

Process integration of metal-organic frameworks (MOFs): market-driven prototyping success

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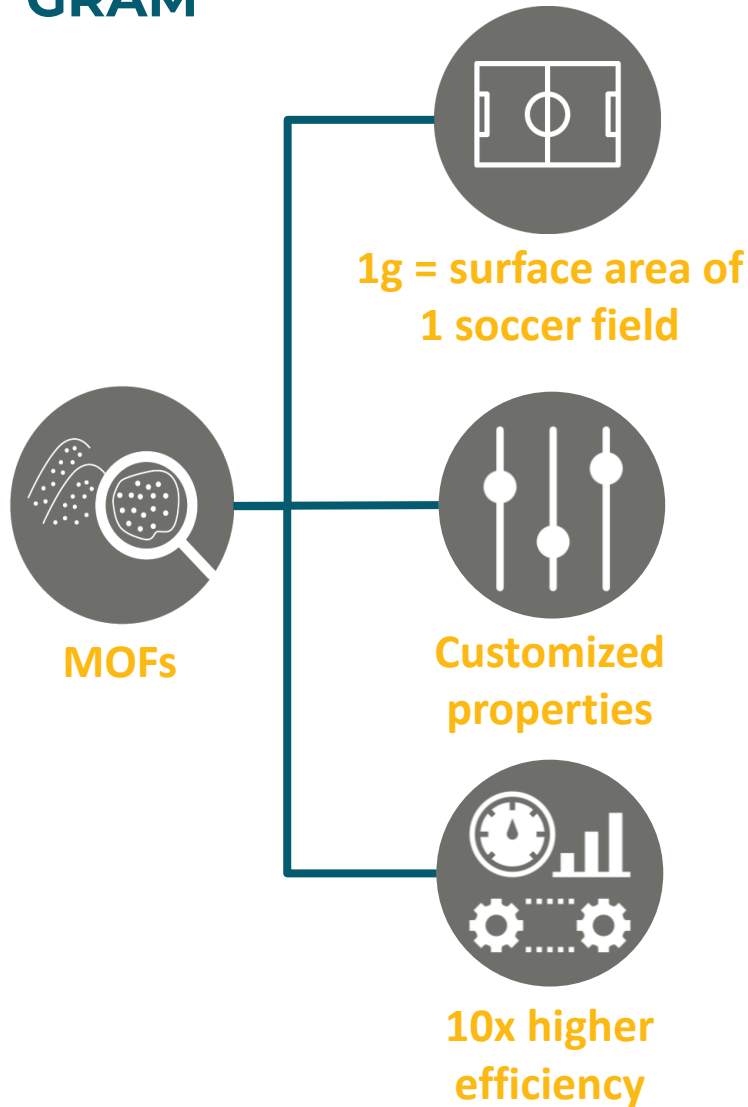
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WHAT ARE METAL-ORGANIC FRAMEWORKS (MOFS)?

