RESEARCH BRIEF

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Evaluating the policy value of dairy biomethane-derived hydrogen in California's Low Carbon Fuel Standard

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INTRODUCTION

Methane is a potent greenhouse gas (GHG) that has a shorter atmospheric lifetime but a higher global warming potential than carbon dioxide (CO_2).[1] Livestock operations are responsible for around half of the methane emissions in California.[2] Half of those methane emissions come from manure management practices at dairies, specifically from lagoon storage of flushed manure (i.e., manure that is spray washed out of animal facilities into drains).[3] Indeed, California has higher methane emissions per dairy cattle than most other states because of extensive use of flush water lagoon systems for manure collection and storage.[4]

To help address the issue of short-lived climate pollutants such as methane, California Senate Bill 1383, which went into effect in January 2022, set emissions reduction targets. It requires that the California Air Resources Board (CARB) develop a strategy to reduce methane emissions from enteric fermentation and manure management by

1 Valérie Masson-Delmotte et al., Climate Change 2021-The Physical Science Basis Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (Intergovernmental Panel on Climate Change, 2023), https://doi.org/10.1017/9781009157896.

2 California Air Resources Board, Analysis of Progress Toward Achieving the 2030 Dairy and Livestock Sector Methane Emissions Target (March 2022), https://ww2.arb.ca.gov/resources/documents/dairy-livestock-sb1383-analysis.

3 California Air Resources Board, Final Short-Lived Climate Pollutant Reduction Strategy (March 2017), https://ww2.arb.ca.gov/resources/documents/slcp-strategy-final.

4 Ruthie Lazenby, *Mitigating Emissions from California's Dairies: Considering the Role of Anerobic Digesters*, (Emmett Institute on Climate Change & the Environment, 2024), https://law.ucla.edu/news/mitigating-emissions-californias-dairies-considering-role-anaerobic-digesters.

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40% from 2013 levels by 2030.[5] In place of developing binding regulations that apply to methane emissions from California farms to meet the short-lived climate pollutants targets, CARB statements suggest the agency plans to rely on the Low Carbon Fuel Standard (LCFS) and other strategies.[6]

When manure decomposes under anaerobic conditions, it produces biogas, which is mainly composed of methane and CO_2 and contains small amounts of hydrogen sulfide and other impurities. If the biogas is upgraded, in other words, if the CO_2 and impurities are removed, the remaining biomethane is chemically equivalent to fossil natural gas. Biomethane, also called renewable natural gas (RNG), can be used for energy production or as transportation fuel (for example, as a substitute for diesel in buses).

Collecting biogas via digesters instead of releasing it into the atmosphere can help reduce methane emissions from dairy farms. Accordingly, California's LCFS provides a strong incentive, in the form of credits, for projects that can claim they result in avoided methane emissions. Qualifying LCFS fuel pathways capture biogas in anaerobic digesters, upgrade it into biomethane, and inject it into natural gas pipelines as RNG. Similarly, avoided methane credits can also be claimed for fuel pathways that produce electricity or hydrogen from biomethane. In addition to livestock manure, biomethane could be sourced from biogas from landfills, wastewater sludge, and organic waste.

LCFS-certified dairy biomethane pathways currently have an extremely low carbon intensity (CI) due to avoided methane crediting from the capture of biogas, which is assumed to be vented into the atmosphere in the absence of LCFS incentives. This avoided methane crediting is ostensibly intended to motivate in-state methane emission reductions, but the LCFS implements a much more geographically flexible system. The LCFS's book-and-claim system is a chain of custody model that connects the environmental attributes of a clean fuel to customers claiming these benefits at a different location. As a result, California fuel producers can claim credits for biogas captured anywhere in the United States. This is based on the logic that avoided methane anywhere in the country is fungible with in-state avoided methane, and that any RNG injected into the national gas grid is deliverable to California's transport sector.

Currently, around 45% of dairy manure-derived biomethane pathways certified in the LCFS are book-and-claim credits from outside of California.[7] For example, a dairy farm in Indiana producing RNG from manure could receive LCFS credits for injecting it into a local pipeline because that local grid is connected to a country-wide natural gas transmission system connected to California's. In this case, the production, and, therefore, the methane reduction, takes place out-of-state. The book-and-claim system resembles an offset program where those producing hydrogen in California can

5 Senate Bill 1383, Short-Lived Climate Pollutants: Methane Emissions: Dairy and Livestock: Organic Waste: Landfills, (2016), http://www.leginfo.ca.gov/pub/15-16/bill/sen/sb_1351-1400/sb_1383_bill_20160919_chaptered.htm.

6 "Dairy Digester Research and Development Program," California Department of Food and Agriculture, accessed May 24, 2024, https://www.cdfa.ca.gov/oefi/ddrdp/; "Alternative Manure Management Program," California Department of Food and Agriculture, accessed July 12, 2024, https://www.cdfa.ca.gov/oefi/AMMP/; California Air Resources Board, "LCFS Petition Response," (2022), https://ww2.arb.ca.gov/sites/default/files/2022-01/LCFS%20Petition%20Response%202021.pdf; California Air Resources Board, "Re: Petition for Rulemaking to Regulate Methane and Other Air Pollutants from California Livestock," May 30, 2024, https://ww2.arb.ca.gov/sites/default/files/2024-05/2024-05-30-CARB-CDFA-Response-to-Dairy-Rulemaking-Petition.pdf.

7 "Current Fuel Pathways," California Air Resources Board, last updated July 26, 2024, https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/fuelpathways/current-pathways_all.xlsx.

buy the environmental attributes of RNG produced out-of-state and continue to use conventional techniques to produce hydrogen while claiming climate benefits.[8]

Though avoided methane emissions are attributed to the LCFS to calculate the CI for fuel pathways, the LCFS does not require the types of additionality assessment typically needed in offset programs to claim credit for such reductions. For example, some digester projects that receive LCFS credits for RNG production were already capturing methane for many years prior to their certification. Before certification, the collected biogas was used to produce electricity for use at the dairy, and the surplus was sold back to the electricity grid. After certification, the biogas was used to produce biomethane under the LCFS instead. The decrease in methane emissions from those existing projects is not necessarily additional or attributable to the LCFS program.[9] This means that even when diverting biogas from its current use into the transport sector, producers could still receive negative emissions credits. Note, too, that in the example case, the displaced share of biogas-derived electricity would likely be replaced with grid electricity.

