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Methane, Cows, and Climate Change: California Dairy's Path to Climate Neutrality

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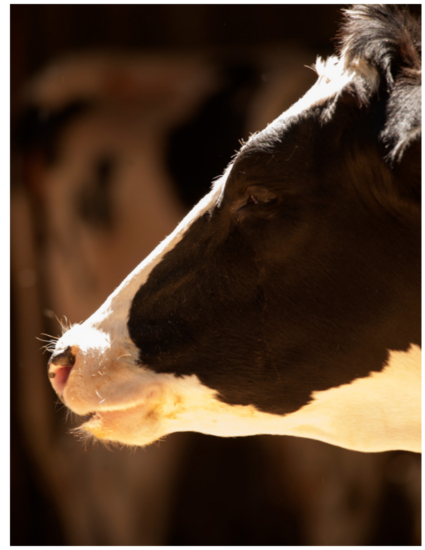
INTRODUCTION



Climate change is a global issue that requires comprehensive and far-reaching solutions across all economic and demographic jurisdictions. The Paris Climate Agreement, adopted in 2015, sets out a global framework to address harmful climate impacts by limiting additional global warming to well below 2 degrees Celsius (°C) (1.5 °C goal). The accord recognizes regional differences and the need for specific actions across all jurisdictions, including developed economies providing leadership and assistance to developing nations in their climate mitigation efforts.

California continues to lead the United States and world in implementing measures to achieve emissions reductions of greenhouse gases (GHGs) that advance climate change. Toward this end, California has established ambitious goals for reducing GHG emissions (Senate Bill 32) by 40 percent by 2030 and 80 percent by 2050. Senate Bill 1383 (2016) also established specific goals for reducing short-lived climate pollutants (SLCPs), such as methane, by 40 percent from 2013 levels. Ultimately, California is working toward a goal of “net-zero” carbon emissions by 2045 (Executive Order B-55-18).

The U.S. dairy industry recently announced efforts to address climate change, boldly aiming for carbon neutral or better (net zero climate impact) by 2050 (Innovation Center for U.S. Dairy, 2020). As part of these important efforts, California’s dairy farms are leading change and making significant progress in reducing the amount of GHG emissions released into the environment. Producing a glass of milk from a California dairy cow generates 45 percent less GHG emissions today than it did 50 years ago. This finding, recently published in the Journal of Dairy Science, comes from a life-cycle assessment of California dairy farms in 1964 and 2014, conducted by researchers at the University of California,

Davis (Naranjo et al., 2020). Significant advancements in farming efficiency, feed crop yields, veterinary care, sustainable feed practices, and animal nutrition have helped reduce the environmental footprint of individual cows. Building on these gains, more can be done to lower the climate footprint of milk production in the coming decade. California's dairy farmers are working closely with the California Department of Food and Agriculture (CDFA) and the California Air Resources Board (CARB) to further reduce dairy methane emissions. **As the efforts continue, it is also important to improve our understanding of how methane and other GHGs contribute to climate impacts, as we seek to limit warming.** Leading climate scientists are now recognizing that moderately reducing methane emissions can quickly stabilize the climate pollutant's powerful impact, and further reductions can actually offset the far more damaging impacts of carbon dioxide (CO_2), which accumulate in the atmosphere for hundreds of years.

California dairies reduced emissions by 45% between 1964-2014.

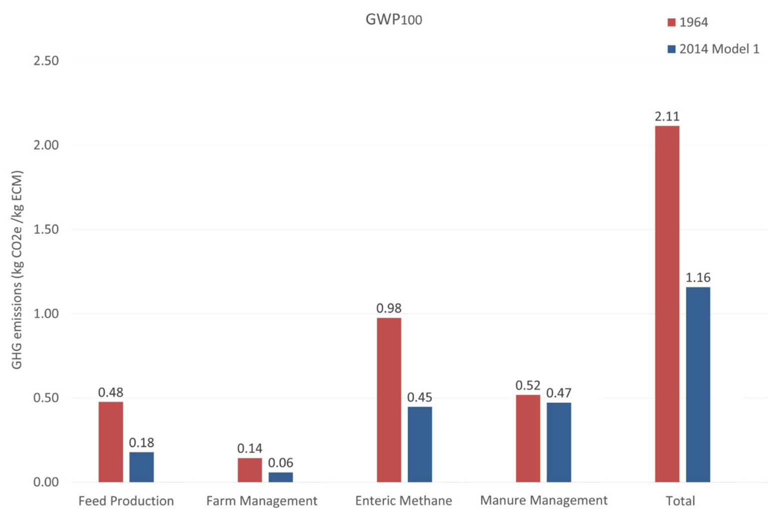


Figure 1. Comparison of global warming potential (GWP) in 1964 and 2014 by emission source for model 1 (using farm sampled diets). GHG = greenhouse gas; CO2e = CO2 equivalents. - Journal of Dairy Science, Naranjo et. al., 2020

California's Greenhouse Gas Emissions

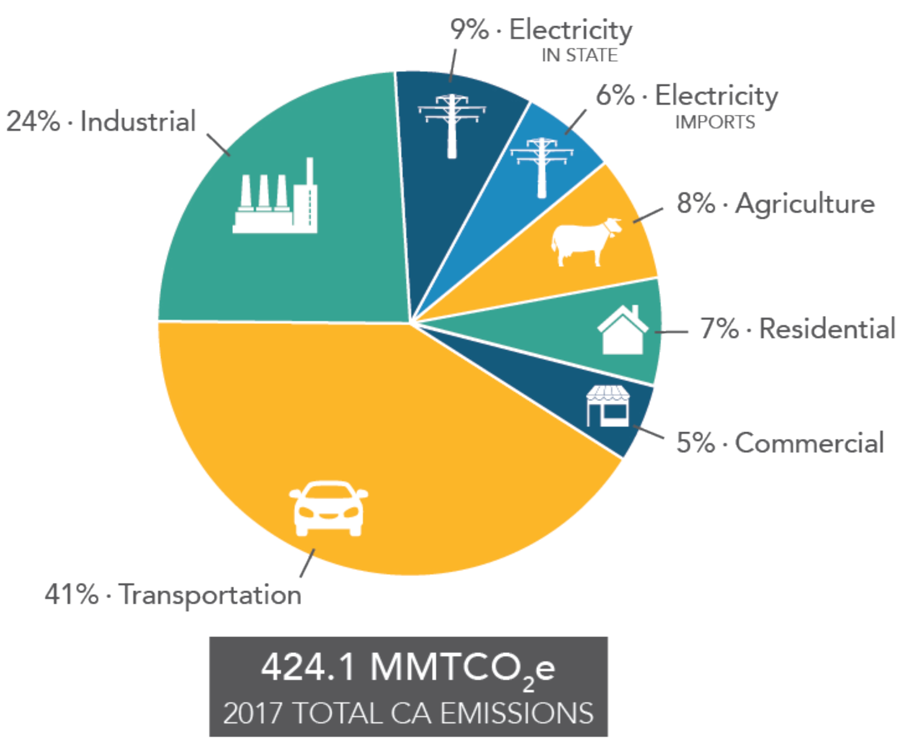


Figure 2. 2017 California greenhouse gas emissions by sector. Source: CARB.

