U.S. DEPARTMENT OF
ENERGY

Assessing Lifecycle Greenhouse Gas Emissions Associated with Electricity Use for the Section 45V Clean Hydrogen Production Tax Credit

Summary

The Inflation Reduction Act (IRA) conditions eligibility for the § 45V tax credit on “lifecycle greenhouse gas emissions” (GHG) from hydrogen production. In doing so, the IRA cites to Clean Air Act 211(o)(1)(H), which requires inclusion of “direct and significant indirect emissions.” In the context of hydrogen production under § 45V, a lifecycle analysis would include induced grid emissions as a source of indirect emissions, consistent with the Environmental Protection Agency’s long-standing interpretation and application of this Clean Air Act section in the context of the Renewable Fuel Standard program.

Energy attribute certificates (EACs) are an established means for documenting and verifying the generation and purchase of electricity. EACs do not directly quantify emissions from specified sources or from induced generation when adding load to the grid. However, when EACs from low-GHG generators have attributes that meet three criteria (incremental generation, geographic matching, and temporal matching, as defined further in the body of this paper), they can serve as a reasonable proxy for calculating induced grid emissions. If hydrogen producers acquire and retire EACs whose attributes meet these criteria, it would be reasonable to treat induced grid emissions as zero and for hydrogen producers to deem their GHG emissions from electricity to be the lifecycle GHG emissions associated with the specific generators from which the EACs were purchased and retired. Use of such EACs is therefore an appropriate approach as part of assessing and documenting qualification for particular tiers of the § 45V production tax credit.

1. Introduction

Clean hydrogen can play a role in decarbonizing up to 25% of global energy-related CO_2 emissions (DOE 2023a). The U.S. Department of Energy (DOE) has published a number of reports that detail the important role of hydrogen in addressing climate change, enhancing energy security and resilience, and creating economic value. These include, among others, *Pathways to Commercial Liftoff* (DOE 2023a) and the *U.S. National Clean Hydrogen Strategy and Roadmap* (DOE 2023b). The DOE is accelerating the commercial liftoff of clean hydrogen through numerous grant, loan, and market facilitation programs.

This paper considers an important supply-side incentive in the larger policy framework, focused on the clean hydrogen production tax credit (PTC) created by the Inflation Reduction Act (§ 45V): specifically, the lifecycle GHG emissions impacts of electricity required for the process of producing hydrogen within a well-to-gate perspective. This well-to-gate lifecycle perspective is required by statute and focuses on production and not downstream emissions effects. Therefore, hydrogen’s potential to reduce emissions by displacing incumbent fuels in various end uses is outside the scope of both § 45V and of this paper. Greater deployment of technologies like electrolyzers could also drive down technology costs, increasing the long-term cost-effective potential of clean hydrogen and resulting in greater emissions reductions potential. Such considerations are also out of scope of this paper.

The clean hydrogen PTC, referred to as § 45V, established a tiered PTC for hydrogen production. The level of the credit is based on the lifecycle greenhouse gas ("GHG") emissions that result from the process of producing clean hydrogen.[1] For example, the highest-value tier of the tax credit requires lifecycle GHG emissions that result from the process of producing hydrogen below 0.45 kg CO_2e per kg of hydrogen.

This paper considers the lifecycle GHG emissions impacts of electricity required for the process of producing hydrogen.[2] One method of hydrogen production—electrolysis—relies on large amounts of electricity (see text box).[3] There are hydrogen production pathways that primarily or exclusively use energy inputs other than electricity that can also qualify for § 45V; the lifecycle GHG impacts of those other energy inputs are not covered in this paper.

Pursuant to the statute, to determine whether hydrogen production using electricity could qualify for a given level of credit, the lifecycle GHG emissions associated with its electricity use must be assessed. These GHG emissions depend in part on whether the hydrogen producer purchases electricity from a generator that is (or was previously) connected to the broader electricity grid. Specifically, if a hydrogen producer uses only electricity from a generator that has only ever been connected to the hydrogen producer and not an electricity grid or other electricity customer, then the assessment of the grid-related or 'induced' lifecycle GHG emissions from electricity use is relatively straightforward: there is no broader grid interaction and the lifecycle GHG emissions of the generator will generally define the lifecycle GHG emissions of the hydrogen producer. This paper does not further address this case.

How is Electricity Used to Produce Hydrogen?

The primary pathway to create hydrogen using electricity is electrolysis. Electrolysis is the process of using electricity to split water into hydrogen and oxygen, a reaction that takes place in a unit called an electrolyzer. Electrolyzers consist of an anode and a cathode separated by an electrolyte. Different electrolyzers function in different ways, mainly due to the different type of electrolyte material involved and the ionic species it conducts, but in all cases produce hydrogen by splitting water intro hydrogen and oxygen. In addition to electrolysis, electricity may also be used as an input to other hydrogen production pathways.

