



Introduction

California has the largest dairy herd in the country and one of the most productive. The waste products generated by this herd can have significant impacts on air and water quality and greenhouse gas (GHG) emissions. California's dairies only account for four percent of the state's GHG emissions. However, methane emissions from dairies are a leading source of short lived climate pollution (SLCP) in California (34% excluding black carbon). Short lived climate pollutants have short lifetimes in the atmosphere compared with CO₂. Currently, scientists use a 100 year time horizon to calculate the global warming potential of GHGs. If a shorter time horizon were used (e.g., 20 years), which would more accurately reflect the impact of SLCPs, the contribution of methane (and, thus, California's dairy sector) would be much higher.

Although California dairies are required to comply with a great many air and water quality regulations, their GHG emissions have not been capped by California's pioneering climate legislation AB32 (2006). As California works towards its new mandate of 40 percent GHG reductions below 1990 levels by 2030, dairies need to be part of the solution.

Recently passed legislation, SB605 (2014), requires the California Air Resource Board (CARB) to develop a comprehensive strategy for reducing SLCP emissions. Given dairies' substantial methane emissions, they will undoubtedly be an important focus of this strategy. Reducing methane emissions from dairies will require flexible, incentive-based strategies that should be evaluated from a systems level perspective to understand their likely co-benefits (e.g., odor and pathogen reduction, air quality including VOCs and H₂S) and impact (e.g., air quality including SO_x, NO_x, and particulate matter). This document provides a brief overview of greenhouse gas emissions from California dairies and some potential abatement strategies.

1 California's 2012 GHG Inventory accounts for 58% of dairy emissions from manure and 42% from enteric fermentation. Some scientists believe that enteric fermentation in fact account for a higher portion of the dairy sector's emissions than manure.

Dairy Emissions

Dairy emissions are primarily in the form of methane, a short-lived climate pollutant. According to CARB, roughly half¹ of the GHG emissions from dairies come from manure management; the rest is from enteric fermentation (i.e., the digestion process of the cows). Assessing greenhouse gas emissions from dairies is much more difficult than assessing end-of-pipe emissions from fossil fuel combustion – dairy emissions are driven by complex biological processes and a detailed estimate requires a complete understanding of on-farm operations. That being said, California's Greenhouse Gas Inventory provides a helpful overview of emissions from dairies and where there are opportunities for abatement. According to the inventory, the manure from 58% of dairy cows is stored in anaerobic lagoons. While there are many operational reasons for lagoons being the primary means of storing dairy manure in California, they are the most GHG intensive method of manure management and the source of most of the state's manure-based emissions.

Dairy Methane Mitigation

The opportunity for realizing greenhouse gas abatement from enteric fermentation is generally believed to be quite limited in the short-term. The dairy industry has steadily increased the productivity of its herds and therefore reduced the enteric emissions per gallon of milk produced. In the near term, additional mitigation options will be quite expensive. However, enteric fermentation is a major source of methane emissions from dairy cows and is an important area for on-going research.

The abatement potential from manure management is more promising in the short-term, although the underlying economics has prevented broad uptake of these projects to-date. Manure generates methane emissions when it is broken down under anaerobic (i.e., oxygen limited) conditions, such as a manure lagoons. There are two broad approaches to reducing methane emissions from dairy manure: 1) capturing and combusting the methane created from anaerobic digestion; and 2) shifting manure storage to more aerobic (i.e., oxygen rich) environments. The following tables outline some of the main strategies for reducing GHG emissions from dairies including information on their mitigation potential, cost, revenues, GHG abatement costs, co-benefits, and associated impacts.

