Duke
NICHOLAS INSTITUTE
FOR ENVIRONMENTAL POLICY SOLUTIONS

Working Paper
NI WP 15-01
REVISED February 2016

www.nicholasinstitute.duke.edu

Incentivizing the Reduction of Pollution at Dairies: How to Address Additionality When Multiple Environmental Credit Payments Are Combined

Brian C. Murray and Tibor Vegh

CONTENTS

Author Affiliation
Nicholas Institute for Environmental Policy Solutions, Duke University

Citation
B. Murray and T. Vegh. 2016. "Incentivizing the Reduction of Pollution at Dairies: How to Address Additionality When Multiple Environmental Credit Payments Are Combined." NI WP 15-01. Durham, NC: Duke University. http://nicholasinstitute.duke.edu/publications.

SUMMARY

Anaerobic digesters (ADs) can reduce waste volumes and capture methane emissions from concentrated animal feeding operations (CAFOs), but their adoption rate is low because their cost is high relative to other forms of waste management. Farmers who use ADs can attempt to sell carbon credits and nutrient credits as well as renewable electricity certificates (RECs) generated by on-site electricity production from captured methane. These credits and RECs can be used as marketable "offsets" that buyers can use to help meet their greenhouse gas and nutrient pollution reduction goals.

One issue is whether a single operation can sell into multiple credit markets by "stacking" credits—that is, receiving multiple environmental payments to finance the AD technology conversion—thereby introducing the possibility that some credits might be "non-additional"—that is, produce no incremental pollution reductions—and thus be suspect pollution offsets.

Non-additionality in environmental credit stacking occurs when multiple payment streams do not produce incremental pollution reductions, thus allowing the credit buyer to pollute more than an AD project is offsetting. A possible solution to the stacking problem may be to allow stacking of all credits available at the time of AD installation, but to prohibit any further stacking if new credit streams become available after installation.

This is a revision of a paper originally published in 2015.

Introduction

Livestock production generates large amounts of manure (solid and liquid waste) and consumes a high volume of process water that producers must manage to control odors and reduce pollution. Livestock waste includes nutrients such as nitrogen (N), phosphorous (P), and potassium (K), and other elements. It is typically treated onsite and subsequently land applied as fertilizer. Concentrated animal feeding operations (CAFOs), and especially dairies, the focus of this paper, produce significant amounts of waste characterized by high organic loads, large variations in pH, and high levels of suspended solids (Kosseva, Kent, and Lloyd 2003). Per day, a single 1,000 pound dairy cow produces approximately 80 pounds of manure, containing 0.45 pounds of N, and 0.07 pounds of P, on average (USDA NRCS 1992).

Nutrients are chemical elements that are essential for plant growth, but their excessive release into waterways can cause serious environmental damage. Various studies have demonstrated that N and P in dairy waste can lead to eutrophication problems in ecosystems (Smith, Tilman, and Nekola 1999). Manure also emits methane (CH_4), a greenhouse gas (GHG) with approximately 25 times the 100-year global warming potential of carbon dioxide (CO_2) (Myhre et al. 2013), as well as ammonia (NH_3) and hydrogen sulfide (H_2S), which contribute to localized air pollution. Thus, manure management at CAFOs has an effect on climate and the environment through changes in GHG emissions and air and water quality.

To avoid environmental problems, CAFOs need to meet water and, potentially, air quality standards under the Clean Water Act [CWA; 33 U.S.C. §1251 et seq. (1972)] and Clean Air Act [CAA; 42 U.S.C. §7401 et seq. (1970)]. CAFOs employ various technologies to reduce contaminants in their waste streams to meet regulatory requirements. These treatment methods, including both aerobic (with oxygen) and anaerobic (without oxygen) processes and filtration of wastes in wetlands (Arvanitoyannis and Giakoundis 2006), can be characterized as biological, chemical, or physical techniques (Kushwaha, Srivastava, and Mall 2011).

Anaerobic digesters (ADs) can be used in CAFOs to capture the CH_4 produced when manure is broken down anaerobically. Policy drivers, primarily through voluntary adoption with cost-share or other forms of subsidy, have increased the use of this relatively mature technology to reduce waste volumes and in some cases produce biogas or bioelectricity with the captured CH_4, but the overall digester adoption rate is still very low (U.S. EPA 2010, 2014).

To cover the higher cost of AD adoption relative to other forms of waste management, farmers may supplement the revenues they generate from the conventional outputs of a livestock operation (e.g., milk or meat) by attempting to sell credits into multiple environmental markets. If they use the captured biogas to produce electricity on site, they may be able not only to reduce onsite energy costs or sell power to the grid, but also to sell renewable electricity certificates (RECs) to buyers seeking credit for using renewable power.

GHG ("carbon") and nutrient credits are examples of products sold in environmental markets that could help livestock producers cover the cost of AD installation and operation. These credits, as described further below, can be used as marketable "offsets" that buyers can use to help meet their GHG goals, their nutrient pollution reduction goals (either regulatory or voluntary), or both. One issue that arises is whether a single operation can sell into multiple credit markets by "stacking" credits—that is, receiving multiple environmental payments to finance the conversion to AD technology. Clearly, multiple payments can increase revenues and thus increase the attractiveness of the AD investment. However, the use of stacked credits also introduces the possibility that some of the stacked credits might be "non-additional" in that they do not produce incremental pollution reductions and thus are suspect for use in offsetting a buyer's pollution. The technical intricacies of these considerations are further explained below.

This paper informs the development of environmental credit markets by exploring various forms of stacking, such as horizontal, vertical, and temporal. If stacking protocols can be developed in a transparent and effective way, project developers could have access to a larger pool of funds to incentivize AD adoption. Similarly, if protocols were designed to clarify when stacking would be acceptable and when it would be problematic, project developers could have increased certainty about the credits that can be sold in environmental markets.

