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Novel Carbon Xerogel Materials for Blue Hydrogen Production

Benjo Đuherić, University of Edinburgh

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Hydrogen Production

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Types of Hydrogen Production

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Types of Hydrogen Production

Grey Hydrogen

- Fossil fuels
- Highest contributor is steam reforming of methane (SMR)
- High CO_2 Emissions

IEA, Global Hydrogen Review (2023). Available at https://www.iea.org/reports/global-hydrogen-review-2023.

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Blue Hydrogen

- SMR with Carbon Capture and Storage (CCUS)
- Possibility of compact design and decentralised production
- Ability to utilise existing gas distribution networks

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Blue Hydrogen
- SMR with Carbon Capture and Storage (CCUS)
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Green Hydrogen
- Electrolysis of water
- High energy input
- Significant land use and capital costs

IEA, Global Hydrogen Review (2023). Available at https://www.iea.org/reports/global-hydrogen-review-2023.

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Net Zero Emissions and Hydrogen Production

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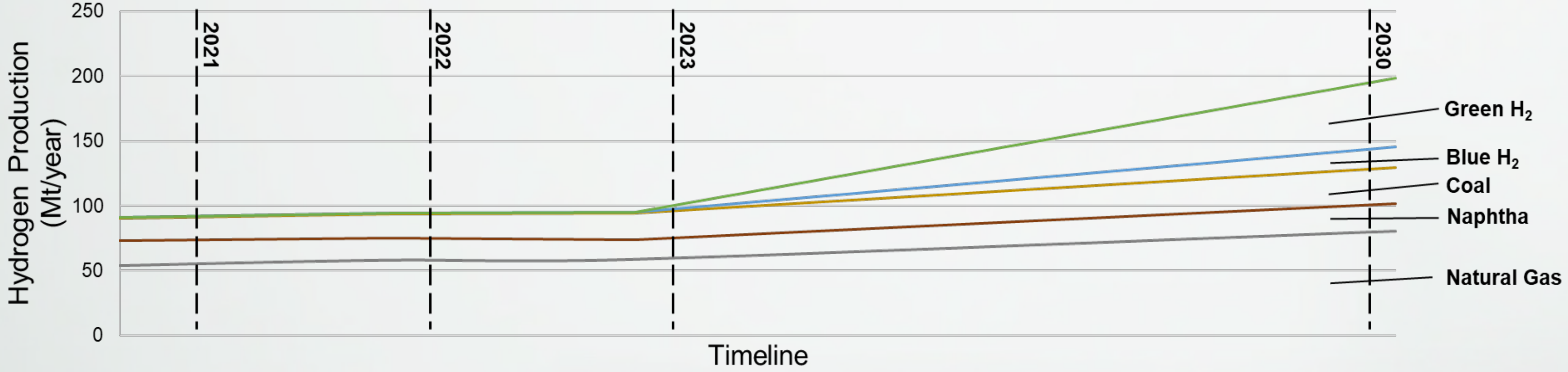
Timeline



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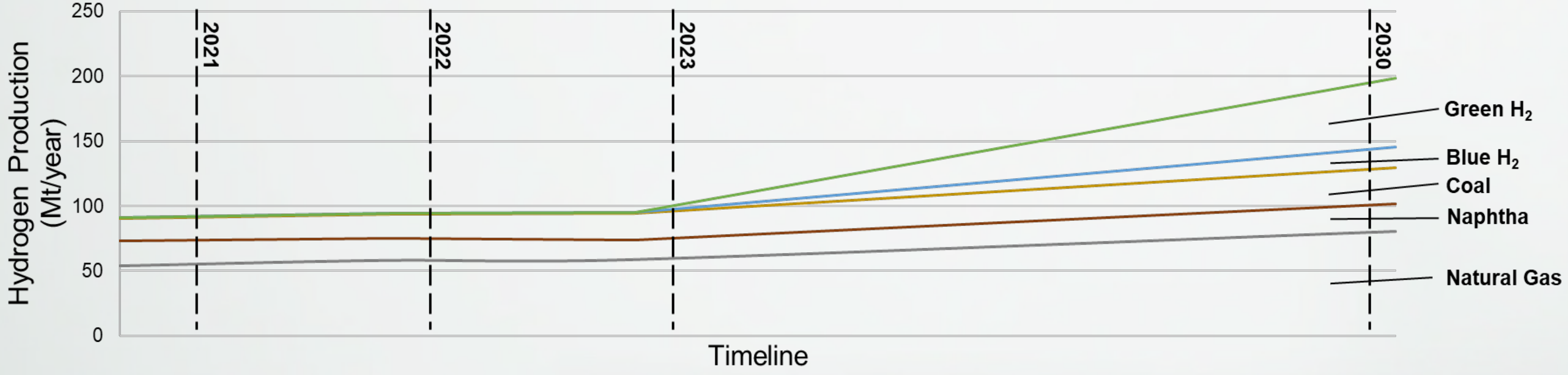

- SMR currently accounted for 62% of all H_2 production in 2022
- CO_2 emissions from current SMR plants (Grey Hydrogen) is 540 Mt annually
- Final Investment Decision is was only around 5% for **blue** and **green** production

IEA, Global Hydrogen Review (2023). Available at https://www.iea.org/reports/global-hydrogen-review-2023.

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What Can Be Done?

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Retrofitting Existing SMR Plants!

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Classification of SMR Plants

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Classification of SMR Plants

Small-Scale SMR Plants

Blank, T. K., Molly, P., Hydrogen's Decarbonization Impact for Industry, 2020.

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Classification of SMR Plants

Small-Scale SMR Plants

- Capacities less than 1000 kg per day
- Compact and decentralised
- Often contained with a 20 ft freight container

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Medium-Scale SMR Plants

- Capacities between 1000 kg and 10,000 kg per day
- Modular in size but often serve several industrial plants
- More permanent than small-scale plants

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SMR Process

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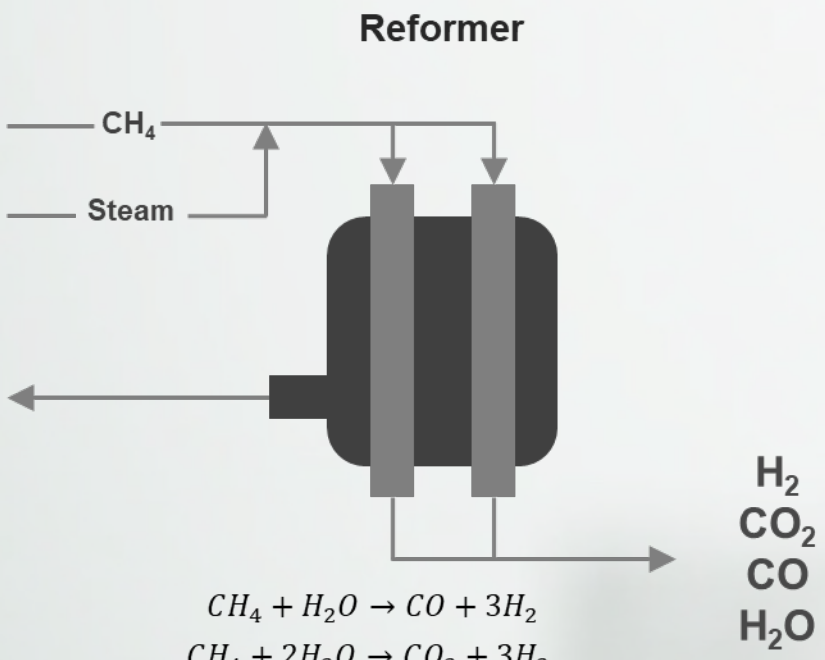
SMR Process



$$CH_4 + H_2O \rightarrow CO + 3H_2$$
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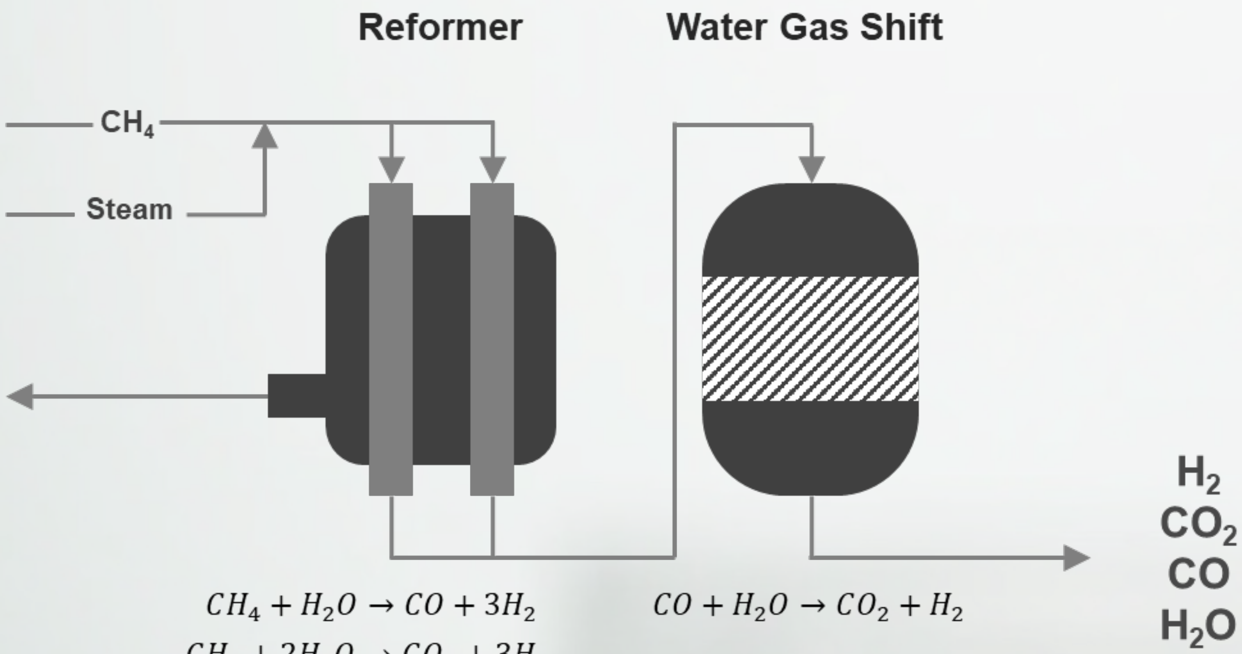
SMR Process



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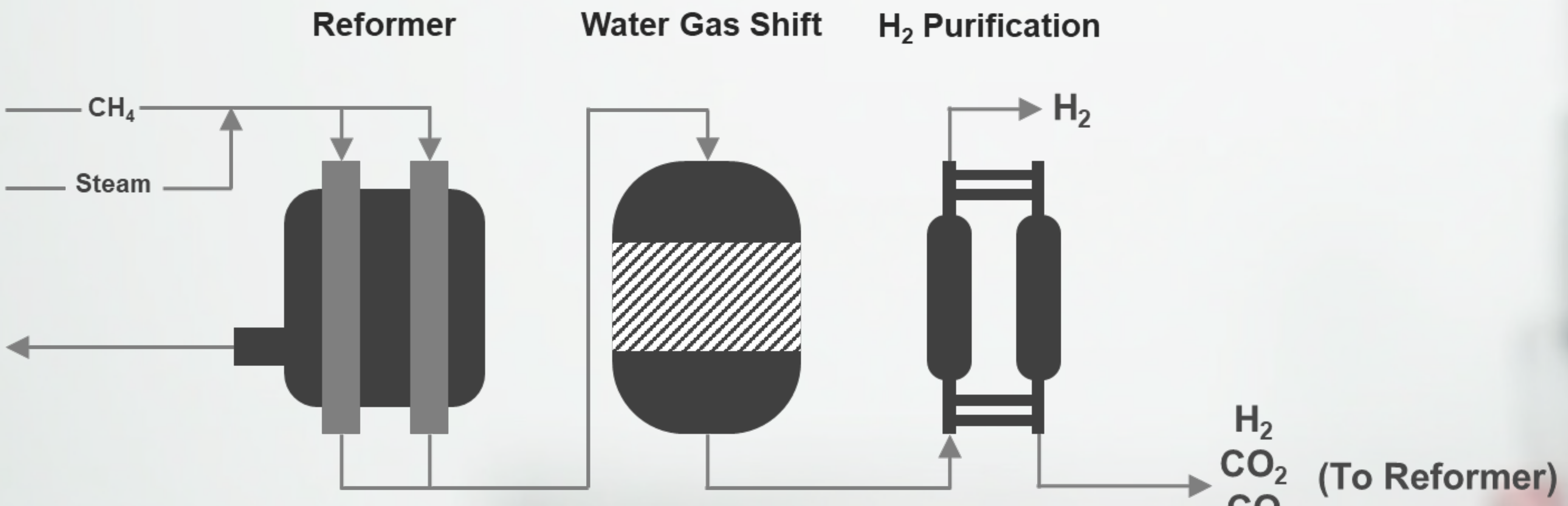

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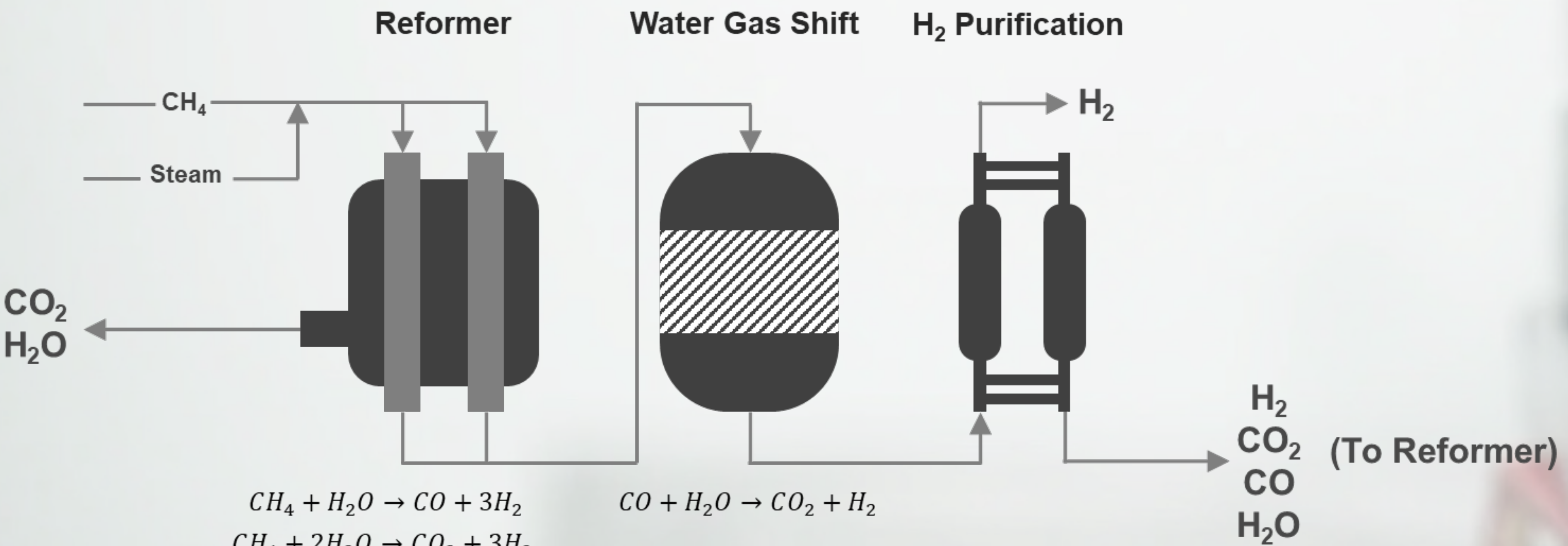

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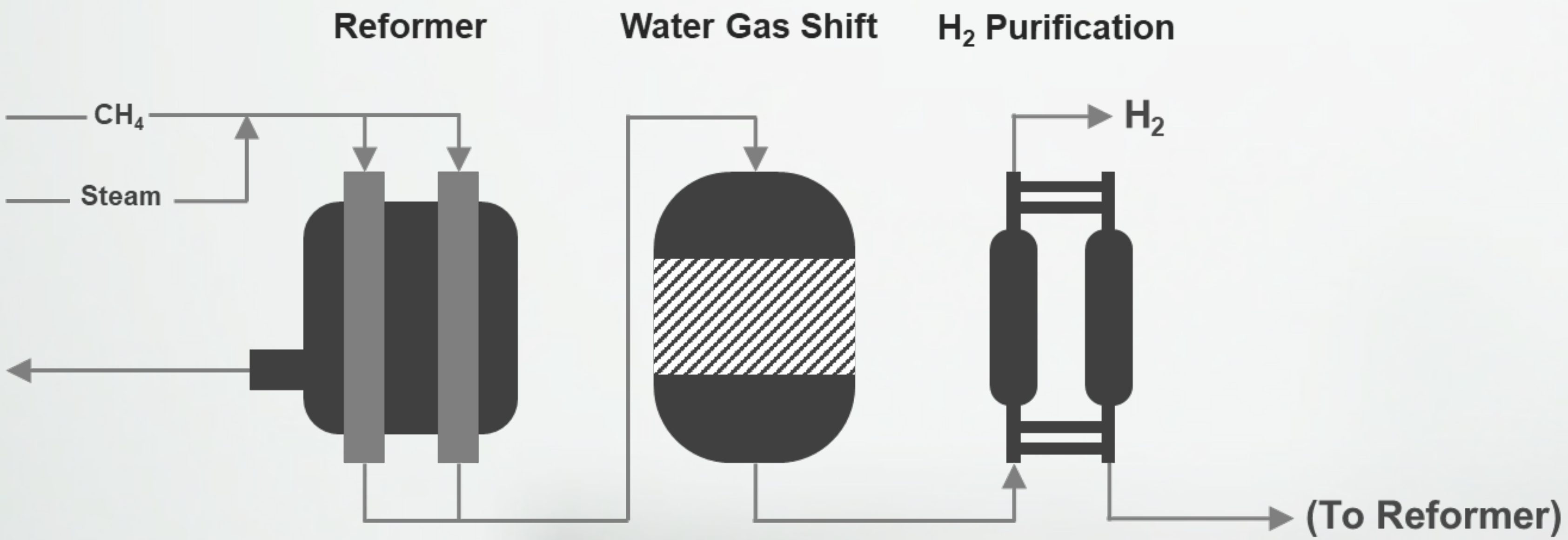

