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Perspectives on new technologies built on anaerobic digestion: insights from Idaho

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Research Paper

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Abstract

The adoption of anaerobic digesters (ADs) and technologies stacked with them (AD+) has the potential to offer benefits to dairy producers and the environment. Production of biochar, hydrochar, and bioplastics can reduce greenhouse gas emissions, offer economic benefits to farmers through the sale of value-added products, reduce the need for fertilizer purchases, and promote a circular economy for dairy producers. We use a diffusion of innovations framework augmented to include economic, environmental, social, and regulatory considerations in addition to the operational aspects of the technologies. We conducted interviews with 21 participants representing for-profit, not-for-profit, governmental, and community service agencies in Idaho, the third-largest U.S. dairy state. Semi-structured interviews explored participants' experiences with and perceptions of how relative advantage, compatibility, complexity, observability, trialability, environmental, economic, and social factors may facilitate or hinder the adoption of AD and three related emerging AD+ technologies. Interviews were analyzed using inductive coding and thematic analysis. Results show that participants were familiar with the need to address dairy manure waste and were interested in the potential benefits to farm revenue and the environment. However, the same factors associated with the relatively low adoption of AD in Idaho may also hinder the adoption of newer AD+ technologies. These include a lack of observability and trialability, installation and maintenance costs, access to technology, uncertain environmental impacts, unrealized economic benefits to dairy producers, and regulatory burden.

Introduction and background

In the United States, 10% of greenhouse gas (GHG) emissions are attributed to agricultural activities, and the livestock sector is responsible for approximately 11% of these (United States Environmental Protection Agency, 2024). Dairy cows contribute 11% of U.S. methane emissions (Wattiaux et al, 2019; Rotz et al., 2021; Wattiaux, 2023). Methane has shown about 80 times the global warming potential of carbon dioxide over a 20-year period (Vallero, 2019). The U.S. dairy industry has a Net Zero Initiative with an objective to achieve GHG neutrality by 2050 (U.S. Dairy, 2020). The United States passed the Methane Emissions Reduction Action Plan, and the U.S. Natural Resources and Conservation Service released an initiative to incentivize the reduction of GHG emissions in U.S. agriculture (The White House Office of Domestic Climate Policy, 2021; Natural Resources and Conservation Service, 2023). These build on the 2010 and 2021 Food and Agriculture Organization's (FAO) climate-smart agriculture plans to assure better nutrition, a better environment, and a better life, leaving no one behind by using technology, innovation, and data. Climate-smart agriculture is an approach that helps guide actions to transform agri-food systems toward green and climate-resilient practices (Food and Agriculture Organization of the United Nations, 2010; 2021).

Anaerobic digestion (AD) is an important technology because it addresses the significant methane emissions from manure and can integrate well with the increasing number of large dairies that handle manure in liquid form (Beck et al., 2023). AD is currently cited as the most effective technology for reducing methane emissions from manure, with dairies hosting 80% of on-farm AD systems (Manning and Hadrich, 2015; Aguirre-Villegas and Larson, 2017; Wattiaux et al., 2019; United States Environmental Protection Agency, 2024). AD systems use bacteria in an oxygen-deprived environment to break down manure and capture the methane-rich biogas generated (United States Environmental Protection Agency, 2019). Biogas produced from AD can supply on-farm energy or be sold to electric grids or renewable natural gas systems. Beyond being an energy source, the digestion process reduces the pathogen load in the manure, improves wastewater quality, and converts manure into additional value-added products, including animal bedding and compost (Pagliano et al., 2020; Ortiz-Liébana et al., 2023).

After AD extracts much of the methane, the remaining digestate is often stored in open systems. Ongoing research is investigating how to improve digestate management using

Table 1. AD and AD+ manure management process, inputs, and value-added products

Process	Input	Value-added product(s)	Proposed uses
Anaerobic digestion, biological	Manure, wastewater biosolids, and other waste	Biogas Digestate	Electricity, heat, fuel, gas, soil amendment, animal bedding, fertilizer, feedstock
Pyrolysis, thermo-chemical conversion	Digestate or liquid manure and agricultural wastewater	Biochar	Water filtration for anaerobic digestors, feed additive, soil amendment high in nitrogen and phosphorus
Hydrothermal conversion (hydrolysis)	Digestate or manure slurry	Hydrochar	Soil amendment high in phosphorus, similar to biochar
Bacterial/biological conversion to polyhydroxyalkanoate (PHA)	Digestate or fermented manure	Bioplastic (PHAs)	Commodity-grade PHA for products such as films, utensils, and packaging

technologies that build on AD systems to produce value-added products from the digestate, including biochar, hydrochar, and bioplastics (i.e., polyhydroxyalkanoates) using processes such as pyrolysis and hydrolysis (Monlau et al., 2016; Guillen et al., 2018; Lauer et al., 2018; Pagliano et al., 2020; Struhs et al., 2020; Belete et al., 2021; Tayibi et al., 2021; Cui and Shah, 2022; Lefebvre et al., 2023; Lim et al., 2023; Ortiz-Liébana et al., 2023). We refer to these technologies as AD+. Stacking AD with AD+ systems may further improve effluent water quality and support the development of a circular economy for dairy manure management, soil enhancement, and value-added products for the system operator to use or sell (Guillen et al., 2018). Table 1 outlines AD and AD+ manure management innovations and associated value-added products considered in this study.

To increase the prospects for the adoption of AD+ technologies, it is important to understand the characteristics of AD adoption on farms and perceptions of AD+ technologies as additional manure management strategies. Our study focuses on the Idaho dairy industry. We interviewed 21 professionals representing the farming community, government, nongovernmental organizations, and other professionals in the community to learn about their experiences with AD and perspectives about AD+ technologies designed to create additional value for dairy producers while mitigating negative environmental impacts from dairy waste.

Technology adoption

Studies related to the adoption of environmental, 'green,' and sustainable agricultural technologies developed significantly beginning in the 1990s focused primarily on physical and operational aspects of the technologies (Rennings, 2000; Jänicke, 2008; Montalvo, 2008; Schiederig, Tietze and Herstatt, 2012). We consider the diffusion of AD and AD+ technologies in the context of managing dairy manure waste. These include cutting methane leaks, protecting workers and communities, and maintaining and creating high-quality jobs. Combined with FAO's concept of food security and better lives and environments, the diffusion of these technologies goes beyond understanding technical aspects (Food and Agriculture Organization of the United Nations, 2009; The White House Office of Domestic Climate Policy, 2021).