Within certified dairy pathways, hydrogen is produced from dairy biomethane via steam methane reforming (SMR), a well-established technology that produces hydrogen from natural gas. In an accelerated decarbonization scenario in its rulemaking to revise the LCFS, CARB estimates that dairy biomethane-derived hydrogen will grow to generate a substantial share of future compliance and volumes—reaching more than 5 million tonnes of credits by the 2030s.[10] Due to the negative CI of dairy biomethane-based hydrogen pathways, the policy value of these credits would exceed the LCFS credits provided for green hydrogen produced from an electrolyzer using renewable electricity.[11] The loose structure of book-and-claim biomethane crediting means it is possible that the high policy value of this pathway would not support California's transition to more advanced technologies such as hydrogen production via electrolysis. Instead, it could largely finance the construction of out-of-state dairy digesters and pipeline interconnections to the national natural gas grid.

In this brief, we estimate the policy value of hydrogen derived from SMR of claimed dairy-biomethane, including the impact that certain life-cycle assessment assumptions about avoided methane and methane leakage rates have on the CI of the pathway. We also assess the implications of using dairy biomethane-derived hydrogen in a sector other than transportation if the uptake of hydrogen as transport fuel is insufficient to justify hydrogen production from dairy manure-derived biomethane. We then illustrate the potential of livestock (i.e., dairy cattle and swine) biomethane projects that may be incentivized under this system, particularly outside of California. We conclude with recommendations for policies to limit the contribution of out-of-state, out-of-sector LCFS credits.

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8 Nikita Pavlenko, "Gray, Blue, or Moo Hydrogen? How Gas Companies Are Milking California's LCFS," International Council on Clean Transportation Staff Blog, June 21, 2023, https://theicct.org/lcfs-hydrogen-crediting-jun23/.

9 International Council on Clean Transportation, "International Council on Clean Transportation Comments on LCFS Application No. B0430," June 2, 2023, https://www.arb.ca.gov/lists/com-attach/980-tier2lcfspathways-ws-Vj8GY1c1ACcLUlc0.pdf.

10 "Supplemental 2023 LCFS ISOR Documentation, Modeling Output Sheets from ISOR, Accelerated Decarbonization Scenario," California Air Resources Board, accessed May 24, 2024, https://ww2.arb.ca.gov/resources/documents/supplemental-2023-lcfs-isor-documentation; California Air Resources Board, *Staff Report: Initial Statement of Reasons* (2023), https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2024/lcfs2024/isor.pdf.

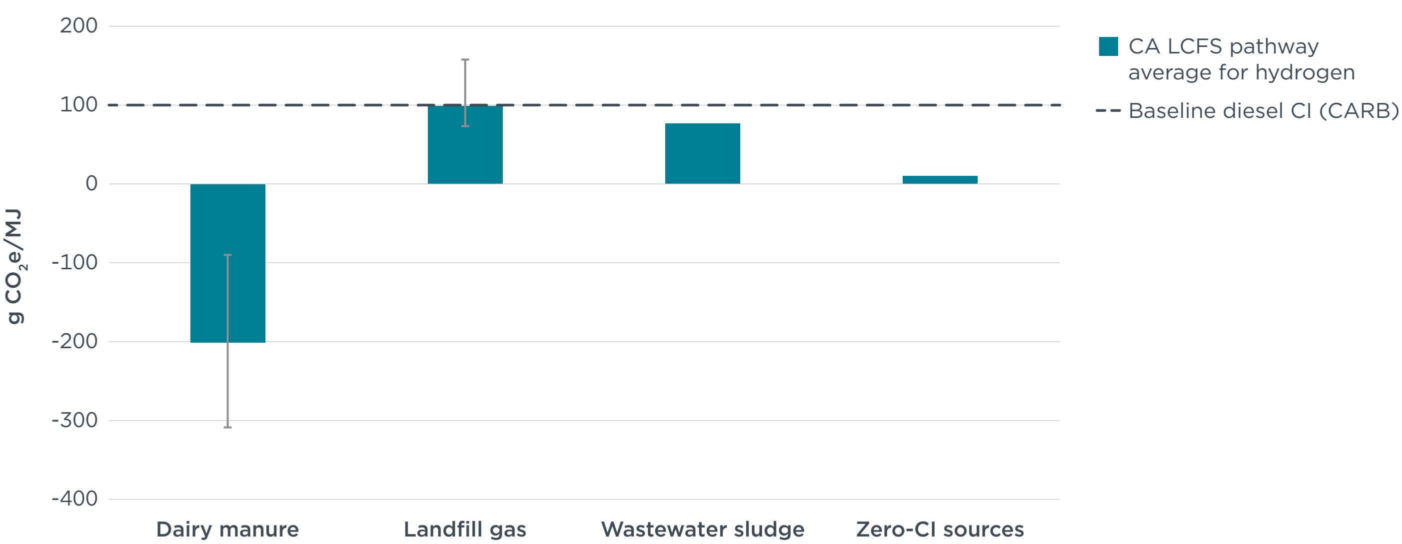
11 Pavlenko, "Gray, Blue, or Moo Hydrogen?"

GHG INTENSITY OF DAIRY BIOMETHANE-DERIVED HYDROGEN

Dairy biomethane-based pathways have an outsized contribution to the LCFS program because of their highly negative CI. LCFS credits are awarded based on CI reductions when compared with the displaced fuel; fuels with lower CI values receive proportionally higher LCFS credits. Figure 1 displays the range of CI values for existing, certified gaseous hydrogen pathways under the LCFS, in grams of CO_2 equivalent per megajoule of fuel (g CO_2e/MJ).[12] The CI of green hydrogen produced from electrolysis using renewable electricity (Zero-CI sources) is included for comparison.[13] Error bars represent the lowest and highest certified CI values for the corresponding pathways. Gaseous hydrogen derived from wastewater sludge and landfill gas-based RNG have average CI values of 77 and 100 g CO_2e/MJ, respectively, while dairy biomethane-derived hydrogen has an average CI of –201 g CO_2e/MJ. Liquid hydrogen pathways from these feedstocks are around 20 g CO_2e/MJ higher due to the additional energy input for the liquefaction step (not shown in Figure 1). To calculate LCFS credits later in this study, we adjust these CI values based on the energy economy ratio (EER) for their end use (i.e., an EER of 1.9 for heavy-duty vehicles accounts for the greater efficiency of fuel cell vehicles). Here, the baseline for comparison is diesel with a CI intensity of 100.45 g CO_2e/MJ fuel shown by the dotted line in Figure 1.

Figure 1

Carbon intensities for gaseous hydrogen pathways certified under California's LCFS



Note: The error bars correspond to the range of CI values from certified pathways.

