Analysis of Progress toward Achieving the 2030 Dairy and Livestock Sector Methane Emissions Target

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CALIFORNIA AIR RESOURCES BOARD

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Executive Summary

California took a major step toward reducing greenhouse gas (GHG) emissions and combatting climate change when the Legislature enacted Assembly Bill 32 (Núñez, Chapter 488, Statutes of 2006), which requires the State to reduce GHG emissions to 1990 levels by 2020. California achieved this target in 2016, four years earlier than mandated. To achieve deeper reductions, the Legislature enacted Senate Bill (SB) 32 (Pavley, Chapter 249, Statutes of 2016), which requires the State to further reduce GHG emissions to 40 percent below 1990 levels by 2030. In the same year, the Legislature enacted SB 1383 (Lara, Chapter 395, Statutes of 2016), which recognizes the immediate climate benefits of reducing short-lived climate pollutants (SLCP). In the 2017 Scoping Plan Update, the plan for achieving GHGs reductions in the State, the California Air Resources Board) CARB describes that short lived climate pollutant (SLCP) reductions account for about one-third of the cumulative GHG emissions reductions the State is relying on to achieve the statewide 2030 GHG emissions target established under SB 32.

Short-lived climate pollutants, including methane, are powerful climate forcers that have a relatively short atmospheric lifetime, but a high global warming potential compared to other GHGs such as carbon dioxide. SB 1383 establishes SLCP reduction targets and requires CARB to implement a Short-Lived Climate Pollutant Reduction Strategy (Strategy) to achieve these targets. The law sets a 2030 methane emissions reductions target for the dairy and livestock sector (2030 target), which produces more than half of the State's methane emissions. This target is a reduction of 40 percent below 2013 levels, or a reduction of 9 million metric tons carbon dioxide equivalent ($MMTCO_2e$) [1] by 2030. SB 1383 also requires CARB, in consultation with the California Department of Food and Agriculture (CDFA), to analyze the progress that the sector has made toward achieving the 2030 reduction target and achieving the goals identified in the SLCP Strategy, including progress made in overcoming technical and market barriers to implementing methane emissions reductions measures identified in the Strategy. This Analysis of Progress toward Achieving the 2030 Dairy and Livestock Sector Methane Emissions Target (Analysis) is responsive to that mandate.

Dairy and livestock methane emissions originate from two primary sources, manure management and enteric fermentation. Manure methane emissions can be reduced through two primary methods—installation of an anaerobic digester and alternative

[1] This emissions reduction estimate is calculated using the 100-year global warming potential (GWP) for methane (IPCC, 2007: Climate Change 2007: Synthesis Report; Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]; IPCC, Geneva, Switzerland, 104 pp (AR4)). The Short-Lived Climate Pollutant Reduction Strategy estimated emissions using the 20-year GWP (AR4).

manure management practices. Anaerobic digesters capture methane-rich biogas for beneficial uses, including in electricity generation and fossil natural gas displacement. Alternative manure management practices reduce manure methane emissions in ways that do not involve an anaerobic digester. Examples include solid separation, conversion to dry scrape, and pasture-based management. Both digester and alternative manure management practices reduce GHG emissions and can improve water quality and nutrient management. Enteric methane emissions can be reduced through genetic selection, diet modification, and feed additives.

This Analysis shows that the dairy and livestock sector is projected to achieve just over half of the annual methane emissions reductions necessary to achieve the target by 2030 through modifications to manure management systems—primarily using anaerobic digesters—and additional reductions through decreases in animal populations. Figure ES-1 shows significant emissions reductions through 2030 absent additional funding after fiscal year 2019-20.[2]

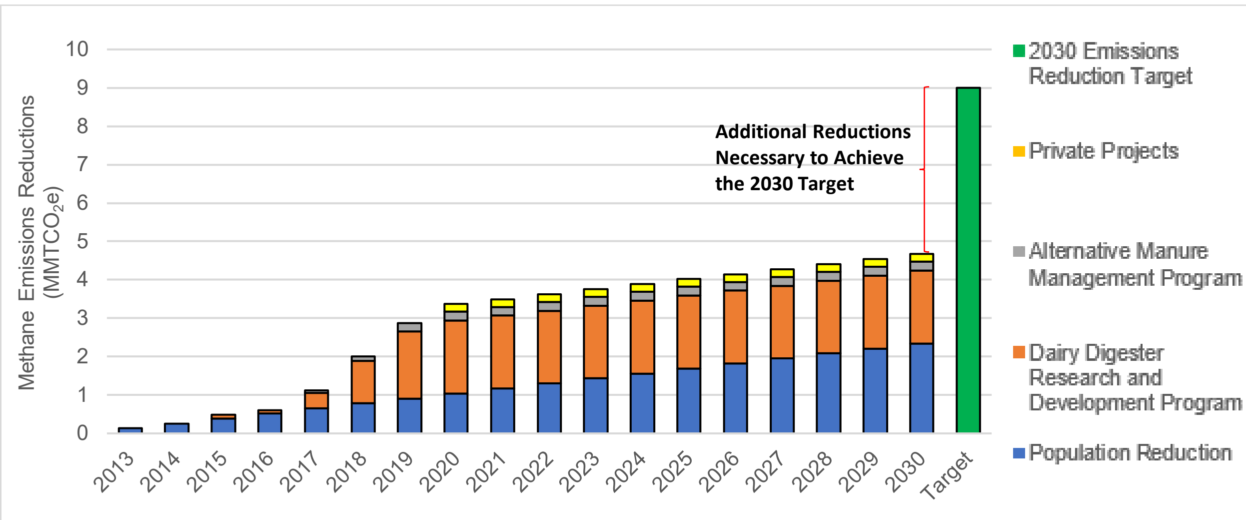

Figure ES-1. Projected Annual Methane Emissions Reductions through 2030 without Additional Funding beyond FY 2020-21

To meet the 2030 target, the dairy and livestock sector will need to achieve considerable emissions reductions from additional manure management projects, proven enteric mitigation strategies, or a combination of both over the next few years.

To understand what level of resources are needed to achieve the target, CARB staff looked at existing dairy methane emissions reduction efforts, including both grant

[2] This does not include $32 million in FY 2021-22 appropriations because it is uncertain how these appropriations will be allocated.

programs that fund the initial capital costs and market-based programs that incentivize GHG emissions reductions or low carbon fuel production.

Over the past six years, California Climate Investments (CCI)—the program that utilizes the State's Cap-and-Trade Program auction proceeds to facilitate GHG emissions reductions—has offset some capital costs through two CDFA grant programs to reduce manure methane emissions: the Dairy Digester Research and Development Program and the Alternative Manure Management Program. An approximate appropriation of $289 million in CCI funds has facilitated the construction of 233 dairy and livestock GHG emissions reduction projects. Many of these manure methane reduction projects are also generating environmental credits through CARB's Cap-and-Trade Program, Low Carbon Fuel Standard (LCFS) Program, and the federal Renewable Fuel Standard (RFS) Program. These projects, cumulatively funded through FY 2019-20, are expected to deliver the 2.0 $MMTCO_2e$ in annual methane emissions reductions noted above from manure management systems by 2030, or about 22 percent of the reductions necessary to achieve the 2030 target.

New or expanded local, State, or federal incentives or funding mechanisms could potentially accelerate the capture and beneficial use of California biomethane, provide additional revenue necessary to ensure that California's dairy manure methane emissions are captured, and direct the biogas to difficult-to-decarbonize sectors. Replacing fossil natural gas with upgraded dairy biogas (biomethane) or other alternatives is important for California's near and longer-term climate goals, but the cost to procure biomethane can be six to ten times more expensive than fossil natural gas. This cost disparity is almost entirely associated with the cost of bringing biomethane to market and will likely persist into the future. This is one of the primary reasons incentives are needed for California's dairy and livestock sector to adopt methane reduction strategies that also support the transition away from fossil natural gas supplies. Additional funding could also accelerate the adoption of alternative manure management projects. These projects provide climate benefits through avoided methane production and environmental co-benefits including water quality improvements and conservation, reduction of synthetic fertilizer usage and improvement of nutrient management, as well as groundwater protection.

Through coordinated State, industry, and utility efforts, the dairy and livestock sector has made meaningful progress in overcoming technical barriers to digester projects, interconnecting to utility electrical grids and pipeline networks, and meeting biomethane pipeline injection standards. Improved environmental credit certainty has also reduced the most considerable market barriers to digester projects by helping project developers obtain funding and financing. Challenging sector economics, insufficient availability of public funds, and underdeveloped markets for value-added manure products are persistent market barriers for both digester and alternative manure management projects. There has been limited progress in overcoming technical barriers to alternative manure management practices because emissions reductions vary based on site-specific factors. There has also been limited progress in overcoming both technical and market barriers to enteric reductions. Enteric methane-reducing feed additives may achieve considerable near-term emissions reductions. There are two commercially available products that were developed for enteric methane mitigation, with potential emissions reductions up to 10-20 percent. Additional feed additives are under development that may provide larger enteric methane emissions reductions.

Despite progress in overcoming barriers, there is more to do to ensure that the State meets the 2030 target. Remaining barriers may be overcome through multiple reasonable efforts, including allocation of additional local, State, or federal funding or incentives. If the remaining reductions needed to achieve the 2030 target are met through a mix of California dairy projects in which half are dairy digesters and half are alternative manure management projects, then at least 420 additional projects may be necessary. This approach would cost an amount between $0.8 and $3.7 billion, which could be supported by local, State, and federal funding, or other financial mechanisms, such as the pilot financial mechanism outlined in SB 1383.[3] If, going forward, only digester projects were developed to achieve the target, approximately 230 additional digesters may be needed, at a cost between $0.7 and $3.9 billion depending on the types of technologies selected. For example, prioritizing deploying digesters with internal combustion engines is the lowest-cost option ($0.7 billion) to achieve the 2030 target, but this would result in on-site criteria pollutant emissions. Alternatively, deployment of digesters that utilize fuel cell technology may avoid these emissions, but at a significantly higher cost ($3.9 billion). Finding 1-6 of this Analysis describes project types, technologies, and cost ranges. With respect to alternative manure management practices, based on currently funded projects and reduction trends observed to date, staff's analysis indicates that the State would be unable to achieve the 2030 dairy and livestock sector target through deployment of alternative manure management practices alone. A combination of dairy digesters, alternative manure management, enteric strategies, and dairy herd size population decreases will be needed to meet the 2030 target.

[3] On February 24, 2022, the California Public Utilities Commission approved Decision 22-02-025 adopting biomethane procurement standards pursuant to SB 1440 (Hueso, Chapter 739, Statutes of 2018), including procurement of biomethane from the California dairy and livestock sector.

Regardless of the project and technology mix used, the most important factors for achieving the 2030 target are ongoing capital funding for new methane emissions reduction projects, continued revenue streams that incentivize dairy biogas capture and beneficial use, and an available and accepted means of reducing enteric methane emissions. Even with considerable progress toward achieving the target since the enactment of SB 1383, the statute requires CARB to adopt a regulation to meet the target, provided that certain conditions are met. Further, CARB is only authorized to implement regulations to meet the 2030 target after January 1, 2024, provided that CARB, in consultation with CDFA, determine the regulations are technologically and economically feasible, cost-effective, include provisions to minimize and mitigate potential leakage, and include an evaluation of the achievements made by incentive-based programs. In designing a regulation for methane emission reductions, CARB staff will consider reasonable strategies to support the sector in meeting the 2030 target, which may include strategies that further support biogas capture and end-uses needed to advance the State's carbon neutrality efforts.

While the California dairy and livestock sector has made significant progress, it must still achieve considerable methane emissions reductions to meet the 2030 target. This will require implementation of additional methane emissions reductions strategies, and continued collaboration among agencies and other stakeholders. In addition, CDFA plans to convene a working group to address market development barriers for facilitate value-added manure products. CARB will continue to track progress of methane emission reductions project funding and outcomes, manure management and enteric methane reduction options, and will evaluate progress in the 2022 Scoping Plan Update.

Introduction

California has long championed environmental protection, and the State has made significant investments and efforts to decarbonize its economy. In 2006, the Legislature passed and the Governor signed the California Global Warming Solutions Act. Assembly Bill (AB) 32 (Núñez, Chapter 488, Statutes of 2006) requires the State to reduce greenhouse gas (GHG) emissions to 1990 levels by 2020. It also tasked the California Air Resources Board (CARB or Board) with developing a climate change scoping plan that details how the State will achieve its climate target and requires CARB to periodically update the plan. The Board adopted the first Climate Change Scoping Plan in December 2008 and updated this plan in 2013 and 2017.

Through aggressive pursuit of regulatory and voluntary GHG emissions reduction measures across economic sectors, California GHG emissions fell below 1990 levels in 2016, 2017, 2018, and 2019. Acknowledging the need to make deeper GHG emissions reductions to help slow climate change, the Legislature passed Senate Bill (SB) 32 (Pavley, Chapter 249, Statutes of 2016), which requires the State to reduce GHG emissions to 40 percent below 1990 levels by 2030. Figure 1 shows these GHG emissions reduction targets as well as the State's additional goal to reduce GHG emissions by 80 percent below 1990 levels by 2050.[4] Meeting these emissions reduction targets will be critical as California strives to achieve another goal – reaching carbon neutrality by 2045.[5] The Intergovernmental Panel on Climate Change (IPCC) has acknowledged carbon neutrality as necessary to limit global warming to 1.5 degree Celsius or less, the goal set by the international Paris Agreement on climate.

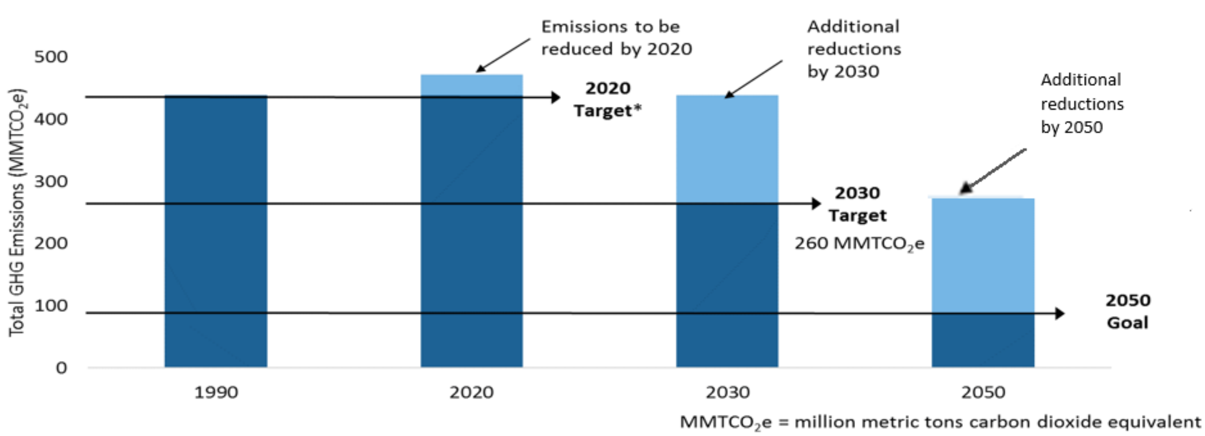

Figure 1. California GHG Emissions Reduction Targets and Goal through 2050

[4] Executive Order S-3-05.
[5] Executive Order B-55-18.

The Legislature also took action to limit emissions of short-lived climate pollutants (SLCP), which are powerful climate forcers that have relatively short atmospheric lifetimes but high global warming potentials (GWP). As a result, SLCP emissions reductions achieved now can have an immediate beneficial impact on climate change. Methane, a powerful SLCP, stays in the atmosphere for approximately a decade before being converted to carbon dioxide.[6] The effect of methane on climate change is 25 times stronger than that of carbon dioxide using the 100-year GWP (GWP 100), and 75 times stronger than carbon dioxide using the 20-year GWP (GWP 20).

CARB uses GWP 100 to quantify statewide methane emissions for inventory and regulatory purposes. GWP 100 is the standard for inventory development and aligns with IPCC and US Environmental Protection Agency (EPA) methods, allowing for comparison of the state inventory with other sub-national and international inventories through common methodologies and requirements for accuracy.

In 2014, the Legislature passed SB 605 (Lara, Chapter 523, Statutes of 2014), which requires CARB to develop a strategy to reduce SLCP emissions in the State. In response, staff developed and the Board approved a comprehensive Short-Lived Climate Pollutant Reduction Strategy (Strategy). In 2016, the Legislature passed SB 1383 (Lara, Chapter 395, Statutes of 2016), which requires CARB to approve and begin implementing the Strategy, and establishes a requirement, among others, for different SLCPs[7] to meet methane emissions reduction targets. More specifically, SB 1383 requires the California dairy and livestock sector to reduce methane emissions from enteric fermentation and manure management to 40 percent below 2013 levels by 2030. It also requires CARB, in consultation with the California Department of Food and Agriculture (CDFA), to adopt regulations to achieve this mandate if certain conditions are met. Specifically, SB 1383 intends to prioritize the use of voluntary and incentive-based measures to achieve those reductions before regulations are implemented. To achieve that end, the law calls for several specific efforts to incentivize reductions, including requiring CARB to work with stakeholders to identify and address technical, market, regulatory, and other challenges and barriers to development of dairy methane emissions reduction projects. Further, CARB is only

[6] While methane itself is not considered a toxic air contaminant, it is a large component of biogas, which may contain a mixture of gases including some toxic air contaminants like hydrogen sulfide. Removing these toxic air contaminants can reduce potential health impacts associated with the processing, transportation, and use of biogas streams.

