Renewable Agriculture and Food Systems: 25(2); 170–180 doi:10.1017/S174217051000013X

Technoscience, anaerobic digester technology and the dairy industry: Factors influencing North Country New York dairy farmer views on alternative energy technology

Rick Welsh[1,*], Stefan Grimberg[2], Gilbert W. Gillespie[3], and Megan Swindal[4]

[1]Department of Humanities and Social Sciences, Clarkson University, Box 5750, Potsdam, NY 13699, USA.
[2]Department of Civil and Environmental Engineering, Clarkson University, Potsdam, NY 13699, USA.
[3]133 Warren Hall, Department of Development Sociology, Cornell University, Ithaca, NY, USA.
[4]Department of Development Sociology, Cornell University, Ithaca, NY, USA.
*Corresponding author: welshjr@clarkson.edu

Accepted 12 February 2010; First published online 30 March 2010 **Research Paper**

Abstract

Structural change in the US dairy industry toward fewer and very large farms has fueled interest and government funding of research into the feasibility of constructing anaerobic digesters (ADs) on large operations as a waste management strategy. Some groups opposed to increasing scale and concentration in the livestock sectors, including dairy, also oppose ADs because of the connection with larger scale operations and the potential for facilitating increased concentration in agricultural production. But the connection between AD technology and large scale is a social construction promoted by its incorporation into the debates over agricultural industrialization. The technology *per se* is essentially scale neutral and its scale-implications are artifacts of design choices, as is seen by its successful application to both very small farms around the world and large-scale agricultural enterprises in the USA. Using a survey of dairy farmers in New York, we find that interest in AD technology occurs at all farm sizes; and that factors other than farm size are important in determining interest in the technology. We conclude that the technoscientific question raised by these findings is: will applications to, and interest by, smaller dairy farmer operators result in shifts in policy and funding priorities toward more diverse agricultural research agendas regarding AD technology?

Key words: anaerobic digester, dairy, farm scale, technoscience

Introduction

The previous few decades have witnessed structural change in the New York dairy industry such that the number of large farms (e.g., 500 cows or more) has steadily increased, although the vast majority of the industry is composed of operations with fewer than 500 cows (see Table 1). The increase in the number of larger operations and their resulting concentration of animals and their manure in relatively small geographic areas have raised concerns about air and water pollution and odor. Traditionally, manure produced on dairy farms in New York has been valued as a fertilizer for crops and a valuable soil amendment. However, with large farms and substantial purchased feed inputs, land application as the sole manure management practice can lead to excesses of nutrients. Also, all other factors being equal, the greater the number of cows and the more manure produced, the more likely rural residents may complain about odors emanating from farms. In addition, rising energy costs have fueled interest in adopting on-farm energy producing technologies using manure as a feedstock to simultaneously address these environmental concerns and reduce expenditures for energy.

On-farm, anaerobic digester (AD) technology is a key manure management option available to farmers concerned about energy costs and odors. AD technology processes the

Table 1. Dairy farms and milk cows in New York State.

Dairy herd size	Number of farms	Percent of farms	Population of cows	Percent of cow population
1–9	683	11.9	1978	0.3
10–19	264	4.6	3753	0.5
20–49	1419	24.7	51,117	6.9
50–99	1854	32.2	125,720	17.0
100–199	872	15.1	115,904	15.7
200–499	375	6.5	115,229	15.6
500–999	145	2.5	99,086	13.4
1000+	142	2.5	227,336	30.7
Totals:	5754		740,123	

Source: 2007 US Census of Agriculture.

manure in such a way as to capture methane gas (a greenhouse gas and also the primary component of natural gas). The methane can then be used for heating or for fueling a generator to produce electricity, which can be used on farm or sold to utilities through net-metering arrangements. The AD process also removes much of the odor-producing components from the manure. And, the deodorized solids produced through the AD process are not only suitable for fertilizing fields near residential development but can also be sold off the farm as a valuable organic fertilizer. Thus, AD technology provides farm operators the potential for their reducing energy costs as well as for addressing potential odor and nutrient surplus issues. The changing political context has also contributed to a surge in farm operator interest, including state subsidies, national partnerships and directives for the production and use of bio-fuels, and carbon trading, all of which involve economic incentives, most of which are particularly applicable to larger farms.

AD technology is more widely used in Europe than in the USA, but researchers, consultants and equipment manufacturers in the USA have developed systems which, with subsidies, are feasible for large-scale dairy farms, given current energy prices. However, although progress has been made on the technical and engineering aspects of AD technology, comparatively little is known about the social and economic aspects of its adoption. How aware are dairy farmers of this technology? How do they feel about AD? Who is interested in this technology and why?

In this study, we picked up a historical theme of social scientists using interviews to measure farmer understanding and interest in new technologies and explored Northern New York State dairy farmers' knowledge of and attitudes toward ADs. The science behind such surveys is predicated on the assumption that socio-demographic, farm structure and attitudinal variables can be constructed and measured, which will allow social scientists, policy-makers and other interested parties to understand the decision-making behavior of farmers, either *ex ante* or *ex post*[1]. We also sought these dairy farmers' opinions on other related agricultural issues important to New York, and gathered information on broader farm structure and socio-demographic factors that will help to understand farmer differences in attitudes and opinions. Our main objectives were to gather knowledge that would be useful for the engineers who are working to improve digester systems in the Northeast, and for the policy-makers, who will determine the levels and types of government investment in the technology.

Technoscience and AD Technology

The term 'technoscience' was invented by the philosopher Gilbert Hottois in the 1970s, and is a popular concept in the field of science and technology studies. Those using the concept to frame their investigations take the theoretical position that scientific knowledge as it is produced through the practice of scientific inquiry, is necessarily historically situated and transmitted and can only be understood through the patterns of social interaction involved in this process and the interpretations of the actors involved. Furthermore, scientific knowledge is facilitated, prolonged and institutionalized by material networks[2].

