Market Competitive Electrolysis in ERCOT

Across US and global markets, demand for hydrogen is increasing. Simultaneously, the cost of producing hydrogen via electrolysis using electricity is decreasing, creating new market opportunities for this low-carbon hydrogen production process. To assess this opportunity, three key cost factors for hydrogen production using an electrolyzer need to be considered: capital, operating, and electricity cost. Of these three, the electricity cost can be assumed to vary most widely by location due to local availability of generating sources and local market rate structures. Although conventional wisdom holds that electrolyzers can only operate profitably if given very low electricity prices, this paper highlights an existing electricity market where electrolysis could be an attractive and profitable option for hydrogen production today.

Since electricity prices vary over time, an electrolysis facility can choose when and to what extent to adjust its hydrogen production to target lower electricity prices and consequently reduce its hydrogen production costs. This white paper uses historical electricity price data from the Electric Reliability Council of Texas (ERCOT), the grid that serves 90% of Texas, coupled with a basic techno-economic model of electrolysis to explore the costs and benefits of flexible electrolysis operation considering variable wholesale electricity prices. With strategic operating schedules, cost reductions, and efficiency improvements, electrolysis shows promise as a low-carbon, cross-sector, market competitive, and flexible source of hydrogen.

Electrolysis techno-economic model

To explore the cost and benefits of flexible electrolysis operation, we use a general model of a PEM electrolysis facility. The facility[1] has fixed costs—including amortized capital costs and fixed annual operating costs—and purchases electricity via a monthly demand charge ($/kW) applied to the facility's peak electricity consumption plus an hourly energy price ($/kWh). We assume the facility has access to potable water, is connected to the Houston hydrogen pipeline network, and operates at an energy efficiency of 60% (55.6 MWh-electricity/tonne-H2).[2]

We assume the electrolysis facility's hourly energy price ($/kWh) equals the wholesale electricity price at ERCOT's Houston price hub[3]. These prices change every 15-minutes due to their dependence on the supply and demand in the ERCOT electricity market.

This energy price variation has a direct impact on the cost of hydrogen production, and thus profitability, at any particular location. The ten-year average cost variation at the Houston hub is summarized in Figure 1. For example, this chart shows that about 80% of the time, the wholesale price of electricity was less than $30/MWh. These data provide the total electrical energy cost if one decides to only operate the electrolyzer when the cost of electricity is below a preselected threshold

[1] Data from the NREL H2A model (version 3.2) for centralized electrolysis facilities: < https://www.nrel.gov/hydrogen/h2a-production-models.html>

[2] For more information on capital costs, fixed costs, efficiency, financing, and demand charges, see the Appendix.

[3] Data from ERCOT: "Historical RTM Load Zone and Hub Prices" < http://www.ercot.com/mktinfo/prices>

level. To explore the benefit of electricity price optimization in this market, we assume the electrolysis facility can turn on and off throughout the day to make use of advantageous prices. This behavior is captured using a simple heuristic: whenever prices exceed a specific "threshold electricity price," the electrolysis unit does not produce hydrogen.

