Regenerative Energy-Efficient Manufacturing of Thermoset Polymeric Materials (REMAT)
EFRC Director: Nancy Sottos
Lead Institution: University of Illinois Urbana Champaign
Class: 2022 – 2026

Mission Statement*: To advance the science of thermochemical reaction-diffusion processes in additive and morphogenic manufacturing and accelerate a transformative, circular strategy for thermoset polymeric and composite materials with programmed end-of-life.*

The Center for Regenerative Energy-Efficient Manufacturing of Thermoset Polymeric Materials (REMAT), a DOE BES Energy Frontier Research Center (EFRC) at the University of Illinois at Urbana-Champaign (UIUC) (lead) and its partner institutions: Sandia National Laboratories (SNL), Massachusetts Institute of Technology (MIT), Harvard University, Stanford University, and the University of Utah will address fundamental scientific challenges required to overcome barriers for energy efficient manufacturing of thermoset polymers and composites with realistic end-of-life strategies. Thermoset polymers and composites possess the necessary chemical and mechanical properties critical for achieving lightweight, durable structures in the energy, aerospace, and transportation industries, but the vast energy input required for initial manufacture (Gigajoules), long cure times to develop desired structural properties (hrs), and lack of end-of-life strategies render these materials unsustainable. The development of thermoset materials manufactured with a far lower energetic and environmental footprint is critically important to a carbon-neutral economy. The Center's goal is to discover thermoset resin formulations that enable (i) closed-loop controlled, energy-efficient additive manufacturing, (ii) moving beyond additive to nascent morphogenic manufacturing strategies, (iii) programmed end-of-life upcycling, and (iv) precise understanding of the chemistry and physics that control properties, performance, and multifunctionality for (re)use in structural materials.

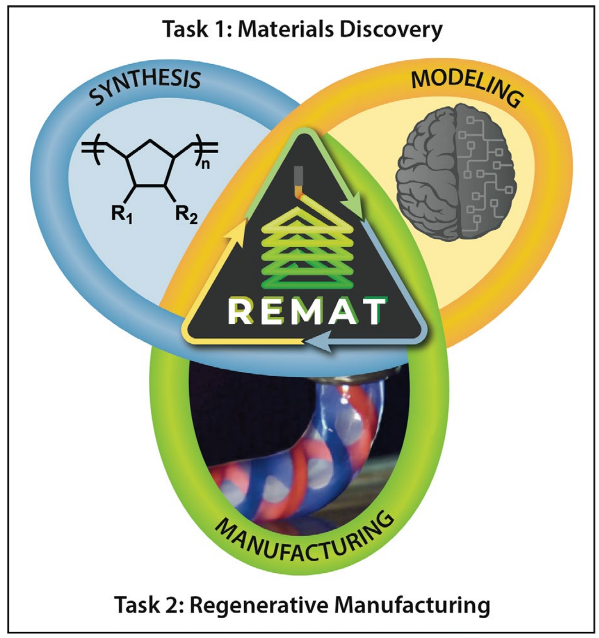

Fig. 1: Organization of the EFRC for Regenerative Energy-Efficient Manufacturing of Thermoset Polymeric Materials (REMAT).

The REMAT EFRC is addressing these multi-faceted scientific challenges through two highly collaborative and integrated Research Tasks (Fig. 1) that bring together synthesis, modeling, high throughput (HTP) experimentation, characterization, and machine learning (ML) to develop transformative manufacturing platforms that harnesses energy-efficient frontal polymerization. The Center will establish a new framework for fundamental research in frontal polymerization chemistry and manufacturing that develops state-of-the-art capabilities and expertise based on the realization that control and understanding of monomer chemical compositions are necessary for sustainable manufacture of thermoset structures. The research flow and subtasks are summarized in Fig. 2.

Task 1 – Materials Discovery for Circular Lifecycle will establish a new class of regenerative thermosetting polymers with controlled network evolution and generation-invariant properties. Subtask 1.1 focuses on resin chemistry. Cross-cutting Subtask 1.2 connects the input degrees of freedom (DOFs) with the output properties through the construction of statistical models. Subtask 1.3 uses automation to both prepare resins and make measurements of FP behavior.

Task 2 – Regenerative Manufacturing will combine additive manufacturing with a non-linear, dissipative curing process to achieve high energy efficiency. Resins developed in Subtask 1.3 are used by Task 2 for advanced manufacturing and materials properties assessment. Oligomers harvested from deconstructed thermosets returned to Task 1 for reactivation and reuse. At the intersection of Tasks 1 and 2 is the science of morphogenic manufacturing, which seeks to harness the mechanisms of dissipative structure formation to produce materials with exceptional durability.

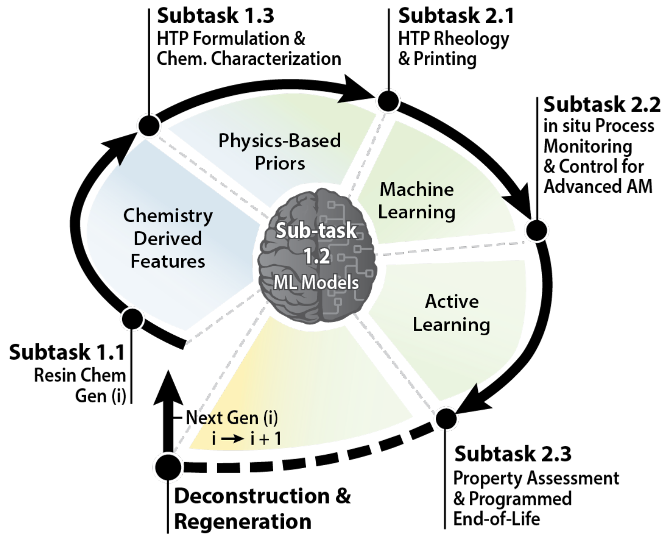

Fig. 2: Overview of end-to-end materials design and development cycle.

REMAT research will enhance the US economic competitiveness in industries ranging from lightweight electric vehicles to wind turbine blades. The integration of end-of-life strategies with materials discovery will enable multiple generations of reuse while reducing our dependence on petrochemical resources. The REMAT EFRC will also train the next generation of graduate students and postdoctoral researchers needed to carry out transformational research at the interface between sustainable materials chemistry and energy-efficient manufacturing in an innovative, inclusive, and interdisciplinary team-oriented environment.

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