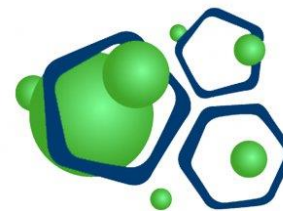
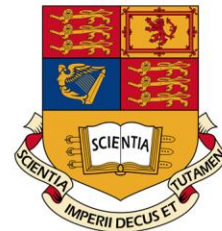




Imperial College  
London



Barrer  
Centre

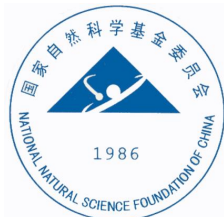
# Functional Ceramic Hollow Fiber --Advanced Fabrication to 3D Characterization

Tao Li & Prof. Kang Li

Barrer Center, Department of Chemical Engineering,  
Imperial College London

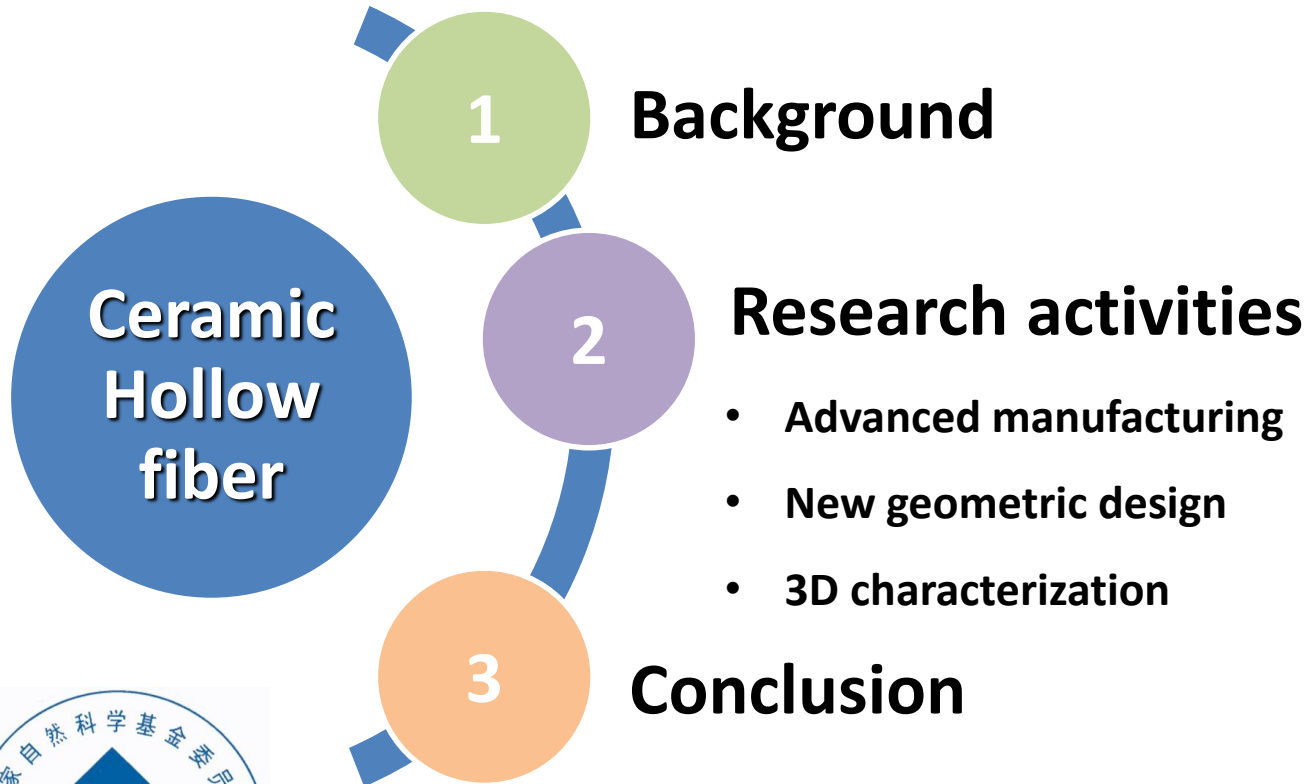


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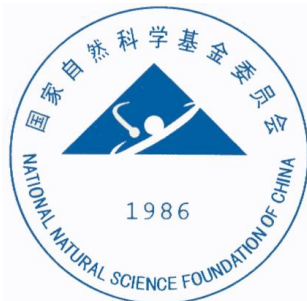


MEEA 2018, 15<sup>th</sup> – 17<sup>th</sup> Oct 2018, Nanjing



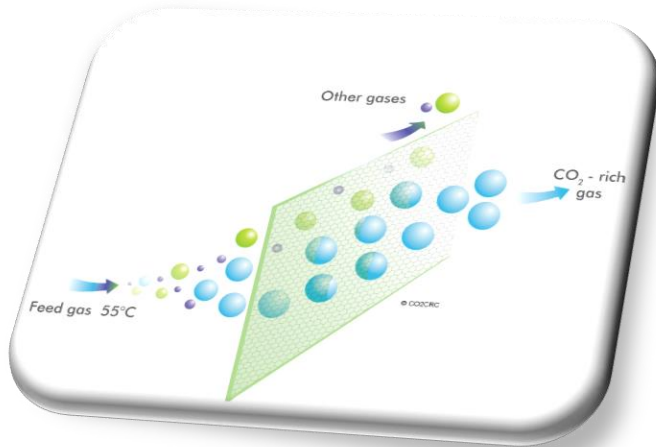


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## What is it?



Inorganic materials

- $\text{Al}_2\text{O}_3/\text{TiO}_2$
- YSZ/GDC/ScSZ
- $\text{Si}_3\text{N}_4/\text{SiC}$
- Perovskites

Flexible Pore structure

- Porous
- Dense

Pros./Cons

- Good chemical/thermal stability
- High packing density/flux/SA
- **Expensive/mechanical issue**

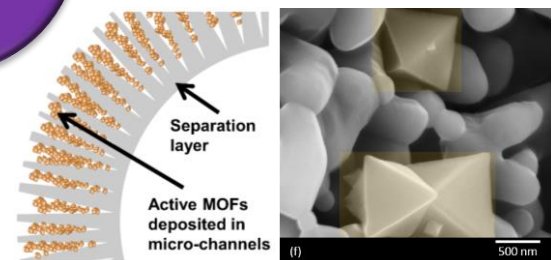
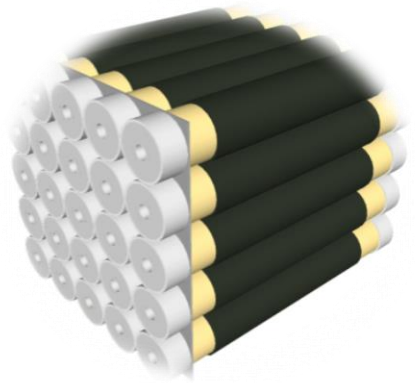
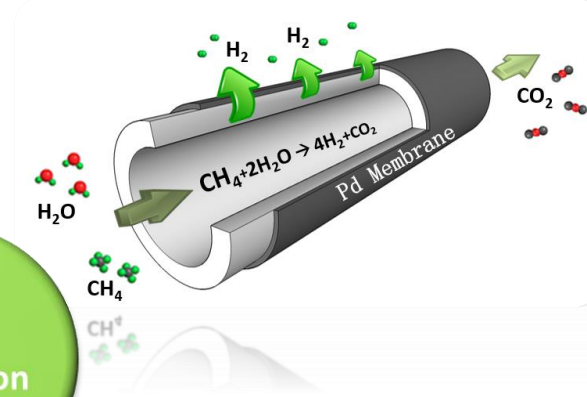
<https://www.nexxwater.com/details/technology>  
<https://www.pinterest.co.uk/pin/262756959479562411/>