Mitigation Options

Options for:

Capturing and Combusting the Methane Created from Anaerobic Digestion

| | ANAEROBIC DIGESTER (AD) + ELECTRICITY | AD + COMPRESSED BIOMETHANE (CBM) | COVER AND FLARE |
|-------------------------------------|--|--|---|
| DESCRIPTION | Anaerobic digesters breakdown biomass under anaerobic conditions. This generates biogas which is captured, cleaned, and combusted in a generator to produce electricity. | Anaerobic digesters breakdown biomass under anaerobic conditions. This generates biogas, which is captured, cleaned, and compressed for use as a vehicle fuel, or pipeline injection. | An anaerobic digester is created by covering an existing manure lagoon with an impermeable cover. The biogas generated from digestion is captured and flared. |
| MITIGATION POTENTIAL | According to California's GHG inventory, emissions from ADs are 73% lower than anaerobic lagoons. Other sources estimate abatement potential of more than 90%. In addition, electricity generated from the biogas can offset fossil fuel based electricity on the grid; however, this is a relatively small fraction of overall abatement. | The mitigation potential of ADs producing compressed biomethane is about the same as digesters that produce electricity (i.e., 73% or more). The main difference is that biomethane will offset the combustion of natural gas or vehicle fuel instead of electricity on the grid. | The mitigation potential of cover-and-flare is similar to other ADs (i.e., about 73% or more), but since the biogas is simply flared there is no additional benefit from offsetting fossil fuel combustion. |
| COST | <p>Capital Costs: ADs have substantial up-front capital costs—total project cost estimates for a recent group of project proposals ranged from 1.4 to 10.1 million dollars. The most significant cost is the upfront cost of the digester itself. To produce electricity, a generation set is also needed. In addition, interconnection to the electricity grid can be expensive.</p> <p>Operational Costs: Operating costs are also significant and are likely in the range of 6–11% of capital costs.</p> | <p>Anaerobic Digester: Capital costs of the AD will be the same for CBM projects as those producing electricity. Instead of a generator producing electricity, these projects will require biogas upgrading equipment (see below).</p> <p>Biogas upgrading: Upgrading, cleaning, and compressing biogas has significant capital and operational costs—especially to meet standards for pipeline injection. There are major economies of scale for this process and so compressed biomethane projects are probably best suited for larger dairies (or dairy clusters).</p> | The capital investment of a cover and flare system will be lower than projects that generate electricity or clean and upgrade biogas, although not as much lower as one might expect. In particular, meeting requirements for criteria pollutants and water quality measures will limit the cost savings of cover-and-flare compared to more complex digester systems. |
| REVENUES | <p>Electricity generated can offset on-farm electricity use or be sold back the grid. SB1122 (2013) created a feed in tariff for manure digester projects, which will be helpful for these projects, but the tariff has yet to be implemented.</p> <p>Carbon offset credits can be generated from digester projects and are currently selling at about \$10 per metric ton.</p> <p>Solid by-products and nutrients that can be produced or extracted from the post-digestion manure can be sold or can offset on-farm costs. Markets for these products, however, are quite immature and therefore they are not typically viewed as secure revenue streams.</p> | <p>Natural gas or vehicle fuel sales, RIN, and LCFS credits: If the biomethane is used as a vehicle fuel, it can generate Renewable Identification Numbers (RINs) under the federal Renewable Fuel Standard or Low Carbon Fuel Standard (LCFS) credits under California's LCFS. These environmental credits can be very attractive financially, but are also quite volatile. Due to their volatility, and short-term contracts for vehicle fuel, lenders are reluctant to back digester projects based on these revenue streams.</p> <p>Carbon offset credits can be generated in addition to LCFS credits and RINs.</p> <p>Solid by-products and nutrients: (See left)</p> | Carbon credits: Cover-and-flare projects can generate verified carbon offsets. |
| COST OF CO ₂ E ABATEMENT | Previous national studies have estimated the cost of CO ₂ e abatement of anaerobic digesters producing electricity in the range of \$0 to \$30 per metric ton, with digesters on larger dairies being more cost-effective. The cost of abatement range for a digester project in CA today, however, is almost certainly higher. A recently completed project and another proposed project in CA have costs of abatement of about \$33 to \$45, but more data is needed to gain confidence in abatement costs in state. | Few projects have been completed that generate compressed biomethane for vehicle fuel, so there is limited data on the cost of abatement. | One study estimated that the cost of abatement for cover-and-flare projects in the Pacific region ranges between \$5 and \$9 per metric ton of CO ₂ e. Industry experts, however, felt that these estimates do not reflect the cost and complexity of a cover-and-flare project in present day California and that the cost of abatement is much higher. Unfortunately, we are not aware of any newer studies that provide a more current and California-specific abatement cost estimate. |