Specific to AD technology, the literature has also primarily focused on technical details, often overlooking other adoption drivers (Morse, Guthrie and Mutters, 1996; Pannell et al., 2006; Geels and Schot, 2007; Montalvo, 2008; Welsh et al., 2010; von Keyserlingk et al., 2013; Latawiec et al., 2017; Sam, Bi and Farnsworth, 2017; Niles et al., 2019; Traub et al., 2021). Economic barriers have been mentioned in the literature and include high upfront capital costs and long payback periods (Morse, Guthrie and Mutters, 1996; Swindal, Gillespie and Welsh, 2010; Welsh et al., 2010; Tranter et al., 2011; Manning and Hadrich, 2015; Bangalore, Hochman and Zilberman, 2016; Hou et al., 2018). Other factors include environmental beliefs, and peer group values and influence (Stephenson, 2003; Bishop, Shumway and Wandschneider, 2010; Cowley and Wade Brorsen, 2018).

We begin with the foundation of Rogers' (1962) diffusion of innovations (DOI) framework characterized by five factors associated with adoption: relative advantage, compatibility, simplicity/complexity, observability, and trialability. Relative advantage is the degree to which an innovation is seen as better than the technology it replaces. Compatibility is how consistent an innovation is with current systems and practices. Complexity refers to how difficult the innovation is to understand or use. Trialability is the extent to which an innovation can be tested or experimented with before a commitment to adopt it. Observability is the extent to which an innovation provides tangible results that can be seen in practice (Rogers, 1962; 2003).

While we use the DOI framework to help identify reasons for adoption, we also consider other adoption drivers less often included in the agricultural technology diffusion literature. Social and regulatory barriers to AD adoption are important drivers of adoption. Swindal, Gillespie, and Welsh (2010) and Welsh et al. (2010) assert that states' promotion of sustainable agricultural practices has generally relied on individualist appeals to private actors through free market environments, providing subsidies, and educating farm operators and not on appeals to public goods production. Bangalore et al. (2016) reported that in the early 2000s, the United States lacked sufficient support for policies that incentivized fossil fuel alternatives. Others note that social costs such as odor annoyances to neighbors, animal and worker safety, ammonia emissions, concerns about increasing herd sizes to meet biogas production needs, producer values, and social injustice can hinder AD adoption (Krakat et al., 2017; Cowley and Wade Brorsen, 2018; Beauchemin et al., 2022; Gittelson et al., 2022; Lamolinara et al., 2022; Keough, 2023). Figure 1 conceptualizes our approach. Understanding the current state of AD diffusion is critical to the adoption of future AD+ technologies.

Materials and methods

The consolidation of the U.S. dairy industry has led to fewer but much larger dairy operations across the country, particularly in the leading dairy-producing states, including our study state of Idaho, the third-largest U.S. dairy-producing state (MacDonald, Law and

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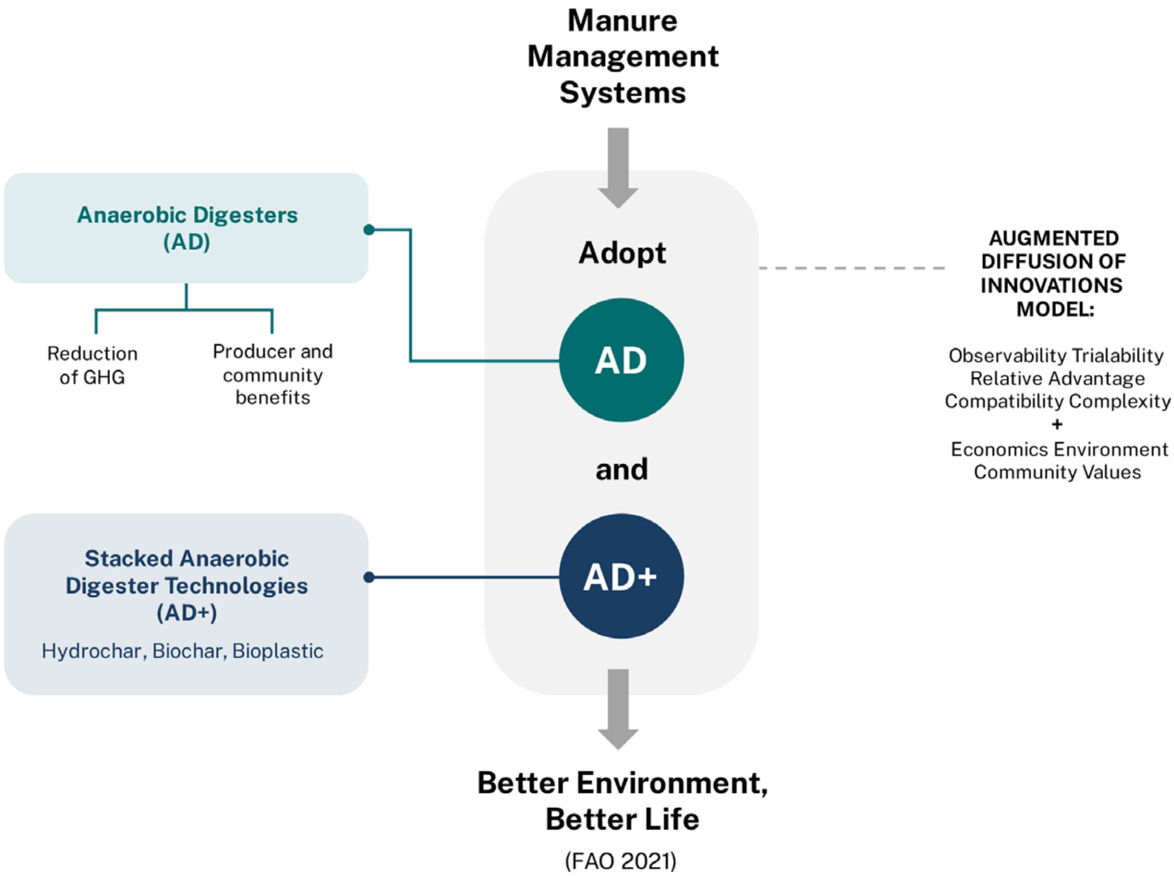

Figure 1. Conceptual framework for the adoption of anaerobic digestion and diffusion of future innovations.

Mosheim, 2020; Economic Research Service, 2024). AD shows promise for mitigating emissions on large dairy farms (>1,000 cows) (Aguirre-Villegas and Larson, 2017; Wattiaux et al., 2019). Idaho has 123 dairies with more than 1,000 dairy cows and another 43 with 500 or more dairy cows (*USDA/NASS State Agriculture Overview for Idaho*, 2022). Table 2 shows the rate at which the number of dairy farms and cows consolidated in Idaho from 2017 to 2022.

Idaho hosts 11 of the 429 AD systems operating on dairies in the United States (Economic Research Service, 2023). Six systems were installed before 2013, and five after 2020 (Economic Research Service, 2023). Adoption in Idaho has been lower compared with other states with fewer larger dairies (>500 cows). For example, Michigan has 13, Pennsylvania has 29, and New York has 35 AD systems on dairies (Economic Research Service, 2023). Our study looks at a state with low adoption rates to better understand factors that facilitate or constrain adoption.

