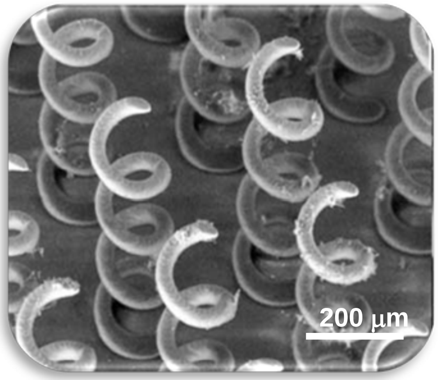
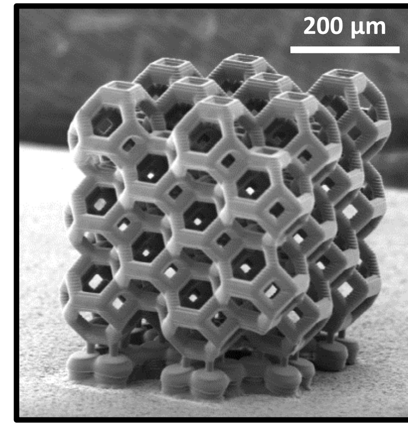
Advanced Manufacturing To Enable New Solvents and Processes For Carbon Capture

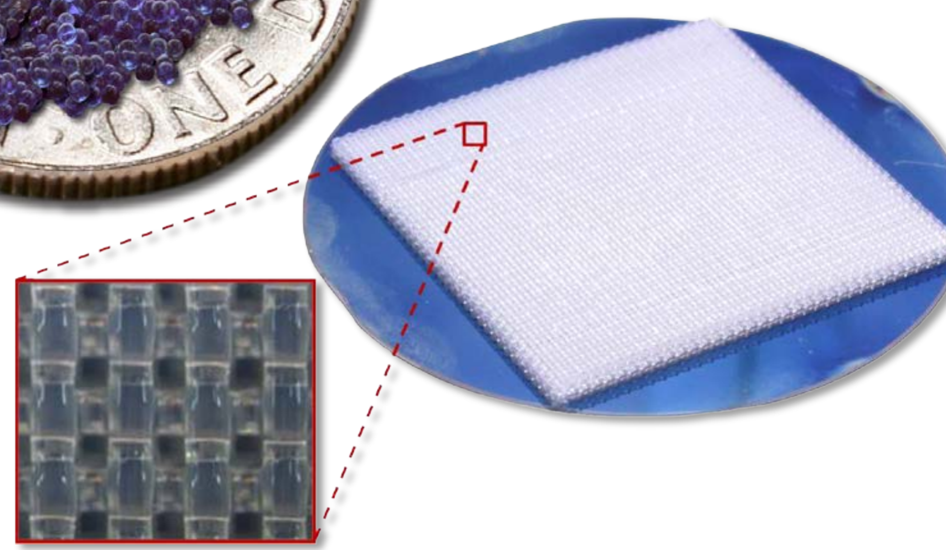
August 10, 2016

NETL CO_2 Capture Technology Meeting

Joshuah K. Stolaroff







Lawrence Livermore National Laboratory

Carnegie Mellon University

HARVARD UNIVERSITY

LLNL-PRES-555917

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New fabrication techniques can enable new materials and processes to achieve low-cost carbon capture.

Designer solvents and sorbents + Advanced Manufacturing

↓

Energy efficiency + Process innovation

↓

Transformational Carbon Capture

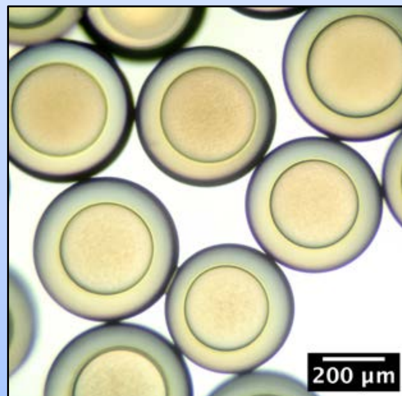
FEW0194: Advanced Manufacturing To Enable Enhanced Processes And New Solvents For Carbon Capture

$4.15M over 3 years (April 15, 2015 – April 14, 2018)

Tasks

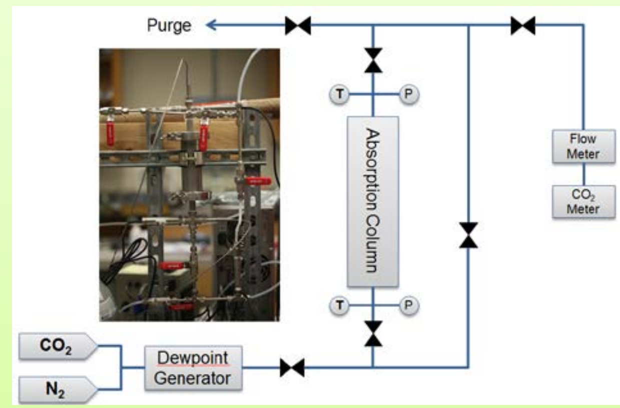
Encapsulation of Advanced Solvents

$475k/yr



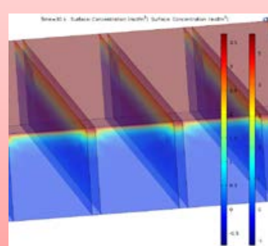
Process design and scaleup with microcapsules

$475k/yr



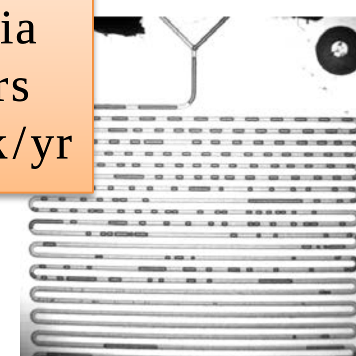
CO_2 absorber design with advanced manufacturing

$250k/yr



Rapid determination of solvent properties via microfluidic reactors

$133k/yr



Project Team

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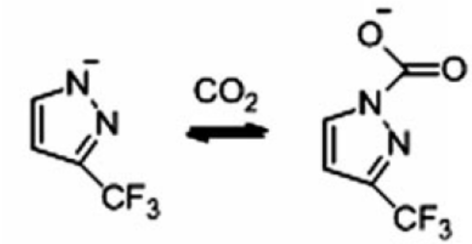
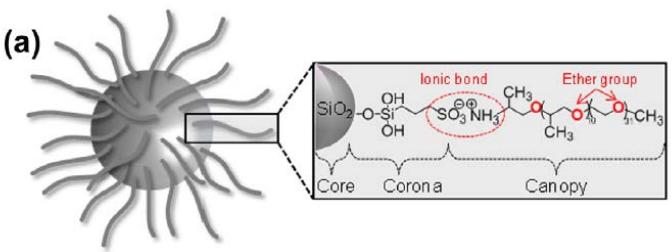
Some solvents with potential for 30—50% energy savings and specific challenges:

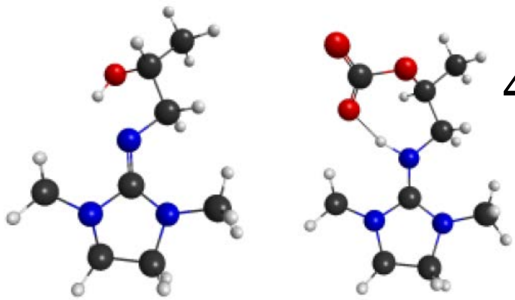
1. **Sodium carbonate** solution: slow CO_2 absorption, precipitates solids.



2. **Ionic Liquids**: water intolerance, precipitate solids (PCIL's)

3. **NOHMs**: high viscosity, slow CO_2 absorption.



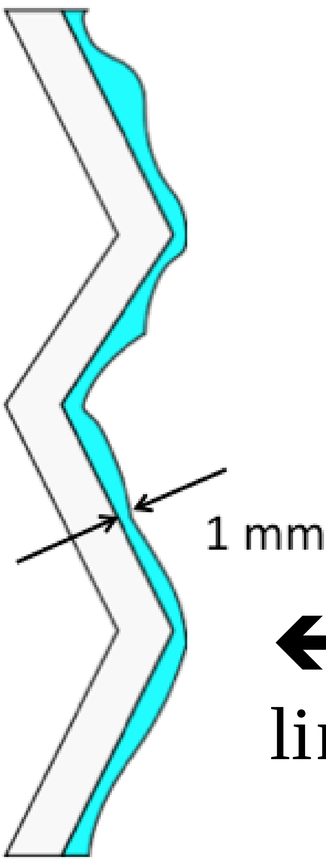


4. **CO_2BOLs**: poor heat transfer rates (high viscosity).

Can packed towers be improved?

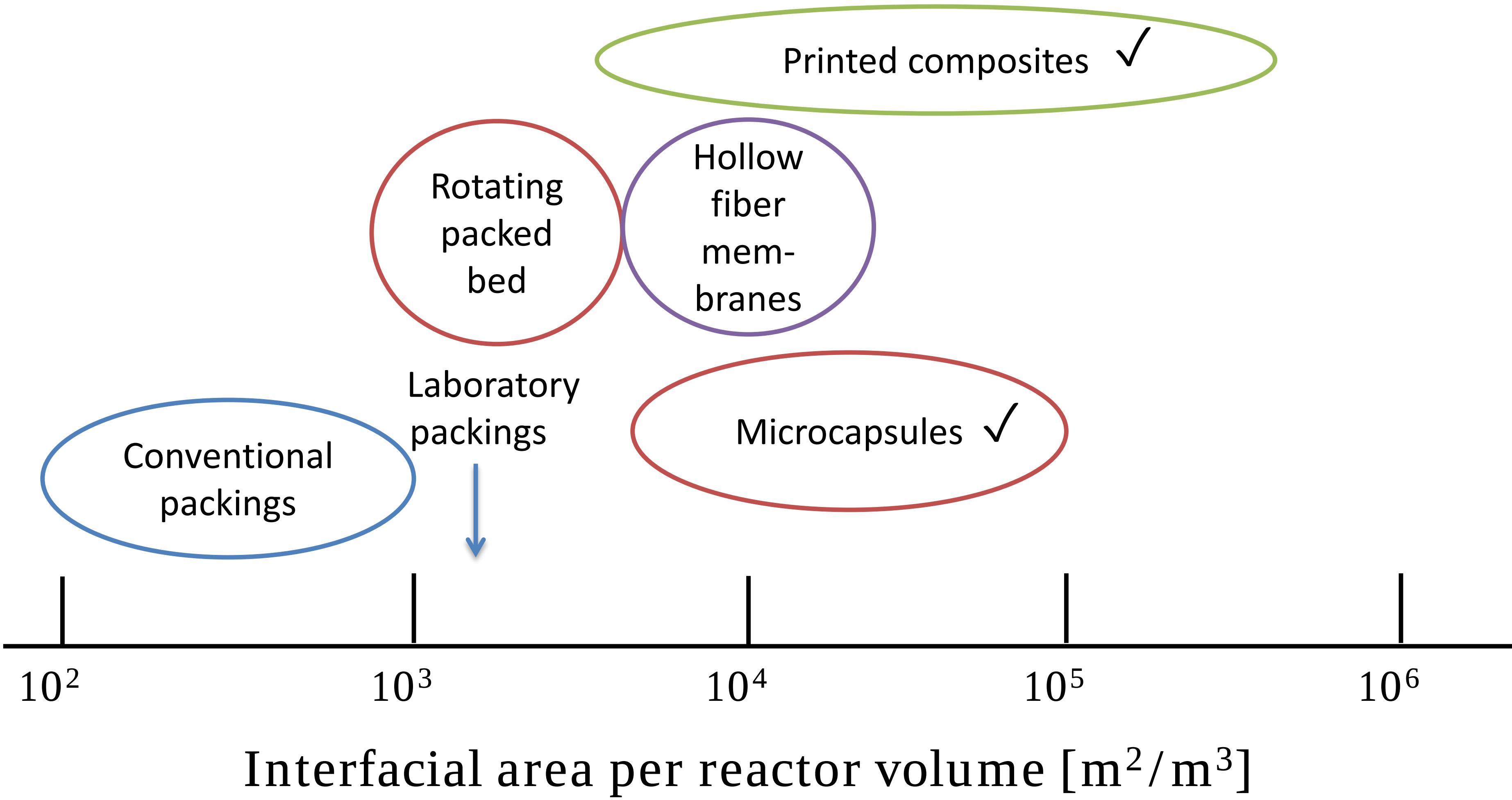
Raschig rings:
"Since 1894"

Structured packing:
"A little better"



