



Metal Organic Frameworks (MOFs) as Solid Sorbents for Energy-Efficient Carbon Capture

Dr Jack Turner, 28th June 2022

Overview

- The Climate Crisis – The Scale of the Problem
- Post-Combustion Carbon Capture – Current Incumbent Technology
- Alternative Technologies for Post-Combustion Carbon Capture
- Metal Organic Frameworks
- Solving the scale problem- Continuous manufacture of MOFs

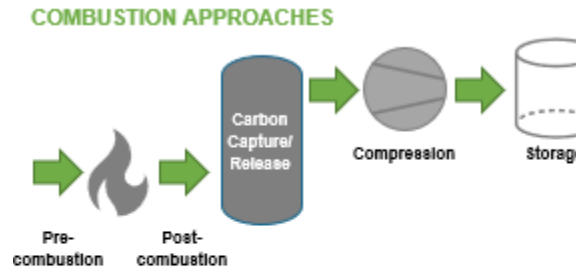
The Climate Crisis – The Scale of the Problem

- In 2021, over 36 billion tonnes of carbon dioxide (CO₂) were emitted to the atmosphere from fossil fuel use
- To limit temperature rise to 1.5°C, global greenhouse gas emissions need to be halved every decade, reaching carbon neutrality by 2050
- Despite the move towards low-carbon energy generation, hard to abate emissions are projected to account for up to 16 Gt of CO₂/year by 2050

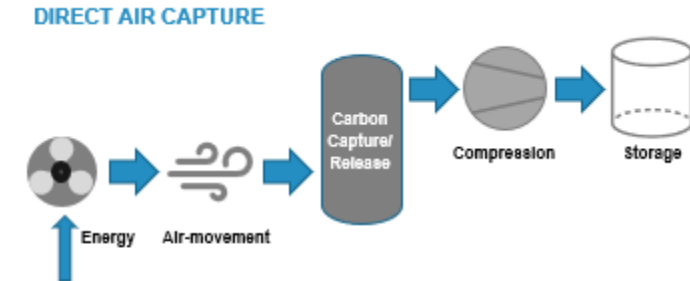


Carbon Capture, Utilisation and Storage (CCUS)

- The process of capturing CO₂, either from point sources or the atmosphere and sequestering it in such a way that it no longer contributes to climate change
- Broadly two types of CCUS:
 - Point source CCUS e.g. Post-Combustion CCUS
 - Direct Air Capture (DAC)
- Significant perceived techno-economic hurdles stand in the way of large-scale adoption of CCUS
- Unlikely that a single technology will solve the problem alone- “Death by a thousand cuts” approach needed



Traditionally carbon-containing fuels are burnt to generate power. The resultant CO₂-containing gas-streams are then passed through a carbon capturing technology, and the gas eventually released, compressed, and stored. Significant effort is being spent on replacing carbon-containing fuels with carbon-free alternatives



Renewable energy is spent to flow air over a carbon-capturing technology. This lower CO₂ concentrated gas-stream is then similarly compressed and stored ready for further use or sequestration.



Case Study – Post Combustion Carbon Capture

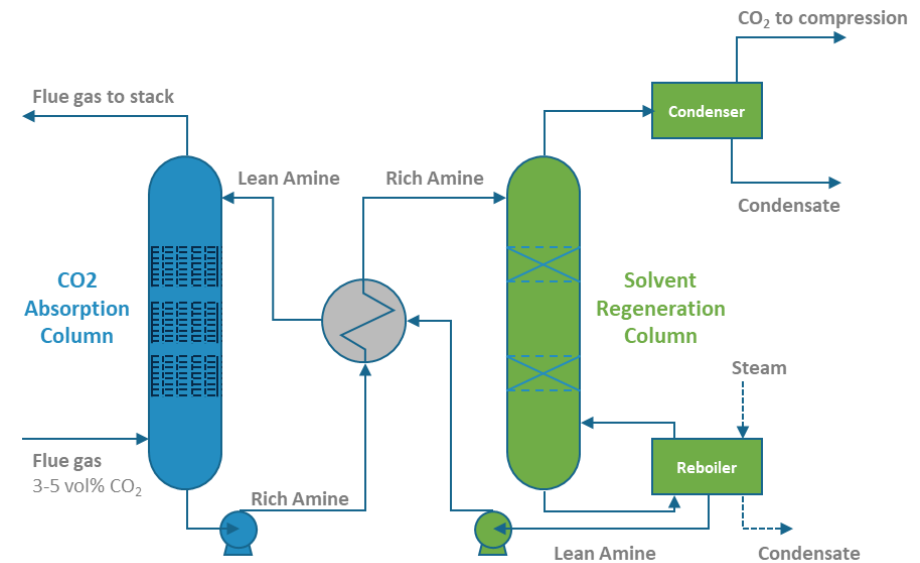
Application Specific Considerations for PCCC

