Emissions Implications for Clean Hydrogen Accounting Methods

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Executive Summary

REsurety uses Locational Marginal Emissions (LMEs) data to analyze the effectiveness of the three carbon accounting methods proposed for compliance with new production tax credits available for clean hydrogen under the Inflation Reduction Act (IRA). This analysis considers 32 electrolyzer-renewable project pairs across 3 different grid regions (ERCOT, PJM, and CAISO) using hourly emissions and generation data from 2022. Seen in Table 1 below, the results show that, due to the difference in carbon intensities on the grid based on location and timing, determining "clean" hydrogen using Annual Energy Matching often results in significant increases in emissions despite the procurement of an equivalent quantity of energy from offsite clean energy to match the electrolyzer's consumption. Further, Table 1 shows that while Local Hourly Energy Matching can help reduce net emissions in some locations, the impact of local transmission constraints often results in significant increases in net emissions even after energy is "matched" by hour. Finally, the Annual Carbon Matching method, using LME data, can ensure low or zero net emissions and qualification for the clean hydrogen production tax credit. The Annual Carbon Matching method also helps to incentivize development of electrolyzers in locations with cleaner grids with lower existing marginal emissions and the procurement of renewable energy in locations with dirtier grids and higher existing marginal emissions, therefore maximizing the 'greening of the grid' impact of the IRA legislation.

Accounting Method	Net Emissions [kg CO_2e / kg H_2]
Annual Energy Matching	-6.6 to +10.6
Local Hourly Energy Matching	-7.3 to +11.2
Annual Carbon Matching	0
Threshold for minimum value PTC qualification ($0.60 / kg H_2)	<4.0
Threshold for maximum value PTC qualification ($3 / kg H_2)	<0.45

Table 1: Net emissions ranges for the three proposed accounting methods.

Background

With the passage of the 2022 IRA, the United States has established a new Hydrogen Production Tax Credit (PTC) to encourage clean hydrogen production. In order to meet the PTC requirements, emissions resulting from hydrogen production must not exceed a threshold of 4 $kgCO_2e/kgH_2$, with the maximum credit ($3 / kg) received only if resulting emissions are below 0.45 $kgCO_2e/kgH_2$ [1]. A natural starting point for guaranteeing low or zero emissions from hydrogen production is co-location: connecting renewable energy generation and electrolyzer consumption behind-the-meter. However, this approach can only be applied in a limited number of locations and circumstances and will not scale sufficiently to support the ambitious growth projections of the U.S. clean hydrogen industry. To achieve the desired scale, offsite renewable energy procurement will be required and therefore an accounting method is required to ensure that emissions associated with electricity consumption by new electrolyzers are sufficiently offset by additional renewable energy generation elsewhere on the grid.

There are three primary accounting approaches currently under consideration:

1. **Annual Energy Matching**: the total annual energy consumption of the electrolyzer is offset by the procurement of an equivalent total annual quantity of energy generated from a renewable energy facility. This method is substantially similar to the current Scope 2 greenhouse gas accounting methodology, which is actively being revised due to concerns over its efficacy [2].

2. **Local Hourly Energy Matching**: the energy consumption of the electrolyzer is controlled in each hour to match the procured generation from a renewable energy facility in the local grid region. "Local" is often referred to as "deliverable". This approach is intended to emulate 'behind the meter' onsite renewable energy paired with an electrolyzer concept. However, the definition of 'local' is important and varies between proposals, but using the same balancing authority as the definition of "local" is most common.

3. **Annual Carbon Matching**: the total annual emissions created through the energy consumption of the electrolyzer must be offset by an equivalent amount of emissions avoided through procurement of onsite or offsite renewable energy generation - typically from a project deemed to be "additional". This method is consistent with the principals of the Emissions First Partnership [3] [4].

