Biogas Applications for Large Dairy Operations: Alternatives to Conventional Engine-Generators

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ABSTRACT

Dairy anaerobic digester systems process cow manure to generate a biogas that is typically used to generate electricity using an engine-generator system. Engine-generators in this service tend to require high-maintenance, and not all local electric utility companies will purchase excess power at rates favorable to full biogas use. Large dairy operations can produce far more biogas than they can use on-site, so alternatives to electric generation may be desirable. This report examines alternatives to conventional engine-generators. They include hot water boilers, absorption chillers, radiant heaters, and other technologies that may be adapted to biogas service. Lessons are derived from published case studies and example systems, and implementation guidance is provided on pursuing an engineering feasibility study. The appendix includes a tabulation of case study data, extensive listings of manufacturers of equipment that may be adapted to biogas service, and a glossary.

Key Words:

anaerobic digestion, biogas, boiler, chiller, cooling, dairy, gas-fired, heat, hydrogen sulfide, radiant, thermal, hot water

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1.0 INTRODUCTION TO BIOGAS APPLICATIONS

Anaerobic digestion of cow manure is a naturally occurring process in which microbes "digest" the organic material in the manure, producing biogas as a byproduct. Increasingly, the process is centralized in a "plug-flow," "mixed," or other type of man-made digester for odor control and other purposes. The biogas produced in this anaerobic (oxygen-free) environment consists of approximately 60% methane (CH_4, a useful fuel), 40% carbon dioxide (CO_2, a diluting gas), and a small-but-potent dose of hydrogen sulfide (H_2S, a corrosive gas). It is also saturated with water vapor. The lower heating value of biogas at atmospheric pressure is approximately 538 Btu/ft^3. This is significantly lower than the value of 896 Btu/ft^3 for pure methane (the primary component of natural gas) or the value of 2,283 Btu/ft^3 for propane. Nonetheless, the fuel value is significant and the biogas can be recovered to produce heat and electricity.

Biogas applications on a dairy farm or a large centralized manure processing system are constrained by limited energy needs, storage complications, difficulties in exporting the energy (e.g., as electricity into the utility system), high capital requirements, and complexities in operation and maintenance. There are many excellent readily available references that detail these constraints for dairy and other biogas systems, so only those pertinent to alternatives to engine-generators are addressed in this report.[1,2,3,4]

Dairy biogas production is not limited to individual farms. Shared, multiple-farm operations are possible, and thus this report refers to "dairy operations" rather than "dairy farms."

Despite the many constraints on economic application of dairy biogas, many factors favor continued development and expansion of the technology. These include:

- Reduction of odors.
- Improvement of fertilizer quality.
- Reduction of surface and groundwater contamination.
- Improvement of financial returns as the cost rises for the electricity and fuel that biogas use can offset. [Deregulation, capacity limitations, and other factors have contributed to significant recent price increases.]
- Recognition of unburned methane as a potent greenhouse gas that may contribute to climate change. [Methane is estimated to have 21 times the global warming potential of its primary combustion byproduct, carbon dioxide.]

These factors are explained in detail in numerous publications.[5,6]

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1.1 Background and History

Lusk and others provide detailed accounts of the history of anaerobic digestion.[7] The background and history sheds light on the progress of farm-based biogas technology:

> Anecdotal evidence suggests that using biogas for heating bath water occurred as early as the 10th century BC.
>
> Sir Humphry Davy determined that methane was present in the gases produced during anaerobic digestion of cow manure in 1808.
>
> Anaerobic digestion has been used to treat municipal and industrial wastes worldwide for many years.
>
> The first farm-based digester in the U.S. began operation in 1972 in response to urban encroachment. Harold McCabe built a digester to combat objectionable odors from his hog production facilities near Mt. Pleasant, Iowa.
>
> Two factors in the 1970's and early 1980's lead to the development of numerous farm-based demonstration projects: (1) the energy crises of the 1970's and (2) the economy of scale as the size of typical American livestock operations increased.
>
> Lusk documents the history of 94 U.S. farm-based digesters (excluding beef farms and university research farms) starting with the McCabe unit in 1972. [Dairy, swine, and caged-layer poultry farms are included.] The results, like those of almost any new complicated technology, are sobering. As of 1998, of the 94 digesters:
>
> - 28 were operating.
> - 29 were not operating.
> - 17 succumbed to farm closure.
> - 10 were under planning/construction.
> - 10 were planned but never built.
>
> Half of the 94 digesters were plug-type units common to dairy farms. Of those 47 digesters:
>
> - 8 were operating.
> - 18 were not operating.
> - 11 succumbed to farm closure.
> - 2 were under planning/construction.
> - 8 were planned but never built.

The overall farm-based digester history would seem to be largely tragic and a basis for turning away from the technology were it not for three critical points:

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1. Lusk and others have done extensive case studies and documented many of the "lessons learned" from those case studies. In that sense, the efforts of the "early adopters" with failed units were not wasted. The "lessons" are readily available, and anyone with the inclination and an Internet connection can access most of them without charge.

2. Most of the units, until recently, have operated in a period of relatively low and stable energy prices. Deregulation of the electric industry is likely to change that. Aside from energy pricing, reliability of supply is an increasing concern. There is a growing interest in "distributed generation," and there is an increasing interest in small generation units. At the same time, however, the local utility is tending to become a distribution company ("poles and wires" company), and electricity generation is deregulating. The impact is difficult to assess, even three to five years down the road. What is certain, however, is that the era of low and stable energy prices and the monolithic single utility company is over in many parts of the U.S. That may bode well for biogas, either for the economics of biogas or the self-sufficiency of biogas or both.

3. Urban encroachment and climate change concerns are increasing and are not going away anytime soon. The pressure (and hopefully the incentive) to install digesters will increase. As Lusk quotes Harold McCabe on the main advantages of having installed the first U.S. farm-based digester in 1972 in response to encroachment: "I'm still in hogs."

1.2 "Lessons Learned" from Case Studies

As previously noted, the case studies available are numerous. Many are also voluminous. The brief set of excerpts in this report addresses only the biogas application issues to set the stage for considering alternatives to the engine-generator option.

Lusk provided case studies for 13 operating dairy biogas systems.[2] Selected data from these case studies is presented as a table in Section 7.1 of this report. The following conclusions can be drawn from the table and additional information from the full case studies:

- Most systems do not clean up the biogas (i.e., they do not remove the hydrogen sulfide).

- Most systems that use engines use only one engine. [A few have back-up engines, but in some cases that is only because an earlier installation required re-sizing.]

- Most systems rely on keeping the engine running (i.e., hot and thus non-condensing) and frequent engine oil changes (e.g., every 300 hours or 12 days) and frequent engine maintenance (e.g., spark plug changes, air filter changes, overhauls) to combat the effects of hydrogen sulfide. [A true accounting of the annual labor and materials costs involved would be illuminating. Koelsch et al[8]

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provide a typical maintenance schedule that suggests that engine maintenance becomes a way of life.]

- Many systems use engine waste heat, but mostly it is used for anaerobic digester heating (i.e., maintaining digester temperature around 100°F). Few of the dairy systems installed in the last 20 years use the heat for anything else.

- Sale of surplus electricity to the utility is often done at a discount. For example, three of the systems buy utility electricity for 9-10 cents/kWh but sell surplus to the utility at 2-3 cents/kWh. [The economic impact in such cases is that the incremental value of a large system may not justify sizing electric capacity larger than on-site needs.]

One can conclude that there is strong case to be made for cleaning up the biogas, limiting engine-generator size based on the economics, and finding additional on-site or nearby uses for thermal energy.

This is perspective on operating units. Lusk also provided his own summary of the failed units, making extensive use of direct quotes from the operators as to the primary causes for failures.[9] These quotes in part included:

"…engine hydrogen sulfide corrosion."

"…needs new generator…"

"Engine overheating; 20% down-time in the first 2.5 years; engine rebuilt… power generation under design figures."

"Shut down because of engine malfunction."

"Shut down due to poor maintenance; level of hydrogen sulfide requires additional scrubber…"

"…sulfide scrubbing/removal problem…"

"Hydrogen sulfide corrosion in engine…"

Clearly, hydrogen sulfide is a major issue that has not been adequately addressed in many cases. It is, however, a solvable problem and one that must be solved for both engine-based systems and alternative biogas application systems.

Koelsch et al[10] offer insights that support the Lusk observations. Here is one selected quotation that perhaps sums it all up: "The rapid accumulation of engine operating hours and the inability of the operator to keep up with the preventative maintenance needs of the cogenerator have been the weak links in several existing biogas installations."

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The U.S. EPA AgSTAR Program provided a digester system update in Spring 2000.[11] Of four operating dairy systems added since the 1998 Lusk report,[2] three are flaring the biogas and one is producing electricity. The energy waste associated with flaring is unfortunate. Clearly, alternatives to flaring and engine-generators need to be explored.

1.3 The Importance of Hydrogen Sulfide Scrubbing

The importance of hydrogen sulfide scrubbing cannot be overstated. Corrosion induced by hydrogen sulfide present in biogas can destroy expensive gas-fired equipment long before the end of its normal life cycle and, as indicated in the case studies, can seriously damage the metal siding and roofing of buildings as well.

The first step in obtaining the long-term performance desired from engine-generators and alternatives is to scrub the hydrogen sulfide out of the biogas supplied. The previously discussed case studies indicate that only a small minority of cases bothered to do so. This is perplexing given the opportunities available. These include many simple "scavenger" options as well as more-exotic technologies such as membrane systems and molecular sieves.

Scavenger Systems

Scavenger systems are widely used in the natural gas business to turn "sour" gas into "sweet" gas at small production facilities. Many scavenger systems are well-established technology: the Iron Sponge scavenger, for example, has been in use in the U.S. and Europe for over 100 years. It consists of iron oxidized onto wood shavings. It is placed in a tank with the "sour" gas flowing through it, and it simply and effectively converts the hydrogen sulfide to a solid that remains in the tank, eliminated from the gas stream.[12]

A scavenger is simply a product that will capture the hydrogen sulfide flowing through it. The capture is chemical, not mechanical, and in most cases the scavenger is simply disposed of and replaced with fresh scavenger after it is spent (i.e., has absorbed all the sulfur it can). An explanation of the fundamentals is readily available on-line.[13]

Choosing a scavenger requires making trade-offs:

- Some are more expensive but scavenge better than others.
- Some permit better gas flow than others do.
- Some are easier to handle than others are.
- Some are more environmentally friendly and easier to dispose of than others are.

A 1994 Gas Research Institute (GRI) report documents evaluations of 15 scavengers conducted by The M. W. Kellogg Company (Houston, TX).[14] Many of the better-performing scavengers are still available today. See Section 7.2.13 for contact information for a sampling of manufacturers of currently available scavenger materials.

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Membrane and Molecular Sieve Systems

Given the simplicity and relatively low cost of scavenger systems, membrane systems and molecular sieve systems are mentioned here as technologies to watch and to consider for niche applications.

Membrane systems, for example, have the capability to separate out not only hydrogen sulfide but also carbon dioxide and water vapor. The "catch" is that they require significant pressurization of the biogas. They may be useful, for example, to clean up biogas for delivery to a neighboring commercial or industrial facility, especially since additional pressurization is necessary anyway. Molecular sieve technology is also applicable, and pressure swing adsorption (PSA) processes are available using molecular sieve adsorbents.

See Section 7.2.13 for contact information for a sampling of manufacturers of membrane systems and molecular sieve systems. Web site links are included to facilitate easily learning more about the manufacturers and products.

1.4 Engine-Generator Pros and Cons

This report is not intended to discourage engine-generator application in dairy operations, but a look at the pros and cons may have that effect.

PROS	CONS
• Electricity is easy to transfer and readily used.	• High maintenance requirements. • Selling power to the utility may be at a deeply discounted rate. • An induction generator cannot operate as a back-up electric supply when utility service is down. • Operating at low loads is very inefficient. • Noise. • Connection to the utility system may be expensive unless close to the existing service line. • A back-up unit is required in the event of a significant component problem, or all capacity is lost. • A significant amount of engine heat is lost to the engine room. • Engine water temperatures are limited to a narrow range.

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Weighting the individual pros and cons should provide a more-balanced perspective. Nonetheless, the analysis supports a consideration of alternatives to engine-generators for at least part of the biogas use.

See Section 7.2.8 for contact information for a sampling of manufacturers of conventional engine-generators. Web site links are included to facilitate easily learning more about the manufacturers and products.

1.5 Alternatives to Conventional Engine-Generators

What can you do with biogas other than producing electricity with a conventional engine-generator? Plenty!

Emerging technologies such as microturbines, fuel cells, and Stirling engines will offer alternative methods of using biogas to produce electricity. Demonstration projects using biogas are underway. Significant commercialization is just a matter of time and money and market shakeout.

Fortunately for the more-conservative dairy operators who do not desire to pioneer far beyond anaerobic digestion itself, there is a wide variety of well-established, gas-fired commercial products that can be adapted to biogas use as partial (if not full-capacity) alternatives to engine-generators.

1.5.1 Emerging Technologies: Fuel Cells, Microturbines, and Stirling Engines

Much work is underway to develop small systems for electricity generation that are more efficient and environmentally friendly than conventional engine-generators:

- Fuel cells have been available for exotic applications such as spacecraft for many years, however a recent surge in interest and new developments in materials science have yielded additional types that hold promise for eventual commercialization of a wide range of capacities at viable prices. Demonstration projects of many types are being conducted, including some using biogas. A few specialized units have been commercialized, but at this point neither the technology nor the price is suitable for unsubsidized dairy applications.

- Microturbines are in the early stages of commercialization. Demonstration projects of many types are being conducted, including some using biogas. At this point, microturbines are significantly more expensive than conventional engine-generators.

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- Stirling engines, which are *external* combustion engines, are an old concept that was commercialized over a century ago and fell out of favor as alternatives such as electric motors became widely available. A recent surge in interest and new developments in materials science have yielded new designs that hold promise for eventual commercialization at viable prices. Demonstration projects of many types are being conducted, including some using biogas. At this point the technology is largely focused on very small engines and is thus not at a suitable scale for most dairy biogas applications.

Basically, all three of these alternatives are in the demonstration project and early commercialization stages, all three have product life uncertainties, and all three are subject to market shake-out.

Fuel Cells Perspective

The process of electrolysis uses electric current to break down water (H_2O) into its constituents: hydrogen (H_2) and oxygen (O_2). Fuel cells reverse the process – they combine hydrogen and oxygen to produce electricity.

There are at least five types of fuel cells:[15]

- Alkaline fuel cells, like those long-used in spacecraft, have thermal efficiencies of up to 70% but are typically too expensive for commercial use.

- Proton exchange membrane (PEM) fuel cells have the potential for the low costs that would make them suitable for home, farm, and similar small applications.

- Phosphoric acid fuel cells are already commercially viable for some applications and can approach thermal efficiencies of 85% if the steam byproduct is applied rather than wasted.

- Molten carbonate fuel cells operate around 1,200ºF and are thus probably limited to industrial applications.

- Solid oxide fuel cells operate around 1,800ºF and are thus probably limited to industrial applications and large power plants.

Aside from the technology of the fuel cell itself, there are two other key technologies typically required for fuel cell application: producing the hydrogen fuel (e.g., from biogas) and converting the electricity produced to a useful form (e.g., 120V, 60 Hz). Producing the hydrogen fuel from biogas (or other gaseous or liquid fuel) is done by "reforming" or "fuel processing," and developments in this area are as critical to commercialization as the fuel cell developments themselves.

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See Section 7.2.9 for contact information for a sampling of developers and manufacturers of fuel cells. Web site links are included to facilitate easily learning more about the manufacturers and products.

Microturbine Perspective

Microturbines are being developed, demonstrated, and commercialized at a pace that challenges a writer to choose words that won't be stale by publishing time. High utility electricity pricing in some areas, reliability concerns associated with electric system capacity and deregulation, and relatively low and stable natural gas prices (until recently) have driven commercialization at a rapid pace.

Microturbines are typically small power plants, usually having a micro-sized gas turbine and an electric generator (and usually these components share the shaft). [Some microturbines are used as engine replacements (e.g., for chiller drive) and do not include electricity generation, but most do.] A combustible gas (such as natural gas or biogas) powers the gas turbine. Electrical output is usually in the 30 kW to 80 kW range, however multiple units can be installed to provide higher capacities. Units as high as 500 kW have been proposed.

The selling points for microturbines compared to conventional engine-generators include qualities such as:

- Quieter operation.
- Higher temperature exhaust for cogeneration and heat recovery.
- Lower air emissions.
- Lower maintenance.
- Higher reliability due to fewer moving parts.

Unfortunately, not all of the units have all of the selling points, nor do they have them to the same degree.

One key to microturbine success is operating life, and that remains to be proven for these recently-developed products, few of which have been tested for more than a couple of years. Several manufacturers indicate a design life of 40,000 hours, which is less than five years of continuous operation. [While this is low for continuous biogas service, it is acceptable in many of the anticipated part-time electrical demand peak shaving applications.]

Another key to long-term, widespread application is cost reduction: the units are currently significantly more expensive than conventional engine-generators. Prices are dropping, however, and the manufacturers are caught between the desire to keep prices up and the desire to get volumes up.

Capstone Turbine Corp. (Chatsworth, CA) was the first to company to obtain UL approval for an entire packaged microturbine assembly. Reflective Energies (Mission

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Viejo, CA) is adapting Capstone's products to low-grade fuel gases such as anaerobic digester biogas and to biomass applications (e.g., wood waste gasifiers).[16]

Other recent developments regarding application of microturbines to biogas use include:

- In a November 15, 2000 press release, New York Governor George Pataki announced a set of NYSERDA projects including two single-dairy-farm demonstration projects involving microturbines: one in Cortland County ("Anaerobic digestion to make electricity using microturbines") and one in Columbia County ("Microturbine cogeneration system for cheese-making facility").[17]

- The City of Allentown, Pennsylvania's Wastewater Treatment Plant is installing twelve 30 kW Capstone units to convert biogas to electricity for on-site use.[18] The system is to be operational in early 2001. The biogas comes from three digesters at about 630 Btu/ft^3. Each of the single-shaft microturbines rotates at up to 96,000 rpm, produces variable-frequency AC power, and exhausts more than 65% of its input energy to a heat recovery system to produce hot water. The performance contract for the system is based on a ten-year investment recovery period.

See Section 7.2.11 for contact information for a sampling of manufacturers of microturbines. Web site links are included to facilitate easily learning more about the manufacturers and products.

Stirling Engine Perspective

The Stirling engine is a heat engine: it converts heat into mechanical work. It is also an *external* combustion engine: the heat is supplied from outside the engine. This location of the heat source to the outside of the engine is enticing because it provides flexibility in heat sources (e.g., biogas, solar, geothermal), seals out corrosive combustion byproducts, bodes well for noise and vibration levels, and generally offers opportunities for low maintenance engines. Heat is supplied directly or via a heat exchanger, and electricity is produced by rotating a generator.

Stirling engines tend to be small and have small outputs. A 1 kW to 5 kW output is not uncommon, though larger units are in development and systems employing multiple small units have also been demonstrated. The target markets are thus residential, small commercial, and small farm – not industrial.

One key to Stirling engine success is engine life, and that remains to be proven for many recently developed Stirling engines.

The potential for biogas and biomass applications is not lost on the developers: they see a huge worldwide market for such applications.[19]

See Section 7.2.7 for contact information for a sampling of developers of Stirling engines. Web site links are included to facilitate easily learning more about the developers and their products.

Conclusion on Emerging Technologies

Unless a dairy operator wants to be a pioneer in the field and risk a large investment of money and time, well-established commercial products are preferable alternatives to these emerging technologies. This may require some new thinking because many of these well-established commercial products that can use biogas are thermal systems, not mechanical/electrical systems such as engine-generators.

1.5.2 Well-Established Commercial Products

Well-established commercial products that are alternatives to conventional engine-generators can be a good fit to the large dairy operation. Central systems are possible, distributing thermal energy in manner that is similar to that in which a central engine-generator distributes electricity and thermal energy. Central systems can include the following biogas-fired systems:

- Hot water boilers.
- Steam boilers.
- Thermal fluid heaters.
- Direct-contact water heaters.

Hot fluid from these systems can be recirculated through secondary systems and used to power absorption chillers for refrigeration and air conditioning, heat the anaerobic digester, heat buildings, and heat service water.

Other well-established commercial products that may be useful for applying biogas on a dairy operation include:

- Engine-driven air compressors.
- Gas-fired absorption chillers for refrigeration and air conditioning.
- Engine-driven chillers.
- Gas-fired radiant space heaters.
- Conventional gas-fired water heaters.

All of these products are capable of using biogas directly and are addressed in more detail later in this report.

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1.5.3 Secondary Systems: Delivery and Use of Thermal Energy

Once chilled water, hot water, heat transfer fluid, or steam is produced from biogas, there are many, many types of equipment available to use them to advantage. Some of these are actually variations of the gas-fired equipment discussed in this report. For example:

- Absorption chillers are readily available in hot water and steam "firing" models in addition to gas-firing models.

- Space heaters are readily available in hot water and steam models in addition to gas models.

- Water heaters are readily available to produce hot water from hotter water or steam.

Aside from these three variations on the gas-fired equipment discussed in this report, there are other end-use products for chilled water, hot water, heat transfer fluid, or steam that are too numerous to detail here. In general categories, they include:

- Air conditioning (e.g., for the residence).
- Central heating (e.g., for the residence).
- Dehumidification.
- Drying (i.e., process uses such as digester product drying).
- Food processing.
- Humidification.
- Hydronic snow melting.
- Radiant floor heating (e.g., for the residence).
- Radiant wall and ceiling heating panels (e.g., for the residence).
- Process cooling (e.g., milk cooling).
- Process heating (e.g., for the anaerobic digester).

