COMPOST: ENHANCING THE VALUE OF MANURE

An assessment of the environmental, economic, regulatory, and policy opportunities of increasing the market for manure compost

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Sustainable Conservation

Contents

EXECUTIVE SUMMARY

California's dairy producers provide significant benefit to local, state, and national economies. They generate 20% of US milk (CDFA, 2016), $9.4 billion in revenue , and 30,000 on-farm jobs (Sumner et al., 2015). 90% of California's dairy cows are located in the San Joaquin Valley (CDFA, 2016), and the milk produced by these cows generates substantial economic benefit to a region suffering from high unemployment and poverty (UC ANR Committee of Experts, 2006; US Census Bureau, 2016). At the same time, the manure generated by these more than 1.5 million cows produces significant environmental impacts to air, water, and climate. Thus, identifying and supporting economically viable solutions for improved manure management is essential to ensure the health of the environment, people, and economy in the San Joaquin Valley.

Findings

In this study, we have examined best-available information on the array of environmental impacts and benefits of manure compost and, more importantly, the interrelationship between those impacts. We found that dairy manure composting has the potential to reduce water quality impacts, improve soils, and reduce greenhouse gas emissions from dairies with comparatively minimal impacts to local air quality. Dairy manure compost's portability gives it the potential to disperse nutrient concentrations further distances than manure. While further research is needed to better quantify these impacts, California need not wait to take proactive steps to promote dairy compost when its benefits are clear. Specifically, production of compost for export of manure off dairies appears to be a clear win.

Several key barriers have hindered the production and sale of manure compost and need to be addressed so the practice can be widely adopted. The inconsistency, complexity, and lack of clarity of regulations has been one of the primary barriers to compost production. In some cases, permitting requirements are simply unclear. In other cases, the regulations are based on limited and/or incomplete data and could prohibit better environmental outcomes. In order to establish effective regulatory and incentive programs, there is a critical need to conduct California-based research on the magnitude of the impacts of manure compost relative to current manure management practices.

The current regulatory approach also does not appropriately consider the net impacts from composting dairy manure across water quality, air quality, and greenhouse gases. This siloed approach to managing pollutants on dairies results in lost opportunities to address the most pressing environmental impacts of manure and could actually lead to negative environmental outcomes at a regional scale.

Fortunately, achieving the environmental benefits of manure compost is within reach, as the market for manure compost seems ripe for growth. Demand for compost is robust and expected to increase, particularly in rural agricultural regions of the state where supply of municipal compost can be scarce. Manure compost can help fill this supply-demand gap, but agricultural producers need their customers to support them using manure compost. There is also significant opportunity to increase the supply of manure compost. Dairies are increasingly interested in composting their manure, and producing manure compost seems economically viable for many dairies. However, they need regulations and permitting requirements that are supportive of manure compost production. Table 1 below summarizes our key report findings.

Conclusion and Recommendations

Based on our research, compost appears to be an economically viable option that enables dairies to reduce their most significant environmental risks. However, we have identified some barriers that are impeding the production and sale of compost. We believe that targeted, short-term efforts by state and local government agencies to address these barriers can enable the market to emerge and grow on its own. We recommend the following specific actions that can be taken by government and associated entities to improve the science, regulatory regime, and market for manure composting while supporting state policies to improve soils and reduce greenhouse gasses. Doing so will help catalyze the market for manure compost, resulting in multiple environmental, social, and economic benefits, many of which will be realized in the San Joaquin Valley.

1. **Research: Initiate comprehensive California-based research comparing dairy manure composting to existing manure management practices in order to quantify the magnitude of impacts across environmental media.**

   The available research indicates that composting manure is environmentally beneficial overall. Composting generates significant benefits to water quality and methane – by far the two greatest environmental impacts of dairy manure management – and relatively minimal increase in air quality impacts, some of which can be easily mitigated. The research we found was primarily conducted outside of California and/or studied non-manure compost feedstocks. While the relative impacts seem clear for most pollutants (the exception being volatile organic compounds), it is not possible to make definitive conclusions about the magnitude of the impacts due to the lack of comprehensive California-based research.

   Therefore, we advocate for field-scale research in the Central Valley to quantify the magnitude of environmental impacts and tradeoffs of production and application of manure compost. This research must be comprehensive, including all of the following: (1) it must compare dairy manure composting to existing manure management practices; (2) it must look across multiple air, water, and greenhouse gas pollutants; and (3) it must measure the full life cycle, e.g. collection, storage/processing, and use (typically land application). The results of this research will help shape more science-based policy and may enable more cross-agency collaborative approaches to regulating environmental impacts – both of which would lead to better environmental outcomes.

2. **<u>Regulatory</u>: Amend air quality, water quality, and waste regulations so that they are clear, science-based, and reflect the net environmental impacts of composting dairy manure.**
    a. The San Joaquin Valley Air Pollution Control District should create clear and science-based Best Available Control Technology Guidelines for new or expanded composting on dairies.
    b. The Central Valley Regional Water Quality Control Board should consider compliance with the existing requirements of the Dairy General Order as constituting compliance with the siting requirements of the new Compost General Order.
    c. CalRecycle should provide clear guidance to ensure Local Enforcement Agencies are consistent in how they interpret and assess compliance with the notification tiers of the Agricultural Material Composting Operations and Green Material Composting Operations.
    d. The California Department of Food and Agriculture, the Administration, and the Legislature should identify funding pools other than the Greenhouse Gas Reduction Funds in order to fund needed research and market development for dairy manure compost.

3. **<u>Market:</u> Support outreach and education to encourage manure compost production and research and demonstrations to bolster demand for manure compost.**
    a. Provide funding to California Department of Food and Agriculture to build producers' knowledge of compost production regulatory requirements and best management practices.
    b. Fund research to compare the soil health benefits and contamination risks of dairy manure compost, green waste compost and food waste compost.
    c. Fund demonstration projects to study and prove economic feasibility of dairy manure composting in the San Joaquin Valley.

4. **<u>Policy:</u> Implement AB 1045, the Healthy Soils Initiative, the Alternative Manure Management Program, and SB 1383 in a manner that promotes beneficial dairy manure composting and encourages coordination across state agencies.**
    a. Address permitting challenges for dairy manure composting through AB 1045.
    b. Recognize and support the role of dairy manure compost in meeting goals of the Healthy Soils Initiative and the Alternative Manure Management Program.
    c. Ensure that the Short Lived Climate Pollutant Strategy fully incorporates the composting of dairy manure in its policy and economic provisions addressing manure methane emissions and the need for new composting facilities.
    d. Encourage agency staffs responsible for implementing AB 1045, the Healthy Soils Initiative, the Alternative Manure Management Program, and SB 1383 to coordinate closely to achieve an integrated multi-agency strategy that maximizes the benefits derived from dairy manure compost.

Table 1. Summary of Dairy Manure Compost Impacts, Barriers, and Opportunities

	Environmental Impacts	Regulations/Permitting	Policy	Overall Assessment
Water Quality	Composting is a clear solution to reducing dairy water quality impacts. It decreases leaching risk during both storage and land application as compared to uncomposted manure. It also provides solution for over-application of manure, which is responsible for 95%+ of nitrate leaching from dairies.	Classification of dairy manure as Tier II in the SWRCB's Compost General Order requires substantial mitigation measures. Lack of clarity about how the CVRWQCB's Dairy General Order could be modified to incorporate elements of the Compost General Order is a significant challenge. Dairy General Order modifications could disincentivize composting on dairies, which is one of the only economically viable options for dairies to export excess nutrients, as required by the Dairy General Order.	Composting manure provides a clear water quality benefit for dairy manure management. Composting is currently one of the only economically viable options for dairies to export excess manure nutrients. Disincentivizing compost could significantly impede meeting policy objectives of protecting surface and groundwater quality.	Manure compost provides a clear benefit to reducing the significant water quality impacts of dairy manure management. However, the current regulatory approach appears to be heading in a direction that indicates that composting manure is detrimental to water quality. Composting of dairy manure should be encouraged, not discouraged, in order to achieve better water quality outcomes, particularly as it relates to leaching of manure nutrients to groundwater.
Greenhouse Gases	Compost produces a net GHG benefit. Significant methane reductions more than compensate for potential slight increases in CO_2 from equipment and N_2O.	N/A at this time. CARB is starting the process to establish regulations for methane emissions from dairy manure management soon. CARB can start regulating dairy methane as early as 2024.	Most of the focus for reduction of methane from dairy manure management has been on digesters. Compost is more practical methane reducing practice for a much larger percentage of California dairies. SB 1383 serves as a statutory requirement to include other methane-reducing practices, but it is unclear to what extent composting (as a standalone practice and as an "add on") will play a significant role in upcoming regulation and budgetary allocations.	Manure compost reduces methane emissions as well as overall CO_2eq as compared to solid manure stored in static piles. It is also more operationally and economically viable for a larger percentage of dairies as compared to other methane reducing practices. Composting should be considered by SB 1383 and related program as a key option – either as a standalone or as an "add on" practice – for achieving industry-wide methane reductions from manure management.
Air Quality	Compost produces a net increase in precursor emissions, although the magnitude of emissions and their impacts on regional air quality and health are unclear. Emissions of NH_3 from manure compost are greater than uncomposted manure, but they are also easier to mitigate because they do not occur during land application. More research is needed to determine net VOC emissions.	Compost does appear to increase air quality emissions from manure, and permitting requirements reflect that. However, VOC emission factors for manure compost are based on research of co-compost, not pure manure compost. Additionally, lack of clarity of what VOC mitigation measures will be required is a major permitting issue. Current regulations do not consider net emissions.	Lack of research on emissions from manure in static piles compared to composting is a barrier to understanding if and how composting could improve air quality outcomes. Current approach of not considering net emissions or precursors' actual formation of criteria pollutants does not ensure improved air quality and health outcomes.	Composting appears to increase air quality impacts, but more directly-relevant research is needed to confirm this and to understand the magnitude of incremental impacts to air quality and health. Permitting requirements should be revised as needed to reflect the findings from this research. Additionally, SJVAPCD needs to provide more up-front clarity on BACT and potential mitigation measures for VOCs so producers can estimate economic feasibility <u>prior</u> to applying for a permit.
Soil Health	Manure and manure compost share many benefits for improving soil health, but manure compost enables soil health benefits to be achieved on significantly more acreage because it is easier to transport can be more readily applied to more crop types.	N/A	CDFA's Healthy Soils Initiative is a significant program to incentivize practices that improve soil health. Compost has received significant attention as part of this program's development and could be one of the major practices incentivized by the program.	Manure compost is widely understood to provide multiple soil health benefits. Recent policy initiatives focus on improving soil health and appropriately recognize and promote the use of compost as a practice to improve the health of our soils
Supply	Composting is one of the only economically viable ways for dairies to export excess manure nutrients, thereby protecting water quality. Composting can also reduce methane emissions from dairy manure management, particularly if coupled with practices that reduce the amount of solids entering anaerobic lagoons.	Lack of clarity on regulations and permitting requirements is the largest barrier to dairies producing compost. This is particularly true for air quality permits due to perception that VOC mitigation measures will be cost-prohibitive. This also true for water quality, as producers are unclear of permitting requirements now that the Composting General Order has been released. Increased permitting requirements for export of manure compost (vs. on-farm use) is a barrier to improved regional distribution of manure nutrients.	Past policy initiatives related to compost have focused on landfill diversion, largely ignoring California's substantial agricultural feedstocks. This has left a gap in funding for research and market development of manure compost. AB 1045 has the potential to significantly impact manure compost supply if it (1) incorporates agricultural feedstocks and on-farm composting into its mandate to streamline the compost permitting process and (2) addresses the major permitting barriers addressed in this report.	Lack of clarity on regulations and permitting requirements is the largest barrier to the production of manure compost. If this barrier is removed, the supply of manure compost is likely to increase substantially. Otherwise, it is unlikely that the supply of manure compost will increase even moderately.
Demand	Composted manure can be used by a much larger customer base than uncomposted manure. By using manure compost, these customers can benefit from increased soil organic matter, increased water holding capacity, decreased pathogens and weed seeds, and increased carbon sequestration, among others. Greater proportion of organic nitrogen can reduce leaching risk compared to use of uncomposted manure.	Existing food safety regulations place only minimal restrictions on the use of manure compost, appropriately reflecting best available science regarding pathogen risk.	Past policy initiatives related to compost have focused on landfill diversion, largely ignoring California's substantial agricultural feedstocks. This has left a gap in funding for research and market development of manure compost. CDFA's Healthy Soils Initiative is a positive step forward in incentivizing the use of compost, but it is funded by GGRF and so can't address most research and market development needs.	The demand for compost is strong and growing in California. For those interested in using compost, manure compost is typically viewed favorably, as long as salt concentrations are not too high. However, customer restrictions sometimes do not reflect best available science on pathogen risk and can limit a producer's ability to use manure compost.

Key			
Positive (Environmental Impacts) Incentivizes (Regulations & Policy)	Neutral / mixed (Environmental Impacts) Neutral / unclear (Regulations & Policy)	Negative (Environmental Impacts) Disincentivizes (Regulations & Policy)	N/A

INTRODUCTION

Context

California's dairy farms provide important benefits to the regional, state, and national economies. They generate 20% of milk produced in the United States (CDFA, 2016), $9.4 billion in on-farm revenue, and 30,000 on-farm jobs (Sumner et al., 2015). To provide these benefits, California dairies milk 1.75 million cows (CDFA, 2016), and these cows generate a lot of manure (approximately 105,000 tons per day). Cow manure contains valuable nutrients and is commonly put to beneficial use to fertilize crops grown for cow feed. However, manure can also pose environmental risks when not managed carefully: manure can create air pollutants, water pollutants, and greenhouse gas (GHG) emissions.

The heart of California's dairy industry rests in the San Joaquin Valley where dairy farms produce about 90% of California's milk from 1.55 million milk cows, generating $5.6 billion in revenue and 20,400 jobs (Sumner et al., 2015). The dairy industry's substantial contribution to employment in the San Joaquin Valley is significant because the region suffers from high poverty (18-28%) and unemployment rates (8-11%) (US BLS, 2015; US Census Bureau, 2016). This region also suffers from some of the worst air and water quality in the country, and poorly managed manure contributes to this water and air pollution (Harter et al., 2012; SJVAPCD, 2013, 2015a). Improved dairy manure management is critical to the health of the environment and human populations of the San Joaquin Valley. While our report focuses on the San Joaquin Valley, many of the findings and recommendations apply to other dairy-producing areas of the state.

Most dairies in the San Joaquin Valley currently store a significant portion of their manure in lagoons and then apply the manure in liquid form onto their fields to fertilize the crops they grow for cow feed. Dairies that produce more manure nutrients than required to grow their feed crops face a serious challenge in how to manage their excess manure. Without economically viable options for dealing with excess manure, some dairies over-apply manure on their cropland, which results in nutrients leaching into groundwater. Dairies with excess manure are becoming increasingly common as the dairy industry consolidates and as dairies convert their feed acreage to more lucrative, human-consumed crops to diversify their revenue (Crowder, 2015). Replacing feed crops with human-consumed crops reduces the amount of land dairy producers have for manure application due to food safety restrictions on applying manure to human-consumed crops.

Composting dairy manure offers an alternative to manure over-application by increasing the land base over which the manure nutrients can be applied. Composting kills pathogens and converts manure into a lighter, more nutrient-dense form. The pathogen kill enables manure compost to be applied to human-consumed crops on the dairy itself, and the lighter material is more easily transported further from the dairy, enabling better distribution of nutrients as compared to uncomposted manure. Better distribution of manure nutrients will reduce the leaching of nitrates to groundwater – one of the dairy industry's most pressing environmental challenges in the San Joaquin Valley. Given the potential for compost to reduce water quality impacts, we conducted this study to determine to what extent widespread adoption of manure composting could provide environmental, human health, and economic benefits to the region.

By providing an assessment of the current state of research on manure composting and the related outstanding questions, this report sheds light on some of the tradeoffs inherent in addressing the environmental impacts of dairy manure. We hope the report will both identify priority areas for research and enable policymakers and regulators to make informed decisions regarding effective and efficient strategies for manure management that achieve multiple environmental goals. Currently, the environmental impacts of dairy manure are regulated and managed by a variety of state and local agencies through several disconnected rules and programs. At the same time, the state has been developing and implementing new policies and programs to improve soil health and reduce methane emissions. More comprehensive information on the real impacts and benefits of manure compost can improve both the regulatory programs aimed at reducing impacts from dairy manure and the public policies that may benefit from promoting manure compost. Although further research is needed to better understand the extent of benefits and impacts from manure compost, this report finds that manure composting offers clear opportunities to cost-effectively reduce some of the most severe environmental impacts of dairy manure – namely, methane emissions and water quality degradation. Realizing these opportunities, however, will require regulatory and policy coordination as well as improved market development.

Report Scope

This report is based on a review of existing literature and extensive interviews (see Appendix 1). The report focuses primarily on composting in open turned windrows when assessing impacts dependent upon composting method. We chose open turned windrows because it is the most widely practiced composting method in the San Joaquin Valley. To assess environmental impacts, this report compares (1) solid manure storage (in static piles) and land application to (2) solid manure compost production (in open turned windrows) and land application. We chose this comparison because the composting process requires solid manure, and the most common current practice for handling solid manure on dairies in the San Joaquin Valley is storage in static piles. We feel using the most common current practices is the best baseline for our analysis.

We are not attempting to compare all potential alternatives, of which there are many. For example, dairies using flush manure management systems could use advanced solid separation to pull more solids out of their flush water, or they could switch to drier management systems. Both of these options would result in additional solid manure available for composting. However, there are also many options available for advanced solid separation or moving to drier systems, each of which would result in different economic and environmental impacts. Conducting research to understand these options is important but is outside of the scope of this study. This study serves as a starting point from which additional environmental, economic, and operational impacts could – and should – be assessed.

Report Objectives

This report is intended to help California policymakers, regulators, and other interested parties understand the opportunities and challenges associated with dairy manure composting. Specifically, our objectives are to:

1. Consolidate and communicate the best available research on the environmental impacts of dairy manure compost compared to the current practice of storing and land-applying solid manure. The report takes a holistic approach by looking at impacts to air quality, water quality, greenhouse gas emissions, and soil health, and identifies the most significant gaps in the current scientific understanding of these impacts.
2. Identify barriers to the development of a robust supply chain and market for dairy manure compost in California.
3. Present recommendations for how regulators and policymakers can help overcome barriers and promote composting to further environmental goals and policies.

Report Roadmap

- **Section 1** provides an overview of dairy manure management.
- **Section 2** describes the overall regulatory regime governing manure composting in the San Joaquin Valley.
- **Section 3** covers existing research on the environmental impacts of the practice.
- **Section 4** identifies regulatory barriers and challenges.
- **Section 5** gives an overview of supply and market potential.
- **Section 6** discusses the intersections between manure composting and key state policy initiatives.
- The report ends with our **Summary Conclusions and Recommendations**.

SECTION 1: THE ROLE OF COMPOSTING IN DAIRY MANURE MANAGEMENT

Traditional Manure Management

Basics

Manure management is a crucial component of dairy operations. Dairy manure must be carefully managed wherever cows are present on the property, which is mostly in freestall barns and/or corrals, but also in milking parlors, sprinkler pens and other holding areas. Managing this manure is a considerable task given that lactating cows excrete 120 lbs. of wet manure per day (Tyson and Mukhtar, 2015) and that the average dairy in in the San Joaquin Valley milks 800-1200 cows (CDFA, 2016).

Each dairy must develop a manure management system to maintain sanitation, comply with environmental regulations, and put its manure to beneficial use. The primary beneficial use for manure is as a fertilizer for crop production.

