

## **4. Storage and Transportation of Biogas and Biomethane**

Dairy manure biogas is generally used in combined heat and power applications (CHP) that combust the biogas to generate electricity and heat for on-farm use. The electricity is typically produced directly from the biogas as it is created, although the biogas may be stored for later use when applications require variable power or when production is greater than consumption.

Biogas that has been upgraded to biomethane by removing the H<sub>2</sub>S, moisture, and CO<sub>2</sub> can be used as a vehicular fuel. Since production of such fuel typically exceeds immediate on-site demand, the biomethane must be stored for future use, usually either as compressed biomethane (CBM) or liquefied biomethane (LBM). Because most farms will produce more biomethane than they can use on-site, the excess biomethane must be transported to a location where it can be used or further distributed.

This chapter discusses the types of systems available for the storage of biogas and/or biomethane as well as modes of biomethane transportation.

### **Storage Systems and Costs**

There are two basic reasons for storing biogas or biomethane: storage for later on-site usage and storage before and/or after transportation to off-site distribution points or systems. The least expensive and easiest to use storage systems for on-farm applications are low-pressure systems; these systems are commonly used for on-site, intermediate storage of biogas. The energy, safety, and scrubbing requirements of medium- and high-pressure storage systems make them costly and high-maintenance options for on-farm use. Such extra costs can be best justified for biomethane, which has a higher heat content and is therefore a more valuable fuel than biogas.

Table 4-1 summarizes on-farm storage options for biogas and biomethane. These options are discussed in more detail below.

Table 4-1 On-Farm Storage Options for Biogas and Biomethane

Purpose of Storage	Pressure (psi)	Storage Device	Material	Size (ft <sup>3</sup> )
Short and intermediate storage for on-farm use (currently used on farms for biogas storage)	< 0.1	Floating Cover	Reinforced and non-reinforced plastics, rubbers	Variable volume usually less than one day's production
	<2	Gas bag	Reinforced and non-reinforced plastics, rubbers	150 – 11,000
	2 – 6	Water sealed gas holder	Steel	3,500
		Weighted gas bag	Reinforced and non-reinforced plastics, rubbers	880 – 28,000
		Floating roof	Plastic, reinforced plastic	Variable volume, usually less than one day's production
Possible means of storage for later on- or off-farm use (could be used for biomethane)	10 – 2,900	Propane or butane tanks	Steel	2,000
	>2,900	Commercial gas cylinders	Alloy steel	350

Source: Ross et al., 1996.

psi = Pounds per square inch, ambient conditions

ft<sup>3</sup> = Cubic feet

### **Biogas Storage**

Both biogas and biomethane can be stored for on-farm uses. In practice, however, most biogas is used as it is produced. Thus, the need for biogas storage is usually of a temporary nature, at times when production exceeds consumption or during maintenance of digester equipment. Important considerations for on-farm storage of biogas include (1) the needed volume (typically, only small amounts of biogas need to be stored at any one time), (2) possible corrosion from H<sub>2</sub>S or water vapor that may be present, even if the gas has been partially cleaned, and (3) cost (since biogas is a relatively low-value fuel).

#### **Low-Pressure Storage of Biogas**

Floating gas holders on the digester form a low-pressure storage option for biogas systems. These systems typically operate at pressures up to 10-inch water column (less than 2 psi). Floating gas holders can be made of steel, fiberglass, or a flexible fabric. A separate tank may be used with a floating gas holder for the storage of the digestate and also storage of the raw biogas.

One advantage of a digester with an integral gas storage component is the reduced capital cost of the system. The least expensive and most trouble-free gas holder is the flexible inflatable fabric top, as it does not react with the H<sub>2</sub>S in the biogas and is integral to the digester. These types of

covers are often used with plug-flow and complete-mix digesters (see Chapter 2). Flexible membrane materials commonly used for these gas holders include high-density polyethylene (HDPE), low-density polyethylene (LDPE), linear low density polyethylene (LLDPE), and chlorosulfonated polyethylene covered polyester (such as Hypalon<sup>®</sup>, a registered product of DuPont Dow Elastomers L.L.C.). Thicknesses for cover materials typically vary from 18 to 100 mils (0.5 to 2.5 millimeters) (Ross, et al., 1996, p. 5-15). In addition, gas bags of varying sizes are available and can be added to the system. These bags are manufactured from the same materials mentioned above and may be protected from puncture damage by installing them as liners for steel or concrete tanks.

