To: U.S Treasury Department

From: The Open Energy Outlook Initiative

Paulina Jaramillo, Mike Blackhurst, Jeremiah Johnson, Anderson de Queiroz, Aditya Sinha, and Cameron Wade.

Re: Proposed Rulemaking Section 45V Credit for Production of Clean Hydrogen; Section 48(a)(15) Election To Treat Clean Hydrogen Production Facilities as Energy Property

I. Introduction

The Inflation Reduction Act (IRA) of 2022 is the first law to support comprehensive climate mitigation efforts for the U.S. energy system. The law includes generous subsidies for a broad set of low-carbon energy technologies, including renewable power sources, end-use electrification technologies, carbon capture and sequestration, and hydrogen. Since burning hydrogen does not emit greenhouse gases, hydrogen may be able to replace fossil-based products and eliminate respective emissions at the point of combustion. However, different hydrogen production pathways can lead to different upstream emissions. The IRA thus subsidizes only "clean" hydrogen (called "45V") by providing a tax credit of up to $3 per kilogram of hydrogen, subject to meeting certain emissions requirements.

The most common hydrogen production method – steam methane reforming using natural gas – releases considerable amounts of CO_2 during production. Other methods for producing hydrogen could have substantially lower greenhouse gas (GHG) emissions than natural-gas-based hydrogen, including electrolytic hydrogen. Electrolytic hydrogen production relies on electricity to split water into hydrogen and oxygen. This production process is very energy-intensive, and associated emissions depend on the source of electricity used. If produced with coal-based electricity, the emissions benefits of electrolytic hydrogen would not materialize. As a result, the Treasury Department has proposed a rule to determine the conditions under which hydrogen producers will be eligible for the 45V tax credit.

The proposed rulemaking includes provisions describing tax credit eligibility for different hydrogen production pathways. This public comment will address the proposed requirements for electrolytic hydrogen production. Under the proposed rulemaking, the Treasury Department calls for implementing the "Three Pillars" requirement for electrolytic hydrogen. The Three Pillars requirement aims to prevent increased emissions from the power sector induced by electrolyzer demand. Under the Three Pillars framework, electrolytic hydrogen production must meet three criteria to receive the full tax credit: (1) the electricity must come from new carbon-free generation sources (incrementality); (2) the generation must be physically proximate to the hydrogen production (deliverability); and (3) starting in 2028, hourly renewable generation must match the hourly electricity consumption from the electrolyzer (hourly matching). Research has shown that, when examining the power sector in isolation, these requirements are necessary to prevent increasing power sector emissions when producing electrolytic hydrogen. The Open Energy Outlook Initiative, a collaboration between researchers at Carnegie Mellon University and North Carolina State University[1], has performed additional analysis to understand better the implications of the Three Pillars requirements on CO_2 emissions from the U.S. energy system. The following sections describe the results of this analysis and their implications for the proposed rulemaking.

II. Overview of Prior Research

Table 1 summarizes recent Three Pillars studies. Ricks et al. (2023)[2] raised concerns about hydrogen's emissions implications, suggesting that 45V compliance requires adhering to the Three Pillars. However, they used a model limited in temporal and geographic scope applied to the electric power system only. Other similar studies reach somewhat different conclusions. Olsen et al. (2023)[3] estimate that annual matching produces 45V-compliant hydrogen for most combinations of operating region, benchmark year,

[1] The comments presented in this document do not represent the opinions of the universities and are the sole responsibility of the authors.

[2] Wilson Ricks, Qingyu Xu & Jesse D. Jenkins, *Minimizing Emissions from Grid-Based Hydrogen Production in the United States*, 18 ENVIRON. RES. LETT. 014025 (2023).

[3] OLSEN, A. ET AL., *Analysis of Hourly and Annual GHG Emissions: Accounting for Hydrogen Production.*, (2023). https://acore.org/wp-content/uploads/2023/04/ACORE-and-E3-Analysis-of-Hourly-and-Annual-GHG-Emissions-Accounting-for-Hydrogen-Production.pdf

and grid mix, and that a 3% increase in renewable capacity brings all scenarios into compliance. They find that hourly matching reduces emissions relative to annual matching but increases hydrogen costs.

Giovanniello et al. (2024)[4] summarize different interpretations and models of incrementality. Some models allow all demands to "compete" for "additional" generation, which is defined as electricity resources "not operating in the system before installation of the electrolyzer." In contrast, "non-compete" incrementality sizes additional generation exclusively for new hydrogen. Giovanniello et al. (2024)[5] find that "compete" incrementality requires hourly matching to comply with 45V, whereas annual matching complies under "non-compete" incrementality. These results emphasize that incrementality has different interpretations that can produce different model outcomes. More broadly, these varying definitions highlight the challenge of reflecting future firm decisions using prospective methods.