Key to any of these applications is efficient delivery of the chilled water, hot water, heat transfer fluid, or steam to the application. For that reason, underground piping insulation, pre-insulated pipe, and pourable trench insulation are briefly addressed here.

Underground Piping Insulation

Insulating or replacing underground pipe is a complicated exercise with many special design, installation, and cost considerations. Energy savings alone will not usually justify an insulation improvement on existing underground heating or cooling pipe unless it is uninsulated.

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Underground piping insulation involves special considerations and must be treated differently than aboveground piping insulation for many reasons including:

- Installation may involve adverse conditions such as weather, minimal access space in the trench, etc.
- Ground temperatures provide potential additional thermal losses to steam and hot water lines year-round.
- Moisture can rapidly degrade insulation performance if it is not excluded.
- Moisture and soil conditions promote corrosion. Cathodic protection may be required.
- Special provisions are necessary to facilitate recognizing and locating leaks.

While conventional piping and insulating systems can be applied to underground applications, in many instances it is preferable to use specialty products such as pre-insulated pipe or pourable trench insulation.

Pre-Insulated Pipe

Industrial-grade pre-insulated pipe is produced in numerous specialty configurations including some suitable for underground installation. Applications include biogas, steam, thermal heat transfer fluids, and water. See Section 7.2.12 for manufacturers that provide pre-insulated pipe.

Pourable Trench Insulation

Pourable trench insulations are typically bagged powders that are poured around piping in a trench. This approach has been around for well over 30 years but is less conventional than the preinsulated, prefabricated pipe approach. The powder (typically a natural calcium carbonate) bonds to provide a load-bearing, water-repelling solid insulation around the pipes.

Installation of these powders is not complicated, but the trenching, pipe, and powder placement must be done carefully to guarantee adequate coverage around the pipe and yet not waste a lot of powder.

See Section 7.2.10 for manufacturers that provide pourable trench insulation.

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2.0 WELL-ESTABLISHED COMMERCIAL PRODUCTS

Numerous gas-fired products are available for potential biogas applications for large dairy operations. As a practical matter though, an extensive biogas piping system is neither financially nor operationally desirable. Piping is expensive, and biogas presents operational problems – even with the hydrogen sulfide removed:

- The biogas is typically not highly compressed, and thus the piping must be relatively large in diameter.

- The useful content of the biogas, methane, is significantly diluted with carbon dioxide. Biogas thus requires larger piping than natural gas to deliver the same energy content at the same pressure.

- Water vapor in the biogas presents condensation and freeze protection problems in cold weather.

Because of these biogas properties, it is advantageous to limit direct biogas applications to a few centralized systems.

Centralized Systems

Centralized systems may include systems to produce compressed air, chilled water, hot water, hot or cold heat transfer fluid, or steam. These fluids can then be readily piped to end-use applications.

Biogas-fired infrared space heating in the barn, shop, or other livestock and work areas near the anaerobic digester constitutes an additional "centralized" system for consideration – provided that the piping is not so extensive as to create condensation and freeze protection problems.

Gas-fired products are typically fueled by natural gas or propane. Conversion to biogas service should be done by the manufacturer or in close consultation with the manufacturer. In many cases, the conversion is as simple as increasing the orifice diameter on the gas restricting nozzle to about 1.3 times that used for natural gas.[20] Other applications may require control system or other adjustments. Some manufacturers, however, may not permit conversion of their products to biogas service, and a few product types may be unsuitable for biogas unless the carbon dioxide is removed.

Gas-fired equipment should be installed in accordance with local laws, codes, and regulations, and only by contractors qualified in the installation and service of gas-fired equipment.

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Products that are strictly residential-grade products are not recommended for the centralized systems due to the long payback times associated with anaerobic digester and biogas application investments: the systems need the durability and life-expectancy of commercial-grade or industrial-grade products.

There are typically many manufacturers for each type of equipment. It is strongly recommended to select well-established manufacturers and well-established models that are likely to continue to be supported for much if not all of the biogas system lifetime.

What About The Tractor?

Biogas is not suitable for mobile applications due to its low density and low energy density. It would take 130 gallons of highly compressed biogas (200 psig) to equal the energy content of one gallon of diesel fuel.[21]

2.1 Air Compressors, Engine-Driven

Biogas-fueled engine-driven air compressors are probably not suitable for most large dairy operations. They are generally of high volumetric output (175 ft^3/minute and up), and compressed air is not generally needed at high volumetric output on a regular basis. [That translates to roughly 50 horsepower and up on the power end.] They also have the same types of engines as used for engine-generators, so they have all of the same problems. Finally, it is not practical to store biogas,[21] so a biogas-fueled air compressor would not be very portable.

Biogas-fueled engine-driven air compressors are included here only because they may fit certain niche applications. For example, compressed air might be sold to a business in close proximity to the dairy operation. The advantages might include:

- Offset of expensive electricity use at the business. [This is particularly useful where the electric utility's selling rate is significantly higher than its buying rate and the dairy operation produces more biogas than it can use.]

- Summer use for biogas. [Anaerobic digesters require less heating in the summer, so more biogas is available in the summer. Furthermore, summer electric rates are higher in many areas.]

- Partial consumption of the compressed air by the dairy operation.

See Section 7.2.1 for contact information for a sampling of manufacturers of gas-engine-driven air compressors. Web site links are included to facilitate easily learning more about the manufacturers and products.

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2.2 Boilers, Hot Water

"Hot water boilers" typically heat recirculating water as in hydronic heating systems. This is not service water heating (i.e., heating water for one-time use such as washing or sanitizing), however hot water boilers can also provide service water. Hot water boilers are available in sizes from about 35,000 Btu/hour input and up.

Hot Water Boiler Ratings[22]

Residential-grade hot water boilers range up to 300,000 Btu/hour input and are rated to standards developed by the U.S. Department of Energy (DOE). The ratings include heating capacity (similar to gross output) and annual fuel utilization efficiency (AFUE), a part-load efficiency at average outdoor temperature and load for a typical boiler installed in the U.S. AFUE permits some comparisons, but it is not directly applicable for biogas applications or for processing applications (i.e., applications other than comfort heating). Even for comfort heating with natural gas, it must be remembered that AFUE is a rating based on *average* outdoor temperatures and loadings in the U.S., and actual performance may vary substantially under other conditions.

Commercial-grade hot water boilers (300,000 Btu/hour and up) are tested for full-load steady-state efficiency according to the standards of the Hydronics Institute (a division of the Gas Appliance Manufacturers Association), the American Gas Association (AGA), or Underwriters Laboratories (UL). Gas boilers are design-certified using tests based on ANSI Standard Z21.13 or UL Standard 795.

Hot Water Boiler Controls[22]

Hot water boilers are typically temperature-controlled with controls mounted on the boiler. Burner control may be on-off, high-low-off, or modulating. Modulating control typically offers higher efficiency and more–precise water temperature control.

"Reset" controls automatically change the high limit water temperature set point to match variable load demands caused by changing outdoor temperatures. This improves efficiency by keeping the water temperature as low as possible. Reset control may be highly beneficial on biogas systems because a substantial part of the heating load is heating the outdoor anaerobic digester.

Hot Water Temperature Limits

Hot water boilers usually operate around 180ºF to 200ºF and are limited to 212ºF maximum (at which water flashes to steam at atmospheric pressure). Higher temperatures are possible with alternative systems, but high pressures are required to prevent flashing. These higher pressures preclude direct use in standard heating equipment. High temperature water (HTW) systems are a specialty unto themselves, and

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there are many considerations that require special engineering design.[23] HTW systems are not suitable for dairy operations. Where it is desirable to exceed 212ºF for distributing a fluid at a high energy density, a steam boiler system or a thermal fluid heater using a specialized heat transfer fluid are preferable in many respects. See Sections 2.3 and 2.7 for details.

Multiple-Boiler Hot Water Systems

The concept of one centralized, biogas-fired heating plant supplying many loads does not preclude multiple-boiler systems. Many manufacturers offer assemblies of multiple hot water boilers connected in parallel. These are controlled in stages, allowing adaptation to a wide range of heat output requirements at higher efficiency than a single larger unit can provide. [A single large boiler has a higher minimum fire requirement than that of a small boiler.] Additional benefits include ease of installation, ease of expanding capacity, and partial operation if one boiler is down for maintenance.[24]

These multiple-boiler systems have many advantages for biogas applications on a large dairy operation. Aside from those already noted, another is the trend toward control that is more sophisticated and troubleshooting options such as remote monitoring. On the cutting edge, one manufacturer (Miura Boiler) is now offering a control system that includes data logging of settings and operating history, extensive diagnostics, and the ability to automatically telephone company headquarters with the data if there is an unusual problem. [Miura Boiler calls it "Miura Online Maintenance" (MOM). MOM can handle up to 37 boilers with a single telephone line.][25]

Multiple-boiler configurations should not be confused with *modular* boiler configurations. Modular boilers have an assembly of boiler modules that is treated as if it is a single boiler, provided that the gas input is no more than 400,000 Btu/hour. The modules cannot be isolated from the main headers with blocking valves. There are additional control distinctions, and these are defined in the ASME Boiler and Pressure Vessel Code, Section IV and ASME CSD-1. From the dairy operation perspective, multiple boilers offer the capability of isolating a single boiler for maintenance while the other boilers are in service; modular boilers do not offer the capability of isolating a single module for maintenance while the other modules are in service.

Applications on the Dairy Operation

A hydronic system can be used on a dairy operation to:

- Power an absorption chiller with hot water instead of biogas.
- Heat service water, heat the digester, and heat enclosures with convection heaters.
- Heat and cool the home.
- Dry grain, manure, etc.
- Power Stirling engines to pump water, generate electricity, etc.
- Heat trace biogas lines to reduce condensation and freezing problems.

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Potential Hazards

See Section 2.8 for information on maintaining safe water temperatures to avoid scalding injury and Legionnaire's Disease risks.

Sources for Hot Water Boilers

See Section 7.2.2 for contact information for a sampling of manufacturers of hot water boilers. Web site links are included to facilitate easily learning more about the manufacturers and products.

2.3 Boilers, Steam

Hot water boilers are usually limited to 212ºF maximum. Steam boilers produce steam at higher temperatures and steam can deliver a lot more energy, but steam systems are more complicated in many respects including:

- Water treatment. [Hotter temperatures complicate scaling problems. Water treatment is essential for all feed water to minimize scaling and other problems in the boiler and the steam distribution and condensate systems. This adds to system first cost and complicates operation with chemical handling, sampling, testing, etc.]

- Pressure. [If controls do not operate properly or if safety valves are not functional, overheating and increased pressures can cause many types of boilers to explode. That includes cast iron boilers (that might be preferred for biogas service due to their corrosion resistance) and that is why cast iron boilers are limited to 15 psig by the ASME Boiler and Pressure Vessel Code.[26]]

- Condensate handling. [Steam traps are required to remove condensate without wasting steam, and they can be expensive and difficult to maintain. Condensate can be corrosive. Unused outdoor condensate lines can create freeze protection problems.]

Low-pressure boilers (15 psig and under) are all that would be warranted on dairy operations since high temperatures (250ºF and up) are not needed for heating. Low steam pressure precludes options such as steam turbines for electricity generation, water pumping, etc.

Control Problems with Steam Comfort Heating

People tend to open windows that are located over steam radiators. That is because the heat output of a steam radiator is inherently erratic at low loads, and that is a strong motivation to switch from steam heating to hot water (hydronic) heating for comfort

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heating applications.[27] The heat output of a steam radiator is inherently erratic at low loads because:

> *Steam in a radiator gives off most of its heat by condensing into water. The pressure at which the steam condenses determines the temperature inside the radiator.*
>
> *If the steam inlet valve is wide open, then the steam pressure is close to the steam supply pressure. This is usually around 10 psig, and the corresponding condensing temperature is about 240ºF. That is full output, and it is often more than is required (unless the windows are open).*
>
> *If less heat is required, the alternative to opening windows is to throttle the steam supply valve to the radiator. This is done either manually or thermostatically. It reduces the steam pressure inside the radiator.*
>
> *When the steam pressure drops, the condensing temperature and the heat output drop. At some valve setting the pressure drops lower than atmospheric pressure and condensate accumulates inside the radiator. This is when the erratic behavior begins.*
>
> *Condensate accumulates inside the radiator until gravity pressure is sufficient to overcome the pressure difference at the steam trap. Then the trap opens, condensate goes down, and air bubbles up. The erratic air bubbling restricts flow through the trap and causes knocking as it bubbles up through the pool of condensate inside the radiator. Pressure changes erratically, air is vented erratically, and the heat transfer is impeded by the condensate levels and dilution of the steam with air. Every aspect of radiator function gets involved in this unstable process.*

There are at least four solutions:

1. Live with erratic temperature control and noise at low loads.

2. Increase the loads by opening the window, thus wasting lots of energy but stabilizing the system.

3. Install a vacuum condensate system and close the window, thus adding more equipment and increasing the complexity and cost of the steam system.

4. Switch to a hot water (hydronic) heating.

Most people choose to switch from steam heating to hot water (hydronic) heating because it is simpler, more reliable, and easier to control.

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Selling Steam to the Neighbors

Large commercial facilities such as office buildings often use steam for heating and hot water production. Unfortunately, the anaerobic digester needs the most heat in the winter, so excess steam is most available in the summer when such a commercial facility needs little or no steam.

Steam System Conclusion

Steam has its place, especially for large commercial and industrial operations. It is indispensable in many processing industries. The large dairy operation is not one of them: hot water systems and thermal fluid systems are alternatives that are easier to operate and easier to maintain in most cases.

Sources for Steam Boilers

Some dairy operations may already have steam systems and may need replacement equipment. See Section 7.2.3 for contact information for a sampling of manufacturers of steam boilers. Web site links are included to facilitate easily learning more about the manufacturers and products.

2.4 Chillers, Absorption

Absorption chillers are refrigeration units that are powered by heat rather than mechanical compressors. The heat is typically supplied as steam, hot water, or combustion of natural gas. Absorption chillers are not as efficient as chillers using mechanical compression, however they have advantages that offset that disadvantage in many cases. The most notable advantages include relatively quiet operation and the ability to use waste heat.

With a few exceptions, absorption chillers tend to be large and are used in commercial buildings, hospitals, etc. Many large units were installed in the 1960's. Due to low efficiency, absorption chilling fell out of favor during the energy crisis in the 1970's. It began a recovery in the late 1980's and 1990's because of lower natural gas prices (particularly in the summer when air conditioning is needed), higher electricity prices (particularly in the summer when air conditioning is needed), natural gas company subsidies, and a general trend toward cogeneration and using waste heat.

In the context of using biogas on a large dairy operation, absorption chillers can use biogas directly or they can be powered by hot water, steam, or a heat transfer fluid that is heated with biogas in a single, centralized biogas-burning system.

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How Absorption Chillers Work

Many references discuss how absorption chillers work, but few make it readily comprehensible. Monger offers one of the best explanations.[28] Here is a paraphrased summary of his introduction to the subject with a few embellishments for non-engineers:

An absorption chiller and a mechanical chiller are similar in that:

- They both use heat to vaporize refrigerant in the evaporator. [The evaporator is on the "cold side" of the cycle, as on the "icebox" side of a residential refrigerator.]

- They both remove the low-pressure refrigerant vapor from the evaporator and deliver it as a high-pressure refrigerant vapor to the condenser. [The condenser is on the "hot side" of the cycle, as on the hot finned coils on the back or underside of a residential refrigerator.]

- They both condense the refrigerant vapor into liquid in the condenser.

- They both recycle the refrigerant.

The main differences between an absorption chiller and a mechanical chiller are:

- Absorption chillers do not use mechanical compressors to move refrigerant from the evaporator to the condenser. They use pressure differences created by the heating of fluids, resulting in concentration and vapor pressure changes instead. The fluids used include an "absorbent" (usually water or lithium bromide) and a "refrigerant" (usually ammonia or water).

- Fluid handling sections called the "generator" and the "absorber" replace the mechanical compressor.

- The energy input comes from the heat supplied to the "generator."

Absorption chillers are quiet because they have no mechanical compressor and only a few small liquid pumps. Larger gas-fired absorption chillers have one or more burner fans and some combustion noise, but that is insignificant compared to the noise from a unit with a mechanical compressor. Cooling the condenser usually requires a fan on air-cooled units and a cooling tower on water-cooled units, regardless of chiller type.

Dairy Applications and Commercial Constraints

Unless a close neighboring operation can use chilled water (e.g., for air conditioning), most dairy operations will not have sufficient applications for large absorption chillers (i.e., 100 tonR and up). [1 tonR or "one ton of refrigeration" is equal to 12,000 Btu/hour of cooling.]

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Chilled water from a large absorption chiller may be sold to a business in close proximity to the dairy operation. The advantages may include:

- Offset of expensive electricity use at the business. [This is particularly useful where the electric utility's selling rate is significantly higher than its buying rate and the dairy operation produces more biogas than it can use.]

- Summer use for biogas. [Anaerobic digesters require less heating in the summer, so more biogas is available in the summer. Furthermore, summer electric rates are higher in many areas.]

- Partial consumption of the chilled water by the dairy operation.

Chilled water supply temperatures for commercial air conditioning applications tend to be around 45ºF. [The chilled water is used to chill air to around 55ºF.] That's what most commercial absorption chillers deliver. Lower temperatures from these models are usually precluded by potential water freezing in the chiller evaporator.

Cooling to 45ºF is a commercial constraint, not an engineering constraint. Some ammonia-based absorption chillers can deliver lower temperatures, but custom design is usually required and the standard, well-established commercial products on the market are limited to the air conditioning field. Custom-designed ammonia absorption systems have been designed for evaporator-side temperatures as low as –76ºF. They are used in the chemical and petroleum industries. Obtaining low temperatures at the evaporator requires the supply of a hot energy source, so waste steam and gas turbine exhaust are commonly used as heat sources. Due to the high cost of custom design and fabrication, custom design is primarily for large capacities [e.g., 200-2,500 tonR (2.4-30 million Btu/hour) at –50ºF and 300-5,000 tonR (3.6-60 million Btu/hour) at 20ºF].[29]

The dairy operation would like cooler temperatures than 45ºF for milk cooling. Unfortunately, the capacities typically required are small (5-15 tonR maximum) compared to the usual range for custom-designed absorption units. Since custom-design at low capacity is not economically viable for a dairy operation, an adaptation of a commercial absorption unit is the only viable absorption approach for milk cooling. [Small low-temperature chillers with engine-driven mechanical compressors are more-commonly available, but there is far more overall flexibility in using an engine-generator to produce electricity and doing the milk cooling with standard equipment.]

The need for small systems limits choices to Robur (Servel) and Yazaki Energy Systems, and these options are addressed in detail below. [Broad U.S.A. is not addressed here because its products are new to the U.S. market. The lower end of the capacity range of Broad U.S.A. units also starts at a higher capacity than do the ranges for Robur and Yazaki Energy Systems products.]

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Small Absorption Chillers from Robur (Servel)

Servel entered the absorption cooling business in 1925 and was widely known for decades for absorption-based refrigerators. By 1954 they had sold four million units. Absorption refrigerators fell out of widespread use as small, more-efficient mechanical compressors became available.

Servel developed gas absorption cooling for air conditioning and introduced a gas air conditioner at the 1939 New York World's Fair. An air-cooled version was commercialized in 1964. In 1991, the Servel air conditioning division was purchased by Robur Group, an Italian company. Robur Corporation is the U.S. subsidiary.[30]

Robur Corporation (Evansville, IN) now makes the Servel brand of gas-fired, air-cooled, ammonia/water absorption chillers. Over 150,000 units have been sold. The units produce chilled water down to 45ºF (based on 95ºF outdoor temperature) and are available in 3 tonR (36,000 Btu/hour) and 5 tonR (60,000 Btu/hour) cooling capacities. Larger multiple-unit combinations supply higher capacity requirements. Units are also offered for pre-chilling dairy products.

Standard features of the 5 tonR single-effect Model ACF60 (as an example) include:

- Microprocessor based control.
- Electronic ignition.
- Stainless steel evaporator.
- Air cooling with variable speed fan.
- Factory charged and performance tested.
- Minimal electrical requirements allow single-phase wiring.

Small Absorption Chillers from Yazaki Energy Systems

Yazaki Energy Systems boasts over 100,000 units operating around the world. They offer two product lines of lithium bromide based absorption chillers:

1. Gas-fired double-effect units that produce 45ºF water. Available in 30, 40, 50, 60, 80, and 100 tonR sizes (360,000 to 1.2 million Btu/hour). Features include:

- Double-effect cycle. [A double-effect cycle uses less fuel and rejects less heat than a single-effect cycle.]
- Microprocessor based control.
- Ability to operate multiple units for higher capacity.
- Can supply either cold water or hot water on command from a remote or built-in switch.
- Remote monitoring unit with a remote control option.
- Factory charged and performance tested.

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The primary drawback is that these are water-cooled units (e.g., using a cooling tower). They also require three-phase electrical service.

2. Hot water powered (167ºF to 212ºF) single-effect units that produce 48ºF water. Available in 10 tonR size (120,000 Btu/hour) or assemblies of up to five 10 tonR units. Features include:

- Microprocessor based control.
- Ability to operate multiple units for higher capacity.
- Nominal cooling capacities can be increased by up to 42% when hot water at 210ºF is used.
- Factory charged and performance tested.
- Minimal electrical requirements allow single-phase wiring.

