High-efficiency, integrated reactors for sorbents, solvents, and membranes using additive manufacturing

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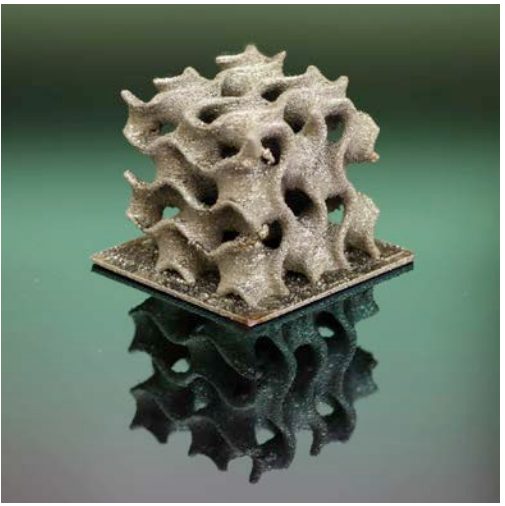
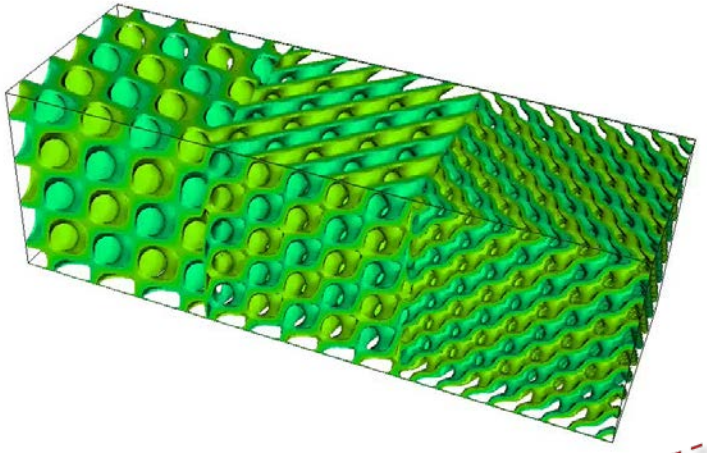
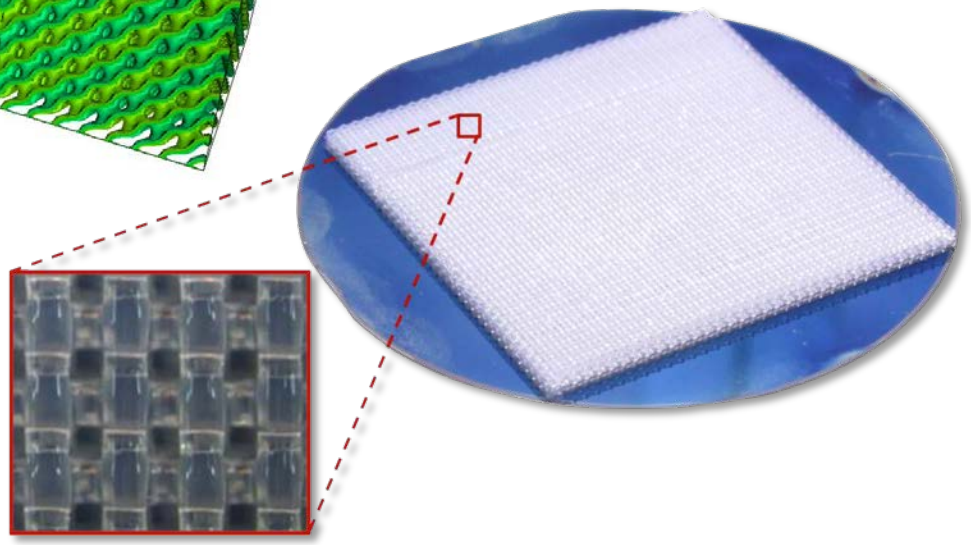
NETL CO_2 Capture Technology Meeting

Joshuah K. Stolaroff







Lawrence Livermore National Laboratory

Objective: design and fabricate high-efficiency reactors that support an advanced sorbent, solvent, or membrane to achieve transformational carbon capture.

Approach:

Additive Manufacturing

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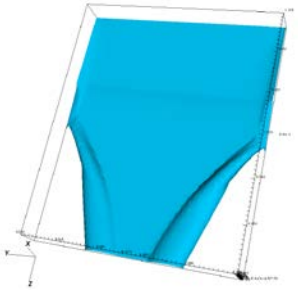

Computational design

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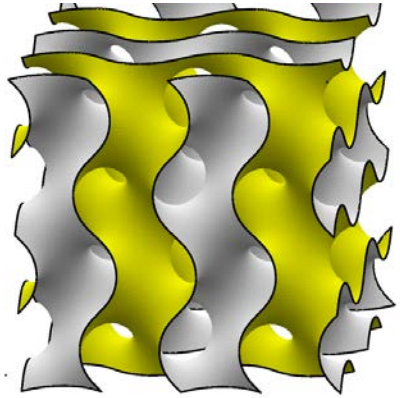
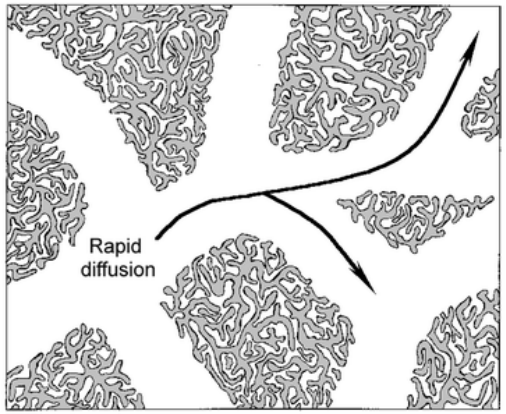
Sorbent, solvent, or membrane

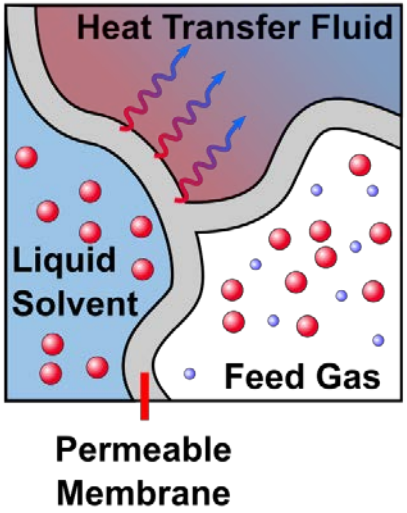
We focus on three design features.