Table 1: Review of studies evaluating the Hydrogen Three Pillars requirements, adapted from EPRI (2023)[6]

Study attribute	Citation				
	Ricks et al. (2023)[7]	Olsen at al. (2023)[8]	Giovanniello et al. (2024)[9]	Haley and Hargreaves (2023)[10]	EPRI (2023)[11]
Energy system scope	Electric power	Electric power	Electric power	Energy system	Energy system
Geographic basis	6 zones in Western Interconnection	SPP, MISO North, ERCOT, PJM	ERCOT, FRCC	U.S. in 27 zones	U.S. in 16 regions
Temporal basis	2030 snapshot	2025 and 2040 snapshots	2021 snapshot	2021; 2024; 2026; 2028; 2030; and 2032	2025 to 2050
Electrolyzer adoption	Exogenous	Exogenous	Exogenous	Endogenous	Endogenous
Hydrogen demand	Exogenous	Exogenous	Exogenous	Exogenous and endogenous	Endogenous and exogenous
Non-electrolyzer electricity demand	Exogenous	Exogenous	Exogenous	Endogenous	Endogenous
Incrementality	Compete	Compete	Compete and non-compete	Compete	Compete
Time matching	Hourly and annual	Hourly and annual	Hourly and annual	Hourly and annual	Hourly and annual

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4 Michael A. Giovanniello et al., *The Influence of Additionality and Time-Matching Requirements on the Emissions from Grid-Connected Hydrogen Production*, NAT ENERGY 1 (2024).
5 *Id.*
6 EPRI, *Impacts of IRA's 45V Clean Hydrogen Production Tax Credit*, (2023), https://www.epri.com/research/products/000000003002028407 (last visited Feb 19, 2024).
7 Ricks, Xu, and Jenkins, *supra* note 2.
8 OLSEN, A. ET AL., *supra* note 3.
9 Giovanniello et al., *supra* note 4.
10 BEN HALEY & HARGREAVES, J, *45V Tax Credit: Three-Pillars Impact Analysis*, (2023), https://www.evolved.energy/post/45v-three-pillars-impact-analysis (last visited Feb 19, 2024).
11 EPRI, *supra* note 6.

Studies that broaden the model scope and treat electrolyzer adoption and operations endogenously produce different results. Haley and Hargreaves (2024)[12] model six annual snapshots and endogenously-estimated hydrogen demand. They find that hydrogen increases net emissions, and that this increase is moderated (but not eliminated) by Three Pillars. If modeled exogenously, EPRI (2023)[13] results confirm findings from Ricks et al. (2023)[14] in showing that all Three Pillars are needed to reduce emissions from electric power. However, EPRI finds that less stringent criteria are needed to reduce emissions when hydrogen is modeled as displacing fossil fuels in the broader energy system. EPRI also finds emissions benefits continue in the future as the grid becomes "cleaner" and hydrogen continues to displace fossil fuels. Findings from EPRI (2023)[15] and Haley and Hargreaves (2023)[16] emphasize that the model scope (time, space, and energy assets) and endogeneity significantly impact expected outcomes such that partial treatment of these features may be misleading.

Location-matching and electrolyzer design are less well studied in the Three Pillars context. However, Bergman and Rennert (2023)[17] show that local marginal emission rates influence emissions from hydrogen produced in PJM. Engineering economic models show that electrolyzer design and operating features influence the cost and emissions of hydrogen production[18]. While currently unclear, we would expect electrolyzer designs – such as onsite storage - to influence systems-level outcomes, all else equal.

III. Simulating the Tree Pillars Requirements in an Energy System Optimization Framework

A. The Open Energy Outlook used an energy system modeling framework, Temoa[19], to evaluate the impacts of the Inflation Reduction Act on the U.S. energy system, considering the different structures of the 45V tax credit for electrolytic hydrogen. Temoa is a least-cost optimization model that minimizes the present value of the costs of building and operating the energy system during a user-specified timeline. Costs in the model include capital costs of new infrastructure, operation and maintenance costs, and fuel costs. Temoa runs in five-year increments but includes a power system representation that simulates hourly operations during eight representative days each year. The U.S. version of the database used for this analysis splits the system into nine regions. Electricity exports between regions are limited by existing transmission capacity and the costs of building new transmission lines. However, electricity used for 45V-compliant hydrogen production must be generated within the same region as the location of the electrolyzers. Unlike other models used to evaluate the Three Pillars requirement, Temoa optimizes the deployment of end-use energy technologies and endogenously estimates the demand for the energy carriers used to meet the end-use service demands. Thus, in contrast with other studies, our analysis accounts for sectoral competition for fuels like hydrogen and electricity.

We are interested in understanding the dynamics of the system while the provisions of the IRA are in place, as well as the implications after these provisions expire. For this purpose, we evaluated five scenarios. As noted before, all these scenarios constrain the generation of electricity used for 45V-compliant hydrogen production to the same region where electrolyzers are located (deliverability). Furthermore, in all the tax credit scenarios, hydrogen produced via steam methane reforming with carbon capture and sequestration (CCS) can receive either the full 45V credit or the 45Q credit included in the IRA to support CCS deployments.

i. No45V: A scenario that implements all the IRA provisions except for the 45Vtax credits.