The basic components of manure management are collection, storage, processing, application, and distribution:

- *Collection*: The collection process removes manure from barns, corrals, milk parlors and other holding areas. Barn manure is collected using a flush system, a scrape system, or a combination of the two (see Box 1). Flush-based systems are the most common in the San Joaquin Valley.
- *Processing:* Manure is typically processed before it is stored and used. Processing commonly involves some degree of separation of the liquid fraction from the solid fraction. Basic separation methods, such as settling basins or mechanical screens, are by far the most common, but more advanced methods, such as screw presses and centrifuges, also exist.

Box 1: Manure Collection

Scrape systems collect manure mechanically, typically by either using an attachment on a tractor to push manure down the feed lanes or using a vacuum truck to collect the manure. In other scrape systems, the scrape tool is built into the barn and runs using a dedicated motor, rather than being manually driven with a tractor. The manure collected is stored in a pit for a short period before being processed. As water is not added, relatively little liquid manure is generated and the manure is mostly in the solid "slurry" form.

Flush systems rely on water, rather than a mechanical tool, to move manure. Recycled lagoon water, which already contains some manure, is released from one end of the barn. The barns are built at a slight angle, so gravity pushes the water down the lanes, picking up manure as it flows. The manure and water is returned to the lagoon. A significant amount of liquid manure results from a flush system.

- *Storage:* Manure is stored after it has been collected and processed but before application or distribution. The liquid portion is stored in lagoons, while the solid portion is typically stored in slurry pits or static piles.
- *Application:* Both solid and liquid manure are typically applied to fields where cow feed is being grown. Liquid manure is predominantly applied via flood irrigation while solids are spread on the surface and incorporated into the soils. In flush systems, separated solids are commonly used as cow bedding once they have been dried.
- *Export:* Excess manure can be exported off a dairy farm for further processing or use. Since volume and weight drive distribution costs, exports of heavy and bulky solid manure are limited to a short distance; liquid manure is very difficult and costly to export.

Box 2: Manure Waste Streams

Solid manure: Manure that has not had water added to it. It can range from fairly solid to a milkshake-like (slurry) consistency, depending on to what extent the liquid fraction evaporates or is absorbed into soil or ground cover.

Separated solids: Solid material that is separated out of liquid or slurry in a controlled fashion using mechanical or chemical methods and then stored separate from liquids.

Liquids: The remaining liquid fraction after any separation has been completed. The liquids are channeled to a holding pond (lagoon) where they are stored along with wastewater collected from the milking parlor, holding areas, and other sources on the farm.

The manure management system affects the type and proportions of manure waste streams (see Box 2) produced by a dairy, and these waste streams will affect the potential for composting, as described below.

Composting

Aerobic composting is the controlled decomposition of organic materials by microorganisms in the presence of oxygen (Aldrich and Bonhotal, 2006). While organic materials decompose naturally, generating consistent and completely finished compost requires technical understanding and active management of the composting process. Historically, compost has been used by agricultural producers to build soil health and provide plant nutrients. More recently, compost has been used in other ways, such as for erosion control, landscaping, and bioremediation.

Composting Process

The composting process entails combining and aerating one or more types of organic materials (feedstocks) to activate decomposition. During this decomposition process, bacteria, fungi, and actinomycetes consume and metabolize the organic matter in the feedstocks, which releases heat. Temperatures can reach over 150 degrees Fahrenheit, killing pathogens and weed seeds in the mixture. The microorganisms also consume oxygen in the pile. In order for decomposition to continue at the desired rate, air must be reintroduced. Eventually, after the original inputs break down into a homogenous product, the rate of decomposition slows and the unfinished compost is set aside to complete the final, slow stage of decomposition, called “curing.” Afterwards, the finished compost is ready for distribution and use.

During the composting process, various factors influence the rate and completeness with which the organic material is decomposed: carbon to nitrogen ratio, moisture, bulk density, temperature, curing, and time. (See Appendix 2 for more detail). Good compost management can reduce the environmental impacts of the composting process, aid in regulatory compliance, and reduce customer concerns about compost quality.

Composting Methodologies

The three primary methods of composting are:

- **Turned windrows** – A windrow is a long uniform pile of material that is mounded in rows that are roughly 3 to 10 feet tall and parallel to one another. In a turned windrow system, machinery is used to churn the contents of the pile to mix the feedstocks, introduce oxygen, control heat, and reactivate the decomposition process. Turned windrows are typically the cheapest and by far the most common method used by composting facilities in California. Biofilters or synthetic covers can be used to reduce emissions, although this adds complexity and cost.

Turned windrows

- **Aerated static piles** – In this system, feedstocks are piled on top of a perforated pipe in which air is either pumped out or drawn in, thereby creating air circulation in the pile such that it needs little to no mixing after establishment. The structure of these piles must be thoughtfully considered, as air must be able to flow throughout them while the materials decompose. Since there is little to no turning with aerated static piles, biofilters or synthetic covers can be more easily added for reduced emissions. Aerated static piles are typically more capital- and management-intensive than turned windrows and can be cost-prohibitive for smaller operations.

Aerated static piles

Photo courtesy of Kevin Barnes, City of Bakersfield - Solid Waste Division

- **In-vessel composting** – This type of composting occurs within a closed container in which air, moisture and temperature can be closely monitored and controlled. The precision of this method allows for shorter composting durations and greater uniformity of results per batch, but requires more expertise and capital to execute successfully. As a result, this method is generally considered cost-prohibitive under most scenarios and is uncommon in California.

Due to the costs and ease of management, the turned windrow system is the most commonly practiced method and will be the preference for the majority of dairies that might consider composting in the future. This paper uses open turned windrows for its analysis. Covered windrows, aerated static piles, and in-vessel composting methods are not covered in the scope of this study, but these methods will typically – although not always – lead to decreasing environmental impacts and increasing costs.

Composting for Dairy Manure Management

Composting dairy manure provides two major benefits to dairy farmers. It allows producers to 1) use their manure nutrients on more crop types, by converting manure to a product that can be safely applied to acres growing human-consumed crops and 2) export excess manure nutrients off-farm by converting manure into a higher-value and more transportable form. Further, the composting of dairy manure is low-tech and one of the only economically viable options for producers to achieve the above benefits.

The potential and scale of composting on a dairy will depend in part on its underlying manure management system. Dairies in the San Joaquin Valley use flush, scrape/vacuum, or some combination of these manure management systems. These systems typically have three waste streams: solid manure, separated solids, and liquid, as described in Box 2 above. However, the percent of compostable manure that ends up in each of these waste streams varies by manure management system and practices. Since liquid materials are not compostable, the extent of the opportunity for composting on a particular dairy depends on the quantity of solid manure and separated solids produced by that dairy. In the purest scrape systems, only 8-19% of the manure ends up in the liquid stream. In hybrid systems, this can increase to 21-48% while in flush systems the manure ending in the liquid stream can range from 42-100% (UC ANR Committee of Experts, 2006). When manure solids are separated in a flush system, 5% to 65% of the solids are removed (Meyer et al., 2003), depending on the type of separation system used.

Composting is possible on any dairy that collects solid manure or separates solids from liquid waste streams. While a dairy using a flush or a hybrid manure management system will generate less compostable material, there are several ways it can maximize its composting potential. First, if a flush dairy uses straw, rice hulls, wood shavings, or similar fibrous material for cow bedding, these materials can be pulled out of the flush water as separated solids and will be good source of carbon and a bulking agent for the compost. Second, if a flush dairy currently has excess manure nutrients, it could use its liquid stream to fertilize its feed crops and dedicate its solid manure and separated solids primarily to composting. By producing compost, the dairy can spread the nutrients to acreage growing human-consumed crops and can more easily export any excess nutrients off-farm. Finally, if needed, a dairy could invest in more advanced solid separation to increase the amount of material and nutrients available for composting.

Composting may require new equipment and new management practices; however, many dairies already have equipment they can use. A local agronomist shared that roughly 40% of his dairy clients already have windrow turners – a key piece of composting equipment – to help dry their manure for bedding. Dairies that do not already have a windrow turner could use an existing front-end loader, but doing so requires more time and management. Dairies looking to compost more than a minimal amount of manure might consider investing in a windrow turner. Dairies that are already managing manure for bedding typically do not actively manage the temperature, air, and moisture in the piles, as required to produce fully composted manure. They would need to dedicate additional time to properly manage the composting process, but these activities are all well within the means and skillset of dairy producers and their employees.

In summary, composting manure fits well with existing operations, infrastructure, and practices on San Joaquin Valley dairies. The extent to which composting could provide a significant opportunity will vary from dairy to dairy depending on factors such as the existing manure management system, practices, and infrastructure. However, most dairies will find that composting integrates relatively easily into their existing operations. Compared to other alternatives, the practice itself should require no significant changes to existing infrastructure, minimal investment in equipment, limited capacity building, and no significant new skillsets. The major obstacle to composting on dairies is not operational integration but rather the significant challenge of clarifying, understanding, and complying with regulatory requirements related to manure management and compost.

SECTION 2: REGULATIONS AFFECTING MANURE COMPOST

The State of California is engaged in a number of important campaigns to address serious environmental challenges to its climate, soil health, and air and water quality. Dairies are regulated to control pollution from manure by several state and local agencies. In addition to these regulations, which are applicable to all dairies in the San Joaquin Valley, composting facilities face their own set of requirements. As a result, dairy operators interested in composting manure on-farm can face a regulatory "double whammy." The policies and regulations governing manure and waste management will affect a dairy's decision to manage manure through compost.

Water Quality: Central Valley Regional Water Quality Control Board (CVRWQCB) & State Water Resources Control Board (SWRCB)

Dairies can pose a significant impact to groundwater quality, both from the dairy production areas and from the application of manure to field crops. In order to address this impact, the Central Valley Regional Water Quality Control Board (CVRWQCB) issued a Waste Discharge Requirements General Order (Dairy General Order) for dairies in 2007. This Dairy General Order regulates the discharge of wastes from dairy production areas and associated cropland. It also defines thresholds for land application of manure and requires storage capacity for runoff from dairy manure or feed.

The CVRWQCB's Dairy General Order has very extensive requirements, including that dairies submit and comply with a waste management plan and a nutrient management plan. The waste management plan must ensure that manure and feed storage areas are designed and maintained to convey all water that has contacted animal wastes or feed to the wastewater retention ponds, and to minimize standing water and the infiltration of water into the underlying soils in those manure and feed storage areas. The nutrient management plan must ensure that dairies manage their land application of manure so that manure nutrients applied do not exceed the agronomic needs of their crops.

The State Water Resources Control Board recently adopted a Compost General Order. The Compost General Order divides allowable compost feedstocks into two categories: Tier I (agricultural /other plant materials, vegetal food waste, paper, etc.) and Tier II (biosolids, manure, non-vegetal food waste, anaerobic digestate from Tier II materials, etc.). The General Order states that manure and anaerobic digestate from manure may only be composted in a facility meeting Tier II regulatory criteria. Tier II regulatory criteria are stricter than Tier I and include pads and drainage ditches of asphalt, concrete, or soil compacted to the depth of at least one foot; wastewater management plans; and lined ponds. The Compost General Order provides an agricultural exemption for composting performed in an agricultural setting using materials generated on site when the resulting compost is used on site or on another site owned by the owner of the composting facility and applied at an agronomic rate. No more than an incidental amount of up to 1000 cubic yards may be given away or sold annually under the agricultural exemption. Composting facilities with a capacity of less than 5000 cubic yards per year of Tier I or Tier II materials are also exempted from full compliance with the regulations, but must completely cover all materials during rain events and manage the application of process water to prevent production of leachate.

The CVRWQCB will be in charge of implementing the SWRCB Compost General Order provisions in the San Joaquin Valley, and it remains to be seen what effect this may have on current and future dairy composting activities. The CVRWQCB has indicated that a dairy that wishes to begin composting and whose manure storage areas are in compliance with the Dairy General Order requirements will be considered to be in compliance with the Compost General Order. However, this will only be the case until the CVRWQCB revises the Dairy General Order, which it proposes to do in 2017. At that time, it is possible that the CVRWQCB will amend the Dairy General Order to correspond more closely to the requirements of the Compost General Order.

Greenhouse Gases: California Air Resources Board

While dairies are not currently a “capped” and regulated source of GHGs under AB 32, the State’s focus on them as a source of both significant methane emissions and potential reductions has intensified over the last few years. The first two iterations of California Air Resources Board’s (CARB) draft Short-Lived Climate Pollutant (SLCP) Strategy created highly ambitious targets for dairy methane emission reductions by 2030 with very little guidance on how they were to be achieved. This changed with the passage of SB 1383 (Lara) at the end of the 2016 legislative session. While SB 1383 directs CARB to begin a rulemaking process for dairy methane emissions reduction in 2017, the regulations resulting from that process will only take effect in 2024, and then only if specified conditions are met. The dairy manure compost implications of SB 1383 and its implementation process are more fully discussed in Section 6.

Air Quality: San Joaquin Valley Air Pollution Control District (SJVAPCD)

A vast majority of California’s dairy herd is located in the San Joaquin Valley, which has been designated as an extreme non-attainment area for ozone pollution by the US Environmental Protection Agency (US EPA). As a result, all manure management on dairies in the region is subject to strict regulation by the San Joaquin Valley Air Pollution Control District (SJVAPCD) in accordance with the Clean Air Act.

About one third of the dairies in the San Joaquin Valley are considered “grandfathered in” and, therefore, are already permitted by the SJVAPCD to compost to some degree on their the dairy (SJVAPCD, 2016). Beyond this, the SJVAPCD considers any new or expanded composting on a site to be a separate stationary source of VOC and ammonia emissions that requires its own permits. Specifically, the SJVAPCD requires new or expanded composting to meet the requirements of its Rule 2201 (new and modified stationary source review), including implementation of Best Available Control Technologies (BACT) for VOC and ammonia emissions. Facilities engaged in the management (including composting) of biosolids, animal manure, and poultry litter operations are regulated under Rule 4565. SJVAPCD considers the composting regulations in Rule 4565 to be the minimum thresholds for BACT for dairy composting. If there are methods that could achieve better emission reductions than those proposed by the applicant that either have been "achieved in practice" or are technically feasible, the SJVAPCD will require these under Rule 2201, and not the minimums laid out in Rule 4565. If the site is expected to emit more than 20,000 lbs. of VOCs per year after BACT is implemented, the facility will be required to purchase VOC offsets in order to mitigate the impact of their emissions. In order for a dairy to understand how many pounds of VOCs will be emitted and what BACT would be required, it needs to apply for a permit and trigger the Rule 2201 review process.

Waste Management: CalRecycle

CalRecycle regulates composting facilities based on the type and volume of materials on-site at any one time. Composting facilities are divided into three tiers for purposes of regulation. The first tier is an agricultural exemption. An agricultural operation (such as a dairy) engaging in composting is exempt from CalRecycle regulation if it composts "agricultural material" derived entirely from the agricultural site and uses a similar amount of compost on the same site or another site owned or leased by the composter. "Agricultural material" refers to material of plant or animal origin, including manure, resulting from agricultural activity. No more than 1000 cubic yards (CY) of compost produced on site may be given away or sold annually. If the agricultural operation wishes to give away or sell more than 1000 cubic yards of compost or wishes to import non-agricultural material for co-composting, the operation would move to the second tier – the notification tier.

The notification tier has two categories of operations relevant to manure composting, both of which must comply with the Enforcement Agency (EA) notification requirements in the CA Code of Regulations (14 C.C.R. § 18100 et seq.). The first category is for agricultural material composting operations, and includes two sub-categories. The first agricultural material sub-category applies to operations composting only agricultural material. These operations are not limited in terms of amount of feedstock they may have on-site at any one time, and they may sell or give away their compost in unlimited amounts. They must be inspected by the local Enforcement Agency (LEA) at least once a year (see Box 3). The second agricultural material sub-category includes operations that compost both

Box 3: Local Enforcement Agencies (LEAs)

LEAs are designated by the governing body of a county or city and, upon certification by CalRecycle, are empowered to implement delegated CalRecycle programs and locally designated activities. LEAs have the primary responsibility for ensuring the correct operation of solid waste facilities (including composting facilities) in the state. LEAs determine which tier a facility falls into and conducts inspections to ensure facility compliance with the requirements of that tier.

agricultural material and “green material” and that have no more than 12,500 CY of green material onsite at any one time. If such an operation sells or gives away more than 1,000 CY of compost per year, it is to be inspected by the LEA once every three months. The second notification tier category is for green material composting “operations” and includes sites that have no more than 12,500 cubic yards of feedstock, compost, or chipped and ground material on site at any given time. Green material composting operations may also handle agricultural material, including manure. The site must comply with the LEA notification requirements and be inspected at least once every three months, unless lesser inspection frequency is approved by the LEA. Compost produced by green material composting operations may be sold or given away in unrestricted quantities.

The third tier includes all commercial compost facilities that handle materials other than green material, and green material composting facilities handling over 12,500 cubic yards of feedstock, compost, or chipped and ground material onsite at any one time. These facilities must obtain a Full Solid Waste Facility Permit from CalRecycle.

Conclusion

Dairies planning to add composting to their current manure management system must contend with several agencies and rules, adding costs and complexity to their operations. While regulators in the state have applied firm standards to the control of pollution from dairies and compost, the regulatory community lacks a common understanding of the net impacts of manure compost across environmental media as compared to uncomposted solid manure, and some key questions remain unanswered. A coordinated and holistic approach among the regulators would help secure the best environmental outcomes from the dairy industry. The following section will review current science on this topic.

SECTION 3: ENVIRONMENTAL IMPACTS OF MANURE COMPOST

Manure management is characterized by complex interactions between a multitude of environmental variables and potential practices. As a result, a practice that limits the emission of a certain compound may bolster the release of another (Amon et al., 2001). Similarly, a practice that reduces emissions of a particular compound in the production/storage phase could increase emissions in the land application phase, and vice versa. Unfortunately, most research has focused on a subset of environmental impacts and/or phases and, therefore, gives an incomplete picture. The environmental analysis in this report attempts to break down those siloes to give a more comprehensive understanding of the impacts of composting manure.

Research Methodology

Scope of Analysis

Manure management is notorious for pollution swapping, where a practice implemented to reduce one environmental impact typically increases another impact. Therefore, this report assesses the environmental impacts across multiple air quality, water quality, greenhouse gases, and soil health indicators. Assessing only one of these areas or a subset of these areas, as is commonly done, does not help us understand how we can move towards more sustainable dairy manure management.

Additionally, any two practices can have very different impacts at different phases in the manure management process. Therefore, this report considers the environmental impacts across two phases: 1) in storage and/or production and 2) in application on fields. Determining the value and risks of manure composting requires a clear comparison of the impacts across both of these phases, e.g. impacts of processing and land application of compost relative to storage and land application of solid manure. We hope that subsequent studies will also take this multi-phase approach to study impacts.

Finally, as discussed in the Introduction section, there are many possible scenarios for generating compost on dairies. This report limits its scope to comparing the most common method for composting (open turned windrows) to the most common management practice for solid manure (storage in static piles and subsequent application to cropland). We believe these baselines give the most direct comparison of impacts. However, we recognize this comparison does not reflect the full range of options for converting to manure composting and their respective impacts. We encourage subsequent studies to assess these alternatives.