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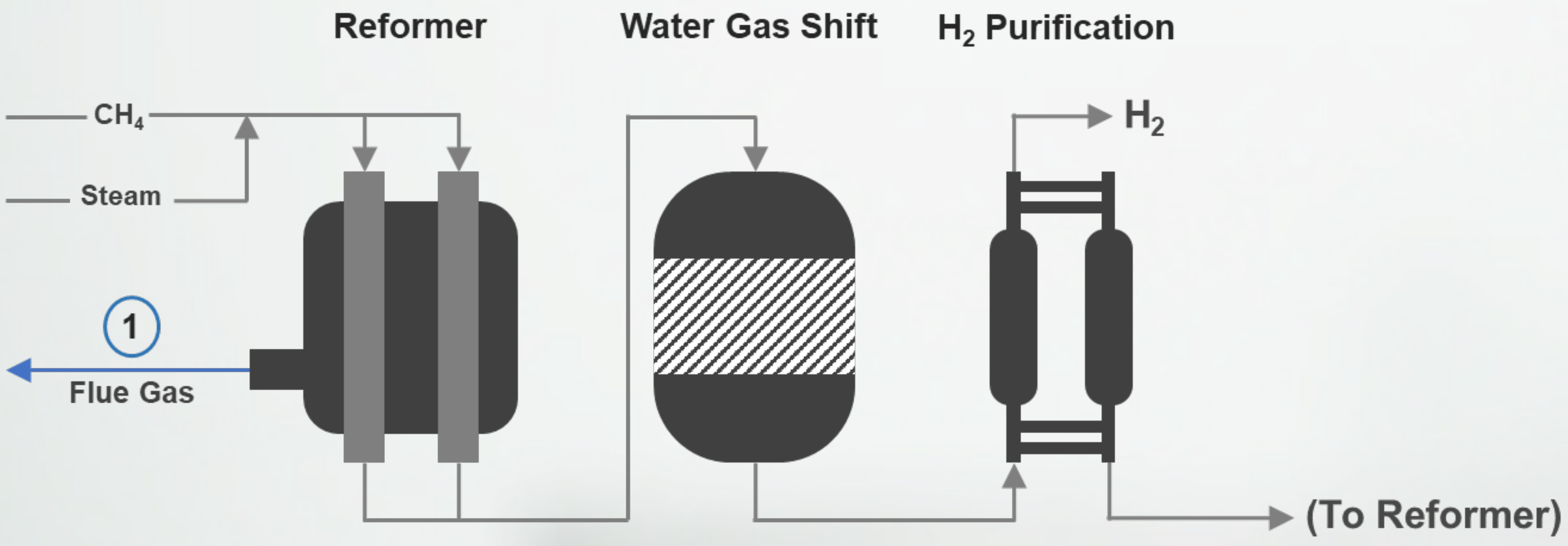

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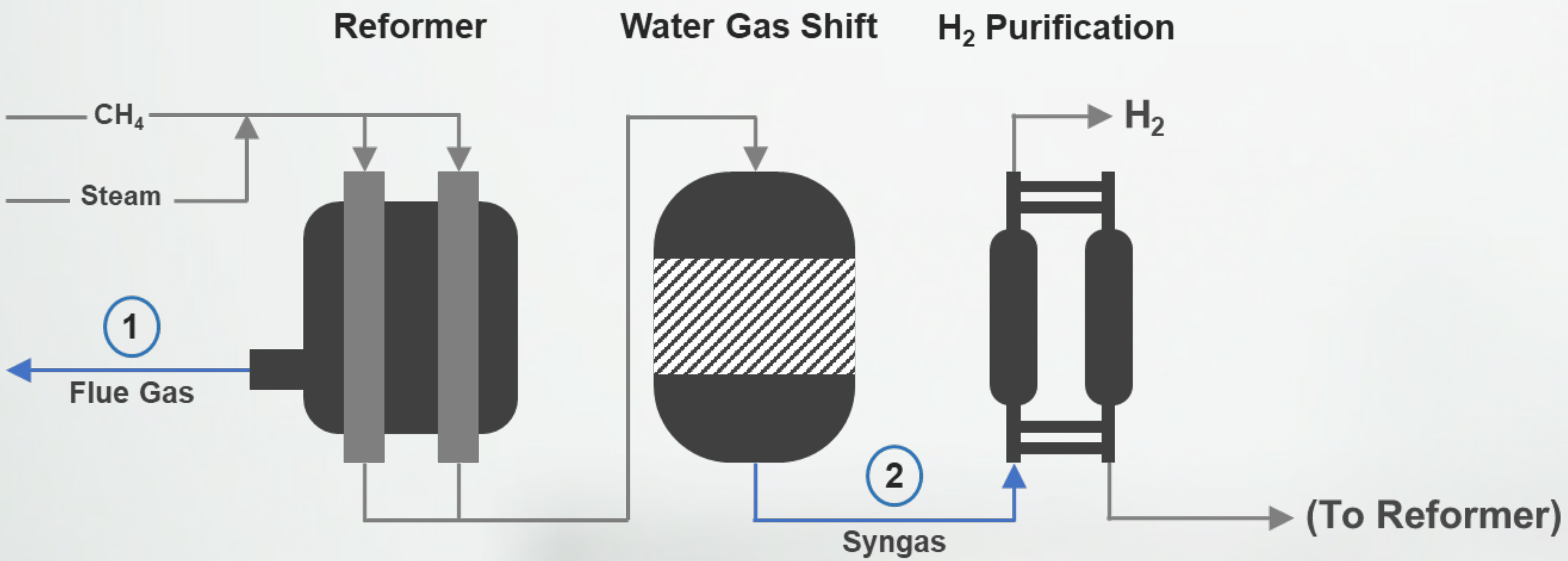

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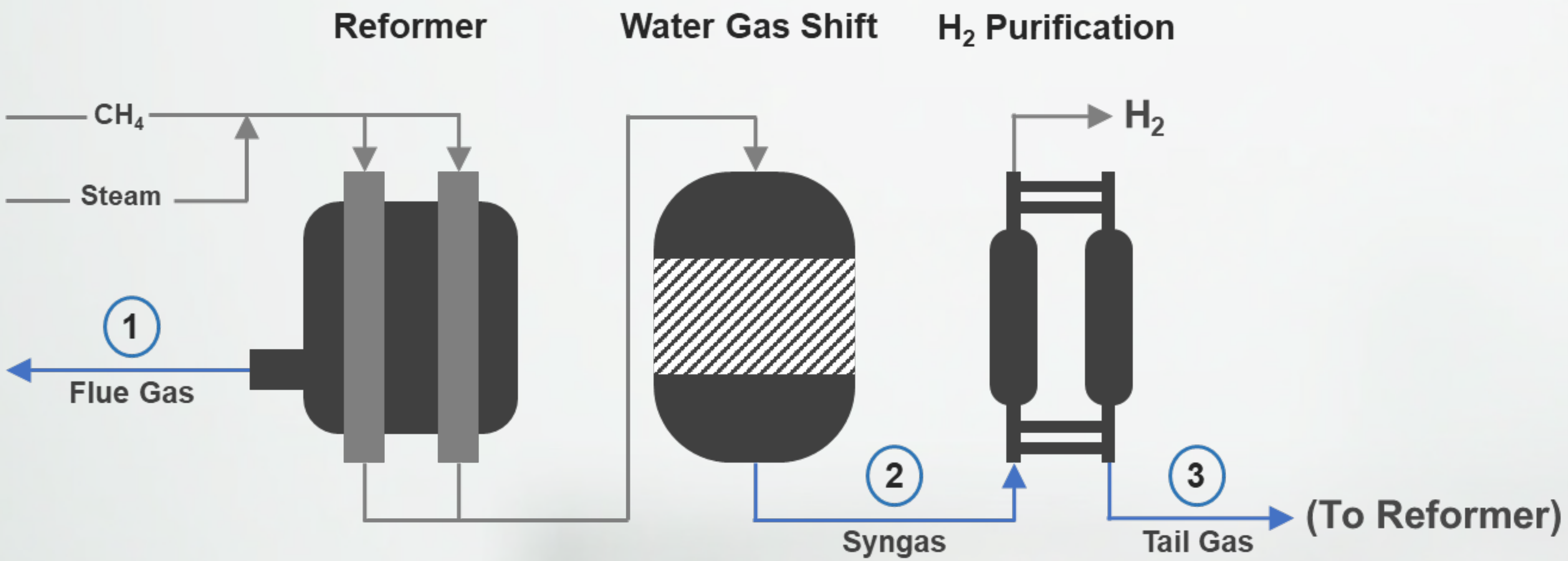

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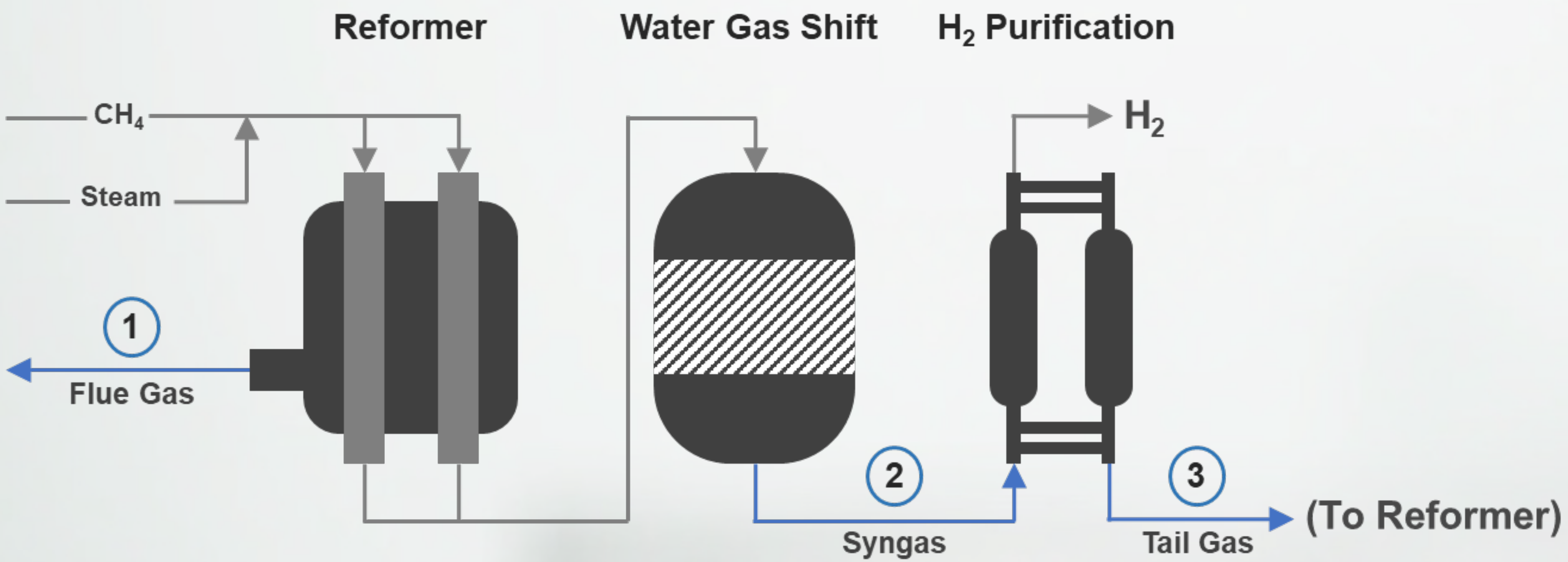

	Flue Gas	Syngas	Tail Gas
CO_2 Fraction	Low	Low	High
Temperature	High	Low	Low
Pressure	Low	High	Low

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Experimental and Materials

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Activated Carbon Xerogels

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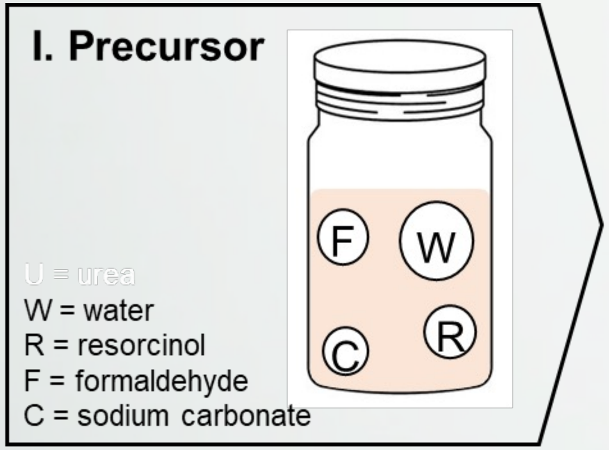
Activated Carbon Xerogels



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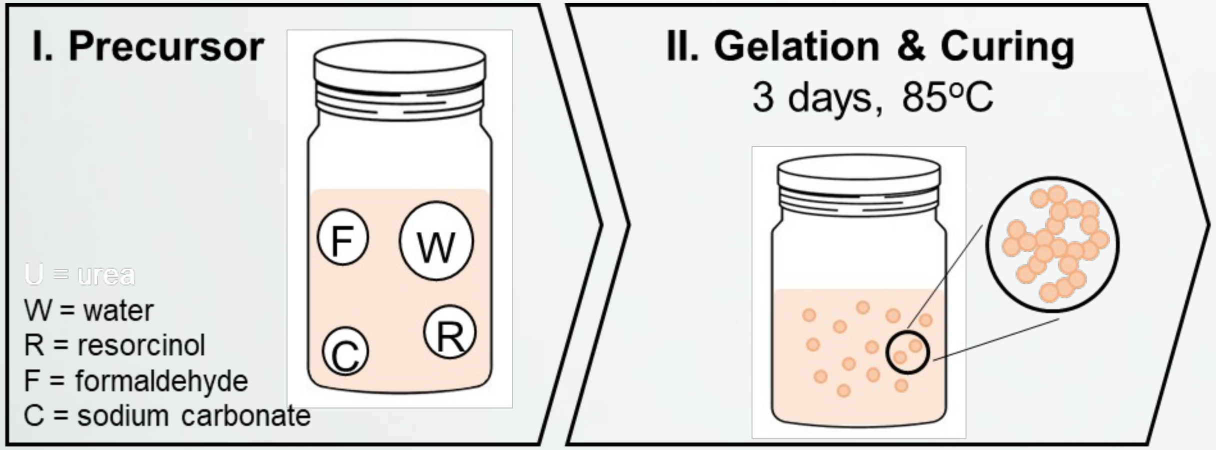

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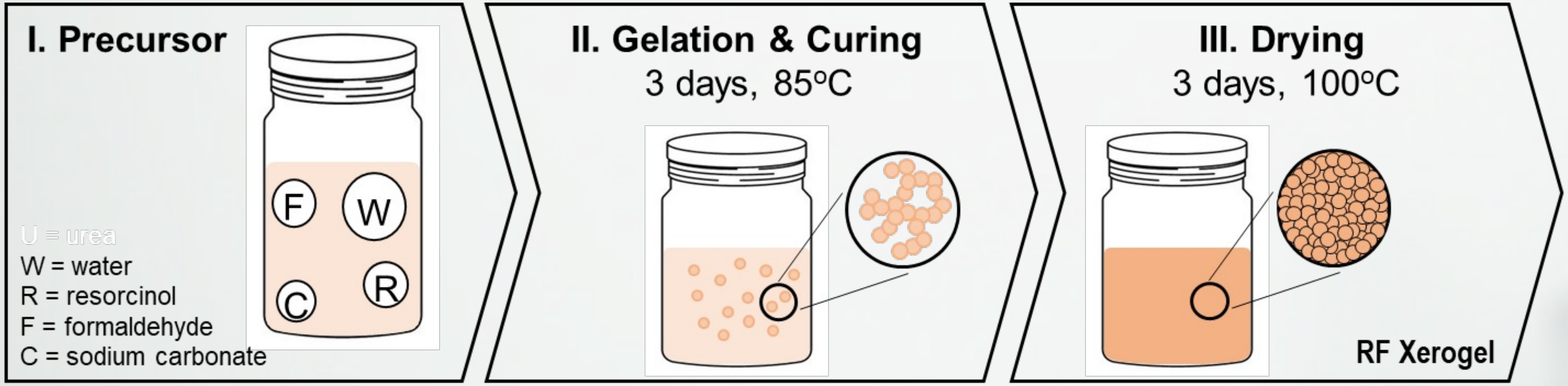

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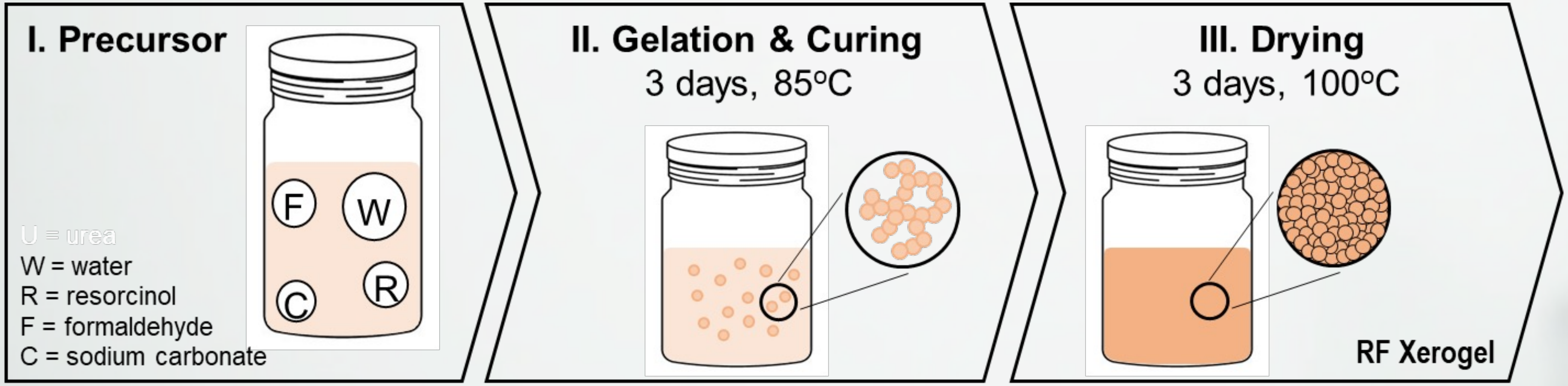

