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Midwest Hydrogen Center of Excellence Detailed Comments in Response to IRS Proposed Guidance for 45V Tax Credit for Clean Hydrogen Production

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THE MIDWEST HYDROGEN
CENTER OF EXCELLENCE

A Key Initiative of the Renewable Hydrogen Fuel Cell Collaborative

February 24, 2024

The Honorable Janet Yellen
Secretary
U.S. Department of the Treasury
1500 Pennsylvania Avenue NW
Washington, DC 20220

RE: IRS Proposed Guidance for 45V Tax Credit for Production of Clean Hydrogen

Dear Secretary Yellen:

On December 22, 2023, the U.S. Department of the Treasury (hereinafter "Treasury") and the Internal Revenue Service (IRS) released proposed guidance on the Clean Hydrogen Production Credit under section 45V of the U.S. tax code as established by the Inflation Reduction Act (IRA).[1] At the same time, Treasury and the IRS requested comments on the proposed regulations before finalizing these rules. This memorandum prepared on behalf of the Midwest Hydrogen Center of Excellence includes recommendations for implementation of the 45V credit for hydrogen production pathways that use either renewable natural gas (RNG) derived from landfill gas (LFG), or that use fossil-based natural gas with carbon capture:[2]

1. ***Phase in accounting for Scope 3 emissions in calculating 45V credit***

   The adoption of clean hydrogen will depend on driving down not just the cost of production, but also on lowering the cost of distribution so that the combined levelized cost per kilogram reaches an amount that end users are willing to pay. For this to happen, the volume of distributed and dispensed hydrogen must increase significantly to realize economies of scale. The current cost of hydrogen from electrolysis is beyond what most end users are willing to pay once the cost of delivery and onsite conditioning are included. According to the *U.S. National Clean Hydrogen Strategy and Roadmap*, the willingness to pay for clean hydrogen among early adopters is around \$5/kg.[3] Electrolytic hydrogen

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[1] U.S. Department of the Treasury, 2023. "U.S. Department of the Treasury, IRS Release Guidance on Hydrogen Production Credit to Drive American Innovation and Strengthen Energy Security." https://home.treasury.gov/news/press-releases/jy2010

[2] Operated by the Stark Area Regional Transit Authority (SARTA) and Cleveland State University's Energy Policy Center, the Midwest Hydrogen Center of Excellence is a regional ambassador for the advancement and adoption of hydrogen-powered, zero-emissions vehicles and infrastructure in the Midwest.

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

can be made for $5 to $7 per kg.[4] The current status of near-term costs for hydrogen delivery and dispensing is at least $4.15/kg.[5] Even with a maximal $3/kg production credit under 45V, electrolytic hydrogen pathways will be challenged to deliver hydrogen at a price that early adopters are willing to pay.

The $5/kg target could be met sooner by production pathways using RNG and fossil-based natural gas with carbon capture where the inclusion of upstream Scope 3 emissions in calculating emissions under 45V was phased in over time. There are prohibitive costs and uncertainty associated with measuring and reporting Scope 3 emissions that could curtail investment into clean hydrogen's midstream segment. These costs and this uncertainty are likely to recede as companies improve the accuracy and availability of emissions data in their supply chains. At the same time, RNG and fossil gas pathways will likely see reductions in methane leakage rates—one of the main drivers of Scope 3 emissions. The added volume of hydrogen distributed from these production pathways would accelerate economies of scale, thus enabling the viability of all clean hydrogen pathways.

2. Enhance functionality of 45VH2-GREET model

There are important input parameters missing from the primary user interface in the 45VH2-GREET model used in calculating lifecycle emissions. For the RNG production pathway, these include the leakage rate at the landfill gas processing facility and whether RNG is itself used as a source of energy to run the LFG-to-RNG processing facility. The calculated lifecycle emissions on which the 45V credit is based are highly responsive to changes in these input parameters. Yet these input parameters are located in the 45VH2-GREET model's more comprehensive dependency file, which some taxpayers may find more difficult to navigate. Input parameters where a reasonable change in value results in a material effect on calculated lifecycle emissions used in determining the 45V credit should be included in the primary user interface.

I. Background

Treasury has adopted Argonne National Laboratory's (ANL) 45VH2-GREET 2023 model for purposes of calculating well-to-gate emissions of hydrogen production facilities for the 45V credit.[6] Figure 1 shows the well-to-gate system boundary for hydrogen production.[7] Scope 1 emissions are direct greenhouse emissions (GHGs) that are controlled or owned by a company, while Scope 2 emissions are indirect GHGs

[4] *Id.*

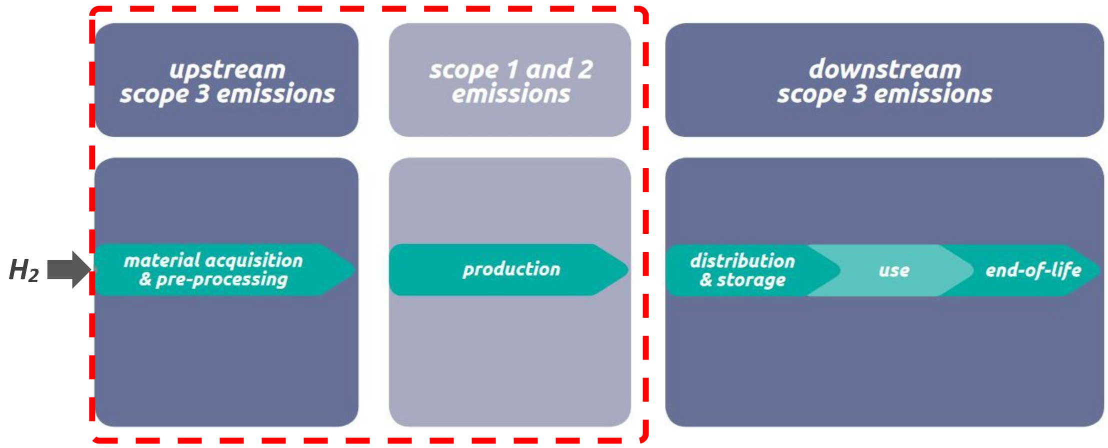
[5] U.S. Department of Energy, 2018. "DOE Hydrogen and Fuel Cells Program Record: Current Status of Hydrogen Delivery and Dispensing Costs and Pathways to Future Cost Reductions." https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/18003_current_status_hydrogen_delivery_dispensing_costs.pdf?Status=Master

