1. Potential Biogas Supply from California Dairies

Biogas is a product of naturally occurring anaerobic fermentation of biodegradable material. Anaerobic bacteria occur naturally in the environment in anaerobic “niches” such as marshes, sediments, wetlands, and in the digestive tract of ruminants and certain species of insects. These bacteria also exist in landfills where anaerobic decomposition is the principal process degrading landfilled food wastes and other biomass.

When collected or captured, biogas can be used as a renewable energy source similar to natural gas, but with significantly lower methane content and thus a lower heating value. Biogas is derived from renewable biomass sources through a process called anaerobic digestion. Within the USA, the biogas industry is comprised primarily of landfills that collect and utilize landfill gas (LFG) and wastewater treatment plants utilizing anaerobic digesters. Digestion of animal manure from dairies and swine farms is gaining importance in the US both as an energy product and as a means for management of environmental impacts. Currently in the US, biogas is used primarily in engine-generators or boilers for generation of electricity and heat.

This report primarily addresses alternate (non-power and heat generation) uses of biogas produced on dairies, and more specifically, with the production and use of biomethane, an upgraded form of biogas that is equivalent to natural gas. This chapter explores the potential supply of biogas from dairies, including on-farm management factors that affect biogas production. In addition, it discusses the possibility of co-digesting dairy and other biomass wastes—that is, of augmenting dairy wastes with other biomass sources to improve overall biogas yield.

California Dairy Industry

California is the largest dairy state in the nation, with approximately 1.7 million cows on about 2,100 dairies. The average California dairy has about 800 cows, and there is a clear trend toward concentration. According to Western United Dairymen, the number of California dairies decreased from more than 9,700 in 1960 to less than 2,200 in 2003 (Tiffany LaMendola, Western United Dairymen, personal communication, 29 June 2004). This represents a 78% reduction in the number of dairies. Despite the decreasing number of dairies, milk production grew from less than 10 billion pounds a year in 1963 to 35 billion pounds a year in 2003 (CDFA 2004, p. 44). The growth in milk production was generated by a significant increase in production per cow and, due to an increase in the average herd size, to an increase in the total number of cattle in the state.

The continuing trend toward an increased concentration of animals on fewer farms is illustrated in Table 1-1.

Table 1-1 Recent Trends in the California Dairy Industry: More Cows, Fewer Dairies

Year	Average Number of Cows per Dairy	Number of California Dairies
2001	721	2,157
2002	776	2,153
2003	806	2,125

Source: CDFA, 2003a

Table 1-2 Number of Cows in California's Dairies, 2003

County	Number of Cows	Number of Dairies	Average Number of Cows per Dairy
Butte	712	5	142
Del Norte	2,540	10	254
Fresno	90,345	109	829
Glenn	19,398	73	266
Humboldt	16,242	93	175
Kern	98,478	46	2,141
Kings	153,475	155	990
Madera	57,099	56	1,020
Marin	10,145	29	350
Merced	224,734	316	711
Monterey	1,632	4	408
Riverside	82,213	74	1,111
Sacramento	16,247	48	338
San Benito	774	3	258
San Bernardino	152,333	169	901
San Diego	5,500	8	688
San Joaquin	106,162	151	703
Santa Barbara	2,296	3	765
Siskiyou	1,677	5	335
Solano	3,643	5	729
Sonoma	31,192	81	385
Stanislaus	177,432	313	567
Tehama	5,103	23	222
Tulare	437,476	323	1,354
Yolo	2,048	3	683
Yuba	3,302	4	826
Total	1,702,198	2,109	807

Source: CDFA, 2004

Milk produced on California dairies is used in five major dairy product categories: fluid milk; soft products such as sour cream, cottage cheese, and yogurt; frozen products; butter and nonfat dry milk products; and cheese. Cheese is the largest category, using 45% of California's milk production compared to fluid milk, which represents 18% (CDFA 2003a).

Most of California's dairy farms are in the Central Valley. As shown in Table 1-2, Tulare County has the highest number of dairy cows, while Kern County has the largest dairies. Large dairies with 5,000 to 6,000 cows are becoming more commonplace as smaller dairies are consolidated or go out of business.