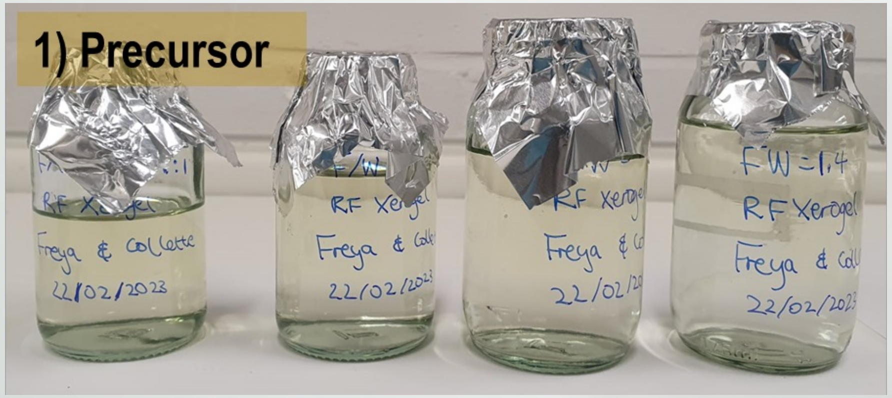

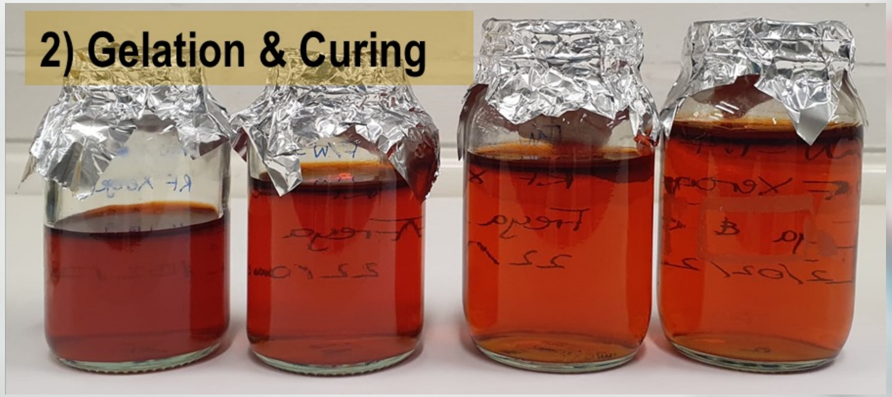

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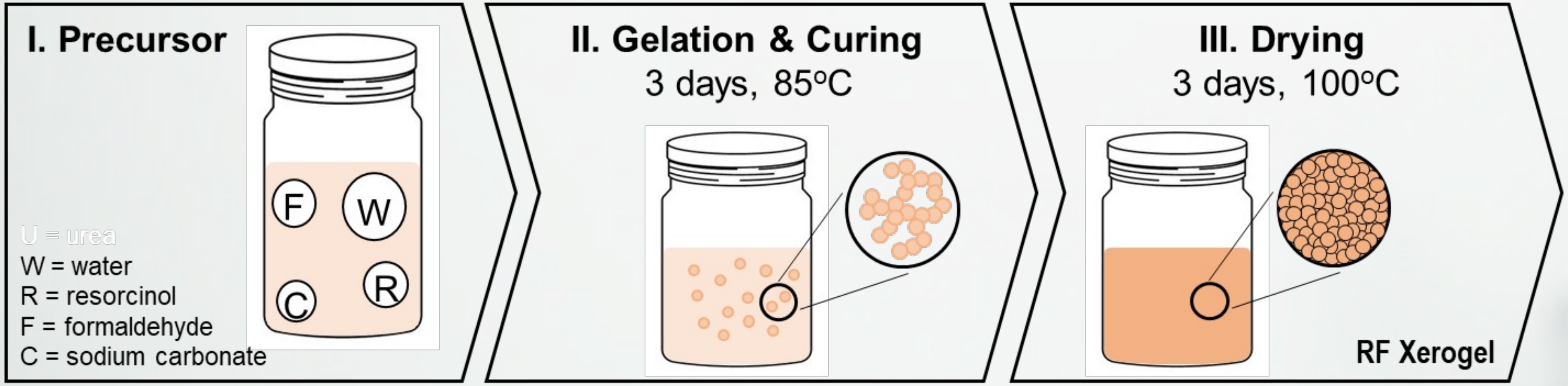

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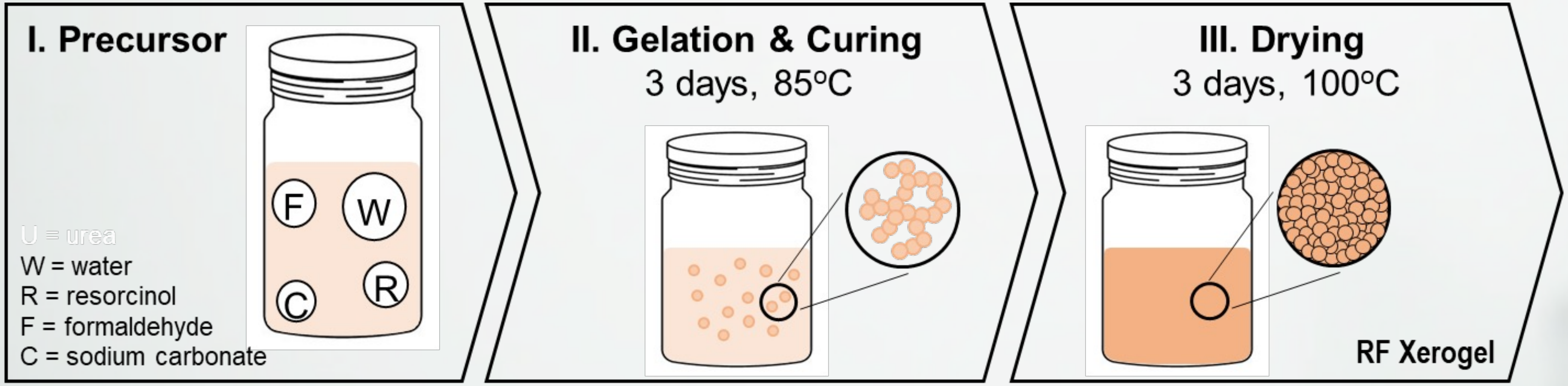

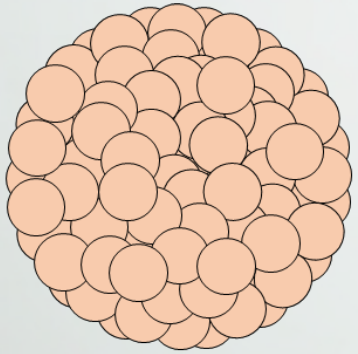

RF Xerogel
RF

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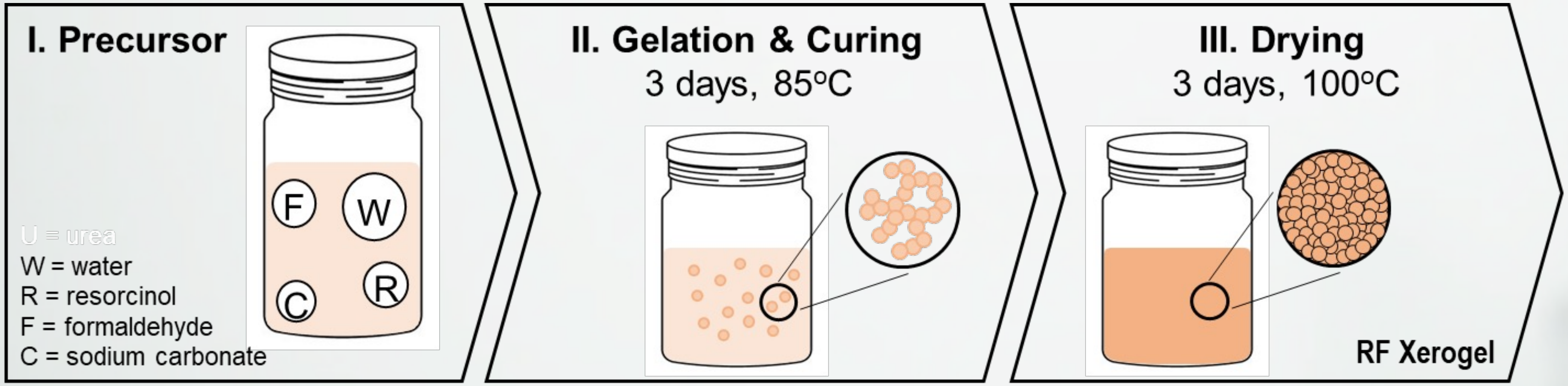
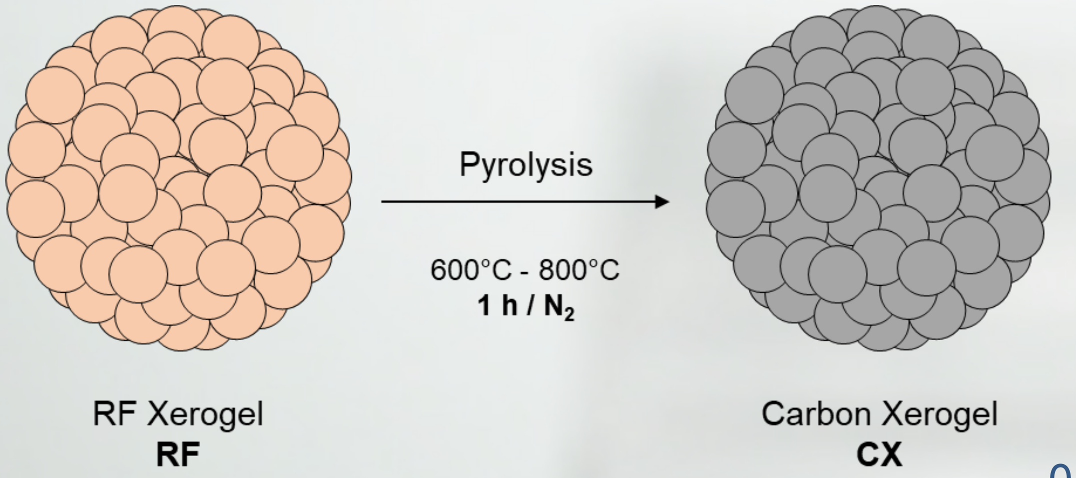
Activated Carbon Xerogels





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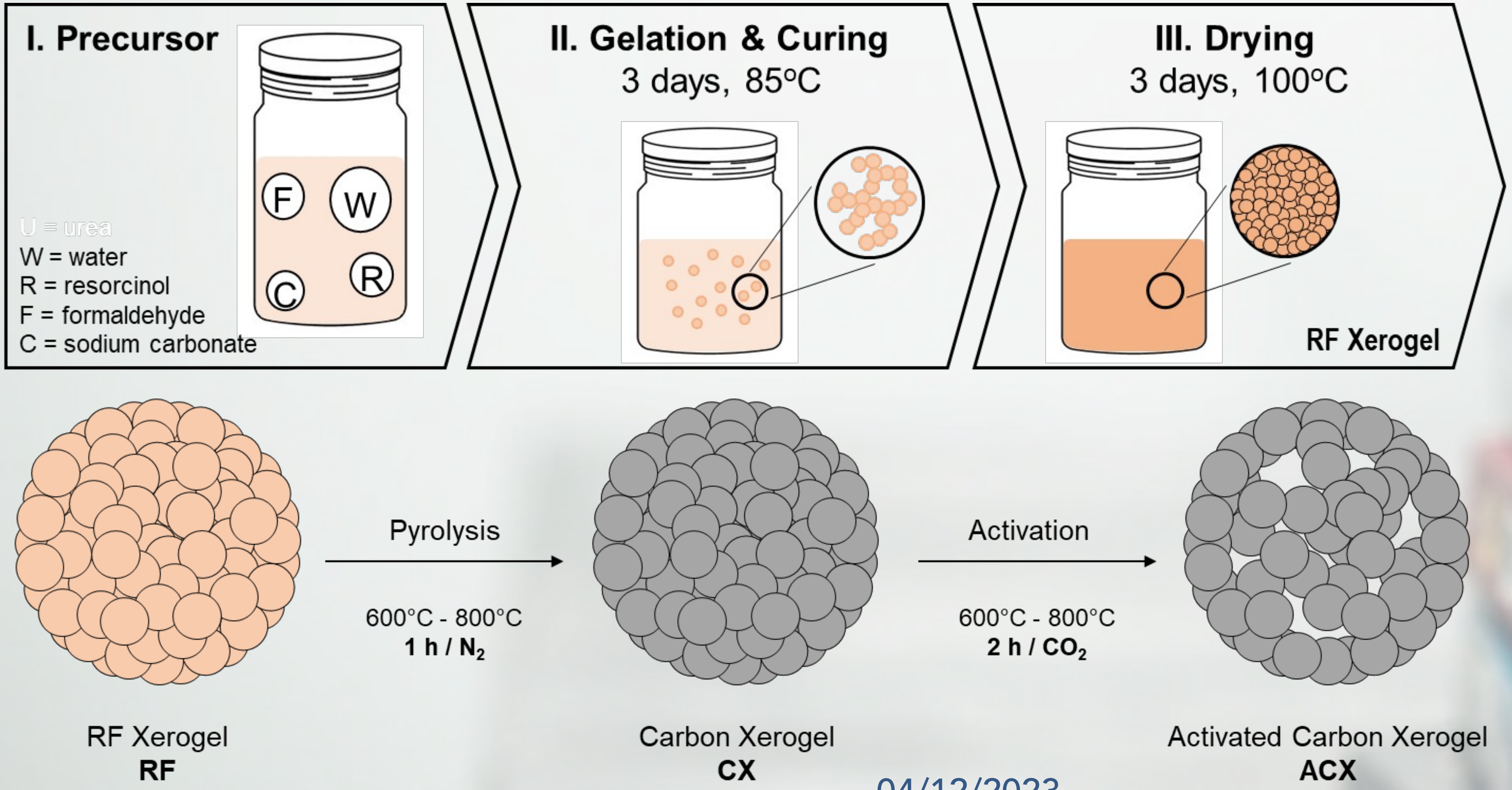

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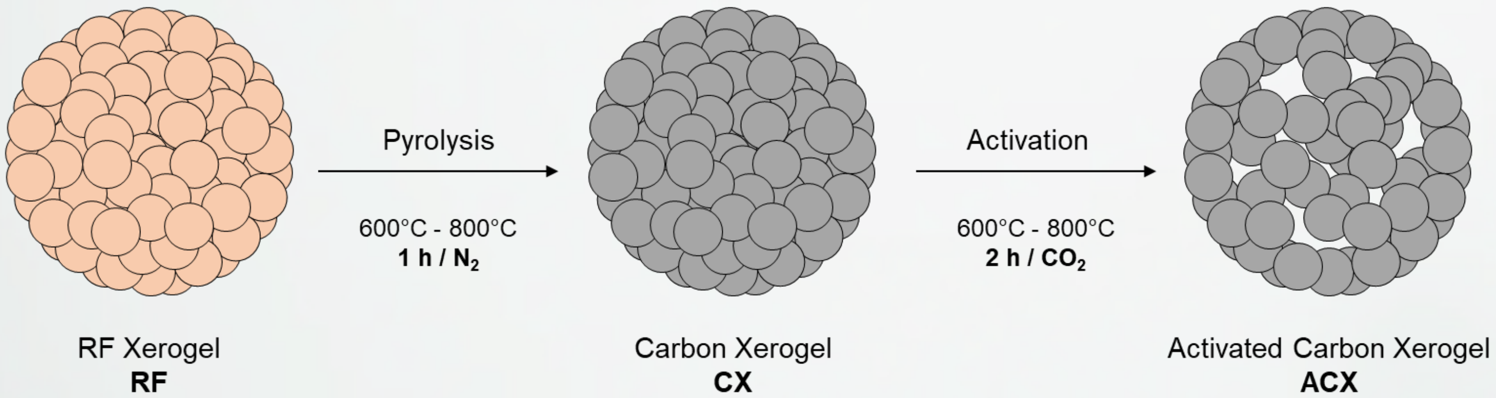

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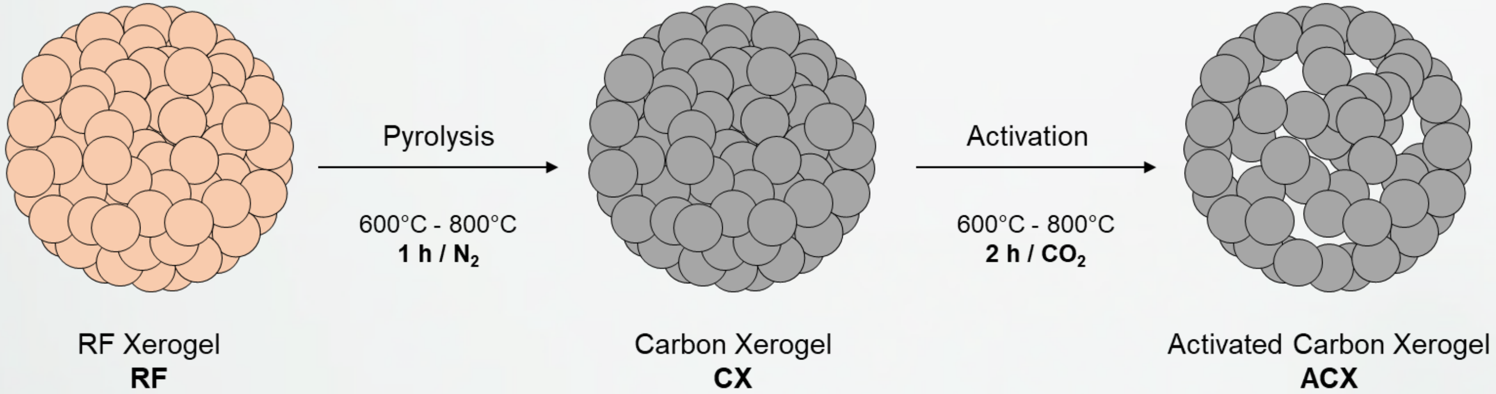

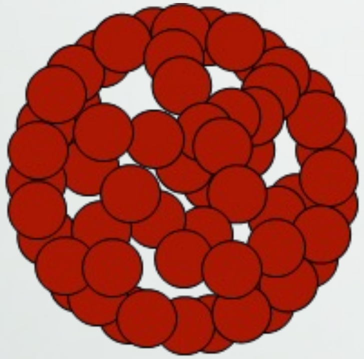

ACX-600
T=600°C

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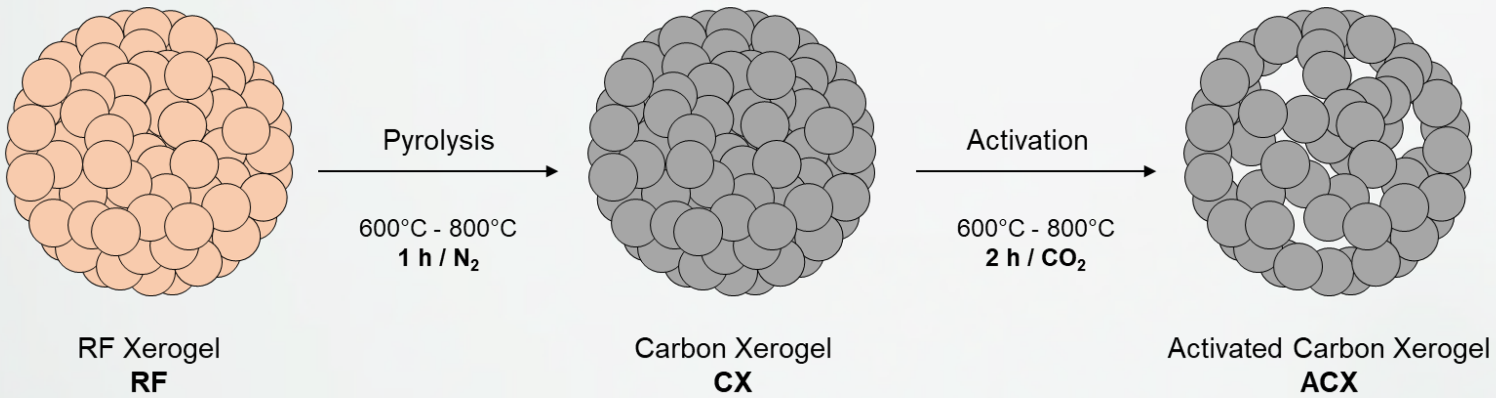
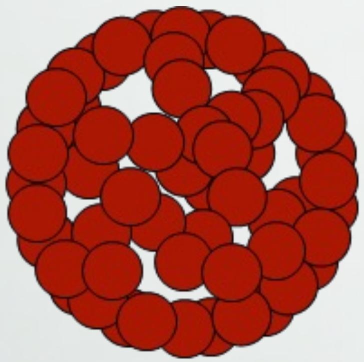
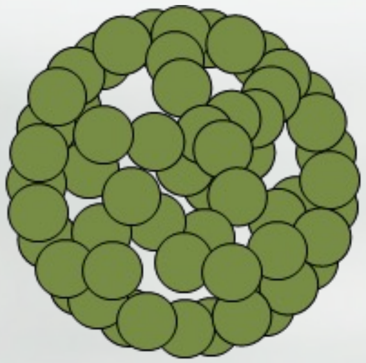
Activated Carbon Xerogels





