

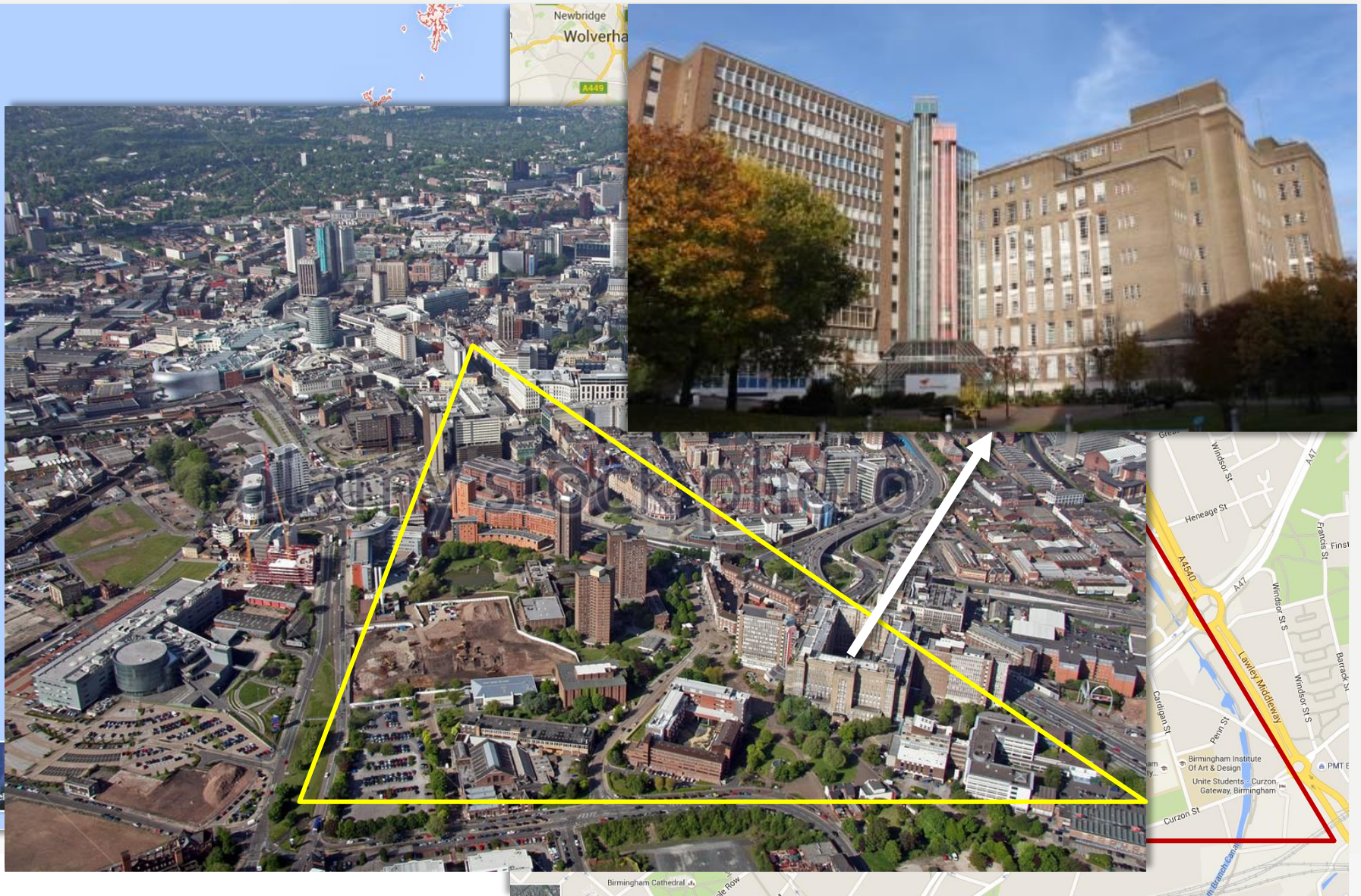
Micro-Structured Ceramic Membranes for Catalytic Reactions

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School of Engineering and Applied Science

MEEA2018, 14-17 October 2018, Nanjing, China

Aston University - location



Aston University – brief history

1895

1948

1955

1966

1997

2016



The entrance to Birmingham Street



Work un
by the Q



Her Maje



The Aston Manor chain, gifted to Aston University on the receipt of its Royal Charter.



12:00 AM
February 1, 1997

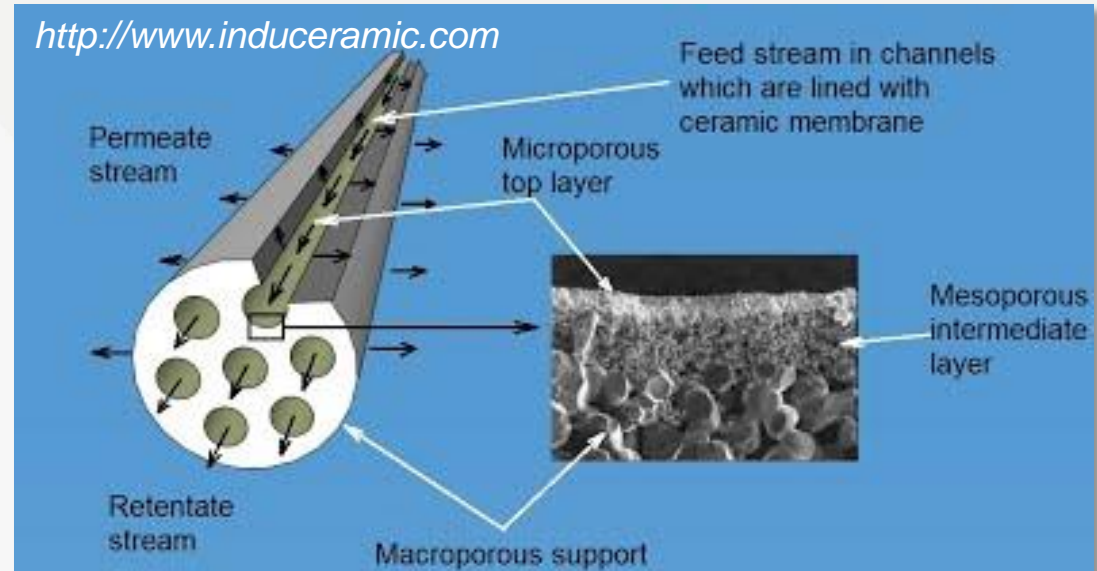
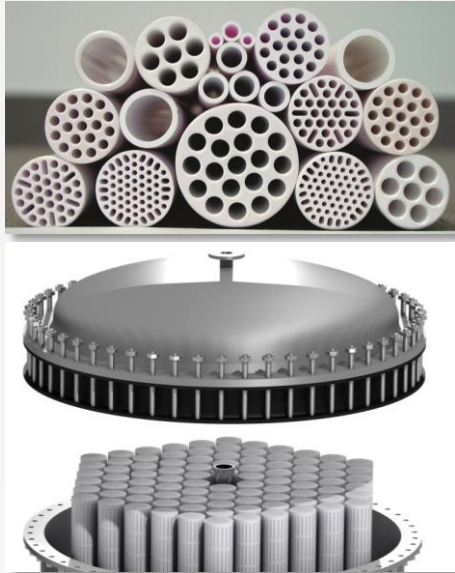
Name Change

The Privy Council approves the renaming of University of Aston in Birmingham to Aston University, recognising the institution's identity within the city and its growing reputation abroad.

the Charter is given the
Royal assent on March 10th.

