Appendix B

Cost Analysis for Venting Ammonia Emissions from Swine Housing to a Wet Scrubber or Biofilter

The U.S. Environmental Protection Agency's (EPA) October 2022 proposed rule disapproval of California's serious area plan for the San Joaquin Valley (Valley) for the 2012 annual PM2.5 National Ambient Air Quality Standard (NAAQS) included the installation of air scrubbers or bio-trickling filters as potential measures to mitigate ammonia emissions from mechanically ventilated pig housing. It has been periodically suggested that significant emission reductions can be achieved by confining livestock in enclosed buildings and using mechanical ventilation to direct the emissions to a control device. Significant obstacles remain that make this option infeasible, and ammonia emissions from swine operations in the Valley represent a very small part of the overall ammonia inventory. There is currently only one swine facility in the Valley that is subject to San Joaquin Valley Air Pollution Control District (District) permitting requirements and District Rule 4570 (Confined Animal Facilities). In addition, the District previously considered and evaluated add-on control devices to control volatile organic compound (VOC) emissions when the District adopted and amended Rule 4570. The District determined that this option was beyond Best Available Control Technology (BACT) because it had not been demonstrated at any facility and would have excessively high costs.

When Rule 4570 was last amended in 2010, the District performed a detailed analysis of the cost effectiveness of using a biofilter to control VOC emissions from confined animal facilities (CAFs). The information from this previous analysis will be updated and used to demonstrate that the ammonia reductions from the use of a biofilter or biotrickling filter to control ammonia emissions from pig housing would not be cost effective. The current analysis also evaluates the use of an acid scrubber to remove ammonia from the air exhausted from mechanically ventilated pig housing. This analysis does not quantify all of the costs or examine all of the potential issues that make this option infeasible but gives an estimate of the costs to implement these measures. Notably, the use of a biofilter as a control device for ammonia is expected to result in much lower costs than other control options. The EPA Clean Air Technology Center (CATC) document "Using Bioreactors to Control Air Pollution" states, "*The capital cost of a bioreaction installation is usually just a fraction of the cost of a traditional control device installation. Operating costs are usually considerably less than the costs of traditional technology, too.*"[1] Therefore, because it has been demonstrated that the use of biofilters to control emissions from animal housing is not

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[1] U.S. Environmental Protection Agency, Clean Air Technology Center (CATC), "Using Bioreactors to Control Air Pollution" EPA-456/R-03-003, (E143-03). September 2003. https://www3.epa.gov/ttncatc1/dir1/fbiorect.pdf

cost effective, other add-on controls are expected to be even less cost effective since these controls typically have higher capital costs and operation costs.

A. Wet Scrubber Information

Wet scrubbers used for control of gaseous pollutants use a liquid to remove pollutants from an exhaust stream. The scrubbing liquid, which is usually water, removes pollutants from gaseous streams through absorption. Most wet scrubbers can have removal efficiencies in excess of 90%, depending on the pollutant absorbed.[2] The rate and amount of contaminants that can be absorbed is related to the amount of soluble gas in the gas stream and the concentration of the solute gas in the liquid film in contact with the gas. When water is used as the scrubbing liquid, other chemicals may be added to the liquid to react with the pollutants being absorbed to reduce the concentration. When liquids other than water are used as the scrubbing liquid, the scrubbing liquid may need to be separated and regenerated to help lower costs of replacing the scrubbing liquid.

Wet scrubbers require large surface areas to facilitate contact between the scrubbing liquid and gas stream. Wet scrubbers pass the liquid over a variety of media (packing, meshing, grids, or trays) and generate spray of droplets to increase the surface area in which the scrubbing liquid and gas are in contact. Wet scrubber designs include spray tower, tray-type, and packed-bed scrubbers. Packed bed scrubbers, in which the liquid is sprayed over packing material in order to provide a large surface area for liquid/gas contact, are commonly used for gas absorption. Packed bed scrubbers often use a countercurrent design in which the gas flows upward as the scrubbing liquid is sprayed downward over the packing material to remove pollutants. The scrubbing liquid is then collected for disposal or regeneration. Packed bed scrubbers are classified according to the relative direction of the gas and liquid flows.