Triply Periodic Minimal Surface (TPMS) structures



Hierarchical flow channels



Multifunctional Reactors

Project Plan

FEW0225: $3.8M over 4 years

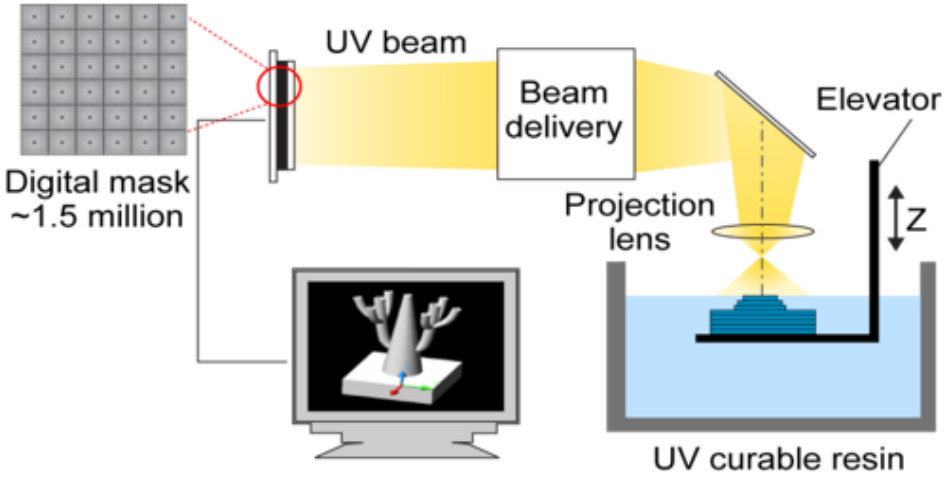
	Year 1	Year 2	Year 3	Year 4
Theoretical Assessment	Downselect			
Fabrication Assessment	Proof of concept reactor			
Generation 1 Reactor		Design→	Bench-scale testing	Prototype demo→
Generation 2 Reactor			Design→	Bench-scale test / Demo design

- 10 tasks in 3 tracks
- Downselect to two reactor concepts, developed in series
- Tech transfer targeted for middle of Year 4 for 1st-gen design

Relevant additive manufacturing techniques

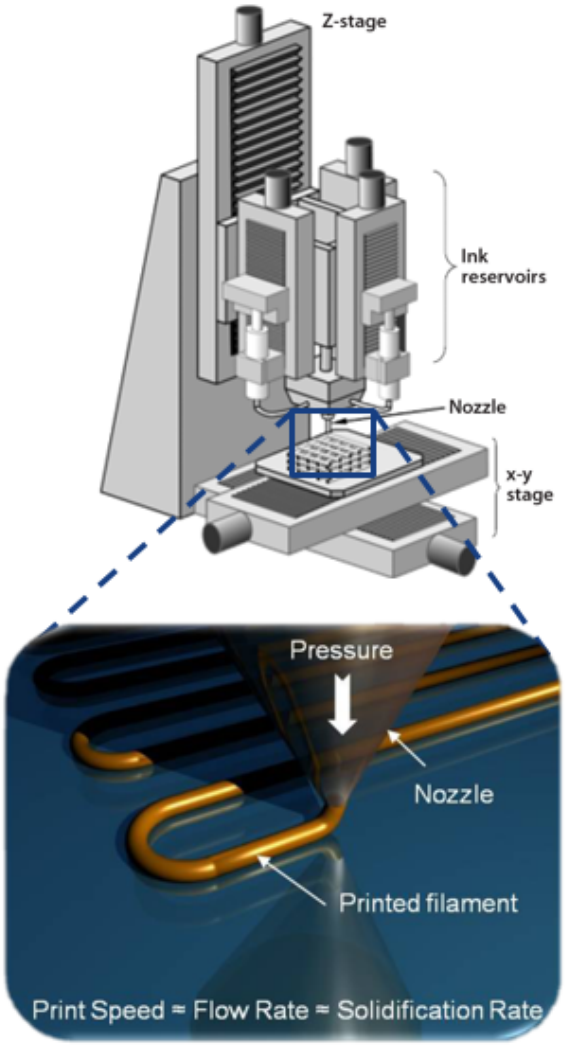
Projection Microstereolithography (PμSL)

A photochemical and optical technique

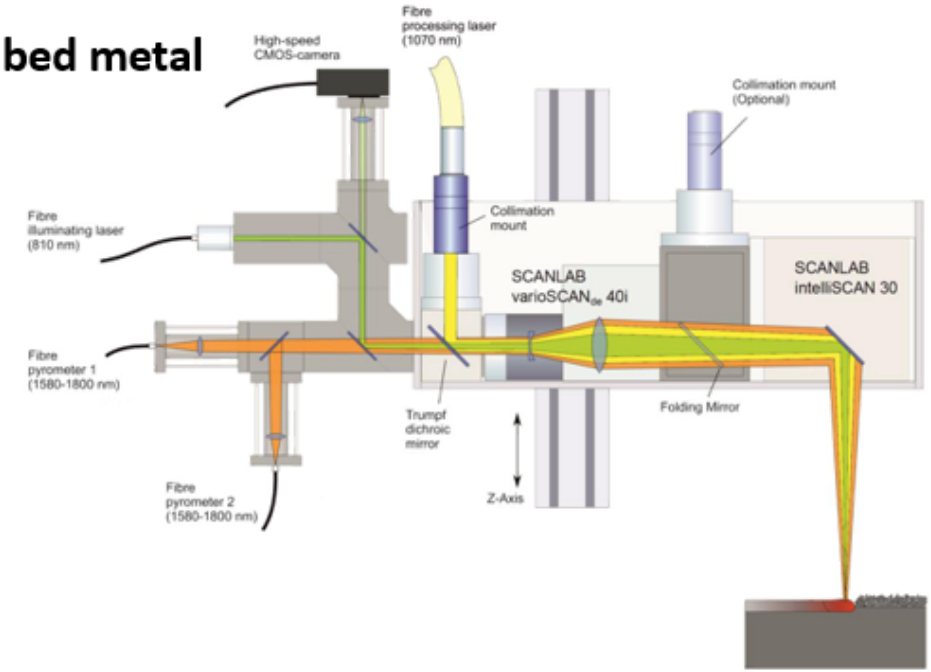


Direct Ink Writing (DIW)

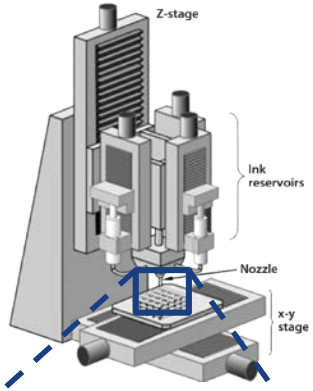
Utilizes unique flow and gelling properties

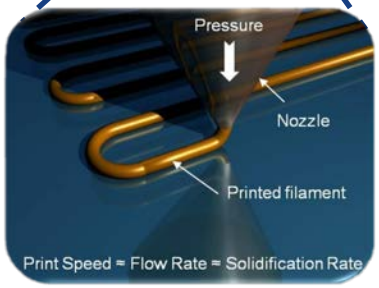


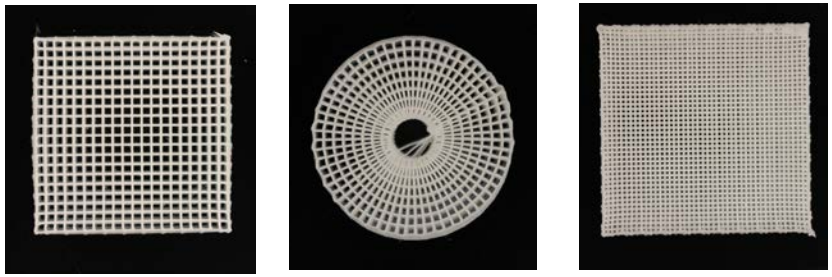
Powder bed metal printing



Printed composite sorbents already demonstrated.