On-Farm Manure Management and Biogas Supply

California's dairy cows generated 3.6 million bone dry tons (BDT) of manure in 2003 (CBC, 2004). To assess the potential for biogas production from this manure, on-farm waste management techniques need to be considered. The methane-generation potential of the manure is directly affected by the methods used to collect and store manure.

Anaerobic digestion of animal manure, described more fully in Chapter 2, is a readily available technology that is limited by the type of feed a digester can receive. Common digesters use manure that is between 1% and 13% solids. Raw dairy manure contains about 15% total solids, of which about 83% is volatile solids. The percentage of total solids in stored manure depends on how much water the dairy uses to flush the manure. Manure collected fresh has greater methane-generation potential due to the retention of volatile solids. To ensure freshness, animal manure must be collected at least weekly, although daily collection is preferable.

On-Farm Manure Management Systems

In California, manure is collected as a semisolid or solid with a tractor scraper, or as a thin slurry formed by flushing water over a curbed concrete alley where manure is deposited. Typically, one of four prevailing manure management schemes is used on California dairies, depending on dairy housing patterns and manure deposition characteristics:

- Flushed freestall
- Scraped freestall
- Drylot with flushed feedlanes
- Scraped drylot

A *flushed freestall dairy* generally includes a milking barn, a separately roofed freestall barn that usually accommodates only the milk cow herd, and drylots for cow lounging. The milking parlor floor is cleaned by hose or flushed with fresh water. Flushed water containing manure is collected at the end of the flush lane and piped either to a separator or to the storage lagoon.

A *scraped freestall dairy* has the same configuration as a freestall flush dairy, except the freestall lanes are scraped using a skid steer tractor, rubber scraper, mechanical scraper, or vacuum scraper. The manure is typically deposited in a gutter that drains into a central pit. The milking parlor floor is cleaned by hose or flushed with fresh water.

A *flushed drylot dairy* has a milk barn that is flushed as well as drylots with flushed feedlanes. The parlor floor is cleaned by hosing or flushing with fresh water and flushed water containing manure is collected at the end of the flush lane and piped either to a separator or to the storage lagoon. However, a significant portion of the manure is deposited in drylots and scraped at random intervals as solid manure. The solids are often scraped into piles and left until there is an opportunity to haul them away.

Most *scraped drylot dairies* are older dairies. In this system, 85% to 90% of the manure is managed by dry scraping and truck removal. Manure is pushed by a tractor or pulled by a hydraulic scraper to a collection point. Drylot feedlanes usually do not have curbs and are not cleaned by flush water.

RCM Digesters (Berkeley, California; <http://rcmdigesters.com/Default.htm>) estimates that 35% of the cows in California are on flushed freestall dairies, 10% are on scraped freestall dairies, 30% are on flushed feedlane drylot dairies, and 25% are on drylot or scrape dairies (Mark Moser, personal communication, 27 May 2004). Many farms use a combination of these manure management systems, but in general most farms in northern California and the Central Valley use flush water and store manure in lagoons, while most Southern California dairies scrape their manure. The farmer chooses between these systems based on the price and availability of water as well as on local regulations and the amount of available land. In some jurisdictions the farmer is obligated to remove the dairy manure from the farm if there is inadequate acreage on which to spread it.

Biogas Production Potential from California Dairies

The quantity of biogas created from the digestion of dairy manure is determined by the dairy's manure management system. Key considerations for biogas production include the freshness and concentration of digestible materials in the manure. In theory, flushed manure collection systems produce less gas than regularly scraped manure systems because the digestible materials are dispersed and diluted. However, if collection of scraped manure is infrequent—which it typically is—the manure in scraped drylots may decompose and become unusable for anaerobic digestion. Dirt lot scraping incorporates dirt and stones into the scraped manure, and these may damage equipment and accumulate in a digester. Manure scraped from concrete surfaces on dirt lots will also include large quantities of inorganics, although manure scraped from freestall barns where cows remain inside is typically relatively clean, unless the bedding is sand or wood chips. Sand tends to collect within the digester and reduce the active volume of the digester over time; sawdust used as bedding passes through the digester untreated; and paper bedding increases gas yield. In practical experience, therefore, because of the infrequency of collection and the incorporation of inorganics into the manure, scraped drylot dairies are usually not good candidates for biogas production.

