

## Article

# Sustainable Swine Manure Management: A Tale of Two Agreements

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**Abstract:** Intensification and concentration of swine farming has provided economic benefit to rural communities but also negative environmental and human health impacts, particularly from the use of the lagoon-sprayfield system for manure management. Although cost effective, this system is susceptible to poor management, unpleasant odor and other emissions, and inundation during extreme weather events. Competition for manure-spreading acres with other livestock or encroaching development can also pose a problem. This study examines two agreements between industry and government designed to develop and implement improved manure management technologies for swine farms: a voluntary agreement between the attorney general of North Carolina and Smithfield Foods and a consent judgment between the State of Missouri and Premium Standard Farms. Individuals involved in executing these agreements were interviewed to gain insight from their perspective on those processes and lessons they learned from their experience. Common themes among participant responses to support transition processes included the need to involve multiple stakeholder groups, clearly define goals, understand the system, allow time for incremental change, and provide adequate “protected space” for technology development and implementation. Viewing these themes through the lens of multi-level perspective theory identifies leverage points throughout the system to support transitioning farms to a more sustainable path of manure management.

**Keywords:** case study; industrial agriculture; swine manure; multi-level perspective theory; sustainability; systems thinking



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## 1. Introduction

### 1.1. Hog Farming and the Lagoon-Sprayfield System

Modern pork production is a complex socio-technical system. In a socio-technical system, interwoven social, technical, and economic elements work together to create a specific output. In the pork industry, some of these elements include geneticists, breeders, feed crops, nutritionists, feed processing facilities, banks, insurance providers, veterinarians, technical specialists, farm equipment manufacturers, transportation providers, processing plants, marketing campaigns, and product distribution chains [1]. Complexity in this system arises from the interactions of all these elements and their reactions to internal and external pressures. These behaviors are dynamic and adaptive, contributing to stability within the system once established.

Integrators are companies that eliminate some of this uncertainty by coordinating system components, streamlining production by sourcing inputs, operating packing plants, and contracting farmers to provide the space (barns) and labor to raise the pigs [2]. Farms vary widely in size and management style, and may be independent, part of a cooperative, operating under a production contract, or company owned. In the past several decades, industry expansion and economic crises have made the contract option attractive

to producers because it reduces the risk in operating costs associated with fluctuating feed and market prices. Integrators benefit through reduced capital investment [3].

In the contract scenarios, producers provide the barns, land, and labor to raise the pigs, and are solely responsible for manure management and mortality disposal [4]. U.S. swine operations typically house animals in barns with slatted floors where excrement falls through to a storage pit below. In warmer climates, the manure is flushed regularly into an open earthen lagoon where bacteria break it down into plant-available nutrients. The nitrogen-rich surface liquid of lagoons is irrigated on hayfields or crops. Sludge that builds up on the bottom of the lagoon, containing mostly phosphorus, is eventually cleaned out and distributed on fields as an organic soil conditioner and fertilizer [5].

The integrators with whom producers contract do not assume responsibility for manure management because regulatory liability rests with the farm owner and differences between farming operations make manure management difficult to write into production contracts [6]. Additionally, there is inherent difficulty in creating value-added products from manure managed through the lagoon system due to its high volume and dilute nature, giving integrators little incentive to take ownership [7].

The lagoon-sprayfield system of manure management is a labor-efficient and reliable technology but can present several challenges. For example, both the manure storage and overhead distribution result in emissions of ammonia, methane, and odorous compounds [8,9]. The open lagoons are subject to inundation by rainfall or catastrophic failure resulting in spills that can impact local surface and drinking water [10]. Additionally, as the number of farms in a region increases, the availability of local land to irrigate or spread manure on decreases. This trend is further exacerbated by competition for manure-spreading acres with other livestock production such as poultry and changing land use where residential and commercial developments encroach on or even consume existing agricultural land [11–13]. As development continues to spread, odor and health complaints from farm emissions also increase, resulting in social and regulatory pressure on producers to find and employ new strategies that reduce the impact of swine manure on the environment and on communities [14].

### *1.2. Barriers to Change in the Lagoon-Sprayfield System*

The establishment and enforcement of hog farming regulation is often tied to the political will of a region, which in turn is swayed by the industry's economic influence. Thus, stricter rules are often reactive and do not always manifest the intended outcome. In North Carolina a Blue Ribbon Commission report led to a moratorium on all new or expanded farms using the lagoon-sprayfield system [15]. Because existing farms were to be exempted from meeting new environmental performance standards, the moratorium actually spurred a brief building boom of farms with lagoons before it went into effect. Afterward, the industry simply shifted further expansion elsewhere. Thus, the law that was intended to eliminate hog lagoons in North Carolina essentially preserved their status in the state [16,17].

When environmental regulation fails to alleviate social pressures, often the only perceived recourse is legal action. Counter to conventional wisdom however, nuisance litigation can also become a barrier to change because alteration or upgrades to a manure management system could be perceived as an admission of wrongdoing. Industry ties can also garner strong legislative support to pass "right-to-farm" bills and other laws countering large payouts from lawsuits, again protecting the status quo [18]. Furthermore, legal action typically takes years to prosecute, making it difficult to maintain the initial grassroots enthusiasm for change that often follows a significant manure spill or flood event, particularly when these issues mostly impact low income and rural communities that lack the resources to litigate successfully [18,19].

