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Photoelectrochemical Hydrogen Evolution from Water Vapor for 1000 Hours at 14% Efficiency

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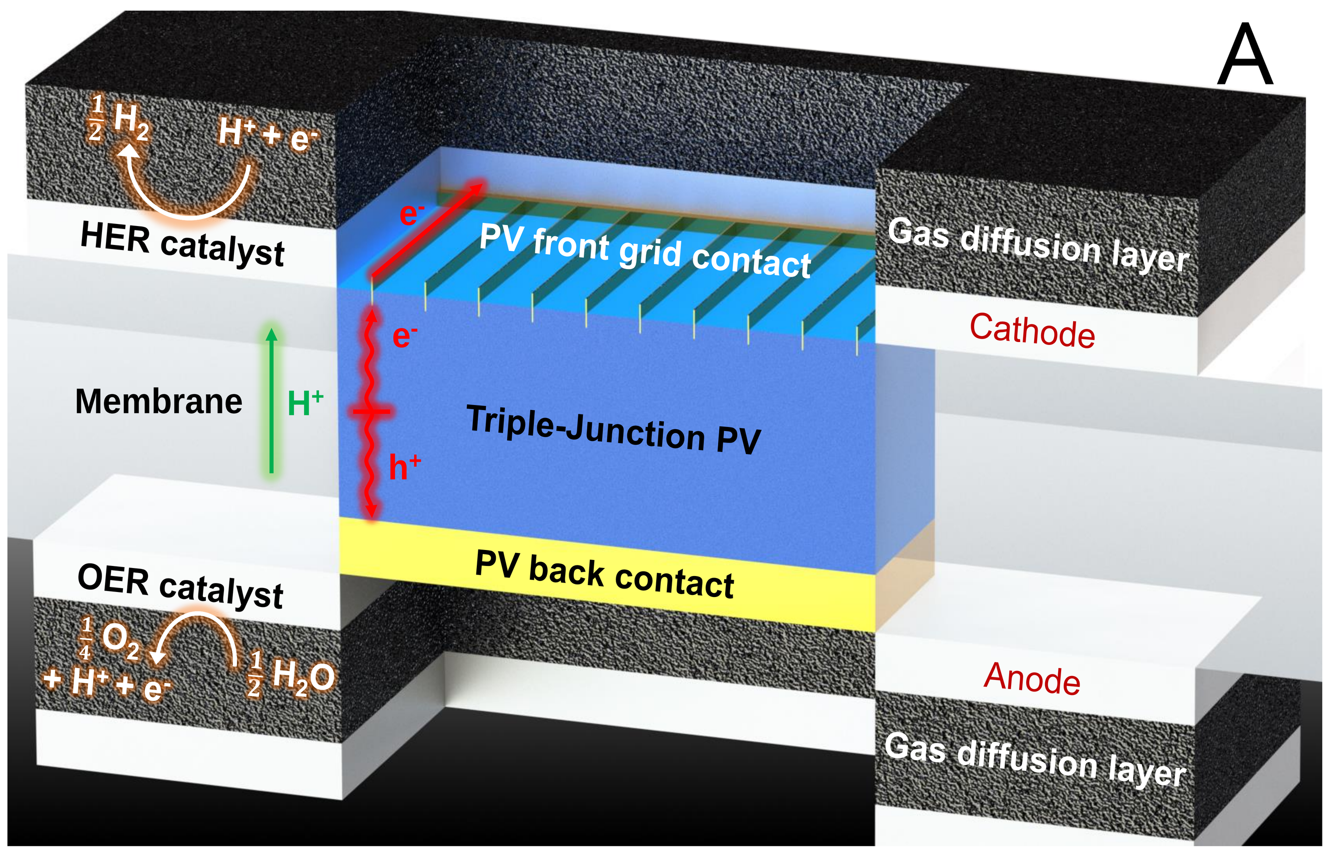
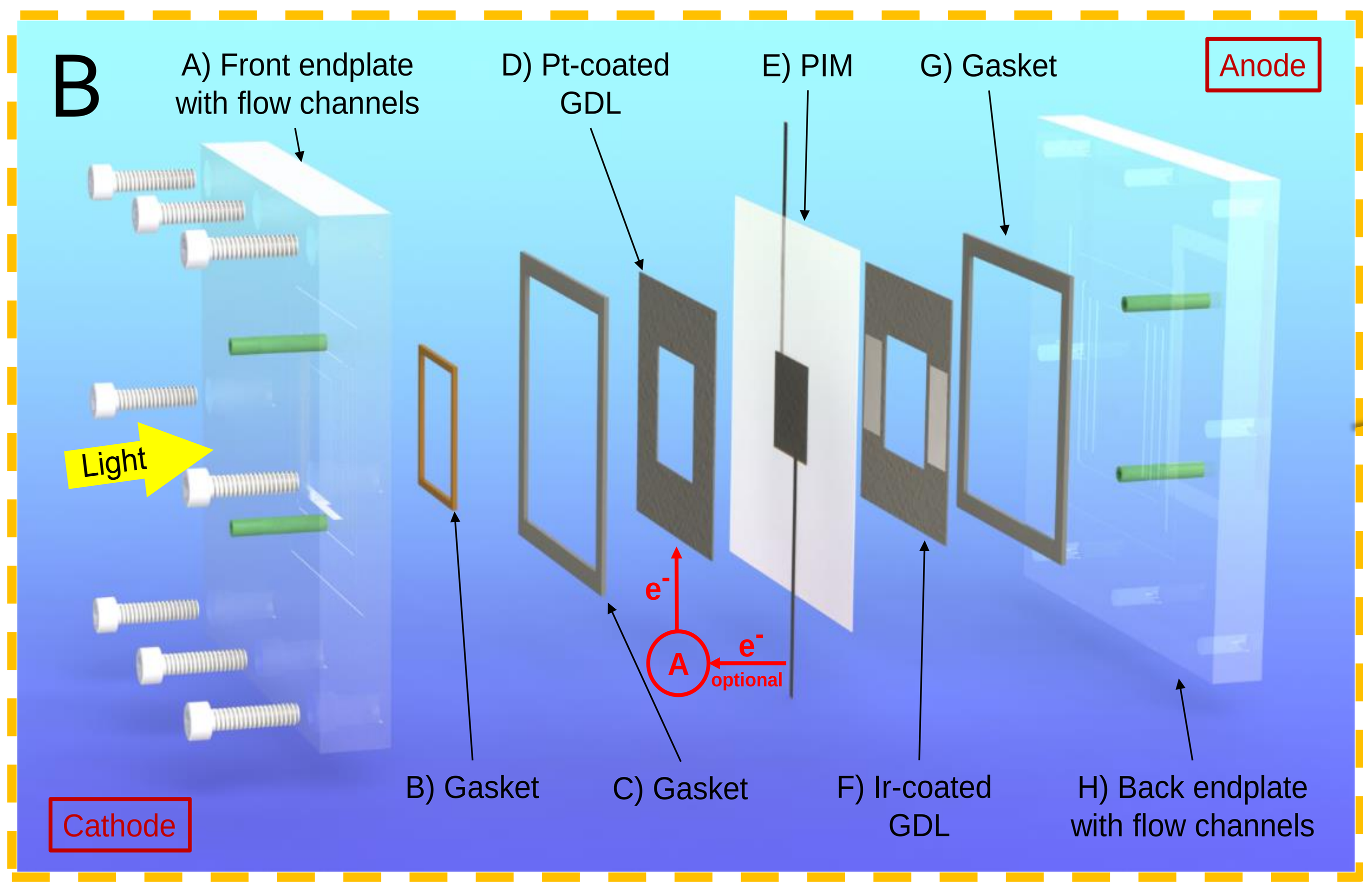
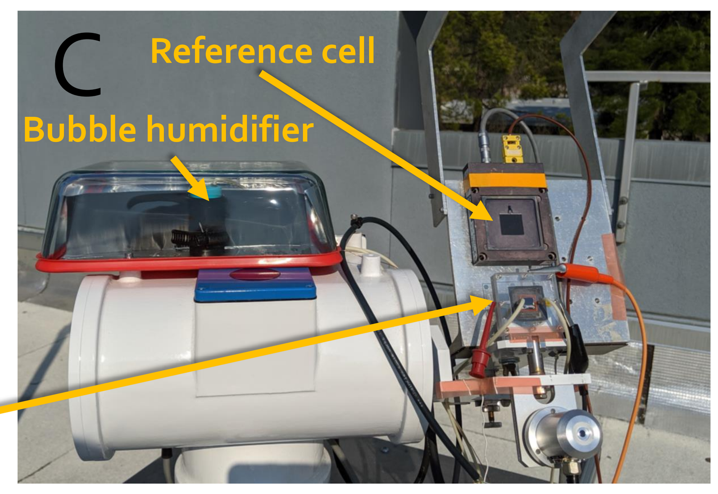
Abstract:

The development of a fully-integrated, photoelectrochemical (PEC) device coupling water oxidation to hydrogen evolution using a III-V triple-junction photovoltaic (PV) embedded in a Nafion membrane is reported. This architecture is genuinely monolithic, with wireless catalyst integration being achieved via compression of metal sputter-coated, carbon electrodes against the front and back PV contacts. The resulting MEA-type, sandwich structure minimizes the path length for proton conduction through the membrane ionomer, while simultaneously preventing PV light attenuation by the catalyst layer, a common issue for monolithic PEC structures. Solar illumination of this construct, when operating with a water vapor feed, yields a stable solar-to-hydrogen efficiency for more than 1000 hours, peaking at 14%. The placement of an electrical shunt between the PV and the cathode catalyst layer allows the measurement of electrical current and calculation of faradaic efficiencies throughout the stability experiment. Concurrent logging of the operating voltage permits the deconvolution of performance losses caused either by PV shading due to condensation or cell dehydration, which can be used to automatically adjust the operating conditions such as the feed gas humidity.

Introduction

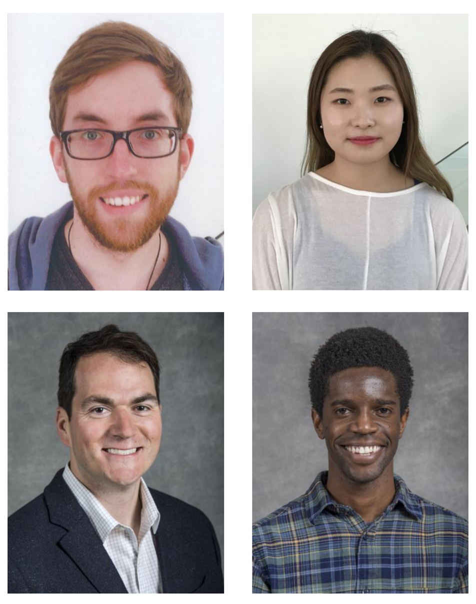






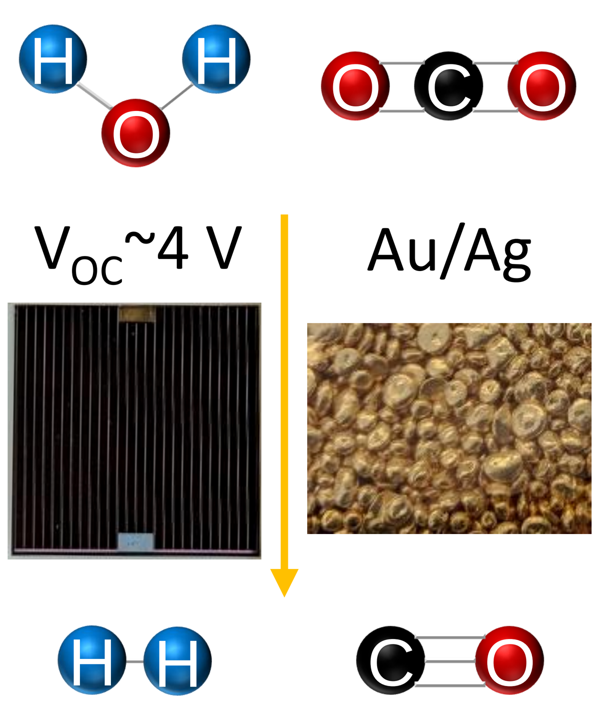
A: Cross section image of the **P**V-**I**ntegrated **M**embrane (PIM) and the catalyst-coated, gas diffusion layer (GDL)
B: Monolithically integrated PEC device, permitting real-time current measurement using an optional shunt path
C: Outdoor setup with a solar-heated bubble humidifier

Team



Outlook

Future work hopes to build on this architecture, by incorporating Au cathode catalysts and PVs with high open circuit voltages (V_{OC}), to drive monolithic PEC CO_2 reduction at a high efficiency.



