Community Manure Treatment Facility Project Description

2024 NCEES Engineering Education Award Submittal: Energy and Sustainability Category

This project centers on the design and siting of a new Community Manure Treatment Facility. The intent of the facility is to reduce watershed phosphorus levels by providing an alternative to spreading manure during frozen conditions. The County will own and operate the facility as a public operation. A local non-profit organization dedicated to improving lakes, streams, and wetlands within the watershed is the Client for the project. A team of five senior engineering students formed a consulting firm for the project design.

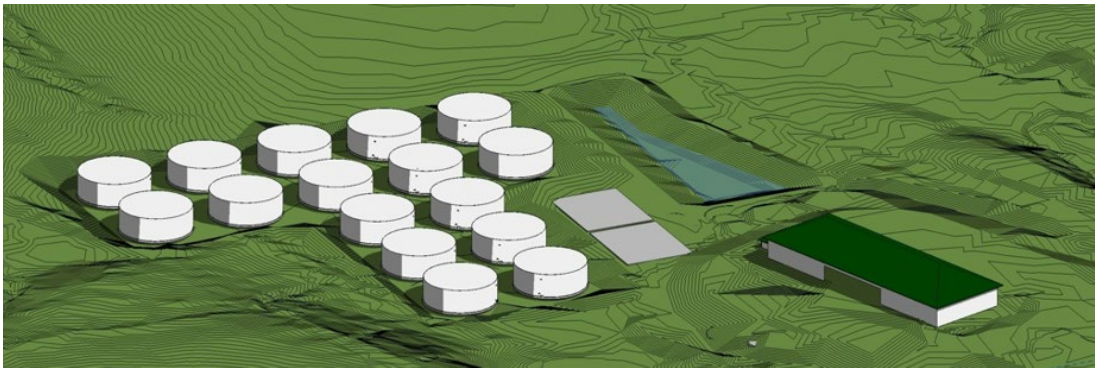

Figure 1: Conceptual view of the Community Manure Treatment Facility facing NW

Project Background – Agriculture is a large part of the County's economy, and the community values its farms. Some of the most highly productive farmlands in the County exist within the headwaters and watersheds of the area's most sensitive rivers and lakes.

Individual farms often lack sufficient manure storage for the entire winter and may resort to spreading manure during frozen ground conditions. This practice is problematic as thaw conditions then result in runoff with high levels of phosphorus. At least 50 percent of the annual total phosphorus load into local lakes comes in late winter and early spring. Phosphorus reaching surface waters causes algal blooms and eutrophication, impacting water quality and recreational use.

Community anaerobic digester facilities offer a pathway for efficient waste treatment and pollution reduction that cannot easily be accomplished on the scale of individual farms. Due to capital costs, independent farms would not be capable of funding a project of this complexity. With the economic backing of the County, this Community Manure Treatment Facility will offer year-round manure treatment for nearby farms. The facility will thereby reduce phosphorus runoff to local waters during spring thaw, strengthen the sense of community and partnership between the County and local farms, and potentially produce revenue from treatment facility byproducts.

Such a project will require millions of dollars in public investment over the next few years, but a large-scale solution is needed to address the challenge at hand and reach phosphorus runoff reduction goals. This Community Manure Treatment Facility will help keep multi-generational family farms working while dramatically reducing phosphorus runoff.

Project Objectives – The Client provided a formal Request for Proposals (RFP) identifying the following objectives for the Community Manure Treatment Facility:

- Reduces phosphorus load in the watershed
- Treats waste from up to 40,000 cows
- Located near the farms it will serve and provides a viable approach to transport manure from farms to the facility
- Has an effective and economical manure treatment process
- Has potential markets and revenue from byproducts
- Effectively integrates with existing practices, including the current manure collection practices on farms and prevalent traffic patterns on roads

Design Constraints and Considerations – Spatial constraints include finding an adequate site for the facility within the proximity of the farms it serves and of sufficient size for infrastructure to treat manure from up to 40,000 cows. The facility will increase traffic volumes due to the trucking of manure and byproducts, so hours of operation will be restricted to limit the impact on local traffic.

Environmental constraints include compliance with permitting requirements during facility construction and operation. Designs include secondary containment to reduce the likelihood of discharge from the site in the event of catastrophic anaerobic digester failure.