[12] HALEY AND HARGREAVES, J, *supra* note 10.
[13] EPRI, *supra* note 6.
[14] Ricks, Xu, and Jenkins, *supra* note 2.
[15] EPRI, *supra* note 6.
[16] HALEY AND HARGREAVES, J, *supra* note 10.
[17] BERGMAN, A & RENNERT, K, *Emissions Effects of Differing 45V Crediting Approaches*, (2023), https://www.rff.org/publications/reports/emissions-effects-of-differing-45v-crediting-approaches/ (last visited Feb 19, 2024).
[18] Abdallah F. El-Hamalawy, Hany E. Z. Farag & Amir Asif, *Optimal Design of Grid-Connected Green Hydrogen Plants Considering Electrolysis Internal Parameters and Battery Energy Storage Systems*, 302 ENERGY CONVERSION AND MANAGEMENT 118127 (2024).
[19] A. Venkatesh et al., *GitHub - TemoaProject/Oeo: Open Energy Outlook for the United States*, (2022), https://github.com/TemoaProject/oeo (last visited Aug 22, 2022).

ii. Lax: A scenario in which any hydrogen produced via electrolysis is eligible for the full 45V credit ($3/kg H_2).

iii. 100Clean: A scenario in which hydrogen produced via electrolysis using clean electricity is eligible for the full 45V credit. Clean electricity includes electricity from existing or new wind, solar, hydropower, geothermal, nuclear power, or bioenergy with CCS.

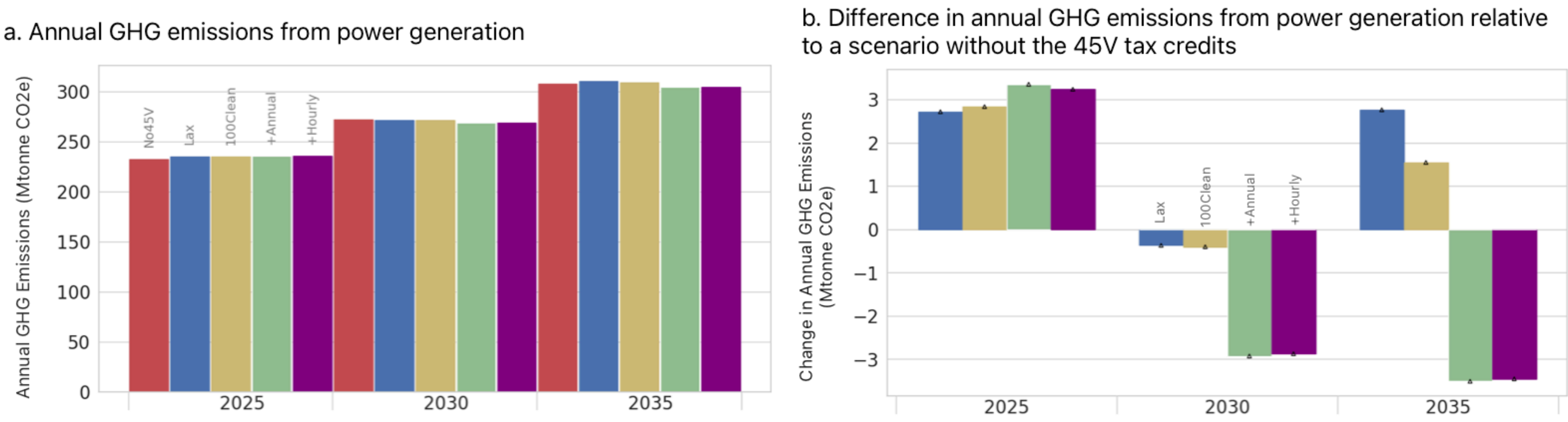
iv. +Annual: A scenario in which hydrogen is produced via electrolysis using electricity considered additional in the non-compete sense (as defined by Giovanniello et al. (2024)[20]), and annual matching of generation and the electrolyzer demand is eligible for the full 45V credit.

v. +Hourly: A scenario in which hydrogen is produced via electrolysis using electricity considered additional in the non-compete sense (as defined by Giovanniello et al. (2024)[21]), and hourly matching of generation and the electrolyzer demand is eligible for the full 45V credit.

B. Previous research found that the Three Pillars requirements are needed to mitigate the risk of increased induced GHG emissions in the power sector. The results of our analysis are generally consistent with these prior findings. Figure 1, below, shows the resulting CO_2 emissions in the power sector under the different structures for the 45V credits. Panel a shows the total CO_2 emissions in the power sector for each analysis period between 2025 and 2039, while panel b shows the difference in annual emissions of the 45V scenarios relative to a no 45V tax scenario. Finally, panel c shows the cumulative CO_2 emissions from power generation between 2025 and 2039. These results highlight that the introduction of additional constraints in the tax credit structure leads to a marginal reduction in emissions in the power sector compared to a scenario without any 45V credits.

Panel c in Figure 1 also includes the estimated consequential emissions intensity of hydrogen associated with induced changes in the power system. While the incrementality requirement leads to the lowest consequential emissions intensity (indeed, it leads to a negative emissions intensity), even the more relaxed structure for the 45V credits results in an emissions factor for hydrogen production below 4 kg CO_2/kg H_2. Prior studies have estimated such emissions intensity to range between -40 and 25 kg CO_2/kg H_2[22]. Our numbers, when considering the emissions impacts in the power generation sector, are lower because of induced changes in electricity demand for all end uses, which is endogenously estimated in Temoa. By contrast, electricity demand in other studies is a fixed exogenous input. These differences in our results relative to those of other studies highlight the importance of including the cross-sectoral effects of policy implementation.

[20] Giovanniello et al., *supra* note 4.
[21] Giovanniello et al., *supra* note 4.
[22] Ricks, Xu, and Jenkins, *supra* note 2; Giovanniello et al., *supra* note 4.



