Resource Assessment for Livestock and Agro-Industrial Wastes – Brazil

Prepared for:

Global Methane Initiative

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EXECUTIVE SUMMARY

The Global Methane Initiative is an initiative to reduce global methane emissions with the purpose of enhancing economic growth, promoting energy security, improving the environment, and reducing greenhouse gases (GHGs). The initiative focuses on cost-effective, near-term methane recovery and use as a clean energy source. The initiative functions internationally through collaboration among developed countries, developing countries, and countries with economies in transition—together with strong participation from the private sector.

The Global Methane Initiative works in four main sectors: agriculture, landfills, oil and gas exploration and production, and coal mining. The Agriculture Subcommittee was created in November 2005 to focus on anaerobic digestion of livestock wastes; it has since expanded to include anaerobic digestion of wastes from agro-industrial processes. Representatives from Argentina, the United Kingdom, and India currently serve as co-chairs of the subcommittee.

As part of the Global Methane Initiative, the U.S. Environmental Protection Agency (U.S. EPA) is conducting a livestock and agro-industry resource assessment (RA) in Brazil to identify and evaluate the potential for incorporating anaerobic digestion into livestock manure and agro-industrial (agricultural commodity processing) waste management systems to reduce methane emissions and provide a renewable source of energy.

The following table summarizes the findings of the RA in terms of potential methane emission reductions and fossil fuel replacement carbon offsets in Brazil. The sector with the highest potential for methane reduction and carbon offsets is the swine sector (64 percent of the potential), followed by sugarcane mills and distilleries (ethanol and cachaça, 20 percent), slaughterhouses (13 percent), and finally tapioca (cassava starch) (1.9 percent), beverages (0.8 percent), and dairy cattle (0.6 percent).

Sector	Methane Emission Reductions (MT CH_4/yr)	Carbon Emission Reductions (MT CO_2e/yr)	Fuel Replacement Offsets (MT CO_2e/yr)	Total Carbon Emission Reductions (MT CO_2e/yr)
Swine	566,300	11,891,500	1,053,400	12,944,900
Distilleries (ethanol, cachaça)	174,400	3,661,800	324,400	3,986,200
Slaughterhouses (beef cattle, pigs, and broilers	114,200	2,397,500	212,400	2,609,900
Tapioca	17,100	359,100	31,800	390,900
Dairy cattle	9,200	193,100	17,100	210,200
Beverages (beer, and carbonated drinks)	7,500	157,200	14,000	171,200
Total	888,700	18,660,200	1,653,100	20,313,300

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LIST OF ABBREVIATIONS

ABAM	Brazilian Association of Cassava Starch Producers
ABEF	Brazilian Chicken Producers and Exporters Association
ABIEC	Association of Brazilian Beef Exporters
ABIPECS	Association of Brazilian Pork Producers and Exporters
ABIR	Brazilian Association of Carbonated and Non-alcoholic Drinks
AMBR®	Anaerobic migrating blanket reactor
ASBR	Anaerobic sequencing batch reactor
BNDES	Brazilian National Bank of Economic and Social Development
BOD	Biochemical oxygen demand
CAFO	Confined animal feed operations
CETESB	Environmental Agency of the State of São Paulo
CH_4	Methane (chemical formula)
COD	Chemical oxygen demand
CWE	Carcass weight equivalent
DAF	Dissolved air flotation
DIPOA	Department of Inspection of Animal Origin Products
EMBRAPA	Brazilian Agricultural Research Corporation
FAO	United Nations Food and Agriculture Organization
FATMA	State environmental agency (state of Santa Catarina)
GDP	Gross domestic product
GHG	Greenhouse gas
HRT	Hydraulic retention time
IBGE	Brazilian Institute of Geography and Statistics
IPCC	Intergovernmental Panel on Climate Change
MCF	Methane conversion factor
$MMTCO_2e$	Million metric tons of carbon dioxide equivalent
MT	Metric ton
$MTCO_2e$	Metric tons of carbon dioxide equivalent
PBDAC	Brazilian Cachaça Development Program
PE	Pernambuco
RA	Resource assessment
SIGSIF	Federal Service Inspection Supervision (for slaughterhouses)

Sindicerv	Brazilian Brewery Industry Union
SP	São Paolo (state)
SUFRAMA	Manaus Tax Free Zone Secretary
TS	Total solids
TSS	Total suspended solids
UASB	Upflow anaerobic sludge blanket
Unica	Brazilian Sugarcane Industry Association
U.S. EPA	United States Environmental Protection Agency
VS	Volatile solids

1. INTRODUCTION

The Global Methane Initiative is a collaborative effort between national governments and others to capture methane emissions and use them as a clean energy source. The initiative, begun in 2004 as the Methane to Markets Partnership, was relaunched in 2010. Partners make formal declarations to minimize methane emissions from key sources, stressing the importance of implementing methane capture and use projects in developing countries and countries with economies in transition. The initiative is focusing on the a few key sources of methane including agriculture, coal mining, landfills, and oil and gas systems.

The role of the initiative is to bring diverse organizations together with national governments to catalyze the development of methane projects. Organizations include the private sector, the research community, development banks, and other governmental and nongovernmental organizations. Facilitating the development of methane projects will decrease greenhouse gas (GHG) emissions, increase energy security, enhance economic growth, improve local air quality, and improve industrial safety.

The Global Methane Initiative is conducting resource assessments (RAs) in several countries to identify the types of livestock and agro-industrial subsectors (e.g., dairy farming, palm oil production, sugarcane processing) with the greatest opportunities for cost-effective implementation of methane recovery systems. The Brazil RA's objectives are to:

- Identify and characterize methane reduction potential in Brazil
- Develop market opportunities
- Provide the location of resources and a ranking of resources

The main objective of this RA is to identify the potential for incorporating anaerobic digestion into livestock manure and agro-industrial (agricultural commodity processing) waste management systems to reduce methane emissions and provide a renewable source of energy in Brazil. This report summarizes the findings of the RA, discusses the most attractive sectors and locations, and prioritizes the sectors in terms of potential methane emission reductions.

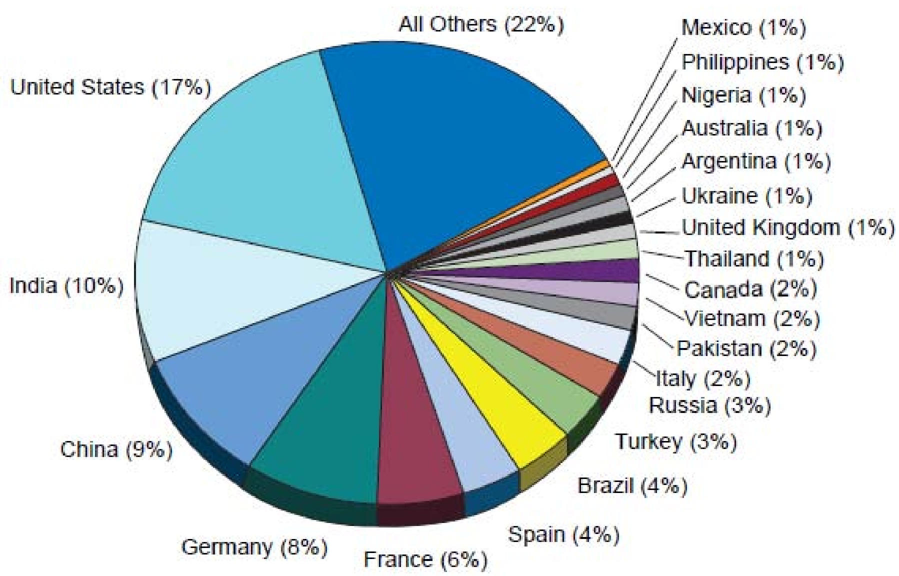
While there are other studies showing methane emissions from the sectors covered in this document, these studies usually consider total population or production levels as the baseline for calculating the emissions. This RA, however, uses a different approach, recognizing that not all waste management practices (e.g., pastures) generate methane. For this analysis, methane emission reduction estimates are based on the actual population (or number of industries) that generate methane from their waste management systems (e.g., lagoons) using the most accurate and validated data available for each subsector. For example, methane emissions from swine and dairy subsectors only take into account a reasonable fraction of the total number of animals and number of operations in the country. This fraction represents the number of animals that are assumed to be using waste management practices that generate methane. Estimating emission reductions using these assumptions provides a better basis for policy development and capital investments and provides conservative estimates of emission reductions.

Finally, it is important to note that this RA limits its scope to emission reduction technical potential. It does not address the economic potential, which still needs to be determined based on subsector-specific feasibility studies.

1.1 METHANE EMISSIONS FROM LIVESTOCK WASTES

In 2005, livestock manure management globally contributed more than 230 million metric tons of carbon dioxide equivalents (MMTCO$_2$e) of methane emissions, or roughly 4 percent of total anthropogenic (human-induced) methane emissions. Three groups of animals accounted for more than 80 percent of total emissions: swine (40 percent); non-dairy cattle (20 percent); and dairy cattle (20 percent). In certain countries, poultry was also a significant source of methane emissions. Figure 1.1 represents countries with significant methane emissions from livestock manure management.

Figure 1.1 – Estimated Global Methane Emissions From Livestock Manure Management (2005) Total = 234.57 MMTCO$_2$e

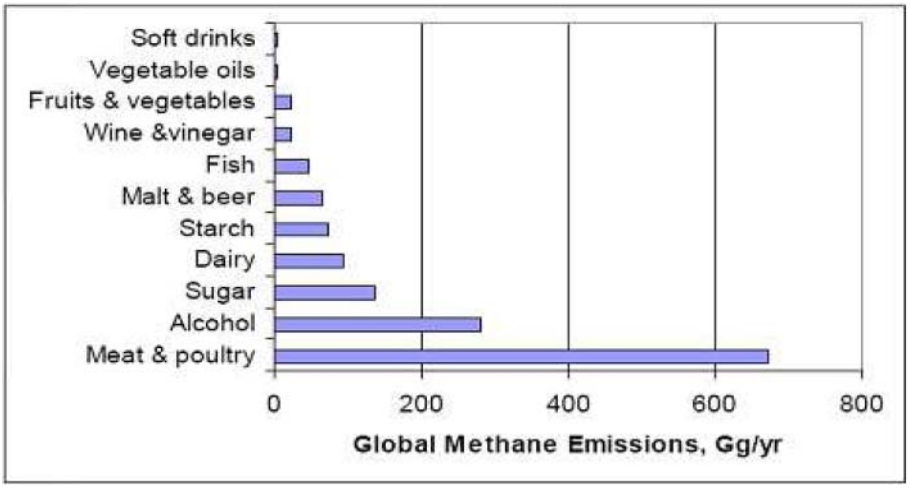


Source: Global Methane Initiative

1.2 METHANE EMISSIONS FROM AGRO-INDUSTRIAL WASTES

Waste from agro-industrial activities is an important source of methane emissions. The organic fraction of agro-industrial wastes typically is more readily biodegradable than the organic fraction of manure. Thus, greater reductions in biochemical oxygen demand (BOD), chemical oxygen demand (COD), and volatile solids (VS) during anaerobic digestion can be realized. In addition, the higher readily biodegradable fraction of agro-industrial wastes translates directly into higher methane production potential than from manure. Figure 1.2 shows global estimates of methane (CH_4) emissions from agro-industrial wastes.

Figure 1.2 – Global Methane Emissions From Agro-Industrial Wastes



Source: Doorn et al., 1997

As shown in Table 1.1, the majority of agro-industrial wastes in developing countries are not treated before discharge, and only a minority are treated anaerobically. As a result, agro-industrial wastes represent a significant opportunity for methane emission reduction through the addition of appropriate anaerobic digestion systems.

Table 1.1 – Disposal Practices From Agro-Industrial Wastes

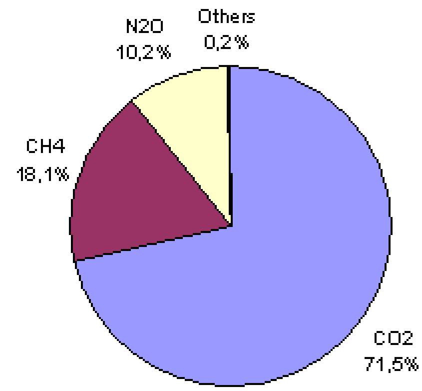
Sector	Region	Percent of Wastewater	
		Untreated Discharge	Onsite Anaerobic Treatment
Meat, poultry, dairy, and fish processing	Africa	60	34
	Asia (except Japan)	70	22
	Eastern Europe	50	23
	Latin America	50	32
Fruit and vegetable processing	Africa	70	6
	Asia (except Japan)	70	5
	Eastern Europe	50	1
	Latin America	60	5
Alcohol, beer, wine, vegetable oil, sugar, and starch	Africa	60	17
	Asia (except Japan)	60	11
	Eastern Europe	20	8
	Latin America	20	13

Source: Doorn et al., 1997

1.3 METHANE EMISSIONS IN BRAZIL

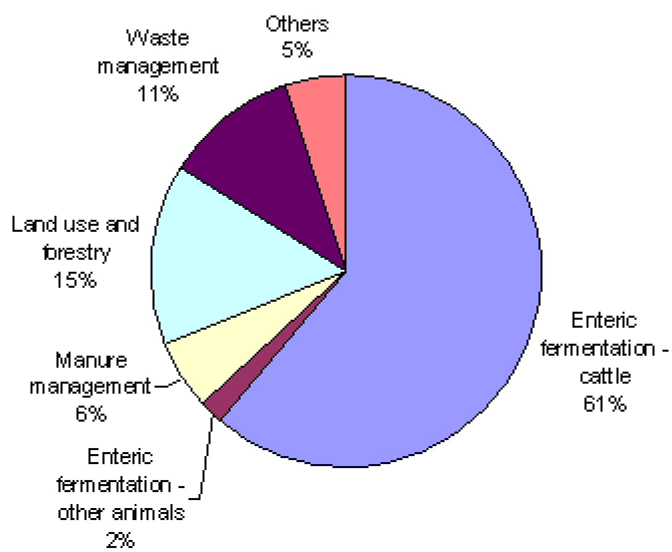
According to the most recent Brazilian GHG inventory (MCT, 2009), methane corresponds to 18.1 percent of the total GHG emissions (see Figure 1.3), with enteric fermentation accounting for 63 percent of all methane emissions (see Figure 1.4), due primarily to the size of the Brazilian beef cattle population. Animal waste management represents 6 percent of the total methane emissions; though it is small compared to enteric fermentation, it represents a significant opportunity for emission reduction with methane capture through the use of anaerobic digestion under controlled conditions with subsequent combustion either as an energy source or for disposal.

Figure 1.3 – GHG Emissions in Brazil (CO_2 Equivalent) (2005)



Source: MCT, 2009

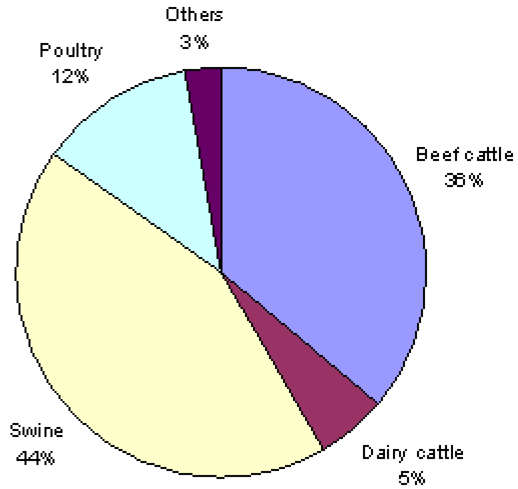
Figure 1.4 – Sources of Methane Emissions in Brazil (2005)



Source: MCT, 2009

Methane emissions from manure management occur mainly from the production of hogs (44 percent), beef and dairy cattle (36 percent and 5 percent, respectively) and poultry (12 percent), as seen in Figure 1.5. These species represent 97 percent of all methane emissions from manure management in Brazil.

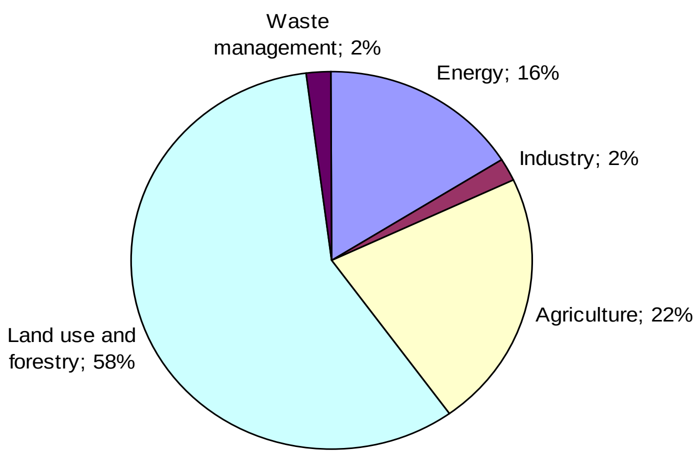
Figure 1.5 – Methane Emissions From Manure Management in Brazil, by Species (2005)



Source: MCT, 2009

A preliminary report on anthropogenic GHG emissions in Brazil for 2005 (published in November 2009) (see Figure 1.5) shows that the agriculture sector is responsible for 22 percent of the total GHG emissions of the country. Of that percentage, livestock manure accounts for 7.8 percent of GHG emissions. Waste management, which includes agro-industrial waste, accounts for 2 percent of GHG emissions (see Figure 1.6).

Figure 1.6 – Sources of GHG Emissions in Brazil (2005)



Source: MCT, 2009

2. BACKGROUND AND CRITERIA FOR SELECTION

This report presents an assessment of methane emissions from wastes of Brazil's livestock and agro-industrial sectors. It focuses on livestock and agro-industrial subsectors deemed to have the greatest potential for methane emission reduction or methane capture.

2.1 METHODOLOGY USED

In conducting the RA, the team used a variety of data sources:

- **Field visits** to sites of various sizes in the various sectors to characterize the waste management systems used and to verify the information collected through other sources.

- **Interviews** with local experts from pertinent industry associations and engineering/consulting companies and professionals working on agriculture and rural development, current users of anaerobic digestion technologies, and other stakeholders.

- **Published data** by national and international organizations (e.g., United Nations Food and Agriculture Organization [FAO] animal production data sets), specific subsector information from business and technical journals, and other documents, reports and statistics.

The team took the following approach, which has also been used in other RAs in this series:

Step 1: The first step in the development of the Brazil livestock and agro-industry RA involved constructing general profiles of the individual subsectors (or commodity groups), such as dairy and swine production and sugarcane and fruit processing. Each profile includes a list of operations within the subsector and the distribution of facilities by size and geographic location. For the various commodity groups in the livestock sector, the appropriate metric for delineating distribution by size is the average annual standing population (e.g., number of lactating dairy cows, pigs). For the various commodity groups in the agro-industry sector, the metric is the mass or volume of annual processing capacity or the mass or volume of the commodity processed annually.