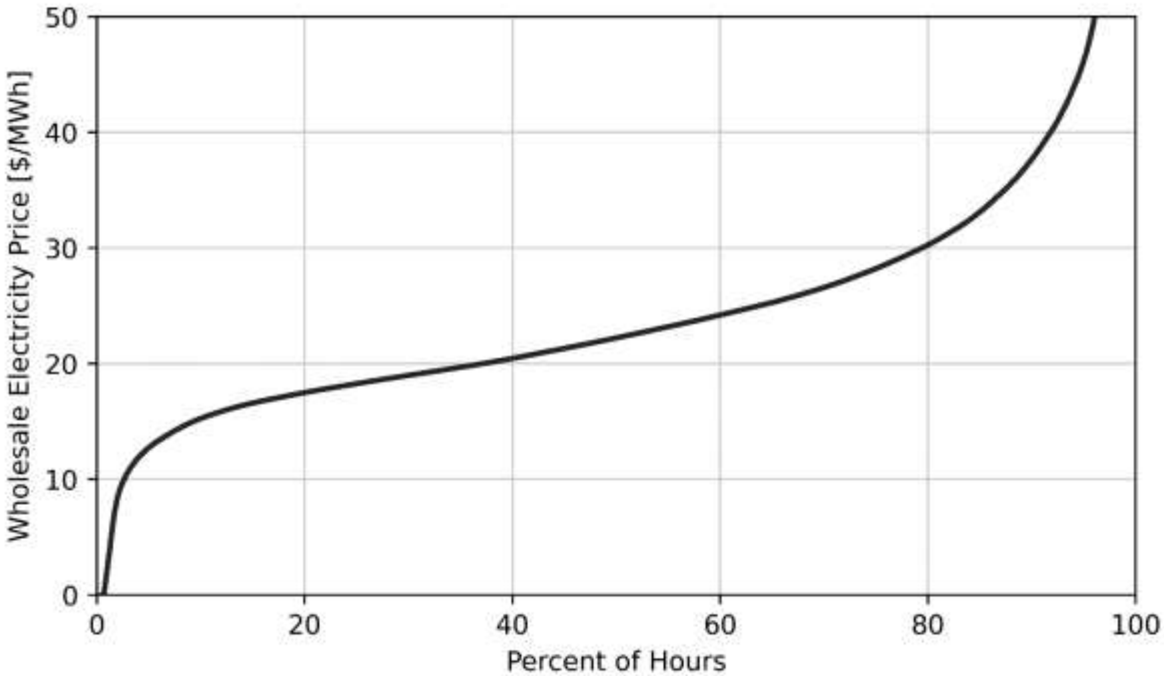

Figure 1: Wholesale electricity prices at the ERCOT Houston price hub from 2011-2020, arranged from lowest to highest. The data show, for example, that 80% of the time, the wholesale price of electricity was less than $30/MWh.

Flat production costs at utilization rates above 65%

Figure 2 shows the tradeoffs between fixed production costs, electric demand charge, and electrical energy cost in terms of the threshold electricity price. A noteworthy trend is that there is little benefit in this particular market to curtail production when electricity prices exceed a predetermined threshold, at least up to a threshold of $50/MWh. This is because, at threshold electricity prices above $26 /MWh—i.e., full load hours above 65%—the electrolysis facility's production cost remains relatively constant: ranging from $1.83-1.90 /kg-$H_2$.

On the other hand, at threshold electricity prices below $26 /MWh, the production cost ($/kg-$H_2$) of the electrolysis facility increases exponentially. Here, variable electrical energy costs are low, but the facility produces too little hydrogen to cover its other costs.

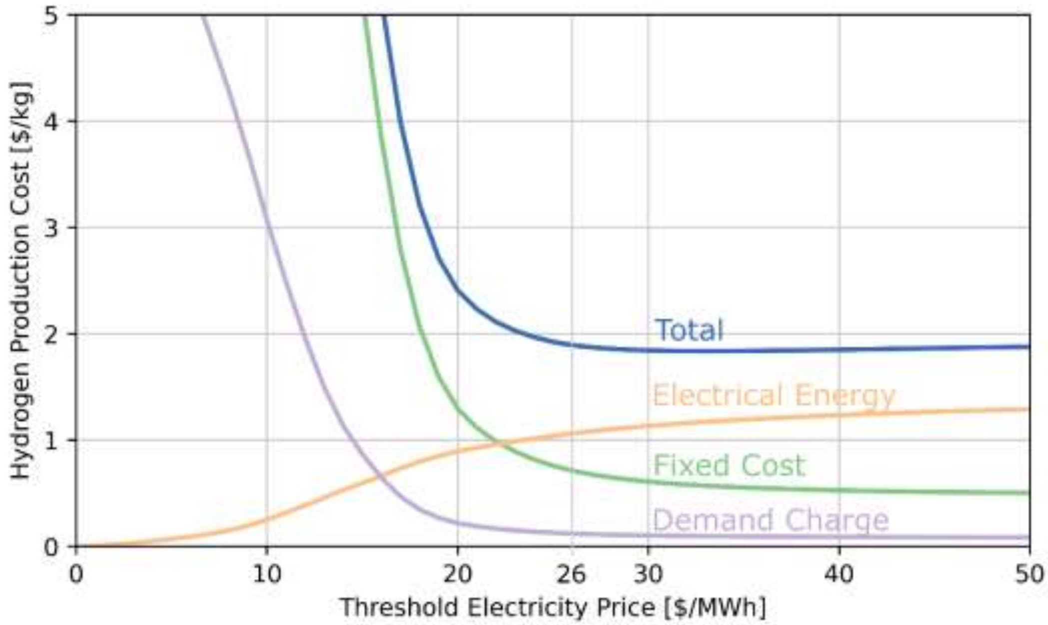

Figure 2: Average production costs ($/kg-$H_2$) and full load hours depend on the threshold electricity price. Whenever prices exceed the threshold electricity price, the electrolysis unit does not produce hydrogen. At threshold prices above 26 $/MWh, higher electrical energy costs are balanced by lower average fixed costs and demand costs. This yields a relatively flat average total production cost curve whenever full load hours exceed 65%.