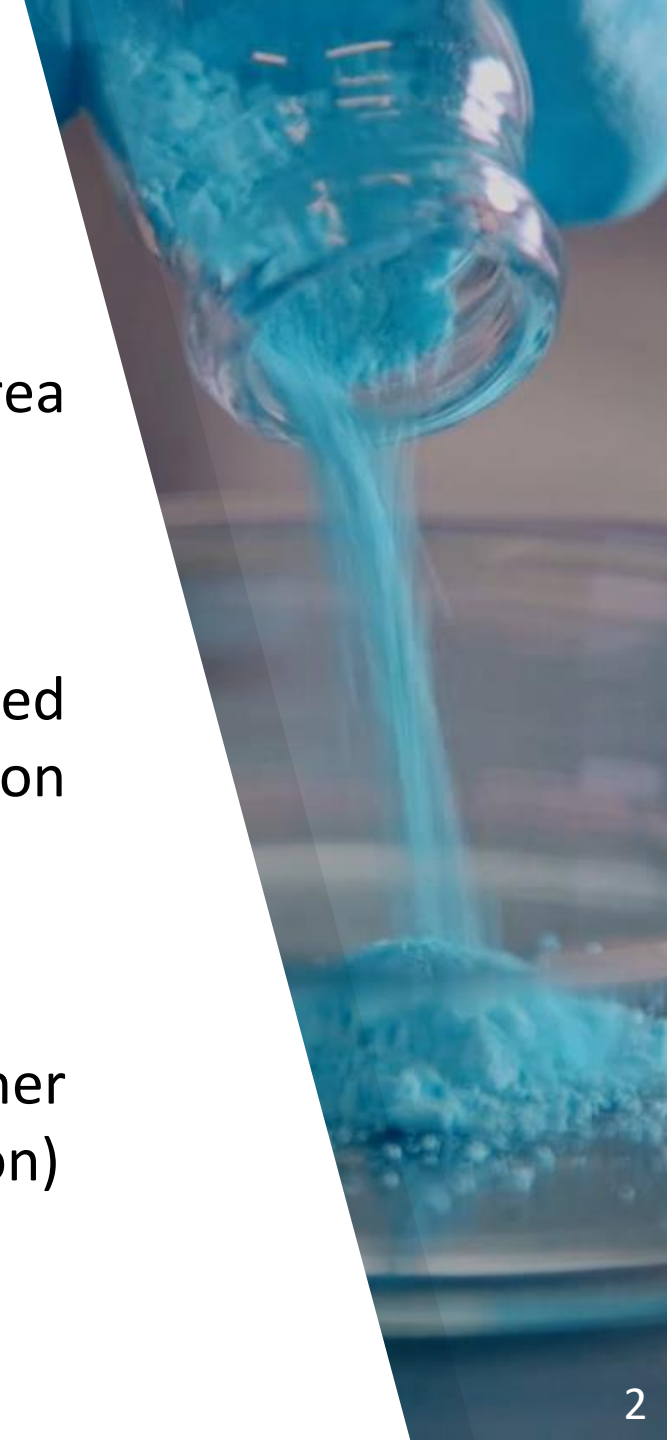
“NANO-SPONGES” WITH UP TO 10‘000 M2 SURFACE AREA PER GRAM



MOFs have the highest surface area ever known to mankind

Properties and behaviour can be tuned precisely to the industrial application due to its modularity

MOF outperform and replace other porous materials (e.g. activated carbon)



MOFS AND POROUS MATERIALS

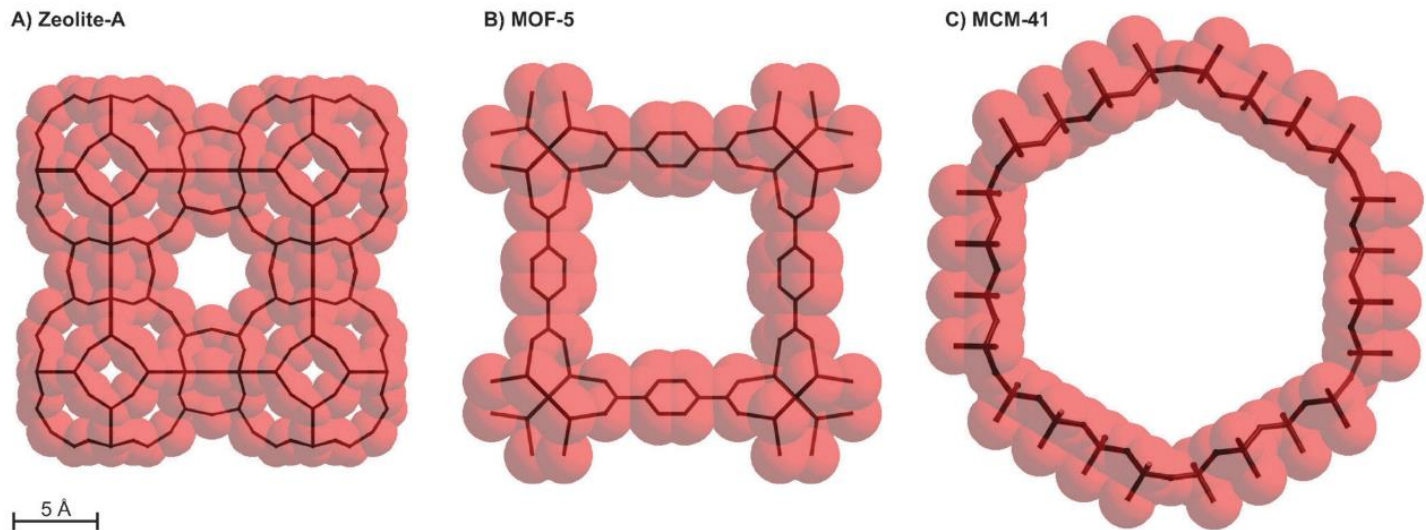


Fig. 3 Space-fill^a comparison between zeolite-A (A),^b MOF-5 (B),^b and an MCM-41 (C) with small pores.^{a,c} (^aCalculated with van der Waals radii. ^bStructure obtained from its single crystal X-ray data. ^cStructure obtained by simulating four silicon atoms per side of the hexagon.)

