Assessment of Grid Connected Hydrogen Production Impacts

Part I Literature Review and Framework Key Insights

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CONTENTS

LIST OF TABLES

ACRONYMS AND ABBREVIATIONS

Acronyms	Description
45V	United States Code [U.S.C.] § 45V, Inflation Reduction Act
ACORE	American Council on Renewable Energy
CI	Carbon intensity
CO_2	Carbon dioxide
Delegated Act	EU's Delegated Act on the methodology for renewable fuels of non-biological origin
DOE	U.S. Department of Energy
E3	Energy and Environmental Economics, Inc.
EAC	Energy attribute certificates
EIA	Energy Information Administration
EDF	Environmental Defense Fund
EPA	U.S. Environmental Protection Agency
ERM	Environmental Resources Management
EU	European Union
FERC	Federal Energy Regulatory Commission
FMV	Fair market value
GC	Granular certificates
GHG	Greenhouse gas
GREET	Greenhouse gases, Regulated Emissions, and Energy use in Transportation
H_2	Hydrogen
IRA	Inflation Reduction Act
IRS	Internal Revenue Service
ISO	Independent System Operator
kg	Kilogram
$kgCO_2/kgH_2$	kilograms of carbon dioxide per kilogram of hydrogen
kWh	Kilowatt hour
M-RETS	Midwest Renewable Energy Tracking System
MIT	Massachusetts Institute of Technology
NERC	North American Electric Reliability
PJM	Pennsylvania-New Jersey-Maryland Interconnection
PTC	Production tax credit
REC	Renewable energy certificates
RFNBO	Renewable fuel of non-biological origin
RMI	Rocky Mountain Institute
SMR	Steam methane reforming
Treasury	U.S. Secretary of the Treasury
U.S.	United States

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Environmental Resources Management (ERM) prepared this report for the Environmental Defense Fund (EDF). The ideas and conclusions in this document are based on the research and guidance available prior to the December 2023 release of proposed guidance on the 45V hydrogen production tax credit and thus may not be complete. EDF and ERM do not endorse every idea and conclusion listed in this report but include herein to foster discussion around the flexibility of a three-pillar framework and advance the overall discussion.

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1. EXECUTIVE SUMMARY

The Inflation Reduction Act (IRA) Section 45V ("45V") established a new clean hydrogen production tax credit (PTC) that will pay an incentive per kilogram of clean hydrogen produced over the first 10 years of a facility's production. The IRA establishes different incentive tiers dependent on a facility's lifecycle greenhouse gas (GHG) emissions rate and directs the United States (U.S.) Secretary of the Treasury ("Treasury") to issue implementing guidance for determining lifecycle GHG emissions.

Three crucial pillars for assessing the GHG emissions of electricity supply for hydrogen production and its lifecycle GHG accounting are incrementality (or additionality), temporality, and deliverability. Extensive industry discussion since the IRA's passage has focused on these three pillars due to the wide implications for electricity required in the hydrogen production process. Some stakeholders argue for stronger requirements to prevent a higher level of emissions from hydrogen production growth under the 45V PTC and to ensure these value chains continue to be robust and grow beyond the term of the tax credits. Other stakeholders assert that strict regulations may increase costs and limit hydrogen deployment and the development of a hydrogen industry.

This document represents Part I of a two-part report. Part I is a literature review and summary of key conclusions from approximately 30 reports. Part I also indicates initial considerations for the implementation guidance on hydrogen lifecycle GHG accounting, which are further explored and discussed in Part II. Together, these reports find that a three-pillar framework will provide protection against emissions increases while enabling sustainable long-term industry growth. It will build confidence and public support for hydrogen deployment while setting an important precedent for future policies and market harmonization efforts.

In December 2023, Treasury released its proposed guidance for the 45V Production Tax Credit; at the time of this report's publication Treasury has not released final guidance. Where appropriate, this report comments on the connections between the proposed guidance and the three-pillar framework.

Visit ERM's website to read the full report: https://www.erm.com/assessment-of-grid-connected-hydrogen-production-impacts.

1.1 THE THREE PILLAR FRAMEWORK

1.1.1 INCREMENTALITY

Incrementality (also sometimes referred to as additionality) emphasizes that new low-carbon energy sources are needed to meet incremental new hydrogen demand to avoid a net increase in grid emissions. For example, if existing renewable generation is diverted to meet the growing hydrogen demand, fossil fuel power plants could be required to increase generation to balance the grid, increasing net grid emissions. This outcome could be avoided through additional new low-carbon generation paired with temporality.

There is consensus across the literature that incrementality or additionality requirements are essential to avoiding a net increase in emissions from the deployment of low-carbon grid-connected hydrogen production. Some even define incrementality as the bedrock principal of the three pillars, as without incrementality requirements and new low-carbon generation added to the grid, the temporality and deliverability pillars themselves alone would not avoid increased emissions.[1] The proposed guidelines define a new resource in this context as an electricity supply resource which comes online within 36 months prior to the hydrogen producer, which aligns with the European Union's (EU's) definition. However, Treasury is evaluating alternative approaches which demonstrate a reduced risk of increased grid emissions and could enable some level of existing generation to qualify. Example circumstances could include avoided plant retirements, curtailed generation, impacts of state policies, or consideration of local grid mix or intensity.

1.1.2 TEMPORALITY

Temporality relates to the granularity in the time periods used to determine the alignment of electricity usage and its associated emissions with that of hydrogen production. For example, it addresses whether an electrolyzer can claim zero carbon procurement by purchasing solar electricity over a year equal to its total annual load, or whether intensity should be based on the source of electricity for each hour of production. Levels of temporal granularity discussed in the literature are annual, monthly, and hourly, each with different accounting implications that may impact project development and production costs.

The literature reaches varying conclusions on the emissions impact of annual versus monthly versus hourly time matching based on the different regions, scenarios, and methodologies used in the assessments. Some reports suggest there is a connection between incrementality and temporality when considering the emissions impact of time matching requirements. For example, in regions analyzed in some of the literature reviewed, when there are lax or no incrementality requirements, annual matching is found to significantly increase net grid emissions. A key consideration across the reviewed literature is the methodologies used for analysis, including whether the emissions are

[1] Energy Innovation Policy & Technology LLC. 2023. "Smart Design of 45V Hydrogen Production Tax Credit Will Reduce Emissions and Grow the Industry." April 2023. https://energyinnovation.org/publication/smart-design-of-45v-hydrogen-production-tax-credit-will-reduce-emissions-and-grow-the-industry/.

calculated on a marginal or absolute basis. The latter serves as a more direct application of book-and-claim or market-based emissions accounting similar to the methodologies used in GHG Protocol Scope 2 accounting.

While there are regions and supply combinations which may be advantageous for hourly matching due to the economic value of excess generation, several studies suggest that hourly matching will place upward pressure on costs. Cost estimates range considerably due to differences in model methodologies and assumptions, such as the ability to optimize utilization rates by oversizing renewables and incorporating sales of excess renewable electricity, as well as assumptions around renewable generation profiles and capital costs. The impact of phasing in hourly matching on project viability will likely depend on reductions in hydrogen capital costs.

A key question around the adoption of strict temporality requirements (e.g., hourly time matching) is data availability. In documentation surrounding the draft 45V rule, the U.S. Department of Energy (DOE) indicated that hourly matching is necessary to address indirect emissions from electricity use and notes proper tracking systems and hourly contracts will take time to develop.[2] There is currently no national platform for hourly tracking of energy attribute certificates (EACs) in the U.S; however, entities working to enable and expand hourly tracking, such as the Midwest Renewable Energy Tracking System (M-RETS) and EnergyTag, estimate that building a national system is feasible within about 12 to 18 months.[3] They also note that scaling the tracking system will be far less complex and lengthy than the process of building out large-scale electrolyzers, particularly since the source data for issuing certificates is hourly generation. The draft rule’s proposed timeline for moving from annual to hourly matching is 1 January 2028.

1.1.3 DELIVERABILITY

Deliverability refers to which geographic boundaries should be used to ensure low-carbon energy is generated in a location that is connected to hydrogen production through the electrical grid. Deliverability of low-carbon electricity to the electrolyzer is another consideration where the literature suggests varying recommendations. Where geographic boundaries are large, there are potential transmission connectivity issues to enabling delivery of low-carbon electricity to hydrogen production facilities; conversely, if geographic boundaries are small, this electricity delivery can be inefficient or infeasible. The challenge is in finding a compromise that can accommodate the diversity of U.S. grid boundaries.

Grid boundaries within the U.S. are not clearly or uniformly defined, particularly in the context of energy attributes. While there was consensus in the literature that low-carbon

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[2] DOE (U.S. Department of Energy). 2023. ‘‘Assessing Lifecycle Greenhouse Gas Emissions Associated with Electricity Use for the Section 45V Clean Hydrogen Production Tax Credit.’’ December 2023. https://www.energy.gov/sites/default/files/2023-12/Assessing_Lifecycle_Greenhouse_Gas_Emissions_Associated_with_Electricity_Use_for_the_Section_45V_Clean_Hydrogen_Production_Tax_Credit.pdf.

[3] RMI (Rocky Mountain Institute). 2022. “RE: Notice 2022-58 Request for Comments on Credits for Clean Hydrogen and Clean Fuel Production.” December 2022. https://www.regulations.gov/comment/IRS-2022-0029-0111.

electricity sources and hydrogen production facilities should be connected to the same grid, different options were posited to define the boundaries of a contiguous grid region. Potential boundaries already leveraged by industry include the North American Electric Reliability (NERC) subregions, NERC assessment areas, eGRID subregions, and balancing authorities. Specific to Independent System Operators (ISOs), these options can also expand or be defined as the entire ISO, an ISO subregion determined by notable transmission constraints, or wholesale pricing zones. The deliverability requirement outlined in the proposed guidance references the boundaries defined by the DOE's National Transmission Needs Study[4] but also specify that a facility's deliverability region, defined as the location of both its hydrogen production and electricity generation, is based on the balancing authority to which it is connected.[5] The Transmission Needs Study regions leverage the market boundaries defined by the ISOs while acknowledging transmission constraints. The U.S. Environmental Protection Agency's (EPA's) eGrid sub-regions are a notable viable alternative to ISOs, as they are designed to reflect limitations on transmission exchanges between regions. Proposed guidance is not specific about whether and how transfers between neighboring grids might be allowable. Treasury could consult with Green-e®, as their approach to evaluating transfers between regions could be provide flexibility in demonstrating deliverability between eGRID or Transmission Needs Study regions.

1.2 CROSS-PILLAR IMPLEMENTATION CONSIDERATIONS

Other implementation elements emerging from the literature review will likely impact multiple pillars and are assessed further in the second part of this report. These include:

- Recognition of the differences and therefore inequities in market structures, operations, and generation resources between ISO and non-ISO regions which could impact ease of accessing and verifying sufficient cost-effective electricity supply;
- Transmission constraints that could create a time lag for access to new renewable energy;
- Data availability and management capabilities for electricity supply to ensure electricity for hydrogen production is low-carbon; and
- Broader impacts to incentivizing optimal system solutions and the long-term economic viability of established value chains post the hydrogen tax credit subsidy period.

Treasury should consider how these additional elements could require agency support, impact phasing considerations, or justify proposed alternatives to ensure implementation and sufficient access to the 45V credits to enable clean hydrogen development while maintaining the IRA's integrity.

[4] DOE (U.S. Department of Energy). 2023. "National Transmission Needs Study." October 2023. https://www.energy.gov/sites/default/files/2023-12/National%20Transmission%20Needs%20Study%20-%20Final_2023.12.1.pdf.