Acknowledgments

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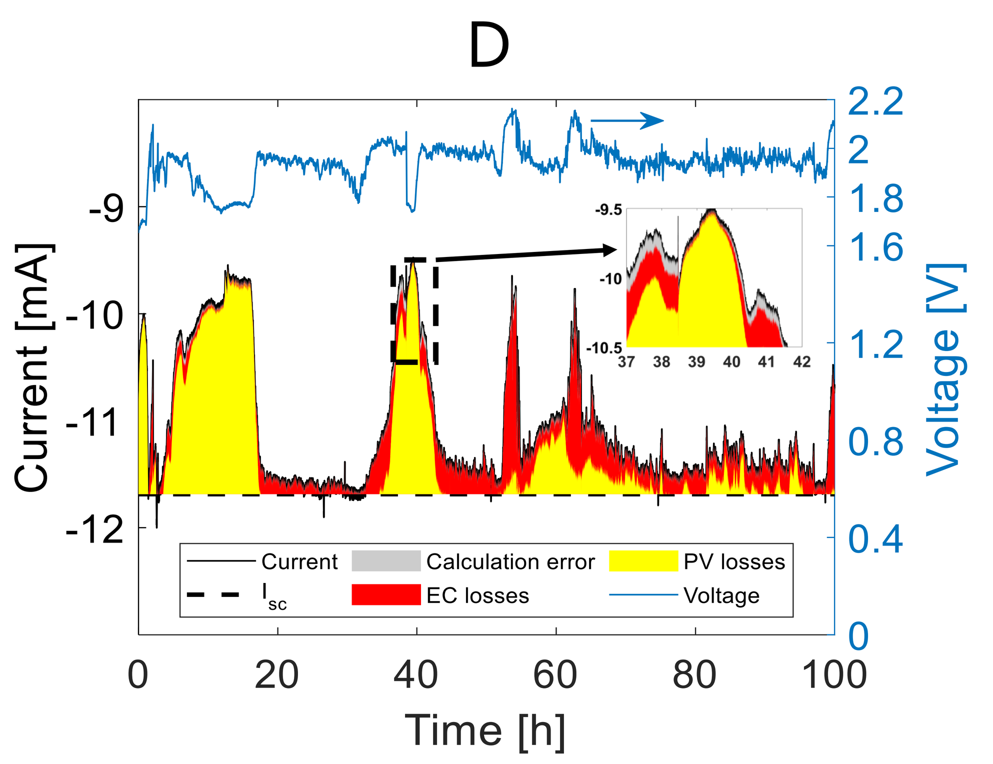