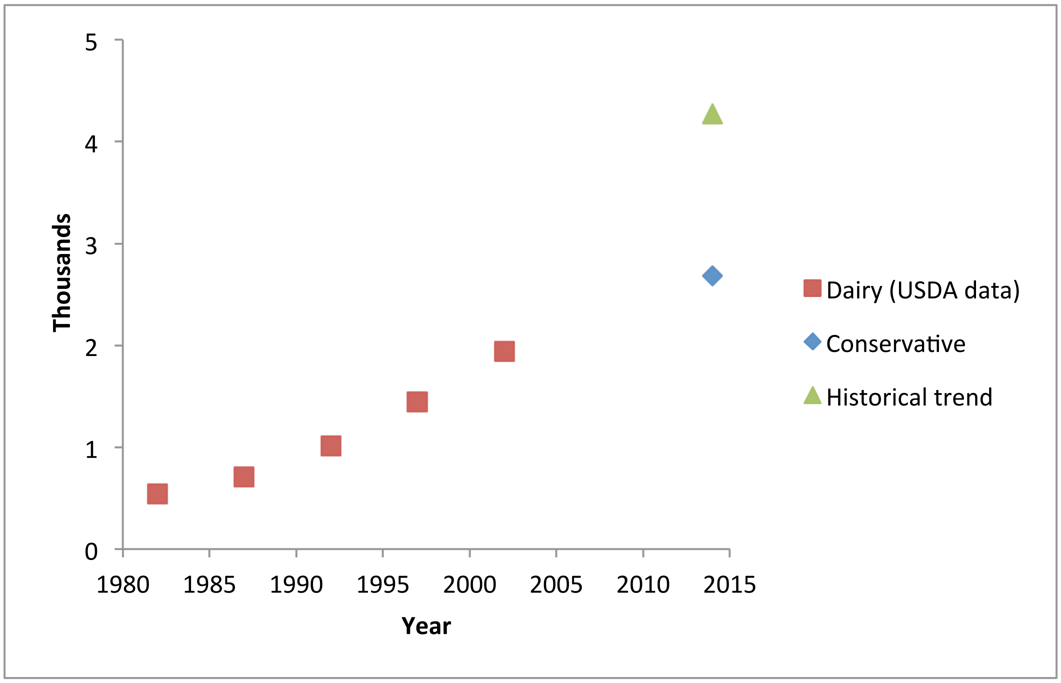
This paper draws on engineering, emissions, and economic information from U.S. dairy CAFOs to elucidate additionality and stacking issues with respect to AD adoption at these operations. It identifies which types of incentives are and are not needed to induce AD adoption and how rules for additionality and stacking affect these incentives. This information could be the basis for identifying the roles that government agencies such as the U.S. Department of Agriculture (USDA) may be able to play in establishing market standards or in gathering data necessary to support private standards. Although the focus is on technology, market, and institutional factors affecting environmental crediting from AD adoption at dairies in the United States, the issues addressed (stacking and additionality) are relevant for a wide range of ecosystem service markets that arise in countries throughout the world.

Waste Management in Concentrated Animal Feeding Operations

Animal feeding operations (AFOs) are defined by the U.S. EPA (40 C.F.R. § 122.23 (2014) as feeding operations in which animals have been, are, or will be stabled or confined and fed or maintained for a total of 45 or more days in any 12-month period and in which crops, vegetation, forage growth, or post-harvest residues are not sustained in the normal growing season over any portion of the lot or facility (U.S. EPA 2008). A CAFO is defined as an AFO that is large (e.g., 700-plus dairy cows), medium size (e.g., 200–699 dairy cows), or a *significant contributor of pollutants to U.S. waters*.

According to the U.S. Government Accountability Office (2008), no federal agency collects consistent and reliable data on CAFOs, which makes it challenging to credibly determine how many there are in the United States. An analysis of historical farm trends from the USDA data cited above shows that a reasonable range for dairy CAFOs in the United States is somewhere between 2,700 and 4,300 operations (U.S. GAO 2008, Figure 1). This number aligns very well with more recent U.S. Department of Agriculture National Agricultural Statistics Service (NASS) data that shows 3,300 dairy operations with more than 500 head of livestock (USDA NASS 2013). These large dairy CAFO operations represent about 60% of the animal inventory or 5.4 million dairy cows (USDA NASS 2013a, 2013b).

Figure 1. Estimated number of dairy CAFOs in the United States



Note: The number of dairy CAFOs has been increasing in the United States. The conservative estimate in this figure is based on the average growth in dairy CAFO numbers from 1982 to 2002 (U.S. GAO 2008); the historical trend estimate is based on increasing growth in the period 1982 to 2002.

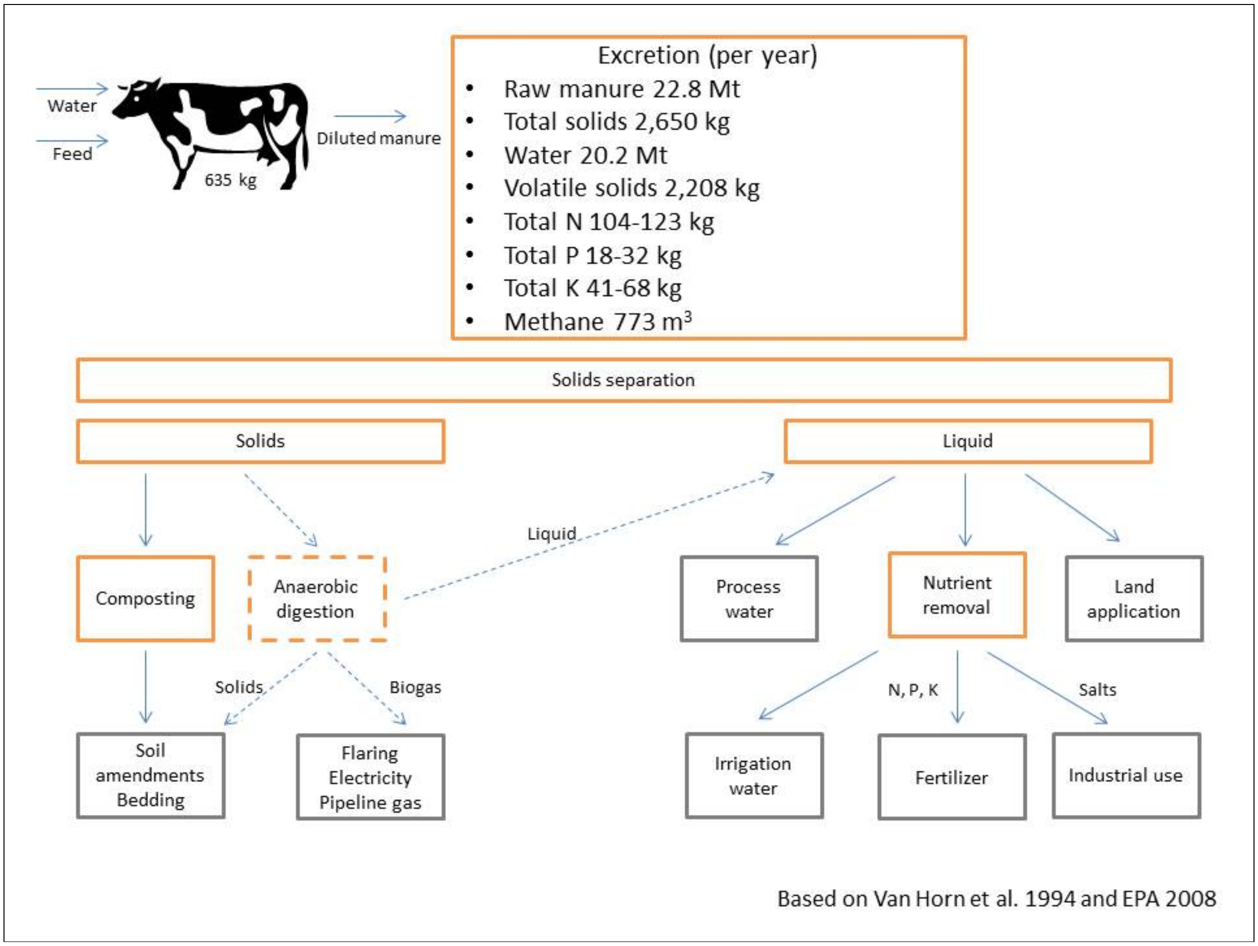
U.S. Environmental Regulations Relevant to CAFOs

CAFOs were identified as *point sources* of pollution in Section 502 of the CWA. The CWA, through the National Pollutant Discharge Elimination System (NPDES) permit program (CFR Title: 40, 122.23(b)(1), 1990), sets effluent limitation guidelines and standards (ELGs) for certain pollutants from CAFOs. Initially, the CWA did not specifically mention CAFOs, which are now considered point sources under the act. In recent years the U.S. Environmental Protection Agency (EPA) has increased regulation of CAFOs, especially those operating anaerobic lagoons for waste management. After a series of changes, the final 2008 CAFO rule requires CAFOs to apply for permits if they discharge or propose to discharge waste and nutrients into waterways (U.S. EPA 2008). Along with the permit application, CAFOs that discharge waste must also develop a nutrient management plan (NMP), which is a tool for managing N and P through best management practices (BMPs) to meet effluent limitations and standards. The CAFO rule states that producers must calculate their nutrient release either in terms of pounds of nutrient per acre (i.e., using the *linear* approach), or the amount of wastewater (using the *narrative rate* approach). In either case, an annual report must be filed with release estimates. Overall, there is evidence that the enforcement of both water and air quality regulations relevant to CAFOs has been very limited to date (EIP 2006; U.S. GAO 2008; Hoover 2013).

