We Hold These Truths to Be Self-Evident: Engineering AFOs for Environmental Protection

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American Agricultural Law Symposium 2001
October 12, 2001 – Colorado Springs, CO

Introduction

The transition from on-farm to industrial-scale livestock and poultry production in the United States has increased the social stress at the rural-urban interface as a result of actual environmental impairments, perceived increases in environmental risk, demographic and cultural shifts within agricultural communities and disillusionment with the nature of the economic growth that has accompanied the transition.[1] This ongoing transition, which has occurred in response to the development of increasingly efficient production practices, economies of scale and technological innovation, has stimulated the growth of regulatory activity directed especially at the larger facilities, commonly known as confined animal feeding operations (CAFOs).[2] The increasingly stringent regulatory requirements on these large facilities have been championed by environmental advocacy groups whose revulsion at the concept of confined animal production is frequently difficult to conceal and whose language often betrays a tacit prepossession with the traditional, small-farm production paradigm:

> The new technologies and mass production promote an unsustainable farming system with too much waste for disposal, too many animals in a small space, and too much dust, gas, and bacteria for a healthy neighborhood and working environment…A sustainable animal production system, by contrast, integrates human, animal and environmental requirements in a holistic way, substituting human labor and resources for capital and commercial inputs, weighing the costs of pollution against the economic benefits (i.e. profit) of the facility, and strengthening rural communities.[3]

Interestingly, because of the substantial cost of complying with them, the evolving regulations appear to have had the perverse effect of further accelerating the transition to large, industrial-scale facilities rather than fostering a return to diffuse, small-scale, pre-industrial production

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[1] Kelley Donham and Kendall Thu, *Understanding the impacts of large-scale swine production: Introduction*, Presented at the Interdisciplinary Scientific Workshop, Des Moines, IA, 6-29-1995, pp. 3-4.

[2] Ron Jones, *Livestock and the environment*, Interim report to the Joint Interim Committee on the Environment, 72nd Texas Legislature, Texas Institute for Applied Environmental Research, Stephenville, TX, 9-1-1992, p. 5.

[3] Consumers Union, *Animal factories: pollution and health threats to rural Texas*, Final report, Southwest Regional Office, Austin, TX, 5-31-2000, p. 2.

schemes. Predictably, the overarching reason is that small producers find it more difficult to pass the costs of compliance onto others than the large producers.[4]

The current regulatory structure, including both federal and state AFO provisions, is a fluid admixture of the reasonable and the arbitrary. One of the higher-profile provisions at the federal level is the "no-discharge" policy under which AFOs subject to the Clean Water Act (as amended) may not allow wastewater to leave the property irrespective of its quality.[5] Many in the agricultural engineering community have criticized this provision because it leaves no room for innovative strategies or systems that can treat the effluent to match or exceed the quality of the receiving water. In that light, the "no-discharge" provision artificially and needlessly restrains technological innovation: why would an AFO operator invest heavily in advanced wastewater treatment systems if the effluent must still be retained on-site? The "no-discharge" provision, therefore, is undoubtedly one of the primary reasons that anaerobic lagoon systems – the bane of many a conservation association – continue to proliferate. In other words, it is an arbitrary restriction that may itself *contribute* to whatever environmental stresses and risks are posed by on-site lagoon systems.

Fortunately, that message is getting a respectful hearing in the current debate over the proposed revisions to the Effluent Limitations Guidelines (ELG) for AFOs. In published comments to EPA on the proposed guideline revisions, the National Center for Manure and Animal Waste Management, a 14-state consortium of land-grant universities having respected expertise in engineering waste management systems for AFOs, summarized the general argument this way:

> We believe that limiting livestock producers to those technology options listed in Table 8-1 [i. e., of the Federal Register rendering of the proposed ELG revisions] is overly prescriptive and removes incentive for innovation that may result in improved waste management techniques and technologies. Prescribing specific technologies stifles the development of new, innovative technologies that may perform better and cost less than technologies currently available…at the same time, there should be a provision in the rules that will allow the discharge of wastewater to surface waters if the wastewater is treated to [standards that apply to publicly owned treatment works]. Such a provision

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[4] Ron Jones, *Livestock and the environment*, Interim report to the Joint Interim Committee on the Environment, 72nd Texas Legislature, Texas Institute for Applied Environmental Research, Stephenville, TX, 9-1-1992, p. 5.