Technology improvement impacts the production cost curve

Figure 3 shows how increased energy efficiency and reduced fixed costs would impact the electrolysis facility's production cost curve.

By raising the electrolysis facility's efficiency from 60% to 70%, the production cost curve shifts down and to the right. Higher efficiency electrolyzers can achieve lower production costs, but if they have higher fixed costs may require more operating hours to generate revenue to compensate for the fixed cost.

By reducing the electrolysis facility's fixed cost by 50%, the production cost curve shifts down and to the left. Lower cost electrolyzers with the same performance can achieve lower production costs and can operate at fewer full load hours without sacrificing production cost.

A combination of increased efficiency (70%) and reduced costs (-50%) brings total production costs down to 1.40 $/kg-H2.

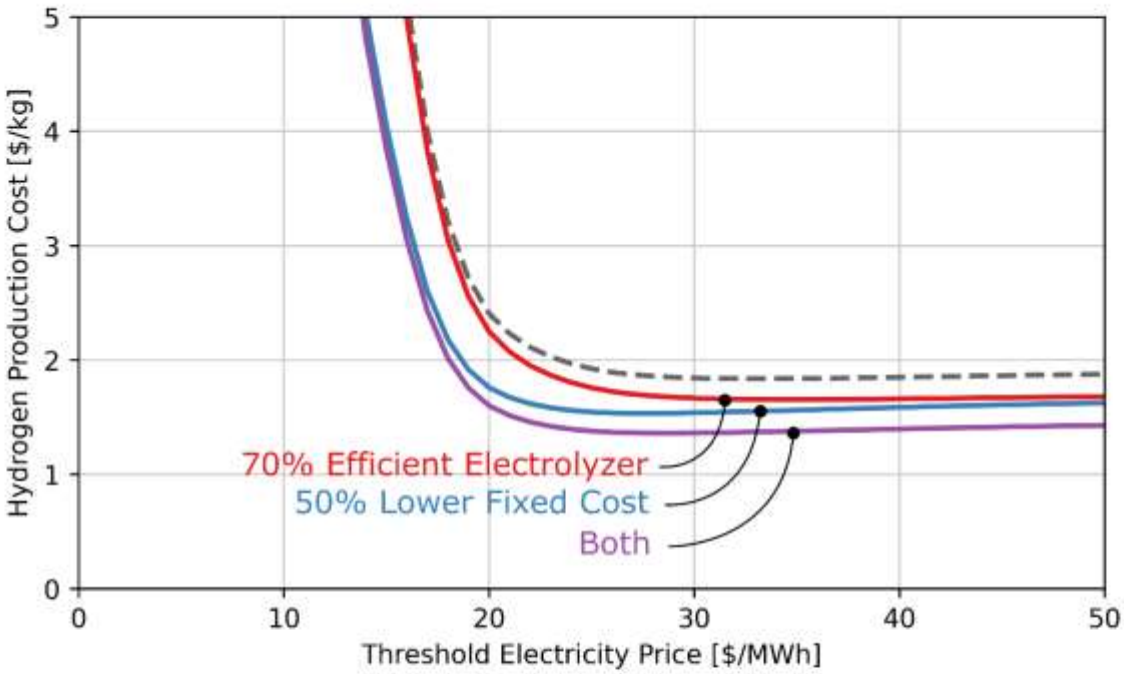

Figure 3: Improved efficiency and lower fixed costs reduce the average production cost curve. Efficiency improvements push the curve down and to the right. Cost reductions push the curve down and to the left.

Reducing carbon intensity via flexible operation

Figure 2 shows that a Houston based electrolysis facility purchasing electricity at the historical variable, wholesale cost can produce hydrogen at roughly the same production cost if full load hours range from 65-98%. Thus, given the right motivation, this electrolysis facility might operate flexibly throughout this range

One motivation to operate at lower utilization rates might be to reduce CO_2 emissions. If the electrolysis facility prioritizes consuming electricity when the CO_2 emissions in the electric grid are low, it can reduce the carbon intensity of its hydrogen production. For example, in 2018, the marginal CO_2 emissions—i.e., the emissions caused by a marginal increase in electricity demand—varies from 385 to 760 lbs-CO_2/MWh[4]. Assuming marginal emissions factors are independent from electricity price[5], the electrolysis facility could reduce its utilization rate to 65% to target lower CO_2 emissions without negatively impacting its $/kg H_2 production cost.