Table 1 Comparison between the structural, physical, and chemical properties of zeolites, mesoporous silica and alumina, and MOFs

	Zeolites	MOFs	Mesoporous silicates and aluminosilicates
Crystalline?	Yes	Yes	No
Homogeneous active sites?	Yes	Yes	No
Surface area	<600 m ² g ⁻¹	Up to 10 400 m ² g ⁻¹ ^a	<2000 m ² g ⁻¹
Cavity size	≤ca. 1 nm	Up to 4 nm ^a	≥ 2 nm
Diffusivity	Low	Low to high	High
Thermal stability	High	Low to medium ^b	Medium
Chemical stability	High	Variable	High
Chemical versatility	Low	High	Medium-low

^a Maximum value published at the moment of this publication. ^b Maximum value published at the moment of this publication: 540 °C.

MOFS ARE AT THE **TIPPING POINT** TO INDUSTRIALIZATION

“MOFs are the fastest growing class of materials in chemistry today.”

- Professor O. Yaghi, UC Berkeley, Nature 2015

Tipping Point

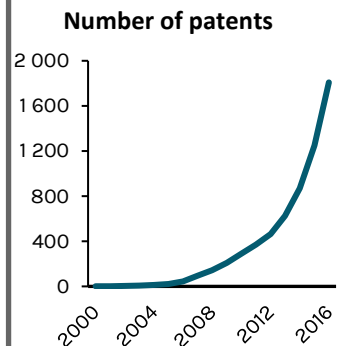
Young materials
in chemistry

Discovered in
the 1990's

100'000+
different MOF
materials
known

Over one
trillion possible

Exponential
increase of
interest in
**academia &
industry**



MOFs have already industrial applications

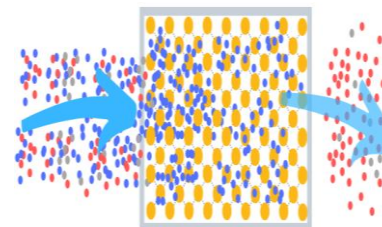
Water Harvesting
Drinking water from
thin air



Food Storage
Increasing storage
life to 9 months



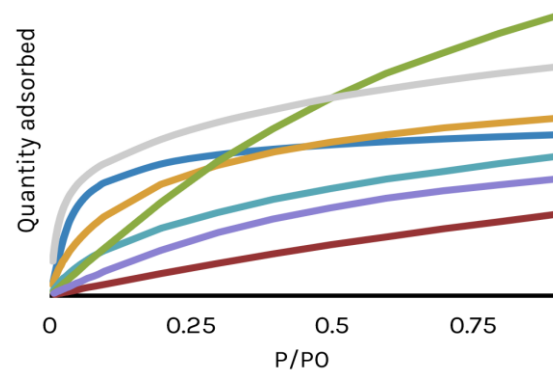
Carbon capture
Adsorbing harmful
gases such as CO₂