Interviews were semi-structured with open-ended questions, conducted by phone or online video calls, and lasted 25–75 minutes. The interview guide covered many topic areas, some of which go beyond this paper and were relevant to the larger USDA study. Related to the DOI, questions were asked about the observability of AD and AD+ technologies, familiarity with these technologies, their advantages/disadvantages, facilitators and barriers to adoption, and their impacts on farms and the broader community. We also asked about participants' experience and roles in the dairy industry, their understanding of and questions about the proposed manure management strategies and resulting value-added products, and their attitudes toward adoption. Interviews included the researcher and the participant, were audio-recorded, and were conducted at a place and time of the participant's convenience. We introduced the innovations described in Table 1 in an informational handout. The interview guide was updated in 2023 after the interviews were conducted in 2021.

Data collection and analysis followed a systematic approach to establish credibility, reliability, and transparency (Prokopy, 2010; Elliott, 2018). Interviews were backed up by notes, transcribed, and then analyzed in the ATLAS.ti qualitative analysis software (Friese, 2019). We developed an initial codebook by independently and inductively coding the first five transcripts. We established inter-rater reliability by coming together to compare and integrate our independent analyses into a single framework (Thomas, 2006; Elliott, 2018). Five researchers continued inductively coding transcripts, iteratively refining, and organizing codes into themes as we added new transcripts to the analysis (Elliott, 2018). Data collection ceased once we reached a point of saturation where no new information was occurring in the transcripts (Ritchie et al., 2013). The research team met weekly throughout the data collection and analysis to discuss codes and themes and evaluate the credibility of findings and interpretations. We selected representative quotations from the data to present findings clearly and transparently, so the reader can interpret and evaluate the analysis themselves (Prokopy, 2010). We presented preliminary results to a project stakeholder meeting in early 2024 where they provided feedback on the findings as a way of ground-truthing the results.

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Table 2. Number of dairy farms and dairy cows (excluding calves) in Idaho, 2017–2022, and percent change (USDA NASS, 2022)

Herd size	2017 Number of dairies	2022 Number of dairies	Percent change (dairies)	2017 Number of milk cows	2022 Number of milk cows	Percent change (cows)
1–9	337	259	−23.15%	648	485	−25.15%
10–19	16	6	−62.50%	201	82	−59.20%
20–49	31	15	−51.61%	1,110	545	−50.90%
50–99	79	17	−78.48%	5,642	1,264	−77.60%
100–199	62	27	−56.45%	8,078	3,824	−52.66%
200–499	79	58	−26.58%	23,485	20,213	−13.93%
500–999	58	44	−24.14%	41,287	29,631	−28.23%
1,000–2,499	61	65	6.56%	100,994	107,083	6.03%
2,500 or more	62	58	−6.45%	422,372	501,352	18.70%
Total	785	549	−30.06%	603,817	664,479	10.05%
<1,000 cows	662	426	−35.65%	80,451	56,017	−30.37%
>1,000 cows	123	123	0.00%	523,366	608,435	16.25%

This study is part of a USDA Sustainable Agricultural Systems-funded project led by the University of Idaho to research how to create value-added products from dairy waste in a northern climate. Our study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board of the University of Idaho (Protocol No. 20-081) as exempt (Category 2). We conducted 21 qualitative, semi-structured interviews with 23 participants in 2021 ($n = 12$) and 2023 ($n = 9$). Participants were identified purposefully and through referrals to represent different perspectives in the dairy industry and the wider community. We had no prior relationships with any of the participants who were recruited through emails and follow-up calls. Informed consent was received from every participant. They included dairy farmers ($n = 3$); crop producers ($n = 2$); other organizations with dairy industry connections, including dairy nutritionists, a cattle veterinarian, industry advocates, and representatives of social service organizations ($n = 6$); environmental nongovernmental organizations (ENGO) ($n = 5$); government agency representatives ($n = 3$); and other non-profit or public organizations ($n = 2$). Two participants responded to recruitment but were unable to participate. Table 3 provides identification codes for each participant.

Table 3. Participant identification codes

Participant identification	Type of interviewee	Year
C1	Crop producer	2021
C2	Crop producer	2021
D1	Dairy producer	2021
D2	Dairy producer	2021
D3	Dairy producer	2021
P1	Cattle veterinarian	2021
P2	Dairy industry advocate	2021
P3	Cattle nutritionist	2021
P4	Service provider (education)	2021
P5	Large agribusiness	2021
P6	ENGO	2021
P7	ENGO	2021
P8	Small agribusiness	2021
P9	Government agency	2023
P10	Food pantry	2023
P11	Government agency	2023
P12	Government agency	2023
P13	ENGO	2023
P14	Economic development	2023
P15	ENGO	2023
P16	School district	2023

Results and discussion

Prior to asking specifically about AD and AD+, we led the semi-structured interviews with the open-ended question, "What do you see as the primary challenges for Idaho's dairy industry as a whole?" Several themes emerged from this question alone: waste management, economic issues, environmental issues, and regulation. Table 4 displays these themes, representative quotes, and the type of participant who shared it.

Waste management implicitly includes environmental components and was the more prevalent theme in participant responses. These themes provided a lead to investigating whether technology adoption also goes beyond physical and operational attributes of AD and AD+ and motivated the inclusion of environmental, economic, and regulatory issues. The next sections present results directly related to the diffusion of AD and AD+ technologies using Rogers' (1962; 2003) framework as a foundation and including other adoption drivers.

Adoption of anaerobic digesters

Observability and trialability

There was a priori reason to believe that the observability of AD systems in Idaho may be low, given the comparatively small numbers of installed systems in a large dairy state (Economic Research Service, 2023). However, most participants indicated familiarity with AD and often brought up the technology without prompts explicit to AD, as shown in Table 5. Participants who were furthest removed from the dairy industry were least familiar with AD technology. AD systems generally were observable, meaning the participants were aware of them. Without observability (awareness), barriers are created to trialability.

Aspects of trialability as seen in Table 5 do go beyond the physical attributes of AD and are related to economics, environment, and regulation in our qualitative sample. Operational issues directly tied to the technology represented only one aspect of trialability and were mentioned by a minority of participants. The economic aspects of installing a digester were most frequently mentioned. Environmental and regulatory aspects were mentioned less frequently.

