Human alteration of the nitrogen (N) cycle via the Haber process, intensive crop cultivation, and fossil fuel use has approximately doubled the rate of N input to the terrestrial environment. Loss of anthropogenic N to natural systems has led to an array of environmental and public health problems, including ammonia toxicity to aquatic life, oxygen depletion, greenhouse gas (nitrous oxide) production, eutrophication of nutrient limited water bodies resulting in vast dead zones in the ocean margins, and direct adverse effects to human health (e.g. “blue baby syndrome” caused by nitrate.) Both nitrous oxide emissions and energy-intensive operation are hallmarks of conventional wastewater treatment plant bioreactors that rely on the microbial processes of nitrification and denitrification to remove reactive N from wastewater. However, the last decade has seen the emergence of several novel microbial ‘players’ in the global biogeochemical N cycle—namely, ammonia oxidation within the archaeal domain, and anammox (anaerobic ammonia oxidizers) that employ NO$_2^-$ as the electron acceptor to oxidize NH$_4^+$ to N$_2$ gas via a unique hydrazine intermediate. In this talk, I will detail efforts to leverage these newly discovered microbial groups to enable low-energy, sustainable bioprocesses for N pollution prevention, with a focus on stability and reliability in combined nitritation-anammox process variations. Work to date has demonstrated significantly different overall performance in two such process variations employing different types of microbial aggregates—suspended growth biomass and biofilm carriers—under both baseline and transient perturbation scenarios. In addition, replicate reactors within each process variation displayed surprisingly consistent patterns of microbial community dynamics and phylogenetic diversity, with greater stability and richness apparent in biofilm versus suspended growth communities. Taken together, our results suggest that biofilm-based systems may be more resistant to perturbations that predominantly impact anammox activity, while suspended growth systems may be more resistant to events that decrease nitrifier activity. Despite the promise of these novel nitritation-anammox processes, such systems still rely on net consumption of energy and resources for the prevention of nutrient pollution. I will conclude this talk by introducing an emerging paradigm in which waste streams are viewed not as costly energy sinks but as feedstocks for energy or resource recovery. I will highlight ongoing research directed at microbial production and capture of nitrous oxide that may allow, for the first time, direct energy extraction from waste N.