According to EPA, wet scrubbing systems are susceptible to several operating problems such as, "*low gas flow rate; low liquid flow rate; condensation of aerosols in the system; poor liquid distribution; use of liquid with high pollutant concentration; tray/plate collapse; air inleakage; pollutant re-entrainment; freezing/pluggage of lines; and scaling.*"[3]

Wet Scrubber Ammonia Control Efficiency

It is assumed that 80% of the gasses emitted from the enclosed animal housing will be captured by the mechanical ventilation system. Based on the information provided by EPA,[4] it will be assumed that a properly functioning wet scrubber will eliminate 90% of

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[2] U.S. Environmental Protection Agency "Monitoring by Control Technique - Wet Scrubber for Gaseous Control." November 29, 2022. https://www.epa.gov/air-emissions-monitoring-knowledge-base/monitoring-control-technique-wet-scrubber-gaseous-control
[3] Ibid
[4] Ibid.

the captured ammonia (NH_3) emissions; therefore, the total control for NH_3 from the enclosed animal housing = 0.80 x 0.90 = 72%.

Cost Estimates for Wet Scrubbers

The capital and operational cost of wet scrubbers will be based on the EPA Clean Air Technology Center (CATC) fact sheets.[5] The costs from these references, converted from 2002 to 2022 dollars, are demonstrated below.

Costs of Wet Scrubbers from EPA Fact Sheets					
Source	Cost Information Year	Capital Cost Range ($/cfm)	2022 Capital Cost ($/cfm)	Operating Cost Range ($/cfm/yr)	2022 Operating Cost ($/yr)
1	2002	$11 - $55	$18.06 - $90.31	$15 - $49	$24.63 - $80.46
2	2002	$2 - $6	$3.28 - $9.85	$1.50 - $30	$2.46 - $49.26

1. EPA Clean Air Technology Center Fact Sheet "Packed-Bed/Packed-Tower Wet Scrubber" (2003)
2. EPA Clean Air Technology Center Fact Sheet "Spray-Chamber/Spray-Tower Wet Scrubber" (2003)

B. Biofilter Information

A biofilter is a device that removes contaminants from a gas by passing it through a media that supports microbial activity by which pollutants are degraded by biological oxidation. During biofiltration, exhaust air containing pollutants passes through a media that contains an established, diverse population of aerobic microorganisms. These microorganisms oxidize the gaseous organic contaminants, ammonia, and sulfur compounds in the exhaust air resulting in carbon dioxide, nitrogen, water, salt, and biomass. The bacterial cultures (microorganisms that typically consist of several species coexisting in a colony) that use oxygen to biodegrade organics are called aerobic cultures. These aerobic cultures are usually supported by organic material contained in the biofilter, such as compost, wood chips, soil, peat, etc. Biofilters must maintain sufficient porosity to allow the contaminated air stream to pass through for treatment and to prevent anaerobic conditions. The moisture content of biofilter beds must also be regulated to ensure that there is sufficient moisture to maintain the microorganisms needed for treatment while avoiding excess moisture that can cause anaerobic conditions. A filtration system may be required upstream of the biofilter to remove particulate matter which will clog the biofilter over time. Biofilters must be maintained free of rodents and weeds to avoid channeling of gases through the filter

[5] U.S. Environmental Protection Agency, Clean Air Technology Center (CATC). (2003) Spray-Chamber/Spray-Tower Wet Scrubber. EPA-452/F-03-016. https://www3.epa.gov/ttncatc1/dir1/fsprytwr.pdf

media and a loss of performance. The filter media of natural biofilters needs to be replaced periodically because of deterioration and loss of porosity.

Since biofilters rely on living organisms to function, the biofilter performance is affected by several factors, including: ambient temperature; temperature of the air stream being treated; the pollutant concentrations in the air stream; moisture content of the filter and air stream, and pH of the filter media. These parameters must be monitored to ensure optimum operating conditions for the biofilter.