To understand the highly negative CI values of dairy biomethane-based hydrogen pathways in the context of other pathways, an analysis of the underlying data is necessary. The data submitted to CARB by the applicants is proprietary, and thus the details of the certified pathways cannot be verified. Certified pathway values are a sum of emissions from manure-derived biomethane and hydrogen production. The second part utilizes the CI values of the "biomethane to gaseous hydrogen from SMR" conversion process from the lookup tables provided by CARB with minor changes

12 California Air Resources Board, "Current Fuel Pathways."

13 The CI of hydrogen is greater than zero due to downstream emissions from compression and distribution.

(e.g., transport distance for hydrogen).[14] For the CI of biomethane production, all pathways include an RNG producer as a joint applicant and use book-and-claim accounting for RNG upgraded from biogas; this is typically a farm producing RNG with a low (negative) CI value. This method causes high variability in the CI values. Negative emission values arise from the awarded credits for avoided methane emissions that would have been vented otherwise. In other words, it is assumed that methane produced from the decomposition of manure would have been released into the atmosphere as the counterfactual scenario if RNG was not produced from it.[15]

For wastewater sludge and landfill gas-derived hydrogen, the counterfactual (i.e., business-as-usual scenario) is assumed to be flaring instead of venting.[16] This assumption is likely based on the perceived common practices at these types of facilities because of CARB regulations requiring methane emission reductions.[17] However, methane emissions from livestock are currently unregulated by CARB and contributing to any type of methane reductions effort is voluntary.

Gas flaring refers to the combustion of collected biogas to generate CO_2 and reduce methane emissions. When flaring is assumed as the counterfactual, CI scores will not be as low because methane is assumed to be converted into CO_2 and not leaked into the atmosphere. As a result, credits due to avoided methane emissions are lower for landfill gas- and wastewater sludge-derived hydrogen pathways.

Given the range of certified emissions, this analysis illustrates the effect of altering the assumptions regarding fugitive methane emissions during hydrogen production. We use CARB'S Tier 1 calculators, which are available to the producers for various feedstock-to-fuel pathways, for CI estimation.[18] These calculators are simplified versions of California GREET (CA-GREET), which is a California-specific version of Argonne National Laboratory's Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies (GREET) life cycle model.[19] Using the calculator for dairy cattle and swine manure, we adjust the emissions to factor in different assumptions for a covered lagoon anaerobic digester. We use the energy inputs from CA-GREET 3.0 as our baseline scenario.

Critically, this analysis assesses the impact of venting practices and leakage assumptions on the final CI of biomethane-derived hydrogen. Biogas capture in anaerobic digesters effectively reduces methane emissions, but leaks can occur during the storage and upgrading of biogas. The certified hydrogen pathways illustrated in Figure 1 typically use the default values within the calculator for leaks instead of

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14 California Air Resources Board, CA-GREET 3.0 Lookup Table Pathways Technical Support Documentation (2018), https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/ca-greet/lut-doc.pdf?_ga=2.96664348.2057484.1711742467-139581412.1706122679; FirstElement Fuel, "Low Carbon Fuel Standard Tier 2 Pathway Application No: B0145, CA-GREET 3.0 Inputs and Results for Proposed FirstElement Pathway," 2020, https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/fuelpathways/comments/tier2/b0145_report.pdf.

15 California Air Resources Board, Tier 1 Simplified CI Calculator Instruction Manual. Biomethane from Anaerobic Digestion of Dairy and Swine Manure (2019), https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/ca-greet/tier1-dsm-im.pdf?_ga=2.154194875.2057484.1711742467-139581412.1706122679.

16 California Air Resources Board, "CA-GREET 3.0 Lookup Table Pathways."

17 "Landfill Methane Regulation," California Air Resources Board, accessed July 12, 2024, https://ww2.arb.ca.gov/our-work/programs/landfill-methane-regulation/about.

18 California Air Resources Board, LCFS Life Cycle Analysis Models and Documentation, CA-GREET3.0 Model and Tier 1 Simplified Carbon Intensity Calculators (2019), https://ww2.arb.ca.gov/resources/documents/lcfs-life-cycle-analysis-models-and-documentation.

19 California Air Resources Board, California GREET 3.0 (2018), https://ww2.arb.ca.gov/resources/documents/lcfs-life-cycle-analysis-models-and-documentation.

reporting specific values. The default leakage rate from a digester is set at 5% in the Tier 1 calculator. The Intergovernmental Panel on Climate Change's (IPCC) default value for losses from a closed digester ranges from 1%–10%, with high-quality digesters on the lower end and low-quality digesters on the higher end of the range.[20] Fugitive methane from biogas upgrade is set at 2% in the calculator based on values from GREET.[21] We use these default values for our baseline scenario.

In addition, uncontrolled venting events can occur when pressure increases in the system. For these, producers can enter information in the Tier 1 calculator; fugitive methane emissions are calculated because no default values are included. Certified pathways typically do not include much information regarding their venting practices in their applications. We input 6 days of uncontrolled venting for our baseline scenario, based on a recent brief from an advocacy organization that reported methane emissions from 16 dairies with digesters that received LCFS credits.[22] Using airborne and satellite imaging data from Carbon Mapper, the authors identified 59 sources of post-installation emissions; 49 had methane emissions rates between 44–1,729 kg of methane per hour. The spectrometer can identify sources of at least 10 kg of methane emissions per hour for airborne imaging. We estimate 10 kg of methane per hour roughly corresponds to a minimum of 6 days of uncontrolled venting per month for a digester with a 30-cubic-feet (0.85 m^3) volume for each lactating dairy cow (2,000 dairy cattle is assumed) and use this for our baseline scenario.[23]

Then, we consider a case where the counterfactual scenario is flaring instead of venting. In cases where it is not feasible to capture and use biogas for energy, flaring would still reduce methane emissions. Flaring could also be assumed as the counterfactual scenario for the dairy manure pathways, given there is evidence that biogas collected at dairy farms is utilized for electricity or other energy purposes instead of being vented, and this is increasingly common since 2000.[24] For example, a current LCFS pathway application for dairy biomethane-based hydrogen mentions the practice of flaring when the generated biogas is not sent to the upgrading facility.[25] Considering this information, we assume methane is flared with 100% efficiency and converted into CO_2. In practice, flaring efficiency can be as low as 91%; this results in methane emissions due to incomplete combustion.[26] Avoided methane emissions due to flaring are then credited. Then, the remaining GHG emissions from biogas-to-RNG upgrading and hydrogen production via SMR are added to estimate the pathway's final CI.