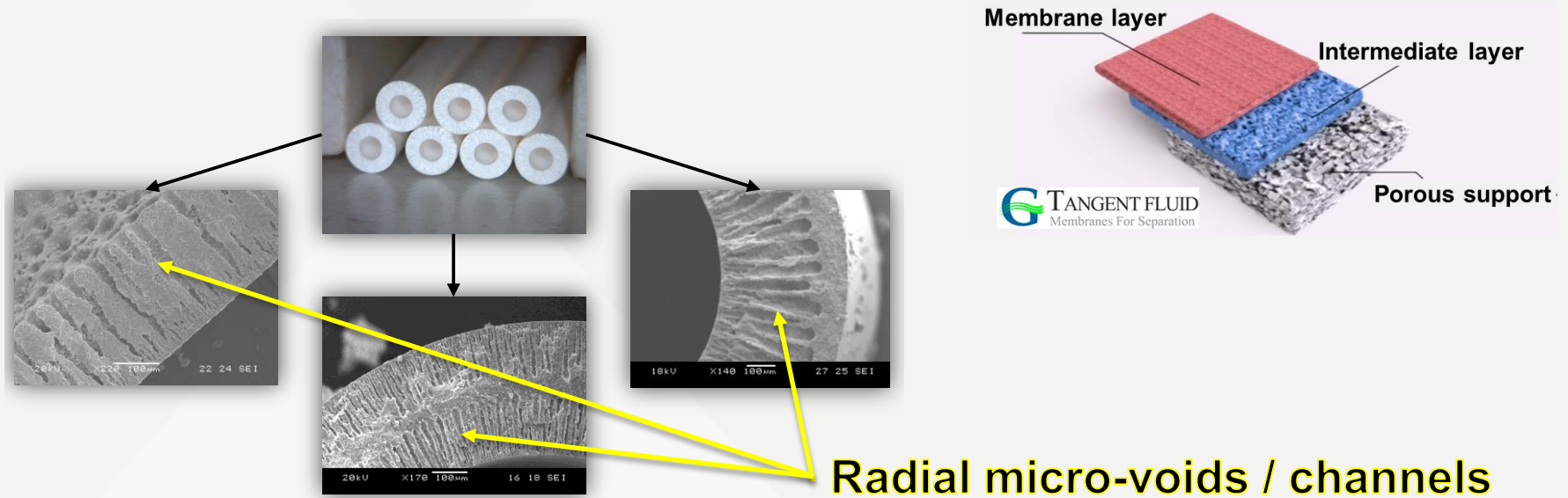
If Google or Baidu “Ceramic Membrane”

- Ceramic membranes – water & wastewater treatment



- Multi-step fabrication with each step involves different technologies
- Repeated high temperature treatments
- Time consuming and energy intensive, thus costly
- Mass production for large-scale projects

Micro-structured ceramic membrane



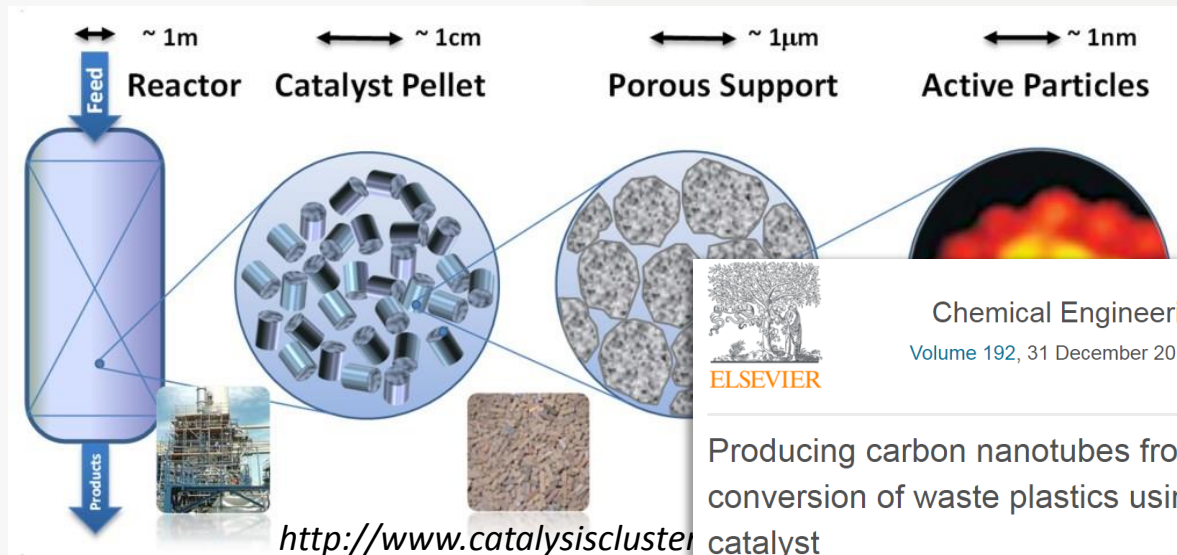
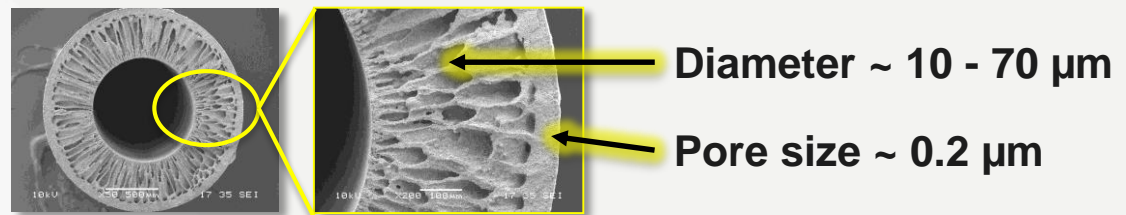
In contrast to Ceramic Membranes with laminated micro-structures

- Made of relatively smaller particles
- Controllable formation of oriented micro-voids or micro-channels
- “Single-step” preparation
- Prepared via a phase-inversion assisted process