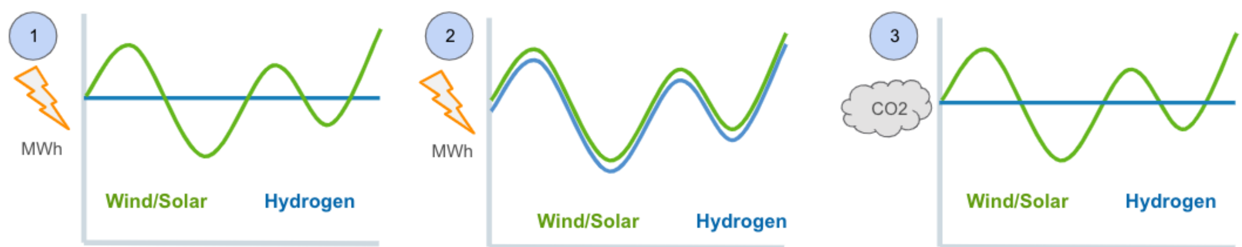


Figure 1: Examples of emissions accounting methods.

The aim of the above three methods is to ensure that hydrogen produced by the new generation of tax credit-qualified facilities will not increase greenhouse gas emissions on a net basis. Methods 1 and 2 use energy (in MWh) as a proxy for emissions and rely on the assumption that the matched megawatt hours have an equivalent carbon intensity. Method 3, Annual Carbon Matching, uses data on emissions intensities where and when energy is consumed and generated in order to directly calculate the net emissions impact of grid energy consumption and clean energy generation.

This analysis uses hourly, nodal LMEs across three different regions of the country to demonstrate the emissions impact of using megawatt hours as "proxy" for emissions - whether via Annual Energy Matching or Local Hourly Energy Matching. This analysis also aims to demonstrate how LME data can be used to enable the Annual Carbon Matching accounting method.

Method

We use hourly generation and marginal emissions data from 2022 for 32 renewable energy projects across the U.S. to simulate the emissions impacts while complying with each of the three accounting methods detailed above. Electrolyzer locations were chosen to represent possible future 'hydrogen hubs' [5] while operational renewable energy projects were used to simulate at locations intended to represent a range of marginal emissions values within each grid region.

LMEs measure the emissions intensity (in CO_2) of the marginal generator as a function of location and time [6] [7]. LMEs are closely related to Locational Marginal Prices (LMPs) and are a function of the local grid constraints and congestion - in an unconstrained grid with no congestion, LMPs and LMEs are uniform everywhere at a given time. However, in reality, transmission constraints often cause wide variations in LMPs and LMEs even within the same grid or sub-grid zone.

The hourly renewable energy generation data used in this analysis is based on the metered output reported to the ISO for each project, where available. Where the hourly metered data is unavailable, REsurety uses satellite-based re-analysis weather data to model the hourly generation of each renewable energy project.

A number of key assumptions are made in this analysis, specifically:

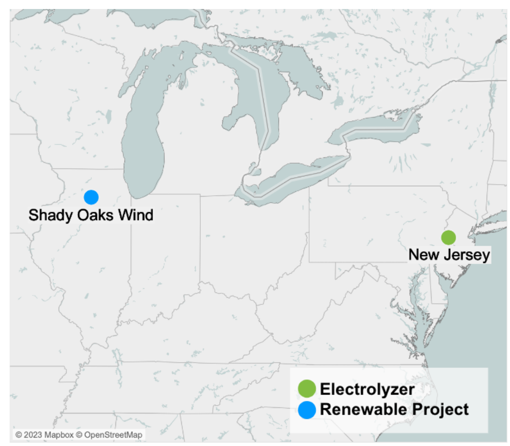
1. Electrolyzer efficiency is assumed to be 45 kWh per kg H_2. This assumption is applied to all electrolyzer locations and for all accounting methods.
2. For the Annual Energy Matching method, electrolyzer consumption is assumed to be constant in each hour.
3. For the Local Hourly Energy Matching method, it is assumed electrolyzer consumption is controlled to perfectly match the generation of the offsite renewable energy project. The physical and economic practicality of controlling electrolyzer output in this manner is not considered in this analysis.
4. Only 2022 data is included in this study. It is assumed that 2022 is a broadly representative year in terms of renewable energy generation and LME rates.