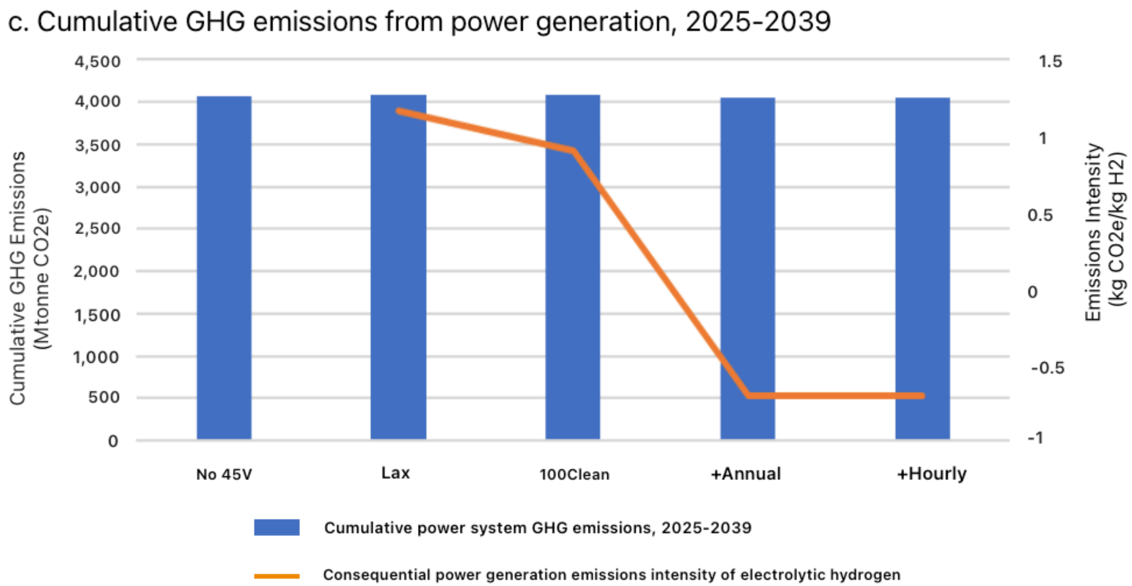


Figure 1: Emissions from power generation under different 45V structure scenarios

C. The emissions reductions observed in the power sector due to the constraints imposed by the Three Pillars are attributed to the rise in renewable generation and a slight decrease in fossil-based generation, primarily influenced by the incrementality requirements. However, when considering the total power generated in each period (ranging from 4,000 to 6,000 TWh per year), the changes in renewable power generation resulting from the incrementality requirement are relatively modest, reaching up to 10 TWh per year. Additionally, the hourly matching requirement does not yield substantial benefits in this context.

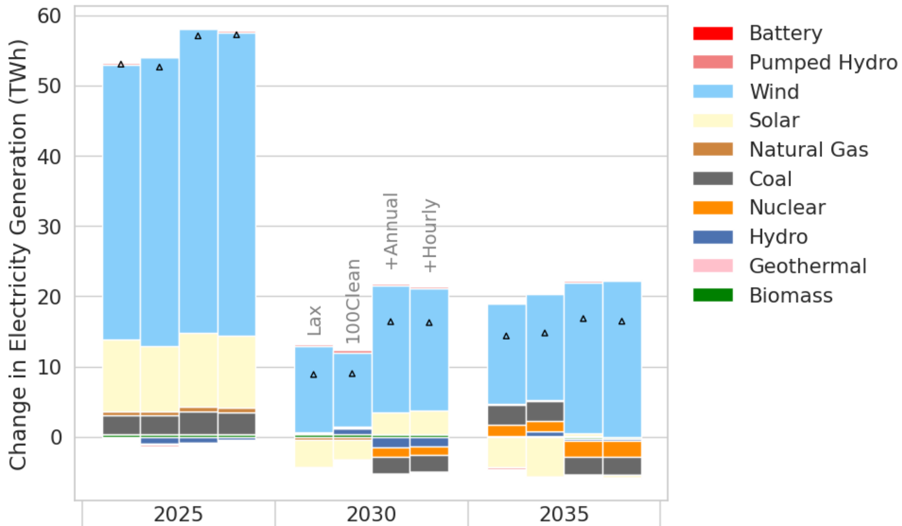


Figure 2: Change in annual electricity generation by fuel type relative to the scenario without the 45V tax credits. The dotted points highlight the net difference in generation.

D. The production of hydrogen incentivized by the 45V tax credits is restricted by capacity limits until 2030, aligning with constraints related to infrastructure expansion. These limitations, alongside differing production costs, influence the selection of technologies for hydrogen production and the timing of their utilization. Despite the tax credits accelerating the adoption of electrolytic hydrogen, we emphasize that the specific structure of these credits has minimal impact on the overall deployment levels of this production pathway.