Assessing lifecycle GHG emissions from electricity used to produce hydrogen becomes more complicated when considering hydrogen producers that are connected to an electricity grid or to a specific source of electricity generation that was previously supplying other electricity customers or the broader electricity grid. Electricity

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[1] For purposes of § 45V, the term "lifecycle greenhouse gas emissions" has the same meaning given such term under subparagraph (H) of section 211(o)(1) of the Clean Air Act (42 U.S.C. 7545(o)(1)), as in effect on August 16, 2022. Further, the term "lifecycle greenhouse gas emissions" only includes emissions through the point of production (well-to-gate), as determined under the most recent Greenhouse gases, Regulated Emissions, and Energy use in Transportation model (commonly referred to as the "GREET model") developed by Argonne National Laboratory, or a successor model (as determined by the Secretary of the Treasury or her delegate).

[2] Specifically, this paper focuses on addressing lifecycle GHG emissions resulting from electricity purchased from a specific generator or combination of generators that are (or were previously) connected to the larger electricity grid. This generally aligns with one pathway for considering emissions associated with electricity use covered by other versions of Argonne National Laboratory's GREET model (GREET: The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model | Department of Energy). In lieu of specifying the source of electricity from specific generation types, prior versions of GREET also permitted users to utilize the average annual grid mix in the region in which the hydrogen production facility is located. Both general pathways will be allowed under the § 45V version of GREET (45VH2-GREET), with this paper addressing a method to do so consistent with the statutory requirement for lifecycle assessment.

[3] Assessing lifecycle GHG emissions from this pathway is especially important because electrolysis projects that use grid electricity have the potential to be several times more GHG intensive than the threshold for the lowest value § 45V tax credit tier (i.e., 4 kg CO2e/kg H2), and could be more GHG intensive than existing forms of conventional hydrogen production (DOE 2023a).

cannot be physically tracked on the networked grid from specific source to specific consumption (also known as “load”). Further, adding electricity load necessitates increasing electricity supply simultaneously because the power grid must be in continuous balance. However, as the power grid is a large, interconnected system, the impact of added electricity load on this added generation and its resulting GHG emissions can be complex.

In the context of the § 45V credit, assessing the lifecycle GHG emissions associated with electricity use generally involves two issues:

1. A method for hydrogen producers to establish a contractual relationship with a specific electricity generation source (or sources); and
2. A method to assess the lifecycle GHG emissions associated with the electricity used to produce hydrogen, including the GHG emissions associated with both the specific electricity generation source (or sources) with which the hydrogen producer has a contractual relationship, as well as the broader grid-level changes in generation and capacity.

This paper addresses both issues for purposes of the § 45V credit. First, it describes how new electricity loads, such as hydrogen production processes that use electricity, result in GHG emissions from the grid due to changes in generation and capacity. Second, it describes how GHG emissions from the grid can be considered in the context of § 45V when hydrogen producers purchase electricity from specific sources substantiated with energy attribute certificates (EACs, see box) whose attributes meet three criteria:

- The generation is incremental (incremental generation);
- The geographic attribute of the generator matches the geographic location of the hydrogen producer (geographic matching); and,
- The temporal attribute of the generation matches the time of electricity consumption by the hydrogen producer (temporal matching).[4]

What are EACs?

EACs are legal instruments that represent an exclusive claim to the attributes of a unit of energy. They include renewable energy certificates (RECs) but are inclusive of certificates from a broader set of electricity generators. Note that EACs can be used for energy sources other than electricity, though this paper solely addresses the electricity use case. In the case of electricity, EACs verify that a certain unit of electricity was generated by a specific entity and has specific associated attributes. Such attributes might include the place and time of generation, source of fuel, or the month and year the generator was constructed. Purchasers of the EACs then can ‘retire’ them to claim in a regulatory or voluntary context that their electricity use was generated with specific attributes associated with the EAC. There are multiple uses of EACs; this paper focuses exclusively on the § 45V use case.

EACs do not quantify induced grid emissions. However, when EACs from low-GHG generators have attributes that meet these three criteria (as further defined and detailed later), it would be reasonable to treat induced grid emissions as zero and for hydrogen producers to deem their GHG emissions from electricity to be the lifecycle GHG emissions associated with the specific generators from which the EACs were purchased and retired. Conversely, EACs whose attributes do not meet the three specific criteria would not provide a reasonable basis for claims about the lifecycle GHG emissions associated with specific generators due to induced grid GHG emissions.

