United States of America
Department of Energy
Office of Energy Efficiency & Renewable Energy

Request for Information: Clean Hydrogen Production Standard (CHPS) Draft Guidance

Response of the Princeton University Zero-carbon Energy systems Research and Optimization Laboratory (ZERO Lab)[1,2]

The Princeton University ZERO Lab appreciates the opportunity to submit comments in response to the Department of Energy's (DOE) request for information regarding implementation of the Clean Hydrogen Production Standard (CHPS). Since its inception the ZERO Lab has endeavored to provide timely, unbiased, and robust energy modeling analysis in support of US energy policy design at the state and federal levels. With the aim of providing decision support for implementation of the Inflation Reduction Act's (IRA) 45V Clean Hydrogen Production Tax Credit (PTC), the lab recently conducted an analysis of the impacts of various clean energy procurement strategies on the embodied emissions of grid-based hydrogen production.[3] The findings of this report are equally relevant to implementation of the CHPS, which has been designed to align with 45V, and we reference them here in response to section 3(c) of the present RFI.

3) Implementation

> *c) Should renewable energy credits, power purchase agreements, or other market structures be allowable in characterizing the intensity of electricity emissions for hydrogen production? Should any requirements be placed on these instruments if they are allowed to be accounted for as a source of clean electricity (e.g. restrictions on time of generation, time of use, or regional considerations)? What are the pros and cons of allowing different schemes? How should these instruments be structured (e.g. time of generation, time of use, or regional considerations) if they are allowed for use?*

We believe that market-based clean energy procurements should be allowable in characterizing the intensity of hydrogen production, but only under very specific conditions. Allowing verification of clean electricity inputs only via direct physical proof would limit qualifying clean hydrogen production to facilities with behind-the-meter clean generation. While connection to the broader electricity grid could enable hydrogen production co-located with end uses and allow for higher electrolyzer utilization rates, physical connection to a system

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[1] **This response reflects the views of the ZERO Lab and its members, and not those of Princeton University or the Andlinger Center for Energy and the Environment.**

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[3] Ricks, Wilson, Xu, Qingyu, & Jenkins, Jesse D. (2022). Enabling grid-based hydrogen production with low embodied emissions in the United States. Working Paper. Zenodo. https://doi.org/10.5281/zenodo.7183516

fed by both clean and emitting generators makes emissions accounting significantly more challenging. Given the impossibility of tracking flows between individual producers and consumers in the bulk electricity system, there should be a positive burden of proof on any market-based clean energy procurement mechanism purporting to allow grid-based hydrogen producers to claim carbon-free electricity inputs. In our analysis, we quantitatively examine the long-run emissions impacts of hydrogen production in modeled electricity systems under various clean energy procurement strategies.

We find that three key conditions must be met for clean energy procured via renewable energy credits, power purchase agreements, or similar market-based mechanisms to enable grid-based hydrogen production *with embodied emissions equivalent to those of behind-the-meter systems*:

1. **Temporal matching**
2. **Additionality**
3. **Deliverability**

The following paragraphs describe each condition and its importance.

It should be noted that equivalence to a behind-the-meter system is not the same as having zero long-run emissions impact. In fact, our modeling demonstrates that even behind-the-meter electrolysis can induce significant increases in electricity system emissions in certain circumstances by ‘using up’ high-quality renewable resources that could otherwise have been used directly for generation. These impacts are an effectively unavoidable consequence of electrolysis development in a world where emitting resources still make up a large portion of total electricity generation and without the imposition of a binding emissions limit on power sector emissions. *However, because behind-the-meter electrolysis supplied exclusively by zero-emitting generation is generally considered to be ‘clean,’ we recommend that grid-connected electrolysis be permitted if it can achieve equivalent or better long-run emissions outcomes as an electrolyzer supplied by behind-the-meter carbon-free resources.* Our work demonstrates that this is the case only when clean energy procurement mechanisms meet conditions for temporal matching, additionality, and deliverability.

