GROWING THE BIOECONOMY:

Opportunities for GHG Reductions and Renewable Fuel Production in the Poultry Industry

ATIP Foundation

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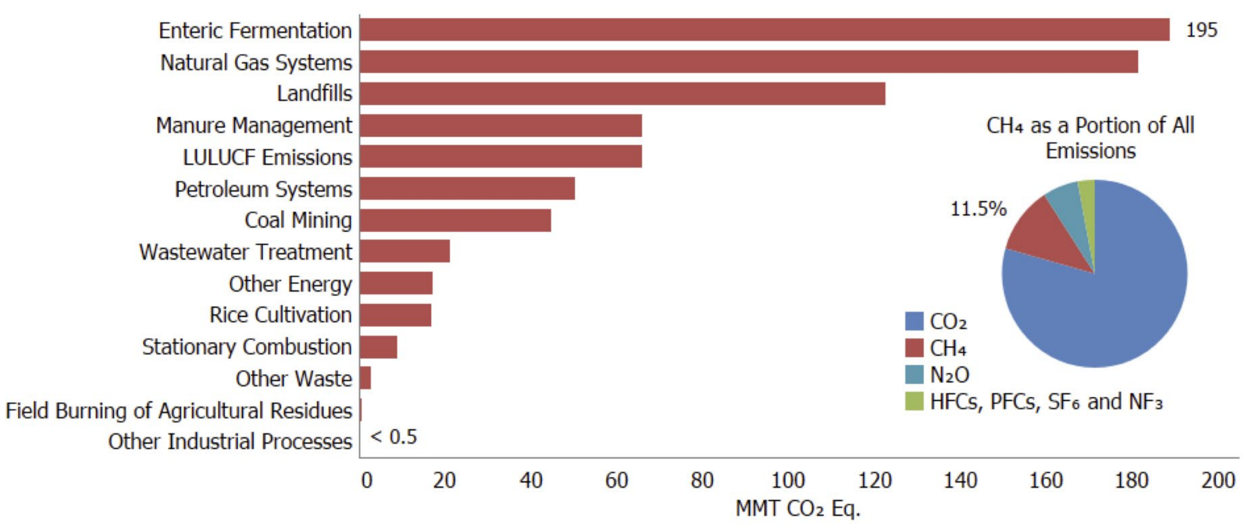
Executive Summary

The objective of this paper is to highlight the potential for avoiding and reducing GHG emissions and promoting renewable energy development in the poultry sector, and to discuss how incentive and credit programs such as California's Low Carbon Fuel Standard (LCFS) can move innovative manure management project development forward, yielding both financial benefits to the nation's farmers and environmental benefits to the world. Without recommending any one manure management system over another, we present the technical evidence here that there exists great opportunity in the poultry industry to deliver millions of tons of annual GHG reductions provided the correct policy signals are in place.

Manure management practices in the agriculture sector release Greenhouse Gases (GHG), primarily methane and nitrous oxide. Innovative manure management systems, such as anaerobic digesters (AD) and dry storage/gasification, can help mitigate the release of GHG while utilizing the waste stream as feedstock inputs to produce renewable natural gas (RNG), syngas and other biofuels, and biobased products, displacing fossil fuel use and immediately providing beneficial environmental services. Individual states and the Federal government have set ambitious 2030 GHG-reductions targets. In order to meet these targets, it is necessary to take measures to continue to incentivize and develop innovative manure management systems across the three leading manure sources of GHG of dairy, swine, and poultry. Poultry, in particular, is currently underrepresented as a feedstock in AD and gasification development and represents a significant opportunity for mitigating GHG emissions and maximizing the production of renewable energy.

Figure 1: 2021 Sources of CH4 Emissions (U.S.)

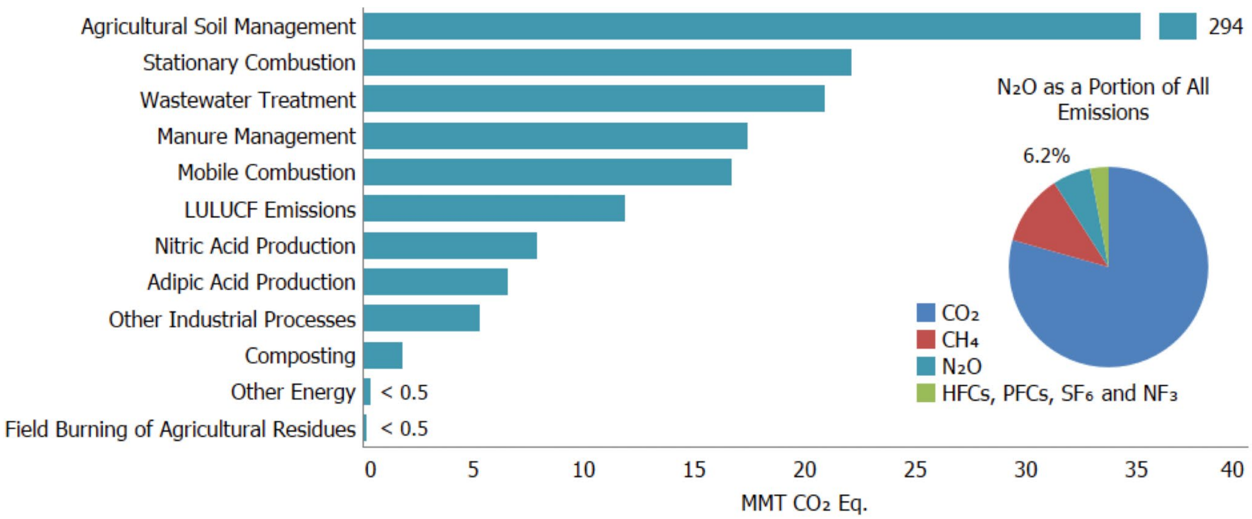


Source: EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021

Methane (CH_4) is more than 25 times more effective than CO_2 at trapping heat in the atmosphere over a 100-year time frame and over 80 times more potent than CO_2 on a 20-year basis which underscores the importance of focusing on both CO_2 and short-lived climate pollutants such as methane as part of an effective climate strategy. Over the last two hundred and eighty years, CH_4 in the atmosphere has increased by 162 percent.[1] Manure management in the agricultural sector is the 4th highest contributor of methane due to the anaerobic breakdown of manure in wet manure handling systems (see Figure 1).

Nitrous oxide (N_2O), also emitted from traditional manure management practices, is close to 300 times more powerful than CO_2 at trapping heat in the atmosphere over a 100-year time frame. Nitrous oxide emissions from manure management were responsible for 17.4 MMT CO_2e or 4.3 percent of N_2O emissions (see Figure 2). Unlike methane, N_2O production is caused by aerobic conditions such as those found in dry manure management systems without digesters. Based on IPCC default values for N_2O emissions factors, these dry systems could substantially increase N_2O emissions,[2] and N_2O emissions from manure management have increased by 5.0 MMT CO_2e, the equivalence of 40.5 percent, from 1990 to 2021.

Figure 2: 2021 Sources of N2O Emissions (U.S.)



Source: EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021

Livestock operations in the U.S. have a longstanding, national trend toward consolidated, larger, efficient operations. Within those larger operations, there has been an industry trend toward liquid manure systems in certain sectors such as dairy, which has decreased the emission of nitrous oxide and increased methane production in manure management. At the same time, the recent development of cage-free poultry legislation has begun to incentivize dry litter-based manure management systems in the poultry sector, which do decrease methane emissions but may increase nitrous oxide production. Both systems offer opportunities for incorporation of innovative technologies to avoid emissions and replace the need for fossil fuel resources.

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[1] EPA (2023) Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021. U.S. Environmental Protection Agency, EPA 430-R-23-002. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2021.