In addition to regulatory and legal challenges, other barriers to innovation persist. Previous studies identified technology costs and a lack of markets for byproducts as imposing a high risk to farmers but yielding low economic return, as well as such barriers

as existing infrastructure and restrictive policy [20–22]. While irrigation alternatives such as trailing hoses or direct injection have become commonplace in other regions globally, overhead spraying continues to dominate in the Southeastern U.S. Pork production companies have invested tens of millions of dollars to develop improved manure management technologies over the past 20 years, yet few of these technologies have been broadly implemented [23–25]. While these investments have led to some overall improvements to lagoon-sprayfield management, the industry as a whole continues to struggle with more innovative solutions. Lacking a clear path to overcome the aforementioned barriers, the pork industry will likely continue only to tweak the current system without more impetus to replace it in regions where lagoon-sprayfield is used.

### 1.3. Multi-Level Perspective Theory

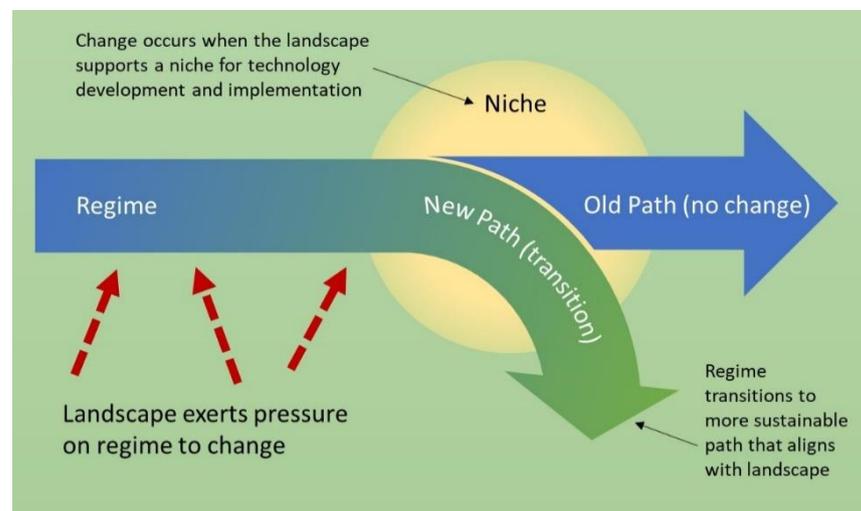
Barriers to the adoption of innovative manure management on hog farms include high-risk investment with low economic return to producers, entrenched infrastructure, regulation favoring the current system, and a lack of policy incentives supporting change. This study seeks to identify how such barriers arise in the context of specific processes designed to implement improved technologies on farms. Viewing these transition processes through the lens of multi-level perspective theory (MLP) can help relate the connections and influence that different stakeholder perspectives have on changes to swine farming and manure management. This is because MLP uses a narrative approach rather than dependent-independent variables to identify patterns in the interactions between the viewpoints within different, nested scales. These patterns help determine when and how sustainable transitions occur in a system [26]. The better aligned the different levels are, the more swift, innovative, and permanent transitions become [27]. Thus, MLP is a useful framework for examining how the interactions between levels either promote or hinder sustainable technology adoption.

Figure 1 illustrates the relationship between the three levels of MLP: landscape, regime, and niche. A regime is all of the people, rules, practices, process technologies, and infrastructure embedded in a particular socio-technological system [28]. The landscape is the collective societal, economic, and political realm surrounding the regime. When the landscape perceives negative effects from the regime, it exerts pressure on the regime to change [29]. Niches are the “windows of opportunity” for change that open in response to landscape pressures if a regime is not adequately able to adjust its own behavior [30]. Successful niche technologies shift the trajectory of the current regime toward a more sustainable direction. However, well-established regimes can raise barriers to change through tensions with niche technologies and the landscape [29].

MLP is often applied to historical events to examine how technological transitions came about and to help identify how barriers form. One example is the transition to sewer systems in the Netherlands in the late 1800s [26]. In this case, the regime included city councils and government agencies who would have been responsible for community sanitation but chose to limit their engagement to keep taxes low. Doctors, recognizing a correlation between poor sanitation and disease, began to pressure the regime to implement better methods for handling human excrement. Over time, these pressures intensified with urban development and industrialization, which increased the problem but also created a cultural (landscape) desire to change it. These growing demands opened a niche for new technology development. Examining this case in full detail using MLP provided researchers a method for following the narrative of each level and how their interactions evolved toward a common goal. When these multi-scale perspectives aligned, a transition to sustainable technology—the modern sewer system—occurred.

MLP has also been studied with regard to transition processes in agriculture. For example, in Europe, policies have been enacted to pressure agri-food regimes to adopt renewable energy technologies in response to climate change. Sutherland et al. detailed several such cases using MLP to break the agri-food system into sub-systems and examine the relation-

ships and impacts between these and other regimes, such as electricity production or urban centers [31].



**Figure 1.** An example of the relationships between landscape, regime, and niche in multi-level perspective theory.

MLP provides a framework from which to explore system relationships at different levels through various stakeholder perspectives. Individual perspectives are important in MLP because they are shaped by the concept of *bounded rationality* [32] (pp. 15–18). Bounded rationality is how people make sense of the world around them and use what they know to inform their decision-making. When individuals have large amounts of information available to them, complexity and uncertainty cause them to filter that information through their culture, habits, and regime rules to make processing it easier [33]. This is especially relevant to a complex socio-technical system like pork production, where different stakeholder interactions involving proximity, culture, technology, environment, regulation, and profit can lead to unintentional outcomes and inequitable power dynamics. Thus, the success of a transition process is very much dependent upon how people at all levels of that process perceive goals and how to reach them.

