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Focus on Energy

Environmental and Economic Research and Development Program

Biogas Storage Farm AD Report

April 30, 2015

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1. EXECUTIVE SUMMARY

Wisconsin is a North American leader in the implementation and operation of successful anaerobic digestion/biogas systems providing numerous benefits to the community, environment, as well as producing clean, renewable baseload energy. As of January 2015, USEPA AgSTAR estimates that that the State of Wisconsin has the most operational anaerobic digester systems (38 out of approximately 247) at livestock farms in the United States. It is the leadership of Focus on Energy and many other stakeholders in the industry that has positioned Wisconsin as an leader in this market. While robust, the Wisconsin market has recently experienced some challenges to ongoing growth in the on-farm anaerobic digester market, with current activity not reflecting the level of past activity.

One area of potential growth is for the generation of biogas derived electricity during periods of peak electricity demand. Focus on Energy contracted with Tetra Tech and the Energy Center of Wisconsin (ECW, Tetra Tech's subcontractor) to research the challenges and opportunities for biogas storage and peak power generation at on-farm anaerobic digesters. Most on-farm digesters that generate electricity do so on a basis similar to a baseload power plant—using the biogas to generate electricity around the clock. As biogas is generated in continuous production, electricity is also generated on a continuous basis.

Short-term biogas storage offers the opportunity to shift the times of day when the electricity is generated, potentially enhancing the value of electricity by taking advantage of electricity rates that are higher on-peak than off-peak. Biogas plants are particularly well suited to serve as on-peak or "peaking" plants as their biogas production is steady, and the incremental cost to the project is relatively modest compared to the overall cost of the facility. Unlike many renewable energy sources such as solar or wind, electricity production from anaerobic digester facilities can be actively scheduled to meet peak demand periods. Anaerobic digester system owners can potentially utilize this flexibility and negotiate for more favorable Power Purchase Agreements (PPAs) if they are able to assure the utility that they will be available during peak power times.

With the theoretical opportunity comes a need to understand the state of the technology and markets. Three methods were used in this research to determine the state of the biogas storage and peak power generation. These were:

1. A literature review of existing information on biogas storage and applicability to on-farm anaerobic digesters
2. Interviews with key biogas market actors, including technology providers and developers/designers, and Wisconsin utility representatives
3. Modeling price and performance for an example system appropriate for Wisconsin's on-farm anaerobic digester market.

The purpose of the research is to determine whether using biogas storage for peak power generation is technically feasible and readily available to the market today. Assuming technical feasibility and availability, a key research issue was to better understand the market barriers and opportunities, including cost factors and perspectives from several stakeholder groups. This report describes research and findings and is meant to help inform Focus on Energy and lead program design considerations and options. The report findings suggest there is strong future potential value in peak power generation. First, with adequate differential between on-peak and off-peak rates, incremental system costs can be an attractive investment. Second, while there is limited practical experience in using digestion systems to generate peak power, the technology required to do so are relatively minor and familiar to the industry. Taken together, it is clear that the industry will be able to act on an opportunity if power market conditions provide for adequate on-peak and off-peak price differentials. While there are gaps in market perceptions and conditions, next steps can be taken by the biogas industry, Focus on Energy, and Wisconsin utilities to move the market forward.

1.1 KEY FINDINGS

Biogas storage is technically feasible and useable at on-farm anaerobic digesters. The research revealed two types of storage technologies that align with farm operations. Recommended storage technologies include concrete slab-mounted dual flexible membrane systems and using larger multiple flexible membrane roofs (i.e., multi-film) for continuous stirred-tank reactor (CSTR) digester vessels. Both approaches are available in the market and could be implemented as a retrofit to existing digesters or designed into new digester systems. Bag style storage systems are also a feasible option, though the experts we interviewed preferred the other two approaches. While some experts expressed concerns over the safety of bag systems when they are kept in an enclosed building, others were less concerned and felt it was a matter of overall system design to meet safety and insurance requirements.

Biogas storage can be used on complete mix or plug-flow anaerobic digesters. Plug flow digesters with fixed roofs can utilize the slab-mounted dual membrane or bag-style storage, which add external gas storage space. Complete mix digesters can use either of these external storage systems or an expanded capacity multi-film membrane system added to the digester vessel. Multi-film membranes would typically have either two or three membrane layers.

Expanded biogas storage is not currently common on US farms. Few farms have added biogas storage beyond that which is designed into their digesters, and we found none using storage for maximizing on-peak electricity generation. Biogas storage is more commonly found at wastewater treatment plants and some centralized digester operations, and some of these do use storage to increase on-peak electricity generation.

***On-farm digester designers and developers have mixed opinions regarding the value of biogas storage and peak power production*.** Our interviews revealed that developers/designers saw no fundamental technical issue but doubted the added complexity or incremental value of electricity were worth pursuing given current electricity market conditions. They agreed that with the right market conditions, storage and on-peak production could be designed in without great difficulty.

Programs are in place to provide a higher buy back price for on-peak power, but it appears that they have not been used for that purpose. We Energies' biogas tariff (CGS 5, now expired) offered 15.5 cents per kWh for on-peak energy as compared to 6.14 cents per kWh for off-peak energy.[1] Despite over a 9 cents per kWh differential between on and off peak prices, no customers are known to be taking advantage of the differential in a way noticeable by the utilities.

[1] https://www.we-energies.com/pdfs/etariffs/wisconsin/ewi_sheet190-192.pdf.

Wisconsin utilities were generally interested in the technology but saw limited value in the current electricity market and regulatory context. Given the potential for biogas system outages, utilities felt individual systems offered limited electricity grid value, particularly at the relatively small (single digit MW) capacities being offered. A system-wide value proposition has not been considered but may offer potential to enhance the value of biogas systems. Some coordination between Wisconsin's electric utilities and the biogas industry may be needed to investigate the issues and opportunities of aggregating on-farm biogas systems.

In the US, there is limited experience operating biogas storage systems to produce on-peak electricity using on-farm digesters. The lack of experience suggests a need for more research and demonstration projects to validate and optimize systems. In the current market, the industry would benefit from demonstration projects to reduce technical and financial risk. A potential role for Focus on Energy and other stakeholders would be to absorb some of the risk by helping fund research and demonstration projects to validate the concept and advance the market.

1.2 SUMMARY SUGGESTIONS

Although current Wisconsin electricity market conditions are not favorable for encouraging the use of biogas storage to facilitate on-peak energy generation, some steps can be taken to help the anaerobic digester market be more prepared if future electricity market conditions become more favorable. Based on the observations gleaned from the research, the following possible activities for either Focus on Energy or the Public Service Commission of Wisconsin (PSCW) to consider.

The Public Service Commission of Wisconsin could consider encouraging the utilities to aggregate biogas projects for purposes of leveraging MISO zonal resource credits and other associated value propositions. Current on-farm systems interconnect at the distribution level, with systems dispersed throughout Wisconsin. Aggregating systems in alignment with MISO zonal resource credits will help develop the biogas market. To the degree that aggregation can affect or otherwise consider the use of biogas storage and on-peak electricity generation, the effort will help increase utility interest assist in the development of the biogas market. This approach should be considered even if on-peak generation is not considered.

Focus on Energy could consider developing demonstration projects using on-farm biogas storage to shift electricity production to on-peak times. The lack of real-life examples with this operational scenario means little information is available to guide early adopters. Demonstration of the viability of this technology and practice would help others make informed decisions as to whether this type of system is worth considering. Carefully designed demonstration projects should enable evaluation of technical, economic and operational aspects that are key to technology adoption decisions. As current electricity market conditions do not exhibit price signals adequate to drive investments for shifting to on-peak electricity production, economic incentives will be needed to entice owners to take the risk.

The Public Service Commission of Wisconsin could consider allowing flexibility with existing* advanced renewable tariffs *(ART) participants to increase peak kW limits without increasing kWh production. With a number of existing on-farm digesters operating under fully subscribed ARTs, a portion of the current digester market is unlikely to be able to economically shift to providing more on-peak electricity. Clear direction from the PSCW that permits utilities to increase their ART capacity caps to take advantage of more on-peak electricity production would remove a key barrier for utilities and their ART participants.

2. OPPORTUNITIES FOR BIOGAS STORAGE ON DAIRY FARMS

2.1 INTRODUCTION

All farm biogas systems have some form of biogas storage. At the very least, the digester vessel provides a small amount of stored biogas that is used over time. However, in the US., on-farm digesters have not used storage as a core strategy to derive added value. Outside of farm biogas markets, storage has been used for two purposes—shifting electricity productions to on-peak/higher value times and for providing biomethane storage used for vehicle fueling. Additionally, there is some potential to use storage to offset or replace retail electricity purchases from utilities via load following, though we were not able to identify any situations where this has been done on farm facilities. In this report, we describe some opportunities that biogas storage may bring to on-farm digesters and examine current conditions that either encourage or discourage its use.

2.2 METHODOLOGY

Understanding the current status and potential of using biogas storage for maximizing on-peak electricity generation on farm digester systems required collecting all information from multiple sources and perspectives. First, we reviewed literature on storage systems used for this specific application, and found that there was little information available—primarily marketing materials, but with some limited industry literature that spoke to expanded biogas storage. Industry stakeholders were interviewed, including storage technology providers, utility representatives, energy generation equipment suppliers, digester system designers and developers, and system owner/operators. Information was sought including biogas storage applicability to farms, feasibility of operating systems to maximize on-peak electricity generation, ramifications for equipment and systems, whether market conditions support that type of operation, and barriers or incentives that affect adoption of this business model. We aggregated the viewpoints from all stakeholder groups noting whenever there were differences of opinion.

2.3 ON-PEAK ELECTRICITY PRODUCTION

Most on-farm biogas systems that produce electricity produce it as the biogas is generated, with only a short lag between generating the biogas and generating the electricity. While tariffs or contracts may offer different on-peak and off-peak rates for selling the electricity to the local utility company, we were unable to identify any farms have taken advantage of this opportunity as a core business strategy influencing digester system design.

Assuming a higher value is placed on on-peak energy, were a farm to utilize storage to shift the times when electricity is being generated, greater returns are possible. We found one farm digester owner who was using a biogas storage system, but not for the operational strategy we studied. That farm is described in the call-out box below.

Farm Using Biogas Storage for Steady Production

Hillcrest Saylor Dairy Farm, located in Pennsylvania, is the only example we found of a dairy farm in the US using biogas storage beyond what is available in a standard digester vessel. Both the digester and the storage system were designed and built by the owner. The storage is a gas bag inside a dedicated storage building. The storage can hold biogas for up to 6-9 hours of generation. Biogas is stored to manage electrical generation with the goal of keeping the engine generator operating at a steady output even when biogas production fluctuates. The farmer has put a lot of work into this system and appears especially adept at working with sensors and adapting equipment to work as needed. He noted that if he were to do it again, he would consider not having the gas bag in an enclosed structure for safety reasons.