[5] Treasury proposed guidance makes one exception for the Midcontinent Independent System Operator balancing authority given that it is split into two regions.

2. DISCUSSION

2.1 INTRODUCTION

To help limit global temperatures from exceeding 1.5 degrees Celsius above pre-industrial levels, domestic and global value chains must integrate significant opportunities for low-carbon fuel sources. Hydrogen is expected to play a key role in global decarbonization efforts, particularly in hard-to-decarbonize sectors, and the IRA recognizes the importance of supporting the early stages of clean hydrogen value chain development by incorporating the 45V PTC. This hydrogen PTC, which will pay a specific dollar amount per kilogram of clean hydrogen produced over the first 10 years of a facility's production, establishes the tax credit value based on various tiers outlined below in Table 1. Tiers are determined by the lifecycle GHG emissions rate of the produced hydrogen. The IRA directs Treasury to issue implementing guidance, including for determining emissions from grid-connected electricity supply within hydrogen lifecycle emissions.

TABLE 1: IRA 45V TAX CREDIT TIERS

Maximum Tax Credit Amount	Hydrogen Lifecycle GHG Emissions Rate
\$3/kg	**Less than 0.45 kilograms** of CO_2e per kilogram of hydrogen
\$1/kg	Between **0.45 and 1.5 kilograms** of CO_2e per kilogram of hydrogen
\$0.75/kg	Between **1.5 and 2.5 kilograms** of CO_2e per kilogram of hydrogen
\$0.60/kg	Between **2.5 and 4 kilograms** of CO_2e per kilogram of hydrogen

45V = United States Code [U.S.C.] § 45V, Inflation Reduction Act; CO_2e = carbon dioxide equivalent; GHG = greenhouse gas; IRA = Inflation Reduction Act; kg = kilogram

There has been extensive debate over three primary aspects of hydrogen lifecycle GHG accounting associated with the electricity required in the hydrogen production process: temporality, incrementality, and deliverability, commonly referred to as the three pillars. This report, which is Part I of a two-part report, summarizes key findings from approximately 30 literature sources on these three aspects of hydrogen lifecycle GHG accounting in the context of the proposed guidance released by Treasury in December 2023, and makes recommendations for areas of further consideration or clarification as part of the commentary period.

Stakeholders who support stronger requirements for incrementality, temporality, and deliverability want to ensure emissions do not increase as a result of hydrogen production growth under 45V and to ensure that these value chains continue to be robust and grow beyond the term of the tax credits. Stakeholders supporting lax requirements express concern that overburdening hydrogen production with regulatory restrictions will be cost-prohibitive and stifle hydrogen deployment. This literature review seeks to explain the divergence in stakeholder positions and report findings based on differing methodologies and assumptions.

The second part of this report elaborates on the three pillars discussion by highlighting key principles that the pillars should align with, including support for economy-wide decarbonization, efficient investment of capital and taxpayer funds, equitable outcomes across disparate regional conditions, durability of hydrogen production after the tax credit expires, and workable solutions across the value chain. It concludes that a three-pillar framework is compatible with both decarbonization goals and sustainable long-term industry growth. It also considers flexible policy design options under the three-pillar framework that can best align with these principles, as well as implementation challenges that Treasury will need to further consider to ensure a successful 45V rollout.

2.2 INCREMENTALITY

2.2.1 NEW ELECTRICITY SUPPLY RELATIVE TO HYDROGEN DEMAND

While the 45V PTC incentivizes the deployment of low-carbon grid-based hydrogen production as a way to decrease economy-wide net GHG emissions, it does not automatically result in a net reduction in grid emissions, which are a material part of economy-wide emissions. Assuming emissions are unconstrained by emissions caps, any new load added to a grid, such as a hydrogen production facility, will increase grid emissions unless it is also responsible for adding sufficient zero-carbon generation to the grid, or enable it to be added, such as with curtailed electricity. Absent a high-integrity emissions cap, the combined impact of both new load and paired supply on the real-time or hourly dispatch of grid generation is what determines the net impact to grid emissions and is the basis for the additionality concept. As such, new generation or incrementality, combined with temporality and deliverability, can be a proxy for true additionality of supply. A whitepaper published by the DOE outlines these impacts in their discussion of understanding emissions from electricity load.[6]

Low-carbon hydrogen production will represent a large new demand for low-carbon electricity. Without the inclusion of incrementality requirements, multiple analyses indicate the demand increase will almost always result in increased net grid emissions.[7,8] Most low-carbon energy sources are already fully accounted for by current electricity demand. Without a sufficient net increase in zero-carbon electricity, the increase in electricity demand

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[6] DOE (U.S. Department of Energy). 2023. "Assessing Lifecycle Greenhouse Gas Emissions Associated with Electricity Use for the Section 45V Clean Hydrogen Production Tax Credit" December 2023. https://www.energy.gov/sites/default/files/2023-12/Assessing_Lifecycle_Greenhouse_Gas_Emissions_Associated_with_Electricity_Use_for_the_Section_45V_Clean_Hydrogen_Production_Tax_Credit.pdf.

[7] Energy Innovation Policy & Technology LLC. 2023. "Smart Design of 45V Hydrogen Production Tax Credit Will Reduce Emissions and Grow the Industry" April 2023. https://energyinnovation.org/publication/smart-design-of-45v-hydrogen-production-tax-credit-will-reduce-emissions-and-grow-the-industry/.

[8] Cybulsky, Anna, et al. 2023. "Producing Hydrogen from Electricity: How Modeling Additionality Drives the Emissions Impact of Time-matching Requirements." April 2023. https://energy.mit.edu/wp-content/uploads/2023/04/MITEI-WP-2023-02.pdf.

caused by the addition of clean hydrogen production, particularly electrolysis, will be met by marginal generation which is predominately fossil fuel based in most power markets today.

Renewable resources are not typically marginal producers because they have zero or low marginal costs and generate at maximum output when able. Baseload demand, excluding low-carbon hydrogen production, is expected to increase as electrification increases, and renewable capacity will need to significantly outpace this demand growth to continue to support net reductions in both grid intensity and absolute emissions. Due to the emissions intensity requirements of the 45V PTC, new hydrogen production will need to secure low-cost sources of low-carbon electricity through bilateral power purchase agreements and utility programs, or simply to purchase clean attributes in the form of EACs. In the absence of incrementality requirements, hydrogen producers could indirectly increase emissions by using the existing renewables on the grid and consequently increasing the use of additional marginal fossil resources to meet overall demand.

The incrementality (also commonly referred to in the literature as additionality) requirement has been referred to by some as the bedrock principle of the three-pillar framework, as without incrementality, temporality and deliverability requirements do not avoid increased emissions.[9] Several studies examine the consequential emissions impact of incrementality requirements, which consider the long-run electricity system-level emissions impact rather than just the attributional emissions directly related to hydrogen production.[10] Energy Innovation finds that neglecting incrementality requirements can increase consequential GHG emissions from hydrogen electrolysis as much as five times compared to steam methane reforming (SMR) and upwards of 100 times above the 45V threshold for the top tax credit value.[11] Ricks et al. models an 82 percent carbon-free California power grid in 2030 with no incrementality requirement, which results in consequential GHG emissions rates greater than 20 kilograms of carbon dioxide per kilogram of hydrogen ($kgCO_2/kgH_2$) and double the intensity of grey hydrogen produced by SMR.[12] Hydrogen with intensity factors greater than current grey hydrogen defeats the purpose of the IRA. Zeyen et al. finds that without the incrementality requirement, consequential emissions can be up to 31 $kgCO_2/kgH_2$.[13] Lastly, the Rhodium Group finds 73 million metric tons higher annual carbon dioxide (CO_2) emissions in a 60-81 percent clean grid in 2030 when examining the impact of no incrementality on GHG emissions as hydrogen production grows under 45V.[14] Although

[9] Zeyen, Elisabeth, et al. 2022. “Hourly Versus Annually Matched Renewable Supply for Electrolytic Hydrogen.” Zenodo, December 2022. https://zenodo.org/record/7457441.
[10] Wilson Ricks, et al. 2023. “Minimizing Emissions from Grid-based Hydrogen Production in the United States.” January 2023. Environ. Res. Lett. 18 014025 https://iopscience.iop.org/article/10.1088/1748-9326/acacb5.
[11] Energy Innovation Policy & Technology LLC. 2023. “Smart Design of 45V Hydrogen Production Tax Credit Will Reduce Emissions and Grow the Industry.” April 2023. https://energyinnovation.org/publication/smart-design-of-45v-hydrogen-production-tax-credit-will-reduce-emissions-and-grow-the-industry/.
[12] Wilson Ricks, et al. 2023. “Minimizing Emissions from Grid-based Hydrogen Production in the United States,” January 2023. Environ. Res. Lett. 18 014025 https://iopscience.iop.org/article/10.1088/1748-9326/acacb5.
[13] Zeyen, Elisabeth, et al. 2022. "Hourly Versus Annually Matched Renewable Supply for Electrolytic Hydrogen." Zenodo, December 2022. https://zenodo.org/record/7457441.
[14] Rhodium Group. 2023. “Scaling Green Hydrogen in a post-IRA World.” March 2023. https://rhg.com/research/scaling-clean-hydrogen-ira/.

the numbers vary based on modeling assumptions, the consensus in the analysis is clear that GHG emissions will increase considerably without incrementality requirements.

While studies agree incrementality is required to achieve the emission reductions goals associated with the 45V credit, they question how to define an incrementality requirement's boundaries in a way that can be operationalized and verified. In the proposed guidance, Treasury has initially defined this as "new" generation brought online within 36 months of hydrogen production and has requested comment on alternative approaches to meet an incrementality requirement which would demonstrate reduced risk to increased grid emissions.[15] The following discussion thus centers around expanded concepts such as curtailed volumes, avoided retirements, repowering or uprating, and/or factoring in local grid mix intensity.

The EU's Delegated Act on the methodology for renewable fuels of non-biological origin (Delegated Act) defines electricity supply as new if the energy source came into operation less than 36 months before the electrolyzer.[16] Energy Innovation explains that this three-year lag gives developers the freedom to build multiple projects, while still linking hydrogen production to the low-carbon energy project through a power purchase agreement as project financing.[17] Project financing typically comes well after the interconnect process is initiated as part of the advanced development stage, approximately one to two years prior to the expected operation date. Developers look to engage with the market for buyers and negotiate agreements in the early part of this stage.[18]

The Delegated Act also provides for a phased approach to incrementality which will be required for all new projects that come into operation in 2028 or later. By 2038, this incrementality requirement will be applicable to all EU hydrogen projects, including those which come into operation before 2028.[19] The Massachusetts Institute of Technology (MIT) Energy Initiative also advocates for this phased approach to additionality based on the assumption that the magnitude of near-term renewable electricity deployment will dwarf near-term electrolytic hydrogen deployment.[20] However, if renewable generation growth does not exceed demand growth inclusive of hydrogen growth, there is a higher probability of increased grid emissions during this interim period absent an additionality requirement. It is important to note that the EU has carbon management mechanisms in place, such as the

[15] Proposed Rules. 2023. "Section 45V Credit for Production of Clean Hydrogen; Section 48(a)(15) Election To Treat Clean Hydrogen Production Facilities as Energy Property." Federal Register 88:246, December 26, 2023, p. 89220, available at https://www.govinfo.gov/content/pkg/FR-2023-12-26/pdf/2023-28359.pdf.
[16] European Commission. 2023. "Delegated Regulation on Union Methodology for RFNBOs." February 2023. https://energy.ec.europa.eu/system/files/2023-02/C_2023_1087_1_EN_ACT_part1_v8.pdf.
[17] Energy Innovation Policy & Technology LLC. 2023. "Smart Design of 45V Hydrogen Production Tax Credit Will Reduce Emissions and Grow the Industry." April 2023. https://energyinnovation.org/publication/smart-design-of-45v-hydrogen-production-tax-credit-will-reduce-emissions-and-grow-the-industry/.
[18] American Clean Power Association. "Project Development Facts." https://cleanpower.org/facts/project-development/.
[19] European Commission. 2023. "Delegated Regulation on Union Methodology for RFNBOs." February 2023. https://energy.ec.europa.eu/system/files/2023-02/C_2023_1087_1_EN_ACT_part1_v8.pdf.
[20] MIT Energy Initiative. 2023. "Production Hydrogen from Electricity: How Modeling Additionality Drives the Emissions Impact of Time-matching Requirements an MIT Energy Initiative Working Paper." April 2023. https://energy.mit.edu/wp-content/uploads/2023/04/MITEI-WP-2023-02.pdf.