Step 2: Based on available data, the team then tried to determine the composition of the livestock production and agro-industry sectors at the national level, as well as the relative significance of each of them geographically.

Step 3: With this information, the team focused on identifying the commodity groups in each sector with the greatest potential to emit methane from waste management activities. For example, a country's livestock sector might include dairy, beef, swine, and poultry operations, but poultry production might be insignificant due to lack of demand or considerable import of poultry products, with correspondingly low methane emissions. Thus, to most effectively use available resources, we focused on identifying those commodity groups with higher emissions. In the best-case scenarios, these livestock production and agro-industry sector profiles were assembled from statistical information published by a government agency. If such information was unavailable or inadequate, the team used a credible secondary source, such as FAO.

Step 4: The team characterized the waste management practices used by the largest operations in each sector. Typically, only a small percentage of the total number of operations in each commodity group will be responsible for the majority of production, and thus the majority of the methane emissions. Additionally, the waste management practices employed by the largest producers in each commodity group should be relatively uniform. When information about waste management practices was incomplete or not readily accessible, the team identified and directly contacted producer associations and local consultants and visited individual operations to obtain this information.

Step 5: The team then assessed the magnitudes of current methane emissions to identify the commodity groups that should receive further analysis. As an example, in the livestock production sector, large operations in a livestock commodity group that relies primarily on a pasture-based production system will have only nominal methane emissions because manure decomposition will be primarily by aerobic microbial activity. Similarly, an agro-industry subsector with large operations that directly discharge untreated wastewater to a river, lake, or ocean will not be a source of significant methane emissions. Thus, the process of estimating current methane emissions was focused on those sectors that could most effectively use available resources—the most promising candidate sectors and/or operations for technology demonstration.

2.2 ESTIMATION OF METHANE EMISSIONS IN THE LIVESTOCK AND AGRO-INDUSTRIAL SECTORS

This section describes the generally accepted methods for estimating methane emissions from livestock manures and agricultural commodity processing wastes, along with the modification of these methods to estimate the methane production potential with the addition of anaerobic digestion as a waste management system component.

2.2.1 Manure-Related Emissions

The team used the 2006 *IPCC Guidelines for National Greenhouse Gas Inventories* Tier 2 method to estimate methane emissions from each commodity group in the livestock production sector. Using the Tier 2 method, methane emissions for each livestock commodity group (M) and existing manure management system (S) and climate (k) combination are estimated as shown in Equation 2.1:

$$CH_{4\,(M)} = \left(VS_{(M)} \times H_{(M)} \times 365 \text{ days/yr}\right) \times \left[B_{o(M)} \times 0.67 \text{ kg } CH_4/m^3 \; CH_4 \times MCF_{S,\,k}\right] \qquad (2.1)$$

where:
- $CH_{4\,(M)}$ = Estimated methane emissions from manure for livestock category M, (kilograms [kg] CH_4/yr)
- $VS_{(M)}$ = Average daily volatile solids excretion rate for livestock category M (kg volatile solids/animal/day)
- $H_{(M)}$ = Average number of animals in livestock category M
- $B_{o(M)}$ = Maximum methane production capacity for manure produced by livestock category M (cubic meters [m^3] CH_4/kg volatile solids excreted)
- $MCF_{(S,k)}$ = Methane conversion factor for manure management system S for climate k (decimal)

As shown, Equation 2.1 requires an estimate of the average daily VS excretion rate for the livestock category under consideration. The default values for dairy cows, breeding swine, and market swine are listed in Table 2.1. Default values for other types of livestock can be found in Tables 10A-4 through 10A-9 in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

Table 2.1 – 2006 IPCC Volatile Solids Excretion Rate Default Values for Dairy Cows, Breeding Swine, and Market Swine (kg/Head/Day)

Region	Dairy Cows	Breeding Swine	Market Swine
North America	5.4	0.5	0.27
Western Europe	5.1	0.46	0.3
Eastern Europe	4.5	0.5	0.3
Oceania	3.5	0.5	0.28
Latin America	2.9	0.3	0.3
Middle East	1.9	0.3	0.3
Asia	2.8	0.3	0.3
Indian Subcontinent	2.6	0.3	0.3

Realistic estimates of methane emissions using Equation 2.1 also require identification of the appropriate MCF, which is a function of the current manure management system and climate. MCFs for various types of manure management systems for average annual ambient temperatures ranging from greater than or equal to 10°C to less than or equal to 28°C are summarized in Table 2.2, and can be found in Table 10.17 of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

Table 2.2 – Default MCF Values for Various Livestock Manure Management Systems

Climate	Manure Management System Default Methane Emission Factor, Percentage								
	Lagoons	Storage Tanks and Ponds	Solid Storage	Dry Lots	Pit < 1 Month	Pit > 1 Month	Daily Spreading	Anaerobic Digestion	Pasture
Cool	66–73	17–25	2	1	3	17–25	0.1	0–100	1
Temperate	74–79	27–65	4	1.5	3	27–65	0.5	0–100	1.5
Warm	79–80	71–80	6	5	30	71–80	1	0–100	2

Finally, use of Equation 2.1 requires specification of the methane production potential (B_o) for the type of manure under consideration. Default values listed in Tables 10A-4 through 10A-9 of *the 2006 IPCC Guidelines for National Greenhouse Gas Inventories* can be used. The default values for dairy cows, breeding swine, and market swine are listed in Table 2.3.

Table 2.3 – 2006 IPCC Methane Production Potential Default Values for Dairy Cows, Breeding Swine, and Market Swine, m^3 CH_4/kg VS

Region	Dairy Cows	Breeding Swine	Market Swine
North America	0.24	0.48	0.48
Western Europe	0.24	0.45	0.45
Eastern Europe	0.24	0.45	0.45
Oceania	0.24	0.45	0.45
Latin America	0.13	0.29	0.29

Region	Dairy Cows	Breeding Swine	Market Swine
Middle East	0.13	0.29	0.29
Asia	0.13	0.29	0.29
Indian Subcontinent	0.13	0.29	0.29

2.2.2 Emissions Related to Agricultural Commodity Processing Waste

Agricultural commodity processing can generate two sources of methane emissions: wastewater and solid organic wastes. The latter can include raw material not processed or material discarded after processing due to spoilage or poor quality, or for other reasons. One example is the combination of wastewater and the solids removed by screening before wastewater treatment or direct disposal. These solid organic wastes may have relatively high moisture content and are commonly referred to as wet wastes. Appendix B illustrates a typical wastewater treatment unit process sequence. The method for estimating methane emissions from wastewater is presented below.

For agricultural commodity processing wastewaters, such as meat and poultry processing wastewaters from slaughterhouses, the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* Tier 2 methods (Section 6.2.3.1) are an acceptable way to estimate methane emissions. This methodology uses COD and wastewater flow data. Using the Tier 2 methods, the gross methane emissions for each waste category (W) and prior treatment system and discharge pathway (S) combination should be estimated as shown in Equation 2.2:

$$CH_{4\,(W)} = [(TOW_{(W)} - S_{(W)}) \times EF_{(W,\,S)}] - R_{(W)})] \qquad (2.2)$$

where:
- $CH_{4\,(W)}$ = Annual methane emissions from agricultural commodity processing waste W (kg CH_4/yr)
- $TOW_{(W)}$ = Annual mass of waste W COD generated (kg/year)
- $S_{(W)}$ = Annual mass of waste W COD removed as settled solids (sludge) (kg/yr)
- $EF_{(W,\,S)}$ = Emission factor for waste W and existing treatment system and discharge pathway S (kg CH_4/kg COD)
- $R_{(W)}$ = Mass of CH_4 recovered (kg/yr)

As indicated above, the methane emission factor in Equation 2.2 is a function of the type of waste and the existing treatment system and discharge pathway and is estimated as shown in Equation 2.3:

$$EF_{(W,S)} = B_{o\,(W)} \times MCF_{(S)} \qquad (2.3)$$

where:
- $B_{o\,(W)}$ = Maximum CH_4 production capacity (kg CH_4/kg COD)
- $MCF_{(S)}$ = Methane conversion factor for the existing treatment system and discharge pathway (decimal)

If country- and waste-sector-specific values for B_o are not available, the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* default value of 0.25 kg CH_4 per kg COD should be used. In the absence of more specific information, the appropriate MCF default value (see Table 2.4) also should be used.

Table 2.4 – Default MCF Values for Industrial Wastewaters, Decimal

Existing Treatment System and Discharge Pathway	Comments	MCF[a]	Range
Untreated			
Sea, river, or lake discharge	Rivers with high organic loadings may turn anaerobic, which is not considered here	0.1	0–0.2
Treated			
Aerobic treatment plant	Well managed	0	0–0.1
Aerobic treatment plant	Not well managed or overloaded	0.3	0.2–0.4
Anaerobic reactor (e.g., UASB, fixed film)	No methane capture and combustion	0.8	0.8–1.0
Shallow anaerobic lagoon	Less than 2 meters deep	0.2	0–0.3
Deep anaerobic lagoon	More than 2 meters deep	0.8	0.8–1.0

[a] Based on IPCC expert judgment.

If the annual mass of COD generated per year (TOW) is not known and it is not possible to collect the necessary data, the remaining option is estimation (as shown in Equation 2.4) with country-specific wastewater generation rate and COD concentration data obtained from the literature. In the absence of country-specific data, values listed in Table 2.5 can be used as default values to obtain first order estimates of methane emissions.

$$TOW_{(w)} = P_{(w)} \times W_{(w)} \times COD_{(w)} \tag{2.4}$$

where: $P_{(W)}$ = Product production rate, metric tons per year
$W_{(W)}$ = Wastewater generation rate (m^3/metric ton of product)
$COD_{(W)}$ = Wastewater COD concentration (kg/m^3)

Table 2.5 – Examples of Industrial Wastewater Data

Industry	Typical Wastewater Generation Rate, m^3/MT	Range of Wastewater Generation Rates, m^3/MT	Typical COD Concentration, kg/m^3	Range of COD Concentrations, kg/m^3
Alcohol	24	16–32	11	5–22
Beer	6.3	5.0–9.0	2.9	2–7
Coffee	NA	NA	9	3–15
Dairy products	7	3–10	2.7	1.5–5.2
Fish processing	NA	8–18	2.5	—
Meat and poultry processing	13	8–18	4.1	2–7
Starch production	9	4–18	10	1.5–42
Sugar refining	NA	4–18	3.2	1–6
Vegetable oils	3.1	1.0–5.0	NA	0.5–1.2
Vegetables, fruits, and juices	20	7–35	5.0	2–10
Wine and vinegar	23	11–46	1.5	0.7–3.0

Source: Doorn et al., 1997

2.3 DESCRIPTION OF SPECIFIC CRITERIA FOR DETERMINING POTENTIAL SECTORS

The specific criteria to determine methane emission reduction potential and feasibility of anaerobic digestion systems are the following:

- **Large sector/subsector:** The category is one of the major livestock production or agro-industries in the country.
- **Waste volume:** The livestock production or agro-industry generates a high volume of waste discharged to conventional anaerobic lagoons.
- **Wastes strength:** The wastewater generated has a high concentration of organic compounds, measured in terms of BOD or COD or both.
- **Geographic distribution:** There is a concentration of priority sectors in specific regions of the country, making centralized or co-mingling projects potentially feasible.
- **Energy-intensive:** There is sufficient energy consumption to absorb the generation from recovered methane.

The top industries that meet all of the above criteria in Brazil are swine and dairy farms, cassava processing for tapioca production, sugarcane mills and sugarcane mills with distilleries (ethanol and cachaça production), slaughterhouses, and beverage manufacturing. Three other sectors were also evaluated: corn starch production, orange juice extraction and milk processing. Although they could emit methane in the course of wastewater treatment, current treatment practices already mitigate or minimize those emissions. Therefore these sectors were not included as part of the main report; more information on these sectors can be found in Appendix C.

2.4 EXAMPLES OF METHANE EMISSION REDUCTION PROJECTS IN BRAZIL

Anaerobic digestion has been used in Brazil to treat wastewater (domestic and industrial) and livestock manure for several decades. Until the 1970s, only long-retention-time anaerobic treatment systems were used, mainly for domestic wastewater. These systems included conventional anaerobic lagoons, complete mix digesters for sludge treatment, and Imhoff tanks. In the 1970s, anaerobic processes began to be used for high-strength industrial wastewaters.

In a 2001 assessment, the Environmental Agency of the State of São Paolo (CETESB, 2001) found that 117 anaerobic systems for industrial wastewater treatment were registered in Brazil. São Paulo was the state with the highest number of anaerobic wastewater treatment systems, mostly in the slaughterhouse, beverage (beer and carbonated beverages), dairy products, and other food processing sectors. On an industry basis, the beverage and cachaça production sectors have the highest number of anaerobic wastewater systems in operation with over 90 percent using the captured methane as fuel. While these figures do not fully represent the number of installed anaerobic digestion systems at the time, they give a good indication of the trends in different industrial sectors.

As for livestock manure treatment, the anaerobic digestion technology was first introduced in Brazil in the 1970s, driven by the global energy crisis. In the 1980s, a governmental program stimulated the adoption of anaerobic digesters for livestock manure treatment in Brazil, focusing on the southern region of the country and on the use of biogas as an energy source to reduce dependence on petroleum fuels. The effort resulted in the installation of nearly 3,000 anaerobic digestion systems in Brazil, mainly to treat cattle manure. Meanwhile, according to the 2002–2003 Agricultural Assessment of the State of Santa Catarina, only 0.8 percent of swine farms with more than 50 pigs had anaerobic digesters. The remainder used conventional anaerobic lagoons.

According to an assessment by Palhares (2008), the attempt to introduce the anaerobic digestion, as an animal manure treatment alternative and as an energy source, failed for several reasons: low education level of farmers, lack of technical training, lack of knowledge of the potential uses of the biogas, and poor design. Further, several reports on fatal accidents (involving inhalation of hydrogen sulfide) during digester operations have caused reluctance among farmers to use anaerobic digestion. However, no official confirmation of these fatalities was located.

Recently, the effort—catalyzed by the Kyoto Protocol and its Clean Development Mechanism—to reduce climate change by reducing GHG emissions has stimulated the construction of anaerobic digestion systems on Brazilian swine farms. This trend started in 2003 and accelerated in 2005, when the Kyoto Protocol was fully implemented and the carbon market stabilized. Since then, a few hundred anaerobic digestion systems (mostly covered lagoons) have been constructed on swine farms in all of the major producing regions for the carbon credits and, less commonly, as an alternative energy source. Anaerobic digestion systems are rare still rare in other livestock subsectors.

Example of Anaerobic Digestion in a Swine Farm – Fazenda Ponte Alta

Fazenda Ponte Alta is a 1,500-sow farrow-to-finish swine farm (approximately 15,000 animals) located in Itararé, São Paolo, 350 kilometers west from the city of São Paulo. The pigs are divided into two production units on the same farm, each with its own manure collection system. This operation contains 34 barns and a feed mill.

The manure is removed from the barns by scraping and flushing with pressurized water, at different frequencies for each animal subcategory. As the standard for intensive swine production in Brazil, Fazenda Ponte Alta was using a conventional anaerobic lagoon as its animal waste management system (AWMS) before land application and/or disposal to surface waters.

Figure 2.1 – Fazenda Ponte Alta Overview and Finishing Facility

Source: LOGICarbon

In 2004, two covered anaerobic lagoons (2,736 and 1,200 cubic meters) were constructed for the treatment of 100 percent of the generated manure (Figure 2.2). The existing conventional anaerobic lagoon has been kept as a storage pond for the resulting effluent from the digesters, which is then sprayed in the cropping areas of the farm with pumps. The manure entering the anaerobic digester is heated using waste heat from the generator sets to maintain a temperature of 3ºC to 4ºC above the ambient temperature. Construction of the two covered lagoons was driven by the farm owner's interest in improving manure treatment, generating a renewable source of energy, and the opportunity to generate revenue through the sale of carbon credits.

Figure 2.2 – Anaerobic Covered Lagoons at Fazenda Ponte Alta

Source: LOGICarbon

Since the completion of the construction of the two covered lagoons, the farm owner has invested in three engine-generator sets to generate electricity from the captured methane. This has reduced electricity purchased from the grid by 80 percent. In addition, the waste heat from the engines is used to generate hot water for farrowing barn heating and to heat the influent to the covered lagoons (Figure 2.3). In 2007, the farm consumed an average of 710 cubic meters per day of methane (approximately 1,100 cubic meters per day of biogas) to generate 630 megawatt-hours of electricity.

Figure 2.3 – Heated Manure Tank (Used Before Covered Lagoons Were Installed) and Engine-Generator Set at Fazenda Ponte Alta

Source: LOGICarbon

3.1 OVERVIEW OF BRAZILIAN AGRICULTURE

Currently, agribusiness is responsible for 33 percent of Brazil's gross domestic product (GDP), 42 percent of exports, and 37 percent of employment. With a diverse climate, consistent rainfall, abundant solar energy, and almost 13 percent of all fresh water on earth, Brazil has 388 million hectares of fertile agricultural land (of which 90 million hectares have not yet been developed) and high productivity. Figure 3.1 shows the five Brazilian regions, the 26 states, and the Federal District.

Figure 3.1 – State Map of Brazil

Brazil is a world leader in the production and export of various agricultural products. It is the leading producer and exporter of coffee, sugar, alcohol, and fruit juices. Moreover, Brazil is the largest exporter of soybeans, beef, chicken, tobacco, leather, and leather footwear in terms of sales. Projections indicate that the country is also becoming the world leader in cotton production and in the production of biofuels from sugarcane and vegetable oils. Corn, rice, fresh fruit, cocoa, walnuts, and pigs and fish also are substantial components of, Brazil's agricultural sector, which currently employs 17.7 million workers on farms (MAPA, 2004).

Brazil is the fourth largest producer of pork in the world, with a total of 37.8 million pigs produced. Intensive operations represent 90 percent of the total pork production and this percentage is increasing. Intensive swine production is mainly concentrated in the South with small operations, the Southeast o Paulo and Minas Gerais) with medium-scale operations, and the Midwest with large-scale operations that benefit from the close proximity of corn (maize) and soybean (soya) crops for feed. Waste management systems vary by the type and size of the farm. We estimate that 70 percent of swine production occurs in operations with lagoons where there is no methane collection.

Brazil is the sixth largest producer of cow's milk in the world, with approximately 27 billion liters produced in 2008. In terms of milk cows, Brazil ranks second, with 21.5 million milked cows in 2008. Dairy farms are concentrated mainly in the Southeast region (39 percent of the total milk production), the South (27 percent) and the Midwest (15 percent). The structure of the dairy industry is gradually changing from very small and low productivity operations (1.8 million dairy farms with an average of 9 cows per farm in 1994) to larger and more specialized operations (1.3 million with an average of 16 cows in 2005). In the vast majority of the farms, the manure is not treated at all and is directly disposed of on cropland. However, in intensive operations (more than 200 cows), which represent less than 2 percent of the total number of cows, all or part of the manure is treated in open anaerobic lagoons (10 to 15 percent in semi-confined systems and 100 percent in confined systems).