In Wisconsin, utilities have previously offered biogas-specific tariffs with differential rates. For example, We Energies' biogas tariff (CGS 5, now expired) offered 15.5 cents per kWh for on-peak energy as compared to 6.14 cents per kWh for off-peak energy.[2] Despite over a 9 cents per kWh differential between on and off peak prices, no on-farm digester customers are known to be taking advantage of the differential to emphasize on-peak electricity production in a way noticeable by the utilities. Current parallel generation tariffs are less than the expired biogas tariffs, and include a much smaller on-peak/off-peak differential. Locational marginal prices currently drive most of these tariffs or contracts, dampening economic motivation to shift electricity production.

Some waste treatment facilities in Wisconsin have shifted electricity production to take advantage of higher energy prices during on-peak times. One operator we spoke with was able to use higher energy feedstocks to boost biogas production over short time intervals and store the gas in their existing CSTR vessels. However, this operator also indicated that they had to continually keep their generators running and that running the generators at 30 percent loading or less led to poor operations and concern over long term generator reliability. The operator indicated that this strategy was used to create a modest boost in revenue and was not a core strategic approach to operating the digester. When they could do it, they did, but only over short time intervals based on available amendments and digester conditions. This facility had a dedicated operator, laboratory, and advanced monitoring and control equipment. Additionally, the facility digested material with high volatility that can be injected into the digester as needed. Similar conditions are more likely to be found on farms that accept co-substrates such as fats oils, and greases (FOG) but are less likely to exist on farms that only digest manure.

2.4 GREATER BEHIND-THE-METER CONSUMPTION

The concept of self-generation to support behind-the-meter electricity loads was also explored. With this strategy, rather than utilizing utility prices for electricity sales, farms could meet their own demand for electricity with biogas, reducing the amount of electricity they bought from the utility. Doing so would enable the farm to offset retail rates, but would require the use of biogas (or other energy) storage to respond their own fluctuating electricity demand throughout the day.

[2] https://www.we-energies.com/pdfs/etariffs/wisconsin/ewi_sheet190-192.pdf.

Ideally, a farm could use its electricity production to meet its electricity load and sell the excess to the host utility.

One non-farm digester operator indicated that once their biogas tariff expired, they would seriously investigate behind the meter generation. Their total electricity load that could be served by the anaerobic digester exceeds the output capacity of the current generating equipment, allowing them to avoid any electricity exports to the utility. At the current time, the biogas tariff is more attractive than offsetting retail electricity purchases and the operator is taking a “wait and see” approach.

In a more extreme scenario, a generation technology representative pointed out that a farm could theoretically disconnect from the utility grid, relying on its own on-site generation to power the farm. However, this representative suggested that this may pose a significant expense and lead to technical challenges. Transient loads, such as the high start-up current of large motors, pose a challenge for natural gas fueled generators (i.e., they may exceed the generator’s capacity and require rapid response). A challenge to this scenario is that short-term on-farm electricity loads are not well understood by design engineers. For this approach to be optimized, the representative suggested a more practical solution would be to leveraging the local utility so the grid can help meet peak and transient loads. In this scenario, the farm would not export power but would manage generation to match on-farm loads.

In summary, using biogas storage to meet on-farm electricity loads is theoretically possible, but is not a common practice. Beyond the scope of this research project, more work is needed to investigate the regulatory environment and PPA requirements in Wisconsin.

2.5 BIOMETHANE AND RENEWABLE COMPRESSED NATURAL GAS

Biomethane refers to biogas that has been upgraded or cleaned to a point approximating the same energy value and quality standards of traditional pipeline-quality natural gas. Biomethane can be injected into pipelines, used to directly fuel natural gas powered vehicles, used to supply fuel cells with a raw energy source, or potentially as a chemical feedstock. In the case of an on-farm system producing biomethane, direct injection into a pipeline would require minimal storage but substantial gas clean-up and compression technology. However, when used for vehicle fuel or a chemical feedstock, gas storage is critical because any flaring or other release of the biomethane is a direct loss of product and all input expenses.

A number of developers/technology suppliers, such as CleanWorld (California), Quasar Energy Group (Ohio), and farms such as Fair Oaks (Indiana), convert biogas to biomethane and/or compressed natural gas (CNG) vehicle fuel. In these cases, upgraded biogas requires storage as the CNG is often transferred to vehicles during short periods (quick fill arrangements). Storage can be achieved using tanks and using the natural gas grid as a form of storage. In the case of Fair Oaks, a majority of the biogas is upgraded to utility-grade biomethane and is either used on site for CNG or injected into the natural gas grid and transported to other locations. In this case the onsite and utility pipeline act as virtual storage units of the biomethane. In the case of Quasar Energy Group, a portion of the biogas goes through biogas cleanup for CNG and a portion is then fed to a generator for some on-site electricity generation. The biogas stream used for CNG goes through advanced biogas cleanup, which is then stored until used. In this way, only the lower volume and higher value biomethane, with CO_2 and other impurities removed, gets compressed and stored. This design option, along with the choice to keep only a short-term supply of biomethane on hand, allowed cost savings through use of a smaller-scale, high-pressure biomethane storage system. In CleanWorld's Sacramento facility all of the biogas is upgraded to CNG fuel. The patristic load required for compression is supplied by lower cost grid supplied electricity.

While our focus is on on-peak electricity production, biomethane is a potential second option that could use on-farm biogas storage. Additional biogas clean-up, compression, and storage would be required over and above that investigated for purposes of on-peak power generation. However, the opportunity should not be overlooked or ignored as industry investigates opportunities for biogas markets. As the value of biomethane increases due to EPA Renewable Portfolio Standards (RFS) and low carbon fuel standards (LCFS) in California, Oregon and several other states, alternative uses for biogas should be considered.

3. OVERVIEW OF BIOGAS STORAGE

3.1 GENERAL DESCRIPTIONS

Storing biogas for variable use is not a new concept or practice. Wastewater treatment plants with anaerobic digesters have stored and used biogas to run blower fans and generate electricity for many years. Anaerobic digesters used to create biomethane for vehicle fueling require some biogas storage. On-farm digesters have their own base level of storage simply as part of the design. However, for farms in the US, the use of biogas storage to facilitate shifting biogas utilization time periods is limited, and modification of systems or adding structures for biogas storage specifically for managing electricity production is rare.

There are two general categories of biogas storage—low pressure and medium/high pressure. Medium and high pressure systems use a steel tank. In interviews with biogas system developers and designers and biogas storage manufacturers, the general consensus was that a low-pressure flexible membrane system was more appropriate for on-farm digesters. Such systems use a variety of containment vessels, but they are all characterized by the use of flexible membranes to maintain gas pressures in the range of 0.1 to 6 psi.[3]

Flexible membrane materials used for biogas storage are the same as those used in many continuously-stirred tank reactor (CSTR) digester vessels and on some plug flow digesters.[4] The material must be able to be affixed to the storage vessel without leaks and be resistant to hydrogen sulfide (H_2S) in the biogas. For one technology—biogas storage bags—the bag is the entire structure used to hold biogas and could be kept inside a dedicated building or tied down with netting. Several industry experts expressed concern with enclosing a biogas storage bag in a building for safety reasons, though others indicate that this approach can be viable with good system engineering and attention to safety codes.

Plug flow digesters with fixed roofs require external storage, as the digester vessels do not have significant biogas storage capacity. For plug flow systems, whether new or retrofit, storage external to the digester vessel would be required.

The following images are examples of biogas storage options applicable to Wisconsin farms. They include the flexible membrane systems that function as the roof of CSTR systems and external storage options that could work for either plug-flow systems or external to a CSTR digester vessel. Another option for biogas storage would be to include a second tank like that used for a CSTR digester and have it function as a dedicated biogas storage vessel. In the latter option, interview respondents felt this might be overly expensive, with simply expanding the storage capacity of the reactor vessel being a more cost effective option.

The external biogas holding bags are an option and are being used, housed in a dedicated building, by Hillcrest Saylor Dairy in Pennsylvania. However, the digester designers we spoke with expressed some concern about using the bags in an enclosed building and tended to favor the use of the CSTR reactor tank system and the outdoor slab mounted system.

[3] Krich, et al. *Biomethane from Dairy Waste.* Western United Dairymen. 2005.
[4] http://www.bioenergyconsult.com/tag/biogas-storage-systems/.