Emissions Trading System, that the U.S. does not, which can largely mitigate the impact of a phased approach to requirements.

2.2.2 EXPANDED OPTIONS FOR ELIGIBLE ELECTRICITY SUPPLY

The EU also makes exceptions for curtailment and local grid mix intensity, two example concepts in Treasury's request for comments on alternative approaches to incrementality which leverage modeling or other evidence to support zero or minimal risk to increased grid emissions. The Delegated Act allows electrolyzers to utilize clean electricity power from the broader grid which may not qualify as new, but that otherwise would have been curtailed as demonstrated by downward dispatch or prices reflective of renewables as the marginal generator.[21] This option allows for electrolyzers to make use of excess low-carbon electricity that would otherwise not be used. In the U.S., this curtailment option will likely not provide a material amount of electricity to support hydrogen production under 45V until much higher levels of renewable penetration are reached. Even in markets considered to be high renewable such as California, curtailment volumes are relatively minimal relative to total volumes of generation[22]; this is further discussed in the second part of this report. To operationalize and validate use of curtailed energy would require data management and accessibility to data at the necessary level of granularity; this may be a particular issue in non-ISOs, given their current lack of centralization and transparency of data relative to ISOs.

In addition to curtailment, the EU makes an exception to incrementality for low emission intensity grids (defined as less than 18 grams of CO_2 per megajoule or less than 143 pounds of CO_2 per megawatt hour) as well as for a high percentage (defined as >90 percent) of renewables in the grid mix.[23] These grid scenarios would be at lower risk for increasing emissions from marginal resources because the overall grid has a low-carbon intensity. A similar consideration could be made in the U.S. for hydrogen production located in regions with regulated emissions limits or caps, typically based on state regulations, provided the emissions limit is effective, the electricity supply is sourced from the exact same regulated region, and any risk of emission leakage is sufficiently addressed.

Besides new projects, another group of low-carbon energy projects that could potentially meet an incrementality requirement are generation assets which are repowered, subject to the 80/20 rule. The Internal Revenue Service (IRS) has previously employed the 80/20 rule to determine if a repower is significant enough to qualify as a new asset eligible for prior generation production and investment tax credit incentives. The 80/20 rule is again used in the proposed 45V guidance in the context of modified facilities. This rule compares the

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[21] European Commission. 2023. "Delegated Regulation on Union Methodology for RFNBOs." February 2023. https://energy.ec.europa.eu/system/files/2023-02/C_2023_1087_1_EN_ACT_part1_v8.pdf.

[22] Energy Innovation Policy & Technology LLC. 2023. "Smart Design of 45V Hydrogen Production Tax Credit Will Reduce Emissions and Grow the Industry.: April 2023. https://energyinnovation.org/publication/smart-design-of-45v-hydrogen-production-tax-credit-will-reduce-emissions-and-grow-the-industry/.

[23] Energy Innovation Policy & Technology LLC. 2023. "Smart Design of 45V Hydrogen Production Tax Credit Will Reduce Emissions and Grow the Industry." April 2023. https://energyinnovation.org/publication/smart-design-of-45v-hydrogen-production-tax-credit-will-reduce-emissions-and-grow-the-industry/.

magnitudes of the fair market value (FMV) of the remaining assets with the cost of the new assets and dictates that the FMV of remaining assets must be less than or equal to 20 percent of the sum of the FMV of the remaining assets plus the cost of new assets. The rule can also be understood as the cost of new assets needing to be greater than or equal to 80 percent of the sum of the FMV of the remaining assets plus the cost of new assets. Generation that is the result of incremental capacity increases, or uprating, can also meet the incrementality requirement on a prorated basis provided the capacity increase is still subject to the same 36 month timeline requirement. For example, if a power purchase agreement with an electrolyzer makes it economically viable for a nuclear facility to increase its capacity, then the prorated generation from this new uprated capacity could qualify as incremental.[24]

2.2.3 EXISTING NUCLEAR

The American Council on Renewable Energy (ACORE) describes a resource in threat of retirement as no different from a new project entering the market from a net impact perspective.[25] Eligibility of existing zero-emission nuclear assets has also become a key subject in the context of incrementality and is an example of the avoided retirements approach referenced in the proposed guidance. Nuclear baseload generators have low marginal costs to operate, typically between thermal generation and renewables, but unlike solar or wind where generation is subject to constantly changing environmental conditions, nuclear can be run at high annual utilization rates only subject to dispatch. Nuclear generators also require significant amounts of initial capital and permitting, even compared to other large-scale generation facilities. Only four new nuclear units have started operations in the U.S. since 1990.[26, 27] Capital costs, permitting challenges, and public opinion can make nuclear extremely challenging as an eligible new supply option. Nuclear is a significant point of debate for forthcoming guidance on 45V, as proponents of nuclear have argued existing nuclear should be entirely exempt from incrementality considerations or that incrementality should be altogether dismissed as a requirement. The IRA does allow a hydrogen producer to claim the 45V tax credit while the electricity-supplying nuclear generator can claim the Section 45U tax credit, available only to existing nuclear plants for zero-emission nuclear power production.[28] However, Congress's decision to allow stacking of these tax credits does not undermine the case for an incrementality requirement given there are different means by which existing nuclear reactors could satisfy such a requirement. For example, uprates of existing facilities above original capacities are included in the proposed

[24] Proposed Rules. 2023. "Section 45V Credit for Production of Clean Hydrogen; Section 48(a)(15) Election To Treat Clean Hydrogen Production Facilities as Energy Property." Federal Register 88:246, December 26, 2023, p. 89220, available https://www.govinfo.gov/content/pkg/FR-2023-12-26/pdf/2023-28359.pdf.
[25] ACORE (American Council on Renewable Energy). 2023. "Analysis of Hourly & Annual GHG Emissions: Accounting for Hydrogen Production." April 2023. https://acore.org/wp-content/uploads/2023/04/ACORE-E3-Analysis-of-Hourly-and-Annual-GHG-Emissions-Accounting-for-Hydrogen-Production.pdf.
[26] U.S. EIA (U.S. Energy Information Administration). 2017. "Most U.S. Nuclear Power Plants were Built Between 1970 and 1990." April 2017. https://www.eia.gov/todayinenergy/detail.php?id=30972#.
[27] U.S. EIA (U.S. Energy Information Administration). 2023. "First New U.S. Nuclear Reactor Since 2016 is Now in Operation." August 2023. https://www.eia.gov/todayinenergy/detail.php?id=57280.
[28] "H.R.5376 - 117th Congress (2021-2022): Inflation Reduction Act of 2022," Congress.gov, Library of Congress, 16 August 2022, https://www.congress.gov/bill/117th-congress/house-bill/5376/text.

guidance as eligible, and existing nuclear plants that would have otherwise retired without IRA support could be an alternative approach to incrementality as referenced in the proposed guidance. In fact, there are several options which could provide avenues for existing nuclear and other baseload low-carbon generators while still avoiding an increase in emissions; these could include a demonstration of financial need (beyond existing state and federal subsidies) or a binding long-term financial agreement between the hydrogen producer and generator on the basis that these generating assets are under financial stress and at threat of retirement. This topic will be discussed in more detail in the second part of this report.

2.2.4 USE OF CERTIFICATES

Current GHG accounting standards allow for the use of EACs such as renewable energy certificates (RECs) to substantiate claims of specific electricity use and its intensity, given that physical energy consumed on a networked electricity grid is indistinguishable by origin and generation source. While certificates may be transacted together with the physical electricity they represent, they may also be detached or unbundled and transacted separately from the delivery of the associated electricity. The use of market mechanisms for a book-and-claim approach, including unbundled certificates, has the potential to increase development flexibility and therefore speed up the deployment of low-carbon hydrogen projects. However, extensive use of unbundled certificates carries risks to the emissions impact of grid-based hydrogen production if clarity is not also provided within the guidelines that the three pillar requirements would apply to these supply sources as well. Studies from Princeton and Energy Innovation associate unbundled certificates with increased emissions, on the basis that the sources of the certificates are existing generating assets. In the Princeton and Energy Innovation studies, electrolyzers use certificates to claim existing low-carbon electricity and increase demand without inducing new low-carbon electricity resources, causing marginal fossil fuel producers to come online.[29,30] In this scenario, low-carbon hydrogen results in an increase in net GHG emissions and results in a carbon intensity higher than hydrogen produced through SMR. As Energy Innovation states, "this hydrogen production would be clean in name only, ignoring upstream GHG emissions impacts caused by electrolysis and the IRA's lifecycle GHG requirements."[31]

The ACORE report defends the use of existing unbundled certificates (that do not meet all three pillars) as a way to demonstrate procurement of specific generation sources, also explaining that REC prices show consumers' willingness to pay more for renewables compared to conventional energy supplies. It is important to note that RECs and other types of EACs were established to verify compliance with states' renewable electricity standards

[29] Wilson Ricks, et al. 2023. "Minimizing Emissions from Grid-based Hydrogen Production in the United States." January 2023, Environ. Res. Lett. 18 014025 https://iopscience.iop.org/article/10.1088/1748-9326/acacb5.
[30] Energy Innovation Policy & Technology LLC. 2023. "Smart Design of 45V Hydrogen Production Tax Credit Will Reduce Emissions and Grow the Industry." April 2023. https://energyinnovation.org/publication/smart-design-of-45v-hydrogen-production-tax-credit-will-reduce-emissions-and-grow-the-industry/.
[31] Energy Innovation Policy & Technology LLC. 2023. "Smart Design of 45V Hydrogen Production Tax Credit Will Reduce Emissions and Grow the Industry." April 2023. https://energyinnovation.org/publication/smart-design-of-45v-hydrogen-production-tax-credit-will-reduce-emissions-and-grow-the-industry/.

and other state policies; as such, there is a diversity of state-based definitions for the attributes represented by certificates and the eligibility of generation for certificate issuance based on state requirements. Renewable electricity standard policies requiring RECs exist in 30 states and the District of Columbia, accounting for only 58 percent of total U.S. retail electricity sales in 2021. ACORE states that demand for RECs is projected to increase enormously over the next decade due to the ramp up of voluntary goals and states' renewable electricity standards targets,[32] although the extent to which this outpaces IRA-driven supply increases is uncertain. With potentially few exceptions, such as in the Northeast, current certificate prices are not high enough to provide sufficient financial backing on their own as a guaranteed revenue source to underpin new generation investments. This, combined with merchant market risk for commodity grid price and inherent volume risk, makes a reliance on the revenue stream from unbundled RECs to support debt financing particularly difficult for generators as a means to incentivize renewable build-out.