[2] Monteny, G., Groenestein, C. & Hilhorst, M. Interactions and coupling between emissions of methane and nitrous oxide from animal husbandry. Nutrient Cycling in Agroecosystems 60, 123–132 (2001). https://doi.org/10.1023/A:1012602911339. Also see Paul Jun, Michael Gibbs, and Kathryn Gaffney, "CH4 and N2O Emissions from Livestock Manure" in *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, https://www.ipcc-nggip.iges.or.jp/public/gp/bgp/4_2_CH4_and_N2O_Livestock_Manure.pdf

Aggregated emissions and sinks by identified sectors defined by the United Nations Framework Convention on Climate Change (UNFCCC) were compiled and reported to provide guidelines for GHG emissions comparability across countries. The goal is to stabilize greenhouse gas concentrations in the atmosphere by decreasing identified industry emissions trends. As seen in Table 1, over the thirty-one-year period of 1990 to 2021, total emissions from the agriculture sector grew by 50.1 MMT CO_2e (8.4 percent).[3]

Table 1: Recent Trends in U.S. Greenhouse Gas Emissions and Sinks by IPCC Sector (MMT CO2 Eq.)

IPCC Sector	1990	2005	2017	2018	2019	2020	2021
Energy	5,368.0	6,351.5	5,418.7	5,589.5	5,460.6	4,894.0	5,196.6
Industrial Processes and Product Use	335.4	356.1	359.1	362.2	366.8	363.2	376.4
Agriculture	548.0	577.7	613.1	629.5	614.5	597.3	598.1
Waste	236.0	192.1	170.9	173.7	176.0	171.5	169.2
Total Gross Emissions (Sources)	**6,487.3**	**7,477.4**	**6,561.8**	**6,754.8**	**6,617.9**	**6,026.0**	**6,340.2**
LULUCF Sector Net Total	(881.0)	(781.1)	(774.2)	(765.1)	(704.0)	(776.2)	(754.2)
Net Emissions (Sources and Sinks)	**5,606.4**	**6,696.3**	**5,787.6**	**5,989.7**	**5,913.9**	**5,249.8**	**5,586.0**

Source: EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021

There are two primary U.S. Environmental Protection Agency (EPA)-identified[4] strategies to reduce GHG emissions in agriculture with manure management practices: 1) controlling the way in which manure decomposes to reduce nitrous oxide and methane emissions, and; 2) capturing methane from manure decomposition to produce renewable energy. Controlling manure decomposition while capturing methane is accomplished via anaerobic digesters, which maximizes methane production and minimizes nitrous oxide emissions, while also capturing the produced methane and converting it to energy sources substituted for fossil fuels. Manure drying and solid storage reduces methane production, and utilizing conversion technologies such as gasification via pyrolysis to transform that dried manure to stable bioproducts, fertilizers, and syngas similarly represent the possibility of offsetting fossil fuel usage through renewable fuel and electricity production.

The AgSTAR program, a collaborative effort of the EPA and the U.S. Department of Agriculture (USDA), has reported on anaerobic digester (AD) systems in the U.S. and their role in supporting the EPA's reduction strategies for the agriculture sector. On-farm AD systems provide a number of ancillary benefits, including: supporting sustainable management of organic matter; reducing odor generated by farm animals or crops; improving water quality; producing renewable natural gas (RNG); and supporting the manufacturing of low-carbon domestic fertilizer products. As of April 2021, there were 45 known AD systems accepting swine manure in the U.S., 221 AD systems processing dairy cow manure, and only eight known AD systems accepting poultry manure.[5]

- For poultry, these systems annually reduce approximately 66,800 MT CO_2e each year. Poultry manure is the nation's third largest source of methane and fourth of nitrous oxide from livestock manure management.

[3] EPA (2023) Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021. U.S. Environmental Protection Agency, EPA 430-R-23-002. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2021.

[4] Ibid.

[5] Agstar-livestock Ag Database, Biogas Recovery in the Agriculture Sector, July 2023

- For swine, these systems reduce approximately 650,000 MT CO_2e each year, with an identified potential for AD systems to reduce 20,800,000 MT CO2e each year.
- For dairy, these systems reduce approximately 4.29 MMT CO_2e each year, with an identified potential for AD systems to reduce 29.9 MMT CO_2e each year.

Figure 3: Poultry Litter Anaerobic Digester

Source: Agriland Media

Over the past decade, federal and state-based renewable fuel programs have helped to drive anaerobic digester and other innovative developments in the dairy and swine industries. This has been done through incentives and credit programs such as California's Low Carbon Fuel Standard (LCFS) credits which have provided the necessary incentive to motivate innovations in manure management practice, thus driving biofuel production while capturing environmental benefits in the dairy and swine sectors. Poultry, although responsible for 6.5% of methane and nitrous oxide emissions from manure management in the U.S.,[6] has not taken advantage at scale of incentives to implement similar innovative manure management strategies.

We begin looking at the poultry industry itself in the United States, including its size, GHG impact, and the energy potential of the manure it produces. We then survey historical, current, and emerging manure management practices in the U.S. poultry industry before taking an overview of national-level data and state-level opportunities to both incentivize and implement new manure management practices that have

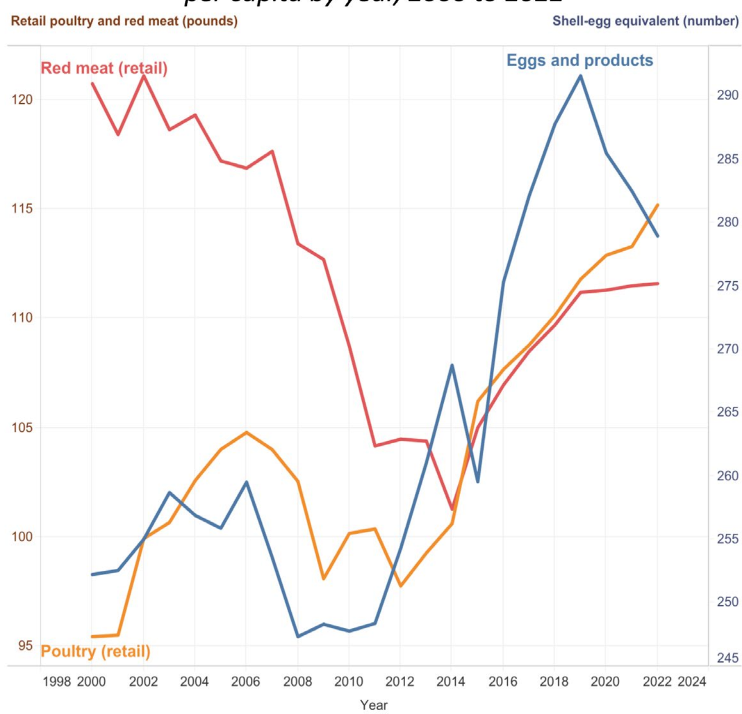
[6] See Table 5-7, EPA (2023) Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021. U.S. Environmental Protection Agency, EPA 430-R-23-002. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2021.

the potential to deliver significant annual GHG reductions and renewable fuel production from the poultry industry.

The Poultry Industry

The poultry industry is the largest producer of animal-based protein in the U.S., with a forecast production for 2023 of over 21 MMT of meat produced[7] and nearly 94 billion table eggs produced in 2022.[8] This production resulted in total poultry sales in 2022 in the U.S. of $76.9 billion,[9] a considerable increase from the previous year as the domestic consumer market increasingly favors poultry over red meat alternatives. These market and consumer trends indicate that the poultry sector will continue to grow in the U.S. in the near-term future, with an expected correlated growth in the size of existing poultry farms and/or the development of larger consolidated farms in the coming years.

