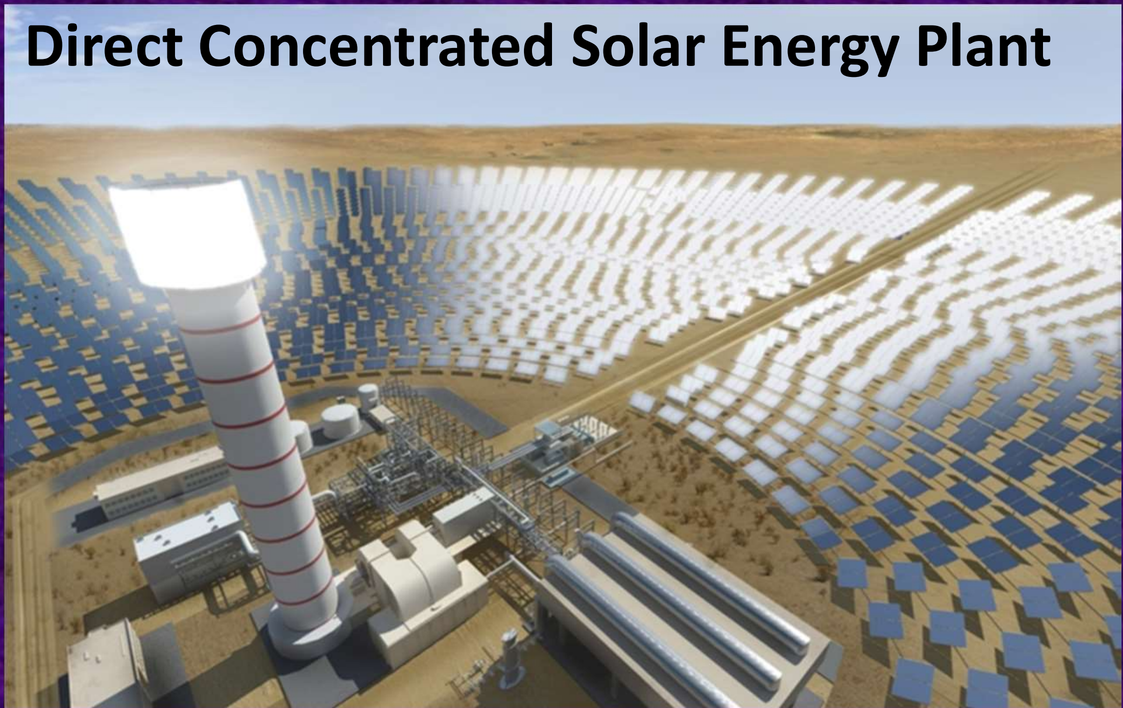


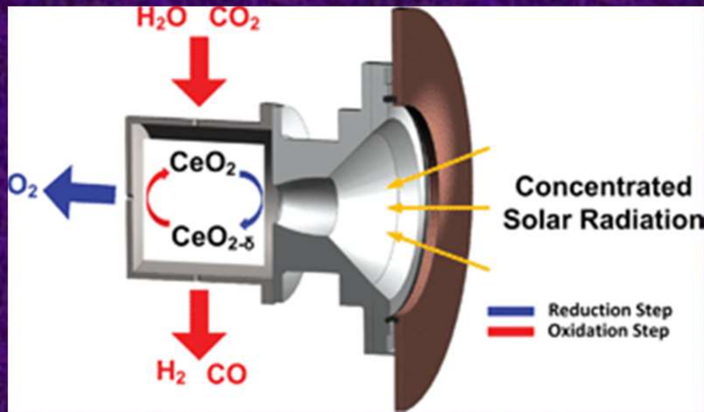
Looking at Applications in Renewable Energy and Hydrogen Generation

Direct concentrated solar energy – a beam of sunlight, NOT photovoltaics

ThermoChemical Fuel Production (TCFP) to split water or CO_2 on ceria at 1500 º C