Relative advantage/disadvantage

We identified seven themes related to the relative advantage of AD and the lack thereof. Two relative advantages commonly described by interviewees included methane reduction and the possibility of ancillary advantages to farmers through decreasing costs and producing value-added products. A community advantage mentioned was enhanced water quality. Themes related to the absence of relative advantage included the dependability of current systems, cost versus benefits, advantages that may not be reached in a cold climate, a lack of realized added value, and an incompleteness in addressing digestate. The costs that inhibit the trialability of AD systems also appear in this section as they were mentioned as a relative disadvantage in addition to hindering trialability. Participants also compared AD to alternative waste

Table 4. Dairy industry challenge themes

Theme	Quote	ID	Participant
Waste management	"It's always looked at in a negative light, nutrients. When the rest of the world beyond the United States is starving for nutrients, we need to figure out how to get our nutrients in a transportable form."	D3	Dairy producer
	"Manure management, I think being the key one, risk with finding a sustainable method to manage manure, especially during the winter months, the lagoon style management."	P13	NGO
	"The experience that I've had, it seems like nutrient management is an ongoing problem."	P5	Large agribusiness
	"… of course, dairy waste has been a concern for a while as what do you do with that? … what productive things can we do with that? I see a number of these dairies do have a composting fertilizer business, but I don't know how efficient that is."	P16	School district spokesperson
Economics	"Shrinking margins…we're always expected to do more with less. How efficient can we be and how cheap can we make milk and do it right?"	D2	Dairy producer
	"Labor has always been a challenge, but it's been heightened with some of the immigration policies. Having a sustainable labor supply is the challenge I think most dairies are dealing with."	P1	Veterinarian
	"You can see this consolidation continue. I don't know what it's going to look like at the end… And large producers tend to be very…cost-conscious."	P3	Animal nutritionist
Environment	"Primary challenges are, in my opinion, to justify its existence in this high desert, as a tremendous user of resources and water and a tremendous potential polluter."	C1	Crop producer
Regulation	"…looking at how to address any concerns…by self-regulating and looking for innovative solutions to some of the concerns that have been raised. So, I think that's a positive impact that they're wanting to…be a positive influence on their communities by being proactive."	P9	Government Agency
	"Keeping up with the regulation. As a medium to small sized dairy, that's the hardest part because of all the paperwork. I can't hire someone to do all the paperwork to keep up with all the regulation, because I can't afford it, whereas a large dairy could."	D1	Dairy producer

Table 5. Anaerobic digester observability and trialability themes

Theme	Quote	ID	Participant
Observability	"There was a lot of interest in [AD] the last two to three years…and [Idaho does] have some that have been online for, I want to say eight to 10 years."	P9	Government agency
	"Pretty far removed for me."	P4	Service provider (education)
	"I don't currently work with [AD], but there are a couple of dairies that…are running anaerobic digesters…to generate electricity and [are] selling it back to Idaho Power."	P10	Non-profit food pantry
Trialability (economics)	"Somebody walks in and says, 'hey, we've got a digester technology we can guarantee it'll work.' And they roll their eyes, like, 'we've been down this road before, and I'm not spending another a $100,000 or more to fail again.'"	P3	Cattle nutritionist
	"I think that is the seismic shift that's really needed to put a dent in the manure-related issues—having the actual significant federal funds available to start making a dent in some of these issues through incentives."	P6	ENGO
	"…just haven't found the right one that will partner with me because I think proactively here, because most dairy farmers are interested in what can they offer me as far as financial restitution."	D3	Dairy producer
Trialability (operational)	"One's been talking to some of the neighbors. But no, most of them [do not have their own digester]. I work with one 7,000-cow dairy, that did put one in that just never worked, and [the dairy] actually started tearing [the digester] back down."	P3	Cattle nutritionist
	"The digesters seem like a really great idea, but I think there's a lot of things on the side that maybe make them not as wonderful as they seem."	P12	Government agency
Trialability (environment)	"I think more on the lines of what will benefit beyond the back door of my farm. I need clean water. I haven't found a digester company that's willing to work with me yet on that."	D3	Dairy producer
Trialability (regulation)	"I think [we want] the dairy industry to take initiative and do these things but I think oftentimes…if the industry isn't forced to do so, they're going to wait and wait until they're handed a bunch of money to be able to change it. But I do think funding incentives do have a role to play here."	P7	ENGO

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management technologies, noting that the advantages of AD may not surpass those of other alternatives or current practices, given the upfront investment required. Values were a subtheme. Thus, technological aspects of adoption are prevalent in participant responses, but responses go beyond these aspects and touch on the environment, economics, and community. Three participants had more to share about relative advantages and disadvantages: D3, P3, and P12. These participants were more knowledgeable of manure waste issues and readily shared their experiences and perspectives. Table 6 displays representative quotes about relative advantages and disadvantages.

Simplicity/complexity and compatibility

Participants had less to say about simplicity/complexity and compatibility compared with relative advantage. Table 7 displays representative quotes. The comments went beyond the technical aspects of adoption. Two themes emerged regarding the diffusion characteristics of (in)compatibility and complexity. Subthemes within compatibility touched on the technical aspect of difficulty in changing current manure management systems and the skill and time necessary to manage working digesters. Participants noted that investments have already been made in simpler systems that work. Another subtheme relates to the environmental impacts of producing a product (fertilizer) with nonstandard proportions of nutrients. Incompatibility with values, including ethics and the environment, was mentioned. Lastly, the number of cows needed to support a digester is related to economic and operational factors. Regulations are seen by some as cumbersome and time-consuming. The burden of regulation was brought up in the broader realm of challenges facing the dairy industry and was not limited to the regulatory burdens of AD.

We now turn to newer and emerging AD+ technologies.

Perceptions of AD+ technologies

Before we moved to the specifics of biochar, hydrochar, and bioplastics, participants commented about newer AD+ technologies in general. Table 8 summarizes these comments. Themes include the general aspects of diffusion, including observability (awareness), relative advantage, and community impact. Responses were spotty; however, a few participants offered general comments about newer AD+ technologies.

Biochar and hydrochar

While biochar has been known as a soil amendment for over 2,000 years, its use has only recently been 'rediscovered' as a method to improve carbon sequestration in U.S. agriculture (Mylavarapu, Nair and Morgan, 2013). Biochar is expected to improve agricultural yields and enhance the efficiency of AD systems (Latawiec et al., 2017; Babaei and Shayegan, 2019; Mylavarapu, Nair and Morgan, 2013). Hydrochar can be produced from dairy manure with an uptake of up to 90% of the phosphorus. Thus, it can be used to recycle nutrients to be used as fertilizer (Wu et al., 2017).

Observability and trialability

As new innovations in the United States, both observability and trialability are nascent in our sample, but a few participants indicated that they knew about biochar or hydrochar production or use. Two themes related to trialability include the environment and economics. Representative quotes are provided in Table 9.

Relative advantage

Overall, participants generally believed that there are or will be relative advantages to AD+ technologies and expressed cautious optimism about the possibilities for biochar or hydrochar. Themes related to relative advantage include operational advantages, including fewer weeds, the concentration of nutrients that decrease trucking costs (economics), and management efficiencies, as displayed in Table 10. These fit with the traditional DOI technical advantages. That said, they also implicitly incorporate economics and the environment. Therefore, it is difficult to separate advantages into discrete categories. Many responses relayed relative disadvantages related to economics, performance, a lack of proof of concept, and even the possible futility of researching biochar. Some participants communicated both advantages and disadvantages (P5 and P7). This is perhaps related to a lack of proof of concept as described below.