[7] SB 1383 requires the reduction in the statewide emissions of methane by 40 percent, hydrofluorocarbon gases by 40 percent, and anthropogenic black carbon by 50 percent below 2013 levels by 2030. Additionally, the bill requires a 50 percent and 75 percent reduction in the level of the statewide disposal of organic waste from the 2014 level by 2020 and 2025, respectively. SB 1383 also sets a goal that not less than 20 percent of edible food that is currently disposed of is recovered for human consumption by 2025.

authorized to implement the regulations to meet the 2030 target after January 1, 2024, provided that CARB and CDFA determine the regulations are technologically and economically feasible, cost-effective, include provisions to minimize and mitigate potential leakage, and include an evaluation of the achievements made by incentive-based programs.

The Strategy put forward a path to achieve the SLCP emissions reduction goals established in SB 1383 in a way that provides both environmental and economic benefits to the State. Using the latest scientific and emissions information on SLCPs, it outlines the emissions reduction progress for specific SLCPs, potential options for additional reductions of these SLCPs, and strategies to achieve the respective emissions reduction targets. SLCP reductions are necessary to achieve the State's 2030 GHG emissions target, as described in the 2017 Scoping Plan Update, as well as the mid-century carbon neutrality goal. Notably, while some State programs incentivize dairy and livestock methane emissions reductions, no existing California programs directly require them or incentivize a sector-wide implementation of reduction measures. For example, CARB's Low Carbon Fuel Standard (LCFS) program provides some incentive for dairy operations to develop digesters and receive credits for biomethane production. However, on its own this program does not require operators to develop projects and through its credit system may not support statewide implementation of anaerobic digesters at dairies, and thus these emissions will not decrease without additional targeted programs or other interventions. In contrast, for the electricity and transportation sectors, the Cap-and-Trade Program acts as a backstop to ensure that GHG emissions reductions are achieved.

The Strategy describes a variety of manure management options that can provide the greatest methane emissions reduction potential, recognizing that not every option is feasible for each facility. The Strategy also recommends additional research to evaluate potential enteric methane emissions reduction options as well as the acceleration of early project development through incentives and market development. Prior to implementing regulations, incentives like California Climate Investments (CCI) allocations using Cap-and-Trade Program auction proceeds will encourage voluntary methane emissions reductions at dairies. The Strategy recognizes that implementing a variety of mitigation measures is necessary to achieve the 2030 target and will deliver significant reductions from the dairy and livestock sector while providing a variety of environmental and economic benefits.

Upon adoption of the Strategy and in compliance with SB 1383, CARB convened an interagency Dairy and Livestock Greenhouse Gas Emissions Working Group (Working Group) consisting of CARB, CDFA, California Energy Commission (CEC), and California

Public Utilities Commission (CPUC) principals. At the initial meeting in May of 2017, the Working Group convened three stakeholder subgroups composed of representatives and subject matter experts from State agencies, industry, academia, and the environmental justice community. The objective of these subgroups was to comply with SB 1383's requirement for CARB to work with stakeholders to identify and address barriers to dairy and livestock methane emissions reductions projects, and to develop actionable recommendations that State agencies could implement to help overcome these barriers.

Subgroup 1 provided recommendations to the Working Group to overcome barriers to non-digester manure management practices that focused on available and potential incentives, and developing value-added manure product markets. Subgroup 2 provided recommendations to the Working Group to overcome barriers to implementing livestock digester projects in California, along with a dairy digester emissions matrix that shows potential GHG and criteria pollutant emissions from dairy biogas use. Subgroup 3 focused on research needs related to dairy and livestock methane emissions reductions including enteric fermentation, and published a comprehensive Dairy Research Prospectus to Achieve California's SB 1383 Climate Goals, which outlines research concepts and needs to guide future funding of research projects in California. Over 18 months, the subgroups developed a set of Final Recommendations to the Dairy and Livestock Greenhouse Gas Reduction Working Group and presented them to the Working Group in December 2018. These recommendations outline potential solutions to overcome barriers to methane emissions reduction projects at California dairy and livestock operations and highlight innovative research on methane emissions reductions.

SB 1383 includes additional requirements on CARB to help provide market and environmental credit certainty to biogas-capturing anaerobic digester projects. These requirements, which CARB staff have fulfilled, include developing a white paper describing a potential pilot financial mechanism that, if implemented, could improve market stability for environmental credits from dairy digester projects. CARB, CDFA, and CPUC collaborated in selecting six dairy biomethane pipeline injection pilot projects to receive rate-recoverable infrastructure funding. Evaluating the factors that affect the cost and technical feasibility of these projects will help the State better understand and refine future incentives and regulatory measures. CARB staff also developed a frequently asked questions document discussing the potential impact that a dairy and livestock methane emissions reduction regulation would have on environmental credits generated under the LCFS Program and Cap-and-Trade Program.

Finally, SB 1383 requires CARB, in consultation CDFA, to analyze the progress that the sector has made toward achieving the 2030 target. This Analysis discusses the expected methane emissions reductions through 2022 and the estimated number of additional projects necessary to achieve the 2030 target. It also explores progress made in overcoming the technical and market barriers to implementing dairy and livestock methane emissions reductions projects.

Dairy and Livestock Sector Methane Emissions

In 2013, methane accounted for 40 million metric tons carbon dioxide equivalent ($MMTCO_2e$),[8] or approximately nine percent[9] of the State's GHG emissions (Figure 2). The dairy and livestock sector has been and continues to be the largest source of methane emissions in California, producing approximately 22 $MMTCO_2e$, or about 55 percent, of statewide methane emissions (Figure 3). Eighty percent of these emissions are from manure management and enteric fermentation at more than 1,300 dairies throughout the State. These dairies house more than 1.7 million milking cows and a similar number of replacement stock.[10]

Methane emissions at dairy and livestock operations come from two main sources—the animals themselves through enteric fermentation and manure management operations, especially at dairies. Enteric and manure emissions are both functions of cattle population, meaning that that more head of cattle there are, the higher the methane emissions. As a result, market dynamics such as changes in cost, revenue, or product demand can lead to fluctuations in methane emissions.

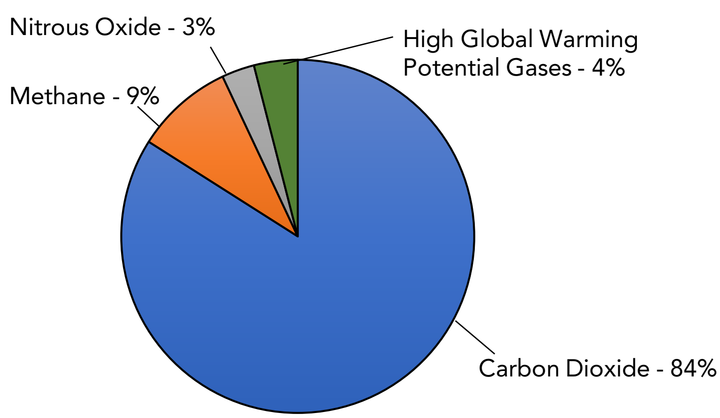

Figure 2. 2013 California GHG Emissions by Gas (Total 2013 Emissions~460 $MMTCO_2e$)

[8] 100-year GWP from IPCC AR4.
[9] California Greenhouse Gas Emissions for 2000 to 2017.
[10] California Agricultural Statistics Review 2018 to 2019.

The dairy and livestock sector has the potential to achieve significant methane emissions reduction from manure management operations at relatively low cost compared to other CCI-funded programs. Projects average $29 and $70 per $MMTCO_2e$ including both public and private funding for dairy digester and alternative manure management projects, respectively.[11,12] Enteric methane mitigation strategies also have important methane mitigation potential, but there is limited cost information available since only a few products are scientifically proven and commercially available.

Enteric fermentation is a natural digestive process that occurs within the digestive tract of ruminant animals such as cattle, sheep, and goats. In 2013, enteric fermentation emissions represented about 30 percent of California’s total methane emissions (Figure 3), with two-thirds from dairy cows and the remaining one-third from other animal types. During the digestive process, microbes in the rumen decompose and ferment plant matter, which produces methane that ruminants subsequently emit, mostly through eructation (burping). A variety of factors influence enteric fermentation emissions including breed, diet, and the presence of feed additives, with the latter offering significant potential methane emissions reductions. In general, methane emissions from enteric fermentation can potentially be reduced through selective breeding, dietary modifications that improve milk production efficiency, and the introduction of methane-reducing feed additives.

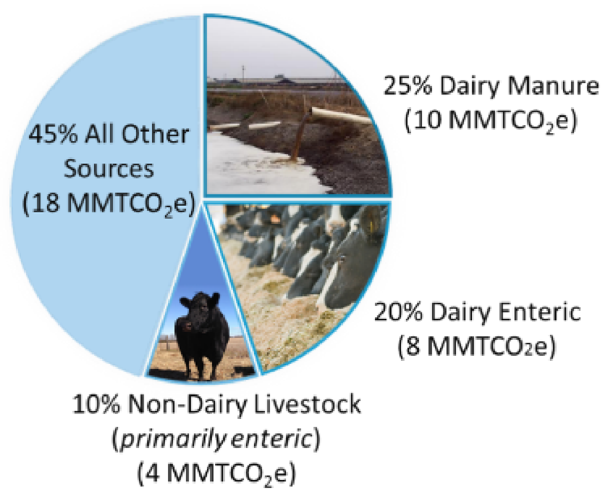

Figure 3. 2013 California Methane Emissions by Source

Anaerobic manure management and storage comprise the other main source of methane emissions at California dairy and livestock operations, accounting for about 25 percent of California’s total methane emissions. Manure management systems that

[11] Dairy Digester Research and Development Report of Funded Project from 2015 to 2019.
[12] Alternative Manure Management Program Webpage.

treat or store manure under anaerobic conditions (i.e., those common to liquid manure management lagoons) are a large source of methane emissions. Anoxic manure treatment and storage conditions, common in manure settling basins and storage lagoons, are conducive to methanogenic bacteria producing methane from volatile solids. Methane emissions from anaerobic manure management can be mitigated through capture and destruction, or through avoidance of production.

Two types of projects—dairy digesters and alternative manure management projects—effectively reduce a significant amount of methane emissions from dairy and livestock operations. Dairy digesters involve installation of an anaerobic digester to capture biomethane produced from dairy waste for beneficial end-uses including but not limited to onsite electricity generation to offset facility needs, or delivery to the electrical grid. Upgraded biomethane that meets utility pipeline specifications set by the California Public Utilities Commission (CPUC) can also be injected into the natural gas pipeline network to offset use of fossil natural gas in multiple sectors. Use of upgraded biomethane in vehicles in place of diesel also provides the additional co-benefit of reducing nitrogen oxides (NOx) emissions. Dairy biomethane can also be used as a heat source in industrial application, or as a feedstock for low carbon fuels including renewable hydrogen and dimethyl ether. The biomethane produced is eligible for credits in CARB's LCFS program, the Federal Renewable Fuels Standard, or CARB's Cap-and-Trade offsets program, which act as an ongoing revenue stream for facilities to help offset the initial high capital costs of development as well as support the ongoing operational costs of the digester.

Alternative manure management practices reduce the amount of manure (and volatile manure solids) managed or stored under anaerobic conditions; the goal of these practices is to limit methane production and emissions. Examples of effective alternative manure management practices include conversion to "solid," "dry," or "scrape" manure management; installation of a compost-bedded pack barn; increase in the time animals spend on pasture; or implementation of solid-liquid separation technology into flush manure management systems (e.g., various types of mechanical separators and weeping walls). Other alternative manure management strategies that may result in methane emissions reductions include but are not limited to acidification, which involves the application of acid(s) to animal manure to reduce emissions; vermifiltration, which is an aerobic decomposition process that produces worm castings; and chemical flocculation, which involves using polymers to increase the solid separation rate from animal manure streams. A more detailed overview of these and other alternative manure management practices is available in the Newtrient technology catalog—a source of information on manure management practices that can reduce environmental impacts.[13]

These practices can also provide important environmental co-benefits including improved water quality and nutrient management, and more easily exportable manure solids. For example, dairies can contribute to groundwater pollution through nitrate and salt leaching when overapplying manure to cropland, however, these components may replace synthetic fertilizer or improve soil health in other regions. Exporting excess nutrients and solids may also help dairy and livestock operations comply with water quality requirements. In California, dairy manure is largely managed in liquid form, making it difficult and cost-prohibitive to export without solid-liquid separation. Certain alternative manure management practices can remove manure solids, nitrogen, and salt from the manure stream and concentrate them in the solids that can be more readily exported as organic fertilizer or converted them into environmentally benign end products such as nitrogen gas. Manure solids may be further processed into value-added manure products like compost or soil amendments that can provide additional revenue, though market development remains a barrier. Alternative manure management strategies also provide flexibility to operations seeking to reduce methane emissions where a digester may be infeasible.

Through the strategies described above, the dairy and livestock sector can make considerable progress toward achieving the target of reducing methane emissions to 40 percent below 2013 levels by 2030. This Analysis describes progress the sector has already made toward achieving the target through manure methane emissions reduction projects. It also assesses progress that may occur based on various funding scenarios, reductions in animal populations, or commercial availability of a methane-reducing feed additive. Additionally, it discusses technical and market barriers to methane emissions reductions strategies that must be overcome to achieve the 2030 target.

[13] Newtrient provides information about manure management strategies and associated environmental impacts to dairy producers through an online technology catalog. Newtrient participated in CARB's Dairy and Livestock GHG Emissions Workgroup but does not have a formal relationship to CARB. Reference to that material does not constitute an endorsement of that catalog, or any associated strategies, technologies, etc., included therein.

Analysis and Findings

Analysis Item 1: California's Dairy and Livestock Methane Emissions Reduction Progress and Projected Annual Emissions Reductions through 2030

Finding 1-1: The Sector Has Made Significant Progress, But Will Not Meet the 2030 Target without Almost a Doubling of Emissions Reductions Projects

The California dairy and livestock sector has predominantly relied on manure management strategies to achieve the methane emissions reductions directed by the Legislature. Even with limited enteric methane mitigation options, the sector is on course to achieve significant emissions reductions. Through private investments and public incentive funding programs, approximately 278 manure methane emissions reduction projects have been completed or are under construction at California's dairy farms. Of these, CCI funded 233 projects through CDFA's Dairy Digester Research and Development Program (DDRDP) and Alternative Manure Management Program (AMMP), which have been instrumental in driving manure methane emissions reduction projects at California dairy operations. DDRDP provides up to half of the capital cost of construction, and AMMP encourages private matching funds. Both programs are consistently over-subscribed, with requested funds usually about twice the amount available.

As of December 2020, 22 DDRDP and 61 AMMP projects were complete and operational. An additional 96 DDRDP and 54 AMMP projects are under construction, with expected completion by the end of 2022. The latest round of CCI funding in fiscal year (FY) 2019-20 funded 12 DDRDP and 13 AMMP projects; all are expected to be operational by the end of 2022. Aggregating the emissions reductions expected from all 233 CCI projects yields an estimated annual methane emissions reduction of 2.0 $MMTCO_2e$[14] by the end of 2022.[15] The emissions reductions counted toward the 2030 target represent over 20 percent of the 9 $MMTCO_2e$ required to achieve that target. Stated differently, CCI funded dairy and livestock projects are expected to

[14] Emissions reduction estimates are in 100-year GWP (AR4). Estimated emissions reductions using 20-year GWPs can be calculated by multiplying 100-year GWP figures in this Analysis by 2.88.

[15] These estimates do not include the anaerobic digestion projects receiving Aliso Canyon Mitigation Settlement funds, which will result in an estimated additional 0.3 $MMTCO_2e$ in annual methane emissions reductions. Since these projects count toward natural gas sector mitigation, they do not count toward the 2030 target.

reduce total methane emissions from the sector to about 9 percent below 2013 levels by the end of 2022.

CARB, in collaboration with air districts and dairy and livestock industry groups, identified as many as 45 additional manure management projects implemented or under development using only private funding throughout the State since January 1, 2013. Of these, 40 involve installation of a solid-liquid separation system, and the remaining five involve installation of an anaerobic digester. Solid separation systems reduce the amount of volatile solids that are managed anaerobically by diverting a fraction of these solids to a dry management system to produce compost, soil amendment, and bedding, preventing them from producing significant methane emissions. To estimate reductions from these projects, CARB staff used average methane emissions reductions for DDRDP and AMMP projects, respectively. The combined annual methane emissions reductions amount to 0.2 $MMTCO_2e$ from these projects, with 0.1 $MMTCO_2e$ each from digester and alternative manure management projects.

Changes in animal populations are an additional driver of methane emissions reductions, caused by factors including reduced product demand, increased costs, insufficient revenue, greater out-of-State competition, and land use changes. For example, consumer preferences may change, reducing the demand for animal-based products. Increased out-of-State competition and decreased national and international demand may also result in oversupply of products and animal population reductions. Increases in production costs for commodities like animal feed, electricity, and fuel can also have significant impacts on the financial viability of animal operations, especially when coupled with low commodity prices. In other cases, competing land uses like conversion to high-value crops or urban encroachment may lead to facility closures and animal population reductions.

Every five years, the U.S. Department of Agriculture (USDA) conducts a Census of Agriculture (Ag Census), which provides the most consistent and reliable population data available in absence of state-level activity data. As part of the Ag Census, USDA reports the number of animals by type on each farm in the U.S., allowing for state-specific population tracking, including for California's GHG Emission Inventory. USDA's two most recent Ag Census reports, from 2012 and 2017, cover dairy and livestock population changes between 2008 and 2017, and provide a basis for estimating methane emissions reductions from average annual population changes. The 2012 Ag Census also provides a reasonable 2013 baseline because it quantifies dairy and livestock populations in California by animal type as of December 31, 2012. Based on the 2012 and 2017 Ag Census reports, CARB staff calculated an average annual decline of 0.5 percent in animal populations from the sector between 2008 and 2017. Assuming that this population change trend will remain constant, methane emissions reduction attributable to sector population decreases will be ~0.13 $MMTCO_2e$ annually or 1.3 $MMTCO_2e$ total through 2022.