Table 1 shows the variation in average carbon intensity compared to other hydrogen production methods. The carbon intensity of centralized electrolysis in Houston is estimated to be 28-30 g-CO_2/MJ. For 70% efficient electrolysis with 50% lower fixed costs, that carbon intensity drops to

[4] Marginal emissions factors quantify the CO_2 emissions created by a marginal increase in electricity demand. Data from CEDM: < https://cedmcenter.org/tools-for-cedm/marginal-emissions-factors-repository/>
[5] See Appendix for a comparison between Houston wholesale electricity prices and ERCOT marginal CO_2 emissions.

24-26 g-CO_2/MJ. Compared to a new SMR facility (75 g-CO_2/MJ), the estimated CO_2 abatement costs are 181-194 and 80-100 $/t-$CO_2$ for these two respective electrolysis scenarios. The high-efficiency, low-cost electrolysis facility is estimated to be cost competitive with SMR+MEA (flue gas CO_2 capture) technology in terms of $/t-$CO_2$ abatement cost.

Table 1: Average carbon intensity of various hydrogen production methods.[6] [7] [8] Abatement cost is the change in production cost divided by the change in carbon intensity when compared to SMR.

Technology	Full Load Hours [%]	Production Cost [$/kg]	Carbon Intensity [g-CO2/MJ]	Abatement Cost [$/t-CO2]
SMR	90%	0.87	75.0	-
SMR+MDEA (shifted syngas)	90%	1.14	34.5	56
SMR+MEA (flue gas)	90%	1.55	8.3	85
Electrolysis (60% eff)	65%	1.89	28.1	181
	98%	1.91	30.3	194
Electrolysis, (70% eff, 50% fixed cost)	65%	1.36	23.9	80
	98%	1.46	25.9	100

The decision to use electrolysis or SMR may change when considering other aspects of hydrogen carbon emissions. The natural gas infrastructure, for example, leaks methane into the atmosphere. This increases the embodied greenhouse gas emissions of natural gas consumers like SMR, and—to a lesser extent—the electric grid that uses natural gas generators to provide some of the electricity powers electrolysis. Electric grid emissions, however, are steadily decreasing over time. Thus, average carbon emissions during an electrolysis facility's lifetime will be lower than the 2018 electric grid emissions used in this study. And in locations where carbon capture and sequestration are geologically impossible or politically unpopular, electrolysis provides a low-carbon alternative.

Conclusions

Given the variability of wholesale electricity prices and the capabilities of PEM electrolysis technology, an electrolysis facility may strategically reduce its full load hours to as little as 65% without impacting its hydrogen production cost.

Flexible operation may produce advantages that lead to new business opportunities. This analysis shows, for example, that flexible operation can reduce electrolysis' carbon intensity and abatement cost, making it a competitive low-carbon hydrogen technology. Flexible operation may enable other business opportunities as well, such as supporting electric grid reliability via responsive demand or

[6] SMR cost data from the NREL H2A model (version 3.2) for centralized steam methane reforming facilities, assuming a natural gas price of 3.50 $/mmBtu: < https://www.nrel.gov/hydrogen/h2a-production-models.html>
[7] SMR carbon intensity data from GREET <https://greet.es.anl.gov/publication-smr_h2_2019>
[8] SMR carbon capture and sequestration data matches abatement costs from the IEAGHG "Techno-economic evaluation of SMR Based Standalone Hydrogen Plant with CCS": < https://ieaghg.org/exco_docs/2017-02.pdf>

ramping up and down with hydrogen demand to reduce the need for centralized hydrogen storage for locations out of range of a pipeline network.

With strategic operating schedules, cost reductions, and efficiency improvements, electrolysis may find a unique market niche as a low-carbon, cross-sector, market competitive and flexible production method of hydrogen.

These conclusions are unique to the electricity rate history of the specific location. Future rate changes at this location or different rate histories at other locations will lead to different, and possibly significantly different, conclusions. However, the result for this location is robust because the electricity price is low during most of the year.

Next Steps

To show more clearly how an electrolysis facility may operate flexibly to reduce its emissions, future work will explore optimal daily and seasonal operation profiles for achieving that objective. These optimal operation profiles will test the effectiveness of the "threshold electricity price" heuristic and reveal more effective control schema or heuristics. Future work will also explore additional costs, such as the cost of cycling the electrolyzer on and off.

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This preliminary report, not peer reviewed, based on information developed during a more comprehensive investigation, which is intended to be published as a peer reviewed document. Comments and suggestions for improvements are welcome and should be sent to the technical leader of this task, Dr. Thomas Deetjen, t.deetjen@cem.utexas.edu.