Simplicity/complexity and compatibility

One theme that emerged in the area of simplicity/complexity related to a lack of proof of concept and the need for more information. This theme goes beyond just the technology involved. More research and testing are needed before producers adopt technology to produce biochar and hydrochar. Themes related to compatibility and (in)compatibility included the ability to use current systems with biochar and the need to invest in an (AD) digester to obtain the additional benefits of AD+ technology. Dairy producer participants were more hopeful compared with other participants regarding both operational and economic factors. Because of the nascent features of biochar and hydrochar, the concepts of simplicity/complexity and compatibility were less frequently mentioned by participants. Representative quotes are displayed in Table 11.

Bioplastics

Because the production of bioplastics from AD digestate is a future technology, participants expressed a limited but curious understanding of bioplastic production from dairy manure. They were both skeptical and optimistic about their potential. As with biochar and hydrochar, participant comments addressed the end product and not the AD+ technology, which is not currently commercially available.

Observability and trialability

Given the lack of commercial availability of the product and process, bioplastics are neither observable nor can our participants in Idaho actually sample the process or output. The overall theme is that participants are not widely aware of bioplastics produced from dairy manure, and there is no trialability until the technical processes are made available. Few participants had heard of them explicitly, "Yeah, I think so. I've heard of the bioplastics before, that's come up before" (P3—Cattle nutritionist) and "Very, very tangentially. I wouldn't want to be quoted on saying I know anything about them" (P11—Government agency). Participants were provided with an informational sheet to which they referred when addressing diffusion of bioplastics.

Relative advantages and disadvantages

Participants provided their opinions on the advantages and disadvantages of bioplastics. They commonly questioned the uses of bioplastics and whether there would be markets for the products.

Table 6. Relative advantages and disadvantages of anaerobic digester themes

Advantages	Quote	ID	Participant
General advantages	"Helping us process our manure, producing value-added product on our facility, generating gas revenue, all that good stuff."	D2	Dairy producer
Methane capture	"I think the digesters that have been put on several dairies, trying to use technology to utilize methane out of the manure to turn it into natural gas, I think that's one way. …it's not something that every dairy can do, but I think it has the potential to have a positive environmental impact or at least balancing some negatives."	P14	Economic development professional
	"There's methane that gets produced, which is good if you can capture it all. I know we do air-quality permitting for those. And so, there's other things that may come off the digestate."	P12	Government agency
Enhanced water quality	"Yeah, definitely if they reduce the risk of downstream water quality contamination, particularly during big storm events, then that would help a larger scale dairy operation track towards certification."	P13	ENGO
Generating a new product	"I've got one large herd I work with that's putting in a digester to generate gas. And I've had a couple of them try, at least one that tried putting one in, but it didn't ever work."	P3	Cattle nutritionist
	"Opportunities for the producers in those arenas or opportunities for the companies supplying the technology?"	P12	Government agency
	"… if we could turn that into something that would be a new industry here in the Magic Valley, whether it's with fertilizers or plastic products, any of those things that could take that waste product and turn it into a new product."	P16	School district professional
Community benefits and values	"We need to be able to export our waste economically to other neighboring states or even countries that would benefit from our waste. It's fertilizer for Pete's sake. People look at it as toxic waste, which it's not. It's fertilizer, what makes things grow."	D3	Dairy producer
	"Anytime we're recycling nutrients, things like that – and I think society's got to the point where they're demanding it to different levels in different parts of the country."	P1	Cattle veterinarian
	"It seems like there could be a reduced impact to infrastructure like our roads because of that waste being managed differently. Instead of land applied, it's reduced down. So, there's not as much truck traffic managing that. That would be a benefit to the community."	P9	Government agency
Less manure	"Well, what I've done is I've gotten a dry hose system, and I have about two miles [3.2 km] of hose where I can reach out to neighbor farms and apply nutrients, subsoil. And that helps."	D3	Dairy producer
Environmental benefits	"And then there's also the containment on the facility itself. So most dairies [currently] have unlined wastewater lagoons, which – if they are unlined then, some of the poo can sneak into the water. And so that's been an issue too. And then for the ammonia…" "Theoretically, it could be a better thing because we're not running many pumps, trucks, tractors, and all that, we could be better for the environment. Anyways, I'm just not sure how that math breaks down."	P6	ENGO
Disadvantages			
General disadvantages	"The digesters seem like a really great idea, but I think there's a lot of things on the side that maybe make them not as wonderful as they seem."	P12	Government agency
	"So, the digesters, I think, have to be continued to be refined and made to work. That's the main thing."	P3	Cattle nutritionist
Economic	"At least with the conversations I'm having, if somebody proposes putting a digester together and they go, 'Well, I can't make it profitable with just my facility's manure going in there."	P12	Government agency
	"… there's been a lot of research about the economies of scale you need to make that effective and it's like you need at least like a 3,000-cow dairy, which there are a lot of in southern Idaho that are at least that big."	P7	ENGO
Biogas	"I believe [the dairy's AD] was supposed to…be able to scrub to make propane. Then they were hoping to run the vehicles on the dairy with propane, and then even sell some back to somebody. But it just never generated the amount of propane it needed to be viable."	P3	Cattle nutritionist
No better than alternatives	"Worm beds have come up. That was kind of a unique and interesting little discussion on how to utilize the nutrients coming out of the manure systems and recycle the phosphorus and the nitrogen using worm castings."	P12	Government agency
Incomplete solution	"So that [AD] process in and of itself does not remove the nutrients from what's left in the manure, but it helps consolidate the manure into a more manageable form."	P6	ENGO

The themes that emerged included new product development, product demand, safety, and environmental impacts. Participants had many ideas about new products. They believed that the most promising are agricultural and industrial applications as opposed to human food storage. If there is no market, then producing bioplastics from dairy manure is not viable. Many thought immediately that the consumer market would be difficult, but the industrial market could be viable. A community-related theme was that if

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Table 7. Anaerobic digester simplicity/complexity and compatibility themes

Theme	Quote	ID	Participant
(in)compatibility (more simple systems work)	"In open lots in the wintertime, we bed it down with straw. So, there's a lot of winter ground manure all mixed with straw, which is good for compost because the carbon and the nitrogen interact and break down better."	D1	Dairy producer
(in)compatibility (environmental and economic)	"The risk of concentrated nutrition is real and has to be managed. That's an environmental risk. There can be a health risk."	C2	Crop producer
(in)compatibility (farm size)	"And so I think that combined with some producers' age, there's a certain producer that have been dairying 500, 800 cows for the last 20, 25 years, had no desire to get bigger and then just hitting an age where they want to get out."	P3	Cattle nutritionist
	"And it's like get bigger or get out. And so that's your two options. If you want to stay in the business, you've got to get bigger. I don't fault anybody for doing it. I mean, that's just the way it is."	P5	Large agribusiness
(in)compatibility (values)	"And again, I'm more of a capitalist than a socialist, but when we start making decisions based solely on profit instead of what it means to the environment or to the people, I have an issue with that. I'm concerned. But how do you do that? That's a challenge. You got to stay in business, so you have to turn a profit, but you shouldn't forsake future generations' moral or ethical values just for the sake of a profit."	P10	Food pantry
Complexity (regulations)	"Keeping up with the regulation as a medium to small-sized dairy, that's the hardest part because of all the paperwork."	D1	Dairy producer
	"We've had several conversations about permitting requirements, mostly as to when a facility that might have an anaerobic digester would require, say, a water permit or…the Department of Environmental Quality to evaluate the engineering plans, that sort of thing… But if they sell [manure] or if they give it out to a third party, then I have to get involved with the regulatory side of that. And that just tends to make the producers nervous, I guess."	P12	Government agency
	"I think the industry as a whole has got so many regulations that it adds to the cost of producing."	P10	Food pantry