Figure 3-1. Flexible Membrane Over CSTR

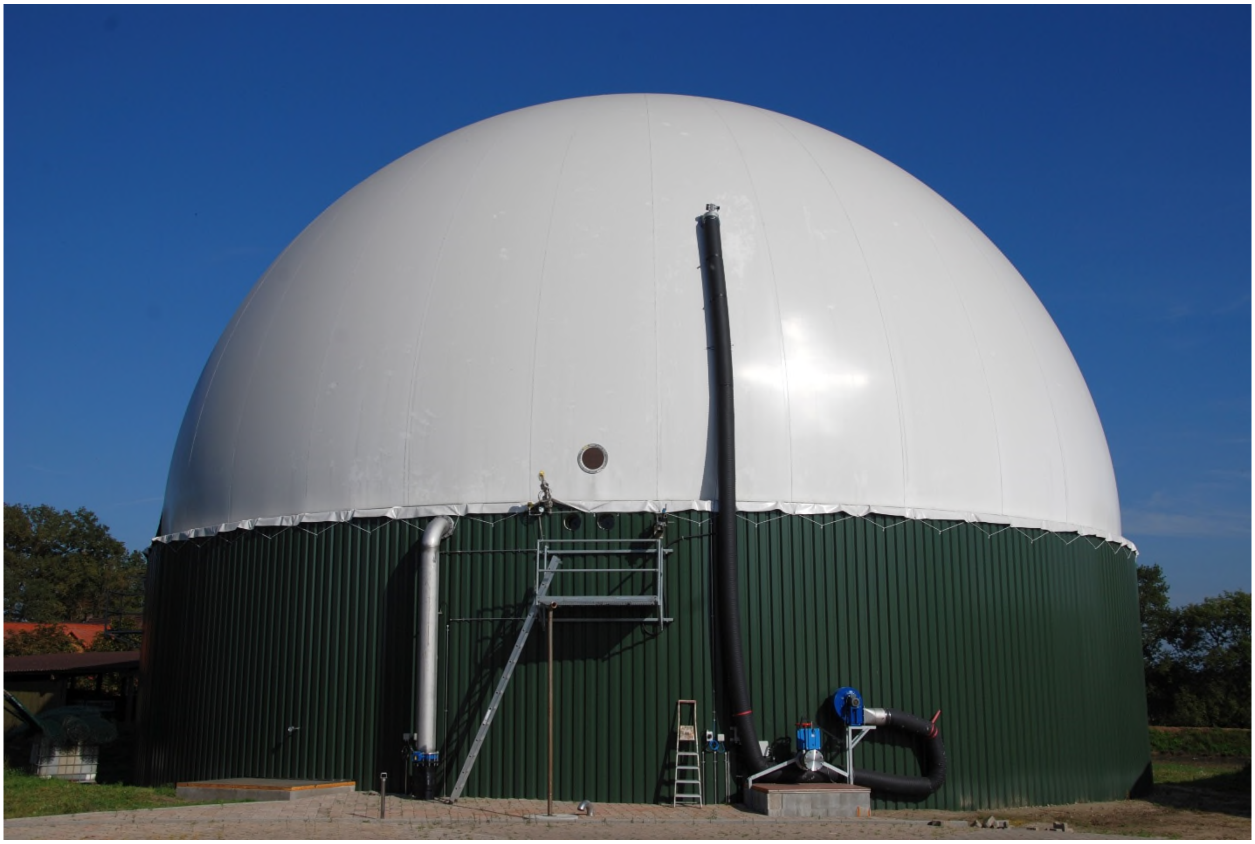

Photo courtesy of Organic Waste Systems: www.ows.be

Figure 3-2. External Partial Dome on Concrete Slab

Photo courtesy of Biogasmart: www.biogasmart.com

Figure 3-3. External Biogas Holding Bags

Photo courtesy of Zorg Biogas: zorg-biogas.com

3.2 INTEGRATING BIOGAS STORAGE

To take advantage of stored biogas, several components not found at typical on-farm anaerobic digesters need to be added. Whether or not the storage is integrated into the digester vessel, the storage space must have a pressurizing system with adequate capacity, and pressure or level sensing integrated into the larger SCADA[5] system.

To use external storage, additional gas piping and valving will be required to integrate the storage and enable movement of biogas. As in all biogas projects, a gas flare is required. The flare for the storage systems would likely be shared with the entire system or, less likely it may have a flare dedicated to the storage system. With external storage, a second blower fan will be needed.

For systems designed to generate electricity on-peak, the SCADA system must be programmed to operate the generator and storage components in response to timing and the level of biogas being stored. The industry experts we spoke with did not express a concern over controls technology or the ability to integrate biogas storage and variable generator scheduling into the SCADA system.

[5] SCADA refers to supervisory control and data acquisition.

Integrating biogas storage to maximize on-peak electricity generation will require a larger generator than would typically be used for a similarly-sized for a system that produces electricity as biogas is produced. The increase in generator size will be dependent on the peak production schedule. For example, a system that is scheduled to work 12 hours per day will require twice the generator capacity as one that would otherwise operate 24 hours per day, assuming the same volume of biogas is used. Increasing generator capacity will increase system costs, explored further in section six.

The utility interconnection is the final major component required for integration. With a larger generator, even a retrofit system that is currently interconnected will need to have a new interconnection study completed by the utility. Whether the system is new or retrofit, the larger generating capacity may require additional distribution system upgrades over what a smaller generator would require. The interconnection costs are a major uncertainty for any given system and could be incrementally higher for systems designed to run on peak.

4. LITERATURE REVIEW

4.1 LITERATURE REVIEW FINDINGS

Tetra Tech and the Energy Center of Wisconsin conducted a literature review on biogas storage and peak power generation technology and markets. The literature review was used to develop an understanding of base-level general knowledge on the subject as well as to inform in-depth interview lines of inquiry. The literature covered anaerobic digester-specific information as well as information related to safety standards and power markets.

In searching for literature related to using biogas storage and peak power generation, we found scant information. Storage-only literature was available, but peak-power generation or other variable electricity production scenarios were only discussed in theoretical terms. We found information on biogas storage in general industry literature from the US Environmental Protection Agency (USEPA) AgStar program, white papers on anaerobic digestion, and industry marketing materials. Information on electric generators operating with a highly variable schedule tended to focus on topics of peak shaving and backup generation. Anaerobic digester specific literature did not address variable operations, but tended to emphasize general topics of corrosion and system design. As such, the findings from the literature review focus on biogas storage, while the interviews were used to inform on issues related to electricity generation. Below we describe and annotate several key industry publications that provided the most substantive and complete set of information regarding biogas storage, one of which makes reference to on-peak power generation.

The BiG>East *Biogas Handbook*[6] is a comprehensive guide for biogas development, operations, and utilization that was produced by the European Union to support biogas project development in Eastern Europe. Although it does not discuss on-peak or variable electricity production, it does discuss biogas storage technology. The handbook notes that “the simplest solution is the biogas storage established on top of digesters, using a gas tight membrane.” However, the handbook also notes that for “larger biogas plants” separate storage may be needed and will allow for low, medium or high storage pressures. The handbook recommends that all biogas storage facilities “not protected by buildings must be UV-, temperature-, and weather proof.” Safety valves are essential for over- and under- pressure conditions to prevent damage and address safety risks. The handbook further recommends that system owners or developers have explosion protection and an emergency flare. The handbook recommends that a “day or two” of storage be available.

For low pressure tanks, the handbook recommends double membrane systems, with single membrane systems requiring a protective building. For low pressure systems, the BiG>East handbook suggests a pressure range less than 1 psi. Medium and high pressure systems can range from tens of psi to thousands of psi. The BiG>East handbook notes that medium and high pressure storage systems are “rarely considered for agricultural biogas plants” due to high costs.

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[6] Al Seadi, et al. *Biogas Handbook*. University of Southern Denmark Esberg, 2008. Available at: http://www.lemvigbiogas.com/.

In 2004, the USEPA AgSTAR program, published *A Manual for Developing Biogas System at Commercial Farms in the United States*.[7] Although the handbook provides a comprehensive set of information to inform farm owners about developing anaerobic digester systems, it is largely silent on the topic of biogas storage and variable electricity production. As such, a key source of information regarding on-farm anaerobic digesters for the US market does not address the issues germane to this research and points to a potential gap in general market information and recommendations for biogas storage and on-peak power in the US.

In 2005, Krich, et al. produced a biomethane guide for the dairy industry. *Biomethane from Dairy Waste: A Sourcebook for the Production and Use of Renewable Natural Gas in California*[8] (the California sourcebook) presents a comprehensive technology and market perspective on anaerobic digesters, associated technologies, and markets. In the chapter related to biogas and biomethane storage, the California sourcebook notes that for storing biogas, “the least expensive and easiest to use storage systems for on-farm applications are low-pressure systems…” Similar to the BiG>East handbook, the sourcebook mentions the high cost of medium and high pressure storage systems, suggesting that only for higher value biomethane might the additional costs of higher pressure systems be justified.

For low-pressure storage, the California sourcebook categorizes low-pressure storage technologies as operating at two psi or less. The low pressure systems are all considered to be flexible membranes and made from a variety of polyethylene materials. The materials are noted for not reacting with hydrogen sulfide. The California sourcebook defines medium pressure systems for biomethane as those that operate between 2 and 200 psi, but notes that these are rarely used. It defines high pressure systems, more appropriate for biomethane storage, as those exceeding 200 psi. The California sourcebook notes that for both medium and high pressure storage, hydrogen sulfide must be removed prior to storage to prevent corrosion. For medium-pressure storage, the California sourcebook notes that energy use for compression requires about 10 percent of the energy available in the biogas, with high-pressure systems requiring about 15 to 20 percent the biomethane’s energy content.

While the California sourcebook does not address using biogas for variable electricity generation, it does note several potential options for direct biogas use on farms, which would likely require biogas storage. One example is to convert diesel engine irrigation pumps to use biogas. Another example is the use of absorption chillers for milk cooling. While these examples are technically feasible, the California sourcebook notes that the expense of these systems does not appear to make them cost effective.

The single publication our research found that addressed the use of biogas storage and on-peak power production came from biogas storage tank marketing literature from Sattler AG.[9] Sattler AG manufactures and sells many biogas system components, including storage systems. The publication notes that the greater the short-term use of biogas relative to average biogas production, the more storage will be needed. Additionally, this marketing brochure notes the pressure of their storage systems as being low-pressure, operating from zero to less than one psi.

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[7] Roos, et al. *A Manual for Developing Biogas System at Commercial Farms in the United States.* US Environmental Protection Agency, 2004.

[8] Krich, et al. *Biomethane from Dairy Waste: A Sourcebook for the Production and Use of Renewable Natural Gas in California*. Western United Dairymen, 2005.

[9] https://www.sattler-global.com/biogas/static_files/media/downloads/Brochure_UT_EN.pdf.

We only found evidence of one farm using biogas storage to control electricity generation—Hillcrest Saylor Dairy Farms in Somerset County, Pennsylvania. Penn State University researchers Deborah and Patrick Topper prepared a case study on the farm's digester operation that is available on the Penn State website.[10] The case study, documenting the on-farm conditions and experiences of the owner in 2009, stated that stored biogas would be used to "take advantage of premium bonus payments for peak hour power generation supplied to the grid." However, we interviewed the owner in 2014, he noted that the biogas storage was used to enable steady generation when biogas production fluctuates.

The prior materials presented as part of this literature review focused on biogas development, storage recommendations, and case studies of anaerobic systems operating with storage and variable electricity production. We found no public literature that directly discussed the issues or opportunities of on-peak electricity production from on-farm biogas. As part of that search, we reviewed chapters four and five of the MISO Resource Adequacy Business Practice Manual, (RABPM).[11] The RABPM was reviewed to understand potential opportunities and barriers for utilities to gain value from on-peak electricity generation from biogas facilities.

Chapter 4 of the RABPM describes the process by which MISO load serving entities (LSE) demonstrate resource adequacy by qualifying and quantifying the capacity in their resource plans. For new power plants, the RABPM uses general assumptions regarding different power sources and their capacity factors. For example, wind farms were assumed to have a capacity factor of 13.3 percent in 2013-2014. For the first year, the resource is assumed to operate at the stated capacity factor and thereafter is based on actual performance.

The planning assumptions for capacity credit are available for a number of generation resources, including types of steam systems, hydroelectric plants, diesel engines, and combustion turbines. Based on our review, natural gas reciprocating engines, commonly used with on-farm anaerobic digesters, are not included. As such, it is unclear whether utilities can build in planning assumptions that allow for resource adequacy capacity credits for MISO.