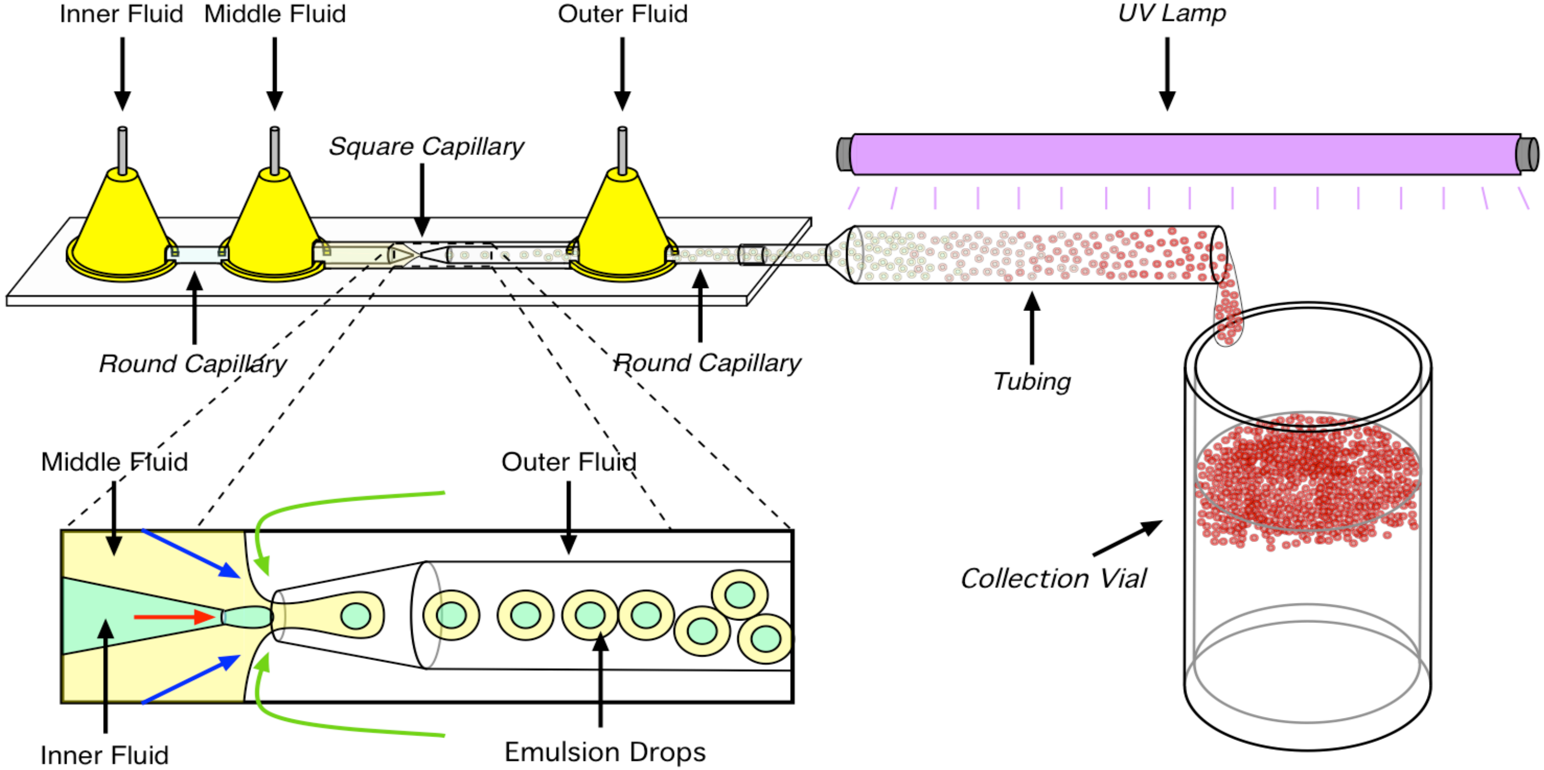
🡐Process intensification limited by film thickness
... and fabrication technology?

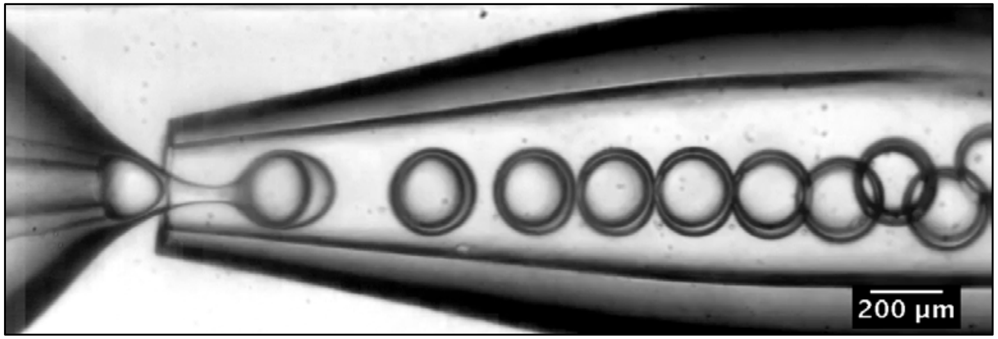
Additional surface area can be formed by permeable solids.

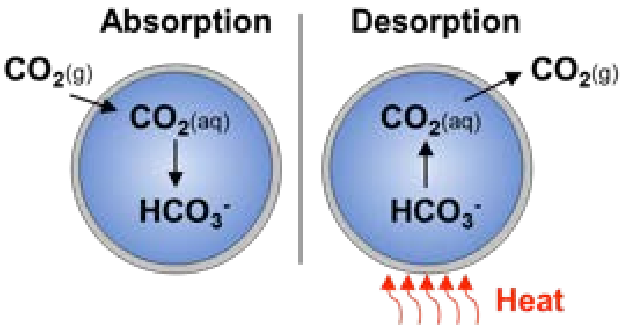


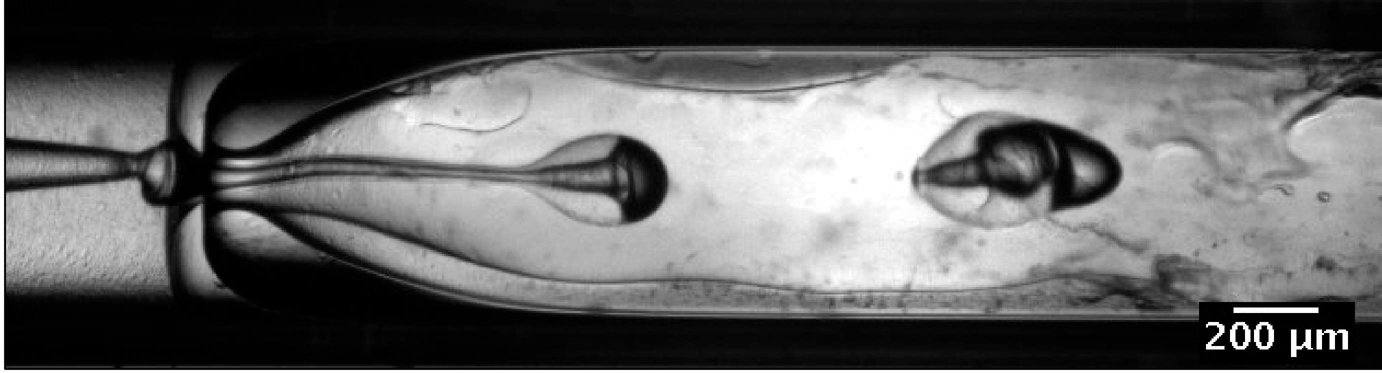
✓ Also tolerates phase changes!

Microencapsulation: an enabling technology for CO_2 solvents.









Major challenges for encapsulation:

- Shell material-solvent compatibility
- Microfluidic-solvent compatibility
- Production scale-up
- Process design and evaluation

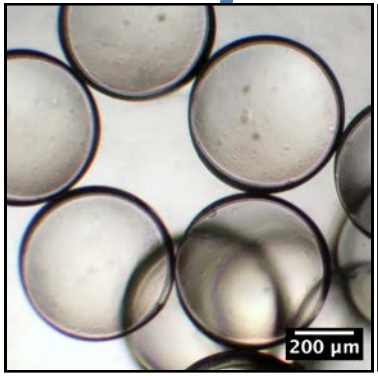
We now have four permeable shell materials (two formulated in-house).

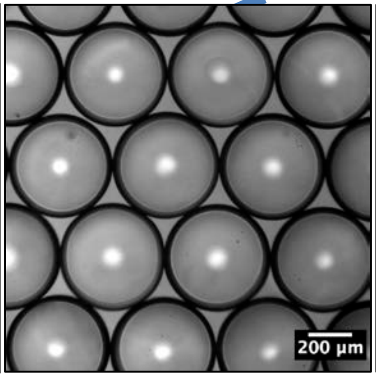
Name	Manufac-turer	Material	Permea-bility (barrer)	Amine Compati-bility	Mecha-nical Properties	Curing Time
Semicosil 949	Wacker	Silicone	3100	No	Elastic, strong, tacky	30 mins
Thiol-ene	LLNL	Silicone	2700	Yes	Elastic, strong, tacky	30 secs
SiTRIS (80:20)	LLNL	Acrylic	400	After curing	Stiff, strong, untacky	10 secs
Tego Rad 2650	Evonik	Silicone	3200	After curing	Elastic, friable, untacky	10 secs

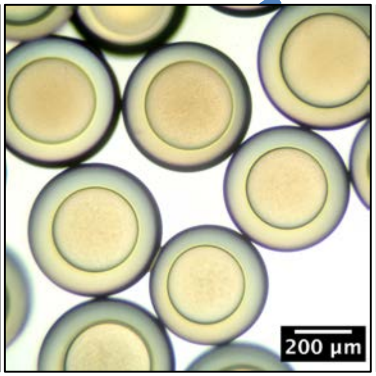
Extensive screening indicates viable candidates for encapsulation.

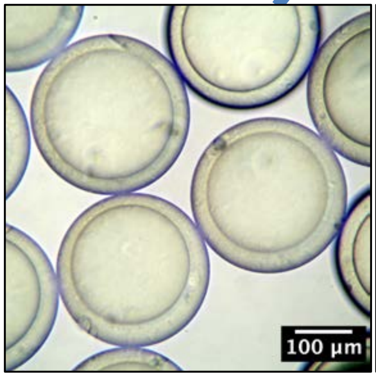
Good properties for encapsulation	Marginal properties for encapsulation	Not compatible

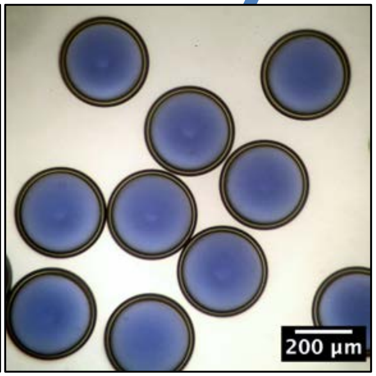
	Koech-anol	Koech-anol w/ 1:1 wt. water	DBU/Hex-anol 1:1	NDIL 0274	NDIL 0252	NDIL 0231	NDIL 0231 w/ 1:1 wt. water	NDIL 0230	NDIL 0230 w/ 1:1 wt. water	NDIL 0309 (solid)	NDIL 0309 w/ 1:1 wt. water	Carbon-ate w/ water
Semi-cosil							X		X			√
Thiol-ene		√									√	√
Si-TRIS							√		√ w/ 1:3			√
T.R. 2650		√ (un-stable)										√