Storage of manure also affects biogas production potential. Drylot storage techniques produce very little biogas because aerobic conditions inhibit the development of the methanogenic bacteria that create biogas. Manure stored in lagoons produces a substantial quantity of methane-rich biogas. If the lagoons are uncovered, this biogas is released into the atmosphere. When the waste is very dilute, solids tend to sink and create a layer of sludge in the bottom of lagoons or float and create a crust. For this reason, many dairies have solids separators to reduce solids loading in storage lagoons. Typical mechanical separators recover 15% to 20% of the solids from manure, while gravity separation may recover up to 40% of the solids. Separation of the solids results in the reduction of volatile solids in the lagoons and a roughly 25% lower methane yield.

Table 1-3 presents the potential daily methane (CH_4) production from California dairies using existing technology and practices. The amount that is produced depends primarily on the quality of the feed for the cows and the manure collection system used. The use of screen separators, which is assumed in the table, tends to reduce methane production by 25%.

Table 1-3 Potential Daily Methane Production from California Dairies [a]

Type of Dairies	Number of Cows	Potential Daily Methane Production [b] (ft^3/d)	
		Per Cow [c]	In California
Flushed freestall	595,769	32.2	19,183,771
Scraped freestall	170,220	32.2	5,481,084
Flushed drylot	510,659	23.8	12,153,691
Scraped drylot [d]	425,550	5.6	2,383,080
Totals	1,702,198		39,201,626

ft^3/d = Cubic feet per day

[a] Updated from (CEC 1997).

[b] Assuming screen solids separators are used, which reduces methane production by 25%.

[c] Note that an average of 30 ft^3/day/cow is used elsewhere in this report; this figure reflects the practical consideration that most of the biogas potential will come from freestall rather than drylot dairies because manure management on these dairies is more conducive to biogas generation.

[d] Although scraped drylot dairies have the potential to generate biogas, most are not good candidates because of infrequent manure collection and storage techniques.

Based on the information presented in Table 1-3, we estimate that California dairies have a methane production potential of about 40 million cubic feet per day (ft^3/d) or 14.6 billion cubic feet per year (ft^3/y). Using the early 2005 delivered price of natural gas (about $10.00 per thousand cubic feet), this is equivalent to over $146 million per year in energy costs.[1] In terms of electricity output, this corresponds to over 1.2 million megawatt-hours (MWh) of energy or about 140 MW of electricity (MW_e). As new technologies are tried and proven the methane yield and electrical production per cow is likely to increase.

Co-Digestion of Dairy and Other Wastes

To augment methane production, manure from dairy cows can be co-digested with additional substrates such as agricultural residues and food-processing waste. Table 1-4 shows the potential methane-generation potential of various biomass sources available in California. The data used to estimate methane potential for these wastes was derived from an early study by Buswell and Hatfield of the Illinois Water Survey (1936); this study is still the most comprehensive information from a single study on the digestion of various waste resources.

Both gross and technical methane potentials are presented in Table 1-4. The gross potential represents the methane potential of all the waste generated within the stated categories in the state. The portion that is technically available is based on evaluations by the author and the various references cited.

The gross potential of swine and poultry layer manure in California is 30,000 and 274,000 BDT, respectively. Of this amount, about half is available for anaerobic digestion (technical potential). This amounts to about 160 million ft^3/yr of CH_4 from swine operations (ASAE, 1990, p. 464), and about 850 million ft^3/yr of CH_4 for poultry layer operations (RCM Digesters, 1985). Swine and poultry farms lend themselves to biogas generation due to the regular collection of manure, and were therefore included in Table 1-4. Manure from cattle feedlot and poultry broiler and turkey operations were not considered to be technically available due to the infrequent collection of manure at these facilities.