[5] This provision distinguishes AFO regulations from those of municipalities and many other industries. Non-AFO sources are generally allowed to discharge effluents to the waters of the United States if the quality of the discharge (i. e., the discharge of pollutants such as nutrients, heavy metals or biochemical oxygen demand) meets some maximum concentration criteria (e. g., milligrams of pollutant per liter of water discharged) or daily mass thresholds (kilograms per day of pollutant discharged) established to protect the quality of the receiving water. The "no-discharge" provision usually prohibits AFOs from releasing effluent except in the case of an extreme precipitation event in which prohibiting the release would threaten a catastrophic release (as would occur, for example, upon failure of a pond embankment).

will stimulate the industry to pursue further processing to achieve the savings that may be available if wastewater is discharged to surface water as opposed to applied to land.[6]

The technology tools available for environmentally safe manure management are diverse, but they all derive from a short list of venerable engineering processes that can be combined in many ways to achieve a variety of objectives. No single process or system of processes is appropriate for all AFOs in all locations. By the same token, none should be ruled out for all operations simply because it is not appropriate for one AFO type or location. Furthermore, all of the systems – particularly the innovations being touted as replacements for, rather than alternatives or supplements to, existing technologies – need their claims evaluated in light of some simple engineering axioms.

Axiom #1. *Conservation of Mass*: It's Not Just a Good Idea, It's the Law

Perhaps the simplest but most profound engineering limitation that natural systems impose on the environmental management of AFOs is the Laws of Conservation of Mass (LCM). In its simplest terms, the LCM says that all of the mass entering a system must be stored in the system, exported from the system or lost from the system,[7] as in Figure 1.

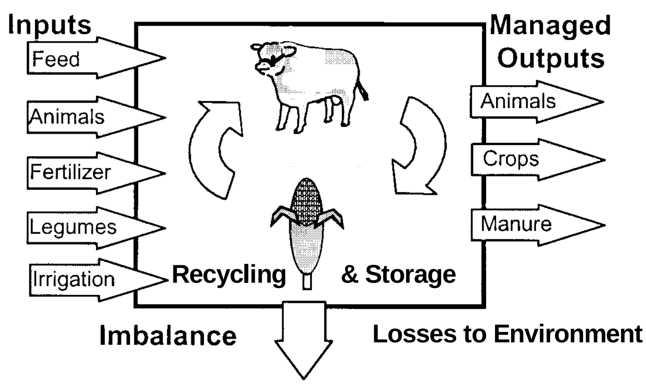

Figure 1. Schematic of the Law of Conservation of Mass as applied to an AFO.[8]

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[6] National Center for Manure and Animal Waste Management, *Comments and recommendations on proposed Environmental Protection Agency rules: National Pollutant Discharge Elimination System permit regulation and effluent limitations guidelines and standards for concentrated animal feeding operations*, North Carolina State University, Raleigh, NC, 8-22-2001, pp. 4-6. (Available on the Internet at http://www.cals.ncsu.edu/waste_mgt/comment.pdf.)

[7] *Exporting* from the system refers to the deliberate act of moving matter out of the boundary of the AFO, observing any applicable environmental guidelines or restrictions. One example of *exporting* nitrogen is the sale of animal carcasses to a packing plant, which moves nitrogen-bearing protein out of the AFO system. By contrast, *loss* refers to the incidental, accidental, negligent or passive movement of matter out of the AFO boundary. Examples of nitrogen *loss* include (a) volatilization of ammonia from a lagoon surface or (b) deep seepage of soil water below the root zone of a standing crop to which lagoon wastewater has been applied. For the sake of this discussion, illegal discharges are also *losses*.