Although biofilters generally have lower costs than other technologies used to control air contaminants, they do have a number of disadvantages. Some of the general disadvantages of the use of biofilters include: large land requirements for traditional biofilter designs; difficulty in determining the control efficiency for open biofilter designs; for biofilters that use inexpensive natural bed media, the filter bed media must be periodically replaced every two to five years; biofilters usually require some time to reach optimum control efficiency after initial startup and after periods of non-use because of the need to establish or re-establish the microbial population; and biofilters can also be a source of nitrous oxide emissions due to denitrification.

Additional disadvantages specifically related to the use of biofilters to control emissions from livestock housing include: animals that may currently have access to outdoor areas for exercise would need to be confined in buildings to maximize emission reductions; facilities that currently use natural ventilation would incur additional costs because of the need to convert to mechanical ventilation; facilities that currently use mechanical ventilation systems may need to upgrade these systems to overcome the increased pressure drop across the biofiltration system; greater energy usage to push air through the biofilter; few reported cases where a biofilter has been shown to be economically viable when applied to animal feeding operations[6]; a very large biofilter system must be used to handle these huge flow rates while maintaining adequate contact time for treatment of emissions. Finally, because of the extremely large airflow rates needed to provide adequate ventilation for livestock, it is not practical and may not be feasible to treat all of the ventilation air from large confined animal housing units.

<u>Biofilter NH3 Control Efficiency</u>
It is assumed that 80% of the gasses emitted from the enclosed animal housing will be captured by the mechanical ventilation system and that a properly functioning biofilter will eliminate 80% of the captured ammonia emissions[7]; therefore, the total control for NH3 from the enclosed animal housing = 0.80 x 0.80 = 64%.

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[6] U.S. Environmental Protection Agency (2001) "Emissions from Animal Feeding Operations" (Draft), EPA Contract No. 68-D6-0011, August 15, 2001, pg. 9-20, https://www.epa.gov/sites/default/files/2020-10/documents/draftanimalfeed.pdf

[7] The SCAQMD Rule 1133.2 staff report (page 18) indicates control efficiencies of 70% to over 90% for NH3 for existing biofilter composting applications and that a well-designed, well-operated, and well-

Cost Estimates for Biofilters

Several reference documents were consulted to determine the expected capital and operating costs of using a biofilter to control emissions from enclosed animal housing. In addition, when Rule 4570 was last amended in 2010, several companies that specialize in building and supplying biofilters and bio-scrubbers for the control of emissions were contacted to request capital cost estimates for biofilter systems specifically for the treatment of VOC emissions from dairy cows housed in enclosed animal housing. The dollar amounts of the estimates provided by these companies and references with the resulting cost information are listed below.

Sources of Cost Estimates for Biofilters

Table 1 summarizes the cost information for biofilters found in literature. The references follow the table.