Table 8. General themes about AD+ technologies

Theme	Quote	ID	Participant
Observability	"But I think there's a lot of different things that the industry is looking at using. Those specific ones that you identified, I don't know that I'm super familiar with them."	P14	Economic development
Relative advantage	"But I know there are limitations to composting anaerobic digesters. I think it solves part of the issue, but not all of it. So something like biochar might be a nice alternative to that as far as the solids and being able to handle that more. I don't know that there'd be competition between the more traditional versus a new one. I think if newer technologies provide an economic opportunity, I think people will gladly invest or explore those."	P15	ENGO
	"I've been reading about innovations in terms of turning waste into new resource on the dairy side, and I think that sounds fantastic."	P13	ENGO
Community	Technologies in general…I really feel preserving our agricultural community perspective and dairy farming, I think it's going to be important. I think I still live here because 10 minutes and I can be in the country and I can still really feel that more rural community and I want my child to still be able to experience rural community and life and ensuring that we have the economic infrastructures in order to preserve that rural kind of life, I think is really important. And the more that we utilize technology to ensure that we're preserving rural life….	P14	Economic development

bioplastics are simply a 'greenwashing' escapade, the dairy industry's reputation could be damaged. Some comments crossed the issues of new product development, economics, community (development), and the environment. Table 12 displays representative quotes.

Simplicity/complexity and compatibility

Participants were generally unfamiliar with the complexity of producing bioplastics, but several commented on this or had questions. Some questioned whether current manufacturing plants could use bioplastic inputs from manure. Because of the nascent nature of bioplastics, many fewer comments were made compared with the discussions of the relative advantages and disadvantages of AD technology. The two themes of operational complexity and compatibility are general and relate directly to Rogers' (1962; 2003) DOI approach. Another theme related to complexity is the need for more information. Table 13 displays representative quotes.

Discussion and conclusions

Participant experiences with AD give indications that it will be important to show people the end products, their properties, and product uses before many farmers would consider upgrading an AD system to include the AD+ technologies of biochar, hydrochar, and

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Table 9. Observability and trialability related to biochar and hydrochar themes

Theme	Quote	ID	Participant
Observability	"Just a little bit, just from what I've read in newspaper articles and some things like that about some of the emerging technologies that could turn some of this into a real positive for the area."	P16	School district professional
	"Well, I guess, probably, I need a little more education on biochar and hydrochar."	C1	Crop producer
	"I don't know of anybody doing anything…. I don't know what hydrochar exactly is."	P3	Cattle nutritionist
	(Do you know anyone using these amendments?) "I do not."	P1	Cattle veterinarian
Trialability (environment)	"I would think if you could ever reduce your need for commercial fertilizers and use something that is natural, I think farmers would go for that."	P2	Dairy industry advocate
Trialability (economics)	"I don't know why [crop producers] wouldn't [use biochar/hydrochar] if it's not cost prohibitive. If it's comparable to what they're doing with fertilizer…now, and it's cost competitive, I don't see any reason [why not]. If it can do the same job, they're probably going to go with whatever's most cost effective for them."	P1	Cattle veterinarian
	"The opportunity is there for [hydrochar] and [dairies] would be open-minded big time, especially if it helps them manage their manure… Honestly, the adoption of that stuff is huge. People want to try and minimize their fertilizer inputs a little bit. I'm sure this biochar would do the same thing. It's a charcoal that…opens up our soils."	P8	Small agribusiness

bioplastic production. Participants were more familiar with AD compared with AD+ technologies, but in general, they could provide commentary on both the relative advantages and disadvantages of the potential new products.

Participants in this study were aware of the negative environmental impacts associated with large amounts of dairy waste. They were most familiar with AD and provided insights into why Idaho has not adopted more AD systems to address dairy manure waste, even though Idaho is the third-largest U.S. dairy state. Therefore, it was difficult for people to observe AD in action and to believe that AD+ systems could yield benefits. In general, participants with AD experience shared that current systems did not perform in a manner that justified the investment costs and required management that stretched already busy farmers. They also believed that income that could be generated from the production of methane currently does not surpass costs and that investment from the private and government sectors is insufficient to induce adoption. Further, questions about the return on investment for AD systems and AD+ technologies remain. These include questions about compatibility with current manure management strategies and the income they might generate. Participants also disliked that the regulatory burden added time costs to adoption.

Regarding AD+ advances, including biochar, hydrochar, and bioplastics, participants had several questions that need to be answered, including about the market for the products, whether these products are truly better than the status quo, if the income generated would be sufficient to justify the costs, and if the technologies just 'juggle' the unwanted nutrients instead of mitigating them.

There were also positives. Participants saw the advantages of AD and AD+ technologies in terms of manure management and the production of value-added soil amendments, biogas, and bioplastics, but they did not believe that these positives with regard to AD have been realized on farms or in the marketplace. Despite this general skepticism, most participants valued the potential benefits of AD and AD+ systems *if* they can cost-effectively meet the challenges of adoption in Idaho.

It is clear that AD adoption criteria continue to include both technological and economic aspects of diffusion theory as found in much of the literature (Morse, Guthrie and Mutters, 1996; Pannell et al., 2006; Geels and Schot, 2007; Montalvo, 2008; Swindal, Gillespie and Welsh, 2010; Welsh et al., 2010; Tranter et al., 2011; von Keyserlingk et al., 2013; Bangalore, Hochman and Zilberman, 2016; Latawiec et al., 2017; Sam, Bi and Farnsworth, 2017; Hou et al., 2018; Niles et al., 2019; Traub et al., 2021). However, given the age of much of the literature, it seems that many of the same obstacles and facilitators of AD adoption remain that will be important to consider in the adoption of AD+ technologies.

It is also clear from our research that adoption characteristics go beyond technological and operational characteristics, and other considerations are important as AD+ technologies are developed. Environmental and social concepts are less common in the literature and should continue to be included in the agricultural technology diffusion literature (Swindal, Gillespie and Welsh, 2010; Welsh et al., 2010; Krakat et al., 2017; Beauchemin et al., 2022; Gittelson et al., 2022; Lamolinara et al., 2022; Keough, 2023).

