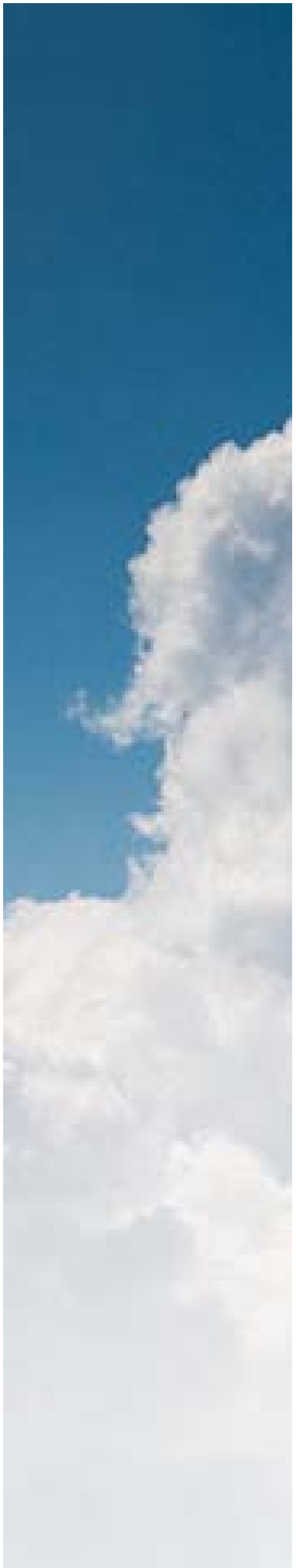
DAIRY RESEARCH PROSPECTUS TO ACHIEVE CALIFORNIA'S SB 1383 CLIMATE GOALS

A document from the Dairy and Livestock Subgroup #3.
Comprehensive outline of dairy research concepts and needs to effectively achieve California's SB 1383 climate goals.

November 26, 2018



The statements and conclusions reported in this document are not necessarily those of the individual members of the Dairy and Livestock Working Group. The mention of commercial products, their sources, and/or their affiliations does not constitute any endorsement. The report is available from the Dairy and Livestock Working Group website hosted by the California Air Resources Board at https://www.arb.ca.gov/cc/dairy/dairy.htm. Any questions regarding this document should be submitted to SLCP@arb.ca.gov.

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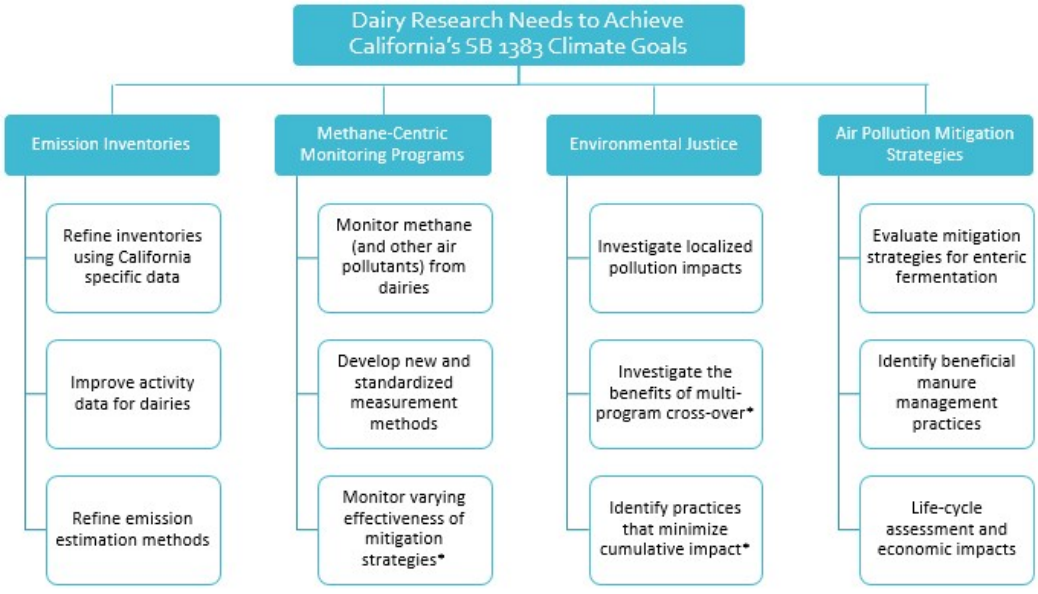
EXECUTIVE SUMMARY

The Dairy and Livestock Subgroup #3 (SG#3) was formed to: (i) identify dairy research needs to improve the emission estimates of short-lived climate pollutants (SLCPs), especially methane (CH_4), associated with dairy operations in California, (ii) better understand the potential to reduce CH_4 emissions from manure through the implementation of mitigation strategies while understanding the air quality and other environmental impacts from the implementation of those strategies, and (iii) better understand the potential to reduce CH_4 emissions from enteric fermentation.

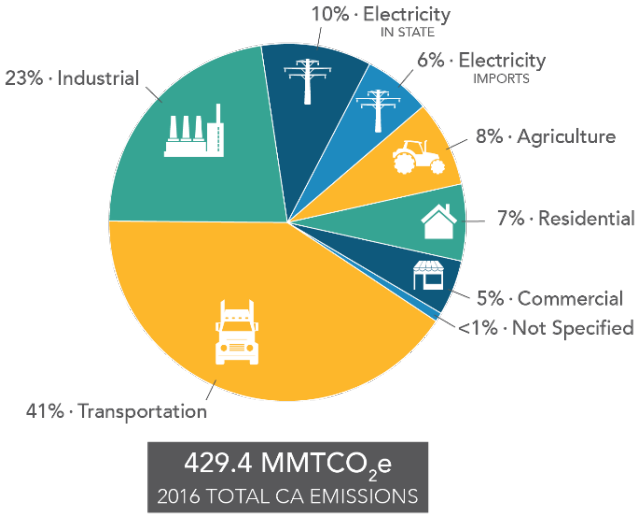
SG#3 held a series of public meetings to discuss past and current research in the dairy sector. Through this process, SG#3 identified the knowledge shortfalls and dairy emissions research needs in California. SG#3 subsequently developed this *Dairy Research Prospectus to Achieve California's SB 1383 Climate Goals* with a broad range of research ideas gathered from the stakeholders including working group members, dairy industry, researchers, government agencies, environmental justice advocates, and others. These ideas formed the basis for the recommended project concepts. Information obtained from such research should improve the understanding of dairy emissions and effective SLCP mitigation strategies. Focused implementation of CH_4 emission reduction measures should achieve the goals of Senate Bill 1383 (SB 1383). These recommended project concepts are shown below:



INTRODUCTION

IMPORTANCE OF CALIFORNIA'S DAIRY INDUSTRY

California dairies lead the nation in milk production. According to the California Agricultural Statistics Review 2016-2017, milk and dairy products produced the largest annual revenues (approximately $6.07 billion) among all agricultural commodities. The dairy industry is an integral part of the State's economy.