#### 1.4. Summary and Objective

The pork industry has spent millions of dollars to research and develop alternatives to the lagoon-sprayfield system. Despite this, no particular technology has been identified as an acceptable broadscale replacement. The literature has identified a number of barriers to the adoption of improved technologies, including high risk to farmers and low economic return, existing infrastructure, and unsupportive policy. However, there appears to be little understanding or application of ways to move the industry past these barriers and transition away from lagoon-sprayfield manure management on swine farms.

MLP is well-suited to examining transition processes in the pork industry. For this case study, the regime being pressured to change is the lagoon-sprayfield system. The regime affects and is affected by landscape pressures to shift to more sustainable manure management. This opens a niche for transition processes which, in the cases examined in this study, take the form of agreements between state governments and major pork-producing companies to enact change. These agreements define parameters that niche technologies must meet in order to be executed on multiple hog farms.

This study seeks to examine participants' perceptions of transition processes designed to develop technology alternatives to the lagoon-sprayfield system. The purpose is to discover emergent patterns in their shared experiences that identify barriers they encountered during the processes, and their views on how to overcome them. These insider views and

the lessons they drew from their experiences may provide insight into how these processes worked and how they could be improved.

## 2. Materials and Methods

This was a collective instrumental case study using MLP to examine past transition processes to identify barriers to innovation in swine manure management. The literature has shown MLP as an effective framework through which to analyze transition processes in complex socio-technical systems [34,35]. However, such guidance is only practically applicable in context, and thus is often demonstrated using case study [36,37]. Crowe et al. define a case study as “a research approach that is used to generate an in-depth, multi-faceted understanding of a complex issue in its real-life context” [38].

In this case study, MLP was used to explore the issue of barriers to innovation in manure management by examining two particular cases involving similar transition processes initiated under different circumstances. Case selection was based on suggestions from academic faculty with knowledge of the cases and their context as appropriate for study regarding innovative manure management technology transition processes. Because the cases are instrumental to understanding the challenges encountered in such transition processes, this study meets Stake’s classification of an instrumental case study. That is, the purpose of the case study is to gain a better understanding of a phenomenon through the context of a case [39] (pp. 3, 77).

### 2.1. Data Collection

Case studies often involve gathering multiple sources of data to build an in-depth narrative of the case(s) and to validate information [40]. Two methods of data collection were used for this study: online searches and semi-structured interviews. Online searches have become a common resource for qualitative data [41] (pp. 156–160). A sampling strategy based on keywords and web resources was developed for determining what types of search results would serve the purpose of the study [42]. Using this strategy, two types of documentation were collected: factual background and structural information with which to develop each case, and news stories and press releases providing “outsider” or landscape views of each agreement. This strategy limited searches to keywords related to the parties in the agreements, relevant time periods, and locations. Documents were only selected from government, industry, academic, or news media sources that publish online. Other social media outlets or unverifiable sources were not included. An extensive initial search was conducted, accumulating approximately sixty articles of information. Subsequent searches were performed as needed to corroborate information during analysis.

The second method of data collection was the semi-structured interview, which uses open-ended questions to allow respondents to express their unique views [41] (pp. 89,90). The purpose of the interviews was to provide an “insider” or regime perspective of the transition processes. The interview protocol was consistent with Patton’s guidelines and focused on participants’ experiences and opinions [43] (pp. 339–428). A sample frame was developed from the initial document analysis used to construct the case narratives [44]. This frame identified individuals representing industry, academic research, or government who had been directly involved in executing the agreements. Because the cases being studied occurred nearly two decades prior, the sampling strategy for selecting potential interviewees from this list was both purposeful and convenience-based, depending heavily on recommendations of faculty familiar with the cases and participant availability [45]. Seven potential participants with knowledge of at least one agreement were contacted via an email invitation through a third party and all accepted the invitation. Due to physical distancing restrictions, only one interview was held in person with the rest conducted by phone. Interviews were audio-recorded and then transcribed using an online transcription service. The interview protocol contained a total of eight questions, appropriate to either agreement, to help standardize the interview process despite the highly variable nature of individuals’ roles and experiences (see Supplementary Materials).

## 2.2. Analysis

The final data set contained information collected online from state and federal websites, industry websites, and various public news and media outlet websites; the transcripts of the seven interviews; and associated field notes. A constant comparative method was used, in which data was grouped and organized as it was gathered in order to identify overarching themes whose relationships could then be used to build a strategy for further analysis and understanding of the data [46] (pp. 101–115). Data was separated into one of three categories: (1) factual background and structural information (case), (2) news stories or press releases about the agreements (media), and (3) interviews. The case and media categories were the product of the online searches and were divided according to source (e.g., journal articles and court documents versus news stories and press releases). The case category was used to construct the historical narrative of each case and provide context for the application of MLP. The media category was used to develop the landscape view of the agreements. The interview category was used to build a regime perspective of the transition processes and niche technology adoption. The coding process of factual documents consisted of organizing data into a timeline of events for the development and implementation of each agreement. The ensuing narratives provide readers an opportunity to familiarize themselves with the similarities and differences in these two cases.