### **Medium-Pressure Storage of Cleaned Biogas**

Biogas can also be stored at medium pressure between 2 and 200 psi, although this is rarely, if ever done, in the USA. To prevent corrosion of the tank components and to ensure safe operation, the biogas must first be cleaned by removing H<sub>2</sub>S. Next, the cleaned biogas must be slightly compressed prior to storage in tanks. Typical propane gas tanks are rated to 250 psi. Compressing biogas to this pressure range uses about 5 kWh per 1,000 ft<sup>3</sup> (Ross, et al., 1996, p. 5-18). Assuming the biogas is 60% methane and a heat rate of 13,600 Btu/kWh, the energy needed for compression is approximately 10% of the energy content of the stored biogas.

### **Biomethane Storage**

Biomethane is less corrosive than biogas and also is potentially more valuable as a fuel. For these reasons, it may be both possible and desirable to store biomethane for on- or off-farm uses.

### **High-Pressure Storage of Compressed Biomethane**

Biomethane can be stored as CBM to save space. Gas scrubbing is even more important at high pressures because impurities such as H<sub>2</sub>S and water are very likely to condense and cause corrosion. The gas is stored in steel cylinders such as those typically used for storage of other commercial gases. Storage facilities must be adequately fitted with safety devices such as rupture disks and pressure relief valves. The cost of compressing gas to high pressures between 2,000 and 5,000 psi is much greater than the cost of compressing gas for medium-pressure storage. Because of these high costs, the biogas is typically upgraded to biomethane, a more valuable product, prior to compression. Compression to 2,000 psi requires nearly 14 kWh per 1,000 ft of biomethane (Ross et al., 1996, pp 5-19). If the biogas is upgraded to 97% methane and the assumed heat rate is 12,000 Btu/kWh, the energy needed for compression amounts to 17% of the energy content of the gas.

The main components of an example on-farm CBM storage system are shown in Figure 4-1.

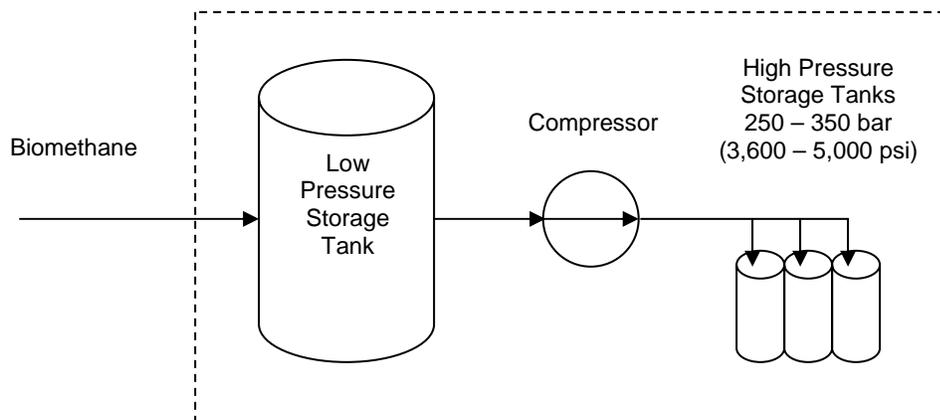


Figure 4-1 Schematic of on-farm storage system for compressed biomethane

The low-pressure storage tank is a buffer for the output from the biogas upgrading equipment. The tank would most likely consist of one or two large, air-tight vessels with sufficient storage capacity for around one to two days worth of biogas production. For example, a dairy with 1,000 cows would yield approximately 30,000 ft<sup>3</sup> biomethane/day. Note that by compressing the biomethane slightly, the amount of gas stored in the low-pressure storage tank can be increased proportionately<sup>1</sup>. Large, stationary low-pressure storage tanks suitable for this application are typically custom designed and are available from many manufacturers.

Because it is highly unlikely that there would be sufficient on-farm vehicle demand for all of the biomethane that a farm could produce, most or all of the biomethane must eventually be transported to a refueling station. Biomethane has an inherently low energy density at atmospheric pressure; therefore, the most economical and efficient way to transport upgraded biogas over the road is in compressed form. (Pipeline distribution of biomethane is discussed in a later section.) Since CNG refueling stations normally provide CNG at 3,000 to 3,600 psi, CBM would be transported at similar or higher pressures to minimize the need for additional compression at the refueling station.