Findings

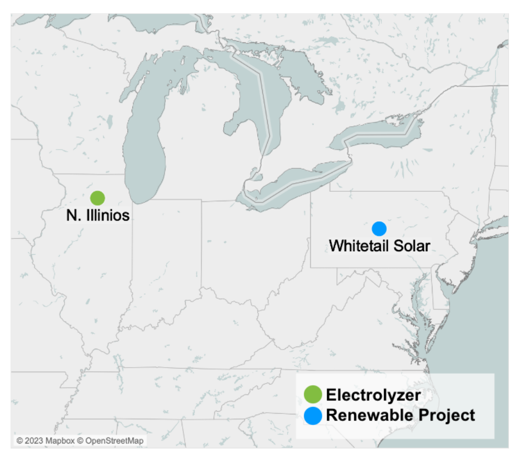
The analysis by REsurety reveals the following three primary findings:

1. **Annual Energy Matching often results in significant net emissions, although results are highly variable.** Marginal emissions intensity varies greatly by location and time and the annual matching process does not account for this variability. If the renewable generation is sourced from a cleaner location on the grid than the location of the electrolyzer, there will be a net increase in emissions despite the annual energy consumption of the electrolyzer being offset by renewable energy.

   As shown in Figure 2 below, the majority of electrolyzer and renewable energy project pairs analyzed exceed the net emissions threshold required for qualification for the maximum production tax credit value of \$3/kgH_2. Many pairs also exceed the minimum \$0.60/kgH_2 qualification threshold.



   Example 1: Electrolyzer in New Jersey paired with the Shady Oaks Wind Farm renewable energy project.
   In this example, the electrolyzer location in New Jersey has higher marginal emissions rates compared to the location of the Illinois wind project, despite being in the same grid (PJM). The Shady Oaks wind project is located near a number of other wind and solar facilities and transmission constraints mean the amount of clean energy that can be exported for consumption elsewhere is often limited. During these periods of congestion (and resulting renewable energy curtailment), new generation from the wind farm is not displacing any conventional fossil-powered generation and therefore the LME rate is low compared to the electrolyzer location. This means the carbon emissions associated with the additional annual consumption in New Jersey caused by the installation of the electrolyzer is greater than the annual emissions avoided by adding a new wind farm in an area with a large existing renewable energy footprint and limited transmission capacity.



   Example 2: Electrolyzer in Northern Illinois paired with the Whitetail Solar renewable energy project.
   In this example, the relationship between marginal emissions at the electrolyzer and renewable energy plant is flipped compared to Example 1. The electrolyzer location in Northern Illinois has lower marginal emissions rates compared to the location of the Pennsylvania solar project. Now the renewable energy project is, on average, displacing more carbon emissions per megawatt hour than the electrolyzer is consuming, resulting in *negative* net emissions when using the Annual Energy Matching accounting method.