In its proposed guidance, Treasury requires the use and retirement of certificates to represent generation that meets incrementality, temporality, and deliverability requirements, whether they are bundled or unbundled certificates. The role of these EACs will be addressed further in Part II of this report, including the relationship with compliance programs.

2.3 TEMPORALITY

2.3.1 GRANULARITY OF TIME MATCHING WITH CLEAN ENERGY

The granularity of matching clean energy to produced hydrogen has been considered by industry and Treasury on an hourly, monthly, and annual basis. Hourly tracking could provide a high level of detail in such a process, ensuring every kilowatt hour (kWh) going into hydrogen production is matched with a kWh of electricity from a zero-emitting generator. Such granular tracking would provide the greatest degree of assurance that hydrogen production is not increasing GHG emissions. Critics of hourly matching mainly argue that it would be costly and therefore stifle hydrogen deployment. They also note that hourly matching or hourly certificates have yet to be widely used in the U.S., and that annual tracking would result in a less restrictive matching scenario and decreased regulatory administration burden that could encourage electrolyzer deployment with higher capacity factors and lower costs. Critics of annual matching emphasize that emissions would increase from the power sector as new annually matched clean energy generation profiles are disconnected from electrolyzer demand profiles, and potentially displace competing clean power developments.[33,34] The emission impacts of temporality are discussed further

[32] ACORE (American Council on Renewable Energy). 2023. "Analysis of Hourly & Annual GHG Emissions: Accounting for Hydrogen Production." April 2023. https://acore.org/wp-content/uploads/2023/04/ACORE-E3-Analysis-of-Hourly-and-Annual-GHG-Emissions-Accounting-for-Hydrogen-Production.pdf.
[33] Wilson Ricks, et al. 2023. Minimizing Emissions from Grid-based Hydrogen Production in the United States. January 2023, https://iopscience.iop.org/article/10.1088/1748-9326/acacb5.
[34] Zeyen, Elisabeth, et al. 2022. "Hourly Versus Annually Matched Renewable Supply for Electrolytic Hydrogen." Zenodo, 2022. https://doi.org/10.5281/zenodo.7457441.

below with an in-depth discussion on profile comparisons in the second part of this report. Compromises between hourly and annual matching include monthly matching and/or phasing to hourly matching at a future date. However, Zeyen et al. suggests that monthly matching has little advantage over annual, as both fail to capture the fluctuations of renewables during the day and would require many of the same restrictions to ensure a lower emissions outcome, such as restricting the full load hours of electrolysis.[35]

2.3.2 TRANSITION TIMELINE AND HOURLY CERTIFICATE AVAILABILITY

Treasury has proposed a phasing period from annual to hourly matching, with hourly matching required for production starting 1 January 2028 as a way of achieving both long-term emissions reductions and enabling market and validation mechanisms to be sufficiently established. Prior to Treasury's proposed guidelines release, dates were proposed for when hourly tracking should be phased in. Energy Innovation recommends the phase-in of hourly matching by 2026, with annual or monthly tracking prior to 2026; their study suggests that by 2026, hourly tracking systems will have had time to scale and mature.[36] The European Commission's methodology requires monthly matching that will phase into hourly matching by 2030; this methodology includes a review clause to examine more granular matching in 2028 and does not include a legacy clause, requiring projects built prior to 2030 to comply with hourly matching by 2030.[37] It is important to note the EU's greater extent of broader carbon policies (relative to the U.S.), which help mitigate potential emissions impacts during the EU's matching requirements transition periods. In the U.S., any phase-in approach with legacy clauses would prolong higher emissions impacts from early hydrogen producers.

Rhodium Group emphasizes that there is not currently a national platform for hourly tracking of EACs, making hourly tracking challenging in most markets.[38] Energy Innovation provides examples of recently deployed regional hourly tracking platforms. For example, in March 2023, PJM, the largest power market in the U.S., began offering hourly certificates.[39] The nonprofit tracking system M-RETS has offered hourly tracking since 2019. The Rocky Mountain Institute's (RMI's) comments on the IRS 45V docket include the remark from the M-RETS CEO that the M-RETS system could be scaled nationally within 12 to 18 months. In the survey of tracking systems referenced in the proposed guidance, four tracking systems indicated a similar timeline with one suggesting buy-in, clarity of guidance, and funding as

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[35] Zeyen, Elisabeth, et al. 2022. "Hourly Versus Annually Matched Renewable Supply for Electrolytic Hydrogen." Zenodo. https://doi.org/10.5281/zenodo.7457441.
[36] Energy Innovation Policy & Technology LLC. 2023. "Smart Design of 45V Hydrogen Production Tax Credit Will Reduce Emissions and Grow the Industry." April 2023. https://energyinnovation.org/publication/smart-design-of-45v-hydrogen-production-tax-credit-will-reduce-emissions-and-grow-the-industry/.
[37] European Commission. 2023. "Supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council by Establishing a Union Methodology Setting out Detailed Rules for the Production of Renewable Liquid and Gaseous Transport Fuels of Non-biological Origin." February 2023, https://energy.ec.europa.eu/system/files/2023-02/C_2023_1087_1_EN_ACT_part1_v8.pdf.
[38] Rhodium Group, "Scaling Green Hydrogen in a Post-IRA World," March 2023, https://rhg.com/research/scaling-clean-hydrogen-ira/.
[39] Energy Innovation Policy & Technology LLC, "Smart Design of 45V Hydrogen Production Tax Credit Will Reduce Emissions and Grow the Industry," April 2023, https://energyinnovation.org/publication/smart-design-of-45v-hydrogen-production-tax-credit-will-reduce-emissions-and-grow-the-industry/.

being key to platform development.[40] The RMI comments also stated that M-RETS is currently the largest granular certificates (GC) registry in the nation and could be fully scaled across 50 states before hydrogen projects have been finalized.[41] EnergyTag is another nonprofit working to establish an hourly tracking platform.[42] EnergyTag's comments to IRS state that "scaling a U.S. GC system is far less complex and lengthy than building large-scale electrolyzers."[43] Energy Innovation also notes that these platforms are already scaling and aim to meet the Biden administration's goal to have 50 percent of government agencies' power demand met by 24/7 hourly-matched supply in support of the target to reach 100 percent net annual carbon-pollution-free electricity by 2030.[44,45]

2.3.3 TEMPORALITY COST IMPACTS AND CONSIDERATIONS

As national hourly tracking seems feasible within a relatively short timeframe, another consideration for time matching granularity is impact on overall costs. Hydrogen production costs are mainly subject to fixed facility costs (e.g., the capital cost of electrolyzer and fixed operation and maintenance), clean electricity costs, and availability within a region. Study results differed based on their assumptions on the magnitude or materiality of the impact of hourly versus annual temporality. Most indicated some level of increased costs across the specific scenarios analyzed, though the magnitude differed greatly. Study assumptions provide valuable context to understanding how and why temporality impacts varied on subsequent levelized hydrogen production costs, and are important to note when referencing and comparing specific results.

Although this literature review did not analyze the underlying data and assumptions used for modeling in each report, Princeton's ZERO LAB Policy Memo reviewed eight studies and took a deep dive into understanding and comparing how cost assumptions differed beyond regional renewable resource impacts. As an example, Princeton's analysis found that Wood Mackenzie's fixed cost assumptions were an outlier and higher than all other examined studies. They concluded that, "when outlier assumptions that do not align with generally accepted capital cost and electricity supply data are corrected, these studies collectively support a conclusion that the economic viability of hydrogen production will not be undermined by application of hourly time matching."[46] A recent research note by Bloomberg

[40] Proposed Rules, "Section 45V Credit for Production of Clean Hydrogen; Section 48(a)(15) Election To Treat Clean Hydrogen Production Facilities as Energy Property," Federal Register 88:246, December 26, 2023, p. 89220, available https://www.govinfo.gov/content/pkg/FR-2023-12-26/pdf/2023-28359.pdf.
[41] RMI (Rocky Mountain Institute), "RE: Notice 2022-58 Request for Comments on Credits for Clean Hydrogen and Clean Fuel Production," December 2022, https://www.regulations.gov/comment/IRS-2022-0029-0111.
[42] Energy Innovation Policy & Technology LLC, "Smart Design of 45V Hydrogen Production Tax Credit Will Reduce Emissions and Grow the Industry," April 2023, https://energyinnovation.org/publication/smart-design-of-45v-hydrogen-production-tax-credit-will-reduce-emissions-and-grow-the-industry/.
[43] EnergyTag, "Response to Notice 2022-58 Request for Comments on Credits for Clean Hydrogen and Clean Fuel Production," December 2022, https://www.regulations.gov/comment/IRS-2022-0029-0030.
[44] RMI (Rocky Mountain Institute), "RE: Notice 2022-58 Request for Comments on Credits for Clean Hydrogen and Clean Fuel Production," December 2022, https://www.regulations.gov/comment/IRS-2022-0029-0111.
[45] Executive Order 14057, "Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability," December 2001, https://www.govinfo.gov/content/pkg/FR-2021-12-13/pdf/2021-27114.pdf.
[46] Princeton ZERO LAB, "Policy Memo: The Cost of Clean Hydrogen with Robust Emissions Standards: A Comparison Across Studies," April 2023, https://zenodo.org/record/7948769.

New Energy Finance concurs, arguing that additional costs are “completely mitigated” by the $3/kg tax credit for hydrogen, as well as the Renewable Electricity PTC, which translates to an additional $1.3/kg subsidy for hydrogen.[47]

An Energy Innovation report emphasized the impact of electrolyzer siting on the financial viability of projects due to the impact of quality renewable resources. Areas with strong wind resources and decent solar, such as the Great Plains, Interior West, and Texas, could support particularly profitable hydrogen production projects.[48] Not only does the renewable resource quality impact electricity costs, but the profile shape can also have a material impact on the utilization factor of an electrolyzer pending the temporality requirements. This aspect is further discussed in the second part of this report. Regional resource quality also determines which supply scenarios are logical to compare when assessing the impact of hourly versus annual matching. Hydrogen producers will optimize their resource supply mix based on the temporality requirements. For example, while a 100 percent solar supply may be plausible under annual matching, it would not be a likely supply scenario under hourly matching, particularly in a region with wind potential. An appropriate comparison to understand the impact of hourly versus annual matching should consider the most likely supply scenario under each of the requirements.

