Union of Concerned Scientists

To: Cheryl Laskowski

From: Jeremy Martin

Date: January 6, 2022

Subject: Manure biomethane analysis

As we mentioned in our 2021 feedback on the Scoping Plan, we are becoming increasingly concerned that the subsidies for manure-based biomethane arising from the LCFS are excessive and likely subsiding the largest confined animal feeding operation (CAFO) dairies, contributing to industry consolidation and putting dairies that use other manure methane strategies at a competitive disadvantage. We urge CARB to revise the lifecycle accounting or otherwise adjust the program to avoid these bad outcomes and ensure that the LCFS is an effective tool for transportation decarbonization without contributing to problems in other sectors of the economy.

We recognize that the capture and productive use of waste biomethane generated by anaerobic digestion (AD) from manure lagoons is a useful mechanism to mitigate methane pollution and can also replace a small amount of fossil methane use in energy and industrial applications. Over the last several years, we have heard conflicting arguments about whether the support from the LCFS was necessary to offset the costs of implementing AD or a huge windfall that was distorting the economics of dairies with harmful consequences. An analysis by Professor Aaron Smith at UC Davis suggested that the subsidy associated with LCFS credits for dairy biomethane was an order of magnitude larger than the cost to run and maintain a digester, and indeed that this value per cow is half as large as the value of the milk[1]. If this is true, it raises methodological and policy questions about the treatment of the manure biomethane under the LCFS.

To get a better handle on the issue, we commissioned Professor Kevin Fingerman and Amin Younes of Humboldt State University and the Schatz Energy Research Center to do some preliminary analysis of the issue, which we attach here. Their findings confirm what Professor's Smith's earlier work suggested, that the value of LCFS credits for a large, confined animal feeding operation (CAFO) dairy vastly exceed the cost of recovering the biomethane. This new analysis is not exhaustive, as it does not conduct a full market analysis of how much of the subsidy value of the LCFS is captured by the biomethane producer, versus what is captured by the biomethane user or other parties to the transaction. However, we believe the analysis suggests a high risk of adverse outcomes that could undermine the goals of the LCFS and broader California policy and warrant further scrutiny at the soonest possible opportunity.

Methodologically, the extremely large negative carbon intensity (CI) values for manure biomethane are the result of several assumptions and judgements made by CARB in the life-cycle analysis that bear reconsideration. In particular, CARB should revisit the assumption that the methane from manure lagoons is purely a waste product with no value that would be emitted into the atmosphere absent the LCFS support for use as a transportation fuel. In light of the large subsidies derived from the LCFS, nearly as large as the value of the milk produced at a large dairy, it is naïve to assume the policy will have no

[1] Aaron Smith. 2021. "What's Worth More: A Cow's Milk or its Poop?" asmith.ucdavis.edu/news/cow-power-rising

impact on the economics of the dairy industry going forward. There are any number of alternative lifecycle treatments that may be appropriate in the development of the CI score, for example treating biomethane as a coproduct rather than a waste. However, it might also be appropriate to address this concern through other means, such as guardrails within the LCFS policy to avoid negative spillover effects in agriculture. For example, it may be appropriate to set a floor of zero on the CI scores for fuels absent compelling documentation of permanent carbon sequestration. Avoided methane emissions could potentially still be sold on carbon offset markets, but their inclusion in the valuable LCFS program is distorting both the market for feedstocks and the market for carbon mitigation. Because the LCFS places an especially high effective carbon price on emissions associated with transportation fuels, it creates an incentive for only and specifically any emission avoidance that can be diverted to fuels – whether or not that's the lowest cost abatement and whether or not fuel is the most efficient pathway for that feedstock.

Aside from methodological concerns, we question whether the current LCFS approach to manure methane is good policy. The LCFS is structured to require producers of polluting transportation fuels to bear the costs of mitigating transportation fuel pollution. However, in the case of the manure biomethane, the majority of the climate pollution at stake is methane from manure, and the fossil methane displacement in the transportation fuel market is a relatively small contribution. Thus, in this instance the largest polluter is the one receiving a large subsidy.

The lifecycle basis of the LCFS is supposed to ensure that support for low carbon fuels is based on a comprehensive assessment of their climate benefits. However, in this instance, this structure is functioning as poorly designed offset program with transportation fuel users paying an extremely high price for manure methane mitigation. This is not good transportation fuel policy or good agricultural methane mitigation policy.

From a transportation policy perspective, a vehicle operating on manure biomethane with a CI score of negative several hundred g CO_2e/MJ appears by the logic of the current accounting to fully offset the CO_2 emissions from several internal engine vehicles running on petroleum fuels. But is a fleet of three diesel trucks and one CNG truck powered with manure biomethane really equivalent to a fleet of four electric trucks powered with solar energy? The extravagant credits awarded to manure biomethane for methane destruction by the current lifecycle analysis come at the expense of support for other low carbon fuels and divert the focus of the LCFS to purposes outside of transportation. The LCFS should work in concert with other policies to minimize the use of combustion fuels in transportation, while also minimizing the supply chain emissions from all fuels. By awarding the most favorable CI score to a combustion technology, the manure biomethane pathway sends a confusing and contradictory policy signal.

From a methane mitigation perspective, there is a reasonable case for public support for strategies that reduce methane pollution, including overcoming the cost barriers to AD. However, this support should be in proportion to the relevant cost barriers and these costs should ultimately be internalized within the food supply chain. While the low rate of AD adoption in the early years of the LCFS policy may have initially justified an assumption of unmanaged methane pollution in the counterfactual scenario, this treatment is not justified indefinitely. AD operators will quickly earn more in credits than they spent on AD installation, especially given additional grants available for these projects. Maintaining indefinitely a counterfactual scenario that assumes no methane control has the effect of paying AD operators their costs many times over to continue to operate equipment that is already paid for. Reducing the level of support for manure methane by revising the counterfactual assumption would still provide a reasonable level of support for AD based on avoided CO2 emissions without a subsidy so large that it risks distorting agricultural markets.

We do not believe it is wise to make the generation of waste methane a substantial ongoing source of profit for CAFO dairies. First, the main climate benefit of AD is reduced agricultural methane pollution, with displaced fossil methane a secondary benefit. But the LCFS incentive puts other methane mitigation strategies at a disadvantage if they do not simultaneously generate transportation fuel. Some of these other strategies, such as alternative manure management, have other significant co-benefits outside the transportation sector. But dairies using alternative manure management strategies could be priced out of the milk market because competitors receive large subsidies for methane destruction associated with transportation fuel production that are not available to diaries adopting methane avoidance strategies that do not result in fuel production. Also, the analysis below suggests that even among facilities with AD systems, smaller facilities may be at a significant disadvantage compared to the largest CAFOs. The largest CAFOs are associated with many ecological and environmental justice problems, and subsidizing their operations is likely to exacerbate these harms and contribute to further industry consolidation with adverse consequences for overall GHG emissions from California's natural and working lands.

It is important to ensure that policies influencing the food system support just and equitable outcomes, including reductions of both global and local pollution, and that transportation fuel policies do not create distortionary subsidies with negative unintended consequences in the food system. We recognize that this is a complicated issue that deserves careful consideration and that the analysis included here is preliminary and incomplete. We urge you to reconsider in the next rulemaking how best to structure the LCFS manure biomethane pathways to ensure they support agricultural methane reductions in an effective and equitable manner without contributing to harmful outcomes outside the transportation sector.