<table>
<tr><th colspan="6">Table 1: Biofilter Costs from Literature</th></tr>
<tr><th>Article Number</th><th>Reference Year</th><th>Capital Cost Range ($/cfm)</th><th>2022 Capital Cost ($/cfm)</th><th>Operating Cost Range ($/cfm/yr)</th><th>2022 Operating Cost ($/yr)</th></tr>
<tr><td>1</td><td>2003</td><td>$5.42 biofilter</td><td>$8.75</td><td>$3.31 biofilter</td><td>$5.34</td></tr>
<tr><td>2</td><td>2003</td><td>$27.11 biotrickling filter</td><td>$43.74</td><td>$6.35 biotrickling filter</td><td>$10.25</td></tr>
<tr><td>3</td><td>1991</td><td>$9.17 - $22.50 open biofilter</td><td>$19.81 - $48.61</td><td rowspan="2">$1.58 - $7.88</td><td rowspan="2">$3.41 - $17.02</td></tr>
<tr><td>4</td><td>1991</td><td>$22.50 - $125 enclosed biofilter</td><td>$48.61 - $270.06</td></tr>
<tr><td>5</td><td>1998</td><td>-</td><td>-</td><td>$2 - $14</td><td>$3.63 - $25.41</td></tr>
<tr><td>6</td><td>2008</td><td>$15</td><td>$21.02</td><td>$2</td><td>$2.80</td></tr>
<tr><td>7</td><td>2005</td><td>$16.99 - $118.93</td><td>$25.60 - $179.18</td><td>$5.10 - $16.99</td><td>$7.68 - $25.60</td></tr>
<tr><td>8</td><td>1996</td><td>$2.50 - $5.00</td><td>$4.69 - $9.39</td><td>$2 - $14</td><td>$3.75 - $26.28</td></tr>
<tr><td>9</td><td>1999</td><td>$13.30 - $18</td><td>$23.53 - $31.84</td><td>$3.33 - $6.67</td><td>$5.89 - $11.80</td></tr>
<tr><td>10</td><td>2002</td><td>$2.79</td><td>$4.58</td><td colspan="2">10% of capital cost</td></tr>
<tr><td>11</td><td>2020</td><td>$20.38-135.92 ($12-80/(m^3/hr))</td><td>$23.31 - $155.50</td><td>-</td><td>-</td></tr>
</table>

1 & 2. U.S. Environmental Protection Agency, The Clean Air Technology Center (CATC), "Using Bioreactors to Control Air Pollution" EPA-456/R-03-003, (E143-03), September 2003, https://www3.epa.gov/ttncatc1/dir1/fbiorect.pdf

maintained biofilter is capable of achieving 80 percent control efficiency for NH3. http://www.aqmd.gov/docs/default-source/rule-book/support-documents/rule-1133/staff-report.pdf

3 & 4. Leson, G. and A.M. Winer. 1991. "Biofiltration: An Innovative Air Pollution Control Technology for VOC Emissions". Journal of the Air and Waste Management Association. 41(8):1045-54.

5. Operating Cost Estimate for a Biofilter (1998): $2-14/cfm (from Boyette, R. A. 1998. "Getting Down to (Biofilter) Basics". Biocycle 39(5):58-62)

6. Bohn, Hinrich, "Biofilter Technology Offers Emissions Abatement Option", Distillers Grain Quarterly, 3rd Qtr 2008

7. Delhoménie, Marie-Caroline; Heitz, Michèle, "Biofiltration of Air: A Review", Critical Reviews in Biotechnology, 1549-7801, Volume 25, Issue 1, 2005, Pages 53 – 72

8. Boyette, R. Allen – E&A Environmental Consultants Inc., "Biofilter Economics and Performance", 1996, https://p2infohouse.org/ref/12/11505.pdf

9. Govind, Rakesh – PRD Tech Inc., White Paper - "Biofiltration: An Innovative Technology for the Future", 1999, https://d3pcsg2wjq9izr.cloudfront.net/files/1367/articles/7436/11s2-PR.pdf

10. South Coast Air Quality Management District, "Technology Assessment for: Proposed Rule 1133: Emission Reductions from Composting and Related Operations", March 22, 2002, http://www.aqmd.gov/docs/default-source/rule-book/support-documents/rule-1133/technology-assessment.pdf

11. Qamaruz-Zaman, N., Yaacof, N., Kamarzaman, F. (2020), The Interaction of Food Industry and Environment, Chapter 9 - Control of Odors in the Food Industry. Academic Press, 2020, https://doi.org/10.1016/B978-0-12-816449-5.00009-6

As stated above, when Rule 4570 was last amended in 2010, several companies that supply biofilters and bio-scrubbers for the control of emissions were contacted to request capital cost estimates for biofilter systems capable of treating emissions from animals confined in enclosed barns. Four vendors responded to the District's request for cost information. They are identified as Vendors A, B, C, and D in the table below. The companies were told that the biofilter would need to be capable of treating airflow rates of 500,000 cfm or more. The estimates that were provided by these companies are listed below and generally fell in the range of values given in the accepted sources listed above. The cost estimates provided for these vendors have been adjusted to 2022 dollars.