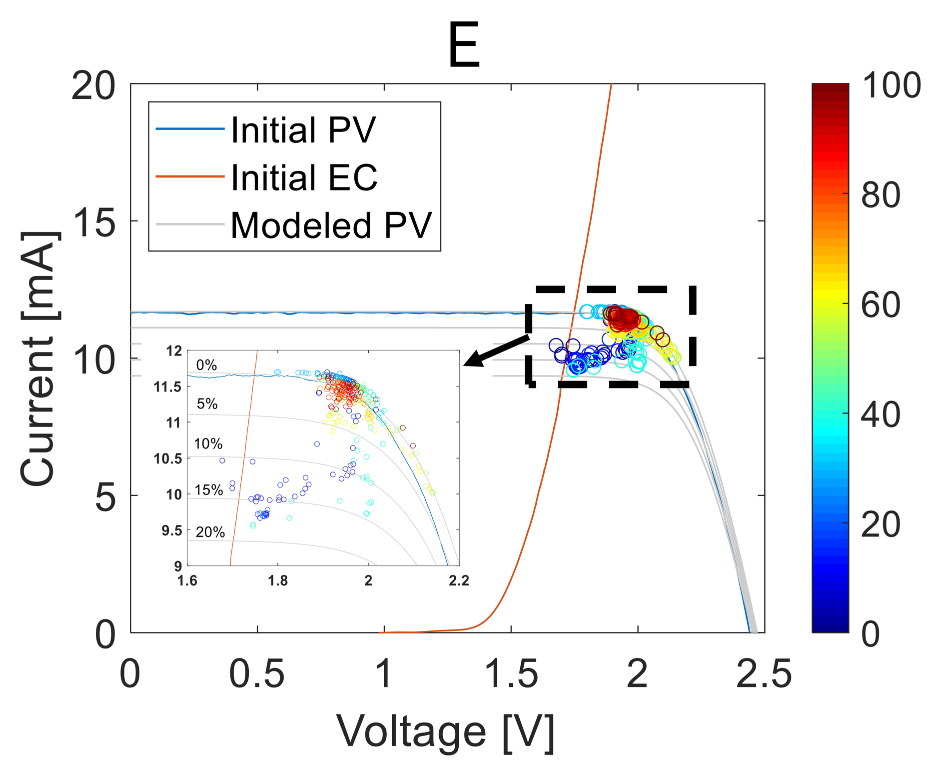
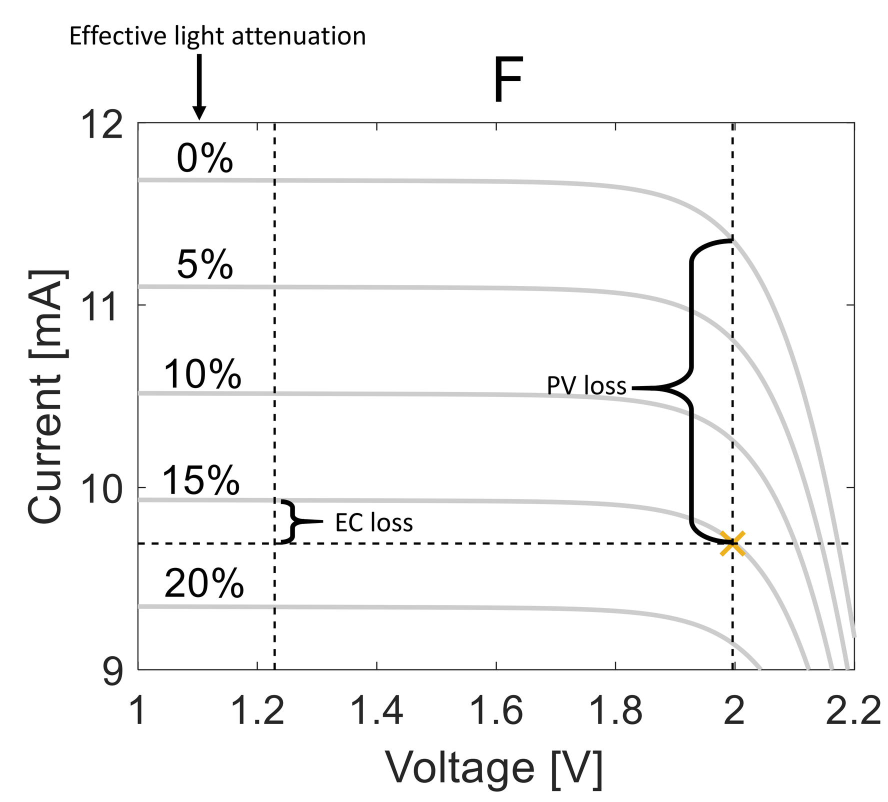