Breakdown of GHG emissions in California (California's 2016 Statewide GHG Emission Inventory, 2018 Edition).

Currently, the agricultural sector contributes to approximately 8% of California's total greenhouse gas (GHG) emissions, and approximately 57% of California's total CH_4 emissions. Of the 57% CH_4 contribution, 11 million metric tons of carbon dioxide equivalent (MMT CO_2e) per year is attributed to enteric fermentation from all cattle (dairy and non-dairy), and 10 MMT CO_2e per year is attributed to dairy manure management.

The carbon footprint per billion pounds of milk produced in 2007 was only 37% of 1944 levels. The dairy industry has been steadily reducing the GHG intensity of milk production through the implementation of research findings, and the improvements primarily in the management of genetics, nutrition, animal husbandry, and farming practices. Additional research and management improvements are needed to accelerate the total amount of CH_4 reductions to achieve California's climate goals. Dairy farmers have used research findings to improve efficiencies and production for decades. Today, California dairies continue to reduce GHG emissions through the implementation of known and newly developed practices. Since the passage of SB 1383, California dairies have been successfully implementing practices to reduce CH_4 emissions from manure.

LEGISLATIVE ACTIVITIES TO COMBAT CLIMATE CHANGE

In September 2014, Senate Bill 605 (SB 605, Lara, Chapter 523) was passed and signed into law, which requires the California Air Resources Board (CARB) to develop a comprehensive strategy to reduce statewide emissions of SLCPs. Subsequent adoption of Senate Bill 1383 (SB 1383, Lara, Chapter 395) in September 2016 requires CARB to approve and implement comprehensive strategies to achieve reduction of CH_4 by 40%, hydrofluorocarbon gases by 40%, and anthropogenic black carbon by 50% below 2013 levels by 2030. SB 1383 includes explicit requirements to reduce CH_4 emissions from landfills and dairy manure management operations. In addition, Assembly Bill 1496 (AB 1496, Thurmond, Chapter 604) approved in 2015 requires CARB to undertake monitoring and measurements of high emission CH_4 hot spots in California, focusing on oil and gas facilities, landfills, and dairies.

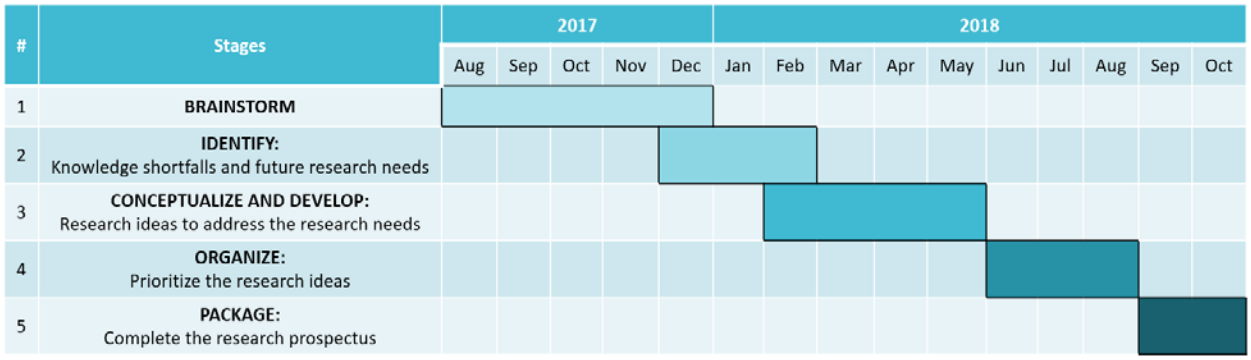
Signing ceremony of SB 1383.

OBJECTIVES OF DAIRY AND LIVESTOCK WORKING GROUP: SG#3

As regulated by SB 1383, CARB, the California Department of Food and Agriculture (CDFA), the California Energy Commission (CEC), and the California Public Utilities Commission (CPUC) assembled a Dairy and Livestock Working Group in 2017 to identify and address technical difficulties, market barriers, and regulatory challenges to facilitate the development of dairy CH_4 emission reduction measures with a broad range of stakeholders. Furthermore, three subgroups were created to effectively address key questions related to dairy manure management and enteric fermentation.

The purpose of SG#3 is to identify and prioritize dairy research needs to improve our knowledge of CH_4 emissions from dairies, improve our understanding of the potential to reduce manure CH_4 emissions through the implementation of mitigation strategies while understanding the other environmental benefits and impacts of such strategies, and evaluate the feasibility of enteric fermentation CH_4 emission reduction strategies. Product quality, consumer acceptance, animal health and welfare, dairy economics, and other environmental benefits and impacts were identified as critical parameters that must also be evaluated to effectively achieve the goals of SB 1383.

SG#3 held a series of public meetings during which the members discussed past and current research in the dairy sector, and identified the knowledge shortfalls and future dairy air research needs. SG#3 also implemented the Request for Ideas (RFI) solicitation process to conceptualize and develop the *Dairy Research Prospectus to Achieve California's SB 1383 Climate Goals* that encompassed a broad range of research ideas gathered from the stakeholders including working group members, dairy industry, researchers, government agencies, environmental justice advocates, and others.



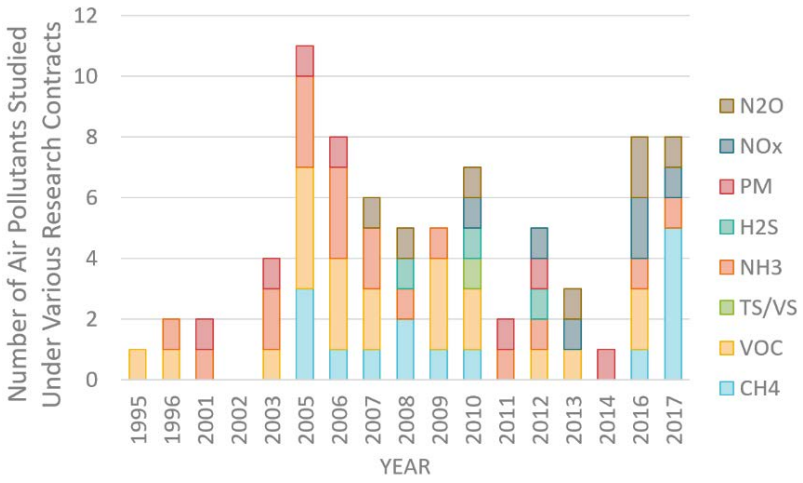
SG#3 activities between August 2017 and October 2018.