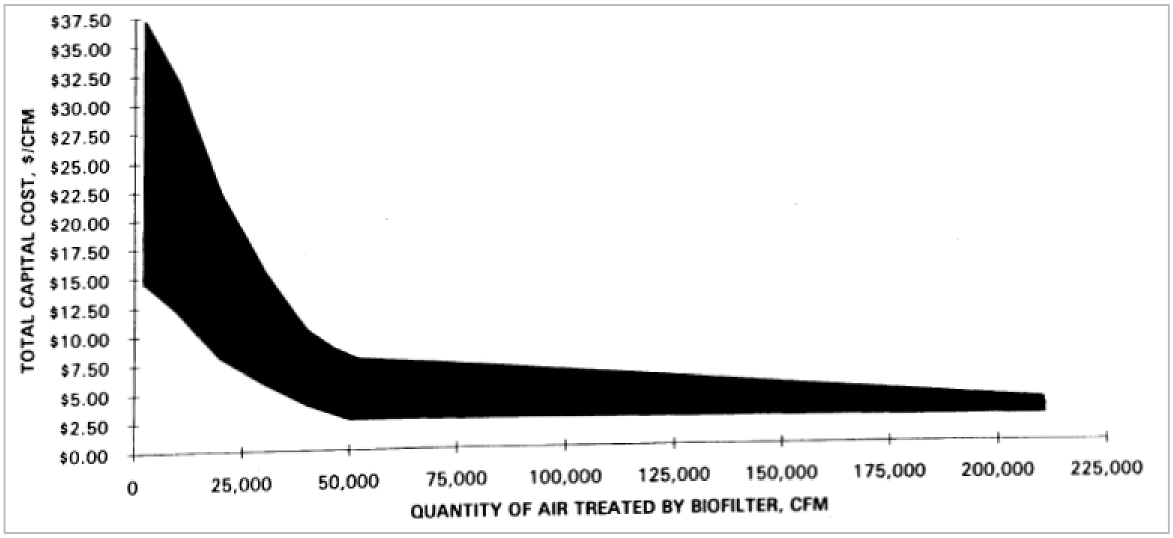
Table 2: Summary of 2010 Biofilter Vendor Cost Information				
Vendor	2010 Capital Cost ($)	2022 Capital Cost ($)	2010 Operating Cost ($/cfm)	2022 Operating Cost ($/cfm)
A	$1.4 - $2.2 million	$1.9 - $3.0 million	$2.80 - $4.40	$3.81 - $5.99
B	$8 - $10 million	$11-14 million	$16 - $18	$22 - $24
C	$7 million ± 20%	$9.5 million ± 20%	$14 ± 20%	$19 ± 20%
D	-	-	$20 - $25	$27 - $34

Reduced Capital Cost from Economy of Scale

The potential for reduced dollar-per-cfm capital costs was previously considered based on the large airflow rates that would be handled by biofilters for confined animal facilities. However, based on the information reviewed, it was determined that there is not any additional cost reduction benefit related to economy of scale for biofilters handling such large flow rates.

The information available indicates significant reductions in biofilter costs per cfm as the flow rate treated increases to a few thousand cfm but diminishing reductions in cost after this until there is no further benefit. This is illustrated in the graph below. The graph shows no additional cost reductions benefits after approximately 50,000 cfm. Also, a biofilter supplier previously indicated that economy of scale cost reductions for biofilter systems were insignificant after approximately 20,000 cfm. This was because multiple individual units are generally required to treat flows greater than this and each unit would still cost about the same. Additionally, single units, and sometimes even multiple units, handling such large flow rates would not be pre-fabricated but would have to be specially constructed on site, which can increase costs. Therefore, any potential cost reduction benefits related to economy of scale have already been captured in the lower biofilter cost estimates given above and no additional cost benefits will be realized at higher flow rates. As a result, the cost estimates for biofilters will be directly proportional to the airflow rate treated and the number of animals housed.