Regards,

Jeremy Martin

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Union of Concerned Scientists

Quantification of Dairy Farm Subsidies Under California's Low Carbon Fuel Standard

Version 1.2, September 2021

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CONTENTS

1. Introduction and Purpose

This report documents a study of the subsidies available to dairy farms from selling low-carbon manure-based bioelectricity under California's Low Carbon Fuel Standard (LCFS). It investigates the potential for this revenue stream to distort dairy market economics in a way that may favor larger cattle-raising operations. Farms are assumed to build covered manure lagoon anaerobic digesters and to generate electricity onsite from the resulting methane (in the form of biogas, a substance about half as methane rich as natural gas), although farms could, and some do, instead upgrade this biogas to renewable natural gas for pipeline injection (see Appendix A).

California's Low Carbon Fuel Standard is a key piece of climate policy aimed at decarbonization of the transportation sector by enabling low-carbon petroleum alternatives [1]. Under the LCFS, a generator of low-CI (carbon intensity) electricity can supply it to the California grid and use a book-and-claim system to generate LCFS credits or allow a third party to generate credits on their behalf [2, Sec. 95488.8(i)], [3], [4]. This electricity must be used as a transport fuel within three calendar quarters of being supplied to the grid, but need not be physically traceable between source and end-use [2, Sec. 95488.8(i)(A)]. This third party may, for example, contract with electric vehicle (EV) fleets to provide electricity needed for charging and use the revenue generated from credits for offsetting electricity costs, purchasing electric vehicles, and "improving dairy economics" [3, p. 3]. The generator must also submit a Tier 2 fuel pathway application including a life-cycle assessment (LCA) showing how much carbon is emitted in the use case relative to a base case for that resource (i.e., manure that is anaerobically decomposing in lagoons). This process allows dairies to generate revenue from the LCFS, creating a potentially valuable subsidy to these farms.

There are currently 42 Tier 2 dairy pathways approved under the LCFS, of which ten deliver electricity and 26 produce compressed natural gas (CNG) which is piped to usage locations within California (the remaining six pathways produce gaseous or liquid hydrogen). Because, as shown in Appendix A, the electricity pathways have the potential for higher profit margins, we focus on these pathways, which currently have certified carbon intensities between -109 gCO_2e/MJ and -762 gCO_2e/MJ [5], though a similar potential exists for CNG used in trucks. The specific details of all certified LCFS pathways are confidential, but negative emissions associated with electricity or natural gas derived from manure is generally attributable to capture and combustion of methane from manure lagoons, which is therefore credited with the avoided open release of that methane [6].

It is worth taking a moment to discuss the negative emissions associated with destruction of methane more broadly. At present, manure is responsible for ¼ of methane emissions in California [7] and methane is responsible for 9% of California's global warming from greenhouse gases (taking into account relative global warming potentials) [8]. The alleged negative emissions in these pathways are due to significant release of methane during storage of manure in lagoons or ponds where it anaerobically decomposes [9]. Methane (CH_4) has a high global warming potential — 25 times higher than carbon dioxide (CO_2) over a 100-year timeframe [10] — so simply capturing and burning methane (i.e., flaring) is an effective way to reduce greenhouse gas emissions relative to its free release. So too are alternative manure management methods such as spreading manure on fields where it *aerobically* decomposes and releases a significantly smaller amount of methane. It is likely that there is some correlation between the size of a dairy operation and the probability that the manure produced is stored in ponds rather than naturally dispersed across rangeland, however, no data was identified by the authors supporting or refuting this claim. There does not appear to be a significant correlation between dairy size and probability of confinement, with 80% to 85% of animals on farms larger than 19 head confined, regardless of farm size (farms smaller than 19 cows were assumed not to confine animals in the study) [11].

In 2017, California was home to some 1,700 dairies with an average size of 1,100 cows per dairy. While the total number of dairy cows in the state rose between 1997 and 2017, the number of farms decreased by 40%, with the average number of animals per dairy doubling, as shown in Figure 1. This consolidation trend well predates the generation of LCFS credits from manure, but the significant value of LCFS credits combined with the economies of scale present in biogas generation and combustion [12] could serve to further distort the market economics in further favor of larger cattle-raising operations.

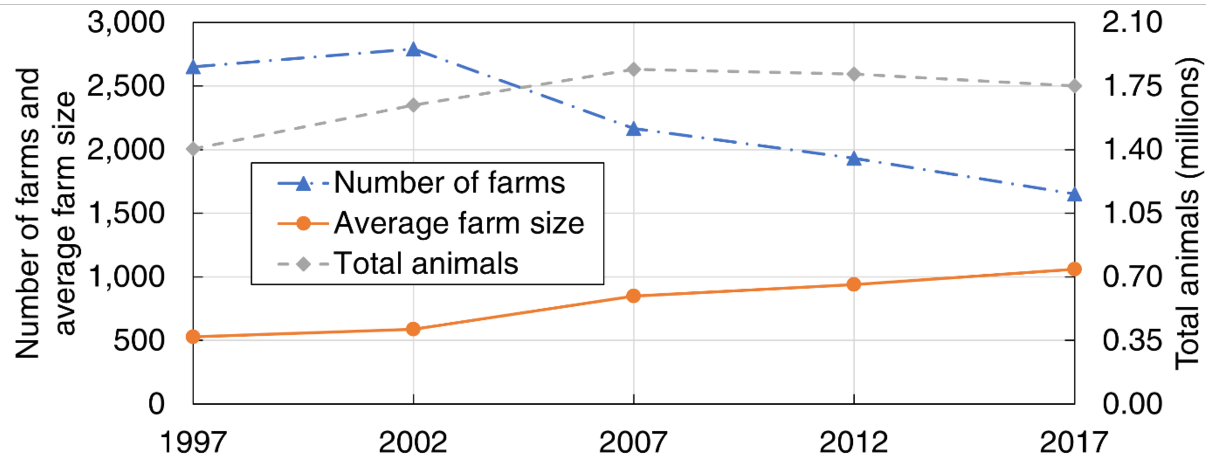

Figure 1. Change in dairy farm quantity and size over two decades [13].

We evaluated the economics of energy generation on dairy farms from the scale of a single cow to 15,000 cows to determine how the profit derived from LCFS credits varies with changing production costs associated with economies of scale. We compared the profit available to the dairy farm from sale of manure-based electricity under the LCFS to the profit derived from the dairy itself and assessed the lifecycle emissions that could be attributed to the manure-based transport fuel using value-based coproduct allocation and revenue-based coproduct allocation.

2. Methods

We began by assessing the value derived from a unit of bioelectricity under the LCFS at several levels of certified CI. Next, we calculated the cost of production and resulting profit as a function of farm size. We then compared these to the dairy's milk production revenue and profit. Finally, we evaluated the impact to the certified CI that would result from attributing some of the dairy production emissions to the energy product via two methods of coproduct allocation.[2]

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[2] In life cycle carbon accounting, when more than one product is created from a single feedstock, some of the emissions associated with the feedstock must be attributed to each product. This can be done by any number of factors, including their relative masses, energy contents, or market values, and is called coproduct allocation. Coproduct allocation is generally not performed when one of the "products" is considered to be a waste, which is how manure is treated at present. We investigate the result if the

2.1. Biolectricity Revenue

The revenue bioelectricity can receive from the LCFS depends on two factors: The value of credits ($/MT), and the emissions displaced by the low-carbon fuel (MT/MJ).