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20 Olga Gavrilova et al., "Emissions from Livestock and Manure Management," in *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*, ed. Calvo Buendia et al. (International Panel on Climate Change, 2019), https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/4_Volume4/19R_V4_Ch10_Livestock.pdf.

21 Jeongwoo Han, Marianne Mintz, and Michael Wang, Waste-to-Wheel Analysis of Anaerobic-Digestion-Based Renewable Natural Gas Pathways with the GREET Model (Argonne National Laboratory Energy Systems Division, 2011), https://greet.anl.gov/files/waste-to-wheel-analysis.

22 Food & Water Watch, The Proof is in the Pluming: Factory Farm Biogas Has No Place in the Low Carbon Fuel Standard (2024), https://www.foodandwaterwatch.org/wp-content/uploads/2024/01/RB_2401_LCFS_Methane.pdf.

23 PennState Extension, "Biogas from Manure, Biogas Generation Terminology," March 9, 2023, https://extension.psu.edu/biogas-from-manure. Average daily methane production from 2,000 dairy cattle was calculated as 91,308 standard cubic feet (2,585 m^3) using a methane-generation rate of 0.24 m3/kg volatile solid (VS) and 17 lb VS/cattle head.

24 "AgSTAR Data and Trends," U.S. Environmental Protection Agency, last updated June 16, 2024, https://www.epa.gov/agstar/agstar-data-and-trends.

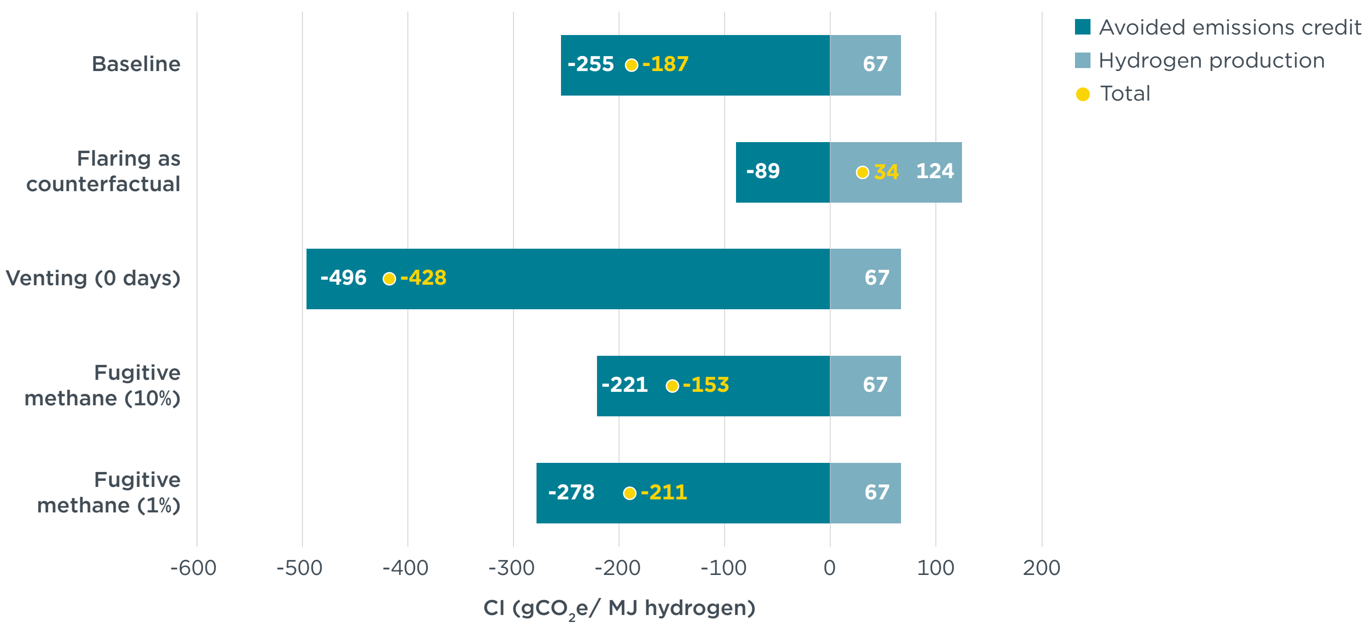
25 California Air Resources Board, "Application No. B0197," 2021, https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/fuelpathways/comments/tier2/b0197_summary.pdf.

26 Genevieve Plant et al., "Inefficient and Unlit Natural Gas Flares Both Emit Large Quantities of Methane," *Science* 377, no. 6614 (2022): 1566–1571, https://doi.org/10.1126/science.abq0385.

In the absence of detailed information on uncontrolled venting from producers' pathway applications, as a sensitivity analysis, we evaluate the CI if no uncontrolled venting is assumed. We also assess the effect of changing the leakage rate from the digester in line with IPCC values and calculate the CI when leakage from the digester is set at 1% and 10% as a sensitivity. Our literature review yielded no alternative information on leakage rates during biogas upgrade, so we used the baseline value of 2% from GREET for this parameter.[27]

Figure 2 illustrates how these parameters affect the overall CI value of the dairy biomethane-derived hydrogen pathway. Our baseline scenario has a CI value of -187 g CO_2e/MJ when 6 days of uncontrolled venting is assumed at the digester, and 5% and 2% of fugitive methane is assumed from the digester and during biogas upgrade, respectively. Our baseline is slightly higher than the average for this pathway, –201 g CO_2e/MJ. However, if flaring is taken as the counterfactual scenario, emissions from dairy biomethane-based hydrogen are estimated to be 34 g CO_2e/MJ hydrogen. The increase in overall emissions is due to the loss of credits from avoided methane emissions of the venting scenario (-255 g CO_2e/MJ of hydrogen). In place of crediting for methane that would have been vented otherwise, we assume the methane would have been converted to CO_2 via flaring and the avoided emissions were credited (-89 g CO_2e/MJ hydrogen). The flaring scenario with 34 g CO_2e/MJ of hydrogen emissions still generates an 82% GHG emissions reduction relative to the petroleum-based diesel that the hydrogen displaces after adjusting for fuel efficiency.

Figure 2
Sensitivity analysis for the dairy biomethane-derived hydrogen pathway



When uncontrolled venting is not assumed, avoided methane emissions increase from -255 to -496 g CO_2e/MJ, almost a twofold increase. When assuming methane venting as the counterfactual scenario, the overall CI of the pathway fluctuates between -428 g CO_2e/MJ and -187 g CO_2e/MJ, depending on uncontrolled venting assumptions. The

27 Han et al., "Waste-to-Wheel Analysis."

results indicate that improved monitoring, reporting, and verification of venting events at digesters is necessary to support accurate crediting of avoided methane emissions.