Figure 1: Biofilter Capital Cost per CFM of Air Treated



Boyette, R. Allen – E&A Environmental Consultants Inc., "Biofilter Economics and Performance", 1996

Cost Estimate for Biofilters for this Analysis

For purposes of this report, the following biofilter cost estimates will be used. The cost estimates are conservative and are significantly lower than some of the capitol cost estimates given in the references listed above.

Capital Cost (2022): **$5-50/cfm**
Operating Costs (2022): **$3-27/cfm**

C. Cost Analysis of Venting Mechanically Ventilated Pig Housing to a Wet Scrubber or Biofilter for Control of Ammonia

The costs of the NH3 emission reductions for venting mechanically-ventilated swine housing to a wet scrubber or biofilter are analyzed below.

Description of Ventilation in Swine Housing

Swine are typically housed in confinement buildings that are either totally enclosed or partially enclosed structures with open sidewalls with curtains. In totally enclosed housing, mechanical ventilation is used throughout the year. Mechanical ventilation is typically provided by an induced draft or negative-pressure system. An induced draft system pulls fresh air into the house from one end and exhausts on the other. A negative-pressure system draws fresh air into the house from side vents and out through the exhaust fan. Partially enclosed swine housing uses natural ventilation the majority of the year. In these buildings the sidewall curtains are opened and closed to control the house ventilation rate. Partially enclosed swine housing may also use mechanical ventilation when the curtains are closed due to weather conditions. Ventilation in swine housing is used to remove excess moisture, ammonia, and hydrogen sulfide from swine housing and to remove excess heat during the summer season. Although the practicality of venting all of the air from mechanically ventilated pig housing to a wet scrubber or biofilter to control emissions has not been demonstrated, the potential cost of this option will be evaluated.

Required Airflow Rate of the Pig Houses

In order to calculate the costs of this control option, the maximum airflow to be treated from the swine housing building must be determined.

The MidWest Plan Service publication “Mechanical Ventilating Systems for Livestock Housing” (MWPS-32), gives minimum ventilation rates for finishing swine, which are listed in the table below.

Table 3: Minimum Ventilation Rates for Finishing Swine (cfm/head)			
Animal Type	Winter	Mild Weather	Summer
Finishing Swine	10	35	120

Minimum Summer Air Requirements for Swine Housing for 3,000 Finishing Head:

The minimum required summer airflow rate for housing the 3,000 head of swine in enclosed housing is calculated as follows:

Summer Ventilation Rate: 3,000 head x 120 cfm/head = 360,000 cfm

Cost of Web Scrubber

The cost estimates for a wet scrubber are based on the references given above. The cost is largely dependent on the airflow rate that the web scrubber must handle. Wet scrubbers used to treat exhaust air should be sized to treat the maximum ventilation rate, which is typically the warm weather rate. The higher cost value is representative of a packed bed/packed tower scrubber, which may be necessary to handle the high air flow rates with low pollutant concentrations exhausted from the houses.

Capital Cost for a wet scrubber: $3.28 – 90.31/cfm
Operating Costs for a wet scrubber: $2.46-80.46/cfm-year

Capital Cost of Biofilter for Swine Housing with 3,000 Finishing Head

The lower cost estimate does not include installation of the required ductwork. The estimated capital costs for a wet scrubber range between $3.28 per cfm and $90.31 per cfm. The capital cost estimates of a biofilter for mechanically ventilated swine housing with 3,000 finishing head are calculated as follows:

Low capital cost estimate: $3.28/cfm x 360,000 cfm = $1,180,800
High capital cost estimate: $90.31/cfm x 360,000 cfm = $32,511,600

Annalized Capital Costs for Wet Scrubber for Swine Housing with 3,000 Finishing Head

The annualized capital cost estimates will be calculated below. The cost for the purchase of the wet scrubber will be spread over the expected life of the system using the capital recovery equation. Therefore, the expected life of the entire system (fans, media, plenum, etc.) will be estimated at 10 years. A 4% interest rate is assumed in the equation and the assumption will be made that the equipment has no salvage value at the end of the ten-year cycle.

