Assessment of solar-to-chemical efficiency using only electrolyzer characteristics Shortcut bridging electrochemistry and photovoltaics

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Significance and Relevance

We developed a new rapid method to assess the Solar-to-Chemical efficiency (STC) potential of electrochemical (EC) cells and stacks with any photovoltaic (PV) device under any irradiance at any relative PV-to-EC scaling and any mode of power coupling. The method does not require numerical simulations or modelling of the PV-EC systems. This comprehensive overview is achieved via a mathematically simple conversion of the EC characteristics in any spreadsheet software. The method is demonstrated via the analysis of CO2-reduction electrolyzer characteristics and verified with dedicated PV-EC experiments.

Preferred and 2nd choice for the topic: Photocatalysis and photoelectrocatalytic approaches, solar energy utilization; Sustainable and clean energy production and transport Preferred presentation: (Oral only)

Introduction and Motivations

Electrochemical (EC) devices represent a promising solution for solar energy storage and industry decarbonization once combined with Photovoltaics (PV) in PV-EC systems. The development of PV-EC systems requires interdisciplinary collaborative efforts of different research groups from both photovoltaic and electrochemical research communities. Therefore, testing a new electrolyzer with a chosen PV device to evaluate its Solar-to-Chemical (STC) efficiency potential can be a difficult and time-consuming task. To minimize the effort, we developed a new rapid method for assessing the STC that an electrolyzer can achieve in combination with PV of any efficiency and scale under any irradiance and mode of coupling. Using basic power balance rules typical EC characteristics are unfolded into the parameter space of PV-EC systems and subsequently to STC. The pairwise correspondence of system parameters and STC allows to establish a map of STC attainable by the electrolyzer in any PV-EC scenario without system modelling. This comprehensive overview is achieved via a mathematically simple conversion of the EC characteristics and can be performed with any spreadsheet software. The method is based on our previous work on the "reverse analysis" of the solar-to-hydrogen efficiency limit in PV-EC water splitting systems¹. In this work, we generalize the method for treating electrolyzers with an arbitrary number of products, nonideal Faradaic efficiencies, and various PV-EC system parameters, including coupling efficiency. The method is demonstrated using the characteristics of an experimental CO₂ reduction reaction EC cell with Ag catalyst, which produces CO as the main product and H2 as a byproduct. The results of the analysis are verified by testing the analyzed electrolyzer in combination with high-efficiency concentrator GaAs solar cells.

Materials and Methods

Experimental validation was performed using a CO_2RR microflow electrochemical cell with IrO_2 anode, Ag GDE cathode, and a Nafion 117 cation exchange membrane. Pure CO_2 was directly purged in the cathode compartment. Both the catholyte and anolyte were CO_2 saturated 1 mol L⁻¹ KHCO₃. The PV-EC experiments were performed with the EC cell direct-coupled to a custom in-house developed PV emulator, which reproduces the required PV current voltage characteristics with precision and accuracy on par with AAA solar simulator ². The emulation approach was selected to achieve the necessary flexibility and accuracy in PV scaling, thus ensuring proper coupling to the small-scale laboratory EC device at different area ratios.

Results and Discussion

The proposed analysis procedure addresses (but not limited to) three key PV-EC system parameters: PV efficiency η_{PV} , solar irradiance G, and PV-to-EC area ratio $A_{\rm R}$ as the minimal set of parameters describing operating conditions of the EC cell. Full set or the analysis results is a part of four dimensional space with three parameter coordinates η_{PV} , G, A_{R} and the corresponding STC values, the dependence of STC(η_{PV} , G, A_R). For practical purposes it is convenient to reduce the dimensionality and consider cross sections of the results set as the dependencies of STC on one or two parameters while other ones are fixed. Examples of such three dimensional cross sections for STC(η_{PV} , G) at constant A_R , STC(η_{PV} , A_R) at constant G, and STC(G, A_R) at constant η_{PV} are presented in Figure 1 for the CO product. The results of the validation PV-EC experiments are presented as stars, with the corresponding experimental STC values. The mathematically simple unfolding of the EC characteristics leads to a surprisingly comprehensive overview of the EC potential in combination with PV of any size and efficiency under any irradiance. In Figure 1 the STC values attainable by the analyzed EC cell in vast variety of PV-coupled scenarios are mapped. The dependencies in Figure 1 are specific to a particular electrolyzer characteristics and any variations of those will change the resulting STC maps. This property can be employed to evaluate how variations in EC parameters are projected onto its STC potential. By comparing the results obtained at different EC states, operating temperatures, electrolyte compositions, catalyst type, loading, degradation or conditioning, electrolyzer design parameters, etc., variations of these parameters can be systematically evaluated in terms of STC limit. Dependencies for the STC limit are useful for loss analysis in already tested PV-EC systems, as well as for systems design and comparison. The method provides an easy-to-use shortcut between electrochemistry and photovoltaics, facilitating and streamlining the development of solar chemistry and fuel solutions.



Figure 1 Contour plots of three-dimensional dependencies of (a) STC on η_{PV} and *G* at constant A_R , (b) STC on η_{PV} and A_R at constant *G*, and (c) STC on *G* and A_R at constant η_{PV} . Results of the PV-EC experiment are indicated by stars with STC values next to symbols.

References

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