The County's budget allows for up to $3 million in funding for feasibility work and acquisition of a site to develop a commercial-scale manure treatment facility. Whether or not the treatment facility is profitable will rely on the price of renewable natural gas and associated renewable energy credits.

Three Design Alternatives Developed – The students found a property for sale where the Community Manure Treatment Facility could be sited. The property is in proximity to the farms generating manure, has adequate topography, and has convenient access to major roadways. The students then developed three design alternatives that can support the Client's goals, foster community partnerships, and be economically sustainable for the County. The student's conversations with local and regional operators at a smaller-scale anaerobic digester facility and information garnered from comparable facilities in the region were central in developing the alternative designs.

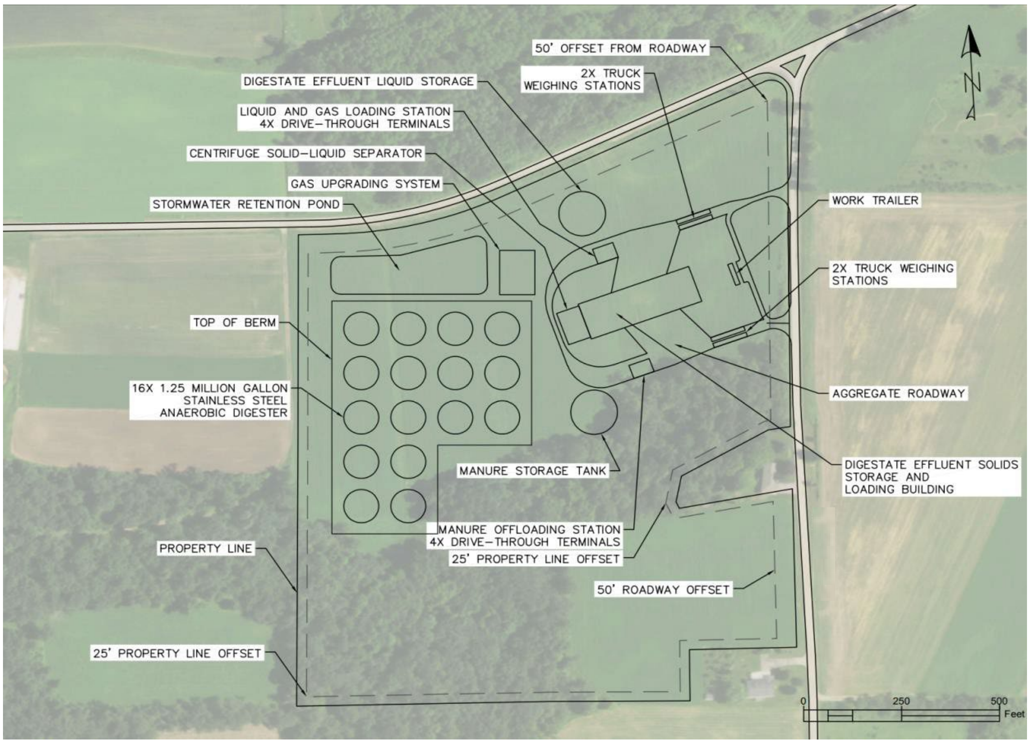

Figure 2: General facility layout

All three alternatives for the treatment facility include:

- **General structures and facilities** including aggregate roadways; truck weighing stations; manure offloading and byproduct loading terminals; concrete underground manure storage tank; solids storage building; liquid effluent storage tank; and pipe and pump networks.
- **16 stainless steel anaerobic digesters** each have a volume of 1.25 million gallons and will be heated to maintain optimal temperature for anaerobic digestion. Digesters have a double-membrane roof allowing for expansion and contraction as gas volumes fluctuate, while maintaining consistent outflow rates to the biogas upgrade system.

- **Biogas upgrade system** to produce renewable natural gas from methane generated during anaerobic digestion. Renewable natural gas is the most profitable byproduct of the facility.
- **Centrifugal solids-liquids separator** to provide mechanical separation of solids and liquids after digestion. Approximately 50 to 70 percent of phosphorus will be in the separated solids with the remainder left in the liquid fraction.

