# Greenhouse Gas Mitigation Strategies for California Dairies

PREPARED FOR SUSTAINABLE CONSERVATION BY
CALIFORNIA ENVIRONMENTAL ASSOCIATES

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Sustainable Conservation

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Sustainable Conservation has partnered with the dairy industry for over fifteen years to identify, test and promote management practices and technologies that protect air and water quality and reduce greenhouse gases.

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## 1. Executive summary

A bio-based economy in the Central Valley, with cheese factories and milk trucks powered by manure-derived electricity and fuel, has been a tantalizing vision for many years. Neither the ideas nor the technologies required to realize this vision are new. In fact, there has been a great deal of effort over the years to make this vision a reality by tackling the suite of barriers that have kept manure-based bioenergy from the market. Slowly and steadily, these barriers have been removed: technologies have improved; permitting has been streamlined; a dedicated bio-energy feed-in-tariff (BioMAT) has been established; and third-party developers have started to enter the market. However, the fundamental economics remain challenging. Projects that can turn dairy manure into electricity or fuel, be they digesters combined with generator sets to generate electricity or digesters combined with cleaning and compressing facilities to generate compressed natural gas for vehicle fuel, require very significant capital investments and depend on multiple revenue streams which have been uncertain and/or volatile for many years. With the establishment of a carbon offset market through California's cap and trade program, which includes an offset protocol for anaerobic digesters, and the establishment of the BioMAT, additional revenue potential is making digester projects more economically attractive. Still, these projects remain risky. Regulatory hurdles may still be significant; interconnection costs are unpredictable and potentially untenable; and there is a lack of certainty over the long-term markets for carbon offsets and other environmental credits. Further, the markets for other byproducts that can be generated alongside biogas and improve project economics (e.g., compost and fertilizers) are immature. The field seems to be at once on the cusp of rapid growth and saddled with enduring challenges.

As California begins to make deeper cuts into its greenhouse gas (GHG) emissions, looking towards its new mandate of 40 percent reductions below 1990 levels by 2030, decision makers will look more actively to agriculture as a source of further emissions reductions. The dairy sector warrants particular attention. It accounts for about four percent of the state's greenhouse gas emissions. However, dairy's contribution would be significantly higher if a shorter time horizon (e.g., 20 years instead of 100 years) was used to assess the impact of short lived climate pollutants (SLCPs), considering that the vast majority of dairy emissions are methane, a strong SLCP. The state is wisely raising the priority of SLCPs, following the passage of SB 605 (2014).

The most widely discussed solution to methane reductions in the dairy sector has been anaerobic digesters. Anaerobic digesters capture the methane generated from stored manure and convert it to biogas which can then either be used for electricity or cleaned and compressed for use as renewable natural gas or vehicle fuel. Very significant greenhouse gas reductions are possible through digesters. They can almost completely eliminate the methane emissions associated with anaerobic lagoons by capturing and combusting the biogas produced during anaerobic digestion, and can also displace fossil fuels by using the biogas to generate electricity, fuel vehicles, or replace natural gas combustion. We estimate that if digesters are installed on all of California's dairies with anaerobic lagoon manure storage, up to 6.6 mtCO2e of annual emissions could technically be mitigated (from the methane destruction alone).[1] Digesters also generate co-benefits: odor reduction, pathogen kill, and potentially improved water quality (by creating a more readily available form of nutrients for plants to up-take) and air quality (by reducing emissions of volatile organic compounds (VOCs) and hydrogen sulfide). There are downsides with digesters as well. Most notably, if they are coupled with a generator set to generate electricity, digester systems emit NOx. The San Joaquin Valley is a non-attainment area for NOx emissions, which means that any increase may pose serious health risks to the population. That said, the generator set and pollution abatement technologies have become more advanced in the last several years.

Digesters are not the only solution for reducing methane from dairies. Other, less capital intensive solutions, most notably solid separators, may also deliver significant greenhouse gas savings. Solid separators will deliver less GHG abatement and do not generate as many co-benefits as digester-based systems, but because they are less capital intensive, they may be a good option for some dairies. Solid manure management systems (i.e., scrape systems, which couple well with composting) also have the potential to reduce manure GHG emissions. However, converting a dairy from an anaerobic lagoon-based management system to a more aerobic, scrape-based system ("flush to scrape") can be expensive, complex, and have negative side effects. Scraped-based manure management systems reduce methane emissions by keeping manure out of lagoons; however, scraped manure tends to be costly and challenging to manage and can lead to increased VOC emissions. Counter-intuitively, scrape-based systems may not provide water savings because flush water has typically already been used elsewhere on the farm (e.g., for washing and cooling cattle) and will be reused again for irrigation. Thus, scrape-based systems might be best reserved for dairies that are land constrained and thus have a need to export their nutrients. For these dairies, the drier form of manure is valuable as it is less expensive to transport off of the farm.

Covering and flaring existing anaerobic lagoons can also substantially reduce GHG emissions. However, these systems have the same negative impacts (e.g., NOx emissions) as anaerobic digesters that produce electricity, but do not put the generated biogas to productive use (e.g., electricity generation, heating boilers, or vehicle fuel). While the capital investment required for cover and flare operations are lower than for digesters, they are still significant. Carbon offsets are the only revenue source from these projects and thus it may be difficult to justify the required capital investment unless carbon prices rise. Even then, systems that productively use the biogas will probably be a better option in California.

In short, a host of solutions could be deployed to significantly reduce methane emissions from California dairies. Flexibility and options for dairies are critical because different solutions will work under different conditions. Most of these solutions are expensive, and supporting policies and infrastructure are still developing. Programs to develop markets (e.g., research, development and demonstrations), efforts to smooth regulatory challenges (e.g., air quality permits for composting facilities), as well as incentives to offset the large capital costs of digesters and other equipment are all necessary to increase the adoption rates of these solutions. Although implementing methane reductions strategies on dairies will be

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[1] Calculation based on California Air Resources Board, 2014. *Annex 3B. Manure Management (IPCC 3A2) to the Technical Support Document for the 2000-2012 California's Greenhouse Gas Emissions Inventory*.

expensive, there may be no better way to control SLCPs than by addressing methane from this sector. If California is committed to reducing SLCPs, then targeted support for digesters and other methane reduction strategies for the dairy industry may well prove to be a worthwhile investment. We provide specific recommendations regarding incentives and research priorities below and in Section 8. Hopefully, over the long run, the markets for bio-gas to electricity, bio-methane for vehicle fuel, and manure-based compost and fertilizers will evolve to the point where incentives can be greatly reduced.

## 1.1 Recommendations

### 1.1.1 Short-term incentives

**Provide incentives to promote early investment by dairies in methane-reduction practices** – Because there is currently no way for most dairies to get compensated for investments in sustainability through their milk revenue, it is particularly important that the state provide incentives for investments in methane reduction solutions, especially when they provide little or no short term payoff.

**Provide flexibility to accommodate high variability across dairies** – There is no one-size-fits-all solution for reducing GHG emissions from dairies. Programs should provide general incentives that encourage the desired outcome of GHG reductions, but offer dairies flexibility as to how they can meet those objectives.

**Use performance-based incentives to the extent possible** – The methane reduction value of all strategies depends entirely on year-on-year operating performance. Incentives for strong operational performance should be put in place and should strike a balance between the amount of funding given in up-front grants and performance-based incentives after projects and/or practices are implemented.

**Provide regulatory coordination** – New or modified practices on dairies are subject to strict air and water quality regulations from several agencies, often with conflicting or duplicative requirements. Effective implementation of methane reduction strategies will require coordination between agencies.

**Revisit type and amount of up-front grant funding for digesters** – Grant programs should continue, and the potential for expanding grant availability should be explored. The processes should be streamlined, provide more certainty to applicants, and be as objective as possible.

**Reduce investment risk for digesters** – Obtaining financing for projects based on revenue streams from products other than electricity generation (e.g., carbon offsets, RINs, LCFS, and vehicle fuel contracts) is currently very challenging because these revenue streams are less secure. Incentive programs that can reduce the risk associated with lending against these revenue streams (e.g., loan guarantees) are worth exploring.

**Explore the possibility of offset protocols for solid separation and conversion from flush- to scrape-based systems** – If solid separation and the conversion from flush- to scrape-based manure management systems are viewed as important strategies for reducing GHG emissions from dairies, then it may be worthwhile to explore the possibility of developing offset protocols for these interventions.

**Use 20-year global warming potential (GWP) for carbon offset projects** – Valuing carbon offsets based on 20-year GWP values rather than 100-year GWP values would significantly enhance the economic potential of digester projects. Such a policy change may be a good way to prioritize methane (a short lived climate pollutant) reductions.

### 1.1.2 Short-term research needs

**Understand manure management practices currently in use on California dairies** – A more granular and nuanced understanding of current manure management practices on California dairies is needed in order to better assess the potential of various greenhouse gas abatement strategies and the appropriate solutions for each dairy.

**Research emissions impacts of solid separation and conversion from flush- to scrape-based systems** – The overall emissions impacts of both solid separation and conversion from flush- to scrape-based manure management systems are not well understood, though both appear to be promising greenhouse gas abatement strategies. Further study of their emissions profiles and abatement potential is warranted.

**Understand water use impacts from converting from flush- to scrape-based systems** – Although it seems that converting from flush- to scrape-based manure management systems does not generate notable water savings, further study would be helpful. A thorough assessment of water usage on dairies and how changes in manure management practices could influence overall water use could help achieve water savings on dairies as well as identify co-benefits of different GHG reductions solutions.

**Provide economic data for solid separation and converting from flush- to scrape- based systems** – There is very little information in the literature about the economics of converting dairies from flush- to scrape-based manure management systems or installing solid separation technologies. More economic data are needed 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.

**Evaluate market potential of manure-based products** – A comprehensive evaluation of the market potential of manure-based products product (e.g., cow bedding, soil amendments, peat moss substitutes, and nutrient products) that assesses their current viability, identifies areas for additional research and development, and provides recommendations for market cultivation is an important next step. Development of markets for these products over time could have an important economic benefit to GHG reduction projects on dairies.

**Integrate methane reduction strategies with other environmental criteria in order to achieve multiple benefits and avoid unintended consequences** – In order to determine what methane reduction strategies provide the most positive outcomes for multiple criteria (e.g., methane emissions, air quality, water quality, water use), we need a clear understanding of how switching from one management practice to another would either increase or decrease impacts across the environmental spectrum.

### 1.1.3 Long-term Research Needs

**Continue research on enteric fermentation** – There is an on-going body of research on methods for reducing enteric fermentation, which accounts for almost half of GHG emissions from dairies in California. We do not know enough to say whether the amount of investment going into this work is sufficient at this time, but we believe that research and investment in this area should continue.

**Continue to track and synthesize lessons learned from the performance of dairy digesters** – 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.

*Because the suite of solutions for methane reduction on dairies has not been widely adopted in California, or anywhere in the US, economic data is very limited. This paper attempts to summarize and synthesize from the available literature and a few dozen expert interviews in order to provide an overview of the economics of these solutions as well as to understand their co-benefits. Hopefully, this synthesis will help California state agencies and other key actors identify useful points of intervention and get a sense of magnitude of the necessary incentives.*

**Table 1 - Summary of greenhouse gas mitigation strategies for California dairies**

| Strategy | Upper GHG potential (vs. baseline practice) | Ability to scale (Could this practice be applied widely?) | Cost (\$/mtCO$_2$e ) | Air quality impacts | | | | | | Water impacts | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Quality | | Quantity |
| | | | | SOx | NOx | PM | VOC | Odor | $NH_3$ | N | Pathogens | |
| Anaerobic digester (AD) + electricity | 90%+[2] | Medium | ?[3] | X | X | X | ✓ | ✓ | ?[4] | ✓?[5] | ✓[6] | N/A |
| AD + compressed biomethane | 90%+2 | Low | ?[7] | ?[8] | ?8 | ?8 | ✓ | ✓ | ?4 | ✓?5 | ✓6 | N/A |
| Cover and flare | 90%2,[9] | Medium | ?[10] | X | X | X | ✓ | ✓ | ?4 | ✓?5 | ✓6 | N/A |
| Flush to scrape | 50-90%[11] | Low | ? | ?[12] | ?[12] | X[12] | X | ? | X? | ?[13] | ? | ?[14] |
| Solid separators | ?[15] | Medium | ? | ?[12] | ?[12] | X[12] | X | ? | X? | ?[13] | ? | N/A |
| Enteric | 3-20%[16] | High | \$244 - 544[16] | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

**Legend**

✓ – Improvement compared to anaerobic lagoon baseline; **X** – Worse relative to anaerobic lagoon baseline

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[2] GHG emissions per dairy cow are 73% lower for anaerobic digesters than anaerobic lagoons in California's 2012 Greenhouse Gas Inventory. Other sources indicate mitigation potential of ~92% (*Owen, et al. Greenhouse Gas Mitigation Opportunities in California Agriculture*). Additional GHG mitigation potential ("+") from displacement of fossil fuel.

[3] National studies indicate cost of abatement between ~\$0 and ~\$40 depending on dairy size, but studies rely almost exclusively on digester cost data compiled by AgSTAR that is believed to be outdated and not applicable to California (See main text body for details on some of these studies). Cost in California will be higher than prior estimates (See text body for more detail).

[4] Some studies indicate decreased ammonia emissions with anaerobic digesters (San Joaquin Valley Dairy Manure Technology Feasibility Assessment Panel, 2005. *An Assessment of Technologies for Management and Treatment of Dairy Manure in California's San Joaquin Valley*), while others have found that ammonia emissions can increase during storage of digestate, but may have lower emissions when field applied (Ma, et al., 2015. *Dairy Manure Management with Anaerobic Digestion: Review of Gaseous Emissions*).

[5] The anaerobic digestion process yields a digestate with more mineralized, plant-available nitrogen than raw manure. This benefit is often cited, but we are unaware of any studies that have demonstrated improved water quality in practice. In addition, digesters do not reduce total nitrogen levels so will not solve excess nitrogen problems.

[6] Pathogen reduction will be much more efficient for mesophilic and thermophilic digesters compared to unheated lagoon digesters. We are not aware of any studies that have demonstrated reduced pathogens in local water sources due to the adoption of an anaerobic digester.

[7] Due to limited projects on dairies upgrading biogas to biomethane, reliable cost ranges could not be generated for this study.

[8] There may be a local reduction in SOx, NOx, and PM depending on how and where the biomethane is ultimately combusted. Similarly, could lead to a slight increase (i.e., if a small generator is used to provide energy for gas cleaning and compression and the fuel is combusted outside of the region or displaces CNG)

[9] Unlike anaerobic digestion for electricity or biomethane; flaring will not offset fossil fuel use.

[10] National studies indicate cost of abatement between \$2 and \$9 per mtCO$_2$e (ICF, International), but costs of a cover and flare system in California are believed to be much higher than what is presented in the literature. See text body for further detail.

[11] Although it may be theoretically possible to achieve a 90% GHG emissions reduction if switching from a fully flush with anaerobic lagoon storage system, to a solid storage system, there are relatively few cases where this would apply. Many farmers are only in a position to do a partial conversion, either because some manure is already handled in a more aerobic system, or because they are only likely to convert a portion of the operation from flush to scrape (e.g., in the freestall barn or feed aprons, but not the milking parlor).

[12] Conversion from flush to scrape or handling of more solid manure may increase the use of on-farm equipment and trucking to handle solid manure (e.g., tractors, etc.). Scraped manure also generates PM10 emissions (Winegar, 2014. *Assessment of Control Methods for PM10 Emissions from Dairy and Feedlot Corrals)*.

[13] Ultimately, manure application practices will determine whether impact on water will be better or worse.

[14] Flush water is typically recycled water from other on-farm uses, and lagoon water is usually field applied. Converting to scrape may be a necessary step in reducing on-farm water use, but additional changes on the farm (e.g., parlor, irrigation) will likely be necessary to achieve savings.

[15] Studies found for this report indicate GHG abatement from solid separators up to 38% for slurry manure, but there is uncertainty about what abatement level can be achieved with separation of flushed manure. No cost of abatement presented due to the high uncertainty around abatement potential.

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

## 2. Introduction

California has the largest and one of the most diversified and sophisticated agricultural sectors in the United States. In 2012, California was the nation's leading agricultural (crops and livestock) producer in terms of sales value and produced almost 20% of national milk sales.[17] The state's productive agriculture industry is operating under some of the most progressive environmental regulations in the country. California has one of the world's only comprehensive climate laws, AB 32, which was adopted in 2006 and launched a cap and trade program in 2012. While agricultural emissions are not specifically capped in the cap-and-trade program, the sector has been highlighted in the AB 32 Scoping Plan as a priority for voluntary emissions reductions. In addition, agriculture could be an important source for the production of carbon offsets.

AB 32 (2006) set forth a short-term goal for the state of California to reduce emissions to 1990 levels by 2020. Two executive orders have created additional long-term goals of reducing emissions by 40% below 1990 levels by 2030 and 80% below 1990 levels by 2050. California is on target to meet the 2020 objective of the legislation,[18] but achieving the longer term targets is a far more daunting challenge that will require emissions reductions from all major sectors of the economy, including agriculture.

As state legislatures and agencies turn their attention towards emissions reduction pathways for 2030 and 2050, short-lived climate pollutants (SLCPs) are attracting more attention. The recent passage of SB 605 (2014) requires the California Air Resources Board (ARB) to develop a comprehensive strategy to reduce emissions of short-lived climate pollutants including methane, fluorinated gases, and black carbon by 2015. These gases have a short residence time in the atmosphere, but have powerful warming impacts many times the impact of carbon dioxide. In addition to reducing SLCPs, SB 605 calls for ARB to identify strategies that have co-benefits, such as reduced emissions of criteria pollutants, water conservation, and water quality benefits. Methane emission from dairies is a leading source (34% excluding black carbon) of SLCP in California.

This paper outlines strategies for reducing methane emissions from dairies, the cost of abatement, associated co-benefits and impacts, and a discussion of the barriers that may be preventing broader adoption. The paper represents the output of a rapid (8-week) review of the available options for SLCP mitigation from dairies, which included interviews with more than twenty subject-matter experts (Appendix A). There are many areas of this assessment that warrant deeper investigation. Therefore, our conclusions, particularly around GHG abatement costs and potential, should be treated as general, preliminary guidelines, rather than definitive conclusions.

[17] USDA, 2012. *Census of Agriculture*.
[18] California Air Resources Board, 2014. *First Update to the Climate Change Scoping Plan*.

## 2.1 GHG emissions and manure management on California dairies

In order for the state to meet its ambitious greenhouse gas reduction goals and to create a comprehensive strategy for reducing short-lived climate pollutants, it will be imperative to address emissions from California's dairy sector. Since 2000, total greenhouse gas emissions in the state have declined slightly, but during the same period emissions from dairies have increased by 27%,[19] driven by an increase in the number of dairy cows in production.[20] Dairies are the source of approximately 19.6 million tonnes $CO_2e$, or 4% of greenhouse gas emissions in California. Since most of these emissions are in the form of the SLCP methane, dairies account for a much larger (34%) share of SLCP emissions (excluding black carbon). About 60% of dairy emissions come from manure management, with the remainder produced through enteric fermentation (Figure 1).[21]

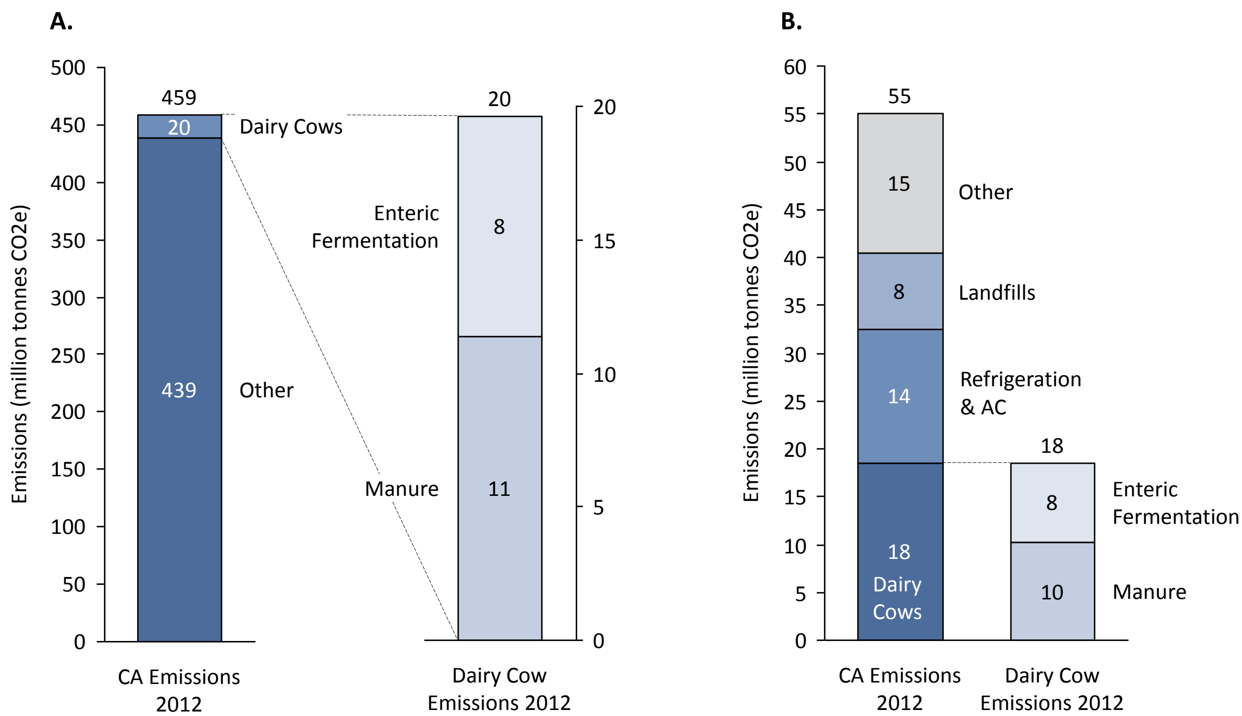


**Figure 1 - A. California greenhouse gas emissions in 2012; B. California short-lived climate pollutant emissions 2012**
***Excludes black carbon**
****Dairy emissions exclude emissions from manure application to soils**
***** Values may not sum to total due to rounding.**

[19] California Air Resources Board, 2014. *California's Greenhouse Gas Inventory by Sector & Activity: 2000 - 2012*.
[20] California Air Resources Board, 2014. *California Greenhouse Gas Emissions for 2000-2012 – Trends of Emissions and Other Indicators.*
[21] California Air Resources Board, 2014. *California's Greenhouse Gas Inventory by Sector & Activity: 2000 - 2012*.

Each dairy cow in California excretes about 144 pounds of manure each day.[22] Dairies dedicate significant resources to manage this formidable waste stream, drawing from a range of tools and strategies.

The following section outlines various manure management systems. For each system we present the share of California's dairy cows estimated to be managed in the system and the associated greenhouse gas emissions based on California's Greenhouse Gas Inventory. It is important to note that while the greenhouse gas inventory assigns cows to a specific manure management system, in many cases a mix of manure management practices may exist on a single dairy. For example, manure from milking parlors may be flushed into an anaerobic lagoon, whereas manure and bedding solids from the barn or corral may be scraped and potentially composted. In flush systems, the solid and liquid components of the manure may be separated before storage encouraging greater aerobic decomposition. Additionally, estimating the GHG emissions from manure management is a lot more complicated than estimating emissions from the combustion of fossil fuels. Therefore, there is greater uncertainty surrounding overall emissions levels. While the necessary assumptions and simplifications uses to develop the Greenhouse Gas Inventory do not reflect the full complexity of manure management, the inventory provides a helpful overview of emissions from California dairies' major emission sources.

**Box 1: Manure Digestion**

**Anaerobic digestion:** In the absence of oxygen (e.g., underwater), bacteria break down the volatile solids component of manure and produce methane gas and carbon dioxide. In addition, products such as ammonia, volatile organic compounds (VOCs), and hydrogen sulfide are also produced.

**Aerobic biodegradation:** In the presence of oxygen, bacteria break down manure into $CO_2$, water, nitrates, phosphates, and sulfates. Depending on the conditions VOCs, ammonia, and $N_2O$ can also be emitted.

**Flush Systems with Anaerobic Lagoons** - The most common method of manure handling on California dairies is flush management in which the alleys of dairy barns are cleaned several times a day by flushing them with water. The diluted mixture of manure (<3% total solids) and water is pumped into storage lagoons where anaerobic break down occurs (see Box 1). This type of system has many advantages. Flushing manure is relatively inexpensive and helps keep dairy barns clean. Lagoons are efficient systems for storing large quantities of manure. In addition, lagoon water can be combined with irrigation water to easily and effectively distribute nutrients to field crops. Anaerobic lagoons, however, are the most GHG intensive method for managing dairy manure (Figure 2). According to California's Greenhouse Gas Inventory, manure from 58% of the state's dairy cows is managed in anaerobic lagoons

[22] Frear, Craig, 2015. Personal communication. Unpublished data that is an average of multiple studies including Mukhtar, 2007; ASABE, 2005; OSU, 2006; Nennich, 2004, and AA Dairy, Roos.

which emit a total of approximately 9 million tonnes of $CO_2e$ each year, or approximately 79% of the state's greenhouse gas emissions from dairy manure.[23,24]

**Liquid / Slurry** - The second most common storage method for manure on California dairies is storage in liquid/slurry ponds. Under this system, dairy manure is scraped from alleys and transferred to ponds as it is excreted by the animals (~13% total solids). Unlike anaerobic lagoons, these ponds are not diluted with large volumes of flush water. The mixture of feces and urine has a thick consistency similar to a milkshake. Manure in slurry ponds undergoes anaerobic digestion, but the conditions in a slurry pond are not as conducive to methane production as in an anaerobic lagoon. Slurry ponds generate about half the greenhouse gas emissions of anaerobic lagoons from the same volume of manure (Figure 2). The manure from twenty percent of California's dairy cows is managed in slurry ponds,[25] accounting for ~14% of the state's GHG emissions from dairy manure.