Wastewater Properties and Management

Livestock waste management operations systems address manure production, environmental residuals, processing, and resource recovery. This paper focuses on dairy CAFOs and describes conventional manure management processes and material flows of waste management (Figure 2). The specifics vary by type of livestock, operation size, and geographic location, but waste management processes include some or all of the following: flushing of waste, recycling of wastewater, waste storage and pumping, digestion of waste, waste spreading, and solids separation and handling. Conventional methods of storage before land application may vary across CAFOs and can include anaerobic lagoons, roofed storage sheds, storage ponds, underfloor pits, or above- or below-ground storage tanks (USDA NRCS 1992). Of these methods, anaerobic lagoons tend to be the least expensive and therefore are often used in the management of wastewater (Pfost and Fulhage 2000).

Figure 2. Process and material flow diagram of dairy manure management



Based on Van Horn et al. 1994 and EPA 2008

Note: Grey boxes represent process outputs, arrows represent material flows, and dotted lines show material flows that are not part of conventional manure management. Dairy manure characteristics per cow are shown for a typical 635kg (1,400 pound) lactating dairy cow.

Pollutants associated with dairy manure management include the GHGs methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2); the nutrients phosphorous (P) and nitrogen (in the forms of N_2O and NO_3, NH_3); hydrogen sulfide (H_2S); and particulate matter (PM_x). Wastewater can be characterized by different physical and chemical properties (Table 1). When manure is land applied, its properties affect soils, ground and surface water quality, and air quality from local to global scales. Some nutrients, such as N, are recyclable through plants, whereas others like salts (Na or Cl) are not and can have adverse effects on soils if applied in excess. From an environmental perspective N, P, K, volatile solids (VS), and salinity are the wastewater properties of most interest.

Table 1. Examples for physical and chemical properties of dairy waste effluent

Physical properties	Chemical properties
Color	Alkalinity
Electrical conductivity	Biochemical oxygen demand (BOD)
pH	Calcium (C)
Salinity	Chemical oxygen demand (COD)
Temperature (F)	Dissolved oxygen
Total dissolved solids (TDS)	Free carbon dioxide
Total solids (TS)	Magnesium (Mg)
Total suspended solids (TSS)	Nitrogen (N)
Turbidity	Total and organic phosphate (P)
Volatile solids (VS)	Potassium (K)
Volatile suspended solids (VSS)	Salts: Sodium (Na) and chloride (Cl)

Sources: Van Horn et al. (1994) and Tikariha and Sahu (2014).

Anaerobic Digestion

During the AD process, bacteria break down organic material in the absence of oxygen and produce biogas, which contains 55–70% CH_4, 30–45% CO_2, and other trace gases (Lazarus 2008). The CH_4 created in the AD process can be captured and either flared to produce the less potent GHG, CO_2, or used as energy that can supplant fossil fuels (Murray, Galik, and Vegh 2014). Consequently, ADs have received attention for their potential to mitigate GHG emissions. However, ADs not only capture CH_4, but also can assist in odor control, reduce air and water quality degradation, and increase nutrient management flexibility, thereby generating environmental benefits other than reduced GHGs (Lazarus 2008; Yiridoe, Gordon, and Brown 2009).

Technology and Economics

The components of an AD include the digester vessel, manure handling system, gas handling and use system, and manure storage tank. Several types of ADs exist, but plug flow, complete mix, covered lagoon, and fixed film ADs are the most widely used in dairy systems (Table 2, Lazarus 2008). The type of AD used depends on manure qualities (e.g., liquid, slurry). Free-stall dairy operations with daily-scraped alleys work well with ADs because the manure does not get mixed with dirt or stones and is moved into the digester while fresh. However, drylot dairies, beef, sheep, and poultry operations are not compatible with ADs because the manure may decompose before it is scraped.

Table 2. Anaerobic digester types and their prevalence among dairies with operating digesters

	Plug flow	Complete mix	Covered lagoon	Other
Description	A long, narrow concrete tank with a rigid or flexible cover	An enclosed, heated tank with a mechanical, hydraulic, or gas mixing system	An anaerobic lagoon sealed with a flexible cover	Induced blanket reactors (IBRs) develop a blanket of sludge that retains anaerobic bacteria; fixed film digesters contain plastic media on which bacteria attach and grow
Manure type	Works well for scrape manure management systems for semi-solid manure	Designed to handle slurry manure effectively	Used for flush or dilute manure in warm climates	IBRs works best with highly concentrated waste; fixed-film technology is suitable for diluted waste
Prevalence (%)	53	32	10	5

Sources: N.C. Cooperative Extension (2012), U.S. EPA (2014), U.S. EPA AgSTAR (2014).

In 2009, the U.S. Secretary of Agriculture set a target to reduce GHG emissions from dairy operations by 25% before 2020, using ADs as the primary method for meeting this goal (USDA 2009). Though costs have been falling steadily over time, AD adoption rates have been low due to the high upfront capital and operating and maintenance (O&M) cost requirements. Of the approximately 3,300 dairy CAFOs with more than 500 animals (USDA NASS 2013) only 193 (6%) have ADs (U.S. EPA 2014). A U.S. EPA AgSTAR report has identified 500 dairy cows or 2,000 head of swine as the minimum for which a digester is likely to provide positive financial returns, but this threshold depends on the cost of alternative (fossil) fuel sources for electric power generation, a factor made more relevant by the recent substantial decline in natural gas prices (U.S. EIA 2016). Based on currently available data (ICF 2013), adoption of a digester in a 500-animal dairy CAFO requires an upfront investment of $600,000–875,000 and an additional $110,000–160,000 annually. For an average size operation (n=2394, U.S. EPA 2014), the capital costs of a covered lagoon, complete mix, or plug flow digester are in the 1.6, 1.8, and 2.2 million 2014 inflation adjusted dollar range (BLS 2014), respectively (ICF 2013). A recent report on digester economics in the state of California, the largest dairy producer in the United States, concluded that the costs of building an AD typically outweigh the benefits (revenue) if ecosystem services (ESs) are not priced (Lee and Sumner 2014). As described above and elaborated on below, these ESs can be priced through a credit program and can include carbon credits, nutrient reduction credits, and—if the AD is producing renewable energy—RECs.