[6] U.S. Dept. of Energy, 2023. "Guidelines to Determine Well-to-Gate Greenhouse Gas (GHG) Emissions of Hydrogen Production Pathways using 45VH2-GREET 2023." https://www.energy.gov/sites/default/files/2023-12/greet-manual_2023-12-20.pdf

[7] *See* World Resources Institute and World Business Council for Sustainable Development, 2011. "Greenhouse Gas Protocol: Product Life Cycle Accounting and Reporting Standard." https://ghgprotocol.org/sites/default/files/standards/Product-Life-Cycle-Accounting-Reporting-Standard_041613.pdf. *See also* International Partnership for Hydrogen and Fuel Cells in the Economy, 2021. "Methodology for Determining the Greenhouse Gas Emissions Associated with the Production of Hydrogen" [Working paper version 1]. https://www.iphe.net/_files/ugd/45185a_ef588ba32fc54e0eb57b0b7444cfa5f9.pdf.

associated with the purchase of electricity, steam, heating, or cooling. The upstream or *partial* Scope 3 emissions are indirect GHGs from the acquisition and processing of raw feedstock materials used in hydrogen production, such as those resulting from the upgrading of raw LFG to pipeline-quality RNG.

Figure 1. Well-to-Gate System Boundary for Hydrogen Production

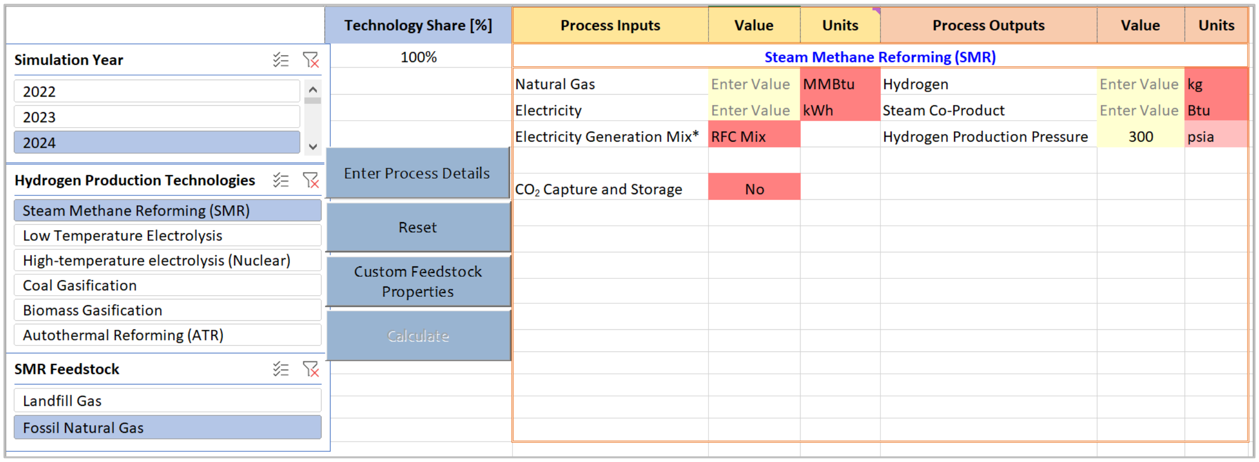


The 45VH2-GREET 2023 model adopted by Treasury is described as having features that "make it easy to use for taxpayers."[8] The model consists of two Excel files. The first file is a simplified user interface for entering input values for a hydrogen production scenario and then calculating associated lifecycle emissions. The primary data items to enter are simulation year, production technology, feedstock type and quantity, hydrogen output, the amount of electricity required, the electricity generation mix, the pressure of the produced hydrogen, whether carbon capture and storage (CCS) will be deployed, and whether steam co-product will be generated.[9] Figure 2 shows this user interface for entering values into the model in the case of hydrogen production from steam reforming (SMR) fossil-based natural gas (NG) without CCS.

[8] *See* Footnote 6.

[9] The electricity generation mix in the 45VH2-GREET 2023 model is based either on the average annual grid mix in the North American Electric Reliability Corporation (NERC) region that the hydrogen production facility is in, or on a combination of user-defined electricity generators such as wind, solar, or natural gas, along with user-specified shares for each energy source.

Figure 2. 45V2-GREET 2023 User Interface



The model's second Excel file—characterized as the *dependency* file—is a 62-tab workbook with thousands of formulas and background data items that are used to calculate emissions based on the scenario defined in the first file's user interface. Advanced users can customize scenarios further by changing some parameter input values in the dependency file. For example, through the dependency file users can model the effect of different methane leakage rates on well-to-gate GHGs for hydrogen production pathways that reform either RNG or fossil-based natural gas.

The result of clicking the *Calculate* button in the user interface shown in Figure 2 is a table of GHGs associated with hydrogen production under the user-defined scenario. Figure 3 shows this emissions table under a hydrogen production scenario of reforming fossil-based natural gas without CCS. The *GHGs* row in Figure 3 represents the total of all 45V-relevant direct and indirect emissions from hydrogen production after converting all greenhouse gases to CO2-equivalents (CO2e), with indirect emissions including both Scope 2 and upstream Scope 3 emissions.