The compressor receives the low-pressure biomethane from the storage tank and compresses it to 3,600 to 5,000 psi. The compressor should be specified to handle the output flow rate from the

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<sup>1</sup> According to Boyle's Law, pressure (P) is inversely proportional to volume (V) for an ideal gas assuming temperature and the amount of gas are held constant, i.e.,  $P \times V = \text{constant}$ .

biogas upgrading equipment. For example, a dairy with 1,000 cows would yield a flow rate of approximately 2,000 ft<sup>3</sup> raw biogas/hour. There are several manufacturers of commercially available compressors in this range (e.g., Bauer Compressors and GreenField Compression).

The CBM output of the compressor is fed to a number of individual high-pressure storage tanks connected in parallel and housed in a portable trailer. (In the case of on-farm CBM refueling, the high-pressure storage tanks could be stationary and potentially much larger.) Portable high-pressure storage tanks rated for this type of application are commercially available from a variety of manufacturers (e.g., Dynetek Industries and General Dynamics).

### **Storage of Liquefied Biomethane**

Biomethane can also be liquefied, creating a product known as liquefied biomethane (LBM). Two of the main advantages of LBM are that it can be transported relatively easily and it can be dispensed to either LNG vehicles or CNG vehicles (the latter is made possible through a liquid-to-compressed natural gas (LCNG) refueling station equipment which creates CNG from LNG feedstock). However, if LBM is to be used off-farm, it must be transported by tanker trucks, which normally have a 10,000-gallon capacity. For obvious economic reasons, the LBM must be stored on-farm until 10,000 gallons have accumulated.

Figure 4-2 shows the generalized process of storing LBM prior to use or transport. The low-pressure storage tank is a buffer for LBM after it exits the biomethane liquefaction equipment. Typical LNG storage tanks are double-walled, thermally insulated vessels with storage capacities of 15,000 gallons for stationary, aboveground applications. (Smaller LNG storage tanks with 6,000-gallon storage capacities are also available, but would only be useful for on-farm applications, and the on-farm demand for LBM is likely to be relatively low.) For a dairy with 1,000 cows, 15,000 gallons is equivalent to approximately six weeks' worth of LBM production. The LBM output of the biogas liquefaction equipment is nominally at 50 psi, which is also the nominal pressure of the LBM in the low-pressure storage tank. LNG storage tanks are available from several companies specializing in LNG equipment (e.g., NexGen Fueling). The typical cost for a 15,000-gallon tank is \$170,000.

Since it is highly unlikely that on-farm vehicle demand will consume all of the LBM produced (see Chapter 5), most or all of the LBM must be transported to a refueling station where it can be dispensed to natural-gas fueled vehicles. Liquid biomethane is transported in the same manner as LNG, that is, via insulated tanker trucks designed for transportation of cryogenic liquids. Standard tanker trucks hold 10,000 gallons of LNG or LBM at approximately 50 psi.

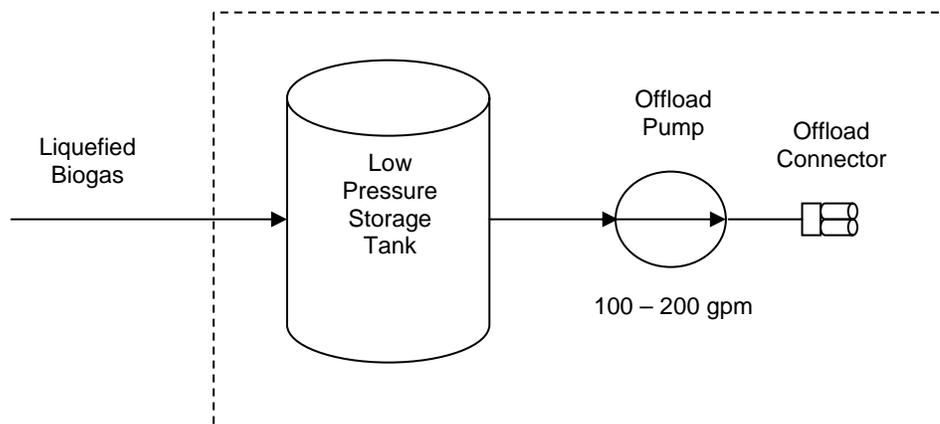


Figure 4-2 Schematic of storage system for liquefied biomethane

An offload pump is needed to pump the LBM from the low-pressure storage tank to the tanker truck (Figure 4-2). Typical flow rates for these types of pumps are 100 to 200 gallons per minute (gpm). Cryogenic pumps for this type of application are available from a variety of manufacturers and typically cost between \$15,000 to 25,000. The offload connector is a standard LNG interface connector and is normally included as part of the offload pump.