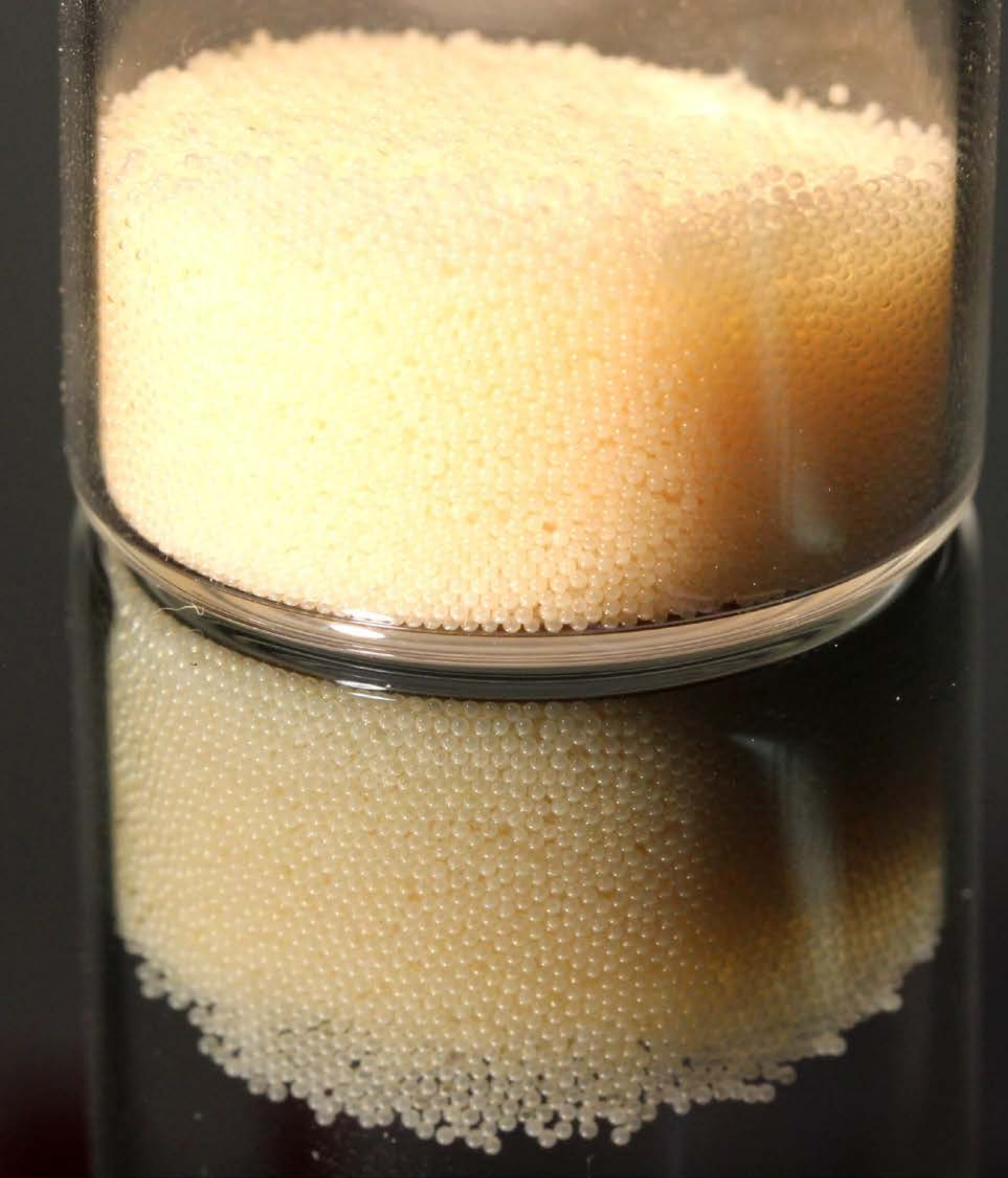




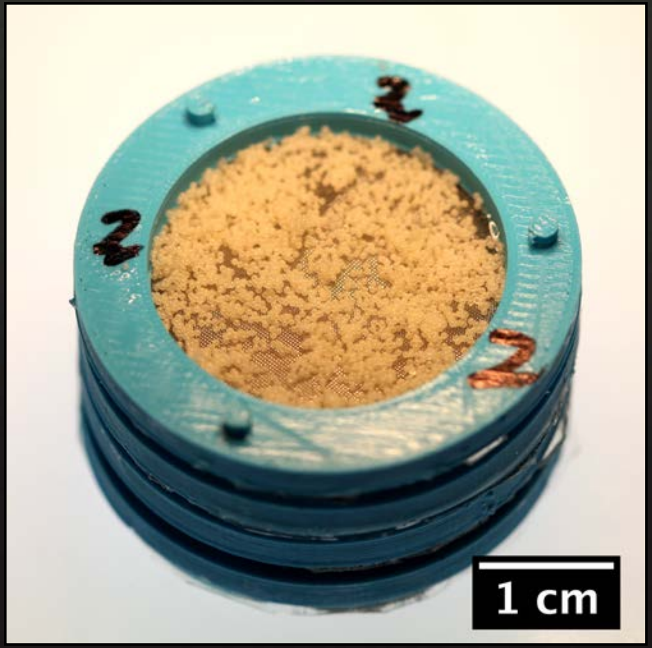




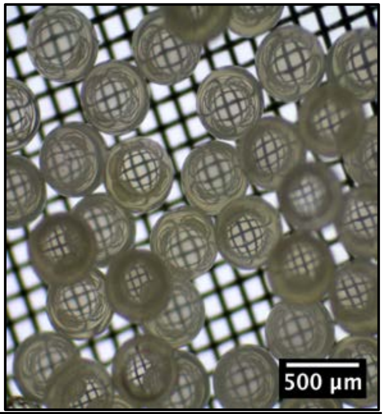


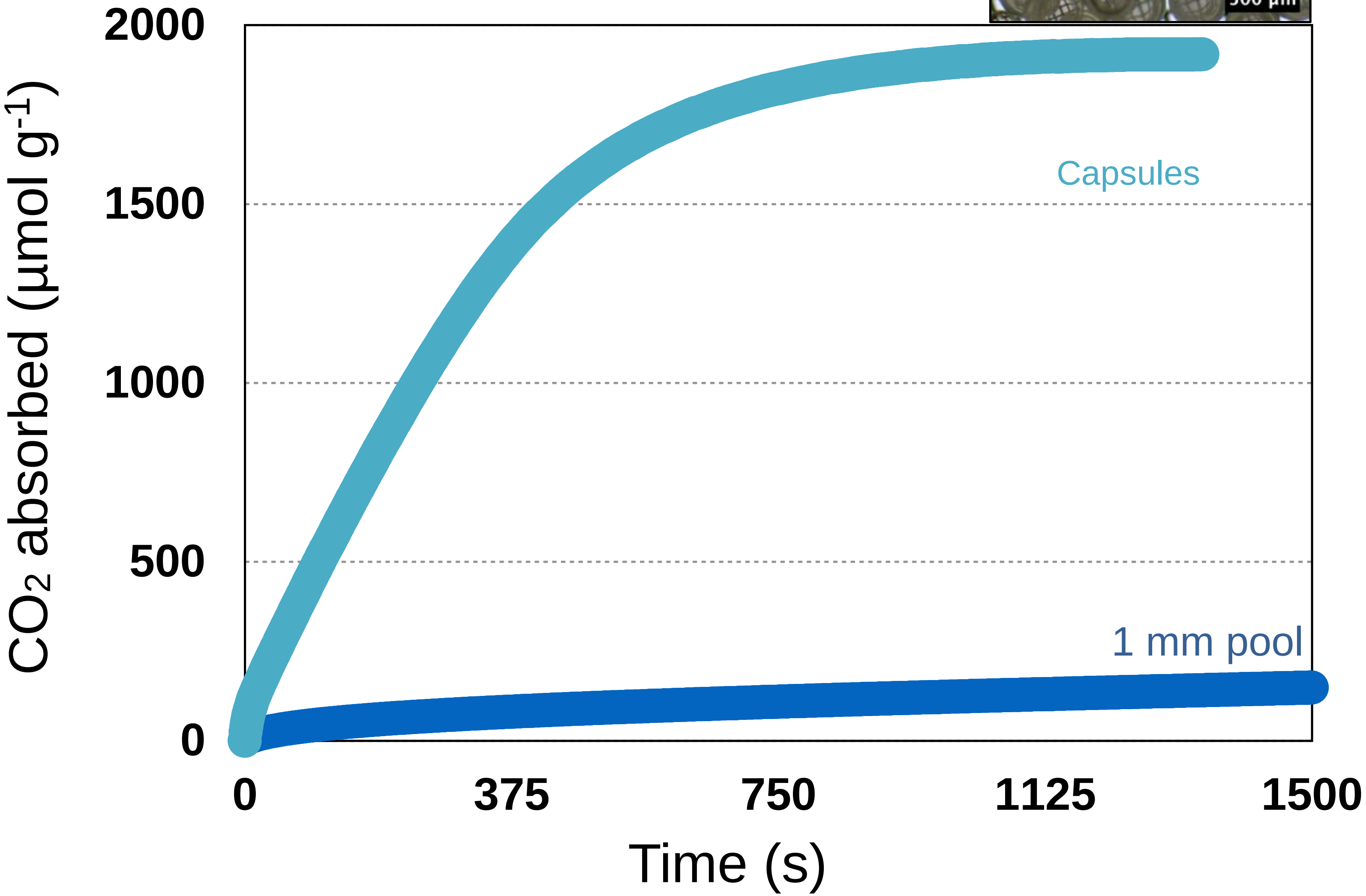


IL-SiTRIS capsules dried and tested for CO_2 absorption

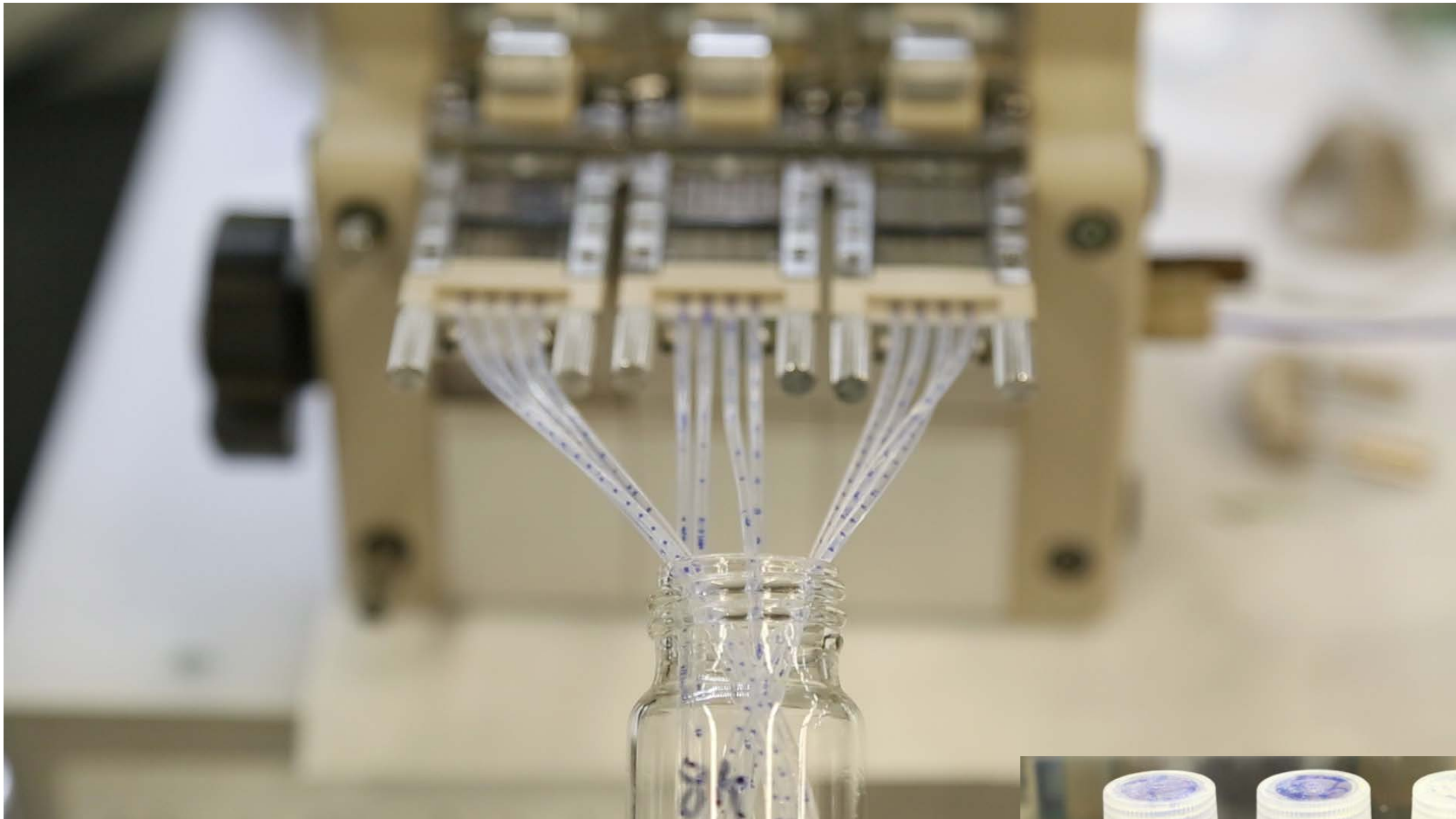


Enhanced absorption rate compared to liquid film is confirmed.





Microcapsule production scaled up by parallelization.

