United States of America
Department of the Treasury and Internal Revenue Service
Request for Comments on Credits for Clean Hydrogen and Clean Fuel Production

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 request for information by the Department of the Treasury (Treasury Department) and the Internal Revenue Service (IRS) regarding implementation of the Inflation Reduction Act's (IRA) clean hydrogen and clean fuel production tax incentives. 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 IRA's 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] In this response we discuss the findings of our report (currently undergoing peer review prior to formal publication) and their relevance for forthcoming Treasury/IRS guidance on 45V. We submit both a narrative discussing broadly our perspective on the issues at hand, followed by a Q&A that addresses specific questions from the RFI.

Section 1: Narrative

Background

The IRA established robust tax incentives for clean hydrogen production in the United States.[4] The new 45V PTC, in particular, provides large subsidies for hydrogen production meeting specified embodied greenhouse gas emissions thresholds. IRA statute specifies that embodied emissions from hydrogen production should be calculated on a well-to-gate basis using the latest version of Argonne National Lab's GREET lifecycle analysis model. For hydrogen produced via electrolysis (sometimes known as 'green' hydrogen), the most important factor in GREET's lifecycle emissions calculation is the embodied emissions rate of the input electricity. This rate depends on the ultimate source of the generation, which is easy to determine for hydrogen produced using directly connected, behind-the-meter clean resources, but much more difficult for facilities connected to the electricity grid. While current average emissions rates on the U.S. grid are far too high to enable hydrogen production meeting even the minimum PTC standard, hydrogen producers may seek to claim clean electricity inputs through energy attribute certificate (EAC) purchases, power purchase agreements (PPAs), or similar market-based clean energy

---

[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.**

[2]Contacts: Wilson Ricks (wricks@princeton.edu), Dr. Qingyu Xu (qingyux@princeton.edu) and Prof. Jesse Jenkins (jdj2@princeton.edu)

[3]Ricks, Wilson, Xu, Qingyu, & Jenkins, Jesse D. (2022). Minimizing emissions from grid-based hydrogen production in the United States. Working Paper. Zenodo. https://doi.org/10.5281/zenodo.7183515.

[4](2022). Text - H.R.5376 - 117th Congress (2021-2022): Inflation Reduction Act of 2022. 117th Congress. http://www.congress.gov/

procurement mechanisms. It will be the responsibility of Treasury and IRS to determine whether, or under what conditions, these market-based procurements can be used to allow grid-connected hydrogen producers to qualify for the 45V PTC.

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 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 in certain circumstances, even behind-the-meter electrolysis can induce significant increases in overall electricity system emissions 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 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, which must adjust their operations based on the generation profiles of their on-site resources. 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 directly reliant on fossil-fired grid electricity (see Figures 2 and 4 in the working paper), 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 $1/kg$H_2$, comparatively much lower than the $3/kg$H_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.[5] 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* (working paper, Figure 2). 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 (working paper, Figure 4). We also find that any excess 'offsets' procured almost always simply displace other clean power from the electricity market, leading to no reductions in long-run emissions. 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 marginally improved at best compared to scenarios with annual matching requirements, and consequential 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).

---

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

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 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 forces other grid users to make up the difference with new generation that has no requirement to be clean. *Our modeling finds that enabling procurement of existing clean resources completely eliminates any emissions benefits of an hourly matching requirement* (working paper, Supplementary Figure 19). 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 can fail to 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 facility.* 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 (working paper, Supplementary Figure 18). 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.*[6] It is therefore important to define a deliverability condition that ensures hydrogen producers are actually using the clean electricity they procure.

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 IRS/Treasury still wish 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 in the working paper 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 (i.e., 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,

---

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

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 of our report, *attributional emissions are zero in cases with full hourly matching, but typically above the minimum PTC threshold under annual matching or weekly 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*.

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 examine this strategy by explicitly modeling outcomes under a marginal emissions offsetting requirement, and find that the approach is entirely ineffective at mitigating real emissions. 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.*

Finally, we note some of the limitations of our study design and their implications. The GenX electricity system model used in this work is designed to minimize the cost of the overall electricity system, replicating the outcomes that would be observed in a perfectly efficient electricity market or a well-run, centrally-planned system. It also assumes perfect foresight by developers and operators across the planning horizon. In the real world, inefficiencies and myopic decision-making will lead to outcomes that diverge somewhat from modeled results. Therefore, rather than a tool for predicting exact outcomes, the model should instead be viewed as a means of understanding the high-level economics that can be expected to drive future investment decisions in the electricity system. In the present case we use it to argue that certain 45V PTC implementations economically incentivize certain electricity system outcomes, but not necessarily that these outcomes are guaranteed.