Alternative 1 – Renewable Natural Gas

This alternative is the simplest of the three. It includes the production of renewable natural gas using a membrane filtration system. Separated liquid and solids from the centrifuge separator would not be further treated to improve byproducts. Moisture content of the separated solids would be too high to use for animal bedding, pelletizing, or other possible products, so phosphorus-rich solids would be trucked to farms in less phosphorus-sensitive watersheds to be used as fertilizer. The liquid fraction would be used by member farms as liquid fertilizer with lower phosphorus concentration and more manageable volume than the untreated unseparated manure. This alternative has the lowest capital and operating costs; however, the revenue streams are restricted to only renewable natural gas.

Alternative 2 – Renewable Natural Gas and Liquid Byproducts

This alternative includes the production of renewable natural gas using a liquid scrubbing system and focuses on improving the environmental and economic outcomes of the liquid byproduct. After solid and liquid separation, digestate liquid would be treated through a reverse osmosis system that produces a large fraction of potable water and a smaller fraction of highly concentrated liquid fertilizer. Potable water can be used for onsite operations such as heat exchangers and liquid scrubbing, trucked to participating farms for irrigation, discharged to a pond (with appropriate permits), or some combination of these. As for Alternative 1, the moisture content of solids generated in Alternative 2 would be too high for most uses and would likely be trucked to farms in less phosphorus-sensitive watersheds for use as fertilizer.

Alternative 3 – Renewable Natural Gas and Solids Byproducts

This alternative builds on the design in Alternative 1 and furthers the treatment of solids to improve the marketability of solid byproducts. Solids from the centrifugal separator would be sent to a drum dryer system to reduce moisture content so the solids are more suitable for use as animal bedding, heat or power generation pellets, soil amendment, peat moss substitute, composite fiber products/building materials, or some combination of these. An in-depth market analysis is necessary to determine the most feasible uses, additional treatment, and profitability. One advantage to drying solids is reduced cost for transporting the solids offsite due to the reduction in weight.

Alternatives Evaluation Matrix – The students compared the three design alternatives using Multiple Criteria Decision Analysis (MCDA) in a decision matrix with environmental impact, capital and operating cost, byproduct revenue, community impact, and ease of system management as the criteria. These criteria and weights were selected to represent the project goals, local community input, and mentor/client feedback. The criteria data was normalized to allow comparison of each alternative.

Table 1: MCDA alternative comparison

Criteria	Input Weight	Alternative 1	Alternative 2	Alternative 3
Environmental Impact	30%	8%	14%	9%
Capital and Operating Cost	25%	10%	8%	6%
Byproduct Revenue	18%	3%	6%	9%
Community Impact	15%	7%	5%	4%
Ease of System Management	12%	3%	5%	4%
Total	100%	30%	**37%**	32%

A key step in the alternative evaluation was the student team's formal presentation where they summarized the three alternatives, with a focus on the pros and cons of each. Each student on the team presented a portion of the project through the lens of their technical specialty. Drawings and engineering analyses of the three designs were presented to describe the technical merits and key differences of each alternative.

Recommendation - The final recommended design alternative is Alternative 2, consisting of reverse osmosis, generation of liquid byproducts, and biogas production. In conjunction with its performance in the multi-criteria decision analysis, this design alternative will allow for the efficient generation of highly useful byproducts: biogas, potable water, and high- concentration liquid fertilizer. This design alternative will thus enable the overall process to perform at a high level, meeting the needs of manure treatment in the County and garnering robust public support in the process.

Student-led Engineering Design

Throughout this semester-long project, the student team gained experience with several focus areas of civil engineering, including:

- **Construction Engineering**: A detailed project schedule with critical path items was developed for the project, resulting in an estimated duration of 365 days. The total annualized cost and total life cycle cost analysis (30-year facility lifespan) was determined for each of the alternatives.

Table 2: Opinion of probable cost summary

	Alternative 1: Renewable Natural Gas	Alternative 2: RNG & Liquid Byproducts	Alternative 3: RNG & Solids Byproducts
Total Annualized Cost	$13,456,000	$13,581,000	$16,126,000
Life Cycle Cost	$403,680,000	$407,430,000	$483,780,000

- **Environmental Engineering:** The site was selected to avoid impacts to sensitive resources including wetlands and threatened and endangered species. The potential uses and extent of treatment for byproducts to improve environmental outcomes of the watershed is a key aspect of the facility design. All three design alternatives focus on capturing and treating methane to generate renewable natural gas. Other environmental considerations include designing secondary containment to protect against discharge of wastes or hazardous materials.
- **Geotechnical Engineering:** Soil boring and soil survey data were used to analyze existing soil conditions, hydrology, and geology for facility design and construction. Topsoil on the site is unsuitable for supporting structures, equipment, and loaded vehicle traffic, requiring excavation in those areas and replacement with engineered fill compacted to meet standards. Anaerobic digesters would be secured to one-foot-thick reinforced concrete mat style foundations, underlain with three feet of compacted gravel fill.
- **Hydraulic Engineering:** The facility design includes several treatment systems and requires a network of pipes for manure and liquid transport.