Crop Residues

The 2003 California Biomass Resource Assessment (CBC, 2004) indicates that the gross potential of waste available from vegetable production in 2003 was 1.2 million BDT. Of this amount, only 100,000 BDT of biomass are estimated to be “technically” available on an annual basis. This waste would have the potential to generate about 1 billion ft^3 of CH_4 per year (Buswell and Hatfield, 1936, p. 170). The CBC assessment (2004) also states that the gross potential for biomass from field and seed production is about 5 million BDT. The main components are rice

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[1] This figure will vary according to the actual price of natural gas. At the time of final manuscript preparation (spring 2005), this price is historically high at around $10 per therm; in the recent past, the price has been between $6 and $7 per therm.

straw (1.5 million BDT), cotton residue, wheat straw, and corn stover (leaves and stalks of corn). About 2.4 million BDT of this is potentially available for anaerobic digestion. As shown in Table 1-4, this 2.4 million BDT of biomass has the potential to generate 5.2 billion ft^3 of CH_4 per year (Buswell and Hatfield, 1936, p. 114) recoverable using existing collection methods. Though not considered in Table 1.4, recent research on rice straw indicates that the 1.5 million BDT of rice straw that is potentially available could produce as much as 6 billion ft^3 of CH_4 per year (Zhang, 1998).

Figures for orchard and vine production biomass wastes are also provided (CBC, 2004); however, these biomass sources were not included in Table 1-4 because the woody nature of the biomass generated in these farming operations does not lend itself to anaerobic digestion. It should be noted that all the crop residues mentioned are relatively undigestible without pretreatment such as screening (to remove dirt) and size reduction, and present significant handling issues for anaerobic digestion. Thus, although they represent a potentially large biomass resource, crop residues may not be a practical source of material for co-digestion with dairy wastes.

Food Processing Waste

The League of California Food Processors estimates that 14 to 16 million tons of fruits and vegetables are processed in California every year by canners, freezers, dryers, and dehydrators (Ed Yates, personal communication, 17 May 2004). These operations generate 1 million tons of waste annually from July through September. The waste material consists of peeled material, core material, culls and extraneous leaves and is 5% to 8% total solids. According to Yates, 49% of the waste is used as cattle feed and another 49% is used as soil amendment (personal communication, 17 May 2004). The 490,000 wet tons of waste material used annually as soil amendment could potentially be available for anaerobic digestion. The technical CH_4 generation potential from this waste would be 359 million ft^3/yr (Buswell and Hatfield, 1936, p. 170). If the material fed to cattle was also used to generate gas, the gross potential is double this amount. However, using these food wastes as cattle feed is a higher value use than using them as a biomass source for gas generation. Also, the seasonal availability of food processing wastes could be problematic (e.g., grape and apple harvests occur over a 60-day period).

The California Milk Advisory Board indicates there are 60 cheese manufacturing plants that produced 1.8 billion pounds of cheese in 2003 (<www.realcaliforniacheese.com>, 17 May 2004). According to Carl Morris, general manager of Joseph Gallo Farms, for every pound of cheese produced, approximately 9 pounds of whey is generated (personal communication, 18 May 2004). The whey is typically converted into a powdered product and sold. However, 4.6% of the whey is in the form of lactose permeate, a waste product with a total solids content of 6%. Based on this, approximately 23,700 tons of lactose-permeate solids waste was generated in 2003 by California’s cheese industry. This waste stream is both continuous and highly digestible, and could easily be combined with dairy wastes. Using Buswell and Hatfield's data (1936, p. 170), lactose permeate waste has the potential to generate 250 million ft^3 of CH_4 per year.

Slaughterhouse Waste and Rendering Plant Wastewater

The 2003 California Biomass Resource Assessment conducted by the California Biomass Collaborative indicates that there are 79,000 BDT of slaughterhouse waste produced annually in the state, of which approximately 63,600 BDT would be technically available for anaerobic digestion. This waste, which includes digestible solids as well as liquids, is continuous and highly digestible and could generate approximately 660 million ft^3 of CH_4 per year (Buswell and Hatfield, 1936, p.155).