1. Temporal Matching

Qualifying clean generation should be consumed in the same tight temporal window in which it is produced. This is to say; the hydrogen producer should be required to actively match their grid electricity consumption with procured clean generation at all times. This is an inherent physical constraint on behind-the-meter systems. We recommend an hourly matching window, as this level of granularity captures the large diurnal variability in electricity prices and emissions rates on the grid while providing a long enough conformance window for hydrogen producers to reliably manage their real-time operations. Hourly matching also aligns with the temporal granularity of day-ahead electricity markets managed by all U.S. regional transmission organizations (RTOs). Hourly matching of consumption with additional, deliverable clean generation ensures that hydrogen producers are never reliant on emitting grid electricity (see Figure 1), and can therefore claim all their electricity inputs as clean. Modeling shows that the added cost for grid-based hydrogen producers to meet such a requirement is less than $\$1/kgH_2$, comparatively much lower than the $\$3/kgH_2$ maximum 45V clean hydrogen PTC.

Traditionally, EPA Scope 2 accounting guidance has allowed corporations to claim 100% carbon-free electricity use as long as they procure enough carbon-free generation to match their total consumption over the course of a year.[4] However, these accounting practices do not consider variations in grid emissions rates with time, nor do they take into account the long-run impacts of clean energy procurements on investments in the broader electricity system. *Our electricity system-level modeling finds that an annual clean energy matching requirement for clean hydrogen producers is almost entirely ineffective at reducing hydrogen's embodied carbon emissions in all circumstances.* This is in part because while annual accounting allows net excess clean procurement in some periods to offset net consumption in others, the emissions rates during periods of net consumption and net generation are not equivalent (see Figure 1). We also find that excess procured clean generation in both cases tends to replace other clean power from the electricity market, leading to larger long-run emissions impacts when excess procurements are relied on as offsets. This problem of displacing competing clean generators in the long-run is notably less prevalent (though not absent) in the case of hourly matched or behind-the-meter systems.

Even modest relaxations of an hourly matching requirement rapidly reduce the effectiveness of clean energy procurements for hydrogen production. In modeled scenarios where we enforce a weekly matching requirement, major outcomes are effectively unchanged compared to scenarios with annual matching requirements and embodied emissions from electrolysis are much higher than the threshold required for the full 45V PTC in all such cases. This finding suggests that a temporal matching requirement is only effective when applied on very granular timescales (e.g., hourly or finer).

2. Additionality

Clean electricity procurement of any kind does nothing to reduce the embodied emissions of grid-based hydrogen production if the procured clean resources are not additional. Here, we consider a resource to be 'additional' if it (or an equivalent resource) would not have been deployed had it not been able to contract with the hydrogen producer. One category of resources that does not meet this requirement is existing carbon-free generators, which will almost certainly remain in operation regardless of whether they are procured for hydrogen production specifically. Procuring generation from one of these plants does not, therefore, increase the total clean generation in the system. While a hydrogen producer may seek to claim clean inputs by procuring an existing resource, the actual additional generation used to meet their additional electricity demand will necessarily come from a mix of clean and fossil resources. From another perspective, procuring existing clean resources for oneself increases the grid emissions rate for

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[4] M. Sotos. (2015). GHG Protocol Scope 2 Guidance. Technical Report ISBN: 978-1-56973-850-4, WRI.

all other users. *Our modeling finds that enabling procurement of existing clean resources completely eliminates any emissions benefits of an hourly matching requirement.* One exception to this rule is if the existing plant was at clear risk of economic retirement, in which case the hydrogen producer could potentially claim responsibility for its continued operation in the system. Even new resources may not meet the standard for additionality if they are counted toward state capacity procurement requirements (e.g., legally required geothermal deployment in California or offshore wind in New York). Because development of these resources is mandated, their deployment lacks any causal relationship with hydrogen, just like existing resources. Resources in this category should therefore be disqualified from procurement for the purpose of hydrogen emissions accounting.

While the electricity system model used to quantify these impacts featured a single planning period with a hard distinction between new and existing resources, generator deployments in the real electricity system happen continuously over time. Only allowing hydrogen producers to contract with clean generators operational on or after their own deployment date would likely be too strict a requirement, leading to low liquidity in markets for qualifying power. *We therefore recommend that hydrogen producers be allowed to procure clean electricity from generators that entered operation up to 18 months before the hydrogen producer.* This window would provide sufficient flexibility in contracting while preserving the demand signal sent by new hydrogen facilities (which typically have construction timelines at least this long) to new clean generators.

