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Research article

Profits from pollutants: Economic feasibility of integrated anaerobic digester and nutrient management systems

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ABSTRACT

There has been sustained interest from both environmental regulators and livestock associations to expand the use of anaerobic digester (AD) technology to mitigate greenhouse gas emissions. However, the generally profitable practice of codigesting off-farm organic waste could increase nitrogen and phosphorus content to the farm and exacerbate nutrient over-application concerns near large animal operations. We examine the economic feasibility of a broad set of dairy waste management systems composed of two technology groups that mitigate air and water pollution: an AD system that includes either animal waste input or combination animal/off-farm organic waste codigestion input and either compressed natural gas (CNG) or combined heat and power (CHP) output; and a filtration system that includes fiber separation, nutrient separation, and/or water recovery. We conclude that AD setups without codigestion are only economically feasible under limited conditions, but scenarios which use codigestion have the potential to contribute to nutrient over-application without nutrient separation technology. Trends for CNG and CHP match closely. Net present value (NPV) is greatest for AD with CNG scenarios. Estimated NPV for AD with CNG and environmental credits is $1.8 million and $39.7 million for dairies with 1600 and 15,000 wet cow equivalents, respectively. For these firm sizes, the addition of codigestion contributes $4.8 million and $47.3 million, respectively, to estimated NPV. Nutrient separation and water recovery both lead to decreases in scenario NPV with codigestion, but with the right policies, dairy owners may be willing to adopt AD with nutrient separation.

1. Introduction

Environmental regulators maintain concerns about greenhouse gas (GHG) emissions and water pollution from nitrogen and phosphorus caused by waste management in large-scale animal agriculture. The UN Food and Agricultural Organization (Gerber et al., 2013) reports that milk production accounts for 2.9 percent of worldwide anthropogenic greenhouse gas (GHG) emissions. GHG emissions include methane (CH_4) and nitrous oxide (N_2O). They cite the following as potentially highly effective mitigating technologies: AD for both CH_4 and N_2O, fiber separation for CH_4, and consideration of soil nutrient balance before manure application and timing of manure application for N_2O. Smith et al. (2007) find similar results. They estimate that CH_4 from all livestock contributes 4.6–5.5 percent of world GHG emissions while nutrient application in crop production contributes 5.4–6.5 percent of world GHG emissions.

The Environmental Protection Agency's (EPA) (2014a) inventory of US GHG emissions found that agriculture contributed 8.1 percent of total carbon dioxide (CO_2) equivalent emissions during the past decade. Soil management, enteric fermentation by ruminant cattle, and manure management contributed 4.7 percent, 2.2 percent and 1.1 percent of total US emissions, respectively. Enteric fermentation and manure management are the first and fourth largest contributors to CH_4 emissions and contribute 24.9 percent and 9.3 percent of total US CH_4 emissions, respectively. Methane emissions increased 68 percent from 1990 to 2012 due to increasing use of liquid systems of dairy and swine manure storage and management.

Water pollution occurs most frequently through the over-application of nutrients on agricultural land. The EPA (2014b) reports that nutrients are the second and third largest causes of

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impairment of bodies of water and waterways, respectively, and agriculture is the third and first largest source of impairment of bodies of water and waterways, respectively. Harms attributed to current nutrient management practices on US dairies include P and N eutrophication in US waterways (Kiely, 1997; Van Breeman and Van Dijk, 1988), the loss of 70 percent of manure N through ammonia volatilization (Council for Agricultural Science and Technology, 2002), the creation of harmful particulate matter through ammonia reactions (Erisman and Schaap, 2004), and blue baby syndrome and reproductive harm in humans from nitrate accumulation in the water supply (Washington State Department of Health, 2005).

Ribaudo et al. (2003) found that US dairy farms on average produced 22 percent more N and 34 percent more P in manure than could be applied to the dairies' available cropland at agronomic rates. Without enforced regulation, Innes (2000) concludes that, when manure transport cost is high, producers will apply nutrients to near fields even if they exceed agronomic requirements.[1] Sanford et al. (2009) find a viable transport distance of only 3.2–7.6 km for dairy manure slurry as a fertilizer product for corn. In addition to over-application of nutrients, failure to incorporate manure into the soil can lead to further N pollutants (Rotz, 2004). Regulators are increasingly enforcing environmental regulations on dairy producers to reduce over-application of nutrients (Schmit and Knoblauch, 1995; Zhang and Parsons, 2001; Huang et al., 2005).

An anaerobic digester (AD) is an enclosed vessel that allows anaerobic bacteria to break down volatile solids in organic waste and convert them to biogas. A variety AD designs exist (Wilkinson, 2011a). AD technology has been used on large livestock operations in the US and Europe for nearly 50 years as a way to mitigate GHG emissions (Wilkinson, 2011a)—and to lesser extent odor (Wright et al., 2004; AgSTAR, 2011).[2] For an overview of the history, engineering, chemistry and economics of agricultural AD, see Wilkinson (2011a). AD technology has also been widely used in municipal wastewater treatment in the US and the UK (Water Environment Federation, 2015; Sadhukhan, 2014). Biogas capture, a similar technology, has been widely used by US landfills (EPA, 2016). For a review of the variety of uses of AD including treatment of municipal solid waste, municipal wastewater, and agricultural waste see Appels et al. (2011).