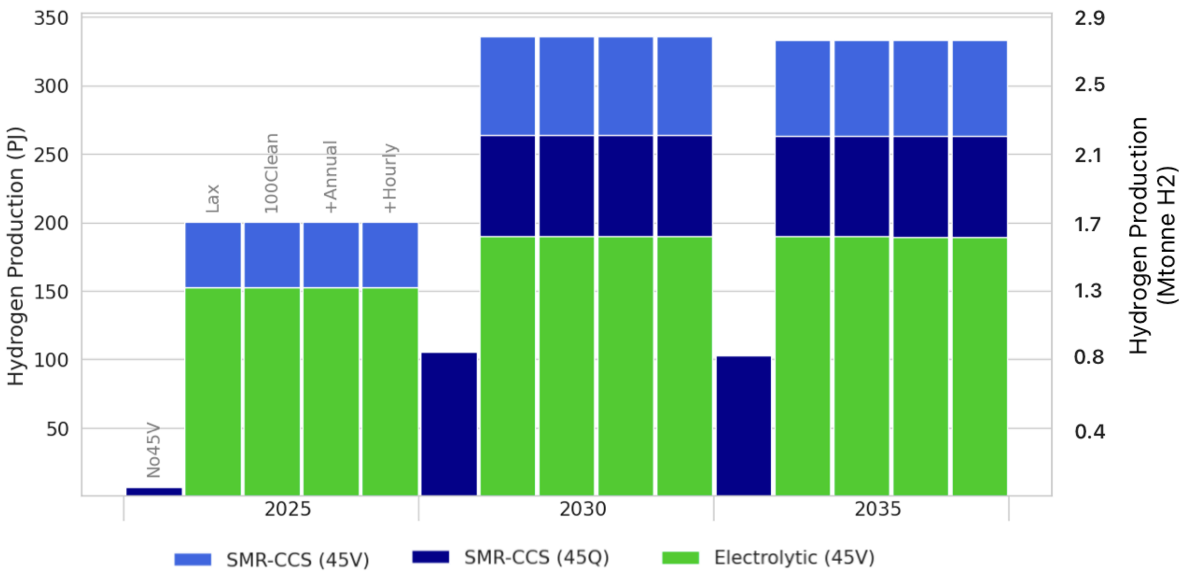


Figure 3: Annual hydrogen production. Production via steam methane reforming is split between production receiving the 45V tax credit and production under the 45Q credit for CCS.

E. Hydrogen and electricity are versatile energy carriers that can be used in all sectors of the energy system. As a result, an evaluation of the emissions implication of the IRA tax credits should consider cross-sectoral effects beyond the power system. Using an energy system optimization model suggests that there are small increases in cross-sectoral GHG emissions associated with the 45V tax credits (as shown in Figure 4). The increase in emissions associated with the 45V tax credit is smaller with the incrementality requirements. However, the changes in absolute emissions from the entire energy sector are trivial relative to total emissions from the system, representing less than a 1% increase in total emissions.

   Panel c in Figure 4 illustrates the consequential emissions intensity of hydrogen generated under the influence of the 45V tax credits. The figure emphasizes that scenarios incorporating the 45V tax credits exhibit slightly higher emissions compared to a scenario without these tax credits, primarily due to induced changes in emissions across the entire energy system. Notably, these consequential emissions factors surpass those estimated when only considering changes in the power sector (panel c in Figure 1). The elevated consequential emissions factors stem from shifts in electricity and fuel consumption within specific end-use sectors, as elaborated in Section III.F below. These findings underscore the challenge of accurately estimating consequential emissions factors for hydrogen, as the chosen system boundary significantly influences the calculated values.

F. The marginal rise in emissions in the industrial and supply sectors attributed to the 45V tax credits stems from shifts in sectoral demand for electricity and fuels, as shown in Figure 5. Within the 45V credits framework, electricity consumption in the industrial sector decreases as certain industries fuel-switch from electricity to natural gas. Consequently, there's a slight uptick in natural gas consumption for industry under the 45V implementation. In contrast, hydrogen finds application in the production of Fischer-Tropch liquids and fuel cells for heavy-duty transport, resulting in a minor reduction in emissions from the transportation sector.