Most studies only analyzed a subset of regional locations; however, two studies highlighted the impacts of regional resources and included the most comprehensive ranges of regional results within the studies that ERM reviewed. These studies are also examples of analysis conducted with a dynamic optimization model. The first of these studies, an analysis by Evolved Energy Research, evaluated the impacts of hydrogen demand and renewable build constraints along with three pillar requirements, limited requirements, and a comparison to a scenario with no tax credit. Their results did not focus on the levelized cost at the hydrogen project level but instead assessed the impact on the regional marginal cost of hydrogen. They concluded, “in regions where electrolysis is competitive [against steam reformation facilities] – which is the vast majority of regions – the three pillars requirement adds $0.10-$0.40/kg to the marginal cost of hydrogen.” [49]

The other study, a joint study between EPRI and GTI Energy, modeled a dynamic economy-wide energy system to incorporate the feedback between the hydrogen and power sectors to better assess the interconnected impacts, both short term (such as dispatch decisions) and long term (such as capacity additional and potential retirements). The joint study concludes “as such, these metrics are conditional on the system characteristics and scenario assumptions for its future evolution and must be modeled in an integrated setting.” As in the Evolved Energy Research study, the EPRI and GTI Energy joint study found that the cost impact of a three-pillars requirement was reflected in the resultant market price for

[47] Bhashyam, Adithya, “US Hydrogen Guidance: Be Strict or Be Damned”, September 2023, BloombergNEF.
[48] Energy Innovation Policy & Technology LLC, “Smart Design of 45V Hydrogen Production Tax Credit Will Reduce Emissions and Grow the Industry,” April 2023, https://energyinnovation.org/publication/smart-design-of-45v-hydrogen-production-tax-credit-will-reduce-emissions-and-grow-the-industry/.
[49] Evolved Energy Research, “45V Hydrogen Production Tax Credits. Three-Pillars Accounting Impact Analysis,” June 2023, https://www.evolved.energy/post/45v-three-pillars-impact-analysis.

hydrogen. Because the study deployed electrolysis in regions where it was competitive and had favorable economics, primarily regions with quality wind resources such as the Midwest, the national average price during the subsidy period mainly reflected the costs in just those regions and meeting all three pillar requirements only added \$0.1-0.2/kgH_2 to the production cost.[50]

ERM also identified a gap in our review of the literature: the lack of attention within either the modeling or transparency of assumptions on how costs may decrease overtime, in terms of both the levelized cost of renewables as well as the relevant value or price of excess generation if sold to the grid. Most studies modeled how annual temporality compares to hourly at a static date. The EPRI and GTI Energy study was the only study included in this literature review which clearly included capital cost reductions over time and included time series results beyond the subsidy period.

2.3.4 EMISSIONS IMPACT

The studies ERM reviewed find varying degrees of impact to GHG emissions when comparing annual and hourly matching requirements, and also find significant interdependency between temporality and incrementality on emissions impact. In this regard, the literature underscores the importance of evaluating the pillars holistically, and the unique significance of the incrementality pillar.

Princeton's study concludes that in the absence of policy requirements, attributional emission intensities from hydrogen produced by electrolysis can be very large, ranging from over 10 kgCO_2e/kgH_2 in all Western Interconnect zones to almost 40 kgCO_2e/kgH_2 in the Wyoming and Colorado zones. These can exceed emission intensities from hydrogen produced via a standard SMR process. In the 100 percent hourly matching scenario, the Princeton study concluded there are zero attributional emissions and near-zero consequential emissions. Hourly matching, in combination with deliverability and incrementality requirements, ensures consequential emissions are no worse than hydrogen production supplied exclusively by behind-the-meter zero-carbon generation sources. The alternatives, 100 percent weekly matching and 100 percent annual matching, do not reduce consequential emissions because they allow for offsetting of net consumption. It was found under these circumstances that hydrogen producers will run electrolyzers at high utilization rates and procure the cheapest renewable generation to match hydrogen production. This type of excess procurement of cheap renewables does not create significant changes in the energy mix; therefore, only requiring new generation to meet hydrogen demand (i.e., with no corresponding hourly requirement) has similar impacts to those observed under the no requirements scenario, in which new electrolysis demand added to the grid is not required

[50] EPRI and GTI Energy, "Impacts of IRA's 45V Clean Hydrogen Production Tax Credit," Nov 2023, https://www.epri.com/research/products/000000003002028407.

to be met by new clean electricity.[51] These findings further illustrates the importance of pairing incrementality and temporality requirements.

The Rhodium Group report stated that with annual averaging, electrolyzer electricity demand could increase GHG emissions by 34-58 million metric tons in 2030.[52] The Wood Mackenzie study, which supported annual averaging, also found that annual matching would increase absolute emissions; their modeling scenarios allowed for RECs in annual matching versus hourly matching aligned with renewable energy generation profiles in Texas and Arizona. The study found that when using annual matching, "although during certain hours the grid must draw more from thermal energy sources, the incremental renewable generation also displaces thermal energy during peak renewable resource hours, resulting in a decline in the carbon intensity (CI) of the grid." This decline in grid CI under annual matching was less than one percent in 2025 for both regions, but there was also a trade-off between CI and absolute emissions. Absolute emissions increased marginally in both markets due to increased demand from electrolyzers driven by increased deployment of thermal units when there was low renewable generation,[53] emphasizing the influence of various metrics when assessing potential emissions impacts.

Similarly, a January 2024 study from MIT found that varying assumptions around additionality will impact emissions assessments. The study found lower emissions were achievable under annual time matching in Texas and Florida (the regions analyzed) when assuming that variable renewable resources for grid electricity demand do not compete with those contracted for hydrogen production, though this results in diminished economic value compared to scenarios where the renewable resources do compete.[54] The proposed guidance does not include a non-compete definition of additionality (referred to by Treasury as incrementality), instead requiring renewables to be placed in service at least 36 months before a new hydrogen electrolyzer. Allowing for competition may improve the economic viability of renewable projects as well as be more feasible for demonstrating the time matching requirements also proposed by Treasury. The MIT study found that a clean energy standard requiring at least 60 percent renewables is a complementary policy backstop to guard against potential emissions increases in a compete-framework.[55]

Lastly, with ERPI and GTI Energy's dynamic modeling approach accounting for the causation to both dispatch and capacity on the power system, they could assess not only the attributed generation for hydrogen production (i.e., what generation is providing the

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[51] Wilson Ricks, et al., "Minimizing Emissions from Grid-based Hydrogen Production in the United States," January 2023, https://iopscience.iop.org/article/10.1088/1748-9326/acacb5.
[52] Rhodium Group, "Scaling Green Hydrogen in a Post-IRA World," March 2023, https://rhg.com/research/scaling-clean-hydrogen-ira/.
[53] Wood Mackenzie, "Green Hydrogen: What the Inflation Reduction Act Means for Production Economics and Carbon Intensity," March 2023, https://www.woodmac.com/news/opinion/green-hydrogen-IRA-production-economics/.
[54] Giovanniello, M.A., Cybulsky, A.N., Schittekatte, T. et al., "The influence of additionality and time-matching requirements on the emissions from grid-connected hydrogen production," 2024, Nature Energy, https://doi.org/10.1038/s41560-023-01435-0.
[55] Giovanniello, M.A., Cybulsky, A.N., Schittekatte, T. et al., "The influence of additionality and time-matching requirements on the emissions from grid-connected hydrogen production," 2024, Nature Energy, https://doi.org/10.1038/s41560-023-01435-0.

attributes for tax credit qualification) but also the consequential generation or the actual change in generation. Their analysis demonstrated that as the three pillar criteria are relaxed, "the difference between the consequential and attributed generation becomes larger." Considering the net economy-wide effect, the change in total cumulative emissions ranges from a reduction of 670 million metric tons of CO_2 with a three-pillar requirement to an increase of 340 million metric tons of CO_2 in a no requirement case relative to a no hydrogen credit case.[56]

2.3.5 VALUE CHAIN IMPACTS

While there are industry criticisms against hourly matching, multiple reports highlight its broader benefits. The most direct benefit is matching low-carbon energy to electrolyzers 100 percent of the time to ensure no increase of GHGs from increased hydrogen production. Energy Innovation and RMI highlight other hourly matching benefits such as incentivizing new technologies (such as broad deployment of long-duration storage batteries) to complement both variable renewables and the build-out of hydrogen storage and transportation solutions to manage intermittent production and demand.[57,58]

Hourly procurement strategies can provide insight into which technology combinations are best for decarbonizing the grid. RMI found certain low-carbon electricity firm resources will be needed, such as geothermal and natural gas generation with carbon capture and storage, to meet electricity demand when renewable generation is low. RMI also found that setting an hourly procurement requirement date will send a demand signal for developers to deploy market-appropriate projects.[59]

Temporality requirements will also impact electrolyzer technology selections. In addition to demand signals for grid solutions, hourly matching would incentivize deployment of more flexible electrolyzers, which are better suited to pairing with variable renewable generation and represent a market opportunity for U.S. manufacturers. Continued advancements in electrolyzer technology will contribute to the pace of cost declines and represent an alternative to the less flexible alkaline technology, which represents the majority of today's electrolyzer manufacturing capacity and is dominated by China.[60] For example, proton exchange membrane electrolyzers are a newer technology with smaller capacities than standard alkaline electrolyzers but also have much faster ramp times.[61] Demand for

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[56] EPRI and GTI Energy, "Impacts of IRA's 45V Clean Hydrogen Production Tax Credit," Nov 2023, https://www.epri.com/research/products/000000003002028407.
[57] Dan Esposito et al, "Smart Design of 45V Hydrogen Production Tax Credit Will Reduce Emissions and Grow the Industry," April 2023, https://energyinnovation.org/wp-content/uploads/2023/04/Smart-Design-Of-45V-Hydrogen-Production-Tax-Credit-Will-Reduce-Emissions-And-Grow-The-Industry.pdf.
[58] Dan Esposito et al, "Smart Design of 45V Hydrogen Production Tax Credit Will Reduce Emissions and Grow the Industry," April 2023, https://energyinnovation.org/wp-content/uploads/2023/04/Smart-Design-Of-45V-Hydrogen-Production-Tax-Credit-Will-Reduce-Emissions-And-Grow-The-Industry.pdf.
[59] RMI (Rocky Mountain Institute), "Clean Power by the Hour," 2021, https://rmi.org/insight/clean-power-by-the-hour/.
[60] Citi GPS, "Hydrogen: A Reality Check on the Hydrogen Craze," August 2023, https://ir.citi.com/gps/oQGaUxGr0wQ9P11B3QW1yueS5BR6oYsmKO5HPysdYgZlRkG82VzEMQRrNixuFX3iSAlH87d2jnT2CmMhPSomLA%3D%3D.
[61] Hannes Lange et al, "Technical evaluation of the flexibility of water electrolysis systems to increase energy flexibility," May 2023, https://www.sciencedirect.com/science/article/pii/S0360319923000459.

dynamic grid solutions and advanced electrolyzer technologies will be needed to support long-term decarbonization of the grid and to establish hydrogen value chains that remain robust post-hydrogen tax credits.

2.3.6 CALCULATION METHODOLOGY AND DATA AVAILABILITY

In addition to the issue of granularity of time matching, debate remains regarding the methodology for calculating emissions and what data may be available to use in those calculations. The two main methodologies found in the literature review reflected either an absolute emissions rate (based on the GHG Protocol Scope 2 emissions approach) or a marginal emissions rate to calculate life cycle emissions from the electricity supply to the hydrogen producer.

The GHG Protocol Scope 2 approach further outlines two options for calculating absolute emissions from purchased electricity: the location-based methodology and the market-based methodology. The location-based methodology, which uses the average grid intensity factor from the EPA's eGRID data, is the default assumption used in the base version of the Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET) model. However, GREET does not enable use of market-based instruments as intended by the IRA. To align GREET to common market practices, it should be updated to include a market-based methodology, i.e., a volume-weighted average of supply sources represented by commercial instruments, including EACs.[62,63]

Whereas the GHG Protocol Scope 2 approach is based on the absolute emissions of the electricity supply, a marginal emissions approach is based on the emissions of the last generator, or marginal generator, dispatched to meet electricity consumption at a particular time and location. This emissions rate focuses on a causal effect and calculates how many tons of emissions are emitted due to a specific change in electricity use.[64] As an example of the marginal approach, an ACORE and Energy and Environmental Economics, Inc. (E3) study calculated the annual net difference of the marginal emissions for an electrolyzer load versus the marginal emissions for the generation source to suggest that annual matching is often sufficient. The analysis assessed the impacts of hourly and annual requirements, each across select markets under a variety of scenarios based on all wind, all solar, and various combinations thereof. Under an annual matching requirement, the study found only 52.5 percent of the scenarios resulted in higher net emissions annually than hourly, with 15

[62] World Resources Institute, "GHG Protocol Scope 2 Guidance," n.d., https://ghgprotocol.org/sites/default/files/2023-03/Scope%202%20Guidance.pdf.

