Supporting Information

Ultra-Cheap Renewable Energy as an Enabling Technology for Deep Industrial Decarbonization via Capture and Utilization of Process CO_2 Emissions

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We use our integrated model to examine the effect of improvements in various parameters relating to H_2 production via electrolysis on methanol production. According to estimates, PEM electrolyzers will reach 70% efficiency by 2030 and close to 80% in the long term.[1] This increase in efficiency would result in reduced energy consumption, which would make electrolytically produced hydrogen more competitive. The efficiency of alkaline electrolyzers is expected to reach 80% in the long run, while that of SOEC should reach 90%, but this technology is still in its infancy.[1] In

Figure S1, we see the effect of improvement in efficiency of PEM electrolyzers on methanol cost, where an improvement of 20% in electrolyzer efficiency results in a reduction in cost of methanol by 16%. As assembly-line production starts to take place along with improvements in technology and the use of cheaper materials; the cost of electrolyzers will decrease, with the PEM type expected to reach a price in the range of 200–900 USD/kW by 2050,[1] which will certainly help in bringing the cost of hydrogen down, thereby affecting the price of methanol being produced (**Figure S2**). The longer stack life and low maintenance of hydrogen electrolyzers will aid in bringing the costs further down; from a current lifetime of approximately 7 years if used at 90% capacity factor, electrolyzers are expected to have lifetime of 15 years by 2050 (**Figure S3**).[1]

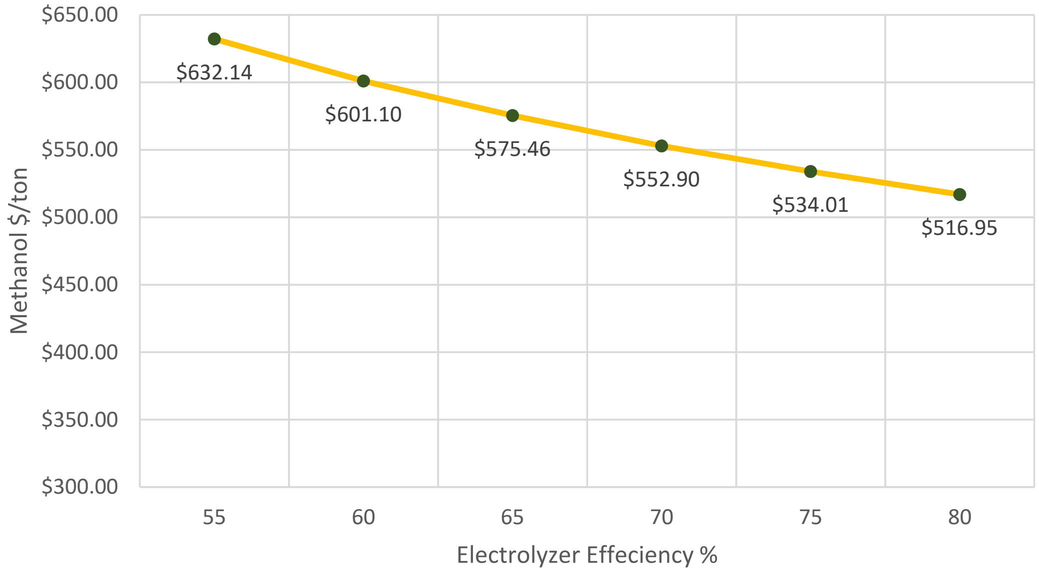

Figure S1. Cost of methanol with change in electrolyzer efficiency (electricity—30 USD/MWh, heat—10 USD/MWh, discount rate—4%, electrolyzer cost—460 USD/kW).