Average credit price rose from $160 in 2018, to $192 in 2019, to $199 in 2020. In the first few months of 2021 (Jan-May), prices have varied between $190 and $198 per credit [14]. We use a credit value of $195/MT, which is the weighted average price in 2021 to date and quite close to recent monthly and annual average prices.

The displaced emissions are calculated from three factors: The carbon intensity (CI) of the bioelectricity (gCO_2e/MJ), the CI of the referent, the 2021 gasoline benchmark, and the energy economy ratio (EER) of the vehicle drivetrain relative to a gasoline vehicle.[3] Displaced emissions were calculated as follows (adapted from [2, Sec. 95486.1]):

$$D = EER \cdot CI_{Referent} - CI_{Bioelectricity}$$

Where:

- EER = 3.4 for light-duty electric vehicle use [2, Sec. 95486.1]. Heavy-duty electric vehicles have higher EER, up to 5.0, and would thus displace more carbon per unit of bioelectricity, but claiming use in these vehicles is likely to be competitive, and presents no outsized opportunity to manure-based bioelectricity, so we use the EER of the far more common light-duty electric vehicles.
- $CI_{Referent}$ = 91 gCO_2e/MJ [2, Sec. 95484], the 2021 gasoline benchmark.
- We consider three values of $CI_{Bioelectricity}$, as described below.

First, we evaluated LCFS revenue for dairies with a certified CI equal to the average[4] of currently approved manure-based bioelectricity pathways: -461 gCO_2e/MJ [5]. Second, we used the largest magnitude (i.e., most negative) value of currently approved manure-based bioelectricity pathways [5], which is -762 gCO_2e/MJ. This value is substantially lower than the average value; however, since life-

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status of manure as a waste were changed, and we use two methods: The relative revenue associated with manure-based electricity versus dairy, and the relative profits of the two.

3 The energy economy ratio reflects the fact that different types of vehicles consume their fuels in different ways and at significantly different efficiencies. In a gasoline or CNG vehicle the fuel is combusted, which is a relatively inefficient process compared to conversion of electricity to mechanical motion in a battery electric vehicle (BEV). As a result, a BEV can travel 3.4 times as many miles compared to a gasoline vehicle per unit of energy consumed. By applying an EER to the carbon intensity score, LCFS comes closer to crediting carbon savings per mile travelled rather than simply per unit of energy delivered.

4 This number is the simple average among the approved pathways. Using the most recent report [15] of credits and generation from non-grid-average and non-zero-CI electricity, which appears to align with the dairy manure pathways plus a single organic waste pathway among approved LCFS pathways [5], and assuming an EER of 3.4 and 2020 reference CI for gasoline yields a weighted average CI of -487, modestly less (5%) than the simple average.

cycle analysis details are fully redacted, it is uncertain where this variability comes from. Finally, we used 0 gCO_2e/MJ, a notional alternative. These resulted in the following three estimates for displaced emissions, *D,* and LCFS credit revenue (per unit of electricity produced), provided in Table 1. For context, the present federal production tax credit available to electricity generated from wind power is $25/MWh, or $0.007/MJ, nearly an order of magnitude less than the subsidy available to zero-CI bioelectricity [16] (though it should be noted that the former is not assumed to be a transport fuel).

Table 1. The displaced emissions per MJ and resulting value derived from credit sales under the LCFS in three emissions scenarios with recent credit pricing of $195/MT.

Estimate	CI (gCO_2e/MJ)	*D* (gCO_2e/MJ)	Revenue ($/MJ)
Highest CI (for reference)	-109	418	$0.082
Average CI	-461	770	$0.150
Most-negative CI	-762	1,071	$0.209
Zero CI (notional)	0	309	$0.060

The above CIs are "adjusted" per California Air Resources Board (CARB) guidance in order "to reasonably limit the LCFS incentive for low-efficiency pathways relative to higher efficiency ones" [17, p. 3]. Without this adjustment, lower efficiency pathways would produce less electricity, but with a lower (i.e., more negative) CI because the total avoided methane emissions remain constant. Therefore, CARB requires biogas to electricity pathways to discount calculated carbon intensities by the engine efficiency relative to a benchmark of 50% ("a reasonable efficiency benchmark based on the average efficiency of NG-derived electricity at California power plants and best available technologies for electricity production"5) [17, pp. 3–4]. The net effect of this CI adjustment is that less efficient pathways produce less electricity at the same CI as more efficient pathways and are thus incentivized to use higher efficiency generators to generate more credits. Therefore, we modeled CI as independent of engine efficiency in the below analysis.

2.2. Bioelectricity Production Cost

We built cost and biogas productivity estimates for farms up to 15,000 cows assuming they build covered lagoon digesters and onsite generators. These facilities show significant economy of scale, enabling much higher profits for larger operations. In principle, these same profits are available to groups of smaller operations which aggregate their manure, although aggregation and transport costs would need to be added in this case. We then calculated total annual costs by annualizing digester and engine capital costs and adding this to the annual operational expenses for engines [19] and digesters [12], respectively. From the annual costs, we subtracted the revenue from electricity sales, assuming electricity is sold at $79 /MWh,6 to determine the annual net cost of building and running the anaerobic

5 The 2019 weighted average thermal efficiency of the California natural gas fleet was 44.2%, largely driven by the efficiency of combined-cycle natural gas plants, averaging 46.6%. Internal combustion engines, such as those that would be used in onsite generation, have a notably lower efficiency, falling into a category ("miscellaneous") with a 2019 average thermal efficiency of 36.6% [18].

6 We used the generation-weighted average power price for the 51 California power plants in the 2019 EIA Power Plant Operations dataset [20] which report using at least 50% qualifying biofuels as feedstock.

digester and onsite electricity generation operation. We then calculated the net electricity production cost (before LCFS credit revenue) per MJ of electricity, by dividing this total cost by the annual electricity production for each farm size. Additional details are provided in Appendix B.

3. Results

Based on the assumptions of this model, farms with 94 or more cows could economically build and operate anaerobic digesters with onsite electricity generation, assuming they achieve the most-negative CI currently recorded within the CARB database [5]. With the more moderate assumption of the average CI within the database, farms would have to be modestly larger, 150 cows, before building a digester would be profitable. In the case of zero-CI manure-based electricity, farms of 580 cows or more could viably build and operate digesters with onsite generation.

For extremely large farms, above 14,000 head of cattle, the net-cost of production falls below one cent per MJ as depicted in Figure 2. Over this range, profits are nearly equal to the value of the LCFS credits, since the net-cost of production is insignificant by comparison. Fifteen-thousand-cow farms would generate a profit of $0.05, $0.14, or $0.20 per MJ produced in the zero-CI, average-CI, and most-negative-CI cases, respectively.

