Nature-inspired Additive Manufacturing of Ceramics with Significantly Reduced Carbon Emissions

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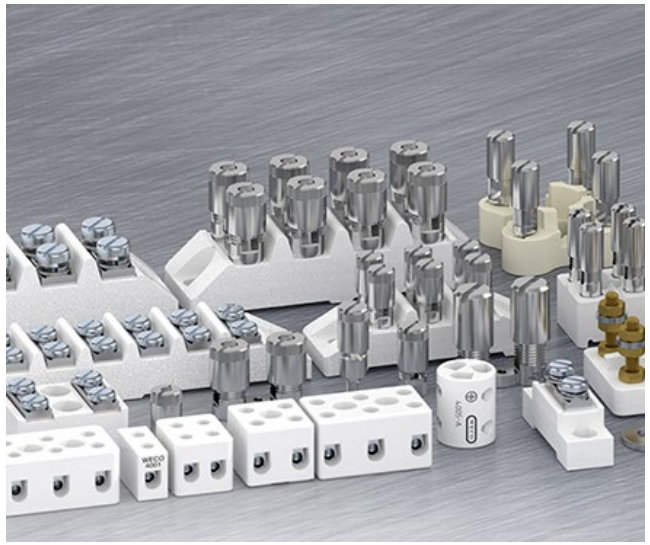
NSF Workshop on Advanced Manufacturing for Industrial Decarbonization
Aug. 3-4, 2023 | Arlington, VA

Acknowledge: NSF grant No. CMMI-1825962 and CMMI- 2236905

Courtesy of [Metallurgical engineering]

Why Ceramics

- **Structural ceramics**: Excellent combinations of physical properties, such as high strength, high thermal resistance, high chemical stability, etc.
- **Functional ceramics**: Dielectric, piezoelectric, magnetic, optical, biological, etc.



Electrical insulator

Transparent ceramics for high-energy applications

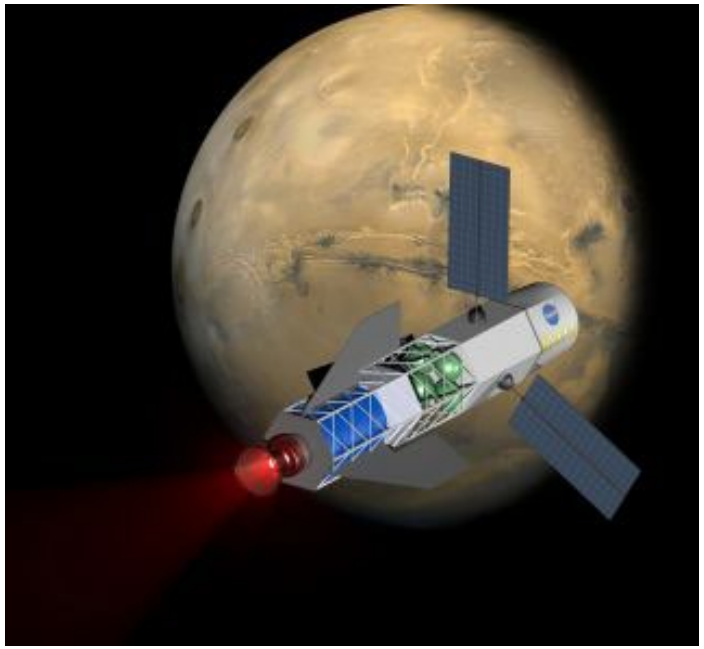
Heat exchanger tubes

Ultrasound transducer

Why Additive Manufacturing (AM) of Ceramics

Ceramic rocket nozzle by Fortify and Tethon3D

Customizable bone grafts (Source: Materic)