Figure 4: Estimated U.S. poultry and red meat disappearance per capita by year, 2000 to 2022



Source: USDA ERS

U.S. poultry populations are typically categorized as egg layers, broilers (meat birds), and turkeys, each with their own historically standard practices of animal and manure management. Traditionally, manure in broiler and turkey farms are managed with a dry litter system, which reduces methane yet may increase N_2O emissions. Large industrial layer farms, on the other hand, have historically caged their birds and handled manure in wet slurry or lagoon systems which emit large amounts of methane,[10] or have dried and stored the manure in a solid storage form. This standard practice is beginning to change as cage-free laws are passed and implemented, as cage-free layer farms also utilize dry litter systems for their manure management. Currently there are two states, California and Massachusetts, requiring eggs to be cage-free, and seven more[11] have legislation that will go into effect in the next several years. As a result, although 66 percent (205 million) of the laying hens in the U.S. are currently managed with conventional caged systems, that number is expected to fall in the coming years.[12] Even so, there will be a considerable number of layers

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[7] https://downloads.usda.library.cornell.edu/usda-esmis/files/73666448x/ff366n54r/5999pk814/livestock_poultry.pdf

[8] https://downloads.usda.library.cornell.edu/usda-esmis/files/fb494842n/2f75sq97s/ws85bx786/ckeg0723.pdf

[9] https://www.ers.usda.gov/topics/animal-products/poultry-eggs/sector-at-a-glance/

[10] https://www.epa.gov/agstar/practices-reduce-methane-emissions-livestock-manure-management

[11] Colorado, Michigan, Nevada, Oregon, Rhode Island, Utah, and Washington.

[12] https://unitedegg.com/facts-stats/

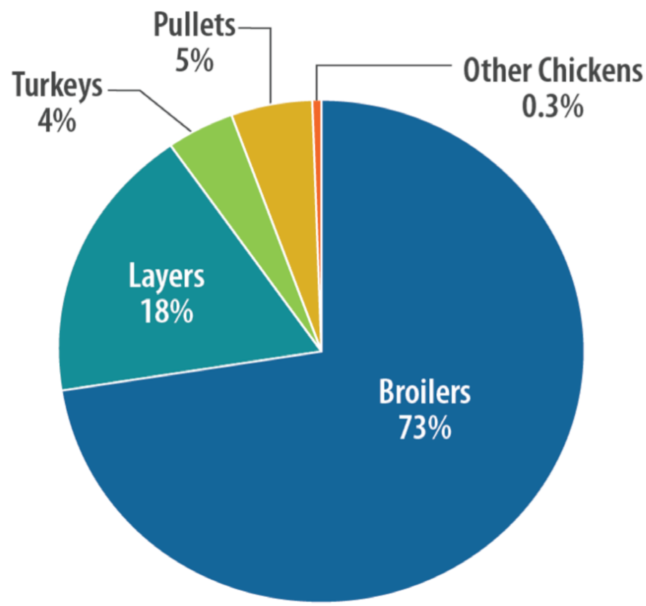
managed via wet, methane-producing manure systems well into the future with conventional layer farming still in practice in nine of the ten top egg-production states.[13]

Although pastured and free-range poultry sales continue to grow as well, it is important to note that cage-free production systems are not pastured or free-range systems. Cage-free systems still have a concentration of birds which allow for easier collection of manure and innovation to take place to increase sustainability. Ultimately, the land requirements if the industry was completely pasture-based, which would require an acre in a temperate climate per 50 - 500 birds, several million acres total, make these systems impractical at scale. It should be expected that pastured system production will continue to grow, but not beyond niche and premium markets as a portion of the overall industry.[14]

The majority of poultry farms in the U.S. are concentrated in the Southeast and in Texas, Mississippi, Iowa, and Missouri. The top broiler producers are in the Southeast while the top layer producers are in the Midwest, along with CA and TX. The states with the highest N_2O emissions in 2021 (MMT CO_2e) from poultry operations were Alabama, Arkansas, Georgia, and North Carolina. For methane emissions in 2021 (MMT CO_2e), the top poultry emitting states were Alabama, Georgia, and North Carolina.[15]

While the bulk of GHG emissions from U.S. manure management come from cattle and swine, poultry represents a statistically significant percentage of the emissions in this sector with 6.5 percent of total emissions, per the EPA Inventory of the U.S. Greenhouse Gas Emission and Sinks (Table 2).[16] The methane emitted by poultry[17] has a heat content of 7.45 MMBTU, the equivalent of 53.69 million gallons of diesel fuel. Indeed, while poultry ranks third behind cattle and swine overall, there are some states, such as California, in which GHG emissions from poultry manure management ranks second only behind cattle.[18] Nationwide, poultry is close behind swine and dairy

Figure 5: U.S. Poultry Population by Bird Type, 2018



Source: EPA

[13] https://app.usda-reports.penguinlabs.net/?crop=eggs&statistic=production_eggs&year=2022

[14] https://www.agmrc.org/commodities-products/livestock/poultry/pastured-poultry-profile

[15] See Tables A-173 and A-175, Annex 3. EPA (2023). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021. U.S. Environmental Protection Agency, EPA 430-R-23-002. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2021

[16] EPA (2023). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021. U.S. Environmental Protection Agency, EPA 430-R-23-002. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2021

[17] 141 kilotons, per Table 5-8 of Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021.

[18] See Table A-173, Annex 3, EPA (2023). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021. U.S. Environmental Protection Agency, EPA 430-R-23-002. While dairy methane emissions in California were 9.0466 MMT CO2e in 2021, poultry ranks second above all other livestock manure management sources with 0.1216 MMT CO2e methane emissions. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2021

production in terms of N_2O from manure management, with 2021 poultry N_2O emissions of 1.5 MMT CO_2e to swine's 1.8 MMT CO_2e N_2O emissions.

Table 2: CH4 and N2O Emissions from Manure Management (MMT CO2 Eq.)

Gas/Animal Type	1990	2005	2017	2018	2019	2020	2021
CH_4	**39.0**	**54.9**	**64.4**	**66.5**	**65.7**	**66.7**	**66.0**
Dairy Cattle	16.0	26.4	35.0	35.8	34.6	35.5	35.9
Swine	17.4	23.5	23.5	24.7	25.0	25.1	24.0
Poultry	3.7	3.6	3.8	3.9	4.0	4.0	3.9
Beef Cattle	1.8	1.9	2.0	2.0	2.0	2.0	2.0
Horses	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Sheep	0.1	0.1	0.06	0.06	0.05	0.05	0.05
Goats	+	+	+	+	+	+	+
American Bison	+	+	+	+	+	+	+
Mules and Asses	+	+	+	+	+	+	+
N_2O	**12.4**	**14.5**	**16.9**	**17.2**	**17.4**	**17.5**	**17.4**
Beef Cattle	5.2	6.4	7.9	8.1	8.2	8.3	8.3
Dairy Cattle	4.6	4.8	5.4	5.4	5.4	5.5	5.5
Swine	1.1	1.4	1.7	1.8	1.9	1.9	1.8
Poultry	1.2	1.4	1.5	1.5	1.5	1.5	1.5
Sheep	0.1	0.3	0.3	0.3	0.3	0.3	0.3
Horses	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Goats	+	+	+	+	+	+	+
Mules and Asses	+	+	+	+	+	+	+
American Bison	NA	NA	NA	NA	NA	NA	NA
Total	**51.4**	**69.4**	**81.3**	**83.7**	**83.1**	**84.2**	**83.4**

Source: EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021

Due to its size, the poultry industry in the U.S. generates tremendous amounts of biomass in terms of manure. Additionally, poultry also holds a distinct advantage over dairy and swine for manure processing in that it has a significantly higher recoverable manure percentage in comparison to dairy and swine, 93.3% vs. 75%.[19] With 368,241,393 layers, 1,621,400,316 broilers, and 104,322,709 turkeys in the country per the 2017 U.S. Census of Agriculture,[20] using NRCS Agricultural Waste Management Field Handbook assumptions we can calculate annual total recoverable manure biomass amounts of more than 28 million tons[21] from layers, broilers, and turkeys in the domestic poultry industry. The energy potential of this biomass will vary based on conversion technologies; in addition, a portion of this total exists in wet and slurry systems, which have additional energy potential from avoided emissions. Nevertheless, given a

