Colorado State University
Fort Collins, CO
Delphine Farmer, Megan Willis, Lauren Garofolo
$1,200,000

The fundamental chemical and physical transformations that occur in buildings are poorly understood due to extreme complexity and variability across indoor environments. How molecules move between phases and chemically transform controls their reactivity and toxicity - and thus human exposure. The underlying reactions of the indoor air system must be constrained to identify relevant molecular properties to understand the spatial and temporal scales of indoor chemistry and thus predict molecular fate. However, the current research paradigm is observational, with intensive study of single buildings and isolated processes. These studies can only infer fate, not directly track fate. The team will directly measure chemical transformations in the complex indoor multiphase system. Instead of treating buildings as engineered air enclosures, they will be treated as manufactured ecosystems. The team aims to discover the biogeochemical cycles of the indoor environment using stable isotopes to label and track molecules as they move and transform through the many phases of real buildings. This will be the first-time chemists directly track the atoms of oxidants and pollutants through the air and surfaces of an ecosystem – let alone a building. Only with a transformative understanding of the indoor web of biogeochemical processes can pollutant exposure be predicted. This project will help develop predictive capacity for indoor chemistry and open an entirely new avenue to advance environmental and multiphase chemistry.

University of California, Santa Barbara
Santa Barbara, CA
Matthew Fisher, Sagar Vijay, David Weld
$1,300,000

It has been understood for more than a century that, in quantum mechanics, measurement is special. Measuring a quantum system gives intrinsically random results and irreversibly alters the system itself. Recent theoretical breakthroughs have extended this concept to the many-body regime, demonstrating that simply observing an evolving quantum many-body ensemble can induce new states of matter which cannot arise in equilibrium. Contemporaneously, recently developed techniques of quantum control have enabled the creation of synthetic quantum matter that can be subjected to repeated partial measurement and manipulated without destroying quantum coherence. Together, these advances open up a totally unexplored frontier for quantum many-body physics, in which not only measurement but also feedback are used to tailor the properties of

quantum matter. According to this new theoretical viewpoint, all our previous understanding of quantum condensed matter has been restricted to the equilibrium, unmonitored, feedback-free regime; what new phenomena can emerge in quantum many-body systems if future control parameters depend on the results of past observations? This team of PIs from the University of California, Santa Barbara will pursue a joint research program to address these foundational questions and establish the new field of quantum interactive matter.

University of Colorado Boulder
Boulder, CO
Scott Diddams
$1,000,000

Phased-array astronomical imaging is a technique by which detected electromagnetic (EM) radiation from multiple smaller aperture telescopes is coherently combined to provide images with higher spatial resolution. This approach is widely applied in the microwave and millimeter-wave regions of the spectrum, but progress in phased-array imaging over the largest baselines in the infrared has been limited by the lack of sensitive and broad bandwidth heterodyne detector technology and the means to phase-coherently link these higher frequencies of EM radiation. This project addresses these challenges with a new coherent modality for heterodyne detection of infrared thermal radiation that leverages advances in optical frequency combs emerging from the field of laser physics. The most ambitious implementation, which the PI calls dual-comb electrooptic sampled detection, will use two optical frequency combs to upconvert infrared radiation to the near infrared for detection with mature telecommunications technology. If successful, these advances will enable 10-300× improved spatial resolution; up to 10,000× increase in detected bandwidth; and femtosecond-scale timing resolution intrinsic to the clockwork of the frequency comb itself. Such a novel detector would underpin the scientific foundation of a new generation of infrared phased-array telescopes aimed at answering outstanding questions related to the early lives of stars, galactic and planetary formation, and the origins of the universe and life itself.

University of Michigan
Ann Arbor, MI
Bryan Goldsmith, Rohini Bali, Jovan Kamcev, Suljo Linic , Charles McCrory, Nirala Singh
$1,300,000

The goal of this work is to develop a more sustainable approach for producing urea ($CO(NH_2)_2$) by electrochemically co-reducing carbon dioxide (CO_2) and nitrate (NO_3^-) using water as the proton source. Urea is an essential fertilizer that is mainly synthesized by reacting ammonia with CO_2 at high temperatures. The team will advance the fundamental science behind designing electrocatalytic systems for the electrochemical production of urea with net-zero CO_2 emissions and innovate the chemistry of C-N coupling, the utility of which extends beyond production of urea. Producing urea from NO_3^- and CO_2 would remediate two major pollutants while producing an essential fertilizer. The work will entail understanding the unique chemistry of the co-reduction of NO_3^- and CO_2 (i.e., C-N coupling) to make urea using novel catalyst-polymer systems. This research has the potential to create a paradigm shift in the production of urea—and transform its real-world environmentally harmful production processes. The research will elucidate the chemistry and reaction mechanism for the coupling of CO_2 and NO_3^- and give molecular insights. Knowledge of C-N coupling would benefit many important reactions involving building-block molecules such as CO_2, CO, N_2, NO, NO_2^- and NO_3^-. The fundamental research on catalyst-polymer composites for C-N coupling will enhance the basic understanding of single-atom alloy (SAA) catalysts and the ability to couple catalysts with polymers that control transport of reactants to and from the reaction site, which will give unique control of the reaction and desired product.

University of Southern California
Los Angeles, CA
Ian Ehrenreich
$1,000,000

Nearly any natural or novel bacterial genome can now be cost-effectively synthesized de novo. Starting with their design in silico, these genomes are fabricated through the progressive assembly of small chemically synthesized DNA pieces into larger molecules using a mix of in vitro and in vivo techniques. Such bacterial genome synthesis has the potential to transform basic research and biotechnology. However, bringing synthetic bacterial genomes to life remains a major challenge. Current approaches for booting up synthetic bacterial genomes have constraints that limit their broader use. The team plans to boot up synthetic bacterial genomes inside mitochondria. Mitochondria are energy-generating eukaryotic organelles that are derived from an ancient endosymbiotic bacterium and have their own small genomes. With some modification, mitochondria might provide a powerful cell-like environment for booting up synthetic bacterial genomes. The team will address three questions using the budding yeast *Saccharomyces*

cerevisiae: (1) Do natural or engineered mitochondria express bacterial genes? (2) Can mitochondria, which use a non-standard genetic code, be converted to a standard genetic code? (3) Can engineered mitochondria bring bacterial genomes to life? The work will culminate in the generation of mitochondria containing *E. coli* genomes and examination of whether these mitochondria turn into bacteria.