- Aim to capture CO₂ from e.g. power station flue gas before it is released to the atmosphere
- CO₂ concentration in flue gas is quite high (5-15% mol% depending on fuel used)
- Flue gas contains water, nitrogen oxides (NO_x). Sulfur oxides (SO_x) and other contaminants (dust, ash) – all of which complicate any separation process due to competitive adsorption/poisoning
- Generally assumed that PCCC process will be retrofit onto existing plants – footprint considerations



The Incumbent Technology for PCCC - Amine Scrubbers

- Liquid phase amine (e.g. monoethanolamine, MEA) binds to CO_2 in flue gas; when heated, amine releases CO_2 through desorption and can be reused
- CO_2 binds strongly through chemisorption ~70-80 KJ/mol binding energy
 - High CO_2 uptake
 - Good selectivity
- Strong binding = energy intensive regeneration
 - ~5 GJ/ton of CO_2 captured energy penalty
 - ~30% of power generated required to regenerate amine
 - Waste aerosols generated (NOx)
- Reboiler and liquid condensers mean amine capture systems require a large footprint



The main drawback of amine scrubber technology is the high energy penalty for regeneration

Alternatives to Amine Scrubbers for PCCCS

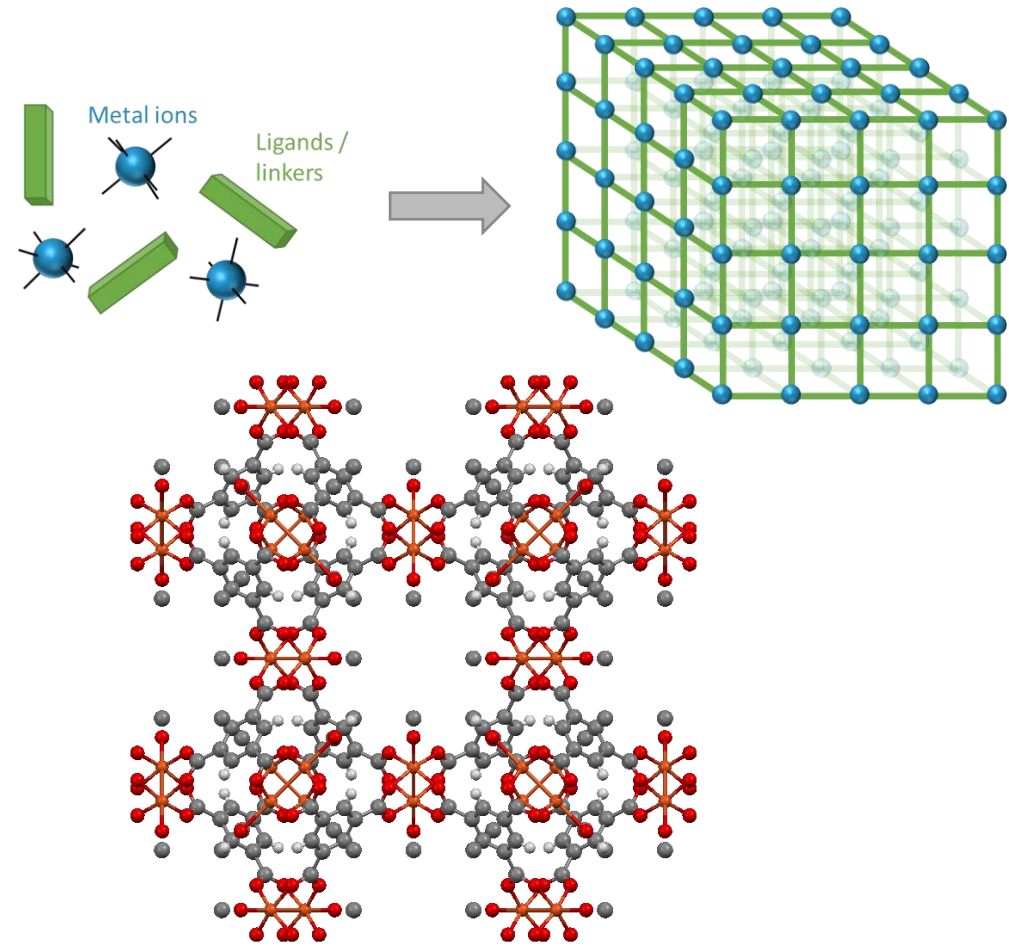
- Cryogenic Sorption
- Photocatalytic breakdown of CO₂
- Solid Sorbents
 - Zeolites
 - Activated Carbon
 - Silicas
 - Calcium Looping
 - Metal Organic Frameworks (MOFs)



