# Maryland Animal Waste Technology Assessment and Strategy Planning

**FINAL REPORT** | September 2023

UNIVERSITY OF MARYLAND

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Our website: https://go.umd.edu/AWTF has additional animal waste technology information, including appendices, summaries, Maryland Extension Briefs and FactSheets.


Final report submitted by the following University of Maryland contributors:

PI: **Stephanie Lansing**, Co-PIs: **Shannon Dill, Kathryne Everts, Amro Hassanein, Marccus Hendricks, James MacDonald, Jonathan Moyle, Nancy Nunn, Sarah Potts, Jennifer Rhodes, David Ruppert, Jeff Semler, and Elizabeth Thilmany**

Post-docs, staff, and students: **Priscila B. R. Alves, Beverly Bolster, Higor Brito, Eric Burnstein, Danielle Delp, Rachele Franceschi, Mimi Sanford, and Derek Wietelman**

# EXECUTIVE SUMMARY

The Maryland Animal Waste Assessment and Strategy Plan was created to guide future Animal Waste Technology Fund (AWTF) awards administered by the Maryland Department of Agriculture (MDA). The stated goal of the AWTF is "to encourage the development and implementation of economically feasible technologies that help protect public health and the environment by reducing the amount of nutrients from animal waste to enable farmers to meet nutrient management requirements and provide alternative animal waste management strategies to farmers." This Assessment and Strategy Plan researched and evaluated animal waste and nutrients in animal waste generated in Maryland (by county). The feasibility of animal waste technologies used in Maryland were evaluated, including anaerobic digestion, gasification, pyrolysis, composting, and manure injection. Policy implications, greenhouse gas (GHG) emissions, and economic analyses were documented for animal waste technologies. Interviews, surveys, and focus groups were conducted to gauge understanding and acceptance of the technologies, expected future changes in manure management, and the effect of waste management technologies on surrounding communities through an environmental justice perspective.

The results showed that three animal species (broilers, cattle, and equine) account for 98.7% of the animal population (total animal units) and 91.9% of state animal waste nutrients (N and P) produced in Maryland (in 2022). Broilers alone accounted for 88.3% of total animal units in Maryland in 2022 (one animal unit is defined as 1,000 pounds of live-weight animals of the same species; animal units are used to compare populations across species). However, broilers accounted for a smaller share of animal waste nutrients: 43% of nitrogen and 56% of phosphorus produced in Maryland, indicating the importance of effectively managing manure from broilers and other species (cattle and equine) to protect natural resources.

Looking ahead to 2032, we project only a small decrease (1-3%) in the total annual volume of animal waste nutrients produced in Maryland, indicating that nutrient management will continue to be important for the state. There is a large projected decline (~25% decline from 2022 baseline) in the state's population of dairy cattle, offset by a ~10% increase in liveweight production of broilers (driven by increased broiler weights rather than number of broilers). Our projections for nutrients were based entirely on changes in animal populations without any expectation of reduced waste or nutrient generation per animal.

The data confirm well known trends in concentrations of cattle production in northern Maryland and poultry production in Eastern Shore counties. Specifically, 65.6% of the cattle and cow inventory in Maryland are located four Maryland counties: Washington (23.8%), Frederick (21.4%), Carroll (11.8%), and Garrett (8.7%), while 86.9% of the poultry inventory is located in four Eastern Shore counties: Worcester (23.5%), Caroline (20.9%), Somerset (19.4%), and Wicomico (19.4%), according to the 2017 USDA Agriculture Census. Due to the larger volume of manure produced per

animal, most manure generated in Maryland is from cattle and cow populations. Yet, most nitrogen and phosphorus in manure (51%) comes from poultry litter, as these nutrients are more concentrated in the litter. Nutrient output from poultry is expected to rise through increases in bird weights over the next ten years. The greatest quantity of nitrogen in manure resources was in Frederick (11.9%), Worcester (11.7%), Somerset (11%), Caroline (10.1%), Washington (9.7%), and Wicomico (8.8%) counties, while the greatest quantity of phosphorus in manure resources was in Worcester (14.3%), Somerset (13.2%), Caroline (12.2%), Wicomico (10.9%), Frederick (9.7%), and Washington (9.7%) counties (2019 data). This data indicates the impact of different animal species' manure on the total and type of nutrient resources.

Even with the decreasing dairy cow inventories and farms in Maryland over the past four years, the highest greenhouse gas (GHG) emissions occurred from open lagoon storage of dairy and beef cattle manure. The annual GHG emissions from manure storage from all animal species in Maryland (533,652 $MtCO_{2e}$/year) was highest in Fredrick (111,527 $MtCO_{2e}$/year), Washington (107,336 $MtCO_{2e}$/year), and Carroll (59,032 $MtCO_{2e}$/year) counties due to the higher populations of dairy cattle. In Frederick County, dairy cattle accounted for 43.7% of the total GHG emissions from manure storage, with similar percentages in Washington (45.4%) and Carroll (37.0%) counties. The reductions in GHG emissions from implementing waste technologies were explored. Anaerobic digestion reduced more than 100% of the GHG emissions from manure storage with renewable electricity production, resulting in negative (sequestering) GHG emissions.

Poultry processing creates a liquid 'Dissolved Air Flotation' (DAF) product. Maryland is the largest importer of DAF in the Delmarva region, receiving shipments from poultry processing facilities in Delaware and Virginia. Data from 2021 indicated a steep drop in DAF imports to Maryland relative to 2020, with increased transport to Pennsylvania. Industry interviews indicated that this change may be due to Maryland's PMT (phosphorus management tool) implementation and more rigorous application restrictions in Maryland compared to Pennsylvania. More than 95% of the DAF utilized in Maryland is land applied as soil amendment, providing ~2 million lbs. N per year; for comparison, this is approximately 9.15% of the N derived from land application of poultry litter manure. The remainder is used as input to anaerobic digesters at two locations (approximately 450,000 gallons/year) or composted.

The status of animal waste technologies in Maryland, including anaerobic digestion, thermochemical processing (gasification, pyrolysis, and combustion), composting, and manure/waste injection, was documented. Two of these technologies, anaerobic digestion and thermochemical processing (gasification and pyrolysis), produce renewable energy in the form of heat, electricity, or transportation fuels. Composting, anaerobic digestion, and thermochemical processing also reduce GHG emissions and create beneficial byproducts, such as fertilizers, soil amendments, biochar, compost, or animal bedding. The use of manure injection on-farm is increasing (currently at 2500 acres in Maryland) and is expected to continue to increase, while most other manure management technologies (composting, anaerobic digestion, and thermochemical processing) are not expected to have large increases in adoption without further economic support. There are currently only four digesters receiving manure or DAF in Maryland, including two digesters receiving poultry litter that are being intermittently operated. There are four more anaerobic digestion systems in the construction or planning processes. There is one poultry litter pyrolysis system under construction and one poultry litter fluidized bed combustion system that was decommissioned. There are five permitted manure composting facilities and an additional 1,085 mortality composting facilities in Maryland.

Surveys were conducted at 17 University of Maryland Extension meetings to gauge the interests of farmers in the adoption of animal waste technologies, with 246 respondents from every county in Maryland (except Baltimore City). The majority of respondents supported implementation of manure technologies (anaerobic digestion, gasification, and manure injection), but most respondents stated that there were barriers to adoption due to high capital costs, long lead times, limited subsidies, complex regulations, lack of technical expertise (to permit, operate, and troubleshoot), and social resistance (often due to lack of education). Our interviews, surveys, and focus groups revealed that more incentives, permit assistance, and education are needed to increase animal waste technology adoption in Maryland.

The market trend analysis projects slow growth (16%) in US electricity consumption over 2020-2050 but with a major shift toward renewable sources, which are projected to account for 60% of US electricity generation in 2050 compared to 22% today. Most of that shift is projected to occur by 2035, with 6-8% annual growth in renewables-based generation.

Our analyses for Maryland found a trend of state renewable energy policies that do not include the terms “biomass” or “waste technologies,” resulting in delays in permitting and hindering the financial success of projects. There is a need to better educate the general public, policy makers, and future animal waste technology adopters of the current permitting process, policies, and the renewable electricity that could be produced from waste technologies in Maryland. For example, if all the manure resources in Frederick County alone were converted to electricity using anaerobic digestion, the annual renewable electricity production would be 34,745 MWh of renewable electricity. The anaerobic digester in Cecil County processing dairy manure and DAF waste produces 2,000 MWh annually, enough electricity to power 190 houses per year and reduces GHG emissions by 20,000 $MtCO_{2e}$/year, offsetting emissions of 4,000 vehicles per year.

Maryland has a GHG emissions reduction goal of 60% (from 2006 levels) by 2031, with net-zero GHG emissions by 2045. The large expansion of renewable electricity generation in the US has been driven by sharply declining prices for wind and solar installations, which presents a significant challenge for manure-based technologies aimed at electricity markets. Biomass technologies, including those based on animal wastes, have not seen similar cost declines and without further innovations may not be cost-competitive with wind and solar in most circumstances. Hence, advocates for biomass-based technologies face an opportunity in the rapid projected growth of renewables-based electricity generation but also a major challenge in developing technologies that can compete with wind and solar in the near term. Public policies that broadly target the adoption of renewables-based sources for electricity generation and transportation will likely be met from solar and wind-based sources. In contrast, biomass-based sources will likely need policies targeted specifically at them, such as California's programs or the cost share for biomass projects under USDA's Environmental Quality Incentives Program (EQIP) program.

Maryland's net-metering standards were based on solar capabilities, not biomass, leading to a lower payout for animal waste technologies generating electricity compared to technologies such as anaerobic digestion, where the energy outputs can be upgraded to renewable natural gas (RNG) and benefit from federal incentives (e.g., renewable fuel standard). The federal and other US state incentives (e.g., California, Washington, Oregon) make RNG production from anaerobic digestion profitable at large dairies. Still, there are no federal or Maryland policies that incentivize electricity production for the smaller animal production facilities more commonly seen in Maryland. It is expected that additional policies in Maryland that incentivize renewable electricity from animal waste-based biomass would increase the adoption and success of smaller and mid-scale anaerobic digestion and thermochemical processing units while reducing methane emissions from manure storage. Currently, the benefits of baseline methane emission reductions from manure storage and the non-intermittent renewable electricity production that increases grid stability when employing anaerobic digestion and gasification/pyrolysis are not internalized in Maryland's current policies.

Maryland's climate change goals are intertwined with environmental justice (EJ) concerns, with new federal initiatives (Justice40 and EPA's EJScreen Mapping & Screening Tool) adding a new conscious layer to project planning. Depending on the site, traffic patterns, and surrounding communities, electricity generation could have less perceived EJ concerns than upgrading to RNG. With any manure technologies employed, better information on GHG emissions from land application and manure transport is needed to accurately calculate reductions in GHG emissions that would occur if more animal waste technologies were employed near concentrated animal feeding operations (CAFOs) sites to reduce the large movement of manure and DAF throughout the state. It would be helpful to use information from manure transportation and nutrient management to identify site priorities based on a manure-shed approach instead of county or state lines.

An EJ framework for animal waste technologies was developed through a thorough literature review, participatory approaches (interviews and focus groups), and geographical information systems (GIS) tools that can be used in other studies. In total, 25 interviews and three in-person focus groups were conducted in different parts of Maryland. Results showed potential exposures, engagement levels, social vulnerability challenges raised by participants, and recommendations for incorporating EJ in AWTF proposals. Evaluation of AWTF proposals should include engagement with residents, communication with communities throughout the project period, and considerations of social vulnerability, exposure, and impact assessments, with monitoring and evaluation of EJ-related communication, engagement, and exposure considerations.

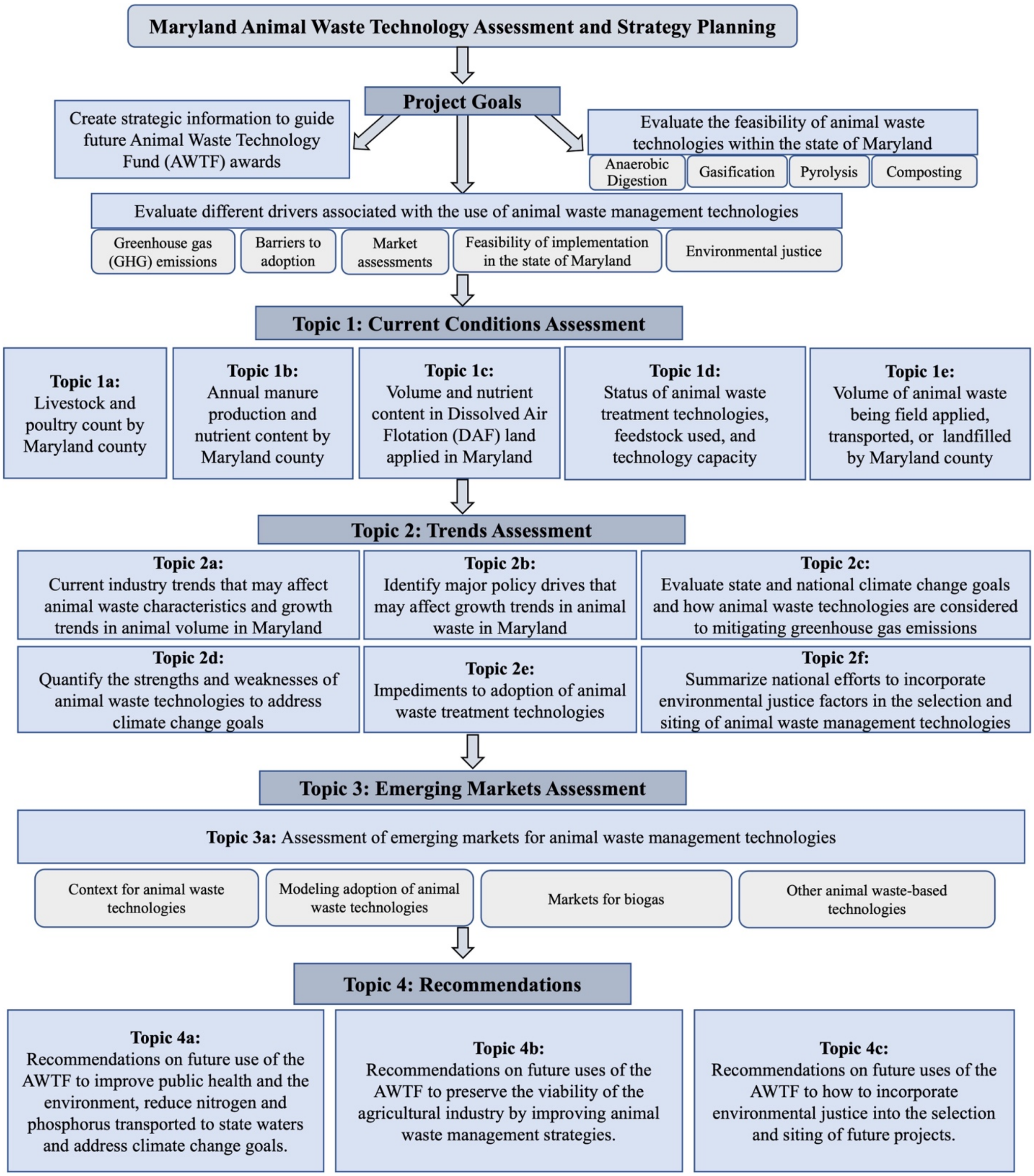
Recommendations for the AWTF include: 1) education, 2) collaboration, 3) data utilization and evaluation tools, and 4) future decision-making based on research and community inclusion. Interviews and EJ focus groups revealed a large need for public education. Education and outreach would increase animal waste technology adoption, project viability, counter misinformation, and engage surrounding communities. Specific outreach to the public and policy makers on animal waste technologies could include FactSheets, websites, and workshops. There is a need for legislation in Maryland to increase in animal waste technology adoption and increased knowledge in how these technologies work towards meeting Maryland's climate change goals. To improve project success, there should also be targeted education to AWTF applicants on permitting, installation, and evaluation of waste technologies as part of the application process, with required attendance for potential applicants at workshops, listening sessions, or outreach events. California's equivalent AWTF has technical support providers that increased both the quality and quantity of applicants.

More collaboration is needed between state agencies, electric companies, farmers, industry, and policy makers to ensure project implementation timelines are not unduly delayed. This needed collaboration should include guidance from government agencies in obtaining required permits and electric interconnection. Enhanced state agency collaboration would help potential adopters understand differing regulations for waste systems, especially for systems that incorporate animal waste and other resources (e.g., food waste). Coordinating climate change, renewable energy, and manure management activities across state agencies would greatly increase impact.

Data mining and analytics of nutrient management plans, CAFO applications, manure transport cost-sharing, Watershed Implementation Plans (WIP) data, and GHG emission reductions are needed to properly determine the effect of nutrient and waste movement throughout the state, farming practices and on-farm technology adoption. Digitization and internal statistical analyses of this data would aid future analyses of the state of Maryland's agriculture. For the AWTF, there should be follow-up data by completed grant awardees to analyze economic and environmental progress, with analyses of GHG emission reduction calculations to aid in understanding MDA's return on investment. Documentation of the role of manure management and waste technologies in meeting legislation for climate change goals is needed. For example, California's Low Carbon Fuel Standard (LCFS) has agriculture-specific methane reduction goals and funds to help farmers meet these goals and could be used as a model for meeting Maryland's climate change goals.

Surveys and interviews indicated that AWTF decisions should be backed by research before implementation, especially regarding GHG emissions and nutrient reductions to meet state compliance and state climate change goals. California has a GHG emission reduction calculator that applicants use for fund submission. Community involvement is needed to incorporate EJ concerns, including letters of support or public hearings. Additionally, having an EJ expert on the AWTF Technical Committee would aid in ensuring community engagement is part of the funding criteria. MDA technical support to applicants using EJ mapping and screening tools would aid in identifying these communities and help guide community engagement.

# Graphical Executive Summary




**Graphical Abstract**: A flow chart of the project goals and four topics explored in Maryland Animal Waste Assessment and Strategy Plan conducted by University of Maryland researchers. The report is organized by the topics requested in the Request for Proposals by the Maryland Department of Agriculture (MDA).

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**TOPIC 1: Current Conditions Assessment**

***Topic 1a. Estimated livestock and poultry count by MD county for 2018, 2019, 2020, & 2021.***

## Topic 1a Summary

County-level estimates of animal inventories for the years 2018-2021 were created using data from the Maryland Department of Agriculture (MDA), Maryland Department of the Environment (MDE), and the US Department of Agriculture (USDA). Livestock and poultry inventory estimates based on animal units were generated and used to calculate manure estimates. A benchmarking process from the 2017 Census in Agriculture data revealed that these multiple data sources produced comparable animal inventory levels. Inventory estimates by county in 2018-2021 confirm well known trends in concentrations of cattle production in northern Maryland and poultry production in Eastern Shore counties. Specifically, 65.6% of the cattle and cow inventory in Maryland are located four Maryland counties: Washington (23.8%), Frederick (21.4%), Carroll (11.8%), and Garrett (8.7%), while 86.9% of the poultry inventory is located in four Eastern Shore counties: Worcester (23.5%), Caroline (20.9%), Somerset (19.4%), and Wicomico (19.4%), according to the 2017 USDA Agriculture Census. The MDA nutrient management annual implementation reports (AIR) and USDA National Agricultural Statistics Service (NASS) data from more recent years yield similar county-level animal shares. Concentrated animal feeding operations (CAFO) sites in the state are shown in Figure 1a.1, providing point data beyond the county-level aggregates. Additionally, the locations of current animal waste technology sites are shown in relational to CAFOs (shown by animal species).

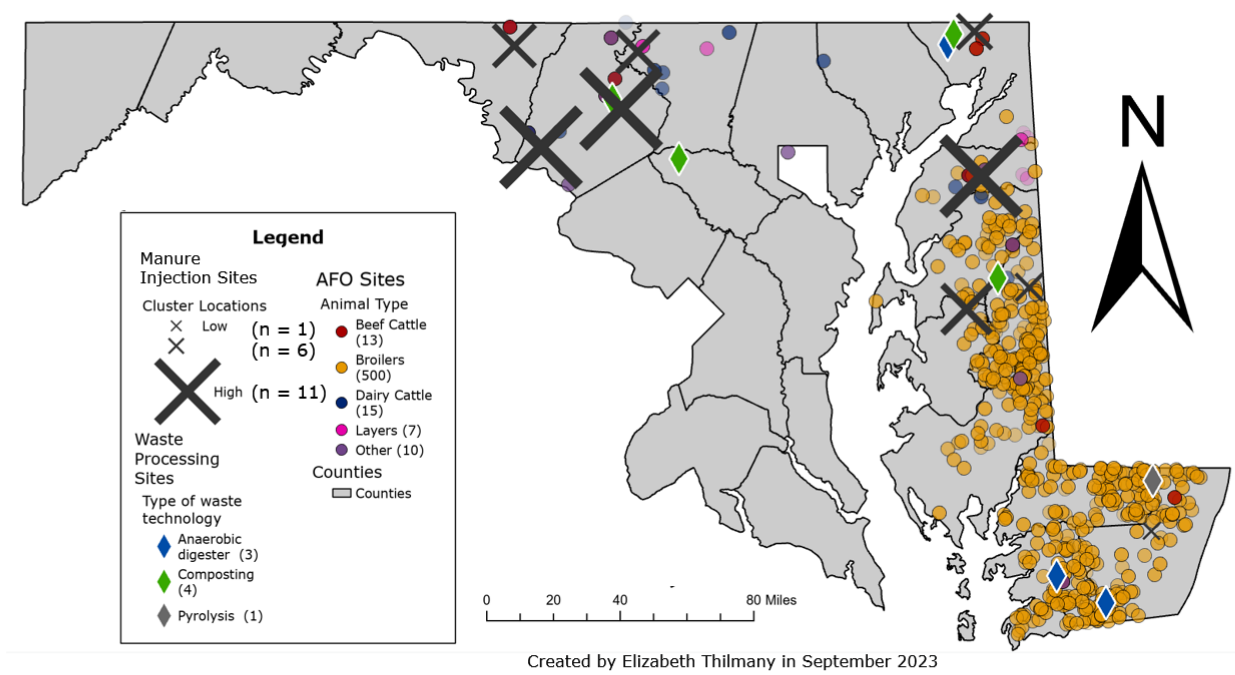


**Figure 1a.1**: Locations of all active concentrated animal feeding operations (CAFO) sites in Maryland, with the locations of animal waste technology sites shown, including anaerobic digesters, pyrolysis units, animal composting sites, and manure injection locations.

**Topic 1a Methods and Materials**

Multiple data sources were used to generate animal estimates at the county-level for 2017-2021 to determine how inventories have changed in Maryland since the last Census of Agriculture conducted in 2017. This comparison allowed us to understand how national trends, such as farm consolidation and geographic shifts, have played out in Maryland and establish accurate manure generation estimates based on animal inventory. The 2017 Census of Agriculture conducted by the U.S. Department of Agriculture (NASS, 2023a) provides county-level estimates for livestock and poultry for Maryland at five-year intervals. The Ag Census estimates for 2022 are not expected to be released until Summer 2024. The proportion of total animals in each MD county for 2018-2021 was provided by MDA's Nutrient Management Annual Implementation Reports (AIR) submitted yearly by farmers to MDA was applied to USDA NASS's statewide species total for 2018-2021 (See Appendix A for more specific details on this process). Additionally, point data was provided by MDE's Animal Feeding Operations (AFO) Public Participation Process website using the AFO Public Information Search Tool (MDE 2022a) for all pending or active permitted CAFOs and Maryland animal feeding operations (MAFO) with active general discharge permits. The permit data includes the farm county, primary animal type, and the number of animals permitted at the operation at one point in time. County-level aggregations of the AFO point data provide comparisons with other data sources to create spatial distribution maps of CAFOs across the state (shown above in Figure 1a.1), with the knowledge that this would underestimate the number of animals within each county. The MDE AFO site does not specify which operations were active as of 2017, and therefore, we limited our analysis to current operations in 2022 and 2023 for this comparison dataset.

In our analyses, the primary data sources were first benchmarked against one another for the year 2017, as this year had both county-level AIR inventory estimates and county-level Ag Census estimates. There are differences in the set of animal species in each inventory, with the AIR data providing a different disaggregation of cattle and cows than the Ag Census data. Specifically, the Ag Census data provides estimates for beef cows, milk cows, other cattle (excluding cows), goats, hogs, and lambs. The Maryland AIR data provides county-level estimates for 11 livestock categories.[1]

County-level estimates of animal units (AU) for the years 2018-2021 were generated by converting estimates of animal inventories to animal units (AU). The value of 1 AU represents 1,000 lbs of animal weight to compare aggregate weights across species. The values used for the AU conversion factors were developed through a series of conversations with experts, including project co-PIs with expertise in the different animal species. Table 1a.1 summarizes the AU conversion coefficients used in our analyses.

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[1] The AIR categories include 'Beef, feeder cattle' > 500 lbs; 'Beef, feeder cattle' < 500 lbs; 'Dairy cows;' Dairy heifers;' 'Dairy calves;' 'Swine sows and boars;' 'Swine growers;' 'Sheep;' 'Goats;' and 'Horses.'

**Table 1a.1**: Conversion coefficients from inventories to animal units (AU).

| Animal type | AU (1,000 pounds) |
|---|---|
| **Cattle** | |
| Beef cow | 1.0 |
| Dairy cow | 1.4 |
| All other cattle | 0.65 |
| **Poultry** | |
| Broiler | 0.007 |
| Layer | 0.0047 |
| **Swine** | |
| Growers | 0.055 |
| Sows and Boars | 0.40 |
| **Other Animals** | |
| Horse | 1.0 |
| Goats | 0.2 |
| Sheep | 0.2 |

**Table 1a.1 Notes:** For most species, average weights of mature animals in each class were used to generate coefficients. Broilers were the average weight produced in the Delmarva in 2021 from NASS and Delmarva Chicken Association (DCA). Turkeys were average across males and females, as males are much larger. For all other cattle, average animal units (AUs) were reported for each component, with 'all other cattle' (0.65) based on a head-weighted average of the components.

**Topic 1a Results**

The results by county in 2017 for the three primary data sources are shown in Table 1a.2 for cattle, cow, broilers, and layers, with summed values across categories (rounded by the tenth place). Note that the analysis team was not provided poultry data by MDA for the MD AIR data and thus relied only on the Ag Census/NASS data. The 2017 USDA Ag Census data showed that 65.6% of the cattle and cow inventory in Maryland are located in Washington (23.8%), Frederick (21.4%), Carroll (11.8%), and Garrett (8.7%) counties, while 86.9% of the poultry inventory is located in Worcester (23.5%), Somerset (19.4%), Caroline (20.9%), and Wicomico (19.4%) counties.

The data did show county-level estimate discrepancies between the sources, which was expected as the definition of what constitutes a farm eligible for each survey varies. Under Maryland law, farms that gross at least $2,500/year or livestock producers with at least 8,000 lbs of live animal weight must adhere to nutrient management plan requirements and submit an AIR form. Conversely, the Ag Census requires all farms that produce and sell more than $1,000 of agricultural products in a year to report, which is a stricter requirement and could include some livestock producers not covered by the AIR data. These competing definitions may explain that in most Maryland counties (16 out of 23), the Ag Census estimates for total cattle and cows is larger than the corresponding estimate in the AIR data. Alternatively, the MDE data only covers CAFOs, so it is likely to be a lower bound on the total animal population by county. The MDE poultry data is more comparable to the Ag Census data, as most poultry operations in Maryland are large enough to be classified as CAFOs.

Despite these discrepancies, broad patterns across counties were consistent with the expectations across data sources. Estimates of total cattle and cows were of the same order of magnitude in each county, and the counties with the largest estimated populations in the Ag Census data were also the counties with the largest estimated populations in the AIR data. The benchmarking process allowed us to conclude that, as of 2017, the data sources are roughly comparable and can be used to generate estimates of animal units and manure content.

**Table 1a.2**: Benchmarking 2017 total cattle and cow, broilers, and layers inventory data from the Maryland Department of Agriculture (MDA) Annual Implementation Reports (AIR), the 2017 USDA Agriculture Census data, and Maryland Department of Environment (MDE) concentrated animal feeding operations (CAFO) data. A dash indicates no data or CAFO in that county. MDA provided no AIR data for poultry.

| | Cattle and Cow Inventories | | | Broiler and Layer Inventories | |
|---|---|---|---|---|---|
| **County** | **MDA AIR Data** | **Ag Census Data** | **MDE CAFO Data** | **Ag Census Data** | **MDE CAFO Data** |
| Allegany | 3,190 | 3,560 | - | 1,090 | - |
| Anne Arundel | 1,230 | 1,470 | - | 2,000 | - |
| Baltimore | 4,280 | 5,530 | 620 | 31,270 | - |
| Calvert | 540 | 1,220 | - | 2,230 | - |
| Caroline | 4,760 | 3,710 | 3,824 | 11,423,830 | 13,401,269 |
| Carroll | 15,030 | 21,920 | 2,935 | 1,060 | 451,380 |
| Cecil | 8,420 | 6,040 | 180 | - | 2,653,790 |
| Charles | 1,590 | 1,790 | - | 20,020 | - |
| Dorchester | 120 | 260 | 20 | 4.998,320 | 5,096,420 |
| Frederick | 32,010 | 39,640 | 8,754 | 72,150 | - |
| Garrett | 12,400 | 16,050 | - | 6,930 | - |
| Harford | 10,970 | 9,120 | - | 27,360 | - |
| Howard | 2,260 | 2,570 | - | 5,220 | - |
| Kent | 7,790 | 9,940 | 5,693 | 1,022,800 | 2,758,478 |
| Montgomery | 2,550 | 4,660 | - | 2,210 | - |
| Prince George’s | 820 | 3,350 | - | 8,040 | - |
| Queen Anne’s | 4,710 | 4,590 | - | 4,607,970 | 5,076,175 |
| Saint Mary’s | 1,520 | 2,610 | - | 21,190 | - |
| Somerset | 580 | 520 | 101 | 12,451,580 | 10,112,600 |
| Talbot | 1,670 | 1,320 | - | 1,292,630 | 802,000 |
| Washington | 34,120 | 44,030 | 10 | 1,290 | - |
| Wicomico | 480 | 920 | - | 10,587,890 | 13,707,233 |
| Worcester | 210 | 490 | 79 | 12,980,080 | 15,159,620 |
| **TOTAL** | **151,250** | **185,310** | **22,216** | **54,567,780** | **69,218,965** |

The full set of inventory estimates for each county and year (2018-2021) presented separately by animal species are shown in Appendix A (Tables 1a.3 - 1a.12). Estimates are presented in animal units (1,000 lbs) and rounded to avoid the appearance of false precision. Data from the AIR was available for certain species and for others species only data from NASS was available. For cattle, we had comparable data from both sources. One key takeaway from this analysis was the fact that the NASS-derived estimates appear to match up closely with the AIR estimates. While this was illustrated for 2017 in Table 1a.1, the relationship between the two data sources seems to largely hold in the years 2018-2021. Trends over time are detailed in the following section (Topic 1b), where we considered county-level trends in total manure production by species.

Figures 1a.2 and 1a.3 display Maryland county-level estimates in AUs for dairy cows and broilers, respectively. Dairy cow production is heaviest in the northern Maryland counties of Garrett (6% of statewide total), Washington (26%), Frederick (25%), and Carroll (11%) counties and lowest in more-urban counties surrounding the District of Columbia as well as some of the Eastern Shore counties. As expected, poultry production is concentrated in the Eastern Shore counties, with

Worcester (22%), Somerset (21%), Wicomico (18%), and Caroline (19%) counties having the most significant shares in 2019. The MDE AFO permitting data allowed us to make use of point data to identify the exact locations of all active CAFO/MAFO operations in 2023 in Maryland (above in Figure 1a.1). The vast majority of CAFO sites in the state of Maryland are broiler operations on the Eastern Shore (of note: most are located relatively far from the Chesapeake Bay coastline), with clusters of other livestock CAFOs in Frederick and Carroll counties.

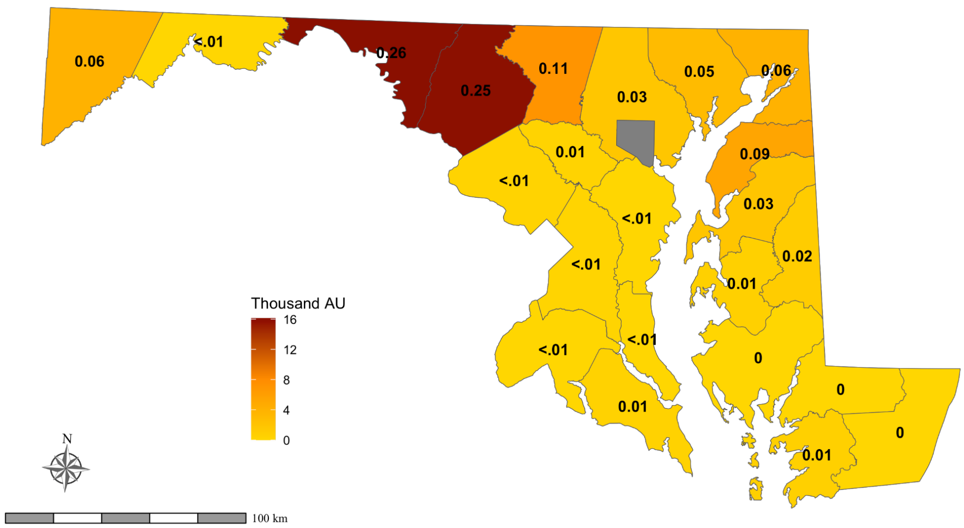


**Figure 1a.2**: Total dairy cow inventories with shading based on thousand animal units (AU) from 2019 AIRs. Each county is labeled with its proportion of the statewide total.

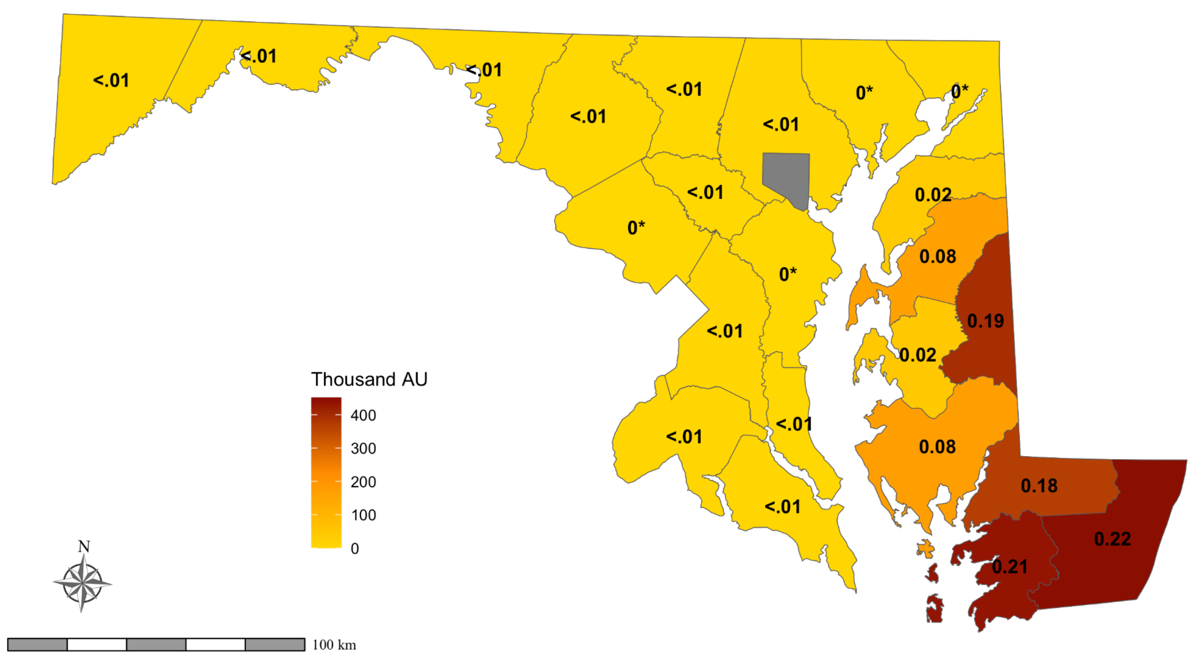


**Figure 1a.3**: Total broiler inventory, with shading showing one thousand animal units (AU) from USDA NASS data, 2019. Each county is labeled with its proportion of the statewide total. Asterisks (*) denote that a value of 0 was assumed for the county since no data was available.

**Topic 1a Key Findings and Recommendations**

1. Multiple data sources at the federal and state level (Ag Census, MDA AIR data, MDE permitting data) provided helpful information for assessing animal inventories by county in Maryland. Considering all data sources together provides a clearer picture of the current state of animal inventories than any single data source alone.
2. Livestock inventories are concentrated in northern Maryland counties, while poultry inventories are concentrated on the Eastern Shore.
3. Most Maryland CAFOs are poultry operations located in the interior of the Eastern Shore.

***Topic 1b. Estimated annual manure and nutrient content generated by livestock and poultry by county for 2018, 2019, 2020, and 2021.***

**<u>Topic 1b Summary</u>**

Coefficients from the UMD Agricultural Nutrient Management Program provided the most accurate snapshot of present-day manure production characteristics to generate county-level manure and nutrient estimates in pounds over the years 2018-2021 for each county-species-year combination, given changing animal sizes and diets over the years in Maryland. The results showed that cattle produce the most overall manure (78% of statewide total in 2019); however, broilers contribute the largest portion of N and P production of any species (51% in 2019). Cattle, however, still produce 36% of statewide nutrients, indicating that effectively managing manure from both broilers and cattle is necessary to protect natural resources. The counties that produce the most nutrients are cattle-heavy counties like Frederick (11% of statewide total in 2019) and Washington (9%), and poultry-heavy Eastern Shore counties like Worcester (12%), Somerset (12%), Caroline (11%), and Wicomico (9%). There are no significant upward or downward trends in overall manure production over the study period of 2018-2021, while nutrient production, driven by broilers, does appear to show a decline in 2021, potentially related to pandemic-era reductions in broiler production.