In summary, the scope for the environmental analysis in this section includes the following:

1. Multiple air quality, water quality, greenhouse gas, and soil health impacts
2. The manure storage/compost production phase and the land application phase

3. Comparison of the most common practices for managing compost and solid manure: composting in open turned windrows to manure storage in static piles

Research Approach and Data limitations

Where possible, our analysis uses California-based research on manure storage and manure composting. Locally based research is important because California has distinct manure management practices and climate compared to other large dairy regions, and these two factors significantly influence the type and degree of environmental impacts. Unfortunately, we found very little directly relevant California-based research. The majority of the California-based research has been focused on either (1) the composting of green waste or (2) the impacts related to dairy manure storage rather than manure composting. Studies on composting of dairy manure were largely sourced from out of the state, or from other parts of the world. Even less information was available on (1) the impacts from land applications of manures and manure-based composts, (2) impacts including both storage/processing and land application phases, and (3) comparison of impacts of manure composting to solid manure storage. Given the large potential for dairies to contribute to the State's environmental goals, there is a critical need to ensure that we have adequate California-specific research on the environmental impacts of composting dairy manure to ensure our policies and regulations are truly driving toward better environmental outcomes.

Water Quality

Water Quality Context

Groundwater quality degradation is a significant concern in California's San Joaquin Valley, where municipalities, rural populations, agriculture, and wildlife vie for limited fresh water, and where many rely on groundwater to augment surface water supplies, particularly in times of drought. Many areas in the San Joaquin Valley suffer from poor groundwater quality stemming from a variety of sources, both natural and manmade. Poor management of dairy manure can contribute to additional groundwater degradation, particularly in areas with high concentrations of cows (van der Schans et al., 2009). Some dairies have been found to contribute to high groundwater levels of nitrates, salts and pathogens (UC ANR Committee of Experts, 2006; Li et al., 2013; Harter et al., 2013), primarily as a result of over-application of manure to cropland due to limited ability to accurately measure and apply manure nutrients. Preliminary results from the representative monitoring program suggest, but do not prove, that up to 96.5% of nitrogen loading may be from cropland (CVDRMP, 2016). Composting manure is currently one of the only readily available, economically viable options to export manure that dairy producers might otherwise over-apply to their fields.

Production & Storage Impacts on Water Quality

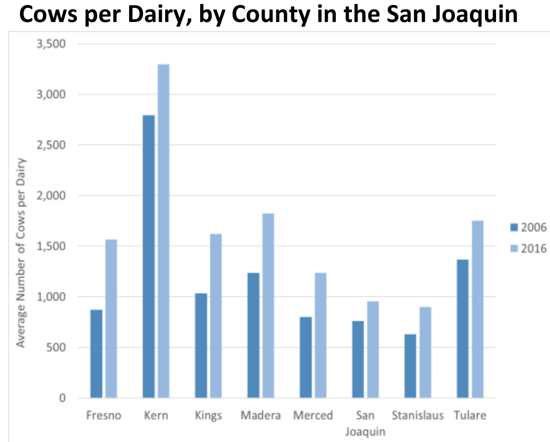
Studies suggest that the active pile management of composting reduces the risk of leachate as compared to storage of manure in static piles. A literature review suggested that turning homogenizes moisture, spreading moisture around instead of allowing it to leave the pile as leachate (Pardo et al., 2015). One of the studies found that a static pile had greater nitrogen losses through leachate in the summer compared to a turned pile (260.1g versus 141.5g per ton of fresh manure, static and turned, respectively) (Amon et al., 2001). The winter trial showed similar losses between both treatments (181.9g versus 200.1g per ton of fresh manure, static and turned, respectively) (Amon et al., 2001). In this study, the authors noted that snow landed on the manure and melted. It is possible that the additional water from the snow eliminated the uniform moisture in the turned pile, leading to greater runoff. It seems that composting reduces the risk of leachate and that compost piles are just as susceptible as static piles to leachate caused by precipitation. Therefore, measures that are already required to mitigate runoff and leaching from static manure piles should be more than sufficient for composting piles.

Land Application Impacts on Water Quality

When comparing application of uncomposted solid manure and composted manure to cropland, manure compost application reduces risk of water quality degradation. Particularly in the San Joaquin Valley, manure compost can benefit water quality by reducing the potential for nitrogen present in manure to enter into surface or groundwater. Studies show that the composting process stabilizes the nitrogen in the dairy manure by tying it up in organic forms and slowly releases it (CBF, 2004). For that reason, composting is recognized as a Best Management Practice by the EPA's Non-Point Source Program (US EPA, 2003). A study by the Rodale Institute (2004) compared nitrogen losses from applications of compost, uncomposted manure, and conventional fertilizer and found that about 4 percent of the nitrogen applied as compost was lost, while about 9 percent was lost through the other two sources (Michalak, 2004).

In addition, proper composting of manure produces sufficient heat to kill off pathogens. This is consistent with CalRecycle's rule (14 CCR § 17868.3) that compost must achieve minimum temperature requirements to treat fecal coliform and Salmonella. Proper composting makes manure safer for use with food crops by killing pathogens in addition to protecting drinking water sources by reducing the risk of nitrate leaching.

Figure 1 - Ten Year Change in Concentration of Cows per Dairy, by County in the San Joaquin



Data Source: CDFA's Dairy Statistics

A primary benefit of composting manure is that it transforms manure into a product that can be applied to more crop types and can be more easily handled and transported greater distances. This is particularly relevant to land-constrained dairies, where manure is highly concentrated. This scenario is increasingly common due to the consolidation of California's dairy industry over the past decade and the resulting higher concentrations of cows per dairy (see Figure 1). Additionally, dairy producers are taking some of their acres out of feed production to grow permanent crops. This reduces the amount of crop acreage that can receive uncomposted manure. Because of its volume and weight, uncomposted manure is transported only very short distances, and almost always within the county of origin, due to transportation costs (Harter et al., 2013). This fact was confirmed by our interviews with manure haulers who have started composting. These third party operators consistently say they only collect uncomposted manure from a radius of about 10 miles. Once they have composted the manure, it is much lighter and less voluminous and can be transported greater distances. A composter in the Tulare Lake Basin shared that he routinely delivers finished compost over distances of 30-50 miles**.** In summary, composting manure enables better protection of water quality by enabling manure nutrients to be spread out and used beneficially by plants over a larger land base. First, farmers can apply manure compost to more crop types and with fewer restrictions as compared to uncomposted manure. Second, the lighter compost can be transported farther away, alleviating highly concentrated applications of manure nutrients.

Water Quality Conclusions

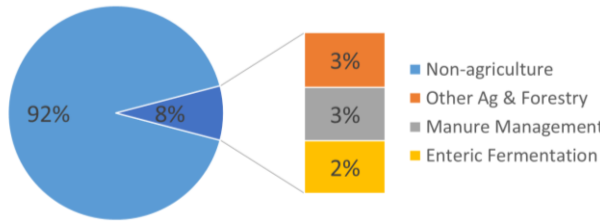
Composting dairy manure provides a significant opportunity to improve dairy-related water quality impacts. Studies show that active management of moisture and piles – as needed for composting – reduces the risk of leachate as compared to static piles. There are also multiple water quality benefits of compost related to land application. First, the nitrogen in finished compost are much more stable, so they are less likely to leave the soil and enter surface and groundwater as compared to applying uncomposted manure. Additionally, the pathogen kill achieved through the composting process enables the manure nutrients to be used in growing human consumed crops. As a result, the nutrients can be utilized by more crops on more acreage. Finally, and importantly, composting manure enables easier transport – again enabling the nutrients to be spread further distances. In summary, proper composting reduces pile leachate and enables manure nutrients to be put to beneficial use on more acreage and across greater distances, thus reducing risk of degradation of groundwater quality due to nitrate leaching in areas of high concentrations of dairies. Composting also gives dairy producers who have excess nutrients an economically viable option to get to nutrient balance, as required by the CVRWQCB Dairy General Order.

Greenhouse Gases (GHGs)

Greenhouse Gas Context

Greenhouse gas (GHG) emissions lead to climate change, broadly affecting global weather patterns and natural cycles. Scientific consensus is that the concentration of CO_2-equivalent (CO_2eq) in the Earth's atmosphere must remain below 350 parts per million (ppm) in order to avoid some of the most severe impacts of climate change (Hansen et al., 2008). However, CO_2eq GHG levels have reached over 400 ppm and continue to climb.

Figure 2: Agriculture and Dairy's Contribution to California's Overall GHG Emissions (CO2eq)

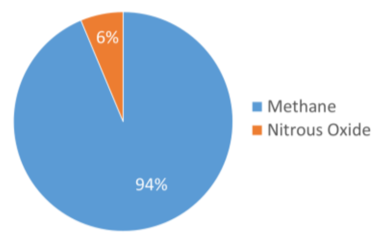


Data Source: CARB's Emissions Inventory

Agriculture is the source of 8% of California's GHG emissions (CARB, 2014). California dairies produce roughly half of this – almost 16 million metric tons of CO_2eq emissions per year or about 3.4% of the statewide GHG total (Lee and Sumner, 2014), as seen in Figure 2. Half of dairy CO_2eq GHGs in California are emitted during the stages of manure management (CARB, 2014). Curbing GHG emissions from dairy manure management can play an important role in reducing not only dairy GHG emissions but also California's total agricultural GHG emissions.

The primary GHGs from dairy operations are methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O).

Figure 3: Non-Biogenic GHG Contributions to Total Livestock GHGs, in CO2eq



Data Source: CARB's Emissions Inventory

Methane (CH_4) is a potent GHG that is roughly 25 times stronger than carbon dioxide (IPCC, 2007a). Methane is also a short lived climate pollutant (SLCP), meaning that it persists in the atmosphere for a much shorter time relative to other greenhouse gases (12 years for CH_4, about 100 years for carbon dioxide[1]) (CARB, 2016). This short atmospheric duration increases methane's importance in efforts to curtail short-term climate change impacts.[2] Dairies are the single largest contributor to California's man-made methane production - approximately 45% of the total (CARB, 2016). About half of California's dairy methane emissions come from manure management and storage. Methane is generated by microbes in environments without oxygen (anaerobic), such as in a wastewater lagoon or, to a lesser degree, in a static pile of manure (CARB, 2016). When biogenic CO_2 emissions are factored out, methane represents 94% of all livestock CO_2eq GHG emissions (see Figure 3).

Carbon dioxide (CO_2) represents over 80% of all CO_2 eq. GHGs emitted by human activity in the United States (US EPA, 2017a). CO_2 also accounts for a significant percentage of total GHG emissions arising from dairy manure management and composting systems. Since CO_2 emissions from manure are biogenic (see Box 4), this

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[1] As noted in other reports, carbon dioxide has a variable atmospheric lifespan that cannot be readily described by a single number (CARB, 2016).

[2] In comparison, the effects of CO_2 emission reductions will take decades or more to take effect (CARB, 2016).

study does not include CO_2 emissions from manure and composting in its analysis of GHG impacts. It is important to note that composting would almost certainly result in limited non-biogenic CO_2 emissions due to increased use of equipment. This study does not attempt to measure those emissions.

Box 4: Biogenic CO_2 Emissions

Evaluating CO_2 emissions from dairies is complicated by the fact that CO_2 from manure is created by biogenic decomposition of organic matter and is thus usually left out of GHG emission studies and accounting protocols (e.g. IPCC). These emissions are argued to be part of the natural carbon cycle, as they would be released regardless of the practice.

Nitrous oxide (N_2O) is an extremely potent greenhouse gas (GHG) that has almost 300 times greater warming potential than CO_2 (IPCC, 2007b). N_2O contributes about one third of the total GHG emissions from California's agriculture sector (Burger et al., 2013), most of which are generated by the application of fertilizers, including those derived from manure (IPCC, 2007a; Davidson, 2009). However, N_2O emissions are often highly variable across operations, seasons, and geographies. N_2O production from dairy manure depends on the materials within the manure, the bacteria community that is present, and environmental conditions, such as temperature and moisture (Mitloehner et al., 2009). Studies suggest that N_2O represents a small percent of total GHG emissions from manure management, relative to CH_4 and CO_2.

Production & Storage Impacts on Greenhouse Gases

Methane (CH_4) is produced by organisms that survive only in anaerobic (oxygen-free) conditions, like those found in lagoons and static piles of manure. Thus, in any manure management system, maximizing methane emissions reductions means minimizing anaerobic conditions. Studies have found that aerobic composting of dairy manure decreases CH_4 emissions relative to storing dairy manure solids in anaerobic static piles. For composting operations, several studies have reported that aeration reduces CH_4 emissions from dairy manure (Lopez-Real and Baptista, 1996; Ahn et al., 2011) and swine manure (Paul et al., 2001; Fukumoto et al., 2003). A meta-analysis of several feedstocks – including dairy waste – found that turned composting systems reduced methane emissions by a mean of 71% compared to static piles (Pardo et al., 2015). In the analysis, turning compost always reduced CH_4 emissions compared to static piles. Forced aeration composting reduced methane in most cases; for the exceptions, the authors suggested the static nature of the compost in aerated static piles allowed anaerobic pockets to form, limiting CH_4 emission mitigation. Active management of piles that ensures aerobic conditions is critical to reducing methane emissions.

Nitrous Oxide (N_2O) emissions are influenced by a wide range of variables (materials within the manure, the bacterial community present, and environmental conditions) and the complex interactions between these variables. Therefore, it is challenging to assess the effect of composting relative to storage in static piles. The conflicting results in available research reflects this complexity. For example, Amon et al, 2001 found that composting decreased N_2O emissions from dairy manure while Ahn et al, 2011 found that composting increased N_2O emissions from dairy manure. Studies suggesting increased N_2O emissions from composting are buttressed by the 2006 IPPC Guidelines for National Greenhouse Gas Inventories, which accounts for double the N_2O emitted from compost piles than from solid manure storage systems. However, a more recent meta-analysis questions the higher N_2O emissions in the IPCC's estimates for compost compared to static piles, given the lack of statistical significance in the limited number of studies available (Pardo et al., 2015).

Land Application Impacts on Greenhouse Gases

We found insufficient data comparing the CH_4 emissions from land applying composted and uncomposted manure. The research we did find showed little or no CH_4 emissions after applying compost (Lessard et al., 1997). Presumably, the CH_4 emissions during and after land application would be relatively low, since manure and compost are spread out when applied, adding oxygen.

Similar to the emissions during production and shortage, N_2O emissions after land application of manures and composts are mixed. Generally, applications of high nitrogen inputs significantly increase N_2O emissions (Eichner, 1990; Bouwman et al., 2002). Application of organic amendments like compost have been suggested as a method to reduce soil N_2O emissions in soils with high N_2O emissions, because compost reduced the nitrous oxide derived from soil nitrogen (Zhu-Barker et al., 2015); however, that has not been explored in depth. There are a variety of factors – moisture, temperature, and microbial activity, among others – that affect the production and release of nitrous oxide emissions in soil. Therefore, it is difficult to make generalizations about composted manure applications versus manure. A relationship between composting and changes to nitrous oxide emissions may exist, but available data suggests other variables overshadow it. Overall, existing information suggests that compost has a minimal effect on N_20 emissions and that N_20 emissions are a small portion of CO_2eq GHG emissions from manure.

Greenhouse Gas Conclusion

The GHG benefit of compost is clear: composted manure significantly reduces methane emissions, and methane is by far the greatest source of non-biogenic GHGs from dairy manure. While switching to compost could slightly increase CO_2 emissions related to equipment use and potentially N_2O emissions, the significant methane emission reductions would more than offset these potential increases. California dairies in particular have significant methane emissions from manure management due to the prevalence of flush systems and storing significant portions of the manure in anaerobic lagoons. However, as stated earlier, this report compares emissions of composting to the alternative of storing manure in static piles and not storage in anaerobic lagoons. Combining composting with manure management practices that reduce the amount of manure solids stored in anaerobic lagoons – such as switching to drier systems or using advanced solid separation – would almost certainly result in additional GHG emission reductions. However, the magnitude of these additional GHG reductions would depend on how these solids are removed and subsequently managed.

There are significant data limitations and a variety of accounting methods that would change the order of magnitude of the GHG benefits of composting, but it is clear that composting is the best manure management option from a climate perspective. It would be worthwhile to conduct California-based studies to quantify the magnitude of methane reduction from different composting scenarios on dairies to inform better policy and regulatory approaches to reduce dairy GHG emissions.

Air Quality

Air Quality Context

Air pollutants can create impacts to human health and the environment. Six air pollutants have been designated as criteria pollutants because they are commonly found and negatively affect human health at an acute, local level. The Clean Air Act requires the US EPA to set National Ambient Air Quality Standards for criteria pollutants. Some criteria pollutants are emitted directly and some are created through atmospheric reactions of other emissions – called "precursors." Though the sources and precursors of each criteria pollutant differ geographically, all criteria pollutants are harmful to human health. Dairy manure can contribute to the criteria pollutants of ground-level ozone and particulate matter through emissions of the precursors ammonia and volatile organic compounds (VOCs).

> **Ammonia (NH_3)**, in its gaseous form, is a significant air pollutant that can also pollute water and soil. In the atmosphere, ammonia can form ammonium sulfate and ammonium nitrate aerosols. Both of these aerosols increase concentrations of fine particulate matter, PM2.5, that lead to smog and impact respiratory health (SJVAPCD, 2015b). The aerosols can also harm ecosystem health through soil acidification and water eutrophication. Though measurements vary, dairies have been cited as being responsible for over 26% of NH_3 emissions statewide (Benjamin, 2000). Manure storage and application typically represent the majority of dairy NH_3 emissions (Pinder et al., 2004), although the percent of emissions at any given location on a dairy will vary based on manure management practices and environmental factors – such as temperature and pH.
>
> **Volatile Organic Compounds (VOCs)** are organic compounds that have a low boiling point, so they are released into the atmosphere under typical indoor and outdoor temperatures. VOCs can react with nitrogen oxides (NOx) and sunlight, producing ground-level ozone. VOCs are not a singular emission – the term encompasses a wide variety of molecules that are both human-made and naturally occurring, and the degree to which they react to form ground-level ozone varies greatly. High concentrations of ground-level ozone in the San Joaquin Valley contribute to the region's air quality and asthma rates being among the worst in the country (SJVAPCD, 2013). As reported by the SJVAPCD, "dairies are among the largest [anthropogenic] sources of VOCs in the Valley, and these smog-forming VOC emissions can have an adverse impact on efforts to achieve attainment with health-based air quality standards" (SJVAPCD, 2012a).

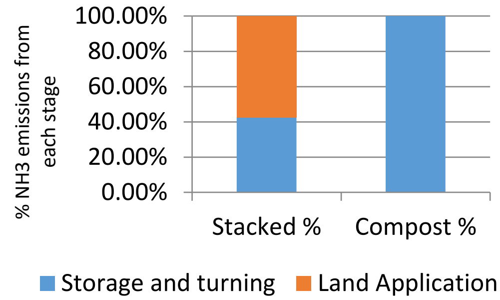
However, research has found that the majority of dairy VOCs come from dairy silage, not manure (Hu et al., 2012; Hafner et al., 2013).

Production & Storage Impacts on Air Quality

Meta-analysis of available research showed that the process of composting manure results in more NH_3 emissions than storing the manure in a static pile (Pardo et al., 2015). The majority of the information about NH_3 emissions found for the present report was drawn from that meta-analysis. One study in that meta-analysis showed that static piles released a median of 9% of the initial total nitrogen as NH_3 during storage while a composting system released a median of 39% (Hou et al., 2015).

This study and others also found that composted manure only releases NH_3 during the storage/turning stage, while manure stored in static piles releases NH_3 throughout storage and land application stages. As an example, one study found that 42.5% of all NH_3 emissions from uncomposted manure were released during storage and 57.5% was released during land application, while 100% of total emissions from composted manure were released during storage/turning (Amon et al., 2001) (see Figure 4). These results are consistent with prior work (Menzi et al., 1997).