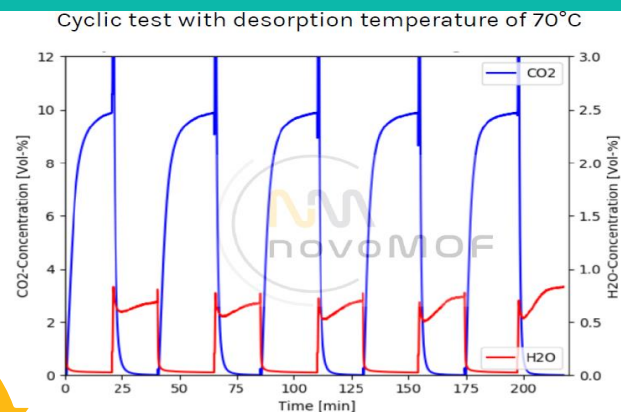
PROCESS INTEGRATION

Novel advanced materials require advanced integration

Material Selection



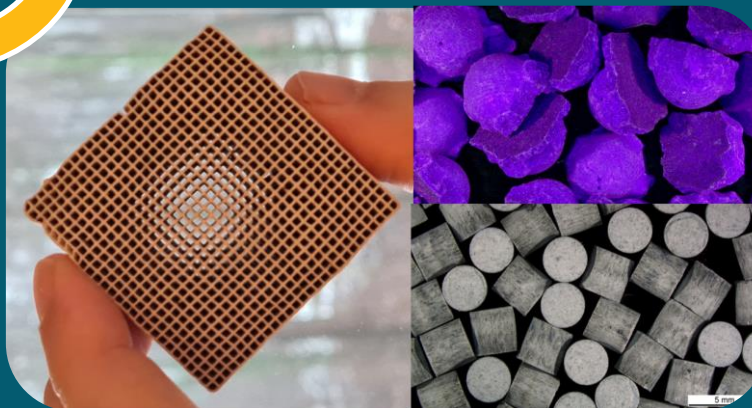
Process Conditions



Material Optimization



Shaping Optimization



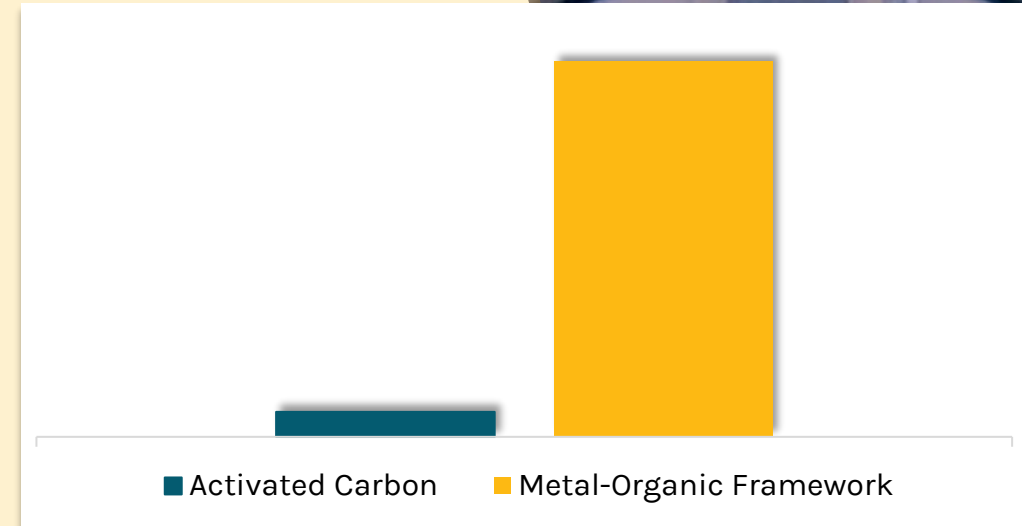
CASE STUDY: CO₂ ADSORPTION

CO₂ emissions is main driver of climate change

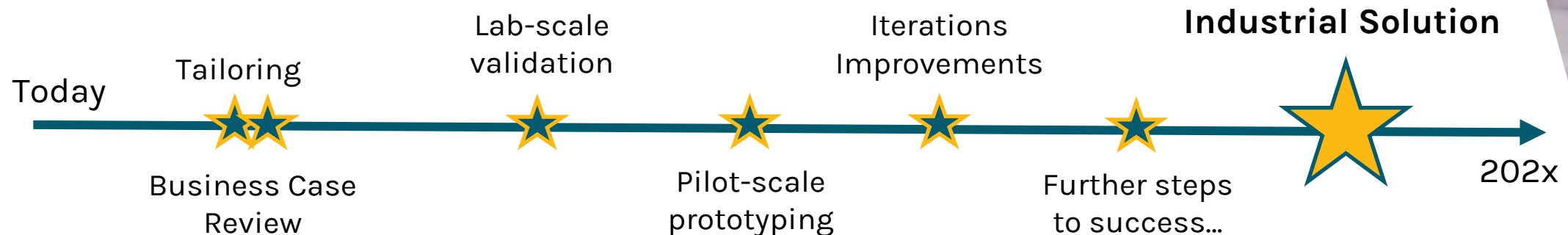
Exhaust gases contain humid CO₂ at concentration between 5-20 Vol.%

Physisorbents are promising alternatives to chemisorbents (amine scrubbing)

MOFs demonstrate 10x higher CO₂ uptake capabilities than activated carbon at 10 Vol.% CO₂



How do we integrate these advanced materials into a working device to realise this potential?