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Appendix

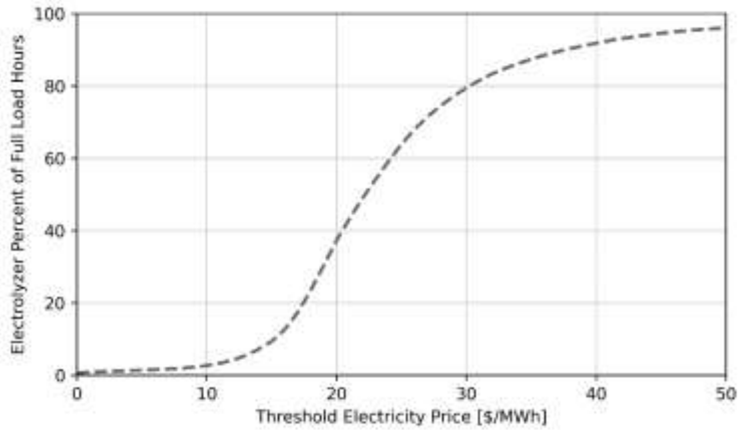

Figure 4: Electrolysis full load hours depends on the threshold electricity price being used by the control heuristic. Raising the threshold electricity price increases the electrolysis facility's average electricity price as well as its utilization.

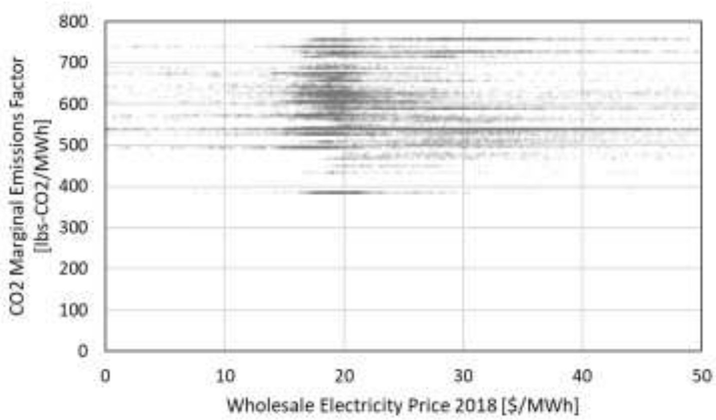

Figure 5: Marginal CO_2 emissions vs wholesale electricity prices in 2018. These variables are independent.

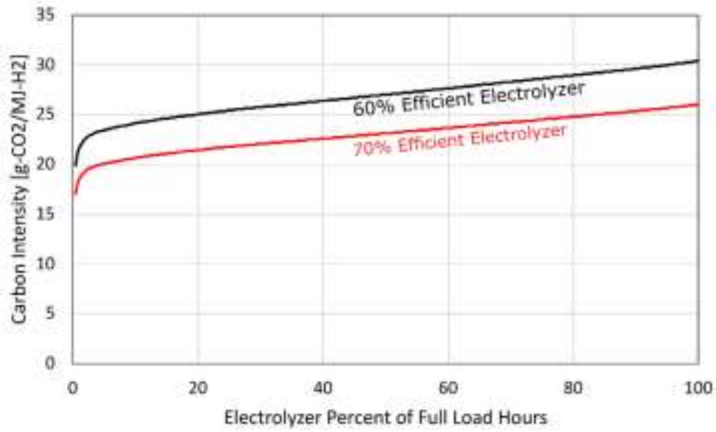

Figure 6: Average carbon intensity of the electrolysis facility at different full load hours. Assumes that marginal electricity emissions are independent from electricity prices (see Figure 5) and that the electrolysis facility operates at the lowest possible carbon intensity to achieve the indicated full load hours.

Table 2: inputs for the electrolysis techno-economic model.

Electrolysis Facility[9]		
capacity	56.5	tonne-H2 per day
efficiency	60	percent
efficiency	55.6	MWh-electricity/tonne-H2
overnight capital cost	59.30	$Million
fixed annual cost	4.8	$Million
Financial[10]		
debt interest rate	0.06	
debt period	20	years
Electricity Rate		
monthly demand charge	4.27	$/kW[11]

[9] Based on the NREL H2A models (version 3.2) for centralized electrolysis facilities: < https://www.nrel.gov/hydrogen/h2a-production-models.html>
[10] Based on the financial assumptions used in the NREL Annual Technology Baseline (ATB, version 2020): < https://atb.nrel.gov/electricity/2020/data.php>
[11] This demand charge was chosen so that the electrolysis unit at 100% full load hours would have an average electricity rate of 0.0488 $/kWh, which equals the average January 2021 rate for industrial electricity in Texas, according to the EIA's "Electricity Power Monthly" report: < https://www.eia.gov/electricity/monthly/>