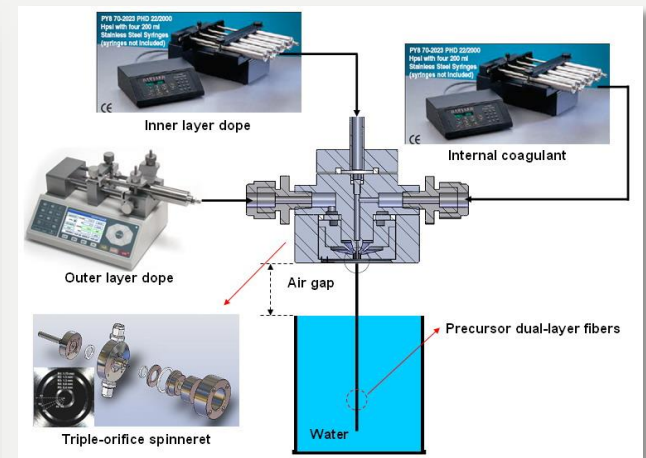
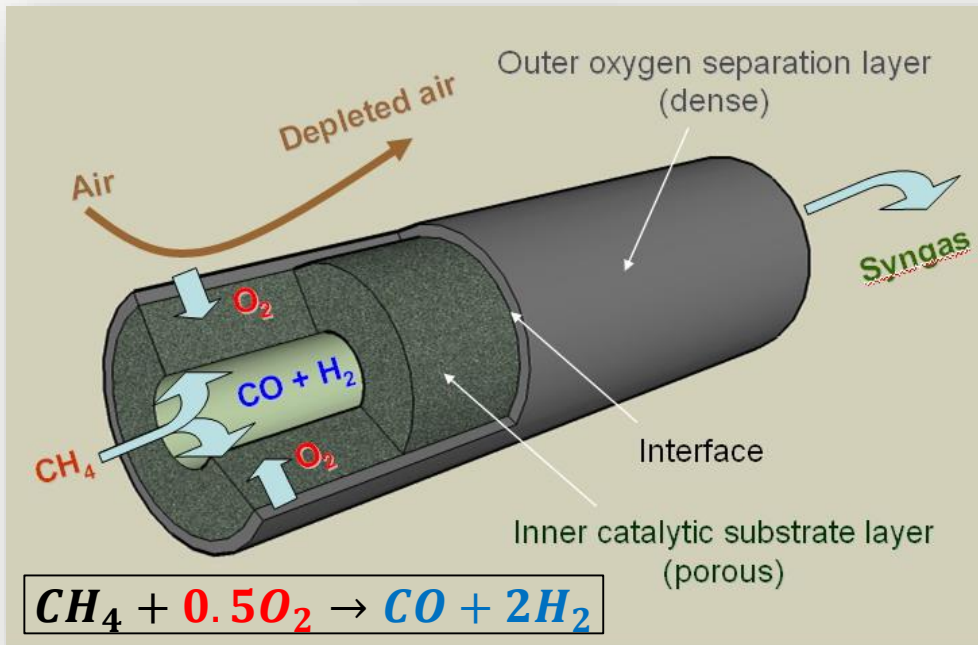
Their linkages to catalytic reactions

Catalysis is the most interdisciplinary and overarching technology in the chemical industry, because to perform a catalytic process requires controlling all the aspects over a multi-dimensional scale, from the molecular aspects of the reaction at the active site (nm scale) to the several meter scale of an industrial catalytic reactor. (www.catalysiscluster.eu)

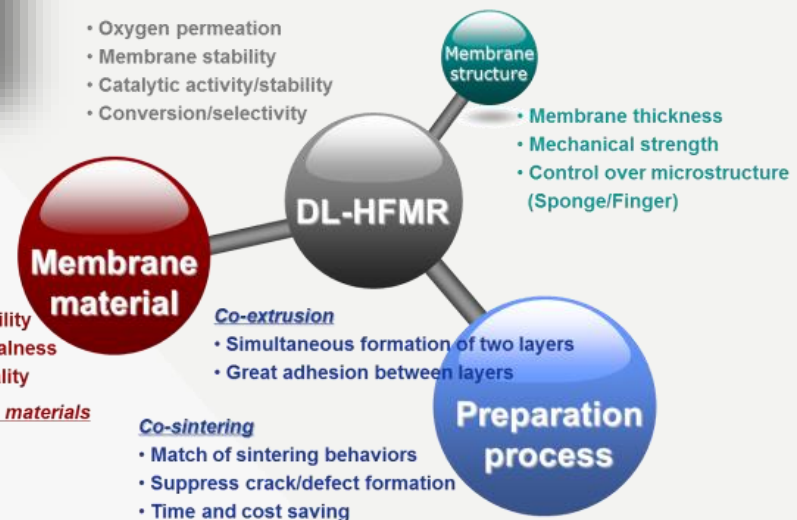
An alternative way promoting transport phenomena at micro-scales



Partial oxidation of CH₄

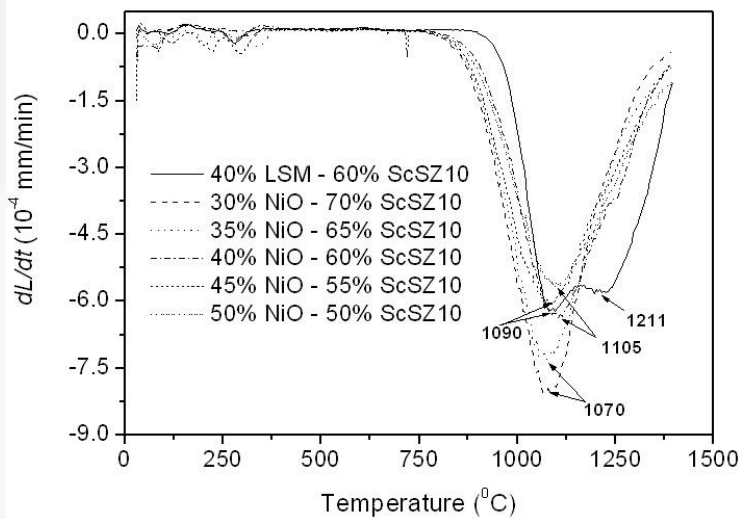
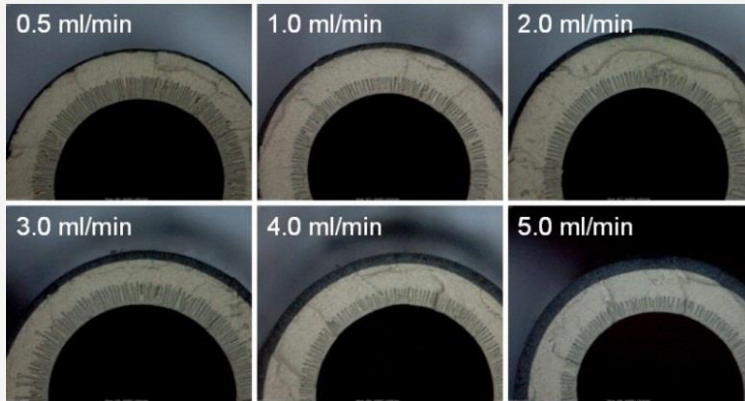


