

Appendix A

List of Ammonia Control Measures and Associated
Studies for Animal Feeding Operations

EPA Region 9: List of Ammonia Control Measures and Associated Studies for Animal Feeding Operations

Last Updated 1/10/2023

Note: This list does not summarize research studies on composting (for biosolids, organic materials, etc.)

Activity / Category	Control Measure(s)	First Author	Study Name	Journal (or Other Publication / Event)	Pub. Date	Reference Point	Citation	Link(s)	Link(s) Good / Bad	Notes
1-Nutrition and Feed Management (Feeding)	COMPILATION: Group and phase feeding; feed additives; feed processing, storage, and delivery; dietary formulation changes	(USDA-EPA)	Agricultural Air Quality Conservation Measures, Reference Guide for Poultry and Livestock Production Systems	(USDA-NRCS and USEPA)	2017	10/5/2022 USEPA proposed rule	Department of Agriculture, Natural Resource	rsc.usda.gov/sites/default/files/2022-06/Ag_AQ_Co	Good	Referenced in 10/5/2022 EPA proposed rule; NRCS Practice for Feed Management (592)
1-Nutrition and Feed Management (Feeding)	COMPILATION: Reduce protein content, phase feeding, increase grazing time	Guthrie	The impact of ammonia emissions from agriculture on biodiversity	(Rand Europe and The Royal Society)	2018	Public Justice et al. Comments	et al, RAND Europe and	/10.7249/RR2695	Good	Exhibit 38 (ref. to full doc), 1/28/2022 Public Justice et al.
Management (Feeding)	Phase-feed crude protein (beef steers)	Cole	carcass characteristics, serum urea nitrogen concentrations,	J. Anim. Sci.	2006	Public Justice et al. Comments	Defoor, M.			(body of letter) 1/28/2022 Public Justice et al.
Management (Feeding)	Reduce crude protein (beef cattle)	Todd	emissions from artificial feedyard surfaces.	J. Environ. Qual.	2006	Public Justice et al. Comments	Cole, R. Clark,	onlinelibrary.wiley.com/doi/10.1002/eq.2695	Good	(body of letter) 1/28/2022 Public Justice et al.
Management (Feeding)	Reduce dietary crude protein (beef cattle)	Cole	on potential ammonia emissions from beef cattle manure.	J. Anim. Sci.	2005	Public Justice et al. Comments	Influence of	mic.oup.com/j	Good	(body of letter) 1/28/2022 Public Justice et al.
Management (Feeding)	Reduce dietary crude protein (pigs)	Hayes	ammonia emissions from finishing pig houses.	Bioresour. Technol.	2004	Public Justice et al. Comments	al., "The			Exhibit 37, 1/28/2022 Public Justice et al.
Management (Feeding)	Reduce dietary protein	Hristov	emitting potential of manure from commercial dairy farms	Scientist	2015	2018 PM2.5 Plan, App. C (CAFs)	Heyler, K.,			
(Housing)	Clean lanes at dairies	Beene	Dairy	Emissions Inventory	2005	2018 PM2.5 Plan, App. C (CAFs)	Krauter, C.,	epa.gov/ttnchi	Good	
2-Animal Confinement (Housing)	Clean lanes at dairies	Schmidt	Assessment of Reactive Organic Gases and Amines from a Northern California Dairy Using the USEPA Surface Emissions Isolation Flux Chamber	(14th USEPA Annual Emissions, Inventory Conference, Las Vegas,	2005	2018 PM2.5 Plan, App. C (CAFs)		http://www.epa.gov/ttn/chief/conference/	Bad	
2-Animal Confinement (Housing)	COMPILATION: Litter amendments and manure additives; (electrostatic precipitation); oil spray/sprinkling; biofilters; wet scrubbers; (wind breaks and shelterbelts)	(USDA-EPA)	Agricultural Air Quality Conservation Measures, Reference Guide for Poultry and Livestock Production Systems	(USDA-NRCS and USEPA)	2017	10/5/2022 USEPA proposed rule	Department of Agriculture, Natural Resource	rsc.usda.gov/sites/default/files/2022-06/Ag_AQ_Co	Good	NRCS Practices for Amendments for Treatment of Agricultural Waste (591), Air Filtration and Scrubbing (371), Windbreak/Shelterbelt Establishment (380), and Windbreak/Shelterbelt