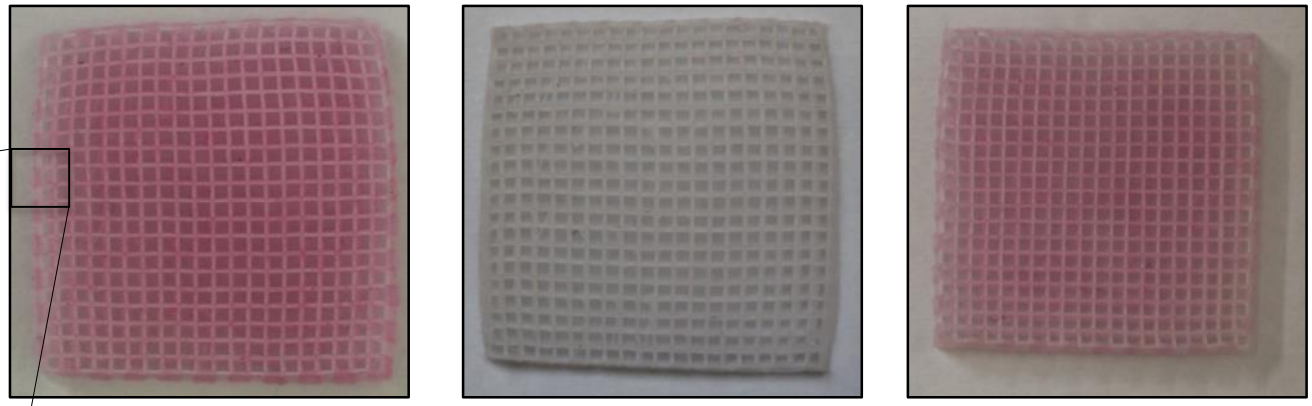


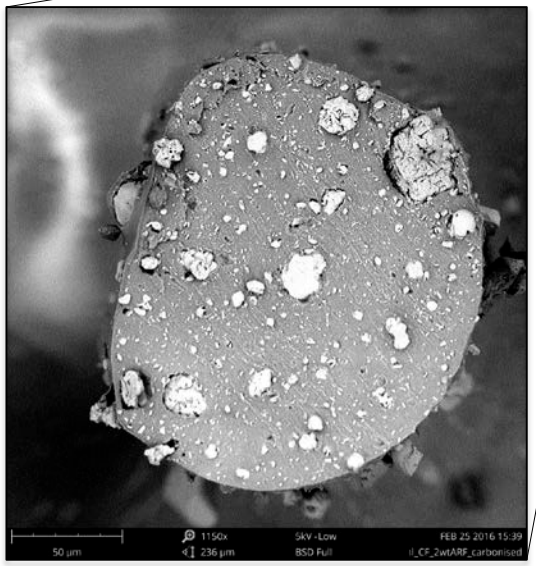




CO_2 →

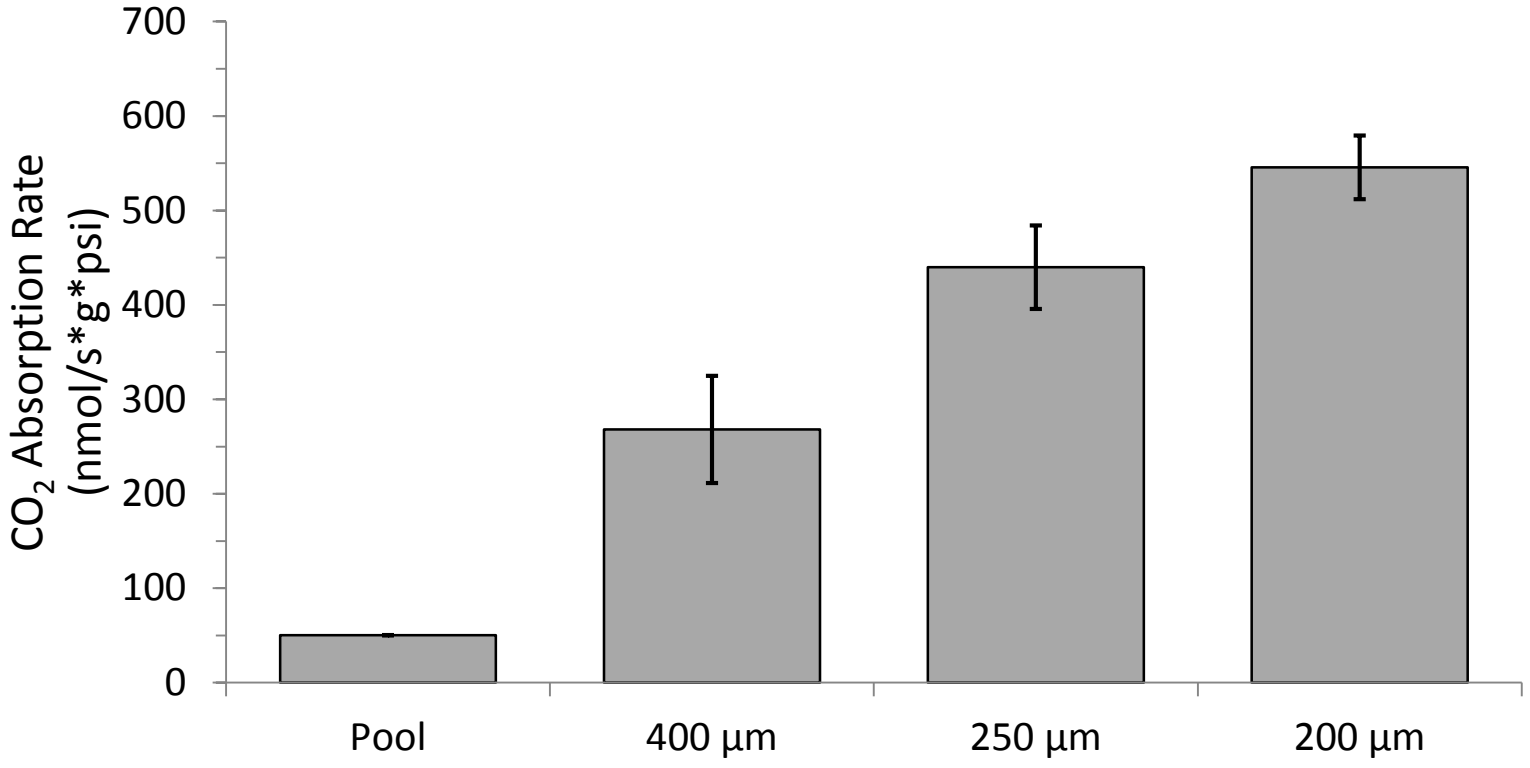
Heat →

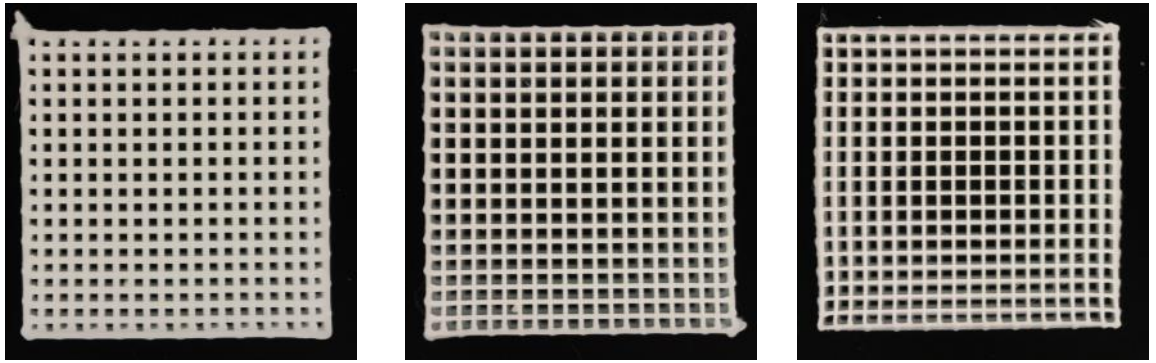




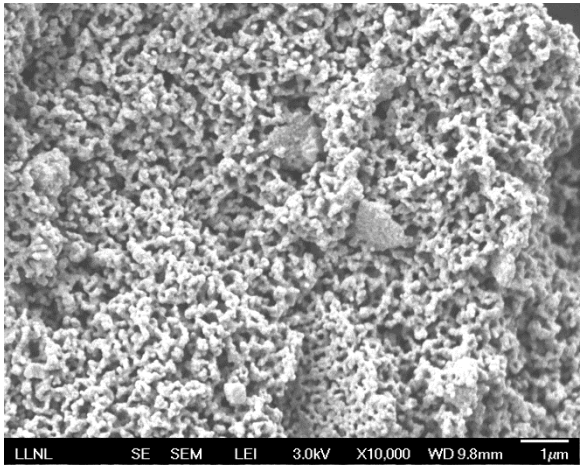
- Composites can include color indicating dyes to identify CO_2 absorption
- Particulate sizes sieved to be smaller than filament diameter

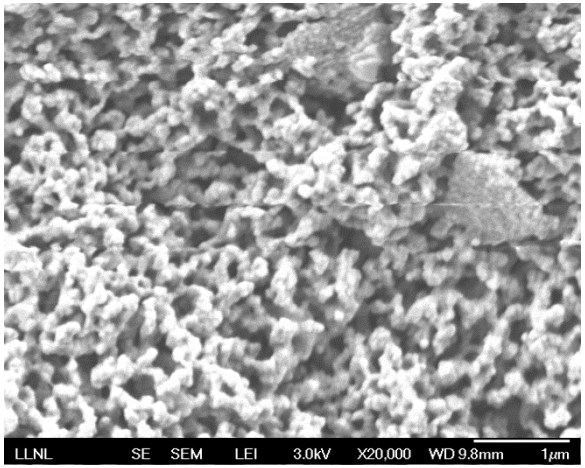
Absorption rate of composites tracks surface area