Figure 4: Ammonia Emissions, Static Piles and Compost



Data source: Amon et al., 2001

Due to the lack of studies found on VOC emissions from dairy manure compost, the present report drew on green waste compost research, as the composting process of each may have similarities. One study on green waste found that composting "resulted in substantially lower [VOC] emissions than the emissions that occur from natural biodegradation of the same type of materials" (Büyüksönmez and Evans, 2007). However, there is not a similar study comparing manure composting compared to static piles, and we cannot be sure that the same would necessarily hold true. Research is needed to compare VOC emissions from manure static piles to emissions from manure compost piles.

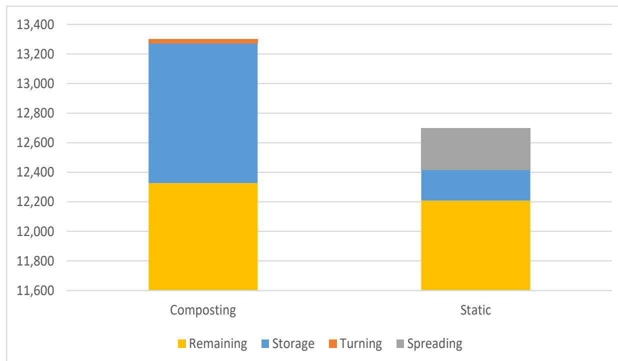
An additional consideration is the extent to which the VOCs that are emitted subsequently react to form ozone. According to one study, up to 80% of the VOCs emitted by green waste composting are of the low reactivity type (Green et al., 2011). Also, the VOCs emitted during green waste composting are already in the feedstocks; that is, the composting process does not seem to create new VOCs or change existing VOCs (Büyüksönmez, 2009). If the same holds true for manure composting, then composting manure would only release the VOCs that fresh manure already contains. A study of cows in a California dairy found that VOCs from fresh manure are of the low reactivity type (Howard et al., 2008). Research on VOC emissions from manure-based compost needs to be conducted, but it is possible that composting manure will only release existing, low reactive VOCs. In that case, composting manure should not increase ozone-forming potential compared to static piles.

CARB states that manure-based composting produces less VOCs and ammonia than biogenic decomposition of manure (CARB, undated; San Joaquin Valley Dairy Manure Technology Feasibility Assessment Panel, 2005), similar to the green waste composting study cited above. However, neither of these documents cites the original research, so we are unable to incorporate these findings into our assessment of existing research on VOCs.

Land Application Impacts on Air Quality

As discussed above, studies show that manure compost does emit more NH_3 than static piles, but 100% of compost emissions occur *before* land application. Manure that is stored in static manure piles continues releasing ammonia during and after land application (see Figure 5).

Figure 5: Ammonia Emissions by Phase



Data source: Amon et al., 2001

This finding is important for mitigating NH_3 emissions. While manure compost may have more NH_3 emissions overall, the fact that these all occur in the production phase means that it will be easier to control NH_3 emissions as compared to static piles. Static piles would require mitigation measures at both the storage phase and the land application phase, and controlling emissions from land application is extremely difficult.

No research was found on the VOCs from the land application of composted solid manure or manure composts.

Air Quality Conclusions

Composting does appear to increase air pollutants compared to manure in static piles, although the magnitude of the increase as well as the resulting impact on air quality and human health are unclear. Ammonia emissions appear to increase with composting, but there is not sufficient research to draw firm conclusions on VOC emissions.

The combined ammonia emissions from storage and spreading of composted manure are higher than static pile manure (see Figure 5 above). However, all of the compost ammonia emissions occur in the processing/turning phase, where they are much easier to control as compared to the land application phase. Researchers have noted that emissions from composting could be reduced through good compost management by: (1) keeping the temperatures in the mesophilic range (Pardo et al., 2015), and (2) adding feedstocks that result in a wider C:N ratio (Amon et al., 2001). Additionally, gaseous ammonia emissions represent the loss of valuable nutrients from dairy manure and compost, which producers certainly do not want. Therefore, mitigating ammonia emissions from dairy manure is desirable from multiple perspectives, and it is easier to accomplish with composting than with uncomposted manure.

Furthermore, it is still unclear what effect reducing ammonia emissions will have on PM 2.5 creation. SJVAPCD cites research specific to the San Joaquin Valley that concludes that ammonia concentrations in the valley are extremely high (SJVAPCD, 2015a), but models created by CARB and supported by the SJVAPCD's monitoring network suggest that significant reductions in ammonia would have limited impact on PM2.5 and smog. For example, the model predicts that even a 50% reduction in ammonia only reduces ammonium nitrate, a PM2.5 pollutant, by 5%. However, a number of researchers think that reducing ammonia in the San Joaquin Valley would have a greater positive impact (SJVAPCD, 2015a).

Research found for the present report was insufficient to draw firm conclusions about VOCs from manure compost. SJVAPCD itself states that there is insufficient data on VOC emissions from dairy manure composting to make a ruling about its contributions to regional VOC loads (SJVAPCD, 2012a). Based on findings from research on green waste composting, we suspect that manure composting produces a similar or lesser amount of VOC emissions than uncomposted manure. Furthermore, research suggests that VOCs from manure are low reactive and thus less likely to react to form ground-level ozone as higher-reactive VOCs, and we expect that VOCs from composted manure would be similar. However, California-based research on VOCs from dairy manure compared to dairy manure compost is needed to understand the true impacts and inform science-based regulations.

Soil Health

Soil Health Context

Soil is a medium through which water, energy, and nutrients flow. It is both foundational to terrestrial systems and essential to agricultural production. Farmers actively manage and invest in their soil via tillage, irrigation, and amendments to optimize crop performance. Intensive agricultural practices, however, have resulted in soil loss at a rate higher than natural soil formation (Montgomery, 2007; Amundson et al., 2015). Agricultural production can also deplete the soil of valuable nutrients and soil organic matter.

There is a need to add organic matter, such as manure or compost, to maintain and/or rebuild healthy soils in all types of agriculture, though these practices are typically associated with organic production.

Land Application Impacts on Soil Health

The addition of organic matter – whether as compost or manure – has been shown to improve soil quality and health. Animal manure was used for thousands of years as a soil amendment to maintain soil fertility (Brady, 1990) before being largely replaced by synthetic fertilizers. While synthetic fertilizers have been effective at delivering nutrients to plants, they have not maintained the health of the soil in which these plants grow. Synthetic fertilizers do not provide broader benefits that compost and manures do, such as the following:

- Increased soil retention of water, thus reducing crop demand for additional irrigation (Celik et al., 2004; Brown and Cotton, 2011).
- Decreased soil bulk density, thus reducing compaction, supporting root growth, and enabling better air and water flow (Celik et al., 2004; Meng et al., 2005; Johnson et al., 2006; Brown and Cotton, 2011).
- Increased soil organic matter, thus improving soil structure, water storage capacity, fertility, biological activity, and buffer against toxins (Min et al., 2003; Celik et al., 2004; Christopher and Lal, 2007; Brown and Cotton, 2011).
- Carbon sequestration from the atmosphere due to building of soil carbon content (Christopher and Lal, 2007; DeLonge and Silver, 2013; Ryals et al., 2014). (See Box 5).

Box 5: Soils and Carbon Sequestration

As soils are degraded and lost, they release greenhouse gases to the atmosphere (Lal 2010). This is significant as the top meter of the world's soils store more than three times the amount of carbon held in the atmosphere (Batjes, 1996; Lal, 2010). In fact, in the United States agricultural soil management contributes about 4 times more GHG emissions than manure management (US EPA, 2017b).

California agriculture contributes to the state's GHG emissions, but it also been identified as one potential solution to the problem (Suddick et al., 2010). Soils can sequester significant amounts of carbon, especially when organic sources of carbon such as manure are added (De Gryze et al., 2009). Research has also shown that the addition of relatively small amounts of compost can have a significant effect on soil's ability to sequester carbon. Agriculture can help reduce greenhouse gases both by reducing emissions as well as by canceling out emissions from other sources.

In addition to the benefits they share, compost has many practical benefits over uncomposted or semi-composted manure. For instance, compost piles reach temperatures that kill weed seeds and pathogens, including *E. Coli*, *Salmonella*, and *Listeria* (Pell, 1997; Rosen and Bierman, 2005; Entry et al., 2005). For farmers, compost reduces the risk of introducing new pathogens and weeds to their fields when applying manure-based amendments.

It should be noted that manure compost contains less inorganic (e.g. "plant available") nitrogen than uncomposted manure and, as a result, is considered to have less agronomic value (Cambardella et al., 2003). In other words, uncomposted manure allows for more short-term nitrogen uptake by plants as compared to composted manure. However, the greater proportion of organic nitrogen in composted manure allows for longer-term nitrogen availability and reduced risk of runoff or leaching.

Soil Health Conclusions

Both composted and uncomposted dairy manure offer soil quality benefits to agricultural lands. Research is clear that using compost and manure as soil amendments benefits soil quality in numerous ways. Among a long list of positive attributes, it can increase soil water holding capacity, enhance soil structure, add nutrients, protect plants from pests and disease, and enhance soil carbon sequestration. However, manure compost has some benefits over uncomposted manure, including fewer food safety concerns and fewer water quality risks. Manure compost has comparatively less immediate agronomic benefit since it contains lower amounts of inorganic nitrogen, but the stability of the organic nitrogen decreases risk of nitrogen runoff and leaching and leaves nitrogen in the soil for later use by plants.

Analysis of Cross-Media Environmental Impacts

In evaluating the potential for dairy manure compost, it is critical to take a holistic approach to ensure the environmental analysis is an accurate reflection of net environmental impacts. For this study, we conducted our research and analysis across several levels:

- Multiple impacts within water, air, GHG, and soil health;
- Impacts at the storage/processing phase and at the land application phase; and
- Impacts of composting manure compared to existing practice of solid manure storage.

This type of comprehensive analysis is particularly important with manure management as there is no perfect solution from an environmental standpoint – there will always be some amount of pollution generated, so the multiple environmental impacts must be assessed.

While more robust, relevant research is needed, available research suggests that dairy manure composting can reduce water quality impacts, improve soils, and reduce GHG emissions from dairies with comparatively minimal impacts to local air quality. These findings are significant given that nitrate leaching to groundwater and methane emissions are by far the two greatest impacts of dairy manure management in the San Joaquin Valley. Our cross-media environmental impacts findings are summarized in Table 2 below.

Table 2 - Summary of Cross-Media Environmental Impacts of Composting Dairy Manure

Pollutant		Storage & Production Impacts	Surface Application Impacts	Conclusion
Water Quality	Nitrates	Composting's active pile management reduces the risk of leachate as compared to storage of manure in static piles.	Compost reduces nitrate leaching risk in soils by stabilizing nitrogen and releasing it slowly over time. Compost can be distributed over larger distances and on more crops, helping solve significant challenge of over-application in concentrated areas.	Composting is a clear solution to reducing dairy water quality impacts. It decreases leaching risk during both storage and land application as compared to uncomposted manure. It also provides solution for over-application of manure, which is responsible for 95%+ of nitrate leaching from dairies.
	Salts	Composting's active pile management reduces the risk of leachate as compared to storage of manure in static piles.	Compost can be distributed over larger distances and on more crops, helping solve significant challenge of over-application in concentrated areas.	
	Pathogens	Composting kills pathogens found in manure.	Composting kills pathogens found in manure.	
Greenhouse gasses	Methane (CH_4)	Composting significantly reduces CH_4 emissions relative to static manure piles by promoting aerobic conditions.	Unclear, but likely similar and minimal for both compost and uncomposted solid manure.	Compost produces a net GHG benefit. Significant methane reductions more than compensate for potential slight increases in CO_2 from equipment and N_2O.
	Carbon Dioxide (CO_2)	CO_2 emissions from manure are biogenic, so are not included. CO_2 emissions from equipment are not included in this report but are likely slightly higher for composting due to pile turning.	CO_2 emissions from manure are biogenic, so are not included. CO_2 emissions from equipment are not included in this report but are likely slightly lower for compost application since it is lighter and less voluminous.	
	Nitrous Oxide (N_2O)	Unclear. N_2O emissions are highly variable based on a variety of conditions unrelated to composting.		
Air Quality	Ammonia (NH_3)	Significantly greater NH_3 emissions from composting compared to static manure piles. However, 100% of NH_3 compost emissions occur in this phase, where mitigation is easier. Unclear contribution of NH_3 to PM2.5	Fully composted manure does not release NH_3 emissions when land applied, while NH_3 emissions from uncomposted manure can be significant. Mitigation of emissions from land application is very difficult.	Compost produces a net increase in air quality impacts, although the magnitude is unclear. Emissions of NH_3 from manure compost are greater than uncomposted manure, but they are easier to mitigate because they do not occur during land application. More research is needed to determine VOC impact.
	Volatile Organic Compounds (VOCs)	**Research needed**. Unclear. Existing research suggests there may be decreased VOC emissions from compost compared to static piles, but this needs to be verified. VOCs from manure and manure compost appear to be low-level contributors to ground-level ozone, but this needs to be verified.		
Soil Health		N/A	Manure and compost share many benefits for improving soil health, but compost enables soil health benefits to be achieved on significantly more acreage since it is easier to transport and the composting process kills pathogens and weed seeds.	

Key			
Positive Impact (Benefit)	Neutral or Little Impact	Negative Impact	Unclear or N/A

We have limited the scope of this report to examining the environmental impacts and benefits of compost compared to the most directly comparable alternative: storing and field-applying uncomposted solid manure. As discussed in Section 1, manure management systems can incorporate compost in different ways. If we were to combine compost with other changes in manure management practices, we would likely see different, and positive, impacts. Thus, manure composting can be a stand-alone solution or an "add-on" solution to other approaches to managing manure and reducing environmental impacts.

Conclusion and Recommendations

The available research indicates that composting manure is environmentally beneficial overall. Composting generates significant benefits to water quality and methane – by far the two greatest environmental impacts of dairy manure management – and relatively minimal increase in air quality impacts, some of which can be easily mitigated. The research we found was primarily conducted outside of California and/or studied non-manure compost feedstocks. While the relative impacts seem clear for most pollutants (the exception being volatile organic compounds), it is not possible to make definitive conclusions about the magnitude of the impacts due to the lack of comprehensive California-based research.

Recommendation 1: Initiate comprehensive California-based research comparing dairy manure composting to existing manure management practices in order to quantify the magnitude of impacts across environmental media.

Relevant research on manure compost in California is scarce, but research in other regions and/or on non-manure feedstocks suggest that composting manure is likely a net environmental benefit. We need field-scale research in the Central Valley to quantify the magnitude of environmental impacts and tradeoffs of production and application of manure compost. This research must be comprehensive, including all of the following: (1) it must compare dairy manure composting to existing manure management practices; (2) it must look across multiple air, water, and GHG pollutants; and (3) it must measure the full life cycle, e.g. collection, storage/processing, and use (typically land application). The results of this research will help shape more science-based policy and may enable more cross-agency collaborative approaches to regulating environmental impacts – both of which would lead to better environmental outcomes.

SECTION 4: REGULATORY BARRIERS FOR MANURE COMPOST

As explained in the previous section of this report, there are significant gaps in our understanding of the environmental impacts and benefits of composting dairy manure, particularly concerning the real impact of VOC and ammonia emissions. Nonetheless, our review of existing research shows that the production and use of dairy manure compost can result in significant GHG emission reductions and water quality benefits – by far the two most significant impacts of California dairies. California policymakers and regulators must make several improvements to current regulatory programs affecting dairies to achieve these environmental outcomes.

We believe that effective regulations and permitting requirements to protect the environment should have three fundamental qualities:

1. They should be based on the best possible science, with sufficient flexibility to respond to changes in the science over time.
2. They should prioritize risk reduction and the achievement of real, beneficial environmental outcomes. Overly prescriptive "one-size-fits all" processes may compromise underlying environmental goals.
3. They should provide clear and certain expectations and requirements for potential permit applicants.

As discussed in Section 2, several different regulations apply to dairy composting. None, however, achieves all three of the fundamental qualities stated above. Instead, current regulations apply excessive emphasis on unclear and/or relatively low-risk impacts, creating a strong disincentive for dairies and composters to engage in manure composting and impeding achievement of more significant environmental outcomes. This is not the result of negligent or obstructionist action on the part of regulators. It is the more or less inevitable result of a system in which individual agency mandates exist in inflexible silos created by state and, in the case of state and regional water and air quality agencies, federal regulations. This section provides details on the regulatory challenges facing dairy operators who wish to implement composting and concludes with recommendations on steps that could be taken to allow regulators to take a more integrated and outcome-based approach to dairy compost.

San Joaquin Valley Air Pollution Control District

Lack of certainty concerning Best Available Control Technology (BACT) requirements

In our conversations with dairy operators, we heard repeatedly that the single greatest obstacle to starting to compost manure on an existing dairy is the lack of clarity about what would be required by the SJVAPCD in order to obtain a permit and the assumption that the requirement would be cost-prohibitive. The crux of the issue concerns Best Available Control Technology (BACT). BACT is defined as the "most stringent emission limitation or control technique…achieved in practice…or…found to be cost effective and technologically feasible...” (SJVAPCD Rule 2201, Sec. 3.10). The district’s Rule 4565 sets forth a list of mitigation options from which an applicant can pick a required number, based on the project’s wet tonnage of throughput. While the applicant’s selection may technically satisfy the requirement of Rule 4565, the new application triggers Rule 2201 – New and Modified Stationary Source Review – which requires a review of BACT. If the review of BACT finds that there are control methods that could achieve better emission reductions than those proposed by the applicant and that these controls have either have been “achieved in practice” or are technically feasible, these controls must be evaluated and potentially incorporated into the requirement of the new permit. The onus is then on the applicant to demonstrate that the technically feasible alternatives are not cost effective. “Cost effective” is currently defined as less than $17,500/ton of VOC reduced. If the technically feasible alternative is shown to be cost effective, it becomes the BACT for the project. Thus, Rule 4565 is the *minimum* standard for BACT – the SJVAPCD is empowered to go beyond it when determining BACT for a project. Consequently, a dairy faces great uncertainty in what will be required to obtain a permit from SJVAPCD to operate a dairy composting system. This is a significant disincentive for a dairy producer who must invest time and money to complete a permit application without reasonable certainty that they could afford the BACT mitigations that would be required.

SJVAPCD is in the process of developing a calculator to be used by a dairy operator to obtain a general idea about what would be required in order to obtain a permit based on the feedstock, method of composting, method of emission control, and the amount of manure being composted. While the actual amount of a project’s potential emissions is determined by the SJVAPCD on a case-by-case basis and involves variables that a calculator cannot capture, the calculator does represent a significant interim step towards providing more clarity for potential dairy manure composters. Using a draft version of the calculator provided by the SJVAPCD, we estimated that VOC offsets would be triggered around 12,000 wet tons of feedstock processed per year using turned windrows and the basic BACT required by Rule 4565. Using more advanced BACT, a compost producer could avoid purchasing VOC offsets for a system processing up to 26,000 wet tons of using turned windrows. For perspective, a dairy producer composting 25% of all the manure generated on-site would hit the 12,000 wet tons threshold at about 2200 cows, and the 26,000 threshold at about 4700 cows. The average size dairy in the San Joaquin Valley is 800-1200 milk cows (CDFA, 2016). The offset threshold is important since VOC offsets can be very expensive. The price fluctuates, but SJVAPCD uses a price of $5,000 per ton of VOCs for offsets in the calculator they provided to us.

To address the uncertainties described above, the SJVAPCD needs to develop a final BACT Guideline for manure composting on dairy sites. BACT Guidelines provide an applicant with both BACTs achieved in practice and those considered to be technically feasible for a particular activity, thereby providing clearer guidance on what BACT would be acceptable to the SJVAPCD. Having such a Guideline in place for composting dairy manure would reduce both uncertainty regarding BACT requirements (enabling proper business planning) and permitting costs.