To understand the landscape view of hog farming in general and manure management in particular, data in the media category were coded according to whether they indicated a bias in favor of or against the use of concentrated animal feeding operations, or CAFOs, for food animal production. This distinction, though not able to capture all of the nuance expressed in the articles, was useful in determining how the landscape perspectives influenced the regime. Interview categories were first coded using a multi-level perspective matrix that identified data as relating to either a landscape, regime, or niche perspective. These data were then further coded over several iterations as themes began to emerge from the data. Responses to a question about what interviewees believed prompted the agreements were used to identify how participants views aligned with the landscape regarding pressures on the regime to change.

## 2.3. Study Validity

Triangulation, pilot interviews, peer examination, field notes, and a reflexivity journal were used to ensure the validity and reliability of this study and the researcher as the instrument. To help counteract the potential for incomplete recall or conflicting details, data was triangulated—or cross-checked—between the case, media, and interview data categories [41] (pp. 215–216). The cases analyzed in this study were initiated two decades ago, requiring the context for each case to be reconstructed from historical documents and data which might not present a full and complete narrative of events as they happened. Additionally, participants were asked to recall their perception of events from memory. It is known that human memory changes over time and is influenced by subsequent experience [47,48]. Therefore, although this study considered the limitations of bounded rationality, participants will likely have altered those boundaries over time regarding how they view their role and the processes in which they participated.

Interviews were all conducted individually on different days by the same researcher. To prepare for interviewing, the researcher conducted practice interviews with a focus on sequence, wording, flow, neutrality, and prompts as suggested by Merriam [41] (pp. 87–107). The researcher kept an e-journal for reflexivity and audit purposes during the study process in which self-reflection, decision points, and other information related to the study were recorded. Field notes were reviewed the same day after each interview in a debrief session with a colleague to discuss the study process and emerging themes.

## 2.4. Study Limitations

In qualitative research, the researcher is the instrument and therefore the validity of a study rests primarily on the skill and competence of the person doing the fieldwork [43]

(p 64). For this study, the researcher was not a direct participant in either case, serving only in the role of observer of the historical data and information gathered online and from the interviews she conducted. Interest in the topic of this study was formed by a desire to understand the history of previous research in the field and why, over two decades, there appeared to be little or no change in how manure is managed on hog farms, despite previous efforts toward improvement. The very nature of this question admittedly introduces bias through its assumption. Therefore, a multi-level perspective framework that includes bounded rationality was chosen that incorporates this “outsider” view into its analysis of change processes in the socio-technical system that is the swine industry.

### 3. Results

Data analysis is presented in the order in which it was performed. Table 1 compares and contrasts the two agreements, providing the context in which participants experienced the implementation of a regime transition process. The landscape perspective is then defined through public media analysis, explaining the pressures on the lagoon-sprayfield regime to change. This is followed by a review of the themes that emerged from interviewees’ perceptions of how the agreements were implemented and their outcomes, identifying barriers to niche technology adoption or measures deemed necessary for success.

#### 3.1. Evolution of Public Pressure for Change

A deeper look at the landscape view can help illustrate the complexity of motives that drive change. Twenty online media articles from local and national news outlets and special interest press releases dated from 1998 to 2018 were used to help define how the landscape pressures evolved.

In both cases, media stories focused largely on a negative public perception of industrial hog production stemming from odor and degraded water quality around farms. This, coupled with a series of lagoon spills, created awareness of a regime whose expansion had until then remained largely under the national radar. As one New York Times article put it, “There are few issues as contentious in the American countryside as the corporate hog industry” [49].

Conflicts with rural culture also emerged in the form of pushback from those who did not view corporate pork production as “real farming”. They claimed that the industry had “shattered the fabric of the rural communities, not only in North Carolina, but across the country” [50]. Fueled by the spills that caused national outrage, environmental and social justice groups joined with high-profile attorneys to file lawsuits for neighbors of large contract or company-owned farms, determined to make their voices heard [51–53].

Analysis of news articles also revealed shifts in the dynamics of the relationship between the pork industry and government. Initially, local governments supported large-scale hog farming to boost lagging rural economies [53,54]. However, the ensuing rapid growth of hog farming created issues that began to complicate the relationships between politicians, communities, and the industry. Large hog farms became the target of both stricter regulation and activist groups concerned about the fate of small farmers. [55]. Anti-industry commentary was critical of the overall corporate structure, manure management, and close political ties that many felt gave a few large company players outsized influence on local economies and policy [50,53]. Politicians were torn between the tradition of supporting rural economies and responding to public frustration over pollution and odor. As the governor of North Carolina noted:

*My views and most views have evolved to where we have to take stronger action to clear up our water and rivers . . . We need a strong economy for our people, but we cannot sacrifice the environment for jobs. [56]*

**Table 1.** Comparison of two agreements to implement transition processes toward more sustainable manure management on hog farms using the lagoon-sprayfield system.