MATERIAL SELECTION

Selection of suitable material candidates for application



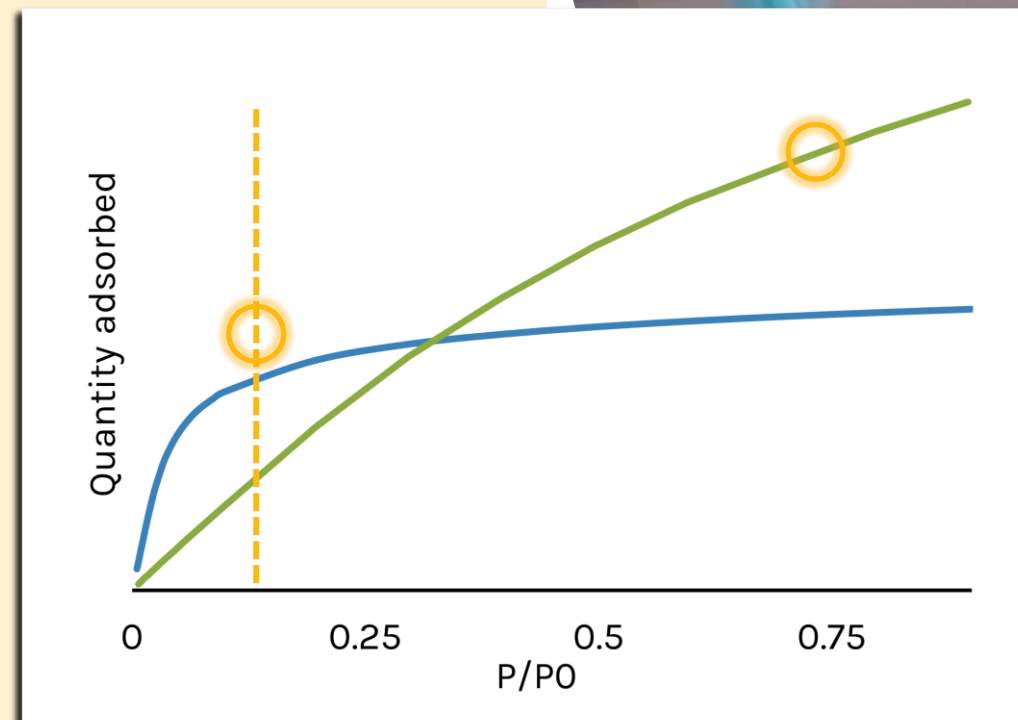
CO₂ adsorption at specified condition



Competitive CO₂ adsorption in presence of humidity



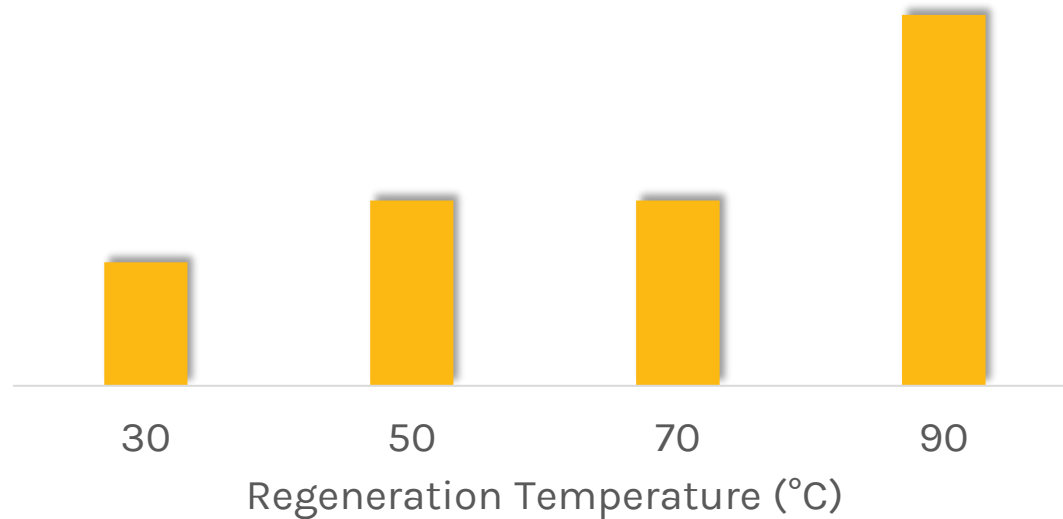
Easily and quickly regenerated at low temperatures – below 100 °C



PROCESS CONDITIONS

At lab scale, it was found that higher regeneration temperature improved CO₂ adsorption capacity over multiple cycles