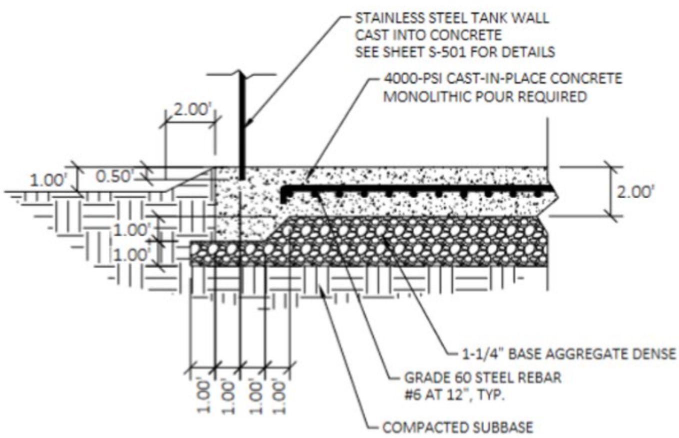

Figure 3: Digester foundation typical section

- **Hydrologic Engineering:** Stormwater management design includes hydrological engineering calculations, siting, and sizing of the site's stormwater detention pond to meet local requirements. The wet pond is placed in the lowest elevation of the site to capture facility runoff.
- **Structural Engineering:** Structural calculations were performed to determine the appropriate digester wall thickness for the anticipated fluid and gas pressures.

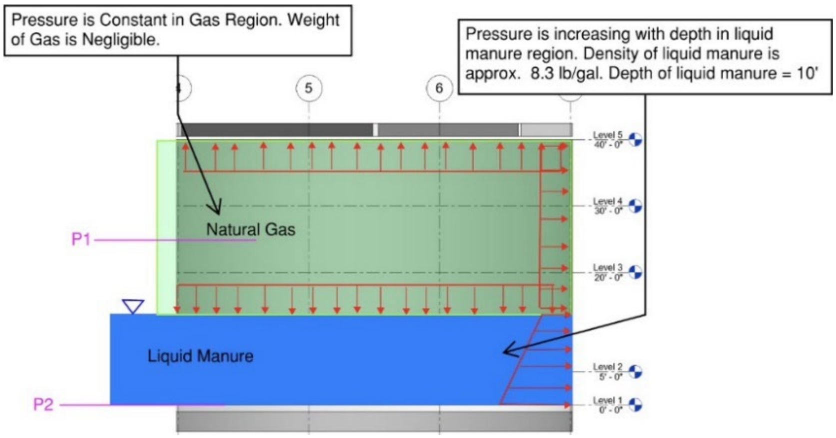

Figure 4: 2-D elevation view of digester tank wall with pressure visualization

- **Transportation Engineering:** Transportation problems addressed in the design include increased local traffic, site accessibility, onsite roads, and onsite vehicle routing. Facility layout was designed to efficiently move vehicles from public roads through weighing and various unloading/loading areas before exiting the facility.

Collaboration of Faculty, Students, and Licensed Professional Engineers

Were licensed professional engineers (P.E.s) involved?

Fourteen P.E.s and one Engineer in Training (EIT) were directly involved with the student team throughout the semester.

- Two P.E.s served as team mentors. They met weekly with the student team, providing design comments, guidance from professional experience, critique of presentations and reports, and advice for client relationships and public meetings. Students also consulted with a professional engineer with expertise in biogas utilization.
- Overall instruction for the course was provided by two P.E.s and an EIT. Specialized engineering topics were presented to students by three additional P.E.s over the course of one or more sessions each.
- Two student team presentations (at the preliminary and final design stages) were delivered to a panel of judges from the local professional community, thereby widening the students' exposure to other professionals and affording opportunities for additional critique of their work. The panel of judges included five P.E.s, an architectural historian, and a university communications instructor.

How did the students, faculty, and P.E.s interact?

