Climate Solutions Living Lab

Spring 2018

Anaerobic Digesters

Technological Innovation for Reduced Agricultural Greenhouse Gas Emissions

IMPLEMENTATION PLAN

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This Report and Implementation Plan are student work product completed to fulfill requirements of the Climate Solutions Living Lab, a 12-week course offered at Harvard Law School. This report and plan were researched and written under tight time constraints to answer specific questions posed to the students in their course assignment. Any opinions expressed in the report are those of the students and not of Harvard University or Harvard Law School. If you would like to learn more about Harvard Law School's Climate Solutions Living Lab, please contact Professor Wendy Jacobs at wjacobs@law.harvard.edu.

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Acknowledgements

First and foremost, we would like to thank Professor Wendy Jacobs, the Emmett Clinical Professor of Environmental Law and Director of the Emmett Environmental Law and Policy Clinic for her inspirational dedication and commitment to the Climate Solutions Living Lab. Her willingness to provide vital resources and connect us to a wide range of industry experts formed the backbone of this pioneering multi-disciplinary effort, one which we hope will be replicated in other capacities at Harvard.

We would also like to thank the tireless teaching fellows and staff that made this report possible: Debra Stump, Drew Michanowicz, Julio Lumbreras, Seung Kyum Kim, Jacqueline Calahong and especially our advisor, Taylor Scott Jones for their subject matter expertise and continued support.

We are also extremely grateful to the numerous experts who took time to share their expertise with us in person or over the phone. Their insights through both the feasibility study and implementation plan phases of the project were invaluable to the outputs we reached:

- James Mandel, Rocky Mountain Institute
- Gavin McCormick, WattTime
- Henry Richardson, WattTime
- Dr. Daniel Andersen, Asst Professor at Iowa State University
- Dr. Douglas Hamilton, Oklahoma State University
- Georgine Yorgey, Washington State University Center for Sustaining Agriculture and Natural Resources
- Nathanial (Tani) Colbert-Sangree, Duke University Carbon Offset Initiative
- Andrew Rodgers, Farm Manager, Clark Farm in Carlisle, MA
- Bob Manning, Director of Harvard Energy & Facilities
- Nick Peters, Harvard Energy & Facilities

Executive Summary

Harvard University has set a goal to become fossil-fuel neutral by 2026. This requires offsetting at least 200,000 tons of carbon dioxide equivalent ($CO_{2(e)}$) per year - an unlikely feat unless Harvard considers off-site reductions projects. In an effort to kick-start this process, our team proposes Harvard financing an anaerobic digester. This implementation report details the project's finances, engineering components, legal requirements, and public health implications for an 8,000-head dairy farm located in Gooding, Idaho. This paper details the process by which Harvard can begin scoping out the project, and provides some ideas for alternative solutions, such as leveraging dairy cooperatives in the northeast region. Our goal is to provide a feasible, practical, and scalable proposal that can help Harvard achieve its climate commitments.

The United States (US) agricultural industry remains largely free of regulation, particularly related to emissions. The US dairy industry is a major source of greenhouse gas (GHG) emissions, accounting for 2% of total emissions nationwide. On-farm emissions contribute 51% of the emissions from every glass of milk produced.[1] This is in part due to the high emissions potential (25 times more potent than carbon dioxide) of methane, the main on-farm source of emissions released from manure.[2] More broadly, agriculture and land management practices contribute 20% of carbon dioxide, 50% of methane, and 70% of the nitrous oxide anthropogenic emissions that lead to global warming.[3] Our project has the potential to reduce these three most important anthropogenic GHGs, which together accounted for 97% of U.S. emissions in 2016.

Compounding the high emissions potential of the agricultural industry are ideological, financial, and regulatory barriers that limit efforts to improve farm sustainability. Despite being an established technology, digesters have high startup costs and burdensome maintenance responsibilities. This project helps farmers reap the benefits of a digester in terms of more economical waste management and extra income streams, as well as socioeconomic benefits associated with reduced air pollution. By leveraging its financial and academic resources, Harvard can help prove that reducing emissions with digester technology is a viable solution ready for implementation at scale.

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[1] Innovation Center for U.S. Dairy. (2013). *U.S. Dairy's Environmental Footprint: A summary of findings, 2008-2012.* Retrieved from Innovation Center for U.S. Dairy: https://www.usdairy.com/~/media/usd/public/dairysenvironmentalfootprintbrochure-july.pdf

[2] Aguirre-Villegas, H., Larson, R. A., & Matthew, R. D. (2016). *Methane Emissions from Dairy Cattle: An Overview.* Retrieved from Sustainable Dairy: http://www.sustainabledairy.org/publications/Documents/DairyCap_Methane_FactSheet_Final.pdf

[3] Eagle, A.., Henry, L, Olander, L, Haugen-Kozyra, K…& Robertson, P. (2011). *Greenhouse Gas Mitigation Potential of Agricultural Land Management in the United States: A Synthesis of the Literature.* Opportunities and Implementation Options for Agricultural Land Management in the United States, Report NI R 10-04, Second Edition.

Project summary

The following implementation plan describes the installation of a complete mix anaerobic digester on an 8,000-head dairy farm in Gooding, Idaho. The project will convert liquid manure from the dairy operation to biogas, which will produce electricity via two generators. The digestate (solids) processed by the digester have the potential to be converted to bedding and fertilizer. Assuming that the digester replaces an existing open anaerobic lagoon, it has the potential to reduce 55,000 metric tons (mt) of $CO_{2(e)}$ per year. The total project cost based on a variety of assumptions detailed later in this paper is $7 million. We propose that Harvard finances $6 million, with the remainder provided by various grant programs.

Design

- One 8,000-cow dairy farm in Gooding Idaho
- Complete mix anaerobic digester with two generators

Emissions Reduction Potential

- 55,000 metric tons (mt) of $CO_{2(e)}$ reduced annually
- Cost per ton = $15

Cost

- $7 million, $6 million from Harvard

Benefits

- Reduces odor as well as air and water pollution
- Provides cheap community waste management
- Jump starts the US digester movement
- Saves the farmer money on electricity and bedding
- Potential for fertilizer sales
- Harvard gets carbon credits

Current Status of Manure Management in US

- Prevalence of uncovered manure lagoons with huge emissions
- Terrible odor and noxious fumes
- Potential for waterbody polluting spills and contamination

Structure of paper

- Section 1 details the process by which we selected this project as opposed to others
- Section 2 outlines the proposed project structure
- Section 3 lists the implementation steps
- Section 4 discusses engineering and technological design requirements
- Section 5 presents financing options and proposes a structure
- Section 6 defines the various legal requirements and processes
- Section 7 considers the project's additionality and various co-benefits
- Section 8 evaluates the public health impact

Implementation Plan

1. Project Selection Process

1.1 Screening Process

Our screening exercise assessed three agricultural technologies: anaerobic digesters for manure; smart pump irrigation technology; and no-till land management. Each had its unique benefits. WattTime-enabled irrigation systems allow for more efficient uses of water resources while minimizing harm associated with carbon-intensive electric grids. Anaerobic digesters provide significant methane emissions reductions in the livestock sector while producing electricity, reducing odors, and mitigating risk of water contamination. No-till agriculture provides a high-impact and low-cost operations model with potentially high appeal for project partners.

The three projects were assessed in terms of feasibility; desirability to clients and project partners; scalability; co-benefits; verifiability; and impact. Ability to meet the course's ambitious emissions reductions goals was given high priority. (See Screening Exercise Outcome Appendix). All three projects satisfied our criteria. WattTime and Anaerobic Digesters were selected for further analysis due to their fitting squarely within our team's technological, rather than behavioral focus.

1.2 Feasibility Analysis Summary

We brought two projects forward into the Feasibility Study phase of the semester - using WattTime.org's emissions reduction software in conjunction with smart irrigation systems on farms to reduce emissions associated with electricity used for irrigation and building an anaerobic digester to capture methane emissions of dairy farms. The goal of the feasibility study phase was to dive deeper into a small set of promising projects and begin identifying all key benefits and barriers of each as an offset project.

While there are reasons that we found why each of these two types of projects have yet to see widespread adoption, both passed feasibility: we proposed ways that we believe are feasible for an unregulated entity like Harvard University to contribute some combination of monetary and expertise support to each of these project concepts

A list of the key takeaways for each project are listed in Table 1 below, and the full feasibility study has been attached as an appendix of this report.

Table 1. Summarized Results of Feasibility Study

	WattTime for Irrigation Efficiency	Anaerobic Digester for Dairy Farm
Total Emissions Reduction	- 45 lbs. $CO_{2(e)}$ per acre per year - 6,075 lbs. $CO_{2(e)}$ per year for a 135 acre farm	- 7 tons $CO_{2(e)}$ per cow per year - 3,500 ton $CO_{2(e)}$ per year for a 500 cow farm[4]
Total Cost	Very Low (less than $10,000), entirely upfront	High (up to $10 million, depending on farm size)
Co-benefits	Energy and/or water savings (if paired as a bundled offering for farmers with a smart tech partner)	Air and water pollution reductions, providing new revenue streams for farms, providing a cheap community waste management option
Biggest Barriers to Adoption	Irrigated locations in the U.S. have unideal grids, project structure is not intuitive, privacy and data concerns	Upfront financing, responsibility for ongoing management and maintenance, competition with other dairy farm priorities
Key Project Decisions	Project structure, method to incentivize farmer participation, technology partners (demand response and/or smart irrigation partners)	Farm size and location, digester vendor-centric or farm-cetric model, digester design, whether to accept waste from other farms and grocery stores, digester vendor partner

Source: Authors

1.3 Selected Project + Selection Process

Following our feasibility study and project goal scoring (see Appendix), we selected anaerobic digesters for further development. Though WattTime is inexpensive and relatively easy to use, our calculations did not show implementation of WattTime yielding large emissions reductions in the agricultural sector. There were also some doubts regarding independent verification of emissions reduction verification, as core components of the technology are proprietary.

Anaerobic digesters on the other hand can deliver over 50,000 tons of GHG emissions reductions per year, assuming sufficient organic material to feed the system. Moreover, with careful maintenance digester facilities can become profitable in a relatively short period of time.

We selected Idaho for implementation due to its large dairy industry and the state satisfying additionality criteria. Project developers however need not only look to Idaho or large dairy operations

[4] Note: Our team switched to a much larger 8000-cow farm size for the Implementation Plan to achieve more significant emissions reductions. The feasibility study assumed an 500 cow farm. This has been left at the 500 cow scale in the Feasibility Study due to feedback and comments received during the final presentation: in addition to the interest in the larger scale model proposed, there was also interest in a smaller scale investment in the Northeast United States.

to implement this project. A cooperative model between several smaller dairies, such as in New England or New York, could provide an attractive alternative. Additional revenue streams provided by digesters, from electricity, bedding, and fertilizer, could help support New England's dairy industry. Improved waste management practices would also mitigate harm to the region's iconic lakes and rivers.

2. Project Structure

2.1 Project Stakeholders

Monitoring and operational costs for the digester should be a priority for all parties involved to ensure that the digester is providing all of the benefits. Validation and verification of the emissions reduction and waste management efficiency should be performed on an ongoing basis. Nutrient levels in the digester effluent (what comes out of the digester after the process is complete) should be carefully monitored to ensure this product does not harm local ecosystems with higher levels of micronutrients such as nitrogen, phosphorus, and potassium. The ideal participants and stakeholders include a main project partner (either a a dairy farm or collection of farms that generate approximately 900,000 pounds of manure per day); an unregulated entity such as a private institution, including Harvard; and a contractor (anaerobic digester vendor) with technological expertise.

Given the high upfront costs, varied revenue streams, and subject matter expertise required to successfully operate an anaerobic digester, we recommend structuring the project so that Harvard provides flexible project financing and legal support, but the project partner (digester site owner) and biogas vendor would be responsible for executing, maintaining, and tracking revenues and offset credits generated by the project. A more "hands-off" approach is consistent to similar digester projects initiated by universities, such as Duke University's project at Loyd Ray Farms. The university's financial commitment signals to the market that digesters could be an attractive investment, but entrusts the developers and operators themselves to train and make the process efficient. As such, Table 2 identifies the following roles for the project's partners:

Table 2. Primary Partners

Entity	Role	Responsibilities
Harvard	Unregulated entity voluntarily purchasing offset credits	• Provide flexible funding support (the "extra push" to make a project financially feasible) via grants and zero-interest loan • Provide legal expertise for structuring/permitting advice via the Emmett Clinic at HLS

Dairy farm (at ~8000 cow capacity or equivalent collective of smaller farms)	Project partner and digester site owner	• Implementing and operating an anaerobic digester system • Main source of manure/input • Using heat and electricity with own combined heating/power (CHP) systems • Selling excess generated capacity to the grid for profit • Selling fertilizer/digestate by-product for profit • Staffing an operator to support daily operation and maintenance of the system, ensure accurate monitoring of GHG offsets • Monetizing on future offsets once Harvard's initial investment is recouped

Biogas digester vendor	Digester expert and project developer	• "One-stop-shop" vendor providing design and development consultation, training and maintenance support, repair and troubleshooting support
		• Provide training materials, best practices for operation
		  ○ The EPA's AgSTAR program offers many resources for biogas implementations, including a comprehensive vendor directory of expert vendors[5]
		  ○ Alternatively, the American Biogas Council's membership list could be a starting point for vendor evaluation[6]

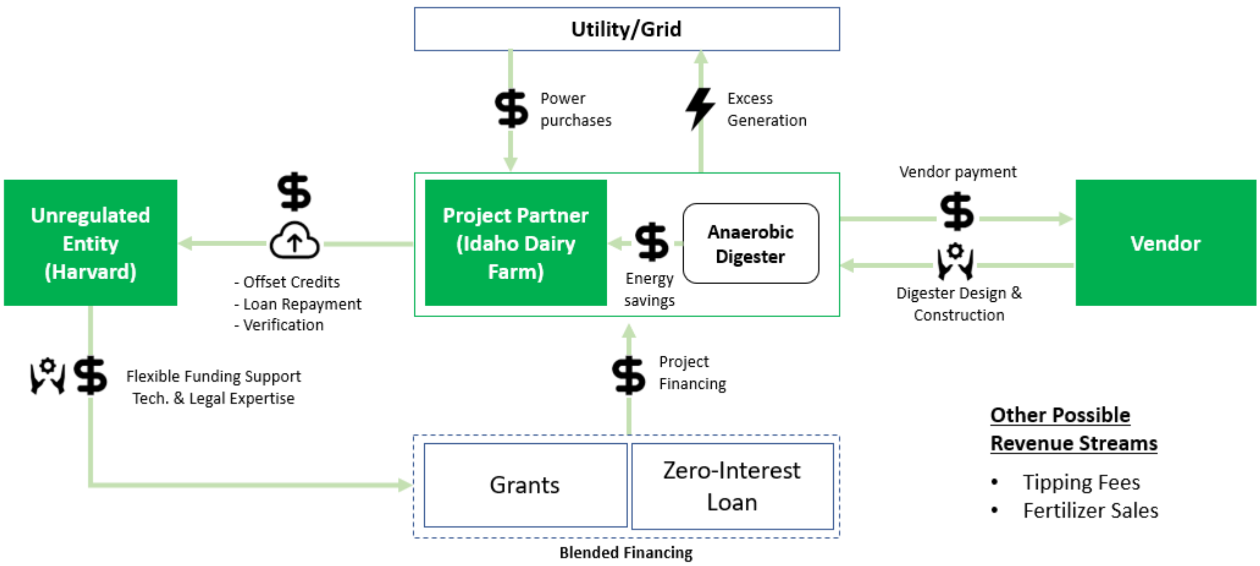
Source: Authors

Other potential stakeholders include:

- Utility grid operator: The operator would need to provide infrastructure to help the project partner sell back excess electricity to the grid and measure against any Power Purchase Agreements set
- Co-digestion partners: The surrounding community (e.g. neighboring university) could participate in transporting other waste streams to the digester for processing by offering the digester a tipping fee, providing another source of revenue
- Other funding sources (e.g. commercial bank loans): Given Harvard's market-making signal, project partners may also choose to take out loans to support this project

[5] EPA. (2018). AgStar Vendor Directory for Manure Digester Systems. Retrieved from https://www.epa.gov/agstar/agstar-vendor-directory-manure-digester-systems.
[6] American Biogas Council. (2018). American Biogas Industry Directory. Retrieved from https://www.americanbiogascouncil.org/membership_list.asp.

Figure 1. Proposed Project Structure Diagram



Source: Authors

2.2 Site selection requirements

To select for future sites, the following criteria should be considered:

Table 3. Project Criteria

Criteria	Description	Goal
Location & Farm Size	Digester facility should be located in proximity to the largest biomass input source (e.g. dairy manure)	- Minimize transportation distance - Meet minimum manure input needs for digester operation
Co-digestion Opportunities	Prevalence of local organic waste sources, such as universities, agricultural processing factories, or wastewater treatment plants	- Provide substrates for digestion process, which can improve methane generation potential given proper processing
Biogas feedstock transportation and grid infrastructure	Biogas transportation from the production site to end use (such as in a CHP) requires capacity for biogas infrastructure and favorable permitting environment that supports biomass-originated[7]	- Minimize transportation costs, maximize energy delivery

Source: Authors

Our initial analysis proposes a digester facility in Gooding County, Idaho given the region's agriculture-heavy industry and potential for substantial co-benefits from transitioning a current manure lagoon to a closed anaerobic digester. With 637 farms in the state, Idaho uses 41.5% of its agricultural land for pastureland, but has only 4 digesters currently in operation (see Figure 3).[8,9] The dairy industry is valued at $2.3 billion and growing but is in need of innovation.

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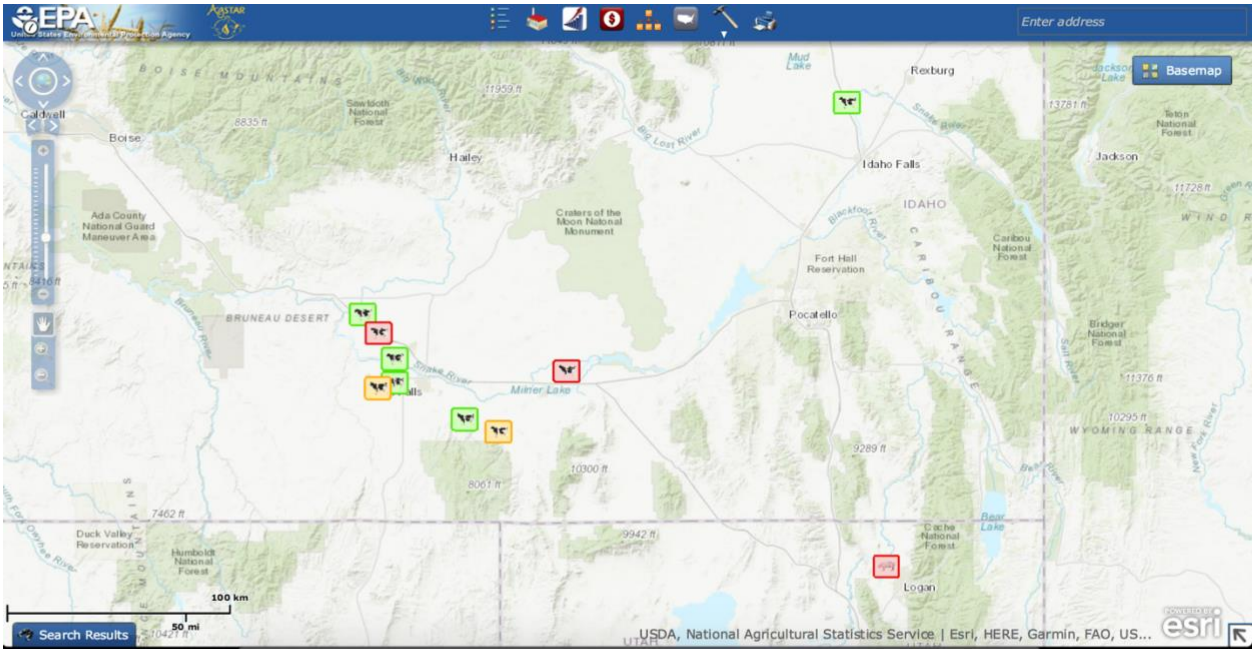
[7] E.J. Hengeveld et al. (March 2016). Biogas infrastructures from farm to regional scale, prospects of biogas transport grids. Biomass and Bioenergy, volume 86, pp. 43-52.
[8] USDA Census of Agriculture. (2012). 2012 Census Publications: Rank of Market Value of Ag Products Sold. Retrieved from https://www.agcensus.usda.gov/Publications/2012/Online_Resources/Rankings_of_Market_Value/Idaho/.
[9] USDA Census of Agriculture. (2012). Idaho State Profile. Retrieved from https://www.agcensus.usda.gov/Publications/2012/Online_Resources/County_Profiles/Idaho/cp99016.pdf.

Figure 2. Map of Idaho with Gooding County highlighted

Source: Idaho Cattle Pastureland, GIS.10

Figure 3. Anaerobic Digesters in southern Idaho



Source: EPA, AgSTAR National Mapping Tool[11]

While this implementation report is based off an 8000-cow dairy farm in Idaho in order to achieve over 50,000 tons of $CO_{2(e)}$ offsets, it's important to note that future iterations of the project could be explored through a combination of agricultural cooperatives and co-digestion streams. In sites with a supportive local infrastructure, regulation, and organic waste sources, a similarly meaningful GHG offset impact could be achieved through the agglomeration of multiple smaller entities. Jordan Dairy Farms in Rutland, MA is one such model closer to Harvard that has partnered with four other Massachusetts farms to form AGreen Energy, LLC. The partnership integrates manure from its own dairy operations with local food companies' organic waste sources in a successful system that has generated 2.24 million kWh of electricity per year.[12]

An agricultural collective of farms in a smaller dairy-producing region in Massachusetts could benefit particularly when working with Harvard University as a project consultant and organic waste source from the university's dining waste streams. The university-farm model has many existing precedents to draw learnings from, such as the Duke-Loyd Ray Farms project, UW Oshkosh biogas system, and Cornell

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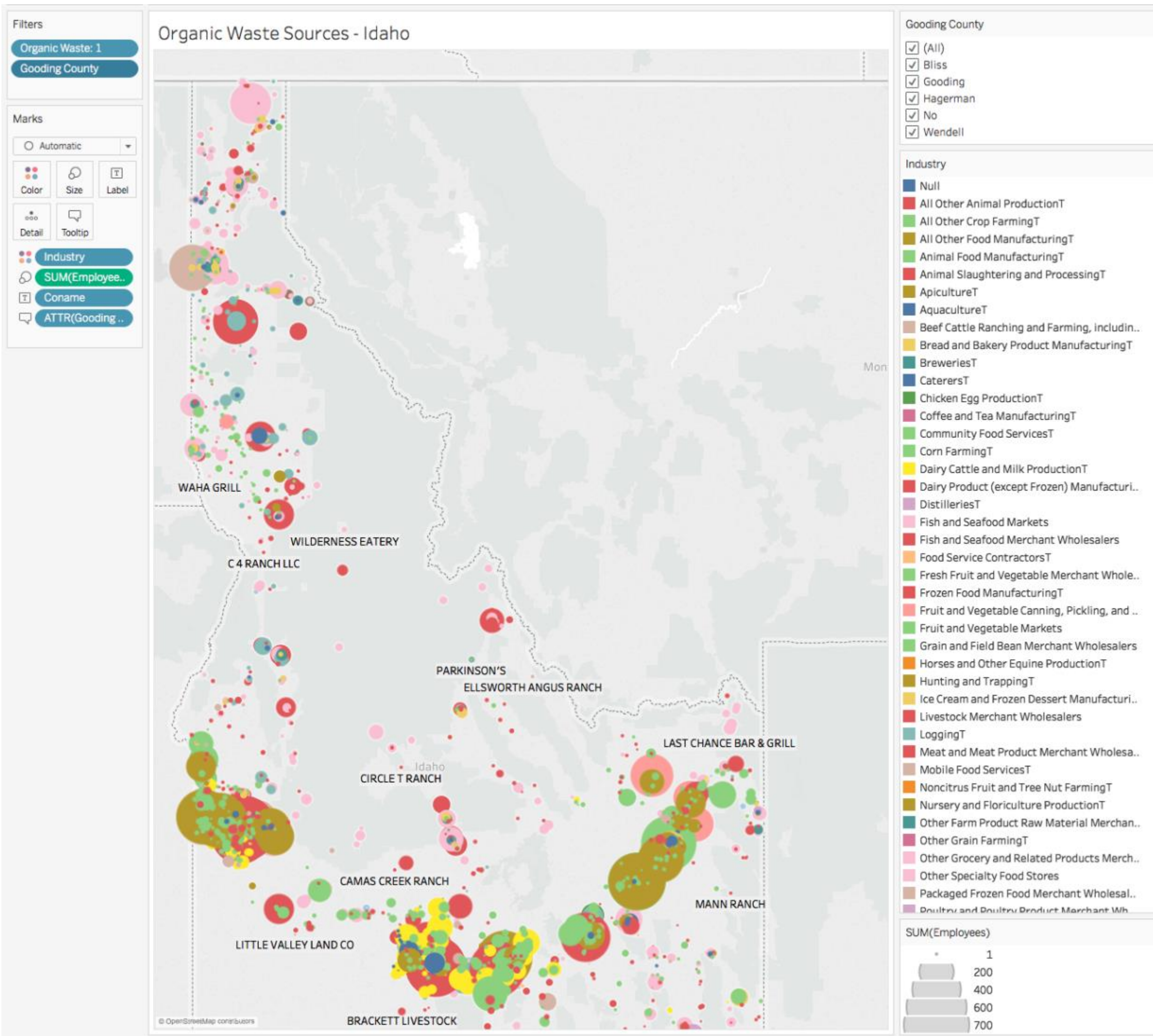
[10] USDA. Idaho Cattle Pastureland. Retrieved from https://www.agcensus.usda.gov/Publications/2012/Full_Report/Volume_1,_Chapter_2_County_Level/Idaho/st16_2_011_011.pdf.

[11] EPA. (2016). AgSTAR National Mapping Tool. Retrieved from https://gispub4.epa.gov/AgSTAR/index.html.

[12] Mass.gov. Anaerobic Digestion Case Studies. Retrieved from https://www.mass.gov/info-details/anaerobic-digestion-case-studies.

University's Dairy Environmental Systems.[13] As a topic, the operational feasibility and offset potential could merit further student investigation in future iterations of the Climate Solutions Living Lab course.

Figure 4. Co-digestion opportunities around Gooding County



Source: Authors, using NAICS Data from Business Analyst

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[13] Newbold, Elizabeth. (2013). "Anerobic Digesters." Cornell Small Farms Program. Retrieved from http://smallfarms.cornell.edu/2013/06/11/anaerobic-digesters/.

3. Implementation Steps

Identify the target farm

- The most critical step of this project is the next one: Harvard University will need to identify the target farm that meets all criteria for this project to be feasible. We have identified a couple of potential routes to aid in the farm selection process, and the general outline of what a target farm and target digester would look like are outlined further below (see Project Structure).
- First, we have identified Idaho as a promising state to focus efforts on. Idaho has a growing dairy industry with larger herd sizes,[14] which has caused some pollution and odor concerns from the public. If not Idaho, other states to consider are Minnesota, Iowa, California, and New York.
- Most large farming states have internal state data sources that identify large commercial farming operations. One option would be to conduct direct outreach (calls and emails) to farms that meet this project's target farm criteria. Another option would be to enlist technical partners (Step 2) - both digester constructors and supporting partners - who may be aware of farms that have expressed interest in digesters but need an extra financial push to make their projects economically feasible.

Enlist technical partners

- The technical partner will be the digester constructor, but a range of technical partners will be critical to successful construction and operation of the digester. This can include EPA (through the AgSTAR program), as well as EPA's AgSTAR partners. The U.S. Department of Agriculture's Natural Resources Conservation Service has local service center and local staff that farmers are much more likely to trust for advice (along with their neighboring farmers).
- Ideally, the University of Idaho (the state's land grant university) would be a critical partner for technical support, both during construction and ongoing operations. University of Idaho and Idaho State University both support research on anaerobic digesters, including extension school industry support activities[15] and advanced research.[16,17]
- Technical partners can be enlisted through informal understandings during initial outreach, but more formal Memorandums of Understanding or Agreement will be necessary before moving further with design and implementation.

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[14] Lund, S. C. (2016). *An Analysis of the Feasibility of Anaerobic Digestion on Small-Scale Dairies in Utah.* Retrieved from Utah State University Digital Commons: https://digitalcommons.usu.edu/cgi/viewcontent.cgi?referer=https://www.google.com/&httpsredir=1&article=5676&context=etd

[15] Chen, L., & Neibling, H. (2014). *Anaerobic Digestion Basics.* Retrieved from University of Idaho Extension: http://www.cals.uidaho.edu/edcomm/pdf/CIS/CIS1215.pdf

[16] Roberts, T. (n.d.). *Spinning Manure Into Money*. Retrieved from University of Idaho: https://www.uidaho.edu/engr/news/features/manure-into-money.aspx

[17] Center for Advanced Energy Studies. (n.d.). *Environmental and Resource Sustainability*. Retrieved from Center for Advanced Energy Studies: https://caesenergy.org/research/core-capabilities/environmental-and-resource-sustainability-2/

Conduct site visit, confirm basic specifications and digester design

- Together with technical partners, Harvard will want to conduct a site visit. This is an important step to build the personal relationship with the project partner, and to get a better sense of any possible complications from a design perspective.
- Speak with County Commissioners and other local stakeholders while on site.

Structure financials

- Large digester projects can be financed and funded through a range of sources, including state and national grants, commercial loans, and contracts for payment for outputs. In coordination with technical partners, a more detailed financial feasibility study will be needed for multiple reasons. Most importantly, such a study will need to show robust enough returns that the farm is willing to agree to moving forward with the project.
- The chosen digester constructor partner will be critical in this phase of the project: we expect them to have proprietary templates for financial models specific to their digester designs that can be compared to the publicly available university models used by our team to conduct this initial feasibility study and implementation plan.

Draft and formalize contracts

- Harvard has the technical expertise at the Law School to oversee the legal process. We propose to utilize the support of the Emmett Environmental Clinic at the Law School or outside counsel to manage the contract process.

Construct and operate digester

- At this stage, Harvard University's role will be largely one of high-level project management and oversight. The project will be built and operated per contract specifications by project partners. That being said, the similar Duke University project provides a lesson learned for Harvard. Duke found that initial cost estimates were incorrect, largely because of various parts of the digester system breaking down (requiring replacements and pausing activity - including emissions offsets - in the interim). Harvard should expect to have as frequently as weekly calls with the digester project manager, if the Duke example proves representative.[18]

Receive offset credits

- Most current digesters have been approved for offsets under standardized verification schemes. We are proposing a largely electronic, automated measurement and verification methodology (see the Monitoring and measuring output section for more details). This saves on costs compared to hiring a verifier. Whatever method is chosen must allow Harvard to claim and retire offsets from the project on a yearly basis.

[18] Colbert-Sangree, N. (2018, April 17). Presentation Q&A Comment.

4. Technological Design

This implementation plan proposes the use of a closed anaerobic digester (AD) as an alternative manure management solution to open anaerobic lagoons, which offers greater greenhouse gas emissions capture and produces renewable energy. Table 4 presents the main properties of the digester system modeled in this report, which are explained and discussed in the sections that follow.

Table 4. Overview of Proposed Digester System

Digester Type:	Complete Mix
Feedstock processed:	Dairy Cow Manure
Number of head:	8,000
Electricity Generation Capacity:	1,420 kW
Biogas generation:	417,000 ft^3/day
Biogas uses:	Electricity, cogeneration[19]

Source: Authors

4.1 Technology Background

Anaerobic digesters (ADs) allow farms to achieve more efficient manure disposal, while simultaneously reducing air pollution and producing renewable energy from a previously untapped resource. They also reduce the foul odor associated with open lagoons that comes from the manure decomposition process. In ADs, anaerobic bacteria metabolize organic matter such as dairy manure and, in the process, generate biogas: a renewable energy resource consisting primarily of carbon dioxide (CO_2) and methane (CH_4).[20] The anaerobic metabolism process in ADs consists of three main steps (Figure 5). First, carbohydrates, fats and proteins contained in the organic waste are broken down and oxygen is used to form water (H2O) in a process called hydrolysis. In the second stage, acidogenesis, volatile fatty acids are produced along with CO_2. The third stage involves the conversion of volatile fatty acids into CH_4, CO_2, and H2O by methanogenic bacteria. ADs allow this third stage to go to completion because they prevent exposure to ambient air, which contains oxygen (O2). Methanogens become dormant upon exposure to O2. The auxiliary benefit of ADs in reducing odor comes from the unique environmental conditions in this third stage; without ADs, the methanogens are exposed to oxygen and other bacteria – those which are not inhibited in the presence of O2 – take over the digestion process and produce the odor of decay that can disturb communities and lead to unpleasant living conditions.

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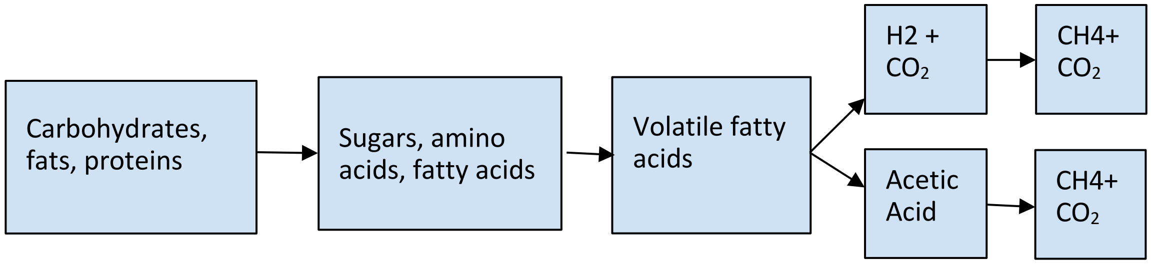
[19] Potential production of CNG to fuel farm tractors and trucks is possible.

[20] US EPA, *Basic Information about Anaerobic Digestion*. Retrieved on 22 February 2018, from https://www.epa.gov/anaerobic-digestion/basic-information-about-anaerobic-digestion-ad#HowADworks

Figure 5. Steps of anaerobic digestion

Source: Authors



Biogas produced in anaerobic digestion is trapped by the digester system, preventing pollution to the atmosphere and reducing odor. The biogas can be used as a fuel in downstream applications by serving as a source of electricity, fuel for boilers and hot water heaters, and cleaned to form natural gas (98% methane). Renewable energy from biogas can also power the digester itself, minimizing operational energy costs to the farm for AD technology.

4.2 Types of Anaerobic Digester Technology

There are several different types of ADs available on the market. In this report, we focus on the two most common types of ADs used in the United States – plug flow (PF) and complete mix (CM) digesters – and a complete description of the analysis of all types of digesters considered for potential use in this project is provided in Appendix 3a. CM and PF digesters produce about the same amount of biogas per unit of dairy manure input, but they have some key differences in operating conditions.[21] PF digesters are the most popular type in the U.S., and they are a simpler, cheaper design: manure is digested in a closed container without mixing.[22] As new manure enters the digester, the manure already present and fully digested exits the back end of the digester. This method moves the manure through the system as "plug" units, with each unit separated from the others. By contrast, CM digesters – the second most common type of digester – involve continuous mixing of the waste inside the digester, which is termed the slurry. Mixing improves exposure of the microbes that perform digestion to the organic influent, leading to a greater CH_4-to-CO_2 ratio in the biogas generated.[23] Mixing is achieved by the use of agitators, which are propellers that mechanically stir the slurry, or by pumping slurry into the digester from a point near the center and having it re-enter at the base.

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[21] Hayes, T., Jewell, W., Chandler, J., Dell'Orto, S. Fanfoni, K., Leuschner, A., & Sherman, D. (1979). *Methane generation from small scale dairy farms*. Department of Agricultural Engineering, Cornell University, Ithaca, New York.
[22] US EPA. (2018). *AgSTAR Data and Trends*. Retrieved 4 April 2018, from https://www.epa.gov/agstar/agstar-data-and-trends#adfacts
[23] Wang, H. & Larson, R. (2015). Effects of Mixing Duration on Biogas Production and Methanogen Distribution in Dairy Manure Anaerobic Digesters. *Waste to Worth: Spreading Science and Solutions.* Seattle, Washington.

Biogas produced in the digestion process is captured by covers fixed tightly over the digester tank, then transported via controlled pipes and valves to a gas collection tank. The remaining material in the digester - the “digestate” - exits the system and is termed effluent. This effluent is further processed to remove water (the wastewater is recycled for use on site as described in a later section), and the solid portion is separated into fibrous material (which can be used as bedding for livestock) and high-nutrient solids (which can be sold or used as fertilizer).

Although CMs can require greater operating costs due to the continuous mixing, they offer a number of benefits related to flexibility of operating conditions. In particular, CM digesters operate effectively in a lower range of total solids (TS) content (3-10% total solids is ideal), while PF require a higher (11-14%) TS content and cannot accommodate much liquid waste.[24] Another benefit of CM digesters is that they operate effectively under moderate, or “mesophilic,” temperatures of around 37 degrees Celsius, while plug flow digesters often demand thermophilic conditions (around 55 degrees Celsius). Mesophilic digestion requires less added energy and is less sensitive to small temperature fluctuations than thermophilic systems.[25] Finally, CM digesters can be located either above ground or below ground, while PM digesters allow only for below-ground operations.[26] This flexibility of CM technology offsets disadvantages of CM relative to PF, which are primarily related to higher equipment and operating costs (but not necessarily overall costs, as will be discussed in a later section).[27] As a result of the flexibility and improved methane-generating potential of CM digesters for the farm scenario of choice, the proposed implementation plan focuses on CM as the digester of choice.

4.3 Proposed System: Complete Mix

Our model assumes a cylindrical CM digester is installed on the 8,000-cow dairy farm in Gooding County, with dimensions of 50 feet in height and 40 feet in radius. This is in line with existing mixed AD tanks.[28] The model assumes that the digester is installed partially above ground, with 20% of the volume located below ground; positioning the lower portion of the digester underground reduces exposure to solar radiation and other ambient environmental conditions that could affect digester’s operational efficiency. The walls and base of the CM will be made of glass-coated steel plates, which prevents corrosion from acidic contents and bacterial degradation and have been successfully used in cylindrical CM digesters as well as water and sewage treatment plants.[29]

Target $CO_{2(e)}$ emissions **reductions:** 50,000 metric tons of $CO_{2(e)}$ per year

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[24] Id.
[25] Fulford, D. (1988). *Running a biogas programme: a handbook*. Intermediate Technology Publications.
[26] Chen, L., & Neibling, H. (2014). *Anaerobic Digestion Basics*. University of Idaho Extension, CIS-1215.
[27] Gooch, C. A. (2007). *Anaerobic digestion in the United States.* Biological and Environmental Engineering Department, PRO-DAIRY Program, Cornell University.
[28] Greene, P. (2015). *Anaerobic Digestion & Biogas*. Natural Systems Utilities.
[29] Campbell, J., Koelcsh, R., Guest, R., & Fabian, W. (1997). On-farm biogas systems information dissemination project. *Final Report 97-5.* NYSERDA, Cornell University, Ithaca, New York.

Location: Gooding County, Idaho

Project partner: ~8,000 dairy cow farm. Farm size for the model was chosen based on U.S. EPA AgSTAR database of Idaho farms with anaerobic digesters that saved at least 50,000 metric tons of $CO_{2(e)}$ emissions per year. There were four farms, which had had 8,900, 7,200, 10,000, and 10,000 cows. We chose 8,000 by averaging the lowest two, as a conservative estimate of farm size.

Anaerobic Digester Type: Complete Mix

Loading schedule: every 2 hours, manure is pumped from the sump to the mixing tank, where it is combined with additional wastewater (10% of volume) from the milking barn and heated, then pumped into the digester.

Flow pattern (digester setup):

- Continuous - manure added once per day, 10 day hydraulic retention time.[30]
- Influent composition (feedstock type): dairy manure of 11% total solids (TS), and 83% of TS is volatile solids (VS) mixed with 10% by volume of wastewater from flushing and milking barn cleaning water
- Wet digester, <15% solids
- Temperature range: Manure is heated via circulating hot water pipes to an internal and constant temperature of 37.8 degrees Celsius.
  - Mesophilic: 35-40 deg. C
- Mixing system: Amaprop submersible mixers[31]

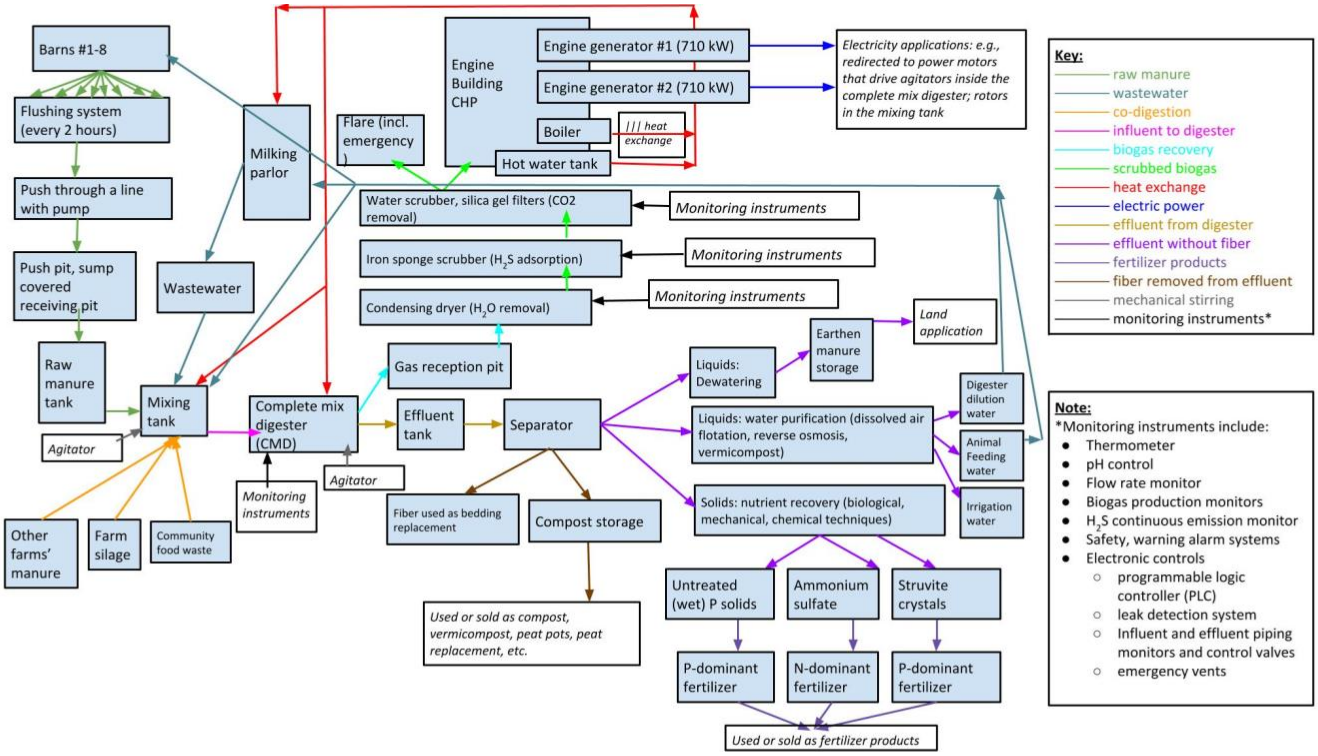
Uses of generated biogas:

- Co-generated heat being used on-site (locally) as part of combined heat & power (CHP). Heat harnessed from engine generator cooling system
- Generated electricity: 1420 kW engine generator capacity, 90% daily online operation time, 25% engine thermal conversion efficiency
- Sales of electricity not consumed on-farm
- Emergency flares

Monitoring and verification: Automated and manual system protocols that comply with U.S. EPA guidelines

[30] Hydraulic retention time (HRT) is the amount of time the liquid ("slurry") spends inside the digester.
[31] https://www.ksb.com/ksb-us/Products_and_Markets/waste_water/Biogas/biogas_waste_water_amaprop/

Figure 6. Complete Mix Digester Structure



Source: [Authors]

The cover of the CM digester will be tightly sealed and consist of two flexible membranes that can expand as gas enters the headspace of the system. The membranes consist of two layers of estane polyurethane with a combined thickness of 0.76mm and a 70% resin coating on top. Estane polyurethane has a thermal conductivity of 0.25-0.33 W/m K, which indicates a lower rate of heat loss than other materials.[32] [33] This material provides superior resistance to acidic and bacterial degradation, high pressure conditions, heat, and solar radiation when compared to other flexible covers made of polyvinyl chloride or chlorinated polyethylene.[34] Flexible digester covers offer superior leak protection and greater capacity for the volume of biogas collected than solid covers do.[35] The double membrane property of the cover will reduce the risk of membrane tearing.[36] Flexible covers must be carefully secured onto the top of the digester to prevent wind disturbance that can break the seal and lead to biogas leakage. The walls, base, and cover of the digester will all be covered with insulation using

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[32] Locite Design for Binding Plastics. Vol. 2. Retrieved on 4 April 2018 from http://www.locite.com/pdf/pbg64-65.pdf
[33] Jumikis, A. (1977). *Thermal Geotechnics.* Rutgers University Press. New Brunswick, New Jersey.
[34] Gebremedhin, K. G., Wu, B., Gooch, C., Wright, P., & Inglis, S. (2005). Heat transfer model for plug-flow anaerobic digesters. *Transactions of the ASAE,* 48(2), 777-785.
[35] Gebremedhin, K. G., Wu, B., Gooch, C., Wright, P., & Inglis, S. (2005). Heat transfer model for plug-flow anaerobic digesters. *Transactions of the ASAE,* 48(2), 777-785.
[36] DeGarie, C. J. (2002). *U.S. Patent No. 6,497,533*. Washington, DC: U.S. Patent and Trademark Office.

polystyrene foam, which resists degradation. Insulating the digester prevents heat loss during the cold winter months in Idaho, reducing the heat input to the system needed during the winter.

Before entering the digester, the manure and wastewater are first homogenized, or combined. This occurs in a mixing tank, where the total solids content and other system properties are adjusted to meet the CM digester operating requirements (e.g., pH, temperature, total solids content). The mixture then enters the digester and is metabolized with continuous mixing for a period of about 10-25 days, the hydraulic retention time (HRT).[37] The HRT dictates how long the organic matter spends inside the digester. As a result of mixing in CMs, the slurry is not necessarily retained for the exact length of the HRT – some slurry is retained for longer than the HRT – but the biogas generation is not hindered. Mixing in the digester system will be performed by agitators. We suggest the use of propellers with large diameter and a slow-moving incline agitator, which increases energy efficiency and achieves excellent mixing quality.[38] The model used in this report assumes mechanical mixing requires 275,940 kWh per year based on previous studies that report energy requirements for mixing of 0.007 kW per cubic meter of digester volume.[39]

4.4 Operating Requirements

To operate an anaerobic digester effectively, specific characteristics related to physical and chemical properties of the equipment and material input, or influent, must be met. Anaerobic microbes degrade the organic material inside a digester are sensitive to numerous physical and chemical properties in the system. For instance, methanogens – the anaerobic bacteria that metabolize organic matter to produce methane and carbon dioxide – are highly sensitive to pH and function best within a pH range of 6.8-7.4.[40] Low pH causes these bacteria to become dormant and no longer produce methane; if the pH falls below 6.8, then basic compounds, usually calcium hydroxide, must be added to raise the pH.

Temperature is another property of the system that can affect methanogen activity. CM digesters operate effectively at 37°C or within the range of 20-45°C.[41] The insulation alone will not keep the digester at the required temperature during the winter months; as such, hot water pipes will be installed in parallel at the base of the digester to heat the slurry inside. To source the energy for the hot

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[37] Chen, L., & Neibling, H. (2014). *Anaerobic Digestion Basics*. University of Idaho Extension, CIS-1215.
[38] Lemmer, A., Naegele, H. J., & Sondermann, J. (2013). How efficient are agitators in biogas digesters? Determination of the efficiency of submersible motor mixers and incline agitators by measuring nutrient distribution in full-scale agricultural biogas digesters. *Energies*, 6(12), 6255-6273.
[39] Environmental Biotechnology Group. *Chapter 8: Anaerobic Sludge Digestion*. Retrieved 2 April 2018 from http://mebig.marmara.edu.tr/Enve424/Chapter8.pdf
[40] Fulhage, C.D., Sievers, D., & Fischer, J.R. (2005). *Generating Methane Gas From Manure*. University of Missouri Extension. Retrieved 2 April 2018, from https://extension2.missouri.edu/G1881
[41] Nasir, I. M., Mohd Ghazi, T. I., & Omar, R. (2012). Anaerobic digestion technology in livestock manure treatment for biogas production: a review. *Engineering in Life Sciences*, 12(3), 258-269.

water pipes, waste heat from operating the pumps of the digester will be recycled and used to heat the water in the pipes in a format modeled off of that of the Australian Antarctic Division.[42]

Properties of the manure itself also affects digester functionality. In particular, the total solids (TS) and volatile solids (VS) fraction of the manure will impact digester efficiency, with higher VS yielding greater methane production. Typical dairy manure comprises 12-14% TS; the VS composition, which is a subset of TS, usually makes up around 83% of the TS.[43] CM digesters operate best when the influent has a TS content of 3-10%, so additional liquid is mixed in with the manure – thereby lowering the ratio of solids to liquids – before it is put into the digester. Other properties of the manure that increase the biogas generating potential in CM digesters include higher manure density, lower potential to form volatile fatty acids, higher chemical oxygen demand (COD), and carbon-nitrogen (C/N) ratios that are in the range of 20-30.[44] The C/N ratio is one parameter that must be measured very frequently, as low C/N ratios indicate whether the digester contents are producing ammonia (NH_3), which is toxic to anaerobic bacteria. Free NH_3 levels should be kept under 80 mg/L and the oxidized form, ammonium (NH_4^+), should be less than 1500 mg/L.[45] Sulfur-containing compounds, heavy metals, and antibiotics are also measured in the manure influent, as these compounds pose threats to human and environmental health at high levels. Sulfides are generated by the reduction of sulfides and degradation of proteins in the manure and should be kept at levels less than 200 ppm.[46]

While AD operation requires frequent monitoring of these and other properties, the methods and equipment for doing so are well-established and many can be automated.[47] Chemical oxygen demand (COD) removal efficiency can be measured quickly with minimal manual labor and serves as an accurate proxy to evaluate digester function; automated titrators are an EPA-approved method that can measure COD as well as alkalinity and volatile acid content in the system.[48] Previous studies indicate that COD removal efficiency should be 41-67% for dairy manure AD.[49]

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[42] Australian Antarctic Division. (2002). *Variable speed drives*. Retrieved on 28 March 2018 from http://www.antarctica.gov.au/living-and-working/station-life-and-activities/power-generation/energy-management/variable-speed-drives

[43] Burke, D. A. (2001). Dairy waste anaerobic digestion handbook. *Environmental Energy Company,* 6007, 17-27.

[44] Atandi, E., & Rahman, S. (2012). Prospect of anaerobic co-digestion of dairy manure: a review. *Environmental Technology Reviews*, 1(1), 127-135.

[45] Gunnerson, C. G., & Stuckey, D. C. (1986). Anaerobic digestion. *Tech. Pap.*, 49, 2181-2187.

[46] State of Washington, Department of Ecology. (2012, March). Technical Support Document for Dairy Manure Anaerobic Digester Systems with Digester Gas Fired Engine-Generators. *General Order of Approval, No. 12AQ-GO-01*.

[47] Nguyen, D., Gadhamshetty, V., Nitayavardhana, S., & Khanal, S. K. (2015). Automatic process control in anaerobic digestion technology: A critical review. *Bioresource technology*, *193*, 513-522.

[48] For examples of automatic titrators, see: https://hannainst.com/titrator

[49] Wilkie, A. C., Castro, H. F., Cubinski, K. R., Owens, J. M., & Yan, S. C. (2004). Fixed-film anaerobic digestion of flushed dairy manure after primary treatment: wastewater production and characterisation. *Biosystems engineering*, *89*(4), 457-471.

4.5 Harnessing Recycled Water and Heat

Figure 7. Manure removal mechanisms in barns: scraping (left) and flushing (right)

Source: British Columbia Ministry of Agriculture (2017)

A novel feature proposed in this implementation plan involves the use of recycled water to remove the manure from barns, where about 85% of all the manure is deposited by cows each day for farms that are not free-range.[50] The model accounts for manure removal from eight barns housing 1,000 dairy cows each. We propose the use of recycled water to employ "flushing" as an alternative manure removal method to "scraping" (Figure 7). Flushing involves flooding the barn floor with water to wash away deposited manure. Flushing removes a greater amount of material than mechanical scraping.[51] However, scraping is the most common means of removing manure from barn floors. In scraping, a mechanical, manually guided tool picks up the waste from the barn floor without the use of additional water. This retains the manure solids level of ~18%, so it can be transported via trucks to move it to the lagoon or other disposal site. By contrast, flushing reduces the solids content to <10% and allows for manure to be moved by pumping it through polyvinyl chloride (PVC) pipes, which reduces fuel costs, air pollution, noise disturbance, and highway traffic.[52] The recycled wastewater is generated by purifying liquid effluent from the digester.