Cyclic CO₂ capacity



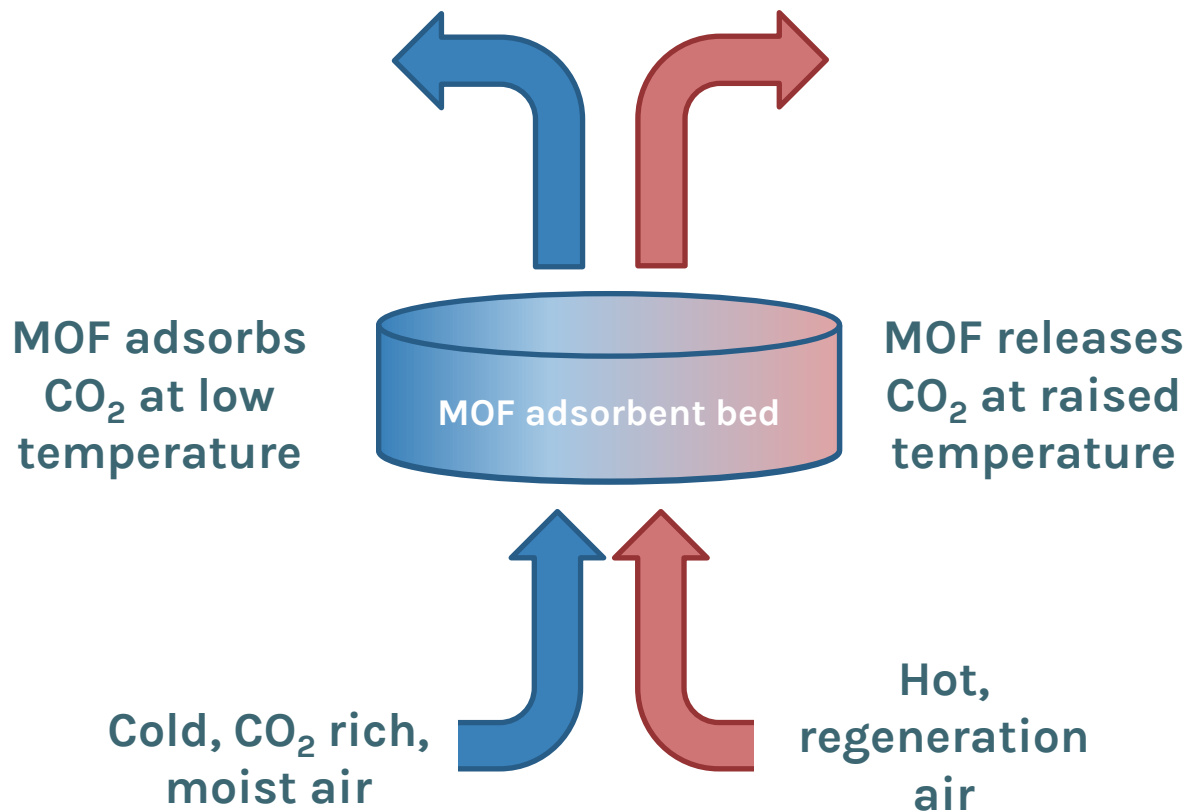
30, 50, 70 °C, material not fully regenerated

Adsorbed water accumulates over multiple cycles
– reduced CO₂ adsorption

90 °C Material fully regenerated – adsorbed water
and CO₂ fully removed

PROCESS CONDITIONS

At pilot scale, higher regeneration temperatures were shown to cause a problem



Takes time to heat and cool adsorbent bed

Higher regeneration temperatures increase cycle time

Overall reduction in productivity
(CO₂ removed / hour)