**New catalytic converter could cut fuel consumption and car manufacturing costs**



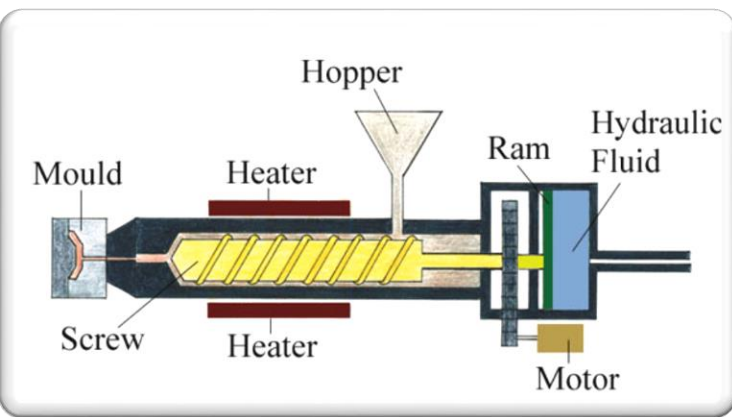
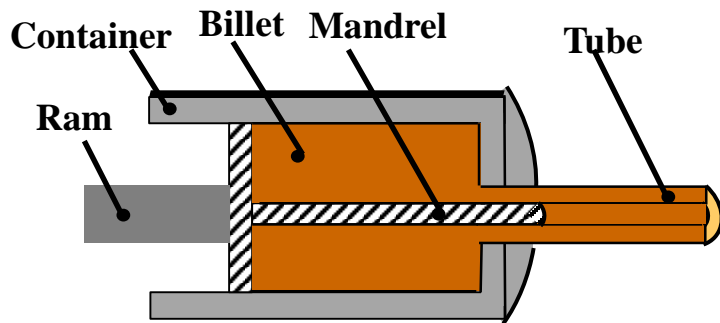
## What applications?





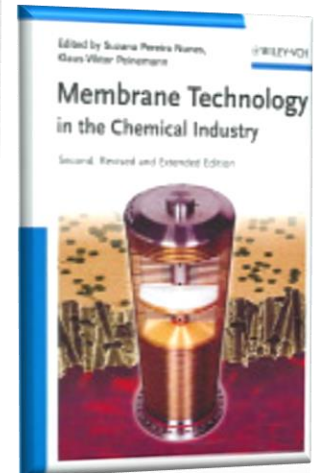
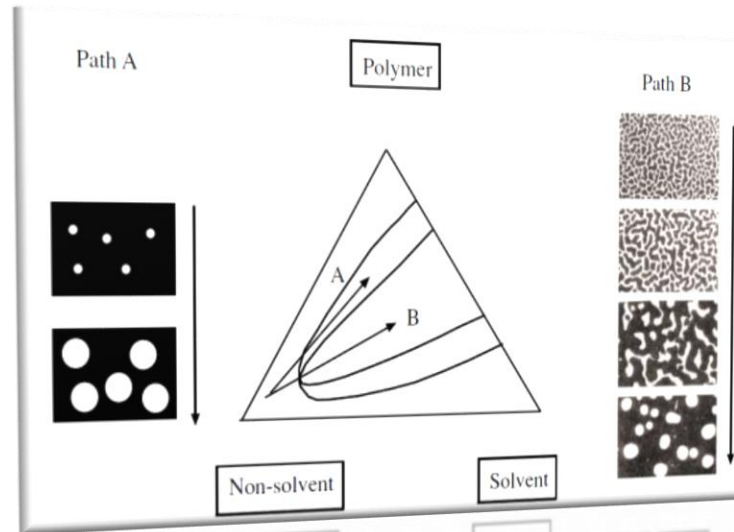
## Manufacturing