Potential for Pollution Reductions

Methane Emissions Reductions

According to ICF (2013), CH_4 generation and capture per dairy cow is approximately 582 to 690 m^3/year/animal (384 to 455 kg/year/animal), depending on AD type. Different types of digesters allow for varying degrees of substrate breakdown and capture. If manure of all 5.4 million cows in large CAFOs (USDA NASS 2013a, 2013b) was treated in an AD, the potential amount of CH_4 emission reductions, depending on AD type, are 1.8 to 2.1 MMt CH_4/year, assuming an 85% collection efficiency (CAR 2009). This is equal to 6.5–7.5% of U.S. CH_4 emissions in 2012—a CO_2 equivalent of 45 to 52.5 MMtCO_2e/year or the subtraction of some 7 million cars off U.S. roads. However, these numbers are not counted against a baseline, which in this case would be an aerobic or anaerobic conventional manure management system with positive emissions.

NPK Reductions

Relative to conventional manure management systems, ADs do not change the amount of nutrients in the waste stream and do not significantly reduce manure volume. In fact, anaerobic digestion does not reduce the mass of total N and P within the waste stream—it only mineralizes organic N and P to inorganic forms, ammonia and phosphate, respectively. Ammonia can be converted to NO_3 for plant uptake and is preferred for minimizing N leaching losses.

As part of conventional manure management systems, solids separation can remove 10–20% of N and 5–20% of P (Frear 2012), and this process can be part of an AD operation. Dedicated nutrient recovery systems and methods such as micro-screens, centrifuges, polymer flocculation, nitrification/denitrification, ammonia stripping, and struvite can help extract additional N and P from waste effluent with varying efficiency (Ma, Kennedy, Yorgey, and Frear 2013). These technologies are traditionally not used at CAFOs but are being developed and tested as post-processors of ADs for the expressed purpose of reducing nutrients from the effluent, typically for land application in lieu of fertilizers. According to one source, current nutrient recovery technology can achieve effluent N recovery rates of 40% and P recovery rates of 80% (Informa Economics 2013). These rates are equivalent to 0.1–13 kg N and 0.04–0.07 kg P/cow/day. A more recent study claims that current technology is capable of removing 98.3% of N, 100% of P, and 99.15% of K, from the effluent, which could result in large credit generation potential, depending on these rates compared to regulatory requirements and baseline practices (Douglas 2012). Whether a nutrient recovery system is installed post digestion or as a standalone operation in a conventional system depends on various factors, such as whether the nutrient reduction benefits justify the additional costs of adding the nutrient recovery system. The nutrient reduction benefits will be affected by dairy operators' ability to sell nutrient reduction credits.

Adoption Economics

Because AD, with or without an additional nutrient recovery system, is a costly addition to conventional waste management systems, dairy operators need some economic or regulatory driver to cover AD's costs and incentivize adoption. The up-front cost of AD adoption has been a large obstacle yet to be overcome at scale even with the availability of numerous funding mechanisms; it will be a larger obstacle if nutrient recovery systems are added (U.S. EPA 2012). Funding for the construction of ADs may come from grants, loan guarantees, or similar funding mechanisms. The Rural Energy for America Program provides grant assistance (25% of eligible costs, $500,000 maximum) and loan guarantees (85% for loans under $600,000, $25 million maximum) for producers. Although these subsidies can be useful in offsetting up-front costs, the focus of this paper is on the potential for AD to generate economic value beyond the core commodity outputs (e.g., milk or meat).

Value Stream from Bioenergy Production

One potential revenue source from AD is from onsite generation of electricity or biogas that can be sold into energy markets or used to reduce onsite energy costs (Murray, Galik, and Vegh 2014). Producers can reduce their energy costs by displacing purchased electricity use with self-generated power, generating revenue by selling the extra power they do not use, or both. One question producers face is whether to use the biogas produced on-farm to produce power onsite or to ship off farm as piped biogas. Broader energy market trends, specifically those in the natural gas market, have a large influence on biogas markets and affect how producers use the biogas captured in ADs. Pipeline biogas, a substitute for natural gas, was found to be competitive with onsite generation when natural gas prices are high, which does not describe the current reality (in 2016) but could if prices returned to historical levels. Another potential source of revenues could come from environmental markets that buy pollution reduction credits, as described below.

Revenue from Credits Sold in Environmental Markets

Other potential revenue sources to finance AD adoption are from environmental markets, in particular those for renewable energy certificates (RECs), nutrient reduction credits, and GHG reduction offsets. These certificates, credits, and offsets can be sold to other entities seeking compliance with renewable energy mandates at the state level or to voluntary buyers. These markets are in various stages of development, and several areas of ambiguity remain.

GHG Credits

When the conventional CAFO waste management technology without AD adoption is an anaerobic technology (e.g., lagoon storage of wastes), it will generate emissions of methane (CH_4), a greenhouse gas. As discussed above, ADs can provide a way to reduce the CH_4 emissions by decomposing the manure in the digester. Though GHGs are now subject to regulation by the U.S. EPA under the Clean Air Act (CAA), agriculture is not expected to be a directly regulated source in the foreseeable future. However, emissions reductions from AD adoption could, in principle, be used to generate GHG offsets for those facilities that are facing GHG regulation, as is the case under the current cap-and-trade law controlling GHGs in California, or these reductions could enter into a voluntary market for emissions reductions without a regulatory driver.

The generation of such credits is typically verified by third-party organizations, registered by a voluntary registry or used for compliance (e.g., in the California market) after the appropriate conversion of CH_4 credits to C credits. This conversion is based on the higher global warming potential of CH_4 relative the CO_2.

In the United States, the California compliance carbon (GHG) market and voluntary carbon markets have published protocols that describe how ADs can generate credits only if an anaerobic system, such as an anaerobic lagoon, was in place prior to adoption of AD technology. The reason is that CH_4 is not generated in aerobic systems and thus installing an AD on an aerobic system would increase CH_4 production rather than reduce emissions below status quo.

Other requirements of protocols also affect ADs. For instance, the Model Rule for the Regional Greenhouse Gas Initiative (RGGI 2013) states that GHG offsets cannot be generated if the offset project has an electric generation component, unless the legal right to credits is transferred from the project sponsor. This caveat would apply to ADs regardless of size.

RECs

RECs represent environmental and other non-power *attributes* of renewable electricity generation but not the electricity itself (U.S. EPA 2008). This definition has been referenced as the conceptual basis for RECs, including GHG benefits (one attribute of renewable electricity), and might by itself suggest that RECs and GHG credits should not be sold separately. There has been an ongoing debate about this issue, however. For example, according to North Carolina's NC Senate Bill 3, GHG effects are not included in RECs (N.C. Gen. Stat. § 62-133.8(a)(6) (2014). Specifically, the statute states that "A 'renewable energy certificate' does not include the related emission reductions, including, but not limited to, reductions of sulfur dioxide, oxides of nitrogen, mercury, or carbon dioxide." Thus, it would appear that legislation such as this, which separates GHGs from other environmental attributes inherent in RECs, can override any presumed restriction on the separation of a GHG credit and a REC.

To others, such as the EPA, a REC represents one megawatt-hour of renewable electricity and the right to claim the attributes (benefits) of the renewable generation source for only one buyer. Specifically, an EPA (2008) report states that "A REC represents and conveys the environmental and other non-power attributes of one megawatt-hour of renewable electricity generation." Therefore, the debate over exactly what attributes a REC does and does not include remains unresolved, and no oversight from government or independent parties currently exists. Therefore, attention should be paid to the governing laws of the system in which RECs are sold.