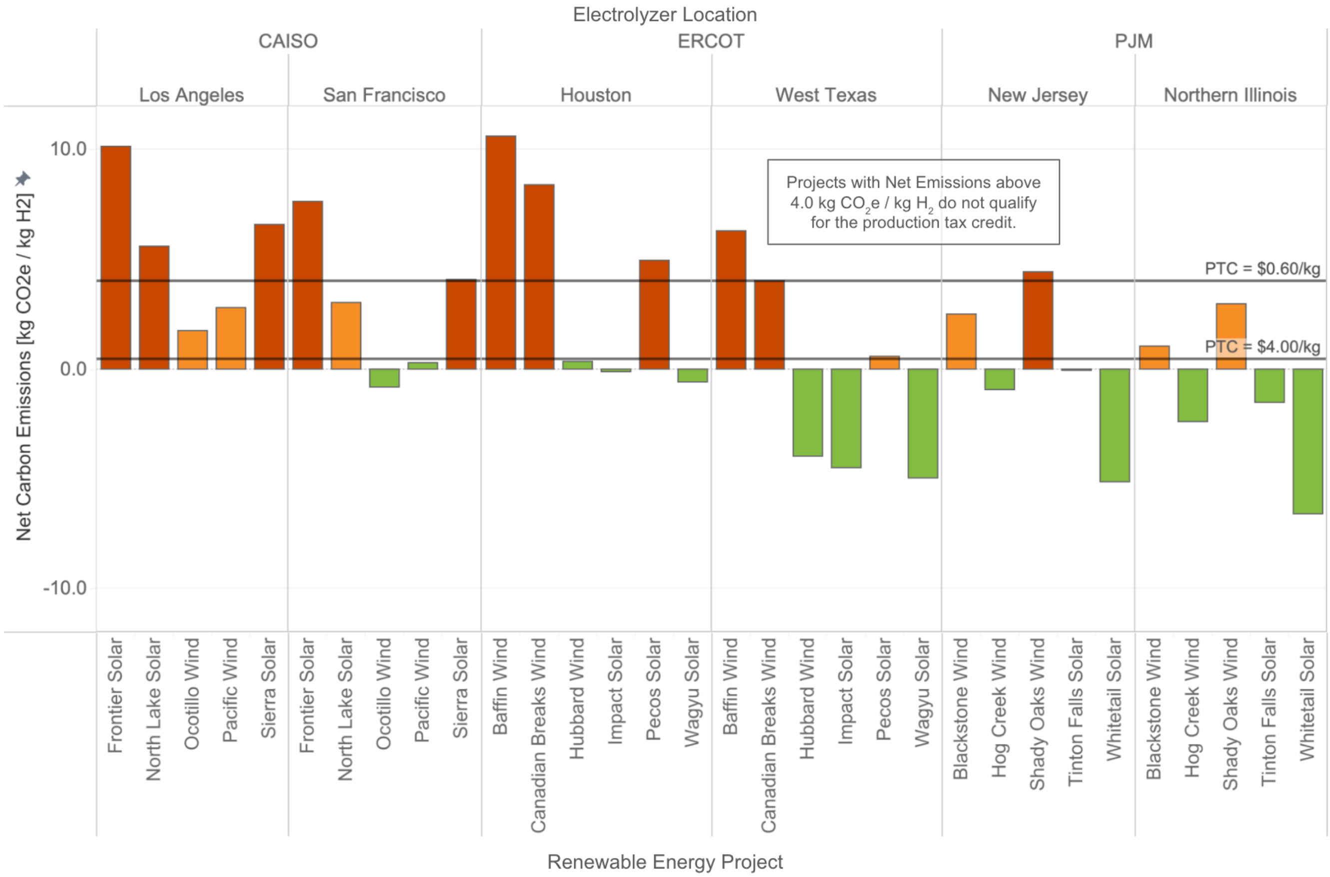
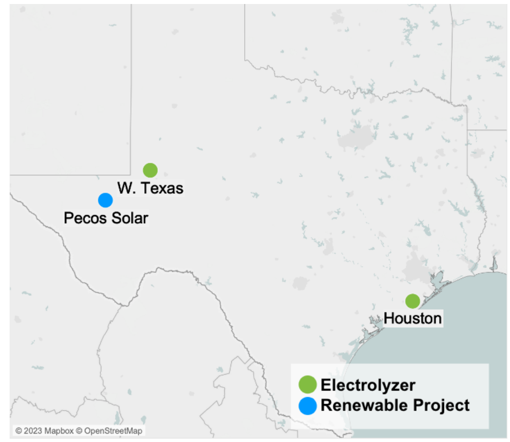


Figure 2: Net CO_2e emissions using Annual Energy Matching method.

2. **Local Hourly Energy Matching produces mixed results.** In some locations, matching the electrolyzer consumption hour-by-hour with local renewable energy generation results in lower emissions compared to the Annual Energy Matching approach. For example, in California, where there is a strong and consistent diurnal pattern of emissions intensity due to the abundance of solar generation in the state, there can be a significant benefit to Local Hourly Energy Matching because the largest variable in marginal emissions rates is timing rather than location. As a result, aligning electrolyzer load with solar generation reduces emissions at the source.

   However, in many locations hourly matching can lead to no change in emissions or even an *increase* in overall emissions. For example, in Texas the impacts of transmission tend to dominate the impact of timing. Furthermore, as shown in Figure 3, even in cases where hourly energy matching reduces net emissions compared to annual energy matching, net emissions are still significant and do not regularly fall below the threshold for the maximum $3/kg$H_2$ production tax credit.

Example 3: Electrolyzers in Houston and West Texas paired with the West of the Pecos Solar renewable energy project.