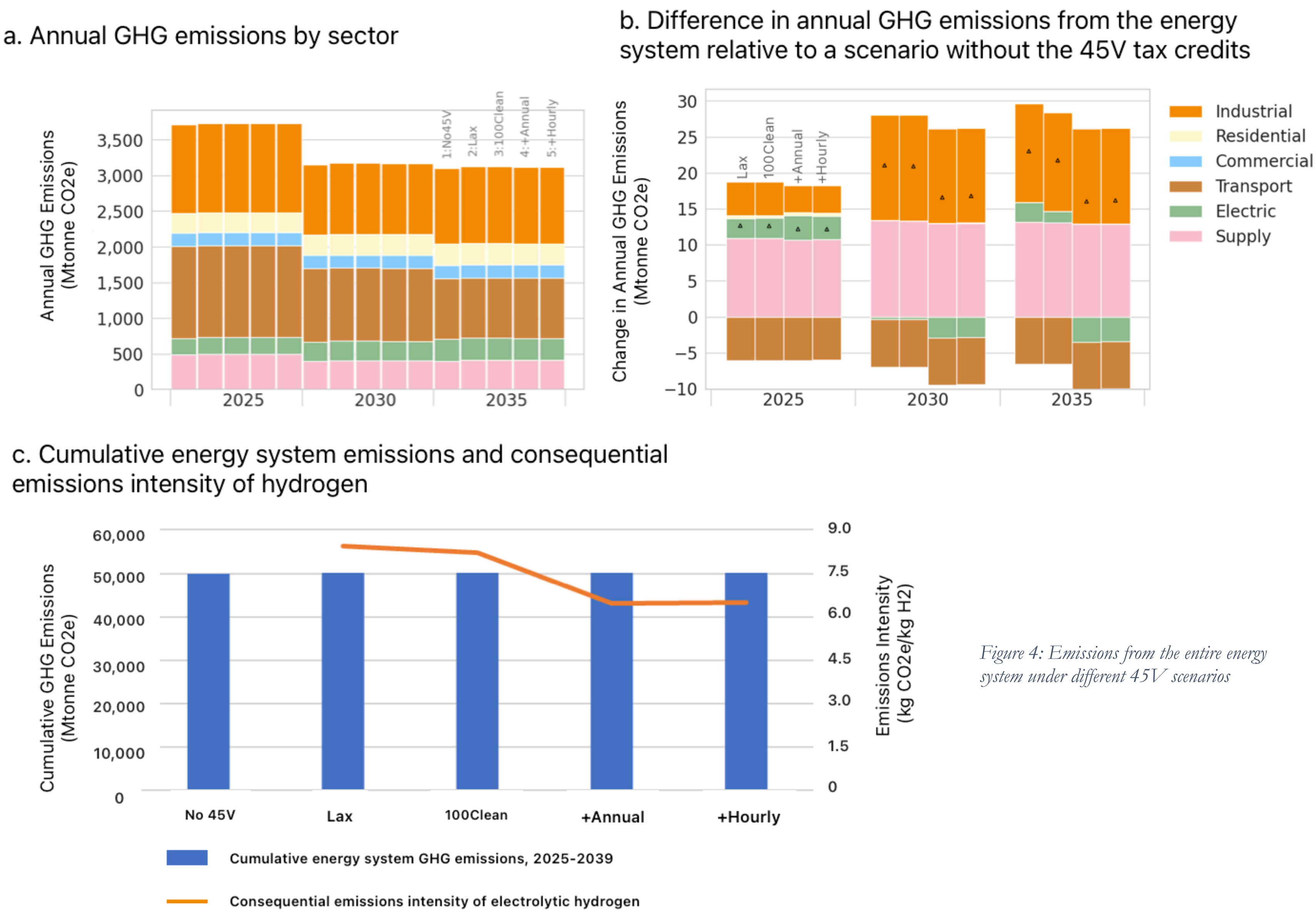
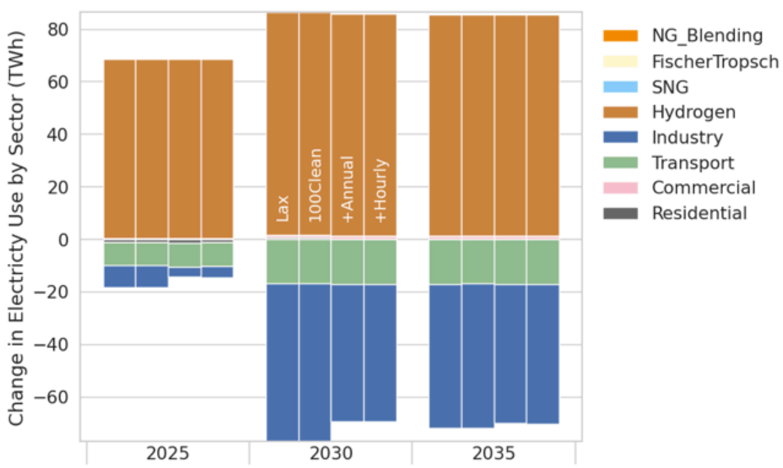
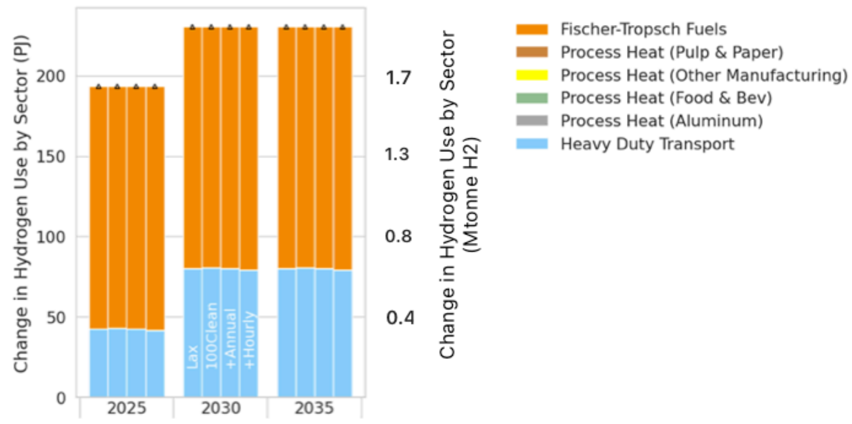


Figure 4: Emissions from the entire energy system under different 45V scenarios

a. Changes in cross-sectoral electricity demand relative to the scenario without the 45V tax credits



b. Changes in cross-sectoral hydrogen demand relative to the scenario without the 45V tax credits



c. Changes in cross-sectoral natural gas demand relative to the scenario without the 45V tax credits