Adding methane emissions reductions expected from State- and privately funded manure management projects with those from expected animal population decreases yields a total methane emissions reduction in 2022 relative to 2013 of ~3.5 $MMTCO_2e$, as shown in

Table 1 below.[16] Assuming that the animal population will continue to decrease at approximately 0.13 $MMTCO_2e$ annually,[17] and not taking into account any additional funding that may be available for manure methane reduction projects beyond FY 2019-20, the total estimated 2030 methane emissions reductions would be approximately 4.6 $MMTCO_2e$. This would be just over half of the 9 $MMTCO_2e$ emissions reductions needed to meet the 2030 target – with about 4.4 $MMTCO_2e$ reductions remaining (Figure 4).

[16] Due to the time required to construct dairy methane emissions reductions projects—especially anaerobic digesters pipeline injecting biomethane (between 18 and 24 months)—a limited number of projects have been completed to date.

[17] Starting in March of 2020, California enacted shelter-in-place orders and temporary closures of public and private gathering spaces due to the global pandemic. Resulting closures of schools and restaurants likely exacerbated dairy sector economic challenges and may have lasting impacts, including accelerated facility closures and decreases in animal population. However, due to uncertainty about net long term impacts the pandemic may have on the dairy and livestock sector, this Analysis assumes that recent trends in animal population trends observed in USDA's 2012 and 2017 Ag Census change will remain consistent through 2030.

Table 1. Estimated California Dairy and Livestock Methane Emissions Reduction by the End of 2022

Reduction Type		Number of Projects Funded through FY 2019-20	Expected Emissions Reductions Through 2022 ($MMTCO_2e$)
Population Change		Not Applicable	1.3
Anaerobic Digester	State-funded (DDRDP)	118	1.8
	Privately funded	5	0.1
Alternative Manure Management Practices	State-funded (AMMP)	115	0.2
	Privately funded	40	0.1
Total		**278**	**3.5**

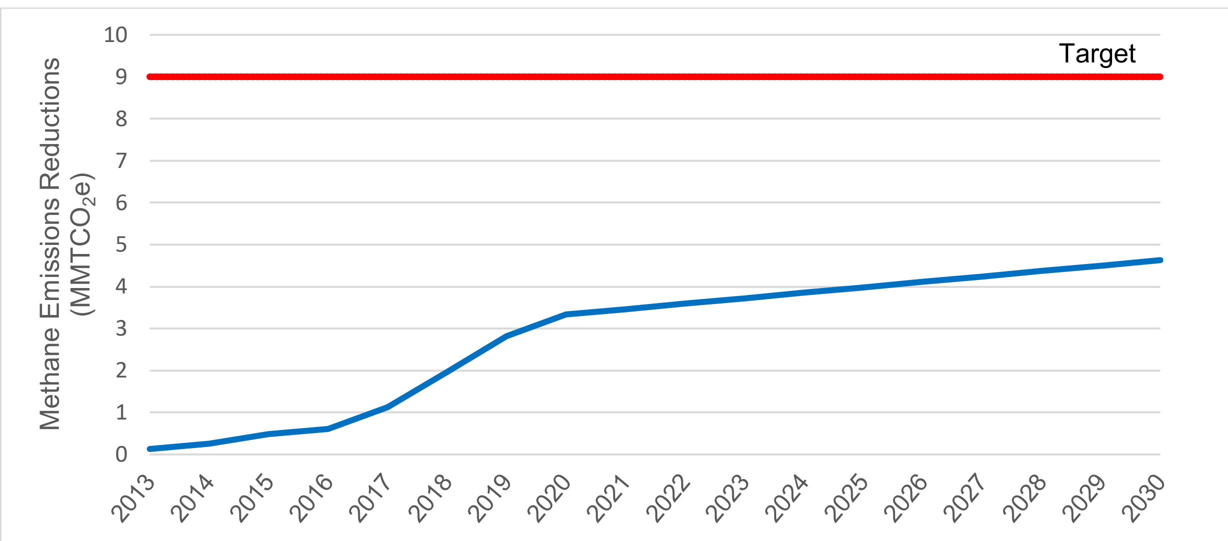

Figure 4. Projected Annual Methane Emissions Reductions through 2030 without Additional CCI Funding beyond FY 2020-21

The remaining 4.4 $MMTCO_2e$ in emissions reductions are expected to be achieved through manure management strategies but may be advanced by widespread adoption of effective enteric methane mitigation strategies. To estimate additional manure methane emissions reductions projects needed to reach the target, CARB staff used average reductions from DDRDP and AMMP projects. Staff calculated average project-level methane emissions reductions by program using figures reported by CDFA through DDRDP and AMMP. Based on the average emissions reductions, staff determined the number of additional projects necessary to achieve the 2030 target. This assumes that distribution of project types will remain roughly equal between digesters and alternative manure management projects, consistent with past practice. Based on this approach, at least 210 anaerobic digestion and 210 alternative manure management projects are necessary to achieve the remaining 4.4 $MMTCO_2e$ in methane emissions reductions. However, future project types may vary dependent upon available incentives and operator preference. If only dairy digester projects were implemented—which are about ten times as effective at reducing emissions than alternative manure management projects—over 230 projects would be necessary to achieve this level of emissions reductions. With respect to alternative manure management practices, based on currently funded projects and reduction trends observed to date, staff’s analysis indicates that the State would be unable to achieve the 2030 dairy and livestock sector target through deployment of alternative manure management practices alone. A combination of dairy digesters, alternative manure management, enteric strategies, and dairy herd size population decreases will be needed to meet the 2030 target.

Finding 1-2: Public and Private Funding Support Methane Emissions Reduction Projects

Significant allocations of CCI funding have enabled the sector to make progress toward the 2030 target. From 2014 through 2020, the Legislature appropriated approximately $289 million in CCI funds for dairy methane emissions reduction projects. These funds, administered through CDFA’s DDRDP and AMMP, have been effective in leveraging private capital investment and achieving cost-effective methane emissions reductions. With local, State, and federal funding, the dairy and livestock sector will be able to implement additional projects to help meet the 2030 target. Table 2 (below) shows that dairy methane projects constructed using CCI funds through the DDRDP and AMMP have successfully leveraged over $1.60 in match funding for each CCI dollar invested.[18]

[18] DDRDP eligibility requirements include a mandatory private match contribution of at least 50 percent of initial project cost estimates. AMMP does not require private match contributions.

Table 2. Private Funding Contributions per CCI Dollar Invested

Funding Sources	Programs		Total Funding
	AMMP	DDRDP	
CCI ($ million)	$67.8	$195.5	$263.3
Private Match ($ million)	$9.9	$413.1	$423.0
Private Match per CCI Dollar Invested ($)	$0.15	$2.11	-

In addition to DDRDP and AMMP, additional State programs, including the Cap-and-Trade Program, the LCFS Program, CPUC's Bioenergy Market Adjusting Tariff (BioMAT), CPUC's Renewable Gas Pipeline Interconnection Incentive Program and CPUC's SB 1383 Biomethane Pipeline Injection Pilot Project Program, have supported dairy and livestock methane emissions reduction projects through credit generation and grants, and other bioenergy and biofuel incentives. To date, more than $1 billion in combined public and private funding has supported approximately 280 anaerobic digester and alternative manure management projects. Additionally, public funds have supported rate-recoverable programs for biomethane pipeline interconnection infrastructure, which help deliver biomethane to end users.

The Strategy recommended a minimum funding amount[19] of at least $100 million per year for five years as necessary to accelerate significantly project development by offsetting capital costs and economic risks for manure management methane emissions reduction projects. CARB and CDFA, working with industry stakeholders and project developers during public development of the Strategy, estimated that $500 million would greatly increase the deployment rate of manure management projects within the State, though that amount was not estimated to be sufficient to achieve the 2030 target. To date, CDFA's DDRDP has awarded approximately $200 million in CCI funds for 118 dairy digesters, nearly an eightfold increase over the number of digesters operating prior to the availability of CCI funds. Similarly, CDFA's AMMP has awarded approximately $68 million for 115 alternative manure management projects and has greatly accelerated adoption of those practices. CARB staff estimates an additional $600 million in privately matched CCI funds, or similar public incentives, is necessary to achieve the emissions reductions still needed to meet the 2030 target through dairy digester projects. Despite considerable State investment and private match funding, incentives have not been sufficient to achieve

[19] In the Strategy, CDFA estimated that at least $100 million in the form of grants, loans, or other incentives would be needed for five years to support the development of necessary methane emissions reducing manure management projects including digesters and alternative manure management projects, as well as associated infrastructure.

the 2030 target. The FY 2019-20 CCI allocation of $34 million was considerably lower than the $99 million available in FY 2017-18 and FY 2018-19, falling $66 million short of annual funding needs. The proposed FY 2020-21 appropriation of $20 million did not materialize because of State budget cuts. The FY 2021-22 budget includes an appropriation of $32 million for CDFA's livestock methane reduction program, with priority given to AMMP.

CDFA's DDRDP projects have been the primary driver of GHG emissions reductions in the dairy and livestock sector since FY 2014-15. Prior to the availability of CCI funds, about 15 digesters were operating in California—far short of the 799 candidate dairies identified by the USDA AgSTAR program and 543 dairies identified in the Strategy[20] as necessary to achieve the 2030 target.[21] Most of the digesters installed prior to the start of CCI (2006-2013) relied heavily on public funding from CEC's Dairy Power Production Program. Emissions reductions resulting from these projects are not counted towards the target because they were online prior to the 2013 baseline year. Figure 5 below shows the number of digesters in place prior to the baseline year, the number of digesters resulting from CCI funding, and the number of additional digester projects necessary to achieve the 2030 target.

[20] The Strategy was adopted prior to the opening of the Alternative Manure Management Program and assumed that most of the necessary methane emissions reductions would result from digester installations.

[21] Noted in Table 17: Sector-wide implementation assumptions, and upfront capital costs of the Strategy.

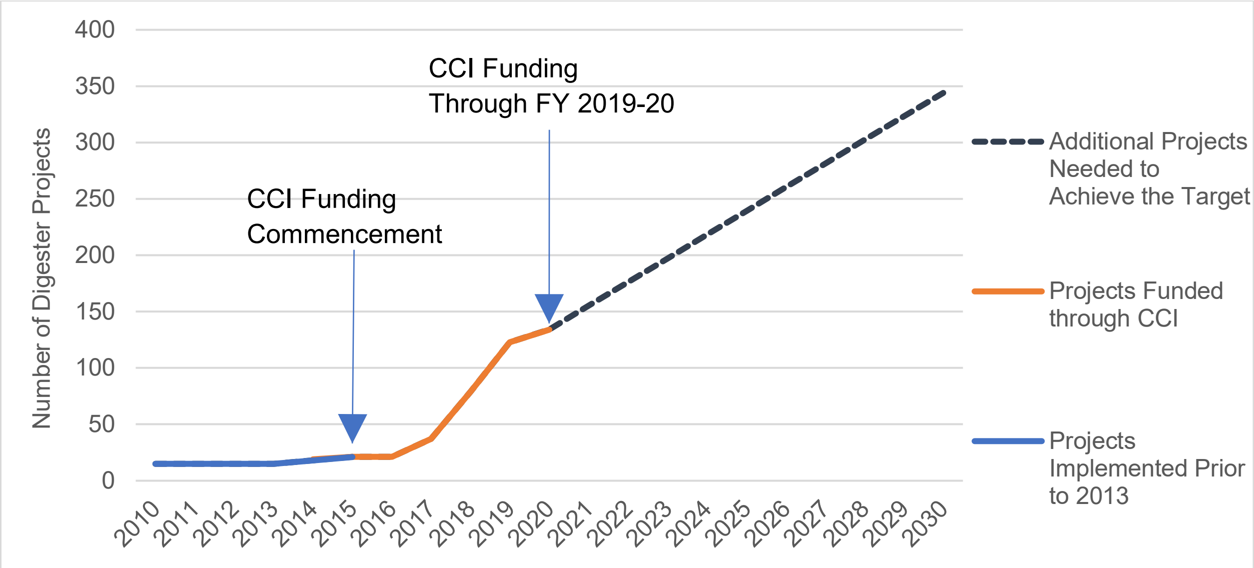

Figure 5. Number of Dairy Digesters in California[22]

Similarly, CDFA's AMMP is a primary source of funds for alternative manure management projects, which also rely heavily on public funds. Project developers are generally smaller dairies that are often not well suited to a digester because of limited financial resources, insufficient herd sizes, or other operational characteristics. While less expensive than a digester, alternative manure management projects on average cost about $600,000 per project. Unlike a digester project, alternative manure management projects do not produce bioenergy or biofuels and are not eligible to generate revenue from environmental credits. Some project developers realize cost savings from bedding purchases or sales of value-added manure products, while others—especially smaller pasture-based operations—are unable to capture any savings or revenue at all.

Infrastructure costs for digester systems producing onsite electricity from biogas including the cost to construct and install an anaerobic digester, construct conditioning facilities to upgrade biogas to necessary specifications, and either convert it to electricity using a reciprocating engine, a microturbine, or a fuel cell. These costs range from approximately $3 million to $17 million depending on the configuration and biomethane utilization option chosen, with average costs between $4 million and $7 million. Infrastructure costs to produce onsite electricity at the lower end assume that a project uses a reciprocating engine generator to produce onsite electricity, while upper end costs (~$17 million) assume the use of a solid oxide fuel cell. Infrastructure costs for digester systems that produce biomethane for pipeline

[22] Numbers shown in Figure 5 do not include the five privately funded dairy digester projects implemented since 2013.

injection (or trucking to injection point or fueling station) including the cost to install an anaerobic digester and a biogas upgrading facility. These costs range from $3 million to $16 million. Project variables include distance to the pipeline and whether the project is on a single dairy or part of a cluster of dairies.

According to CCI reports published to date, DDRDP and AMMP have delivered some of the most cost-effective GHG emissions reductions on a per-metric ton CO_2e basis compared to other CCI funded programs. Table 3 details State, private, and total investments into dairy manure methane emissions reduction projects.

Table 3. Estimated Cost Effectiveness of California Dairy and Livestock Methane Emissions Reductions through 2022

Program	State Investment ($/MTCO$_2$e)	Private Investment ($/MTCO$_2$e)	Total Investment ($/MTCO$_2$e)
DDRDP	$9	$20	$29
AMMP	$61	$9	$70

Alternative manure management projects can be further subdivided into three project types, including compost bedded pack barns, flush-to-scrape conversions, and solid-liquid separation systems. Methane emissions reduction potential and cost-effectiveness varies across these project types. Table 4 shows the average methane emissions reductions and cost-effectiveness of these alternative manure management project types. According to the table, solid-liquid separation projects have the highest per-project average methane emissions reductions and the lowest implementation costs among these alternative manure management practices. Importantly, site-specific conditions affect methane reductions potential and cost-effectiveness across all project types.

Table 4. Estimated Methane Emissions Reduction Potential and Cost-Effectiveness of Alternative Manure Management Projects through 2022

AMMP Practices	Reduction per Project (MTCO$_2$e)	Cost-effectiveness ($/MTCO$_2$e)	
		State Investment	Total Investment
Compost Bedded Pack Barn	1,880	$73	$91
Flush-to-Scrape Conversion	1,420	$78	$88
Solid-Liquid Separation	2,120	$54	$58

In addition to public funding of digester construction costs, incentive funds and other mechanisms are available to provide ongoing support to project developers. This includes the BioMAT, the Cap-and-Trade Program, and the LCFS Program. The Cap-and-Trade Program allows dairy digester developers to quantify the methane emissions reductions resulting from the installation of a digester using the CARB Compliance Offset Protocol for Livestock Projects. These methane emissions reductions can generate carbon offset credits that developers can sell to capped entities. The Cap-and-Trade Program is designed to encourage capped entities to reduce their GHG emissions while providing flexibility in how those reductions are achieved. The LCFS Program is designed to reduce the average carbon intensity of transportation fuels[23] in California by incentivizing the production and use of low carbon fuels. Alternative fuels like biomethane generate credits in the LCFS program that can be sold to entities generating deficits for supplying high carbon fuels for sale in California.

Dairy digester projects are increasingly participating in the LCFS credit market,[24] where credit prices averaged $192 in 2019.[25] A hypothetical 3,000 milking cow dairy supplying transportation fuel could generate approximately $3.5 million in annual LCFS credit value.[26] Equivalent emissions reductions from the same dairy project might generate $250,000 in annual compliance offset credit value through the Cap-and-Trade Program, using the weighted average price for livestock offset credit transfers.[27,28] However, these potential credit revenue values do not include project-specific variations in additional revenue streams or costs, which may be considerable, even among projects with similar sizes and designs. While dairy digesters offer significant and cost-effective methane emissions reductions, without large-scale public incentives, the rate of adoption would likely decrease greatly. Incentives such as the

[23] Information on current fuel pathways can be obtained through the CARB Current Fuel Pathways Spreadsheet, which is searchable and sortable, by feedstock, fuel, classification, and/or facility name. Accessed in December 2020.

[24] Anaerobic digester projects cannot simultaneously generate both LCFS and Cap-and-Trade credits.

[25] Monthly LCFS Credit Transfer Activity Reports. Accessed in August 2020.