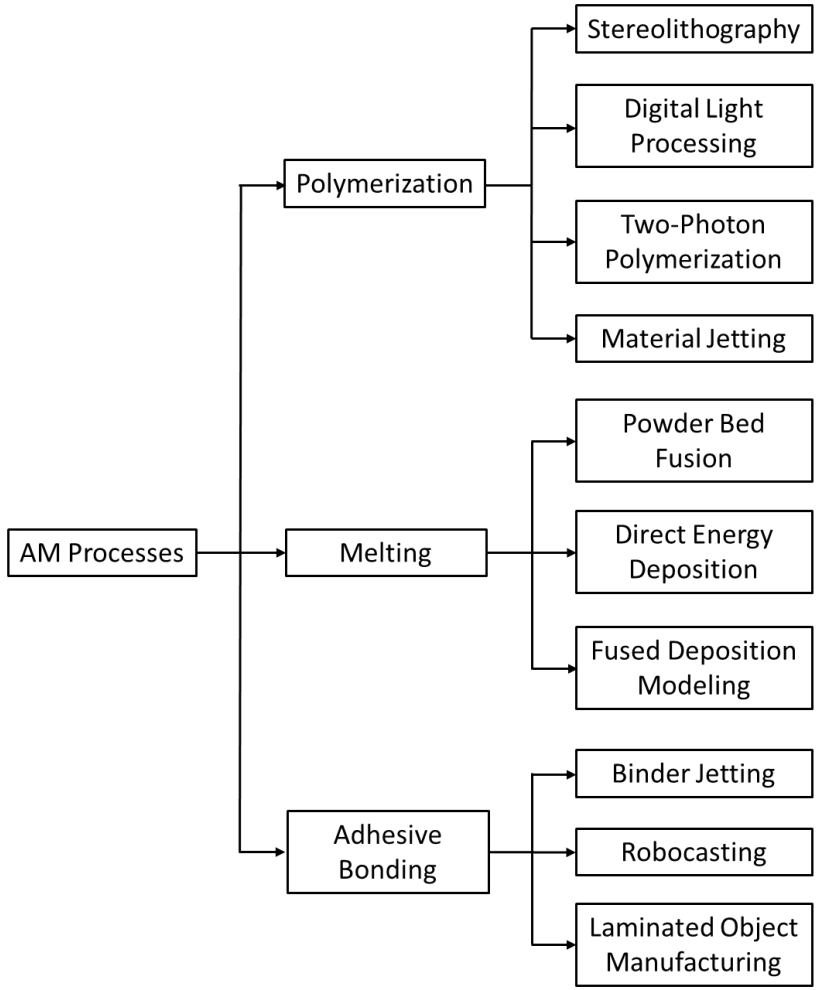


Future nuclear applications as structures or fuel (Source: UW, MSNW)

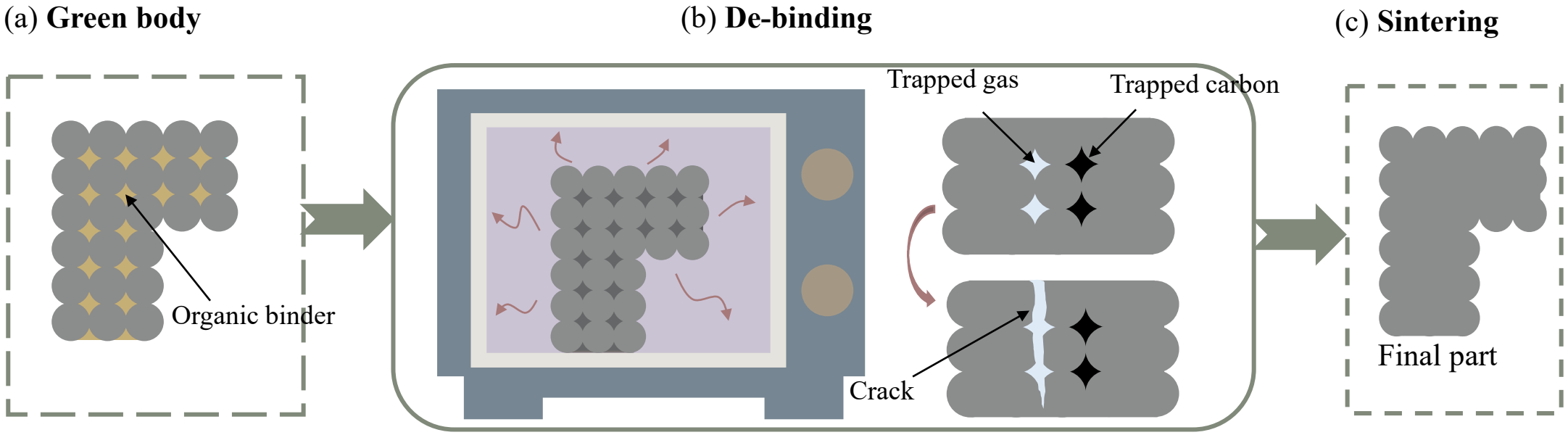
- Emerging ceramic applications, including defense, space, healthcare, and many others, are in need for much more complex designs.
- Ceramic AM: The solution to the inherent brittleness of ceramics, enabling complex geometries and compositions for ceramic-based materials.