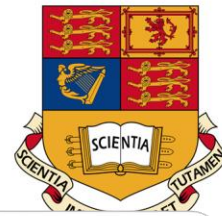
### 1. Ram extrusion



### 2. Phase inversion-based extrusion

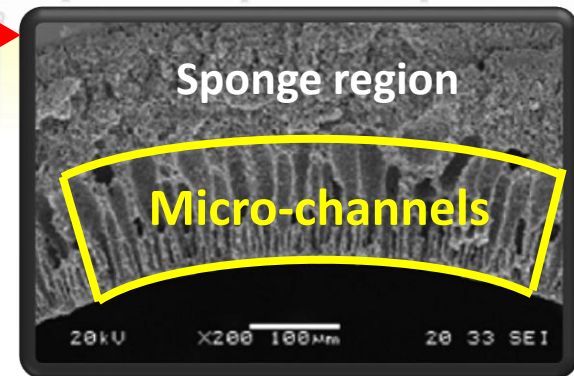
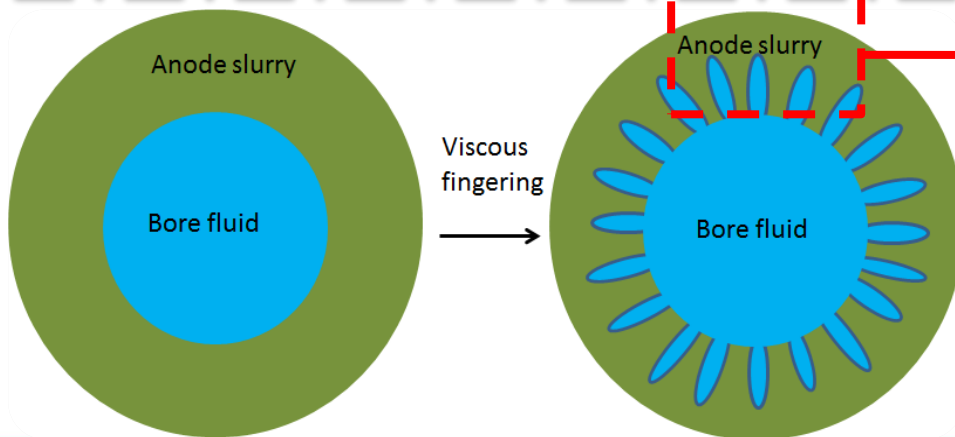
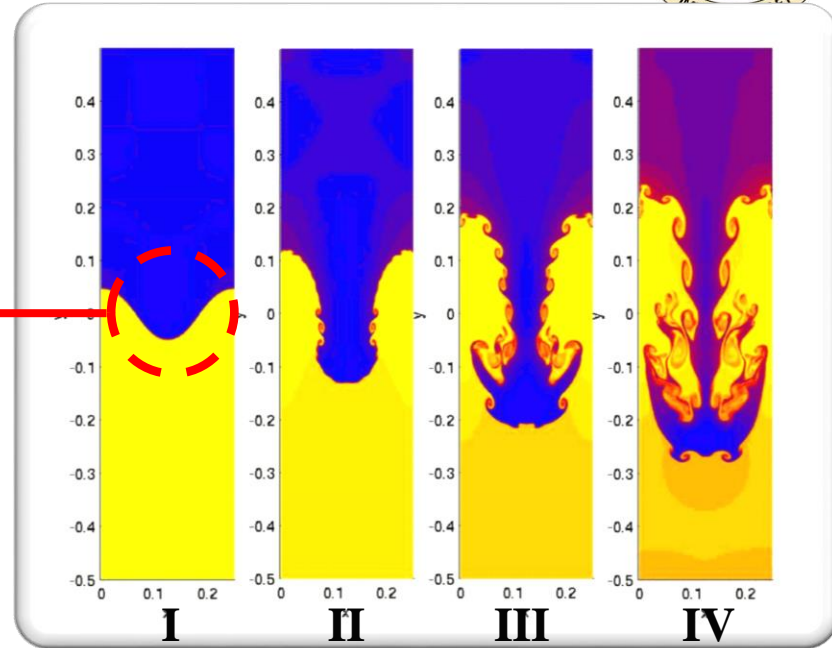
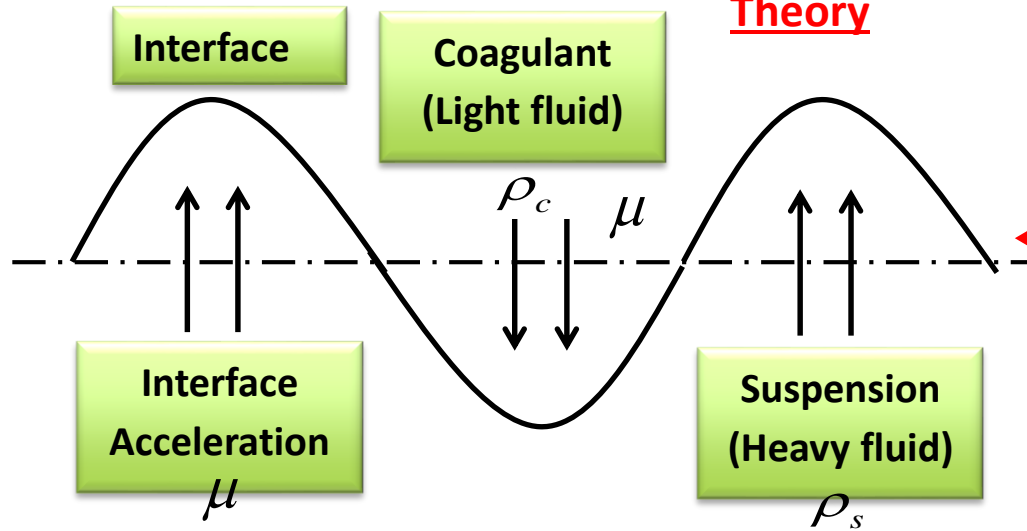
The phase inversion process consists of the induction of phase separation in a previously homogeneous polymer solution either by temperature change, by immersing the solution in a non-solvent bath (wet process) or exposing it to a non-solvent atmosphere (dry process).





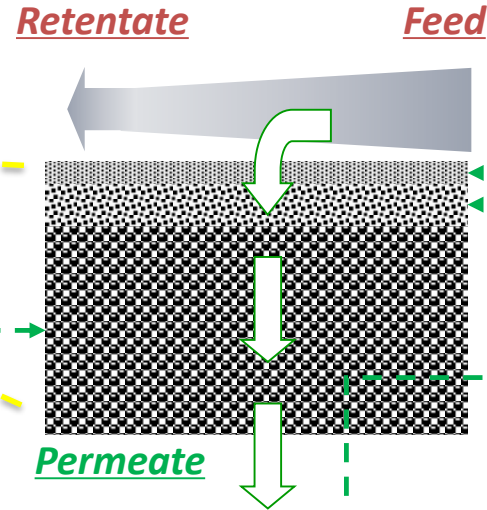
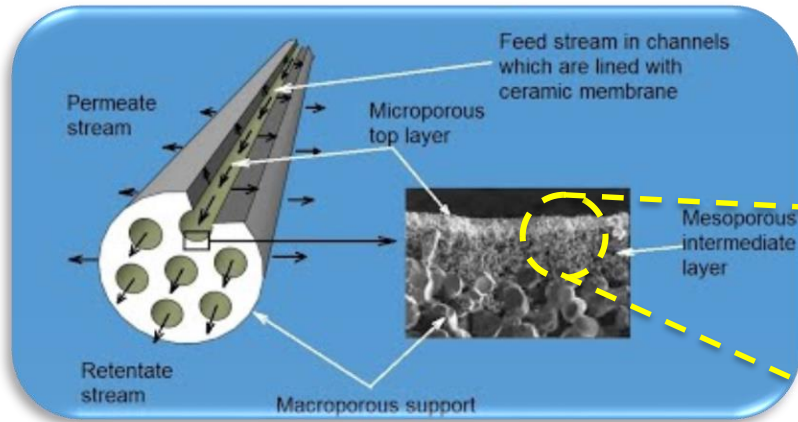
## Rayleigh–Taylor Instability