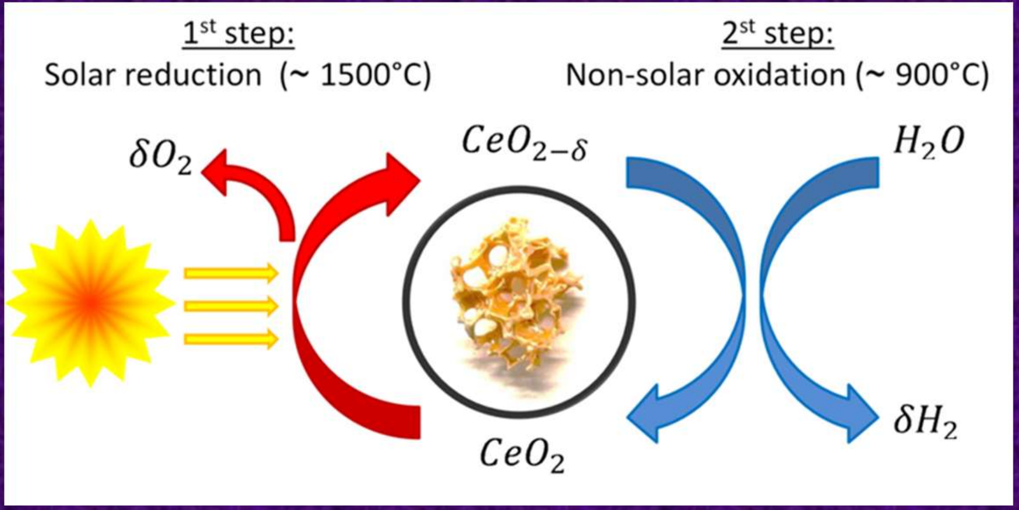


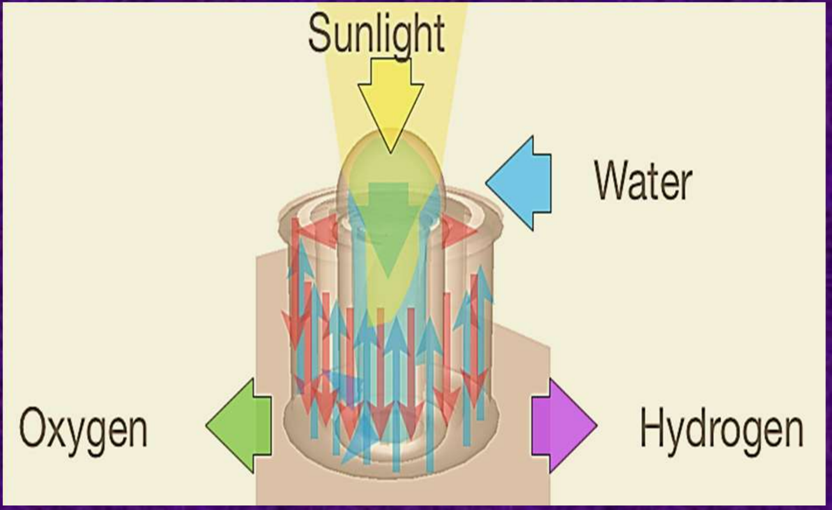




Why Cork based CeO_2 Ecoceramics could be Good for TCFP Water & CO_2 Splitting

Two-step redox thermochemical cycle, requires temperatures up to 1500 °C (thermolysis), so needs a high temp ceramic (CeO_2)





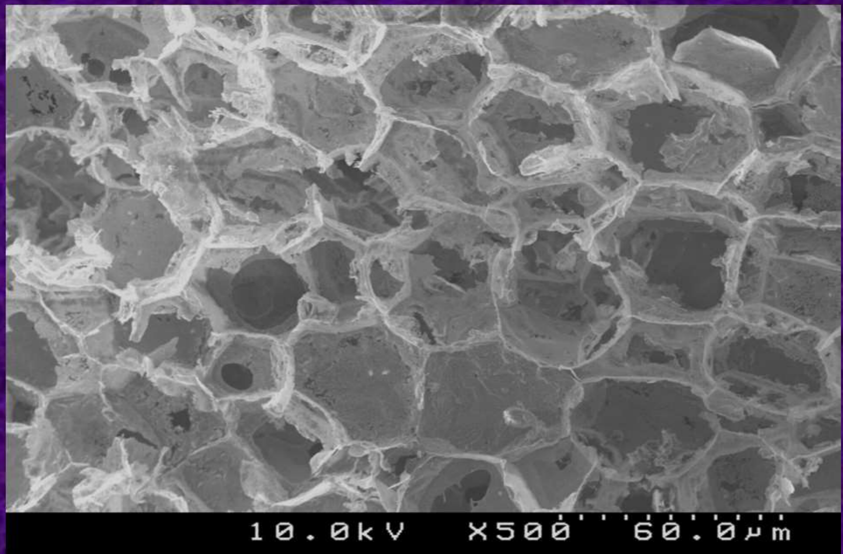
Non-stoichiometric ceria combines excellent reactivity (high O_2-ion conductivity) and good cyclability (high-temp stability)

