One of the goals of Biochemistry is to understand how living organisms convert chemical potential energy and matter into biological work such as growth and reproduction. By studying the biochemistry and physiology of organisms that exist near the “thermodynamic limit of life” (the boundary between inorganic and biological matter), we can gain insight about how living systems control the flow of mass and energy through the environment. I will discuss our group’s efforts to uncouple and manipulate the rates of growth and methane production by methane-producing archaea (methanogens). Methanogens have an “ancient” metabolism that allows them to grow solely on inorganic carbon and energy sources. They are found in nearly all anaerobic habitats from deep-sea thermal vents, to Antarctic tundra soil, to the human digestive tract. Worldwide, methanogens are harnessed to generate renewable methane fuel from biomass. Our results indicate it is indeed possible to rationally direct carbon flow in methanogens. Furthermore, our methodology may be broadly applicable to other organisms and complex multi-organism biological systems.