The compilation of the ideas submitted, along with input from all three subgroups and community groups were considered and incorporated into *the Dairy Research Prospectus to Achieve California's SB 1383 Climate Goals.* This prospectus prioritizes future dairy research projects and serve as a guide for California's funding agencies and organizations.

SECTION 1: PREVIOUS DAIRY AND LIVESTOCK GHG AND AIR QUALITY RESEARCH IN CALIFORNIA

SUMMARY OF PAST RESEARCH FINDINGS

Experimental measurements and model simulations have been used in California to identify the conditions under which CH_4 is formed/produced, and to determine the environmental impacts of dairy and livestock related air pollutants that are typically emitted from various parts of their operations. Air pollutants include GHGs, such as CH_4 and nitrous oxide (N_2O), and other important air quality drivers such as volatile organic compounds (VOCs), ammonia (NH_3), hydrogen sulfide (H_2S), oxides of nitrogen (NO_x), and particulate matter (PM)[1-8]. By 2017, more than 40 research projects have been funded in California by government agencies, non-government organizations, and the dairy industry. Nationally, dairy and livestock research efforts addressed a variety of topics including, but not limited to the following:



Number of California dairy research studies on various air pollutants associated with dairies.

- Estimating emission rates and calculating emission factors to evaluate and improve emission inventories[2, 9-11],
- Developing process-based emission models[12-14],
- Assessing impacts on regional air quality and climate change[1, 5, 15-16], and
- Investigating various mitigation practices for air pollution emission reductions[17-19].

Despite considerable variabilities in when, where, and how much air pollutants are emitted by California dairies[20, 21], previous studies have determined that:

- Dairy and livestock operations are one of the largest emission sources of GHG (and other air pollutants such as NH_3) in some regions of California such as the San Joaquin Valley (SJV)[22, 23],
- Some research suggests that emissions of CH_4 and NH_3 from California dairies may be underestimated in the current inventories[24-27],
- Process-based emission models were incomplete and needed additional improvements to better represent real-world conditions (e.g., chemical, biological, and physical processes that affect emissions) and to improve quantitative estimation of dairy emissions in California[13, 28, 29],
- Dairy-related CH_4 measurements are spatially sparse and lack temporal resolution in California, and
- Potential mitigation options are available in California, but need further evaluation to ensure that there are no significant public health and environmental impacts[30-35], and that the strategies are cost-effective[36].

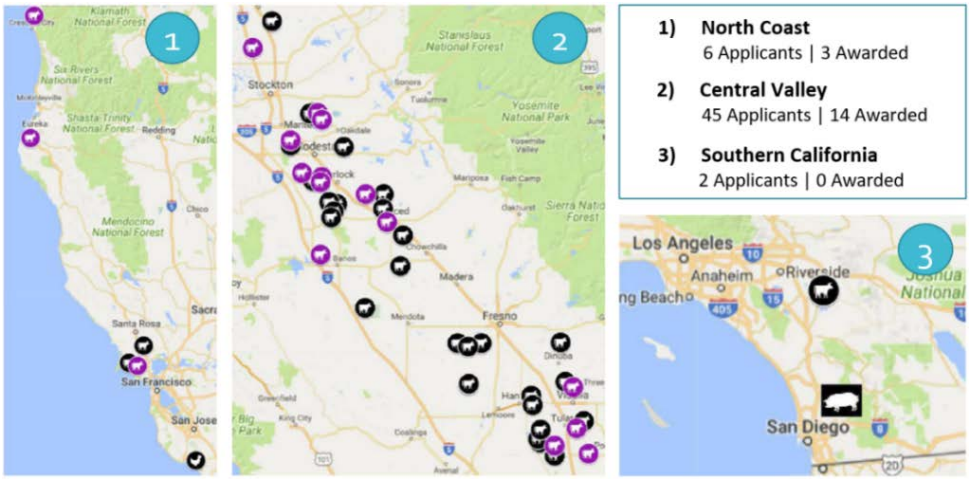
SECTION 2: CURRENT DAIRY AND LIVESTOCK GHG AND AIR QUALITY PROGRAMS AND RESEARCH IN CALIFORNIA

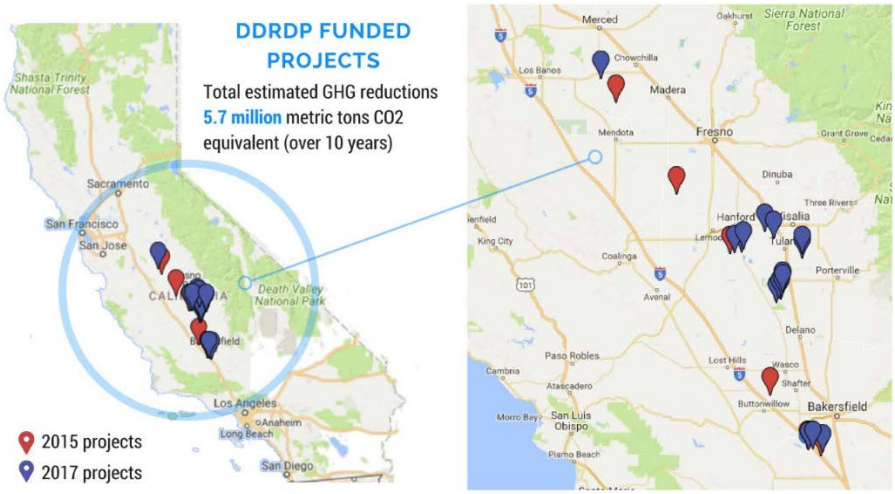
The California Legislature has invested considerable resources in various government agencies to research and reduce GHG emissions associated with dairy operations. As a result, many dairy air research projects are in progress.

CDFA SPONSORED DAIRY INCENTIVE PROGRAMS AND RESEARCH PROJECTS

CDFA currently is managing two major incentive programs related to dairy GHG emission research and mitigation. The Dairy Digester Research & Development Program (DDRDP) strives to have CH_4 produced, collected, and utilized with the goal of preventing it from being emitted to the atmosphere. This program provides financial assistance for the installation of dairy digesters in California. The Alternative Manure Management Program (AMMP) strives to reduce or prevent anaerobic conditions, thus curbing the formation of CH_4. This program incentivizes the development and implementation of non-digester manure management practices to reduce GHG emissions. CDFA received $99 million from the Greenhouse Gas Reduction Fund (GGRF) in 2017 (AB 109 – Budget Act of 2017), which supported the DDRDP and AMMP. The figures below show the geographical distribution of CDFA funded DDRDP and AMMP application locations in the State.