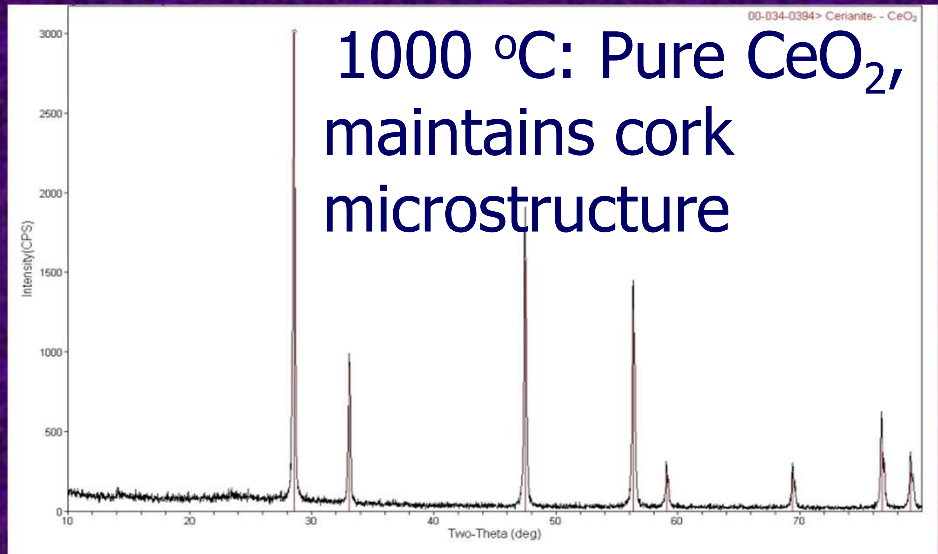
However, currently low H_2 & CO yields – very inefficient process

Reaction kinetics would be enhanced using 3-DOM CeO_2

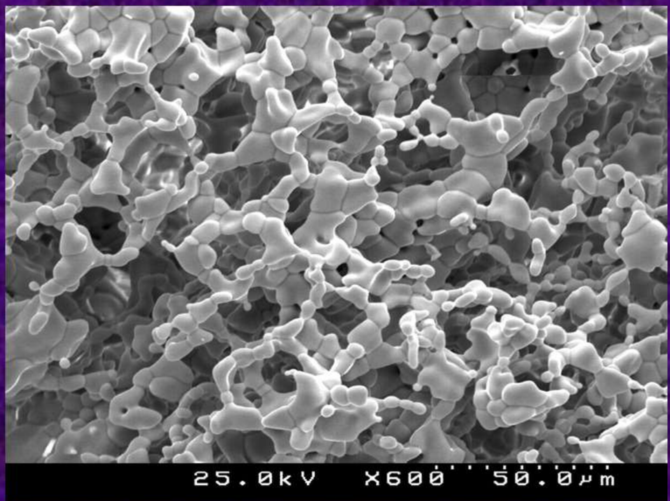
Cork could be an ideal biomimetic and sustainable template