One of the main disadvantages of LNG and thus LBM is that the cryogenic liquid will heat up during storage, which will result in loss of LBM to evaporation through a release valve on the tank. To minimize these losses, LBM should be used fairly quickly after production. It is generally recommended that LBM be stored for no more than a week before it is either used or transported to a fueling station. Storage for a longer period will result in an economically unacceptable level of evaporative loss. Since standard LNG tankers carry about 10,000 gallons, a small-scale liquefaction facility should produce at least 3,000 gallons of LBM per day. However, the production of this much LBM requires approximately 8,000 cows—which could only be found at an extremely large dairy or a central digester facility.

## Distribution of Biomethane

Biogas is a low-grade, low-value fuel and therefore it is not economically feasible to transport it for any distance (although there are two locations in California where it is sent through a 1- or 2-mile pipeline to a generator). Likewise, biogas cannot be economically trucked.

In contrast, biomethane can be distributed to its ultimate point of consumption by one of several options, depending on its point of origin:

- Distribution via dedicated biomethane pipelines
- Distribution via the natural gas pipeline
- Over-the road transport of CBM
- Over-the-road transport of LBM

### ***Distribution via Dedicated Biomethane Pipelines***

If the point of consumption is relatively close to the point of production (e.g., less than 1 mile), the biomethane would typically be distributed via dedicated biogas pipelines (buried or aboveground). For example, biomethane intended for use as CNG vehicle fuel could be transported via dedicated pipelines to a CNG refueling station. For short distances over privately owned property where easements are not required, this is usually the most cost-effective method. Costs for laying dedicated biomethane pipelines can vary greatly, and may range from about \$100,000 to \$250,000 or more per mile. Note that biomethane distributed via dedicated biomethane pipelines must compete with natural gas prices in the marketplace.

### ***Distribution via the Natural Gas Pipeline Network***

The natural gas pipeline network offers a potentially unlimited storage and distribution system for biomethane. Since the natural gas pipelines are typically owned by either private or municipal gas utilities, the biomethane producer must negotiate an agreement with the pipeline owner (i.e., the local gas utility) to supply biomethane into the natural gas pipelines. One prerequisite for such an agreement would be to ensure that biomethane injected into the natural gas pipeline network meets the local gas utility's pipeline gas quality (e.g., gas composition) standards. Once the biomethane is injected into the natural gas pipeline network, it can be used as a direct substitute for natural gas by any piece of equipment connected to the natural gas grid, including domestic gas appliances, commercial/industrial gas equipment, and CNG refueling stations.

As mentioned, any gas (including biomethane) transported via the natural gas pipeline network is required to meet the local gas company gas quality standards set by the owner of the natural gas pipeline network. In California, the two major private natural gas pipeline distribution networks are owned by PG&E and Southern California Gas Company (SoCalGas); these networks provide natural gas for most of northern and southern California, respectively. In addition to PG&E and SoCalGas, there are a number of municipal gas utilities throughout the state which own and operate their own natural gas pipeline distribution networks. Default gas quality and interchangeability requirements for the two networks are set forth in PG&E's Rule 21 and SoCalGas's Rule 30 (although these requirements may be superseded by specific agreements).

In reality, there is likely to be significant resistance by the local gas utility toward attempts to distribute biomethane via the natural gas pipeline network. One reason for this resistance is the justifiable concern that poor gas quality might have potentially devastating effects on gas equipment. As a result, there are likely to be severe requirements for gas quality monitoring and fail-safe disconnection of the biomethane supply from the natural gas pipeline network, which may lead to prohibitively high costs for biomethane producers. In addition, biomethane distributed via the natural gas pipeline network would probably be sold to the local gas utility and therefore must compete with the wholesale price of natural gas offered by other natural gas suppliers, though it might be possible to wheel the gas to an industrial user at a negotiated price.