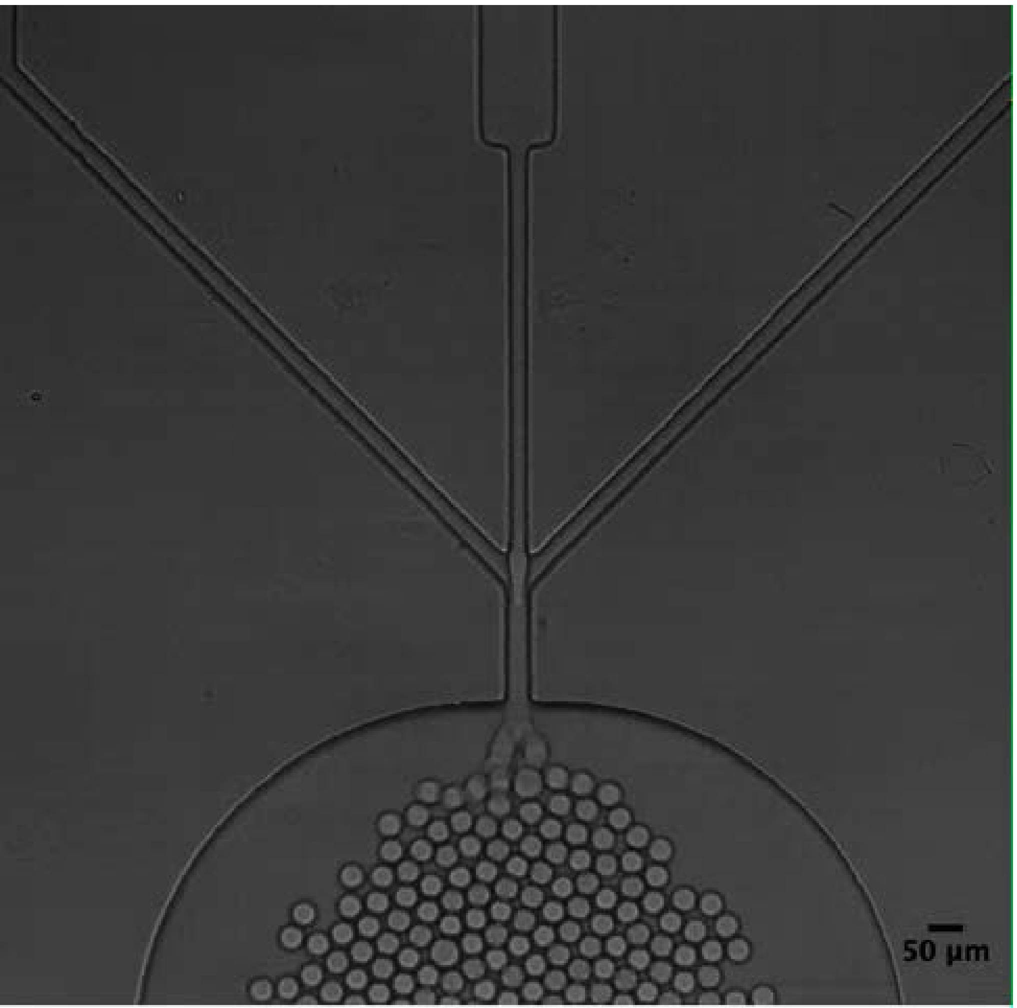


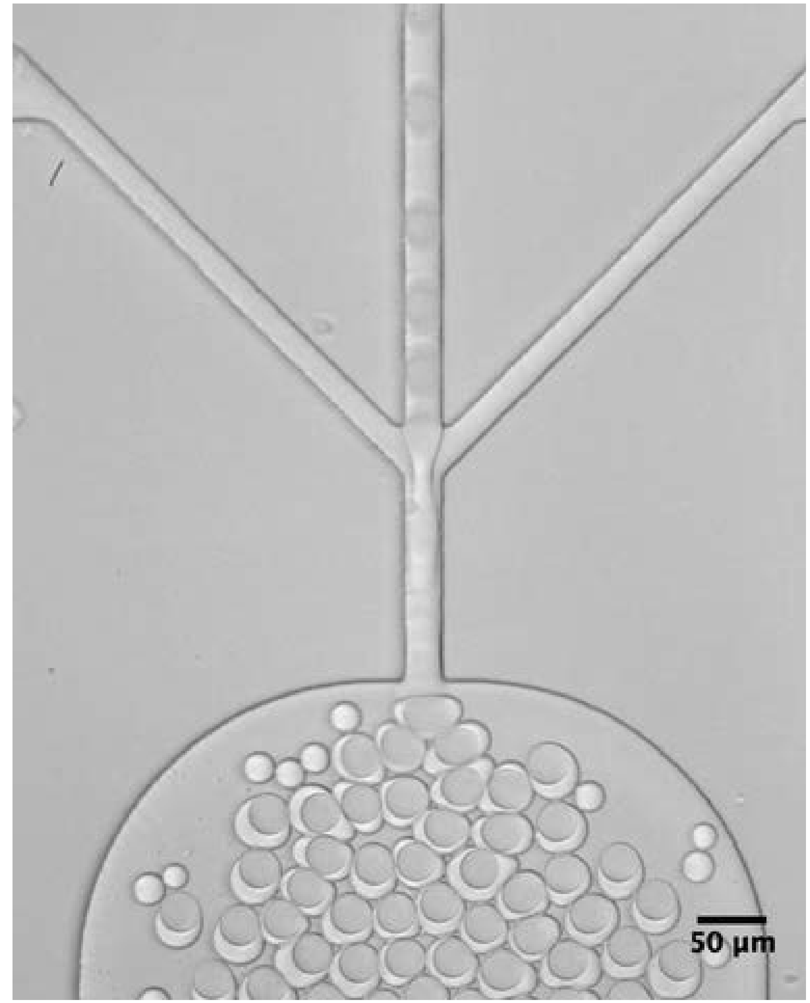
→ 500 g/day

Alternative scale-up technique: 2-part production

Device 1 - hydrophobic

Device 2 - hydrophilic





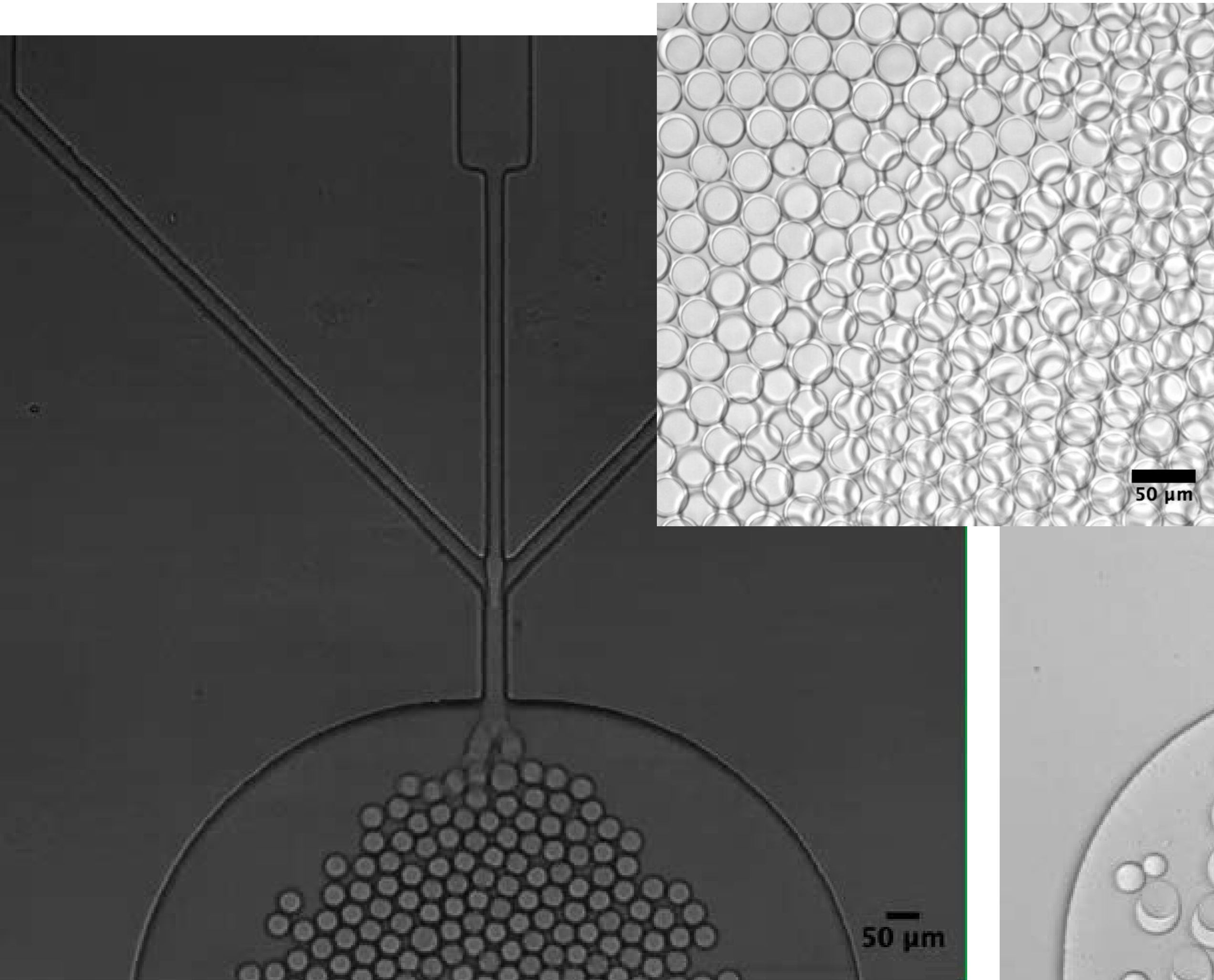
Inner phase: DI water 500 ul/h
Outer phase: HFE 7500 w/ 1 wt.% Krytox

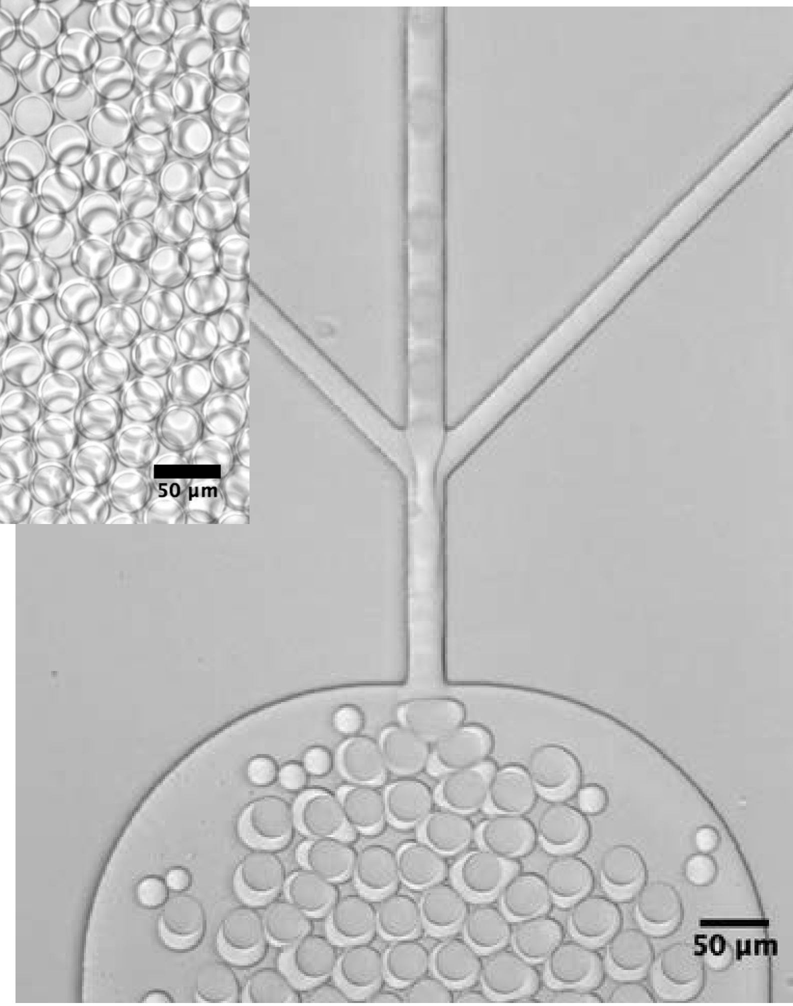
Inner phase: DI water 500 ul/h
Middle phase: HFE 7500 w/ 1 wt.% Krytox 500 ulh
Outer phase: DI water w/ 1 wt.% Triton-X100 1000 ulh

Alternative scale-up technique: 2-part production

Device 1 - hydrophobic

Device 2 - hydrophilic





Inner phase: DI water 500 ul/h
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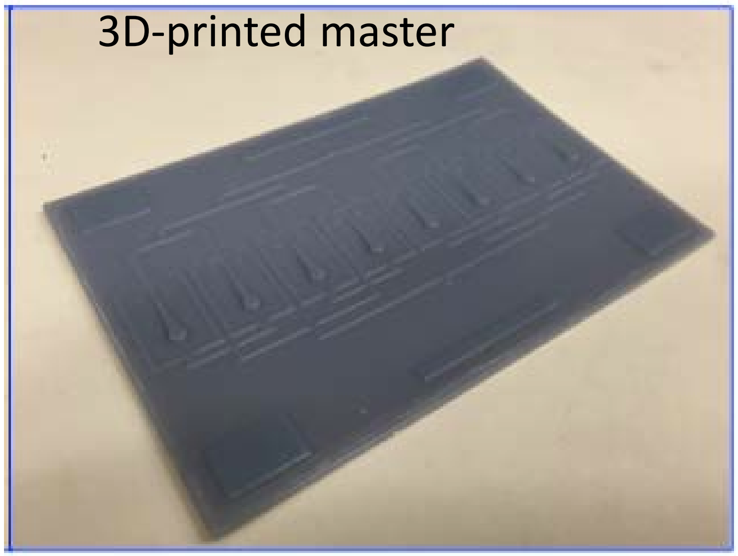
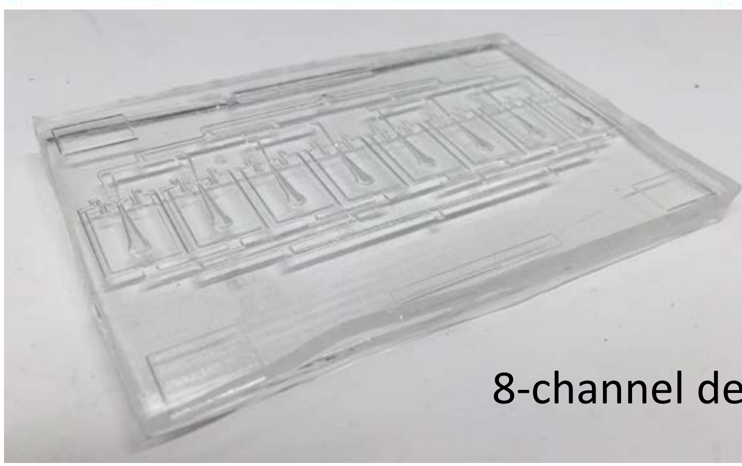
Outer phase: DI water w/ 1 wt.% Triton-X100 1000 ulh

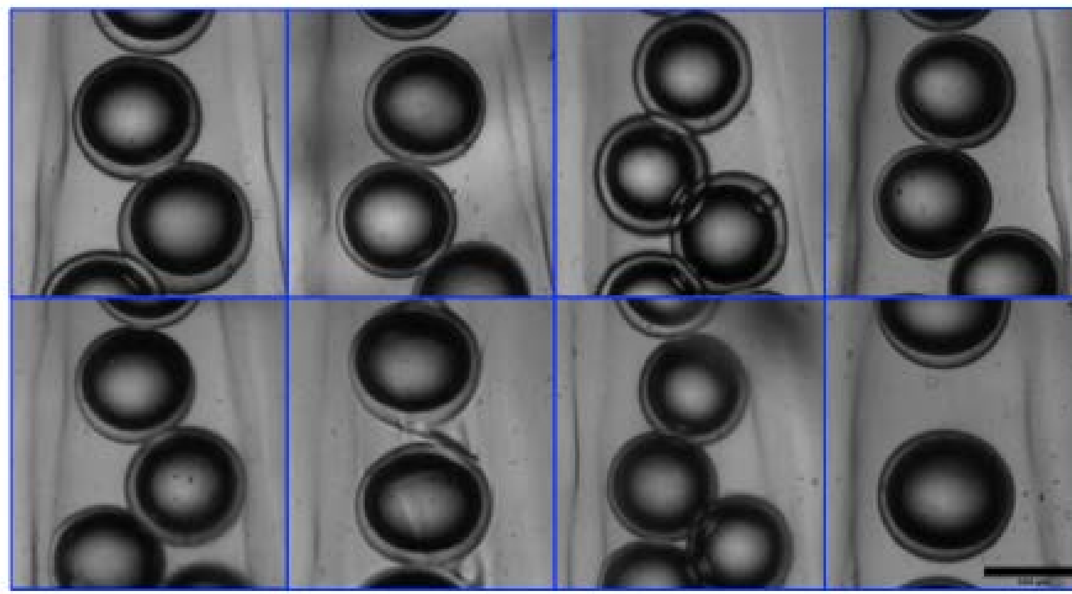
We used 3D printing to rapidly prototype microfluidic devices

