**Title:** Fundamental understanding of rheological behavior of granular hydrogel during direct-ink writing additive manufacturing to facilitate 3D printing process design

**Team:** PI: Xiang Zhang; Assistant Professor, Mechanical Engineering
Co-PI: John Oakey; Professor, Chemical and Biomedical Engineering

**Total amount:** $25,000

**Research problem and its long-term benefits:** As additive manufacturing (AM) is becoming increasingly significant in various fields, it is also gaining importance in the energy industry, particularly in solar, wind, hydrogen, and nuclear energy. These are some of the fastest-growing energy sectors in the state of Wyoming that are enabling economic diversification during Wyoming's historic transition from fossil fuels to renewable sources. This transition also enhances the nation's energy resilience and sustainability. Therefore, currently there is an increasingly urgent need for advanced AM techniques and workforce development to facilitate this transition at UW and in Wyoming. Both the PI and co-PI have been actively developing AM related methods and applications. For example, Zhang has been developing both computational and experimental research, form polymer composites 3D printing levering a printing technique called frontal polymerization, where a localized and self-propagating exothermic polymerization front follows the nozzles and cure the ink instantaneously during the printing (Fig. 1 (a)). In a complementary manner, Oakey has been focused upon the 3D printing of biomaterials and tissue scaffolds, as shown in Fig. 1(b). This work focuses not upon 3D printing hardware or software, but the understanding of the rheological behavior of the ink, and development of novel resins for biomedical applications, particularly granular hydrogels and cell-laden biomaterials.

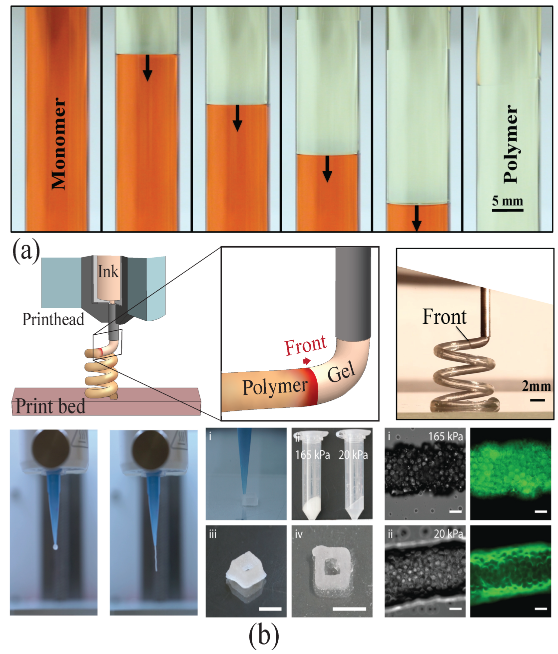


*Figure 1 AM research from Zhang and Oakey's group: a) an energy efficient composites 3D printing (Zhang); b) 3D printing of granular gels (Oakey).*

Both of their AM research is based on a so-called direct-ink writing additive manufacturing (DIW-AM) process, where the ink is extruded through a nozzle and deposited on a substrate to deliver the printed parts. ***This collaborative project is based upon a commonly identified bottleneck: the need for predictive control over rheological behavior during DIW-based 3D printing. If addressed this will: 1) produce a fundamental understanding of an ink's rheological behavior during the DIW process, which is suitable for developing proposals for NSF Advanced Manufacturing Program; and 2) guide the ink development and printing process design, that can improve their printing techniques for different applications suitable for fundings from NASA (Zhang) and the NIH (Oakey).***

AM-based research is transformative and has vast potential for commercialization. In the current case, the developed capability has great potential to support Wyoming's energy innovation by developing AM composites for wind energy, AM catalytic and absorptive device for $CO_2$ capture and conversion, AM for workforce training, and the need for machine learning for printing process monitoring and optimization on the fly, among others. As the proposed research matures into a sustainable research area, it will accrue long-term benefits to educational excellence, research expertise and diversification, and entrepreneurship development at Wyoming.

**Research plan:** This collaborative project will combine Zhang's expertise in 3D printing hardware and software development with Oakey's expertise in resin design. Here, we choose to use a granular ink system based upon hydrogel microparticles and microfibers, due to their broad application in biomedical fields. Granular hydrogels, a subclass of granular materials, are composed of jammed micron-scale hydrogel building blocks. Because of their packed structure, granular hydrogels are viscoelastic on the macroscale while retaining micron sized interstitial voids. Zhang's group will leverage their expertise in computational modeling and utilize the *reactive-flow* module in the COMSOL Multiphysics software (acquired from a previous EI funds led by Oakey), to develop the modeling capability that can study the extrusion behavior. While developed specifically for granular hydrogel, the model is generalizable to any type of viscoelastic ink filled with particles. Oakey's group will study the rheological behavior experimentally and couple microstructure with 3D printing behavior, process quantification, and material characterization.

**Short-term objective and work plan:** In the current project period, we will conduct preliminary studies to: 1) experimentally couple rheological behavior of granular hydrogels with printed properties using different nozzle diameter, flow rate and composition; 2) develop a preliminary understanding of how to control rheological behavior for successful printing; 3) develop a preliminary rheological modeling framework to simulate the printing process; 4) exercise the model to understand the factors that affects the rheological behavior most in the printing process; 5) Develop a plan for moving forward that integrates model and experimental development to fully reveal the rheological behavior of granular hydrogel, and 6) *develop and submit an external proposal to the NSF Advanced Manufacturing program or similar*.

**A list of potential future partners:** Zhang has previously submitted collaborative external proposals with the following partners in AM and these collaborations will be further enhanced based on the outcome of the current proposal: Patrick Johnson (UW CBE; NASA EPSCoR and NSF REU), Qian-Quan, (UW Zoology; Wyoming INBRE), Tyler Kerr and Ike Ruse (UW CEPS staff; NSF REU), Mostafa Yourdkhani (CSU ME; NSF CMMI), John Pojman (LSU Chemistry; DoD). Oakey has previously submitted collaborative external proposals with April Kloxin (University of Delaware), Mark Tibbitt (ETH Zürich), and Hadley Sikes (MIT), among others.

**A list of funding sources suitable for the current research: This work will be developed as a full proposal for submission to the** NSF Advanced Manufacturing program by the end of summer 2025. Beyond the primary target, this collaboration broadens the scope of potential applicatiosn and therefore funding targets, including NASA EPSCoR, (pre-proposal Fall 2024 and full proposal early 2025); DEPSCoR (preproposal Fall 2024); Wyoming Innovation Partnership (WIP); Idaho National Laboratory LDRD proposal with Dr. Humberto Garcia (Spring 2025), the NSF Partnerships for Innovation (September 2024), and the NIH P01 program.

**Budget justification:**

**Graduate students support: $23,380 -** To ensure sufficient preliminary data will be generated to consolidate the proposal to be developed and submitted to the NSF Advanced Manufacturing Program, one semester's support for two M.S. students (one from the PI's group, the other from the co-PI's group) are requested, leading to a total of $11,690x2=$23,380 based on the graduate expense listed at: https://www.uwyo.edu/research/proposal-development/proposal-tool-kit/graduate-assistantships.html

**Supply costs: $1,620** - Due to the nature of the 3D printing work, consumables and labware are needed to conduct the preliminary study. Additionally, there will be other small research supply costs. A total of $1,620 is requested. Both the PI and co-PI will use other resources to complement the supplies cost, as the requested amount is less than what we expect, but the total budget already reaches the budget ceiling.

The total cost from the above calculation is $25,000.