Figure 3. Table of Associated GHGs for SMR Hydrogen Production from Fossil-based Natural Gas

Emissions	Direct Facility Emissions	Indirect Emissions	Co-Product Credits	Total	Units
CO2	96997	13105	0	110102	g/MMBtu H2
CO2 (w/ C in VOC & CO)	97007	13253	0	110260	g/MMBtu H2
GHGs	97123	24353	0	121476	g_CO2e/MMBtu H2
				14	kg_CO2e/kg H2

The number in green in Figure 3 is the calculated well-to-gate emissions per kg of hydrogen production. This metric is the basis for determining what credit can be claimed—if any—under 45V. Table 1 lists the maximum tax credit that can be claimed for ranges of emissions per kg of hydrogen produced as defined under 45V.[10]

[10] Prevailing wage and apprenticeship requirements must be met to claim the maximum credit under 45V. Otherwise, all credit amounts shown in Table 1 are reduced by a factor of 5.

Table 1. Emissions Thresholds and Maximum Credit for 45V

Kilograms of Well-to-Gate Emissions Per Kilogram of Hydrogen Produced	Maximum 45V Credit Per Kilogram of Hydrogen Produced
2.5 to 4.0	$0.60
1.5 to 2.5	$0.75
0.45 to 1.5	$1.00
Less than 0.45	$3.00

II. Analysis

The 45VH2-GREET 2023 model was run under different plausible scenarios for SMR hydrogen production pathways to determine what 45V credit—if any—such scenarios might qualify. The SMR production scenarios for which emissions were calculated using the 45VH2-GREET 2023 model are as follows:

- SMR of RNG from LFG without CCS and without accounting for the sale of steam co-products.
- SMR of RNG from landfill gas with CCS but without accounting for the sale of steam co-products.[11]
- SMR of RNG from landfill gas without CCS but with accounting for the sale of steam co-products.[12]
- SMR of fossil-based natural gas with CCS.

Emissions for all four scenarios were calculated under three electricity generation mixes for the power running the SMR plant: (1) the average grid mix for the Reliability First Corporation (RFC) NERC region, which includes Ohio; (2) 100% solar power; and (3) 100% power from natural gas combined cycle turbines (NGCC) with CCS. All scenarios assumed hydrogen production of 1,000 kg. Table 2 lists the other parameter values that were entered into the 45VH2-GREET 2023 model user interface to calculate emissions for the different production scenarios.

[11] The 45VH2-GREET 2023 model allows users to account for either the deployment of CCS or the sale of steam co-products, but not both.
[12] For scenarios that include the sale of steam co-products, the 45VH2-GREET 2023 model allows a maximum of 17.6% of the total energy content of all steam and hydrogen produced to be accounted for.

Table 2. Parameter Values Used to Calculate Emissions for SMR Hydrogen Production Pathways

Parameter	Value and Units	Data Source
Natural gas feedstock	3.53 kg per kg of hydrogen	National Energy Technology Laboratory (NETL)[13]
Methane unit conversion	0.0527 MMBtu per kg of methane	US EPA[14]
Electricity required	0.63 kWh per kg of hydrogen	NETL[15]
CO2 capture rate	96.2% yielding 10.63 kg of CO2 per kg of hydrogen	NETL; ANL[16]
Steam co-product	24,290 Btu per kg of hydrogen	ANL[17]
Hydrogen production pressure	300 psia	ANL[18]
Power source for process energy at LFG-to-RNG plant	100% grid electricity	ANL[19]
Total methane leakage rate for fossil-based NG (includes recovery, gathering, processing, transmission)	0.94%	ANL[20]
Methane leakage at LFG-to-RNG processing plant	2.0%	ANL[21]

Table 3 shows the resulting well-to-gate emissions under these scenarios for hydrogen production in 2024, as well as the amount of 45V credit these scenarios would qualify for. The full credit of $3.00/kg is realized only for RNG with CCS. The source of electricity for running the SMR plant has a relatively small influence on well-to-gate emissions. For example, an SMR plant reforming RNG without deploying CCS nor accounting for steam co-products would have a reduction in well-to-gate emissions of 0.28 kg of CO2e per kg of hydrogen produced by switching from grid power to solar power—yet would still not meet the lowest threshold to qualify for a credit under 45V. This slight difference may become significant in the marginal case when emissions are closer to the qualifying threshold endpoints.

[13] NETL, 2022. "NETL Life Cycle Inventory Data—Unit Process: Steam Methane Reforming." https://netl.doe.gov/projects/VueConnection/download.aspx?id=dac9f299-4ef9-45b8-a791-f2fa2d7c7395&filename=DS_O_Steam_Methane_Reforming_2022.01%20v2.xlsx

[14] US EPA, 2023. "Updated Coal Mine Methane Units Converter." https://www.epa.gov/cmop/updated-coal-mine-methane-units-converter

[15] *See* Footnote 13.

[16] NETL's recent assessment of the performance of SMR hydrogen production plants with CCS is based on a CO2 capture rate of 96.2%. This capture rate is reached in the 45VH2-GREET 2023 model by entering 10.63 kg of sequestered CO2 per kg of produced hydrogen. *See* NETL, 2022. "Comparison of Commercial, State-of-the-Art, Fossil-Based Hydrogen Production Technologies." https://netl.doe.gov/projects/files/ComparisonofCommercialStateofArtFossilBasedHydrogenProductionTechnologies_041222.pdf

[17] This is the amount of steam co-product at which the 17.6% maximum allowed by the 45VH2-GREET 2023 model is reached.

[18] This is the default hydrogen production pressure in the 45VH2-GREET 2023 model.

[19] This is the default value for process fuels in the 45VH2-GREET 2023 model. Alternatively, RNG can be modeled as the source of energy for operating the RNG processing facility, up to 100% of the energy requirement. Under this scenario, a portion of RNG would be diverted back to the processing facility for heat and power.

[20] This is the default leakage rate for conventional and shale gas pathways in the 45VH2-GREET 2023 model.

[21] This is the default leakage rate for landfill gas upgrading in the 45VH2-GREET 2023 model.