More specifically, as described further in this paper, for purposes of § 45V:

- EACs are a sound mechanism to establish contractual claims of electricity purchases from specific sources, but EACs from low-GHG generators must have attributes that meet certain criteria to address the impacts of a hydrogen producer’s electricity load on induced grid GHG emissions.
- The three necessary EAC attribute criteria are: incremental generation, geographic matching, and granular

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[4] Definitions and details related to these specific terms are described further later in the paper.

temporal matching (as defined and detailed later). These criteria are necessary to address the impacts of a hydrogen producer's load on grid GHG emissions regardless of whether the hydrogen producer is purchasing electricity from power plant(s) located at some distance from the hydrogen producer or is instead using electricity from a co-located, behind-the-meter power plant that is (or was previously) connected to the broader electricity grid.

- If a hydrogen producer's load is matched with EACs whose attributes meet these three criteria, lifecycle GHG emissions from the hydrogen producer's electricity use can be reasonably deemed to reflect the lifecycle GHG emissions associated with the specific generators from which the EACs were purchased and retired.[5]
- If hydrogen producers rely on EACs whose attributes do not meet these three criteria, and have not otherwise adequately demonstrated low induced emissions, there is a strong likelihood that the hydrogen production would in many cases significantly increase induced grid GHG emissions beyond the allowable levels required to qualify for § 45V.[6]
- An administrable and practical approach to applying these three criteria is feasible. However, time may be required to allow development of the necessary EAC tracking infrastructure and verification protocols.

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[5] While EACs are an established mechanism to establish contractual claims of electricity purchases from specific sources, and, with the three necessary criteria, can be used as a reasonable methodological proxy in lieu of calculating induced grid emissions, EACs may not in all respects, presently, be a sufficient mechanism to establish or verify all relevant attributes of emitting generators (such as the presence of, rate of, and temporal use of carbon capture equipment) from which a hydrogen producer purchases electricity. Either new EAC attributes will have to developed and put to widespread use, or additional mechanisms beyond merely the purchase and retirement of an EAC may be needed to verify a specified source's lifecycle emission claims.

[6] In 45VH2-GREET, by default, if a hydrogen producer does not document electricity purchases via EACs whose specific attributes meet the criteria described in this paper, users are presumed to instead utilize the average annual grid mix in the geographic region in which the hydrogen production facility is located.

2. Understanding GHG Emissions from Electricity Load

The physical electric grid is an interconnected system that includes thousands of electricity generators that must—collectively—constantly balance electricity load. An increase in electricity load must necessarily result in an increase of the same amount of electricity supply on the grid at the same time. Constraints on the transmission network mean that load and supply must be balanced both in time and in geography: an electricity generator located in Florida is not able to meet load in Montana.

Given this context, it is important to understand how an increase in electricity load results in (also referred to as "induces") grid GHG emissions when receiving power from the broader electricity network. (It is also important to understand how these effects change when an electricity user purchases specific types of supply—a topic explored in depth in the next section.) New electricity load (such as from new hydrogen production) can cause an increase in GHG emissions from the broader power grid.[7] The GHG emissions from that new electricity load are the difference between the grid's total GHG emissions when including the user's load, compared to the grid's total GHG emissions had that increased load not occurred (Ekvall 2019; NESP 2020). At minimum, estimating these effects requires assessing:

- how the new electricity load influences GHG emissions from currently operating electric generators (referred to as operational impacts), and
- how the new electricity load influences generator retirement and new build decisions and the associated GHG emissions of those decisions (referred to as structural impacts).[8]

Operational impacts: Consuming electricity from the electric grid can influence the output and GHG emissions from existing generators. For example, any added load from hydrogen production requires an increase in electricity generation to match that added load. In the short run, increased electric load will predominantly be met by dispatchable generators—in today's electricity grid, primarily natural gas or coal that emit GHGs (Holland et al. 2022). Even if the hydrogen producer enters a contractual arrangement to purchase electricity from a specific existing low-GHG generator, if that generator would otherwise have been running anyway, these operational impacts occur as other existing (likely emitting) generators increase their supply to serve the existing load that the low-GHG generator was previously serving. Ultimately, the amount, location, and temporal profile of electricity load influences both which generators are committed (turned on) and dispatched (turned up) to ensure that load and supply are balanced. Given these impacts, operational GHG emissions vary with time (e.g., due to changes in total load and generation dispatch) and by location (e.g., due to transmission delivery constraints).[9]

Structural impacts: Generators are built and retired in part in response to changes in electricity load—therefore, changes to load can influence when and what type of generators are built or when generators are retired. For example, increased electricity load for hydrogen production in a region may cause a generator to be built that otherwise would not have been or defer the retirement of a generator that would otherwise have been decommissioned.