2-Animal Confinement (Housing)	COMPILATION: Scrub air, wash floors, increase outdoor grazing, floor design (slats, grooves, v-shaped gutters, sloping floors), acclimatize barn (insulation, auto-controlled natural ventilation), cool manure surface, acidify slurry / shift chem. balance from ammonia to ammonium, straw bedding for cattle housing	Guthrie	The impact of ammonia emissions from agriculture on biodiversity	(Rand Europe and The Royal Society)	2018	Public Justice et al. Comments	et al, RAND Europe and The Royal Society, "The impact of ammonia	https://doi.org/10.7249/RR2695	Good	Exhibit 38 (ref. to full doc), 1/28/2022 Public Justice et al.
(Housing)	Corrals: Constantly manage corrals	Card	Estimation Procedure	(Final Report to CARB)	2006	2018 PM2.5 Plan, App. C (CAFs)	Schmidt, C.,	b.ca.gov/ag/ca	Bad	
(Housing)	Corrals: Frequency of corral manure management	Schmidt	Factors and Emission Estimation Procedures	SJVUAPCD)	2009	2018 PM2.5 Plan, App. C (CAFs)	2008 Dairy			
(Housing)	Enclosed barns with biofiltration systems	Kresge	County's Air Quality and Public Health	Rural Studies)	2007	Public Justice et al. Comments	Institute for			Exhibit 19, 1/28/2022 Public Justice et al.
(Housing)	Scrape / flush freestall lanes	Mendes	Houses via Improved Management or Design-Based Strategies: Environment	Environment	2017	2018 PM2.5 Plan, App. C (CAFs)	Pieters, J.G.,	10.1016/j.scj.2017.06.001	Good	
(Housing)	Separate urine/manure with 3% floor slope	Braam	emission from cubicle houses for dairy cows	Life Sciences	1997	2018 PM2.5 Plan, App. C (CAFs)	Effects of floor	wur.nl/ojs/ind	Good	
3-Manure Management (Storage)	Anaerobic digesters	Kresge	Clearing the Air: Mitigating the Impact of Dairies on Fresno County's Air Quality and Public Health	(California Institute for Rural Studies)	2007	Public Justice et al. Comments	Institute for Rural Studies, "Clearing the			Exhibit 19, 1/28/2022 Public Justice et al.
3-Manure Management (Storage)	COMPILATION: Litter amendments and manure additives; biofilters; manure storage covers; solid-liquid separation; oxygenation of liquid manure lagoons; composting; anaerobic digester	(USDA-EPA)	Agricultural Air Quality Conservation Measures, Reference Guide for Poultry and Livestock Production Systems	(USDA-NRCS and USEPA)	2017	10/5/2022 USEPA proposed rule	Department of Agriculture, Natural Resource	rsc.usda.gov/sites/default/files/2022-06/Ag_AQ_Co	Good	NRCS Practices for Amendments for Treatment of Agricultural Waste (591), Air Filtration and Scrubbing (371), Roofs and Covers (367), Waste Separation Facility (632), Waste Treatment (629),
3-Manure Management (Storage)	COMPILATION: Solid cover, floating cover, natural crust, floating crust, replace lagoons with deep tanks, storage bags	Guthrie	The impact of ammonia emissions from agriculture on biodiversity	(Rand Europe and The Royal Society)	2018	Public Justice et al. Comments	et al, RAND Europe and The Royal	https://doi.org/10.7249/RR2695	Good	Exhibit 38 (ref. to full doc), 1/28/2022 Public Justice et al.
Management (Storage)	Cover manure piles	Chadwick	Cattle Manure Heaps: Effect of Compaction and Covering	Environment	2005	2018 PM2.5 Plan, App. C (CAFs)	(2005)	ienccdirect.co	Good	
Management (Storage)	Farm lagoons effect on env., health	Marks	Threaten Environmental and Public Health	(NRDC)	2001	Public Justice et al. Comments	Clean Water	https://www.n	Good	Exhibit 18, 1/28/2022 Public Justice et al.
4-Land Application	COMPILATION: Incorporate manure into soil (w/in minute, 4 hours, or 24 hours), lower slurry pH to 6 or less, band spreading, trailing hose, trailing shoe, injector	Guthrie	The impact of ammonia emissions from agriculture on biodiversity	(Rand Europe and The Royal Society)	2018	Public Justice et al. Comments	Susan Guthrie et al, RAND Europe and	https://doi.org/10.7249/RR2695	Good	Exhibit 38 (ref. to full doc), 1/28/2022 Public Justice et al.