Table 3. Well-to-Gate Emissions and Qualifying 45V Credit for SMR Hydrogen Pathways

Hydrogen Source	CCS or Steam Co-product?	Electricity Source	Well-to-Gate Emissions (kg of CO2e/kg of H2)	45V Credit ($/kg of H2)
RNG (landfill gas)	None	Grid	4.50	N/A
	CCS	Grid	-6.13	$3.00
	Steam Co-product	Grid	2.28	$0.75
	None	Solar	4.22	N/A
	CCS	Solar	-6.41	$3.00
	Steam Co-product	Solar	2.00	$0.75
	None	NGCC w/ CCS	4.29	N/A
	CCS	NGCC w/CCS	-6.33	$3.00
	Steam Co-product	NGCC w/CCS	2.09	$0.75
Fossil natural gas	None	Grid	13.84	N/A
	CCS	Grid	3.21	$0.60
	Steam Co-product	Grid	11.62	N/A
	None	Solar	13.56	N/A
	CCS	Solar	2.93	$0.60
	Steam Co-product	Solar	11.34	N/A
	None	NGCC w/ CCS	13.62	N/A
	CCS	NGCC w/CCS	2.99	$0.60
	Steam Co-product	NGCC w/CCS	11.41	N/A

The financial viability of clean hydrogen production will, of course, depend on more than the 45V credit that a scenario is qualified to receive. It will also depend on the unsubsidized cost of hydrogen production. To that end, the current unsubsidized cost of hydrogen per kg was calculated for the SMR production pathways listed in Table 3.[22] Table 4 lists important input values that were used to estimate the cost of hydrogen production from RNG and fossil-based natural gas, such as the regional cost of electricity and natural gas. Table 4 also lists the resulting cost of hydrogen production per kg for these pathways. The cost of electricity by source (e.g., solar power, grid power, etc.) is not included in Table 4 as it was found not to have a material effect on the resulting production cost of hydrogen per kg.[23]

[22] Estimated hydrogen production costs are based on data and research from 2022 and 2023.

[23] According to EIA, generation represents 63% of the end-use price of electricity in the PJM West market region. Generation would therefore represent around $0.05/kWh of the $0.08/kWh average retail price for industrial end-users in the region. EIA projects by 2028 a cost of generation in the PJM West market of $0.036/kWh for advanced NGCC, $0.044/kWh for solar PV without any tax credit claimed under the inflation reduction act (IRA), and $0.022/kWh for solar PV with a 30% investment tax credit claimed under the IRA. Using NREL's Hydrogen Analysis Lite Production Model, it was found that a reduction in the cost of electricity generation from $0.05/kWh to $0.022/kWh would reduce the cost of hydrogen production per kg for SMR pathways by less than one-half cent. *See* EIA, 2023. "Annual Energy Outlook 2023" [Table 56.11]. https://www.eia.gov/outlooks/aeo/tables_ref.php. *See also* EIA, 2023. "Levelized Costs of New Generation Resources in the *Annual Energy Outlook 2023*." https://www.eia.gov/outlooks/aeo/electricity_generation. *See also* NREL, 2023. "Hydrogen Analysis Lite Production Model" [Version 1.4]. https://www.nrel.gov/hydrogen/h2a-production-models.html

Table 4. Cost Basis for SMR Hydrogen Production

Item	Amount	Source
Average retail price of electricity for industrial end-users in the East North Central Census Division	\$0.08/kWh	U.S. Energy Information Administration (EIA)[24]
Average price of natural gas delivered to industrial end-users in the East North Central Census Division	\$7.40/MMBtu	EIA[25]
Credit for steam co-product sales	\$0.12/kg of hydrogen produced	National Renewable Energy Laboratory (NREL) Hydrogen Analysis Lite Production Model[26]
Cost of CO2 capture	\$0.48/kg of hydrogen produced	NETL[27]
Cost of hydrogen production from RNG without CCS or steam co-product sales	\$2.00/kg of hydrogen produced	Strategen (on behalf of the Connecticut General Assembly)[28]
Cost of hydrogen production from fossil-based natural gas without CCS or steam co-product sales	\$1.50/kg of hydrogen produced	NREL[29]

Table 5 shows the cost of hydrogen production for SMR pathways after accounting for any 45V credit. The electricity source for all pathways in Table 5 is NGCC with CCS, which was the middle case for well-to-gate (WTG) emissions among the three electricity sources as seen above in Table 3, regardless of whether CCS was deployed or steam co-product was sold. (The use of NGCC with CCS to run the SMR plant instead of solar power increased well-to-gate emissions by no more than 0.09 kg of CO2e per kg of hydrogen for any scenario listed in Table 3.)

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[24] Reflects average monthly price of electricity for industrial end-users across IL, IN, MI, OH, and WI for calendar year 2023. *See* EIA, 2024. "Electric Power Monthly" [Table 5.6.B]. https://www.eia.gov/electricity/monthly/

[25] Reflects average monthly price of natural gas delivered to industrial end-users across IL, IN, MI, OH, and WI for calendar year 2023. *See* EIA, 2024. "Natural Gas Data" [Data viewer]. https://www.eia.gov/dnav/ng/ng_pri_sum_dcu_nus_m.htm. Natural gas prices were converted from \$/Mcf to \$/MMBtu using a conversion factor of 1.038 MMBtu per Mcf. *See* EIA, 2023. "FAQs: What are Ccf, Mcf, Btu, and Therms? How Do I Convert Natural Gas Prices in Dollars per Ccf or Mcf to Dollars per Btu or Therm?" https://www.eia.gov/tools/faqs/faq.php?id=45&t=8

[26] Reflects a credit from the sale of steam co-product based on an industrial electricity price of \$0.08/kWh and an industrial gas price of \$7.40/MMBtu at the maximum of 17.6% allowed for steam co-product by the 45VH2-GREET 2023 model. This steam co-product credit (in 2022\$ dollars) was calculated using NREL's Hydrogen Analysis Lite Production Model available for download at https://www.nrel.gov/hydrogen/h2a-lite.html.

[27] *See* Footnote 13. The cost of CO2 capture (at a rate of 96.2%) reflects the difference in the cost of hydrogen production per kg for an SMR plant with and without CCS as estimated by NETL in its 2022 assessment.