ACX-600
T=600°C



ACX-700
T=700°C

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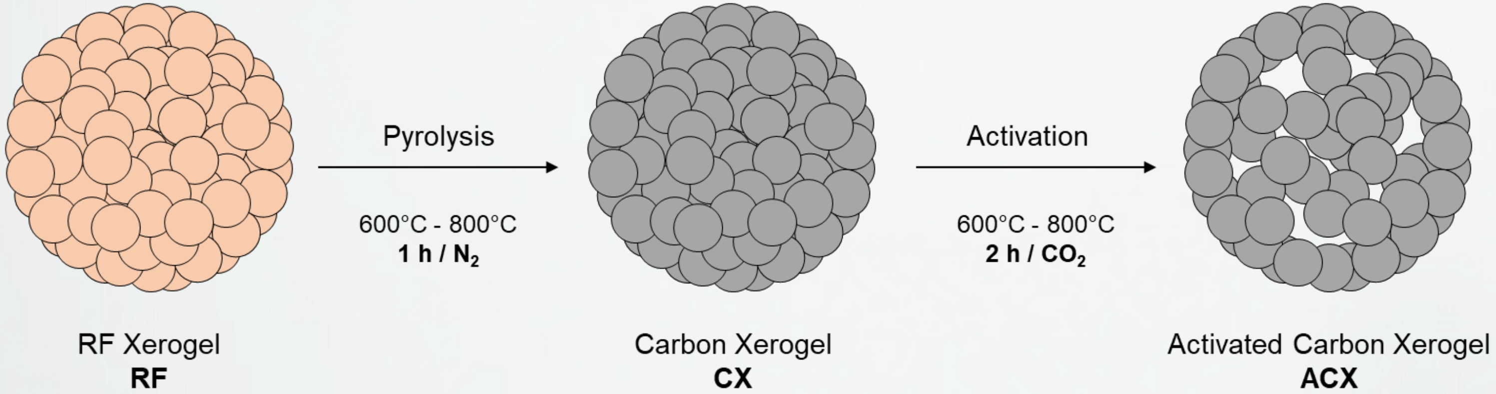

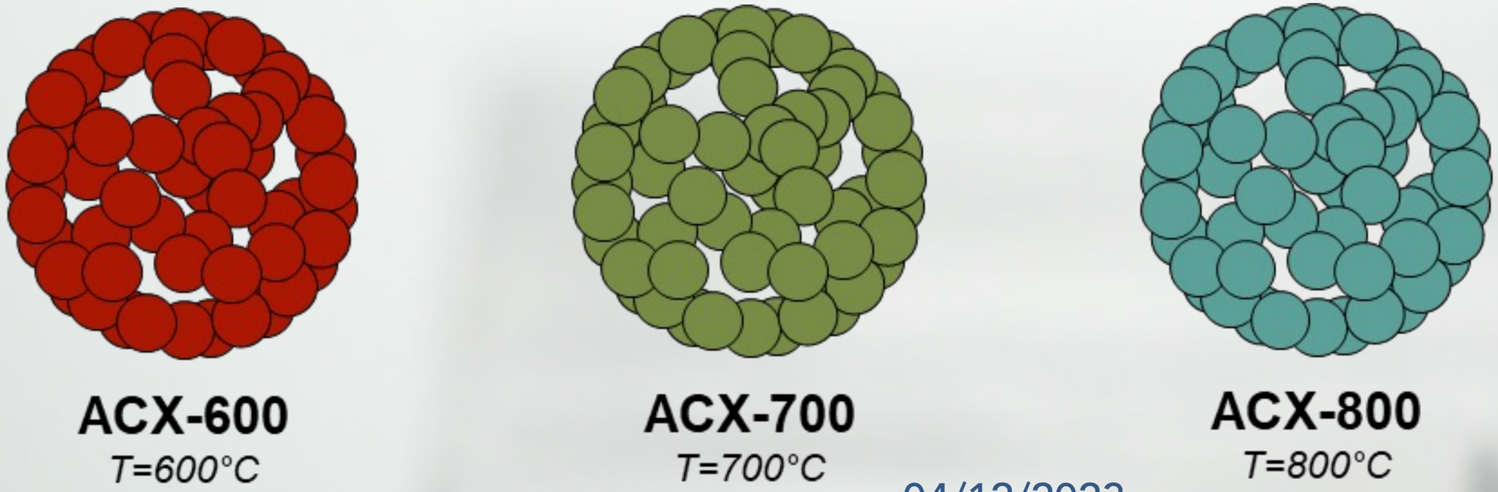

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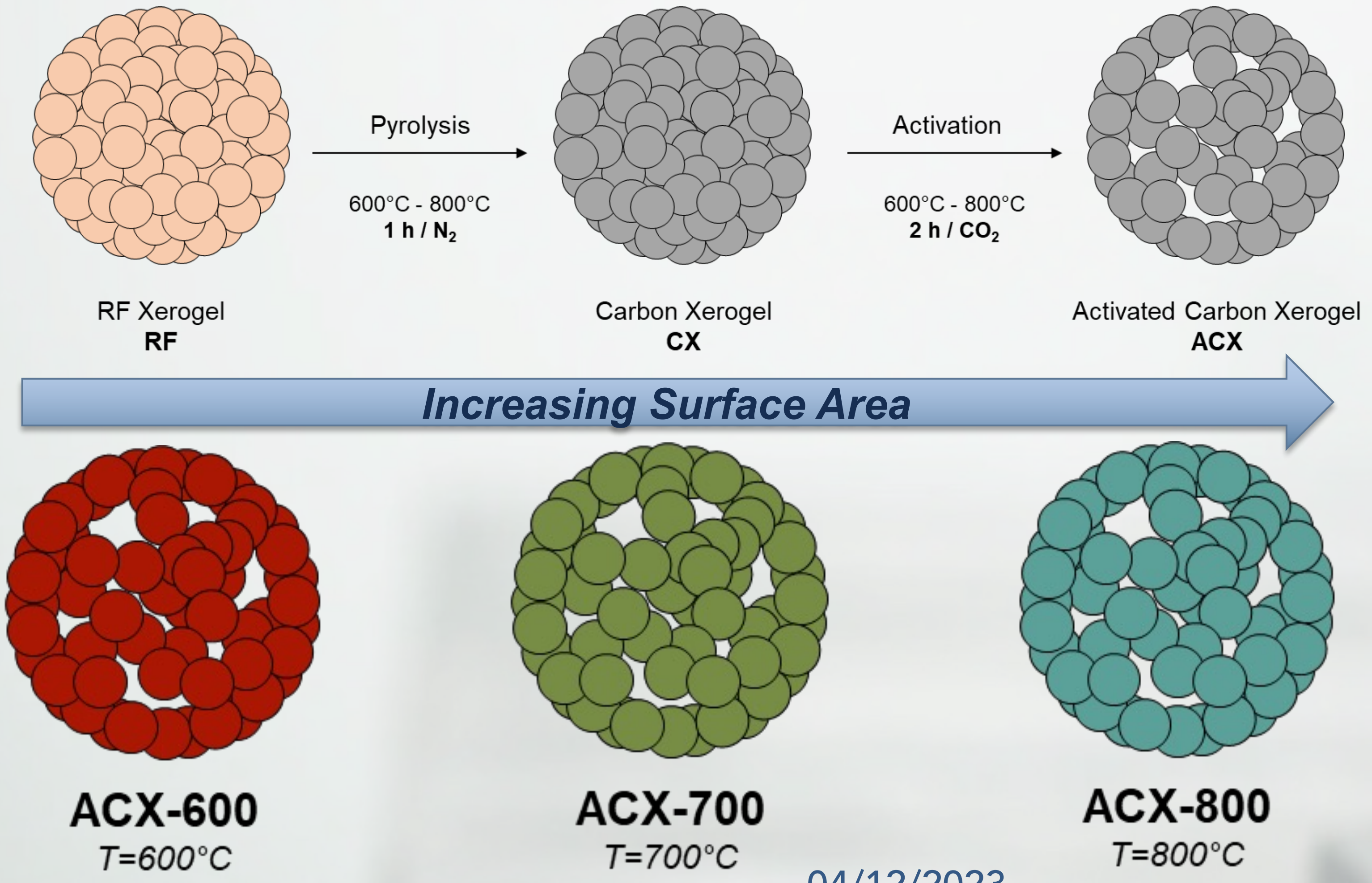
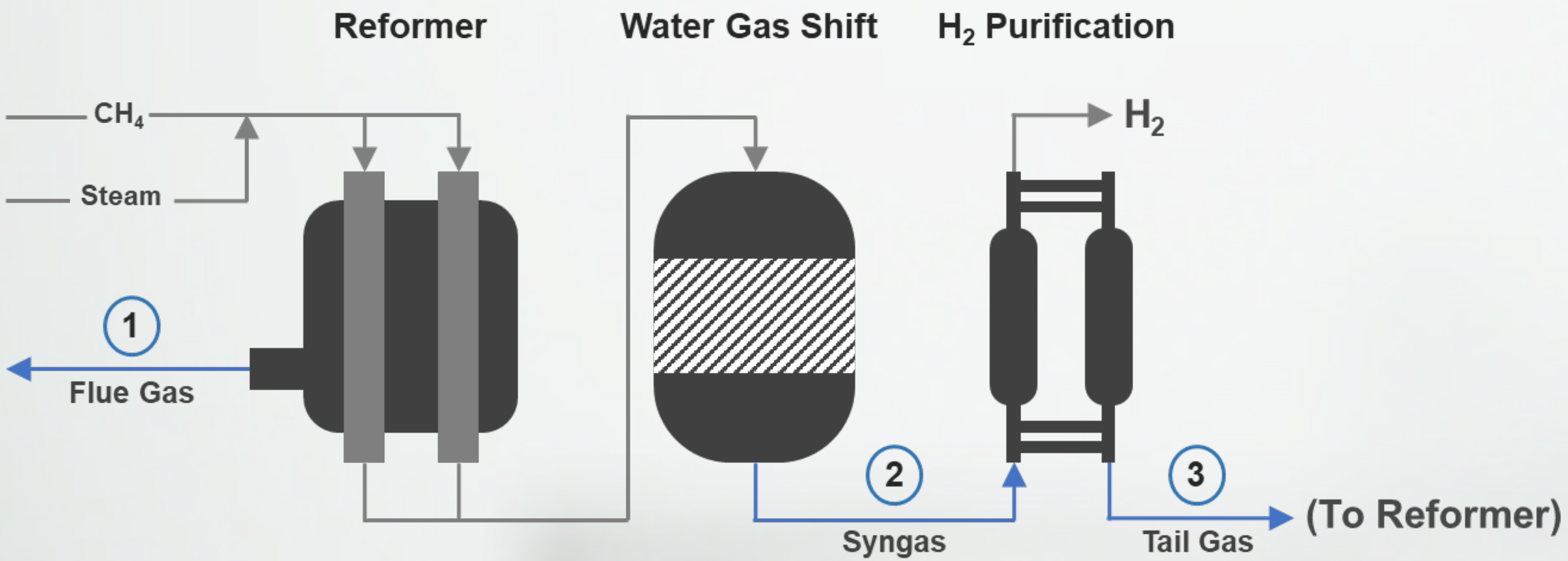


SMR Process



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CO_2 Fraction	Low	Low	High
Temperature	High	Low	Low
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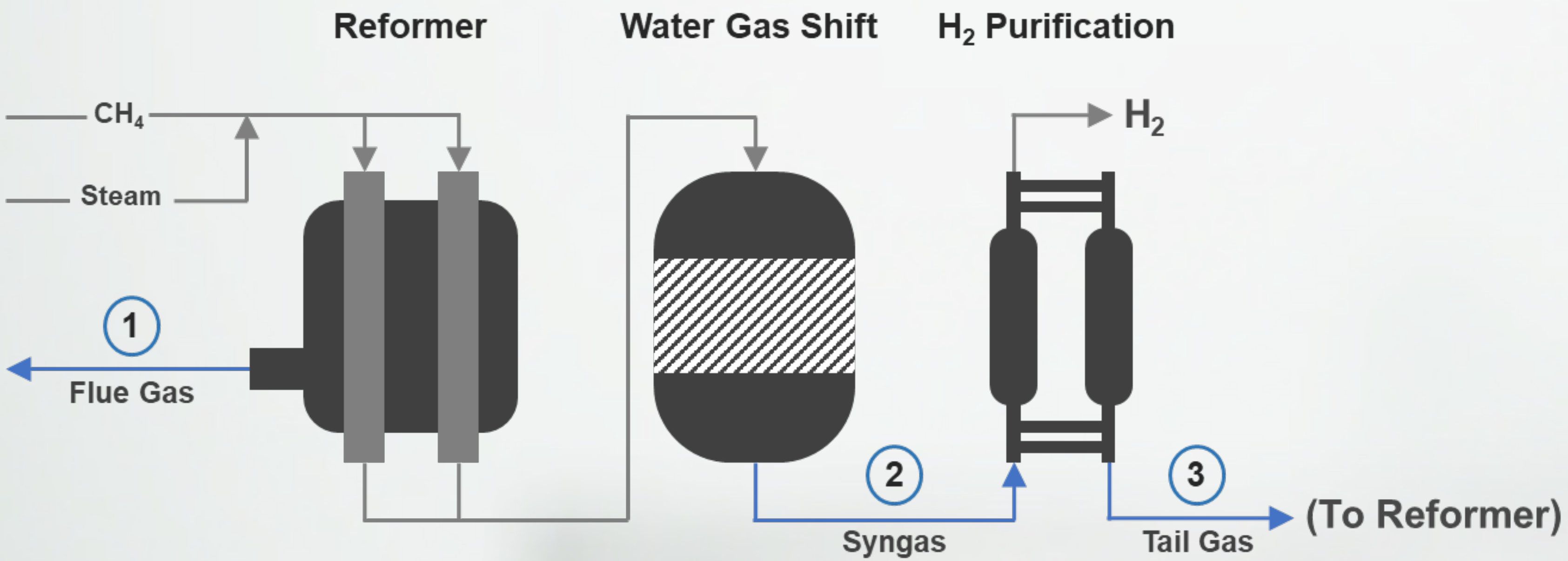
SMR Process



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Breakthrough Curve Experiments

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Breakthrough Curve Experiments

Feed Conditions (Typical H_2 SMR Tail Gas)

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Breakthrough Curve Experiments

Feed Conditions (Typical H_2 SMR Tail Gas)

50% CO_2 | 15% CH_4 | 10% CO | 25% N_2

Flowrate	Temperature	Pressure
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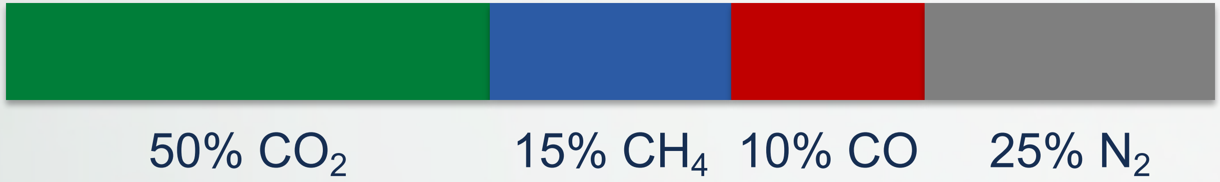

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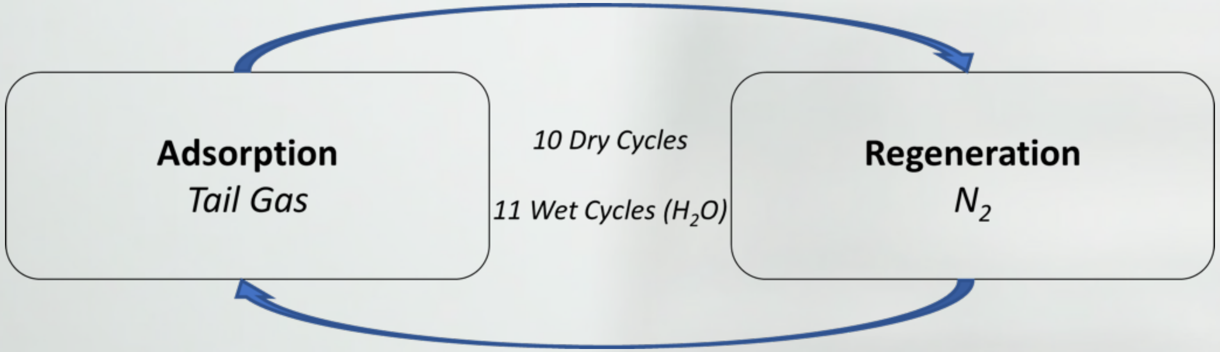

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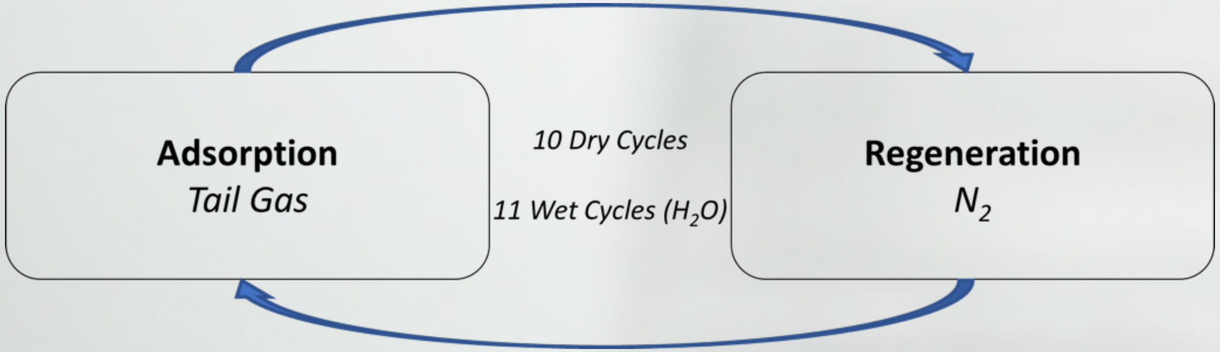
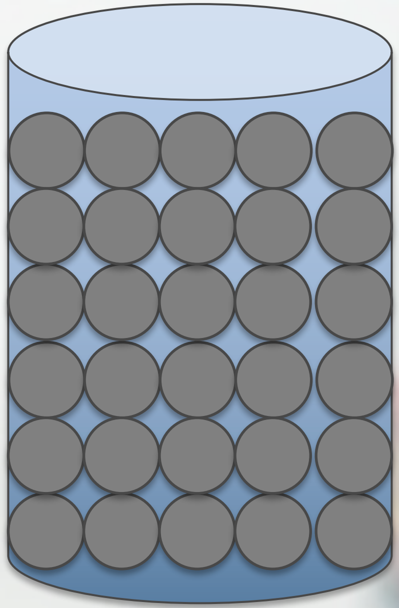