4-Land Application	COMPILATION: Timing of land application; injection; incorporation; banding	(USDA-EPA)	Agricultural Air Quality Conservation Measures, Reference Guide for Poultry and Livestock Production Systems	(USDA-NRCS and USEPA)	2017	10/5/2022 USEPA proposed rule	Department of Agriculture,	rsc.usda.gov/sites/default/files/2022-06/Ag_AQ_Co	Good	Referenced in 10/5/2022 EPA proposed rule; NRCS Practices for Nutrient Management (590)
4-Land Application	Dilute liquid manure applied to land	n/a	Managing Dairy Manure in the Central Valley of California	Division of Agricultural	2005	2018 PM2.5 Plan, App. C (CAFs)	California	avis.edu/sites/	Good	
4-Land Application	Incorporate manure into soil	Atia	Ammonia volatilization from manure application.	Food and Rural	2008	2018 PM2.5 Plan, App. C (CAFs)	Ammonia	https://open.a	Good	
4-Land Application	Sprayfields effect on env., health	Marks	Threaten Environmental and Public Health	(NRDC)	2001	Public Justice et al. Comments	Clean Water	https://www.n	Good	Exhibit 18, 1/28/2022 Public Justice et al.
4-Non-org. fert. app.	(Potential nitrogen loss to groundwater, Central Valley)	Horwath	Assessment of Nitrous Oxide Emissions in California's Dairy Systems	(Final Report to CARB)	2013	2018 PM2.5 Plan, App. C (fertilizer application)	Horwath, W. R., Burger, M.,	https://www.rsb.ca.gov/research	Good	
4-Non-org. fert. app.	COMPILATION: Mix/inject (non-organic) urea-based fertilizer directly into soil quickly after application, apply urea fertilizer with a urease inhibitor, spread manure in optimal weather, replace urea fertilizer with another nitrogen form (e.g., ammonium nitrate)	Guthrie	The impact of ammonia emissions from agriculture on biodiversity	(Rand Europe and The Royal Society)	2018	Public Justice et al. Comments	et al, RAND Europe and The Royal Society, "The impact of	https://doi.org/10.7249/RR2695	Good	Exhibit 38 (ref. to full doc), 1/28/2022 Public Justice et al.
4-Non-org. fert. app.	Fertilizer application	Tomich	The California Nitrogen Assessment: Challenges and solutions for people, agriculture, and the environment	(Univ of California Press)	2016	2018 PM2.5 Plan, App. C (fertilizer application)	Brod, S. B., Dahlgren, R.	avis.edu/sites/g/files/dgvnsg/files/dgvnsg	Good	
4-Non-org. fert. app.	Increase precision of manure and fertilizer application; reduce overall amount of nitrogen applied to crops	Harter	Groundwater Perspective (Revised Manuscript from Proceedings)	Symposium, December 13-15, 2004, San Diego,	2005	2018 PM2.5 Plan, App. C (fertilizer application)	Menke, J., (2005) Cow	http://groundwater.ucdavis.edu/	Good	
4-Non-org. fert. app.	Manure application methods (trailing shoe, open-slot injection, trailing hose, plough)	Webb	The impacts of manure application methods on emissions of ammonia, nitrous oxide and on crop response—a review	Agric. Ecosyst. Environ.	2010	Public Justice et al. Comments	Pain, S. Bittman, J.	cienccdirect.com/science/artic	Good	(body of letter) 1/28/2022 Public Justice et al.
4-Non-org. fert. app.	Nitrogen fert. application amount and timing	Chang	Managing Dairy Manure in the Central Valley of California	Division of Agriculture	2005	application)	Harter, T.,	water.ucdavis.edu/	Good	
5-Other	(Pasture and range management: stocking density)	(USDA-EPA)	Guide for Poultry and Livestock Production Systems	(USDA-NRCS and USEPA)	2017	10/5/2022 USEPA proposed rule	Department of	rsc.usda.gov/si	Good	NRCS Practices for Prescribed Grazing (528)
x-Em. character.	(assoc. b/n individual VOCs, NH3 em.)	Feilberg	Online Proton-Transfer-Reaction Mass Spectrometry	Technology	2010	2018 PM2.5 Plan, App. C (CAFs)	Liu, D.,			
x-Em. character.	(assoc. b/n non-methane VOCs, NH3 em.)	Hobbs	Livestock Agriculture	J Sci Food Agric	2004	2018 PM2.5 Plan, App. C (CAFs)	Webb, J.	lleyair.org/busi	Good	
x-Em. character.	(Manure mngmnt em. factors; sources, chem., depos.)	Behera	atmospheric chemistry and deposition on terrestrial bodies	Env Sci Pollut Res	2013	Public Justice et al. Comments	Ammonia in	ringer.com/art	Good	

