Introduction
A diverse portfolio of clean energy solutions is needed to break humanity’s dependence on fossil fuels. However, intermittency often complicates direct use of renewable energy sources like wind and solar. To store solar energy for thermal requirements (i.e., transportation fuels, industrial processes, residential heating), solar radiation can be concentrated and stored indefinitely in the form of chemical bonds, accomplished by driving an endothermic reaction. Applying process intensification principles to this problem, several ideas were developed to make solar fuel production more efficient, compact and practical. Ultimately, a reduced capacity cost (i.e. $/kg fuel/day) will make solar fuels more competitive.

Bi-/Tri- Reforming Modal Switching for Continuous Syngas Production
Economy of scale and continuous operation are what make conventional chemical processing profitable. However, the future will see safer, decentralized chemical processes in the form of modules. Solar energy systems benefit from modularity; large scale power towers with heliostat arrays, for instance, present large initial capital investment and financial risk. Modules can be “numbered up” over time to meet capacity goals, delivering solar fuels at or near point of use (i.e. Hydrogen Fuel Station), no costly pipelines needed.

The solar concentrator dish is a major cost driver in such a system. Micro- and milli-scale reactor channel dimensions are utilized to greatly increase efficiency of a module, wasting as little concentrated solar heat input as possible to reduce capacity cost. Solar intermittency is another roadblock to competitive solar fuels, restricting operation only to times when the dish sees the sun. Bi-/Tri-reforming modal switching is presented here as an option to maintain high temperatures required for reforming during times of solar intermittency or diurnal cycles.

In this scheme, Bi-reforming of methane (3CH₄ + 2H₂O + CO₂ → 8H₂ + 4CO) is performed over a nickel catalyst. Oxygen is then predictively throttled into the stream and reacted over the same catalyst when clouds pass over. Partial oxidation of methane provides exothermic heat of reaction that is used by the endothermic steam and CO₂ methane reforming reactions. This autothermal operational mode is called Tri-reforming of methane (5CH₄ + 2H₂O + CO₂ + O₂ → 12H₂ + 6CO).

PI Principles
- PI in the thermodynamic domain. Judicious control of the flow of energy in the system.

Integrated Reactor/Solar-Receiver/Heat Exchanger
In-situ gas recovery and thermally coupled endothermic and exothermic reactions are implemented in this device to increase solar-to-chemical efficiency without the need for an external high temperature recuperator. Feeding gas to the perimeter cools sealing features below their melting point, and conductive micro-pillars facilitate rapid gas recuperation to heat the feed to reaction temperatures before delivery to the methane reforming catalyst. Addition of a exothermic reaction in series – positioned radially in the correct temperature range – will provide additional heat to the feed stream, boosting efficiency further and converting syngas into more practical liquid fuels.

PI Principles
- PI in the spatial domain. Microchannel reactor design facilitates intensified heat and mass transfer.
- Synergy is maximized by integrating components in a single, compact device.
- PI in the thermodynamic domain. Thermally coupled reactions reduce external heating duty.