Although flushing from barns uses more water upfront (as much as 220-620 gallons per cow per day), the total amount of water used in flushing is not as much greater than the quantities used in scraping because flushing brings the influent composition to an ideal composition of about 3-10% total solids.[53] In scraping, additional liquid must be added to the manure downstream in the mixing tank before entering the digester in order to meet the digester requirements of 3-10% total solids (TS); the manure collected

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[50] Bartram, D., & Barbour, W. (2004, June). Estimating greenhouse gas reductions for a regional digester treating dairy manure. In *13th International Emission Inventory Conference*.
[51] Wilkie, A. C., Castro, H. F., Cubinski, K. R., Owens, J. M., & Yan, S. C. (2004). Fixed-film anaerobic digestion of flushed dairy manure after primary treatment: wastewater production and characterisation. *Biosystems engineering*, 89(4), 457-471.
[52] Marufuzzaman, M., Ekşioğlu, S. D., & Hernandez, R. (2015). Truck versus pipeline transportation cost analysis of wastewater sludge. *Transportation Research Part A: Policy and Practice*, *74*, 14-30.
[53] Kirk, D., & Faivor, L. (2014). The impact of dairy housing and manure management on anaerobic digestion.

during scraping is only ~8-18% total solids alone.[54] Additional drawbacks of scraping include the fact that it leaves more manure residue on the barn floor; this leads to greater direct air pollution emitted from the barn floor, as the manure off-gases pollutants. In addition, scraping leaves the barn floor moist for a longer period of time, as the manure does not evaporate as easily as water residue after flushing, which can cause health and safety issues due to unwanted bacterial growth. A final benefit of flushing over scraping manure removal is that flushing can be easily automated, whereas the less efficient scraping method requires manual operation.[55] For these reasons, the implementation plan proposed here includes an automated flushing system that removes manure from the barn floors once every two hours. Finally, the proposed project incorporates the use of recycled heat harnessed from the engine generator cooling system and the pump operating equipment as described in Section 4.3: Proposed System: Complete Mix Anaerobic Digester. Together, using recycled wastewater and harnessing heat that would otherwise be dissipated are novel applications of existing technology that improve the carbon footprint of the project and reduce costs.

4.6 Biogas

4.6.1 Generation Potential

In order to transform the biogas generated into usable energy, the gas must be first treated via "scrubbing" to remove non-combustible components (carbon dioxide, water vapor) and toxic gases (hydrogen sulfide). This increases energy yields from combustion of the gas, and it also reduces damage to the generators and boilers, which can be corroded by sulfuric acid that is formed from the precursor gas, hydrogen sulfide, if it is not scrubbed out prior to combustion. After cleaning, the scrubbed biogas - consisting of about 60% methane and 40% carbon dioxide - is diverted to the engine room for production of electricity via engine generators. Co-generated heat harnessed from the engine cooling system can be used to fuel hot water heaters and boilers for direct use on the farm, such as heaters in the milking barn. The electricity and heated water can be used to operate the digester as well, warming the influent to the mixing tank and digester to the ideal 37 °°C. Filters, dehumidifiers, and scrubbers can help remove contaminant gases like H_2S, CO_2, water vapor (H_2O), or siloxanes to prevent corrosion of the AD and maximize potential energy production. Biogas consists of about 60% methane, which is the combustible component; other contents include 30-40% is carbon dioxide, 5% water, and trace amounts (0-5%) of other gases such as hydrogen sulfide, nitrogen gas, oxygen, and ammonia (NH_3).[56] As such, the biogas generated must first be processed to make it combustible and reduce emissions of toxic gases including hydrogen sulfide. is first treated via scrubbing to remove hydrogen sulfide gas, then it is diverted to the engine building for production of energy via engine generator, heat via

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[54] British Columbia Ministry of Agriculture. (2017). Summary of Manure Handling Systems in the Context of Hullcar. *Hullcar Situation Review: Nutrient Management Practices - Technical Report, File No. 631.700-6*.
[55] British Columbia Ministry of Agriculture, 2017.
[56] Mojica, E. E., Ardaniel, A. A. S., Leguid, J. G., & Loyola, A. T. (2018, February). Development of a low-cost biogas filtration system to achieve higher-power efficient AC generator. In *AIP Conference Proceedings (Vol. 1930, No. 1, p. 020042)*. AIP Publishing.

cogeneration/engine cooling system, hot water heater, and boiler. Some of the latter two applications can be recycled for heating the influent to the mixing tank, digester, and milking barn.

The biogas quantification modeled in this report does not include co-digestion of other organic wastes – such as corn silage, restaurant and municipal food waste, and expired food from grocery stores – which could increase the amount of biogas produced. However, the setup leaves room for future expansion to include additional waste streams. The volume of manure from the 8,000-cow farm fills only 159,000 ft^3 of the 300,000-ft^3 digester vessel, leaving ~45% more volume of influent able to be added without disrupting the digester function. Unused volume in the digester does not hinder biogas production rates; in fact, the gas in the headspace of the tank helps insulate the system from heat loss. Co-digestion of other waste streams would yield additional biogas generation; however, other features of the system must be adjusted to accommodate this additional energy production. For example, the engine generators that combust biogas and produce electricity have a capacity of 1420 kW, and the manure from the farm requires 1025 kW of power, leaving the capability of generating an additional 405 kW; if co-digestion produces biogas that, when combusted, requires greater than 405 kW of engine generator capacity, then the farm would need to install more generators or discard the excess biogas using flares. In the current plan, flares are included only as a safety measure for emergency burning of biogas only. A flare consists of an ignition point located about 10 meters above ground level that lights when needed to combust biogas. If excess biogas from co-digestion requires flaring, then assessment of the farm's carbon footprint must account for air pollutants emitted by flares such as CO_2 and N_2O.

4.6.2 Quantifying Generation

This report includes both a top-down and bottom-up quantification of the biogas generated in the digester system, as a combined approach improves accuracy and verification of the calculations. In the bottom-up method, properties of the manure (volume of manure, physical-chemical composition, etc.) and the digester (tank volume, operating temperature, etc.) can be used to estimate the amount of biogas produced.[57] The accuracy of this model was verified using the model of biodegradation rate provided in the Appendix. In the top-down quantification method, data from flowmeters measuring the amount of gas exiting the digester are combined with measures of the engine electricity and heat power that is generated to quantify the total amount of biogas produced and used by the system. In this model, we assume that the digester collection efficiency is 99% and the biogas destruction efficiency is 98%, as suggested by previous studies.[58,59] Several parameters (Table 5) must be input for the model to be accurate.

Table 5. Key features used to calculate biogas produced

Parameter used for Biogas Quantification	Target Value

[57] Lazarus, W. F., & Rudstrom, M. (2007). The economics of anaerobic digester operation on a Minnesota dairy farm. *Review of Agricultural Economics*, *29*(2), 349-364.
[58] USEPA. (2009). *2008 U.S. greenhouse gas inventory report.* Washington, D.C.: U.S. Environmental Protection Agency
[59] Alberta Government. (2017). *Quantification Protocol for Biogas Production and Combustion*. Carbon Competitiveness Incentive Regulation, Version 1.0.

Weight of each dairy cow	1,333 lbs/cow[60]
Manure production rate	13.5 gallons/cow/day[61]
Manure volatile solids (VS) content	13.24 lbs/cow/day[62]
Methane (CH_4) content of the generated biogas	62.5% CH_4[63]
Theoretical maximum of dairy manure, B_0	0.24 m^3/kg-VS[64]
Methane conversion factor (MCF)	0.67[65]
Retention time in digester	10 days

Source: Authors

All system parameters should be verified by the digester operating staff once per week and any changes should be update in the biogas estimation models to ensure accurate production calculations (monitoring expectations are described in the later section, System Operation Verification and Maintenance. If discrepancies are found between the bottom-up and top-down estimates of biogas generation, this alerts digester operators who can execute a more thorough assessment of digester function, looking for common issues a leak in the piping or a defect in the automated controls that are supposed to adjust pH, temperature, and total solids content.

4.6.3 Electricity Potential

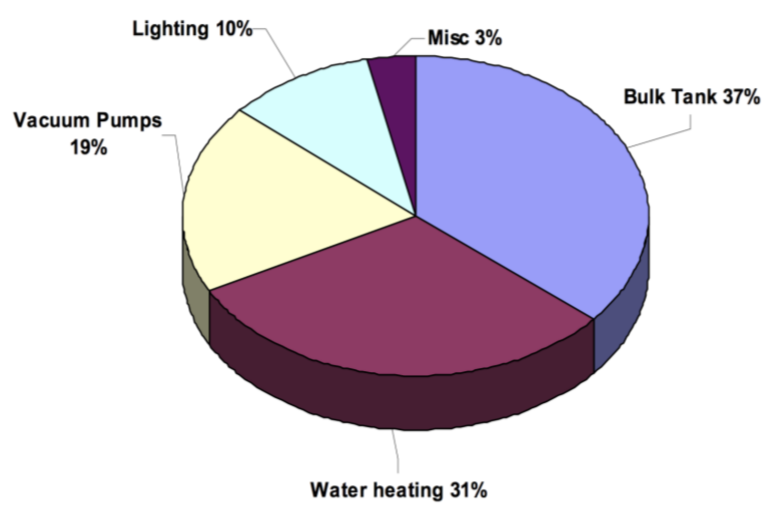
In the proposed digester system, biogas enters the gas collection tank where it is processed by "scrubbing" to remove water vapor, hydrogen sulfide, and carbon dioxide with three separate filters, respectively. Then, the scrubbed biogas is combusted in engine generators. Biogas consisting of ~60% methane has an energy content of 600 Btu/ft^3, which is lower than that of other common fuels including natural gas (1,000 Btu/ft^3), propane (92,000 Btu/ft^3), diesel (138,000 Btu/ft^3), and coal (25,000,000 Btu/ft^3).[66] Nonetheless, the engines in this report are coupled to electricity generators, which produce about 8 million kWh/year with a daily operating percent of 90%.[67] We propose the use of two Guascor 500 series engines with a capacity of 710 kilowatts (kW) each; however, different engines can be used so long as they are capable of burning biogas with 60% methane and 40% carbon dioxide composition. In

[60] Stone, J. B., Trimberger, G. W., Henderson, C. E., Reid, J. T., Turk, K. L., & Loosli, J. K. (1960). Forage Intake and Efficiency of Feed Utilization in Dairy Cattle. *Journal of Dairy Science*, *43*(9), 1275-1281.
[61] Burke, D. (2001). *Dairy Waste Anaerobic Digestion Handbook*. Environmental Energy Company, Olympia, WA, p.17.
[62] Lorimor, J., Powers, W., Sutton, A. (2004). Manure Characteristics. *Manure Management Systems Series, MWPS-18 Section 1, Second Edition*.
[63] Atandi, E., & Rahman, S. (2012). Prospect of anaerobic co-digestion of dairy manure: a review. *Environmental Technology Reviews*, 1(1), 127-135.
[64] US EPA. (2006, October). Table IIa: Animal Waste Characteristics. *Climate Leaders Draft Manure Offset Protocol*, p. 18.
[65] US EPA. (2011). *2009 EPA Greenhouse Gas Inventory, Annex 3.10.* Retrieved 2 April 2018 from http://epa.gov/climatechange/emissions/downloads09/Annex3.pdf
[66] Barker, J. (2001). *Methane Fuel Gas from Livestock Wastes: A Summary.* North Carolina State University Cooperative Extension Service, EBAE 071-80.
[67] Faulhaber, C. R., Raman, D. R., & Burns, R. T. (2012). An engineering-economic model for analyzing dairy plug-flow anaerobic digesters: cost structures and policy implications. Transactions of the ASABE, 55(1), 201-209.

this model, two Guascor engines produce a total capacity of 1420 kW. Complete calculations are provided in Appendix 3.

These factors were applied to a typical electricity consumption on a farm of 7.3 kWh/cow/week as reported by Upton et al. (2010).[68] Dairy farms in particular source a lot of energy requirements from electricity, and many of these key components are related to the milk collection and storage processes. An example of direct-use electricity breakdown on dairy farms is provided in Figure 8. For the farm analyzed in this report, about 3 million kWh per year will be needed for on-site use in applications such as milking pumps, ventilation, and milk refrigeration. All 3 million kWh per year could be fueled by the AD. In fact, the total amount of electricity generated on the farm in our model was about 8 million kWh per year after deducting 400,000 kWh/year needed for the digester itself.[69]

Figure 8. Electricity usage breakdown on dairy farms



Source: From Upton et al. (2010)[70]

While these applications represent direct energy use, additional electricity use from indirect applications, such as consumables, fertilizers, bought-in feed for cows, and milking equipment may also underestimate the electricity savings generated from the implementation of an anaerobic digester if some of these indirect uses could be rerouted to occur on site. Indirect energy use is the energy required to manufacture equipment, machinery, and associated operational products. Not including these additional electricity expenditures, the total electricity usage on the farm is about 3 million kWh/year. This is much less than the biogas electricity generation of 8 million kWh/year from the engine generators, leaving approximately 5 million kWh/year for sale to the electric grid in Idaho.

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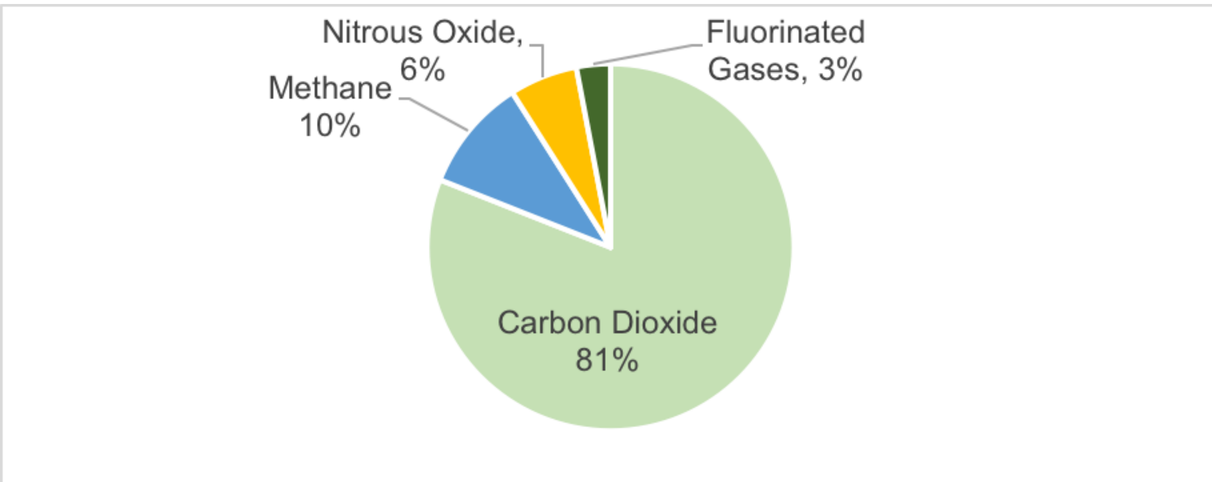
[68] Upton, J., Murphy, M., French, P., & Dillon, P. (2010). Dairy farm energy consumption. In *Dairying: Entering a decade of opportunity.* Teagasc National Dairy Conference (pp. 87-97).
[69] Lazarus, W. (2010). *Anaerobic Digester Economics*. University of Minnesota Extension.
[70] Upton, J., Murphy, M., French, P., & Dillon, P. (2010). *Dairy Farm Energy Consumption*. Livestock Systems Department, Animal & Grassland Research and Innovation Centre, Teagasc Moorepark, Fermoy, Co. Cork. Teagasc National Dairy Conference 2010.

4.7 GHG Reduction Potential

Animal agricultural accounts for about 20% of non-CO_2 greenhouse gas (GHG) emissions globally, the majority of which comes from methane (CH_4).[71] On dairy farms in the United States, 43% of methane emissions on farms come from manure management processes.[72] Manure management on dairy farms also contributes smaller quantities of carbon dioxide (CO_2) and nitrous oxide (N_2O),[73] as well as trace amounts of hazardous gases, including hydrogen sulfide (H_2S), ammonia (NH_3), and siloxanes.

Figure 9. U.S. Greenhouse Gas Emissions, 2016.
Total Emissions = 6,511 million metric tons of $CO_{2(e)}$.



Source: EPA, 2018[74]

By installing an anaerobic digester on a daily farm, the proposed project reduces emissions of the three most important greenhouse gases – CO_2, CH_4, and N_2O. Together these three gases 97% of U.S. greenhouse gas emissions in 2016.[75] In the sections that follow, we describe the properties of the

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[71] EPA. (2012). *Summary Report: Global Anthropogenic Non-*CO_2 *Greenhouse Gas Emissions: 524 1990 - 2030*. Office of Atmospheric Programs, Climate Change Division, US 525 Environmental Protection Agency, Washington, DC.
[72] Owen, J. J., & Silver, W. L. (2015). Greenhouse gas emissions from dairy manure management: a review of field-based studies. *Global change biology*, *21*(2), 550-565.
[73] Li, C., Salas, W., Zhang, R., Krauter, C., Rotz, A., & Mitloehner, F. (2012). Manure-DNDC: a biogeochemical process model for quantifying greenhouse gas and ammonia emissions from livestock manure systems. *Nutrient Cycling in Agroecosystems*, *93*(2), 163-200.
[74] US EPA. (2018*). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2016*. Retrieved from: https://www.epa.gov/ghgemissions/overview-greenhouse-gases
[75] Ibid*.*

digester and methods used to estimate the GHG reduction, which abide by U.S. Environmental Protection Agency (EPA) methodology.[76,77]

When we subtract the digester emissions from the baseline emissions, we arrive at our final estimate of 55,000 metric tons of $CO_{2(e)}$ savings per year by installing the digester on the 8,000-cow dairy farm in Gooding, Idaho. In later sections, we describe the methodology to generate this emission reduction by quantifying the emissions on a dairy farm using an anaerobic digester and comparing it to the same farm's estimated GHG emissions using a baseline manure management practice: an open anaerobic lagoon. In open lagoons, the manure degrades slowly and, in the process, emits polluting gases directly to the atmosphere. The open lagoon as a baseline practice is a reasonable assumption because the majority of U.S. farms (about 62%) employ liquid slurry lagoons as their manure management system.[78]

Installing an anaerobic digester instead of an open lagoon manure management system would reduce hazardous GHG emissions. At a time when the animal agriculture industry is being strongly encouraged to try new practices that reduce the carbon footprint, digesters present an opportunity to meet policy aims, while also providing economic benefit to the farmer and client alike.[79]

The proposed project reduces 55,000 metric tons of $CO_{2(e)}$($CO_{2(e)}$) per year of operation of the digester for manure on an 8,000-cow dairy farm (Figure 10). This emissions reduction is found by subtracting the total emissions from the CM digester system from the emissions in the baseline scenario, an anaerobic lagoon.

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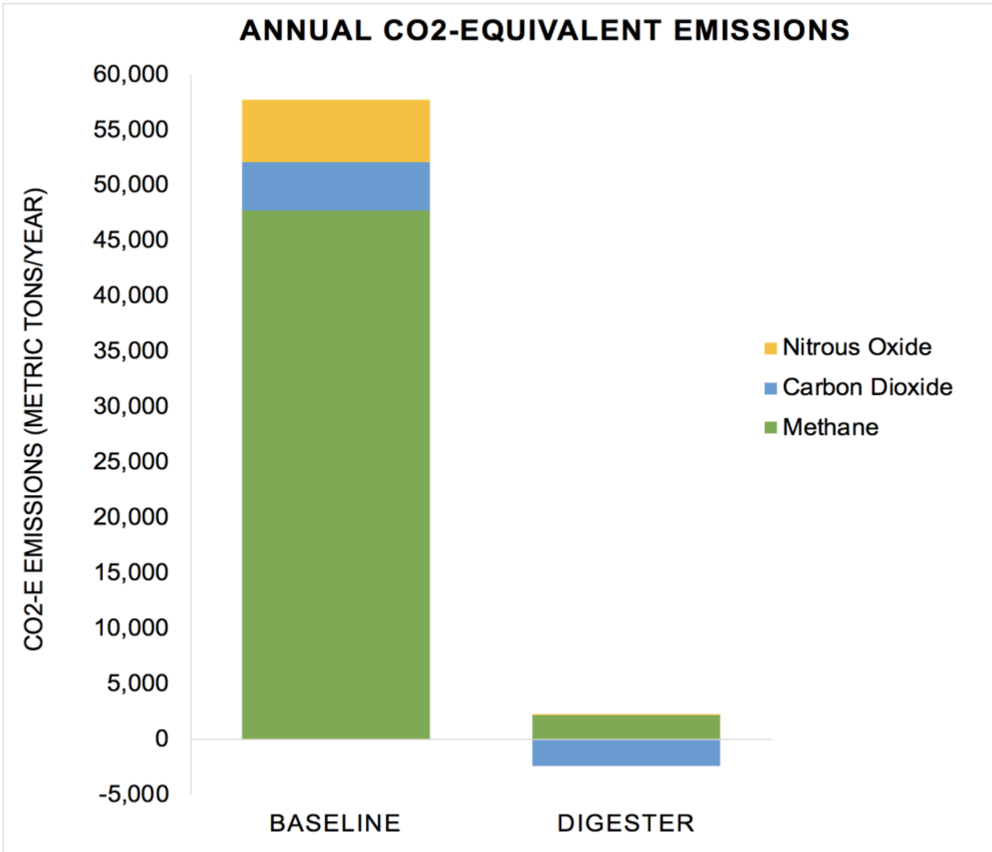
[76] US EPA. (2004, February). AgSTAR Handbook: A Manual For Developing Biogas U.S. Environmental Systems at Commercial Farms in the United States. Air and Radiation, 6062J, EPA-430-B-97-015.
[77] Lazarus, W. F., & Rudstrom, M. (2007). The economics of anaerobic digester operation on a Minnesota dairy farm. *Review of Agricultural Economics*, 29(2), 349-364.
[78] Klavon, K. H. (2011). Design and economics of plug-flow, small-scale anaerobic digesters for temperate climates. University of Maryland, College Park.
[79] Prof. Dan Anderson, Iowa State University. *Personal communication (telephone conversation).* 2 April 2018.

Figure 10. Estimated greenhouse gas emissions, in CO_2 equivalent units, per year in the baseline (open lagoon) and digester scenarios for an 8,000-cow dairy farm in Idaho



Source: Authors

While the main reduction in $CO_{2(e)}$ emissions by installing a digester arises from preventing methane emissions directly from the lagoon as seen in the baseline scenario, the AD system proposed here reduces all three of the most important anthropogenic greenhouse gases (GHGs): carbon dioxide, methane, and nitrous oxide. Each of these gases warms the atmosphere by absorbing radiation and reducing the amount of radiation that escapes out to space. However, each greenhouse gas exerts different global warming effects because of differences are due primarily to the atmospheric lifetimes and radiative efficiency of these gases. In order to directly compare the global warming impact of changes in emissions of different GHGs, a metric called the Global Warming Potential (GWP) is used. In essence, GWP reflects how much heat a greenhouse gas traps in the atmosphere relative to carbon dioxide. GWP creates a standard unit of CO_2-equivalents ($CO_{2(e)}$) into which a concentration of any GHG can be converted. For the purposes of this report, we use a methane GWP of 25 and nitrous oxide of 298, which are based on the 100-year timescale. To illustrate, a GWP of 25 means that emissions of 1 ton of CH_4 is equal to 25 tons of $CO_{2(e)}$ and 1 ton of N_2O equals 298 tons of $CO_{2(e)}$; together, these two yield a total of 323 tons of $CO_{2(e)}$. It should be noted that the 100 year timescale for GWP values is more conservative than the 20 year timescale, but we chose the former option because it is commonly used by regulators such as the California Air Resources Board.[80] Some studies recommend the use of the 20-year timescale for methane, with a GWP of 86, given it's relatively short atmospheric lifetime (~10 years), but for the purposes of this report we use the more conservative 100-year timescale. If the 20-year timescale was considered instead, the decrease in methane emission in the digester scenario yields an emissions savings of 155,000 metric tons (mt) of $CO_{2(e)}$ per year instead of 55,000 mt $CO_{2(e)}$ per year.

In order to estimate the air pollution impact of our proposed digester project, we subtracted the digester emissions from the baseline emissions amounts to obtain a reduction in units of metric tons of $CO_{2(e)}$ per year. A number of conditions were held constant between the baseline and digester scenarios. For instance, we assume equal emissions between the baseline scenario and anaerobic digester scenario with respect to fertilizer volatilization of N_2O from land applications and enteric fermentation of cows that releases methane. We also held constant the features of the manure quantity, properties, and processing, such as the number of cows, manure characteristics (e.g., pH, total solids). In the sections that follow, key assumptions and parameters used to arrive at the final emissions estimates for the baseline and digester scenarios are presented. An important component of the implementation plan is the verification and monitoring to ensure the modeled emissions (next section) are accurate, and a detailed scheme for executing this verification system is described in a subsequent section.

4.7.1 Baseline (Open Lagoon) Greenhouse Gas Emissions

The majority of dairy manure farms use anaerobic lagoons, so this is the manure management system that we assume in the baseline, pre-digester scenario.[81] Most emissions in the baseline scenario – 47,700 metric tons of $CO_{2(e)}$ per year – come from methane emitted directly from the anaerobic lagoon. In addition, smaller quantities of nitrous oxide gas are emitted from the lagoon. The high GWP value of 298 for this gas yields a substantial contribution to global warming and constitutes over 5,000 metric tons of $CO_{2(e)}$ per year from the lagoon. Barn floor direct emissions are greater in the baseline scenario because the manure is only removed once per day by scraping, compared to flushing in the digester scenario which occurs every two hours and removes more comparatively manure. The baseline scenario yields barn emissions of 370 mt $CO_{2(e)}$/year from N_2O and 390 mt $CO_{2(e)}$/year from CH_4 emissions directly from the barn floor compared to the digester scenario.

Since biogas is not generated, the farm must purchase electricity from the Idaho power grid in the baseline scenario. Previous studies report that an average dairy farm uses about 7.3 kWh of electricity per cow per week in its operations.[82] Idaho Power electricity has an average carbon intensity of 0.00052 metric tons of $CO_{2(e)}$/kWh.[83] To verify assumptions about the electric grid carbon intensity, we compared Idaho Power regional utility carbon intensity of 0.00052 metric tons of $CO_{2(e)}$/kWh to the International

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[80] Huang, A. (2018). California's Greenhouse Gas Emission Inventory. California Air Resources Board, Emission Inventory Analysis Section.
[81] Mangino, J., Bartram, D., & Brazy, A. (2001). Development of a methane conversion factor to estimate emissions from animal waste lagoons. In *US EPA's 17th Annual Emission Inventory Conference, Atlanta GA*.
[82] Upton, J., Murphy, M., French, P., & Dillon, P. (2010). Dairy farm energy consumption. In *Dairying: Entering a decade of opportunity*. Teagasc National Dairy Conference (pp. 87-97).
[83] M.J. Bradley & Associates. (2017). Benchmarking Air Emissions of the 100 Largest Electric Power Producers in the United States.

Energy Association (IEA) national electricity carbon intensity of 0.0092 metric tons of $CO_{2(e)}$/kWh to confirm that these figures were within the same order of magnitude, justifying that the regional carbon intensity is within a reasonable range. The estimated electricity emissions in the baseline scenario amount to 3,280 mt $CO_{2(e)}$ per year.

There is indication that the $CO_{2(e)}$ estimation is underestimated because it does not account for open lagoon emissions of the GHG ammonia (NH_3). In an open lagoon, aerobic bacteria exposed to oxygen at the surface would produce ammonium (NH_4), which may volatilize to generate NH_3.[84] By contrast, NH_3 production can be prevented by transferring the manure to an anaerobic storage unit – or a digester.[85] In the lagoon storage scenario, up to 70% of nitrogen contents in manure can be emitted as NH_3, which further pollutes ecosystems by contributing to excess levels of nitrogen in water bodies and transforming into nitrous oxide.[86] However, there is no current consensus about the change in cumulative NH_3 released in digester systems compared to anaerobic lagoons, so this pollutant was not included in the emissions quantifications.[87] [88] From first-order calculations, the net emissions of ammonia (NH_3) are approximately equal between the digester scenario and baseline scenario, which is consistent with previous studies that found no significant difference in NH_3 contributions.[89,90]

4.7.2 Digester Greenhouse Gas Emissions

Digester scenario emissions differ from the baseline due to the prevention of open lagoon emissions, removal of manure from the barn more frequently, and the production of electricity on site instead of purchasing it from the Idaho power grid. The model assumes all other non-digester features – such as temperature of ambient air, number and weight of the cows, energy required for milking processes, etc. – are consistent with the baseline scenario to control for potential confounding variables. One change in emissions from the baseline scenario arises from a change in the frequency with which manure is removed from the barns; the implementation of the complete mix digester involves flooding of the barns using recycled wastewater once every two hours. While the primary motivation for flooding as manure removal mechanism is to increase the biogas yield because flooding removes more material

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[84] Li, C., Salas, W., Zhang, R., Krauter, C., Rotz, A., & Mitloehner, F. (2012). Manure-DNDC: a biogeochemical process model for quantifying greenhouse gas and ammonia emissions from livestock manure systems. *Nutrient Cycling in Agroecosystems*, *93*(2), 163-200.

[85] Hansen, M.N., Henriksen, K., Sommer, S.G. (2006). Observations of production and emission of greenhouse gases and ammonia during storage of solids separated from pig slurry: effects of covering. *Atmos. Environ. 40*, 4172–4181.

[86] Hristov, A. N., Zaman, S., Vander Pol, M., Ndegwa, P., Campbell, L., & Silva, S. (2009). Nitrogen Losses from Dairy Manure Estimated Through Nitrogen Mass Balance and Chemical Markers. *Journal of environmental quality*, *38*(6), 2438-2448.

[87] Sun, F., Harrison, J. H., Ndegwa, P. M., & Johnson, K. (2014). Effect of manure treatment on ammonia and greenhouse gases emissions following surface application. *Water, Air, & Soil Pollution,* 225(4), 1923.

[88] Holly, M. A., Larson, R. A., Powell, J. M., Ruark, M. D., & Aguirre-Villegas, H. (2017). Greenhouse gas and ammonia emissions from digested and separated dairy manure during storage and after land application. *Agriculture, Ecosystems & Environment*, *239*, 410-419.

[89] Martin, J. (2003). A Comparison of Dairy Cattle Manure Management with and without Anaerobic Digestion and Biogas Utilization. EPA Contract No. 68-W7-0068 Task Order No. 400.

[90] Neerackal, G., Ndegwa, P., Joo, H., Wang, X., Harrison, J., Heber, A., Ni, J., Frear, C. (2015). Effects of anaerobic digestion and solids separation on ammonia emissions from stored and land applied dairy manure. *Water Air Soil Pollut*.

than scraping, there are additional emissions reduction benefits in the proposed setup.[91] Flushing achieves greater removal efficiency and more frequent manure removals per day (once every two hours in the proposed scenario), so ammonia (NH_3) emissions are reduced because less nitrogen is volatilized.[92] Flushing leads to reduced direct-barn emissions of methane and nitrous oxide (N_2O) by approximately 92% compared to the baseline scenario. An auxiliary benefit from recycling the water extracted from the digester effluent is that it reduces groundwater resources by nutrients in the effluent. With digester collection and destruction efficiencies of 99% and 98%, respectively, some methane leaks from the system, creating emissions of about 2,100 mt $CO_{2(e)}$ per year. However, this leakage is much smaller than the direct methane emissions from the open lagoon of ~47,000 mt $CO_{2(e)}$/year.

There is a reduction in $CO_{2(e)}$ emissions from electricity use on the farm. In the baseline scenario, the farm purchases about 3 million kWh/year of electricity from the Idaho electric grid, and this quantity can be fully replaced by electricity generated on site by combustion of biogas. The electricity generators produce 8 million kWh per year from combusting biogas, so the remaining 5 million kWh of electricity is sold back to the Idaho grid. In this way, we are able to treat the 5 million kWh that enter the Idaho grid as perfectly clean, since this is energy that was previously completely untapped (that is, it would have been emitted as methane directly to the atmosphere in the baseline scenario).

Digester scenario emissions from biogas combustion are lower than the emissions reductions from not having to purchase electricity from the Idaho electric grid, but they are not negligible. When the biogas is combusted to produce electricity, the generators emit about 1,800 tons of $CO_{2(e)}$($CO_{2(e)}$) per year. The total emissions breakdown in units of $CO_{2(e)}$ and the associated emissions factor for the biogas combustion engines are provided in Table 6. All estimates from biogas combustion follow EPA guidelines[93,94]. The proposed system includes a number of features that reduce the air pollution contribution from biogas combustion, leading to negligible air pollution contribution from non-CO_2 gases. The two engine generators will be fitted with Selective Catalytic Reduction (SCR) units, which provide additional emissions benefits by removing nitrogen oxides (NO_x) and carbon monoxide (CO) pollutants from the exhaust as the biogas is combusted. Particulate matter (PM) and other volatile gases in biogas-fueled generators occur only in trace amounts.[95,96,97]

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[91] Wilkie, A. C. (2005). Anaerobic digestion of dairy manure: Design and process considerations. *Dairy Manure Management: Treatment, Handling, and Community Relations*, *301*, 312.
[92] Wilkie, A. C. (2005). Anaerobic digestion of dairy manure: Design and process considerations. *Dairy Manure Management: Treatment, Handling, and Community Relations*, *301*, 312.
[93] Brenan, J., Pierce, C., & Hickey, R. (2016). *Dairy Co-digestion: Using an Anaerobic Digester Research Project*. California Energy Commission. Publication Number: CEC-500-2016-020.
[94] US EPA. (2016). Greenhouse Gas Inventory Guidance: Direct Emissions from Stationary Combustion Sources. Center for Corporate Climate Leadership.
[95] Oliver, J. & Gooch, C. (2016, July). Emissions from Biogas-Fueled Distributed Generation Units: Part 1 - What are the potential emissions from engine-generation sets? Dairy Environmental Systems Program, Cornell University.
[96] Braun, R. 2007. Anaerobic digestion: A multi-faceted process for energy, environmental management and rural development. In: P. Ranalli (ed.), *Improvement of Crop Plants for Industrial End Uses*, 335–416.
[97] State of Washington, Department of Ecology. (2012, March). Technical Support Document for Dairy Manure Anaerobic Digester Systems with Digester Gas Fired Engine-Generators. General Order of Approval, No. 12AQ-GO-01.

Table 6. Greenhouse gas emissions from digester biogas combustion

Pollutant gas	Units	Emissions Factor	Emissions from Engine Generator ($CO_{2(e)}$ tons/year)
Carbon dioxide (CO_2)	kg-CO_2/mmBTU	52.07	1,367.3
Methane (CH_4)	g-CH_4/mmBTU	3.20	2.1
Nitrous oxide (N_2O)	g-N_2O/mmBTU	0.63	4.9

Source: Authors

A few precautions should be taken when employing a flooding, or flushing, removal process. Fiber removal via pre-processing of the influent is needed to remove non-digestible fibers in the manure, which are also recovered in greater quantities than with scraping.

4.7.3 Validation of the model emissions estimates

To support the modeled estimates in the baseline and digester scenarios, we conducted several checks. First, we manually calculated the methane conversion factor (MCF) to verify that the EPA standard MCF value for dairy manure in Idaho was representative of Gooding County. The MCF indicates the fraction of volatile solids that is converted to methane compared to the theoretical maximum methane generating potential of manure (B0). Previous studies indicate that accounting for temperature and retention time of manure in waste management systems improves estimates of the methane generating potential in a given system. The MCF is found by the formula:

$$MCF = \frac{Annual\ Methane\ Production}{B_0 * Annual\ Volatile\ Solids\ Production}$$

, where B_0 is the theoretical maximum of methane converted from volatile solids in dairy manure.[98] The annual methane production and volatile solids production calculations used to estimate the MCF account for a number of local parameters for the farm in this implementation plan, which include timing and frequency of manure processing, length of storage (retention time), manure characteristics including percent total solids (TS), temperature of the manure storage system, monthly ambient temperature estimates and seasonal temperature variations. The calculated MCF for Gooding County was 0.64, which was only 4% different than the EPA recommended MCF of 0.67 for dairy manure in anaerobic lagoons in Idaho.[99] Further details of the methods and parameters used in the manual collection are provided in Appendix 3.

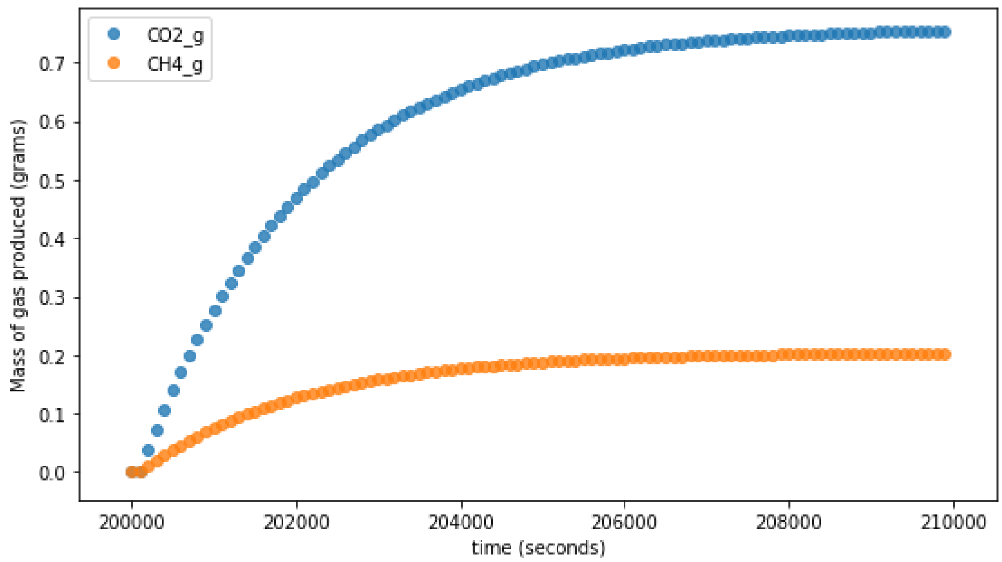
We conducted an additional exercise to confirm the biological degradation rate inside the complete mix digester meets existing EPA standards used for the biogas production calculation. A script written in Python was created to assess the relative production of methane and carbon dioxide from a complete mix digester processing dairy cow manure. This model was used to verify that the retention time in the digester was sufficiently smaller than the length of time to reach maximum biogas generation capability

[98] U.S. EPA. (2011). Table A- 184: Waste Characteristics Data. In Annex 10 of Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2009, EPA 430-R-11-005.

[99] U.S. EPA. (2011). Table A- 190: Methane Conversion Factors by State for Liquid Systems for 2009 (percent). In *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2009,* Annex 10, EPA 430-R-11-005.

from the manure. Conditions input into the model were identical to those of the digester except for the total volume of the influent and digester, which does not affect the digestion rate. Figure 11 illustrates the time to reach near maximum production of biogas is $2.1*10^5$ seconds, which is lower than the digester retention time of $8.6*10^5$ seconds.

Figure 11. Simulation of biological degradation of dairy manure in CM digester



Source: Authors

4.7.4 System Operation Verification and Maintenance

The substantial air pollution reductions achieved in the proposed system are contingent on the proper maintenance and verification of the digester system, which can be facilitated by a combination of manual and automated protocols. We propose monitoring protocols that align with previously published guidance documents conducted under the auspices of the U.S. EPA.[100] The unregulated entity should hire an outside contractor to perform a specified number of on-site verifications each year, which will ensure that the digester is operated efficiently and in compliance with regulations. All parties will work closely with the digester operations staff to ensure ongoing maintenance and updates to the automated and manual digester components alike. This includes regular farm equipment checkups, random sampling of manure and analysis, as well as safety training and record-keeping assessments. To offset labor requirements and make the process of verification as easy as possible, the proposed system will harness the latest technologies that allow us to automate as much of the digester operations as possible, such as the measurement of biogas production and utilization, automatic weighing of the manure input to the digester, and random sampling of the digester contents at different stages in the digester process.

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[100] Wagner, D. (2007). *Test/QA Plan for Verification of Anaerobic Digester for Energy Production and Pollution Prevention*. Environmental and Sustainable Technology Evaluations, Environmental Technology Verification Program.

A carefully orchestrated plan and ongoing communication is necessary among all project agents to ensure that personnel are dedicated to the task of system monitoring and verification. Some key aspects of these two protocols are displayed in the text boxes that follow.

One full-time, on-site staff member at all times of digester operations will manage the following key responsibilities:

- Actively monitor all aspects of operations daily, including daily logs of waste loads
- Summarize data in weekly and monthly operating reports
- Records kept > 5 years
- Regular safety training
- Reporting of farm management practices
  - Animal protection and dairy conditions rigorous evaluation daily.
- Influent and effluent: physical and characteristics
  - Moisture content, volatile solids (VS), nitrogen (N), phosphorus (P), and potassium (K)
  - Tipping scale on digester to measure total weight of influent; density for estimation of weight if scale downtime
  - Random sampling of raw manure, recording of manure characteristics
    - Evaluation of biogas generation, MCF, B_0

To reduce the manual labor required, this proposed implementation includes the use of latest technologies to maximize automation of digester monitoring and validation. These same technologies can be used to include additional measurements to verify the estimates in the baseline lagoon scenario. In addition to the properties measured in digester samples (total solids, volatile solids, moisture content, etc.), lagoon emissions require other data on the manure characteristics including electrical conductivity to reflect ammonium-to-nitrogen (NH_4^+/N) ratios and chlorides to monitor salt levels.

Automated electronic systems

- Digester operating conditions
  - Automatic adjustment of temperature and pH to optimal conditions
  - Calibrate meter to standard requirements
- Flow meters measuring gas throughput
  - Sensors to measure waste (daily loadings of volatile solids)
  - Calibrate meter to standard requirements
  - Measure and log biogas input rates to flares, engines, boilers
- Continuous Emission Monitoring System (CEMS)
  - Measure gas composition throughout system
  - Flag for excess levels of contaminant gases (e.g. H2S)
  - Permit for digester requires this component

- Remote control of influent, biogas, and effluent movement
    - Programmable logic controller (PLC) to
    - Piping monitors and flow valves adjustable in real time or pre-scheduled
- Digital data back-ups
    - Records maintained for counting carbon credits
    - Required to maintain a meter totalizer, back-up records
- Emergency safeguards
    - Leak detection system
    - Alarm and emergency flare for biogas combustion
    - Emergency vents

4.7.5 Monitoring and measuring output

To measure and monitor the output of the anaerobic digester for both GHG emissions and system maintenance, most biogas vendors will already include a gas analysis meter as part of the installation. The permits for digesters may already legally require installation of flow rate monitoring or an alternative monitoring/record keeping process (monitoring on a daily basis in units of MM scf/day). Best practices for monitoring the operation of a biogas system suggest the development of an Operations & Maintenance (O&M) manual in order to prove adherence to permit accordances. This manual should be in addition to the manufacturer's provided specifications, and developed by the permittee, our project partner.[101]

To comply, the system should log:

- Inlet and outlet process flow rates
- Desulfurization scrubber media pH
- Desulfurization scrubber media flow rate
- H_2S concentration entering methane separation system

Closed anaerobic digesters typically use flow meters to estimate the volume of gas produced to model relevant GHG emissions reductions, given that methane yield from a storage tank is roughly linearly related to hydraulic retention time.[102] Given that we are working with closed anaerobic digesters that are 99% effective in gas collection with minimal leakage, the resulting emissions will be closely correlated to the amount of volatile solid input feed. Anaerobic digesters typically produce 60% methane and 40% carbon dioxide, with a few trace gases (O_2, H_2S, H_2, CO) that must be monitored to prevent corrosion to the system. Hydrogen sulfide, in particular, is required to be monitored in digester

[101] Southfield Dairy Biorefinery (Wendell permit)
[102] Linke, B…, Liebetrau, J., & Dumont, M. (2016). *Methane emissions in biogas plants - Measurement, calculation and evaluation*. IEA Biogas. Retrieved from http://www.iea-biogas.net/files/member-upload/DRAFT_Methane%20Emissions.pdf.

permits given its toxicity.[103] As such, biogas monitoring systems should include a continuous emissions monitoring system (CEMS) or hand-held hydrogen sulfide monitor to check exhaust gas for H_2S levels.

The technical specifications for Landtec's Biogas 3000 (fixed) or 5000 (portable) instrument for digester gas analysis (see Appendix 3b) demonstrate how such a meter can be used to measure gas levels, temperature, atmospheric pressure, differential pressure, and gas flow. At approximately $5400 per unit, the Landtec system is a small fraction of the overall digester installation but can be critical to preventing equipment degradation. It uses additional sensors to detect for the corrosive trace gases, as an overabundance of these gases can reduce the overall methane generating potential of the system.

Landtec's system comes with a gas analyzer software that allows for online monitoring of local data outputs, which can greatly automate an otherwise manual data collection process for meeting carbon offset standards. Even with the aid of remote online data collection, more successful digester implementations still require a system manager. AgSTAR has released a recording protocol with best practices around sampling procedures, including details regarding monitoring ports, standardized calibration procedures, and appropriate error rates (+/- 3% error).

An example of the data collection during manure random sampling is provided in the Appendix; important measurements include total solids, nitrogen- and phosphorus-containing compounds in the manure sample, obtained by random sampling (total of four samples) once per month. Leakage of methane calculations can be double-checked by subtracting the sum of methane combusted from the methane generating potential of the manure input to the system.

4.8 Fertilizer production as byproduct

Additional cost savings and environmental benefits alike arise from post-processing of the digestate – the effluent that is removed from the digester after processing – into a nutrient-rich product used for fertilization of agricultural lands on site or sale in fertilizer markets.[104] Effluent from digesters can contain high amounts of many micronutrients including nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, manganese, copper, zinc, chlorine, boron, iron, and molybdenum. Some of these elements - particularly nitrogen (N) and phosphorus (P) - can be concentrated in the effluent and must be carefully controlled. Monitoring of effluent composition will ensure that it is disposed of correctly, so as to prevent damage to local ecosystems. One method of using the high-nutrient effluent is by further processing it for sale as N or P fertilizer, it must meet additional requirements as defined by the USDA.

The effluent coming out of AD contains much less volatile solids, animal and plant pathogens, and odors, and it can be further processed to prevent air and water pollution by micronutrients, especially nitrogen,

[103] Southfield Dairy Biorefinery (Wendell permit)
[104] Eagle, A. J., Henry, L. R., Olander, L. P., Haugen-Kozyra, K., Millar, N., & Robertson, G. P. (2010). Greenhouse gas mitigation potential of agricultural land management in the United States. A Synthesis of the Literature. *Technical Working Group on Agricultural Greenhouse Gases (T-AGG) Report*.

phosphorus, and potassium.[105] In addition, at an early stage in the processing of effluent, fibers can be removed and repurposed to serve as livestock bedding, which dairy farmers normally pay $184/cow per year to purchase as of 2013.[106]

4.9 Model Uncertainty and Data Gaps

The baseline and digester scenario calculations included exercises to validate the assumptions made in the model as discussed in earlier sections. However, a number of uncertainties remain and it is imperative that the monitoring and verification systems work to reduce them as the project progresses. For example, a number of assumptions were made about energy use on a dairy farm. It is possible that the farm project partner's energy breakdown differs from the assumed parameters, which may call for an adjustment of the amount of electricity that is routed to farm operations versus sold on the grid. In addition, U.S. EPA estimates of emissions factors and methane conversion factor (MCF) for dairy manure also come with a degree of uncertainty.[107] Further, the digester effluent must be carefully managed to ensure that bedding and fertilizer do not contain dangerous amounts of micronutrients or other contaminants that would threaten local ecosystems.

Uncertainty remains about the farm's capacity to incorporate additional waste streams. While the current model allows for over 40% of co-digested waste in the volume of the digester vessel, great care is required to ensure that the operating parameters of the digester – such as the total solids content of the influent – are met. Finally, the current model does not account for heat loss from the digester system; in cold winter months, it is possible that the heat needed for digester operation is underestimated and that additional accommodations could reduce the heat input needs to meet the mesophilic temperature requirements.[108]

We assume that the additional capital and operational costs of refining the biogas (scrubbing) and the effluent (fiber separation, nutrient recovery, water recovery, etc.) are outweighed by the benefits associated with the co-products that result from this additional processing. However, if circumstances change such that these steps are no longer optimal, then alternative schemes exist for processing the effluent and flaring the biogas.

We assume no siloxanes are present in the biogas generated, as this contaminant is present in wastes that contain soaps and detergents but not in dairy manure. If present, siloxanes pose an additional

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[105] Eagle, A. J., Henry, L. R., Olander, L. P., Haugen-Kozyra, K., Millar, N., & Robertson, G. P. (2010). Greenhouse gas mitigation potential of agricultural land management in the United States. A Synthesis of the Literature. *Technical Working Group on Agricultural Greenhouse Gases (T-AGG) Report*.
[106] Smith, M. M., Simms, C. L., & Aber, J. D. (2017). Case Study: Animal bedding cost and somatic cell count across New England dairy farms: Relationship with bedding material, housing type, herd size, and management system. *The Professional Animal Scientist,* 33(5), 616-626.
[107] Owen, J. J., & Silver, W. L. (2015). Greenhouse gas emissions from dairy manure management: a review of field-based studies. *Global change biology*, *21*(2), 550-565.
[108] Gebremedhin, K. G., Wu, B., Gooch, C., Wright, P., & Inglis, S. (2005). Heat transfer model for plug-flow anaerobic digesters. *Transactions of the ASAE,* 48(2), 777-785.

operational and cost risk, as the mineral deposits created during siloxane combustion must be removed from the combustion equipment.[109]

As previously mentioned in the Baseline Emissions section, there may be additional pollution from NH_3 in the baseline open lagoon scenario that were not accounted for in the model. However, given the inconsistent and conflicting results of previous studies on NH_3 emissions from anaerobic digester processed effluent compared to other solid processing and manure treatments, it is recommended that rigorous monitoring be performed on the effluent storage unit prior to compost disposal to confirm that no significant environmental hazards are produced by the digester. In addition, stringent solid liquid separation (SLS), which is proposed in the implementation of this digester project using an Agpro® separator, would likely reduce NH_3 emission risk.[110]

4.10 Project Expansion for Additional Digester Benefits

Co-digestion of waste streams from local farms, restaurants, and municipal waste is a potential avenue for expansion. From a technology perspective, the instrumentation in the current digester scenario does not require significant modification to process additional waste. A large part of this ease in accepting additional waste comes from the novel application of recycled wastewater used in flushing and milking.

The liquid wastewater recycled from flushing the barns can be used to optimize the liquid content for digester functionality, with an ideal value of ~10% solids total entering the digester. Corn silage, for example, while more energy-dense than manure, contains a lower amount of moisture content at about 30-40% total solids so would require a greater amount of liquid influent to reach the ideal digester solids percent.[111]

In the current system, there is no need for biogas flaring to manage excess biogas because the electricity generator capacity is sufficient to process the amount of biogas produced. However, co-digestion may increase the need for further options to store and export the energy. One potential solution is to compress the generated biogas and generate compressed natural gas (CNG). CNG can be used in trucks, with 80% CNG and 20% diesel, or tractors, which can run on a combination of about 90% CNG and 10% diesel.

5. Financing

Building anaerobic digesters is a cost-effective and environmentally friendly way to deal with manure and liquid waste treatment and processing. The system allows farm owners to capture biogas from waste, which can then be converted into electricity for on-farm use or sales to the grid. Digesters have the potential to produce other commercially viable products from the resulting digestate, such as

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[109] Clarke Energy. (2018). Retrieved from: https://www.clarke-energy.com/biogas/
[110] For examples of manure separators see: http://www.agprousa.com/products/manure_separators.htm
[111] Braun, R., Weiland, P., and Wellinger, A. (2015). *Biogas from Energy Crop Digestion*. IEA Bioenergy.

fertilizer and bedding for livestock. At first glance, a digester seems to be a win-win scenario, but few farms have successfully installed them. This is usually due to a lack of financing to cover the high upfront capital costs of installation. Other barriers include maintenance costs (sometimes quantified as opportunity costs), and a general lack of information on how to make the digester a profitable investment. Fortunately, programs such as AgSTAR (jointly sponsored by the EPA, USDA, and DOE) encourage the use of biogas capture systems and provide tools and guidance to support informed business decisions for those considering implementing the technology.

Once a farmer has determined if their farm is technologically suitable for a digester, they must conduct an economic feasibility study. This involves answering the following questions[112]:

1. How do I determine which biogas utilization option will maximize economic return?
2. What are the potential costs and revenues associated with the project?
3. What electricity generation and utility sales options are available?

Once these components have been determined and the project is determined financially feasible, it is time to consider financing options. This involves researching state and national funding resources, determining any project partners, and evaluating personal finances should a loan be required. The following section presents the economic feasibility and financial implementation of a complete mix digester on an 8,000 head dairy farm in Idaho. Electricity produced by the system will be used on farm with the remainder sold to the grid. Digestate will be converted to fertilizer and bedding. The bedding will be used on farm and the fertilizer will be sold.

5.1 Determining economic feasibility

5.1.1 Potential costs and revenues

Generally speaking, the feasible financing of digester projects varies with size, geographic location, and type of digester system, all of which varies depending on the user's needs. Fortunately, once technical feasibility has been established, the steps to evaluating financial feasibility are proven and straightforward.

There are several main sources of costs and revenues, with the most cost-effective projects either using or selling energy derived from biogas. In many cases, the value of the energy produced is enough to offset the cost of collecting and processing the gas, and it is up to the farmer to decide whether they (1) convert it to electricity to be used on-site or sold to grid or (2) use the gas in other ways, such as for fueling boilers or heaters.[113] Other uses that will not be considered in this implementation plan include flaring.

[112] EPA. (2004). AgSTAR Handbook. Retrieved from: https://www.epa.gov/agstar/agstar-handbook
[113] EPA, 2004

Table 7. Potential costs and revenues for digesters

Potential costs	Potential revenues
(-) Purchase and installation (location, biogas production potential, type of digester)	(+) Electricity sales
(-) Operations and maintenance	(+) Fertilizer sales
(+) Avoided electricity costs	(+) Bedding sales
(+) Avoided fertilizer costs (if farm had agriculture)	(+) Carbon credits
(+) Avoided bedding costs	(+) Renewable energy credits

Source: Authors

5.1.2 Financial forecasting

To determine financial feasibility, we utilized the NRCS Anaerobic Digester Economics spreadsheet, available online free of charge.[114] This tool was created by Bill Lazarus at University of Minnesota. Using the tool and the assumptions listed in Table xx, we calculated the payback period (number of years it takes to generate profit equal to initial capital cost), net present value (combines discounted costs and benefits to find future cash flow), and the internal rate of return (the discount rate at which NPV is equal to zero, showing the total rate of return achieved by the project).