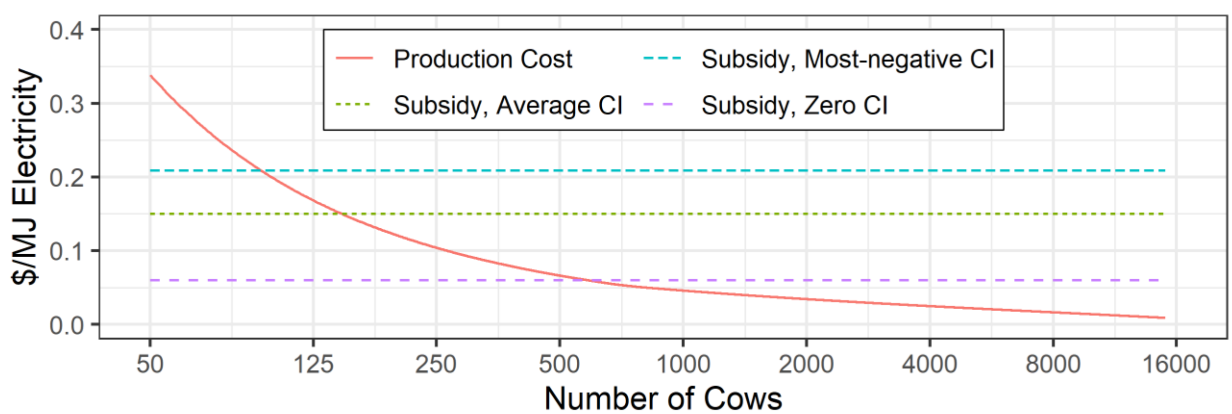

Figure 2. Net production cost (total cost minus electricity revenue) and LCFS credit revenues (i.e., subsidy) by farm size. Note that the x-axis is logarithmic.

There are two important sources of potential error to consider in this analysis: First, smaller operations may have additional unaccounted for costs of manure aggregation, especially if these operations do not currently confine their cattle or aggregate their manure in lagoons (in fact, farms which do not aggregate manure in lagoons would not be able to receive LCFS credits, as discussed earlier). Second, our engine model is built from data for systems 100-kW and larger, and we do not extrapolate outside this range. This results in farms under 700 head of cattle having an oversized generation unit, which

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This yielded a wholesale price of bioelectricity of $78.59/MWh (SD: $34.24). This is a relatively high price for wholesale power, but it is reflective of current market conditions. In part, these high prices may reflect the value of bundled Renewable Energy Credits (RECs) generated under CA's Renewable Portfolio Standard as well as other price supports such as Feed-in Tariffs or Production Tax Credits that are available in some jurisdictions.

could lead to an overestimate of their costs. Smaller engines have been tested [21], [22]; however, they may not be grid compatible due to instabilities [23].

3.1. Subsidy Value Per Gallon of Milk Produced

To add additional context to these results, we brought milk production into the picture by calculating the electricity profit (i.e., LCFS subsidy - production cost in Figure 2) per gallon of milk. We assumed that each dairy cow produces 2,720 gallons (23,500 lbs.) of milk per year [24].

The profit derived from LCFS credits reaches \$0.14 and \$0.39, and \$0.55 per gallon of milk for the largest studied farm size (15,000 cows), across the three CI cases (0, -461, -762 gCO_2e/MJ), as depicted in Figure 3. A 2,000-cow dairy would derive somewhat lower subsidies, and a 100-cow dairy little to no profit, as shown in Table 2.

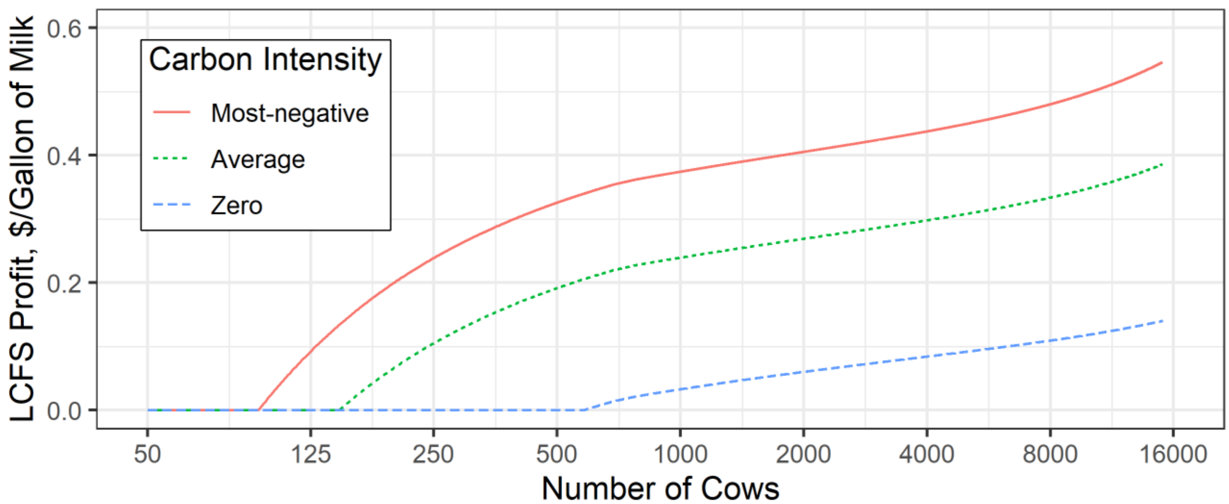

Figure 3. LCFS profit to dairies per gallon of milk under three different CI conditions. Note that the x-axis is logarithmic. The point of departure from \$0/gallon indicates the farm size at which electricity generation becomes profitable at a given CI.

Table 2. LCFS credit profit per gallon of milk across farm sizes and conditions of bioelectricity CI.

	LCF Profit, \$/Gallon of Milk		
Number of Cows	Most-negative CI (-762 gCO2e/MJ)	Average CI (-461 gCO2e/MJ)	Zero CI
100	\$0.02	\$0.00	\$0.00
500	\$0.33	\$0.19	\$0.00
1,000	\$0.37	\$0.24	\$0.03
2,000	\$0.41	\$0.27	\$0.06
10,000	\$0.50	\$0.35	\$0.12
15,000	\$0.55	\$0.39	\$0.14

We can compare the profit generated under the LCFS to the profit from milk sales. To do so, we assumed the profit from the milk to be $4.30/cwt, [7] an estimated profit margin of 25% [25] times the wholesale price of $17.20/cwt.[8] [27], [28] This is equivalent to $1.48 wholesale per gallon, or $0.37 of profit per gallon. The results of this comparison are depicted in Figure 4, which shows the profit derived from the LCFS as a fraction of total profit (LCFS profit + dairy sales profit). In the case where the CI of manure-based bioelectricity is assumed to be zero, the profit which dairies accrue from the LCFS only exceeds 25% of their total profit for large farms—11,000 head and larger. Conversely, in the other two cases, farms over 280 head derive over 25% their profit from LCFS credits.