State of Missouri v. Premium Standard Farms Consent Judgment (MO Judgment)	North Carolina Attorney General and Smithfield Foods (NC Agreement)
<b>The Companies</b>	
<ul style="list-style-type: none"> <li>■ Premium Standard Farms (PSF) started in 1988 to emulate North Carolina’s successful integrated pork production model in the Midwest to become the third-largest pork producer in U.S. by 1994; they began expanding to other states.</li> <li>■ 1998: Competitor ContiGroup Companies (CGC) bought controlling interest in PSF; CGC added to lawsuits.</li> <li>■ PSF was fully integrated; all farms were company-owned and operated; they were fully responsible for manure management.</li> <li>■ PSF farms were arranged in very large complexes in north-central Missouri.</li> </ul>	<ul style="list-style-type: none"> <li>■ Smithfield Foods began as a small packing company in 1936 in Virginia; they began expanding and purchasing competitor companies in 1975; they became the largest global pork producer by 2000.</li> <li>■ 2006: Smithfield purchased PSF.</li> <li>■ Majority of Smithfield’s hog production done through contracted farms; farm owners responsible for manure management.</li> <li>■ NC hog farms generally concentrated in southeastern region of the state.</li> </ul>
<b>Society and Economy</b>	
<ul style="list-style-type: none"> <li>■ Rural North Missouri counties welcomed PSF’s positive economic impact on the depressed economy through jobs and social benefits.</li> </ul>	<ul style="list-style-type: none"> <li>■ Rural North Carolina counties embraced hog farming and contract production for its stability and economic benefits as tobacco production declined.</li> </ul>
<b>State Policy and Regulation</b>	
<ul style="list-style-type: none"> <li>■ Missouri had a family farm law to prevent corporate farming; an exemption was granted to PSF.</li> </ul>	<ul style="list-style-type: none"> <li>■ North Carolina has a Right to Farm law to protect agricultural operations from nuisance litigation.</li> </ul>
<b>Impetus for Change</b>	
<ul style="list-style-type: none"> <li>■ 1995: Lagoon spills on PSF farms threatened surface and drinking water; this prompted new state regulation to improve waste management systems.</li> <li>■ 1997: Additional spills led to lawsuits from both citizen groups and the state.</li> </ul>	<ul style="list-style-type: none"> <li>■ 1995: A 95 ML (25M gal) lagoon breach gained national attention and prompted public outcry.</li> <li>■ 1996: Blue Ribbon Study Commission Agriculture Waste Report determined that alternative technologies were needed in lieu of lagoon-sprayfield; along with an “institutional arrangement” for testing such technologies.</li> <li>■ 1997: Moratorium placed on construction of new hog farms that do not use advanced technology to eliminate all discharge to surface and groundwaters and substantially eliminate ammonia emissions, odor, disease-transmitting vectors, nutrients, and heavy metals.</li> </ul>

Table 1. Cont.

State of Missouri v. Premium Standard Farms Consent Judgment (MO Judgment)	North Carolina Attorney General and Smithfield Foods (NC Agreement)
Agreements	
<ul style="list-style-type: none"> <li>■ 1999: Judicial Consent Judgment between MO Attorney General and PSF.</li> <li>■ Goal: develop and implement Next Generation Technology (NGT).</li> <li>■ Purpose: improved waste handling and storage that reduces or eliminates release of contaminants, odor, and/or pollutants from all barns, lagoons, and wastewater application acreage.</li> <li>■ Funds: \$25M initial investment (\$49M total).</li> <li>■ Timeline: 5 years (extended to 12 years).</li> <li>■ Oversight: court-appointed three-member independent expert panel.</li> <li>■ Technology Selection and Evaluation: conducted by PSF with final approval by expert panel.</li> <li>■ Objectives: <ul style="list-style-type: none"> <li>- protect public health and the environment</li> <li>- implement changes to how animal waste was handled at PSF's facilities</li> <li>- maintain compliance with permits</li> <li>- prevent future discharges</li> <li>- employ reduction technologies to limit emissions from wastewater and land application</li> <li>- reduce the amount of land to which effluence was applied</li> <li>- monitor the emissions from facilities</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>■ 2000: Voluntary agreement between NC Attorney General and Smithfield Foods.</li> <li>■ Goal: develop and implement Environmental Superior Technologies (ESTs).</li> <li>■ Purpose: to develop and implement innovative technologies to replace the lagoon-sprayfield system on hog farms that meet the five environmental performance standards.</li> <li>■ Funds: \$15M R&amp;D; \$50M over 25 years for environmental enhancement activities.</li> <li>■ Timeline: 5 years.</li> <li>■ Oversight: appointed designee with final authority; multi-stakeholder advisory panel.</li> <li>■ Technology Selection and Evaluation: 15-step process managed by 25-member advisory panel and designee.</li> <li>■ Objectives: <ul style="list-style-type: none"> <li>- quantify the five performance criteria</li> <li>- develop comprehensive environmental management systems plan for hog farms</li> <li>- develop ESTs that meet the five performance criteria and that are deemed both technically and economically feasible</li> <li>- implement approved ESTs on all company-owned farms and support implementation on all contracted farms</li> </ul> </li> </ul>

Table 1. Cont.

State of Missouri v. Premium Standard Farms Consent Judgment (MO Judgment)	North Carolina Attorney General and Smithfield Foods (NC Agreement)
<p>■ Outcomes Enacted:</p> <ul style="list-style-type: none"> <li>- 90% reduction of traveling irrigation sprayers</li> <li>- extensive air and water data collection and analysis</li> <li>- up to 90% reduction in land-applied nitrogen by nitrification-denitrification</li> <li>- manure-based fertilizer production plant</li> <li>- lagoon covers</li> <li>- barn scrapers</li> </ul>	<p>■ Outcomes Enacted:</p> <ul style="list-style-type: none"> <li>- quantifiable environmental performance standards by which to measure EST performance</li> <li>- ISO-14001 international environmental standards certification achieved for all company-owned farms</li> <li>- evaluation of 15 ESTs that met the environmental performance standards, none deemed economically feasible</li> </ul>

A North Carolina county commissioner expressed a similar struggle at the local level:

*On one side you have people talking about health promotion and on the other side you have people talking about wealth promotion. [57]*

Thus, the impetus for change evolved within the landscape over time. Social pressures concerned not only odor and water quality issues related to lagoon-sprayfield manure management, but also the shift from smallholder farms to large industrial-style complexes. These social pressures capitalized on a series of lagoon breaches and weather-related events to gain national attention and drive policy and regulatory shifts that impacted regime behavior.