California, the fifth largest economy in the world, is responsible for about 1 percent of all global GHG emissions. More than 80 percent of California's emissions come from the transportation (41 percent), industrial (23 percent) and electrical (16 percent) sectors. Even though California is the United States' largest agricultural producer—producing fruits, vegetables, nuts, livestock, and other commodities for much of the U.S. and world—the sector's GHG contribution is only 8 percent of the state's total. California's largest-in-the-nation dairy sector accounts for about half of the agricultural share, or 4 percent of the state's total GHG emissions. The U.S. dairy sector accounts for 2 percent of the nation's total GHG emissions.

While CO_2 is the primary GHG driving climate warming, methane (CH_4), nitrous oxide (N_2O), and refrigerants are also important GHGs in California. According to CARB, carbon dioxide accounts for about 83 percent of California's GHG inventory. In comparison, methane accounts for 9 percent, and N_2O accounts for about 3 percent. In addition to knowing how much of each gas is being emitted, understanding how each gas causes actual warming is most critical to fully understanding and addressing climate change. Recent work by leading climate scientists at the Oxford Martin School and Environmental Change Institute at Oxford University has shed light on important differences among these GHGs and their impact on climate change (Lynch, 2019).

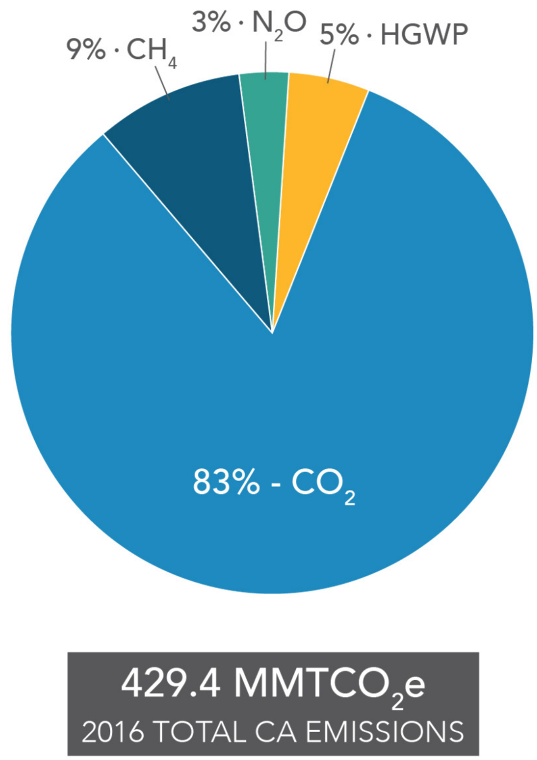


Figure 3. 2017 California greenhouse gas inventory. Source: CARB.

Methane emissions are generated by a number of processes, both those resulting from human-related activity (anthropogenic) and natural (biogenic). Fossil-fuel methane (more commonly known as "natural gas") results from the process of extracting coal or oil, or from leakage during the extraction, storage, or distribution of natural gas for homes and businesses. Fossil methane is largely converted to CO_2 when we burn natural gas in our homes, factories, buildings, and other businesses. Biogenic methane emissions are created by wetlands, rice cultivation, and ruminant livestock, as well as the waste sector, when microbes digest organic matter in our landfills and sewage treatment plants. Animal agriculture activity (all livestock) in California represents the largest source of biogenic methane emissions, accounting for roughly 55 percent of all human-related methane emissions in the state. California is the largest dairy state, producing roughly 18.5 percent of the nation's milk (USDA, 2019). The dairy livestock sector accounts for about 45 percent of all methane emitted in the state (CARB, 2015), primarily from two sources. Roughly half (55 percent) of dairy methane emissions come from manure management (storage, handling, and utilization), and the remaining 45 percent comes from enteric emissions. In ruminant animals, methane is produced during manure decomposition as well as during enteric fermentation, where microbes decompose and ferment plant materials in the first compartment of their stomach, known as the rumen. This methane is expelled by the animal through belching.

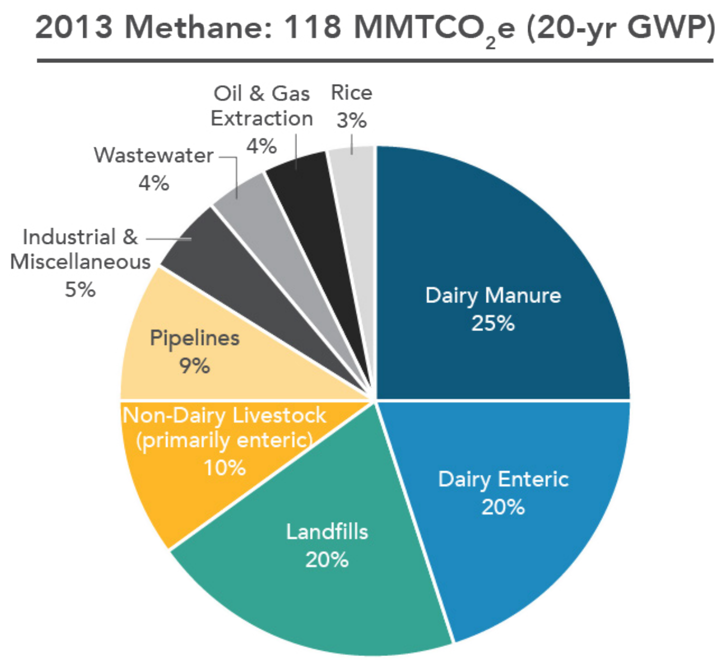
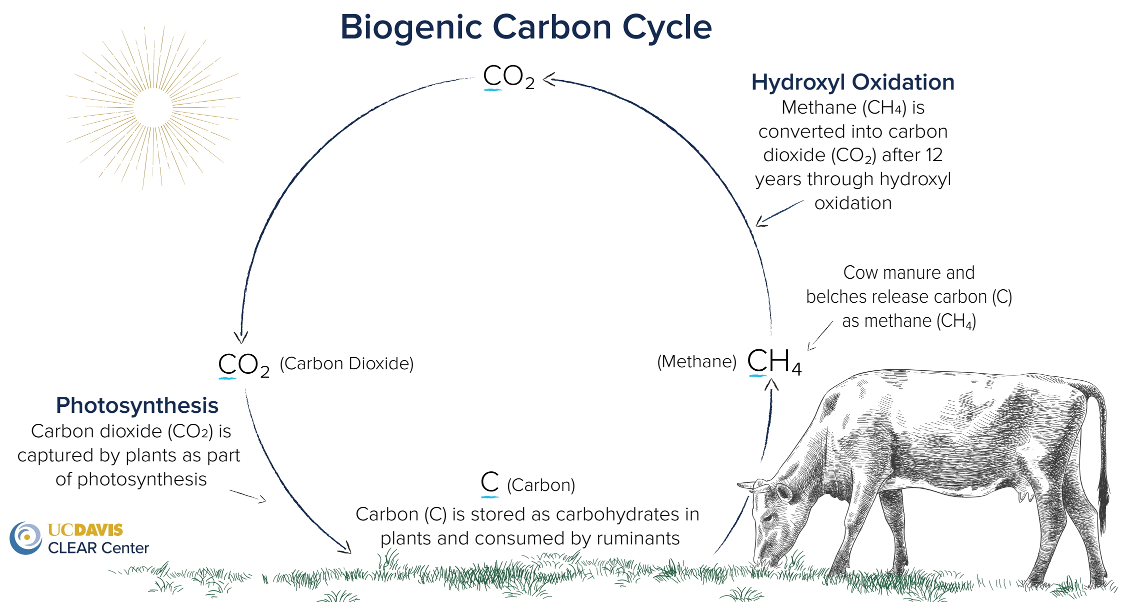