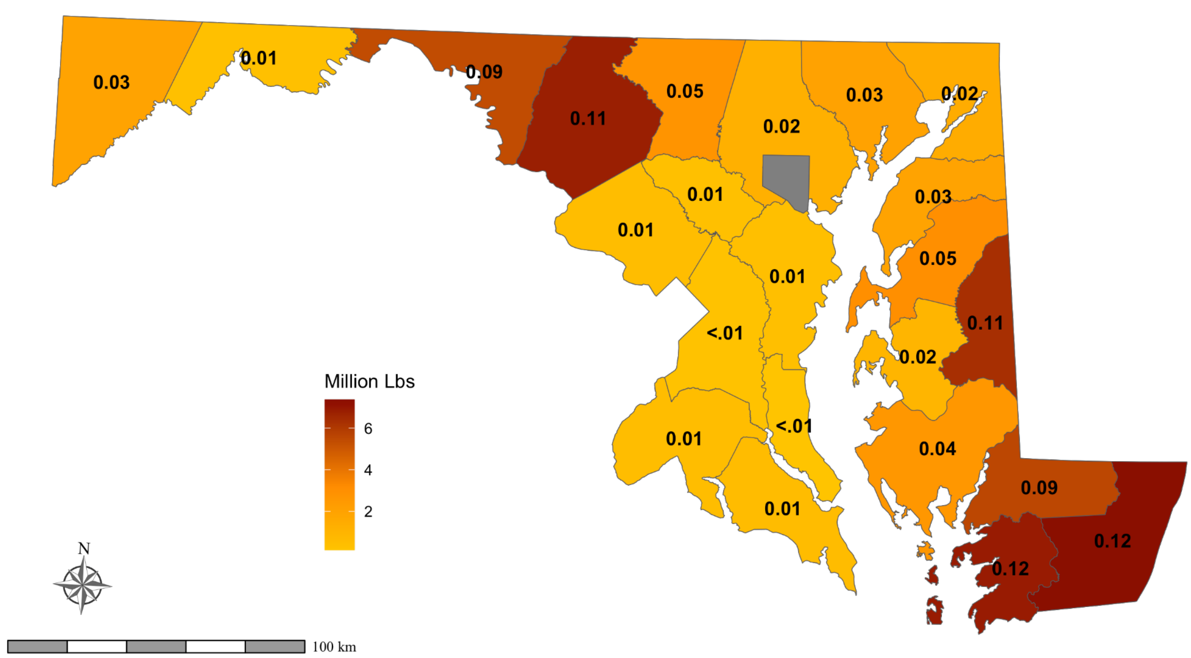


**Figure 1b.1**: Total nutrient production (N + P) by county, 2019. The shading in each county represents million pounds of nutrients, while the labeled proportions represent the share of the statewide total in 2019.

**Topic 1b Methods and Materials**

The estimates of animal inventories from Topic 1a were translated to total manure production. Coefficients were used to translate animal species to manure volume and manure nutrient concentrations (nitrogen (N) and phosphorus (P) generated) in pounds (lbs) at the species-county-year level for cattle categories, broilers, layers, and an aggregate of the remaining animal categories together given their relatively low inventories. Our primary manure coefficient source was the UMD Agricultural Nutrient Management Program (NMP), which estimates manure volume and nutrients generated by each species (University of Maryland Agricultural Nutrient Management Program, 2022). Using these coefficients gave the most accurate estimate of current manure production in Maryland as the coefficients were derived from test samples taken from Maryland farms and conducted from 2017-2021, which coincides with the sample period considered in this analysis. The NMP coefficients rely in part upon data from Chapter 4 of the USDA/NRCS Agricultural Waste Management Field Handbook (2008). In previous iterations of the analysis, we relied on data from the American Association of Agricultural and Biological Engineers (ASABE, 2005) industry-standard set of manure transfer coefficients commonly used by both academics and practitioners; however these values are outdated since animal sizes and diets have changed since 2005. The exact data used for each species manure estimate is detailed in Appendix A (Tables 1b.1-1b.7) and Appendix B (Tables 2a.4 - 2a.12) under the table for each species.

**Topic 1b Results**

The complete set of results for our county-year manure production are displayed in Tables 1b.1 - 1b.7 in Appendix A. Results in Tables 1b.1 - 1b.3 and 1b.6 were generated using AIR inventory, while results for broilers and layers (Table 1b.4 and 1b.5) were generated using NASS/Census inventory estimates. Figure 1b.2 summarizes the manure information presented in Tables 1b.1-1b.7 (Appendix A) at the state-level. Manure production in each year is plotted, with the contribution coming from each species illustrated by the shaded areas. The cattle categories and broilers are Maryland's primary drivers of manure production. Layers and horses generate smaller but significant amounts of manure. Dairy cows, all other cattle, and beef cows produce the three largest shares of manure (37%, 27%, and 14% of the statewide total in 2019, respectively). Despite much larger broiler inventories, cattle produce the most manure statewide due to their relatively large size and higher manure production per animal.

Figure 1b.2 shows that manure production has stayed roughly the same over the sample period. There is a visible decline in manure production in 2021, largely driven by a significant drop in the number of dairy cows in the AIR data from 2021.[2] It is the opinion of the analysis team that this significant drop is likely unrealistic and presents a potential data error. The same decline is not observed statewide in the NASS data for 2021. We therefore cautiously conclude that statewide aggregate manure estimates are largely stagnant over the sample period.

[2] The analysis team has made MDA aware of this potential data issue.

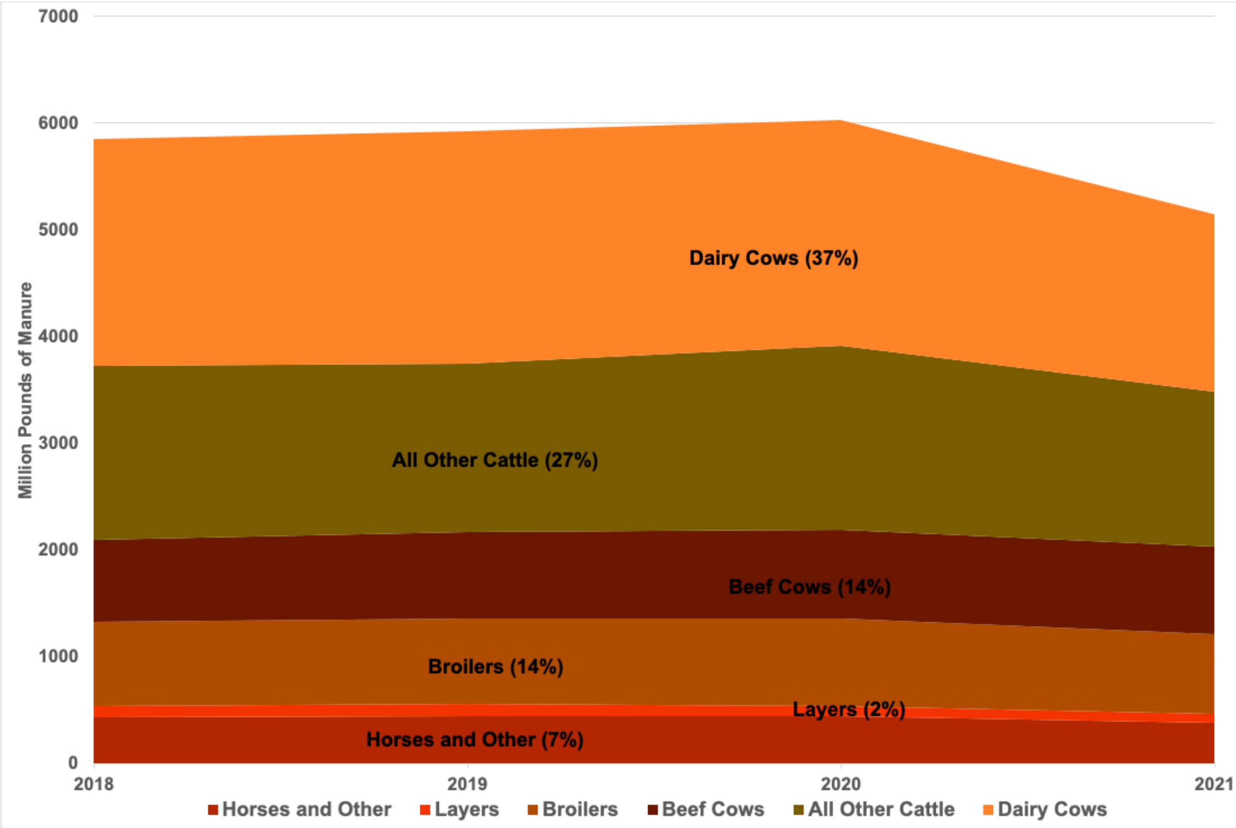


**Figure 1b.2**: Statewide manure production by species and year. The labeled percentages of the 2019 statewide total.

Figure 1b.3 shows yearly nutrient production at the state level (in million pounds) and shows the contribution from each species. As opposed to manure production, broilers are by far the most significant contributor to N and P production in the state (51% of statewide total), which is concentrated in the Eastern Shore. All cattle categories together account for 36% of statewide nutrient production. While much less than their share of overall statewide manure production, this illustrates that nutrient production from cattle should still be taken seriously by farmers, nutrient management officials, and policymakers.

The county-level nutrient production aggregate estimates in total nutrient production (N+P) are presented in Figure 1b.1 in the representative year 2019 (shown above in the section summary). As expected, the broiler-heavy Eastern Shore counties and the northern livestock-heavy counties produce the highest amounts of nutrients, with relatively lower amounts produced in the relatively more urban/suburban counties surrounding Washington, D.C. The six largest counties by share of nutrient production in 2019 are Worcester (12%), Somerset (12%), Caroline (11%), Frederick (11%), Wicomico (9%), and Washington (9%) counties.

Given the high production of nutrients on the Eastern Shore from concentrated poultry production, county-level time trends in total nutrient production for the Eastern Shore counties were explicitly examined in Figure 1b.4 (shown in million pounds of combined N and P). The figure shows a slight decline in 2021, possibly attributable to pandemic-era production volatility. Most counties show a largely stagnant trend over the sample period. Caroline, Somerset, Wicomico, and Worcester were the largest nutrient-producing counties on the Eastern Shore.

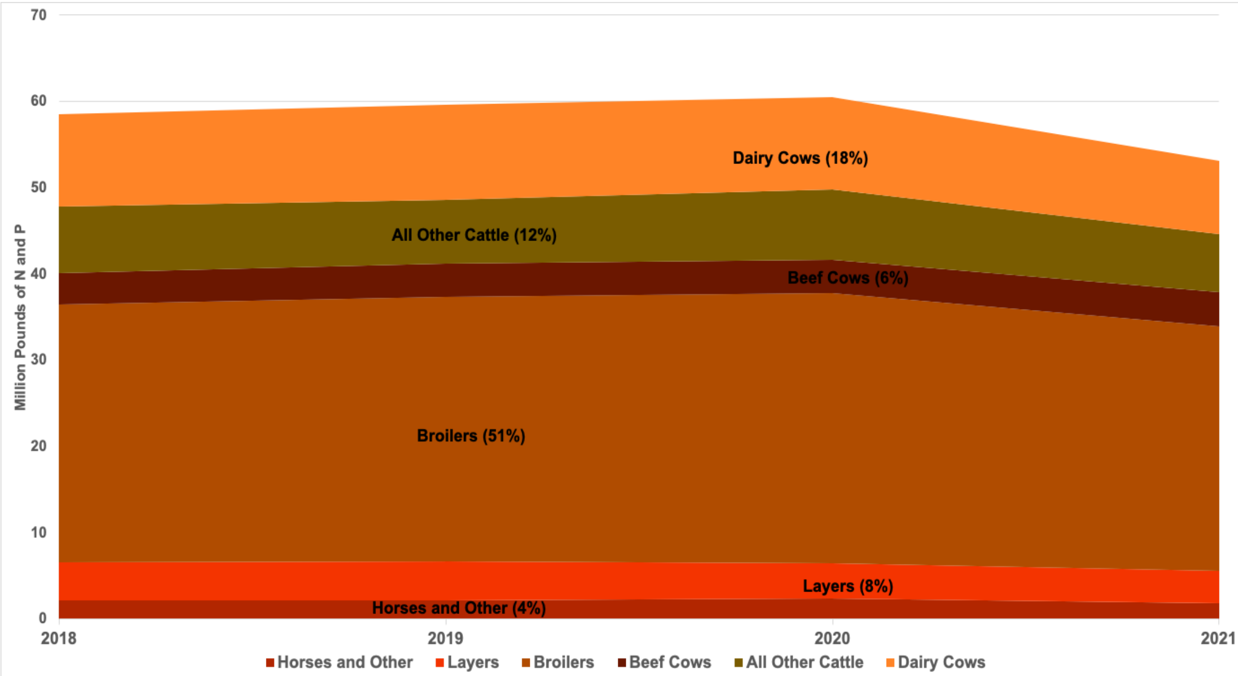


**Figure 1b.3**: Statewide N and P production by species and year. The labeled percentages of the statewide total are for 2019.

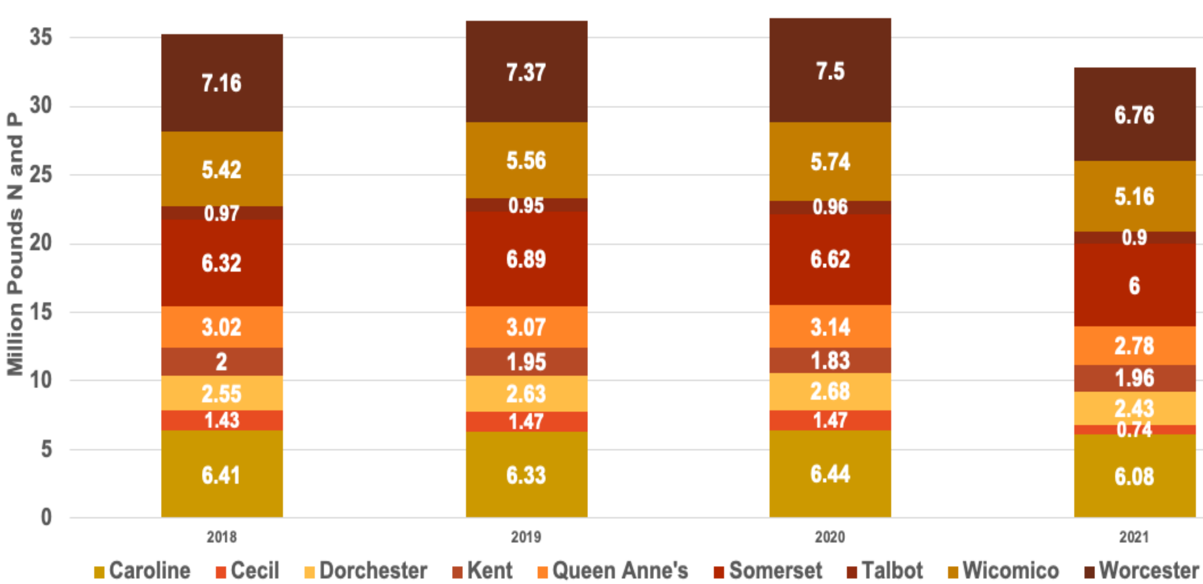


**Figure 1b.4**: Trends in total nutrient production (N + P) in Eastern Shore counties, 2019.

**Topic 1b Key Findings and Recommendations**

1. Manure transfer coefficients from the University of Maryland's Agricultural Nutrient Management Program provide the most accurate snapshot of current manure production in Maryland.
2. Cattle produce the largest quantity of total manure followed by broilers. Conversely, broilers contribute the single largest share of nutrient production (N and P) due to higher concentrations of nutrients in their litter.
3. On the Eastern Shore, Caroline, Somerset, Wicomico, and Worcester counties produce the most nutrients.
4. There do not appear to be any notable trends in overall manure production statewide between 2018-2021. There may be some evidence of a pandemic-era decline in nutrient production, specifically in Eastern Shore counties.

## *Topic 1c. Estimated volume and average nutrient content of nitrogen and phosphorus in Dissolved Air Flotation (DAF)*

**Topic 1c Summary:**

Dissolved air flotation (DAF) sludge is an animal waste byproduct from animal mortality and processing facilities composed of flocculated solids, proteins, and fat that rise to the surface and removed by mechanical scraping. Maryland generates DAF at three poultry processing facilities and receives substantial shipments from Delaware and Virginia. Most of the DAF Maryland receives is field applied as a soil amendment in Dorchester and Wicomico counties (Appendix A, Table 1c.3). The sludge from DAF has potential as a feedstock for anaerobic digesters and composting; two MD digesters are already accepting DAF shipments to co-digest with food and manure wastes. However, poorly executed DAF land application has caused smell and insect nuisances in surrounding communities, which prompted the updating of MDAs 'Nutrient Application Requirements' to include special requirements for land application of 'food processing residuals' in 2022. We analyzed data from MDA and industries that generate and ship DAF to better understand the generation, shipment, and usage of this unique animal waste, and how its management impacts nutrient loading in the state. It is estimated that between 2019 and 2021, 93.9 million gallons of DAF were imported into MD counties, containing 4.78 million lbs of N, 1.75 million lbs of P, and 0.273 million tons of K.

**Topic 1c Methods**:

Data on the generation and composition of DAF sludge at animal processing facilities in the Delmarva region was obtained via anonymous interviews and MDA data. Interviews and the AIR were used to estimate DAF transport into and out of Maryland counties for disposal. Shipment data was also used to estimate DAF generation since the AIR questions related to DAF import (Q#51) and export (Q#52) do not specify what animal processing facility the DAF originated at or how much DAF these facilities generate each day. The DAF transport data from the AIR was only available up to county-level specificity. Product registration records and laboratory test results from the MD State Chemist's office were used to identify agricultural products derived from DAF used in Maryland as fertilizers and soil amendments.

The DAF shipment volumes in the AIR and the lab reports from the State Chemist were used to estimate the total nutrient loading in Maryland from DAF. When analyzing quantitative DAF records in the AIR, it was found that reporting units used were inconsistent; some farms reported DAF shipments on a volume basis (i.e., gallons) and others on a mass basis (i.e., US tons). All AIR records were converted to volume basis for this analysis, using 1 US ton = 239.65 gallons as a conversion factor. Similarly, laboratory reports provided by the state chemist reported nutrient content in DAF products in inconsistent units. All nutrient results from these reports were converted to lbs/1000 gallons for consistency in the calculations. Broader regional trends were also estimated using anonymous interviews with industry and farmers.

**Topic 1c Results**:

No comprehensive public databases track DAF generation, shipment, and composition of DAF Maryland. Animal processing facilities that generate the DAF have their waste managed by a shipping company, which acts as an intermediary to transport the waste to storage or disposal sites. The AIR, State Chemist office and industry interviews indicated that almost all of Maryland's

DAF is derived from poultry processing, which was expected due to the high numbers of poultry counted in Topic 1a relative to other animal types. Shipments of poultry DAF designated for land disposal on agricultural fields are accounted for in the AIR, which notes the originating and receiving county of the shipment and how much of it was land-applied at the receiving site. As of 2023, the MD State Chemist's office has 15 DAF-derived soil amendment products currently registered for land application, however, the AIR shipment data does not specify which of these products is used in the shipment or information about the production facility of origin.

Industry and AIR data indicate that: 1) the total amount of DAF generated in the Delmarva region does not change much from year to year (58-64 million gallons from ~4.4 billion chickens, industry estimation), 2) that most regionally generated DAF is generated in states other than MD, 3) MD is a major sink for DAF from both in- and out-of-state sources and 4) that the transport of DAF from state to state is changing, based, in part, on regulation (industry estimation). Farmers in MD indicated in AIR filings the importation of nearly 30 million gallons of DAF in 2019 and ≥37 million gallons in 2020, which respectively accounted for 50% and ≥62% of the ~60 million gallons generated regionally (Appendix A Table 1c.1). One industry interviewee indicated that in 2019, approximately 85% of the DAF their company applied in Maryland was generated out of state; in 2022 72%. Industry indicates 1) strong export of DAF from VA to MD, NC, and PA due to VA law restricting land application in that state, 2) shipment of some DAF generated in MD for composting (industry source; quantity not provided), and 3) increasing shipments of DAF to PA rather than MD (800,000 gallons 2020; 6.8 million gallons 2022) due to a relatively favorable application regime (i.e. no winter-time land application restrictions in PA) and increasing regulation in MD (i.e. full 2022 implementation in MD of the PMT). The industry interviewees also indicated more limited DAF storage capacity in MD than PA, making it logistically easier to ship the DAF to PA. These trends are consistent with the 13-million-gallon drop in imported DAF appearing in the 2021 MD AIR (Appendix A, Table 1c.1).

The interviews indicate that the physical and chemical properties of a DAF product vary depending on the facility where it is generated. For example, the industry estimated that raw DAF shipments have approximately 7% solids on average, with dewatering down to 25% solids possible if the processing facility integrates solids-liquids separation; this results in a higher concentration of nutrients per volume. Analytical results from MD's registered DAF soil amendments report an even wider degree of variability, with solid contents ranging from 1.80-46.4% with an average of 11.9 ± 2.8% between products. The solids and nutrient content of the DAF products delivered to the fields may also vary by shipment since transport companies combine loads from multiple different facilities during transport.

Industry interviewees estimated that the average nutrient content of Delmarva DAF shipments is 14.5 lbs plant-available N (PAN)/1000 gallons (1,740 mg N/L), 10 lbs $P_2O_5$/1000 gallons (1200 mg $P_2O_5$/L) and 0 lbs K/1000 gallons (N-$P_2O_5$-$K_2O$ 0.17-0.12-0). Analytical reports from the State Chemist conflict with this estimate, with results showing the actual nutrient content of registered DAF soil amendments as 50.9 ± 4.5 lbs total N/1000 gallons (6100 ± 540 mg total N/L), 18.6 lbs ± 1.4 lbs $P_2O_5$/1000 gallons (2230 ± 162 mg $P_2O_5$/L), and 2.91 ± 0.16 lbs K/1000 gallons (348 ± 19 mg K/L). Most of the total N in MD's registered DAF products is in the form of organic N, rather than PAN. This is important because PAN consists of the mineralized forms of N (e.g., ammonia and nitrate) that are more immediately bioavailable (Table 1c.2). Time is required for organic N to be converted into mineralized forms via microbial processes, which increases the chance for runoff from fields before crops can metabolize it. This indicates that raw DAF soil amendments may be a poor choice to limit nutrient runoff and may benefit from pre-treatment via processes like anaerobic digestion and composting that mineralize N within a controlled environment.

**Table 1c.2**: Summary of chemical analysis of registered Maryland soil amendments derived from dissolved air flotation (DAF) sludge from MD State Chemist data. Values given are average ± standard error for n samples.

| Analyte | lbs/1000 gallon | mg/L | Samples (n) |
|---|---|---|---|
| Organic Nitrogen | 49.3 ± 5.6 | 5,910 ± 674 | 13 |
| Ammonia Nitrogen | 6.11 ± 0.38 | 733 ± 45 | 13 |
| Nitrate Nitrogen | 0.183 ± 0.032 | 21.9 ± 3.8 | 13 |
| Total Nitrogen | 50.9 ± 4.5 | 6,100 ± 540 | 15 |
| Phosphorus | 18.6 ± 1.4 | 2,230 ± 162 | 14 |
| Potassium | 2.91 ± 0.16 | 348 ± 19 | 15 |

Industry interviews indicate that most DAF disposed of in MD is land applied as-is, except for a small portion that is processed in two anaerobic digesters (450,000 gallons/year, <5% of overall DAF usage in MD) as a co-digestion feedstock with dairy manure and food waste, respectively. The shipment data from the AIR is the only means of estimating how much DAF is land-applied in MD; however, due to current regulations not requiring farmers to indicate how much tonnage of soil amendments were derived from DAF separate from other fertilizers in their reports to the State Chemist's office. The millions of gallons of imported DAF applied in MD indicates hundreds of thousands of pounds of N and P (Table 1c.3). Given that an estimated 21,849,000 lbs of N were derived from broiler litter in 2019, the total N from DAF would account for an additional ~2 million lbs of N from the MD poultry industry (see Appendix A, Table 1b.5).

**Table 1c.3:** Estimated nutrient loading into Maryland from dissolved air flotation (DAF) sludge from AIR transport and State Chemist laboratory analysis data (2019-2021).

| Parameter | 2019 | 2020 | 2021 |
|---|---|---|---|
| Total DAF Imported (gal) | 29,700,000 | 38,700,000 | 25,500,000 |
| Total N (lbs) | 1,510,000 | 1,970,000 | 1,300,000 |
| Plant-available N (lbs) | 187,000 | 243,000 | 160,000 |
| Total P (lbs) | 552,000 | 720,000 | 474,000 |
| Total K (lbs) | 86,400 | 113,000 | 74,200 |

The current trend of falling DAF imports to MD corresponds to lower nutrient loading in 2021 compared to prior years. However, it should be noted that this may not result in a real net reduction of nutrients to the Chesapeake Bay Watershed if PA becomes the preferred disposal site for the DAF; it would merely shift disposal to a point further upstream in the watershed. Nutrient loading from DAF shipped between DE and MD is more complex since only ⅓ of DE falls within the

Chesapeake Bay Watershed. Net nutrient changes at the watershed level depend on the watershed of origin for a given DAF shipment. Transport of DAF from VA to MD is expected to continue due to MD's proximity to poultry processing facilities in the Shenandoah Valley. However, interviews with industry indicate that newer facilities in the southern regions of the state are expected to also ship DAF to NC (a net decrease from the Chesapeake Bay Watershed) in coming years due to reduced shipping distance. From a regional standpoint, further investigation is needed for a more comprehensive analysis of watershed-level impacts of nutrients derived from DAF.

To summarize the limitations to the utility of DAF-related data currently available:

1) Current reporting to the State Chemist office does not require the registrants of the soil amendments to segregate DAF tonnage used from other registered amendments in biannual reporting to that group, leaving the shipments data in the AIR the only means of estimating DAF usage in MD.
2) Questions about DAF usage did not appear explicitly in AIRs until 2019.
3) The structure of Q51 in the 2019-2021 AIR leaves open the possibility that a producer receiving DAF and other nutrient sources from the same provider might entangle DAF volume or tonnage with other sources being reported under that supplier.
4) In Q53 of the 2019-2021 AIR DAF falls anonymously within 'other organic sources.'
5) In Q57 of the 2019-2021 AIR DAF, according to the understanding of the producer, it might be listed anonymously under 'manure, litter, process wastewater' or might have its identity provided under 'other nutrient source.'
6) The actual density of DAF not been reported; therefore, the density of water was used to generate volumes from tonnages in all estimates.

**<u>Topic 1c Key Findings and Recommendations</u>:**

1. Statistics regarding DAF transport in the region are available only from recent years (2018 and on).
2. There are currently 15 soil amendments derived from DAF registered for land use in Maryland, however, only 4 explicitly use "DAF" in the name to specify its composition.
3. Maryland produces little DAF relative to the larger Delmarva region but it is a major importer with most of it going to land application.
4. DAF production is relatively static regionally, but trends in transport vectors change over time due to differing state laws and regulations; most recently, this has resulted in PA becoming a more preferred location for DAF disposal than MD.
5. Industry perceives state-wide policy as impactful regarding trends in DAF transport and usage.
6. While millions of gallons of DAF are imported to MD annually, the amount of nutrients relative to that in poultry litter is minor.
7. Soil amendments derived from DAF mostly contain organic N rather than PAN, so pre-processing with animal waste technology that mineralizes N (e.g. anaerobic digestion, composting) may be suitable to improve its effectiveness as a fertilizer and reduce runoff.

***Topic 1d. Current operational status of animal waste treatment technologies, feedstock, and technology capacity to accept animal waste in Maryland.***

**Topic 1d Summary:**

The operational status of animal waste treatment technologies in Maryland was determined through cost-sharing information provided by MDA, the Natural Resource Conservation Service (NRCS), and interviews. Collected data included the type of animal waste storage, capacity, and site location. Waste technologies evaluated include anaerobic digestion, gasification, pyrolysis, composting, liquid-solids separation, and manure/waste injection. Most manure technologies employed in Maryland are basic waste storage facilities, followed by storage ponds and treatment lagoons. Poultry litter has the highest storage capacity in the state through covered, padded storage facilities and treatment lagoons. Dairy and beef manure has the next highest storage capacity through storage facilities, storage ponds, and treatment lagoons.

It is estimated that there are 2500 acres in Maryland utilizing manure injection (see Figure 1a.1). While there are anaerobic digesters, composting, and gasification/pyrolysis facilities in Maryland, the overall number of sites is small and not necessarily co-located with concentrations of nutrients in manure (Figure 1d.1). There is one operating manure and food waste digestion facility in Maryland, one food waste only digester, and two poultry litter digestion systems being intermittently operated. There are four more digestion systems in various states of construction and planning (two dairy and food waste systems, one poultry litter and food waste system, and one poultry litter and cover crop system). One poultry litter pyrolysis system is under construction and one fluidized bed combustion system was decommissioned. There is no central database of composting that encompasses both on-farm and registered commercial composting, with data provided showing only six permitted composting facilities accepting manure out of 22 total facilities. An additional 1,085 on-farm mortality composting structures were also accounted for. A similar lack of data prevented the estimation of solids/liquids separation technology used in Maryland. It is recommended that future reporting, possibly in the AIRs, allow farmers to report on-farm technologies used to manage their animal waste.

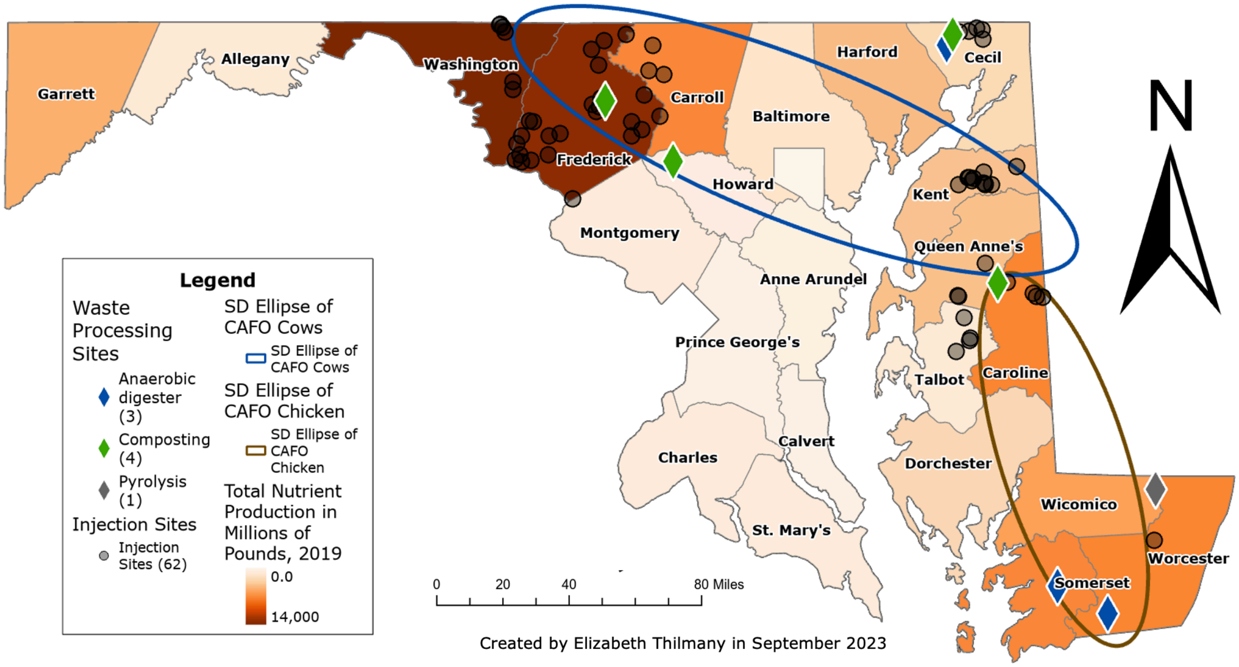


**Figure 1d.1**: Map of current animal waste technology sites in Maryland, including anaerobic digesters, composting sites, pyrolysis, and manure injection sites. Also included in the map is the standard deviation (SD) ellipse showing 66.2% of the concentrated animal feeding operations (CAFO) for cattle and cows (in blue) and poultry (in brown), with total produced manure in 2019 in each county from all livestock and poultry operations shown in gradient shade of orange that correspond with previous figures.

**<u>Topic 1d Methods:</u>**

Storage capacity for on-farm animal waste was estimated using data provided by MDA from the Watershed Implementation Plan (WIP) reports organized by NRCS codes. This data includes the date that a storage facility was installed, the date of the most recent inspection or shutdown (if a site is retired), and storage capacity for agricultural waste, animal waste compost structures, animal mortality compost facilities, waste storage facilities, waste storage ponds, and treatment lagoons from 1965-2019. Except for animal waste compost facilities, the capacity for each of these storage systems was given in terms of animal units (AU). For waste storage facilities, waste ponds, and treatment lagoons, the type of animal waste stored is specified.

The surface area covered by manure storage lagoons at CAFOs was also estimated using digitization of aerial photography data in ArcGIS Pro. Polygons were traced around the visible exterior of the ponds visible at registered CAFOs and then analyzed for surface area using the basic tools suite of the program.

The number of anaerobic digesters in the state was estimated using data from the 2017 Census of Agriculture's on-farm renewable energy generation data, with more recent anaerobic digester data available via the EPA's AgSTAR program. However, this database had missing data for known operational digester sites in MD and inaccurate data for others. MDA data on projects previously funded through the AWTF was used to account for novel animal waste technologies not reported in the other databases, such as pyrolysis units. Interviews confirmed locations of manure waste technologies in MD and corrected any inconsistencies in the databases.

There is no single database that documents on-farm and commercial composting. Data was drawn from multiple sources, including the MDA database on storage organized by NRCS codes, the EPA Excess Food Opportunities Map (EPA, 2022b), and the MD Organics Diversion and Composting program, which document the location of commercial composting facilities that accept food and residential waste, with some sites also accepting manure.

Manure injection data was obtained from Sustainable Chesapeake to assess acreage treated in Maryland and to identify additional sites that utilize this technology in neighboring states (PA and VA) that receive animal waste from MD. No data on solid-liquid separation system on-farm was available, as it is not currently a reporting criterion for any state entity.

**Topic 1d Results:**

Animal waste storage capacity

County-level animal waste storage capacity in Maryland from the WIP data are provided in Tables 1d.1-1d.4 in Appendix A. As of 2021, waste storage facilities have the highest capacity in Maryland (2,970,000 AU), followed by waste storage ponds (11,000 AU), and treatment lagoons (8,070 AU). An additional 97,900 AU of temporary waste storage was also identified for use prior to waste amendment or treatment prior to disposal. The temporary storage capacity is present in six counties (Caroline, Dorchester, Kent, Queen Anne's, Talbot, Wicomico, and Worchester), with Caroline County accounting for almost half (43,300 AU) of the state's total. The WIP data did not specify what type of animal waste was used to calculate the AU of this capacity or clarify what type of storage (facility, pond, or treatment lagoon) is used for this temporary storage.

Poultry waste storage facilities had the highest capacity overall (2,710,000 AU) followed by dairy (126,000 AU) and beef (30,900 AU). Animal waste storage ponds were used for beef (6,540 AU) and dairy (4,440 AU) waste. The data indicates that poultry waste storage ponds were installed historically in the state; however, 100% of the cataloged capacity was retired as of 2021. Treatment lagoons were used to store beef (266 AU), dairy (3,750 AU), and poultry waste (4,050 AU). The data provided does not specify the form of the waste (i.e., raw vs. separated manure) or if any pre-treatment was used prior to storage, which could affect runoff potential and GHG emissions from storage.

Animal waste storage facilities are present in every county in the state. The highest capacity was identified in Wicomico (654,000 AU), Somerset (648,000 AU), and Caroline (551,000 AU) counties, which have the highest poultry litter inventories. Waste storage ponds had a more limited distribution, with the operational capacity in only eight Maryland counties, with 76% of the systems in Caroline County. Treatment lagoons were located in 10 counties, with the highest proportion (37%) in Frederick County. Using ArcGIS, the surface area of treatment lagoons or storage ponds on Maryland's CAFOs was estimated to be 383,000 $m^2$, with the highest lagoon surface area in Kent County (174,000 $m^2$) (Table 1d.5 in Appendix A).

Anaerobic Digestion

The 2017 Census of Agriculture identified six on-farm anaerobic digesters in MD and two on-farm digesters were identified in the EPA AgSTAR database. Based on interview data, there are actually three on-farm operating units, four planned on-farm units, one on-farm offline system in Maryland, and one off-farm digester receiving DAF. One on-farm operating digester is receiving dairy manure, DAF, and food waste, one off-farm operating food waste digester receives DAF, and two poultry litter-only on-farm digestion systems are being intermittently operated. Additionally, there are four more on-farm digestion systems in the planning stage (two dairy manure, DAF, and food waste systems, one poultry litter and food waste system, and one poultry litter and cover crop system). One small dairy manure digestion facility at a research facility is not operational. Three on-farm digesters received funding from the AWTF. There are eight digesters operated at wastewater treatment facilities in Maryland that do not accept animal waste or food waste, but some stated they would be amenable to taking food waste in the future if the nutrients in the treatment effluent did not increase. The location of each digester by county is listed in Table 1d.6 in Appendix A.

Gasification/Pyrolysis/Fluidized Bed Combustion

There were two units in Maryland processing poultry litter. The Dorchester County fluidized bed combustion is decommissioned, and the Wicomico County pyrolysis system is under construction to generate bio-oil and syngas. Both received funding from the AWTF. Gasification/pyrolysis processes are suited to drier feedstocks, such as poultry litter, prevalent on the Eastern Shore. There is no gasification/pyrolysis US database nor a reporting option in the 2017 Census of Agriculture; thus, all data collected was through interviews.

Composting

The data provided by MDA for the Watershed Implementation Plan (WIP) reports indicate five operational on-farm animal compost facilities in MD, of which four are sited in Caroline County and one in Cecil County. The WIP data only lists the number of farms with composting (5) without specifying capacity, farm type farm, or composting substrates.

The MDE Organics Waste Diversion Program lists 22 commercial composting facilities permitted by MDE. Of these, 20 systems are currently operational and accepting waste, with 14 accepting yard trimmings, 5 accepting a mixture of residential and agricultural waste (food scraps, yard trimmings, manure), and 1 accepting agricultural waste only (straw, hay, and manure). The combined capacity of all permitted composting sites is 563,000 tons/year of waste. Smaller facilities (Tier I) almost exclusively accepted yard trimmings, while larger (Tier II) sites accepted food scraps and manure. There are 1085 registered animal mortality composting facilities as of 2019, however, the capacity or animal type was not reported.

Both the Maryland WIP and MDE Organics Waste Diversion Program data use “animal waste” and “manure” as catch-all terms without specifying the type of animal waste being composted. An MDA fact sheet titled Composting and Maryland’s Horse Industry specifically identified horse manure as a target for composting in the state to prevent runoff and included guidelines for mixing the manure with other compost materials, such as food waste, straw, and lawn clippings. The lack of information about the on-farm and commercial manure compost characteristics in the state, including horse manure composting, makes it difficult to determine if this guidance has been adopted.

Manure Waste Injection

There were 62 farms that reported using manure injection for waste disposal, with most clustered in the northern area of the Eastern Shore (Cecil, Kent, Queen Anne's, Caroline, and Talbot Counties) and the north central region of Maryland (Washington, Frederick, and Carroll Counties), with Frederick County having the overall largest number of injection sites in MD (25). The report by Sustainable Chesapeake on 2022 manure injection indicates that 2,496 acres of land was injected from Spring through Fall that year.