Location of AMMP Funded Projects in California. Source: SB 1383 Subgroup #1 Presentation, https://www.cdfa.ca.gov/oefi/AMMP/docs/SB1383_Subgroup1-Presentation.pdf





Location of DDRDP Funded Projects in California. Source: CDFA DDRDP Report of Funded Projects (2015-2017), https://www.cdfa.ca.gov/oefi/ddrdp/docs/DDRDP_Report_February2018.pdf

In addition to GGRF, CDFA and stakeholders jointly funded a research project focusing on the evaluation of AMMP practices. Baseline emissions at six selected dairy farms in the SJV, which received AMMP grants, will be quantified. The objectives include the analysis of various air pollutants (including CH_4, N_2O, NO_x, VOCs, NH_3, H_2S, and PM) before the implementation of AMMP practices. The project will also evaluate existing dairy emission modeling tools and identify/recommend an appropriate model for estimating baseline emissions in California. CARB is coordinating with CDFA and the researchers to conduct studies that will evaluate emissions after the AMMP practices have been implemented (described in the section below).

In a separate contract, CDFA and California's dairy industry are also investigating the effect of solid-liquid separation technologies on reducing CH_4 emissions from dairy manure lagoons. The researchers are collecting and analyzing liquid manure samples from six dairy farms equipped with different types of separators to examine the removal efficiency of volatile solids (VS) and their CH_4 emission reduction potential.

In addition, under the Small Dairy Climate Change Research program, CDFA recently initiated a project to conduct economic evaluations of strategies for CH_4 emission reduction effectiveness and appropriateness in small and large California dairies. Authorized by the Budget Act of 2017-18, this study will contribute to the Small Dairy Climate Action Plan.

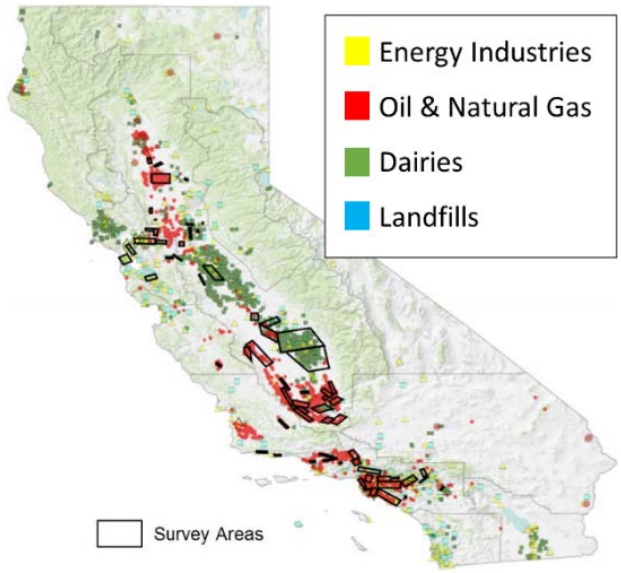
CARB SPONSORED DAIRY RESEARCH PROJECTS

CARB is currently working with researchers to characterize California-specific cattle feed rations and to improve the modeling of enteric fermentation for California's GHG emission inventory. The existing Cattle Enteric Fermentation Model developed by the United States Environmental Protection Agency (U.S. EPA) does not represent the animal diet and management variabilities observed throughout the nation. The objective of this project is to create a set of empirical mathematical models for estimating enteric CH_4 emissions from California's cattle using California-specific inputs.

CARB is also working with researchers to characterize the physical and chemical properties of manure in California dairy systems to improve GHG emission estimates. Researchers are conducting surveys of manure management pathways at representative dairy farms. Furthermore, representative samples of manure are used to determine the flow of VS. Results will be compared to U.S. EPA's assumptions about VS in manure management systems modeled according to farm size, temperature, and other factors related to CH_4 production.

In addition, CARB is funding a research study on strategies to reduce CH_4 emissions from enteric and lagoon sources. The project will conduct a literature review, database analysis, and life cycle assessment to evaluate the potential and feasibility of using additives in animal feed and manure storage lagoons as a strategy to reduce CH_4 emissions.

As part of the AB 1496 research efforts, CARB and CEC co-funded NASA's Jet Propulsion Laboratory to conduct a large-scale statewide aerial survey to identify "hot spots" of CH_4 emissions in California using an imaging camera onboard a research aircraft. The survey identified various CH_4 sources in California including dairies. CARB has also contracted with Scientific Aviation to perform airborne measurements at specific survey areas in California to quantify facility-level CH_4 emission fluxes using small aircraft equipped with advanced instruments. This project estimated CH_4 emission rates from large diffuse sources such as dairies.



AB 1496 Airborne Campaign Area. Source: https://ww2.arb.ca.gov/our-work/programs/methane/ab1496-research

More recently, CARB funded a companion study on AMMP practices to compare the emissions from pre- and post-AMMP dairies. This project will quantitatively determine the effectiveness of different AMMP strategies on CH_4 emission reduction. The research project includes not only on-site measurements, but also a scenario-based air quality forecasting model to understand the impact of AMMP practices on local and regional air quality. Specifically, the concentrations of PM and ozone (O_3) in the SJV through 2050 will be predicted using the emission monitoring results. The modeling effort will help identify AMMP practices that would avoid otherwise unforeseen environmental impacts. This research will lead to a comprehensive evaluation of dairy manure CH_4 emission reduction strategies in California.

UCD Mobile Air Quality Laboratory that will be deployed for pre- and post-AMMP research studies.

UNIVERSITY OF CALIFORNIA SPONSORED DAIRY RESEARCH PROJECTS

The University of California Office of the President (UCOP) funded a group of researchers to study the climate impact of manure management from California dairies. The researchers will measure, model, and estimate the emissions of GHGs and other air pollutants from dairies using a multi-tiered approach (including field sampling, surface-level mobile measurements, aerial measurements, air pollution dispersion modeling, and process-based modeling). Furthermore, the researchers will construct a high-resolution map of CH_4 and N_2O emission sources in the SJV.

SECTION 3: FUTURE DAIRY AND LIVESTOCK GHG AND AIR QUALITY RESEARCH NEEDS IN CALIFORNIA

IDENTIFYING KNOWLEDGE SHORTFALLS AND RESEARCH NEEDS

SG#3 identified four major dairy research areas in which California has knowledge shortfalls and research needs. These topics were presented at the public meeting on December 18, 2017 (https://www.arb.ca.gov/cc/dairy/dsg3/dsg3.htm). To promote transparency and public involvement, SG#3 initiated a RFI solicitation process requesting for research ideas from the general public, dairy industry, researchers, government agencies, and environmental justice advocates. This process gathered information to help prioritize the most important research needed to achieve the goals of SB 1383 while promoting a collaborative environment. The RFI process was introduced during the public meeting on February 28, 2018. CARB hosted the RFI Submission Docket under the Dairy and Livestock SG#3 website (https://www.arb.ca.gov/cc/dairy/dsg3/dsg3-archive.htm), which was made public in March 2018. Outreach efforts were extended to the SJV Ag Tech Group, California Dairy Research Foundation, CDFA, CEC, CPUC, United States Department of Agriculture (USDA) Agricultural Air Quality Task Force, USDA Sustainable Dairy Project Team, University of California, California State University, and more. California's dairy industry provided significant support and constructive input during various SG#3 processes.