[63] Per the GHG Protocol Scope 2 Guidance, EACs such as renewable energy certificates are the most precise reference for source emissions using the market-based methodology, followed by contracts (where certificates are not issued), supplier intensities, residual intensities (intensity of unclaimed generation attributes), and location-based average grid emission rates. Within the proposed guidelines, EACs are the only eligible commercial instrument referenced to demonstrate grid-connected electricity. A residual mix intensity factor is an average emission rate of generation with unclaimed energy attributes. It excludes volumes tied to claimed energy attributes from an average grid emissions rate to avoid double counting. Residual emission rates are not systematically available in the U.S. currently as they are in the EU and are only available from select retail providers or utilities, but they represent a future opportunity for accuracy as data management improves.

[64] Resources for the Future, "Options for EIA to Publish CO2 Emissions Rates for Electricity," August 2022, https://media.rff.org/documents/Report_22-08.pdf.

percent of scenarios exceeding 0.45 $kgCO_2e/kgH_2$. [65] However, as noted previously on the importance of appropriate comparisons, not all of these supply scenarios are plausible under hourly time matching, and three of the four markets assessed have both high quality wind and solar resources (suggesting a combination of resources is most realistic). Moreover, such marginal emissions approaches are complex, even in a theoretical modeling environment, and access to marginal emissions data is limited, particularly with regards to the impact of imported volumes. A Resources for the Future report notes that uniform marginal emissions data is not currently available across the U.S.[66] Using marginal emissions also requires hourly data to conduct the calculations. Though a marginal emissions approach would be challenging to operationalize and validate, it may be a consideration for a modeling-based approach to incrementality.

2.4 DELIVERABILITY

The draft guidance related to deliverability requires that both the generator and hydrogen facility be located in the same region as defined by the Transmission Needs Study. This aims to ensures that "clean electrons are delivered into the same market as the electrolyzer."[67] Certain transmission constraints, particularly in the absence of deliverability requirements, could prevent the deliverability of purchased clean power from reaching its destination, thus leading to the consumption of local fossil fuels instead. Emissions may increase to as high as 25 $kgCO_2/kgH_2$, even in the case of 100 percent hourly matching, if clean energy is produced in one region and used in another when transmission constraints exist between the two locations.[68,69] The further apart the generation supply is from the load geographically, the more likely a constraint will exist. Although a hydrogen producer may contract for clean energy, they may in fact be consuming local fossil generation which was dispatched to meet their demand. For this reason, it is important to understand what clean energy source is being claimed and what is being consumed. While commercial markets, especially those for energy attributes, may not be as physically constrained as the electricity flow itself, the physical constraints represented by transmission should be taken into consideration when determining eligibility under 45V, and the intricacies of these boundaries must be further analyzed. Hence, the Transmission Needs Study, which primarily focuses on transmission constraints, is the basis for the deliverability region boundaries in the proposed guidance.[70] These regions are pictured on Figure A1 in the attached Appendix.

[65] ACORE (American Council on Renewable Energy), "Analysis of Hourly & Annual GHG Emissions: Accounting for Hydrogen Production," April 2023, https://acore.org/wp-content/uploads/2023/04/ACORE-E3-Analysis-of-Hourly-and-Annual-GHG-Emissions-Accounting-for-Hydrogen-Production.pdf.
[66] Resources for the Future, "Options for EIA to Publish CO2 Emissions Rates for Electricity," August 2022, https://media.rff.org/documents/Report_22-08.pdf.
[67] Rhodium Group, "Scaling Green Hydrogen in a Post-IRA World," March 2023, https://rhg.com/research/scaling-clean-hydrogen-ira/.
[68] Wilson Ricks et al, "Minimizing Emissions from Grid-based Hydrogen Production in the United States," January 2023, Environ. Res. Lett. 18 014025 https://iopscience.iop.org/article/10.1088/1748-9326/acacb5.
[69] Resources for the Future. "Emissions Effects of Differing 45V Crediting Approaches". June 2023. https://media.rff.org/documents/Report_23-07_noEM5zX.pdf.
[70] DOE (U.S. Department of Energy), "National Transmission Needs Study," October 2023, https://www.energy.gov/sites/default/files/2023-10/National_Transmission_Needs_Study_2023.pdf.

The consensus across the literature is that a boundary should be defined by some type of local or regional grid, with mixed views on whether electricity should be allowed to be imported from adjacent regions. There are a range of established grid and market boundary definitions to leverage within the U.S.; however, regional differences related to size and market operations should be considered and which DOE's Transmission Needs Study boundaries try to balance. For markets within an ISO there are several boundary options, ranging from the entirety of the ISO (also a balancing authority), ISO subregions determined by notable transmission constraints, or wholesale pricing zones.

Entire ISO regions are one of the larger market boundary options, as pictured on Figure A2 in the attached Appendix. For some ISOs, ISO regions could be a feasible market boundary, but many others face material transmission constraints, such as between the Midcontinent Independent System Operator North and South regions. This constraint is reflected in the Transmission Needs Study, which divides the Midcontinent Independent System Operator into two regions. A more granular level of division would be to use ISO-defined subregions that are used as wholesale pricing zones, which offer more detailed, smaller boundaries that indicate transmission constraints and help inform the Transmission Needs Study. The use of smaller zones brings some challenges, though; for example, not all ISOs report marginal emissions within these zones, though the Pennsylvania-New Jersey-Maryland Interconnection (PJM) and ISO-NE do. Also, as effective as these pricing zones are for reporting actual grid operations, PJM has found that locational marginal emissions rates may be sensitive to minor changes in load. In summary, each of these ISO boundaries has its own strengths and weaknesses compared both to each other and to non-ISO boundaries.

Beyond boundary references specific to the ISOs, there are several options for boundaries which can be helpful to outline relative to the Transmission Needs Study regions: NERC subregions, NERC assessment areas, eGRID subregions, and balancing authorities.[71] NERC serves as a nonprofit North American regulatory authority to oversee grid reliability and security.[72] For NERC-based boundaries, both subregions and assessment areas are divisions that can serve as boundaries. As noted on Figure A3 in the Appendix, there are a total of seven regional assessment areas across North America which combine to build larger NERC regions. These regions may be too large, leading to connectivity issues, and thus are not feasible boundaries. For example, the Transmission Needs Study defines three regions within the Western Electricity Coordinating Council. As noted on Figure A4 in the Appendix, these assessment areas can be further refined into 25 market model regions across North America based on a combination of NERC and ISO boundaries. The eGRID subregions, the primary reference used for location-based emissions, are very similar to market modeled regions and are a viable alternative to Treasury's proposal, as they are designed to reflect limitations on transmission exchanges between regions. Proposed guidance is not specific

[71] Green-e® Energy and REC Products, "Green-e® Energy Code of Conduct for Canada and the United States," December 2020, https://www.green-e.org/docs/energy/Green-e%20Energy%20Code%20of%20Conduct.pdf.

[72] NERC (North American Electric Reliability). "2022 Long-Term Reliability Assessment," December 2022, https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC_LTRA_2022.pdf.

about whether and how transfers between neighboring grids might be allowable. Treasury could consult with Green-e®, as their approach to evaluating transfers between regions could provide flexibility in demonstrating deliverability between eGRID or Transmission Needs Study regions.

Balancing authorities vary in size from large ISOs to small utilities in non-ISO regions. In non-ISO regions, these balancing authorities are generally defined by utility service areas and serve dozens of market participants. Balancing authorities are not a feasible boundary in themselves, as their size results in inefficiencies that limit commercial and physical supply options for smaller regions. However, the Transmission Needs Study also aligns balancing authorities with their defined regions, which is leveraged in the proposed guidance by defining a facility or generator's deliverability region by the balancing authority to which they are connected.

Flexibility to the deliverability requirement may be addressed through demonstration of transmission rights and similar concepts outlined in Green-e®'s approach to market boundaries in their electricity product standards. Green-e®'s guidelines allow an avenue for electricity, bundled with a REC, to be wheeled from an adjacent region into the respective region of the customer.[73] The Green-e® governance board must approve cross-region transmission actions. The board can also limit electricity sourcing to certain subregions, thus requiring customers to be served by electricity generation in their own subregion. The flexibility within the Green-e® standards could serve as an example of a viable and functional approach.

In conclusion, a flexible and technically feasible approach must be considered for deliverability. The geographic boundary cannot be so large that there are transmission connectivity issues, but also cannot be so small that problems such as data availability and market access arise. The regions defined by the Transmission Needs Study aim to lend this balance while options for deliverability that recognize and appreciate the impact of transmission constraints can provide additional flexibility.

2.4.1 TRANSMISSION LINE LOSSES

Electricity lost when transmitted from one point to another, also known as transmission line loss, should be accurately accounted for based on established grid factors and whether the hydrogen production facility is connected at the transmission or distribution level of the grid. Line losses can be easily corrected by procuring additional clean energy instead of supplementing energy lost with fossil fuel-fired electric generating units.[74] Line loss factors are published by utilities and/or ISOs for their service regions and are generally included in electricity invoices. The Energy Information Administration (EIA) also estimates line loss

[73] Green-e®. "Renewable Energy Standard for Canada and United States," 2023, https://www.green-e.org/docs/energy/Green-e%20Standard%20US.pdf.
[74] Energy Innovation Policy & Technology LLC, "Smart Design of 45V Hydrogen Production Tax Credit Will Reduce Emissions and Grow the Industry," April 2023, https://energyinnovation.org/publication/smart-design-of-45v-hydrogen-production-tax-credit-will-reduce-emissions-and-grow-the-industry/.

factors. Accounting for line loss factors should be required because they are a component of lifecycle emissions.

2.4.2 PHASING AND PERMITTING CONSIDERATIONS

Regional boundaries and transmission constraints, as well as incrementality concerns with interconnection queues, should be less of an issue with intended grid investments. Treasury could consider updating or reevaluating regional boundaries pending the pace of the transmission build-out. While additional funding has been supported through the IRA and the Bipartisan Infrastructure Law, transmission build-out will be further aided by permitting reform discussions currently ongoing in Congress. The permitting reform aims to streamline and shorten timelines for permitting energy projects and transmission, enabling faster deployment of both.

A study by Bloomberg New Energy Finance highlighted that to capitalize on IRA's investments most effectively, implementation issues such as permitting regulations will need to be addressed. The report states the federal permitting process can be slow and laborious for energy infrastructure projects, taking between two to six years.[75]

On 3 June 2023, President Biden signed the Fiscal Responsibility Act of 2023 (H.R. 3746) into law. This bill is related to the federal debt limit but has permitting reform attached to it. Included in the permitting reform provisions are National Environmental Policy Act reforms, narrowing definitions, increasing categorical exclusions streamlined across different agencies, and setting page and time limits for National Environmental Policy Act environmental assessments and environmental impact statements, among other actions. The act Also requires the North American Electric Reliability Organization to undertake an interregional transfer capability study to examine transfer capability between neighboring transmission regions.[76] Congress is still discussing and trying to pass additional permitting reform that would streamline permitting and decrease timelines for transmission build-out and connecting new renewable generation to the grid.

2.5 ADDITIONAL IMPLEMENTATION CONSIDERATIONS

2.5.1 ISO VS. NON-ISO IMPLEMENTATION CONSIDERATIONS

At an organizational level, ISOs and non-ISOs utilize varied market and operational structures. In addition to the geographical boundary issues addressed in this document's section on deliverability, these result in other nuances between ISO and non-ISOs which drive inequities between them and should be taken into consideration.