We find that methane leaks from digesters more modestly affect the overall CI of the pathway. Changing the leakage rate from the default to 1% and 10% creates a -13% and an 18% change, respectively, in the pathway's overall CI.

Finally, in the advantageous scenario (i.e., the scenario that receives the most credits), where days of uncontrolled venting are zero and fugitive methane from the digester is 1%, the CI of the pathway becomes -452 g CO_2e/MJ, more than twice as low as our baseline scenario.

POLICY VALUE OF DAIRY BIOMETHANE-DERIVED HYDROGEN

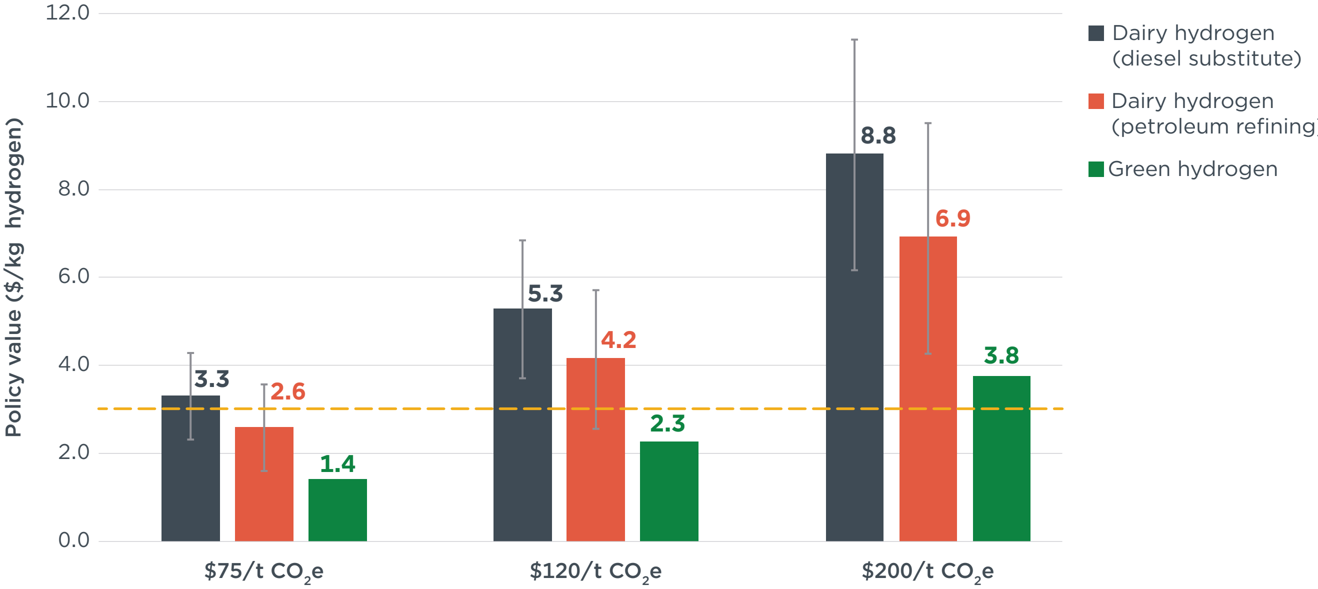
To assess the policy value of the dairy biomethane-derived hydrogen pathway, we use the CARB credit value calculator and input the average CI score of the certified pathways from Figure 1 (-201 g CO_2e/MJ).[28] Credits estimated using the minimum (-309 g CO_2e/MJ) and maximum CI (-90 g CO_2e/MJ) scores for the dairy hydrogen pathways are shown with error bars (Figure 3). We assume low, medium, and high trajectories for carbon prices using sample credit values of $75, $120, and $200 per tonne of CO_2e abated. Hydrogen is assumed to displace diesel fuel for heavy-duty vehicles and the credit values are EER-adjusted accordingly, but we also consider a case where hydrogen is used as process fuel in another sector. The policy value of green hydrogen within the LCFS from electrolysis using renewable electricity is included for comparison. The dotted yellow line in Figure 3 indicates the maximum clean hydrogen production tax credit ($3/kg hydrogen) that could be received as detailed in Section 45V of the Inflation Reduction Act (IRA), which provides tax credits for hydrogen produced with minimal GHG emissions.[29] The IRA provides tax reductions to producers over a 10-year period; this discounts the impact on the net cost of hydrogen. Still, this comparison sheds light on the proportion of the LCFS policy value for this pathway because LCFS credit values are also subject to change over time.

28 California Air Resources Board, "The LCFS Credit Price Calculator V1.3," 2019, https://ww2.arb.ca.gov/sites/default/files/2022-03/creditvaluecalculator.xlsx.

29 Yifan Ding, Chelsea Baldino, and Yuanrong Zhou, *Understanding the Proposed Guidance for the Inflation Reduction Act's Section 45V Clean Hydrogen Production Tax Credit* (International Council on Clean Transportation, 2024), https://theicct.org/publication/proposed-guidance-for-the-inflation-reduction-act-45v-clean-hydrogen-tax-credit-mar29/.

Figure 3

Policy values for dairy biomethane-derived gaseous hydrogen at sample LCFS credit prices estimated using the average CI of LCFS-certified pathways



Note: The error bars correspond to the range of CI values from certified pathways. The dotted yellow line indicates the maximum tax credit ($3/kg hydrogen) that could be received via the IRA's Clean Hydrogen Production Credit (Section 45V).

Dairy biomethane-derived hydrogen could generate a credit value between $3.3–$8.8/kg hydrogen, depending on the LCFS credit price and assuming the average CI value from Figure 1. Even with a conservative credit price of $75/t CO_2e, the policy value for dairy hydrogen surpasses the maximum tax credit a producer could receive from the IRA (Section 45V), awarded to low CI hydrogen pathways with GHG emissions less than 0.45 kg CO_2e/kg hydrogen (3.8 g CO_2e/MJ hydrogen).

The policy value of the baseline scenario from our sensitivity analysis is $3.3/kg hydrogen for the lowest credit price as shown in Figure 3. If credits due to avoided methane emissions are not counted in the CI of the baseline scenario, the policy value becomes $0.9/kg hydrogen. However, if the counterfactual scenario is flaring instead of venting, the policy value of the dairy pathway becomes $1.2/kg hydrogen, like the LCFS policy value of green hydrogen ($1.4/kg hydrogen).