Brazil produced 26.3 million metric tons of cassava root in 2008. Almost half was converted into cassava meal, 40 percent was used for direct human consumption and animal feed, and 9.5 percent was turned into tapioca starch. In general, 4 metric tons of cassava are needed to produce 1 metric ton of starch. Thus, the tapioca starch production in Brazil reached 565 thousand metric tons in 2008. The majority of starch is consumed domestically in food (69 percent), paper (17 percent), and textile (5 percent) production. Most of the large tapioca starch plants are located in the states of Paraná, São Paulo, and Mato Grosso do Sul. Alves (2003) studied 73 tapioca starch plants operating in Brazil found that 50 plants had processing capacity lower than 300 metric tons per day, 19 could process between 300 and 599 metric tons per day, and only four could process more than 600 metric tons per day. Based on the data reviewed, we assume that the average wastewater generation is 3.68 cubic meters per ton of processed cassava, with an average COD concentration of 10,000 milligrams per liter (the IPCC default value for starch production), and that 93 percent of the plants treat their wastewater in open lagoons.

Brazil is also the world's leading sugarcane producer with 605 million metric tons of sugarcane, 24 million metric tons of sugar and 28 billion liters of ethanol projected for the 2009/2010 harvest. Production of cachaça (a liquor produced from sugarcane) is around 1.5 billion liters per year. Sugarcane is grown mainly in south central Brazil (over 85 percent of total production) and northeastern Brazil (13 percent). There are about 230 combined sugarcane mills and distilleries and about 100 additional distilleries that only produce ethanol. All mills generate electricity by burning bagasse. About 30,000 distilleries produce cachaça, but large-scale distilleries are responsible for 75 percent of the total production. Regarding the wastewater generation and characteristics, 10 to 15 liters of vinasse (distillery slops) are generated for each liter of ethanol produced (9 liters per liter for cachaça) and the average

COD is 28 kilograms per cubic meter. Regarding the waste management system, vinasse is used directly as fertilizer in the south central region; in the northeast region, open anaerobic lagoons are common.

With 42.8 million beef cattle slaughtered annually, Brazil is the second largest beef producer in the world. It ranks fourth in pork production (with 35.5 million pigs slaughtered annually) and third in broiler chicken production (with 4.9 broilers slaughtered annually). Slaughterhouse operations are concentrated in the Midwest, the Southeast, and the South. The wastewater generation is 1.3 cubic meters per head in the case of beef, 0.31 for swine, and 0.035 for poultry. The COD concentration is 4.1 kilograms per cubic meter for beef and swine and 2.4 for poultry. About 95 percent of the beef cattle and 80 percent of the swine and poultry slaughterhouses use open anaerobic lagoons.

Brazil is the third largest carbonated drink market in the world, with total sales of 14.3 billion liters in 2007. It is also the fourth largest beer producer, with 10.3 billion liters produced in 2007. Two multinational companies (Coca-Cola and AmBev) held about 73 percent of the carbonated beverage market share in 2009; the rest was held by several small regional producers. Beverage production is mainly located around big cities in the Southeast region. Based on the data reviewed, we assume that the COD content of wastewater from breweries is 4.5 kilograms per cubic meter and the COD content of wastewater from carbonated beverage production is 2.1 kilograms per cubic. The rate of wastewater generation is 4 cubic meters of wastewater per cubic meter of beverage produced and 4.5 cubic meters of wastewater per cubic meter of beer produced. Use of open anaerobic lagoons is common for less than 2 percent of the beer production and 27 percent for carbonated beverages.

Table 3.1 shows the top food and other agricultural commodities produced in Brazil in 2007. From the tonnage standpoint, sugarcane is, by far, the main agricultural product, with 550 million metric tons per year, followed by soybeans and corn, with 58 and 52 million metric tons, respectively. From the value standpoint, beef and soybean ranks first and second, while sugarcane is third and chicken meat fourth.

Table 3.1 – Food and Other Agricultural Commodities Production in Brazil, 2007

Rank	Commodity	Production (Int $1,000)	Production (MT)
1	Beef	13,867,900	6,705,041
2	Soybeans	12,287,500	57,857,200
3	Sugarcane	11,375,880	549,707,328
4	Chicken meat	10,929,360	9,370,000
5	Cow milk, whole, fresh	7,093,812	26,944,064
6	Oranges	3,283,702	18,685,000
7	Rice, paddy	2,309,714	11,060,700
8	Pork	2,068,830	2,042,986
9	Cotton lint	2,013,801	1,356,570
10	Coffee, green	1,838,701	2,249,010
11	Tobacco, unmanufactured	1,656,722	908,679
12	Corn	1,510,189	52,112,200
13	Beans, dry	1,314,878	3,169,360
14	Laying hens, shell eggs	1,197,523	1,779,190
15	Bananas	1,011,586	7,098,350

Rank	Commodity	Production (Int $1,000)	Production (MT)
16	Cassava	956,279	26,541,200
17	Tomatoes	812,961	3,431,230
18	Grapes	636,266	1,371,560
19	Wheat	594,643	4,114,060
20	Pineapples	517,592	2,676,417

Source: U.N. Food and Agriculture Organization[1]

3.2 SUBSECTORS WITH POTENTIAL FOR METHANE EMISSION REDUCTION

As discussed in Section 2.1, two criteria were used to rank sectors: 1) the sector or subsector size and 2) the geographic concentration (particularly for anaerobic digestion centralized systems).

Table 3.2 below summarizes the important subsectors of the livestock production and agricultural commodity processing sectors in Brazil, as identified in this RA. These sectors include swine, tapioca starch, ethanol, slaughterhouses, and cachaça. A more detailed discussion of each of these subsectors is provided in Sections 3.3 to 3.8. Subsectors that were evaluated but not considered to have the potential for methane reduction are beef and dairy cattle, poultry, sugarcane processing, beer, carbonated beverages, corn starch, orange juice, and milk processing.

Table 3.2 – Identified Potential Sectors for Methane Emission Reductions in Brazil

Subsector	Size (Production/Year)	Geographic Location	Potential
Beef cattle	World's second largest producer of beef—185 million head in 2007	Midwest region (34.2%): states of Mato Grosso, Mato Grosso do Sul, and Goiás	Currently very low, because of extensive use of pasture and range
Poultry (broiler chickens)	World's third largest producer of chicken meat—1.13 billion head	South region (50%), São Paulo (19%)	None, because waste is handled as a solid
Swine	World's fourth largest producer of pork—37.8 million pigs, of which 32.7 million are in intensive operations	South region (59.2%), Southeast region (20%), Midwest region (11%)	Very large, because 70 percent of intensive farms use open anaerobic lagoons
Dairy cattle	World's sixth largest producer of cow's milk—21.5 million cows	Rio Grande do Sul, Minas Gerais, Paraná, and Santa Catarina	Low, because only a small percentage is totally or partially confined
Tapioca starch	2.5 million metric tons	Paraná (62%), Mato	Medium, because 93%

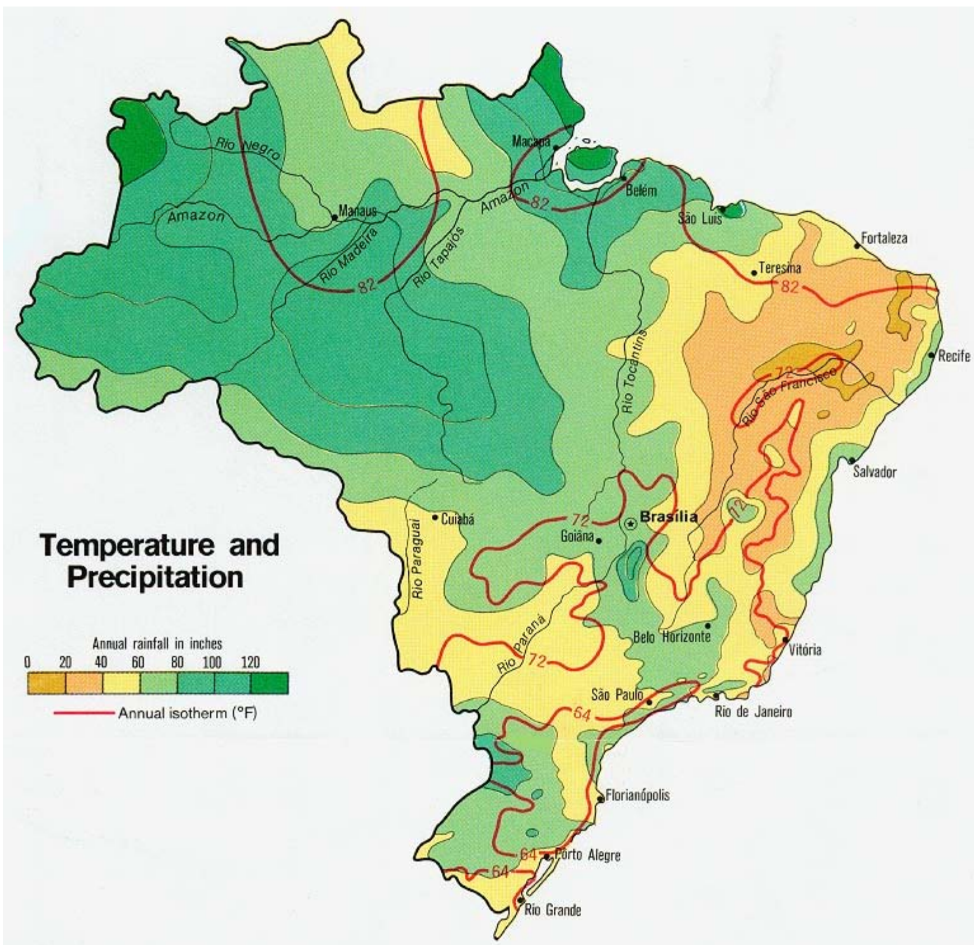
[1] http://faostat.fao.org/site/339/default.aspx

Subsector	Size (Production/Year)	Geographic Location	Potential
	of cassava roots processed for tapioca production, 565,000 metric tons per year	Grosso do Sul (19%), São Paulo (14%)	of the plants use open anaerobic lagoons
Sugarcane processing	World's leading sugar producer—31 million metric tons of sugar in 2007–2008	Southeast region (69.5%), Northeast region (15.5%), South region (8.1%)	None, because molasses is used either to produce ethanol or to feed animals
Ethanol	22.5 billion liters	Southeast region (68.8%), Midwest region (13.2%), Northeast region (9.5%), South region (8.3%)	Large, even if only 9.6% of the production uses open ponds
Cachaça	1.5 billion liters	Southeast region (63%), Northeast region (27%), Midwest region (8%)	Medium—27% of the production uses open ponds
Slaughterhouses: beef cattle	42.8 million beef cattle slaughtered	Midwest region (47% of the plants), Southeast region (27%), North region (15%)	Large, because 95% use lagoons
Slaughterhouses: swine	35.5 million pigs slaughtered	South region (72% of the plants), Southeast region (15%), Midwest region (13%)	Low, given the low COD concentration and low wastewater volume per animal, although 80% use lagoons
Slaughterhouses: poultry	4.9 billion broilers slaughtered	South region (62% of the plants), Southeast region (23%), Midwest region (13%)	Large, because 80% use lagoons
Beer	World's fourth largest producer—10.3 billion liters in 2007	Southeast region (57%), Northeast region (17%, South (15%)	Low, because less than 2% of the production use open lagoons
Carbonated beverages	14.3 billion liters in 2007	Widely distributed	Low potential—27% of the production uses open ponds
Corn starch	World's fourth largest producer of corn—59 million metric tons of corn in 2008	São Paulo, Minas Gerais, Paraná, Pernambuco, and Santa Catarina	None, because use aerobic treatment due to proximity with urban centers
Orange juice	World's largest producer of oranges and orange juice—16.6 million metric tons of oranges for 2009/10	São Paulo (95%)	None, because of use of anaerobic treatment with biogas capture and lagoons with forced aeration
Milk processing	30 billion liters in 2009	Southeast region (37%), South region (29%), Midwest region (15%), Northeast region (13%), North (6%)	None, because no treatment or already have biogas capture

[a] Low potential: less than 200,000 $MTCO_2e$/yr. Medium potential: 200,000–1,000,000 $MTCO_2e$/yr. Large potential: 1,000,000–10,000,000 $MTCO_2e$/yr, Very large potential: more than 10,000,000 MT CO_2e/yr.

Because methane production is temperature-dependent, an important consideration in evaluating locations for potential methane capture is the temperature. In Brazil, the annual average annual temperature ranges between 64°F and 82°F and the average rainfall is between 39 and 78 inches per year (Figure 3.2).

Figure 3.2 – Temperature and Precipitation Map of Brazil



Source: University of Texas Libraries[2]

[2] http://lib.utexas.edu/maps/americas/brazil_temp_1977.jpg

3.3 LIVESTOCK PRODUCTION

From 1990 to 2003, Brazilian beef production increased by 85 percent, from 4.1 million to 7.6 million metric tons per year (MAPA, 2004). During the same period, pork production increased by 173.3 percent from 1 million to 2.87 million metric tons per year. Globally, Brazil is a major player in animal protein production, being the second largest producer and largest exporter of beef, the third largest producer and largest exporter of chicken, the fourth largest producer and exporter of pork; and the sixth largest producer of cow's milk.

3.3.1 SWINE PRODUCTION

a. DESCRIPTION OF SIZE, SCALE, AND GEOGRAPHIC LOCATION OF OPERATIONS

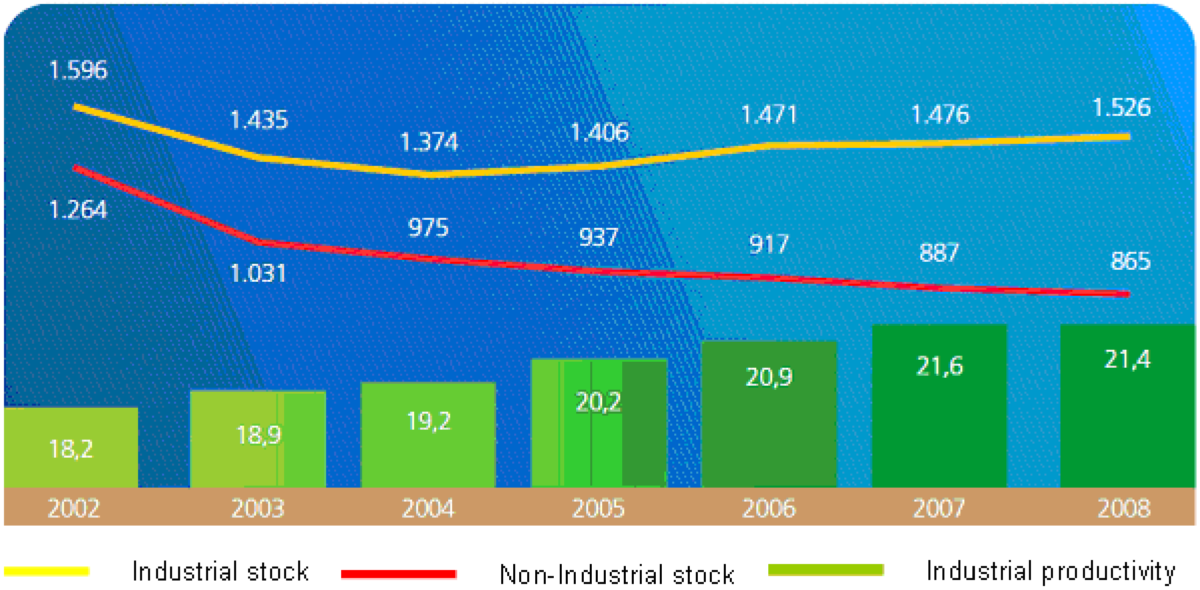
Swine production is a growing and very important business in Brazil (see Figures 3.3 and 3.4). During the last decade, productivity and the quality of pork products have increased, while production costs have decreased due to new animal management techniques, improved genetics, improved feeding programs, and better disease control.

In 2008, there were 2.39 million sows in Brazil. Of these, 64 percent (1.53 million sows) were located in intensive operations, which accounted for 90 percent of total pork production. In these operations, 21.4 pigs on average were produced per sow, resulting in the marketing of 32.7 million fed hogs from intensive operations in 2008.

These figures put Brazil in a very competitive position in the global market, as the fourth largest pork producer and exporter worldwide, behind China, the United States and the European Union. In 2008, Brazil exported 17 percent of its pork production to Russia, Hong Kong, Ukraine, Singapore, and Argentina (Abipecs, 2008).

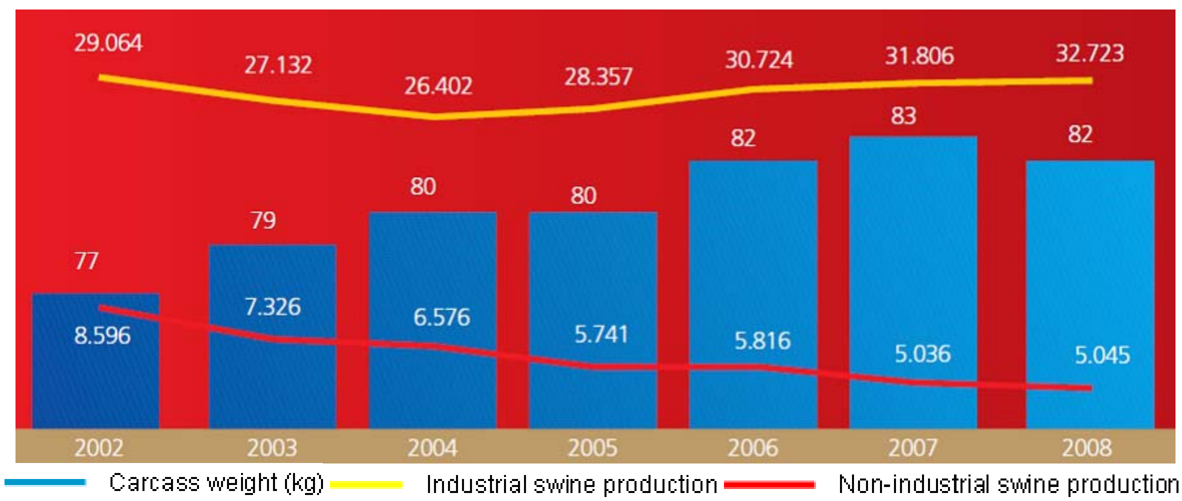
It is estimated that 400,000 people depend directly on the Brazilian swine industry, which has a total estimated annual income of US$1.8 million, representing an important activity with major social and economic benefits in the country (Roppa, 2007). According to the 2006 Brazilian Agriculture Census, 76.5 percent of the pigs produced in Brazil are raised in farms with areas between 5 and 500 hectares, with a higher concentration of 54.4 percent of the swine population in 10 to 100-hectare farms. It is also estimated that there are about 30,000 operations producing hogs using intensive production methods. In the state of Santa Catarina, this activity generates 18,000 urban jobs and 30,000 jobs on farms (Gosmann, 2005).