State renewable portfolio standards (RPSs) require a certain percentage of the electric power to be supplied by renewable sources such as wind, solar, and bioenergy. Renewable energy certificates (RECs) are generated by renewable electricity producers and are used by power utilities to collectively meet their renewable generation requirements under state RPSs. Renewable power producers thus produce two distinct commodities: undifferentiated electricity (renewable power has the same characteristics as non-renewable power) and RECs. They sell the power into the grid like any other producer, but they sell RECs into a separate commodity market. The buyers in the REC commodity market are the power companies within states that are obligated to meet the RPS target.[1] A company is compliant if the ratio of RECs to total generation equals the RPS target. In some cases, there are special "carve outs" for specific types of power. For instance, in North Carolina, the RPS target is 12.5 percent by 2021 for investor-owned utilities (10% by 2018 for cooperatives and municipalities), but 0.2 percent of power must be met by bioenergy from swine operations and 900,000 MWh from poultry waste, both of which are tied to AD production methods.

Wherever the electricity produced from CH_4 through the AD process qualifies under an RPS, digester operators can sell RECs at the actual market price separately from the actual electricity. Conventional manure management systems typically do not produce electricity or biogas because CH_4 collection is difficult without an AD. The producer that does produce power using biogas from an AD system typically signs a power purchase agreement with a utility company to sell the generated electricity, which is equal to the total renewable electricity production in the AD. Alternatively, the producer can use the electricity on-farm to run equipment and reduce operating costs.

Nutrient Credits

In 2003, the EPA issued a Water Quality Trading Policy that stipulated the conditions under which water quality trading could be used to meet compliance with total maximum daily load (TMDL) limits for nutrients (N and P) and sediments (U.S. EPA 2003). Under these provisions, regulated sources of these pollutants can, in principle, engage in nutrient trading to meet the loading requirements more cost effectively. Nutrient credit trading is defined as the sale of a unit of nutrient credit that was generated by a source as a result of nutrient reduction below that source's permit limit that the buyer can use to compensate for its own exceedance of that limit by a corresponding amount. Agriculture operations are typically considered *nonpoint sources* (NPSs), which include all sources and means other than *point sources* (PSs), by which pollutants may end up in water bodies.

In the case of ADs, the regulatory process for credit calculation is conceptually straightforward but can be difficult in practice (Douglas 2012). CAFOs and ADs are regulated *point sources* under the CWA and can discharge no more than their waste load allocation (WLA), which is included in their NPDES permit. CAFOs are required to be "zero discharge" for the production area itself per 40 CFR 412, but CAFOs are still assigned a WLA because of possible overflows from the production area. However, by installing an AD to digest manure, *and a dedicated nutrient recovery system* (emphasis added) to remove nutrients, the CAFO may earn PS nutrient credits by reducing nutrient outflows to below that specified on its NPDES permit. Thus, the credit is calculated as the amount of pollution reduction below the CAFO's permit limit, or:

$$\text{Credit} = \text{WLA}_{\text{before AD}} - \text{Waste Load}_{\text{with AD}} \quad (1)$$

---

[1] Power producers in states facing an RPS are typically allowed to use RECs that are generated in other states, as long as the credits are verified and have cleared a registry to ensure that they are used only once in any state.

Nutrient credit trading can take one of three forms: (1) credits generated by PSs available for other PSs for regulatory compliance, (2) credits generated by PSs and NPSs for regulatory compliance for PSs, and (3) credits generated by PSs and NPSs sources for regulatory compliance for both PSs and NPSs. ADs can best take advantage of nutrient credit markets in the third scenario because of higher credit prices due to higher demand.

Baselines and Additionality

Two of the environmental credit markets of interest in this paper—GHGs and nutrients, but not RECs—generally seek to pay only for *additional* pollution reductions below some baseline level. The fundamental calculation for a pollution reduction (offset) credit can be expressed:

$$\text{Credit} = \text{Baseline pollution} - \text{Pollution with AD}$$

$$\text{Nutrient Baseline} = \text{WLA}$$

"Baseline" pollution refers to the pollution expected from an operation if standard operating practices are followed and, in the case of water pollution, mandated nutrient load allocations are met. For example, the baseline level of nutrient pollution for a CAFO is the WLA specified on its NPDES permit. Because nutrient loads from CAFOs are regulated, the only additionality requirement for nutrient crediting is that the waste load with AD be below the waste load allowance (WLA), as discussed above and defined in Equation 1.

For other pollutants that are not directly regulated at CAFOs such as GHGs, baseline determination is more complicated. In principle, it is the quantity of that pollutant generated under current conventional management practices, which include practices at similar-size operations in a similar location. If a comparable cohort is not available, or if a new facility is being considered, an alternative way to define a baseline might be to estimate the most profitable management alternative under a "no environmental credits" scenario and deduce that this alternative is what the baseline practice (and pollutant load) would be.

In principle, crediting occurs when emissions are reduced below the baseline, as long as the action is deemed additional to what otherwise would have occurred under business-as-usual circumstances. In practice, the application of baselines and additionality principles can be complicated. In environmental markets, four forms of additionality are typically considered (WRI 2014):

- regulatory additionality refers to environmental benefits beyond those required by law;
- temporal additionality refers to new practices implemented after a certain point in time;
- performance standard (also known as "baseline") additionality establishes a performance standard above which the adopted action is considered a material improvement over business as usual; and
- financial additionality means that projects would not have occurred without the revenue provided by a crediting market or program.

Using the CAR protocols for GHG credits as examples, regulatory additionality is proven with a legal requirement test and baseline additionality, with a performance test to determine standard practice for the latter. In the case of an AD, the legal requirement test would find that there are no laws, statutes, regulations, or mandates requiring installation of an AD in livestock operations (CAR 2013a) or that limit GHGs from CAFOs in any way. The performance standard test would require a detailed analysis, including baseline emissions modeling and a calculation of projected methane emissions, the difference of which is the amount of credits calculated.

Temporal additionality is fairly straightforward, but it is not clearly relevant for AD adoption scenarios of interest here. The financial additionality criterion, though not used by CAR, could be used in other future protocols and is most relevant criterion to the issue of credit stacking. The underlying question is whether stacking leads to a situation in which some projects would be financially viable without some of the credits being issued. When does stacking undermine financial additionality?

Stacking of environmental market credits allows producers to receive payments for multiple ecosystem services generated by a new project or practice, such as AD adoption. In the case of a CAFO, stacking can take four forms (WRI 2014):

- Horizontal: different environmental credits issued for different projects on the same property.
- Vertical: different environmental credits issued for one project.
- Temporal: different environmental credits issued over time.
- Payment: combining other forms of finance (e.g., government cost-share programs) with environmental credits.

From a financial additionality standpoint, the least concerning for a CAFO is horizontal stacking, because each project, if fully independent, should have its own distinct set of financial and additionality requirements. Consider a large farm that plants trees to sequester carbon for GHG credits, uses best cropland management practices to reduce N runoff, and adopts an AD to manage CAFO wastes and possibly generate GHG credits. Each of these projects stands on its own and should present no additionality problems if all credits on the separate projects go to one landowner.