Hydrogen production using SMR is a mature technology that has downsides including local air pollution. The net benefit of subsidies is, therefore, debatable, especially when compared with green hydrogen. Given the uncertainties surrounding the CI of the dairy pathway, the amount of support it needs, and its limited potential contributions to decarbonizing transport in California, the high policy value of this pathway is likely disproportional compared with green hydrogen.

Hydrogen production via electrolysis using renewable electricity is a key focus of multiple decarbonization policies for transportation and industry.[30] Yet a kilogram of green hydrogen generates less than half the credit value of dairy hydrogen within the

30 Office of Clean Energy Demonstrations, "Regional Clean Hydrogen Hubs Selections for Award Negotiations," accessed May 24, 2024, https://www.energy.gov/oced/regional-clean-hydrogen-hubs-selections-award-negotiations.

LCFS. While dairy hydrogen may indirectly incentivize methane reductions, such LCFS credits do not support a technology transition in California to renewable electrolysis hydrogen. Instead, the value provided under the current LCFS is more likely to be used for agricultural sector investments such as digesters and natural gas pipeline interconnections instead of long-term transportation decarbonization investments (e.g., electrolyzers and renewable electricity). Note, too, that digester projects are also eligible for federal and other state-level grant funding to reduce the cost of methane capture and help with agricultural sector decarbonization.[31] These grants can be combined with LCFS credits because they do not involve the use of environmental attributes from captured biogas. The ability to combine these funding measures exacerbates the additionality risk for dairy hydrogen pathways; it becomes difficult to understand if a digester was built due to the LCFS incentive alone.

Given the high LCFS compliance values from these estimates, policy safeguards such as increased geographical deliverability or additionality requirements may be warranted for biomethane-derived gaseous hydrogen to better ensure that this pathway's GHG reductions are attributable to the LCFS and that the fuel is being used in the transport sector. Although there is progress toward the use of zero-emission vehicles that run on hydrogen, there are still challenges to their widespread adoption. As a result, if the market uptake of hydrogen as a transport fuel is insufficient, hydrogen could be used elsewhere. For example, it could be used in refineries for petroleum or biofuel (e.g., renewable diesel) refining.[32] We also estimated the policy value of dairy hydrogen if it is used in a sector other than transportation, using hydrogen as an input to petroleum refining (Figure 3). The credit value of hydrogen decreases slightly because there is no multiplier due to hydrogen's EER. Still, the value of credits is high, on average between $2.6 and $6.9 per kilogram hydrogen depending on the credit price.

IMPACT OF DAIRY BIOMETHANE-DERIVED PATHWAY CREDITING ON CALIFORNIA'S METHANE EMISSIONS

The LCFS's current book-and-claim system allows for indirect accounting of biomethane use in hydrogen production, if the biomethane is injected into the U.S. natural gas grid. Most LCFS credits attributed to RNG in 2022 came from RNG producers outside of California.[33] Adding deliverability requirements to ensure eligible RNG is carried through pipelines that physically flow within California would encourage methane reductions in California, as RNG would displace fossil natural gas used in the state. If RNG has no geographical connection to California, the impact of LCFS credits on California's methane-reduction goals would be limited. According to the proposed deliverability requirements mentioned in the Initial Statement of

31 California Department of Food and Agriculture, "Dairy Digester"; California Department of Food and Agriculture, "Alternative Manure Management"; California Public Utilities Commission, "Renewable Gas," accessed May 24, 2024, https://www.cpuc.ca.gov/industries-and-topics/natural-gas/renewable-gas; U.S. Department of Agriculture, "Rural Energy for America Program Renewable Energy Systems and Energy Efficiency Improvement Guaranteed Land & Grants in California," accessed May 24, 2024, https://www.rd.usda.gov/programs-services/energy-programs/rural-energy-america-program-renewable-energy-systems-energy-efficiency-improvement-guaranteed-loans/ca; SoCalGas, "Biomethane Monetary Incentive Program," accessed May 24, 2024, https://www.socalgas.com/sustainability/renewable-gas/biomethane-monetary-incentive-program.

32 Fuel Pathway Application Requirements Applying to All Classifications, California Code of Regulations § 95488.8.(i)(2), https://govt.westlaw.com/calregs/Document/I0CC5C1305A2111EC8227000D3A7C4BC3?viewType=FullText&originationContext=documenttoc&transitionType=StatuteNavigator&contextData=%28sc.Default%29&bhcp=1.

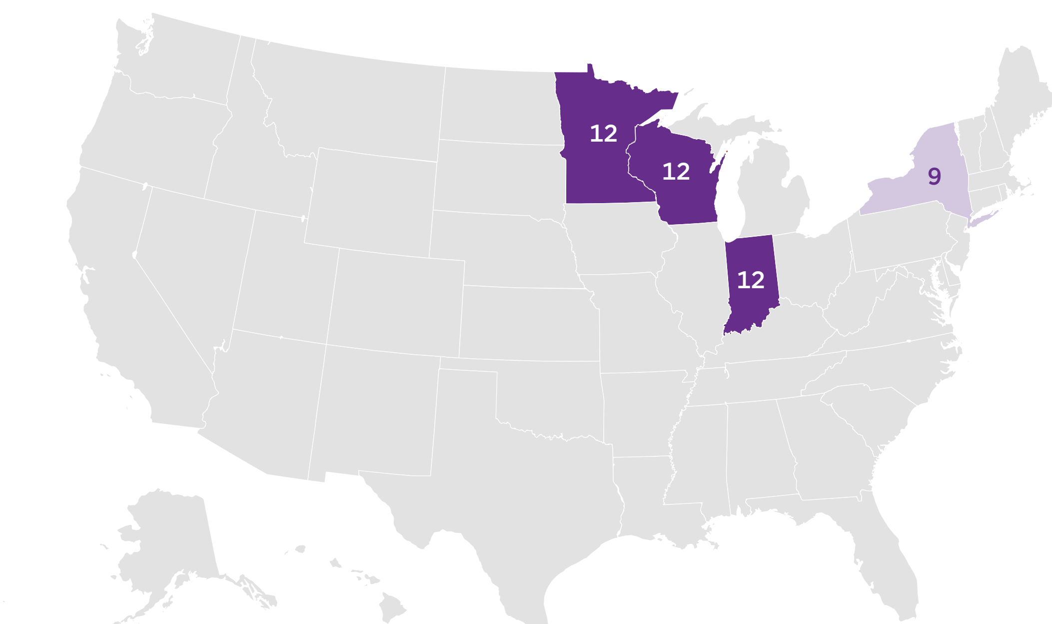
33 California Air Resources Board, *Initial Statement of Reasons*.