Suggestions for improving adoption include research that provides proof of concept for AD+ technologies; setting up demonstration sites where people can observe the technologies at work; providing evidence of markets for the outputs of the technology, including methane, soil amendments, and bioplastics; providing a path for transition to the use of new systems compatible and proven superior to current practices; and easing or helping adopters navigate the regulatory burdens associated with new technologies. Since AD+ adoption requires AD systems, further adoption of AD is a prerequisite for widespread adoption of AD+ systems, Even if AD+ technologies are proven to be advantageous, their adoption will take place in an area skeptical and cautious based on their experience with AD systems. This points to a need for substantial communication about how these systems work, what has changed to make them more viable in Idaho, and the benefits and tradeoffs of their use, including technological, economic, and social factors.

This study is based on qualitative methods and includes interviews with dairy producers and other participants in Idaho representing a wide range of for-profit, not-for-profit, and governmental organizations representing dairy producers and closely allied

Table 10. Relative advantages and disadvantages of biochar and hydrochar themes

Theme	Quote	ID	Participant
Advantages			
Operational advantages (operational environmental, economic)	"I guess I would be curious if there was really something different about biochar made from dairy manure. Maybe there was a nutrient component that it had that other biochars didn't have. That's a real possibility and maybe that would give it some advantage over other sources."	P5	Large agribusiness
	"To me, these biochar, hydrochar, and things like that, as long as we could get it out there, get it tested, see what it's going to do for us, the market is open for it. I think there's an opportunity for it, for sure. …Putting these…types of products on [and] trying to minimize the amount of fertilizer they're putting on."	P8	Small agribusiness
	"Biochar can be transported. You can bring it in with a semi-truck in the beginning of the day, you take it out in a pickup truck. I think that pyrolysis is part of the solution…beyond digesters."	D3	Dairy producer
	"One of the main concerns with spreading manure, and compost for that matter, is introducing weeds, seeds, and all that when we spread it. Through the biochar process, some weeds would be unviable. So, I think it would be a cleaner way of getting manure out there."	P7	ENGO
	"That's where I was telling you earlier about pyrolysis. It burns our nutrients, cow manure down to 92 to 94% less yet retains all the nutritional value in the ash. And that's where the biochar comes in. I think pyrolysis is much more efficient, yet no money is put into it."	D3	Dairy producer
	"…but my understanding is that they should be applied at a modest level on high value crops, where the return on the investment can be justified, and hopefully it can be done at a scale – or the scale it can be produced at is sufficient that it could be applied to all crops, to all ag systems. I think rather than selling it in a bag to home gardeners, it should go back on the crop land."	C1	Crop producer
	"I think if newer technologies provide an economic opportunity, I think people will gladly invest or explore those."	P15	ENGO
Disadvantages			
Economics	"…we've done a fair amount of experimentation with biochar. We have not seen any agronomic benefit to doing it at an economic – the economics just aren't there. Any incremental benefits that you get from applying biochar, it's been so expensive that people aren't going to buy it. And then also from a practical standpoint, you have to get them applied on the field and they're not very compatible with other applications that – you're making a fertilizer. It's just a big poof of black dust. It's an exercise in futility. That's been my experience with biochar."	P5	Large agribusiness
	"I haven't seen [crop producers] be that interested, so I don't know why it would be any different for a new flavor of biochar."	P5	Large agribusiness
Environment	"For example, there may be chemicals in the dairy waste that then become a part of that char product, or bioplastics, for that matter."	P14	Economic development professional
	"I guess the concerns I would have probably fall under the idea of folks thinking more is always better. So, if I get a little bit of phosphorus on my land and my plants grow really well, then more phosphorus is going to be even better…. The plants can only take so much up, and then anything that the plants don't use…filters through the soil to some degree, and then eventually ends up in our groundwater, which can come up through our surface water. So, we end up having nutrient issues in our ground and our surface waters."	P12	Government agency
	"Some of these technologies are being talked about as 'this will make dairies environmentally friendly,' or 'this will solve our problems.' And with most of the technologies that I've seen, and I think biochar fits in this category…they don't actually deal with the nutrient issue, they're dealing with maybe the greenhouse gas emissions or the odors or various things. But, to me, until we get some technology that efficiently deals with the nutrient issue, that's always going to be the elephant in the room."	P7	ENGO

industries, environmental organizations, regulatory agencies, and those living in and serving the dairy community but removed from the dairy industry. As such, a wide variety of input was obtained in a state with low AD adoption considering the size of its dairy industry. However, the results cannot be generalized and therefore caution should be used in extrapolating these results to other states or other agricultural commodities. That said, this study represents a research-based approach to understanding local factors necessary to improve the effectiveness of the adoption of new agricultural technologies. As seen in this study, technology adoption goes

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Table 11. Simplicity/complexity and compatibility biochar and hydrochar themes

Theme	Quote	ID	Participant
Complexity (information)	"Are there any studies as of yet on this biochar?"	P8	Small agribusiness
	"I'd want a real understanding of…the consistency of the nutrition. I would want some pretty guaranteed analysis in a pretty tight range. How it performed in the soil, I'd want to see a couple of years of replicated plot trials. We love those and really discount the snake-oil people that do strip trials and claim huge changes."	C2	Crop producer
Complexity (logistics)	I guess it's just more of the logistics. Can you get the supply to meet demand? Is there enough demand? Is there enough supply of manure?	P15	ENGO
Compatibility (operations)	"I think char could be incorporated into pivots….You could actually incorporate it into the pivot and sprinkle it right along with your water."	D3	Dairy producer
(In)compatibility (operations)	"…the problem is I don't have a methane digester and I'll need – my first cost would be building that cross pit or freestall, and then I would need a methane digester just because – I could run all my Honey-Vac manure through the methane digest, but I've heard rumors that they've been talking about building centralized methane digesters."	D1	Dairy producer
(In)compatibility (economics)	"It all comes down to cost…It's hard being the small to medium producer because the guys are all doing cross pits already and they're getting set up for this. But it's just going to be an extreme amount of cost to get it going. Because you have to build a barn, and then you're going to have to build the methane digester and other processes that are required to get the biochar and the other char. I don't know what kind of – if it's going to take extra buildings or what for that whole process to happen or if it's just going to be a giant filter that runs through at the end."	D1	Dairy producer