**Other Systems** - The manure from most of the remainder of the state's dairy cows (~22%) is managed in more aerobic systems (e.g., solid storage, compost, daily spread) or with anaerobic digesters. In total, these other systems account for just 7% of greenhouse gas emissions from dairy manure in the state.[26]

While the data from the Greenhouse Gas Inventory may not capture the full complexity of manure management on dairies, it does provide a helpful overview of the main sources of emissions. The inventory shows that anaerobic lagoons have the most GHG emissions per unit of manure and are also the most widely used manure storage systems on dairies in California, and thus present the best opportunity for abatement.

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[23] Note that % of manure emissions includes emissions from dairy heifers, while the share of dairy cows does not include dairy heifers.
[24] California Air Resources Board, 2014. *California's 2000-2012 Greenhouse Gas Emissions Inventory: Technical Support Document: Annex 3B. Manure Management*
[25] Ibid.
[26] Ibid.

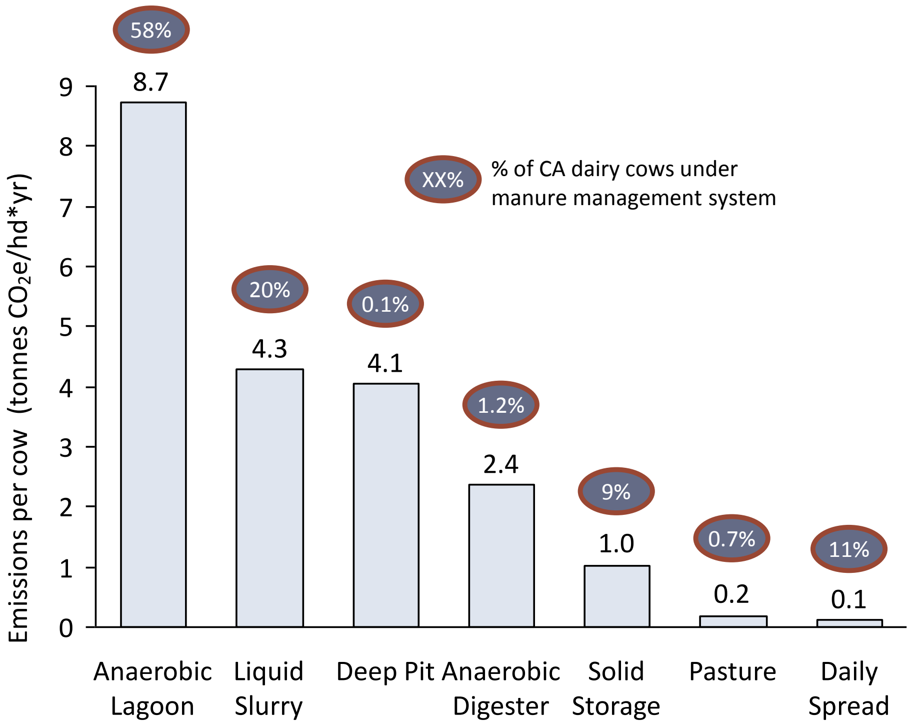


**Figure 2 - Greenhouse gas emissions of various manure management systems and percentage of dairy cows in California managed under each system.[27]**

## 2.2 Options for reducing GHG emissions from manure on California dairies

Manure generates methane emissions under anaerobic conditions. As noted above (see Box 1), anaerobic digestion occurs when the volatile solids in the manure break down in an environment that lacks oxygen (e.g., in a lagoon). There are two main 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 environments. These two approaches are detailed below:

- Capturing and combusting methane – The process of capturing and combusting biogas converts methane into carbon dioxide and water. Each unit of methane has a 100-year global warming potential of 25,[28] while each unit of carbon dioxide has a global warming potential of 1. Thus every unit of methane that is captured and combusted reduces greenhouse gas emissions by roughly 95 percent. This paper evaluates the use of anaerobic digesters for capturing and combusting methane. The methane captured with anaerobic digesters can be used in a variety of ways including, generating electricity, injecting it into natural gas pipelines, fueling vehicles, or simply flaring the gas.
- Maintaining aerobic conditions in manure management—Conversion from primarily anaerobic systems (e.g., lagoons) to more aerobic systems (e.g., solid storage, compost) of manure management reduces methane emissions. This paper covers two options for converting manure

[27] Ibid.

[28] IPCC, 2007. *Climate Change 2007: The Physical Science Basis.*

management to more aerobic systems. The first option is to convert from flush management to dry, scrape systems in which manure is scraped from barns and stored without the addition of water. The raw manure scraped out of barns can be subsequently composted. (Compost is covered in Section 5 Nutrients/Compost.) The second option is to use solid separators which extract a portion of the solid content of flushed manure liquid before it reaches the anaerobic lagoon. Separated solids can then be dried and managed in a more aerobic system (e.g., solid storage or compost).

Each of the strategies discussed above can achieve greenhouse gas reductions. However, manure management on dairies is complicated and implementing new practices can result in both positive co-benefits and negative impacts. For example, the capture and combustion of methane to generate electricity using anaerobic digesters will result in increased emissions of NOx, SOx, and particulate matter but may also reduce emissions of volatile organic compounds (VOCs) and hydrogen sulfide ($H_2S$). Converting from a flush to a solid manure management system will reduce methane emissions, but will increase $N_2O$, VOC, and possibly ammonia emissions.

Each manure management practice can also have impacts on water quality and efficient nutrient management. Manure contains high concentrations of nitrogen and phosphorous. In some parts of California, excess or poorly managed manure can cause nutrient loading in surface and groundwater, which can be toxic to aquatic life and dangerous for humans. However, these nutrients are also valuable for crop fertilization. If managed well, manure can provide valuable byproducts for the agriculture sector that may prove to be profitable sources of revenue for the dairy industry. This paper evaluates compost, advanced nutrient recovery, and bio-filtration as three nutrient management approaches that can complement methane reduction measures.

In this paper we will provide information on the positive co-benefits and negative impacts associated with each methane reduction strategy to encourage a holistic evaluation beyond the single goal of GHG emissions reductions. There are no “silver bullet” solutions and any decision regarding how to reduce greenhouse gas emissions from dairies should be thought through carefully from a systems perspective.

## 3. Anaerobic digesters

Anaerobic digesters are widely considered to be the most effective and comprehensive approach to reducing methane from manure. Anaerobic digesters are systems that breakdown biomass under anaerobic conditions. This process generates biogas, a combination of methane (~60%), carbon dioxide, and small volumes of other gases such as hydrogen sulfide and ammonia. Captured biogas can be flared, injected into natural gas pipelines, or used to generate electricity, heat boilers, or produce vehicle fuel.

In addition to biogas production, solids from the digested manure (“digestate”) can be used either as bedding for cows or as a soil amendment. Further processing of digestate can capture nutrients (nitrogen and phosphorous) which can be sold or used on the farm. A simplified flow diagram of the dairy manure management process with an anaerobic digester is shown in Figure 3.

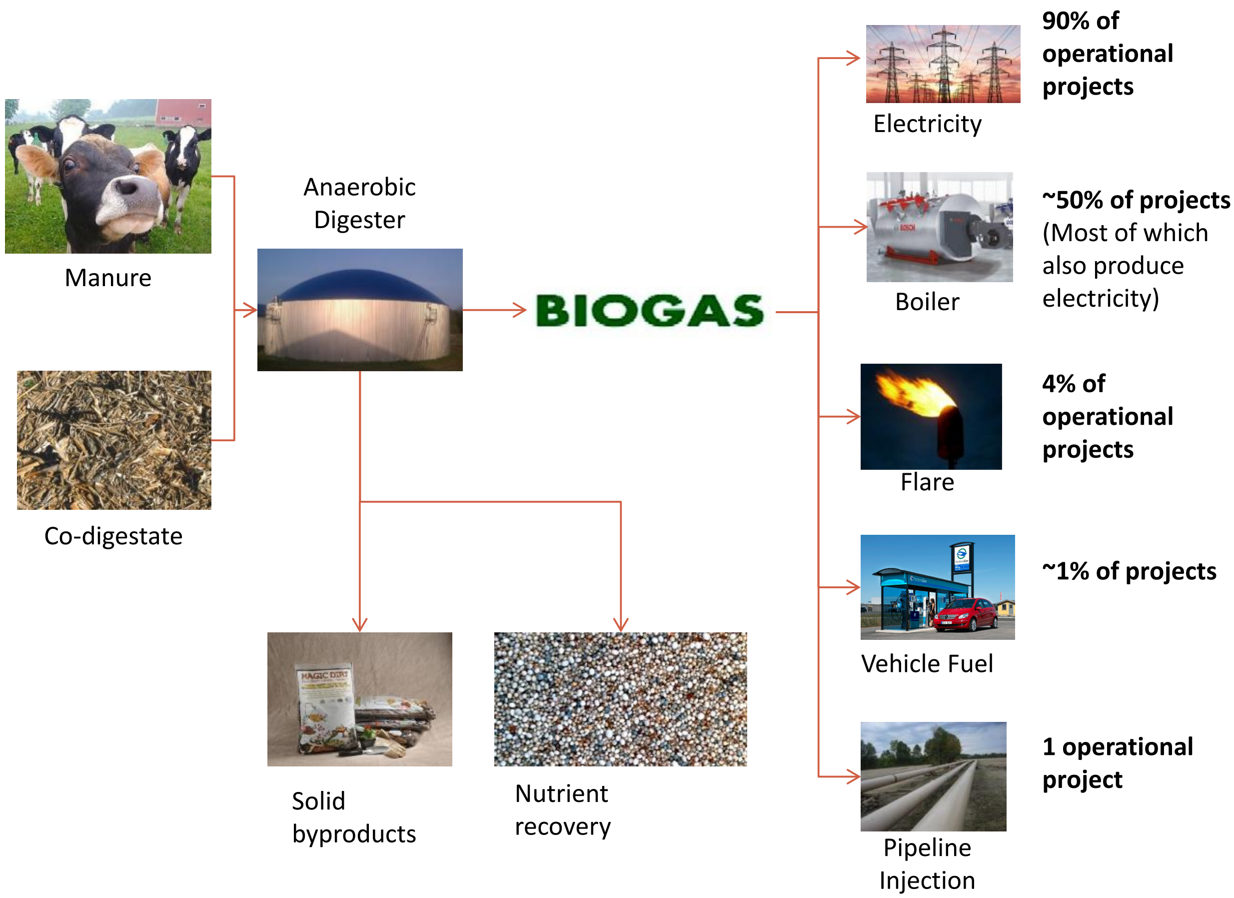


**Figure 3 – Simplified process flow diagram for anaerobic digestion of dairy manure and the distribution of the end use of biogas as a percentage of operational projects on dairy farms in the United States.**[29]

Anaerobic digesters on dairies have a multi-decade history in California; the first digester in the state was installed in 1989. In total, twenty-nine digesters have been installed to date (Figure 4).[30] Financial distress and operational cost and complexity have caused nine dairies to shut down their digesters. The remaining twenty dairies with operational digesters represent about 2% of the 500-head or larger dairy farms in California. This data on operational digesters comes from AgSTAR's livestock digester database, but according to industry experts, several digesters listed as operational in the AgSTAR database may no longer be operating. By one estimate, only 13 digesters were still operating in the state as of July 2015.

[29] Distribution of projects from Environmental Protection Agency, 2015. *AgSTAR Database of Livestock Digesters*. Accessed July, 2015.
[30] Ibid.

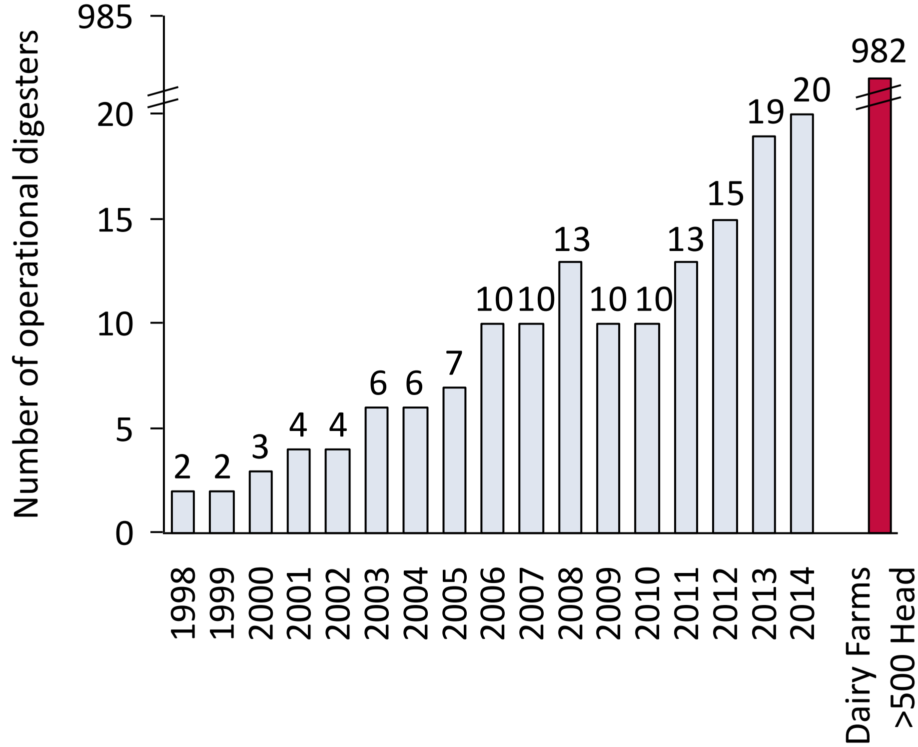


**Figure 4 - Number of operational digesters on dairy farms in California by year and total number of dairy farms larger than 500 head.**

There are three main types of digesters, each of which are described below.

**Covered Lagoons** – Covered lagoons are the simplest and least expensive type of digester: an impermeable cover is placed over a manure lagoon, and biogas is collected from the top of the system. Covered lagoon digesters are able to break down manure with low solids content (less than 3%) and are thus best suited for flush dairies. In addition, because anaerobic digestion is more efficient in warm temperatures and covered lagoons cannot be heated efficiently, these digesters are best suited for dairies in warm climates. While covered lagoons are less costly than other digesters, they also tend to be less efficient in terms of biogas generation and pathogen reduction. Due to the prevalence of flush management systems, the warm climate, and the low cost, covered lagoons have been a popular choice in California – thirteen of the twenty operational digesters in the state are covered lagoons.[31]

**Complete Mix** – Complete mix digesters are fully enclosed tanks that are maintained at a constant temperature and whose contents are continually mixed. These systems are compatible with manure streams that have moderate solids content (between 3 and 10 percent) and, therefore, are compatible primarily with scraped manure. Capital costs are higher than for covered lagoons, but because conditions in the reactor vessel are controlled, complete mix digesters can deliver biogas at a more consistent rate. In addition, complete mix digesters can accept a wide range of input materials, making

[31] Ibid.

them better suited to co-digestion (see section 3.5 Co-digestion), which can increase biogas production and revenue streams. Four of the twenty operational digesters in California are complete mix.[32]

**Plug Flow** – Plug flow digesters are typically horizontal vessels in which low moisture plugs of manure are pushed through the vessel. As manure is added to the input end of a plug flow digester, the content of the reactor is pushed towards the exit and eventually forced out. The vessel is usually maintained at a constant temperature and can provide steady levels of biogas production. Plug flow digesters are best suited for manure streams that have a high solids content (~7% to 13%), and are therefore best suited for dairies that use scrape manure management systems. There are three operating plug flow digesters in California.[33]

## 3.1 Digesters with electricity generation

Production of electricity from combusted biogas is the most common use of digester systems on dairies in the United States, representing roughly 90% of operational digesters. Electricity generation has been a popular choice as long-term power purchasing agreements, feed-in-tariffs, and net-metering provide secure revenue streams for these projects. The security of these contracts helps digester projects obtain financing by reducing risk associated with long-term pay-back.

### 3.1.1 Costs

#### Digester

The most important cost of a dairy digester project is the capital cost of the equipment. There have been numerous studies that have investigated the cost of digesters and estimates vary widely. A 2014 study aggregated cost estimates from several prior studies on digester capital costs and found ranges from $373 per cow up to $1,259 per cow for dairy farms between one thousand and five thousand head.[34] Estimates for smaller farms were even higher; one study estimated capital costs of $1,608 per cow for a 500 head farm.[35] All of the studies reviewed in the 2014 paper were from 2011 or earlier, and several industry experts have stated that these costs are no longer representative of the costs of building digesters systems today, especially in California. A more stringent regulatory environment creates additional project costs such as low NOx technology, $H_2S$ treatment, and possibly double lining of lagoons. Additionally, interconnection costs in California may be substantially higher. Looking at a handful of recently completed or planned digester projects in California, capital costs for manure-only covered lagoon digesters (i.e., digesters that use only manure as an input and do not co-digest with green waste or food waste) appear to have ranged between $1,350 and $2,200 per milk cow, higher than what is referenced in the academic literature. The project at the lower end of this range was able to cover an existing lagoon, which may be an unusual circumstance for future digester projects. Recent projects in California using other digester technologies (e.g., complete mix, mixed plug flow) have been even more expensive, although these digesters can provide additional benefits, such as more consistent biogas generation and the ability to use a wide variety of other materials as feedstock.

[32] Ibid.
[33] Ibid.
[34] Lee, H. et al. 2014. Greenhouse Gas Mitigation Opportunities in California Agriculture: Review of the Economics.
[35] Ibid

While digester costs reported in the literature are lower than the costs to develop new projects in California, they also highlight substantial economies of scale (Figure 5). This finding holds true in California as well; projects will be the most economically attractive on larger dairies.

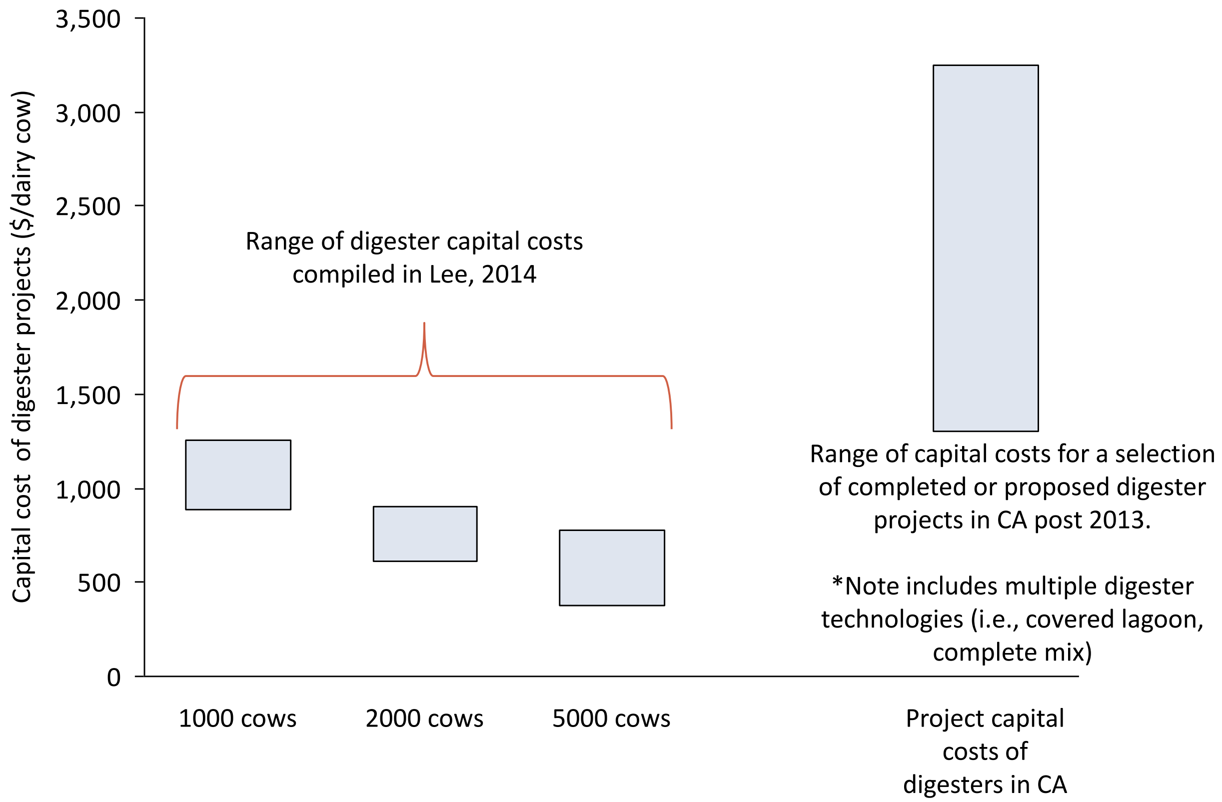


**Figure 5 - Range of capital costs ($/cow) for anaerobic digesters by size of dairy and the capital cost ($/cow) of a *selection* of recent projects in California.**
***Note that the cost ranges in Lee, 2014 do not include ancillary charges (e.g., interconnection, post digestion solid separation)**

Where digester costs will eventually settle in California is not yet clear. This will depend on numerous factors, such as which technology rises to the top (e.g., Are the cost savings of covered lagoons sufficient to accept lower biogas generation?), what types of projects become the norm (e.g., manure-only, co-digestion, regional digesters), and whether developers can substantially reduce costs as they move along the learning curve.

### Generator

Once biogas is produced, it must be combusted in a generator to produce electricity. The digester system cost estimates reported above include the cost of generation equipment, but one study of 38 digester systems estimated that the electricity generation components account for 36% of capital costs.[36]

### Interconnection

Dairy digesters which export power for sale to a utility will need to interconnect to the electric grid. Dairy farms are typically located in rural areas at the extremities of the electric grid where generation interconnection can require significant system upgrades (e.g., installation of circuit breakers or reconductoring). These upgrades can come at a high cost to the project owner. Some project developers and consultants report that interconnection fees typically range from $100 thousand up to $1 million.[37] While this is a typical range, industry experts interviewed for this project provided anecdotes of interconnection cost estimates in excess of $1 million. The preliminary business plan for a very large digester project at a cluster of 11 dairies with 40 thousand cows in Kern County budgeted electricity interconnection costs at $5.5 million, about 8% of total project costs.[38]

### Operations and maintenance (O&M)

In addition to the up-front costs, anaerobic digesters also require ongoing operations and maintenance. Estimates for annual O&M costs for digesters vary from between 1.5% to 11% of the total capital cost of a project.[39] Based on reports from two recent digester projects in California, operational costs are more likely to be in the upper portion of this range (i.e., 6%-11% of capital costs).[40,41]

## 3.1.2 Revenues

### Electricity

The most important revenue stream from dairy digester projects connected to the grid is the sale of electricity or the offset of electricity purchases on a farm. One challenge in evaluating the cost effectiveness of digester projects is that the economic viability of these projects will depend heavily on the amount of electricity generated, but the performance of existing and historical digester projects has varied widely. Actual generation from dairy digesters has often fallen short of the theoretical estimates. There are several reasons for the variance of generation output including the type of digester system used, composition of inputs, the volume of manure generated on the farm that is fed into the digester, management effectiveness, incentives for electricity generation, sizing of the generator, and the percent of time the generator is operational. As more anaerobic digesters come on line it will be helpful to track their electricity production efficiency. Developing a stronger understanding of the generation performance of digesters, and the factors that drive this performance will improve up-front assessments of the viability of projects.

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[36] USDA, 2007. *An Analysis of Energy Production Costs from Anaerobic Digestion Systems on U.S. Livestock Production Facilities.*

[37] California Dairy Campaign, 2013. *Economic Feasibility of Dairy Digesters in California: A Case Study.*

[38] Ibid.

[39] Lee, et al. *Greenhouse Gas Mitigation Opportunities in California Agriculture: Review of the Economics.*

[40] Maas Energy Works. *Van Warmerdam Dairy Digester Final Report Including Technology Transfer Report*. (n.d.)

[41] Williams Engineering Associates, 2014. *Final Report: New Hope Dairy Digester and Engine-Generator.*

A combination of stronger incentives for electricity generation (e.g., power purchase agreements vs. net metering) and the transition to 3rd party operation of digesters seems to have led to more electricity generation from newer digester projects. For example, two digesters in the state, completed in 2013, reported generation rates of more than 1,500 kWh per milk cow per year,[42,43] compared to an average of about 650 kWh per milk cow per year for eight digesters that were built or refurbished in the mid 2000's as a part of the Dairy Power Production Program.[44,45]

The bioenergy feed-in-tariff (FiT) program created by SB 1122 in 2012 has the potential to significantly increase the attractiveness of digester-based electricity production on California dairies. While details of the program and standard tariffs are still being finalized, the program (referred to as the "BioMAT") will require utilities to pay a stable and premium rate for electricity from bio-energy generators smaller than 3 MW. The initial rate for dairy projects will be 12.77 cents per kWh – compared to current wholesale rates on the order of 3.5 cents per kWh[46] – but the price for new contracts can adjust up or down every two months based on the number of projects that accept contract offers.[47] The BioMAT is an attractive revenue source for biogas-to-energy projects on California dairies, but the initial rate of 12.77 cents/kWh is unlikely to be sufficient to incentivize new installations without additional grant funding. An analysis of the SB 1122 legislation estimated that the levelized cost of generation from dairy manure would be between 21.8 and 34.6 cents per kWh.[48] While digester projects could capture additional revenue streams (see below), the initial FiT rate is significantly below this estimated cost of generation. One digester project developer estimated projects would start to become economical once the FiT reached 16 to 18 cents per kWh.