Packed Bed



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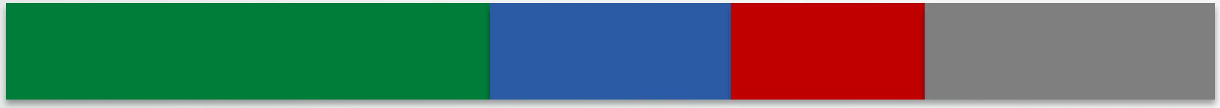

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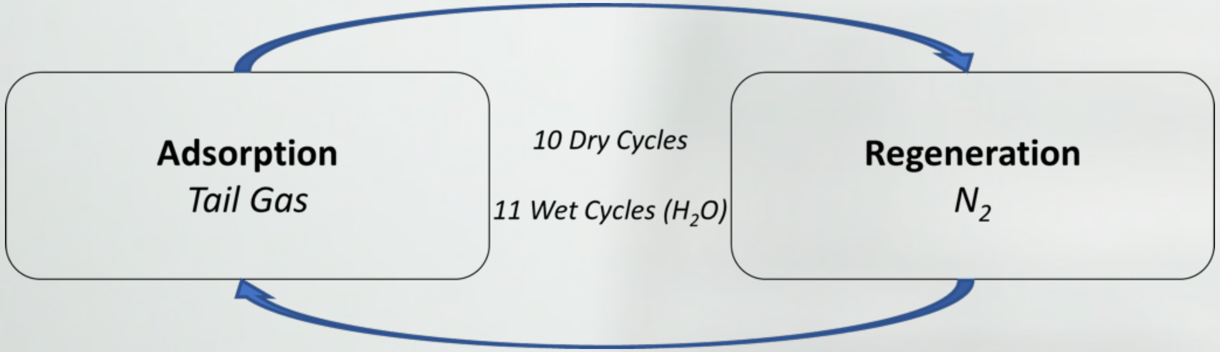

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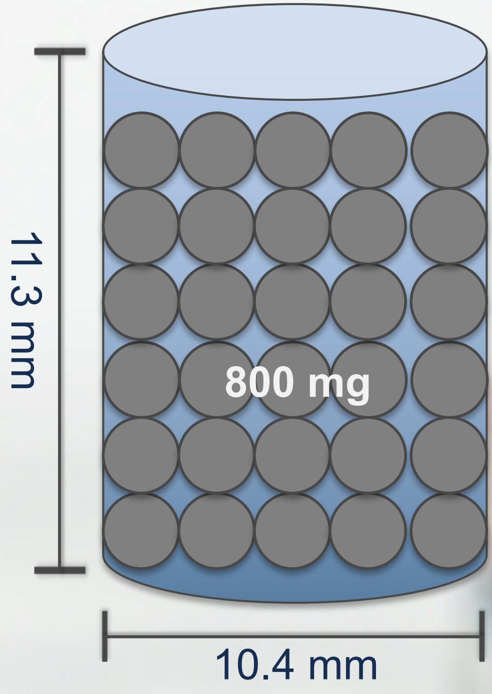

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Adsorption Theory

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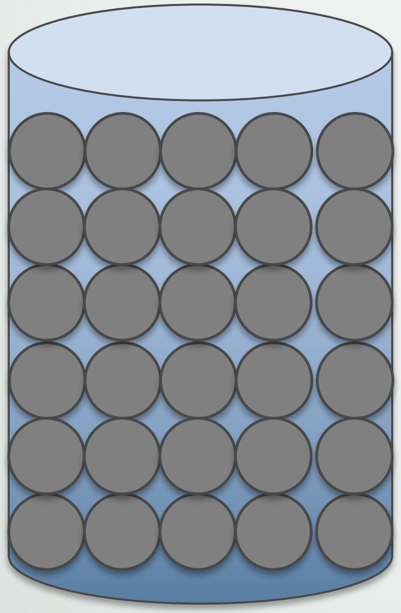
Adsorption Theory



Bed initially in inert N_2 atmosphere

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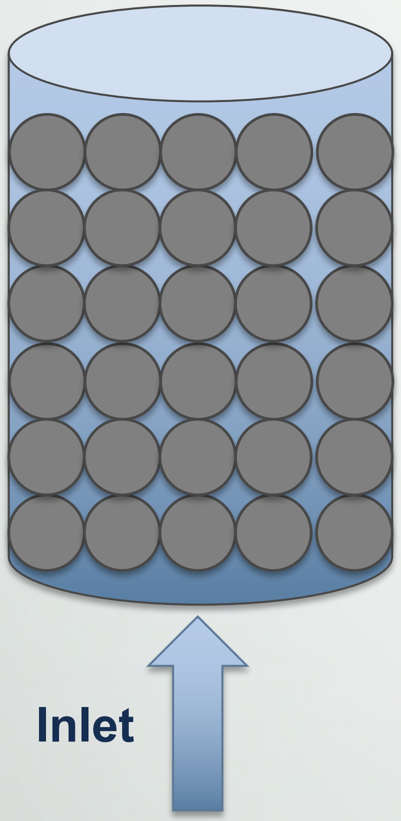
Adsorption Theory



Bed initially in inert N_2 atmosphere

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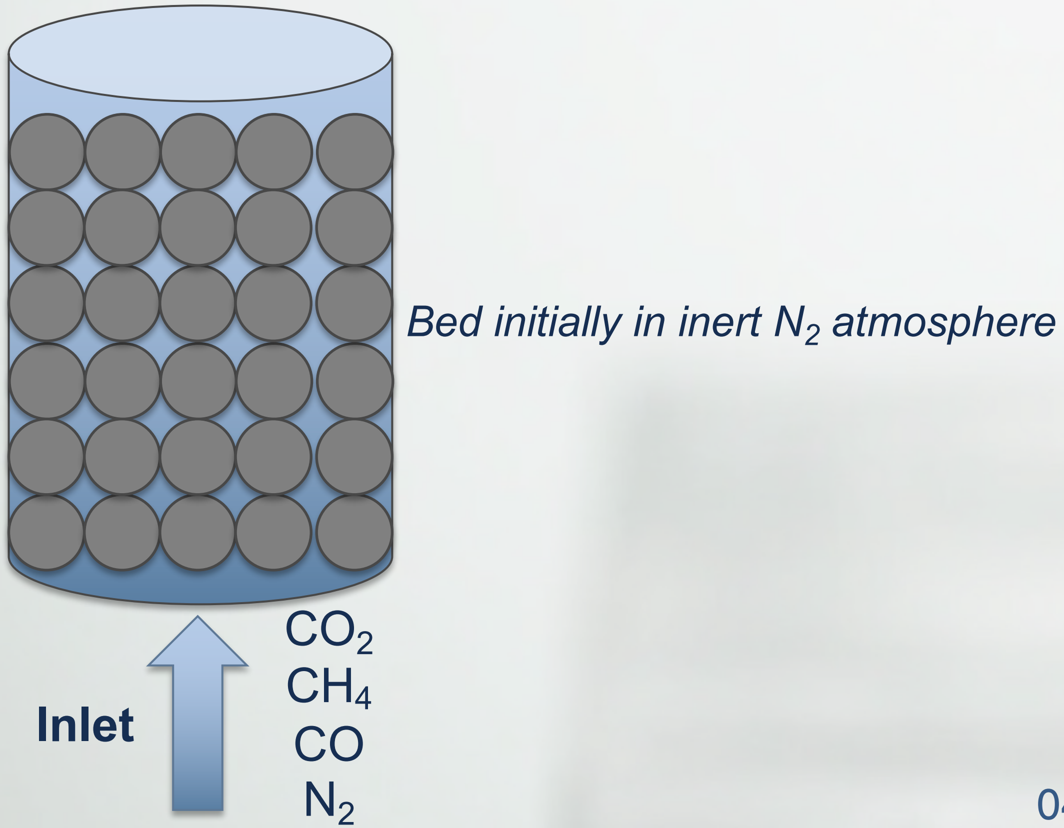

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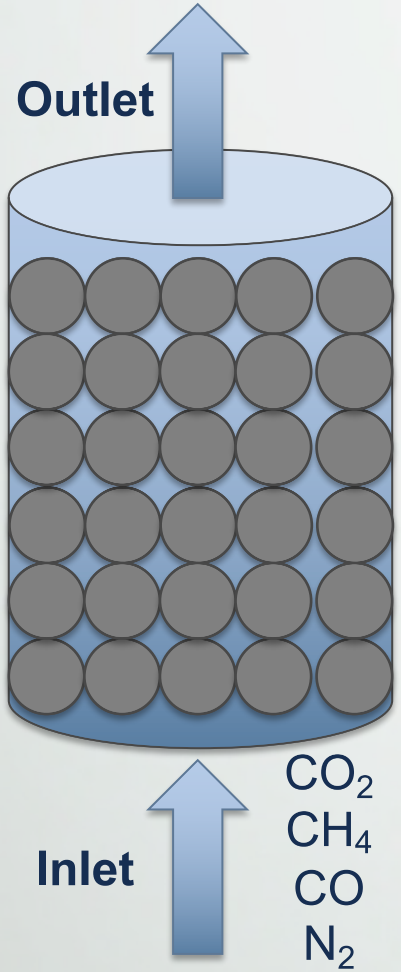

Bed initially in inert N_2 atmosphere

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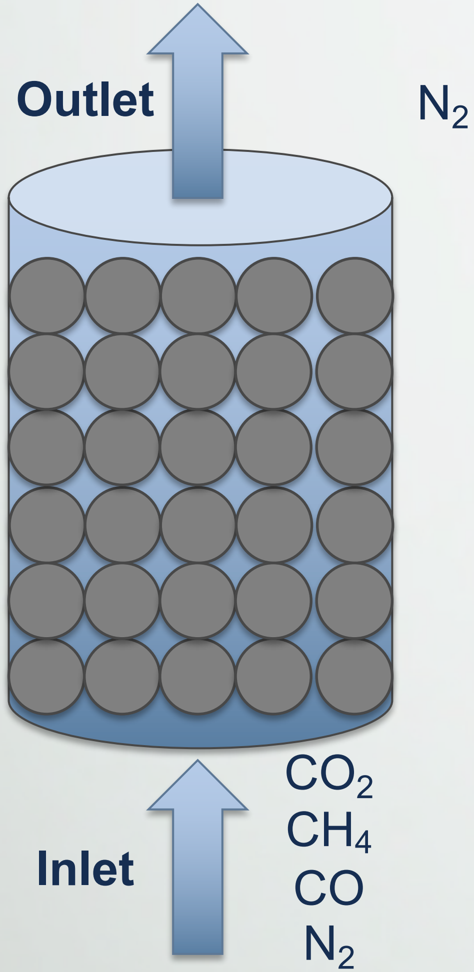
Adsorption Theory



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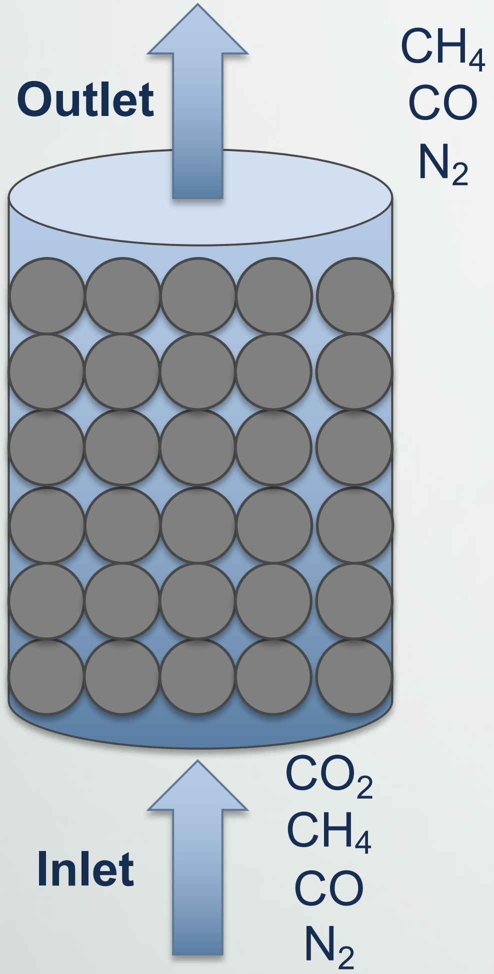
Adsorption Theory



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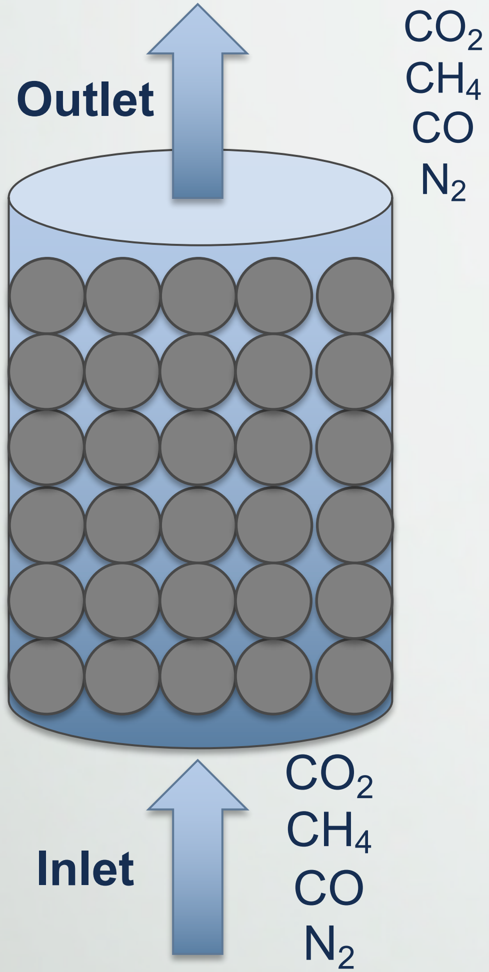
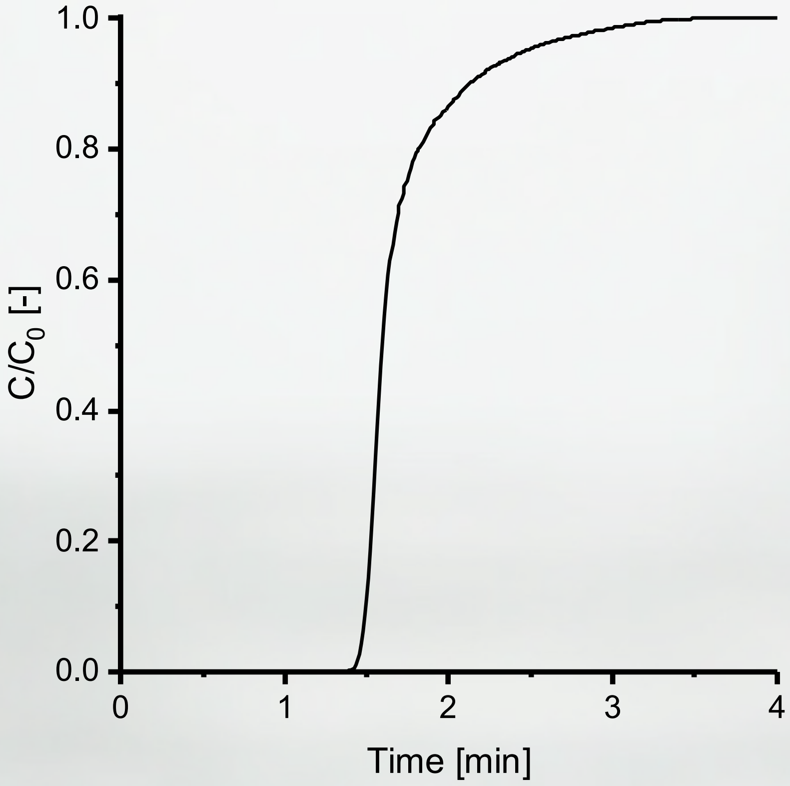
Adsorption Theory





Breakthrough Curve

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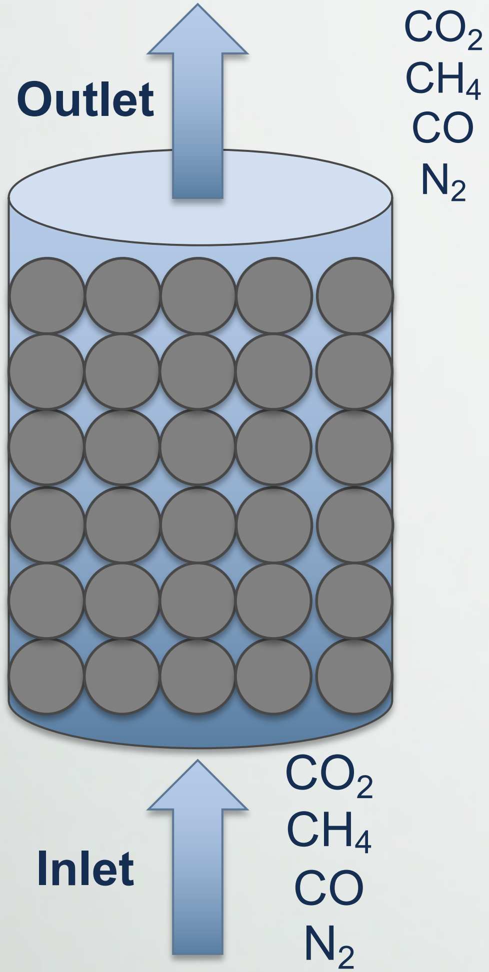
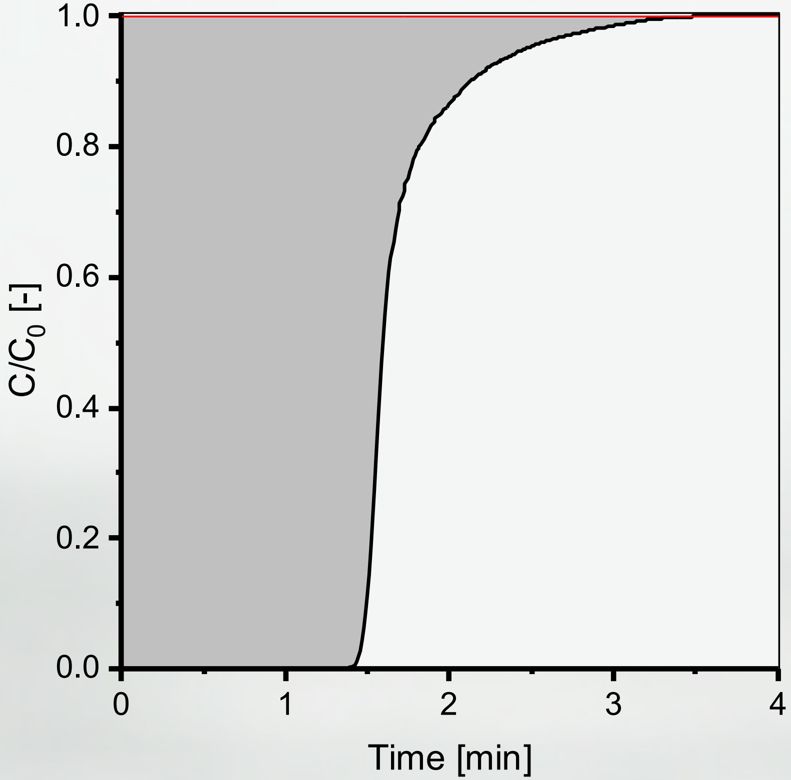
Adsorption Theory





