

# Economics



## Designing Policy Instruments for Controlling Air and Water Emissions from Agriculture

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### Abstract

Impacts of agricultural production on water quality have long been a leading environmental policy concern and have stimulated a large literature on the economics of designing policy instruments to control water quality impacts of agriculture. This literature has been particularly concerned with how to contend with the measurement problems that emerge from the nonpoint character of water pollution from agriculture. More recently, there is growing interest in the air quality impacts of agriculture, particularly wastes from confined animal operations. Because air and water quality impacts of agriculture are produced jointly, initiatives to protect one environmental medium have impacts on the other. This paper explores the design of policy instruments to simultaneously address air and water emissions from agriculture, drawing on and extending results from prior literature.

### Introduction

While agriculture has long been recognized as a source of air and water pollutants, government regulation of agriculture for environmental protection has evolved slowly by comparison to other economic sectors (Shortle and Abler 1999). Since the enactment of the 1972 Clean Water Act (CWA), the principal approach to water quality protection in the US has been effluent limits on industrial and municipal sources of water pollution. While these controls have done much to improve the quality of the nation's surface waters, water quality goals in many rivers, lakes and estuaries have not been met, often because significant nonpoint sources of water pollution, principally agricultural, remain largely unregulated (Ribaldo 2001). Similarly, the air quality regulations developed under legislation such as the Clean Air Act and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) have been largely focused on easily identifiable and regulated point sources such as power plants and factories, and to highway vehicles (Ribaldo and Weinberg 2005).

Policy makers have taken increasing notice of the air and water quality impacts of agriculture, and there are increasing pressures to tackle these problems, especially those resulting from water pollution. The most important federal water quality initiatives are new rules beefing-up regulation of Confined Animal Feeding Operations (CAFOs) under the National Pollutant Discharge Elimination System (NPDES), and EPA's Total Maximum Daily Load (TMDL) Program. NPDES permits are required under the CWA for point sources of water pollution. The permits specify technology-based effluent standards and are the primary regulatory tool for controlling point sources of water pollution under the CWA. EPA's TMDL Program is intended to guide compliance with Section 303(d) of the 1972 CWA, which requires states and certain other jurisdictions to identify waters that do not meet water quality standards even after point sources of pollution have installed the minimum required levels of pollution control technology. The law requires that these jurisdictions establish priority rankings for impaired waters and develop TMDLs for these waters. A TMDL specifies the maximum amount of a pollutant that a water body can receive and still meet water quality standards, and allocates pollutant loadings among point and nonpoint pollutant sources. While TMDLs were required by the 1972 CWA, there was little progress in developing them until EPA's recently initiated TMDL Program. Nutrients from agriculture are a major cause of remaining water quality problems and, accordingly, a major target in TMDL development (EPA 2006)

Concern for air quality impacts of agricultural production tends to be less intense than those for water quality, reflecting the greater relative importance of agriculture to the nation's water quality problems. Yet, there are also new federal policy developments in this area, primarily addressing air emissions from animal feeding operations (Aillery et al. 2005). Most notably, EPA is developing new regulations for fine particulates. Ammonia from animal feeding operations (AFOs) is a major precursor of fine particulates, making AFOs in non-attainment areas with high concentrations of animals a likely target of regulations (Aillery et al. 2005, EPA 2000).

Important in the new policy developments addressing agriculture's environmental impacts is an emphasis on air and water quality impacts of wastes from intensive, confined animal production systems. This speaks to the multi-media character and policy significance of intensive, confined animal production systems. Also important is that the multi-media problems associated with animal wastes are being approached through uncoordinated single-medium regulations for protecting air and water quality. This single-medium approach fails to account for complex air-water interrelationships at various scales and may lead to unintended environmental consequences and unnecessary costs. For example, reducing ammonia losses to air by injecting animal waste directly into cropland can increase the amount of nitrogen that enters water resources (Ribaudo and Weinberg 2005). Accordingly, policies designed to mitigate either air or water pollution problems should take into account the cross-media linkages to avoid unintended and adverse effects on environmental quality. More fundamentally, an explicit multi-media approach of air and water regulations is essential to cost-effective achievement of environmental goals.

Our interest in this paper is in the design of policy instruments to cost-effectively address air and water emissions that are jointly produced in agricultural production. We begin with a review of the existing literature on the design of policies to control nonpoint pollution. The relevance of this literature follows from the fact that both air and water emissions from agriculture are largely of the nonpoint type (i.e., diffuse and stochastic, making routine accurate metering by source prohibitively costly). The nonpoint policy design literature has been largely generated in response to the challenges of nonpoint water pollution control; indeed, the literature on the economics of air quality policy for agriculture is very thin. However, the theory and some key empirical findings from the water quality research are applicable to air quality protection in a single medium context. A limitation of the applied and theoretical nonpoint policy literature is that it focuses on management for the protection of a single medium. We discuss the particular challenges involved in addressing the nonpoint cross-media problem, and discuss policy tools that for addressing the multi-media problem. We focus in particular on pollution trading.

### **Nonpoint Pollution Policy Design Issues**

Several features of nonpoint pollution problems complicate the choice of policy instruments. First, agricultural nonpoint emissions are generated diffusely over a potentially broad land area, prohibiting accurate and cost-effective measurement given existing monitoring technologies. Second, agricultural nonpoint emissions and the fate and transport of these emissions within airsheds and watersheds are highly stochastic due to stochastic environmental processes, such as weather, that move nutrients and other chemicals off of farms and transport them to air and water resources. Taken together, these first two features result in substantial uncertainty about the decision makers who are responsible for nonpoint pollution and about the degree of each farm's or household's responsibility. One implication is that the emissions-based instruments that economists usually advocate for cost-effective pollution control are eliminated from the set of nonpoint pollution control instruments (Shortle and Horan 2001). Other constructs must therefore be used to monitor performance and as a basis for the application of pollution control instruments. These could include polluting inputs such as fertilizers and pesticides, pollution-reducing practices such as nutrient management and pollution control equipment, or estimates of emissions based on observations of on-farm management practices. In each case, monitoring is likely to be costly and imperfect, creating the potential for moral hazard with respect to imperfectly-monitored practices (e.g., shirking on a contract to undertake a particular practice because the implementation of the practice cannot be verified) and substitutions to non-monitored practices having adverse environmental consequences.

A third characteristic of nonpoint emissions is that many site-specific factors such as hydrology, climate, and location often play key roles in determining the processes that move and transport emissions, as well as the eventual environmental and economic impacts of these emissions. The result is extreme spatial variation in the feasibility, effectiveness and cost of technical options for reducing emissions. This greatly

limits the applicability of the uniform technology-based regulatory approaches that are often used to control point sources (see e.g., Shortle and Horan 2001).

An array of innovative policy instruments (e.g., taxes and/or subsidies on practices affecting nonpoint pollution, taxes on ambient concentrations of pollutants in environmental media, taxes and/or subsidies tied to farm level environmental performance indicators, contracts for adoption of best management practices) have been proposed to meet the unique challenges nonpoint pollution control. Economic research indicates that no approach offers a panacea, but some have more merit than others (Shortle and Horan 2001). Among the later is pollution trading. This approach has significant merit as means for minimizing the costs of achieving environmental objectives, and has also achieved a high degree of political acceptance, and is the focus of the remainder of the paper.

We begin with a discussion of single-medium trading mechanisms that could be used to address air or water pollution from agricultural sources. Single medium trading is the primary focus of the literature on the design of trading mechanisms, and it is the focus of current trading initiatives. We then take up the challenges of multi-media trading.

### **Single Medium Trading**

Pollution trading is a mechanism for allocating pollution loads among alternative sources in order to achieve an overall pollution load target (e.g., TMDL, mean annual loads, etc.) set by environmental authorities. Water pollution trading involving both point and nonpoint sources is being promoted by the US EPA, has been adopted by several states and some multi-state regional water quality authorities, and is being actively considered by still others as means for achieving water quality goals, especially within the context of EPA's TMDL Program.

The development of water quality trading is part of a broader trend towards the use of market-based strategies to address environmental and natural resource problems. Trading has already become, for example, a major tool for air quality protection, and is of great interest as a mechanism for managing greenhouse gas emissions as well as water quality and other environmental resources (OECD 2002). This broad interest in trading has a variety of origins, but economic arguments, and increasingly empirical evidence, about the potential cost-savings from trading by comparison to traditional command-and-control approaches have been particularly compelling (OECD 2002; Hahn 2000; Tietenberg 2006; EPA 2001).

The economic appeal of the mechanism is that trading can ensure that environmental quality goals are achieved cost-effectively because individual polluters will respond to the market in a way that allocates load reductions at minimum costs. Cost minimization essentially requires allocating greater pollution abatement to sources with lower costs than to sources with higher costs. Trading achieves this outcome in theory by creating incentives for high cost sources to pay low cost sources to reduce their discharge (subject to restrictions that water quality is equal or better as a result of the trade). As high cost (HC) sources can pay low cost (LC) sources an amount less than the amount it would cost HC sources to make the reduction, but greater than the amount actually incurred by LC sources, trading is to their mutual benefit. But this market system can only work to provide economic and environmental benefits if the markets are properly designed and implemented. Initial experiments in water quality trading have perhaps suffered because of poor market design (Ribaud et al. 1999).

The fundamental element of any trading system is a tradeable permit. Permits define legally allowable emissions; tradeable permits allow sources to adjust their legal allowances through market transactions. The number of permits must be set appropriately for environmental quality goals to be attained. Moreover, rules governing trading in well-designed programs facilitate trading to promote the economic objective of cost-minimization, while assuring that environmental quality goals will be met after trades. The key challenges in designing trading programs are to assign the correct number of permits and to design rules that foster the dual environmental and economic objectives.

### **Load Limits and Permits**

For a trading program to reliably satisfy environmental goals, it is essential to specify the maximum load from point and nonpoint sources consistent with the goals, and to cap the number of available emissions permits to satisfy this maximum load. The simple creation of trading as an option for reducing effluents is

not enough to lead to trading or to trading that achieves water quality goals. As emphasized recently by King (2005), markets are not an alternative to water quality regulations. Markets are fundamentally and most appropriately viewed as a mechanism for allocating emissions among sources within the context of a regulatory restriction on total loads. They should not be the determinant of the total load. In the current context where point sources generally face strong regulatory restrictions while nonpoint sources often do not, an essential key to success in trading is meaningful restrictions on nonpoint sources. Tight restrictions on point sources simply cannot produce the trades needed to achieve water quality goals where nonpoint sources are the major cause of water quality problems.

The main challenge for trading with nonpoint sources is the immeasurability of individual pollutant loads. Point source permits can be based on actual emissions as these are generally meterable. But nonpoint source emissions are unobservable. This problem is addressed in theory and practice by basing nonpoint permits on modeled or estimated nonpoint emissions. This means that farmers or other nonpoint sources must make observable and measurable management changes, either in production (i.e., nutrient management) or on the landscape (i.e., plant buffer strips), the water quality impacts of which are then estimated by a simulation model to gauge compliance.

### Trading Rules: The Type of Trading

Within the context of an overall restriction, a key issue is the type of trading to implement to achieve the target. The most straight forward design for achieving water quality goals is the *cap-and-trade* model. A cap-and-trade program begins with an explicit determination of total allowable discharges. Permits for the total allowable discharges are then allocated among polluters. Methods for the initial allocation include auctions, lotteries, and “grandfathering” (Tietenberg 2006). The initial allocations can then be traded, to determine equilibrium allocations among sources. The main alternative to cap-and-trade is *credit trading*. In a credit trading program, polluters generate credits by reducing discharges below a baseline, typically defined as a legal limit on emissions.<sup>3</sup> Credits generated by one source may sold to another to offset emissions in excess of the legal limit. The earliest air pollution trading programs in the U.S. were of this type (Tietenberg 2006, Ellerman 2005). The subsequent SO<sub>2</sub> and NO<sub>x</sub> trading programs are of the cap-and-trade type.

Cap-and-trade systems allow planners to dispense with the knotty issues involved in defining individual baselines for credit generation, and focus instead on total allowable level of pollution. An emerging literature indicates that cap-and-trade programs promise both better environmental and economic performance than credit-trading (Shabman et al., 2002; Dewees 2001), although the US EPA’s water quality trading policy calls for the credit trading approach.

### Trading Rules: Nonpoint Risk and Trading Ratios

Point source permits based on actual emissions and nonpoint source permits based on estimated emissions are fundamentally different things, and so trading them on a one-for-one basis would be like trading apples for oranges. A trading ratio is generally used to account for these differences. In water quality markets the trading ratio is usually only applied to trades involving point and nonpoint sources, and it is defined as the required reduction in emissions from a nonpoint source that are needed for a point source to increase emissions by one unit. Essentially, the trade ratio is used to define equivalence between point and nonpoint loads.