### Theory

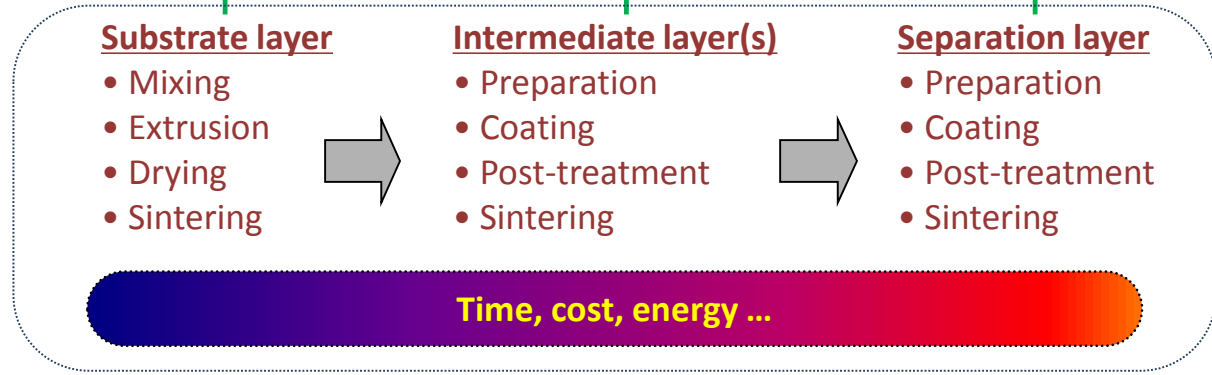




# 1. Single-step manufacturing



## Membrane for water treatment:





# 1. Single-step manufacturing

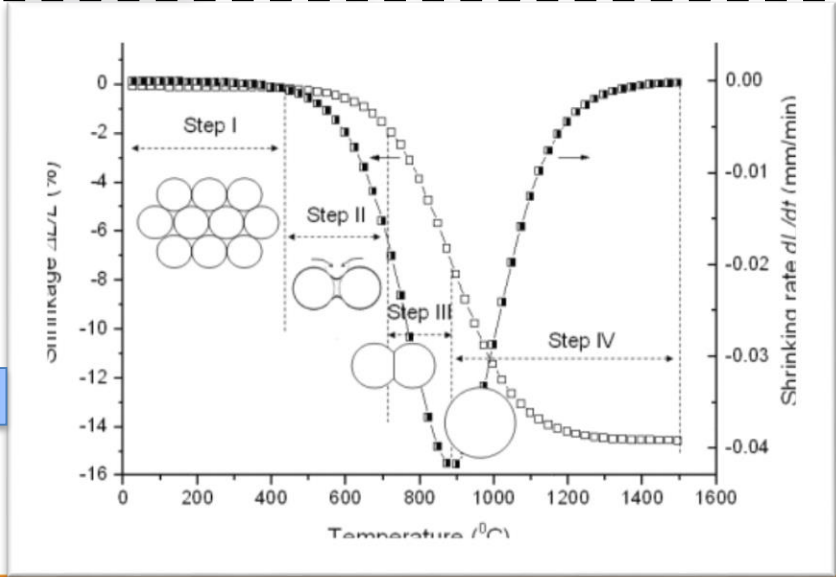
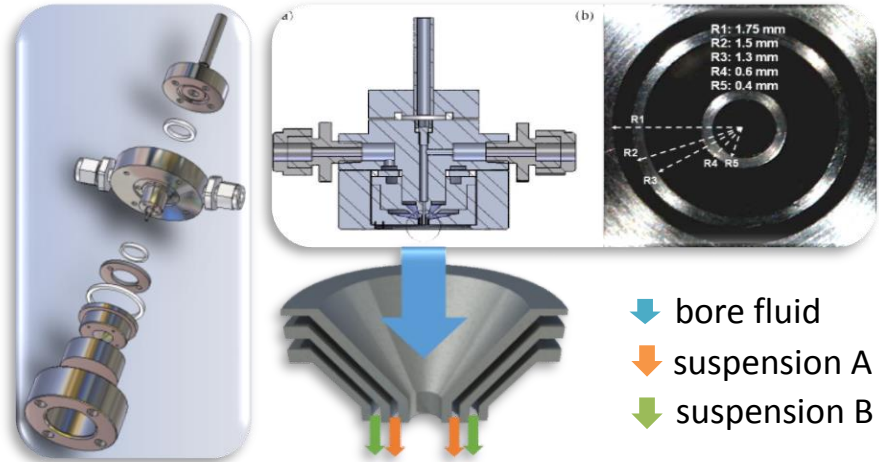
## Co-extrusion/ sintering

Advantages

- |   |   |
|---|---|
| <ul style="list-style-type: none"> <li>1. Improved adhesion</li> <li>2. Time/energy efficient</li> <li>3. Flexible thickness control</li> </ul> | <ul style="list-style-type: none"> <li>1. Varied sintering behaviours</li> <li>2. Interactions between layers during extrusion</li> </ul> |
|---|---|

Challenges

- ✓ Shrinkage rate difference: **20-50%**
- ✓ Sintering rate difference: **200-300%**



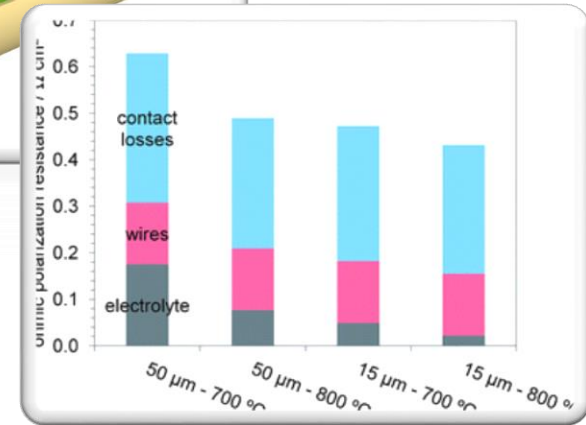
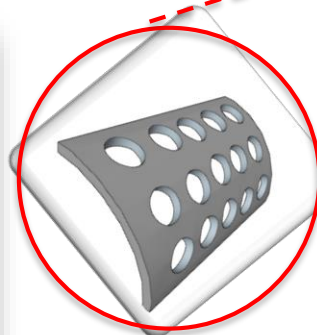
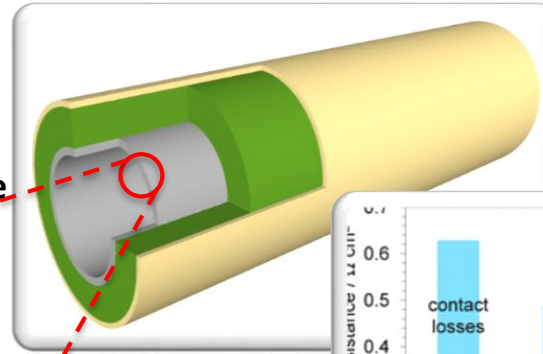




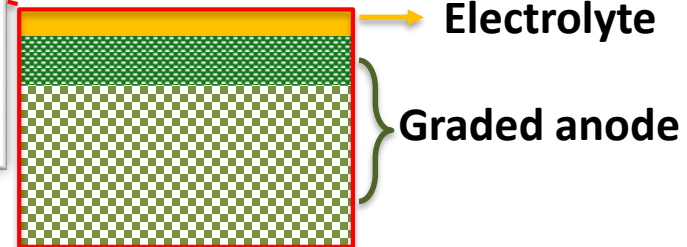
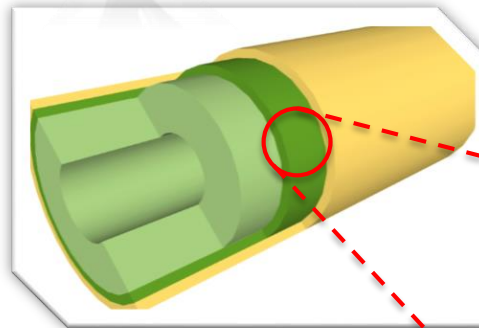
# 1. Single-step manufacturing

