Novel Multi Scale Systems Integration of a Hydrogenase Centered Universal Energy Chassis (Hcuec) for Multi Environment Biogenic Hydrogen Production and Renewable Energy Deployment

Weeraratne, Radheeka (School: Dickinson High School)

Hydrogen is a promising clean fuel, yet most global production still relies on fossil fuel intensive processes. Biogenic hydrogen offers a renewable alternative, but natural microbes suffer from low efficiency, narrow environmental tolerance, and oxygen sensitive hydrogenases. This project integrates experimental microbiology, synthetic systems design, and multi scale energy modeling to develop the Hydrogenase Centered Universal Energy Chassis (HCUEC) and a scalable BioE platform for continuous, multi environment hydrogen production. R. palustris TIE 1 was used to quantify how 6 light conditions, 3 pH values, and 4 oxygen removal strategies influence hydrogen output. Red light, pH 7, and combined L cysteine + nitrogen purging produced the highest yield (16.55mL H2 per 34mL culture in 24 h). Parallel tests with C. reinhardtii produced significantly lower hydrogen, demonstrating that hydrogenase behavior varies across organisms and motivating the need for a synthetic chassis. Using these data, the HCUEC was designed with multi wavelength photosystems, encapsulin protected hydrogenases, gas vesicle oxygen barriers, sulfur/iron redox pathways for nighttime metabolism, and toxin antitoxin containment circuits. A custom simulation converted measured hydrogen output into electrical energy (kWh). Scaling the experimentally derived rate with a modeled 20x HCUEC improvement yields 43,500kg H2/day from a 0.01 square km platform, equivalent to 1.4 GWh/day of clean electricity. This corresponds to a theoretical electricity cost of $0.002/kWh and a modeled hydrogen cost of $0.06/kg. This work presents a data driven blueprint for a universal biological power plant capable of delivering ultra low cost, zero carbon energy across terrestrial and extraterrestrial environments.

Awards Won: