H amann Group Research: There is a LOT of energy from sunlight striking the Earth’s surface: approximately $10^{17}$ Joules/second. For comparison, the averaged worldwide energy demand is approximately $10^{13}$ Joules/second. The Hamann group is engaged in interdisciplinary research to address basic science issues related to new methods and materials for utilizing this incredible resource to produce electricity and chemical fuels. Of specific interest are regenerative and non-regenerative photoelectrochemical cells, including dye-sensitized solar cells and thin-film absorber photocatalytic systems. In addition, we are interested in the use of ammonia as an energy (hydrogen) carrier and are investigating the electrocatalytic synthesis and electrolysis of ammonia.

Dye Sensitized Solar Cells: We are investigating the fundamental role of the relevant dye-sensitized solar cell, DSSC, components (redox shuttle, photoanode and sensitizer) involved in key efficiency-determining processes. Ultra-fast electron injection from a photoexcited sensitizer into a photoanode produces a charge separated state with typically high quantum efficiency. We are primarily interested in the subsequent processes of dye regeneration and recombination which control the efficiency of charge collection. We systematically vary the components involved in each reaction and interrogate them with a series of photoelectrochemical measurements. The general lessons learned will ultimately be used to develop design rules for next generation DSSCs comprised of molecules and materials which are capable of overcoming the kinetic and energetic constraints of current generation cells.

Thin Film Absorber Solar Cells: We are interested in exploring the use of thin films to overcome the problems associated with short collection length materials. One absorbing material of current interest is $\alpha$-Fe$_2$O$_3$ (hematite). Hematite is an attractive material for solar energy conversion due to the abundance of iron in the earth’s crust, the extremely low cost, chemical stability and environmental harmlessness. In addition, hematite has been shown to be a promising water oxidation photocatalyst in a fuel-forming (non-regenerative) photoelectrochemical cells. We are currently elucidating the rate limiting steps as well as water oxidation mechanism on the electrode surface. Additional topics of recent interest include understanding the effect of substrate and underlayer materials, incorporation of dopants, and surface layers (e.g. catalysts) on the water oxidation efficiency. Additional oxide, nitride and oxynitride semiconductor materials are also under current investigation.

Ammonia Electrocatalysis: Nitrogen is the most abundant gas in Earth’s atmosphere and water is the most abundant liquid on Earth’s surface: combining the catalytic reduction of N$_2$ with the oxidation of H$_2$O to produce NH$_3$ offers a route to scalable renewable energy storage. Liquid ammonia has an energy density comparable to methanol, and the stored chemical energy can in principle be used to generate electricity or H$_2$ on demand. The electrolysis of liquid NH$_3$ has received limited attention to date, however. We are therefore exploring the electrocatalytic conversion of liquid NH$_3$ to H$_2$. We are also engaged on a broader collaborative effort to develop and investigate new electro-catalysts based on earth-abundant materials for NH$_3$ synthesis and electrolysis.

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