Research has shown that both operational and structural impacts can significantly change GHG emissions, such that capturing both is important in accurately assessing the ways in which increased loads can impact GHG emissions (e.g., see Gagnon and Cole 2022). This is especially true given the current state of the U.S. electric

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[7] The phenomena discussed in this section apply to electricity production (i.e., electricity generated by plants connected to the grid) as well as electricity consumption (i.e., electricity load). For parsimony, this paper only refers to electricity load as that is most relevant for the purpose of § 45V.

[8] Operational impacts correspond to the *operating margin* and structural impacts correspond to the *build margin in* prior literature (WRI 2007).

[9] Several organizations have begun to report marginal operational GHG emissions rates on a regional or national basis, employing multiple methods (Palmer et al. 2022; CEBI 2022). Research has shown significant temporal and locational variation in operational emissions rates both in the United States (Miller et al. 2022; de Chalendar et al. 2019) and in other countries (Khan et al. 2018; Stoll et al. 2014).

grid: operational impacts from increased loads are likely to predominantly come from increased dispatch of existing natural gas and coal power plants, whereas structural impacts from increased load appear most likely to cause increased deployment of both GHG emitting (e.g., natural gas) and non-emitting (e.g., wind and solar) resources as well as to defer the retirement of existing generators. The GHG emissions intensity of the two can be markedly different, so capturing both operational and structural effects is necessary for comprehensive lifecycle assessment. Moreover, these impacts are dependent on the amount, location, and temporal profile of the load. Studies have demonstrated that induced GHG emissions differ substantially both geographically and over time, with the latter varying significantly not only from month-to-month and day-to-day, but also on an hourly basis within a day.[10]

Notably, these operational and structural impacts apply to all electric loads and generators that are (or were) connected to the broader electricity grid, even when loads and generators are co-located.[11] For example, if an existing low-GHG power plant (other than one discussed in Section 3.3) reduces its output to the grid to support a new on-site hydrogen production facility, it would generally be expected to cause induced GHG emissions as the grid responds to the loss of one of its supply resources by dispatching electricity from existing power plants or building or deferring the retirement of other power plants.

Pursuant to the statute, to receive a § 45V credit, a clean hydrogen producer must appropriately document the lifecycle GHG emissions that result from its process of producing hydrogen. To reflect relevant GHG emissions impacts, the method needs to take into account induced GHG emissions, considering operational and structural effects. The method also needs to recognize that hydrogen producers can contract with specific sources of electricity supply and that those contracts may be part of the basis for assessing the lifecycle GHG emissions from hydrogen production. The next section describes a reasonable and administrable approach to meeting these needs, focused on electricity purchases substantiated with EACs whose attributes meet certain criteria.

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[10] Methodologies for calculating marginal GHG emissions rates that consider operational and structural effects include, for example, Gagnon et al. (2023), CPUC (2021), and Synapse (2021).

[11] In cases where the load and generator are (and have been) completely isolated from the broader electricity grid and other electricity consumers, such induced grid impacts are absent. This paper does not address that narrow case.

3. A Role for Energy Attribute Certificates in Section 45V

For § 45V purposes, it is necessary to establish a reasonable and administrable approach for hydrogen producers to document the lifecycle GHG emissions of their electricity use, considering both the specific electricity generation source (or sources) with which the hydrogen producer has a contractual relationship, as well as any broader grid-level changes in generation and capacity. This section outlines an approach by which hydrogen producers can document those GHG emissions by specifically contracting for low-GHG electricity generation through the purchase and retirement of EACs whose attributes meet certain criteria as relates to load.

The approach outlined below starts with the understanding that grid emissions are addressed when an incremental unit of low-GHG electricity generation is supplied to the grid at the same location and time as an incremental unit of load consumes power from the grid. Absent other secondary effects, the attributes of the incremental load and those of the incremental generation in this case would be matched one-for-one, yielding no significant net change to the pre-existing electrical grid, and so limiting induced GHG emissions impacts. In this instance, the lifecycle GHG impacts from the process of producing hydrogen can be assumed to be the lifecycle GHG emissions of the incremental low-GHG generation.

This section of the paper discusses a reasonable methodological proxy for quantifying lifecycle GHG emissions of electricity purchases by which electricity purchases substantiated through EACs whose attributes meet certain criteria could be used by a hydrogen producer to document such load and generation matching.[12] This would in turn allow the hydrogen producer to reasonably claim that the lifecycle GHG emissions of their electricity use reflects only the lifecycle GHG emissions associated with the specific generators from which the EACs were purchased and retired.

3.1 EACs are a sound contractual mechanism

EACs have a long history in the form of RECs and are a sound mechanism for establishing contractual claims of electricity purchases from specific sources (EPA 2018; Jones 2023; Sumner et al. 2023). Electricity cannot be physically tracked on the networked grid from specific source to specific load, so tracking of claims of physical electricity use is not feasible.[13] Instead, EACs serve as a widely accepted legal instrument that represents the exclusive rights to make claims regarding the attributes of a unit of electricity generation, enabling contract-based purchases of electricity with specific attributes (Jones 2023; O'Shaughnessy and Sumner 2023).