Figure 3.3 – Number of Swine Sows in Brazil (Thousand Head)



Source: Abipecs, EMBRAPA, and Pork Meat Industry Association

Figure 3.4 – Swine Production in Brazil (Thousand Head)

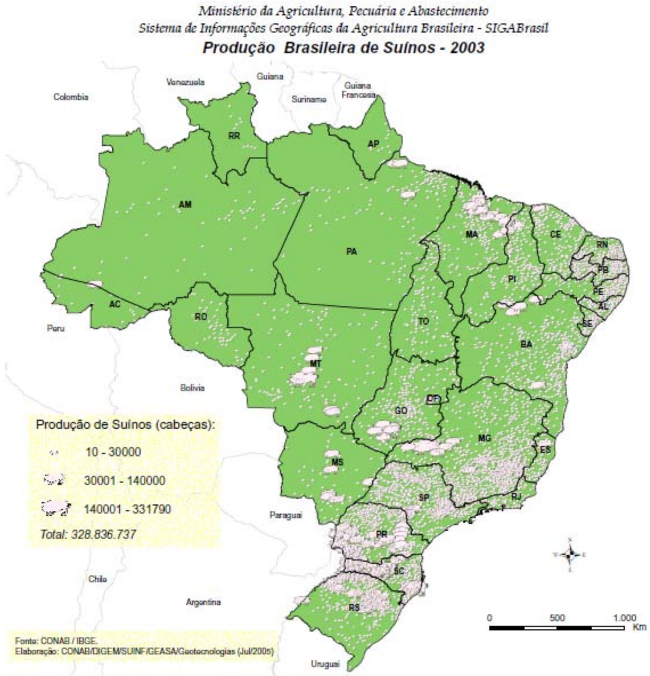


Source: Abipecs, 2008

Note that the composition of the swine herd in the country is changing over time. As the market consolidates, the number of intensive, larger, more efficient operations is growing and putting pressure on small and subsistence swine businesses with low productivity.

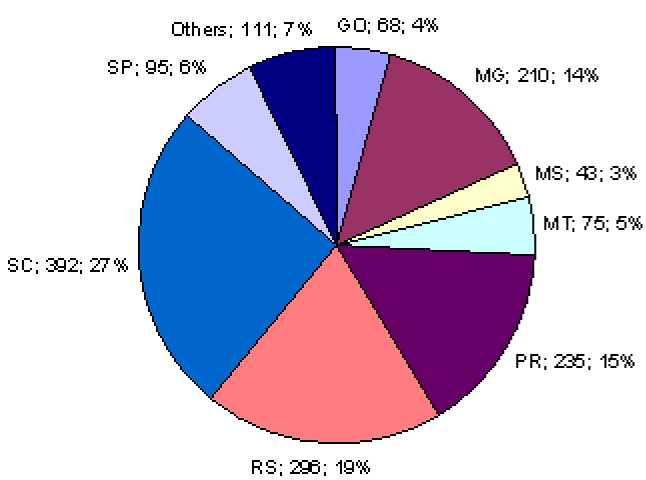
Figure 3.5 shows the geographic distribution of swine production in Brazil in 2003. Production is concentrated mainly in the South, Southeast, and Midwest. As shown in Figure 3.6, a 2008 compilation of the geographic distribution of sows closely mirrors the distribution of production in 2003.

Figure 3.5 – Swine Production in Brazil, 2003*



GO: Goiás; MG: Minas Gerais; MS: Mato Grosso do Sul; MT: Mato Grosso; PR: Paraná; RS: Rio Grande do Sul; SC: Santa Catarina; SP: São Paolo

Figure 3.6 – Distribution of Sows by State in Brazil (Thousands, Percent of Total)



GO: Goiás; MG: Minas Gerais; MS: Mato Grosso do Sul; MT: Mato Grosso; PR: Paraná; RS: Rio Grande do Sul; SC: Santa Catarina; SP: São Paolo

Source: Abipecs, 2008

The largest and most technologically advanced operations are located in the Midwest region (Mato Grosso do Sul, Goiás, and Mato Grosso) and also the Southeast region (mainly Minas Gerais and São Paulo). In the last few years, there has been a major shift of Brazilian swine production to the midwestern states of Goiás and Mato Grosso from the south and southeast. The operations in Goiás and Mato Grosso are fairly new and have associated slaughterhouses reflecting the trend toward vertical integration. The main advantage of this region is proximity to the primary corn- and soybean-producing region of the country. This significantly lowers the cost of feed, which accounts for approximately 60 percent of the cost of swine production in Brazil (Moore, no date.).

There are no official statistics characterizing the Brazilian swine industry. However, the small to medium operations appear to be concentrated in the southern states, with a high percentage of these operations providing nursery pigs to larger operations on a contractual basis. Under these contracts, feed and technical services are provided. For example, according to data from the Agriculture Assessment of the State of Santa Catarina (2005), elaborated by Instituto Cepa and cited by Oliveira (2005), the average swine population per farm in the state of Santa Catarina is 392 pigs (Table 3.3). Three states in the South region (Rio Grande do Sul, Santa Catarina, and Paraná) contain 61 percent of the Brazilian swine population and it can be assumed that they have similar production systems and characteristics In the states of São Paulo and Minas Gerais, the swine operations are medium-sized (150- to 500-sow) integrated operations as well as independent farmers without any type of contract.

Table 3.3 – Number of Farms and Animal Population, According to the Production Type, in the State of Santa Catarina

Production Type	Number of Farms	Animal Population	(%)	Average Population per Farm
Piglets producers	3,793	1,464,949	40.49	386
Finishing	2,926	1,311,608	31.24	448
Farrow-to-finish	2,585	852,678	27.60	330
Reproduction	63	38,780	0.67	616
Total	9,367	3,668,015	100.00	392

Source: Oliveira, 2005

The smallest swine farms are located primarily in the north and northwest regions of Brazil, where the intensive swine production is not common, as illustrated in Table 3.4.

Table 3.4 – Distribution of Sows on Large and Medium Versus Small Farms by Region in 2006

Region	% National Population	
	Large and Medium	Small
South	59.2	9.9
Southeast	20	6.5
Midwest	11	14
North and Northwest	9.8	69.6
Total	100	100

Source: Abipecs, 2007

In the states of Goiás and Mato Grosso, where intensive swine production is more recent, average production is 22.8 and 22.5 fed hogs (finished pigs) per sow-year. The states of the South region, Rio Grande do Sul, Santa Catarina, and Paraná—with traditional and integrated small farmers—produce between 21.5 and 22 fed hogs per sow-year, while the states of São Paulo and Minas Gerais, with independent operations, have the lowest level of productivity, 20 to 21.5 fed hogs per sow-year. Thus, productivity can be characterized as relatively uniform among the various sizes of operations in the Brazilian swine industry.

b. DESCRIPTION OF WASTE CHARACTERISTICS, HANDLING, AND MANAGEMENT

Wastes from swine production facilities are composed of urine and feces along with spilled drinking water, water used for sanitation, wasted feed, hair, and dust (Konzen, 1983). The physical and chemical characteristics can vary depending on management practices including the amount of water used for sanitation. Typical characteristics for Brazil as reported by the Brazilian Agriculture Research Institute (EMBRAPA) are listed in Table 3.5.

Table 3.5 – Average Chemical Composition of Swine Manure Found by EMBRAPA

Parameters	Average (mg/L)
Chemical oxygen demand	25,542.9
Total solids	22,399.0
Volatile solids	16,388.8
Fixed solids	6,010.2
Suspended solids	428.9
Total nitrogen	2,374.3
Total phosphorous	577.8
Total potassium	535.7

Source: Silva, 1996

Brazilian swine production operations use a substantial amount of water for sanitation resulting in manure volumes per head as listed in Table 3.6. Thus, total solids (TS) concentration in manure leaving confinement facilities ranges from only 1 to 3 percent.

Table 3.6 – Swine Manure Generation, According to the Production Type

Production Type	Dilution		
	Low	Average	High
Farrow-to-finish (L/sow/day)	100	150	200
Piglet production (L/sow/day)	60	90	120
Finishing (L/head/day)	7.5	11.2	15

Source: Perdomo, 1999

There is little information about swine manure management practices in Brazil except for a 2006 EMBRAPA report on methane emissions from livestock production for 1990 to 1994. In this report, EMBRAPA estimated that only 10 percent of the swine operations in the South region and only 5 percent in the Southeast region and the Midwest region had systems for manure stabilization and storage. These systems consisted of conventional anaerobic lagoons followed by disposal by application to cropland. In the remainder of the country, direct discharge to adjacent surface waters was considered the common method of manure disposal. Generally, the recommended hydraulic retention time for conventional anaerobic lagoons in Brazil is 120 days to ensure a high degree of stabilization and pathogen inactivation, but there is some variation in state environmental regulations. To maintain anaerobic conditions, a minimum depth of 2.5 meters is required (Kunz et al., 2005).

In a more recent (2004) regional assessment in the state of Santa Catarina, it was estimated that 98 percent of contract and integrator-owned swine production operations and 83 percent of independent operations have conventional anaerobic lagoons. However, it was found that 67.6 percent of these lagoons had hydraulic retention times of less than 120 days, reflecting the failure to increase lagoon size as production capacity increased (Palhares, 2007). For this RA, it was assumed that the more recent Santa Catarina study provides a better indication of current swine manure management practices, at least at large and medium-size operations. (Santa Catarina has 27 percent of the Brazilian swine population.)

According to the leading supplier of covered anaerobic lagoon technology and construction materials in Brazil, Sansuy, there are about 700 anaerobic digestion systems on large and medium Brazilian swine farms. This translates into the capacity to anaerobically digest and capture the methane from farrow-to-finish operations with a combined population of nearly 300,000 sows (Table 3.7). However, it is estimated that only 70 percent of these anaerobic digestion systems are fully operational. Thus, it is estimated that the manure from only 13 percent of swine manure generated on large and medium farms is anaerobically digested with methane capture. Assuming a total sow population of 1,270,000 on large and medium-size farms and the use of conventional anaerobic lagoons by 83 percent of those operations, the potential exists to capture methane from the equivalent of a farrow-to-finish operation with 1,006,000 sows.

Table 3.7 – Estimated Number of Anaerobic Digesters for Swine Manure Treatment in Brazil

	Number of Farms	Average Sow Farrow-to-Finish Equivalent Population per Farm	Total Sow Farrow-to-Finish Population
Total installed digesters	692	420	290,640
Operating digesters	484	420	203,280

3.3.2 DAIRY CATTLE

a. DESCRIPTION OF SIZE, SCALE, AND GEOGRAPHIC LOCATION OF OPERATIONS

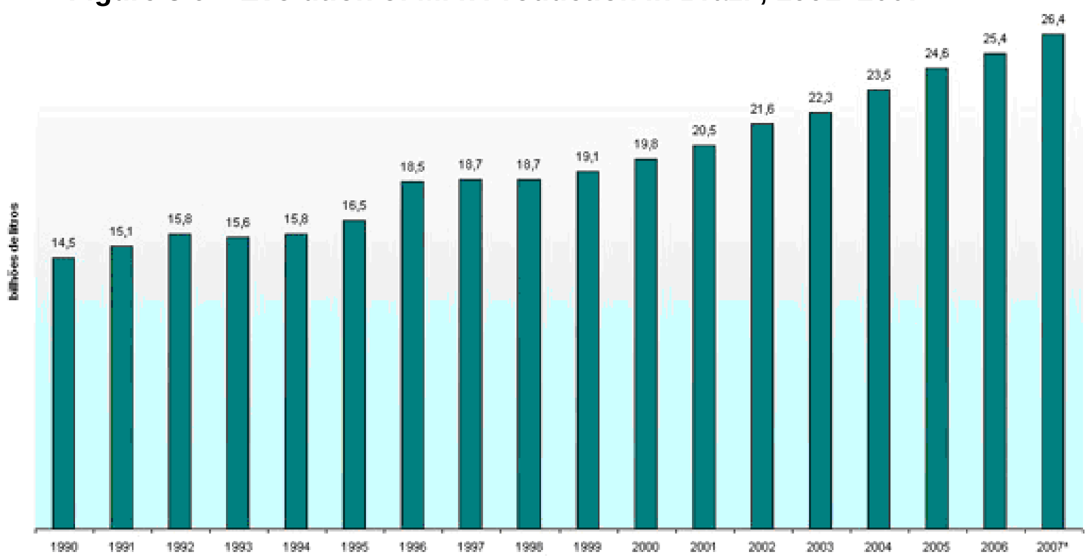
Brazil produced about 27 billion liters of cow's milk in 2008 and is the sixth largest milk producer in the world, behind the United States, India, China, Russia, and Germany (Table 3.8). Milk production has increased significantly since 1990 (Figure 3.7). Brazil ranks second to India in number of lactating cows, with 21.5 million in 2008. However, Brazil ranks 21st in milk produced per cow. The top 10 leading countries in milk productivity produce on average more than 6,000 liters per cow per year (U.S. productivity was 9,129 liters per cow per year in 2007); Brazil's average is significantly lower at 1,224 liters per cow per year (Zoccal, 2008).

Table 3.8 – World Milk Producers in 2007

Rank	Area	Production (Int $1000)	Production (MT)
1	United States of America	22,270,180	84,189,067
2	India	11,406,170	42,890,000
3	China	9,460,634	35,574,315
4	Russian Federation	7,699,117	31,914,914
5	Germany	7,293,936	28,403,000
6	Brazil	7,093,812	26,944,064
7	France	6,375,566	24,373,700
8	New Zealand	4,200,954	15,841,624
9	United Kingdom	3,667,579	14,023,000
10	Poland	3,105,117	12,096,005

Source: FAOSTAT, 2010

Figure 3.6 – Evolution of Milk Production in Brazil, 1991–2007



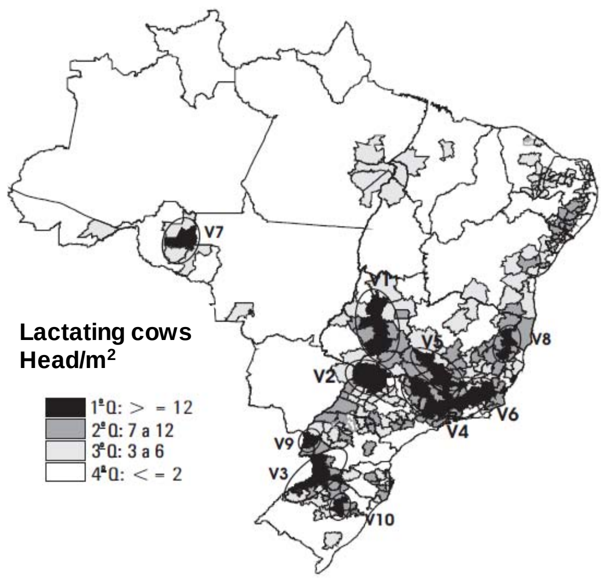
* Estimated EMBRAPA Gado de Leite
Source: Zoccal, 2008

Based on the Brazilian Institute of Geography and Statistics (IBGE) census of 2005, 39.1 percent of Brazilian milk production occurs in the Southeast region, followed by the South and Midwest regions with 26.6 and 15.4 percent of national production, respectively. The remainder of Brazilian milk production occurs in the Northeast (11.5 percent) and North regions (7.1 percent).

The analysis of data by number of dairy cows per square kilometer shows that the highest concentration of dairy cows (≥ 12 cows/km^2) are distributed predominantly in 10 production zones, as shown in Figure 3.7. As also shown in Figure 3.7, the principal dairy production areas are in zones V4, V5 and V6, with densities that vary from 14.5 to16.9 cows per square kilometer, which include the region west of São Paulo, a large part of Minas Gerais, and the region south of Rio de Janeiro.

With respect to the geographic distribution of milk production, 39 out of 558 production zones (7 percent) with the highest milk production density (≥ 24,100 L/km^2/yr) were responsible for 25 percent of the national milk production. As shown in Figure 3.8, the 39 highest-producing production areas are mainly distributed in two zones in the South, five zones in the Southeast, one in the Midwest, and one in the Northeast regions.

Figure 3.7 – Distribution of Dairy Cows in Brazil, 2004



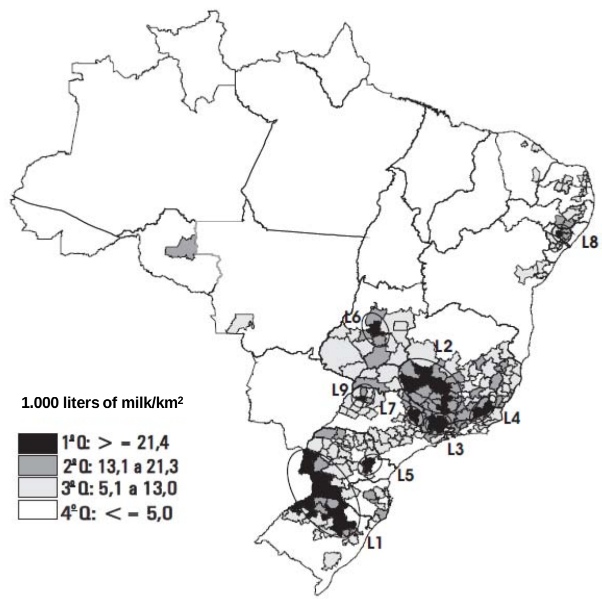
Distribution of the national heard of lactating cows in quartiles, for the microregions, in 2004.

Source: Zoccal, 2006

The 45 production zones with milk production equal to or greater than 2,000 liters per cow per year accounted for 25.4 percent of Brazilian milk production in 2004. Fifteen of these areas are in Rio Grande do Sul, nine in Minas Gerais, nine in Paraná, and seven in Santa Catarina as shown in Figure 3.8.

The structure of the milk production system in Brazil is changing gradually. According to EMBRAPA and IBGE, the country's milk production in 1994 occurred on 1.8 million dairy farms, with an average of 9 cows per farm producing an average production of 3.1 liters per cow per day. Stock (2005) estimated that the number of Brazilian dairy farms had dropped to 1.3 million, with an average of 16 cows per farm, by 2005. However, average milk production had increased to 3.3 liters per cow per day. Stock's findings indicate a trend toward fewer but larger dairy farms in Brazil, with increased productivity in terms of milk produced per cow per day.

Figure 3.8 – Distribution of the Milk Production in Brazil, 2004



Source: Zoccal, 2006

Stock (2005) classifies Brazilian dairy farms as follows:

- **Extensive production:** farms with less than 30 cows. Productivity is less than 4 liters per cow per day; production per farm is less than 100 liters per day; nutrition is based on pasture, with no supplemental feeding beyond common salt.

- **Semi-extensive production:** farms with 30 to 70 cows. Productivity is between 4 and 7 liters per cow and production per between 100 and 400 liters per day; animal feeding typically mixes pasture with supplemental forage and grains during winter and the dry season. Some operations may feed supplemental forage and grain throughout the year.