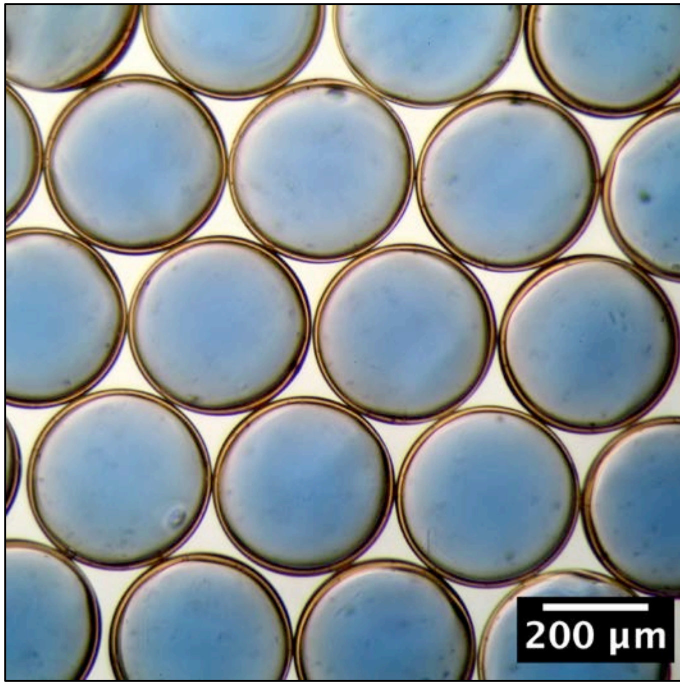


3D-printed master

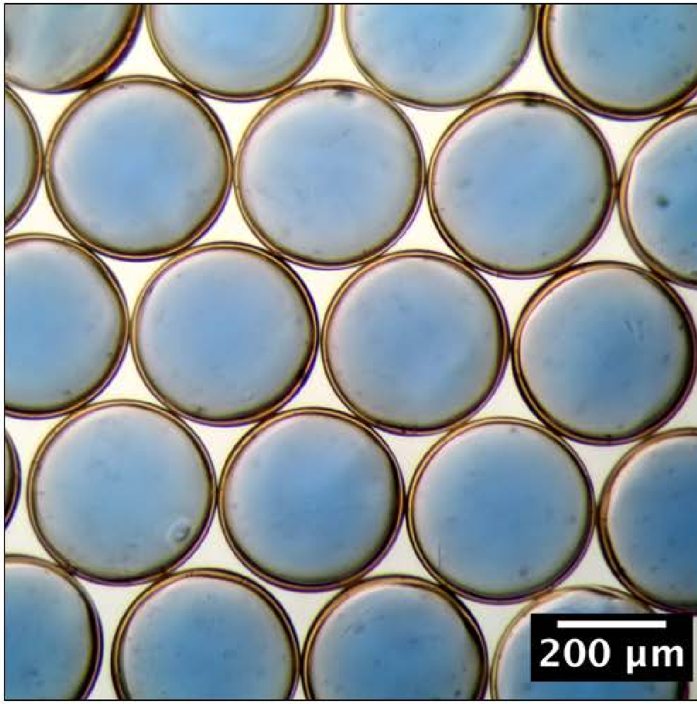


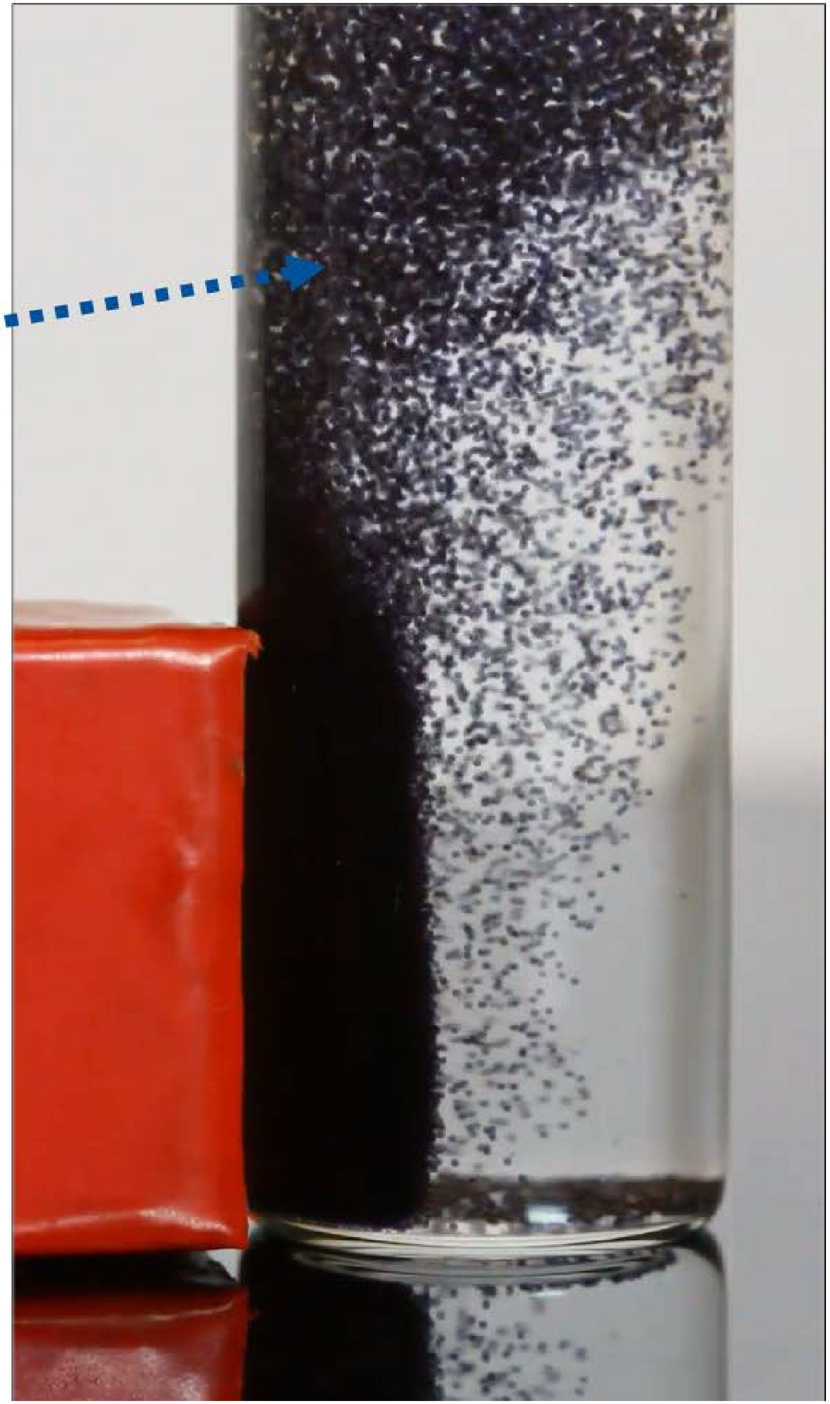
8-channel device in PDMS





Capsules doped with magnetic nanoparticles

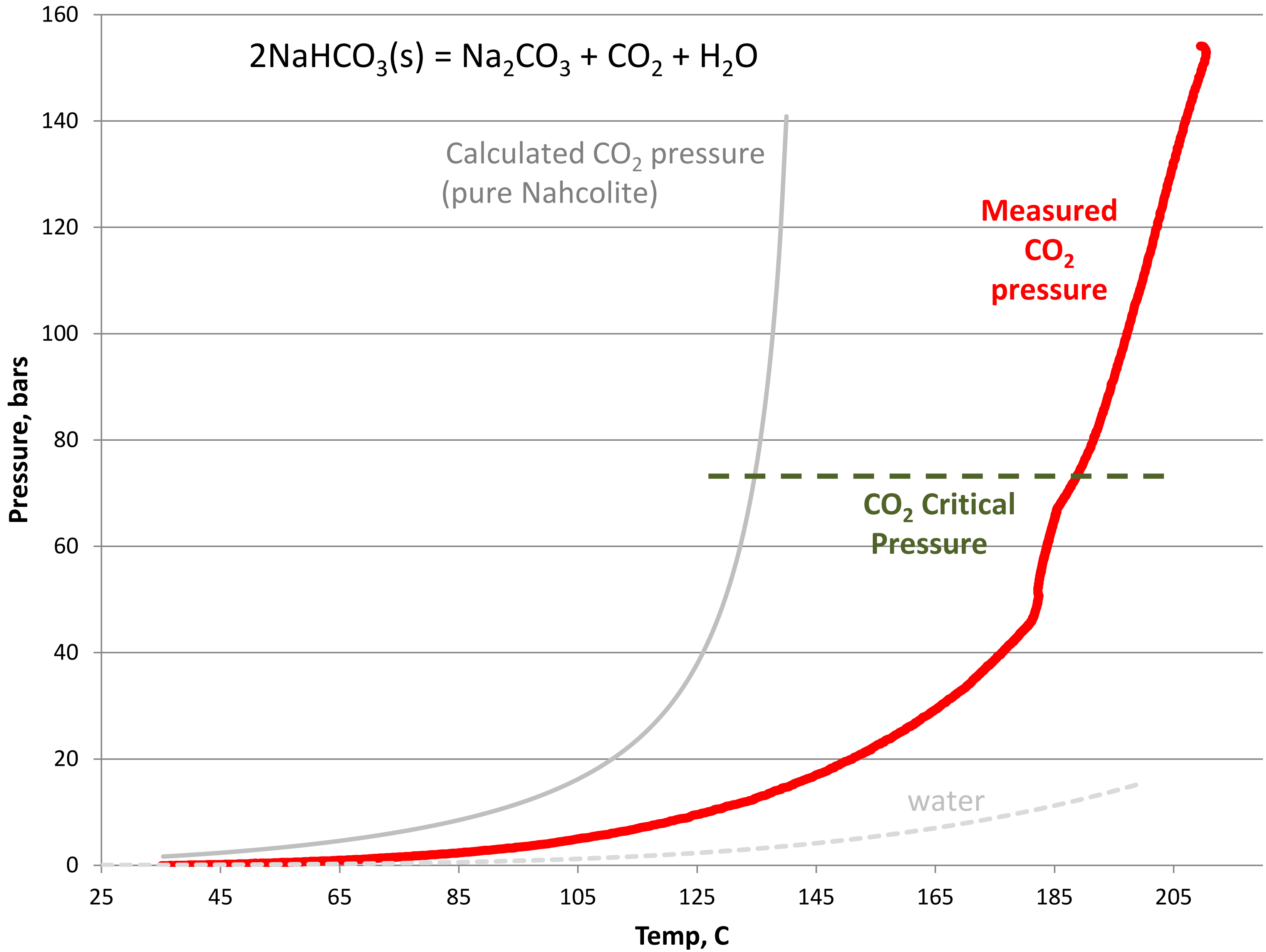




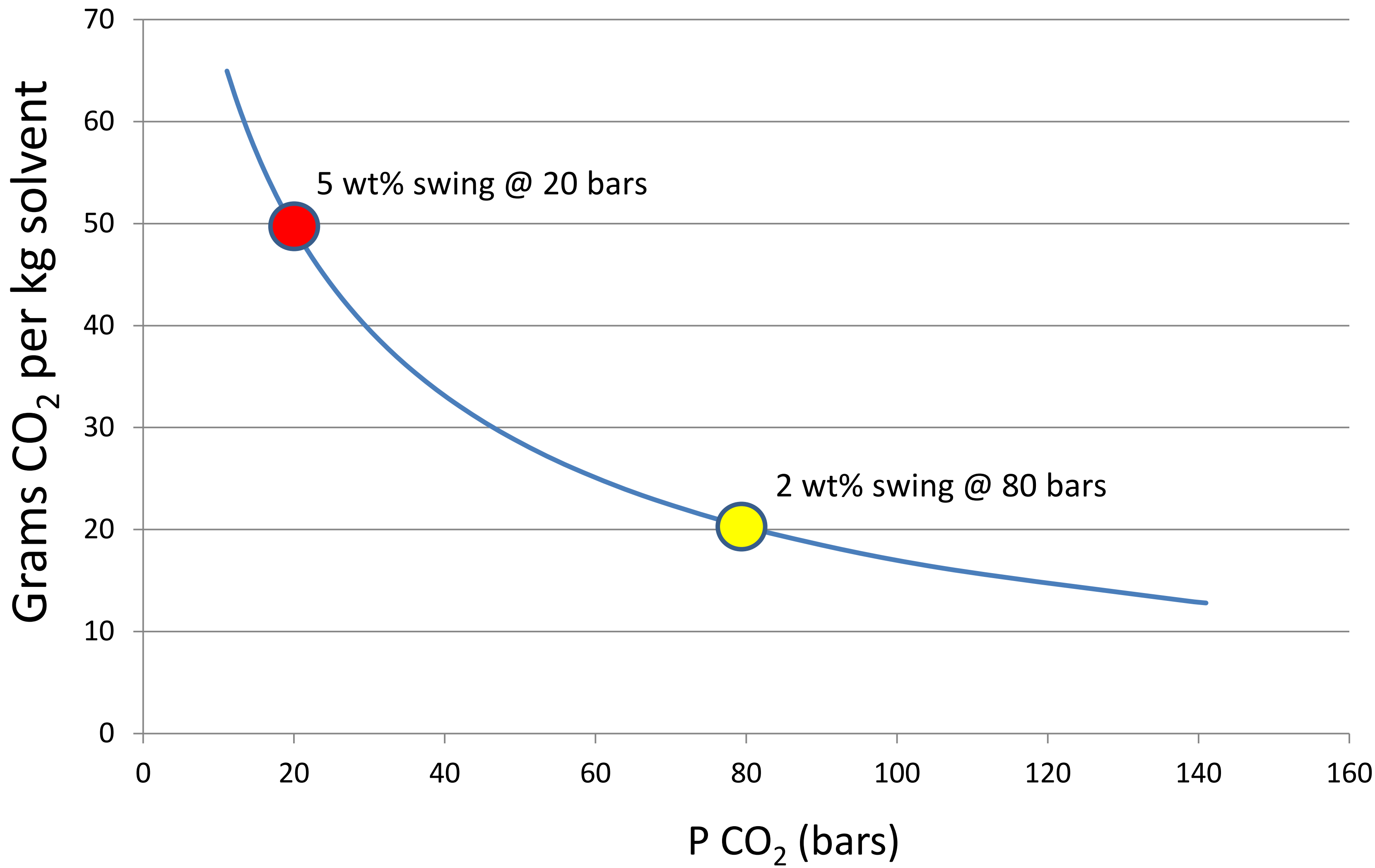
Capsules doped with magnetic nanoparticles