[8] National Center for Manure and Animal Waste Management, 2001, p. 34.

The LCM applies to every type of physical matter on which an AFO depends, e. g., water, total feed and individual nutrients (nitrogen, phosphorus). It implies that once an AFO operator decides to import some type of physical matter, he necessarily imposes upon himself the need to store it somewhere on the AFO property or arrange for its export via some marketable product. Furthermore, it implies that if the export rate is lower than the import rate, the matter inevitably accumulates within the AFO boundary – unless, of course, the loss rate makes up the difference. That loss rate, in turn, represents the pollution risk. Moreover, in some cases, the accumulation of matter within a system boundary actually increases the loss rate, which means that the accumulation itself increases the risk of pollution. Thus does mass conservation exert its influence over the environmental risk posed by AFOs.

Nowhere is the influence of the LCM more starkly clear than in the context of the principal macronutrients nitrogen (N) and phosphorus (P). Both of these two elements are subject to the LCM, and both are imported by an AFO in large quantities. As we will note later in more detail, biological systems such as livestock are inherently inefficient; in fact, N retention in the lean body mass of a beef steer may be as low as 10%, which means that up to 90% of the N in the imported feed may be excreted by the animal as waste products. For the sake of illustration, it is safe to assume that at least 50% of both N and P ends up in the waste stream.

Consider first the mass balance of P. Phosphorus is relatively immobile compared to N, and its plausible loss pathways are only in the solid (e. g., attached to particles, as in runoff-induced soil erosion) and liquid (dissolved: e. g., seepage or rainfall runoff) phases. Excreted P is found predominantly in the solid manure fraction. Consequently, most of the 50% of the imported P that is excreted accumulates in the solid phase. If the manure is handled as a solid, that P accumulates in a manure stockpile; if as a liquid, as in hydraulic flushing of feeding areas, then it accumulates in retention pond or lagoon sediments, with small amounts dissolving into the pond supernatant. Either way, the P accumulates over time unless it is intentionally exported by selling the manure (or giving it away to off-site users), recycled as a feedstuff to replace a fraction of the imported P or applied to land outside the boundary of the AFO proper. If none of those options is feasible, or if their magnitudes do not approach the P excretion rate, then P continues to accumulate in the stockpiles or in the pond sediments. We first consider the pond sediments.

A detailed explanation of retention pond design is beyond the scope of this discussion, but suffice it to say that accepted professional design practice for these ponds includes a volume allowance for sediment accumulation.[9] Further, if sediment accumulates beyond the design allowance, it begins to encroach on other design volumes dedicated to stormwater detention or anaerobic treatment. (Those two design volumes have direct and critical implications for environmental protection.) Thus, the sediments must be removed from the pond whenever the design sediment volume is appropriated, and the AFO operator must move those sediments to the solid-manure stockpile, or he must export them as above. Either way, the P in the sediment has not gone away; it has simply been sequestered out of sight and out of mind.

In the AFO setting, N flows in considerably more directions after leaving the animal. In addition to the accumulation of organic N in sediments and the dissolution of N in pond

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[9] American Society of Agricultural Engineers, *Engineering practice EP403.1: design of anaerobic lagoons for animal waste management*, ASAE Standards, 3-31-1990, pp. 475-477.

supernatant, N may also leave the AFO system in the gas phase and in numerous gaseous forms including ammonia (NH_3), dinitrogen gas (N_2) and a variety of nitrogen oxides (e. g., N_2O, NO). Because it is highly soluble compared to P, N may also be lost more quickly than P via seepage as soluble ammonium (NH_4^+) or nitrate (NO_3^-) ions. Where hydraulic manure handling systems terminate in an anaerobic lagoon system, the aggregate loss of N from excretion through land application of lagoon supernatant may exceed 80%,[10] although proper selection of management practices can reduce those losses markedly.