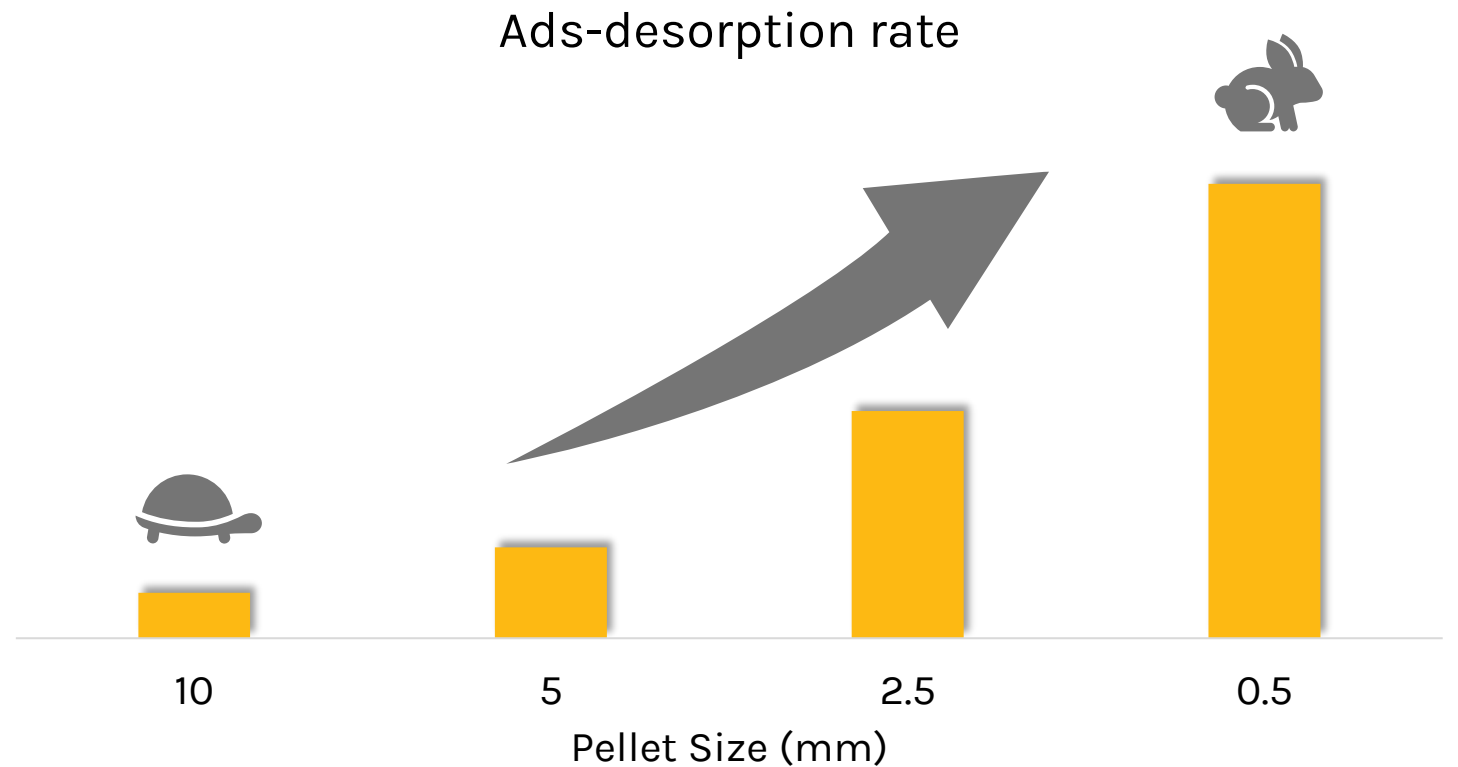
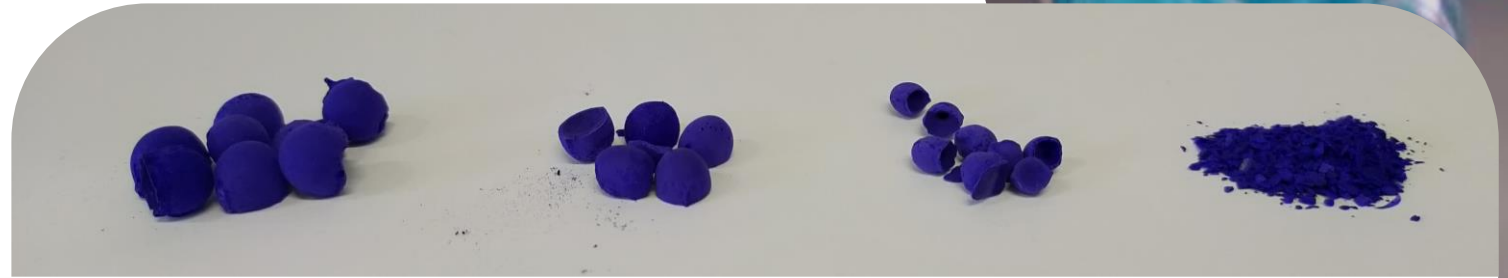
Lab scale process conditions need to
consider all stages of
adsorption/desorption cycle

SHAPING OPTIMIZATION

Size and shape of adsorbent beads affects kinetics of gas uptake

Shaping must also consider other parameters including:

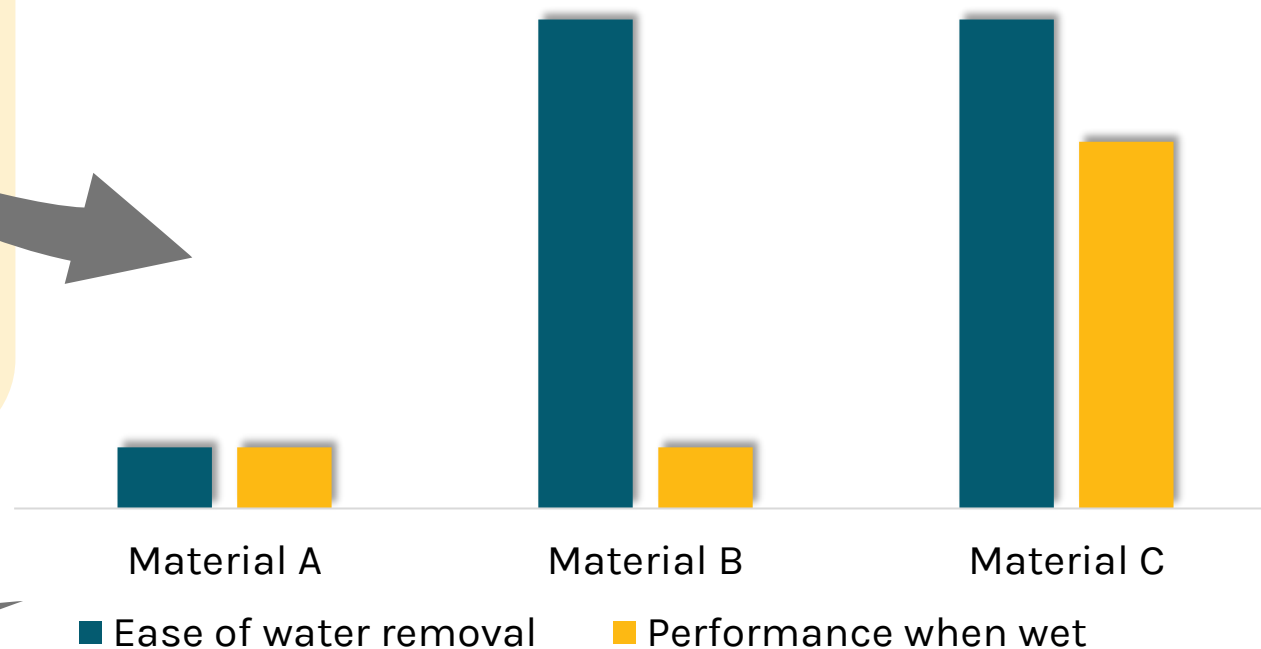
- Mechanical stability,
- Pressure drop,
- Fluid dynamics