New reactor concepts

Sodium carbonate: supercritical CO_2 without a compressor

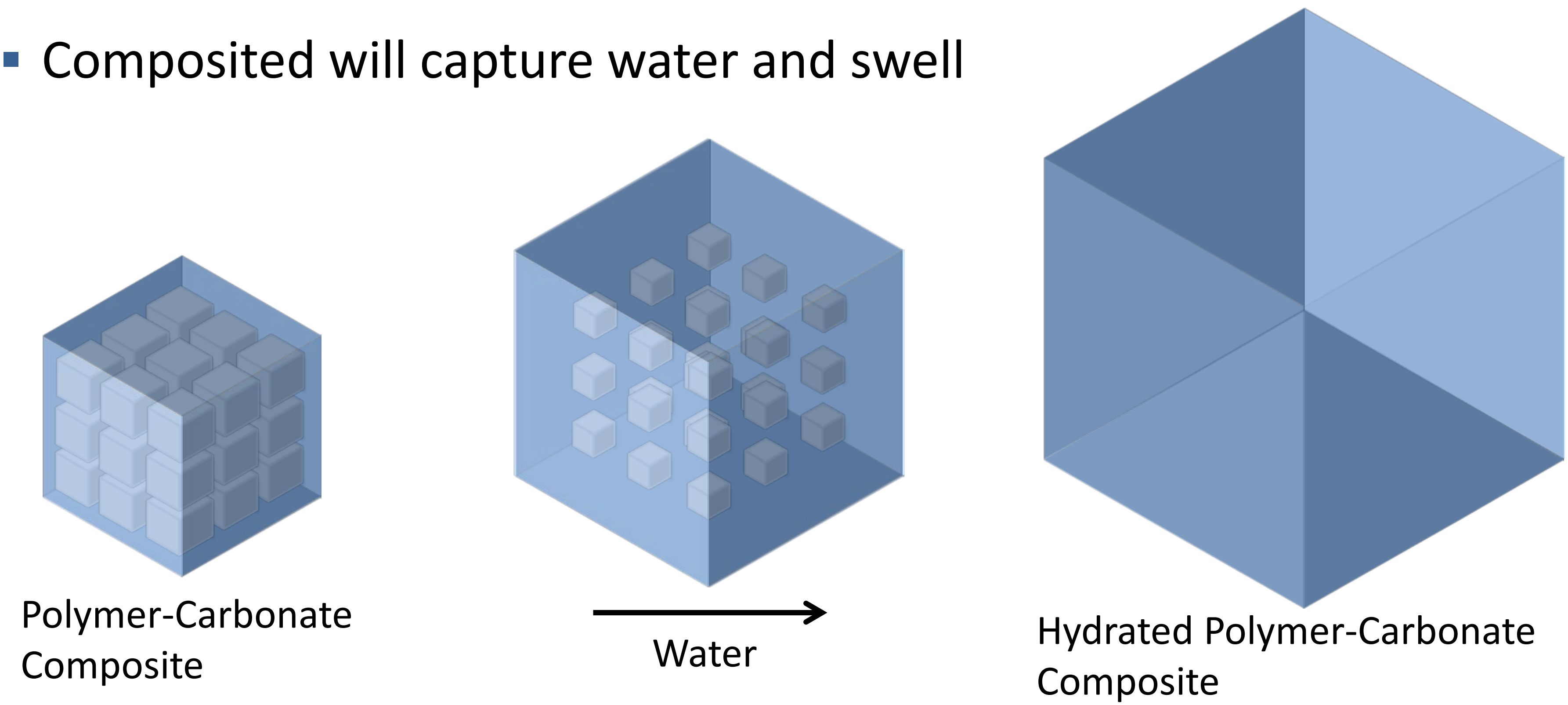


Swing capacity depends on release pressure.

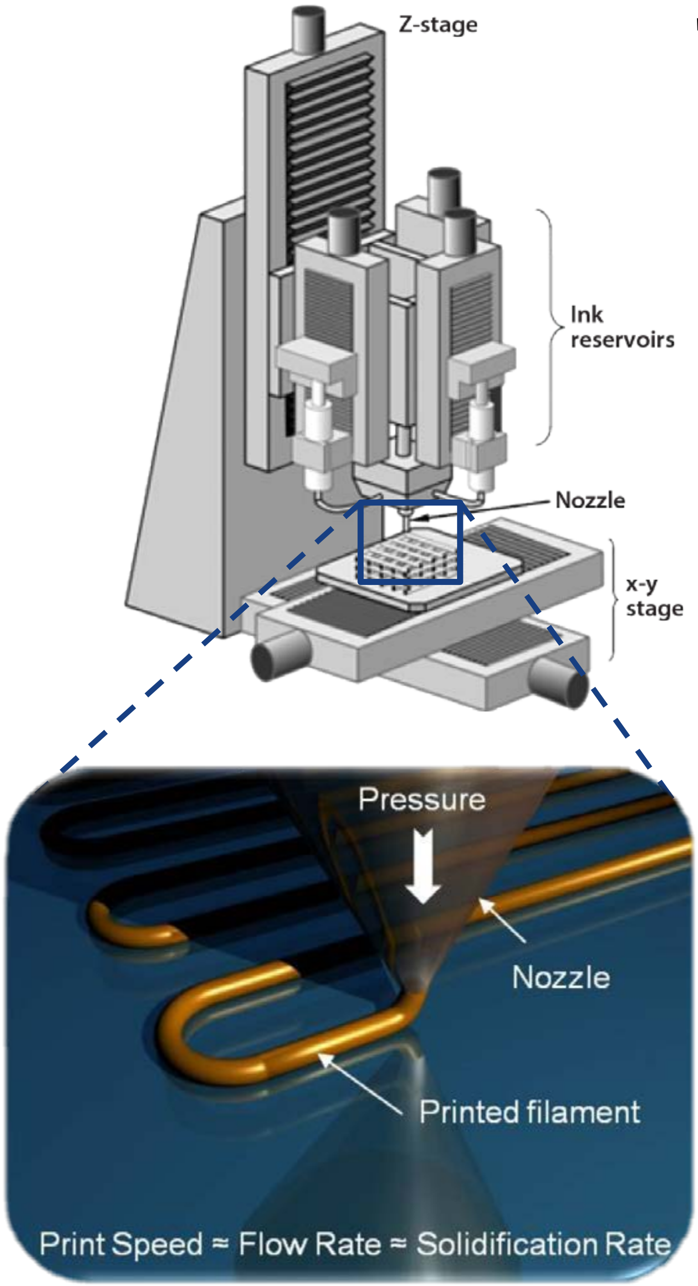


Sorbent-polymer Composites

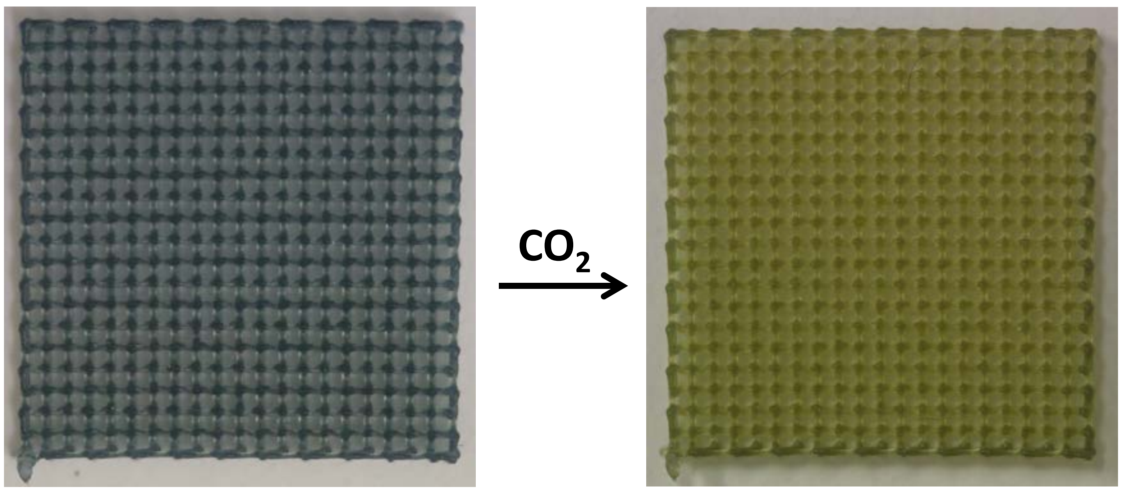
- Carbonate particles embedded within a CO_2 permeable polymer (silicones)
- Composited will capture water and swell



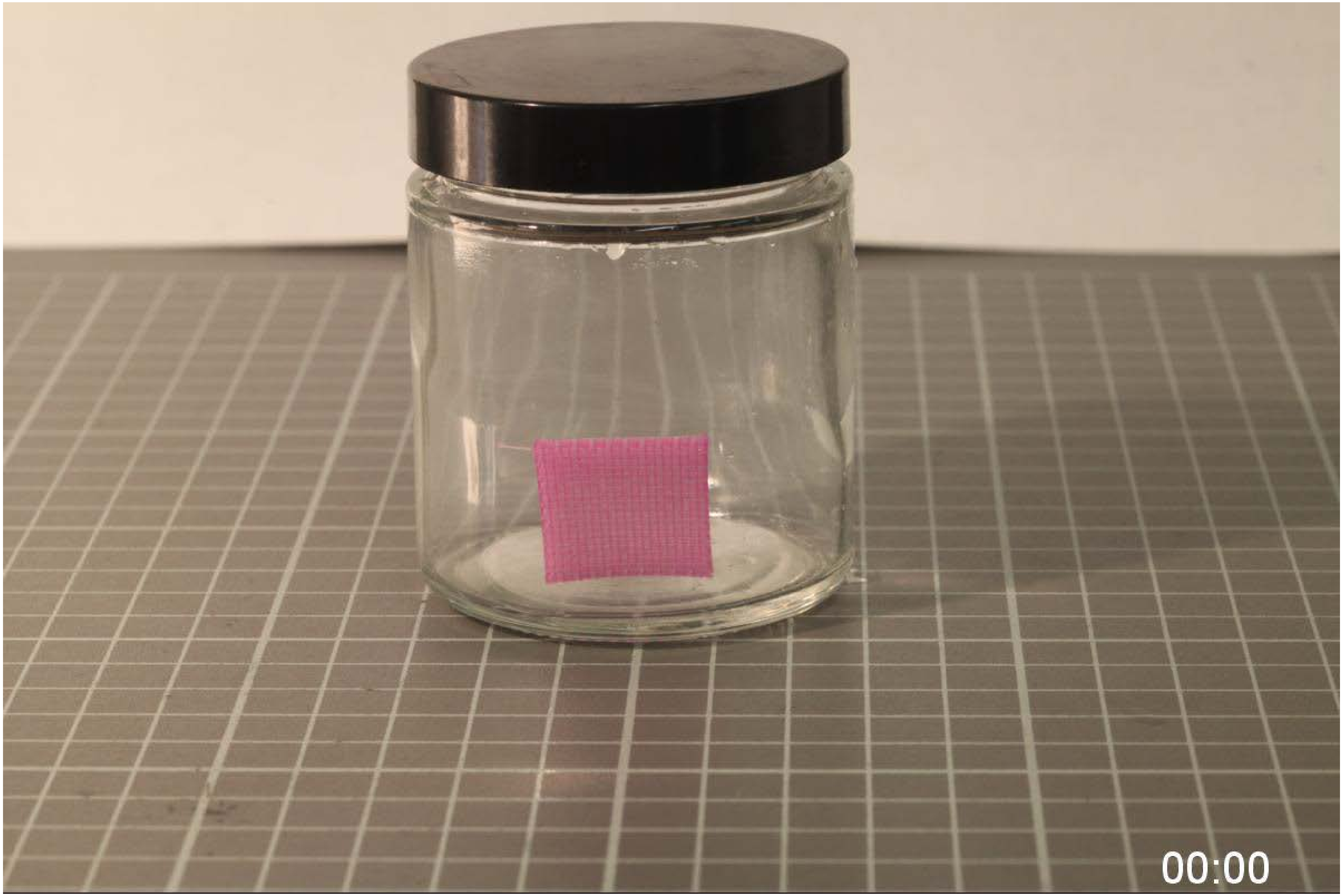
3D Printed Composites



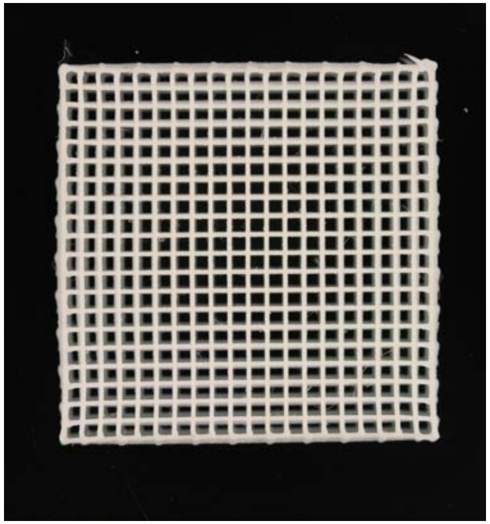
- Shear-thinning polymer allows for Direct Ink Write (DIW) of composites
  - Can include color indicating dyes to identify CO_2 loading