[26] The LCFS credit value represents potential gross revenue from sale of LCFS credits in 2020; this does not include revenues from the sale of fuel, nor the potential revenue from sale of Renewable Identification Numbers (RIN) under the federal EPA Renewable Fuel Standard (RFS). Project development costs are not included in these estimates due to significant variability; costs may include but are not limited to project feasibility, design, and interconnection studies, digester and gas upgrading equipment and installation, and pipeline interconnection infrastructure construction.

[27] Cap-and-Trade Compliance Offset Credits from livestock projects were valued at $13.67 on average per metric ton for transactions occurring in 2019. Summary of Market Transfers Completed in 2019.

[28] Offset credit revenue from livestock projects may vary considerably, even across similarly sized and designed projects resulting from variations in project costs, location, and additional revenue streams. The gross revenue values provided in this Analysis are intended to illustrate potential offset credit revenue for programmatic comparison but may not accurately describe actual net project revenues.

Cap-and-Trade Program, LCFS Program, or RFS Program significantly improve the attractiveness of investment in digester projects.

Finding 1-3: The 'Social Cost of Methane' Metric Cannot be Used to Determine the Net Societal Benefits or Disbenefits of Methane Emissions Reduction Projects Comprehensively; Methane Reduction Benefits or Disbenefits Vary by Project Type

In addition to mandating SLCP emissions reductions, the Legislature passed AB 197 (Garcia, Chapter 250, Statutes of 2016), which directs CARB to consider the social costs associated with GHG emissions mitigation rules and regulations. The social cost of methane is a measure of the long-term damages caused by emitting one ton of methane in a given year. Using the methodology developed in 2009 by a federal interagency working group convened by the U.S. Council of Economic Advisors and the Office of Management and Budget, CARB staff estimated the potential range in the social cost of methane emissions from 2015 through 2030 in the 2017 Climate Change Scoping Plan.[29] The current analysis focuses on the social costs of methane emissions in 2030 using different discount rates[30] in 2020 dollars[31]—or the value today of preventing environmental damages in the future (Table 5).

The social cost of methane is a metric that can contribute to understanding the societal benefits or disbenefits that accrue from reducing methane emissions. The social cost of methane accounts for damages that occur from the release of methane, including damages due to changes in human health, changes in net agricultural productivity, property damages from increased flood risk, changes in energy system costs, non-market amenities (based on outdoor recreation), and changes to human settlements and ecosystems. Importantly, the models used to estimate the social cost of methane emissions cannot assess the monetary value of all physical, ecological, or economic impacts of climate change. As such, actual societal benefits or disbenefits could differ considerably from the calculated values used in this analysis.

Furthermore, when conducting a complete cost benefit analysis, net societal benefits from a specific project may accrue despite an estimated project disbenefit (negative values shown in Table 5) associated solely with the social value of reducing methane

[29] More information is available in Table 8 in the 2017 Climate Change Scoping Plan.

[30] Discount rate is the rate at which society is willing to trade present benefits for future benefits. Discount rate affects decision making parameters including net present value, cost-effectiveness ratio, internal rate of return, return on investment.

[31] All social cost values have been adjusted to 2020 dollars using the U.S. Bureau of Labor Statistics Historical Consumer Price Index for All Urban Consumers. Accessed in December 2020.

emissions. A methane emissions reduction project may yield a social disbenefit when only accounting for methane emission reductions but may result in substantial improvements to air quality and water quality that are not quantified or monetized by only looking at the social cost of methane. For example, for the dairy and livestock sector, manure management projects such as anaerobic digesters have been successful at reducing methane emissions. The captured methane from digesters can be converted to an energy product, such as renewable electricity produced through fuel cells and internal combustion engine generators, resulting in potential net societal benefits or disbenefits associated with methane emissions reductions before considering other environmental and socioeconomic co-benefits.

Staff used the social costs of methane in Table 5 to estimate the societal benefits and disbenefits of various methane mitigation projects, including fuel cells and internal combustion engine generators at discount rates of 2.5, 3.0, and 5.0 percent. Subtracting the project investment costs from the social cost of methane estimates the net societal benefits or disbenefits of reducing methane emissions by investing in specific manure methane emissions reduction projects, solely from a methane mitigation perspective.[32] Depending on project types, societal benefits or disbenefits from reducing one metric ton of methane vary, ranging from a societal disbenefit of $2,806 to a societal benefit of $1,878. However, as previously noted, this methodology does not fully assess the monetary value of all environmental and socioeconomic co-benefits that may result from establishing these projects, nor does it fully assess any additional societal disbenefits that may arise from non-methane emissions. For example, implementing such strategies may offer improved nutrient management to farms through more precise application of manure solids to crop lands at agronomic rates and potential reductions in synthetic fertilizer use. Conversely, adoption of other methane emissions reductions strategies such as converting biogas to electricity using internal combustion engine generators may increase NOx and other air pollutant emissions, resulting in societal disbenefits. Given that most California dairies are in or near disadvantaged communities that may be disproportionately exposed to air quality impacts, ensuring air quality and other environmental benefits in these communities to the extent feasible is important, independent of the limitations to current social cost of methane estimates.

[32] The overall societal value of a project maybe positive even if a methane emissions reduction project has a social cost of methane disbenefit. Without conducting a comprehensive cost analysis of all environmental and socioeconomic factors, actual net societal benefits of a project remain unknown.

Table 5. Social Cost and Societal Benefits or Disbenefits of Reducing One Metric Ton of Methane Emissions in 2030

Discount Rate	Social Cost of Methane ($/MT CH_4)	Methane Emissions Reduction Cost ($/MT CH_4)		Net Societal Disbenefits (-) or Benefits (+)‡ ($/MT CH_4 Reduced)
		Fuel Cell	IC Engine	
5.0%	$949	$3,755	$773	$-2,806 to $176
3.0%	$1,997	$3,145	$648	$-1,148 to $1,349
2.5%	$2,496	$3,002	$618	$-506 to $1,878

Methane emission reduction scenarios shown in Table 5 assume methane is captured using a dairy digester and destroyed using either fuel cell or an internal combustion engine. These examples provide upper and lower bound estimates for net social benefits and disbenefits. (While pipeline injection projects are the most frequently implemented project types, they are not shown here because costs are highly variable based on project site. However, they would fall within the range shown.)

‡Net societal benefits or disbenefits of reducing one metric ton of methane emissions do not account for all environmental and socioeconomic co-benefits resulting from that reduction.

Finding 1-4: Feed and Manure Additive Methane Mitigation Strategies Could be Scaled to Help Achieve the 2030 Target

In addition to the manure management practices described above, additional strategies are under development to achieve further reductions from the sector. For example, certain markets have begun using additives that reduce methane emissions from enteric fermentation in ruminants, though use in North America is limited due to pending regulatory approval. Additives to reduce methane emissions from manure management are also under development. Such additives may potentially achieve important, cost-effective methane emissions reductions from dairy and livestock operations while offering increased flexibility and avoiding the significant upfront capital investment associated with installing a digester or implementing an alternative manure management practice.

Animal Feed Additives

Methane emissions from enteric fermentation in dairy and livestock account for about 30 percent of statewide methane emissions, or approximately 12 $MMTCO_2e$ annually. This presents an opportunity to achieve significant methane emissions reductions, potentially at a cost of approximately $50 per metric ton on a carbon dioxide equivalent basis.[33] Potential strategies to reduce emissions from the digestion process

[33] Assumes use of a product with a ten percent enteric methane emissions reduction effectiveness at an annual cost of approximately $48 per ton ($0.05 per cow per day) on a carbon dioxide equivalent basis.

include diet modifications, feed additives, feed efficiency improvements, and selective breeding of low methane producing animals. Of these, feed additives offer the greatest potential for sector-wide methane emissions reductions because they potentially deliver considerable methane emissions reductions shortly after adoption. In comparison, strategies like diet modifications, feed efficiency improvements, and selective breeding require a relatively long time to achieve significant emissions reductions. Unlike the manure management strategies described above, these strategies can be implemented at existing operations with minimal need to modify facility design and without significant upfront capital requirements. This makes these strategies potentially attractive for dairy and livestock operations, especially rented or leased operations.

Research suggests that certain feed additives may have promising methane emissions reduction potential. For example, 3-Nitrooxypropanol (3-NOP under the commercial name of Bovaer®),[34] has shown an emissions reduction potential between 20 and 40 percent across multiple ruminant species under various testing conditions.[35,36,37] The additive 3-NOP has undergone both laboratory-scale and on-farm testing for effectiveness in reducing methane emissions safely, and for potential impacts on animal health, reproduction, and productivity. It is a chemical product that is currently undergoing US Food and Drug Administration (FDA) approval and may become available within the next few years.[38] Nitrate is another feed additive that has shown an

[34] Mention of trade names or commercial products does not constitute or imply CARB endorsement or recommendation.

[35] Kim, S., Lee, C., Pechtl, H. A., Hettick, J. A., Campler, M. R., Pairis-Garcia, M. D. Beauchemin, K. A., Celi, P., Duval, S. M. (2019). Effects of 3-nitrooxypropanol on enteric methane production, rumen fermentation, and feeding behavior in beef cattle fed a high-forage or high-grain diet. *Journal of Animal Science*, 97(7), 2687–2699.

[36] Gonzalo, M., Stephane, D., Kindermann, M., Schirra, H, J., Denman, S. E., McSweeney C. S. (2018). 3-NOP vs. Halogenated Compound: Methane Production, Ruminal Fermentation and Microbial Community Response in Forage Fed Cattle. *Frontiers in Microbiology*, 9, 1582.

[37] Van Wesemael, D., Vandaele, L., Ampe, B., Cattrysse, H., Duval, S., Kindermann, M., Fievez, V., De Campeneere, S., Peiren, N. (2019). Reducing Enteric Methane Emissions from Dairy Cattle: Two Ways to Supplement 3-Nitrooxypropanol. *Journal of Dairy Science*, 102(2), 1780-1787.

[38] Mitloehner, F. M., Kebreab, E., Tricarico, J., Wallace, J., Gooch, C., Gibbs, C. (2020). Dairy Feed Additives to Reduce Enteric Methane Emissions. Newtrient.

emissions reduction potential between 10 and 20 percent.[39,40,41,42,43] However, existing research is insufficient to conclude that microbes in the rumen will acclimate to increased nitrate without causing adverse animal health impacts. Agolin® Ruminant,[44] an essential oil mix, has shown methane reduction potential between 10 and 20 percent for dairy cows without impacting milk yield and composition. Mootrol® Ruminant, a pelleted product made from garlic and orange extract, has also shown methane mitigation potential in both *in vitro* and *in vivo studies* [45,46] and researchers are currently investigating its long-term effectiveness in beef cattle. Both Agolin® Ruminant and Mootral® Ruminant are commercially available and are Generally Regarded As Safe (GRAS)[47] by the FDA. Novel additives, such as lemongrass and seaweed[48] have also shown emissions reduction potential but lack sufficient *in vivo* (animal) studies to demonstrate long-term effectiveness and potential impacts on

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[39] Alemu, A. W., Romero-Pérez, A., Araujo, R. C., Beauchemin, K. A. (2019). Effect of Encapsulated Nitrate and Microencapsulated Blend of Essential Oils on Growth Performance and Methane Emissions from Beef Steers Fed Backgrounding Diets. *Animals (Basel)*, 9(1), 21.

[40] Klop, G., Hatew, B., Bannink, A., Dijkstra, J. (2016). Feeding nitrate and docosahexaenoic acid affects enteric methane production and milk fatty acid composition in lactating dairy cows. *Journal of Dairy Science*, 99(2), 1161-1172.

[41] Raleng, A. O. (2008). The Potential of Feeding Nitrate to Reduce Enteric Methane Production in Ruminants.

[42] Meller, R. A., Wenner, B. A., Ashworth, J., Gehman, A. M., Lakritz, J., Firkins, J. L. (2019). Potential roles of nitrate and live yeast culture in suppressing methane emission and influencing ruminal fermentation, digestibility, and milk production in lactating Jersey cows. *Journal of Dairy Science*, 102(7), 6144-6156.

[43] Zijderveld, S. V., Gerrits, W., Dijkstra, J., Newbold, J., Hulshof, R., & Perdok, H. B. (2011). Persistency of methane mitigation by dietary nitrate supplementation in dairy cows. *Journal of dairy science*, 94(8), 4028-38.

[44] Carrazco, A. V., Peterson, C. B., Zhao, Y., Pan, Y., McGlone, J. J., DePeters, E. J., Mitloehner, F. M. (2020). The Impact of Essential Oil Feed Supplementation on Enteric Gas Emissions and Production Parameters from Dairy Cattle. Sustainability, 12(24), 10347

[45] Eger, M., Graz, M., Riede, S., Breves, G. (2018). Application of Mootral™ reduces methane production by altering the Archaea community in the rumen simulation technique. Frontier in microbiol, 9, 2094. doi: 10.3389/fmicb.2018.02094

[46] Roque, B. M., Van Lingen, H. J., Vrancken, H., Kebreab, E. (2019). Effect of Mootral—a garlic- and citrus-extract-based feed additive—on enteric methane emissions in feedlot cattle. Translational Animal Science, 3(4), 1383–1388

[47] "GRAS" is an acronym for the phrase Generally Recognized As Safe by the FDA. Under sections 201(s) and 409 of the Federal Food, Drug, and Cosmetic Act (the Act), any substance intentionally added to food is a food additive, that is subject to premarket review and approval by FDA, unless the substance is generally recognized, among qualified experts, as having been adequately shown to be safe under the conditions of its intended use, or unless the use of the substance is otherwise excepted from the definition of a food additive (https://www.fda.gov/food/food-ingredients-packaging/generally-recognized-safe-gras).

[48] Abbott, D. W., Aasen, I. M., Beauchemin, K. A., Grondahl, F., Gruninger, R., Hayes, M., Huws, S., Kenny, D. A., Krizsan, S. J., Kirwan, S. F., Lind, V., Meyer, U., Ramin, M., Theodoridou, K., von Soosten, D., Walsh, P. J., Waters, S., Xing, X. (2020). Seaweed and Seaweed Bioactives for Mitigation of Enteric Methane: Challenges and Opportunities. *Animals*, *10*, 2432.

productivity and human or animal health.

To better understand the potential contribution of feed additives in achieving the 2030 target, staff evaluated six potential enteric methane emissions reduction scenarios that focused on the use of feed additives. These scenarios shown in Figure 6 (below) illustrate potential annual methane emissions reductions resulting from the use of feed additives with methane mitigation effectiveness of 10, 30, and 50 percent,[49] representing the low, medium, and high potential of different feed additives, at adoption rates of 50 and 75 percent. The 2030 target is shown as a red dotted line at the top of the graph. At the bottom of the graph, a solid red line shows the methane emissions reductions attributed to dairy and livestock population change and manure methane emissions reduction projects already completed or under construction. It assumes that no additional projects will be implemented.[50] As the figure shows, if solely enteric feed additives are utilized beyond 2022 and no additional manure methane projects are implemented, a feed additive with a methane emissions reduction effectiveness of at least 50 percent would need to be adopted by at least 75 percent of ruminants in the sector to achieve the 2030 target.

[49] These values represent the enteric methane mitigation effectiveness of various feed additives. Ten percent represents a conservative estimate of mitigation effectiveness for currently available products; thirty percent represents a median estimated effectiveness for 3-NOP, which shows mitigation potential between 20-40 percent, and is expected to become commercially available in the near future; fifty percent represents a conservative estimate for the most effective emerging approaches, such as seaweed.

[50] Additional manure methane emissions reduction projects are expected to be developed but have been omitted from Figure 6 to illustrate the potential of feed additive-based enteric methane emissions reductions.

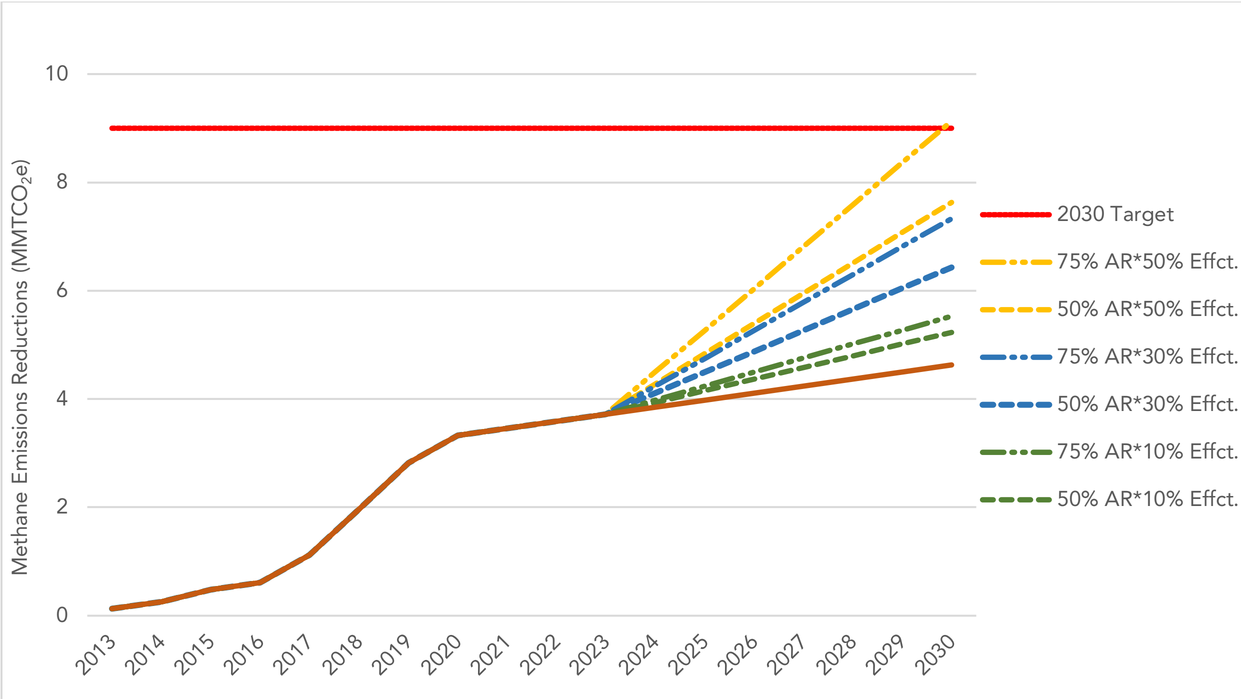

Figure 6. Projected Annual California Dairy and Livestock Sector Enteric Methane Emissions Reductions through 2030 Under Various Feed Additive Adoption Rates (AR) and Methane Mitigation Effectiveness (Effct.)