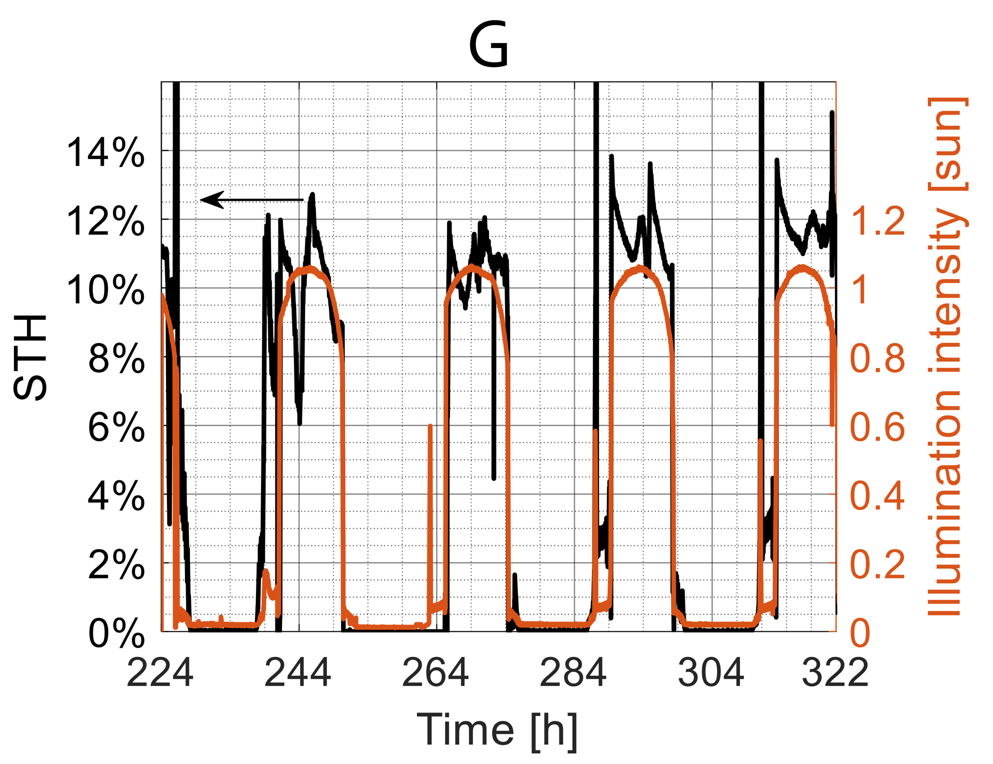
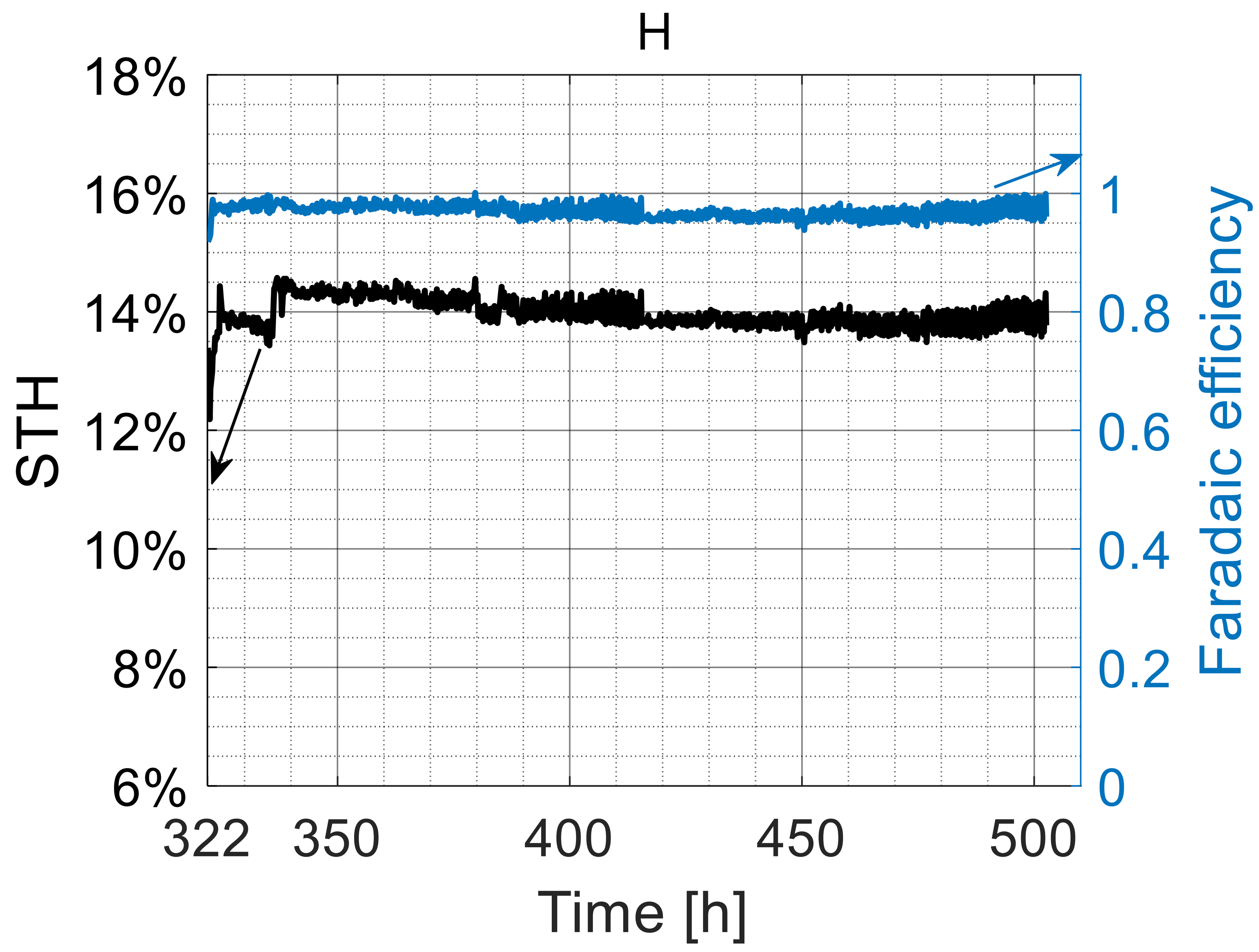
Results, Highlights, and Accomplishments