### 3.2. Key Interview Themes

Despite participants' varying backgrounds and fields of expertise, analysis of interview transcripts revealed several consistent patterns across their responses to questions about the agreements, the implementation processes, outcomes, and lessons learned. These patterns are discussed below. It should be noted that these elements did not evolve independently from each other. For example, the number and types of stakeholders involved and how well goals are defined can both have an impact on time and resources required to implement change.

#### 3.2.1. Transition Processes Should Involve Multiple Stakeholder Groups, but not Necessarily with Regard to Decision-Making

Most participants felt stakeholder diversity was important and they were generally satisfied with who had been involved and how, even though each process engaged different groups of stakeholders in different ways. The sentiment was well-summarized by this remark:

*I personally think the broader stakeholder group the better in anything you do. I feel like you can't exclude stakeholders and feel like you're going to have something of value later.*

Some participants also felt that although multiple stakeholder input was valuable, actual decision-making should be left to a smaller group. These comments were generally made when contrasting the independent three-member expert panel in Missouri with North Carolina's large and diverse advisory panel:

*I think that in Missouri it was a limited scientific panel making the judgment on which technologies might work and whether they worked. Whereas here in North Carolina, you had that very broad advisory panel. Very hard to come to a consensus. The larger the group, the harder it is to come to a consensus.*

Community engagement was managed differently in each agreement. In Missouri, regular public meetings were mandated as part of the consent judgment while North Carolina's approach was more indirect and focused on transparency through public advisory board meetings and reports. Participants generally felt both strategies worked well, although in North Carolina some also thought local community leaders and elected politicians should have been present at the advisory board meetings, perhaps to be better informed of policy and economic challenges that are faced by these types of transition processes.

In Missouri, several people noted the lack of an academic presence, which had been a critical part of North Carolina's agreement. Engaging academia was mentioned as beneficial because having researchers from universities involved helped to build a level of trust in the independence of the process. Participants also felt that the processes provided real-world experience to an upcoming generation of professionals concerned with solving future challenges in agriculture:

*... you educated a whole cadre, a whole array of graduate students and new faculty, which is highly essential so that ... you've got newer workforce com[ing] to the table. I would never diminish the value of that.*

### 3.2.2. Regime Transitions Require Clearly Defined Goals and Definitions

Participants felt clear communication was critical among stakeholders. For example, in Missouri, goals were defined in specific and measurable terms, such as the reduction of land-applied manure nitrogen by 50%. In North Carolina, although the agreement borrowed criteria language from a recently passed law, participants felt the language used was unclear:

*Part of the problem from my perspective with that from the very beginning, was that they took that EST language from legislation that said, substantially eliminate the constituents, nitrogen, odor, pathogens, rather than quantifying what that meant . . .*

As a result, to determine whether technologies met those standards, they first had to be quantified through the development of a set of environmental performance criteria. Participants felt this extra step complicated the process, and some believed that not having quantifiable standards at the outset led to wasting resources on technologies that had no chance of meeting agreement criteria:

*. . . the whole process was handicapped from the very beginning because you didn't know what targets you were shooting for . . . there was a lot of money spent on technologies that in retrospect had no possibility of exceeding or meeting that criteria because we didn't know what that criteria was until the end of the process.*

Participants were also frustrated by the requirement that technologies be “economically feasible” without explicitly stating how that would be determined. Thus, on this one critical issue, the advisory panel’s diverse interests kept it from reaching consensus which effectively precluded broadscale implementation of any of the evaluated technologies:

*I do think having a robust discussion earlier in the process about what economic feasibility meant, and what it didn't mean . . . I think that probably should've been the first thing we worked on . . . The economic feasibility report has a majority report and a minority report. And they have fundamentally opposite views of the definition of the terms involved.*

### 3.2.3. Stakeholders Need to Understand the System

Pork production is a complex system, and participants expressed a number of ways in which either a lack of understanding of the system or its context presented challenges:

*We would get people that had familiarity with municipal water treatment facilities. They'd have very little knowledge about livestock operations and how they work. We spent sometimes a lot of time trying to be educators or inform them of how a livestock operation works or how is it different than a treatment for a major city or from industry.*

Economics was clearly a factor in both agreements. Those familiar with Missouri felt that allowing Premium Standard Farms (PSF) to select technologies worked well because the industry understood what was technically and economically feasible for them. In North Carolina, because most farms were contracted rather than company-owned, the economic feasibility assessment was viewed as a critical component of that agreement. Although that economic analysis ultimately precluded widespread implementation of any technologies as a result, participants felt what they learned in the process was still very valuable:

*You're wasting your time if you do this work without an economic analysis. Economic feasibility has got to be part of the equation.*

### 3.2.4. Sustainable Transitions Require Incremental Change and These Processes Take Time

Participants in both cases were well aware of the regime’s resistance to change, despite the initial enthusiasm expressed by stakeholders and the industry. They frequently stated that they thought incremental improvement was a more effective process than seeking a single overarching solution to sustainable manure management. For example, several

people felt that relaxing the performance standards in North Carolina would have made more technologies qualify under the terms of the agreement:

*The agreement terms say, okay, what we're going to do is eliminate 100% of the ammonia emissions. Well, eliminating 100% relative to 90% makes a big difference in technology and the technology cost.*