Table 12. Relative advantages and disadvantages of bioplastics themes

Theme	Quote	ID	Participant
Advantages			
Cross cutting	"So I recognize that the front end, the inputs and the outputs are both environmentally really friendly. It's a great story to tell, but what happens in the middle? Like what's the cost there?"	P2	Dairy industry advocate
New products	"…the possibilities. Anything plastic could be replaced. They started having plastic grocery bags in California. It'd be biodegradable. That'd be a huge market that that can tap because there's a couple other states that cut out plastic bags too, that they could have the monopoly on, essentially."	D1	Dairy producer
	"Especially with the 3D printing stuff that's going on. I thought there'd be a lot of just even localized opportunity for using our own plastics. Agricultural manufacturing would be a cool way to do it, close the loop."	D2	Dairy producer
	"I think the market is going to be more industrial uses and…commercial uses, of which there's a massive market, so there should be plenty of room…. You can use it to make dairy feed bags, for example. There's a lot of plastic use in the dairy industry right now that could come from recycled manure. It could be used to make baling twine."	C2	Crop producer
	"If you can make up a couple of parts and pieces for somebody's vehicle that's being bought through General Motors or something like that, or Ford, [where consumers] don't really even know [it was derived from manure]."	P3	Cattle nutritionist
Markets	"People use a lot of plastic."	D2	Dairy producer
	"The ag pesticide market. We use a lot of plastic containers. And in fact, the ag pesticide manufacturers, we fund a recycling program called ACRC, Ag Container Recycling something."	P5	Large agribusiness
Economics	"Obviously, that plastic already exists, but if we produce enough of it at the dairy industry, that might become a cost point where it's feasible for people to use plastic bags. I don't know. I'm not sure where the cost points are on that right now or how much it costs for that much plastic."	D1	Dairy producer
	"It just adds more economic value to the whole system we got going in the community."	D2	Dairy producer
	"Maybe in some…of the more rural areas that are becoming more urban, it could be a real – it's kind of one of those deals, a community that has a facility that's going to create plastic out of manure, that's something to be proud of."	P1	Cattle veterinarian
Environment	"I'm so tired of seeing the people are litterbugs and you just see plastic everywhere. And then you read about plastic, microplastic in the ocean and that kind of stuff. And that sounds like a whole lot more palatable or more promising market than in the biochar."	P5	Large agribusiness
	"Obviously, plastic pollution is a big issue nationally…but this one's a little different in that at the very least you're taking the manure and turning into something else."	P6	ENGO
Reputational	"Environmental, I think those kinds of products are nothing but good or even good imagery for dairy."	D2	Dairy producer

(*Continued*)

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Table 12. (*Continued*)

Theme	Quote	ID	Participant
Disadvantages			
Environment	"… be curious about when you say biodegradable, what does that mean? Does it mean to take 20 years in the landfill to biodegrade? Does that mean you can stick it in your backyard composting bin and it'll make great swill in a year. And so, I would wonder that. I would wonder what does that biodegradable mean? If we could get to something where people compost it on their own or it's very easy, there's really not a negative impact to it sitting in a landfill for a little while. I'd just be curious about that time of breakdown."	P2	Dairy industry advocate
	"…there may be chemicals in the dairy waste that then become a part of that char product, or bioplastics, for that matter. And I don't know much about that except they turned dairy waste into a type of something similar to a plastic."	P14	Economic development professional
Demand	"Like I said before, the ew factor, people will think it's gross that they're touching old dairy manure, but I don't think it will be that big of a hurdle."	D1	Dairy producer
	"I see the biggest challenge is using this for food-grade plastics because of just the image, even if it's totally clean and safe. What are people going to think if their milk carton was produced from manure? I don't know."	P2	Dairy industry advocate
	"What would the chemical breakdown be if I was eating a bag of M&Ms made out of manure plastic? Is it safe?"	P8	Small agribusiness
	"But again, it comes back to education of people, what they're getting, and so do you want your beverages inside a container that's manure?"	P1	Cattle veterinarian
Reputational	"Well, yeah. In the sort of way, I just said that it would – it's the way to greenwash the dairy industry and justify its existence to some degree or offset its negative impacts without actually changing its true nature of an energy intensive, extractive business. Extractive both in human and environmental costs."	C1	Crop producer
Regulatory	"Then politically, maybe you don't like the idea of being told you have to do this kind of stuff. We want to do it and try to be as efficient as possible, but when people tell us to do it, it bites the wrong way."	D2	Dairy producer

Table 13. Complexity and compatibility of bioplastics themes

Theme	Quote	ID	Participant
Complexity (operational)	"Probably getting the manufacturing facilities here [would be difficult]. The overall investment of getting those facilities built in Idaho."	P7	ENGO
	"Technical, not so sure. I've seen some of the equipment used for those processes and that's all up to those guys."	D2	Dairy producer
	"…it's possible and they scale appropriate infrastructure."	C1	Crop producer
	"I guess I can't envision how you would make the plastics. Changing manure to plastic? That's a stretch for me in my mind, but I'm sure…there's microbial processes that would help with that."	P1	Cattle veterinarian
	"You would need a methane digester for that wouldn't you?…"	P6	ENGO
Complexity (information)	"…what's actually happening with the nutrients in this process, like the nitrate and phosphorus, is it going into the plastics, which I'm not really sure it does. In which case, then there's probably some residue left over from the process that's highly enriched in nitrogen and phosphorus then you've got to do something with that. That would be very potent to put on a field compared to just even normal manure if it's concentrated. So yeah, I have to learn more about that."	P6	ENGO
Compatibility (operational)	"We have a Hilex poly bag manufacturer here in the Magic Valley. Can they use these plastics in their production? Dow Chemical has a Styrofoam plant in Burley. Can any of their ingredients be substituted – these bioplastics be substituted for that, so that they're not shipping in plastic belts from wherever else they're produced? I guess, as a Styrofoam plant in Burley. And maybe there's an opportunity there. I'm not a chemical engineer."	P2	Dairy industry advocate
	"There's less manure that's going to be stacked up or going through some of the other processes. I think the environmental question is…do we have a different source to…create the plastic than we've had in the past? And that's really a good thing."	P1	Cattle veterinarian
Compatibility (economics)	"I'd probably ask questions around the scalability, competitiveness and then definitely the receptiveness of the commercial or industrial user to the functionality of the biodegradable manure-based plastic."	C2	Crop producer
	"Obviously, the plastic manufacturers that make it out of petroleum plastics probably aren't going to be too excited about competition, but as far as if they could do this, I don't see where the downside would be."	P3	Cattle nutritionist

(*Continued*)

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Table 13. (*Continued*)

Theme	Quote	ID	Participant
Compatibility (demand)	"Some people would maybe be a little cautious just because of its origins, but with education I think that could be negated pretty easily."	P7	ENGO
(In)compatible (environment)	"You think about it here and you go back 200 years when the bison were roaming across the plains. To me it almost seems like it's the natural thing to put it back into the earth… I feel like its place is back in the soil because like the bison of old, that's what fed the grasslands that used to be out there…in the central United States. The soil used to be a high organic matter soil. That's what puts organic back into the soil, feeds the microbes, and helps the process. To me that's where it belongs, but obviously not over done like it is today."	P8	Small agribusiness

beyond the technical and operational aspects of newly introduced technologies. Context is also critical as are regulatory, community, economic, and environmental considerations.

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