The primary drawback is that these are water-cooled units (e.g., using a cooling tower). The units also produce 48ºF rather than 45ºF water.

Sources for Absorption Chillers

See Sections 7.2.4 and 7.2.5 for contact information for a sampling of manufacturers of absorption chillers. Large chillers are included for benefit of unusual applications. Web site links are included to facilitate easily learning more about the manufacturers and products.

2.5 Chillers, Engine-Driven and Dual-Drive

Biogas-fueled engine-driven chillers are probably not suitable for most dairy operations. They are generally of high cooling capacity (30-55 tonR and up), and chilled water is not generally needed at that high capacity on a regular basis. [1 tonR or "one ton of refrigeration" is equal to 12,000 Btu/hour of cooling.] They also have the same types of engines as used for engine-generators, so they have all of the same problems. [The author has done numerous industrial energy audits at facilities having a mix of electric-motor-driven and natural-gas-engine-driven chillers, and he has usually found the engine-driven units to be out of service, even when the fuel costs suggested that they should be running.]

Biogas-fueled engine-driven chillers are included here only because they may fit certain niche applications. For example, chilled water may be sold to a business in close proximity to the dairy operation. The advantages may include:

- Offset of expensive electricity use at the business. [This is particularly useful where the electric utility's selling rate is significantly higher than its buying rate and the dairy operation produces more biogas than it can use.]

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- Summer use for biogas. [Anaerobic digesters require less heating in the summer, so more biogas is available in the summer. Furthermore, summer electric rates are higher in many areas.]

- Partial consumption of the chilled water by the dairy operation.

Chilled water supply temperatures for large commercial air conditioning applications tend to be around 42ºF to 44ºF. [The chilled water is used to chill air to around 55ºF.] That's what most large commercial chillers deliver. Lower temperatures are precluded by potential water freezing in the chiller evaporator. For process applications requiring lower temperatures, units cooling process fluid, ammonia, or water/glycol are usually used. Engine-driven, lower-temperature process chillers also tend to be available only in larger capacities, and there are fewer choices on the market than in the air conditioning field.

The dairy operation would like cooler temperatures than 42ºF to 44ºF for milk cooling. These cooler temperatures are best obtained by an electric unit, not a biogas-fueled engine-driven unit. If an engine must be operated, there is far more overall flexibility in using an engine-generator to produce electricity and doing the milk cooling with standard equipment.

Sources for Engine-Driven Chillers

See Section 7.2.6 for contact information for a sampling of manufacturers of engine-driven chillers. There is also contact information for a few manufacturers who offer dual-drive equipment (i.e., chillers packaged with both engine-drive and electric-motor-drive on the same compressor). [Dual-drive is a simple but relatively new concept arising in response to aspects of electric utility deregulation including high peak-capacity pricing and reliability concerns.[31]] Web site links are included to facilitate easily learning more about the manufacturers and products.

2.6 Space Heaters, Radiant

A gas-fired infrared radiant heater burns gas to heat a radiating surface that emits infrared energy when at high temperature.

Infrared energy is similar to visible light except that it lies between the visible and microwave sections of the electromagnetic spectrum. Like light, it travels in straight lines. Air does not absorb infrared energy well, so most of the heating is direct to solid objects. The heated objects then release heat to the air by convection and radiate some heat to surrounding objects.

Infrared radiant heaters are very effective for spot heating and are also used for heating large areas.

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There are three types of gas-fired infrared heaters with characteristics as follows:[32]

Type	**Indirect**	**Porous Matrix**	**Catalytic Oxidation**
Usual configuration	tube or panel	porous panel	porous panel
Combustion location	internal	surface	catalyst surface
Operating temperature	up to 1,200ºF	1,600ºF to 1,800ºF	650ºF to 700ºF
Heat intensity, Btu/hour-ft^2	up to 7,500	17,000 to 32,000	800 to 3,000
Heat-up time, sec	180	60	300
Visible light	to dull red	yellow red	none
Wind resistance	good	fair	very good
Venting	optional	non-vented	non-vented

Biogas-fueled infrared heating systems offer many advantages for space heating requirements in the barn, shop, or other livestock and work areas near the anaerobic digester. Advantages of radiant heating include:

- Radiant heat is not absorbed by the air, so it is highly efficient in areas that require frequent air changes or that have high infiltration rates.

- Radiant heating warms cold bodies directly without needing to heat up all of the air in the room or building. This rapid heat-up capability allows the heat to be off when the room or building is unoccupied, thus saving fuel.

- Radiant heating minimizes heat losses though the roof and roof vents. The energy is directed radiantly down toward the area needing heat and the minimal air heating minimizes stratification and the rise and escape of warm air.

- Radiant heating does not require forced air circulation in the room or building and thus minimizes circulation of airborne particles.

- Radiant heating allows zone control. Different areas can be heated to different temperatures as required.

- Radiant heat is directional. Very specific areas can be heated without heating an entire room or building.

- Radiant heat can be used effectively outdoors.

The indirect tube-type radiant heater is probably the most common type for heating spaces such as those found on a dairy. All combustion occurs within the metal tube, and the units are usually vented.

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Venting of Radiant Heaters

"Venting" refers to how the combustion byproducts from a radiant heater are handled. Radiant heaters are available in both vented and non-vented models.

Vented models vent the combustion byproducts to the outside of the building and are appropriate for tightly enclosed areas. The exhaust flue is relatively small – often roughly three inches in diameter. Multiple units can share a common exhaust flue duct system in many cases.

In some cases, the exhaust flue duct can be located inside the combustion air inlet duct. For example, a three-inch exhaust flue duct may be centered inside a five-inch combustion air inlet duct. This requires only one wall or roof penetration.[33]

Use of unvented units in enclosed areas may require some room air intake and exhaust ventilation to remove carbon dioxide (CO_2) and water, the principal combustion byproducts. Adding this ventilation is not as inefficient as it may sound because the combustion byproducts are heated and that heat, which would otherwise be vented outside, is being added to the room.

Specialty Options for Radiant Heaters

Radiant heaters designed for corrosive environments are available.[34] These may have applications in areas where hydrogen sulfide or biogas combustion byproducts may be present.

Sources for Gas-Fired Radiant Heating Equipment

See Section 7.2.14 for contact information for a sampling of manufacturers of gas-fired radiant heating equipment. Web site links are included to facilitate easily learning more about the manufacturers and products.

2.7 Thermal Fluid Heaters

Hot water boilers are usually limited to 212ºF maximum. Steam boilers produce steam at higher temperatures and steam can deliver a lot more energy, but steam systems are more complicated in many respects (water treatment, control, pressure, blowdown, condensate handling, maintenance, etc.). A thermal fluid heater is a high-temperature alternative to steam that can also be used at lower temperatures.

Thermal Fluid Heaters Defined

A thermal fluid heater is an industrial unit somewhat similar to a hot water boiler except that the fluid heated (the "heat transfer fluid," usually a liquid) is not water and the temperatures produced are typically higher than 212ºF, though not necessarily. Many

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heat transfer fluids are available, and the particular choice depends on many considerations including:

- Service temperature required.
- Efficiency (viscosity, density, specific heat, thermal conductivity).
- Impact if the fluid leaks into end-use systems.
- Environmental issues such as spill ramifications (toxicity, biodegradability, etc.).
- Regulatory requirements, if any.
- Fluid properties when the unit is out of service in cold weather.
- Fluid reprocessing availability (for fluid breakdown or contamination).

What it really comes down to is finding the lowest-cost heat transfer fluid that will meet all the criteria – and using no more of it than necessary.

Examples of heat transfer fluids include glycols and mineral oils. The water and antifreeze solution in your car is a heat transfer fluid. Frankly, there are many fluids, fluid manufacturers, and fluid formulas, and involving the thermal fluid heater manufacturer in the choice is probably wise.

Why Use A Thermal Fluid Heater?

Aside from the drawbacks of using steam, the selling points for thermal fluid heaters include:

- Higher temperatures deliver the same energy with less flow. Thus the pipes can be smaller than hot water pipes.

- High temperature translates into smaller heat exchangers. For example, a convective heater can be smaller using hot thermal fluid than if using hot water.

- Unlike water, most heat transfer fluids don't freeze in winter outdoor temperatures when they are not in use.

There are other benefits in the processing industries. They include tight temperature control, very high temperatures, and elimination of steam boiler licensing complications, but they are not particularly applicable on a dairy operation.

Applications on the Large Dairy Operation

What can you do with a hot thermal fluid? Here are a few possibilities that may be applicable to a large dairy operation with a biogas-fired centralized thermal fluid system:

- Power an ammonia absorption chiller. [With higher temperatures to drive a chiller, obtaining units to actually refrigerate or freeze (rather than just chilling water to 45ºF) becomes viable.]
- Heat service water, heat the digester, and heat enclosures with convection heaters.

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- Heat and cool the home.
- Dry grain, manure, etc.
- Power Stirling engines to pump water, generate electricity, etc.
- Heat trace biogas lines to reduce condensation and freezing problems.

Aside from doing any or all of these things, using a thermal fluid heater consumes biogas in a single, robust, low-maintenance piece of industrial equipment that is relatively quiet compared to an engine-generator and has very few moving parts.

Disadvantages of Thermal Fluid Systems

There are three main disadvantages to applying these systems as biogas-fired centralized heating systems on a large dairy operation:

- A dairy operation is not well suited for dealing with potential leaks and spills of heat transfer fluid. [That will limit the choices of suitable heat transfer fluids, and may limit service temperatures as a result.]

- Thermal fluid heaters are industrial-grade equipment, and that means "expensive." [On the other hand, that also means robust and durable.]

- Though thermal fluid heaters are customized, the large dairy application is on the small end of typical capacities. Not all of the manufacturers will be interested.

Sources for Gas-Fired Thermal Fluid Heaters

See Section 7.2.15 for contact information for a sampling of manufacturers of gas-fired thermal fluid heaters. Web site links are included to facilitate easily learning more about the manufacturers and products.

2.8 Water Heaters, Conventional

Conventional gas-fired water heaters are service water heaters (i.e., they heat water for one-time use) as opposed to "hot water boilers" (i.e., typically heating recirculating water as in hydronic systems). [Note, however, that many hot water boilers can also provide service water. See "Boilers, Hot Water."] The most common type of service water heater, which is addressed here, is the automatic storage water heater that is found in many homes with gas service. Other types (e.g., instantaneous water heaters) are available, and numerous good references are available for all types of service water heaters and their applications, including commercial-grade applications.[35]

Automatic storage water heaters include the burner(s), hot water storage tank, insulation, and controls in a single packaged unit. They are usually designed for services in which the hot water demand is intermittent, not continuous. The amount of storage required depends on the hot water demand pattern and on the recovery rate of the unit. The

recovery rate is the flow of hot water that the water heater can continuously produce, typically as gallons per hour that can be maintained for a specified temperature rise through the unit.

Multiple units may be manifolded together (installed in parallel) where necessary to achieve the required capacity or to fit into the available space. Similar specifications should be used for each unit, and a balanced parallel flow is recommended. Balance can be achieved by using reverse/return piping. The unit with the inlet closest to the cold water supply is connected so that its outlet will be the farthest on the hot water supply line.[36] Circuit setters (special balancing valves used in commercial and industrial applications) can also be used.[37] Circuit setters are preferable to globe valves because carefully-determined globe valve settings are easily lost during system maintenance.

Potential Hazards

High water temperatures may be advantageous to maximize energy storage and to minimize flue gas condensation, but there is a risk of scalding injuries. Thermostatically controlled mixing valves can be used to blend hot water with cold water to produce safe service hot water temperatures (e.g., 120ºF). It only takes one second of exposure at 140ºF to get third-degree burns.[38] Thermostatically controlled mixing valves are available from Amtrol, Danfloss Automatic Controls, Encon Safety Products, Enerjee, INTEC Controls, ITT Hoffman, Lawler Mfg., Leonard Valve, Siebe, Sparco, Symmons Industries, and Watts Regulator.[39]

Low water temperatures can present a hazard too. The Legionella pneumophila bacterium can grow in systems at 115ºF or less and can cause serious illness (Legionnaire's Disease) if inhaled.[40]

Sources for Conventional Gas-Fired Water Heaters

See Section 7.2.16 for contact information for a sampling of manufacturers of conventional gas-fired water heaters. Web site links are included to facilitate easily learning more about the manufacturers and products.

2.9 Water Heaters, Direct-Contact

Direct-contact gas-fired water heaters put the water in direct contact with the combustion gases. This is typically done by spraying water down through a bed of stainless steel packing material while the hot combustion gases rise up through the same packing. The hot water is accumulated in an integral storage tank below. Additional hot water storage is provided with a supplemental tank.

Similar units are available that are heated using flue gases diverted from boiler exhaust stacks. Other units are available that bubble flue gases through a volume of water.

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Good News and Bad News

First, the good news:

a. Hot water availability is virtually instantaneous.

b. Units with high turndown ratios are available, so the units can track demand without excessive thermal cycling.

c. Water temperatures to around 185ºF are possible.

d. This process can be extremely thermally efficient – easily more so than most boiler or alternative gas-fired water heaters. The manufacturers tout thermal efficiencies of 99% and higher. Very little energy is wasted. In normal operation, the exhaust temperature is only a few degrees warmer than the inlet water temperature.

> *Typical well-maintained gas boilers and steam generators without waste heat recovery run around 78% to 83% thermal efficiency. Some hot water systems that are not direct-contact types reach the 93% to 97% range.*
>
> *Electric water heaters don't waste much heat at the water heater either, but they waste a lot at the generation plant. That's why electric water heating is expensive.*

e. The process helps to reduce oxygen in the heated water. Much of the oxygen in the water is consumed in the combustion. Reducing oxygen in the hot water helps to reduce corrosion in the water distribution piping.

f. The units operate at atmospheric pressure. There are no pressure vessels or related maintenance or safety concerns.

g. Units are available with USDA, FDA, and UL approval. The units are approved by the USDA and FDA to provide heated potable water for direct food contact in the food and dairy industries, at least when burning natural gas. Chemical contamination from biogas may be a problem; biological contamination from biogas is not likely a problem if the units are used to produce water at sanitizing temperatures as they frequently are in the food and beverage industries.

Now the bad news:

a. It is not at all clear that the units retain approvals when used with biogas. Any contaminants in the biogas will end up in the water. [This is actually not an insurmountable problem if the unit is used to deliver heat like a conventional hot water boiler (i.e., like a hydronic heating system). The contaminated water can be

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circulated through a heat exchanger to heat clean service water for uncontaminated end use. The drawback is that the additional heat exchanger adds expense.]

b. This author's experience in doing energy audits around the country is that people who have used these systems either love them or hate them – there is no middle ground. Those who hate them have had very bad experiences with hot water piping system corrosion shortly after installation of direct-contact water heaters. A variety of possible circumstances have probably contributed to the problems, including but not limited to:

- Some piping that may have needed replacement anyway.
- Improper water treatment for the water supply to the unit.
- Change of water pH when the new unit is operated improperly.
- Change of water supply temperature affecting pre-existing deposits.

Suffice it to say that this author is aware of units in the food processing industry that have been performing well without problems for over a decade.

c. Very hard water is a problem. It will foul the unit. Water treatment is required. [That's true for many other types of water heating as well.]

Applications on the Large Dairy Operation

How does a direct-contact biogas-fired water heater fit into the large dairy operation? Think of it as a highly efficient hot water boiler for a hydronic system. The hot water can be used to:

- Power absorption chillers with hot water instead of biogas.
- Heat service water, heat the digester, and heat enclosures with convection heaters.
- Heat and cool the home.
- Dry grain, manure, etc.
- Power Stirling engines to pump water, generate electricity, etc.
- Heat trace biogas lines to reduce condensation and freezing problems.

Potential Hazards

See Section 2.8 for information on maintaining safe water temperatures to avoid scalding injury and Legionnaire's Disease risks.

Sources for Direct-Contact Gas-Fired Water Heaters

See Section 7.2.17 for contact information for a sampling of manufacturers of direct-contact gas-fired water heaters. Web site links are included to facilitate easily learning more about the manufacturers and products.

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3.0 SYSTEM CONFIGURATIONS

Section 2 examined some of the implications of using well-established commercial products for biogas applications. Product capabilities and constraints were addressed. This section considers the integration of those products into systems. System capabilities and constraints are addressed for several generalized system configurations.

3.1 "All Options" Configuration

Figure 3-1 illustrates the "All Options" Configuration. This is a schematic overview, not a detailed flow diagram. Details such as equipment configuration, valves, bypass lines, bleed lines, return lines, etc. are omitted for conceptual clarity. The intent is to provide the "big picture" of what options are available and how they relate to each other in general terms (i.e., "from a 35,000 ft elevation").

Note the labels on the connecting lines such as "raw biogas," "H_2S-free biogas," "engine waste heat," etc. These help to distinguish systems and groups of equipment options. For example, raw biogas feeds the H_2S scavenger system, the H_2S-free biogas feeds the gas users, and the engine waste heat sources feed the anaerobic digester heating system.

The utility of Figure 3-1 is that it conceptually ties together all of the options. It is unlikely that there will ever be a dairy biogas system that uses all of these options, so a few simplified subsets of Figure 3-1 are presented in Sections 3.2 through 3.4.

Components of the "All Options" Configuration that are not addressed in this section include:

- Gas-fired radiant heating systems. [See Section 2.6 for background and Section 7.2.14 for manufacturer listings.]

- Gas-fired absorption chillers. [See Section 2.4 for background and Sections 7.2.4 and 7.2.5 for manufacturer listings.]

- Engine-driven chillers. [See Section 2.5 for background and Section 7.2.6 for manufacturer listings.]

- Engine-driven air compressors. [See Section 2.1 for background and Section 7.2.1 for manufacturer listings.]

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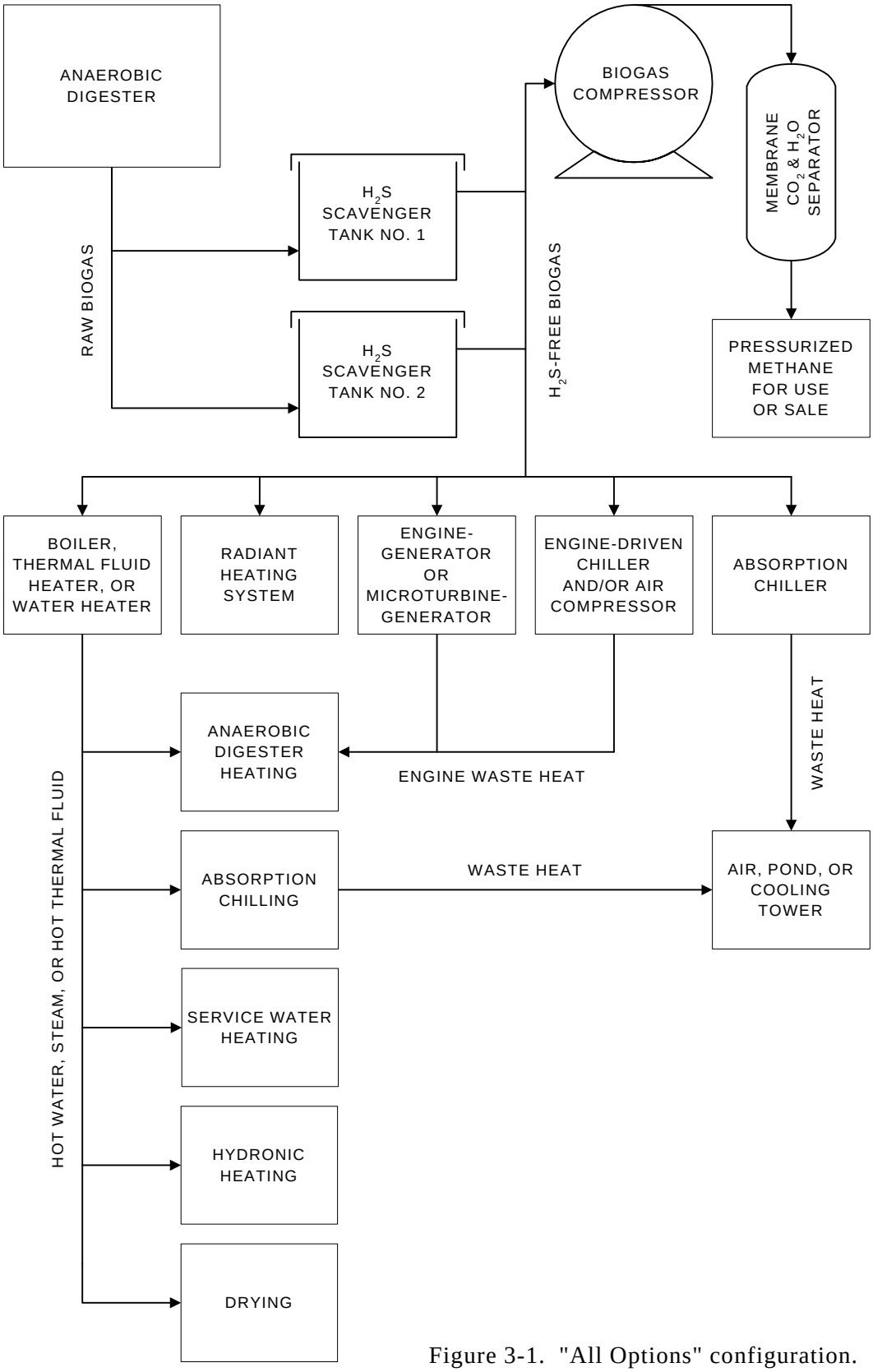

Figure 3-1. "All Options" configuration.