- **Specialized production:** farms with 70 to 200 cows. Productivity is between 7 and 12 liters per cow per day and farm production ranges between 400 and 2,000 liters per day. Feeding system is specialized, mostly mixing fertilized pasture, sugarcane, and silage, supplemented with forage and grains.

- **Intensive production:** large farms with, as a rule, more than 200 cows. Productivity is higher than 12 liters per cow per day and more than 2,000 liters per farm; feeding is all provided in bunks throughout the year.

In 2005, more than 1 million farms produced less than 20 percent of the total milk in Brazil, while 11 percent of the dairy farms produced 81 percent of the milk. The more specialized farms (2.3 percent) were responsible for 44 percent of the total production.

According to a recent Brazilian publication (Milkpoint 2009), which lists and classifies the 100 largest milk producers of Brazil, 44 percent of the 100 top dairy farms had fully confined operations, while 42 percent had their animals in semi-confinement and 14 percent had them in pasture-based systems. This 100-farm list represents 54,300 cows, considering the average production of 24.8 liters per cow per day, which is more than the double of the minimum productivity of the intensive production group of farms. Thus, from this list, about 24,000 cows would be under 44 full confinement operations (Table 3.9).

Using the above-mentioned classification by Stock (2005), it is possible to conclude that 44 percent of these farms (fully confined) are intensive production farms and 56 percent are specialized production farms (semi-confined and pasture-based systems). Stock also states that in 2005 there were about 387,000 dairy cows with high productivity (> 12 L/cow/day) in 1,497 farms, which, according to the classification, should be classified as intensive production.

According to Leite Brasil vice president Roberto Jank Jr., only 100 dairy farms in Brazil produce more than 100,000 liters per day. The Dutch colonies of Castro, Arapoti, and Carambei, in the state of Paraná, have the highest concentration of medium-sized farms with advanced technology.

Crossing numbers from the Top 100 2009 and Stock (2005), it could be assumed that 44 percent (648 farms) of the intensive production farms operate with full confinement, which would represent, on average, 170,000 cows. However, the largest dairy operations listed by the Top 100 2009 cannot be used to make correlations with the majority of the dairy population, since they correspond to 0.1 percent of the total dairy cow population and they are based on the national averages.

Therefore, the most conservative approach would be considering that only the 44 dairy farms, which account for 24,000 dairy cows, are under full confinement operations.

Table 3.9 – Estimated Milk Production and Number of Dairy Farms in Brazil by Production Type in 2005

Type	Definition			Milk		Farms		Cows	
	L/cow/day	Cows/farm	L/farm/day	1000 tons	%	#	%	1000 heads	%
Extensive	<4	<30	<100	4,598	19%	1,151,931	89.4%	11,938	58%
Semi-extensive	4-7	30-70	100-400	9,061	37%	107,130	8.3%	5,400	26%
Specialized	7-12	70-200	400-2,000	9,023	37%	28,110	2.2%	2,906	14%
Intensive	>12	>200	>2,000	1,889	8%	1,497	0.12%	387	2%
Total				24,572		1,288,668		20,632	

Source: Stock, 2005

b. DESCRIPTION OF WASTE CHARACTERISTICS, HANDLING, AND MANAGEMENT

Dairy cows raised in extensive, semi-extensive, and specialized production systems represent a very low potential for methane emissions from manure management. At the majority of these farms, most if not all of the manure is not treated at all or directly disposed of on cropland. Only the manure collected in the milking parlor can be treated in open ponds for further application on cropland.

In intensive production systems, animals may be fully or semi-confined. In the majority of the cases the milking parlor is paved and the manure generated in this area is collected to be spread daily or treated in open anaerobic lagoons for further application on cropland. Fully confined operations generally use freestall barns, where manure is scraped or flushed (using water) from feeding alleys. The most common manure treatment occurs in open anaerobic lagoons, where solid separators and decanters are used before the manure ponds to reduce the quick buildup of solids in the treatment system. Usually, the removed solids are directly applied on croplands.

Table 3.10 – Methane Emission Potential by Production Type

Type		Cows		Waste Treatment System	Methane Emission Potential
		1,000 Head	Percent		
Extensive		11,938	58	Not treated at all or directly disposed of on cropland	Low
Semi-extensive		5,400	26		Low
Specialized		2,906	14		Low
Intensive	Semi-confined	363	1.8	Open anaerobic lagoons, only for the manure collected in the milking parlor (10–15%)	High
	Fully confined	24	0.12	Open anaerobic lagoons, 100% of the manure	High
Total		20,632			

As Table 3.10 shows, there is a high potential to reduce methane emissions from 100 percent of the manure from the 24,000 fully confined cows, and 10 to 15 percent of the manure from the 363,000 semi-confined cows.

3.4 AGRO-INDUSTRIAL SECTORS

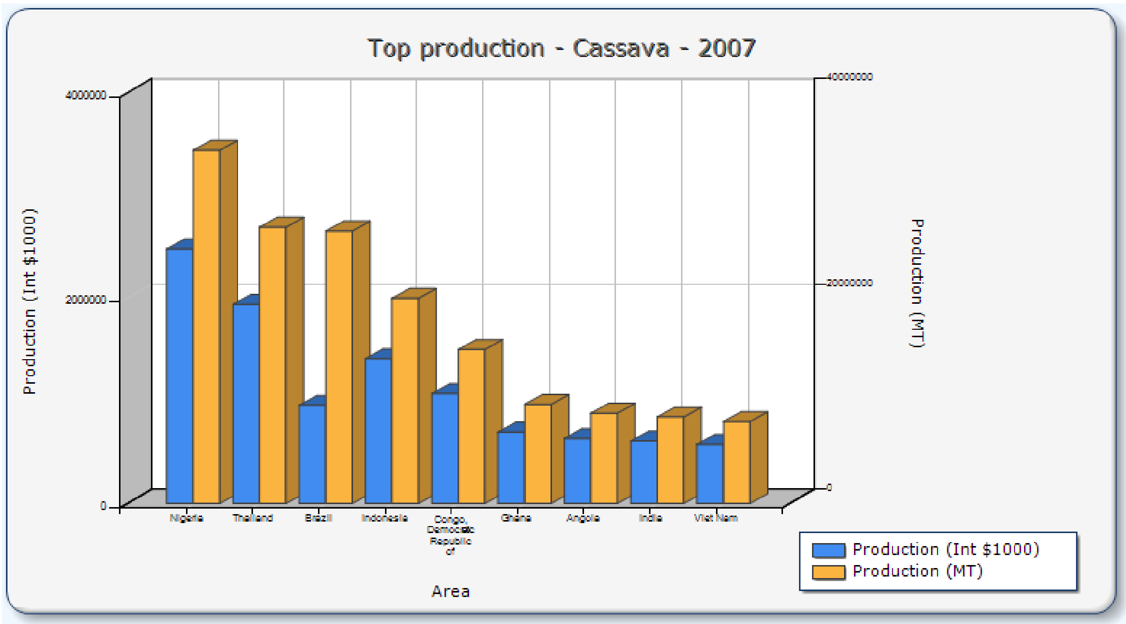
This section focuses on cassava starch production, sugarcane milling and production of ethanol and cachaça from the resulting molasses, slaughterhouses (beef, swine, and poultry), and beer and carbonated beverage production—the sectors with the greatest potential for methane emissions or capture and use.

3.4.1 CASSAVA STARCH INDUSTRY

a. DESCRIPTION OF SIZE, SCALE, AND GEOGRAPHIC LOCATION OF OPERATIONS

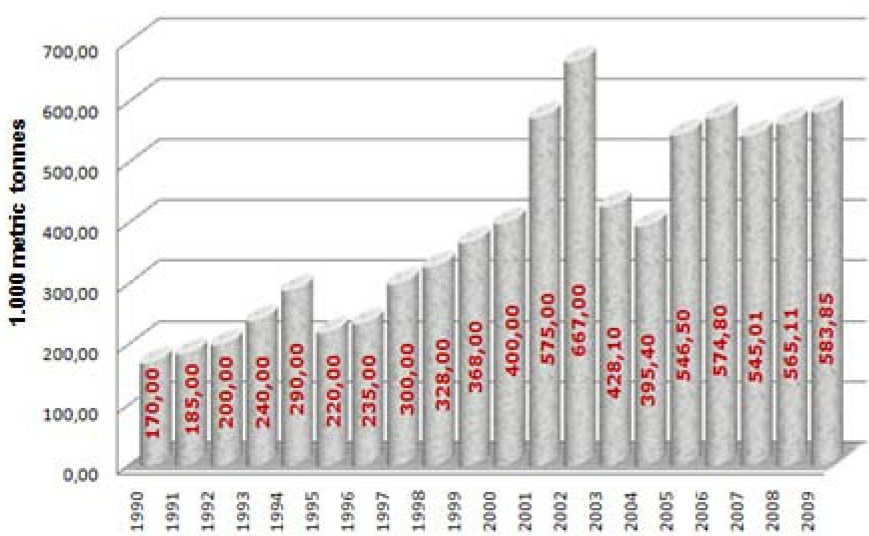
Brazil is the third largest cassava producer in the world behind Nigeria and Thailand (FAOSTAT, 2010) with a production of 26 million metric tons in 2009 (IBGE, 2010) (Figure 3.9). Around 90 percent of the cassava is turned into meal, of which 49.5 percent is consumed as flour, 40 percent is used for human direct consumption and animal feed, and the remaining is used for starch production, mainly in the Southern region. Cassava production generates 10 million direct and indirect jobs in Brazil (Agência Brasil, 2009). Brazil produced 565 thousand metric tons of cassava starch in 2008 (Figure 3.10) and is expected to produce 600 thousand metric tons in 2009.

Figure 3.9 – Top Cassava Producers Worldwide in 2007



Source: FAOSTAT, 2010

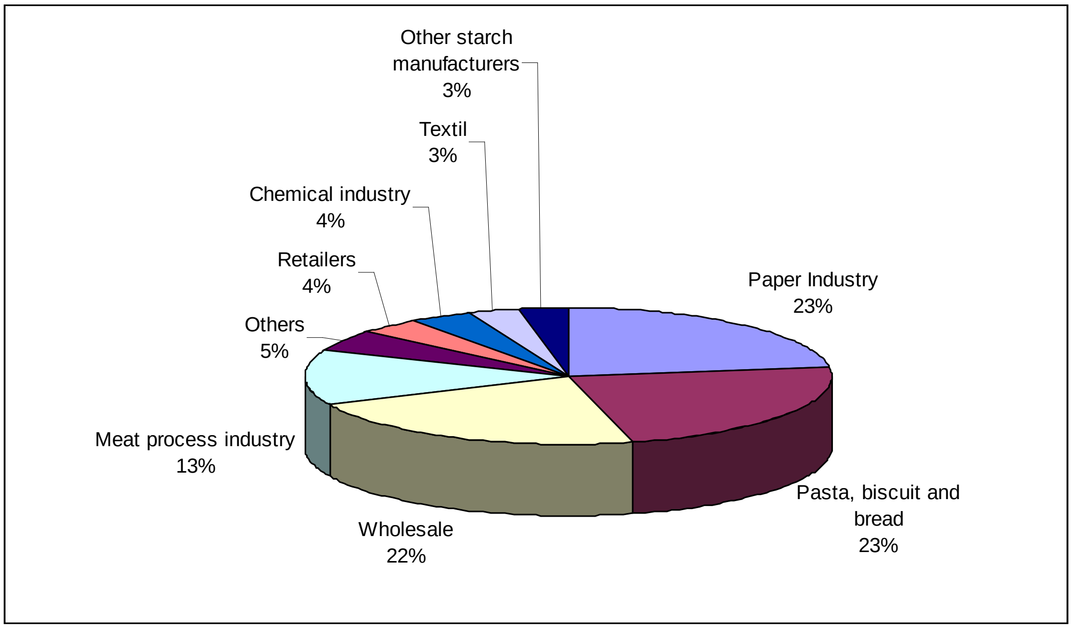
Figure 3.10 – Cassava Starch Production in Brazil, 1990–2009



Source: ABAM, 2010

Globally, the demand for starch is being driven by its use in the food and other industries and demand is increasing more rapidly than supply. While corn is the most significant source, accounting for 75 percent of world production, cassava (along with wheat and potatoes) is also an important starch source. In the food industry, starches are used as thickeners and binders and in the production of syrups and sweeteners for baking and confections. Starches also are used extensively in the paper, textile, and chemical industries and to a lesser extent in the metal, petroleum, and construction industries (Figure 3.11). One factor driving the increase in the global demand for starch is the production of ethanol for use as a fuel. Starch products can be divided into three groups: natural, modified, and hydrolyzed (Silva et al., 2000).

Figure 3.11 – Main Cassava Starch–Consuming Industry Sectors in 2008

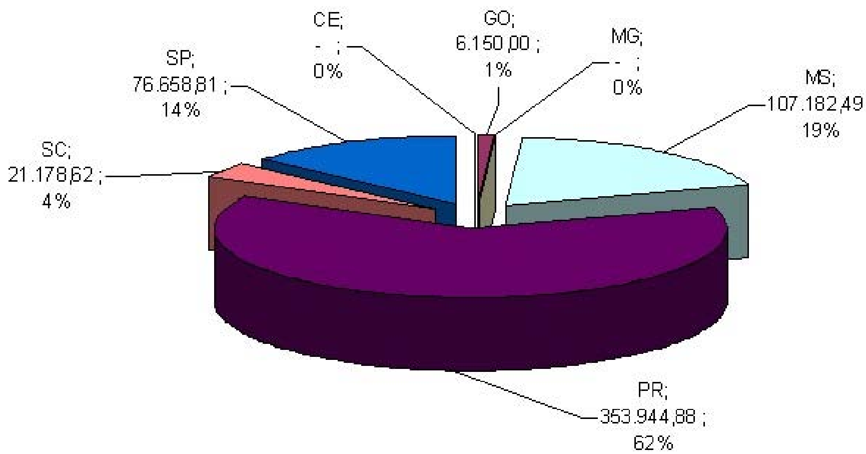


Source: ABAM, 2008

In Southern Brazil, cassava is gradually changing its status from a seasonal crop to a year-round crop. The increase in production period influences the cassava root starch yield. From May to August, a metric ton of cassava root typically produces 280 to 300 kilograms of starch. (In general, according to ABAM, a metric ton of cassava root is necessary to produce 250 kilograms of starch.)

According to ABAM, most of the large cassava starch plants are located in the states of Paraná, São Paulo, and Mato Grosso do Sul. Figure 3.12 shows the distribution of cassava production by state in 2008.

Figure 3.12 – Brazilian Cassava Starch Production by State, 2008



GO: Goiás; MG: Minas Gerais; MS: Mato Grosso do Sul; MT: Mato Grosso; PR: Paraná; RS: Rio Grande do Sul; SC: Santa Catarina; SP: São Paolo

Source: ABAM, 2008

According to an assessment of the 73 operating cassava starch plants in Brazil conducted by EMBRAPA in 2003, 68 percent (50 plants) had processing capacity lower than 300 metric tons of cassava per day, while 19 (26 percent) were able to process between 300 and 599 metric tons per day and four (5.5 percent) could process above 600 metric tons per day.

Based on an analysis by Alves (2003), the cassava starch plants are mainly located in the states of Paraná (PR) with 42 mills (58 percent of the total number of mills), followed by Mato Grosso do Sul (MS) with 13 mills, Santa Catarina (SC) with 11 mills, and São Paolo (SP) with 7 mills (Table 3.11).

Table 3.11 – Distribution of Cassava Starch Facilities in Brazil, by State in 2001

State	# of mills	Milling capacity (t cassava/day)	%	Average capacity per mill (t/day)
PR	42	12.330	58	294
MS	13	3.100	18	238
SC	11	1.320	15	120
SP	7	1.430	10	204
Brazil	73	18.180	100	249

MS: Mato Grosso do Sul; PR: Paraná; SC: Santa Catarina; SP: São Paolo

Source: Alves, 2003

Most companies produce natural starch, but the number of firms producing modified starches (e.g., cationic, dextrin, maltodextrin, pre-gelatinized) has increased significantly in the last 10 years. Diversification within the cassava industry is inevitable as more cassava starch firms penetrate into the traditional cornstarch markets and compete with multinational companies.

b. DESCRIPTION OF THE CHARACTERISTICS OF WASTES, HANDLING, AND MANAGEMENT

According to ABAM, the cassava starch extraction process uses 3.5 to 4 cubic meters of water per metric ton of cassava. On average, the cassava starch extraction generates 3.68 cubic meters of wastewater per metric ton of processed cassava (Fundação Cargill, 2001).

In analyzing wastewater from several cassava-producing plants, the Cargill Foundation reported an average COD concentration of 6,351 milligrams per liter. However, in site visits carried out for this study, some plants reported COD values as high as 74,000 milligrams per liter. Due to conflicting data, we used the IPCC default value for starch production of 10,000 milligrams per liter for this assessment.

From the 73 plants assessed by EMBRAPA in 2003, 63 plants (93 percent) treated wastewater in open lagoons, 6 plants (8 percent) applied the wastewater to cropland daily and 1 was discharging the wastewater directly to a natural water body. From the ones that were using lagoons to treat the wastewater, 17 plants (23 percent) added lime, with or without aeration and 2 plants (3 percent) added microorganisms to the lagoons (Alves, 2003).

3.4.2 SUGARCANE PROCESSING INDUSTRY

a. DESCRIPTION OF THE SIZE, SCALE, AND GEOGRAPHIC LOCATION OF OPERATIONS

Brazil is the world's leading sugarcane producer. The 2007–2008 harvest year produced a record crop estimated at 496 million metric tons of cane (Unica, 2009). Sugarcane is, by far, the number one crop in Brazil in terms of tons produced, as shown in Table 3.12. The main products obtained from the sugarcane produced in Brazil are ethanol, sugar, and cachaça. Sugarcane processing also generates bagasse, which can be used to produce electricity.