Vertical stacking and temporal stacking create potential financial additionality issues for CAFOs with ADs. That is because the AD system with dedicated nutrient removal and bioelectricity generation can potentially supply GHG and water quality credits as well as RECs, and it is possible that credits from a subset of those activities would provide sufficient incentives for adoption, leaving the remaining credits unnecessary—and, in principle, non-additional. Similarly, payment stacking of multiple sources of funding for the same *project* is also concerning, because financial additionality in each environmental market or other funding source may be affected.

Stacking and GHG Additionality under Joint Production of Pollution Reduction

AD with nutrient recovery can generate multiple forms of pollution reduction jointly, meaning roughly in fixed proportions at the same time. This reality complicates the notion of a baseline, especially when, by stacking, the AD operation is simultaneously paid for RECs, GHG credits, and nutrient credits or two of the three. The complication arises from the fact that the revenue streams from the other environmental credits and energy generation by an AD might be sufficient to make the AD profitable (i.e., the new "business as usual") without credits for decreasing GHGs, raising the question of whether reductions in GHGs are financially additional and should be allowed to generate reduction credits.

The joint-production-stacking example can be shown by the hypothetical example in Table 3. Although based on no particular AD system or data, this example provides a conceptual frame for examining the stacking and additionality issue. This issue is illustrated by the profitability of AD adoption under five scenarios, ranging from a single revenue stream from conventional agricultural commodities (e.g., milk and meat from a dairy) to multiple revenue streams from agricultural commodities, bioenergy, RECs, nutrient credits, and GHG credits.

Table 3 shows that adoption becomes profitable once the nutrient credits are added to the stack, which alone might suggest that AD with revenues from agricultural commodities, bioenergy, RECs, and nutrient credits is a viable economic proposition. If so, it could be asserted that the availability of these revenue streams creates a new standard of performance or a "new baseline" (see equation at the top of this section) against which the generation of GHG credits would be evaluated. This new performance standard or baseline could, in principle, place some restrictions on the stacking of nutrient credits on top of the other credits. For instance, because nutrient reduction would be presumed to occur under the new baseline for

GHG crediting, it could be argued that no GHG credits should be issued given that no additional reductions are being realized. The reasoning is that the buyer of a GHG credit would be given the right to emit a corresponding quantity of GHGs elsewhere. Thus, if the credited action is not associated with a real reduction, the exchange would effectively allow pollution to increase rather than to attain pollution neutrality as intended.

Alternatively, if the AD investment in Table 3 were determined *not* to be profitable with the nutrient credits in place, the additionality of the GHG credit stack would not be as questionable. Presumably the GHG payments would be necessary to adopt AD and produce the corresponding level of GHG reductions (and nutrient credits, RECs, and electricity).

Table 3. Hypothetical example of impact of credit stacking on profitability of AD adoption

Revenue Stream	NPV of AD Adoption
Ag commodities only	Negative (unprofitable)
Ag commodities Bioenergy revenues (or cost reductions)	Negative (unprofitable)
Ag commodities Bioenergy revenues (or cost reductions) RECs	Negative (unprofitable)
Ag commodities Bioenergy revenues (or cost reductions) RECs Nutrient credits	Positive (profitable)
Ag commodities Bioenergy revenues (or cost reductions) RECs Nutrient credits GHG credits	Positive (profitable)

Now consider stacking over time. In the Table 3 example, AD adoption might be expected to occur if the first four revenue streams (commodities, energy sales, RECs, and nutrient credits) can be stacked, because the NPV of adoption is positive. However, if GHG crediting becomes available a couple years after AD adoption at a specific dairy, the GHG credits might not be considered additional, because no actual change in practice would occur to generate the credits. Because of the path dependence illustrated in Table 3, contemporaneous stacking presents difficulties in determining which credit streams are non-additional; with temporal stacking, it is easier to flag such streams as non-additional.[2]

Environmental Crediting Programs Do Not Currently Address Stacking

Temporal, horizontal, and vertical stacking are not discussed in crediting programs reviewed in this paper. The California (AB32) cap-and-trade regulatory compliance protocol for GHG offsets does not mention stacking. However, the Climate Action Reserve (CAR) has been trying to tackle the stacking issue since 2011, when it formed its Credit Stacking Subcommittee. Currently, only the CAR Nitrogen Management offset protocol (CAR 2013b) mentions stacking, but only credit and payment stacking forms of the issue. The protocol does not comment on the former, but it provides detailed analyses of stacking where government payments are used for financing. Because most environmental payment systems have

---

[2] It is not inconceivable that project investors could claim that they invested in AD in the *expectation* that a GHG credit market would materialize and therefore claim that the GHG credit should be additional. No case law appears to address this issue.

developed independently of one another, changes in their structures are likely needed to achieve a more streamlined system of environmental markets (WRI 2014).

Discussion of Key Policy Design Questions

Several questions arise under the unique constellation of market opportunities that could present themselves to AFOs, particularly dairies, adopting AD.

Environmental versus Traditional Goods

Why are revenues from environmental markets treated differently than traditional goods? In particular, why do additionality and stacking need specific consideration in environmental markets, when they do not for, say, milk and butter?

There are important differences between traditional goods like milk and environmental goods like GHG reductions. The former arises from purely innate preferences for milk products (taste, nutrition), the associated willingness to pay for those attributes, and the technology and costs to produce them, all of which determine a market price and quantity. The role for government in this market is primarily limited to ensuring milk is produced safely, dependably, and competitively.

Environmental goods, such as GHG reductions, are public goods, which mean that they typically lack "natural" markets to facilitate their exchange (Keohane and Olmstead 2007). Inherent problems such as lack of excludability and non-rival consumption lead to free-riding, which makes it difficult to create and sell GHG reductions in a private setting. As such, pollution control usually occurs through regulatory mandate. That is the case here, with one further twist: an environmental credit generated through AD adoption can be sold to another party using the credit as a right to pollute elsewhere (an "offset," Murray 2010). Therefore, if the action underlying the credit does not lead to a real pollution reduction, allowing the credit transfer to occur will lead to an unintended increase in pollution rather than to a net zero change. Prudent efforts to ensure that reductions are additional to what would have occurred anyway are important to protect the environmental integrity of the exchange. In short, environmental goods and services *are* different from traditional goods and services.

GHG Credit Amount

Should a digester be given credit for all of the methane and greenhouse gases captured or only the methane and greenhouse gases that would have been emitted if the digester had not been used?

The general notion of crediting an action for its level of emissions reduction is that it captures a level of emissions that is lower than if the action had not been taken. But what would have happened otherwise? Under AD adoption, the most reasonable assumption is that the "conventional" forms of waste management would have been undertaken (e.g., solids separation, land application; see Figure 1). Therefore, what should be credited is the net difference in methane and other GHG emissions under AD and an estimate of those emissions under conventional management. Crediting all GHGs captured under AD would only make sense if all those GHGs would have ended up in the atmosphere if conventional practices were followed.