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| CO-BENEFITS | <ul style="list-style-type: none"> • Odor reduction • Reduction of VOCs and H₂S • Pathogen reduction • Offsets fossil-fuel based electricity • (potentially) Reduction of ammonia • (potentially) producing a form of nitrogen more readily accessible by plants | <ul style="list-style-type: none"> • Odor reduction • Reduction of VOCs and H₂S • Pathogen reduction • Offsets vehicle fuel, propane, or natural gas • (potentially) Reduction of ammonia • (potentially) producing a form of nitrogen more readily accessible by plants | <ul style="list-style-type: none"> • Odor reduction • Reduction of VOCs and H₂S • Pathogen reduction • (potentially) Reduction of ammonia • (potentially) producing a form of nitrogen more readily accessible by plants |
| NEGATIVE IMPACTS | The combustion process produces SO _x , NO _x , and particulate matter. | The combustion process produces SO _x , NO _x , and particulate matter. | The combustion process produces SO _x , NO _x , and particulate matter. |

Options for:

Shifting Manure Storage to More Aerobic Environments

Enteric Fermentation

| | FLUSH TO SCRAPE | SOLID SEPARATORS | ENTERIC FERMENTATION INTERVENTIONS |
|----------------------|--|---|--|
| DESCRIPTION | Transitioning manure management from a flush system (i.e., manure is flushed out with water) to a solid manure management system (i.e., manure is mechanically scraped out) changes the storage environment for the volatile solids in the manure from predominantly anaerobic to aerobic. | Solid separators can be used to extract solid particles from flush water before it reaches an anaerobic lagoon. If these separated solids are then stored in an aerobic environment, it will reduce overall greenhouse gas emissions from the farm because less manure, and therefore less volatile solids, will end up in the lagoon. | Methane is a byproduct of the digestion process of dairy cattle. Improved nutrition can increase the productivity of the herd and, therefore, reduce the emissions per unit of production. Supplements and additives that target methane are in the research and development stage. |
| MITIGATION POTENTIAL | Changing from anaerobic to aerobic conditions can greatly reduce the methane emissions from manure. If all of a farm's manure storage was transitioned from anaerobic lagoon to solid storage, GHG emissions could be reduced by almost 90%. | There is some uncertainty as to what portion of the manure solids can be separated from flush water. In addition, many dairies in California already use solid separators so it is unclear how much opportunity there is for more separation. That said, reductions of almost 90% are possible for every unit of manure that is separated and handled in a solid storage system instead of in a lagoon. | The mitigation potential for enteric fermentation in California is low because dairy cows in California already have good nutrition, specifically diets high in proteins and lipids. One study estimates the mitigation potential to be 16%. ² |
| COST | Costs to transition will depend greatly on the specifics of the dairy, but can be significant. On-going operations are typically more expensive than flush systems; and processing, storage, and field application of scraped manure (which has the consistency of a milkshake) can be logistically challenging. | Costs of solid separators vary significantly depending on the type of separator and whether significant infrastructure upgrades are required on the dairy. Basic mechanical separators may cost as little as \$15 to \$75 thousand, while more enhanced separators could cost upwards of \$1 million. | Based on the sparse available literature, it seems that the cost for emissions reduction through improved diet management and nutrition of dairy cattle in California is about \$250 to \$550 per mtCO ₂ e. ³ |
| REVENUES | If further processed, solid manure can be turned into valuable soil amendments (such as compost). However, the markets for such products are immature and the costs of further processing can be significant. | Separated solids may be used as bedding material which can be used on farm or sold. Compost could also be produced if the separated solids are processed further; however, the markets for manure compost are immature and the costs of further processing can be significant. | There are no additional revenue streams associated with enteric fermentation mitigation. |
| CO-BENEFITS | Some have posited that converting to scrape will yield water savings by eliminating water used to flush the lanes of the barn. However, many industry experts maintain that water savings would be small because flush water is recycled from other parts of the barn and the resulting lagoon water is used to irrigate fields. | Reducing the amount of solids in anaerobic lagoons can reduce the frequency (and therefore the cost) of dredging. | There are no notable co-benefits associated with enteric fermentation emissions reductions. |
| NEGATIVE IMPACTS | Increased particulate matter, VOCs, and (potentially) ammonia | Increased particulate matter, VOCs, and (potentially) ammonia | There may be some human- and animal-related health concerns associated with some supplements. |