In this example, the net emissions associated with annual and hourly energy matching are calculated for two different electrolyzer locations, in Houston and West Texas, offsetting energy consumption from the same solar energy facility, also in West Texas. There are a large number of existing renewable energy facilities subject to transmission constraints in West Texas, meaning the total amount of renewable energy that can be exported to elsewhere in the ERCOT footprint is often limited during periods of high output. During these times the electrolyzer in Houston is consuming electricity that is largely unaffected by the solar generation in West Texas. In fact, the emissions associated with the electrolyzer's energy consumption are actually *increased* by aligning to periods of high solar generation in West Texas. Meanwhile, the electrolyzer located in West Texas close to the solar facility is already located in a region of the grid with an abundance of clean electricity and is on the same side of the transmission constraint as the renewable energy projects. Now in this case, matching the electrolyzer output to coincide with the generation from the solar facility achieves the aim of reducing the net emissions associated with hydrogen production.

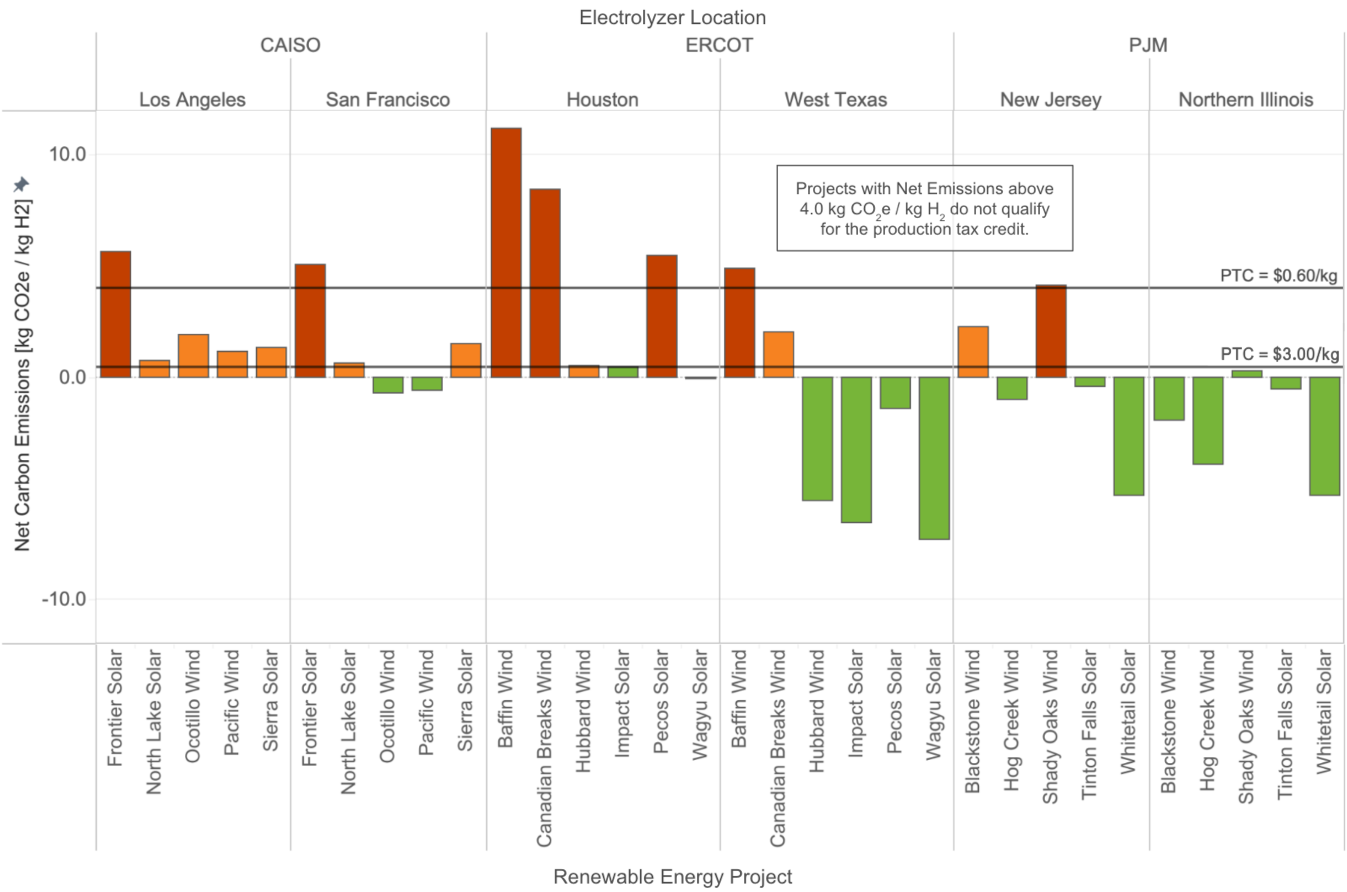


Figure 3: Net CO_2e emissions using hourly energy matching method.