- Oxygen permeation
- Membrane stability
- Catalytic activity/stability
- Conversion/selectivity



- Dual-layer hollow fibre membrane
- formed in one step
- & densified in one step
- Separation layer: MIEC+IC
- Catalytic support layer: NiO+IC

Partial oxidation of CH₄

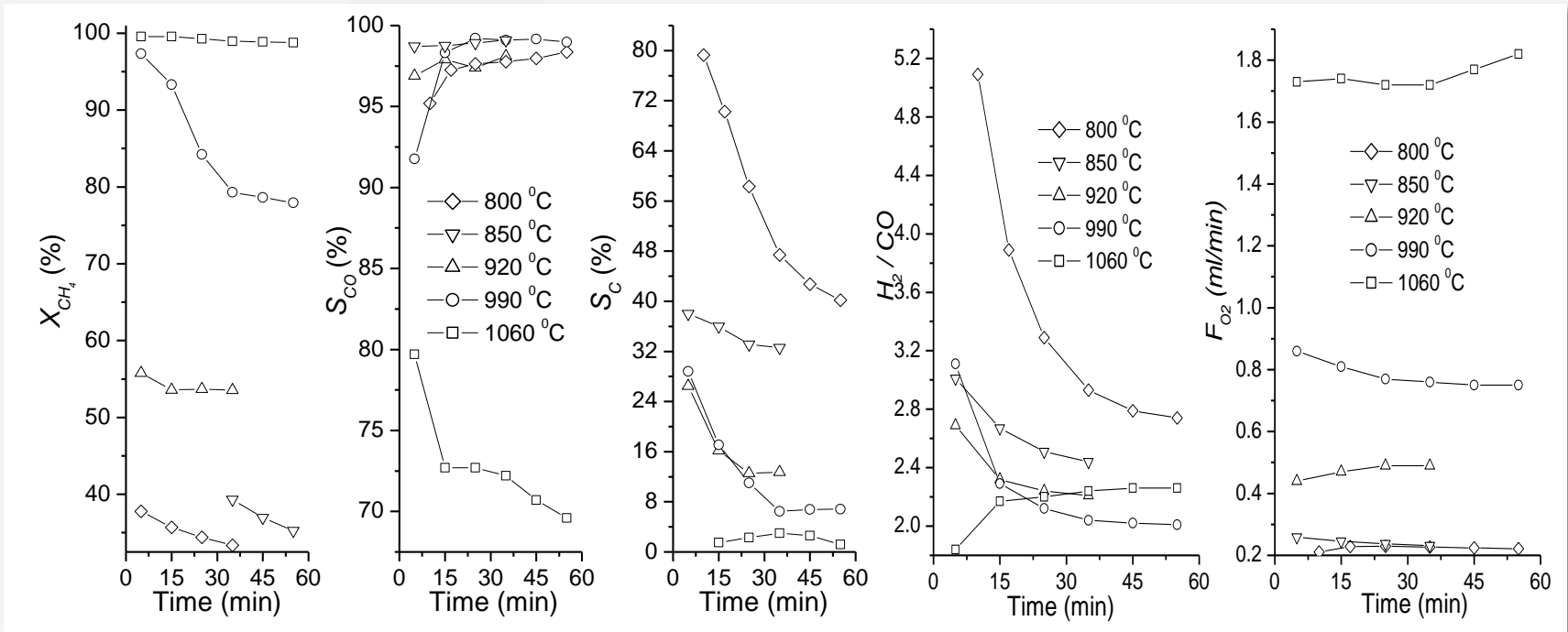


Substrate layer Separation layer

Precursor fibre

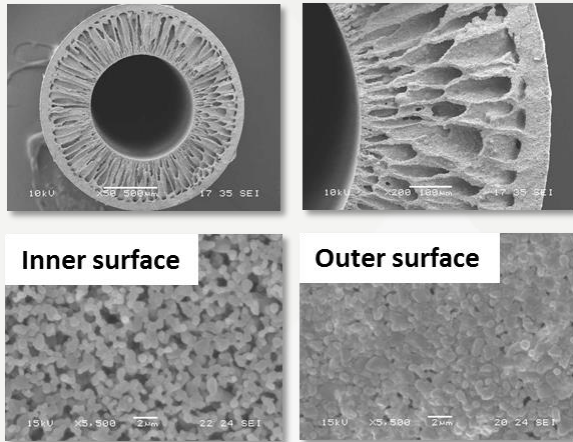
- ⋯ Precipitated polymer binder
- LSM (electronic conductive pha)
- ScSZ (ionic conductive phase)
- NiO (before reduction)
- Ni (after reduction)

Partial oxidation of CH₄

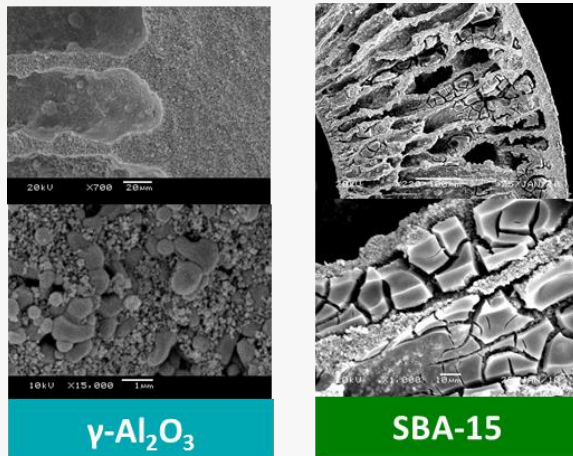


- Higher temperature → higher O₂ permeation/CH₄ conversion, & lower carbon formation → less POM and more full oxidation
- **Material design:** oxygen separation layer & catalytic support layer
- **Material processing:** match of sintering behaviours & thermal expansion

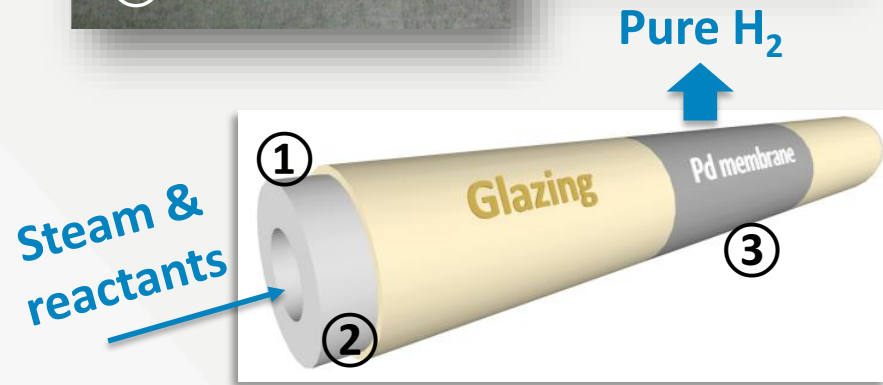
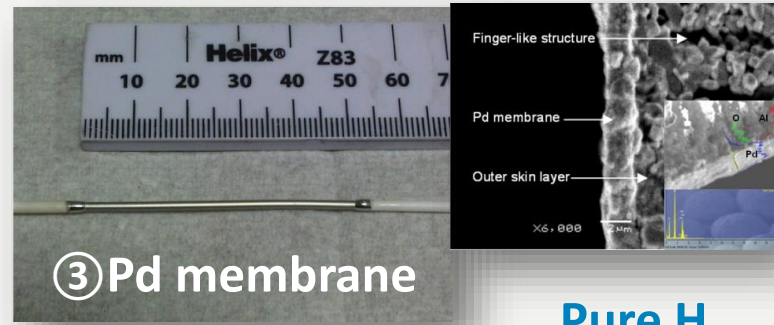
H₂ via reforming reactions