Figure 4. 2015 California methane inventory. Source: CARB.

FOSSIL METHANE vs. BIOGENIC METHANE

Fossil methane impacts the climate differently than biogenic methane. Fossil methane, such as natural gas, is carbon that has been locked up in the ground for millions of years and is extracted and combusted in homes and businesses. The burning of fossil methane directly transfers carbon that was stored in the ground (geologic carbon) into the atmosphere as CO_2. That carbon continues to accumulate and persist in the environment, contributing to climate change for hundreds of years. **Bottom line: Fossil methane increases the total amount of carbon in the atmosphere, which drives warming.**

Biogenic methane from cows is part of a natural carbon cycle, where after about 12 years it is removed from the atmosphere. As part of photosynthesis, plants capture CO_2 from the atmosphere, absorbing the carbon and releasing oxygen. That carbon is converted into carbohydrates in the plant, which are then consumed by the cows, digested, and released from the cows as methane (CH_4). After about 12 years in the atmosphere, that methane is oxidized and converted into CO_2. These carbon molecules are the same molecules that were consumed by cows in the form of plants. **As part of the biogenic carbon cycle, the carbon originally utilized by the plant is returned to the atmosphere, contributing no net gain of CO_2.**



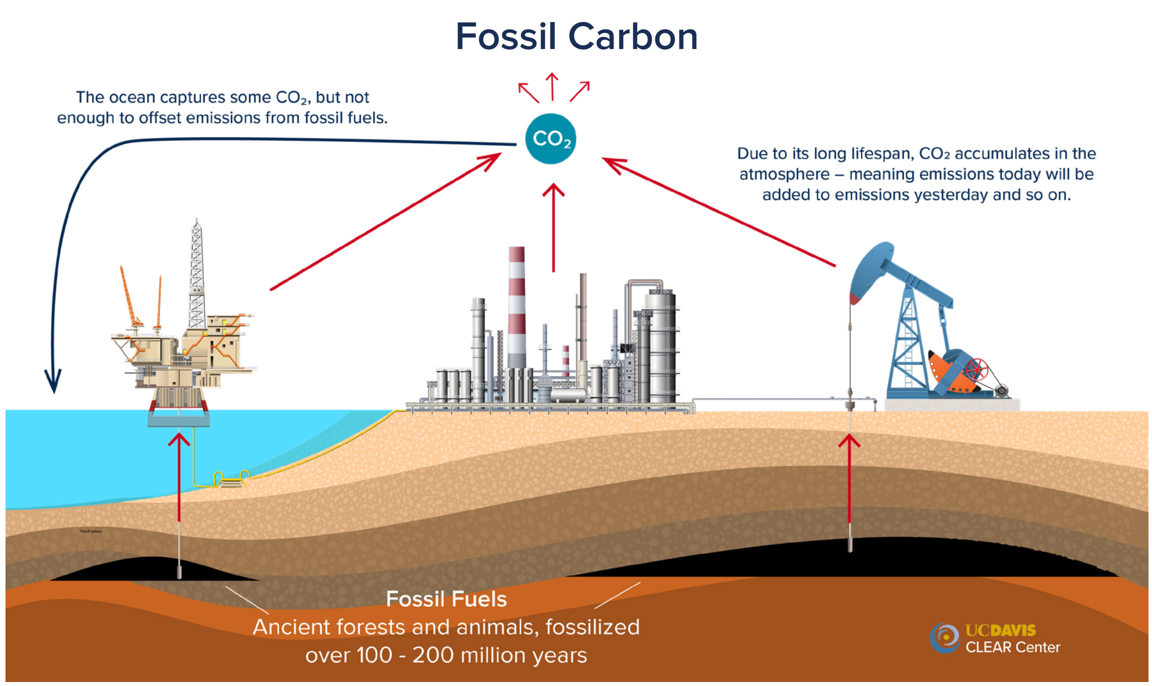


Figure 5. Top, the biogenic carbon cycle shows how carbon moves from the atmosphere to plants, and then to animals, and then back into the atmosphere. This process is further explained in the CLEAR Center video "Rethinking Methane."

Figure 6. Bottom, the burning of geologic carbon – including fossil methane – is a one-way process, resulting in CO_2 accumulating in the atmosphere.

Global Warming Potential of California's Primary Greenhouse Gases

Each GHG captures and retains heat at a unique rate, known as its global warming potential or GWP (as shown in Table 1 as GWP 100). For example, CH_4 has 28 times the warming potential of CO_2 over a 100-year period. Understanding how emissions impact global climate; however, requires consideration of not just the potency, but also how long each type of GHG will last in the atmosphere (atmospheric lifetime).

Global Warming Potential (GWP_{100}) of Main Greenhouse Gases

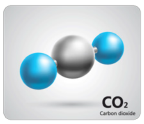
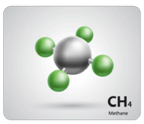
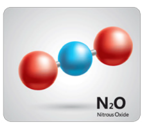
		AR4	AR5
	Carbon Dioxide (CO_2)	1	1
	Methane (CH_4)	25	28
	Nitrous Oxide N_2O	298	265

Table 1. This table is adapted from the IPCC Fourth Assessment Report (AR4), 2007 and the IPCC Fifth Assessment Report (AR5), 2014. Note, CARB uses AR4.