Reasons (ISOR) released by CARB last year, at least 50% of the annually produced biomethane for hydrogen production would be required to physically flow through the initial injection point toward the fuel dispensing facility starting from January 1, 2046.[34] Although the proposed amendments mention deliverability requirements, they would only go in effect for biomethane-derived hydrogen projects that break ground after December 31, 2029. For projects that break ground before January 1, 2030, there would be no requirements. In addition, the LCFS's most recent proposal mentions a gas system map that would support the implementation of deliverability at an earlier date for biomethane.[35] If this map is approved by July 2026, then the deliverability requirements for biomethane would be updated to match this map by December 31, 2037. However, this requirement would not apply to biomethane-derived hydrogen pathways.

Currently, all the dairy biomethane for hydrogen production in California is sourced from out-of-state digesters.[36] Figure 4 shows the numbers and original geographic sources of biomethane for certified dairy hydrogen projects in California.[37]

Figure 4

Number of projects and geographic source of dairy biomethane for certified hydrogen pathways in California



To assess the potential risk from out-of-state farms (which could continue to grow in number), we draw upon data from the Census of Agriculture to identify the number

34 California Air Resources Board, *Initial Statement of Reasons*.

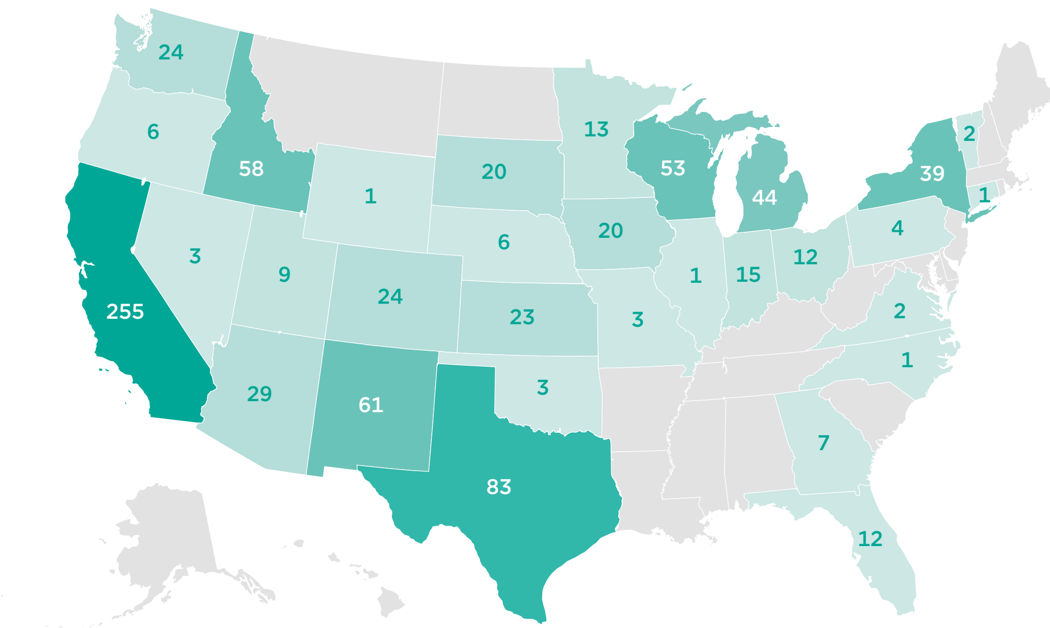
35 California Air Resources Board, "Attachment A-1:Proposed 15-Day Changes to Proposed Regulation Order," August 12, 2024, https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2024/lcfs2024/15day_atta-1.pdf.

36 International Council on Clean Transportation, "ICCT Comments on the Proposed Low Carbon Fuel Standard Amendments," February 20, 2024, https://theicct.org/international-council-on-clean-transportation-comments-on-the-proposed-low-carbon-fuel-standard-amendments-feb24/.

37 California Air Resources Board, "Pathways."

of large-scale centralized farms that could be eligible to participate in the LCFS.[38] In a previous assessment of cost-viable RNG production potential over a 10-year project crediting period, we performed a discounted cash flow analysis and estimated the size of dairy projects that would result in break-even project cost.[39] That analysis showed a farm would need to have at least 2,300 dairy cattle to be economically feasible. As the census only provides data on certain ranges, here we use 2,500 dairy cattle as a cutoff. Figure 5 displays the distribution of farms with corresponding dairy cattle numbers indicating the risk for potential out-of-state farms making use of the LCFS crediting system. While California is home to 255 break-even farms (31%), there are also a substantial pool of at least 579 out-of-state farms that could qualify for LCFS credits.

Figure 5
Distribution of dairy farms per state with 2,500 or more dairy cattle



Note: Grayed-out states have zero farms with at least 2,500 dairy cattle.

Agricultural Census data also shows that the number of California farms with 2,500 or more dairy cattle has increased 17% from 2017–2022. Though it is difficult to identify causality, there is also the potential for consolidation in the industry that might make it easier for larger farms to use high LCFS credits for RNG.[40] Installing digesters can reduce methane emissions when administered properly, but potential risks need to be carefully considered.

The potential for out-of-state farms to capture biogas and use LCFS crediting is particularly relevant for the swine industry, which is largely concentrated outside of California. Figure 6 illustrates this; we treat farms with more than 5,000 heads of swine as the cutoff because manure per head is lower for swine and this is the highest

38 U.S. Department of Agriculture, *Census of Agriculture, 2022 Census Volume 1, Chapter 1: State Level* (2024), https://www.nass.usda.gov/Publications/AgCensus/2022/Full_Report/Volume_1,_Chapter_1_State_Level/.