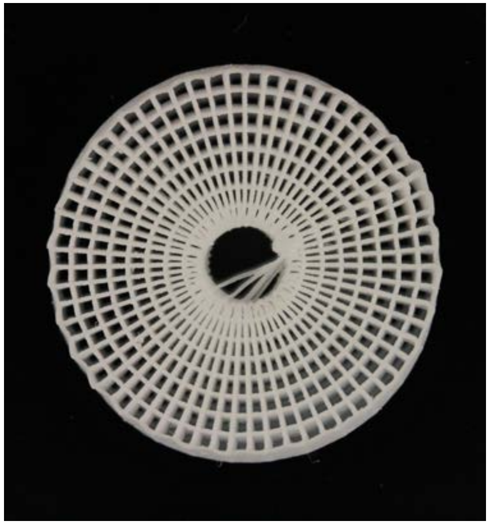
The Breath Test



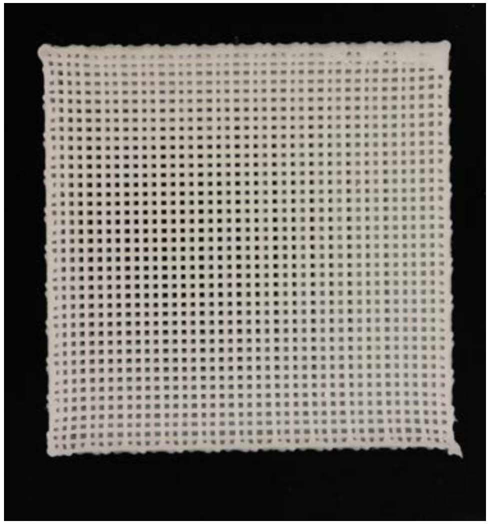
Geometries can be optimized for gas flow and reactor shape



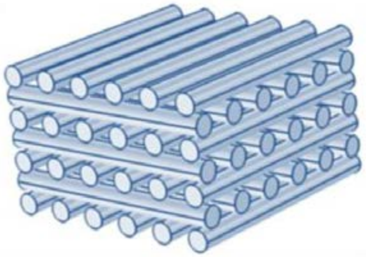
Simple Cubic

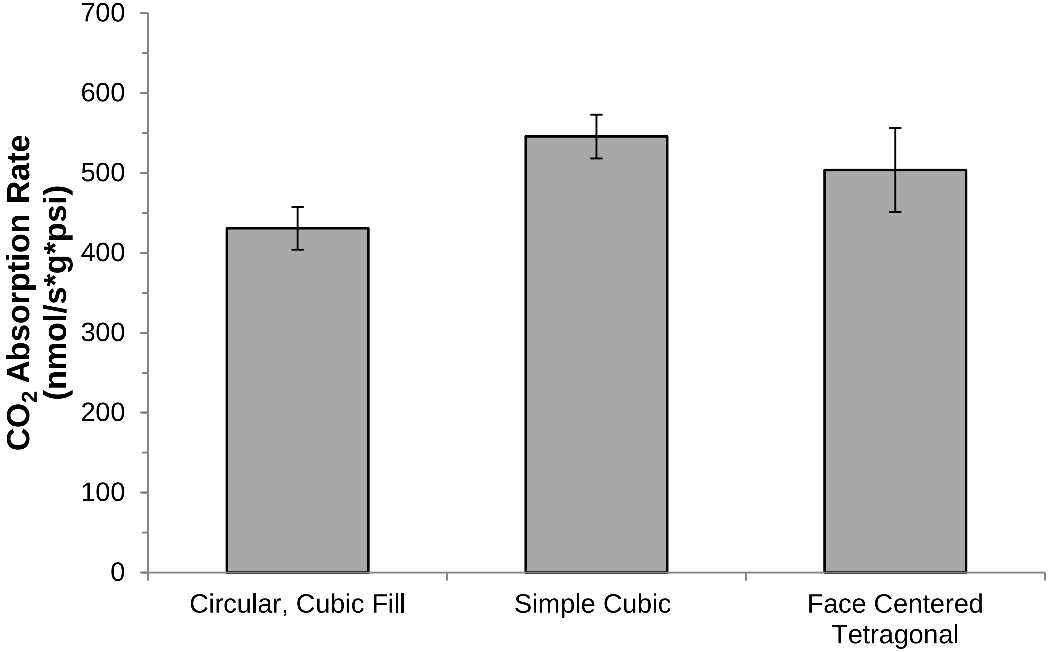


Radial Simple Cubic

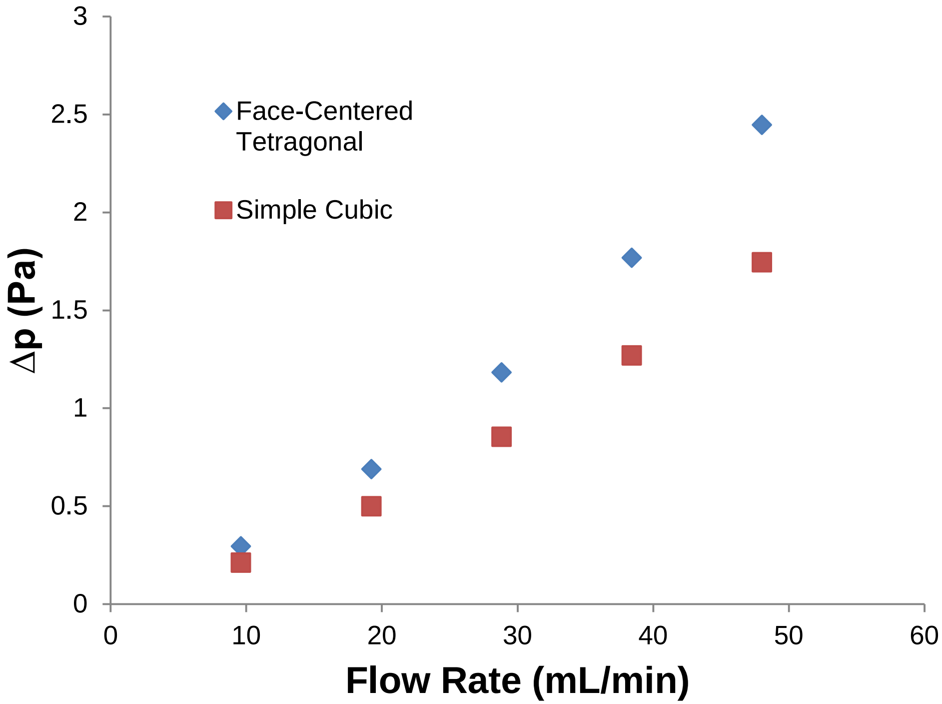


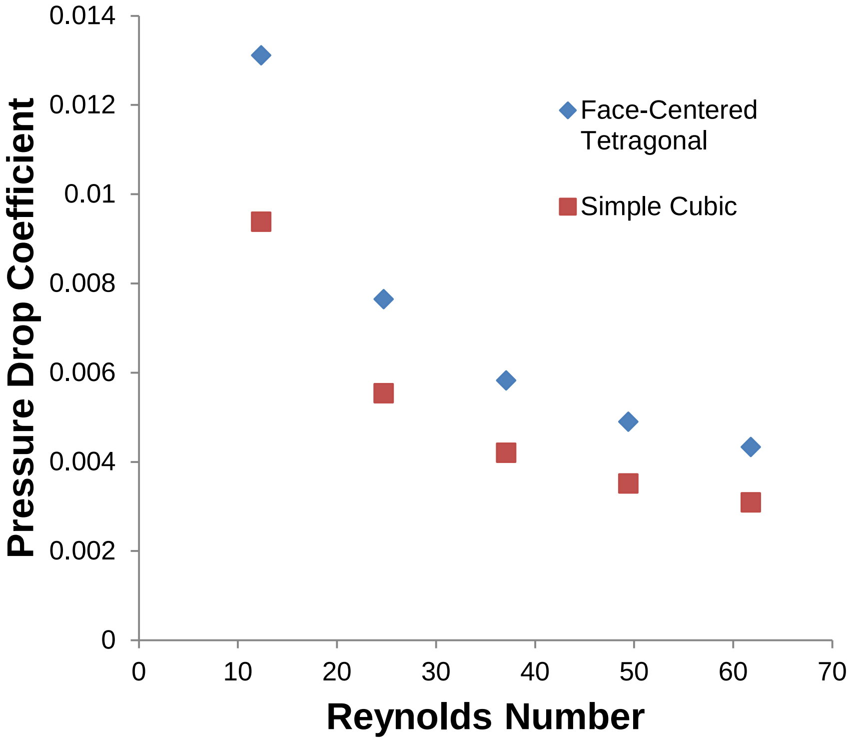
Face Centered Tetragonal



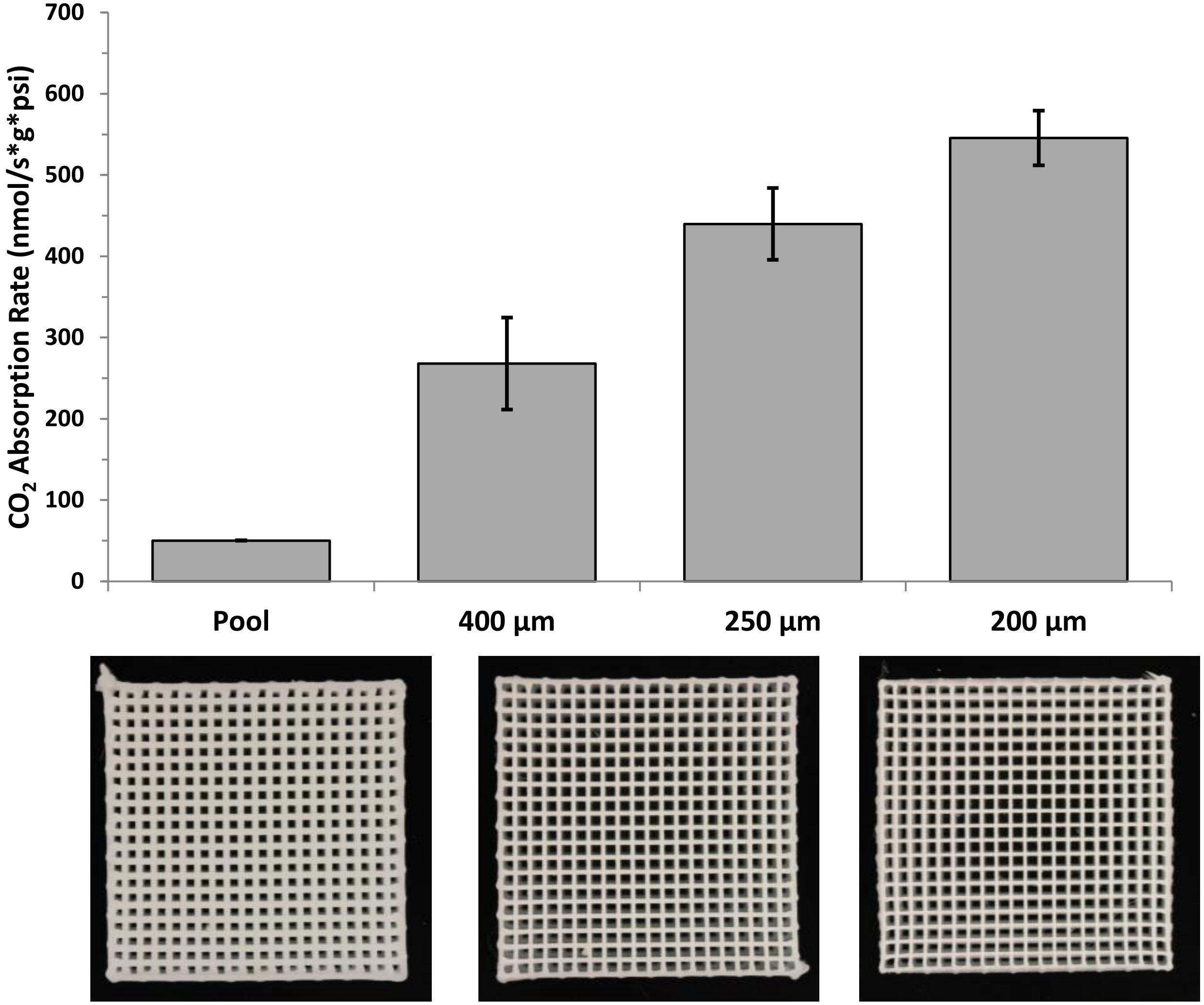


Geometry affects mass transfer and pressure drop.