Well-designed trading ratios are influenced by the uncertainty about actual loads stemming from the measurement problem, but also by the inherent riskiness of nonpoint emissions resulting from the inherent variability or stochasticity of nonpoint loads (often due to weather-related events). Accordingly, nonpoint pollution cannot be controlled deterministically. This nonpoint risk has important implications for the design of the trading ratio. There are two opposing perspectives on this issue.

The most common perspective in practice is that *diverting controls from point sources to nonpoint sources is risky*. This perspective comes from the view that the appropriate policy objective is to maintain a particular level of control of emissions. Point source controls are viewed as relatively certain, since point source emissions are not highly stochastic and they are fairly easily measured. In contrast, nonpoint controls are highly uncertain due to the stochastic and unobservable nature of nonpoint emissions. Trades that involve point sources purchasing nonpoint permits are therefore seen as reducing the certainty of

controls, creating risk. The best policy response in this case is to increase the trading ratio (Horan 2001). On the one hand, a larger ratio provides a margin of safety as point sources must purchase more nonpoint permits in order to increase their emissions. On the other hand, a larger ratio increases the cost of purchasing nonpoint permits, thereby discouraging trades between point and nonpoint sources. Typical ratios used in practice are greater than unity, and range between 2:1 and 3:1 to address this margin of safety issue (Horan 2001).

The second perspective on nonpoint risk comes from the economic theory on point-nonpoint trading (Shortle 1990; Malik et al. 1993). Here, the appropriate policy objective, consistent with TMDLs and other water quality goals, is to reduce the probability of water quality damages from point source and nonpoint source emissions. Given this objective, it turns out that *failure to control nonpoint emissions is risky*. The reason is that highly variable nonpoint emissions result in highly variable damages, and it is this variability in damage costs that are risky. Since risk is socially costly, the appropriate policy response is to reduce the trading ratio in order to encourage more nonpoint controls and thereby reduce this important source of risk. Economic welfare theory indicates that this perspective is the correct one, in which case the large ratios used in practice are counter-productive in two important ways: (i) they increase rather than decrease water quality risk, thereby increasing the economic damages from water quality impairments, and (ii) they discourage trades involving nonpoint sources, which can only increase aggregate control costs. Economic simulations find optimal trading ratios to be much lower than those found in most trading programs, in large part because of these risk effects (Horan et al. 2002a,b; Horan et al. 2004).

Although we have discussed the choice of permit levels and trading ratio separately, they are in fact a joint decision. For instance, Horan and Shortle (2005) have shown that if the trading authority only has power to choose the trading ratio (and not permit levels), then the economically optimal trading ratio may be much different than the ratio the agency should choose if it has control over both choices.

### **Multimedia Trading**

Fully realizing the benefits of trading for air and water quality programs cannot be achieved through the application of single media trading schemes. The interdependence of the problems requires the development of multi-media trading mechanisms that can effectively address complementarities and tradeoffs, facilitating the achievement of beneficial trades while assuring the achievement of air and water quality objectives. Essentially, multimedia trading would create property rights for sources that emit pollutants affecting different environmental media simultaneously. Like any other trading system, multimedia trading must satisfy four basic conditions outlined by the OECD (2002): (i) a quantitative environmental performance target to be achieved individually or collectively; (ii) a defined spatial and temporal flexibility given to regulated agents in the choice of location of resource extraction or pollution emission; (iii) enforcement capacities to ensure that actual performance of agents matches their obligations and initial allocation of permits/property rights (OECD 2002). And like single media trading, the nonpoint character of agricultural emissions pose problems that can be addressed with careful attention to program design. The primary new challenges, as we describe below, really stem from the interdependence of the air and water systems.

### **Joint Determination of Air and Water Quality Goals**

Current policy frameworks generally call for limits on emissions to air and water to be determined independently. To the extent that air and water emissions are jointly produced by the management decisions of nonpoint source and point source emitters, and to the extent that there are cross-media interactions from the emissions (e.g. air emissions may be deposited into water resources, while volatilization of pollutants may occur from water resources), a multi-media approach will call for integrated goal setting. The need for integrated goal setting will hold with even more force if costs and benefits are considered in goal-setting (as is required under the Clean Water Act but not the Clean Air Act).

### **Multiple Markets**

Single media trading schemes generally imply participation in a single market. But cost-effective multi-media approaches will imply a market for each medium, with rules governing trades both within and between markets. Environmental groups are often uncomfortable with the notion of trading between markets, for fear that such trades could improve environmental quality in one market at the expense of

environmental quality in the other. But this concern can be alleviated with a coordinated approach to program design. Moreover, it should be stressed that an uncoordinated approach involving separate markets can run a greater risk of reducing environmental quality in one or more of the media. The reason is that air and water emissions are jointly produced by the management decisions of an emitter – particularly agricultural nonpoint sources. If the markets are not developed jointly, then trades in one market could lead to investments that could improve the environmental quality of one media at the expense of the other, reducing the ability to cost-effectively attain goals in either market. Indeed, it is well-established that uncoordinated environmental programs can lead to unintended, adverse economic and environmental consequences (e.g., Weinberg and Kling 1996). On the other hand, a coordinated approach can lead to cross-subsidization of emissions reductions, as a trade to reduce air emissions can lead to a change in management practices that simultaneously reduces both air and water emissions (see Horan et al. 2004 for a discussion of a similar issue in a different context). But whether or not this cross-subsidization can occur will depend on whether the trading rules are designed to take advantage of this possibility, so that a polluter can attain credit in both markets from a single management action.

### Conclusion

Multi-media pollution trading has great potential as a policy approach for addressing air and water quality problems, but its usefulness ultimately depends on how the program is designed. Research, that utilizes the lessons learned from single-media markets, is needed to fully comprehend the design issues that will be pertinent for the multi-media case.

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## Reducing Ammonia Emissions from Animal Operations: Potential Conflicts with Water Quality Policy

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### Abstract

Animal waste from confined animal feeding operations is a potential source of air and water quality degradation from evaporation of gases, and runoff to surface water and leaching to ground water. The multi-media nature of pollution from animal waste poses challenges to farmers and to environmental protection agencies. Failure to account for the multi-media nature of animal waste in policy design and implementation can lead to unintended consequences in terms of costs to farmers and degradations of environmental quality. This paper assesses the potential economic and environmental tradeoffs between water quality policies and air quality policies that require the animal sector to take potentially costly measures to abate nitrogen pollution (nitrates and ammonia). We found that implementing ammonia emission restrictions on top of existing Clean Water Act requirements for Concentrated Animal Feeding Operations could increase the cost of meeting water quality requirements, degrade water quality, and impose costs on farmers that could have been avoided if policies were coordinated from the start.

### Introduction

Animal production generates byproducts such as organic matter, urea, ammonia, nitrous oxide, phosphorus, methane, carbon dioxide, pathogens, antibiotics, and hormones. Without proper management, these materials can degrade surface water, ground water, air quality, and soils. Mitigating pollution can be difficult when more than one environmental medium is affected by a single pollution source. The correction of a single problem without simultaneously addressing others may not increase societal welfare as much as anticipated, and may even decrease it. U.S. environmental laws typically address only a single environmental medium, and coordination between policies is rare.

Nitrogen emissions from confined Animal Feeding Operations (AFOs) are a good example. Animal waste can contain significant amounts of nitrogen. Nitrogen moves freely between the soil, air, and water, and there is a high degree of interdependence between the forms and paths it takes. Emissions to air and water are linked by the biological and chemical processes that produce various nitrogen compounds. Nitrogen enters the system in animal feed. Some of the nitrogen is retained in the animal products (meat, milk, eggs), but as much as 95 percent is excreted in urine and manure (Follett and Hatfield, 2001).

Manure can collect in or under the production house for a few hours or several years, depending on the collection system. Production houses are ventilated to expel gases that are emitted, including ammonia. The manure is eventually removed from the house to a storage structure (lagoon, tank, pit, or slab) and stored anywhere from a few days to many months. Losses of nitrogen to the air and water can occur during this time, depending on the system and the extent of contact with rain and wind. The stored manure is eventually transported to fields where it is applied. Losses to air and water from the field vary, depending on application method, timing, and rate.

The form nitrogen takes in its journey from animal to field depends on a host of factors, including storage technology, manure moisture content, temperature, air flow, pH, and the presence of micro-organisms. Reducing nitrogen movement along one path by changing its form will increase nitrogen movement along a different path (National Research Council, 2003). For example, reducing ammonia emissions from a field by injecting waste directly into the soil increases the amount of nitrate available for crops, but also the risk to water resources (Oenema et al., 2001; Abt Associates, 2000). Ignoring the interactions of the nitrogen cycle in developing manure management policies could lead to unintended and adverse effects on producers' costs of managing manure and environmental quality.

Current Clean Water Act (CWA) regulations require that animal feeding operations meeting certain size and discharge characteristics (known as Concentrated Animal Feeding Operations or CAFOs) obtain a National Pollutant Discharge Elimination System (NPDES) permit (U.S. EPA, 2003). The NPDES permit for CAFOs requires a nutrient management plan covering the land on farms receiving manure. The plan must specify an application rate for manure nitrogen or phosphorus based on the agronomic needs of the crop. Research has found that most CAFOs over-apply manure nutrients, meaning that implementing a nutrient management plan could significantly increase the cost of land-applying manure (Ribaud et al., 2003). Increased hauling costs make up a significant percentage of the total cost of meeting the land application requirements (Ribaud et al., 2003). In this analysis we assume that CAFOs must implement a nitrogen-based nutrient management plan that contains an application standard based on the nitrogen needs of crops receiving manure.

Atmospheric emissions of pollutants are regulated by the Clean Air Act (CAA) and the Comprehensive Environmental Response Compensation and Liability Act (CERCLA). AFOs are not explicitly covered by either, but concerns over ammonia emissions are prompting discussions about how these laws might be used to regulate such emissions. In this analysis we assume that all or some animal feeding operations are required to reduce ammonia emissions.

When a production activity pollutes more than one environmental medium, addressing a single problem can lead to further resource misallocations (Lipse and Lancaster, 1956). In this paper we examine the economic and environmental consequences of adding ammonia reduction requirements on top of the CWA requirements already placed on animal feeding operations.

## Methods and Results

This study uses three separate but related analyses to capture a broad range of economic decisions (and consequences) that result from farmers' meeting environmental regulations. Data from the 1998 Agricultural Resources Management Survey (ARMS) of hog producers were used to estimate the tradeoffs that occur at the farm level when air and water policies are introduced. The broader, national scale impacts of controlling runoff and emissions, including welfare impacts on both producers and consumers and regional shifts in production, were examined with a national model of the agriculture sector. A case study of the Chesapeake Bay watershed was used to demonstrate the challenges facing farms and resource management agencies when hypothetical ammonia emission reductions are required for farms meeting the CAFO regulations in a region where land for applying manure is relatively scarce.

At the heart of all three analyses are nitrogen loss coefficients that are derived from a mass-balance accounting of nitrogen in manure. We used as our starting point the manure management "trains" (MMTs) or paths developed by EPA (2004). This inventory of current animal production and manure management systems takes a mass balance approach that is central to our study. Nitrogen in manure excreted in the production facility is accounted for through storage and application to fields. However, these MMTs did not include management practices for reducing ammonia emissions. We adapted MMTs for systems incorporating recognized ammonia reduction technologies such as lagoon covers and field injection by using reduction efficiencies reported in the published scientific literature to redirect nitrogen along the different paths (table 1). In all three analyses, CAFOs were first required to meet CWA requirements for land application of manure. Then, restrictions on ammonia emissions were applied to all AFOs.

### Farm-Level Analysis

To examine the effect of potentially conflicting policies on a farmer's production decisions, we constructed a hog farm economic model. A positive mathematical programming model with calibrated cost functions captures the essential farm-level tradeoffs between ammonia air emissions and nitrogen water discharges for hog operations that are large enough to be considered CAFOs. Farmers maximize profits given input prices, output prices, regulatory requirements, and available cropland by choosing a manure management technology, the amount of land on which to spread manure, the acreage of each crop to plant, the amount of commercial fertilizer to purchase, and the number of hogs to produce. We assume that the baseline manure storage system (pit or lagoon) would not change. Farmers would meet environmental requirements by making adjustments within these systems. Water quality impacts are assumed to be directly related to the amount of nitrogen applied to cropland that is in excess of crop needs, after accounting for losses to the

atmosphere. Air emissions are derived from total animal production and the type of storage/handling technology employed by the operation. For operations using pits for storage (slurry), ammonia nitrogen emissions are constrained to 10 percent above the minimum obtainable if all manure is injected into the soil. For lagoon operations, ammonia emissions are constrained to 20 percent above what is obtainable if lagoons are covered.