## Triple-layer Co-extrusion/sintering

**Design I:**  
Current collector/anode/electrolyte



**Design II: Graded anode/electrolyte**

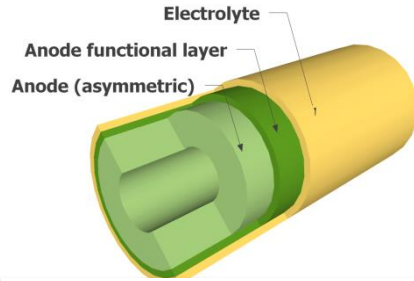


Electrolyte

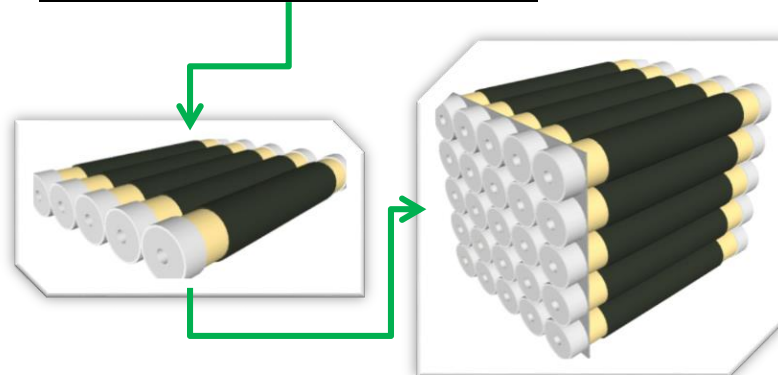
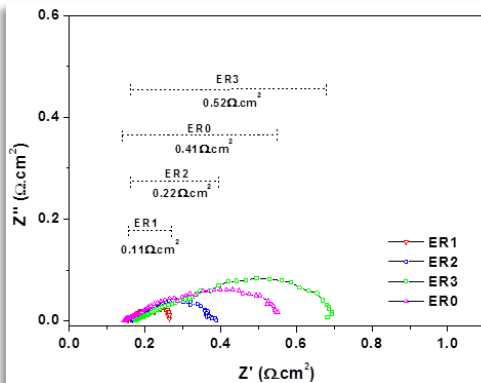
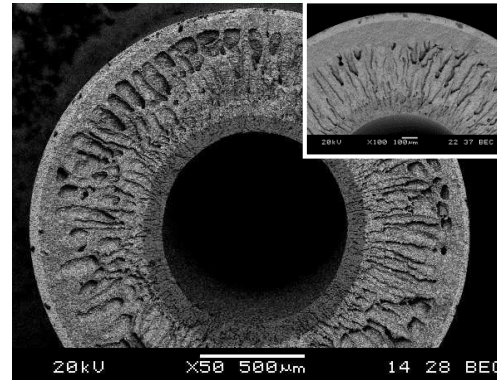
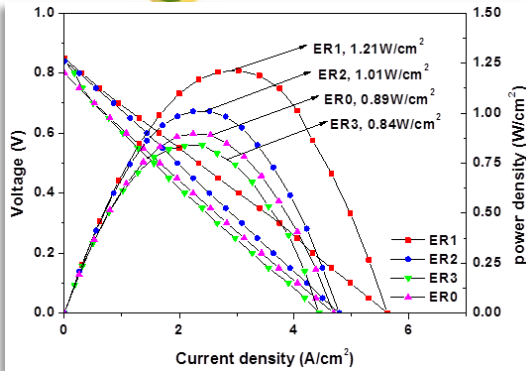
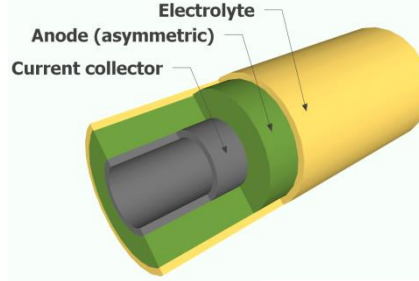
Graded anode



## Graded Anode/Electrolyte



## Current collector/Anode/Electrolyte



**Power density**  
( $1.2 W/cm^2$ ):  
**↑20-40%**

**Current collection efficiency:**  
**↑5-10 times**

**Manufacturing time/energy consumption:**  
**↓100%**

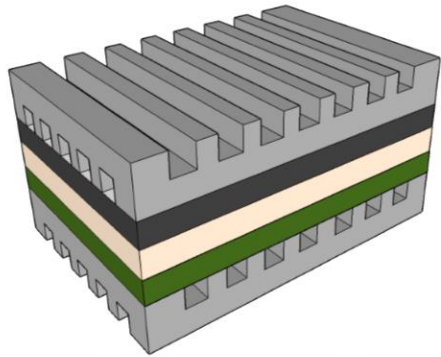


## 2. New Geometric Design

### Conventional SOFCs

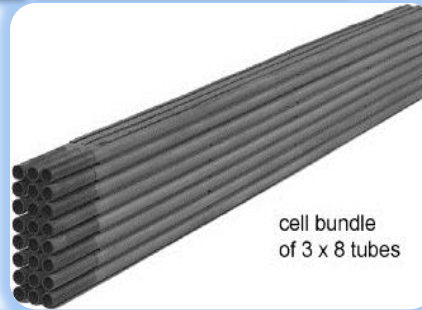
(1) Planar

$> 2 \text{ W/cm}^{-3}$

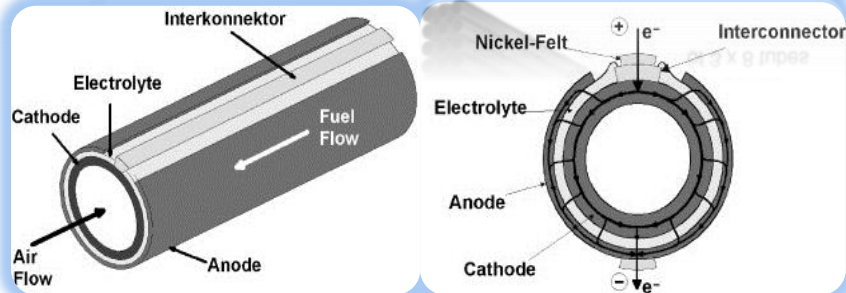


(2) Tubular

$\sim 0.66 \text{ W/cm}^{-3}$

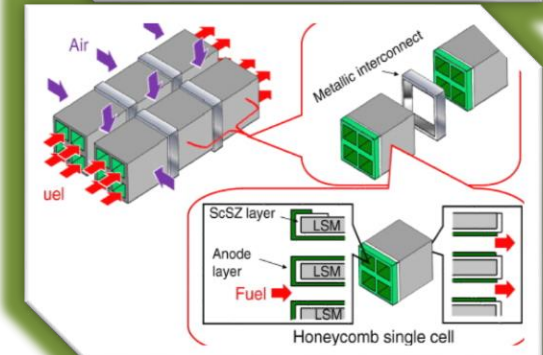
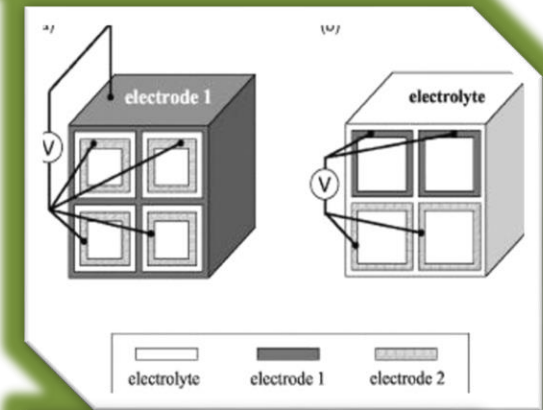