Table 8. Financial assumptions

Indicator	Figure	Source
Number of cows	8000	Team assumption
Tons carbon reduced per year	55,000	Team calculation
Discount rate	10%	Team assumption
Operations and maintenance (as % of installation cost)	5%	NRCS model
Bedding price per cow (avoided cost)	$ 30	NRCS model
Fertilizer price per ton (sold)	$ 88.24	NRCS model
Value of electricity purchases avoided $/kWh)	$ 0.07	NRCS model
Value of electricity sale price to grid ($/kWh)	$ 0.04	NRCS model
Investment structure: Harvard (86%) EQIP (6%) REAP (7%)	$ 7,000,000 $ 6,050,000 $ 450,000 $ 500,000	

Source: Authors

Table 9. Summary of costs and revenues

COSTS

[114] Lazarus, William. (2010). Anaerobic Digester Economics Spreadsheet. Retrieved from: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/16/nrcs143_022290.xls

Installation (one time cost)	$ (7,000,000)
Operations and maintenance ($/yr)	$ (266,000)
Avoided electricity purchases ($/yr)	$ 240,576
Avoided bedding costs ($/yr)	$ 240,000
Cost per ton of $CO_{2(e)}$ reduced	$ 15
REVENUES	
Electricity sales ($/yr)	$ 186,127
Fertilizer sales ($/yr)	$ 677,859

Source: Authors

Assuming Harvard invests $ 6,050,000 (86% of the total project cost with the remainder funded through EQIP and REAP) and based on the financial assumptions in Table 9, it will take six years for the project to generate the amount Harvard invested in the project. The entire project will be profitable after seven years. A positive net present value of $ 1,333,884 indicates that the project will be profitable. The project has an average annual return of 13%.

Table 10. Financial performance indicators

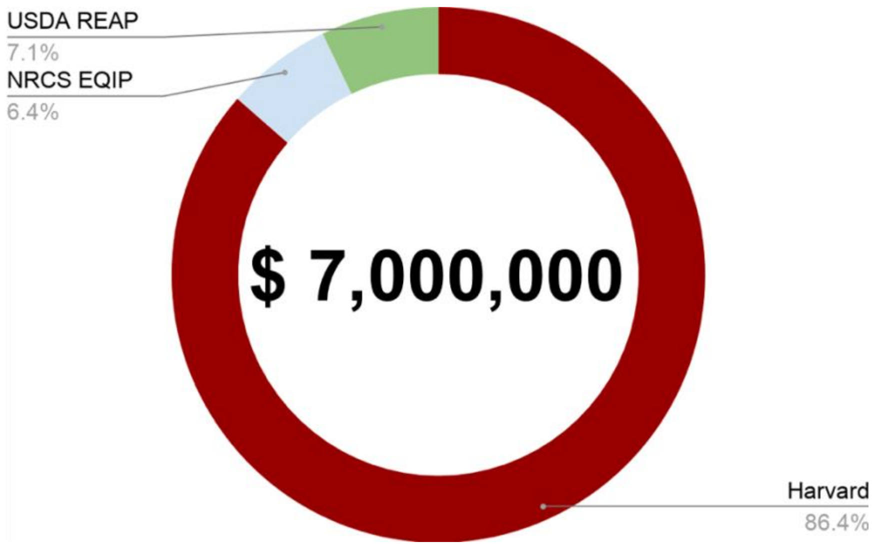
Payback period for Harvard	6 years
Payback period **for entire project**	7 years
Net present value	$ 1,333,884
Internal rate of return	13%

Source: Authors

5.3 Recommended funding structure

There are many potential sources of funding for digester projects. Details on all available sources can be found in the Appendix. For our project, we propose that the implementer secure the maximum amount of funding from the USDA Rural Energy for America Program (REAP) and the Environmental Quality Incentives Program (EQIP). These two resources will provide 13% of total project costs. The remaining 86% will be supplied by Harvard via a no interest loan in exchange for carbon credits. Harvard will receive carbon credits until their initial investment has been recouped by the project, which we anticipate to be six years. Until the project is able to pay Harvard back the initial $6 million, Harvard will receive the carbon credits. We advise that Harvard should exit the project at this time, allowing the implementer to sell carbon credits if they wish. This way, Harvard has provided a demonstration effect and allowed the implementer to operate independently. More details on how we will ensure that the project does not deteriorate after Harvard's exit can be found in the legal section.

Figure 12. Proposed funding structure



Source: Authors

5.3.1 USDA Rural Energy for America Program (REAP) = $ 500,000

The USDA Rural Energy for America Program (REAP) program aims to support American energy independence by supporting the private sector's contribution to renewable energy supply. The program accepts combination loan and grant applications year round for a minimum of $5,000 and a maximum of $25 million. The program provides guaranteed loan funding to agricultural producers such as dairy farmers in support of the development of renewable energy systems (including complete mix digesters) or energy efficiency improvements.[115]

To be eligible, the applicant must be either an agricultural producer with at least 50% of its gross annual income derived from agricultural operations or be a small business located in a rural area (defined as a town or city with less than 50,000 inhabitants). Agricultural producers can be in either rural or non-rural areas. Funding can be used to develop renewable energy systems, including anaerobic digesters. If the project costs more than $200,000, applicants must provide a technical report.[116]

We propose applying for the maximum grant amount of $ 500,000 to help fund the purchase and installation of the digester unit. There does not appear to be any issue with double-counting carbon credits, but a detailed consultation should be conducted with the appropriate Idaho program contact.[117]

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[115] USDA NRCS. (2015). Rural Energy for America Program: Renewable Energy & Energy Efficiency. Retrieved at: https://www.rd.usda.gov/files/RD_FactSheet_RBS_REAP_RE_EE.pdf
[116] USDA NRCS, 2015
[117] USDA NRCS, 2015

Table 11. REAP Terms[118]

Loan guarantee	Grant	Combined
• $5,000 minimum - $25 million maximum • Up to 85% loan guarantee • Applicants must provide at least 25% of the project cost if applying for loan guarantee only • Rates and terms negotiated with lender and subject to USDA approval • Max term - real estate: 30 years • Max term - machinery & equipment: 15 years • Max term - capital loans: 7 years • Max term - combined real estate & development: 30 years	$2,500 minimum - $500,000 maximum If applying for grant only, applicants must provide at least 75% of project cost	Applicants must provide at least 25% of the project cost

Source: Authors

5.3.2 Environmental Quality Incentives Program (EQIP) = $ 450,000

The Natural Resources Conservation Service (NRCS) Environmental Quality Incentives Program (EQIP) works with farmers to develop voluntary conservation programs that preserve natural resources and improve agricultural operations.[119] EQIP provides both financial and technical assistance to farmers as a co-investor in projects such as anaerobic digesters. In addition to general EQIP funding, Idaho also offers the National On-Farm Energy Initiative, which provides assistance for developing an Agricultural Energy Management Plan and conducting an energy audit.[120] In 2016, EQIP distributed $ 28 million over 455 projects in Idaho, $ 23 million of which was directed towards financial assistance.[121]

We propose applying for $ 450,000 of combined financial and technical assistance, depending on the auditing process outcome. The contract term for EQIP is ten years. Since the payback period is expected to be a maximum of eight years, this fits within our project's timeline.

5.3.3 Harvard University Investment = $6,050,000

Harvard University has ambitious goals to reduce its GHG emissions. Investing in projects such as this proposed digester allows Harvard to both demonstrate the viability of related projects and reap the benefits inthe form of carbon credits. As mentioned previously, in exchange for a 0% interest loan of $ 6,050,000, Harvard receives carbon credits annually until its initial investment has been repaid, which we estimate to be six years. During this time, there is ample potential for various groups and colleges

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[118] USDA NRCS, 2015
[119] USDA NRCS. (2018). Environmental Quality Incentives Program. Retrieved at: https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/eqip/
[120] USDA NRCS. (2018). National On-Farm Energy Initiative. Retrieved at: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/id/programs/?cid=stelprdb1142956
[121] USDA NRCS. (2018). EQIP Financial Information. Retrieved at: https://www.nrcs.usda.gov/Internet/NRCS_RCA/reports/fb08_cp_eqip.html#contracts

within the University to become involved with the project, providing significant non-monetary value to students and implementers alike.

5.4 Financing case studies

In order to better contextualize why we recommend the proposed financing structure, we provide several case studies.

- **$500,000** USDA REAP grant
- **$250,000** USDA NRCS EQIP
- **$250,000** Municipal energy grant
- **$200,000** CA energy commission grant
- **$500,000** conventional bank loan @ 5.3% interest

$1.7 million

Complete mix – 900 cow California dairy

5.4.1 Tolenaar Holsteins Dairy[122]

Tolenaar Holsteins Dairy is located in California. It is the most technologically similar project to ours since it uses a complete mix digester, although on a much smaller scale. It also currently only operates on manure, which we propose as well. While there are opportunities for co-digestion, we believe it's better to start with a simpler set up before expanding to include other feedstocks. See section xx for more information on co-digestion.

Due to its smaller size, the digester costs significantly less, but it has a similar payback period of ten years, likely due to the conventional bank loan repayment. Tolenaar has a sell-all agreement with the utility whereby the farm sells electricity to the grid at $0.06 per kWh and does not use any on-farm. Since our project is a larger scale, it is possible to both power the farm and sell excess electricity to the grid.

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[122] EPA AgSTAR. (2014a). Tolenaar Holsteins Dairy - El Grove, CA. Retrieved at: https://www.epa.gov/sites/production/files/2014-12/documents/tolenaar_holsteins_agstar_site_profile_508_022614.pdf

5.4.2 Loyd Ray Farms

Loyd Ray Farms in located in the Piedmont region of North Carolina, near Duke University, one of the project sponsors. It's home to over 8,500 swine and had a functioning anaerobic digester basin system installed in 2011.[123] The digester is part of a demonstration project funded by a combination of investment from Google, Inc. and Duke University and grants from the North Carolina Division of Soil and Water Conservation's Lagoon Conversion program and NRCS EQIP.

Duke University and Duke Energy provided $700,000 to cover capital costs and shares O&M costs with Google, Inc. in return for a portion of carbon offsets. The project offsets about 5,000 metric tons of $CO_{2(e)}$q and produces enough electricity to earn approximately 500 RECs annually[124] that are registered and verified under the Climate Action Reserve (CAR) Livestock Methane Protocol.[125] Duke University

- **$115,000** grant from NC Lagoon Conversion Program
- **$385,00** USDA NRCS EQIP
- **$700,000** three-party cost sharing agreement with Duke Energy, Duke University, and Google Inc.

$1.2 million

In-ground Digester + Aeration Basin
8,640 North Carolina swine

students from the Pratt School of Engineering and Nicholas Institute for Environmental Policy Solutions engage directly with the farm, resulting in data gathered and multiple publications.[126] While the arrangement has worked fairly well over the years, expansion initiatives are working to employ a more hands-off approach to project management. Duke's Carbon Offset Initiative, which manages the project, hopes to send a price signal to the industry that instead Duke could be seen as a potential purchaser of biogas if they install similar systems. DCOI is also working directly with the local utility provider to ensure that future projects are additional to existing state-required renewable portfolio requirements. DCOI hopes to eventually switch from using natural gas to heat buildings to use biogas, which would allow them to claim carbon neutral heating.[127]

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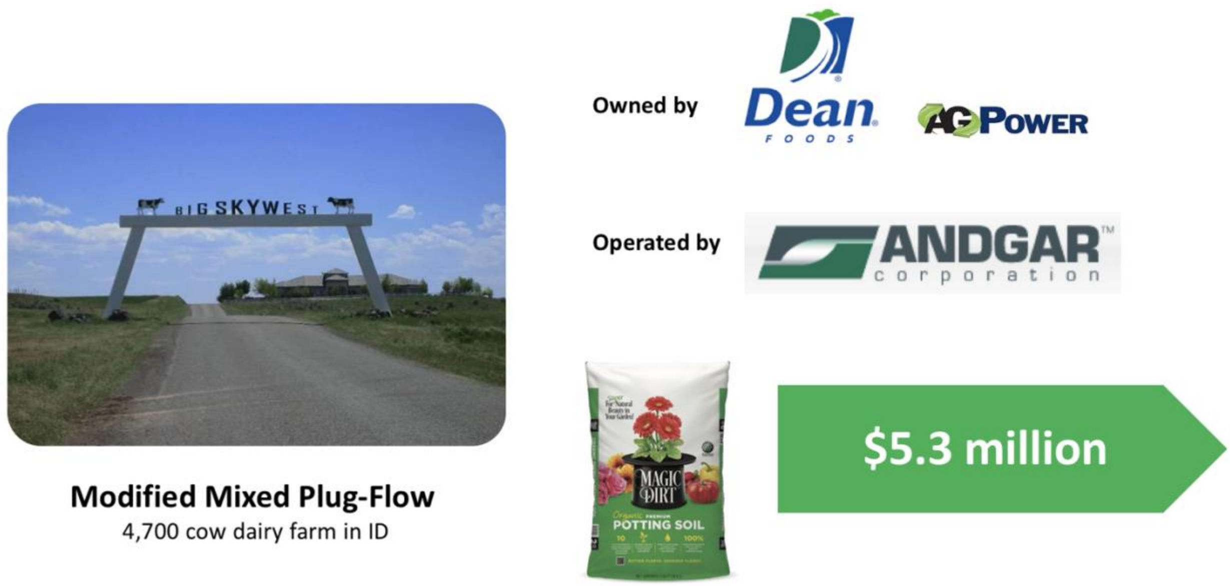
[123] EPA AgSTAR. (2014b). Loyd Ray Farms - Booneville, NC. Retrieved at: https://www.epa.gov/sites/production/files/2014-12/documents/loyd_ray_agstar_site_profile_508_022614.pdf
[124] EPA AgSTAR, 2014b.
[125] EPA AgSTAR, 2014b.
[126] Offset Network. 2018. Loyd Ray Farms. Retrieved at: https://offsetnetwork.squarespace.com/loyd-ray-farms
[127] Email with Nathanial Colbert-Sangree, Duke Carbon Offset Initiative Program Coordinator. (2018).

This innovative approach led us to consider proposing a smaller amount of funding from Harvard, for example, setting a price of $15 per ton of carbon reduced would work out to under $1 million for this scale of project. This would only be ideal if the farmer was able to obtain a bank loan for the remaining capital costs. However, it does provide an interesting alternative with less upfront costs.[128] The project is different technology than what we propose, but its financial structure greatly informed our model.



5.4.3 Big Sky West Dairy

Big Sky West is a modified mixed plug-flow dairy farm with 4,700 cows located in Gooding County, Idaho. This project is located in the same area and uses the same feedstock as our project. The digester has been operational since 2009 and is owned by a joint venture between Dean Foods and AgPower partners and is operated by Andgar Corporation.[129] What makes Big Sky West interesting is that in addition to selling electricity to the loca utility, Idaho Power Co., there is a two stage solid-liquid separation system that converts digestate both to bedding (about 40%) which is used on farm as well as a commercial soil amendment called Magic Dirt.[130]

The owner of the dairy had a progressive perspective on the potential of his dairy waste, but also understood the benefits of having a third party own and operate the system so he could still focus on the dairy operation. The dairy farm is saving money on bedding, and AgPower benefits from electricity sales, carbon credits, and RECs. One of the project managers points out that the permitting and contract

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[128] Colbert Sangree, 2018
[129] EPA AgSTAR. (2016). Big Sky West Dairy - Gooding, ID. Retrieved at: https://www.epa.gov/sites/production/files/2016-07/documents/big_sky_west_-_rev_7-18-16.pdf
[130] Lee, Karen. (2012). Third party places anaerobic digester on dairy. Progressive Dairyman. Retrieved at: https://www.progressivedairy.com/topics/management/third-party-places-anaerobic-digester-on-dairy

process was quite costly and lengthy with the utility, which presents another way where Harvard Law School could provide support free of charge with its clinics.[131]

The project represents a unique partnership within the private sector. Bob Joblin, president of the company which initially developed the project, was approached by the National Renewable Energy Laboratory (NREL) to investigate the economic feasibility of anaerobic digesters on dairy farms. Their goal was to provide the evidence for Dean Foods, a food and beverage company, to demonstrate the potential for digester implementation amongst its dairy clients. Magic Dirt is now sold in close to 1,500 Walmart stores in around 20 states.[132]

5.5 Successes and failures

According to the AgSTAR handbook, rising oil prices in the 1970s triggered the first large-scale adoption of commercial biogas systems in the U.S. Between 1975 and 1990, about 140 systems were installed. Table 12 provides some reasons for success and failure based on this timeframe.

[131] Lee, 2012
[132] Goldstein, Nora. (2017). Selling Your Sustainability Story. BioCycle. Retrieved at: https://www.biocycle.net/2017/03/08/selling-sustainability-story/

Table 12. Reasons for on-farm biogas digester success and failures (1975-1990)[133]

Successes	Failures
The owner/operator realized the benefits biogas technology had to offer and wanted to make it work	Operators did not have the skills or the time required to keep a marginal system operating
The owner/operator had some mechanical knowledge and ability and had access to technical support	Producers selected digester systems that were not compatible with their manure handling methods
The designer built systems that were compatible with farm operation	Some designer/builders sold "cookie cutter" designs to farms. For example, of the 30 plug flow digesters built, 19 were built by one designer and 90 percent failed
The owner/operator increased the profitability of biogas systems through the utilization and sale of manure byproducts. Some facilities generate more revenues from the sale of electricity and other manure byproducts than from the sale of milk	The designer/builders installed the wrong type of equipment, such as incorrectly sized engine generators, gas transmission equipment, and electrical relays
	The systems became too expensive to maintain and repair because of poor system design
	Farmers did not receive adequate training and technical support for their systems
	There were no financial returns of the system or returns diminished over time
	Farms went out of business due to non-digester factors

Source: Authors

6. Legal Requirements

6.1 Contracts and Agreements

6.1.1 Master Agreement between Harvard University and Farm

Harvard will provide a zero-interest loan to the farm covering initial financing costs not otherwise provided for with grants. Harvard will additionally provide legal support via its law school's legal clinic, assisting with permit and grant applications, permit renewals, and ongoing regulatory compliance.

[133] EPA, 2004

The farm agrees to pay back the loan over the projected eight-year repayment period, providing all carbon offset credits generated on-site in lieu of interest on the start-up loan. The farm furthermore agrees to maintain a dairy herd sufficient to generate at least 50,000 tons of offset credits per year, as well as to dedicate as many employee hours as necessary to provide requisite supervision and maintenance of the facility.

In return, the farm receives all electricity necessary for its needs, as well as bedding and fertilizer produced by the digester (to be used on-site or sold to third parties).The farm is free to draw from whichever revenue streams it chooses (electricity sales, fertilizer sales, third-party waste processing fees, or avoided costs) to meet its debt obligations. The farm may wish to pursue agreements with other third parties to assure purchasers of digester outputs.

6.1.2 Service Agreement between Farm and Vendor

The vendor will design and construct the digester. The vendor will also provide initial training to farm staff dedicated to the facility's maintenance and operations. Harvard may also provide its own technical experts from its graduate science programs to assist in designing the digester and training maintenance personnel.

6.1.3 Firm Energy Sale Agreement between Farm and Utility

(See "Sale of Electricity: Utility Agreement" under "Permitting and Approvals.")

6.1.4 Other Contracts

Farm will increase in general liability insurance (up to $1,00,000) to satisfy interconnection requirements with utility; farm will dedicate personnel to operate and maintain digester; waste disposal agreements; fertilizer sale agreements.

6.2 Permitting and Approvals

The project requires air, water, and solid waste permits from state agencies; zoning and construction authorization from the county; and a state commission-approved energy sales agreement with the local utility. These processes together entail permitting fees in excess of $100,000 (not including legal fees and professional certification costs), and will likely take 1.5 – 2 years to complete. Some approval processes, such as zoning board review and formation of the utility agreement, may require significant revisions to the facility's design,[134] whereas other processes may significantly limit siting choices. The various approval processes are described in the following section and in the appendices.

[134] Koch, Blair. (Dec. 11, 2010). "Permit Approved for Buhl Anaerobic Digester," *Magic Valley Times-News*. Retrieved from http://magicvalley.com/business/local/7cc9b854-04c6-11e0-a8dc-001cc4c002e0.html (limiting digester feedstock to manure-only, but allowing the facility to process off-farm matter).

Strategy: Local regulators should be contacted early in the project development process and be made aware of the significant co-benefits of anaerobic digesters on dairy farms (i.e., odor reduction and better water pollution risk management).

6.2.1 Clean Air: Permit to Construct

Permits to Construct (PTC) issued by the Idaho Department of Environmental Quality (IDEQ) act as both a state-level construction permit and an air emissions operations permit. Any new or modified stationary source which emits or may emit air pollution must obtain a PTC from IDEQ prior to beginning construction or modification. A 15-day pre-permit construction approval can be obtained to enable project construction while the PTC is in process.[135]

"Air pollutant" is defined broadly under administrative code to include "any substance, including but not limited to, dust, fume, gas, mist, odor, smoke. . . or particulate matter."[136] The permitting requirement is triggered by any amount of emissions to be released by a new or modified facility (other than fugitive emissions).[137]

Please see the appendix for analysis explaining why a Tier I Operating Permit is not required.

Authority: IDAPA 58.01.01.202–208

Governing agency: IDEQ.

Components: Ambient air impact assessments; pollution dispersion modeling; emissions inventories; description of operating processes planned; process flow diagram; description of equipment to be used (including, e.g., make and model, proposed process rate, maximum process rate); uncontrolled potential to emit; scaled plot plan; and construction schedule.[138]

Processing fees:

- Initial Application fee: $1,000 (covers both the PTC and pre-PTC)
- Permit Processing Fee: as determined by the tons of pollutants released by the proposed project (e.g., Emissions = 1-10 tons per year: $2,500; Emissions = 10-100 tons per year $5,000, etc.). As noted above, the definition of "pollutants" is extremely broad.

Timeframe: About ten months.[139]

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[135] *See* http://www.deq.idaho.gov/permitting/air-quality-permitting/forms-and-checklists.aspx#ptc, "15-Day Pre-Permit."
[136] I.D.A.P.A. § 58.01.01.006.05 (2018).
[137] I.D.A.P.A. § 58.01.01.006.40 (2018).
[138] A list of forms and guidance to complete the PTC application is available through the following link: http://www.deq.idaho.gov/permitting/air-quality-permitting/forms-and-checklists.aspx#ptc
[139] IDEQ. (April 11, 2017). "Final Permit Letter, Facility ID No. 067-00022." Retrieved from http://www.deq.idaho.gov/media/60179904/burley-ptc-permit-0417.pdf (permitting certificate for another digester project).

6.2.2 Clean Water: Nutrient Management Plan

Discharges of water pollutants from Idaho's large dairy farms are regulated under a general National Pollution Discharge Elimination System ('NPDES') permit administered by the EPA.[140] In order to comply with this state-wide NPDES permit, large dairy farms are required to develop and register a 'nutrient management plan' with program administrators. This plan quantifies animal waste production on-site, analyzes threat to water sources, and details waste management and removal processes.[141] Though the general permit expired in 2017, it was automatically administratively continued in lieu of reissuance of a new general permit. [142] Such plans also satisfy requirements for waste management plans also separately required by the Idaho State Department of Agriculture (ISDA).[143]

Governing agency: Most likely IDEQ. EPA is currently reviewing an application to transfer administration of Idaho's NPDES program to state hands.[144] If approved, the transfer could occur as early as July 1, 2018.

Components: Under the administratively-continued general CAFO permit, dairy owners and operators must notify the administrator of modifications to their Nutrient Management Plan.[145] Applications are submitted with the EPA. This notice must include the facility's location, descriptive maps, production diagrams, information on the number and type of animals, type of storage ("anaerobic lagoon" is explicitly contemplated in the permit), waste production estimates, and quantities of waste third-party transfers.[146] A state-certified specialist must be used to develop the plan.[147] The permit requirements are geared broadly to minimizing rain run-off and soil monitoring following land application of manure, concerns which should not prove prohibitive for a digester.

Because installing an anaerobic digester apparatus is likely "substantial" under the terms of the permit, a public comment period will need to be held prior to approval of the revised Nutrient Management Plan.[148] Being classified as a new source CAFO is possible where "modifications totally replace the process or production equipment that causes the discharge of pollutants" or "waste handling processes are substantially independent of the pre-existing source.[149] "New Source" CAFOs would need to submit a Finding of No Significant Impact or an Environmental Impact Statement in order to receive coverage under the general permit.

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[140] IDEQ. *Concentrated Animal Feeding Operations*. Retrieved from http://www.deq.idaho.gov/water-quality/wastewater/cafos/.
[141] *Id.* at 16.
[142] *Id*. at 10.
[143] "Rules Governing Dairy Byproduct," I.D.A.P.A.§ 02-04-14 *et seq.* (2018).
[144] U.S.EPA. *Idaho NPDES Program Authorization*. Retrieved from https://www.epa.gov/npdes-permits/idaho-npdes-program-authorization.
[145] U.S. EPA CAFO Idaho general permit, at 10.
[146] EPA CAFO Idaho general permit, *above* note 10, at 5-6.
[147] EPA Permit, p. 27-28.
[148] EPA Permit, p. 26.
[149] 68 Fed. Reg at 7200.

Fees and timeframes: Unavailable at this time because IDEQ has not yet begun administering the NPDES program. A new general permit for CAFOs are planned to be issued by IDEQ two years after authority to administer the IPDES program is transferred from the EPA (approx. July 1, 2020).[150] The EPA may at any time require any dairy farm otherwise authorized by the general permit to apply for an individual NPDES permit.[151]

Sale of Electricity: Utility Agreement

Sale of electricity would occur through a Firm Energy Sales Agreement (FESA) with the Idaho Power Company, the electric power utility in southern Idaho.[152] Because the digester and generators would be a "qualifying facility" under the Public Utility Regulatory Policies Act (PURPA),[153] the electric utility would be required to enter into negotiations to purchase power from the project at an "avoided cost" rate. (The avoided cost rate is the cost borne by the utility to produce one additional unit of power — that is, the marginal cost of that unit of power).[154] As of 2017, the Idaho Power Company's avoided cost rate for the digester would be $36.36 per MWh produced in 2022, increasing gradually to $84.86 by 2037.[155]

To give an example, a digester selling an estimated 648 MW hours per month to Idaho Power Company received in 2010 a rate of $75.65 per MW hour, scaling up over a 15 year period to $128.31 per MW a year.[156] The farm has 3,200 milking cows, 380 dry cows, and 300 calves. The agreed-upon rate was higher due to a different mix of generating units on the grid in 2010. In order to connect with the grid, the project would need to meet Idaho Power Company's interconnection and transmission requirements (equipment, siting, operations, and certifications).

Once all interconnection requirements have been satisfied, the utility will enter into a FESA with the project. The terms will include rate-of-sale, operating and maintenance requirements, penalties for default, choice of forum and law, force majeure provisions, engineer certifications, and stipulations for liquid security.

The FESA must in turn be approved by the Idaho Public Utilities Commission. The Commission's review process includes a public comment period, and in the past has run three months between filing and final determination.[157]

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[150] Public Notice of State of IDaho National Pollutant Discharge Elimination System (NPDES) Program Submission for EPA Approval, 82 Fed. Reg. 37,583, 586 (Aug. 11, 2017).
[151] 40 C.F.R. § 122.28
[152] Idaho Power Company, *Filings and Testimony in Idaho*. Retrievedfrom https://www.idahopower.com/about-us/company-information/rates-and-regulatory/filings-testimony-idaho/.
[153] *See* 18 C.F.R 292.203 (2018) (qualifying those facilities under PURPA [§3(18)(B)] which use biomass to generate power but do not exceed 80 MW in size).
[154] Independent Energy Producers Association, *Avoided Cost*, (2018), *available at* http://www.iepa.com/avoid.asp.
[155] Idaho Public Utility Commission. (Oct. 5, 2017). *Idaho Power Company Avoided Cost Rates* at 5. Retrievedfrom http://www.puc.idaho.gov/electric/Idaho%20Power%20rates%2010-05-17.pdf.
[156] Blair Koch, *above*.
[157] Idaho Public Utilities Commission, case no. IPC-E-08-09, (filed Apr. 28, 2008). Retrieved from. http://www.puc.idaho.gov/fileroom/cases/summary/IPCE0809.html.

Fees: $1,000 for interconnection application; $30,000 for facility study deposit (if required by utility)[158]; $26,410 for FERC certification[159] (if required by utility).

6.2.3 Waste Management: Permitting

Federal requirements for the management of non-hazardous wastes Resource Conservation and Recovery Act (RCRA) Subtitle D are carried out through state statute and regulations.[160] The project will need to obtain Tier III Processing Facility permitting in order to add off-farm, third party waste to its digester.[161] Tier III, rather than Tier I or Tier II, permitting is required due to the very high volume of material processed within the system and the volatile nature of the biogas created.[162]

Operating requirements include: covering, disease vector control, methane monitoring and control, and compliance with operating procedures required by authorities. Intake waste must be carefully sorted in order to avoid accidental processing of hazardous materials, such as household waste.[163] A nutrient management plan must address contamination threats to local water sources.[164] Further design, site, and operating requirements are provided in full in the appendix of this document.

Authorities: Idaho Code § 39-7401 et seq. and I.D.A.P.A. § 58.01.06.

Governing agencies: IDEQ (site and design plan); local public health district (operating, closure, and odor management plan).

Procedure: Applications for approval of site, design, operation, and closure must be filed with the relevant authorities. A public comment period must be held prior to approval by the reviewing panel.

Fees: Given the facility's large volume, the application fee will be $7,500.[165]

6.2.4 County-Level Zoning Approval166

Rezoning and zoning variances may be necessary to accommodate the digester. Zoning requirements may impose requirements on setbacks, operations, facility access, and structure height.[167]

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[158] Idaho Power Company, PURPA QF Interconnections, *available at* https://www.idahopower.com/about-us/doing-business-with-us/generator-interconnection/purpa-qf-interconnections/.
[159] FERC, Filing Fees, (Feb. 5, 2018). Retrieved from ttps://www.ferc.gov/docs-filing/fee-sched.asp.
[160] Idaho Code § 39-7401 (2018).
[161] I.D.A.P.A. § 58.01.06 (2018); see also IDEQ. (Oct. 2013). Processing (Composting) Facility Guidance and Checklists for Tier II and Tier III Processing Facilities.
[162] *Guidance*, at 6.
[163] Idaho Code § 39-7412 (2018).
[164] U.S. EPA. (May 14, 2012).*Case Study Primer for Participant Discussion: Biodigesters and Biogas*. Retrieved from https://www.americanbiogascouncil.org/pdf/biogas_primer_EPA.pdf
[165] I.D.A.P.A. 58.01.6.994 (2018).
[166] The guidance in this section was created by examining zoning requirements in Canyon County, Idaho, which has a digester facility located within it. The zoning requirements of other counties will vary, but will likely resemble those of Canyon County in content and procedure.
[167] Canyon County Development Services, http://www.canyonco.org/elected-officials/commissioners/development-services/planning-division/?doing_wp_cron=1523391360.4277729988098144531250.

Authority: County zoning ordinance promulgated under Idaho Code §67-6511.

Governing agency: Local zoning board.

Components: Zoning and classification map; aerial photo; soil maps; water maps; preliminary site plan; description of facility and operations; identity of future users of end products; and completed land use worksheet.[168]

Process: After submission of the zoning application, local agencies will be notified as will the public through newspaper advertising. The zoning board will convene for final determination following a public comment period

The requirements imposed by the county through the zoning process will be memorialized in a Development Agreement between the facility operators and county. The agreement will include conditions given by the county for approval and assurances of compliance with requirements of with the Department of Water Resources, IDEQ, Highway District, Fire District, Health District, and Idaho Transportation Company.

Time frame: The process can take about five-and-a-half months.[169]

6.2.5 County-Level Building Permits170

The project will need obtain a building permit from the county prior to construction. The filing fees associated with this process are relatively high.

Authority: Local ordinance.[171]

Governing agency: County Development Services Department.

Components: Building permit application; deed or sales agreement (with legal description of property); site plan; building plans; certificate for private road or driveway; and any other necessary material identified by the civic planner.

Fees: $70 Zoning Compliance fee, $180 plan review fee; and a Building Permit fee. The building permit fee will vary depending on the value of the digester. For example: $11,300 for a 1M project; $19,737.50 for a 2.5M project; and $33,380 for a 5M project.

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[168] Canyon County Idaho, Planning and Zoning Commission Staff Report (PH2016-71). The permitted site analyzed in the report included a fertilizer processing facility (anaerobic digesters, in turn producing biogas, fertilizer, compost, and livestock bedding).
[169] Id.
[170] Canyon County Building Dept., Permits, *available at* http://www.canyonco.org/elected-officials/commissioners /development-services/building-department/?doing_wp_cron=1523391550.7365360260009765625000
[171] For Canyon County, Building Code 06-01-09.

6.2.6 Fertilizer Sales: Registration

Fertilizer sold to third parties must be registered with the ISDA. The application includes a description of the material, laboratory analysis of the material, and any reference material relied on for statements on the fertilizer's packaging. ISDA may request an official sample of the product for independent testing. Registration must be renewed annually. Animal waste-derived soil amendment must be labeled as such on its packaging, which may impact market uptake of the product.

Authority: Idaho Code §§ 22-2205 et seq. (2018).

Governing agency: ISDA

Fee: Registration fee is $100. The state levies a tax of 15 cents per ton of fertilizer sold.

6.2.7 Other Permitting Analysis

Surface Water: Department of Environmental Quality short-term activity exemption (STAE) should construction temporarily requires dewatering of ground and discharge.

County-level Development Permit: Necessary if the site is located in a Flood Plain.

Recycled Water Permit: Dairy farms are excluded from water recycling permitting administered by the Department of Environmental Quality,[172] so such a permit is likely not required. If the farm no longer qualifies for the dairy farm exclusion because of the digester facility, the project should apply for discretionary exclusion from the Director, citing implementation of management procedures already required through solid waste and NPDES permitting.[173]

Dairy Clean Air Permit-By-Rule (PBR) Insufficient for Digesters: Almost all Idaho dairies receive authorization of their air emissions by filing a simple registration form with IDEQ (rather than by obtaining individual permits).[174] A PBR is insufficient to cover a digester, because the generators would produce federal criteria pollutants such as carbon monoxide, particulate matter, volatile organic compounds, and nitrogen oxides.

Tier II Operating Air Permits: In addition to requiring a "Permit to Construct" for air emissions, IDEQ may also require a Tier II Operating Permit.[175] Such a permit may impose other emissions standards or operating limitations in addition to those described in the PTC.[176] Exercise of this discretionary authority

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[172] I.D.A.P.A. § 58.01.17.100.02.a (2018).
[173] *Id.* at b.
[174] IDEQ, State Permits. Retrieved from http://www.deq.idaho.gov/permitting/issued-permits/ (sorting list to "Air – PBR – Dairy").
The PBR implements regulations to control ammonia emissions, a serious by-product of animal waste. Best management practices are assigned point value, and dairies emitting 100 tons or more of ammonia per year are required to meet a certain number of points by combining any number of BMPs. Anaerobic digesters are listed as a potential source under BMPs but have not been assigned a point value due to the technology still being "under development." *See* http://www.deq.idaho.gov/media/635604-dairy_bmps.pdf (IDAPA § 58.01.01).
[175] IDEQ. *Tier II Air Quality Operating Permit*. Retrieved from http://www.deq.idaho.gov/air-tier-two.
[176] I.D.A.P.A §.58.01.01.401.01 (2018).

relies on facility impacts on ambient air quality standards or increments of the prevention of significant deterioration (PSD) program.[177]

Dairy Waste Management Requirements: ISDA has promulgated additional waste management requirements for digesters in order to limit adverse impacts on surface water and groundwater.[178] For example, dairy farms must be able to store at least 180 days worth of animal waste, and those storage containers must meet certain explicit design requirements (e.g., 2 vertical feet of freeboard, inside bottom of storage facility at least 2 feet above the water table.[179] Dairy Storage and Containment Facilities must meet the standards and specifications of the USDA Natural Resources Conservation Services, the ASABE, or equally protective criteria approved by ISDA.[180]

7. Additionality and Co-Benefits

7.1 Additionality

The American Carbon Registry has an approved methodology, for which numerous dairy farms have already received offset credits for completed digester projects. The methodology involves calculating baseline emissions are laid out in more detail in the ACR methodology document,[181] but generally use a performance standard approach to assess baseline emissions.

Under the ACR guidelines, additionality simply calls for the facility to be operating in a geography where there is no regulation that requires livestock facilities to destroy methane from manure.[182] It is important to note, however, that the project must not be "double dipping" on credits for the GHG reductions; either renewable energy credits or carbon offset credits should be counted, but not both for the same emissions reductions. For this project, offsets are more logical due to the significant methane emissions reductions that can be achieved.

A number of the comments received following our presentation on April 17 centered around this idea of additionality: the financials for our project seem so strong that it is hard to imagine why there aren't many more digesters being built on large-scale farms around the United States. Based on these numbers there should be many more digesters on the way, regardless of Harvard's participation in this space.

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[177] *Id.* at § .03 (2018).
[178] ISDA, *Environmental Nutrient Management Program*, *available at* https://agri.idaho.gov/main/animals/environmental-nutrient-management/
[179] IDAPA 02.04.14.03.01 a-c (2018).
[180] IDAPA02-04-14-010-11.
[181] United Nations Framework Convention on Climate Change. (2015). *AMS-III.D: Methane recovery in animal manure management systems.* Retrieved from American Carbon Registry: https://americancarbonregistry.org/carbon-accounting/standards-methodologies/methane-recovery-in-animal-manure-management-systems/ams-iii-d-methane-recovery-in-animal-manure-management-systems.pdf
[182] United Nations Framework Convention on Climate Change, 2015.

Private project developers and digester companies should be able to move the industry forward without the support of unregulated entities like Harvard.

To this point, the key counterargument is one of revealed preference: despite a 2010 study from EPA showing that there are over 8,000 feasible sites for digesters around the U.S. (including over 2,600 dairy farms), there are still only 250 completed projects today.[183] Something is clearly preventing these projects from seeming worth it to farmers. Three of the key barriers to digester uptake (as described by subject matter experts we interviewed) are described below, and this Implementation Plan outlines the various ways in which our project and the participation of Harvard address each of these barriers.

1. **Financials**. While many digester projects have various sources of revenue, they are often not quite there in terms of economic feasibility when accounting for insurance against unexpected challenges like broken parts[184], or disruptions in certain revenue streams.[185] With certain helpful Obama era incentive programs sunsetting[186] and cheap energy in many parts of the U.S.[187], the projects really do need an extra financial boost to achieve viability.
2. **Operations and Maintenance**. Famers do not usually have expertise on their staff to manage operating a digester. Hesitancy to take on a technologically complex project without training or support on how to operate it prevents many farms from moving forward with digester projects.
3. **Other Priorities**. As dairy farm owners are assessing how to spend their limited time, pulling together all the pieces required for a successful digester project is low on the list. It falls below other concerns receiving significant attention in recent years, including nutrient management and profitability in the face of declining prices.[188] At a time dairy farmers are struggling with mental health issues as extreme as suicide due to the crises in the industry[189], taking on new supplementary projects does is not top of mind.

Harvard's contributions in the form of technical support, aligning partners, conducting some of the activities outside of normal farm expertise like permitting, and financial assistance for initial construction address each of the issues presented above. We believe there is a strong case to be made for why entities like Harvard University can be crucial to these projects moving forward, and for why Harvard in specific can provide a project model for other unregulated entities to emulate.

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[183] EPA AgSTAR. (2017, November). *AgSTAR Data and Trends*. Retrieved from U.S. Environmental Protection Agency: https://www.epa.gov/agstar/agstar-data-and-trends
[184] Colbert-Sangree, 2018.
[185] Yorgey, G. (2018, April 4). Phone Interview with Georgine Yorgey, Associate Director at Washington State University's Center for Sustaining Agriculture and Natural Resources. (Authors, Interviewer).
[186] N.C.Clean Energy Technology Center. (2018). *Database of State Incentives for Renewables & Efficiency (DSIRE)*. Retrieved from N.C. Clean Energy Technology Center: http://programs.dsireusa.org/system/program
[187] Andersen, 2018.
[188] Yorgey, 2018.
[189] Maruca, K. (2018, April 17). Presentation Q&A Comment.

7.2 Co-benefits

Would be helpful to include a table or visualization of the various costs of co-benefits (i.e., value of odor reduction and other non-market goods). Would probably want to include these figures in the financing section as well.

7.2.1 Demonstration Effect

Digester uptake is at a turning point in the United States. On one hand, enough projects have been implemented that there this is no longer completely novel technology. There are digester experts at some land grant universities in major livestock states,[190] and best practice technologies are emerging through the 250 operational projects around the U.S. already.[191]

The next step is to bring this technology to the vast majority of remaining farms that do not have digesters even though they could. EPA estimates that as of 2011 "biogas recovery systems are technically feasible at over 8,000 large dairy and hog operations. These farms could potentially generate nearly 16 million megawatt-hours (MWh) of energy per year and displace about 2,010 megawatts (MWs) of fossil fuel-fired generation."[192] Furthermore, new farms built since then are often much larger in scale and are therefore very strong candidates to build a digester as part of initial construction.[193]

Now is an especially exciting moment for entities like Harvard to get involved, according to subject matter experts we have spoken with: successful projects often require these kinds of outside entities involved that are driving for farm sustainability (both for the emissions reductions and the other benefits discussed in this section).[194] Harvard's core values include an "accountability to the future,"[195] and in a future in which dairy consumption and production in the U.S. has consistently risen over the past years (every year except 2009)[196], the dairy industry needs to become sustainable. Beyond the direct institutional action on emissions reductions proposed here, the project also builds in opportunities for research and teaching (e.g., inclusion of the Emmett Clinic for legal support) and the opportunity to take national leadership on a pressing issue, touching on other core Harvard values.[197] With the federal government taking a step back, the digester movement needs a leader to provide a case study of the project structure for how unregulated entities like universities can push the industry to

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190 EPA AgSTAR. (2018). *AgSTAR Partners*. Retrieved from U.S. Environmental Protection Agency: https://www.epa.gov/agstar/agstar-partners
191 EPA AgSTAR, 2018.
192 EPA AgSTAR, 2018.
193 Andersen, D. (2018, April 2). Phone Interview with Dr. Daniel Andersen, Assistant Professor at Iowa State University. (Authors, Interviewer)
194 Andersen, 2018.
195 Harvard University. (2018). *Commitment*. Retrieved from Harvard University Sustainability: https://green.harvard.edu/commitment
196 USDA Economic Research Service. (2018). *Dairy Data*. Retrieved from U.S. Department of Agriculture: https://www.ers.usda.gov/data-products/dairy-data/
197 Harvard University. (2018). *About: Together we are building a healthier, more sustainable community*. Retrieved from Harvard University Sustainability: https://green.harvard.edu/about

widespread adoption. By investing in this project and the related technical support network and then providing publicly available documentation of all of the work products required to make the project happen, Harvard University can be the catalyst that brings digesters to thousands of farms across the country.

Beyond the direct emissions reduction benefits and the demonstration effect that could push a broader cohort of digester project forward, there are a range of potential environmental and social co-benefits to consider for this project:

7.2.2 Educational

Right now, there are very few operators well-versed in management of digesters in the United States.[198] When farms choose to build digesters, workers who previously were in charge of something entirely different are tasked with managing the digester, with limited or no training and support. Building out a cohort of digester operators across the country will be beneficial for future construction and operation of digesters around the country. This human educational capacity could be further augmented if part of the project involves support of roundtables and other training for digester operators in key livestock farming states.[199] Our project model proposed to build technical support partnerships with digester constructors and land grant universities to solidify these relationships and build this type of community in key dairy farming states.

7.2.3 Economic Development

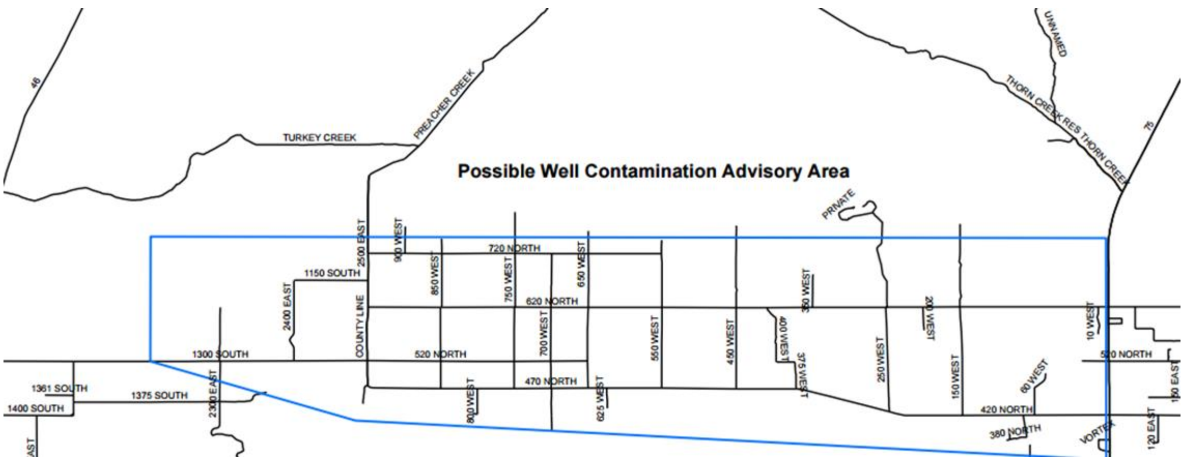
Depending on partner selection, digester installation could contribute to economic development in various ways:

- Employment: Both digester construction and operation will provide jobs that otherwise would not have existed.
- Sustainable Meat: Meat consumption will continue to be a primary source of protein and calories, both within the United States and increasingly around the world as countries develop. Large-scale farms with digesters will be critical to the long-term economic development of a sustainable livestock agricultural system.

[198] Andersen, 2018.
[199] Andersen, 2018.

7.2.4 Ecological/Environmental

Compared to pits and other manure storage and management options available, digesters are considered effective at water pollution management.[200] This is key because in 2017 Gooding County experienced widespread contamination from a dairy farm. The farm had a large amount runoff that included animal waste and was additionally directly discharging effluent. This water flowed into the Milner-Gooding Canal, and affected 40 domestic wells. As a result, the water from multiple counties, including Gooding and Lincoln, tested positive for fecal coliform and E. coli.[201]



Implementing a digester has public health benefits (see Health Implications section), as well benefits to ecosystems and to humans in other ways. Manure, replete with nitrogen and phosphorus pollution, contributes to dead zones like the one in the Gulf of Mexico that kill fish and create unsightly (and potentially toxic) algae blooms.[202]

7.2.5 Social Capital

While the proposed project design focuses on manure management for the farm where it is installed, other projects in the U.S. receive organic waste from other nearby sources, including other farms and grocery stores. Given the challenges disposing of this waste, the digester can benefit its community by providing waste utilization at a cheaper cost than alternatives. While providing cheap community waste management, the farm itself also realizes another revenue stream to help achieve economic feasibility. While the calculations in this document do not include this co-digestion component, the digester was sized to allow the option for receiving waste from other sources. If using co-digestion, the project adds an additional connection between rural and urban economic systems, creating social capital and goodwill.

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[200] https://ageconsearch.umn.edu/bitstream/93418/2/Steglin%20Sustainable%20Systems.pdf
[201] http://magicvalley.com/news/local/authorities-investigating-claims-dairy-polluted-drinking-water/article_9837c7e4-06b4-56e9-8ede-5ab177d8f32f.html
[202] https://www.epa.gov/nutrientpollution/problem

7.2.6 Additional Benefits

- Tourism: Nutrient-polluted water bodies cause close to $1 billion in losses each year for the tourism industry. The largest impact is to fishing and boating activities in water bodies affected by nutrients and the resulting harmful algal blooms.[203]
- Commercial Fishing: Algal blooms kill fish and contaminate shellfish, causing annual losses estimated to be in the tens of millions of dollars to the commercial fishing industry in the U.S.[204]
- Real Estate: Clean water can raise the value of a nearby home by up to 25 percent, and conversely, waterfront property values can decline due to unsightly and odorous algal blooms.[205]
- Water Treatment: Cleaning nitrates and algal blooms from drinking water sources is very costly. Nitrate-removal systems in Minnesota caused supply costs to rise from 5-10 cents per 1000 gallons to over $4 per 1000 gallons.[206] In one case, a downstream city in Iowa even sued its upriver farming neighbors regarding nutrient pollution.[207]
- Odor: Property owners of real estate in close proximity to odorous farms have challenged in courts that their property valuation should be lower due to this downside of the property. In fact, one appraiser valued a property ¾ of a mile from a large pig farm as 30 percent lower than it otherwise would have been.[208] A property within range of an odorous livestock farm would be less desirable than one near a far less odorous farm, all else equal. Digester systems are considered excellent at odor control.[209]

7.3 Negative Externalities of Digester Construction and Operation

If operated correctly, digesters have very few downsides. However, as noted in the public health section, a poorly operated and malfunctioning digester (like many other types of large-scale projects, when managed poorly) can cause worker injuries, less effective achievement of primary and secondary benefits, and potential for spills.

The types of farms most suitable for economically viable digesters are some of the largest farms in the country. As such, there is a social equity consideration to take into account with this proposal: it will be the already-wealthier large farmer operations that see the best returns for installing a digester due to economies of scale, rather than smaller-scale farmers who are likely more in need of additional sources of revenue to stay competitive and stay in business.

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[203] https://www.epa.gov/nutrientpollution/effects-economy
[204] https://www.epa.gov/nutrientpollution/effects-economy
[205] https://www.epa.gov/nutrientpollution/effects-economy
[206] https://www.epa.gov/nutrientpollution/effects-economy
[207] https://www.wateronline.com/doc/iowa-utility-dealt-setback-in-nutrient-case-0001
[208] https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1004&context=coopext_swine
[209] https://ageconsearch.umn.edu/bitstream/93418/2/Steglin%20Sustainable%20Systems.pdf

One can imagine a future point at which parts of the country that have many large livestock farms are receiving a significant portion of energy from a wide range of digesters. Management of an electric grid under these conditions could be difficult given the decentralized and variable nature of the energy inputs from digesters to the grid, similar to how other distributed energy resources present a challenge to electrical grid management. However, this is a very long-term issue given the number of digester currently in operations, and this could be managed if it actually becomes an issue in the future (e.g., with storage or other small-scale supply management tools of the future) - and would unlikely be an issue to the degree that solar net metering already is.

8. Public Health Assessment

8.1 Health Impact Assessment

To evaluate the impact the digester will have for the farm and the community, a full health impact assessment will be used. The HIA will evaluate the digester and ensure that the following areas are covered:

- "Screening: Determines the need and value of an HIA
- Scoping: Determines which health impacts to evaluate, analysis methods, and a workplan
- Assessment: Provides 1) a profile of existing health conditions and 2) evaluation of potential health impacts
- Recommendations: Identifies strategies to address health impacts identified
- Reporting: Includes the development of the HIA report and communication of findings and recommendations
- Evaluation and monitoring: Tracks impacts of the HIA on decision-making processes and the decision, as well as impacts of the decision on health determinants"[210]

8.1.1 Screening

To fully convey the health impact of installing an anaerobic digester on a dairy farm it was determined to conduct an independent HIA to assess potential health issues.

8.1.2 Scoping

Scoping was conducted to determine the main health impacts and additional benefits that would be affected with the implementation of the digester. Research was conducted on the variety of benefits of digesters. The casual relationship between installing a digester and the resulting impacts were identified.

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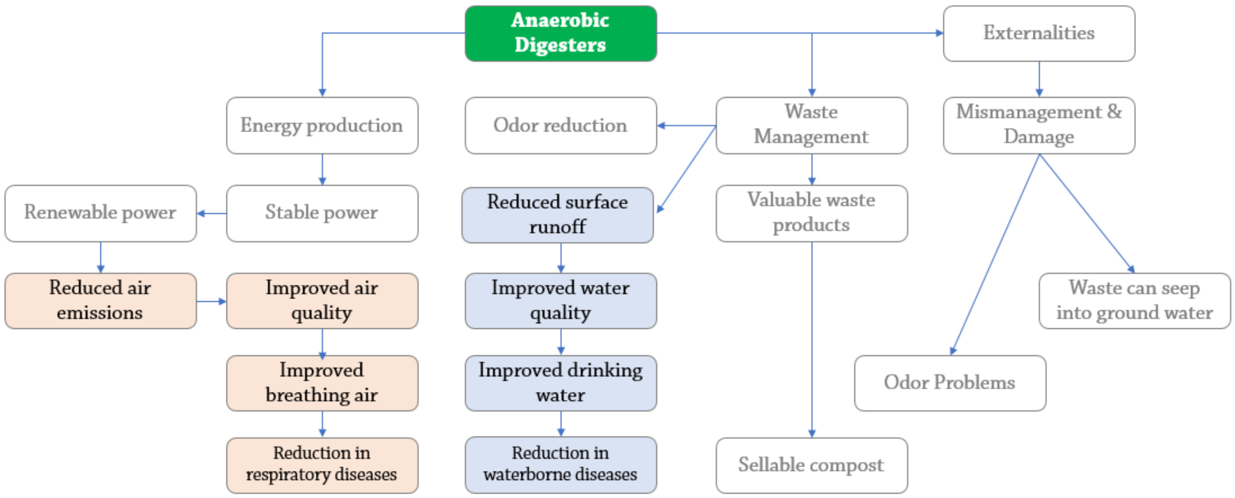
[210] https://humanimpact.org/wp-content/uploads/2017/09/SampleHIATrainingBinder.Kentucky2016.pdf

Figure 13. Causal Impacts Installing an Anaerobic Digester



Source: Authors

The digestor can lead to reduction in surface runoff, because there is not open pit lagoons for rain to wash the waste into drinking water. Air emissions can decrease as the digester will reduce methane reaching the atmosphere, resulting in a reduction in ground level ozone (smog). As a result, water and air quality can both improve. These improvements are able to lead to potential reductions in the contraction of waterborne diseases and onset of respiratory diseases. Additionally, the digester could reduce odor and produce sellable compost, from the nutrient rich digestate that the digesters produce.

The project does have a few possible adverse consequences. Mismanagement and damage of the digester, could result in odor problems and the potential for waste to seep into groundwater. Groundwater contamination could result in an increase in waterborne diseases. Odor can provide a nuisance to individuals and high levels can lead to nausea and fainting. Identifying the benefits and unintended consequences was integral in determining the impact on health from the project.