Animal Waste Technology overview and CAFO locations

In Figure 1b.1, the locations of the existing animal waste processing systems in Maryland, total manure production by county (averaged from 2018-2021), and the two standard deviation ellipses that include 66.2% of the cattle and 66.2% of the poultry CAFOs in 2022. This map indicates the current spatial relationships of CAFO sites, manure locations, and how animal technologies are being employed within these areas.

Figures 1d.2-1d.4 visualizes the distribution of current waste technology sites with the location and density of CAFO animal production in Maryland. Data was also analyzed for three regions defined by NASS (Northern Eastern Shore, Southern Eastern Shore, and North Central). While these maps do not account for smaller farms in MD, they account for the largest generators of animal waste that would greatly benefit from animal waste technology.

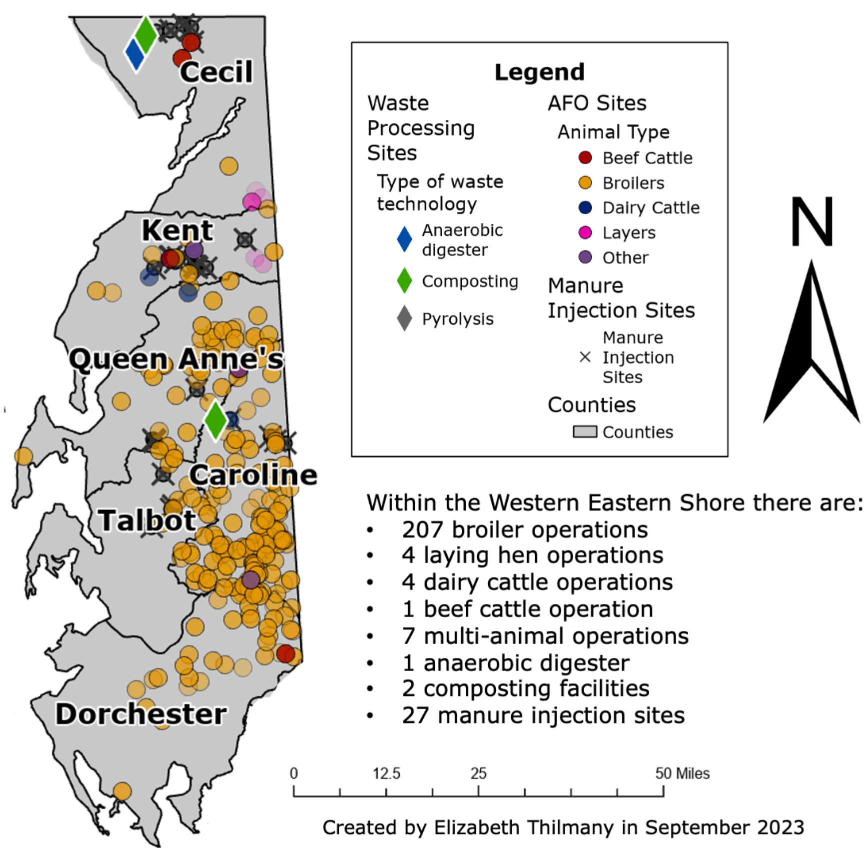


**Figure 1d.2:** Distribution of confined animal feeding operations (CAFOs) and animal waste technology systems in Maryland's Northern Eastern Shore region.

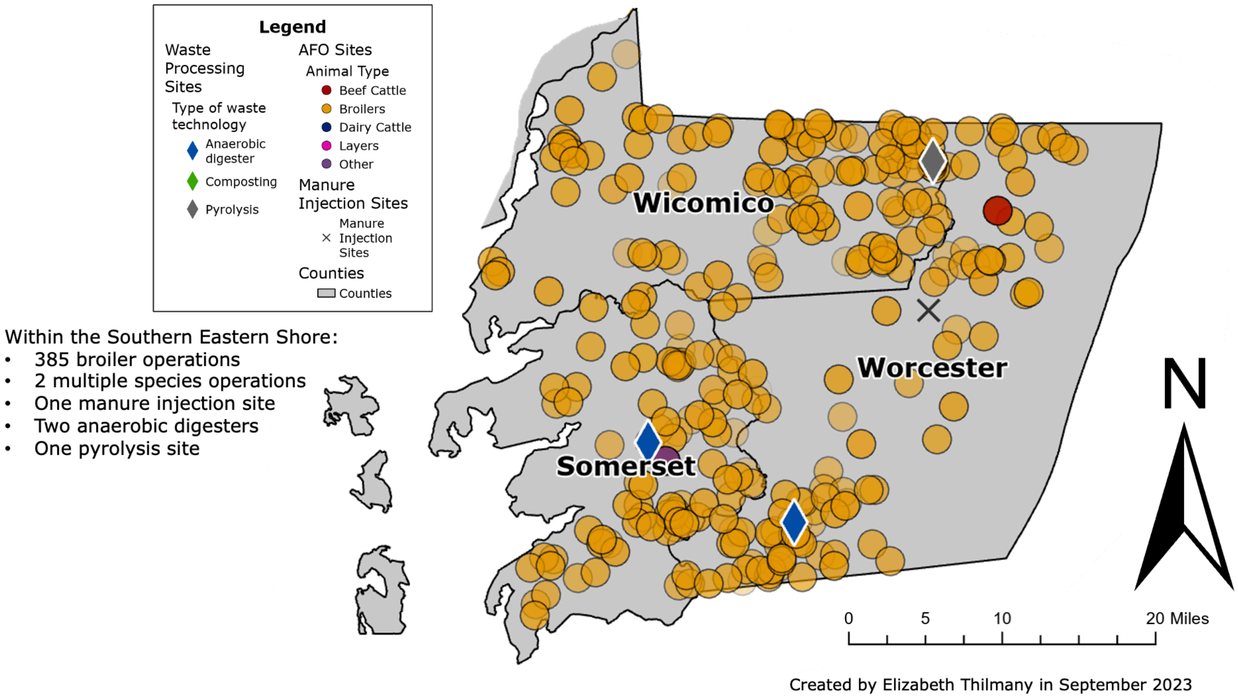


**Figure 1d.3**: Distribution of confined animal feeding operations (CAFOs) and animal waste technology systems in Maryland's Southern Eastern Shore region.

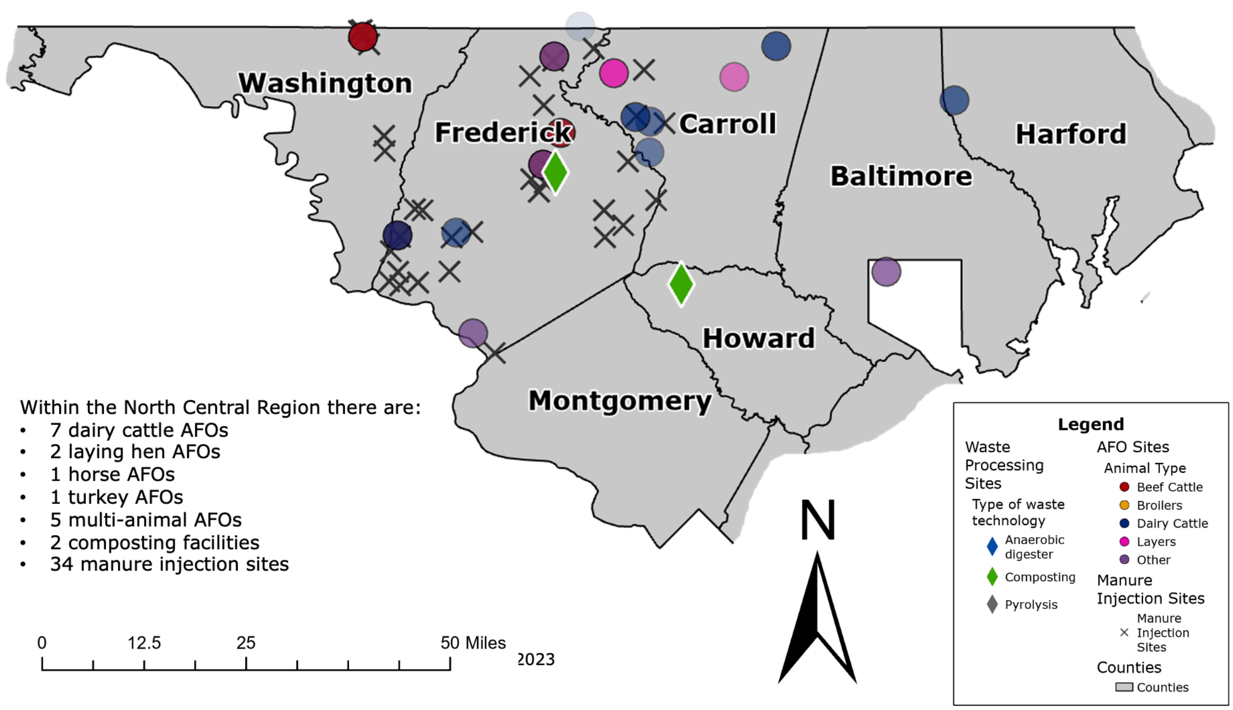


**Figure 1d.4:** Distribution of concentrated animal feeding operations (CAFOs) and animal waste technology systems in the North Central region of Maryland.

The CAFO sites in the Northern Eastern Shore region are sited near anaerobic digester and composting sites in Queen Anne's, Talbot, and Caroline counties. No waste technology sites are listed in Dorchester County, despite having over 45 CAFOs. There are facilities located in adjacent counties, including an anaerobic digester in Wicomico County. Cecil County has a manure-based digester and manure injection sites. Few CAFOs (11) are sited in the North Central region of MD relative to the two Eastern Shore regions (501 CAFOs). However, there are more manure injection sites, as the dairies generate waste more suitable for waste injection than the drier poultry waste generated on the Eastern Shore.

<u>Nutrients and animal waste technology</u>
No databases are reporting how much of MD's animal waste (see Topic 1b) is currently being processed through each animal waste technology. Anaerobic digesters generally do not change the total amount of nutrients in a waste but transform them from a solid to a liquid state. Specifically, anaerobic digestion converts organic-based nitrogen within biomass into aqueous ammonium, which is more bioavailable and less likely to leach when land applied. Gasification and pyrolysis processes volatilize some of the nitrogen in the poultry litter into gaseous nitrogen oxides but do not reduce phosphorus, which is contained in the produced biochar, which can be used as a soil amendment. Composting can reduce nitrogen through ammonia volatilization but does not reduce phosphorus concentrations. Manure injection allows the nutrients to be stored below the soil surface, reducing runoff potential. Additional data on the volume of manure processed through animal waste technology is needed to better visualize net nutrient loading in MD and how it affects runoff to the Chesapeake Bay Watershed.

**Topic 1d Key Findings and Recommendations:**

1. Animal waste technologies (anaerobic digestion, gasification/pyrolysis, manure injection, and composting) are being implemented in Maryland on a limited scale. Land application, manure injection, and animal waste composting remain the most established waste/nutrient management processes.
2. There are limited reporting requirements or databases for many animal waste technologies, such as on-farm composting, solids-liquids separation, and pyrolysis/gasification facilities. There is a need for state-level reporting and data collection on the use of these technologies.
3. Most commercial composting facilities in Maryland do not accept manure waste.
4. Manure injection and anaerobic digestion facilities are slowly increasing, with a much greater increase in the use of manure injection due to lower capital costs and no interconnection, construction, or permits needed, which causes delays in planning new digesters.

***Topic 1e. Estimated the volume of animal waste being field applied, transported to waste treatment technology, or land-filled by county for 2018, 2019, 2020, and 2021.***

**Topic 1e Summary:**

The results from Topics 1a, 1b, 1c, and 1d were used to estimate the volume of animal manure transported for field application (acres), transported to waste treatment technologies, land-filled, or otherwise disposed of in Maryland (by county, calendar year, and farm type) from 2018-2021. Land application of manure was quantified using data from the WIP, AIR, and NASS data, as well as the 2012 and 2017 Census of Agriculture, which asked respondents to report the acres of cropland and pastureland to which manure was applied. Data from MD's cost-shared manure transport program was used to estimate the amount of manure being shipped with assistance from the program.

The findings indicate that Maryland is a net importer of animal waste for land application purposes. Dairy manure was initially the type of animal waste with the highest volume shipped by the transport program (502,000 wet US tons imported or exported to MD counties in 2018). However, shipments have declined over time; in 2021, only 11,600 wet US tons of dairy manure were shipped from Baltimore to Harford County. Waste from the poultry industry (broilers, layers, and poultry waste) has become the most transported waste as of 2021, with a total of 110,400 wet US tons imported or exported from MD counties that year. Waste from beef transported for land application remained within the county where it was generated, and cost-shared shipments ceased entirely in 2021. An estimate of animal waste transport for use in animal waste technologies was not possible since the available data only specified whether the land application was to be used. Additionally, accurate estimates of emissions from transport could not be made due to transport data only being available up to county-level specificity. To improve future analyses, it is recommended that regional animal waste transport and use reporting contain more specifcity about the origin and destination of waste shipments, waste handling, storage, and disposal.

**Topic 1e Methods:**

Manure transport for land disposal was estimated using county-to-county shipment from the MDA provided data from the WIP reports. Cost-shared manure transport for years 2018-2021 was provided by MDA and classified by the 8-digit HUC code as well as the five-digit county code (FIP). The WIP data was used with the AIR data to better understand the waste application, transport, or landfilling and was augmented through interviews. Transport for all other waste management purposes (i.e., anaerobic digestion) was classified as "other" in the WIP, with only the origin of the waste indicated. The manure applied to pasture manure is based on animal numbers and interviews, as this information is not captured in AIR.

**Topic 1e Results:**

<u>Transport of waste for land disposal</u>

Tables 1e.1-1e.4 in Appendix A report county-level transport of cost-shared animal waste into and out of MD counties for 2018-2021, respectively, with imported and exported waste from adjacent states during this time, including PA, DE, VA, and WV. Maryland imported more waste than it exported for all waste types analyzed between 2018-2020. However, the net gain of waste differed

by species. Dairy manure was imported in the greatest quantities (134,000 - 220,000 wet tons) between 2018-2020. Beginning in 2021 however, dairy manure transport shifted to exclusively in-state with 11,600 wet tons shipped from Harford to Baltimore County that year (0 imports into MD). It is unclear if this is a reporting error or a new trend. The second highest imported waste by mass was broiler litter (2000 wet tons/year), with shipments consistent between 2018-2020 and considerably higher imports (14,600 wet tons) in 2021. Layer litter followed a similar trend, with net waste import increasing from 2,000 wet tons imported from 2018-2020 to 19,700 wet tons in 2021. Other poultry waste decreased from net imports of 10,000 wet tons from 2018-2020 to only 101 wet tons in 2021.

While this analysis does not account for manure land-applied to the same site it was generated at, it indicates a broad trend away from dairy towards broiler and layer waste import in 2021. It should be noted that a limitation of this analysis is that county-level data poorly express the net transport within the same county. While this is accounted for in net imports on a state level. For example, in Carroll County, there were 675 dry tons of manure imported to and exported from the county due to shipments between in-county facilities in 2018. While the net mass transported for the county is 0, the shipment of the waste generates traffic and associated greenhouse gas (GHG) emissions even when it remains within the county.

Transport of waste for non-land disposal

Table 1e.2 details the wet tons of animal manure transported for non-land disposal purposes. Caroline, Dorchester, Queen Anne's, St. Mary, Somerset, Wicomico, and Worcester counties shipped waste to alternative animal waste technology disposal sources, with 100% of the waste coming from broilers in 2020 and 2021. A relatively small amount of swine waste (~191 wet tons) was also shipped in 2019. This data neither specifies which animal waste technology was utilized nor the final disposal method or the final disposal location.

Reporting of animal waste storage and transport in Maryland

The biggest challenge to assessing the current state of animal waste storage and use for all types of waste in MD was limitations observed in the data obtained from the AIR and other data available. To exemplify this, Table 1e.5 summarizes an analysis of questions asked in the AIR, how asymmetries exist between the questions being asked, and what data is needed to understand the bigger picture of waste storage and transport in the state. For example, none of the questions in the AIR require reporting of animal waste stored from the previous year that arrived before or during winter spreading restrictions. Some questions ask about the waste generated on-farm and stored overwinter. Still, additional cross-referencing of data from multiple years is required to compensate for the lack of a specific question for this topic. This may be complicated if the AIR reporting structure changes between years, for example, when the AIR was changed in 2019 from 2018.

It was also determined that there are no reporting requirements for importing or storing waste derived from animal waste technology, such as anaerobic digester effluent or composted manure. It is unclear if these wastes would still count as "animal waste" for the cost-share program,which is more bioavailable to plants. The lack of data prevents adequate tracking of the nutrients from these wastes, which contradicts the objective of the Animal Waste Technology Fund to better manage nutrient use in Maryland. Better data collection and management could allow future analyses to directly compare land use of inorganic and organic fertilizers in Maryland. Additionally, more specific phrasing of questions in reporting waste transport, more consistent data reporting requirements, and higher specificity in the questions asked to farmers could help refine analyses of animal waste movement and usage in MD in the future.

**Topic 1e Key Findings and Recommendations:**

1. Maryland is a net importer of waste, primarily derived from dairy, broilers, and layers being the most common types of waste shipped in Maryland between 2018-2021.
2. The state's cost share data only designates waste as "land applied" or "other animal waste management," with no additional details about the fate of the transported waste.
3. County-level transport data may not be suited for assessments of animal waste technology, as more specific site-to-site data on transport to assess sustainability is required.
4. Higher specificity for the fate of transported waste is advised, as current county-level summary data only distinguishes between land application and all other technologies. It is recommended that MDA make more specific specifications of the fate of agricultural waste in the future.

## TOPIC 2: Trends Assessment

### *Topic 2a: Current Industry Trends that May Affect Animal Waste Characteristics and Growth Trends in Animal Waste Volume in Maryland.*


**Topic 2a Summary**

In this section, we sought to understand how industry trends over the next decade are expected to shape the growth of animal waste production in Maryland. The team compiled information from USDA baseline projections for each relevant animal species in Maryland and used that data to calculate contemporaneous inventories, manure, and nutrient concentration in 2022, as well as projections for such numbers in 2032. We supplemented these projections with information gathered from surveys with relevant Maryland agricultural stakeholders. Several strong trends emerged from the analysis.

In 2022, the results showed that three animal species (broilers, cattle, and equine) that account for 98.7% of animal population (total animal units) also account for 91.9% of state animal waste nutrients (N and P) produced in Maryland. Broilers alone accounted for 88.3% of total animal units in Maryland in 2022. Results from calculated manure and nutrient estimates revealed that broilers contribute 43% of nitrogen and 56% of phosphorus produced in Maryland, indicating the importance of effectively managing broiler manure from the Eastern Shore.

Looking forward, Maryland broiler production is projected to increase by 13% over the decade, with the increase coming largely from increased bird weights rather than number of heads. Maryland has experienced a steady decline in dairy cow inventories since the late 1980s, which is expected to continue. Beef cow inventories have remained constant, which is also expected to continue. In total, these trends are offsetting. Increased production of nutrients from increased broiler production offsets declines in nutrient production from decreased cattle production. In total, we project a small decline in N and P production over the next decade.


**Table 2a.1**: Maryland nutrient production, by species, in 2022 and projected for 2032.

| | **2022** (million pounds) | | **2032** (million pounds) | | **Percent of Total (2032)** | **Percent of Total (2032)** |
|---|---|---|---|---|---|---|
| | N | P | N | P | N | P |
| Broilers | 20.9 | 8.5 | 23.0 | 9.3 | 48.9% | 61.6% |
| Layers | 2.9 | 1.1 | 3.1 | 1.1 | 6.6% | 7.3% |
| Turkeys | 0.1 | 0.1 | 0.03 | 0.03 | 0.1% | 0.2% |
| Milk cows | 8.1 | 2.0 | 6.2 | 1.4 | 13.2% | 9.3% |
| Beef cows | 3.8 | 0.9 | 3.7 | 0.9 | 7.9% | 6.0% |
| Other cattle | 6.4 | 1.5 | 5.2 | 1.3 | 11.1% | 8.6% |
| Hogs | 0.2 | 0.02 | 0.1 | 0.02 | 0.2% | 0.1% |
| Horses | 5.7 | 0.9 | 5.0 | 0.8 | 10.6% | 5.3% |
| Sheep | 0.4 | 0.1 | 0.4 | 0.1 | 0.9% | 0.7% |
| Goats | 0.2 | 0.1 | 0.3 | 0.1 | 0.6% | 0.7% |
| **Totals** | **48.7** | **15.2** | **47.0** | **15.1** | | |

**Topic 2a Methods and Materials**

Estimates of Maryland animal populations, by species, in 2022 were used to develop population projections for 2032 based on prior trends in Maryland animals and USDA baseline projections for nationwide growth in meat and dairy production and animal populations to 2032 (Dohlman et al., 2023). The USDA projections were derived from models relating the production of animals and animal products to prior production trends and to estimated future US and global trends in population, economic growth, prices, interest rates, and exchange rates.

These population measures and model trends were combined with manure and manure nutrient production estimates, by species, to develop animal waste generation projections for 2022 and 2032 in Maryland. Manure production data were derived from Maryland AIR reports and estimates of nutrient concentrations in manure were derived from laboratory tests done as part of those programs. Current estimates of per-animal manure generation and nutrient concentrations were used for nutrient production in 2032.

USDA's National Agricultural Statistics Service (NASS) has published annual state-level estimates of inventories and production for the major animal species. Those estimates cover many years and in some cases show powerful long-run trends that are likely to continue. NASS reports on relatively minor species only at five-year census intervals, such as turkeys, with county-level inventory estimates reported only in the five-year census of agriculture.

Our statistical analyses were supplemented with information from Maryland stakeholders. First, we surveyed 246 Maryland stakeholders (such as farmers, extension agents, agribusinesses, and agricultural consultants) for their views on likely developments in Maryland livestock production and animal waste generation in the near future. Second, we conducted a series of personal interviews with stakeholders, and as part of those interviews solicited stakeholder views on likely future trends in Maryland animal production.

**Topic 2a Results**

Stakeholder Survey Results on Animal and Manure Trends

We surveyed 246 stakeholder respondents: 64% male, 94% white, with 63% farmers, 14% extension, and 8% farm consultants. Respondents were from each MD county except Baltimore City. The survey found that 51% of the 168 respondents to the question "How do you expect your total animal population to change on your farm (or within your commodity group, if you do not have a farm) in the next five years?" expected animal populations would remain the same over the next five years, with 15% expecting a decrease and 34% expecting an increase in populations (Figure 2a.1). The most important factors driving expected increases or decreases in populations were personal circumstances (48% ranked #1), market forces (30% ranked #2), and right to farm (20% ranked #3). Full survey results are found in Appendix C.

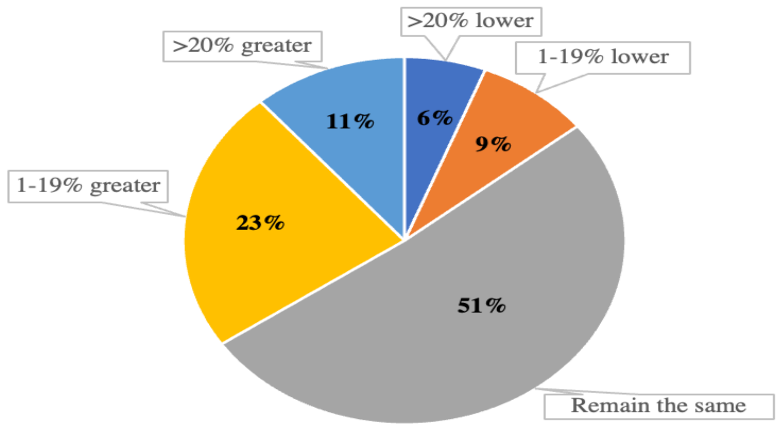


**Figure 2a.1:** Survey results from 168 respondents to the question "How do you expect your total animal population to change on your farm (or within your commodity group, if you do not have a farm) in the next five years?"

Of the 63% of crop farmers that use manure or poultry litter on their fields, 63% expect the quantity applied to stay the same over the next five years, while 26% expect that quantity to increase (Figure 2a.2). For respondents that do not use manure or poultry litter, only 22% were likely to start using these sources in the next five years. Only 5% of respondents use animal waste products, such as DAF, on their fields, with 87% of those using DAF expected to remain the same and 13% expected to increase 1-19% (8 respondents). Of the respondents that do not use animal waste products, only 9% are likely to start. The three greatest challenges for manure management (about equally ranked) were nutrient management planning, moving manure off-site/hauling, and land limitations.

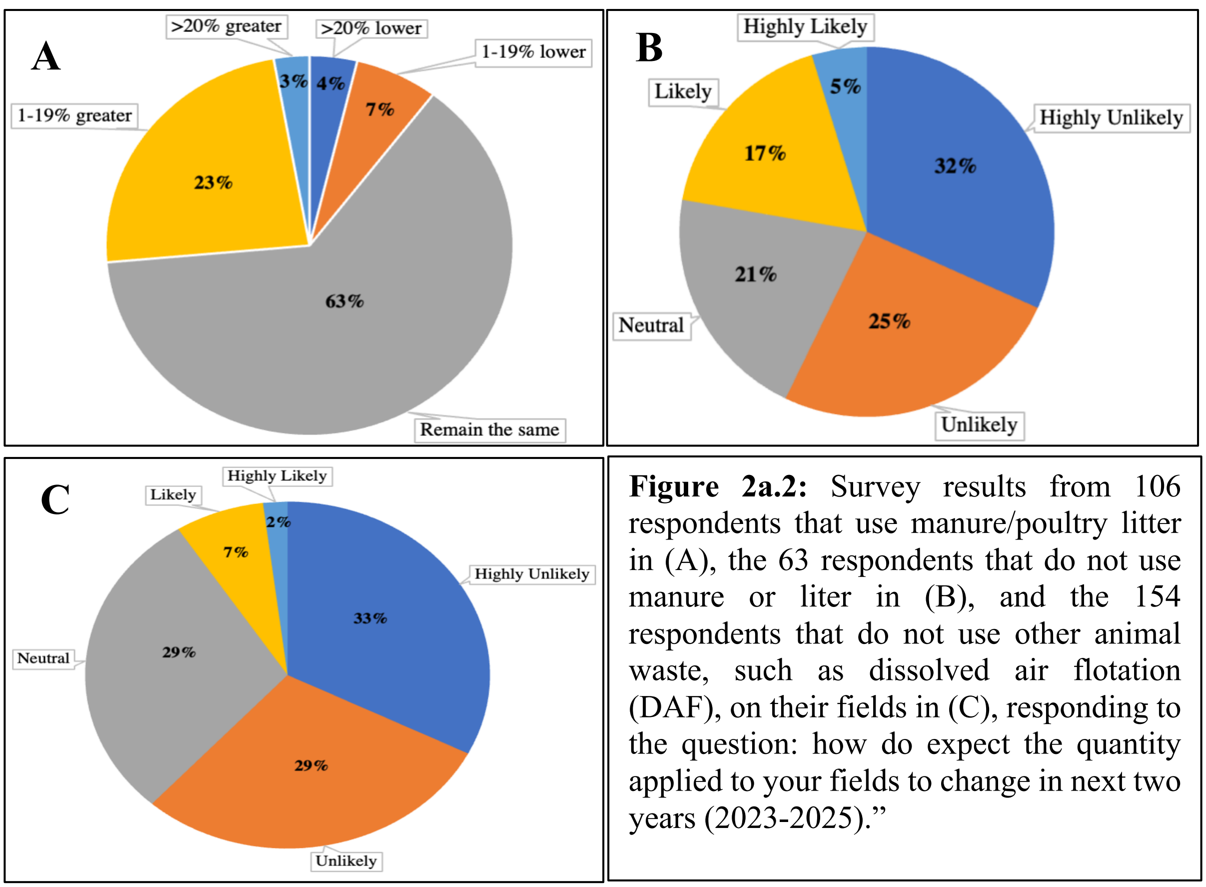


**Figure 2a.2:** Survey results from 106 respondents that use manure/poultry litter in (A), the 63 respondents that do not use manure or liter in (B), and the 154 respondents that do not use other animal waste, such as dissolved air flotation (DAF), on their fields in (C), responding to the question: how do expect the quantity applied to your fields to change in next two years (2023-2025)."

The primary motivations for farmers to use manure, poultry litter, or other animal waste products on their fields were cost of commercial fertilizers (34 respondents), fertilizer (32 respondents), good source of nutrients (18 respondents), and high availability (15 respondents). Their primary concerns were government regulations (33 respondents), availability (17 respondents), runoff (14 respondents), and nutrient management (13 respondents). Most respondents do not see opportunities for creating an income source from their manure and do not see changes expected in their farm management, but most expect to see more regulations/restrictions in the next five years.

Animal Trends based on Statistical Estimates and Projections

The USDA's "baseline" projections for nationwide agricultural production through 2032 projections start with fundamental assumptions about growth in the human population (6.9%) and economic activity (1.9% per year) in the US, as measured by real, or inflation-adjusted, gross domestic product (Dohlman et al., 2023). Higher global population growth and economic growth (2.8%) should induce higher US agricultural exports, but higher US economic growth should have only minimal impacts on US meat and dairy product consumption (Table 2a.2), as meat and dairy product consumption is more responsive to the growth in GDP at lower income levels. Hence, increases in per-capita GDP in the US will have minimal impact on meat and dairy consumption in the US, while GDP growth in Asia, Africa, and Latin America will have larger impacts on consumption and on imports from the US.

**Table 2a.2**: USDA Baseline Livestock Projections based on gross domestic product (GDP) and population (Dohlman et al., 2023).

| Variable | 2022-2032 (% growth) | Average Annual (% growth) |
|---|---|---|
| **US Baseline Assumptions** | | |
| US Population | 6.9 | 0.61 |
| World Population | 10.4 | 0.90 |
| US Real GDP | 22.8 | 1.90 |
| World Real GDP | 35.8 | 2.80 |
| **Key US agricultural projections** | | |
| Broiler production (pounds) | 17.1 | 1.44 |
| Egg production (million dozen) | 11.1 | 1.06 |
| Pork production (pounds) | 13.8 | 1.31 |
| Beef production (pounds) | -0.0013 | -0.00013 |
| Milk production (pounds) | 11.9 | 1.13 |

Animal Projections for Maryland in 2032

Animal inventories were used for some species while annual animal production was used for others. For example, broilers are raised from hatching to harvest in 6-8 weeks. Consequently, the broiler inventory at any point in time is just a fraction of the number of broilers raised in a year, and inventory only represents a fraction of the total manure produced by broilers in a year. Therefore, to measure manure production, the calculations started with broiler production instead of inventories. Similar reasoning applied to hogs and turkeys.

For cattle, annual inventories were sorted by classes (i.e., cows, calves, heifers) and used as measures of the animal numbers over a year in MD. Similarly, annual inventories of horses and egg layers provided effective bases for estimating annual manure production (Table 2a.3).

**Table 2a.3**: Projections for 2032 animal numbers in Maryland.

| | Number of head | | Animal units (AU) | |
|---|---|---|---|---|
| **Animal type** | **2022 estimate** | **2032 projected** | **2022 estimate** | **2032 projected** |
| Broilers (head removed) | 269,200,000 | 275,000,000 | 1,884,400 | 2,117,500 |
| Broilers, liveweight, billion lbs | 1.88 | 2.12 | | |
| Egg layers (inventories) | 2,500,000 | 2,700,000 | 11,750 | 12,690 |
| Turkeys (production) | 100,000 | 100,000 | 1,500 | 1,500 |
| Cattle, all (inventories) | 165,000 | 137,900 | 146,275 | 121,977 |
| Milk cows | 41,000 | 29,900 | 57,400 | 42,860 |
| Beef cows | 42,000 | 40,000 | 42,000 | 40,000 |
| All other cattle | 82,000 | 68,000 | 46,875 | 39,117 |
| Hogs, all (inventory) | 20,550 | 20,000 | | |
| Breeding hogs (inventory) | 3,500 | 3,400 | 1,400 | 1,360 |
| Market hogs (production) | 42,600 | 40,600 | 5,538 | 5,278 |
| Horses (inventory) | 68,500 | 60,650 | 75,350 | 66,715 |
| Sheep and lambs (inventory) | 23,000 | 22,000 | 4,600 | 4,400 |
| Goats (inventory) | 15,000 | 17,000 | 3,000 | 3,400 |
| **All** | | | **2,133,813** | **2,334,820** |

Estimates of 2022 and 2032 numbers (in head) for Maryland are provided in Table 2a.3, with animal numbers converted to animal units by multiplying our 2032 projections by the appropriate conversion coefficient for comparison of production and inventory numbers across species (an animal unit (AU) is 1,000 lbs of liveweight animal).

Broilers dominate animal numbers in Maryland, accounting for 88% of AUs in 2022, with a slight growth between 2022 and 2032. This reflects a continued recovery from sharp pandemic related declines in 2020-21, but we do not project a return to average annual production levels of 300 million per year seen in the 2010s. We do project a continued growth in bird sizes, and hence project 20% growth in liveweight production over 2022-2032. We project a decline in cattle numbers over 2022-2032, driven by a continuing decline in dairy production in the state. We also project a decline in horse inventories, although as noted below that estimate is subject to considerable uncertainty. Specific information on projects for each species and assumptions used in calculations are located in Appendix B, with more information on poultry, cattle, and equine projections below. Appendix B has all the information on less common species in Maryland.

Broiler Production Trends

The USDA projects that national broiler production will grow by 17.1% through 2032 (Table 2a.3) in response to increases in the US population, in US per-capita chicken consumption, and in exports of chicken products. Broiler production is Maryland's largest agricultural sector, with Maryland accounting for about 3%, and the Delmarva Peninsula about 7%, of all US production. In Maryland, total production (in liveweight pounds) has increased at a trend rate of 1.44% per year over 1988-2022. While Maryland production fluctuates from year to year, the trend increase has been persistent (Figure 2a.3). However, increases in Maryland production have come about almost entirely through increases in the average weight: the number of head produced in Maryland fluctuated around 300 million between 1992 and 2019, before falling off to 260 million by 2021 as poultry companies reduced nationwide placements during the pandemic (and more so in the Delmarva than other parts of the country). The region recovered some production in 2022, to 269 million birds, but total annual Maryland broiler production is unlikely to rise above 300 million birds.

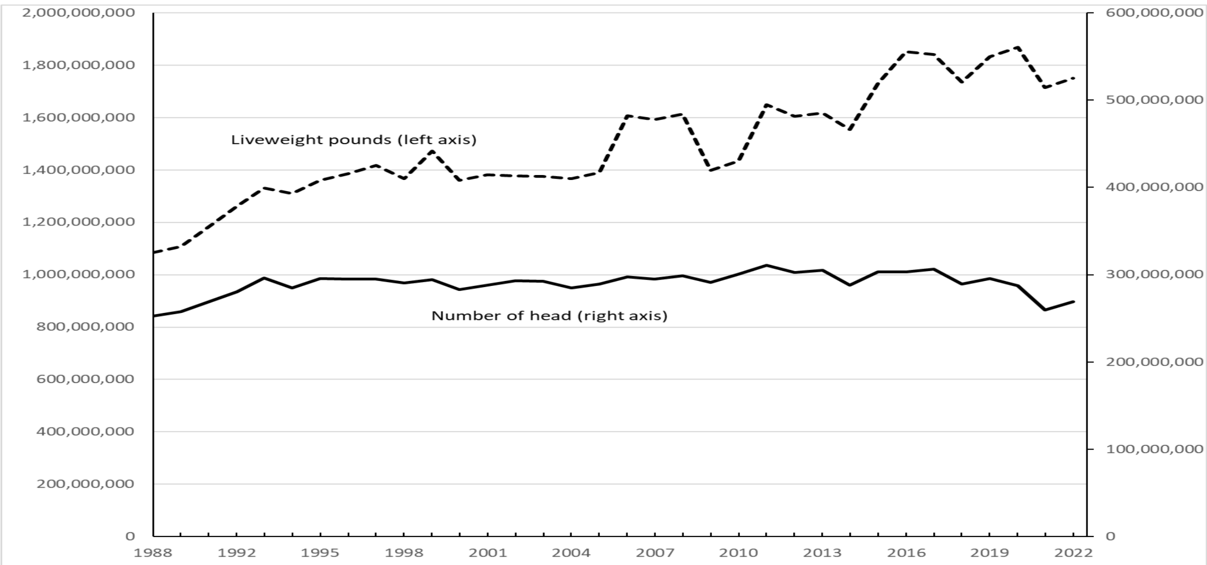


**Figure 2a.3**: Maryland Broiler Production, 1988-2022.

Another indicative trend arises from Maryland's share of total US broiler production. In 1988, Maryland accounted for 4.8% of US production. The state's share has declined persistently since, reaching a 3.1% share in 2020 and 2.9% in 2022, as industry expansion occurred primarily in other regions. US broiler production has grown at a faster rate than Maryland production for three decades and that is unlikely to change. Expanded production across the US has come through the development of new poultry complexes and more intensive production within existing complexes. Neither of those developments are likely in our region, as the Delmarva faces growing population and environmental pressures. The resident population in the poultry-producing counties of the Delmarva increased by 51% between 1990 and 2021, considerably faster than nationwide population growth over that period [3].

If Maryland's share remained at 3% of US production, and the USDA nationwide baseline projection holds, then Maryland would likely produce 300 million birds in 2032, which is similar to the average number of head produced in the State over 2008-2019 and noticeably greater than the average of 272 million in 2020-2022. However, a linear projection of the 1988-2022 share trend to 2032 would yield a Maryland share of 2.6%, or 260 million birds (Figure 2a.4). A linear projection may understate the likely 2032 Maryland share, since the rate of decline slowed after 2004. If the Maryland share fell to 2.75%, which is more likely, then Maryland production would amount to 275 million birds in 2032.

[3] Calculation combined Sussex County in Delaware with Accomack in Virginia and eight Maryland counties (Caroline, Dorchester, Kent, Queen Anne, Somerset, Talbot, Wicomico, and Worcester).