Studies undertaken under the rubric of technoscience are often focused on the location and technology of scientific inquiry and how this shapes the production of scientific knowledge[3]. Technoscience as a theory helps to illuminate how boundaries are drawn between science and lay inquiry, between scientific disciplines and between what is considered legitimate science what is considered bad science or quackery. And technoscience is a conceptual tool for uncovering the hidden assumptions and biases that often undergird particular scientific findings and their social and economic interpretations and applications, as well as the resulting ways in which technologies are developed[2]. Technoscience is also a useful conceptual framework for understanding the current scientific, policy-maker and civil society interest in AD technology; and exultations and debates about its appropriateness for addressing environmental problems linked to livestock agriculture in the USA in general, and the dairy industry in particular.

Livestock intensification has been characterized by the emergence of fewer, but larger—sometimes very large—operations of the type indicated as emerging in Table 1. Accidents are a 'normal' outcome of complex technological systems[4], and large-scale livestock enterprises have led to manure spills, intense and sustained odors, and other externalities that have mobilized opposition by environmental and rural advocacy groups. These groups have promoted enactment of state and local laws that hobble the development of large-scale livestock facilities[5]. These include bans on corporate ownership of farming operations, mandating very large buffer zones or even moratoriums. Within the US Department of Agriculture (USDA), many state departments of agriculture, the larger agricultural private sector firms and the livestock commodity groups, the response to the externalities linked to intensification has been different. These parties press for public research and extension funds to subsidize the development of environmental management technologies and incentives for their

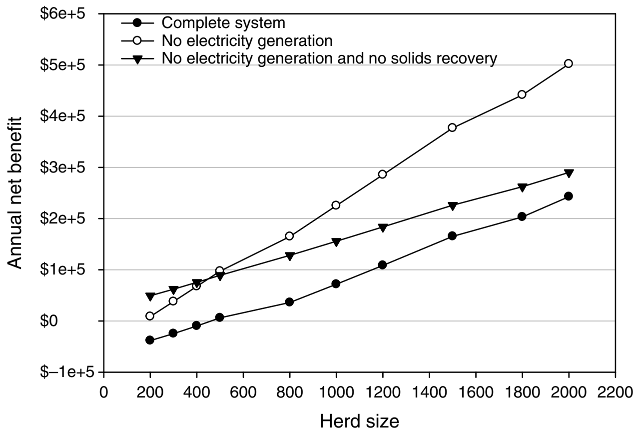

Figure 1. Comparison of benefit–farm size relationships with and without co-generation and organic solids recycle[9,15].

adoption. Livestock intensification linked to large food manufacturing and input suppliers through national and international supply chains is viewed as the future of agriculture and is deemed to be the most likely vehicle for agriculturally driven rural development[5]. One of these environmental management technologies for ameliorating the externalities of large-scale livestock facilities is ADs that use manure as a feedstock.

The association of large-scale livestock operations and particular technologies for dealing with many environmental ills has been reinforced by much of the academic and government literature on the topic. The EPA AgStar handbook lists a minimum of 500 cows as a condition for installing AD technology[6,7]. And Farm Bill funding of AD research and extension has been limited to larger farms[8]. Other analyses have shown that payback periods become more attractive at a minimum of 500 cows, but herds should be no smaller than 200–250 cows[9]. The linkage of AD technology with larger scale and, therefore, livestock intensification has caused some environmental and rural advocacy groups to oppose or to look with skepticism on AD technology. AD technologies are said to be scale-biased and part of the industrialization of agriculture; and are inadequate end-of-the-pipe technologies that do not address the underlying causes of environmental problems. For instance, the GRACE Factory Farm Project (2003)[10] argues that the current interest in AD technology is driven by excess manure generated from very large ‘factory’ farms and cannot address adequately the odor and other issues associated with such operations[10]. And the main-line environmental group, the Sierra Club (2004) asserts that ‘CAFO waste streams are so large and contaminated that methane digesters mitigate only a small fraction of their environmental damage[11]’.

But the experience of farmers in the developing world illustrates that AD technology exists that is appropriate for farms with only a few animals. The engineering of such applications of this technology is much less capital intensive. These installations typically produce too little gas to power an engine to generate electricity, but produce sufficient gas for heating water or cooking[12]. And some smaller US dairy farms have installed AD technology that is based on different engineering and operation assumptions than the now dominant capital-intensive model[12]. In addition, manure is a relatively unproductive feedstock for biogas compared to other materials, many of them present on farm. Therefore, current appraisals of AD feasibility, assuming that electricity production is the desired goal and that manure from the farm’s animals represents the dominant feedstock, will focus only on larger farms, missing the opportunity to employ AD technology on smaller farms.

The Engineering and Economics of AD Technology

Current farm AD system design is relatively simplistic, dictating a minimum hydraulic residence time of 15 days in the reactor to achieve manure stabilization without consideration of biodegradation kinetics or substrate composition[6]. AD systems commonly consist of: (1) a digester, where organic matter is converted into biogas through microbial biodegradation; (2) a boiler and/or combined heat and power system in which the biogas is converted into heat and/or electrical energy; and (3) a solids separator where digested solids are separated from the liquid waste stream. Separated solids can be sold off the farm, reducing the nutrient loading (especially phosphorus) of the farm, or dried and used as bedding material. Digested liquids are commonly land applied for fertilizer value. Before AD systems can be adopted widely, several challenges have to be overcome. First, the capital costs for a typical AD system are high, requiring the need to reduce the initial costs and market the various AD end products to compete with alternative manure management options. The capital cost for constructed AD systems varies significantly with farm size[13]. After accounting for inflation, capital costs for installed AD systems ranged between $664, $948 and $1363 per cow for a 1300-, 500- and 250-head dairy farm, respectively. Another study reported that the AD system costs between $1288 and $830 per cow for a 250- and 1500-head dairy, respectively[14]. Second, typical farm digesters operate in the mesophilic temperature range, which requires that the process temperature has to be maintained in a narrow range around 38°C to sustain the acetogenic and methanogenic bacteria that drive the AD process and yield biogas. Maintaining reactor temperature, particularly for smaller reactors, can be difficult and energy intensive, especially in regions such as Northern New York State where winter temperature may reach −40°C.