The use of AD technology in agriculture varies throughout the world. Lebuhn et al. (2014) report that more than 7 million household-size anaerobic digersters are used for inexpensive cooking fuel in China and more than 1 million in India. Germany has over 7700 larger scale, farm level digesters. Use of AD technology in the US has lagged well behind Germany, but adoption rates have increased in recent years. Of the 209 anaerobic digersters on dairies in the US, 176 have been built since 2005 (AgSTAR, 2016). Combined, these farm projects reduce methane emissions by 2.41 million metric tons of CO_2 equivalent (tCO_2e) per year (AgSTAR, 2016). AgSTAR (2011) estimates that there are another 2645 US dairy farms that are likely candidates for AD adoption with a potential to reduce methane emissions by nearly 1.8 million tons per year or 41 million ton CO_2 equivalent per year.

The biggest factors affecting the adoption of AD technology are environmental penalties and incentives, high initial capital costs, and sale price of AD coproducts. AD tends to favor larger operations (Leuer et al., 2008). Due to their potential to generate jobs in rural areas and reduce environmental harm, many of the ADs built in the US have been funded in part by government grants through programs like the Rural Energy for America Program, the Conservation Innovation Grants program, and the Environmental Quality Improvement Program. Grants have a large impact on the economic feasibility of AD projects, and most projects undertaken in the US have used grants to defray part of the initial capital expense (Cowley, 2014). Germany has seen widespread AD adoption in agriculture through the use of price guarantees (Lebuhn et al., 2014). Funding assistance programs for AD have been recommended as cost-effective policy instruments for reducing GHG emissions from livestock operations (Njuki and Bravo-Ureta, 2015).

Recent economic research indicates that anaerobic digesters may be economically viable in the US, but only with some combination of codigestion, fiber separation, capital cost subsidies, and/or environmental credits (Bishop and Shumway, 2009; ECOregon, 2010; Key and Sneeringer, 2012; Camarillo et al., 2012; Klavon et al., 2013; Manning and Hadrich, 2015). Codigestion is profitable for AD operators due to tipping fees for taking organic waste and the additional methane produced by digestion. Food waste from restaurants or food processing plants is the most common organic waste codigested with on-farm animal waste.[3] In order to divert recyclable materials, some US states (e.g., Connecticut, Vermont, Massachusetts, California, and Rhode Island) and cities (e.g., New York City and Seattle) have placed bans or mandates on disposing commercial food waste in landfills (Henricks, 2014; US Composting Council, 2014; Executive Office of Energy and Environmental Affairs of the Commonwealth of Massachusetts, 2015). Bans and mandates would greatly increase the demand for food waste disposal through ADs.

Food waste generally contains much higher amounts of volatile solids than animal waste and leads to disproportionately larger amounts of methane generated per volume digested (Lisboa and Lansing, 2013). Higher methane output directly impacts the amount of electricity or natural gas generated by the AD. Additionally, methane capture from organic wastes qualify for many of the same environmental credits as methane capture from animal wastes, although at a lesser rate. Typically the AD owner will be paid a tipping fee for accepting the waste which generates additional income.

Codigestion of off-farm organics can greatly increase the economic value of an AD, but there is evidence that acceptance of certain forms of off-farm organic waste could increase nitrogen and phosphorous content to the farm (Atandi and Rahman, 2012). Thus, codigestion mitigates GHG emissions by making AD technology more economically viable, but likely exacerbates nutrient over-application and water pollution. Integrating nutrient separation technologies with ADs that practice codigestion has the potential to mitigate both GHG emissions and water pollution. Life cycle assessment has been used extensively to estimate the environmental value of GHG reduction by AD (Sadhukhan, 2014) or nutrient separation in municipal wastewater treatment (Piao et al., 2016; Niero et al., 2014; Corominas et al., 2013; and Ontiveros and Campanella, 2013). Environmental value may not be attained, however, if economic incentives are not aligned.

We examine the economic feasibility of a broad set of dairy waste management systems composed of two technology groups that mitigate air and water pollution: an AD system that includes

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[1] The agronomic rate of N is the amount applied to maximize plant growth and minimize excess N percolating beyond the root zone into the groundwater (Natural Resources Conservation Service, 2011, p.503-68).

[2] Glover (1996) refers to a lawsuit brought against a US livestock producer in which it was determined that the producer was a source of unbearable odor for neighbors and required payment to the plaintiffs of $500/day for each “smelly” day and $100/day for all other days. Palmquist et al. (1997) estimate that rural residences near US swine operations lost 9 percent of their value.

[3] Other research examines the use of a biorefinery to produce chemicals from food waste either independently (Matharu et al., 2016) or in conjunction with AD (Sadhukhan et al., 2016).

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