Biological systems are driven far from equilibrium through the consumption and dissipation of energy. However, it is unclear if the quality or efficiency of a biological process is enhanced the further the system is driven from equilibrium. To address this fundamental question, we develop experimental approaches to control the consumption of energy in biological systems, and theoretical approaches to measure its dissipation. Together, we gain an understanding of the regulation of energy during the assembly and performance of biological machinery across diverse time and length-scales. At the molecular scale, we develop technologies to precisely coordinate the de novo assembly of the protein-based mechanical machinery of the cell and control its consumption of chemical energy. In doing so, we seek to mimic the physical behaviors of living cells through modulating the internal, non-equilibrium “activity” in a non-living system. We then apply frameworks from stochastic thermodynamics to estimate the production of entropy using phase space fluxes and the breaking of time reversal symmetry. At the mesoscopic scale, we study the physical behaviors of cells and tissues by abstracting them as driven liquids, whose behaviors are described by models of capillarity and wetting adapted to reflect activity gleaned from molecular studies. Together, these experimental and theoretical methods can enable an understanding of the relationship between dissipation and the efficiency of biological processes with significant impacts on phenotypic outcomes such as cancer metastasis, and wound healing.