It is possible to illustrate variations in the annual net benefits of the overall AD system by isolating individual system components of a generic digester system (Fig. 1). The complete generic AD system in Northern New York consists of a plug-flow in-ground digester operated at a 20-day hydraulic residence time, a solid separation system

Table 2. Annual estimated heat generated and revenues made from the AD system without a co-generator for ten farm sizes[9].

Farm size head	Boiler recovery mmbtu yr^{-1}	Heat surplus mmbtu yr^{-1}	Annual surplus $\$yr^{-1}$
2000	26,230	16,723	$551,406
1800	23,607	15,004	$494,733
1500	19,672	12,429	$409,803
1200	15,738	9856	$324,992
1000	13,115	8144	$268,540
800	10,492	6435	$212,183
500	6557	3879	$127,917
400	5246	3031	$99,938
300	3934	2185	$72,048
200	2623	1343	$44,288

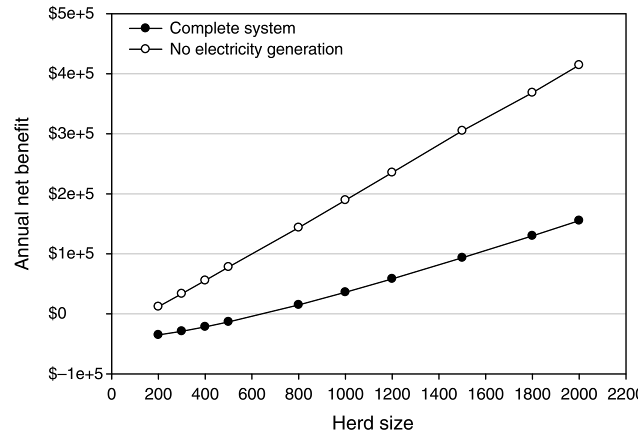

Figure 2. Comparison of benefit–farm size relationships for a farm using sand bedding with and without co-generation[9,15].

assuming a solids separation efficiency of 85% and a combined heat and power internal combustion engine[9]. Mass and energy balances for the system are solved computing annual biogas and heat generation rates. Capital costs for the system are estimated and converted into annual expenditures assuming a 10-year loan period at a 6% interest rate. The model also assumes that 25% of the capital cost will be covered by state or federal grants. Revenues due to sale of electricity are calculated using New York State net metering law[16]. The model assumes that all excess heat will be used to replace fossil fuels purchased. This represents a maximum potential revenue stream due to the AD system. The model further considers revenue streams from New York State or federal incentives programs such as the Renewable Energy Portefolio Standards[17], carbon and renewable energy credits.

There are fewer benefits from generating electricity on smaller farms (complete system; Fig. 1). Smaller farms therefore may opt to reduce the AD capital cost by installing a boiler only, rather than an engine/generator set (no electricity generation; Fig. 1). For even smaller farms, separating solids from the digested manure may not be cost effective (no solids separation; Fig. 1). This process design would yield higher returns than a traditional AD system configuration assuming that the generated heat from burning biogas could be used to offset propane use on the farm (assumed at $2.40/gallon) (complete; Fig. 1). The system without an engine-generator has a smaller break-even point, and the net benefits are more sensitive to the farm size (larger slope). While it may be realistic to assume that a small farm may use all its available excess heat on site (Table 2), larger farms may not be able to sell their excess heat. Accordingly for larger farms, the installation of engine-generators in the AD system will yield higher financial benefits. Higher fossil fuel and electricity prices will increase overall benefits of the digester, thereby lowering the minimum farm size at which the digester becomes uneconomical.

The choice of bedding affects overall economic assessment of AD systems. Recycling of digested solids for use as bedding material has a significant impact on the overall yearly benefits of the AD system (Figs. 1 and 2). Owing to the high bedding cost of saw dust (assuming the use of 10 lb/d/cow of saw dust at $127 ton^{-1}), a farmer forgoing solids separation (Fig. 1, no solids separation) will lose significant revenue (Fig. 1, no electricity generation), at farm size up to 400 cows. Below 400 cows, the cost for the capital equipment relative to the annual bedding cost will be too high. Farms that use sand for bedding will need to separate sand from the manure before AD in order to prevent sand settling in the digester (Fig. 2). The break-even point for a farm with sand bedding and electricity generation is higher (600 cows; Fig. 2) than for a farm using saw dust bedding (500 cows; Fig. 1). If no electricity is generated, the break-even point for a farm using sand bedding is below 200 cows (Fig. 2), which is comparable for a farm using organic bedding (Fig. 1). Changes in bedding prices and daily bedding rates will have a significant effect on this result.

On an annual basis, digesters produce excess heat (Table 2). However, in the winter (depending on the AD system location and size), heat from biogas combustion may not be sufficient to maintain the AD system temperature of 38°C. A diversified farm that has a constant need for heat (e.g., through the operation of greenhouses or small-scale cheese manufacturing) may be able to offset fossil fuel cost and thus improve the viability of the farm. Alternatively, a small farm that has a source of excess heat (e.g., using the heat from an electricity generator run on biodiesel) in the winter may be able to maintain the operating temperature of the AD system without added expense. Several process variations have been proposed to improve AD-systems economics. The energy content of dairy manure is relatively low compared to other potential materials available at farms[18] (Fig. 3). Supplementing manure with highly biodegradable wastes has been shown to positively affect digester economics[19]. In a typical single-stage digester, corn silage, for example, has eight times the biogas yield compared to dairy manure. Many dairy farms find themselves with surplus or spoiled corn silage, and