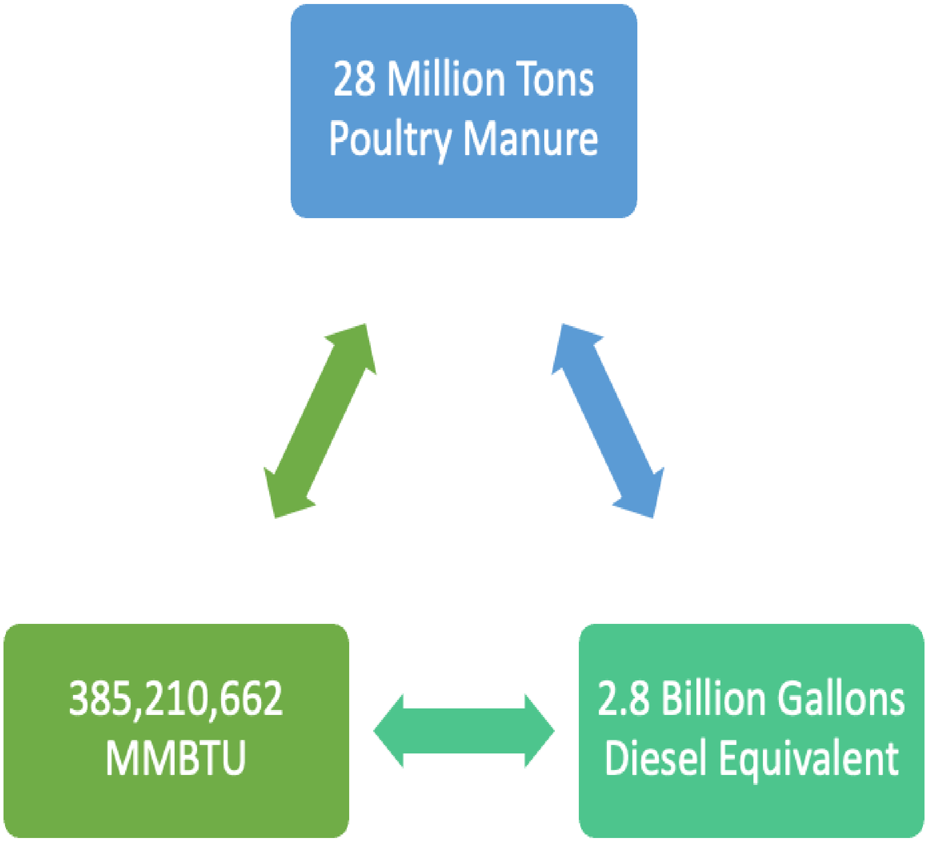
[19] See Table 5.1, 'Descriptions of Animal Type, Body Weight, Manure Production, and Recoverable Manure' in Pramod Pandy and E.R. Atwill, 'Microbial Pathogens in Extensive and Intensive Systems' in *The Welfare of Cattle*, edited By Terry Engle, Donald J. Klingborg, DVM, Bernard E. Rollin, CRC Press, 2019.

[20] https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_1_US/usv1.pdf

[21] Tables 4-11 and 4-16 in "Chapter 4 Agricultural Waste Characteristics", NRCS Agricultural Waste Management Field Handbook, March 2008. The Handbook gives average manure/recoverable litter generated per bird per day for layers (.19 lb/day, estimated 75% moisture), broilers (.044 lb/day litter, estimated 31% moisture), and turkeys (.24 lb/day litter, estimated 30% moisture).
https://policy.nrcs.usda.gov/OpenNonWebContent.aspx?content=31475.wba

higher heating value of 16 MJ/kg for poultry litter,[22] we can estimate the energy potential of this biomass to be equivalent to more than 2.8 billion gallons of diesel fuel per year.

Figure 6: Energy Potential of Recoverable Poultry Industry Manure



Source: US Census of Ag, NRCS, Kantarli et al.

Despite this fact, poultry has been largely ignored in terms of GHG-reduction monetization and renewable fuel production. As a result, of the 436 anaerobic digesters (AD) operational in the U.S. as of January 2023, only 7 process poultry manure.[23] In terms of untapped potential for reducing GHG emissions and producing renewable fuels and other value-added products via innovative manure management systems, poultry farms, and the biomass they produce, represent a significant opportunity. The evidence is clear that there are opportunities to increase sustainability with lower GHG emissions per animal unit with adoption of innovative technologies which can support revenue-positive conservation strategies. The following section reviews manure management practices in the poultry industry, which is trending toward dry litter-based systems even in egg-laying farms. Even with these trends toward cage-free dry manure management systems, however, there remains ample opportunity to avoid emissions and to create additional marketable products that replace the need for fossil fuel through proactive manure management strategies in both wet and dry systems where there is ample concentration of manure.

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[22] Poultry litter has an HHV (MJ/kg) of 16, per Table 1 of Ismail Cem Kantarli, Arzu Kabadayi, Suat Ucar, Jale Yanik, "Conversion of poultry wastes into energy feedstocks," *Waste Management* 56 (2016) 530-539. https://doi.org/10.1016/j.wasman.2016.07.019

[23] https://www.epa.gov/agstar/livestock-anaerobic-digester-database. There is one additional poultry digester listed in the AgSTAR database, but it processes waste from a poultry processing facility, not manure, and there are two other digesters that will process poultry that are listed as under construction.

Practices for Poultry Manure Management

There are various poultry manure management systems typically utilized in the U.S. poultry industry, and depending on the operation, treatment, and storage capabilities, the release of methane and GHGs in each system varies. Broadly speaking, these systems can be categorized in terms of wet and dry manure management. Of the standard practices, wet systems such as uncovered anaerobic lagoons (in which manure is collected in a shallow pit directly underneath cages and frequently flushed, scraped, or moved via a belt to a holding lagoon) and liquid/slurry pit storage below animal confinements (in which manure is held in deeper stacks below the animal cages) emit the highest percentage of methane.[24] Per the IPCC regional averages for poultry animal waste management systems and conversations with industry experts, we can estimate 30% of layers in North America are managed by lagoon or liquid/slurry wet systems.[25] These operations in particular emit greater quantities of GHGs – approximately 10 to 50 times more methane than dry systems[26] – and are therefore prime candidates for conversion to anaerobic digester systems.

Dry litter-based systems use different bedding materials depending on locality – including wood shavings, sawdust, wheat straw, peanut hulls, or rice hulls – which absorb and dry manure as it is mixed in. This litter is removed from the barn, typically once a year, and stored under cover or directly applied to fields as a fertilizer product. In drying the poultry manure as it is excreted this system does reduce methane emissions, although as the litter is continually re-wet with fresh manure there does continue to be microbial activity in poultry litter that releases methane. In addition, the aerobic conditions of dry litter can increase the production of ammonia and nitrous oxide emissions.[27] Historically, dry litter manure management systems have been used for turkey and broilers, and with the recent development of cage-free egg laws, has become more prevalent in layer barns as well.

AD systems are particularly effective at reducing GHG emissions. The 221 dairy digesters that were in service in 2021 are estimated to have reduced emissions by 4.29 MMT CO_2e annually.[28] AD systems for poultry manure are not yet nearly as standard of a manure management practice, and the existing poultry digesters operate on average on a much smaller scale than the existing dairy digesters in the country. Even so, the eight known U.S. poultry AD systems operational in 2021 are estimated to have reduced GHG emissions by 66,800 MT CO_2e annually.[29] This gap represents a significant opportunity for poultry operations to innovate with AD. As of January 2023, there are only seven known AD systems in the U.S. per the AgSTAR database that process manure from nearly 2 million birds in Mississippi, South Carolina, Kentucky, Maryland, Ohio, and Pennsylvania.[30]

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[24] USDA NRCS Waste Management Field Handbook; (210–VI–AWMFH, Amend. 47, December 2011)

[25] See Table 10A.9, IPCC "Ch. 10 Emissions from Livestock and Manure Management," *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

[26] Calculated from IPCC Methane Conversion Factors for Manure Management Systems Table 10.17. Poultry dry storage is estimated at a 1.5% methane conversion factor, versus 13% - 55% for pit storage systems and 73% for anaerobic lagoons, all in warm/temperate/moist climate zones. See IPCC "Ch. 10 Emissions from Livestock and Manure Management," *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*, pp. 67-68.