[28] *See* Strategen, January 2023. "Connecticut Hydrogen Task Force Study." https://president.uconn.edu/wp-content/uploads/sites/2794/2023/03/Connecticut-Hydrogen-Task-Force-Study-FINAL.pdf. This estimate for the cost of RNG-derived hydrogen was based on an RNG price of \$18.55/MMBtu.

[29] Reflects a cost of hydrogen production based on an industrial electricity price of \$0.08/kWh and an industrial gas price of \$7.40/MMBtu. This cost of production per kg of hydrogen (in 2022\$ dollars) was calculated using NREL's Hydrogen Analysis Lite Production Model. https://www.nrel.gov/hydrogen/h2a-production-models.html

Table 5. Total Subsidized Cost of SMR Hydrogen Production

Hydrogen Source	CCS or Steam Co-product?	WTG Emissions (kg of CO2e/kg of H2)	45V Credit ($/kg of H2)	Unsubsidized Cost of Hydrogen Production ($/kg)	Subsidized Cost of Hydrogen Production ($/kg)
RNG (landfill gas)	None	4.29	N/A	$2.00	$2.00
	CCS	-6.33	$3.00	$2.48	-$0.52
	Steam Co-product	2.09	$0.75	$1.88	$1.13
Fossil natural gas	CCS	2.99	$0.60	$1.98	$1.38

The 45V credit would seem to make the production of hydrogen from RNG with CCS favorable, contributing to a negative production cost of $0.52/kg. However, the financial viability of clean hydrogen production will also depend on the willingness of consumers to pay for the *delivered and dispensed* cost of clean hydrogen. According to the U.S. Department of Energy's (DOE) current assessment, as referenced in the *U.S. National Clean Hydrogen Strategy and Roadmap*, the cost of hydrogen delivery and dispensing is expected to range from $4.15/kg to $4.90/kg by 2025, with an ultimate long-term target of $2.05/kg to $2.95/kg.[30] Table 6 shows the delivered and dispensed cost of hydrogen for the SMR production pathways listed in Table 5 in the near term after accounting for 45V.

In the case of hydrogen production by reforming fossil-based natural gas with CCS, claiming the 45Q credit for carbon capture and sequestration may be more favorable than claiming the 45V credit for hydrogen production.[31] As seen above in Table 2, a 96.2% CO2 capture rate at the SMR plant would yield 10.63 kg of CO2 per kg of hydrogen. Under the 45Q credit, taxpayers can receive $85 per metric ton of captured CO2 from point sources such as SMR plants.[32] This works out to a credit of $0.90 per kg of produced hydrogen, which would lower the subsidized cost of this pathway from $1.38/kg under 45V to $1.08 under 45Q.

[30] The lower bounds for the cost ranges result from high-volume manufacturing that drives economies of scale. *See* DOE, 2018. "Current Status of Hydrogen Delivery and Dispensing Costs and Pathways to Future Cost Reductions." https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/18003_current_status_hydrogen_delivery_dispensing_costs.pdf?Status=Master. *See also* DOE, June 2023. "U.S. National Clean Hydrogen Strategy and Roadmap." https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/us-national-clean-hydrogen-strategy-roadmap.pdf

[31] Taxpayers may take one or the other of these credits, but not both.

[32] Prevailing wage and apprenticeship requirements must be met to claim the maximum credit under 45Q.

Table 6. Cost to Produce, Deliver, and Dispense Hydrogen by 2025 with 45V

Hydrogen Source	CCS or Steam Co-product?	Subsidized Cost of Hydrogen Production ($/kg)	Cost to Produce, Deliver, and Dispense Hydrogen by 2025 with 45V ($/kg)
RNG (landfill gas)	None	$2.00	$6.15 - $6.90
	CCS	-$0.52	$3.63 - $4.38
	Steam Co-product	$1.13	$5.28 - $6.03
Fossil natural gas	CCS	$1.38	$5.53 - $6.28

As shown in the DOE's *U.S. National Clean Hydrogen Strategy and Roadmap*, most near-term end-users are not willing to pay an all-in cost for clean hydrogen of more than $5/kg, with many industrial end-users not willing to pay more than $3/kg (*See* Figure 4). As seen above in Table 6, hydrogen from RNG with CCS that qualified for the full 45V credit could possibly meet the $5/kg threshold. However, uncertainty in the price of RNG can create uncertainty in the cost of the resulting hydrogen for this pathway. The production cost of $2.00/kg for hydrogen from RNG as seen in the above tables was based on a price for RNG of $18.55/MMBtu, as estimated in a 2019 study by the American Gas Foundation.[33] As seen below in Figure 5, the price for RNG has since then surged to more than $25/MMBtu on average.[34]

According to NREL's Hydrogen Analysis Lite Production Model, a $1/MMBtu increase in the cost of natural gas—whether it were conventional fossil-based natural gas or RNG, which are chemically identical—increases the production cost of hydrogen by 15.7 cents per kg.[35] An increase in the price of RNG from $18.55/MMBtu to $25/MMBtu therefore translates to an increase in the cost of RNG-based hydrogen production of $1.01 per kg.[36] This would eliminate the previously calculated negative production cost for hydrogen from RNG with CCS as seen in Table 5. It would also push the delivered and dispensed cost of hydrogen from RNG with CCS beyond the $5/kg price that most near-term end users are willing to pay.