cell bundle  
of 3 x 8 tubes



(3) Honeycomb

$< 0.8 \text{ W/cm}^{-3}$



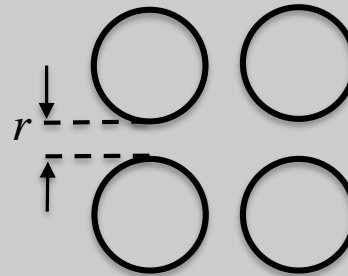
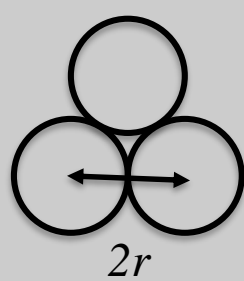
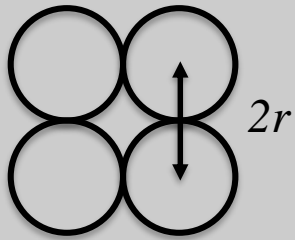
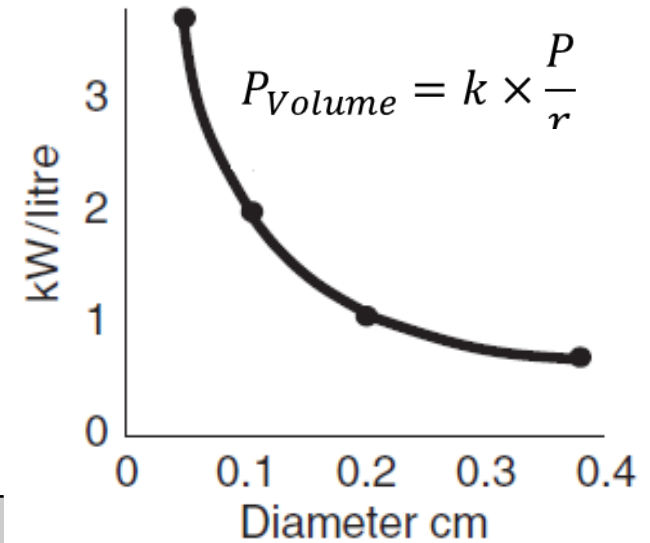
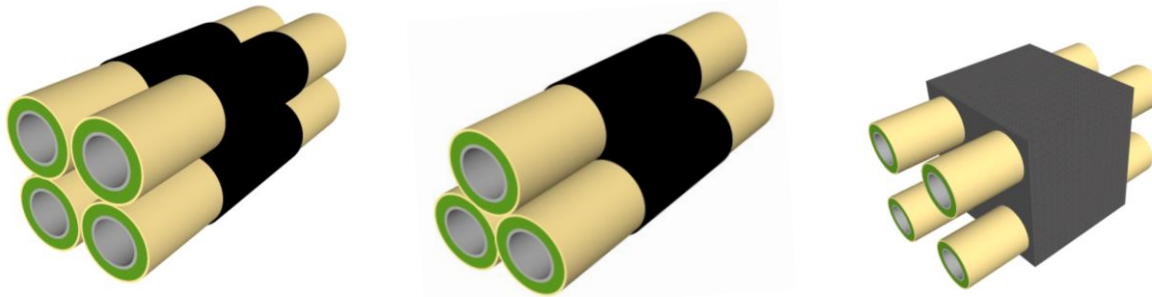
[3] T Yamaguchi, T Suzuki, et.al. Materials Letters, 63 (2009) 2577-2580

[4] R A George, Journal of Power Sources 86 (2000) 134-139



## 2. New Geometric Design

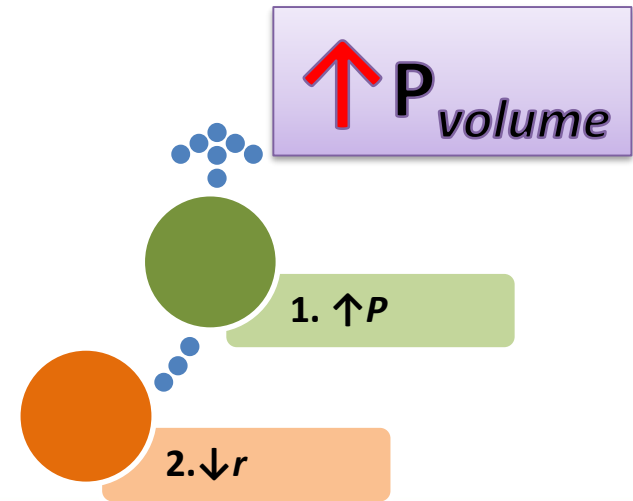
### Power density vs Radius



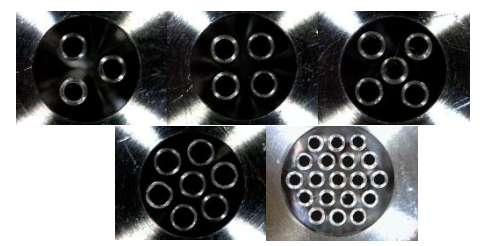
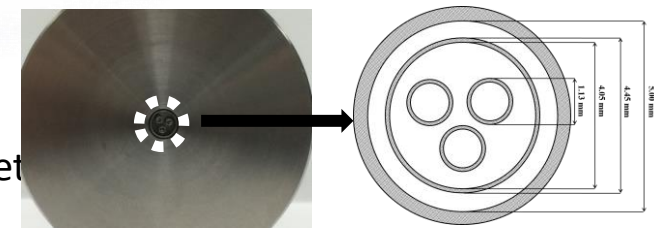
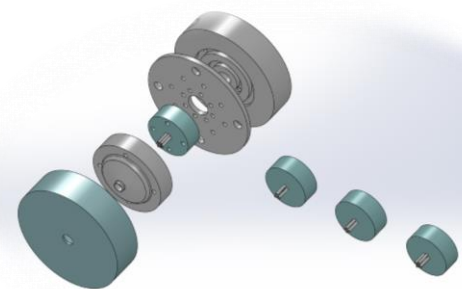
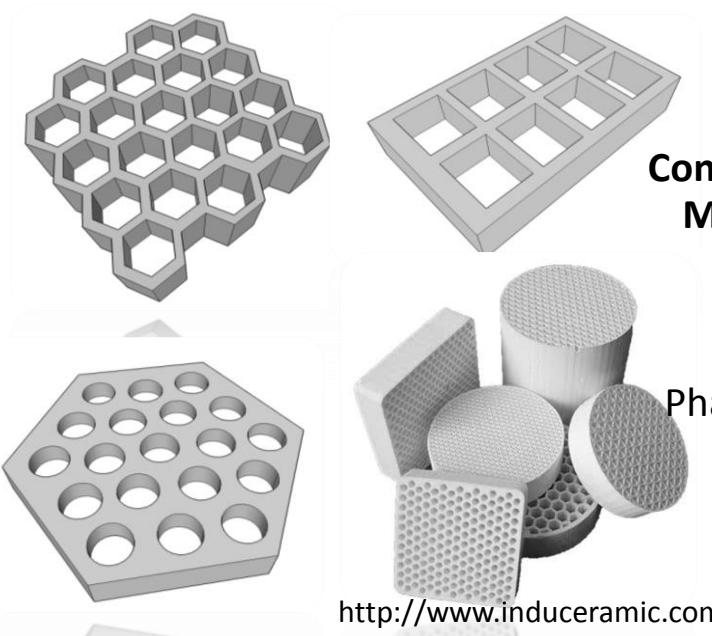
$$P_{Volume} = \frac{\pi}{2} \cdot \frac{P}{r}$$