Another option for anaerobic digesters generating electricity is to enroll in net metering. Under this program, a generator can reduce the amount of electricity it must purchase from the utility and "sell" surplus electricity exported to the grid at retail rates.[49] To be approved for the program, generators must be no larger than 1 MW and sized to match expected electricity consumption on site. Generation potential on dairy farms in California are typically much greater than consumption meaning dairies enrolling in net metering will either need to build relatively small digesters, be co-located with food processing facilities, and/or find additional uses or markets for the excess biogas.

See section 7 of this report for more details on revenue and funding available for sale of electricity from digesters.

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[42] Ibid.
[43] Maas Energy Works. *Van Warmerdam Dairy Digester Final Report Including Technology Transfer Report*. (n.d.)
[44] Western United Resource Development, Inc. 2009. *Dairy Power Production Program: Dairy Methane Digester System Program Evaluation Report.*
[45] Note: multiple reasons for low generation including, no compensation for generation beyond on-farm use, generator system downtime, and inconsistent biogas production.
[46] U.S. Energy Information Administration, 2015. *Wholesale Electricity and Natural Gas Market Data.* July 9th Release.
[47] California Public Utilities Commission, 2014. *Decision 14-12-081.*
[48] Black and Veatch, 2013. *Small-Scale Bioenergy: Resource Potential, Costs, and Feed-in-Tariff Implementation Assessment.*
[49] The current NEM program is nearing the cap and a successor tariff is being developed by the CPUC in Rulemaking (R.) 14-07-002. This could affect the rates at which electricity can be sold back to the utility.

## Heat

Generating electricity in a digester produces significant amounts of heat which can be captured for on-farm use. Thermally regulated digester systems can direct heat energy to maintain the right system temperature in the digestion vessel. Additionally, waste heat can be applied to other on-farm uses (e.g., boilers) which may reduce fuel or electricity expenses. However, the on-site demand for heat energy on dairies is limited, especially in California, and thus the economic impact of this byproduct for most projects will be limited.[50]

## Carbon offset credits

Anaerobic digesters can generate tradable, verified carbon emission reductions (carbon credits) which can be sold to generate additional revenue. For a dairy currently managing all of its manure in an anaerobic lagoon, a digester can reduce emissions by approximately 6.4 mtCO2e per dairy cow each year,[51] although the amount of verified carbon offsets that a project can generate will be lower.[52] This estimate is based on the difference in emissions per dairy cow from anaerobic lagoons and anaerobic digesters in CARB's 2012 greenhouse gas inventory. Actual emissions reductions will depend on the specific characteristics of the dairy and the amount of credits generated will be determined by the carbon offset protocol and metered reductions.[53] Historically, offset projects in the United States have sold into voluntary markets, but California's cap-and-trade program has opened up a potentially more lucrative carbon market. Recent prices of carbon credits have been a little over $12.50 per mtCO2e, with offsets selling at about a 25 percent discount to the credit price.[54]

The process of earning offset credits for sale in the compliance market comes with costs. The most important cost is annual emissions verification, which typically runs about $10 thousand per year for a manure digester project.[55] Administrative costs may also be significant, particularly in the initial years of a project. These costs do vary with the complexity of the project, but do not change much with scale. As a result, carbon offset production will be most attractive to larger digester projects—one developer suggested that he would consider generating and selling carbon offsets with a dairy of one thousand cows or more.[56]

The sale of carbon offsets from dairy digester projects has become more common following approval of the official livestock offset protocol. There are now offset credits approved from at least 38 dairy digesters by the California ARB,[57] but interestingly, none of these projects are located in the state of California. Despite the maturation of the offset market and digester projects, individuals interviewed for this paper reported that lenders are still reluctant to provide financing to projects based on future

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[50] ESA, 2011. *Economic Feasibility of Dairy Manure Digester and Co-Digester Facilities in the Central Valley of California.*

[51] California Air Resources Board, 2014. *California's 2000-2012 Greenhouse Gas Emissions Inventory: Technical Support Document: Annex 3B. Manure Management*

[52] Ma, et al., 2015.Dairy Manure Management with Anaerobic Digestion: Review of Gaseous Emissions.

[53] Actual credits generated from dairy digester offset projects have been lower than 6.4 mtCO$_2$e per cow.

[54] Industry expert interview. *Personal communication*. May, 2015.

[55] ibid

[56] Industry expert interview. *Personal communication.* May, 2015.

[57] California Air Resources Board, 2015. *ARB Offset Credits Issued*. Updated April 22nd, 2015.

revenues from carbon offsets (i.e., carbon offsets for digesters are still not bankable).Technically, California's carbon offset program is only authorized through 2020, so there is some risk to these revenue streams. However, the market is widely expected to not only be reauthorized, but to grow substantially.

#### Solid byproducts

The solids remaining following digestion of dairy manure may have economic value. Digested solids can be used as bedding material or soil amendments, or be further processed into compost. These products can be used on the dairy farm or sold. However, markets for solid byproducts are not well established.

The use of digested solids as bedding material may not create savings if a farm already uses separated solids as bedding material. A survey of dairies in Tulare and Glenn counties in California found that the most common type of bedding for dairy cows in freestalls (~80 percent) was separated solids and corral scrapings.[58] The prevalence of these bedding types reduces the likelihood that solid byproducts could provide additional revenues or savings for California dairies. Given the variability and uncertainty of these revenue streams, they have not been included in any of the economic modeling in this paper.

#### Nutrients

After solids are removed from digested material, the remaining liquids can be further processed to extract nitrogen and phosphorous in the form of high-end fertilizers. There are a variety of processes that can strip nutrients from digestate. (These options are discussed in further detail in Section 5.) However, despite the potential for reaching high-value markets with these products, broadly speaking, extracting nutrients from digestate has not been proven to be commercially viable yet, and there are few nutrient recovery systems currently operating with dairy digesters. This may, however, be an interesting area for future research and market development.

Industry experts hold a wide range of opinions about the importance of solid byproducts and nutrients to the economic viability of digesters on dairy farms. One developer said that he places zero value on solid byproducts and nutrients when scoping out potential investments, while another developer said that solid byproducts and nutrients (see Section 5) were underpinning his business model.

### 3.1.3 Net present value analysis

Numerous studies have performed net-present-value analyses of digester projects, including actual analyses of historical projects, forecasts of potential projects, and broad assessments of the economics of anaerobic digesters based on farm size and various levels of incentives. These analyses are helpful in assessing the economic viability of anaerobic digesters, but it is important to be aware of the limitations of these studies. Given the set of embedded assumptions that can significantly impact the economic profile of a project (such as discount rate, lifetime of the project, and the characteristics of a specific dairy farm) these assessments should be used as general guidelines rather than precise analyses. Despite these caveats, it is still worthwhile to acknowledge that previous assessments have generally determined that digester projects are uneconomical without substantial incentives. Below is a brief summary of some of the findings from the literature on the economics of digesters on dairies.

[58] Meyer, D. et al. 2011. *Survey of Dairy Housing and Manure Management Practices in California.*

- **Black and Veatch, 2013** – As part of an assessment of small-scale bioenergy and implementation of a feed-in-tariff as required by Senate Bill 1122, Black and Veatch evaluated the levelized cost of generation of a manure-only anaerobic digester project. The analysis assumed a 5,500 head dairy and a relatively sophisticated digester, which is more expensive than covered lagoons but may have better electricity generation performance. The study estimated levelized cost of generation between 21.1 and 33.4 cents per kWh, much higher than the initial BioMAT FiT of 12.77 cents per kWh for dairy manure projects.[59]
- **California Dairy Campaign, 2013** – The California Dairy Campaign modeled the economics of a hub and spoke digester project for a cluster of dairies with approximately 40 thousand milk cow equivalents in Kern County. The project modeled several different scenarios: electricity generation, biomethane pipeline injection sold as renewable natural gas (RNG), and biomethane pipeline injection sold as a vehicle fuel. For the electricity generation project, the authors estimated that at an electricity price of 8.9 cents per kWh, carbon offset prices would need to be \$60 per mt$CO_2$e to make the project economical. Alternatively, if the carbon price were \$10 per mt$CO_2$e, electricity prices would have to reach 19 cents per kWh to make the project economical. Thus, even with the BioMAT FIT of 12.77 cents per kWh and current carbon prices of about \$10 per mt$CO_2$e this project would require substantial grant funding.
- **ICF, 2013** – This study found that the breakeven price of carbon to make digester projects economical on farms in the Pacific region currently using anaerobic lagoons was between \$2 and \$30 per mt$CO_2$e (Table 2).[60] Although carbon offset prices are approaching \$10 per tonne, digester projects are not moving forward without grant funding or additional incentives, which indicates that the estimates of this study may be too low.

**Table 2 - Break even carbon price (\$/mt$CO_2$e) for digester projects on dairies in the Pacific region generating electricity**

| Digester Type | 5,000 head | 1,000 head dairy | 600 head |
|---|---|---|---|
| **Covered Lagoon** | \$2 | \$17 | \$30 |
| **Complete Mix** | \$7 | \$14 | \$20 |

- **Environmental Science Associates**, **2011** – In a study for the California Regional Water Quality Control Board, the authors modeled the finances of a manure-only digester generating electricity on a 1,000 head dairy. The authors estimated that the levelized cost of electricity production (LCOE) for the modeled project was 28 cents/kWh, far greater than wholesale or retail rates of electricity.[61]
- **Key and Sneeringer, 2011** – In an economic brief published by the USDA Economic Research Service, modeling by the authors indicated that with no price for carbon, digesters would be

[59] Black & Veatch, 2013. *Small-Scale Bioenergy: Resource Potential, Costs, and Feed-in Tariff Implementation Assessment.*
[60] ICF International, 2013. *Greenhouse Gas Mitigation Options for Agricultural Land and Animal Production within the United States.*
[61] Environmental Science Associates, 2011. *Economic Feasibility of Dairy Manure Digester and Co-Digester Facilities in the Central Valley of California.*

economical on just 69 dairies nationwide. A carbon price of $13 per $mtCO_2e$ would make digesters economical at an additional 491 dairies nationwide and would make dairies with anaerobic lagoons larger than 250 head economical in California.[62] The estimates in this paper seem to be optimistic, and, in spite of offset prices approaching $10 per tonne, there are no projects moving forward without substantial grant funding.

- **California Energy Commission, 2009** – This study evaluated existing dairy digester projects in California. The study found that without grant funding, the simple payback period (e.g., how many years it takes to payback the initial capital investment assuming no time-value of money) ranged between 8.5 and 70.3 years. The average simple payback period for covered lagoon digesters was 16 years and 43.8 years for plug flow digesters. In other words, digesters were unattractive investments without substantial grants or other incentives.[63]
- **California Energy Commission, 2008** – In a presentation at the BioCycle conference, levelized cost of generation for existing digesters in California was estimated to be between 10 and 37 cents per kWh assuming a 17% discount rate. The ten cents per kWh LCOE for the Hilarides Dairy project was determined to be potentially economical without subsidies, but this was an outlier of the study.[64]

Each of these analyses uses their own unique assumptions, so it is difficult to compare across studies, but the references above clearly illustrate that dairy digesters are not economical without substantial grant funding or other incentives.

Previous digester projects have been able to move forward through the provision of grant funding. For future projects, this will be complemented with revenue from the BioMAT and carbon offsets. Figure 6 below illustrates the magnitude of the main revenue streams for a digester project producing electricity. The example assumes that each cow can yield 1,433 kWh of electricity and generates 5 $mtCO_2e$ in offset credits annually.[65] This analysis indicates that incentive payments for renewable energy generation (BioMAT) and for greenhouse gas abatement (carbon credits) comprise the bulk of the operating revenues of digester projects producing electricity.

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[62] Key, N., Sneeringer, S. 2011. *Carbon Prices and the Adoption of Methane Digesters on Dairy and Hog Farms.*
[63] Western United Resource Development, Inc. 2009. *Dairy Methane Digester System Program Evaluation Report. Prepared for the California Energy Commission.*
[64] Zhang, Z., Braun, G. 2008. *Cost of Electricity and Pipeline Quality Gas from Biogas.*
[65] Although California's Greenhouse Gas Inventory estimates that emissions from anaerobic digesters are 6.4 $mtCO_2e$ per dairy cow*yr, actual verified offsets produced by anaerobic digester projects have been lower and wide ranging.

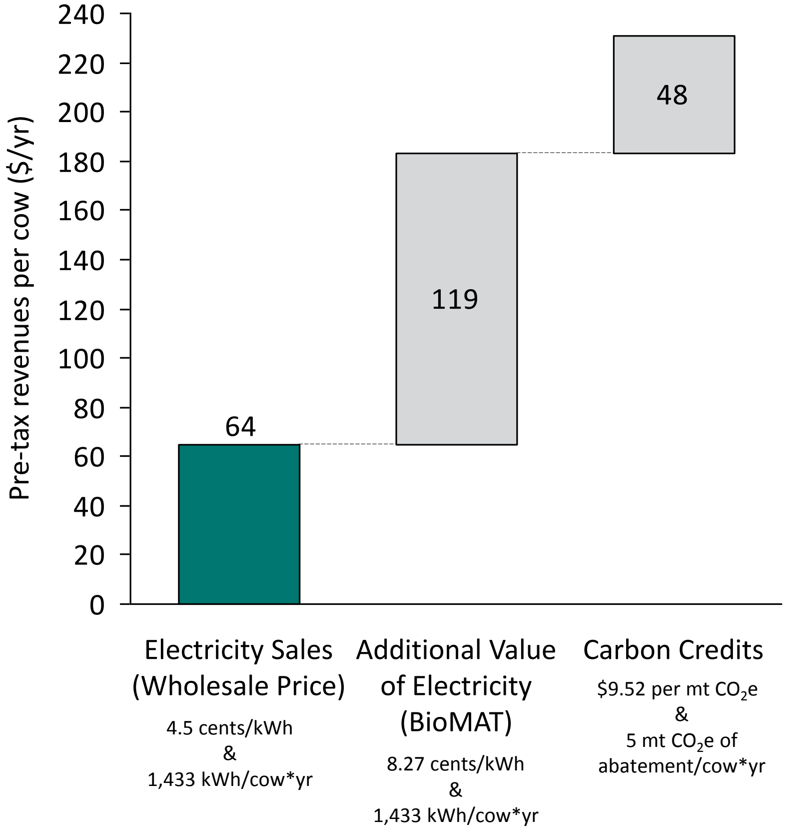


**Figure 6 - Modeled revenues for a manure-only anaerobic digester project producing electricity**

### 3.1.4 Environmental costs and benefits

#### Greenhouse Gas Reductions

The greenhouse gas benefits of anaerobic digesters are substantial. According to California ARB, anaerobic digesters in California emit 73% less GHGs per dairy cow than anaerobic lagoons (2.36 mt$CO_2$e per dairy cow for anaerobic digesters vs. 8.74 mt$CO_2$e for anaerobic lagoons). For a dairy farm in California that directs all of its manure to an anaerobic lagoon, this amounts to GHG abatement of ~6.4 tonnes of $CO_2$e reductions per cow each year by installing an anaerobic digester.[66] Actual greenhouse gas reductions may be less depending several factors, such as the manure capture efficiency of the farm,

[66] California Air Resources Board, 2014. *California's 2000-2012 Greenhouse Gas Emissions Inventory: Technical Support Document: Annex 3B. Manure Management*

handling of the manure prior to digestion, leakage rates from the digester system, the combustion efficiency of the generator, and whether a solid separator is present prior to storing flushed manure. If a dairy is using a manure management system other than an anaerobic lagoon, the greenhouse gas benefits of a digester project will be lower due to lower baseline emissions.

In addition to the greenhouse gas benefits of combusting biogas, there is also a benefit from offsetting fossil fuel generation on the electricity grid. As mentioned before, the amount of electricity generation per cow can vary quite widely from project to project, but assuming that 1.5 MWh of electricity can be generated per cow each year, 0.65 tonnes of $CO_2$e emissions per cow annually could be mitigated (using marginal emission factor)[67] by displacing fossil fuel generation on the grid.[68] Due to the high global warming potential (GWP) of methane, the greenhouse gas savings from combusting biogas are far greater (~10x) than the savings achieved in offsetting fossil-based generation on the grid in California.

Beyond gross emissions reduction potential, it is important to evaluate any GHG mitigation strategy on a cost-per-tonne abated basis. Carbon abatement curves can be a helpful tool for getting an overall sense of the abatement potential and the associated costs. But, creating a robust carbon abatement curve for anaerobic digesters on dairies requires good data on the costs of projects and how they vary with dairy size. AgSTAR has published regressions that can be used to estimate the cost of digester projects based on the number of cows, which were created using data on the cost of pre-2010 digester projects in the United States. We tested the AgSTAR regression against the reported capital costs of historical projects in the state (i.e., pre-2010) and found it to be quite accurate for most projects. But, a number of industry experts interviewed for this paper felt that these regressions are not applicable to new digester projects, particularly in California, which are more costly due to several factors, including more stringent regulatory requirements. Interviewees were also concerned with the regressions for complete mix digesters which implied that they could be less expensive than plug flow and covered lagoon digesters.

In an effort to create a carbon abatement curve for California, we tried to adapt the AgSTAR regression for the cost of covered lagoon digesters to the present day California context. Adaptations that we included were inflating costs to 2015 dollars, adding in the cost of selective catalytic reduction technology, adding interconnection costs ranging between $100 thousand and $1 million based on project size, and adding costs for solid separation. We then compared the results of this modified regression against a handful of covered lagoon, manure-only digester projects that have been constructed since 2013 or are planned to be constructed. The adapted regression was reasonably accurate for a couple of digester projects, but had very large residuals for others (i.e., more than 100%). Given the small sample size of new projects and the large residuals, we cannot present a carbon abatement curve at this time. Moving forward, it will be helpful to consistently track the cost and performance of new digester projects in the state to develop an abatement curve that is representative of the current context in California.

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[67] Marginal emissions factor is the change in emissions from a unit change in electricity generation (i.e., the emission rate of the generator that a dairy digester project will be displacing on the electricity grid).
[68] PG&E, 2013. *Greenhouse Gas Emission Factors: Guidance for PG&E Customers.*

In spite of the lack of comprehensive data, a couple of recently completed or proposed digester projects can be used to ballpark carbon abatement costs for a covered lagoon, manure-only digester project generating electricity. In a preliminary business plan for a cluster of digesters at 11 farms in Kern County with 40,520 dairy cows, the authors estimated that at an electricity price of 8.9 cents per kWh, carbon prices would have to be \$60 per mt$CO_2$e to make the project economical. An electricity price of 19 cents per kWh with \$10 per mt$CO_2$e carbon credits would also make the project economical,[69] so if the project could sell electricity at the BioMAT tariff rate of 12.77 cents the required offset price would be somewhere in the range of \$40 - \$45 per mt$CO_2$e.

The second case is the Van Warmerdam covered lagoon digester project on a 1,200 cow dairy, completed in 2013. According to the developer's report submitted to Sacramento Municipal Utility District, the levelized cost of generation for the project is 25.59 cents per kWh assuming no incentives or carbon revenues, higher than the power purchase agreement price of 14.645 cents per kWh.[70] Using the parameters outlined in their report (e.g., debt terms, cost of equity), we estimate that the project would require a carbon price on the order of \$33 per mt$CO_2$e to break even with no grant or other incentive funding. It is important to note that this project covered an existing lagoon, so it was able to avoid the expense of constructing a new lagoon or adding a liner to the existing lagoon. This may be an exception for new projects in the state, and thus, the cost of this project is probably on the lower end of the spectrum for a covered lagoon digester on dairies of comparable size.

### Co-benefits

In addition to reducing greenhouse gas emissions, anaerobic digesters can provide co-benefits. The following is a list of co-benefits of anaerobic digestion.

- **Odor reduction** – Anaerobic digestion systems can substantially reduce the odor from manure management on dairies. This is an important co-benefit of digesters as it can improve relationships with people and businesses that live in close proximity to large dairies. According to one interviewee, nation-wide, odor reduction has been one of the most important drivers for dairies to install digesters. Another, however, felt that odor reduction has not been an important driver in California.
- **Water quality**
    - **Pathogen reduction** - Anaerobic digestion at mesophilic or thermophilic temperatures kills a large portion of bacteria in manure. Studies have shown that plug flow and continually mixed digesters can reduce generic E-coli by more than 98% and enterococci by more than 84%.[71] This pathogen kill may reduce the risk of bacterial loading on local waters. The degree of pathogen reduction depends on the length of time material

[69] California Dairy Campaign, 2013. *Economic Feasibility of Dairy Digesters in California: A Case Study.*
[70] Maas Energy Works. *Van Warmerdam Dairy Digester Final Report Including Technology Transfer Report*. (n.d.)
[71] Harrison, et al. Evaluation of the pathogen reduction from plug flow and continuous feed anaerobic digesters. (n.d.)

spends in the digester and the operating temperature of the system. Heated digester systems are more efficient at killing pathogens than unheated systems.[72]

- **Nitrogen** - The anaerobic digestion process converts organic nitrogen, which is not easily assimilated by crops, to ammonium. Ammonium can be readily converted by microorganisms in soils to nitrate, a form of nitrogen that is most easily assimilated by crops.[73] Since the forms of nitrogen in digested material are more readily and predictably assimilated, field application of post-digestion manure could result in less nitrogen pollution of local water systems depending on management. This benefit of digesters is often referenced anecdotally, but we have not identified any studies that demonstrate reduced nitrogen pollution of local water sources when replacing lagoon water with post-digestion manure for field application. It is also important to note that digesters do not reduce the overall quantity of nitrogen; they simply change its form, so a digester alone will not solve the problems of a farm that has excess nitrogen.

**Hydrogen Sulfide, VOCs, and Ammonia –** During the process of scrubbing and combusting biogas, these gases are either filtered ($H_2S$ treatment) or partially destroyed. The digestion process also breaks down volatile fatty acids which are contributors to VOC emissions. Of these gases, changes in ammonia emissions may be the most uncertain when converting from an anaerobic lagoon to a digester. At least one expert interviewed for this study said that digesters would reduce ammonia emissions, and an assessment of technologies for management and treatment of dairy manure came to the same conclusion.[74] Another study, however, concluded that ammonia emissions during the storage of digested manure are higher than undigested manure.[75] The picture is further complicated when taking into account downstream emissions, as one study has demonstrated that emissions from digested manure can be lower than undigested manure when field applied.[76]

### Negative Impacts

- **NOx, SOx, and PM –** Generating electricity with an anaerobic digester will require combusting the biogas. Through the combustion process there will be emissions of SOx, NOx, and particulate matter. These emissions are regulated through new source review permitting and best available control technology (BACT) requirements but are a serious concern, especially in air districts that are out of attainment of national ambient air quality standards (NAAQS), including San Joaquin Valley.

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[72] Environmental Protection Agency. *Anaerobic Digesters Control Odors, Reduce Pathogens, Improve Nutrient Manageability, Can be Cost Competitive with Lagoons, and Provide Energy Too!* (n.d.)
[73] Topper, P. et al. *The Fate of Nutrients and Pathogens During Anaerobic Digestion of Dairy Manure.* (n.d.)
[74] San Joaquin Valley Dairy Manure Technology Feasibility Assessment Panel, 2005. *An Assessment of Technologies for Management and Treatment of Dairy Manure in California's San Joaquin Valley.*
[75] Ma, et al. 2015. *Dairy Manure Management with Anaerobic Digestion: Review of Gaseous Emissions.*
[76] Neerackal, et al. 2015. *Effects of Anaerobic Digestion and Solids Separation from Stored and Land Applied Dairy Manure*.

### 3.1.5 Barriers to adoption of anaerobic digesters generating electricity

#### Economics

The primary barrier to broader adoption of anaerobic digesters on dairies in California is economics. Although the technology is fairly well-established, projects do not generate enough revenue to justify the capital investment. Digester projects in California have typically received substantial grant funding (30% to 60% of capital costs), without which projects likely would not have been built. The implementation of a feed-in-tariff for electricity generated from dairy manure (SB 1122) will be helpful, but without additional incentives, the rate will most likely have to increase from the initial 12.77 cents per kWh to make dairy biogas-to-power projects economical. Similarly, carbon offset credits are improving the economic return on digesters, but it seems that a higher price is needed to catalyze digester development absent grant funding.

Although supplementary revenue streams or cost savings from byproducts (carbon credits, soil amendments, bedding, nutrients) can improve the economics of anaerobic digesters, these markets are variable and not well-established. Thus, it is difficult to secure financing based on these revenue streams. Several studies have highlighted the potential of byproduct revenue streams, including the recent Biogas Roadmap study which concluded that the market potential of byproducts far exceeded the value of electricity generation. [77] However, until the markets for these products have matured, few developers will be willing to rely on byproduct revenues to justify investments.

#### Interconnection

As discussed above, the process of interconnecting to the electricity grid can be both time consuming and expensive. Interconnection costs can be a substantial portion of project costs and are not very predictable. As one developer said, “I am in denial of the interconnection process.” The uncertainty of interconnection costs and timing creates a serious challenge and risk for project planners.

#### Regulatory process

Dairy digesters in California must comply with a number of air quality, water quality, and waste regulations. Navigating the regulation and permitting process is a complicated and time consuming endeavor. To respond to this challenge, CalEPA has initiated a consolidated permitting process for dairy digesters which allows a dairy to request one state agency to coordinate all state environmental permits.[78] While permit and compliance requirements may continue to be a barrier to methane reduction at dairies, the involvement of third-party digester companies with regulatory expertise and experience may help ameliorate this challenge. In addition, standard solutions (e.g., selective catalytic reduction) exist to meet these regulatory requirements.