**Table 1. Examples of manure management systems and nitrogen losses**

Animal	System	N excreted	Losses from building	Losses from storage	Losses from field	Total losses to air	Total available for crops
		lbs N/head/year					
Hogs	Lagoon - uncovered	18.3	4.9	9.5	0.8	15.2	3.1
Hogs	Lagoon-covered	18.3	4.9	0.5	2.8	8.2	10.1
Hogs	Deep pit-surface apply	18.3	6	0	2.6	8.6	9.7
Hogs	Deep pit-incorporate	18.3	6	0	0.4	6.4	11.9
Dairy	Flush barn – surface apply	220	44	125	11.2	180.2	39.8
Dairy	Flush barn – incorporate	220	44	125	2.8	171.8	48.2
Dairy	Daily spread – surface apply	220	15.2	2.2	37.7	55.1	164.9
Dairy	Daily spread – incorporate	220	15.2	2.2	8.3	25.7	194.3
Poultry	Surface apply	0.9	0.18	0.03	0.17	0.38	0.51
Poultry	Incorporate	0.9	0.18	0.03	0.04	0.25	0.65
Poultry	Alum – surface apply	0.9	0.03	0.04	0.21	0.28	0.62
Fed beef	Solid storage - surface apply	102	0	20.8	13.8	34.6	67.4
Fed beef	Solid storage - incorporate	102	0	20.8	0.7	21.5	80.5

The model is calibrated with data from the 1998 USDA-ARMS survey of hog operations. In the model, nitrogen in waste may be released into the atmosphere as ammonia or preserved in the manure storage and handling system until applied to cropland. We consider two technological options for reducing ammonia emissions: injection of manure into the soil and covering lagoons.

Meeting a nitrogen fertilizer application standard was estimated to reduce hog enterprise profits by 6.9 percent, while reducing excess nitrogen applications to the soil by 100 percent. Almost 70 percent of the manure that had been applied on the farm was moved off the farm to adjacent land, increasing hauling costs by \$205 million (table 2).

When air quality-based ammonia emission controls are also required, profits are reduced an additional 8.9 percent. Only part of this is due directly to ammonia management costs. Covering tanks and lagoons and injecting waste into the soil reduces ammonia emissions but increases the quantity of manure nitrogen farmers must deal with. As a consequence, the cost of meeting the CWA requirements increases by 12.8 percent as more land is needed for spreading manure and hauling costs increase. This impact on water-quality control costs might not be anticipated when ammonia control policies are developed.

**Table 2 . Production, profits, emissions, and technology adoption under nitrogen application standard (NAS) to protect water and ammonia nitrogen emission standards (ANS).**

	1. Base	2. NAS		3. NAS+ANS	
			% chg.		% chg.
Hogs (mil. cwt.)	119.10	117.96	-0.96	115.61	-2.93
Total profits (mil. \$)	3,700	3,487	-5.77	3,187	-13.87
Hog enterprise profits (mil. \$)	3,047	2,837	-6.89	2,568	-15.72
Ammonia N - storage (1000 tons)	327.5	325.3	-0.68	198.8	-39.29
Ammonia N - field (1000 tons)	33.8	34.9	3.38	52.1	54.15
Ammonia N – total (1000 tons)	361.3	360.2	-0.30	250.9	-30.55
Excess N - soil (1000 tons)	137.7	0.0	-100.00	0.0	-100.00
Application rate (factor of agronomic rate)	7.3	1.0	-86.38	1.0	-86.38
Manure transport costs (mil. \$)	0.0	205.6	-	231.9	-
Manure N on-farm (1000 tons)	183.6	51.8	-71.81	42.3	-76.96
Manure N off-farm (1000 tons)	0.0	127.7	-	235.7	-
Cover lagoon (% farms, all farms)	0.00	0.00	0.00	36.42	-
Inject manure (% land, all farms)	25.56	22.55	-11.78	37.46	46.54

### National Effects

Having examined the implications of addressing nitrogen concerns over water and air quality for one farm-level sector, we now take a larger view. Here, potential changes in commodity prices and shifts in production among regions are estimated assuming adoption of land application standards for manure generated on CAFOs and reductions in ammonia emissions from manure generated on *all* animal feeding operations. Tradeoffs are not limited to the farm, but extend to regions and to consumers.

We use the U.S. Regional Agricultural Sector Model (USMP model) to assess secondary price and quantity interactions across crop and animal production (USMP; House et al., 1999) at the national and regional levels. The USMP model accounts for production of major crops (corn, soybeans, sorghum, oats, barley, wheat, cotton, rice, hay, and silage) and confined animals (beef, dairy, swine, and poultry) across 10 geographic regions, comprising approximately 75 percent of crop production and more than 90 percent of livestock and poultry production in the United States. USMP is a comparative-static, spatial, and market equilibrium model that incorporates agricultural commodity, supply, and demand, environmental impacts, and policy measures.

Various adjustments to crop rotation, tillage, production, and technology can be made to meet the nitrogen application or ammonia emission constraints. The composition of cropping or animal production could change to alter the amount of manure nutrients demanded (by the crop sector) or supplied. Storage, handling, or application technologies can reduce ammonia emissions and alter nitrogen content of manure. Our model selects the optimal combination of technology, crop, and animal changes across the sectors and regions in order to minimize the net cost to society of meeting different environmental constraints (measured as changes in net returns and consumer surplus). Storage, handling, and application technologies, available in the model for meeting the CAFO nutrient standards and for reducing AFO emissions of nitrogen, are consistent with those in the farm-level analysis.<sup>1</sup> We also consider treatment of poultry litter with aluminum sulfate (alum) to reduce nitrogen storage losses and to decrease the bioavailability<sup>2</sup> of phosphorus. Our baseline for comparison is the USDA 2010 baseline projections for prices and production.

<sup>1</sup> We assume a crop producer willingness to accept manure of 30 percent, meaning that up to 30 percent of available cropland in each region will utilize manure nutrients. Alternative levels of manure utilization have been considered, but are not included here.

<sup>2</sup> Bioavailability of phosphorus refers to the amount of phosphorus in runoff that is available for aquatic and terrestrial plant growth.

Meeting the Clean Water Act requirements raises the storage, handling, treatment, and application costs for the national agricultural sector by \$534 million. Nitrogen runoff declines about 12 percent, due to CAFOs meeting a nitrogen application standard and an overall decline in farm production resulting from higher production costs. Because of the decline in production, prices rise for consumers. The total cost to producers and consumers from the CWA requirements was estimated at \$850 million per year. An unintended benefit is a 10-percent reduction in overall ammonia emissions from the animal sector, brought about by the decline in production as well as a change in the mix of animals produced and regional production shifts.

When ammonia emission restrictions are required for all AFOs, an important environmental tradeoff emerges (figure 1). A 10-percent reduction in ammonia emissions for each farm results in an increase in total nitrogen runoff, even though the total number of animals declines. The reason is that ammonia restrictions are applied not only to CAFOs that must continue to meet nitrogen application standards, but to smaller AFOs that do not have to meet such standards. The increased nitrogen content of manure due to emission-reducing management measures results in higher nitrogen application rates and higher nitrogen losses to surface water. The water quality gains from the CWA requirements for CAFOs are reduced as more stringent ammonia reductions are required. The increase in nitrogen runoff could be avoided if CWA requirements were extended to all farms that must reduce ammonia emissions. The consequence, however, would be higher costs for producers and higher prices for consumers.

### Chesapeake Bay Case Study

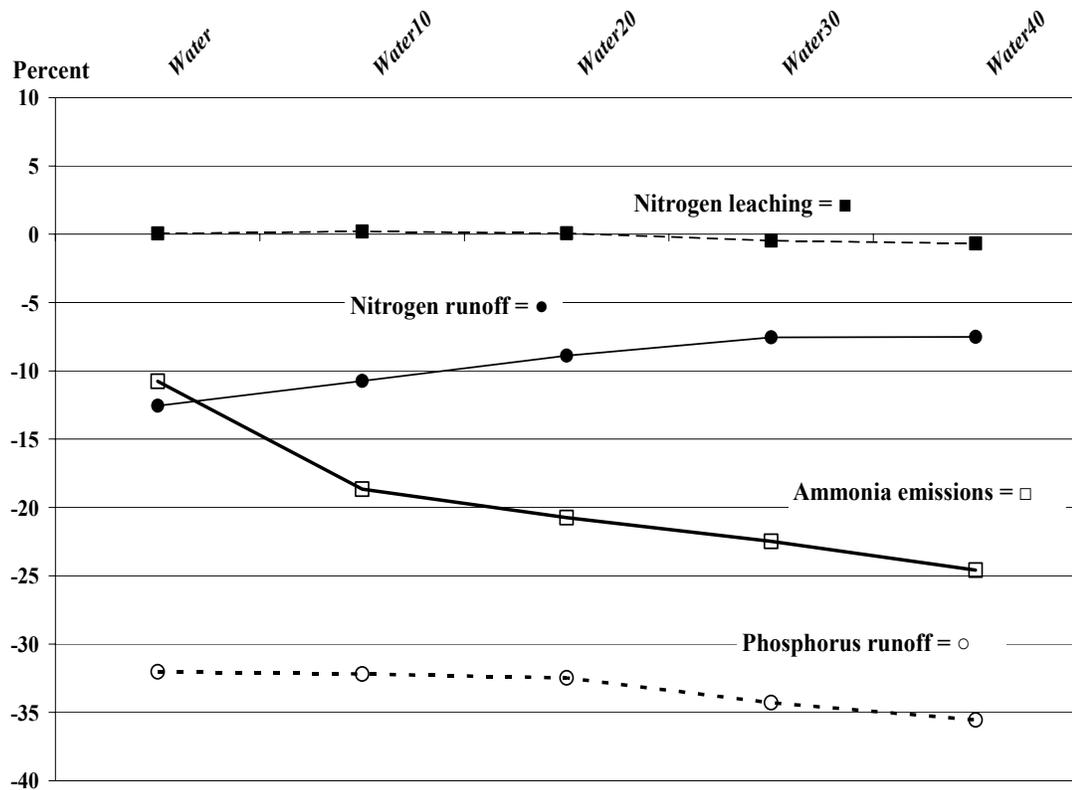
Acquiring enough land for spreading manure to meet a nutrient management plan is an issue in regions with high concentrations of animals relative to land available for spreading. The Chesapeake Bay Watershed (CBW) is one such region. Nutrient discharges to water in the region have resulted in eutrophication and related ecological shifts that have harmed wildlife and aquatic resources. Manure from confined animal feeding operations is a primary source of nutrient runoff and local air emissions (Follett and Hatfield, 2001).

Ribaudo et al. (2003) found that if cropland application remains the primary disposal method for manure, implementing nutrient management regulations would pose significant challenges. More than 30 percent of CBW crop farms would need to accept manure in order for the region's annual manure production to be land-applied according to a nitrogen-based management plan. Any change in manure handling that increases the nutrient content would only exacerbate the problem and raise the costs of hauling and applying manure.

In this analysis we used a regional modeling framework designed to capture spatial consideration in manure production and land availability for manure spreading (Aillery et al., 2005). The model and its results reflect a regional planning perspective in evaluating key cost determinants and alternative policy strategies at a watershed scale. The model does not restrict ammonia emissions directly. Instead, it requires producers to implement technologies for reducing emissions, including lagoon covers, injection, and treating poultry litter with alum. We assume that the operators of 30 percent of the cropland in the watershed are willing to use manure as a nutrient source (nationally, the willingness to accept manure is in the 10 to 20 percent range).

The annual cost of meeting a nitrogen-based application standard for water quality is estimated to be about \$30 million if applied only to CAFOs (Case A in figure 1). When ammonia restrictions are also required for CAFOs, the cost of air emission-control practices totals about \$9 million (Case B). However, with ammonia restrictions CAFOs must bear additional land application costs because the nitrogen content of manure increases. Roughly twice as much land on which to spread manure is required, resulting in a \$9 million increase in annual hauling and application costs. The annual cost to CAFOs of reducing ammonia emissions is therefore estimated to be about \$18 million.

Extending ammonia reduction requirements to all AFOs increases the total costs of reducing emissions by \$32 million per year (Case C). However, as seen in the other analyses, the nitrogen content of manure produced by non-CAFOs increases because of the measures taken to reduce ammonia emissions (roughly doubles in this analysis). Unless this manure is spread according to a nutrient management plan, the risk of nitrogen runoff to the Bay is greatly increased.