During the last ten years, agricultural researchers have quantified the accumulation of feed-borne nutrients at a variety of scales, from the individual animal to the AFO to the county and state. Smolen et al.[11] found that in two Oklahoma counties where AFOs are concentrated, annual N imbalances exceeded 50% when considering all imported N sources including animal feed and crop fertilizers. A meta-analysis of Nebraska livestock systems showed that N and P imbalances across 33 livestock-intensive counties also exceeded 50%; on individual livestock farms, imported N and P exceeded managed exports by as much as 300%.[12] The same scenario holds across the United States. In fact, unless environmental regulations are so lax that all uncontrolled losses are allowed, the same scenario is fundamentally inevitable.

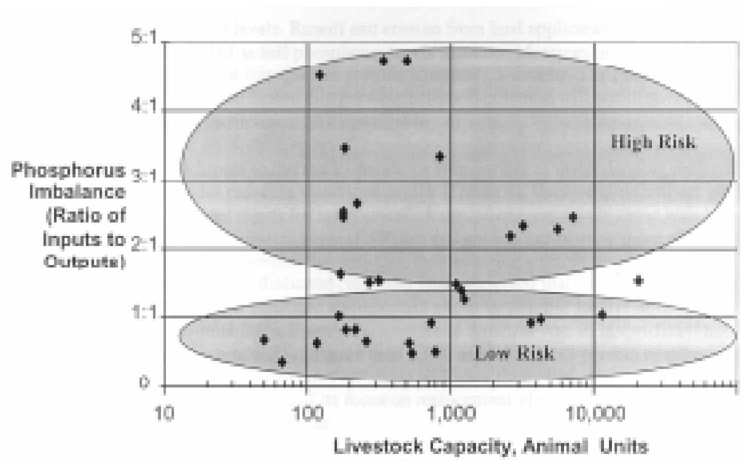

Figure 2. Phosphorus input/output ratio for 33 livestock operations in Nebraska (Koelsch and Lesoing, 1999).

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10 J. J. Meisinger and G. W. Randall, *Estimating nitrogen budgets for soil-crop systems*, In: Ron F. Follett, D. R. Keeney, and R. M. Cruse (Eds.), Managing Nitrogen for Groundwater Quality and Farm Profitability, 12-31-1991, Soil Science Society of America, Madison, WI, pp. 92-107.

11 Michael D. Smolen, Daniel E. Storm, D. Peel, and P. Kenkel, *Mass balance analysis of nutrient flow through feed and waste in the livestock industry of the southern plains*, Presented at the Great Plains Animal Waste Conference on Confined Animal Production and Water Quality, Englewood, CO, 6-1-1994.

12 Rick Koelsch and Gary Lesoing, *Nutrient balance on Nebraska livestock confinement systems*, 77 Journal of Animal Science 63 (1999).

What is the environmental significance of these mass imbalances of N and P, particularly in the context of selecting advanced waste-treatment technologies for AFOs? The answer depends on the environmental objective or the type of pollution to be mitigated. Where eutrophication of surface water is the most prominent environmental risk, excessive losses of P (as opposed to managed exports) via runoff and shallow seepage are usually to blame. Where N enrichment of lakes and streams is a problem, the sources may include wet deposition of atmospheric ammonia or runoff and seepage. Because manure is a relatively low-value product that is expensive to haul, where nutrients are accumulating the major temptation seems to be over-application (i. e., in excess of realistic crop requirements) of manure near its source.[13] This process is a means of relieving the accumulation of nutrients within the AFO boundary, but it does not relieve the accumulation of nutrients within a larger system boundary encompassing the AFO and its closest land-application fields. Essentially, this scenario trades (a) point-source pollution potential for (b) non-point source pollution potential as nutrients – especially phosphorus – accumulate in soils beyond the soil's capacity to assimilate them.