① Substrates



② Substrates + Catalyst



- Good flexibility of incorporating different catalysts for various reactions
- Separating hydrogen increases conversion
- & may increase coke formation at the same time

Journal of the European Ceramic Society, Volume 37, Issue 16, December 2017, Pages 5281-5287

Chemical Engineering Science, Volume 137, 1 December 2015, Pages 364-372

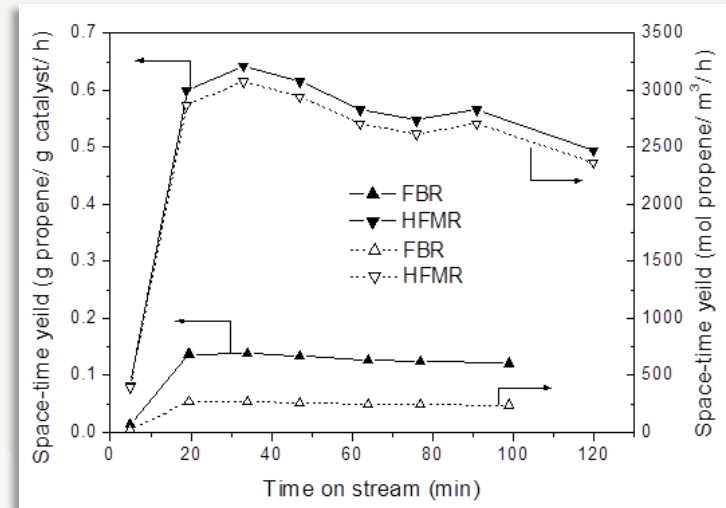
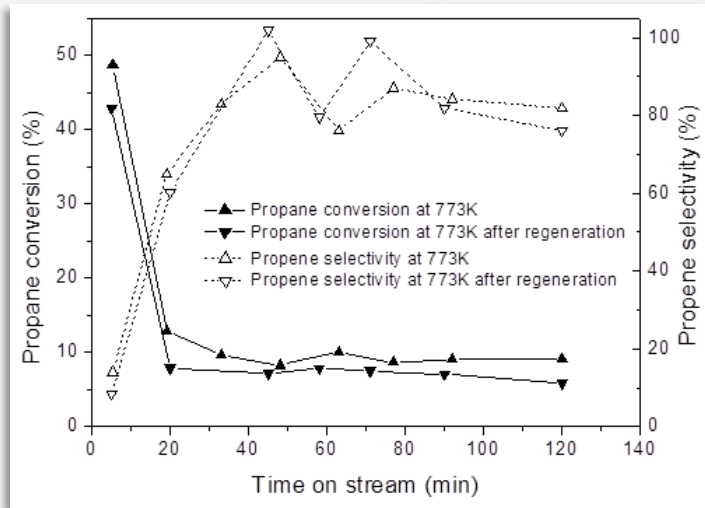
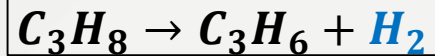
Applied Catalysis A: General, Volume 506, 5 October 2015, Pages 188-196

Ind. Eng. Chem. Res., 2015, 54 (21), pp 5563-5571

International Journal of Hydrogen Energy, Volume 40, Issue 8, 2 March 2015, Pages 3249-3258

H₂ via reforming reactions

For example

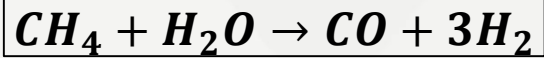


- Very quick deactivation due to coke formation
- Catalyst can be regenerated by removing coke
- Space-time yield (propene) of membrane reactor is much higher than fixed bed reactor

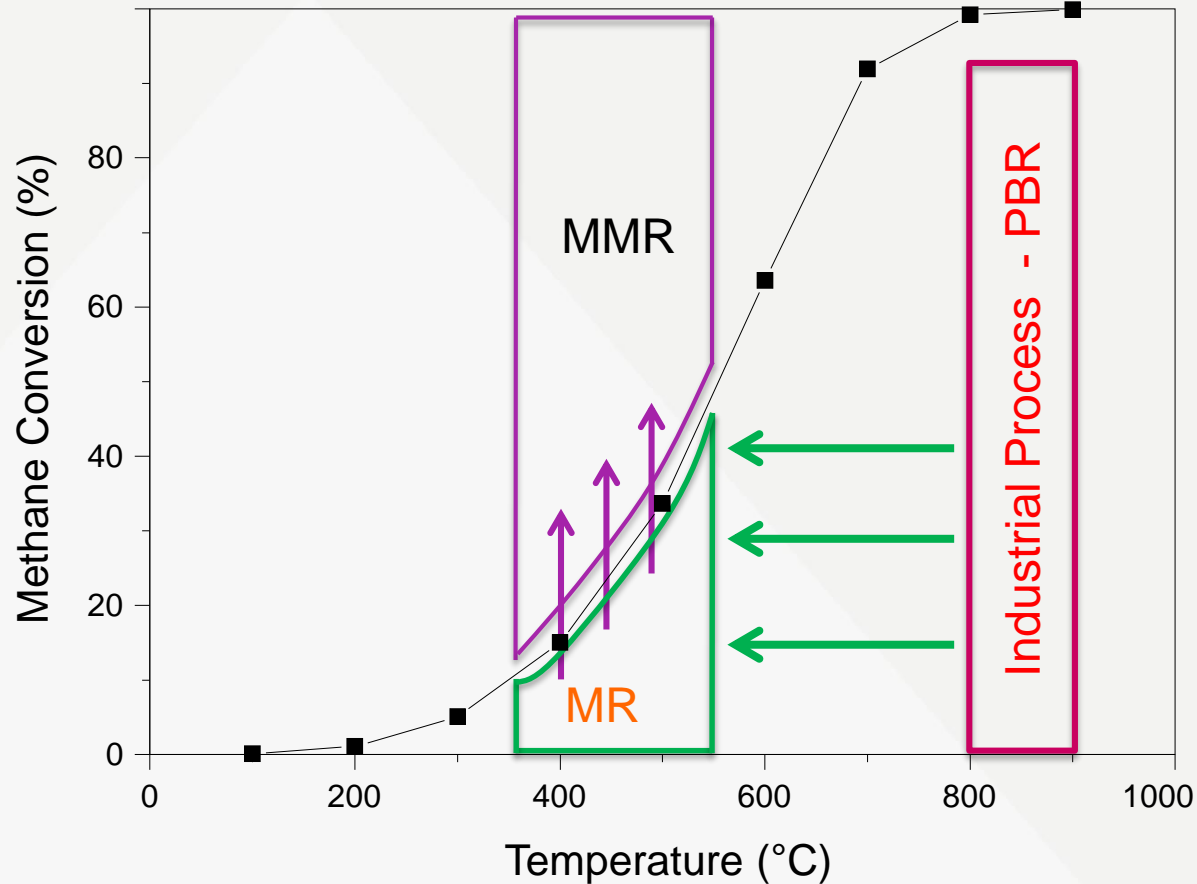
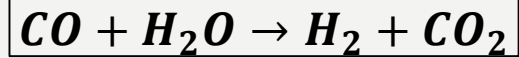
Methane steam reforming