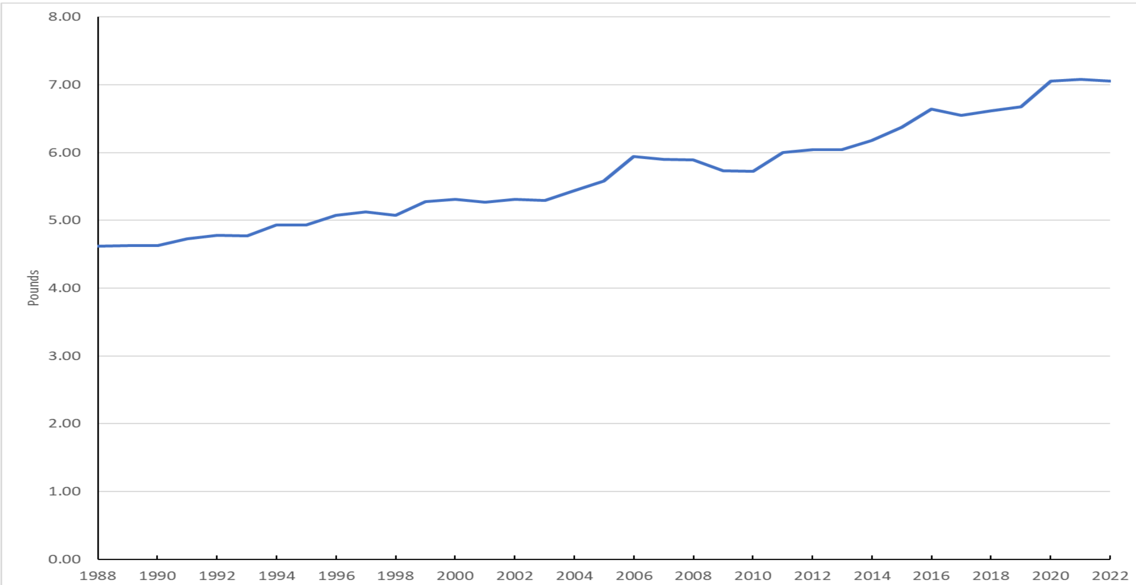


**Figure 2a.4:** Average Broiler Weight in the Delmarva, 1988-2022.

Average weights for broilers produced in Maryland have increased steadily throughout the period 1988-2022, mirroring national growth in average bird size. If the same 1988-2022 trend in average weights were to continue to 2032, we would expect average broiler size to reach 7.7 pounds, up from 7 pounds in 2022. In turn, total liveweight broiler production in Maryland would be projected to reach 2.12 billion pounds in 2032, about 13% more than in 2022.

Stakeholder Interviews - Broilers

Because of the importance of broiler production in Maryland, we interviewed a range of broiler industry stakeholders, including growers, integrator staff, extension agents, and consultants. In considering their responses, note that they are all quite familiar with the trends through 2022, as shown in Figures 2a.3 and 2a.4.

In considering future growth in the annual number of head produced, respondent views fell into three categories: a) a return to average production over 2008-2019 of 300 million head; b) a modest increase over 300 million head; or c) a decline, with some envisioning 2020-22 average production (275 million head) and some foreseeing further decline. In making those projections, respondents cited growing demand (reflecting population growth) as set against constraints rising from processing plant capacity, the cost of adding housing, and the state's regulatory environment, which they saw as restrictive compared to other states. Some respondents expected an increase in production in some cases due to a bounce-back from pandemic-related declines toward the capacities of processing plants, and in some cases citing continued demand growth (from rising populations). Others expect recent production numbers to continue, and thus a decrease from the 2008-2019 averages. Those respondents tend to cite constraints arising from processing capacity and from housing construction costs in the Delmarva, and tighter (cost-increasing) regulation in MD. Specific interview quotes and responses to production trends and projected broiler weight increases are given in Appendix B.

Milk Production and Milk Cow Inventory Trends

USDA projects that US milk production will grow by nearly 12% over 2022-2032, or 1.1% per year. Most of that increase will come from greater milk production per cow. USDA projects that the nationwide inventory of milk cows will increase by about 2% by 2032, from 9.4 to 9.6 million cows. However, milk cow inventories in Maryland are likely to decline, continuing a long-term trend. USDA/NASS reports that there were 310 Maryland herds licensed to sell milk in 2022, down from 510 in 2011 and from 715 in 2003 (USDA, 2023b). The Maryland milk cow inventory fell by 63% over the last 34 years, from 111,000 cows in 1988 to 41,000 in 2022, and this decline has been quite persistent (Figure 2a.5). Maryland follows the US dairy industry trend of increasing inventory on each farm, with the number of MD herds declining by 4.4% annually while inventories declining by only 3.1% annually.

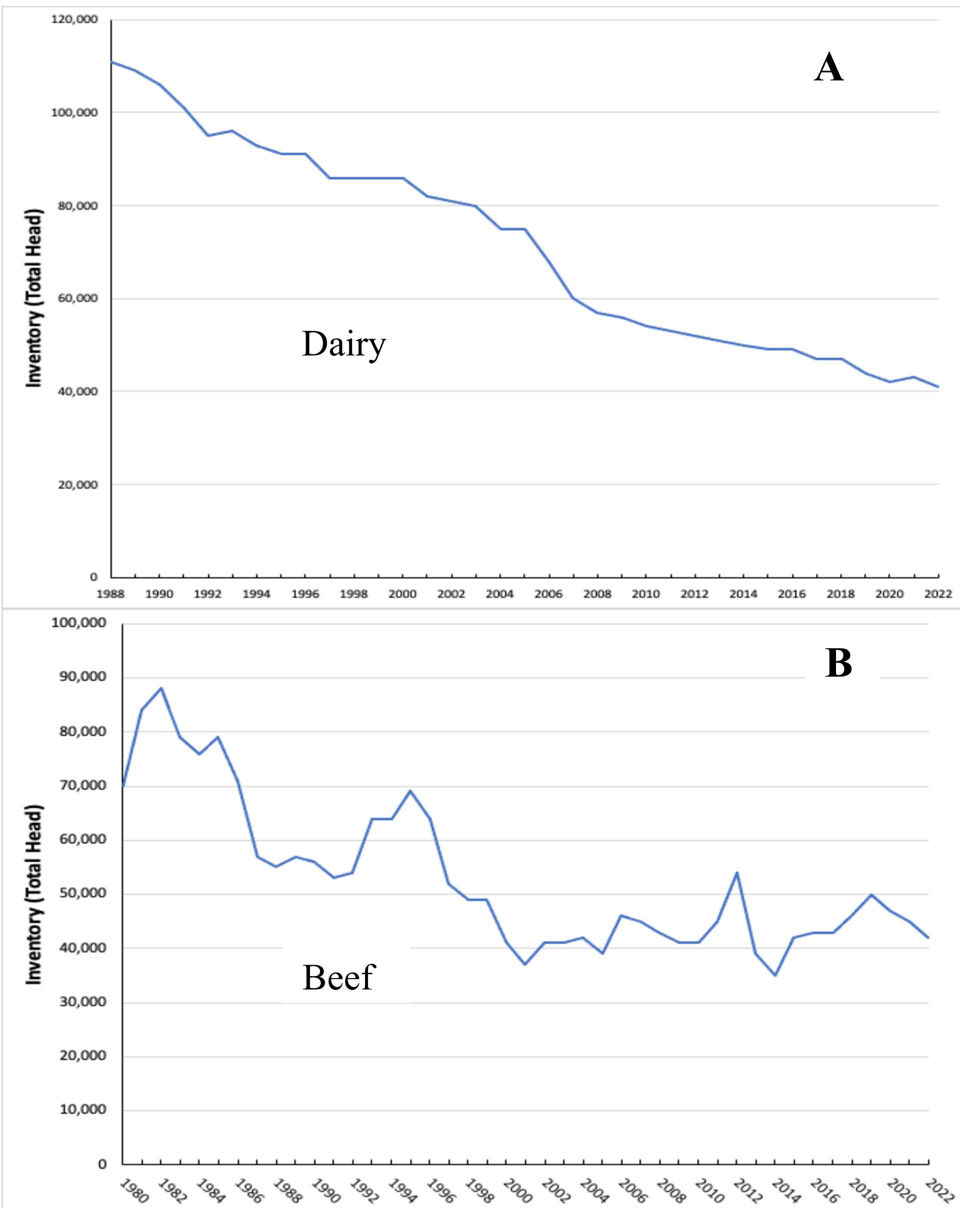


**Figure 2a.5**: Maryland milk cow inventory (1988-2022) and (A) and beef cow inventory (1980-2022) in (B).

The decline in Maryland cow inventories reflect the following powerful and ongoing national developments in US dairy production (MacDonald et al. 2020 - note MacDonald is a co-PI):

- Positive but modest growth in domestic consumption, driven largely by growth in dairy products like cheese, yogurt, and ice cream rather than fluid milk;
- A strong shift of milk production and cow inventories to Western states, a decline in Southern states, and stability to modest declines in traditional dairy states in Upper Midwest and Northeast;
- Major shift of inventories to larger dairies (over 1,000 cows) and closure of smaller farms.

Large dairy farms tend to be located in rural areas, with lots of land for feed production. The regional and size-related changes in dairy production are not slowing down, and do not favor Maryland dairy production, which is dominated by relatively small and high-cost farms. According to the 2017 Census of Agriculture, farms with fewer than 100 milk cows accounted for 24% of Maryland's milk cow inventory, while farms with at least 1,000 head accounted for 12%; the corresponding nationwide figures were 12% for farms with less than 100 head and 55% for farms with more than 1,000 head. Production and inventory almost certainly continue to move to those much larger farms.

If these expected trends continue, the milk cow inventory in MD will decline by another 27% by 2032, leading to a projected cow inventory of 29,924 cows in 2032, with the number of licensed herds expected to fall by 36%, to just over 200 farms (Table 2a.3). Specific interview quotes and responses to production trends in dairy are given in Appendix B, with all but one respondent expecting these trends to continue in MD, with one having hope for expansion of smaller-scale dairy production.

<u>Beef Cow Inventories and Production Trends</u>

USDA projects that total US beef production in 2032 will be no higher than in 2022 (Table 2a.3). With a growing US population (Table 2a.2), this implies declining per-capita beef consumption (about 5% over the 10 years in the USDA baseline) and lower exports in 2032 than in 2022. Declining per-capita consumption is not unprecedented: US per-capita consumption peaked in 1976, declined sharply through 1993, and then declined again between 2009 and 2015 (ERS, 2022). USDA further projects a slightly higher (4%) national inventory of beef cows in 2032 than in 2022, reflecting a declining national cattle cycle of beef cow inventories through 2022, followed by modest recovery. Illustrated in Figure 2a.5, the beef cow herd displays significant year-to-year fluctuations in MD, but no discernable trend since 2000 (after halving over 1980-2000). With no national growth, and no trend in MD beef cow inventories over the last two decades, we project no marked change in MD inventories over the next decade, remaining in the range of 40,000 to 42,000 head by 2032. Stakeholders pointed to pressures on land base for ruminants and a small and declining volume of commercial beef production, while also noting the likely continued presence of small operations with often non-commercial goals, with specific interview quotes in Appendix B.

<u>Horse Trends</u>

Counting horses can be a challenge, because many are not located on farms. For example, USDA reported that there were 27,635 horses and ponies on Maryland farms in the 2017 Census of Agriculture, down from 28,662 in 2012 and 30,747 in 2007. Maryland's AIR system reported only

18,520 horses on reporting farms in 2018, with a decline to 15,521 by 2021. However, USDA only counts horses on farms. Boarding stables are not counted as farms, and residences with few horses but no other agricultural activity are unlikely to be counted as farms. For its AIR program, Maryland requires all farms with at least $2,500 in gross sales or at least 8,000 pounds of live animal weight to follow nutrient management plans and to file AIR forms. USDA defines farms, for statistical purposes, as places with at least $1,000 in gross sales; hence USDA reporting ought to capture more farms than AIR reporting. In the case of horses, where many are kept off farms, USDA and AIR data may substantially undercount the number of horses in the state, and the manure they generate.

Maryland's Horse Industry Board ran an equine census in 2010 in cooperation with the Maryland Department of Agriculture and USDA's National Agricultural Statistics Service and reported an inventory of 79,100 horses, ponies, mules, burros, and donkeys, down from 87,100 in the 2002 census (with 71,600 of the animals being horses, with the rest ponies, donkeys, and burros in 2010). Each source reports declines in horse numbers in the 21st century at a rate of 1-2% per year. At that rate, we project that an equine census, projected to 2022, would generate an estimate of 68,500 horses, and if the rate of decline continued to 2032, there would be 60,650 horses. We should emphasize that this is the thinnest data for any of our species.

Egg Layers, 'Other Cattle,' Hogs, Lamb, Sheep, and Goat Trends

The information from Egg Layers, 'Other Cattle,' hogs, lamb, sheep, and goats are given in Appendix B; Figures 2a.6 to 2a.9), with the 2032 trends and projection calculations explained.

Projecting Statewide Manure Production

The statewide animal population estimates were used to estimate manure production in 2022, with projections of manure production in 2032. We started with estimates of the production of nutrients (nitrogen and phosphorus) per pound of manure for different species and status (such as lactating versus dry dairy cows). Those estimates are drawn from laboratory tests of manure samples collected as part of Maryland's Nutrient Management Program (UMD NMP 2022), for samples collected over 2019-2021.[4] We combined those with estimates of daily manure production drawn from the NMP and from the Agricultural Waste Management Field Handbook produced by USDA's Natural Resource Conservation Service (USDA, 2008).

The aggregation steps vary across species. Details of those aggregations are provided in Appendix B in a series of tables (Tables 2a.4 to 2a.12). In the notes to each table, we detail our aggregation steps (by which we go from per-animal coefficients to state-wide aggregates) and discuss industry developments that may affect our estimates. Our statewide annual estimates are reported by species and for all animals in Table 2a.1 (in Summary section).

Broilers account for 43% of total estimated N production in 2022 and 56% of estimated P production. Cattle and horses are also significant contributors to aggregate N and P production. We project a modest decline in N (3%) over 2022-2032 and a small decline in P. Those changes

[4] We originally drew on coefficients for manure and nutrient production reported by the American Society of Agricultural and Biological Engineers (ASABE, 2005). However, those estimates are over twenty years old: diets and animal attributes have changed considerably since publication.

reflect two offsetting drivers: increased liveweight broiler production set against significant declines in dairy production (and associated milk cows, dairy heifers, and dairy calves).

**Topic 2a Key Findings and Recommendations**

1. We expect Maryland broiler production to grow by 13% between 2022 and 2032, with the increase coming almost entirely from increased bird weights.
   a. Growth in live-weight broiler production will fuel modest growth in aggregate N and P production, assuming no change in N and P concentrations per pound of manure.
   b. Egg layers make a small but noticeable contribution to aggregate N and P production (6-7% of total) with no substantial increases expected in layer numbers over 2022-2032.
2. Maryland has experienced a persistent and steady decline in milk cow inventories since 1988. This trend is projected to continue given macro-level factors, such as geographic shifts in the location of dairy farms and continued consolidation in the dairy industry.
   a. If past trends continue, the number of milk cows in the state will decline by 27% by 2032, with concomitant declines in dairy calves and replacement heifers.
   b. Beef cattle inventories are expected to remain largely constant over the next 10 years.
   c. The net effect of the dairy contraction will be a noticeable decline in aggregate N & P production associated with cattle by 2032.
3. Horse numbers are difficult to count. We believe that the Maryland horse inventory is much larger than that reported in the Census of Agriculture or in MDA's AIR data.
   a. We relied on survey estimates of horse inventories from the Maryland Equine Council.
   b. Consequently, we estimate much larger production of N and P than would be implied by the USDA and MDA inventory estimates.
   c. Because of limited historic data, projections of horse populations are quite uncertain.
4. We do not project substantial increases in hog, sheep, goat, or turkey populations over the next decade, and their current populations are small enough as to account for very small shares of state-wide N and P estimates.
5. Future AWTF decisions should incorporate technologies that address the manure coming from the highest projected N and P generation for 2032, which is broilers (48.9 and 61.6%, respectively) followed by milk cows (13.2 and 9.3%, respectively), other cattle (11.1 and 8.6%, respectively), and horses (10.6 and 5.3%, respectively).

***Topic 2b. Identification of major policy drivers that may affect growth trends in animal waste within Maryland.***

**Topic 2b Summary:**

Maryland's agricultural landscape reflects national trends and related policy, including:

- *Clean Energy Goals:* Many states and municipalities have GHG emission reduction plans around electrifying and upgrading heating and cooling, with "clean energy" often associated with electric-based energy. This has led to a boom in solar energy, but less forethought and emphasis on animal waste technologies for renewable electricity.
- *Circular Economics:* With minimizing land mass and farm concentration, farms have begun using animal waste technologies to close their economic loops and gain revenue.
- *Global Trade Impacts:* Fertilizer prices have risen in the 2020s, aided by the ongoing war in Ukraine, resulting in increased interest in using animal waste as an organic fertilizer. Poultry litter in Maryland is a widely accepted and desired commodity.
- *Agricultural Sector GHG Contribution:* Different sectors have been identified to meet climate change goals, with agriculture often lumped as one sector and only a few states showing the possibility for certain animal waste technologies to be used to meet goals.
- *Strict Nutrient Management:* Due to specific Chesapeake Bay restoration and protection programs, Maryland is one of the few states that require intense vigor and regulation of nutrient management plans, which has affected DAF application and animal production.

*It is important to note that the national Justice40 initiative to support underserved and disadvantaged communities is a driver across all aspects of policy in the current political environment, but it is not specifically directed to animal waste growth trends (see Topic 2f).

**Topic 2b Materials and Methods**:

This analysis included analyzing drivers and trends in animal waste, with the results analyzed using sensitivity analyses and creations of scenarios to understand the effect of policy trends and other drivers on overall animal waste and food waste volumes. Interviews with Maryland industry groups, state officials, and researchers were used to understand animal trends, funding opportunities, and future initiatives that could impact manure, other animal waste, and food waste quantity/utilization in on-farm applications.

Ground-truthing sessions were conducted with detailed follow-up discussions and interviews with a variety of individuals in different interest groups to understand current trends. Drivers that could affect the growth trends in animal within in Maryland analyzed include the phosphorus management tool (PMT), nutrient management plans (NMPs), MDA's Watershed Implementation Plan (WIP), MD litter transport program, renewable energy policies, food waste policies, MD climate change goals, and changes in permitting and regulation.

Analyses also included results from surveys conducted at 17 of the University of Maryland Extension meetings, which included 246 respondents located in every county in Maryland (except Baltimore City). The survey results are shown in Appendix C. Survey questions included trends in agriculture from personal circumstances, market forces, right to farm issues, use of manure, and cost of fertilizer, as well as understanding and willingness to adopt advanced manure technologies.

Comparative research on other states was conducted to assist with predicting trend patterns and create scenarios that could be adopted in Maryland. The comparison states included California (for its ambitious regulations, complex energy incentives, and large dairy cattle operations), Michigan (for its advancement in anaerobic digester technologies and research), North Carolina (for exploration of its integrator relationship in the swine and poultry industry), Pennsylvania (for its proximity and shared WIP goals of Maryland), and Vermont (for its Universal Recycling Law and efforts to divert organic waste from landfills).

The 2023 Maryland Legislative session was tracked, with bills of note shown in Appendix D. The bills were tracked for several criteria, including those that directly affect animal waste technologies, specific animal waste technologies, haulers and transportation farming practices, renewable energy standards, underserved and highly impacted communities (in relation to agriculture and the environment), the economic value of certain agricultural products, or Maryland's goals toward climate change. The following keywords were used to search MD House and Senate bills weekly: 'agriculture,' 'anaerobic digestion,' 'animal,' 'animal waste,' 'climate change,' 'compost,' 'environment,' 'farm,' 'food,' 'food waste,' 'net-metering,' 'solid waste,' 'soil amendments,' and 'waste.'

**Topic 2b Results:**

California

According to California Department of Food and Agriculture's (CDFA) 2021 crop year, the top agricultural commodity of the state was dairy products, milk with 1,725,00 heads of cattle dedicated to dairy and milk as of January 2023 (California, n.d.; USDA/NASS, 2022). In 2006, AB 32: 'Global Warming Solutions Act' was passed in CA to reduce greenhouse gas emissions to the 1990 levels by 2020, which was achieved early in 2016. This act was modified to have a goal for a sustainable market for plug-in and zero-emission vehicles by 2025, reduce greenhouse gas levels to 40% below 1990 levels by 2030, creating energy-efficient state-owned buildings, and to have the state be carbon neutral by 2045 (AB 32, 2018).

As a result of these extensive efforts to achieve these state goals, the CDFA developed two animal waste technology funds. The Dairy Digester Research & Development Program (DDRDP) is dedicated solely to anaerobic digestion, while the Alternative Manure Management Program (AAMP) is dedicated to alternative technologies (CDFA, n.d.; CDFA, n.d.-a). The AAMP fund has recently used some of the overall fund to pay for the employment of Technical Assistance Providers (TAP), composed of a mix of experts from academia and industry that assist applicants in the application process by explaining the possibility of a proposed project's success and assist in repreparing and submitting the grant application. The TAPs are not allowed to provide vendor recommendations. This process has allowed applicants, specifically farmers, to fully plan out their budget, project implementation, and short- and long-term success while increasing the application pool applying for the fund. The DDRDP grant requires public comments on the location of these projects in the application. More information on the DDRDP application process is discussed in Topic 4 and Appendix E.

It has been stated that building a digester to obtain energy credits available through California's Low Carbon Fuel Standard (LCFS) combined with US Renewable Fuel Standard adds 50% to the value of milk produced (Abbott, 2022). California is the only US state to have a methane law that requires 40% reduction of methane ($CH_4$) by agriculture and other sectors by 2030. Through funding and state support, CA dairies have already achieved 30% of the total 40% reduction goal (equivalent to 12% of the total state methane reduction) through covering lagoons and building digesters. The thriving LCFS market in CA has been attributed to initial incentive (i.e., 'carrot') policies and ample funding, with regulations (i.e., 'stick') for farms not in compliance not beginning until 2024 (Lessons, 2023). In June 2023, there was public outcry to halt SB1383 on California food waste diversion due to the lack of organic recycling centers and adequate transportation services. It was highlighted that it can take six years for an anaerobic digester to acquire permitting (Sternfield, 2023).

Maryland does not have a state-based LCFS incentives, which provides incentives for biogas upgrading to renewable natural gas to >99% $CH_4$. Maryland does have a net metering policy for biogas or syngas (gasification/pyrolysis) to electricity but the policy only allows 200% net-metering due to its intent as a solar regulation and desire to maintain grid stability. Anaerobic digestion or pyrolysis/gasification do not have grid stability issues that arise with solar or wind, as these processes can produce electricity 24 hours a day, 7 days a week, and the produced gas can be held in holding vessels for use when the need is higher, which increases grid stability.

Michigan

Interviews with experts in Michigan stated that population changes across the state has resulted in a consolidation of the state's medium- and large-sized dairy farms, with the average dairy farm acreage increasing from 205 to 211 acres from 2012 to 2021. Overall, the total number of farms has decreased, and the remaining farms continue to consolidate Census of Agriculture, 2017; NASS, 2022). Michigan's "Right to Farm " law protects individual farmers and has resulted in greater adoption of on-farm digesters, as opposed by industry-owned digesters (Michigan Right to Farm Act, 1981).

Maryland has also seen an increase in head dairy cattle per farm (see Topic 2a). Maryland has also seen an increase in head dairy cattle per farm (see Topic 2a). Unlike Michigan, Maryland has varied, county-by-county "Right to Farm" laws. Michigan's growth in farm-owned digesters would only be applied to counties with matching policies, and trends in dairy cow populations, which are concentrated in the central and western part of the state.

North Carolina

In 2021, North Carolina's top two livestock commodities were broilers with 971,400,000 head and turkeys with 30,000,000 heads, reflecting Maryland's Eastern Shore's demographic with concentrated areas of broiler chickens. In addition, North Carolina is included in the top five states in hogs, with an estimated 8,000,000 heads raised annually. North Carolina also has experienced salt- water intrusion and loss of cropland, similar to Maryland's lower eastern shore (Edwards, 2018). Several hurricanes (Floyd, Matthew, and Florence) caused extensive damage to the state's crops and livestock operations resulting in billions of dollars of lost income and environmental emergencies. The flooding of hog waste lagoons during Hurricane Floyd created catastrophic conditions causing manure to contaminate local waterways and drinking sources (Davis & Davis, 2023.). Currently, any new or expanding swine farm must meet five performance standards detailed in the North Carolina Administrative Code, 15A NCAC 02T .1307-.1308 and 15A NCAC 02D .1808 (NC DEQ, n.d.).

Following Hurricane Floyd, the Smithfield Agreement by the Attorney General of North Carolina, Smithfield Foods, Inc. and five subsidiaries (Smithfield-Agreement, 2019) recognized that the current anaerobic lagoon and spray field system for swine waste management was acceptable for swine waste management, but the public interest would be better served by the implementation of environmentally superior swine waste management technologies, such as anaerobic digestion. The agreement outlined five actions and committed $15 million for the development of 'Environmentally Superior Technologies' for managing swine waste, installing these technologies on each Company-owned Farm in North Carolina, and providing financial and technical assistance to Contract Farmers for installing these technologies. Another $50 million was committed to environmental enhancement activities.

North Carolina's Clean Energy Plan of 2019 (North Carolina Department of Environmental Quality State Energy Office, 2019) pledges to reduce their greenhouse gas emissions by 40% by 2025. A year later, a commission-led report stated that the state should adopt a 70% reduction goal from 2005 and carbon neutrality by 2050. This legislation is in addition to the 2007 Renewable Energy and Energy Efficiency Portfolio Standard (REPS) requiring 12.5% of NC electricity sales through renewable energy sources by 2021, with the use of swine and poultry manure for renewable energy specified within the legislation. From 2018 onward, at least 0.2% of the total electric power sold to retail electric customers must be supplied by swine waste, and from 2014 onward, at least 900,000 MWh must be from poultry waste combined with wood shavings, straw, rice hulls, or other bedding material (Clean Energy Plan, 2007). As a result of this requirement, several poultry and swine companies have been engaged in implementing waste to energy technologies. Perdue Farms and GreenGasUSA is capturing methane from Perdue's onsite wastewater treatment facility and converting it to renewable natural gas (RNG). Smithfield Foods and Dominion Energy created AlignRNG and developed projects to capture methane from Smithfield's swine farms and convert it to RNG (Perdue, n.d.; Align RNG, n.d.). A new project is digesting swine waste from 19 farms in two counties, which is estimated to reduce 142,000 metric tons of $CO_2$. However, this project has received negative comments from the local communities concerned about the health impacts and transparency of the process (Observer, 2021). Equivalent issues arose in the Delmarva with poultry litter digestion (see Topic 2f).

Furthermore, North Carolina is considered the "birthplace" of environmental justice (EJ). Back in 1982, Warren County residents experienced environmental and public health disparities when the utility nearby was disposing of its toxic waste in the surrounding fields and farmlands (Atwater & Atwater, 2022). As environmental justice has grown and developed into a complex movement (see Topic 2f), North Carolina's rich history and similar agricultural integrator abundance can be used to mirror against Maryland. In North Carolina, swine and poultry have the most abundant and often seen operated as concentrated animal feeding operations (CAFOs). Most EJ conversations revolve around the swine industry specifically, and their relationship with animal waste technologies that create biogas. There are many activist groups (Waterkeepers Carolina, 2021) and research articles (Nicole, 2013) that highlight the odor and air pollution concerns from the operations themselves and the potential leaks from the digesters as well. However, there are often layers of misinformation to the problem, as these technologies are quite often described improperly and without the correct scientific and chemical analyses.

Emulating North Carolina's state mandate of a discrete amount of electricity to be created from animal waste could streamline the adoption of these technologies and increase the number and types of applicants to Maryland's AWTF. Net-metering electricity protocols are a barrier to Maryland to mimic the high quantities of renewable energy seen in North Carolina, with a lower financial return from electricity-based waste technologies compared to digesters that produce RNG and obtain associated federal renewable fuel standards and higher rates of returns. In Topic 2c, analysis from the MDE Climate Pathways Report indicate similar industry-specific contributions in Maryland to North Carolina's initiatives (i.e., better effort to show how agriculture could contribute to climate change goals) could enable Maryland to be more resilient with their manure management, reduce GHG emissions, and produce energy. Additionally, Maryland can take away the importance of community engagement and education in the funding/application to help the public discern safe versus hazardous practices in their communities.

Pennsylvania

Pennsylvania's Watershed Implementation Plan (WIPs) output has shown the importance of having an education component and certificate program to aid in commitment and longevity of the program (Meinen, 2020). The 2022 report examined how vertical integration of the swine and poultry industry has affected nutrient allocation and has led to integrators choosing future farm sites based on the soil's nutrient needs. This report details nutrient "sinks" (areas low in nutrients that can take volumes of phosphorus and/or nitrogen) and nutrient "sources" (areas high in nutrients that need to move high volumes of phosphorus and/or nitrogen) and used this analysis to suggest locations to place feeding/future farms in nutrient sinks areas, and created manure shed lines when creating their WIPs goals instead of county lines (Meinen, 2022). Interviews with PA experts indicated that this holistic view enabled them to address feed, crop, and conservation best management practices on a larger scale. As one individual noted, *"I think that a good step would just be watershed wide cooperation. More reciprocity between the States…Why do our agencies stop at the Mason-Dixon line?"* Interviewees stated that nutrient management was a key factor for integrators in determining future farming sites. Maryland integrators could adopt their approach of selecting future farm sites by nutrient requirements and alleviating the need to rely on hauling and brokering systems for litter and manure. This application of advanced waste technologies in manure-dense areas and according to manure shed lines could be a criteria for future AWTF funding in Maryland.

In 2005, the PA Phosphorus Index (Agriculture, n.d.) allowed individuals to still apply nutrients and amendments year-round but have limitations when in proximity to moving bodies of water. In PA, there is not a similar winter spreading timeline to Maryland's (December 16th to March 1$^{st}$), which has caused an increased movement of DAF from Virginia, through Maryland, to Pennsylvania. Some DAF does stop in Maryland to be stored, but the sporadic stops and unclear final destinations of DAF make tracking DAF difficult, as detailed in Topics 1c and 1e. The NPK ratio of DAF (17.5:6.39:1) initially indicates that DAF would be a good source of nutrients for fields, however the N is mostly organic N and may take time to degrade into inorganic forms. Additionally, the high P concentration (18.6 ± 1.4 lbs/1000 gallons) makes it challenging to apply in Maryland due to the state's PMT and overall structure nutrient management planning. There is a higher volume of storage capacity needed to apply DAF in MD due to winter spreading limitations and manure incorporation requirements, which makes DAF use in PA more advantageous due to the year-round application opportunities matching the year-round production of DAF.

Vermont

Vermont's 2020 Universal Recycling Law –which banned food waste in landfills– has been cited both as a source for the success in new digester implementation and a reason for closures due to delayed phase out of waste hauling systems and competing with large regional operations (Vermont, n.d.; Gribkoff, 2019). A community digester at Vermont Tech built in 2014 had the capability to receive 16,000 gallons of manure and organic residuals to produce 8,880 kWh/day, with waste heat used for heating campus buildings, bedding material for the college dairy herds, and recycled nutrients as crop fertilizer (Hall & O'Leary, 2016). Yet, a six month gap from lack of available trucks resulted in insufficient feedstock to the community digester (Gribkoff, 2019). However, there have been successes in on-farm digesters in VT (Rouleau, 2023).

Comparing this law to Maryland's CH0439/HB0264 "Solid Waste Management - Organics Recycling and Waste Diversion – Food Residuals" indicates a similar trajectory (MD House of Delegates, 2021). A delayed implementation rollout was seen with an update to the MDE website six months after the law's start date of January 2023. Many of MD dairies are in prime locations to be organic waste acceptors, according to the information from the MDE maps. Maryland could help digester secure consistent feedstock quantities from the start, as a learning experience from Vermont's community digester experience, and ensure food diversion success.

Maryland-Specific Drivers and Relevant Legislation

Most stakeholders surveyed or interviewed noted that there is not a "silver bullet" to solve the management of manure in Maryland. The following quote summarizes this sentiment:

- "*I guess the first thing I would say is that anything that deals with managing land is very complicated. And that there's no silver bullet. There's always cause and effect. And what we try to do is we look at what are the positives versus negatives and kind of put them on the ledger and make our decision making based on are there more positives and negatives*."

The recent committee hearings of the 2023 House Bill 087 and the Senate Bill 0447, "Anaerobic Digestion Workgroup", saw this type of technology as *"dirty energy"* and should not be classified as *"clean energy"* or *"renewable energy"*, as it could considered *"greenwashing."* As this report has explored across Topic 1 analysis of GIS maps of nutrients and heads of animals, and life cycle assessments in Topic 2d, animal waste technologies can be used to transform nutrients, generate electricity, and create RNG. The senate-version of the bill stated animal waste technology - specifically anaerobic digestion - is an *"untapped renewable energy source in Maryland"* (MD Committees, 2023). This pushback and general lack of bills dedicated towards education and outreach indicate a disconnect between the general public and agricultural practices that alleviate environmental concerns.

The "Climate Solutions Now Act of 2022" law establishes explicit climate change goals for greenhouse gas emission reductions, electrifying infrastructure, creating energy standards for municipalities, and adopting zero-emission practices" (MD House of Delegates, 2022), with new 2023 legislation proposed to extend and expand the scope of climate solutions. Interviews from industry experts and advocates noted that new MD legislators are *"a very progressive group."*

However, there was recognition that *"we're going to have some bad budget years coming up. I think they thought they were going to have a lot of money. And now reality sets in. So, we're going to see a pretty tight squeeze next year."* This is true nationwide after the Inflation Reduction Act (IRA) funds are fully utilized without additional funds provided, which has led to inconsistent funding flows and more scrutinized state budgets. Not to mention the overall concern of lack of technical expertise to fully tap into IRA funding for overlapping and specialized grant opportunities. Many of these related grants have late 2023 deadlines for application leading to possible missed opportunities.

According to https://legiscan.com/MD, 2284 bills were introduced to the legislative session, with 45 specific bills (Appendix D) relevant to the AWTF (2% of the legislative session). Only 20 of these relevant 45 bills introduced were approved by the Governor (Appendix D), with 15% under the jurisdiction of MDA, 35% under MDE, 5% under MEA, and 45% under the jurisdiction of various other agencies (Figure 2b.1). This indicates that in new policies, animal waste technologies are falling more under the role of MDE than MDA, with MDE's guide on permitting for anaerobic digester focused on wastewater treatment plants rather than agricultural facilities. MDA does not have a permitting guide for agricultural digesters.

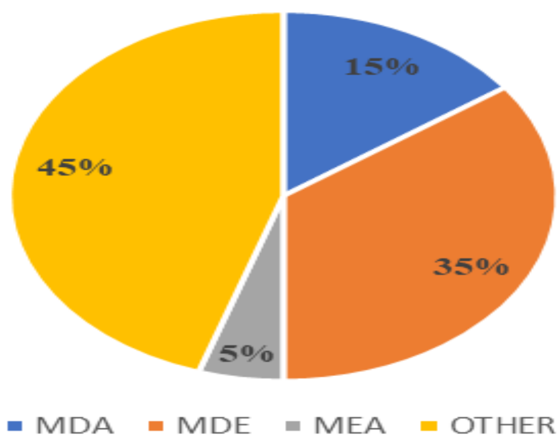


**Figure 2b.1:** Breakdown of the 20 bills in the 2023 Maryland Legislative Session bills relevant to the AWTF that were approved by the Governor, showing the state agency designed as the responsible agency.

The Net Metering Flexibility Act (Senate Bill 143, 2023) did not change the 200% net generation but allows individuals to enroll in net-metering indefinitely, be credited yearly for the average of the 12 month rate, set a community choice or electric supplier set rate, and created a pilot program for virtual net-metering set-up (Community Solar Energy Generating System Program). With this law, animal waste technologies have a better chance of being properly accommodating in net-metering, but it is up to the "eligible customer-generator," as defined in the law, to file the correct application for the program for the technology they are utilizing. Most utilities do not have an application for animal waste net-metering, and any changes in accreditation programs can only be approved by the electrical company.

The 2021 "Organics Recycling and Waste Diversion-Food Residuals" law (Organics Recycling and Waste Diversion-Food Residuals, 2021) requires certain waste generators (local school systems, supermarkets, and institutional cafeterias, but not restaurants) that generate two tons of food waste each week (by Jan 2023) and one ton of food waste per week (by Jan 2024) located within 30 miles of a composting or digestion facility to either reduce or divert food waste to food rescue organizations, farms for animal feed operations, compost, or anaerobically digest the residual. Interviewees mentioned the potential of the bill but noted a lack of understanding about execution of the legislation's requirements. MDE's updated website (as of June 2023) lists viable sites, possible haulers, and methods to reduce food waste. Anaerobic digestion and composting are second to last in priority, with food diversion and animal feed being prioritized (MDE, 2023). The bill does not detail the contracting process, how often the organic waste is diverted, who is covering the cost of transportation, who stores it when it cannot be processed, or set up matching for food generators and accepting facilities. In digestion and composting facilities, having a consistent feedstock and loading rate is important for the microbial process.

There are five counties (Allegany, Garret, Somerset, Wicomico, and Worcester) that are more than 30 miles away from a permitted composter or anaerobic digester according to the MDE's "Organic Waste Recyclers" screening tool (Organic Waste Recyclers, 2023), yet have high concentrations of dairy and poultry operations (Figure 1a.2 and 1a.3 respectively). There is also the implied responsibility on the food waste creator to reach out to the local soil conservation districts for proper implementation of food waste going to feed animals or be composted or digested, but it is unclear if there has been any training at local soil conservation districts on these technology and how to help entities with this task.

Outside the updates to the 2021 Organics Recycling and Waste Diversion-Food Residuals implementation, food waste and food resilience of the local systems is a high priority for the state. The Maryland Food System Resiliency Council (CH0573 / CH0574) was officially created this session under the Office of Resilience in the Maryland Department of Emergency Management. This council can aid in the gaps of research, communication, and be a place to advocate certain legislative actions to be seen as its various roles with municipalities, residential, agricultural, and food processing. Additionally, many state agencies, like MDA and MDE, reside on the Council and could offer two-way insight between the needs of food resiliency, and the ability to incorporate animal waste with food waste. Food waste is not limited to residential food, even though that is the number one contributor according to a recent EPA webinar (EPA et al., 2023). Food waste can include feedstocks from animals, edible and inedible food parts, and wastes/byproducts of food processing plants (such as DAF explicitly mentioned in Topic 1c). To further emphasize the relationship between food waste and animal waste technologies that is often oversighted, the EPA states that in 2019, 42.6% of the 40 million tons of food waste created by the food and beverage processing and manufacturing sectors was anaerobically digested. Comparatively, the other 60 million tons of food waste from the other major sectors (food retailers, providers, and the residential) went majorly to landfills (60%) (US EPA, 2023). It can be inferred then that animal waste technologies utilizations could be due to integrators' involvement with all aspects of growing and processing, and overseeing the end product such as DAF to be handled under their authority. Which means, loosely, agriculture has a better handle on ways to incorporate food waste into common recycling practices than other sectors and often uses these technologies to keep food waste out of landfills.