8.1.3 Assessment

The assessment included:

1. Defining potentially impacted communities, observing the baseline health, assessing the current economic and environmental conditions
2. Identifying health studies that survey the surrounding area
3. Reviewing data that is associated to potential project impacts

4. Synthesizing data to related to community conditions, health pathways, and the project impact to summarize and communicate the possible health impacts[211]

Table 13. Counties in Idaho[212 213 214]

County	Population	Per Capita Income	Value of Agricultural Products Sold	Percent that is Livestock and their Products	Chronic Lower Respiratory related deaths in 2011	Respiratory Cancer Deaths (Trachea, Bronchus, and Lung) in 2011	Total Respiratory Deaths
Madison	37,536	$13,735	$131,062,000	6%	6	1	7
Jerome	22,374	$16,947	$617,088,000	76%	11	7	18
Owyhee	11,526	$17,373	$291,557,000	68%	11	5	16
Gooding	15,464	$17,694	$942,815,000	89%	9	7	16
Minidoka	20,069	$17,747	$368,924,000	27%	12	6	18
Cassia	22,952	$17,782	$953,728,000	73%	9	6	15
Oneida	4,286	$17,950	$32,466,000	42%	1	3	4
Franklin	12,786	$17,967	$106,108,000	77%	7	2	9
Boundary	10,972	$18,011	$27,825,000	16%	8	11	19
Benewah	9,285	$18,312	$23,854,000	3%	13	8	21

It was important to determine that there would be an location where installing a digester could results in health benefits. To identify a location that would have a high impact screening was conducted across the State of Idaho. The screening including retrieving the population, per capita income, value of agricultural products sold, percent of agriculture that is livestock and their products. Additionally, chronic lower respiratory deaths and respiratory cancer deaths were retrieved for the 10 counties. Furthermore, the overall chronic lower respiratory deaths and respiratory cancer deaths, and asthma were identified across Idaho.

[211] Michanowicz. (2018). Health impact assessment. PowerPoint presentation.
[212] US Census. (2010a). Selected Economic Characteristics more information 2006-2010 American Community Survey 5-Year Estimates. Retrieved from https://factfinder.census.gov/faces/nav/jsf/pages/community_facts.xhtml
[213] US Census. (2010b). Profile of General Population and Housing Characteristics: 2010 more information 2010 Demographic Profile Data. Retrieved from https://factfinder.census.gov/faces/nav/jsf/pages/community_facts.xhtml
[214] USDA. (2012). Census of Agriculture: 2012 Idaho state and county profiles. https://www.agcensus.usda.gov/Publications/2012/Online_Resources/County_Profiles/Idaho/

Table 14. Idaho Respiratory Cause of Death

Messages:
▸ Rows with suppressed Deaths are hidden, but the Deaths and Population values in those rows are included in the totals. Use Quick Options above to show suppressed rows.

State	Cause of death	Deaths	Population	Crude Rate Per 100,000
Idaho (16)	J18.9 (Pneumonia, unspecified)	156	1,683,140	9.3
Idaho (16)	J43.9 (Emphysema, unspecified)	31	1,683,140	1.8
Idaho (16)	J44.0 (Chronic obstructive pulmonary disease with acute lower respiratory infection)	96	1,683,140	5.7
Idaho (16)	J44.1 (Chronic obstructive pulmonary disease with acute exacerbation, unspecified)	37	1,683,140	2.2
Idaho (16)	J44.9 (Chronic obstructive pulmonary disease, unspecified)	665	1,683,140	39.5
Idaho (16)	J45.9 (Asthma, unspecified)	20	1,683,140	1.2
Idaho (16)	J61 (Pneumoconiosis due to asbestos and other mineral fibres)	10	1,683,140	Unreliable
Idaho (16)	J69.0 (Pneumonitis due to food and vomit)	99	1,683,140	5.9
Idaho (16)	J84.1 (Other interstitial pulmonary diseases with fibrosis)	84	1,683,140	5.0
Idaho (16)	J84.9 (Interstitial pulmonary disease, unspecified)	30	1,683,140	1.8
Idaho (16)	J98.4 (Other disorders of lung)	14	1,683,140	Unreliable
Idaho (16)	**Total**	**1,370**	**1,683,140**	**81.4**
Total		**1,370**	**1,683,140**	**81.4**

Source: Centers for Disease Control215

Idaho	
Adult Asthma Rates	8.6%
Child Asthma	7%
Total Deaths	**21**

After comparing the respiratory deaths and disease rates in the counties to national averages, locations that had higher than average levels were identified. Gooding County was selected because it depends heavily on the dairy industry for economic products, has higher than normal respiratory deaths, and experienced a wide-spread water contamination from a dairy farm in 2017.

[215] Centers for Disease Control and Prevention. (2018). Idaho cause of death. Retrieved from wonder.cdc.gov

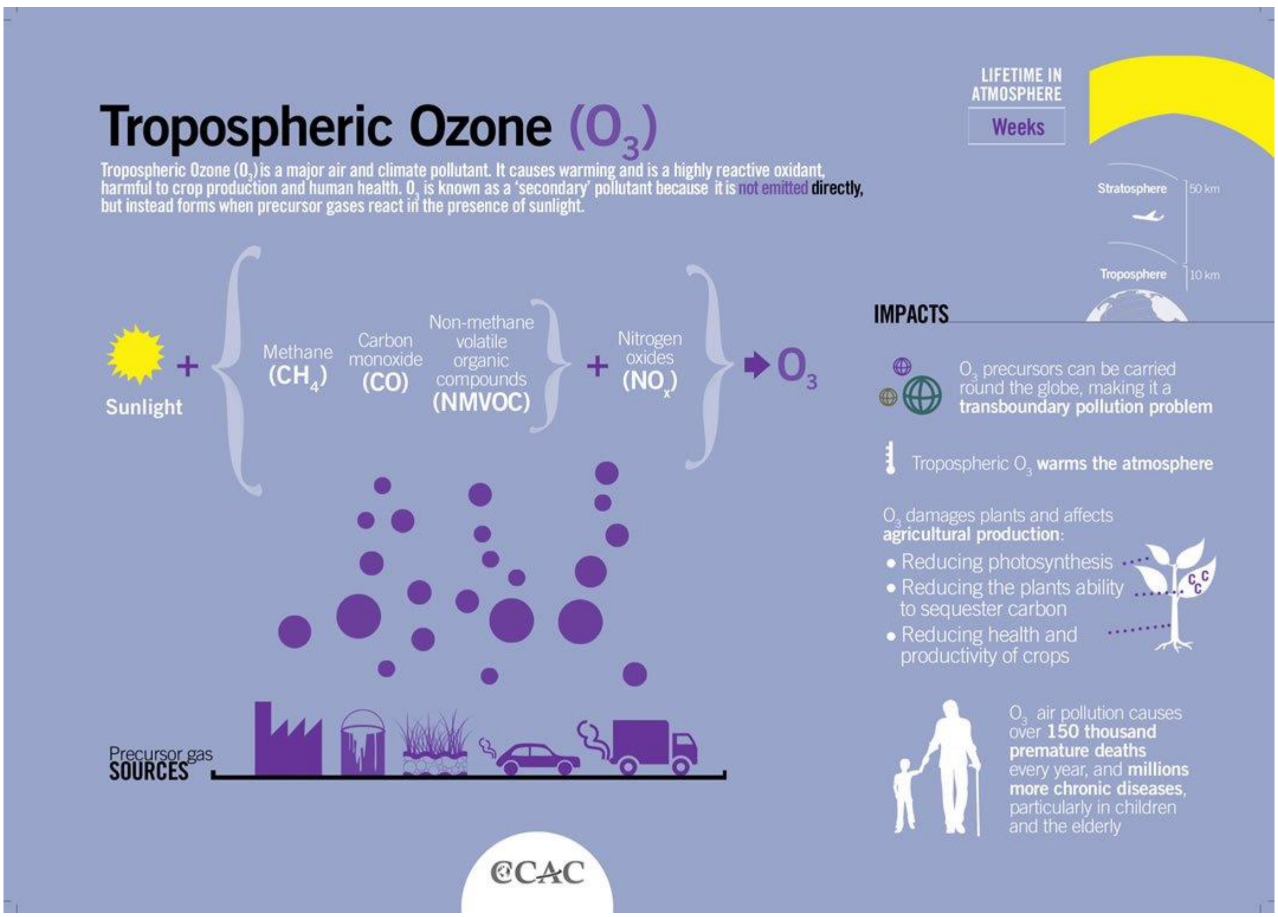
8.1.4 Recommendations and Reporting

The information from this HIA will be shared with the farmers, unregulated entity, and community members. The benefits and potential risks will be compiled in variety of materials that are open access. Additionally, there will be meetings that allow for stakeholder participation and input before the project is enacted.

8.1.5 Scientific evidence

Methane has been found to turn into ground level ozone when it interacts in the atmosphere.

Figure 14. Tropospheric Ozone Formation[216]



Sunlight along with methane and nitrogen oxides can result in ozone formation. Because methane is directly related with ozone, reducing the amount in the atmosphere leads to a reduction ozone. This can decrease the impacts of ozone which include air pollution and agricultural impacts. Reducing ozone air

[216] http://www.ccacoalition.org/en/slcps/tropospheric-ozone

pollution can result in reducing the 150,000 premature deaths and million plus chronic diseases that ozone causes.[217]

8.1.6 Data sources and analytic methods

The United States Census was used to obtain the population and economic data for the 10 counties. Agricultural data was retrieved from United States Department of Agriculture 2012 Census of Agriculture. County respiratory deaths statistics were retrieved from Idaho Department of Health and Welfare. Asthma data was retrieved from the CDC state asthma data, and children rate was retrieved from Idaho Department of Health Welfare Asthma Prevention and Control.

8.2 Monitoring and Evaluation

The digester will be monitored through the life of use. This to ensure that it is maximizing utility and reaching the identified health. If problems are found they will be addressed and fixed to ensure long-term stable and beneficial use.

8.3 Health Impacts

8.3.1 Reduced waterborne diseases

As the manure is adequately managed there is less likelihood for it to runoff to water. This can improve water quality. This results in lower nutrients in the water, as well as less E. Coli and fecal coliform. Reducing nutrients in the water can reduce the chance of eutrophication occurring in the water.

[218]

[217] http://www.ccacoalition.org/en/slcps/tropospheric-ozone
[218] Matthews, M. (2017). Dairy faces $70,000 fine in wastewater violations. *Magic Valley*. Retrieved from http://magicvalley.com/news/local/dairy-faces-fine-in-wastewater-violations/article_efb30b31-4f09-5603-811c-25a1a82c0bd4.html

Improving water quality is key to Gooding County because in 2017 much of their drinking water supply was contaminated from the 4 Brothers dairy. This resulted in eutrophication in the drinking water supply and water having to be pumped into the county to be used.

8.3.2 Reduction in respiratory diseases

Capturing the majority of pollution improves air quality by reducing the chance of smog from the methane. Improve air quality can lead to less respiratory diseases such as COPD, asthma, emphysema, bronchitis, etc.

8.3.3 Reduction in climate related health impacts

Emitting less greenhouse gases decreases amount of substances that add to the global warming potential. Methane specially has a high global warming potential as it up 25 times higher than carbon dioxide.This can help keep the environment in stable condition, and reduce impacts on ecosystems and health.

8.4 Quantifying Health Impacts

8.4.1 Health and Environmental damages

The impacts on health and the environment can be calculated using the social cost of carbon puts a dollar value on the impact of 1 ton of specific greenhouse.[219] These estimates help the overall impact from the emitting carbon into the atmosphere. The social of Valuation of 2010 Emissions[220]

Table 15. Valuation of 2010 emissions (damages per ton in $2007 US)

	CO_2	CH_4	N_2O
Median Total (3%)	$84	$4,600	$37,000

Source: Authors

The median total includes additional health and economic impacts that are not accounted for in the standard social cost. A 3% discount rate after evaluating the discount rates used in other projects.

8.4.2 Value of a Statistical Life (VSL)

The VSL is the willingness to pay for mortality risk reductions. Adding up these reductions could save a statistical. In order to save 1 life when the risk 1 in 100,000, $100 would need to be spent on each person, resulting in $10 million being necessary to save a statistical life. Currently the United States based VSL is $7.5 million. The global vsl is $1.7 million, adjusted for country specific income differences,

[219] Shindell, D. T. (2015). The social cost of atmospheric release. *Climatic Change*, *130*(2), 313-326. Retrieved from https://link.springer.com/content/pdf/10.1007%2Fs10584-015-1343-0.pdf
[220] Shindell, D. T. (2015). The social cost of atmospheric release. *Climatic Change*, *130*(2), 313-326.

relative magnitude of carbon aerosols and density.[221] For this project the global VSL was chosen due the the global impact that air emissions can have climate.

Using the costs of damages accrued per ton of emissions it was possible to calculate the number of statistical lives saved with the implementation of digester systems.

Figure 15. Summary of health valuation statistics

55,500 tons CO_2e reduction	**5.7 statistical lives saved** **Median Total:** $9.7 mm in damages avoided Global Value of Statistical Life: $1.7 mm	**Social Cost of CH_4+CO_2: $9 mm** **Median Total** 3% Discount Rate, $84/ton CO2, $4600/ton CH4	**Social Cost of N_2O: $710,000** 19.12 tons/year reduction **Median Total** 3% Discount Rate, $37,000/ton N2O

Source: Authors

Implementing the digestrr project led to $9.7 million in damages that were avoided. This would result in 5.7 statistical lives saved.

8.5 Mortality Calculations

8.5.1 Emission Reductions

It is possible to calculate the amount of mortalities that were prevented from reduction in a teragram of emissions for CO, NH_3, SO_2, NO_3, SO_4, NOx, and Primary $PM_{2.5}$.[222]

[221] See above.

[222] Dedoussi, I. C., & Barrett, S. R. (2014). Air pollution and early deaths in the United States. Part II: Attribution of PM 2.5 exposure to emissions species, time, location and sector. *Atmospheric environment*, 99, 610-617. Retrieved from https://ac.els-cdn.com/S135223101400822X/1-s2.0-S135223101400822X-main.pdf?_tid=9eea766c-af55-4900-a55f-3a5b30763270&acdnat=1525650647_3b0ebe86392231e99235946eff92e30d

Table 16. Mortalities Associated with Annual Emissions by Sector[223]

Equivalent mortalities reduction benefit expressed in avoided equivalent deaths/Tg of annual emissions. This metric quantifies how many mortalities are avoided for 1 Tg emissions reduction of each species and from each sector, assuming a spatially uniform reduction in the domain, and an equal toxicity for each of the $PM_{2.5}$ constituents.

	Electric power	Industry	Commercial	Road	Marine	Rail
CO	2.17	2.80	3.3	3.14	3.71	3.27
NH_3	1.79×10^4	2.93×10^4	6.53×10^4	5.58×10^4	8.98×10^4	3.16×10^4
SO_2	1.66×10^3	1.60×10^3	1.72×10^3	1.59×10^3	1.72×10^3	1.48×10^3
NO_3^-	1.66×10^3	5.27×10^3	7.98×10^3	10.3×10^3	11.6×10^3	6.30×10^3
SO_4^{2-}	0.51×10^4	1.20×10^4	1.70×10^4	1.63×10^4	0.79×10^4	1.16×10^4
NO_x	4.29×10^2	5.89×10^2	9.56×10^2	8.61×10^2	7.66×10^2	7.01×10^2
Primary $PM_{2.5}$	0.80×10^4	1.60×10^4	1.95×10^4	2.67×10^4	2.06×10^4	1.62×10^4

Moving forward if data is available for the emissions associated to the table then additional health benefits can calculated.

223 Dedoussi, I. C., & Barrett, S. R. (2014). Air pollution and early deaths in the United States. Part II: Attribution of PM 2.5 exposure to emissions species, time, location and sector. *Atmospheric environment*, 99, 610-617. Retrieved from https://ac.els-cdn.com/S135223101400822X/1-s2.0-S135223101400822X-main.pdf?_tid=9eea766c-af55-4900-a55f-3a5b30763270&acdnat=1525650647_3b0ebe86392231e99235946eff92e30d

Feasibility Analysis

Summary

The urgent need to address climate change is deeply and widely understood. In the face of continued inaction by the federal government and in many state legislatures, unregulated private sector entities are uniquely positioned to take leadership on this front. Doing so is not only good policy — it's good business sense. Millennial workers care deeply about environmental and social issues and want to work with organizations whose institutional actions accord with their values. Entities who seize the opportunities presented by this moment can therefore generate tremendous goodwill from consumers and employees alike.

Carbon offsets are a very useful tool for companies to meet their greenhouse gas (GHG) reduction objectives. The idea is simple: new carbon reductions in one part of the economy can "offset" difficult-to-reduce emissions in another. The agricultural sector in particular has largely escaped regulation and presents largely untapped potential for offsets, given the amount of the emissions released on farms, the potential low cost of reductions, and the lack of strong federal environmental oversight. Worldwide, farms contribute 13 percent of total global greenhouse gas (GHG) emissions and represent the second-largest emitting sector, after energy.[224] In the United States, agriculture, land use, and forestry contribute 24% of GHG emissions, and the agriculture sector alone constitutes 10% of the nation's GHG emissions.[225]

The feasibility analysis portion of this report explores two approaches for developing carbon offsets within the agricultural sector. First, it examines use of **smart irrigation pumps** and a web-based software application called **WattTime** to reduce grid-based emissions through smarter timing of their electricity for irrigation at times when the grid is being supplied by the highest proportion of renewable sources. Second, the report explores the construction and operation of **anaerobic digesters** on dairy farms. Digesters use manure excreted by cows to produce electricity and fertilizer, while preventing potent GHGs like methane from seeping into the atmosphere and ecosystem.

Potential offset clients like Harvard University play a unique role within the development of mitigation tactics. Universities can help implement pilot projects for promising new carbon offset solutions that are not yet ready for the more established offset markets. The two approaches selected for this feasibility study bear this in mind, honing in on the opportunities for innovation within these two potential solutions.

[224] Russell, S. (2017). Everything You Need to Know About Agricultural Emissions. World Resources Institute.
[225] USDA, Economic Research Service using data from U.S. Environmental Protection Agency, 2016. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014.*

Key Findings

- In assessing the feasibility of these projects, we broadly examine criteria such as feasibility (scientific and technical implementability), desirability (to the project partner, either monetarily or for other reasons), scalability (works for both smaller- and larger-scale operations), and impact (both emissions reductions and other co-benefits/negative externalities).
- Both projects passed the feasibility study, despite significant differences in the merits of each and the methods for implementation:
    - WattTime is a promising new technical solution with potential to reduce emissions associated with electricity for irrigation pumping across key agricultural areas in the United States. If a strong project partner - a demand response (DR) or smart irrigation technology company - is identified, marginal costs for adoption and barriers to adoption on additional acres would both be minimal after the initial technology integration. The biggest barrier may be that the total emissions reduction potential is not particularly high, but otherwise, signs point to a relatively straightforward and successful path to implementation thus far.
    - Anaerobic digester (AD) projects are proven most effective on large dairy farms. A number of these projects have previously been built and are already receiving emissions offset credits. The biggest barrier is financial: a project financing model with low-cost capital from federal and state governments and the unregulated entity will be critical to making these projects financially feasible.
- After selecting a project and location, next steps involve testing key assumptions and conducting in-depth financial feasibility studies. Additional discussions with potential project partners will be critical to verify the true potential emissions reductions associated with either potential solution.

Option A. WattTime

1.1 Concept

The American electricity grid is in dire need of modernization. To meet this need, the country's various utilities plan to invest more than $1 trillion in enhancing existing infrastructure, amounting to $50 to $80 billion annually. Coupled with an electricity market seeing declining sales, retail electricity prices have the potential to increase.[226] In the background, there are more options for consumers to take-up of behind-the-meter distributed energy resources ("DER"). DER allows consumers to choose how much, when, and what kind of electricity they consume. There is also an increasing trend in the interest and opportunity for individuals and firms to generate (and potentially sell) their own electricity.[227] WattTime has harnessed this momentum with its automated emissions reduction (AER) approach, which is a low-to-no-cost add-on to DR systems with high emissions reduction potential.

Of the almost 500 trillion BTU of direct energy consumption for crop products in the U.S., just under 100 trillion BTU are consumed in the form of electricity, largely for groundwater pumping for irrigation.[228] For this proposed concept, farms would utilize WattTime's software to run electricity-intensive irrigation practices only at the times when the electricity grid mix is the cleanest. Project partners (farms) would install existing WattTime software onto internet-connected smart pumps used to irrigate agricultural land. The software would automatically direct the system to operate when more renewable energy supplies the grid rather than fossil fuel energy. The system would thereby reduce GHG emissions by reducing the emissions intensity of electricity used. If paired with installation of the smart irrigation system itself (with soil and atmospheric monitoring to reduce evapotranspiration[229]), these projects could result in reduced electricity bills and reduced water usage for farmers. WattTime's approach is known as "environmental demand response" ("EDR"). EDR uses real-time grid emissions, weather, and market data to provide a 24-hour forecast of the emissions intensity, at five-minute intervals, of grids across the United States.[230]

Assumptions:

- Internet-connected automated irrigation system
- Reasonably flexible irrigation schedule

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[226] Bronski, P., Dyson, M., Lehrman, M., Mandel, J., Morris, J., Palazzi, T., … Touati, H. (2015). *The Economics of Demand Flexibility: How "Flexiwatts" Create Quantifiable Value for Customers and the Grid*. Retrieved from http://www.rmi.org/electricity_demand_flexibility
[227] Ibid.
[228] Hicks, S. (2014). Energy for growing and harvesting crops is a large component of farm operating costs. U.S. Energy Information Agency. Retrieved from https://www.eia.gov/todayinenergy/detail.php?id=18431.
[229] Evapotranspiration is loss of water from the soil both by evaporation and by plant transpiration. (2018). *Merriam-Webster's*. Retrieved from https://www.merriam-webster.com/dictionary/evapotranspiration.
[230] WattTime. (2018). WattTime Technology. Retrieved March 5, 2018, from http://watttime.org/technology/

    - Note: Flexibility of irrigation scheduling on an hourly basis is critical to the success of this project, as discussed further in Section 1.2 under the emissions reductions calculations subsection.
- Farmer interest
- Target population:
- Target farmers who irrigate using electromechanical processes (e.g. groundwater pumping or center-pivot sprinklers) with:
    - Excess irrigation capacity (they are not operating their irrigation systems 24/7 and can vary the times of irrigation as WattTime requires flexible scheduling depending on the energy mix)
    - Some consideration or implemented technology around irrigation schedule optimization/energy optimization
- Potential locations include:
    - The Midwest, such as Iowa (large-scale irrigation and would qualify as an additional for offset credit)
        - Our model system is a sprinkler-irrigated farm in Iowa. Iowa was chosen because farming and specifically irrigation farming is common in the state (lower precipitation than other parts of the Midwest), and approximately 70% of the state's irrigated farms use sprinkler systems.
    - California (due to large number of irrigated farms, abundant clean energy supply, financial incentives, although there are additionality concerns)
    - Location choice will be influenced by the electric grid's emissions intensity variability (discussed in section 1.2, under the emissions reductions calculation subsection)

1.2 Scientific & Technological Process

Agriculture in the United States uses approximately 57 billion gallons of water per day, which is more than double the daily water use of the industrial and municipal sectors combined.[231] The majority of this water requirement is for irrigation of crops.[232] In 2010, 56 million acres in the U.S. were irrigated, mainly with either sprinkler or flood irrigation methods.[233] Acreage of irrigated land doubled between 1950 and 2012, and this growth could continue if irrigation becomes a more central requirement to meet water needs under future climate change predictions. To pump groundwater up to the surface level for this growing irrigation use, farms use pumping systems often powered by electricity from the grid. Irrigation needs therefore both put a strain on water resources and contribute to greenhouse gas emissions associated with energy use.

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[231] *Water Use Trends in the United States.* Retreived March 2018 from http://pacinst.org/wp-content/uploads/2015/04/Water-Use-Trends-Report.pdf
[232] United Nations Food and Agriculture Organization (FAO), Land and Water Division. (2000). *FAO AquaSTAT Database.*
[233] National Agricultural Statistics Service. (2014). Farms and Farmland: Numbers, Acreage, Ownership, and Use. In *2012 Census of Agriculture: Highlights*, ACH12-13. U.S. Department of Agriculture.

1.2.1 Irrigation energy savings using WattTime

With the assistance of WattTime's lead analyst, Henry Richardson, we estimated the irrigation energy requirements for a farm growing 175 acres of corn in Iowa and applied WattTime's algorithm to calculate the potential emissions reductions from switching the irrigation energy to occur during cleaner times of the day. Iowa farms are under the auspices of the Midcontinent Independent System Operator, Inc. (MISO) utility, and WattTime would help the farmer choose the cleanest time of the day on the MISO grid to perform the irrigation. The model assumes center pivot irrigation, which is the most common type in the U.S. today.[234] High-level assumptions of the model are outlined below, and the calculations that underlie these figures are elaborated on in the sections that follow. Given the similarity in conditions of corn agriculture in regions of the Midwest and the fact that MISO, Nebraska, and Texas all rely on the High Plains aquifer for irrigation water, we also estimated the emissions reductions estimates for two other regions – NPPD for Nebraska and ERCOT for Texas – based on the assumption that energy demands would be similar in future climate scenarios (Table 1).[235] If we choose to pursue this project for the implementation stage, will validate these calculations by developing our own, proprietary emissions reductions optimization based on MISO fuel mix data available online, which can supplement the WattTime algorithm.[236] More than half of that irrigated corn relies on the over-exploited High Plains aquifer that underlies eight states, including Nebraska, Kansas and Texas.

- Each week (168 hours), the pump must operate for a period of at least four days (99 hours). These 99 hours of operation can occur anytime within the 168-hour period.
- Henry normalized the results per MWh of electricity consumed, so that it can be scaled to any pumping energy demand.
- For every MWh of pumping electricity that can be shifted to AER, we anticipate an annual savings of 68 lbs CO_2/MWh for a total of 4 metric tons of CO_2-equivalents (CO_2e) per year.

Table 17. Emissions reduction from WattTime for irrigation on the model Iowa Farm

Balancing Authority	MISO	NPPD	ERCOT
Emissions Reduction (%)	4.0%	0.6%	2.4%
Emissions Reduction per Unit of Energy (lbs CO_2/MWh)	68.4	11.4	30.2

[234] Nurzaman, F. P. (2017). *Irrigation Management in the Western States.* Department of Civil and Environmental Engineering, University of California - Davis, Davis, California.

[235] Barton, B. (2015). Corn Remains King in USDA Irrigation Survey. Retrieved 10 March 2018, from https://blog.nationalgeographic.org/2015/02/10/corn-remains-king-in-usda-irrigation-survey/.

[236] For an example of the MISO fuel mix data available online, see: https://www.misoenergy.org/markets-and-operations/real-time-displays/

1.2.2 Irrigation Technology and Energy Use

Energy input in irrigation comes largely from pumping water, including lifting the water to surface level from groundwater resources.[237] The energy required to lift 1 m^3 of water (1 m^3 H_2O = 1,000 kg H_2O) is 0.0027 kWh.[238] Energy demand for lift in irrigation agriculture can be estimated by the equation:

Energy(kWh) = (9.8(m s^{-2})*lift(m)*mass(kg))/(3.6*10^6*efficiency(%))

Other aspects of the system can affect the energy requirements, such as pump efficiency, pipe friction, system pressure, friction losses, and application method.[239] Furthermore, as groundwater tables decline in regions where extraction exceeds recharge, energy requirements will continue to increase. In the sections that follow, we describe the other energy calculations for center pivot irrigation used in our model.

Crop-specific irrigation energy needs

In order to calculate the energy requirements for irrigation in agriculture, it is essential to consider crop-specific requirements. For the purposes of this analysis, we consider corn as the agricultural product. The U.S. is the world's largest producer of corn, and state-level productivity is highest in the Midwest.[240] At the same time, California is the nation's second largest producing state[241], and sweet corn is one of the largest crops by production value in Massachusetts and Maine.[242] While this report uses corn as an example for irrigation calculations, many other irrigated crops are suitable for this solution. For example, potatoes are another candidate, as this crop requires large water input or soil moisture: 75% minimum water availability for potatoes, compared to 50% for corn.[243]

The technologies available for irrigation application vary widely in their methodology, efficiency, and ease of use. Sprinkler irrigation systems are one of the most common irrigation methods in the U.S. today (Figure 15) and effective on non-tree crops.

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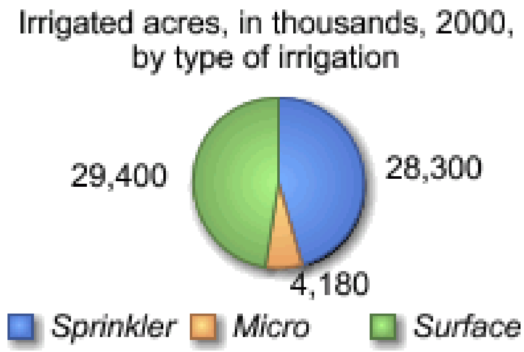
[237] Gellings, C. (2018). Energy Efficiency in Pumping and Irrigation Systems. In *Efficient Use and Conservation of Energy, Vol. II*.
[238] Rothausen, S. G., & Conway, D. (2011). Greenhouse-gas emissions from energy use in the water sector. *Nature Climate Change*, 1(4), 210.
[239] Daccache, A., Ciurana, J. S., Diaz, J. R., & Knox, J. W. (2014). Water and energy footprint of irrigated agriculture in the Mediterranean region. *Environmental Research Letters*, 9(12), 124014.
[240] Capehart, T. (2017). *Corn and Other Feed Grains: Trade.* U.S. Department of Agriculture, Economic Research Service. Retrieved from https://www.ers.usda.gov/topics/crops/corn/trade/
[241] Monfreda, C., Ramankutty, N., & Foley, J. A. (2008). Farming the planet: 2. Geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000. *Global biogeochemical cycles*, 22(1).
[242] U.S. Department of Agriculture. (2018). *2017 State Agriculture Overview: Massachusetts*. Retrieved from https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=MASSACHUSETTS
[243] Hobbs, E. H., Krogman, K. K., & Sonmor, L. G. (1963). Effects of levels of minimum available soil moisture on crop yields. *Canadian Journal of Plant Science*, 43(4), 441-446.

Figure 16. Breakdown of Irrigation System Types in the U.S.



Source: Perlman (2018).[244]

The newer, albeit more expensive, drip irrigation method applies water to the roots instead of spraying on top of the plants. It is rising in popularity due to its superior performance with respect to water conservation. A detailed comparison of existing irrigation technologies is provided in the Appendix.

Center pivot sprinkler irrigation is the most common technology choice for farms growing corn in regions with a soil type of silty clay loam, although many of the technology options discussed herein can be applied to other irrigation systems as well.[245] To minimize water loss due to wind drift in sprinkler irrigation and therefore maximize efficiency of the irrigation system, new technologies offer the conversion of a pivot or linear move sprinkler irrigation system to Low Energy Precision Application (LEPA), which applies irrigated water at the soil surface.[246] Retrofitting existing sprinkler pivots with this technology involves the installation of hoses or drag socks.[247]

Irrigation scheduling parameters allows farmers to estimate their energy requirements per water application and over the entire course of the production season. Many farm managers to maximize their energy and water efficiency is through the use of optimization methods for irrigation scheduling. The "checkbook balance" method is widely used to achieve this. This method calculates the water availability, projected use, and crop demands to estimate the next time to apply irrigated water. An example of a checkbook balance for sweet corn in western Massachusetts is provided in the Appendix. One component of the checkbook balance and other irrigation optimization technologies is the use of technology to monitor soil moisture content, evapotranspiration, and other land-dependent variables in irrigation scheduling optimization. An illustration of the in-field processes that affect irrigation frequency

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[244] Perlman, H. (2018). *Irrigation: Typical sprinkler (spray) irrigation.* U.S. Geological Survey. Retrieved from https://water.usgs.gov/edu/irsprayhigh.html

[245] Evans, R. G., Han, S., Kroeger, M. W., & Schneider, S. M. (1996). Precision center pivot irrigation for efficient use of water and nitrogen. *Precision agriculture*, 75-84.

[246] Perlman, H. (2018). Irrigation: *Typical sprinkler (spray) irrigation*. U.S. Geological Survey Water Science School. Retrieved from https://water.usgs.gov/edu/irsprayhigh.html

[247] Morris, M., & Lynne, V. (2006). *Energy Saving Tips for Irrigators.* National Sustainable Agriculture Information Service, IP278, Slot 278, Version 071806. Retrieved from https://attra.ncat.org/publication.html

and an illustration of the in-field processes that dictate soil moisture, which in turn affect irrigation scheduling, is provided in the Appendix.

One component of the checkbook balance and other irrigation optimization technologies is the use of technology to monitor soil moisture content, evapotranspiration, and other land-dependent variables in irrigation scheduling optimization. Soil moisture is measured on farms by tensiometers, manual devices that are inserted into the soil to detect soil matric water potential, which can be converted to an estimate of soil moisture. For a three-foot root depth, a shallow tensiometer is inserted 12-24 inches into the soil. A vacuum gauge at the top of the monitoring rod inserted into the soil displays the level of soil moisture. Maintenance once per year is needed to ensure that the gauge is properly calibrated.[248] Another option for assessing soil moisture is an atmometer, which measures evapotranspiration as a proxy for available soil water and has been used in irrigation scheduling for corn crops with success.[249]

Precision technology and machine learning advances present the opportunity to combine forecasted or real-time meteorological data to improve irrigation scheduling in U.S. agricultural operations, particularly by providing improved estimates of soil moisture and projected precipitation levels.[250] Programs and technologies that could enable the use of big data include NASA's Soil Moisture Active Passive (SMAP) mission and the use of drones.[251] While more farmers likely take weather forecasts into account in their irrigation practices in some way or another, automated, remote monitoring notification systems that wirelessly transfer information can empower farmers to alter pumping or other irrigation operations remotely and avoid the potential for human error.[252,253] However, automating the sprinkler or drip irrigation system may not be achievable if farmers lack the technical knowledge - one of the main reasons why the practice is still not as widespread as it could be.[254] Some technologies are more easily implemented and could still lead to substantial emissions reductions. For example, the OpenSprinkler provides smart sprinkler control for farm irrigation that incorporates real-time weather data, rain sensors, flowmeters to take much of the human input requirements out of irrigation pump management.[255] Variable frequency drive (VFD) adapters are another technological resource that can be applied to irrigation pumps. VFDs provide automatic load maintenance by reducing the inrush current needed for the motor and spreading the voltage drop over a longer period of time.[256] Installing a VFD on

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[248] Ross, E. & Hardy, L. (2005). U.S. Department of Agriculture National Engineering Handbook (NEH), Part 652, Irrigation - New Jersey supplement. Retrieved from https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs141p2_017781.pdf

[249] *Scheduling Irrigation using an Atmometer (ET Gauge) for Arkansas Corn*. University of Arkansas Division of Agriculture.

[250] Stubbs, M. (2016). *Big Data in US Agriculture*. Washington, DC: Congressional Research Service.

[251] NASA Jet Propulsion Laboratory, Soil Moisture Active Passive Mission. https://smap.jpl.nasa.gov/

[252] Stubbs, M. (2015). Irrigation in US Agriculture: On-Farm Technologies and Best Management Practices. *Washington DC: Congressional Research Service.*

[253] Bausch, W. C. (1995). Remote sensing of crop coefficients for improving the irrigation scheduling of corn. Agricultural Water Management, 27(1), 55-68.

[254] Gunston, H., & Ali, M. H. (2012). Practices of Irrigation and On-Farm Water Management-Volume 2. *Experimental Agriculture*, *48*(1), 155.

[255] https://opensprinkler.com/product/opensprinkler/

[256] White, J. & Parks, A. (2012). *Irrigation Pump Variable Frequency Drive (VFD) Energy Savings Calculation Methodology.* Public Utility District No. 1 of Chelan County.

an existing irrigation system has been shown to reduce energy consumption of sprinkler systems.[257] Once installed, VFDs require minimal manual input other than maintenance.

1.2.3 Calculations for a Model Farm in Iowa

To provide a context-specific example of how this proposed project could achieve emissions reductions, we created a model for a farm in Iowa to calculate sprinkler irrigation energy emissions from using WattTime for irrigation scheduling – choosing the specific time of day that the farm will apply water to corn crops. An Iowa farm growing corn on 175 acres (approximately the median farm size in the state[258]) was chosen because irrigation is becoming more common in the state,[259,260] and the MISO region is well-suited for WattTime to be effective in reducing emissions, as discussed in more detail at the end of this Section. Our calculations estimate: the energy demand of large-scale sprinkler irrigation systems for corn farming in Iowa, the CO_2 emissions that correspond to these energy requirements, and the potential emissions reductions offered by using WattTime technology.

Parameters and assumptions:

We consider a farm in Iowa with a total irrigated area of 175 acres, using a center pivot operating at 120 feet total dynamic head (TDH), or 52 psi. TDH reflects the height that the water must be pumped including friction losses from water passing through the pipes. In the model used in this report, we assume the lift height is 80 feet from the groundwater resource and the water is pumped at a rate of 991 gallons per minute (gpm). The lateral length of the center pivot is 400 meters, the pipe span is 120 feet per tower, and 10 towers in total. All of these features are based on typical center pivot designs in U.S. farms.[261] Pumping is achieved by a centrifugal pump with the following features:

- Maximum flow rate: 1100 gpm
- Pump efficiency: 70%
- Capacity impeller rotation: 1600 RPM
- Input shaft requirement accounting for power losses: 43 brake horsepower (BHP)

A complete description of the sprinkler and pump system specifications for the model system is provided in the Appendix.

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[257] Natural Resources Conservation Service. (2010, January). Variable Speed Drive (VSD) for Irrigation Pumping. In *Engineering Technical Note No. MT-14*, United States Department of Agriculture.
[258] U.S. Department of Agriculture, National Agriculture Statistics Service. (2012). *Table 37. Specified Crops by Acres Harvested: 2012 and 2007.* Retrieved from 2012 Census of Agriculture: https://web.archive.org/web/20150907201525/http://www.agcensus.usda.gov/Publications/2012/Full_Report/Volume_1,_Chapter_1_State_Level/Iowa/st19_1_037_037.pdf
[259] Hadish, C. (2012, July 28). Some Iowa farmers turning to irrigation to help crops. *The Gazette*. Retrieved May 5, 2018, from http://www.thegazette.com/2012/07/28/some-iowa-farmers-turning-to-irrigation-to-help-crops
[260] CropMetrics. (2013, November 19). *Irrigation in the Western Corn Belt: A 4 State Breakdown*. Retrieved from CropMetrics: http://cropmetrics.com/2013/11/irrigation-in-western-corn-belt-4-state-breakdown/
[261] Allen & Merckley. (1995). *Center Pivot Irrigation.* Retrieved 1 March 2018 from http://ocw.usu.edu/Biological_and_Irrigation_Engineering/Sprinkle___Trickle_Irrigation/6110__L12_Center_Pivot_Design_and_Operation.pdf

Determine the amount of water to be applied:

To determine the total number of hours required for each irrigation application, we consider the crop and soil type in the region of interest (Iowa). Corn roots grow and draw water from the top three feet of soil. For the soil type in Iowa, a sandy loam, about 1.25 inches of water can be stored per foot. We calculate the total water holding capacity of the soil in the root zone is 1.25 in/ft * 3 ft = 3.75 inches. Corn roots can extract about half of total available water from the soil, since the surface tension binding water to the soil makes it harder to extract in drier conditions. As such, the effective water soil content is 50% * 3.75 in = 1.9 in. In order to account for variations in water application and soil absorption, 95% efficiency in irrigation is a reasonable assumption,[262] so that would mean about 2 inches of water in the soil is needed to meet the 1.9 inches of water applied to ensure soil moisture content is met.

Example irrigation schedule for corn (grain) in Iowa[263,264]						
Soil available water holding capacity = 1.25 inches Maximum available soil moisture = 2 inches						
Week	**Stage of Growth**	**Evapotranspiration (in/week)**	**Rainfall (in/week)**	**Irrigation amount (in/acre-week)**	**Moisture balance**	**Profile soil moisture**
1	Seedling	0.4	1.5	0.0	1.1	2.0
2	2-4 leaf	0.4	0.0	0.0	-0.4	1.6
3	4-6 leaf	0.6	0.0	0.0	-0.6	1.0
4	6-8 leaf	0.8	1.2	0.0	0.4	1.4
5	8-10 leaf	1.1	0.0	1.0	0.1	1.3
6	10-12 leaf	1.4	0.0	1.5	0.1	1.4
7	12-14 leaf	1.4	0.0	1.4	0.0	2.4
8	14-16 leaf	1.5	2.3	0.0	0.8	3.0
9	pollination	2.3	3.0	0.0	0.7	3.0
10	pollination	2.3	0.0	1.0	-1.3	1.7
11	grainfilling	1.8	0.0	2.0	0.2	1.9

[262] Matthews, M., Schwankl, L., & Snyder, R. (1997). *Corn Irrigation in a Dry Year*. University of California – Davis.
[263] Rhoads, F. & Yonts, C. (2000). Irrigation Scheduling for Corn—Why and How. *National Corn Handbook.* Iowa State University Extension.
[264] Kelley, L. (2016). *Peak water use needs for corn*. Michigan State University Extension.

12	grainfilling	1.8	0.0	2.0	0.2	2.1
13	grainfilling	1.8	0.0	2.0	0.2	2.3
14	grainfilling	1.7	1.5	0.0	-0.2	2.1
15	grainfilling	1.7	1.0	1.0	0.3	2.4
16	maturity	1.6	0.0	1.5	-0.1	2.3
17	maturity	1.6	0.0	1.0	-0.6	1.7

Calculate the flow rate (Q) required from the center pivot (CP):

The average irrigation amount per week is 1.1 inches during growth season. We assume that the irrigation will take place over the course of 3.5 days, with 20 hours of operation per day to allow for 4 hours per day of unexpected maintenance, power outages, etc. In the next section, we use these parameters to estimate the flow rate required by the pump of the center pivot.

The formula is Q = 453*A*D/(F*H), where A = irrigated area (acres), Q = flow rate (gallons per minute, gpm), D = depth of water applied (in), F = frequency (days), and H = hours of operation per day. For our scenario:

Q = (453)*(175 acre)*(1.1 in)/((3.5 days)*(20 operating hours)) = 990 gallons per minute (gpm)

Estimate the hours per week required to irrigate:

Using this flow rate of 990 gpm, we calculate the hours required to complete one full circle of the center pivot. Based on the pump and efficiency information calculated previously, in order to achieve this, it would take about 12 hours of continual operation of the pump to achieve the desired results. Within the course of each day, the timing of irrigation be flexible, as reported by previous studies and explained in detail later in this section.[265]

- Horsepower in (HP_{in}) required by the sprinkler system[266]:

  HP_{in} = (Flow)*(TDH)//(39.6*OPE),

  where Flow = flow rate of center pivot in gallons per minute (gpm), TDH = total dynamic head in feet, 39.6 = conversion factor, and OPE = overall pump efficiency

[265] Heiniger, R. (2011). Corn Information for Corn Growers. In *Irrigation Management in Corn.* North Carolina State University, Rahleigh, North Carolina.
[266] Fipps, G. (1995). *Calculating horsepower requirements and sizing irrigation supply pipelines*. Texas Agricultural Extension Service.

This yields:

HP_{in} = (990 gpm)*(120)//(39.6*70) = 43 hp

Hours required to complete the irrigation in a given day:

Hours = Gross*Acres*452.5/Flow

, where gross = gross irrigation needed (in), acres = irrigated area, 452.5 = conversion factor, and flow = flow rate of center pivot

This yields:

Hours = (0.15 in)*(175 acres)*452.5/(990 gpm) = 12 hours per day to complete one full circle of the center pivot

Calculate the energy requirements over entire growing season:

Using the hours per day for the center pivot operation and the horsepower required, we calculate the total electricity needs per growing season in the model scenario:

→ (12 hr)*(43 hp)*(1 kW/1.34 electric hp)*(7 day/week)*(13 weeks[267]) = 35,041 kWh/season

→ Assume OPE of 70%[268] → 45,824*1.3 = 45,553 kWh/season

We cross-checked this figure using a method published by Martin et al. (2011)[269]:

→ 1,000 gpm center pivot = 2.21 acre-in of water/hour

→ 1.74 gallons of diesel fuel needed to lift ~80 feet and 50 psi per acre-inch

→ 14.12 kWh of electricity per 1 gallon of diesel fuel

→ (2.21 acre-in/hr)*(1.74 gal diesel/acre)*(14.12 kWh/gal diesel) = 54 kWh/hr

→ 54 kWh * 12 hours/day = 651 kWh/day

→ 651 kWh/day * 7 days/week * (13 weeks) / (1.43)[270] = 41,427 kWh per season

These two calculations yield similar results, thereby supporting our methodology. To maximize the accuracy, we averaged the two kWh electricity estimates per season for irrigation on the model farm,

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267 Missouri Crop Resource Guide. (2018). *Corn Irrigation and Water Use*. University of Missouri Extension.
268 Fipps, G. (1995). *Calculating horsepower requirements and sizing irrigation supply pipelines*. Texas Agricultural Extension Service
269 Martin, D. L., Dorn, T. W., Melvin, S. R., Corr, A. J., & Kranz, W. L. (2011, February). Evaluating energy use for pumping irrigation water. In *Proceedings of the 23rd Annual Central Plains Irrigation Conference* (pp. 22-23)
270 Factor to adjust for 70% efficiency in pump, from Martin et al. (2011).

leading to a total of 43,490 kWh of electricity will be consumed over the course of the 13-week corn irrigation season.

Estimate CO_2 emissions before WattTime is applied:

Farms in Iowa are part of the MISO utility region. To extrapolate the emissions of the sprinkler irrigation scenario, we use the value of 43,490 kWh, or 43.5 MWh, to approximate the energy per growing season. In the Midcontinent Independent System Operator (MISO, which covers our model farm in Iowa), a rough average conversion estimate of CO_2e emissions from electricity is 1,100 lb CO_2e/MWh.[271] The CO_2 emission conversion factor is based on marginal emission rates per MWh of the lifecycle greenhouse gas emissions for each fuel source,[272] weighted by their contribution to the MISO grid mix. This would yield emissions of 47,850 lb CO_2e per growing season. The total emissions on the model farm before the use of WattTIme would 24 metric tons of CO_2e per year.

1.2.4 Quantifying emissions reduction potential from using WattTime

We estimate that an average of about 50% of irrigation time per growing season can be shifted to low-emissions periods by using WattTime technology. Switching emissions hours for MISO to the lowest emissions hour (4 a.m.) during the growing season on the farm in this model reduces emissions by approximately 68.4 lb CO_2e per MWh, based on Table 1.[273] This yields a total savings on the farm of about 3,000 lb CO_2e, or a reduction of 1.5 metric tons of CO_2e per year (one season per year).

WattTime Emissions Reduction Model Assumptions

The success of WattTime technology in reducing irrigation energy consumption on the model farm relies on assumptions about the system to which it is applied, described below, and if moving forward with this project idea, it would be necessary to conduct a more detailed examination of farm irrigation practices and grid emissions intensity across all parts of the U.S. to identify the best possible sites for implementation. The two key assumptions categories discussed within this section are:

1. The energy use timing needs to be flexible. If a farm has a large amount of excess pumping capacity and therefore is only operating its pump fewer hours a week (rather than 20 hours per day), it has more flexibility to avoid high-emissions hours. On the other hand, if the irrigation needs to be operating during the daytime to cool down plants under scorching heat, then the benefits of installing WattTime would be limited if the grid is dirtiest during the day.
2. The grid needs to have variable emissions intensity. If the grid is always run entirely on coal, then varying the hours of electricity use will not reduce emissions at all. For this very reason,

[271] Calculated by Authors, based on hourly emissions profile data from MISO for June 1-7, 2016.
[272] Schlömer S., T. Bruckner, L. Fulton, et al. (2014). Annex III: Technology-specific cost and performance parameters, Table A.III.2. In *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
[273] Calculated by Authors, based on hourly emissions profile data from MISO for June 1-7, 2016.

farms in the MISO region are a strong candidate for adopting this practice. Different grids in the U.S. have different variability of emissions intensity, based largely on installed renewable (wind and solar) capacity.

With respect to the first assumption, our model assumes that half of irrigation timing is flexible, which serves as a proxy to account for both inflexibility in timing due to farmer preference, and if some hours that are currently used for irrigation are already below the average emissions.[274] The 50% assumption in flexibility of irrigation scheduling is a conservative estimate based on previous studies, which recommend, "the soil profile should be near the 50 percent depletion level when irrigation begins."[275] Corn crops must be irrigated before water has been depleted in the root zone. Calculating the depletion level that is acceptable without harm to crops is related to the feature of management allowable depletion (MAD). MAD represents the portion of total available water in the soil (TAW) that can be depleted before water stress occurs in the crop. For corn or maize, the MAD level is 0.50-0.55.[276] The assumption of flexibility is further bolstered by the fact that corn is relatively more resilient compared to other crops with respect to crop ability to withstand dry periods.[277] The intra-weekly flexibility is much larger than the seasonal dependence of irrigation scheduling, which must be more finely tuned to the amount of water and frequency of application.[278] The resulting emissions reductions would be 45 lb CO_2e per acre. If just 1 percent of America's 60 million irrigated acres were successfully using WattTime, we could achieve emissions reductions equivalent to approximately 27,000,000 lb CO_2e, or 12,245 metric tons of CO_2e per year.

For the second assumption related to the variable emissions intensity in the region of choice, the region will significantly affect the impact of the project on automated emissions reduction (AER) effects from using WattTime. For example, according to Henry Richardson, the Nebraska Public Power District (NPPD) is dominated by homogeneous coal generators and offers limited variation in marginal carbon emissions as a result. By contrast, the Midcontinent Independent System Operator (MISO) offers significant variability in emissions due to marginal generator switching between coal and natural gas. Finally, the Electric Reliability Council of Texas (ERCOT) is less reliable in its degree of marginal generation change, although generally offers greater potential for AER than NPPD.

Conclusions about emission reductions from WattTime on the model farm

The total emissions reduction number per farm is not particularly large. This makes logical sense: the project concept (and WattTime's method more generally) is one of making small, marginal changes in

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[274] Datta, S., Taghvaeian, S., & Stivers, J. (2017). *Understanding Soil Water Content and Thresholds for Irrigation Management*. Division of Agricultural Sciences and Natural Resources, Oklahoma State University.
[275] Rhoads, F. & Yonts, C. (2000). Irrigation Scheduling for Corn—Why and How. *National Corn Handbook.* Iowa State University Extension.
[276] Datta, S., Taghvaeian, S., & Stivers, J. (2017). *Understanding Soil Water Content and Thresholds for Irrigation Management.* Oklahoma Cooperative Extension Service.
[277] Larson, E., & Krutz, J. (2017). *When is the Right Time to Start Irrigating your Corn?* Mississippi State University Extension.
[278] Ingram, T., Burr, C., & Kranz, W. (2018). *Scheduling the Last Irrigation of the Season*. University of Nebraska-Lincoln. Retrieved 5 March 2018 from https://cropwatch.unl.edu/scheduling-last-irrigation-season

electricity use that put no additional burden on the farm. To increase the total emissions reduction, it would be necessary to scale these small changes from WattTime by applying it to many farms using sprinkler irrigation technology. Another potential alternative to improve the total emissions reduction would be to alter the project structure, for instance by pairing WattTime with a smart irrigation system while also converting the farm from using diesel for pumping electricity to using the grid. Similarly, pairing WattTime with a smart, precision irrigation technology for a farm. A coupled approach like this could create more significant emissions reductions and simultaneously generate water and electricity savings co-benefits, raising the overall project value. The farm-specific, bundled model is worth exploring further, with the understanding that it would dramatically increase complexity of the project structure.

1.2.5 Case Study: Tom Rogers Almond Farm (Madera County, CA)

Tom Rogers owns and operates a 117 acre almond orchard in Madera County, California.[279] Using "PureSense" smart irrigation technologies, the farm has reduced water use in some fields by up to 20% as well as better yields through better water management. Instruments in the field measure soil moisture levels every 15 minutes at 5 different layers within the soil. Weather stations record humidity, rainfall, temperature, and wind speed. The system can send automatic reports on dozens of parameters (such as water level) to the operator's phone or email.

Rogers says a key benefit of the technology is that it provides information justifying the farm's water use.[280] Using the equipment's readouts, Rogers can show regulators and the local community that his almond trees do in fact need the water apportioned by the farm: "That's going to be a key consideration in the future. With [this technology] we can show we're beneficially using the water and not wasting water." WattTime's software could be incorporated into Tom's system with relative ease, either by partnering directly with him or with his smart irrigation provider of choice, PureSense.

1.2.6 Design Considerations

Most irrigation in U.S. agriculture sources energy from either the local power grid or diesel.[281] While connecting farmers using diesel pumps to the grid and also installing WattTime would increase the emissions reduction potential significantly, for project structure simplicity and to be conservative in emissions reductions estimates we are focusing on partner farms using electricity from the grid for pumping (just under 100 trillion BTU of energy is consumed on farms in the form of electricity, so finding eligible farms will not be a challenge).[282] For WattTime's demand response to be integrated into a farm's

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[279] Allen, L. Smart Irrigation Scheduling: Tom Roger's Almond Ranch. *Pacific Institute*. Retrieved from http://pacinst.org/wp-content/uploads/2013/02/smart_irrigation_scheduling3.pdf

[280] Pacific Institute. (2011, Nov. 18). *Tom Rogers – Almond Grower, Madera County* [Video file]. https://www.youtube.com/watch?v=COD-aeAZCHk.

[281] Roblin, Stéphanie. (2016, August 3). *Solar-powered irrigation: A solution to water management in agriculture?* Retrieved from http://renewableenergyfocus.com/view/44586/solar-powered-irrigation-a-solution-to-water-management-in-agriculture/.

[282] Hicks, S. (2014). Energy for growing and harvesting crops is a large component of farm operating costs. U.S. Energy Information Agency. Retrieved from https://www.eia.gov/todayinenergy/detail.php?id=18431.

sprinkler optimization scheme, the software must be combined with a smart device. “Smart device” is defined here as a “IoT” (Internet-of-Things) device that can connect to other devices or networks via wireless protocols such as Bluetooth, NFC, Wi-Fi, 3G, etc.[283] Particularly on larger scale farms, precision agriculture and improved agricultural technologies are ubiquitous and present many opportunities for smart devices: plugs, sprinklers, timed pumps, cloud-enabled pumps, and more.