Water – nitrogen application standard land receiving manure

Water10 – nitrogen application standard plus a 10 percent reduction in ammonia emissions

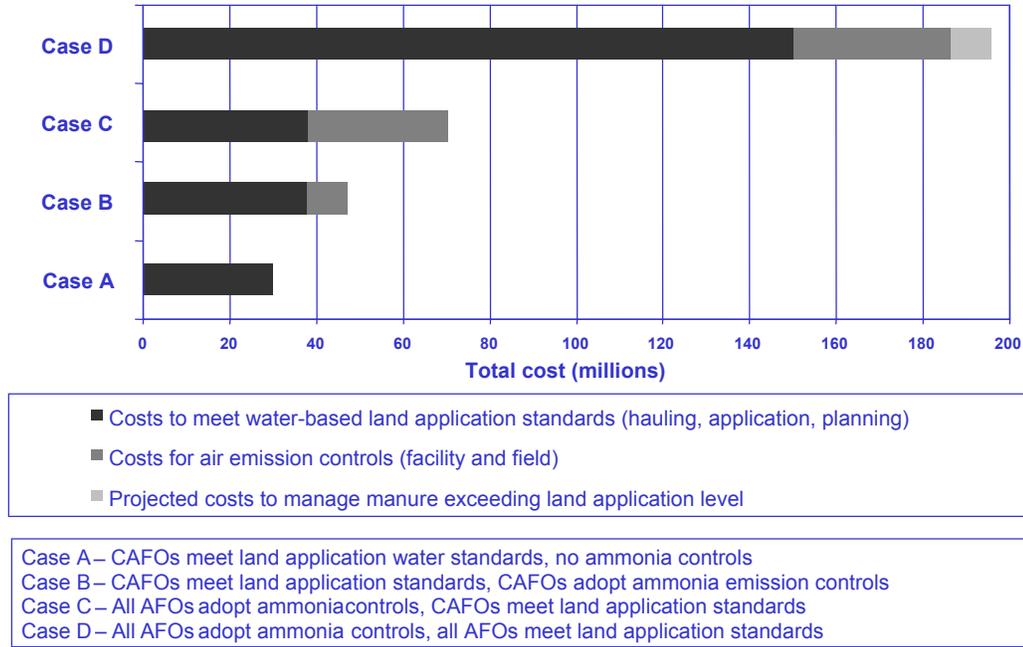
Water20 – nitrogen application standard plus a 20 percent reduction in ammonia emissions

Water30 – nitrogen application standard plus a 20 percent reduction in ammonia emissions

Water40 – nitrogen application standard plus a 20 percent reduction in ammonia emissions

**Figure 1. Changes from baseline in ammonia and nutrient losses to the environment, U.S.**

One solution would be to require all farms that must meet ammonia restrictions to also develop and implement a nutrient management plan to protect water quality (Case D). However, coordination of policies would increase overall annual costs for managing manure in the watershed to \$187 million, and create an additional problem: what to do with excess manure. If all farms were to follow both a nutrient plan and reduce ammonia emissions, there would be inadequate farmland in the watershed under an assumed 30 percent willingness to accept manure to spread all manure produced at agronomic rates. Manure would have to be moved outside the watershed, or directed to other uses that do not require land application, such as energy or fertilizer production. If we use the rates Delaware pays to haul manure out of the State, moving the excess manure out of the CBW would add an additional \$9 million per year to total manure management costs in the watershed.



Source: Aillery et al., Economic Research Service, 2005

**Figure 2. Annual costs of meeting nitrogen application standards with alternative emissions controls on CAFOs and AFOs, Chesapeake Bay Watershed**

### Conclusions

Addressing the pollution problems generated by production activities can be difficult when more than one environmental medium is affected by a single pollution source. This paper illustrates the potential tradeoffs between air and water quality when nitrogen losses from animal feeding operations are policy targets. Nitrogen in manure can take a number of forms; reducing one form of nitrogen to protect one environmental medium can increase the amount of another form moving to a different medium.

Should ammonia emission standards induce farmers to adopt manure management practices that reduce air emissions, the manure applied to land would have a higher nitrogen content. Depending on how the air quality regulations are applied, this could have two impacts on CAFOs and water quality. First, those farms identified as CAFOs might need to increase the amount of land they are spreading on to meet nutrient application standards if they are also required to reduce ammonia emissions. This would be particularly costly in a region where animal concentrations are high and cropland available for spreading manure is relatively scarce. In our analysis of the costs of spreading manure in the Chesapeake Bay watershed, nitrogen content of manure increases substantially if ammonia restrictions are introduced, which would increase the costs of meeting nitrogen application standards. The higher cost of meeting water quality regulations might not be considered in an assessment that focuses on the cost of air quality regulations.

Second, a failure to coordinate water and air policies could lead to an unanticipated loss of water quality benefits. If air quality regulations were to result in States requiring ammonia reductions on smaller farms as well as current CAFOs, the water quality benefits of the CAFO regulations could be diluted by excess nutrient applications on the smaller farms. This was the case in both our regional and national analyses. Without regulations for spreading manure at agronomic rates, farms reducing ammonia emissions would be more likely to over-apply manure, thus increasing the potential for nitrogen discharges to surrounding waters. It would be difficult to achieve ammonia emission reductions and still maintain water quality gains of the CAFO regulations if water quality regulations were not extended to smaller operations. Doing so would increase the costs to producers and consumers, but provide greater overall environmental improvements.

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## Valuation of Air Emissions from Livestock Operations and Options for Policy

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### Abstract

Animal husbandry is a major emitter of methane, which is an important greenhouse gas. It is also a major emitter of ammonia, a precursor to fine particulate matter, which is arguably the number one environmentally related public health threat facing the nation. This paper presents an integrated process model of the engineering economics of technologies to reduce methane and ammonia emissions at dairy operations in California. Three policy options are explored including greenhouse gas offset credits for methane, particulate matter offset credits for ammonia, and expanded net metering policies to provide revenue for sale of electricity generated with methane. Individually any of policies appear sufficient to provide the economic incentive for farm operators to reduce emissions. This paper reports on initial steps to develop fully the integrated process model to provide guidance for policymakers.

### Introduction

Animal husbandry is a major emitter of methane and ammonia in the United States. Methane, which is a greenhouse gas (GHG) with 23 times the potency of CO<sub>2</sub>, constitutes nearly one tenth of all US GHG emissions. Although methane has a shorter residence time than CO<sub>2</sub>, its radically higher effect makes it an attractive target for policy measures, especially in the near term. Ammonia, on the other hand, is a precursor to fine particulate matter (PM<sub>2.5</sub>), arguably the number one environmentally related public health threat facing the nation.

The main technology to control methane emissions in animal husbandry involves using methane digesters that generate and collect methane from manure. The generated biogas can then be burned and converted into heat or electricity. Electricity generation through methane digesters reduces farmers' need to purchase electricity and also can create surplus electricity that is available for sale back onto the electricity grid. Control of methane is also a potential offset for CO<sub>2</sub> emissions with prospective value of tens of dollars per ton at forecasted levels of costs for CO<sub>2</sub> control in the regional programs under design in the US (RGGI, 2005). Control of ammonia, in contrast, has potential to be tied to particulate control policies offering offsets or emission reduction credits. However, a large fraction of the benefits from the control of methane and ammonia in animal husbandry accrue outside of existing markets and cannot be appropriated by individual dairy operations choosing whether to invest in methane and ammonia control technology. For example, reductions in GHG emissions from livestock operations are currently not economically rewarded. As a consequence, dairy operations face only limited incentives for emission control using methane digesters. This, in turn, can result in less than overall optimal adoption of emission control technology by the dairy industry.

In this study, we seek to examine the full potential for methane and ammonia control in animal husbandry. Our objectives are to identify: (1) the methane and ammonia emission reduction potential of manure process control; (2) the cost thresholds that determine sensible adoption of different emission control technologies; (3) the benefits from emission control that accrue outside the dairy industry; and (4) the policies or institutions that are necessary to achieve these benefits. This information will be essential to future public policy that may give shape to either the formation or new markets for emission reductions or to direct financial and technical assistance to methane and ammonia control in agriculture.

We select the California dairy industry for our application. California is a particularly well-suited study area, since it is the number one ranked dairy state in the US and represents about one fifth of all US cows and milk production. California dairy also generates nearly \$5.4 billion in cash receipts and almost a billion dollars in exports, which makes it one of the economically most important agricultural sectors in California.

The quantity of manure generated by California cows is massive—over 70 billion tons each year—and amounts to more solid organic waste than is generated by the state's 35 million residents (US EPA 2006).

Problems associated with the dairy manure in California are heightened by the increase in the average dairy size and their concentration in areas with rapidly growing population and multitude of air quality problems. While California had about 4,000 dairies in 1992, the total number had dropped to 2,100 by 2004. During the same time period, the total number of cows increased from roughly 1.2 million to 1.7 million, meaning that the average number of cows per dairy more than doubled from about 370 in 1992 to over 800 in 2004. California dairy farming is concentrated in the Central and San Joaquin Valley regions, where the five largest dairy counties in the US (Tulare, Merced, Stanislaus, San Bernardino, Kings) are situated. These counties have roughly 1.1 million cows in total, which is about 12% of US dairy cows. Tulare County by itself has approximately 440,000 dairy cows (4.5% of all US dairy cows), which is more than the total number of cows in any US state outside California except for Wisconsin, New York, Pennsylvania, and Minnesota. These counties, as well as many other California counties with significant dairy presence, are also non-attainment areas for particulate matter and ozone, meaning that they do not meet the minimum federal air quality standards (EPA Green Book). Population growth in the top-five dairy counties in California was over 20% between 1990-2000, which is well over the state average of 13.6% (US Census), meaning that the human population exposure to pollution is worsening.

California has initiated several programs to encourage the treatment of manure using methane digesters. These programs include Dairy Power Production Program, Self-Generation Incentive Program, and the net metering Assembly Bill. The Dairy Power Production and Self-Generation Incentive Programs provide cost-share funding for capital investments towards new installations of methane digesters.<sup>3</sup> Assembly Bills 2228 (signed into law in 2002) and 728 (signed into law in 2005) require the state's three largest investor-owned utilities (PG&E, SCE, and SDG&E) to offer net metering to dairy farms that install methane digesters. These initiatives encourage the dairy industry to adopt methane digesters, but do so without considering all the costs and benefits associated with the reductions of methane and ammonia emissions.

In this paper, we develop an integrated model to examine the control of methane and ammonia in dairy farming. We pay special attention to comprehensive accounting of both private and social benefits and costs of methane and ammonia control. The analysis focuses on the interaction of methane and ammonia with climate, energy, and public health policies, including the potential use of offsets for GHG policies or regional air pollution policies. The model is designed to provide policymakers a tool to understand the technical and economic relationships in order to realize the benefits of managing air emissions and waste discharges from agriculture.

In the rest of this paper, we first explain the air pollution issues in dairy operations. Then, we describe the integrated process model of manure management, which constitutes the core of our analysis. The description of the model includes a depiction of baseline emissions, control technologies for ammonia and methane, and the potential electricity generation, green house gas reductions, and health benefits from the adoption of control technologies. Thereafter, we utilize the model to evaluate different policy options in California. Conclusions and discussion of results close the paper.

## **Air Pollution Issues in Dairy Operations**

### **Methane**

Methane is produced from the decomposition of livestock manure under anaerobic conditions. According to EPA, in 2003 roughly 545 CO<sub>2</sub> equivalent tons of methane were emitted from human related activities in the U.S. Approximately 28% of these emissions were from animal husbandry, either from enteric fermentation during digestion by ruminant animals or from manure management.<sup>4</sup> Enteric fermentation, which accounts for about ¾ of methane emissions from animal husbandry, occurs when microbes in the animals fore-stomach convert feed into digestible products and create methane as an exhaled byproduct.

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<sup>3</sup> Some federal programs can also provide cost-share funding for methane digesters include Environmental Quality Incentives Program (EQIP), Conservation Innovation Grants Program (CIG), and Conservation Security Program (CSP). (CEC 2006; NDESC 2005).

<sup>4</sup> For more information see [www.epa.gov/methane/sources.html](http://www.epa.gov/methane/sources.html) (accessed 2/14/06).

The rest of methane emissions from livestock operations come from manure management (US EPA 2005)<sup>5</sup>, which accounts for roughly 7% of total anthropogenic methane emissions in the US. Methane from manure management is produced during the anaerobic decomposition of organic material in manure. Methane production is particularly abundant when lagoons and holding tanks are used for liquid manure management. When manure is deposited on fields in a dry form, methane emissions are much less.

The main approach for controlling methane emissions from manure management is to capture the methane and burn the biogas as a way to generate electricity for on-farm use and, potentially for sale in the market. Combustion of methane for electricity generation results in emissions of carbon dioxide (CO<sub>2</sub>), another important GHG, but burning one ton of methane (equivalent to 23 tons of CO<sub>2</sub> if allowed to vent) yields 2.75 tons of CO<sub>2</sub> and thus a large reduction in the net contributions of greenhouse gases from the farm. In addition, the electricity supplied from this activity substitutes for other forms of electricity generation including fossil fuels and thereby potentially leads to a net reduction in GHG.

Several methane digester systems are currently being implemented on dairy farms in California. Over 30 dairies have applied for California Energy Commission's cost-share grants for the installation of methane digesters, and at least a dozen installations are in already operation (Sustainable Conservation 2005, 2006). As of February 2006, assessment data are available for four methane digesters that were co-financed by the California Energy Commission: Blakes Landing, Castelanelli Bros., Cottongwood, and Meadowbrook Dairies. Table 1, which is compiled using project evaluation reports to California Energy Commission (CEC 2005a-d), summarizes information about these dairies and their methane digesters.