*I think to make this industry better or improve our systems, we don't necessarily apply the five strict criteria to that. Obviously, we know what those are and we think they're important. But we look at things that are incrementally improved and add value to our business . . . and so that would be what I learnt from that process is incremental improvement is something that I think really leads to change.*

In this regard, the Missouri process was viewed as more flexible, leading to more tested technologies being approved for implementation:

*Had we been able to have specific criteria, or had had the flexibility that I felt like we had in the Missouri project of making a professional determination on what the environmental performance would be, that would have been less tedious than what we were mandated to do with the North Carolina agreement.*

Indeed, trying to achieve ambitious goals all at once could be a barrier to any change at all, as one participant commented:

*I think if you set very lofty expectations, you set the bar extremely high, sometimes that might preclude you from seeing technologies that are improvements over what's in place.*

Several participants also recognized a general belief among stakeholders that they would find a “one-size-fits-all” replacement for the lagoon-sprayfield system. However, they were again quick to acknowledge that context matters, even when the regime itself appears to be essentially the same across industry:

*I think there were a lot of people that maybe thought there was some sort of off-the-shelf technology that could just be plugged in to the swine industry. And I think what was learnt through that is . . . it's not that simple.*

Closely tied to incremental change and understanding the system was the realization that transition processes often take longer than expected. Stated reasons included variability between farms, natural factors, existing infrastructure, and unanticipated challenges:

*The legal aspects of getting all of the necessary [paperwork] . . . That took far, far longer than I ever imagined . . . there was a lot of things to deal with that I never, never once thought about before having to deal with it.*

*In hindsight, it would've been unreasonable to think that we could have gotten environmentally superior technology deployed on 200 company owned farms in that (five year) window . . . it took us a while to put even a pilot project in place and test it on all these farms . . . there were some real life supply chain and logistical constraints.*

### 3.2.5. Niche Technologies Need Adequate Protected Space within the Regime to Develop and Grow

It was the agreement itself in each case that laid the groundwork to open a niche for the development and adoption of alternative manure management technologies. Participants seemed to have an intuitive understanding that any promising technologies would need help breaking through the regime's resistance to change. Some of these “safeguards”—recognized across both agreements—included industry funding and contributions of multiple stakeholders. In North Carolina it was noted that:

*without the resources, the research wouldn't have been done and the performance standards probably would not have been developed or would not have the same sort of cachet that they have now.*

The ability to conduct actual on-farm testing of technologies was another key element participants focused on as a vital “proof of concept” step toward implementation:

*We were trying things at a production-scale level . . . things can work in a laboratory, on a bench-top situation, but don't work when it gets out in the real world for a number of reasons.*

Participants identified policy incentives and market development as key elements missing from the agreements that would have helped provide a safe space for niche technologies to gain traction. In North Carolina it was noted that if the value-added product of a technology did not already have an existing market, then the value of that product was not included in the economic analysis of the technology. Since most advanced technologies rely on some sort of marketable nutrient or energy by-product to help offset the costs, this was viewed as the main reason technologies were not adopted:

*The idea with most of the technologies was that they were going to be able to recover value from the byproducts of the process and that was going to help offset the cost for the treatment . . . they were all nutrient-based byproducts . . . a couple of them had energy recovery and the value of that associated with it, but none of them met the economics.*

Participants also suggested that both society and policy have a role in supporting the development and broadscale adoption of niche technologies. The importance of understanding and incorporating social aspects into a transition process seemed to be a key takeaway for many participants from their experience:

*Lessons learned is that from my perspective, the timelines have to be reasonable for implementation, and I think the implementation has to be supported from a public policy perspective by all of society, and that includes government having its fingerprints on it.*

#### 4. Discussion

The five key themes identified by participants—the need to involve multiple stakeholder groups, clearly defined goals, incremental change, understanding the system, and providing adequate “protected space” for technology development and implementation—do not appear to exist independently of one another. Indeed, the execution (or lack thereof) of any of these elements impacts the others in aligning the levels of MLP. For example, having clearly defined goals requires coordination and agreement between multiple stakeholder groups from the landscape (public institutions), the regime (industry and its practices), and the niche (technology researchers and developers). Because this kind of coordination takes time and effort, it seems reasonable that participants in this study felt identifying a small independent body for decision-making would make reaching consensus more efficient. This was the strategy set up by the court for the Missouri consent order. However, the success of that approach relied on community support in terms of trust in the independence of the expert panel and local outreach by Premium Standard Farms to assure that neighbors’ concerns were being addressed. The strategy of the North Carolina agreement sought to foster trust between stakeholders by creating a larger advisory panel to give all parties involved “a seat at the table.” However, despite directly engaging more stakeholder groups, this process was in some ways less democratic because only the designee had final decision-making authority.

Another challenge to clearly defining goals was to identify the actual conditions required to satisfy each agreement. While the Missouri order focused on compliance with existing regulatory statutes as a result of the lawsuits, the North Carolina agreement included only vague legislative language from the moratorium to define the performance criteria an Environmental Superior Technology (EST) would have to meet. Therefore,

part of the process of executing that agreement became quantifying those criteria into actual performance standards. This took time, while also hindering technology evaluation because neither developers nor those evaluating knew the design standards at the outset. Some participants suggested that those standards should have been determined prior to enacting the agreement. It is unlikely, however, that this could have been done without the ability to study alternatives to lagoon-sprayfield, which was the stated purpose of the agreement. The process may have been better served by either incorporating enough time into the agreement to accommodate development of the performance standards or by encouraging incremental improvements to existing farms in addition to the all-or-nothing approach required by the moratorium rules for new farms.