Porous ceramics can also be printed

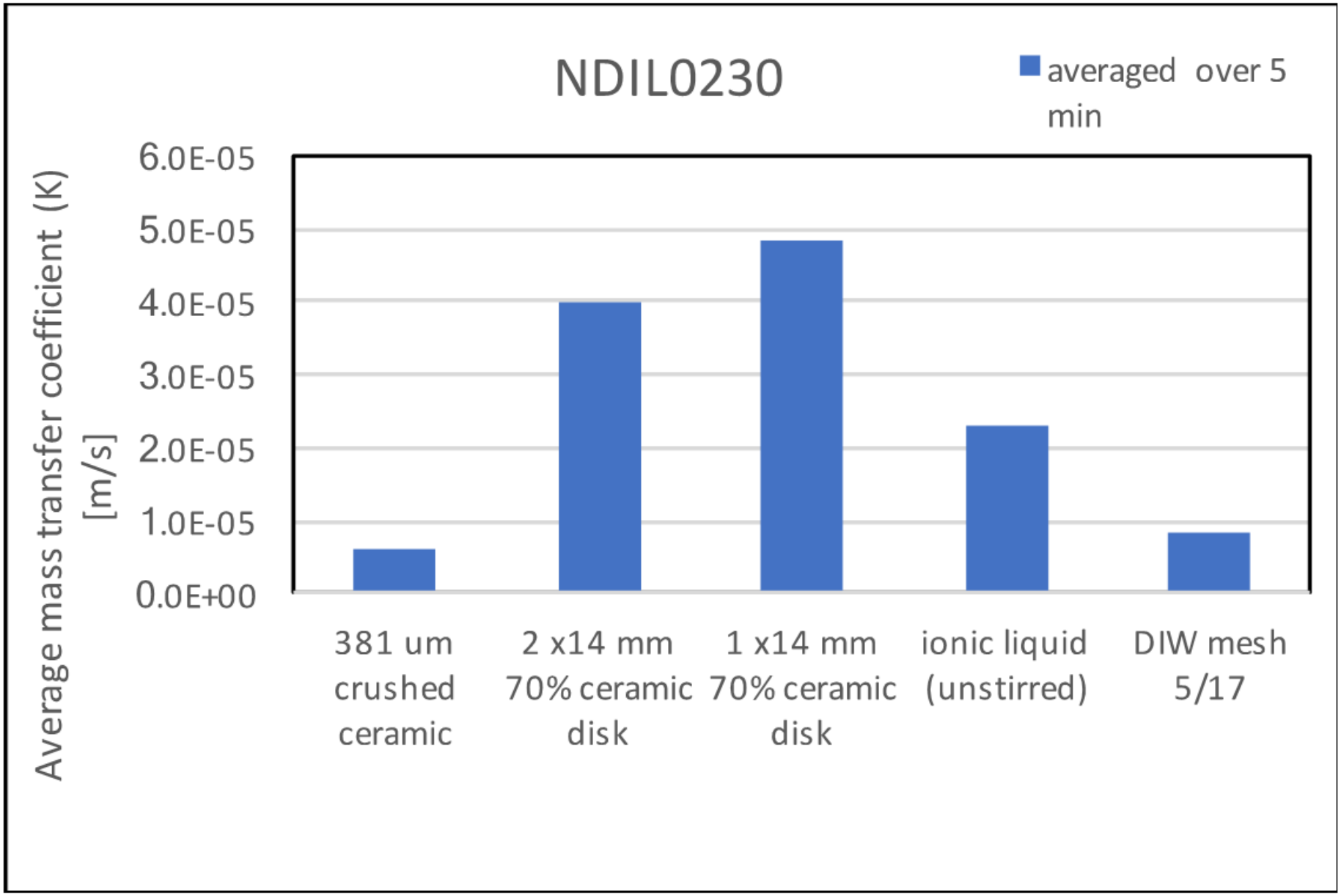




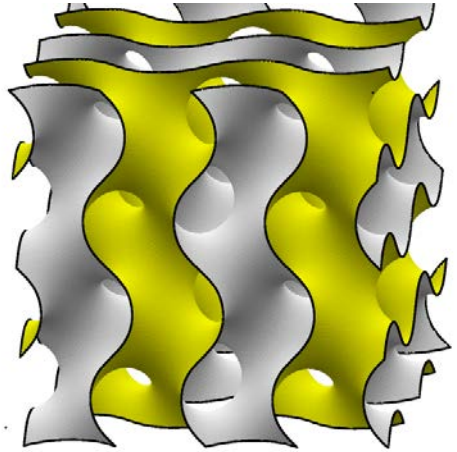
3% Y_2O_3 doped ZrO_2 material developed for high-temperature KOH membranes

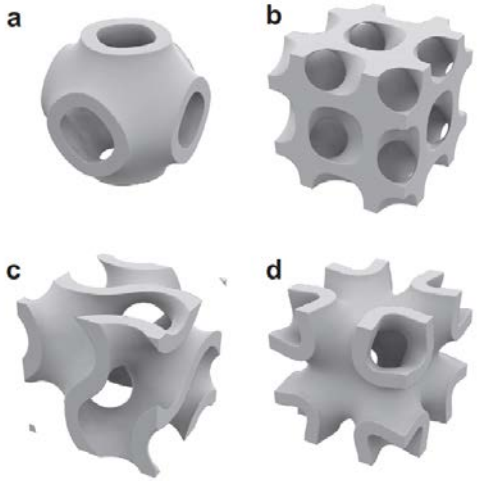
- Through-porosity
- Adjustable void fraction
- Stable, non-reactive to high-T