In reviewing Chapter 4 of the RABPM, it appears that biogas plants that operate with storage could meet the requirements of a "Use Limited Resource."[12] Such a resource must be able to provide the energy equivalent of its claimed capacity across four hours of the MISO peak. Additionally, such resources are required to notify MISO of outages, demonstrate performance results to MISO, and be dispatchable with physical limitation. The resource must be identified as "use limited" when being registered and MISO will need to review the conditions of the asset or PPA to validate that it meets the "use limited" requirements.

In Chapter 5 of the RABPM, MISO presents a map of resource zones used for planning resource adequacy.[13] Wisconsin is split across two zones with roughly the eastern two-thirds of the state in Zone 2 and the western third of the state in Zone 1. Within a zone, it is possible to aggregate resources for purposes of gaining resource adequacy credit, suggesting a possible opportunity for biogas systems to increase their apparent capacity contribution.

[10] http://extension.psu.edu/natural-resources/energy/waste-to-energy/resources/biogas/documents/hillcrest-saylor-1209.pdf.
[11] MISO. *Business Practice Manual Resource Adequacy, Manual 011*. MISO, January 2014.
[12] Ibid, page 38.
[13] Ibid, page 73.

4.2 LITERATURE REVIEW CONCLUSIONS AND RECOMMENDATIONS

Our review of industry literature provides several observations and recommendations. First, it is apparent that while biogas storage *by itself* is fairly well understood and established as a technology category, the use of biogas storage as part of an on-peak generation scheme is not. Biogas industry literature is largely silent on the topic of on-peak generation and any technological or market issues. While we did identify case studies of specific systems that used on-peak generation, details regarding operations or technology and market issues were not present. This suggests that the biogas industry has limited experience with utilizing biogas for on-peak generation, reflecting an immature market. Alternatively, the lack of discussion around on-peak power generation in industry case studies may reflect a lack of understanding of the electrical generation industry on the part of the biogas industry.

The review of the MISO RABPM suggests that Wisconsin utilities may be able to aggregate or pool many of their biogas assets within a MISO resource zone. Typically operating at 1 MW or less, these resources are dispersed and may have less value as dispersed resources that do not add to a utility's resource adequacy total and may not be part of current PPA negotiations. Having system designed and controlled to meet MISO requirements may be such a way to gain that credit, with biogas storage appearing to be one approach that aligns with MISO resource definitions. However, without an initial planning assumption regarding capacity credit, MISO may or may not accept such resources into capacity planning and thus the host utility may not be able to build that value into contract negotiations. These two issues point to an opportunity for Wisconsin utilities to investigate opportunities for pooling biogas resources and developing the metrics that will allow for an assumed capacity value for the first year of operations and on a metered basis thereafter.

5. INTERVIEW FINDINGS

Tetra Tech and the Energy Center of Wisconsin spoke with numerous market actors about the concept of using biogas storage to emphasize on-peak electricity production. The interview respondents ranged from biogas developers and designers, to equipment manufacturers and distributors, and Wisconsin electric utilities. One farm operator currently using biogas storage, and a non-farm system operator doing on-peak generation maximization were also interviewed (neither of these was operating in Wisconsin). In general, respondents felt that there was not a fundament technical barrier to operating on-farm biogas storage and maximizing on-peak electricity production. Indeed, the market can supply the technology and general know-how to develop and deploy such systems. Respondents indicated that the greatest barriers or concerns were in the management of such systems and the overall economics.

Below we describe different interview groups and their responses to the interview questions. The responses are organized around the key stakeholder groups we spoke with, including storage technology providers, generator providers, digester designers and developers, and Wisconsin electric utility representatives. Several findings also cut across or otherwise do not align with the specific component break-out and are included in a section covering other considerations raised by the interview respondents.

5.1 STORAGE TECHNOLOGY PROVIDERS

Biogas storage technology is a central core to this research. We interviewed storage technology providers (i.e., vendors) to understand available equipment and market issues. We included companies that distribute biogas storage technology within the United States as well as companies that make and sell CSTR vessels that could have their capacity be expanded to store greater volumes of biogas. The technology is readily available and could be installed at on-farm systems at the present time. However, equipment suppliers have focused primarily on the wastewater treatment market and therefore have had limited experience with on-farm digesters. Respondents indicated that there is no fundamental difference in these two applications. The exception was with CSTR equipment providers; their equipment already stores biogas as part of the core equipment design.

There was unanimous agreement that low-pressure flexible membrane systems were the best option for on-farm systems. Although several companies offered more-expensive higher pressure equipment to the waste water treatment industry, the general view was that the wastewater treatment industry had greater tolerance for higher capital costs and longer investment time horizons than farms.

There was somewhat less agreement on whether storing biogas would lead to a need for additional biogas scrubbing. Most felt there was no need for additional biogas scrubbing when using their storage systems. One storage technology provider felt that the industry should, in general, do more biogas scrubbing because of possible long term effects on equipment and maintenance, suggesting that more study on this was needed.

Storage equipment providers felt their businesses were prepared to provide systems and assistance to farm digester owners if the demand was there. Much like digester projects, they note that “every project is unique,” requiring custom design and application. They felt that their storage products could be made to meet customer needs for project specific digester designs and storage volumes, and in both new and retrofit situations.

Storage technology providers offered varying levels of design and operational support based on their technology types. Companies that sold concrete slab-mounted biogas storage offered support for design and installation assistance. CSTR storage providers viewed additional storage capacity as simply part of the base system, and provided the information necessary to complete construction. They expected that any firm with experience in constructing CSTR systems could handle any differences related to larger storage capacity. Generally, firms provide support to ensure a project's success on a case-by-case basis.

Storage supply firms were interested in the concept of using their systems to generate on-peak electricity. None saw a fundamental problem with that application, but none indicated having extensive experience with it either. None were aware of any farms using storage to shift power to on-peak times, though several were aware of wastewater treatment plants doing so. They shared no concerns related to safety or insurance outside of those associated with standard digester design. However, some pointed out potential safety issues with "bag" systems kept in enclosed buildings.

Storage technology providers were reluctant to provide pricing details because costs of systems were quite variable and project-specific. They also have little or no experience in providing their systems in the agricultural market, so have some uncertainty as to what pricing might be. Cost estimates they did provide generally ranged from $120,000 to $150,000 (exclusive of generator and interconnection costs), with CSTR retrofits being the lowest cost. These estimates did not necessarily include balance of system costs (e.g., flaring or controls) as the storage providers do not provide all components. These estimates were presented as general "back-of-the-envelope" numbers. Most of this group had a difficult time isolating the additional costs to standard anaerobic digester systems

Overall, the current market for expanded on-farm biogas storage is currently very small, but service providers appear capable and willing to increase activity should demand appear. System providers do not recognize a substantial difference from their end on whether a storage system is used for production smoothing, maximizing on-peak generation, or for some other purpose. Pricing for farm applications will evolve as a market emerges.

5.2 GENERATOR TECHNOLOGY PROVIDERS

We interviewed biogas engine generator set and microturbine equipment providers to find out what issues they saw for their products if on-farm biogas storage was used to maximize on-peak electricity generation. These interviewees included two suppliers of reciprocating engines and one manufacturer representative who had experience with microturbines and biogas. This section also includes perspectives from some other market actors on possible issues for generation equipment with this operating scenario.

For both generating technologies, control systems were not viewed as a barrier. Respondents indicated that the biogas storage and on-peak scheduling were simply one more control point to add and monitor in the system. Controls can handle variable output, allowing generators to run at full or part load, as well as with on/off sequencing.

The main focus of concern for generators was the part-load operations. Reciprocating engine representatives indicated that below 50 percent loading, the generators did not work well and may incur additional maintenance. One food waste digester owner indicated that they had experimented with their reciprocating engines and observed operational concerns at 30 percent loading. For reciprocating engines, running at a minimum of 50 percent load appears to be a general good practice. The reciprocating engine representatives said that on/off cycling was not an issue.

For microturbines, we were able to speak to a manufacturer representative who had experience working with microturbines in the food processing and wastewater industries. Similar to reciprocating engines, on/off cycling was not a concern[14] and the company recommended not going below 50 percent loading. In contrast, a designer/operator (equipment owner) indicated that they sometimes ran microturbines to 10 percent loading.

Manufacturer recommendations are that operational configurations to maximize on-peak electricity production should consider only scenarios in which engines or microturbines are run at at least 50 percent of capacity or are cycled on and off over several hours.

A number of respondents agreed that operating at part-load (down to 50 percent) and on/off cycling would not increase maintenance costs. However, running generation at below capacity can lead to other cost issues since maintenance costs are based on hours of operation, not output. Therefore, running equipment for some time at 50 percent will mean costs of maintenance are spread over fewer kWh of production. In contrast, on/off cycling would not create higher per kWh maintenance costs compared to part-load operations.

Similar to the storage technology providers, providers of generation equipment were reluctant to give price estimates. This was in part due to key major costs, such as interconnection and balance of system costs. Interconnection costs are variable, unpredictable, and beyond their control, but are a key component of sizing and designing the system. They are not knowable until a specific project is identified, with defined loading and scheduling schemes, and presented to the servicing utility. Balance of system costs are also variable and are based on generator sizing and utility infrastructure requirements.

In short, those respondents familiar with operating generators (whether reciprocating engines or microturbines) saw no fundamental issue with variable operations on the generators. Manufacturers said operating at part-loads below 50 percent could affect warranties and should be avoided. Ultimately, how a generator was used would affect storage system sizing. For both microturbines and reciprocating engines, on/off cycling over relatively long periods did not create a concern. All respondents who sold generating equipment indicated that substantial customer support was part of their business model. Each of these firms indicated that providing help during design, construction, and operation were standard practices.

[14] This refers to on-off periods that are at least several hours, and not more frequent cycling which could be harmful to the equipment.

5.3 DESIGNERS AND DEVELOPERS

We also interviewed a number of anaerobic digester designers and developers to get their views on the biogas storage and peak electricity generation operational scenario in Wisconsin. The developers we spoke with all have a hand in the design as well. All had some experience with on-farm digesters and half identified food processing and wastewater treatment facilities as their core business. All developers and designers agreed that biogas storage could technically be used in this manner on farms. However, those who were most familiar with the Wisconsin market had serious reservations about proposing this type of project in Wisconsin due to current market conditions. They expressed strong dissatisfaction and said that they are focusing their efforts outside Wisconsin where economic and policy conditions are more favorable

Developers and designers perceived several issues for the overall biogas market (i.e., not specific to biogas storage scenarios) in Wisconsin. These include:

- Current utility PPAs offer an insufficient price per kWh
- It is unclear whether third-party ownership of distributed generation is legal in the state
- Utilities and coops in Wisconsin do not need the power or to make progress toward renewable portfolio standard requirements
- Interconnection costs are seen as prohibitive.