Generally, dairies can generate more electricity using a methane digester than they consume. Therefore, financial benefits to the dairy from a methane digester depend on the electricity output from the digester, on-farm usage of electricity, and the retail and regeneration credit prices of electricity. The effective financial benefit to the dairy operation from generating a kilowatt of electricity using the methane digester varies between the net-generation credit and the retail price of electricity (weighted by the relative volumes of on-farm electricity purchase offsets and net generation credits). For example, the Castellanelli dairy reports an average agricultural and residential energy usage of about 56,736 kWh/month, which would cost about \$6,240 at the retail rate of \$0.11/kWh. This is the amount of monthly cost savings at the dairy from the methane digester, given sufficient methane digester capacity to generate this much energy. In addition, the surplus energy output generates revenue if it can be sold to the grid for a positive price. The amount of compensation for net-generation is not yet well established. The two dairies, for which regeneration credit pricing has been described (Castelanelli and Meadowbrook dairies), suggest that a roughly \$0.06/kWh regeneration credit is realistic.

## Ammonia

Animal husbandry operations are a source of approximately half of US ammonia emissions, contributing roughly 2.5 million tons of ammonia emissions per year.<sup>6</sup> Dairy farms are responsible for a little over 20% of the emissions from animal husbandry.<sup>7</sup> The amount of ammonia emissions from livestock farms depend on how animal waste is managed and will vary substantially depending on concentrations of ammonia, temperature, pH and how long the waste is stored before applied to land as fertilizer. Ammonia concentrations and therefore emissions tend to be higher with higher temperatures and higher pH and lower the longer waste is stored before land application.

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<sup>5</sup> Enteric fermentation and manure management contribute methane approximately equal to 115 and 39 TgCO<sub>2</sub> equivalent emissions, respectively. All GHG emission resulting from human activities total 6,072 TgCO<sub>2</sub> equivalents (U.S. EPA 2005).

For more information see [www.epa.gov/methane/sources.html](http://www.epa.gov/methane/sources.html) (accessed 2/14/06).

<sup>6</sup> Total ammonia emissions in the US are about 4.8 million tons per year. "PM Overview and Sources," WESTAR PM EI Workshop, Denver CO, March 2004, OAQPS, US EPA.

<sup>7</sup> US EPA 2004. National Emission Inventory - Ammonia Emissions from Animal Husbandry, (January 30), <http://www.epa.gov/ttn/chief/net/2002inventory.html>.

**Table 1: Examples of Dairy Methane Digester Systems in California**

		<i>Blakes Landing</i>	<i>Castelanelli Bros.</i>	<i>Cottonwood</i>	<i>Meadowbrook</i>
Cows (lactating)		247	1,600	5,351	2,133
Gas production, cf/day					
• Total	Tot	20,000	70,751	241,990	67,912
• Per cow	Per	84	44	45	31.84
Electric Output					
• Generator, kW	Gen	75	160	300 (700 planned)	160
• Total, kWh/year	Tot	229,220	1,132,595 (~50% gas flared)	2,334,095 (~55% gas flared)	931,144
• kWh/cow/day	KW	2.54	1.94	1.14 (for 300kW)	1.20 (design 1.68)
• Retail rate, \$/kWh	Ret	\$0.10	\$0.11 (regeneration credit \$0.058)	\$0.115	\$0.069 regeneration credit (not final)
Capital Costs		\$336,362	~\$800K (design \$773K)	~\$2.7M (design \$1.29M)	~\$800K (design \$524K)
O & M, per month		~\$100-800	~\$600	~\$5,000	~\$560
Manure collection		Covered lagoon	Covered lagoon	Covered lagoon	Plug flow digester
Agricultural and residential energy usage (kWh/month)		9,941	56,736 (summer 107,353)	N/A	42,778

Source: Compiled using California Energy Commission's 90-day evaluation reports (CEC 2005a-d).

Numerous methods have been discussed for reducing ammonia emissions using different strategies for different sources of emissions including livestock housing facilities, manure storage facilities and land application of manure.<sup>8</sup> One of the more effective approaches for use with housing facilities is the use of filters or biofilters to remove emissions from ventilation exhaust systems. These systems, which have been shown to remove approximately 74% of total emissions at a relatively low cost per animal, are also the main focus in our analysis. The effectiveness of other approaches such as impermeable barriers to prevent air movement out of livestock housing facilities and dietary manipulation is currently being studied. Other approaches that focus on the manure storage are currently being tested including urine/feces separation, acidification and the use of additives to prevent ammonia production and volatilization. Among these approaches urine/feces separation appears to promise the largest percentage reductions in ammonia emissions. As much as 35% of total ammonia emissions have been estimated to take place during or after land application of manure. One way to reduce these emissions is to inject the manure into the ground, or through the use of urease inhibitors following land application.

<sup>8</sup> The approaches to reducing ammonia emissions discussed in this paragraph are all described in greater detail in Iowa State University Extension (2004).

## A Process Farm-Level Model of Animal Waste Management

### Model Structure

In this paper, we develop a conceptual integrated model for methane and ammonia emissions from concentrated animal farm operations<sup>9</sup>. The integrated model framework includes methane and ammonia emissions from a baseline with no emissions controls and from a variety of emissions management strategies, including electricity and heat recovery as well as various ammonia emission control strategies. Such a model is transparent and useful for conducting comparative analysis. The model also considers the costs associated with these strategies and their benefits, such as GHG credit revenue and air quality (ozone and PM<sub>2.5</sub>) impacts. Table 2 provides a complete list of the components of the conceptual model and identifies which are currently available.<sup>10</sup> The model is developed using software called Analytica, which provides a graphical representation of relationships in the model (Figure 1) and easily incorporates quantitative measures of uncertainty. This latter capability is particularly important because there is considerable uncertainty and variability in emission factors estimation, technology performance and control costs.

### Baseline Emissions

The model includes estimates of baseline emissions of methane and ammonia in the absence of specific controls.<sup>11</sup> These estimates will vary depending on characteristics of the farming operation and where it is located.

Methane emissions include both emissions from enteric fermentation and from the decomposition of animal waste under anaerobic conditions. Animal and feed characteristics have a significant impact on methane emissions. This paper focuses on methane emissions from dairy operations, however the model includes enteric fermentation for six types of animals (non-dairy cattle, dairy cattle, swine, sheep, goats and horses). Methane emission factors also vary by region as a result of temperature and altitude differences and the methane emission factors for enteric fermentation by region are obtained from AP-42 (USEPA, 1998).

The amount of methane produced during waste decomposition is affected by the climate (temperature and rainfall) and the condition (oxygen level, water content, pH and nutrient availability) in which the manure is managed. Manure decomposes more rapidly when the climate encourages bacterial growth. For liquid manure systems, methane production increases with temperature. In our current model, methane emission factors by climate region are obtained from *Revised 1996 IPCC guidelines for National Greenhouse Gas Inventories* (IPCC, 1996).

The emission factors for ammonia used in the model come from EPA (2004), a study that developed ammonia emission factors by animal type for 18 different manure management trains (MMTs). Zhang et al (2005) are developing a processed based ammonia emission model.

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<sup>9</sup> NRC has suggested using a process-based model farm approach that incorporates “mass balance” constraints for some of the emitted substances of concern, in conjunction with estimated emission factors for other substances, may be a useful alternative to the model farm construct defined by EPA (NRC, 2003). However, in this paper we use emission factor approach to demonstrate our concept. After careful calibration, this simple conceptual model could be useful for policy analysis and for identifying data gap and research needs. Outputs from more sophisticated process based approaches could be incorporated/adopted in the integrated conceptual model.

<sup>10</sup> At this moment, some components are created as place holders. We plan to refine the model components and fill the data gap as our research advances. One of the advantages of such an integrated model is that we are able to identify the information needs.

<sup>11</sup> Other types of livestock will be added.

**Table 2. Conceptual Model Components**

- 
- Baseline Enteric Methane Fermentation\*
  - Baseline Methane Emission\*
  - Baseline Ammonia Emission\*
  - Ammonia Emission Control\*
    - Dietary Manipulation
    - Filtration and Biofiltration\*
    - Impermeable Covers
    - Permeable Covers
    - Urine Feces Segregation
    - Acidification
    - Additives
    - Control Land Application
    - Manure Amendments
  - Methane Production and Energy Recovery\*
    - Covered Lagoon
    - Plug Flow Digester\*
    - Complete Mix Digester
    - Gasifier
    - Gas Turbine Electricity Generation\*
  - Ammonia Control Cost\*
  - Methane/Electricity Production Cost\*
  - Heat Recovery Cost Saving
  - GHG credit revenue\*
  - Air Quality Externality\*
    - PM<sub>2.5</sub> wrt ammonia emission control\*
    - PM<sub>2.5</sub> wrt NO<sub>x</sub> emission from energy recovery facility\*
    - Ozone wrt NO<sub>x</sub> emission from energy recovery facility\*
- 

\* indicates that the component currently has data available in the model

### Ammonia Control Options

Ammonia emissions to the atmosphere are an environmental concern because they can contribute to odor, to eutrophication of surface water and to nitrate contamination of ground water. Ammonia emissions also contribute to the formation of fine particulates, which have a negative impact on animal and human health. Strategies to reduce ammonia emissions include both preventing ammonia formation and volatilization and downwind transmission of ammonia after it is volatilized. Iowa State University (2004) provides information on relative costs and effectiveness of nine different ammonia control practices, which are listed in Table 2. For example, the ammonia emissions can be reduced by 40 to 50 percent using biofiltration at the animal housing area. According to Iowa State University (2004), the biofiltration costs for a 700-head farrow-to-wean swine facility are estimated at \$0.25 per piglet, amortized over a 3-year life of the biofilter. In the model, this cost (\$0.25 per animal) is assumed to apply to biofiltration applications at dairy operations as well.

### Options for Methane Capture and Electricity Production

A biogas recovery system is one of three manure management techniques that can be used to capture methane. (The other two are gasification systems and composting.) Biogas recovery systems, sometimes known as anaerobic digesters, can provide renewable energy and alleviate some of the environmental problems associated with manure from large animal operations. During anaerobic digestion, bacteria break down manure in an oxygen-free environment. One of the natural products of anaerobic digestion is biogas, which typically contains between 60 to 70 percent methane, 30 to 40 percent carbon dioxide, and trace

amounts of other gases, with combined heating value of 600 BTU per cubic ft (natural gas is about 1100 BTU per cubic ft). The biogas recovery systems offer a number of environmental benefits, including odor control, GHG reduction, ammonia control and water quality protection.

There are three different types of biogas recovery systems have been commercialized for managing manure. These systems range from the simple covered lagoon to the more complex plug flow and complete mix digesters. Which system is most appropriate depends on how the manure is collected and on the total solids content of the collected manure. For example, the suitable total solids content for these three systems are 0.5 to 3 percent, 3 to 10 percent and 11 to 13 percent, respectively (USEPA, 2002).

At this time, our model only considers using the plug flow digester biogas recovery system. Other recovery systems (covered lagoon and complete mix digesters) and other energy technology (gasifier) will be added in the future.

The amount of electricity generated from the plug flow digester biogas recovery system depends on daily manure production, number of animals, solid content of the manure, a fixed biogas production coefficient, the methane content of the biogas and the efficiency of the electricity generator. We conducted model verification by comparing the electricity generation using our model with numbers reported in the literature. Our estimate, 104 kW for a farm with 1000 cows is in the range of reported values.

We develop a capital cost function, using data collected from four dairy farms and reported in Table 3. We first convert the cost to 2004 dollars. We estimate the cost function using the following functional form:

$$y = ax^b$$

where, the left hand side dependent variable,  $y$ , is the average cost per cow and the right hand side variable,  $x$ , is the number of cows. In the equation,  $a$  and  $b$  are cost function parameters. Actually,  $b$  is the estimate of the scale elasticity. In our case, coefficient estimate  $b$  equals  $-0.76$ , which means that every one percent increase in farm size (in terms of number of cows), the average capital cost decreases by 0.76 percent. Cost function parameters  $a$  and  $b$  are assumed to be normally distributed, using their estimates and standard errors. We amortized the capital cost by assuming 7% compound interest rate and a twenty-year lifetime. Annual operation and maintenance cost is assumed to be 20% of annual capital cost by default and can be changed easily in the model.

The GHG credit is calculated based on the difference between baseline methane emissions (in CO<sub>2</sub> equivalent) and CO<sub>2</sub> emissions from biogas combustion (including both biogas CO<sub>2</sub> and CO<sub>2</sub> from biogas methane combustion). As noted above, we assume methane has global warming potential 23 times that of carbon dioxide. We also assume that combustion of one ton of methane yields 2.75 tons of CO<sub>2</sub>. GHG credit revenue is equal to the product of the number of credits and the credit price.