Table 1-4 Potential Methane Generation from Biomass Sources, California

Biomass Waste Material	Annual Methane Production [a] (million ft^3/y)	
	Gross Methane Potential	Technical Methane Potential
Swine manure [b]	320	160
Poultry layer manure [c]	1,700	850
Poultry broiler manure [d]	1,800	0
Turkey manure [d]	1,300	0
Dairy manure	21,100	14,300
Cattle feedlot manure [d]	4,100	0
Crop residues	10,700	5,220
Vegetable residue	11,300	940
Meat processing	660	530
Rendering (wastewater) [e]	120	120
Cheese whey (lactose permeate)	250	250
Food processing waste	720	360
Processed green waste [f]	18,000	0
Landfilled manure [f]	220	0
Landfilled composite organic waste	15,200	0
Landfilled food waste [f]	19,900	0
Landfilled green waste [f]	16,500	0
Total	123,890	22,730

ft^3/y = Cubic feet per year

[a] Unless otherwise indicated, these figures calculated based on Buswell and Hatfield data (1936).

[b] ASAE, 1990, p. 464.

[c] RCM Digesters, 1985.

[d] CBC, 2004 amended by personal communication from R. Williams, June 29, 2005.

[e] Metcalf & Eddy, 1979, p. 614; US EPA, 1975, p. 61.

[f] Al Seadi, Undated.

According to the California Integrated Waste Management Board (<http://www.ciwmb.ca.gov/FoodWaste/Render.htm>, 26 May 2004), there are 21 rendering operations in California. Waste from these plants amounts to approximately 2.45 million gallons per day (gpd) of high-strength organic wastewater (Fred Wellen, Baker Commodities, Inc., personal communication, 26 May 2004). The waste is typically treated in open lagoons to reduce the biological oxygen demand (BOD) prior to release to sewage treatment facilities or land application. This wastewater is highly digestible and could potentially be digested at the plant or co-digested with manure, especially if the rendering operations are in close proximity to the dairy. Rendering plant waste has the potential to generate 120 million ft^3 of CH_4 per year (US EPA, 1975, pp. 61, 87).

Green Waste from Municipal/Commercial Collection Programs

According to a June 2001 report entitled *Assessment of California's Compost and Mulch Producing Infrastructure*, composters and processors in California process over 6 million tons of organic materials per year (CIWMB, 2001). From this raw material, about 15 million cubic yards of organic material products are produced, including compost, boiler fuel, mulch and various blends (CIWMB, 2001). Although this material, unprocessed, is generally not suitable for anaerobic digestion because of its high lignin and low digestibles content, Sweden and other European countries digest significant portions of this waste stream. The presence of pesticides, fertilizer, wood chips, and other debris in domestic greenwaste adds further complexity. If these problems can be surmounted greenwaste could substantially augment the production of dairy biogas. The Inland Empire Utilities Agency is now in the planning stages for building such a system using dairy waste and local greenwaste. The California Energy Commission has provided funding to build a research digester designed by Dr. Ruihong Zhang of University of California Davis that will utilize greenwaste.

Conclusions Regarding Co-Digestion

The gross and technical potential for methane generation from biodegradable wastes in California, including dairy wastes and landfilled wastes, is summarized in Table 1-4. The total gross potential is about 124 billion ft^3 CH_4/year, enough gas to produce about 10.4 million megawatt-hours (MWh) of electricity or about 1,200 MW of electrical capacity (at a heat rate of 12,000 Btu/kWh, assuming an energy conversion factor of 28%). However, most of this waste is not technically available due to inefficiencies in collection, contamination with other waste products, and other uses. Therefore the technical potential is estimated at only 23 billion ft^3 of CH_4/year, or about 220 MW_e, with dairy manures representing about two thirds of this amount. To put these figures in perspective, the total statewide demand for natural gas is about 6 billion ft^3/day, or 2,200 billion ft^3/year.

For co-digestion with dairy manures, only a relatively small fraction of potential or even technically available wastes would actually be usable, due to the many constraints on co-digestion, which range from location to seasonal availability to process constraints. Most importantly, only a few waste resources (whey, meat processing, rendering, fruit and vegetable processing) lend themselves to co-digestion without introducing major difficulties (e.g., pretreatment). Although co-digestion may be important on a site-specific basis, on a statewide basis we do not expect that co-digestion of other biomass wastes would augment the dairy waste methane potential shown in Table 1-2 by more than 10% to 20%.