Concerns developers and designers expressed that are directly related to using on-farm storage to maximize on-peak generation include:

- Insufficient price differential between on- and off-peak rates
- Need for professional and dedicated management of biogas systems due to added complexity
- Need for demonstration and proof of concept at a Wisconsin farm to validate the technology, operational strategy, and power market.

The combination of low per-kWh rates and little differential between on- and off-peak prices offered in Wisconsin PPAs mean owners have little incentive to modify their generation approach if additional equipment or operational expenses would be required. Still, some designers said they regularly look at alternative generation scenarios to help project paybacks, but currently do not see them as promising in Wisconsin. The call-out box, below, describes an example of a third party owned and operated manure digester with biogas storage and on-peak generation project in Minnesota.

Rural Non-farm Digester Using Biogas Storage and Maximizing On-peak Generation

Hometown Bioenergy in Le Seur, Minnesota, is a facility designed, built and managed by Avant Energy. The facility includes two CSTR digester vessels and external biogas storage. The digesters process manure, food processing and other agricultural wastes from nearby operations, but are not located on a farm. They use biogas storage to maximize on-peak electricity generation because their PPA with Minnesota Municipal Power Agency offers a significantly higher price for on-peak power. They have two above ground, low pressure, dual membrane domes that can store biogas for up to 12 hours of generation. System operators report that it is working as planned.

Developers who have used biogas storage for on-peak generation maximization (not yet used on farms in this manner) had some concerns about use of these systems in a farm environment. The primary issue they see is the availability of qualified operators to manage the systems and ensure high reliability. Another concern is capital availability for up-front costs of the system and maintenance, and a perceived tendency to choose less costly options even when performance may suffer.

Similarly, designers and developers with a focus on food processing and water treatment and with experience using storage systems and on-peak power generation had doubts about how these systems would fare in a farm environment. They were concerned that farm systems would not have adequate financial investment and personnel to properly manage a more complex system. On farms, manure treatment is not a core business focus, whereas with wastewater treatment, it is.

One view all the designers and developers shared was a concern over system management. They felt that adding the complexity of biogas storage and on-peak electricity generation to an already complex biological system magnifies the need for professional management and support.

This group also was concerned about the economics of biogas systems that sell electricity to utilities in Wisconsin. They identified interconnection costs as a potentially substantial cost that adversely affects overall project economics and makes system pricing difficult. In addition, Wisconsin electricity prices currently offered for biogas generated power are considered low, even for on-peak power. Their opinion was that the price differentials for on-peak versus off-peak power was an insufficient incentive to drive on-peak production.

Overall, digester designers and developers were intrigued by the concept of using biogas storage to increase on-peak electricity sales. However, they are unhappy with the current market conditions in Wisconsin and do not see biogas storage with maximized peak generation as a viable strategy in the near term. To move the market forward, this group felt that demonstration projects were needed that tested the proof of concept from both a technology and market perspective.

5.4 UTILITY PERSPECTIVES

We spoke with five representatives of Wisconsin electric utilities that had biogas industry knowledge. Electric utilities are the market for on-peak power generation and play a key role in whether generation using on-farm biogas storage would be viable from technology and market perspectives. The goal of the interviews was to understand whether any utilities had experience with biogas storage for on-peak power generation, get their perspectives on the concept, and identify potential opportunities or barriers they perceive for the market.

Knowledge and experience. Most utilities were not aware of any customers using biogas storage to emphasize on-peak electricity sales. While one utility indicated that a wastewater treatment plant was operating their electricity generating equipment in such a way, they were unsure about their operational details but had not experienced any issues.

All the utilities were prepared to negotiate PPAs with biogas systems that sought to emphasize on-peak generation. A common refrain was that the utilities wanted to work with their current and potential digester owners to find solutions that worked for both parties. However, with limited experience in biogas storage and a need to take a case-by-case approach to adding biogas-derived generating capacity, it was very difficult to generalize and speculate on what the future held, much less take a proactive stance to move the market forward.

General renewables. First, utilities in Wisconsin are all on track or have already achieved their prescribed renewable generation targets in the state renewable portfolio standard. Therefore, they see little value in adding renewable generation capacity.

Second, utilities that had offered Advanced Renewable Tariffs (ARTs), which included attractive rates for biogas derived electricity, indicated that those tariffs had been filled. The ARTs had been capped by the total interconnected kW of the participants. If an ART participant shifted their electricity production to emphasize on-peak times and increased their interconnected kW, the contracted limits would then exceed the utility's ART limit. These utilities suggested that new contracts would need to be written, likely with rates far less than the ART's current per kWh value. While there was speculation that separate contracts could be written to account for the incremental kW over the ART contracted kW, the on-peak valuation would still likely be less than the value of the ARTs. Another factor that would discourage some existing systems from expanding their generation capacity to maximize on-peak generation is the possibility that it might require a new interconnection study, which could be a substantial additional cost.

On-peak generation. There is also currently excess generating capacity available in the northern Midwest (one representative noted that MISO currently values capacity near zero). Utilities indicated that the current wholesale power market showed locational marginal price differentials between off-peak and on-peak values as approximately one cent per kWh. This small price differential means efforts to shift generation to on-peak periods, from whatever source, are unlikely to be rewarded. In their view, the current market does not exhibit sufficient capacity constraints to drive a greater price differential. However, the utilities did indicate that in the future, the situation could change, with greater differences between on-peak and off-peak electricity prices emerging.

Dispatchability. Another possible route to increasing the value of biogas storage enabled electricity generation is if it could be available on demand for utilities. This distinguishes biogas energy from other renewable technologies because it is not dependent on whether or not the sun was shining or wind blowing. Utilities felt that dispatchability value for this resource was unlikely for two reasons. First, biogas generation systems (i.e., engine generator sets) have not proved as reliable when operating in a farm environment as utilities would like. They noted that if it is not guaranteed available, it is not of much use to them. Also, premiums with dispatchability would be mirrored by penalties if resources are not available when called, which they thought would not be tolerated by digester owners. Second, farm-based biogas systems tend to be below the capacity level that would be worth activating for utilities given the transaction costs of doing so. The threshold for interest in dispatch ranged from 5 MW to 50 MW, far higher than any single on-farm system would produce.

Despite the capacity issue, all indicated that some level of dispatch control could be useful. One utility suggested that such control might be more valuable in the current market if that control was used to curtail electricity generation at some points in time, rather than increase electricity production. In this regard and when combined with currently low LMP prices, the near-term value proposition for biogas storage may simply be in providing the utilities some level of control over generators. One utility respondent indicated that rural distribution system peaks may not always align with general utility system peaks. Thus, producing power during general on-peak times could be misaligned with how a specific feeder operates and could create problems, or at least reduce the value of generation from the specific location.

They pointed out that these issues could change over time. Improvements in controls and infrastructure might one day allow control of multiple farm systems as one unit and thus overcome the scale and transaction cost issue. Further, the current state of over-capacity in the Midwest will likely not last forever. New rules on carbon emissions or a more aggressive renewable portfolio standard could add value to biogas generation.

Location of farm-based systems. Another issue utility representatives mentioned was that most digesters are located far from distribution circuits. This complicates matters, and peaks on rural feeders do not always match utility generation load peaks. There are likely locations where having additional on-peak generation would be valuable to a utility for voltage support, but these are very site-specific and the generator would have to guarantee the capacity availability, be well-matched to the load, and have an acceptable response time. Additionally, while there are known points of grid weakness that could benefit from added capacity, those locations are kept confidential for security reasons, limiting the ability of the market to proactively address solutions.

In summary, Wisconsin utilities do not see value in adding biogas generation, even if it is focused on peak demand periods for several reasons. These reasons include:

1. No need for excess capacity
2. Little price differential between on- and off-peak LMPs
3. Problems with dispatchability, and remote locations of farm systems.

However, they note that these conditions could change in the future with new standards, regulations and technology. Utility representatives also indicated that they were looking for ways to participate in the larger anaerobic digester market and create value for their farm customers. One representative emphasized a need for all potential value of digesters to be accounted for and valued as part of a larger set of policies to encourage on-farm anaerobic digesters. From their perspective, the value of digesters included not just biogas and electricity, but also water and air quality, bedding, and helping maintain a strong farm economy.

5.5 INTERVIEW CONCLUSIONS AND RECOMMENDATIONS

The results of the market actor interviews reveal a biogas market that is not poised to proactively offer biogas storage for on-peak power generation. Equipment providers and digester developers/designers all agreed that the technology is ready and able to be deployed but that there is no compelling market reason to do so, particularly in Wisconsin. Wisconsin utilities are not familiar biogas storage technology and operations, and also did not see a clear market-driven opportunity to move biogas storage and on-peak power generation forward at present. Among all the market actors, there was general interest in seeing a market develop but recognition that some level of market intervention at the policy or program level, and potentially both, would be needed.

6. COST AND PERFORMANCE MODEL

6.1 INTRODUCTION

Our literature review and interviews with market actors indicated that on-farm biogas storage was technically feasible and that the market could deliver and integrate working systems. However, due to limited market knowledge for the application, our interview respondents could not address financial performance, a key aspect of feasibility. Further, there are myriad possible configurations, power generation, and electricity pricing combinations, complicating the interview respondents' ability to address a theoretical financial performance estimate. As such, Tetra Tech developed a model to investigate key financial factors and sensitivities to key incremental capital cost categories and incremental revenues.

The financial performance of a biogas storage system is based on the capital costs and the recovery of those costs through revenues. In the case of a biogas storage system used to produce on-peak electric power, the capital costs are the incremental cost to implement the storage system, which are then recovered by the incremental revenue of the differential between on-peak and off-peak contract pricing.

The model is simplistic by design and meant to be a starting point for supporting policy or program directions, additional research, or as a base framework for project specific financial modeling. The model is based around a theoretical 2,000 head dairy farm. This size of farm is an approximate average of Wisconsin farms that have implemented anaerobic digesters to produce electricity. Such a farm would support a 600 kW generator operating at steady output. The model allows for comparisons between storage systems installed on a new anaerobic digester or as a retrofit. Two types of anaerobic digesters are included- plug-flow and CSTR. The model compares peak periods of 8 and 12 hours in duration.