In screening for a potential project partner, we propose evaluating the sophistication of a farm’s connected irrigation and electrical systems at four tiers (correlated with a farm’s scale), for which level 3 and 4 would be most suitable to adopt WattTime demand response technology:

- Level 1. Traditional analog system with no smart (connected) devices for irrigation scheduling or electrical automation
- Level 2. Partial implementation of timed irrigation scheduling, but not necessarily with WiFi-connected devices
- Level 3. More comprehensive implementation of timed irrigation scheduling via smart, distributed devices like pumps, sprinklers, and moisture sensors but no demand response
- Level 4. Fully connected farm with smart pumps, Wi-Fi-enabled irrigation scheduling, as well as use of demand-response

WattTime’s software pings the server to receive a binary (0/1, or on/off) signal, and thus can control for use during times with lower marginal emissions.[284] Due to the existing irrigation control infrastructure and level of irrigation timing flexibility required, WattTime is most promising on larger scale farms with some level of sophistication in their water management system.

Estimates of emissions can change as frequently as every 5-15 minutes, when the portfolio of generators dispatches energy to accommodate for different grid changes. Farmers and irrigation demand systems can set boundaries on how much WattTime can deviate from existing irrigation schedules, but with such a rapid 5-15 minute change period, small shifts in the timing pumping activity can reduce emissions within the irrigation schedule bounds. It is important to note that this assumes that pumps are not running nonstop for the majority of the day, which could limit the effectiveness of this solution.

Depending on a project partner’s resistance or hesitancy to ceding irrigation timing controls to WattTime’s software, a potential implementation could also incorporate the use of soil moisture sensors to measure and prove the negligible impacts of WattTime’s timing adjustments. Soil moisture sensors are cheap and ubiquitous, and available at multiple levels of sophistication.[285]

Most farmers operating at large enough scales (and Level 3+ in our technological sophistication scale) are already interested in monitoring soil moisture and/or irrigation controls, so the addition of WattTime is a fairly straightforward decision. In the event that partner farms do not already have soil

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[283] Smart device. (n.d.) In *Wikipedia*. Retrieved March 5, 2018, from https://en.wikipedia.org/wiki/Smart_device.
[284] McCormick, Gavin. (2018, March 5). Phone interview.
[285] Garg, Anchit & Munoth, Priyamitra & Goyal, Rohit. (2016, December). APPLICATION OF SOIL MOISTURE SENSORS IN AGRICULTURE: A REVIEW.

moisture sensors, incorporating them into a proposed smart ecosystem (such as energy-efficient pumps or sprinklers) could dramatically improve the quality of data available to farmers. Quantifying these metrics can also detect for leaks in the irrigation system to prevent the draining or waste of unwanted water.

1.2.7 Data Verification and Impact Measurement

Previously, emissions were very roughly measured by estimating emissions from historical electrical grid data. The design of WattTime technology enables accurate real-time monitoring of emissions and energy usage on connected devices via their API, focusing specifically on marginal emissions data. The primary project design consideration is the structure by which stakeholders would be responsible for monitoring the reduction data, as the ubiquity of smart devices and ease of incorporating WattTime's demand response software lower the technical implementation barriers.

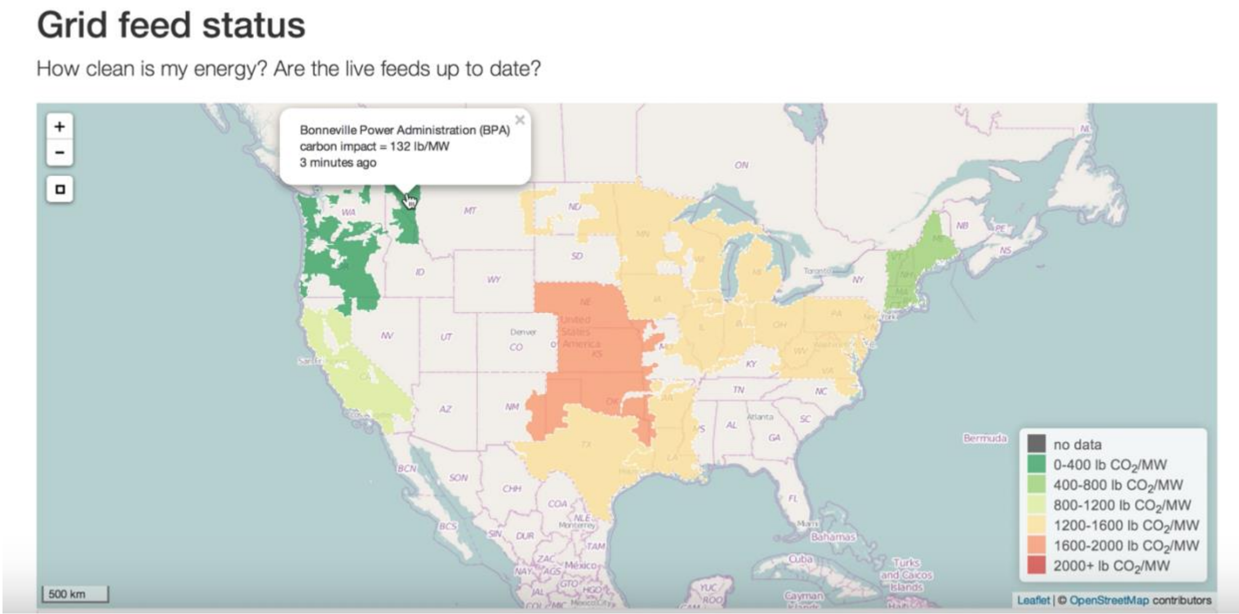
WattTime's API provides companies the data to actively monitor:

- Balancing authorities (e.g. ISOs)
- Grid data points
- Fuel-to-carbon conversion intensities
- Generation/fuel types
- WattTime allows for better emissions management by:
- Adjusting the timing of a **partner farm's** energy use with limited additional investments and negligible quality of service impact
- Flexibly changing the source of a **partner farm's** energy use and generation
- Quantifying additional emissions reductions as the system operates

The emissions reduction data can be accessed by a technical analyst via authenticated requests to the API, which returns in JSON or CSV format. In lieu of a technical analyst, clients or partners can also receive aggregated periodic summary reports (with monthly or annual data) from the WattTime team.[286]

[286] McCormick, Gavin. (2018, March 5). Phone interview.

Figure 17. The WattTime Explorer shows regional level marginal carbon emissions data.[287]



This solution also presents opportunities to scale the participation of partner farms, as unregulated entity could invest in the one-time set up with a visualization and data aggregation vendor like Microsoft Azure's cloud computing platform for understanding the impacts of demand response implementation on marginal emissions.

Microsoft Azure has already created a demonstration of Smart Energy Foundation, a carbon emissions data platform showing the potential of integrating WattTime API data with other data streams (e.g. Wunderground global weather forecasting API). This platform creates a precedent of not only visualizing and understanding carbon emissions, but also potentially using Azure IoT services to minimize marginal emissions.[288]

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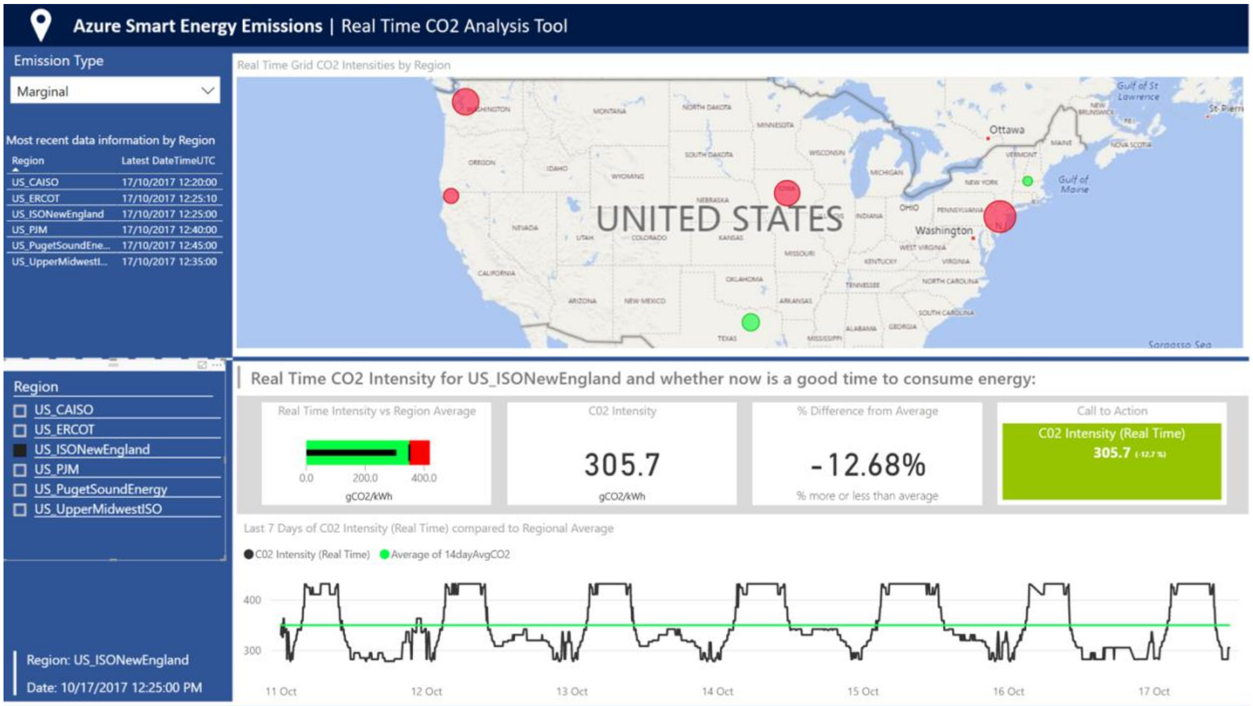
[287] *WattTime Explorer. (n.d.)* Retrieved March 3, 2018 from http://explorer.watttime.org

[288] Microsoft Azure. Smart Energy Foundations, Azure Carbon Emissions Platform. (2018). Github Repository. Retrieved from https://github.com/Microsoft/Smart-Energy-Foundation-Demo-Stack

Figure 18. Microsoft Azure's Smart Energy Emissions Dashboard[289]



289 Ibid.

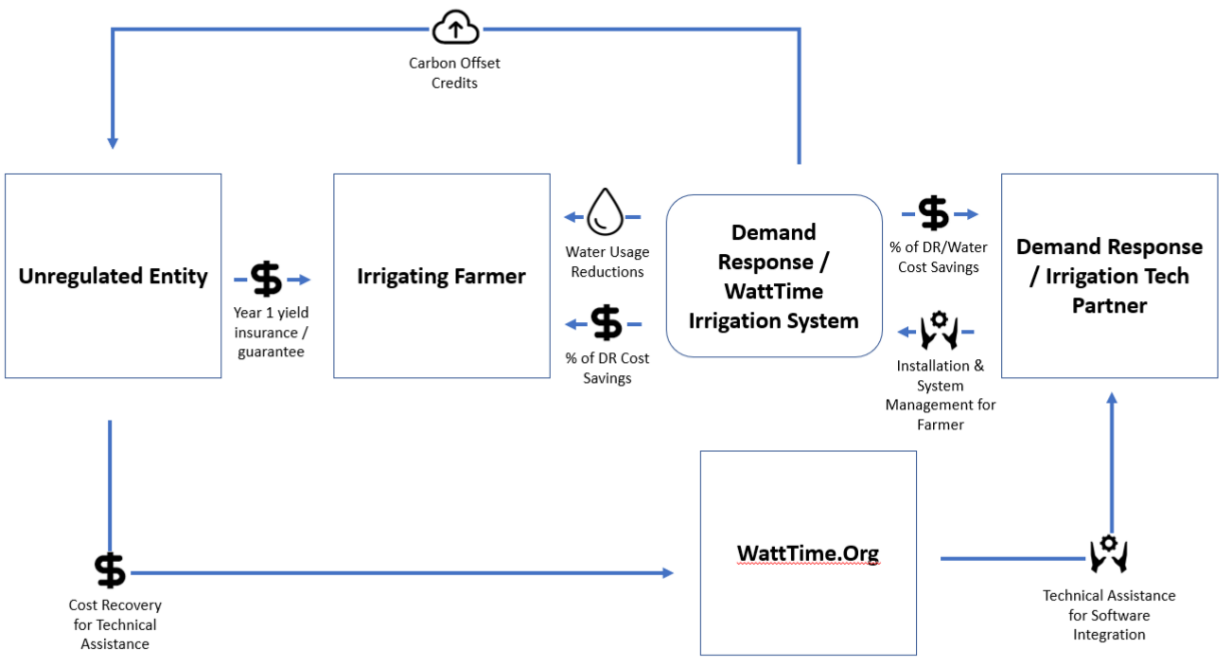
1.3 Project Structure

The biggest challenge with agricultural solutions is the decentralized, unregulated nature of the project partners; the farmers. One promising model is having a demand response or smart irrigation technology partner incorporate the WattTime software as part of their standard product offering to irrigating farmer customers. This obviates the need to spend time and funding identifying and recruiting farmers - as this objective is already aligned with the customer acquisition goals of the technology partner.

Technology partners get the additional green marketing benefit for their products as carbon offset tools, while for farmers there is no perceivable change in the benefits of installing or continuing to use the system, and operational/maintenance burden on the farm is expected to be no greater than it would be simply to install the demand response or smart irrigation system already (receiving the associated cost reductions in return). To highlight this important point: farmers are not receiving many direct benefits from the additional installation of WattTime (beyond the benefits associated with the smart irrigation or demand response system overall) because WattTime is only making changes in use across times in which the farmer is indifferent. If for some reason the addition of WattTime proves to be an added barrier to uptake for the farmer, then yield insurance (described directly below) should be a cost-effective way to easy concerns.

The role of the unregulated entity would be twofold. First, they would provide cost recovery funding to WattTime.Org and the technology partner for integration of this software with demand response or smart irrigation partners targeting irrigating farmers as customers. Second, the unregulated entity could provide an insurance or guarantee of a baseline yield for the farmers to incentivize adoption - benefitting both the farmer (mitigated risk, and as a source of “compensation” for participation) and the tech partner (improved customer acquisition). In return, the unregulated entity receives all carbon offset credits related to the switch to irrigation during times of the day with lower-carbon grid generation mixes.

Figure 19. Potential WattTime irrigation project structure



Source: Authors

The above project structure diagram was designed to highlight all key stakeholders needed for this system to work (key parties described directly below as well). However, it is worth noting that in our base scenario, the irrigating farmer already has the demand response or smart irrigation system installed and is already receiving the related water or demand response savings. The addition of WattTime in that case has no significant impact on their operations at all:

Table 18. Required parties for implementation

Entity	Responsibilities	Concerns
Irrigating Farm (target locations include the Midwest and California - total addressable market size shouldn't be an issue as these are some of the largest agricultural markets)	- Implementation of any smart (Wi-Fi-enabled) device supported by WattTime, if not already in place	- Must have sufficient scale and resource bandwidth to implement WattTime's features into existing electrical/pumping system - Security/costs of smart systems - Abdication of irrigation timing could compromise soil moisture/crop health - Must be located in a part of the country with hourly variability in the grid mix to achieve significant emissions reductions

Demand Response or Smart Irrigation Partner (e.g. THG Energy, PureSense)	- Control smart devices to use electricity when the marginal emissions are lowest - Automate crop irrigation according to water needs assessed by sensors or other smart technology	- Must be in area where demand response is available - Irrigation schedule should be time flexible
WattTime.org	- Assist demand response/smart irrigation partner with initial technology integration - Continue building out and maintaining WattTime functionality, distributed through software updates	- One of many priorities for the organization (limited staff dedication to this initiative)
Unregulated Entity (e.g. Harvard)	- Support project partner (varies by implementation level of existing smart energy/water metering)	- Most effort goes into first implementation (support and coordination with demand response partner and WattTime staff) - Should either have bandwidth to create/view a dashboard UI of reduction reports, review aggregated reduction data periodically, or partner with an auditing partner to confirm and measure additionality of reductions

Source: Authors

Other project structure models we have considered and will explore further include:

- Partnership with WattTime.Org and Demand Response providers to upload WattTime software to Demand Response systems that are already implemented on farms
- Partnership with utilities — permutations of the following two options:
    - Offering incentives to participate in already-established smart metering and demand response programs from the utility, which can have WattTime software incorporated into them.
    - Offering incentives for farmers to switch from diesel pumps to electricity - with a smart irrigation system - for their irrigation needs.
- Partnership with a smart irrigation/soil moisture monitoring system, such as CropX or any number of smart sensor/smart pump providers available in the market, to offer WattTime software as one part of a bundled package to farmers, perhaps at a discounted price subsidized by the unregulated entity to encourage faster uptake.
    - This option targets farmers with limited to no existing smart monitoring of moisture/water use on their farms and provides the added value of soil moisture monitoring to alleviate farmer concerns about the impacts of demand response technologies on their crop health.

  - The biggest benefit of this option is one of additionality: the unregulated entity's role in encouraging additional adoption and leading to additional emissions reductions (beyond those related to sending a software out to existing customers) is much clearer.
- The unregulated entity could also be the technology partner itself - developing the relevant technology as part of a living lab educational project.

1.4 Financial overview

1.4.1 Noteworthy Economic Trends

Two main trends are driving electricity market disruption: increasing retail cost of grid electricity and falling costs for DER alternatives. While these elements are mostly understood at the level of consumer markets, there are certain takeaways that can be applied to the agricultural sector as well. The most important takeaway is that DER has expanded demand flexibility and supply differentiation in a mostly supply-driven market.

The beauty of WattTime is that it allows for demand flexibility and emissions reductions without altering consumer experience. That is, the consumer still receives the electricity needed to power their devices at no extra cost, but via an automated system that reduces GHG emissions by turning the system on during times of clean power while potentially reducing electricity bill prices (in many parts of the U.S., solar and wind are cheaper than natural gas or oil). Studies have shown that if properly scaled, demand flexibility can reduce grid electricity costs from 10 to 15% and customer electric bills by 10 to 40% in the residential sector.[290]

1.4.2 Opportunities

As with all new technologies, adoption rates vary significantly for a complex array of reasons. Arguably the biggest influencer are the full costs and benefits of the proposed investment.[291] In this case, financial incentives to farmers (assuming they do not already have the required system in place, at which point there would be no costs) must be sufficient enough to warrant expenditures required to participate.[292] A study from the USDA Economic Research Service (USDA-ERS) found that precision agriculture technologies were twice as likely to be taken up by larger farms, suggesting that farm scale may influence the feasibility of investment.[293]

California has several successful example of farmers adopting Auto-DR. Comverge (intelligent energy management solutions company), EnerNOC (energy technology and solutions company), and PureSense (irrigation consultants in Fresno, CA - see Case Study) have conducted pilot programs that provide cash

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[290] Ibid.
[291] Schimmelpfennig, D. (2016). *Farm Profits and Adoption of Precision Agriculture*. Retrieved from https://www.ers.usda.gov/webdocs/publications/80326/err-217.pdf?v=42661
[292] Marks, G., Wilcox, E., Olsen, D., & Goli, S. (2013). *Opportunities for Demand Response in California Agricultural Irrigation: A Scoping Study*. Retrieved from https://esdr.lbl.gov/sites/all/files/LBNL-6108E.pdf
[293] Schimmelpfennig, D. (2016).

or incentives for farmers to use specific well pumps with automatic controls at no additional cost to the grower. Users preferred the product that had higher cash incentives and was easier to use. Fortunately, WattTime is easily added at the energy source and requires no upkeep or additional costs as long as the system meets basic connectivity requirements.

Consumer preference plays a large role in the success of WattTime. Studies have shown that electricity customers have a positive preference for GHG reductions, with U.S. consumers willing to pay an additional $0.27 to $0.34 on a monthly basis for a one percent increase in renewable power.[294] This feasibility report assumes that farmers already have IoT-enabled smart irrigation devices, so they would not be required to pay more, but it remains compelling that consumers are willing to pay to reduce their emissions. Finally, WattTime's flexible algorithm identifies only the zero-cost method to reduce GHG emissions, creating value through marginally "free" emissions.

It is important to note that research on the willingness of industry-scale operations to pay for renewable energy remains sparse. However, there is evidence that utilities are increasingly considering implementing "green-pricing" options, which offers the choice to pay more for renewable energy to help cover the utility costs. As public perception becomes friendlier to renewable energy, utilities are finding that offering this option increases their competitiveness.[295]

Figure 20. Average willingness to pay for changed fuel mix and lower emissions.[296]

	For 1% decrease in GHG emissions ($/month)	For 1% increase in renewable fuel and 1% decrease in fossil fuels ($/month)	For 1% increase in nuclear fuel and 1% decrease in fossil fuels ($/month)	1% decrease in GHG emission 1% increase in renewable fuel 1% decrease in fossil fuels[c] ($/year)	1% decrease in GHG emissions 1% increase in nuclear fuel 1% decrease in fossil fuels[c] ($/year)
United States[a] *this study 2012	0.31	0.71	−0.11	12.21	2.43
—California	0.32	0.72	−0.11	12.48	2.45
—Michigan	0.27	0.69	−0.02	11.43	2.93
—New York	0.34	0.74	−0.19	12.97	1.78
—Texas	0.31	0.69	−0.09	11.98	2.55
Japan *this study 2013	0.26	0.31	−0.72	6.90	−5.48
United States[b] *Roe et al., 2001	0.03–0.47			0.11–14.22	1.03–14.43

[a] The US average values of the four states.
[b] Roe et al. (2001) found significant differences across regions, different segments, such as income level and education, and environmental organization affiliation. The range of results is shown here.
[c] This WTP value is obtained by summing related values, assuming that interaction among marginal preferences for variations, such as increase in renewable power and GHG emission reduction are zero or little different from zero, within a limited extent.

Furthermore, WattTime has found that customers are more likely to purchase Watt-Time enabled devices like thermostats over non-enabled devices when the price is the same.[297],[298] This speaks to the

[294] Murakami, K., Ida, T., Tanaka, M., & Friedman, L. (2015). Consumers' willingness to pay for renewable and nuclear energy: A comparative analysis between the US and Japan. *Energy Economics*, *50*, 178–189. https://doi.org/10.1016/j.eneco.2015.05.002
[295] Farhar, Barbara C. and Ashley H. Houston. (1999). "Willingness to Pay for Electricity from Renewable Energy." *National Renewable Energy Laboratory.* Retrieved at: https://aceee.org/files/proceedings/1996/data/papers/SS96_Panel9_Paper08.pdf
[296] Murakami (2015)
[297] McCormick, Gavin. (2018, March 5). Phone interview.
[298] WattTime. (2017). Results of 5 studies of the effect of WattTime's Automated Emissions Reduction (AER) feature on sales, pricing, and customer engagement for IoT device sales and ADR programs.

marketing value of "green" or environmentally-friendly devices like WattTime. One WattTime study even found that adding environmental impact in the form of AER to a DR program actually increased signups more than financial gains (reduced electricity bills) did.[299] Another study from EMotorWerks sold 431 electric vehicle charging stations with and without WattTime's AER feature. WattTime-enabled chargers cost $50 more, but 82% of customers selected that option over a regular charging station.[300]

Beyond integrating WattTime into already-installed systems, there are huge opportunities for irrigation pump and valve manufacturers to partner with WattTime to sell pre-enabled systems, reaping the marketing and public relations benefits. A Transparency Market Research report forecasts that the global smart irrigation market will expand at a compound annual growth rate (CAGR) of 13.1%, reaching an estimated value of US$ 2.32 billion by the end of 2026.[301] As droughts become more frequent and water sources scarcer, farmers are increasingly looking to employ efficient and sophisticated irrigation methods.[302]

1.4.3 Costs and Challenges

The main costs of implementation of the proposed project structure will be borne by the unregulated entity. Most costs are related to upfront implementation and coordination between the technology partners (WattTime and the demand response or smart irrigation system provider). Following the initial integration and installation, additional operations and maintenance costs are marginally negligible and borne by WattTime and the smart irrigation partner as part of their normal business activities.

If we assume that 40 hours of work will be required on the part of one employee each at WattTime and the demand response or smart irrigation partner to set up the technology integration (based on a conversation with WattTime, this is a very high estimate - the integration is relatively straightforward)[303], the unregulated entity could offer those project partners each $2,000 ($50/hour * 40 total hours). This **$4,000 one-time cost** would then affect all current or future farmers using those systems. If working directly with an individual farm, we will expect a cost of $4,000 for each farm.

The only other project cost in our model is the potential for the unregulated entity to provide insurance for the first year of yields to the farmer. Given that WattTime is a zero-risk addition to a farmer's current system, we do not expect that this will be necessary. However, we have included this as a potential additional incentive if suspicion of decreased yields ends up being a barrier to adoption. We will explore the legal structure and cost of such a guarantee or insurance scheme if this WattTime option is carried forward to the implementation plan phase, but it could add to the marginal cost significantly if it proves necessary.

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[299] Ibid.
[300] Ibid.
[301] Transparency Market Research. (2018). Global Smart Irrigation Market: Snapshot. Retrieved March 8, 2018, from https://www.transparencymarketresearch.com/smart-irrigation-market.html
[302] Stubbs, M. (2015). *Irrigation in US Agriculture: On-Farm Technologies and Best Management Practices*. Retrieved from http://nationalaglawcenter.org/wp-content/uploads/assets/crs/R44158.pdf
[303] Richardson, Henry. (2018, March 7). Phone interview.

Based on the assumptions in this feasibility study, there are no foreseen additional costs to the farmer. However, depending on the location of the farm, irrigation system requirements, local energy mix, and uncontrollable weather events, it is possible that WattTime will not achieve substantial GHG emissions reductions. However, there is no risk that the addition of WattTime to a farmer's irrigation system will increase the price of electricity, water usage, or require maintenance from the farmer.[304]

1.5 Potential Benefits and Negative Externalities

1.5.1 Benefits

WattTime can offer a myriad of benefits for farmers that integrate the software to manage their irrigation. These benefits include opportunities to make farm water systems more efficient, reducing health impacts from irrigation, decrease intensity on the electric grid, and cost savings. When coupled as part of installation of a smart irrigation system (one of our possible project models, along with integration into existing systems), farmers can produce more crops utilizing the same the amount water they had previously used.

1.5.2 Expected Project Outcomes

When coupled as part of installation of a smart irrigation system, implementing WattTime is projected to decrease water consumption used by the farm. Additionally, because the software optimizes the cleanest fuel source when irrigation occurs, it decreases the amount of fossil fuels used in irrigation.

In partnering with a smart irrigation provider, water use efficiency should increase when the bundled system is implemented. It is important to note that these water use efficiency benefits would only be additional for systems that are installed after the integration (not farms that already have the smart irrigation systems installed and just receive a WattTime software update to reduce greenhouse gas emissions of their systems) - i.e. for cases where the addition of labeling the smart irrigation system as emissions-reducing causes more farms to adopt the combined technology. These systems prevent overwatering, which reduces total water use and limits runoff pollution. Using the grid when its energy sources are the cleanest not only decreases GHG emissions, but also correlates with times when the grid's other air pollution emissions are the lowest.

1.5.3 Potential Health Outcomes

Across the world 7 million people die a year due to air pollution related events.[305] Emissions such as particulate matter, sulfur dioxide, ozone, carbon monoxide, mercury, and carbon dioxide can lead to respiratory effects such asthma, chronic obstructive pulmonary disease, emphysema, chronic bronchitis, and other adverse health effects caused by poor air quality. Since WattTime focuses on finding the times

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[304] McCormick, Gavin. (2018, March 5). Phone interview.
[305] *World Health Organization. (2014). 7 million premature deaths annually linked to air pollution. Retrieved from www.who.int/mediacentre/news/releases/2014/air-pollution/en*

that have the cleanest generation, utilizing it can decrease respiratory diseases in the immediate area, climate change impacts, and injuries and deaths associated with fossil fuel extraction and production. Using the social cost of carbon if WattTime was installed in 1 person of the US 60 million irrigated acres resulting in a reduction ~27,000,000 lb CO2e, this would equate to $1,028,580 in avoided damages. Using the global value of a statistical $1.7 million, this results in more than half a VSL saved.[306]

Figure 21. Mortalities Associated with Annual Emissions by Sector

Equivalent mortalities reduction benefit expressed in avoided equivalent deaths/Tg of annual emissions. This metric quantifies how many mortalities are avoided for 1 Tg emissions reduction of each species and from each sector, assuming a spatially uniform reduction in the domain, and an equal toxicity for each of the $PM_{2.5}$ constituents.

	Electric power	Industry	Commercial	Road	Marine	Rail
CO	2.17	2.80	3.3	3.14	3.71	3.27
NH_3	1.79×10^4	2.93×10^4	6.53×10^4	5.58×10^4	8.98×10^4	3.16×10^4
SO_2	1.66×10^3	1.60×10^3	1.72×10^3	1.59×10^3	1.72×10^3	1.48×10^3
NO_3^-	1.66×10^3	5.27×10^3	7.98×10^3	10.3×10^3	11.6×10^3	6.30×10^3
SO_4^{2-}	0.51×10^4	1.20×10^4	1.70×10^4	1.63×10^4	0.79×10^4	1.16×10^4
NO_x	4.29×10^2	5.89×10^2	9.56×10^2	8.61×10^2	7.66×10^2	7.01×10^2
Primary $PM_{2.5}$	0.80×10^4	1.60×10^4	1.95×10^4	2.67×10^4	2.06×10^4	1.62×10^4

Source: Dedoussi and Barnett 2014 [307]

Using the mortalities associated with annual emissions by sector, it is possible to calculate additional lives saved due to emissions reductions from WattTime. Finally, if installed in a bundle with smart irrigation systems, increasing resilience to drought could improve food security.

1.5.4 Health Impact Assessment

To evaluate the impact the WattTime will have for the farm and the community, a full health impact assessment will be used. The HIA will evaluate the effect of WattTime and ensure that the following areas are covered:

- Screening: Determines the need and value of an HIA
- Scoping: Determines which health impacts to evaluate, analysis methods, and a workplan
- Assessment: Provides 1) a profile of existing health conditions and 2) evaluation of potential health impacts
- Recommendations: Identifies strategies to address health impacts identified
- Reporting: Includes the development of the HIA report and communication of findings and recommendations
- Evaluation and monitoring: Tracks impacts of the HIA on decision-making processes and the decision, as well as impacts of the decision on health determinants"[308]

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[306] Shindell, D. T. (2015). The social cost of atmospheric release. *Climatic Change*, *130*(2), 313-326. Retrieved from https://link.springer.com/content/pdf/10.1007%2Fs10584-015-1343-0.pdf
[307] Dedoussi, I. C., & Barrett, S. R. (2014). Air pollution and early deaths in the United States. Part II: Attribution of PM 2.5 exposure to emissions species, time, location and sector. *Atmospheric environment*, 99, 610-617. Retrieved from https://ac.els-cdn.com/S135223101400822X/1-s2.0-S135223101400822X-main.pdf?_tid=9eea766c-af55-4900-a55f-3a5b30763270&acdnat=1525650647_3b0ebe86392231e99235946eff92e30d
[308] https://humanimpact.org/wp-content/uploads/2017/09/SampleHIATrainingBinder.Kentucky2016.pdf

Screening

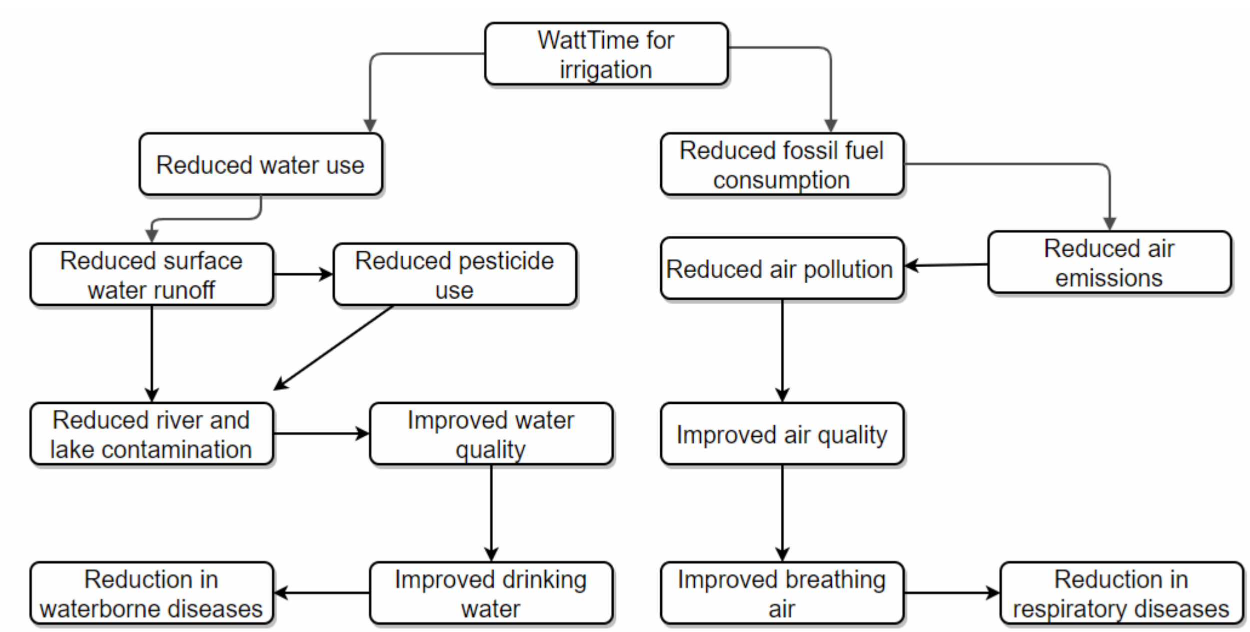
To fully convey the health impact of implementing WattTime for irrigation on a farm it was determined to conduct an independent HIA to assess potential health issues.

Scoping

Scoping was conducted to determine the main health impacts and additional benefits that would be affected with the implementation of WattTime. Research was conducted on the variety of benefits of installing WattTime. The casual relationship between installing WattTime the resulting impacts was

Figure 22. Causal impacts of using WattTime for irrigation

identified.



Source: Authors

Using WattTime can lead to reduction in water use due to optimizing water systems. Additionally, using less water results in less surface water runoff. Water quality can improve, and there is a decreased chance for eutrophication to occur from nutrient runoff. Air emissions can decrease as WattTime uses the cleanest energy source water on the farms. This can lead in reduction of air pollutants from energy generation. As a result, water and air quality can both improve. These improvements are able to lead to potential reductions in the contraction of waterborne diseases and onset of respiratory diseases.

On the other hand, in many cases (such as the case study described in Section 1.2.2), smart irrigation can achieve increased yields while also reducing water use. As such, while increased water use is a possibility, the net impact across many farms implementing smart irrigation systems is likely negligible.

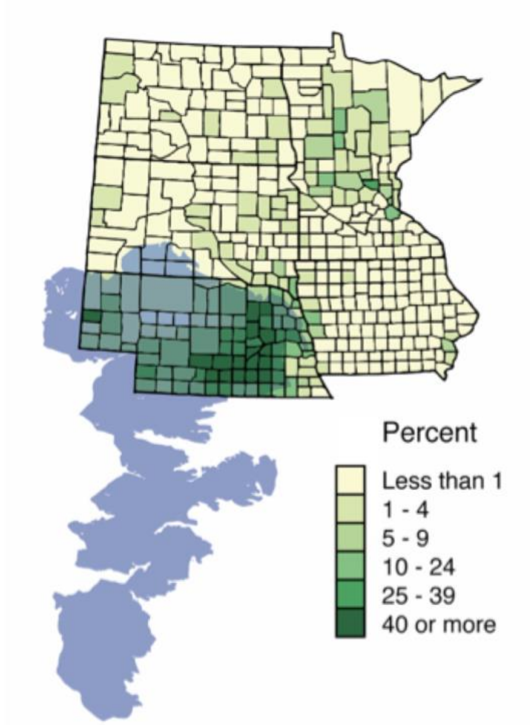
The assessment included:

1. Defining potentially impacted communities, observing the baseline health, assessing the current economic and environmental conditions
2. Identifying health studies that survey the surrounding area
3. Reviewing data that is associated to potential project impacts
4. Synthesizing data to related to community conditions, health pathways, and the project impact to summarize and communicate the possible health impacts[309]

It was important to determine that there would be an location where installing WattTime could results in health benefits. Locations were identified based on the ability to install WattTime. Locations included: the Midwest, such as Iowa, as well California. Iowa was chosen to calculate the benefits of installing WattTime.

Figure 23. Acres of Irrigated Land in the Western Corn Belt as Percentage of Land in Farm's Acreage: 2007[310]

[309] Michanowicz. (2018). Health impact assessment. PowerPoint presentation.
[310] Cropmetrics. (2013). Irrigation in the western corn belt: A 4 state breakdown. Retrieved from http://cropmetrics.com/2013/11/irrigation-in-western-corn-belt-4-state-breakdown/



Iowa was selected as a potential location due to the high amount of irrigation that occurs in the state. Increases in corn prices and the occurrence of droughts, has lead to farmers to implement additional irrigation systems.[311] Non-point source pollution is a major water quality problem for Iowa which due to surface water runoff that includes agriculture runoff, such as fertilizers and manure.[312]

Figure 24. Iowa Impaired Waterbodies[313]

[311] Cropmetrics. (2013). Irrigation in the western corn belt: A 4 state breakdown. Retrieved from http://cropmetrics.com/2013/11/irrigation-in-western-corn-belt-4-state-breakdown/
[312] Iowa Department of Natural Resources. (n.d.). Watershed basics. Retrieved from http://www.iowadnr.gov/Environmental-Protection/Water-Quality/Watershed-Improvement/Watershed-Basics
[313] Kulhman, M. (2017). A watershed approach to improving Iowa water quality. *Public News Service*. Retrieved from http://www.publicnewsservice.org/2017-12-20/water/a-watershed-approach-to-improving-iowa-water-quality/a60718-1

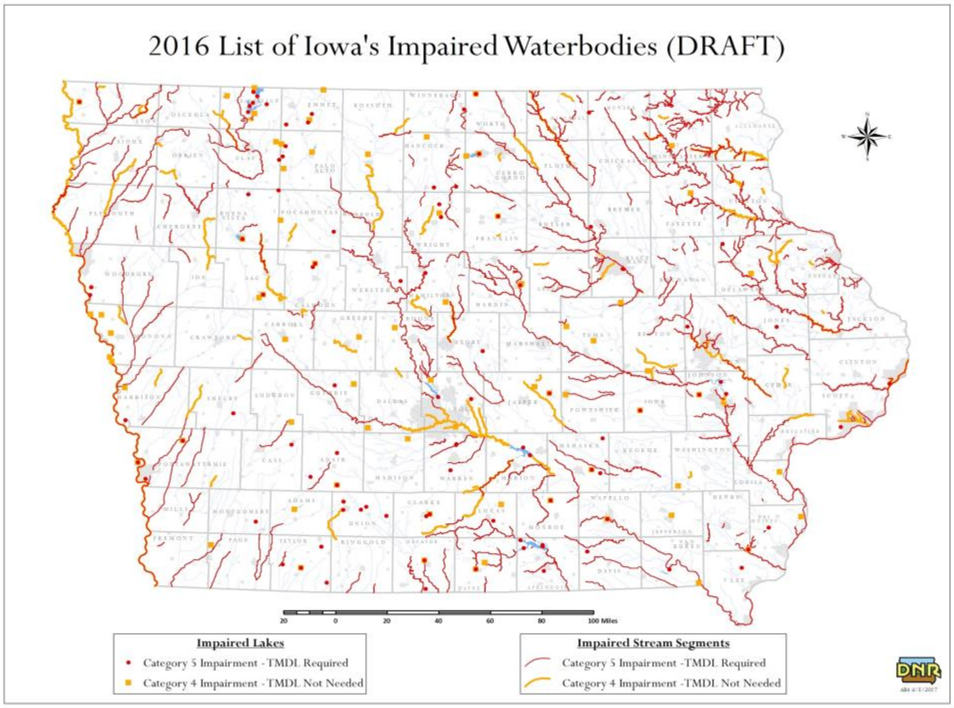
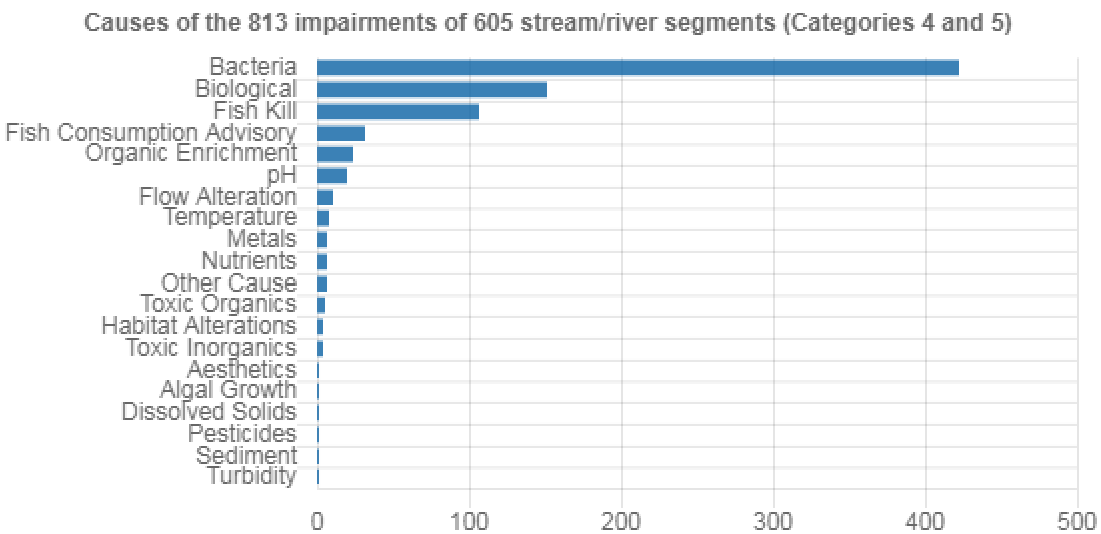
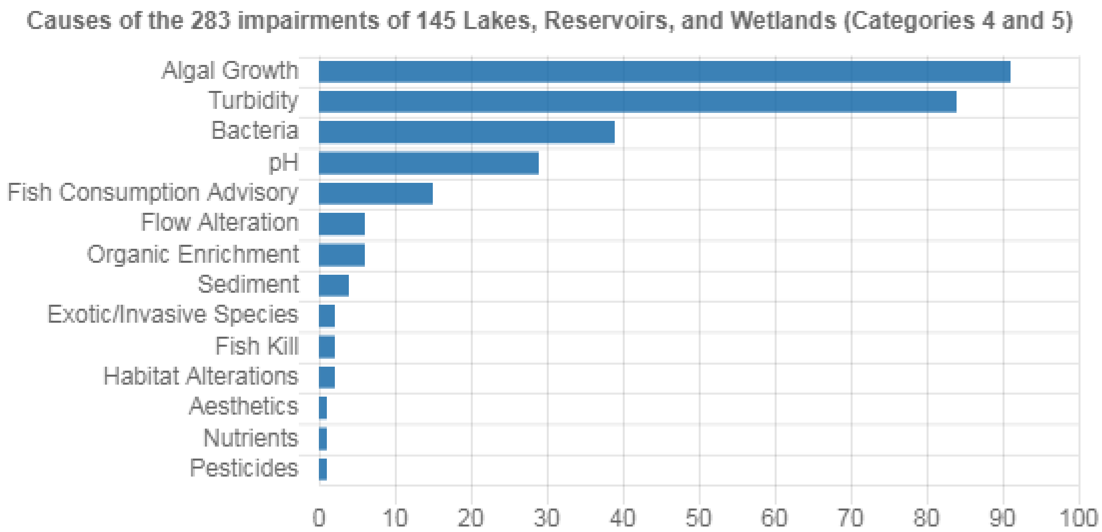


Figure 25. Causes of Impairments[314]



[314]Iowa Department of Natural Resources. (2018). 2016 Impaired Waters List: Approved by U.S. EPA January 16, 2018. Retrieved from https://programs.iowadnr.gov/adbnet/Assessments/Summary/2016



After analyzing the amount of impaired water in Iowa it was determined that across the state there are many impaired waters. These problems are largely due to surface water runoff. As a result, adverse health effects such as waterborne disease contraction and exposure to harmful chemicals can result from drinking the water. Because of these water issues combined with the benefits of reducing air pollution in the surrounding area, Iowa was chosen as a good location to implement the WattTime project.

1.5.5 Recommendations and Reporting

The information from this HIA will be shared with the farmers, unregulated entity, and community members. The benefits and potential risks will be compiled in variety of materials that are open access. Additionally, there will be meetings that allow for stakeholder participation and input before the project is enacted.

1.5.6 Data sources and analytic methods

The Idaho Department of Natural Resources was used to obtain the information on impaired water and the causes. Agricultural data will be retrieved from the United States Department of Agriculture 2012 Census of Agriculture. County respiratory deaths statistics will be retrieved from Iowa Department of Health and Human Services. Asthma data will be retrieved from the CDC state asthma data, and children rate will be retrieved from Iowa Department of Health and Human Services.

1.5.7 Monitoring and Evaluation

The use of WattTime will be monitored. This is to ensure that it is maximizing utility and reaching the identified health goals. If problems are found they will be addressed and fixed to ensure long-term stability and beneficial use.

1.5.8 Unintended Consequences

WattTime presents a variety of benefits, though there are possible unintended consequences that are associated with its utilization. WattTime farmers may end up running irrigation systems in the middle of the night, causing a nuisance to nearby residents.

Most importantly, there is the question of water use. For farms that are already using the demand response or smart irrigation software and are just receiving a software update to incorporate WattTime, there will be no change to water use at all. This is our base scenario used to calculate emissions reductions. However, for farms adopting new technology systems that have WattTime incorporated, those water and energy use changes could be considered associated with the unregulated entity's intervention. For example, if water use efficiency is increased with the smart irrigation systems, farmers may choose to increase the amount they irrigate, given the new and improved water-to-yield trade off they will exhibit. This could reduce river discharge flows or groundwater tables, and impact soil salinity. It is important to note that increased water use does not universally translate to improved yields, so this is likely not a huge concern, but still worth mentioning. The risk of this becoming a negative externality could be reduced with education to farmers on diminishing water-to-yield tradeoffs.

1.6 Legal Analysis

No legal barriers identified would render the project infeasible. Careful contracting will nonetheless be required to minimize risk of breach and alleviate project partners' perceived risks of implementation. For example, contracting must accommodate project partners' inability to guarantee regular offsets, as emissions reductions delivered via WattTime-enabled irrigation systems will largely arise from factors beyond individual control (such as weather patterns and energy market behavior).

1.6.1 Risk of Judgment-Proof Partners

Many farmers may be "judgment proof," meaning it would be very difficult for the unregulated entity to recover damages in the event of breach. Farmers may be judgment proof due to highly leveraged or insufficient assets, or through breaches warranting insufficient damages to justify the costs of litigation. A critical screening component would therefore be identifying farmers with sufficient resources to compensate the unregulated entity in the event they are unable (or unwilling) to meet their contractual obligations. Specifically, requiring funds be held in escrow for liquidated damages, or potential liens on farm equipment, could help reduce risk of breach. The unregulated entity should also screen for "good faith" partners, discussed at some length in the next subsection.

1.6.2 Countering Moral Hazard with Good Faith

Project partners who contract and operate in good faith greatly reduces risk of breach.[315] "Good faith" project partners would value the climate mitigation goals of implementing WattTime and value a client relationship with a large and potentially prestigious institution. Doing so would counter the risk of "moral hazard," a term which describes situations where one party provides misleading information during negotiation or is more likely to take risks to the disadvantage of the other party.[316]

Finding good faith partners for a climate change mitigation project may prove particularly challenging in the agricultural sector. Though many farmers are already adjusting their agricultural practices to adapt to changing climate systems, a large proportion remain skeptical of climate science and the underlying human causes of global warming.[317] Financial incentives and equipment giveaways in themselves may prove sufficient to convince project partners into participation, as may the fact that the potential risks and costs to the farmers themselves are minimal. That being said, enthusiasm matters here, as project implementation may require monitoring, reporting, and maintenance, as well as tolerance for increased vulnerability to cyber-attacks (note: data privacy is also discussed in more detail below, see Section 1.6.6). As such, screening by partnering with other organizations interested in climate action for farms to develop a pipeline of potential farms may aid in reducing transaction costs of identifying project partners.

1.6.3 Approaches to Stronger Carbon Offset Contracts

Considerable academic attention has been paid to contract breach and compliance in the context of carbon sequestration through forest conservation.[318] In these arrangements, clients pay landowners who would otherwise raze or log their forests in order to keep carbon sequestered in the forest. There is significant risk in forest sequestration offsets when implemented in regions where the arable value of land is unknown or concealed, or where formal contract enforcement is non-existent or prohibitively expensive.[319] Though neither of these problems would arise when working with farmers in the United States, the contract concepts used in such contexts may still prove attractive, as contracting approaches that can survive within dysfunctional marketplaces and corrupt states are extremely hardy. They are described below.

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315 *Id*. p. 20.

316 "Moral Hazard." (2018). *Investopedia*. Retrieved from www.investopedia.com/terms/m/moralhazard.asp.

317 Julie E. Doll et al., American Meteorological Society. (2017, Jun.) *Skeptical But Adapting: What Midwestern Farmers Say about Climate Change*. Retrieved from https://journals.ametsoc.org/doi/abs/10.1175/WCAS-D-16-0110.1, *last accessed* Mar. 3, 2018.

318 *See e.g.*, Codero, P. et al., World Bank Development Economics Group. (May 31, 2012). *Addressing Additionality in REDD Contracts When Formal Enforcement Is Absent*. Retrieved from https://ageconsearch.umn.edu/bitstream/124505/2/Salas_AAEA.pdf. *See also* Mason, C. & Plantinga, A., National Bureau of Economic Research. (2011 Apr.). *Contracting for Impure Public Goods: Carbon Offsets and Additionality*. Retrieved from http://www.nber.org/papers/w16963.pdf; *and* Palmer C. et al., Center of Economic Research (CER-ETH) at ETH Zurich. (2009, Jul.). *Life's a Breach! Ensuring 'Permanence' in Forest Carbon Sinks under Incomplete Contract Enforcement*. Retrieved from https://www.ethz.ch/content/dam/ethz/special-interest/mtec/cer-eth/cer-eth-dam/documents/working-papers/WP-09-113.pdf.

319 Codero, P., *above*.

1.6.4 Preventing Opportunistic Contract Breach

Opportunistic breach . . .

"Opportunistic breach" poses significant risk when working with carbon offset partners. Such breaches occur when outside circumstances make contracted performance more difficult or less attractive than when the agreement between the parties was first made.[320] For example, a sudden drop in price in electricity produced by carbon-intensive sources could dramatically skew the electricity markets against clean energy sources, making less compelling financial incentives for continued use of WattTime (especially if the smart irrigation / demand response partner's timing incentives are counter to those preferred for the cleanest energy mix by WattTime). For example, Secretary of Energy Rick Perry has made numerous attempts to prop up faltering coal-fired power plants with increased rates.[321] Were he to succeed, the projected future energy mix of the grid would become dirtier as the lifespans of legacy coal-fired units extend.

Alternatively, irregular rainfall could require farmers in dry climates to pump and apply water regardless of the minute-to-minute carbon intensity of the grid.[322]

The risk of opportunistic breach rises concurrently with the risk of moral hazard, emphasizing once again the need for the client to locate project partners who appreciate the overall goal of the project, or who are drawn strongly to the other benefits of adoption of demand response or smart irrigation technologies (energy or water use savings). It may also help to target clusters of farmers, as uptake can be spurred significantly when one farmer hears about it from their neighbor. Incentives for opportunistic breach with WattTime include marginal costs associated with maintenance and changing perspectives on risks posed by "smart" technologies.

WattTime's low upfront costs fortunately reduce the risk of breach, since performance requirements can be rapidly met with minimal expense from project partners and by extension reduces the odds of abandonment before delivery of carbon credits.[323] Low upfront costs would also allow the client to provide more financial incentive throughout the lifespan of the project.

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[320] MacKenzie, I. et al. (2012, Apr.) Enforcement-proof Contracts with Moral Hazard in Precaution: Ensuring 'Permanence in Carbon Sequestration. *Oxford Economic Papers, 64*, 350-374. Retrieved from https://academic.oup.com/oep/article/64/2/350/2362219.

[321] Megan Geuss. (April 15, 2018). "Perry Seems in Favor of Emergency Order to Bail out Coal, Nuclear Plants." Ars Technica. Retrieved from https://arstechnica.com/tech-policy/2018/04/perry-seems-in-favor-of-emergency-order-to-bail-out-coal-nuclear-plants/.

[322] Risk of this particular motivation for breach can be reduced by selecting project partners who are already using most or all of the water allotted to them under existing water rights and water sharing agreements.

[323] Stockholm Environment Institute and GHG Management Institute. *Carbon Offset Research & Education (CORE): Contract Terms*. Retrieved from http://www.CO_2offsetresearch.org/consumer/contracts.html.

. . . And Its Prevention

Very low upfront payments with incremental compensation may be the most efficient means of preventing opportunistic breach, especially where start-up costs are minimal.[324] This is because performance-contingent payment effectively acts as a built-in enforcement mechanism

Another measure could include indexing the price of emission credits sold within the agreement to their price on the broader carbon market.[325] It may prove optimal for the client and project partner to form a "carbon bank" via their agreement. A carbon bank would lower risk of failure to meet delivery targets by banking surplus emissions reductions against future or past shortfalls.[326]

1.6.5 Water Rights

Though water right issues may limit the extent to which WattTime can reduce GHG emissions, they do not present an absolute bar to the project. Potential project partners will already have irrigation systems in place and the necessary rights or permissions to appropriate and transport water sufficient for their current needs. There will however very likely be a cap to the amount of water project partners can draw in order to irrigate crops. This cap will limit their ability to use more water to offset increased evaporation rates from suboptimal watering times, though this should not affect our project significantly as we expect WattTime only to be shifting operations within windows that the farmer is indifferent across for water efficiency or electricity cost reasons. As discussed earlier (Sections 1.1 and 1.2.1), farms may be restricted in their ability to take advantage of solar resources during the day, when solar energy is most plentiful, but evaporation rates are highest.[327][328]

Ideal project partners will therefore have access to grids with a sizeable number of wind-powered generating resources and other RE resources operable during low-daylight hours.[329] As noted earlier, further study of which areas of the U.S. meet both farm and grid characteristics for optimal implementation should be conducted as a next step to move forward with the concept.