Maryland has 17 small-scale slaughter and processing specific plants across the state (University of Maryland Extension, 2021). Those locations can be cross-referenced with areas of interest for animal waste technologies, especially those in need of consistent feedstock to maximize the efforts of food waste diversion while also meeting the state mandates of no land application of DAF. This point can be further emphasized with the reference of Maryland permitting practices (specifically those of MDE) in the Zero Food Waste Coalition's 2023 report (M. Broad Leib et al., 2023). The report highlights the separate composting permit MDE has on source-separated waste, allowing an expedited way for composting facilities to be built in comparison to the rest of the country. The report notes that zoning, vague/umbrella permitting, and operation size/exemptions as the top barriers when creating food waste recycling methods to offset dumping to landfills. Maryland could take another step forward, and work on animal waste specific permits, especially with anaerobic digesters, to distinguish their unique role from waste treatment plants (as they are currently lumped in with permitting).

As seen in the survey results, regulation was the number one concern or barrier regarding future animal waste usage (Figure 2b.2).

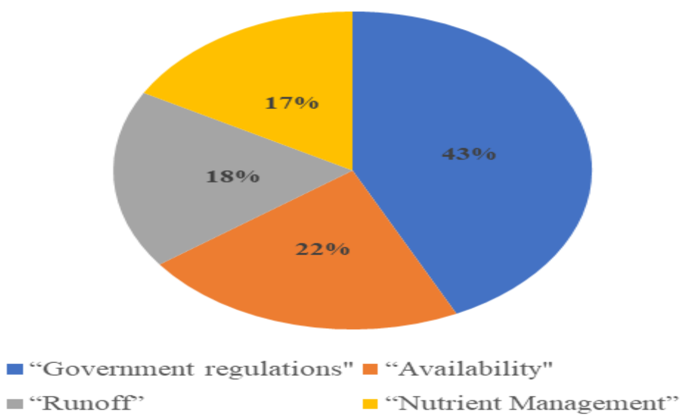


**Figure 2b.2:** Survey results from the question "What are the primary concerns or barriers for farmers to use manure, poultry litter, or other animal waste products on fields?" from 77 respondents.

Industry experts recognized the need to consistently look at new technologies and avenues to improve their industry both economically and environmentally. Yet, experts shared a concern about the number of regulations imposed in the state and uncertainty regarding the impact of future regulations on the ag industry's economy.

- *"I think unchecked regulation without justification and without reassurance that you're not manipulating the free-market system can really have an unintended negative consequence on the industry. . ."*
- *"I think there's going to be a big opportunity to educate folks …Farmers are the first environmentalists. There's no incentive for farmers or for agriculture as an industry to do anything but what's the best and most sustainable. Now, it's going to come at a cost and trying to figure out if that cost makes sense and if it's viable economically and sustainable economically to take whatever approach it is we're working towards. But I think with these new technologies …with kind of the right focus, the right education, we could really kind of change the narrative of what those waste streams mean and what they can do."*

Another concern for farmers and industry leaders was the use of biosolids on fields and potential presence of polyfluoroalkyl substances (PFAS), which are permanent microplastics.

- *“So, we have a lot of interest in using biosolids as an alternative. But guess what we learned: solids contain PFAS. Forever chemicals. So now that creates challenges, because now people are concerned, well, we got to stop using biosolids for agricultural land because of PFAS.”*
- *“Food waste and biosolids. I would say, I see that [usage] decreasing as a result of concerns around PFAS contamination. So I know that over the last, probably eight months or so, we started to see some concerns, specifically around biosolids.”*
- *“Biosolids. I would say definitely. The PFAS contamination is a concern with the continued use of that because ultimately the risk and liability. If your farm ends up being contaminated with PFAS, it falls on the farmer and not the biosolids, the wastewater treatment plan, or wherever those biosolids are coming from.”*

**Topic 2b Key Findings and Recommendations:**

1. Stakeholders agree there is no ‘silver bullet’/specific alternative waste technology solution.
2. 2% of the 2023 MD legislative session was related to animal waste technologies, with MDE and MDA responsible for implementing 35% and 15%, respectively, of the passed laws.
3. Maryland legislation is heavy on food waste diversion and electrification, both of which can aid animal waste technologies’ adoption but neither explicitly mentions animal waste.
4. There are concerns from stakeholders about an increase in regulation, while noting there is still a lack of education for the multiple parties involved.
5. The California program has technical experts to help applicants in their application process.
6. Michigan has a “Right to Farm” law that supports farmers over third-party vendors when it comes to animal waste technology investment and ownership.
7. North Carolina has specific electricity goals from manure sources, with an alternative technology program funded from a settlement due to Hurricane Floyd manure overflows.
8. Pennsylvania situates their WIP goals using a manure shed nutrient management approach that drives site selection based on reducing transportation and soil nutrient overloads.
9. Vermont’s has had digesters close prematurely due to the delay of hauler rollout for the Universal Recycling Law and food waste diversion efforts.
10. The lack of widespread adoption and maintenance of animal waste technologies in Maryland is likely due to lack of specific regulation and governmental support directed towards animal waste and a lack of educational guides geared to the agricultural community to aid applicants in determining the best technology for their operations.
11. MDA should work more closely with other government agencies, such as MDE and MEA, to create unity in the process of permitting, energy rebates, and tax credits, and creating a regional approach to funding waste technologies that includes out-of-state impacts.

***Topic 2c. An evaluation of state and national climate change goals and how animal waste technologies are considered in mitigating greenhouse gas emissions.***

**Topic 2c Summary:**

Maryland's climate change goals are aligned with federal goals and goals in many other US states. Animal waste technology implementation aligns with efforts to mitigate GHG emissions (Topic 2d), but widespread adoption has been minimal in MD and in most parts of the US due to the following trends/drivers:

- *Animal Populations:* Regional concentrations of specific species have resulted in higher concentrations of animals on farms. Larger farms have the capital and large feedstocks to use these technologies for renewable energy generation and mitigating GHG emissions, but the time to deployment and lack of incentives in Maryland have limited implementation.
- *'Clean' Energy Goals:* Maryland's emission reduction plan is 60% below 2006 levels by 2031, which is more ambitious than the federal goal of 50-52% reduction to 2005 levels by 2030. In Maryland, 'clean' has become synonymous with electric-based energy, leading to a boom in solar energy but less emphasis on waste technologies for renewable electricity.
- *Circular Economics:* Farmers have begun using animal waste technologies to close their economic loops and gain revenue. Federal credits for RNG have the largest return on investment, which reduces electric production investment, which is a state-specific policy.
- *Justice40 Efforts:* Federal IRA funds prioritized the efforts of the national Justice40 initiative, including disadvantaged and underserved communities and indigenous populations, who may need additional capital to incentive animal waste technologies.
- *Strict Nutrient Management:* Maryland is one of the few states that require rigorous nutrient management with the PMT, which has resulted in increased transportation of animal waste. With an increased move to electrify vehicles, there is also a GHG emissions impact from the movement of nutrients across 'sources' and 'sinks' across the state.

**Topic 2c Materials and Methods**:

This analysis includes analyzing drivers and trends in the US and Maryland for climate change goals to mitigate greenhouse gas emissions in relation to animal waste technologies. The results were analyzed using sensitivity analyses and scenarios to understand the effect of policy trends and other drivers on US climate change goals, state goals, and how animal waste technologies fit into these goals. Scenario-based trends and assessments with manure/waste technology adoption were conducted. The scenarios included how various adoption rates of manure/waste technology will reduce GHG emissions in Maryland. Additionally, policies utilized in other states were evaluated and compared then to Maryland policies.

Ground-truthing sessions and interviews were conducted with different interest groups to understand trends GHG policy, drivers that affect consideration of animal waste technologies to mitigate GHG emissions, the effect of the Inflation Reduction Act (IRA), federal natural gas (RNG) policies, EPA's consideration of biofuels, electricity, and biogas for Renewable Fuel Standard (RFS), market for Renewable Identification Number (RIN), and net-metering from electricity produced by animal waste technologies.

**Topic 2c Results:**

Federal and State Climate Change Efforts

The US and Maryland state goals are largely aligned. The federal goal is a 50-52% reduction to 2005 levels by 2030, with a focus on emission reduction, solar adoption, net-zero by 2050, and a socially conscious environmental justice effort through Justice40 (The White House, 2023a). Justice40's goal is that 40% of benefits of certain federal investments flow to disadvantaged communities that are marginalized, underserved, and overburdened by pollution (The White House, 2023b). There is heavy emphasis on pollution and air quality, resulting in emphasis on energy infrastructure and transportation. There is little explicitly on animal waste technologies in these discussions. What could impact possible future adoption of animal waste technologies from a federal basis is legislation that changes current agricultural practices. This could range from impact on the operating style of CAFOs to economic and environmental accountability (Justice for Black Farmers Act, 2023; Zero Food Waste Act; Farm System Reform Act, 2023; Industrial Agriculture Accountability Act, 2023). Other proposed legislation, such as the USDA Environmental Quality Incentives Program (EQIP) Improvement Act, which suggests modifications to cost-share programs and technical assistance for farm operations (EQIP, 2023).

In Maryland, climate change goals focus on emissions with a reduction plan of 60% below 2006 levels by 2031 and net-zero by 2045. The MD Climate Pathways Report by MDE and the UMD's Center for Global Sustainability cited electricity and transportation as the top two areas of interest due to the largest $CO_2$ emissions to be reduced. Agriculture was last of prioritized interest groups, with only a 3% reduction needed (from 6% of total contribution of emissions reduction to 9%) (MDE & UMD Center for Global Sustainability, 2023). The report highlights methane reduction and animal waste as the best mitigation strategies but does not explicitly state animal waste technologies. The 'Waste Management' section focuses on municipality and landfill waste. Agriculture is alluded to these waste management efforts in the section pertaining to Maryland's "Organic Recycling and Waste Diversion-Food Residuals" law that was just enacted. There were some key areas missing deep analysis for the agriculture sector of the report, especially in comparison to this report; animal numbers, manure and nutrient volumes, and land use/zoning. Granted, it is important to note that the Climate Pathways Report report looks more at policies and the behaviors of the average Maryland resident, who live in some form of municipalities and not farmland generally. This animal waste technologies report is a specialized report with different intentions and resources. Additionally, the Climate Pathways Report is currently taking feedback from various listening sessions to hone in on specific policy recommendations for the 2024 legislative session. If the two reports were combined together, a more holistic viewpoint on Maryland agriculture could be best interpreted for policymakers and the average Maryland resident.

Overall, Maryland's focus is on energy and transportation, without an initiative on how agriculture can play into both these sectors. Interview with government officials stated:

- *"But it's important to note that globally, there's been a shift in GHG assessment to treat agriculture, forestry, and land use as one full bucket or sector. Because of ag and forestry, they both can produce emissions, but they can also play important roles in helping."*
- *"You would expect that a lot of the [climate change goal] discussion is going to focus on those types of huge policy shifts that are really going… to move the needle in big sectors like*

*transportation and buildings and energy, electricity. But. I know we're going to need all good ideas because 60% [reduction] is a big number."*

Animal Waste & Renewable Energy

One realm that meets the needs of energy, transportation, and agriculture is the use of the biogas from digesters or syngas from gasification systems as an electricity source. Separate analyses were conducted based on the use of the biogas from digesters as renewable natural gas (RNG), syngas from gasification systems, and biogas for electricity, which have different associated policies (EPA, 2021). Analyses of policies affecting other products, such as the digestate, compost, or biochar, were conducted, but there are far less enacted policies in this area. There were more policies associated with anaerobic digestion, due to its more widespread use.

The EPA released new guidance on Renewable Fuel Standards (RFS) for digesters producing renewable natural gas (RNG) in December 2022 (EPA, 2022c; EPA, 2022d ), with the new standards released in June 2023 for 2023, 2024, and 2025. There were increases in D5 RINs and unchanged values for D4 RINs. Cellulosic biofuel showed the least expected growth compared to other biofuels (0.5 million RINs increase compared to 1.5-2.0 billion RINs increase), and there was a controversial non-addition of expected eRINs (Growth Energy, 2023).

Any RNG upgraded from biogas from anaerobic digestion of food waste or wastewater treatment plant sludge are considered D4 and D5 fuels, respectively, and estimated to have a 50% reduction in GHG emissions compared to conventional fuel production. Biogas from manure-based digesters, classified as D3 and D7 fuels, are considered cellulosic biofuels and are estimated to have a 60% reduction in GHG emissions. The feedstocks and the starch content of the original feedstock used in digestion affect the fuel rating. To qualify for the RFS program and receive a Renewable Identification Number (RIN), biogas produced through digestion must meet certain criteria, including being produced from renewable feedstocks, used to generate electricity or transportation fuel, and have reduced GHG emissions compared to fossil fuels. RINs can be bought and sold on the open market, allowing renewable fuel producers to sell their RINs to obligated parties, who must purchase RINs to demonstrate compliance with the RFS program. The RIN market was developed to provide incentives for the production and use of renewable fuels and reduce reliance on fossil fuels. There is a "101 for RINS" from the Biocycle Magazine that explains how these policies relate to digester operators and federal incentives (Greene, 2017). Estimated RINs can be calculated using the predicted biogas production from the waste feedstocks, with the conversion of biogas to RINs based on 77,000 BTUs being equivalent to one gallon of fuel, or 1 RIN (EPA, 2023b).

The RFS program is moving from an annual basis to a 3-year basis, increasing the market value time to create a more stable market. The complexity of this change is that if the EPA allows too many RINs, then the prices drop and investment is not attractive. If the EPA overestimates and makes the market too aggressive, then the volume targets for each of these sub-D classifications will decrease. Most lobbyists for biogas support the value increases but are frustrated with the lack of the eRIN crediting system, which would have allowed electricity produced from biomass systems for use in electric vehicle charging to be a viable marketplace for earning and trading/selling credits. Only 0.2% of the natural gas in the US is RNG, and experts don't think it will ever fully replace fossil fuels (Evans, 2023). Many advocacy and industry groups suggest at least a 20-30% minimum growth rate (Rosengren, 2023), yet, the EPA growth rates stayed in the low teens.

With the push to electrify utilities and transportation, entities are looking at creating electricity to sell as possible future eRIN credits. This separate classification would track electrons and prevent double counting of Renewable Energy Credits (RECs). A REC, also known as a green tag or renewable energy credit, is a tradable paper instrument that represents the right to the environmental, social, and other non-power attributes of one MWh of renewable electricity generation delivered to the grid (Renewable Energy World, 2022). Without eRINs, the focus for electricity is receiving REC credit, while RINs credits are received for RNG production.

Inflation Reduction Act (IRA) and Impact of Subsidies

For funding support of renewable energy projects, many look towards the IRA funding; yet, each state is utilizing IRA funding differently and entities may not be eligible for awards based on technicalities, qualifications, or timing of funding. The Environmental Policy Innovation Center stated: "the Congressional Budget Office estimates that USDA will not be able to spend all the [IRA] money. Where is the bottleneck? One answer is in what USDA calls 'Implementation Technical Assistance'" (Huntley, 2022). Additional paperwork and modifications to existing programs could further complicate the situation.

In February 2023, the EPA released the Greenhouse Gas Reduction Fund (US EPA, 2023), which will be divided into a $20 billion General and Low-Income Assistance Competition and a $7 billion Zero-Emission Technology Fund Competition. However, both competitions appear to focus on funding non-profits, which excludes most of the agriculture community, and there is no mention of animal waste technologies in the Zero-Emissions Technology Fund.

The IRA is expanding the Solar Investment Tax Credit program, which was supposed to end in 2022 but now is in effect until 2034. Similar to California's net-metering 3.0 program, there will be an expansion from the original investment tax credit (ITC) program, with a push to add solar rooftops with expanded battery capacity to 3 KWh, or 300% net-generation. In 2032, the tax credit decreases from 30% to 26% as a way to push individuals to commit to solar in the previous decade (2022-2032), dropping to 22% in 2034 to determine grid stability and finalizing battery capacities (Office of Energy Efficiency & Renewable Energy, 2022). This could benefit Maryland with a possible 300% net-generation limit from the current 200%, and would be both more appropriate and affordable for animal waste technologies in the state.

State funding has played a role in animal waste technologies nationwide. According to a recent report from UC Davis, the exploration of manure subsidies across the nation and the effects on dairy operations and the adoption and use of animal waste technologies, specifically anaerobic digestion, were studied. The report notes 70 of the roughly 90 new anaerobic digesters from 2019-2022 came from California. The report emphasized the effect of California's Low Carbon Fuel Standard (LCFS) on economic trends. It did mention that RNG production and methane reduction is a short-term profit, due to its dependency on the fossil fuel market prices as competition. The largest revenues come from the crediting systems, such as the LCFS, and not the value of GHG reductions, biogas sales, or soil amendment sales (Smith, 2023a; Smith, 2023b).

Maryland stakeholders support these observations on need for state support and RINs:

- "*That [the byproduct] doesn't pay the bills. The RECs, the renewable energy credits, is really where the value is. That's the only reason why the solar projects work is they have an SREC that is significantly higher than that we can get through a biomass REC. We're basically on the same market as the wind. So like SRECs are $80 to $100 MW, and we're at $5. So it's like it just won't pay.*"
- *"[Someone] needs the RECs to make it work, and they can't do it at a two megawatt facility. They have too much manure. They would need to go larger than 2 MW. And the net metering prevents them from doing that so that's another hiccup. That is why you couldn't really do any kind of larger regional piece because you would move into a different type of energy generation source than you become. A commercial utility if you did that, so you got to stay under 2 [MWH] to do net metering."*

Transportation and Nutrient Management

In Maryland, the passing of Senate Bill 0224 (Clean Trucks Act of 2023) could impact waste hauling and litter transportation, as these vehicles in the future will have to be zero-emissions vehicles (ZEVs) and have a way to power on-site outside of technologies that can only create electricity with net-metering. Having medium and heavy-duty ZEVs impacts agriculture communities significantly, as these are the core vehicles types used in farming operations. A charging station that can fast charge a class-8 truck will need a 1 MW capacity. A five fleet semi-truck charging station needing a 50 MW capacity; this is equivalent to a small power plant capability (Liao, 2023). Animal waste technologies that create electricity on-site could offset this massive electrical need.

The national and state level of adoption of ZEVs could become an impediment for agricultural practices. Transporting litter from the phosphorus dense Eastern Shore to the phosphorus depleted Western and Central Maryland is already constrained by transportation mileage, haulers options, crop growing season, and poultry house clean-out schedule. And as seen in Topic 2d, transportation minimizes the GHG reduction effects of animal waste technologies; thus a further inclination for people to adopt renewable energy sources for transportation. There is a high influx of litter movement February to September, as with no land application from December 16th to March 1st, yet, litter is produced year-round. While most farms would accept litter before planting season, with storage in sheds or pads built through NRCS cost share, adding the stressor of using ZEV could result in litter build-up on the Eastern Shore.

**Topic 2c Key Findings and Recommendations:**

1. Electrifying infrastructure and transportation is a large climate change goal, yet there is minimal language in the specification in these goals for agriculture.
2. Upgrading biogas to RNG is eligible for RIN credits due to the 60% reduction in GHG emissions and listing as a renewable fuel. Thus, there has been a large push to larger systems that upgrade to RNG due to these financial benefits; less financial benefits are given to electricity production from digestion and gasification and the eligible RECs.
3. Net-metering has a heavy focus on solar projects rather than animal waste technologies.
4. Zero emission vehicles (ZEV) are on the rise in state mandates of adoption, which could impact animal waste hauling of animal waste and farm operations in Maryland.

5. MDA through the AWTF should collaborate with MEA, MDE, or UMD Extension to create educational pathways to aid applicants in understanding electric net-metering or RNG potentials, including regulatory and environmental justice implications, grid connections, and/or pipeline infrastructure.
6. MDA through the AWTF should consider how proposed animal waste technologies will reduce transport-based GHG emissions due to the current use of large trucks to transport liter long distances.

***Topic 2d. Quantify the strengths and weaknesses of animal waste technologies to address climate change goals.***

**Topic 2d Summary**:
Anaerobic digestion consistently reduced GHG emissions compared to baseline manure lagoon storage. Composting of wet manure (dairy and swine) resulted in net GHG emissions due to only the solid fraction of the manure being compostable, while the liquid fraction was assumed to remain in storage untreated. The total GHG emissions between each type of facility analyzed varied according to the waste being treated (Figure 2d.1), with annual GHG emissions from all manure in MD (533,652 $MtCO_{2e}$) concentrated in Fredrick and Washington counties. These GHG emissions could be eliminated through use of anaerobic digestion (Figure 2d.2). Frederick County had 111,527 $MtCO_{2e}$ annual GHG emissions from animal manure, followed by Washington (107,336 $MtCO_{2e}$) and Carroll (59,032 $MtCO_{2e}$) counties.

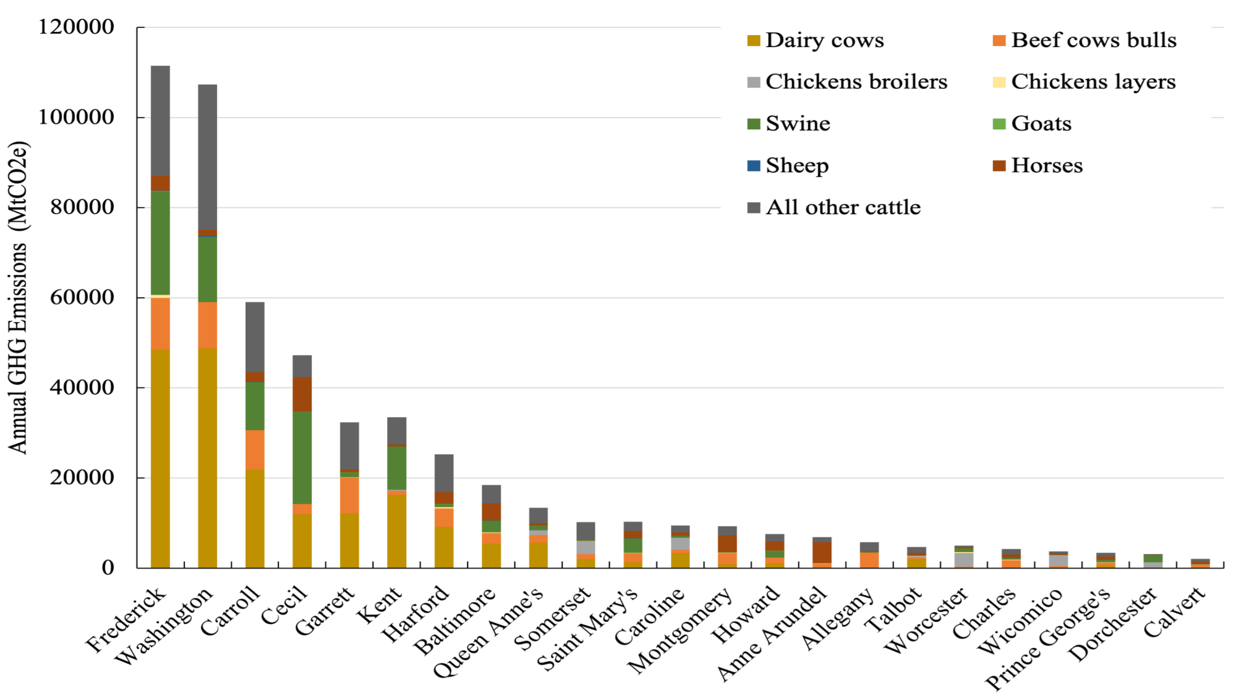


**Figure 2d.1:** Annual greenhouse gas emissions from different types of manure sources in MD. Dairy cattle were the primary contributors to the high GHG emissions in MD. In Frederick County,

GHG emissions from dairy cattle were 48,488 $MtCO_{2e}$ annually, followed by Washington (48,733 $MtCO_{2e}$) and Carroll (21,844 $MtCO_{2e}$) counties. By covering open manure lagoons, these GHG emissions could be eliminated. Additionally, sealed lagoons help in conserving water, reducing odors, and preventing the contamination of surrounding ecosystems.

All MD counties would achieve significant reductions in GHG emissions by implementing composting or anaerobic digestion (Table 2d.1). In Frederick County, composting all manure resources would reduce emissions by 75,421 $MtCO_2e$, which is a 67.6% decrease, while anaerobic digestion would decrease GHG emissions from all manure resources by 118,367 $MtCO_2e$, which is a 106% reduction (Figure 2b.2). Both composting and anaerobic digestion present substantial opportunities for GHG emission reductions. However, the ability of anaerobic digestion to achieve reductions exceeds 100% due to reductions of GHG emissions naturally occurring in open air lagoons combined with the ability to turn this captured biogas into renewable energy. Frederick County could provide 34,745 MWh of renewable electricity from anaerobic digestion of all manure resources in the county.

**Table 2d.1**: Expected annual GHG emissions and annual GHG emissions reduction from different feedstock with loading rate of one ton manure per day using EPA AD screening tool.

| | Annual GHG Emissions production MtCO$_{2e}$ | | | |
|---|---|---|---|---|
| | **Without compost or AD or Thermal conversion (baseline)** | **Compost only** | **Thermal conversion** | **AD only** |
| **Dairy manure** | 70.4 | 23.5 | - | -3.9 |
| **Other cattle** | 66 | 20 | - | -3.62 |
| **Broiler litter** | 13.8 | 1.7 | 0.1 | -14.6 |
| **Layer litter** | 12.6 | 1.6 | 0.1 | -13.3 |
| **Swine manure** | 154 | 51.2 | - | -8.58 |
| **Horses** | 85 | 31.8 | - | -4.71 |

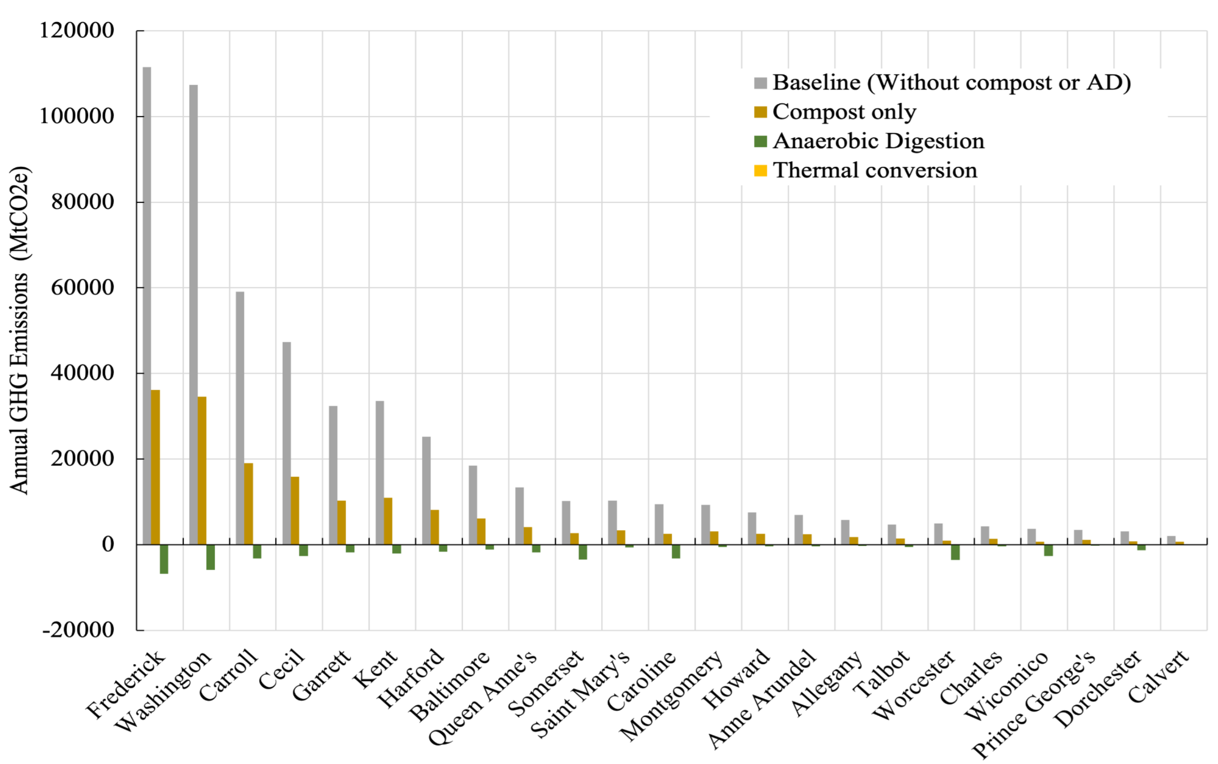


**Figure 2d.2:** Annual greenhouse gas emissions (MtCO$_{2e}$) from all manure types, calculated using daily manure generation data from Topic 1b. Scenarios tested included no animal waste technology utilized (baseline), composting, thermal conversion, and anaerobic digestion (AD) using all the manure resources available in that county for each animal waste technology adopted.

**<u>Topic 2d Methods:</u>**
Agriculture, forestry, and other land use is the second largest contributor to GHG emissions (24%) after fossil fuels (25%), as stated by the EPA (Global Greenhouse Gas Emissions Data | US EPA, 2023). Between 1961 and 2010, global livestock GHG emissions grew by 51%, driven by a 54% rise in methane and nitrous oxide emissions from manure (Nexus, 2019). The contribution to climate change from Maryland's animal waste was evaluated as well as the effects of animal waste technologies, such as anaerobic digestion, gasification, pyrolysis, manure injection, and composting to mitigate said contribution. Various life cycle assessment (LCA) tools were used to evaluate the carbon footprint and eutrophication potential (nutrients) of each animal waste technology under different scenarios.

<u>Assessment of Greenhouse Gas (GHG) Emissions</u>
The procedure for assessing the GHG emissions from a waste is described in Figure 2b.3, including data acquisition to build the models, chemical characteristics of the waste (nutrients, solids, organics), expected GHG emissions from generation, storage, and transport of the waste, and the rate of waste generation. In the LCA analyses for each animal waste technology, four modeling programs were compared: Simapro, the EPA Anaerobic Digestion (AD) tool, the Alternative Manure Management Program (AMMP) tool, and the Dairy Digester Research and Development Program (DDRDP) tool. Further information on utilization of each tool can be found in Appendix B, with a summary of methods below.

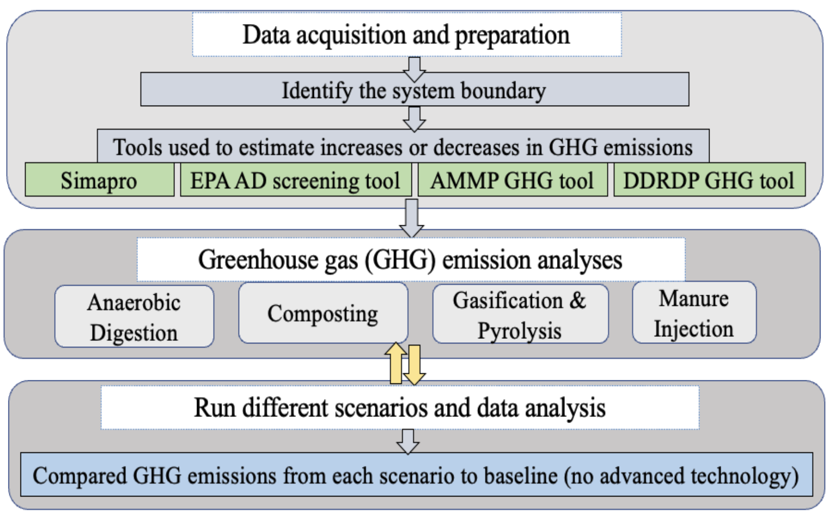


**Figure 2d.3:** Assessing GHG emissions of waste technologies using life cycle assessment (LCA) tools: Simapro, the EPA anaerobic digestion (AD), the alternative manure management program (AMMP), and the dairy digester research and development program (DDRDP).

Simapro was used to analyze data from a 12-month study of a dairy manure, DAF, and food processing waste digester in Cecil County (detailed in Appendix B). The EPA AgSTAR AD Screening Tool was used to assess GHG emissions from anaerobic digestion of six types of animal waste in Maryland: dairy manure, other cattle manure, broiler litter, layer litter, swine manure, and goats/sheep manure. Each proposed digester was assumed to process one ton of manure per day (i.e., equivalent to 22 dairy cows, 20,000 hens, or 262 swine). It should be noted that the EPA AgSTAR program does not distinguish between biogenic and fossil methane when calculating emissions from electricity production. To compensate, we supplemented the model output with manual calculations for this parameter to determine avoided emissions from generating electricity through biogenic methane. This GHG analysis was conducted twice to compare the data from two different scenarios: heating the digester (which is an ideal situation for maximizing energy production) and covering the lagoon without applying heat (unheated).

Emissions from composting animal waste were calculated to compare with anaerobic digestion. While specific tools do predict emissions from composting, such as the EPA Waste Reduction Model (WARM), they do not account for solids-liquids separation that occurs on farms prior to composting some types of animal waste, and thus, tend to underestimate emissions. The calculation of GHG emissions from composting dairy and swine manure were based on the reduction in solids from the liquid fraction after separation (13%, and 10% of the total solids, respectively), with the liquid being stored in an uncovered lagoon and contributing to emissions. The GHG emissions from the other animal waste types assumed composting of the whole manure, due to their lower moisture content relative to dairy and swine manure.

For the baseline scenario without anaerobic digestion, compost, or thermal conversion, it was assumed that dairy and swine manure were stored in uncovered lagoons, while poultry litter was stored as a solid substrate on a compost pad under a roof. The methane conversion factor in the EPA AD Screening tool for the average temperature in Maryland (18°C) for uncovered lagoons (swine and dairy manure) was 0.77 and 0.04 for solid storage (poultry litter).

California Department of Food and Agriculture Modeling Tools

Two tools developed by the California Department of Food and Agriculture were used to analyze GHG emissions from manure: the Alternative Manure Management Program (AMMP) and Dairy Digester Research and Development Program (DDRDP) GHG tools. The AAMP GHG tool calculates emissions for dairy manure applications, including solid separation, composting, and alternative manure treatment technologies. It estimates the GHG emission reductions associated with each practice and helps farmers select the most cost-effective options in terms of $ per GHG emission reduction. The user manual for the AMMP serves as a comprehensive resource for assessing the practicality of composting and solid separation systems for managing livestock manure, with detailed steps to conduct the analysis using the AMMP GHG tool in the manual. The inputs to the AMMP Benefits Calculator Tool include loading rates, number of animals, technology type, and baseline scenario (open storage), which are used to estimate GHG emission reductions from the proposed project.

The DDRDP GHG tool also assesses the GHG emissions from dairy manure, but this tool is specifically for emission reductions with the use of anaerobic digesters and helps farmers select the most cost-effective options in terms of dollar per GHG emission reduction. The manual provided the steps to conduct the analysis using the DDRDP GHG tool. To estimate a project's GHG emission reductions and co-benefits, a project boundary is identified, and inputs are defined (loading rate, number of animals in the farm, type of digestion system used, biogas used for RNG or electricity, and the baseline scenario).

The GHG emissions estimated by the DDRDP for digesters were compared with results from the EPA AD Screening Tool based on tonnage of manure processed. It should be noted that both the AMMP and DDRDP GHG tools were pre-programmed with temperature data from only CA counties, with no option to manually input data from other states. Merced County, CA was chosen to compare with MD scenarios, as this region is the closest match to Maryland's temperature patterns. These tools offer additional insights into the environmental impact of manure management systems, allowing for more effective decision-making in the design and implementation of such systems. There were no tools available to specifically model GHG emissions from pyrolysis/gasification, composting, or manure injection. Emissions from these studies were estimated from review of the literature, prior studies in our laboratory, or by manual calculation using a modified version of one of the previously discussed tools.

**Topic 2d Results:**

SimaPro Modeling of Greenhouse Gas Emissions from a MD Anaerobic Digestion System

A digester in MD that processed separated liquid dairy manure, DAF, and food processing waste, with dairy manure solids composted on-site was analyzed. The annual biogas production from the digester was 58 million ft$^3$, which produced 1,984 MWh/yr (using a 240 kW CHP system) of renewable electricity, which is significantly higher than the energy production from the unheated digester (past digester operation) of 770 MWh/yr. This is enough power for 190 homes in the US each year. The overall yearly reduction in $CO_2$ emissions compared to the baseline was 20,000 tons/year, which is equivalent to the yearly emissions from 4,000 vehicles.

The reductions in GHG emissions and other environmental impact factors included in the LCA output compared to the baseline are shown in Figure 2d.4 and Table 2d.2. Both the heated digester (current digester operation) and unheated digester (past digester operation) showed significant decreases (81% and 79%, respectively) in GHG emissions compared to baseline (open lagoon manure storage). The eutrophication impact category showed 448% and 411% decreases, respectively, and the acidification impact category showed 319% and 300% decreases, respectively, compared to the baseline scenario. There were decreases in smog and carcinogens, with increases in fossil fuel and ozone depletion due to the food waste transport.

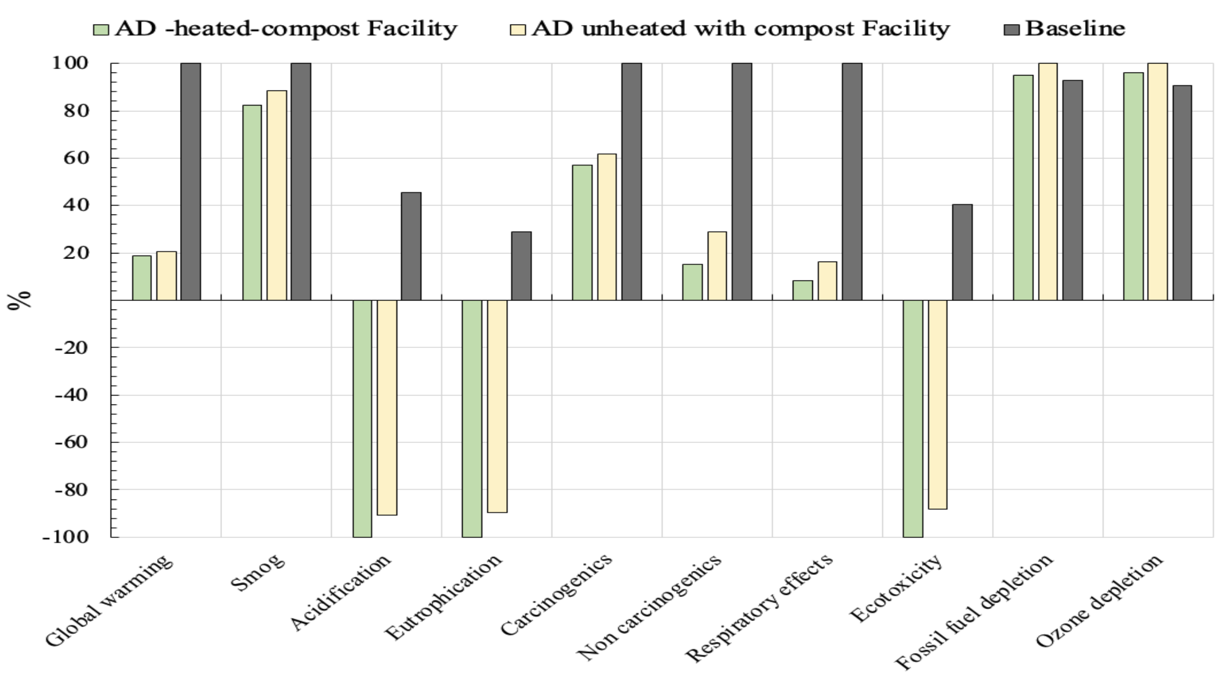


**Figure 2d.4**: Life cycle assessment (LCA) of 10 impact categories and three scenarios: heated digester with solids composting, unheated digester with solids composting, and baseline with no digester. The digester processed liquid dairy manure, DAF, and food processing waste.