The point of sensitivity for financial performance centers around the differential between on-peak and off-peak rates. The incremental revenue is generated by shifting production from off-peak periods and to on-peak periods. The greater the price differential, the greater the revenue to pay for the incremental cost of the storage system.

While the price differential is the major point for the sensitivity analysis, the development of the model also points to major cost centers for the storage system. To develop the model, our research found that the cost of the storage equipment, installation, and operations are not the most significant factors. The two most significant cost centers were found to be the cost of the incremental generator capacity and the cost of interconnection to the electricity grid. Interconnection costs are a point of substantial uncertainty, as they can vary from system to system and location to location based on utility requirements.

Below we describe the details of the model assumptions and the results. In summary, it appears that biogas storage *can* be cost effective as an investment, but that the financial performance is sensitive to the on-peak/off-peak price differential, with interconnection costs being a major contributor to system profitability.

6.2 ELECTRICAL GENERATION AND OPERATING ASSUMPTIONS

As indicated in the introduction section above, the theoretical dairy could produce 600 kW of power on a continuous basis. If the on-peak duration was 12 hours per day, the electrical production rate would be 1,200 kW. If the on-peak duration was eight hours per day, the electrical production rate would be 1,800 kW. For continuous operation, we assumed that the generator will operate for 24 hours per day, 52 weeks per year, at an availability factor of 90 percent for a total of 7,862 hours per year. For the on-peak period of 12 hours per day, we assumed that the generator will operate 12 hours per day, 5.5 days per week, and 52 weeks per year, for a total of 3,432 hours per year. For an on-peak period of eight hours per day, it is assumed that the generator will operate eight hours per day, five days per week and 52 weeks per year, for a total of 2,080 hours per year. Total kWh per year for each operating period is:

- 24 hour operation = 4,727,813 kWh per year
- 12 hour operation = 4,118,400 kWh per year
- 8 hour operation = 3,744,000 kWh per year.

Consideration must be made to maintaining the digester's operating temperature during off-peak hours when the waste heat from the cogeneration system is not being created. For existing digesters, the existing heating system might be adequate for transferring the required heat during peak operating hours alone and relying on insulation to retain the heat during off peak hours. It may be possible to increase the hot water temperature or flow rate to increase transfer efficiency. In the worst case, a small biogas boiler would need to be operated during off-peak hours to maintain proper working temperatures. This could occur in the coldest winter months, but this is very site specific and does not lend itself to generalization. For this analysis, we can assume that the system operations can be modified to allow heating on an intermittent basis during peak generating hours. The projected economics, therefore, represent the best case for existing units.

6.3 BIOGAS STORAGE ASSUMPTIONS

For this evaluation it is assumed that storage for the peak periods will require the capacity to store the entire biogas production during non-generating hours plus an additional three hours to allow for fluctuations in biogas production and to maintain biogas in the storage vessel at all times. The required storage volumes are shown below.

Table 6-1. Biogas Storage Volumes at Atmospheric Pressure

Operating hours	kW	Gas Storage hours	Gas Storage Volume
24	600	3	25,576
12	1,200	15	127,880
8	1,800	19	161,981

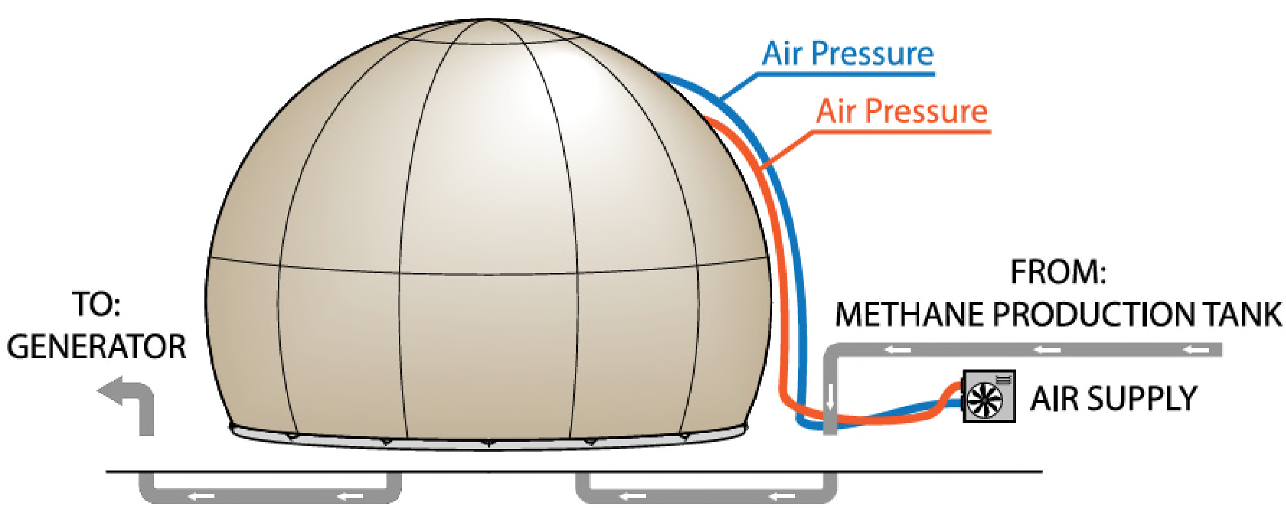
Depending on the anaerobic digestion technology, some portion of this storage will be internal in the digester itself. Additional external storage will also be needed. In order to determine the required storage for the theoretical dairy, certain assumptions need to be made relative to water usage, the collection method of manure and the herd's average daily milk production. As most Wisconsin dairies employ a scraped barn manure collection system, the analysis is based on a high solids manure content (approximately 10 percent total solids) and high milk production (95 pounds per day per cow). This type of manure is generally placed in an anaerobic digester for a period between 21 and 30 days. The resulting required digester volume is between 900,000 and 1,400,000 gallons. In Wisconsin, two digester technologies are most common—(1) in-ground modified plug flow and (2) continuous stirred-tank reactor (CSTR). For an in-ground modified plug flow, this will generally be in a single external structure, while in a CSTR, either one or two vessels may be required, depending on the supplier.

6.3.1 Modified plug flow

Plug flow digesters are built into the ground. In Wisconsin, these digesters utilize a fixed roof, with very little biogas storage in the digester itself. For this reason, we assume that all in-ground digesters will require an external storage vessel to utilize storage and generate on-peak electricity. The simplest such system is a double bladder installed on either a storage tank or as ground-mounted balloon style structure on a concrete slab. These systems are available from a number of companies and generally include the covers, the blower system to maintain constant pre-determined operating pressure, safety equipment, and operating controls. For purposes of the model, we assume a ground-mounted balloon-style structure.

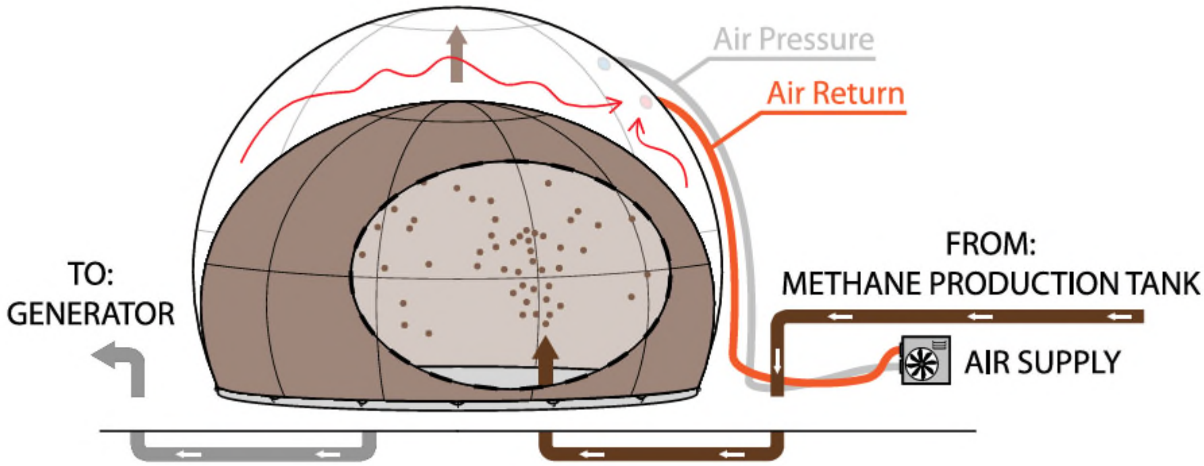
The systems are illustrated below:

Figure 6-1. Illustration of an Outer Membrane of a Ground-mounted Bladder Structure



Courtesy of Monolithic Constructors, Inc.

Figure 6-2. Illustration of the Inner Workings of a Double Membrane Ground-mounted Bladder Structure



Courtesy of Monolithic Constructors, Inc.

During 12 hours of peak sales, the gas bladder would be approximately 65' in diameter by 48.75' high. This is referred to as a ¾ dome, where the height is ¾ of the radius. During eight hours of peak sales the gas bladder would be approximately 70' in diameter by 52.5' high. Dependent on the supplier, the biogas can be stored at pressure from 0.14 psi to 0.87 psi.

6.3.2 Continuously stirred reactor

Most CSTR digesters in Wisconsin utilize a double bladder membrane roof. These roofs are generally installed using a ¼ dome. For the theoretical dairy utilizing a single CSTR, the assumed diameter of the tank is 90'. A ¼ dome for this size tank would have approximately 70,000 cubic feet of storage. A ½ dome for this same structure would have approximately 172,000 cubic feet of storage. This volume would be adequate for all assumed peak sales conditions.

For the theoretical dairy utilizing two CSTR reactors, the assumed diameter of the tanks is 76'. A ¼ dome for this size tank would have approximately 42,000 cubic feet of storage, with a total on-site of 84,000 cubic feet. Additional storage of 44,000 to 78,000 cubic feet will be required for the peak sales options. A ½ dome for a 76' tank will add 73,000 cubic feet of storage to either digester. One ½ dome and one ¼ dome roof will provide approximately 157,000 cubic feet of storage, adequate for either peak sales scenario.

Figure 6-3. Example of CSTR with ¼ Double Membrane Dome

UW Oshkosh Biodigester at Rosendale Dairy – photo by David Palmer

6.3.3 Equipment summary

Whether biogas storage is being considered for a new digester or retrofit onto an existing digester, other than the underlying storage system (as described above), the difference between plug-flow and CSTR digesters is minimal. Table 6-2 and Table 6-3 illustrate the additional equipment that needs to be included for a retrofit or new system producing solely on-peak power.