Breakthrough Curve

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Experimental Summary

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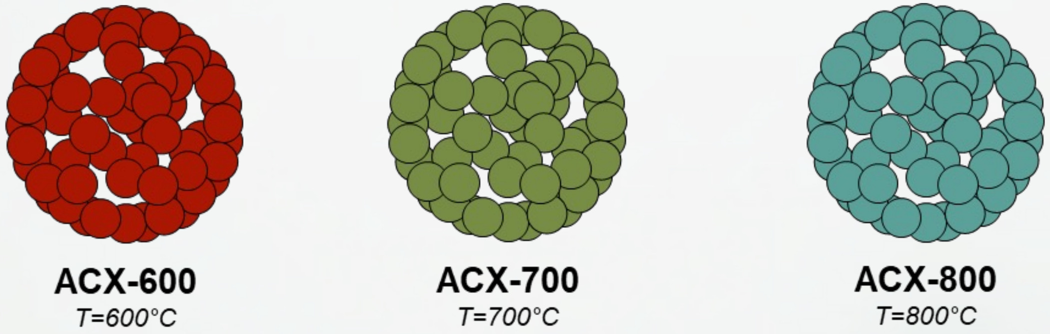
Experimental Summary

Materials
Activated Carbon Xerogels



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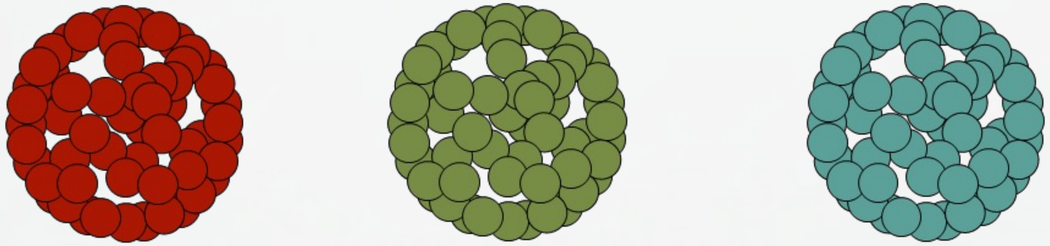
Experimental Summary

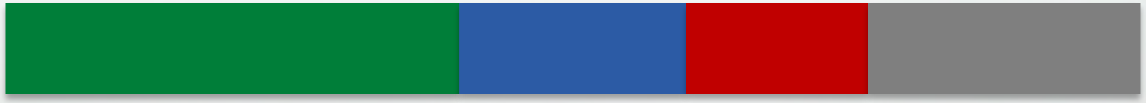
Materials
Activated Carbon Xerogels



ACX-600 *T=600°C* | **ACX-700** *T=700°C* | **ACX-800** *T=800°C*

Conditions
Typical Tail Gas

Feed Conditions (Typical H_2 SMR Tail Gas)



50% CO_2 | 15% CH_4 | 10% CO | 25% N_2

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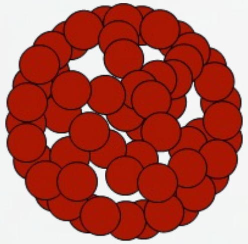
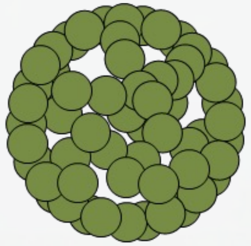
Experimental Summary

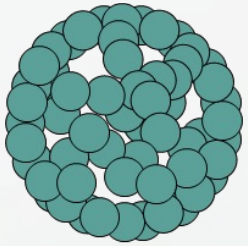
Materials
Activated Carbon Xerogels



ACX-600
T=600°C



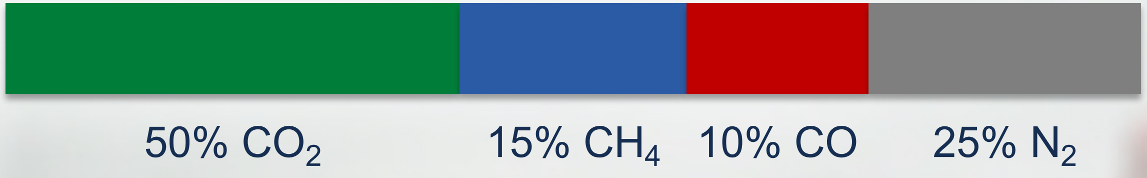
ACX-700
T=700°C



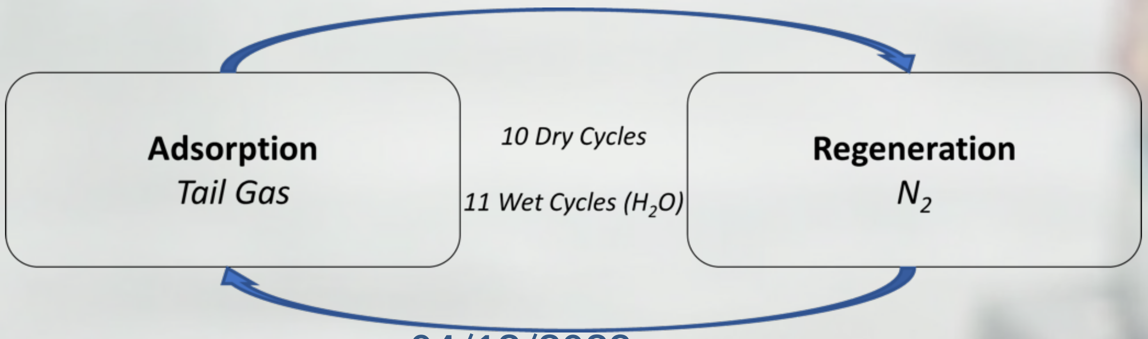
ACX-800
T=800°C

Conditions
Typical Tail Gas

Feed Conditions (Typical H_2 SMR Tail Gas)



Process
Dry and Wet Adsorption Cycles



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Performance

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Cyclic Experiments – Dry Cycles

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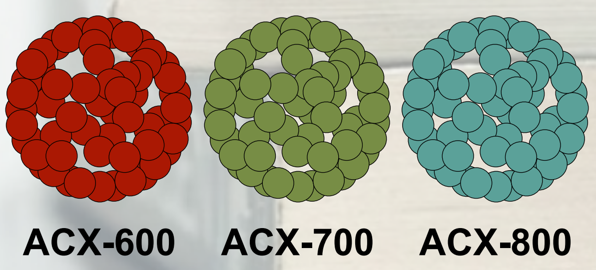
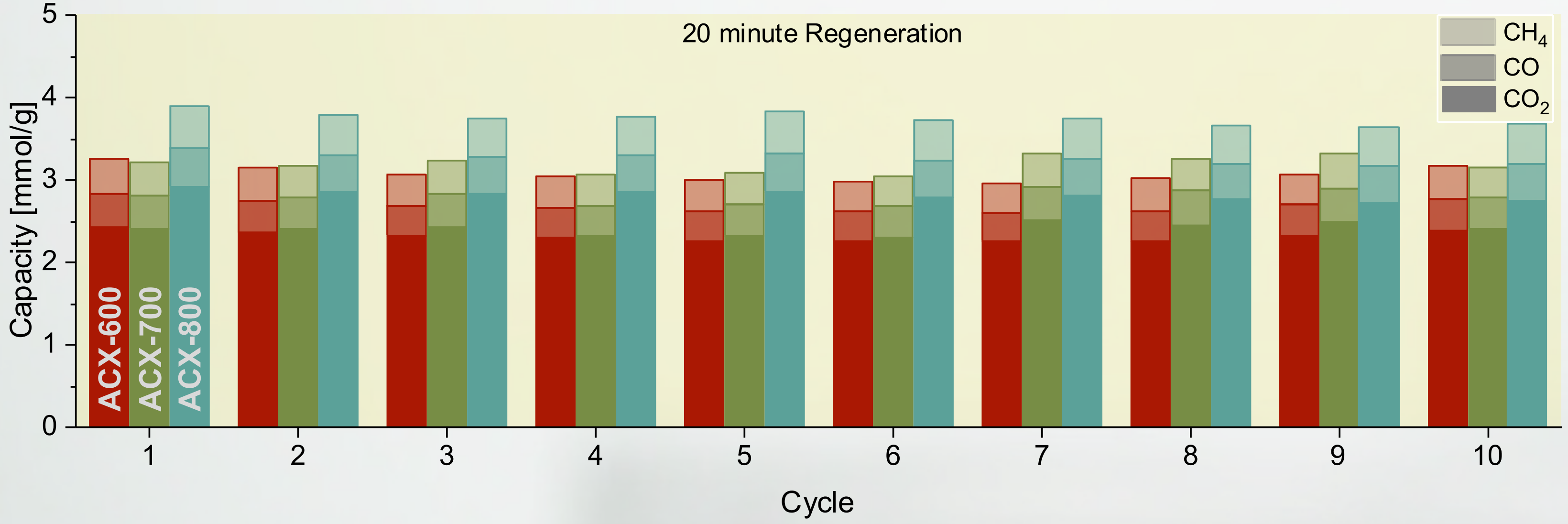
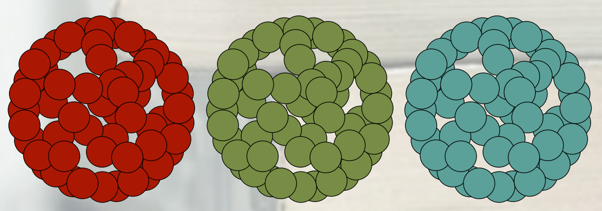
Cyclic Experiments – Dry Cycles



Cyclic Experiments – Dry Cycles

Dry Cycles

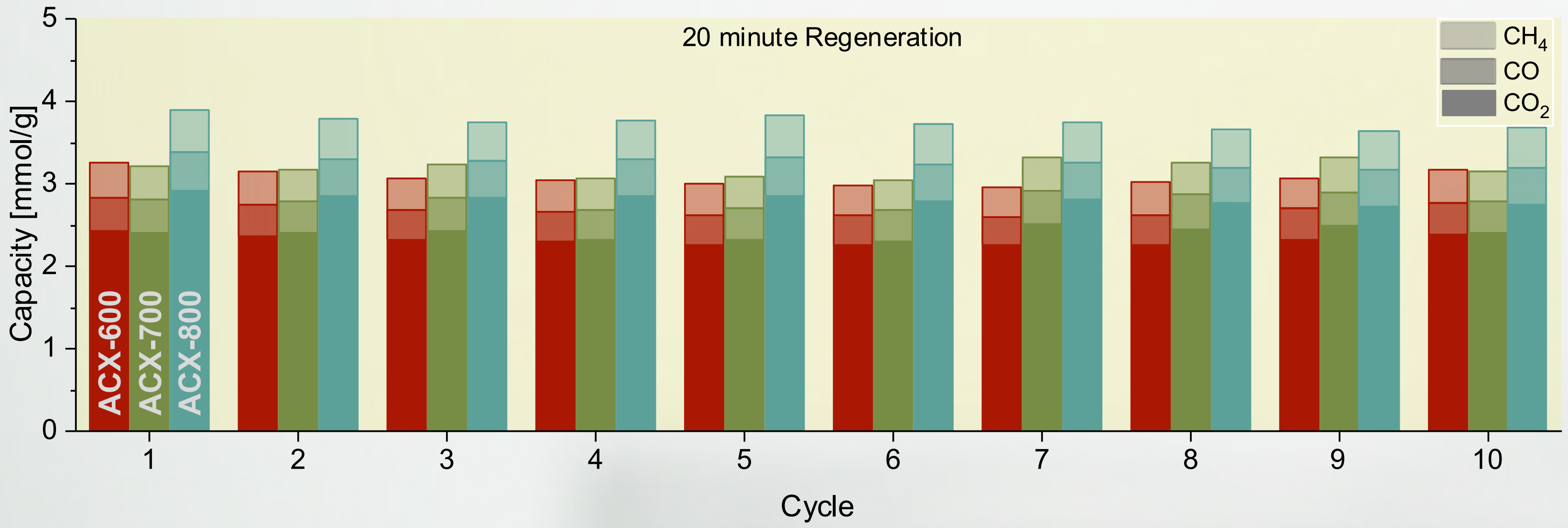


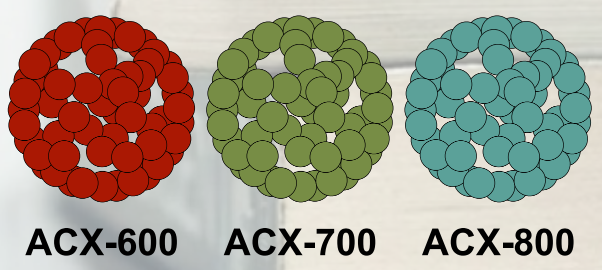


ACX-600 ACX-700 ACX-800

Cyclic Experiments – Dry Cycles

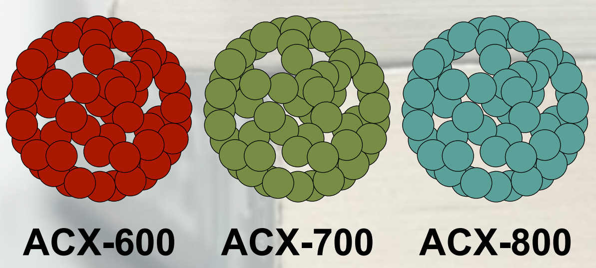
Dry Cycles





- Higher Activation Temperature = Higher Capacity
- 6.2 CO_2 / CO Selectivity for all ACX
- 7.4 CO_2 / CH_4 Selectivity for all ACX

Cyclic Experiments – Wet Cycles



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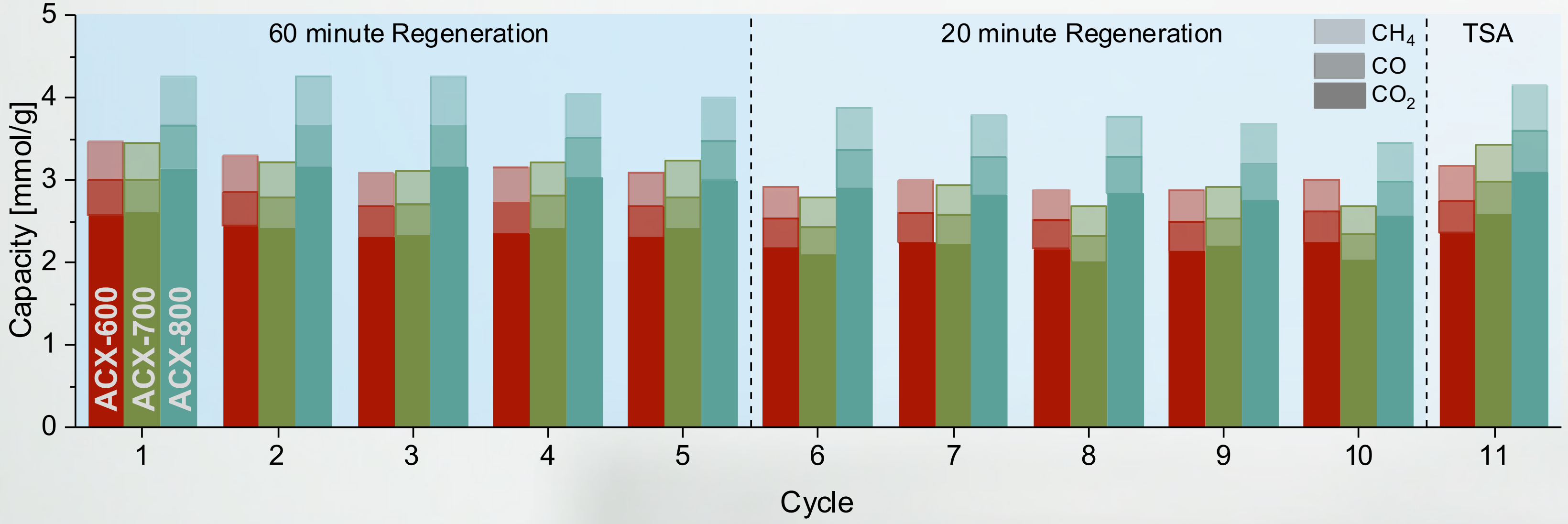
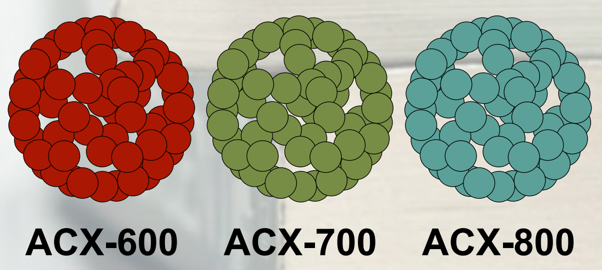
Cyclic Experiments – Wet Cycles

Wet Cycles





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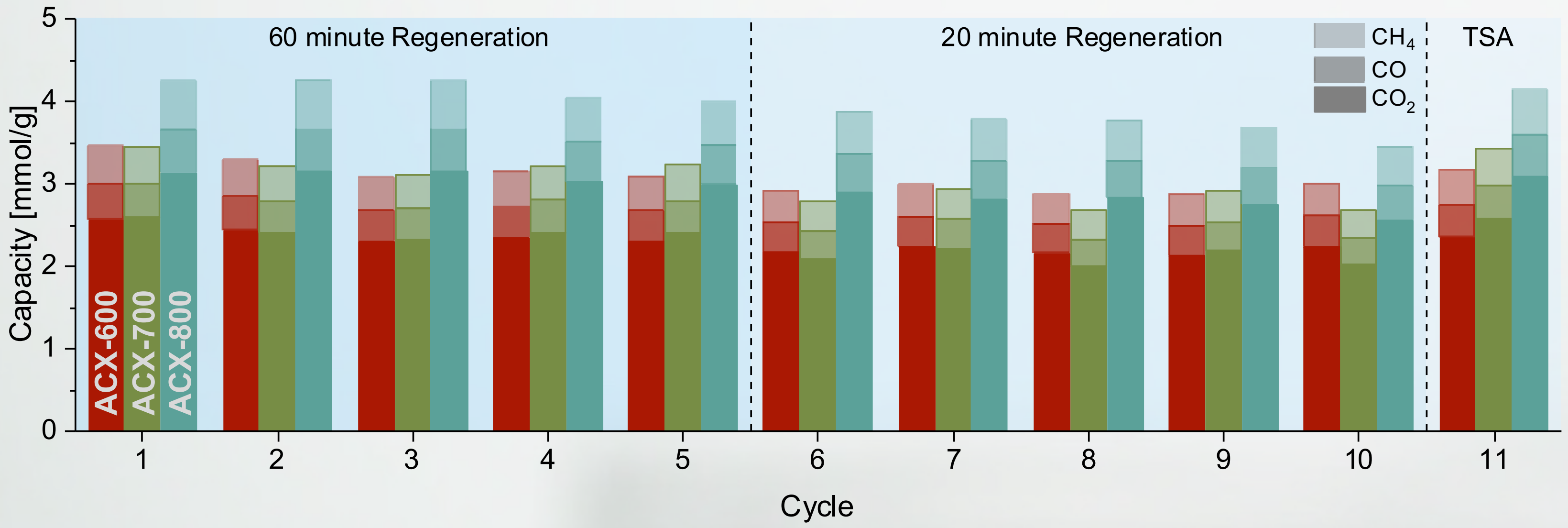
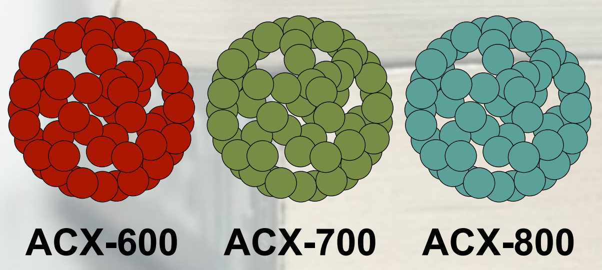
Cyclic Experiments – Wet Cycles