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[77] USDA, USEPA, USDOE, 2014. *Biogas Opportunities Roadmap.*

[78] California Environmental Protection Agency, 2012. *Cal/EPA Consolidated Fact Sheet.* Accessed July, 2015. http://www.calepa.ca.gov/Digester/Documents/2012/PermitFacts.pdf

**Air quality**

The San Joaquin Valley Air Pollution Control District (SJVAPCD) has been classified as a "severe non-attainment" area for ozone by the EPA. As a result, the local air district has developed many rules and requirements towards a plan to come into attainment with the national ambient air quality standards. The most stringent requirement is SJVAPCD's Rule 2201: the New and Modified Stationary Source Review Rule.[79]

Dairy digesters that use combustion engines to generate electricity will produce nitrogen oxides (NOx). The emissions threshold that triggers regulation of a source under Rule 2201 (Amended 2011) is emissions of 2 lb. /day or greater. Given this low threshold, it is safe to assume almost all new and modified biogas-to-power projects on dairies will be covered by the regulation. For context, a digester proposal (2010) for a 2,400 milk cow dairy estimated that the system would emit over 40 lb. NOx/day.[80]

Rule 2201 requires new and modified sources to obtain an Authority to Construct (ATC) permit and implement Best Available Control Technology (BACT) emissions controls, a limit set by SJVAPCD based on cost effectiveness and technological feasibility.[81] The BACT requirement for a new digester limits NOx emissions to a standard of 0.15 g/bhp-hr. [82,83] This is equivalent to 9 – 11 ppmv[84] NOx at 15% $O_2$ concentrations.[85]

BACT requirements for dairies in the Central Valley were first developed and implemented in 2004. Early on, engineering and engine control issues made it difficult for a dairy digester to meet the standard on a continuous basis.[86] Today, the 0.15 g limit is typically achieved by either employing catalytic reduction systems (SCR) in combination with a lean-burn engine or, for smaller systems, installing a three-way catalyst in a rich-burn engine. Catalyst technologies are used in other larger industries, including trucking; these controls are thus readily available and may benefit from greater technology development and cost reductions then would otherwise be realized for a technology specific to the dairy biogas-to-power sector. Alternatives, such as micro turbines, fuel cells or Stirling engines may also achieve the BACT standard but have typically been too expensive -- fuel cells cost $7,000/kW—or are not commercially available, in the case of Stirling engines.[87] The cost and burden of compliance with

[79] San Joaquin Valley Air Pollution Control District, 2011. *Rule 2201: New and Modified Stationary Source Review Rule. Amended April 21, 2011.*
[80] San Joaquin Valley Air Pollution Control District, 2010. *Notice of Preliminary Decision – Authority to Construct Project Number: S-1080811 & S-1103627.*
[81] San Joaquin Valley Air Pollution Control District, 2011. *Rule 2201: New and Modified Stationary Source Review Rule. Amended April 21, 2011.*
[82] Norman, R. 2011. *Reducing Air Emissions from Digester Projects in the San Joaquin Valley.*
[83] g/bhp-hr: grams per brake horsepower * hour;
[84] Ppmv – parts per million volume
[85] San Joaquin Valley Air Pollution Control District, 2010. *Notice of Preliminary Decision – Authority to Construct Project Number: S-1080811 & S-1103627.*
[86] Norman, R. 2011. *Reducing Air Emissions from Digester Projects in the San Joaquin Valley.*
[87] San Joaquin Valley Air Pollution Control District, 2010. *Notice of Preliminary Decision – Authority to Construct Project Number: S-1080811 & S-1103627.*

NOx BACT may decrease moderately over time, but this regulation will likely continue to pose the greatest challenge for dairies considering investments in biogas-to-power projects.

Digesters with combustion equipment must also comply with Rule 2201 BACT requirements for volatile organic compounds (VOCs) and Sulfur Oxide (SOx) emissions. Achieving the BACT limit for SOx typically requires installation of scrubbers to reduce sulfur content of the biogas or absorption on $H_2S$ from fuel gas. Sulfur controls are required not only to achieve BACT requirements but also to prevent sulfur from harming the SCR. VOC limits are generally achieved through implementation of NOx controls and the addition of an oxidation catalyst, a relatively affordable device compared to SCR.[88]

**Water quality**

Dairy digesters in central California must receive permits from the Central Valley Regional Water Quality Control Board (the Water Board) for discharges of waste that may affect surface or ground water. In 2010, the Water Board adopted the General Order for Dairies with Manure Anaerobic Digester or Co-Digester Facilities which streamlines the Water Board's permitting process for digesters and regulates the discharge of digestate when field applied.[89] Requirements under the General Order include submission of a waste management plan, ground water monitoring, specific requirements for storage and settlement ponds, nutrient management planning and land application area specifications (limits on non-nutrient salt applications per acre).[90] Ponds that are modified or newly installed for digestion or wastewater storage, or existing ponds used for co-digestion must be constructed to the specifications of the General Order, which generally requires high density polyethylene double liners and a leachate collection-and-removal system. Alternatively, dairies must complete a technical report demonstrating that their proposed system protects groundwater quality.[91]

**Waste**

Dairies that sell or transfer over 1,000 cubic yards of solid waste product annually will be regulated by CalRecycle as Compostable Material Handling Facilities or Transfer Processing Facilities. CalRecycle requires regulated facilities to be permitted and subject to regular inspections by a local enforcement agency.[92,93] Farms that handle agricultural waste produced and kept onsite or that transfer small quantities of waste offsite are generally exempt from these requirements.

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[88] Ramon Norman, SJVAPCD, *Personal Communication.* June, 2015.
[89] California Regional Water Quality Control Board Central Valley Region, 2010. *Order R5-2013-0130: Waste Discharge Requirements General Order for Dairies with Manure Anaerobic Digester or –Co-Digester Facilities..*
[90] Ibid.
[91] Ibid, pg. 16.
[92] California Integrated Waste Management Board, 2009. *How Anaerobic Digestion Fits Current Board Regulatory Structure.*
[93] California Environmental Protection Agency, 2011. *Permit Guidance for Anaerobic Digesters and Co-Digesters*, pg. 34

## 3.2 Digesters producing biogas for vehicle fuel

An alternative to on-site combustion of biogas is the production of vehicle fuel. Biogas captured by a digester can be cleaned to produce renewable forms of compressed biomethane (CBM; equivalent to compressed natural gas) or liquefied biomethane (LBM; equivalent to liquefied natural gas). To produce fuel, raw biogas is processed to create more energy-dense biomethane by removing other constituents of biogas, such as $CO_2$, $H_2S$, and $H_2O$, and is then compressed or liquefied. If a dairy has a fleet of CBM vehicles, the entire fuel system, including production equipment, biomethane storage tanks, and fueling stations, can be located on farm. In other cases, the CBM or LBM can be shipped via truck, dedicated pipeline, or a utility natural gas pipeline to its final destination.[94]

By potentially displacing diesel trucks or fossil fuel emissions from other vehicles, these systems can provide air quality benefits beyond the capture of methane on the dairy farm. Such systems are poised to take advantage of significant state and federal renewable fuel incentives (see section 7). In some cases, they can also achieve significant cost savings from displacing diesel gasoline from trucks. However, because of the need for costly gas upgrading equipment (fueling stations, CBM vehicles, and/or or pipeline interconnection) such systems are best suited to large dairy operations in proximity to vehicle fleets, where economies of scale can be achieved and gas need not be transported far. Thus far, there are only two such operations on dairies in the U.S. (Hilarides Dairy in California and Fair Oaks Dairy in Indiana), and it is not clear what sort of scope there is for expansion. Overall economics, the volatility of revenue streams, access to natural gas vehicle fleets, and short-term contracts are the primary hurdle preventing more widespread adoption.[95]

### 3.2.1 Costs

Biogas to vehicle fuel projects start with a digester, just as biogas to electricity projects do (see Figure 4). But instead of a generator set, these systems require biogas cleaning and compression equipment. Generally speaking, capital costs for biogas to vehicle fuel systems are comparable in magnitude to capital costs for anaerobic digesters used for electricity, although the gas upgrading and distribution systems tend to have higher operating costs.[96] This means that the entire life cycle cost of the system can be higher, depending on the design. For example, when the compressed biomethane will be used as vehicle fuel on-site, it will require an on-site fueling station and may also require upgrading the vehicle fleet. If gas is to be shipped offsite via pipeline or truck, or as liquefied biomethane, transportation is required and gas cleaning costs may be higher. In general, costs for biogas to vehicle fuel systems are not well-quantified, as there are only a handful of such systems operating nationwide.

Costs can be broken down by system components: the digester, upgrading, and delivery / use (on-site or off-site).

#### Anaerobic digester

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[94] If moved via natural gas pipeline the gas may have to be purified to a higher quality standard.

[95] For a more in-depth review of the potential scope and scale of dairy biomethane in California, please refer to Kirch et al., 2005. *Biomethane from Dairy Waste: A Sourcebook for the Production and Use of Renewable Natural Gas in California.*

[96] Ibid.

Biogas for vehicle fuel employs essentially the same anaerobic digester infrastructure as biogas for electricity generation, but lacks a generator set, reducing capital costs on the order of 36%. Please see section 3.1.1 for discussion on the cost of digesters.

### Biogas upgrading

Biogas upgrading and cleanup can are a major expense for biomethane projects. Whereas raw biogas has an energy density of about 600 BTU/$ft^3$, biomethane has a density of 900-1000 BTU/ $ft^3$. $H_2S$, $CO_2$, $H_2O$, and potential trace gases must be removed to create clean biomethane. Gas cleaning standards are higher for pipeline injection than for vehicle fuel. A 2010 study estimated the costs of upgrading biogas to vehicle fuel at $3.92 per 1000 $ft^3$ for a medium sized facility (>2,500 cows) and $7.12 per 1000 $ft^3$ for a small one (<2,500 cows).[97] These cost estimates may be a bit low as an earlier study (2005) found that costs of upgrading biogas for a 1,500 cow dairy were $8.12 per 1000 $ft^3$, and between $5.45 and $8.56 for an 8,000 cow dairy.[98] Biogas upgrading costs in both studies were higher than the cost of biogas production (i.e., the digester), and exhibited substantial economies of scale.

### Biogas delivery and use

**Pipeline distribution**: If the fuel is to being used off-site, transportation adds additional costs that will vary depending on proximity to existing gas lines, distance to fueling station, and the type of land that the pipeline is passing through. Pipelines might cost on the order of $100,000-250,000 per mile.[99] Thus the most promising site for a CBM project is likely a location where existing CBM stations are in close proximity to large dairies.[100]

**Interconnection:** If a dairy producing vehicle fuel intends to inject its gas into a utility pipeline, it will have to pay an interconnection fee. The scale of these fees will depend on several factors, such as the proximity to pipeline infrastructure suitable to accept the expected production volumes. A scoping study for a pipeline injection project in Washington for a farm with more than five thousand cows estimated that interconnection costs would be $1 million.[101] Another study scoping pipeline injection of biogas at a single injection point from a cluster of dairies with 40,000 total cows estimated interconnection costs of $2 million, or about 4% of total project cost.[102]

**Fuel station**: Costs of fuel stations vary depending on their speed (fast, slow, and variable). A small, slow-fill, 6-vehicle fueling station might cost only $100,000, but a similarly sized fast fuel station would cost closer to $200,000.[103] A medium-large slow-fill station serving 25-40 trucks would fuel a total of 5,000-8,000 gallons of gas equivalent per night and might cost on the order of $550,000-850,000.[104],[105]

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[97] Chen et al. 2010. *Economic assessment of biogas and biomethane production from manure.*
[98] Kirch et al., 2005. *Biomethane from Dairy Waste: A Sourcebook for the Production and Use of Renewable Natural Gas.*
[99] Ibid.
[100] Ibid
[101] Coppedge, et al. *Renewable Natural Gas and Nutrient Recovery Feasibility for Deruyter Dairy.*
[102] California Dairy Campaign, 2013. *Economic Feasibility of Dairy Digester Clusters in California: A Case Study.*
[103] Biogas, 2013. *Developers guide to biomethane as a vehicle fuel.*
[104] California costs may skew to the upper end of this spectrum.

**Vehicle fleet**: Upgrading vehicle fleets to compressed natural gas (CNG) by upgrading or buying new, CNG-specific vehicles will be a significant cost. SUVs can be converted to run on CNG for $5,000 to $6,000, and tractor trailers for roughly $50,000-60,000.[106] As of mid-2014, a new heavy-duty CNG truck costs $200,000, which is about $50,000 more than a diesel-powered truck.[107] The economic payback of upgrading or converting vehicles will vary depending on the situation, but they may be partially or wholly offset by savings from avoided diesel purchases. However, this may be tempered by a shorter lifespan of heavy-duty CNG trucks.

**Liquefied natural gas**: Liquefied biomethane is biomethane that is compressed into a liquid state; it takes up a fraction the volume of regular CBM and can be transported more cost-effectively than CBM. With the proper equipment, it can then be dispensed to both LNG and CNG vehicles. However, the costs of compressing gas are significant. LBM is unlikely to be a viable option for dairies.

### 3.2.2 Revenues

There are two main sources of revenue for biogas to vehicle fuel projects: the value of the biomethane itself and the value of the associated environmental credits. The revenue earned for the biomethane will depend on the structure of the project, but in all cases the environmental credits comprise a substantial share of overall project revenues (Figure 9).

#### Biomethane as a vehicle fuel

Biomethane can have a wide range of values for digester projects, depending on how a project is structured. If the digester developer sets up and operates their own fueling station, they may be able to realize the retail price of CNG as a vehicle fuel. Current prices are about $3.06 per diesel gallon equivalent. Another option may be to sell the biomethane to a separately owned CNG fueling station, in which case the biomethane producer would receive a wholesale price for the product. If the project developer will use the biomethane to fuel their own fleet of vehicles they will realize savings equivalent to the cost of retail diesel fuel that they are displacing (although they would incur additional expense of converting their fleet to CNG). Current diesel prices in California are about $3.22 per gallon. Using biomethane for transportation purposes greatly improves its value as the wholesale price of natural gas is just 64 cents per diesel gallon equivalent, or about one fifth the price of a gallon of diesel fuel. In addition, using the biomethane for vehicle fuel also unlocks the potential to generate RINs and LCFS credits (see below).

#### RINs

Using biomethane as a vehicle fuel allows projects to generate renewable identification

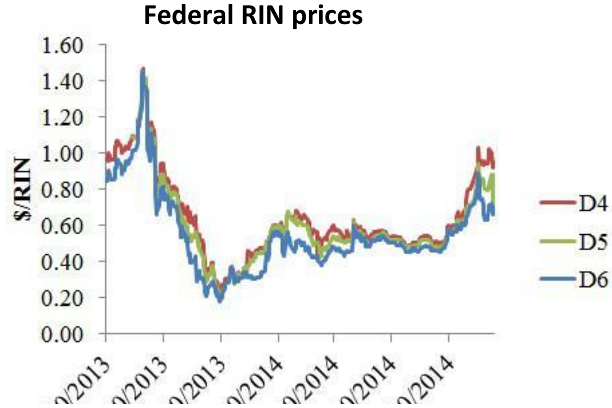

Figure 7 - RIN prices

[105] At Fair Oaks Dairy, 11,000 cows power 42 trucks -- *Inn*
*Gas Replaces Diesel Fuel in Milk Delivery Trucks, Revealin*
[106] Biogas, 2013. *Developers guide to biomethane as a veh*
[107] Tita, 2014. *Slow Going for Natural-Gas Powered Trucks*

numbers (RINs) under the federal Renewable Fuel Standard program. Every MMBTU of biomethane used as a vehicle fuel can generate thirteen RINs. The price of RINs for biogas are quite variable (Figure 7),[108] but assuming a price of 80 cents per RIN,[109] the value of these renewable fuel credits would be worth an additional $1.48 per diesel gallon equivalent. This high value makes RINs attractive, but price volatility and concerns about the long-term market make RINs a high-risk revenue stream and one that lenders are unwilling to lend against.

### LCFS

California's Low Carbon Fuel Standard (LCFS) requires covered entities (fuel suppliers) to supply a fuel mix that meets a specific carbon intensity. Dairies in California that are producing biogas for vehicle fuel that will be used in the state can opt into this program and generate LCFS credits. These credits can be stacked on top of RINs and at current prices of $25 per $mtCO_2e$ this amounts to an additional 29 cents per diesel gallon equivalent of biomethane produced. Similar to RINs, LCFs credit prices have been quite volatile (Figure 8),[110] although after spiking in 2013 at around $90 per credit (each credit is equivalent to 1 $mtCO_2e$) the price of LCFS credits has since stabilized between $20-30 per $mtCO_2e$. Despite this recent stabilization, LCFS credits are still viewed as high risk and it is difficult to obtain financing for digester projects based on future LCFS credit revenue.

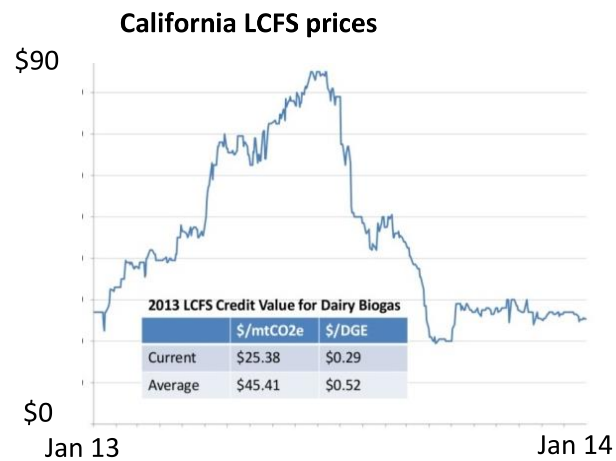


Figure 8 - California low carbon fuel standard credit prices

[108] Brown, Tristan, 2015. *As RIN Prices Fly, a Look Back at Their Impact on Refiners.*
[109] There is poor market information on the price of D3 RINs, so we have used 80 cents, the recent price of D5 RINs as a conservative estimate.
[110] Weisberg, Peter, 2015. *Oregon's Clean Biofuels Program and Biogas*. Presentation at BioCycle West Coast Conference.

### Carbon offsets

Like digesters used for electricity, biomethane projects are eligible for carbon offsets, which can be generated in addition to RINs and LCFS credits. The value of carbon credits will depend on the amount of biomethane generated per cow, the verified greenhouse gas abatement, and the price of carbon offsets, but they may be worth on the order of 50 cents per diesel gallon equivalent of biomethane at current offset prices of approximately $9.50 per $mtCO_2e$ (Figure 9).

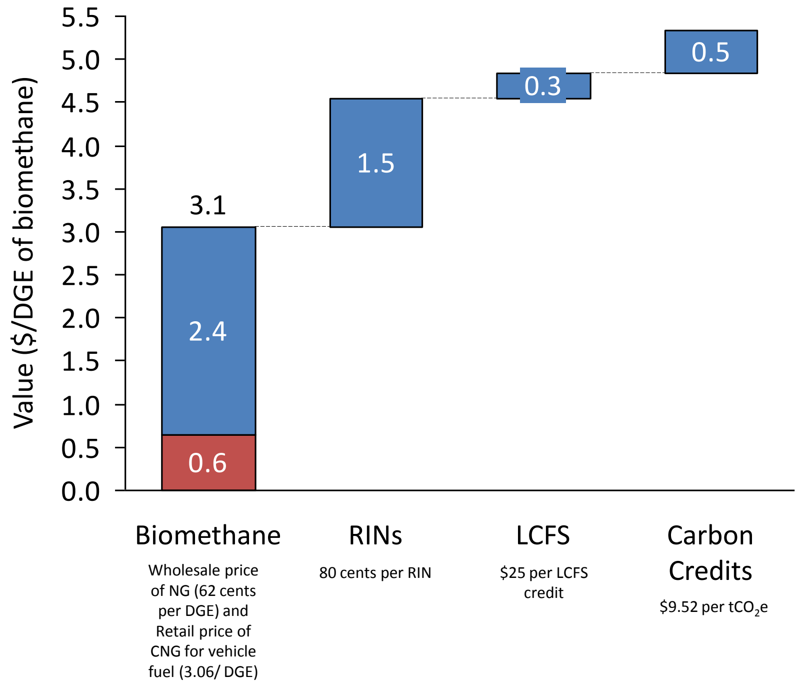


**Figure 9 - Contribution of different revenue sources to a biogas to vehicle fuel project. Assumes 36 scf daily biomethane production per cow and 5 $mtCO_2e$/cow*yr of carbon credits.**

### Solid byproducts and nutrients

As with electricity generation, it is also possible to monetize the byproducts of the anaerobic digestion process, including soil amendments, and nutrient products. However, as previously stated, these markets remain relatively immature or are not secure enough to provide a guaranteed revenue stream in many cases.

## 3.2.3 Environmental costs and benefits

### GHG potential

Biomethane projects from dairy manure not only reduce the methane associated with the dairy, but also help to reduce diesel particulate emissions which themselves are short-lived climate pollutants.

- **Greenhouse gas reductions from the digester**: The primary benefit of biomethane vehicle fuel projects, like digester electricity projects, is that they capture and utilize the methane emitted from anaerobic lagoons on dairies. The greenhouse gas reduction potential from this part of the system is identical to a project developed for electricity: roughly 73% GHG reduction per dairy cow, or 6.4 tons of $CO_2e$ reductions per cow each year.[111]

- **Displacement of fossil fuel**: CBM reduces GHG emissions 86-94% compared to petroleum diesel, without even considering the effects of black carbon.[112] Reductions compared to conventional CNG are slightly less.[113] For a typical manure-only digester project, each cow will generate

[111] California Air Resources Board, 2014. *California's 2000-2012 Greenhouse Gas Emissions Inventory: Technical Support Document: Annex 3B. Manure Management*

[112] Han et al. 2011, *Waste-to-wheel analysis of anaerobic digestion-based RNG with GREET model*.

[113] Ibid.

enough biomethane to abate ~0.9 metric tonnes of $CO_2e$ emissions by displacing diesel fuel.[114] If the biomethane actually displaces natural gas, the carbon displacement would be a bit lower.

- **Reduces black carbon emissions from heavy-duty diesel trucks**: Almost all U.S. milk is delivered in refrigerated, Class 8 diesel trucks.[115] Particulate matter from diesel engines is a significant source of black carbon, which is a short-lived climate pollutant with significant health impacts.[116] Upgrading old diesel vehicles to accept CBM will reduce black carbon emissions. When CBM is compared to new diesel trucks, the emissions benefit is less clear.[117,118]

### Co-benefits

The co-benefits of anaerobic digestion for vehicle fuel will be largely the same as for projects that generate electricity (see section 3.14). The one notable exception is the potential for a digester to biomethane project to reduce criteria pollutants by displacing vehicle fuel.

- **NOx, SOx, and PM –** Unlike anaerobic digesters that are producing electricity, biomethane projects may actually reduce emissions of SOx, NOx, and PM in the area by displacing diesel fuel use. Since these pollutants have localized effects, the actual impact will depend on where the vehicle fuel is used and what type of fuel it is displacing. For example, if the biomethane project leads to the replacement an old diesel truck fleet there will be reductions in NOx, SOx, and PM, but if the vehicle fuel used outside of the area the benefits may not be realized locally.

### Impacts

There are few negative impacts associated with a digester project for vehicle fuel. Perhaps the development of a CNG fueling station would attract additional traffic to the area, or a project may include a small electric generator to provide energy for biogas cleaning and upgrading, which may result in local SOx, NOx, and PM emissions. But, by in large, these concerns are probably less worrisome than the potential impacts from an electricity generation project or the conversion of a dairy from flush to scrape.

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[114] Assuming 22.38 lbs of $CO_2$/ gallon of diesel.
[115] Ulrich, et al. 2013. *Tailpipe greenhouse gas emissions from tank trucks transporting raw milk from farms to processing plants*, pp 3.
[116] New diesel technology is much cleaner than old, and PM emissions from diesel trucks in California have been falling due to air control measures.
[117] Schaeffer, California Air Resources Board, 2008. *Diesel Technology and Black Carbon*
[118] Lowell, 2012. *Clean Diesel versus CBM Buses: Cost, Air Quality, & Climate Impacts.*

### 3.2.4 Barriers

**High risk** – Digester to vehicle fuel projects may be able to deliver more revenue than projects generating electricity, but given current market conditions these projects are much higher risk and difficult to move forward. Several factors contribute to the risk profile of pipeline injection projects.

- **Few active projects** – There are just two operating dairy digesters projects supplying vehicle fuel in the U.S. (Hilarides and Fair Oaks). There is a lot more experience and security in pursuing an electricity generation model of which there are more than 180 existing projects on dairies. Until more vehicle fuel projects come on line and the model is more proven there will be a limited pool of developers and investors that will be willing to take on these projects.
- **Volatility and uncertainty of environmental credits** – Vehicle fuel projects depend heavily on the value of environmental credits. Prices of these credits are quite volatile, and there is also some regulatory uncertainty surrounding the future of these markets. Thus, these credits, although potentially lucrative, are viewed as too risky to rely on when making investment decisions.
- **Finding or building a CNG fleet** – Another problem for fuel producers is finding a willing buyer that is geographically well-placed to receive the fuel. While CBM may be used onsite, many milk fleets will be too small to utilize the quantity of biogas being produced, and fleets that are well suited to CBM will be costly to upgrade. The number of California dairies with the necessary mix of conditions (significant scale, large milk delivery fleet or proximity to pipeline or other buyer, willing financiers, etc.) to convert dairy manure to vehicle fuel is likely limited.
- **Short-term contracts** – Unlike electricity, sales contracts for CBM are often too short to obtain financing. Over the last couple decades, the average length of gas contracts has decreased and long-term contracts are now scarce.[119] With no security that there will be a long-term customer to off-take the produced biomethane, these projects are viewed as much more risky than electricity projects.
- **Large scale of investment** – There are large economies of scale associated with manure digesters producing vehicle fuel, especially with the equipment for cleaning and upgrading gas to vehicle fuel quality standards. Because of these economies of scale, these projects are probably only viable at the largest dairies or a cluster of dairies. This means that not only are the projects viewed as high risk, they will also be limited to a handful of operations in the state.