Table 6-2. Additional Equipment for Retrofitting an Existing Anaerobic Digester

CSTR	Plug Flow
New roof, ½ dome, incl. blower upgrade	Above ground biogas dome
600 kW or 1200 kW genset (not CHP)	Same as CSTR
Additional switchgear	Same as CSTR
Upgraded/additional biogas blower, clean-up and gas line	Same as CSTR
Upgraded/additional interconnection	Same as CSTR
Modify biogas flare	Same as CSTR
Additional heating/insulation	N/A
Updated system controls	Same as CSTR

Table 6-3. Additional Equipment for a New Anaerobic Digester

CSTR	Plug Flow
Utilize ½ dome instead of ¼ dome	Above ground biogas dome
Upgraded heating system	N/A
CHP size upgrade	Same as CSTR
Increased biogas blower, clean-up and gas line	Same as CSTR
Upgraded switchgear	Same as CSTR
Upgraded interconnection	Same as CSTR
Upgraded insulation	N/A

In most cases, whether retrofit or new, or plug-flow or CSTR, similar equipment upgrades or additions are necessary. In the case of an existing system adding generator capacity (and not replacing the existing generator), there are some savings as additional combined heat and power equipment is not necessary—the existing generator and system will still serve that purpose. However, additional insulation may be needed for the CSTR system to help retain heat during off-peak times when the generator is not producing electricity and generating heat. CSTR systems are not typically designed for periodic heating and rely on a steady heat input to balance heat losses. In the on-peak generation scenario, added insulation reduces heat losses during times the generator is not operating. For a new system, the controls and biogas flare will be designed to incorporate storage and do not create an additional cost that retrofitting storage on an existing digester would require.

6.4 MODELING COST FACTORS

To model the capital costs, Tetra Tech gathered information from vendors and general market knowledge to arrive at estimates for capital costs of several scenarios. A total of 12 scenarios were developed to approximate differences between new and retrofit systems, CSTR and plug-flow systems, and 8 or 12 hour peaks. Costs were modeled as incremental costs for each scenario to avoid co-mingling costs with the underlying digester system. Depending on the scenario, costs ranged from $1 million to $2 million. Table 6-4 summarizes the costs for each scenario.

Table 6-4. Model Cost Assumptions

Option	System Detail	Equipment Cost	Installation	Total
Existing CSTR	90' CSTR, 12 Hour Peak Sales	$1,216,625	$130,000	$1,346,625
	90' CSTR, 8 Hour Peak Sales	$1,863,625	$130,000	$1,993,625
	76' CSTR, 12 Hour Peak Sales	$1,205,000	$130,000	$1,335,000
	76' CSTR, 8 Hour Peak Sales	$1,855,000	$130,000	$1,985,000
New CSTR	90' CSTR, 12 Hour Peak Sales	$992,254	$75,000	$1,067,254
	90' CSTR, 8 Hour Peak Sales	$1,642,254	$75,000	$1,717,254
	76' CSTR, 12 Hour Peak Sales	$990,400	$75,000	$1,065,400
	76' CSTR, 8 Hour Peak Sales	$1,640,400	$75,000	$1,715,400
Plug Flow	Existing Plug Flow, 12 Hour Peak Sales	$1,266,500	$165,500	$1,432,000
	New Plug Flow, 12 Hour Peak Sales	$912,500	$125,000	$1,037,500
	Existing Plug Flow, 8 Hour Peak sales	$1,916,500	$165,500	$2,082,000
	New Plug Flow, 8 Hour Peak Sales	$1,562,500	$125,000	$1,687,500

The development of costs brought out several key findings:

- Integrating biogas storage into a new system is less expensive than retrofitting a system.
- Costs for moving from a 12 hour peak to 8 hour peak are substantial due to interconnection and generator cost increases—roughly 45 percent to 70 percent higher.
- For CSTR systems, the cost of greater storage (76’ to 90’) is minimal.

Generator costs and interconnection costs were significant cost centers. Depending on whether or not additional switchgear was needed and the incremental kW of the generator, these costs were modeled between $670/kW and $800/kW (as-delivered costs). Interconnection costs were based on recent past experience in Wisconsin and were assumed to be $500,000 for an incremental 600 kW used for the 12 hour peak and $750,000 for an incremental 1200 kW used for the 8 hour peak.

Table 6-5 presents the total cost and percent of total cost of each major cost center. Costs are allocated for core equipment and installation related to adding generator capacity and interconnection capacity, with the storage system itself absorbing the balance of the system costs. Depending on the scenario, the cost contribution of the storage itself is relatively small, ranging from approximately 15 percent to 25 percent of the total cost. Additionally, for a narrower on-peak time period, generator and interconnection costs contribute a larger percentage to the total costs.

Table 6-5. Biogas Storage Major Cost Centers

Option	System Detail	Total System Cost	Generator	Inter-connection	Storage
Existing CSTR	90' CSTR, 12 Hour Peak Sales	$1,346,625	43%	37%	20%
	90' CSTR, 8 Hour Peak Sales	$1,993,625	49%	38%	13%
	76' CSTR, 12 Hour Peak Sales	$1,335,000	43%	37%	19%
	76' CSTR, 8 Hour Peak Sales	$1,985,000	49%	38%	13%
New CSTR	90' CSTR, 12 Hour Peak Sales	$1,067,254	49%	23%	27%
	90' CSTR, 8 Hour Peak Sales	$1,717,254	54%	29%	17%
	76' CSTR, 12 Hour Peak Sales	$1,065,400	49%	23%	27%
	76' CSTR, 8 Hour Peak Sales	$1,715,400	54%	29%	17%
Plug Flow	Existing Plug Flow, 12 Hour Peak Sales	$1,432,000	40%	35%	25%
	Existing Plug Flow, 8 Hour Peak sales	$2,082,000	47%	36%	17%
	New Plug Flow, 12 Hour Peak Sales	$1,037,500	53%	24%	23%
	New Plug Flow, 8 Hour Peak Sales	$1,687,500	56%	30%	14%

Although a system with eight hours of on-peak sales is more expensive by 45 percent to 70 percent than for a 12 hour peak sales system, the cost per incremental peak kW is less. With minimal differences in storage component costs and lower per kW interconnection costs, the eight hour peak system appears more cost effective than the 12 hour peak system. Table 6-6 illustrates the per kW costs between the scenarios.

Table 6-6. Biogas Storage Model Cost per kW

Option	System Detail	Total System Cost	Incremental kW	$ per incremental kW
Existing CSTR	90' CSTR, 12 Hour Peak Sales	$1,346,625	600	$2,244
	90' CSTR, 8 Hour Peak Sales	$1,993,625	1,200	$1,661
	76' CSTR, 12 Hour Peak Sales	$1,335,000	600	$2,225
	76' CSTR, 8 Hour Peak Sales	$1,985,000	1,200	$1,654
New CSTR	90' CSTR, 12 Hour Peak Sales	$1,067,254	600	$1,779
	90' CSTR, 8 Hour Peak Sales	$1,717,254	1,200	$1,431
	76' CSTR, 12 Hour Peak Sales	$1,065,400	600	$1,776
	76' CSTR, 8 Hour Peak Sales	$1,715,400	1,200	$1,430
Plug Flow	Existing Plug Flow, 12 Hour Peak Sales	$1,432,000	600	$2,387
	New Plug Flow, 12 Hour Peak Sales	$2,082,000	1,200	$1,735
	Existing Plug Flow, 8 Hour Peak sales	$1,037,500	600	$1,729
	New Plug Flow, 8 Hour Peak Sales	$1,687,500	1,200	$1,406

Installing biogas storage as part of a new digester system is likely less expensive than retrofitting an existing digester to use storage. In order for a dairy with an existing digester to produce all its saleable energy during peak periods, the system will require expenditures related to biogas storage equipment, added generating capacity, interconnection upgrades, and miscellaneous support equipment. All else held equal, a new anaerobic digester can be designed for on-peak generation by incorporating the storage and larger generating equipment into the initial facility. The incremental cost to a project for providing storage and peak generating capacity will be greater for an existing facility than a new facility incorporating storage compared to a base system cost. For example, the cost of a larger dome on a new CSTR digester will be relatively minor, whereas a retrofit would result in paying the full cost of a new membrane roof. The exception would be for a retrofit situation in which the existing roof was being replaced due to being at the end of its useful life.

The digester must maintain its operating temperature during non-peak hours when the waste heat from the cogeneration system is not operating. For existing digesters, the existing heating system might be adequate for transferring the required heat during peak operating hours alone and relying on insulation to retain the heat during off-peak hours. It may be possible to increase the hot water temperature or flow rate to increase transfer efficiency. In the worst case, a small biogas boiler would need to be operated during non-peak hours to maintain proper working temperatures. This could occur in the coldest winter months, but this is very site specific and does not lend itself to generalization. For this analysis, we assume that the system operations can be modified to allow heating on an intermittent basis during peak generating hours and not requiring an additional boiler system. The projected economics, therefore, represent best case for existing units, notwithstanding assumptions related to interconnection costs.

6.5 MODELING PERFORMANCE FACTORS

Power production modeling is based on 100 percent of the power being generated during peak periods. The model compares the difference of costs and revenues of an 8 hour or 12 hour electricity production period—all assumed to be on-peak, with the 8 hour period requiring greater storage. Holidays and weekends are treated as off-peak hours. This strategy of operation maximizes the potential revenue from the storage system while simplifying the modeling. Myriad scenarios could be developed that incorporate some level of off-peak production, but our interviews found that generators exhibit performance issues when loaded less than 50 percent. A scenario with variable generator output to produce off-peak power removes a substantial portion of the revenue while still incorporating most of the costs of the system.

The model assumes that the system is operated in a professional manner and with high up-time. In the interviews, respondents expressed a general concern about operating digesters without professional support and emphasized that a system incorporating storage would be more difficult for a non-professional to operate, though not necessarily more expensive. Well-run digesters have exhibited good up-time, supporting the 90 percent availability factor used in the model.

Simple payback is used to describe the revenue performance and financial return. Simple payback is based on the incremental capital cost of the systems divided by the incremental annual revenue that is earned by shifting off-peak generation to on-peak periods. The implicit assumption is that on-peak electricity revenue is worth more than off-peak revenue, with higher revenue needed to justify the full incremental cost of the storage system.