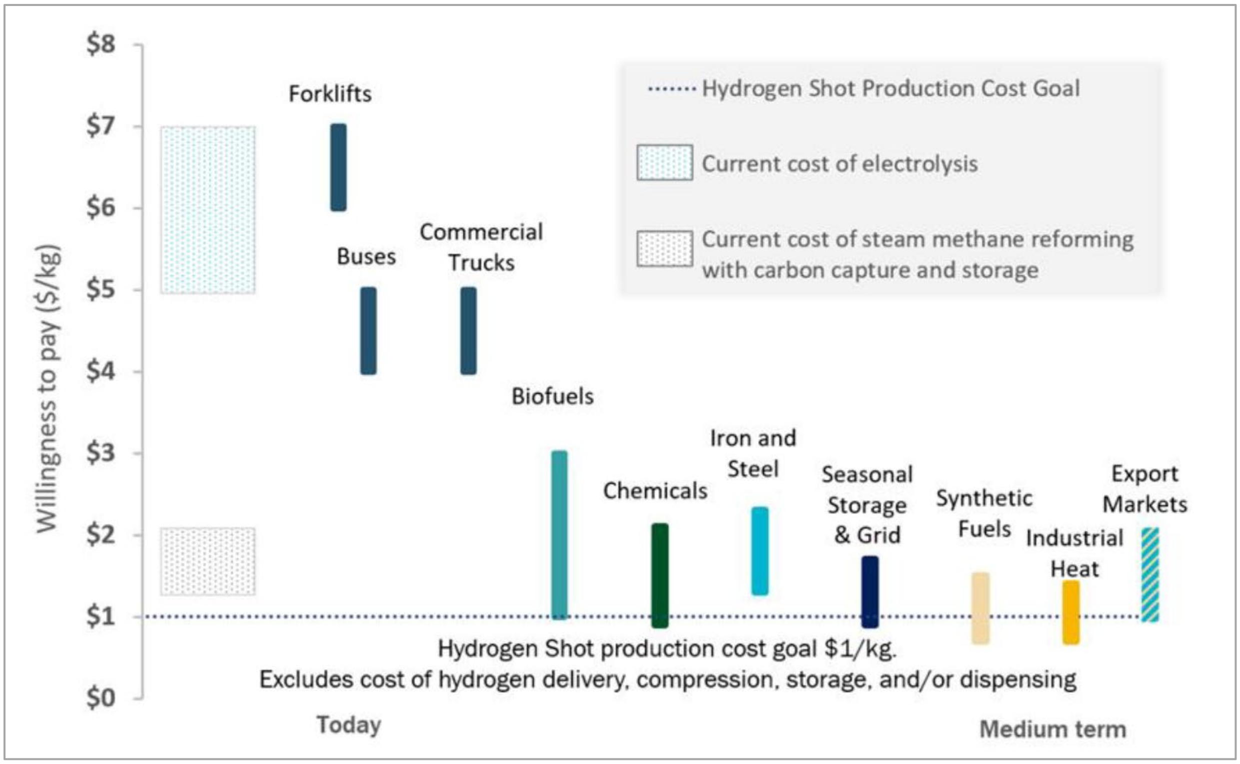
[33] *See* Footnote 28.

[34] Renewable Identification Numbers (RINs) are credits used for compliance under the federal renewable fuel standard (RFS) program that are generated upon the gallon-equivalent production of a renewable fuel. RINs are the currency of the RFS program and are regularly traded. Renewable fuels are classified as one of four RIN types based on the feedstock used, with each RIN trading at a different price. U.S. EPA tracks these transactions and regularly releases the average weekly prices at which trades occur. Under U.S. EPA rules, fuels derived from landfill biogas qualify for cellulosic biofuel RINs, also known as D3 RINs. The energy content of a single D3 RIN such as biogas is 77,000 Btu. After accounting for a loss factor, there are approximately 11.7 RINs/MMBtu. *See* U.S. EPA, 2024. "Renewable Identification Numbers (RINs) Under the Renewable Fuel Standard Program." https://www.epa.gov/renewable-fuel-standard-program/renewable-identification-numbers-rins-under-renewable-fuel-standard#lifecycle. *See also* U.S. EPA, 2024. "RIN Trades and Price Information." https://www.epa.gov/fuels-registration-reporting-and-compliance-help/rin-trades-and-price-information. *See also* U.S. Department of Energy, 2015. "Clean Cities Coalition Network: Renewable Natural Gas and RINS" [Webinar text version]. https://cleancities.energy.gov/webinars/59

[35] This rise in the production cost of hydrogen assumes that all other input costs are held constant.

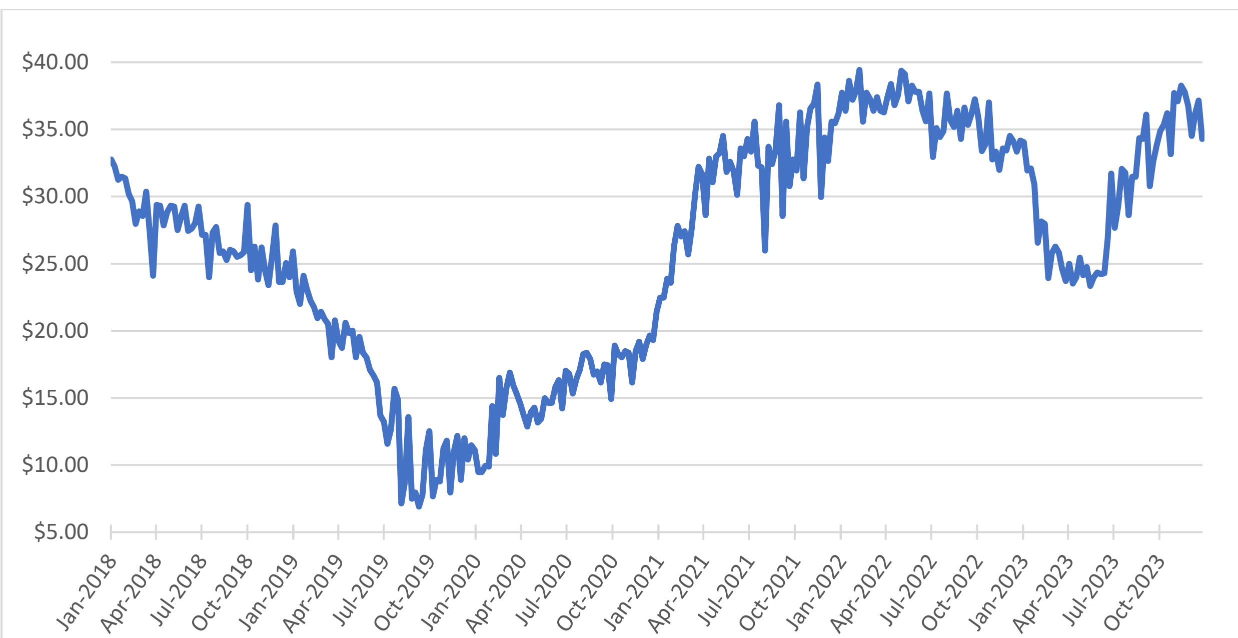
[36] $(\$25.00\ per\ MMBtu - \$18.55\ per\ MMBtu) \times \frac{\$0.157\ per\ kg\ of\ hydrogen}{\$1\ per\ MMBtu} = \$1.01\ per\ kg\ of\ hydrogen.$