2 CARB, 2008. Recommendations of the Economic and Technology Advancement Committee. Technologies and Policies to Reduce Greenhouse Gas Emissions in California.

3 Lee, et al. 2014. *Greenhouse Gas Mitigation Opportunities in California Agriculture: Review of the Economics*.

Recommendations

Although there are a wide range of options for reducing methane emissions from dairies that have been technically feasible for some time, broad uptake has been elusive. For most California dairies, none of these interventions are currently economically viable without additional incentives.

In the near term:

Incentives should be flexible in nature to accommodate the high variability across dairies, and as much as possible, they should be performance-based to ensure strong operational performance on an on-going basis.

Regulatory coordination and programs that can reduce the risk to investors (e.g. loan guarantees) will also be important for encouraging investment. This kind of risk mitigation is particularly important for projects that depend on revenue streams that are less reliable than electricity contracts (e.g., fuel contracts, carbon credits). Finally, the state might explore the development of carbon offset protocols for solid separators and conversion to flush- to scrape-based systems as well as changing to a 20 year global warming potential for carbon offset projects.

Over the long term:

Better information and data are needed on manure management systems of California dairies in order to better assess the potential of various greenhouse gas abatement strategies and the appropriate solutions for each dairy.

The emissions impacts and the economics of solid separators and conversions from flush- to scrape-based manure management systems, as well as the water savings benefits of the flush-to-scrape transition, need to be analyzed and quantified using current California-based information in order to accurately assess the advantages and disadvantages of these strategies and the kinds and amounts of incentives that may be needed to implement them more fully.

A comprehensive evaluation of the market potential of manure-based products product (e.g., cow bedding, soil amendments, and nutrient products) is warranted. Development of markets for these products over time could have an important economic benefit to GHG reduction projects on dairies.

Finally, as methane mitigation projects in California's dairy industry proliferate, it will be important to track their performance and synthesize the lessons learned.

A comprehensive tracking effort for projects going forward could refine the understanding of how much digesters should cost to build and operate and what performance metrics they should be able to achieve. Most economic data currently available is outdated and long-term performance data is lacking. This kind of tracking will allow for on-going adjustment and optimization of incentive programs.

See the full report on *Greenhouse Gas Mitigation Strategies for California Dairies* here:

http://suscon.org/news/pdfs/GHG_Mitigation_for_Dairies_Final_July2015.pdf

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Conclusion

There is no silver bullet for addressing methane emissions from California's dairies. However, if the state is committed to reducing SLCPs, then targeted support for anaerobic digesters and other methane reduction strategies for the dairy industry may well prove to be a worthwhile investment. It will certainly be important to design these strategies in a way that is economically viable for dairies; an exodus of dairies from California will not be beneficial for our agricultural communities and will not solve the world's climate problem.