6.6 MODEL FINANCIAL RESULTS

The performance model was used to estimate simple payback periods across a range of possible on-peak rates. The rates are *incremental* rates—the increment over the off-peak production rate. The incremental revenue earned by shifting to on-peak production is compared to the cost of the biogas storage system—additional storage, generator, and interconnection costs. A single system is presented to illustrate the general pattern of payback and relationship to the on-peak and off-peak rate differential. The findings are based on the preceding modelling assumptions and should not be viewed as a comparison between optimal systems or a generalizable result. Given the nascent nature of on-farm biogas storage and on-peak power production, significant differences can be expected for any specific application of the technology, with wide cost swings likely to differ from this model result. However, the results are useful to show an approximate financial performance.

Tetra Tech modeled financial performance for a new CSTR system and compared results between the 12 hour and 8 hour peak scenario. On-peak/off-peak price differentials ranged from $0.02 per kWh to $0.12 per kWh. The results are fairly clear—the greater the price differential, the better the financial performance. Figure 6-4 illustrates the relationship for the 12 hour peak period and Figure 6-5 illustrates the relationship for the 8 hour peak period.

Figure 6-4. Simple Payback of 12 Hour Peak Period

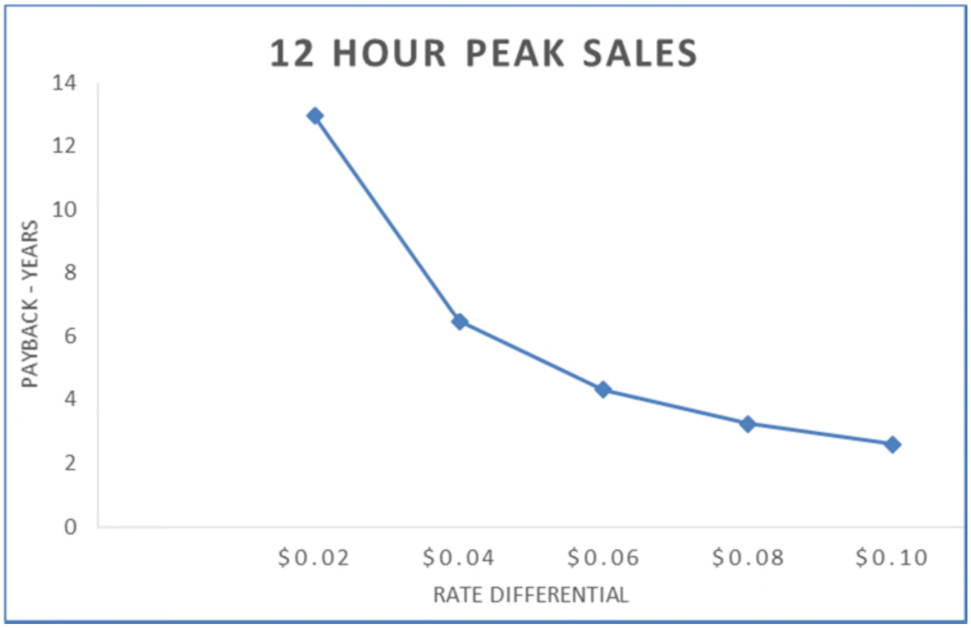
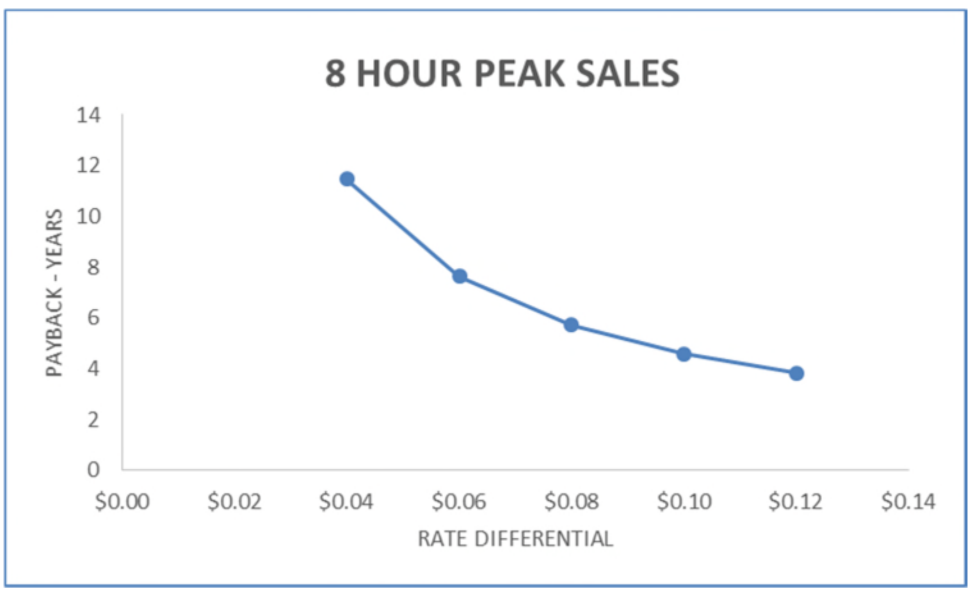


Figure 6-5. Simple Payback of 8 Hour Peak Period



The model result shows a clear curve in the simple payback- below $0.04 per kWh, paybacks extend over ten years. However, there is not a significant difference in financial performance for on-peak rate differentials over $0.08 per kWh. Secondly, the 12 hour on-peak system exhibits better financial performance for a given rate differential—at $0.04 per kWh, the 8 hour system simple payback is approximately double that of the 12 hour system. This better financial performance is partly driven by somewhat higher kWh sales, but also with those sales being spread over lower system costs. For an existing dairy that is reaching the end of its current PPA, peak sales might allow the facility to continue to continue to operate profitably.

6.7 MODELING CONCLUSIONS AND RECOMMENDATIONS

The theoretical model presents cost estimates for a number of possible system designs that might be encountered for a 2,000 head dairy operation in Wisconsin. Generator and interconnection costs are major cost drivers that affect the financial performance, with storage costs being a relatively modest portion of the overall system cost. With an adequate differential between on-peak and off-peak rates it is possible to achieve reasonable financial returns, assuming the costs and performance characteristics in the model hold true. If costs are lower for a specific system, financial performance can be improved. However, the general conditions of the model should be expected to differ for any specific real-world system.

The model has several key assumptions that will be tested in real-world applications:

1. Additional O&M is minimal compared to operating a traditional continuous power producing system.
2. A peaking system will be able to respond to the utility's peak period consistently and reliably (e.g., the system will achieve 90 percent uptime during peak periods).
3. For retrofits at existing digesters, system operations can be modified to allow for adequate heating during non-peak generating hours.

The modeling exercise leads to several recommendations and considerations for next step decisions for a real-world application:

1. Detailed discussions with utility representatives of both technical and price factors will be necessary to identify key cost and revenue options in order to convert from theoretical to actual conditions.
2. Actual conditions should be simulated at existing facilities for both a new digester and existing digester—this exercise would be part of a detailed feasibility study that leads to greater cost and revenue accuracy with each feasibility stage.
3. Greater research is needed to understand the range of costs and develop more specific cost sensitivities to cost center parameters that drive financial performance. We expect these to be centered on generator and interconnection costs, but may also relate to the balance of system storage costs.
4. A real world demonstration is needed to develop proof of concept and expand market experience. A detailed verification evaluation should accompany such a demonstration.

The market has limited experience with on-farm digesters producing peak power—lessons learned from a demonstration should be executed and shared with the farm community, digester industry, and electric utility industry.

7. FINAL CONCLUSIONS AND RECOMMENDATIONS

Based on the research, including the literature review, interviews with biogas market actors and Wisconsin utilities, and the system modeling, we make the following conclusions regarding the use of on-farm biogas storage for on-peak power generation:

From the perspective of the biogas industry,

- The biogas industry has the technology, market channels, and ability to provide the technology and develop such projects.
- The biogas industry does not have substantial experience delivering such projects for the on-farm anaerobic digester market, though does have experience with on-farm digesters and wastewater treatment plants that can leverage the respective knowledge bases.
- Wisconsin's current market for biogas derived electricity is unattractive, though with changes to the electricity market, could become attractive again.

From the perspective of Wisconsin utilities,

- There is little to no experience working with the issues associated with an on-farm anaerobic digester producing on-peak electricity.
- The current electricity market is not favorable for encouraging on-farm anaerobic digesters to emphasize on-peak electricity generation from their biogas systems.

Both the biogas industry and Wisconsin utility representatives saw substantial future potential for on-peak power production from biogas systems. The gaps we identified are manageable but are unlikely to be crossed without some level of intervention from a programmatic or regulatory body. The two major activities that would bridge the gaps are:

- Development of experience and knowledge for on-farm systems using more storage to shift production to on-peak times.
- Development of a mutual understanding between utilities and the biogas industry of pricing factors, options, and value propositions to facilitate aligning system design with utility benefits.

As both the biogas industry and Wisconsin utilities appear willing to collaborate, a practical approach to moving forward is to start an initiative to validate the technology and develop a common understanding of power market value propositions. The central recommendation we are making from the research presented in this report is that Focus on Energy and/or the PSCW should work to develop a collaborative demonstration project between the biogas industry and Wisconsin utilities.

A demonstration project's goals should be focused on creating a working project that is designed to deliver on-peak power. While the end goal would be a working system, the process of collaboration will be equally important and help develop both biogas and utility experience and knowledge as the nuances and details are sorted. The process will need to consider myriad factors, including utility interconnection, system control options, electricity pricing, and process for selecting the system control strategy. With Wisconsin host to a large number of farm digesters, the demonstration host could be a retrofit on an existing system and avoid the complexity and cost of designing and building the base anaerobic digester system.

Should a demonstration project be developed, it is likely to require substantial risk mitigation. The uncertainty of project specifics means that project financial returns have greater risk than typical biogas projects. From the interviews with the biogas industry, developers are unlikely to pursue a speculative project without financial risk mitigation and a clear signal of cooperation and collaboration with a host utility. As such, funding from external stakeholders is likely to be needed in order for the project to get started, much less continue through to development and operations.

Underpinning the logic for a demonstration project and external funding is the opportunity to expand the on-farm biogas market in Wisconsin and develop a new avenue for Wisconsin dairy farms, the biogas industry, and Wisconsin utilities to benefit. As such, the project should be transparent in all aspects and have evaluations conducted at key points. The development phase of the project will focus on pricing, technology options, PPA structures and understanding the factors behind electricity pricing. Once operational, the focus will shift to testing the system under different operating parameters in an effort to optimize system operations. Opportunities for designing in utility dispatch controls or other systems that interact with the digester staff will lead to a rich source of data and knowledge for all stakeholders. The testing of such systems under different parameters will lead to findings that inform next-stage market-driven designs, having helped prepare all key stakeholders in the market for a time when an expanded opportunity emerges.