The student team was responsible for meeting pre-established goals for time management, presentations, design components, deliverables, and schedules. Weekly meetings between mentors and the student team allowed the students to gain insights and advice grounded in the P.E.s' many years of experience, helping guide project success. The student team also consulted with a P.E. who has expertise and experience in biogas utilization. Throughout the semester, mentors and faculty made themselves available for phone or email discussions and review of the team's deliverables.

What did the students learn through the collaboration that would not have been learned in the classroom?

Collaboration between engineers, stakeholders, regulatory agencies, and the public is difficult, if not impossible to teach in the classroom. To experience these interactions, the student team:

- Met with the client on multiple occasions to provide information on the project progress and status and incorporated the client's feedback into their design.
- Visited an existing smaller-scale digester and biogas facility and spoke with the facility's operations and maintenance managers, as well as the company's vice president of legislative and regulatory affairs. From this interaction, the students learned about practical issues associated with facility operation and applied what they learned to improve their design.
- Delivered formal presentations to and fielded questions from a mixed audience including the Client, mentors, instructors, judges, and peers.

Insights from these interactions guided the team's design and gave them a sense of broad stakeholder involvement.

Protection of Health, Safety, and/or Welfare of the Public

Did the project include aspects that affect the health, safety, and/or welfare of the public?

This project centers on public health, safety, and welfare through its ability to address watershed pollution reduction on a scale that could not be achieved by individual farms.

How was public protection addressed?

Careful consideration of siting the facility, limiting impacts to local traffic, and steps taken to protect the environment help protect the public on this project.

Which project features raised students' awareness about the impact of engineering decisions?

Facility siting, layout, and containment raised students' awareness of how engineering decisions can impact a community. Additionally, students met with community-based learning representatives four times during the semester to reflect on the community impacts associated with their project.

Did the project highlight how engineering can help solve problems faced by communities nationally or worldwide?

The Community Manure Treatment Facility highlights how manure treatment and pollution reduction can be addressed at the community-level in a way that cannot be accomplished on the scale of individual farms.

Did the project foster student self-reliance, cooperation, or responsibility?

Students were responsible for staying on schedule, managing their time, cooperating to split up tasks and pull together information, reaching out to experts as needed for guidance, and conducting research and calculations for the project.

Multidiscipline and/or Allied Profession Participation

Was more than one engineering discipline involved?

The P.E.s working with the students included civil engineers with collective expertise in environmental, geotechnical, and transportation engineering. One session was also presented by a P.E. with a degree in mechanical engineering, and students also consulted with a licensed engineer who has expertise in biogas utilization.

Did the project include other professions?

The students met with industry professionals to tour a digester and biogas facility and learn more about day-to-day operations as well as design considerations. Aside from P.E.s, the panel of presentation judges also included an architectural historian and a university communications instructor.

Was more than one branch of a particular engineering discipline involved?

Yes, seven branches of civil engineering are involved on this project, as listed below, with work led by the student team.

- Construction engineering
- Environmental engineering
- Geotechnical engineering
- Hydraulic engineering
- Hydrologic engineering
- Structural engineering
- Transportation engineering

Knowledge and Skills Gained by Students

What engineering and other non-technical knowledge/skills did the students gain?

Students gained a variety of hands-on, real-world engineering experience through this project including:

- working in a technical team
- responding to an RFP and preparing a competitive project proposal
- managing their time to stay within budget and on schedule
- identifying constraints and uncertainties
- designing a project to meet client objectives
- considering the ethics and sustainability of their design
- project design to meet applicable standards and regulations
- preparing technical reports and construction drawings
- presenting their designs and recommendations to a multi-disciplinary audience with both engineering and non-technical backgrounds

How were the knowledge/skills gained important to professional practice?

The knowledge and skills gained during the course simulate project procurement, project management, stakeholder involvement, and preliminary project design in professional practice, which are integral aspects of their future careers.

Did the project include consideration of professional practice concepts such as project management, ethics, contracts, or law?

The student team assigned a project manager who was the primary spokesperson and contact for the team's interactions with mentors and the Client. The project manager was also responsible for delegating work and keeping the project on schedule.

In both facility siting and design, the students addressed ethical issues such as impacts to the environment and the community, which are included in their community-based learning ethics reflections resulting from the project.

The students also prepared construction contract documents specific to their project. As part of the design process, students identified applicable standards and regulations and applied them to the project design, schedule, and cost.