**Table 3. Capital Cost of Plug Flow Biogas Systems with Electricity Generation on Select Farms**

Farm	Installation Year	Animal Production	Installed Cost	\$2004/head
Haubenschild <sup>a</sup>	2002	1,000		\$373
Craven <sup>b</sup>	1997	650	\$253,000	\$458
AA Dairy <sup>b</sup>	1998	550	\$240,300	\$506
Haubenschild <sup>b</sup>	1999	480	\$295,800	\$699

Source: (a) Nelson and Lamb (2002); (b) Moser and Matocks (2006).

## Health Effects of Air Emissions

The air quality impacts of farm operations considered in the model include reduced emissions associated with ammonia emission controls and additional  $\text{NO}_x$  emission from the biogas combustion for electricity generation. Ammonia is a precursor of fine particulate matter. Once it is emitted, it could react with nitric acid to become ammonium nitrate, a secondary pollutant, in the air.  $\text{NO}_x$  is a precursor of both ozone and particulate matter. To evaluate the health impact of particulates and ozone due to the ammonia control and new  $\text{NO}_x$  emissions, we will have to analyze both emissions transport and air chemistry and changes in exposures and impacts on human health. The first task requires the development of pollutant source-receptor relationship, which is how much secondary pollutant concentration will change at the receptor site due to emission change of primary pollutant at source site. The second task requires estimates of changes in exposure and related health impacts due to the change of the secondary pollutant exposure.

In the current model, for task 1, we need source-receptor relationships for ozone with respect to  $\text{NO}_x$  emissions,  $\text{PM}_{2.5}$  with respect to  $\text{NO}_x$  emissions, and  $\text{PM}_{2.5}$  with respect to reductions in ammonia emissions. The authors of this paper have done research to quantify the source-receptor coefficients at the state level for the first two (Palmer et al, 2005; Shih et al, 2004). The authors could not find any farm level empirical source-receptor coefficient. So for ozone with respect to  $\text{NO}_x$  emissions, we average the eight-hour ozone source-receptor coefficients in the source-receptor coefficient matrix (for the entire study domain) as our default in the current model. We do the same thing for  $\text{PM}_{2.5}$ , using twenty-four hour source-receptor coefficient matrix.

We were unable to locate any source receptor coefficients for  $\text{PM}_{2.5}$  with respect to ammonia control. The literature offers a range of perspectives on this issue, with some papers arguing that ammonia control has no effect on  $\text{PM}_{2.5}$  concentration (LADCO 2006) for a specific region, while other research suggests that ammonia control has positive effects (Erisman and Schaap, 2004). The differences in these findings depend on whether the region being studied is ammonia limited or not. These differences in the literature suggest that there is a huge uncertainty about as well as variability in this coefficient among different regions/locations.

In this model, we develop a simple box model to estimate the source receptor coefficient for  $\text{PM}_{2.5}$  with respect to ammonia control. We assume that emitted ammonia reacts with nitric acid completely to become ammonium nitrate and this ammonium nitrate is uniformly mixed within the box (after considering deposition since emissions from farm operation tend to be near the ground surface).<sup>12</sup> We then calculate the average change of ammonium nitrate concentration within this box due to one unit of ammonia emission reduction. Given limited time and resources, we use the simple box model approach to produce the upper bound estimate of the  $\text{PM}_{2.5}$  with respect to ammonia source-receptor coefficient. We then use a uniform distribution between 0 and this upper bound to characterize this coefficient in our model.

To estimate the health benefits, we develop simple composite health benefit coefficients for ozone and  $\text{PM}_{2.5}$  exposure using TAF (ORNL, 1995). The health benefit coefficient is defined as benefit in dollars per pollutant concentration change per year. The health effects considered include the number of days of acute morbidity effects of various types, the number of chronic disease cases, and the number of statistical lives lost. The pollutant concentration-response functions are found in the peer-reviewed literature, including epidemiological articles reviewed in EPA's Criteria Documents that, in turn, appear in key EPA cost-benefit analyses (Palmer et al, 2005). We first estimate pollutant concentration change at a receptor by multiplying emission reduction from the source by the relevant source-receptor coefficient. We then multiply the concentration change with the health benefit coefficient to get the health benefit estimate.

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<sup>12</sup> In personal correspondence, Professor Ted Russell of Georgia Tech has pointed out that this assumption is not strictly correct because the reaction is an equilibrium and also there is a limited amount of nitric acid in the atmosphere and ammonia would not be able to convert to ammonium nitrate in a fully efficient manner (100 percent). The effect of this assumption is to overestimate the source-receptor coefficient which would serve as an upper bound for the reduction in  $\text{PM}_{2.5}$  that would result from a reduction in ammonia. We plan to refine this estimate through more comprehensive 3-D air quality simulation model in the future.

## Policy Simulations and Results

The integrated assessment model is used to study the atmospheric emissions from animal husbandry and their environmental consequences, and to investigate potential policies to improve the environmental and economic performance of the industry. In the ongoing program of research we investigate two types of policies – performance-based policies that would require specific technologies or management practices, and market-based policies that could provide economic incentives to reduce emissions. Some policies would involve the agricultural extension service in its traditional role of outreach, education and technical assistance. Other policies could require mandated practices. However, the policies we describe for this presentation involve the creation of new markets that allow farm operators to internalize social benefits from more efficient management.

We illustrate the model by exploring three policies. One is the creation of GHG credits to account for the social benefit of reduction in methane emissions. The second is the creation of particulate matter (PM<sub>2.5</sub>) offset credits to account for the social benefit of reduction of ammonia emissions. The third is expanded net metering of electricity to provide financial payments to farm operators for electricity provided back to the electricity grid. Underlying parameters in the model such as population of farm operations, temperature and background emission inventories exhibit large variability, and several parameters in our model are very uncertain or based on nonlinear processes. In the future, we plan to account for this variability and uncertainty using simulation-based methods such as Monte Carlo analysis. To illustrate the model in this exercise we rely primarily on mid-point values for many parameters, often erring intentionally on the side of cautious choices that may under-estimate the potential benefits of the policy options, partly to guard against bias due to omitted features of the problem at this juncture. We vary two fundamental parameters to give a flavor for the potential sensitivity of the results.

### Greenhouse Gas Policies

There are two pathways that offer the potential to avoid GHG emissions. One is to change management practices including diet and capture of methane. The second is to use the methane byproduct for electricity generation. Change in management practices could be mandated by fiat but the regulatory burden of enforcement would be enormous and the economic impact on the farm sector would be severe. A market-based approach could lead to a more efficient technology choice at much less cost to government and with positive economic benefits for the industry.

We model a market-based policy that provides a payment for emission offsets under GHG cap and trade programs. One such cap and trade program is in place in the EU, another has been approved in seven states in the northeast US, and others are under consideration in California and elsewhere, as well as at the federal level.<sup>13</sup> In various ways these programs are expected to allow for the use of offset credits awarded for emission reductions achieved outside the emission sources that are directly regulated by the program. One tenet of this approach is that offsets qualify only for emission reductions that would not have happened anyway, for example, those that are additional to current laws, regulations or practice. A key feature of offset programs is the documentation of baseline emissions, and the certification of changes in practices that would lead to emission reductions. To this end the model calculates emissions under the baseline (in absence of a policy) as well as changes under various policies and management strategies.

In our central case we model a specific management practice using a plug flow digester for a farm operating in a warm climate such as California with a size of 500 head. We consider offset credits valued at \$11 per ton of CO<sub>2</sub> equivalent. This value is midpoint to values that might emerge given current policy.<sup>14</sup> Under the creation of an offset market for these emission reductions the economic value of avoiding additional reductions at facilities regulated under the emission cap flows through to the farm operator. Electricity generation with the captured methane leads to residual emissions of CO<sub>2</sub>, which are accounted for in the net emission reductions.

<sup>13</sup> See: <http://europa.eu.int/comm/environment/climat/emission.htm>; <http://www.rggi.org/>; and <http://www.climatechange.ca.gov/>.

<sup>14</sup> Emission allowances under the EU ETS are currently trading at about \$30 per metric ton CO<sub>2</sub>. The northeast Regional Greenhouse Gas Initiative Memorandum of Understanding includes a trigger price of \$10 per short ton in order to expand the offset market to include states outside the region.

The costs of the digester that we account for include installation and operating costs, and a generator that combusts methane to produce electricity, but it does not include opportunity costs such as the alternative use of land for the digester. The value of the electricity depends on its potential use on farm or resale onto the grid. Whether independent power producers can realize the value of sale back onto the grid depends on the whether distribution companies pay for the power. Net metering policies require payment to independent power producers at an avoided cost. We assume that net metering is not available to the farm operator in our central case, and vary this in sensitivity analysis.<sup>15</sup> In the absence of net metering policy the farm operator can capture only the value of electricity at the farm, equivalent to displaced purchase from the grid, but extra electricity generation capability is unutilized. We assume a weighted value of \$0.06 per kWh for electricity generated.<sup>16</sup> In addition, we note that electricity generation results in an increase in emissions of NO<sub>x</sub>, which is a precursor to PM and ozone. The social cost of the increase in NO<sub>x</sub> is accounted for below.

**Table 4. Costs and benefits to farm operator of methane and ammonia capture under market-based policy scenario.**

Climate	Warm			Cold		
Farm Size (head)	400	500	1,000	400	500	1,000
Baseline CH4 (CO <sub>2</sub> e tons)	769	961	1,923	364	455	911
Digester Cost	29,680	31,350	37,160	29,680	31,350	37,160
CO <sub>2</sub> in electricity generation (tons)	332	414	829	332	414	829
Ammonia Control Cost	120	150	300	120	150	300
Electricity revenue	21,910	27,380	54,770	21,910	27,380	54,770
GHG credit revenue	4,811	6,014	12,030	358	448	896
Health benefit-ozone	-263	-328	-656	-263	-328	-656
Health benefit-PM25	12,030	15,040	30,070	12,030	15,040	30,070
NET Benefits	8,689	16,606	58,754	4,236	11,040	47,620

Monetary estimates are dollars per year (2006 dollars). The example excludes transportation costs and heat recovery value, and the potential GHG credits from reduced generation of fossil fired facilities. Electricity revenue excludes the benefits of net metering.

Table 4 reports that methane capture for electricity generation at a farm in a warm climate with size of 500 head imposes costs of \$31,350 as an annualized cost. The electricity savings on the farm operation total about \$27,380, which is not sufficient to justify the investment. However, the additional revenue from GHG offset credits would yield \$6,014, which is sufficient to tilt the balance producing net economic benefits of \$2,014 per year.

One important aspect of the incentive structure of a GHG offset market that is made apparent in the integrated assessment model is the consequence of changing diet. We do not model offsets for diet

<sup>15</sup> There was a CA law passed in 2002 to encourage net metering for farms that use digesters (see <http://sfgate.com/cgi-bin/article.cgi?f=/c/a/2004/05/14/BAGJG6LG3R15.DTL>). PG&E has offered a limited net metering policy for biogas facilities called NEMBIO that became available in August 2003. Initially, this opportunity is available to farms that generate less than 1 MW and limited to the first 5 MW that apply (on a first come first serve basis). In 2005, AB 729 extended these limits to authorize up to 3 digesters with up to 10 MW of capacity to be eligible for net metering and the cap on total MWs of biogas digesters eligible for net metering was extended to 50. (see [http://www.dsireusa.org/library/includes/incentive2.cfm?Incentive\\_Code=CA02R&state=CA&CurrentPageID=1](http://www.dsireusa.org/library/includes/incentive2.cfm?Incentive_Code=CA02R&state=CA&CurrentPageID=1))

<sup>16</sup> Based on representative statistics we calculate that about 54% of the electricity generating potential would be used on-farm, displacing retail electricity purchases that average \$0.11/kWh for agricultural customers in California. The remaining generation potential would be unutilized. Hence, the weighted value of the electricity, in the absence of net metering, is \$0.06/kWh.

management, although such a credit could be attractive. However, we do note that changes in diet would affect ultimate methane production. If the farm operator receives payment for offsets from methane capture from manure, the operator would lack the incentive to change diet to reduce enteric methane because this would also reduce methane that is available for capture in manure. Indeed, an unintended consequence of the GHG offset market associated with capture for electricity generation might be an increase in enteric methane along with methane in manure. Policy may need to link these management practices, perhaps making aspects of diet management a pre-requisite for GHG credits for capture of methane from manure.