- Infiltrate with polar solvents

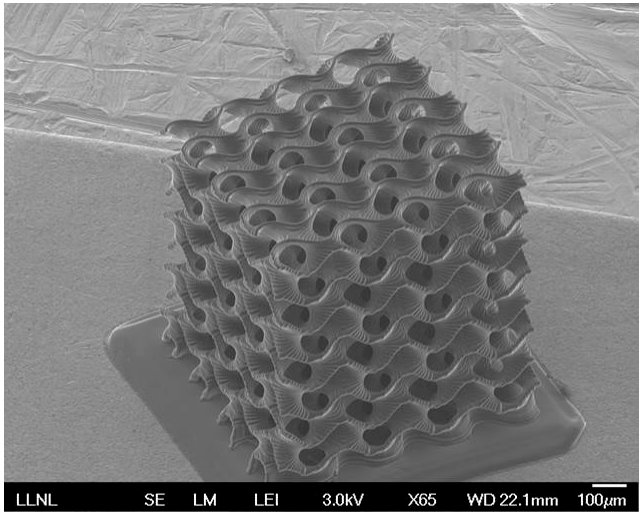
Printed ceramics demonstrated with ionic liquid



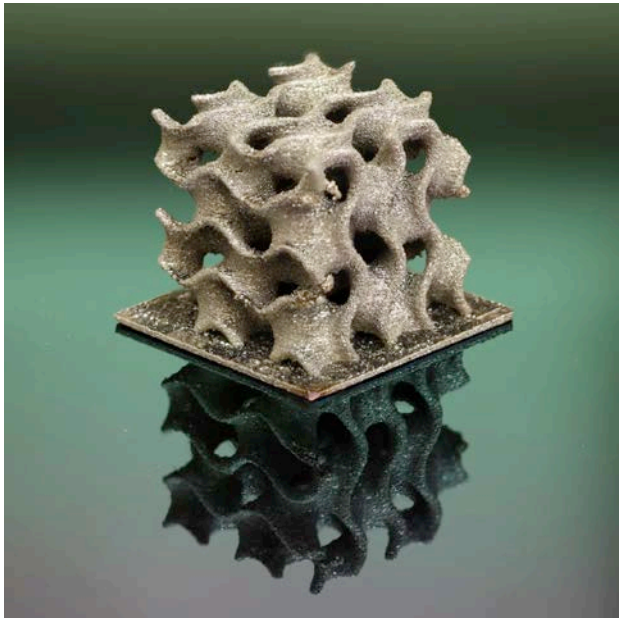
TPMS reactors: only possible with additive manufacturing





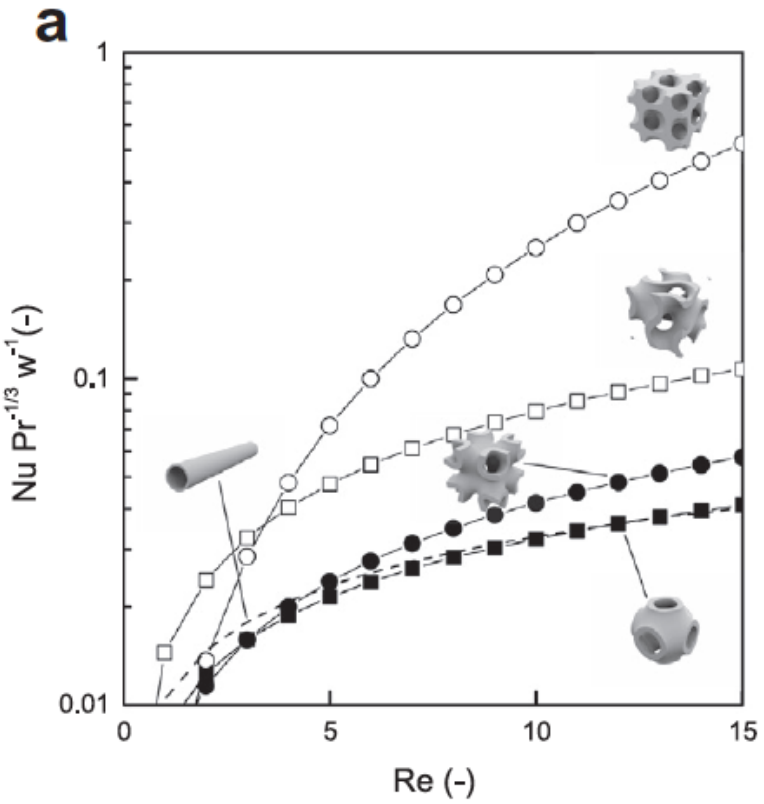


Printed at LLNL with Projection Microstereolithography (PµSL)

