The energetics of anabolism in natural settings

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In an effort to better understand the origin, evolution and extent of life, significant effort has gone into finding the limits of temperature, pressure, pH, salinity and other compositional and physical variables that define habitability. However, one variable in particular – energy – has received much less attention. Virtually every aspect of microbial behavior requires energy, including growth; nutrient uptake; motility; excretion of biomolecules; synthesis of external structures; and changes in stored nutrients. Although some of these fall within the definition of maintenance functions, many, like growth, require the synthesis of biomolecules. Consequently, the energy required to make biomolecules is a fundamental limit to the habitability of an environment.

The environmental conditions that describe an ecosystem define the amount of energy available to the resident organisms and the amount of energy required to build biomass. Here, we quantify the amount of energy required to make biomass as a function of temperature; pressure; redox state; the sources of C, N and S; cell mass and the time that an organism requires to double or replace its biomass. Specifically, these energetics are calculated from 0 to 125ºC, 0.1 to 500 MPa and -0.38 to +0.86 V using CO2, acetate or CH4 for C, NO_3^- or NH_4^+ for N and SO_4^{2-} or HS- for S. The amounts of energy associated with synthesizing the biomolecules that make up a cell, which varies over 39 kJ (g cell)$^{-1}$, are then used to compute energy-based yield coefficients for a vast range of environmental conditions. Taken together, environmental variables and the range of cell sizes leads to a ~4 orders of magnitude difference between the number of microbial cells that can be made from a Joule of Gibbs energy under the most (5.06×10^{11} cell J^{-1}) and least (5.21×10^{7} cell J^{-1}) ideal conditions. When doubling/replacement time is taken into account, the range of anabolism energies can expand even further.