MOFs are an exciting category of solid sorbent materials with huge potential for PCCC

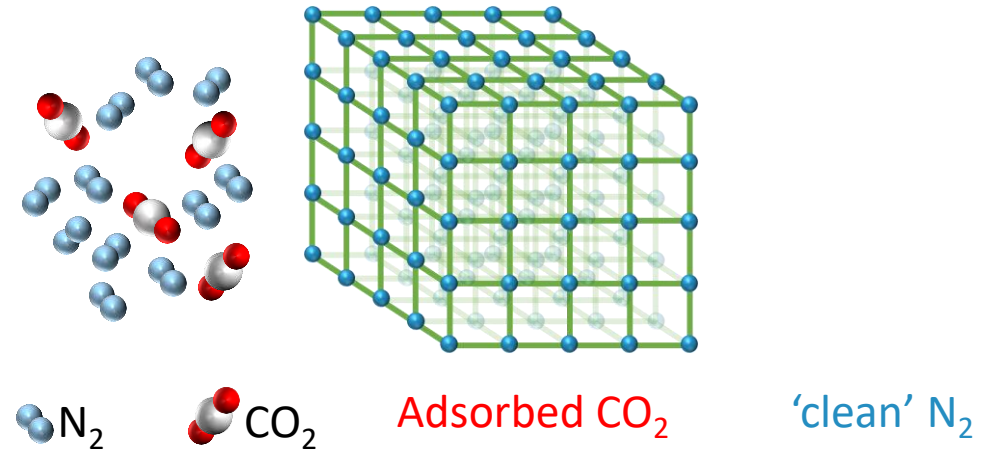
Metal Organic Frameworks – MOFs

- Multivalent metal clusters bonded to organic linkers in a regular crystalline array
- Choice of metals and linkers allows tuning of pore shape and size – over 90,000 MOFs reported so far
- Extremely porous structures with ultra-high surface areas
 - Up to 7,000m²/g
- Can tune pore size/internal chemistry to selectively trap (adsorb) certain chemical species



MOFs for CCUS

- High surface area and binding site densities lead to high CO₂ uptake capacities
- Comparable uptake capacity to amine solutions – up to 8 mmol/g @ 25°C, 1 bar
- By carefully tuning the pore environment to be a “perfect fit” for CO₂, selective physisorption can be achieved
- Physisorption binding energy << chemisorption binding energy
 - 30-40 KJ/mol
 - ~2 GJ/ton of CO₂ captured energy penalty