[27] https://secure.caes.uga.edu/extension/publications/files/pdf/B%201382_5.PDF

[28] https://www.epa.gov/agstar/anaerobic-digestion-dairy-farms

[29] Anaerobic Digestion on Poultry Farms, AgSTAR, EPA, Last updated on February 9, 2023

[30] https://www.epa.gov/agstar/livestock-anaerobic-digester-database

AD systems are easier to implement in wet-system caged-layer farms and it is in these farms that the highest potential for avoided emissions exists. However, even in farms utilizing dry litter systems, anaerobic digesters and other innovative manure management systems can yield significant benefits, including reducing emissions, producing renewable fuel, and creating consistent and usable fertilizer products. MAC Farms in Campbellsville, Ky has been one of the leaders in demonstrating the utility of using anaerobic digestion on dry poultry litter, with a digester that has been in operation since 2014. Co-digesting poultry litter from broilers with other food waste and agricultural material, MAC Farms has proven the ability for AD systems to process poultry litter, producing 3,300 MW/year[31] from digester-produced biogas while also creating a consistent digestate fertilizer product with stable forms of nutrients.[32] Likewise, Flintrock Farms in Lititz, PA has been at the forefront of demonstrating the possibility of gasification as a conversion technology for producing syngas and fertilizer from poultry litter, with a successful demonstration system installed under a technology license agreement with technology company Ecoremedy in 2014.[33]

Figure 7: Poultry Lagoon Anaerobic Digester

Source: Aqualimpia Engineering

The research in this area, and in particular in developing scalable AD systems to process poultry litter, is ongoing and has shown recent promising results. Jun Zhu, director of the Center for Agricultural and Rural Sustainability and professor of biological and agricultural engineering for the University of Arkansas

[31] https://www.epa.gov/agstar/livestock-anaerobic-digester-database

[32] Manure Manager, A Long Road, Kentucky's MAC Farms takes litter from 1.6 million broilers and turns it into energy, March 20106, by Diane Mettler.

[33] https://ecoremedyllc.com/experience/flintrock-farms/

System Division of Agriculture, has led these efforts. Dr. Zhu's research into the anaerobic digestion process of poultry manure and litter (regardless of the manure management on-farm practice) shows the role these systems can play in the nation's biogas and domestic fertilizer production needs,[34] supporting the EPA's emission reduction goals. Working in collaboration with the University of Idaho and Virginia Tech with funding from USDA, in 2022 Dr. Zhu's team successfully built[35] a prototype that captures methane, produces the fertilizer struvite, and emits clean water. As this new system is refined and scaled up with further deployments, it represents the kind of new, cost-effective techniques that are being developed for individual poultry farms to solve poultry manure and litter issues.

The next section looks to national data to both highlight the potential of deploying innovative manure management systems and also to demonstrate the necessity of financial incentives to motivate their development, deployment, and widespread adoption. There is the potential for innovative solutions, which show the promise to result in GHG reductions, renewable fuel production, environmental benefits, and financial benefits for poultry farmers, to be implemented across the country and help to drive forward the nation's clean air and water future.

National-level Data

The further development of new, innovative systems for livestock manure management supports many national level environmental and agricultural development goals. The EPA's 2022-2026 Strategic Plan presents 7 long term performance goals (see Figure 8). Increasing innovative agriculture manure management practices, such as AD or gasification on well-suited livestock farms in the U.S., directly supports goals 1, 4 and 5.

AD ranks the highest in methane reduction compared to all other on-farm manure management practices, as methane emissions are directly reduced with AD systems. In addition, gasification via pyrolysis is shown to produce similar GHG emission reductions.[36] Further, when the generated biogas is used for energy, methane emissions are indirectly reduced from avoided fossil fuel use, both of which contribute to Goal 1. Anaerobic digestion systems emit less methane compared to uncovered anaerobic lagoons because the methane emissions are captured and destroyed or utilized, helping to meet Goal 4. Innovative manure management systems support farmers by allowing for diversified farm revenue streams, such as animal bedding, fertilizer, and tipping fees (payments for taking organic waste). These systems support rural economic growth, improve soil health by converting the nutrients in manure to a more accessible form for plants to use, help protect the local water resources by reducing nutrient run-off and destroying pathogens (Goal 5), develop sustainable regional resilient food systems, and build farm-community relationships. These systems also provide an opportunity for farm energy independence, as the biogas produced can meet on-farm needs and support grid energy needs.

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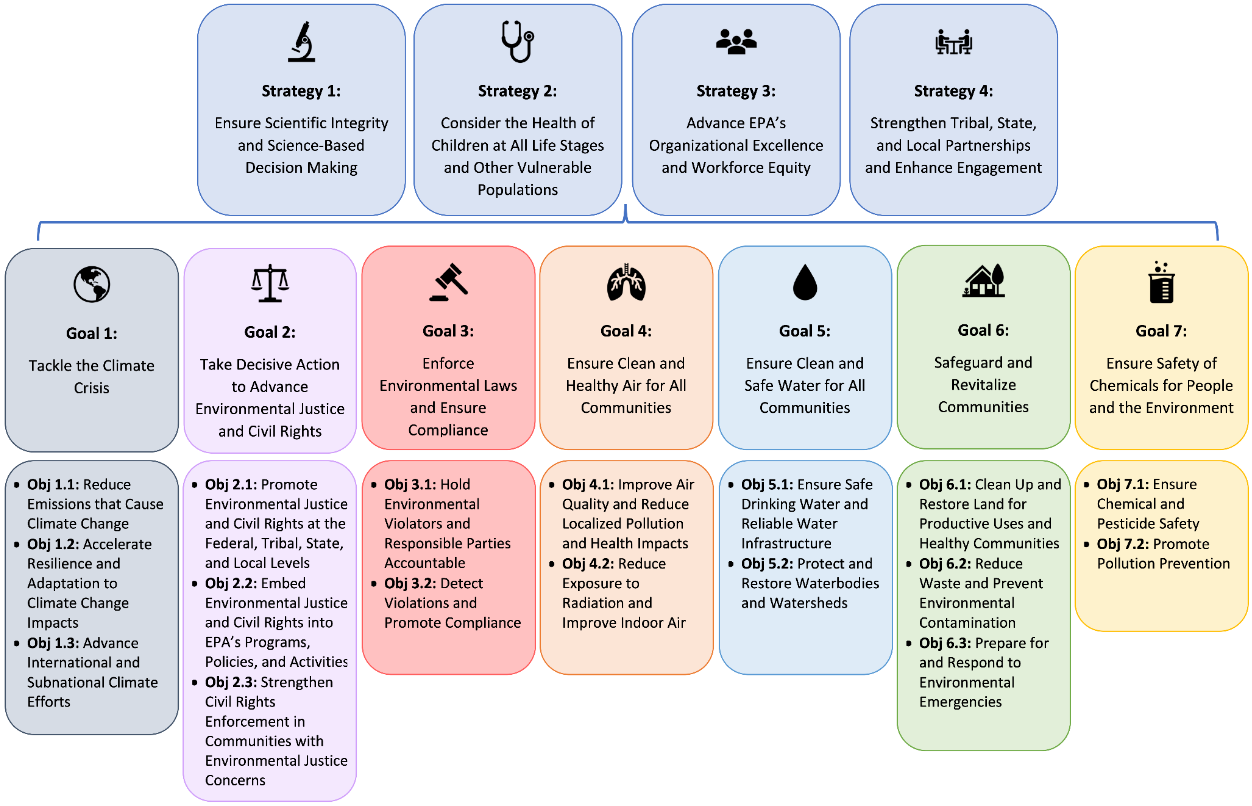
[34] Liquid-State Poultry Litter Digestion System under Development to Make Organic Fertilizer, Biogas, University of Arkansas System Division of Agriculture, November 2021