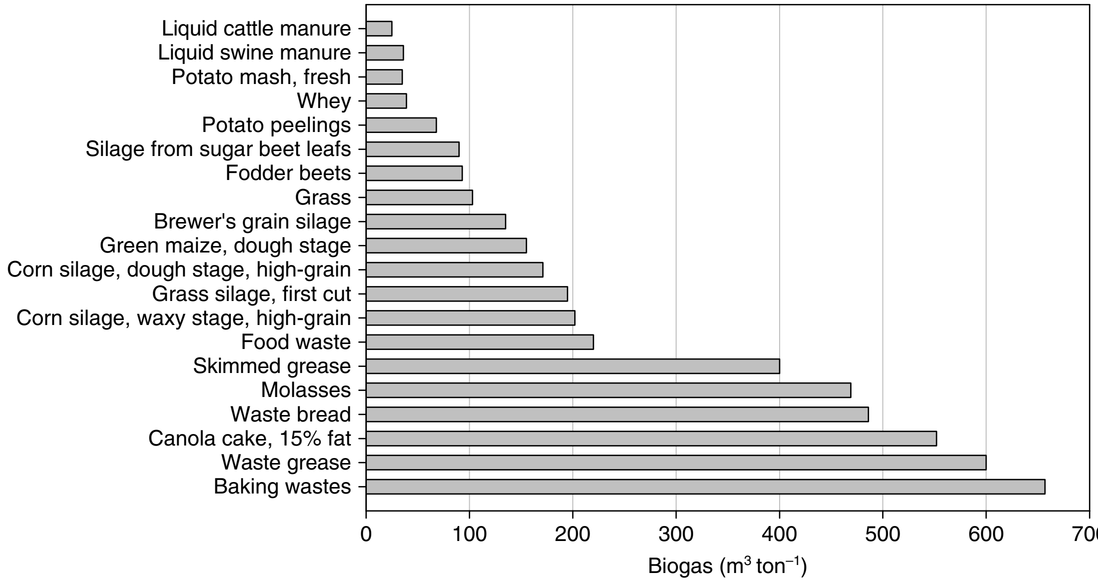

Figure 3. Relative biogas potential of alternative digester feedstocks (redrawn using data from Eder and Schulz[18])[5].

such high energy waste products from the farm operation could be blended with the manure to increase biogas production. In summary, the economic evaluation of AD systems depends on the process configuration, the farm diversity and its size. Employing a systematic evaluation of the farm's energy needs and production capacity may result in process configurations that yield economical systems even at the very small scale.

Therefore, from a technoscience perspective, the contemporary AD technology in the USA is being socially coded as only large-scale appropriate, i.e., scale-biased, because of the social, political and economic conditions surrounding its development and adoption. This is driven in part by the policy agendas of the funding agencies charged with the development and adoption of the AD technology and therefore, influence the scientific inquiry in this area toward larger scales. So what is socially defined as scientifically legitimate or feasible regarding AD technology, for instance, is that which is a larger farm technology and which contributes to the industrialization of agriculture (whether one views this as good or bad or neither). Social, as used in this sense, is an umbrella term that includes the embedded economic and political processes and institutions. This does not mean that the scientific inquiry and experiments that have undergirded AD technology development are not viable or produce wrong or invalid results. The science is measuring real things and the public and private funds spent in this area are building real working digesters—but the questions being asked and the direction of the inquiry are determined by social factors. As Langdon Winner puts it, artifacts or technologies have politics[20].

Extension and Outreach Models

In addition, the model being employed to extend the AD technology is a variant on the traditional version of the scientist-centric, diffusion of innovations model relating to agriculture[21–23]. This model is grounded in the presuppositions that the capital-intensive, labor-saving technologies of the industrializing agricultural system are 'progress' and that the early adopters are, by definition, leaders among their peers, other farmers, and therefore will foster progress by influencing their peers' behavior in this area. Information is also disseminated through public agencies such as Cooperative Extension and private firms. Farmers are categorized by the speed at which they adopt new technologies: early, middle, late and laggards[21–23]. From this perspective, a logical strategy is to identify a few innovative farmers, i.e., early adopters, and then subsidize them through information, privileged access to technology, or financial incentives to induce them to foster progress by adopting new technologies. From this frame, agricultural science produces knowledge which is provided to farmers, particularly those few who are 'innovators.'

In contrast to the diffusion of innovations model, another, more farmer-centric technology development and extension model has been employed widely in the developing world. This comes out of the farmer-first and local knowledge scholarship and the efforts originated in the developing world agriculture context. Over the past couple of decades, this has migrated to the USA and has been gaining traction, becoming established through alternative agriculture networks such as early organic agriculture or management-intensive rotational grazing networks in dairy[24–26]. From this perspective, farmers develop knowledge through their own practice in the contexts of the biological and agronomic processes on their farms, with the knowledge stimulated and shared through their interactions with each other. The knowledge so produced is often unique or idiosyncratic to particular agro-climatic and social situations, and therefore may be difficult to model through conventional scientific inquiry. All farmers are

Figure 4. 'North Country' New York Counties (encompassed by bold line).

seen as innovators and experimenters, even on a par with traditional scientists[26,27]. From this frame, the proper role of agricultural scientists is to interact with farm-level workers in scientific research and technological development and extension focused on topics driven largely by needs and interests generated at the farm level.

A broadly based farmer-centric approach to the AD technology issue might entail querying dairy farmers of all types about their interest and needs in this area and about their real environmental problems linked with livestock agriculture. Accordingly, we undertook this study to obtain interesting and useful information that could inform public funding of research and extension activities, and forestall social controversy and conflict around the development of a potentially beneficial technology with widespread applications.

Data Collection

The data for this study were collected in two stages. The first stage was in-depth interviews with six dairy farmers located in New York State. The farmers had milking herds ranging in size from 250 to 1200 cows and had already implemented AD into their manure management programs. We identified these six farmers through Cornell University's Manure Management website; all of the interview subjects had received technical assistance from Cornell engineers. These sessions generated information about the attitudes, farm-structure characteristics and socio-demographic characteristics associated with the adoption of the AD technology. We then used the findings from the interviews to create a six-page questionnaire that we mailed to the population of dairy farmers in the six-county North Country region of New York State (see Fig. 4).