The solution to this entire conundrum is conceptually rather simple: increase what Koelsch and Lesoing[14] term "managed exports" such that exports and imports are in balance, and the potential for losses is thereby minimized. Unfortunately, increasing "managed exports" of low-value products like manure and wastewater is often an expensive proposition and cannot easily be achieved without regulatory fiat. In watersheds where AFOs and the associated land-application areas are perceived to contribute directly to water quality impairment via non-point source losses, regulators are now developing special rules requiring that new or expanding AFOs export all or most of the increased manure beyond the watershed boundary.[15]

Corollary #1: If It Seems Too Good to Be True, It Probably Is

As innovators have anticipated the possible elimination or modification of the "no-discharge" doctrine as applied to AFOs, the animal-feeding industry has seen a dramatic increase in technologies being promoted as solutions to this or that environmental challenge within the AFO system or its associated land-application areas. Although many of these innovations are nothing more than rearrangement, repackaging or operational enhancement of well-known processes, some vendors are marketing lagoon additives and other compounds or processes for their alleged ability to "liquefy pond sediments," "remove phosphorus," "treat waste" or any number of other nebulous environmental benefits. The marketing rhetoric can be seductive, and in fact, many of these products and processes are being marketed successfully, particularly in areas where AFO

[13] One indicator of this concept is the "break-even hauling distance," the distance at which the hauling cost of a given quantity of manure equals the sum of the purchase price and hauling costs for conventional fertilizers having an agronomic value equivalent to the manure. Even when fertilizer prices spiked in early 2001, the break-even hauling distance for standard feedyard manure was only about 10-12 miles, depending on the crop to which the manure was to be applied.

[14] Rick Koelsch and Gary Lesoing, *Nutrient balance on Nebraska livestock confinement systems*, 77 Journal of Animal Science 63 (1999).

[15] Texas Natural Resource Conservation Commission, *Proposed Rule Log No. 2001-041-321-WT*, p. 5. The proposed rule may be found at http://www.tnrcc.state.tx.us/oprd/rule_lib/proposals/01041321_pro.pdf.

density is high, water-quality impairments have a high profile and AFO owners and managers are looking for immediate assistance to respond public pressure against their facilities.[16] The marketing rhetoric is not necessarily intentionally misleading, but it is often incomplete and fails to recognize the insurmountable challenge posed by the LCM. For example, as a practical matter one cannot simply "remove phosphorus," as if by using the product one could reduce the number of acres needed for land application of manure on the basis of P uptake by crops.[17] One may remove P from a particular waste stream (e. g., via solid-liquid separation) and thereby create another waste stream rich in P, but the net quantity of P that must eventually be exported in some form has not changed. If the AFO does not own or control sufficient acreage for environmentally safe land application of manure P – or have sufficient export arrangements in place – before the installation or use of the innovative "removal" process, the AFO will remain in that situation after its installation or use unless that process generates a P-enriched waste stream that may be marketed in an added export pathway. In that case, however, the LCM is still inviolate, and the solution inevitably depends on establishing a new export pathway, not simply "removing" the source of the imbalance between imports and exports – which is impossible.

Corollary #2: The Law of Unintended Consequences

The picture is slightly different for volatile nutrients such as nitrogen (N). To date, AFOs have not been required to limit the gaseous losses of N such as ammonia (NH_3). In fact, until soil phosphorus pools in certain regions of the nation began to increase P losses dramatically from land application fields via rainfall runoff, nutrient management plans designed for AFOs were written almost exclusively on the basis of N mass balances. As long as N losses to the atmosphere are permitted, enhancing those losses is a key design objective of the nutrient management plan and the waste management system that implements it. In other words, the atmosphere has traditionally served as an ammonia "sink" for the sake of AFO nutrient planning.