$$P_{Volume} = \frac{\pi}{\sqrt{3}} \cdot \frac{P}{r}$$

$$P_{Volume} = \frac{2\pi}{9} \cdot \frac{P}{r}$$



## Micro-monolithic Design



## Micro-monolith

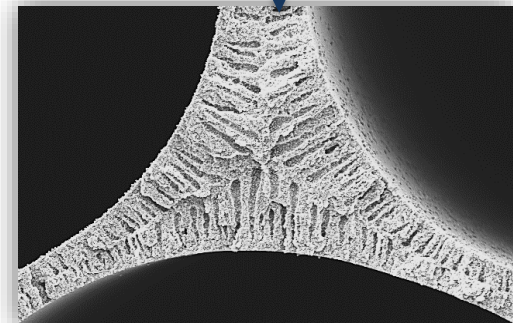
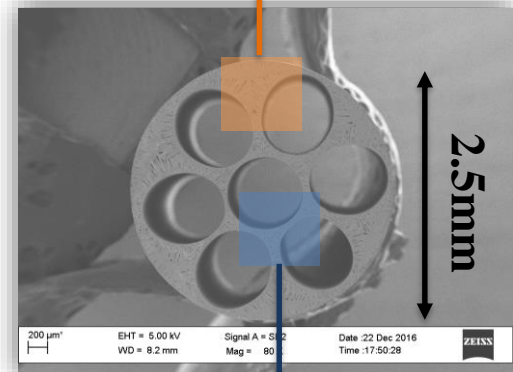
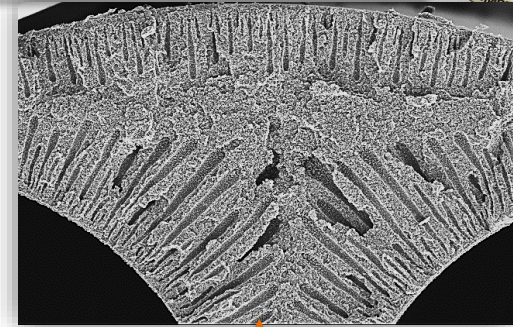
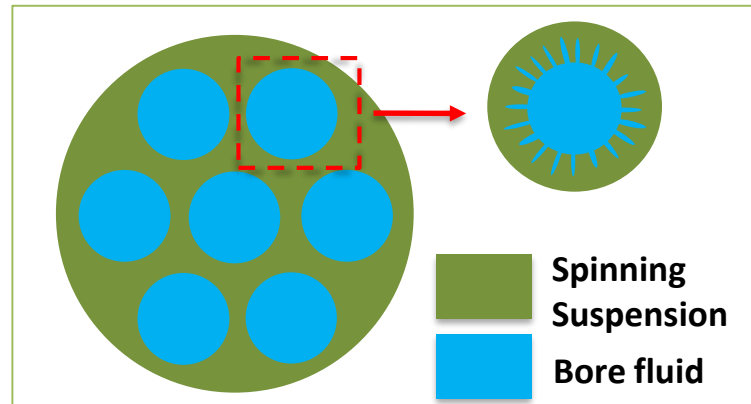
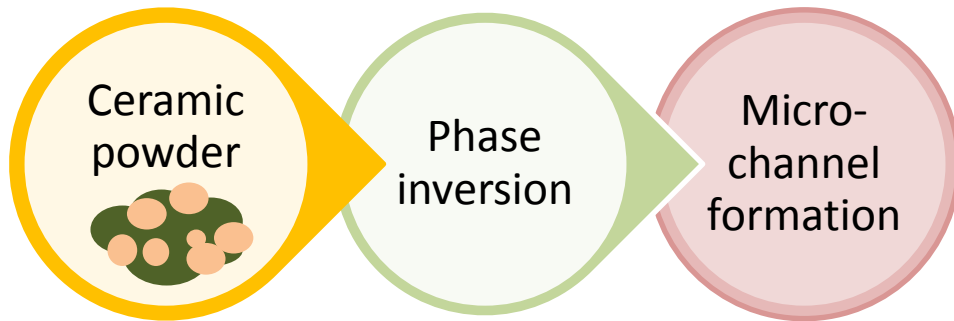


- ❖ Honeycomb structure:
  - an array of hollow channels;
  - good compression/shear stability;
  - difficult thickness reduction/structural tailoring



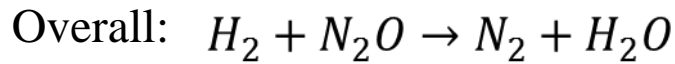
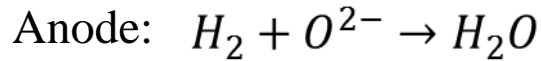
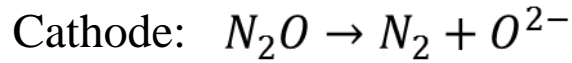
## 2. New Geometric Design

### Micro-monolithic Membrane

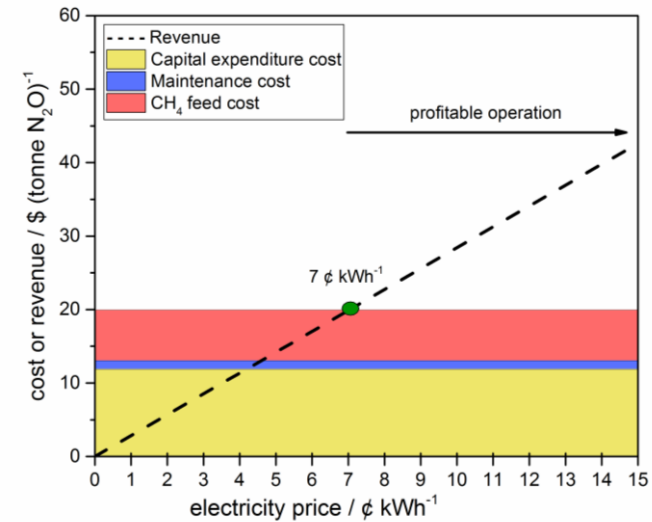




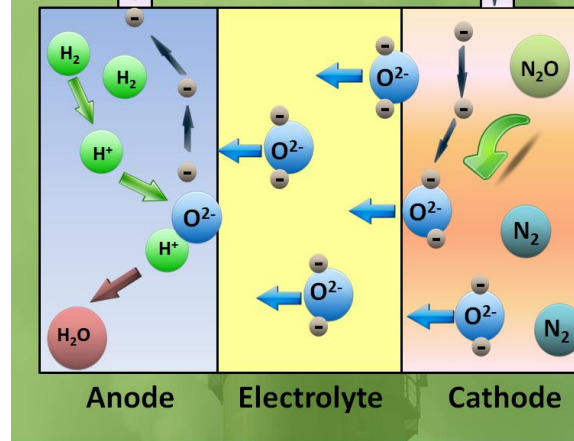
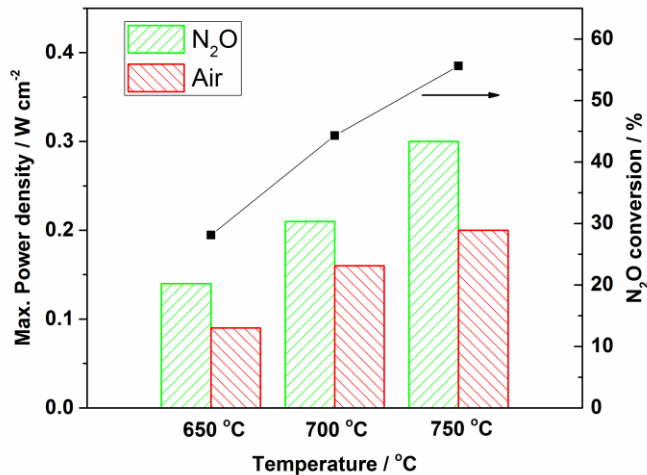
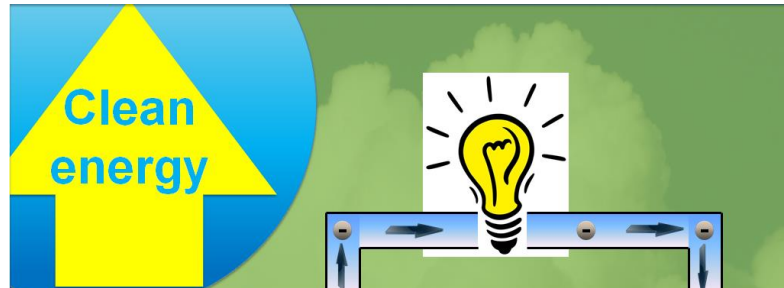
## Multi-function Solid Oxide Cell