3. **Annual Carbon Matching** can be used to ensure the energy consumption of hydrogen electrolyzers is offset with the appropriate level of renewable energy to result in low or zero net emissions. By relaxing the requirement to co-locate within the same grid, this method also incentivizes the development of electrolyzers in relatively clean grids and

procurement from new renewable energy facilities in relatively dirty grids, thereby maximizing the 'greening' impact of the Inflation Reduction Act legislation.

By optimizing the procurement of renewable energy to achieve zero net emissions, rather than to match for each MWh consumed at the electrolyzer location, it's possible to reduce the level of investment required. Figure 4 shows the ratio of renewable energy procurement required to offset the carbon emissions of electrolyzers in different locations. Electrolyzers located in areas with high marginal emissions rates need to procure more offsetting clean energy, on average, than equivalent electrolyzers located in cleaner grids.

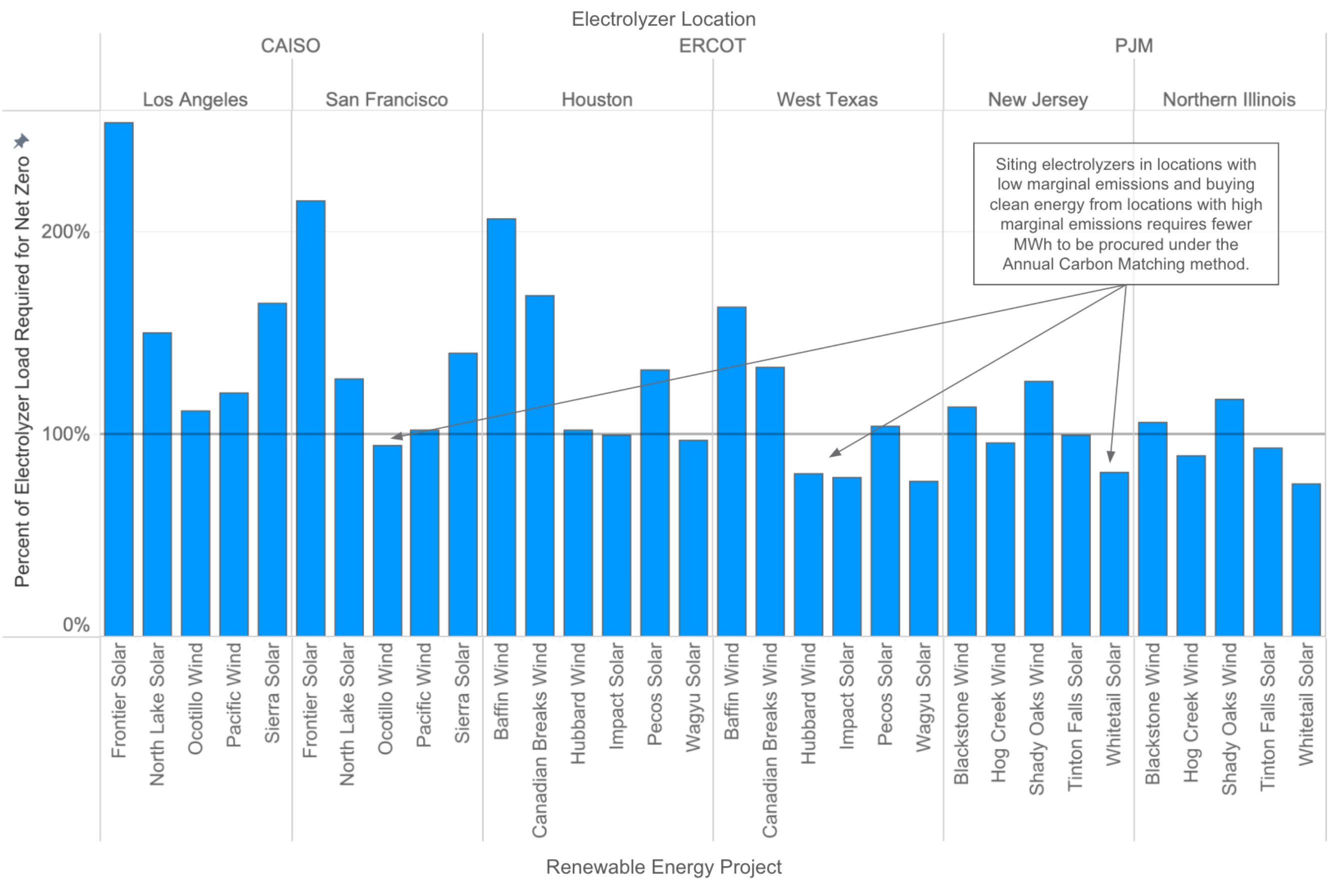
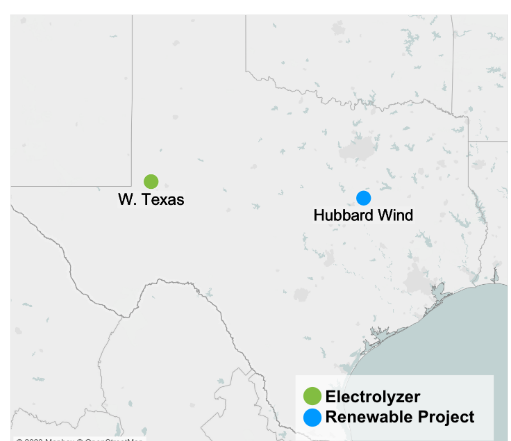