Implementation

We recommend that the 45V PTC 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 (or potentially marginal)[7] grid emission rate. This approach is fully consistent with the current iteration of the GREET model,[8] which has 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 GREET model, without modification, for calculation of embodied emissions of hydrogen producers for 45V qualification.* 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.[9,10] 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 or weekly matching have little if any demonstrable emissions advantage over basic grid procurements. This accounting approach will allow hydrogen producers to

---

[7]While GREET uses average grid emissions rates by default, and we follow this convention in our Attributional emissions rate calculations, accounting based on *marginal* rates may better reflect the true emissions impact of grid electricity consumption by hydrogen producers. Under an averages-based approach, hydrogen production in regions with large amounts of hydropower and very low average emission rates could meet the minimum PTC emissions threshold without any clean electricity procurements, even if most of the *new* generation used to supply the new electrolysis demand came from fossil resources. Marginal emissions accounting captures these impacts and more appropriately penalizes unabated hydrogen production in hydro-heavy regions (see Supplementary Figure 2 in our report). It would also potentially allow hydrogen producers to take advantage of existing clean resources that would otherwise be curtailed, by allowing consumption from the grid in hours when marginal emissions rates are zero.

[8]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

[9](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

[10](2021). Executive Order (EO) 14057: Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability.

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[11] and the U.S. federal government have already established international standards for time-based energy attribute certificate (T-EAC) issuance.[12] In the U.S., a recent pilot program between M-RETS and Google successfully performed hourly certification of hourly clean electricity procurements.[13] 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 45V PTC until such time as qualifying market-based procurement mechanisms are widely available.

Section II: Q&A

In this section we respond to individual relevant questions from the RFI, listed below in bold.

01: Credit for Production of Clean Hydrogen.

(1) Clean Hydrogen. Section 45V provides a definition of the term "qualified clean hydrogen." What, if any, guidance is needed to clarify the definition of qualified clean hydrogen?

(a) Section 45V defines "lifecycle greenhouse gas emissions" to "only include emissions through the point of production (well-to-gate)." Which specific steps and emissions should be included within the well-to-gate system boundary for clean hydrogen production from various resources?

For electrolysis-based production, emissions from consumption of grid electricity without a qualifying market-based clean energy procurement mechanism (i.e. one with hourly matching, additionality, and deliverability) should be included in the well-to-gate system boundary. These should be attributed based on the level of net consumption and the local grid's average or marginal emission rate. While accounting based on the average emission rate is consistent with the current iteration of GREET, accounting based on short-run marginal emissions rates may better capture the true emissions impact of grid electricity consumption

---

[11]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.

[12](2022). Granular Certificate Scheme Standard: Version 1. EnergyTag. https://energytag.org/wp-content/uploads/2022/03/20220331-EnergyTag-GC-Scheme-Standard-v1-FINAL.pdf

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

(i.e. the resources whose generation increases to supply the new electrolysis load). Accounting should include emissions from direct consumption of non-qualifying grid electricity, but not potential indirect emissions impacts from sales of excess clean electricity or competition for limited renewable electricity resources (which are unmeasurable). ‘Offsets’ that aim to reduce attributed emissions in some hours and locations through excess clean electricity procurements in others should not be permitted, as modeling has demonstrated these to have little to no impact on long-run emissions outcomes.

(e) How should qualified clean hydrogen production processes be required to verify the delivery of energy inputs that would be required to meet the estimated lifecycle greenhouse gas emissions rate as determined using the GREET model or other tools if used to supplement GREET?

(i) How might clean hydrogen production facilities verify the production of qualified clean hydrogen using other specific energy sources?

Production facilities could verify use of specific energy sources either via direct consumption (through on-site supply or a dedicated transmission line) or by procuring time-based energy attribute certificates (T-EACs) or similar third-party-verified proof of supply from qualifying (i.e. deliverable and additional) resources.

(ii) What granularity of time matching (that is, annual, hourly, or other) of energy inputs used in the qualified clean hydrogen production process should be required?

Hourly granularity should be required for time-matching. Our analysis indicates that longer intervals (even weekly) are almost entirely ineffective.