[35] https://aaes.uada.edu/news/poultry-litter-digester-update/

[36] https://doi.org/10.1016/j.jclepro.2020.124969

Figure 8: FY 2022-2026 EPA Strategic Plan Framework



Source: EPA

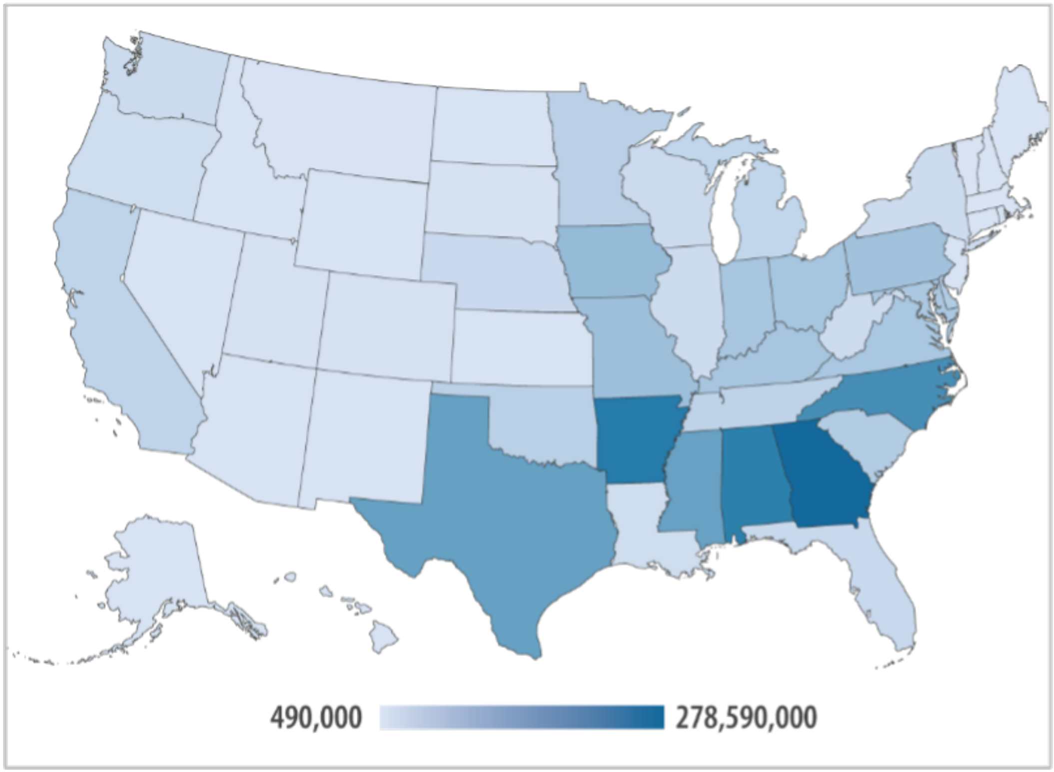
There are 343 manure-based AD systems in the U.S. as of January 2023; 290 Dairy, 46 Hog, 8 Poultry, 9 Beef. The benefits of these systems in 2022 for direct and indirect GHG emissions avoided was 10.43 MMT CO_2e, while generating 2.42 million MWh equivalent in energy.[37] AD and gasification remain uncommon manure management practices in the poultry industry. To incorporate innovative manure management systems such as these into poultry, the sector needs technical support and financing opportunities. Such systems are challenging for small poultry farms and family businesses with narrow profit margins. When the cost is perceived to outweigh the benefits, there is limited incentive for farmers to pursue innovative manure management solutions. The EPA has proposed a number of ways to overcome the technical and economic challenges of developing poultry manure-based management systems, including: education and outreach; market incentives for biogas produced from poultry manure; strategic partnerships; third party build/own/operate models; codigestion; nutrient concentration; and federal, state, or local funding.[38]

Areas of interest for innovative manure management systems on poultry farms are related to poultry population density. U.S. poultry populations are concentrated in the Southeast, with over 41 percent located in Georgia, Arkansas, Alabama, and North Carolina. Texas, Mississippi, Iowa, and Missouri are the next most populous states for poultry, together making up about 20 percent of the U.S. poultry population. Successful AD systems have been developed in these areas. Brightmark Energy is third party

[37] Environmental protection Agency, AgSTAR Data and Trends
[38] EPA, Anaerobic Digestion on Poultry Farms, May 2023

owner and operator of a covered lagoon AD system at Pilgrim's Pride's poultry processing facility in Sumter, South Carolina.[39] Mac Farms, a broiler operation in Campbellsville, Kentucky,[40] operates a successful AD system that is profitable in part due to tipping fees. In addition, Mac Farms is creating nutrient fertilizers from the digestate, and the Mac Farms AD system output is certified as a fertilizer with the Kentucky Department of Regulatory Services and used onsite for crop production. Similarly, the Bioenergy Devco project in Delaware[41] is planning to use digestate to create compost for distribution.[42]

Figure 9: U.S. Poultry Population, 2018



Source: EPA

Even with these national benefits, the development of innovative manure management systems has been driven in recent years by state action and incentives, and it is at the state level that there exists the most significant opportunities to both drive the adoption of these manure management practices through incentive and credit programs and to reap the rewards in terms of clean air and water and the production of renewable fuels offsetting fossil fuel use.

[39] https://www.brightmark.com/renewable-natural-gas/projects/the-sumter-project
[40] https://www.epa.gov/agstar/meet-anaerobic-digester-operator-mac-farms
[41] https://delawarebusinesstimes.com/news/industry/environment/sussex-approves-bioenergy-devco-litter-digester-plant/
[42] EPA, Anaerobic Digestion on Poultry Farms, May 2023; https://www.epa.gov/agstar/anaerobic-digestion-poultry-farms

State-level Opportunities

California is the world's fifth largest economy and leads the nation with the strongest environmental policy for reducing GHGs. In many instances, environmental policies and incentives set in California have shaped behavior nationwide, including with the incentivization of GHG-reducing and renewable fuel producing innovative manure management systems in the agricultural sector. The state is tackling the issue with three strong frameworks:

1. The California Air Resource Board (CARB) released a 2022 scoping plan for achieving carbon neutrality. The goal is to achieve carbon neutrality by 2045. One identified strategy for success for the CARB plan is to utilize innovative agriculture energy use and carbon monitoring and planning tools to reduce on-farm GHG emissions from energy and fertilizer application or to increase carbon storage, as well as to promote on-farm energy production opportunities.[43]

Figure 10: CARB Scoping Plan 2045 Goals

Source: CARB 2022 Scoping Plan Executive Summary

2. The Short-Lived Climate Pollutant Reduction Strategy (SLCP Strategy) is a reduction strategy to reduce emissions of high global-warming potential gasses, including methane and hydrofluorocarbons (HFCs). State law mandates a 40 percent reduction in methane and HFC emissions by 2030 and a 50 percent reduction in anthropogenic emissions of black carbon by 2030.

3. The CA Senate Bill 1383, which requires the state board, in consultation with the Department of Food and Agriculture, to adopt regulations to reduce methane emissions from livestock manure management operations.

In California GHG emissions from poultry rank 2nd behind cattle in the livestock category and ahead of swine according to California's 2022 Greenhouse Gas Inventory[44] and corroborated in the U.S. EPA inventory (see Tables 3 and 4 below).

CA has 139 dairy digesters working to reduce GHG emissions on dairy farms, but no swine or poultry digesters. Livestock operations are recognized under the Low Carbon Fuel Standard as agricultural sectors that can help decrease the carbon intensity of California's transportation fuel pool and provide RNG using manure waste in collaboration with energy companies and rural development waste planning. Much like swine, which has a limited presence in California itself but significant potential nationwide for GHG

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[43] CA Air Resource Board, 2022 Scoping Plan to Achieve Carbon Neutrality, December 2022; https://ww2.arb.ca.gov/sites/default/files/2023-04/2022-sp.pdf

[44] https://ww2.arb.ca.gov/sites/default/files/classic/cc/inventory/ghg_inventory_by_sector_all_00-20.xlsx

reduction and RNG production, poultry is another agricultural sector for which California policy could help to generate innovative manure management implementation nationwide.

According to data from the ATIP Foundation, there are 247 poultry operations in CA with 83 million chickens.[45] The U.S. poultry industry is the world's largest producer and second largest exporter of poultry meat and a major egg producer. California produced over 4,019,600,000 eggs based on USDA National Agricultural Statistics Service (NASS) from December 1, 2020 through November 30, 2021, ranking CA in the top 10 for egg producing states.