3.2 "Methane" Configuration

Figure 3-2 illustrates a "Methane" Configuration that is a subset of the "All Options" Configuration.

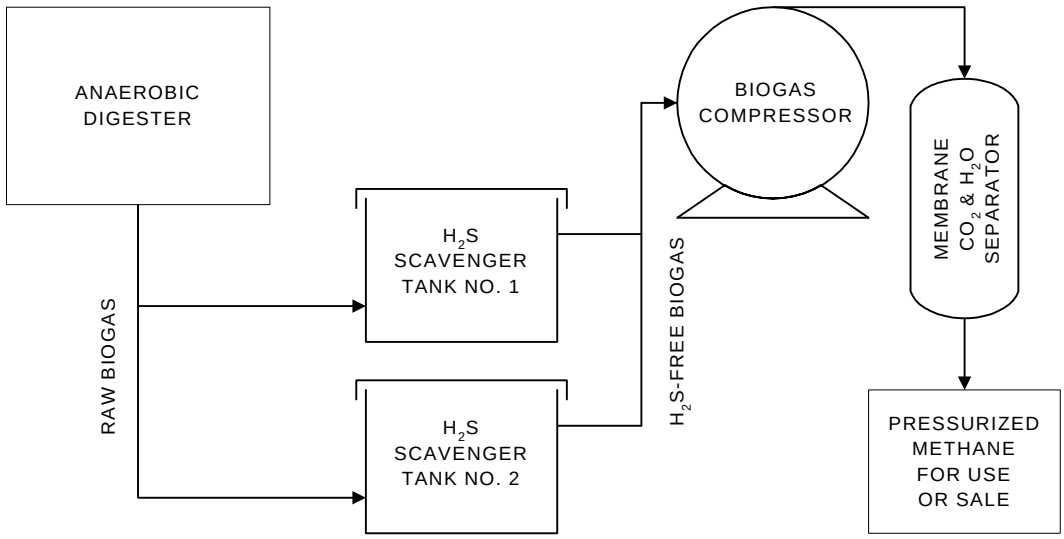

Figure 3-2. "Methane" configuration.

The anaerobic digester produces raw biogas at a low pressure. The rate of biogas production and the quality of the biogas will vary with herd size, manure composition, digester type and size, temperature, and many other variables. See Section 7.1 for an overview of the dairy case studies presented by Lusk.

For a plug-flow anaerobic digester and a herd size of 500 Holstein dairy cows in New York, Lusk assumes an average biogas production of 35,700 ft^3 per day.[41] The methane content is 62.3% and the hydrogen sulfide content is 1,500 ppm.

Koelsch et al discuss biogas transfer details including metering, pressure, pressure relief, and piping.[42] The digester system should supply gas for engines at 6 inches or more of water column pressure, and it is preferable to accomplish this with digester design rather than a blower.

Figure 3-2 shows two scavenger tanks for removing the corrosive hydrogen sulfide (H_2S) to protect downstream piping and equipment. There are many scavenger systems available. See Sections 1.3 and 7.2.13 for details. The point of showing two tanks in

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Figure 3-1 is that it is desirable to have a parallel back-up scavenger system so that scavenging can continue uninterrupted during scavenger system maintenance.

Koelsch et al provide some details on sizing an iron sponge scavenger system for a dairy operation.[43] For example, one bushel of Grade 7 iron sponge (7 lb iron/bushel) will remove 2,000 ppm of hydrogen sulfide from 35,000 ft^3 of biogas. Koelsch et al also note that the system can be highly effective if properly operated and maintained: "One biogas installation in the Northeast has successfully reduced hydrogen sulfide levels in biogas from more than 2,000 ppm to less than 1 ppm with an iron sponge scrubber."[44]

Lusk reports that dairy biogas hydrogen sulfide levels can vary from 480 ppm to 2,000 ppm. Lusk's 500-cow biogas system could require as much as a bushel of iron sponge each day. Scavenger efficiency, cost, and disposal options are important considerations.

Once the biogas is free of significant hydrogen sulfide, it can be distributed to on-site equipment that is adapted for biogas use. It is still a long way from commercial natural gas quality though, primarily because it is high in carbon dioxide (CO_2) and water vapor (H_2O). There is at least some motivation to further "clean it up" prior to piping it long distances or delivering it to systems that are not adapted for biogas use. One means of doing this is to compress the H_2S-free biogas and separate out the carbon dioxide and water vapor using a membrane system. See Sections 1.3 and 7.2.13 for details. The carbon dioxide waste stream can be used in greenhouse operations.

Selling the resulting high-methane fuel off-site is not without potential complications. Aside from controlling the composition, pressure, metering, and contracting, there are regulatory issues in some locations. For example, in some states the transactions fall under the control of the state Public Utilities Commission (PUC) or Public Service Commission (PSC) equivalent as soon as the gas is sold or transported across a property line. Sellers beware!

3.3 "Engine-Generator" Configuration

The typical approach to using biogas has been to send it to an on-site engine-generator to produce electricity, primarily for on-site use. See Sections 1.2 and 1.4.

Figure 3-3 illustrates the system configuration including the hydrogen sulfide removal. The Lusk 500-cow scenario discussed in Section 3.2 can, with an engine-generator approach, fuel a 67 kW engine-generator and net approximately 453,000 kWh annually. Offsetting electricity purchase at an average rate of 7.0 cents/kWh, this would reduce the electric bill by about $32,000 annually. This savings, however, must cover the engine-generator investment and the operating and maintenance costs.

Manufacturers of conventional engine-generators are listed in Section 7.2.8.

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Using a microturbine-generator to produce the electricity is a similar operation using an emerging (and currently higher cost) technology. See Sections 1.5 and 1.5.1 for background and 7.2.11 for manufacturers.

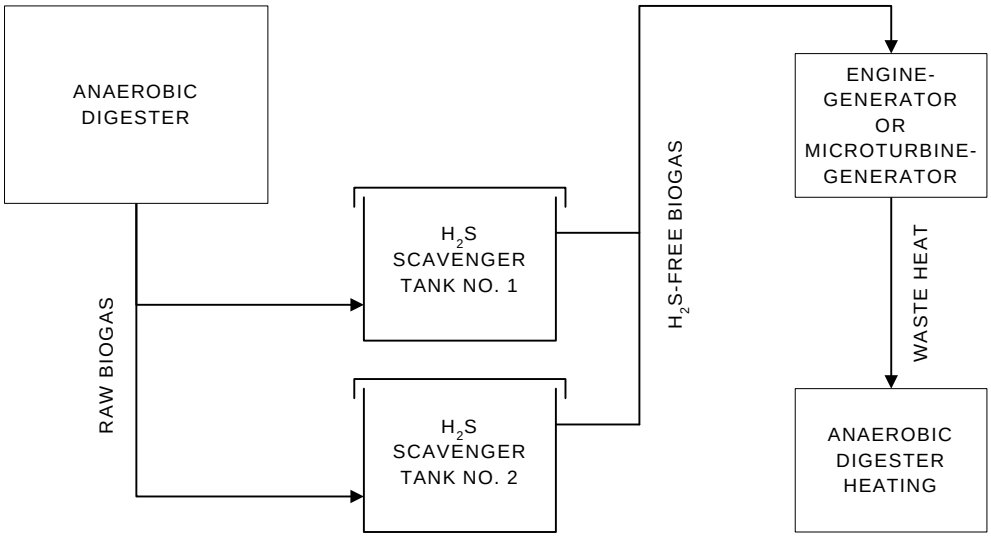

Figure 3-3. "Engine-Generator" configuration.

Regardless of whether an engine-generator or a microturbine generator is used to produce electricity, there is a significant amount of waste heat that should be recovered and put to good use. Uses include anaerobic digester heating, service water heating, and other heating. Using heat for hot water applications is discussed in Section 3.4.

Connecting into the electric utility system, with or without selling excess electricity "into the grid," requires switchgear and interconnection equipment plus permission from the electric utility company. Do not assume that the permission will be granted quickly or at all! Lusk documents one case study of a Cooperstown, New York dairy that learned in 1985 that "The decision to install the engine/generator was not without complications. The electrical agreement allows no recognition of surplus sales, and although local utility personnel were cooperative, overall negotiations with the utility were frustrating. Intertie negotiations with the utility were not encouraging, and inhibited prospects for a speedy contract."[45]

Location of the engine-generator relative to the electric utility service is very important for interconnection economics. Lusk documents one case study of a Candor, New York dairy that was forced to run 265 ft of 3-phase power cable at a cost of $8,000 due to poor engine location during initial design.[46]

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3.4 "Hydronic" Configuration

Figure 3-4 illustrates a "Hydronic" Configuration that is a subset of the "All Options" Configuration. Hydronic systems are covered in Section 2.2 and hot water boiler manufacturers are listed in Section 7.2.2.

Boilers are rarely noted in the documented case studies to date. Most cases strictly involve engine-generators for biogas use. One notable exception is an East Canaan, Connecticut dairy that began using a modified 400,000 Btu/hour boiler for heating the digester, residence, and nearby greenhouses in 1997.[47] There is no engine-generator – only the boiler. The 1998 summary included: "Many small modifications still required to get system fully functional, but overall 'very happy with the digestion system'."

What can be done with a hydronic system other than heating a digester, residence, and nearby greenhouses? Consider these possibilities:

- Heat service water.
- Power an absorption chiller with hot water instead of biogas. [See Sections 2.4 and 7.2.5.]
- Dry grain, manure, etc.
- Heat trace biogas lines to reduce condensation and freezing problems.
- Power Stirling engines to pump water, generate electricity, etc. [See Sections 1.5, 1.5.1, and 7.2.11.]

We speak of hydronic heating in regard to recirculating hot water, but it should be noted that the addition of some antifreeze is routine and helps to provide freeze protection and raise the boiling point. The resulting liquid may be considered a "heat transfer fluid" not unlike those discussed in Section 2.7 on "Thermal Fluid Heaters." In fact, for large dairy operations, the industrial thermal fluid heater may be a robust substitution for the hot water boiler typically used in a hydronic heating system. See Section 7.2.15 for manufacturers.

For the more adventurous and highly energy-conscious large dairy operator, a commercial-grade or industrial-grade direct-contact water heater may provide a significantly more efficient substitution for a hot water boiler. See Sections 2.9 and 7.2.17 for details.

Finally, it should be noted that all of these hydronic options have one advantage in common that is not readily available for biogas, electricity, or steam: hot water and hot heat transfer fluid are readily stored in tanks to facilitate system stability, "coast through," and load peak-shaving.

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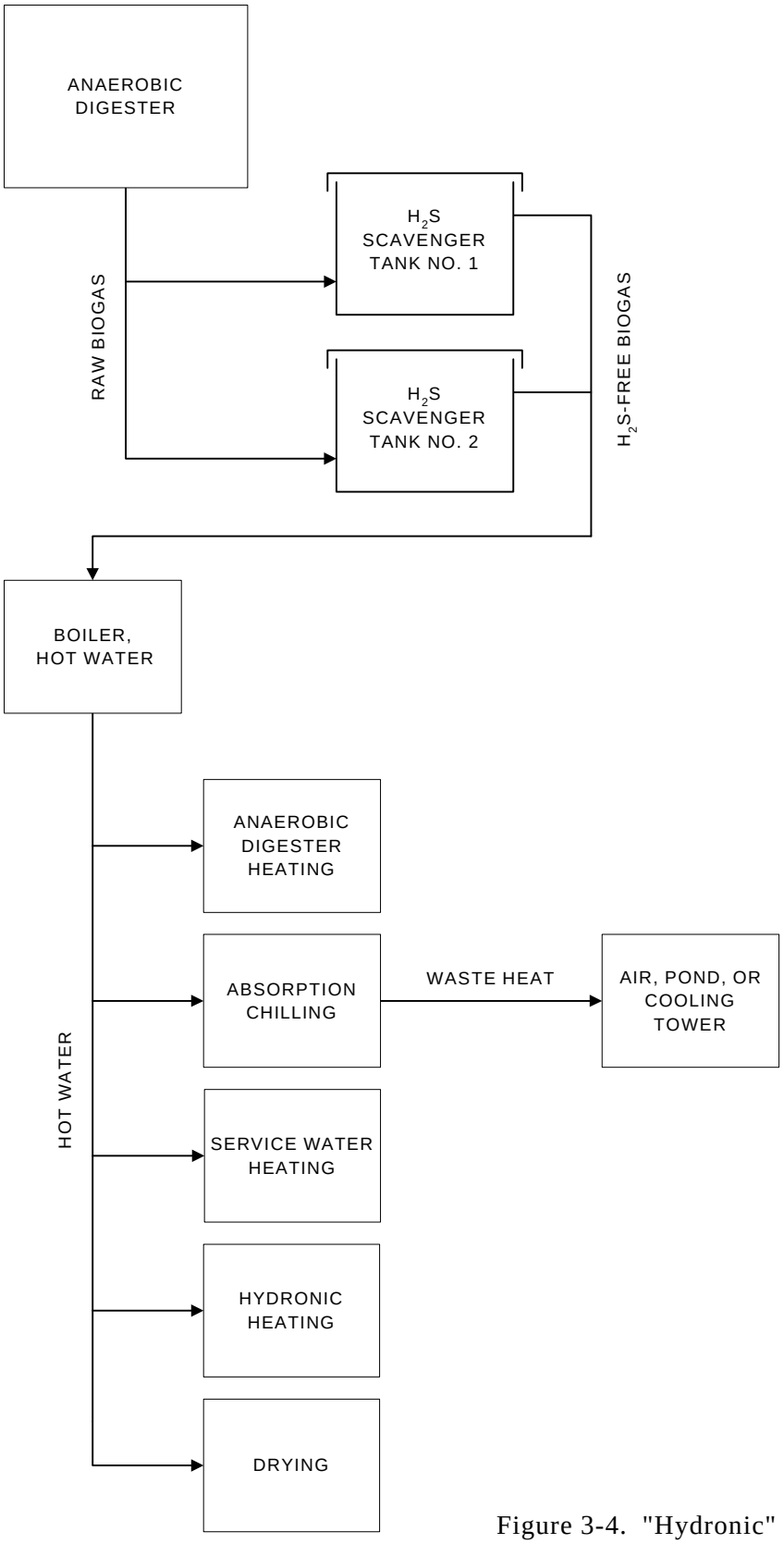

Figure 3-4. "Hydronic" configuration.

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3.5 "Optimum" Configuration

Obviously there are many, many permutations of possible systems. However, what is the optimum configuration?

Qualitative Analysis

In part, the task of selecting the optimum configuration for a particular large dairy operation is subjective. Some questions just can't be resolved quantitatively. For example:

- Is there a willingness to supply utilities (e.g., biogas, hot water, chilled water) to neighboring businesses on a long-term basis?
- Are engine-driven systems (e.g., generators, air compressors, chillers, water pumps) acceptable options?
- Is there a willingness to pursue unusual systems if they fit (e.g., custom absorption systems, thermal fluid heaters, direct-contact water heating)?
- Are emerging technologies (e.g., microturbines) acceptable or desirable?
- Is odor control a big enough issue that a full-capacity anaerobic digester is desired even if there are insufficient biogas applications to use all of the energy?
- How much time and effort can be put into system operation and maintenance, and what are the capabilities of those available for the work?

There are probably dozens of these issues, and they must be resolved and understood by the system designer before or in the earliest stages of the system design.

Quantitative Analysis, On-Site

Once the major qualitative questions are addressed, the quantitative analysis can begin. To minimize the capital cost, this requires sizing the biogas application system to fit the energy needs, including off-site energy use.

To some extent, this is a straightforward task. It starts with an energy audit of the dairy operation: a tally of all of the energy uses that can be readily supplied using biogas-based systems – and all of the potential future biogas applications (e.g., retrofit of the residence to hydronic heating). The energy audit should take into account:

- When the energy is consumed. [Some uses are seasonal, some vary hourly, etc. Extensive load profiles are required to properly size equipment without resorting to "safety factors" that drive up capital costs.]

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- Uncertainties of biogas supply. [Herd size changes, etc.]

- Efficiencies of biogas application. [Different biogas applications have different thermal efficiencies, etc.]

Once the entire on-site picture is clear to the system designer, the off-site implications can be considered. The key is whether there will be off-site implications. If the dairy operation is large, and if all manure is to be processed through the digester, and if all biogas is to be used if possible (rather than vented or flared), then there will almost certainly be off-site implications.

Biogas production increases with herd size, but applications like residence heating don't. Furthermore, many dairy applications don't use much energy anyway. For example, AgSTAR reports that milk precooling for one cow only requires 15% of the potential biogas production from the same cow.[48] The result is that export or waste of biogas energy becomes inevitable for larger dairy operations if the digester size is not scaled down to less than full manure capacity. See Figure 3-5.

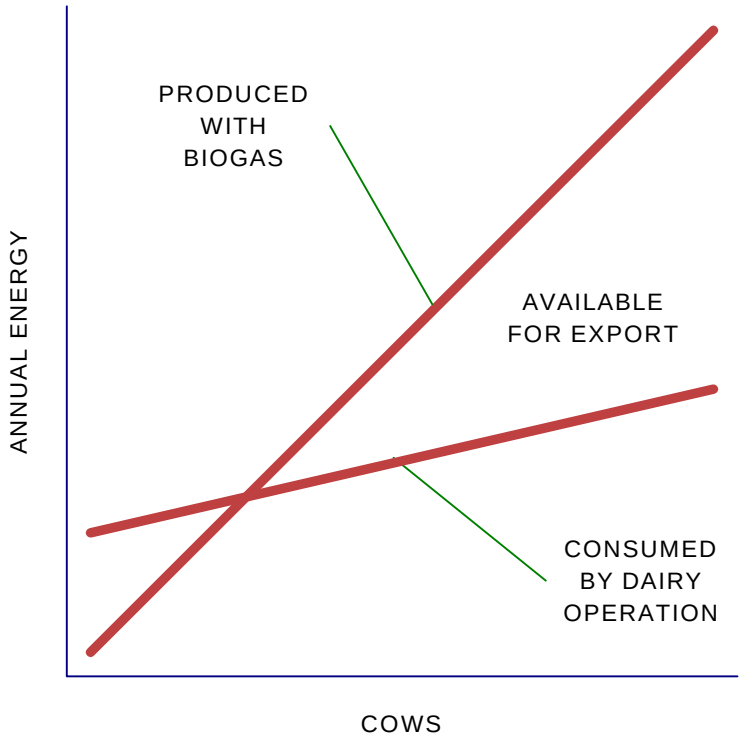

Figure 3-5. Energy production exceeds consumption for large dairy operations.

If energy is to be exported, the system designer's options are limited:

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- Electricity can be generated and fed into the electric utility system (if the utility will permit it). The designer must determine whether the economics of selling electricity to the utility justifies the higher incremental capital cost of a larger engine-generator, the associated higher maintenance costs, and increased hydrogen sulfide removal costs.

- Thermal energy (e.g., hot water, steam, and/or chilled water) and/or biogas can be sold to close neighbors. There is no readily accessible "grid" in which to pump thermal energy and/or biogas, and storage and transport have practical limits. Either a close neighbor has a good application for thermal energy and/or biogas, or this is not an option.

Selling electricity is addressed in detail in many places (e.g., the AgSTAR Handbook[49]), so it is not addressed here. The issue addressed here is the system designer perspective on selling thermal energy or biogas.

Quantitative Analysis, Off-Site

Off-site applications for thermal energy require as extensive an energy audit as on-site applications. As with the on-site applications, the subject load profile must be well understood.

The good news is that commercial facilities like office buildings are well understood by heating, ventilating, and air conditioning (HVAC) engineers, and load profiles are easily predicted with good accuracy. Other commercial facilities such as food processing plants also have predictable load profiles.

The bad news is that the thermal energy and/or biogas available for export from the dairy operation must be sufficient to supply needs without resorting to complicated controls and/or bouncing back and forth between systems. That may not be possible. For example, consider Figure 3-6.

> *A neighboring office building may need chilled water for air conditioning, but only from May to October with demand peaking in July or August.*
>
> *In Case 1, the large dairy operation can supply sufficient chilled water, but note that there is a tremendous excess of export capacity from October to May, and even from May to July to some extent. Perhaps hot water can be supplied for heating the office building in the cold season, but more export energy is available in the summer when digester heating is not required.*
>
> *In Case 2, the large dairy operation cannot support the peak demand for office building air conditioning. Is it worth the bother to the office building personnel who must run a chiller on their site anyway?*

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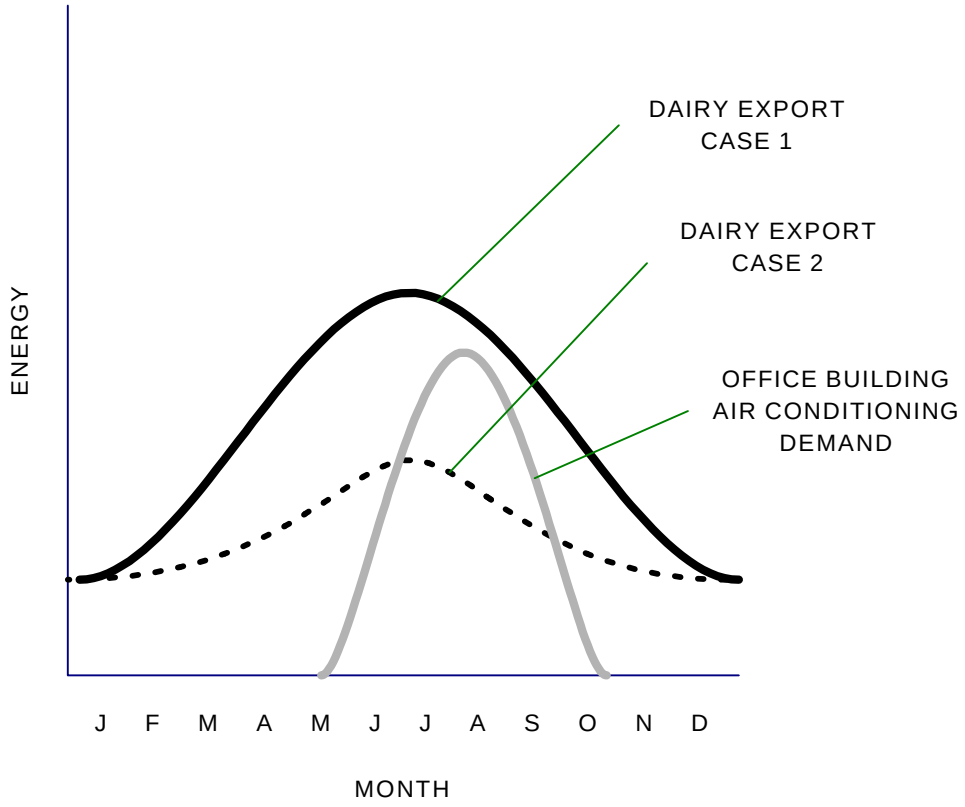

Figure 3-6. Seasonal and operational factors affect energy export by large dairy operations and demand from neighboring businesses.