This is particularly important for methane, as it is a SLCP, with emissions breaking down after about 12 years (Farlie 2019; Lynch, 2019). In contrast, a significant proportion of CO_2 emissions are expected to persist in the atmosphere for hundreds of years, or even longer (Farlie, 2019; Lynch, 2019). As a result, **the treatment of all GHGs as CO2 equivalent (CO2e) using GWP—and failure to consider the atmospheric removal of SLCPs—misrepresents the impact of methane on future warming** (Frame et al., 2018; Cain, 2018). Recognizing this shortcoming, leading climate scientists expanded on GWP and developed GWP* (GWP-Star), which quantifies a GHG's actual warming potential, instead of just its CO_2 equivalence, by factoring in how much more or less methane is being emitted from a source over a period of time. GWP* appropriately builds on the conventional GWP approach employed in typical reporting of GHG emissions (Lynch, 2019). GWP* recognizes the rate and degradation of methane emissions, in addition to the total amount of CO_2 and other long-lived gases emitted (Lynch, 2019; Cain, 2018; Frame et al., 2018).

Climate Impact Potential/GWP* (GWP-Star)

Recognizing the important differences in how methane and carbon dioxide affect climate change is critical to quantifying their actual climate impacts. GWP* was developed to better and more completely account for the warming impacts of short- and long-lived gases and better link emissions to warming (Cain, 2018). GWP* is still based on GWP, but recognizes how different gases such as methane affect warming (Cain, 2018).

Because CO_2 emissions last in the atmosphere for so long, they can continue to impact warming for centuries to come. New emissions are added on top of those that were previously emitted, leading to increases in the total atmospheric stock or concentration of CO_2. As a result, when additional CO_2 is emitted, additional global warming occurs (Frame et al., 2018).

In contrast, methane emissions degrade in the atmosphere relatively quickly, after about 12 years, and do not act cumulatively over long periods of time. For a constant rate of methane emissions, one molecule in effect replaces a previously emitted molecule that has since broken down. This means that

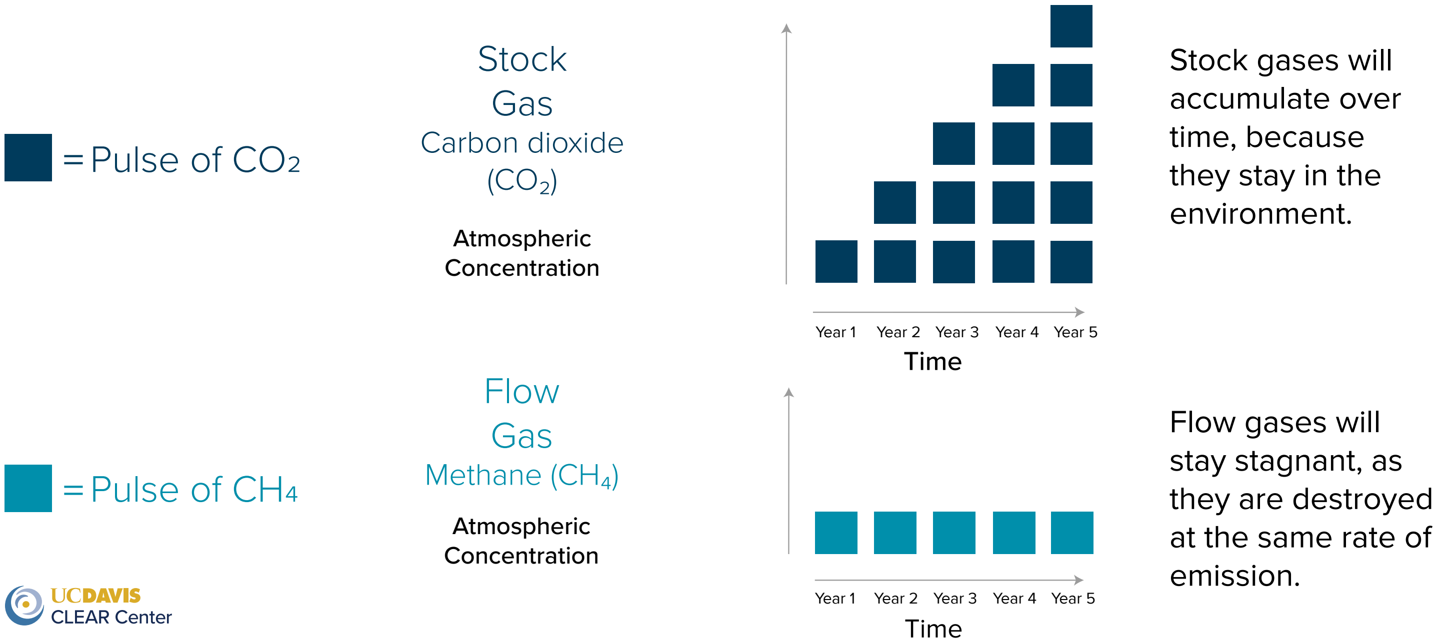
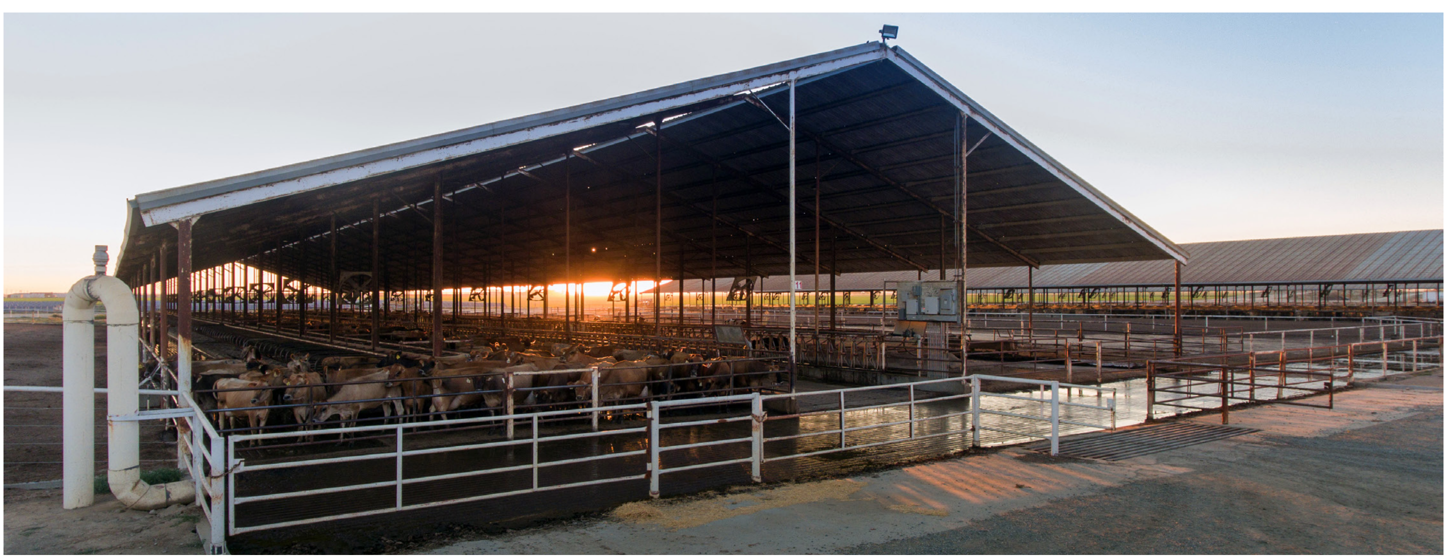


Figure 7. Based on research by Myles R. Allen, Keith P. Shine, Jan S. Fuglestvedt, Richard J. Millar, Michelle Cain, David J. Frame & Adrian H. Macey. Read more here: https://rdcu.be/b1t7S

for a steady rate of methane release—as emitted by a constant number of dairy cows, for example—the amount of methane in the atmosphere (concentration) stays at the same level and does not increase. As a result, when a steady amount of methane is emitted for more than 12 years, no additional global warming occurs (Frame et al., 2018).