Most AD projects in the poultry sector are now developed through partnerships between integrators and project developers, utilities, and other stakeholders. Currently, all poultry-based AD systems in the U.S. generate electricity; however, several new projects, as discussed above, are planned to or are producing RNG, helping to meet the emission reductions goals of CARB, SLCP, and the EPA. Regardless, AD remains an uncommon and underutilized manure management practice in the poultry industry. To help overcome this deficit of poultry AD systems, Purdue University conducted a study to determine how AD can become a more common tool in poultry manure management. Their solutions include the following: farmer access to an advisor when putting in a poultry AD system; leverage LCFS and RNG incentives to make AD systems more financially enticing; partner with a utility company or business looking for renewable energy or carbon offsets to reduce their carbon footprint; engage a 3rd party, e.g. an energy company, to own and operate the AD system so the farmer can focus on product production; add food waste or other organics to increase energy and charge tipping fees to remove waste; create nutrient fertilizers from poultry manure digestate; use Federal, state, or local direct financial assistance for feasibility studies.[46]

The state of CA has led the way for many years in driving innovative manure management systems with incentives for emissions reductions. The California Department of Food and Agriculture, through such programs as the Dairy Digester Research and Development Program and the Alternative Manure Management Program, has driven the adoption of digesters and other innovative manure management systems to reduce agriculture methane emissions within the state. Another example is CARB's Low Carbon Fuel Standard (LCFS), which has been successful in incentivizing reductions across sectors, including in manure management. Although CA's emissions from the swine sector are low - much lower than poultry (see Tables 3 and 4 below) - the LCFS has been successfully bringing low carbon fuel into the California market with 31 approved swine pathways. This California-based action has driven the development and implementation of manure management systems exclusively in other states, with the currently approved pathways representing swine farms in Missouri, Utah, and Texas.[47] This has proven the value to CA of incentivizing renewable fuel production from high-emitting sources in other states, and has helped CA and the nation as a whole meet clean energy goal benchmarks. Energy partners, waste collaborators, and funding through grant and incentive programs have supported innovative manure management systems for swine and dairy alike. Poultry has the potential to be the next sector poised to deliver significant reductions in GHGs provided CARB sends clear policy signals.

[45] http://atipfoundation.com/

[46] Purdue University, Poultry Manure Management Planning, Purdue University Cooperative Extension Service and Indiana Soil Conservation Service, reviewed September 1999.

[47] https://ww2.arb.ca.gov/resources/documents/lcfs-pathway-certified-carbon-intensities

Table 3: Methane Emissions for CA from Livestock Manure Management for 2021 (MMT CO2 Eq)

Sector	2021 MMT CO2 Eq
Dairy	9.0446
Beef	0.0772
Swine	0.0398
Poultry	0.1216

Source: EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021

Table 4: Total (Direct and Indirect) Nitrous Oxide Emissions for CA from Livestock Manure Management for 2021 (MMT CO2 Eq)

Sector	2021 MMT CO2 Eq
Dairy	1.0644
Beef	0.3106
Swine	0.0023
Poultry	0.0483

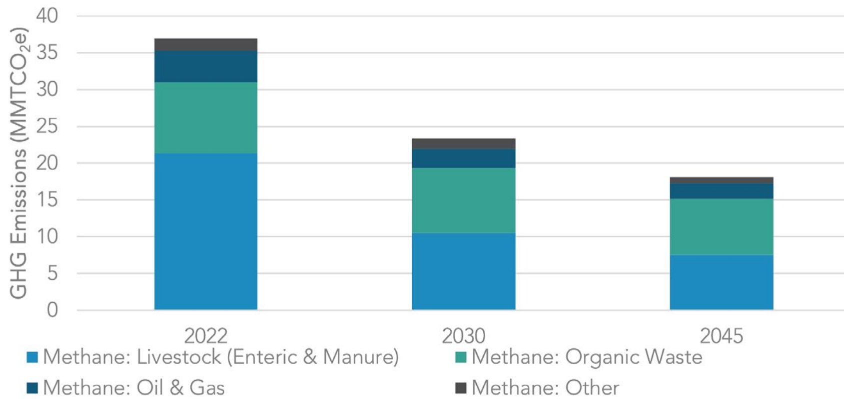
Source: EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021

North Carolina is one state with significant opportunity in this area. With more than 830 million chickens along with approximately 9 million hogs and 430,000 cattle, and as one of the states with the highest levels of methane emissions from the poultry industry, North Carolina has the opportunity to reap significant rewards from the adoption of innovative manure management systems in the poultry industry. A 2016 analysis of waste lagoons in North Carolina by the Environmental Working Group and Waterkeeper Alliance (EWG/Waterkeeper) found North Carolina has 4,145 waste lagoons in the state, covering almost 7,000 acres.[48] Additionally, the research found 170 waste lagoons were within a 100- year floodplain and 136 lagoons were within a half-mile of a public water well, indicating the potential for immediate air and water quality improvements as well as the financial incentive of renewable fuel production. Alabama and Georgia also have significant methane emissions from poultry operations, and according to the EPA anaerobic digester project profiles there are no systems in either state. Other states with a high percentage of layers are Iowa, Indiana, Pennsylvania, and Texas. In measuring total methane emissions from manure management by state, CA leads the nation with 9.292 (MMT CO_2e) and Iowa is second with 7.1613 (MMT CO_2e).[49] Each of these indicators point toward the potential for further development of revenue- and climate-positive innovative manure management systems.

[48] Environment America Research and Policy Center

[49] See Table A-173, Annex 3. EPA (2023). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2021. U.S. Environmental Protection Agency, EPA 430-R-23-002. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2021

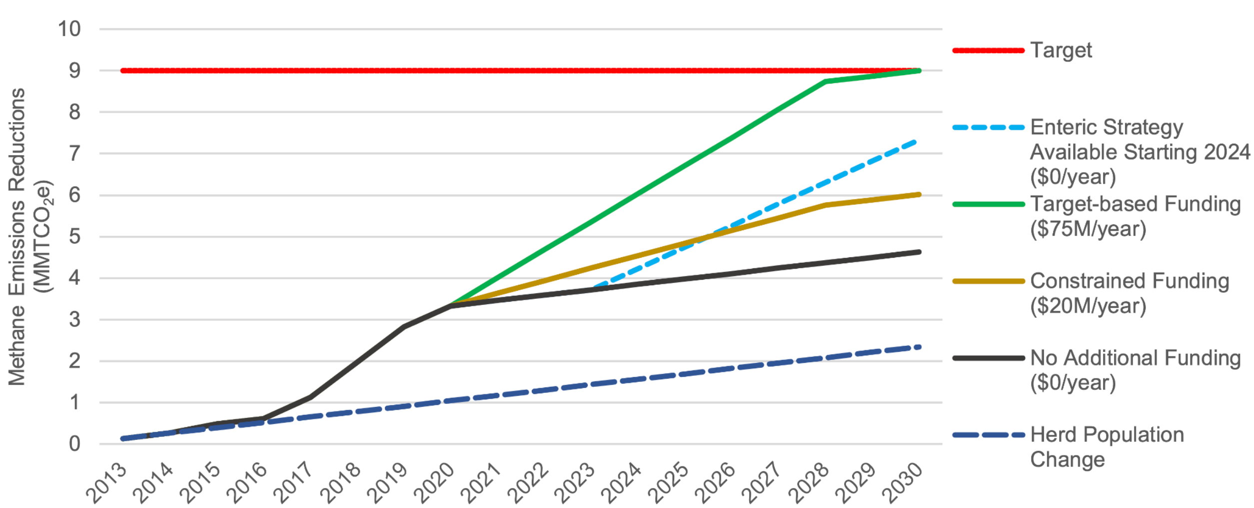
Figure 11: Methane emissions in 2022, 2030, and 2045 in the Scoping Plan Scenario



Source: CARB 2022 Scoping Plan

State plans such as the CARB Scoping Plan have mapped out the necessary decreases in GHG emissions to meet state targets (Figure 11). To date, methane emissions have been reducing in the dairy and livestock sector, which has been driven both by a decreasing animal population and the growing adoption of manure management strategies, including anaerobic digesters and conversion to dry manure systems. CARB recently conducted a detailed analysis of the emission reductions expected by 2030 and the additional investments (see Figure 12) needed to meet the state's methane reduction through 2050.[50] The report concludes that additional agricultural reductions are needed to meet the methane reduction target. Even with a continued annual animal population decrease of 0.5 percent per year through 2030, further reductions of approximately 4.4 MMT CO_2e will be needed to achieve the emission reduction goals, and the implementation of incentivized methane-reducing manure management systems on all methane-emitting farms, including poultry, will be needed to reach this goal.