**Table 2d.2**: Impact category reductions (quantity) for three scenarios (heated digester with solids composting, unheated digester with solids composting, and baseline with no digester), with a functional unit of one year.

| Impact Category | Unit | Scenarios | | | Annual GHG Emission Reductions | |
|---|---|---|---|---|---|---|
| | | Heated Digester | Unheated Digester | Baseline (No Digester) | Heated digester (compared to Baseline) | Unheated digester compared to Baseline |
| Global Warming | T $CO_2$ eq/year | 4,495 | 4,876 | 23,751 | 81% decrease | 79% decrease |
| Acidification | T $SO_2$ eq/year | -166 | -150 | 75 | 319% decrease | 300% decrease |
| Eutrophication | T N eq/year | -65 | -58 | 19 | 448% decrease | 411% decrease |

Greenhouse Gas Emission Models from EPA AgSTAR and CA Dept. of Agriculture Tools

Table 2d.3 presents GHG emissions and energy production of three types of livestock waste (dairy manure, poultry litter, and swine manure) using the EPA AgSTAR Digester Screening tool. The baseline analysis showed that swine manure had the highest annual GHG emissions (153.7 $MtCO_{2e}$), followed by dairy manure (70.4 $MtCO_{2e}$), and poultry litter (12.6 $MtCO_{2e}$). Adding a digester resulted in 100% GHG emissions reduction in unheated AD for dairy manure and swine manure, and a 102% reduction for poultry litter. The use of a heated anaerobic digester results in GHG emissions reductions ranging from 100% to >200%, depending on the type of waste. The data shows that adding a dairy digester with heating results in greater energy production (20 MWh of electricity and 3,081 $m^3$ of RNG annually), while a dairy digester without heating only produces 0.42 MWh of electricity and 64.1 $m^3$ of RNG annually.

**Table 2d.3**: Annual greenhouse gas (GHG) emissions, electricity, or renewable natural gas (RNG) production from one ton manure per day using the EPA AD Screening tool.

| | | Unit | Scenarios | | | Annual GHG emissions reductions | |
|---|---|---|---|---|---|---|---|
| | | | No digester (baseline) | Unheated digester | Heated digester | Heated digester (compared to Baseline) | Unheated digester compared to Baseline |
| Dairy manure | GHG emissions | $MtCO_2e$ | 70.4 | -0.08 | -3.9 | 100% | 106% |
| | Electricity | MWh | 0 | 0.42 | 20 | | |
| | RNG | $m^3$ | 0 | 64.1 | 3,081 | | |
| Poultry litter | GHG emissions | $MtCO_2e$ | 12.6 | -0.28 | -13.32 | 102% | 206% |
| | Electricity | MWh | 0 | 1.41 | 68 | | |
| | RNG | $m^3$ | 0 | 217 | 10447 | | |
| Swine manure | GHG emissions | $MtCO_2e$ | 154 | -0.18 | -8.58 | 100% | 106% |
| | Electricity | MWh | 0 | 0.91 | 43.7 | | |
| | RNG | $m^3$ | 0 | 140 | 6727 | | |

Table 2d.4 presents a scale up of the numbers presented in Table 2d.3, with estimated manure production, GHG emissions, and annual electricity and RNG production for farm sizes ranging from 100 - 600 animal units (AU) for dairy cows, poultry, and swine using the EPA AD Screening tool. As the number of AUs increases, the manure production and GHG emissions from uncovered systems (no digester) increase, and with a digester installed the GHG emission reductions are greater, as are the electricity and RNG outputs. Swine manure had the highest GHG emission reductions through digester installation, followed by dairy manure and poultry litter. These calculations are based on the inputs to the EPA AD Screening tool, with the default energy production values for swine manure at 275 L $CH_4$/kg volatile solids (VS), 148 L $CH_4$/kg VS for dairy manure, and 275 L $CH_4$/kg VS for poultry litter.

**Table 2d.4**: Expected annual project emissions and annual energy production via electricity Production or renewable natural gas (RNG) from different feedstocks for farm sizes ranging from 100 - 600 animal units (AU) using the EPA AD Screening tool.

| | | **100 AU** | **200 AU** | **400 AU** | **600 AU** |
|---|---|---|---|---|---|
| **Dairy manure** | Number of animals | 71.4 | 142.9 | 285.7 | 428.6 |
| | Manure production (ton/day) | 3.27 | 6.54 | 13.1 | 19.6 |
| | GHG emissions ($MtCO_{2e}$/year) | -12.8 | -25.5 | -51.0 | -76.6 |
| | Annual Electricity Production (MWh) | 65.4 | 131 | 262 | 393 |
| | Annual RNG Production ($m^3$) | 10,082 | 20,164 | 40,328 | 60,493 |
| **Poultry litter** | Number of animals | 13,514 | 27,027 | 54,054 | 81,081 |
| | Manure production (ton) | 0.67 | 1.35 | 2.70 | 4.05 |
| | GHG emissions ($MtCO_{2e}$) | -8.98 | -18.0 | -35.9 | -53.9 |
| | Annual Electricity Production (MWh) | 45.8 | 91.7 | 183 | 275 |
| | Annual RNG Production ($m^3$) | 7,044 | 14,088 | 28,176 | 42,264 |
| **Swine manure** | Number of animals | 1,818 | 3,636 | 7,273 | 10,909 |
| | Manure production (ton) | 6.93 | 13.9 | 27.7 | 41.6 |
| | GHG emissions ($MtCO_{2e}$) | -59.4 | -119 | -238 | -357 |
| | Annual Electricity Production (MWh) | 303 | 605 | 1,211 | 1,816 |
| | Annual RNG Production ($m^3$) | 46,602 | 93,204 | 186,408 | 279,611 |

The amount of manure produced by each type of animal varies, with 100 dairy cow AUs producing 3.27 tons of manure per day, 100 poultry AUs producing only 0.67 tons of manure per day, and 100 swine AU producing 6.93 tons of manure per day. At 400 AUs, dairy manure can produce 262 MWh of electricity and 40,328 $m^3$ of RNG annually, while poultry can produce 183 MWh of electricity and 28,176 $m^3$ of RNG, and swine manure can produce 1,211 MWh of electricity and 186,408 $m^3$ of RNG. Adding a digester reduced GHG emission from dairy manure by 51.0 $MtCO_{2e}$/year, 35.9 $MtCO_{2e}$/year from poultry litter, and 238 $MtCO_{2e}$/year from swine manure.

Table 2d.1 (in Summary) presented the annual GHG emissions reductions when composting dairy manure, poultry litter, and swine manure calculated by the EPA AD Screening Tool. Composting dairy manure results in 23.5 $MtCO_{2e}$ emissions, with 1.6 $MtCO_{2e}$ for poultry litter, and 51.2 $MtCO_{2e}$ from composting swine manure, which is still a 66.7% reduction in GHG emissions from the baseline. Composting dairy manure reduces GHG emissions by 66.7% compared to the baseline scenario, while digestion reduces GHG emissions by 106%. Similarly, composting poultry litter reduces GHG emissions by 84.1% compared to the baseline scenario, while digestion reduces it by 206% and thermal conversion reduces it by almost 100%. This highlights the effectiveness of composting, thermal conversion, and digestion in reducing GHG emissions and sequestering carbon beyond the baseline values.

It should be noted that the DDRDP baseline scenario with no digester had lower emissions (94 $MtCO_{2e}$) for dairy manure compared to the EPA AD Screening tool (70.4 $MtCO_2e$). The EPA AD Screening Tool showed 100% reductions in GHG emissions compared to the DDRDP tool for the dairy manure heated digester scenario showed 88% reduction in GHG emissions. Figure 2d.2 (shown above) combines GHG emissions modeling outcomes with 2019 Maryland manure data (Topic 1b) to project yearly emissions from manure across counties under various management approaches. Each bar represents a scenario where the entire daily animal waste of a county is managed using a specific strategy.

The total GHG emissions between each type of facility analyzed varied according to the waste being treated (Figure 2b.1), with annual GHG emissions from all manure in MD (533,652 $MtCO_{2e}$) concentrated in Fredrick and Washington counties. These GHG emissions could be eliminated through use of anaerobic digestion (Figure 2b.2). Frederick County had 111,527 $MtCO_{2e}$ annual GHG emissions from animal manure, followed by Washington (107,336 $MtCO_{2e}$) and Carroll (59,032 $MtCO_{2e}$) counties. Dairy cattle were the primary contributors to the high GHG emissions in MD. In Frederick County, GHG emissions from dairy cattle were 48,488 $MtCO_{2e}$ annually, followed by Washington (48,733 $MtCO_{2e}$) and Carroll (21,844 $MtCO_{2e}$) counties. By covering open manure lagoons, these GHG emissions could be eliminated.

All MD counties would achieve significant reductions in GHG emissions by implementing composting or anaerobic digestion. In Frederick County, composting all manure resources would reduce emissions by 75,421 $MtCO_{2e}$, which is a 67.6% decrease, while anaerobic digestion would decrease GHG emissions from all manure resources by 118,367 $MtCO_{2e}$, which is a 106% reduction (Figure 2). Both composting and anaerobic digestion present substantial opportunities for GHG emission reductions. However, the ability of anaerobic digestion to achieve reductions exceeds 100% due to reductions of GHG emissions naturally occurring in open air lagoons combined with the ability to turn this captured biogas into renewable energy. Frederick county could provide 34,745 MWh of renewable electricity production from anaerobic digestion of all manure resources in the county, followed closely by Washington and Carroll with 30,036 MWh and 16,512 MWh, respectively (figure 2d.5). Thermal conversion also reported low emissions; however, thermal conversion was only used when processing dry waste (e.g., poultry litter) and is therefore only viable in counties with predominantly poultry-based agriculture. Composting was effective at reducing emissions under all scenarios in all counties. However the degree of change was not as large as anaerobic digestion due to only the solid fraction of high-moisture waste (e.g., dairy manure) being suitable for composting.

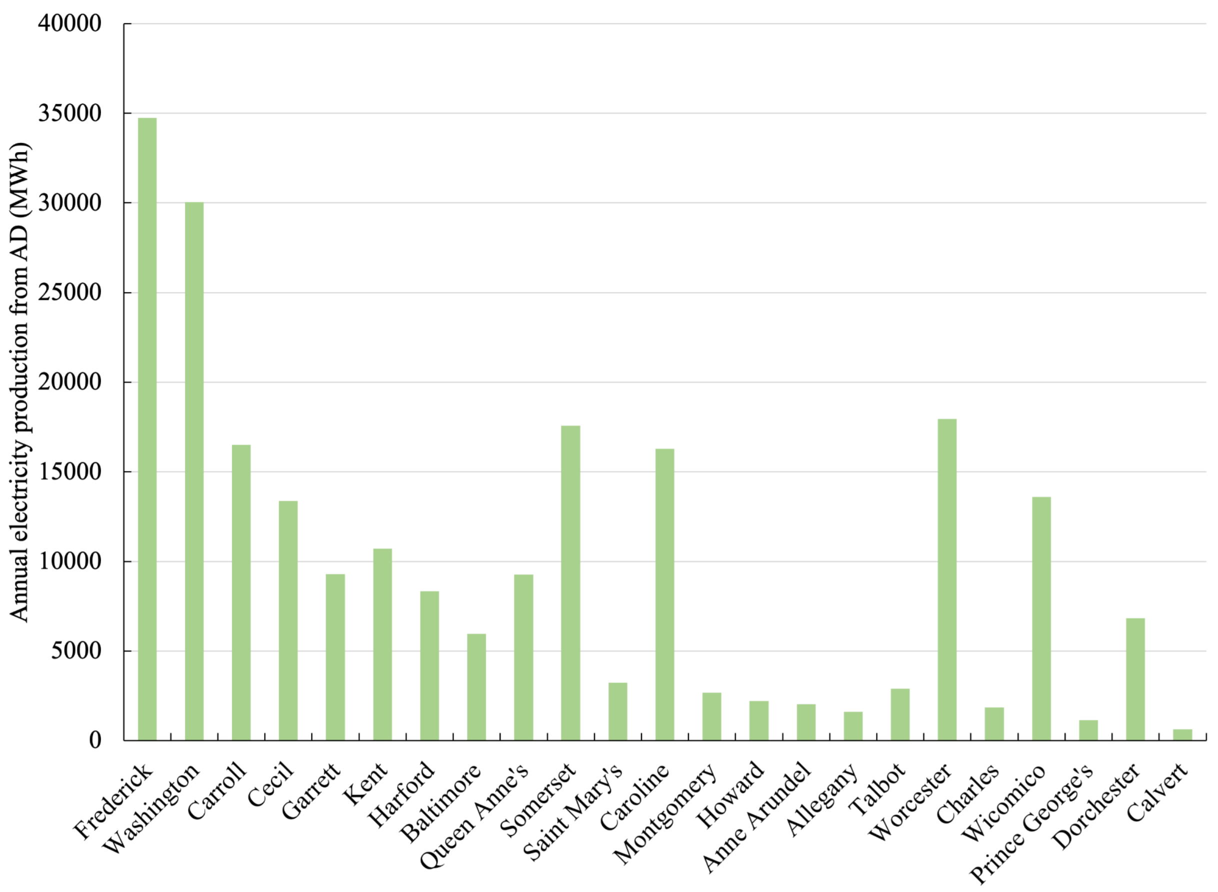


**Figure 2d.5:** Annual electricity generation from MD countries when anaerobic digestion is to convert all manure resources to renewable energy.

Table 2d.5 has the estimated daily emissions from manure generated at all seven animal types in CAFOs sites across Maryland. Dairy manure has the highest baseline emissions (147,000 $MtCO_2e$), followed by other cattle (20,500 $MtCO_2e$). Swine, horses, broilers, and layers CAFOs each contribute approximately 4,000 $MtCO_2e$ at baseline. Sheep and goats only emit 2 $MtCO_2e$. Composting reduced baseline GHG emissions by 88.3 - 88.7% for broiler and layer litter, and 66.2 - 66.7% for all other waste. The higher reduction was observed for drier waste that is composted without liquids-solids separation. Thermal conversion of broiler and layer litter reduced emissions by 99.2 - 99.3% from the baseline. Anaerobic digestion yielded net reduction in GHG emissions of 206% for broilers and layer litter, and 105 -106% reductions from the baseline for all other waste types.

**Table 2d.5:** Estimated daily emissions from all concentrated animal feeding operations (CAFOs) in MD using CAFOs data from 2022, showing no animal waste technologies (baseline) and applying compost, thermal conversion, or anaerobic digestion to the manure from all CAFOs.

| CAFO Type | No waste technology (baseline) ($MtCO_2e$) | Compost ($MtCO_2e$) | Thermal conversion ($MtCO_2e$) | Anaerobic digestion ($MtCO_2e$) |
|---|---|---|---|---|
| Broiler Litter | 4,200 | 517 | 30 | -4,440 |
| Layer Litter | 4,260 | 541 | 34 | -4,510 |
| Dairy | 147,000 | 49,200 | - | -8,160 |
| Horses | 3,120 | 1,164 | - | -173 |
| Other Cattle | 20,500 | 6,202 | - | -1,123 |
| Sheep and goats | 2 | 1 | - | -0.199 |
| Swine | 3,850 | 1,281 | - | -215 |

The total emissions estimated from agricultural manure management in 2019 without animal waste technology (534,000 $MTCO_2e$/year) is consistent with the ~500,000 $MTCO_2e$/year reported in the Maryland Climate Pathway Report (MDE & UMD Center for Global Sustainability, 2023). The Climate Pathway initiative concluded that Maryland must reduce its emissions by a further 10,600,000 $MTCO_2e$ to meet its GHG emissions targets for 2031. That study assumed that agricultural manure emissions would remain consistent at the 2020 levels through 2031. However, our modeling indicates that the state could reduce or eliminate emissions from this category entirely by shifting manure management towards animal waste technology. This would account for almost 5% of the emissions the state must remove to meet its 2031 climate goals.

Thermal Conversion: Pyrolysis and Gasification

Our previous study of a fluidized bed combustion system of poultry litter (shown in Appendix B) did not show reduced GHG emissions under the operational scenario with limited electricity production, but a 66% reduction in GHG emissions if operated at a higher biomass production rate and higher use of the on-site generator for the renewable electricity production. A previous LCA study found that digestion of dairy and swine manure had lower GHG emissions compared to pyrolysis, with a reduction of 20-60% in GHG emissions per ton of manure treated (Varma et al., 2021; Wang et al., 2021). Another study compared the environmental impact of three different methods for managing poultry litter: thermal conversion, composting, and co-digestion (Table 2a.6), and found thermal conversion had the lowest GHG emissions production 99.5 kg $CO_{2e}$, while composting and co-digestion of poultry litter with fodder maize had higher impacts at 397 and 168 kg $CO_{2e}$, respectively (Nusselder et al., 2020). This study indicated that thermal conversion is a more environmentally friendly option for managing poultry litter in terms of climate change impact, while co-digestion was the most sustainable method for managing poultry litter in regards to freshwater eutrophication. It should be noted that the GHG emissions in Table 2d.6 for composting and digestion from the literature may not be directly comparable to the results presented from the EPA AD Screening tool due to differences in location, loading rate system design, modeling methods, and coefficients used.

**Table 2d.6**. Life Cycle Impact Assessment impact categories per ton of poultry litter treated (Nusselder et al., 2020).

| | Unit | Thermal conversion | Composting | Co-digestion |
|---|---|---|---|---|
| Climate change | $MtCO_2e$ | 0.10 | 0.40 | 0.17 |
| Terrestrial acidification | kg $SO_2e$ | 0.3400 | 42.5000 | 12.0000 |
| Freshwater eutrophication | kg Pe | 0.3820 | 0.5000 | 0.1540 |

Manure Injection

Aguirre-Villegas and Larson (2017) identified GHG emissions of current manure management practices on Wisconsin dairy farms, including liquid manure, solid separation, anaerobic digestion, and daily land-application of solid manure at small farms. The GHG emissions per ton of manure varied depending on the practice and farm size, ranging from 2200 to 12,000 g $CO_2e$ for collection, 200 to 2400 g $CO_2e$ for transportation, 16,000 to 84,000 g $CO_2e$ for storage, and 16,400 to 33,500 g $CO_2e$ for land-application. Their results are presented in Table 2d.7 for small and large farms, with a large farm defined as > 1000 AUs.

**Table 2d.7:** Greenhouse gas (GHG) emissions from different manure management practices in small and large farms (Aguirre-Villegas and Larson, 2017). The emissions are shown for surface application of manure, or land application of liquid manure after solid separation (SS), after anaerobic digestion (AD), and/or with manure injection.

| Farm size | Manure management | GHG Manure | GHG Energy | Total GHG |
|---|---|---|---|---|
| | | kg $CO_{2eq}$ /ton manure | kg $CO_{2eq}$ /ton manure | kg $CO_{2eq}$ /ton manure |
| Small farm | Surface application, no storage | 28.1 | 5.5 | 33.6 |
| | Surface application, storage | 25.6 | 5.5 | 31.1 |
| | Reference (Surface) | 35.3 | 10.2 | 45.5 |
| Large farm | Injection after SS + AD* | 12.1 | 11.5 | 23.6 |
| | Surface after SS + AD* | 12.1 | 7.44 | 19.5 |
| | Injection after SS | 14.3 | 11.5 | 25.8 |
| | Surface after SS | 14.3 | 7.44 | 21.7 |
| | Reference (Surface) | 101 | 4.3 | 105 |

*Note that any GHG emissions reductions associated with AD are not included – only emissions associated with land application.

The analysis indicated that the size of the farm has a significant impact on GHG emissions, with large farms emitting substantially higher levels of both $NH_3$ and GHG emissions. The use of advanced manure management technologies, such as solid separation and anaerobic digestion significantly reduced emissions, particularly when combined with manure injection (Aguirre-Villegas and Larson, 2017). Injection after solid separation and digestion on both small and large farms resulted in the lowest daily GHG emissions per ton of manure and per AU, while surface application without storage on a small farm resulted in the highest daily GHG emissions per ton of manure and per AU.

**Topic 2d Key Findings and Recommendations:**

1. Anaerobic digestion of dairy manure reduced GHG emissions by 106%, while composting had 66.7% reductions in GHG emissions compared to open lagoon storage (baseline)..
2. Digestion of poultry litter resulted in greater GHG emissions reductions (206% reduction) compared to composting (102%), yet the baseline value for GHG emissions for poultry litter (12.6 $MtCO_2e$) was much lower than dairy manure (70.4 $MtCO_2e$).
3. When normalized by animal units (AU), the largest reductions in GHG emissions resulted from digestion of swine manure from 100 AUs of swine (-59.4 $MtCO_2e$), compared to digesting dairy manure from 100 AUs of dairy (-12.8 $MtCO_2e$), and digesting poultry litter from 100 AUs of poultry (-8.99 $MtCO_2e$).
4. The dairy manure, DAF, and food waste digester operating in Maryland reduced GHG emissions by 81% compared to the baseline (23,751 $MtCO_2e$ emitted annually from the uncovered lagoon to 4,495 $MtCO_2e$), with a 448% reduction in eutrophication potential and produced 2000 MWh of electricity annually, enough to power 190 houses.
5. Uncovered lagoons or manure stored on-site emit high volumes of total GHG emissions in each MD county (Figures 2d.1; and 2d.2), which could be completely mitigated through use of animal waste technologies. This should be better factored into the MD's climate change goals.

***Topic 2e. Impediments to adoption of animal waste treatment technologies.***

**Topic 2e Summary**

There are a number of obstacles to animal waste technology adoption, including technical, economic, regulatory, and social factors, as summarized below.

- *Upfront Economics:* Many animal waste technologies require a substantial initial investment, which could include erecting buildings, a generator, and interconnection lines.
- *Limited Subsidies:* There is limited funding in MD to support the adoption of animal waste technologies, with the AWTF often funding one project annually, resulting in less adoption.
- *Complex Regulatory Environment:* The permits and regulations required at the state, county, and with private energy companies are difficult to navigate and delay progress.
- *Technical Expertise:* There is a lack of technical expertise available to support writing grants, navigating permits, and troubleshooting adoption of animal waste technologies.
- *Social and Cultural Resistance*: Concerns about the impact on the local environment and communities, combined with a lack of understanding of the benefits of these technologies, can cause social and cultural resistance to the adoption of animal waste technologies.

To fully assess the impediments to adoption of animal waste treatment technologies, interviews and surveys were conducted along with an intensive literature review on previous survey work that evaluated the barriers to adoption, the value to adopters of treatment technologies, costs associated with adoption, and the impact of public initiatives on adoption rates as well as perceived and real barriers to adoption.

**Topic 2e Methods**:

There are previous studies on barriers to adoption of animal waste management strategies, operational costs, neglect of end users in manure treatments technologies, barriers specific to anaerobic digestion, and policy barriers across Europe, Australia, and the United States that were analyzed (Tan, M et al., 2021; Nevzorova & Kutcherov, 2019; Edwards et al., 2015). These previous works, in coordination with our survey results (results in Appendix C) and interviews on barriers and impediments to adoption identified specific trends in Maryland.

**Topic 2e Results:**

Upfront Economics and Long Lead Times to Operation

In 2007, it was noted that the payback period of a digester on a dairy farm can range from four years, when subsidies are provided, to decades when no financial support is provided (Lazarus and Rudstrom, 2007; Tan et al., 2021). Despite the original paper being published in 2007, the statement holds merit in today. In our interviews, industry experts stated that their project's construction phase "has been going for four years now," which means there is no income and contributions to the payback period due to the lack of sales from electricity or other products. High upfront capital costs impact the ability to start and complete projects in a timely manner. Construction delays for grant-funded technologies could result in changes to the proposed project intent, especially if delays occur before construction (Nevzorova and Kutcherov, 2019).

Additionally, concerns were expressed that if the public and private sector do not have clear guidelines for participation, a competitive market could develop into a monopoly where there is a lack of diverse investors and technologies. Many industry experts stated that the poultry litter broker system in Maryland faces similar critiques to those highlighted in the literature on barriers to digestion technology adoption, with instances in which the private sector controls the market and limits competitive involvement. There is concern that with this dynamic already established in poultry transport that the large capital costs for animal waste technology businesses will limit this competitive landscape in the future. While there is federal funding available for some capital costs, these funds are often competitive, with no guarantee of funding prior to starting the cumbersome applications, especially for farmers without resources.

Limited Subsidies

China had large government subsidies for anaerobic digestion, solid-liquid separation, and composting for dairy, swine, and poultry operations to support the 2015 "zero-increase" synthetic fertilizer policy (Tan et al., 2021). Yet, the practice of only providing subsidies for upfront cost resulted in less maintenance and long-term operation of the supported products. The study concluded that governments should consider reverting from subsidies on initial investments in manure treatment techniques to subsidies the technology operation, while removing subsidies for synthetic fertilizers and focus on subsidizing the use of manure and waste technology output for crop fertilizer (Tan et al., 2021). In Maryland, most state subsidies aid in the construction and upfront costs without providing maintenance costs. However, the NRCS EQIP program does have specific funding for the use, maintenance, and improvement of conservation practices. Comparatively, most MD state agencies use funding for project start-up, such as the cover crop program (MDA), the older version of pay-for-success, which is under revision (MDE), and the Commercial, Industrial, and Agricultural Grant Program (MEA).

Complex Regulatory Environment

There is a complexity of regulation at different levels. In Maryland, one of the most complex issues for animal waste technology could be diversion of food waste. As seen in various subtopics of Topic 2 and Appendix F, there are quite a few new policies related to diverting food waste from landfills to be digested or composted. But when bills like HB0847/SB0447: "Anaerobic Digestion Workgroup" do not succeed and HB0253/SB0262 "Environment - On–Farm Composting Facilities – Permit Exemption" do succeed, there could be a mismatch in policy intention and implication. This could be due to a trickle-down effect, as the federal government provides little guidance for regulation of waste management or waste diversion targets from landfill, which is often left to county governments. The result is a waste management policy that is complicated, with a vast amount of food waste and food processing waste imported or exported across state lines due to market and policy forces, as is seen in DAF transport trends (Topic 1c). States have enacted legislation to preserve their own landfill sites for their citizens' waste, through import levies or bans, but it is a complicated landscape (Edwards et al., 2015). This labeling of "waste" is also true for animal waste, as many stakeholders express the frustration with the inability to apply DAF at all in Virginia without a permit, and with Maryland's new incorporating, composting or digestion policy for DAF, more DAF is going to Pennsylvania. Additionally, the WIPs initiatives often stop at state and county lines, while water (and waste) could be analyzed within a manure shed framework to create a regional approach to waste utilization.

In federal climate change goals (Topic 2c,) the EPA's RIN and REC markets directly impact the adoption of animal waste technologies that create renewable energy sources, as well as the type of energy production (electricity vs RNG). It is not just the complexities of the regulatory environment but also the fluctuations in regulations. With the IRA funds affecting USDA and EPA climate change goals for the time being, there is much uncertainty what adoption will take place without these funds. As evident in the newly announced GHG Reduction Fund (Topic 2c,) the EPA announced $7 billion dollars would go to the Zero-Emission Technology Fund Competition, with no mention of animal waste technologies as renewable energy sources but a focus on solar, wind, and water. Due to these uncertainties, investment may be delayed until new manure-specific funds are announced (as was done in California – see Topic 2b) and/or more guidelines are developed for potential applicants. There is a need for a global framework climate change mitigation and renewable energy that incentives, subsidizes, and reduces cost for these technologies to overcome temporary funding fluctuations (Edwards et al., 2015).

Technical Expertise

There is a level of knowledge needed to operate animal waste technologies efficiently and manage the market of by-products. Outside labor may be needed to operate and efficiently manage the operation. Unlike other renewable energy sources, such as wind, hydropower, and solar, animal waste technologies require daily management, including daily inputs, responses to climate conditions, overseeing daily treatment efficiencies, maintaining temperature (especially in winter), and managing the nutrient-rich outputs, especially in winter in Maryland when land application is not allowed (Tan et al., 2021). If the byproduct cannot be applied, it needs to be stored or transported to an area that can use the byproduct during this time.

In China, where there are millions of installed digestion systems, it was stated that high operation cost and technical failures may explain the fact that only 44% of the solid–liquid separators and only 11% of the biogas plants were operating after initial installation (Tan et al., 2021). A fear of accidents, connected to a low level of knowledge, highlighted the importance of safety and training for these systems (Nevzorova and Kutcherov, 2019). Technical expertise is not an isolated impediment but often tied to the other economic impediments.

Finally, there is the technical expertise needed for navigating energy output, power purchase agreements, greenhouse gas credits, and by-product sales. Obstacles may include lack of engagement from the power companies, lack of infrastructure and transfer stations, methane upgrading and distribution to RNG challenges (especially if truck transportation is needed for pipeline injection), lack of quality waste separation, inconsistent loading for food waste inputs, general availability of feedstock, and lack of assistance with maintenance and operator training throughout the project period (Nevzorova and Kutcherov, 2019).

Social and Cultural Resistance

Social and cultural resistance will be further explored in Topic 2f, including the related lack of education for farmers/operators and the general public on these technologies. There are a vast range of public health and environmental justice concerns related to nutrient runoff, air pollutants, and their continuous impact on marginalized groups and underserved communities. Many of the bills noted in Appendix F faced intense public pushback, often denoted by lack of education on the actual technologies during the committee hearings of these bills, including the commentary in the 'Anaerobic Digestion Workgroup' failed legislation (Topic 2b).

Survey Results on Support for Manure Technologies

Our survey results (Appendix C) showed that 66% (214 respondents) moderately or strongly supported anaerobic digestion, with 7% likely to adopt digestion, 24% were unsure about adopting anaerobic digestion, and 10% did not support anaerobic digestion (Figure 2e.1). The greatest benefits to anaerobic digestion were overwhelmingly attributed to renewable energy production, followed by reduction of waste and waste management, and odor management. By-far, the biggest concern was 'cost, too expensive, huge investment,' as well as more regulations, and collection/transportation of manure.

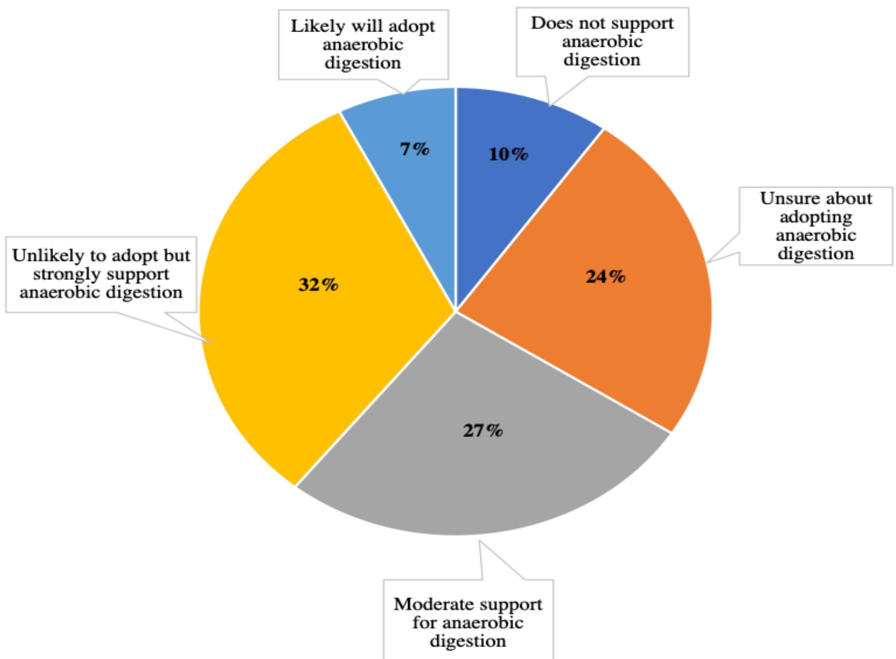


**Figure 2e.1:** Survey results from the question "Which of the following best describes your outlook on anaerobic digestion in the next five years (2023-2028)?" from 214 respondents.

The survey showed that 56% (209 respondents) moderately or strongly supported gasification/pyrolysis, with 6% likely to adopt gasification/pyrolysis, 34% unsure about adopting gasification/pyrolysis, and 10% did not support gasification/pyrolysis (Figure 2e.2). The greatest benefits to gasification/pyrolysis were overwhelmingly attributed to renewable energy production, followed by environmental health. By-far, the biggest concern was cost (54 respondents), followed by many respondents (24 respondents) unsure due to not enough knowledge, and waste of nutrients (7 respondents).

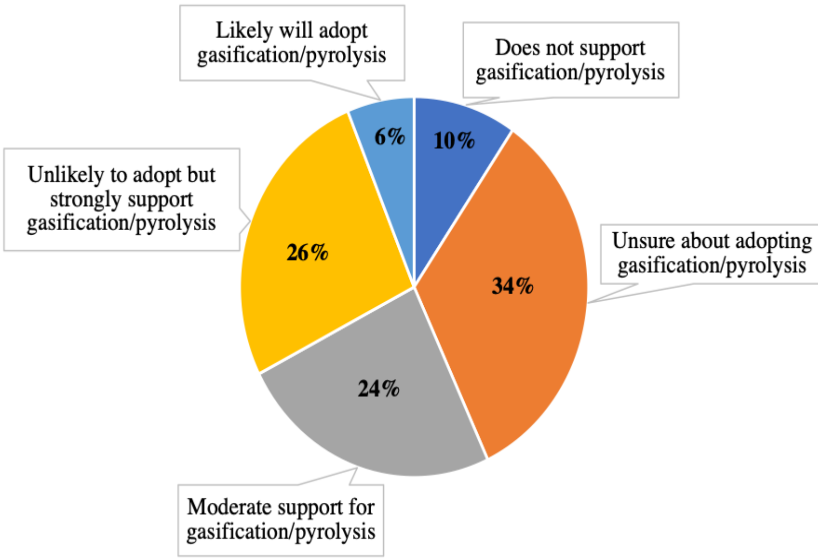


**Figure 2e.2:** Survey results from the question "Which of the following best describes your outlook on gasification/pyrolysis in the next five years (2023-2028)?" from 209 respondents.

The survey showed that 75% (211 respondents) moderately or strongly supported manure injection, with 15% likely to adopt manure injection, 19% unsure about manure injection, and 6% did not support manure injection (Figure 2e.3). The greatest benefits to manure injection were that nutrients kept in place (maximized nutrient efficiency), followed by odor reduction and less runoff. The biggest concern was overwhelming cost (61 respondents), followed by soil disturbances/application usage (23 respondents), and regulations/restrictions (4 respondents).

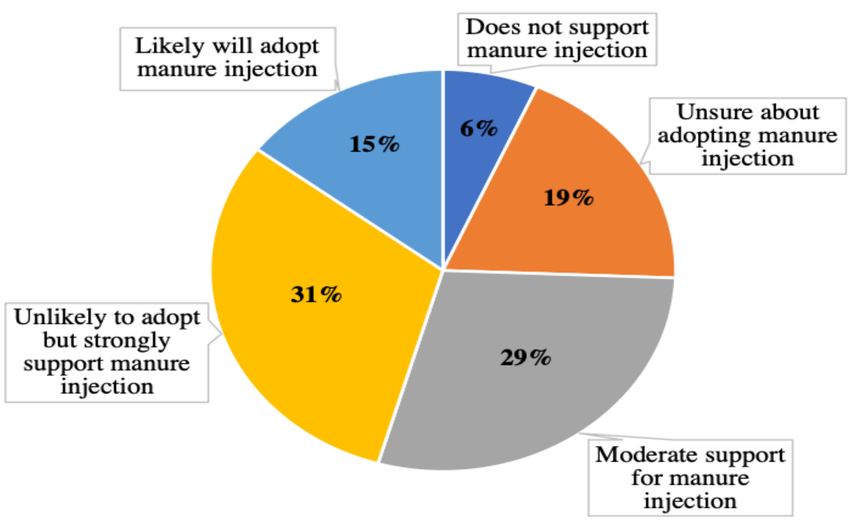


**Figure 2e.3:** Survey results from the question "Which of the following best describes your outlook on manure injection in the next five years (2023-2028)?" from 211 respondents.

It is important to note that none of these impediments can be solved independently. There are multi-faceted and intertwined issues involving farming operations on commodity basis and technology confidence. For digester adoption, the value to adopters may include reduced commercial purchases of electricity, potential revenues from the sales of natural gas or electricity, and/or the fertilizer value of nutrients remaining from digester processes or use of digested fibers as bedding. The costs include the capital, labor, and materials costs of the operating technologies, training and maintenance cost, and the cost of land (as well as the opportunity cost). For community-based facilities, transportation costs will also be a large factor as well as land ownership. While there are larger financial incentives for RNG from digesters due to federal regulations compared to electricity production from digesters or gasification/pyrolysis, RNG production needs a larger capital investment, resulting in more industrial-owned digesters and less farm-owned digesters. Better electricity-based incentives at the state-level could increase the number of digesters located on farms and owned by farmers. The size of the livestock operation does affect costs and must be considered in evaluation of adoption incentives. Larger regional digesters that produce RNG might increase traffic and have other impacts (See Topic 2f) on the community compared to the lower state-based financial subsidies for electricity-based digesters.

**Topic 2e Key Findings**:

1. Economic barriers include high upfront cost and limited subsidies, with federal incentives favoring larger digester systems that produce RNG and have higher capital costs.
2. Technical barriers range from inexperience navigating complex funding application processes to safety concerns and technical long-term operation of the equipment.
3. Social and cultural resistance is based on environmental justice and public health concerns from nutrients and pollutants. Education, in multiple parties, is lacking and causing stagnant growth and adoption and misconceptions amongst the public.
4. The surveys showed widespread support for anaerobic digestion, gasification/pyrolysis, and manure injection, with more uncertainty associated with gasification/pyrolysis due to lack of knowledge, with cost being the highest barrier to adoption for all three technologies.
5. There is a need for more funding of smaller, electricity-based systems to increase adoption, but there also needs to be more engagement with power companies to navigate this process. It seems that electricity generation has less perceived environmental justice concerns.