Incremental change as a path to sustained transformation is a common premise in MLP. This approach contributed to the success in Missouri, where individual technologies such as covered lagoons and barn scrapers were tested and evaluated prior to broad implementation. However, even in Missouri the process of satisfying the consent order required two extensions beyond the initial five year deadline. In North Carolina, this piecemeal approach would not have been able to satisfy all of the performance criteria simultaneously as required by the legislation, and certainly not in the five-year period stipulated in the agreement, leaving no opportunity for incremental improvement.

It should be noted that MLP literature distinguishes between incremental change and niche technology adoption. Incremental change improves the existing regime, but the regime generally remains on its current trajectory. Adoption of a niche technology represents a true transition to a new regime, redefining both the rules and the path. Although both are a type of transition, the latter is typically a more radical shift [26]. However, implementing incremental change can lead to sustainable transformation within a regime over time if it has the internal resources and capacity to innovate [58]. In this regard a few participants noted that Smithfield, as the world's largest pork producer, could eventually become an industry leader for innovation. However, such internally driven shifts occur slowly and are unlikely to satisfy some landscape drivers for change without additional policy incentives or other support.

Another issue to consider is that both of the transition processes initiated by the agreements and the participants in those processes focused just on mitigating the environmental impacts of the lagoon-sprayfield system. Although structural challenges presented by the corporate nature of the industry itself were rarely addressed, some participants astutely acknowledged that these issues may also have influenced agreement outcomes. For example, the technical and economic evaluation of alternative manure management strategies were internal to Premium Standard Farms, pending approval by the expert panel, while in North Carolina the technology selection and the technical and economic evaluations were primarily performed by the advisory panel and not Smithfield itself. While the North Carolina agreement did not threaten to shut down farms that failed to implement ESTs, there seemed to be a public perception that Smithfield could easily afford to update its own farms and to assist its contracted operations in doing so as well. This presumption gave no consideration to any barriers such as Smithfield's internal corporate structuring, legal issues, regulatory responsibility, contract liability challenges, or even the time and expense of ramping up infrastructure to implement change to hundreds of company and independently owned farms.

Thus, regardless of how a transition process is designed, efficient orientation of multiple perspectives toward commonly defined goals requires stakeholders to understand both the overarching system as well as individual roles within it. Embedded in each stakeholder group is their own cognitive understanding of a regime, their motive for change, and a bounded view of other stakeholders' roles in that change. If these perspectives do not align with one another, the result is differing and potentially opposing views of how to achieve goals in practice, which can slow or prevent tangible progress. A clear advantage for Premium Standard Farms was the ability to identify, research, and develop technologies without many of the necessary negotiations and liability consid-

erations that plagued pilot installations on independently owned farms in North Carolina. Furthermore, PSF's good-faith efforts continued to foster support within its community, despite the lawsuits, helping the company get extensions to the order and achieve its goals.

To this point, participants correlated social engagement in transition processes to the offset costs and benefits to society as more sustainable manure management technologies were implemented. This is tied to the notion of protected space, where a social landscape, for its own benefit, has an obligation to help support niches and the adoption of innovative technology. If outside influencers like social organizations and policy makers better understand the system, it would be easier to align their goals for sustainable behavior with the pork industry to ensure effective and lasting technological transitions. Thus, this concept of protected space—also a common theme in MLP—must be fostered by the landscape to help niche technologies integrate into or supplant the existing regime. Of course, to do this effectively requires an understanding of the overall system in order to know which leverage points can be triggered to provide that protected space, such as funding, policy, and social support.

The common themes identified from participants' experiences are applicable to the relationships across all scales, from the landscape to the regime to the niche. These key points suggest that participants not only understood underlying causes of barriers to technology adoption, but also identified through their experiences—though often in hindsight—ways to improve transition processes to address those barriers.

## 5. Conclusions

Despite continuing research to develop sustainable swine manure management technologies [59,60], most improvements involve adjustments to the current regime rather than radical shifts in technology adoption. Such adjustments include changes to animal diet, implementing comprehensive nutrient management plans, and buy-out programs for farms in flood-prone areas [61–63]. Still, to the landscape surrounding the lagoon-sprayfield regime, it may appear largely unchanged from the time the two agreements discussed in this study were brokered in 1999 and 2000 [64–66]. This suggests that while the regime path illustrated in Figure 1 is beginning to curve, it has not yet fully aligned with landscape drivers for change. Thus, a more intentional approach that acknowledges multi-level system perspectives, impacts, barriers, and opportunities to the design and implementation of sustainable technologies is needed. Participants in agreements designed to transition swine farms away from lagoon-sprayfield learned through their experiences that these transition processes are more likely to succeed when the processes (1) involve multiple stakeholder groups, (2) have stakeholders that understand the system they are trying to change, (3) have clearly defined goals and a realistic timeline for accomplishing them, (4) are able to execute change in incremental steps, and (5) are able to devote adequate social and political resources to support the transition. These five key themes provide a template for future efforts to replace anaerobic lagoons on swine farms by taking a more holistic view of how to integrate innovative technologies into the existing system. This is done through the lens of multiple perspectives, including how the landscape can support the implementation of such technologies. That support should include community engagement, funding for the scope of the desired change, iterative development, a feasible path to production-scale testing, and policies and incentives that are flexible and responsive to drivers of change.

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