> *Finally, Case 2 may be the same dairy operation as Case 1 except that the cows are sent out to the pasture in the summer. The system designer must anticipate this or the dairy and its neighbor may regret their association.*

The moral to this story is a simple one that applies to all thermal energy alternatives to engine-generators for large dairy operations:

> *Thermal energy systems have many advantages, but the available loads will rarely be a good fit year-round, and the only recourse may be accepting a significant waste of energy. [Even if an engine-generator is added, there may not be good applications for all of the waste heat from the engine-generator.] The only exception is in the case of a large, energy-intense neighbor such as a food processing plant that can absorb thermal energy in large quantities at all times.*

It is important to find the optimum configuration, but there is no guarantee that the optimum configuration will make use of all of the energy that can be produced.

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4.0 EXAMPLE DAIRY OPERATIONS

The purpose of examining the following example dairy operations is to illustrate some "real world" considerations that are not readily evident from some of the references.

The first and second example dairy operations are actual cases in Wyoming County, NY. Except as otherwise noted:

- All background information is based on year 2000 as collected and provided by Diane Chamberlain of the Western New York Farm Bureau Office in February 2001.[50]

- Electric service is provided by New York State Electric & Gas (NYSEG).[51] All rate and tariff information is available on-line.

- No adjustments have been made to Example Dairy No. 1 account for the sales tax exemption on electric service available effective September 1, 2000.[52]

The third example dairy operation is hypothetical and illustrates an all-thermal biogas application (i.e., no engines).

4.1 Example Dairy No. 1 (The Ransom-Rail Farm)

This dairy is the Dueppengiesser farm (Ransom-Rail Farm, Inc.) near Perry in Wyoming County, NY. The dairy operation increased from 600 to 800 milking cows during year 2000 and had no anaerobic digester.

Natural Gas Consumption

The farm is unusual in that heating tasks such as service water heating and building heating are currently performed using natural gas from on-site wells. Unfortunately there is no natural gas metering, so there is no consumption data available. Data is always preferable, however the natural gas consumption can be estimated during an engineering feasibility study.

Electricity Consumption

Although the electric rate has time-of-use and demand components, the total annual electric cost of $34,900 and the total consumption of 321,000 kWh yields an average rate of $0.109/kWh or 10.9 cents/kWh. This is relatively high and is encouraging in regard to an engine-generator application. For perspective, the average commercial electricity price in the continental U.S. in year 2000 was between 7 and 8 cents/kWh.

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Demand charges were typically around $11.70/kW monthly. This is also relatively high and is also encouraging in regard to an engine-generator application. Demand peaked at 98 kW in late July or early August, and at that time the demand charge alone accounted for over 25 percent of the electric bill.

The electric cost breakdown by application is shown in Figure 4-1. Milk precooling is the single highest cost. Note that milk precooling is a potential thermal energy application (e.g., it can be done with an absorption chiller using hot water or waste heat from an engine-generator). Eliminating electric costs for milk precooling would reduce the annual electric bill to around $25,000.

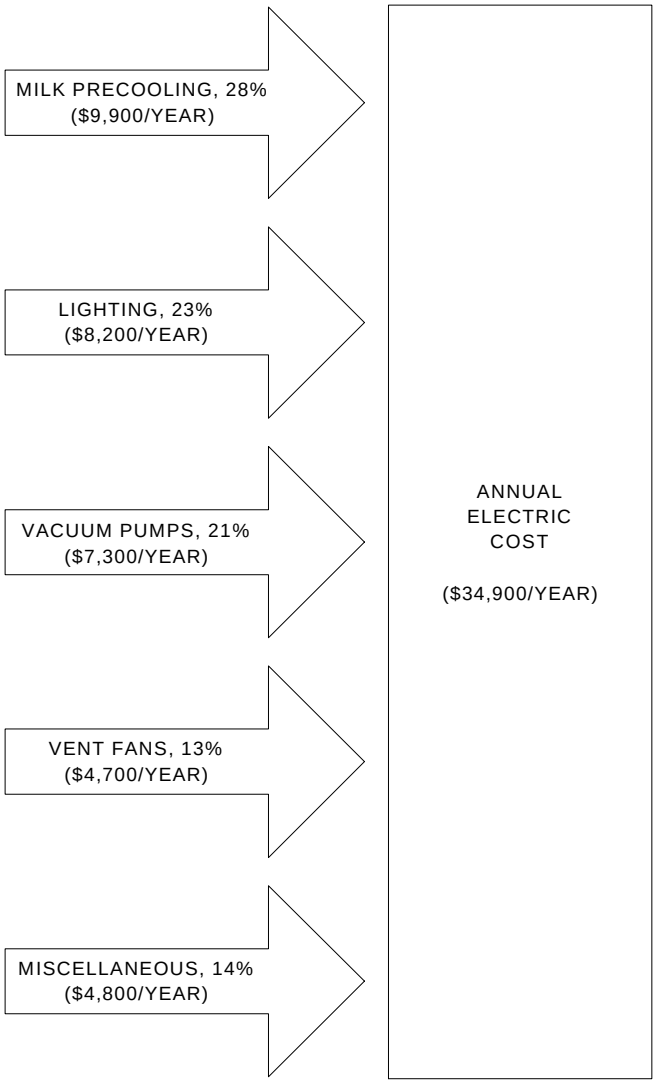

Figure 4-1. Annual electric costs for Example Dairy No. 1.

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Biogas Potential

Using the Lusk estimating assumptions[41] and assuming 700 milking cows, daily biogas production with an anaerobic digester would have averaged approximately 50,000 ft^3/day and this would have been sufficient to fuel a 94 kW engine-generator. This is encouraging because it nearly satisfies the peak demand of the dairy: the dairy would be electrically self-sufficient for most of the year and there would almost always be excess electricity for sale to the utility.

Options

For illustrative purposes, we will at first ignore the on-site natural gas system and its heating loads. Even in this simplified case that has few additional thermal applications, there are numerous biogas application options to consider:

1. Engine-generator sized for full biogas capability (800 milking cows).

With this option, all electricity can be provided on-site and excess can be sold to NYSEG. Excess would be sold under the terms of NYSEG Service Classification 10.[51] Back-up power would be purchased under the terms of NYSEG Service Classification 11 to cover scheduled maintenance outages and any unscheduled outages.[51] These rates are rather complicated, and modeling for a typical year would have to be done during the engineering feasibility study to assess economic impact. [A special provision that allowed sale of electricity to the utility at a flat rate of about 2.5 cents/kWh is no longer available to new customers on these rates.]

2. Engine-generator sized for partial biogas output.

This option would accommodate herd size variations without purchasing engine capacity of limited application. The impact of not being able to cover full peak demand of the dairy is that supplemental electricity would be purchased under the terms of NYSEG Service Classification 11.[51] The engineering feasibility study would address cost for the next incrementally-larger engine-generator versus the economic benefit of occasional use of the incrementally-higher capability.

On-site natural gas considerations aside, there is little incentive to size an engine-generator for annual peak electrical demand unless there is good economic incentive to sell excess electricity to the electric utility. Annual peak demand is a rare event. Refer to the table below for this dairy in year 2000:

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Month	Electric On-Peak Demand (kW)
January	47
February	56
March	48
April	72
May	65
June	84
July	98 (annual peak)
August	88
September	83
October	54
November	44
December	39

On this dairy operation, the year 2000 peak for billing demand was 98 kW in July. Examination of the table reveals that the billing demand was substantially lower for most of the year. What the table does not show is that the 98 kW peak may also be an anomaly during the month in which it occurred: it is the highest peak (during the "on-peak" rate periods) for all of the 15-minute intervals during that month. It could be an isolated load spike. For electric self-sufficiency, an on-site generation system would have to satisfy that peak.

If electric self-sufficiency is not essential, there may be no incentive to buy a engine-generator to deliver 98 kW, especially if the electric company offers low compensation for excess electricity supplied to it by the dairy. The average demand year-round (annual kWh / 8,760 hours per year) was only 37 kW.

Note, however, that a smaller engine will provide less engine waste heat for winter digester heating, so that may provide one lower bound for engine-generator sizing. Also, occasional biogas venting or flaring may be necessary when the combination of engines and other biogas-consuming equipment provides insufficient load for the biogas generated. Individual project economics aside, using all of the biogas rather than wasting it may be attractive to those with high environmental standards. [Why contribute more methane to global warming, and why waste the biogas when doing so will only cause the electric company to burn more fuel to meet electric demand?]

3. Engine-generator with gas-fired absorption chiller.

One advantage to this option is biogas load diversification: a problem with one biogas appliance (i.e., engine or chiller) does not put the other biogas appliance out of service. A second advantage is obtained by giving the chiller the capability to produce back-up hot water for heating the digester in the event of a wintertime engine problem.

The only significant chilling load on this farm is milk precooling, and this only requires a 5 tonR to 10 tonR chiller capacity. In this low-capacity range, the only commercially-available gas-fired absorption chiller line that does not require custom design is the

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Robur "Servel" line. These are air-cooled units – which is convenient – and they can be controlled to produce hot water instead of chilled water. The downside is that they can't produce hot water and chilled water at the same time, so digester heating precludes milk precooling. This may be perfectly acceptable so long as the conventional milk precooling system is retained for back-up.

4. Engine-generator with hot water boiler and hot-water-fired absorption chiller.

As with the previous option, one advantage to this option is biogas load diversification: a problem with one biogas appliance (i.e., engine or chiller) does not put the other biogas appliance out of service. Also, there is capability to produce back-up hot water for heating the digester in the event of a wintertime engine problem.

This is also a very attractive option for additional reasons:

- It vastly increases the number of manufacturers that can be considered for the biogas-consuming equipment (i.e., the hot water boiler instead of the small gas-fired absorption chiller).

- It can provide back-up digester heating and milk precooling simultaneously.

- It opens the possibility of using biogas-produced hot water for other purposes such as hot service water, service water heating, hydronic heating of buildings, etc.

Unlikely Options

Two additional options are possible but unlikely:

5. Engine-generator with waste heat-fired absorption chiller.

Waste heat from the engine-generator could be used to fire an absorption chiller. The primary advantage to this option is either (a) more electricity for sale (i.e., due to full biogas capacity to the engine and reduced on-site electricity use with the chiller) or (b) capability to use a smaller engine-generator (because refrigeration is no longer electric). The problem is that it puts chiller performance at the mercy of engine performance, which may be an unacceptable relationship when the chiller service is milk precooling. Engine waste heat recovery temperature variations would probably introduce unacceptable variations to the milk precooling process through the absorption chiller.

6. Stand-alone biogas-fired absorption chiller (i.e., no engine-generator).

This option can be thought of as "better than flaring, and with no engine maintenance," but it is dubious at best for this dairy operation that requires relatively little chiller capacity. Saving less than $9,900/year on milk precooling is hardly worth:

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- The biogas and chiller system investment.
- Biogas operational complications and costs such as hydrogen sulfide scavenging.
- System maintenance.

There is also the complication of not having sufficient heat for digester temperature maintenance from this approach, so a digester heating alternative (preferably using biogas) would be necessary.

The stand-alone chiller option is best applied in situations requiring larger chiller capacity such as selling chilled water to a neighboring business for air conditioning or food processing.

Preferred Thermal Option

If an alternative to a straight engine-generator application is desired (i.e., a thermal option is desired), Option 4 (engine-generator with hot water boiler and hot-water-fired absorption chiller) is probably the best choice. Figure 4-2 illustrates the concept and shows the energy flows for one scenario assuming a "700 cow" digester.

Detailed Commentary on Figure 4-2

Using the Lusk estimating assumptions[41] and assuming 700 milking cows, daily biogas production with an anaerobic digester would be approximately 50,000 ft^3/day. At 538 Btu/ft^3 for dairy biogas,[53] this has a heating value of approximately 27 million Btu/day. [Compare this to something like a household furnace which may be rated at 90,000 Btu/hour (2.2 million Btu/day). In such case, the Example Dairy No. 1 biogas output could be thought of as heating for a dozen homes. Unfortunately, that doesn't include the heat required by the digester, so it's not that grand.]

The biogas would be sufficient to fuel an engine-generator at about 94 kW average output. [In actual practice, this would require an engine rated for 110-120 kW. The low quality of biogas requires de-rating of the engine from the standard rating basis.] If biogas is also put to another use such as a hot water boiler, then the engine-generator capacity must be downsized accordingly. In this case, we want a 10 tonR absorption chiller that requires 5 million Btu/day of hot water input and that requires a hot water boiler with a 6 million Btu/day input. The result is a 73 kW electrical generation capacity rather than a 94 kW capacity.

Generating electricity with a smaller engine also produces less engine waste heat. This must be carefully considered in the engineering feasibility study because heat is required for the digester and, although there are other sources of heat (e.g., from the hot water boiler), control is simplified by having only one source for digester heating under normal operating conditions.

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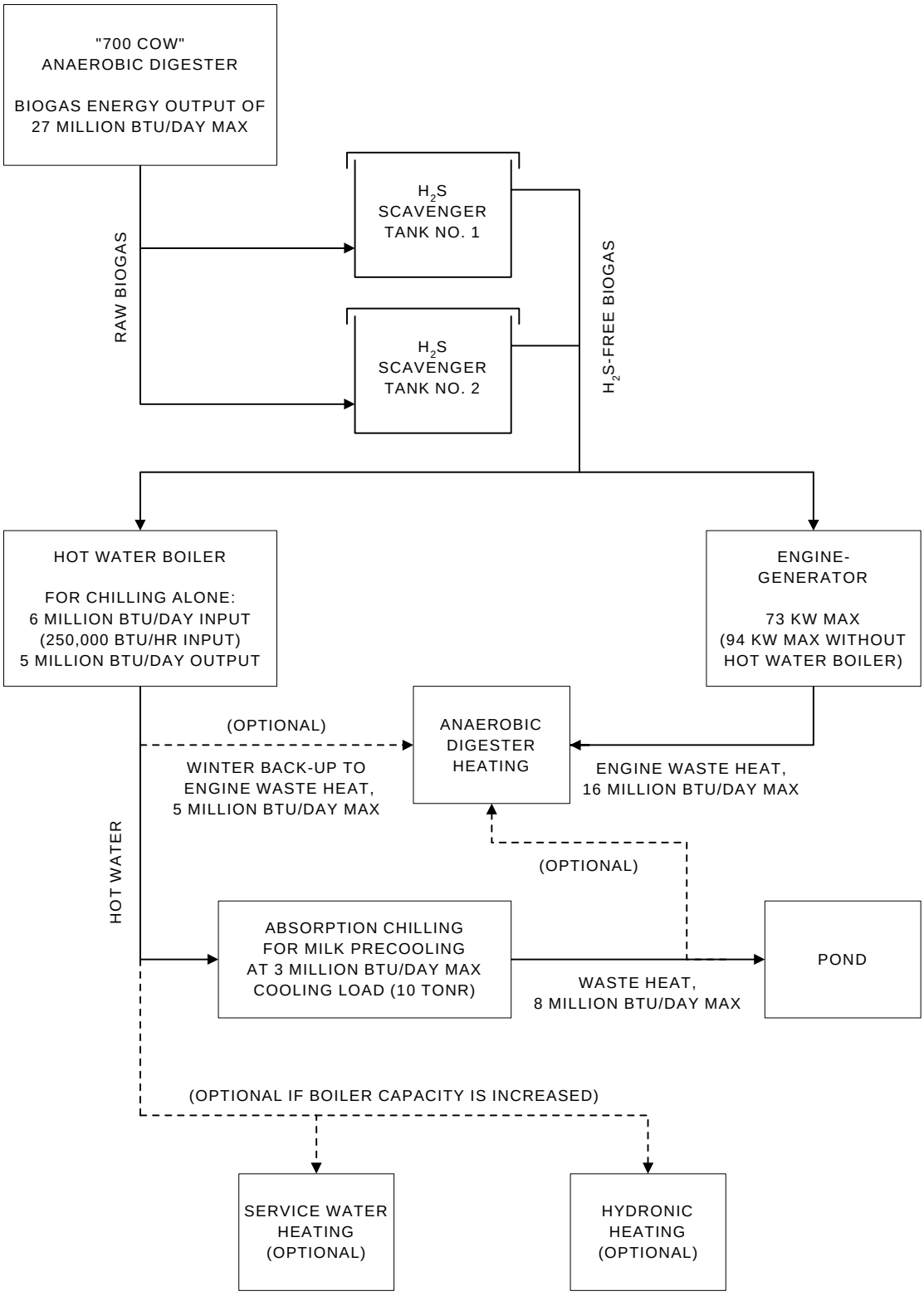

Figure 4-2. Thermal option for Example Dairy No. 1.

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Now consider the impact of using an absorption chiller for milk precooling. Hot water at 5 million Btu/day is required for 3 million Btu/day of cooling. All of that heat (i.e., 8 million Btu/day) must be discharged somewhere, and Figure 4-2 shows it going to the pond. The existing mechanical refrigeration system uses the pond too, but there will be more heat discharged to the pond with the absorption chiller because absorption chilling is inherently less thermally efficient than mechanical refrigeration.

Additional hot water capacity is optional and can be added as desired to replace heating tasks such as service water heating and building heating that are currently performed using natural gas from on-site wells. This requires a hot water boiler capacity increase, which in turn results in an engine-generator capacity decrease.

The moral to this story of Figure 4-2 is a simple one: the energy flow must balance, so optimum sizing of the engine-generator will require sizing decisions for the hot water boiler and its loads. More service water heating, for example, will mean less electricity production.

The engineering feasibility study must sort out all of the possibilities and offer one or more scenarios, if any, that are energy-balanced year-round and make the best set of compromises based on mutually agreeable criteria.

Boiler/Chiller Efficiency

An engine is not a highly efficient device, but then neither is the combination of a hot water boiler and an absorption chiller. In this example, 21 kW of electric generation capability has been sacrificed to provide 10 tonR of milk precooling. Let's re-word that: 6 million Btu/day of energy input to electric generation has been sacrificed to provide 3 million Btu/day of milk precooling (i.e., 50 percent thermal efficiency). That is better than an engine alone (25 percent), but worse than an engine with good waste heat recovery and a large waste heat application. [Waste heat recovery from absorption chiller is rarely practiced because the temperatures of the waste streams are relatively low and thus there are few good applications.]

On-Site Natural Gas Considerations

The use of natural gas from on-site wells at this dairy farm raises other considerations that should be pursued during any biogas project engineering feasibility study:

- Is there economic advantage to supplementing biogas with on-site natural gas to boost electric generation to maximum generator capacity? [This involves questions of part-load engine efficiency, maximizing payback on engine-generator investment, impact on on-site gas reserves, etc.]

- Which equipment is best suited to which type of gas (biogas or on-site natural gas)?

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- To what extent can the biogas and on-site natural gas systems be interconnected to further stabilize the operation of the systems, particularly in regard to maintaining optimum anaerobic digester temperature?

The on-site natural gas at this dairy farm thus presents unusual opportunities that may make this potential project especially interesting to energy performance contractors (and other parties offering financing) that may otherwise have marginal interest in dairy biogas projects.

Project Economics

Lusk provides a cost and benefits analysis for a plug-flow anaerobic digester and biogas project scenario for a herd size of 500 Holstein dairy cows in Tioga County, New York.[54] Example Dairy No. 1 is larger, and the Lusk projections can be extrapolated accordingly for a rough evaluation.

The cost of adding a hot water boiler and absorption chiller for Example Dairy No. 1 is significantly offset by the required engine-generator size reduction from 94 kW to 73 kW. Lusk notes that the basic cost of engine-generators (including heat recovery and controls) is about $1,050/kW, so the value of a 21 kW engine-generator size reduction is roughly $22,000. That's more than the basic cost for the 250,000 Btu/hour hot water boiler and 10 tonR absorption chiller, so extrapolating the Lusk example to Example Dairy No. 1 is a reasonable initial assessment. [Equipment costs are discussed further in Section 5.2 of this report.]

There is no substitute for the site-specific engineering feasibility study, but the owners of Example Dairy No. 1 can contemplate that extrapolating the Lusk example by a ratio of (700 cows / 500 cows =) 1.4 yields a total capital cost of $401,000 and a project first-year after-tax income of $27,000. Also, Lusk's example project scenario yields a positive after-tax income in every year of the project's life.