[119] Petrash, 2006. *Long-term natural gas contracts.*

## 3.3 Pipeline injection

Given the difficulty of making anaerobic digester projects economical based on revenues from electricity, there is increasing interest in identifying alternative business models. One such model is to clean and upgrade biogas in order to inject it into natural gas pipelines. In this process, biogas is captured from the digestion process, cleaned to remove impurities (e.g., $CO_2$, $H_2S$, etc.), and compressed to suitable pressures and composition standards for injection into natural gas pipelines. Nationally, five dairy anaerobic digester projects were developed that injected upgraded biogas into pipelines, but all but one have subsequently shut down.[120] One additional project in New Mexico has been in the planning stages for a while,[121] although it may be encountering significant challenges getting off the ground and may be completely stalled. DeRuyter Dairy in Washington is also considering converting their combined heat and power digester system to biomethane pipeline injection. Natural gas prices are incredibly low ($3.13 per thousand cubic feet in April, 2015)[122] due to the fracking boom, so the most viable model for pipeline injection at this time appears to be using the pipeline to distribute the fuel for vehicle use (See previous section). So long as the project has a contract with a transportation fuel customer located on the pipeline system, the project will be able to generate RINs and LCFS credits.

Injection into the pipeline is a bit of a trade-off compared to generating and using/selling CNG on site. By injecting gas into the pipeline, producers will face a lower price for the gas than if they sold the CNG on site or used it to replace diesel gas use in their own vehicle fleet. However, injection in the pipeline opens up a much broader market for their product and mitigates the challenge of finding a nearby natural gas vehicle fleet for the product. Unless prices for natural gas change, pipeline injection models will be unlikely to stand on their own unless they are able to sell the fuel for vehicle use and access the valuable associated environmental credits (RINs and LCFS). Even with those credits, it will still be difficult to make projects pencil out and even harder to find financing.

In 2012, the state legislature passed AB 1900 which requires the CPUC to develop standards for constituents found in biogas in order to protect health, safety, and pipeline integrity.[123] The development of standards creates a pathway for dairy digester projects to inject biomethane into pipelines, but also brings regulatory scrutiny to these projects. The CPUC opened a rulemaking to implement AB 1900 and issued a decision in January 2014 that adopted concentration standards for 17 constituents in biomethane and certain monitoring, testing, and reporting requirements for biomethane producers and gas utilities.[124,125] In May of 2015, the CPUC issued a proposed decision which assigns the costs of compliance (i.e., treatment and conditioning of biomethane) to the biomethane producer rather

[120] Fair Oaks Dairy injects a portion of biomethane produced into the utility pipeline, but is not identified as pipeline injection in AgSTAR's database

[121] Environmental Protection Agency, 2015. *AgSTAR Database of Livestock Digesters*. Accessed July, 2015.

[122] Energy Information Administration. *Natural Gas Citygate Price in California*. Accessed July, 2015.

[123] California Air Resources Board, 2013. *Recommendations to the California Public Utilities Commission Regarding Health Protective Standards for the Injection of Biomethane into the Common Carrier Pipeline.*

[124] Ibid.

[125] California Public Utilities Commission, 2015. *Decision Regarding the Costs of Compliance With Decision 14-01-034 and Adoption of Biomethane Promotion Policies and Program*. pg. 35.

than to the utility ratepayers, but also a establishes a $40 million monetary incentive program to help cover the costs of interconnection.

## 3.4 Cover and flare

Much of the literature on anaerobic digesters focuses on using biogas for electricity generation, vehicle fuel, or pipeline injection. Some projects, however, have utilized a simpler approach: capping anaerobic lagoons with an impermeable cover and flaring the biogas that is produced. This approach is less capital intensive than generating electricity or upgrading the biogas for pipeline injection or vehicle fuel, and should have lower operating costs due to the simplicity of the system. In some cases, these projects may be able to achieve almost the same level of greenhouse gas abatement as more sophisticated digester projects since the bulk of the carbon savings come from the destruction of methane during combustion rather than from offsetting fossil fuel use, although digestion in these systems can be less efficient and some have implied that leakage rates can be higher. There are currently nine operational digesters on dairy farms in the United States that simply flare biogas, eight of which are on covered lagoons.[126] The most recent project was installed in 2011 and there are no additional cover and flare projects under construction.

In some locations, cover and flare may be a relatively cheap option on a cost per ton basis to reduce methane emissions from dairies, especially when the cover can be placed on an existing lagoon, but we found few studies in the literature that have investigated this option thoroughly. The most comprehensive study was also regional in scope and therefore does not reflect the additional cost and complexity of implementing a cover and flare project in California. When taking into account the additional measures that would be required to do a cover and flare project in California (e.g., low NOx SCR, potentially double lining the lagoon), it may not be a viable option. Simply combusting the biogas and not putting it to productive use (e.g., generating electricity, heating boilers, etc.) also misses out on the important co-benefit of displacing fossil fuel that digester to electricity or digester to biomethane projects generate. Although there are clear downsides to these projects, cover and flare may be a mitigation option that warrants additional research to fully understand the cost-effectiveness and complications associated with this approach.

### 3.4.1 Costs

The capital investment of a simple cover and flare system is lower than projects that generate electricity or clean and upgrade biogas. An ICF, International study in 2013 investigated the capital costs of cover-and-flare systems for existing lagoons and estimated cost ranges between $183 and $366 per cow for dairies between 5,000 and 600 head, respectively, substantially lower than the cost estimates for digesters generating electricity.[127]

As another data point, a carbon offset developer said that the cost of covering and flaring an existing lagoon for a 2,000 head dairy is between $300 thousand to $400 thousand. This price could be a bit

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[126] Environmental Protection Agency, 2015. *AgSTAR Database of Livestock Digesters*. Accessed July, 2015.
[127] ICF International, 2013. *Greenhouse Gas Mitigation Options for Agricultural Land and Animal Production within the United States.*

higher in California given more stringent regulatory requirements, perhaps $500 thousand.[128] While this cost estimate is much lower than the costs for covered lagoon digesters generating electricity, it is important to note that this is just one anecdote, and may not reflect the true cost and complexity of implementing a project in California.

People involved with digesters in California that we spoke with for this investigation felt that contrary to the ICF study, there are probably little savings to be realized by implementing a cover and flare project instead of a covered lagoon digester that generates electricity. By the time cover and flare projects included all of the necessary equipment to meet air and water quality requirements (e.g., ultra-low NOx flare, $H_2S$ treatment, potentially double-lining the lagoon), costs would be approaching the same level as a digester project that could generate electricity. Thus, the general view was that adding on electrical generation or biogas upgrading equipment would a more economically attractive option than flaring the biogas.

### 3.4.2 Revenues

#### Carbon offsets

Carbon offsets are the key revenue stream for cover and flare systems. Theoretically, a cover and flare project could generate as many carbon offsets as a covered lagoon digester project that generates electricity, but existing cover-and-flare projects that have been issued offset credits by ARB have generated relatively low emissions abatement per cow (approximately .75 tons - 1.5 $mtCO_2e$/cow*yr.).[129] An offset project developer said that these projects generated relatively few credits for several reasons (e.g., projects were in a cold climate in New York, the project structures did not incentivize maximum carbon capture and monitoring), and that well-managed cover-and-flare projects in warm climates can achieve abatement levels approaching those of electricity-generating lagoon digesters.

### 3.4.3 Net present value analysis

We are only aware of one study that has investigated the net present value of cover and flare projects. In a 2013 study for the USDA, ICF evaluated the price of carbon necessary to make covering existing lagoons and flaring the biogas economical.[130] This study determined that cover and flare projects for dairies with anaerobic lagoons would become economical at carbon prices between $5 and $9 per $mtCO_2e$ (Table 3). This is below the current offset price for compliance under AB32, but still no new cover and flare projects for dairies are underway in California or the rest of the United States. This may be an indication that costs of cover and flare projects are actually higher than estimated in this study, or that digester projects that use biogas for productive purposes (e.g., electricity) can create better returns. As noted above, the general consensus among people we interviewed is that these prices do not reflect

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[128] Project Developer. *Personal communication*. June, 2015.

[129] California Air Resources Board, 2015. *ARB Offset Credits Issued.* Updated April 22nd, 2015. Per cow abatement calculated by CEA based on information in individual project documents.

[130] ICF International, 2013. *Greenhouse Gas Mitigation Options and Costs for Agricultural Land and Animal Production Within the United States.*

the current reality in California. The fact that carbon offset prices are approaching $10 per $mtCO_2e$ and no projects are moving forward is further evidence that the estimates in this study are too low.

**Table 3 – ICF's assessment of the price of carbon to make cover-and-flare projects in the Pacific region NPV positive**

| Dairy Size (# of head) | Price of carbon required to make projects NPV positive ($/$mtCO_2e$) |
|---|---|
| 5,000 | 5 |
| 1,000 | 7 |
| 600 | 8 |
| 300 | 9 |

### 3.4.4 Environmental costs and benefits

#### GHG mitigation potential

In the warm climate of California, covering existing lagoons and flaring the biogas may be able to approach the same levels of greenhouse gas abatement as more complex digester systems (6.4 $mtCO_2e$/cow*yr). The relatively warm climate in California can make for more efficient digestion in a cover and flare project compared to cooler regions, but may still have lower abatement than a more sophisticated digester project. One cover and flare project developer estimated that projects in California can achieve verified greenhouse gas reductions (i.e., carbon credits) of 4 $mtCO_2e$ per cow per year.[131]

#### Co-benefits

Similar to other digester systems, covering and flaring biogas should reduce emissions of VOCs (from the breakdown of volatile fatty acids during the digestion process), $H_2S$ emissions (if proper gas treatment systems are in place), and odor. The impact on ammonia emissions seems less clear. Some sources indicate that ammonia emissions will be lower with a digester,[132] while others conclude that ammonia emissions during the storage of digested manure are higher than undigested manure.[133] The picture is further complicated when taking into account downstream emissions, as one study has demonstrated that emissions from digested manure can be lower than undigested manure when field applied.[134]

#### Impacts

Flaring biogas will produce NOx, SOx and PM emissions as described in the section on anaerobic digesters generating electricity (Section 3.1.4).

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[131] Project Developer. *Personal Communication*. June, 2015.

[132] San Joaquin Valley Dairy Manure Technology Feasibility Assessment Panel, 2005. *An Assessment of Technologies for Management and Treatment of Dairy Manure in California's San Joaquin Valley*

[133] Ma, Et al. 2015. *Dairy Manure Management with Anaerobic Digestion: Review of Gaseous Emissions.*

[134] Neerackal, Et al. 2015. *Effects of Anaerobic Digestion and Solids Separation from Stored and Land Applied Dairy Manure*.

### 3.4.5 Barriers

#### Economics

A key barrier to greater adoption of cover and flare projects is economics. Even though these systems are cheaper than digesters that produce electricity or upgraded biogas, they also have very limited revenue potential. The regulatory requirements in California may also limit the cost savings compared to a digester that generates electricity or cleans and upgrades biogas. The economic viability of these projects is completely dependent on a strong price and stable market for carbon offsets. As mentioned in the digester section, there are substantial costs associated with getting offsets registered and verified each year, and these costs generally do not scale with project size. Therefore, carbon offsets will become more profitable the larger the project.

#### Regulatory

Dairies implementing cover and flare projects will be regulated for the emissions associated with biogas combustion (e.g., SOx, NOx, PM). Dairies located in the San Joaquin Valley face stringent regulations due to the district's non-attainment with federal NAAQS. As with combustion of biogas for electricity production, capture and flare projects must obtain an Authority to Construct permit that demonstrates compliance with SJVAPCD's Rule 2201 BACT standards. A cover and flare project expected to produce more than 2 lb./day of a criteria pollutant must achieve BACT standards for that pollutant. The BACT for digester flares is 0.06 lb./MMBtu of NOx, which can be achieved through use of an ultra-low-NOx flare, which can cost several times the cost of a standard enclosed flare.[135] In addition, a cover and flare project which requires the construction of a new or expanded waste retention pond will be subject to more stringent pond design requirements (e.g., double liners) under the CRWQCB General Order for Existing Milk Cow Dairies.[136] With limited revenue opportunities from cover and flare, this process may be more harmful to overall project economics than if the digester were producing electricity or upgraded biogas for productive uses. A developer of cover-and-flare projects said that with current carbon prices they are interested in developing projects in California, but are hesitant because of the regulatory complexity.

## 3.5 Co-digestion

"Co-digestion" means adding other organic materials to manure feedstock, such as food waste, food processing byproducts, or other agricultural residues. Most co-digestion materials have high energy contents, and may help to balance and improve biogas production. Adding these materials can also help improve digester economics, especially if the digester owner is able to avoid food waste disposal costs or charge a "tipping fee" for receiving waste material from another facility. For example, cheese processing plants that send organic-material-rich wastewater to a digester can save tens of thousands of dollars a year in wastewater treatment costs. However, as technologies and uses for what were formerly

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[135] San Joaquin Valley Pollution Control District, 2010. *Notice of Preliminary Decision - Authority to Construct Project Number: S-1080811 & S-1103627*.

[136] California Regional Water Quality Control Board Central Valley Region, 2013. *Order R5-2013-0122: Reissued Waste Discharge Requirements General Order for Existing Milk Cow Dairies.*

considered "waste" materials proliferate, competition for these materials will increase, driving the revenue received from tipping fees down, and making it more difficult to secure high-value feedstocks.

There appear to be somewhat competing views as to the opportunity for co-digestion projects moving forward. For some, a combination of the growing desire to better manage organic wastes, and the potential to increase the biogas output of digesters leads them to believe that co-digestion projects will be the model of choice moving forward. For others, the complexity and expense of developing a co-digestion project are major barriers and they see co-digestion being limited to a handful of projects in the near future.

### Barriers

While co-digestion can improve gas production and add revenues, it also adds additional cost and can pose other problems. First of all, projects that will use feedstocks other than manure will typically require a more sophisticated digester (i.e., not a covered lagoon) that will be more costly. This additional expense may be warranted by the additional biogas production potential, but will depend on the project characteristics. Perhaps even more importantly, adding non-dairy material means that the producer can no longer access the favorable rates expected for anaerobic digestion of manure provided by the BioMAT incentive program. Co-digestion and manure-only digestion are in two different categories in the BioMAT. Manure with co-digestion projects must compete with other cheaper co-digestion projects in the BioMAT, and thus are not likely to receive favorable prices. However, digesters selling into the manure-only category cannot include an ounce of non-manure feedstock.[137]

Co-digestion can also exacerbate nutrient problems on the farm; adding additional materials to the digester means that there will be additional nutrients in the resulting digestate solids, which are usually spread on fields or sold. As many California dairies are already struggling to manage the nitrogen and other nutrients produced by their herd in a way that complies with regulatory requirements to avoid groundwater pollution, adding additional waste streams may add complexity or cost to their nutrient management activities.

Co-digestion can complicate efforts to comply with water quality requirements in other ways as well: adding co-digestion products to an existing lagoon may prohibit a dairy from receiving a grandfathered exception to certain requirements of the Central Valley's Digester General Order. This may require a dairy to install new, more expensive double-lined lagoons or to undertake ground water monitoring.

Finally, co-digestion adds complexity to digester operation. Variation in the composition of co-digestion feedstocks necessitates continuous fine-tuning of digestion processes in order to maintain maximum gas production potential. In addition a co-digestion project must secure a steady flow of organic feedstock to feed the digester. In some cases the project may control a steady supply of organic material, but for many projects they may have to compete in the market place to procure feedstock.

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[137] California Public Utilities Commission, 2013. *Staff Proposal on Implementation of SB 1122.*

### 3.6 Regional digester models

Digester projects that involve multiple farms can achieve economies of scale that improve economic viability compared to a single-farm project. There are a number of possible permutations for establishing a digester system for multiple farms: manure can be piped or trucked to a central location and then digested; manure can be digested in multiple locations and then the biogas can be piped to a central location for combustion or upgrading to biomethane (a "hub and spokes" model); or multiple independent digesters can be intentionally clustered together to generate a critical mass of technical expertise, maintenance capacity, and information sharing to increase efficiency. In nearly all cases, multiple-farm projects are likely to be most effective in areas with high cow density where the transportation costs can be minimized.

All of these arrangements involve a level of operational complexity usually absent in other projects, although clustering of independent digesters is much less complex than hub and spoke models. To be effective, the dairies must institute clear contractual arrangements that spell out all parties' obligations. Getting this sort of alignment—and the written guarantees that project financers are likely to require—can be difficult. For this reason, regional digester models may be difficult to operationalize. Regional digester models may also face some of the same challenges as large digestion projects; for example, because of their large size, utility interconnection for regional digester models may be quite expensive, requiring upgrades to nearby electrical substations. These connection costs could significantly impact project economics.

## 4. Converting to aerobic manure management systems

### 4.1 Flush to scrape

Most California dairies use some form of flush management, either just for their milking parlors or for all the areas where cows are housed. In theory, it is possible for many dairies to convert to solid manure management (either partially or entirely) using tractors, rubber or mechanical scrapers, or vacuum scrapers to manage manure as a solid. Most dairies prefer flush systems because they tend to have lower labor and operating costs, require less frequent maintenance of floors, arguably have cleaner facilities, and allow for the distribution of nutrients onto fields through lagoon water. Flush systems are particularly practical for large facilities as it is easier to move liquid around to multiple barns by hydraulics than to employ manual labor across multiple sites. However, dairies that store manure in solid systems generate far fewer greenhouse gas emissions than flush systems because they allow for aerobic rather than anaerobic bacterial breakdown.

Converting to scrape manure management systems can significantly reduce methane emissions from stored manure. However, the transition can be costly, on-going operations are typically more expensive than with flush systems, and storage and field application of scraped manure can be logistically challenging. Realizing the full potential of the greenhouse gas benefits will depend on having a well-managed system for handling and storing the scraped manure. For example, if scraped manure is stored in slurry ponds there will be much less greenhouse gas abatement than if it is stored in a solid pile or composted.

Contrary to popular belief, transitioning from flush to scrape manure management may not generate notable water savings on dairies because water is reused multiple times. Specifically, new water is first utilized for washing and cooling cattle, then reused to flush the stalls, and finally flushed water (stored in lagoons) is used to irrigate fields. Scrape systems are probably best used by dairies that are land constrained, or those wishing to expand their herd without expanding their land footprint, and therefore need to export their manure in order to be in compliance with the General Order. These dairies can benefit from having as dry manure as possible as it makes transport off of the farm cheaper and logistically easier.

There are several factors that could complicate converting a dairy from flush to scrape, discussed below.

### 4.1.2 Economics

#### Costs

A range of factors influence the feasibility and cost of switching from flush to scrape systems, including barn layout, presence of gutters, slope and layout of manure alleys, presence of pumps, and manure storage systems. Because existing manure management systems vary, it is not possible to estimate the costs of converting from flush to scrape management for a generalized farm. However, anecdotal information suggests that transitioning from flush can trigger a cascade of barn structure and operating changes that are onerous and costly.

That said, in some cases, the general layout of flush and scrape systems in barns are quite similar. Both can involve wide, relatively flat alleys with curbs to prevent manure for entering into cow stalls when it is being flushed or scraped out.[138] In these cases, a farm might be able to add a scraping blade to an existing tractor and simply scrape alleys that would otherwise be flushed provided the alley is sufficiently wide and flat enough to allow the tractor to pass through and constructed in a way that the concrete floor can handle the additional wear and tear from scraping machinery. The farm may be able to use an existing space, which conforms to water permitting requirements, to store and manage these solids.

Regardless of the costs of transitioning from flush to scrape, it seems clear that scrape systems entail higher operating costs. Moving, drying, and storing large volumes of scraped manure, is non-trivial in terms of facility and equipment requirements as well as labor and operational complexity, especially for large dairies.

#### Revenues

Converting to solid manure management may provide new revenue streams if the solids are composted and sold. High value compost can command a premium price, $18 per short ton or more, compared with

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[138] British Columbia Ministry of Agriculture and Food, 1990. *Dairy scraping manure management systems for dairy farms.*

$3 - $5 per short ton for raw manure.[139] However, robust compost operations are costly to develop and operate and the end markets are not well developed or reliable. There is currently little confidence that compost operations can reliably generate profits for dairies. Compost is discussed in further detail in section 5.

If farmers are not already employing dried manure solids as bedding material, then the avoided costs of using solids as bedding may help offset the costs of conversion (though solid separation may be a more economic, less disruptive means of achieving this outcome).

### 4.1.3 Environmental costs and benefits

#### Greenhouse gases

Switching from an aerobic lagoon to a solid storage system may reduce net greenhouse gas emissions by up to 88%,[140] though actual emissions reductions will be dependent on how the scraped manure is handled. Converting from an anaerobic lagoon to solid storage has slightly higher abatement potential to installation of an anaerobic digester, about 7.7 mt$CO_2$e per cow each year.[141]

#### Co-benefits

**Water use**: Interviewees generally agreed that the difference in water use between flush and scrape systems is relatively small, largely because much of the water used in flush system is recycled from other parts of the barn and the resulting lagoon water is used to irrigate fields. Conversion from flush to scrape may be a necessary step in reducing the water use on the farm, but a water saving strategy will require looking at water use across the whole farm (e.g., irrigation, in the milk parlor). It is worth noting that switching from flood irrigation to drip irrigation or center pivot irrigation is the change that could generate by far the biggest water savings for dairies. A challenge with these systems is that they are not as effective in spreading lagoon water because the pipes can get clogged.

**Avoiding the need to install or upgrade lagoons**: Installing new flush ponds or upgrading ponds when the dairy expands can be costly and difficult. Because of the General Order on water, new or modified lagoons must be double-lined or undertake a study demonstrating that they will be protective of groundwater quality. If an operation increases the number of head and must expand an existing lagoon or add lagoon(s), double-lining may add significant extra cost—cost that can be avoided by managing more manure as a solid so that less pond volume is needed. Similarly, if a dairy is land-constrained and wishes to expand then there may not be space for the expanded lagoon footprint. In these cases scrape management (or, alternatively, solid separation or biofiltration) can help to avoid costs and constraints.

#### Impacts

[139] "Opportunities and challenges for reducing methane from manure management at California dairies", a presentation to CDFA's SB 605 working group.
[140] California Air Resources Board, 2014. Annex 3B. Manure Management (IPCC 3A2) to the Technical Support Document for the 2000-2012 California's Greenhouse Gas Emissions Inventory.
[141] Ibid.

**Particulate matter –** Converting to scrape systems may increase concentrations of particulate matter in the air. Solid manure produces 0.3-3.6 lb. $PM_{10}$/ head-year, while flush dairies are assumed to have much lower particulate matter emissions.[142]

**VOCs –** Volatile organic compounds may increase under scrape management, particularly if a large surface area of manure is exposed. Studies have shown higher in-barn emissions of VOCs in scrape management systems,[143] and VOC emissions are of particular concern if the scraped solids are further processed into compost.

**Ammonia –** Several interviewees cautioned that ammonia emissions may be higher for scrape management depending on whether the solids are kept concentrated or spread out to dry. However, according to one review, scrape dairies produce perhaps half as much ammonia as flush dairies (52 kg/ hd-year versus 97 kg/ hd-year).[144] Another study showed no significant differences.[145]

### 4.1.4 Barriers

**Economics and operational complexity –** Converting a farm from a flush system to a scrape system will require substantial capital costs. These will vary depending on the farm configuration but will be substantial. Once the conversion has been made, scrape systems tend to have higher operating and labor costs. Effectively managing solid manure, especially for large dairies will be a major challenge. Revenues to offset these costs are limited. No carbon offset protocol is available for converting to solid manure management and markets for compost are variable.

**Manure handling –** Because many California dairies grow feed crops on their land, converting manure management systems may require changing the way in which manure is distributed on the land. Solid manure requires a manure spreader, whereas liquid manure can be applied via flood irrigation, or, less commonly, with a tank wagon or flexible drag hose. Farmers can apply manure to crops year-round via flood irrigation, whereas they can only apply solid manure in more limited timeframes.

**Cow health** – Some have expressed concern about higher slip and fall rates for cows in scrape systems. This worry may be unfounded as dairies in much of the world, including large portions of the United States, operate with scrape systems (flush is not feasible in cold climates), and there is no indication that these dairies experience any higher prevalence of slip and fall injuries than flush dairies. Some have argued that the concern lies in the conversion of flush dairies to scrape because the floors do not have the texture that would be present if the barn was designed to have a scrape system from the beginning. But, again we do not know of any data that exists to support or refute this claim.

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[142] Winegar, 2014. *Assessment of Control Methods for PM10 Emissions from Dairy and Feedlot Corrals*.
[143] Calvo, et al. 2008. *Effects of Waste Management Techniques to Reduce Dairy Emissions from Freestall Housing.*
[144] Quebec. Department of Environmental Quality. *Oregon. Emission Factors Research Worksheets.* (n.d.)
[145] Vaddella et al. 2011. *Ammonia Loss from Simulated Post-Collection Storage of Scraped and Flushed Dairy-Cattle Manure.*

**Worker Safety** – Some have expressed concern that converting dairies from flush to scrape may also present a safety concern for dairy staff. We have not seen any studies that validate this concern, but this is something that may warrant deeper investigation if dairies are considering changing from flush to scrape systems.