[75] Bloomberg New Energy Finance, "Sustainable Energy in America Factbook," March 2023, https://bcse.org/images/2023%20Factbook/2023%20BCSE%20BNEF%20Sustainable%20Energy%20in%20America%20Factbook.pdf.
[76] "H.R.3746 - 118th Congress (2023-2024): Fiscal Responsibility Act of 2023," Congress.gov, Library of Congress, June 2023, https://www.congress.gov/bill/118th-congress/house-bill/3746.

A key challenge that arises is the potential inequity of commercial access to specific electricity supply.[77] In unregulated markets, hydrogen producers are more limited in commercial source supply options. To the extent possible, guidance for how regulated and unregulated suppliers can structure product offerings to meet end-user requirements would be informative. The impact of market regulatory structures is discussed further in the second part of this report.

Another nuance between ISOs and non-ISOs is the scope and scale of accessible data that can be used to calculate and validate electricity emissions for hydrogen production.[78] As these entities have different organizational structures resulting from centralized and decentralized models, they collect and store data using guidelines that are not consistent with each other. The resulting inconsistencies make the implementation of the 45V tax credit at a national level difficult, because there is no uniform data collection standard or requirement across the U.S. A federal agency-led data system would create a more homogeneous dataset across ISOs and non-ISOs and would provide the type and level of information required for more robust emissions calculations even beyond a 45V use case. An example is claimed energy attributes and residual intensity factors tracking. Centralized data collection could encompass required system-level data that is granular and publicly available for reference. Over time, this centralized system would allow for easy comparison between different entities.

2.5.2 IMPACT TO CONSUMER ELECTRICITY PRICES

Beyond the cost impact to hydrogen producers and overall grid emissions, consideration should also be given to the overall impacts on electricity prices to consumers, which would manifest in both the underlying energy commodity price as well as transmission and grid management costs. The more reliant hydrogen production is on the grid to find solutions to balance their demand and directly sourced supply, the greater the impact to the overall market and consumers. This includes using grid solutions over hydrogen storage and infrastructure solutions to manage hydrogen deliverability needs. Zyen et al.'s study found, "hourly matching is the only scenario which provides incentives for demand flexibility and storage [both electricity and hydrogen]. It also prevents electricity prices rising in the case that hydrogen demand rises faster than the conventional power plant fleet can adapt." In the case of inflexible hydrogen demand or utilization factors with annual matching, Zyen et al. found electricity prices for German scenarios could increase as much as 43 percent if the electricity system couldn't adapt in time, while hourly had no effect. [79,80] Although this study modeled European markets, the general price setting mechanics via a supply dispatch curve are the same. An analysis by Energy Innovation illustrates this concept of marginal

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[77] Resources for the Future, "Electricity Markets 101," 2022, https://www.rff.org/publications/explainers/us-electricity-markets-101/.

[78] Congressional Research Service, "Electricity Portfolio Standards: Background, Design Elements, and Policy Considerations," October 2020, https://sgp.fas.org/crs/misc/R45913.pdf.

[79] Zeyen, Elisabeth, et al., "Hourly Versus Annually Matched Renewable Supply for Electrolytic Hydrogen," Zenodo, December 2022, https://zenodo.org/record/7457441.

[80] Europe electricity prices are also impacted by carbon prices on power generation, which is a contributing factor to the magnitude of the referenced 43 percent price increase.

pricing, the impact of both supply and demand on electricity prices, and the role the collective three pillars can have in mitigating the risk of both emission and price increases for hydrogen production.[81] Impacts will be location-dependent based on the grid mix and demand profiles and should be assessed through dynamic dispatch modeling to take into account system-wide causation as much as possible, as previously mentioned and as demonstrated in the EPRI and GTI Energy study.

2.5.3 ECONOMIC VIABILITY POST SUBSIDY PERIOD

In order to be eligible for the 45V PTC, projects must begin construction by 2033, and the tax credit is limited to 10 years of production. This makes it important to consider how hydrogen production can retain economic viability to maintain stability in these newly established value chains once the 45V PTC is no longer active. The ultimate final guidance for the 45V PTC is an important factor in the success of a future hydrogen market. The guidance as drafted – combining incrementality and temporal matching – likely sends a stronger signal to developers to build flexible systems that can optimize their operation in the post-subsidy future.

The DOE has specific initiatives that seek to reduce the cost of hydrogen. In June 2021, the DOE introduced the Hydrogen Energy Earthshot, which set a goal to reduce the cost of clean hydrogen to $1 per kilogram within a decade. The Clean Hydrogen Electrolysis Program established under the Infrastructure Investment and Jobs Act will provide $1 billion in funding to improve efficiency and cost-effectiveness of electrolysis technologies through funding research and development, commercialization, and deployment. These programs target a reduction in electrolysis costs to $2/kg by 2026.[82] Though these programs will help decrease hydrogen costs, the DOE predicts that once the 45V PTC expires, hydrogen will have to be produced at approximately $0.4/kg to be capable of serving all focused sector end-use applications.[83] To support a low production cost post-IRA tax credit:

- Electrolyzers should be concentrated in regions with high renewable resources, specifically wind;
- Hydrogen should serve high-value applications, such as industrial feedstocks, that will be willing to pay higher prices for low-carbon hydrogen longer term;
- Projects that start under 45V should ensure they are able to grow and continue to operate after 45V expires, which requires flexibility to adjust demand based on power prices; and

[81] Gimon, Eric, "Consumer Cost Impacts of 45V Rules," November 2023, https://energyinnovation.org/publication/consumer-cost-impacts-of-45v-rules/.
[82] DOE (U.S. Department of Energy), "U.S. National Clean Hydrogen Strategy and Roadmap," June 2023, https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/us-national-clean-hydrogen-strategy-roadmap.pdf.
[83] Energy Innovation Policy & Technology LLC, "Smart Design of 45V Hydrogen Production Tax Credit Will Reduce Emissions and Grow the Industry," April 2023, https://energyinnovation.org/publication/smart-design-of-45v-hydrogen-production-tax-credit-will-reduce-emissions-and-grow-the-industry/.

- Hydrogen storage and transportation solutions should be deployed at scale.[84]

EPRI and GTI Energy modeling resulted in hydrogen from electrolysis peaking in 2035 and declining with a return to unsubsidized prices, even with declines in capital electrolyzer costs. The joint report notes "production in the post-subsidy period depends on the future policy environment and company goals, as net-zero targets could create additional incentives for low-carbon hydrogen." EPRI and GTI Energy also assessed the fiscal expenditures and effective abatement cost of the IRA 45V tax credits, which they found could exceed $750 per ton of CO_2.[85] While part of this cost is an investment in the learning curve to drive down capital costs, such high expenditures also necessitate an emphasis on the emissions impacts. With enough lead time in place, DOE should leverage this opportunity to ensure a robust hydrogen economy exists to support the economic viability of low-carbon hydrogen production inclusive of efficient investment of capital and taxpayer funds.

[84] DOE (U.S. Department of Energy), "U.S. National Clean Hydrogen Strategy and Roadmap," June 2023, https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/us-national-clean-hydrogen-strategy-roadmap.pdf.

[85] EPRI and GTI Energy, "Impacts of IRA's 45V Clean Hydrogen Production Tax Credit," Nov 2023, https://www.epri.com/research/products/000000003002028407.

3. CONCLUSIONS AND NEXT STEPS

Treasury guidance will be critical to ensuring that hydrogen production qualifying for tax credits is achieving the lifecycle GHG emissions levels required by the legislation. This literature review discussed how requirements such as the three pillars can avoid material increases in emissions from electrolyzer demand, while still providing enough flexibility to support hydrogen deployment and incentivize development of hydrogen value chains that will continue to be viable post expiration of the tax credits.

This review also highlighted that incrementality requirements will be a material factor in avoiding increased emissions and supporting the effectiveness of the other two pillars. Incrementality requirements drive new low-carbon generation to be added to (or remain on) the grid to meet increased electricity demand from electrolyzers. Without new low-carbon generation, temporality and deliverability requirements alone would not be sufficient to avoid increased emissions.

In literature discussing a need for incrementality requirements, there is consensus to define a new low-carbon resource as one which comes online no earlier than 36 months prior to a hydrogen producer. Discussion is ongoing for how to potentially include other low-carbon resources, as emphasized in the various requests for comment indicated in the proposed guidance. These resources could include avoided retirements, existing nuclear, repowered facilities, and curtailed renewables. Part II of this report further evaluates specific implementation elements of alternative approaches.

Hourly matching of low-carbon electricity to hydrogen production is deemed necessary to drive alignment of clean supply and demand and to avoid consequential emissions increases on the grid. However, implementation will benefit from the proposed transition period to the hourly requirement. This approach could ensure that availability of hourly EACs can be expanded, and electricity market participants can ensure sufficient data management systems are in place for transactional and validation needs. A major focus area of the literature review was on the impact of temporality on electricity prices, electrolyzer utilization rates, and subsequent hydrogen production costs. One critique of hourly matching is that it would increase costs compared to annual matching, stifling hydrogen production project development; however, many others claim it would not cause a material impact in key markets, particularly where electrolysis is most viable long term. In this sense, phasing in stricter requirements over time will also allow hydrogen capital costs to decline and reduce the impact from electrolyzer utilization factors driven by renewable generation availability. Part II of this report further evaluates this regional context on hydrogen production and the three-pillar framework along with associated implementation considerations.

Although there was consensus in the reviewed literature on electricity being supplied from the same grid, there were several boundary definitions or references suggested for policymakers to consider that would guarantee low-carbon energy is delivered to the electrolyzer. While commercial or market boundaries may or may not be as limiting, transmission constraints are an important consideration that could prevent the deliverability of low-carbon power to its purchaser and thus require fossil fuel generation to meet hydrogen production demand in any given period. Part II of this report contains an assessment of this regional balance of commercial and physical boundaries and highlights potential implications to flexibility options and implementation of the guidance.

In Part II of this report, ERM refines the recommended framework elements associated with the three-pillar framework and additional implementation considerations, including considerations for regional diversity. Part II also provides an overall assessment of the three-pillar framework in the context of supporting the development of a robust hydrogen market.