Electricity generation creates another potential source of value external to the electricity market that is not included in this example. In the face of a cap and trade program for CO<sub>2</sub> the electricity generation may qualify for additional offset credits associated with the avoided emissions from fossil-fired power plants. The avoided emissions are not equivalent to the average emissions of electricity on the grid. Instead the proper measure is the change in generation at other facilities due to the methane-powered electricity. To identify this measure with confidence requires solution of an electricity market model, which is a component of our ongoing research project. For a proxy, it might be reasonable to assume that the displaced emissions comes from a gas-fired facility since natural gas is typically the marginal generation technology, especially in California. A short cut for regulators might be to associate the avoided emissions with the avoided generation source that determines the payment under a net metering program. In any event, this potentially substantial source of GHG credit revenue is not included in the results presented above.

### Ammonia/Fine Particulate Related Policies

A second external effect of management practices is due to emission of ammonia, which is a precursor to fine particulate matter. Management practices could reduce the emission of ammonia, but at a cost to the farm operator. One way to provide positive incentive for improved management would be to account for the reduction in PM<sub>2.5</sub> that is associated with reductions in ammonia. NO<sub>x</sub> and sulfur dioxide (SO<sub>2</sub>) are regulated directly through a variety of programs and they are important precursors to PM<sub>2.5</sub>, but they require ammonia for the conversion to PM<sub>2.5</sub>. In areas that are not in attainment with the National Ambient Air Quality Standards any new source must obtain offsets of emission reductions at another source. Those offsets have potentially significant economic value, depending on the air quality management district, ranging from hundreds of dollars to tens of thousands of dollars per ton, varying by year due to changes in local economic conditions and other factors.

We consider the creation of offset credits for ammonia in the nonattainment districts in California. Using the model we solve for the expected changes in health effects due to reductions in PM<sub>2.5</sub> and increases in ozone that may be likely to occur were ammonia reductions to be achieved. Emission reductions would be achieved through the use of biofilters, which impose a cost of \$120 per year. Table 4 indicates the PM<sub>2.5</sub> benefits would be substantial and would dominate the change in ozone, and these values sum to \$14,712 per year in our central case. The net benefit of this management strategy would be \$14,592 per year.

### Important Uncertainties

There are numerous uncertainties revealed already in our preliminary modeling. An important variable is the availability of net metering and the net generation credit price. In the main analysis, we assumed that net generation of electricity is not rewarded financially. If we assume instead that the farm operation can sell its surplus electricity back onto the electricity grid at \$0.06 per kWh, annual net benefits in our central case increase from \$16,606 to \$28,936.

The climate (temperature) in the location of the farm affects methane and ammonia emissions in the absence of control strategies. Table 4 indicates that differences between cold and warm climates cause the net benefits of the GHG offset management strategy including electricity production for a farm operation with 500 head to vary from \$11,040 to \$16,606.

One of the most important policy considerations is the size of the farm. We characterize a range of size from 400 to 1,000 head. This range provides opportunities for net benefits to vary by nearly an order of magnitude. For a 1,000 head farm operation in a warm climate, we find annual benefits can total \$58,754.

From a scientific standpoint, one item with great uncertainty in this analysis is the characterization of atmospheric dispersion of ammonia and its contribution to ultimate particulate formation. The relevant values will vary significantly with geography and region of the country, with assumptions about background pollution, etc. Nonetheless, the proper accounting for ammonia reductions as offset credits for associated PM reductions could offer significant economic benefits to the farm operation and significant social benefits as well.

### Conclusion

Animal husbandry is a major emitter of methane, an important greenhouse gas, and ammonia, a precursor to fine particulate matter, arguably the number one environmentally related public health threat facing the nation. Technologies are available to dramatically reduce these emissions, but their adoption by dairy operations has been limited. In this paper we explore market-based policies to provide farm operators with financial incentives to reduce emissions by adopting methane and ammonia control technology. We develop and exercise an integrated process model of dairy operations. Three policy options are explored including greenhouse gas offset credits for methane, particulate matter offset credits for ammonia, and expanded net metering policies to provide revenue for sale of electricity generated with methane. We find that taken individually, any of policies appear sufficient to provide the economic incentive for farm operators to reduce emissions. The magnitude of the benefit depends of the scale of the system, location in specific climate region and technology adopted and also on important assumptions in the model regarding ammonia to PM source receptor coefficients. This paper reports on initial steps to fully develop the integrated process model to provide guidance for policymakers.

In future work we plan to explore additional features of the policies discussed here. We plan to link the model with a dispatch model of the California electricity sector to estimate the CO<sub>2</sub> emissions displaced by expanded generation from methane digesters. We also plan to explore the effect that scaling up of these operations and the use of multi-farm digesters and associated transportation costs. We also could develop an optimization model for siting such an energy facility, taking into account its environmental cost and benefit and integration with the existing power grid. Farm level source-receptor coefficients for specific locations could affect our estimation results and this deserves further investigation. Finally, we could extend the integrated model by considering a water quality impact component. This research is expected to provide further insights about how to reduce the financial burden for the agriculture industry to improve productivity as well as environmental quality.

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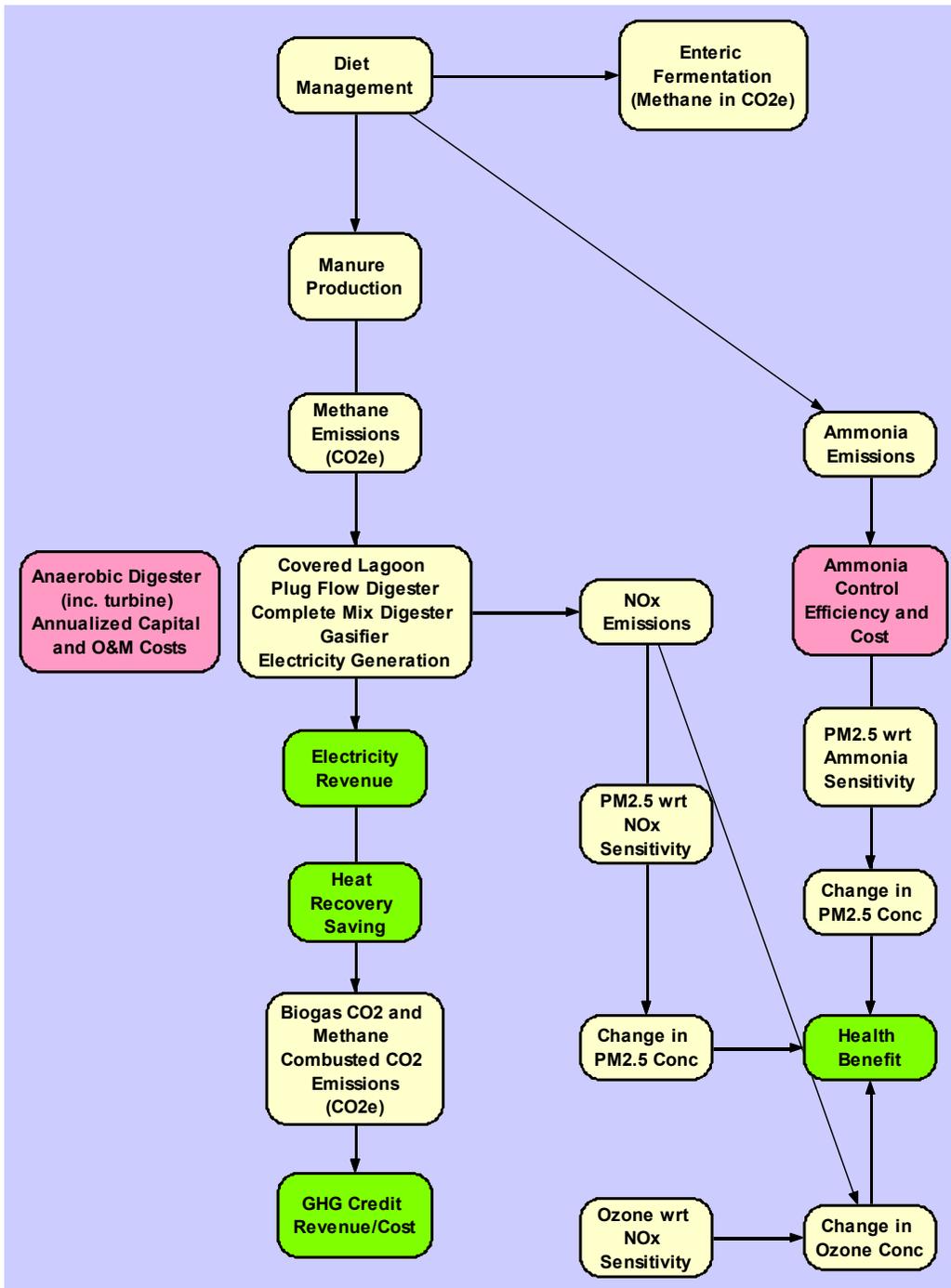


Figure 1. The Influence Diagram of the Integrated Animal Waste Management Model



## **Shelterbelts and Livestock Odor Mitigation: a Socio-economic Assessment of Pork Producers and Consumers**

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### **Abstract**

Pork production in the United States is expanding, especially in the Midwest. With expected economic benefits from expansion come potential environmental and social costs from odor. Scientific evidence suggests that shelterbelts – living tree barriers – can be cost-effective, biologically active buffers that reduce odor, and complement other odor control strategies used by producers. Previous research has suggested that some consumers accept partial responsibility in environmental degradation and exhibit an ininterest in purchasing “environmentally friendly” products including pork meat. Market mechanisms that allow price premiums for environmentally friendly pork meat to flow back to producers can reduce financial constraints faced by producers and directly link producers to consumers through joint socially-valuable efforts. Surveying both pork consumers and producers in three different states - Iowa, North Carolina and Washington State - we have examined attitudes regarding market-based incentives for odor control and identified producer/consumer values regarding odor management in general and odor management involving the use of shelterbelts. Results from consumer willingness to pay (WTP) surveys indicate strong consumer interest and WTP for “environmentally friendly” pork products. Across all states, 82% of the respondents indicated a positive WTP for pork products that originated on farms that made odor management a priority. The maximum mean WTP was \$0.14/ pound of pork meat purchased. Consumer acceptance of the use of shelterbelts specifically for on-farm odor mitigation was significantly higher than other listed odor control technologies. The mean cost that pork producers across all three states were willing to pay to plant and maintain shelterbelts for odor management was \$0.14/ head produced. Additionally the producers all expressed interest in raising pigs with extra odor management if the prices received covered additional costs. With regards to variables that strengthen the behavioral intention represented by the consumer WTP figures, consumers surveyed expressed low to moderate environmental values when it came to making food purchasing decisions in general and moderate label reading behavior but expressed strong attitudes about odor management at the swine farms that produce their pork. Consumers expressed high concern about air quality around hog facilities in general (Iowa consumers being the most concerned). Non-meat attributes such as production methods also figures high in consumer importance. The results of this research will support cooperative approaches to solving odor problems that include natural odor control strategies, and help to sustain two vitally important parts of agriculture – pork production and rural communities.

### **Introduction**

Pork production in the United States is expanding, especially in the Midwest. With expected economic benefits from expansion come potential environmental and social costs from odor. Scientific evidence suggests that shelterbelts – living tree barriers – can be cost-effective, biologically active buffers that reduce odor, and complement other odor control strategies used by producers. Previous research has suggested that some consumers accept partial responsibility in environmental degradation and exhibit an ininterest in purchasing “environmentally friendly” products including pork meat. Market mechanisms that allow price premiums for environmentally friendly pork meat to flow back to producers can reduce financial constraints faced by producers and directly link producers to consumers through joint socially-valuable efforts. Surveying both pork consumers and producers in three different states - Iowa, North Carolina and Washington State - we have examined attitudes regarding market-based incentives for odor control and identified producer/consumer values regarding odor management in general and odor management involving the use of shelterbelts.

### **Consumer Surveys**

Analysis of the statistically representative consumer surveys indicates strong consumer interest and willingness to pay (WTP) for “environmentally friendly” pork products across all three states examined – Iowa, North Carolina and Washington State (total completed interviews 349: Iowa=145; North Carolina=77; Washington=127). Across all three states, 82% of the respondents indicated a positive WTP for pork products that originated on farms that made extra odor management a priority. The maximum mean willingness to pay was \$0.14/ pound of pork meat purchased. North Carolina consumers expressed the highest mean WTP at \$0.16/ pound of pork meat. The mean WTP between the states does not vary significantly. However, there are statistically significant ( $p = .05$ ) differences between the states with regards to overall environmental and social concerns within agriculture. On an aggregate socio-environmental concern index (which factored in concern for air and water quality, family farms, and antibiotics in food) consumers from Iowa and North Carolina had significantly higher scores than consumers from Washington. Multivariate regression analysis failed to find acceptable models of WTP using demographic information and variables that show strong attitudes towards environmental quality. However, logistic regression examination of likelihood to express a positive WTP for environmentally showed that up to 33% of the variation (based on pseudo R squared statistics) between those WTP nothing and those WTP some positive value can be explained by Key variables such as gender, overall environmental values, and attitude about on-farm reduction of hog odor. Females are 3.2 times more likely to have a positive WTP than males and those consumers with strong attitudes about hog farms making efforts to reduce odor from their farms are 7.4 times more likely to express a positive WTP.