Technology Gaps in Additive Manufacturing of Ceramics

- Current AM processes for ceramics are primarily based on technologies developed for other materials such as polymers and metals, and do not fully exploit the unique processing characteristics of ceramics.
- Ceramic processing technologies other than thermal sintering: microwave sintering, spark plasma sintering, flash sintering



Technology Gaps in Additive Manufacturing of Ceramics



- Ceramic AM requires higher fractions of organic binders. The more complex a shape is, the more binders the fabrication will need.
- The debinding and sintering steps are extremely energy-intensive and produce a significant amount of greenhouse gases, contributing to over 80%* of carbon emissions during the fabrication process (*my rough estimation).

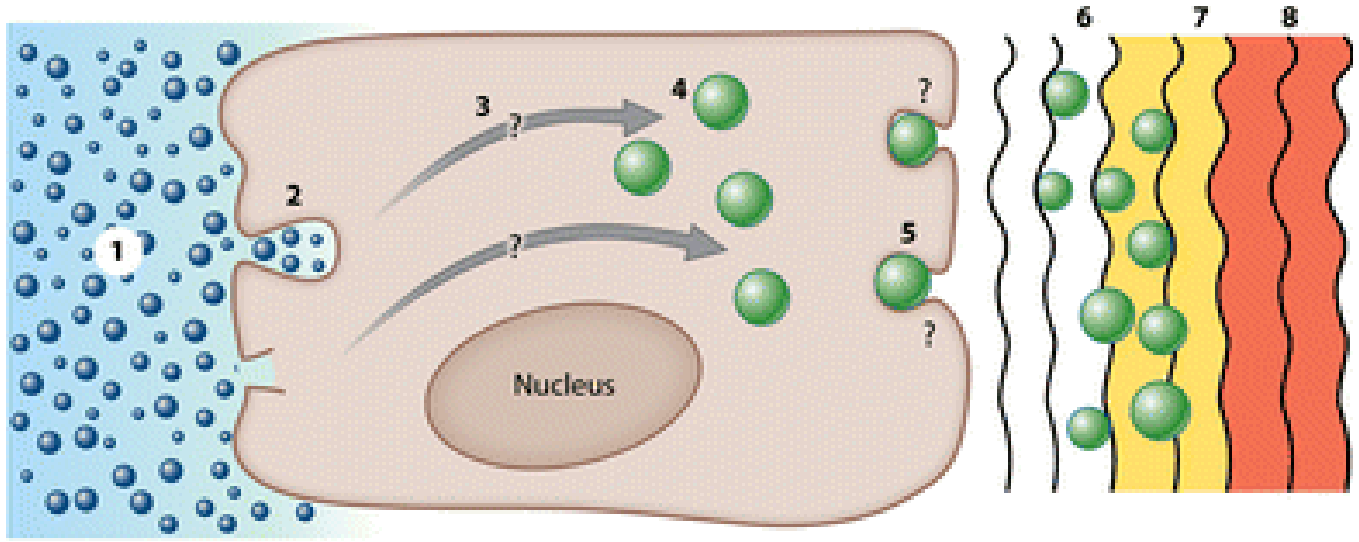
Ceramic Formation in Nature

Pearl in the clam

Rocks in the Grand Canyon National Park

Question: Can we learn from these gentle material-forming processes in nature to decarbonize ceramic AM?