Inflexible VOC standards that are based on insufficient data and fail to account for comparative risk

While an approved BACT Guideline for dairy composting would be a step forward, its value will depend on whether and to what extent BACT standards are based on relevant scientific data and the environmental outcome. The first challenge is that there is insufficient data on VOC emissions from composting of dairy manure. SJVAPCD has identified a VOC emission factor for manure compost of 1.78lbs VOCs/wet ton (SJVAPCD, 2010). However, this emission factor was established based on research on co-composting of green waste, biosolids, and/or animal manure and not on composting of animal manure itself. Further, the guideline does not evaluate how those emissions compare to the alternative, common practice of storing solid manure in static piles. Collecting directly relevant, California-based data on VOCs from manure and manure compost is critical to ensure permitting requirements reflect actual, incremental environmental impacts.

The SJVAPCD has stated that "dairies are among the largest [anthropogenic] sources of VOCs in the Valley, and these smog-forming VOC emissions can have an adverse impact on efforts to achieve attainment with health-based air quality standards" (SJVAPCD, 2012b). However, this statement fails to make two important distinctions relevant to compost production on dairies. First, the large majority of VOC emissions from dairies come from dairy silage, not manure. Second, not all VOCs are created equal in ozone formation: research suggests that the VOCs from manure do not react as easily as other types of VOCs (refer to Section 2 – Air Quality for a more detailed discussion of these issues). The necessary California-based research on VOCs from manure should also measure the reactivity of the VOCs emitted during manure composting. This research should be a high priority for SJVAPCD and CARB to ensure that any permitting restrictions are based on real, scientifically proven environmental and health impacts instead of a one-size-fits-all approach that lumps highly reactive and low-reactive VOCs into the same regulatory approach.

Obtaining solid scientific data on the impact of dairy composting on VOC emissions is only the first step. Local agencies must also be empowered to utilize this data and adjust their programs accordingly. The SJVAPCD is responsible for implementing and enforcing air quality standards established by the US Environmental Protection Agency (US EPA) under the federal Clean Air Act. US EPA not only sets the goals that the district must meet – it also creates strict limits on how the district goes about meeting them. US EPA currently does not allow the SJVAPCD to make any distinction between VOCs based on different reactivity levels. This restricts SJVAPCD from prioritizing more targeted and efficient regulation of the highly reactive VOCs that present the greatest threat to public health.

Lack of a whole-system approach for evaluating emissions from dairies

Currently, if an existing dairy wishes to start composting its manure, or expand existing composting, that activity is considered by the SJVAPCD to be a "new" stationary emission source separate from the dairy, requiring a separate permit. As a result, the composting facility is assumed to be starting at an emissions level of zero – any emissions determined to be resulting from the operation are necessarily an increase in emissions. However, this premise is entirely false – as dairy manure produces emissions before and without composting – and fails to reflect composting's net impact on emissions from manure management. SJVAPCD should revise its approach to new source review to account for the net impact of implementing dairy manure composting compared to a dairy's existing manure management system. Furthermore, as stated in Section 3, some findings referenced by CARB suggest that composting manure generates fewer VOCs than the biogenic deterioration of manure. If further research confirms these findings, then the SJVAPCD not factoring in existing emissions results in regulations that impede a practice that reduces air quality emissions.

State and Regional Water Boards

Uncertainty about the implementation of the Compost General Order and possible conflict with agency water quality mandate

The State Water Resources Control Board (SWRCB) recently adopted a Compost General Order that imposes stringent requirements on any facility that wishes to compost manure. The CVRWQCB will be in charge of implementing the Compost General Order provisions in the San Joaquin Valley, and it has indicated that a dairy whose manure storage areas are currently in compliance with its Dairy General Order requirements will be considered to be in compliance with the Compost General Order. This appears to be a sensible example of non-duplicative, outcome-based regulation, but it is complicated by the CVRWQCB's stated plans to revise the Dairy General Order in 2017 to be more in line with the requirements of the Compost General Order. While the SWRCB has stated that the CVRWQCB will continue to have discretion concerning the standards to apply to an individual application, it has also stated that its policy goal is to establish the Compost General Order as the "floor" for all the Regional Water Quality Control Boards. This adds considerable uncertainty to the prospects of permitting on-farm dairy manure composting.

If the CVRWQCB revises the Dairy General Order to require that on-dairy composting meet the Compost General Order's Tier II regulatory criteria for a site (pads and drainage ditches of asphalt, concrete, or soil compacted to depth of at least one foot, wastewater management plans and lined ponds, etc.), it will create a disincentive for composting manure and will significantly impede the achievement of its own mandate to improve water quality in the region.

Disincentivizing compost is counterproductive to the CVRWQCB's mandate for two reasons. First, the Dairy General Order requires practices to avoid surface runoff and leaching of contaminated water. As mentioned previously (see Section 3 – Water Quality), research suggests that compost reduces the risk of leachate as compared to storing manure in static piles. Therefore, composting should be the preferred option over static piles to reduce risk of surface runoff and leaching. Second, the Dairy General Order requires dairies to achieve on-farm nutrient balance. An important means for doing so is through the export of excess nutrients. As this report shows, compost is currently one of the few options for nutrient export when considering environmental impacts, potential customer base, and dairy economics.

CalRecycle

Need for Clear Guidelines for Enforcement Agencies

Out of all of the agencies with jurisdiction over permitting composting facilities, CalRecycle's requirements appear to be the most straightforward and least onerous for a dairy proposing to compost manure on-site. CalRecycle provides an agricultural exemption for farms that compost on-site if they handle material derived solely from the site and return an equal amount of compost to the same site or to another site owned or operated by the same entity. No more than 1000 cubic yards of compost generated from such a site can be sold or given away in year. The agency also provides a relatively straightforward permitting process for composting facilities handling agricultural material and up to 12,500 cubic yards of green material (including manure) on site at any time. Such facilities must meet CalRecycle's filing and record-keeping requirements for notification-tier facilities and be inspected by a Local Enforcement Agency (LEA) either once per year (if only agricultural materials are composted) or three times a year (for combination green/agricultural material operations).

The main concern that arises from this notification-tier permitting process is a lack of predictability and uniformity in how the LEA defines certain regulatory terms that determine tier classification and how it assesses compliance during inspections. For example, it is up to LEAs to determine whether certain woody materials constitute an "agricultural material" versus a "green material" as well as what classifies as "material" versus finished compost. How an LEA defines these will determine the tier under which the facility would be placed. Additionally, the LEA must determine whether adequate controls for flies and odors are in place for the composting operation when they do their inspections. Flies and odors already exist on dairies, and it is up to the LEA to determine what is existing and what might be new due to the composting operation. LEAs could approach these scenarios very differently, leading to inconsistent implementation of a seemingly clear regulation. Creating and communicating clear guidelines that apply to all LEAs would provide consistency and certainty for both the facility operators and LEAs.

CalRecycle, the Administration, and the Legislature

Funding Imbalance

California has a long history of enacting laws that mandate that solid waste, and particularly organic waste (food, lawn clippings, etc.) be diverted from landfills, starting with AB 939 (50% diversion) and leading to AB 341 (75% diversion) and AB 1826 (mandatory commercial organics recycling). SB 1383 requires that there be a 50% reduction from 2014 levels in the landfilling of organics by 2020, and a 75% reduction by 2025, along with a 20% reduction in disposal of food waste by 2025. These mandates have resulted in significant funding and support being provided to pay for research and market development for composting of municipal green waste.

Composting of agricultural materials, including dairy manure, has not benefited from this funding, as its feedstocks do not go to landfills and are therefore not included in the legislative mandates for diversion. As this report shows, both research and market development for dairy manure compost are needed to ensure success in achieving the state's goals in SLCP/SB 1383, the Healthy Soils Initiative, and AB 1045 (see Section 6 for more on these initiatives). Currently available funding that could be directed to manure compost comes from the Greenhouse Gas Reduction Fund (GGRF), and GGRF money generally cannot be spent on research and market development. Agencies, the Governor's Office, and the Legislature need to identify or create and provide money to other funding pools and direct those resources to provide the scientific and economic foundation needed for dairy manure compost to contribute fully to the state's climate and water quality goals.

Conclusion and Recommendations

The inconsistency, complexity, and lack of clarity of regulations has been one of the primary barriers to compost production. In some cases, permitting requirements are simply unclear. In other cases, the regulations are based on limited and/or incomplete data and could actually prohibit better environmental outcomes. In order to establish effective regulatory and incentive programs, there is a critical need to conduct California-based research on the magnitude of the impacts of manure compost relative to current practices.

Finally, and importantly, the current regulatory approach does not appropriately consider the net impacts from composting dairy manure across water quality, air quality, and greenhouse gases. This siloed approach to managing pollutants on dairies results in lost opportunities to address the most pressing environmental impacts of manure, and could actually lead to negative environmental outcomes at a regional scale.

Recommendation 1: The SJVAPCD should create clear and science-based BACT Guidelines for new or expanded composting on dairies.
First, policymakers should obtain more California-based data on the quantity and reactivity of the VOCs emitted during manure composting, and base compost regulation on its real, scientifically proven environmental and health impacts. This includes evaluating and regulating the emission impacts of composting on a dairy based on the dairy's net change in emissions from its previous manure management system, which the regulations currently do not do. By ignoring existing emissions, the regulations could actually disincentivize adoption of a new practice that has lower emissions.

Recommendation 2: The CVRWQCB should consider compliance with the existing requirements of the Dairy General Order as constituting compliance with the siting requirements of the new Compost General Order.

Composting dairy manure can greatly reduce water quality impacts of dairies. The stringent requirements of the Compost General Order will disincentivize adoption of composting on dairies. Composting reduces risk of leachate and is one of the only economically viable options for dairies to export excess manure. Therefore, disincentivizing composting through Dairy General Order requirements will inhibit dairy producers from meeting the requirement of that same Dairy General Order, and could lead to poorer water quality outcomes.

Recommendation 3: CalRecycle should provide clear guidance to ensure Local Enforcement Agencies are consistent in how they interpret and assess compliance with the notification tiers of the Agricultural Material Composting Operations and Green Material Composting Operations.

While CalRecycle's permitting requirements for facilities composting agricultural materials and up to 12,500 cubic yards of green materials on-site are not overly onerous or unclear, they often require notification of and inspections by LEAs. Currently, the interpretation of CalRecycle's requirements is left to the individual LEA's discretion. It is important to ensure clarity and consistency by providing clear guidance to LEAs in how they interpret, and assess compliance with, the regulation.

Recommendation 4: CalRecycle, the Administration, and the Legislature should identify funding pools other than the GGRF in order to fund needed research and market development for dairy manure compost.

The state has dedicated significant resources to support diversion of organics from landfills. Given its significant potential to help achieve the state's environmental goals, dairy manure composting should be provided the same level of support for research and market development. Currently, only GGRF funds have been allocated for efforts related to manure compost, and these funds cannot be used to fund research or market development.

SECTION 5: MARKET FOR MANURE COMPOST

While there is very little published information available about the market for compost in California – and even less on the market for manure compost – findings from our interviews suggest that the market is strong and growing (see Appendix 1). Whether a dairy should begin composting its manure is a decision that depends on both demand-side and supply-side factors. Demand-side factors include sale price, customer proximity and size, and customer expectations for product consistency, quality, nutrient content, and contamination levels. Supply-side factors include the following: quantity of compostable material, land availability, equipment needs, permitting, and production and transportation costs.

Demand

Demand for Compost in General

We could not find any robust publically available analyses on the demand for compost in California. However, findings from our interviews with compost producers and industry professionals suggested that demand has generally outstripped supply for several years. At the same time, compost markets are geographically sensitive due to shipping costs that limit the feasibility of moving supply long distances to meet demand. Thus, while macro-level demand may outstrip supply, it has been common to see excess supply in some regions while other regions experience shortages. This supply-demand disconnect can occur when large municipal composting operations, where most compost is currently being produced, are located far from rural agricultural areas, where demand is high due to the sheer acreage available for use. A 2008 CalRecycle survey found that agriculture accounted for 71% of the 2.79 million cubic yards of compost sold in the Central Valley (CalRecycle, 2010).

Portions of the San Joaquin Valley experience this supply-demand disconnect and would benefit from a more decentralized production model utilizing agricultural materials, including manure from dairies. Filling this gap will be even more critical as demand for compost in the agricultural sector increases. Experts we interviewed were consistent in their opinion that demand will increase because agricultural producers, especially younger generations, are increasingly interesting in building soil health and see compost as one tool toward this goal.

Agriculture's key role in compost demand, now and into the future, is supported by a 2010 CalRecycle report, which states that "…agriculture continues to be the largest single market for compost in 2008…there is still much that is not known and potentially a great deal of capacity within this market segment" (CalRecycle, 2010). We would agree. Over 10 million acres were planted and harvested in the San Joaquin Valley in 2015 (USDA-NASS, 2017). If just 5% of those acres applied three tons of compost per acre (the lower threshold for application under CDFA's Healthy Soils Incentive Program), the demand for compost would be about 1.5 million tons, or about 3.37 million cubic yards. This represents about 1.4 million cubic yards more than was sold to agriculture in the entire Central Valley (e.g. not just the San Joaquin Valley (CalRecycle, 2010).

Demand for Manure Compost

Although we could not find any demand forecasts, our interviews with experts and potential customers suggest that the demand for manure compost could be quite large. Dairies in the San Joaquin Valley are surrounded by vast agricultural production, a significant customer base. Many agricultural producers already appreciate the value of manure – a material that has been used for generations to build soil health and provide plant nutrients. Compost is increasingly seen as an alternative to manure that can also be used more readily on human-consumed crops. However, finished compost can vary widely in quality and content based on the source of raw materials (feedstocks) and the composting process. Therefore, the likelihood of agricultural producers purchasing compost produced from manure depends on their expectations for content, quality, and cost. Manure compost has some advantages and some disadvantages compared to compost produced from other feedstocks.

Customer Preferences for Manure Compost

The primary advantage of manure compost is that it tends to be much "cleaner" than compost derived from municipal feedstocks. Municipal compost feedstocks can contain large amounts of inert contaminants such as glass and plastics arising from poor separation (see Box 6). Although some composters are using very sophisticated mechanisms to separate out inerts before and after composting, some of these contaminants will nonetheless make it into the final product. Additionally, yard scraps can contain herbicides, oils, and other chemicals, some of which may persist through the composting process. These chemical contaminants can be of particular concern for some customers, especially agricultural producers. Unless it is very poorly managed and cross contaminated, manure should not contain these inert and chemical contaminants.

Box 6: Municipal feedstock pile compared to dairy manure feedstock pile

Municipal feedstock pile

Photo courtesy of Kevin Barnes, City of Bakersfield - Solid Waste Division

Dairy manure feedstock pile

A second advantage of manure compost is that it typically has a higher nutrient value as compared to compost from municipal feedstock. While most customers typically do not look at nutrient content as a primary driver for use of compost, it is nonetheless one of the factors used when comparing different types of compost. In fact, some agricultural and horticultural representatives stated that when fertilizer prices surge, compost with higher nutrient content can become somewhat competitive with synthetic fertilizers, depending on plant needs.

This combination of a “cleaner” compost and higher nutrient content means that manure-based compost is typically sold at a premium over compost made from municipal feedstocks.

Customer Concerns about Manure Compost

Customers’ primary concerns with manure-based composts are that it is susceptible to contamination from veterinary pharmaceuticals, pathogens, and salts. Fortunately, each of these threats can be greatly diminished through the composting process, as described in Box 7.

Box 7: Manure Compost Contaminants

Pathogens: Manure contains pathogens such as *E. coli*, *Salmonella*, and *Listeria* that pose serious risks to human health and the environment. However, the composting process has been found to be very effective at killing these pathogens, and composting standards are designed to ensure the proper practices are followed to achieve this pathogen kill. Composting standards by CalRecycle, OMRI and USDA, require that compost piles reach temperature levels of 131-170^{o}F for three consecutive days for static aerated piles, or for 15 consecutive days for turned windrows. These practices have been found to sterilize the pile, eliminating over 99% of *E. coli*, *Salmonella*, and *Listeria* (Larney et al., 2003; Grewal et al., 2006; Shepherd, Jr. et al., 2007). It is important to note that compost piles can have temperature stratifications – particularly non-turned piles. However, attention to detail and proactive management strategies such as turning/mixing, appropriate carbon to nitrogen ratios, thorough temperature monitoring, and sufficient lab testing can overcome these obstacles.

Salinity: Elevated levels of salinity can be harmful to water quality, soil health, and plant production. Highly saline soil amendments are of particular concern in some parts of the San Joaquin Valley where groundwater and/or soils already contain high salt concentrations. Compost made from manure or food waste feedstocks typically has higher salinity than compost made from green waste feedstocks. The higher salinity is a result of both the higher nutrient content (some forms of nitrogen, phosphorus, and potassium are salts) as well as other non-desirable salts, such as sodium and chloride. Therefore, it is important to understand what salts are present and the tolerance for those salts. While a farmer with highly saline soils should exercise caution, a study at UC Riverside concludes that agricultural application rates are unlikely to introduce enough salinity to stunt plant growth (Reddy and Crohn, 2012). The study found that, while the salt in composts can decrease plant growth in the same fashion as other sources of salinity, the benefits of compost generate a net increase in plant growth rates. This finding is consistent with other research (Wright et al., 2008; Tartoura et al., 2014).

Pharmaceuticals: The persistence of pharmaceuticals can harm human health and the environment. Veterinary pharmaceuticals (e.g. hormones, steroids, antibiotics) are routinely administered to livestock. 70% to 90% of these pharmaceuticals (Kumar et al., 2005; Chee-Sanford et al., 2009; Massei et al., 2014) are not absorbed by the animal, and are excreted in urine or manure. However, several studies have demonstrated that composting generally reduces or eliminates these compounds from animal manure (Dolliver et al., 2008; Arikan et al., 2009; Ramaswamy et al., 2010; Derby et al., 2011; Wu et al., 2011; Hu et al., 2011; Bartelt-Hunt et al., 2013; Zhang et al., 2014). These findings could help explain why pharmaceuticals did not emerge as a customer concern in our interviews with agricultural and composting stakeholders.

Supply Chain Restrictions on Manure Compost

Although composting reduces pathogen contamination in manure, food safety concerns will remain a hurdle for widespread adoption of manure-based composts. Manure compost producers will have to contend with strict standards from regulators, trade associations, and voluntary certifications, and agricultural producers will have to navigate inconsistencies in recommendations and restrictions for application of manure compost to human-consumed crops.

An early draft of the federal Food Safety Modernization Act's Produce Safety Rule required a 45-day delay between the application of manure compost and the harvest of produce crops due to concerns about pathogens. However, the final Produce Safety rule removed any restrictions for manure-based compost, assuming it has met proper composting standards. This decision reflects the science showing that composting reduces manure's risk to human health. However, other organizations have adopted strict requirements for application of manure compost that are not reflective of best available science.

Certain food trade associations, wholesalers, handlers, and processors have taken extra precautions to prevent contamination risks. One such group that has taken a risk-averse stance is the Leafy Green Marketing Agreement (LGMA) whose members grow about 99% of all leafy green produce in the United States (LGMA, 2014). LGMA requires that growers not apply compost within 45 days of harvest, which can be limiting for management of fast-growing crops (LGMA, 2016). As a result, some of their growers have moved toward using alternative soil amendments. Processors, aggregators, and brands across the agricultural sector have adopted similar rules or outright bans on manure-based compost. These stricter stances on compost application are the result of "an abundance of precaution" – as one association representative explained – that extend beyond current scientific justification.