EACs (at least in the form of RECs) are currently tracked through a network of nine electronic tracking systems, with national coverage (Terada 2023). EAC tracking systems create EACs as a function of generation output, enable EACs to change ownership, and ensure that EACs are removed from circulation or "retired" once an EAC buyer has claimed the energy attribute. Importantly, EAC tracking and retirement helps prevent double counting of energy attribute claims (Braslawsky et al. 2016). Though the specific design of these tracking systems varies, each offers similar basic functionality, and each can expand its functionality as dictated by market and policy interest. The most recent of these tracking systems was launched 7 years ago; the oldest systems have been in existence for more than 20 years.

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[12] In addition to specifying the source of electricity from specific generation types, GREET users have historically also been permitted to utilize the average annual grid mix in the geographic region in which the hydrogen production facility is located. Other approaches may be feasible in the future, especially if advances in GHG emissions assessment capabilities enable broadly accepted estimates of induced GHG emissions considering both operational and structural effects. In the meantime, 45VH2-GREET's use of the regional annual-average grid mix is an acceptable approximation for default use.

[13] Electricity on the grid involves the transmission of energy from one energized electron to an adjacent electron, such that tracking of physical electricity flow from generating source to load is infeasible.

EACs have been used for various purposes, including utilities demonstrating compliance with renewable portfolio or clean energy standards; programs to support existing nuclear power plants that are otherwise at risk of retirement; retail electricity customers buying the right to make claims regarding the use of clean energy; power source disclosure to end-use customers; and corporations reporting clean energy use for GHG accounting (Sotos 2015; O'Shaughnessy et al. 2021; O'Shaughnessy and Sumner 2023; Sumner et al. 2023; Barbose 2023). EACs are broadly recognized as valid legally and practically (FTC 2012; Jones 2023; Sumner et al. 2023). Though EACs are simply a mechanism for tracking contractually transferred property, policymakers and market actors regularly establish eligibility rules for specific use cases: sometimes constraining the temporal or geographic transferability of EACs or restricting eligibility to certain generation types and vintages (Sumner et al. 2023; Barbose 2023). EAC requirements created for any specific use case are dictated by the needs of policymakers or other market actors (Sumner et al. 2023).

3.2 Use of EACs to inform the lifecycle GHG emissions from adding load to the grid

EACs do not directly quantify induced emissions when adding load to the grid. However, EACs whose attributes meet certain criteria can serve as a reasonable proxy for calculating induced grid emissions, enabling entities seeking tax credits under § 45V a means to verify the purchase of specific sources of electricity while taking into account induced GHG emissions from the electricity grid. This use case is different from past and current use cases because implementation of § 45V requires lifecycle assessment in consideration of GHG emissions that result from the process of producing hydrogen via an administrable, consistent, and robust framework.

Given the impacts of adding load to the grid described earlier, purchasing an EAC from any low-GHG generator is not in and of itself sufficient to justify a claim of low lifecycle GHG emissions due to the presence of induced effects. Instead, as discussed earlier, an electricity buyer can limit induced grid emissions if each incremental unit of electricity load is matched with an incremental unit of generation at the same location and time. Applying this insight to § 45V, the GHG emissions from a hydrogen producer's electricity use may in this case be reasonably deemed to be the lifecycle GHG emissions of any incremental generation purchased by the hydrogen producer. Electricity purchases from specific sources, substantiated with EACs whose attributes meet certain criteria, could be used to document this load-generation alignment.

Taken together (ensuring load-generation alignment to address induced grid emissions and tracking electricity purchases from specific sources), such EACs can inform the assessment of the lifecycle GHG emissions impacts of hydrogen production suitable for § 45V. Moreover, EACs also provide an administrable tool that can be consistently applied at scale, as has been demonstrated in existing use cases.

For EACs to accomplish these goals, there are three critical EAC criteria:

1. **Incremental generation**: EACs must represent electricity generation produced from an incremental source or from a source under circumstances that will not lead to induced grid emissions (whether that comes from new power plants or, under certain circumstances, existing ones).
2. **Geographic matching**: The generation that created the EACs must have occurred in the same grid region as, or be physically deliverable to, the EAC buyer's load.
3. **Temporal matching**: The generation that created the EACs must have occurred at the same time as the EAC buyer's load.

Without the three specific criteria for EAC attributes, EAC purchases associated with new hydrogen load will not reflect important ways in which added loads can impact grid GHG emissions under a lifecycle framework. To elucidate this point, the next paragraphs explore counterfactual examples where one or more of the criteria are absent.