Figure 4. Willingness to Pay for Clean Hydrogen by Sector



Source: DOE's *U.S. National Clean Hydrogen Strategy and Roadmap* (2023)[37]

Figure 5. Weekly RNG Price ($/MMBtu), 2018 - 2023



Data Source: U.S. EPA RIN Trades and Price Information. Reflects verified D3 RIN prices adjusted by a factor of 11.7 RINs/MMBtu.

[37] *See* Footnote 3.

III. Policy Recommendations

A large majority of well-to-gate GHGs calculated using the 45VH2-GREET 2023 model for the scenarios defined herein are Scope 3 emissions. In the case of hydrogen production by reforming RNG, for example, nearly 80% of all well-to-gate emissions used in determining the 45V credit were the Scope 3 emissions associated with upgrading landfill gas to pipeline quality RNG. Table 7 shows a breakdown of all emissions for the RNG pathway without CCS and without selling steam co-products, where the power to run the SMR plant comes from the grid.

Table 7. Well-to-Gate GHGs for Hydrogen from RNG by Emissions Scope

Emissions Type	Description	Calculated GHGs for Determining 45V Credit (kg of CO_2e/kg of H_2)	Share (%) of WTG GHGs for Determining 45V Credit
Scope 1	Direct facility emissions at SMR plant	3.41	0.3% (net)
	Credit for using LFG that would have otherwise been flared	-3.40	
Scope 2	Electricity to runs SMR plant	0.25	5.5%
Scope 3	Upgrading LFG to RNG	3.57	79.4%
	Other Scope 3 emissions	0.67	14.8%
	TOTAL	**4.50**	**100%**

There is appreciable uncertainty in how the 45VH2-GREET 2023 model measures well-to-gate emissions within the lifecycle analysis (LCA) framework. In the model's accompanying dependency file, a qualifier for the RNG pathway states, "The LCA results of RNG are subject to further revisions to address technical uncertainties, especially related to counterfactual scenario assumptions for wastes that are used for RNG production."[38] The RNG-to-hydrogen pathway is the only pathway for which such a proviso on the uncertainty of LCA results is inserted in the dependency file. It is unclear how future versions of the 45VH2-GREET 2023 model will be revised in determining tax credits for RNG production pathways.

Further, recent versions of the GREET model calculated lower well-to-gate emissions for RNG-to-hydrogen pathways than those calculated for this memorandum. For example, ANL calculated WTG GHGs of 0.2 kg of CO_2e/kg of hydrogen from RNG derived from landfill gas (without CCS or steam co-product sales) using *GREET 2022*.[39] This compares to the greater than 4 kg of CO_2e/kg of hydrogen calculated herein using the 45VH2-GREET 2023 model for the same pathway. (In the same analysis, ANL calculated WTG GHGs of 3.4 kg of CO_2e/kg of hydrogen for SMR of fossil-based natural gas with CCS that relied on the U.S. average electricity grid generation mix to power the SMR plant, which is comparable to the 3.21 kg of CO_2e/kg of hydrogen calculated herein for the same pathway that relied on a regional grid generation mix.)[40] It is unclear how boundary conditions are likely to develop in future iterations of the 45VH2-GREET 2023 model and how this might affect emissions calculations for SMR production pathways, especially for RNG-derived hydrogen.

[38] *See* cell A26 of the RNG worksheet tab in the 45VH2-GREET 2023 model dependency file.
[39] *See* ANL, October 2022. "Hydrogen Life-Cycle Analysis in Support of Clean Hydrogen Production." https://publications.anl.gov/anlpubs/2022/10/179090.pdf
[40] *Id.*

To scale up clean hydrogen utilization that enables decarbonization, the subsidized cost of production will have to be well below $1/kg given the added cost of delivering and dispensing hydrogen, along with how these costs relate to market demand. These distribution costs will fall as higher production volumes for components serving hydrogen's midstream segment drive economies of scale. SMR-based hydrogen pathways for RNG and those that leverage fossil-based natural gas in conjunction with CCS can contribute to national decarbonization goals towards net zero while supporting sufficient volumes to generate cost reductions.[41] For this to happen, administration of 45V credits must be consistent with fostering a growing, yet nascent, clean hydrogen industry where projects trending towards economic competitiveness are supported.

To spur investment into clean hydrogen pathways, the IRS and Treasury should consider a phase-in period for including upstream Scope 3 emissions in the calculation of well-to-gate emissions for the 45V clean hydrogen production credit. The evolving scope of what constitutes these *partial* Scope 3 emissions creates uncertainty for investors. This uncertainty could stall development of the clean hydrogen economy by restraining private investment.

45V credits as currently specified under the proposed guidance would likely fall short of stimulating the development of SMR-based clean hydrogen at scale as these pathways struggle to produce competitively priced hydrogen. The cost of measuring Scope 3 emissions and ensuring compliance with IRS rules further adds to the levelized cost of delivered and dispensed hydrogen in a manner that has not yet been addressed. What is known is that this cost could be burdensome. The U.S. Securities and Exchange Commissions (SEC) concluded as much in its own proposed guidance for climate-related disclosures that publicly listed companies must start including in annual reports. The SEC recognized that "the calculation and disclosure of Scope 3 emissions may pose difficulties compared to Scopes 1 and 2 emissions," especially as it may be difficult to obtain relevant emissions information from suppliers in a company's value chain.[42] The SEC estimated that companies would spend $420,000 to $640,000 annually to measure and report GHGs.[43] Given the unique challenge of calculating Scope 3 emissions, it is reasonable to assume that a large part of this cost would be to account for this particular source of indirect emissions.