Cautions: Lusk's scenario, though detailed, is theoretical. It does not include a storage tank to hold liquid filtrate from the digester. It also makes assumptions about propane use and costs that do not apply directly to Example Dairy No. 1 that has "free" on-site natural gas. There is no substitute for the site-specific engineering feasibility study.

4.2 Example Dairy No. 2 (The True Farm)

This dairy is the True farm near Perry in Wyoming County, NY. The dairy operation has 750 milking cows and 650 heifers for a manure-collection equivalent of about 900 milking cows. [Manure collection from one heifer is about one fourth that from a milking cow.] There is no anaerobic digester.

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Natural Gas Consumption

Heating for the barn space heat, residence heat, and all hot water is provided with natural gas. Year 2000 natural gas consumption was 4,452 therms at a cost of $3,883, yielding an average rate of $0.85/therm or $8.50/million Btu. [One therm equals 100,000 Btu.]

The energy audit established that total barn hot water use requires about 1,330 therms per year, or about 30 percent of the natural gas use. This is 133 million Btu/year for an average of about 15,200 Btu/hour for barn water heating.

Electricity Consumption

Alas, Example Dairy No. 1 cannot provide good natural gas consumption data and Example Dairy No. 2 cannot provide good electricity consumption data. Less than a half year of year 2000 electric bills were available for the energy auditor. An engineering feasibility study will require obtaining the details of consumption from the utility, New York State Electric & Gas (NYSEG).

A comparison of the Example Dairy No. 1 peak summer bill to the Example Dairy No. 2 bill for approximately the same period is as follows:

	Billing Demand (kW)	Energy (kWh)	Total Cost
Example Dairy No. 1	98	39,200	$4,357
Example Dairy No. 2	101	49,920	$5,199

For illustrative purposes, this study will assume the following for Example Dairy No. 2:

- The annual peak demand is approximately 101 kW.
- Annual electrical energy use and cost are 25 percent higher than for Example Dairy No. 1. That yields annual electrical energy use of approximately 400,000 kWh and annual electric cost of approximately $44,000.

Since these two dairy operations are in the same county (and thus experience the same climate) and are on the same utility and rate structure, this is a reasonable approximation for illustrating a few basic principles.

The electric rate for this dairy is the same as for Example Dairy No. 1 and has time-of-use and demand components. The average rate is probably very close – about 10.9 cents/kWh. This is relatively high and is encouraging in regard to an engine-generator application. For perspective, the average commercial electricity price in the continental U.S. in year 2000 was between 7 and 8 cents/kWh.

Demand charges were typically around $11.70/kW monthly. This is also relatively high and is also encouraging in regard to an engine-generator application.

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Biogas Potential

Using the Lusk estimating assumptions[41] and assuming manure collection equivalent to 900 milking cows, daily biogas production with an anaerobic digester would have averaged approximately 67,500 ft^3/day and this would have been sufficient to fuel a 121 kW engine-generator. This is encouraging because it more than satisfies the peak demand of the dairy: the dairy would be electrically self-sufficient and there would always be excess electricity for sale to the utility.

Thermally, at 538 Btu/ft^3 for dairy biogas, this level of biogas production averages 36.3 million Btu/day. That's 1.5 million Btu/hour or 15 therms/hour or 131,400 therms/year. On an annual basis in New York State, roughly 33 percent of the biogas is required for digester temperature maintenance.[55] Thus about 88,000 therms/year are available and that dwarfs the year 2000 natural gas consumption of 4,452 therms. Adding 10 tonR of milk precooling with a hot water boiler and an absorption chiller as in Example Dairy No. 1 would increase thermal energy consumption by an additional (60 therms/day x 365 days/year =) 21,900 therms/year. At most then, on-site thermal applications could use about 30 percent of the available biogas energy.

This example illustrates that there is almost no escaping installation of an engine-generator for a large dairy operation unless there is a secondary or neighboring business that can use the excess thermal energy or unless the dairy operator is willing to downsize the digester or waste biogas.

Options

The options for Example Dairy No. 2 are the same as those for Example Dairy No. 1 except that biogas production and engine-generator size are somewhat larger. This is illustrated in Figure 4-3. In this case, however, using hot water for an absorption chiller for milk precooling and thus downsizing the engine-generator to 100 kW still leaves ample engine-generator capacity to cover annual peak electric needs (101 kW less electric milk precooling reduction). An engineering feasibility study would likely determine that an optimum engine-generator size based on capital cost and electricity sales rate is somewhat less than 100 kW. As with Example Dairy No. 1, the availability of natural gas raises additional considerations for evaluation.

There is no substitute for the site-specific engineering feasibility study, but the owners of Example Dairy No. 2 can contemplate that extrapolating the Lusk example by a ratio of (900 cows / 500 cows =) 1.8 yields a total capital cost of $515,000 and a project first-year after-tax income of $35,000. Also, Lusk's example project scenario yields a positive after-tax income in every year of the project's life.

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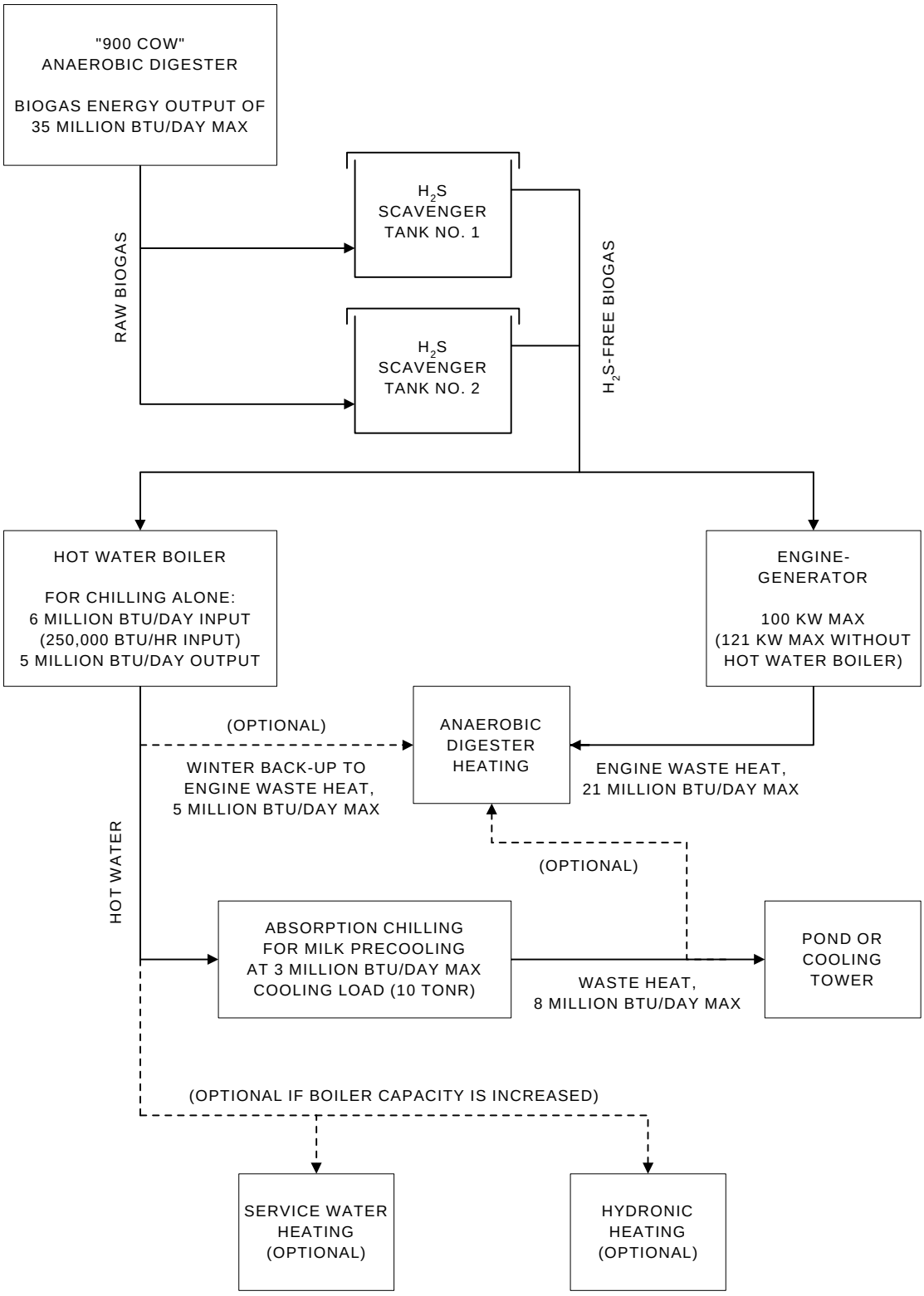

Figure 4-3. Thermal option for Example Dairy No. 2.

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4.3 Example Dairy No. 3 (A Hypothetical Farm)

This dairy is a hypothetical one in New York that has a neighboring business customer. The purpose of this example is to illustrate the capabilities of a large dairy to provide thermal utility services to a neighboring business.

Biogas Potential

Using the Lusk estimating assumptions[41] and assuming 1,000 milking cows, daily biogas production capability with the plug-flow anaerobic digester averages approximately 71,400 ft^3/day. This is sufficient to fuel a 134 kW engine-generator, however the local electric utility pays low rates for farm-generated electricity. A close neighboring business could use the electricity at a good "avoided" rate, but the dairy operator prefers to avoid the maintenance and other complications of an engine and a private electrical system. The thermal energy available from the biogas is 538 Btu/ft^3 for an average of 1.6 million Btu/hour.

The neighboring business uses hot water for a variety of purposes including hydronic heating in cold weather, office air-conditioning with an absorption chiller in warm weather, and service water heating year-round.

Configuration

The dairy operation contributes to business customer hot water production by burning all biogas in a hot water boiler and delivering all of the hot water to the business customer except that needed for digester temperature maintenance. The biogas-heated water is pumped to the neighboring business where it circulates through a plate-and-frame heat exchanger, delivers its heat to the business hot water system, and then returns to the dairy. This is a closed-loop system and amounts to a very simple hydronic system.

The advantages of a closed-loop system include:

- The business customer has no concerns about the quality of delivered hot water other than plate-and-frame heat exchanger fouling that requires occasional cleaning.

- The dairy operator has no concerns about pumping his water wells dry to support the business.

- Circulating hot water requires little water treatment and does not require freeze protection. A gasoline-powered pump or emergency generator can be provided for back-up pumping. This is preferable to adding glycol and potentially leaking or spilling glycol.

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- Delivered energy is easily metered. Flow, inlet temperature, and outlet temperature at the plate-and-frame heat exchanger are all that are required to quantify delivered energy, and the combination is readily metered with a commercial "Btu meter."

- The dairy system supplements the business system, essentially providing "preheating" of the business customer's hot water. There are no control issues to complicate operations.

Economics

The average 1.6 million Btu/hour available thermal energy is not all available for business customer needs. Roughly 20 percent is lost in the heating process (e.g., boiler stack losses). Also, on an annual basis in New York state, roughly 33 percent of the biogas is required for digester temperature maintenance.[55] In addition, there are thermal losses associated with the long run of piping. The result is delivery of no more than 800,000 Btu/hour on average to the business system. That's 8 therms/hour year-round average and, at $0.85/therm, the value of that is $60,000 annually. That's the maximum possible income from the business customer.

[It does not take a large business to absorb 800,000 Btu/hour. For a general business office, a 25,000 ft^2 building is probably sufficient during the heating and cooling seasons. Larger offices are required to also absorb that energy in the spring and fall. A business location doing any kind of thermal processing is likely to absorb that energy easily.]

Assuming a 20ºF temperature drop at the plate-and-frame heat exchanger, a hot water circulation of roughly 80 gpm is required to deliver 800,000 Btu/hour. The business is almost a quarter-mile away, so the total piping run there and back is about 2,600 ft. For a 3-inch diameter water pipeline and a total 15 psi pressure drop across the boiler and heat exchanger, the total system pressure drop is about 50 psi (i.e., about 115 ft of water column head loss). The 80 gpm at 115 ft head loss requires a pump of roughly 5 hp. At 10 cents/kWh the pumping electricity will cost about $4,000 annually.

The maximum income less the pumping cost is thus $56,000 annually.

Lusk's analysis for an engine-generator and 500 milking cows yielded 453,000 kWh annually. For 1,000 milking cows, that's 906,000 kWh annually. To obtain $56,000 income on that would require a rate of 6.2 cents/kWh – far more than most dairies have received for electricity sale to their electric company. See example cases in Section 7.1.

At this point, any good skeptic should be questioning the capital costs. The boiler should be under $30,000 installed. The pump and heat exchanger should total no more than $20,000. Insulated underground piping at $30/ft is another $78,000 – a major investment. That totals $128,000 in equipment costs. Compare that to an engine-generator cost of around $140,000 for 134 kW (at $1,050/kW per Lusk).

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Conclusion

This example demonstrates that a strictly thermal alternative to an engine-generator may be a viable option if there is a close neighboring business that can use the thermal energy. This is especially of interest when the dairy operation is large and the rate received for selling electricity to the electric company is low. [See Section 7.4 for a capacity tabulation showing water heating and absorption cooling capacities for herd sizes from 500 to 1,500 cows.]

4.4 "Lessons Learned" from Examples

The "lessons learned" from these three examples for New York area dairy conditions (climate, electric pricing, etc.) include:

- The biogas produced using 700 to 900 milking cows is probably sufficient to generate enough electricity to make the dairy farm electrically self-sufficient even during peak summer electrical demand.

- The economic wisdom of sizing an engine-generator for full biogas capacity hinges on the selling price for electricity to the electric company. A poor selling price may not justify a full-sized engine-generator.

- Heat required for digester temperature maintenance provides a lower bound on engine size if engine waste heat is recovered to provide the digester heating.

- A boiler/absorption chiller combination has a better thermal efficiency than an engine alone, but worse than an engine with good waste heat recovery and waste heat application.

- A 700-milking-cow project is theoretically around a $400,000 capital project and can yield a positive after-tax income in every year of the project's life.

- The thermal needs of a large dairy are significantly less than the biogas thermal capability. There is almost no escaping installation of an engine-generator for a large dairy operation unless there is a secondary or neighboring business that can use the excess thermal energy or unless the dairy operator is willing to downsize the digester or waste biogas.

- A strictly thermal alternative to an engine-generator may be a viable option if there is a secondary or close neighboring business that can use the thermal energy. This is especially of interest when the dairy operation is large and the rate received for selling electricity to the electric company is low.

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- A sufficiently large neighboring business that is within a quarter mile is a possible candidate for thermal energy sale from an all-thermal biogas system (i.e., no engines). Beyond that distance, piping costs begin to inflate the project capital cost to levels where an engine-generator approach may be decidedly preferable.

- The economic viability of any project is highly sensitive to herd size and electricity and fuel pricing. Anyone signing an agreement for a biogas project is agreeing to a set of long-term predictions for herd size and electricity and fuel pricing.

- The engineering feasibility study must sort out all of the possibilities and offer one or more scenarios, if any, that are energy-balanced year-round and make the best set of compromises based on mutually agreeable criteria.

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5.0 THE IMPLEMENTATION PROCESS

The large dairy operator contemplating a biogas project needs first and foremost to obtain a clear understanding of what is involved in the implementation process. There are several simple and inexpensive ways to obtain that understanding. They include:

- Reviewing dairy biogas case studies. See references 2, 3, and 4 for plenty of good case study material.[2,3,4]

- Studying useful references on the implementation process. See Section 5.1 below.

Once there is both a clear understanding and a continuing interest, the single most important factor in ultimate success or failure will be selecting an engineering contractor. See Section 5.4 for guidance. There is also work that can be completed by the dairy operator prior to the engineering feasibility study to expedite that study. See Section 5.5 for details.

5.1 Useful References for Getting Started

Numerous references provide useful guidance in implementation of a dairy biogas project. For examples:

a. *Anaerobic Digesters for Dairy Farms*[1] includes a section on "Matching a Biogas System to an Individual Farm" that addresses with both text and worksheets:

- Compatibility of anaerobic digestion with the dairy. [pp. 8-11]
- Estimation of component size and energy production. [pp. 12-13]
- Estimation of economic benefits. [pp. 14-16]

There is also guidance on applicable codes and standards. [pp. 48-50]

b. *Methane Recovery from Animal Manures: A Current Opportunities Casebook*[2] provides sections on:

- Economic evaluation of anaerobic digestion. [Section 3]
- System designer/installer contacts. [Section 6]

c. The *AgSTAR Handbook*[3] includes chapters on:

- Selecting a gas use option. [Chapter 3]
- Technical and economic feasibility assessment. [Chapter 4]
- Securing and energy procurement contract. [Chapter 5]

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- Selecting a consultant/developer/partner. [Chapter 6]
- Obtaining project financing. [Chapter 7]
- Permitting and other regulatory issues. [Chapter 8]

A list of designers, equipment suppliers, and vendors is also included in the handbook. [Appendix I]

5.2 Costing Prior to Feasibility Study

Any estimating of costs prior to a bona fide feasibility study by an engineering contractor is risky business. That said, few dairy operators would want to begin a study without at least some idea of what they may be getting into long-term. In such circumstance, the best reference is probably *Methane Recovery from Animal Manures: A Current Opportunities Casebook.*[2] Lusk addresses the subject in some detail and includes capital cost data in the case studies. [See Section 7.1 of this report to help identify case studies of particular interest.] Lusk does not include information on alternatives to engine-generators, so additional references are required.

One good source for estimating costs for boilers, chillers, electrical equipment, hydronic equipment, and other HVAC equipment and accessories is the R.S. Means Company[56] "Cost Data" series of books including:

- *R.S. Means Building Construction Cost Data 2001*
- *R.S. Means Electrical Cost Data 2001*
- *R.S. Means Mechanical Cost Data 2001*

The data in this series is extensive and the books are revised annually. Installation cost data is included, as are adjustment factors for location and other variables.

Another useful reference that includes cost data, though not so frequently updated, is the *National Mechanical Estimator* by Victor Ottaviano and John Ottaviano.[57] In this case, the age of the data (last published in 1995) is offset by the advantages of numerous diagrams, charts, etc. that give a broader perspective than tables of costs alone.

For those who just want a few "ballpark figures" for illustration, the following gas-fired equipment costs may be of interest but do not include customization for biogas, accessories, or installation and are not in any way warranted for accuracy:

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Item	Equipment Cost Range (Material Only)
Absorption chiller, 3 tonR, air cooled	$3,500-$5,000
Absorption chiller, 10 tonR, air cooled	$11,000-$15,000
Hot water boiler, cast iron, 250,000 Btu/hr output	$2,500-$4,000
Hot water boiler, cast iron, 1 million Btu/hr output	$7,000-$10,000
Hot water boiler, cast iron, 4 million Btu/hr output	$22,000-$28,000
Hot water boiler, cast iron, 6 million Btu/hr output	$45,000-$55,000
Radiant heater, unvented, 30,000 Btu/hr input	$350-$500
Radiant heater, unvented, 120,000 Btu/hr input	$800-$1,000

Readers are cautioned that costs for the major pieces of equipment are but a small part of the total project costs. In the case of a hot water boiler, for example, there are numerous pieces of site-specific accessory equipment such as a foundation and shelter, the water piping and insulation, water pumps, gas piping, electrical equipment (for lighting, controls, etc.), the stack, water treatment, etc. As a practical matter, there is no good intermediate option between the available case studies and a detailed, site-specific feasibility study by an engineering contractor.

5.3 Implementation Overview

The biogas project implementation process is flowcharted in Figure 5-1. The following points supplement the figure:

- Scoping of the feasibility study requires at least some project definition on the part of the dairy operator. For example, the dairy operator should determine whether a neighboring business has interest in biogas thermal applications, whether the existing dairy and residence heating systems should be replaced or supplemented, etc. Defining all known project constraints will help to minimize the feasibility study costs.

- Selection of the firm to do the engineering feasibility study requires careful attention and should not be rushed. The feasibility study will set most if not all of the design parameters and will establish the equipment specifications and "investment grade" project cost estimates. [There are nine different designers represented in the 13 case study projects summarized in Section 7.1, and there are certainly many other design firms that are capable of executing the study.]

- Capital project design costs incurred in the feasibility study can usually be rolled into the capital project and depreciated over many years. Consult a tax advisor.

- Some of the case study projects summarized in Section 7.1 have benefited through government subsidies. There is no reason to believe that the availability of subsidies is declining given the current levels of interest in global warming, renewable energy, and air and water pollution control.