This improved understanding of how short-lived versus long-lived emissions affect climate differently is critical to addressing further global warming. Limiting climate change requires that we bring emissions of CO_2 and other long-lived GHGs down to net-zero (Frame et al., 2018). For methane, however, it is possible to have steady ongoing emissions that do not result in additional warming (Frame et al., 2018).

This does not mean that methane can or should be ignored. Increasing methane emissions would result in significant warming. Because of its short-lived atmospheric lifetime, reducing methane emissions can lead to a drop in atmospheric concentration relatively quickly. **So, reducing methane emission rates presents an important mitigation opportunity, which could reverse some of the warming the planet has already experienced (Lynch, 2019). Put simply, a reduction in methane emissions has climate cooling effects (Cain, 2018).**



Climate-Neutral Dairy: Achievable in California's Near Future

Understanding how methane impacts global warming is critical to understanding the role of dairy production as a contributor to climate change. California's dairy sector is an excellent case in point. It is no longer growing and expanding production. The number of milk cows raised in the state reached a peak in 2008, around the same time that California passed its first climate policy (2006). Since then, the number of cows has declined by a little more than 7 percent (CDFA, 2017). Total milk production has also decreased in recent years. As a result, the amount of methane in the atmosphere contributed by California milk production is less today than in 2008, as more methane is being removed from the atmosphere each year through its natural breakdown process (biogenic methane cycle) than is created by fewer dairy cows.

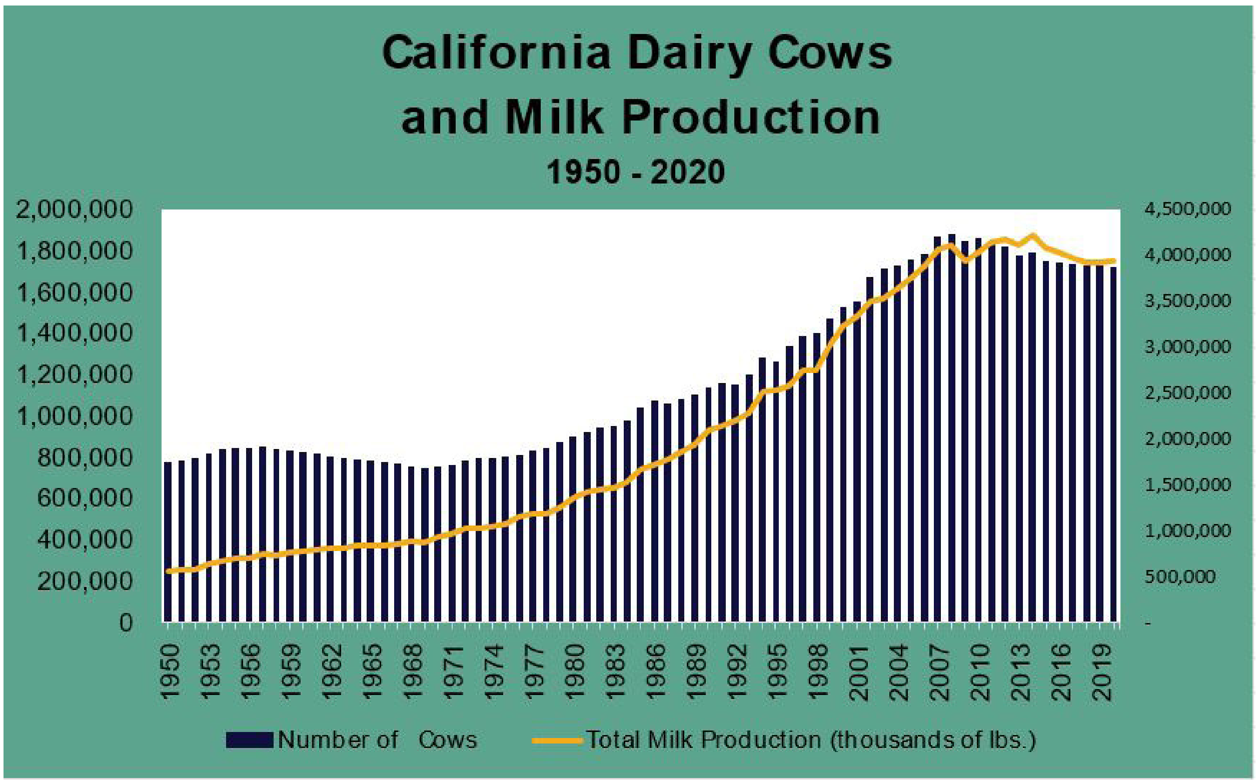


Figure 8. Number of California Dairy Cows and Volume of Milk Production: Sources: CDFA Dairy Marketing, Milk Pooling, and Milk and Dairy Foods Safety Branches; USDA Milk Production Report

California dairy farms are also taking important, voluntary steps to further reduce methane from farms by installing anaerobic digesters designed to capture methane. Other projects, such as compost pack barns and solid separators, are designed to reduce methane production on farms. More than 213 dairy methane reduction projects have been incentivized with state funds to date (CDFA, 2019). These efforts alone are expected to achieve more than 2.2 million additional metric tons of GHG reduction each year, as the projects continue to be implemented (CDFA, 2019). Hundreds of additional dairy methane reduction projects are expected in future years.

Figure 9. Manure solid separator, climate-smart dairy project on a California dairy farm.

As discussed earlier, enteric emissions (belching) from cows account for a significant share (45 percent) of total dairy methane emissions in California. Identifying solutions to reduce these emissions will also be necessary to meet state goals. While research into enteric emission mitigation is being conducted, and some feed additives show promise, commercially proven and cost-effective solutions are not yet available (Webinar on CARB's Analysis of Progress Toward Achieving Methane Emissions Target from Dairy and Livestock Sector, 2020).

What is Climate Neutrality?