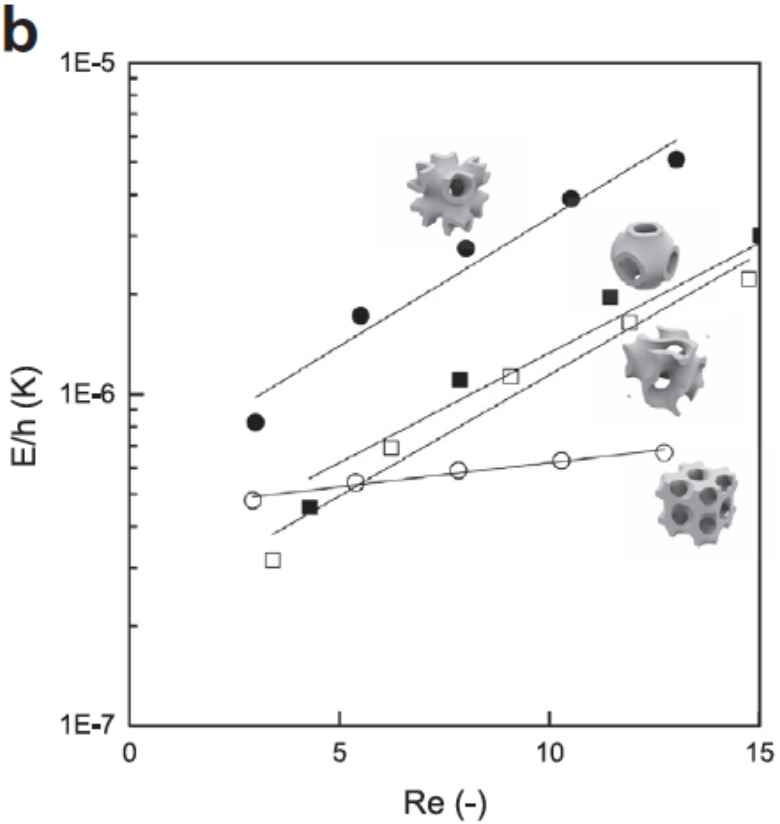


Stainless steel gyroid printed at LLNL.

Order-of-magnitude improvement in heat transfer performance over tubes and flat plates.



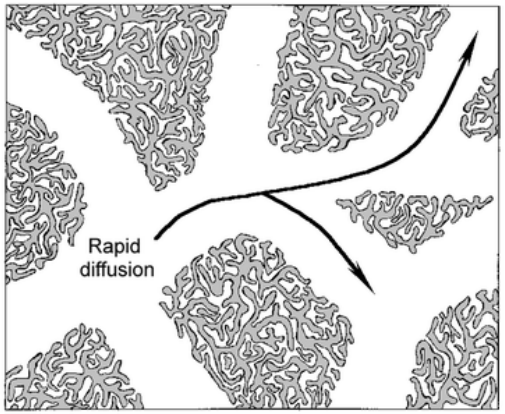
Heat transfer per unit surface area

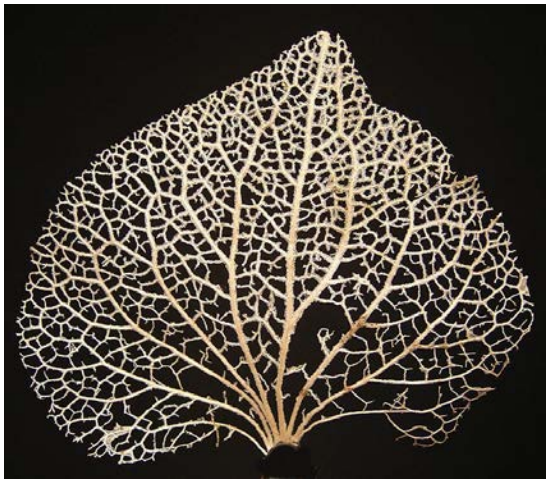


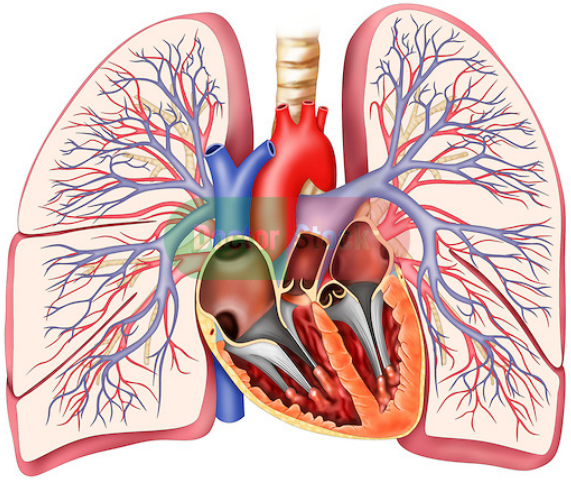
Friction loss per unit heat transferred at $\Delta T=1^{\circ}C$

From: T. Femmer et al. *Chemical Engineering Journal* 273 (2015) 438–445.

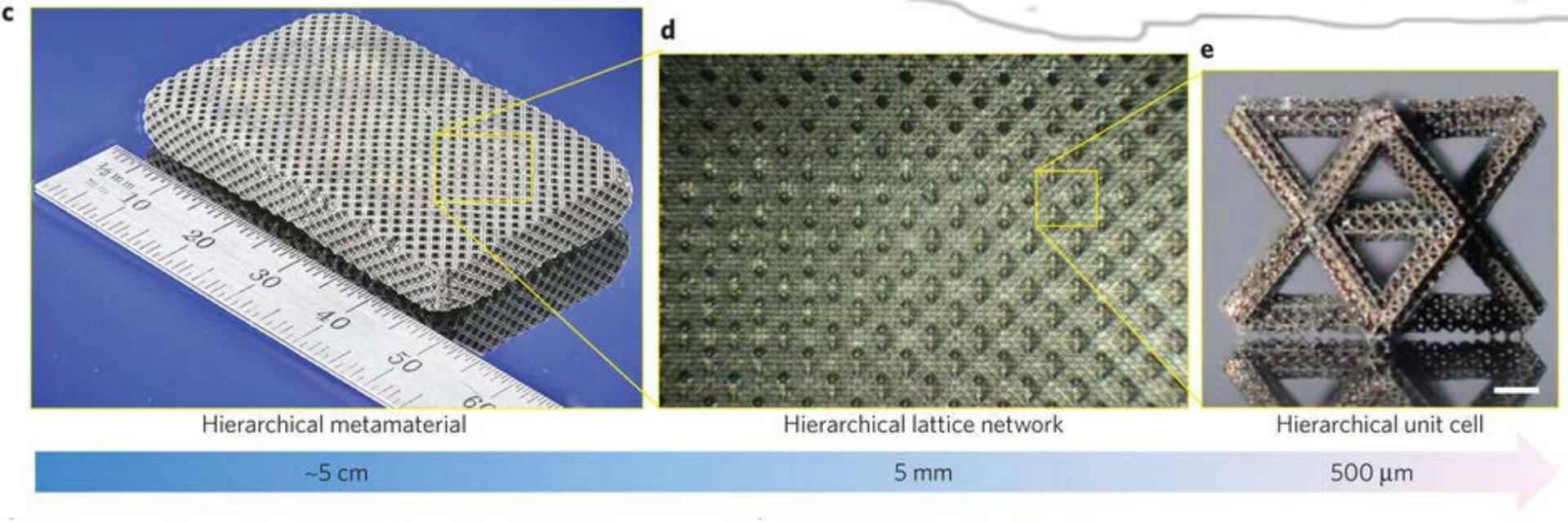
Hierarchies are common in nature for high interfacial area with low pressure drop.