## 4.2 Solid separators

Solid separators filter manure streams into liquid and solid components. The primary reason that dairies install solid separators is to keep solids out of the lagoons in order to reduce dredging frequency and cost. However, because they keep organic matter out of the anaerobic conditions in lagoons, solid separators may be an effective method of reducing greenhouse gas emissions. They are also considerably cheaper than more technically complex interventions like anaerobic digesters (although they may not be able to achieve as much overall abatement and the costs per tonne of GHG may not be any lower). Although there is interest in the potential of solid separators to reduce greenhouse gas emissions, there is still a lot of uncertainty about the amount of abatement that can be achieved. Perhaps the biggest question is how much methane producing solids are removed from the manure stream with various separation technologies as opposed to more fibrous solids that will not generate methane even if they were to make it into a lagoon. Several industry experts flagged this as a potential research priority.

Most dairies already employ some form of separation. While dairies have traditionally preferred to use settling ponds for solid separation because they are cost effective and easy to operate, more dairies may be starting to install mechanical solid separators. Dairies may see benefits from switching to more efficient separators or adding additional stages of separation (e.g. adding a screw-press to further dewater material coming from a screen separator, making it more appropriate for bedding material). The Waste Discharge General Order could also be contributing to adoption of solid separators so that dairies can add additional animal units while still using an existing lagoon.

Separators are useful for both flush and scrape manure management systems. There are three main types: gravity, mechanical, and chemical.[146] Best-in-class separators may be more effective at filtering out material, particularly fine material, but often cost more and may require additional labor.

- **Gravity separators** include settling basins and stationary inclined screens ("weeping walls") that prevent large solids from passing into a settling pond. Settling basins have traditionally been the most common and least labor-intensive of the separation methods. They involve putting flush manure in large ponds with a semi-permeable barrier or weir at one end so that liquid can seep out over time. The remaining solids might be cleaned out 1-4 times a year. Gravity basins may have significant GHG emissions because they display many of the same characteristics as anaerobic lagoons, although we have not seen any studies that quantify GHG emissions from settling ponds or weeping walls.

[146] Environmental Protection Agency Region 9. *Dairy Manure Management Technologies for Treating Dairy Manure.* http://www.epa.gov/region9/ag/dairy/tech/solid-liquid.html, Accessed July, 2015.

- **Mechanical separators** involve pumps and/or motors and include screens, cones, cyclones/ centrifuges, or presses. Vibrating screens are ideal for flush manure, though slurries with higher solids content may cause clogs.
- **Chemical separators** allow for precipitation and flocculation of solids and are an effective way to remove phosphorous from the waste stream. Flocculation is an additional separation step that can be applied to remove finer solids that are difficult or impossible to remove with gravity or mechanical separators.[147] Chemical separators are very uncommon on dairies.

Separated solids can be used as bedding, field applied, further processed into compost, or transported off-site. Using dried manure solids as bedding material can help avoid significant costs of buying other types of bedding; this is one reason many California dairies already use manure solids as bedding.

### 4.2.1 Economics

Costs of solid separators will vary depending on the type of separator and the specifics of the manure handling process, ranging from thousands to hundreds of thousands of dollars. Mechanical separators may cost merely $15,000-$75,000+ for the separators themselves,[148] but often involve associated pumps, towers, agitators, or other equipment that could increase the average cost of a static screen or mechanical separator for a 1,000 cow dairy to $100,000 or more, with larger scale separators costing as $300,000 or more.[149,150] Because many dairies already have simple separators, the more efficient separators that they might upgrade to (e.g. duel screen separators) to achieve enhanced separation could be on the upper end of the cost spectrum, costing up to a million dollars.[151] Because adding a separator will result in additional solids, there may also be costs associated with managing these solids, such as installing a concrete pad and storage space or adding equipment with which to compost solids (e.g., a windrow turner).

Operating costs will vary depending on what type of separator is employed but include electricity to run motors and pumps as well as time needed to clean and maintain the separator. Operating costs for a $75,000 screw-press separator, plus associated agitator, feed pump, and controls, on a 700 cow dairy have been estimated at $30,000 per year.[152]

In theory, the most significant potential cost savings is in avoided bedding costs, by using dried manure solids. In one study of five farms, farms that used dairy manure bedding saved an average of $37,000 annually, after accounting for total fixed and variable costs of solid separation.[153] Bedding for a 1,000 cow dairy in Wisconsin cost $72,800 per year prior to the installation of a separator that allowed for recovery of bedding material, reducing this expense to only $16,640.[154] However, most California dairies

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[147] California Dairy Campaign, 2009. Flocculation/Precipitation of Solids in Dairy Lagoons.
[148] Inflation-adjusted number from Mukhtar, Sweeten, and Auvermann, 1999. *Solid-liquid separation of animal manure and wastewater.*
[149] Solid Separator Supplier. *Personal Communication*, June, 2015.
[150] Shepherd 2010. *Cost to produce dairy manure solids bedding.*
[151] J.P. Cativiela. Personal communication. July, 2015.
[152] Shepherd 2010. *Cost to produce dairy manure solids bedding.*
[153] Bonhotal et al. 2008. *Dairy manure solids cut bedding costs*.
[154] Ripp, 2014. *Adapting our dairies.* Presentation at VitaPlus Dairy Summit 2014.

already use separated solids for at least some bedding, so it is not clear what additional cost savings are possible. Alternatively, the solids may be composted and sold off-farm, which can provide an additional revenue streams and/or help the farm manage total nutrient load.

### 4.2.2 Environmental costs and benefits

#### GHG benefits

In total, studies tend to suggest that solid separation can reduce greenhouse gas emissions by up to 40%, depending on how manure is handled to begin with, the separation method employed, environmental conditions, and other aspects of manure management. However, the available data is quite limited and does not cover all types of separation technologies. One study found a 37% reduction of GHG emissions from solid separation and composting of dairy cattle slurry as compared to untreated manure.[155] Another study found a 24% reduction of greenhouse gases using a screw press and a 38% reduction using chemically enhanced settling during storage, and only slightly increased methane emissions from field application of materials.[156,157] It is important to note that these studies were looking at solid separation of slurry manure, and the effectiveness of separators to reduce methane emissions from flushed manure may be different. In another test, centrifuge solid separation reduced $CH_4$ emissions in barns by 3.7% and $N_2O$ by 51.7%.[158] Yet another study found little difference in methane emissions between untreated and separated cattle manure slurry at both low and high temperatures.[159] Unfortunately, the literature on the potential for solid separators to reduce methane emissions from flushed dairy manure is quite thin. While there are lots of studies that have evaluated how efficiently solid separators remove solid material, this does not necessarily equate to an equivalent amount of methane reductions as they are more efficient at removing larger or more fibrous material that is less likely to generate methane in anaerobic lagoons than the smaller particles that remain in the liquid fraction.

#### Barriers

It is not clear what the potential is for expanding the use of solid separators in California. According to a survey of farms in Glenn and Tulare Counties, about one third of farms already employ some form of mechanical separation, one-third use only settling ponds, and one-third do not employ any form of solid separation.[160] It is not clear what proportion of farms with flush systems use solid separators; however, it seems likely that many farms that are in a position to install separators may have already done so

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[155] Amon et al. 2006. *Methane, nitrous oxide, and ammonia emissions during storage and after application of dairy cattle slurry and influence of slurry treatment.*

[156] Fangueiro et al. 2008. *Effect of Cattle Slurry Separation on Greenhouse Gas and Ammonia Emissions during Storage.*

[157] Fangueiro et al. 2008. *Cattle slurry treatment by screw press separation and chemically enhanced settling: effect on greenhouse gas emissions after land spreading and grass yield.*

[158] Ndegwa et al. 2015*, Manure management practices for mitigation of gaseous emissions from naturally ventilated dairy barns.*

[159] Dinuccio, Berg, & Balsari, 2008. *Gaseous emissions from the storage of untreated slurries and the fractions obtained after mechanical separation.*

[160] Meyer et al. 2011. *Survey of dairy housing and manure management practices in California.* Percentages indicate weighted, blended estimates using both Tulare and Glenn County data.

because of the favorable economics of using dairy manure solids as bedding material. While adding on enhanced solid separation could (further) reduce GHG emissions, there is no strong incentive to do so.

Depending on type, separators may increase labor requirements on farms because the separated solids must be stored and managed. Although solid separators yield greenhouse gas benefits, the amount of emissions abatement from different designs is not well understood, and there is no approved offset protocol allowing farmers to receive credit for this environmental attribute. Therefore, the decision to install a separator is entirely determined by potential avoided costs or sales of soil amendments or compost, which is only available if the solids are further processed.

## 5. Nutrients/compost

Management of nutrients in any agricultural setting is important and challenging. California's Central Valley is no exception. Nitrogen, phosphorous, and potassium are all essential nutrients for plant growth and are imported in large volumes to fertilize crops across California. At the same time, excess nutrients can have negative impacts on ecosystems and human health. For example, excess nitrogen and phosphorous can cause eutrophication and algal blooms in waterways and nitrates can contaminate groundwater, threatening drinking water sources for hundreds of thousands of Californians.

Manure from dairies and other livestock facilities is a major source of nutrients. Since 2007 dairies in the Central Valley have been under a new General Order from the Central Valley Region of the CRWQCB. The General Order broadly requires that field application of manure and wastewater use reasonable agronomic rates, meaning rates not in excess of what crops can use. It further requires that farmers either double line new or modified wastewater ponds or complete a technical report demonstrating that the lagoon will be protective of groundwater. Finally, dairies must develop Nutrient Management Plans designed to protect both surface and groundwater.[161] In order to apply wastewater to fields, farmers must adhere to the volume and composition limits specified in a certified Nutrient Management Plan. Thus, a dairy must maintain sufficient cropland area to enable land-application at approved volumes. Some dairies can overcome limited acreage by exporting raw manure to their neighbors. However, if the overall density of dairy cattle in a given area becomes too high, land constrained dairies risk being out of compliance with the General Order and these regions risk the negative effects of nutrient contamination.

Adopting on-farm composting systems and/or other nutrient recovery technologies as a part of waste management is one way for dairies to address nutrient management challenges. There are three main options for dairies wishing to adopt high-end nutrient management systems:

1) Compost: Composting is an aerobic form of decomposition whereby organic material is broken down through controlled microbial activity into a chemically stable, valuable soil amendment. The process of composting manure stabilizes nutrients, kills pathogens and weed seeds, and

[161] California Regional Water Quality Control Board Central Valley Region, 2013. *Order R5-2013-0122: Reissued Waste Discharge Requirements General Order for Existing Milk Cow Dairies.*

reduces the volume of raw manure so that it is easier to store and export.[162] Composting requires the maintenance of conditions that support microbial activity, including a balance of carbon and nitrogen, oxygen levels that support aerobic conditions, enough moisture to permit biological activity without creating anaerobic conditions, and temperatures that are favorable to microbial activity. Careful management of these conditions throughout the composting process is critical to control of air emissions and creation of high quality compost. There are a number of different methods for creating compost from dairy manure, all of which are relatively simple and low-tech. The most common method involves stacking organic waste into windrows that are turned periodically. Other organic waste streams can be combined with dairy manure to change the nutrient profile, depending on the needs of the end user and the availability of other waste streams.

2) Advanced nutrient recovery:[163] Commercialization of a handful of highly technical nutrient recovery systems that can remove phosphorous and nitrogen from dairy manure is slowly increasing. Typically, these are used to process post-digester effluent after larger solids have been separated out. Advanced nutrient recovery technologies include secondary screening, mechanical processes (e.g., centrifuge), chemical flocculation, polymers, struvite crystallization, and ammonia stripping. These techniques can recover 60-90 percent of phosphorous and nitrogen, compared with only 15-20 percent nutrient recovery from solid separators. There are a number of imperatives for capturing a greater percentage of nutrients from waste streams. Phosphorous is a finite resource that is mined and recent projections estimate that global reserves may only last 50-100 years. Nitrogen recovery is important for both reducing damaging nitrogen losses to the environment and for reducing the amount of fossil fuels required to generate new synthetic nitrogen, which our agricultural systems have come to depend upon.

3) Biofiltration:[164] Biofiltration systems can be deployed as a strategy for reducing the nitrogen concentration in dairy wastewater. In simple terms, these systems run wastewater through some kind of biological filter where microbial activity removes nitrogen. With support from a grant from the Natural Resource Conservation Service, one dairy near Hilmar is testing a worm-based system in which wastewater is sprayed into a large concrete box containing worms and wood shavings. This system is able to filter out 60 to 90 percent of the nitrogen from the wastewater, allowing the dairy to field apply the remaining water on a much smaller footprint than would be possible without the biofiltration. Additionally, the worm castings may be able to be sold as a high value soil amendment and the worms themselves (which reproduce quickly) could be sold for bait. One important potential issue is that the remaining water may have very high salt concentrations, which can be harmful to soils.

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[162] Composting can reduce both the volume and mass of the initial material by as much as half, primarily due to water loss. Source: Rynk, Robert, 1992. *On-farm composting handbook*.

[163] Ma et al., 2013. *Review of Emerging Nutrient Recovery Technologies for Farm-Based Anaerobic Digesters and Other Renewable Energy Systems.*

[164] Modesto Bee. *Worms help with waste at a dairy farm near Hilmar.* May 2, 2015.

## 5.1 Economics

### Costs

To date, the body of literature that has been published on the economic profile of any of these three options is very limited. Advanced nutrient recovery technologies are still relatively new and are only in commercial use in a handful of places in the country. Generally speaking, they are quite expensive and only make economic sense when the end product can reach high-end fertilizer markets. Available literature indicates that the capital costs for nutrient recovery technologies range from about $50 to over $600 per cow. Additionally, operating costs for these systems range from $25 to $200 per cow per year.[165] The higher cost systems provide higher nutrient recovery rates. The economics for biofiltration systems have not yet been well studied. However, an economic assessment is planned for the worm-based system near Hilmar.

Compared with advanced nutrient recovery technologies and biofiltration systems, compost systems are in relatively common use and thus the economics are better understood, although they vary depending on the scale and level of sophistication of the operation. No case studies of dairy-based compost systems in California have been found, so this report only draws on limited literature and anecdotes.

The most common method for composting is windrows, compost piled in rows roughly 10 to 15 feet wide by 5 to 8 feet high and roughly 75 feet long. Composting in windrows requires: 1) equipment able to turn the piles, 2) up to several acres of leveled, impermeable, well-drained land, 3) a system for catching and storing the leachate from the windrows, 4) a watering tank or other equipment able to apply water to the piles as needed, 5) permits from the San Joaquin Valley Air Pollution Control District (SJVAPCD), and possibly CalRecycle and the State Water Control Board, and 6) certification of the product.[166] Additionally, once a certain scale and level of sophistication is reached, the composting facility will likely need the equivalent of a full time employee to manage the turning, watering, and monitoring of the system.

Additional costs would be incurred if BACT is required, either through covered windrows or aerated static piles. The latter system does not require turning, but instead uses piping and fans to push or pull air through the piles, allowing for capture and filtration of air emissions. Currently, there is a considerable lack of clarity about which technologies are required for compliance with air quality regulations, making a reliable economic analysis difficult. SJVAPCD is considering developing a BACT guideline for manure composting that may provide greater certainty. If costs can be kept relatively low and good markets for the end product are captured, compost can provide a small revenue stream to dairies while providing important co-benefits.

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[165] Ma at al. 2013. *Review of Emerging Nutrient Recovery Technologies for Farm-Based Anaerobic Digesters and Other Renewable Energy Systems.*

[166] Certification of compost ensures that the product is pathogen free and in compliance with organic standards. The Organic Materials Review Institute (OMRI) is the most commonly used certification system.

### Revenues

While there is evidence of great demand for dairy-based compost from crop producers and nurseries across the valley, the market is immature and prices vary greatly by region and season. Based on anecdotal information from interviewees, it seems that the price range for dairy manure-based compost is in the range of $18 to $50 per ton. Prices vary depending on who is responsible for the hauling and field application of the compost, as well as the quality of the compost and the local supply/demand dynamics.

## 5.2 Environmental costs and benefits

### Greenhouse gases

Broadly speaking, compost and other nutrient management systems – on their own - do not provide greenhouse gas reductions.[167] Composting should be considered an add-on to any existing manure management system. Composting works particularly well with scrape systems because the raw manure in any dry system begins much closer to the moisture content level required for the composting process when nutrients have not been diluted by flush water. However, both separated solids and digester effluent can be composted, allowing composting to be a viable element of a flush-based manure management system. If compost is considered as an add-on, then the critical comparisons from a greenhouse gas perspective are: a) how compost systems perform compared to a static pile and land application of raw manure from a scrape system or b) compared to land application of digester effluent. Unfortunately, studies that address this comparison have not been found.

As nutrient recovery technologies develop, they have the potential to displace fossil-fuel based, synthetic fertilizers, by enabling greater recycling of nutrients within the state. Looking farther into the future, if dairy-based compost is ever able to effectively displace peat moss (a common input for the nursery industry), additional greenhouse gas and conservation benefits could be achieved.[168]

### Co-benefits

The co-benefits provided by composting systems are significant.

**Water quality –** As noted above, the primary benefit of composting systems is their ability to stabilize nutrients and turn them into a high-value, exportable product, thus reducing the risk of nutrient loading on the farm and improving both groundwater and surface water quality. Advanced nutrient recovery technologies and biofiltration serve the same purpose, albeit in slightly different ways.

**Soil fertility –** In addition to the water quality benefits, compost has the additional benefit of being a soil amendment that can enhance crop production and soil fertility for other agricultural uses across

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[167] The exception may be biofiltration which can reduce the level of anaerobic activity in dairy lagoons by filtering out nutrients.

[168] A recent study indicates that replacing peat moss with dairy-based fibers, across the US market, could avoid 5.8 million metric tons of $CO_2e$, or 0.8% of US methane emissions. Peat moss is currently mined in Canada and is an important carbon stock. Source: Quantis, 2013. *Preliminary assessment of the environmental advantages of replacing horticultural peat moss with dairy farm digester-derived fiber in the United States.*

California. There is even evidence that application of compost to managed grasslands can help soils sequester carbon.[169]

**Pathogen kill –** Compost systems also kill pathogens and weed seeds which make it possible for the end product of composted manure to be used on crops for humans. (Raw manure can only be applied to forage crops because of pathogen concerns.)

**Odor reduction –** Finally, compost systems reduce odor compared with anaerobic lagoons or static piles of raw manure.

## 5.3 Barriers

The primary barriers to broad adoption of composting across the Central Valley are regulatory.

**Air quality permits –** Active composting produces VOCs, a precursor to ozone. The San Joaquin Valley Air Pollution Control District (SJVAPCD) regulates VOC emissions.

- Rule 2201 – The most stringent regulation is Rule 2201, New and Modified Source Review. If they emit more than 2 lb/day of VOCs, dairies that begin new composting operations or that sell compost off-site may be considered new or modified sources. As discussed in Section 7, Rule 2201 requires regulated sources to achieve a certain BACT emissions standard. SJVAPCD is developing a BACT rule specifically for emissions from dairy composting that will likely require composting facilities to implement mitigation measures similar to those approved for compliance with Rule 4565, discussed below (e.g., covering compost piles).[170]
- Rule 4570 – Rule 4570 regulates volatile organic carbons (VOCs) from confined animal facilities.[171] A large dairy which implements new composting practices may be regulated under Rule 4570 if it is not already subject to VOCs emissions limits through Rule 2201. The Rule requires farmers to obtain a permit and adopt a certain number of approved practices for reducing VOCs emissions.[172]
- Rule 4565 – Co-composting and off-site facilities may be subject to SJVAPCD's Rule 4565 if they process over 100 wet tons/year.[173] Rule 4565 requires operators to implement a selection of approved mitigation measures to limit VOC emissions (such as covering compost piles, maintaining certain carbon to nitrogen ratios, and injecting biosolids below soil surface).[174]

Overall, the management practices required to comply with the valley's VOCs regulations are likely to pose a significant burden only to very large composting facilities.[175] Until SJVAPCD's dairy compost BACT

[169] DeLonge, et al. 2013. *A lifecycle model to evaluate carbon sequestration potential and greenhouse gas dynamics of managed grasslands.*
[170] Ramon Norman. *Personal Communication*, June, 2015.
[171] San Joaquin Valley Air Pollution Control District, 2010. *Rule 4570: Confined Animal Facilities*.
[172] California Environmental Protection Agency, 2011. *Permit Guidance for Anaerobic Digesters and Co-Digesters*, pg. 26
[173] San Joaquin Valley Air Pollution Control District, 2007. *Rule 4565: Biosolids, Animal Manure, and Poultry Litter Operations.*
[174] Ibid.
[175] Ramon Norman. *Personal Communication*, June, 2015.

is finalized and dairies gain experience implementing the standard, there will be uncertainty and concern over the potential costs of permitting. This can pose a barrier to a dairy that is considering adding a composting system. Indeed, it seems that dairies that are currently composting are either grandfathered in and exempt from new permit requirements or are keeping their composting activity under the radar to avoid the permitting process.

**CalRecycle permits** – Any composting facility must obtain a Compostable Materials Handling Facility Permit unless exempt under CalRecycle's Title 14 requirements. Composting of agricultural waste derived from an agricultural site that is used on-site or on a property under the same ownership or control is exempt from permitting requirements, unless over 1,000 cubic yards of compost product are given away or sold annually.[176] A dairy which processes materials generated off-site or which sells or gives away large quantities of compost will likely require a permit and regular inspections.

**Water quality permits** – It is our understanding that the General Order for Dairies from the Central Valley Water Board is comprehensive enough to cover any composting activity (i.e., as long as the composting activity is in compliance with the General Order and the dairy's Nutrient Management Plan, then additional permits are not required). There is one important caveat to note. The State Water Resources Control Board has proposed a new General Order for composting facilities, which is now under development. The draft General Order includes a permeability requirement which could effectively require that composting operations sit on top of concrete slabs, adding considerable upfront cost to any compost facility. It is currently unclear how this general order will mesh with the regional General Order. Resolving this permitting issue will also help to provide clarity around the economics of composting in the Central Valley.

**Immature markets** – Finally, the co-benefits associated with composting and nutrient recovery may only be viable if robust markets are developed. Currently, these markets are immature and prices are unstable. Potential buyers, including crop producers and nurseries, seem broadly interested in purchasing compost and nutrients from dairies; however, they have concerns about the high levels of salt in dairy manure compost as well as the variability of the nutrient profile of the product. These product quality concerns could be addressed as composting facilities become more sophisticated, suggesting an opportunity for third party developers and/or centralized composting facilities with the ability to create a consistent product with a desirable nutrient profile.

**Salts** – Once a high proportion of nitrogen and phosphorous are removed from digestate, through advanced nutrient recovery systems, salt is the primary material remaining. Dairies will be challenged to manage excess salt which, if deposited on to fields, can be damaging to soils. It will be important to further investigate this salt issue and explore possible solutions.

## 6. Enteric fermentation

About half of the methane emitted from the dairy sector in California is a result of enteric fermentation, which is part of the digestion process of the cattle. While this methane can be reduced slightly, at least

[176] CalRecycle. *Chapter 3.1 Compostable Handling Operations and Facilities Regulatory Requirements.*

on an intensity basis (i.e., greenhouse gas emissions per unit product), it is inherent in the biology of the cow and thus provides less potential for GHG reductions than manure management. These gains will be especially difficult and costly to achieve in California because the dairy industry is already managing feed, diets, and supplements effectively for optimal cattle productivity.

There are three main ways to reduce enteric fermentation from cattle.

- Improved Diet and Nutrition: Improving the quality and the digestibility of feed can increase the productivity of dairy cattle, which can reduce overall herd size required to sustain a given level of production, and therefore reduce emissions per unit of product. Specific strategies include improving the quality of forages, improving the nutrition profile of the diet, and better processing of the feed to enhance digestibility. This strategy presents a significant GHG mitigation opportunity in many developing countries where livestock nutrition is sub-optimal. However, in California, there is little room for improvement and the small margin for improvements that may exist for some dairies in the state will be costly to capture.
- Supplements: There are a handful of supplements (such as lipids, nitrates, and ionophores) that can be added to the diet of dairy cattle in an attempt to change the microbiology of the rumen[177] and reduce methane. To date, these supplements have not proven to increase productivity, and therefore provide no return on investment to the dairy. Supplements that are effective in reducing methane are still largely in the research phase and/or are not cost effective. There is a great deal of uncertainty around their mitigation potential, with some indication that the rumen ecosystem adjusts over time to wipe out initial gains.
- Herd management and breeding: This approach includes general herd management, culling practices, and reproductive health as well as breeding and genetics. Herd management can increase the overall productivity of a dairy and therefore reduce the emissions per unit of product. Again, in most developed countries, and certainly in California, herds are already very well managed for productivity and therefore few improvements are achievable. There may be some mitigation potential from improved breeding and genetics, both from breeding for general productivity gains and by selecting for genetics that reduce methane. However, this strategy is limited in its mitigation potential, is costly, and requires further research and development.

Because these strategies are largely still in the research and development phase, cost information is quite limited. 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 $mtCO_2e$.[178] Again, there are no additional revenue streams associated with enteric fermentation mitigation, although there can be some productivity gains for improved nutrition and herd management.

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[177] The rumen is a part of the cow's stomach.
[178] Lee, et al. 2014. *Greenhouse Gas Mitigation Opportunities in California Agriculture: Review of the Economics*.

There is also a great deal of uncertainty around the greenhouse gas reduction potential for enteric fermentation strategies. Available literature indicates mitigation potential of 3 to 20 percent for California dairy cattle, compared with up to 90 percent for methane digesters.

There are no notable co-benefits associated with enteric fermentation emissions reductions. In fact, there may be some human- and animal- related health concerns associated with some supplements.