Atmospheric NH_3 has long been known as a gaseous precursor of aerosol particles.[18] In the presence of atmospheric water, it may react with nitrate (NO_3), sulfate (SO_4) and chloride (Cl) ions to form fine particles. In 1998, the Desert Research Institute published a report on Denver's "brown cloud" that linked agricultural NH_3 emissions to the enrichment of fine particles in the South Platte River valley along the Front Range of the Rocky Mountains.[19] Regulators in

[16] Personal communications with Joe Pope, Robert Whitney and Larry Spradlin, County Extension Agents-Agriculture, Counties of Erath, Hamilton and Hopkins, TX, 1997-present.

[17] Acreage requirements for land application of manure are vitally important to the AFO operator, particularly where the reservoir of P in the soil has reached regulatory thresholds above which nutrient management plans must be based on P rather than N. In most cases of practical interest, and certainly in the case of most cereals and forage crops, acreage requirements for manure P disposal exceed those for manure N disposal by a factor of 3 or more. When a soil P threshold is reached, the AFO operator suddenly requires much more land even if his AFO capacity and cash flow have not increased.

[18] Kvetoslav R. Spurny, *Analytical Chemistry of Aerosols*, 1999, New York: Lewis Publishers, p. 105.

[19] John G.Watson, Eric M.Fujita, Judith C.Chow, Barbara Zielinska, L.Willard Richards, William Neff and David Dietrich, *Northern Front Range air quality project (NFRAQS)*, Final report to the Cooperative Institute for Research in the Atmosphere (CIRA), Colorado State University, Fort Collins, CO, 1998.

polluted airsheds are considering tighter regulations for AFOs, particularly in regard to NH_3 emissions.[20] Because the success of AFO nutrient management plans frequently hinges on enhancing NH_3 loss in the gas phase, the net consequence of imposing any emissions limits on AFOs will be dramatic, forcing them in some cases to capture ammonia in the dissolved or solid phases and either to acquire more acreage for crop uptake or to arrange for the controlled export of the additional N in some marketable form.

That entire scenario begins to illustrate the interdependent nature of processes and systems subject to the LCM. In waste management systems, as in all systems, changes in one discrete process necessarily give rise to changes in other processes, inventories or flows. A *robust* system, in which a change in one component or condition results in only a modest or minor change in the system's operating state, is by definition only marginally affected by such changes. Unfortunately, no real system is perfectly robust, and unless policy proposals are flexible enough to account for the varying degrees of robustness among waste management systems, those policies may have unintended results that are at worst disastrous and at best expensively counterproductive. As discussed in the next section, recent developments in the United States provide a window for exploring the unfortunate nexus of non-holistic thinking and the neglect of economic factors in technology selection.

Axiom #2: Anything is Possible If You Throw Enough Money At It (Except: See Axiom #1)

Engineers and scientists have recognized the energy potential of manure, wastewater and other biomass for many years. Animal feeding operations may generate electricity from the potential energy in manure and organic-laden wastewater in several different ways, most prominently (a) direct combustion in mixtures with fossil fuels[21] and (b) combustion of biogas produced in covered lagoons or specially designed anaerobic digesters.[22] Because direct combustion of dry manure with coal or other fossil fuels usually represents an export pathway for the AFO, biogas production receives the most attention as an on-farm waste processing technology.

The biogas system generally consists of (a) slurry or liquid manure delivery at >80% moisture by volume (wet basis) into (b) an enclosed reactor or covered lagoon in which volatile solids are digested by microbes that thrive in the absence of oxygen, generating a stream of biogas that fuels (c) a flare, (d) an internal-combustion engine for generating electricity or (e) a boiler for direct heat recovery and use. These systems have high capital costs and, depending on the use of the biogas, potentially high management demands and maintenance requirements. Sophisticated biogas systems may incorporate a combination of any or all three of the combustion options to provide operational flexibility during all seasons of the year and for a wide range of

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[20] Anonymous, *Regulators trying to cut dairy cattle manure gases*, High Plains Journal, 9-24-2001, p. 25-B.