Manure Additives to Reduce Methane Emissions

Most of California's manure methane emissions originate from anaerobic manure treatment and storage lagoons. Manure additives can potentially modify environmental conditions in manure treatment and storage facilities, including but not limited to pH, redox potential, and microbial composition, to levels that are less conducive to methane production. Examples of potential manure additives include incorporation of biochar or proprietary lagoon additives, as well as the use of manure acidification. However, these strategies require additional investigation of their methane emissions mitigation effectiveness, applicability to California dairy and livestock manure management systems, and potential unintended impacts to air or water quality. For example, biochar has been shown to reduce methane emissions through incorporation into manure slurry; however, it may not be practical or effective in liquid manure management systems that are predominant on California dairy operations. Similarly, acidification of manure slurry may be effective at reducing methane emissions but may be impractical for California operations due to the need for large acid volumes that require special handling and safety equipment. CARB will continue tracking developments in manure additives as they become available, especially those with long-term studies that detail potential methane emissions mitigation effectiveness and environmental co-benefits.

Finding 1-5: Dairy and Livestock Sector May Fall Short of the 2030 Target absent an Enteric Strategy and Sufficient Public Funds[51]

To estimate potential emissions reductions from manure management projects under various public funding scenarios, CARB staff developed scenarios to extrapolate funding outcomes through 2030. These projections are based on project development costs and emission reductions described above, and do not account for environmental credit values on project costs. The impact of LCFS and RFS environmental credit prices on project economics is discussed in the following section. Figure 7 (below) illustrates potential methane emissions reductions achievable through the combination of an available enteric strategy, changes in animal populations, and from manure management projects at different levels of CCI funding assumptions.52 The 2030 target is shown as a red dotted line at the top of the graph. Potential methane emissions reductions from average animal population changes (discussed in Finding 1-1) are shown as a dark blue dashed line at the bottom of the graph.

[51] Trends discussed in this section are based on publicly available data wherever possible. In instances where available information was incomplete or insufficient, CARB staff used reasonable and conservative assumptions based on existing trends and available information.

[52] Funding projections assume that DDRDP and AMMP will fund an approximately equal number of projects, consistent with past practice.

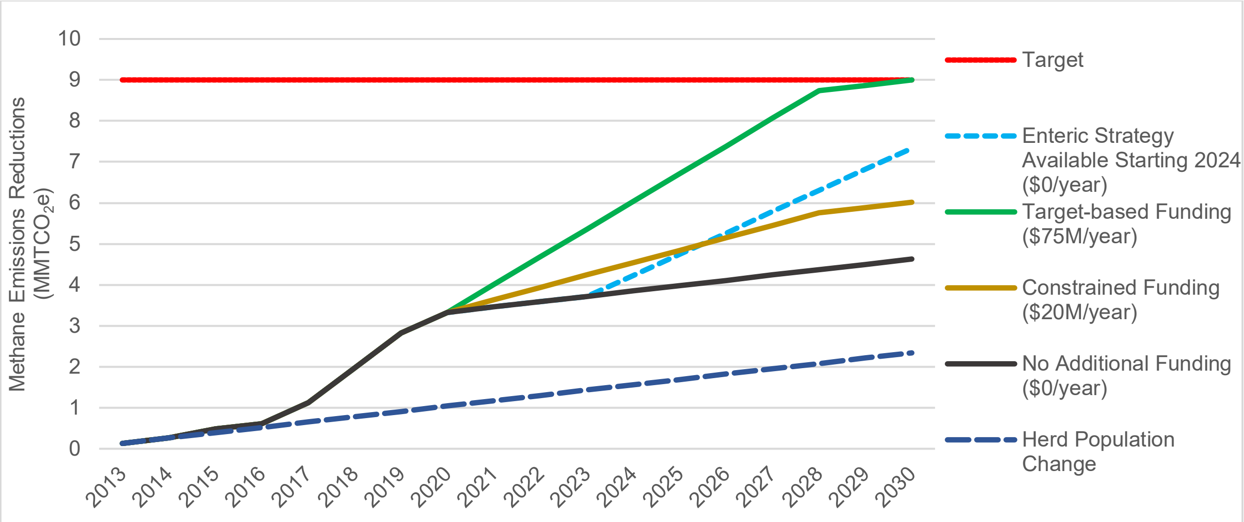

Figure 7. Projected Annual California Dairy and Livestock Sector Methane Emissions Reductions through 2030[53][54]

Additionally, Figure 7 shows methane emissions reductions expected under three different funding scenarios from FY 2020-21 through FY 2027-28 (green, brown, and dark gray solid lines).[55] It also shows potential emissions reductions from herd population changes and a potential enteric strategy (dark and light blue dashed lines, respectively). The funding scenarios assume that the observed decline in animal populations will continue at a constant rate through 2030. While emissions reductions attributable to a potential enteric strategy are shown in the figure, those emissions reductions are not accounted for in any of the funding scenarios above.

Each scenario includes emissions reductions expected from changes in population through 2030 as well as reductions expected from DDRDP and AMMP projects funded through FY 2019-20.

Incentive Funding Scenario 1: No Additional Funding

This scenario assumes that no additional appropriations of local, state, and federal funds are available for DDRDP and AMMP beyond FY 2019-20. Methane emissions reductions expected under Scenario 1 are shown in Figure 7 by the gray line labeled "No Additional Funding." This scenario assumes that funding is the limiting factor in new projects coming online. The y-axis difference between this line and the population

[53] Funding levels identified in Figure 7 do not reflect potential revenue from the generation of Cap-and-Trade, LCFS, or RFS RIN credits.
[54]Funding levels identified in Figure 7 do not reflect potential revenue from the generation of Cap-and-Trade, LCFS, or RFS RIN credits.
[55] Funding levels do not reflect private match funding that is required for DDRDP projects.

change line represents emissions reductions attributed mostly to State funds, emphasizing their importance in achieving the methane emissions reductions through 2022. Staff estimates this scenario will achieve 4.6 $MMTCO_2e$ of methane emissions reductions by 2030, falling 4.4 $MMTCO_2e$ short of the 2030 target.

Incentive Funding Scenario 2: Constrained Funding

This scenario assumes that consistent annual appropriations of $20 million for DDRDP and AMMP from FY 2020-21 through FY 2027-28. Methane emissions reductions expected under Scenario 2 are shown by the yellow line in Figure 7. This scenario assumes that allocations between DDRDP and AMMP will fund an approximately equal number of projects, consistent with past practice. With constrained funding through FY 2027-28, all funded projects will likely be operational by 2030. Staff estimates this scenario will achieve 6.0 $MMTCO_2e$ of methane emissions reductions by 2030, falling 3.0 $MMTCO_2e$ short of the 2030 target.

Incentive Funding Scenario 3: Target-Based Funding

This scenario assumes annual appropriations of $75 million for DDRDP and AMMP beyond FY 2019-20 through FY 2027-28—a level sufficient to achieve the 2030 target through manure emissions mitigation projects. This scenario accounts for a 20 percent project cost increase over current levels due to projects with smaller cattle populations and increased distances to the nearest natural gas pipeline with sufficient capacity. Methane emissions reductions expected under Scenario 3 are shown by the green line in Figure 7. Staff estimate that this scenario will achieve the 2030 target of 9.0 $MMTCO_2e$.

Enteric Strategy Scenario

Staff also estimated that a scientifically proven, cost-effective, safe, and consumer-accepted enteric methane mitigation strategy may be commercially available within the next three to five years to help achieve the 2030 target, shown by the light blue dashed line near the top of Figure 7. This assumes adoption of a feed additive with 30 percent enteric methane mitigation potential across ruminant species in California starting in 2024, and a linear annual adoption rate of approximately 11 percent through 2030, totaling 75 percent of the ruminant population.

For simplicity, the target-based funding scenario assumes that no enteric strategy will be available before 2030. Similarly, the enteric strategy scenario described below assumes that no public funding will be available beyond FY 2019-20. While both scenarios are based on reasonable estimates and are illustrative of potentially achievable methane emissions reductions, actual methane emissions reductions may vary.

While these scenarios focus on the outcomes of public investments and required private match funding to meet the 2030 target, revenue available through the California Cap-and-Trade Program and LCFS Program, as well as the federal RFS Program, can substantially reduce or eliminate the need for public funding of these projects. These revenue streams have become strong drivers of anaerobic digestion projects, helping ensure their long-term operation and financial stability.

Alternative Manure Management Practice Scenarios

Staff also evaluated the potential for different adoption rates of alternative manure management practices at California dairies to help achieve the 2030 target. As above, staff used average methane emissions reduction values to calculate potential reductions from various numbers of additional projects at California dairies. Staff also assumed that the approximately 280 dairy operations that had already implemented a manure methane strategy would not incorporate additional manure or implement enteric methane reduction strategies, leaving approximately one thousand dairies available for project implementation. Staff evaluated potential annual methane emission reductions resulting from alternative manure management project adoption under three different scenarios with 250, 500, and 750 additional dairies.

The estimated annual emissions reductions for each scenario are shown in Figure 8 (below). The 2030 target is shown as a red dotted line at the top of the graph. At the bottom of the graph, a solid red line shows the methane emissions reductions attributed to dairy and livestock population change and manure methane emissions reduction projects already completed or under construction. It assumes that no additional digesters projects and no enteric methane reduction strategies are implemented, showing the potential impact of alternative manure management projects on progress towards the 2030 target. The blue, yellow, and gray lines show expected annual emissions reductions from implementing new alternative manure management practices on 250, 500, and 750 additional dairies, respectively. On their own, none of these scenarios are estimated to provide sufficient methane emissions reduction to achieve the 2030 target.

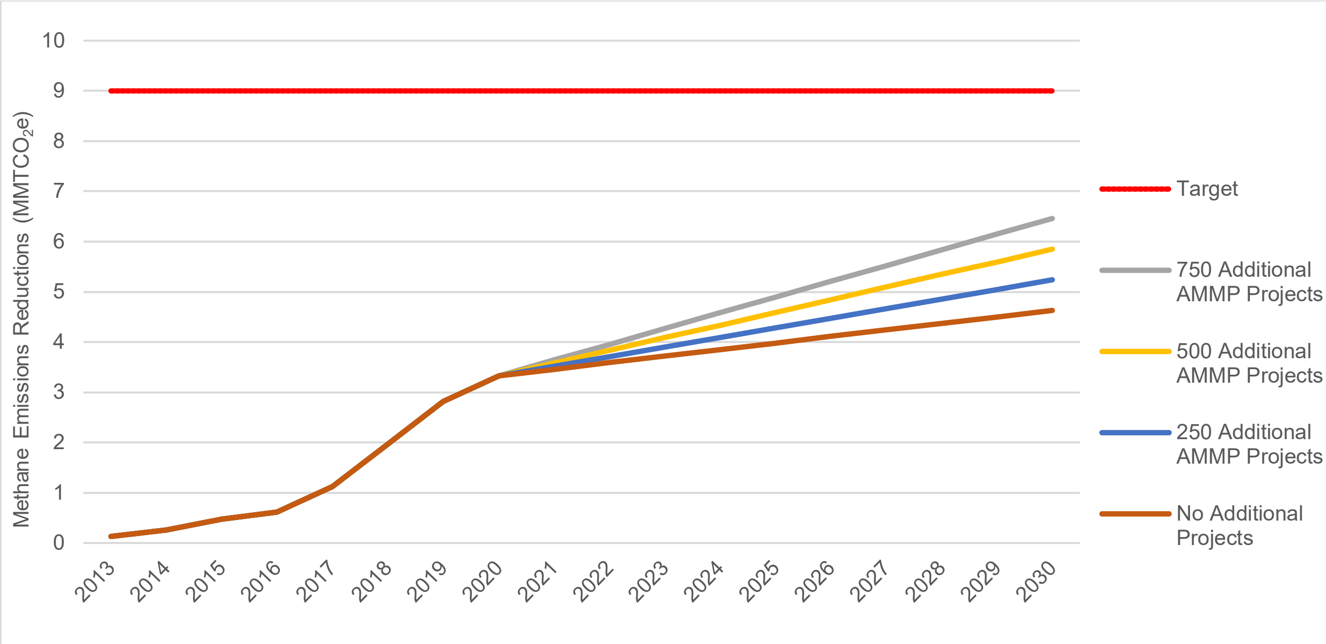

Figure 8. Projected Annual California Dairy and Livestock Sector Methane Emissions Reductions through 2030 Resulting from Implementing Additional Alternative Manure Management Projects

However, alternative manure management practices are important strategies that may provide significant additional environmental co-benefits. First, these practices may be more broadly implemented across the sector, including at small- and medium-sized dairies due to reduced upfront capital and maintenance costs compared to digesters. They may also provide flexibility to dairies with configurations that make digester implementation infeasible. Second, implementing certain alternative manure management practices alone or in combination with practices incentivized by other programs such as State Water Efficiency and Enhancement Program may provide additional water conservation and GHG benefits. These practices include conversion to scrape manure management, use of sub-surface drip irrigation, or pasture dairy conversion. Third, alternative manure management practices may improve solids and nutrient management, reduce nitrate leaching and improve water quality, reduce chemical fertilizer use, increase crop yield, and provide cost savings to dairy and livestock operations.

In addition to solid-liquid separation, compost bedded pack barns, conversion to scrape manure management, and pasture dairy conversion, stakeholders have proposed eligibility for other alternative manure management practices. These practices include but are not limited to manure acidification, vermifiltration, advanced chemical flocculation, and dissolved air flotation. Given the emergent nature of these strategies, additional research or observation at California dairy and livestock operations is necessary to evaluate methane reduction potential, long-term effectiveness, and potential unintended environmental impacts. Staff will continue monitoring deployment of these and other promising alternative manure management practices as they become available.

In some cases, alternative manure management practices can be combined with digesters to achieve greater emissions reductions than either strategy might on its own. Solid-liquid separators are commonly installed in conjunction with covered lagoon digesters to remove coarse solids, potentially reducing digester maintenance needs. These separated solids can be used for animal bedding, providing cost savings to the farmer. These same solids and nutrients can also be further processed into compost or soil amendment for onsite land application or export offsite, potentially generating additional revenue or cost savings while reducing chemical fertilizer needs. Stricter control of solids and nutrients can also help minimize water quality impacts by reducing nutrient leaching to groundwater.

Finding 1-6: Dairy Digester Development Will Need Significant Policy and Incentive Support, Providing Additional Methane Emissions Reduction Potential and Biomethane Supply

Generating environmental credits through the California Cap-and-Trade Program, LCFS Program, and federal RFS Programs can provide important revenue streams to dairy operators and project developers. As a result, these credit values are likely to drive additional dairy digester project development, methane emissions reductions, and increases in-State biomethane supply.

To estimate statewide dairy biomethane supply and production cost, staff reviewed existing literature and reports[56,57,58] as well as recent dairy population data from Regional Water Quality Control Board permits and annual reports. As part of that evaluation, and to refine supply estimates, staff adjusted underlying datasets to reflect facilities that had implemented an alternative manure management practice[59] or had closed. Staff assume that the remaining dairies can implement a digester project and

[56] Jaffe, A. M. (2016). Final Draft Report on The Feasibility of Renewable Natural Gas as a Large-Scale, Low Carbon Substitute.

[57] Jaffe, A. M., Dominguez-Faus, R., Ogden, J., Parker, N. C., Scheitrum, D., McDonald, Z., Fan, Y., Durbin, T., Karavalakis, G., Wilcock, G., Miller, M., Yang, C. (2017). The Potential to Build Current Natural Gas Infrastructure to Accommodate the Future Conversion to Near-Zero Transportation Technology.

[58] Parker, N., Williams, R., Dominguez-Faus, R., & Scheitrum, D. (2017). Renewable natural gas in California: An assessment of the technical and economic potential. *Energy Policy*, *111*, 235-245.

[59] Facilities with alternative manure management practices implementation are less likely to divert animal waste to anaerobic digesters for biomethane production.

estimate that at least an additional 210 digester projects are necessary to achieve the target (in addition to 210 alternative manure management projects).

The six project technology options below describe potential pathways to use methane captured in a digester. These options include onsite electricity production using a reciprocating engine, a microturbine, or a solid oxide fuel cell, as well as direct injection into a natural gas pipeline from a single dairy, cluster of dairies, or through trucking to an existing interconnection point where it can displace fossil natural gas. While these technology options may result in similar methane emissions reductions, criteria pollutant performance, potential carbon intensities, project costs, and project revenues may vary considerably. Staff assume that project developers will select the digester technology option that is most suitable for their facility.

Anaerobic Digestion Technology Option 1: Reciprocating Engine Generator for Electricity Generation

This technology option involves using a reciprocating engine generator to generate electricity on site using biogas and offset fossil fuel-derived electricity for a variety of end uses, including but not limited to electric vehicle charging.[60] However, reciprocating engine generators also result in new sources of air pollutant emissions that adversely impact regional air quality, attainment of ambient air quality standards, and public health outcomes. For example, the San Joaquin Valley is home to the majority of the State's dairy and livestock operations, it has among the worst air quality in the country and is home to many of the State's most disadvantaged and low-income communities. Given the potential for further impacts, utilizing even the cleanest reciprocating engine generator is the least desirable option.