1.6.6 Data Security and Privacy

Though not a bar to feasibility, privacy concerns are among the most pressing challenges facing the implementation and expansion of smart devices.[330] Risks include unauthorized accesses and misuse of

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324 Codero, P., *above*. p 4–5.
325 Palmer, C., *above*.
326 SEC. (2011, Mar. 24) *Carbon Dioxide Purchase and Sale Agreement Example*. P. 10 (Mar. 24, 2011), *available at* *https://www.sec.gov/Archives/edgar/data/1346980/000119312511080561/dex1031.htm*.
327 Electric Power Research Institute, DOE (2014, Feb.) *The Integrated Grid*. p. 20. Retrieved from https://www.energy.gov/sites/prod/files/2015/03/f20/EPRI%20Integrated%20Grid021014.pdf. (Showing solar production rising rapidly after sunrise, peaking midday for four hours, and then rapidly dropping off).
328 Zazueta, F., University of Florida, IFAS Extension. (2014, Oct.) *Evaporation Loss During Sprinkler Irrigation.* p. 6. Retrieved from https://edis.ifas.ufl.edu/pdffiles/AE/AE04800.pdf. (Average evaporation loss is highest during early afternoon in the summer, while lowest during the night, the early morning, and early evening).
329 Dyer, J. & Mercer, A. (2014) A New Scheme for Daily Peak Wind Gust Prediction Using Machine Learning. 36 *Complex Adaptive Systems*, 593-598. Retrieved from https://www.sciencedirect.com/science/article/pii/S1877050914013088.
330 FTC. (2015). Internet of Things: Privacy and Security in a Connected World. Retrieved from https://perma.cc/6D8N-G4AU.

personal or proprietary information and cyber-attacks. There may also be increased vulnerability to government surveillance under existing 4th Amendment doctrine,[331] though there are indications that such searches may soon become more difficult to execute.[332] Contracting between the client and project partners will need to provide assurances to farms in the event of breach, perhaps in the form of sharing recovery costs between the parties.

Project partner concerns about data security can be mitigated to some extent by establishing a data security plan addressing stewardship of data.[333] The stipulations should accord with applicable regulatory requirements, industry best practices, and project partner / service provider needs.[334] Concerns about installation of smart pumps can be alleviated through a fulsome cost-benefit analysis with project partners: the time-savings advantages to implementation are potentially large, while the risk and potential severity of breach are comparatively small.[335] Clarifying these trade-offs may help farmers warm to the technology despite its associated risks. WattTime itself presents only minimal data security concerns, as the company does not host or query personal data.[336]

1.7 Additionality

This type of project is novel, and we are not aware of any standardized and approved methodology for measuring GHG reductions in irrigation systems that employ WattTime technology. Project-Specific Baseline procedures should be used in these scenarios: all farms are unique, but past emissions should be relatively straightforward to calculate with utility bills or fuel receipts, field operational logs, and pump efficiency tests for the preceding six months (ideally one year), following the procedures of California's SWEEP Grants program.[337] This baseline setting methodology could be feasible both for farms that already are using the grid for irrigation electricity and for those switching from diesel pumps.

These baselines will be compared to reductions calculated and reported through the WattTime software. One large additionality challenge is for the switch from a diesel pump to using the electric grid for irrigation electricity: some studies have shown that current price trends make electricity the preferred economic choice,[338] so one could argue that farmers would be making this switch anyway and

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[331] Note. (2016, Dec. 9). If These Walls Could Talk: The Smart Home and the Fourth Amendment Limits of the Third Party Doctrine. *Harvard Law Review, 130*, p. 61. The article discusses *Couch v. United States*, 409 U.S. 322 (1973) (no reasonable expectation of privacy for document turned over to an accountant) *and United States v. Miller*, 425 U.S. 435 (1976) (documents "voluntarily conveyed" to a third party can be shared with the government).
[332] Miller, S. & Clarke, R. (2018, Feb. 7) Supreme Court Tackles Fourth Amendment Case Involving Cellphone Privacy. The *Legal Intelligencer.* Discussing currently-pending Supreme Court case *Carpenter v. United States*, Doc. No. 16-402, argued Nov. 29, 2017, reviewing the constitutionality of warrantless acquisition of location information from cellphone records.
[333] Lewis, M, Association of Corporate Counsel. *Data Security and Commercial Contracts*. Retrieved from http://www.acc.com/chapters/del/upload/2015-04-21_Morgan-Data_Security-Commercial_Contracts-PPTX.pdf
[334] Rosenfeld, D. & Hutnik, A. (2011). *Data Security Contract Clauses for Service Provider Arrangements (pro-customer)*. Retrieved from https://iapp.org/media/pdf/resource_center/Rosenfeld_Hutnik_Contract-clauses_Service-provider.pdf
[335] Ibid.
[336] J. Mandel, Rocky Mountain Institute. Personal communication. 2018, Mar. 8.
[337] http://www.almonds.com/sites/default/files/2016.07.13_4-page_sweep_guide_7.14.16.pdf
[338] https://www.ksre.k-state.edu/irrigate/oow/p11/Kranz11a.pdf

that the resulting GHG reductions are not additional. While this additionality calculation would be project/site-specific, we posit that the history of operations through which no changes to irrigation practices were made indicates that in almost all cases this change would not have been made without the additional incentives to switch provided by our project.

As for additionality related to use of WattTime over the standard demand response, trends in utility time-of-use incentive programs, or automated irrigation technologies: since there are no past examples of using WattTime for irrigation, it is safe to assume that no farmers would be achieving the reductions that WattTime can without our incentives for them to incorporate WattTime into their irrigation systems. This is a set of reductions *beyond* any other demand response or time-of-use incentives - i.e., WattTime shifts electricity use in the remaining flexible space only after the bounds of those other systems have already been incorporated. If moving forward with this project, the unregulated entity would want to confirm with WattTime.Org whether and how additionality above and beyond demand response cues is calculated as part of the metrics and reporting of the software itself.

Finally, given that integration of WattTime into existing demand response software is a one-time small cost, ongoing additionality of future reductions would be difficult to prove. For instance, it would be unrealistic to assume that all future offsets from every smart system installed would be credited to the unregulated entity. Any implementation plan for this project concept should provide a clear timeline and project structure that outlines a concrete endpoint of the relationship between the unregulated entity and other project partners (including an agreed time for the offset credit stream).

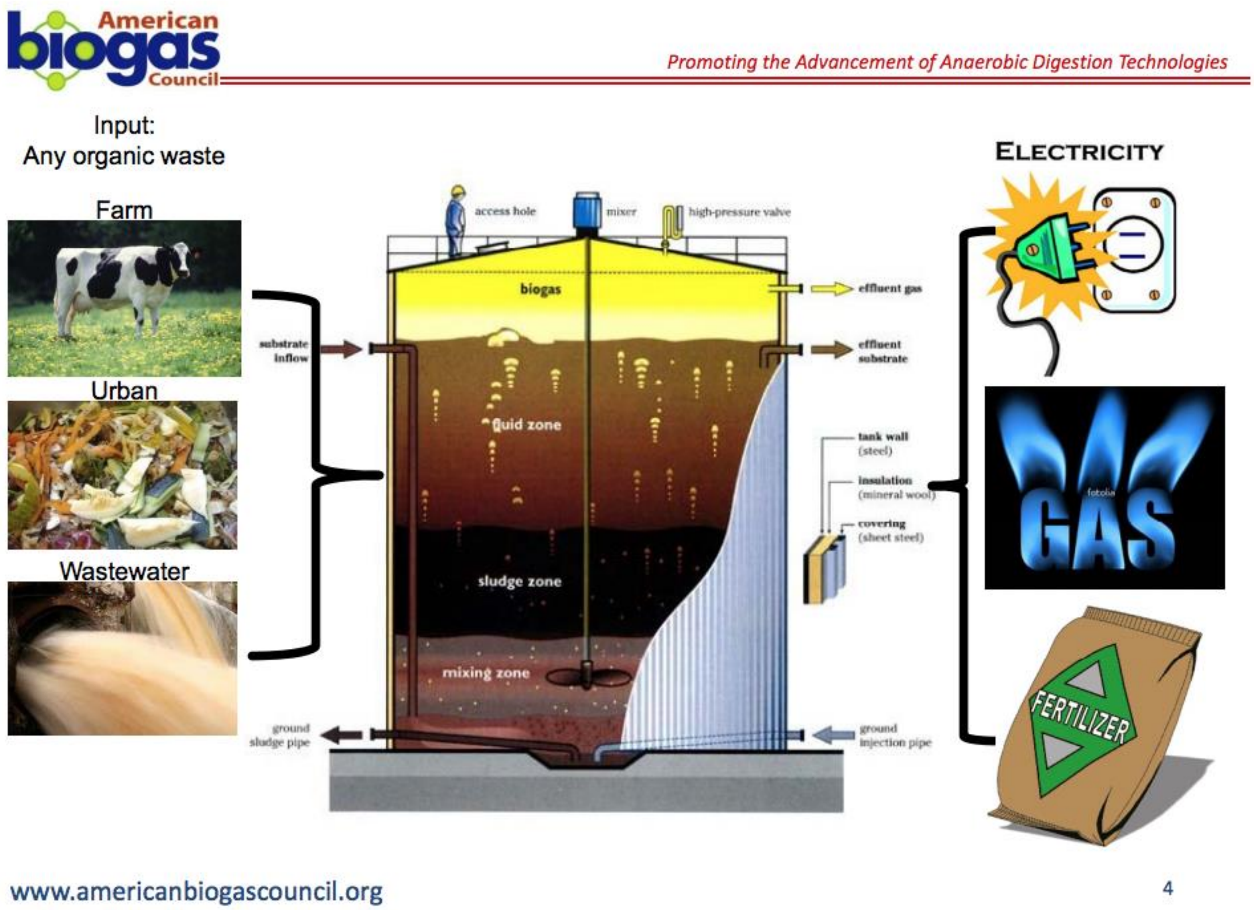
Option B. Anaerobic Digesters

2.1 Concept

- The livestock sector was responsible for 250.51 million metric tons of CO_2 equivalent emissions in 2015, second in emissions only to fossil fuel production[339]
- This project concept proposed to install an anaerobic digester on a 500-cow dairy farm (or collection of localized smaller farms) to process manure and other organic waste streams to produce a biogas that can either be used to generate electricity and heat for either on-site use or sold back to local communities.
    - Note: Our team decided to move forward with the digester project idea for our Implementation Plan, but with a much larger 8000-cow farm size with to achieve more significant emissions reductions. This feasibility study sticks with the 500 cow assumptions and structure, in part due to feedback and comments received during the final presentation: in addition to the interest in the larger scale model proposed, there was also interest in a smaller scale investment in the Northeast United States. Our hope is that in keeping this feasibility study focused on the smaller scale option, we can provide the foundation for both smaller- and larger-scale projects between this document and the Implementation Plan. That being said, more comprehensive analyses (financial technical, etc.) can be found in the Implementation Plan. Many of these could be adapted to the smaller scale model as well if desired.
- Target locations for this project include major dairy methane regions such as New York, California, Idaho, or Iowa (See Maps 1, 2, and 3). Out of those options, smaller-scale farm cooperatives such as the model proposed here may be more prevalent in New York.
- Beyond the primary benefit of reducing methane emissions from livestock, considerable co-benefits in electricity generation income, reduced costs of heating, and sale or use of by-product digestates as fertilizer make this an attractive solution

[339] United States Environmental Protection Agency, Greenhouse Gas Inventory Explorer. (2018). Retrieved from https://www3.epa.gov/climatechange/ghgemissions/inventoryexplorer/

Figure 26. Basic digester diagram

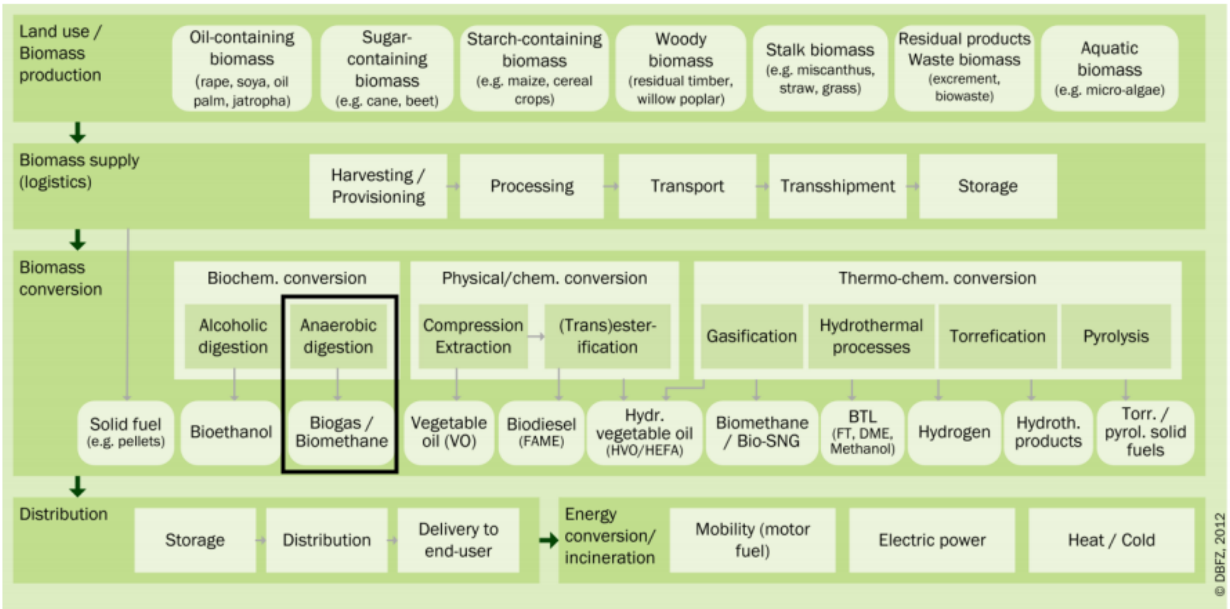


2.2 Science, Technology Process Description

Anaerobic digestion for producing biogas is one of the many applications of biomass energy production. Agricultural digesters focus on waste inputs like manure but are often flexible for other types of organic waste.[340]

[340] Pohl, Marcel and Jan Postel. (2018, January 29). New Measuring Methods for Commercial Scale Biogas Plants. Deutsches Biomasseforschungszentrum, Large Scale Bioenergy Lab 2 workshop. Retrieved March 7, 2018.

Figure 27. Biomass to energy conversion [341]



In the United States, hundreds of millions of tons of solid waste are produced by industrial agricultural operations each year.[342] Recent technological advances have allowed for improvements in the mechanism and efficiency of livestock waste management on farms. One such area of innovation is in the design of anaerobic digestion (AD) reactors, which treat animal waste by harnessing microbiological metabolic processes. Since the 1990s, operational anaerobic digestion systems have been installed in the U.S., leading to benefits for waste management practices, as well as the generation of renewable energy. While there are clear benefits of this technology for environmental objectives, the functional specifications required to establish new – and manage existing – anaerobic digestion reactors in industrial farms must be carefully constructed to ensure continual benefit to the client and ongoing support to the customer.

[341] Ibid.
[342] U.S. Department of Agriculture, Agricultural Research Service. (2005). *National program 206: Manure and byproduct utilization* (FY-2005 Annual Report). Retrieved February 24, 2018.

Table 19. Overview of Anaerobic Digester System Technologies [343,344,345]

AD System	Operating Conditions	Added heat? (Y/N)	Hydraulic retention time (HRT) (days)	Percent solids (%)	Co-digestion optimal? (Y/N)
Plug Flow	Tank below ground with gas-collecting cover (GCC); vertical mixing; appropriate for dairy manure with minimal bedding.	Y	>15	11-13	N
Covered Lagoon	In-ground lagoon with GCC; little to no mixing; preferred in warmer climates	N	40-60	0.5-3	N
Complete Mix/Continuous Stir-Tank Reactor (CSTR)	Tank above or below ground with GCC; mixing via motor/pump; ideal for diluted manure.	Y	>15	3-10	Y
Up-flow Anaerobic Sludge Blanket (UASB)/Induced Blanket Reactor (IBR)	Tank above ground; heated; high-rate; continuous addition of biomass enables bacterial suspension	Y	<5	<3 (UASB); 6-12 (IBR)	Y
Fixed-Film/Attached Media Digester/Anaerobic Filters	Tank above ground; growth media (e.g., wood chips) for bacterial growth; manure is passed by the media; preferred in temperate-warm climate.	Y	<5	1-5	Y
Anaerobic Sequencing Batch Reactors (ASBR)	Tank above-ground with GCC; manure added in batches; process is stepwise; preferred for dilute waste processing.	Y	<5	2.5-8	Y
High-Solids Fermentation	Tank above ground; preferred for high solids manure.	Y	2-3	>18	Y

Source: Authors

An overview of available AD system technologies is presented in the table above. In batch digestion, biomass (manure) is only added at the beginning of the process and biogas generation follows a normal distribution over time; farms that use multiple batch digesters can obtain a continuous flow of biogas.

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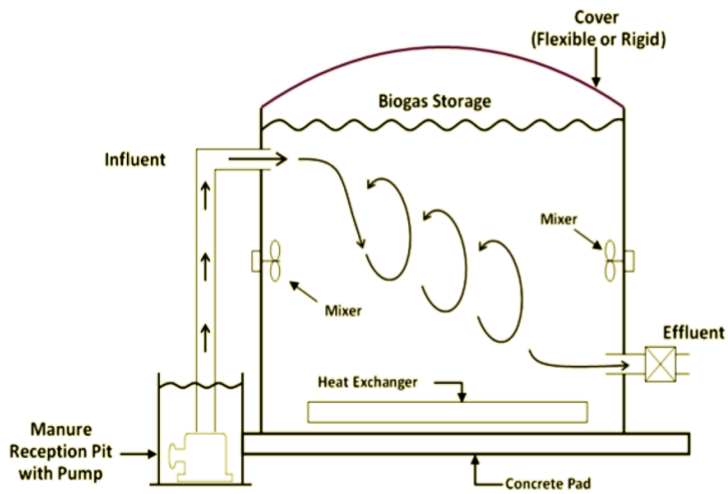
[343] Roos, K., Martin, J., & Moser, M. (2004). *AgSTAR Handbook: A Manual For Developing Biogas at Commercial Farms in the United States, Second Edition*. Environmental Protection Agency, Office of Air and Radiation, EPA-430-B-97-015.
[344] AgSTAR. (2011). Recovering Value from Waste: Anaerobic Digester System Basics. U.S. EPA, Office of Air & Radiation.
[345] Nasir, I. M., Mohd Ghazi, T. I., & Omar, R. (2012). Anaerobic digestion technology in livestock manure treatment for biogas production: a review. *Engineering in Life Sciences*, *12*(3), 258-269.

Continuous digestion requires consecutive additions of biomass and can be achieved through technologies such as upflow anaerobic sludge blankets, internal circulation reactors, and continuous stirred-tank reactors (CSTRs). A schematic of the CSTR mechanism is illustrated below.[346]

Figure 28. Schematic of Continuous Stirred-Tank Anaerobic Digester [347]



AD, the process of microbial digestion of organics in the absence of oxygen, can be conceptually separated into two separate stages: the first comprises acid fermentation, and the second involves methane fermentation.[348] The latter stage presents the opportunity to harness methane gas or biogas, which comprises (in percent by volume) approximately 60-75% methane (CH_4), 19-33% carbon dioxide (CO_2), <1% nitrogen gas (N_2), and 6% water vapor (H_2O).[349] Dairy manure, with high concentrations of biomass and lower concentrations of lignocellulosic materials, is a suitable input for AD biogas generation (although adding other organic waste material in limited quantities can actually provide an ever more optimal composition). After conditioning to remove H_2O and hydrogen sulfide (H_2S), the gas generated can then be used as a form of alternative energy for applications including cooking, heating and cooling, and electricity.[350] Further processing to remove CO_2 converts the biogas to 'biomethane', which has a higher energy content and can be integrated into natural gas pipelines and used as vehicle fuel.[351]

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346 Moss, A. (2013). *Anaerobic Digesters: Designs*. University of Maryland Extension, Fact Sheet FS-2013.
347 Moss, A. (2013). *Anaerobic Digesters: Designs*. University of Maryland Extension, Fact Sheet FS-2013.
348 Kelleher, B. P., Leahy, J. J., Henihan, A. M., O'dwyer, T. F., Sutton, D., & Leahy, M. J. (2002). Advances in poultry litter disposal technology–a review. *Bioresource technology*, 83(1), 27-36.
349 Rasi, S. (2009). Biogas composition and upgrading to biomethane. University of Jyväskylä.
350 Balsam, J., & Ryan, D. (2006). *Anaerobic digestion of animal wastes: factors to consider.* National Sustainable Agriculture Information Service.
351 Zhao, Q., Leonhardt, E., MacConnell, C., Frear, C., & Chen, S. (2010). *Purification technologies for biogas generated by anaerobic digestion*. CSANR Research Report 2010 – 001.

Despite the energy benefits of a potentially untapped resource on farms, biogas use has its limitations. For example, biogas provides an energy content of 600 Btu ft^{-3}, which is lower than other fuels available on the market today (e.g., natural gas provides 1,000 Btu ft^{-3}).[352] In addition, energy input can be required to heat the digester tank; this can be provided from the biogas output itself, and the energy input is approximately 10-20% of the energy output from the biogas.

AD of livestock manure not only generates biogas, but also digestate: remnants of biodegradation that are not metabolized by bacteria, which is typically about 80% by mass of the input value. This digestate, or effluent, presents the opportunity to convert agricultural waste into soil fertilizers through reuse of the digestate, as well as a feedstock for composting. Digestate results from both the acidogenic and methanogenic processes of AD; however, the properties of digestate from each stage differs. Acidogenic digestate is high in lignocellulose content and retains moisture, while methanogenic digestate (also termed "sludge") is marked by high concentrations of ammonium and phosphate. The fact that AD does not reduce phosphorus content in the solid byproducts can present a problem for environmental health as phosphorus is a micronutrient – an element that, when in excess, can lead to the eutrophication of freshwater systems.[353] As such, this property must be carefully managed in AD effluent.

The phosphorus content of the effluent is not the only component of the AD reactor that must be continually and rigorously monitored. AD of agricultural manure can generate hydrogen sulfide (H_2S) and ammonia (NH_3) gases, which must be carefully managed due to their toxicity to environmental and human health. Furthermore, the effective operation of an AD reactor in and of itself demands careful planning of numerous physical and chemical properties of the reactor. These include the temperature, pH, carbon-nitrogen (C/N) ratio, as well as the concentration of compounds including volatile fatty acids (VFAs), ammonia (NH_3), total N or total Kjeldahl nitrogen (TKN), potassium (K_2O), phosphorus (P_2O_5), sulfides, and heavy metals.[354]

This feasibility study encompasses the opportunity to help improve the U.S. biogas market potential. According to the U.S. EPA: "The United States currently lacks adequate environmental, technical, and economic performance data related to biogas-system production of energy, co-products, GHG and other emissions, and water quality benefits"[355] and there are just 250 digesters despite an order of magnitude more potential sites.[356] It is hoped that this project might contribute to the knowledge base of biogas generation data from dairy farms through harnessing the latest flowrate technology to measure outflow

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352 Barker, J. C. (2001). *Methane fuel gas from livestock wastes: A summary.* North Carolina State University Cooperative Extension Service, Publication No. EBAE, 071-80.

353 Sharma, L. K., Bali, S. K., & Zaeen, A. A. (2017). A Case Study of Potential Reasons of Increased Soil Phosphorus Levels in the Northeast United States. *Agronomy,* 7(4), 85.

354 Sakar, S., Yetilmezsoy, K., & Kocak, E. (2009). Anaerobic digestion technology in poultry and livestock waste treatment—a literature review. *Waste management & research*, *27*(1), 3-18.

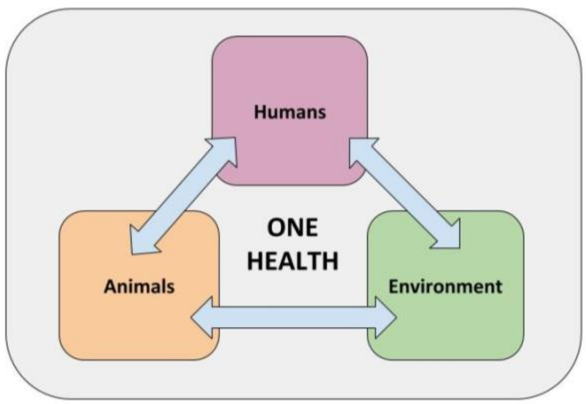
355 U.S. Department of Agriculture, U.S. Environmental Protection Agency, & U.S. Department of Energy. (2014). *Biogas Opportunities Roadmap: Voluntary Actions to Reduce Methane Emissions and Increase Energy Independence*.

356 U.S. EPA. (2016). *Anaerobic Digestion Facilities Processing Food Waste.* Retrieved from https://www.epa.gov/sites/production/files/2016-07/documents/three_types_of_ad_facilites_processing_food_waste_july_2016.pdf. The report tallies eight digesters in Massachusetts alone, three of which are on farms.

of biogas. The system could be made more user-friendly for farmers, who may lack the desire and technological knowledge to operate flow meters manually. The simple addition of a “smart” device would allow for remote data collection using flow meters such as the Model ST51 from Fluid Components International, LLC.[357]

Farmers and governments have heightened concerns about the environmental and economic challenges faced by industrial agriculture, particularly in light of future climate change and growing populations worldwide.[358] Recent efforts to address these concerns have focused on the one-health model, which emphasizes efforts that account for the close interconnection between human, environmental, and animal health.[359] So long as the precise conditions for AD reactors are met and maintained, AD of dairy farm manure fits into this paradigm because it provides potential benefits to all three of these stakeholder categories, such as by generating renewable energy in the form of biogas or methane, minimizing the environmental footprint of farm waste, and improving yields through reuse of the AD effluent in the form of fertilizers.

Figure 29. One Health Framework



Source: Authors

2.2.1 Design Considerations

Given the capital costs and scale it takes to implement and operate an anaerobic digester, the ideal partner may be an agricultural cooperative of cattle farmers with approximately 500 cattle in order to achieve the scale to meet minimum economic effectiveness, while also having relationships already in place around coordination and pooling of resources.[360] A single larger facility would be another option, if

[357] http://www.fluidcomponents.com/products/mass-flow-meters/st-series-flow-meters/st51-mass-flow-meter
[358] Demirer, G. N., Chen, S., Anaerobic digestion of dairy manure in a hybrid reactor with biogas recirculation. World J. Microbiol. *Biotechnol.* 2005, 21, 1509–1514.
[359] Gebreyes, W. A., Dupouy-Camet, J., Newport, M. J., Oliveira, C. J., Schlesinger, L. S., Saif, Y. M., ... & Hoet, A. (2014). The global one health paradigm: challenges and opportunities for tackling infectious diseases at the human, animal, and environment interface in low-resource settings. *PLoS Neg. Trop. Dis*., 8(11), e3257.
[360] Csebristol (2015)

a facility of this size exists that does not already have a digester installed. A herd of this size would be sufficient to run a 1MW plant.[361]

Given the considerable co-benefits (and potential negative externalities) from using anaerobic digesters to their surrounding communities and local infrastructure, project partner selection requires careful consideration of the context of their surrounding community. Local regulations, neighbor attitudes, infrastructural support for biogas and biogas-generated electricity, transportation networks and storage capacity all figure strongly in this decision.

Table 20. Considerations for partner selection

Scale of livestock operations, impacting amount of available manure, methane emissions, and electricity-generation potential	- Of the 19.6 billion pounds of U.S. livestock methane emissions (estimated from the EPA and Penn State study), the highest regional emissions came from "central California, eastern North Carolina, eastern Wisconsin, northwest Iowa, southeast Pennsylvania, southern Idaho, and the Texas Panhandle"[362] - The emissions map against livestock density maps showing the most manure available for ADs is in the Southeast, Midwest, and West[363,364] - Transportation costs between manure sources and digesters affects the generation costs for AD-generated electricity.[365] For waste-to-energy generators, logistics and transportation costs (and associated greenhouse gas emissions) could significantly affect project financials and offset credits. Conducting an assessment of possible project siting locations - taking into account these costs - is an important next step and may tip the balance towards larger-scale operations where all waste is generated on-site rather than cooperatives.
Intended biogas use and required infrastructure (e.g. on-site use, injecting into pipelines, upgrading to biomethane)	- Electricity rates, which are sometimes offered at higher rates to encourage biodigester electricity generation, affect whether biogas production is more profitably used for electricity generation or natural gas - To inject biogas to pipelines, it must either be compressed (as CNG, Compressed Natural Gas) or delivered in vehicles, sometimes to interstate pipelines if local utilities do not allow injection[366]

[361] Ibid.
[362] Penn State: EPA's livestock methane emission estimates on-target. (2017, December 12). American Agriculturalist. Retrieved from http://www.americanagriculturist.com/livestock/penn-state-epa-s-livestock-methane-emission-estimates-target
[363] Wint W.; Robinson T.Gridded Livestock of the World; FAO: Rome, 2007; p 131
[364] U.S. EPA. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2008; EPA 430-R-10-006; Washington, DC, 2010.
[365] Zaks, D. P. M., Winchester, N., Kucharik, C. J., Barford, C. C., Paltsev, S., & Reilly, J. M. (2011). Contribution of Anaerobic Digesters to Emissions Mitigation and Electricity Generation Under U.S. Climate Policy. *Environmental Science & Technology*, *45*(16), 6735–6742. http://doi.org/10.1021/es104227y
[366] Lydersen, Kari. (2017, March 3). Challenges remain for bringing Wisconsin biogas to the market. Midwestern Energy News. Retrieved on March 7, 2018 from http://midwestenergynews.com/2017/03/03/challenges-remain-for-bringing-wisconsin-biogas-to-the-market/

	- To sell biogas for certain uses, such as fueling natural gas vehicles, biogas must be upgraded ("conditioned") with extra equipment to produce pipeline-quality renewable natural gas (RNG), or biomethane
State and local regulations (e.g. ability to sell electricity or inject gas back into grid)	- Regulations vary widely around storage and transportation of manure for public health reasons - Utility regulations vary from state to state as to whether individuals can inject gas into their pipelines (e.g. Wisconsin utilities like We Energies and Alliant Energy forbids this)[367]

Source: Authors

Given the potential shared benefits of electricity generation and heat production, project partners could seek financing structures whereby local businesses receive heating from this more sustainable source, or even partner with local urban waste and wastewater streams to augment farmer manure supply. When inviting community partners to contribute to digester input streams, transportation distance affects economics and potential regulations around transporting organic waste, and negatively impacts the related greenhouse gas reductions (although the net effect may still be positive).

2.2.2 Data Verification and Impact Measurement

Given the growing popularity of anaerobic digesters in recent years, most of the accounting difficulty lies in the inability to accurately measure methane emission reductions from anaerobic digesters. More broadly, methane emissions calculations as a whole are difficult to conduct. Current bottom-up estimates of methane emissions are focused on livestock production, as measuring emissions from manure are markedly harder. Open anaerobic digestion systems (such as an outdoor collection pool covered by a tarp) are much more economical but lack the specific rigor, but even a closed anaerobic digestion system relies on protocols for data collection that require the AD operator to standardize data collection. For farms willing to support more advanced technological systems, Wi-Fi-connected smart meters have the potential to streamline and systematize methane emissions data collection.

Current Challenges with Methane Emission Estimation

Broadly, emission estimate discrepancies as large as 90% exist between "top-down" estimates (derived from atmospheric measurements, largely conducted by NASA and global models such as EDGAR, the Emission Database for Global Atmospheric Research) and "bottom-up" estimates, reflecting the difficulties in measurement and estimation techniques attributed to livestock and agriculture.[368] These differences present an opportunity for anaerobic digester implementation to help standardize data capture for the bottom-up strategy.

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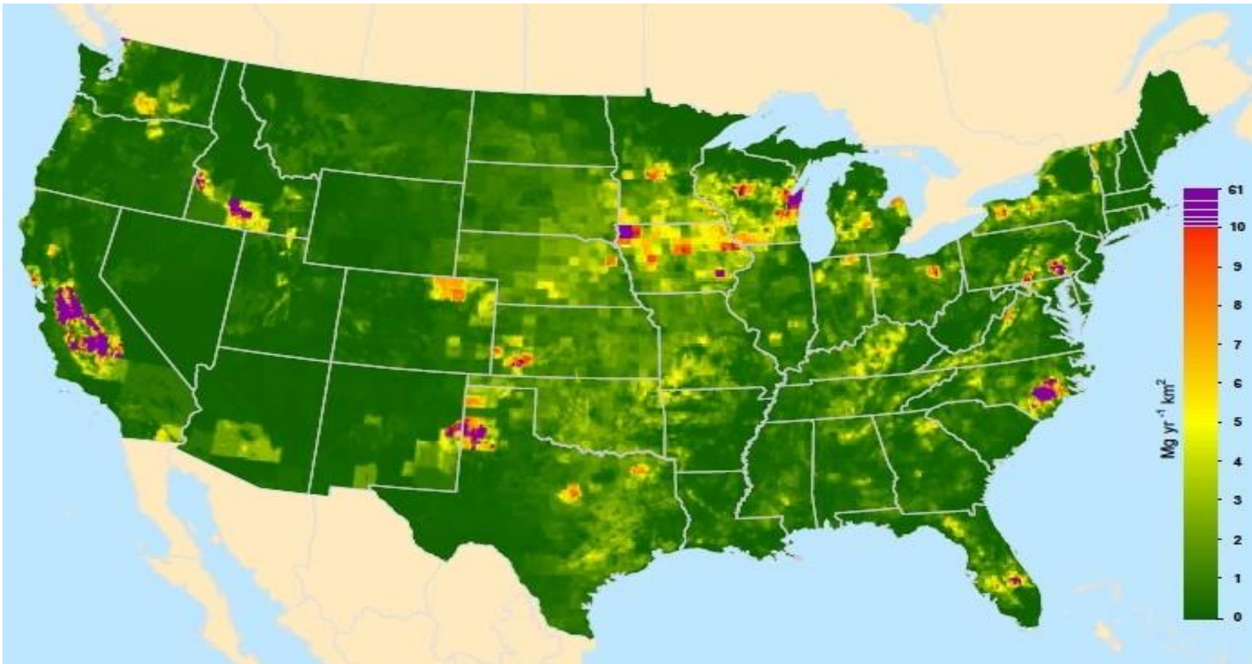
[367] Ibid.
[368] Mulhollem, Jeff. Uncertainty surrounds U.S. livestock methane emission estimates. 2017, November 30. Penn State News. Retrieved from http://news.psu.edu/story/496182/2017/11/30/research/uncertainty-surrounds-us-livestock-methane-emission-estimates

The study conducted by the EPA includes more spatialized source distributions than EDGAR (top-down, atmospheric estimates) and is corroborated by the Penn State “gridded” study.

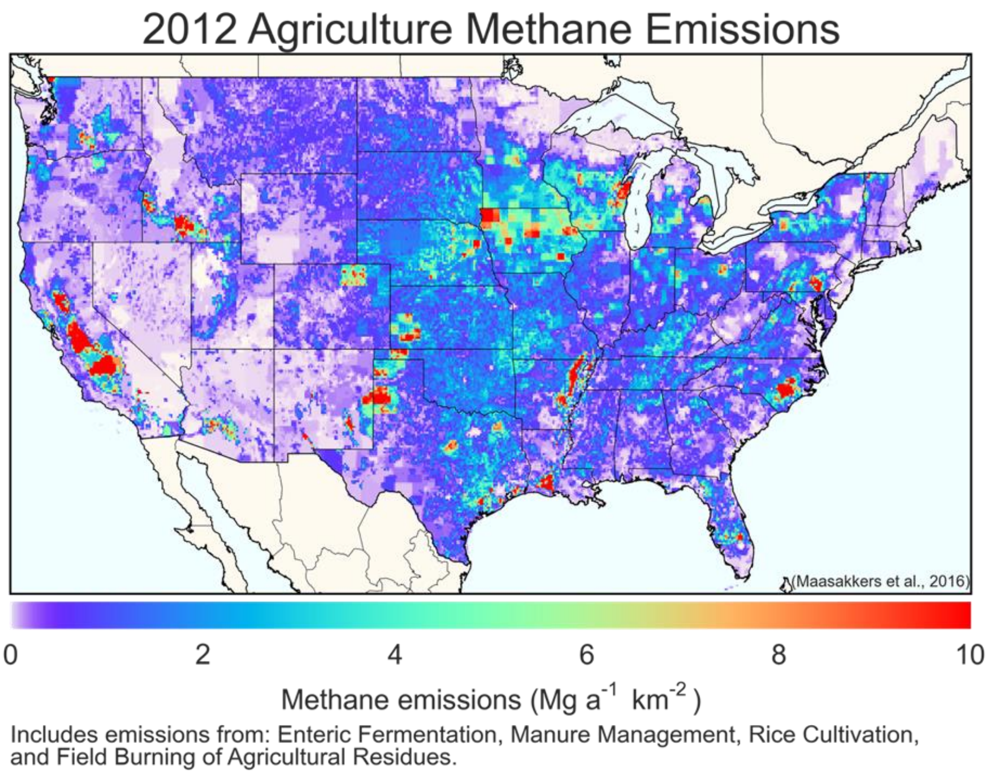
Figure 30. Livestock Methane Emissions (EPA)



Source: Livestock Methane Emissions, EPA (2012)

Penn State's "bottom-up" methane emissions calculation based on a spatial "gridded" approach. Researchers divided the U.S. into 0.1-by-0.1-degree GIS units (31 square miles in the northern U.S. and 42 square miles in the southern U.S.) and evaluated livestock methane emissions from the resulting units. The study (partially funded by ExxonMobil Research and Engineering Company) found no differences from the EPA's aggregate measurements of methane emissions, but some variance in spatial distribution.[369]

Figure 31. Livestock Methane Emissions (Penn State)

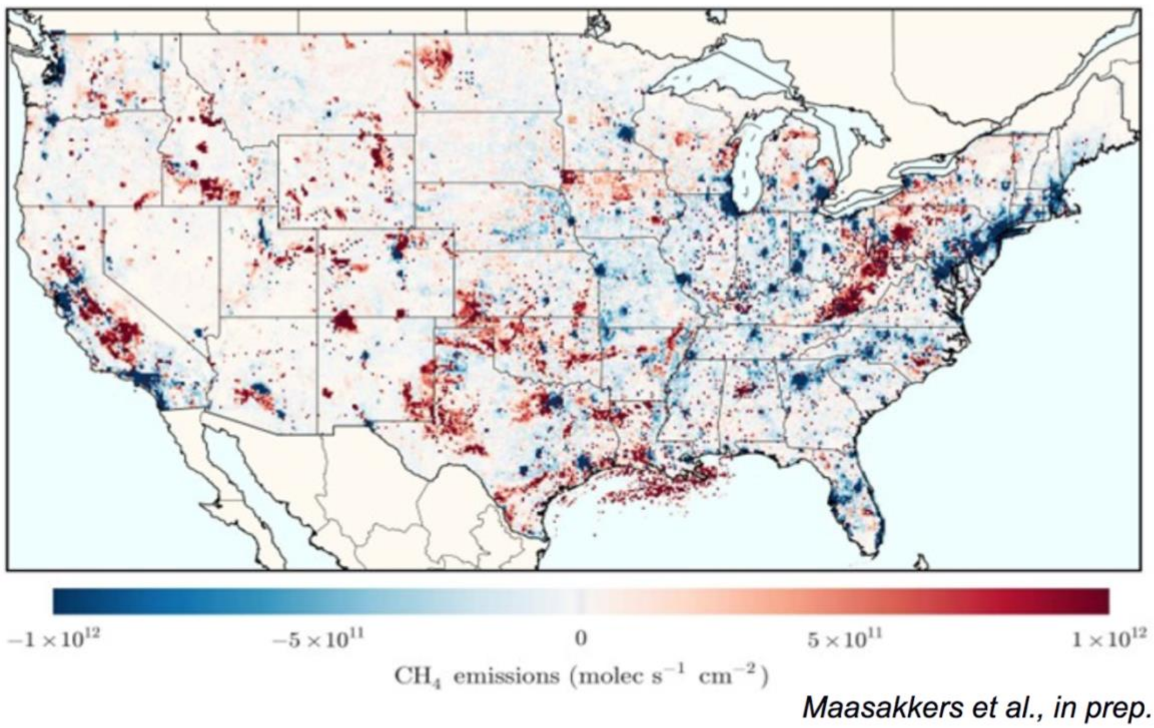


Source: Livestock Methane Emissions, Penn State (2017).

[369] Mulhollem, Jeff. Uncertainty surrounds U.S. livestock methane emission estimates. 2017, November 30. Penn State News. Retrieved from http://news.psu.edu/story/496182/2017/11/30/research/uncertainty-surrounds-us-livestock-methane-emission-estimates

Differences in EDGAR's atmospheric estimates against bottom-up livestock emissions show as much as 90% difference in methane sources.[370]

Figure 32. Differences between EDGAR (atmospheric) and EPA methane emissions.



Source: Jacob et al (2016).

Biogas Reporting Standardization

In an effort to standardize, a detailed protocol has been developed for the U.S. EPA's AgSTAR program to estimate the impacts of Anaerobic Digesters, particularly around utilization and estimation methods for biogas production.[371] Biogas reporting seeks to capture:

- The fraction of captured biogas utilized beneficially
- Thermal conversion efficiency of process
- Reliability of the process (actual vs. maximum potential operating hours)

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[370] Jacob, Daniel J., Bram Maasakkers, Jianxiong Sheng, Melissa. (2016). Methane emission trends in the United States and new bottom-up inventories for flux inversions. Retrieved from http://slideplayer.com/slide/9760587/

[371] Martin, J.H. (2011). A Protocol for Quantifying and Reporting the Performance of Anaerobic Digestion Systems for Livestock Manures, International Symposium on Air Quality and Waste Management for Agriculture. Lexington, MA: U.S. Environmental Protection Agency AgSTAR Program.

- Information about gas processing practices used

Most of the standards are around the use of manual data collection from meters, such as standardizing the interval of data collection and maintaining backups of data at monthly or annual intervals.

Measurement methods are further complicated if co-digestion from another waste stream is being practiced. The common practice of estimating on a per-head basis of methane emissions becomes inaccurate and should instead be reported as a function of the average daily loading of volatile solids (VS) and chemical oxygen demand (COD) over the period.[372]

Streamlining Emissions Measurement with Smart Meters

To push the boundaries of technological possibilities for a biodigester implementation, data collection could be automated using Wi-Fi-connected meters that store data in the cloud, which can be accessed by either the project partner or the unregulated entity. The implementation of a smart system could automatically calculate the volume of volatile solids and chemical oxygen demand, reducing both the effort and potential for error in manual data collection techniques.

Most of the reporting requirements set by the protocol that guide data collection can be automated and streamlined by a connected, smart system, improving quality of data and decreasing manual resources required by a project partner.

Table 21. Benefits of automated reporting with a smart system

Manual Reporting Requirements[373]	Automated Reporting Opportunities
Calibrate a standardized biogas meter to the manufacturer-recommended method and frequency	Sensors to measure waste input (e.g. daily loadings of volatile solids and chemical oxygen demands)
Back-up copy of digester operator records monthly and use a meter totalizer that isn't manually resettable to avoid accidental data loss	Digital backups of data records stored with the redundancy of server backups
Record date/time with every sample	Software can trivialize and standardize the time reporting, or additionally record at more frequent intervals

Source: Authors

There are a few biogas measuring devices in market, such as the GF90 Flow Meter, Vortab Flow Conditioner, and Siemens Ultramat 23 Continuous Gas Analyzer, which also includes an optional data acquisition model that stores up to 43,000 samples of CH_4, CO_2, and O_2 data.[374] These devices improve upon methane estimation techniques by using flow meters to calculate gas volume by measuring gas

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[372] Ibid.
[373] Ibid.
[374] Landfill and biogas monitoring: renewable energy from landfill and biogas. (N.d.) Siemens. Retrieved from https://www.industry.usa.siemens.com/automation/us/en/process-instrumentation-and-analytics/process-analytics/pa-brochures/Documents/PIAFL-00030-0310-landfill-biogas.pdf

flow in and out of an inflatable digester bag.[375] The flow meters are connected to a programmable logic controller (PLC) that calculates the real-time amount of gas in the bag system and communicates the information to a control system, which could be easily connected to store the measurement data in a cloud-based hosting system. Especially for large-scale anaerobic digesters, a real-time flow meter can monitor for excess gas in the system and prevent risk of leaks.

2.3 Case Studies

Anaerobic digesters have been implemented with great success on large-scale farms, industrial food processors, and universities. The below case studies give a sense of scale and output of other anaerobic digester systems.

2.3.1 University: Michigan State University South Campus Anaerobic Digester (East Lansing, MI)

Michigan State's digester processes over 17,000 tons of organic waste per year, including feedstock from 180 milking cows and 180 heifers as well as food waste from restaurants and a nearby food processing plant.[376] Feedstock is first homogenized in a central mix tank, after which the blended material is pumped into a heat exchanger and then fed into the digester (the volume of which is 45,000 gallons). The matter is heated to 100 degrees Fahrenheit and remains in the digester for 20 to 30 days.[377] The system produces 2.8 million kWh per year, sufficient to power 8 to 10 buildings on campus. The project's $5 million-dollar cost has a projected payback period of less than 15 years.[378]

2.3.2 Dairy Farm: Big Sky West Dairy Project (Gooding, ID)

Dean Foods and AgPower Partners worked together to set up a modified "mixed plug-flow" digester, fed by a mixture of manure from 4,700 dairy cows and a small amount of other organic wastes.[379] The biogas produced is used to fuel two 710 kW engines, producing electricity which is then sold to the local utility.

The digestate (the remaining material after digestion processes are complete) is sold to consumers as a potting soil under the brand name "Magic Dirt." Selling points for Magic Dirt, beyond the emissions

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[375] Craig, Steven. (N.d.) New Flow Meter Optimizes Digester Biogas Measurement. WaterWorld, Volume 23, Issue 9. Retrieved from http://www.waterworld.com/articles/print/volume-23/issue-9/weftec-exhibitors/new-flow-meter-optimizes-digester-biogas-measurement.html
[376] U.S. EPA. (2016, May). *Microbes at Work: Stand-Alone Anaerobic Digesters.* Retrieved from https://www.epa.gov/sites/production/files/2016-05/documents/msu_project_profile_v3_may_12.pdf.
[377] MSU Infrastructure Planning and Facilities. (2013, Jun. 24). *The Anaerobic Digester at MSU*. [Video file]. Retrieved from https://www.youtube.com/watch?v=aULRryCVMyY.
[378] Michigan State University Today. (Aug.13, 2013). "New MSU Anaerobic Digester to Supply Power for South Campus Buildings. Retrieved from https://msutoday.msu.edu/news/2013/new-msu-anaerobic-digester-to-supply-power-for-south-campus-buildings/.
[379] U.S. EPA. (2016, Jul.) *Big Sky West Dairy Project*. Retrieved from https://www.epa.gov/sites/production/files/2016-07/documents/big_sky_west_-_rev_7-18-16.pdf

reductions associated with its production, include better root growth and less watering due to higher moisture retention.[380] Potting soils made from digester digestate are preferable to peat moss (the more widely used competing material) because peat moss harvesting releases significant amounts of methane gas when it is extracted from bogs.

Partnership model

The facility is owned and operated by a third party, which handles project financing and continued maintenance, while the farm provides necessary manure.[381] The digester operator and manufacturer further guarantee that the digester will operate as promised. An "off-take" agreement with another party provides a guaranteed purchaser of digester products (e.g., emissions credits and fiber). Risk falls on the digester operator rather than the farm.

2.3.3 Swine Farm: Danny Kluthe Swine Farm Project (Dodge, NE)

The Danny Kluthe Swine Farm partnered with Nebraska Public Power Grid and used grants from USDA and the Nebraska Environmental Trust to install Nebraska's first digester system.[382] The complete mix digester uses an in-ground concrete tank with an insulated flexible cover, generating methane as it stirs and heats the waste. The biogas is used to fuel an internal combustion engine, which produces electricity sold to the utility under a by-all, sell-all contract.[383] The 6,000-head swine operation produces 730 kWh of energy annually, an amount sufficient to power 53 homes a year.

In the words of Danny Kluthe, the farm's owner and operator, "[Digesters] make so much sense that once producers understand them and see the value of them, there will not be a hog unit built or a dairy put in that probably will not want these installed immediately on it."[384]

2.4 Project Structure

Project finance provides an appropriate outline for a digester project structure. Project financing works best for large infrastructure projects that have high upfront costs, but then will be expected to generate a steady, relatively predictable stream of revenue cash flows in the future. All contracts - including the financing, offtaking, design, and construction - run through this central project owner entity. To access industrial revenue bonds and avoid transaction costs of setting up a separate entity, it is likely more

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[380] Magic Dirt. *Better Plants. Greener Planet.* Retrieved from http://www.magic-dirt.com/

[381] Innovation Center for U.S. Dairy. (2012).Case Study -- Third Party Partnership for Anaerobic Digesters.

[382] U.S. EPA. (2016, Jul.) *Danny Kluthe Swine Farm Project* (Jul. 2016). Retrieved from https://www.epa.gov/sites/production/files/2016-07/documents/danny_kluthe_-_rev_7-18-16.pdf.

[383] In a "buy-all, sell-all" contract, utilities offer to continue selling the farm all electricity, while buying all generator output. There are few advantages to such an arrangement in a low-cost energy market, as the utility often pays only 25-33% of the charged retail rate per kWh. *See* U.S. EPA. (Feb. 2004). *A Manual for Developing Biogas Systems at Commercial Farms in the United States*. p. 45. Retrieved from https://www.epa.gov/sites/production/files/2014-12/documents/agstar-handbook.pdf

[384] Danny Kluthe Swine Farm Project, above.

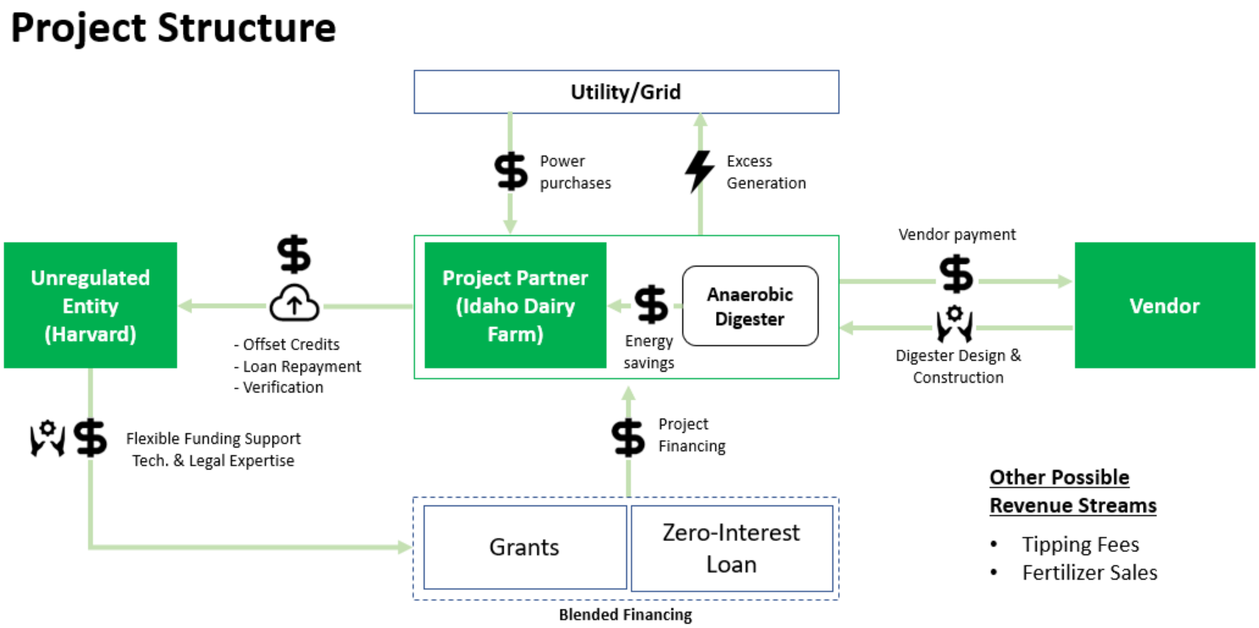
feasible to keep the digester on the balance sheet of the farm, but the digester could technically also be owned and operated by the constructor.

The proposed project design includes multiple outputs that serve as revenue sources for the project. Since energy generation usually is in excess of on-site needs, electricity sales back to the local utility through a power purchase agreement will allow the digester to generate cash flows both through avoided energy costs and additional excess revenues (further discussion of the relationship with the local utility is discussed in Section 2.7.2, but this is a common arrangement for digesters in many states). Furthermore, the digester output materials can serve as sources of bedding (high-quality fiber) and nutrient-rich fertilizer to be sold or used on-site for grazing land. Cash flows from these revenue streams are initially used to pay back any debt accrued for construction. After all debt has been paid back, additional revenue goes to the digester owner and operator. Similar example projects have reached simple payback in anywhere from 6-20 years.[385]

The role of the unregulated entity in this project is to serve as a flexible source of additional financing or funding to make the project financially feasible - the final piece of financing to get a relatively attractive project “over the hump.” The type of financing needed will be project-specific, but likely will be in the form of a loan guarantee, cost sharing agreement, grant, or low-cost direct loan. There may also be a role for the unregulated entity to provide technical support or funding for project development costs (legal contract structuring, specific project identification). The specific financing structure and exact roles of the unregulated entity for a specific project proposal will be explored further in the Implementation Plan.