3. Deliverability

Our modeling finds that the emissions benefits of an hourly matching requirement with strict additionality may not materialize if the procured clean electricity is not physically deliverable. Even within the same synchronized electricity grid, balancing area (BA), or regional transmission organization (RTO) territory, transmission congestion can prevent procured resources from actually contributing additional clean generation to supply additional electrolysis load. When transmission pathways between procured clean generators and hydrogen electrolyzers are congested, local resources, including fossil generators, increase their output to meet any incremental electricity demand from hydrogen production. The severity of the resulting emissions impact increases with the frequency of congestion, though it is also dependent on the relative emissions rates of the two grid regions. However, *when there is no grid congestion between hydrogen producer and contracted clean electricity supplier(s), there is effectively no functional difference between a grid-based hydrogen producer procuring hourly-matched, off-site clean energy and one consuming directly from behind-the-meter clean resources.*[5] It is therefore important to define a deliverability condition that ensures hydrogen producers are actually using the clean electricity they procure.

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[5] One minor difference is the presence of 1-3% average transmission losses in grid-connected systems, for which reason DOE may wish to 'de-rate' grid clean electricity procurements by a small amount in any implemented accounting system.

We recommend a delivery requirement for grid-based hydrogen producers that allows procured clean generation to be counted toward clean hydrogen production in a given hour only if it can be proven that there is an uncongested transmission pathway between the point of generation and the point of offtake. Locational marginal electricity prices (LMPs) can be used to verify deliverability in real time in grid regions where they are available, with large LMP differences between two grid nodes being indicative of congestion along the transmission pathways connecting them. Under an LMP-based deliverability validation mechanism, procured clean generation would be considered deliverable in a given hour only if (a) the generation and consumption occurred in the same synchronous electricity grid, and (b) the LMP at the point of offtake did not exceed that at the point of generation by more than a given threshold (set suitably high to account for the impact of transmission losses on LMP). This method of enforcement would be easy to apply within the territories of RTOs, which calculate and publish LMPs at real-time, day-ahead, and other intervals. However, robust deliverability validation would not be possible in grid regions without RTOs, where LMPs and other congestion measurement metrics are not readily available. If DOE still wishes to allow grid-based clean hydrogen production in non-RTO regions, electrolysis facilities located in these regions could be required to source qualifying clean electricity from within their own local balancing area (BA). This requirement would minimize (though not necessarily eliminate) the risk of deliverability violations, as BAs are generally geographically limited in scope in non-RTO regions.

Caveats

As noted above, an hourly matching requirement (even with mandated deliverability and procurement of new clean resources) still cannot guarantee low long-run emissions impacts in all cases. Figure 2 shows emissions outcomes under different policies in each of the six zones of our Western Interconnection grid model. Emissions are measured on both an **attributional** basis, which assigns emissions to hydrogen producers based on their net consumption (e.g., consumption less procured generation in each hour) and the local average grid emissions rate, and a **consequential** basis, which uses counterfactual scenarios to calculate the system-wide emissions impact of deploying electrolysis in a given setting (relative to a scenario with no electrolysis demand). Attributional emissions would likely be used to certify the cleanliness of hydrogen production (see the below section on Implementation). In contrast, consequential emissions cannot be observed or measured in the real world, but provide a useful means of projecting the overall emissions impact of policy choices.

As shown in Figure 2, *attributional emissions are zero in cases with full hourly matching, but typically above the CHPS threshold under annual matching. Consequential emissions under hourly matching cases range from negative in some model zones to very high in others, while annual matching leads to consistently high consequential emissions across all zones.* High consequential emissions impacts in hourly matched cases occur primarily due to electrolysis competing with grid users for limited high-quality clean resources. We demonstrate this by including cases with hourly matching that forbid sales of excess procured electricity back to the grid. In these cases, the net of electrolysis consumption and procured clean generation is always zero, and the only impact of the hydrogen producer on the grid at large is through the high-quality renewable resource sites they compete for. Although consequential emissions in these cases can be quite large, the exact same outcomes could occur for behind-the-meter electrolysis facilities using the same renewable resource sites. The same can be said for any indirect emissions resulting from sales of excess clean electricity, either from grid-based or behind-the-meter installations. As a general rule, *we recommend that grid-based hydrogen producers not be penalized for any indirect emissions that could also be incurred by behind-the-meter producers*.