No matter what the requirements, it will be important for composters to follow accepted production standards and monitoring protocols to secure customer trust about the quality of manure-based compost. Consistent and extensive in-field monitoring, third-party lab testing, and certifications like OMRI, National Organics Program (NOP), or the US Compost Council's Seal of Testing Assurance will be crucial for dairies producing compost for sale. However, certifications require a more exacting process for consistent compost production and documentation that may be a barrier for some dairies.

Supply

Supply of Compost in General

California has a long history of policy efforts to divert material from landfills, starting with AB 939 in 1989. Over the years, these efforts and the associated funding helped establish a robust infrastructure and knowledge base for recycling and composting in the state. As a result, the supply of compost increased as feedstocks from urban areas were collected and processed.

Compost supply is expected to grow again with new policy efforts to divert even more organics from landfills, such as the Short-Lived Climate Pollutants strategy and Mandatory Commercial Organics Recycling (MORe). However, much of this new supply from landfill diversion will likely be located near urban areas and not rural agricultural areas. Given the high cost of transportation, increasing the amount of locally produced compost will be critical to meet increased rural demand. Agricultural material, including dairy manure, is an underutilized feedstock that can help to meet the growing gap between supply and demand in rural agricultural areas.

Supply of Manure Compost

Manure-based compost can help meet the projected demand increases for compost in rural agricultural areas due to its logistical advantages. While a few dairies have recognized the market opportunity to export excess manure by composting, they represent a small percentage of the dairies in the San Joaquin Valley, leaving substantial opportunity for more production. Additionally, many dairies are already drying manure and separated solids for bedding, so they likely already have some of the basic knowledge and equipment needed for composting. For these producers, switching to actively managed compost will be less of an operational challenge than for those starting from scratch.

The potential supply of manure compost from a given dairy is a function of many factors, including total manure generated, existing manure management system, and the dairy's crop needs for field application of manure. However, we can provide several basic, conservative estimates of the potential supply at the regional scale. At about 120lbs of wet manure produced per cow per day (Tyson and Mukhtar, 2015), the 1,553,788 dairy cows in the San Joaquin Valley (CDFA, 2016) produce about 34 million tons of manure per year. Therefore, composting just 1% of all the dairy manure generated in the San Joaquin Valley would mean composting about 340,000 tons of manure. If we assume that about 50% of that weight would be lost through the composting process (Michel et al., 2004), composting 340,000 tons of manure would result in about 170,000 tons of finished compost per year. Using an average bulk density of about 2.24 cubic yards per ton of compost (CalRecycle, 2010), this would result in production of about 381,000 cubic yards of manure compost. This is equivalent to about 0.11 tons (or 0.25 cubic yards) of compost produced for every 1% of manure generated per cow per year. See Table 3 below for additional compost production scenarios.

Table 3. Manure Compost Production Scenarios: San Joaquin Valley

Manure Composted (% of Total Manure Generated)	Manure Composted (Tons per Year)	Compost Produced (Tons per Year)	Compost Produced (Cubic Yards per Year)
1%	340,280 tons	170,140 tons	381,113 yd^3
5%	1,701,398 tons	850,699 tons	1,905,566 yd^3
10%	3,402,796 tons	1,701,398 tons	3,811,131 yd^3

This potential supply is significant compared to the current production of compost. A 2008 survey showed that only 7% of composting facilities in California produced more than 200,000 cubic yards of compost per year. Therefore, composting just 1% of San Joaquin Valley dairy manure would produce more compost than even the largest of existing facilities currently produce. If 5% of the manure were composted, that would be almost equivalent to the 1.99 million cubic yards of compost sold to agriculture in the entire Central Valley (CalRecycle, 2010).

Economics of Manure Compost Production

It is difficult to calculate with any great deal of certainty the profitability or breakeven point for composting manure due to the lack of published information and the highly varied possibilities for compost production. Therefore, this study relies heavily on information received through our extensive interviews (see Appendix 1). We focused on the costs and revenue potential for on-site composting of dairy manure using open turned windrows since that is consistent with our focus throughout this report.

Depending on the location and vendor, bulk manure compost is sold for $20-$40 per ton in the agricultural sector, excluding transportation and spreading costs. A 750-cow dairy composting about 10% of its manure could produce about 821 tons of compost per year, resulting in about $16,425-$32,850 in annual revenue. A 2000 cow dairy doing the same could produce about 2,190 tons of compost, resulting in $43,800-$87,600 in annual revenue.

Production costs for open windrow composting vary greatly depending on existing equipment and operational scale. Regulatory compliance costs are also unclear and potentially significant. Table 4 below reflects our best knowledge of baseline costs for on-dairy composting with open turned windrows (see Appendix 3 for more details). It is worth underscoring that the "variable" costs noted could be quite large.

Table 4. On-site Composting Expense estimates

Expense Type	Basic Operation, Using Existing Resources	Advanced Operation, Purchasing New Equipment
Total Capital Costs	**$0**	**$105,000 - $1,700,000**
Inputs (fuel, water, bulking agents, etc.)	High, variable	High, variable
Labor	$21,500 - $32,500	$21,500 - $32,500
Equipment	$0 (+ variable O&M)	$105,000 - $1,700,000 (+ variable O&M)
Certifications & Compliance	$1,950 - $4,200 (+ variable and unknown compliance costs)	$1,950 - $4,200 (+ variable and unknown compliance costs)

Total Annual Costs	**$23,450 - $36,700 (+ high variable costs)**	**$23,450 - $36,700 (+ high variable costs)**

Based on the above costs, we would expect that a dairy with 750 cows would need to compost more than 20% of its manure to have a chance of breaking even with even the most basic operation. A 2000 cow dairy would be processing enough manure that they likely need more sophisticated equipment, but they could potentially break even utilizing 10% of their manure, particularly if they are able to sell their compost for $30-$40 per ton.

On-farm composting using open turned windrows is just one business model, and the costs and profitability will vary greatly between different business models. We have identified three general business models that appear practical in California's Central Valley: on-site owner-operated, on-site third party operated, and off-site dedicated facility. Due to existing regulatory and permitting environments in the Central Valley, smaller and distributed production on-site on existing dairies seems more viable than development of new large, centralized facilities. Dairies are already subject to strict permitting requirements, though there is a lot of uncertainty around what the additional requirements for on-dairy composting might be, as discussed in Section 4. Dairies using a third party may be more commercially successful than dairies composting themselves, because customers will likely assume that a third-party composter will create a product that is more consistent and of higher quality – two of their top concerns related to manure compost. Off-site facilities are the most difficult and expensive to permit and construct, but if they are sited near large dairies and a sufficient customer base, they offer substantial opportunity for larger profit margins through economies of scale and development of a recognized and trusted brand. Additional details on the advantages and disadvantages of each manure compost business model are provided in Appendix 4.

Regardless of the type of operation, our interview findings and analysis suggest that composting manure can be economically viable, although the profit margin would likely be small. These slim margins necessitate careful financial planning and a degree of scale in order for a new composting operation to be successful.

Manure Compost Market in California

The market infrastructure to facilitate the growth of a supply chain for dairy manure composting is underdeveloped. Currently, most dairies in the San Joaquin connect with composters and customers via word of mouth, limiting scalability. There is very little support, and indeed many obstacles, for building supply infrastructure. Finally, there are no programs to understand and promote best practices for using manure-based compost, which many still perceive as a food safety issue despite contrary findings from the best available science.

California has invested significant time and money, primarily through budget allocations to CalRecycle, to build market knowledge, supply infrastructure, and demand base for compost from municipal feedstocks. These efforts were largely done as part of a policy effort to mitigate the negative environmental impacts of organic material that was being sent to landfills. They did not include the huge amount of organic material, including dairy manure, which is a by-product of agricultural production because most of this material does not go to landfills. However, these agricultural by-products also lead to negative environmental impacts that could be mitigated by composting. Given the significant potential for dairy manure composting to help achieve the state's environmental goals, it makes sense that the state invest resources to build the market knowledge, supply infrastructure, and demand base for manure-based compost. Fortunately, the investments do not need to be significant, or perpetual. The market is emergent due to the need for dairies to export excess manure and the nearby increasing agricultural demand for compost. However, there are a few barriers, especially related to lack of clarity around permitting, that limit market scaling. Smart, short-term investments to address these barriers and build a thriving market will go a long way to achieve positive environmental outcomes.

Conclusion and Recommendations

There seems to be significant market opportunity for manure-based compost. Agricultural demand in the San Joaquin Valley is expected to grow, and opportunities to grow supply from traditional municipal sources are limited. Additionally, compost produced and sold in the San Joaquin Valley should have an advantage over compost produced from feedstocks shipped from Southern California due to lower transportation costs. Manure-based compost should receive a price premium over municipal compost due to its many advantages, including higher nutrient values and lower levels of contaminants. With 1.5 million cows in the San Joaquin Valley, there is enough potential manure feedstock, and producing manure compost, while not highly profitable, does seem to be economically viable.

Consequently, we believe there is a considerable market opportunity to increase the amount of manure compost produced and sold in the San Joaquin Valley. Doing so will require investments to build the market knowledge, supply infrastructure, and demand base for manure-based compost. All of these things have been successfully done with municipal green waste compost by CalRecycle and others. Given the significant potential for composting to help the state meet its environmental goals by mitigating the environmental impacts of dairy manure management, it is critical that the state make targeted, short-term investments to help build the market for manure-based compost.

Recommendation 1: Provide funding to California Department of Food and Agriculture to build producers' knowledge of compost production regulatory requirements and best management practices.

Scaling up the number of dairy operations that compost their manure will require increasing access to information about how to perform this task to meet existing standards. Critically, dairies and manure composters need a resource that clearly lays out requirements for permitting and regulatory compliance for on-farm composting. Dairies that decide to compost will need information on production techniques and best management practices specific to production of high quality, manure-based compost.

Recommendation 2: Fund research to compare the soil health benefits and contamination risks of dairy manure compost, green waste compost and food waste compost

The associated soil health benefits and contamination risks of compost produced from different feedstocks is not well known. We recommend a two-stage approach. First, conduct a literature review of existing research, culminating in practical guidance for producers in the near-term. If significant holes are identified, then move onto the second stage to generate original, field-scale research. The highest priority topics of both stages are a comparison of the relative benefits of compost created from dairy manure, green waste, and food waste in terms of effects on soil nutrient availability, microbial activity, water holding capacity, and carbon sequestration. Research should also compare the contamination risks associated with each source of compost, particularly as it relates to pathogens, pharmaceuticals, herbicides or oils, and inert contaminants like plastic or glass. Both stages of research should culminate in clear, concise guidance on the merits of, and best management practices for, successfully incorporating different types of compost into agricultural production systems.

Recommendation 3: Fund demonstration projects to study and prove economic feasibility of dairy manure composting in the San Joaquin Valley.

As with any nascent business, dairy farmers adding a new composting system into their existing operations will face economic uncertainties. This uncertainty is heightened for on-site composting due to lack of clarity around permitting requirements and the associated costs. State and locally funded demonstration projects, similar to those developed by the SJVAPCD's Technology Advancement Program, could improve our understanding of the economics of dairy manure composting. In turn, dairy producers would be better able to assess whether composting is viable for their operation.

SECTION 6: POLICY OPPORTUNITIES

While the regulatory requirements for composting dairy manure are formidable, there are a number of initiatives at the state level that – taken together – could help galvanize a coordinated effort to streamline and improve the regulatory process while ensuring environmental protections.

Dairy manure compost has the potential to be a significant tool in the successful implementation of several state policies: AB 1045, the Healthy Soils Initiative, the Alternative Manure Management Program, SB 1383, and the SLCP Strategy. Dairy manure composting also provides an opportunity for the state to develop a process for inter-agency collaboration in service to multiple state initiatives.

AB 1045

AB 1045 (Chapter 596, Statutes of 2015) directs the CA Environmental Protection Agency (CalEPA), in coordination with CARB, SWRCB, and CDFA to develop and implement policies to aid in "promoting the use of agricultural, forestry, and urban waste as a feedstock for compost…" It also requires CalRecycle, in coordination with CARB and SWRCB, to develop a policy that "promotes the development of coordinated permitting and regulation of composting facilities while protecting the environment." The composting of dairy manure was not expressly included in AB 1045, but the statute creates a valuable opportunity for CalRecycle and the regional and state water and air boards to develop a coordinated permitting system for all facilities that are composting, including dairies.

At the first public workshop on AB 1045 implementation held on December 22, 2016, CalEPA, CalRecycle, CARB, CDFA and SWRCB staff referred to dairy manure compost as part of their proposed implementation process. The agencies also indicated that they intend to apply the consolidated permitting process (developed pursuant to Public Resources Code Sec. 71020 et seq.) to compost facility applicants. This progress is certainly encouraging, although, as the agencies acknowledged, further outreach and education to permit applicants is needed. As this process is employed, we hope that the participating agencies will identify and correct conflicting, confusing, or excessively onerous permitting requirements, including, but not limited to, the challenges identified in Section 4 of this report.

Healthy Soils Initiative (HSI) and the Alternative Manure Management Program (AMMP)

The Governor's Healthy Soils Initiative (HSI) seeks to promote the development of healthy soils on California's farm and ranchlands through innovative farm and ranch management practices that contribute to building adequate soil organic matter in order to increase carbon sequestration and reduce overall greenhouse gas emissions. CDFA received $7.5 million from the Greenhouse Gas Reduction Fund (GGRF) in the 2016-17 Budget to begin implementing a Healthy Soils Incentive Program as part of the HSI. This budget allocation refers specifically to "no-till and compost applications." Among other practices, CDFA has proposed to incentivize the use of compost in order to increase carbon sequestration in soil and improve overall soil health. While CDFA has stated that its incentive program is about increasing *demand* for compost, not supply, the state must address both. The level of compost application envisioned by the HSI will require a very large quantity of compost, particularly in the agricultural regions that are home to the state's dairies. Therefore, encouraging dairies to produce a compost supply stream to meet new demand is a logical component of the HSI.

CDFA also received $50 million of GGRF money in the 2016-17 Budget to fund its Dairy Methane Program. In previous years, CDFA has spent these funds exclusively on dairy digester projects. However, through SB 859 (2016), "The Legislature finds and declares that a diversity of dairy methane management practices, including anaerobic digesters and non-digester dairy methane management strategies, can effectively reduce greenhouse gas emissions." In response to this legislative directive, CDFA is developing a separate Alternative Manure Management Program (AMMP) to fund non-digester projects, including but not limited to pasture-based systems, solids separation, compost, and flush-to-scrape conversion. CDFA proposes to direct $9-16 million of its Dairy Methane Program allocation to the AMMP and has begun stakeholder outreach to develop a draft grant program by the summer of 2017.

As discussed in Section 3 above, dairy manure composting has intrinsic methane reduction benefits, and even more so if combined with advanced solid separation in a flush system or conversion to scrape. CDFA should give high priority to AMMP grant applicants with projects incorporating the composting of dairy manure given its methane and multiple co-benefits.

SB 1383 and the Short-Lived Climate Pollutants Strategy (SLCP)

The Governor and CARB have placed significant emphasis on developing ways to reduce emissions from short-lived climate pollutants (SLCPs) – methane, black carbon, and hydrofluorocarbon gases – due to both their potency and the potential for SLCP reductions to contribute to demonstrable progress towards meeting the state's GHG emission targets. SB 605 (Lara) required CARB to develop an SLCP Strategy. CARB issued a first draft of the strategy in late 2015, and a revised draft in mid-2016. These early drafts set highly ambitious targets for reduction of methane emissions from dairy manure management, eventually reaching 75% below 1990 levels by 2030. However, these drafts failed to provide sufficient guidance on how this target should be achieved. A number of organizations, including Sustainable Conservation, expressed serious concerns about the potential consequences of implementing a strategy with highly ambitious targets, significant data gaps, and a short time frame a roadmap for implementation and compliance.

After hearing these concerns, Senator Ricardo Lara (author of SB 605) amended his bill, SB 1383, near the end of the 2016 legislative session to revise both the goals of and the process for the SLCP Strategy's dairy methane provisions. SB 1383 sets the dairy methane reduction goal at 40% below 2013 levels by 2030. Prior to adopting regulations, CARB must assemble a stakeholder work group to "identify and address technical, market, regulatory, and other challenges to the development of dairy methane emissions reduction projects." The statute explicitly refers to "compost producers with experience composting dairy manure" as stakeholders that must be part of the work group. SB 1383 further directs CARB to research the emission reduction potential of a range of manure management practices. CARB has issued another draft of the SLCP Strategy that largely incorporates the new mandates and procedures created by SB 1383. This draft explicitly recognizes the need for additional data in order to quantify the costs and benefits of different manure management practices.

The current draft SLCP Strategy refers specifically to research into the emissions reduction potential of conversion of "wet" (flush) manure management systems dairies to "dry" (scrape) systems while acknowledging information gaps and potential for air and water quality impacts. Studies show that aerobic composting of dairy manure decreases methane emissions relative to storing dairy manure solids in anaerobic static piles. Thus, composting can prolong and increase the methane reductions obtained by conversion from a flush to a scrape manure management system. Composting also potentially reduces the cross-media impacts of a scrape system. Alternatively, using advanced solid separation and composting on a flush system could reduce methane by pulling out and aerobically processing volatile solids that would otherwise have generated methane in the anaerobic lagoon. Therefore, composting dairy manure should be included in both the research, and, ultimately, the guidelines for implementing this component of the SLCP strategy.

More generally, SB 1383's explicit direction to include composters in the stakeholder work group is a clear signal from the Legislature to CARB that composting should be a key element in the development of a dairy manure methane emission strategy. Composting advocates in the work group now must ensure that CARB adequately addresses the "technical, market, regulatory, and other challenges" to manure composting.

Finally, SB 1383 has the potential to bring the agencies implementing AB 1045, the Healthy Soils Initiative, and the Alternative Manure Management Program together to create a coordinated strategy for the production and use of dairy manure compost. CalRecycle and CDFA have already made it clear that the implementation process for SB 1383 will inform and integrate into their own efforts.

Conclusion and Recommendations

The policies and programs described above present several opportunities for agency coordination and synergies to further state environmental goals through dairy manure composting. For instance, successful implementation of AB 1045 could simplify the permitting process for on-dairy composting facilities in areas where, under the HSI, both the demand for local compost and the need for soil improvements are high. In addition, the HSI and AMMP should collaboratively support projects that improve soils and reduce dairy methane emissions through composting. Finally, research into non-digester alternatives to dairy methane reduction authorized by SB 1383 will provide the data necessary to develop strong compost project proposals for AMMP funding. It is essential that staff involved in the SB 1383 implementation process coordinate with the staffs working on AB 1045 and HSI/AMMP to achieve an integrated multi-agency strategy that maximizes the benefits derived from dairy manure.

Recommendation 1: Address permitting challenges for dairy manure composting through AB 1045.

AB 1045's goal of developing better inter-agency coordination on permitting compost facilities is admirable and very welcome, but the agencies involved in implementing the statute have the opportunity to move beyond simple agency coordination and identify and correct conflicting, confusing, or excessively onerous permitting requirements for dairy compost. These include, but are not limited to, the challenges identified in Section 4 of this report. On-farm composting should be included in AB 1045 implementation on an equal footing with dedicated composting operations, and the participating agencies should increase outreach to potential applicants on the availability of the consolidated permitting process.

Recommendation 2: Recognize and support the role of dairy manure compost in meeting goals of the Healthy Soils Initiative and the Alternative Manure Management Program.