[385] https://www.epa.gov/sites/production/files/2014-12/documents/funding_digestion.pdf

Figure 33. Potential project structure for digester



Source: Authors

Table 22. Required parties for digester implementation

Entity	Responsibilities	Concerns
Project Partner & Owner (e.g. ~500 cattle dairy farm or equivalent collective)	- Implementing and operating the AD system - Supplying and transporting the digester with manure and other organic waste - Selling or using the heat and generated electricity from the digester	- High capital costs (may require coordination to pool with local sources) - Social stigma - Concerns with regulations - Difficulty connecting with utilities and biogas grid
Unregulated Entity (e.g. Harvard)	- Funding project partner - Accounting for GHG and market co-benefits	- Difficulty conducting accurate methane emissions accounting
Utility Grid Operator	- Provide infrastructure connecting to the digester to receive electricity - Manage and measure excess generation for Power Purchase Agreement	- Little direct benefit to participating and cooperating, while shouldering costs of grid support
Project Designer & Developer	- Design and develop the project to match the farm's needs	- Solutions are bespoke for the specifications of any given farm

	- Implement smart technology solution to facilitate GHG reduction measurement and Power Purchase Agreement enforcement	- Smart technology solutions may not be a standard part of the company's offerings
Other Funders (e.g., state or federal grants, commercial banks)	- Conduct due diligence on the project - Provide financing	- Creditworthiness of farm (may cause financiers to want a higher rate of return than the farm can withstand)
(Optional) Co-Digestion partners (e.g. neighboring schools)	- Supplying and transporting other streams of organic waste to digester	- Logistics and cost of transporting waste
(Optional) Biogas Purifier	- Conditioning (refining) biogas for pipeline-ready quality for use in some industries (e.g. transportation)	- Cost-effectiveness of taking the extra step to condition biogas further, if there's not enough demand for the unprocessed biogas

Source: Authors

Other project structure models we have considered and will explore further include:

- Jointly owned and/or operated digester by the concentrated cooperative of farms, all of which
- Digester constructor builds, owns, and operates the digester (serving as the main project partner), while the farm provides just the land and manure feedstock
- Unregulated entity serving as the backer of a project developer with experience in this space, who then is responsible for developing the project entirely

2.5 Financial Analysis

Generally speaking, the feasible financing of digester projects varies with size, geographic location, and type of digester system, all of which varies depending on the user's needs.[386] Fortunately, once technical feasibility has been established, the steps to evaluating financial feasibility are proven and straightforward. First, estimate the potential annual revenue the project could generate based on the following technical components[387]:

- The amount of biogas to be produced and how it will be sold or used
- Financial assistance (loan, bond, co-financer, government funding, etc.)
- Renewable energy and carbon credits

[386] Anderson, R., Hilborn, D., Weersink, A. (2013). An economic and functional tool for assessing the financial feasibility of farm-based anaerobic digesters. *Renewable Energy*, *51*, 85-92. https://doi.org/10.1016/j.renene.2012.08.081
[387] EPA. (2016). Financing Anaerobic Digestion Projects. Retrieved March 9, 2018, from https://www.epa.gov/agstar/financing-anaerobic-digestion-projects#colorbox-hidden3

- Estimate the annual expenses, including one-time (initial capital) and ongoing annual (operation and maintenance) costs of the system

2.5.1 Refining the plan

After finding potential annual revenue (if any), there are many other tools to evaluate various other financial components based on dynamic inputs. The financial success of an anaerobic digester project greatly depends on site-specific factors that influence the amount and quality of methane generated, variability in electricity prices, availability of incentives, and financing rates - all of which vary at the state and sub-state level.[388]

Desirable outcomes for successful projects include[389]:

- Increasing income from electricity sales (such as tariffs for biogas) or other types of energy sales.
- Avoiding energy costs from on-farm electricity and heat production
- Getting direct financial assistance for further feasibility studies and/or up-front costs.
- Using creative financing mechanisms such as tax credits and low interest program investment loans.
- Developing lower cost digester systems.
- Seeking additional revenue-generating options (finding additional uses for on-farm heat; accepting off-farm wastes for tipping fees; concentrating nutrients for fertilizer products).
- Implementing different business models, such as third-party build/own/operate models.

2.5.2 Steps for detailed financial modeling[390]

(1) Model revenue and expenses

There are ample resources available from the U.S. government as well as research and academic institutions that can support potential projects, particularly creating financial models. Some examples are:

1. Cost of Renewable Energy Spreadsheet Tool (CREST): Developed by the National Renewable Energy Laboratory (NREL), CREST assesses project economics with a specific tool for anaerobic digestion technologies. The free tool allows inputs for project size and performance, capital costs, O&M, construction financing, permanent financing, taxes, depreciation, reserve account funding, working capital, capital expenditures during operations (equipment replacement), state rebates/tax credits/REC revenue, federal incentives, market value forecasting, tariff rate structure, and tipping fees.
2. Economic and Functional Tool for Assessing the Financial Feasibility of Farm-based Anaerobic Digesters: Journal article discussing a workbook that determines the financial feasibility of

[388] Ibid.
[389] Ibid.
[390] Ibid.

farm-based anaerobic digestion. The workbook identifies technical and financial parameters that affect returns, as well as sensitivity of the assumptions to changes in parameter values. The tool also creates outputs based on different types of systems.

3. System Advisor Model (SAM): Developed by NREL, calculates financial metrics for power projects based on a project's cash flows over an analysis period based on installation, operating costs, and system design.

(2) Determine equity share and sources

Estimate how much funding that is feasible to contribute as equity and where it will come from. A minimum of 10% is generally required, but investors and lenders prefer project owners take the highest possible share.

(3) Identify funding sources to fill the gap between equity and the project cost

Information is available to identify grants, loan guarantees, and financial assistance from federal and state governments, nonprofits, and private companies. Some examples are:

- Database of State Incentives for Renewables & Efficiency (DSIRE): (funded by U.S. Department of Energy, updated monthly) Includes information about renewable energy incentives and policies to help fund energy-producing digesters.
- USDA Energy Matrix identifies alternative and affordable energy solutions, funding for projects, available programs and program information, and research and development. (USDA)
- USDA Rural Energy for America Program (USDA)
- USDA Rural Development Business Programs (USDA)
- USDA Rural Development Value-Added Producer Grants (VAPG) (USDA)
- USDA Farm Service Agency Energy Programs – Biomass Crop Assistance Program (USDA)
- Sustainable Agriculture Research & Education Sustainable Agriculture Grants (SARE)

(4) Calculate return on investment

Compare the annual revenue against expenditures to estimate when the initial investment will be paid back and the rate of return on the money invested. Several methods include discounted cash flow analysis (DCF) (estimates net present value of future cash flows), internal rate of return (IRR) (rate of return which can be compared to rates from other options), and payback period (the number of years it takes for the project to recoup initial capital investment).

(5) Select financing method

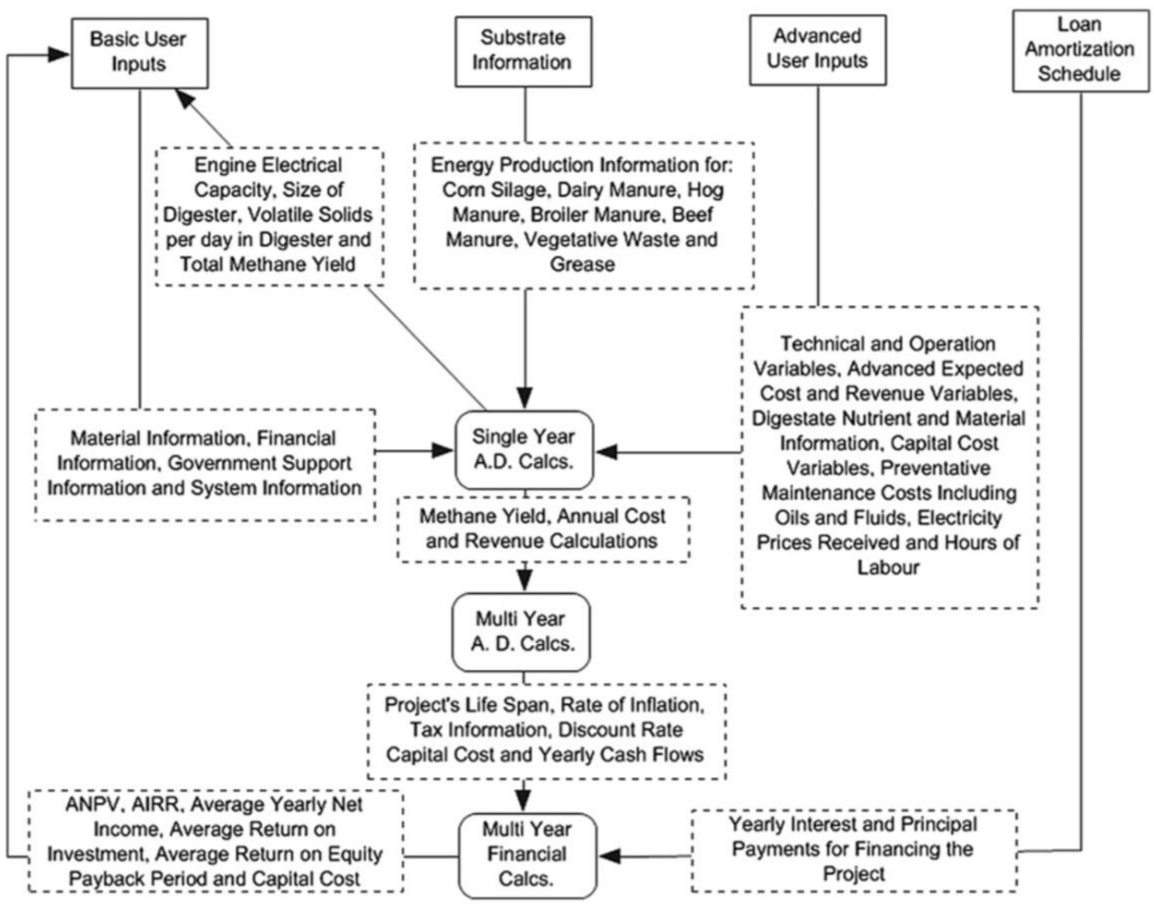
The ROI should be the main metric for attracting financing from either a lender or investor. The Vendor Directory maintained by AgSTAR provides a comprehensive list of financing specialists who provide loans specifically for agricultural projects, have a history of funding biogas systems for profit, and brokering carbon offset sales and RECs. Other options for financing include cost-sharing, which is when project coordinators retroactively apply for funding after the digester has been built. An example of cost-share programs would

include the USDA Natural Resources Conservation Service (NRCS)
Environmental Quality Incentives Program (EQIP).[391]

(6) Negotiation utility agreement

If the project is productive enough to provide gas to the grid, the project must establish a power purchase agreement (PPA) with a utility contract. There are three options: buy all-sell all, surplus sale, and net metering.

Figure 34. Flow diagram of Anderson (2013) workbook[392]



[391] AgStar. *Funding On-Farm Anaerobic Digestion*. (2012). https://www.epa.gov/sites/production/files/2014-12/documents/funding_digestion.pdf
[392] Anderson (2013)

2.5.3 Potential challenges

Cost (particularly upfront capital cost) is always the biggest challenge for successfully starting and implementing an anaerobic digester. Studies have found that anaerobic digesters can be poor investments for private firms that lack public assistance.[393] Generating public assistance in the form of financing can be challenging depending on how the project is marketed and its ROI. Fortunately, there are plenty of incentive and funding programs created for these types of projects. As long as the project has a clear technical design and financial feasibility has been conducted based on location and energy mix, there are national and state-level opportunities worth pursuing.

2.6 Potential Benefits and Negative Externalities

2.6.1 Benefits

Anaerobic digesters provide a variety of benefits that help farmers reduce cost and their environmental impact. By capturing methane from waste to use for energy, this limits the GHGs emitted to the atmosphere (note: even though conditions in the digester are being optimized for methane creation and there is some leakage, net emissions are much lower - this approach is a proven greenhouse gas reduction method and numerous currently operating facilities have received verified offsets for their emissions reductions[394]). It also reduces the farms use of grid electricity, which is almost always more emissions intensive than the biogas (discussed below in Section 2.6.4). The system provides stable a stable renewable power source. Storing waste in the digester can reduce runoff in water, in turn improving local water sources.

Additionally, digesters are beneficial for soil through the production of the nutrient rich digestate. While this same nutrient-rich manure is already often applied as part of farms' Nutrient Management Plans, digestate can be refined and optimized better than other waste management systems. When then applied to soil, the benefits include: decreasing erosion and runoff; improving plant growth; decreasing the use of pesticides and fertilizers; increasing water retention and reducing the need of irrigation. Products from the digesters are also to provide animal bedding. A properly maintained system can reduce the odor permeating around the farm. Digesters turn waste into valuable output products and sellable compost for farmers.[395]

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[393] Anderson (2013)
[394] American Carbon Registry (2018) "Public Registry." Retrieved from https://americancarbonregistry.org/how-it-works/registry-reports.
[395] U.S. EPA. (2017). *Environmental Benefits of Anaerobic Digestion (AD).* Retrieved from https://www.epa.gov/anaerobic-digestion/environmental-benefits-anaerobic-digestion-ad

2.6.2 Expected Project Outcomes

Installing an anaerobic digester would be able to provide the farmer with a stable renewable power source. This reducing the need to use grid transmitted fossil fuels. Generating power saves the farmer on electricity costs and provides additional products such as digestate that they can use or sell.

2.6.3 Expected Immediate Outcomes

Initially after installing a digester the farmer will be able to store their manure and waste in the system. This can reduce smells and odors permeating around the farm. In addition, the farmer will have a surplus of power that can be utilized on additional farm activities, and better fertilize may reduce expenses creating more available income for farmers to improve their livelihoods.

2.6.4 Potential Health Outcomes

Surface runoff commonly pollutes bodies of water across the United States and the world. As a resulty, drinking water becomes contaminated with substances such as pathogen and nutrients. Storing livestock and agricultural waste in a digester can reduce the amount of runoff that occurs in water sources. Cattle feces is a common reservoir for *E. coli* and streptococci, consumption of water contaminated with these bacteria can cause waterborne diseases.[396] Food can be contaminated as well from agricultural runoff, leading to an additional pathway to be harmed by agriculture wastes.Installing a digester that stores the waste help prevent the spread of *E. coli,* streptococci, and fecal coliform. Additionally, water contaminated with nutrients can lead to eutrophication, resulting in fish kills, and a reduction in water quality. A digester limits the chance for eutrophication to occur.

Producing renewable energy from biogas reduces the amount of air pollutants deposited in the atmosphere. Compared to burning coal, supplying electricity with biogas can reduce pollutants such as particulate matter, sulfur dioxide, mercury, carbon monoxide, and carbon dioxide.[397] At the moment all the methane from the farm is being released into the atmosphere, which results in the creation of ground level ozone.[398] Ground level ozone is a criteria pollutant and is associated with a variety of respiratory effects. Breathing ozone can cause “chest pain, coughing, throat irritation, and airway inflammation, as well as reduce lung function and harm lung tissue.”[399] Additionally, it can lead to worsening bronchitis, emphysema, and asthma.[400] Air pollution reduction can benefit air quality

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[396] Weaver, RW. Entry, JA., & Graves, A. (2005) Numbers of fecal streptococci and Escherichia coli in fresh and dry cattle, horse, and sheep manure. *Canadian journal of microbiology*, *51*(10), 847-851.
[397] Pathak, H., Jain, N., Bhatia, A., Mohanty, S., & Gupta, N. (2009). Global warming mitigation potential of biogas plants in India. *Environmental monitoring and assessment*, *157*(1-4), 407-418.
[398] Climate and Clean Air Coalition. (n.d.). Tropospheric ozone. Retrieved from http://www.ccacoalition.org/en/slcps/tropospheric-ozone
[399] United States Environmental Protection Agency. (2017). Basic information about ozone. Retrieved from https://www.epa.gov/ozone-pollution/basic-information-about-ozone#effects
[400] United States Environmental Protection Agency. (2017). Basic information about ozone. Retrieved from https://www.epa.gov/ozone-pollution/basic-information-about-ozone#effects

resulting in a reduction of respiratory related impacts. Reduced greenhouse gases also can reduce climate impacts, preventing future adverse health impacts.

2.6.5 Negative Externalities

Anaerobic digesters are not without the potential for unintended consequences if managed poorly. Mismanagement and damage could lead to waste seepage into groundwater as well as odor problems. Odor problems can cause a nuisance for passersby. Groundwater contamination can cause drinking water contamination. This can result in individuals getting waterborne diseases such as *E. coli* and streptococci from the contamination. If the system completing fails, due to a natural disturbance or negligence, this could lead to high levels water contamination. Most of these risks can be mitigated through a combination of proper technical design, and proper training and risk management enforced through the project contract.

Furthermore, "free" digester energy may encourage farmers and ranchers to use more energy to increase operational activity. While this will provide the farmer economic benefits, it may offset some slight portion of the emissions benefits of switching to the less emissions-intensive energy source.[401] Finally, methane leakage from the digester could be considered a negative externality. However, as noted in Section 2.6.1, this is incorporated as part of net emissions calculations and is therefore subtracted from benefits, still leaving significant net mitigation of methane by implementing this system.

2.6.6 Health Impact Assessment

The assessment included:

1. Defining potentially impacted communities, observing the baseline health, assessing the current economic and environmental conditions
2. Identifying health studies that survey the surrounding area
3. Reviewing data that is associated to potential project impacts
4. Synthesizing data to related to community conditions, health pathways, and the project impact to summarize and communicate the possible health impacts[402]

It was important to determine that there would be an location where installing a digester could results in health benefits.To identify a location that would have a high impact screening was conducted across the State of Idaho. The screening including retrieving the population, per capita income, value of agricultural products sold, percent of agriculture that is livestock and their products. Additionally, chronic lower respiratory deaths and respiratory cancer deaths were retrieved for the 10 counties.

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[401] Pehme, A., & Veromann, E. (2015). Environmental consequences of anaerobic digestion of manure with different co-substrates to produce bioenergy: A review of life cycle assessments. *Agronomy Research*. 13(2), 372-381. Retrieved from http://agronomy.emu.ee/vol132/13_2_12_B5.pdf
[402] Michanowicz. (2018). Health impact assessment. PowerPoint presentation.

Furthermore, the overall chronic lower respiratory deaths and respiratory cancer deaths, and asthma were identified across Idaho.

2.7 Legal Analysis

Perhaps the best evidence of the legal feasibility of anaerobic digesters are the 250+ facilities currently operating in the United States.[403] The majority of the facilities are larger than that contemplated in this feasibility study, as larger facilities benefit from the economics of scale that can make these projects more financially viable without the contributions of an unregulated entity like Harvard University.[404] This section maps the various contracting and regulatory compliance requirements facing these small-scale digesters.

2.7.1 Permitting

(NOTE: state-specific permitting analyses, including processing times, application components, and fees, are included in the project implementation plan.)

State and local permitting requirements will vary, and likely require close coordination with local regulators. Early contact with regulating agencies and emphasizing pollution and odor control aspects of the project can make the permitting process less burdensome.[405]

As described at length in the implementation plan, permitting should take approximately one-and-a-half to two years. Filing fees will be in excess of $100,000, not accounting for legal fees and necessary professional certifications. Legal work associated with permitting and regulatory compliance will be spearheaded by the Emmett Environmental Law and Policy Clinic at Harvard Law School.

Air Permits

The AD's themselves do not trigger federal permitting requirements under the Clean Air Act.[406] State-level air permitting will however likely be required for the generator creating electricity with AD biogas.[407] This is because the combustion of biogas produces carbon dioxide, nitrogen oxides, sulfur

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[403] U.S. EPA. (2016). *Anaerobic Digestion Facilities Processing Food Waste.* Retrieved from https://www.epa.gov/sites/production/files/2016-07/documents/three_types_of_ad_facilites_processing_food_waste_july_2016.pdf. The report tallies eight digesters in Massachusetts alone, three of which are on farms.

[404] Csebristol. (2011, Mar. 10). Considering an Anaerobic Digester. [Video file]. Retrieved from https://www.youtube.com/watch?v=TVUAaIhZQUM.

[405] U.S. EPA. (2004, Feb.) *A Manual for Developing Biogas Systems at Commercial Farms in the United States*. Retrieved from https://www.epa.gov/sites/production/files/2014-12/documents/agstar-handbook.pdf,

[406] Ibid.

[407] *See e.g.,* Vermont Dept. of Environmental Conservation. (2017). *Anaerobic Digesters*. Retrieved from http://dec.vermont.gov/air-quality/permits/source-categories/anaerobic-digesters. The guidance recommends reaching out to state permitting agencies to secure a pre-construction air permit, the terms of which varying depending on the precise use of the biogas.

dioxide, and other hazardous air pollutants.[408] The generator used to produce electricity with digester biogas would still however need to meet emissions limitations for non-road internal combustion engines under 40 C.F.R. 60.[409] These requirements include purchasing an engine from a certified manufacturer and keeping the engine in good working order.

Solid Waste Permits

Financial and emissions models within this feasibility study and implementation plan contemplate digester systems processing waste produced on-site only. AD's themselves do not require solid waste permits under existing federal requirements, though accepting third-party organic material may cause the digester to be classified as a waste processor under state law.[410]

Water Permits

Anaerobic digesters do not specifically trigger any national water-related permit requirements.[411] However, if the development site contains or is adjacent to a wetland, a section 404 permit from the Army Corps of Engineers would likely be required for construction.[412] No National Pollutant Discharge Elimination System (NPDES) permit for the digester will be needed as effluent from the system will be recycled back into the digester's manure flush processes, rather than expelled into the "waters of the United States."[413]

The process for amending an existing NPDES permit to accommodate a digester is described in the Implementation Plan.

2.7.2 Relationship with Local Utilities

Most farms producing electricity via biogas use generators which operate in tandem with a utility.[414] These arrangements require close coordination with the local utility but should not present insurmountable barriers to sale or use of farm-produced electricity.

Utilities are legally required to work with farmers producing electricity onsite with biogas.[415] Given the relatively small amount of electricity produced (less than 1 MW per year), it is unlikely that the utility will have formal rules or procedures in place to govern production and sale. The project partner will still

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408 VT Dept. of Environmental Conservation, *above*.
409 *See also* Moriarity, K., NREL. (2013, Jan.) *Feasibility Study of Anaerobic Digestion of Food Waste in St. Bernard, Louisiana*. Retrieved from https://www.nrel.gov/docs/fy13osti/57082.pdf
410 AgSTAR, U.S. EPA. *Guidelines and Permitting for Livestock Anaerobic Digesters*. Retrieved from https://www.epa.gov/agstar/guidelines-and-permitting-livestock-anaerobic-digesters#permitting.
411 U.S. EPA. *Guidelines and Permitting for Livestock Anaerobic Digesters*. Retrieved from https://www.epa.gov/agstar/guidelines-and-permitting-livestock-anaerobic-digesters#permitting
412 *See* 33 U.S.C. § 1344 (2018).
413 The jurisdictional and hydrological scope of "waters of the United States" has proven to be an amorphous concept. Its extent would shrink dramatically under a proposed rulemaking by the EPA. *See* 82 *Fed. Reg.* 34,899 (Jul. 27, 2017). Retrieved from https://www.epa.gov/sites/production/files/2017-07/documents/2017-13997.pdf.
414 *Id.*, p. 27.
415 *Id.,* p. 44.

be required to meet whatever interconnection requirements the utility has, including equipment purchases in order to safeguard against transmission or generation failure.

Utility Sale Schemes: Net Metering

Net metering is the recommended approach for exchanging electricity between the larger grid and the project partner's farm. In net metering, the electrical output on the farm is offset on a monthly or annual basis against the farm's consumption from the macrogrid. Surplus power is purchased by the utility, and shortages are purchased by the farm. Net metering eligibility varies state by state. State-specific analysis is provided in the implementation plan.

2.7.3 Alternative to Net-Metering: Direct Distribution

As an alternative to a net metering scheme, the client and project partners may wish to explore local distribution of power produced by anaerobic digesters. Power produced on site would be transferred to neighboring entities via electrical lines, with this microgrid integrated into the larger macrogrid.[416] Implementation would require state- and location-specific analysis and would likely be more structurally complex as a project. In Massachusetts for example, the free distribution of power to neighboring properties, or the sale of farm-generated power to local entities is allowed.[417] Though state law requires the consent of the local municipality in order to run an electric line over a public way like a street, the governing statute in Massachusetts does not require consent of the incumbent distribution company.[418]

2.7.4 Liability and Risk Reduction

There are significant health and safety risks associated with anaerobic digesters, but these risks can be managed with sound workplace safety practices and through purchasing additional insurance. Livestock feedstock for digesters can cause asphyxiation within contained spaces even when only a little material is present.[419] The biogas produced is also an asphyxiant and furthermore is potentially explosive.[420] Electricity generator noise can damage hearing, while transmission lines present risk of electrocution.[421]

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[416] Emmett Environmental Law & Policy Clinic. (2014, Sep.) *Massachusetts Microgrids: Overcoming Legal Obstacles*. p. 6. Retrieved from http://environment.law.harvard.edu/wp-content/uploads/2015/08/masschusetts-microgrids_overcoming-legal-obstacles.pdf.
[417] *Ibid.* p. 8.
[418] *Ibid.* p. 11.
[419] AgStar, U.S. EPA. (2011, Dec.) *Common Safety Practices for On-Farm Anaerobic Digestion Systems*. Retrieved from https://www.epa.gov/sites/production/files/2014-12/documents/safety_practices.pdf. ***See also*** U.S. EPA. *Frequent Questions About Anaerobic Digestion*. Retrieved from https://www.epa.gov/anaerobic-digestion/frequent-questions-about-anaerobic-digestion
[420] *Ibid.* p. 14.
[421] Ibid. p. 4.

Severe spills of digester material have been reported in the United Kingdom, which can contaminate land and water resources and severely disrupt production capacity.[422]

Existing liability insurance on farms can likely be expanded to cover the unique risks presented by a digester, though the availability and cost of additional insurance will prove an important screening criteria for project partners.[423] Contracting between the project partner and the client should also contemplate such contingencies in a "force majeure" provision.[424] Workplace hazards can be mitigated through clear signage, installation of guardrails, and thorough employee and operator education in harm-minimizing practices.[425]

Ecological risks can similarly be minimized with use of forethought and careful siting. For example, digesters should be placed outside 100-year flood plains where possible.[426] Design choices should contemplate the water table beneath the farm (i.e. building digesters above ground, notwithstanding higher costs, to avoid contamination risk).[427]

2.8 Additionality

The American Carbon Registry has an approved methodology, for which numerous dairy farms have already received offset credits for completed digester projects. We propose to follow this methodology. Baseline emissions calculations are laid out in more detail in the methodology document,[428] but generally use a performance standard approach to assess baseline emissions.

Under the ACR guidelines, additionality simply calls for the facility to be operating in a geography where there is no regulation that requires livestock facilities to destroy methane from manure.[429] It is important to note, however, that the project must not be "double dipping" on credits for the GHG reductions; *either* renewable energy credits or carbon offset credits should be counted, but not both for the same emissions reductions. For this project, offsets are more logical due to the significant methane emissions reductions that can be achieved.

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422 Miller, D. (2014, May 30). What the Muck! *Daily Mail*. Retrieved from http://www.dailymail.co.uk/news/article-2644056/Eco-friendly-university-power-station-explodes-covering-area-stinking-cows-muck.html. A violent explosion in a digester ripped through the facility's housing and spilled thousands of gallons of slurry.
423 A Manual for Developing Biogas Systems at Commercial Farms in the United States, above.
p. 47–48
424 See, e.g., SEC, Carbon Dioxide Purchase and Sale Agreement Example, above. p. 36.
425 See generally AgStar, Common Safety Practices for On-Farm Anaerobic Digestion Systems, above.
426 U.S. Dept of Agriculture, Natural Resources Conservation Service. (2017, Jun.) *Conservation Practice Standard: Anaerobic Digester*. Retrieved from https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_026149.pdf
427 Csebristol (2011, Mar. 10). *Considering an Anaerobic Digester*. [Video file]. Retrieved from https://www.youtube.com/watch?v=TVUAaIhZQUM.
428 United Nations Framework Convention on Climate Change. (2015). *AMS-III.D: Methane recovery in animal manure management systems, Version 20.1.* Clean Development Mechanism.
429 Ibid.

Appendices

1. Screening Exercise Outcome

1a. Waste Reuse & Pollution Reduction: Manure Anaerobic Digestion

- Description
    - Livestock Manure Capture System(s) for intensive livestock farms (geographic area TBD, but likely intensive livestock areas like the Midwest or southeast U.S. dairy or meat farms[430]). Will include:
        - Collection & storage facility
        - Temperature & aeration of manure
        - Capturing biogas from anaerobic process
        - Manure deposition & application
- Feasibility
    - These systems are already well-established and are considered a best practice ready for implementation. Will require the right policies/incentives, and training (especially for smallholders). There may be some social/cultural barriers as well. Can work for mixed and intensive systems, but some space for the capture facility is needed.
    - Timeline-wise, the benefits accrue pretty quickly once the system is in place, and there's no reason why it wouldn't last for quite a while with limited ongoing effort, once it's built.
    - Measurement of reductions should also be relatively straightforward if you're burning the methane emissions.
- Desirability
    - These systems require high upfront costs and don't necessarily reach economic payback on their own. Ways in which it pays back include saved fertilizer costs (more tech innovation needed on best methods for nutrient recovery in this area), energy generation, avoiding pollution regulations (air or water).
- Scalability
    - The systems would look much different for different type of farms, but the general concept is well-established both for smallholders and larger-scale commercial operations. It may make sense to build a centralized facility that receives inputs from a range of nearby farms.
- Impact
    - Livestock systems, including energy use and land-use change along the supply chain, accounted for an estimated 14.5% of total global greenhouse gas (GHG) emissions from human activities in 2010. More than half of these (about 65%) are related to cattle.

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[430] Minnesota Department of Agriculture. "Energy from Waste." Retrieved from https://www.mda.state.mn.us/renewable/waste.aspx.

Manure management accounts for 10% of total livestock emissions. Impact of any one given project would depend on the system size. Efficient systems can capture 60-80% of the system's original emissions.[431]

- Co-benefits include reduced water pollution, increased renewable energy generation, energy access in remote locations, reduced odor, potential reuse of nutrients in manure
- Several manure-related options received the highest possible emissions reduction assessment score according to the Sustainable Agriculture Initiative.[432]

- Verification method:
    - Sensors on a connected IoT smart tank as "oracles" to track either:[433]
        - 1) energy produced from methane capture and combustion from the system; or
        - 2) use of anaerobic digester (weight scale).
    - Smart contracts to compensate client for project partner's digester use.[434]

1b. Farming Best Management Practice Adoption: No-Till Agriculture

- Description
    - Encourage farmers to adopt no-till practices for their perennial crop farming (potentially focusing on rice).[435] Tillage is the agricultural preparation of soil by mechanical agitation of various types, such as digging, stirring, and overturning. No-till, by contrast, does not disturb the soil through such techniques, increasing water retention, reducing soil erosion, and maximizing the land's ability to act as a "sink" for harmful gases.
- Feasibility
    - This is a well-established practice that has been adopted by a number of farmers already. There is even a National No-Tillage Conference.[436]
    - Verification challenges arise from quantification of emissions benefits and ensuring compliance.
    - Cultural preference for tillage techniques may make identifying project partners more difficult.
    - Yield impacts may lead to shifting to more fertilizer use -- careful examination of unintended consequences required.
- Desirability

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[431] Global Research Alliance. "Reducing greenhouse gas emissions from livestock: best practice and emerging options.' Retrieved from http://www.saiplatform.org/uploads/Modules/Library/lrg-sai-livestock-mitigation_web2.pdf.
[432] Id.
[433] CORDIS. "Final Report Summary - Smart Tank (Project ID 262241). Retrieved from https://cordis.europa.eu/result/rcn/143053_en.html
[434] Kathi Vian. (Jun. 9, 2016). "The Blockchain climate fix." Retrieved from https://blockchainfutureslab.wordpress.com/2016/06/09/the-blockchain-climate-fix/.
[435] Harada, H., Kobayashi, H., & Shindo, H. (2007). Reduction in greenhouse gas emissions by no-tilling rice cultivation in Hachirogata polder, northern Japan: Life-cycle inventory analysis. Soil Science and Plant Nutrition, 53(5), 668-677.
[436] No-Till Farmer. "National No-Tillage Conference." Retrieved from https://www.no-tillfarmer.com/nntc.

- Despite potential preferences for continued use of tillage techniques, there is a rising desire in the farming community to employ no-till methods. It could be easier to get a farmer to agree to the project (aside from a monetary incentive), depending on how it will affect their yields
    - The change is relatively low-cost to implement for the project partner, which in turn leads to lower costs for the client: the infrastructure and methods are available, but what is needed is training and implementation for the farmers themselves.
- Scalability
    - Better suited to smaller-scale farms.
    - Unclear if large-scale Midwest farms would be interested or capable in adopting this.
- Impact
    - Large potential reductions in nitrous oxide emissions. Food production accounts for about 58 percent of all emissions of the gas in the United States, of which about 38 percent comes from soil. A 2010 study found that no-till reduces nitrous oxide emissions by 57 percent over chisel tilling (which mixes crop residue into surface soil) and by 40 percent compared to moldboard tilling (which completely inverts soil as well as the majority of surface residue).[437]
    - Co-benefits include reduced soil erosion and improved soil organic matter.[438]
    - Negative externalities can be nutrient leakage, low soil organic carbon levels, and reliance on fossil fuel-based inputs that carry possible health risks.[439]
    - Opportunity for perennializing crops[440]

- Verification method

- Sensors (measuring soil disturbance, cameras, etc.)
- Blockchain accounting for GHG[441]
- Quantify emissions of: CO_2, N_2O, CH_4
- Potentially could use smart contracts to penalize for disturbance and/or compensate for successful implementation of no-till

1c. Efficient Use of Materials: Smart Pumps for Irrigation

- Description

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437 Purdue University. (Dec. 20, 2010). "No-till, rotation can limit greenhouse gas emissions from farm fields." Retrieved from http://www.purdue.edu/newsroom/research/2010/101220VynNitrous.html.
438 The Land Institute. "Perennial Crops: New Hardware for Agriculture." Retrieved rom https://landinstitute.org/our-work/perennial-crops/ .
439 Id.
440 Id.
441 Datafloq. "How Blockchain Can Help Combat Climate Change." Retrieved from https://datafloq.com/read/how-blockchain-can-help-combat-climate-change/2531 .

- Software that reduces emissions associated with electrical energy used to pump irrigation water. (Tech name: "WattTime")
- WattTime uses data analytics to produce accurate estimates of marginal emissions[442] intensity on the grid, at a specific location and time, which then discloses to users' emissions impact of their energy use. WattTime also has automated demand response software, which automatically shifts energy use to times when marginal energy is produced by cleaner units (perhaps solar or wind), thus achieving emissions reductions.
- WattTime is non-profit tech start up originating with UC Berkeley research, built by volunteers from MIT, Climate Corp, Dept. of Energy and others.

- Feasibility
    - The environmental benefits can be precisely quantified [since the tech relies on that quantification].
    - Unclear where and how it has already been implemented.
    - Project partners may be difficult (relies on grid attributes, water needs, and existing smart pump infrastructure).
    - Devices already have proven capable of reducing peak demand and lower energy costs. Emissions reductions are an emerging possibility.
    - Empirical, rather than theoretical, assessment of impacts, which would make an easier sell to potential clients.
    - Would need to verify how the technology actually works and what its limitations are.
    - Desirability
    - Low cost
    - Flexible technology
    - Fits within a cultural shift to smart devices, but unclear whether this is occurring with farms
    - Potentially less invasive than wholesale shifting of farming techniques
    - Does not require large amounts of capital
    - Data sharing concerns and vulnerability to hacking
    - Financial savings, PR and marketing benefits, increased control/engagement with power use
    - Unclear how well this would mesh with water usage on farms. Potential evaporation problems (marginal energy cleanest during the middle of the day, when solar peaks, but the middle of the day is also non-optimal for watering crops)
- Impact
    - Potentially very high. Theorized that current generation AER can reduce CO_2 equivalent of up to 1 mil. cars.
    - Co-benefits flow from reduced reliance on fossil fuels (less mercury pollution, NOx, PMs, O3, acid rain, etc.).
    - Reducing demand on traditional fossil fuels may accelerate job losses in these sectors.

[442] "Marginal energy" is energy supplied to the grid by "marginal units" in order to meet new demand. "Marginal units" are in turn the cheapest energy generation not already operating at full capacity to meet unmet demand on the grid.

    - First generation allowed for 3% CO_2 reductions; current generation = ~10%; possible reductions of up to 40% [assuming perfect information].
    - Shifting demand now can accelerate shifts in grid investments
    - WattTime may be underestimating emissions savings, according to analysis by RMI.
- Verification method: WattTime Software

2. Project Selection: Digesters v. WattTime

2a. Team Project Goals Scoring Averages

	WattTime used in irrigation	Digesters, small/med scale, biogas used locally	Digesters, large-scale, biogas injected into grid
client goals	3.6	2.5	2.5
charisma/innovation	3.6	2.5	2.5
impact	2.4	3.7	3.1
scale	3.7	3.3	3.4
additionality	2.0	4.0	3.1
cobenefits	1.7	3.7	2.8
feasibility	3.6	2.8	3.3
simplicity	3.9	3.0	3.5
financing	4.0	2.2	3.2
verifiability	3.0	3.3	3.2
desirability	2.1	3.5	2.8
project partner	2.1	3.5	2.8
cost-effectiveness	3.2	3.4	3.7
(bang 4 buck)	3.2	3.4	3.7
achieve 50,000 tons CO_2/year	1.8	2.4	2.3
(given what we currently know)	1.8	2.4	2.3
average, all cells	**2.9**	**3.1**	**3.0**

Source: Authors

3. Engineering Appendices

3a. Digester Type Comparison[443]

The most successful digester implementations require significant system management and while they do not replace manure management systems but work best on sites with existing manure management systems.

DIGESTER TYPE	ADVANTAGES	DISADVANTAGES
Covered lagoon	- Low cost (relatively) - Low tech, easy to construct - Varying effectiveness of gas collection	- Cover maintenance/life - Large footprint - Solids/nutrient accumulation - Less efficient reductions: Closed AD systems can reduce emissions by 47.2% (in practice, with some challenges) to 86.4% (peak) compared to anaerobic lagoons[444]
Complete Mix Digesters - Complete Stirred Tank reactors (CSTR) - Completely Mixed Flow Reactors (CMF) - Continuous Flow Stirred Tank (CFST)	- High level of experience - Works over wide range of influent total solids (for scrape or flush systems) - Improved odor control (over open systems) - 100% effective gas collection	- Poor biomass immobilization - Mechanical mixing requirement
Plug Flow Digesters (continuous process)	- Good track record with dairy manure - Works well with scrape systems - Improved odor control (over open systems) - 100% effective gas collection	- Requires 11-14% (high) solids manure - Not compatible with sand bedding
Anaerobic Sequencing Batch Reactor	- Works over wide range of influent total solids - Solid retention time (SRT) partially decoupled from hydraulic retention time (HRT) - 100% effective gas collection	- Limited full-scale experience - Potential for solids build-up in reactor

443 Burns, R. T. (2007). *Animal waste anaerobic digester basics.* Agricultural & Biomass Engineering, Iowa State University.
444 Artrip, K. G., Shrestha, D. S., Coats, E., & Keiser, D. (2013). GHG emissions reduction from an anaerobic digester in a dairy farm: Theory and practice. *Applied engineering in agriculture*, 29(5), 729-737.

Fixed Film Digesters	- Short hydraulic retention times - Excellent biomass immobilization - Works with flush waste systems - 100% effective gas collection	- Cannot handle medium/high TS manures - Solids separation required - Potential for plugging problems

Source: Authors

3b. Biogas Measurement Packages

1) Landtec BIOGAS 3000 Fixed Biogas Analyzer: fixed gas analysis system for anaerobic digesters and bio-methane upgraders designed to measure gas production yield and detect/minimize corrosive contaminant gases

Features: customizable to site requirements, provides local support, 3 years warranty on analyzer, 1-year warranty on cabinet and parts

Technical specs:[445] ATTACH PDF OF DATA SHEET IN FINAL REPORT http://www.landtecna.com/wp-content/uploads/2016/11/BIOGAS3000-Tech-Specs-for-Website.pdf

2) Landtec BIOGAS 5000 Portable Biogas Analyzer: portable field instrument for anaerobic digester gas analysis, designed to "meet Global Renewable Energy and Carbon Credit digester project requirements" to measure gas composition and flow

Package includes: Instrument, hoses, heavy duty water trap filter, soft case, A.C. battery charger, electronic manual accompanies software, LANDTEC System Gas Analyzer Manager (LSGAM) software, USB download cable and hard-case. Reads: Methane, Carbon Dioxide, Oxygen, temperature (when used with optional probe), atmospheric pressure, differential pressure and calculates gas flow.

Technical specs:[446]

[445] http://www.landtecna.com/product/biogas3000-2/
[446] http://www.landtecna.com/product/biogas5000/

Gas Ranges

Gases Measured	CH_4	By dual wavelength infrared cell with reference channel		
	CO_2	By dual wavelength infrared cell with reference channel		
	O_2	By internal electrochemical cell		
	H_2S	By internal electrochemical cell		
Ranges	CH_4	0-100% (vol)		
	CO_2	0-100% (vol)		
	O_2	0-25% (vol)		
	H_2S	0-5000ppm**		
Gas Accuracy*	CH_4	0-5% ± 0.3% (vol)	0-70% ± 0.5% (vol)	70-100% ± 1.5% FS
	CO_2	0-5% ± 0.3% (vol)	0-60% ± 0.5% (vol)	60-100% ± 1.5% FS
	O_2	0-25% ±1.0% (vol)		
	H_2S	0-5000ppm ± 2.0% FS		

* Typical accuracy after calibration as recommended in the operations manual.
**Additional ranges available, contact LANDTEC for more information

Other Parameters

	Unit	Resolution	Comments
Energy	BTU/hr	1000 BTU/hr	Calculated from specific parameters
Static Pressure	in. H_2O	0.01 in. H_2O	Direct Measurement
Differential Pressure	in. H_2O	0.001 in. H_2O	Direct Measurement

Important Note: The information in this document is correct at the time of generation. We do, however, reserve the right to change the specification without prior notice as a result of continuing development.

Pump

Flow	Typically 550cc/min
Flow with 80 in. H2O vacuum	Approximately 80cc/min

Environmental Conditions

Operating Temperature Range	14°F – 122°F (-10°C - 50°C)
Operating Pressure	-100 in. H_2O, +100 in. H_2O (-250mbar, +250mbar)
Relative Humidity	0-95% non condensing
Barometric Pressure	± 14.7 in.Hg (±500mbar) from calibration pressure
Barometric Pressure Accuracy	± 1% typically

Power Supply

Battery Life	Typical use 8 hours from fully charged
Charge Time	Approximately 3 hours from complete discharge

Certification Rating

ATEX	II 2G Ex ib IIA T1 Gb (Ta= -10°C to +50°C)
ISO17025	ISO/IEC17025:2010 Accreditation #66916
CSA	Ex ib IIA T1 (Ta= -10°C to +50°C) (Canada), AEx ib IIA T1 (Ta= -10°C to +50°C) USA

3c. Emissions Estimate Models

Details of the Anaerobic Digester Parameters (Table 1), Energy Parameters (Table 2), and Emissions Parameters (Table 3) follow in this section.

Methane Conversion Factor (MCF) Calculation and Arrhenius Temperature Relationship 447,448

Month	T_{avg} (C)	$E(T_2-T_1)/(R*T_1*T_2)$	f	VS available (kg)	VS consumed (kg)	CH_4 (m^3)	Annual MCF
January	-5	-3.31	0.04	4,308,708.69	158,124.36	37,949.85	0.64
February	-3	-3.09	0.05	5,341,997.87	242,119.31	58,108.64	
March	0.8	-2.70	0.07	6,291,292.09	422,237.31	101,336.95	
April	6.7	-2.11	0.12	7,060,468.32	853,453.53	204,828.85	
May	12.8	-1.53	0.22	7,398,428.33	1,601,713.21	384,411.17	
June	17.8	-1.07	0.34	6,988,128.65	2,395,220.58	574,852.94	
July	20.4	-0.84	0.43	5,784,321.60	2,502,129.49	600,511.08	
August	19.5	-0.92	0.40	4,473,605.65	1,786,206.55	428,689.57	

447 The World Bank Group. (2018). *Average Monthly Temperature and Rainfall for United States from 1901-2015.* Retrieved from http://sdwebx.worldbank.org/climateportal/
448 Mangino, J., Bartram, D., & Brazy, A. (2002). Development of a methane conversion factor to estimate emissions from animal waste lagoons. In: *11th International Emission Inventory Conference*. U.S. Environmental Protection Agency.

September	15.2	-1.31	0.27	3,878,812.64	1,049,027.91	251,766.70	
October	8.3	-1.96	0.14	1,191,413.54	168,212.20	40,370.93	
November	1	-2.68	0.07	2,214,614.87	151,690.08	36,405.62	
December	-3.7	-3.17	0.04	3,254,338.32	137,043.17	32,890.36	

Source: Authors

Notes:

- MDP factor = 0.8.[449]
- B_0 = 0.24.[450]
- MCF = (Annual methane production) / (B_0 * Annual Volatile Solids Production)
- MCF was adjusted by a factor of *f* according to the Arrhenius relationship and mean monthly temperatures in Gooding County, Idaho:

$$f = \exp\left[\frac{E(T_2 - T_1)}{RT_1T_2}\right]$$

Arrhenius Equation for Temperature Dependence of MCF, where:

T_1 = 303.16 K

T_2 = mean monthly temperature in Gooding County, Idaho (K)

E = activation energy constant = 15,175 cal/mol

R = ideal gas constant (1.987 cal/K/mol)

- Our calculation of 0.64 is very close to the EPA's estimate for anaerobic lagoons in Idaho of 0.67.[451]
- Agitators/mixing mechanism of the digester:
    - Risk management in the engineering system depends crucially on both automated and manual monitoring on an ongoing basis. Automated electronics and manual farm staff responsibilities are tabulated below

Note: A complete Excel workbook containing the data tables below can also be provided upon request. This workbook contains live fields and formulas with references cited.

[449] Mangino et al., 2002
[450] US EPA. (2011). Table A- 184: Waste Characteristics Data. In Annexes of Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2009.
[451] US EPA. (2011). Table A- 190: Methane Conversion Factors by State for Liquid Systems for 2009. In Annexes of Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2009. (percent)

Table 23. Biogas Generation Calculation Parameters

Parameter	Units	Quantity
Manure excreted	gallons/cow/day	13.5
Manure density	lbs/gallon	8.3
Manure excreted	lbs/cow/day	112
Additional volume from milkhouse washwater, drinkers, etc.	percent	10%
Manure total volume to the digester	lbs/cow/day	124
Convert manure lbs to ft^3	lbs/ft^3	62.32
Manure total volume to the digester	ft^3/cow/day	1.99
Θ Retention time	days	10
Digester influent volume	ft^3	158,812
Total solids % of manure (by mass in lbs)	%	12.9%
Manure total solids to the digester	lbs/cow/day	15.95
Volatile solids % of total manure	%	10.7%
Manure volatile solids to the digester	lbs/cow/day	13.24
K, kinetic parameter for dairy		1.64
B0, Methane converted from volatile solids, theoretical maximum, dairy	L CH_4/m3	0.24
Digester operating temperature in Fo	Degrees F	100
µm Max. specific microbial growth rate, days-1	µm Max. specific microbial growth rate, days-1	0.36
Yv volumetric methane prod., ft^3 CH_4/influent ft^3/day retention	ft^3 CH_4/influent ft^3/day retention	0.21
methane prod., ft^3 CH_4/day retention time	ft^3 CH_4/day retention time	3.13
methane percentage in biogas	decimal	0.6
biogas ft^3/day of retention time	biogas ft^3/day of retention time	5.22
biogas ft^3/lbs. volatile solids	biogas ft^3/lbs. volatile solids	3.94
methane (CH_4) ft^3/lbs. vs	methane (CH_4) ft^3/lbs. vs	2.36
biogas ft^3/day/cow	biogas ft^3/day/cow	52

Source: Authors

Table 24. Electricity Generation Assumptions

Electrical Conversion Parameters	Units	Quantity
Energy conversion constant	BTU/kWh	3,412
Engine thermal conversion efficiency	%	25%[452]
Engine daily online percent	%	90%
Electricity generated if all biogas is converted	kWh/cow/day	2.77
Farm total per year	kWh/year	8,089,991
Generator size that biogas BTU would power	kW	1,025
Generator size planned	kW	1,420
Farm electricity that can be replaced by AD	kWh/year	3,036,800
Electricity requirements for AD[453]	kWh/cow/year	50
Electricity required to operate the model AD	kWh/year	400,000

Source: Authors

Methane Conversion Factor

- MCF was adjusted by a factor of *f* according to the van't Hoff-Arrhenius relationship for forecasting biological reactions based on mean monthly temperatures in Gooding County:

$$f = \exp\left[\frac{E(T_2 - T_1)}{RT_1T_2}\right]$$

- MDP factor = 0.8.[454]
- B_0 = 0.24.[455]
- MCF = (Annual methane production) / (B_0 * Annual Volatile Solids Production)
- The model MCF calculation of 0.64 is very close to the EPA's estimate for anaerobic lagoons in Idaho of 0.67.[456]

[452] US EPA. (2015, July). Chapter 6: Power Generation Technologies. In *Biomass CHP Catalog.* Combined Heat and Power Partnership.
[453] Lazarus, W. F., & Rudstrom, M. (2007). The economics of anaerobic digester operation on a Minnesota dairy farm. *Review of Agricultural Economics*, 29(2), 349-364.
[454] Mangino, J., Bartram, D., & Brazy, A. (2001). Development of a methane conversion factor to estimate emissions from animal waste lagoons. In *US EPA's 17th Annual Emission Inventory Conference, Atlanta GA*.
[455] US EPA. (2011). Table A- 184: Waste Characteristics Data. In Annexes of Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2009.
[456] US EPA. (2011). Table A- 190: Methane Conversion Factors by State for Liquid Systems for 2009. In *Annexes of Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2009.*

Month	T_{avg} (C)	E(T2-T1)/(R*T1*T2)	f	VS available (kg)	VS consumed (kg)	CH_4 (m3)	Monthly MCF	Annual MCF
January	-5	-3.31	0.04	4,308,709	158,124	37,950	0.11	0.64
February	-3	-3.09	0.05	5,341,998	242,119	58,109	0.16	
March	0.8	-2.70	0.07	6,291,292	422,237	101,337	0.28	
April	6.7	-2.11	0.12	7,060,468	853,454	204,829	0.57	
May	12.8	-1.53	0.22	7,398,428	1,601,713	384,411	1.08	
June	17.8	-1.07	0.34	6,988,129	2,395,221	574,853	1.61	
July	20.4	-0.84	0.43	5,784,322	2,502,129	600,511	1.68	
August	19.5	-0.92	0.40	4,473,606	1,786,207	428,690	1.20	
September	15.2	-1.31	0.27	3,878,813	1,049,028	251,767	0.70	
October	8.3	-1.96	0.14	1,191,414	168,212	40,371	0.11	
November	1	-2.68	0.07	2,214,615	151,690	36,405.62	0.10	
December	-3.7	-3.17	0.04	3,254,338	137,043.17	32,890.36	0.09	
TOTAL	7.57					2,752,122.65		

Source: Authors

Table 25. Nitrogen Emissions Estimate Parameters [457]

	Units	Value
Total Kjeldahl Nitrogen (TKNex)		
TKNex = TAM * Nex * 365.25 * # Head		
TAM	lbs	1,333.00
Nex	lbs N/cow/day	0.72
Head	# cows	8,000.00
TKNex	lbs N/year	2,103,840.00
Direct barn N_2O emissions (Barn N_2O)		
Barn N_2O = TKNex*Barn Man * Barn N_2O EF * 44/28		
Percent of manure managed in the barn	%/100	0.05
N_2O conversion factor for barns	kg N_2O-N/(kg N excreted)	0.02
N_2O conversion factor for barns	lbs N_2O-N/(kg N excreted)	0.02
Conversion factor for N_2O to Nitrogen Gas		1.57
Barn N_2O	lbs N_2O(g)/year	2,479.53
Lagoon Emissions (Lagoon N_2O)		
Lagoon N_2O = TKNex * Lagoon Man * Lagoon N_2O EF * 44/28		
Lagoon Man, % of manure managed in the lagoon	%/100	0.85
Lagoon N_2O Emission factor	kg N_2O-N/(kg N excreted)	0.020
Lagoon N_2O	lbs N_2O(g) / year	35,765.28
$CO_{2(e)}$ saved N_2O from lagoon		
Baseline N_2O = Barn N_2O + Lagoon N_2O		
GWP of N_2O (100-year)		298.00
Baseline N_2O	lbs N_2O_g/year	38,244.81
$CO_{2(e)}$ of N_2O from BARN ONLY per year	tons/year	369.45
Tons of N_2O emissions from lagoon	tons/year	19.12
$CO_{2(e)}$ saved from less N_2O emissions from lagoon	tons/year	5,698.48

Source: Authors

[457] Rotz, C., Chianese, D., Montes, F., & Hafner, S. (2012). *Dairy Gas Emissions Model, Reference Manual, Version 2.6*. U.S. Department of Agriculture, Agricultural Research Service.

Table 26. Greenhouse Gas Emissions Estimates for Electricity Generation from AD Biogas

Engine emissions	Units	Value
CO_2	kg CO_2/mm BTU	52.07
CH_4	g CH_4 / mm BTU	3.20
N_2O	g N_2O / mm BTU	0.63
Energy per cow	BTU/cow/day	10,496.25
Energy per day on farm	BTU/day	83,970,032.26
Energy per day on farm	mm BTU/day	83.97
Energy generated per year on farm	mm BTU/year	30,670.05
$CO_{2(e)}$ engine emissions per day on farm	kg CO_2/year	1,596,989.73
$CO_{2(e)}$ engine emissions per year on farm	tons CO_2/year	1,760.38
CH_4 engine emissions per year on farm	g CH_4 /year	98,144.17
CH_4 engine emissions per year on farm	ton CH_4/year	0.11
Convert to CO_2-e q	25 ton CH_4/ 1 ton CO_2	25.00
CO_2-e q of CH_4 from engine emissions per year on farm	tons CO_2-e q/year	2.70
N_2O engine emissions per year on farm	g N_2O / year	19,322.13
tons of N_2O emissions from engine generation per year	tons N_2O/year	0.02
GWP of N_2O	298 tons N_2O / 1 ton CO_2	298.00
CO_2-e q of N_2O engine emissions per year on farm	tons CO_2-e /year	6.35

Source: Authors

Table 27. Direct CO_2(e) emissions from Lagoon and Barn

Emission location	Quantity	Units
Barn Floor*	121.42	kg CO_2/day
Barn Floor	390.83	ton CO_2/year
lagoon $CO_{2(e)}$ emissions	748.00	$CO_{2(e)}$Rs (g head-1 day-1)
lagoon $CO_{2(e)}$ emissions	2407.62	ton/year

Source: Authors

* Barn Floor calculation: ECO_2,floor = max (0.0, 0.0065 + 0.0192 *T)*Abarn, where: ECO_2,floor = daily

rate of $CO_{2(e)}$mission from the barn floor, kg CO_2/day; T = ambient temperature in the barn, °C; Abarn = floor area covered by manure, m2; assumed average monthly temperature of 7.567°C.