Finally, given that significant consequential emissions can occur even for hourly-matched or behind-the-meter hydrogen producers, there may be some interest in clean electricity procurement strategies that are explicitly emissions-based. One possible option is a requirement that hydrogen producers achieve net-zero short-run marginal emissions, i.e. that their clean electricity procurements offset the same total marginal emissions that are incurred by their consumption over the course of a year, regardless of when (or even where) these emissions take place. We model this marginal emissions offsetting based requirement for the case of a single zone, and find that the emissions accounting approach is inferior to an hourly matching approach from a consequential emissions perspective. Thus, *while hourly matching cannot guarantee low consequential emissions, it is still the best available strategy for minimizing the long-run emissions impact of grid-based hydrogen production in the United States.*

Implementation

We recommend that the CHPS be implemented in a manner that allows hydrogen producers flexibility in operating their systems while ensuring that all production meets the standard of a behind-the-meter system.

As a baseline, any electricity generated by behind-the-meter resources and consumed in the process of hydrogen production should be considered to have embodied emissions equivalent to those of the installed resources, and any electricity consumed from the grid without a qualifying market-based clean electricity procurement mechanism should be considered to have embodied emissions equivalent to the regional average grid emission rate. This approach is consistent with the current iteration of the GREET model,[6] which has also been designated in IRA statute as the means by which hydrogen's emissions intensity should be calculated for the purpose of 45V PTC qualification.

We further recommend that in addition to this baseline accounting methodology, *any grid electricity procured under a qualifying market-based clean electricity procurement mechanism be considered functionally equivalent to electricity consumed from a behind-the-meter resource of the same type.* Qualifying market-based mechanisms should meet requirements for hourly temporal matching, additionality, and deliverability, as outlined above. For example, grid-based solar generation procured by the hydrogen producer under a qualifying mechanism (e.g., meeting temporal matching, additionality, *and* deliverability conditions) should be handled identically to behind-the-meter solar in GREET. *This approach facilitates use of the current version of the*

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[6] Elgowainy, A. (2022). GREET Model for Hydrogen Life Cycle GHG Emissions. Argonne National Laboratory. https://www.energy.gov/sites/default/files/2022-06/hfto-june-h2iqhour-2022-argonne.pdf

GREET model, without modification, for calculation of embodied emissions of hydrogen producers for both CHPS and 45V implementation. These requirements are also consistent with recommendations made by the White House Council on Environmental Quality regarding implementation of Executive Order 14057, which directs federal agencies to pursue time-based procurement of carbon-free electricity.[7,8] Grid electricity procured under non-qualifying mechanisms should not have its emissions rate discounted in any way, as looser clean electricity procurement mechanisms like annual matching have little if any demonstrable emissions advantage over basic grid procurements. This accounting approach will allow hydrogen producers to combine behind-the-meter generation, qualifying clean grid power, and unabated grid power to best suit their own needs while preventing large system-level increases in greenhouse gas emissions.

Finally, we stress that logistics are unlikely to be a barrier to implementation of a robust hourly matching standard for clean electricity procurements with additionality and deliverability requirements. Existing 24/7 clean energy procurement initiatives supported by demand from corporate entities[9] and the U.S. federal government have already established international standards for time-based energy attribute certificate (T-EAC) issuance.[10] In the U.S., a recent pilot program between M-RETS and Google successfully performed hourly certification of hourly clean electricity procurements.[11] These existing mechanisms and standards could be rapidly scaled to support robust and credible verification of clean, grid-based hydrogen production in the U.S. Under our recommended approach, hydrogen producers would also be free to use behind-the-meter clean generation to qualify for the CHPS until such time as qualifying market-based procurement mechanisms are widely available.