The RFI submission process started on March 15, 2018 and ended on May 31, 2018. All potential contributors had the opportunity to submit ideas under one or more of the knowledge shortfalls and research needs identified during the earlier activities of SG#3. The RFI Submission Guideline

CALIFORNIA AIR RESOURCES BOARD

Request for Ideas (RFI) for Dairy Research

Subgroup #3 (Research Needs, Including Enteric Fermentation)

The Dairy and Livestock Subgroup #3 (Research Needs, Including Enteric Fermentation) is requesting RFI submissions to define research needs and knowledge shortfalls that can be addressed to facilitate the reduction of dairy and livestock methane emissions. All interested parties are invited to submit research ideas that can help California effectively achieve SB 1383 goal

RFI submissions will be pre-screened for completeness and appropriate content. Pre-screened submissions will be reviewed by Subgroup #3 committee members before they are drafted into a Dairy Air Research Prospectus. The completed prospectus will be used to provide recommendations for the most feasible research needed to address SB 1383 goals under each of the knowledge shortfalls identified previously by Subgroup #3.

Completed RFI Submission Forms are to be sent to SLCP@arb.ca.gov. The deadline to submit is **May 31, 2018 at 5:00 pm (PDT)**.

Interested parties are encouraged to learn more about the RFI submission process by visiting the Subgroup #3 website.

Disclaimer: There are no intentions from any partners or affiliations in awarding a contract for funding based on RFI submissions, and participation in this RFI solicitation process does not translate to future funding, nor lack thereof.

More Information

Listserv notification of RFI Solicitation and announcement of RFI Submission Docket

(https://arb.ca.gov/cc/dairy/dsg3/rfi-submission-guideline.pdf) was provided to the public in order to help participants better understand the purpose of the solicitation, general submission procedure, and submission requirements. In addition, the RFI Submission Evaluation Guideline was created and discussed by SG#3 members in order to review submissions.

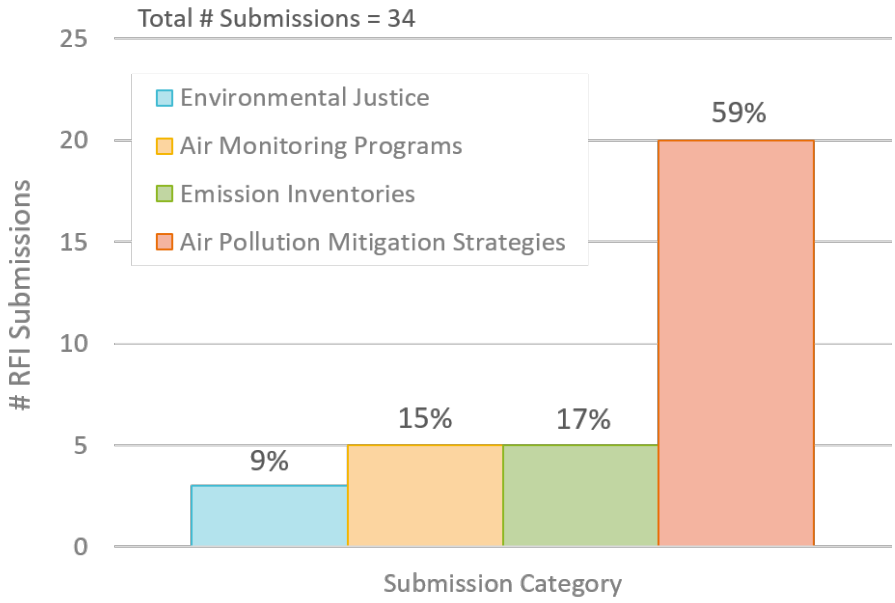
RFI EVALUATION PROCESS

All RFI submissions were first reviewed by CARB staff. This initial review process removed unqualified submissions that did not follow the RFI Submission Guideline developed by SG#3. This led to the removal of submissions that included unrealistic demands, inappropriate language, and those that did not pertain to the SB 1383 CH_4 emission reduction objectives.

The SG#3 members were grouped into two reviewing committees based on the number (34) of the submissions that passed the initial review. This strategy was developed to promote a thorough review of each RFI submission in a timely manner. The committee members were distributed between the two groups to reflect similar composition of experts, and were responsible for evaluating all of the submissions that were assigned to the respective group. Personally identifiable information was removed from all of the submissions before being reviewed by the committee members to prevent any potential biases. The members of the reviewing committees were not allowed to evaluate their own submissions. For example, one SG#3 member submitted dairy research ideas and another member was involved in the development of RFI submittals. These two members did not review the submissions in which they participated. To maintain a consistent review of individual submissions, the SG#3 members used a set of common criteria, which was designed based on the RFI evaluation criteria and included environmental impacts, industry impacts, policies/regulations/programs, and feasibility. In order to promote consistency in the evaluation of RFI submissions, clear definitions for the scoring criteria were established before the submissions were sent to the reviewing committee members.