First, consider a situation where incremental generation is a required attribute, but either the geographic attribute or the temporal attribute of the EAC did not match the hydrogen load. In this scenario, an increase in electricity use would be matched in quantity by an equal increase in electricity supply—however, that increase in supply could occur at a different location or time than the EAC buyer's load. As discussed earlier, the induced grid GHG emissions impacts of load and generation vary substantially across space (e.g., due to transmission constraints) and time (e.g., due to generator dispatch). Therefore, in this situation, because the generation can occur at a different location and/or at a different time than the buyer's load, there is risk that the buyer's load would induce significant GHG emissions from other sources of generation. This demonstrates that the absence of either geographic or temporal matching between load and generation would not reflect important ways in which new loads can impact GHG emissions.
A tangible example would be a new hydrogen producer that produces on a 24x7 basis, but buys EACs only from new solar generators that, necessarily, produce electricity only during the daytime. During the nighttime hours of hydrogen production, the GHG emissions from generating the electricity used to supply the hydrogen producer are effectively the same as if the hydrogen producer had merely made grid purchases.[14] Or consider an example of a hydrogen producer that purchases EACs that are temporally matched and come from incremental clean generation, but without a geographic match. If the hydrogen producer operates in a grid region that is heavily dependent on high-GHG emitting generators but the clean generation operates in an otherwise low-GHG emitting region, then the net effect would be an increase in overall GHG emissions as the emissions caused by the producer would not be fully counterbalanced by the emissions displaced by the clean generation.

Second, consider EACs that are geographically and temporally matched to the buyer's load but do not come from sources of incremental generation. In this case, EACs could be sourced from existing power plants that do not increase their output (e.g., an existing wind plant) to meet the needs of the hydrogen producer. In such a circumstance, the overall load on the system is increased due to the buyer's new load but that increase is not compensated by an increase in new supply from the generator selling the EACs—thus requiring other existing generators (e.g., GHG emitting dispatchable generators such as natural gas or coal) to supply the overall increase in load immediately and causing structural effects over time to accommodate the overall increase in load. These operational and structural responses would be expected to generally yield induced grid GHG emissions from the generators that ramped up and/or were added to the grid. This demonstrates that the absence of an incremental generation attribute would yield an inaccurate assessment of induced grid GHG emissions from the incremental hydrogen load.

The three EAC attribute criteria also generally apply in cases of co-located electricity generation and hydrogen production when there is (or was) a grid connection.[15] Even if all the electricity used for hydrogen production comes from co-located generation, if the <u>new</u> hydrogen load is co-located with an <u>existing</u> electricity generator that was previously providing electricity to the grid and that is not otherwise at risk of retirement, the same induced grid GHG emissions impacts as described above occur.

Consider an example of a hydrogen producer that locates their production facility at the site of an existing low-GHG power plant that was not otherwise at risk of retirement. To the extent the power plant reduces its electricity supply to the grid below what it would have been without the new hydrogen load, the broader power system is required to respond to the loss of one of its supply resources by dispatching and/or building other power plants to meet the existing load on the system—likely increasing induced grid GHG emissions.

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[14] Purchased solar generation EACs would exceed the load of the hydrogen producer during the daytime hours in this case, further reducing GHG emissions in those hours. But those reductions may not match the GHG emissions increases during the nighttime hours.

[15] Note that EACs can be created by grid-supply and behind-the-meter generation sources.

Only when all three criteria are met do EACs reflect generation whose attributes match the buyer's load, thereby capturing important operational and structural GHG emissions impacts. The three attribute criteria provide guiding principles for developing a practical and administrable EAC framework discussed in the following section.

3.3 Implementation of the EAC attribute criteria

When putting the above three criteria into practice, there are choices about how to implement each one. Practical considerations may necessitate a tailored transitionary period for some of the criteria. Potential practical and administrable approaches are discussed here.

First, an implementable framework for **incremental generation** requires administrable definitions of "incremental." In general, potential sources of incremental generation supply include:

- EACs from new low-GHG power plants: A precise definition for "new" is required, but EACs from power plants that have commercial operation dates within some specified window relative to the hydrogen producer's placed in service date (or the date on which a producer begins producing hydrogen eligible for the § 45V credit) could reasonably be deemed to be "new."
- EACs from capacity uprates from existing low-GHG plants: Buyers could purchase EACs associated with the incremental generation from power plants that have newly increased their capacity.
- EACs from existing high-GHG plants that retrofit to deliver low-GHG electricity: For example, an existing fossil-fuel power plant that has recently added carbon capture and storage. Such a plant could potentially also be considered incremental (and low-GHG, if its capture rate is sufficiently high), because it is a new source of lower-GHG generation.

