Growth kinetics and gene expression in a hyperthermophilic methanogen during H_2-limited and syntrophic growth

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Thermophilic methanogens are primarily H_2 limited in hot subseafloor environments [1,2] but persist in low H_2 hydrothermal vents, methane seeps, and petroleum reservoirs. This may be due to physiological adaptations to low H_2 conditions and a reliance on H_2 syntrophy for survival. The hyperthermophilic methanogen *Methanocaldococcus jannaschii* was grown in a chemostat at high (80 μM) and low (15-30 μM) aqueous H_2 concentrations and syntrophically in bottles with the hyperthermophilic, heterotrophic H_2 producer *Thermococcus paralvinellae*. The purpose was to measure changes in growth parameters and gene expression in *M. jannaschii* with changes in H_2 flux. Growth rates and cell-specific CH_4 production rates of *M. jannaschii* decreased with decreasing H_2 availability, and decreased further during syntrophy. Growth yield (biomass produced per mole of CH_4 produced) however increased significantly when *M. jannaschii* was grown on low H_2, but were at their lowest levels during syntrophy. Differential gene expression analyses using RNA-Seq showed that the enzyme responsible for the reduction of methenyl group to a methylene group during carbon fixation switches from a H_2-dependent enzyme to a coenzyme F_{420}-dependent enzyme with decreasing H_2 availability and into syntrophy. During syntrophy, the genes for energy generation on the membrane decreased in their expression levels. The results suggest that *M. jannaschii* cycles H_2 internally for CH_4 and energy production in high H_2 environments but increases its carbon use efficiency under low H_2 conditions, and produces CH_4 at low rates when dependent on H_2 syntrophy.

T. paralvinellae produced formate when inhibited by excess H_2 [3]. *T. paralvinellae* growth rates were the same during monoculture and syntrophic growth, but formate was only produced in monoculture suggesting amelioration of H_2 inhibition during syntrophy.

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