$A = [P \times I(I+1)^n]/[(I+1)^n-1]$

Low Annualized Capital Cost Estimate =
$[(\$1,180,800) \times 0.04(1.04)^{10}]/[(1.04)^{10}-1] = \$145,582$/year

High Annualized Capital Cost Estimate =
$[(\$32,511,600) \times 0.04(1.04)^{10}]/[(1.04)^{10}-1] = \$4,008,386$/year

Operating Costs for Wet Scrubber for Swine Housing with 3,000 Finishing Head

Low operating cost estimate: $2.46/cfm-yr x 360,000 cfm = $885,600/year
High operating cost estimate: $80.46/cfm-yr x 360,000 cfm = $28,965,600/year

Total Annual Cost Estimates

The total annualized capital costs and operating costs for the wet scrubber are given below.

Total annual cost estimate = (total annualized capital cost) + (operating cost)

Low total annual cost estimate = ($145,582/yr) + ($885,600/yr)
= $1,031,182/year

High total annual cost estimate = ($4,008,386/yr) + ($28,965,600/yr)
= $32,973,986/year

NH3 Emission Reductions for Wet Scrubber for Swine Housing with 3,000 Finishing Head

The annual NH3 emission reductions for mechanically-ventilated swine housing for 3,000 finishing head vented to a wet scrubber are calculated as follows:

[Number of Head] x [Pig NH3 EF (lb/head-year)] x [Capture Efficiency] x [Wet Scrubber Control Efficiency]

Table 4: NH3 Reductions from Enclosed Swine House Vented to a Wet Scrubber										
Animal	# of Head	x	EF* (lb/head-yr)	x	Capture (%)	x	Control (%)	=	lb-NH3/yr
Finishing Swine	3,000	x	18.5	x	80%	x	90%	=	**39,960**

* Assuming that the proportion of ammonia emissions from the pig houses is similar to VOC emissions. Based on a study by Rumsey, 91% of swine facility VOC emissions are assumed to be from housing barns and 9% of VOC emissions are assumed to be from lagoons[8]

Cost of NH3 Emission Reductions

Low Estimate = ($1,031,182/year)/[(39,960 lb-NH3year)(1 ton/2000 lb)]
= **$51,611/ton of NH3 reduced**

High Estimate = ($32,973,986/year)/[(39,960 lb-NH3/year)(1 ton/2000 lb)]
= **$1,650,350/ton of NH3 reduced**

As shown above, the costs for a wet scrubber for swine housing would cause the cost of the NH3 reductions to be greater than $51,611/ton. There are additional costs related to increased electricity use, and regulatory compliance and testing that have not been quantified in this analysis. Even without these costs, it is clear that the cost of the NH3 emission reductions achieved are far beyond best available control measure (BACM) and best available control technology (BACT) levels.

Cost of Biofiltration

The cost estimates for biofiltration are based on the references given above. The cost is largely dependent on the airflow rate that the biofilter must handle. Biofilters used to treat exhaust air should be sized to treat the maximum ventilation rate, which is typically the warm weather rate. The higher cost value is representative of a biotrickling filter, which may be necessary to handle the high air flow rates from the houses.

Capital Cost for a biofilter: $5-50/cfm
Operating Costs for a biofilter: $3-27/cfm-yr

Capital Cost of Biofilter for Swine Housing with 3,000 Finishing Head

The lower cost estimate does not include installation of the required ductwork. As stated above, the estimated capital costs for a biofilter range of between $5 per cfm and $50.00 per cfm. The capital cost estimates of a biofilter for mechanically ventilated swine housing with 3,000 finishing head are calculated as follows:

[8] Rumsey, I. C., "Characterizing Reduced Sulfur Compounds and Non-Methane Volatile Organic Compounds Emissions from a Swine Concentrated Animal Feeding Operation" (2010) – PhD dissertation submitted to the Graduate Faculty of North Carolina State University