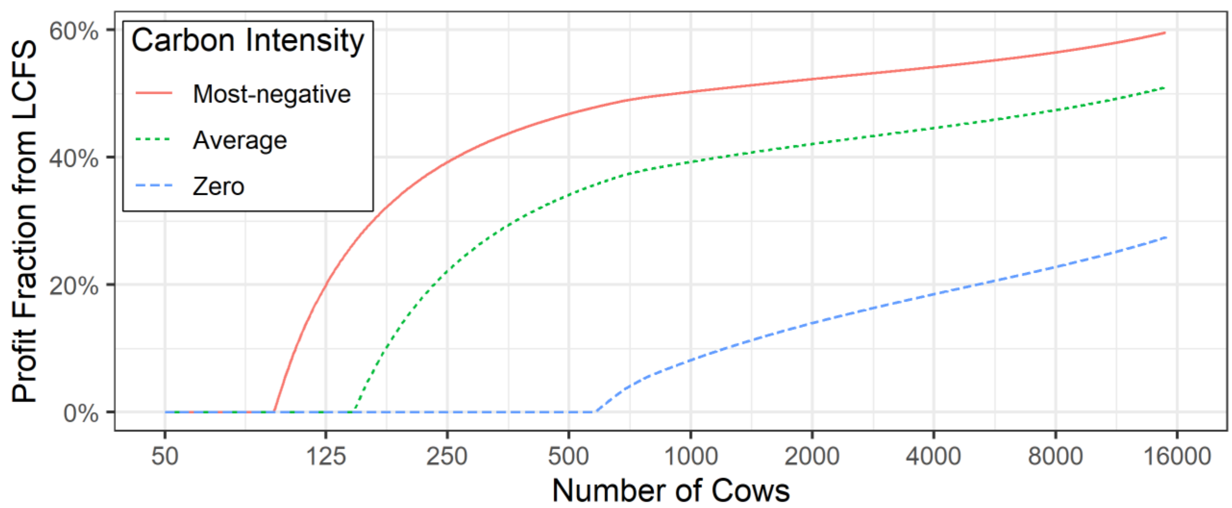

Figure 4. Fraction of profit attributable to LCFS credits as a function of dairy size and the CI of manure-based bioelectricity. Note that the x-axis is logarithmic. The point of departure from 0% indicates the farm size at which electricity generation becomes profitable at an assumed CI.

If, instead of considering the estimated profit fraction from LCFS credit revenue, we observe the calculated fraction of income from electricity (inclusive of electricity sales and LCFS credit sales) compared to the income from milk (i.e., $1.48/gallon), the result is far less dependent upon the scale of the facility,[9] but remains significantly dependent on the certified CI of the electricity. For the average CI case, the revenue fraction from electricity sales ranges from 21% to 24% of the total revenue, and for the most-negative CI case it varies from 26% to 30%. In both cases, smaller farms derive slightly less of their revenue from electricity.

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7 Wholesale milk prices use the units of hundredweight, which are abbreviated as ‘cwt’ and equal to 100 pounds.

8 Based on historic data [26] we assume that 30% of milk is class I, 40% is class III, and the remainder is split evenly between class II and class IV. The most recent prices for class I-IV respectively are: $18.29/cwt [27] $15.56/cwt, $17.67/cwt, and $15.42/cwt [28]. This leads to a weighted-average price of $17.20/cwt.

9 Since the economy of scale of electricity production is no longer a factor, the only impact is the ratio of milk sales to electricity sales which decreases slightly at larger scale due to the higher efficiency engines used in our model.

3.2. Coproduct Allocation

Manure is, at present, considered to be a waste product. Therefore, none of the emissions from milk production are allocated to manure or manure-based bioelectricity production. However, as was shown above, a significant fraction of the revenue of a dairy farm with anaerobic digesters and a significant fraction of the profit from medium-to-large dairies with anaerobic digesters could come from manure that has been concentrated into anaerobic lagoons such that methane is created. The principles of lifecycle assessment suggest that some of the emissions associated with raising dairy cattle should therefore be attributed to this "valuable" coproduct.

Thoma et al. [29] estimate a life-cycle GHG emission of 2.05 kg-CO_2e per kg of milk consumed. Downscaling this to account for the 30% lost before consumption and the 24% of emissions from manure management — which will be largely eliminated via the biogas-to-electricity pathway — results in an estimate of 1.09 kgCO_2e per kg of milk produced.

Dividing the emissions associated with milk production by the quantity of electricity produced by the same farm allows comparison between the scale of methane emissions avoided by capturing and combusting biogas and those stemming from dairy production. As depicted in Figure 5, the emissions from cattle raising (excluding those associated with manure) are significantly larger than those avoided by capturing and combusting biogas (and linearly decrease as farm size increases due entirely to the higher efficiency of larger engines in our model). The scale of these emissions is 2-2.5 times the magnitude of displaced emissions with the most-negative CI and 3.5-4 times the magnitude of those using average CI, meaning that attribution of a portion of these emissions to biogas-based electricity will significantly impact its CI.

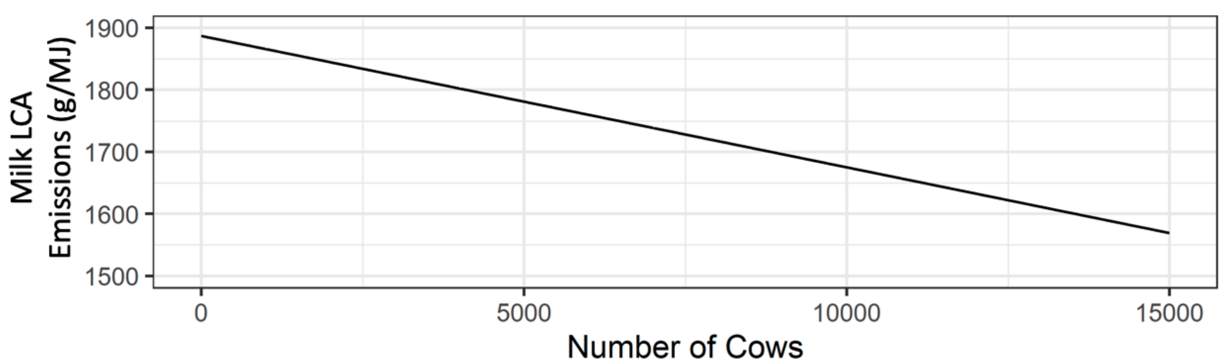

Figure 5. Variation in Milk LCA emissions per MJ of electricity with farm size.

To explore the effect of this allocation on pathway CIs, we attributed a portion of the emissions from dairy production to electricity based upon either the relative revenue or the relative profit. This caused the CI of the electricity to increase (i.e., move towards zero), resulting in lower displaced emissions and lower LCFS revenue. Because the revenue or profit from the electricity would then be lower, thereby changing the relative fractions of profit or revenue, we iterated the CI calculation until it converged to a stable result. This result is summarized in Table 3 for both revenue-based allocation and profit-based allocation methods, and graphically in Figure 6 for profit-based allocation (revenue-based allocation is not shown graphically because the variation is small across notional farm sizes).

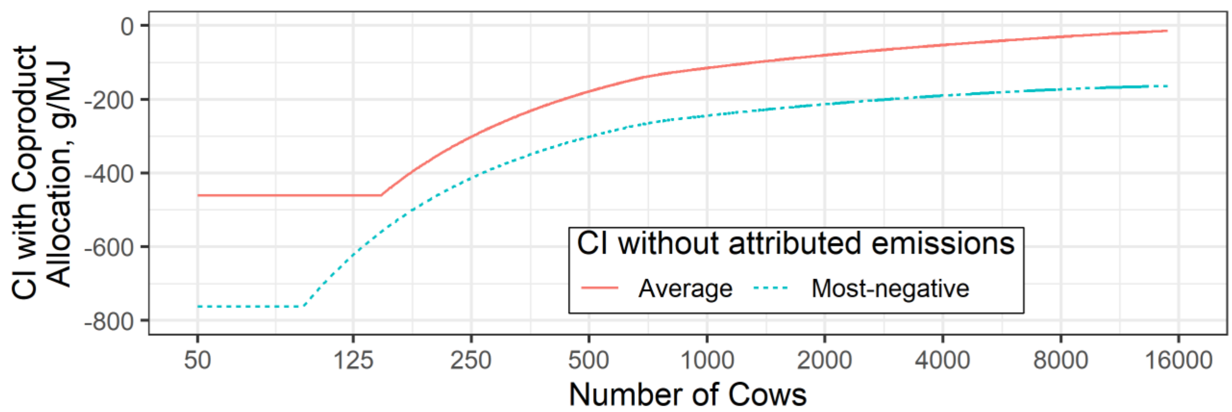

Figure 6. Updated CIs using coproduct allocation based upon relative profit.