Anaerobic Digestion Technology Option 2: Microturbine for Electricity Generation

This technology option involves using a microturbine certified under the CARB Distributed Generation (DG) Certification Program to generate electricity using biogas. The DG Certification Program requires manufacturers of electrical generation technologies that are exempt from air district permit requirements to certify their technologies to specific criteria pollutant emission standards before selling products in California. Common DG technologies certified under this program include fuel cells and microturbines. Microturbines have higher costs compared to reciprocating engine generators but produce fewer air pollutant emissions, and therefore have fewer associated impacts on regional air quality and public health. As with all onsite

[60] The LCFS Program includes three California dairies projects that use reciprocating engine generators, one of which received a -630.92 g/MJ carbon intensity score, the lowest LCFS carbon intensity score to date.

electricity generation projects, microturbines do not require pipeline interconnection, improving their locational flexibility compared to pipeline projects.

Anaerobic Digestion Technology Option 3: Fuel Cell for Electricity Generation

This technology option involves using a fuel cell to generate onsite electricity using biogas to support electric vehicle charging.[61] Fuel cells generate onsite electricity with very low air pollutant emissions, especially when compared to emissions associated with reciprocating engine generators. These projects provide electricity using biogas that avoids up to 90 percent of the NOx and up to 80 percent of the particulate matter emissions resulting from other combined heat and power technologies on a life-cycle basis.[62] Fuel cells installed at dairies have the potential to be certified for ultra-low carbon intensity scores, and the potential LCFS credit revenue may make them competitive in the long-term. As with all onsite electricity generation projects, fuel cells do not require pipeline interconnection, improving their locational flexibility compared to pipeline projects.

Anaerobic Digestion Technology Options 4a & 4b: Onsite Injection of Biomethane into a Natural Gas Pipeline

These technology options include either single dairy or cluster pipeline interconnection projects. These are the most common options and involve biogas capture, upgrading to pipeline biomethane specifications, and injection into a natural gas pipeline. These projects reduce GHG emissions further when they replace fossil natural gas. They also avoid onsite combustion for electricity generation and the associated onsite air pollutant emissions and public health impacts. As a result, these projects are preferable to onsite combustion projects but may not be feasible due to factors including distance to the nearest natural gas pipeline with enough capacity, and whether the facility is part of a cluster. Project cost between these two categories differ notably, with single dairy projects costing considerably more compared to cluster projects due to lack of ability to share upgrading facility and pipeline extension costs.

Anaerobic Digestion Technology Option 5: Trucking Biomethane to an Existing Interconnection Point for Injection into Natural Gas Pipeline

This technology option involves trucking biomethane to the closet injection point or natural gas vehicle refueling station. This option assumes that biomethane is

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[61] Two DDRDP projects use Bloom Energy solid oxide fuel cells.
[62] An Assessment of Energy Technologies and Research Opportunities: Chapter 4: Advancing Clean Electric Power Technologies September 2015.

transported by a zero-emissions electric or natural gas heavy duty truck with few criteria pollutant (including oxides of nitrogen) and particulate matter emissions compared to a diesel heavy-duty truck. Using natural gas or electric heavy-duty trucks reduces criteria pollutant emissions and avoids emissions of harmful diesel particulate matter from biomethane transport, with negligible impact on project cost compared to using a diesel truck. Trucking biogas, referred to as a "virtual pipeline," may reduce project costs and provide flexibility compared to construction of dedicated pipelines. It also mitigates the risk of stranded infrastructure in the event of reduced demand from a site-specific large downstream consumer (e.g., milk processing operation). Trucking biomethane to existing injection points may be a cost-effective delivery option that results in fewer emissions than reciprocating engine generator and microturbine projects. However, it will also increase vehicle miles traveled, likely in disadvantaged communities, so incentives or regulatory approaches should encourage facilities to reduce reliance on trucking where feasible and use of zero emission vehicles or natural gas heavy-duty trucks when necessary.

Potential Biomethane Supply from Anaerobic Digestion

The preceding anaerobic digestion technology options describe potential pathways to deliver biomethane to market through electricity generation or pipeline injection. This section illustrates the potential biomethane supplied to market and associated costs under each of these options in a baseline scenario, and under various environmental credit price scenarios. Figure 9 below shows potential biomethane supply and market delivery cost under a baseline scenario, which is absent any State or federal financial incentives. The dashed red line shows expected biomethane supply by 2022, approximately 4.7 trillion British thermal units (Btu). The dashed black line indicates the estimated amount of biomethane supply (~13.5 trillion Btu) needed to achieve the 2030 target. Without State or federal financial incentives like the State's LCFS Program or the federal RFS Program, none of the technology options described above (Figure 9) are financially viable.

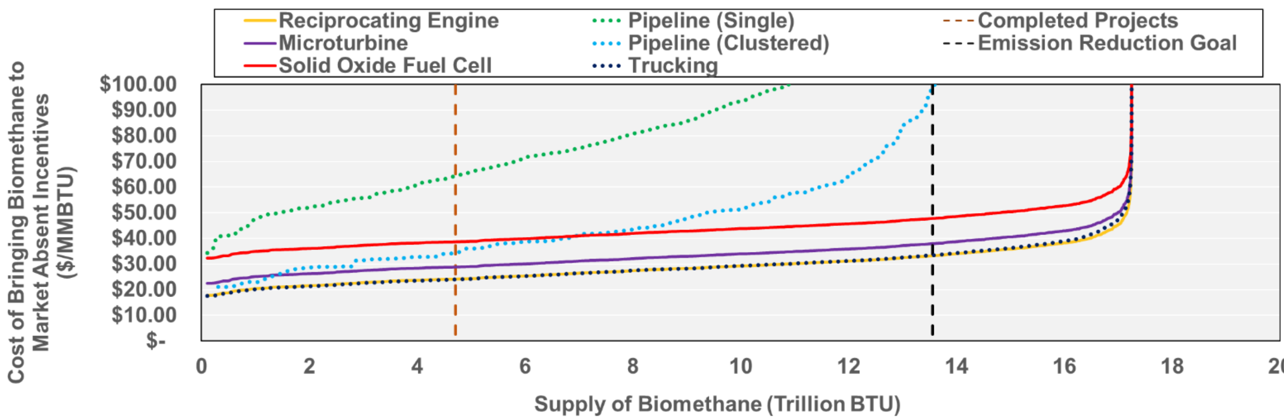

Figure 9. Biomethane Supply and Market Delivery Cost under Different Technology Options absent Federal and State Incentives

Figure 9 illustrates the cost of bringing biomethane to market under each technology option absent any public incentives (e.g., CCI funds, Cap-and Trade Program compliance offset credits, LCFS credits, RFS RIN credits). The costs portrayed for this curve and the subsequent supply curves in Figures 10 through 12 show levelized cost, and therefore includes financing assumptions for the digester projects as well as the additional capital and operating expenses associated with the technology that uses the dairy gas produced through anaerobic digestion. For instance, the levelized cost of pipeline projects is inclusive of the covered lagoon and anaerobic digestion system, upgrading the gas, building the pipeline, and injecting the gas into the pipeline. For the other technologies, the costs include any upgrading costs, as well as any additional equipment costs (e.g., solid oxide fuel cell) required to bring the gas to market.

In general, the supply curves for pipeline-based technologies have a substantially greater upward slope. Pipeline interconnection distances vary for each facility, and facilities that are further away from pipelines will have higher costs to build the network relative to facilities that are closer to pipeline interconnection points. Additionally, facilities that produce more biomethane (i.e., larger facilities) will be able to recoup fixed pipeline costs by distributing these costs over larger quantities of produced biomethane over time. As such, the lowest cost pipeline projects will generally be for large facilities that are closer to pipeline interconnections. The other technologies largely scale linearly with the size of the facility. As such, the slope for non-pipeline technologies is generally more gradual.

The cost to deliver biomethane to market may be as low as $30 per MMBtu if trucked to an existing pipeline interconnection or used to produce onsite electricity using a reciprocating engine generator. In contrast, delivering biomethane to market may cost as much as $100 per MMBtu for pipeline injection at a cluster of dairies—the costliest option with sufficient capacity to achieve the 2030 target. For comparison, in October 2020 wholesale fossil natural gas prices on Henry hub were approximately $3 per MMBtu, but has increased to approximately $5 per MMBtu in October 2021. Given that the price of fossil natural gas is approximately one tenth to one sixth that of biomethane, it is uneconomic to utilize biomethane without incentives beyond sale price.

Staff used biomethane delivery costs and volumes from Figure 9 to estimate potential costs for implementing at least 210 additional digester projects necessary to achieve the 2030 target. To be conservative, staff developed estimates using expected biomethane delivery costs from the 2030 target line to reduce potential underestimation of the total cost to achieve the target for feasible scenarios. Project costs on this line are expected to be the highest over time and assumes that more financially feasible projects have already been implemented.

To bound the potential total cost of achieving the 2030 target, staff used the solid oxide fuel cell scenario costs as an upper bound and costs associated with trucking biomethane to an existing interconnection point and producing onsite electricity using a reciprocating engine generator as the lower bound value. Though cluster pipeline projects may also potentially deliver sufficient biomethane to meet the 2030 target, this scenario is unlikely to be implemented at enough facilities to achieve the target. The costs associated with constructing additional pipelines to supply enough biomethane to achieve the target make it increasingly unlikely that the more costly projects would be implemented. Instead, it is more likely that these facilities will choose the lower cost options of generating onsite electricity or trucking biomethane to an existing interconnection point. As such, it is inappropriate to use direct pipeline injection as an upper cost bound.

Staff also assumed, as previously discussed in Finding 1-1, that at least 210 alternative manure management projects may be implemented at an assumed per project cost of $0.6 million, resulting in a total cost of $0.1 billion. Staff added this $0.1 billion to the total costs associated with the lower and upper bound cost of implementing the additional 210 digester projects. Based on these assumptions, the estimated total cost to achieve the 2030 target range from $0.8 to $3.7 billion absent any public incentives. The 2030 target may also be achieved solely through implementation of as few as 230 additional digester projects costing between $0.7 and $3.9 billion.

With public incentives like LCFS credits and RFS RINs, the need for upfront public investment in digester projects[63] may be reduced or even eliminated, assuming project developers will have access to debt financing for upfront project construction cost. These incentives can be sufficient to offset project development, operational, and financing costs in some cases depending on the level of incentive available, providing a positive project revenue stream and making the project financially viable.

Staff evaluated the same methane emissions reduction technology options used in the baseline scenario above to estimate biomethane supply and cost under various combinations of LCFS and RFS RIN credit prices.[64,65,66] These credit value scenarios range from $150-$200 per credit for LCFS and $0-$2 per RIN. Table 6 shows potential credit values from delivering one MMBtu of biomethane to market at these price ranges under different technology options. Potential credit values at such levels may make these projects competitive with fossil natural gas and with other sources of biomethane.

Table 6. Potential Environmental Credit Value ($) from Producing One MMBtu of Biomethane under Different Technology Options at Various LCFS and RIN Credit Prices[67]

Biomethane Delivery Option	LCFS $150			LCFS $200		
	RIN $0	RIN $1	RIN $2	RIN $0	RIN $1	RIN $2
Reciprocating Engine	$41	$41	$41	$55	$55	$55
Microturbine	$55	$55	$55	$74	$74	$74
Solid Oxide Fuel Cell	$64	$64	$64	$85	$85	$85
Pipeline (Single or Cluster)	$49	$62	$75	$66	$79	$92
Trucking	$44	$57	$70	$59	$72	$85

[63] Alternative manure management projects are not eligible for State and federal biomethane incentive programs because, while they do reduce dairy methane emissions, they do not produce biomethane.
[64] Assumes D3 cellulosic RIN
[65] Electricity generation projects are not currently able to generate RFS RIN credits and have been assigned a $0.00 RIN price across all evaluated credit price scenarios.
[66] Offset credits are not evaluated because the LCFS credits value is considerably more than the Cap-and-Trade program.
[67] The assumed carbon intensities, energy efficiency rating (EER), and percent efficiency rating for the identified biomethane delivery options are as follows:

- Reciprocating Engine: -490 grams per mega Joule (g/MJ), 3.4 EER, 32% efficiency
- Microturbine: -490 g/MJ, 3.4 EER, 44% efficiency
- Solid Oxide Fuel Cell: -400 g/MJ, 3.4 EER, 57% efficiency
- Pipeline (Single or Cluster): -230 g/MJ, 0.9 EER, 100% efficiency
- Trucking: -230 g/MJ, 0.9 EER, 100% efficiency

Figure 10 through Figure 12 below illustrate the potential biomethane supply and market delivery cost under three different combinations of LCFS and RIN credit prices. These scenarios illustrate a potential lower bound, a potential upper bound, and a scenario with medium credit values. They are described in greater detail below. Values below $0.00 on the y-axis provide positive revenue to projects making them financially viable because revenues exceed project costs. Conversely, values above $0.00 indicate that revenues are insufficient to offset project costs, making the projects infeasible because supply costs are too high.

Environmental Credit Price Scenario 1: $150 LCFS and $0 RIN

This scenario estimates biomethane supply and production cost assuming values of $150 for LCFS credits and $0 for RIN credits (Figure 10). Under this scenario, single dairy pipeline projects can supply approximately 1 trillion Btu of biomethane to the market, falling far short of the required volume to meet the 2030 target. Previously funded projects exceeded this capacity, which suggests that future single pipeline injection projects are not viable at these prices.

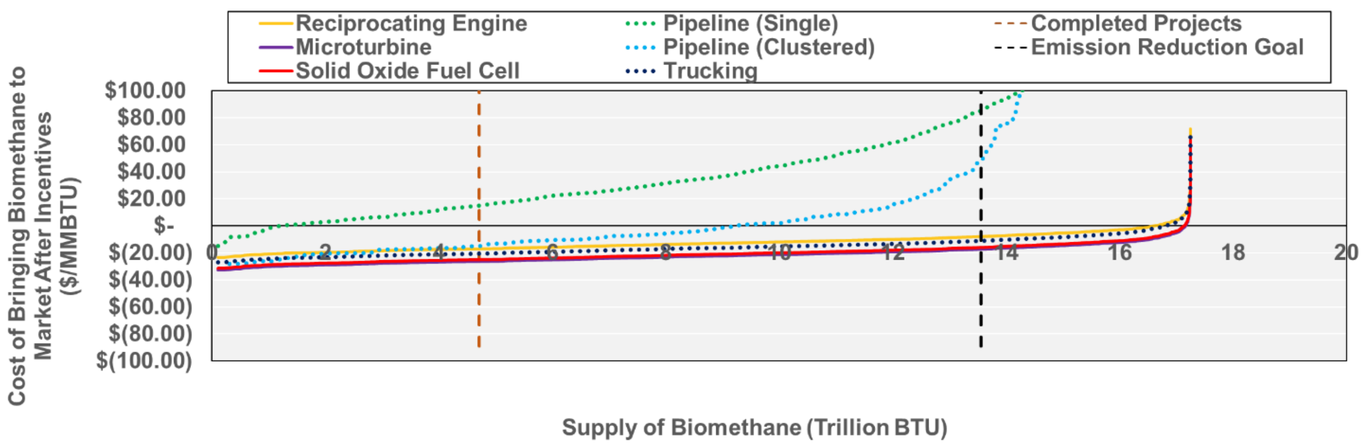

Figure 10. Biomethane Supply and Market Delivery Cost at LCFS and RIN Credit Prices of $150 and $0, Respectively

For comparison, clustered pipeline projects can supply approximately 9 trillion Btu. While a significant increase over the single pipeline projects, this still falls short of the volume required to meet the target. Under Scenario 1, both the single and cluster pipeline injection options are unable to bring sufficient dairy biomethane to market to meet the target without additional incentives.

However, biomethane-to-electricity projects and trucking biomethane to existing interconnection points may provide enough biomethane volume to the market to meet the 2030 target. In this scenario, the solid oxide fuel cell technology option generates the highest revenue with an LCFS environmental credit value of $64 per

MMBtu. Biogas-to-electricity projects that use reciprocating engines and microturbines result in less revenue but cost less than solid oxide fuel cell projects.

Environmental Credit Price Scenario 2: $200 LCFS and $1 RIN

This scenario estimates biomethane supply and production cost assuming values of $200 for LCFS and $1 for RIN (Figure 11). Under this scenario, single-dairy pipeline projects can cost-effectively supply approximately 8 trillion Btu of biomethane to the market, which is a considerable increase over Scenario 1, but still more than 5 trillion Btu short of the 2030 target. Cluster pipeline injection projects will not be able to cost-effectively supply sufficient biomethane to achieve the target either, falling short by approximately 1 trillion Btu. Consistent with Scenario 1, biogas-to-electricity, solid oxide fuel cell projects, and biomethane trucking projects can supply sufficient biomethane to achieve the 2030 target, with the latter two offering the considerably higher credit revenue. Under this scenario, only dairy pipeline injection projects would require additional incentives to achieve the target.