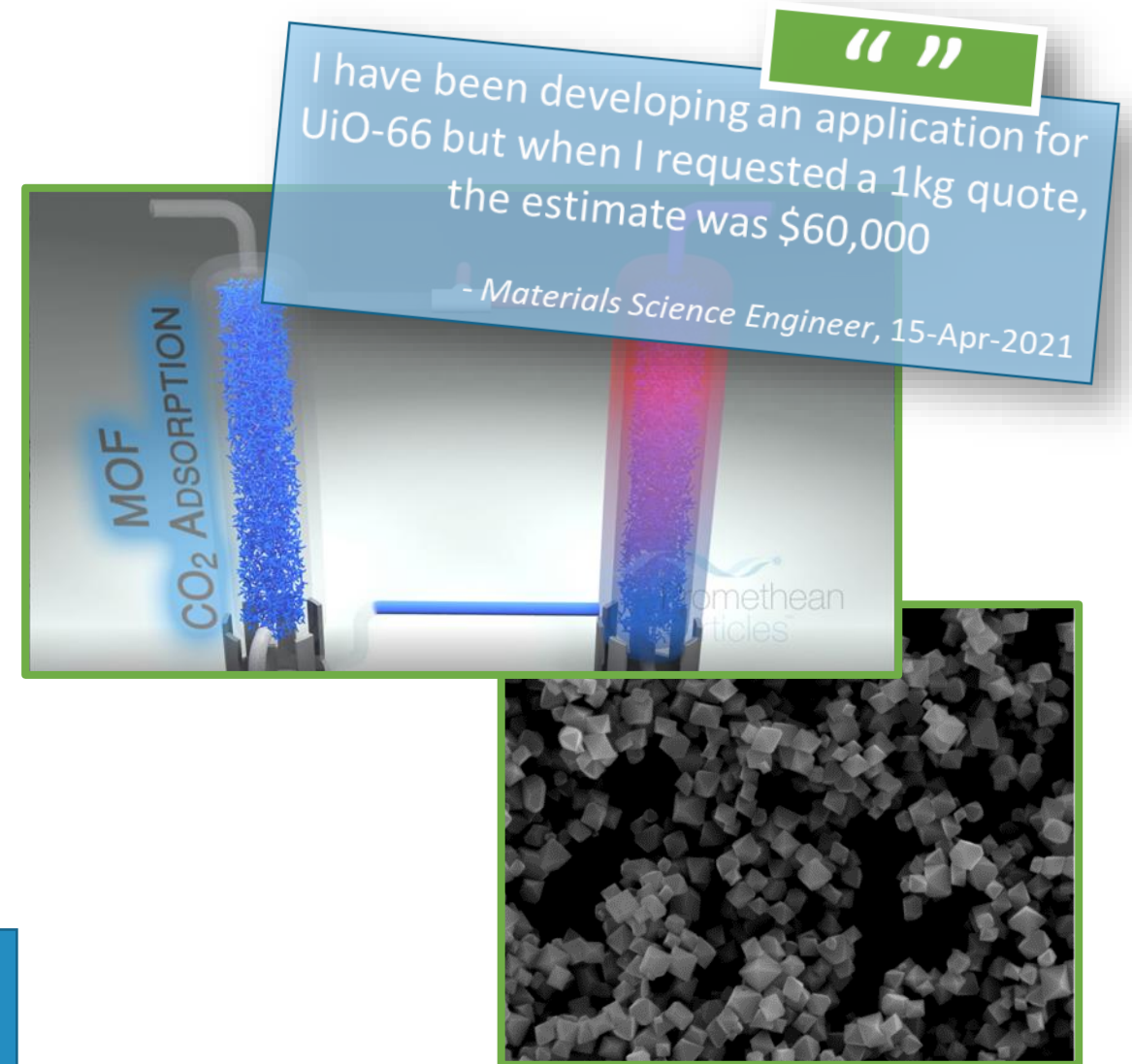


MOFs offer greatly reduced regeneration energy compared to amine scrubbers

Solving the Scale Problem

- MOFs traditionally manufactured by batch methods
 - Long reaction times (up to several days)
 - Limitations in production scale
 - Subsequent high production and material cost
- Resulting perception that MOFs are ‘academically interesting’ with little commercial viability
 - Perceived as low volume, prohibitively expensive despite excellent performance
- Continuous route to MOF manufacture drives scale and favourable economics
 - Immediate industrial scale capacity
 - Economies of scale significantly reduce cost
 - CO₂ capture costs of <£50/ton within reach

Promethean uniquely positioned to make MOFs a viable industrial carbon capture solution



Demonstrating MOFs for PCCC: PICASSO Project

- Pilot Scale Carbon Capture using Solid Sorbents
- Part-funded by UK Carbon Capture and Storage Research Centre
- Collaboration between Drax, University of Nottingham and Promethean – project currently underway
- Aim to demonstrate viability of MOFs for PCCCS
 - Advancing TRL from 3 to 5
 - Pilot scale production of MOFs
 - CO₂ capture from Drax's flue gas using MOFs
 - Assess purity of captured CO₂
 - Life Cycle Assessment
 - Cost Analysis (whole system, not just MOF material component)
- Success will validate MOFs as a feasible alternative to amine scrubbers
 - Create a persuasive case for power generators and construction, steel and chemical sectors which collectively represent ~40% of UK's CO₂ emissions
 - Open up development of capture systems for small-medium emitters



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Thank You! Any Questions?

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