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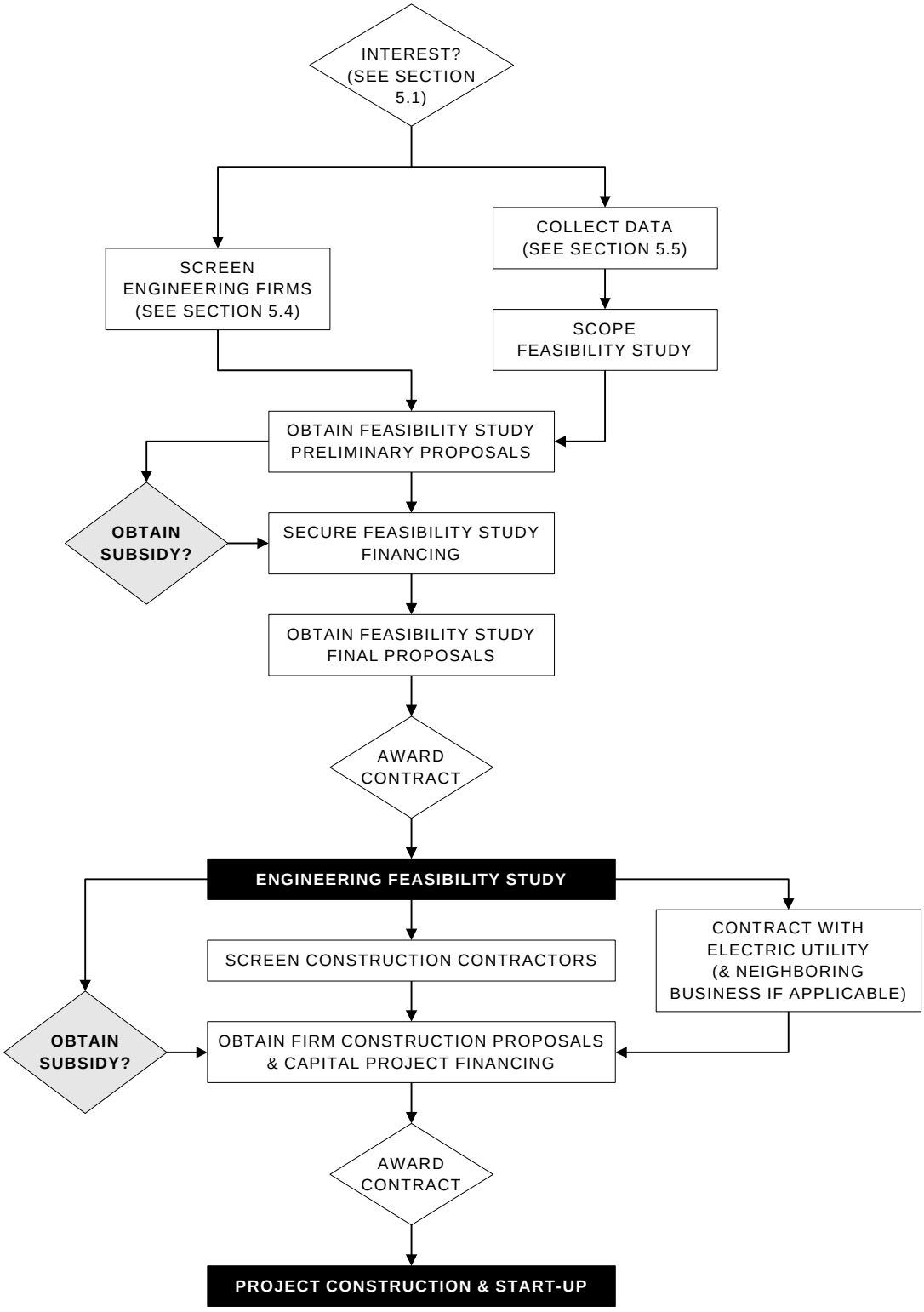

Figure 5-1. Implementation overview.

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5.4 Selecting an Engineering Contractor

Outside technical expertise is usually needed to implement a project. That expertise will come in the form of an engineering firm, a design/build engineering contractor (providing engineering design and implementation), or an energy performance contractor (a specialized design/build/finance contractor that uses savings to finance the initial investment). A word of caution: although design/build and energy performance contracting have many advantages, the engineering firm approach is most likely to give you an unbiased feasibility study. The other approaches are fine after an unbiased feasibility study is done, but don't compromise the validity of the initial study with a longer-term arrangement at the outset. Take everything in stages that will provide flexibility and options.

Characteristics of a Good Engineering Firm for a Biogas Project

Broad technical capabilities. The firm should have at least one full-time civil/structural engineer, one full-time mechanical/HVAC engineer, and one full-time electrical engineer. Chemical engineering, environmental engineering, and estimating specialists are also highly desirable. If a hydronic system is a part of the project, an HVAC engineer with strong hydronic experience is essential.

Willingness to consult with outside specialists. Let's face it: the specialist with the strong anaerobic digester background is not the same person as the specialist with the strong hydronic heating system background or the strong engine-generator background or the strong absorption refrigeration background – and one is not likely to find them all in the same engineering firm. A good firm will be enthusiastic about subcontracting to acquire expertise where it needs it.

There is an in-house estimating department. It's not that your job is so big that it requires professional estimators; it's simply that an engineering firm with an estimating department has internal checks and balances, "keeps score" on projects, and learns from its estimating mistakes.

Small to medium size with a stable workforce (i.e., not a "revolving door"). Hire an engineering firm where engineers stay, not one used as a career stepping-stone. Test this by examining resumes for a few of the technical specialists that may be involved in your project – the actual technical specialists, not their managers. A good selection would be a mechanical engineer, an electrical engineer, and an environmental engineer. Why not hire a large firm? Large firms are typically optimized for large projects and, even though it may seem like one to you, your project is not a large one.

Professional engineering licensure in your state. Frankly, too many consultants and contractors who are not licensed engineers overstep their bounds. For example, they avoid or evade state engineering license requirements by pushing the major engineering obligations onto the equipment suppliers. This is a prescription for serious trouble:

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many suppliers don't have strong engineering staffs to start with, and they are certainly in no position to provide the overall system design and integration that should be done by a professional engineer. Furthermore, in many states it is actually illegal for a non-engineering general contractor or other third party to hire the engineer: the engineer must provide service directly to the client without any unlicensed third party in between them. This avoids introducing other interests (such as the financial interests of the third party) that could adversely affect the quality of the engineering service received by the client.
How do you tell if a candidate engineering firm or its principals are licensed in your state? Ask to see licenses. In most states, they are required to be on display in the place of business.

Access to and familiarity with the applicable codes and standards. Most "laymen" do not appreciate the importance of codes and standards beyond satisfying the law. Many applicable codes and standards provide design requirements that have been carefully honed by technical committees of engineers experienced in the associated field. If the candidate engineering firm does not provide its engineers ready access to the latest versions, it is not the firm for this project. Test each candidate engineering firm for access to the latest versions of codes such as these available from the National Fire Protection Association (NFPA):[58]

- NFPA 54: "National Fuel Gas Code"
- NFPA 37: "Standard for the Installation and Use of Stationary Combustion Engines and Gas Turbines"
- NFPA 70: "National Electrical Code"

How do you test a firm? Ask to see one or more of these codes while visiting the office. Do not accept the excuse that few codes are required by local law in a rural area: a good firm will design to code whether the law requires it or not.

Costs and justifications are evaluated with a realistic life-cycle cost perspective. Money has "time value" – a dollar spent on equipment today is not justified by a dollar of savings five years from now. The true cost and value of a project is assessed by considering the "time value" of all initial capital investments, start-up costs, operating costs, maintenance costs, etc. If the economics of the system is important to you, you need an engineering firm that looks beyond the end of the capital project and realistically assesses the costs and benefits over the projected life of the system.

The client will receive "as built" drawings and documents, clean copies of all vendor literature, and maintenance and spare parts recommendations. If the candidate engineering firm is not going to look out for your long-term interests, it is the wrong engineering firm.

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Finally, a good engineering firm has lots of repeat business. Examine the client list and references and inquire as necessary to determine that the candidate engineering firm routinely does a good enough job to be invited back as new projects arise.

5.5 Assembling Data Prior to Feasibility Study

To avoid delays, the following dairy data should be assembled prior to beginning an engineering feasibility study:

- **Electricity bills.** The engineer will want details of kW, kWh, and cost for several past years if possible. If there are multiple accounts (e.g., farm and residence), you will need to provide details for all accounts. Prepare copies of all available electric bills.

- **Heating fuel bills (natural gas, propane, fuel oil).** The engineer will want details of consumption and cost for several past years if possible. Prepare copies of all available heating fuel bills.

- **Nameplate details for all thermal equipment.** Provide make, model, size, age and any other significant details for any equipment that burns a fuel (except vehicles), uses hot water, provides air conditioning, or provides refrigeration. Note when it is used during the year (e.g., seasonal basis, daily basis, back-up basis).

- **Special contracts.** Provide copies of any special contracts for electricity, gas, water, etc. [A special contract is one that is not a standard utility tariff arrangement.]

- **Property plot plan, deed, and easements.** Provide copies of the property plot plan, deed, and easements if biogas, chilled water, electricity, hot water, or steam may be sold to a neighboring business. Easements are especially important if they restrict right-of-way for required interconnections.

If there is a close neighboring business of any kind that may be interested in buying biogas, chilled water, electricity, hot water, or steam, that business should prepare the same information.

In addition to the information listed above, the dairy operation should also compile:

- **Herd details.** Provide counts of milking cows, dry cows, and heifers covering the last two years and a projection for the next ten years. [If providing herd projections seems tough, try projecting electric or heating fuel rates!]

- **Energy audit details.** If the site has had a recent energy audit, copies of all energy audit documents should be provided to the engineering contractor.

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- **Evaluation worksheets.** Completing the worksheets in *Anaerobic Digesters for Dairy Farms*[1] in advance provides lots of valuable perspective for the engineer and allows more reflection on the subjective items than is likely with oral interviews. There are three worksheets:

    - Compatibility of anaerobic digestion with the dairy. [pp. 10-11]
    - Estimation of component size and energy production. [p. 13]
    - Estimation of economic benefits. [pp. 15-16]

Ideally, copies of all of the data that is assembled in advance should be presented to all of the candidate engineering contractors before they prepare prices and schedules. This can minimize costs by reducing the uncertainties that must be covered in their feasibility study pricing.

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[5] Lusk, p. 5-6.

[6] Roos, p. 1-5.

[7] Lusk, p. 2-2.

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[15] Adapted from Nuvera Fuel Cells web site. See http://www.nuvera.com/tech.html.

[16] "Small Modular Biopower Project." Report produced for Midwest Research Institute, National Renewable Energy Laboratory by Reflective Energies under Subcontract No. NREL ACG-8-18073-03. [Available on-line for download as a ".pdf" file at http://www.eren.doe.gov/biopower/projects/ia_tech_sm_exec.htm.]

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[20] Koelsch, p. 36.

[21] Koelsch, p. 35.

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[33] See the Enerco Technical Products (Cleveland, OH) "Ener-Radiant GT" model at http://www.enerco.com/gt.html for example.

[34] See the Ambi-Rad (Fishers, IN) "GX series" at http://www.ambi-radusa.com/hazduty.htm for example.

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[43] Koelsch, p. 45.

[44] Koelsch, p. 64.

[45] Lusk, p. 4-36.

[46] Lusk, p. 4-63.

[47] Lusk, p. 4-61.

[48] Roos, p. 3-5.

[49] Roos, Chapter 5.

[50] Western NY Farm Bureau Office, 41 Liberty Street, Batavia, NY 14020. Phone (716) 343-3489 or (877) 383-7663. Fax (716) 343-8179.

[51] See http://www.nyseg.com. Electric rates/tariff are available at this web site.

[52] See http://www.nyfb.org/aglinks/taxes.htm for more information on the sales tax exemption applicable to New York dairy electricity and fuels effective September 1, 2000.

[53] Koelsch, p. 35.

[54] Lusk, pp. 3-10 through 3-17.

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[55] Campbell, p. 2-27.

[56] R.S. Means Company, Inc.; 100 Construction Plaza; P.O. Box 800; Kingston, MA 02364-0800. Phone: (781) 585-7880. See http://www.rsmeans.com.

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7.0 APPENDIX

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7.1 Case Study Data Tabulation

This is a tabulated summary of Lusk's case studies of DAIRY biogas systems OPERATING in 1998.

Case No.	State	Date Began	Milking Cows	Biogas (ft^3/day)	Digester Types	Hydrogen Sulfide Scrubber	Engines	Generation Capacity (kW)	Annual Generation (kWh)	Thermal Uses	Notes
4.2	-----	1979	2,200	190,000	plug, slurry	none	4	150+150+ 150+150	1.5-1.7 million	digesters, home	Buys at $0.09/kWh, sells at $0.02-0.025/kWh.
4.3	NY	1981	250	12,000	slurry	none	1	18	145,000-150,000	digester, 2 buildings	Buys at $0.12/kWh.
4.4	MI	1981	720	50,000-57,000	plug	none	1	85	435,000-620,000	digester	Buys at $0.105/kWh.
4.5	VT	1982	340	28,000	plug	limestone	2	125+85	450,000-510,000	digester	
4.6	CA	1982	340	15,000-20,000	plug	mercaptan filter	1	85	190,000-230,000	none	Operates net metering at $0.12/kWh.
4.10	PA	1983	250	18,000-20,000	slurry	none	1	50	200,000-250,000	none	Formerly used iron sponge scrubber.
4.11	NY	1985	270	25,000	mix	iron sponge	1	65	300,000-350,000	digester, wash water	
4.12	CA	1985	400	11,000	mix	unknown	0	0	0	digester	Using boiler rather than engine.
4.16	MD	1994	150	13,000	slurry	unknown	0	0	0	digester	Biogas digester heating.
4.17	OR	1997	650	42,000	plug	unknown	2	65+65	unknown	digester	Buys at $0.028/kWh, sells at $0.035/kWh!
4.19	CT	1997	600	40,000-45,000	mix	unknown	2	80+40	425,000-500,000	digester	Net metering; buys at $0.096/kWh, sells at $0.029/kWh.
4.20	CT	1997	200	4,000-14,000	slurry	unknown	0	0	0	digester, home, greenhouses	Boiler, modified 400,000 Btu/hour.
4.21	NY	1998	500	42,000	plug	none	1	130	430,000-455,000	future	Buys at $0.09/kWh, sells at $0.02/kWh.

Case Studies Source: Lusk, Philip. (1998). *Methane Recovery from Animal Manures: A Current Opportunities Casebook. Third Edition*. NREL/SR-25145. Golden, CO: National Renewable Energy Laboratory. Work performed by Resource Development Associates, Washington, DC. [For a summary, see http://www.biogasworks.com/Reports/MOC-3.htm. Download the complete document at http://www.nrel.gov/docs/fy99osti/25145.pdf.]

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7.2 Product Contacts

The following are manufacturers of commercial-grade, institutional-grade, or industrial-grade products unless otherwise noted. Some of these companies also produce residential-grade products.

The gas-fired products are typically fueled by natural gas or propane. Conversion to biogas service should be done by the manufacturer or in close consultation with the manufacturer. Some of the manufacturers may not permit conversion of their products to biogas service.

Gas-fired equipment is to be installed only in accordance with local laws, codes, and regulations, and only by contractors qualified in the installation and service of gas-fired equipment.

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7.2.1 Air Compressors, Engine-Driven

These manufacturers produce gas-fired engine-driven air compressors:

Manufacturer / Location	Web Site / Telephone
Dearing Compressor & Pump Youngstown, OH	http://www.dearingcomp.com (web site under construction) http://www.plasticssuite.com/aircomp/dearing.htm (330) 783-2258 213-2,450 ft^3/minute
Hurricane Compressors (GrimmerSchmidt) Franklin, IN	http://www.hurricane-compressors.com http://www.grimmerschmidt.com (317) 736-3800 175-2,065 ft^3/minute
Ingersoll-Rand Mocksville, NC	http://www.ircmg.com/portables/product.html http://www.plasticssuite.com/aircomp/ingersoll.htm (336) 751-6706 650-1,600 ft^3/minute
Quincy Compressor Division Quincy, IL	http://www.quincycompressor.com http://www.quincycompressor.com/products/rotary/qss/index.htm (217) 222-7700 370-1,500 ft^3/minute

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7.2.2 Boilers, Hot Water

These manufacturers produce natural-gas-fired boilers for making hot water. Manufacturers exclusively offering extremely large capacities are not included. These are "hot water boilers" (i.e., that typically heat recirculating water as in hydronic systems) as opposed to service water heaters (i.e., that heat water for one-time use), however many can also provide service water.

Manufacturer / Location	Web Site / Telephone
AERCO International Northvale, NJ	http://www.aerco.com (800) 526-0288
Ajax/Ace Boiler Santa Ana, CA	http://www.aboilerinc.com (714) 437-9050
Aldrich Co. Wyoming, IL	http://www.aldrichco.com (309) 695-2311
A. O. Smith Water Products Co. Irving, TX	http://www.hotwater.com (800) 527-1953
Bryan Boilers Peru, IN	http://www.bryanboilers.com (765) 473-6651
Buderus Hydronic Systems Salem, NH	http://www.buderus.net (603) 898-0505
Burnham Corp. Lancaster, PA	http://www.burnham.com (717) 397-4701
Cleaver-Brooks Milwaukee, WI	http://www.cleaver-brooks.com (414) 359-0600
Columbia Boiler Co. Pottstown, PA	http://www.columbiaboiler.com (610) 323-2700
Crown Boiler Co. Philadelphia, PA	http://www.crownboiler.com (215) 535-8900
Fulton Boiler Works Pulaski, NY	http://www.fulton.com (315) 298-5121
Hurst Boiler Coolidge, GA	http://www.hurstboiler.com (877) 994-8778
HydroTherm Hanover, NH	http://www.hydrotherm.com (603) 643-3441
Laars Heating Systems Moorpark, CA	http://www.laars.com (805) 529-2000
Lattner Boiler Manufacturing Co. Cedar Rapids, IA	http://www.lattner.com (800) 345-1527
Lochinvar Corp. Nashville, TN	http://www.lochinvar.com (615) 889-8900
Miura Boiler West Wheeling, IL	http://www.miuraboiler.com (847) 465-0001

(continued on next page)

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Continuation of 7.2.2 Boilers, Hot Water –

Manufacturer / Location	Web Site / Telephone
Parker Boiler Co. Los Angeles, CA	http://www.parkerboiler.com (323) 727-9800
Patterson-Kelley East Stroudsburg, PA	http://www.pkboilers.com (570) 421-7500
Peerless Heater Co. Boyertown, PA	http://www.peerless-heater.com (610) 367-2153
Precision Boilers Morristown, TN	http://www.precisionland.com (423) 587-9390
PVI Industries Ft. Worth, TX	http://www.pvi.com (800) 784-8326
Raypak Oxnard, CA	http://www.raypak.com (805) 278-5300
Slant/Fin Corp. Greenvale, NY	http://www.slantfin.com (516) 484-2600
Smith Cast Iron Boilers Westfield, MA	http://www.smithboiler.com (413) 562-9631
Triad Boiler Systems West Chicago, IL	http://www.triadboiler.com (630) 562-2700 ext. 23
Utica Boilers Utica, NY	http://www.uticaboilers.com (315) 797-1310
Weil-McLain Michigan City, IN	http://www.weil-mclain.com (219) 879-6561

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7.2.3 Boilers, Steam

These manufacturers produce natural-gas-fired boilers for making steam. Manufacturers exclusively offering extremely large capacities are not included.

Manufacturer / Location	Web Site / Telephone
Ajax/Ace Boiler Santa Ana, CA	http://www.aboilerinc.com (714) 437-9050
Aldrich Co. Wyoming, IL	http://www.aldrichco.com (309) 695-2311
Bryan Boilers Peru, IN	http://www.bryanboilers.com (765) 473-6651
Burnham Corp. Lancaster, PA	http://www.burnham.com (717) 397-4701
Clayton Industries El Monte, CA	http://www.claytonindustries.com (800) 423-4585
Cleaver-Brooks Milwaukee, WI	http://www.cleaver-brooks.com (414) 359-0600
Columbia Boiler Co. Pottstown, PA	http://www.columbiaboiler.com (610) 323-2700
Crown Boiler Co. Philadelphia, PA	http://www.crownboiler.com (215) 535-8900
Fulton Boiler Works Pulaski, NY	http://www.fulton.com (315) 298-5121
Hurst Boiler Coolidge, GA	http://www.hurstboiler.com (877) 994-8778
Kewanee Boiler Lancaster, PA	http://www.kewaneeboiler.com 717-239-7650
Lattner Boiler Manufacturing Co. Cedar Rapids, IA	http://www.lattner.com (319) 366-0778
Miura Boiler West Wheeling, IL	http://www.miuraboiler.com (847) 465-0001
Parker Boiler Co. Los Angeles, CA	http://www.parkerboiler.com (323) 727-9800
Peerless Heater Co. Boyertown, PA	http://www.peerless-heater.com (610) 367-2153
Precision Boilers Morristown, TN	http://www.precisionland.com (423) 587-9390
PVI Industries Ft. Worth, TX	http://www.pvi.com (800) 784-8326
Smith Cast Iron Boilers Westfield, MA	http://www.smithboiler.com (413) 562-9631
Superior Boiler Works Hutchinson, KS	http://www.superiorboiler.com (800) 444-6693
Triad Boiler Systems West Chicago, IL	http://www.triadboiler.com (630) 562-2700 ext. 23
Utica Boilers Utica, NY	http://www.uticaboilers.com (315) 797-1310
Weil-McLain Michigan City, IN	http://www.weil-mclain.com (219) 879-6561

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7.2.4 Chillers, Absorption (Ammonia)

Small Standard Units

This manufacturer produces gas-fired ammonia-based absorption chillers for chilling water.

Manufacturer / Location	Web Site / Telephone
Robur Corp. (Servel) Evansville, IN	http://www.robur.com (web site under construction) http://www.michgasinc.com/servel.htm http://apexaircon.com/robur-1.htm (812) 424-1800 3 tonR and 5 tonR gas-fired, air-cooled

Large Customized Units

Manufacturer / Location	Web Site / Telephone
Colibri BV via **Stork Thermeq BV** The Netherlands	http://www.colibri-stork.nl http://www.thermeq.storkgroup.com http://www.thermeq.storkgroup.com/product_range/heat_recovery/absorption_systems/absorption_systems.html 31 74 240 1060 28 tonR (100 kW) to 840 tonR (3 MW) and higher; temperatures down to –76ºF

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7.2.5 Chillers, Absorption (Lithium Bromide)

These manufacturers produce gas-fired lithium-bromide-based absorption chillers for chilling water.