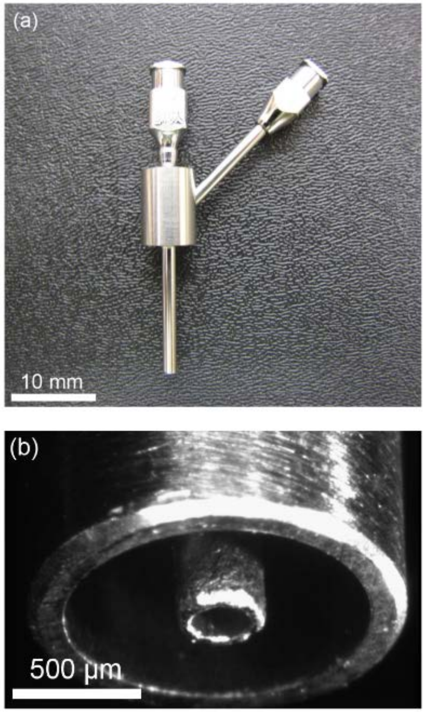


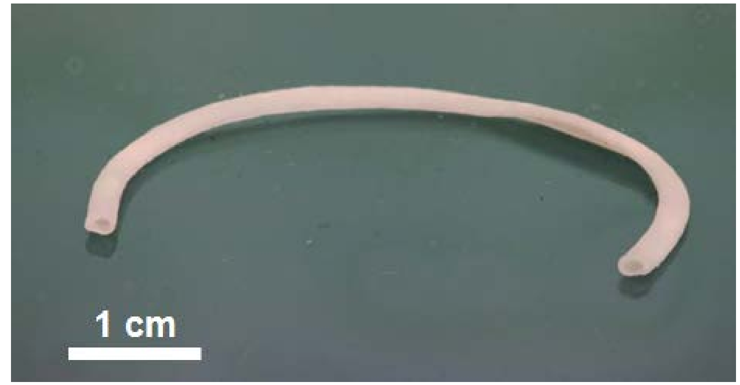


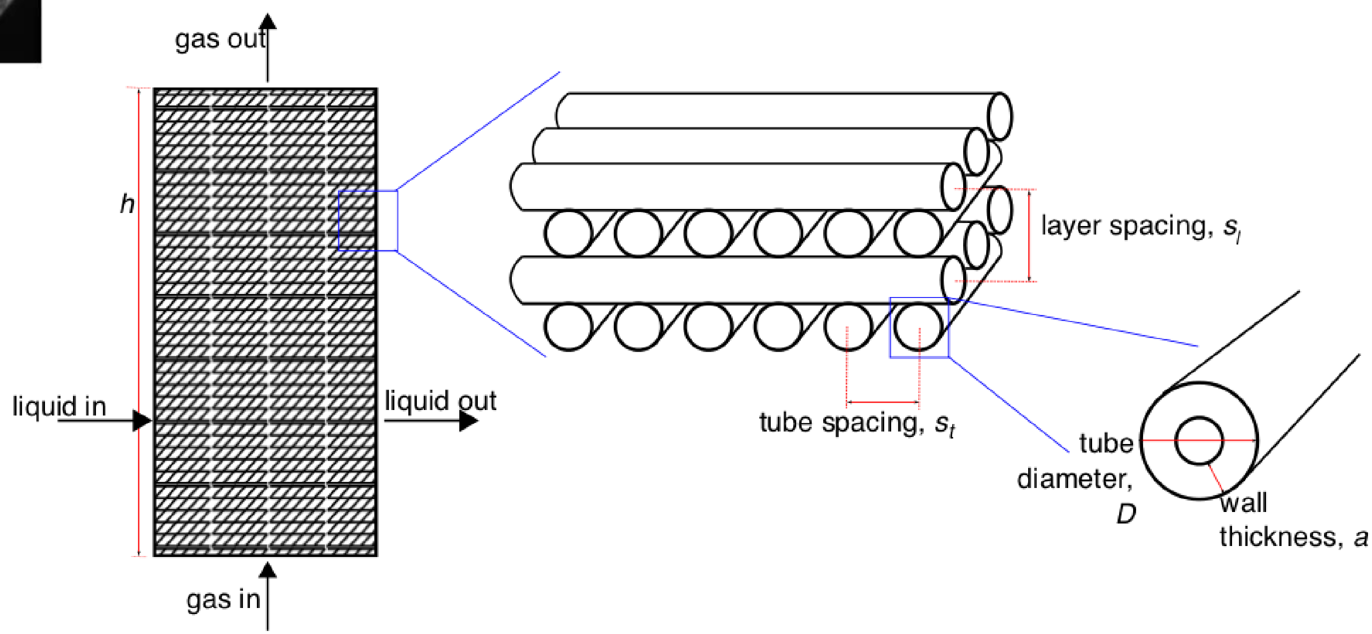
Smaller struts yield higher absorption rates.



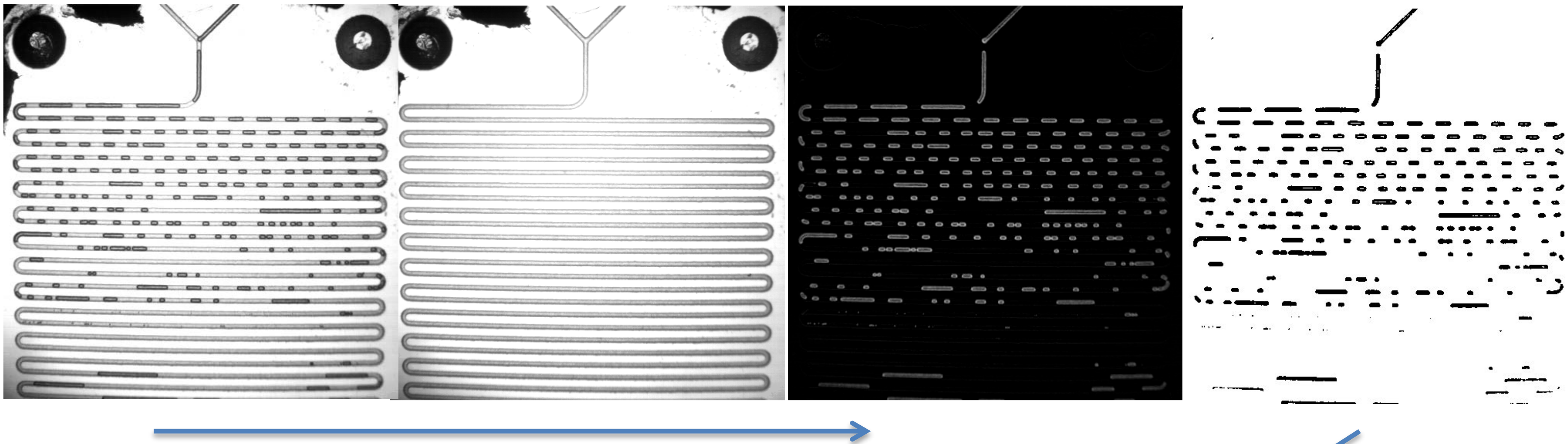
Tube-lattice reactors expand the process options.

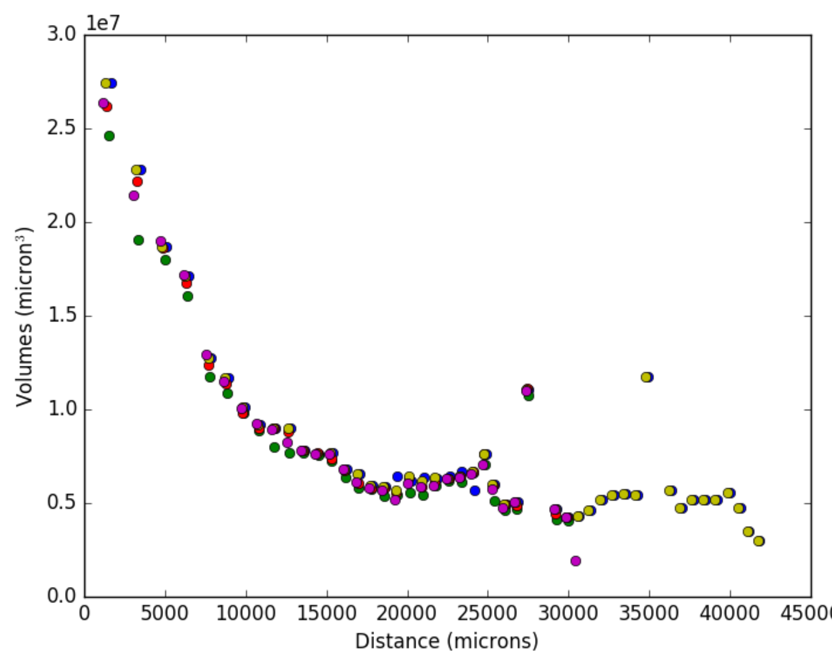






Microfluidic determination of solvent properties: New "snapshot" approach

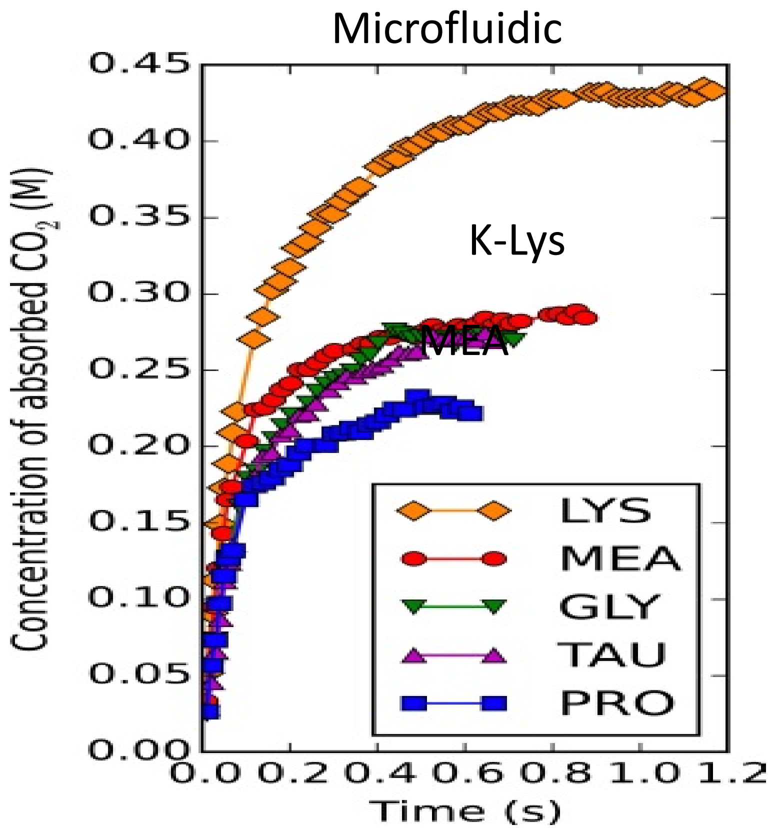


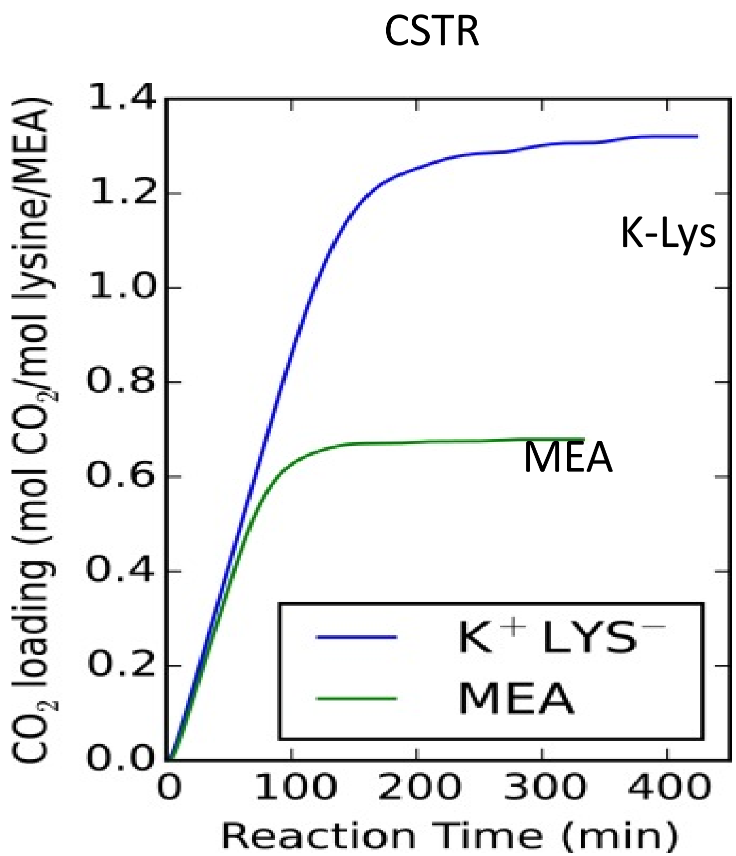


Bubble volume vs. distance traveled

⇒ CO_2 absorbed vs. time

Microfluidics used to characterize amino acid-based solvents.





Potassium lysinate outperforms MEA

Results consistent with CSTR.

Comparative microfluidic screening of amino acid salt solutions for post-combustion CO_2 capture, International Journal of Greenhouse Gas Control, Volume 43, Pages 189–197 (2015).
http://dx.doi.org/10.1016/j.ijggc.2015.10.026

Acknowledgements

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Questions