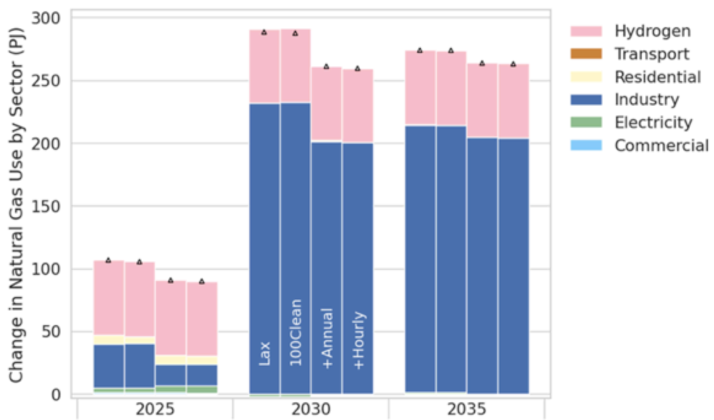


Figure 5: Changes in electricity and fuel demand by sector or end-use relative to a scenario without the 45V credits

G. After the IRA provisions expire, additional policy support will be needed to reach net-zero CO_2 emissions by 2050 and meet the targets of the Paris Agreement, as shown in panel a of Figure 6. The structure of the 45V tax credits has little impact on pathways to net zero after 2035. A net-zero energy system would require a massive expansion of hydrogen production infrastructure, potentially reaching 4,000 PJ, as shown in panel b of Figure 6. A major benefit of the 45V tax credits is to accelerate the deployment of such infrastructure.

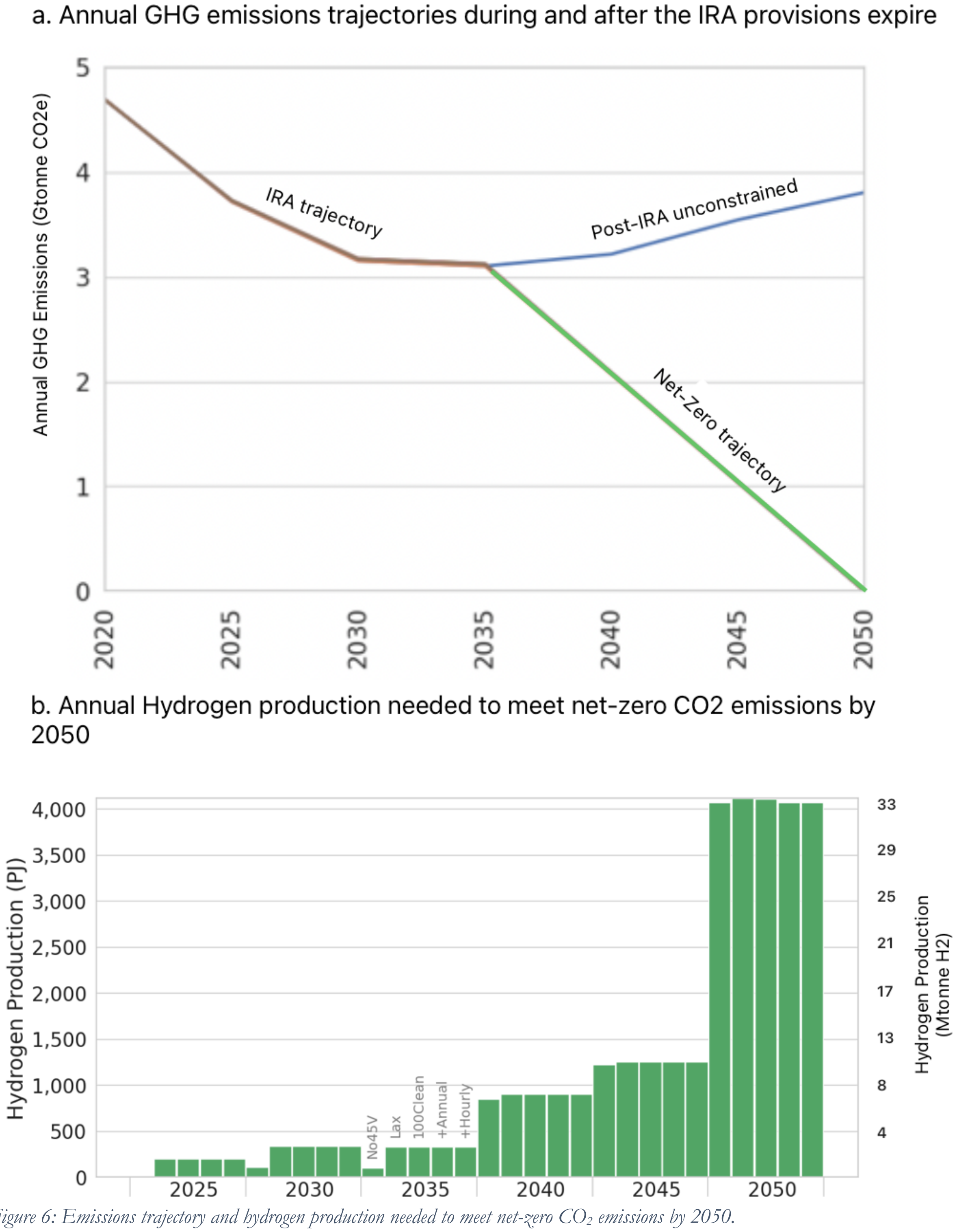


Figure 6: Emissions trajectory and hydrogen production needed to meet net-zero CO_2 emissions by 2050.

