As photovoltaic technologies gain increased prominence in the global renewable energy portfolio, an outstanding challenge is the development of systems that can robustly store solar energy with high density. Within this context, the capture of sunlight and its direct conversion to chemical fuels in artificial photosystems provides a promising route for sustainably meeting future energy demands, including within the transportation sector. While functional photoelectrochemical fuel generators comprising semiconductor light absorbers coupled to catalysts have been demonstrated, progress has been hindered by a lack of materials that are simultaneously stable, efficient, and chemically selective.

Here, recent research advances and future opportunities for creating assemblies capable of efficient and stable solar energy conversion to fuel are presented. First, the quest for new and chemically robust semiconductors, in which basic mechanisms underlying the competition between photocarrier recombination and chemical reaction remain poorly understood, are discussed. Second, opportunities for creating new functionality from established semiconductors and catalysts via nanoscale engineering of interfaces are explored. Third, a new approach to creating hybrid photovoltaic and photocatalytic systems, which could provide electrical power or stored chemical fuel on demand, is discussed.

Combining these three parallel approaches to tailoring materials, interfaces, and device architectures is expected to advance a next generation of artificial photosystems for generating high energy density chemical fuels from sunlight.