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[7] (2022). Implementing Instructions for Executive Order 14057: Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability. White House Council on Environmental Quality. https://www.sustainability.gov/pdfs/EO_14057_Implementing_Instructions.pdf

[8] (2021). Executive Order (EO) 14057: Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability.

[9] M. Dyson, S. Shah, and C. Teplin. (2021). Clean Power by the Hour: Assessing the Costs and Emissions Impacts of Hourly Carbon-Free Energy Procurement Strategies. Technical report, RMI. http://www.rmi.org/insight/clean-power-by-the-hour.

[10] (2022). Granular Certificate Scheme Standard: Version 1. EnergyTag. https://energytag.org/wp-content/uploads/2022/03/20220331-EnergyTag-GC-Scheme-Standard-v1-FINAL.pdf

[11] https://www.mrets.org/hourlydata

Figures

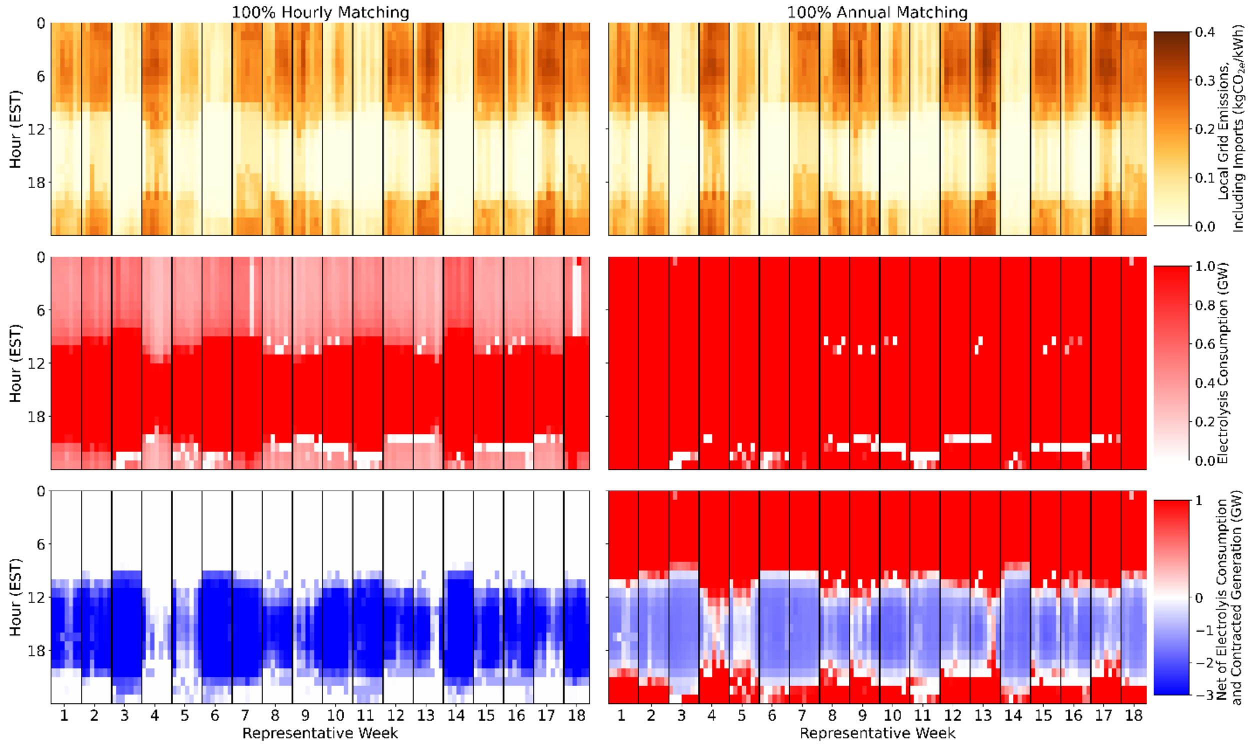

Figure 1: Patterns of hourly average grid emissions, hydrogen electricity consumption, and procured clean generation for cases with hourly matching (left) annual matching (right) requirements in northern California. Hourly matching ensures electrolysis consumption never exceeds procured generation. With annual matching, net consumption occurs during periods with high grid emissions rates.