Waste Cork-based Ceria Ecoceramics heated to 1000 ºC and 1600 ºC

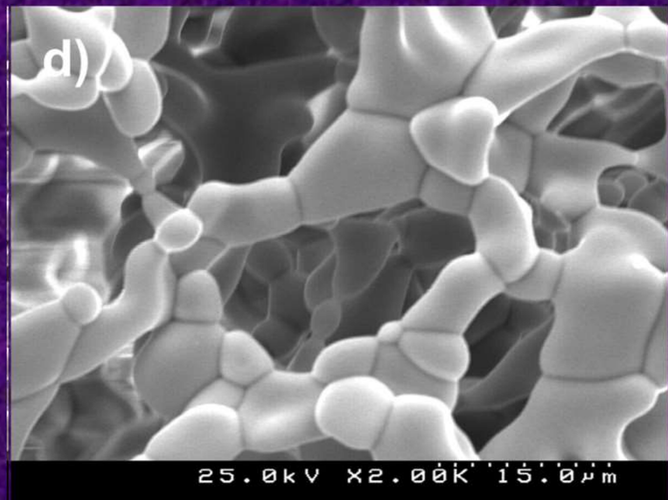




1000 ºC: Pure CeO_2, maintains cork microstructure

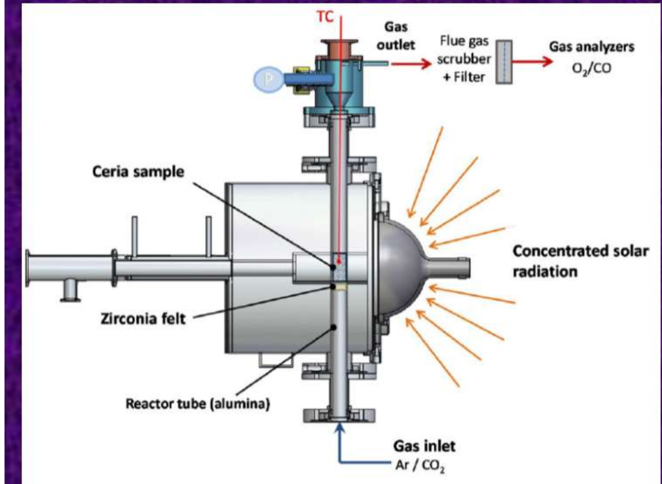


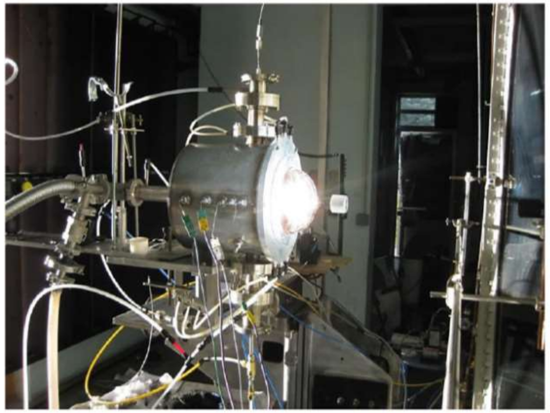
1600 ºC: Grains have grown greatly up to 10 μm, cork structure damaged but porosity greater