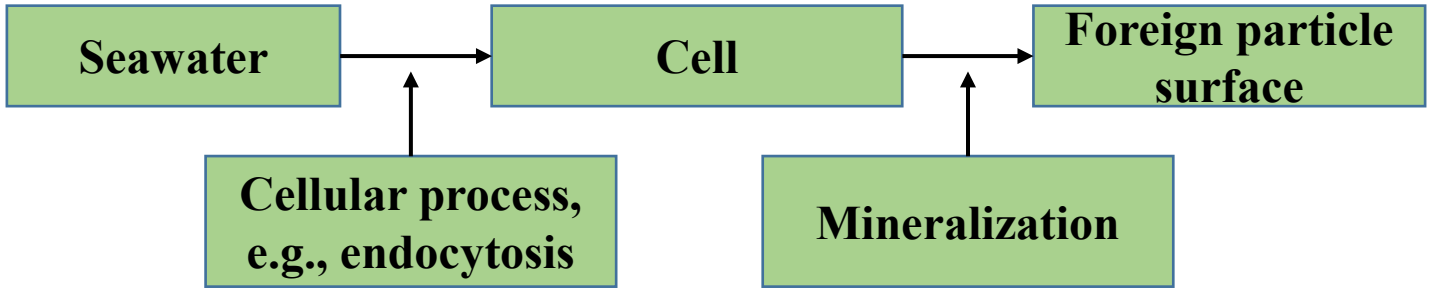
Ceramic Formation in Nature



Weiner, S. and Addadi, L., 2011. Crystallization pathways in biomineralization. *Annual review of materials research*.

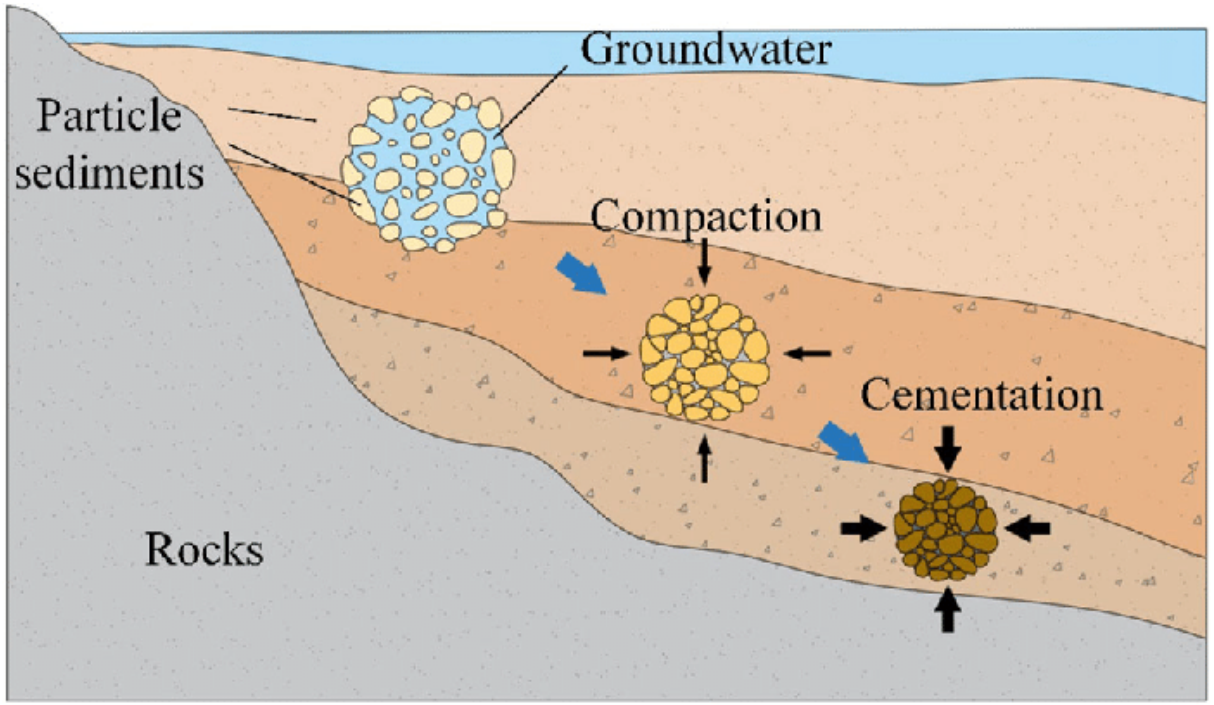
Pearl formation:
Nacre biomineralization