In addition to the above situations, there are other specific circumstances in which reliance on existing low-GHG generation would not lead to significant induced grid emissions. It may be difficult to precisely identify and predict when these circumstances occur, given data constraints. However, if these circumstances can be reliably identified, then EACs representing those circumstances could also provide a workable framework to demonstrate qualification for § 45V:

- EACs from existing low-GHG plants with extended lifetimes: If the purchase of EACs from 'at risk' existing generators has the effect of extending those plants' lifetimes by avoiding retirement, there would not be a net increase in induced grid emissions.
- EACs from existing low-GHG plants during times when low-GHG electricity is being or otherwise would have been curtailed: These times tend to occur when wholesale electricity prices are negative and low-GHG plants are on the margin, so marginal grid emissions rates are low or zero.
- EACs from increased production from existing low-GHG plants without capacity uprates: Buyers could purchase EACs associated with the incremental generation from power plants that have made new investments to increase electricity production, even in the absence of capacity uprates.
- EACs from existing low-GHG plants in locations where additional load does not cause induced emissions: Such conditions could potentially include locations where grid electricity is 100% generated by zero-GHG generators or where state policies ensure that total GHG emissions are capped with sufficient effectiveness and stringency to require that new load is met with zero-GHG electricity.

This list demonstrates that, in principle, new and existing low-GHG plants can be considered to meet incrementality criteria in certain circumstances if other conditions are met. To be implemented within § 45V, however, all the cases above would require specific frameworks and verification standards. Frameworks and verification standards may be feasible and relatively straightforward in some of the cases. Administration, verification, and EAC tracking for others, however, may be especially challenging or even impossible.

Absent simplified proxies, administration may require predictions of future retirement risk, counterfactual ‘what if’ assumptions, or complex geographically and temporally granular modeling and data of operational and structural effects. Further deliberation—including stakeholder feedback—is required to identify and develop administrable and effective verification procedures or appropriate potential proxy approaches for those cases. Additionally, while some of the existing nine tracking systems capture all generators in their regions, other tracking systems currently only track renewable electricity.[16] In the latter cases, tracking systems would need to expand their functionality to capture a broader suite of generators that might sell eligible EACs to clean hydrogen producers. Thus, while some practical approaches to demonstrate that incrementality criteria have been met may be readily available today, others will need to be further developed and refined over time.

Second, an implementable framework for **geographic matching** between load and generation requires establishing certain geographic boundaries (Millet et al. 2023). Under many renewable portfolio or clean energy standards, geographic boundaries are often established to define EAC eligibility, such as states, independent system operator regions, or collections of states. In many cases, not only are generators that are located within the defined geographic boundary allowed to sell eligible EACs but so too are generators located outside the boundary if the electricity from such generators is transmitted, scheduled, dispatched, and financially settled in the receiving market.[17] Alternatively, or in addition, knowledge of transmission limitations between regions could help define geographic matching requirements (DOE 2023c).

Third, to implement **temporal matching**, EACs can be tagged with the time they were generated and issued and thereafter matched with load. Until relatively recently, EAC use cases have mostly required annual matching. However, more granular, and therefore more accurate, timeframes are likely to be available nationally over time, and hourly matching of EACs will provide significantly greater certainty about lifecycle GHG emissions outcomes by ensuring that there is actual alignment between load and generation. As described earlier, an annual matching standard means that changes in supply on a month-to-month, day-to-day, and hourly basis during the year are not necessarily matched with load over those same timeframes. That unmatched load can drive induced GHG emissions because of the significant temporal variation in grid-system GHG emissions on a monthly, daily, and even hourly basis. Given hourly changes in grid GHG emissions, an hourly energy-matching standard provides much stronger assurance that changes in load are matched by changes in supply.

Hourly tracking systems for EACs are not yet broadly available across the country and, while they are in effect or under development in some regions, widespread availability and functionality will take time. The federal government is helping advance hourly matching capabilities through a 2021 Executive Order requiring federal agencies to procure hourly-matched clean energy (Exec. Order 14057; Hausman and Bird 2023). Moreover, to ensure reliable electric grid operations, power grid operators across the country already track the real-time production of all electric generators connected to the transmission system. Nonetheless, data, software, regulatory structures, and market practices will need to evolve to enable hourly matching at scale (EPRI 2022). Two of the largest EAC tracking systems, Midwest Renewable Energy Tracking System, Inc. (M-RETS) and the PJM Generation Attribute Tracking System (PJM-GATS), have recently begun offering EACs with hourly data to generators that register in the system and provide the necessary data exchange—albeit even in these cases, the systems have limited functionality (Terada 2023).[18] The North American Registry (NAR) is also piloting hourly EACs. Fully developing the functionality of these systems will take time, as will the creation of and

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[16] The Northeastern tracking systems (NEPOOL-GIS, NYGATS and PJM GATS) each cover all generation sources; the other six tracking systems largely or exclusively track renewable energy sources (Terada 2023). Some of the tracking systems can register and issue EACs nationwide.