Dairy manure compost can play an important role in achieving the goals of the Governor's Healthy Soils Initiative and CDFA's Dairy Methane Program. A steady supply of compost from all sources will be needed to implement HSI, and composting has a key role to play in reducing greenhouse gas emissions through alternative manure management strategies. CDFA should take steps to ensure that dairy manure composting receives full consideration in the development of the Alternative Manure Management Program's grant eligibility standards and the Healthy Soils Initiative.

Recommendation 3: Ensure that the Short Lived Climate Pollutant Strategy fully incorporates the composting of dairy manure in its policy and economic provisions addressing manure methane emissions and the need for new composting facilities.

The passage of SB 1383 in 2016 has given CARB a road map for achieving real methane emission reductions from dairy manure. The Legislature specifically included "compost producers with experience composting dairy manure" in the list of parties required to be included in the stakeholder work group advising CARB on SB 1383 implementation. CARB should take advantage of these producers on the stakeholder work group to thoroughly address the "technical, market, regulatory, and other challenges" facing the composting of dairy manure. CARB and the Legislature should also provide sufficient funding to carry out the research identified in the SLCP Strategy to quantify the costs and benefits of different manure management practices, including composting of dairy manure.

<u>Recommendation 4:</u> Encourage agency staffs responsible for implementing AB 1045, the Healthy Soils Initiative, the Alternative Manure Management Program, and SB 1383 to coordinate closely to achieve an integrated multi-agency strategy that maximizes the benefits derived from dairy manure compost.

The implementation of SB 1383 has the potential to bring the agencies engaged in AB 1045, the Healthy Soils Initiative, and the Alternative Manure Management Program together to create a coordinated strategy for the production and use of dairy compost. It is essential that staff involved in the SB 1383 implementation process coordinate with the staffs working on AB 1045 and HSI/AMMP to achieve an integrated multi-agency strategy that maximizes the benefits derived from dairy manure.

SUMMARY CONCLUSIONS AND RECOMMENDATIONS

Summary Conclusions

The composting of dairy manure solids offers an economically viable opportunity for dairy operators to reduce their most significant environmental risks in California's San Joaquin Valley. Manure management is a complicated logistical and environmental challenge for dairies. California must continue to develop and support solutions for manure management that reduce dairies' environmental impacts and are economically viable. In doing so, California dairy regions will benefit from improved environmental conditions while maintaining an important source of revenue and jobs. Doing so is particularly important in the major milk-producing region of the San Joaquin Valley, which suffers from multiple environmental and socio-economic challenges.

In this study, we have examined best-available information on the individual environmental impacts and benefits of manure compost and, more importantly, the interrelationship between those impacts. We found that dairy manure composting has the potential to reduce water quality impacts, improve soils, and reduce GHG emissions from dairies with comparatively minimal impacts to local air quality. Dairy manure compost's superior portability gives it the potential to disperse nutrient concentrations further distances than uncomposted manure, and pathogen kill achieved through the process enables it to be used more readily on a wide range of crops. While further research is needed to better quantify the extent of the impacts and benefits, California need not wait to take proactive steps to promote dairy compost now where benefits are clear. Specifically, production of compost for export off dairies appears to be a clear win.

Fortunately, achieving the environmental benefits of manure compost is within reach because the market for manure compost seems ripe for growth. Demand for compost is robust and expected to increase, particularly in rural agricultural regions of the state where availability of municipal compost can be scarce. Manure compost can help fill this gap, but agricultural producers need customers that are supportive of manure compost use. There is also significant supply potential. Dairies are increasingly interested in composting their manure, and producing manure compost seems economically viable for many dairies.

However, several key barriers have hindered the production and sale of manure compost and need to be overcome in order for the practice to be widely adopted. The inconsistency, complexity, and lack of clarity of regulations has been one of the primary barriers to compost production. In some cases, permitting requirements are simply unclear. In other cases, the regulations are based on limited and/or incomplete data and could actually be prohibiting better environmental outcomes. In order to establish effective regulatory and incentive programs, there is a critical need to (1) conduct California-based research on the magnitude of the impacts of manure compost relative to current practices and (2) base regulatory and permitting requirements on that data.

Finally, and importantly, the current regulatory approach does not appropriately consider the net impacts from composting dairy manure across water quality, air quality, and greenhouse gases. This siloed approach to managing pollutants on dairies results in lost opportunities to address successfully the most pressing environmental impacts of manure and could actually lead to negative environmental outcomes at a regional scale. Dairies need regulations and permitting requirements that are supportive of manure compost production and the co-benefits it can provide to other important environmental efforts.

Summary Recommendations

Based on our research, we believe that targeted, short-term efforts by state and local government agencies can – and should – be taken to enable the market to emerge and grow on its own. As a result, dairies will have an economically viable option that enables them to reduce their most significant environmental risks. We recommend twelve specific actions that can be taken by government and associated entities to improve the science, regulatory regime, and market for manure composting while supporting state policies to improve soils and reduce greenhouse gasses. Doing so will help catalyze the market for manure compost, resulting in multiple environmental, social, and economic benefits, particularly, though not at all exclusively, in the San Joaquin Valley.

1. **Research: Initiate comprehensive California-based research comparing dairy manure composting to existing manure management practices in order to quantify the magnitude of impacts across environmental media.**
   The available research indicates that composting manure is environmentally beneficial overall. Composting generates significant benefits to water quality and methane – by far the two greatest environmental impacts of dairy manure management – and relatively minimal increase in air quality impacts, some of which can be easily mitigated. The research we found was primarily conducted outside of California and/or studied non-manure compost feedstocks. While the relative impacts seem clear for most pollutants (the exception being volatile organic compounds), it is not possible to make definitive conclusions about the magnitude of the impacts due to the lack of comprehensive California-based research.

   Therefore, we advocate for field-scale research in the Central Valley to quantify the magnitude of environmental impacts and tradeoffs of production and application of manure compost. This research must be comprehensive: it must compare composting to existing manure management practices; it must look across multiple air, water, and GHG pollutants; and it must measure the full life cycle, e.g. collection, storage/processing, and use (typically land application). The results of this research will help shape more science-based policy and may enable more cross-agency collaborative approaches to regulating environmental impacts – both of which would lead to better environmental outcomes.

2. **Regulatory: Amend air quality, water quality, and waste regulations so that they are clear, science-based, and reflect the net environmental impacts of composting dairy manure.**
    a. The San Joaquin Valley Air Pollution Control District should create clear and science-based BACT Guidelines for new or expanded composting on dairies.
    b. The Central Valley Regional Water Quality Control Board should consider compliance with the existing requirements of the Dairy General Order as constituting compliance with the siting requirements of the new Compost General Order.
    c. CalRecycle should provide clear guidance to ensure Local Enforcement Agencies are consistent in how they interpret and assess compliance with the notification tiers of the Agricultural Material Composting Operations and Green Material Composting Operations.
    d. The California Department of Food and Agriculture, the Administration, and the Legislature should identify funding pools other than the Greenhouse Gas Reduction Funds in order to fund needed research and market development for dairy manure compost.

3. **Market: Support outreach and education to encourage manure compost production and research and demonstrations to bolster demand for manure compost.**
    a. Provide funding to California Department of Food and Agriculture to build producers' knowledge of compost production regulatory requirements and best management practices.
    b. Fund research to compare the soil health benefits and contamination risks of dairy manure compost, green waste compost and food waste compost
    c. Fund demonstration projects to study and prove economic feasibility of dairy manure composting in the San Joaquin Valley.

4. **Policy: Implement AB 1045, the Healthy Soils Initiative, the Alternative Manure Management Program, and SB 1383 in a manner that promotes beneficial dairy manure composting and encourages coordination across state agencies.**
    a. Address permitting challenges for dairy manure composting through AB 1045.
    b. Recognize and support the role of dairy manure compost in meeting goals of the Healthy Soils Initiative and the Alternative Manure Management Program.
    c. Ensure that the Short Lived Climate Pollutant Strategy fully incorporates the composting of dairy manure in its policy and economic provisions addressing manure methane emissions and the need for new composting facilities.
    d. Encourage agency staffs responsible for implementing AB 1045, the Healthy Soils Initiative, the Alternative Manure Management Program, and SB 1383 to coordinate closely to achieve an integrated multi-agency strategy that maximizes the benefits derived from dairy manure compost.

APPENDIX 1: ORGANIZATIONS INTERVIEWED

Thank you to the many dairy producers, agricultural producers, manure haulers, and third party composters who took time out of their busy schedules to share their invaluable experiences and perspectives with us.

We would also like to thank the representatives of the following organizations for their time and expertise:

- Almond Board of California
- Association Of Compost Producers
- Belmont Nursery
- CalCAN
- California Air Resources Board
- California Climate and Agriculture Network
- California Department of Food and Agriculture
- California Leafy Green Products Handler Marketing Agreement
- CalRecycle
- Central Coast Compost
- Central Valley Regional Water Quality Control Board
- City of Bakersfield, Solid Waste Division
- Dairy Cares
- E & J Gallo Winery
- Ecoconsult
- Edgar and Associates, Inc.
- Environmental and Energy Consulting
- Harvest Power
- Integrated Waste Management Consulting, LLC
- Malibu Compost
- Marin Carbon Project / Carbon Cycle Institute
- Materra LLC
- Milk Producers Council
- National Resource Conservation Service
- New Era Farm Service
- Newtrient, LLC
- Recology
- San Joaquin Valley Air Pollution Control District
- State Water Resources Control Board
- UC Davis
- UC Riverside
- USDA-ARS (Maryland)
- Western United Dairymen

APPENDIX 2: FACTORS AFFECTING COMPOSTING

Carbon to Nitrogen (C:N) Ratio

A carbon to nitrogen ratio between roughly 40:1 and 20:1 is suitable for starting materials, with 25:1 to 30:1 being ideal. Woody and fibrous materials are typically carbon-rich – e.g. wood shavings are roughly 400:1 in carbon to nitrogen – and food scraps, grass clippings and manures are higher in nitrogen – e.g. uncomposted solid dairy manure has a ratio of 18:1. During the composting process, nutrient loss will result in this ratio decreasing. For example, starting with a 30:1 ratio could result in finished compost near a 20:1 ratio. The C:N ratio is an important measure to track both for producing quality compost and for reducing emissions.

Moisture

Microorganisms that decompose organic matter require moisture in order to survive and multiply. Because of their respiration and the high temperatures that compost piles reach, water is often released as steam during composting and more needs to be applied to piles. This is exacerbated in the summer when ambient temperatures are high. Maintaining between 40%-65% moisture levels is generally the target, with 50%-60% considered ideal.

Bulk density

The density of compost is an indicator of its porosity, texture, and structure. These characteristics indicate the degree at which air will be able to flow through a pile and how quickly its contents will break down. Density also comes into play at the end, as heavy compost results in high shipping costs. The conventional wisdom is that the bulk density of compost should be less than 1100 lbs. (40 lbs. per cubic foot).

Temperature

When microorganisms actively decompose organic matter, the chemical reactions release heat. This heat is what eventually kills pathogens (~131°F) and weed seeds (~145°F) in the pile. In order to meet basic standards for composting, it is necessary to keep the pile above 131°F for 15 consecutive days for turned windrows, and for 3 days for aerated static piles (14 C.C.R. § 17868.3). It should be noted, however, that too much heat could also be detrimental. Excessive temperatures (above 160°F) can kill off beneficial, thermophilic bacteria and stunt the composting process. In these circumstances, mixing the pile can release heat and quickly cool the interior.

Temperature is also a key tool for gauging how best to manage a compost pile. This heat will build while the piles are highly functioning and dissipate when the process is either complete or needs more aeration or water. When the pile begins to lose more heat than it generates, one should aerate it and add water as necessary. If the temperature does not go up as a result, the pile is likely ready to be cured.

Curing:

Once the temperature of a compost pile stabilizes, it is time to let it rest. The curing stage allows the compost to complete its last stages of decomposition slowly.

Curing is necessary because immature compost can be detrimental to plants. If decomposition is still occurring, the compost will not only contain high levels of organic acids, but it will also continue to consume oxygen, which affects plant roots. A general rule of thumb is to let the compost cure for a minimum of 1 month and usually closer to 3 months. During the curing phase, the compost does not need to be turned but it still requires adequate natural or passive aeration so that it does not become anaerobic. For this reason, in addition to water quality, it is a best practice to cover these piles during the rainy season.

Total time:

The total time required to start and finish a batch of compost will range. The different methods of composting allow for greater control over variables that affect the rate of decomposition. For turned-windrow composting, it typically takes more than 2 months and sometimes up to 6 months to finish a batch of compost. Aerated static piles can process materials in 3-5 weeks. Under the ideal conditions (e.g. with an in-vessel system), it is possible to finish a batch within merely 3 weeks.

APPENDIX 3: ON-FARM COMPOSTING COST ESTIMATES

Expense Type		Basic, Using Existing Resources	Advanced, Purchasing New Equipment	Notes
Inputs	Bulking agent	Variable	Variable	
	Fuel	Variable	Variable	
	Water	Variable	Variable	
Labor	Moving raw manure & compost	$16,000 - $27,000	$16,000 - $27,000	0.75-1.25 FTE @ $10.50/hour
	Monitoring/measuring	$5,500	$5,500	0.25FTE @ $10.50/hour
Equipment	Turner/Windrow		$100,000 - $600,000	
	Water Trailer / Water Truck		$5,000 - $40,000	
	Grinder (Not necessary with only manure)		$0 - $660,000	
	Powerscreen (Not necessary with only manure)		$0 - $400,000	
	Operations & Maintenance	Variable	Variable	
Certifications and Compliance	Certification fees (ex: OMRI, STA)	$750 - $3,000	$750 - $3,000	
	Lab Analysis	$1,200	$1,200	4 samples each year at $300 each.
	Labor for certification	Variable	Variable	
	Regulatory fees	Unclear	Unclear	
	Labor for regulatory compliance	Variable	Variable	

APPENDIX 4: MANURE COMPOST BUSINESS MODELS

On-Site, Owner-Operated

In this model, a dairy builds and operates the composting process on its property. This is desirable in that it reduces initial transportation costs and handling requirements. When the dairy has available space, this model of composting can be done with minimal impact on the remainder of the dairy's operations.

While some permitting requirements remain unclear, there will likely be less additional requirements for composting on-site at a dairy than at a large, centralized facility. A dairy can make the greatest financial gains in this scenario, but it also takes on the greatest risk. The dairy will need to purchase equipment it does not already own and takes on sole responsibility for maintenance. Dairies currently composting manure dedicate approximately 0.75 to 1.0 full-time equivalent (FTE) employees to moving materials to and from the compost pad, as well as turning the materials, cleaning the equipment, and keeping proper documentation. Any risk from product contamination or code violations will also be the dairy's responsibility.

Aside from the compost production itself, a dairy operator will need to take on the extra demands of sales and distribution. New responsibilities will include investments into marketing and building a customer-base, as well as logistics pertaining to shipping, billing, and taxes. Due to the many competing priorities already inherent in milk production, we expect that this business model will likely have the greatest challenge in building a trusted brand through production of a consistent product, with adequate monitoring and documentation, and customer service. If the dairy producer has a strong business acumen and reputation in the area, these hurdles may be inconsequential.

On-Site, 3rd Party-Operated

In another model, a separate business entity can manage the composting operation on a dairy site. This situation capitalizes on the potential permitting advantages of on-site composting, while allowing the dairy producers to focus time and energy on milk production. Presumably, a 3rd party operator will be better suited for managing the composting process and can dedicate more time and resources to market development and customer relations. In addition, it is possible that the 3rd party could manage composting operations at several dairies and sell the product under a single brand.

While this scenario offers many advantages, certain tradeoffs are worth noting. For instance, the 3rd party would need to arrange for access to the dairy's equipment or provide its own. If the 3rd party manages several dairy composting operations, it could split the equipment cost between sites but would incur additional costs for transporting equipment between sites. Lastly, there will be some degree of revenue sharing between the dairy and the composter that may make this less financially advantageous.

Currently, only a few 3rd-party entities compost manure at dairy facilities in California's Central Valley. They often operate at multiple dairies.

Off-Site, Dedicated Facility

In this third model, manure feedstocks are shipped to a centralized location dedicated to processing manure compost. This could be a new or existing facility, and would be modeled after large composting operations that accept municipal green waste and food scraps. This scenario is more feasible in the northern part of the San Joaquin Valley since dairies are more land constrained and, consequently, have greater incentive to get rid of their manure (for free or at a very low cost) and have less capacity for compost operations on-site.

This model has an advantage in that there is significant potential to build a strong brand and customer base. If the up-front permitting and equipment costs can be overcome, the opportunity to establish a high quality product, loyal customers, and a profitable venture is significant. In addition, a dedicated facility will have greater capacity to follow robust measurement, sampling, and reporting protocols required to achieve certain certifications.

Dedicated facilities will face greater regulatory hurdles, compared to the aforementioned scenarios, which benefit from dairy's agricultural exemptions or utilize on-site existing infrastructure. In addition, for an adequate return on investment a dedicated facility would need to operate at a scale that would exceed the SJVAPCD and CalRecycle's lower-tier permitting thresholds. This means that advanced pollution mitigation measures, and potentially purchase of emissions offsets, would be necessary, which would be much more costly.

Additional costs would include the lease or purchase land and all of the needed equipment (e.g. tractors, turners, etc.). This could amount to several hundred-thousand to millions of dollars of up-front capital costs. Based on conversations with composting professionals, the inbound transportation costs for shipping the manure would also require that all dairies providing feedstocks be within approximately 10 miles of the composting facility for this to be economical. This geographic constraint further limits the scenarios in which this option could work.

To our knowledge, currently only one large, centralized facility exists in the San Joaquin Valley that creates a compost made from 100% manure feedstock. This facility composts manure in response to the demand from one very large customer.

Off-Site Mixed Facility

It is unlikely under current market conditions that existing composting facilities will accept large volumes of dairy manure. The business model of these facilities is based on charging tipping fees for waste diversion from landfills. Manure, however, is a valuable product for which a dairy would expect $1 to $4 per ton, given current prices. There is little incentive for existing composting operations to incorporate a feedstock that is an expense rather than a revenue generator, particularly if they are already at or near their production capacity.

REFERENCES

Ahn, H.K., W. Mulbry, J.W. White, and S.L. Kondrad. 2011. Pile mixing increases greenhouse gas emissions during composting of dairy manure. Bioresour. Technol. 102(3): 2904–9.

Aldrich, B., and J. Bonhotal. 2006. Aerobic composting affects manure's nutrient content. Available at http://cwmi.css.cornell.edu/aerobiccomposting.pdf (verified 9 May 2017).

Amon, B., T. Amon, J. Boxberger, and C. Alt. 2001. Emissions of NH3, N2O and CH4 from dairy cows housed in a farmyard manure tying stall (housing, manure storage, manure spreading). Nutr. Cycl. Agroecosystems 60(1–3): 103–113.

Amundson, R., A.A. Berhe, J.W. Hopmans, C. Olson, A.E. Sztein, and D.L. Sparks. 2015. Soil and human security in the 21st century. Science 348(6235): 1261071.

Arikan, O., W. Mulbry, D. Ingram, and P. Millner. 2009. Minimally managed composting of beef manure at the pilot scale: Effect of manure pile construction on pile temperature profiles and on the fate of oxytetracycline and chlortetracycline. Bioresour. Technol. 100(19): 4447–4453.

Bartelt-Hunt, S.L., S. DeVivo, L. Johnson, D.D. Snow, W.L. Kranz, T.L. Mader, C.A. Shapiro, S.J. van Donk, D.P. Shelton, D.D. Tarkalson, and T.C. Zhang. 2013. Effect of Composting on the Fate of Steroids in Beef Cattle Manure. J. Environ. Qual. 42(4): 1159.