The North Country of New York is an appropriate socio-economic and geographic location for a study of this type. Dairy farming is a major part of the economic and cultural landscape. St. Lawrence County has been ranked in the top-third of dairy production counties in the USA and dairy farming is the dominant model of successful commercial farming in the area. Dairy is also important culturally to the area, as illustrated by the fact that several counties still select dairy queens and their courts from among the local farm-connected population of young women. USDA data and other scholarship on the dairy industry in the North Country[28] illustrate that the structural change toward fewer and larger farms has begun. For example, Kellogg et al.[29] found that livestock farms with more than 300 units of confined animals increased substantially in North Country counties from 1982 to 1997.

The mail survey of North Country dairy farmers was conducted in January through May of 2007 based on the New York State Department of Agriculture and Markets brucellosis test list. We contacted addressees up to five times: a pre-survey postcard describing the study, a recruitment letter with a copy of the questionnaire, a thank-you postcard, another recruitment letter and a replacement questionnaire, and for those who had not yet responded and for whom we could locate a telephone number, a telephone call. Out of a total of 1400 names on the list, we mailed letters and questionnaires to the 1312 names for which the initial postcard was not returned as having a bad address by

Table 3. Respondents as percentage of 2007 census for North Country Counties.

Herd size	Cases	% Census total
1–9	7	6.7
10–19	7	19.4
20–49	108	51.2
50–99	168	41.8
100–199	63	34.1
200–499	40	54.8
500+	16	40.0
Total farms	409	

the time of the second mailing. Our primary method for determining whether an addressee on our list was eligible was Question #1 on our questionnaire, which asked if the addressee was currently in dairy farming and, if not, to return the blank questionnaire in the stamped envelope provided. We also deemed ineligible those who had died or whose postcards and letters were returned as having invalid addresses. We determined that any current farmers who were on the farms of a former operator on the list would remain eligible. Names that were on our initial list but who did not respond to our mail or phone contacts were also deemed 'eligible' for determining the response rate. After all the mailings and phone calls, 409 farmers responded out of the total of 1011 names that we had not otherwise determined were ineligible. This yielded a raw response rate of 41.3%. Since we knew from the telephone calls that some people on the list who had gotten out of farming did not bother to respond, applying the phone-generated ratio of ineligible to eligible farms among non-respondents would raise the overall response rate to 45.5%. The highest rate of response was among farmers with herds of 200–499 cows; the second highest among farmers with 20–49 cows followed by farms with 50–99 cows and farms with more than 500 cows. The lowest rate of response was among farmers with 1–9 cows; the second lowest among farms of 10–19 cows. Thus, this suggests that those with very small farms were less likely to participate in the study, and therefore, the results represent their views less well than the views of those with larger herds (see Table 3).

Analysis and Results

As explained above, our primary goal was to better understand the relationships between dairy farmers' attitudes toward AD technology and their farm sizes and types and their own characteristics. Our six preliminary interviews indicated three main considerations central to our interviewees' adoption of AD: the size of their herds, their proximity to nearby communities (linked to concerns about odors and pollution), and a favorable attitude toward new conventional dairy management technologies. These farmers told us that farms with herds below about 250 cows would not produce enough manure to make the investment worthwhile. Nor did they think that smaller herds would provoke the odor complaints from non-farming residents that close proximity made likely. Although all these interviewees were in Agricultural Districts, five out of the six had received complaints from non-farm neighbors and the prospect of minimizing such complaints through the biological AD process was an important motivation for them. Interviewees also noted that a favorable technological orientation, that is, an interest in the whole complex AD system, was a consideration that attracted them to adopt AD as part of their manure management strategy.

Interviewees also cited a number of reasons for installing the technology, or benefits obtained, including odor control, good neighbor relations and capturing value from manure (i.e., power, compost and tipping fees). In addition, all the interviewed farmers indicated they would install AD technology if given the opportunity again. The problems mentioned included generator and pump failures, lack of availability of replacement parts, gas leaks and difficulties in regulating the internal temperature of the digester. And obstacles to adoption of AD technology included high cost and complexity of technology and net metering issues (i.e., utility companies as uncooperative buyers of their surplus electricity).

Also, these farmers with adopted AD technology were skeptical of organic farming as a viable method of environmental management and generally supportive of agricultural biotechnologies, such as recombinant bovine somatotropin (rBST) and transgenic crops. We conclude from our interviews that the six farmers with installed digesters conceptualize this technology as a capital-intensive conventional environmental management technology, which is part of a conventional dairy management trajectory. Also the technologies are adopted primarily to control odor near non-farm residential areas and that policy reform in the electrical power sector would be needed to boost the importance of AD technologies as an alternative source of power.

Using the data collected from the mail survey, we created a model to measure the factors that influenced interest in AD technology. The dependent variable (interest) is an additive scale composed of six items.

- Interest in reducing odor.
- Interest in on-farm power.
- Interest in power sale.
- Interest in reducing pathogens.
- Interest in solids produced.
- Interest in tipping fees.

Respondents could indicate one of four responses: no interest (= 0), a little interest (= 1), some interest (= 2) and a great deal of interest (= 3). Therefore, interest scores could range from 0 to 18. We developed two models using the AMOS 7.0 structural equations modeling (SEM) software developed by SPSS Inc. (Chicago, IL). In the first model, we regressed farm size as measured through a multi-dimensional latent variable composed of number of lactating cows (milknow), acres farmed in 2006 (acre06) and number of full-time employees in 2006 (empft06) on the