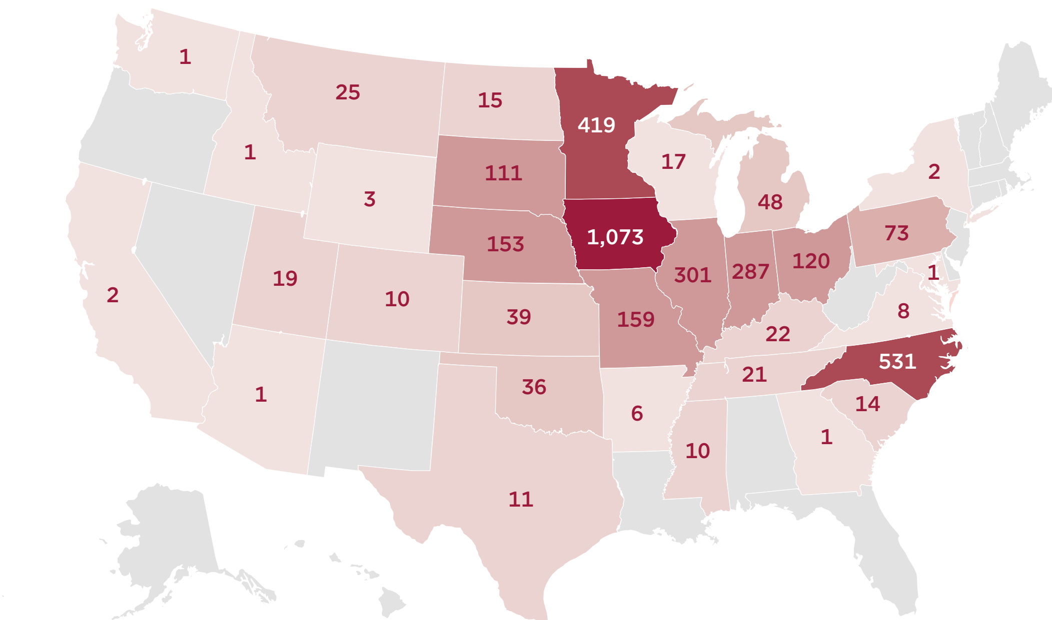
39 Jane O'Malley, Nikita Pavlenko, and Yi Hyun Kim, *2030 California Renewable Natural Gas Outlook: Resource Assessment, Market Opportunities, and Environmental Performance* (International Council on Clean Transportation, 2023), https://theicct.org/publication/california-rng-outlook-2030-may23/.

40 Lazenby, *Mitigating Emissions*.

range of data available from the Census of Agriculture. The data show there are 3,540 swine farms of this size and just two of them are in California. In this case, the lack of geographical deliverability requirements for biomethane-derived hydrogen could lead to an abundance of out-of-state credits generated by an industry without a sizeable in-state counterpart. There are already a few certified pathways for swine manure-derived RNG from Missouri being used as an offset for CI reductions for hydrogen production in California. These have low CIs similar to the dairy farms, an average of -357.4 g CO_2e/MJ of hydrogen.

Figure 6

Distribution of swine operations per state with 5,000 or more swine



Note: Grayed-out states have zero farms with at least 5,000 swine.

Thus, if they persist in the long term, loose book-and-claim requirements could facilitate the deployment of digesters at out-of-state farms with little impact on California's methane goals or transport sector emissions. There are hundreds of out-of-state dairies and thousands of swine farms that could use these incentives.

CONCLUSIONS AND POLICY RECOMMENDATIONS

The above analysis shows that the high compliance value of dairy biomethane-derived hydrogen and the questionable linkage of attributing avoided methane emissions to the LCFS warrants (1) greater scrutiny of this pathway's likely impact on long-term emissions goals and (2) additional safeguards on the deliverability of biomethane for hydrogen and the additionality of avoided methane emissions. This section summarizes the four key takeaways from our analysis and their related policy recommendations for the LCFS's amendment process:

1. **The high policy value of the dairy biomethane-derived hydrogen pathways does not support advanced hydrogen conversion technologies or in-sector GHG reductions for transportation.** Dairy biomethane-derived hydrogen produced via well-established SMR technology is rewarded with a credit value per kilogram

of hydrogen that is more than double what is granted to electrolysis hydrogen produced using renewable electricity. The policy value here does not support California's transition to more advanced technologies, which would help ensure long-term emission reductions. Additionally, as the LCFS is a crediting system based on emissions from transportation fuels, using it as a nationwide agricultural carbon offset program dilutes its goals. Instead, separate policies could target agricultural methane emissions. For example, a low-carbon milk/dairy standard could help reduce emissions from the dairy sector.[41]

2. **Phasing out avoided methane emissions for biomethane-derived hydrogen would more effectively align it with its impact on transport-sector emissions.** To calculate emission reductions for biomethane hydrogen pathways, CARB assumes the LCFS is the primary driver for methane capture at dairy farms and that emissions from manure would be vented to the atmosphere in a business-as-usual scenario. However, this may not be the case; facilities claiming LCFS credits could have already been capturing biogas for other uses. Additionally, assuming methane venting as the counterfactual scenario could cause misinterpretations regarding the methane reduction potential of digester projects. A rapid phaseout of avoided methane credits could help prevent this. For example, CARB could consider phasing out avoided methane credits for new pathway applications and for existing, certified pathways by the end of their 10-year crediting cycle.

3. **Improved monitoring, reporting, and verification for leakage and venting at digester sites would help improve the GHG accounting of biomethane pathways.** CARB does not require facility-level monitoring besides the first engineering review by an independent third-party verifier. As illustrated by our sensitivity analysis, the CI value of the dairy biomethane pathway is substantially impacted by venting events and leaks at digester facilities. We find the overall CI of the pathway may fluctuate between -428 g CO_2e/MJ and -153 g CO_2e/MJ due to the assumptions about venting practices and leaks. Therefore, more frequent monitoring or verification of onsite practices could help support the accuracy of pathway certifications.

4. **Stricter deliverability requirements for manure-based pathways would help ensure that biomethane-derived hydrogen production is achieving emissions reduction goals in California.** Out-of-state biomethane crediting via book-and-claim dilutes progress toward reducing California's methane emissions. Currently, all 45 dairy-based RNG projects credited for hydrogen production are out-of-state dairy farms. While this number may seem low, the Agricultural Census data illustrates that when larger dairy farms are considered, there is potential for more out-of-state crediting of RNG. Furthermore, out-of-state swine operations pose an additional risk, as these could contribute more manure pathways from an industry without a sizeable counterpart in California. That would further dilute the potential of the LCFS to achieve California's methane reduction goals.

41 Jeremy Martin, "Something Stinks: California Must End Manure Biomethane Accounting Gimmicks in Its Low Carbon Fuel Standard," *The Equation* (Union of Concerned Scientists blog), February 15, 2024, https://blog.ucsusa.org/jeremy-martin/something-stinks-california-must-end-manure-biomethane-accounting-gimmicks-in-its-low-carbon-fuel-standard/#2fe66601-1b2e-4cfa-b457-d9cabba80a3c.

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