100

MSR



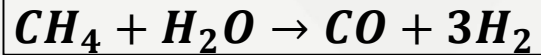
WGS



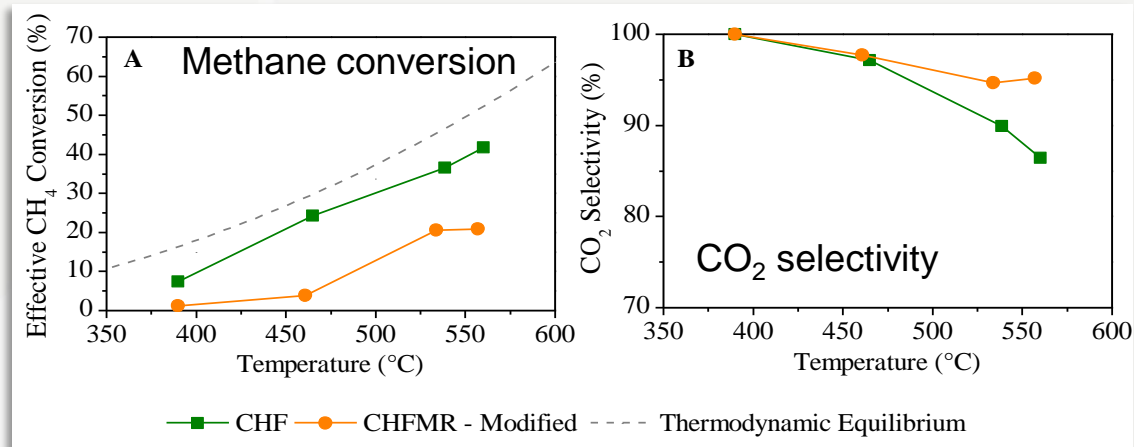
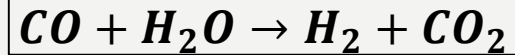
PBR – Packed Bed Reactor MR – Micro-reactor MMR – Membrane Micro-reactor

Methane steam reforming

MSR



WGS

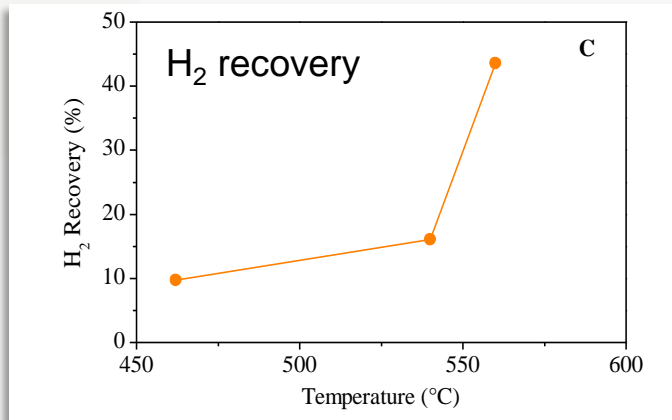
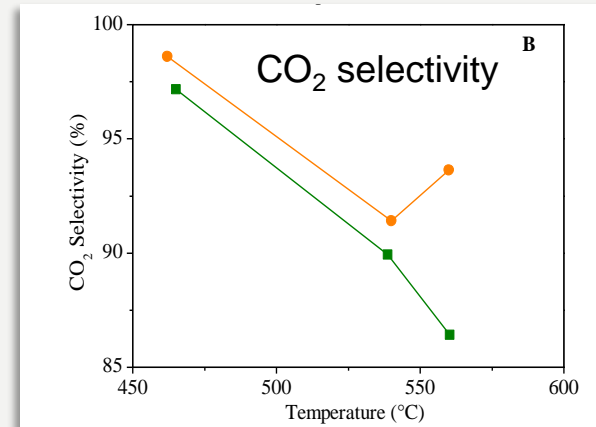
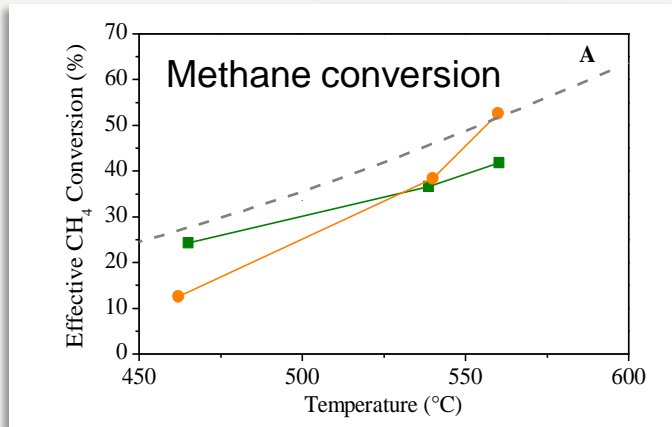


CHF: hollow fibre + Ni-based catalyst

CHFMR: hollow fibre + Ni-based catalyst + Pd membrane

- CHF is close to equilibrium conversion of methane
- CO₂ selectivity decreases with increasing temperatures
- CHFMR performs worse in terms of methane conversion. One reason is due to the removal of hydrogen that increases catalyst deactivation