Climate neutrality is when an entity or industry has no net global warming impact. Same as "warming neutral."

Dairy farms also create other GHGs, such as CO_2 and nitrous oxide (N_2O), from the use of farm equipment for dairy management and the utilization of manure for growing crops. These emissions account for about 20 percent of all GHGs produced by the dairy production sector (Naranjo et al., 2020). Reducing or offsetting these emissions will also be necessary for the state's dairy production sector to achieve climate neutrality, or the point at which operations and resulting emissions are stable and no longer adding to global warming (no net global warming impact). California dairies are also reducing the amount of CO_2 they emit into the atmosphere through the adoption of solar energy and electrification of feed mixing and water pumping operations. Fossil fuel use per unit of milk produced has dropped by 58.5 percent from 1964 to 2014 (Naranjo et al., 2020). As dairy methane emissions are reduced further below current levels, then resulting cooling effects can offset some of the remaining CO_2 and other gases contributed by dairy production.

Conclusions and Policy Considerations

A continued focus on methane is necessary, as it is a powerful GHG and an important contributor to climate change. Under all scenarios, methane is significant, second only to carbon dioxide in terms of its overall contribution to global, human-driven climate change (Lynch, 2019). Over the last decade, global methane concentrations have increased (Lynch, 2019). Agriculture, including animal agriculture, is partially responsible for the increase, as dairy and meat production and consumption continue to expand globally, particularly in low- and middle-income countries. That notwithstanding, evidence is growing that shale gas production is a larger source of methane emissions than previously assumed (Howarth, 2019). Like every sector of the global economy, agriculture must do its part if we are to succeed in achieving the overarching goal of limiting global warming. Equally important, California acting alone cannot accomplish significant global dairy methane emission reductions.

A renewed focus on how we consider and address the climate impact of methane emissions is also warranted (Lynch, 2019). As discussed in this paper, rethinking methane's role in climate is important, because there are significant differences in how methane and carbon dioxide—the main human-generated GHG—affect climate (Lynch, 2019). Different goals should be identified and set for CO_2, CH_4, and other GHGs. Designing effective policies to limit global warming also requires knowledge of how different mitigation measures impact temperature, including in targeting appropriate programs to incentivize voluntary adoption of methane reduction technologies and practices. Voluntary dairy methane reduction will need to be continued, as it is an important climate mitigation tool.

Recognizing how methane impacts global climate is also critical to assessing whether the state and world are on track to meet the goals of the Paris Agreement and limit warming to well below 2°C. Comparing GHGs with each other using GWP* preserves the link between emissions and warming or cooling of the atmosphere (Schleussner et al., 2019). It also provides an informative and better suited way to assess the relative merits of different options for reducing GHG emissions, especially in ambitious mitigation scenarios (Cain, 2019). More accurate expression of mitigation efforts in terms of their direct contribution to future warming also better informs burden-sharing and long-term policies and measures in pursuit of ambitious global temperature goals (Allen, 2018; Schleussner et al., 2019).

Figure 10. California climate-smart dairy with a digester, manure solid separator, and solar installation.

Reducing methane emissions and achieving climate neutrality is no small undertaking. California is among the most efficient producers of milk and dairy products, and its life-cycle carbon footprint (per gallon of milk produced) is among the lowest of any region in the world. Achieving these or similar levels of production efficiency (more milk with fewer cows) is a critical first step for other dairy regions to begin stabilizing methane emissions and work toward climate neutrality. The impact of such an accomplishment would have profound climate effects. Attaining California's level of production efficiency in all global dairy production regions could reduce total global GHG emissions by as much as 1.73 percent (E. Kebreab, calculations based on Naranjo et al., 2020 and FAO & GDP, 2018).

A full understanding of the potential climate impact of all greenhouse gases is also important in ensuring effective policies are developed to address methane and other flow pollutants in line with their effects. Dairy production primarily produces flow emissions (80 percent is methane) with smaller amounts of stock emissions, such as CO_2 and N_2O (Naranjo et al., 2020). Policy or consumption decisions that trade off and result in greater concentrations of CO_2 and N_2O, while reducing methane, may ultimately leave a warmer planet behind in the long term (Frame et al., 2018).

Attaining California's level of production efficiency in all global dairy production regions could reduce total global GHG emissions by as much as 1.73 percent.

California's experience and efforts have identified crucial approaches that have worked to create low-carbon livestock and reduce the climate impacts of dairy production. Adopting sustainable farming practices to vastly improve production efficiency is probably the single-most important step other dairy-producing countries can take to begin to stabilize regional and global methane emissions and begin to achieve climate neutrality. The United Nations Food and Agriculture Organization (FAO) estimates that improved management practices alone could reduce net global methane emissions by 30 percent (FAO, 2019). These efforts will be critical to reduce livestock methane emissions and present important opportunities for reaching global climate mitigation targets. Further reductions in methane emissions will lead to atmospheric concentrations falling relatively quickly, which could reduce some of the warming already experienced (Lynch, 2019).

CASE STUDY: CALIFORNIA DAIRY METHANE REDUCTION

Figure 11. Digester on California dairy farm.

Fully understanding the climate cooling potential of dairy methane reduction efforts in California is critical for state regulators and policymakers. California is seeking to reduce dairy methane emissions by roughly 7.2 million metric tons (MMT) per year by 2030 (40% reduction). What will this mean for California's overall emissions reduction goal of being "net zero" by 2045?

Achieving the state's goal of reducing dairy methane emissions by 7.2 MMTCO2e annually will provide about 20 MMT of annual reduction (cooling) equivalent each year from 2030 to 2045. These reductions will be critical to mitigate continually accumulating CO_2 emissions from other sectors of the economy, and the achievement of the state's "net zero" long-term goal. In the race to manage global warming, reducing methane can provide fast returns.

This analysis using GWP* shows the true value of the state's dairy methane reduction efforts and programs such as CDFA's Dairy Digester Research and Development Program (DDRDP) and Alternative Manure Management Program (AMMP), which are expected to incentivize more than half of the 7.2 MMT of methane reduction. This analysis also underscores the importance of continuing to fully fund these California Climate Investment Programs at a minimum of $85 million per year. (CARB Preliminary Analysis of Dairy Methane Reduction Progress, May 2020).