[21] Stephen Frazzitta, Kalyan Annamalai, and John M. Sweeten, *Performance of a burner with coal and coal-biosolid fuel blends*, 15 Journal of Propulsion and Power 181 (1999).

[22] For example, see Carl Nelson and John Lamb, *Haubenschild Farms anaerobic digester*, Final report to The Minnesota Project, St. Paul, MN, December 2000.

utility market conditions. Electrical energy may be used entirely on the farm to replace grid power, or it may be sold to a nearby energy utility to supplement power plant output during periods of peak demand.

In addition to the energy potential, anaerobic digesters and covered lagoons present several potential benefits related to air quality and greenhouse gas emissions. Methane, which comprises about 65% by volume of the biogas produced from anaerobic digestion of manure, is a potent greenhouse gas;[23] the end products of its combustion, carbon dioxide and water, have a lower greenhouse gas potential per unit of organic matter digested in the reactor or lagoon. Second, well designed and properly managed reactors carry the digestion processes to completion, avoiding the buildup of intermediate, trace metabolites that are primarily responsible for manure odors.[24] Furthermore, the combustion step oxidizes any odorous gases that persist in the digester systems, including hydrogen sulfide, generating end products that are virtually odor-free.

In light of the numerous environmental benefits of biogas production from animal manure, it has received a lot of attention as (a) a potential substitute for lagoon systems or (b) an operational enhancement of existing lagoon systems for odor control.[25] However, there are a number of drawbacks as well. Impermeable covers are expensive ($0.37 to $5.81 per square foot of lagoon surface area), require considerable maintenance to operate properly and change the operating characteristics of the lagoon by reducing evaporation and gas volatilization.[26] An anaerobic lagoon *originally* designed to operate as a covered bioreactor (especially a heated bioreactor) would likely be much smaller than an open-air anaerobic lagoon designed only for waste stabilization and storage. Floating covers on these large ponds are susceptible to severe damage by wind and ultraviolet radiation.[27] Aside from the costs and unintended consequences of retrofitting existing systems to produce biogas, biogas systems have a long track record of marginal profitability or outright failure unless subsidized by (a) grants or cost-sharing

[23] Mark A. Moser, *AgSTAR digest*, Report # EPA-430/F-00-012, USEPA Office of Air and Radiation, Washington, DC, Spring 2000.

[24] *Ibid*.

[25] See Code of Colorado Regulations, 5 CCR 1001-4, promulgated in 1999 to implement Colorado Revised Statute 25-7-109(2)(d) resulting from a 1998 ballot initiative known colloquially as Amendment 14. The passage of Amendment 14 required, among other things, that swine feeding operations cover their anaerobic lagoons with impermeable covers and harvest the biogas for combustion, wet scrubbing or other technology that will control odors using the best available control technology.

[26] Restricting ammonia volatilization may increase dissolved ammonia concentrations to levels toxic to the methane-producing bacteria. See Don D. Jones. John C. Nye and Alvin C. Dale, *Methane generation from livestock waste*, Report AE-105, Department of Agricultural Engineering, Purdue University, West Lafayette, IN, 1980.

[27] Kurt F. Roos, Mark A. Moser and A. G. Martin, *Agstar Charter Farm Program: experience with five floating lagoon covers*, Presented at the Fourth Biomass Conference of the Americas, Oakland, CA., Aug. 29-Sept. 2, 1999.

arrangements against the considerable capital costs or (b) uncommonly favorable pricing structures for the electricity offset or sold back to the grid by the AFO.[28]

The potential value of these systems, obviously, will vary over time as energy prices fluctuate. It is also likely that the design and operation of anaerobic digesters will improve over time as the industry gains experience with them. Finally, public and private utilities may decide that the potential environmental benefits of anaerobic digesters are worth subsidizing on a large scale. But the larger point is that technology alternatives to existing waste management systems should be adopted carefully, not only in light of economic costs and benefits, but also with an understanding of the operational consequences and engineering implications that may accrue to the whole system. Otherwise, promising technologies may cause as many environmental problems as they solve.