Abatement cost ↓

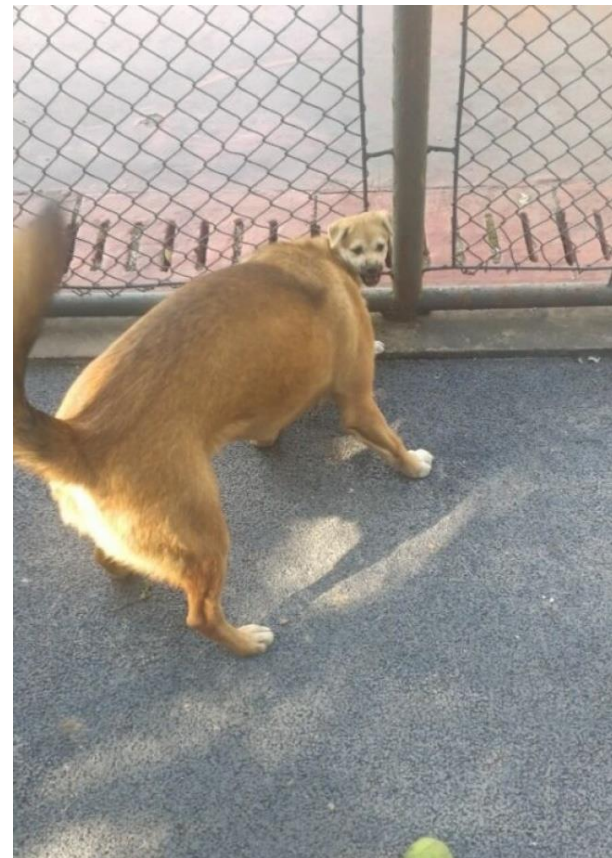


Power density ↑ up to  
30% compared to air





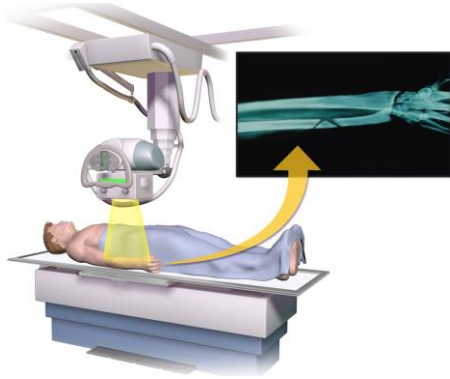
### 3. Advanced 3D Characterization







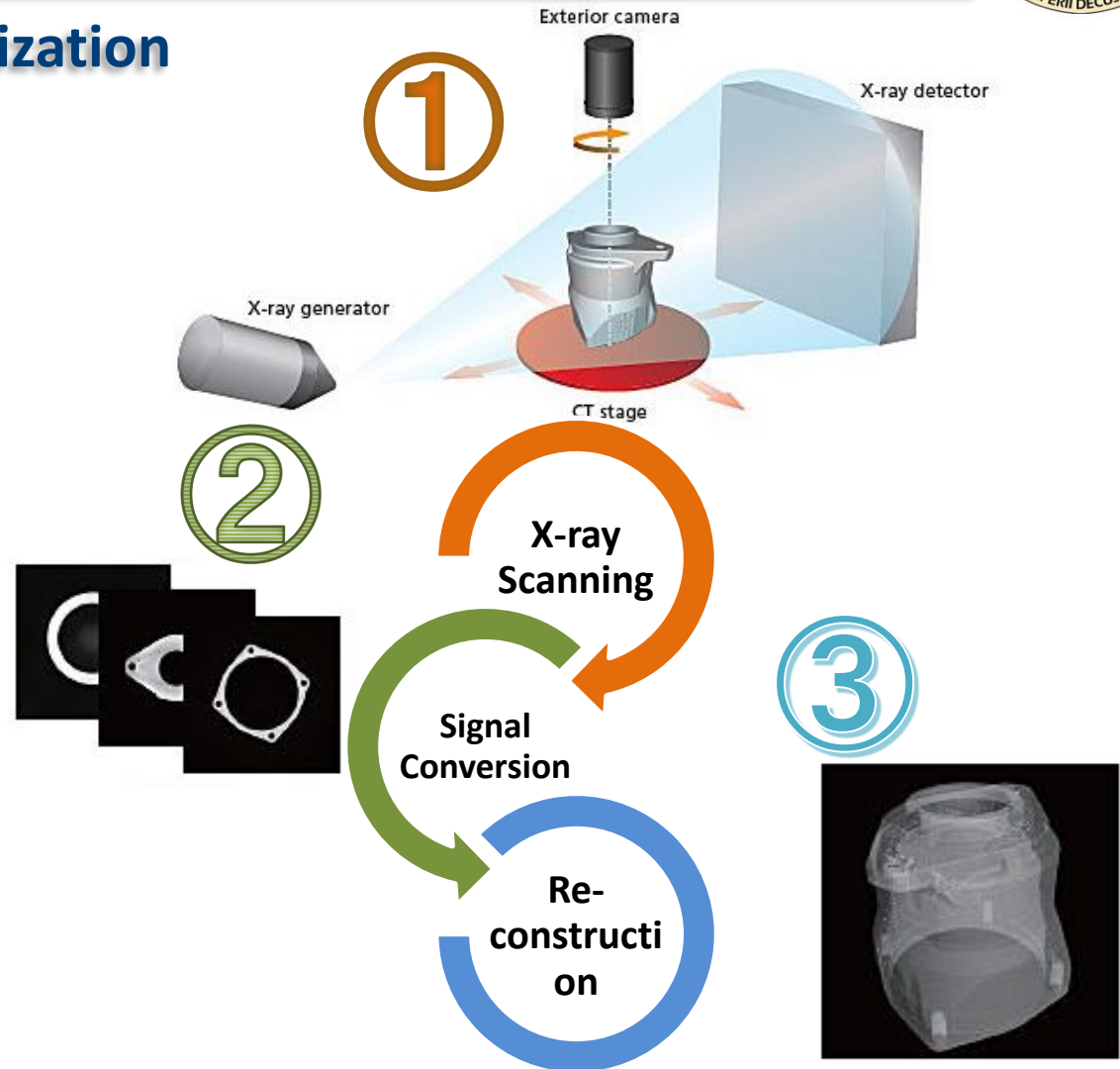
### 3. Advanced 3D Characterization



Medical CT



Micro-CT (microtomography)





1. For decades, there has been significant progress in the field of ceramic hollow fibers, some bottlenecks are yet to be tackled before future commercialization.
2. Phase inversion-assisted co-extrusion technique has been demonstrated to be promising by simplifying manufacturing process.
3. The novel micro-monolithic design has been proved to be more advantageous by displaying both superior performance and excellent mechanical robustness.
4. 3D X-ray CT has been demonstrated to be very helpful in terms of advanced characterization and modelling.



1. EPSRC for research funding.
2. Prof. Kang Li and membrane research group.
3. Other collaborating institutions.



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RESEARCHER  
LINKS





**Thanks  
for Listening !!**

