Electronic Supplementary Material (ESI) for Energy & Environmental Science.

Hybrid solar converters for maximum exergy and inexpensive dispatchable electricity

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SUPPLEMENTARY INFORMATION

1. Cost of electricity from thermal storage today.

To estimate the cost per cycle (CPC) addition to the levelized cost of electricity (LCOE) due to use of an energy storage system, we calculate the total power-related and energy-related capital costs per kWh_e produced[1,2] and divide by the total number of cycles provided over the equipment lifetime. We then double the calculated CPC to account roughly for the costs of financing and operations and maintenance (O&M).[a] The main power-related contribution (C_P) is the cost of the generator ($\$/kW_e$) divided by the number of hours it is utilized per cycle (here, 10 hours per day). The energy-related contribution (C_E) is the cost of the thermal energy storage material and associated containment in $\$/kWh_e$, divided by its round-trip exergetic efficiency (RTE). Finally,

[a] We estimate this factor by calculating representative LCOE values using standard financial parameters for CSP in the National Renewable Energy Laboratory Solar Advisory Model (SAM).

we estimate the total number of daily cycles to be about 11,000, assuming a 30-year life of the storage. This is shown symbolically and numerically below, for two representative thermal storage temperatures: 580 °C (with \$30/kWhth and a 40% power cycle for \$75/kWh$_e$) and 386 °C (with \$80/kWh$_{th}$ or and a 36% power cycle for \$222/kWh$_e$).

The formula for CPC is then:

$$CPC\ [\$/kWh_e] = [C_P\ [\$/kW_e] / (10\ hours) + C_E\ [\$/kWh_e]/RTE] / (\#\ total\ cycles) \quad (Eqn\ S1)$$

At 580°C Eqn. (S1) yields

$$CPC \sim [(\$1000/kW_e)/(10\ hours) + (\$75/kWh_e)/0.95]/11{,}000 \sim \$0.016/kWh_e\ .$$

At 386°C Eqn. (S1) yields

$$CPC \sim [(\$1000/kW_e)/(10\ hours) + (\$222/kWh_e)/0.95]/11{,}000 \sim \$0.03/kWh_e\ .$$

Note that the calculation separately takes into account the heat engine generation efficiency, so 95% exergetic efficiency for storage itself is realistic. Here the main exergetic losses are in the piping, tanks, and heat exchanger. Doubling the CPC values calculated above to account for financing and O&M, we estimate that the actual CPC addition to LCOE is about \$0.03 at 580°C and \$0.06 at 386°C.

2. Furture cost of electricity from electrical storage

By comparable methodology to that used in Section 1, we estimate the addition to LCOE from a future battery costing \$200/kWh$_e$, with 92% round trip efficiency and a cycle life of 3650 daily cycles over its 10-year life:

$$CPC[\$/kWh_e] = C_E[\$/kWh_e]/RTE/(\#\ total\ cycles) = (\$200/kWh_e)/0.92/3650 = \$0.06\ /kWh_e$$

Advanced membranes in flow batteries are projected to last about 10 years, while Li ion batteries have similar limited lifetimes. We increase this CPC value less than the 2X for thermal storage (Section 1, above) to account for financing, the associated power electronics and presumed lower battery O&M costs; we estimate that the actual CPC addition to LCOE may be about $0.10/kWh$_e$ in the future.

REFERENCES

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