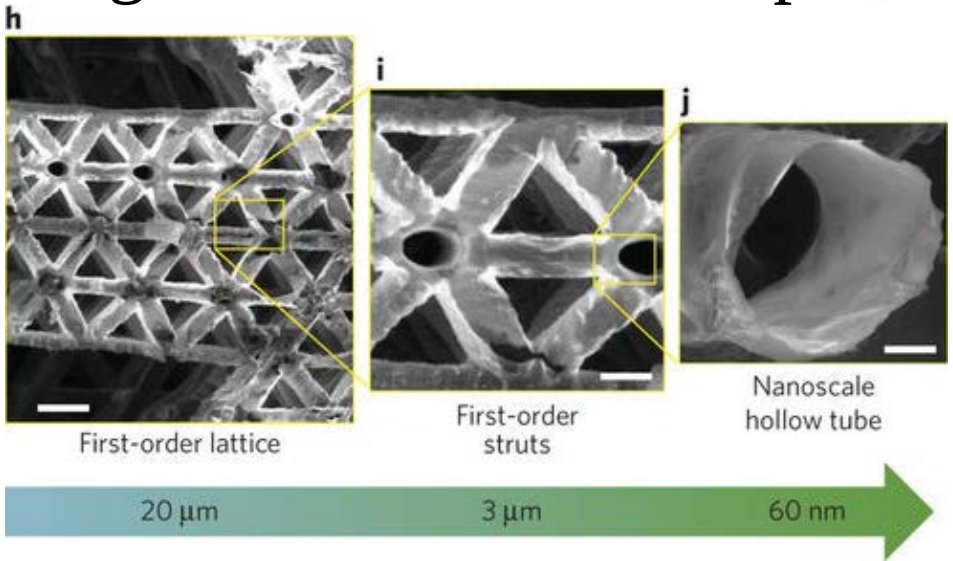




Achieved with direct printing (down to ~10 um scale)

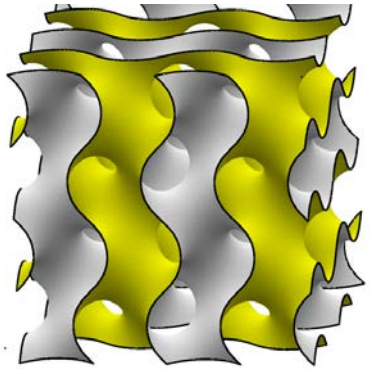


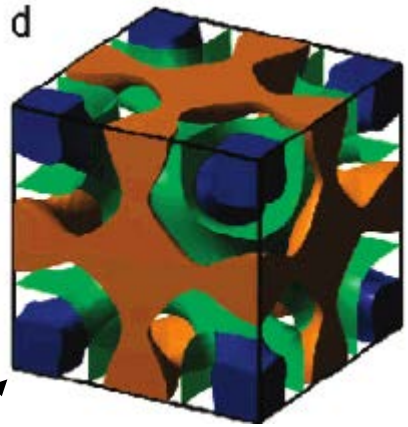
...or combination of printing and material manipulation (down to nanoscale).



Zheng et al, *Nature Materials* 15, 1100–1106 (2016)

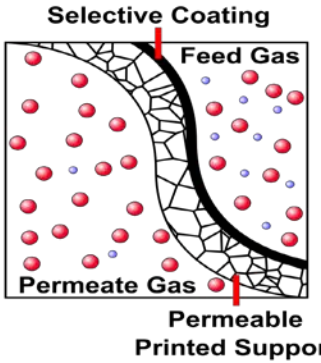
Many reactor configurations possible with additive manufacturing.



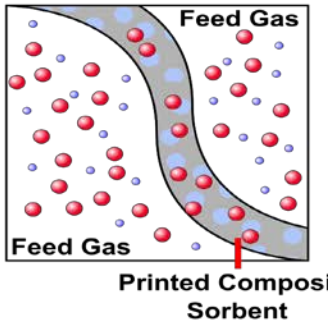


from Toombes et al., Macromolecules 40(25):8974-8982, 2007

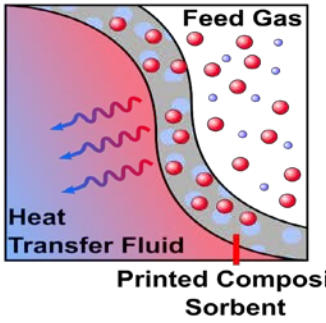
Gas Separation Membrane



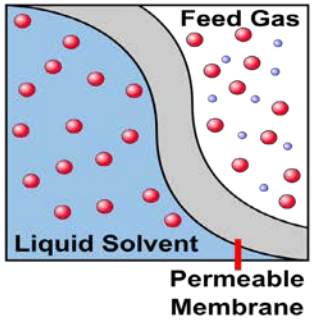
Gas Absorption Monolith



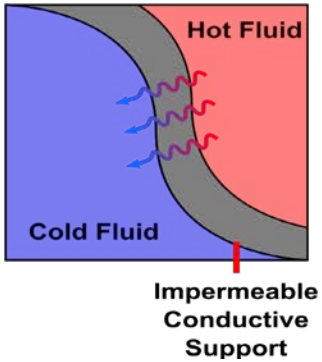
Gas Absorption Monolith w/ Heat Exchange