However, ADs can be accompanied by complicating factors. ADs capture a higher percent of methane relative to conventional anaerobic non-AD systems, such as anaerobic lagoons, so the reductions are presumably creditable if a conventional anaerobic technology would otherwise have been used. However, if the otherwise-used technology had been an aerobic system, little to no CH_4 would have been generated, so there would be little to no emissions to reduce. In this case, AD is only capturing the methane that the alternative (aerobic) technology would not have generated. As such, no emissions reduction occurs. Based on the Climate Action Reserve (CAR) protocol, the baseline emissions equal those from the *anaerobic* system used before AD adoption. Thus, if an aerobic system was used, no methane would have been generated, and no credits would be issued. There are also intermediate cases; for instance, co-digesting manure with solids (e.g., straw) that would not have been broken down anaerobically in a conventional system lowers the amount of emissions reduction attainable by the AD.

Nutrient Credit Amount

Should the digester earn nutrient credits for all of the nutrients captured and removed from an impaired watershed? What if the producer using that digester is also importing fertilizer to replace the removed nutrients? And what if the removed nutrients are just applied to land elsewhere in the watershed?

As with the question on GHG credit scope, AD, specifically the nutrient removal technology, should in principle earn nutrient credits for the difference in nutrient loadings relative to the WLA without the AD. For example, if manure is now processed by AD, and nutrients are removed by a separate process rather than land applied, the avoided loadings relative to the WLA from land application are, in principle, creditable. However, a consistent approach would, at a minimum, consider the *net change* in loadings from the whole CAFO system. Thus, if imported fertilizers are now land applied in lieu of manure on the CAFO property, which used to apply manure at agronomic rates (e.g., to grow feed), loadings from those fertilizers should also be included in the credit calculation. It may still be the case that the loadings from fertilizer application are less than those from manure application, making for a net improvement, but the credits should be reduced by any loadings that will occur in the new system.

Matters are more complicated when nutrients from the AD are applied to land outside the boundaries of the CAFO property, leading to concerns of spillover effects (leakage) if pollution is simply displaced. If the nutrients are applied on lands subject to NPDES permitting, the loadings are controlled—or at least are controllable—and spillovers are less of a concern. If nutrients are applied on lands not subject to NPDES permitting, there may be spillover effects to consider. If the land is not subject to NPDES permitting because it is in an unimpaired watershed, spillover concerns may be minimized. However, spillover effects at a scale large enough to transform unimpaired watersheds into impaired watersheds would clearly be a problem. One solution is more careful monitoring of loadings on all watersheds, but that has a cost. Another solution would be to avoid over-application by requiring nutrient management plans for farms that receive nutrients from an AD. Policy makers should weigh the benefits of nutrient trading against the potential risks to currently unimpaired watersheds and the costs of enhanced monitoring to make a reasoned decision.

Stacking

How can stacking concerns best be addressed with AD adoption?

As discussed above, stacking can create problems in an offset crediting system when the technology of interest (AD here) jointly produces multiple creditable benefits. The problem occurs when credits are assigned for some benefits that would be produced anyway—the non-additionality problem—as when AD adoption is profitable only if a subset of the benefits are paid for, thereby generating the extra benefits "for free." Any credits issued for the free benefits are problematic if they allow the credit buyer to pollute more. Solutions to this situation are difficult, and environmental protocols have largely sidestepped the issue. The main difficulty is the arbitrary assignment of crediting streams for purely joint production technologies; which benefit streams come first? If each type of credit can be generated only with incremental effort and cost, additionality is less of a problem, because the revenue from the additional credits can be compared to that cost.

One solution to the stacking problem may be to allow stacking of all credits available at the time of AD installation, but to prohibit any further stacking if new credit streams become available after installation. The rationale for this approach is that additional elements cannot be separated from non-additional elements at inception but that non-additionality can be inferred if new credits are made available in the future for benefits that are being generated from the start. Although some non-additional credits might be allowed in this way, this error of commission must be measured against errors of omission—legitimate AD projects left out if stacking is not allowed (Woodward 2011).

References

Arvanitoyannis, I.S., and A. Giakoundis. 2006. “Current Strategies for Dairy Waste Management: A Review.” *Critical Reviews in Food Science and Nutrition* 46: 379–390.

BLS (Bureau of Labor Statistics). 2014. “CPI Calculator.” Accessed 10/15/2014. http://www.bls.gov/data/inflation_calculator.htm.

CAR (Climate Action Reserve). 2009. “Livestock Calculation Tool, Beta v. 2.1.3.” Accessed 10/10/2014/ http://www.climateactionreserve.org.

CAR. 2013a. “U.S. Livestock Project Protocol. V 4.0.” Accessed 11/22/2014. http://www.climateactionreserve.org/wp-content/uploads/2009/03/U.S._Livestock_Project_Protocol_V4.0_Package_012114.pdf.

CAR. 2013b. “Nitrogen Management Project Protocol.” Accessed 11/22/2014. http://www.climateactionreserve.org/how/protocols/nitrogen-management.

Douglas, R. 2012. “How to Generate Tradable Nutrient Credits.” *BioCycle* 53(6): 48–51.

EIP (Environmental Integrity Project). 2006. “EPA and State Failures to Regulate CAFOs Under
FAO (Food and Agriculture Organization of the United Nations). 1996. “Management of Waste from Animal Product Processing.” Accessed 8/28/2014. http://www.fao.org/wairdocs/lead/x6114e/x6114e07.htm.

Federal Environmental Laws. Accessed 3/10/2015. http://www.environmentalintegrity.org/pdf/publications/EPA_State_Failures_Regulate_CAFO.pdf.

Frear, C.D. 2012. “Anaerobic Digestion and Nutrient Recovery.” Accessed 10/10/2014. http://www.epa.gov/agstar/documents/conf12/10b_Dvorak-Frear.pdf.

Hoover, J.N. 2013. “Can’t You Smell That Smell? Clean Air Act Fixes for Factory Farm Air Pollution.” *Stanford Journal of Animal Law and Policy* 6: 1–29.

ICF (ICF International). 2013. “Greenhouse Gas Mitigation Options and Costs for Agricultural Land and Animal Production within the United States.” Washington, D.C.

Informa Economics. 2013. “National Market Value of Anaerobic Digester Products.” Accessed 10/18/2014. http://www.quasarenergygroup.com/pages/National%20Market%20Potential%20of%20Anaerobic%20Digester%20Products%20for%20the%20Dairy%20Industry%20(4-01-13).pdf.

Keohane, N.O., and S.M. Olmstead. 2007. *Markets and the Environment*. Washington, D.C.: Island Press.

Kosseva, M.R., C.A. Kent, and D.R. Lloyd. 2003. “Thermophilic Bioremediation Strategies for Dairy Waste.” *Biochemical Engineering Journal* 15: 125–130.

Kushwaha, J.P., V.C. Srivastava, and I.D. Mall. 2011. “An Overview of Various Technologies for the Treatment of Dairy Wastewaters.” *Critical Reviews in Food Science and Nutrition* 51: 442–452.

Lazarus, W.F. 2008. “Farm-Based Anaerobic Digesters as an Energy and Odor Control Technology. Background and Policy Issues.” USDA OCE AER 843. Accessed 3/13/2015. http://www.usda.gov/oce/reports/energy/AnerobicDigesters0308.pdf.

Lee, H., and D.A. Sumner. 2014. “Greenhouse Gas Mitigation Opportunities in California Agriculture: Review of the Economics.” NI GGMOCA R 7. Durham, NC: Duke University.