IV. Implications for policy consideration

A. The Open Energy Outlook Initiative employed a least-cost optimization model to assess the impact of the Three Pillars requirements proposed under the 45V tax credits on greenhouse gas emissions from the entire energy system between 2025 and 2039. In our analysis, we used a reference scenario where all provisions of the IRA, except for the hydrogen-related ones, are implemented, resulting in a 40% reduction in greenhouse gas emissions from the energy sector by 2040 compared to 2020 levels.

Our findings suggest that the inclusion of the 45V tax credits for electrolytic hydrogen producers may lead to slightly higher greenhouse gas emissions from the entire energy system during the analysis period compared to a scenario without hydrogen tax credits under the IRA (while keeping all other provisions intact). However, the cumulative difference in emissions between 2025 and 2039 in these scenarios is less than 1%. The incrementality requirement helps mitigate these emissions impacts to some extent. In scenarios adhering to this requirement, cumulative emissions from the entire energy system between 2025 and 2039 are less than 0.5% higher than in the scenario without hydrogen tax credits. Conversely, the hourly matching requirement does not yield additional benefits.

Highlighting the importance of energy systems modeling, it's crucial to acknowledge their inherent limitations. These models are useful for prospective comparisons under a common set of assumptions. Our analysis is useful in, for example, highlighting that competition for hydrogen by end-use sectors could affect demand for electricity and ultimately result in changes to emissions from the entire energy system that have not been accounted for in other studies. However, energy models do not encompass all real-world dynamics that can affect outcomes, including the behavior of firms and grid operators. It's thus essential to recognize that the results presented in this document or in any of the other analyses of the Three Pillars requirements are not predetermined. Applying concepts like "causality" or "counterfactuals" to energy system models can be misleading. It is thus vital that the Treasury Department and the IRS consider how the Three Pillars requirements could influence technical and behavioral aspects that are not well-represented in available energy system models. Finally, the Treasury Department may wish to consider that the implementation of the Three Pillars requirements could preclude an unbiased understanding of hydrogen's role in the energy system, potentially introducing longer-term risks to emissions that would, in turn, have implications for meeting a net-zero emissions target by 2050. Allowing for policy flexibility to "correct" unexpected outcomes could be beneficial.

B. While the IRA provisions could bring about a substantial 40% reduction in annual GHG emissions from the energy system by 2040 compared to 2020, achieving the temperature targets outlined in the Paris Agreement necessitates reaching net-zero CO_2 emissions by 2050. In scenarios aiming for such a target, the hydrogen supply must expand to unprecedented levels. The presence of the 45V tax credits would expedite the deployment of hydrogen infrastructure. The value of these early deployments, supporting a trajectory toward net-zero CO_2 emissions after the IRA provisions expire, may sufficiently justify the less than 1% higher cumulative emissions resulting from the 45V credits between 2025 and 2039 compared to a scenario without such tax credits. It's essential to recognize that requirements, such as the Three Pillars, might cause private decisions to postpone investments in hydrogen infrastructure compared to what would happen with less stringent tax credits. This delay could potentially undermine the benefits of the 45V policy. Additionally, such an outcome could worsen the "chicken and egg" problem, where potential hydrogen consumers hesitate to invest due to uncertain supply, and suppliers refrain from investing due to insufficient demand. The Treasury Department should weigh these factors to ensure that the Three Pillars requirements align with the overarching goals of the 45V policy.

C. Policy complexity introduces additional costs for both regulatory agencies and the entities they regulate. The intricate nature of regulatory requirements can heighten the administrative burden related to compliance and enforcement. Research[23] indicates that such complexity may result in the misallocation of resources, increasing administrative costs for regulatory agencies. Moreover, it can lead to higher judicial costs due to elevated litigation. Additionally, such research suggests that

[23] Juan de Lucio & Juan S. Mora-Sanguinetti, *Drafting "Better Regulation": The Economic Cost of Regulatory Complexity*, 44 JOURNAL OF POLICY MODELING 163 (2022).

heightened regulatory complexity imposes administrative costs on regulated entities and may even discourage investments.

In the context of the 45V Three Pillars requirements, discrepancies in existing analyses of rules may significantly impact the IRS's ability to review and audit tax credit applicants effectively. The question arises: How can the IRS ensure fair evaluations when state-of-the-art tools yield differing results? This variation in analyses also poses a risk for the IRS, as it may need to demonstrate posterior compliance with incrementality and hourly matching in a dynamic market.

The proposed rulemaking acknowledges the complexity of the Three Pillars requirements. For instance, it recognizes the necessity for clear rules to account for incrementality from existing generators that might face output curtailments or retirement without electrolyzer demand. Similarly, the proposed rulemaking acknowledges the limited availability of hourly tracking systems, delaying the implementation of the hourly matching requirement until 2028.

While some policies may justify the social benefits of regulatory complexity, it remains unclear whether the emissions benefits resulting from the Three Pillars requirements in the 45V tax credits are substantial enough to outweigh the increased direct and indirect costs associated with such complexity. Of particular concern is the potential reaction of electrolytic hydrogen producers to these rules. Although the industry welcomes tax credits, anecdotal evidence suggests that some developers might refrain from investing in new projects if the Three Pillars requirements are part of the final rule. Therefore, the Treasury Department should conduct additional analysis of the direct and indirect costs of the Three Pillars components to perform a comprehensive cost-benefit analysis. Considering the limited emissions benefits associated with implementing the Three Pillars requirements, there is a possibility that the additional regulatory costs could be unjustified.