Activity / Category	Control Measure(s)	First Author	Study Name	Journal (or Other Publication / Event)	Pub. Date	Reference Point	Citation	Link(s)	Link(s) Good / Bad	Notes
y-Compilation	(AFO emissions and background, including measures)	(USEPA) y	Emission Operations from Animal Feeding Operations	(USEPA) q y y	2001	2018 PM2.5 Plan, App. C (CAFs)	Emissions	epa.gov/ttn/ch	Good	
y-Compilation	(Analysis of 10 categories of manure treatment tech.)	Manure	Treatment of Dairy Manure in California's San Joaquin Valley	Manure Technology	2005	Rule 4570 Dev. (mid-2000s)	Valley Dairy	p.g		Supported original SJV Rule 4570/CAF dev.
y-Compilation	(Compilation building on Price (2011), Bittman (2014), Preece (2017/2018), and others)	Guthrie	The impact of ammonia emissions from agriculture on biodiversity	(Rand Europe and The Royal Society)	2018	Public Justice et al. Comments	et al, RAND Europe and	/10.7249/RR2695	Good	Exhibit 38 (ref. to full doc), 1/28/2022 Public Justice et al.
y-Compilation	(Compilation of ~1 dozen measures)	Pinder	reducing atmospheric particulate matter in the eastern	Environ. Sci. Technol.	2007	Public Justice et al. Comments	Pinder et al.,			Exhibit 33, 1/28/2022 Public Justice et al.
y-Compilation	(Compilation of ~1/2 dozen measure, including slurry, manure, and synthetic fertilizer to land, and cost info)	Eory	On-farm technologies for the reduction of greenhouse gas emissions in Scotland	ClimateXChange	2016	Public Justice et al. Comments	al, ClimateXChang			Exhibit 46, 1/28/2022 Public Justice et al.
y-Compilation	(Compilation of ~1-2 dozen measures)	Preece	Ammonia Emissions from Cattle Feeding Operations	Extension, College	2017	Public Justice et al. Comments	Preece et al.,			Exhibit 36, 1/28/2022 Public Justice et al.
y-Compilation	(Compilation of ~2 dozen measures)	Bittman	Task Force on Reactive Nitrogen	Hydrology, Edinburgh,	2014	Public Justice et al. Comments	Dedina, M.,	uzt.cz/svt/vuzt	Good	Exhibit 40, 1/28/2022 Public Justice et al.
y-Compilation	(Compilation of ~2 dozen measures)	(USDA-EPA)	Guide for Poultry and Livestock Production Systems	(USDA-NRCS and USEPA)	2017	10/5/2022 USEPA proposed rule	Department of			Referenced in 10/5/2022 EPA proposed rule
y-Compilation	(Compilation of ~several dozen measures)	Price	effects on diffuse water pollution, greenhouse gas emissions	and ADAS)	2011	Public Justice et al. Comments	al., ADAS and	ory.rothamste	Good	Exhibit 39, 1/28/2022 Public Justice et al.
y-Compilation	(Multi-pollutant review of managing solid waste, including manure)	Pardo	Gaseous emissions from management of solid waste: a systematic review	Global Change Biology	2015	2018 PM2.5 Plan, App. C	Moral, R., Aguilera, E.,	/10.1111/gcb.12806c	Good	
z-AQ/em. red. effect	PM2.5 response to em. changes (NOx, VOC), Eastern US	Tsimpidi	Oxides of Nitrogen and Anthropogenic Volatile Organic Response of Inorganic Fine Particulate Matter to Emission	Waste Management Journal of the Air &	2008	Public Justice et al. Comments	Tsimpidi ,	/10.3155/1047	Good	Exhibit 34, 1/28/2022 Public Justice et al.
z-AQ/em. red. effect	PM2.5 response to em. changes (SO2, NH3), Eastern US	Tsimpidi	Changes of Sulfur Dioxide and Ammonia: The Eastern United	Waste Management	2007	Public Justice et al. Comments	Alexandra P. Tsimpidi ,	/10.3155/1047	Good	Exhibit 32, 1/28/2022 Public Justice et al.
z-AQ/health effect	Ag. em. impact on PM2.5 and public health	Pozzer	matter and public health	Copernicus GmbH	2017	Public Justice et al. Comments	Tsimpidi, A. P.,	/10.5194/acp-	Good	Exhibit 31, 1/28/2022 Public Justice et al.
z-AQ/health effect	Air quality-related health damages of food	Domingo	Air quality-related health damages of food	National Academy of	2021	Public Justice et al. Comments	Domingo et al,			Exhibit 45, 1/28/2022 Public Justice et al.