Ma, J., N. Kennedy, G. Yorgey, and C. Frear. 2013. “Review of Emerging Nutrient Recovery Technologies for Farm-Based Anaerobic Digesters and Other Renewable Energy Systems.” Accessed 3/13/2015. http://csanr.wsu.edu/wp-content/uploads/2014/07/ICUSD-Emerging-NR-Technology-Report-Final.121113B.pdf.

Murray, B.C. 2010. “Emissions Offsets in a Greenhouse Gas Cap-and-Trade Policy.” In *Issues of the Day: 100 Commentaries on Climate, Energy, the Environment, Transportation, and Public Health Policy*, edited by I.W.H Parry and F. Day, 30–31. Washington, D.C.: RFF Press.

Murray, B.C., C.S. Galik, and T. Vegh. 2014. “Biogas in the United States: An Assessment of Market Potential in a Carbon Constrained Future.” NI R 14-02. Durham, NC: Duke University.

Myhre, G., D. Shindell, F.M. Bréon, W. Collins, J. Fuglestvedt, J. Huang, D. Koch, J.-F. Lamarque, D. Lee, B. Mendoza, T. Nakajima, A. Robock, G. Stephens, T. Takemura, and H. Zhang. 2013. “Anthropogenic and Natural Radiative Forcing.” In *Climate Change 2013: The Physical Science Basis*: *Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley. Cambridge and New York: Cambridge University Press.

N.C. Cooperative Extension. 2012. “Types of Anaerobic Digesters.” Accessed 3/13/2015. http://www.extension.org/pages/30307/types-of-anaerobic-digesters/print/#.VQM-GUtFvcs.

Pfost, D.L., and C.D. Fulhage. 2000. “Anaerobic Lagoons for Storage/Treatment of Livestock Manure. MU Extension, University of Missouri – Columbia.” Accessed 2/16/2016. http://extension.missouri.edu/explorepdf/envqual/eq0387.pdf

RGGI (Regional Greehouse Gas Initiative). 2013. “Model Rule.” Accessed 3/10/2015. http://www.rggi.org/docs/ProgramReview/_FinalProgramReviewMaterials/Model_Rule_FINAL.pdf.

Smith, V.H., G.D. Tilman, and J.C. Nekola. 1999. “Eutrophication: Impacts of Excess Nutrient Inputs on Freshwater, Marine, and Terrestrial Ecosystems.” *Environmental Pollution* 100(1): 179–196.

Tikariha, A., and O. Sahu. 2014. “Study of Characteristics of and Treatments of Dairy Industry Waste Water.” *Journal of Applied and Environmental Microbiology* 2(1): 16–22.

U.S. EIA (U.S. Energy Information Administration). 2016. “Henry Hub Natural Gas Spot Price.” Accessed 2/16/2016. https://www.eia.gov/dnav/ng/hist/rngwhhdd.htm

U.S. EPA (U.S. Environmental Protection Agency). 2003. “Final Water Quality Trading Policy.” Accessed 11/6/2014. http://water.epa.gov/type/watersheds/trading/finalpolicy2003.cfm.

U.S. EPA. 2008. “CAFO Final Rule 2008.” Accessed 7/14/2014.http://water.epa.gov/polwaste/npdes/upload/cafo_final_rule2008_comp.pdf.

U.S. EPA. 2008. “Renewable Energy Certificates.” Accessed 9/14/2014. http://www.epa.gov/greenpower/documents/gpp_basics-recs.pdf.

U.S. EPA. 2010. U.S. “Anaerobic Digester Status Report.” Accessed 11/13/2014. http://www.epa.gov/agstar/documents/digester_status_report2010.pdf.

U.S. EPA. 2014. U.S. “Anaerobic Digesters.” Accessed 3/13/2015. http://www.epa.gov/agstar/anaerobic/ad101/anaerobic-digesters.html.

U.S. EPA AgSTAR (AgSTAR Program). 2014. “Anaerobic Digester Database.” Accessed 11/20/2014. http://www.epa.gov/agstar/projects/index.html.

U.S. EPA AgSTAR. 2012. “Funding On-Farm Anaerobic Digestion.” Accessed 10/12/2014. http://www.epa.gov/agstar/documents/funding_digestion.pdf.

U.S. GAO (U.S. Government Accountability Office). 2008. “Concentrated Animal Feeding Operations.” GAO-08-944. Accessed 11/20/2014. http://www.gao.gov/new.items/d08944.pdf.

USDA (U.S. Department of Agriculture). 2009. “News Release No. 0613.09.” Accessed 7/24/2014. http://www.usda.gov/wps/portal/usda/usdamediafb?contentid=2009/12/0613.xml&printable=true&contentidonly=true.

USDA NASS (National Agricultural Statistics Service). 2013a. “Farms, Land in Farms, and Livestock Operations.” Accessed 10/25/2014. http://www.nass.usda.gov.

USDA NASS. 2013b. “Cattle Inventory.” Accessed 11/10/2014. http://www.nass.usda.gov.

USDA NRCS (U.S. Department of Agriculture, Natural Resources Conservation Service). 1992. “Agricultural Waste Management Handbook.” Accessed 10/15/2014. http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/?&cid=stelprdb1045935.

Van Horn, H.H., A.C. Wilkie, W.J. Powers, and R.A. Nordstedt. 1994. “Components of Dairy Manure Management Systems.” *Journal of Dairy Science* 77: 2008–2030.

Woodward, R.T. 2011. “Double-dipping in Environmental Markets.” *Journal of Environmental Economics and Management* 61(2): 153–169.

WRI (World Resources Institute). 2014. “How Can Conservation Programs Effectively Interact with Environmental Markets?” Accessed 11/22/2014. http://www.usda.gov/oce/environmental_markets/files/WRI_Conservation%20Programs%20and%20Env%20%20Markets.pdf.

Yiridoe, E.K., R. Gordon, and B.B. Brown. 2009. “Nonmarket Cobenefits and Economic Feasibility of On-Farm Biogas Energy Production.” *Energy Policy* 37(3): 1170–1179.

Acknowledgments
Financial support for this work was provided under a cooperative agreement with the U.S. Department of Agriculture's (USDA) Office of Environmental Markets. We appreciate comments on an earlier draft of this manuscript by USDA as well as feedback from our Nicholas Institute colleague, Lydia Olander. All errors and omissions are those of the authors.

Nicholas Institute for Environmental Policy Solutions
The Nicholas Institute for Environmental Policy Solutions at Duke University is a nonpartisan institute founded in 2005 to help decision makers in government, the private sector, and the nonprofit community address critical environmental challenges. The Nichols Institute responds to the demand for high-quality and timely data and acts as an "honest broker" in policy debates by convening and fostering open, ongoing dialogue between stakeholders on all sides of the issues and providing policy-relevant analysis based on academic research. The Nicholas Institute's leadership and staff leverage the broad expertise of Duke University as well as public and private partners worldwide. Since its inception, the Nicholas Institute has earned a distinguished reputation for its innovative approach to developing multilateral, nonpartisan, and economically viable solutions to pressing environmental challenges.

Contact
Nicholas Institute, Duke University
P.O. Box 90335
Durham, North Carolina 27708

1201 New York Avenue NW
Suite 1110
Washington, D.C. 20005

Duke Marine Lab Road
Beaufort, North Carolina 28516

919.613.8709 phone
919.613.8712 fax
nicholasinstitute@duke.edu
www.nicholasinstitute.duke.edu