# 7. Funding opportunities for greenhouse gas reduction projects on dairies

To achieve broad adoption of methane reduction measures on dairies in California, the state will need to provide additional incentives to increase revenue opportunities for farmers. Each methane-reduction strategy discussed previously in this paper comes at a cost to the farmer. Installing digesters requires significant upfront capital, and even with existing incentives (e.g., BioMAT, carbon credits) additional incentives are probably still needed for even the most attractive digester projects. Many of the current incentives also have fluctuating prices or regulatory uncertainty (e.g., carbon offsets, RINs) and therefore are not viewed as reliable revenue streams when projects are seeking funding.

## 7.1 Overview of current funding sources

As shown in Table 4 below, there are a variety of existing grants and incentives which could support the implementation of methane reduction practices and technologies on California dairy farms. The majority of public funding and market incentives are driven by greenhouse gas reduction policies, but additional funding may be available through water conservation, pollution control, and rural development programs. There are many more programs and funds available to support the installation of digesters than there are for low-tech measures such as conversion from flush to scrape manure management or installation of solid separators. The section below provides an overview of the most significant funding sources available to California dairies today.

**Table 4 - Overview of available incentives for methane reduction projects on dairies in California**

State and Federal Funds for Methane Reduction Projects in California Dairies

| Policy | Flush – Scrape | Power | Vehicle Fuel | Pipeline Injection |
|---|---|---|---|---|
| GHG Emissions reductions | | • Bioenergy FiT<br>• NEM<br>• SGIP<br>• CTR Revenues<br>• CTR offset credits<br>• EPIC – T D&D | • ARFVTP<br>• CTR Revenues<br>• LCFS credits<br>• CTR offset credits<br>• EPA RFS RINs<br>• USDA-DOE Biomass Research and Development Initiative<br>• USDA Advanced Biofuel Payment | • LCFS credits<br>• CTR Revenues<br>• ARFVTP<br>• CTR offset credits<br>• EPA RFS RINs<br>• USDA-DOE Biomass Research and Development Initiative<br>• USDA Advanced Biofuel Payment |
| Water Conservation | • USDA CSP & RCPP | • USDA CSP & RCPP | • USDA CSP & RCPP | • USDA CSP & RCPP |
| Nutrient Pollution/ Water Quality | • *Loan:* SWRCB Clean Water State Revolving Fund<br>• CA Healthy Soils<br>• USDA EQIP- General<br>• USDA CSP & RCPP | • *Loan:* SWRCB Clean Water State Revolving Fund<br>• CA Healthy Soils<br>• USDA EQIP- General<br>• USDA CSP & RCPP | • *Loan:* SWRCB Clean Water State Revolving Fund<br>• CA Healthy Soils<br>• USDA EQIP- General<br>• USDA CSP & RCPP | • *Loan:* SWRCB Clean Water State Revolving Fund<br>• CA Healthy Soils<br>• USDA EQIP- General<br>• USDA CSP & RCPP |
| Air Quality | • *Loan:* CPCFA and CAEATFA<br>• USDA EQIP – Air Quality | • Air District TAP and Clean Air Funds<br>• *Loan:* CPCFA and CAEATFA<br>• USDA EQIP – Air Quality | • Air District TAP and Clean Air Funds<br>• *Loan:* CPCFA and CAEATFA<br>• USDA EQIP – Air Quality | • Air District TAP and Clean Air Funds<br>• *Loan:* CPCFA and CAEATFA<br>• USDA EQIP – Air Quality |
| Rural Development | | • USDA REAP loans and grants<br>• USDA Value-Added Producer Grants | • USDA REAP loans and grants<br>• USDA Value-Added Producer Grants | • USDA REAP loans and grants<br>• USDA Value-Added Producer Grants |

### 7.1.2 State funding opportunities: grants

#### Cap and Trade revenues

Proceeds generated from the auction of greenhouse gas emissions "allowances" in the state's Cap and Trade program (CTR) are deposited in the Greenhouse Gas Reduction Fund (GGRF). The Governor and Legislature create yearly expenditure plans for appropriation of funds from the GGRF. The Legislative Analyst's Office estimates that total CTR revenues will exceed $15 billion from 2012 to 2020.[179] Sixty percent of these revenues are continuously appropriated to specific programs (e.g., high speed rail) while forty percent are allocated on a discretionary basis.[180] In the 2014-2015 Cap and Trade budget and 2015-2016 expenditure plan, the state allocated funding to the Department of Food and Agriculture (CDFA) specifically for dairy digesters.

[179] Legislative Analyst's Office, 2014. *The 2014-15 Budget: Cap-and-Trade Auction Revenue Expenditure Plan*, pg. 4
[180] Legislative Analyst's Office, 2015. *Governor's May Revision: 2015-16 Cap-and-Trade Expenditure Plan*. pg. 2

Following the Governor's May 2015 expenditure plan revisions, the state could allocate $25 million for "Dairy Digester Research and Development" for the 2015-2016 budget year.[181] Cap and Trade revenue disbursement is dependent on actual revenues generated in auction and is subject to approval by the legislature. Therefore, funds currently slated for dairy digesters may be changed or removed. Ultimately, Cap and Trade funds for dairy digester implementation will be administered by the CDFA through a series of grants. CDFA used 2014-2015 GGRF funds to offer $11 million in funding for dairy digester implementation (up to 50% of project costs or $3 million per project) and $500,000 for research and demonstration projects.[182,183]

GGRF funding for dairy digesters must be appropriated by the Governor and legislature annually and is therefore unguaranteed. However, assuming funding for digesters continues at somewhere between 2014-2015 and 2015-2016 levels and the majority of this funding is allocated to implementation of digesters, this could amount to $10 - $25 million/year or $60 - $150 million total between 2015 and 2020.

In addition, the May 2015 Cap and Trade Expenditure plan will provide $20 million for "improved agricultural soil management practices."[184] CDFA will coordinate with other state agencies to launch the Healthy Soils program, "several new initiatives to increase carbon in soil and establish long term goals for carbon levels in all California's agricultural soils."[185] Although the program is still under development, CDFA has included the identification of financing opportunities as a priority action for the program's first five years. Thus this program may generate new funding to support the production and distribution of compost from dairies. The program will also seek to permit 100 new composting and digester facilities in California.[186]

### Electric Program Investment Charge (EPIC)

The Electric Program Investment Charge was created by the Public Utilities Commission (CPUC) in 2011 to support clean energy research, demonstration, and deployment.[187] Every three years, the California Energy Commission (CEC) creates a triennial investment plan for approval by the CPUC. The 2015-2017 EPIC Investment plan allocates $145 million for technology demonstration and deployment (TD&D) for the purpose of evaluating pre-commercial technology, not yet deployed at scale. One of six strategic objectives in the TD&D area is to "demonstrate and evaluate biomass-to-energy conversion systems,

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[181] Ibid, pg 4

[182] California Department of Food and Agriculture, 2015. *Dairy Digester Research and Development Program: Request for Grant Applications 2015.*

[183] California Department of Food and Agriculture, 2015. *Dairy Digester Research and Development Program: Request for Research Proposals.*

[184] Legislative Analyst's Office, 2015. *Governor's May Revision: 2015-16 Cap-and-Trade Expenditure Plan*. pg 4.

[185] California Department of Food and Agriculture. Healthy Soils Initiative. http://www.cdfa.ca.gov/EnvironmentalStewardship/HealthySoils.html, Accessed July, 2015

[186] California Department of Food and Agriculture. *Healthy Soils Initiative: Short-Term Actions.* http://www.cdfa.ca.gov/EnvironmentalStewardship/pdfs/ShortTermActions.pdf , Accessed July, 2015.

[187] California Energy Commission. *Frequently asked Questions about the Electric Program Investment Charge Program.* http://www.energy.ca.gov/research/epic/faq.html. Accessed July, 2015.

tools, and deployment strategies." This strategic objective has two parts, one covering wood/dry biomass and another covering agriculture, municipal and solid waste.

Dairy digester demonstration projects that address limitations to full-scale deployment, reduce waste and provide additional co-benefits will be eligible for EPIC funding through specific "Program Opportunity Notices" issued by the CEC.[188] If funding for the TD&D category is split evenly across the six strategic objectives this would mean $12M to biogas-to-energy projects in 2015-2017. In 2014, the CEC awarded $21 million in grants for biochemical conversion and deployment strategies, including $8 million to two biogas-to-electricity projects at dairies.[189] If the CEC continues to fund biogas-to-energy technologies and allocates roughly one-third of these funds to dairy digesters, this could amount to $1.3 to $2.6 million/year. It is important to note, however, that as a research program, EPIC awardees will be expected to report data and results to the CEC – a requirement which may be costly and dissuade some dairies from applying for these funds.

#### Alternative and Renewable Fuel & Vehicle Technology Program (ARFVTP)

Through the ARFVTP, the CEC is authorized to provide up to $100 million annually for innovative transportation and fuel technologies until 2024. In the last three years, the CEC has allocated $18 – 23 million to biofuel production and supply projects, including $20 million for fiscal year (FY) 2014-2015. Twelve biomethane projects have received $38.9 million through the ARFVTP since 2006.[190] Although dairy methane to fuel projects could be eligible for this funding, recent CEC biofuel funding opportunities have not included funding for dairy projects.[191] If dairy biomethane projects received 10% of the funding allocated to biofuels production in the FY 2014-2015 investment plan, this would provide a total of $2 million.

### 7.1.3 State funding opportunities: performance incentives

In addition to grant funding, California dairies can generate revenue through either market-based incentives or performance-based incentive programs.

#### Sale of carbon offsets

Dairies which capture and destroy methane are eligible to generate carbon credits. The market for carbon offsets in California is driven by the state's Cap and Trade program. Entities which are covered by the regulation may use offset credits to meet up to 8% of their compliance obligations in a given year. 1.6 million offset credits (1 mt$CO_2$e each) were surrendered in November 2014 to meet 2013

[188] California Energy Commission, 2014. *Application of the California Energy Commission for Approval of Electric Program Investment Charge: Proposed 2015 through 2017 Triennial Investment Plan*, pg 132

[189] California Energy Commission, 2015. *Electric Program Investment Charge Demonstrating Bioenergy Solutions That Support California's Industries, the Environment, and the Grid PON-14-305 , Amended January 23, 2015.*

[190] California Energy Commission, 2014. *Investment Plan Update for the Alternative and Renewable Fuel and Vehicle Technology Program*, pg. 10

[191] California Energy Commission, 2014. *Revised Notice of Proposed Award Round 2: Alternative and Renewable Fuel and Vehicle Technology Program: Grant Solicitation PON-13-609*

obligations.[192] Carbon allowances have recently traded at around \$12/ $mtCO_2e$ and carbon offsets generally to sell for less than or close to the price of allowances.[193]

The Air Resources Board (ARB) has approved an "Offset Protocol" for livestock projects that quantifies the greenhouse gas emissions reductions resulting from methane management on dairy and swine farms.[194] ARB will issue credits to projects registered through an ARB approved Offset Project Registry (OPR) following a verification. To date, ARB has issued over 252 thousand offset credits to livestock projects in the U.S. (not including "early action" offsets issued). This represents only 3% of all offsets issued.

However, because the offset verification process is expensive and time consuming, a carbon offset price below \$10 per $mtCO_2e$ may not be sufficient to incentivize methane capture projects at smaller dairies.[195]

### Bioenergy Feed-in-Tariff (BioMAT)

California's bioenergy feed-in-tariff program was enacted by SB 1122 and is expected to commence this year following final approval of the utilities' proposed tariff and contract by the CPUC (expected in 2015). The program will require Pacific Gas & Electric (PG&E), San Diego Gas & Electric (SDG&E) and Southern California Edison (SCE) to purchase electricity from a total of 250 MW of new bioenergy generators, including a total of 90 MW from "Category 2" dairy and other agricultural bioenergy projects (33.5 MW from PG&E and 56.5 MW from SCE).[196] Projects may be no larger than 3 MW and must interconnect and export power to the grid. The utility will pay for the power through a Power Purchase Agreement (PPA) with price determined by the Market Adjusting Tariff: an auction mechanism which will adjust prices by \$4-\$12/MWh every two month based on the demand (the portion of qualifying bids that accept the previous price and a minimum number of entities that must submit a bid to trigger a price change).[197] The starting price for the BioMAT will be \$127.72/MWh[198] and this rate will adjust separately for each category through the auction mechanism. Assuming dairy digesters take two-thirds of the 90 MW Category 2 allocation, digesters run at an average 80% capacity factor, and the price remains close to starting price on average, this amounts to \$53.7 million in revenue for 20 or more dairy digester projects.

Although the BioMAT offers a new, secure, long-term (up to 20 years) revenue stream for dairy digesters, the new program also presents certain challenges. First, dairies may have trouble competing with other agricultural bioenergy sources. A Black and Veatch analysis for the CPUC estimated the levelized cost of energy (LCOE) for dairy manure to be between \$218-\$346/MWh compared to other

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[192] California Air Resources Board, 2014. *2013 Compliance Obligation Detail for ARB's Cap-and-Trade Program.* http://www.arb.ca.gov/cc/capandtrade/2013compliancereport.xlsx
[193] Gonzales, Gloria. 2015. *Study Finds Symbiotic Relationship Between Voluntary And Compliance Markets In North America.*
[194] California Air Resources Board, 2014. *Compliance Offset Protocol: Livestock Projects.*
[195] Digester developer. *Personal Communication*. May, 2015
[196] California Public Utilities Commission, 2014. *Decision 14-12-081: Decision Implementing Senate Bill 1122.* pg. 41
[197] Ibid, pg. 58
[198] Ibid, pg 54.

agricultural residues where the LCOE is expected to be $138-$258/MWh.[199] In addition, given the nascent nature of the dairy digester industry in California, it may be difficult to achieve the five independent bid minimum that is required to trigger a PPA price increase. (The field of developers is still very thin.) These two challenges may restrict the BioMAT price from rising sufficiently high enough to compel installation of new digesters. Second, bioenergy facilities that use manure and any co-digestion feedstocks are classified as a separate category in the BioMAT which means it will be challenging for a dairy to realize savings from co-digestion without accepting a much lower PPA price. Finally, the BioMAT requires the digester owner to pay for transmission interconnection fees in excess of $300,000.[200] As noted earlier, most dairies are located far from load centers, which means interconnection to the grid often costs much more than $300,000.

The BioMAT will be an important incentive to encourage installation of digesters at dairies. However, farmers will likely require additional incentives in order to manage start-up costs and successfully compete with bioenergy projects using cheaper feedstocks. The investor owned utilities (IOU) have proposed to retain the valuable "green attributes" associated with the kilowatt-hours exported under the BioMAT tariff, meaning that the utilities rather than the digester developers would have the right to the carbon offset revenues.[201] According to a digester developer, if this proposal is approved, the inability to sell carbon credits would increase the PPA price required to incentivize dairy digesters by 20 – 40%.[202]

### Net Energy Metering Aggregation

Net Energy Metering is a system in which small generators (less than 1 MW) interconnected to the utility grid are compensated for power generated in excess of consumption through a bill credit. Customer-generators receive a full retail-rate bill credit for the power generated and fed back into the grid. New generators may apply for participation in the state's current net metering program until July 1, 2017 OR when the total generating capacity of all renewable generators has exceeded 5% of an IOU's aggregated customer peak demand cap.[203]

Net Metering Aggregation (NEMA) was authorized by SB 594 (2012) and allows a single customer to aggregate the electrical load across several meters located on a single property. This is particularly beneficial for a farm where sources of electric demand may be spread across a wide area. NEMA customers must size systems to match load and cannot install systems larger than 1 MW. Unlike regular

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[199] California Public Utilities Commission, 2013. *Energy Division's Staff Proposal on SB 1122 Implementation and B&V Study.* Attachment 1, I-5

[200] California Public Utilities Commission, 2011. *PG&E, SCE, and SDGE's Joint Submission of Proposed Tariffs and Standard Forms to Implement Senate Bill 1122.* pg 50.

[201] California Public Utilities Commission, 2011. *PG&E, SCE, and SDGE's Joint Submission of Proposed Tariffs and Standard Forms to Implement Senate Bill 1122.* pg. 23

[202] Digester developer. *Personal Communication.* May, 2015

[203] A successor program to Net Metering is in development at the PUC; the new NEM program is likely to differ substantially from today's program.

net metering customers, NEMA customers will not receive monetary payment for net surplus electricity exported to the utility over a twelve month period.[204]

Net metering of dairy digesters will not provide direct revenue to a farmer but could provide savings to the farmer if the levelized cost to install and operate a digester is lower than the farmer's electric rate. For example, if the LCOE for a 1 MW digester is $200/MWh and the farmer's average electric rate is $300/MWh, NEMA could produce substantial savings for a farmer. However, given the high costs of installing and operating manure digesters it may be unlikely that a dairy digester can "beat" retail electric rates for agricultural customers, unless sufficient grant funding is secured to offset the upfront costs.

### Self-Generation Incentive Program (SGIP)

California's Self-Generation Incentive Program (SGIP), originally developed to reduce peak electricity demand in the wake of the 2001 energy crisis, provides up to $83 million in funds each year to incentivize on-site electricity generation. Facilities that install up to 3 MW of generation on-site to serve all or a portion of their own energy demand receive a per-watt incentive based on technology type. SGIP can be a nice complement to NEMA for dairies that use biogas fueled electricity on-site.

In 2015, $77 million in incentives will be available, 75% of which are devoted to renewables. Biogas turbines, including dairy biogas-to-power projects, are currently eligible to receive a $1.90/watt incentive by combining the conventional combustion engine incentive with the biogas "adder," which will decline annually by 10%.[205] SGIP incentives are tiered so that a project larger than 1 MW will receive smaller incentives for the portion of the project over 1 MW (50%) and for the portion of the project over 2 MW (25%). For projects 30 kW and larger, 50% of the incentive will be paid when the project comes on line and 50% will be paid annually based on the recorded kWh produced in the previous year. If the project operates at the expected capacity factor, it will receive total performance payments within five years.[206] Thus, with 2015 incentives, a 1 MW biogas combustion facility would receive $950,000 upon installation and an additional $950,000 over the next five years of project operation.

If dairy biogas projects were to obtain 10% of the total annual SGIP incentive funds, this program could provide close to $8 million in incentives per year (dispersed over five years following installation).

### Sale of Low Carbon Fuel Standard credits

California's Low Carbon Fuel Standard (LCFS) requires covered entities (fuel suppliers) to supply a fuel mix that meets a specific carbon intensity (CI) standard by 1) supplying a mix of fuels and volumes that collectively meet the standard or 2) using purchased or banked LCFS credits. Fuel producers who are not covered by the regulation – e.g., a biogas fuel producer – may voluntarily opt-in to the program to earn and sell LCFS credits. Out-of-state producers may opt in as long as they have demonstrated to ARB a physical pathway for importing those fuels into the state. The initial "regulated party" capable of generating credits for a specific quantity of biogas CNG or LNG is generally the producer or importer of

[204] PUC. §2827(h)(4)(B)
[205] Center for Sustainable Energy, 2015. *2015 Self-Generation Incentive Handbook*, pg 10
[206] Center for Sustainable Energy, 2015. *2015 Self-Generation Incentive Handbook*, pg 6

that fuel. For non-blended biogas CNG or LNG produced in California and used in vehicles in California, the regulated party is the producer of the biogas fuel.[207] Thus a dairy which produces biogas fuel can generate credits by producing and either using or selling those fuels. The opt-in process requires the clean fuel producer to register with ARB's LCFS Reporting Tool and commit to certain reporting and recordkeeping obligations.[208] Credits are generated on a quarterly basis and can be sold once they've been officially reported through the Reporting Tool.[209]

The number of LCFS credits a low-carbon fuel generates is based on the difference between the CI value of the low-carbon fuel compared to the CI standard. CNG produced from dairy digester biogas has a CI value of 13.45 gCO2e/MJ.[210] The Average Carbon Intensity compliance schedule under the LCFS program is 96.48 gCO2e/MJ for gasoline in 2015, decreasing to 89.06 gCO2e/MJ in 2020.[211] Thus, in 2015, a dairy which produces 100,000 scf of biogas CNG per day (2,500 -3,000 head dairy) would produce 2,800 credits ($mtCO_2e$) in a year. At a price of $25/credit, this incentive would generate $70,000 per year.

In 2014, 1.6 million LCFS credits (each 1 $mtCO_2e$) were transferred between parties. In 2015, the average price of an LCFS credit has ranged from $22 – $25.[212] The LCFS program is a market-driven mechanism and thus the price and demand for LCFS credits is likely to vary. However, if the market for LCFS credits remains at 1.5 million credits and credit price is $20, the LCFS market will be $25 million annually.

### 7.1.4 Federal opportunities: performance incentives

#### Sale of EPA Renewable Fuel Standard "RINs"

The national Renewable Fuel Standard, referred to as "RFS2" established by the Energy Independence and Security Act of 2007, is a renewable fuel volume mandate implemented by the U.S. Environmental Protection Agency (EPA).[213] Obligated parties (refineries and fuel importers) must produce or import and sell or blend a certain quantity of renewable fuels each year, as determined by the EPA on an annual basis (a total of 16.3 billion gallons for 2015). The total RFS2 renewable fuel requirements are divided among nested categories, as shown in Figure 10.[214] Obligated parties must comply with the regulation by retiring Renewable Identification Numbers (RINs) corresponding to a specific volume and category of fuel. Clean fuel producers can opt-in to the program

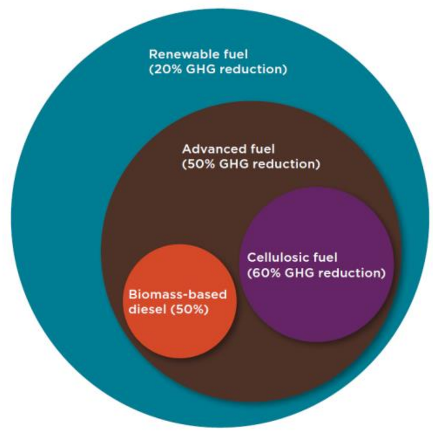


**Figure 10 - Nested categories of the Renewable Fuel Standard**

[207] California Air Resources Board. *Final Regulation Order: Low Carbon Fuel Standard.*
[208] California Air Resources Board, 2011. *Low Carbon Fuel Standard Question and Answer Guidance Document (Version 1.0),* pg. 7
[209] Ibid, pg 17
[210] California Air Resources Board. *Final Regulation Order: Low Carbon Fuel Standard*, pg. 63
[211] Ibid, pg. 19
[212] California Air Resources Board, 2015. *Monthly LCFS Credit Transfer Activity Report for April 2015*.
[213] U.S. Environmental Protection Agency. *Renewable Fuel Standard (RFS).* http://www.epa.gov/oms/fuels/renewablefuels/, Accessed May, 2015.
[214] ICCT, 2014. *How the Renewable Fuel Standard Works*, pg. 3

in order to sell RINs (either bundled with the fuel itself or after separation through sale, use or blending) to an obligated party.

Following 2014 changes to the regulation, Biogas LNG or CNG qualifies under the "Cellulosic" fuel category qualified to generate D3 RINs.[215] D3 RINs are highly valuable because 1) D3 RINs count toward an obligated party's Cellulosic, Advanced, and Renewable Fuel requirements and 2) historically there have been far too few D3 RINs produced to meet the cellulosic requirement. To address this second issue, the EPA sells a quantity of Cellulosic Waiver Credits based on projections of cellulosic based fuel which will be produced in a given year.[216] An obligated party must combine a Cellulosic Waiver Credit with a Renewable or Advanced Fuel RIN in order to satisfy with its Cellulosic Fuel obligations in the absence of D3 RINs.[217] Cellulosic Waiver Credits are priced at the greater of $0.25 or $3.00 minus the wholesale price of gasoline, adjusted for inflation.[218]

While there is a minimal record on the price of D3 RINs due to the lack of D3 RINs available in the market, it is reasonable to assume that the price of a D3 RIN will be close to the price of an advanced biofuel D5 RIN plus the cost of a waiver.[219] D5 RINs in 2015 are selling at $0.76 while cellulosic waiver credits are priced by the EPA at $0.64 cents for 2015.[220] Thus a D3 RIN could sell for as much as $1.40. For each MMBTU of biogas produced, roughly 13 RINs are generated. As in the LCFS, RFS2 is market-based regulation and the price of D3 RINs will vary over time. At a price of $1 per D3 RIN, one MMBTU of dairy biogas fuel could generate $13 in revenue for the producer.

### 7.1.5 Federal opportunities: grants

Additional funding for emissions reductions at California dairies may be available through the U.S. Department of Energy (DOE) and Department of Agriculture (USDA).

The DOE funds some bioenergy projects through the Office of Energy Efficiency and Renewable Energy, but funds have recently been directed to research institutions and labs for development of cellulosic and algae feedstocks.[221] Similarly, the USDA-DOE Biomass Research and Development Initiative provides funding for biofuel development ($8.7 million in 2015) but is not likely to provide significant funding for demonstration or deployment projects.

Incentives administered by the USDA are likely to offer more substantial funding for dairy methane reduction efforts. In April 2015, Secretary of Agriculture Tom Vilsack announced plans to address climate change through partnerships with agricultural producers and voluntary incentives. One of ten "Building

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[215] U.S. Environmental Protection Agency. *Renewable Fuel Standard (RFS): Approved Pathways.* http://www.epa.gov/otaq/fuels/renewablefuels/new-pathways/approved-pathways.htm; Accessed May, 2015.

[216] U.S. Environmental Protection Agency, 2015. *Cellulosic Biofuel Standard Guidance*.

[217] Ibid.