Low capital cost estimate: \$5/cfm x 360,000 cfm = \$1,800,000
High capital cost estimate: \$50/cfm x 360,000 cfm = \$18,000,000

Annualized Capital Costs for Biofilter for Swine Housing with 3,000 Finishing Head

The annualized capital cost estimates will be calculated below. The cost for the purchase of the biofilter will be spread over the expected life of the system using the capital recovery equation. Therefore, the expected life of the entire system (fans, media, plenum, etc) will be estimated at 10 years. A 4% interest rate is assumed in the equation and the assumption will be made that the equipment has no salvage value at the end of the ten-year cycle.

$A = [P \times I(I+1)^n]/[(I+1)^n-1]$

Low Annualized Capital Cost Estimate =
$[(\$1,800,000) \times 0.04(1.104)^{10}]/[(1.04)^{10}-1]$ = \$221,924/year

High Annualized Capital Cost Estimate =
$[(\$18,000,000) \times 0.04(1.04)^{10}]/[(1.04)^{10}-1]$ = \$2,219,237/year

Operating Costs for Biofilter for Swine Housing with 3,000 Finishing Head

Low operating cost estimate: \$3/cfm-yr x 360,000 cfm = \$1,080,000/yr
High operating cost estimate: \$27/cfm-yr x 360,000 cfm = \$9,720,000/yr

Total Annual Cost Estimates

The total annualized capital costs and operating costs for the biofilter are given below. For the least expensive biofilters, the biofilter media (e.g., soil, compost, wood chips) must be replaced after 3-5 years in order to remain effective and this may be an additional cost. There would also be increased electricity usage to overcome the pressure drop caused by the biofilter. This cost was not quantified.

Total annual cost estimate = (total annualized capital cost) + (biofilter operating cost)

Low total annual cost estimate = (\$221,924/yr) + (\$1,080,000/yr)
= \$1,301,924/year

High total annual cost estimate = (\$2,219,237/yr) + (\$9,720,000/yr)
= \$11,939,237/year

NH3 Emission Reductions for Biofilter for Swine Housing with 3,000 Finishing Head

The annual NH_3 emission reductions for mechanically-ventilated swine housing for 3,000 finishing head vented to a biofilter are calculated as follows:

[Number of Head] x [Pig NH3 EF (lb/head-year)] x [Capture Efficiency] x [Biofilter Control Efficiency]

Table 5: NH3 Reductions from Enclosed Swine House Vented to a Biofilter									
Animal	**# of Head**	**x**	**EF* (lb/head-yr)**	**x**	**Capture (%)**	**x**	**Control (%)**	**=**	**lb-NH3/yr**
Finishing Swine	3,000	x	18.5	x	80%	x	80%	=	**35,520**

* Assuming that the proportion of ammonia emissions from the pig houses is similar to VOC emissions. Based on a study by Rumsey, 91% of swine facility VOC emissions are assumed to be from housing barns and 9% of VOC emissions are assumed to be from lagoons[9]

<u>Cost of NH3 Emission Reductions</u>

Low Estimate = ($1,301,924/year)/[(35,520 lb-NH3year)(1 ton/2000 lb)]
= **$73,307/ton of NH3 reduced**

High Estimate = ($11,939,237/year)/[(35,520 lb-NH3/year)(1 ton/2000 lb)]
= **$672,254/ton of NH3 reduced**

As shown above, the costs for a biofilter for swine housing would cause the cost of the NH3 reductions to be greater than $73,307/ton of ammonia. There are additional costs related to increased electricity use, ductwork, and regulatory compliance and testing that have not been quantified in this analysis. Even without these costs, it is clear that the cost of the NH3 emission reductions achieved are far beyond BACM and BACT.

[9] Rumsey, I. C., "Characterizing Reduced Sulfur Compounds and Non-Methane Volatile Organic Compounds Emissions from a Swine Concentrated Animal Feeding Operation" (2010) – PhD dissertation submitted to the Graduate Faculty of North Carolina State University