Ionic pathway:

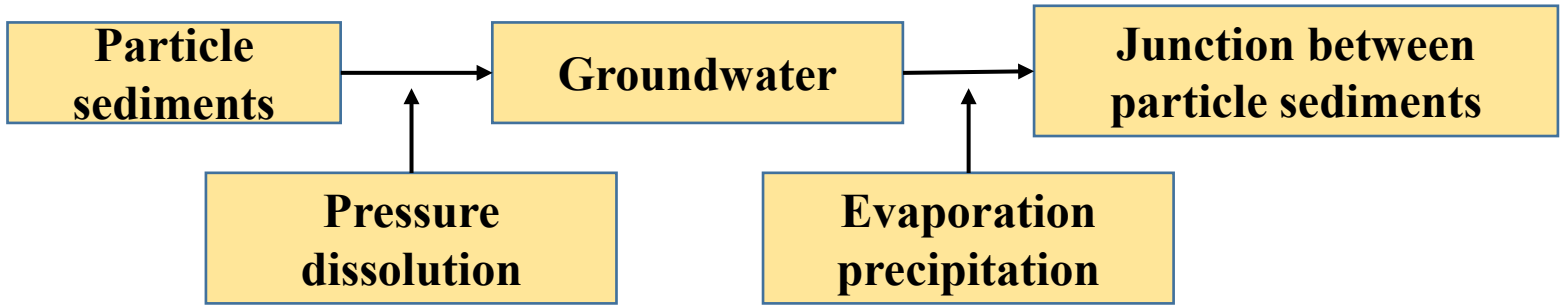


Ceramic Formation in Nature

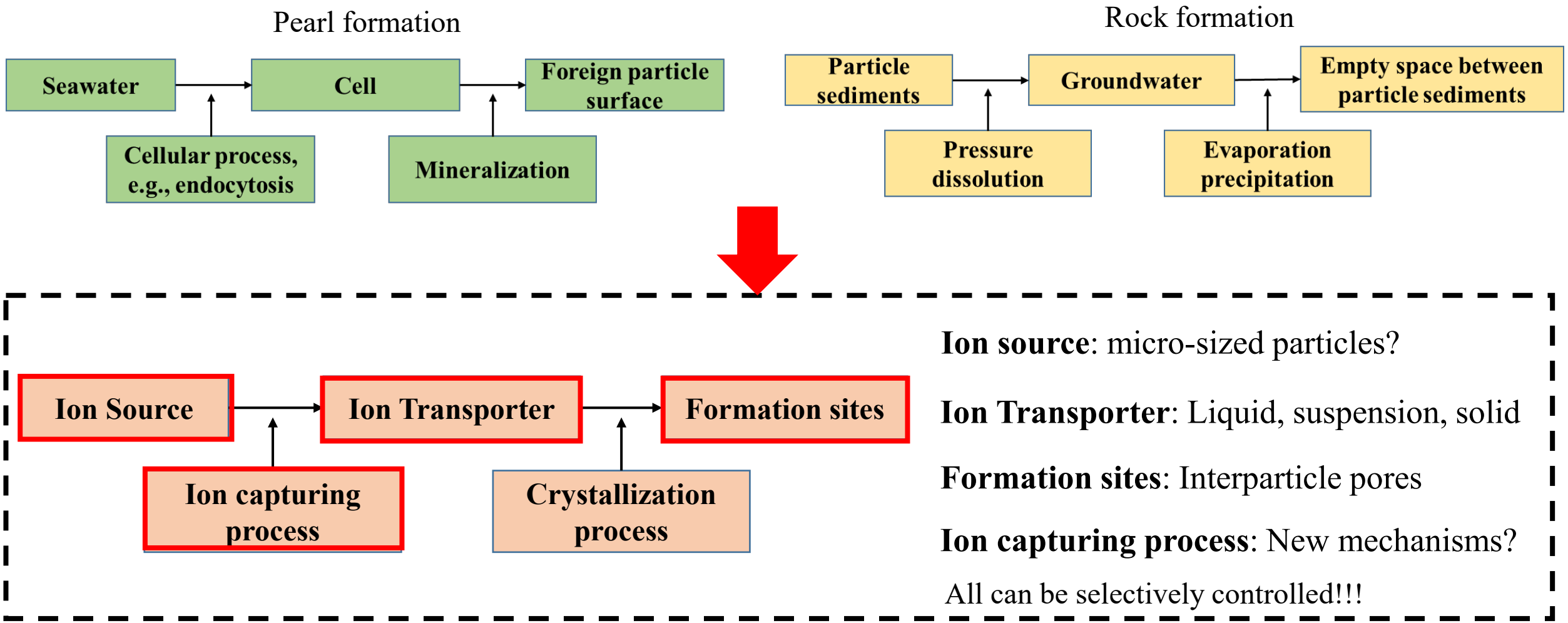
Rock formation:
Lithification process



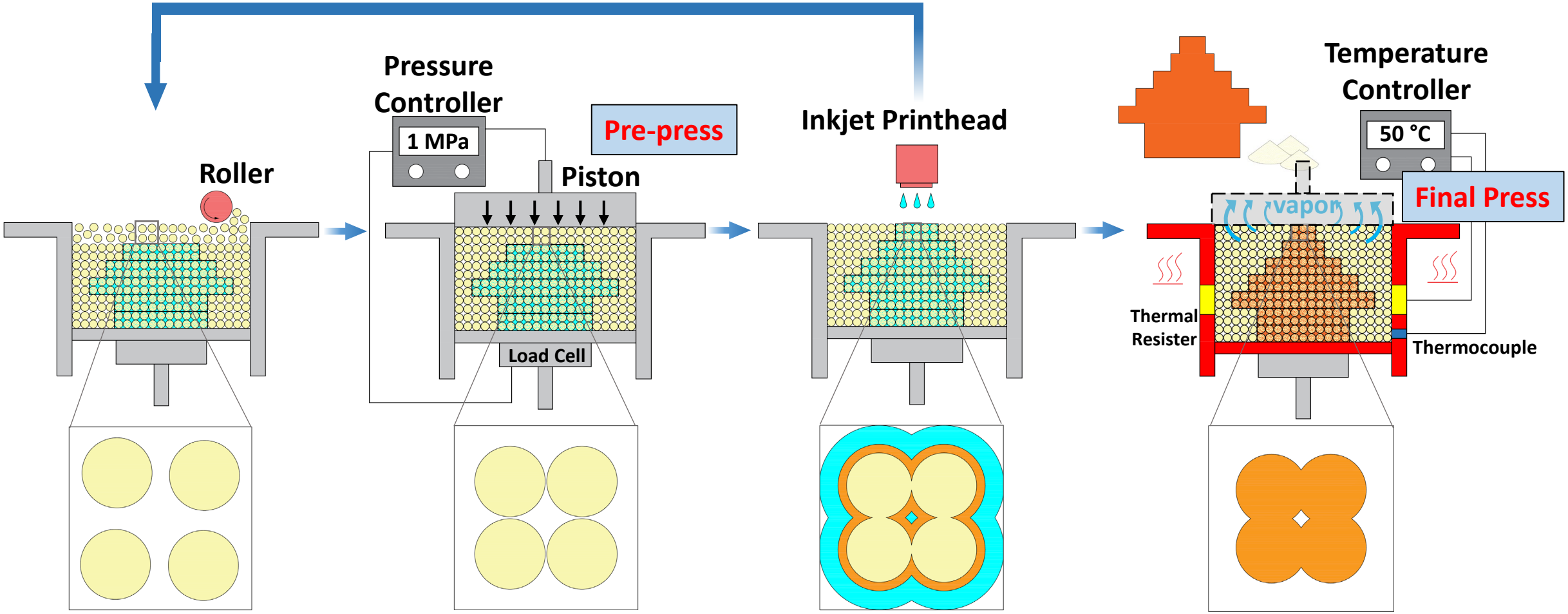
Ionic pathway:



Generalized pathway to decarbonize ceramic AM



Hydrothermal-assisted jet fusion – Schematic



Fei, F., et al. 2023. *Journal of the European Ceramic Society*.

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Thank you!
Questions?

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