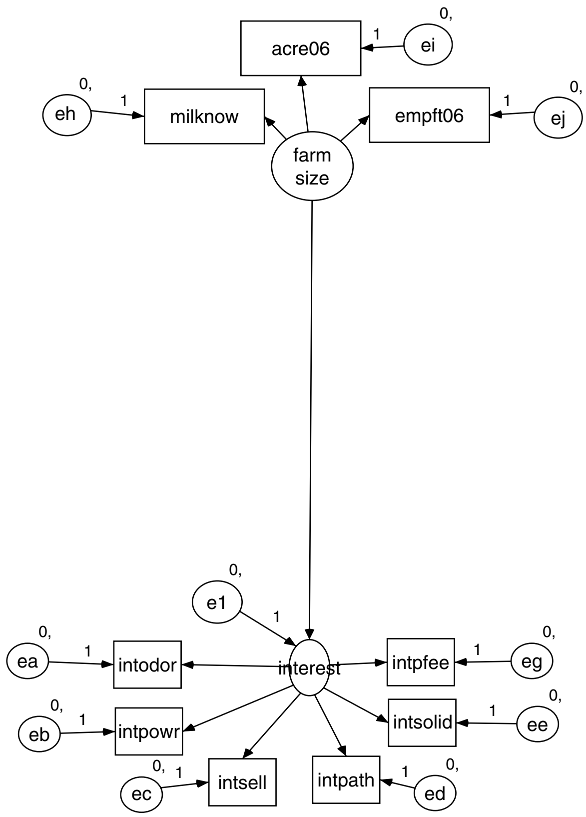

Figure 5. Partial SEM model, farm size and interest.

Interest scale (see Fig. 5). In the second or full model (Fig. 6), we insert mediating variables based on our interview results and important control variables to discern if the effect of farm size on interest is mediated by other factors. The potential mediating variables are:

- a 5-point Likert scale on the degree of agreement with the statement that biotechnology is contributing to the sustainability of US agriculture (1 = strongly disagree to 5 = strongly agree),
- a binary variable measuring whether the barn or a field on which manure is spread is within one-half mile from a non-farm residence,
- the percentage of feed obtained from pasture during the grazing season, and
- the percentage of household income earned from the farm operation.

Table 4 presents descriptive statistics for the dependent and independent variables included in the model.

In SEM models, the single direction arrows (→) represent analyzed associations between variables where we have posited explanations to account for co-variation[30]. The 'e' variables are error terms. The single direction arrows (→) imply causality but in a probabilistic sense. Making a distinction between deterministic causality and probabilistic causality is important, according to Kline[30], because

> '... the causes of exogenous variables are not represented in path models. In contrast endogenous variables are specified as *caused* by exogenous variables or other endogenous variables. Every endogenous variable has a disturbance, which represents variance unexplained by other observed variables in the model. A disturbance can also be seen as an unmeasured exogenous variable that represents all omitted causes of the endogenous variable. Path models thus assume that causality is probabilistic rather than deterministic. Deterministic models assume a one-to-one correspondence between cause and effect[30].

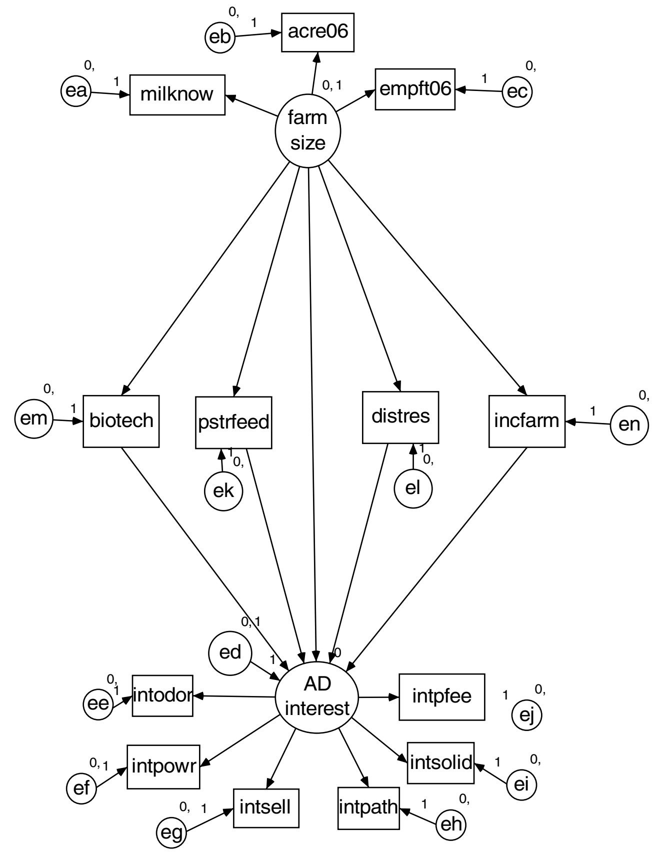

Figure 6. Full SEM model with mediating variables.

SEM factor analysis results indicated that the proposed multi-dimensional variables (farm size and interest) measured single constructs and therefore are valid latent variables (result not presented). Table 5 presents the SEM regression results. In the initial (partial) model, farm size is a strong predictor of interest. Larger farms with more lactating cows, employees and farming more acres were more likely to be interested in the benefits of AD technology. This is consistent with the dominant assumptions underlying the research funding and extension programs currently underway serving almost exclusively larger farms. However, the full model results tell a radically different story. The farm size variable is mediated completely by the other variables in the model. This indicates that farm size has little or no influence on interest in AD technology independent of other variables—especially those measuring relative reliance on pasture for feed, support for conventional technologies such as agricultural biotechnology and, to a lesser degree, proximity to non-farm neighbors. The farm size effect is accounted for almost entirely by the indirect effects of farm size as mediated through the

Table 4. Means of selected variables used in analysis.

Variable (abbreviation)	*N*	Mean	Standard deviation
Interest in reducing odor (intodor)	405	1.39	1.130
Interest in on-farm power (intpowr)	409	2.13	1.104
Interest in power sale (intsell)	406	1.96	1.171
Interest in reducing pathogens (intpath)	396	1.39	1.111
Interest in solids (intsolid)	402	1.41	1.127
Interest in tipping fees (intpfee)	392	1.34	1.155
Biotechnology contributes to sustainability of US agriculture (biotech)	415	2.64	1.329
Percent of feed from pasture during the grazing season (pstrfeed)	395	34.80	35.777
Cows milked now (milknow)	416	130.13	200.058
Percent of net income from farming (incfarm)	402	83.07	26.098
Residence is within a half-mile of the dairy farm: 1 = yes; 0 = no (disres)	417	0.89	0.308

Interest variable scale: 0 = no interest; 1 = little interest; 2 = some interest; 3 = great interest.
Biotech scale: the range is from 1 = strongly disagree to 5 = strongly agree.