Small Units (Under 100 tonR)

Manufacturer / Location	Web Site / Telephone
Broad U.S.A. Headquartered in Hunan, China New York, NY	http://www.broad.com (212) 775-0665 33-2,600 tonR steam or gas
Yazaki Energy Systems Headquartered in Japan Dallas, TX	http://www.yazakienergy.com (972) 385-8725 30-100 tonR double-effect gas 10 tonR hot water

Large Units (100 tonR and Up)

Manufacturer / Location	Web Site / Telephone
Carrier Corp. Syracuse, NY	http://www.carrier.com (315) 432-6000 108-680 tonR steam or hot water (no gas)
Dunham-Bush Harrisonburg, VA	http://www.dunham-bush.com (540) 434-0711 100-1,400 tonR gas or steam or hot water
McQuay International Minneapolis, MN	http://www.mcquay.com (612) 553-5330 100-1,500 tonR gas or steam
The Trane Company La Crosse, WI	http://www.trane.com 100-1,100 tonR gas 112-1,660 tonR water or gas
York International York, PA	http://www.york.com (717) 771-7890 100-1,500 tonR steam or hot water (no gas)

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7.2.6 Chillers, Engine-Driven and Dual-Drive

These manufacturers produce gas-fired engine-driven chillers for chilling water.

Engine-Driven

Manufacturer / Location	Web Site / Telephone
Alturdyne Energy Systems San Diego, CA	http://www.plasticssuite.com/chillers/alturdyne.htm (no company web site) (858) 565-2131 30-3,500 tonR
Cummins Southwest (PowerChill) Phoenix, AZ	http://www.plasticssuite.com/chillers/cummins.htm (no company web site) 602-257-5980 55-200 tonR
GASAIR Kingwood, TX	http://www.plasticssuite.com/chillers/gasair.htm (no company web site) (713) 360-0893 55-2,000 tonR
Tecogen Waltham, MA	http://www.tecogen.com (781) 622-1400 50-1,000 tonR
York International York, PA	http://www.york.com (717) 771-7890 400-2,100 tonR

Customized industrial refrigeration products are available from FES (div. of ThermoPower), Frick (div. of York International), Vilter Manufacturing, etc.

Dual-Drive

Manufacturer / Location	Web Site / Telephone
Alturdyne Energy Systems San Diego, CA	http://www.plasticssuite.com/chillers/alturdyne.htm (no company web site) (858) 565-2131 100 tonR
Jenbacher Energiesysteme Farmington Hills, MI	http://www.jenbacher.com (248) 324-4400 800-2,000 tonR
PowerCold Corp. **(Rotary Power International)** Cibolo, TX	http://www.ucsc.com/powercol (210) 659-8450 Up to 150 tonR

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7.2.7 Engines, Stirling

Note: Many of the Stirling engines produced by companies on this list are developmental and have not been commercialized in significant quantities.

Manufacturer / Location	Web Site / Telephone
Kockums AB Sweden	http://www.kockums.se/Products/kockumsstirlingm.html 46 40 34 80 00
Sigma Elektroteknisk AS Norway	http://www.sigma-el.com 47 64 98 24 00
SOLO Kleinmoteren GmbH Germany	http://sesusa.hypermart.net/solo.htm
Stirling Energy Systems Phoenix, AZ	http://www.stirlingenergy.com (602) 957-1818
Stirling Technology Co. Kennewick, WA	http://www.stirlingtech.com (509) 735-4700 ext. 130
Stirling Technology, Inc. Athens, OH	http://www.stirling-tech.com (800) 535-3448
Sunpower Athens, OH	http://www.sunpower.com (740) 594-2221
Tamin Enterprises Half Moon Bay, CA	http://www.tamin.com (650) 563-9077

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7.2.8 Engine-Generators, Conventional

These manufacturers produce spark-ignited engine-generators for both natural gas and propane and operating in the 20 kW to 300 kW power output range at 480V or less, except as noted.

Manufacturer / Location	Web Site / Telephone
Alturdyne Energy Systems San Diego, CA	http://home.att.net/~alturdyne (no company web site) (858) 565-2131
Caterpillar Peoria, IL	http://www.caterpillar.com (309) 675-1000
Generac Power Systems Waukesha, WI	http://www.generac.com (414) 544-4811
Jenbacher Energiesysteme Farmington Hills, MI	http://www.jenbacher.com/cogren.htm (248) 324-4400
Katolight Corp. Mankato, MN	http://www.katolight.com (800) 325-5450
Kohler Co. Kohler, WI	http://www.kohlergenerators.com (800) 544-2444
Lister-Petter Olathe, KS	http://www.lister-petter.com (913) 764-3512 Note: 7.0-18.5 kW.
O'Brien Energy Services Wilmington, DE	http://www.obrienenergy.com 800-879-0879
Onan (Cummins) St. Peter, MN	http://www.onan.com (800) 888-6626
Spectrum Detroit Diesel Sheboygan, WI	(no company web site) (920) 459-1877
T&J Manufacturing Oshkosh, WI	(no company web site) (800) 872-7697
Waukesha Engine Waukesha, WI	http://www.waukeshaengine.com (414) 549-2813 See "Enginator® " on web site.

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7.2.9 Fuel Cells

Note: Many of the fuel cells produced by companies on this list are developmental and have not been commercialized in major quantities.

Manufacturer / Location	Web Site / Telephone
Avista Labs Spokane, WA	http://www.avistalabs.com (509) 495-4817
Ballard Power Systems Burnaby, BC, Canada	http://www.ballard.com (604) 454-0900
Energy Partners West Palm Beach, FL	http://www.energypartners.org (561) 688-0500
FuelCell Energy Danbury, CT	http://www.fuelcellenergy.com (203) 825-6000
Global Thermoelectric Calgary, Alberta, Canada	http://www.globalte.com (403) 236-5556
H Power Clifton, NJ	http://www.hpower.com 973-450-4400
Hydrogen Burner Technology Rancho Dominguez, CA	http://www.hydrogenburner.com (310) 900-0400
Hydrogenics Corp. Mississauga, ON, Canada	http://www.hydrogenics.com (905) 361-3660
IdaTech Bend, OR	http://www.idatech.com (541) 383-3390
International Fuel Cells South Windsor, CT	http://www.internationalfuelcells.com (860) 727-2200
Nuvera Fuel Cells Cambridge, MA	http://www.nuvera.com (617) 498-5398
Plug Power Latham, NY	http://www.plugpower.com (518) 782-7700
Proton Energy Systems Rocky Hill, CT	http://www.protonenergy.com (860) 571-6533
Siemens-Westinghouse Orlando, FL	http://www.siemens.com/kwu/fossil/en/products_n_services/sofc/index.htm (407) 736-5660 for Northeast U.S. Sales

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7.2.10 Insulation, Underground

These manufacturers produce pourable trench insulations for underground piping applications.

Manufacturer / Location	Web Site / Telephone
American Thermal Products Bonita Springs, FL	http://www.gilsulateatp.com (800) 833-3881
DriTherm Parsippany, NJ	http://www.dritherm.com (800) 343-4188

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7.2.11 Microturbines

Note: Many of the microturbines produced by companies on this list are developmental and have not been commercialized in major quantities.

Manufacturer / Location	Web Site / Telephone
Honeywell Power Systems Albuquerque, NM	http://www.honeywell.com/businesses/page6_9.html Parallon 75™ brand. Formerly AlliedSignal Power Systems. Soon to be General Electric.
Capstone Turbine Corp. Chatsworth, CA	http://www.capstoneturbine.com (818) 734-5300
Ingersoll-Rand Energy Systems Woodcliff Lake, NJ	http://www.ingersoll-rand.com/energysystems http://www.ingersoll-rand.com/energysystems/powerworks.html http://www.ingersoll-rand.com/energysystems/chillers.html (201) 573-0123 Formerly NREC. PowerWorks™ brand.
Elliott Power Systems Lexington, TN	http://www.elliottpowersystems.com http://www.iesl.com/IESLMicroturbines.html http://www.ipsi.net/micro.htm (901) 967-9393
Reflective Energies Mission Viejo, CA	(no web site) (714) 380-4899

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7.2.12 Piping, Pre-Insulated Specialty

These manufacturers produce pre-insulated pipe in numerous specialty configurations including some suitable for underground installation. Applications include biogas, steam, thermal heat transfer fluids, and water.

Manufacturer / Location	Web Site / Telephone
Perma-Pipe Niles, IL	http://www.permapipe.com (847) 966-2235
Rovanco Piping Systems Joliet, IL	http://www.rovanco.com (815) 741-6700
Thermacor Process Ft. Worth, TX	http://www.thermacor.com (817) 847-7300
Thermal Pipe Systems New Castle, DE	http://www.thermalpipesystems.com (215) 945-7443

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7.2.13 Separations, Hydrogen Sulfide and Carbon Dioxide

Scavenger Systems for Hydrogen Sulfide Removal

Manufacturer / Location	Web Site / Telephone
Baker Petrolite Sugar Land, TX	http://www.bakerhughes.com/bakerpetrolite/oilgas (281) 276-5400
Coastal Chemical Co. (Sulfaguard®) Abbeville, LA	http://www.coastalchem.com (337) 898-0001
Connelly-GPM (Iron Sponge) Chicago, IL	(no web site) (773) 247-7231
SulfaTreat Co. Chesterfield, MO	http://www.sulfatreat.com (800) 726-7687
United States Filter (USFilter), Gas Technology Products Group (Sulfur-Rite® & The Scavenger™) Schaumburg, IL	http://www.gtp-usfilter.com (847) 706-6900

Membrane Systems

Manufacturer / Location	Web Site / Telephone
Medal, LP (Air Liquide) Newport, DE	http://www.airliquide.com/ww/chapter02/medal/en/default.htm (302) 999-6130
NATCO Group Houston, TX	http://www.natcogroup.com (713) 683-9292
Permea (Air Products and Chemicals) St. Louis, MO	http://www.apci.com/hydrocarbon/petro.htm (314) 995-3300

Molecular Sieve Systems

Manufacturer / Location	Web Site / Telephone
Atofina (Siliporite®) Houston, TX	http://www.atofinachemicals.com/newelf/adsorbents (713) 532-0027
Bettis Corp. Waller, TX	http://www.bettis.com/products/molecular.htm (281) 463-5100
CarboTech Anlagenbau GmbH Essen, Germany	http://www.an.carbotech.de/e/technologie4.htm 49 201 172-19 15
Zeochem Louisville, KY	http://www.zeochem.com/applications/procind.htm (502) 634-7600

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7.2.14 Space Heaters, Radiant

These manufacturers produce gas-fired radiant space heaters.

Manufacturer / Location	Web Site / Telephone
Ambi-Rad Fishers, IN	http://www.ambi-radusa.com (888) 330-4878
Combustion Research Rochester Hills, MI	http://www.combustionresearch.com (888) 852-3611
Detroit Radiant Products Warren, MI	http://www.reverberray.com (810) 756-0950
Enerco Technical Products Cleveland, OH	http://www.enerco.com (800) 251-0001
Fostoria Industries Fostoria, OH	http://www.fostoriaindustries.com (419) 435-9201
Panelbloc Mentor, OH	http://www.panelbloc.com (800) 562-9518
Roberts Gordon Buffalo, NY	http://www.rg-inc.com (716) 852-4400
Solaronics Rochester, MI	http://www.solaronicsusa.com (800) 223-5335
Space-Ray Charlotte, NC	http://www.spaceray.com (800) 438-4936
Superior Radiant Products Stoney Creek, ON, Canada	http://www.superiorradiant.com (800) 527-4328

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7.2.15 Thermal Fluid Heaters

These manufacturers produce gas-fired thermal fluid heaters.

Manufacturer / Location	Web Site / Telephone
First Thermal Systems Chattanooga, TN	http://www.first-thermal.com (800) 665-4251
Fulton Heat Transfer Pulaski, NY	http://www.fulton.com (315) 298-5121
Heatec Chattanooga, TN	http://www.heatec.com (800) 235-5200
Parker Boiler Co. Los Angeles, CA	http://www.parkerboiler.com (323) 727-9800
Thermal Fluid Systems Marietta, GA	http://www.tfsheat.com (770) 425-5556
Vapor Power Group Niles, IL	http://www.vaporpower.com (888) 874-9020

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7.2.16 Water Heaters, Conventional

These manufacturers produce a wide size range of commercial and industrial gas-fired water heaters for both natural gas and propane. These are service water heaters (i.e., they heat water for one-time use) as opposed to "hot water boilers" (i.e., typically heating recirculating water as in hydronic systems). [Note, however, that many hot water boilers can also provide service water. See "Boilers, Hot Water."]

Manufacturer / Location	Web Site / Telephone
AERCO International Northvale, NJ	http://www.aerco.com (800) 526-0288
Aldrich Co. Wyoming, IL	http://www.aldrichco.com (309) 695-2311
A. O. Smith Water Products Co. Irving, TX	http://www.hotwater.com (800) 527-1953
Bradford White Corp. Ambler, PA	http://www.bradfordwhite.com (800) 538-2020
Buderus Hydronic Systems Salem, NH	http://www.buderus.net (603) 898-0505
Columbia Boiler Co. Pottstown, PA	http://www.columbiaboiler.com (610) 323-2700
Laars Heating Systems Moorpark, CA	http://www.laars.com (805) 529-2000
Lochinvar Corp. Nashville, TN	http://www.lochinvar.com (615) 889-8900
Parker Boiler Co. Los Angeles, CA	http://www.parkerboiler.com (323) 727-9800
Patterson-Kelly Co. East Stroudsburg, PA	http://www.pkboilers.com (877) 728-5351
Precision Boilers Morristown, TN	http://www.precisionland.com (423) 587-9390
PVI Industries Ft. Worth, TX	http://www.pvi.com (800) 784-8326
Raypak Oxnard, CA	http://www.raypak.com (805) 278-5300
Rheem Manufacturing Co. Montgomery, AL	http://www.rheem.com (334) 260-1500
Weil-McLain Michigan City, IN	http://www.weil-mclain.com (219) 879-6561

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7.2.17 Water Heaters, Direct-Contact

These manufacturers produce gas-fired direct-contact water heaters.

Manufacturer / Location	Web Site / Telephone
Inproheat Industries Vancouver, BC, Canada	http://www.inproheat.com (604) 254-0461 Submerged combustion units.
Kemco Systems Clearwater, FL	http://www.kemcosystems.com (800) 633-7055
Ludell Manufacturing (now owned by Ellis Corp.) Milwaukee, WI	http://www.elliscorp.com http://www.cyber-pete.com/scludell.htm (800) 558-0800
Sofame Montréal, Québec, Canada	http://www.sofame-tech.com (514) 523-6545
QuikWater Sand Springs, OK	http://www.quikwater.com (918) 241-8880

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7.3 Other Contacts

Contact / Location	Web Site / Telephone
AgSTAR Program (a U.S. EPA program) Washington, DC	http://www.epa.gov/agstar (800) 952-4782
American Gas Association (industry association representing 189 gas utilities) Washington, DC	http://www.aga.org (202) 824-7000
American Gas Cooling Center (industry association) Washington, DC	http://www.agcc.org (202) 824-7141
Cornell Cooperative Extension of Wyoming County Warsaw, NY	http://www.cce.cornell.edu/wyoming (716) 786-2251
Energy User News (magazine) Troy, MI	http://www.energyusernews.com (248) 362-3700
Gas Technology Institute (formerly the Gas Research Institute) Des Plaines, IL	http://www.gri.org (847) 768-0500
Mears, Darrell T. (author) Langhorne, PA	http://www.optimumus.com (215) 757-4360
New York Farm Bureau Glenmont, NY	http://www.nyfb.org (800) 342-4143
Process Cooling & Equipment (magazine) Des Plaines, IL	http://www.process-cooling.com (847) 297-3727
Process Heating (magazine) Troy, MI	http://www.process-heating.com (847) 291-5224
U.S. Fuel Cell Council (industry association) Washington, DC	http://www.usfcc.com (202) 293-5500

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7.4 Capacity Tabulation

Approximate biogas system average utility supply capacity for large dairy operations in New York using plug-flow digesters. See "Basis" below for additional assumptions.

Cows	Biogas Energy, Btu/hour	Electric Power, kW	Electric Energy, kWh/year	Water Heating, Btu/hour	Absorption Cooling, tonR
500	840,000	67	451,000	673,000	38
600	1,010,000	80	544,000	807,000	45
700	1,180,000	94	634,000	942,000	53
800	1,350,000	107	725,000	1,080,000	60
900	1,510,000	121	815,000	1,210,000	68
1,000	1,680,000	134	906,000	1,350,000	75
1,100	1,850,000	147	997,000	1,480,000	83
1,200	2,020,000	161	1,090,000	1,610,000	90
1,300	2,190,000	174	1,180,000	1,750,000	98
1,400	2,350,000	188	1,270,000	1,880,000	105
1,500	2,520,000	201	1,360,000	2,020,000	113

Basis:

"Cows" is milking cow equivalents based on manure production and includes allowance for both manure production and proportion of time on hard collecting surface by animal type:

Cows = milking cows + (heifers/4) + (dry cows/20).

[See Koelsch, p. 13.[1]]

"Biogas Energy" is based on 35,700 ft^3 biogas per 500 cows per day[41] and biogas at 538 Btu/ft^3.[53]

"Electric Power" is based on 67 kW per 500 cows.[41]

"Electric Energy" is based on a net of 452,980 kWh per year per 500 cows.[41] This assumes a heat rate of 14,000 Btu/kWh, an annual capacity factor of 80 percent, and allowance for digester parasitic losses (e.g., mixing motors, solids separators).

"Water Heating" is hot water boiler output based on using all biogas (i.e., no engine-generator) and 80% hot water boiler thermal efficiency. On an annual basis in New York, approximately one-third of this energy must be used for digester heating. Less digester heating is required in warmer climates.

"Absorption Cooling" is the maximum capacity of a single-effect absorption chiller having a COP of 0.67 and using all hot water (i.e., summer peak period when digester heating requirement is negligible). A double-effect unit would offer higher capacity, but it would require higher capital cost.

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7.5 Glossary

Absorption	A process in which one substance absorbs another, resulting in a chemical and/or physical change.
Anaerobic	Occurring without oxygen.
Biogas	A gaseous byproduct of the anaerobic digestion of manure or other biomass composed primarily of methane and carbon dioxide.
Blowdown	The removal of water from an evaporative system to reduce mineral concentration that can cause scaling.
Boiler	A closed vessel in which steam is generated and/or water is heated by the application of heat from a fuel.
Boiler, firetube	A boiler in which the heat and combustion gases pass through boiler tubes surrounded by water.
Boiler, watertube	A boiler in which the water passes through boiler tubes and the heat and combustion gases surround the tubes.
Btu	British Thermal Unit. A unit of heat energy. The heat required to raise one pound of water by 1ºF at 60ºF.
Carbon dioxide	(CO_2) A gaseous component of biogas that does not support combustion. Also, a gaseous byproduct of combustion.
Chiller	An equipment package for air conditioning or refrigeration that typically cools water that flows through it using refrigerant in a closed refrigeration cycle.
Coefficient of performance	(COP) A measure of refrigeration efficiency. The ratio of the rate of heat removed (cooling effect) to the rate of heat input required, expressed in the same units.
Condenser	A heat exchanger in which high pressure refrigerant gas is condensed to liquid by transferring heat to a cooling medium such as air or cooling tower water.
Cooling tower	A device for cooling water by evaporating a portion of the water in air.
Efficiency	Useful energy output divided by total energy input.
Evaporator	A heat exchanger in which a refrigerant evaporates by absorbing heat from a medium being cooled.
Hardness	The amount of dissolved calcium salts and/or magnesium present in water. Hardness is measured in units of parts per million (ppm) or grains per gallon (gpg). [gpg x 17.1 = ppm]
HVAC	Heating, ventilation, and air conditioning.
Hydrogen sulfide	(H_2S) A corrosive gas present in biogas.
Hydronic	Pertaining to circulating water in a closed system as in a heating system.
kW	Kilowatt. A unit of electric power or capacity equal to 1,000 watts. "Demand" or "capacity" charges for electricity are usually based on the peak kW occurring during the billing period, often only as measured during times defined as "on peak" hours.

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kWh	Kilowatt-hour. A unit of electric energy consumption equal to that consumed in using a power level of one kilowatt (1,000 watts) for a duration of one hour. Example: Illuminating ten 100-watt bulbs for one hour consumes 1 kWh.
Methane	(CH_4) A gaseous fuel that is the primary combustible component of natural gas and biogas.
Natural gas	A gaseous fuel occurring in nature and consisting of a mixture of methane, ethane, propane, and butane typically having a heating value averaging around 1,000 Btu/ft^3.
pH	A value indicative of the tendency of water to either corrode metal or form scale. The pH scale extends from 0 (highly acidic) to 7 (neutral) to 14 (highly alkaline).
Scavenger	A substance that chemically binds with a contaminant (such as hydrogen sulfide) and thus removes it from the gas stream.
Steam trap	An automatic valve designed to drain off condensate from a steam distribution system.
Therm	100,000 Btu. A common unit for quantifying the energy content of natural gas delivery.
Ton of refrigeration	(tonR) 12,000 Btu/hour of cooling capacity.
Water, service	Water for direct use such as washing (as opposed to water circulated as a heating or cooling medium).
Water heater, direct-contact	A gas-fired water heater in which the water and the combustion gases are commingled to heat the water.

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