Epilogue: We Need More Tools, Not Fewer

The contemporary debate about the legitimacy of anaerobic lagoons as an element of a waste management system for AFOs is an excellent illustration of how failure to appreciate the scientific constraints and possibilities inherent in complex systems results in precipitous, ill-conceived policy proposals. In a movement echoing the arguments advanced to promote the "no discharge" provision discussed earlier, front-line environmental interest groups are vocal and ardent about their intent to abolish the anaerobic lagoon from the waste management toolbox, apparently on the premise that lagoons are inherently and invariably vehicles for environmental pollution and the intermediate conclusion that waste management systems based on anaerobic lagoons are therefore unsustainable:

> When the existing technology standard was promulgated over twenty years ago, animal operations were smaller and lagoons were built on a much smaller scale. Today with the enormous quantities of manure that is [*sic*] generated and stored in lagoons, there are multiple ways for discharges to occur through the air, surface water and groundwater…To protect the environment and public health, EPA should use all regulatory avenues possible to ensure that no new lagoons will be built.[29]

The National Resources Defense Council (NRDC) correctly points out that lagoon systems and the "no-discharge" provision are products of an earlier age when AFOs were considerably smaller and located more diffusely across the landscape than they are today. Lagoon systems and discharge prohibitions were conceived when waste management systems of any kind were scarce. Moreover, because environmental risk is a multi-faceted composite of social values and ecological realities *as well as* the facility's engineering design, it is undoubtedly wise to abandon

[28] For examples of each, see Oregon Office of Energy, *Anaerobic digester at Craven Farms: a case study*, available on the Internet at http://www.energy.state.or.us/biomass/digester/craven.htm; and Carl Nelson and John Lamb, *Haubenschild Farms anaerobic digester*, Final report to The Minnesota Project, St. Paul, MN, December 2000.

[29] Robin Marks, *Cesspools of shame: How factory farm lagoons and sprayfields threaten environmental and public health* , National Resources Defense Council, Washington, DC, 2001, pp. 47-48.

any simplistic notion that environmental risk is merely proportional to size or scale.[30] Still, NRDC's conclusion that anaerobic lagoons are fundamentally unable to meet accepted environmental objectives is, scientifically speaking, a *non sequitur*, if for no other reason than their implicit assertion that the lagoons of yesterday did not have "multiple ways for discharges to occur through the air, surface water and groundwater." Today's risk pathways are not new; they merely have greater ecological implications than yesterday's, perhaps even out of proportion with their scale. A mandate to eliminate those pathways (as if that were entirely possible no matter what alternative is adopted) does not follow.

The engineer's philosophy, in contrast, is that the environmental threat posed by earthen storage of liquid waste (a *real* threat) can be mitigated to an arbitrarily high degree by sufficiently rigorous design, construction, operation and maintenance of the facility provided that (a) the uncertainties associated with system components are taken into account and that (b) the facility is sufficiently profitable to ensure that AFO operators can sustain a rigorous level of management. The net result of abolitionism is to reduce the number of tools at the industry's disposal, marginally reducing its flexibility and its consequent sustainability under changing market, environmental or social conditions. The net result of the engineer's approach is to maintain or increase the number of tools at the industry's disposal, increasing its adaptability to different ecological conditions in the context of science-based management options whose implementation costs are logically related to the risks the practices or facilities pose to the environment. In that light, the proper function of policy is not to prescribe (or proscribe) technologies, which are dynamic and evolving, but to facilitate their evolution in the service of performance objectives that directly and dynamically express ecological values and political priorities.

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[30] Some manifestations of environmental pollution, such as eutrophication of phosphorus-limited water bodies, are (a) events precipitated by crossing physical thresholds of assimilative capacity rather than (b) ecological changes occurring incrementally with incremental changes in environmental state variables.