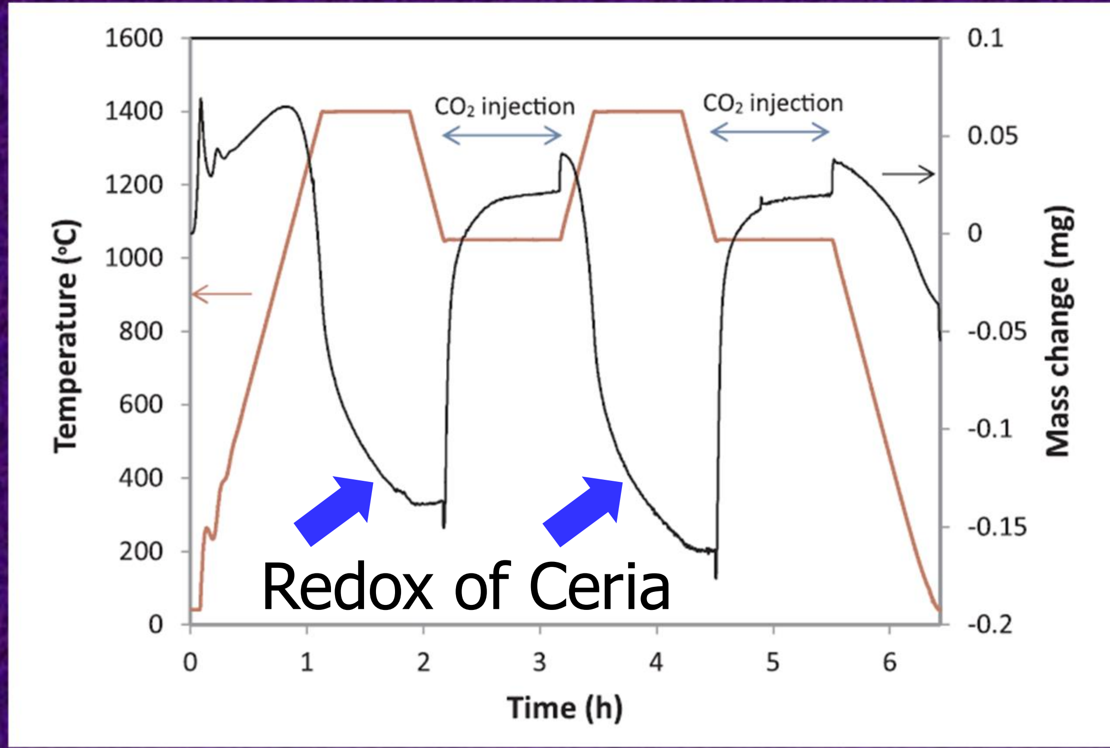


Solid–Gas Thermochemical Reactions to Split CO_2 → $CO + O_2$ (for syngas)

- Using a solar chemical reactor mounted on a medium size solar furnace (MSSF) facility at CNRS-PROMES – 2 m diameter parabolic dish concentrator, 15 mm diameter cavity receiver