Batjes, N. h. 1996. Total carbon and nitrogen in the soils of the world. Eur. J. Soil Sci. 47(2): 151–163.

Benjamin, M. 2000. Estimating Ammonia Emissions in California. Available at http://www.arb.ca.gov/research/seminars/india/india.htm (verified 25 February 2016).

Bouwman, A.F., L.J.M. Boumans, and N.H. Batjes. 2002. Emissions of N2O and NO from fertilized fields: Summary of available measurement data. Glob. Biogeochem. Cycles 16(4): 1058.

Brady, N.C. 1990. The nature and properties of soils. Macmillan ; Collier Macmillan, New York; London.

Brown, S., and M. Cotton. 2011. Changes in Soil Properties and Carbon Content Following Compost Application: Results of On-farm Sampling. Compost Sci. Util. 19(2): 88–97.

Burger, M., C. Lazcano, and W.R. Horwath. 2013. Assessment of Nitrous Oxide Emissions in California's Dairy Systems. California Air Resources Board, Sacramento, CA.

Büyüksönmez, F. 2009. Comparison of Mitigation Measures for Reduction of Emissions Resulting from Greenwaste Composting. San Joaquin Valleywide Air Pollution Study Agency, San Diego, CA.

Büyüksönmez, F., and J. Evans. 2007. Biogenic Emissions from Green Waste and Comparison to the Emissions Resulting from Composting Part II: Volatile Organic Compounds (VOCs). Compost Sci. Util. 15(3): 191–199.

CalRecycle. 2010. Third Assessment of California's Compost- and Mulch-Producing Infrastructure - Management Practices and Market Conditions. California Department of Resources Recycling and Recovery, California.

Cambardella, C.A., T.L. Richard, and A. Russell. 2003. Compost mineralization in soil as a function of composting process conditions. Eur. J. Soil Biol. 39(3): 117–127.

CARB. undated. Composting - A Manure Treatment Technology. Available at http://www.arb.ca.gov/ag/caf/dairypnl/compovrvw.pdf (verified 25 February 2016).

CARB. 2014. California Greenhouse Gas Emissions Inventory: 2000-2012. California Air Resources Board, California.

CARB. 2016. Proposed Short-Lived Climate Pollutant Reduction Strategy. California Air Resources Board, Sacramento, CA.

CBF. 2004. Manure's Impact on Rivers, Streams and the Chesapeake Bay: Keeping Manure Out of the Water. Chesapeake Bay Foundation, Annapolis, MD.

CDFA. 2016. Dairy Statistics. Calif. Dep. Food Agric.Available at https://www.cdfa.ca.gov/dairy/dairystats_annual.html (verified 9 May 2017).

Celik, I., I. Ortas, and S. Kilic. 2004. Effects of compost, mycorrhiza, manure and fertilizer on some physical properties of a Chromoxerert soil. Soil Tillage Res. 78(1): 59–67.

Chee-Sanford, J.C., R.I. Mackie, S. Koike, I.G. Krapac, Y.-F. Lin, A.C. Yannarell, S. Maxwell, and R.I. Aminov. 2009. Fate and Transport of Antibiotic Residues and Antibiotic Resistance Genes following Land Application of Manure Waste. J. Environ. Qual. 38(3): 1086.

Christopher, S.F., and R. Lal. 2007. Nitrogen Management Affects Carbon Sequestration in North American Cropland Soils. Crit. Rev. Plant Sci. 26(1): 45–64.

Crowder, V. 2015. Milking Cows or Going Nuts? RaboResearchAvailable at https://research.rabobank.com/far/en/sectors/dairy/milking-cows-or-going-nuts.html (verified 11 May 2017).

CVDRMP. 2016. Executive Summary. *In* Central Valley Dairy Representative Monitoring Program Year 4 Annual Report. Central Valley Regional Water Quality Control Board, Central Valley.

Davidson, E.A. 2009. The contribution of manure and fertilizer nitrogen to atmospheric nitrous oxide since 1860. Nat. Geosci. 2(9): 659–662.

De Gryze, S., M.V. Albarracin, R. Catala-Luque, R.E. Howitt, and J. Six. 2009. Modeling shows that alternative soil management can decrease greenhouse gases. Calif. Agric. 63(2): 84–90.

DeLonge, M.S., and W.L. Silver. 2013. Effects of compost and manure additions on the greenhouse gas dynamics of managed grasslands. *In* AGU Fall Meeting Abstracts. American Geophysical Union.

Derby, N.E., H. Hakk, F.X.M. Casey, and T.M. DeSutter. 2011. Effects of Composting Swine Manure on Nutrients and Estrogens: Soil Sci. 176(2): 91–98.

Dolliver, H., S. Gupta, and S. Noll. 2008. Antibiotic Degradation during Manure Composting. J. Environ. Qual. 37(3): 1245.

Eichner, M.J. 1990. Nitrous Oxide Emissions from Fertilized Soils: Summary of Available Data. J. Environ. Qual. 19(2): 272.

Entry, J.A., A.B. Leytem, and S. Verwey. 2005. Influence of solid dairy manure and compost with and without alum on survival of indicator bacteria in soil and on potato. Environ. Pollut. 138(2): 212–218.

Favoino, E., and D. Hogg. 2008. The potential role of compost in reducing greenhouse gases. Waste Manag. Res. 26(1): 61–69.

Fukumoto, Y., T. Osada, D. Hanajima, and K. Haga. 2003. Patterns and quantities of NH3, N2O and CH4 emissions during swine manure composting without forced aeration—effect of compost pile scale. Bioresour. Technol. 89(2): 109–114.

Green, P.G., G. Kester, S. Tong, J. Swaney, S. Brown, G. Kuter, P. Leonard, and D. Woltering. 2011. Biosolids Co-Composting VOC and Ozone Formation Study. Water Environment Research Foundation.

Grewal, S.K., S. Rajeev, S. Sreevatsan, and F.C. Michel. 2006. Persistence of Mycobacterium avium subsp. paratuberculosis and Other Zoonotic Pathogens during Simulated Composting, Manure Packing, and Liquid Storage of Dairy Manure. Appl. Environ. Microbiol. 72(1): 565–574.

Hafner, S.D., C. Howard, R.E. Muck, R.B. Franco, F. Montes, P.G. Green, F. Mitloehner, S.L. Trabue, and C.A. Rotz. 2013. Emission of volatile organic compounds from silage: Compounds, sources, and implications. Atmos. Environ. 77(0): 827–839.

Hansen, J., M. Sato, P. Kharecha, D. Beerling, R. Berner, V. Masson-Delmotte, M. Pagani, M. Raymo, D.L. Royer, and J.C. Zachos. 2008. Target Atmospheric CO2: Where Should Humanity Aim? Open Atmospheric Sci. J. 2(1): 217–231.

Harter, T., J.R. Lund, J. Darby, G.E. Fogg, R. Howitt, K.K. Jessoe, G.S. Pettygrove, J.F. Quinn, J.H. Viers, D.B. Boyle, H.E. Canada, N. DeLaMora, K.N. Dzurella, A. Fryjoff-Hung, A.D. Hollander, K.L. Honeycutt, M.W. Jenkins, V.B. Jensen, A.M. King, G. Kourakos,

D. Liptzin, E.M. Lopez, M.M. Mayzelle, A. McNally, J. Medellin-Azuara, and T.S. Rosenstock. 2012. Addressing Nitrate in California's Drinking Water with a Focus on Tulare Lake Basin and Salinas Valley Groundwater. Report for the State Water Resources Control Board Report to the Legislature. Center for Watershed Sciences, University of California, Davis.

Harter, T., M. Young, and K. Lockhart. 2013. Nitrate and Salinity in Shallow Groundwater Beneath Dairy Farms in the Central Valley, California Task Report 1. State Water Resources Control Board, University of California Davis.

Hou, Y., G.L. Velthof, and O. Oenema. 2015. Mitigation of ammonia, nitrous oxide and methane emissions from manure management chains: a meta-analysis and integrated assessment. Glob. Change Biol. 21(3): 1293–1312.

Howard, C.J., W. Yang, P.G. Green, F. Mitloehner, I.L. Malkina, R.G. Flocchini, and M.J. Kleeman. 2008. Direct measurements of the ozone formation potential from dairy cattle emissions using a transportable smog chamber. Atmos. Environ. 42(21): 5267–5277.

Hu, J., C.J. Howard, F. Mitloehner, P.G. Green, and M.J. Kleeman. 2012. Mobile Source and Livestock Feed Contributions to Regional Ozone Formation in Central California. Environ. Sci. Technol. 46(5): 2781–2789.

Hu, Z., Y. Liu, G. Chen, X. Gui, T. Chen, and X. Zhan. 2011. Characterization of organic matter degradation during composting of manure–straw mixtures spiked with tetracyclines. Bioresour. Technol. 102(15): 7329–7334.

IPCC. 2007a. Climate change 2007 - The Physical Science Basis (S Solomon and Intergovernmental Panel on Climate Change, Eds.). Cambridge University Press, Cambridge ; New York.

IPCC. 2007b. IPCC Fourth Assessment Report.

Johnson, G.A., J.G. Davis, Y.L. Qian, and K.C. Doesken. 2006. Topdressing Turf with Composted Manure Improves Soil Quality and Protects Water Quality. Soil Sci. Soc. Am. J. 70(6): 2114.

Kumar, K., S. C. Gupta, Y. Chander, and A.K. Singh. 2005. Antibiotic Use in Agriculture and Its Impact on the Terrestrial Environment. p. 1–54. *In* Advances in Agronomy. Elsevier.

Lal, R. 2010. Managing Soils and Ecosystems for Mitigating Anthropogenic Carbon Emissions and Advancing Global Food Security. BioScience 60(9): 708–721.

Larney, F.J., L.J. Yanke, J.J. Miller, and T.A. McAllister. 2003. Fate of Coliform Bacteria in Composted Beef Cattle Feedlot Manure. J. Environ. Qual. 32(4): 1508.

Lee, H., and D.A. Sumner. 2014. Greenhouse Gas Mitigation Opportunities in California Agriculture: Review of the Economics. Duke University, Durham, NC.

Lessard, R., P. Rochette, E.G. Gregorich, R.L. Desjardins, and E. Pattey. 1997. CH4 fluxes from a soil amended with dairy cattle manure and ammonium nitrate. Can. J. Soil Sci. 77(2): 179–186.

LGMA. 2014. 2013/2014 Annual Report. California Leafy Greens Marketing Agreement.

LGMA. 2016. Commodity Specific Food Safety Guidelines for the Production and Harvest of Lettuce and Leafy Greens. California Leafy Greens Marketing Agreement.

Li, X., E.R. Atwill, and T. Harter. 2013. Microbial pathogen risks to dairy groundwater. Department of Land, Air, and Water Resources. University of California, Davis, Davis, CA.

Lopez-Real, J., and M. Baptista. 1996. A Preliminary Comparative Study of Three Manure Composting Systems and their Influence on Process Parameters and Methane Emissions. Compost Sci. Util. 4(3): 71–82.

Massei, G., L. Rocchi, L. Paolotti, S. Greco, and A. Boggia. 2014. Decision Support Systems for environmental management: A case study on wastewater from agriculture. J. Environ. Manage. (0)Available at http://www.sciencedirect.com/science/article/pii/S0301479714004150.

Meng, L., W. Ding, and Z. Cai. 2005. Long-term application of organic manure and nitrogen fertilizer on N2O emissions, soil quality and crop production in a sandy loam soil. Soil Biol. Biochem. 37(11): 2037–2045.

Menzi, H., P. Katz, R. Frick, M. Fahrni, and M. Keller. 1997. Ammonia emissions following the application of solid manure to grassland. p. 265–274. *In* Jarvis, S.C., Pain, B.F. (eds.), Gaseous Nitrogen Emissions from Grasslands. CAB International.

Meyer, D., J.P. Harner, W. Powers, and E. Tooman. 2003. Manure Technologies for Today and Tomorrow. p. 186–195. *In* Proceedings of the 6 th Western Dairy Management Conference. Reno, NV.

Michalak, P. 2004. Water, Agriculture and You. The Rodale Institute, Kutztown, Pennsylvania.

Michel, F.C., J.A. Pecchia, J. Rigot, and H.M. Keener. 2004. Mass and Nutrient Losses During the Composting Of Dairy Manure Amended with Sawdust or Straw. Compost Sci. Util. 12(4): 323–334.

Min, D.H., K.R. Islam, L.R. Vough, and R.R. Weil. 2003. Dairy Manure Effects on Soil Quality Properties and Carbon Sequestration in Alfalfa–Orchardgrass Systems. Commun. Soil Sci. Plant Anal. 34(5–6): 781–799.

Mitloehner, F.M., H. Sun, and J.F. Karlik. 2009. Direct measurements improve estimates of dairy greenhouse-gas emissions. Calif. Agric. 63(2): 79–83Available at http://californiaagriculture.ucanr.org/landingpage.cfm?article=ca.v063n02p79&fulltext=yes# (verified 23 September 2015).

Montgomery, D.R. 2007. Soil erosion and agricultural sustainability. Proc. Natl. Acad. Sci. 104(33): 13268–13272.

Pardo, G., R. Moral, E. Aguilera, and A. del Prado. 2015. Gaseous emissions from management of solid waste: a systematic review. Glob. Change Biol. 21(3): 1313–1327.

Paul, J.W., C. Wagner-Riddle, A. Thompson, R. Fleming, and M. MacAlpine. 2001. Composting as a strategy to reduce greenhouse gas emissions. p. 14. *In* Canadian Nuclear Society, Toronto, Ontario.

Pell, A.N. 1997. Manure and Microbes: Public and Animal Health Problem? J. Dairy Sci. 80(10): 2673–2681.

Pinder, R.W., N.J. Pekney, C.I. Davidson, and P.J. Adams. 2004. A process-based model of ammonia emissions from dairy cows: improved temporal and spatial resolution. Atmos. Environ. 38(9): 1357–1365.

Ramaswamy, J., S.O. Prasher, R.M. Patel, S.A. Hussain, and S.F. Barrington. 2010. The effect of composting on the degradation of a veterinary pharmaceutical. Bioresour. Technol. 101(7): 2294–2299.

Reddy, N., and D.M. Crohn. 2012. Compost Induced Soil Salinity: A New Prediction Method and Its Effect on Plant Growth. Compost Sci. Util. 20(3): 133–140.

Rosen, C.J., and P.M. Bierman. 2005. Using Manure Compost as Nutrient Sources for Vegetable Crops. Available at http://www.extension.umn.edu/garden/fruit-vegetable/using-manure-and-compost/docs/manure-and-compost.pdf (verified 20 April 2017).

Ryals, R., M. Kaiser, M.S. Torn, A.A. Berhe, and W.L. Silver. 2014. Impacts of organic matter amendments on carbon and nitrogen dynamics in grassland soils. Soil Biol. Biochem. 68: 52–61.

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. California Air Resources Board, Sacramento, CA.

van der Schans, M.L., T. Harter, A. Leijnse, M.C. Mathews, and R.D. Meyer. 2009. Characterizing sources of nitrate leaching from an irrigated dairy farm in Merced County, California. J. Contam. Hydrol. 110(1–2): 9–21.

Shepherd, Jr., M.W., P. Liang, X. Jiang, M.P. Doyle, and M.C. Erickson. 2007. Fate of Escherichia coli O157:H7 during On-Farm Dairy Manure–Based Composting. J. Food Prot. 70(12): 2708–2716.

SJVAPCD. 2010. Compost VOC Emission Factors. San Joaquin Valley United Air Pollution Control District, Fresno, CA.

SJVAPCD. 2012a. Air Pollution Control Officer's Revision of the Dairy VOC Emission Factors. San Joaquin Valley United Air Pollution Control District, San Joaquin Valley.

SJVAPCD. 2012b. Air Pollution Control Officer's Revision of the Dairy VOC Emission Factors. San Joaquin Valley United Air Pollution Control District, San Joaquin Valley.

SJVAPCD. 2013. Chapter 2: Scientific Foundation, Trends, and Modeling Results. p. 12. *In* 2013 Plan for the Revoked 1-Hour Ozone Standard. San Joaquin Valley Air Pollution Control District, San Joaquin Valley.

SJVAPCD. 2015a. Chapter 2: PM2.5 Challenges and Trends in the San Joaquin Valley. *In* 2015 Plan for the 1997 PM2.5 Standard. San Joaquin Valley.

SJVAPCD. 2015b. Executive Summary. p. 6. *In* 2015 Plan for the 1997 PM2.5 Standard. San Joaquin Valley Air Pollution Control District, San Joaquin Valley.

SJVAPCD. 2016. Public Information Request.

Suddick, E.C., K.M. Scow, W.R. Horwath, L.E. Jackson, D.R. Smart, J. Mitchell, and J. Six. 2010. Chapter Four - The Potential for California Agricultural Crop Soils to Reduce Greenhouse Gas Emissions: A Holistic Evaluation. p. 123–162. *In* Donald L Sparks (ed.), Advances in Agronomy. Academic Press.

Sumner, D., J. Medellín-Azuara, and E. Coughlin. 2015. Contributions of the California Dairy Industry to the California Economy: A Report for the California Milk Advisory Board. University of California Agricultural Issues Center, California.

Tartoura, K.A.H., S.A. Youssef, and E.-S.A.A. Tartoura. 2014. Compost alleviates the negative effects of salinity via up-regulation of antioxidants in Solanum lycopersicum L. plants. Plant Growth Regul. 74(3): 299–310.

Tyson, T., and S. Mukhtar. 2015. Liquid Manure Storage Ponds, Pits, and Tanks. eXtensionAvailable at http://articles.extension.org/pages/15476/liquid-manure-storage-ponds-pits-and-tanks (verified 12 May 2017).

UC ANR Committee of Experts. 2006. Managing Dairy Manure in the Central Valley of California. UC ANR, Sacramento, CA.

US BLS. 2015. Unemployment in the San Joaquin Valley by County - August 2015. Western Information Office, U.S. Bureau of Labor Statistics.

US Census Bureau. 2016. QuickFacts. Available at //www.census.gov/quickfacts/ (verified 9 May 2017).

US EPA. 2003. National management measures to control nonpoint source pollution from agriculture. Office of Water, Nonpoint Source Control Branch, U.S. Environmental Protection Agency, Washington, DC.

US EPA. 2017a. Overview of Greenhouse Gases. Available at https://www.epa.gov/ghgemissions/overview-greenhouse-gases (verified 9 May 2017).

US EPA. 2017b. Chapter 5 Agriculture. p. 1–49. *In* Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015. US EPA, United States of America.

USDA-NASS. 2017. County Ag Commissioners' Data Listing. Available at https://www.nass.usda.gov/Statistics_by_State/California/Publications/AgComm/Detail/ (verified 9 May 2017).

Wright, A.L., T.L. Provin, F.M. Hons, D.A. Zuberer, and R.H. White. 2008. Compost Impacts on Sodicity and Salinity In a Sandy Loam Turf Grass Soil. Compost Sci. Util. 16(1): 30–35.

Wu, X., Y. Wei, J. Zheng, X. Zhao, and W. Zhong. 2011. The behavior of tetracyclines and their degradation products during swine manure composting. Bioresour. Technol. 102(10): 5924–5931.

Zhang, H., J. Shi, X. Liu, X. Zhan, J. Dang, and T. Bo. 2014. Occurrence of free estrogens, conjugated estrogens, and bisphenol A in fresh livestock excreta and their removal by composting in North China. Environ. Sci. Pollut. Res. 21(16): 9939–9947.

Zhu-Barker, X., T.A. Doane, and W.R. Horwath. 2015. Role of green waste compost in the production of N2O from agricultural soils. Soil Biol. Biochem. 83: 57–65.