Wet Cycles





- Initial 7% increase in capacity from dry to wet conditions
- Surface saturation with H_2O visible (cycle 4)
- Ability to regenerate to full capacity with heat (cycle 11)

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Hollow Fibre-Based Adsorption Systems

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Ceramic Hollow Fibres

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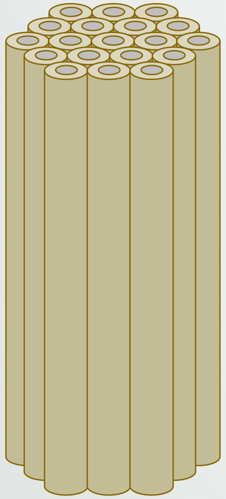
Ceramic Hollow Fibres



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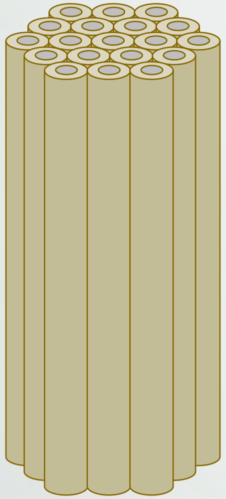
Ceramic Hollow Fibres



- Lower CAPEX
- Higher adsorption capacity
- Faster kinetics

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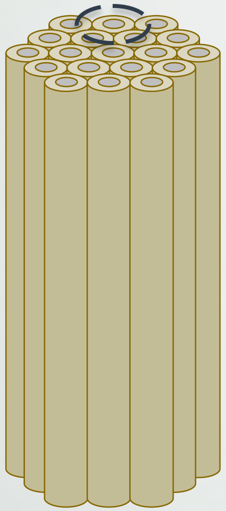
Ceramic Hollow Fibres



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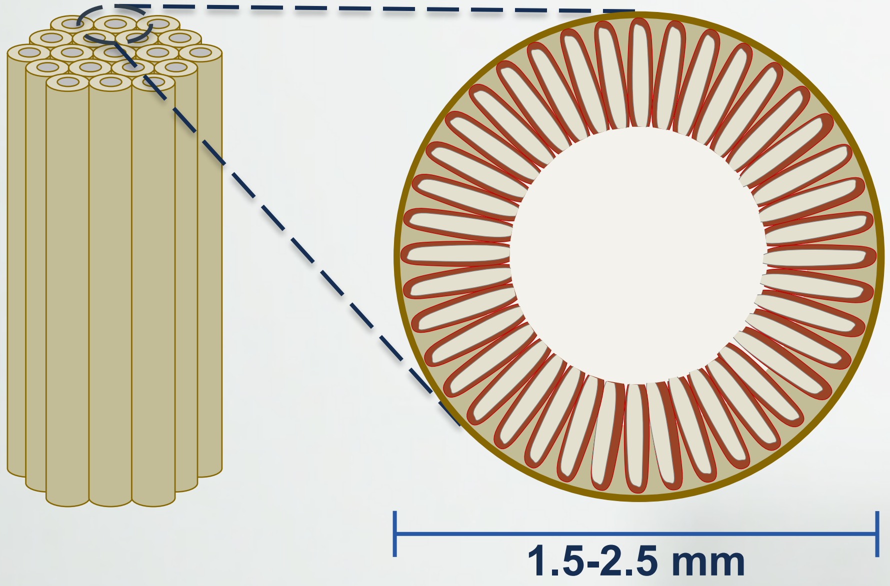
Ceramic Hollow Fibres



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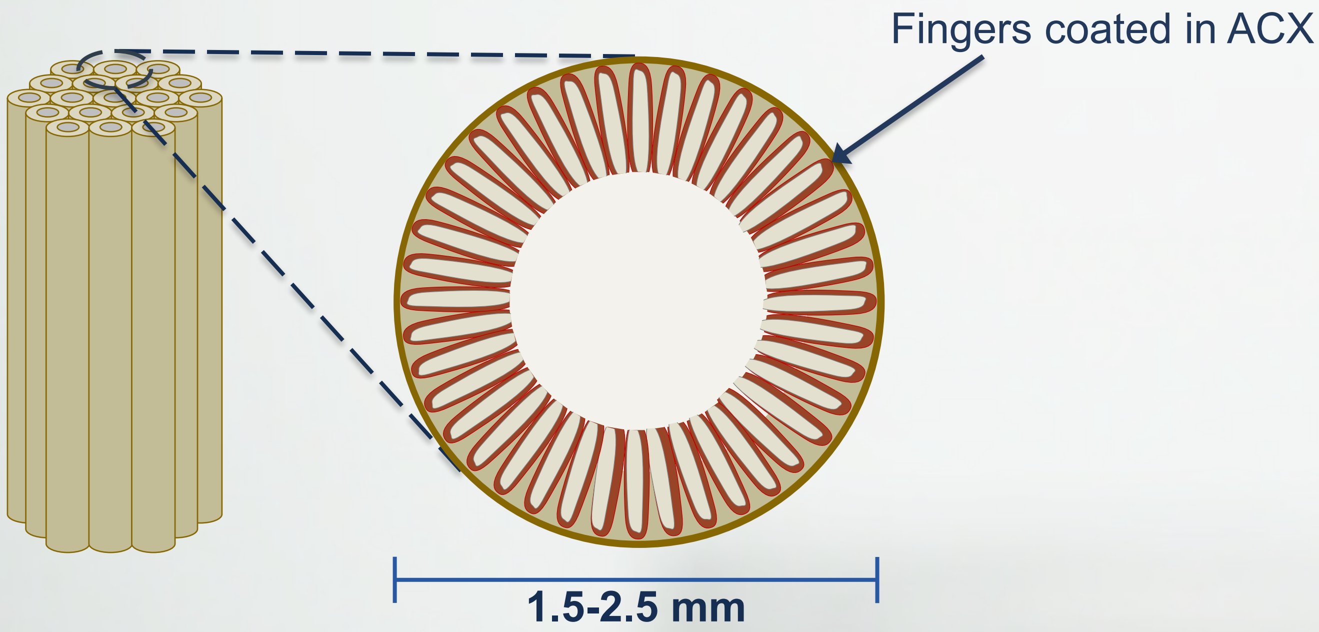
Ceramic Hollow Fibres



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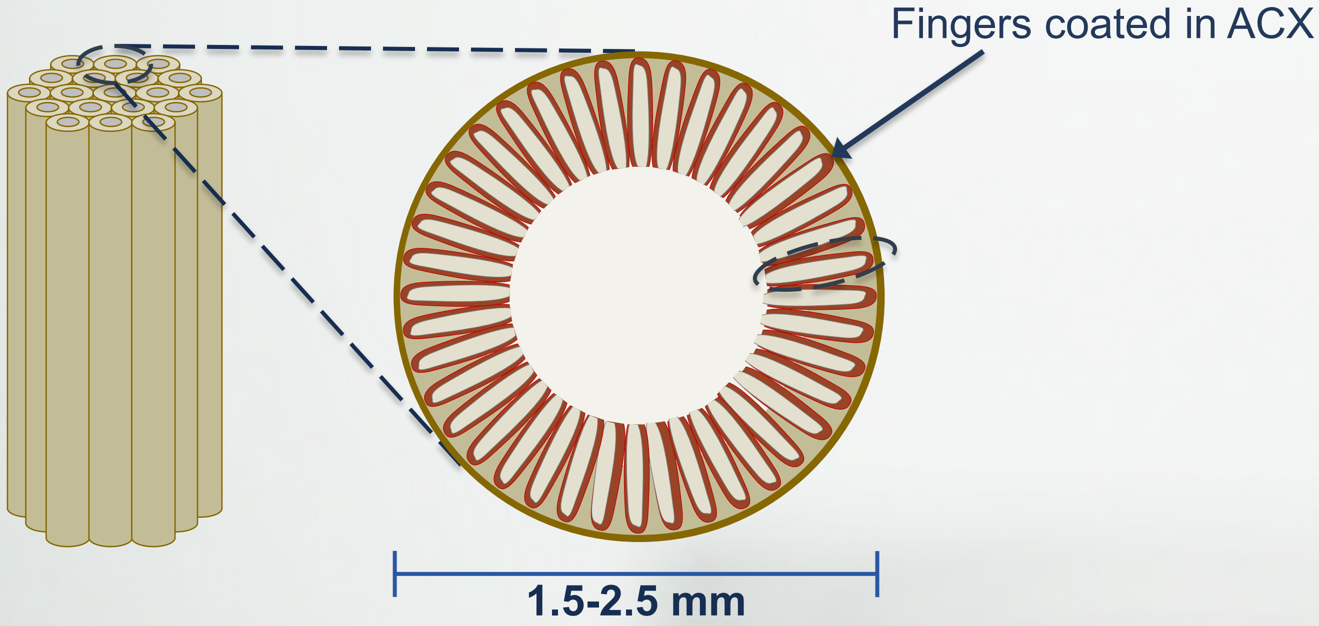
Ceramic Hollow Fibres



- Lower CAPEX
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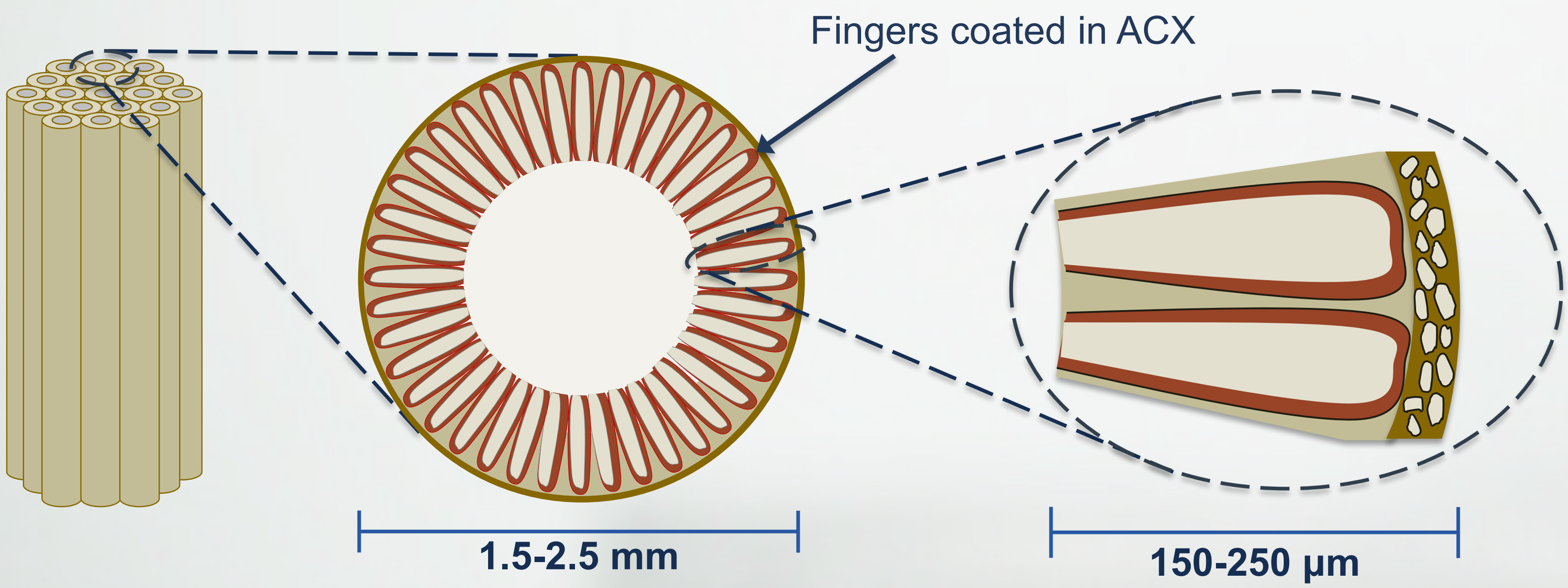
Ceramic Hollow Fibres



- Lower CAPEX
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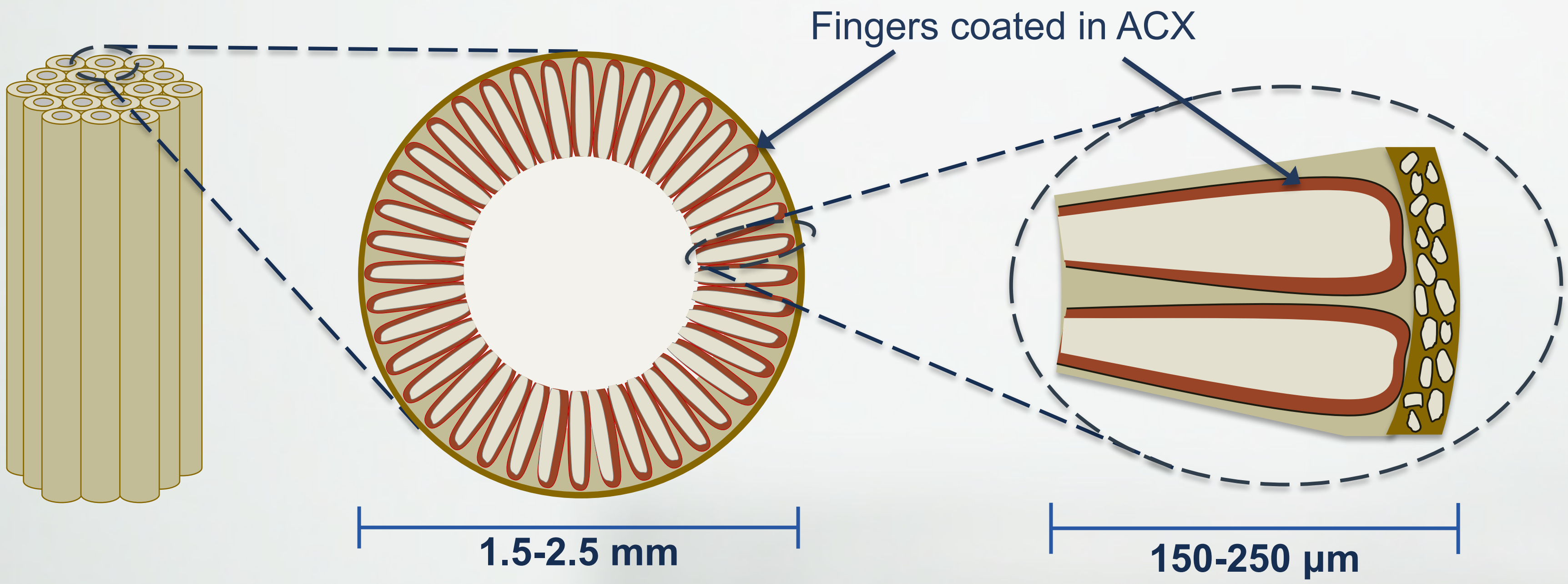
Ceramic Hollow Fibres



- Lower CAPEX
- Higher adsorption capacity
- Faster kinetics

- 'Finger-shaped' pore structures
- Each pore acts as a "micro-reactor"
- Layer of ACX is 1-5 µm thick

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Hollow Fibre Impregnation

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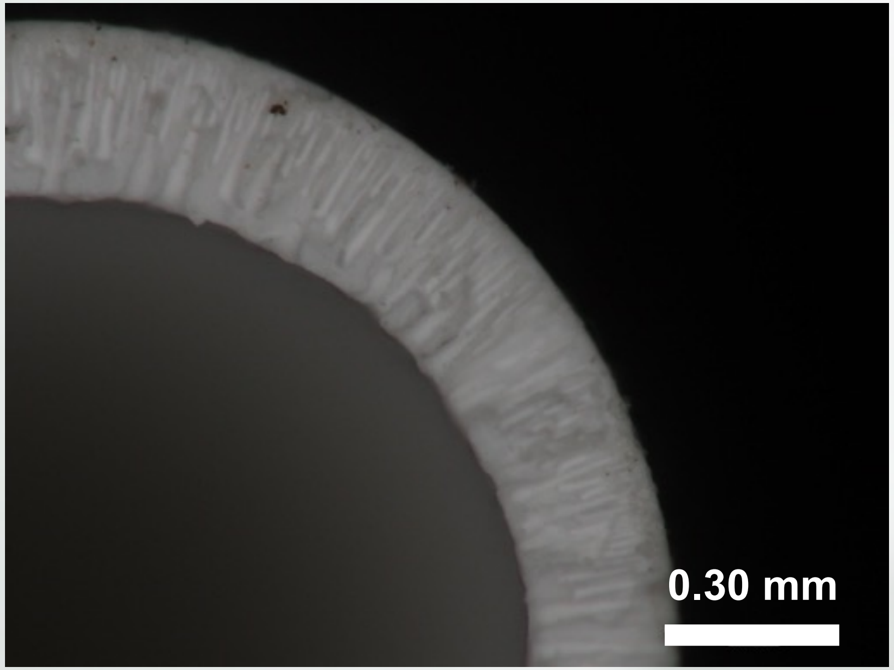
Hollow Fibre Impregnation