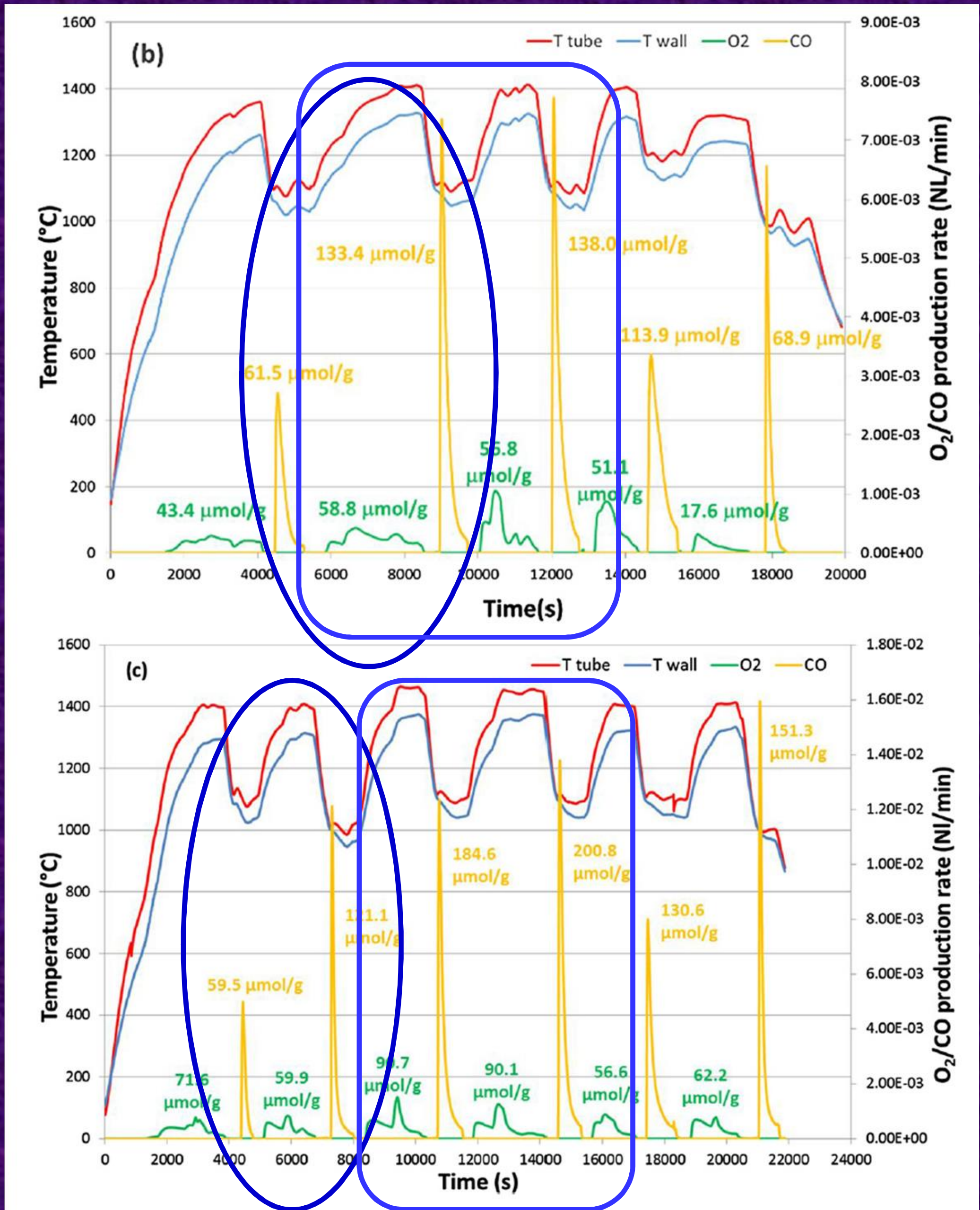






Two steps – CO_2 split at 1050 ºC, ceria reduced at 1400 ºC, all in solar reactor

CO_2 Splitting with CeO_2 Cork Ecoceramics



Top (b) = 750 w / m^2

Bottom (c) = 1000 w / m^2

Yellow = CO production in oxidation step @ 1050 ºC

Green = O_2 production in reduction step @ ~1400 ºC

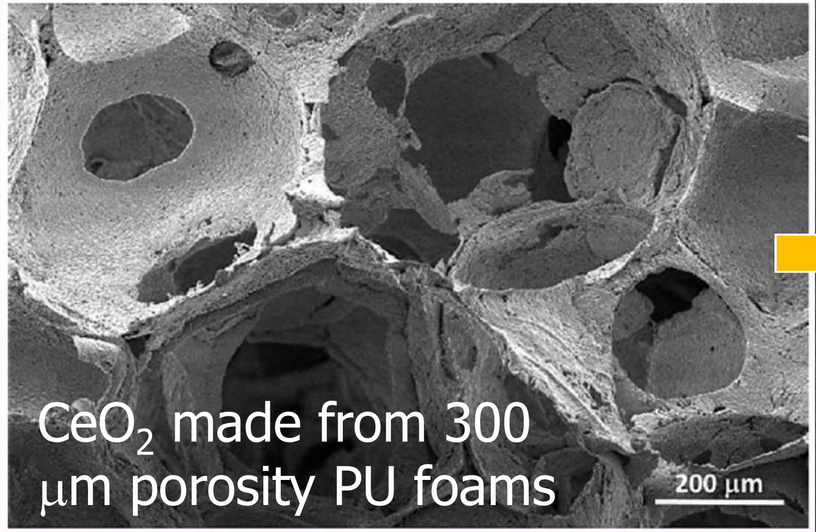
Very repeatable cycling

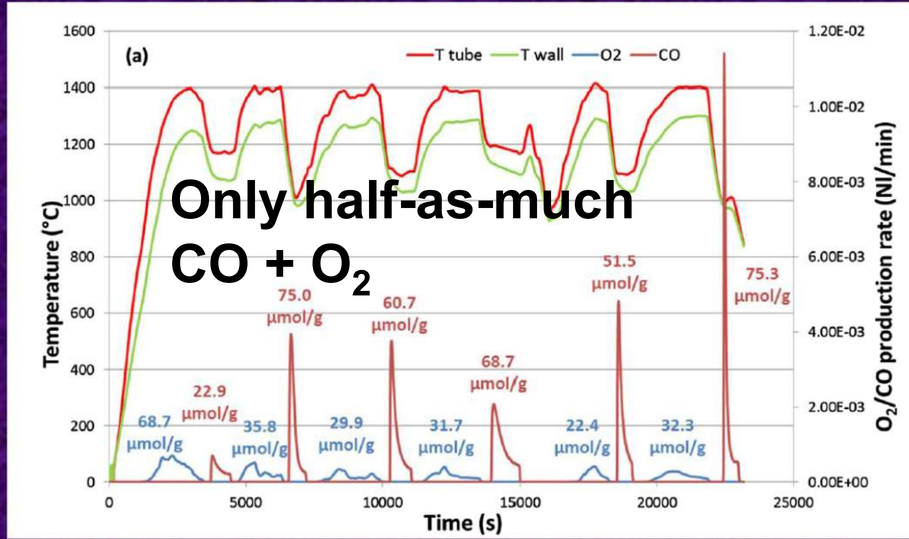
Produced ~130 µmol/g CO and ~60 µmol/g O_2 with reduction at 1400 ºC