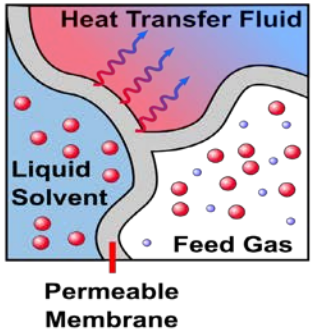
Gas Liquid Contacting



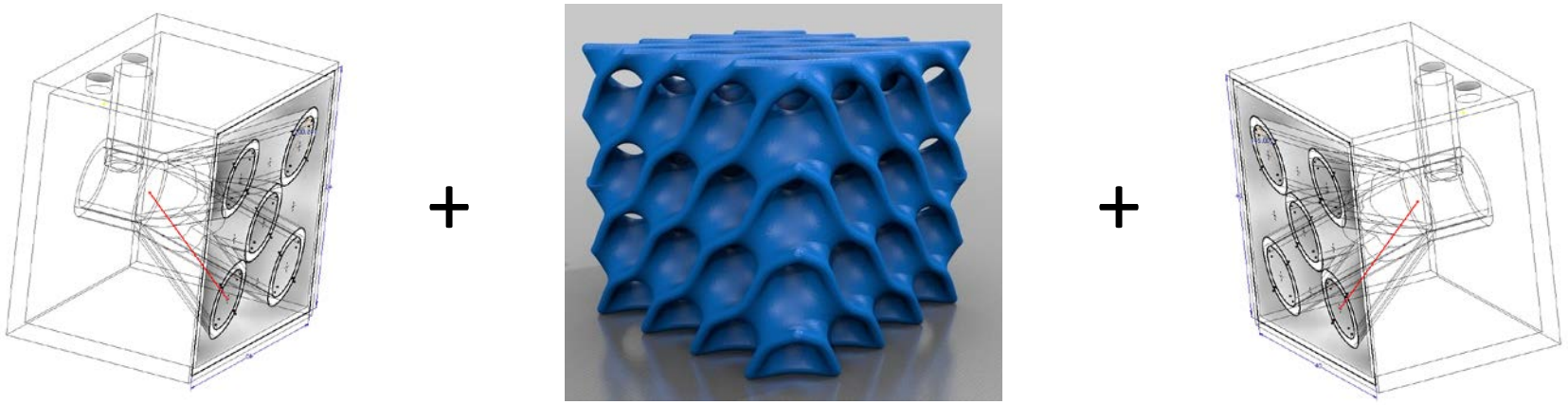
Heat Exchange

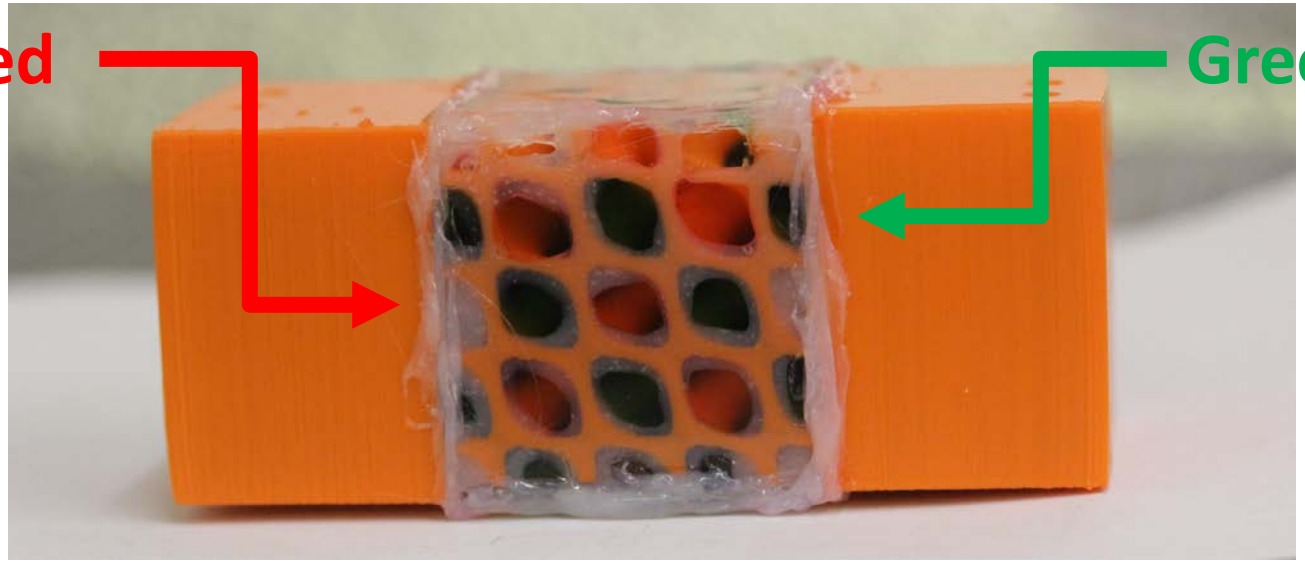


Gas Liquid Contacting w/ Heat Exchange

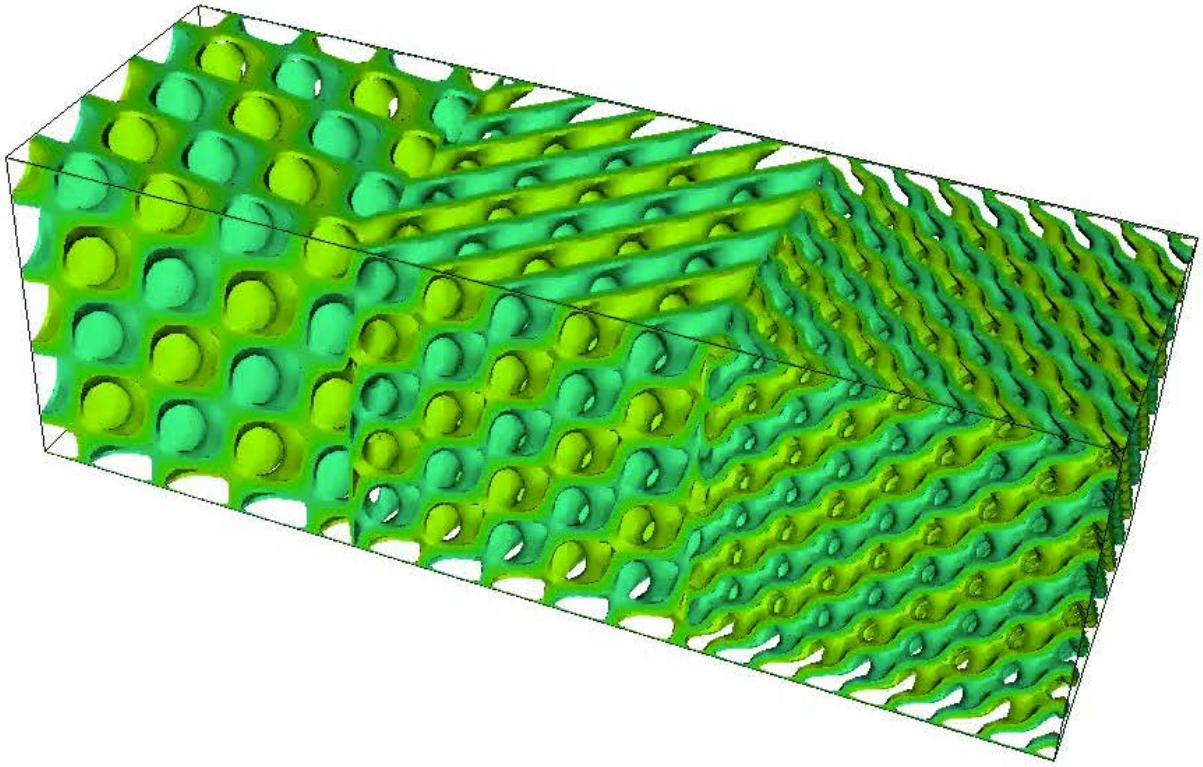


Reactor housings and connections can be printed along with internals.





Hierarchy and geometry can be combined.



Project goal:

Develop reactors with reduced volume and improved material utilization (by at least 30%) compared to conventional alternatives.

Project Team

Joshuah K. Stolaroff, Du Nguyen, Katherine Ong, Phillip Depond, Sarah E. Baker, James S. Oakdale, Pratanu Roy, Christopher M. Spadaccini and TBD...

Acknowledgements

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Questions