Table 3. Updated CIs using coproduct allocation based upon relative profit and from relative revenue comparison.

Number of Cows	Using Profit-Based Allocation[10] Average CI (-461 gCO_2e/MJ)	Using Profit-Based Allocation[10] Most negative CI (-762 gCO_2e/MJ)	Using Revenue-Based Allocation[10] Average CI (-461 gCO_2e/MJ)	Using Revenue-Based Allocation[10] Most negative CI (-762 gCO_2e/MJ)
100	-461	-724	-175	-393
500	-178	-301	-175	-393
1,000	-115	-244	-175	-393
2,000	-80	-213	-176	-393
10,000	-24	-169	-179	-399
15,000	-14	-164	-181	-403

For small farms, little to no profit is generated from the LCFS, and emissions would be attributed entirely to milk production; however, for larger farm sizes, profit margins on electricity sales quickly outpace profit margins on wholesale dairy, and more emissions are therefore attributable to bioelectricity, bringing the CIs of dairy-derived electricity towards zero. Revenue allocation leads to similar CIs across farm sizes, with the increased ratio of electrical output to milk output (due to increased engine efficiency) leading to slightly lower CIs for larger farms because the milk LCA emissions are spread across more MJ of electricity.

After performing the coproduct allocation, we revisit the enabled LCFS credit profit per gallon of dairy as a function of the original CI and allocation method in Figure 7. LCFS profit generally falls between the

10 Because the certified CI is representative of a physical phenomenon, namely avoided emissions due to combustion of biogas from manure via the bioelectricity pathway, the new CI is dependent upon the original CI. Lower certified CIs lead to more profit or revenue being attributed to electricity, and thus more of the dairy-related emissions being allocated to it, but not enough to wipe out the lower initial CI entirely.

average CI without allocation and zero-CI values, both shown previously in Figure 3. One advantage of profit-based coproduct allocation becomes apparent with this visualization: It leads to the flattest profit for farms greater than 500 head, indicating that this method is the best choice to reduce the market distortion favoring larger dairies currently caused by the LCFS. More broadly, any of the studied alternatives (i.e., zero CI, revenue-based coproduct allocation, or profit-based coproduct allocation) would reduce the tremendous imbalance in profits available to larger farms.

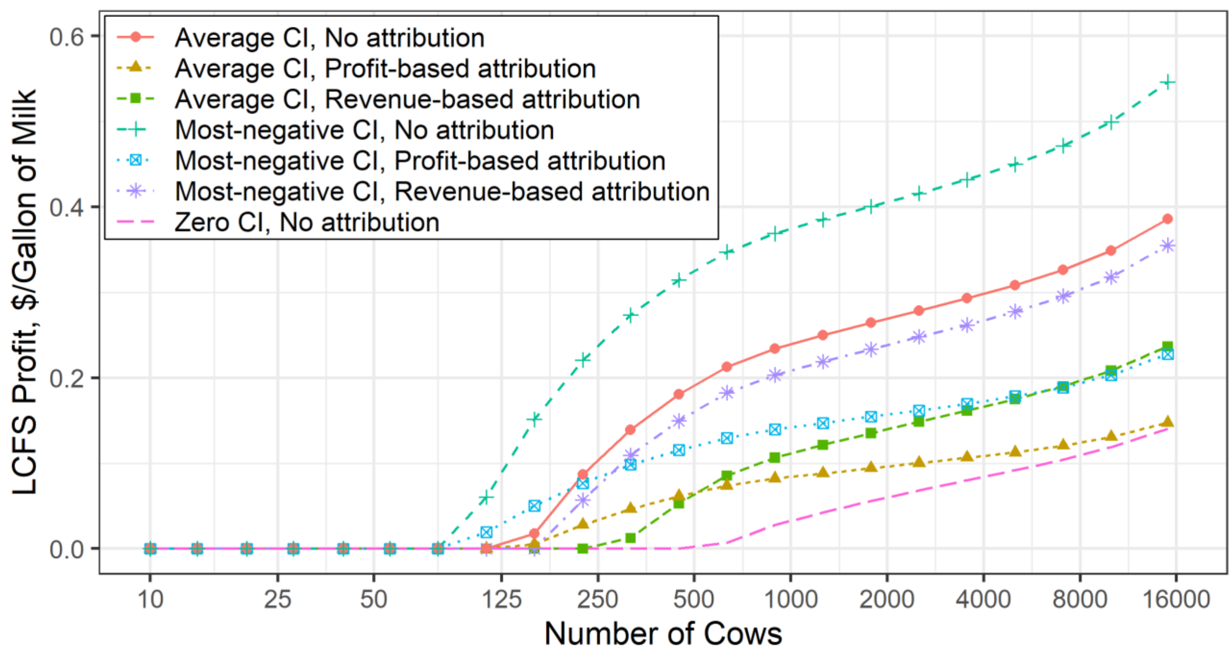

Figure 7. LCFS profit to dairies per gallon of milk under seven different CI conditions. The first half of each legend entry indicates the original CI, and the second half indicates which, if any, method was used to update the CI. Note that the x-axis is logarithmic. The point of departure from $0/gallon indicates the farm size at which electricity generation becomes profitable at a given CI.

4. Discussion

For farms above 1,000 head, attributing milk LCA emissions via revenue or value results in significant increases to pathway CIs, by 300 to 600 gCO_2e/MJ, depending upon farm size and whether profit or revenue is used in allocation. This is not enough to bring calculated CIs above zero, though they approach zero for large farms using profit-based allocation. Thus, implementing coproduct allocation would still allow dairies to generate significant revenue and profit under the LCFS, but at a reduced level compared to today. Using either a revenue- or a value-based coproduct allocation approach appears to be viable, though the former has the advantage of requiring much less knowledge of farm-specific economic factors while the latter is better at removing the market distortion which presently supports large operations (though it by no means eliminates it). This market distortion leads to two probable outcomes: First, dairies are incentivized to consolidate in order to take advantage of the economies of scale. Second, dairies are incentivized to purchase more cows, independent of consolidation. The resulting trend is expected to be one of an increased number of animals across the state *and* a greater size of individual herds, both of which were already happening before creation of the LCFS, as shown in Figure 1. If profit-based coproduct allocation is used, it is also tremendously sensitive to dairy and bioelectricity economics and therefore requires a deep look into the technical and accounting factors of these operations.

There is also a third, and very important, outcome created by the LCFS, and that is an incentive towards worse manure handling practices as a baseline. A farm which at present allows its herd to range free and deposit manure without aggregation does not have methane emissions from manure management to mitigate, and thus cannot generate the significant profits identified herein. That farm is being penalized for its lower-impact practices and is incentivized to confine its cattle and aggregate their manure into a methane-emitting pond, which enables it to then receive LCFS credits in exchange for capture and combustion of this methane. Moreover, insofar as smaller farms may be less likely to manage their manure in lagoons, this factor exacerbates the market distortion created by LCFS preferencing larger cattle farming operations.