Consumers expressed high concern about air quality around hog facilities in general with Iowa consumers the most concerned. When purchasing meat products, meat quality factors are the most important attributes (freshness and flavor) with price coming in second, yet non-meat attributes such as farming/production methods also are importance. The respondents also showed high familiarity with other kinds of differentiated pork products (i.e. organic or natural pork) but indicated low levels of purchasing such products. Consumer acceptance of the use of shelterbelts specifically for on-farm odor mitigation was higher (statistically significant) than other listed odor control technologies. The order of acceptance is shelterbelts, organic manure additives, mechanical air filtration, organic feed additives, and chemical feed/manure additives – the latter two scoring very low in acceptance. Overall and across the three states the socio-demographic variables of income and education show significant but low positive correlations with WTP and number of people in household under the age of 18 show significant but low negative correlations. There seems to be no differences between urban and rural respondents. Also, proximity to pork production and experience with swine odor shows limited influence on WTP. Continued analysis will examine within state characteristics.

### **Producer Surveys**

The analyses of the producer survey of marketing and management (total completed interviews 587: Iowa=410; North Carolina=141; Washington=36) is ongoing. Across all three states, the vast majority of those interviewed were the owners and/ or key managers of the production. Almost all of the production operations were under individual, corporate, or family ownership. Just under 30% of those interviewed has less than 5,000 head at their primary facility, 67% were over 5,000 head and about 5% had over 50,000 head. Forty one percent of the producers raised other livestock and 76 % also raised crops. Eighty three percent operated feeder operations and 93 % utilized confinement building systems. The vast majority (92%) of producers had their primary facility within one mile from their nearest neighbor; almost 60% were within one half mile. With specific regards to use of and opinions of shelterbelts almost 60% of the producers have trees/shrubs planted in and around their facilities; thirty-two percent were planted specifically as an odor mitigation technology, the remainder as general landscaping. Out of those who do not use shelterbelts 64% said they were interested in planting trees for odor mitigation. In response to an open ended question asking about possible advantages to using shelterbelts producers mentioned odor reduction, “out of sight, out of mind” benefits, and improvement of facility aesthetics most often. Producers also weighed in on possible reasons why some hog producers do/would not use shelterbelts and listed excessive cost, labor requirements, and interference with building and site ventilation as the top three reasons respectively. Still, 73% of the producers surveyed somewhat to strongly agree that shelterbelts bio-physically remove odor from the air and 67% somewhat to strongly disagree that shelterbelts are not worth the expense.

Across all three states, the mean willingness to pay for planting and maintaining shelterbelts (for effective hog odor control) is \$0.14/hog produced. There are statistically significant ( $p = .05$ ) differences between the states on mean WTP. North Carolina producers are WTP \$0.07/ hog produced, Iowa producers \$0.14/hog produced and Washington State \$0.24/hog produced.

Less than half (41%) of the producers interviewed are involved in market the hogs they raise; of that forty percent, 12% are involved in a marketing coop and 9% direct market pork to consumers. Twenty percent are involved in a marketing contract with a specific packer. Fifteen percent of the producers are involved in growing differentiated (specialty) pork with differentiated meat quality (15%), animal welfare (12%), and environmental quality (10%) being the three main attributes. Price premiums and steadier demand were listed as relevant outcomes to selling such products. Overall, across all three states 51% of the producers are interested to very interested in producing differentiated pork. Seventy percent stated that they are interested to very interested (48%) in producing pork specifically with “extra odor control” as long as the prices received covered additional odor management costs. Contracting this differentiated product with either a packer or the owner of the hogs (for those who are contract feeders), or direct marketing to consumers or through a marketing coop are the four top preferred ways to arrange for the creation of such products respectively.

### **Aesthetics Focus Group Information**

Focus groups with pork consumers and pork producers were performed in Iowa and North Carolina during the summer of 2004. Part of the focus groups for both consumers and producers involved a short presentation about the bio-physical aspects of odor mitigation using shelterbelt systems. There was also a photo elicitation session where participants rated the visual quality of a static scene showing a facility with varying degrees of shelterbelts present (i.e. no trees to fairly extensive shelterbelt systems).

With regards to the producers, a total of 15 hog producers took part in the discussions. All of the participants in North Carolina ( $n=6$ ) were large scale producers and for Iowa ( $n = 9$ ) there was a mix of large and small producers. Producers from both states had very similar opinions about odor issues in their respective states. For example all the producers felt that odor is not the problem that the media is making it out to be. Producers also shared similar opinions about shelterbelts in general with most of them neither agreeing nor disagreeing that it is more pleasant to work at a facility that has trees. They did tend to disagree that shelterbelts might harbor rodents and other pests. North Carolina producers tended to be slightly pessimistic about the financial expense and labor requirements of shelterbelts. Collectively they neither agreed nor disagreed that shelterbelts actually help filter air of odor. They also agreed that shelterbelts useful in terms of providing general shelter from summer and winter winds, controlling wind erosion and in providing wildlife habitat. In terms of their opinions about the aesthetic appeal of shelterbelts planted in and around hog facilities, producers tended to view a “basic buffer” (one that has some clear shelterbelts but not a whole complex of them) as being preferred. This was explained by concerns for cost and maintenance of the more complex systems actually impacting the visual component of the trees.

For the consumers, there were a total of 27 people taking part in the discussions (Iowa  $n = 13$ ; North Carolina  $n = 14$ ). Overall, there were some interesting differences between the consumers in Iowa and those in North Carolina. There were high preferences for more trees in Iowa landscape in general and specifically that shelterbelts improve the aesthetics of confinement livestock production *landscape* – that is the production site as well as the overall, broader landscape that the facility is a part of. The Iowa consumers also expressed a high appreciation for “visual” response to odor issues. For the consumers in North Carolina, shelterbelts per se were not as important in the landscape largely because NC is heavily forested. They did however have strong appreciation of the idea that shelterbelts were actually a technology and they liked the innovativeness of their use.

### **General Conclusion**

Results indicate that pork consumers are likely to pay more for meat originating from farms with higher air quality management. Moreover, consumers indicate a preference for the “natural look and feel” of shelterbelts (of trees) relative to other bio-chemical-mechanical odor control technologies. Shelterbelts are generally accepted as add-on aesthetic or public-relations technology by producers rather than highly

effective in controlling odor. Producers and consumers agree that shelterbelts can and should play a role in mitigating swine odor. Some pork producers are willing to explore new ways to capture the extra money that consumers are seemingly willing to spend for “fresh air pork” through innovative marketing strategies while others value the addition of shelterbelts to farms. Shelterbelts should provide a suite of benefits for the pork industry, producer, consumer, and communities. Ultimately, the results of this research will support cooperative approaches to solving odor problems that include natural odor control strategies, and help to sustain two vitally important parts of agriculture – pork production and rural communities.



## The Role of Agricultural Emissions in European Air Quality Policy

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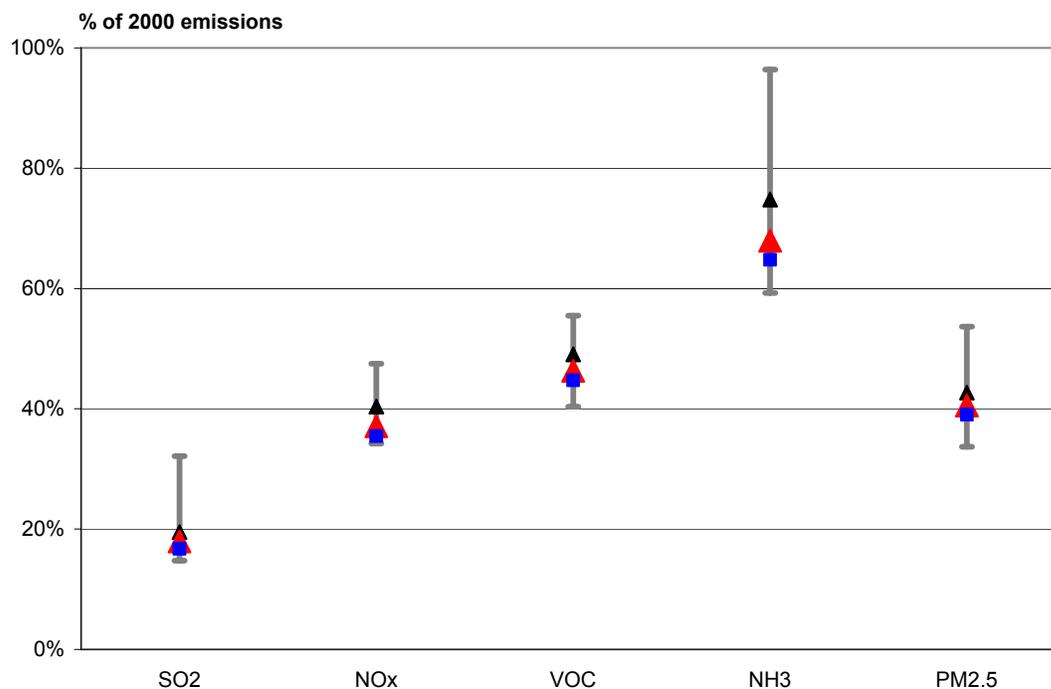
### Abstract

For Europe several hundred thousands of premature deaths, increased hospital admissions, and millions of lost working days have been associated with increased levels of air pollution. The costs of these health impacts are large. In addition, substantial damage is estimated from acidification and eutrophication of ecosystems and agricultural crops.

Ammonia emissions from agricultural activities have been recognized as a significant contributor to the acidification and eutrophication of ecosystems. They also play a critical role in the formation of secondary particulate matter. Model estimates suggest that in the year 2020, after substantial reductions of emission from the other sources, approximately half of the European damage due to acidification, eutrophication and particles will be associated with ammonia emissions.

The Regional Air Pollution Information and Simulation (RAINS) model (e.g., Schöpp et al., 1999) has been used to explore cost-effective emission control scenarios to inform the policy discussion of the European Commission on the ambition level of the EU Thematic Strategy on Air Pollution (CEC, 2005). The analysis that served development of this strategy (e.g., Amann et al., 2005) outlined the likely development of emissions of SO<sub>2</sub>, NO<sub>x</sub>, primary PM, NH<sub>3</sub>, and NMVOC and their impact on air quality in Europe, and explored the scope for cost-effective measures that achieve further environmental improvements. On this basis, the European Commission has proposed to aim for 2020 at a reduction in the loss of life expectancy from the exposure to PM by half, and to significantly cut the area where deposition exceeds the critical loads for acidification and eutrophication. To achieve these environmental targets, the strategy indicates a need for reducing ammonia emissions by about 27 percent beyond the current commitments (Figure 1; CASE "B" is close to the final proposal made by the Commission), which comes at an estimated costs of about 2.6 billion €/year. These costs represent about 36% of the total thematic strategy costs for all economic sectors.

The results of the analysis and the proposed strategy indicate that agriculture needs to face a challenge of reducing significantly emissions of ammonia; without this reduction the ambitious environmental targets of the European Union cannot be met. In the final discussion stages of the thematic strategy three principal scenarios were evaluated that reflected three different ambition levels with respect to environmental targets (e.g., Amann et al., 2005). The results for these scenarios in terms of necessary emission reduction are presented in Figure 1. The gray range indicates the scope of further reduction beyond the current legislation baseline case (top end of the gray range) up to the maximum technically feasible reductions (bottom end). The current baseline shows a stark difference in level of emission reductions foreseen for various pollutants with ammonia emissions lower by only few percent compared to the 2000 levels. And in contrast to other pollutants most of this reduction is due to decline in livestock numbers rather than application of specific ammonia reduction measures; exceptions are Netherlands and Denmark. The overall technical potential for emission reduction in agriculture is relatively small (typically does not exceed 40 percent) compared to the other air pollutants where especially application of end-of-pipe measures brings high reductions. To reach the targets set by the thematic strategy, however, large part of this potential would need to be explored also in agriculture since emission of ammonia were estimated to be reduced by about 30 percent compared to 2000. This, in turn, is associated with high costs that represent a significant part of the total strategy cost as indicated earlier.



Gray range: CLE to MTRF ▲ Low ambition ▲ Medium ambition ■ High ambition

**Figure 1. Emission reductions in EU-25 in relation to the levels in the year 2000.**

The proposed thematic strategy, mid-term review of the Common Agriculture Policy, reform of the European sugar sector puts European agricultural policy in a very prominent place and lead to requests for further analysis of impacts of recent developments on emissions of various pollutants. In fact, not only ammonia since there are strong interactions between policies targeting ammonia and greenhouse gas emissions from agriculture. The RAINS model framework has been recently extended to include Kyoto gases and allow for such analysis (Klaassen et al., 2004).

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