Figure 12: Projected Annual CA Dairy and Livestock Sector Methane Emissions Reductions through 2030



Source: CARB Analysis of Progress toward Achieving the 2030 Dairy and Livestock Sector Methane Emissions Target

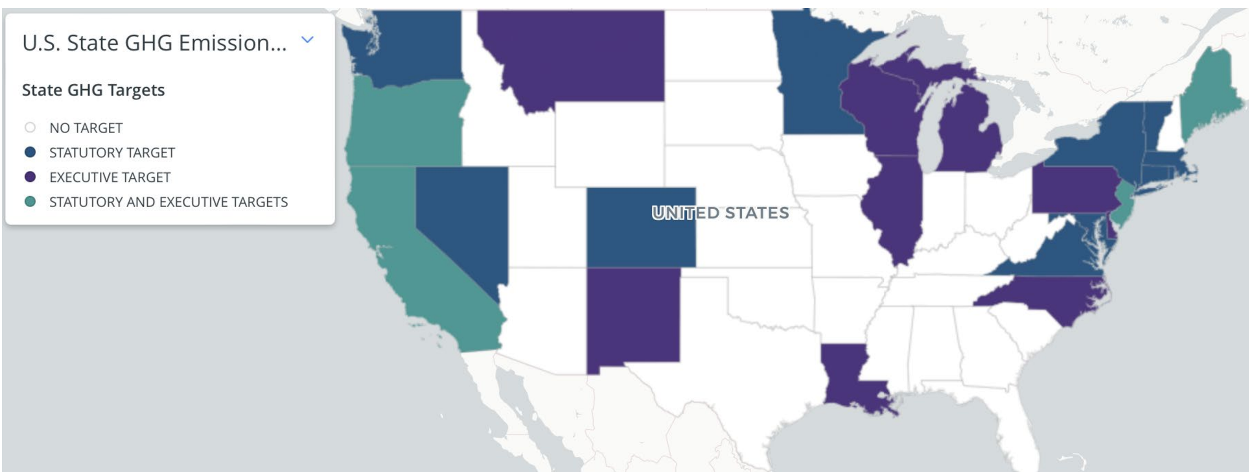
[50] CARB. March 2022. Analysis of Progress toward Achieving the 2030 Dairy and Livestock Sector Methane Emissions Target. https://ww2.arb.ca.gov/sites/default/files/2022-03/final-dairy-livestock-SB1383-analysis.pdf

Maximizing alternative manure management systems on poultry farm operations can help CA get closer to this target. If CA maximizes anaerobic digester deployment on technologically feasible dairies that have not yet implemented a manure management project by 2030, there will still be an additional estimated 420 digesters projects that could potentially be implemented on technologically feasible dairy and other livestock operations, such as poultry.

Conclusion

In April 2021, the White House announced a new target for the United States to achieve a 50-52 percent reduction from 2005 levels in economy-wide net greenhouse gas pollution by 2030.[51] In order to meet these GHG emission reduction goals, all states will have to implement reduction measures. Many states have implemented a variety of policies aimed at mitigating emissions, thereby modeling efforts to combat climate change. Maine was the first to enact legislation in 2003, setting specific GHG reduction targets, and California followed in 2006. Since then, several other states have enacted statutory targets, with Virginia being the most recent.

Figure 13: U.S. State Greenhouse Gas Emissions Targets



Source: Center for Climate and Energy Solutions

As the U.S. and various states look to implement programs to further drive GHG reductions, the incentivization of innovative manure management systems such as anaerobic digesters or gasification technologies should be a focus. California has a long history of taking a proactive and aggressive stance on reducing GHGs and met its AB32 GHG reductions target 7 years ahead of schedule. As part of this effort, CA has been a leader in incentivizing AD systems and successfully driving down emissions in the state. This success underscores the value of the clear, trackable emissions reductions from AD systems and the key role of policy signals.

Managing manure waste not only supports GHG reduction target goals in the agriculture sector but in other IPCC recognized industry sectors as well: the energy sector is looking to reduce GHG emissions by using renewable energy sources, such as RNG produced via anaerobic digesters or syngas produced via

[51] https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/22/fact-sheet-president-biden-sets-2030-greenhouse-gas-pollution-reduction-target-aimed-at-creating-good-paying-union-jobs-and-securing-u-s-leadership-on-clean-energy-technologies/

gasification, rather than fossil fuel to generate electricity; the transportation sector is aiming to use fuels that emit less CO_2 than fuels currently being used, such as biofuels produced from anaerobic digesters and other technologies; and the industry sector plans to increase production of industrial products from materials that are recycled or renewable, such as fertilizer production from anaerobic digester systems and biochar from gasification pyrolysis, rather than producing new products from raw materials.[52]

Supporting farms looking to install innovative manure management systems with incentive programs that encourage leveraging partner collaboration across industries will reduce GHG emissions in the energy, industry, transportation, agriculture, and waste sector all at once, having a compounded impact. As we continue to see extreme weather events due to climate change, these innovative manure management systems which protect our air and water resources are important for all farm operations. and the installation will be supported by states like CA with leading GHG emission reduction programs.

There exist significant unrealized opportunities within the poultry industry to contribute meaningfully to both state and national GHG-reduction targets through the deployment of innovative manure management systems. Further, as we have seen in the dairy and swine sectors, the adoption of these systems on a scale that will help to meet GHG targets is most likely to happen when incentivized through credit programs such as California's LCFS. With properly applied incentives, innovation in the poultry industry is poised to make a meaningful difference in our clean air, water, and energy future.

[52] United State Environmental Protection Agency, Greenhouse Gas Emissions, Sources of Greenhouse Gas Emissions, 1990-2021

Bibliography and Methodology

The Intergovernmental Panel on Climate Change (IPCC) data was used for this report. IPCC is the United Nations body for assessing the science related to climate change. The *2006 IPCC Guidelines for National Greenhouse Gas Inventories (2006 IPCC Guidelines)* and the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* provide a technically sound methodological basis of national greenhouse gas inventories.

The California Air Resource Board (CARB) reports and data were also utilized. CARB is CA's primary state agency responsible for actions to protect public health from the harmful effects of air pollution. In 2022 CARB released a scoping plan to achieve carbon neutrality. Specifically, this plan identifies a path to keep California on track to meet its SB 32 GHG reduction target of at least 40 percent below 1990 emissions by 2030. The CARB report was developed using the latest scientific information. The recent Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) summarizes the latest scientific consensus on climate change and was utilized and analyzed for the CARB report.

This report also used figures and GHG emission numbers from USDA and EPA reports. USDA's Greenhouse Gas Inventory and Assessment Program, managed by OCE, maintains state-of-the-science metrics of greenhouse gas sources and sinks from lands and links these metrics to Department-wide efforts to mitigate climate change and produce reports. USDA works closely with agencies across the Department and other Federal agencies to improve data collection. USDA supports a variety of efforts and tools to quantify GHG emissions from agriculture and forestry, and the potential for GHG mitigation through conservation practices and carbon sequestration. USDA regularly releases an inventory of agriculture and forestry emissions and also supports the EPA's annual GHG inventory.[53]

In addition, this report made use of interviews with subject matter experts in the University of California system, including UC Davis and UC Agriculture and Natural Resources.

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