4.1. Comparison to Existing Literature

Aaron Smith [30] performed a comparison of dairy revenue and energy revenue for a 2,000-cow dairy, with similar costs and revenue to those identified in our study. Notably, Smith assumes a pipeline injected compressed natural gas (CNG) pathway for the fuel, whereas we assume a cheaper electricity pathway (though we also provide some of our own analysis for CNG pathways in Appendix A), leading to distinct, but similar results. As Smith says, "[e]qual numbers of California digesters are employed to produce CNG for transportation and to generate electricity."

Smith uses a cost of $636 per cow-year[11] and a CNG revenue of $1,935 per cow-year. In our model, a 2,000-cow dairy would have a capital payment of $234/cow-year[12], and an operational expense of $123. However, since Smith's analysis entails the much more expensive process of upgrading to CNG for pipeline injection, we also looked at the underlying data used [31], which apply a capital cost of $2.9 million for the digester and an operational cost of $174,000. These estimates are slightly below our estimates of $3.3 million in capital expense and $186,000 in annual operational costs for a 2,000-cow dairy.

In comparison to our estimates of CNG cost, our total cost per cow-year is $882, with $302 due to operational expenses. The former is quite a bit higher than Smith's estimate of $636 while the latter is quite close to his estimate of $294.

We estimated an LCFS credit value of $951/cow-year and $1,320/cow-year in our average and most-negative CI cases for electricity, respectively, less than Smith's estimate of $1,935. More comparable are our estimates for CNG, which are also much closer to Smith's, at $1,400 and $2,190 per cow per year in the average and most-negative cases, respectively.

In summary, while Smith does not account for capex cost in his analysis, and assumes a more expensive pathway than we do, these two assumptions approximately cancel out, leading to a cost of $294/cow-year, 82% of our estimate of $357/cow-year. LCFS credit revenues per cow, on the other hand, are much

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11 $294 from operations and $342 from capital, which Smith eliminates because these are often grant funded. Smith also uses a higher CRF of 0.142 compared to the 0.117 which we used.

12 $284 with a CRF of 0.142.

higher in Smith's analysis, 50% to 100% larger than ours due to the low conversion efficiency of electricity production.

5. Conclusions & Policy Recommendations

This model provides only a second-order estimate of the costs, revenues, profits, and emissions from dairies, all of which depend on case-specific factors which we have not characterized, including: varying labor costs, feed choices, animal breed, confinement, the availability of grants for digester capital costs, and much more.

As it stands, our analysis indicates that the LCFS is offering a significant competitive advantage to large-scale dairy operations over smaller-scale operations, and that profits are available only to farms with poor (i.e., methane generating) manure handling practices. We estimate that the value of subsidy available to a 10,000-cow farm range from $0.35 to $0.50 per gallon of milk, which is 1.5 to 1.8 times that available to a 500-head farm assuming the same certified CIs for both facilities. Furthermore, our economic analysis indicates that a small, 100-cow, farm would derive little to no value from LCFS, regardless of avoided methane emissions when producing bioelectricity, even when confining their cattle and aggregating manure into methane-generating ponds. This creates clear market distortions in favor of large, confined operations, which could exacerbate the already-present trend of market consolidation. Furthermore, this study illustrates that the negative emissions associated with use of anaerobic manure digestion are at least in part an artifact of accounting choices that increase the revenue particularly to large dairy operations. These include the policy of considering manure to be a true waste from an LCA standpoint even where it accounts for a significant portion of total revenue, and the base-case assumption of uncontrolled methane release. We recommend one of three possible approaches to alleviate the above concerns:

1. Carbon intensity for CNG and electricity derived from anaerobic digestion of cow manure could be limited to zero. This would reduce subsides to many farms from as high as $0.57/gallon to $0.16/gallon of milk. Per our model, farms larger than 580 head would still be incentivized to produce electricity, and grants could be used to assist smaller farms with manure management practices (whether through capture and destruction of methane or via elimination of the anaerobic decomposition which creates methane in the first place) as well as to account for differences between this model and the reality on the ground.
2. Farms could be required to flare rather than vent biogas generated by manure as a baseline. This would have a similar impact to the option above, since it would mean the carbon intensity of generated electricity would be close to zero rather than significantly negative.
3. LCFS pathways could use coproduct allocation to account for the lifecycle emissions of dairy production in the CIs calculated for manure-based bioelectricity. We calculate that this would lead to a lower limit of CI values for farms above 500-head of cattle of -400 gCO_2e/MJ compared to present day values as low as -762 gCO_2e/MJ. This could lead to a stable condition in which large profits from bioelectricity lead to higher CIs of manure-based bioelectricity and vice-versa, stabilizing the generation of credits, but this would require a more detailed study to fully assess. Using either a revenue- or a value-based coproduct allocation approach appears to be viable, though the former has the advantage of requiring much less knowledge of farm-specific economic factors, while the latter is better at removing the market distortions which presently support large operations.

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Appendix

Appendix A Comparison Between Compressed Natural Gas and Electricity Generation

Several factors affect the relative economics of electricity and compressed natural gas (CNG) pathways from dairy-manure. The first are the certified CIs in the LCFS, which are smaller in magnitude among present CNG pathways: While approved electricity pathways have an average value of -461 gCO_2e/MJ and a lowest value of -762 gCO_2e/MJ, CNG pathways have an average value of -309 gCO_2e/MJ and a lowest value of -533 gCO_2e/MJ [5]. Second, compressed natural gas vehicles have an EER of 0.9 or 1, relative to EERs between 2.6 and 5 for electric vehicles. Third, the costs associated with biogas upgrading into natural gas and pipeline injection[13] differ from the costs of onsite production. The first two of these factors are captured in the subsidy levels shown in Figure A-1 while the third factor is captured in the production cost curves.

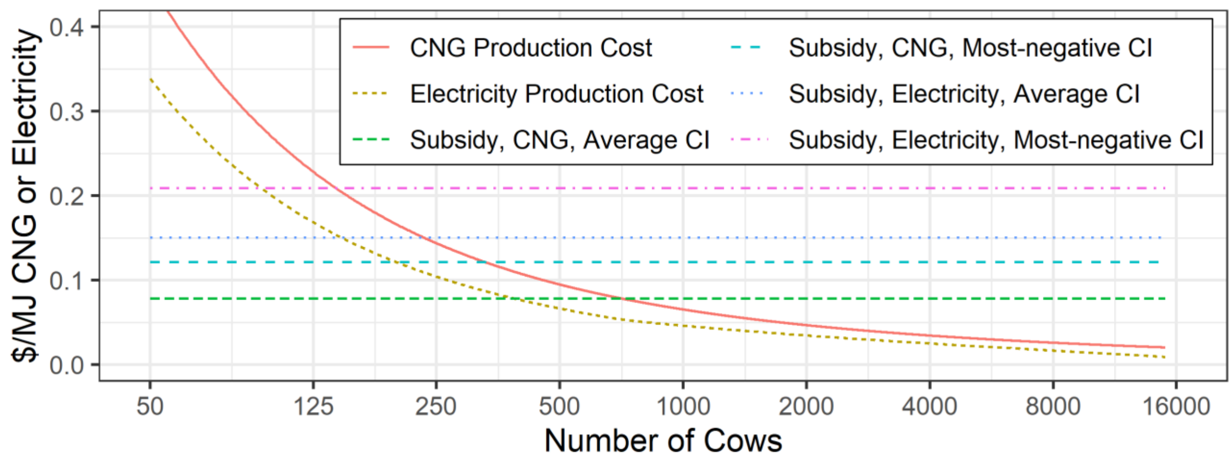

Figure A-1. Net production cost (total cost minus revenue from energy sales) and LCFS credit revenues (i.e., subsidy) by farm size. Note that the x-axis is logarithmic. CNG refers to pipeline injected compressed natural gas.