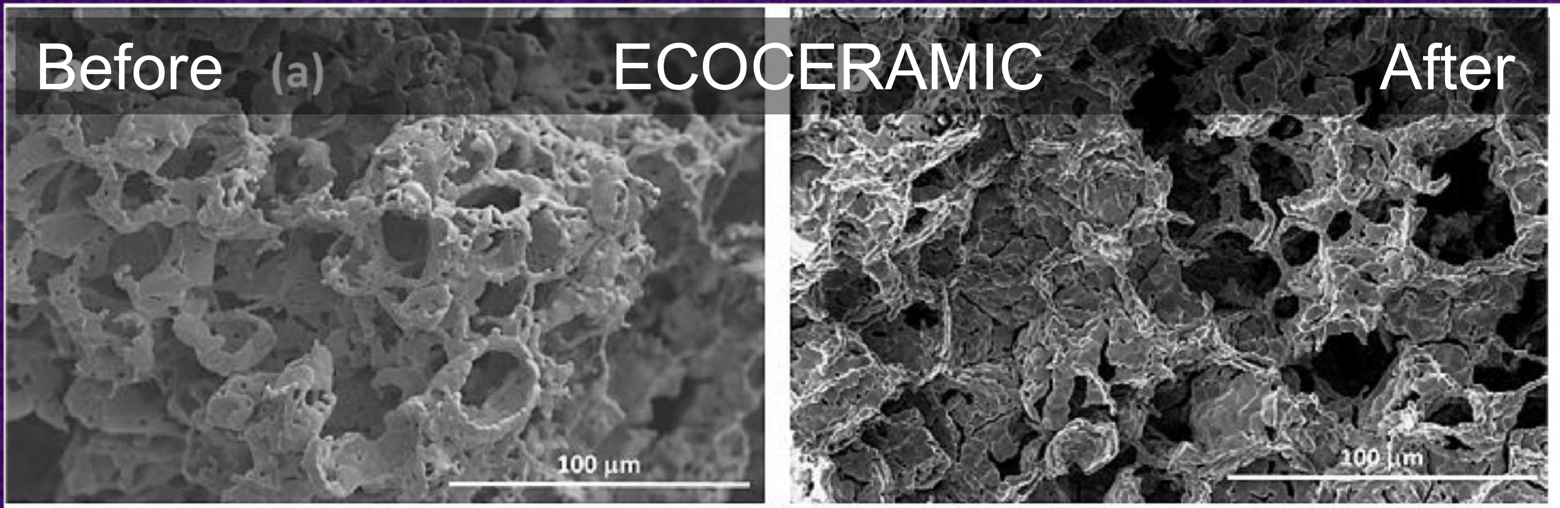
~200 µmol/g CO and ~90 µmol/g O_2 with 1450 ºC

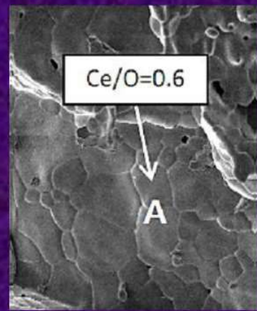
CO production rate 3 x more than other reported cerias

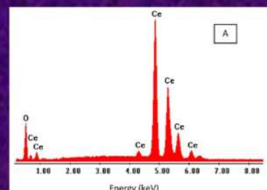
CeO_2 Ecoceramics twice as good as CeO_2 Foams made from Non-Sustainable PU Templates