***Topic 2f. Summarize national efforts to incorporate environmental justice factors in the selection and siting of animal waste management technologies.***

**<u>Topic 2f Summary</u>**

In both the past and present, waste management facilities and other polluting land uses have been disproportionately placed in areas home to vulnerable communities such as racial and ethnic minorities, immigrants, and areas with high concentrations of low-income and low-education residents. In addition to bearing the brunt of exposure, these groups often have the fewest options for mitigating the negative effects of such conditions. Animal waste management sites are overwhelmingly concentrated in low-income, rural communities, although no consensus emerged on whether race is significantly correlated. Historically, waste facilities were disproportionately located near minority communities, especially black and indigenous communities. Communities exposed to waste management sites can be more vulnerable to air pollutants due to pre-existing diseases, other exposures/stressors, and poor access to medical services.

This context also has a pervasive belief that the general public does not understand new animal waste management technologies including anaerobic digestion and fast pyrolysis, leading to recommendations that further education is needed. However, public engagement by institutional stakeholders has been minimal, and representatives of vulnerable communities, such as minority advocates, have highlighted this lack of communication or engagement. The core refrain of environmental justice, "Nothing about us without us," remains valid for these stakeholders. Regardless of the specific risks and benefits for these communities associated with new waste management technologies, the absence of procedural justice - the substantive engagement of marginalized communities in policy decisions - is notable.

To understand the context of communities near to waste management facilities, we developed the 'Environmental Justice Framework' with an aim to assess Environmental Justice (EJ) factors in the selection and siting of animal waste facilities and/or animal waste treatment technologies in the current and future context. The specific EJ Framework developed for this study was divided into six phases (Figure 2f.1). This section outlines the development and implementation of the EJ framework in Maryland, including the recommendation of next steps for the future.

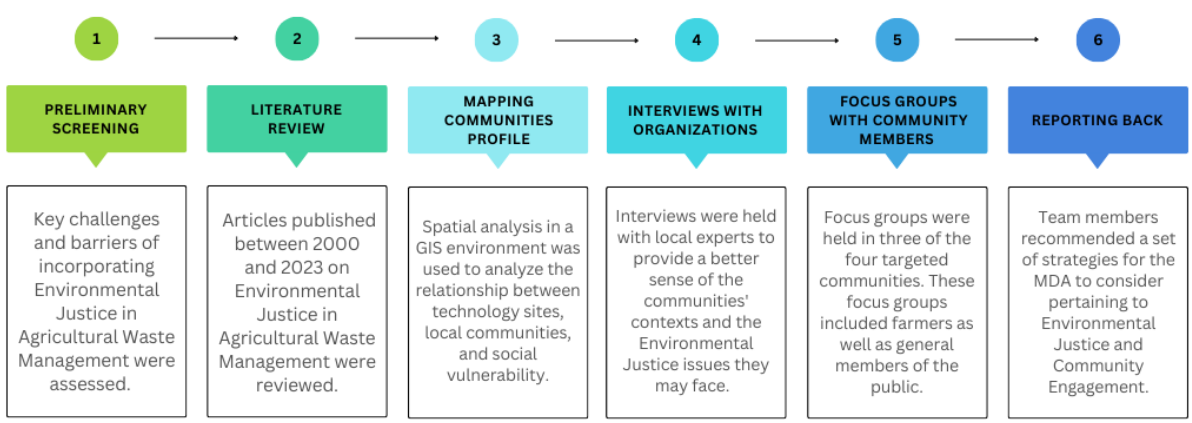


**Figure 2f.1**: The Environmental Justice Framework for the selection and siting of waste animal technology or waste treatment facilities combines the review of literature, spatial analysis, and participatory approaches with organizations and community members.

**Topic 2f Materials and Methods**

Phases 1 and 2 of the EJ Framework assessed current literature and existing policy to identify key challenges and barriers as well as current practice for incorporating EJ in animal waste management. Articles detailing barriers and challenges faced by community members related to animal waste management in the United States were selected from database searches using search terms such as: 'agricultural waste', 'anaerobic digestion', 'animal waste', 'community engagement,' 'environmental justice', and 'pyrolysis', 'waste management'; with further restricted to publishing dates between January 1, 2000 and April 18, 2023 using the Web of Science database. The review detailed what is currently known in this field, explored how similar projects across the country have incorporated environmental justice concerns into their processes, and identified knowledge gaps or unmet needs to be addressed.

In Phase 3, these key findings were used to analyze the spatial distribution of selected animal waste facilities and their proximity to communities with EJ concerns using geographic information systems (GIS). Maps of waste facilities and surrounding communities were created and potential impacts on community health and well-being analyzed in order to determine vulnerability and exposure. Stakeholders were engaged in a participatory process to gather input and feedback on the analysis. Specific data used in the GIS analyses are detailed in Appendix B.

The EJ team identified four sites for participatory studies based on the preliminary screening and input from the project team (Table 2f.1). The participatory approaches in Phases 4 and 5 included interviews with local "grass tops" stakeholders such as local politicians, social service providers, representatives of environmental groups, and engaged farmers. In addition, the research team held focus groups with community members in 3 of the 4 sites. In Phase 4, individuals in organizations and institutions engaged with social and environmental issues in the selected communities who could speak knowledgeably about environmental justice were interviewed. Initially, searches were conducted that included "environmental justice," "social services," "community organization," and "economic development" combined with the community's name. County and local municipal websites were scanned for agencies and organizations that partner with the government, as well as umbrella organizations such as the United Way.

**Table 2f.1**: General information about the analyzed facilities.

| Site or Organization | County | Animal Waste Technology | Sources |
|---|---|---|---|
| A | Cecil | Active, full-scale digester receiving dairy, DAF, and food waste for 13 years; Producing electricity. | MD Dept of Agriculture |
| B | Worcester | Active, demonstration-scale digester for 6 years receiving poultry litter, with funding to build a full-scale system at another location to digest poultry litter and cover crops; Producing electricity, but exploring RNG. | US Env. Protection Agency (EPA) |
| C | Wicomico | Active, demonstration scale system receiving poultry litter, with the construction of larger-scale system at the same site almost complete; Will produce electricity. | MD Dept of the Environment |
| D | Sussex | Permit phase for digesting DAF and poultry litter; Active composting site for decades of poultry litter and DAF; Will produce RNG. | Devco; DE Dept of Nat Resources |

In Phase 4, we interviewed 25 individuals in these targeted organizations to 1) gather on-the-ground insights in engaged communities, 2) probe for information on local opportunities or tensions surrounding agricultural waste management, and 3) gather information relevant to recruitment for grass-roots focus groups, including how to reach community members effectively and potential local venues for focus groups (see Zhaghaghi et al. (2011)) for an overview of comparable recruitment techniques, including snowball sampling). The interviewees included local government officials and their staff, farm/facility owners and their employees, non-profit employees, and local community organizers (Table 2f.2).

In Phase 5, one farm visit and three in-person focus groups (Rising Sun in Cecil County, Pocomoke City in Worcester County, and Salisbury in Wicomico County) were conducted. Due to ongoing legal challenges surrounding the development of the facility D site, the focus group in Seaford, DE was replaced with additional interviews. The focus groups were designed to gather perspectives on environmental justice concerns around animal waste management from a range of local stakeholders, both from their individual experiences and from their knowledge of their communities.

**Table 2f.2:** Respondent types to each site selected.

| Site | Technology | Current Projects | Data Collection |
|---|---|---|---|
| Cecil County | Anaerobic Digester (on-farm) | Active full-scale digester (dairy manure, DAF, food waste) on a single farm. Composts food waste from a local school. Operated for 13 years. Another dairy and DAF digester planned. | - 5 farm visits<br>- 1 farm site visit<br>- 1 focus group (3 participants) |
| Wicomico County | Pyrolysis | Demonstration-scale pyrolysis system for poultry litter in construction phase. | - 6 interviews<br>- 1 focus group (10 participants) |
| Worcester County | Anaerobic digester (on-farm) | A demonstration scale digester for poultry litter on a single farm operated for 6 years active. One full-scale poultry litter and cover crop digester planned | - 5 interviews<br>- 1 focus group (8 participants) |
| Seaford, DE (Sussex County) | Centralized anaerobic digester | Permit phase for full-scale digester (off-farm) for poultry litter and DAF. Currently, an active composting facility. | - 10 interviews |

Phase 6 aimed to report results and develop recommendations for including EJ in animal waste management based on the feedback received. Recommendations considered different audiences, including 1) people that have waste technologies on their property, 2) the digestion community in general, 3) community members which participated in our approach, and 4) members of the waste management sector.

**Topic 2f: Results**:

Environmental Justice and Animal Waste Management Literature Review (Phases 1 and 2)

A total of 40 distinct publications were found by combining the key terms for US publications since 2000 between (Figure 2f.2). Over half of these results (23 of 40) were published between

2019 and 2023, indicating recent interest in considering environmental justice and agricultural waste management. The exact counts that each query produced and each query's share of the total number of publications is shown in Figure 2f.3, where duplicates were included in the totals to accurately reflect what each term combination produced. The results showed that no specific term combination dominated the results. Of the articles returned, 14 articles were tangentially related and 8 most closely to EJ and animal waste technologies (Baskin-Graves, 2019; Chan, 2020; Khanjar, 2021; Saxe, 2019; Stingone, 2011; Wing, 2002; Yeboah, 2007; Younes, 2022). These articles investigate animal waste technologies, animal feed operations, and impact assessments with a focus on sustainability and US environmental justice concerns and barriers.

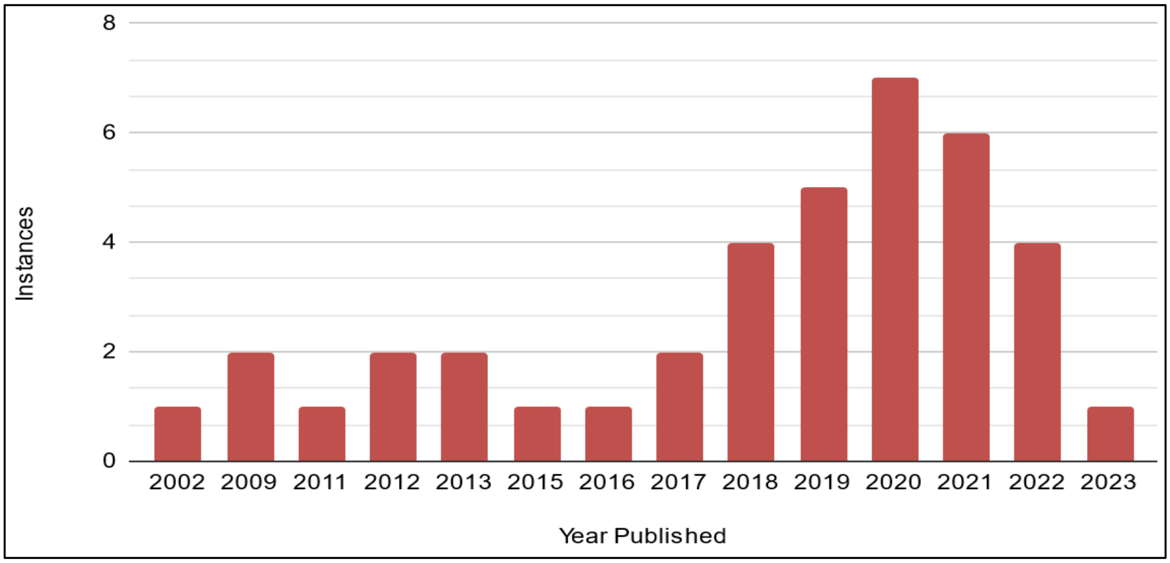


**Figure 2f.2**: Articles published based on the search terms 'environmental justice,' 'waste management,' 'animal,' 'agricultural,' 'anaerobic digestion,' 'pyrolysis,' and 'community engagement' by year of publication.

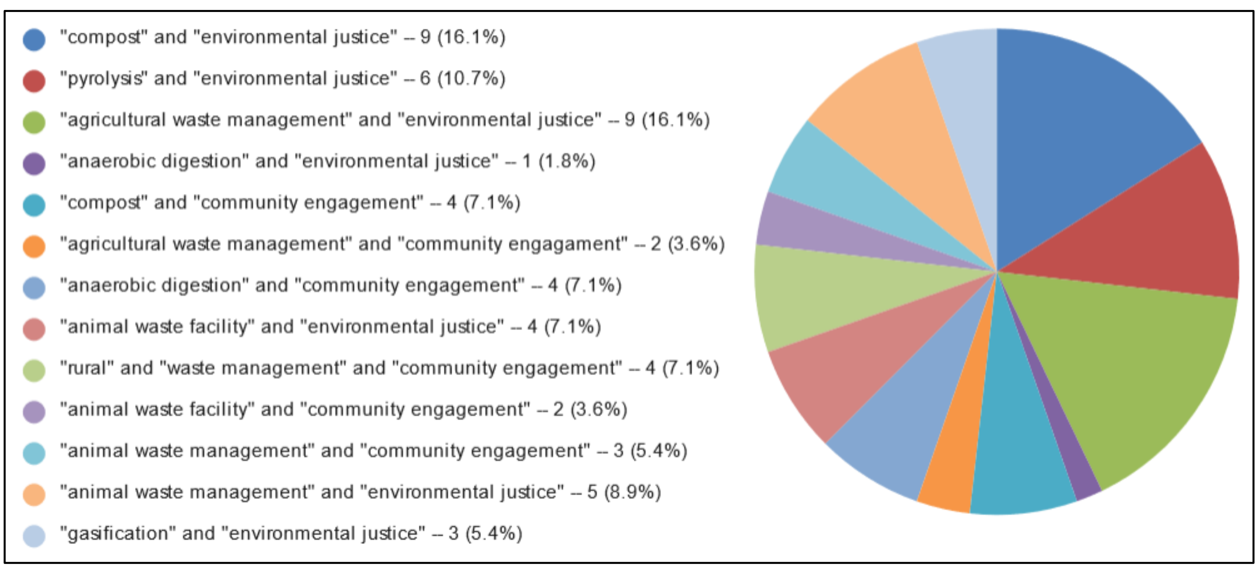


**Figure 2f.3**: Summary of search terms that returned results in Web of Science.

The literature showed that environmental justice is important to consider in both the siting and operation of waste technology, as past and present waste management facilities have been disproportionately constructed in areas home to vulnerable communities (Chan, 2020; Khanjar, 2021; Stingone, 2011; Wing, 2002; Yeboah, 2007; Younes, 2022). Some studies disagree on the level to which race plays into this disproportionate siting. Khanjar et al. (2021) did not find significant correlation, while Yeboah et al. (2007) found a correlation due to the historical disenfranchisement of Black communities. Many poorer Black communities lack the income, political influence, information, organization, and general resources to put up significant resistance against polluting land uses. Still, the same can be said of poorer White communities, although perhaps to a lesser extent. The exact relationship between race, income, and the siting of polluting land uses is therefore a subject for debate. Yeboah et al. (2007) stated that minorities might not have been directly targeted in the siting of agricultural facilities, but that their exposure may instead be explained by their association with poverty and being rural dwellers.

Environmental justice in this study was concerned with unequal siting of these facilities based on all possible socioeconomic factors. Every geographical area has different marginalized groups that must be taken into careful consideration during the siting of such facilities, and therefore, flexible tools should be used when addressing environmental justice concerns. Baskin-Graves et al. (2019) details a rapid health impact assessment (HIA) of a proposed poultry processing plant in Delaware, and Saxe et al. (2019) details the importance of an environmental justice-focused analytic framework when siting solar, pyrolysis, or biochar production facilities. An HIA is "a systematic process that uses an array of data sources and analytic methods and considers input from stakeholders to determine the potential effects of a proposed policy, plan, program, or project on the health of a population and the distribution of those effects within the population." An HIA provides recommendations on monitoring and managing those effects, regardless of the characteristics of a community. In Baskin-Graves et al. (2019), a rapid HIA revealed existing socioeconomic and health disparities in the region targeted for a new poultry processing plant. Based on the size of the proposed plant, it projected the potential increased pollution, odor, traffic, and safety issues. While this particular rapid HIA was conducted to help residents oppose a plan that had already been approved by the local government, it could also be used earlier in the process as a way to determine whether a proposed site disproportionately impacts a vulnerable community or communities that have already borne significant impacts of pollution.

Saxe et al. (2019) concluded that environmental justice concerns regarding the siting and operation of renewable energy facilities (biochar production facilities, in this case) should be determined in the pre-planning phase. Rather than a rapid HIA, this study used screening tools, such as EJSCREEN (the EPA's national EJ screening tool), as a way for developers and governmental agencies to consider the environmental, health, and economic impacts of such a facility on a community before a project can move beyond the planning phase. EJSCREEN brings potential environmental justice concerns to light before they can become an issue later on. This article included a formula and index to calculate the feasibility of a biochar production facility based on EJ concerns (Saxe, 2019, Section 4.2), which would need to be adapted for other waste-to-energy facilities.

Mapping Community Profiles - GIS Analyses (Phase 3)

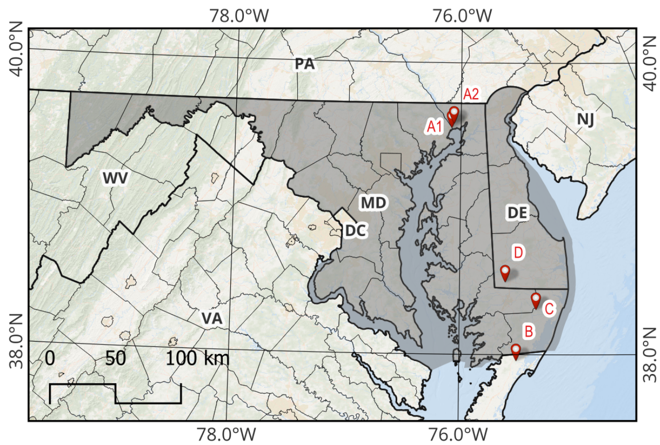


**Figure 2f.4:** Map of five selected facilities.

Figure 2f.4 illustrates the spatial distribution of the four analyzed sites (Table 2f.2) in Maryland and Delaware. Spatial maps can play a crucial role in identifying communities that are environmentally vulnerable to waste digestion facilities. When comparing health and education facilities, site A has more nearby facilities than site D (Appendix B). Communities with less access to important facilities, such as hospitals and schools, may be less prepared to deal with the negative effects of these environmental hazards, and have increased vulnerability. Elevation maps show the areas at most risk of experiencing foul odors, with reduced risk of exposure to toxic gases at higher elevations due to gases dispersing more easily at these elevations (Appendix B). Highway maps can identify communities near significant traffic routes more likely to be exposed to pollutants. These maps can also help identify more appropriate transportation routes for the disposal of product movement that reduces local traffic disruptions (Appendix B). Facilities A2 and D are accessed via highways that traverse urbanized areas, which could impact the traffic flow in these locations. Land Use/Land Change (LULC) maps provide insights into the crop areas and environmental protection areas that need to be protected. Site D's proximity to water bodies, woody wetlands, and evergreen forest may increase the risk of negative environmental impacts compared to other facilities (Appendix B).

The socioeconomic vulnerability maps (Appendix B) identify communities most vulnerable to the impacts of waste technology facilities and provide information on relevant indicators, such as the average income of the local population, education level, and the number of unemployed individuals. Site D is in a region with high social vulnerability, while facilities A1 and A2 are in regions with moderate and very low social vulnerability, respectively. Tailored mitigation measures should address the specific needs of these communities. The high social vulnerability of the region where D is located indicates that the surrounding communities may be more affected by the negative impacts of the facility, including possible impacts on health, access to safe water and food, quality of life, and public safety. In this context, it is fundamental that the assessment of impacts includes active participation of affected communities, ensuring that their concerns and expectations are considered in decisions about the facility and that mitigation and compensation measures are adopted for possible social and economic damages resulting from the activities.

Interview and Focus Group site descriptions

The four sites selected for this study included three Maryland communities where new waste management technologies funded by the Animal Waste Technology Fund have been constructed, and one Delaware site where a large-scale centralized anaerobic digestion facility is currently in development.

The sites were:

- **Cecil County, MD.** An anaerobic digester is in operation on a dairy farm in rural Cecil County, near the community of Rising Sun. The digester is primarily used to process waste produced on premises, although the local school district and a nearby private school both utilize the facility for processing organic waste as well. The resulting products of methane and electricity are used for farm operations, and electricity is provided back to the grid, and is used by neighboring homes and farms. In general, the nearby community is wealthy and is less racially diverse than sites to the south. Interviews and focus group participants report a community that is generally supportive of agriculture, and report the main environmental concern is associated odors, which when present, are pervasive and distributed evenly across the community.
- **Wicomico County, MD.** A demonstration fast pyrolysis facility is in development on a farm in far eastern Wicomico County, near the town of Willards. When operational, the facility will receive waste from the farm on which it is located. As a demonstration project, the facility will primarily be used to test concepts ahead of plans by the developer (an upstart located in the county seat of Salisbury) to build at greater scale. The community in proximity to the facility is primarily rural and white. However, the county overall is diverse, with African Americans making up 28% of the county population, and 6% identifying as Hispanic or Latino. In addition, almost 9% of the population is foreign-born, including a significant community of Haitians and a growing number of South Asians.[5] The county has previously seen tensions around agricultural waste management, particularly the storage and management of DAF. The county also has a well-developed network of environmental and civil rights advocacy and service organizations who have been active in environmental justice issues.
- **Worcester County, MD.** An anaerobic digester is in operation on a poultry farm outside of Pocomoke City, the county seat of Worcester County. Originally independently run (and constructed with the help of AWTF), the digester has recently been sold to Chesapeake Utilities. The county is significantly more rural and less diverse than Wicomico County to the north. While the community has broadly shown support for the project, former managers report some opposition from local and regional environmental groups.
- **Seaford, DE**. The digester purchased a composting facility from Perdue just south of Seaford, Delaware with plans to expand it to include a commercial-scale anaerobic digester. Although the facility is outside of the most densely populated core of Seaford, some lower-income households still reside in the area, most notably a mobile home park approximately a mile from the facility. Many of these nearby residents are Latino or Haitian Creole, though a large portion of these populations were not recorded by the Census and may not appear in official datasets. Due in part to the presence of these populations, there has been some pushback from both local and national activists regarding the expansion of the facility, including a civil rights complaint with the Environmental Protection Agency that was filed in December of 2022. In September of 2023, DNREC approved permits associated with the expansion of the facility and the project appears to be moving forward.

[5] All demographic data is based on the 2017-2021 American Community Survey

*Interview and focus group key findings*

The following findings are a result of analysis across all interviews and focus groups. Transcripts of the interviews and focus groups were reviewed by research team members, with passages sorted into themes. All findings reflect the information gathered from the diversity of sources engaged.

*Exposure Issues*

- **Residential exposure to the harms of agricultural waste is perceived as equally distributed within communities.** Interview respondents and focus group participants overwhelmingly identified odor as the primary environmental "bad" experience by residents in their communities, and broadly attested that odors are not typically geographically concentrated. Other negative impacts observed by residents and stakeholders include increased rates of asthma and cancer which they linked to local air quality resulting from chicken farming, and water quality, especially in Pocomoke City.

- **Residents do not have good access to resources that would help mitigate negative impacts of agricultural waste management, such as high-quality healthcare and insurance.** Focus group participants, particularly in the lower Delmarva area (Wicomico and Worcester County sites) noted generally low access to quality healthcare for all residents. One key issue is a lack of any doctors. As one focus group participant noted, "it took us two years to find a new GP." Generally, focus group participants noted declining access to care and quality of care due to consolidation of healthcare facilities into a single hospital system, and the need to "cross the (Chesapeake Bay) bridge" for any specialist and pediatric care. Focus group participants also noted high levels of uninsured residents, especially in Worcester County. Participants reported that those agricultural employees working for large employers, such as Perdue, have access to some health insurance, while those working for smaller farms are less likely to have insurance. Small farm workers are also more likely to be directly exposed to varying qualities of working conditions.

- **Farm employees are likely to be from vulnerable populations, including immigrants (frequently from Haiti), temporary workers (often Spanish speaking), and low- and very-low-income populations.** African American populations, while present across employment and social sectors, are reported to be more likely to be employed in larger facilities, such as the main Perdue processing plant, and therefore have somewhat more reliable access to health insurance and on-site protections such as PPE.

*Engagement Issues*

- **Generally, community members were unaware of what waste management technologies exist in their communities and didn't understand potential benefits or costs.** Most focus group respondents noted that they were not aware of anaerobic digestion or fast pyrolysis facilities. This was corroborated by interviewees, some of whom themselves were unaware of the facilities.

- **Farmers typically view community engagement as a compliance or permitting issue; others view it as a community responsibility.** When asked about public engagement, farmers in interviews and focus groups universally responded that they followed appropriate permitting guidelines, including public notice of the new development, and that beyond that, they have the right to build on agricultural zoned land (through local right-to-farm policies), so no other engagement is necessary. Community members, on the other hand, see community engagement as a way to ensure that the public is informed about local environmental issues (including waste management techniques), and a venue to have their voices heard on issues that affect them. The two understanding viewpoints in the agreement of community engagement reflects a need for improved procedural justice in the funding allocation process for the AWTF. While farmers believe they have done what is needed to comply with local and state requirements, others do not see a voice for themselves in the system.

- **Community members who do not work in agriculture do not feel they have a voice in decision making about technology used in their communities.** Focus group participants attributed this sentiment to a lack of current information on new technologies being used locally, as well as a lack of opportunities to engage in decision making on state support for the use of new waste management technology.

**Topic 2f Key Findings and Recommendations**

1. Fund awardees should have an environmental exposure plan for employees and neighbors. This could include reliable PPE access, local interpreters for visits, affordable health insurance, and plans to reduce odor, traffic, and emissions.
2. MDA should encourage farmers to consider all potential environmental justice issues before a project begins. This is beneficial to developers, governmental agencies, and community members. Support for farmers could be done through conducting analysis of exposure using tools such as EJSCREEN, MD EJSCREEN, or a health impact assessment tool (see more in the topic 4). While conducting this analysis, it should be noted that vulnerable communities near waste management sites may not appear in official data sources due to the presence of migrant and seasonal workers. Spatial analysis should be conducted to help locate and profile the communities most vulnerable to the impacts of animal waste technologies and develop mitigation measures tailored to their specific needs based on surrounding social, economic, and environmental data.
3. In order to ensure that the public is well-informed of the benefits and risks of new waste management technologies being used in their communities, AWTF awardees should have a public engagement plan included in their application. Such a plan could include strategy to publicize the project locally using sources relevant to the local population (e.g., Facebook groups, local print media, etc.), proactively provide information and opportunities for questions before and during facility construction and operation, and engaging with local community organizations.
4. In order to ensure that minority and vulnerable populations are not excluded from the decision making process, boards advising, reviewing, and apportioning funds for AWTs should maintain seats for community representatives from varied vulnerable populations.
5. In addition to providing funds to install and use new waste management technologies, MDA should consider setting aside funds for vulnerable and historically marginalized populations to engage in empowerment activities on local land use and agricultural decisions, such as the formation of local advisory committees. This would provide a permanent and reliable avenue for local communities to provide feedback, express local priorities, and address concerns.
6. MDA should consider establishing a monitoring and evaluation component of the AWTF program to include regular evaluations of awardees' efforts at public engagement and reducing environmental exposure.

## TOPIC 3: Emerging Market Assessment

## Topic 3. Assessment of Emerging Markets for Animal Waste Management Technologies


**Topic 3 Summary**

Markets for technologies to both convert manure for alternative uses and improve manure's value as fertilizer are continuously evolving. Farmers can be expected to adopt these technologies if the present value of expected revenues outweighs the project's expected costs. Currently, Europe produces half of global biogas, with US production lagging behind and mostly coming from landfills as opposed to agricultural sources. Future development of markets for biogas-producing technologies will be shaped by several factors. While the U.S. is committed to decarbonization efforts, the costs of other renewable energy technologies, like wind and solar, have fallen below that of biopower in recent years, making them a more attractive option. Adoption of some technologies, like on-farm anaerobic digesters, have thus far been limited by basic economic constraints, as economies of scale make render on-farm adoption profitable at only the largest dairy operations.


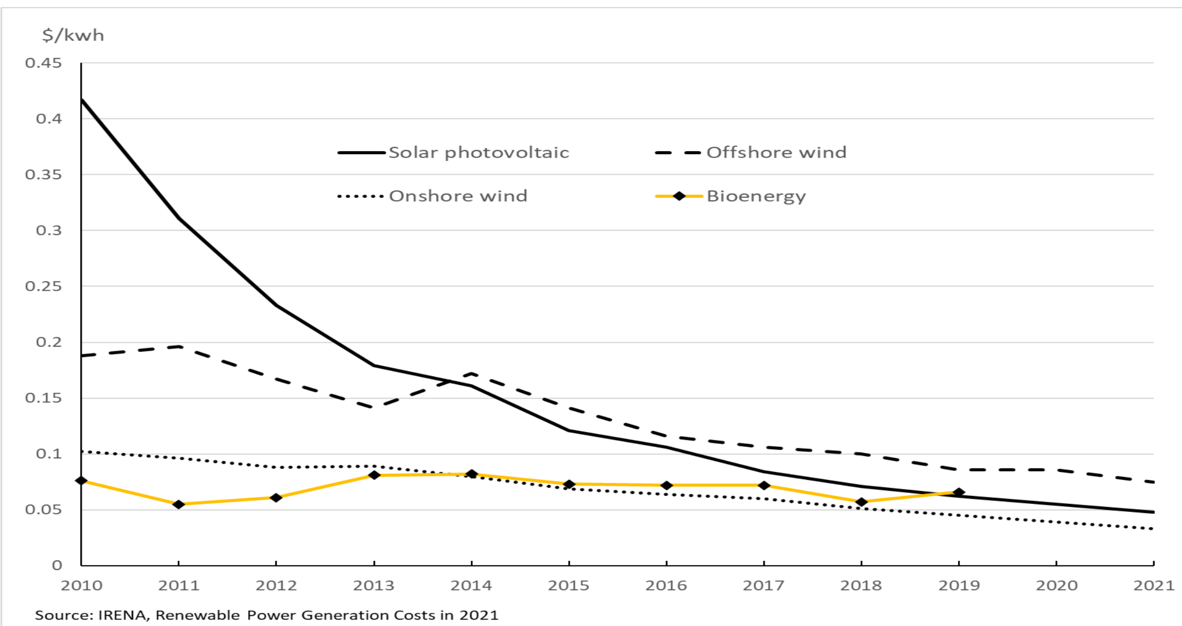


**Figure 3.1**: Levelized Cost of Solar, Wind, and Bioenergy Power, 2010-2021 (IRENA, 2022).

**Topic 3 Methods and Materials**

There is great interest in finding alternative uses for animal waste for energy generation, repurposed materials for packaging, or animal bedding. There is also interest in improving the value of animal waste as fertilizer by altering the nutrient content of manure, improving the take-up of manure fertilizer by crops, or reducing transporting cost of manure to crop fields. Driving interest in alternative uses of manure has focused on renewable energy, specifically the use of biogas for electricity or RNG. Biogas can be derived from animal manure, landfills, food waste, or other organic sources. Emerging markets for biogas derived from animal manure are based on a range of factors:

- Future domestic and global demand for energy, particularly (for the US) electricity and transportation;
- The likely share of future energy use to be provided by renewable sources;
- The relative competitiveness of different renewable sources in serving various uses, including solar and wind energy, biogas derived from non-manure sources like landfills or crop residues, and biogas derived from manure. Relative competitiveness encompasses the current costs of producing biogas from alternative sources, and the likely future path of costs considering input prices, technology improvements, and developments in manure-producing industries;
- The role of government policy on use of various renewable sources, via mandates, regulations, subsidies, and research support.

Notable reports and data sources from the large body of literature drawn upon for emerging markets for animal waste treatment technologies included:

- Intl. Energy Agency's Outlook for Biogas & Biomethane: Prospects for Organic Growth (2020);
- Intl. Renewable Energy Agency's Renewable Power Generation Costs in 2021;
- US Energy Info Admin's Annual Energy Outlook 2023: With Projections to 2050 (2023);
- US EPA's AgSTAR database tracking the operations of anaerobic digesters;
- US Dept of Agriculture's Agricultural Resource Management Survey on dairy farm sizes;
- US Census of Agriculture on cropland and land use in Maryland.

Topic 3.1: Context for Animal Waste Technologies

Animal waste can be used for renewable energy–that is, energy derived from natural sources that can be replenished at a higher rate than they are consumed. Renewable energy sources include solar power, wind power, geothermal, hydro, and biomass derived from animals and plants, including wood, crops and crop residues, landfills, municipal waste, and animal waste. Landfills, municipal waste, and agricultural waste can all produce biogas–a combination of methane, carbon dioxide, and other gases–used for heat, electricity, or upgraded to renewable natural gas (RNG) by separating methane from other gases. Biogas will compete with wind and solar power as feedstocks for electricity generation, as well as landfills or municipal waste facilities for either electricity or RNG.

Topic 3.2: Modeling Adoption of Animal Waste Treatment Technologies

We used a simple technology adoption model developed by Key and Sneeringer (2011), which draws on standard economic analyses of adoption to sort and evaluate the evidence presented below. This is an investment model, evaluating the decision to make a capital investment (almost all treatment technologies involve a capital investment). In their example, of a farm decision to invest in an anaerobic digester, we expect that the farm will proceed with the investment if the Net Present Value (NPV) of the investment is positive, with NPV equal to the present value of revenues minus the present value of costs. Present values were used to account for the fact that revenues flow in and costs are expended over time. Because a dollar earned today (in the present) is more valuable than a dollar earned in the future, we must discount future revenues streams and costs to present values.[6] Moreover, capital costs are often incurred at the beginning of the project while revenues accrue later, making it imperative to adjust the streams of revenues and costs to present values to properly compare revenues to costs.

It is useful to sort revenues into categories: 1) on-farm energy expenditures avoided, 2) energy sales, and 3) carbon offset sales.

- On-farm production allows the farm to reduce its expenditures on purchased energy (electricity or gas), and the value to the farm is the energy expenditures that are avoided.
- Avoided expenditures are larger for larger farms and vary across regions, depending on rates paid for commercial gas and electricity and weather-related variations in energy use.
- Energy produced on-farm may be sold to off-farm users; revenues will vary with the prices paid by utilities and other buyers, and with the quantities that they are willing to purchase.
- The nascent, volunteer carbon offset markets have established a price for carbon. There is continued policy interest in a full carbon market, and carbon offset markets remain a potential revenue source.

Similarly, it is useful to sort costs into several categories: 1) capital costs, 2) maintenance costs, 3) transportation costs, and 4) carbon offset costs. Some of these costs may not accrue to farm-based operations, but the classification speaks to economies of scale and agglomeration.

- Capital costs are the costs of acquiring and emplacing a waste technology and associated storage facilities. They are largely borne early in the project, before production.
- Facilities typically also require ongoing expenditures for operation and maintenance.
- Facilities may need to bear additional costs for cleaning gas (for sale to off-farm entities) or for obtaining carbon offset credits.
- There is considerable interest in community digesters involving multiple farms and other feedstocks, such as food waste; such operations would incur costs for transportation.

Capital and operating/maintenance costs typically increase with the amount of waste to be processed, but often less than proportionately, and thus, are often subject to economies of scale. Small farms often bear modest energy expenses, thereby generating only modest revenues from avoided expenditures, while very large operations can realize significant savings from avoided energy costs; this revenue scale economy can reinforce production scale economies.

Community facilities, serving multiple farms and often processing food, provide a channel for realizing scale economies in production and in revenues. However, waste must be shipped to community facilities from various source locations, and transportation costs will rise with the distance transported. Additionally, manure type and state can affect volume density ratios, limiting quantities than be transported in one haul (i.e. mostly liquid dairy manure versus mostly solid poultry litter). Thus, community facilities must trade off scale economies against transportation costs, favoring sources located close to the facility.

Governments have several policy levers to support adoption of facilities that can affect expected revenues by directly buying biogas, mandating the purchase price of electricity or RNG by utilities,

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[6] One dollar earned today can be invested, such that its value in a year will be $1*(1+r)$, where r is the rate of interest. In two years the dollar will be worth $1*(1+r)^2$, and in n years it will be worth $1* (1+r)^n$.

supporting prices that producers receive for biogas, RNG, or electricity sales, facilitating the creation of carbon offset markets, or taxing or otherwise limiting the use of competing fossil fuels. Government policy can also affect costs by directly paying for part or all of the capital or operating costs, supporting transportation of animal waste feedstocks, or providing tax credits for facility investment or operation, thereby, sharing costs indirectly.

Topic 3.3 Markets for Biogas

Sales revenues for biogas are affected by the quantity that may be sold and by the price received. The International Energy Agency (IEA) argues for the significant potential for biogas to meet future global energy needs (IEA, 2020): estimated world production of biogas amounted to 35 million tons of oil equivalent in 2018, a small fraction of the estimated potential (730 million tons).[7] The IEA notes that agriculture accounts for 60% of the global potential, based on global crop (36%) and animal manure (24%) potential oil-equivalent production.

As of 2018, Europe accounted for most global biogas production (18 of the 35 million oil-equivalents), with 75% coming from crop residues and animal manure digestion. The EU has set ambitious goals for renewable fuels, including biogas, resulting in member states introducing subsidies, regulations mandating renewable sources, and bidding requirements for energy producers (Scarlat, et al., 2018). By contrast, the IEA estimates that the US generated 4 million oil-equivalents, and most of that biogas derived from landfills and very little coming from agricultural projects.

The IEA sees great potential for future growth in RNG for use in transportation and power generation. At present, RNG is more costly to produce than natural gas, although the IEA argues that the gap is closing. It further argues that a major global shift to RNG will require technological improvements to reduce biogas and RNG costs, market developments and government interventions to raise the price of natural gas, and availability of biogas feedstocks.

Projections of Future US Energy Consumption and the Role of Renewable Feedstocks

The US market for animal waste-based electricity production technologies will depend on the expected future growth in US electricity production, the likely role of renewable sources in providing electricity, and comparative costs of alternative renewable sources. The US EIA projects that total energy use for electricity will grow slowly through 2050 (0.5% per year). However, there will be a substantial shift to renewables, projected to account for 60% of electricity production in 2050, up from 22% in 2022 (Figure 3.2a), continuing the sharp shift toward renewable sources over the past decade (2012-2021).[8] Almost all projected renewable growth comes from wind and solar, with projected 5.7% annual growth in production through 2034, slowing to 1.3% per year through 2050. Renewable sources accounted for 12.807 quads of energy production in 2022, with 5.097 quads from wind and solar, and 7.71 quads from hydro, geothermal, and biomass (primarily wood) sources.[9] In 2050, EIA projects renewables will account for 30.511 quads, with 22.395

[7] An oil equivalent is the quantity of a substance necessary to replace the energy on one barrel of oil—thus "35 million oil equivalents" refers to a quantity of biogas capable of replacing 35 million barrels of oil.