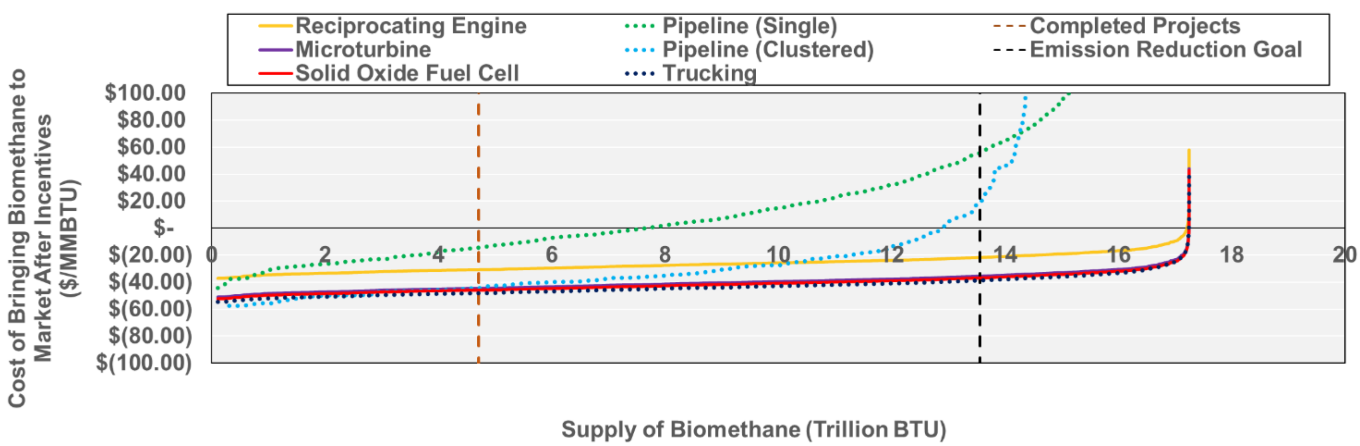

Figure 11. Biomethane Supply and Market Delivery Cost at LCFS and RIN Credit Prices of $200 and $1, Respectively

Environmental Credit Price Scenario 3: $200 LCFS and $2 RIN

This scenario estimates biomethane supply and production cost assuming values of $200 for LCFS and $2 for RIN (Figure 12). In this scenario, single-dairy pipeline injection projects can cost-effectively bring about 10 trillion Btu of biomethane to market, the highest volume across scenarios but still fall short of the target by 3 trillion Btu. Cluster pipeline injection projects can cost-effectively bring over 13 trillion Btu of biomethane to market, nearly achieving the target. Trucking projects are the most cost-effective overall resulting from credit revenue available and relatively low project development costs. Solid oxide fuel cell projects are another cost-effective option given the estimated credit value. Under this scenario, all but pipeline injection projects can cost effectively bring enough biomethane to market without the need for additional incentives.

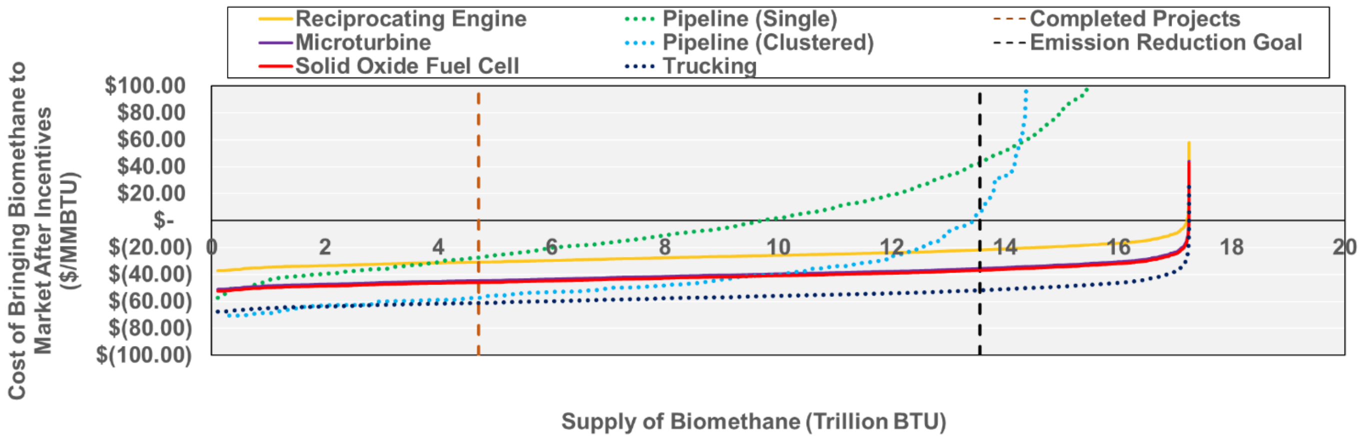

Figure 12. Biomethane Supply and Market Delivery Cost at LCFS and RIN Credits Prices of $200 and $2, Respectively

Current Federal and State Environmental Credits, Combined with Project Development Incentives, May Be Sufficient to Support Dairy Biomethane Projects

As the scenarios above illustrate, LCFS and RFS RIN credit prices are significant drivers of economic feasibility for anaerobic digestion projects at California dairy and livestock operations. This is especially true for projects that do not receive public funding. It is also clear that, given sufficient and sustained credit prices, most of these project types can cost-effectively supply sufficient biomethane to achieve the 2030 target with no additional public incentive funding, potentially reducing the need for those resources.

While each of these anaerobic digestion scenarios can potentially generate revenue or even profits to support construction and operation of digester projects, LCFS and RFS credit markets may be perceived as relatively uncertain as compared to conventional project financing options. Developers unable to obtain debt financing will need additional equity, assets, or public funding like that available through CCI to avoid delays in project implementation, or foregoing projects altogether. In these cases, local, state, and federal funding can ensure that projects will continue to move forward.

State law requires DDRDP expenditures funded by CCI to prioritize projects based on criteria pollutant emissions reduction benefits. While environmental credit prices may be sufficient to drive and sustain projects without additional public funds, the absence of these incentives may result in less desirable projects. For example, projects that use a reciprocating engine generator to produce electricity from biogas are often lower cost than other options but result in criteria pollutant impacts, potentially in some of California's most disadvantaged communities.

Similarly, trucking of biomethane to existing interconnection points may be a lower-cost option but may result in increased criteria pollutant emissions and vehicle miles traveled throughout the State. Reducing or eliminating CCI or other public funding for dairy and livestock methane emissions reduction projects may eliminate prioritization of projects that deliver important environmental and public health co-benefits.

Alternative Manure Management Projects Are Unlikely to be Implemented Without Incentives

Alternative manure management practice projects are not eligible to generate environmental credits because it is difficult to quantify methane emissions reductions relative to facility baseline emissions. This results from site-specific project variations that influence methane emissions mitigation. Variability in outcomes is a barrier to develop an offset quantification protocol for alternative manure management practices, so these projects are currently ineligible to generate carbon offset credits under CARB's Cap-and-Trade Program. As a result, financial viability is dependent on public funding, cost savings, and potential sales of value-added manure products like soil amendments and compost. In many cases, these combined savings and revenues are insufficient to offset project development costs, so public investments are critical. Without them, it is unlikely that a large number of projects will be implemented, which may impede the sector's ability to maximize its contribution to the target. These projects also provide important environmental and economic co-benefits through production of high-quality soil amendments, destruction of pathogens, reduction in nitrates and salts that threaten water quality, and production of a product that can be cost effectively transported to replace chemical fertilizer across the State.

Additional State Policies and Incentives Can Support Dairy Biomethane Projects

Long-term policies and incentives can play critical roles in supporting ongoing capture and use of biomethane from the dairy sector to achieve the 2030 target and the State's broader carbon neutrality goals. For example, a funding mechanism that incentivizes the capture of biomethane in California could expand to advance the production and use of biomethane and could provide market certainty to help project developers obtain project financing. While dairy biomethane is currently directed to the transportation fuel market through the LCFS Program, other market-based programs could play a role in directing the biomethane to alternative end uses, including towards industries that are difficult to electrify and otherwise decarbonize.

As described in the 2017 Scoping Plan Update, California must prioritize electrification wherever possible to in order to achieve its GHG emissions reduction goals. The State's electricity sector has already made considerable progress in moving toward zero- or low-GHG emissions generation, but other sectors including transportation, residential, and commercial still offer significant potential to decarbonize using electricity from sources like wind and solar. Some sectors, however, are difficult to electrify so directing dairy and livestock biomethane to these sectors can help decarbonize them, contributing to State carbon neutrality goals. The Scoping Plan Update will discuss additional policies to diversify dairy biomethane use and ensure long-term success of these projects to contribute to State's climate targets.

Analysis Item 2: Progress Made in Overcoming Technical and Market Barriers to Dairy and Livestock Methane Emissions Reductions Projects

The Strategy identifies barriers to methane emissions reductions measures that the dairy and livestock sector must overcome to achieve the 2030 target. These include technical barriers that impede project development based on various factors including technology limitations, incomplete development, or lack of standardized information. Market barriers impede project development based on factors including cost, availability of financing, environmental credit uncertainty, consumer acceptance, cost-effectiveness, and sector economics. This section will provide a short summary description of how to understand the technical and market barriers in this sector, followed by findings regarding the identified technical barriers and market barriers. Ultimately, the findings support that investment by the State and successful collaborations between agencies, developers, and stakeholders have largely overcome previously significant barriers.

Technical Barriers

Technical barriers impede both manure management methane emissions reduction projects and enteric mitigation strategy development. Specific to manure management, technical barriers impact both anaerobic digestion and alternative manure management projects. As described in the Strategy, technical barriers to anaerobic digestion include difficulties interconnecting with utility electrical grids and natural gas pipeline networks.

Technical barriers to alternative manure management projects result from inconsistent methane emissions reductions across project types and the resultant difficulty with accurately quantifying methane emissions reductions. In some cases, technical barriers may reinforce market barriers, making them even harder to overcome. For example, challenges in quantifying alternative manure management projects impedes the development of offset protocols or other market mechanisms that could improve their financial viability.

Market Barriers

Like the technical barriers discussed above, market barriers also impede both anaerobic digestion and alternative manure management projects. As detailed in the Final Recommendations to the Dairy and Livestock Greenhouse Gas Reduction Working Group, existing market barriers for manure methane reduction projects include project development costs, perceived lack of environmental credit certainty, out-of-State RNG competition, and underdeveloped markets for manure-based products. In addition to competition from out-of-State RNG, electricity and biofuels from California dairy waste faces competition from other sources of in-State renewable electricity such as solar and wind electricity, and competition from other sources of biomethane like landfills. As a result, dairy project developers rely on incentive funding or environmental credit revenues to make projects feasible. However, demand for incentives has consistently outpaced supply, especially for grant funding. Table 7 summarizes the status of progress for each technical and market barrier discussed in this section.

Table 7. Technical and Market Barriers to Implementing Manure Management and Enteric Fermentation Methane Emissions Reductions Projects

	Technical Barriers	**Market Barriers**
Manure Management	Alternative manure management projects ✗ Inconsistent reductions ✗ Difficulty quantifying reductions Anaerobic Digesters ✓ Grid and pipeline interconnection ✓ Biomethane quality standards	✓ Project development costs and financing ✓ Environmental credit certainty ✗ Sector economics ✗ Insufficient public funds ✗ Undeveloped markets for value-added manure products
Enteric Fermentation	✗ Transient effect/rumen adaptation ✗ Potential animal health impacts Limited availability ✓ Limited products with commercial availability ✗ Seasonal products	? Consumer acceptance ? Cost-effectiveness

✓ = Progress made ✗ = Persistent barrier? = Limited information available

Finding 2-1: Technical Barriers: Progress Has Been Made on Grid and Pipeline Interconnection and Biomethane Quality Standards, but Other Technical Barriers Remain

Technical Barriers to Anaerobic Digestion Projects

The dairy and livestock sector has made progress in overcoming certain technical barriers of manure methane emissions reductions projects, including access to pipeline networks and utility electrical grids. Project developers and utilities collaborated to understand technological and cost requirements for pipeline and electricity grid interconnection to reduce project development timelines.

Specific to pipeline injection projects, state agencies, utilities, project developers, and suppliers of biomethane upgrading equipment collaborated to identify technology immediately available for dairy operations to upgrade biomethane onsite.[68] Raw biogas from dairy and livestock facilities is mostly comprised of methane and carbon dioxide, with traces of many other constituents including oxygen, nitrogen, hydrogen sulfide, and water. To be injected into the utility pipeline, it must be upgraded, conditioned, and compressed to required pressures. Since the adoption of the Strategy, in Proceeding R.13-02-008, CPUC lowered the minimum heating value required for biomethane injected into natural gas pipelines. Prior to this change, achieving minimum heating value standards was a significant technical challenge and cost barrier for biomethane injection projects. This change resulted in decreased upgrading costs and removed the technical barrier without endangering public health or pipeline integrity.

In 2008, Pacific Gas and Electric Company (PG&E) interconnected the first dairy biomethane pipeline injection project, the first of its kind in California. PG&E continues to allow biomethane producers like dairy and livestock operations to interconnect to the natural gas pipeline system within their coverage area where sufficient capacity and downstream demand within the local pipeline exists. Interconnecting to the PG&E natural gas pipeline network consists of three steps. The first step involves an interconnection screening study which PG&E uses to determine the closest pipeline that can accept a producer's pipeline quality biomethane supply. Step two involves a preliminary engineering study where PG&E reviews the safest, most efficient interconnection route before developing a preliminary cost estimate for the

[68] Online Article. Xebec Enters California Dairy RNG Market with Maas Energy Works. Accessed on December 05, 2019.

interconnection. The final step consists of a detailed engineering study followed by construction of the interconnection.

In 2015, Southern California Gas Company (SoCalGas) began offering the Biogas Conditioning/Upgrading Services Tariff to allow the utility to plan, design, procure, construct, own, operate, and maintain biogas conditioning and upgrading equipment on customer premises. This optional fee service can further assist customers in their coverage area to overcome technical difficulties associated with interconnecting to the natural gas pipeline system. These potential biogas upgrading options help facilities achieve biomethane quality standards necessary for pipeline injection.

PG&E and SoCalGas are also working with dairy biomethane producers to engineer and construct pipeline infrastructure for six dairy biomethane pilot projects pursuant to SB 1383. These projects will help producers, utilities, and the State better understand the technical and economic factors affecting biomethane injection while ensuring and demonstrating successful biomethane delivery into the pipeline network. Additionally, three in-State projects that currently inject biomethane to the utility pipeline system have consistently met SoCalGas biomethane delivery specifications. In 2019, one of these projects completed construction of a digester cluster in Pixley, California and began delivering biomethane to the SoCalGas natural gas pipeline network. While costly, achieving pipeline quality specifications is technically feasible and no longer considered a technical barrier. In fact, in response to CARB's May 2020 webinar on this Analysis, SoCalGas submitted comments clarifying that the utility no longer views achieving pipeline quality specifications for biomethane injection a significant technical barrier.

Project developers and electric utilities have also overcome financial and technical barriers to accessing utility electrical grids. Interconnecting to utility electrical grids requires initial feasibility studies, which can cost several hundred thousand dollars, to outline site-specific technology requirements. Equipment and installation costs for system upgrades can be up to $1 million or more. While the costs and timelines associated with interconnections have not decreased considerably, experience from initial projects has helped to improve understanding of the processes and technical requirements and increased the deployment rate of electricity generation at dairy facilities. Three in-State dairy operations currently have certified LCFS pathways to deliver renewable electricity to the grid for electric vehicle charging with additional facilities—including two solid oxide fuel cell projects under development—that will pursue similar electric vehicle charging pathways to capitalize on potential LCFS credit revenue.

Technical Barriers to Alternative Manure Management Projects

Methane emissions reductions from alternative manure management practices vary substantially based not only on the technology chosen, but also on project-specific implementation variables. For example, a properly operated single stage slope screen solid-liquid separation system might reduce total and volatile solids sent to anaerobic storage by 17 percent. That same separation system operating in exceedance of its throughput capacity may process the same manure stream but with a reduced separation efficiency, allowing manure solids to bypass separation and proceed directly to anaerobic storage, eliminating the benefits intended by the system. Similarly, the composition of manure streams may affect the solid-liquid separation efficiency of the system with some manure streams being more readily separated than others. Such factors can cause considerable variability in solids removal and overall methane emissions reduction effectiveness, making it difficult to quantify reductions accurately and with certainty. In conclusion, alternative manure management practices have great methane emissions reduction potential, but many operational factors can affect their efficiencies, resulting in difficulties to quantify with appropriate certainty the methane emissions reductions benefits. CDFA and CARB have invested in the following research projects consistent with Dairy and Livestock Subgroup 1 Recommendations to better understand the methane emissions reduction potential of various alternative manure management practices:

- **Evaluation of Dairy Manure Management Practices for Greenhouse Gas Emissions Mitigation in California**
  In 2015, CDFA funded this University of California (UC), Davis study to measure the efficiency of various solid-liquid separation technologies. Results showed high variability across technologies resulting from factors including project design, operational capacity, and material throughput, and the associated report recommended additional research, particularly on weeping walls. This study also included an economic analysis to evaluate the cost-effectiveness of methane mitigation strategies on California dairy farms.

- **Characterize Physical and Chemical Properties of Manure in California Dairy Systems to Improve Greenhouse Gas Emission Estimates**
  In 2016, CARB funded this UC Davis research to characterize the physical and chemical properties of manure in California dairy systems.

- **Research and Technical Analysis to Support and Improve the Alternative Manure Management Program Quantification Methodology**
  In 2017, CARB funded this UC Davis literature review to assess methane emissions reduction potential of various alternative manure management practices, including solid-liquid separation and weeping walls. Results found all studied technologies had variable performance and the associated report recommended additional research on factors affecting performance of these systems.

- **Benchmarking of Pre- and Post-Alternative Manure Management Program Dairy Emissions and Prediction of Related Long-Term Airshed Effect**
  Between 2016 and 2018, CARB and CDFA collaborated to fund these complementary studies to monitor GHG and air pollutant emissions before and after implementation of various alternative manure management practices at six AMMP-funded dairies. In a separate but complementary effort, CARB installed flux towers to measure methane emissions on three of the six AMMP-funded dairies.