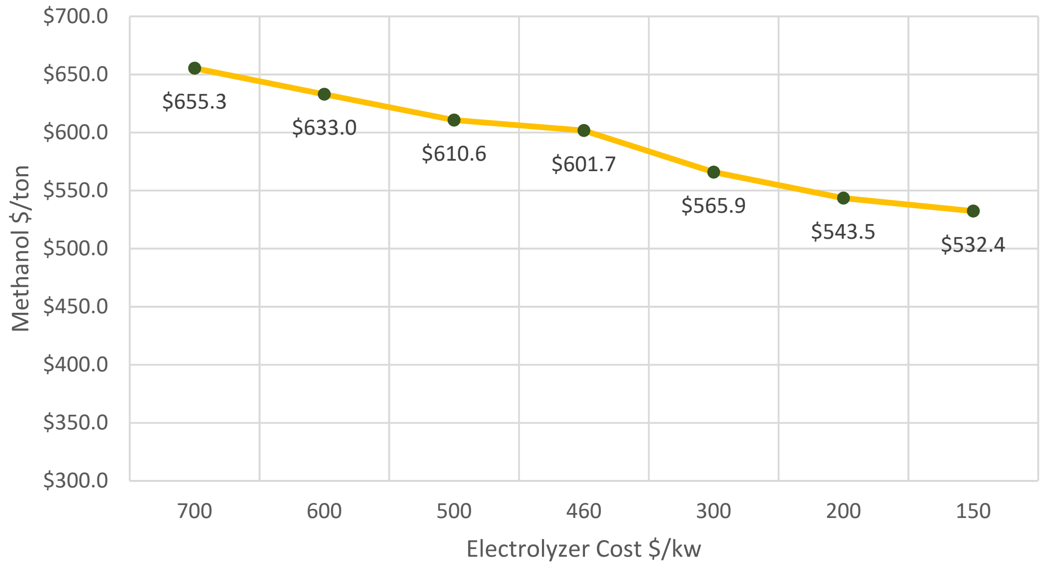

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Figure S2. Cost of methanol with change in electrolyzer cost (electricity—30 USD/MWh, discount rate—4%, system efficiency—60%, electrolyzer cost—460 USD/kW).

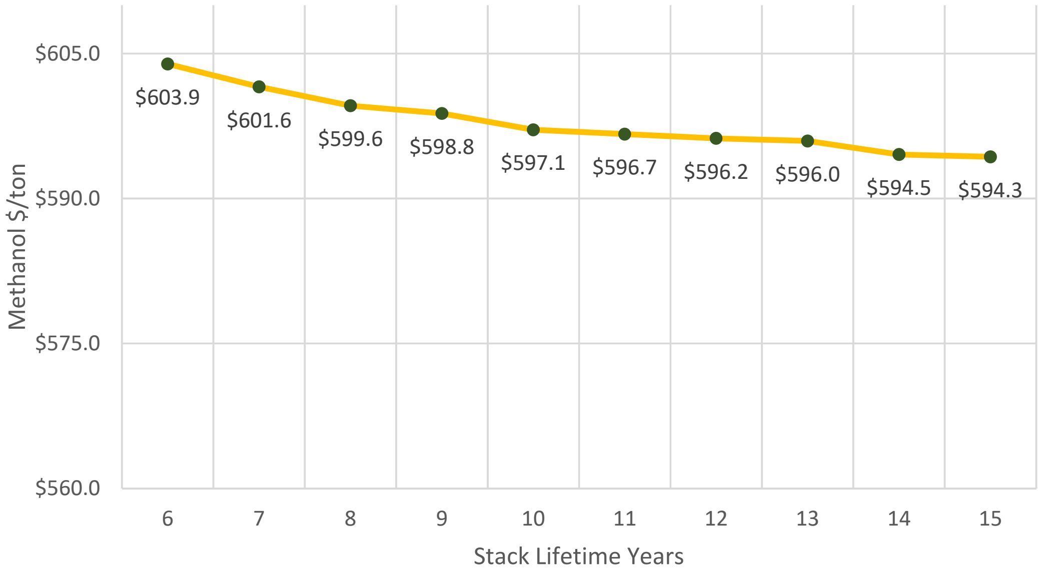

Figure S3. Effect of electrolyzer stack lifetime on methanol cost (PV electricity—13.5USD, CSP + storage—73 USD/MWh, heat—18 USD/MWh, discount rate—4%, system efficiency—60%, electrolyzer cost—460 USD/kW).

When analyzing the effect of varying capacity factors, the average cost of electricity needs to be determined. Systems running on renewable energy at 90% capacity factor use store power at night when electricity is more expensive. In order to take advantage of the cheapest electricity, we assume that the plant runs at full capacity when PV electricity is available. The overall electricity price can, in principle, be lowered by reducing operations at night. The average cost of electricity for varying capacity factors was determined in **Figure S4**; with this new set of electricity prices at different capacity factors, we can then determine the cost of methanol using the integrated model (**Figure S5**). As the share of electricity cost is much higher than Capex for hydrogen synthesis, which is the main cost contributor in methanol production, we see the lower electricity prices having a greater impact (**Figure 3**) than lower operating hours (**Figure S5**) on methanol cost. The overall effect of the reduction in capacity factor is a slight decline in the price of methanol on account of moving away from costly nighttime electricity.