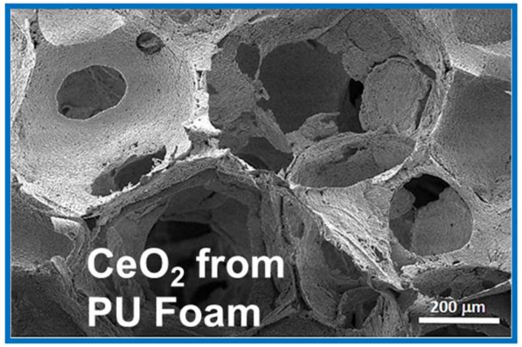




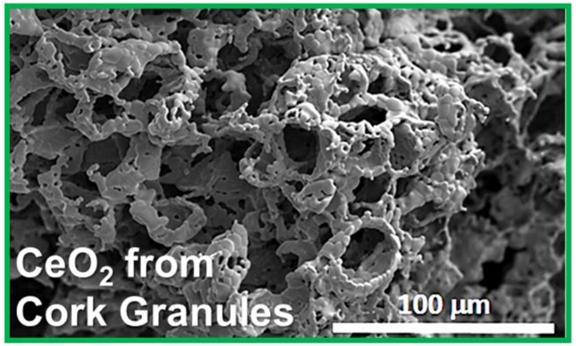


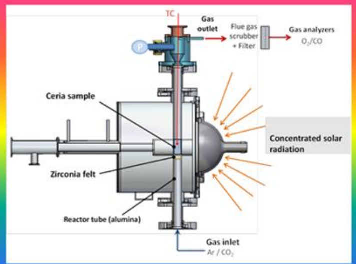
After 6 cycles cork structure mostly maintained, evidence of $CeO_{2-\delta}$

Conclusions: Sustainable CeO_2 Ecoceramics Made from Cork used to successfully split CO_2 using Concentrated Solar Energy

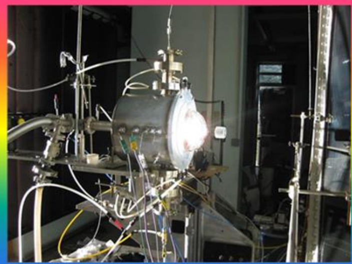


Templated 3-DOM CeO_2 Catalysts made from PU & Cork

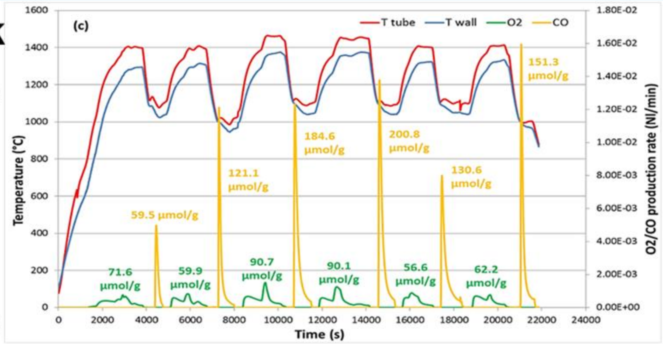




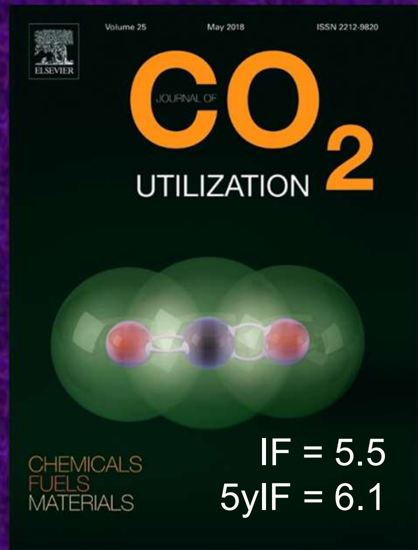
Thermochemical Splitting of CO_2 → CO + O_2 in a Concentrated Solar Furnace



PU Foam & Cork templated CeO_2 survived many Redox Cycles without losing their 3-DOM Microstructures



CeO_2 from Cork gave TWICE the amount of CO + O_2 with Cycles of 1400°C & 1000°C using Solar Energy



Thank you for your attention

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Solar thermochemical CO_2 splitting using cork-templated ceria ecoceramics

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