Methane steam reforming

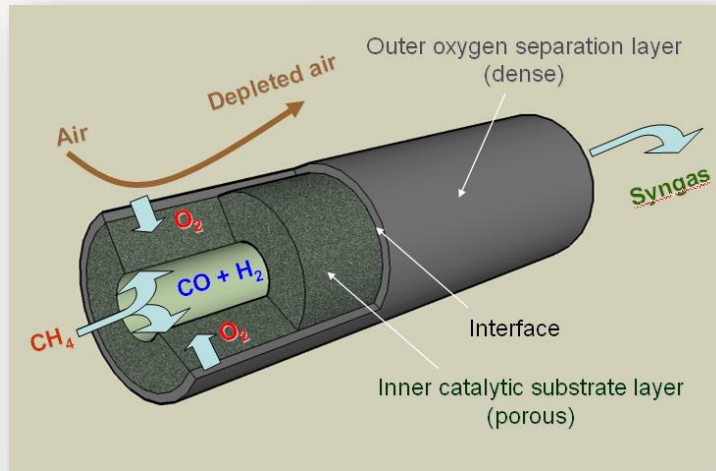


- To maintain a good amount of hydrogen at the reaction side, use a higher kicking-off temperature
- Methane conversion can “reach” equilibrium value
- CO2 selectivity increased at higher temperatures, due to “shift” effects on WGS reaction

CHF: hollow fibre + Ni-based catalyst

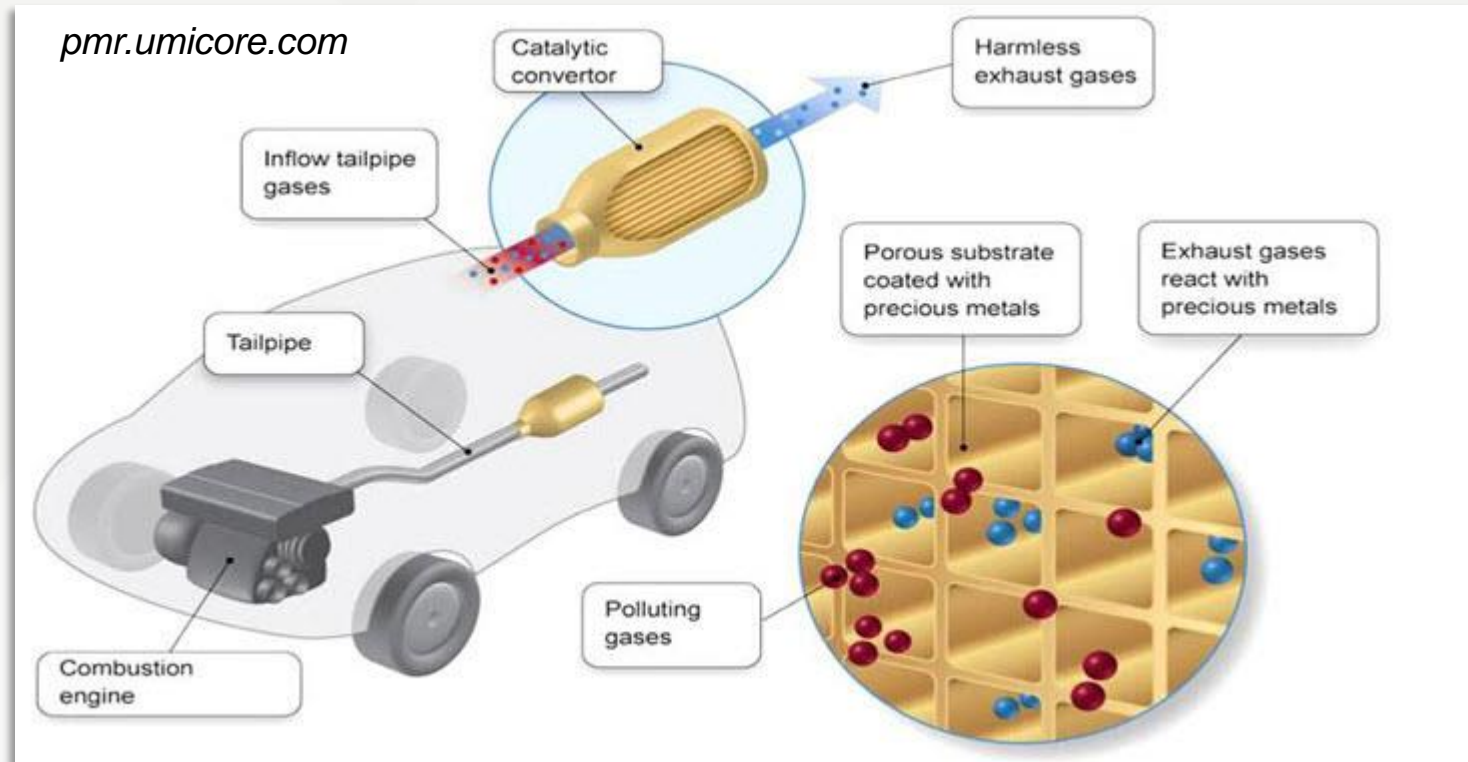
CHFMR: hollow fibre + Ni-based catalyst + Pd membrane

A quick summarization



- The idea of combining micro-reactor phenomena and membrane separation is great
- It works well for some cases, while is challenged by others
- Various challenges to be addressed in order for achieving expected performance (catalyst-membrane-reactor)

What if no membrane separation?



Ceramic monolith or honeycomb in Catalytic Converter

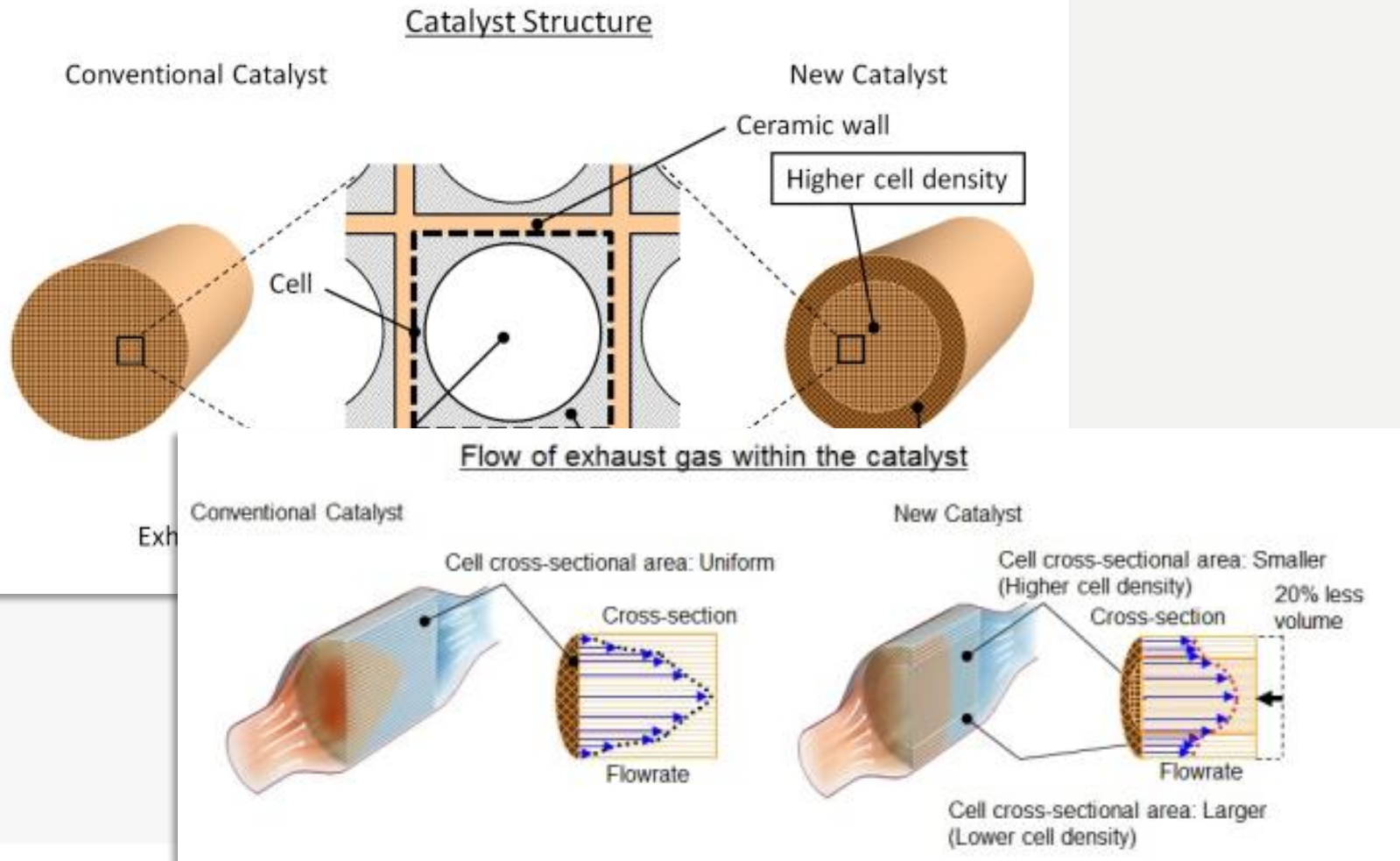
What if no membrane separation?