[218] U.S. Environmental Protection Agency, 2015. *EPA Issues Minor Amendments to the Cellulosic Waiver Credit Provisions and Other Renewable Fuel Standard Regulations.*

[219] Weisberg, Peter. 2014. *Biogas Projects Qualify as Cellulosic Fuel under the Renewable Fuel Standard.*

[220] U.S. Environmental Protection Agency, 2015. *EPA Issues Minor Amendments to the Cellulosic Waiver Credit Provisions and Other Renewable Fuel Standard Regulations.*

[221] U.S. Department of Energy, *Bioenergy Technology Office: Past Solicitations and Awardees from 2007 – Present*. http://www.energy.gov/eere/bioenergy/past-solicitations#Process_Development_Facility. Accessed May, 2015.

Blocks for Climate Action" will be to "encourage broader deployment of anaerobic digesters, lagoon covers, composting, and solids separators to reduce methane emissions from cattle, dairy, and swine operations, including the installation of 500 new digesters over the next 10 years."[222] The climate programs will be administered through USDA's existing authorities under the 2014 Farm Bill; no new funding has been budgeted at this point. While it is unclear whether USDA will implement the announced climate action strategies by establishing new incentive programs or by allocating funds through existing programs, it is reasonable to expect that the Secretary's announcement will lead to an increase in federal funding for installation of digesters at dairies.

USDA currently administers grants and loans through two broad program areas which could provide funding for methane reduction projects on dairies: rural development (RD) and natural resource conservation (NRCS). Table 5 lists the most promising USDA incentive programs reauthorized through the 2014 Farm Bill which could potentially support the USDA Climate Action Goal's dairy methane emission reduction strategies.

**Table 5- USDA Incentive Programs which could support California dairy methane reductions**

| | **Incentive** | **Incentive details** | **2014 Farm Bill Funding[223,224]** |
|---|---|---|---|
| NRCS | Environmental Quality Incentives Program (EQIP) | Awards up to $450K for various projects including general conservation, on-farm energy, and air quality initiatives | $1- 2 million per year |
| Rural Development | Rural Energy for America Program[225] | Loans and grants for agricultural producers and small businesses in rural areas. Biomass digesters eligible. Loans up to $25 Mil, grants up to $500,000. | $50 – 70 million/year through 2018 |
| | Value-Added Producer Grants | Grants up to $200K and 50% of costs for agriculture producers processing and marketing new products (e.g., fuel or power). | $63 million through 2018 |
| | Advanced Biofuel Development[226] | Payments based on quantity of advanced biofuel. Must be a final product producing at least 345 days/year. | $15 million/year through 2018 |

[222] U.S. Department of Agriculture, 2015. *Agriculture Secretary Tom Vilsack and Senior White House Advisor Brian Deese Announce Partnerships with Farmers and Ranchers to Address Climate Change.*
[223] U.S. Department of Agriculture, 2014. *USDA Rural Development: Highlights of the Agriculture Act of 2014*.
[224] U.S. Department of Agriculture. *2014 Farm Bill Update.* http://www.rrva.org/02262014/Farm%20Bill%20Update.pdf. Accessed May, 2014.
[225] U.S. Department of Agriculture. *Rural Energy for America Program Renewable Energy Systems & Energy Efficiency Improvement Loans & Grants.* http://www.rd.usda.gov/programs-services/rural-energy-america-program-renewable-energy-systems-energy-efficiency. Accessed May, 2015.
[226] U.S. Department of Agriculture. Advanced Biofuel Payment Program. http://www.rd.usda.gov/programs-services/advanced-biofuel-payment-program. Accessed May, 2015.

### 7.1.6 Combined incentives

As mentioned above, the greatest funding opportunities are for installation of digesters. To maximize funding and cover costs, a dairy owner will likely need to make use of a variety of incentives. Figure 11 shows the combined total state grant funding likely available for installation of digesters at California dairies based on the assumptions described above.

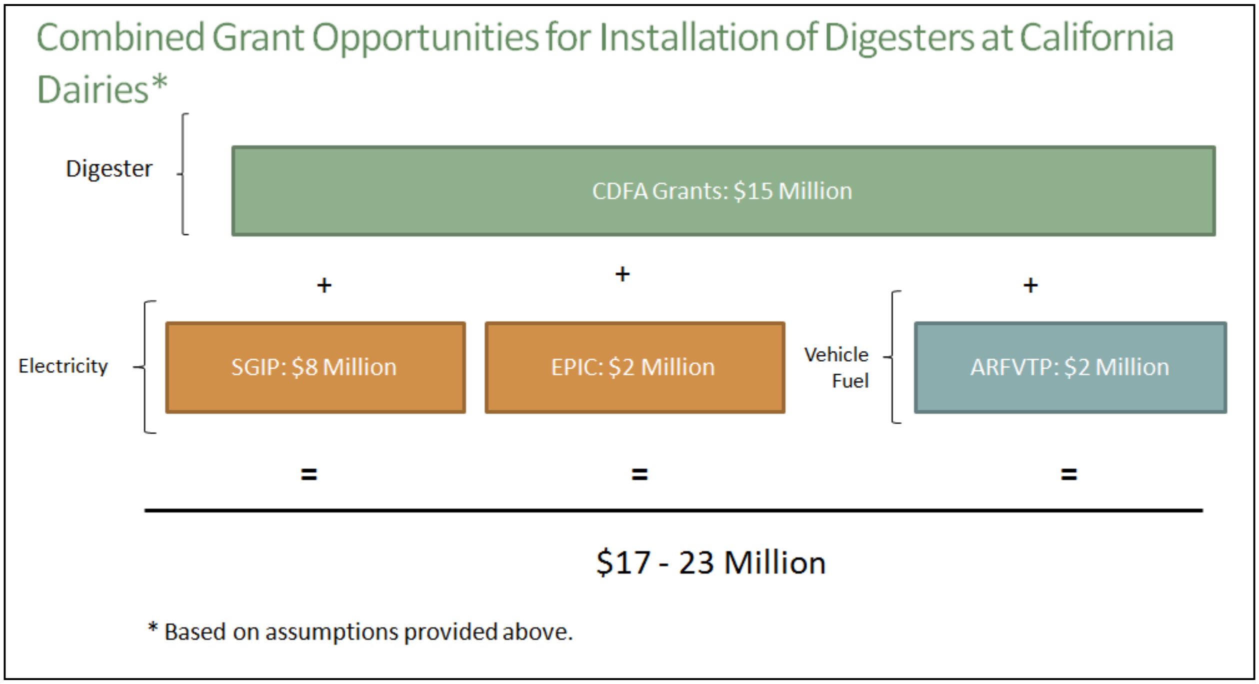


**Figure 11- Combined state grant funding opportunities for installation of digesters**

**** Note that a portion of CDFA's $15M goes to research, admin, and renewable fuel standards work.**

## 7.2 Discussion of funding strategies

To properly incentivize implementation of methane reduction activities at dairies, California policymakers must balance multiple objectives and financing challenges.

First, the upfront funding required to install a digester is a significant barrier. Grants which are designed as incentives based on the installation of digesters are important for overcoming this challenge. The CDFA Grant program, EPIC grants, and ARFVTP grants provide largely up-front, lump sum funding to contribute to initial capital costs. The Federal "Section 1603" cash grants in lieu of Investment Tax Credits were another incentive which supported the installation of over 85 GW of renewable projects.[227] On the other hand, incentives based on the sale of products or credits (LCFS, RINs, carbon offsets, and the BioMAT) provide on-going revenues based on successful on-going operation of the digester. While these performance-based incentives can help assure policy-makers that real emissions reduction benefits are achieved, some dairies may not be able to overcome upfront capital costs based on future

[227] U.S. Department of Treasury, 2015. Overview and Status Update of the §1603 Program.

revenue expectations. The financing challenge will be even more severe for investments premised on uncertain or variable future revenues. Of the various performance-based incentives, only the BioMAT offers a fixed payment over a long contract term (10 to 20 years). The Self-Generation Incentive Program is a promising model that combines up-front funding with additional funding dependent on actual operation of the digester and production of power. A successful combination of funding programs will both contribute to a dairy's initial capital costs and ensure that public investments result in real emissions reductions over the long-term.

However, it's also important to recognize that competitive funding opportunities, in the form of grants or tariffs, are not guaranteed for any single project. Thus, with the expiration of federal Section 1603 funding at the end of 2012, a lot of time and effort is required to apply for grant funding that may never be realized.

# 8. Recommendations

California dairies are a major source of the state's methane emissions. In order to meet the state's GHG targets, we will have to find ways to reduce dairy methane. However, the only way that methane reduction solutions can work for California's dairy industry will be through the investment of resources and energy in the development of incentives and policies to make them economically viable. Additionally, the best GHG reduction solution for one dairy might not be the best option for another dairy. Therefore, the state should not mandate specific practices or technology solutions. We feel that a model in which the state establishes goals for GHG reductions and then provides both flexibility and incentives to allow individual dairies to find the optimal way to achieve those goals will allow the state to achieve its targets while maintaining an industry that is important to the California economy and the global food chain, and in the process create a global model for how to reduce emissions in an effective and economically efficient manner. Conversely, creating overly prescriptive mandates for dairies could limit GHG reduction potential, and also run the risk of exporting the problem to other states – most likely ones with significantly more lax environmental regulation - thus exacerbating the global GHG problem.

## 8.1 Short-term incentives

**Provide incentives to promote early investment by dairies in methane-reduction practices** – Our study has shown that many options for dairy methane emission reduction aren't yet economically viable. This is a particular challenge for dairy producers since the price of milk is regulated (dairies don't control their prices) and there is currently no way for many of them to get compensated for investments in sustainability through their milk revenue (they can't obtain premiums for their milk by making sustainability claims). If the state wants dairies to adopt a wide range of practices to reduce methane emission, it needs to look at how to incentivize them to make investments that otherwise will have no, or little, payoff, at least in the short term.

**Provide flexibility to accommodate high variability across dairies** – Through our research, the one thing that has become clear is that there is no one-size-fits-all solution for reducing GHG emissions from dairies. What may work for one dairy may not be appropriate for another. Choosing the right solution on a dairy (e.g., a covered lagoon digester, a complete mix with co-digestion, converting from flush- to scrape-based manure management systems) will depend on a number of variables that are difficult to fully understand from a centralized level of operation. Programs should provide general incentives that encourage the desired outcome of GHG reductions, but offer dairies flexibility as to how they can meet those objectives. Overly prescriptive command-and-control mandates will not be cost-effective solutions and they will likely lead to suboptimal GHG reductions and/or emissions exports to other states.

**Use performance-based incentives to the extent possible** –We suggest providing a balance between the amount of funding given in up-front grants and the amount given in performance-based incentives for projects and/or practices after they've been implemented. Using digesters as an example, we know that the methane reduction value depends on a digester's year-on-year operating performance, yet we also know that many previously installed digester projects have failed to meet forecasted levels of performance. Operating and maintaining digesters is not a trivial task, and the previous model of farmer owned and operated digester systems often resulted in substantial amounts of downtime. The challenge of running a digester system while continuing with regular dairy operations, paired with low prices for electricity, created little incentive to make sure generators ran at high utilization rates. The third party developer model for digesters appears to have overcome these challenges, but incentives for strong operational performance should be put in place to encourage high utilization rates. The BioMAT and carbon credits are examples of performance-based incentives. Their overall impact on driving digester development should be continually evaluated.

**Provide regulatory coordination** – In the San Joaquin Valley, where most CA dairies are located, serious air and water quality problems have significant impacts on local populations. Consequently, any new or modified practices on dairies are subject to strict air and water quality regulations from several agencies, often with conflicting or duplicative requirements. In order to implement effective methane reduction strategies and still comply with existing regulatory requirements, agencies will need to work together to reconcile conflicting requirements, avoid duplicative efforts, and expedite permitting of projects that provide the widest range of benefits.

**Revisit type and amount of up-front grant funding for digesters** – Even with performance incentives in place (e.g., BioMAT, carbon credits), digester projects will likely still need additional grant funding to get off of the ground. Grant programs should continue, and the potential for expanding grant availability should be explored. However, many digester developers and advocates have stated that the existing process of applying for grants is cumbersome and is akin to a beauty contest – the most attractive application prevails, and the most attractive application may not be the best project for long-term GHG reductions. Streamlining the process, providing more certainty to applicants, and making the process as objective as possible would be helpful for project developers.

**Reduce investment risk for digesters** –Obtaining financing for projects based on revenue streams from products other than electricity generation is currently very challenging. While electricity generation provides long-term contracts and revenue security that are easy to lend against, there is far more uncertainty associated with carbon offsets, RINs, LCFS, and vehicle fuel contracts. Contracts for these products are typically short-term and prices are more volatile. Financing is essential because the upfront costs of digester projects are so high. It may be worth exploring an incentive program that can reduce the risk associated with lending against these revenue streams (e.g., loan guarantees, guaranteed minimum price for carbon offsets or LCFS credits). Alternatively, loan funding could be provided directly to projects that rely on these less secure revenue streams. Incentives targeted at unlocking additional financing could reduce the overall need for grant funding.

**Explore the possibility of offset protocols for solid separation and conversion from flush- to scrape-based systems** – The use of solid separation and the conversion from flush- to scrape-based systems do not have any associated performance-based incentives. If these are viewed as important strategies for reducing GHG emissions from dairies, then it may be worthwhile to explore the possibility of developing offset protocols for these interventions. These protocols will undoubtedly be more complex than those for digesters and may prove too complex to develop and implement. That said, an initial exploration of this approach as a way to incentivize these emission reduction strategies seems worthwhile.

**Use 20-year global warming potential for carbon offset projects** – If the state would like to emphasize the impacts of GHG emissions from SLCPs (including methane) and incentivize their reduction, then consistently valuing carbon offsets based on 20-year GWP values rather than 100-year GWP values may be a desirable policy to implement. This approach would significantly enhance the value of offsets for digester projects and potentially make some of the most effective projects economically viable without grant funding.

## 8.2 Short-term research needs

**Understand manure management practices currently practiced on California dairies** – The overall opportunity for greenhouse gas mitigation on dairies, and the appropriate solutions for each dairy, will depend on an accurate assessment of current manure handling practices. While the classification of manure management practices used in California's Greenhouse Gas Inventory works well for the task of assessing overall GHG emissions, a more granular and nuanced understanding of manure management practices on California dairies is needed in order to better assess the potential of various greenhouse gas abatement strategies. What are the different manure management practices used on California dairies? How much manure goes to each practice? To what extent are solid separators currently being used and what types are being used? What volume of volatile solids is making it to an anaerobic lagoon? To what extent are dairies in the state land constrained? Answers to these and other questions can help paint a more complete picture of greenhouse gas emissions from California dairies and the potential for various mitigation strategies.

**Research emissions impacts of solid separation and conversion from flush- to scrape-based systems** – Solid separation appears to have some promise as a greenhouse gas abatement strategy. However, the literature is very thin on what types of solid separation are already in use in California, what the actual greenhouse gas abatement potential is from the use of different types of solid separation, and what the emissions are from the separated solids through their storage, processing, and application.

Similarly, the overall emissions impacts of converting from flush- to scrape-based manure management systems are not well documented in the literature. While theoretical estimates are available from greenhouse gas inventories and emissions calculation methodologies, a more comprehensive understanding requires further study because there are many different permutations of how scraped manure can be handled and stored.

**Understand water use impacts from converting from flush- to scrape-based systems** – Most experts that we spoke with noted that converting from flush- to scrape-based manure management systems in dairies does not generate significant water savings because water is typically recycled for different uses across the dairy and ultimately used for irrigation. Water will need to be generated for irrigation regardless of whether the dairy uses flush- or scrape- based systems and irrigation is by far the largest water use on dairies. However, dairies that are land constrained (e.g., they do not have sufficient crop acreage to agronomically take up the nutrients in their manure) may need to export some of their manure. These dairies would benefit from having drier manure because it is cheaper to export off the farm. If these dairies have low irrigation needs because of limited acreage, they may generate water savings by changing from flush- to scrape-based systems. Finally, if dairies are able to transition from flood irrigation to drip irrigation, it is possible that irrigation may no longer be the leading use of water on the farm and may make scrape systems attractive from a water savings perspective. A thorough assessment of water usage on dairies and how changes in manure management practices could influence overall water use could be helpful. Such an assessment could identify the circumstances in which conversion to scrape could result in water savings (e.g., land constrained dairies, dairies using drip irrigation). Another element of this assessment could be an examination of the potential for using lagoon water in drip irrigation systems. Although changes in irrigation methods are unlikely to have significant GHG reduction benefits[228], they are critical to achieving water reductions on dairies and may help encourage more efficient water use in parlors and flush systems.

**Provide economic data for solid separation and converting from flush- to scrape- based systems** – There is very little information in the literature about the economics of converting dairies from flush- to scrape-based systems or installing solid separation technologies. There is a dialogue about the general concerns and benefits of each approach, but we have not found any information that fully captures the economic impact, particularly in the California context. More economic data are needed 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.

**Evaluate market potential of manure-based products** – There is a great deal of discussion in the literature about supplemental revenue streams that can result from dairy digester projects, specifically by converting the digestate into a valuable product (e.g., cow bedding, soil amendments, peat moss substitutes, and nutrient products). However, the opportunity goes beyond digesters. Other solutions discussed in this paper, including switching from flush- to scrape- based systems and installing solid separators, also increase the amount of material readily available to produce valuable manure-based

[228] There is some speculation that flood irrigation using lagoon water can result in anaerobic conditions on the field, however the degree to which this practice generates methane emissions has not been well studied.

products. Building a market for these products would help reduce both methane emissions and potential for groundwater contamination from over-application of manure. However, realizing revenue from these opportunities has been irregular and quite idiosyncratic from project to project. In general these opportunities have not been consistently realized. A comprehensive evaluation of the market potential of manure-based products that assesses their current viability, identifies areas for additional research and development, and provides recommendations for market cultivation is an important next step. Development of markets for these products over time could have an important economic benefit to GHG reduction projects on dairies.

**Integrate methane reduction strategies with other environmental criteria in order to achieve multiple benefits and avoid unintended consequences** – While reducing methane from dairies is important, dairies are trying to manage a range of practices that each has a suite of environmental impacts. Manure management is particularly complex. Each of the many different practices and technologies a dairy might employ could have positive effects on some of the relevant environmental factor (e.g., methane emissions, air quality, water quality, water use) and negative effects on other areas. For example, converting to a drier manure management system could reduce methane emissions and water quality impacts but increase air quality-related impacts. Alternately, a management option might be effective at solving one environmental problem but of no use in addressing another problem (e.g., digesters reducing methane but not doing anything to reduce nitrogen leaching to groundwater). In order to determine what methane reduction strategies provide the most positive outcomes for multiple criteria, we need a clear understanding of how switching from one management practice to another would either increase or decrease impacts across the environmental spectrum.

Our study has shown that environmental co-benefits can be obtained from methane-reducing practices, but the effort must be approached in an integrated, whole-system way in order to assure that these benefits will be realized, and unintended negative consequences are avoided.

## 8.3 Long-term Research Needs

**Continue research on enteric fermentation** – Enteric fermentation accounts for almost half of GHG emissions from dairies in California. Enteric fermentation emissions are difficult to address because they are generated from the digestion system of all cattle. Emissions intensity (emissions per unit of milk) can be substantially reduced through good nutrition and diet management of dairy herds. Diet and nutrition also support production efficiencies and are therefore investments that California dairies have already made. California has one of the most productive dairy sectors in the world. That said, there is an on-going body of research on additives and supplements that can reduce enteric fermentation. There is some evidence of efficacy in the use of additives and supplements, but to date they have not been found to be cost effective. We do not know enough to say whether the amount of investment going into this work is sufficient at this time, or whether there might be opportunities to conduct California-specific research on this topic, we believe that this research and investment in this area should continued.

**Continue to track and synthesize lessons learned from the performance of dairy digesters** – There are several studies available on the cost and performance of dairy digesters, but it is difficult to distill the information into a cohesive set of lessons learned and cost-benefit assessment of digesters. This limitation is somewhat inevitable given the low number of digesters installed in the state of California. However, a concerted effort to track performance going forward will help to develop a set of best practices. A comprehensive tracking effort could refine the understanding of what digesters should cost to build and operate and what performance metrics they should be able to achieve. Previous cost estimates that have been published (e.g., CEC's Dairy Methane Digester System Program Evaluation, AgSTAR data) are outdated and do not reflect the realities of building and operating digesters in California today. Operations and maintenance costs and the actual performance of digesters (e.g., biogas production, electricity generation) should also be tracked to make sure that they are appropriately accounted for in digester business plans and the design of incentive programs. The number of inoperable digesters in the state highlights that simply constructing a digester project will not secure long-term greenhouse gas abatement and that careful attention must be paid to making sure they operate effectively throughout their expected lifetime.

This comprehensive analysis should make clear distinctions between different types of digester models (cluster models, co-digestion, pipeline injection, etc.). The economics and performance of these different permutations vary significantly, and the blurring of distinctions between them currently confuses the discussion around digesters. Similarly, the different types of digesters (e.g., covered lagoon, complete mix, modified plug flow) all have different costs and benefits. The analysis should aim to provide clear guidance on when a certain type of digester is preferable (e.g., does the increased biogas production and consistency of a complete-mix digester justify the costs; does the option value of being able to add a wide array of co-digestate justify the higher cost of a complete-mix digester, what are the key dairy characteristics that will lead you to one design option over another?).

# 9 Conclusion

Despite impressive reductions in greenhouse gas intensity (i.e., emissions per unit of milk) in the dairy section in recent decades, California's dairies remain one of the state's primary sources of methane, a potent short-lived climate pollutant. Manure management in particular is a major source of these greenhouse gas emissions. There are a wide range of options for reducing these emissions, including anaerobic digestion for electricity, compressed biomethane; covering and flaring biogas from manure lagoons; separating out manure solids from liquids; and changing to dry (or drier) manure management. (Another way to reduce dairy emissions is to cut enteric emissions from cow digestion through the use of feed supplements.) In the case of anaerobic digestion, there has already been an impressive amount of attention and progress towards making these projects feasible: carbon offset protocols, grant and incentive programs, efforts to streamline permitting, and other initiatives have helped springboard several digesters into operation in California.

Broad uptake of mitigation solutions, however, has remained elusive. Farmers operate within a constantly evolving environment, balancing feed costs, animal health, milk prices, regulations, time limitations, and myriad other factors in a constantly evolving operation, of which manure management is just one component. No two farms are the same, so the feasibility of switching manure handlings systems will vary widely.

Ultimately, any intervention must make financial sense. For most California dairies, none of these interventions are currently economical without additional incentives. The literature on anaerobic digesters producing electricity indicates abatement costs in the range of \$0 to \$40 per $mtCO_2e$, but this range is almost certainly too low for new projects in California. While the data on new projects is thin, a couple of recent case studies in California point to abatement costs on the order of \$33 to \$45 per $mtCO_2e$, although the costs of individual projects will vary substantially depending on the project characteristics. Comparatively, the costs of CBM and pipeline injection are not well-studied because there have been so few projects in the United States, but there is a lot of interest in the model due to the high value of vehicle fuel and the associated environmental credits. Similarly, solid separators may be a promising mitigation solution for a subset of dairies, but due to the uncertainty surrounding their GHG abatement potential it is difficult to quantify their cost of abatement. The interventions differ in their potential to reduce baseline emissions and in their ability to scale; anaerobic digesters are perhaps the greatest total mitigation potential because they may feasibly be applied on a large number of farms and can slash manure management emissions on the order of 73%.

The air quality, water quality, and manure composition effects of switching manure management systems are poorly quantified, but in all cases there are both benefits and negative impacts. For example, anaerobic digesters that use the biogas to generate electricity significantly reduce methane but may lead to an increase in NOx and SOx. While additional research will help to clarify the magnitude of different impacts, and allow them to be weighed more completely against each other, determining which of the co-impacts deserves to be prioritized will also represent a value judgment.

Greater adoption of GHG-reducing manure management practices across California dairies can continue to be advanced on multiple fronts. More research remains important, particularly for solid separators and compressed biomethane. Loan guarantee programs can help backstop projects and give lenders the security they need to invest, while rotating loan funds can likewise help ensure available capital. However, this sort of creative finance will only be effective for the small percentage of projects that are already on the verge of economic viability. In many cases, additional incentives or revenue streams must be developed in order to ensure projects move forward. Incentive programs can be structured to defray capital or operating costs or to reward project developers for performance and may help prove concepts or provide a bridge as technology advances and projects become cheaper. Meanwhile, despite inherent difficulty, developing markets for byproducts, such as composted manure solids or fertilizers, remains worthy of long-term support.

## Appendix A: Research interviewees

| Name | Organization |
|---|---|
| Ladi Asgill | Sustainable Conservation |
| Tom Barcellos | Barcellos Farms |
| Jerry Bingold | Innovation Center for U.S. Dairy |
| Neil Black | California Bioenergy |
| Michael Boccadoro | Dairy Cares |
| J.P. Cativiela | Dairy Cares |
| Allison Costa | AgSTAR (EPA) |
| Erin Fitzgerald | Dairy Management, Inc. |
| Ryan Flaherty | Sustainable Conservation |
| Michael Frantz | Frantz Wholesale Nursery |
| Craig Frear | Washington State University |
| Nathan Heeringa | Innovative Ag Services |
| Robert Joblin | Cenergy |
| Marco Lemes | Sacramento Municipal Utility District |
| Daryl Maas | MAASEnergy |
| Bob Madeiras | Independent |
| Deanne Meyer | University of California Davis |
| Frank Mitloehner | University of California Davis |
| Phil Muller | SCD Energy Solutions |
| Ramon Norman | San Joaquin Valley Air Pollution Control District |
| Robert Parkhurst | Environmental Defense Fund |
| Paul Sousa | Western United Dairymen |
| Scott Subler | Environmental Credit Corp. |
| Kristin Walker | U.S. Department of Agriculture |
| Peter Weisberg | ClimateTrust |