[8] Projected renewable growth over the next decade is quite high, with total electricity use growth of only 2.5% over 2022-2034, but renewable-based electricity production growth of 94% from an already substantial base.

[9] A quad is one quadrillion ($10^{15}$) British thermal units (BTUs).

quads from wind and solar, and other renewable sources, including biomass sources, at 8.12 quads, just 5% more than in 2022.

Wind and solar are projected to account for 73% (from 40%) of renewable energy by 2050, due to sharp continued price declines in solar (90%) and wind (60-70%) sources, resulting in smaller shares from hydro, geothermal, and biomass sources. Bioenergy generation costs were the lowest of all renewable sources in 2010 but showed no clear trend over the next 10 years, while on-shore wind and solar costs were below bioenergy by 2019, driven by technological advances (Figure 3.2b).

The IRENA cost estimates and EIA use projections create a challenge for manure-based energy projects, as they will compete not only with fossil-fuels but also with wind and solar. This solar cost advantage persists in Maryland. Modeling from the National Renewable Energy Laboratory projects that by 2030, the levelized cost of biopower energy will be roughly $60/MW, higher than both land-based wind ($34/MW) or solar ($43/MW) but lower than coal at $94/MW (NREL 2023).

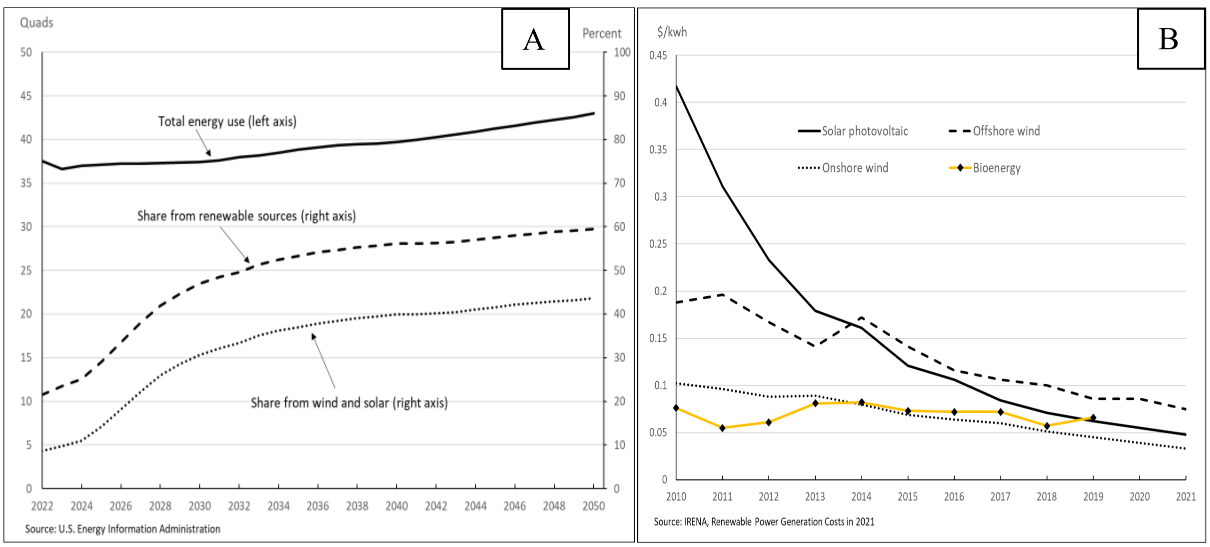


**Figure 3.2**: Energy use in electricity, with projections to 2050 in (A), and levelized cost of solar, wind, and bioenergy power from 2010-2021 (IRENA, 2022) in (B) in dollars per kilowatt hour (kWh) of electricity.

If wind and solar facilities continue to hold cost advantages over animal waste-based facilities, then mandates and carbon taxes that support all renewable sources are unlikely to favor biogas technologies. However, some policies do provide specific financial support to animal waste technologies, via tax credits or capital or operating subsidies. The 2022 Inflation Reduction Act offered tax credits to biogas facilities used for electricity or for transportation fuels. Other policies support the collection of food and agricultural waste, thus effectively reducing transportation costs for community and industrial biogas facilities. South Korea, Vermont, and California have policies banning the disposal of food waste through landfills (see Topic 2b for comparative analysis of Vermont policies). In South Korea, the policy has diverted most food waste to biogas facilities (Yoon, 2023). New York City and Maryland municipalities have introduced curbside food waste collection programs, on a limited scale, with household food waste sent to composting or biogas facilities.

There have been substantial investments in animal waste-based RNG digesters in recent years, both on-farm and at community facilities.[10] While many are in California, reflecting the state's expansion of support for dairy digesters, others can be found in Arizona, Colorado, Idaho, Indiana, Missouri, New York, North Carolina, Ohio, South Dakota, Texas, and Vermont. Expanded financial support for RNG facilities, provided in the 2022 Inflation Reduction Act, will likely fuel greater investment.

At present, fossil fuel-based natural gas is much cheaper than RNG, although the EIA argues that price gaps are narrowing. RNG costs vary widely with the type of RNG facility, the volume produced at the facility, and the attributes of the feedstock used. A 2022 study for Michigan estimated that animal waste-based RNG could be produced at costs ranging from $14.02 to $47.50 per thousand cubic feet of gas (ICF, 2022). By contrast, the average 2022 city-gate price for fossil fuel-based natural gas was $6.83, still less than half the low range for animal waste based RNG.[11] The comparison suggests that RNG will not be competitive with fossil fuel-based natural gas without substantial financial or policy support.

Use of RNG in Transportation

There are about 175,000 RNG-fueled vehicles in the US, over 4 million RNG vehicles in Central and South America, and over 6 million in the Asia-Pacific region. The US EIA estimates that 53.2 million $ft^3$ of natural gas were used in vehicles in 2022, up from 8.3 million 25 years before. RNG-fueled vehicles are less than 0.1% of the 278 million registered vehicles in the US. Most RNG-fueled vehicles are buses or light trucks operated by fuel providers, who in some cases act under government mandates to use RNG for a share of their fleets. Such agencies can provide their own refueling facilities, and the lack of a broad public refueling infrastructure presents a barrier to the private spread of such vehicles. California accounts for 47% of RNG use for transportation, followed by Florida (11%).

The US Market for On-farm Anaerobic Digesters

On-farm digesters typically process manure from a single livestock operation with or without added food waste, while community digesters combine food waste and/or manure from multiple facilities. The EPA AgSTAR database shows that on-farm digesters are primarily on dairy farms– 322 (83%) of the 388 US digesters (Figure 3.3). Of the remaining 66 digesters, 48 were on hog operations and 10 were on poultry operations (mainly egg laying farms). There were 94 closures of on-farm digesters over 1994-2022, including some opened prior to 1994. There were surges in digester openings following state-specific and federal policy initiatives[12]. The recent surge (2018-2022) is largely due to California's Low Carbon Fuel Standard (LCFS), which provides substantial

[10] Argonne National Laboratories maintains a spreadsheet listing the RNG facilities, with only 10 agriculture-based RNG projects each year from 2005 through 2017, followed by rapid growth to reach 109 in 2022.

[11] The city-gate price, drawn from EIA data, is the price paid by a distribution utility for natural gas and reflects the transportation cost of shipping gas from the wellhead to the local utility. The cited gap between RNG and fossil fuel-based natural gas accords with estimates produced in the IEA's Outlook for Biogas (2020).

[12] Earlier surges reflect USDA Rural Energy for America Programs and State renewable energy mandates that required utilities to use renewable energy for target shares of electricity production (MacDonald, et al., 2009).

financial support to farmers for capturing methane from uncovered manure lagoons via digestion (Smith, 2022; Lim, et al., 2023).

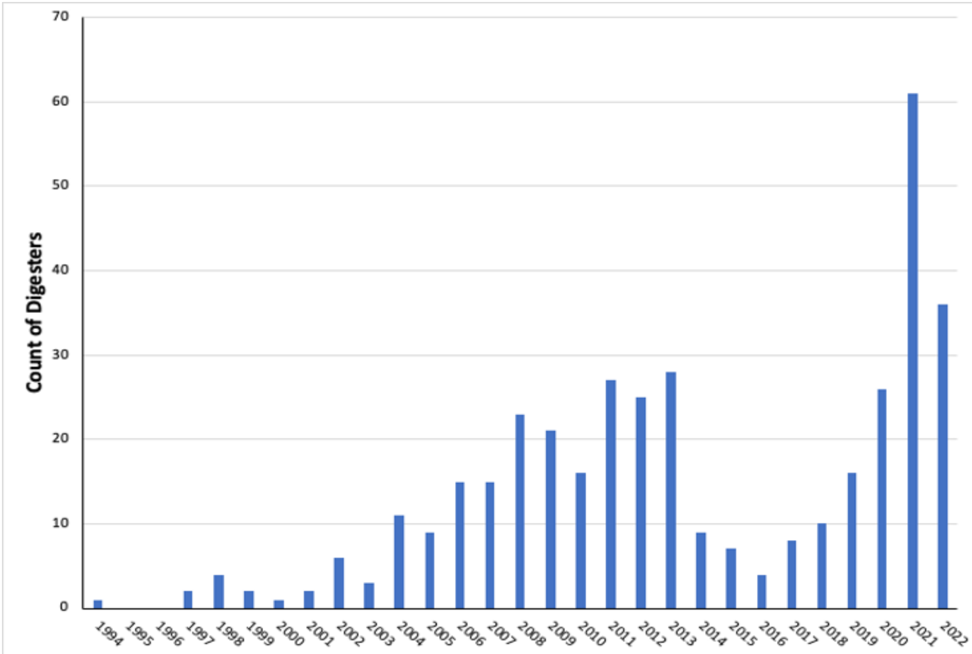


**Figure 3.3**: US anaerobic digesters based on the year of opening (1994 to 2022) created from data on the EPA AgSTAR database.

California is the leading dairy state with many large-scale operations where digester adoption is potentially feasible. About half of CA's dairy farm digesters generate electricity and half generate RNG (Smith, 2022). RNG use for transportation in CA more than doubled from 2011 to 2021, mainly captured from landfills, but the digester share of RNG has grown rapidly since 2019. The 2022 Inflation Reduction Act provides significant new support for on-farm digesters through tax credits and expanded support for USDA's Environmental Quality Incentives Program (EQIP), which shares costs for on-farm digesters and associated storage facilities.[13]

Most digester adopters are large farms, and adoption has been shifting to larger farms over time (Figure 3.4). Before 2002, the average adopting farm had < 1,000 cows, but the average herd size of recent adopting farms has increased to 4,000 - 7,000 head. To put this in context, only 6% of US dairies have > 1,000 head, while 78% have < 200 head.[14] (Figure 3.4). The 91 dairy farms that adopted digesters in 2021-22 accounted for 7% of all US milk cows.[15] Dairy farms that adopted digesters since 1994 collectively account for 1.28 million cows, only 13% of US milk cows in 2022, showing that digesters have been adopted on only a small fraction of US dairy farms.

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[13] Tax credits are valuable investment incentives for firms with taxable income. Many farms have low taxable incomes, in part due to favorable depreciation policies. On-farm digesters are often owned by off-farm entities who finance and operate the digesters and make effective use of the tax shelters.

[14] From the 2021 dairy version of the annual Agricultural Resource Management Survey (ARMS) by ERS.

[15] EPA's AgSTAR database reports the name and location of adopting farms, digester type, livestock species, and herd size (number of cows) for most dairy farms. Missing herd values were calculated to achieve this value.

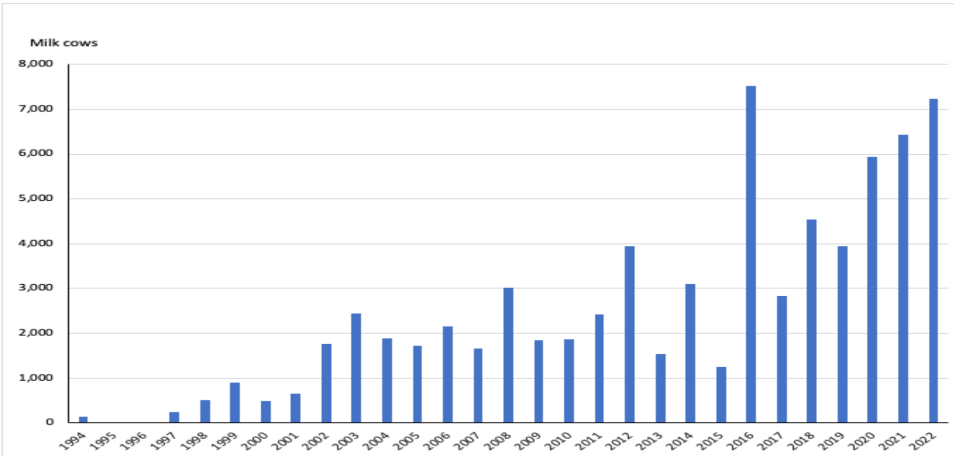


**Figure 3.4**: Average herd size of dairy farm digester adopter, which were calculated from EPA AgSTAR data (1994 to 2022).

There are substantial economies of scale in on-farm digester operation, with average digester costs falling sharply as herd size increases. Valdes-Donoso and Sumner (2019) estimated average annualized digester capital costs of $434,000 and annual operating and maintenance costs of $588,000 for CA dairy farms based on researching the 34 projects funded by the CA Dept of Food and Agriculture[16]. They reported that costs per cow continued to fall sharply, especially as herd size increased from operations with 2,000 cows to 12,000 cow operations.

Given the cost of digesters, adoption is simply not economic for most US dairy farms without substantial subsidies. California has introduced an Alternative Manure Management Program (AMMP) aimed at smaller dairy operations to support alternative waste management technologies, including conversion to pasture-based dairies, composting, drying, solids separation, and dry scraping for manure collection. Moreover, support for digesters has come under criticism for providing incentives to consolidate dairy production into larger operations, and thereby exacerbate water quality risks through agglomeration of manure. Some argue that current levels of digester support in CA could cause farmers to expand dairy production, thus increasing methane produced by animal agriculture (Smith, 2021). However, dairy production across the US has been shifting to larger farms, even without support for digesters, in response to substantial production scale economies (Table 3.1).

**Table 3.1**: Dairy Production Shifts to Much Larger Farms

| Herd size (milk cows) | 2005 | 2010 | 2016 | 2021 |
|---|---|---|---|---|
| | --Share (%) of US Milk Cow Inventory-- | | | |
| 10-49 | 6.9 | 5.8 | 3.8 | 2.9 |
| 50-99 | 15.7 | 13.2 | 9.7 | 7.9 |
| 100-199 | 16.4 | 13.9 | 9.9 | 6.4 |
| 200-499 | 17.7 | 14.5 | 11.8 | 10.9 |
| 500-999 | 13.3 | 13.9 | 13.3 | 10.8 |
| >999 | 30.0 | 38.7 | 51.5 | 61.1 |

Source: U.S. Department of Agriculture, Agricultural Resource Management Survey, version 4, for the years noted.

[16] Annualized costs would add about 5% to total costs at dairies with > 2,000 cows based on US ERA milk cost (https://www.ers.usda.gov/data-products/). The addition at smaller farms would be 10% to 20% of total costs.

While it is possible that policy initiatives and financial trends might move most dairy manure in the US through digesters, those initiatives are unlikely to have significant effects in MD, where the dairy sector is largely composed of small operations. Maryland has very few farms with or more than 1,000 milk cows (4 in the 2017 Agricultural Census, accounting for just 12% of the State's milk cow inventory). We do not expect a substantial increase in the number of large dairy farms in MD, and therefore do not see a major role for expansion of on-farm digesters on MD's dairies, unless there is co-digestion with food waste and that comes with substantial subsidies to incentive the diversion of waste to digestion.

Community Digesters

Anaerobic digesters are subject to considerable economies of scale in construction, operation, and feedstock quantity, and consequently have been used primarily on large dairy and hog farms. Community digesters are designed to serve multiple users, sourcing manure, food waste, and/or industrial waste from multiple farms or off-farm sources. The AgSTAR database reports that on-farm digesters make up almost 90% of agriculture-based digesters, with community digesters representing less than 10% (1% being research facilities). Community digesters must trade off scale economies in operation against transportation costs of moving manure and waste from multiple locations to the digester and moving digestate residues from the facility to fields for fertilizer application or treating the liquid digestate. Transportation costs appear substantial enough to make community digesters feasible only for farms within 10-15 miles of the facility. Community digesters require considerable commitments to maintenance and skilled operators, as the waste flows to the facility may vary considerably across sources and over time –especially with the varied characteristics of food waste in comparison to the more stable qualities of animal waste if co-digestion occurs. In short, they are most feasible in locations with a fairly dense concentration of participating industrial sources and small-to-midsize dairy farms. Economics will depend on transportation cost for land application compared to the high costs of digestate treatment of the liquid component after extraction of available nutrients. Solids residuals have available markets as compost materials.

Digestate residues: Fibers, bedding, and fertilizers

Anaerobic digestion processes produce biogas and digestate residues, liquids and solids, which may be separated in further processing. The precise composition of residues varies, depending on the feedstocks used. Liquid residues from digestion of animal manure are usually dense with plant nutrients and should be used as crop fertilizer or treated. The separated fibrous solids in residues contain microbial biomass, animal hairs, undigested organic materials, and nutrients. Digestate manure-based solids can be converted into animal bedding for use on-farm, sold to other farms, or sold as a soil amendment.

Most animal manure is land applied as fertilizer, directly or after digestion or composting. According to the Census of Agriculture, manure is applied to only about 6% of cropland in the US, while applications in Maryland are substantially higher. Nonetheless, cropland in the state has been declining over time (Table 3.2), by about 4% over 2002-2017. Animal manure can be costly to transport and apply, especially if it has a high liquid content. Competing inorganic (synthetic) fertilizers can be mixed to realize the precise nutrient content that a farmer wants, while manure often combines nitrogen (N), phosphorus (P), and potassium (K) in ratios that depart from the optimal mix that a farmer desires.

**Table 3.2**: Land use in Maryland.

| Year | Acres of cropland | Acres receiving manure |
|---|---|---|
| 2002 | 1,487,218 | 251,097 |
| 2007 | 1,405,442 | 241,641 |
| 2012 | 1,396,144 | 208,568 |
| 2017 | 1,426,671 | 204,000 |

Source: USDA National Agricultural Statistics Service, Census of Agriculture.

Animal manure does provide a substantial share of the fertilizer nutrients applied to Maryland fields (Table 3.3): 14.9% of N, 47.1% of $P_20_5$, and 31.5% of $K_2O$, according to 2019 AIR reports filed by farmers.[17] The percentages vary across crops, but corn is the major user of nutrients. This crop, which accounts for just under one-third of Maryland farmland receiving any nutrients, received 83% of N applications in 2019, 62% of $P_2O_5$ applications, and 49% of $K_2O$ applications.

**Table 3.3**: Use of Manure-Based Nutrients in Maryland in 2019

| Crop | Acres Planted | Nutrients Applied | | |
|---|---|---|---|---|
| | | N | $P_20_5$ | $K_20$ |
| | | Share (%) of manure nutrients | | |
| All crops | 1,531,983 | 14.9 | 47.1 | 31.5 |
| Corn | 485,736 | 12.4 | 53.3 | 40.3 |
| Soybeans | 463,668 | 26.5 | 17.4 | 8.4 |
| Small grains | 298,997 | 10.5 | 34.3 | 24.9 |

Notes: "Small grains" include wheat, barley, oats, and rye. "All crops" include corn, soybeans, small grains, tobacco, vegetables, hay, and pasture. Source: 2019 Maryland AIR reports

Animal manure accounted for over half of $P_20_5$ applications in corn, and over a third of $P_2O_5$ applications in small grains. This is remarkable, in that many farms do not apply animal manure; meaning that many of those who do apply with animal manure get almost all of their recommended P applications from said manure. Specifically, the AIR reports indicate that 936 farms applied manure-based $P_2O_5$ to their corn acreage, but over 1,300 farms applied inorganic $P_20_5$. The reports further show that 236 farms applied manure-based $P_2O_5$ to small grains acreage, but more than twice as many applied synthetic $P_20_5$. Now, farms may apply both synthetic and manure nutrients, but the data show that many farms that apply nutrients do not apply manure. In turn, that finding suggests that manure provides all, or nearly all, of the $P_2O_5$ needs for many farms, and that they cannot apply more manure, even if they are short of N, because any additional manure will add more $P_2O_5$ and instead farms will add synthetic N. In consequence, the high $P_2O_5$ levels in animal manure often limit the amount that can be spread as fertilizer.

[17] $P_20_5$ refers to phosphate and $K_20$ refers to potassium oxide, P and K as reported on the AIR forms.

**Table 3.4**: Use of Manure-Based Nutrients, 2019, in Selected Maryland Counties

| County | Share (%) of Nutrients Provided by Manure | | | |
|---|---|---|---|---|
| | Corn | | Soybeans | |
| | **N** | **$P_20_5$** | **N** | **$P_20_5$** |
| Baltimore | 5.0 | 21.5 | 15.9 | 7.7 |
| Caroline | 32.5 | 83.9 | 43.1 | 26.7 |
| Carroll | 10.1 | 36.3 | 20.1 | 5.9 |
| Cecil | 10.4 | 35.2 | 15.2 | 7.0 |
| Dorchester | 18.2 | 76.9 | 30.4 | 29.7 |
| Frederick | 9.2 | 34.4 | 27.4 | 16.8 |
| Harford | 11.6 | 27.7 | 11.8 | 5.0 |
| Kent | 23.1 | 75.0 | 38.2 | 28.4 |
| Montgomery | 0.5 | 2.6 | 0.0 | 0.0 |
| Queen Anne | 11.0 | 53.6 | 33.0 | 27.8 |
| St. Mary | 16.8 | 62.0 | 2.0 | 2.0 |
| Somerset | 18.8 | 84.5 | 2.5 | 58.2 |
| Talbot | 11.5 | 42.0 | 24.8 | 13.1 |
| Washington | 16.4 | 49.7 | 75.6 | 58.5 |
| Wicomico | 13.5 | 71.4 | 0 | 0 |
| Worcester | 16.1 | 75.3 | 21.1 | 17.3 |

Source: Maryland AIR reports.

The use of manure-based nutrients varies widely across Maryland counties (table 3.4). For brevity, we reported on two nutrients and two crops for counties with at least 30,000 acres of cropland. Farmers in different counties may face different prices and availability for manure, and their choices are also likely affected by soil attributes and crop choices. Nevertheless, it should be noted that manure accounts for over 70% of $P_20_5$ applications in corn fields in six Eastern Shore counties, suggesting that the phosphorus content of Eastern Shore animal manure limits expanded use for field application.

There have been ongoing efforts to reduce concentrations of $P_20_5$ in animal manure, through changes in breeding and feed composition. For example, many growers use feed additives to increase the absorption of phosphorus in feed, and reduce the amount excreted in manure. These efforts had some success in the early 2000's, to judge from tests of the nutrient composition of manure, but further improvements have not come about.

Topic 3.4: Other Animal Waste-Based Technologies

Thermochemical Conversion for Energy

Thermochemical conversion processes use heat, applied in a controlled environment, to set off chemical changes to manure, generating gases, which can be used for heat, electricity generation, or upgraded to transportation fuels, as well as bio-oil and biochar, with outputs depending on process conditions, which vary in sophistication and heat applied from simple combustion to more advanced (and less oxygen introduction) gasification and pyrolysis. Thermochemical processes can provide faster conversion than biological processes, such as digestion and composting, but consume/combust some of the nitrogen during conversion. They can also exacerbate air quality concerns through emissions arsenic, dioxins, nitrous oxide, and sulfur oxides (Lim, et al., 2023), depending on the thermal conversion process used (gasification and pyrolysis has less emissions however) as well as any filters utilized.

Manure-fired power generation plants have operated in California, Minnesota, and Texas, and as of 2008 there were announced plans to build several more (MacDonald et al., 2009). The operating and proposed plants used poultry litter as the primary feedstock, with some reliant on manure from beef cattle feedlots. Even at that time, manure was a relatively expensive fuel source due to high transportation costs and the high liquid content relative to coal or wood. Several of the plants benefitted from state policy mandates that required utilities to base target shares of generation on renewable sources and some received capital or operating subsidies from state governments (MacDonald et al. 2009). The manure-fueled combustion plants in operation in 2009 later shutdown due to lower costs of other renewables (wind and solar) and the expansion plans did come to fruition. At present, no full-scale combustion plants using manure are in operation in the US (Lim, et al., 2023).

Gasification converts biomass, such as manure, into more concentrated forms, producing gases, such as carbon dioxide and hydrogen, and a biochar residual byproduct. The gasification steps require increasing amounts of heat applied, generating a low-energy fuel that can be burned directly for heat or electricity production. Biochar, a light charcoal-like substance, is a value-added product as a soil amendment and fertilizer, since it retains the feedstock's phosphorus and mineral content and part of its nitrogen. But, it must still be transported back to fields for application. A poultry litter gasification plant in Pennsylvania is co-located with a large egg-laying facility to provide a large, steady feedstock at minimal transportation costs. However, the plant has needed to rely on support from state agencies to remain financially viable over the last decade.[18]

Pyrolysis converts manure into gases for fuel, the solid biochar, and a liquid bio-oil. The gas and bio-oil offer promise as feedstocks for heat or electricity generation, while biochar can be applied as fertilizer. As the type and number of value-added products increase from the thermochemical process (from combustion to gasification to pyrolysis), so does the process sophistication and the capital-intensiveness of the facilities. Thermochemical plants have primarily been used to generate electricity. As such, they compete with solar and wind, and their declining costs will favor adoption over thermochemical conversion plants.

Algae Production

Research projects, some funded by or performed at USDA facilities, have explored the use of manure as a feedstock in the production of algae, which can be harvested and used for biofuels, fertilizers, or animal feed. The research has primarily focused on swine and dairy manure, with some research exploring the use of residues from digester operations as feedstock to algae production. Closed algae systems consist of tubes or plates with much higher capital costs, while less expensive open pond or tank systems are sensitive to temperature drops in most parts of the country. Algae has high liquid content and harvesting requires the use of separation and drying

[18] The plant's history points to a second challenge: developing accurate data for incentive programs to manage manure. The facility's 5 million layers were not recorded in county-level estimates in the Census of Agriculture to maintain confidentiality rules that prohibit disclosing an individual's identification (Blankenship 2022).

equipment to sort out the solids for commercial use. Algae production remains in the development stage, with no current commercial applications. However, there has been significant corporate investment in development projects.[19] It remains to be seen whether commercial algae production will rely on animal waste-based feedstocks for the future to come.

**Topic 3 Key Findings and Recommendations**

1. There is growing policy interest in renewable energy. Solar and wind-based energy are expected to account for almost all the growth in renewable energy use for electricity. Without state or federal policy support improvements, we may not see substantial growth in animal waste-based electricity generation due to this steep competitive landscape.
2. Anaerobic digesters, and other technologies for converting animal waste to energy, do not eliminate the need for a land base for nutrient application, as those technologies leave nutrient-dense residuals. Total cropland and available cropland receiving manure is declining in Maryland over time.
3. Animal wastes provide a substantial share of the nutrients applied to farmland in Maryland. In many locations, manure application meets all of a crop's need for phosphorus, even as it meets a much smaller share of nitrogen requirement. In that sense, the phosphorus content of manure constrains the amount that can be applied.
4. Maryland counties vary widely in their use of manure for nutrient applications, suggesting opportunities for expanded applications in some areas, especially if transportation costs and phosphorus content can be reduced.
5. Federal and some state policies (California, for one) make renewable natural gas (RNG) facilities more profitable, resulting in a sharper rise in upgrading biogas to RNG for use as a transportation fuel on larger dairy farms due to the higher capital investment needed.
6. Digesters are far more economic on very large dairy farms, with adopter herd size averaging 4,000-7,000 milk cows in recent years due to substantial scale economies in both digester operations and the dairy industry. Maryland has few large dairy farms, which limits the likelihood of on-farm adoption in the state, without subsidies.
7. There are far fewer thermochemical processing units, making it difficult to conduct full analysis, but the few existing plants produce electricity and must compete with wind and solar, which is challenging due to lower costs of these technologies compared to biomass.
8. The main drivers for digestion and thermochemical adoption are scale for on-farm systems and transportation distances for community systems.

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[19] In March of 2023, United Airlines announced a $5 million investment in a Chicago-based algae producer. In 2019, Nestle announced an agreement with an algae producer to develop algae-based food ingredients; Nestle is also a major producer of sustainable aviation fuels, and has pursued projects on algae-based fuels.

## TOPIC 4: RECOMMENDATIONS

**Topic 4a. Detailed recommendations on future use of the Animal Waste Technology Fund to improve public health and the environment, reduce nitrogen and phosphorus transported to the waters of the State, and address climate change goals.**

- Animal waste technology funding should take into account the manure distribution sources in the state and target locations that would have the largest reductions in GHG emissions and eutrophication. There should be targeting of specific areas in the state and matching of the best technological option and/or mitigation practice with the nutrient and GHG reduction needs in that location. CAFO mapping should be used in decision making. A manure-shed concept mapping effort could be utilized in Maryland, similar to Pennsylvania's effort, where nutrient "sinks" and "sources" are identified for targeted future mitigation efforts.
- The fund should consider assisting in locations to store, compost, digest, or otherwise process DAF in Maryland. There is a large quantity of DAF moving through the state of Maryland to be processed, stored, field applied, or transported to Pennsylvania. There is a need for safer DAF holding units that can process DAF year-round while not causing concerns to the locals in the communities, such as composting or anaerobic digestion to remove odor concerns and aid with application of DAF-based soil amendments.
- The fund should link with state-wide efforts to reduce GHG emissions. As dairy farms are decreasing in Maryland, manure sources are being concentrated on fewer farms and stored uncovered in anaerobic lagoons. Covering these lagoons would reduce GHG emissions and bring alternative income to dairies during the current time of instability in milk prices.
- There should be more direct linkage between efforts at MDE to reduce food waste and MDA's efforts in assisting on-farm manure technologies. Procedural alignment of food waste diversion efforts would ensure consistent feedstocks are brought to a composting or digestion facility and help in securing long-term contracts and reducing economic instability.
- Interviews revealed there is an interest for waste technologies and manure storage systems for large crop farms, which could incorporate manure and/or food waste but permitting these facilities is not allowed under current code. Many farmers and agencies have noted the inability to get certain waste (i.e. poultry litter from the Eastern Shore) to Central and Western Maryland, especially during off-peak seasons. If poultry houses had more local technology options and/or storage capacity to hold litter during the off-peak months, this could reduce long-haul transportation during peak-litter demand season, which would improve local traffic patterns and reduce GHG emissions associated with this transportation.
- There needs to be more education and technical support/tools. There is a lack of education on waste technology systems in the state, both among the public and within state agencies and utility companies (who do not have incentives to engage). Current policy does not recognize the multiple benefits of digesters beyond energy production. Educating applicants in the technologies could lead to designs more tailored to the needs of the agriculturalists as well as meeting climate change mitigation efforts of the state. Additionally, more education could create more robust applicants with varied projects and ideas and help applicants with other federal and state co-funding. Educating the public could lead to more internal expertise and policy changes that incentive animal waste technologies and reduce misinformation.
- There should be specific educational outreach to the public and interested parties prior to applications being submitted. Limited funding has discouraged many from applying or

unsuccessful applicants from reapplying. One option might be moving the AWTF applications to two-year basis, with Year 1 being an educational/instructional year devoted to public and industry education, developing timelines for permits and planning, and technical assistance on the application (ideally in conjunction with UMD Extension, county Soil Conservation Districts, and current farms using these technologies). For example, the California's fund sets aside funds for a dedicated technical board staff to work year-round solely on application support. The following year (Year 2), applicants would submit project proposals, with criteria that applicants participate in a certain amount of provided educational and outreach programs in Year 1 to qualify for the fund. Past projects from the previous years of the fund should be initially contacted and analyzed to see if this type of education and technical support would address some of the past project failures.

## RECOMMENDATIONS

**Topic 4b. Detailed recommendations on future uses of the Animal Waste Technology Fund to preserve the viability of the agricultural industry by improving animal waste management strategies.**

- The fund should consider devoting funds to aid local communities, like county Extension offices or county Soil Conservation Districts, to provide technical support and purchase and maintain equipment for manure injection, composting, or biogas upgrading equipment. A equipment loan program would allow more farms the opportunity to use animal waste technologies and strengthen the relationship and trust between the community and MDA.
- The members of the AWTF boards and committees should consider using portions of the fund for developing or enhancing current state databases, with digitizing information on manure, AIRs, and various manure-based technologies to better understand the current state and the effect of technology implementation on nutrient and GHG emissions reductions.
- The fund could designate portions of the fund to pay for technical service providers to aid applicants in their applications and possibly increase both quantity and quality of applicants.
- The fund should encourage farmers and potential applicants in locations that would be positively impacted from the byproducts and benefits of animal waste technologies. This effort could include cross-referencing with food waste diversion efforts, areas in need of renewable energy, and potential for community-based technological sites. This can be done by highlighting targeted locations and marketing in this area for specific application years.
- Policymaker should be provided with educational and technical knowledge of animal waste technology efforts and the effect of technology adoption incentive programs. For example, increasing electric net-metering for biomass projects to match the resiliency and capabilities of these technologies, or ensuring “biomass” is included in “renewable energy” policies.
- The fund should consider supporting projects that would help reach the state reach mandated climate change goals for 2031 and 2045. This effort could include creating more inclusive language that acknowledges the role that animal waste technologies have in climate change mitigation, GHG reduction calculators for these technologies (similar to California), or other aids to help biomass projects in  competitive market for renewable energy production.
- The fund could have a required follow-up, lessons learned to ensure success and longevity of awarded projects. Anonymized follow-up materials could be posted to the AWTF’s website to aid future applicants and allow them to hear directly from successful applicants.
- The fund should provide ways to determine return on investment for GHG mitigation and reduction. The California Department of Food and Agriculture's "Dairy Digester Research and Development Program" puts a dollar value on the GHG emissions reduction of each project as part of the application process. It is important to estimate expected GHG emissions before starting a project. Additionally, the fund has evaluation criteria that includes technical feasibility, GHG emissions reductions and co-benefits, NOx reduction, cost-effectiveness, project readiness, community engagement and outreach (i.e. environmental justice), and impact on the California dairy industry (Appendix E). This model could be replicated in Maryland to provide a more inclusive criteria for funding projects based on state goals.

**RECOMMENDATIONS**

**Topic 4c. Detailed recommendations on future uses of the Animal Waste Technology Fund to incorporate environmental justice into the selection and siting of future projects.**

In general, recommendations are derived from analysis of information shared in interviews and focus groups by community members and stakeholders that participated in the Environmental Justice Framework (see more details in Topic 2f).

- **Environmental Exposure Plan and Community Impacts Assessment:** Applicants could conduct community impact assessments focusing on exposure and social vulnerability as part of the application process using a tool such as EJScreen, MD EJScreen, Affirmatively Furthering Fair Housing (AFFH) mapping, or a rapid Health Impact Assessment (HIA) (Baskin-Graves et al., 2019) to identify populations and critical services (e.g. schools, healthcare facilities) located in proximity to the proposed site. Specific attention should be paid to vulnerable populations including:
    - Groups with limited mobility and higher risk of illness, including children and seniors.
    - Groups that have historically been disproportionately burdened by the siting of environmental impacts, including BIPOC, low-income, and low-education populations.
    - Groups with limited access to system resources, including limited-English proficiency.
    - If possible, the presence of migrant and undocumented labor populations.
- **Communication:** Community members have highlighted the need for improving the communication and dialogue between funders, farmers, and residents about environmental issues before the project begins. This can be done by using tools, such as EJSCREEN or health impact assessments and starting communication early in the planning process.
- **Social Vulnerability**: When discussing what makes communities more vulnerable in the context of animal waste management, participants shared their experiences, which included the distribution of harms in the community, diseases or odors concentration, the resources to mitigate impacts, health insurances, and nationalities of residents. While conducting EJ analysis, it should be noted that vulnerable communities near waste management sites may not appear in official data sources due to the presence of migrant and seasonal workers. Spatial analyses are suggested to help locate and profile the communities most vulnerable to the impacts of animal waste technologies and develop mitigation measures tailored to their specific needs based on surrounding social, economic, and environmental data.
- **Education:** Recipients should engage in community education on the immediate and longer-term risks and benefits of the specific technologies the grantee is using or plans to use. Application could include a space for an education plan with the following features:
    - Available in appropriate local languages and in terms understandable to the local public and media.
    - Education could include flyers, events, town meetings, and public announcements.
    - Applicant could provide evidence that the methods chosen for education were selected to reach the appropriate audiences identified in the community impacts assessment.

- **Engagement:** AWTF may consider evidence of engagement with community members prior to application and/or during implementation. Engagement should incorporate groups identified in community impacts assessment.
  - Engagement could include in-person or virtual options in appropriate languages.
  - Time of day for engagement should be based on local needs.
  - Evidence of engagement could include attendance sheets, notes showing collection, and consideration of feedback.
  - Engagement could be combined with education efforts if substantial time is given to ensure comprehension and feedback.
  - Minority and vulnerable populations should be included in the decision-making process, advising boards, and apportioning funds for AWTF, with seats maintained for community representatives from vulnerable populations or EJ experts who engage with these groups.
- **Monitoring and Evaluation:** The AWTF could request an EJ evaluation plan, which could include continued contact with diverse community members, updates on areas of concern identified in Engagement, and revision (as appropriate) of the community impacts assessment.
- **Funding:** Engagement with vulnerable and historically marginalized populations can include funds for empowering communities on local land use and agricultural decisions, such as the formation of local advisory committees.
- **Representation:** The fund should have community members and under-represented demographics accounted for in the decision-making process of the AWTF, such as having an EJ expert reside on the Technical Advisory Committee to guide and educate decisions for the application review and ensure community engagement is met.
- **Understanding the "California" model:** The Dairy Digester Research and Development Program funded by the California Department of Food and Agriculture emphasizes public acceptance and environmental justice, with grant applications required to provide detailed plans for mitigating negative environmental impacts and evidence of community outreach efforts. In-person community meetings are mandatory, with supplementary materials, such as at least three letters of support and/or documentation of outreach efforts, required at the time of application (see Appendix E). The evaluation criteria for the California Dairy Digester Research and Development Program includes sections on community impacts and mitigation, localized economic benefits, and benefits to priority populations. The program does not restrict project location but requires individual digester projects at unique sites to address community impact guidelines. Applicants are required to complete the CARB Community Engagement Questionnaire and provide supporting documentation, including letters of support and information on outreach efforts. The program provides guidance and clarification through a Frequently Asked Questions section (see Appendix E). AWTF can also reference EJ factors by using procedural processes from other states which considers EJ efforts and concerns in their regulations.

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