Table 3.12 – Brazilian Sugarcane, Sugar, Ethanol, and Cachaça Production in 2007/2008

Region/State	Sugarcane Production (Million Metric Tons)	Percent of Total	Sugar Production (Million Metric Tons)	Ethanol Production (Billion Liters)	Cachaça Production (Billion Liters)
Southeast	**339.8**	**68.54**	**21.56**	**15.49**	**0.95**
São Paulo	296.3	59.76	19.11	13.35	0.675
Minas Gerais	35.7	7.20	2.12	1.78	0.12
Midwest	**50.9**	**10.27**	**2.10**	**2.98**	**0.12**
Goiás	21.1	4.26	0.95	1.21	0.12
Mato Grosso	14.9	3.01	0.54	0.89	
Mato Grosso do Sul	14.9	3.01	0.62	0.88	
Northeast	**63.7**	**12.85**	**4.79**	**2.15**	**0.41**
Alagoas	29.4	5.93	2.52	0.85	

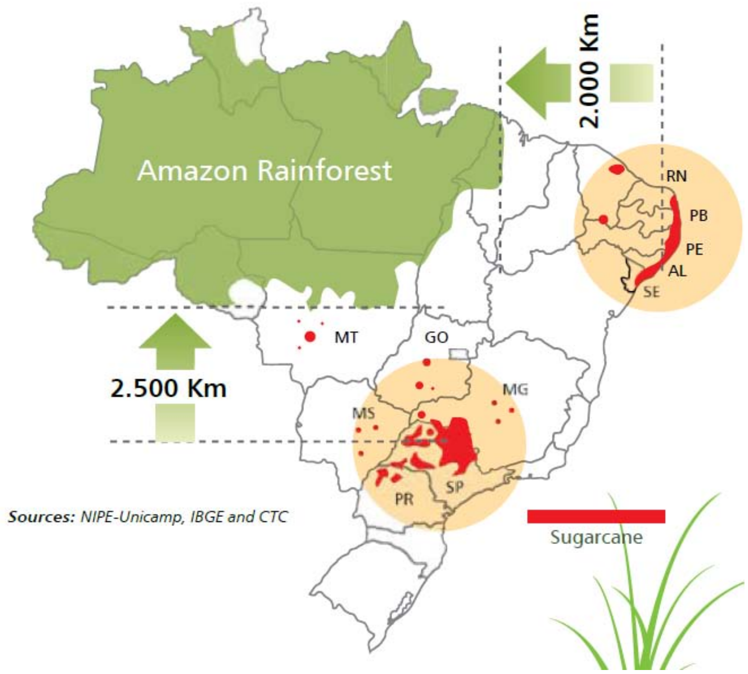
Region/State	Sugarcane Production (Million Metric Tons)	Percent of Total	Sugar Production (Million Metric Tons)	Ethanol Production (Billion Liters)	Cachaça Production (Billion Liters)
Pernambuco	19.8	3.99	1.68	0.51	0.18
Paraíba	5.5	1.11	NA	NA	0.03
South	**40.5**	**8.17**	**2.51**	**1.87**	**0.03**
Paraná	40.4	8.15	2.51	1.86	0.03
North	**0.9**	**0.18**	**0.04**	**0.04**	
TOTAL	**495.8**	**100.00**	**31.00**	**22.53**	**1.5**

Sources: Unica, 2009, elaborated by LOGICarbon

Annual gross earnings from the sugar and ethanol sectors stood at around US$20 billion in the 2007–2008 crop year, with about 44 percent of that generated by sugar sales, 54 percent from ethanol, and the remaining 2 percent from electricity sold to the domestic market. Sugar sales were split 35 percent domestic and 65 percent foreign. Ethanol sales were heavily concentrated on the domestic market, which generated 85 percent of revenues (Unica, 2009). Sugar production is forecast at 24.36 million metric tons and ethanol 28.45 billion liters in the 2009–2010 harvest (USDA, 2009).

Sugarcane crops occupy 7.8 million hectares, or 2.2 percent of the country's total arable land. Sugarcane is grown mainly in south-central and northeastern Brazil (Figure 3.13), with two different harvest periods: April to December in south-central Brazil and September to March in the northeast. The south-central area accounts for over 85 percent of total production. The state of São Paulo produces around 60 percent of all Brazil's sugarcane (Unica, 2009).

Figure 3.13 – Distribution of Sugarcane Production in Brazil

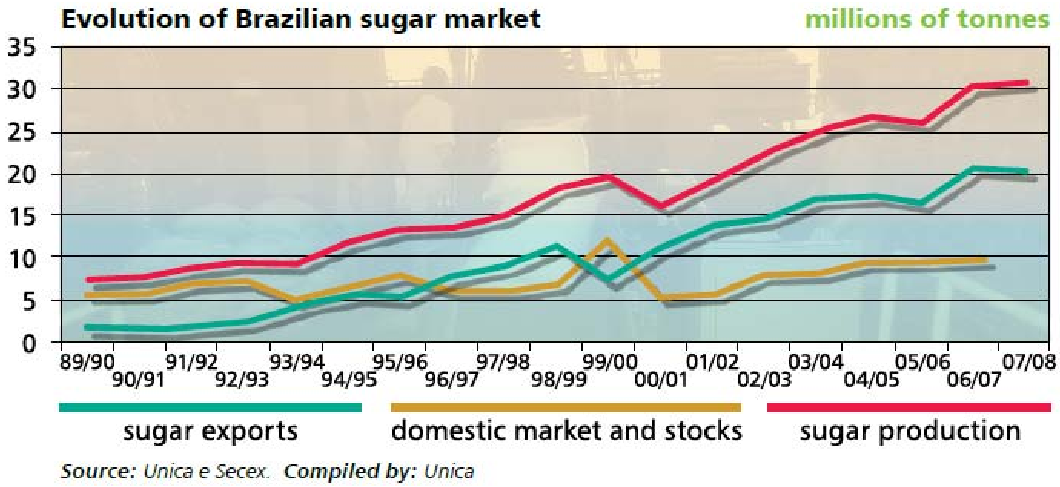


Source: Unica, 2009

Brazilian sugarcane is processed in about 250 mills. About 230 of these are combined mills and distilleries, producing both sugar and ethanol; the remainder produce only sugar and molasses. In addition, there are about 100 distilleries producing ethanol from purchased molasses.

Sugar: Brazil is the world's leading sugar producer and exporter, accounting for approximately 20 percent of global production and 40 percent of world exports. National production reached an estimated 31 million metric tons in 2007–2008 (Figure 3.15). Roughly two-thirds of the sugar produced in Brazil (18.6 million metric tons) is exported and more than 100 countries in the world import sugar from Brazil. In recent years, major markets for Brazilian sugar have been the Russian Federation, Nigeria, the United Arab Emirates, and Canada.

Figure 3.14 – Evolution of Brazilian Sugar Market



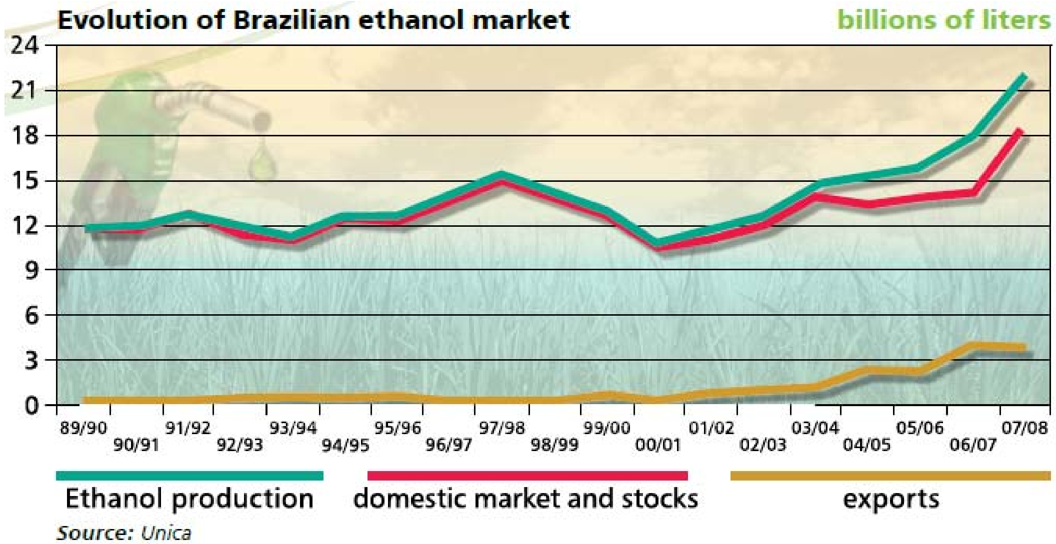
Source: UNICA, 2009

Ethanol: Ethyl alcohol, also known as ethanol, can be produced by the fermentation of sugarcane juice or molasses. It has recently emerged as an important fuel for internal combustion engines. Since March 2008, more than 50 percent of Brazil's gasoline consumption has been replaced by ethanol.

Brazil produces two types of ethanol: hydrous, which contains about 5.6 percent water by volume; and anhydrous, which is virtually water-free. Hydrous ethanol is used to power vehicles equipped with pure ethanol or flex-fuel engines, while anhydrous ethanol is mixed with gasoline before sale.

The Brazilian ethanol production reached 22.5 billion liters in the 2007–2008 sugarcane harvest, up 27 percent from the previous year (Figure 3.14). As in the past, the domestic market will absorb most of this—18.9 billion liters (84 percent)—with the remaining 3.6 billion liters (16 percent) exported.

Figure 3.15 – Evolution of Brazilian Ethanol Market

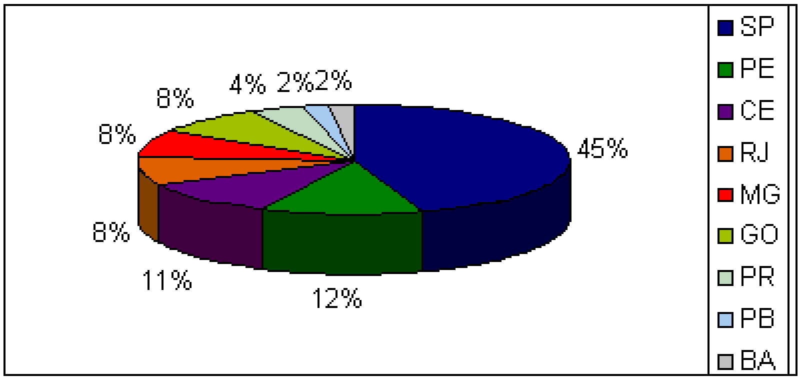


Source: UNICA, 2009

Cachaça: Cachaça is a liquor obtained by the fermentation and distillation of sugarcane molasses and is the most consumed distilled drink in Brazil. Brazil produces 1.5 billion liters of cachaça per year and exports about 20 million liters (1.2 percent) per year. This production generates about 800,000 jobs; exports reach 70 countries, including Germany, the United States, and France (Portal Cachaçaria Brasileira, no date). Since the production process for cachaça is similar to the ethanol production process, the opportunity for methane capture from the resulting wastewater is discussed in this section rather than the section on beverages.

Cachaça is produced in all Brazilian states, even where the cultivation of cane sugar is not favorable. The largest producers of cachaça are São Paulo (45 percent), Pernambuco (12 percent), Ceará (11 percent), Rio de Janeiro (8 percent), Minas Gerais (8 percent), Goiás (8 percent), Paraná (4 percent), Paraíba (2 percent), and Bahia (2 percent) (Figure 3.15). Production in São Paulo, Pernambuco, and Ceará accounts for nearly all of the industrial production, which is conducted using continuous column stills. Production takes place in about 30,000 facilities, and industrial distilleries are responsible for 75 percent of the total production. The remaining 25 percent of production is done by smaller facilities that produce artisanal cachaça using copper pot stills. The production of artisanal cachaça is concentrated in the states of Minas Gerais, Rio de Janeiro, Bahia, and São Paulo. Rio de Janeiro and Minas Gerais account for nearly 50 percent of the production (MAPA, no date).

Figure 3.16 – Distribution of Cachaça Production in Brazil by State, 2007



BA: Bahia; CE: Ceará; GO: Goiás; MG: Minas Gerais; PB: Paraíba; PE: Pernambuco; PR: Paraná; RJ: Rio de Janeiro; SP: São Paulo
Source: Martinelli, 2000

b. DESCRIPTION OF THE CHARACTERISTICS OF WASTES, HANDLING, AND MANAGEMENT

Ethanol production through sugar juice or molasses fermentation generates a high-organic-content wastewater called by various names including vinasse. As mentioned above, the fermented material can be sugarcane juice, molasses, or a mixture of both. For each liter of ethanol produced, 10 to 15 liters of vinasse (UNESP, 2007) are generated, depending on the technology. In the case of cachaça, 9 liters of vinasse are generated for each liter of cachaça produced.

The composition of vinasse varies from plant to plant and within each plant mainly due to the day of the season, the sugarcane variety, the maturation levels, and the soil fertility. The temperature of vinasse ranges from 65ºC to 105°C. Vinasse has a light brown color with a total solids (TS) content from 20,000 to 40,000 milligrams per liter when obtained from straight sugarcane juice, and a black-reddish color with TS from 50,000 to 100,000 milligrams per liter when obtained from sugarcane molasses. In addition, vinasse is acidic (with a pH between 4 and 5) and has a high COD concentration. The inorganic solids contain considerable amounts of nutrients such as phosphorus, nitrogen, and potassium (Baez-Smith, 2006).

Table 3.13 presents the range of values observed for the physical and chemical characteristics of vinasse from sugarcane mills in the state of São Paulo.

Table 3.13 – Composition of Sugarcane Vinasse

Parameter	Value		
	Lower	Average	Higher
Vinasse generation (L/L ethanol)	5.11	10.85	16.43
pH	3.50	4.15	4.90
Temperature (ºC)	65.00	89.16	105.0
BOD_5 (mg/L)	6,680	16,950	75,330
COD (mg/L)	9,200	28,450	97,400
TS (mg/L)	10,780	25,155	38,680

Source: UNESP, 2007

Since 1967, the direct discharge of vinasse into rivers has been prohibited by Brazilian federal law. In the state of São Paulo and in most of the south-central region, vinasse is used as a fertilizer on sugarcane fields. Vinasse is distributed through channels, pipes, or tank trucks to the sugarcane crop areas and directly spread as fertilizer (see Figures 3.17 and 3.18). Therefore, the south-central area does not yield a high potential for methane emission reduction from treatment of vinasse.

Figure 3.17 – Typical Concrete Channels for Vinasse Distribution

Source: Rocha, 2009

Figure 3.18 – Application of Vinasse on Sugarcane Cropland

Source: Rocha, 2009

In the northeast region, which produces 12.85 percent of Brazil's sugarcane, it is common practice to store vinasse in open lagoons before application on sugarcane crops or disposal in rivers. According to interviews with local experts, storing vinasses in open lagoons reduces its organic content and temperature, allowing it to be spread on cropland or discharged to water bodies. Usually, ethanol and cachaça distilleries store vinasse in sequential deep open lagoons, during a variable period of time (20 to 120 days). Analyses of vinasse stored in anaerobic lagoons at three sugarcane distilleries in the northeast region showed COD removal rates of 70 to 87 percent. Thus, the storage of vinasse in open anaerobic lagoons in the northeast region provides a significant opportunity to reduce methane emissions.

Besides the treatment of vinasse in open lagoons and its use as fertilizer, there has been little use of alternative technologies for its treatment and disposal, such as anaerobic digestion. Currently, there is only one small anaerobic digester treating vinasse in the state of São Paulo.

3.4.3 SLAUGHTERHOUSES

a. DESCRIPTION OF SIZE, SCALE, AND GEOGRAPHIC LOCATION OF OPERATIONS

Brazil is one of the largest producers and exporters of beef, pork, and chicken in the world. Slaughterhouses are usually located in strategic areas related to the livestock production and the consumer centers. According to DIPOA (the Department of Inspection of Animal Origin Products), slaughterhouses are classified according to their slaughtering capacity, which is defined by the slaughtering rate, as presented in Table 3.14.

Table 3.14 – Classification of Slaughterhouses in Brazil

Type of Slaughterhouse	Class	Slaughtering Rate
Beef cattle	MB1	> 80 head/hour and > 20 metric tons/day
	MB2	> 80 head/hour
	MB3	40–80 head/hour
	MB4	20–40 head/hour
	MB5	≤ 20 head/hour
Poultry	MA1	> 3,000 head/hour
	MA2	1,500–3,000 head/hour
	MA3	600–1,500 head/hour
	MA4	≤ 600 head/hour
Swine	MS1	> 800 head/day
	MS2	400–800 head/hour
	MS3	200–400 head/hour
	MS4	80–200 head/hour
	MS5	≤ 80 head/hour

MB: matadouro bovino (bovine slaughterhouse), MA: matadouro avícola (poultry slaughterhouse), MS: matadouro suíno (swine slaughterhouse)

Source: DIPOA, no date

Beef production: According to ABIEC (the Association of Brazilian Beef Exporters), the 190-million-head Brazilian beef cattle herd is the largest commercial herd in the world, exceeding India's and China's. In 2008, Brazil was the largest exporter of beef in the world, by exporting 2.16 million metric tons of carcass weight equivalent (CWE) (Table 3.15). The production of 9 million metric tons of beef CWE, from 42.8 million slaughtered cattle, ranks Brazil as the second largest producer of beef worldwide, behind the United States. It is important to note that only 21.4 million cattle (50 percent) were slaughtered under the Brazilian Federal Service Inspection Supervision (SIGSIF) in 2008.

Table 3.15 – Brazilian Beef Export in 2008

Product	2008			
	US$ (000)	Tons	US$/t	CWE
Fresh beef	4,006,246	1,022,883	3,917	1,501,887
Processed	853,331	200,294	4,260	500,735
Offals	244,104	70,201	3,477	70,201
Casings	177,892	84,570	2,103	84,570
Salted	43,906	5,916	7,421	5,916
Total	**5,325,480**	**1,383,865**	**3,848**	**2,163,310**

Source: ABIEC, 2009

Figure 3.19 shows how beef slaughterhouses owned by ABIEC associates are distributed in Brazil. Although it does not include all beef slaughterhouses registered under SIGSIF, it provides a representative picture.

Figure 3. 19 – Geographic Distribution of Beef Slaughterhouses From ABIEC

Source: ABIEC, 2009

According to the SIGSIF registry system (Table 3.16), the regions with the most beef slaughterhouses are the Midwest, with 120 facilities (22 type MB1 and MB2); the Southeast, with 78 slaughterhouses (10 type MB1 and MB2); and the South with 58 slaughterhouses (12 type MB1 and MB2). In 2008, the Midwest and Southeast accounted for 74 percent of the total of beef cattle slaughtered under SIGSIF supervision.

Table 3.16 – Distribution of Beef Cattle Slaughterhouses by State/Region, 2008

		Number of Beef Slaughterhouses							Share of Beef Slaughtered	
		Capacity Classification					Total			
Region	**State**	**MB1**	**MB2**	**MB3**	**MB4**	**MB5**	**State**	**Region**	**State**	**Region**
North	AC	-	-	1	2	-	3	43	-	15%
	AM	-	-	-	1	1	2		-	
	PA	-	1	5	9	2	17		7%	
	RO	-	1	7	4	8	20		8%	
	RR	-	-	-	-	1	1		-	
Notheast	BA	-	-	4	-	2	6	13	2%	2%
	MA	-	-	1	3	1	5		-	
	RN	-	-	-	1	-	1		-	
	SE	-	-	1	-	-	1		0%	
Middlewest	GO	2	4	7	9	10	32	120	12%	47%
	MS	-	3	5	12	18	38		14%	
	MT	6	6	7	15	6	40		17%	
	TO	-	1	4	4	1	10		4%	
South	PR	3	2	12	8	8	33	58	5%	8%
	RS	2	4	6	4	2	18		3%	
	SC	-	1	1	3	2	7		0%	
Southeast	ES	1	-	-	1	2	4	78	1%	27%
	MG	1	2	7	14	12	36		10%	
	RJ	-	-	-	-	1	1		0%	
	SP	2	4	13	11	7	37		16%	
Total	**Brazil**	**17**	**29**	**81**	**101**	**84**	**312**			

AC: Acre; AM: Amazonas; BA: Bahia; ES: Espírito Santo; GO: Goiás; MA: Maranhão; MG: Minas Gerais; MS: Mato Grosso do Sul; MT: Mato Grosso; PA: Pará; PR: Paraná; RJ: Rio de Janeiro; RN: Rio Grande do Norte; RO: Rondônia; RR: Roraima; RS: Rio Grande do Sul; SC: Santa Catarina; SE: Sergipe; SP: São Paulo; TO: Tocantins

Source: SIGSIF, 2009

Broiler chicken production: ABEF (the Brazilian Chicken Producers and Exporters Association) indicates that Brazil is the world's third largest broiler chicken producer, with 10.9 million metric tons produced, and the world's largest exporter, with 3.6 million metric tons exported. According to IBGE, Brazil produced 10.1 million metric tons of chicken from 4.9 billion birds slaughtered in 2008.