Figure 4: Clean energy procurement required to achieve zero net emissions, ratio of electrolyzer load compared to Annual Carbon Matching.

Example 4: Electrolyzer in West Texas paired with the Hubbard Wind renewable energy project.

By locating an electrolyzer in a cleaner part of the ERCOT grid (West Texas), it is only necessary to procure approximately 80% of the annual energy consumption of the electrolyzer when buying power from a wind farm in a relatively dirtier part of the grid (Hubbard Wind outside Dallas) therefore cutting the potential cost of achieving zero net emissions. Further, it's possible to reduce the requirements even more by procuring clean energy from a grid with higher emissions rates. The zero emissions procurement requirement drops to 61% for the West Texas-based electrolyzer when offsetting consumption with renewable energy from the Whitetail solar facility in Central Pennsylvania (not shown in Figure 4 for simplicity).



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Summary

The emissions associated with energy generation or consumption vary meaningfully by time and by location. Locational Marginal Emissions provides the data required to accurately and precisely quantify the emissions caused by electricity consumption or avoided by clean energy generation, and is utilized in this analysis to calculate the net emissions impact of generating “clean” hydrogen that complies with the 3 different proposed accounting methods, respectively.

This analysis shows that a wide range of net emissions outcomes occur under both the Annual Energy Matching and Local Hourly Energy Matching methods. In some locations, Local Hourly Energy Matching results in meaningful reductions in net emissions compared to the Annual Energy Matching method. These meaningful reductions in net emissions primarily occur in CAISO where the marginal emissions rates are driven more strongly by timing and less strongly by location as a result of the high penetration of solar, and the resulting impact on the diurnal pattern of grid emissions intensity. However, if significant local transmission constraints exist between the electrolyzer and renewable energy project location, as is common in grids such as ERCOT and some parts of PJM, emissions can actually be increased under the Local Hourly Energy Matching method. In these regions, during periods of high renewable generation, incremental wind or solar megawatt hours are often displacing existing clean generation while the incremental electrolyzer consumption is being supplied by a fossil-powered generator.

By calculating emissions impact directly in units of tons of CO_2e, the Annual Carbon Matching method is the only method that consistently results in low or zero net emissions. This finding is consistent with similar results recently published by energy research firm Tabors Caramanis Rudkevich [8]. Further, the Annual Carbon Matching method enables maximum ‘greening’ of the grid as a result of the Inflation Reduction Act by incentivizing the development of electrolyzer demand in grids with already abundant renewable energy and incentivizing the development of new carbon free energy generation sources in grids that have historically relied upon a higher proportion of fossil-based generators.

For more information on Locational Marginal Emissions data, please visit: http://resurety.com/lme or contact us directly at carbon@resurety.com.

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