[17] Some of the EAC tracking systems validate these delivery transactions. In other cases, that validation occurs outside the EAC tracking systems through, for example, third-party verification.

[18] M-RETS is also able to register and issue EACs in some regions outside of the Midwest.

developing the functionality of hourly tracking infrastructure in other regions of the country. In a recent survey of nine existing EAC tracking systems, apart from the two systems mentioned above that have already initiated hourly tracking, albeit with limited functionality, two declined to give a timeline to develop this functionality, four systems gave a timeline of two years or less, and one system gave a timeline of three to five years; in the latter case, the respondent noted that the timeline could be closer to three years if there is full state agency buy-in, clear instructions are received from federal or state agencies, and funding for stakeholder participation is made available. In the same survey, tracking systems identified a number of challenges to hourly tracking that will need to be overcome, including cost, regulatory approval, interactions with state policy, sufficient stakeholder engagement, data availability and management, and user confusion (Terada 2023). Once the tracking software infrastructure is in place nationally, it may take additional time for transactional structures and efficient hourly EAC markets to develop. Among the issues that require resolution as EAC tracking systems move to hourly resolution is the treatment of electricity storage.[19] Given the current lack of highly functional hourly tracking capabilities across the entire U.S., different requirements may be required in the near term.

Modeling Induced Grid GHG Emissions

Though EACs do not quantify induced grid emissions, when EACs have attributes that meet certain criteria it would be reasonable to treat induced grid emissions as zero and for hydrogen producers to deem their GHG emissions from electricity to be the lifecycle GHG emissions associated with the specific generators from which the EACs were purchased and retired. Induced GHG emissions, considering operational and structural effects, can also be estimated with sophisticated power-sector models. Such models are complex and require many important input assumptions. These characteristics suggest that applicant or administrator modeling is not currently a practical, primary solution for lifecycle GHG assessment within 45VH2-GREET for purpose of § 45V.

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[19] Logically, with hourly matching, purchasers who store and shift power to align with their load should be credited for the hour in which the power is consumed while also reflecting the efficiency losses associated with storage.

4. Conclusion

As shown in this paper, assessing lifecycle GHG emissions from the electricity grid associated with increased electricity load requires consideration of induced GHG emissions from operational and structural effects. More specifically, for the purpose of implementing the clean hydrogen production tax credit under § 45V, this paper finds that:

- EACs are a sound mechanism to establish contractual claims of electricity purchases from specific sources, but EACs from low-GHG generators must have attributes that meet certain criteria to address the impacts of a hydrogen producer's electricity load on induced grid GHG emissions.
- The three necessary EAC attribute criteria are: incremental generation, geographic matching, and granular temporal matching. These attribute criteria are necessary to address the impacts of a hydrogen producer's load on grid GHG emissions regardless of whether the hydrogen producer is purchasing electricity from power plant(s) located at some distance from the hydrogen producer or is instead using electricity from a co-located, behind-the-meter power plant that is (or was previously) connected to the broader electricity grid.
- If a hydrogen producer's load is matched with EACs whose attributes meet these three criteria, lifecycle GHG emissions from the hydrogen producer's electricity use can be reasonably deemed to reflect the lifecycle GHG emissions associated with the specific generators from which the EACs were purchased and retired.[20]
- If hydrogen producers rely on EACs whose attributes do not meet these three criteria, and have not otherwise adequately demonstrated low induced emissions, there is a strong likelihood that the hydrogen production would in many cases significantly increase induced grid GHG emissions beyond the allowable levels required to qualify for § 45V.[21]
- An administrable and practical approach to applying these three attribute criteria is feasible. However, time may be required to allow development of the necessary EAC tracking infrastructure and verification protocols.

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[20] While EACs are an established mechanism to establish contractual claims of electricity purchases from specific sources, and, with the three necessary attribute criteria, can be used as a reasonable methodological proxy in lieu of calculating induced grid emissions, EACs may not in all respects, presently, be a sufficient mechanism to establish or verify all relevant attributes of emitting generators (such as the presence of, rate of, and temporal use of carbon capture equipment) from which a hydrogen producer purchases electricity. Either new EAC attributes will have to developed and put to widespread use, or additional mechanisms beyond merely the purchase and retirement of an EAC may be needed to verify a specified source's lifecycle emission claims.

[21] In 45VH2-GREET, by default, if a hydrogen producer does not document electricity purchases via EACs whose specific attributes meet the criteria described in this paper, users are presumed to instead utilize the average annual grid mix in the geographic region in which the hydrogen production facility is located.

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