Table 5. Partial and full SEM model; dependent = interest.

Variable	Beta	Sig
Partial model		
Farm size	0.255	0.000
Full model		
Farm size	0.078	0.183
Mediators regressed on interest		
Pstrfeed	−0.261	0.000
Biotech scale	0.159	0.003
Incfarm	0.033	0.510
Distres	0.087	0.074
Mediators regressed on farm size		
Pstrfeed	−0.392	0.000
Biotech scale	0.419	0.000
Incfarm	0.101	0.044
Distres	0.097	0.048
NFI	0.913	
CFI	0.930	

Pstrfeed and Biotech variables. Specifically we find that pasture-based farms show less interest in AD technology than confinement systems; supporters of biotechnology are also interested in AD technology; and having non-farm neighbors close to one's barn or field on which manure is spread is associated with interest in AD technology. These variables have strong effects and are significant independent of the size of the farm. This makes sense since confinement systems allow the collection of manure more readily than pasture systems. And pasture systems are often linked with alternative approaches to dairy production, such as organic dairy, where biotechnology applications are prohibited. Regarding model fit, AMOS returns a number of fit measures. We report results for the Normed Fit Index (NFI) and the Comparative Fit Index (CFI). The value of NFI provides an estimate of the fit of the model compared to a null model. The CFI is interpreted the same as the NFI, but may be less sensitive to sample size[30]. For the NFI and CFI, values range from 0 (no fit) to 1 (a perfect fit). Scores above 0.90 generally indicate an acceptable fit between the model and the data[31]. Our model scores of 0.913 and 0.930 for the NFI and CFI, respectively, indicate an acceptable fit for the model[30].

Discussion and Conclusions

The current and opposing social definitions of AD technology as either a nifty technological fix or an unwise subsidy for large to very large dairy and other livestock farms stem from differing perspectives on structural change and the industrialization of agriculture[32]. The storage of livestock manure and the capture of methane gas for human use is not an innately scale-biased concept, process or technology. It is the framing of digester technology by social and economic actors engaged in the promotion or contestation of certain types of structural change in the livestock, in this case dairy, industry that results in the technology achieving scale bias. If owners of larger farms install AD technology, it can be argued that they are progressive managers and being proactive in their environmental management. And if AD technology is framed as an environmentally sound, capital-intensive technology, then 'large scale' becomes less of an environmental liability and more of an advantage. This is reinforced by studies using the assumption of capital intensiveness as a base finding that the advantages of installing AD technology increase as farm size increases. These studies are not wrong or biased in their analyses, but rather the implicit assumptions about AD technology shape the questions asked, which, in turn, shapes the kinds of results. Groups opposed to the industrialization of dairy and other livestock sectors reinforce this dynamic and interpretation by arguing against AD technology, because they also interpret it as inherently biased toward larger farms. The AD technology plays the villain instead of the hero in their version, but the technoscientific outcome is the same as that from the diffusion of innovations—the emergence of scale bias in AD technology use in the USA. What we argue here is that this bias has social and political, not engineering, origins.

And in this way, AD technology becomes a vehicle for the continued industrialization of the livestock industry, for better or worse.

However, we find that variables other than size of the milking herd play important roles in generating interest in the benefits of digesters. Reasons for this might include the fact that smaller farms (e.g., between 100 and 200 lactating cows) may also provoke odor complaints from very close non-farm neighbors, especially if the neighbors are recent migrants from urban areas. Or, confinement dairy farms with less than 200 milk cows may be interested in generating power of some type for their farms from the cow's manure or reducing pathogen numbers in the manure to promote herd and farm family health. Future research in this vein could focus on specific determinants of smaller farm interest in AD technology.

In addition, there are important public policy implications of our findings regarding agricultural pollution control and climate change. Methane is a potent greenhouse gas, and controlling its emission through AD technology adoption on dairy farms has potential environmental benefits, depending on a number of factors. In New York State, there are over 298,000 dairy cows on farms with 200 cows or less. This accounts for about 41% of total dairy cows in the state. It is myopic to ignore smaller dairy farms and their cows when investing in technologies that can limit the greenhouse gas, and other pollutants', footprint while enhancing farm profitability.

The technoscientific question that is raised by our findings is: will the fact that large numbers of operators of smaller dairy farms express an interest in adopting AD technology lead to resources being leveraged to address their needs? At this point it is clear that public resources are directed toward the needs of larger farms, including dairy farms. On the one hand, this is appropriate, since many of the benefits from the installation of AD technology on larger farms (e.g., odor control, reduction in pathogens and capturing greenhouse gases) spread beyond the farm gate and, therefore, constitute public goods. Also, larger dairy farms produce most of milk consumed in the USA. On the other hand, much of the research money devoted to the development of AD technology is public money. And it is clear that, in aggregate, smaller dairy and other livestock farms constitute the vast majority of total farms and control significant livestock resources[33]. Therefore, from public good and equity perspectives, devoting public monies to smaller farm digester technology inquiry and development, is appropriate.

Acknowledgements. This work was supported through funding from USDA, US Department of Energy (USDOE), New York Ag and Markets and New York State Energy Research and Development Authority (NYSERDA).

References

1 Dillman, D. 2007. Mail and Internet Surveys: The Tailored Design Method. John Wiley and Sons, New York.

2 Sismonde, S. 2004. An Introduction to Science and Technology Studies. Blackwell Publishing, Oxford, UK.

3 Latour, B. and Woolgar, S. 1986. Laboratory Life: The Construction of Scientific Facts. Princeton University Press, Princeton, NJ.