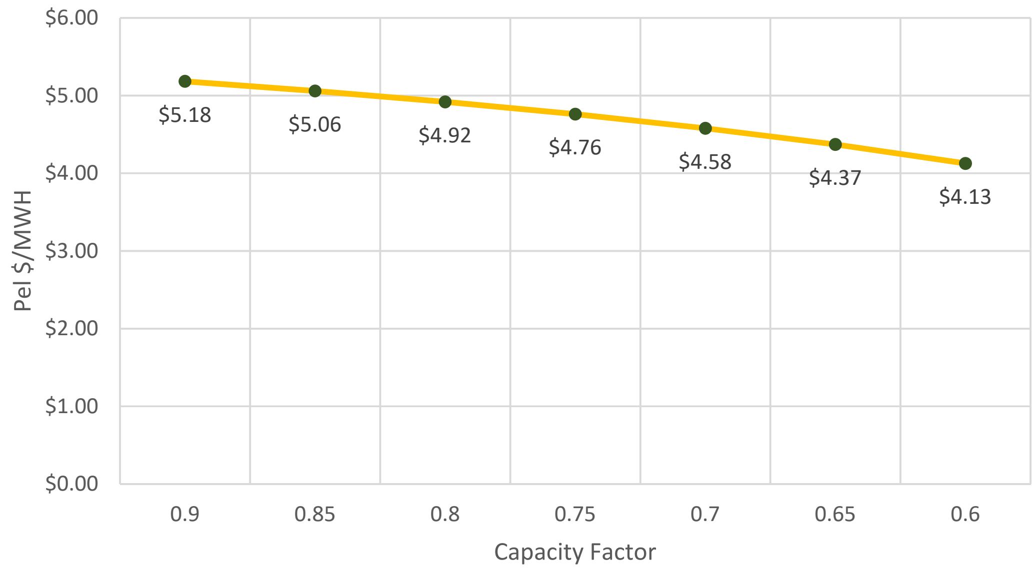

Figure S4. Effect of capacity factor on price of electricity (PV electricity—13.5 USD/MWh, CSP + storage—73 USD/MWh).

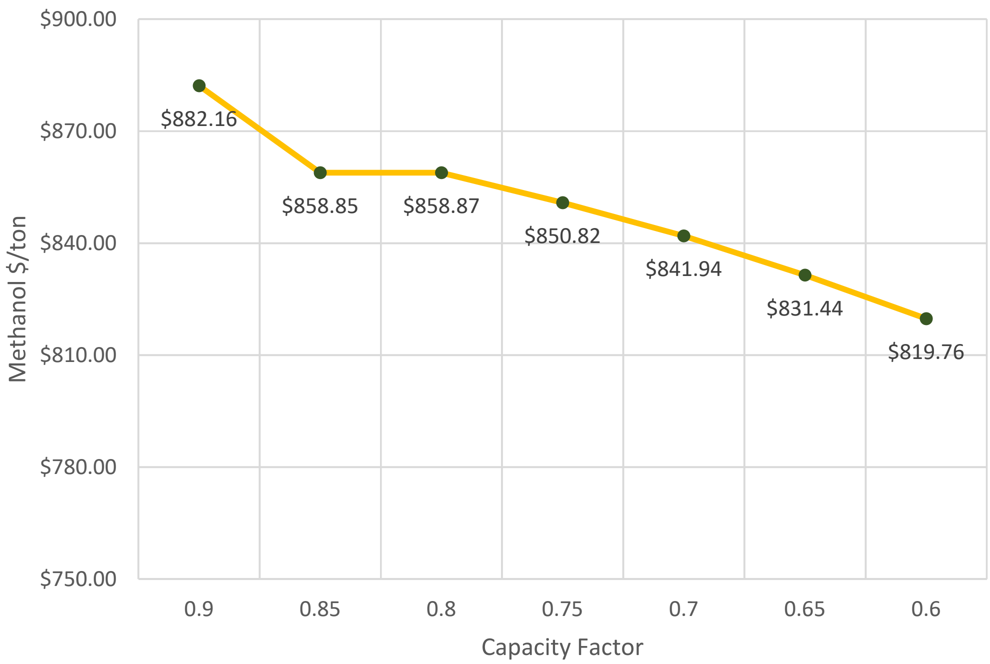

Figure S5. Effect of capacity factor on methanol (PV electricity—13.5 USD, CSP + storage—73 USD/MWh, heat—18 USD/MWh, discount rate—4%, system efficiency—60%, electrolyzer cost—460 USD/kW.

References

[1] IEA. *The Future of Hydrogen*; IEA: Paris, France, 2019.