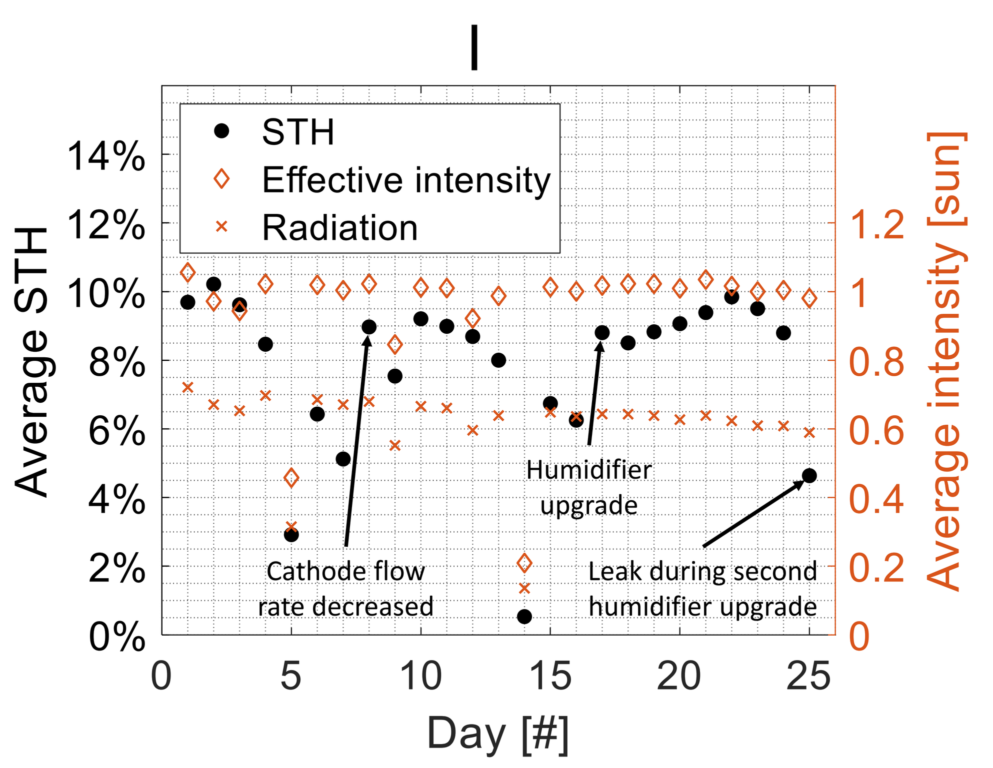












D: Deconvolution of current losses into PV and electrochemical (EC) losses, plotted with the operating current and voltage
E: Concurrent logging of voltage and current throughout the experiment enables live tracking of the operating point
F: Loss calculation example for one specific operating point, dividing the total current loss into PV and EC losses
G: Solar-to-hydrogen (STH) efficiency and illumination intensity during an on-sun experiment on a roof at Berkeley Lab
H: Stable STH efficiency near 14% for 180 hours at a faradaic efficiency for hydrogen close to 1, under 1 sun illumination
I: Long-term, on-sun testing with a solar-heated bubble humidifier, peaking at 10% average STH between 10 AM – 4 PM

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