4 Perrow, C. 1984. Normal Accidents: Living with High-Risk Technologies. Basic Books, New York, NY.

5 Hinrichs, C.C. and Welsh, R. 2003. The effects of the industrialization of U.S. livestock agriculture on promoting sustainable production practices. Agriculture and Human Values 20:125–141.

6 EPA (US Environmental Protection Agency). 2007. Anaerobic Digesters Continue Growth in U.S. Livestock Market, November. Available at Web site http://www.epa.gov/agstar/pdf/2007_digester_update.pdf (verified 20 December 2007).

7 Kramer, J. 2006. Practical information about anaerobic digesters. A Presentation to the Ohio Public Utilities Commission. Energy Center of Wisconsin.

8 Resource Strategies Inc. 2006. Anaerobic Digester Implementation Issues: Phase 1-A Survey of U.S. Farmers (Farm Bill Section 9006). Final Project Report Submitted to the California Energy Commission's Public Interest Energy Research Program.

9 Xu, R. 2007. Mathematical modeling of plug-flow anaerobic dairy manure digester in Northern New York. Thesis for Masters of Sciences in Civil Environmental Engineering, Clarkson University, Potsdam, NY.

10 GRACE, Global Resource Action Center for the Environment. 2003. Factory Farm Project's Position Statement on Methane Digesters. Available at Web site http://www.energyjustice.net/digesters/ (verified 20 December 2007).

11 Sierra Club. 2004. Sierra Club Guidance: Methane Digesters and Concentrated Animal Feeding Operation (CAFO) Waste. Available at Web site http://motherlode.sierraclub.org/MethaneDigestersSIERRACLUBGUIDANCE.htm (verified 20 December 2007).

12 Wisconsin Chapter of the American Society of Farm Managers and Rural Appraisers. 2004. Small Scale Bio-gas Resources. Available at Web site http://www.wcasfmra.org/biogas.htm (verified 20 December 2007).

13 Wright, P. and Graf, K. 2003. Anaerobic digester at AA Dairy: Case study. Manure Management Program, Case Study AD-1, Cornell University. Available at Website http://www.manuremanagement.cornell.edu/Docs/AA%20Case%20Study%20draft%20(6-11-04).htm

14 Gooch, C.A. and Pronto, J.L. 2009. Capitalizating on energy opportunities on New York dairy farms. In Dairy Power New York Summit: Creating a Greener, Cleaner Future, Innovation Center for U.S. Dairy, Syracuse, NY, 29–30 October 2009.

15 Brouwer, A.F., Grimberg, S.J., Powers, S.E., and Thacher, E.F. 2009. Assessing the economic viability of anaerobic digesters on dairy farm in NYS through the use of mathematical models. Presented at the Environmental Monitoring, Evaluation and Protection (EMEP) Conference, Albany, NY, 14–15 October 2009.

16 New York State Net Metering Law. 2009. A.B. 2442, Available at Web site http://assembly.state.ny.us/leg/?bn=A02442&sh=t (verified January 2010).

17 New York State Renewable Portefolio Standards. 2010. Available at Web site http://documents.dps.state.ny.us/public/Common/ViewDoc.aspx?DocRefId={30CFE590-E7E1–473B-A648-450A39E80F48} (verified January 2010).

18 Eder, B. and Schulz, H. 2007. Biogas-Praxis: Grundlagen, Planung, Anlagenbau, Beispiele, Wirtschaftlichkeit. Ökobuch Verlag, Staufen, Germany.

19 Scott, N. and Ma, J. 2004. A Guideline for co-digestion of food wastes in farm-based anaerobic digesters. Fact Sheet FW-2, Cornell Manure Mangement Program, December. Available at Web site http://www.manuremanagement.cornell.edu/Docs/Food%20Waste%20fact%20sheet%202.htm (verified March 2008).

20 Winner, Langdon. 1980. Do artifacts have politics? Daedalus 109:121–136.

21 Rogers, E.M. and Burdge, R.J. 1972. Social Change in Rural Societies. Meredith Publishing, New York.

22 Rogers, E.M. 2003. Diffusion of Innovations. 5th ed. Free Press, New York.

23 Feldman, S. and Welsh, R. 1995. Feminist knowledge claims, local knowledge, and gender divisions of agricultural labor: Constructing a successor science. Rural Sociology 60:23–43.

24 Bell, M. 2004. Farming for Us All: Practical Agriculture and the Cultivation of Sustainability. The Pennsylvania State University Press, Pennsylvannia, PA.

25 Hassanein, N. 1999. Changing the Way America Farms: Knowledge and Community in the Sustainable Agriculture Movement. University of Nebraska Press, Nebraska, NE.

26 Kloppenburg, J. 1991. Social theory and the de/reconstruction of agricultural science: local knowledge for an alternative agriculture. Rural Sociology 56:519–548.

27 Thorlindsson, T. 1994. Skipper science: a note on the epistemology of practice and the nature of expertise. The Sociological Quarterly 35:329–345.

28 Harper, D. 2001. Changing Works: Visions of a Lost Agriculture. University of Chicago Press, Chicago, IL.

29 Kellogg, R.L., Lander, C.H., Moffitt, D.C., and Gollehon, N. 2000. Manure Nutrients Relative to the Capacity of Cropland and Pastureland to Assimilate Nutrients: Spatial and Temporal Trends, for the US. Natural Resources Conservation Service and the Economic Research Service/US Department of Agriculture.

30 Kline, R.B. 1998. Principles and Practice of Structural Equation Modeling. Guilford Press, New York.

31 Bentler, P.M. and Bonnet, D.G. 1980. Significance tests and goodness of fit in the analysis of covariance structure. Psychological Bulletin 88:588–606.

32 Wojcik, J. 1989. The Arguments of Agriculture: A Casebook of Contemporary Agricultural Controversy. Purdue University Press, West Lafayette, IN.

33 Perry, J. 1998. Small farms in the U.S. Agricultural Outlook, May 1998: 22–26. Economic Research Service/US Department of Agriculture.