Blank Hollow Fibre

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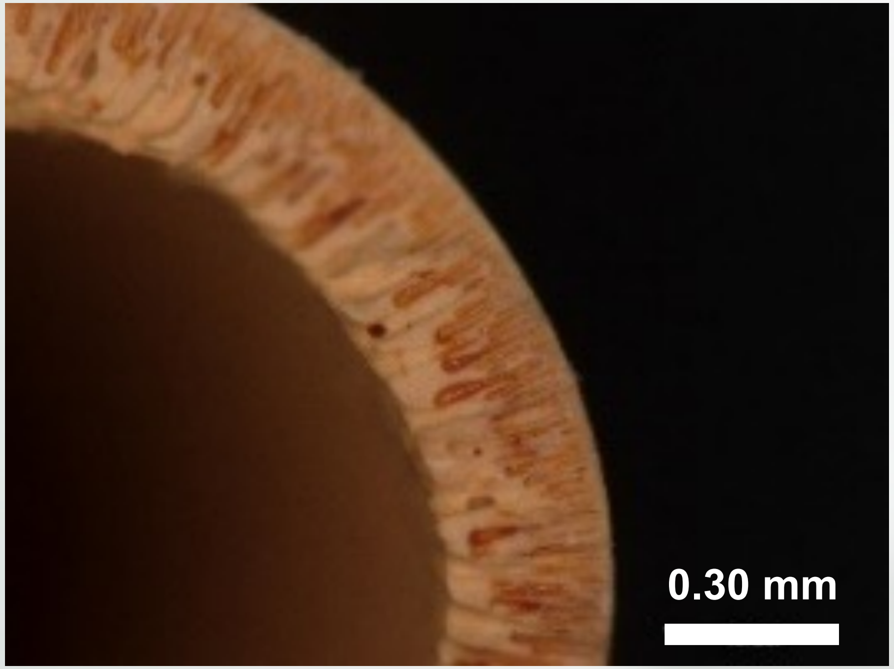
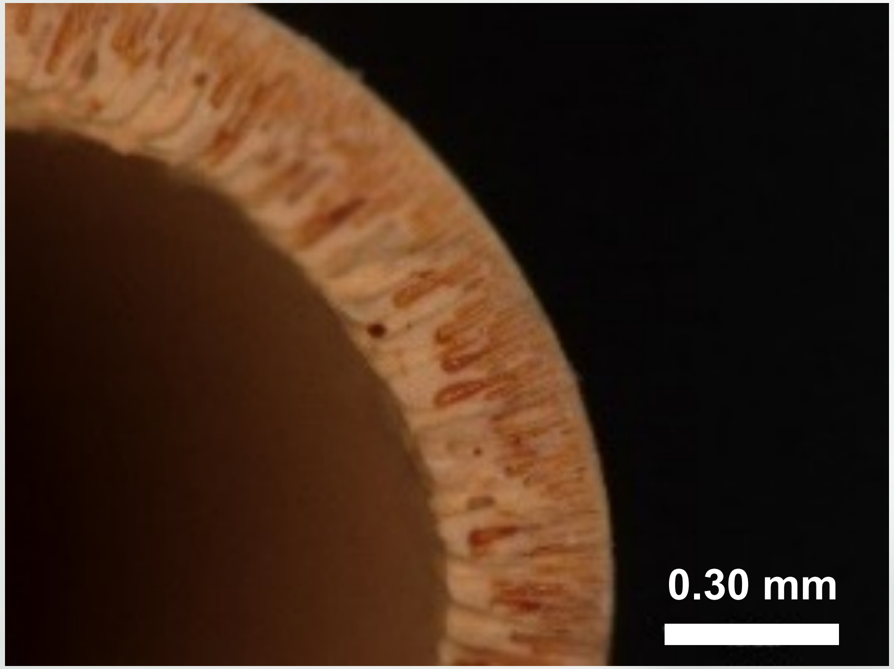
Hollow Fibre Impregnation

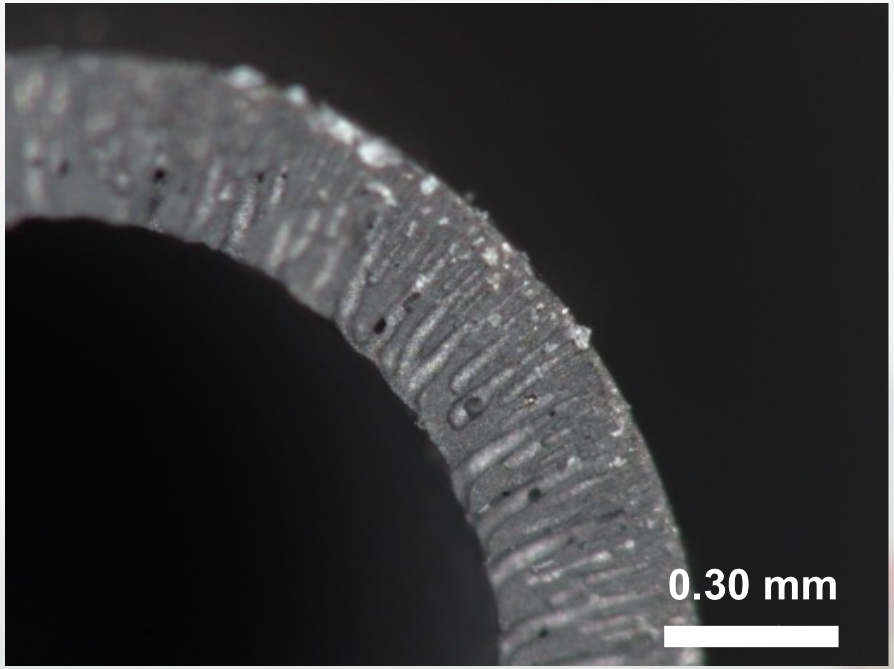


Hollow Fibre Impregnated with RF

Hollow Fibre Impregnation



Hollow Fibre Impregnated with RF



Hollow Fibre Coated with ACX-800

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Applying Hollow Fibre-Based Adsorption Units

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Applying Hollow Fibre-Based Adsorption Units

On-Board Capture for a HGV Vehicle (14% CO_2)

C. Larkin, et al., Retrofitting hollow fibre carbon capture systems to decarbonise surface transport, CO_2 Utilisation 67, 2023, 102336)

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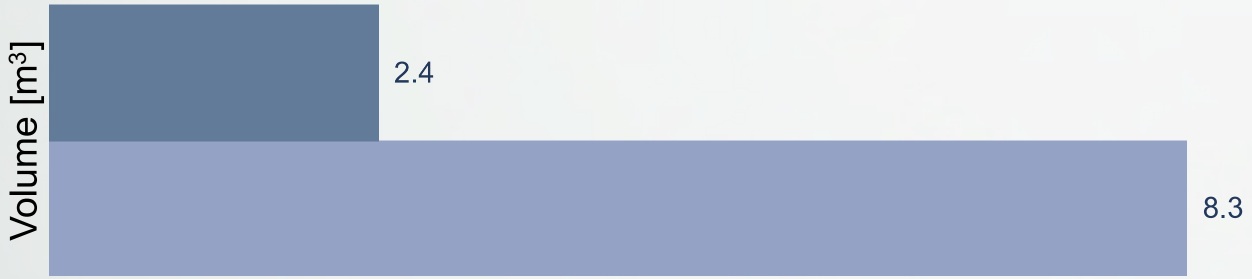
Applying Hollow Fibre-Based Adsorption Units

On-Board Capture for a HGV Vehicle (14% CO_2)



x3.5 Smaller

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C. Larkin, et al., Retrofitting hollow fibre carbon capture systems to decarbonise surface transport, CO_2 Utilisation 67, 2023, 102336)

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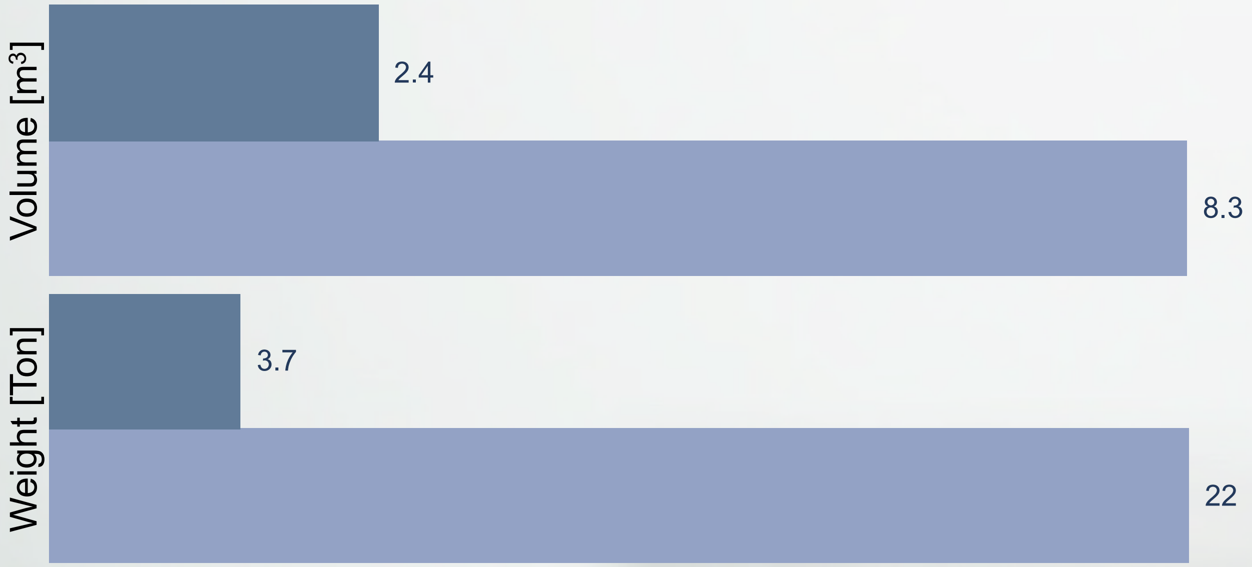

x3.5 Smaller

x5.8 Lighter

C. Larkin, et al., Retrofitting hollow fibre carbon capture systems to decarbonise surface transport, CO_2 Utilisation 67, 2023, 102336)

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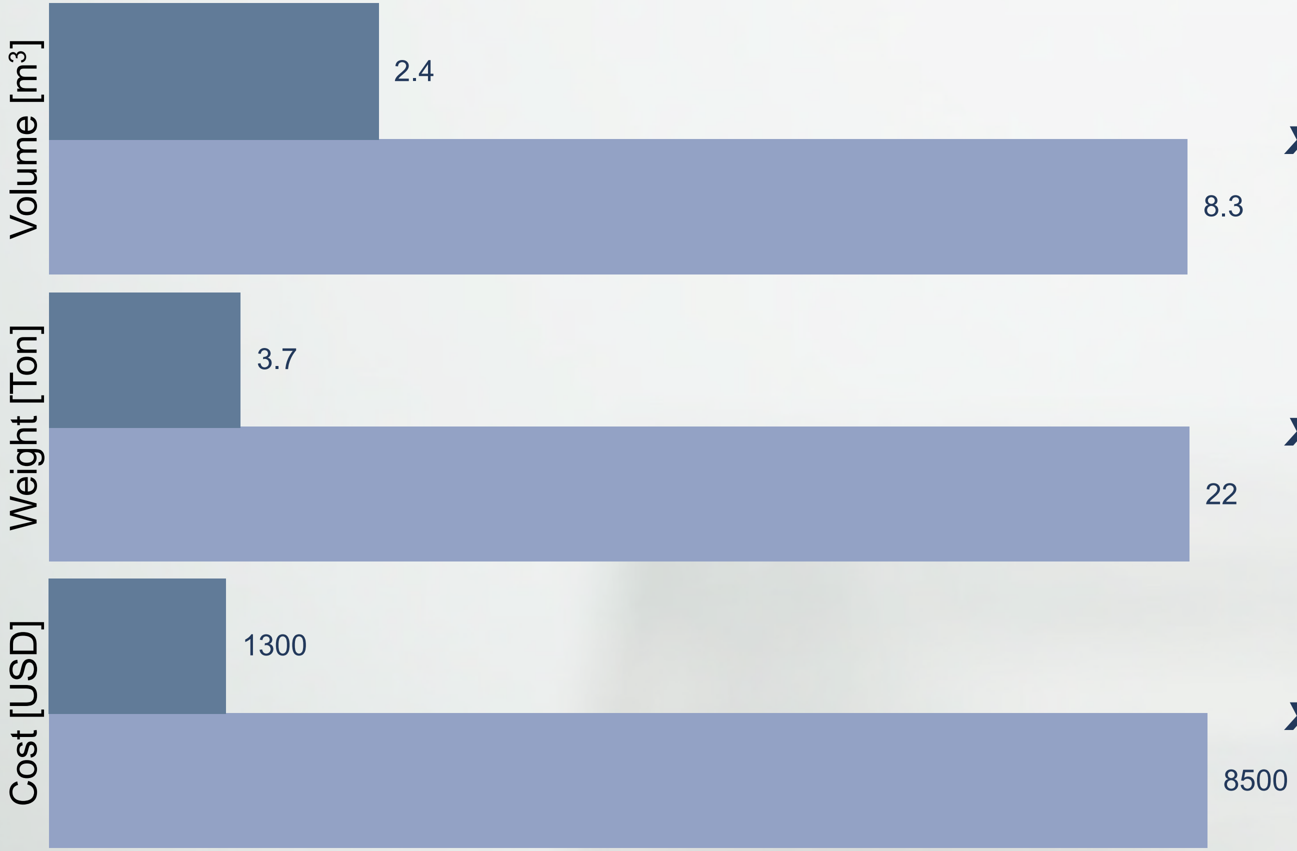
Applying Hollow Fibre-Based Adsorption Units

On-Board Capture for a HGV Vehicle (14% CO_2)



x3.5 Smaller

x5.8 Lighter

x6.6 Cheaper

C. Larkin, et al., Retrofitting hollow fibre carbon capture systems to decarbonise surface transport, CO_2 Utilisation 67, 2023, 102336)

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Applying Hollow Fibre-Based Adsorption Units

On-Board Capture for a HGV Vehicle (14% CO_2)

Journal of CO2 Utilization 67 (2023) 102336

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Retrofitting hollow fibre carbon capture systems to decarbonise surface transport

Collette Larkin [a], Kyriaki Lampri [a], Simona Mazzone [a], Fermín Oliva [b], Kang Li [c], Francisco R. García–García [a,*]

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[b] Repsol S. A., Calle Méndez Álvaro, 44, 28045 Madrid, Spain
[c] Department of Chemical Engineering, Imperial College London, Exhibition Road, London SW7 2AZ, UK

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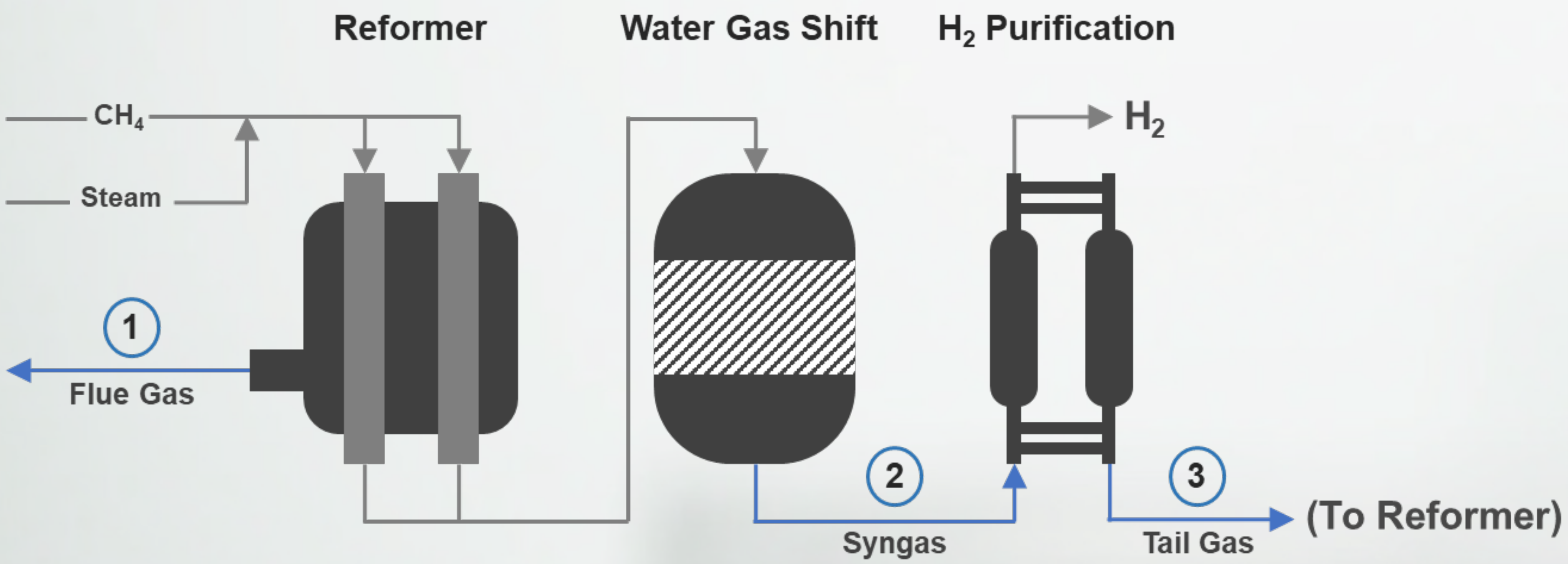
Applying Hollow Fibre-Based Adsorption Units



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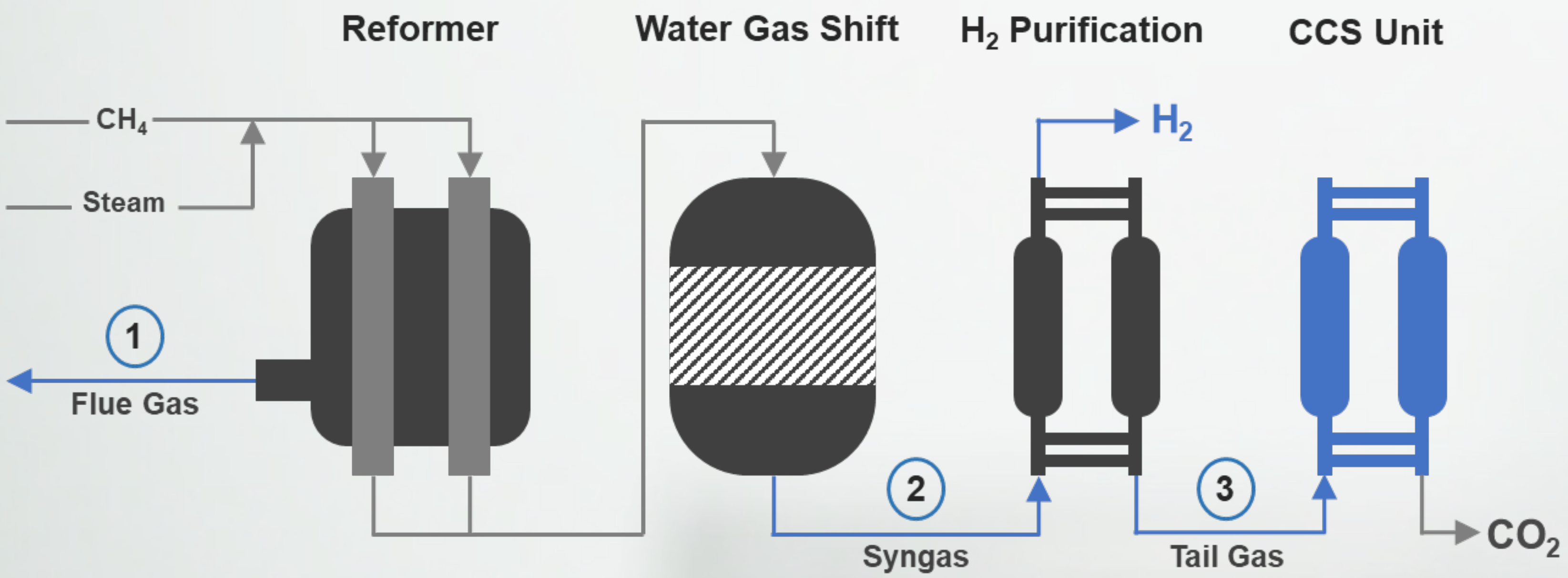
Applying Hollow Fibre-Based Adsorption Units



Retrofitting Small Scale H_2 SMR Facilities with Compact Hollow Fibre-Based Systems!

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Engineering and Physical Sciences Research Council

Thank you

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Dr Francisco. R. García-García
Collette Larkin

Imperial College London

Prof. Kang Li