- **Development of the California Dairy Emissions Model**
  In 2019, CARB funded UC Davis to develop a California dairy emissions model to evaluate the effectiveness of potential mitigation strategies and to estimate GHG and other air pollutant emissions from California dairies.

Technical Barriers to Enteric Methane Mitigation Strategies

Enteric strategies, especially feed additives, hold considerable methane mitigation potential from all ruminant species. However, limited commercial availability and seasonal availability of effective feed additives, a lack of long-term effectiveness, and the potential for adverse impacts on animal health for certain products remain persistent technical barriers.

A few methane reducing feed additives with proven long-term effectiveness and no adverse impacts on animal or human health have become commercially available, indicating progress towards overcoming that barrier. However, limited availability of proven strategies remains a barrier for enteric mitigation strategies. For example, the most well-studied potential feed additive, 3-NOP, is expected to become commercially available in the United States in 2024.[69] There is a significant body of evidence to support the effectiveness of 3-NOP in reducing enteric methane emissions by approximately 30 percent. 3-NOP is currently undergoing long-term trials as part of

[69] Mitloehner, F., Kebreab, E., Tricarico, J., Wallace, J., Gooch, C., Gibbs, C. (2020). Dairy Feed Additives to Reduce Enteric Methane Emissions. Newtrient.

the FDA evaluation and approval process before final approval for commercial distribution.

Grape pomace is another additive that may reduce emissions and may not require FDA approval. However, it is only available in late summer and early fall during grape harvest, limiting its feasibility for year-round emissions reductions. Some novel additives such as seaweed also show methane emissions mitigation potential, but with limited *in vivo* (animal) studies to evaluate their long-term effectiveness and potential impacts on animal health, productivity, and product safety. For example, *Asparagopsis,* a special species of seaweed, shows mitigation potential of up to 90 percent during *in vitro* (non-animal studies using rumen simulation technologies) studies,[70] while *in vivo* studies show a mitigation potential of approximately 50 percent during enteric fermentation.[71] However, this additive is still under development, with many unaddressed technical barriers including the potential risk of elevated bromide residues in milk (a food safety concern), palatability concerns causing decreased feed intake and milk production, and low availability and high cost for the product.

Another persistent technical barrier for enteric methane mitigation strategies is limited long-term information about product effectiveness for most available or emerging options. There are a variety of products in various stages of commercial development that face barriers mentioned above. For example, some additives may impact animal health and productivity. Others may have limited long-term effectiveness due to rumen adaptation leading to rapid additive breakdown.[72] While some additives show great mitigation potential, their long-term impacts on animal health, availability, and cost-effectiveness are not well known. In short, feed additives offer promising potential as a mitigation strategy, but require further research and development before being required for use as part of any CARB regulation. SB 1383 requires that only incentive-based mechanisms are authorized for enteric emissions reductions until CARB, in consultation with CDFA, determines that another mechanism is cost-effective, considering the impact on animal productivity and must be scientifically proven to reduce enteric methane emissions, and that adoption of the enteric

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[70] Machado, L., Magnusson, M., Paul, N., Kinley, R., de Nys, R., Tomkins, N. (2015). Dose-response effects of Asparagopsis taxiformis and Oedogonium sp. on in vitro fermentation and methane production. *Journal of Applied Phycology*, 28(2).

[71] Roque, B. M., Salwen, J. K., Kinley, R., Kebreab, E., (2019). Inclusion of Asparagopsis armata in lactating dairy cows' diet reduces enteric methane emission by over 50 percent. *Journal of Cleaner Production*, 234: 132-138.

[72] Hook, S.E., André -Denis G.W., McBride, B.W. (2010). Methanogens: Methane Producers of the Rumen and Mitigation Strategies. Archaea, 11 pages.

emissions reduction method would not damage animal health, public health, or consumer acceptance.

Additional Research to Address Technical Barriers

The California legislature appropriated $5 million for research grants for FY 2021-22 to measure and verify emissions reductions associated with dairy livestock methane emissions reduction projects. Specifically, the Legislature requires additional research in the following areas:

- Assessment of the cost-effectiveness of various dairy and livestock methane mitigation strategies on a per ton basis including a comparison of projects funded under AMMP and DDRDP
- Assessment of the cost-effectiveness of enteric methane mitigation strategies
- Additional research on value-added manure-based products development
- Measurement of greenhouse gases and criteria pollutants before and after livestock methane reduction projects are implemented

These research projects will further the State's understanding of the effectiveness of anaerobic digestion and alternative manure management projects at achieving methane emissions reductions and environmental co-benefits. In addition, these studies will allow further investigation of the efficacy and cost-effectiveness of enteric strategies, should additional strategies become available.

Finding 2-2: Market Barriers: The State and Federal Incentive Programs Have Helped Achieve Progress with Project Funding and Incentives

Similar to the technical barriers detailed above, the State, along with others, have made considerable progress in overcoming market barriers to implementing methane emissions reductions projects. Improved understanding of project development costs and significant allocations of CCI funding for manure methane emissions reduction projects have contributed to progress in overcoming barriers related to project funding (Table 8).

Table 8. State Investment in Manure Methane Emissions Reduction Projects

State Investment Program	Investment ($ million)
DDRDP	$196
AMMP	$68
Pilot pipeline construction	$319
Renewable Gas Pipeline Incentive Program	$40
Total	**$623**

This Analysis has already discussed the critical role that market-based programs like Cap-and-Trade and LCFS, RFS, and grant programs like DDRDP and AMMP, have played in driving manure management project development. In addition to those programs, with year-over-year funding to support project development, the Legislature also enacted other initiatives to reduce market barriers for anaerobic digestion projects. Through SB 1383, the Legislature directed CPUC, along with CARB and CDFA, to select six pilot projects to demonstrate biomethane injection into the common carrier pipeline network. This pilot program committed $319 million in rate-recoverable funding to 45 dairies for pipeline infrastructure and operational expenses over 20 years with no private match funding requirement.[73] These projects will provide valuable information on pipeline interconnection processes and the associated costs.

CPUC also administers BioMAT, which provides long-term power purchase agreements with a guaranteed price to projects that generate onsite electricity from certain biogenic feedstock and deliver that electricity to the grid. This market program allows three utilities (Pacific Gas and Electric Co., San Diego Gas & Electric Co., and Southern California Edison) to offer favorable rates to onsite generation projects using a market adjusting mechanism that periodically increases the rate until there are enough market participants. BioMAT has funded two projects for a cumulative total of $8 million, with eight additional projects pending. To date, dairy electricity generation projects have filled nearly 19 megawatts (MW) of the 90 MW available. Another program administered by CPUC is the Renewable Gas Pipeline Interconnection Incentive Program, which provides cost share for dairy biomethane pipeline injection projects. The Legislature appropriated $40 million for pipeline interconnection projects, with up to $3 million in infrastructure cost share available for single-dairy projects, and up to $5 million for dairy cluster projects. Although these programs predate SB 1383, both have seen increased interest since it was enacted.

These incentive programs have been critical to funding the upfront costs of anaerobic digesters, and have also been consistently oversubscribed, which shows an unmet need for additional local, state, and federal investment. However, the availability of incentives coupled with environmental credit revenue has led to increased private investment. Private equity firms and companies have invested in anaerobic digesters, creating additional opportunities for project developers and financers. Increased private funding may result in projects that are financially solvent without upfront incentives, but these funding sources are limited. Sustained environmental credit

[73] California Public Utilities Commission. (December 3, 2018). CPUC, CARB, and Department of Food and Agriculture Select Dairy Biomethane Projects to Demonstrate Connection to Gas Pipelines.

revenue can further reduce risk to lenders and deliver quicker returns on investments, making these projects increasingly attractive to private capital.

One important consideration about the role of public funding is its ability to prioritize multiple benefits. For instance, private capital will pursue biomethane or electricity options that minimize costs and maximize revenue available through environmental credits. In contrast, the State can require funded projects to meet multiple goals. For example, CDFA prioritizes DDRDP projects that minimize environmental impacts including NOx and air pollutants and maximize the environmental co-benefits and community benefits as required by the Legislature when it passed SB 859 (Chapter 368, Statutes of 2016). Implementation of SB 859 has resulted in widespread implementation of pipeline injection projects due to their lower air quality impact compared to relatively lower-cost onsite combustion or trucking projects.

Alternative manure management practices and enteric methane mitigation strategies have not seen similar progress in project funding; without additional local, State, and federal funding, these project types are unlikely to move forward.

Finding 2-3: Market Barrier: Clarity from the State Has Improved Environmental Credit Certainty

California's Cap-and-Trade Program and LCFS Program, and the federal RFS Program, are the primary policy and programmatic mechanisms that provide environmental credit revenue for dairy digesters. To improve market certainty of the Cap-and-Trade Program and LCFS Program for dairy digesters, CARB developed the following two documents:

- Credit Generation for Reduction of Methane Emissions from Manure Management Operations helps project developers better understand potential impact to environmental credit generation that a methane emissions reduction regulation may have, to provide greater market certainty.

- The SB 1383 Pilot Financial Mechanism Paper describes a potential pilot financial mechanism that, if implemented, could improve stability and certainty around LCFS credits generated from anaerobic digestion at dairy operations. The white paper describes two potential approaches—put options and contracts for differences—to ensure that participating facilities can receive a set minimum LCFS credit price. Increasing revenue certainty helps project developers access private financing, potentially reducing or eliminating the need for long-term public support. For the mechanism to be implemented, however, it would need an administrator and initial funding. The white paper notes that CARB should not administer this program because of a conflict of interest as the LCFS Program administrator.

Finding 2-4: Market Barriers Remain for Value-Added Manure Products, Alternative Manure Management Projects, and Enteric Methane Mitigation Strategies

Despite progress, persistent market barriers for alternative manure management projects and enteric methane mitigation strategies create an enduring need for funding to support these methane emissions reduction strategies.

Market Barriers for Value-Added Manure Products

Underdeveloped markets for value-added manure products is a persistent market barrier that, if addressed, could improve the financial viability of manure management projects and provide a variety of environmental co-benefits. Most alternative manure management practices produce compost that could be further commodified to provide an additional revenue stream for dairy operators. Improved markets for such products may also drive additional upstream or downstream GHG emissions reductions. For example, manure compost typically contains fewer contaminants and has higher nutrient content than municipal green waste. Similarly, dairy-based organic fertilizers avoid the upstream GHG emissions resulting from manufacture and distribution of synthetic, fossil-based fertilizers. As a result, value-added manure products can potentially provide an important revenue stream to dairy and livestock operations that could reduce reliance on public funding.

Additionally, these products can provide important environmental co-benefits, including soil health, water retention, and potential displacement of petrochemical fertilizers. Market maturation would offer more opportunity to export nutrient-rich manure solids and reduce potential for water quality impacts from land application of manure. These benefits may be especially important in the San Joaquin Valley, where representative groundwater monitoring shows widespread water quality impacts.[74]

Despite considerable potential benefit to producers and consumers, there is limited information available about the demand for value-added manure products or the quantity that can be cost effectively delivered to the market. To help overcome market barriers and facilitate value-added manure products market development, CDFA is

[74] Shrestha, A. & Luo, W. (2017). An assessment of groundwater contamination in Central Valley aquifer, California using geodetector method. *Annals of GIS*, 23(3), 149-166.

planning to convene a focused working group to address these obstacles and improve financial viability of alternative manure management projects.

Market Barriers to Alternative Manure Management Projects

In many cases, adopting alternative manure management practices at dairies may not be cost-effective due to the lack of revenue streams to generate attractive rates of return to farmers and developers. Additionally, many of the dairies that implement these practices may not have the have the resources to diversify their operations to take advantage of new or expanded market opportunities. In the absence of public funding, these operations—often smaller and less able to capitalize on economies of scale—will need to rely on cost savings and revenue from the sale of value-added manure products (e.g., compost and soil amendment). However, the limited financial benefits of these projects are often insufficient to offset project costs. Additionally, ineligibility for environmental credits and underdeveloped markets for value-added manure products present additional market barriers. As a result, the availability of debt financing is limited.

Market Barriers to Enteric Methane Mitigation Strategies

Limited information is available for a comprehensive analysis of market barriers for enteric mitigation strategies, though market barriers may arise as options become available. However, to be viable, the market requires potential products to gain consumer acceptance and be cost-effective. SB 1383 requires cost-effectiveness of products, among other requirements, prior to requiring their use. Additives that fail to meet these requirements are unlikely to be adopted as effective enteric methane mitigation strategies.

Next Steps

Moving forward, the dairy and livestock sector must still achieve considerable methane emissions reductions to meet the 2030 target. Achieving the target will require careful consideration of potential methane emissions reductions strategies and coordination with other agencies, the dairy and livestock sector, and the public, including environmental justice and disadvantaged communities. Implemented strategies must not only reduce methane emissions from the sector sufficient to achieve the 2030 target but should also be consistent (to the extent feasible) with other State objectives. These objectives include reduced impacts to air and water quality, improved soil health, reduced impacts to environmental justice communities, and maximized GHG emissions reductions while minimizing emissions leakage. This will require coordinated action between the State and the dairy and livestock sector to overcome barriers to implementing proven methane emissions reduction projects and emerging mitigation options, especially for enteric fermentation. Improved accuracy in tracking and quantifying methane emissions reductions achieved by operational manure management projects or expected from future projects—especially alternative manure management projects and emerging enteric methane reducing feed additives—is also critical to evaluating progress toward the 2030 target. These improvements will help identify effective incentives and policies in the near-term and will aid in the design of potential regulations should that be necessary for achieving the 2030 target. The 2022 Scoping Plan Update will further assess and describe the role that the dairy and livestock sector can play to help achieve carbon neutrality.

CARB staff will continue to monitor the dairy and livestock sector's methane emissions reductions progress and refine its understanding of emissions sources, emissions reduction potential, and the achievements of incentives. CARB will continue to research additional technology options and management practices that can achieve methane emissions reductions, as well as research the effectiveness of practices used today. CARB will consider potential options to improve quantification of methane emissions reductions from manure management projects as well as ways to refine GHG emissions accounting for the sector. In order to comply with the statutory direction, CARB will consider regulation development to ensure that the 2030 target is achieved, assuming the conditions outlined in the statute are met. These next steps are described in greater detail below.

Continue Tracking Progress of Methane Emissions Reduction Projects and Funding

The State's appropriation of $289 million in CCI funds for manure methane emissions reductions to date has resulted in 233 dairy manure management projects that will achieve an estimated 2.0 $MMTCO_2e$ in annual reductions by 2022. This funding delivers some of the most cost-effective SLCP emissions reductions to date. CARB staff will continue to track the availability of local, State, and federal incentive funding, the progress of existing projects, and future projects implemented using both public and private funds. Additionally, CARB staff will continue to monitor market developments for value added manure products, and CDFA will convene a working group to reduce market barriers and improve the financial viability of alternative manure management projects.

Continue Tracking Manure Management Methane Emissions Reduction Options

CARB staff will track advancements in manure methane emissions reductions. Specifically, staff will continue to monitor the results of ongoing research including the monitoring emissions at AMMP project sites pre- and post-implementation, CPUC pilot pipeline infrastructure projects, methane emissions flux monitoring, literature reviews, and the development of a dairy emissions model to better understand changes from manure management methane emissions reduction projects. CARB, in collaboration with CDFA, will also continue to evaluate the potential for additional alternative manure management practices.

Continue Tracking Enteric Methane Emissions Reduction Options

There are limited commercially available animal feed for mitigating enteric methane emissions reductions additives in the United States. Some regions, including Brazil, Chile, and Europe have recently approved the use of 3-NOP.[75,76] CARB staff will continue to track the progress of these enteric methane emissions mitigation strategies, analyze their cost-effectiveness, and assess consumer acceptance.

Address GHG Emission Inventory Challenges

In addition to tracking enteric and manure methane emissions reductions options, CARB staff is evaluating options to improve the accuracy of the annual GHG Emission Inventory. Gathering operational or "activity data"[77] from facilities within the sector is an important first step to refining inventory models and associated assumptions to be more California-specific. These refinements would improve GHG Emission Inventory accuracy and inform incentive planning and regulatory development efforts.

Detailed facility activity data on the parameters that affect methane emissions should be collected annually. Specific data may include animal breed, population, production stage, diet composition, animal housing type, and the manure collection rate, storage conditions and length, treatment methods, and land application rates of manure. A more accurate accounting of these parameters can help assess methane mitigation strategies and calibrate emission models.

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[75] https://www.bloomberg.com/news/articles/2021-09-09/world-s-top-beef-supplier-approves-methane-busting-cow-feed

[76] https://www.dsm.com/corporate/news/news-archive/2022/dsm-receives-eu-approval-Bovaer.html

[77] Activity data refers to important factors that can impact emissions from dairy and livestock operations. Some example factors include animal population size, breed, age, lactation status, diet, and type of manure management.

CARB recommends a collaborative effort including public agencies and industry to gather activity data from dairy and livestock operations. Specifically, it may evaluate leveraging or modifying existing reporting structures like annual water quality reports to gather additional activity data from the sector. This approach may increase the likelihood of a high response rate, reduce resources needed to develop a new reporting structure, and reduce the reporting burdens to dairy and livestock operations. A voluntary survey of the sector could also provide useful activity data if a new or modified reporting structure is infeasible.

If these efforts are infeasible or are unsuccessful, a recordkeeping and reporting regulation developed pursuant to SB 1383[78] could provide a mechanism to obtain the necessary activity data. Reported information would be used to improve inventory accuracy, evaluate methane emissions reduction progress, and inform design of potential emissions reduction regulations, should that be necessary.

[78] Section 39730.7(h).