Cumulative Overview of the DDRDP & AMMP

	Number of Projects Funded	Total State Funding Awarded	Total GHG Reductions	State Cost Per 1 Ton GHG Reduced
Dairy Digester Research and Development Program (DDRDP)	108 (total 2015, 2017, 2018, 2019)	$181.6 million	19.7 million $MTCO_2e$ (10-yr project life)	$9 Ranked #2 of 68 programs
Alternative Manure Management Program (AMMP)	105 (total 2017, 2018, 2019)	$63 million	1.1 million $MTCO_2e$ (5-yr project life)	$49 Ranked #7 of 68 programs

Sources: Report of Funded Projects - CDFA DDRDP 2020; Report of Funded Projects - CDFA AMMP 2020; California Climate Investments 2020 Annual Report

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Frank Mitloehner is a professor and air quality specialist for Cooperative Extension in the Department of Animal Science at the University of California, Davis. Dr. Mitloehner has served as chairman of a global United Nations Food and Agriculture Organization partnership project to benchmark the environmental footprint of livestock production. Dr. Mitloehner serves as the North American scientific lead for the Global Feed LCA Institute. Dr. Mitloehner is a work group member of the President's Council of Advisors on Science and Technology (PCAST) and a member of the National Academies of Science Institute of Medicine (IOM) committee on "A Framework for Assessing the Health, Environmental, and Social Effects of the Food System."

Ermias Kebreab, Ph.D., Professor and Sesnon Endowed Chair, Director, World Food Center, Associate Dean of Global Engagement, UC Davis

Ermias Kebreab serves as the Sesnon Endowed Chair in Sustainable Animal Agriculture at the Department of Animal Science, UC Davis. Dr. Kebreab was appointed Associate Dean of Global Engagement and Director, World Food Center in 2018. He is a contributing author to the 2019 Intergovernmental Panel on Climate Change (IPCC) guideline and chairs the feed additive committee at the Food and Agriculture Organization of the United Nations. Dr. Kebreab conducts research on reducing the impact of animal agriculture on the environment, including the sustainable use of feed additives. Dr. Kebreab received several awards, including International Agriculture Award and AFIA Ruminant Nutrition Award from American Society of Animal Science.

Michael Boccadoro, Executive Director, Dairy Cares

With more than 30 years of experience in the public affairs arena, Michael Boccadoro has distinctive expertise in the areas of energy, environmental regulation, and sustainability. Mr. Boccadoro serves as the Executive Director of Dairy Cares, a statewide coalition that works to ensure the long-term sustainability of California's family dairy farms. He has been at the forefront of California's dairy methane reduction efforts and the development of incentive programs to encourage voluntary implementation. Mr. Boccadoro received his Bachelor of Arts degree in economics and political science from the University of California, Davis.

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Appendix A: Calculation of CA Dairy Methane Reduction Projections, using GWP*

1. Obtain Raw data from CA GHG inventory: https://ww2.arb.ca.gov/ghg-inventory-archive

Total CH4 emission from CA Dairy Sector (MMT CO2e)

			14.22	14.51	15.69	16.09	15.43	15.89	16.29	18.31	18.56	17.88	18.51	18.45	18.96	18.11	18.37	17.94	17.84
Livestock population	GHG	GWP	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Dairy cows	CH4	25	5.38E+00	5.26E+00	5.89E+00	5.95E+00	5.85E+00	5.97E+00	6.09E+00	6.94E+00	6.82E+00	6.48E+00	7.04E+00	6.98E+00	6.91E+00	6.74E+00	6.79E+00	6.64E+00	6.60E+00
Dairy replacements 12-24 mo	CH4	25	8.80E-01	9.10E-01	9.33E-01	9.52E-01	8.66E-01	9.02E-01	9.32E-01	9.70E-01	9.75E-01	9.53E-01	9.24E-01	9.24E-01	1.02E+00	9.45E-01	9.10E-01	8.88E-01	8.83E-01
Dairy replacements 0-12 mo	CH4	25	2.47E-01	2.54E-01	2.63E-01	2.62E-01	2.45E-01	2.59E-01	2.61E-01	2.74E-01	2.72E-01	2.71E-01	2.59E-01	2.59E-01	2.81E-01	2.63E-01	2.56E-01	2.50E-01	2.49E-01
Dairy calves	CH4	25	2.39E-01	2.39E-01	2.47E-01	2.57E-01	2.56E-01	2.62E-01	2.67E-01	2.81E-01	2.88E-01	2.87E-01	2.75E-01	2.74E-01	2.81E-01	2.81E-01	2.80E-01	2.73E-01	2.72E-01
Dairy cows	CH4	25	1.10E-03	2.39E-03	4.64E-03	1.73E-02	1.75E-02	5.16E-02	3.68E-02	1.13E-01	8.49E-02	3.90E-02	4.22E-02	4.39E-02	4.41E-02	4.27E-02	4.38E-02	4.27E-02	4.25E-02
Dairy cows	CH4	25	6.38E+00	6.68E+00	7.17E+00	7.42E+00	7.05E+00	7.31E+00	7.45E+00	8.34E+00	8.68E+00	8.45E+00	8.64E+00	8.63E+00	8.94E+00	8.41E+00	8.62E+00	8.42E+00	8.37E+00
Dairy cows	CH4	25	8.39E-03	8.43E-03	9.11E-03	9.23E-03	8.98E-03	9.18E-03	9.36E-03	1.07E-02	1.07E-02	1.04E-02	1.07E-02	1.07E-02	1.08E-02	1.04E-02	1.07E-02	1.04E-02	1.04E-02
Dairy heifers	CH4	25	1.34E-03	1.38E-03	1.41E-03	1.44E-03	1.30E-03	1.36E-03	1.40E-03	1.52E-03	1.52E-03	1.49E-03	1.44E-03	1.45E-03	1.59E-03	1.48E-03	1.43E-03	1.39E-03	1.39E-03
Dairy cows	CH4	25	1.10E-02	1.18E-02	1.20E-02	1.14E-02	9.32E-03	8.10E-03	7.18E-03	6.63E-03	6.81E-03	6.45E-03	6.13E-03	6.17E-03	6.87E-03	6.62E-03	6.78E-03	6.63E-03	6.59E-03
Dairy heifers	CH4	25	3.21E-02	3.33E-02	3.43E-02	3.49E-02	3.15E-02	3.29E-02	3.39E-02	3.68E-02	3.69E-02	3.62E-02	3.51E-02	3.51E-02	3.86E-02	3.59E-02	3.46E-02	3.38E-02	3.36E-02
Dairy cows	CH4	25	9.86E-01	1.05E+00	1.06E+00	1.11E+00	1.03E+00	1.02E+00	1.13E+00	1.26E+00	1.30E+00	1.26E+00	1.20E+00	1.20E+00	1.34E+00	1.29E+00	1.32E+00	1.29E+00	1.29E+00
Dairy heifers	CH4	25	6.55E-03	7.30E-03	7.19E-03	7.62E-03	6.55E-03	6.75E-03	7.16E-03	7.75E-03	7.98E-03	7.64E-03	6.80E-03	6.85E-03	8.34E-03	7.74E-03	7.47E-03	7.29E-03	7.25E-03
Dairy cows	CH4	25	2.36E-03	2.27E-03	2.34E-03	2.25E-03	2.07E-03	2.00E-03	1.91E-03	2.04E-03	2.04E-03	1.98E-03	2.05E-03	2.05E-03	2.06E-03	1.99E-03	2.04E-03	1.99E-03	1.98E-03
Dairy heifers	CH4	25	3.76E-04	3.71E-04	3.63E-04	3.70E-04	3.33E-04	3.49E-04	3.59E-04	3.90E-04	3.90E-04	3.83E-04	3.71E-04	3.72E-04	4.08E-04	3.80E-04	3.67E-04	3.58E-04	3.56E-04
Dairy cows	CH4	25	5.64E-02	5.72E-02	6.24E-02	6.33E-02	6.17E-02	6.31E-02	6.45E-02	7.37E-02	7.37E-02	7.17E-02	7.41E-02	7.40E-02	7.44E-02	7.20E-02	7.38E-02	7.20E-02	7.16E-02

CA Senate Bill 1383 requires the livestock industry to cut methane emissions to 40 percent of 2013 levels by 2030.