RESULTS FROM OPEN RFI PROCESS

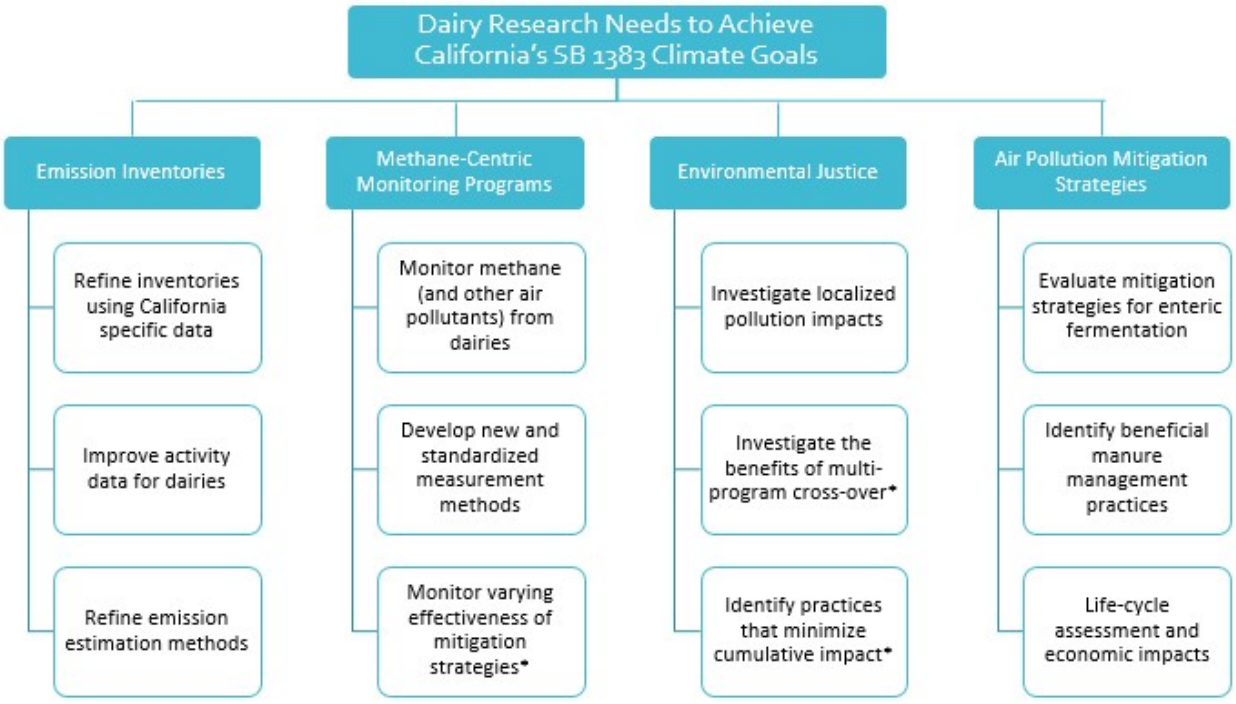
There were 34 RFI submissions which passed the completeness review conducted by CARB staff. RFI submitters included academic institutions, non-governmental and non-profit organizations, government agencies, and industry. A summary of each submission can be found in the appendix of this document. During the public meeting on June 26, 2018, SG #3 members discussed the RFI results and decided to categorize the submissions by summarizing the broad concepts based on the information collected during the RFI process. CARB staff worked with SG #3 members to develop the categorized dairy research needs which are described in the following section of this document.



Statistics on the breakdown of RFI submissions.

RECOMMENDATIONS

The 34 RFI submissions were grouped into twelve major project concepts based on objectives, methods, and evaluation procedures. Additional comments from the stakeholders (Dairy and Livestock Subgroups #1 and #2, community groups, academia, etc.) were also incorporated. A summary of the dairy research needs to achieve California's SB 1383 climate goals can be found below:



Research project concepts that address dairy research needs based on the RFI submissions.

**Note: New major project concepts added in response to comments received at the August 27, 2018 SG #3 meeting.*

EMISSION INVENTORIES (Submissions # 2, 8, 10, 16, 17, 24)

Research Project Concepts		
Concept Title	**Motivation/Problem**	**Solution/Approach**
Refine inventories using California specific data	California utilizes national dairy data to develop the CH_4 emission inventory. However, dairies and manure management strategies in California are often different, which significantly affects the emission rates of air pollutants. Existing inventories need further refinement using California specific data to reflect realistic conditions.	Conduct a comprehensive measurement campaign to quantify emissions of GHGs (and other air pollutants) from a variety of dairy and livestock operations in California to develop a more accurate understanding of dairy CH_4 emissions. This quantification is critical to identifying the largest and most cost-effective opportunities for reductions.
Improve activity data for dairies	Comprehensive information on dairy activities is necessary to help California regulators, lawmakers, and industry realize the most feasible CH_4 emission reduction and mitigation strategies. However, detailed dairy activities data are very limited in California (e.g., feed types; manure collection, storage, treatment, and application; housing facilities and maintenance). These activities significantly affect CH_4 emissions, and therefore must be evaluated to the fullest extent possible in order to further refine the CH_4 emission inventory.	Conduct a comprehensive survey of dairy activities in California, which includes information on feed types; manure collection, storage, treatment, and application; and housing facilities and maintenance from diverse dairy operations. Devise and evaluate potential strategies to improve our understanding of on-farm air pollutant emissions. This effort should incorporate downstream activities during dried manure application on croplands and associated irrigation practices, etc. Gaining a better understanding of dairy activities will allow California funding agencies and organizations to make more informed decisions regarding funding of practices with the largest environmental impact reductions.
Refine emission estimation methods	Parameterization of dairy emission estimation methods has relied on limited data that are specific to the evaluated dairy farms. Additional model and method verification measures are needed to improve CH_4 emission estimates that has transferability to the diversity of dairies in California.	Compile comprehensive information (e.g., enteric-, silage-, and manure-related management activities) and collect additional and better data (e.g., on-farm air pollutant emissions) for California dairies to update, calibrate, and validate emission models and methods. Determine the feasibility of incorporating new data into existing emission inventories, and refine the emission inventory where deemed appropriate. Improvement of the estimation methods is critical to identifying the largest and most cost-effective opportunities for reductions.

METHANE-CENTRIC MONITORING PROGRAMS (Submissions #1, 11, 13, 26, 29, public comments)

Research Project Concepts		
Concept Title	**Problem**	**Solution/Approach**
Monitor methane (and other air pollutants) from dairies	Dairy CH_4 emissions vary based on on-site animal and manure management practices and seasonal weather conditions. Long-term air monitoring at multiple dairies is needed to improve our understanding of the impacts of farm specific management practices and seasonal weather conditions on California' dairy emissions.	Install long-term air monitors at various dairy facilities in California to measure emissions of CH_4 (and other air pollutants). Performing these measurements before and after the implementation of GHG emission reduction strategies may provide insight into effective and economically viable manure management practices.
Develop new and standardized measurement methods	Establishment of an agreed upon set of operating procedures and methodologies to measure dairy emissions would allow the comparison of results from one dataset to another. Having data collected by similar instruments and techniques would better inform process-level emission models, improve our understanding of spatiotemporal variabilities of emissions, and lead to further refinement of the CH_4 emission inventory. Additionally, development of new technologies for improved measurements would enhance the current suite of measurement capabilities for dairy emission quantification.	Develop standardized methods of dairy emission analyses to allow for greater integration of research findings and encourage the identification and implementation of new technologies to further reduce methane emissions.
Monitor varying effectiveness of mitigation strategies*	Ability to monitor CH_4 emission changes from the implementation of mitigation strategies is critical in determining their effectiveness. Mitigation strategies will impact individual dairy operations differently. Developing a fully informed strategy requires understanding of the varying effectiveness of a CH_4 mitigation strategy and its transferability from one California dairy farm to other California dairy farms.	Expand emission monitoring efforts at more California dairies to understand the varying effectiveness of similar CH_4 emission mitigation strategies on emissions at different farms. Incorporate the findings into emission models to better parameterize CH_4 emissions from California dairies.