Significantly, the production cost per unit is higher for CNG while the revenues under the LCFS would be lower. On the other hand, due to the inefficiencies of combustion engines, many more units of energy could be sold in the CNG case — 2.7 times as many for a representative 2,000 cow dairy — raising the potential for higher total profits, though lower profit margins, for CNG. It is important to keep in mind that this lower profit margin is reflective only of the CNG generation process and not of the dairy operation as a whole—it is possible that, due to the higher total revenues from CNG, the dairy operation's profit margins are improved relative to the electricity operation.

These higher total profits are shown to actualize in Table A-1, which reproduces the result of Table 2 for the average and most-negative cases alongside the equivalent values for two CNG pathways. LCFS profit per gallon of milk is generally lower for CNG pathways than for electricity pathways except for relatively

[13] Natural gas upgrading and pipeline costs from Parker et al. [12] assuming an average interconnection distance of 2 miles, approximately the average value in Jaffe et al. [32]

large farms (i.e., over 1,000-head) with the most-negative certified CIs. Here, the CNG pathway could enable up to 30% increased total profit (or profit per gallon of milk, as shown) from fuel production compared to the electricity pathway. While the higher revenues do not significantly alter the picture, the increase in relative profit between medium and large farms (e.g., 1,000 and 10,000 head) is noteworthy. CNG pathways under the LCFS appear to magnify the identified market distortion (see Section 4) in further favor of large operations. However, this effect is mitigated somewhat by the fact that it only affects the exceptionally negative CI case, and not average or subaverage CIs.

Table A-1. LCFS credit profit per gallon of milk across farm sizes, certified CI, and fuel type.

	LCFS Profit, $/Gallon of Milk - Electricity		LCFS Profit, $/Gallon of Milk - CNG	
Number of Cows	Most-negative CI (-762 gCO2e/MJ)	Average CI (-461 gCO2e/MJ)	Most-negative CI (-533 gCO2e/MJ)	Average CI (-309 gCO2e/MJ)
100	$0.02	$0.00	$0.00	$0.00
500	$0.33	$0.19	$0.18	$0.00
1,000	$0.37	$0.24	$0.37	$0.08
2,000	$0.41	$0.27	$0.50	$0.21
10,000	$0.50	$0.35	$0.65	$0.36
15,000	$0.55	$0.39	$0.67	$0.38

Appendix B Electricity Generation Model Details

We built cost and productivity estimates for farms from a single cow up to 15,000 cows. We then calculated the resulting biogas production for each farm size using the biogas production and methane concentration [33] of each farm and heating value of methane of 1,012 BTU/scf.

Digester capital and annual costs were calculated from Parker et al. [12], assuming that each farm purchases its own stirred tank digester [12].

To assess conversion from biogas to electricity, we created an economic model based on Jaramillo & Matthews' [19] generator data. Their paper provides point estimates of heat rate, operational expenses, and annual expenses for five scales each of reciprocating engine and gas turbine. Because a more efficient engine will generate more revenue under the LCFS, we applied only the more efficient (though also more expensive) reciprocating engines in our model.

The 15,000-cow farm produces 64% as much biogas as the largest engines in Jaramillo & Matthews can handle, but the smallest farms extrapolate capital and annual costs below that of their smallest engines. We therefore limited our linear model, capping values which extrapolated outside the range provided (i.e., heat rate, total annual cost and total capital cost were limited to their lowest reported values). We used a capacity factor of 93% [34] to determine necessary engine size, which resulted in the linear models summarized in Table B-1 and Figure B-1 after converting to 2021 dollars.

Table B-1. Linear model created from reciprocating engine data [19].

Parameter	Unit	Equation (flow_rate in mmbtu/hr)	Minimum Value
Capital cost	$2021	$172,710*flow_rate-$19,852	$236,643
Annual cost	$2021	$14,192*flow_rate-$469	$23,414
Heat rate	mmbtu/MWh	0.0572*flow_rate + 11.0	8.758

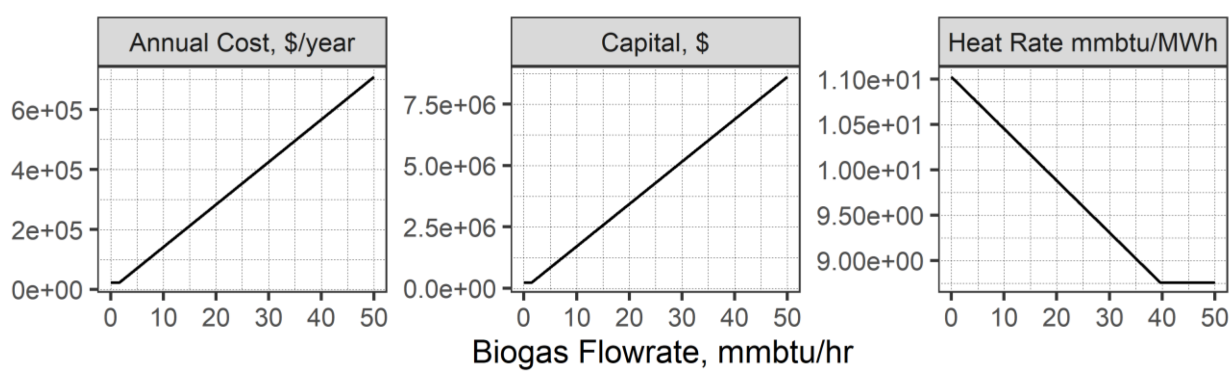

Figure B-1. Linear model created from reciprocating engine data [19].

We then calculated total annual costs by annualizing digester and engine capital costs using a capital recovery factor of 0.117, consistent with 15-year financing at an 8% interest rate, and adding this to the annual expenses in Jaramillo & Matthews [19] and Parker et al. [12] for engines and digesters, respectively. From the annual costs, we subtracted the revenue from electricity sales, assuming electricity is sold at $79 /MWh[14], to determine the annual net cost of building and running the AD and onsite combustion operation.

We then calculated the net electricity production cost (before LCFS credits) per MJ of electricity, by dividing this total cost by the annual electricity production for each farm size.

[14] We used the generation-weighted average power price for the 51 California power plants in the 2019 EIA Power Plant Operations dataset [20] which report using at least 50% qualifying biofuels as feedstock. This yielded a wholesale price of bioelectricity of $78.59/MWh (SD: $34.24). This is a relatively high price for wholesale power, but it is reflective of current market conditions. In part, these high prices may reflect the value of bundled Renewable Energy Credits (RECs) generated under CA's Renewable Portfolio Standard as well as other price supports such as Feed-in Tariffs or Production Tax Credits that are available in some jurisdictions.