Table 28. Emissions Reduction Calculations: Baseline and Digester

Avoided CH_4 emissions from anaerobic lagoon		
Manure volatile solids from the lactating dairy cows	lbs/cow/day	13.24
Methane content of biogas	%	62.50%
Methane converted from volatile solids, theoretical maximum (B0)	m3/kg VS	0.24
Conversion factor from m3/kg to ft^3/lbs.	--	16.02
Methane converted from volatile solids, theoretical maximum	ft^3/lbs. VS	3.85
Methane converted from volatile solids, theoretical maximum	ft^3/cow/day	51
Methane conversion factor	%	0.67
Expected digester methane yield	ft^3/cow/day	34.1
Methane kilograms per cubic foot	convert kg/ft^3	0.0191
Convert daily data to an annual basis	days/year	365.25
Baseline methane emissions per year	mt/year	1,908
Convert methane to CO_2-e based on mass and GWP	CH_4 GWP	25
CO_2-equivalent baseline methane emissions per year	$CO_{2(e)}$ mt/year	47,701
$CO_{2(e)}$ emissions avoided by AD-produced electricity		
Electricity generated	kwh / year	6,283,767
$CO_{2(e)}$ emissions/kWh if generated from Idaho electric mix	mt/kWh	0.00052
$CO_{2(e)}$ emissions/kWh if generated Idaho electric grid	$CO_{2(e)}$ mt/year	3,280
Minus digester leakage, CO_2-equivalents:		
Expected digester methane yield	ft^3/cow/day	51
Digester collection efficiency	%	99%
Destruction efficiency	%	98%
Methane kilograms per cubic foot	kg-CH_4/ft^3-CH_4	0.0191
Convert methane to $CO_{2(e)}$ based on mass and GWP	CH_4 GWP, 100 year timescale	25
Convert daily data to an annual basis	days/year	365.25
CO_2-equivalent baseline methane leakage per year	$CO_{2(e)}$ mt/year	2,122
Plus digester $CO_{2(e)}$ emissions reduction from not having to ship the manure to the dump site[458]		
$CO_{2(e)}$ emission factor for manure transportation	g/mile	1,346.50
truck mileage per trip	miles	100.00
conversion factor lbs to kg	kg to lbs	2.2
truck load trips per year	loads	2
conversion factor pounds to tons	mt/lbs	0.0005
Emissions reduction from not having to ship off manure	CO_2 mt/year	0.30
Plus digester emissions savings from reduced N_2O emissions		
Calculations from "Nitrogen" sheet	$CO_{2(e)}$ tons/year	5,698.48
Total savings of $CO_{2(e)}$s (tons/year)		

[458] Prior to AD, assume used a dump truck twice per year.

Net $CO_{2(e)}$ in AD compared to baseline	tons $CO_{2(e)}$/year	54,558

Source: Authors

Table 29. Example data form for influent/effluent characteristic analysis, random samples

Parameter measured	Analysis Method	Sampling Frequency	Sample Type	Samples per analysis	Location of processing
Total solids	EPA 160.3	Monthly	Influent & effluent composites	4	Nearby Lab
Total volatile solids	EPA 160.4	Monthly	Influent & effluent composites	4	Nearby Lab
Chemical Oxygen Demand	EPA 410.4	Monthly	Influent & effluent composites	4	Nearby Lab
Ammonia (NH_3)	EPA 350.1	Monthly	Influent, filtrate, & effluent composites	4	Nearby Lab
Total Kjeldahl Nitrogen	EPA 351.2	Monthly	Influent, filtrate, & effluent composites	4	Nearby Lab
Total Phosphorus	EPA 365.4	Monthly	Influent, filtrate, & effluent composites	4	Nearby Lab

Source: Authors

4. Financial Appendices

4a. Detailed financial analysis

	Year	0	1	2	3	4	5	6	7	20
		2019	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2039**
COSTS										
Installation cost	$	$ (7,000,000.00)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Annual O&M	$/yr	$ -	$ (350,000.00)	$ (350,000.00)	$ (350,000.00)	$ (350,000.00)	$ (350,000.00)	$ (350,000.00)	$ (350,000.00)	$ (350,000.00)
Avoided electricity costs	$/yr	$ -	$ 240,576.00	$ 240,576.00	$ 240,576.00	$ 240,576.00	$ 240,576.00	$ 240,576.00	$ 240,576.00	$ 240,576.00
Avoided bedding costs	$/yr	$ -	$ 240,000.00	$ 240,000.00	$ 240,000.00	$ 240,000.00	$ 240,000.00	$ 240,000.00	$ 240,000.00	$ 240,000.00
TOTAL COSTS	$/yr	$ (7,000,000.00)	$ 130,576.00	$ 130,576.00	$ 130,576.00	$ 130,576.00	$ 130,576.00	$ 130,576.00	$ 130,576.00	$ 130,576.00
REVENUES										
Electricity sales	$/yr	$ -	$186,127.64	$ 186,127.64	$ 186,127.64	$ 186,127.64	$ 186,127.64	$ 186,127.64	$ 186,127.64	$ 186,127.64
Fertilizer sales	$/yr	$ -	$ 677,859.00	$ 677,859.00	$ 677,859.00	$ 677,859.00	$ 677,859.00	$ 677,859.00	$ 677,859.00	$ 677,859.00
TOTAL REVENUE	$/yr	$ -	$ 863,986.64	$ 863,986.64	$ 863,986.64	$ 863,986.64	$ 863,986.64	$ 863,986.64	$ 863,986.64	$ 863,986.64
Net revenue	$/yr	$ (7,000,000.00)	$ 994,562.64	$ 994,562.64	$ 994,562.64	$ 994,562.64	$ 994,562.64	$ 994,562.64	$ 994,562.64	$ 994,562.64
Cumulative revenue		$ -	$ 994,562.64	$ 1,989,125.28	$ 2,983,687.92	$ 3,978,250.56	$ 4,972,813.20	$ 5,967,375.84	$ 6,961,938.48	$ 7,956,501.12

Harvard investment	$	$ 6,050,000.00
Payback period for Harvard investment	years	6
Payback period for entire project	years	7
Discount Rate	%	10%
Net present value	$	$1,333,884.01
Internal rate of return	%	13%

Harvard investment	**$**	**$ 6,050,000.00**
Payback period for Harvard investment	years	6

Payback period for entire project	years	7
Discount Rate	%	10%
Net present value	$	$1,333,884.01
Internal rate of return	%	13%

Source: Authors

4b. Tools available for detailed financial modeling[459]

(1) Model revenue and expenses

There are ample resources available from the U.S. government as well as research and academic institutions that can support potential projects, particularly creating financial models. Some examples are:

1. Cost of Renewable Energy Spreadsheet Tool (CREST): Developed by the National Renewable Energy Laboratory (NREL), CREST assesses project economics with a specific tool for anaerobic digestion technologies. The free tool allows inputs for project size and performance, capital costs, O&M, construction financing, permanent financing, taxes, depreciation, reserve account funding, working capital, capital expenditures during operations (equipment replacement), state rebates/tax credits/REC revenue, federal incentives, market value forecasting, tariff rate structure, and tipping fees.
2. Economic and Functional Tool for Assessing the Financial Feasibility of Farm-based Anaerobic Digesters: Journal article discussing a workbook that determines the financial feasibility of farm-based anaerobic digestion. The workbook identifies technical and financial parameters that affect returns, as well as sensitivity of the assumptions to changes in parameter values. The tool also creates outputs based on different types of systems.
3. System Advisor Model (SAM): Developed by NREL, calculates financial metrics for power projects based on a project's cash flows over an analysis period based on installation, operating costs, and system design.

(2) Determine equity share and sources

Estimate how much funding that is feasible to contribute as equity and where it will come from. A minimum of 10% is generally required, but investors and lenders prefer project owners take the highest possible share.

(3) Identify funding sources to fill the gap between equity and the project cost

Information is available to identify grants, loan guarantees, and financial assistance from federal and state governments, nonprofits, and private companies. Some examples are:

- Database of State Incentives for Renewables & Efficiency (DSIRE): (funded by U.S. Department of Energy, updated monthly) Includes information about renewable energy incentives and policies to help fund energy-producing digesters.
- USDA Energy Matrix identifies alternative and affordable energy solutions, funding for projects, available programs and program information, and research and development. (USDA)

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[459] EPA. (2016). Financing Anaerobic Digestion Projects. Retrieved March 9, 2018, from https://www.epa.gov/agstar/financing-anaerobic-digestion-projects#colorbox-hidden3

- USDA Rural Energy for America Program (USDA)
- USDA Rural Development Business Programs (USDA)
- USDA Rural Development Value-Added Producer Grants (VAPG) (USDA)
- USDA Farm Service Agency Energy Programs – Biomass Crop Assistance Program (USDA)
- Sustainable Agriculture Research & Education Sustainable Agriculture Grants (SARE)

(4) Calculate return on investment

Compare the annual revenue against expenditures to estimate when the initial investment will be paid back and the rate of return on the money invested. Several methods include discounted cash flow analysis (DCF) (estimates net present value of future cash flows), internal rate of return (IRR) (rate of return which can be compared to rates from other options), and payback period (the number of years it takes for the project to recoup initial capital investment).

(5) Select financing method

The ROI should be the main metric for attracting financing from either a lender or investor. The Vendor Directory maintained by AgSTAR provides a comprehensive list of financing specialists who provide loans specifically for agricultural projects, have a history of funding biogas systems for profit, and brokering carbon offset sales and RECs. Other options for financing include cost-sharing, which is when project coordinators retroactively apply for funding after the digester has been built. An example of cost-share programs would
include the USDA Natural Resources Conservation Service (NRCS) Environmental Quality Incentives Program (EQIP).[460]

(6) Negotiate utility agreement

If the project is productive enough to provide gas to the grid, the project must establish a power purchase agreement (PPA) with a utility contract. There are three option, buy all-sell all, surplus sale, and net metering.

[460] AgSTAR. Funding On-Farm Anaerobic Digestion. (2012). https://www.epa.gov/sites/production/files/2014-12/documents/funding_digestion.pdf

5 Legal Appendices

5a. Requirements for Tier II and Tier III Waste Processing Facilities[461]

Application Site Map —A map (or maps) containing the information [below to] help identify potential issues or considerations during the review/approval process. IDAPA 58.01.06.012.02 or IDAPA 58.01.06.013.02

Site Map Requirements—

- Highways, roads, and adjacent communities
- Property boundaries
- Total acreage of the site
- Off-site and on-site access roads and service roads
- Types of land use adjacent to the facility and a description of all facilities on the site
- All water courses, ponds, lakes, reservoirs, canals, irrigation systems, and existing water supplies, within one-quarter (¼) mile of the proposed facility property lines
- High tension power line rights-of-way, fuel transmission pipeline rights-of-way, and proposed or existing utilities
- Proposed and existing fencing and structures at the facility and within 500 feet of the facility boundary. This shall include location of employee building and scales (if provided).
- Direction of prevailing winds

Waste Types — Only the solid waste types listed in the approved operating plan may be accepted for processing. IDAPA 58.01.06.012.03.c

Discussion: The facility's operating plan must identify specific wastes to be processed and how unauthorized waste will be excluded from the site.

Waste Monitoring and Measurement — Provisions shall be made for monitoring or measuring all solid waste delivered to a facility. A daily written log listing the types and quantities of waste received; plan for monitoring and handling receipt of unauthorized waste; Routine characterization of the waste received ; Other measures included in an approved operating plan. IDAPA 58.01.06.012.03.d or IDAPA 58.01.06.013.03.d

[461] Source: IDEQ, *Processing (Composting) Facility Guidance and Checklists for Tier II and Tier III Processing Facilities* 15-23 (Oct. 2013) (Unless otherwise indicated, the information presented in this appendix directly quotes the source material. The requirements have been slightly reordered.)

Discussion: To process waste in a timely manner, facility owners/operators must know how much waste they are managing and the volume of different waste in order to have the right mixture of carbon and nitrogen sources. In addition, owners/operators need to be prepared to manage unauthorized waste that may be mixed with incoming loads. Other measures may be incorporated in a plan to deal with specific waste or provide greater protection.

Resources: US Composting Council—*http://compostingcouncil.org/*

Cornell Waste Management Institute—http://cwmi.css.cornell.edu/composting.htm

Flood Plain Restriction — A facility shall not be located within a 100-year flood plain if the facility will restrict the flow of the 100-year flood, reduce the temporary water storage capacity of the flood plain, or result in a washout of solid waste so as to pose a hazard to human health and the environment. IDAPA 58.01.06.012.01.a

Discussion*:* Flood plains are natural areas along rivers that provide water storage areas during floods. Owners/operators should exercise caution when planning to locate a composting operation in a 100-year flood plain. Owners/operators will need to establish emergency plans to remove waste/compost in the event a flood is likely. These plans must include equipment to load and haul waste/compost and an alternative site outside of the flood plain where the waste/compost can be stored until flood waters recede.

The site approval application must include a Federal Emergency Management Agency (FEMA) flood map with the site clearly indicated on the map. For facilities proposed within a 100-year flood plain, the operating plan must incorporate actions the owner/operator will implement in the event of flood.

Resources: FEMA map website—
https://msc.fema.gov/webapp/wcs/stores/servlet/FemaWelcomeView?storeId=10001&catalogId=10001&langId=-1

Park, Scenic, or Natural Use — The active portion of a facility shall not be located closer than 1,000 feet from the boundary of any state or national park, or land reserved or withdrawn for scenic or natural use including, but not limited to, wild and scenic areas, national monuments, wilderness areas, historic sites, recreation areas, preserves, and scenic trails. IDAPA 58.01.06.012.01.d or IDAPA 58.01.06.013.01.g ; *also* 39-7407 (2)(e)

Discussion: The 1,000-foot separation distance from parks and scenic or natural use areas is intended to reduce potential impacts to park/scenic/natural use visitors.

The site application must contain a map indicating the distance to the nearest park and scenic/natural use area.

Resources: National Atlas website for wilderness areas and federal lands—
http://www.nationalatlas.gov/mapmaker?AppCmd=CUSTOM&LayerList=wa&visCats=CAT-boundary,CAT-boundary

http://nationalatlas.gov/printable.html#fedlands

Property Line Setback — The active portion of a facility shall not be located closer than 100 feet to the property line. IDAPA 58.01.06.012.09.a.iii or IDAPA 58.01.06.013.01.f

The intent of the setback is to provide a physical separation between facility activities and surrounding neighbors. Even well-run facilities can have some dust, odor, noise, and vectors. By providing this setback, the impact to neighbors can be reduced, thereby reducing complaints.

The site application must contain a scaled map of the site with the location of all stockpiling areas, active composting areas, processing/screening areas, and finished compost storage areas. The scaled site map must depict a 100-foot setback from the property line and all areas identified above outside the 100-foot setback

Endangered and Threatened Species — A facility shall not cause or contribute to the taking of any endangered or threatened species of plants, fish, or wildlife or result in the destruction or adverse modification of the critical habitat of endangered or threatened species as identified in 50 CFR Part 17. IDAPA 58.01.06.012.01.b

Discussion: To limit impacts to endangered and threatened species, the owner/operator must obtain a determination from the US Fish and Wildlife Service or the Idaho Office of Species Conservation that the proposed facility will not cause or contribute to the taking of any endangered or threatened species.

If a determination is made that the proposed site may impact endangered or threatened species, the owner/operator may be required to conduct a survey on the proposed site to determine if endangered or threatened species are on site or if the site contains critical habitat for the species. If the site contains endangered or threatened species or critical habitat, the owner/operator may need to undertake mitigation to address the endangered or threatened species.

Resources: US Fish and Wildlife Service—*http://www.fws.gov/endangered/*

Idaho Office of Species Conservation—*http://species.idaho.gov/*

Surface Water — The active portion of a facility shall be located such that the facility shall not cause contamination of surface waters, unless such surface waters are an integral part of the non-municipal solid waste facility's operation for stormwater and/or leachate management.

IDAPA 58.01.06.012.01.c or IDAPA 58.01.06.013.01.c

Discussion: Surface water such as streams, rivers, lakes, and reservoirs can be impacted from composting operations by the leachate that may wash off site during storm events and/or snowmelt. Adequate stormwater control and site grading are effective ways to prevent surface water impacts from composting.

Site applications must indicate nearby surface water on a scaled map and identify how the site will not impact surface water. A US Geological Survey 7.5-minute topographic map can be used to show surface water features in the area of the proposed site.

Resources: US Geologic Survey topographic maps—*http://nationalmap.gov/ustopo/index.html*

Ground Water — The active portion of a facility shall be located, designed, and constructed such that the facility shall not cause contamination to a drinking water source or cause contamination of the groundwater. IDAPA 58.01.06.012.09.a.i or IDAPA 58.01.06.013.01.d

Discussion: Groundwater protection is an important goal of DEQ. Idaho citizens rely on groundwater for drinking, irrigating crops, watering livestock, and industrial purposes. Improperly sited, designed, and/or operated solid waste management facilities can negatively impact groundwater.

Solid waste management facility owners/operators need to demonstrate that their proposed composting operation will not impact groundwater. The site application should include depth to the highest known groundwater, an evaluation of the soils and geology under the proposed site, design features that will prevent the downward migration of leachate, and operations to limit the generation of leachate.

Resources: Idaho Department of Water Resources well driller report—
http://www.idwr.idaho.gov/WaterManagement/WellInformation/DrillerReports/dr_default.htm

Contact a qualified geologist/hydrogeologist for assistance.

Geologic — No facility may be located on land that would threaten the integrity of the design.

IDAPA 58.01.06.012.09.a.ii or IDAPA 58.01.06.013.01.e

Discussion: Fault areas, seismic impact zones, and other unstable natural or man-made features may impact a facility's site and design elements that are intended to protect human health and the environment. A site evaluation for these factors should be conducted by a qualified professional to determine if potential geologic issues exist with the site.

Resources: http://www.usgs.gov/

Contact a qualified professional geologist for assistance.

Prohibited Activities — Disposal of regulated waste from health care, support to health care businesses, or medical diagnostic services that has not been decontaminated; speculative accumulation; and disposal of radioactive materials. IDAPA 58.01.06.012.03.a or IDAPA 58.01.06.013.03.a

Discussion: Unless specifically provided for in a facility's operating plan, waste from medical care facilities that would be considered infectious or bloodborne pathogen waste is prohibited.

Speculative accumulation occurs with stockpiles of material or recyclables to be processed for reuse or disposal when 50% of the material is not reused or disposed by the end of the following calendar year after the date of first receipt by the facility.

Radioactive waste shall not be accepted.

The operating plan must describe steps the owner or operator will take to prevent unauthorized waste from incorporation into the compost process. The operating plan must also describe how waste will be managed to prevent speculative accumulation.

Resources: OSHA Bloodborne Pathogen Requirements

Signs — Facilities open to the public shall clearly post visible and legible signs at each entrance to the facility. The signs shall specify at a minimum the name of the facility, hours of operation, waste accepted at the facility, and an emergency phone number. IDAPA 58.01.06.012.03.b

Discussion: Proper signage informs customers of the hours of operation, types of waste accepted, and emergency contact information. Having informed customers prevents waste from being dumped when the facility is closed, reduces the amount of unacceptable waste requiring off-site disposal, and allows for quicker emergency response time in the event of an emergency.

The operating plan must specify the proposed information to be displayed on the facility's sign and state that a sign containing the proposed information will be posted at every entrance to the facility.

Communication — Communication devices shall be available or reasonably accessible at the site. IDAPA 58.01.06.012.03.e or IDAPA 58.01.06.013.03.e

Discussion: Communication devices allow workers to communicate and also provide communication to emergency response if needed.

Fire Prevention and Control — Adequate provisions shall be made for controlling or managing fires at the site. IDAPA 58.01.06.012.03.f or IDAPA 58.01.06.013.03.f

Discussion: Fires can occur at composting sites for a variety of reasons. Compost piles and/or feedstock piles can become hot enough to spontaneously combust. In addition, equipment can contact feedstock and cause fires. Owners/operators need to be prepared and have a plan in place to deal with fires. Site staff also needs to know when a situation requires emergency response personnel.

Facility Access — Unauthorized vehicles and persons shall be prohibited access to the facility. A facility open to the public shall accept waste only when an attendant is on duty. The facility shall be fenced or otherwise blocked to access when an attendant is not on duty. IDAPA 58.01.06.012.03.g or IDAPA 58.01.06.013.03.g

Discussion: To prevent "midnight dumping," vandalism, and liability from an injury, owners/operators need to secure their composting site.

Scavenging and Salvaging — Scavenging by the public at a facility is prohibited; however, salvaging may be conducted in accordance with a written operations plan and only by the owner, operator, or an authorized agent. **IDAPA 58.01.06.012.03.h**

Discussion: Feedstock at a composting facility is not typically valuable for scavenging or salvaging. If salvaging is to be conducted, the owner/operator must be sure the person conducting the salvaging is aware of the potential dangers and is provided proper personal protection equipment.

Nuisance Control — The owner and operator shall control nuisances, including but not limited to the following: Disease or Discomfort: operations at any facility shall not provide sustenance to rodents or insects that cause human disease or discomfort; Vector: vector control procedures shall prevent or control vectors that may cause health hazards or nuisances; Odor: the facility shall be operated to control malodorous gases; Litter: effective measures shall be taken to minimize the loss of debris from the facility. IDAPA 58.01.06.012.03.i or IDAPA 58.01.06.013.03.i

Discussion: Nuisance issues are one of the biggest public concerns surrounding a compost site. Considering meteorological conditions when turning piles can also limit odor impacts to neighbors. An operating plan must detail how nuisance conditions will be controlled and contingency measures should nuisance conditions arise. See below for details about the odor management plan.

Resources:

- Cornell Waste Management Institute[462]
- CalRecycle[463]

Bird Hazards to Aircraft — No facility may handle putrescible wastes in such a manner that may attract birds and increase the likelihood of bird/aircraft collisions. Facilities located within 10,000 feet of any airport runway used by turbojet aircraft, or within 5,000 feet of any airport used by only piston-type aircraft, shall operate the facility in such a manner that birds are not a hazard to aircraft. IDAPA 58.01.06.012.03.j or IDAPA 58.01.06.013.03.i

Discussion: Food waste accepted at composting facilities can attract birds, which may fly in the path of aircraft and become a serious hazard. Bird strikes can cause damage to aircraft resulting in a crash. Owners/operators need to ensure that their site manages waste properly if their facility is in the vicinity of an airport.

Open Burning and Fires — Open burning is prohibited at facilities except as authorized by the “Solid Waste Management Rules” and IDAPA 58.01.01, “Rules for the Control of Air Pollution in Idaho.” IDAPA 58.01.06.012.03.k or IDAPA 58.01.06.013.03.k

Discussion: Most composting operations should not be conducting open burning since materials allowed for open burning are the same types of materials used as feedstock in the compost pile.

Stormwater Run-On/Runoff Controls — The operating plan shall include sufficient stormwater management provisions, which may incorporate a National Pollutant Discharge Elimination System (NPDES) stormwater pollution prevention plan, to prevent contamination of surface and ground water and prevent the spread and impact of contamination beyond the boundary of the facility. IDAPA 58.01.06.012.03.l or IDAPA 58.01.06.013.03.l

Discussion: Feedstock piles and unfinished compost piles can release contaminants to the environment that, if not managed appropriately, may impact human health and the environment. Compost facility

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[462] http://compost.css.cornell.edu/odors/odor.html
[463] http://www.calrecycle.ca.gov/Publications/Documents/Organics%5C44207001.pdf

owners/operators must ensure their site manages stormwater run-on and runoff to minimize these impacts. In addition, collecting stormwater run-on and runoff provides an opportunity to reuse this water as make-up water in the composting process.

Resources: EPA Stormwater Control—http://cfpub.epa.gov/npdes/stormwater/swbasicinfo.cfm

Odor Management Plan — The owner and operator of a processing facility shall implement a health district-approved odor management plan designed to minimize malodorous gases. The plan shall include specific operating criteria for oxygen, moisture, and temperature levels appropriate for the wastes to be processed and processing technologies to be employed; methods used to maintain the specific operating criteria; and a monitoring strategy that includes the frequency and parameters for monitoring the specific operating criteria. IDAPA 58.01.06.012.09.c.i or IDAPA 58.01.06.013.11.a

Discussion: Nuisance issues including odor are one of the main concerns with a composting facility. Developing a plan to both minimize odors and reduce odors when generated will demonstrate to neighbors that the facility owner/operator is a good neighbor.

Documentation Requirement — The owner and operator of a processing facility shall maintain documentation of compliance with the "Solid Waste Management Rules," Section 012 or 013, including an operational log of the methods used to maintain the operating criteria and sampling results. IDAPA 58.01.06.012.07 and 09.c.ii or IDAPA 58.01.06.013.09 and 11.e

Discussion: In addition to maintaining documentation for waste types and volumes, compost facility owners/operators are also required to maintain documentation for monitoring temperature, moisture, aeration, and other conditions that demonstrate the composting process is optimized to process the waste as quickly as possible and minimize odors.

Ground Water — The active portion of a facility shall be located, designed, and constructed such that the facility shall not cause contamination to a drinking water source or cause contamination of the groundwater. IDAPA 58.01.06.012.09.a.i or IDAPA 58.01.06.013.01.d

Discussion: Compost facility designs can vary significantly based on the types of waste to be managed, volume of waste to be managed, and site-specific geologic conditions beneath. The design may be as simple as natural soils providing adequate protection to ground water or may involve a constructed liner. Any proposed design plan will need to adequately document that groundwater will be protected. The design will also need to incorporate stormwater controls to ensure run-on/runoff is managed appropriately.

Resources: Contact a qualified professional engineer and/or geologist for assistance in determining an adequate design based on the volume of waste, types of waste, and other site-specific conditions that will ensure protection of public health and the environment.

Table 1. Ceiling concentrations of metals in biosolids.

Pollutant	Ceiling concentration (milligrams per kilogram)[a]
Arsenic	75
Cadmium	85
Copper	4300
Lead	840
Mercury	57
Molybdenum	75
Nickel	420
Selenium	100
Zinc	7500

Source: 40 CFR 503.13, Table 1
[a] Dry weight basis

Source: EPA Stormwater Pollution Prevention Plan[464]

Table from Tier II and III Guidance, p. 8.

[464] http://www.epa.gov/npdes/pubs/industrial_swppp_guide.pdf

[Above requirements are for Sewage sludge under 40 CFR 503.13 (2017) and incorporated into Idaho state regulations. Failure to meet these requirements bars land application of said sewage “sold or given away in a bag or other container.”]

Table 2. Pathogen limits for land application of biosolids.

Class A Pathogens	Units	Determination	Density Limit
Fecal coliform	CFU or MPN/g total solids (dry-weight basis)	Geometric mean of ≥7 individual grab samples taken over a 14-day period	<1,000 fecal coliform/g total solids
Salmonella sp.	CFU or MPN/g total solids (dry-weight basis	Arithmetic mean of ≥7 individual grab samples taken over a 14-day period	<3 MPN/4 g total solids
Enteric virus PFU/4g total solids (dry-weight basis)	PFU/4 g total solids (dry-weight basis)	One composite sample of ≥7 individual grab samples taken over a 14-day period and the arithmetic mean of 4 duplicate analysis of the composite	<1 PFU/4 g total solids
Viable helminth ova	Viable ova /4 g total solids (dry-weight basis)	One composite sample of ≥7 individual grab samples taken over a 14-day period and the arithmetic mean of 4 duplicate analysis of the composite	<1 viable ova/4 g total solids

Note: This list is subject to change, either due to modification to Part 503 or because of new knowledge regarding previously noninventoried substances. For the latest updates, search http://www.gpo.gov/fdsys for 40 CFR 503.32.

Table from Tier II and III Guidance, p. 9.

(MPN = most probable number; PFU= plaque-forming unit)

[Above listed numeric requirements under 40 CFR 503.32 (2017) for “Sewage sludge – Class A” incorporated into Idaho state regulations.]

5b. Additional Air Permitting Requirements and Analysis

- Title V Classification: Not applicable due to very low emissions associated with the combustion of scrubbed biogas. The designation is triggered by 100 tons of emissions per year for particulate matter, ozone, carbon monoxide, sulfur dioxide, lead, and nitrogen oxide, or by 10 tons of emissions per year of any one harmful air pollutant (HAP) or 25 tons of emissions per year per year for all HAP combined. If below these thresholds, not Tier 1 facility per IDAPA 58.01.01.006 and 58.01.01.301 (also, 40 C.F.R. Part 70).

- Prevention of Significant Deterioration (PSD) Classification: (40 CFR 52.21) … not a "major stationary source" defined under federal regulations;[465] therefore per 40 CFR 52.21 (a)(2), PSD requirements not applicable to this permitting action. Further, not a designated facility under 40 CFR 52.21(b)(1)(i)(a) and does not have facility-wide emissions of any criteria pollutant in excess of 250 tons per year.
- 40 CFR 60 Subpart JJJJ (Requirements for spark-ignited internal combustion engine / generators)
    - Criteria pollutant limits set for NOx, VOCs, CO, and PM:
    - Emissions limits for generators with horsepower greater than 500 but less than 1350 and manufacture date after July 1, 2010:
    - NOx 1 g/bhp-hr [grams/ brake horsepower-hour], CO 2 g/bhp-hr, VOC .7 g/bhp-hr
    - Engine maintained in accordance with 40 CFR 60.4234; 60.4243 (maintenance plan, regular maintenance pollution minimizing practices); conduct performance test within 60 days of "achieving maximum production rate" but no later than 180 days after initial start up; subsequent testing every 8760 hours (or every 3 years, if sooner).
- Other Operating Requirements (found in other permits on file with IDEQ)
- Combust "pipeline quality" natural gas exclusively in boilers and generators
- Oxidation catalyst temp: 550 F and 1250 F at inlet and below 1350 F at outlet
- Maintain maintenance records, use history of flares, engine usage, fuel usage.

5c. Governing Authorities and Professional Consultations Needed

Governing Agencies

- U.S. EPA Region 10
- IDEQ
- Idaho Department of Water Resources
- ISDA
- FERC
- Idaho Power Company

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[465] 40 C.F.R. 52.21 (b)(1)(i) "Major stationary source means:
"(a) Any of the following stationary sources of air pollutants which emits, or has the potential to emit, 100 tons per year or more of any regulated NSR** pollutant: Fossil fuel-fired steam electric plants . . . coal cleaning plants . . . kraft pulp mills, portland cement plants, primary zinc smelters, iron and steel mill plants, primary aluminum ore reduction plants . . . primary copper smelters, municipal incinerators . . . hydrofluoric, sulfuric, and nitric acid plants, petroleum refineries, lime plants, phosphate rock processing plants, coke oven batteries, sulfur recovery plants, carbon black plants . . . primary lead smelters, fuel conversion plants, sintering plants, secondary metal production plants, chemical process plants . . . fossil-fuel boilers. . . petroleum storage and transfer units . . . taconite ore processing plants, glass fiber processing plants, and charcoal production plants;
"(b) Notwithstanding the stationary source size specified in paragraph (b)(1)(i) of this section, any stationary source which emits, or has the potential to emit, 250 tons per year or more of a regulated NSR pollutant; or
"(c) Any physical change that would occur at a stationary source not otherwise qualifying under paragraph (b)(1) of this section, as a major stationary source, if the changes would constitute a major stationary source by itself."
[**NSR pollutants are particulate matter, ozone, carbon monoxide, sulfur dioxide, lead, and nitrogen oxide]

- Idaho Public Utilities Commission
- County Zoning Board
- Local Idaho Public Health District, Highway District, Fire District
- Idaho Transport Company

Professional Consultations Needed

- Geologist (for solid waste permitting)
- Electrical engineer (for utility agreement)
- Environmental scientist (for air emissions modeling)
- Civic planner (for zoning board approval)
- Nutrient management planner (for NPDES permit modification)
- Natural Resources Conservation Service
- Waste and Remediation Manager (groundwater contamination analysis)
- County Planner (building and zoning permits)
- Idaho Power Company representatives
- Idaho Office of Species Conservation (Endangered Species Act Certification)

6. Public Health Appendices

6a. Valuation of 2010 Emissions (Damages per ton in $2007 US) [466]

Table 1. Valuation of 2010 emissions (damages per ton in $2007 US)

Valuation; discount rate	CO_2	CH_4	BC	SO_2	CO	OC	N_2O	HFC-134a
Climate[1]; 5%	11	560	15000	-1000	270	-2100	3300	22000
Climate[1]; 3%	35	1100	24000	-1700	490	-3300	11000	43000
Climate[1]; 1.4%	140	2700	57000	-3900	1200	-7800	44000	108000
Regional climate, aerosols; 5%	0	0	22000	2600	0	5100	0	0
Regional climate, aerosols; 3%	0	0	31000	3800	0	7600	0	0
Regional climate, aerosols; 1.4%	0	0	55000	7700	0	15000	0	0
Climate-Health[2]; 5%	10	700	57000	2300	340	4600	2600	27000
Climate-Health[2]; 3%	19	1000	65000	2500	480	5000	5200	40000
Climate-Health[2]; 1.4%	42	1500	74000	2500	720	5100	12000	61000
Composition-Health; 5%	0	490	34000	17000	*	27000	0	0
Composition-Health; 1.4%	0	680	34000	17000	*	27000	0	0
Composition-Agricultural; 5%	**	22						
Composition-Agricultural; 1.4%	**	30						
Sum; 5% discounting[3]	16 ±10	1400 ±700	100000 ±50000	20000 ±14000	440 ±310	33000 ±22000	4600 ±3000	36000 ±25000
Sum; 3% discounting[3]	44 ±27	2200 ±1100	120000 ±70000	20000 ±14000	730 ±490	34000 ±22000	14000 ±8000	63000 ±41000
Sum; 1.4% discounting[3]	160 ±90	4100 ±2200	180000 ±100000	22000 ±14000	1600 ±1000	38000 ±23000	50000 ±28000	140000 ±80000
Sum; declining discounting[3]	56 ±33	2200 ±1100	120000 ±60000	20000 ±14000	760 ±490	34000 ±22000	17000 ±10000	64000 ±41000

466 Shindell, D. T. (2015). The social cost of atmospheric release. *Climatic Change*, *130*(2), 313-326. Retrieved from https://link.springer.com/content/pdf/10.1007%2Fs10584-015-1343-0.pdf

6b. Valuation of Anthropogenic Emissions at Different Times (Damages per ton in $2007 US)[467]

Table 4. Valuation of anthropogenic emissions at different times (damages per ton in $2007 US)

Year/discount rate	CO_2	CH_4	BC	SO_2	CO	OC	N_2O	HFC-134a
2010 / 5%	16	1400	100000	20000	440	33000	4600	36000
2030 / 5%	24	1900	140000	21000	700	36000	7300	57000
2050 / 5%	38	2800	200000	24000	1100	41000	12000	91000
2010 / 1.4%	160	4100	180000	22000	1600	38000	50000	140000
2030 / 1.4%	240	6100	260000	25000	2400	43000	75000	210000
2050 / 1.4%	370	9100	380000	29000	3800	51000	120000	340000

[467] *Ibid.*

7. WattTime Irrigation Feasibility

7a. Example Checkbook Balance for Corn Irrigation

Table 1. Available-Water Holding Capacity of Ten Soil Types.

Soil Type	Textural characteristics	Storage capacity
		in./ft.
0	Sandy clay loam	2.0
1	Silty clay loam	1.8
2	Clay loam	1.8
3	Loam	
Low (2%)	Very fine sandy loam	2.0
O.M.	Silt loam	
4	Loam	
High (3%)	Very fine sandy loam	2.5
O.M.	Silt loam	
5	Fine sandy loam	1.8
6	Sandy loam	1.4
7	Loamy sand	1.1
8	Fine sands	1.0
9	Silty clay	
	Clay	1.6

To determine how often to apply irrigated water (and therefore power requirements), one method is the 'checkbook balance.' The following outline present steps to do this for corn in one region (MA):

1. Determine soil type - corn grows in a variety of different soil types; much of MA qualifies as "fine, sandy loam."[468] The corresponding water holding capacity by soil type is presented in the table below.[469]
2. Determine rooting depth. The root depth influences the irrigation system setup; for corn, the root depth is 3 feet at silking.
3. Determine available water (how much water the soil can store in the zone of rooting depth)
   a. available water = 1.8 in/ft. for fine sandy loam.[470]
4. Determine available water in the active root zone for our crop
   a. (1.8 in/ft) * (3 ft) = 5.4 in. available water in active root zone
5. Calculate current water balance, which is the amount of water available that remains in the active root zone at the time of analysis. The minimum amount for corn is 50%, so this is the number used in subsequent calculations. In practice, a farmer would use a soil moisture meter or simply go by the "feel" of the soil. Instrumentation options include tensiometers and atmometers, as discussed in the main body of this report. In addition, a number of environmental factors affect the soil water balance; the processes are depicted in the figure below.

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[468] Fletcher, P. (1993). *Soil Survey of Barnstable County Massachusetts.* United States Department of Agriculture, Natural Resources Conservation Services: Massachusetts. Retrieved from https://www.nrcs.usda.gov/wps/portal/nrcs/detail/ma/soils/surveys/?cid=nrcs144p2_013984
[469] Rhoads, F. M. (2000). Irrigation Scheduling for Corn – Why and How. *National Corn Handbook, Water Management (Irrigation), NCH-20.* Iowa State University, University Extension.
[470] Melvin, S. R., & Yonts, C. D. (2009). Irrigation scheduling: Checkbook method. Extension Circular (EC), 709.

Illustration of In-Field Processes Affecting Irrigation Schedule.[471]

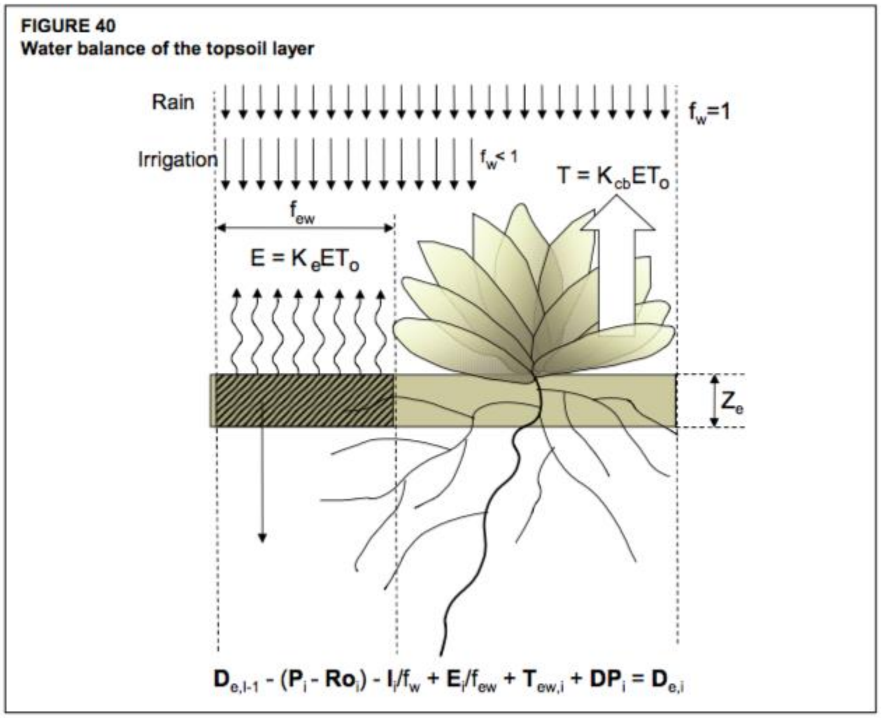

FIGURE 40
Water balance of the topsoil layer

a. Assuming 50% available water remaining in active root zone:
 i. 1.8 in/ft * 3 ft * 0.5 = 2.7 in.

6. To determine irrigation for the corn, the farmer will need to know how much rainfall has occurred since the last irrigation application.
 a. for the sake of analysis, we assume 1.0 inches precipitation. We can assume no runoff if storage is available in the root zone at the time of rainfall which, in this scenario, is the case.
 b. We will also need to estimate previous gross irrigation applied (e.g., assume 2 inches gross irrigation applied with a center pivot, the most efficient form of sprinkler irrigation, with efficiency of 85% as described in the table provided in the main body of this report).
 c. Estimate crop water use, which is dependent on growth stage. We assume 0.3 in/day or 2.1 in/ week inches of crop water use.

[471] Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). *FAO Irrigation and drainage paper No. 56*. Rome: Food and Agriculture Organization of the United Nations, 56(97), e156.

Table 30. Water Use Rates for Corn[472]

Stage	Water Use Rate (in/day)
12-leaf	0.24
Early tassel	0.28
Silking	0.3
Blister	0.26
Milk	0.24
Begin Dent	0.2
Full Dent	0.18

7. Use the previous water balance: 2.7 inches of initial soil water status.
8. Determine net irrigation for previous week:
  a. net irrigation = 2 inches gross irrigation * 0.85 = 1.7 in. net irrigation
9. Determine crop water use for previous week: Assume 0.3 in/day for corn, or 2.1 in/week (see table below).
10. The new current water balance = previous water balance + rainfall + net irrigation - crop water use
  a. in our example: 2.7+1+1.7-2.1 = 3.3 in. current water balance
11. The remaining water storage available for rain and irrigation is equal to the available water - current water balance = 5.4 in - 3.3 = 2.1 in. storage available
12. Next, weekly water storage can be estimated by corn water use rate plus available storage: 0.3 in/d * 7 d + 2.1 = 4.2 in.
13. If no rain, the gross irrigation needed (assuming center pivot) = 4.2 in. *1/0.85 = 4.94 in. of gross irrigation needed assuming 0 in precip.
  a. Note: corn at the silking stage is best kept fairly wet (60-90% of available water, compared to corn generally is just 50%).
14. Minimum allowable balance in active root zone for corn at silking stage = minimum allowable balance * root zone = 0.9 in/ft * 3 ft = 2.7 in. minimum allowable balance
15. Remaining usable water = current water balance minus minimum balance = 3.3 in - 2.7 in = 0.5 in. remaining usable water
16. Days until irrigation needed to prevent crop stress = remaining usable water divided by crop water usage rate = 0.5 / 0.3 in/d = 1.667 days. So, irrigation should be completed within 1.7 days to prevent crop damage.

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[472] Melvin, S. R., & Yonts, C. D. (2009). Irrigation scheduling: Checkbook method. Extension Circular (EC), 709.

7b. Calculations to Estimate Irrigation Energy Demand

Table 31. Irrigation Systems Overview[473,474,475476]

Irrigation Method	Application Efficiency[477] (%)	Description
Sprinkler (spray)		
Center pivot and lateral move	85-90	sprinkler sprays around central circular pivot
Skid tow/Side roll	75-80	sprinklers attached to a lateral pipe that rolls along on a wheel
Big gun traveler	70-75	large gun-like sprinkler moved along by a tractor
Low-flow micro	88	sprays water at low pressure over wider area
Solid set and permanent	90	sprinklers attached to above ground portable pipes or permanent buried system
Hand move	83	sprinklers attached to above ground pipes that can be moved by hand
Micro-irrigation		
Surface drip irrigation	95	small diameter tubing applies water directly to root zone via emitters
Subsurface drip irrigation	90-95	same as surface drip, but buried in the ground to minimize evaporation loss
Surface/gravity/flood		

473 Melvin, S. R., & Yonts, C. D. (2009). *Irrigation scheduling: Checkbook method.* Extension Circular (EC), 709.
474 Stubbs, M. (2015). Irrigation in US Agriculture: On-Farm Technologies and Best Management Practices. Washington DC: Congressional Research Service.
475 Amosson, S. H., New, L., Almas, L., Bretz, F., & Marek, T. (2002). *Economics of irrigation systems*. Texas FARMER Collection.
476 Reinders, F. B. (2011). Irrigation methods for efficient water application: 40 years of South African research excellence. *Water SA,* 37(5), 765-770.
477 The metric is net-to-gross ratio to estimate application efficiency.

Furrow	60	Partial surface flooding in which water applied to the end of small parallel channels (rows), with water flowing down the slope (minimal pressure)
Gated pipe with reuse	70-75	Portable pipes connected to main water supply deliver water using a riser distribution assembly; in reuse, water from runoff is recycled back into the irrigation system.
Gated pipe without reuse	50-55	Lack of reuse leads to a lower application efficiency but does not require energy to pump the collected water to the next area as done in reuse
Gated pipe with surge	75-80	Hydraulic surges provide intermittent flow into the irrigation system, allowing for improved water efficiency and reduce variations in advance rates between furrows
Siphon tube without reuse	45-50	Siphon tubes serve each furrow and operate using the height difference between water level in the irrigation canal and the field.
Siphon tube with reuse	65-70	In reuse irrigation systems, the runoff is either diverted to another field or returned to the same field through pumps

Sprinkler and pump system specifications for the model system:

- irrigation technology = center pivot with high-pressure impact sprinklers
- system length = 900 ft
- end gun wetted distance of 100 ft
- area irrigated by the center pivot = 72 acres
- application efficiency of 85%
- soil texture = silty clay loam
- region of the state = Anteloupe County
- net system capacity (amount of water to replace crop water use) = 4.24 gpm/acre
- hours of pumping = 20 hours/day
- water pump rate needed = ~650 gpm
- pump type and operating specs:
- type = centrifugal
- capacity = 900 gpm
- 120 ft total dynamic head (TDH)
- using this standard pump curve, the pump will run at peak efficiency of ~72%, speed of 1,600 RPM.

- using brake horsepower (BHP) curves to estimate the continuous horsepower rating of the power unit, the pump would require ~40 BHP on the input shaft
  - Check: calculate BHP using the formula BHP = (water horsepower)/(pump efficiency * drive efficiency) → result is BHP = 38, validates use of the curve.

Example calculation for energy needed per irrigation application:

Convert to gallons from acre-inch:

(1.25 in)*(175 acre) = 218.8 acre-in

218.8 acre-in * (27154 gallons / 1 acre-in) = 5,939,938 gallons

If pump operating at 1000 gallon / min:

(5,939,938 gallons) * 1 min/800 gallons = 5728 min = 99 hours = 4.12 days

So it would take 4.12 days (which we will round down to 4 for simplicity of these initial calculations) to provide the irrigation coverage needed.

Another means of calculating the energy required, based on USDA irrigation energy calculator:

Groundwater source is from a 130-foot-deep well located conveniently to all parts of the irrigated area. We used information from the USDA irrigation energy calculator. Horsepower (HP) in = flowrate*TDH/(39.6*OPE). For a pump of 70% efficiency, the HP input required is 43.3 HP. Given that 1 kiloWatt = 1.34 HP, the total KW required for each irrigation 'cycle' of 99 hours is 43.3 HP*1/1.34*99 hr = **3197.9 kWh, per irrigation cycle of ~4 days.**

7c. Farm-wide energy usage for WattTime Emissions Reduction Estimate

Farm Energy Usage to Estimate Potential WattTime Savings

Equipment	Average kWh Use*	Quantity	Units	Quantity in kWh/month	Assumptions to make monthly quantity estimate	Additional comments
Barn Cleaner	120 annually	120.0	kWh/year	10.0		
Barn Lighting	60/month	60.0	kWh/month	60.0		
Barn Ventilation (approx.)	2 ½/cow/month	2.5	kWh/cow/mo	3,750.0	1500 cows	
Clipper	1/10 hours of Use	0.1	kWh/(hours of use)	2.0	20 hours per month	
Dairy Water Heater	1/3.6 gallons	0.3	kWh/gallons	1,691.0	100 gallon water heater (https://www.phcppros.com/articles/5007-hot-water-for-dairy-farms); heated 2x/day	Heated from 50° to 165° @ 100% efficiency
Engine Heater (truck or tractor)	1-2/hour	1.5	kWh/hour	137.0	3 hours/day	1000 to 2000 watts
Fence	7/month	7.0	kWh/month	7.0		
Grain Dryer (no heat)	1/bushel	1.0	kWh/bushel	15,000.0	150 bushels/acre/mo, on 100 acre farm in NE USA (https://www.nass.usda.gov/Statistics_by_State/Maryland/Publications/News_Releases/2016/2016%20November%20Crop%20Production.pdf)	Varies with weather & moisture to be removed
(heated with electric heat)	2/bushel	2.0	kWh/bushel	30,000.0	150 bushels/acre/mo, on 100 acre farm in NE USA (https://www.nass.usda.gov/Statistics_by_State/Maryland/Publications/News_Releases/2016/2016%20November%20Crop%20Production.pdf)	Type of dryer (heat or no heat) mutually exclusive
Grain Elevator	4/1000 bushel	0.0	kWh/(bushel)	60.0		
Grain Grinder	.2/100 pounds	0.0	kWh/(pounds)	1,680.0	56 pounds of shelled corn per bushel (ftp://www.ilga.gov/JCAR/AdminCode/008/00800600ZZ9998bR.html)	
Incubator	1/25 eggs set	0.0	kWh/(eggs set)	11.5	21 days in the incubator (https://aglifesciences.tamu.edu/posc/wp-content/uploads/sites/20/2012/08/EPS-001-Incubating-and-Hatching-Eggs1.pdf); 288 eggs per incubator run (https://www.strombergschickens.com/product/1500-Profesional-Incubator/cabinet-incubator-accessories?s=GSHP&gclid=EAIaIQobChMIrluy7uiC2gIVWEwNCh0bAgt6EAQYBSABEgKGkfD_BwE)	
Milking Machine (portable)	1 ½/cow/month	1.5	kWh/cow/mo	2,250.0	1500 cows	
Milking Machine (pipeline)	1 ½/cow/month	1.5	kWh/cow/mo	2,250.0	1500 cows	
Milk Cooler (can)	1/10 gallons	0.1	kWh/gallons	29,676.6	6.5 gallons per cow per day (https://www.uaex.edu/4h-youth/activities-programs/docs/Dairy%20Facts.pdf)	¼ to 5 H.P.
Milk Cooler (bulk)	11/100 gallons	0.1	kWh/gallons	32,644.2	6.5 gallons per cow per day (https://www.uaex.edu/4h-youth/activities-programs/docs/Dairy%20Facts.pdf)	½ to 7 ½ H.P.
Motor	1/H.P./hour	1.0	kWh/H.P./hour	1,268.2	20 hours, 50 HP (http://articles.extension.org/pages/27773/energy-efficiency-of-electric-motors-on-the-farm)	sizes ½ to 10 H.P.
Poultry House (incandescent)	6/100 birds/month	0.1	kWh/birds/mo	12.0	200 laying hens in a deep litter house measuring 6 m by 11 m can hold a stock density of 3 birds/m2 (3.6 ft2/bird) (http://www.fao.org/docrep/008/y5169e/y5169e05.htm)	
Poultry House (fluorescent)	2/100 birds/month	0.0	kWh/birds/mo	4.0	200 laying hens in a deep litter house measuring 6 m by 11 m can hold a stock density of 3 birds/m2 (3.6 ft2/bird) (http://www.fao.org/docrep/008/y5169e/y5169e05.htm)	
Poultry Water Warmer	1/day	1.0	kWh/day	30.4		
Silo Unloader (grass)	4/ton	4.0	kWh/ton	1,680.0	14 lbs/bushel, 150 bushels/acre/mo, 2000 lbs/ton (ftp://www.ilga.gov/JCAR/AdminCode/008/00800600ZZ9998bR.html)	3 to 5 H.P.
Silo Unloader (corn)	2 ½/ton	2.5	kWh/ton	1,050.0	14 lbs/bushel, 150 bushels/acre/mo, 2000 lbs/ton (ftp://www.ilga.gov/JCAR/AdminCode/008/00800600ZZ9998bR.html)	3 to 5 H.P.
Tool Grinder	½/hour of use	0.5	kWh/(hour of use)	2.5	5 hours of use per month	
Water Pump (deep well)	1 ½/1000 gallons	0.0	kWh/gallons	91.3	2000 gallons/day (https://extension.psu.edu/water-system-planning-estimating-water-needs)	rate: 8 gallons/min.
Water Pump (shallow well)	1/1000 gallons	0.0	kWh/gallons	60.9		rate: 8 gallons/min.
Water Stock Tank Heater –Hog	193/season	193.0	kWh/season	48.3	season = 3 months	sheltered area
Water Stock Tank Heater-Cattle	193/season	193.0	kWh/season	48.3	season = 3 months	in barn
Water Stock Tank Heater-Cattle	469/season	469.0	kWh/season	117.3	season = 3 months	open shed
Cattle-Hog Combination	535/season	535.0	kWh/season	133.8	season = 3 months	open shed
Cattle-Hog Combination	1208/season	1,208.0	kWh/season	302.0	season = 3 months	open lot
Welder	100/year	100.0	kWh/year	8.3		variable
70 Watt Sodium Vapor	31/month	31.0	kWh/month	31.0		Yard Lighting (dusk to dawn)
100 Watt Sodium Vapor	47/month	47.0	kWh/month	47.0		Yard Lighting (dusk to dawn)
175 Watt Mercury Vapor	73/month	73.0	kWh/month	73.0		Yard Lighting (dusk to dawn)
250 Watt Mercury or Sodium Vapor	105/month	105.0	kWh/month	105.0		Yard Lighting (dusk to dawn)
400 Watt Mercury or Sodium Vapor	161/month	161.0	kWh/month	161.0		Yard Lighting (dusk to dawn)

Sum of reasonable farm composition monthly energy usage:	kWh/month	58,273.6
Adjust per year	kWh/year	699,283.0
Adjust to MW	MWh/year	699.3
WattTime emissions reductions from Henry Richardson in MISO region:	WattTime emissions reduction in MISO from Henry Richardson of WattTime: 68.4 lbs CO2/MWh	
Estimate emissions reductions based on example farm's energy requirements:	Amount in lbs of CO2 that would be reduced from this farm per year: 47,830.96 lbs CO2/year	
Final estimate of tons of CO2/year reduced:	Equals this many tons of CO2/year 23.92 tons CO2/year <--- Nowhere near the 50,000 ton goal	

**Table Sources, in addition to those listed in "Assumptions" column [REFORMAT]*
http://www.fmcs.coop/index.php/services/energy-audits/farm-energy-estimator
http://www.delavalcorporate.com/globalassets/sustainability/energy-report/delaval_energyreport.pdf