Green Car Congress

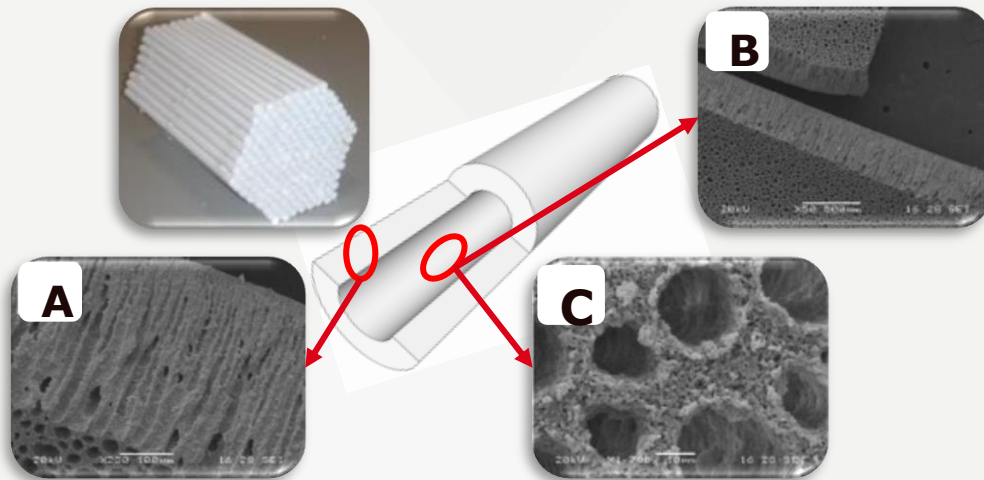
Energy, technologies, issues and policies for sustainable mobility

Toyota
prec
unif

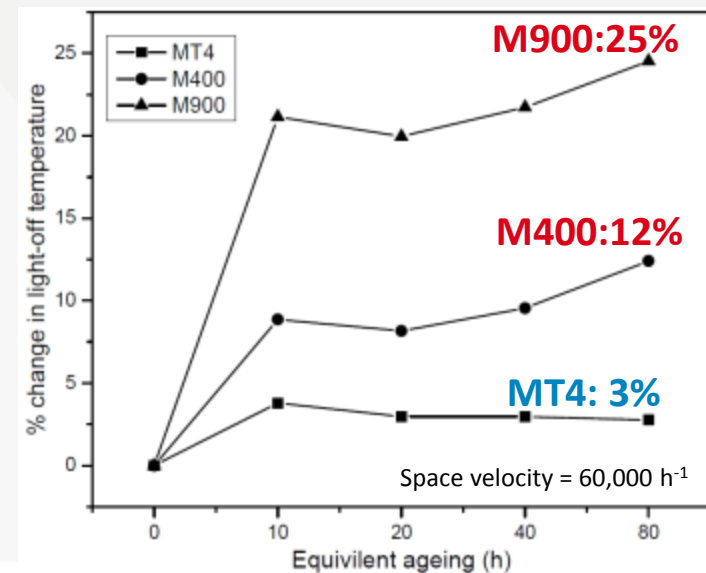
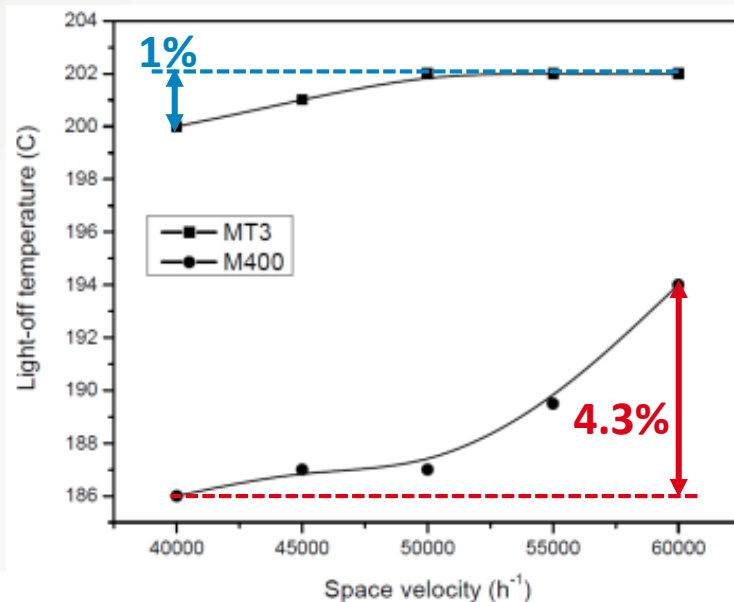
22 February



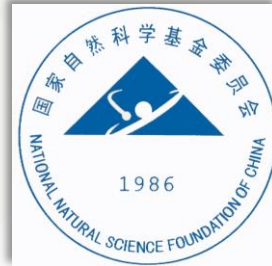
Hollow fibre monolith



- Smaller volume
- Save over 50% of precious metal catalyst
- Perform better at high space velocity
- More durable during aging test



Acknowledgement



**Thanks for your
attentions !**