As of 2005, the only location in the USA where biomethane is sold to a gas utility as a supplemental equivalent for natural gas is the King County South Wastewater Treatment Plant in Renton, Washington. This plant includes an anaerobic digester and water scrubbing unit that produce pipeline quality biomethane. The biomethane is sold to the local gas utility, Puget Sound Energy, which in turn resells the biomethane to its natural gas customers. Local circumstances support this scenario: electric power is extremely cheap in the Seattle area (\$0.025 to \$0.03/kWh), and thus the biomethane produced by the Renton plant is more valuable than the electric power that could have been produced by the biogas. In California, where electric power costs are currently much higher (e.g., 0.08 to \$0.10/kWh), it would be more economical to generate electric power from the biogas rather than upgrade it to biomethane.

### ***Over-the-Road Transportation of Compressed Biomethane***

If distribution of biomethane via dedicated pipelines or the natural gas grid is impractical or prohibitively expensive, over-the-road transportation of compressed biomethane may be a distribution option. The energy density of biomethane is extremely low at ambient pressure and as a result it must be compressed to relatively high pressures (e.g., 3,000 to 3,600 psi) to transport economically in over-the-road vehicles.

Compressed natural gas bulk transport vehicles, often referred to as “tube trailers,” are used when over-the-road transportation of CNG or compressed biomethane is required. U.S. Department of Transportation (DOT) regulations classify CNG as a Class 2 (gas), Division 2.1 (flammable) hazardous material; it is assumed that over-the-road transportation of compressed biomethane would be held to the same requirements. Major requirements include the following:

- Transportation in DOT-approved tanks (e.g., DOT-3AAX seamless steel cylinders) that do not exceed the rated tank pressure
- Water vapor content of less than 0.5 lbs/million scf (i.e., less than 10 ppm H<sub>2</sub>O)
- Minimum methane content of 98%
- Appropriate hazardous materials markings

Given the transportation and capital equipment costs associated with over-the-road transportation of compressed biomethane as well as the probable need for additional compression at the point of consumption, this method of biomethane distribution is generally not considered a long-term, cost-effective solution. Rather it is used as a temporary solution in certain situations, for example, as a means of expanding the use of compressed biomethane vehicle fuel into a new market prior to the installation of permanent refueling infrastructure.

### ***Over-the-Road Transportation of Liquefied Biomethane***

Over-the-road transportation of liquefied biomethane is a potential way of addressing many of the infrastructure issues associated with biomethane distribution; however, this distribution method presents additional technical challenges. Bulk LNG is transported in LNG tankers. These are

typically class 8 vehicles consisting of a tractor towing a 10,000-gallon LNG tanker. Liquid natural gas is transported at relatively low pressures (e.g., 20 to 150 psi), but because it is a cryogenic liquid (i.e., its nominal temperature is -260° F), it requires special handling. U.S. DOT regulations classify LNG as a Class 2 (gas), Division 2.1 (flammable) hazardous material; it is assumed that over-the-road transportation of liquefied biomethane will be held to the same requirements:

- Transportation in DOT-approved tanks (e.g., double-walled insulated steel tanks)
- Presence of two independent pressure relief systems
- Maximum one-way-travel-time marking
- Appropriate hazardous materials markings

One of the most attractive features of over-the-road transportation of liquefied biomethane is that an infrastructure and market already exist. (In addition to acting as a fuel for LNG vehicles, liquefied biomethane can also be used to provide fuel for CNG vehicles via LCNG refueling stations which turn LNG into CNG.) In California, where almost all LNG is currently imported from other states, in-state production of LBM would gain a competitive advantage over LNG with respect to transportation costs. While liquefaction of landfill gas has been demonstrated at a number of locations throughout the USA, this technology has never been applied to biomethane produced from dairy manure or similar feedstocks.

As noted, a significant disadvantage of LBM is that it must be used fairly quickly after it is produced (typically within one week) to avoid significant fuel losses from thermal evaporation. Since standard LNG tankers carry about 10,000 gallons of LNG, a small-scale LNG liquefaction facility should produce about 3,000 gallons of liquefied biomethane/day. This would allow a full LNG tanker to be loaded approximately every four days for cost-effective distribution to the ultimate point of consumption.