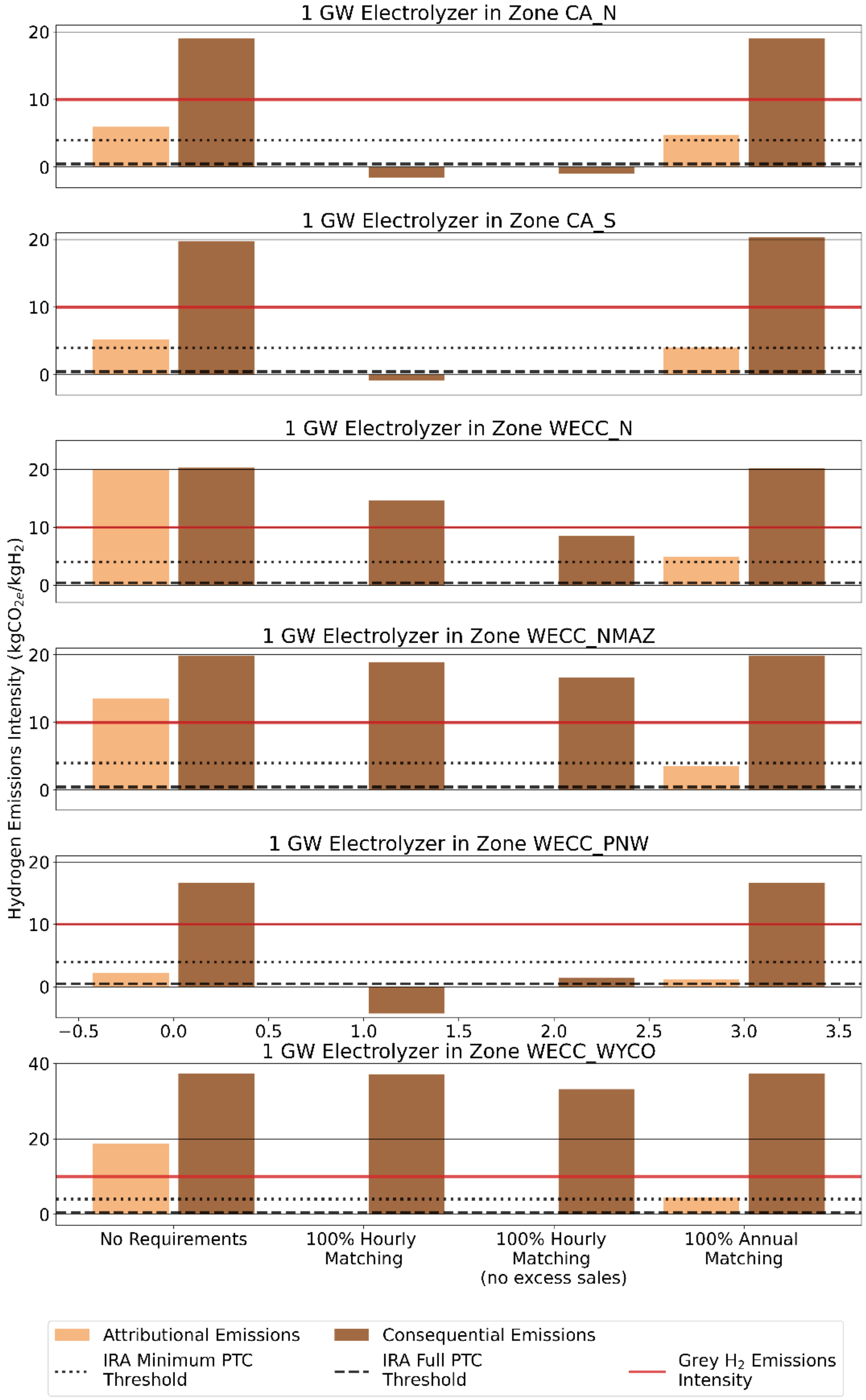

Figure 2: Attributional and consequential emissions from hydrogen production under various clean energy procurement strategies, in each of six modeled zones in the Western Interconnection. Both emissions rates are consistently lower in cases with hourly matching. Even with hourly matching, procurement of limited high-quality renewable sites can lead other grid users to rely more heavily on fossil resources (third, fourth, and bottom rows).