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APPENDIX A REGIONAL BOUNDARY MAPS

FIGURE A 1: DOE NATIONAL TRANSMISSION NEEDS STUDY GEOGRAPHIC REGIONS

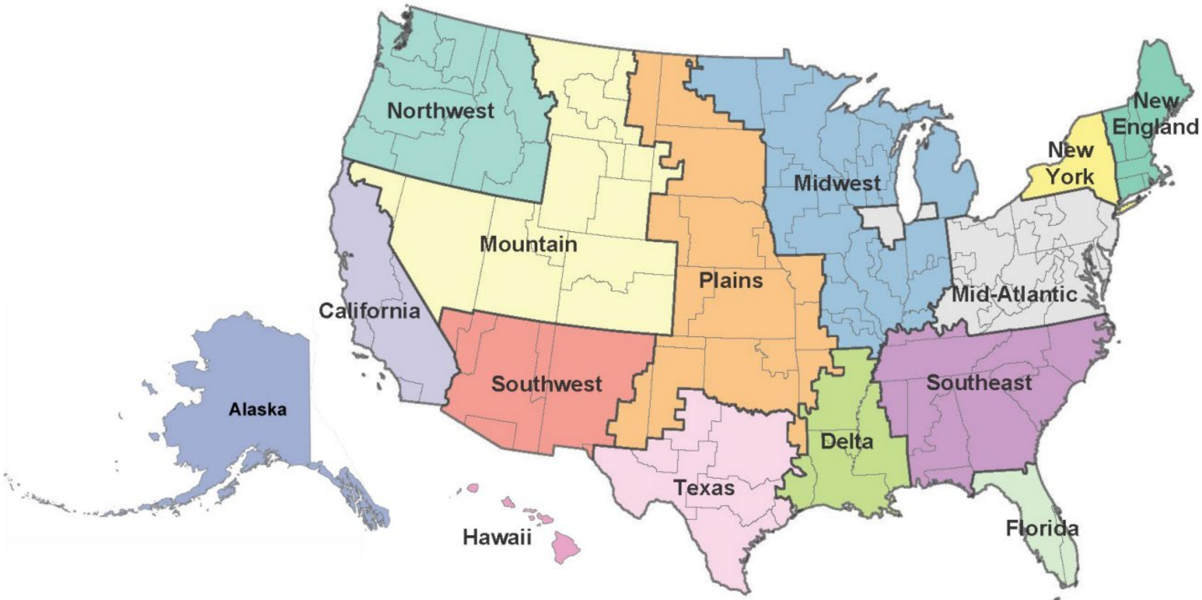


FIGURE A 2: FERC WHOLESALE ELECTRICITY POWER MARKETS

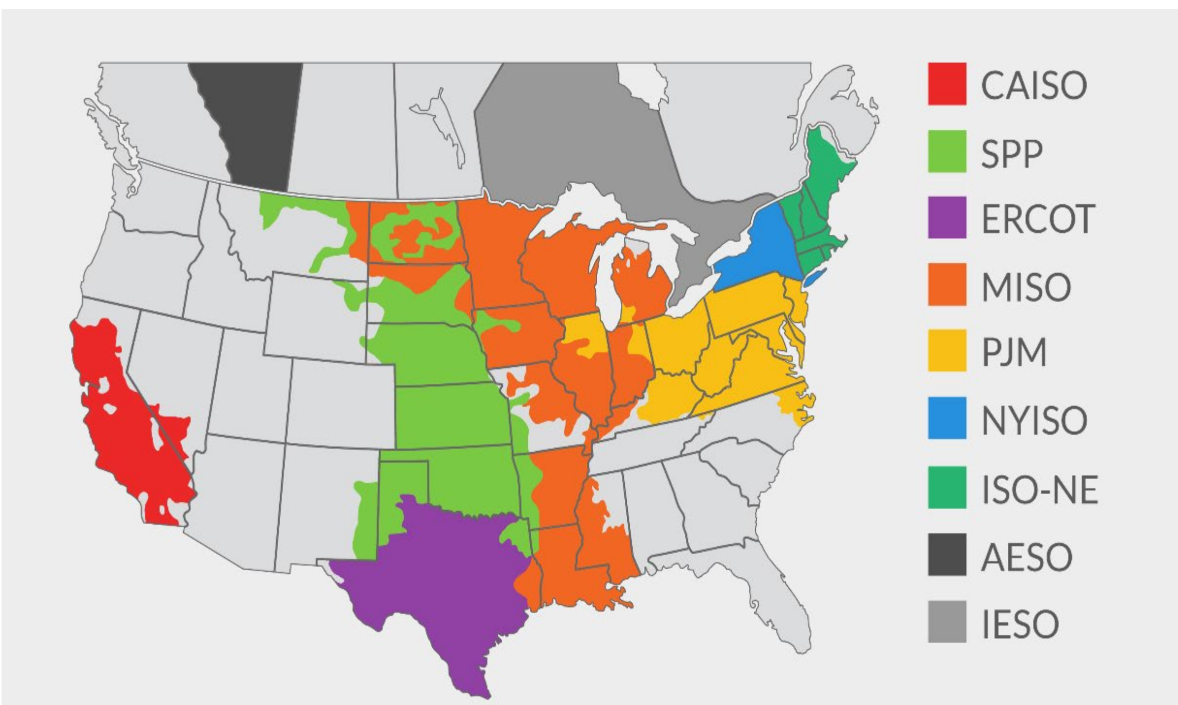


FIGURE A 3: NERC ASSESSMENT AREAS

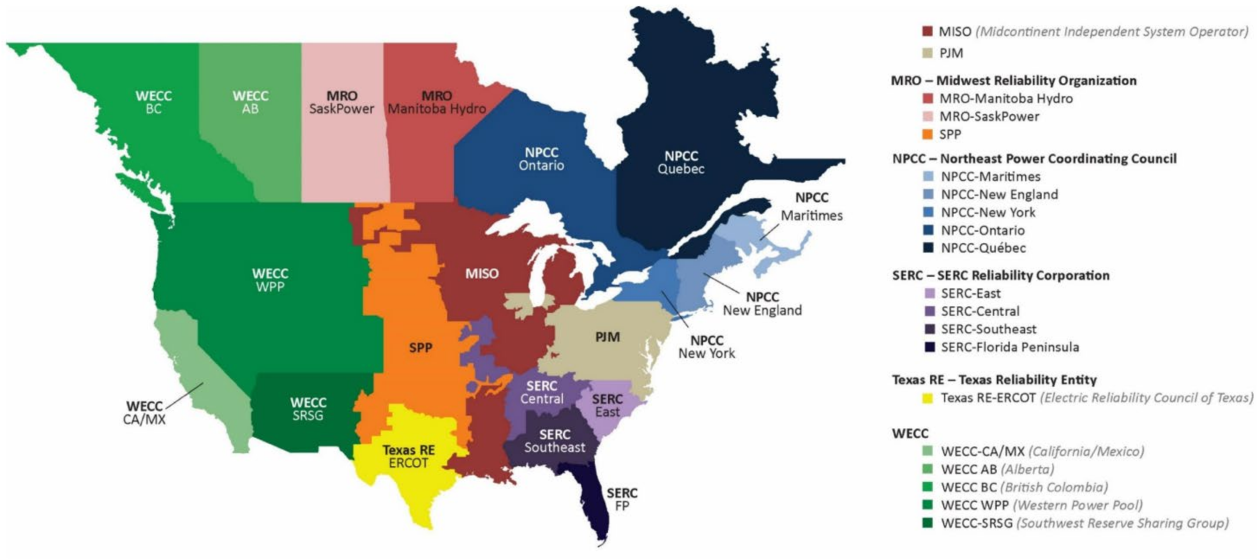
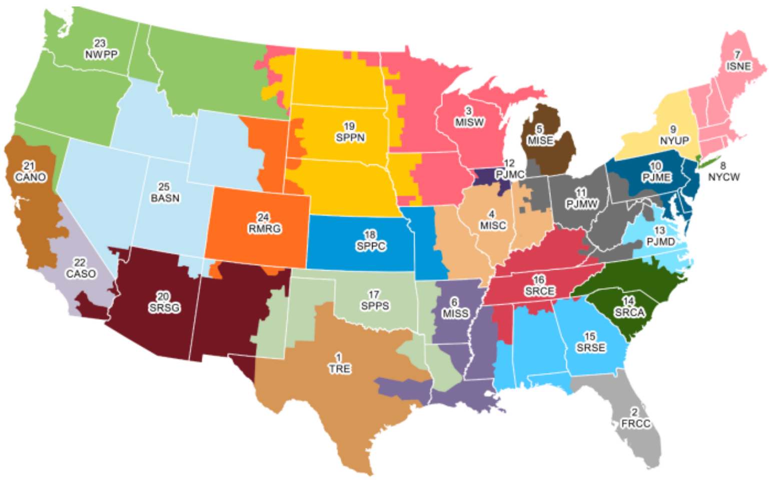


FIGURE A 4: EIA ELECTRIC MARKET MODEL REGIONS (NERC/ISO SUBREGIONS)



Region ID	NERC/ISO subregion	Geographic Name*
1- TRE	Texas Reliability Entity	Texas
2- FRCC	Florida Reliability Coordinating Council	Florida
3- MISW	Midcontinent ISO/West	Upper Mississippi Valley
4- MISC	Midcontinent ISO/Central	Middle Mississippi Valley
5- MISE	Midcontinent ISO/East	Michigan
6- MISS	Midcontinent ISO/South	Mississippi Delta
7- ISNE	NPCC/ New England	New England
8- NYCW	NPCC/NYC & Long Island	Metropolitan New York
9- NYUP	NPCC/Upstate NY	Upstate New York
10- PJME	PJM/East	Mid-Atlantic
11- PJMW	PJM/West	Ohio Valley
12- PJMC	PJM/Commonwealth Edison	Metropolitan Chicago
13- PJMD	PJM/Dominion	Virginia

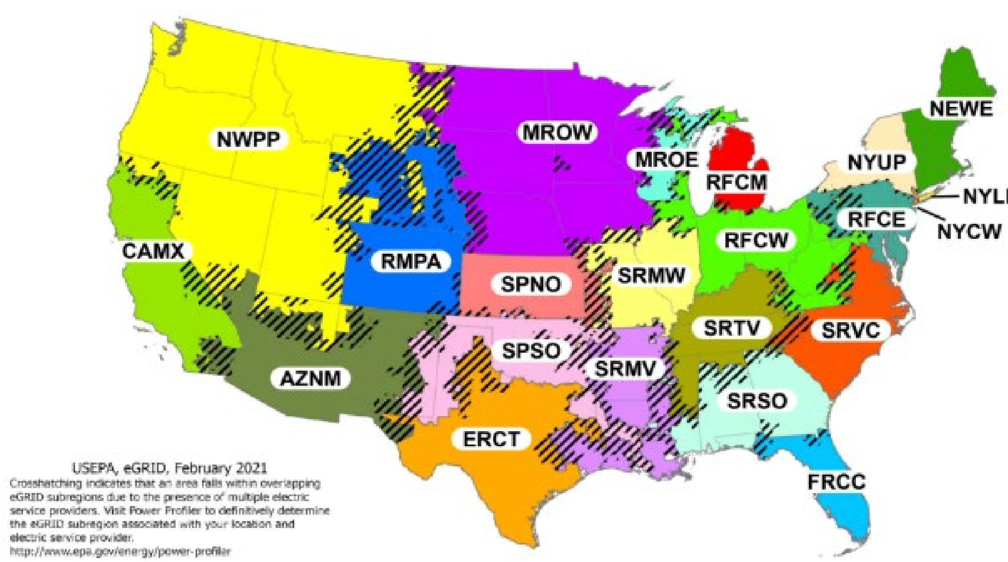
Region ID	NERC/ISO subregion	Geographic Name*
14- SRCA	SERC Reliability Corporation/East	Carolinas
15- SRSE	SERC Reliability Corporation/Southeast	Southeast
16- SRCE	SERC Reliability Corporation/Central	Tennessee Valley
17- SPPS	Southwest Power Pool/South	Southern Great Plains
18- SPPC	Southwest Power Pool/Central	Central Great Plains
19- SPPN	Southwest Power Pool/North	Northern Great Plains
20- SRSG	WECC/Southwest	Southwest
21- CANO	WECC/CA North	Northern California
22- CASO	WECC/CA South	Southern California
23- NWPP	WECC/Northwest Power Pool	Northwest
24- RMRG	WECC/Rockies	Rockies
25- BASN	WECC/Basin	Great Basin

NERC=North American Electric Reliability Corporation, ISO=Independent System Operator NPCC = Northeast Power Coordinating Council, WECC = Western Electricity Coordinating Council

* Names are intended to describe approximate locations. Exact regional boundaries do not necessarily correspond to state borders or to other regional naming conventions.

Source: U.S. Energy Information Administration.

FIGURE A 5: EGRID SUBREGIONS



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Kenya

Malaysia

Mexico

Mozambique

The Netherlands

New Zealand

Peru

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