The SEC proposed a 3-year phase-in for the requirement to report Scope 3 emissions that was based on the size of the company making the disclosure, with larger companies required to report these emissions sooner.[44] The IRS and Treasury should consider something similar with respect to the 45V credit, either where the inclusion of Scope 3 emissions in calculating well-to-gate emissions is delayed according to company size, or where a graduated percentage of the calculated Scope 3 emissions is included in total well-to-gate GHGs when determining the amount of 45V credit qualified for (e.g., 0% in year 1, 25% in year 2, 50% in year 3, 75% in year 4, and 100% in year 5 and thereafter). Phasing in Scope 3 emissions in

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[41] NREL previously estimated the hydrogen potential of landfill gas in the United States at 648,000 metric tons annually, which it stated was a conservative figure as it was based on the potential of *candidate* sites under the U.S. EPA's Landfill Methane Outreach Program (LMOP) and did not include those landfills classified as *potential* or *other*. *See* NREL, 2014. "Renewable Hydrogen Potential from Biogas in the United States." https://www.nrel.gov/docs/fy14osti/60283.pdf

[42] SEC, 2022. "The Enhancement and Standardization of Climate-Related Disclosures for Investors." [Propose Rule No. 33-11042]. https://www.sec.gov/files/rules/proposed/2022/33-11042.pdf

[43] *Id.*

[44] *Id.*

these ways would allow SMR-based hydrogen pathways to deliver and dispense hydrogen at a cost of less than $5/kg to end users while furthering decarbonization towards net zero. Table 8, for example, shows two of the SMR pathways from Table 6 above that become financially viable by suspending the inclusion of Scope 3 emissions for purposes of 45V.

Table 8. Total Cost to End-User of SMR Pathways With and Without Scope 3 GHGs Under 45V

Hydrogen Source	CCS or Steam Co-product?	Electricity Source for SMR	Total Cost to End-user by 2025 with Scope 3 GHGs in 45V ($/kg)	Total Cost to End-user by 2025 without Scope 3 GHGs in 45V ($/kg)
RNG (landfill gas)	None	NGCC w/ CCS	$6.15 - $6.90	$3.15 - $3.90
Fossil natural gas	CCS	NGCC w/ CCS	$5.53 - $6.28	$3.13 - $3.88

The challenges of reporting Scope 3 emissions are expected to recede over time.[45] As more companies improve the accuracy and availability of their Scope 1 and 2 emissions data, this reduces the Scope 3 reporting burden for other companies. Methane leakage rates will also likely improve over time. One of the dominant forms of LFG-to-RNG upgrading—pressure swing adsorption (PSA)—has methane leakage rates of around 2%, which is the default leakage rate for RNG processing in the 45VH2-GREET 2023 model. Alternative methods for RNG processing, while currently more expensive, have seen increasing use and could provide methane losses of less than 0.1%.[46] For the hydrogen from RNG pathways modeled herein, this leakage rate would all but eliminate well-to-gate emissions for projects that sold steam co-products, while RNG projects with neither CCS nor steam co-product sales would see well-to-gate emissions reduced from over 4 kg of CO2e/kg hydrogen to less than 2.5 kg of CO2e/kg hydrogen. As these improvements are made and total well-to-gate emissions fall, the full accounting of these emissions for purposes of claiming the 45V credit would be phased in.

IV. Technical Recommendations

As previously noted, methane leakage rates have a material effect on the calculation of well-to-gate emissions for RNG production pathways in the 45VH2-GREET 2023 model. A one percentage point decrease in the leakage rate at the RNG processing facility was found to reduce well-to-gate GHGs by 1.08 kg of CO2e/kg of hydrogen. At this rate, projects that could demonstrate leakage rates lower than the default value of 2% stand to significantly increase the credit they qualify for under 45V. For example, at a 0.5% leakage rate, an RNG-based hydrogen production project that sold steam co-products could increase its 45V credit to $3/kg compared to the $0.75/kg it would receive under a 2% leakage rate. Yet this

[45] *Id.*

[46] Chemical scrubbing, for example, with leakage rates of less than 0.1%, has an investment cost of around $3,200 per cubic-meter-per-hour of biogas processing capacity, compared to $2,500 for PSA, although the annual operating costs for chemical scrubbing are about 2.5% less than those for PSA. *See* Ardolino, et al., 2021. "Biogas-to-Biomethane Upgrading: A Comparative Review and Assessment in a Life Cycle Perspective." https://www.sciencedirect.com/science/article/pii/S1364032120308728. *See also* ANL and NREL, 2021. "Life Cycle Analysis of Renewable Natural Gas and Lactic Acid Production from Waste Feedstocks." https://www.osti.gov/servlets/purl/1847646

parameter is not included in the Excel file with the simplified user interface but is rather found in the more difficult to navigate dependency file.

Similarly, well-to-gate emissions for RNG pathways are responsive to the source of energy used to run the LFG-to-RNG processing facility. By default, the 45VH2-GREET 2023 models grid electricity as the sole source of energy to drive the RNG processing facility. Alternatively, RNG itself can be modeled as the source of energy for operating the RNG processing facility. By modeling the latter—where a portion of RNG is diverted to deliver 100% of the process energy to run the LFG-to-RNG processing facility—well-to-gate emissions for RNG-derived hydrogen without CCS or steam co-product sales is reduced from 4.5 kg of CO2e/kg of hydrogen to 3.0 kg of CO2e/kg of hydrogen. Here again, a parameter input with such a large effect on WTG GHGs is not included in the Excel file with the simplified user interface but is instead located in the dependency file. Parameters to which well-to-gate GHGs are so responsive should be included in the Excel file with the simplified user interface. Enhancing the 45VH2-GREET 2023 model's ease of use will increase its adoption in the planning process as companies consider hydrogen-related investments that will drive the American-led global clean energy transition.

Sincerely,

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