**Note: New major project concepts added in response to comments received at the August 27, 2018 SG #3 meeting. The concepts have implications for achieving SB 1383 climate goals effectively and efficiently. However, the views expressed here may not coincide directly with the SG#3's recommendations and have not been evaluated under the same extensive process as the other research concepts.*

ENVIRONMENTAL JUSTICE (Submissions #3, 6, 15, public comments)

Research Project Concepts		
Concept Title	**Problem**	**Solution/Approach**
Investigate localized pollution impacts	The implementation of various CH_4 mitigation strategies may alter the emissions of other air pollutants such as NH_3 from dairies. Consequently, different CH_4 mitigation strategies can have varying impact on air quality. Studying the changes in CH_4 and other associated air pollutant emissions due to the adoption of digester and non-digester practices at California dairies will inform decisions that can simultaneously minimize the climate and air quality impacts on disadvantaged communities.	Conduct comprehensive evaluations of various environmental effects, especially near disadvantaged communities, from changing dairy operations (e.g., digesters, AMMP, on-site transportation, and the consolidation of dairies) to understand the effectiveness of various CH_4 emission reduction strategies and their impacts on other emissions. Evaluations of the impacts on methane emissions and other pollutants resulting from dairy operations' implementation of methane reduction strategies can also inform considerations of other factors such as impacts on dairy workers, number and types of jobs, occupational risks and exposures, and overall health of the dairy industry.
Investigate the benefits of multi-program cross-over*	Various GHG and air pollution programs exist in California, which employ a variety of monitoring efforts and environmental impact evaluations. Potential bridges between these programs should be evaluated to effectively develop future CH_4 emission reduction strategies that realize the most beneficial and integrated approach for both climate and public health.	Evaluate new and existing programs that pertain to the objectives of SB 1383 to determine the feasibility of developing a well-integrated approach to reducing CH_4 emissions from dairies while benefiting the environment and the public health, especially for disadvantaged communities.
Identify practices that minimize the cumulative impact on health and the environment *	Implementation of digesters and non-digester manure management practices will change the daily operation of California dairy farms. Identification of effective CH_4 mitigation strategies will require a holistic evaluation of the changes in the cumulative impact on health and the environment posed by changing management strategies.	Develop a comprehensive matrix of guidelines that will help dairy farmers and stakeholders maximize the benefits of CH_4 emission reduction strategies based on a cumulative impact assessment. The information derived from this effort should address the substantial variabilities in dairy farm operations as well as downstream cumulative environmental and health impacts.

**Note: New major project concepts added in response to comments received at the August 27, 2018 SG #3 meeting. The concepts have implications for achieving SB 1383 climate goals effectively and efficiently. However, the views expressed here may not coincide directly with the SG#3's recommendations and have not been evaluated under the same extensive process as the other research concepts.*

AIR POLLUTION MITIGATION STRATEGIES (Submissions #4, 5, 7, 9, 12, 14, 18, 19, 20, 21, 22, 23, 25, 27, 28, 30, 31, 32, 33, 34)

Research Project Concepts		
Concept Title	**Problem**	**Solution/Approach**
Evaluate mitigation strategies for enteric fermentation	Manipulation of animal diets through feed additives can reduce CH_4 emissions from enteric fermentation. Preliminary studies show repeatable CH_4 emission reductions from the use of feed additives, but a comprehensive assessment of the potential impacts of feed additives on the long-term health of dairy cattle, dairy products, consumer acceptance, dairy economics, microbial activities in manure, condition of manure applied to croplands, and plant growth/health has not been conducted.	Conduct a comprehensive assessment of environmental and other impacts of dairy feed additives to ensure proper incorporation without negative side effects.
Identify beneficial manure management practices	Different manure handling and treatment options to reduce CH_4 emissions may be economically viable for individual dairies depending on housing type, herd size, manure collection processes, and climate. However, not all manure management strategies (such as anaerobic digesters, alternative manure management practices, and manure lagoon additives) have been fully evaluated for their effectiveness in reducing CH_4 emissions while demonstrating economic feasibility.	Identify economically viable manure management strategies in California, quantify CH_4 emission reduction potentials from various practices and measures, and develop a process to evaluate the cost-effectiveness.
Life-cycle assessment and economic impacts	CH_4 mitigation strategies for manure and enteric fermentation should be holistically evaluated (from cradle to grave) including their economic impacts on the dairy and agricultural industry, and environmental impacts at both local and regional scales that result from the potential CH_4 emission reduction strategies. While CH_4 emission reduction is the primary goal for SB 1383, the dairy industry in California is an integral part of the larger agricultural economy and its sustainability is critical.	Identify the most environmentally and economically feasible CH_4 mitigation strategies that lead to both climate and air quality benefits while ensuring effective CH_4 emission reduction.

OTHER RECOMMENDATIONS (FROM SUBGROUP MEMBERS, ORGANIZATIONS, COMMUNITY GROUPS, ACADEMIA, AND INDUSTRY)

This section describes other recommendations compiled from Dairy and Livestock Subgroups #1 and #2 as well as academic institutions, non-governmental and non-profit organizations, government agencies, and industry. The views expressed in this section may not coincide directly with SG#3's recommendations and have not been evaluated under the same extensive process as the core recommendations presented in this document. However, SG#3 determined that the following research project concepts have implications for effectively achieving California's SB 1383 climate goals. Therefore, these other recommendations were presented to provide further guidance to improve our understanding of dairy emissions and beneficial farming practices that will help California realize additional economic, health, and environmental benefits.

Concept	Description
Investigating root cause of CH_4 production to improve emission inventory	• Understand the seasonal variations of management practices and their impacts on VS in the manure management systems. • Refine process-based models for estimating dairy emissions using information about physical and chemical properties of manure (including pH, oxygen/moisture content, and microbial populations), and manure handling through housing, storage, and land application.
Education and outreach	• Summarizing scientifically sound research findings to develop robust outreach and education program for dairymen.
New technologies and dairy farm products	• Conduct research on value-added products from manure and digestate to help identify promising technologies/practices and evaluate the economic impacts/cost effectiveness. • Use robust results from research and development to advance new technologies to reduce dairy CH_4 emissions.
Comprehensive approach to study the effectiveness of mitigation strategies	• Conduct research to compare cross-media emissions due to the implementation of various CH_4 mitigation strategies that would determine and evaluate other benefits and impacts of CH_4 emission reduction measures (e.g., changes in emissions of other air pollutants). • Develop comprehensive research methodologies to investigate the full impact of digester and non-digester technologies on dairy emissions (whole farm versus individual components/operations).

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APPENDIX

Submission #1 *"Towards a comprehensive inventory of dairy emissions via microsatellite sensors"* (industry): The proposed research will use satellite-hosted sensors to measure dairy CH_4 emissions. The end product will be a near-daily CH_4 mapping.

Submission #2 *"Improved inventories and modeling of greenhouse gas emission from dairy lagoons"* (academic): The proposed research will perform long-term measurements at manure lagoons to evaluate the impacts of emission mitigation strategies, and develop/improve the modeling tool for predicting GHG emissions.