2. Calculate projected methane emissions (MMTCO2e) from CA dairy (2017-2045), highlighted in green.

3. Calculate GWP* from 2000 - 2045 and obtain the reduction average between 2030 to 2045.

Based on AR4 GWP100 = 25 for consistency

		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
CH4 emission (GWP)	(MMT CO2e)	14.2245697	14.5136493	15.6902132	16.0893447	15.4337949	15.8896823	16.2933885	18.3082896	18.5623299	17.8830598	18.5081353	18.4484971	18.9550121	18.106066	18.3656318	17.9379584	17.8386093
CH4 emission	(ton)	568982.787	580545.972	627608.528	643573.79	617351.797	635587.29	651735.54	732331.584	742493.195	715322.394	740325.413	737939.885	758200.486	724242.642	734625.272	717518.337	713544.371
Target reduction (by 2030)	(MMT CO2e)														7.24242642			
Target annual reduction (by 2030)	(annual reduction,														0.51731617			
Projected emission	(MMT CO2e)	14.2245697	14.5136493	15.6902132	16.0893447	15.4337949	15.8896823	16.2933885	18.3082896	18.5623299	17.8830598	18.5081353	18.4484971	18.9550121	18.106066	18.3656318	17.9379584	17.8386093
GWP*	MMT CO2e	Reference Period																

		2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
CH4 emission (GWP)	(MMT CO2e)															
CH4 emission	(ton)															
Target reduction (by 2030)	(MMT CO2e)															
Target annual reduction (by 2030)	(annual reduction,															
Projected emission	(MMT CO2e)	17.3212931	16.8039769	16.2866608	15.7693446	15.2520284	14.7347122	14.2173961	13.7000799	13.1827637	12.6654476	12.1481314	11.6308152	11.113499	10.5961829	10.5961829
GWP*	MMT CO2e				9.73524209	6.58192884	0.10054949	-3.46545848	-3.07641135	-6.85525353	-10.4384166	-20.0635605	-23.0854762	-22.6074782	-27.020776	-26.7971327

		2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	**Annual reduction** (2030 - 2045)
CH4 emission (GWP)	(MMT CO2e)															
CH4 emission	(ton)															
Target reduction (by 2030)	(MMT CO2e)															
Target annual reduction (by 2030)	(annual reduction,															
Projected emission	(MMT CO2e)	10.5961829	10.5961829	10.5961829	10.5961829	10.5961829	10.5961829	10.5961829	10.5961829	10.5961829	10.5961829	10.5961829	10.5961829	10.5961829	10.5961829	
GWP*	MMT CO2e	-28.6965641	-25.5130162	-26.4863878	-24.8826126	-24.5100533	-22.5701177	-20.630182	-18.6902464	-16.7503108	-14.8103751	-12.8704395	-10.9305038	-8.99056816	-7.05063252	-19.8249949

Appendix B: Calculation of GHG reductions to be achieved if all global dairy production regions achieved the same level of production efficieny (carbon intensity).

1. Obtain California dairy industry's carbon intensity, or kg of CO2e per kg of energy and-protein corrected milk (ECM). Highlighted in green.

https://www.journalofdairyscience.org/article/S0022-0302(20)30074-6/fulltext

2. Obtain carbon intensity data for dairy regions throughout the globe:

https://dairysustainabilityframework.org/wp-content/uploads/2019/01/Climate-Change-and-the-Global-Dairy-Cattle-Sector.pdf

3. Calculate percent of GHG reduction that would be achieved if the entire global dairy sector achieved California's carbon intensity, using both models.

REG_ANNEX5	2015 Data				Business As Usual	IF production was like CA model 2		IF production was like CA model 1	
	Billion kg milk	**% share**	**Billion kg FPCM**	**kg CO2e/ kg FPCM**	**billion kg CO2e/region**	**billion kg CO2e/region**	**% reduction by country**	**billion kg CO2e/region**	**% reduction by country**
Central & South America	80.75	12.0%	80.87	3.36	271.7232	90.5744	67%	93.8092	65%
East Asia	53.19	8.1%	54.4	2.43	132.192	60.928	54%	63.104	52%
Eastern Europe	42.06	6.3%	42.68	1.34	57.1912	47.8016	16%	49.5088	13%
North America	102.07	14.5%	97.41	1.29	125.6589	109.0992	13%	112.9956	10%
Oceania	31.43	5.1%	34.07	1.31	44.6317	38.1584	15%	39.5212	11%
Russian Federation	30.52	4.6%	31.03	1.39	43.1317	34.7536	19%	35.9948	17%
South Asia	97.39	14.6%	98.55	4.1	404.055	110.376	73%	114.318	72%
Sub-Saharan Africa	22.04	3.4%	23.18	6.67	154.6106	25.9616	83%	26.8888	83%
West Asia & Northern Africa	60.31	9.2%	62.12	4.41	273.9492	69.5744	75%	72.0592	74%
Western Europe	146.73	22.1%	149.1	1.37	204.267	166.992	18%	172.956	15%
Global	**666.49**	100%	**673.41**		1711.4105	754.2192	56%	781.1556	54%
california model 2	CDFA model			1.12					
california model 1	sampled dairies model CAD			1.16					

4. Convert "Business as Usual" Global Dairy CO2e into MTCO2e.

5. Obtain Total Global GHG emissions data: https://www.ipcc.ch/site/assets/uploads/2018/12/UNEP-1.pdf

6. Calculate Percent of Total Global GHG emissions that would be reduced if entire global dairy sector achieved California's carbon intensity, using both models.

			IF production was like CA model 2	IF production was like CA model 1
Global Dairy GHG Emissions (BAU)	(MTCO2e)	1,711,800,000		
Total Global GHG Emissions	(Gigatons)	53.5		
Total Global GHG Emissions	(MTCO2e)	53,500,000,000		
Global Dairy Emissions (at CA carbon intensity)	(MTCO2e)		754,390,853	781,333,383
Percent of Total Global GHGs reduced			1.79%	1.74%