Most broiler slaughterhouses are located near high broiler production areas. The South region has 85 facilities (36 type MA1 and MA2) and the Southeast has 70 plants (25 type MA1 and MA2). The Midwest region has 22 facilities (10 type MA1 and MA2). In 2008, the SIGSIF registry system showed that 85 percent of the chickens were slaughtered in the South and Southeast regions, with 62 percent being slaughtered in the South region (Table 3.17).

Table 3.17 – Distribution of Broiler Slaughterhouses by State/Region, 2008

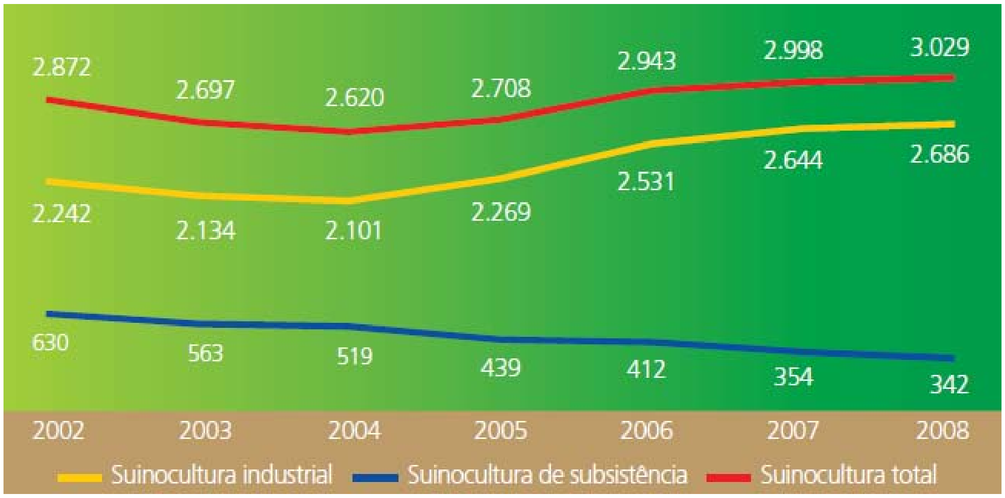
		Number of Poultry Slaughterhouses							Share of Poultry Slaughtered Heads in 2008	
		Capacity Classification					TOTAL			
Region	**State**	**MA1**	**MA2**	**MA3**	**MA4**	**MAV**	**State**	**Region**	**State**	**Region**
North	**RO**	-	1	-	-	-	1	1	0%	0%
Northeast	**BA**	-	1	-	-	1	1	8	1%	1%
	CE	-	-	1	-	-	1		-	
	PB	1	-	-	-	-	1		-	
	PE	1	-	-	3	-	4		0%	
	PI	-	-	-	1	-	1		0%	
	SE	-	-	-	-	1	0		0%	
Middlewest	**DF**	1	-	-	1	-	2	22	1%	13%
	GO	2	1	4	-	1	7		6%	
	MS	3	-	1	2	2	6		3%	
	MT	2	-	1	2	-	5		3%	
	TO	-	1	-	1	-	2		0%	
South	**PR**	8	3	24	4	2	39	85	27%	62%
	RS	8	5	5	3	-	21		17%	
	SC	11	1	7	6	1	25		18%	
Southeast	**ES**	1	-	1	1	-	3	70	0%	23%
	MG	4	5	7	2	-	18		7%	
	RJ	-	-	1	-	-	1		0%	
	SP	7	8	24	9	4	48		16%	
Total	**Brazil**	**49**	**26**	**76**	**35**	**12**	**186**			

BA: Bahia; CE: Ceara; DF: Distrito Federal; GO: Goiás; ES: Espírito Santo; MG: Minas Gerais; MS: Mato Grosso do Sul; MT: Mato Grosso; PB: Paraiba; PE: Pernambuco; PI: Piaui; PR: Paraná; RJ: Rio de Janeiro; RO: Rondônia; RS: Rio Grande do Sul; SC: Santa Catarina; SE: Sergipe; SP: São Paulo; TO: Tocantins

Source: SIGSIF, 2009

Pork production: According to ABIPECS (the Association of Brazilian Pork Producers and Exporters), Brazil is the world's fourth largest pork producer, with 3.03 million metric tons produced from 35.5 million slaughtered hogs, and the world's fourth largest exporter, with 529,000 metric tons exported in 2008 (Figure 3.20).

Figure 3.20 – Brazilian Pork Production From 2002 to 2008 (1,000 Tons)



Source: ABIPECS, 2009

Swine and poultry slaughterhouses are similar in that both are commonly part of vertically integrated enterprises. Like poultry, swine slaughterhouses are mostly located in the South region (57 slaughterhouses, 17 of which are type MS1 and MS2), followed by the Southeast region (48 slaughterhouses, 10 type MS1 and MS2) and the Midwest region (14 facilities, two type MS1 and MS2). The South and Southeast regions accounted for 87 percent of the slaughtered pork in 2008 (Table 3.18).

Table 3.18 – Distribution of Swine Slaughterhouses by State/Region, 2008

		Number of Swine Slaughterhouses								Fraction of Swine Slaughtered under Federal Inspection Service in 2008	
		Capacity Classification						Total			
Region	**State**	**MS1**	**MS2**	**MS3**	**MS4**	**MS5**	**FPS**	**State**	**Region**	**State**	**Region**
North	**PA**	—	—	—	1	—	—	1	5	—	0%
	RO	—	1	—	1	1	—	3		—	
	RR	—	—	—	—	1	—	1		—	
Northeast	**AL**	—	—	—	—	1	—	1	5	—	0%
	BA	—	—	1	—	1	—	2		—	
	MA	—	—	—	1	—	—	1		—	
	PE	—	—	—	1	—	—	1		—	
Mid-west	**GO**	1	—	1	1	1	—	4	14	6%	13%
	MS	—	—	1	1	2	—	4		3%	
	MT	1	—	1	2	2	—	6		4%	
South	**PR**	—	4	3	6	8	2	21	57	17%	72%
	RS	3	3	2	2	4	7	14		25%	
	SC	7	—	3	7	5	4	22		30%	
South-east	**ES**	—	1	—	—	—	—	1	48	—	15%
	MG	1	1	3	5	14	1	24		9%	
	SP	1	6	5	7	4	—	23		6%	
Total	**Brazil**	**14**	**16**	**20**	**35**	**44**	**14**	**129**			

AL: Alagoas; BA: Bahia; GO: Goiás; ES: Espírito Santo; MA: Maranhão; MG: Minas Gerais; MS: Mato Grosso do Sul; MT: Mato Grosso; PA: Pará; PE: Pernambuco; PR: Paraná; RO: Rondônia; RR: Roraima; RS: Rio Grande do Sul; SC: Santa Catarina; SP: São Paulo
Source: SIGSIF, 2009

b. DESCRIPTION OF WASTE CHARACTERISTICS, HANDLING, AND MANAGEMENT

Slaughtering operations generate many waste products, including blood, bones, fat, trimmings, viscera, and other animal parts. The process for disposing of the wastes or byproducts of slaughtering is governed by health and environmental laws and regulations and depends largely on the local markets. For example, blood can be sold for processing as whole blood or as its components (plasma, albumin, fibrin, etc.), but it can also be dried to produce blood meal to be used in animal feed.

The wastewater generated in slaughterhouses correlates directly with water use for processing and sanitation; the amount used depends on sanitation requirements imposed by health authorities. As well as being used for the periodic required cleaning of plant and equipment, water is used during the slaughtering process to wash live animals and carcasses, scald hog and poultry carcasses for hair and feather removal, chill carcasses, and move solid wastes such as viscera. Water also is used to generate steam and cool refrigeration compressors. Tables 3-19 and 3-20 present rates of water consumption in beef cattle and swine slaughterhouses from various references. As shown in these tables, the ranges of values are substantial.

Table 3.19 – Water Consumption in Beef Cattle Slaughterhouses

Type of Operation	Consumption (L/Head/Day)	Source
Slaughter	389–2,159	IPCC, 2006
Slaughter	1,000	CETESB, 2008
Slaughter	700–1,000[a]	Envirowise; WS Atkins Environment, 2000
Slaughter	500–2,500	CETESB, 2001
Slaughter and rendering	1,700	UNEP; WPG; DSD, 2002
Slaughter and further processing	1,000–3,000	CETESB, 2001
Slaughter, further processing, and rendering	3,864	CETESB, 2005

[a] Benchmark.

Source: CETESB, 2008

Table 3.20 – Water Consumption in Swine Slaughterhouses

Type of Operation	Consumption (L/Head/Day)	Source
Slaughter	100–519	IPCC, 2006
Slaughter	160–230[a]	Envirowise; WS Atkins Environment, 2000
Slaughter	400–1,200	CETESB, 1993
Slaughter and further processing	500–1,500	CETESB, 1993

[a] Benchmark.

Source: CETESB, 2008

For broiler slaughterhouses, slaughtering consumes 20 to 50 liters per bird (Pimenta and Gouvinhas, 2004; Maldaner, 2008; Zanotto et al., 2006; Bliska and Gonçalves, 1998).

Between 80 and 95 percent of slaughterhouse water use is discharged as wastewater (CETESB, 2008). Slaughterhouse wastewater is characterized mainly by:

- A high concentration of organic matter due to the presence of blood, fat, meat particles, and manure.
- A high fat content.
- pH fluctuations due to the use of both acidic and basic cleaning agents.
- A high concentration of nitrogen, phosphorus and salts.
- Variation in temperature (use of hot and cold water).

Therefore, slaughterhouse wastewaters have high BOD_5, COD, and suspended solids concentrations, with blood being a significant source of both BOD_5 and COD (CETESB, 2008).

In slaughterhouses, it is common to segregate the wastewater generated in the slaughtering and carcass cutup areas from the wastewater generated in other areas of the operation such as holding pens and truck washing areas. This segregation facilitates have more effective primary treatment and reduces loading rates to secondary treatment. Representative BOD_5 generation rates and concentrations for cattle and swine slaughtering operations with and without further processing are listed in Table 3.21 and physical and chemical characteristics are listed in Table 3.22. Table 3.23 shows the average volume and BOD_5 content of beef cattle slaughterhouse wastewater by effluent stream.

Table 3.21 – Representative BOD_5 Generation Rates and Concentrations for Cattle and Swine Slaughtering Operations With and Without Further Processing

Animal	Type of Slaughtering Operation	Organic Load (kg BOD_5/Head)	Concentration of BOD_5 in the Effluent (mg/L)
Cattle	Slaughter with further processing	3.76	1,250–3,760
	Slaughter only	2.76	1,100–5,520
Swine	Slaughter with further processing	0.94	620–1,800
	Slaughter only	0.69	570–1,700

Source: CETESB, 2008

Table 3.22 – Slaughterhouse Wastewater Physical and Chemical Characteristics From Four Different Sources

Parameter	Content (kg/MT Live Weight)		Content (kg/MT of Carcass Weight)	
	(1)	(2)	(3)	(4)
COD	—	—	12–66	—

BOD_5	12–15	6–16	—	8–66
Suspended solids	9–12	4–18	4–14	—
Total nitrogen	1–1.7	—	1–3	0.9–3.4
Ammonia nitrogen	—	0.08–0.25	—	—
Organic nitrogen	—	0.3–0.8	—	—
Total phosphorus	—	—	0.1–0.5	0.1–0.5
Soluble phosphorus	—	0.06–0.21	—	—
Sodium	—	—	0.6–4.0	—
Oil and grease	1.5–8.0	1.5–23.0	2–12	—

Source: CETESB, 2008

Table 3.23 – Average Volume and BOD_5 of Beef Cattle Slaughterhouse Wastewaters

Effluent Stream	Average Flow	Average Organic Content
Slaughter and carcass cutup	1,630 L/head	2.5 kg BOD_5/head
Holding pens, etc.	540 L/head	0.9 kg BOD_5/head
Domestic sewage	122 L/employee/day	31 g BOD_5/employee/day

Source: CETESB, 2008

In the case of the wastewater from broilers, layers and turkeys slaughterhouses (the layers and turkeys represent a minor share), the COD content varies from 1,000 to 3,700 mg/L (Philippi et al., 2004). Slaughterhouses must treat the wastewater before discharge according to local environmental laws and regulations. The treatment system varies from company to company, but according to CETESB, a typical wastewater treatment system for this sector, regardless of the type of animal slaughtered, has the following steps:

- Primary treatment consisting of coarse screening followed by removal of suspended solids and fat by gravity or flotation or both. Primary treatment typically is carried out separately for the holding pen and slaughter waste streams.

- Flow equalization of the combined waste streams to reduce variation in flow rate and organic loading to the secondary treatment process employed.

- Secondary treatment, which converts the remaining colloidal and dissolved organic compounds to settleable solids by microbial activity for removal by secondary clarification. Use of conventional anaerobic lagoons, possibly followed by facultative or aerobic lagoons is common.

- Tertiary treatment (if necessary due to discharge requirements) for additional removal of suspended solids, nutrients (nitrogen and phosphorus), and microorganisms indicating the possible presence of pathogens. Tertiary treatment may include filtering, nitrification-denitrification, phosphorus precipitation, and disinfection.

When a rendering operation is attached to the slaughterhouse, variations may occur, such as separate primary treatment with subsequent mixing of the other waste streams (CETESB, 2008).

Anaerobic digestion is not commonly used for slaughterhouse wastewater treatment in Brazil. In 2001, 44 anaerobic systems (mainly anaerobic reactors) were reported to be in operation at Brazilian slaughterhouses. However, no data were available on biogas collection or use.

The use of conventional anaerobic lagoons as the primary treatment system is the most common practice of the slaughterhouse industry in Brazil. Although official data are lacking, the poultry and swine slaughterhouse sectors appear to be more advanced than the beef sector with respect to anaerobic digestion technology. In addition to the reported use of anaerobic reactors, there are about 10 large beef cattle slaughtering plants—with a capacity of more than 1,000 head per day—that use covered lagoons as secondary treatment, according to information obtained from a digester technology and manufacturer provider. Thus, for purposes of this report, it is assumed that 80 percent of the swine and poultry slaughterhouses and 95 percent of the beef slaughterhouses use open anaerobic lagoons as their primary wastewater treatment.

3.4.4 NON-ALCOHOLIC AND ALCOHOLIC BEVERAGE INDUSTRY

a. DESCRIPTION OF SIZE, SCALE, AND GEOGRAPHIC LOCATION OF OPERATIONS

For purposes of this report, the Brazilian non-alcoholic and alcoholic beverage industries will be treated as the same sector. According to the analysis of the Brazilian National Bank of Economic and Social Development (BNDES, 2006), the segments of the beverage industry can be grouped as follows:

- Bottled water: drinking, mineral, mineralized.
- Traditional drinks: coffee, tea, chocolate.
- Other non-alcoholic: carbonated, juices, other (sports drinks, energy drinks, etc.).
- Alcoholic: beer, wine, distilled (whiskey, vodka, gin, rum, etc.), others ("ice drinks," beer-based drinks, etc.).

The beverage industry is characterized by the production of relatively homogeneous products intended primarily for domestic consumption (BNDES, 2006). Thus, production and consumption figures are essentially the same. The total consumption per capita of all drinks in Brazil is around 246 liters per year. Based on the 2007 annual production of each beverage category, carbonated beverages, water, and beer are predominant, accounting for 80.5 percent of the total beverage production in the country, as shown in Table 3.24. Since bottled water production does not represent an opportunity for methane emission reduction, this report focuses on carbonated drinks and beer production (BNDES, 2006).

Table 3.24 – Beverage Consumption/Production in Brazil by Category, 2007

Beverage categories		Production in 2007 (billion liters)	%
Non-alcoholic	Carbonates	14.32	30.9%
	Water	12.62	27.3%
	Others	7.16	15.5%
	Total	**34.10**	**73.7%**
Alcoholic	Beer	10.34	22.3%
	Cachaça	1.30	2.8%
	Others	0.54	1.2%
	Total	**12.18**	**26.3%**
TOTAL		**46.28**	

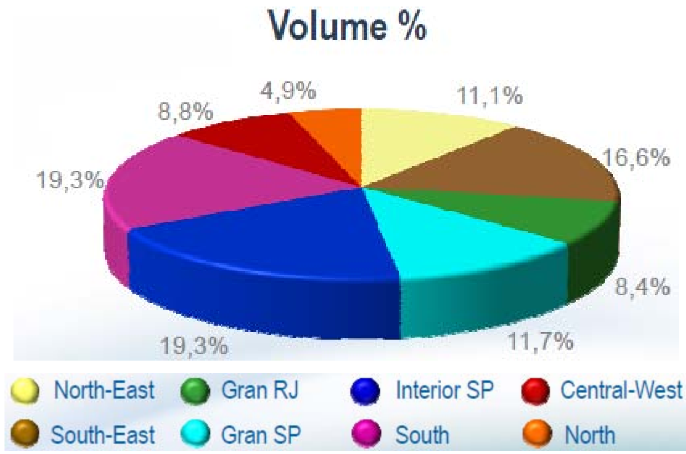
Sources: ABIR, ABRABE, Sindicerv, MAPA. Developed by LOGICarbon

Carbonated beverages: Carbonated drinks are manufactured, non-alcoholic beverages that contain flavorings. They are produced from the mixture of water with concentrated flavor and sugar or other sweetener and produced in a number of flavors including cola, guarana, orange, lemon, grape, raspberry, and cinnamon. After the United States and Mexico, Brazil is the third largest carbonated beverage market in the world, with total sales of approximately 12.3 billion liters in 2004, equivalent to US$14.2 billion. Nevertheless, in terms of consumption per capita, Brazil ranks 28th (BNDES, 2006).

The Brazilian market for carbonated beverages can be classified in two main groups. The first is composed of two multinational companies, Coca-Cola and AmBev, that account for about 73 percent of the carbonated beverages market share in 2009 (AmBev, 2009). The second group is formed by several small regional producers offering low-price products.