Submission #3 *"Full analysis of local air and water impacts of biomethane production"* (others): The proposed research will conduct a holistic assessment of environmental impacts of dairy waste-to-energy projects and programs in environmental justice communities.

Submission #4 *"California dairy lagoon gaseous emissions reductions using additive A"* (industry): Preliminary results have shown significant reductions in CO_2, CH_4, N_2O, and NH_3 emissions from liquid manure using additive A. It also can decrease odor intensity.

Submission #5 *"Effect of nitrate and lipids on enteric CH_4 emissions"* (others): The proposed research will evaluate the combined impact of nitrate and lipids feeding on enteric CH_4 emissions.

Submission #6 *"Assessment of dairy workers' exposure to on-farm air pollutant emissions"* (others): The proposed research aims to understand how California dairies may impact the health of workers, and how CH_4 mitigation strategies affect dairy workers' exposure to other air pollutants at farms.

Submission #7 *"Developing cost-effective CH_4 mitigation strategies in the SJV's dairy industry"* (others): The proposed research aims to better understand how manure is handled and utilized at California dairies, especially the ones that will not install anaerobic digesters.

Submission #8 *"Central database of manure management emissions data"* (others): The proposed research will create a database including information about emissions from manure management practices at all stages based on past and current projects.

Submission #9 *"Best practices for managing and applying digestate"* (others): The proposed research aims to better understand the physical and chemical properties of digestate, the potential economic and environmental impacts of digestate, and the best practices of utilizing digestate.

Submission #10 *"Create spatially comprehensive dairy activities and CH_4 emissions data for emission inventory"* (others): The proposed research will collect dairy activity data to refine CH_4 emission inventory in California.

Submission #11 *"Dairy CH_4 mapping"* (industry): The proposed research aims to better understand the spatiotemporal variations of CH_4 emissions from California dairies using drones.

Submission #12 *"AMMP and digested-manure soil application"* (academic): The proposed research aims to better understand how the soil application of digested-manures and effluents affect the nutrient cycling and GHG emissions from soils.

Submission #13 *"Identifying best dairy practices to reduce both CH_4 and NH_3 emissions"* (academic): The proposed research will conduct mobile measurements to investigate CH_4 and NH_3 emissions from dairies due to the implementation of mitigation strategies.

Submission #14 *"Evaluation of supplemental strategies to reduce air emissions from dairy lagoons"* (others): The proposed research aims to better understand the potential benefits and dis-benefits of using additives to reduce CH_4 emissions from dairy lagoons and other manure management strategies.

Submission #15 *"Dairy air emission quantification and impact assessment of small dairies on nearby communities"* (others): The proposed research will evaluate small dairies near environmental justice communities to ensure that their CH_4 emissions are also evaluated while studying the impact of direct NH_3 emissions and other air pollutants in downwind communities.

Submission #16 *"Measuring and modeling the GHG emissions from manure solids on dairies"* (academic): The proposed research will evaluate the impacts of manure solid management practices on CH_4 emissions and develop a modeling tool.

Submission #17 *"Establishing baseline of existing manure management practices"* (others): The proposed research aims to better understand the existing dairy manure management systems in California and develop a baseline for assessing the reduction progress in the future.

Submission #18 *"Enteric CH_4 reduction by an inhibitor from dairy"* (academic): The proposed research will evaluate the effectiveness of additive B under California conditions.

Submission #19 *"California bovine enteric gaseous emission reductions using additive C"* (industry): The proposed research will evaluate the impacts of additive C on enteric CH_4 emissions in California.

Submission #20 *"Effect of condensed and hydrolysable tannins on enteric CH_4 emissions from dairy cows"* (academic): The proposed research aims to better understand how supplementing a mix condensed and hydrolysable tannins reduce CH_4 emissions.

Submission #21 *"Understanding value-added market opportunities for manure"* (industry): The proposed research aims to better understand the markets for manure, how to handle manure for potential customers, and how to utilize manure in a cost-effective way.

Submission #22 *"Use of a CH_4 inhibitor to decrease dairy enteric- and lagoon CH_4 emissions"* (academic): The proposed research will evaluate the impacts of additive D on enteric and lagoon CH_4 emissions under California conditions.

Submission #23 *"Environmental and economic assessment of manure management systems"* (others): The proposed research will conduct a holistic assessment of the benefit, impact, and cost-effectiveness of various manure management practices on GHG emission reduction.

Submission #24 *"Survey California dairies and identify potential reporting method"* (others): The proposed research will conduct a survey of representative dairies to collect data pertinent to emissions, and then identify parameters, variables, and pathways most useful and feasible for potential future reporting of dairy activities and emissions.

Submission #25 *"Enteric CH_4 reduction by seaweed in California diets"* (academic): The proposed research will evaluate the impacts of seaweed under different diets on CH_4 emissions.

Submission #26 *"Long-term air emission quantification at dairy facilities using flux towers"* (others): The proposed research aims to install long-term air pollution emissions monitoring systems such as flux towers at various dairy facilities to quantitatively determine the variabilities of CH_4 and other air pollution emissions.

Submission #27 *"Comprehensive compost emissions cross-media analysis"* (industry): The proposed research aims to better understand the benefits and impacts of composting from a life-cycle perspective.

Submission #28 *"Mitigation of enteric CH_4 from dairy cattle through feeding of additive E"* (academic): The proposed research will evaluate the impacts of additives E on enteric CH_4 emissions under California conditions

Submission #29 *"Establishing a uniform experimental testing procedure for dairy air emission measurements"* (others): The proposed research will establish an appropriate experimental/laboratory testing procedure/method that can be utilized by the researchers/regulators/stakeholders to measure dairy air emissions for the purpose of evaluating mitigation strategies.

Submission #30 *"Effects of co-supplementing additive F and nitrate on CH_4 emissions from finishing beef cattle"* (academic): The proposed research will evaluate the impacts of co-supplementing additive F with nitrate on enteric CH_4 emissions.

Submission #31 *"Liquid/Solid separation with high pressure membrane filter press"* (industry): The proposed research will evaluate the cost-effectiveness of high pressure membrane filter press for GHG emission reductions on dairy manure slurry.

Submission #32 *"Pilot/California demonstration of nutrient recovery projects"* (industry): The proposed research aims to develop a process to incentivize new projects to evaluate CH_4 mitigation strategies that have not been tested under California conditions.

Submission #33 *"Additive G for feed and methane mitigation"* (academic): The proposed research will evaluate the impacts of additive G on enteric CH_4 emissions under California conditions.

Submission #34 *"Assessing the potential to combine manure with other agricultural wastes to reduce GHG and air impacts"* (others): The proposed research aims to better understand cross-media impacts and benefits by optimizing the utility of agricultural waste.