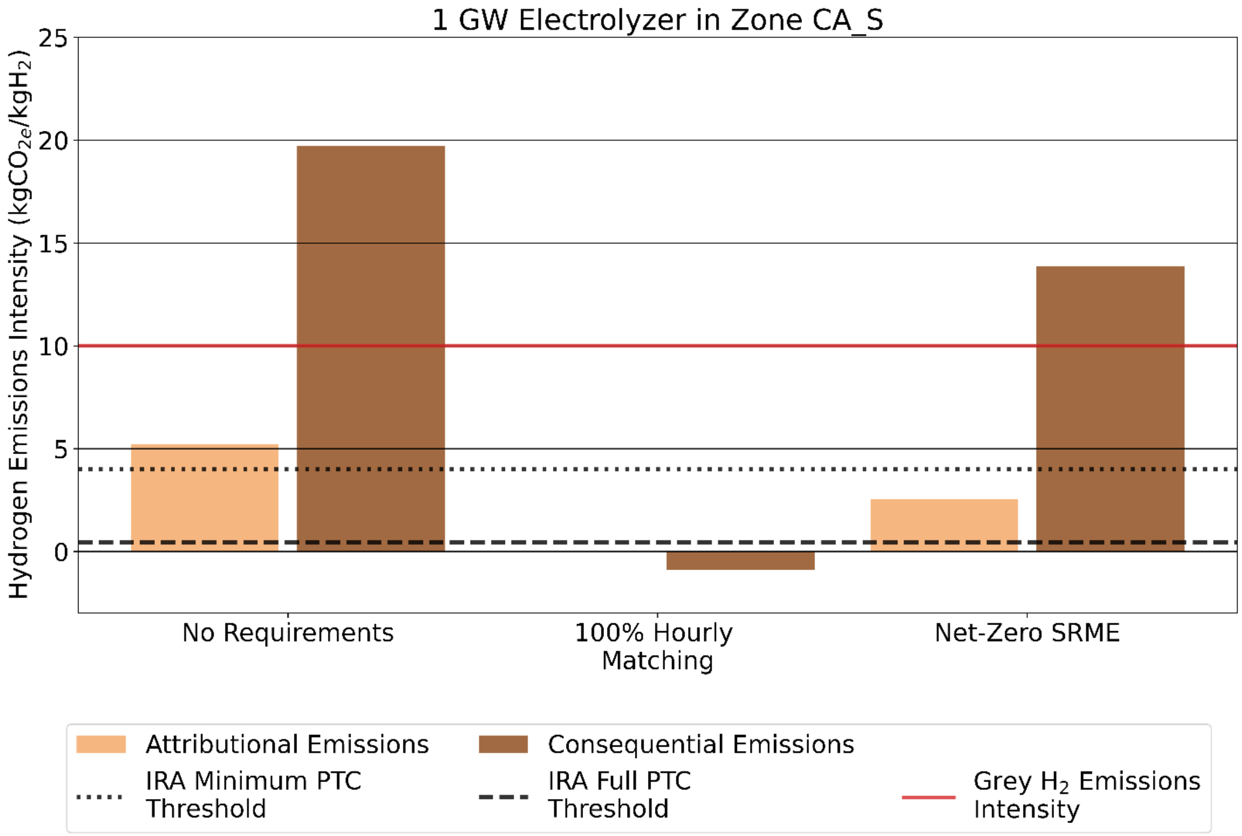

Figure 3: Model results showing the emissions impacts of a clean energy procurement strategy focused on hourly marginal emissions accounting, in comparison with an hourly matching strategy. The net-zero short-run marginal emissions (SRME) approach is an improvement compared to no clean energy procurements, but is significantly inferior to hourly matching in this scenario. Note that because the SRME approach relies on offsetting positive emissions in some hours with negative emissions (via excess clean generation) in others, it incurs a positive emissions penalty under our attributional emissions accounting scheme, which does not allow negative emissions. Both the 100% Hourly Matching and Net-Zero SRME approaches achieve annual net marginal emissions less than or equal to zero when offsets are included in the accounting.