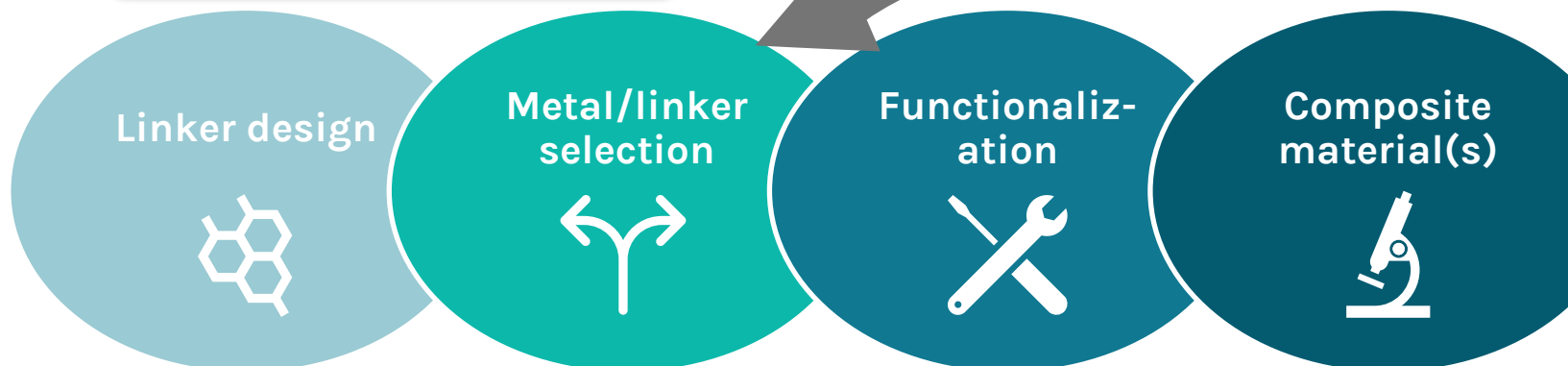
MATERIAL OPTIMIZATION

Can we optimize the material so that it is

- regenerated more easily
- performs better with humidity



How is this done?



Composite with advanced materials?

Graphene
Metal oxides
Polymers

TAKEAWAY MESSAGE



MOFs provide advantages compared to activated carbon and zeolites for CO₂ capture applications



MOFs are a tuneable material that can be optimized for specific processes



Process integration is required to make the most of these materials



This approach is required for, and can even be facilitated by, other advanced materials



1

SELECTION



Your business challenges drive us in the identification of the right MOFs.

2

SYNTHESIS



You receive synthesized MOFs at the highest quality.

You can test them for your application.

3

OPTIMIZATION



You benefit from support in optimizing the performance of your process.

4

PRODUCTION



You leverage your commercial application with us, your trusted supply partner.

We scale production according to your needs from grams to tons.

Let's engineer your MOF success together!



DRIVING **SUCCESS** THROUGH MOF INNOVATION AT EXHIBITION BOOTH 18-720



Serge Niederkorn
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MSc ETH Mechanical
Engineering



Cristina Lendvai
Marketing Manager
MSc in Business
Administration



Wilhelm Steitz
CFO
Dipl.-Eng. Mechanical
Engineering



Daniel Steitz
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MSc ETH in Chemical
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Dr. Charles Toft
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Dr. sc. Chemistry



Dr. Anna Chomiak
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