According to BNDES, in 2004 over 835 facilities in Brazil produced carbonated beverages. The production of carbonated beverages by the two major manufacturers takes place in 16 facilities for Coca-Cola and 18 facilities for AmBev with four dedicated to carbonated beverages and 14 also producing beer (AmBev, 2009). Production facilities for carbonated beverages are widely distributed throughout Brazil, but usually close to large cities. Fifty-six percent of carbonated beverage consumption is concentrated in the Southeast region (ABIR, 2009), as shown in Figure 3.21.

Figure 3.21 – Consumption of Carbonated Drinks in Brazil by Region, 2008



Source: ABIR, 2009

Beer: Beer is produced through the fermentation of barley, which converts the sugars and starches present into alcohol. Fermentation is the principal component of the brewing process and its effectiveness depends on several previous operations, including preparation of raw materials (CETESB, 2008). Brazil is the fourth largest beer producer in volume, behind China (35 billion liters per year), the United States (23.6 billion liters per year) and Germany (10.7 billion liters per year). The total consumption of beer in Brazil in 2007 was 10.34 billion liters (Sindicerv, no date). The brewing industry employs more than 150,000 people, including direct and indirect jobs (BNDES, 2006).

There were 47 breweries in operation in Brazil in 2005, generally large and medium-sized operations and mostly located close to major population centers in the country. The Southeast region accounts for 57.5 percent of production (approximately 4.6 billion L/yr), the Northeast accounts for 17.3 percent (1.4 billion L/yr), the South region accounts for 14.8 percent (1.2 billion L/yr), the Midwest region accounts for 7.5 percent (0.6 billion L/yr) and the North region accounts for 2.9 percent (0.3 billion L/yr) (CETESB, 2005).

In 2005, 54 percent of the plants were producing exclusively beer while the rest was producing both beer and carbonated drinks (CETESB, 2005). The beer market in Brazil is also significantly concentrated, with AmBev having 67.2 percent of the market share in 2009, Schincariol having 13 percent, Petrópolis having 9.9 percent, and FEMSA (Fomento Económico Mexicano SA) having 7.9 percent.

b. DESCRIPTION OF WASTE CHARACTERISTICS, HANDLING, AND MANAGEMENT

Beer: In general, the breweries have relatively large facilities to treat their wastewater, due to the high volume of wastewater generated (thousands of cubic meters per day) and its high pollution potential (1,200 to 3,000 mg/L of BOD). Because of the need for frequent cleaning of equipment, floors, and bottles, the brewery industry generates significant amounts of wastewater. The composition of these wastewaters is strongly influenced by the type of beer produced, type of yeast used, quality of filtration processes, type of additives used, and the efficiency of cleaning equipment (CETESB, 2005).

An average of 1.5 liters of water is consumed in the production of one liter of beer, and approximately 3 to 6 liters of wastewater are generated per liter of beer produced. The percentage of wastewater generated in each step of the production process varies greatly in volume and characteristics. For example, washing bottles generates large volumes of wastewater with reduced pollution potential, while the fermentation and filtering steps generate only 3 percent of the volume of wastewater but accounts for 97 percent of the pollution potential.

Brewery wastewaters typically contain high concentrations of organic compounds and total suspended solids and also contain nitrogen and phosphorus. Reported flow rates and BOD and COD concentrations are listed in Table 3.25 (CETESB, 2005).

Table 3.25 – Flow Rates and Characteristics of Brewery Wastewaters

Parameters	Unit	USA, 1971	São Paolo, 80s	USA, 1997	USA, 1993	Brazil, 1993	World Bank, 1997
Flow	L/L of beer	5.5–8.3 (6.9)		1.3–2.0 (1.6)			
BOD	mg/L	1,611–1,784 (1,718)	3.045		419–1,200	1,000–1,800	1,000–1,500
COD	mg/L		4.448				
	g/L of beer		25				

Source: CETESB, 2005

Carbonated beverages: Water use for washing recycled bottles and plant equipment is the principal source of wastewater in the carbonated beverage industry. When not segregated, spills and defective product become a part of the wastewater flow. Carbonated beverage production wastewaters are typically alkaline, due to the cleaning and sanitizing agents used, and have a high concentration of BOD due to the use of sugar syrups and plant extracts in the manufacturing process (CETESB, 2005). Data from the state of São Paulo indicate that about 4 liters of wastewater with a BOD concentration of 1.2 grams per liter are generated per liter of product. More advanced bottle-washing equipment can reduce the rate of wastewater generation to about 2 liters per liter of product (CETESB, 2005). The characteristics of wastewater in the carbonated beverage industry can vary with both location depending on spill and defective production disposal, and routine plant and equipment sanitation practices. They also can vary with time of day, depending on the phase of the production cycle. Table 3.26 illustrates the degrees of variation in BOD and COD concentrations that can be expected, as well as comparing these concentrations for carbonated beverage only versus combined beer and carbonated beverage production.

Table 3.26 – BOD and COD Concentrations (for Combined Beer and Carbonated Drinks and Carbonated Drinks Only) in Wastewater From Facilities in the State of São Paulo

Parameter	Unit	Beer and Carbonated drinks facilities, SP (1985)	Carbonated drinks facilities, SP (1985)
BOD	mg/L	3,045	940 - 1,335 (1,188)
COD	mg/L	4,448	1,616 - 3,434 (2,149)

Source: CETESB, 2005

As mentioned earlier, Brazil has four dominant beer producers (Ambev, Schincariol, Petrópolis, and FEMSA) and two dominant carbonated beverage producers (Coca-Cola and AmBev). All of these corporations provide at least secondary treatment for the wastewater generated at their facilities, typically by the UASB process. In 2001, the Brazilian beer and carbonated beverage industries were using 42 anaerobic systems (CETESB, 2001)and most of the biogas was flared. However, Coca-Cola and AmBev are currently capturing and using the biogas from the anaerobic treatment of their wastewaters. Therefore, the opportunity for methane emission reduction in the beverage industry (alcoholic and non-alcoholic) will be at smaller facilities representing less than 27 percent of the carbonated drink production and 2 percent of the beer production in Brazil, where the use of open anaerobic lagoons is still a common practice.

4. POTENTIAL FOR METHANE EMISSION REDUCTION

This section presents an estimate of the potential for reducing GHGs from livestock manures and agricultural commodity processing wastes through the use of anaerobic digestion. Anaerobic digestion reduces GHG emissions in two ways. First, it directly reduces methane emissions by capturing and burning biogas that otherwise would escape from the waste management system into the atmosphere. Second, it indirectly reduces carbon dioxide, methane, and nitrous oxide by using biogas to displace fossil fuels that would otherwise be used to provide thermal energy or electricity. Section 4.1 explains the potential methane emission reduction from manure management systems and agricultural commodity processing waste.

The feasibility of modifying existing livestock manure and agricultural commodity processing waste management systems by incorporating anaerobic digestion will depend on the ability to invest the necessary capital and generate adequate revenue to at least offset operating and management costs, as well as provide a reasonable return to the invested capital.

A number of options exist for anaerobically digesting wastes and utilizing the captured methane. For a specific enterprise, waste characteristics will determine which digestion technology options are applicable. Of the technically feasible options, the optimal approach will be determined by financial feasibility, subject to possible physical and regulatory constraints. For example, the optimal approach may not be feasible physically due to the lack of necessary land. Section 4.2 briefly describes the types of anaerobic digestion technologies, methane utilization options, costs and benefits, and centralized projects. Appendix B provides more information regarding emissions avoided when wet wastes are sent to landfills, as well as emissions from leakages and waste transportation in co-substrate projects.

4.1 METHANE EMISSION REDUCTION

Anaerobic digestion projects for both manure and agricultural commodity processing wastes may produce more methane than the existing waste management system, because anaerobic digesters are designed to optimize methane production. For example, the addition of anaerobic digestion to a manure management operation where manure was applied daily to cropland or pasture would produce significantly more methane than the baseline system. As such, the direct methane emission reduction from a digester corresponds not to the total methane generated, but rather the baseline methane emissions from the waste management system prior to installation of the digester. The indirect emission reduction, as explained in Section 4.1.3, is based on the maximum methane production potential of the digester and how the biogas is used.

4.1.1 Direct Emission Reductions From Digestion of Manure

The methane production potential from manure is estimated as shown in Equation 2.1 and the methane conversion factor for the baseline manure management system used at the operation as shown in Equation 4.1:

$$CH_{4\,(M,\,P)} = \left(VS_{(M)} \times H_{(M)} \times 365 \text{ days/yr}\right) \times \left[B_{o(M)} \times 0.67 \text{ kg } CH_4/m^3 \text{ } CH_4 \times MCF_{AD}\right] \qquad (4.1)$$

where: $CH_{4\,(M,\,P)}$ = Estimated methane production potential from manure (kg/yr)

$VS_{(M)}$ = Daily volatile solids excretion rate for livestock category M (kg dry matter/animal/day)
$H_{(M)}$ = Average daily number of animals in livestock category M
$B_{o(M)}$ = Maximum methane production capacity for manure produced by livestock category M (m^3 CH_4/kg volatile solids excreted)
MCF_{AD} = Methane conversion factor for anaerobic digestion (decimal)

Table 4.1 shows the estimated GHG emission reduction potential for swine and dairy operations in Brazil. The swine sector by far has the largest potential, with more than 14 MMTCO_2e per year.

Table 4.1 – Methane and Carbon Emission Reductions From Manure

Parameter	Swine	Dairy		Assumptions
$H_{(\#)}$	22,906,100	24,000 (confined)	363,000 (semi-confined)	• **Swine:** Only considered large scale swine operations with lagoon systems not yet covered. Used IPCC default values of VS and B_0 for swine in North America due to similar feed and genetics.
% manure collected	100%	100%	12.5%	
VS (kg/head/day)	0.27	5.4	2.9	
B_0 (m^3 CH_4/kg VS)	0.48	0.24	0.13	
MCF	0.78	0.78	0.78	
CH_4 (MT/yr)	566,263	5,933	3,263	
CO_2 (MT CO_2e/yr)	11,891,530	124,594	68,534	• **Dairy:** Only considered dairy farms with total confinement (100 percent of manure) or semi-confinement (12.5 percent of manure). Used IPCC default values of VS and B_0 for dairy cattle in North America (fully confined) and Latin America (semi-confined).
Indirect emission reduction (MT CO_2e/yr)	2,239,698	14,611	12,906	
Total CO_2 (MT CO_2e/yr)	14,131,228	139,205	81,429	• **Indirect emission reduction:** Assumed biogas is used to generate electricity and replace fuel oil.

4.1.2 Direct Emission Reduction From Digestion of Agricultural Commodity Processing Wastes

The methane production potential from agricultural commodity wastes is estimated as shown in Equation 2.2 and the MCF for the baseline waste management system used at the operation is estimated as shown in Equations 4.2 and 4.3:

$$CH_{4(W)} = (TOW_{(W)} - S_{(W)}) \times EF_{(W,S)} \qquad (4.2)$$

where: $CH_{4\,(W)}$ = Annual methane emissions from agricultural commodity processing waste W (kg CH_4/yr)

$TOW_{(W)}$ = Annual mass of waste W COD generated (kg/yr)
$S_{(W)}$ = Annual mass of waste W COD removed as settled solids (sludge) (kg/yr)
$EF_{(W, S)}$ = Emission factor for waste W and existing treatment system and discharge pathway S (kg CH_4/kg COD)

The methane emission rate is a function of the type of waste and the existing treatment system and discharge pathway, as follows:

$$EF_{(W,S)} = B_{o\,(W)} \times MCF_{(S)} \quad (4.3)$$

where: $B_{o\,(W)}$ = Maximum CH_4 production capacity (kg CH_4/kg COD)
$MCF_{(S)}$ = Methane conversion factor for the existing treatment system and discharge pathway (decimal)

Table 4.2 summarizes the assumptions used for calculating the methane emission reduction potential from eight agro-industrial subsectors in Brazil.

Table 4.2 – Summary of the Assumptions Used for the Calculations of the Methane Emission Reduction Potential

Sector	Percentage of the Production Using Lagoons	COD and W Values
Cassava starch	93 percent use open lagoons	COD: IPCC default value for starch production W: Cargill Foundation
Ethanol	9.6 percent (Northeast) use open lagoons	COD: average in SP W: UNESP
Cachaça	27 percent (Northeast) use open lagoons	COD: average in SP W: UNESP
Beer	2 percent use open lagoons	COD and W: CETESB, 2005
Carbonated drinks	27 percent use open lagoons	COD and W: study in SP state in CETESB, 2005
Slaughterhouses beef	95 percent use open lagoons	COD: IPCC default value for meat and poultry W: IPCC, 2005, in CETESB, 2008
Slaughterhouses swine	80 percent use open lagoons	COD: IPCC default value for meat and poultry W: IPCC, 2005, in CETESB, 2008
Slaughterhouses poultry	80 percent use open lagoons	COD and W: different publications see Chapter 3

Table 4.3 shows the estimated GHG emission reduction potential for eight agro-industrial subsectors in Brazil. When indirect emissions are considered, the emission reduction potential ranges from 20,901 $MTCO_2e$ for beer production to 3.8 $MMTCO_2e$ for ethanol production. The total potential emission reduction potential across all subsectors is 7.8 $MMTCO_2e$. Based on limited data and best professional judgment, the MCF_{AD} values of 0.80 appear to be reasonable estimates for ambient temperature digesters for first-order estimates of methane production potential.

As for the potential for indirect emission reduction through fuel replacement, it was assumed that 44 percent of the biogas would replace distillate fuel oil and 4 percent would replace natural gas in all the subsectors. For the sugarcane sector, it was assumed that captured biogas would be used to generate electricity for onsite use and delivered to the grid, thereby reducing emissions from the generation of electricity. Because the sugarcane mills burn the bagasse as a fuel source, their baseline emissions are very low.

Table 4.3 – Methane and Carbon Emission Reductions From Agro-Industrial Waste

	Cassava Starch	Ethanol	Cachaça	Beer	Carbonated Drinks	Slaughterhouses (Beef Cattle)	Slaughterhouses (Swine)	Slaughterhouses (Poultry)
P (MT or m3/yr)	2,323,605	2,160,000	405,000	206,800	3,866,400	40,660,000	28,400,000	3,920,000,000
W (m^3/MT or m^3 or head)	3.68	12.5	9	4.5	4	1.3	0.3	0.035
COD (kg/m^3)	10	28.45	28.45	4.5	2.1	4.1	4.1	2.4
TOW (kg COD/yr)	85,508,664	768,150,000	103,700,250	4,187,700	33,235,574	212,383,444	36,038,180	322,420,000
B_0 (kg CH_4/kg COD)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
MCF	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
EF (kg CH_4/kg COD)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
CH_4 (MT CH_4/yr)	17,102	153,630	20,740	838	6,647	42,477	7,208	64,484
CO_2 (MT CO_2e/yr)	359,136	3,226,230	435,541	17,588	139,589	892,010	151,360	1,353,164
Indirect emission reduction (MT CO_2e/yr)	31,800	285,800	38,600	1,600	12,400	79,000	13,400	120,000
Total CO_2 (MT CO_2e/yr)	391,000	3,512,000	474,100	19,100	152,000	971,000	164,800	1,474,100

4.1.3 Indirect GHG Emission Reductions

The use of anaerobic digestion systems has the financial advantage of offsetting energy costs at the production facility. Biogas can be used to generate electricity or supplant the use of thermal fuels. Using biogas energy also reduces carbon emissions by displacing fossil fuels. The degree of emission reduction depends on how the biogas is used. Table 4.4 shows the potential uses of the biogas in each of the subsectors.

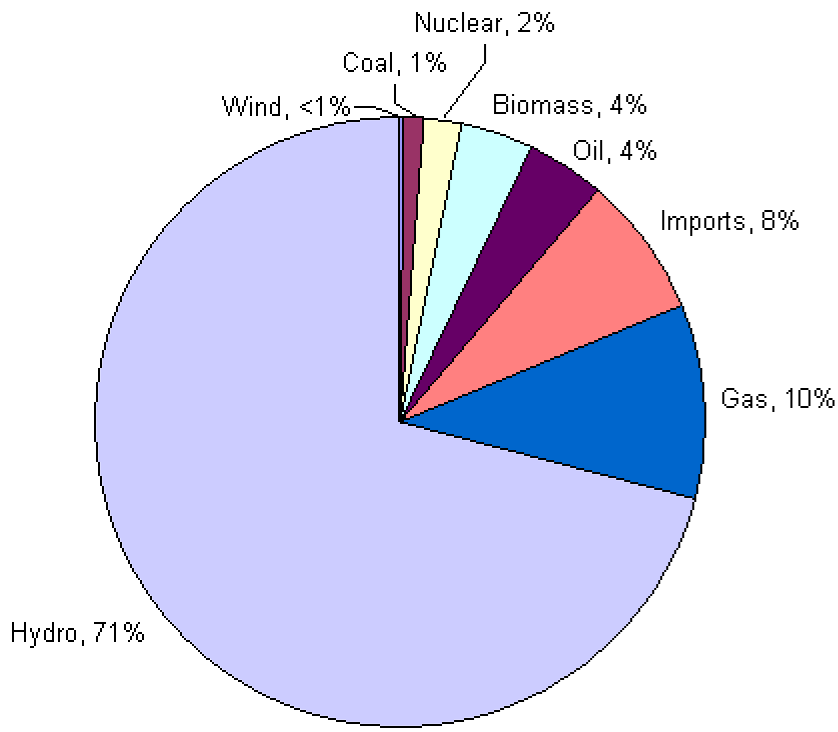
Table 4.4 – Potential Biogas Energy Use by Sector

Sector	Electricity Use	Thermal Energy Replacement
Swine	Feed mills	LPG to heat farrowing houses and nurseries
Dairy	Energy-intensive, particularly during milking operations	LPG for water heating
Cassava starch	Energy-intensive—milling process	Natural gas or fuel oil as a boiler fuel
Slaughterhouses	Energy-intensive—coolers, freezers, pumps, and general equipment	Natural gas or fuel oil as a boiler fuel
Combined sugarcane mills and distilleries	Energy-intensive; sugarcane mills and co-located distilleries do not require electricity from the grid during harvest, since they burn bagasse, but they could sell electricity generated from captured methane.	
Beverages	Energy-intensive	Natural gas or fuel oil for boiler

When biogas is used to generate electricity, the emission reduction depends on the energy sources used by the central power company to power the generators. In Brazil, the electricity generation sector is mainly comprised of hydroelectric r plants (70.72 percent), and thermal plants (19.7 percent), as illustrated in Figure 4.1. The fuels used by the thermal plants are natural gas, distillate fuel oil, biomass and coal. Table 4.5 shows the associated carbon emission reduction rate from the replacement of fossil fuels when biogas is used to generate electricity in Brazil.

Indirect emissions are estimated by first ascertaining the maximum production potential for methane from the digester and then determining the emissions associated with the energy that was offset from biogas use. For Tables 4.1 and 4.2, it was assumed that the collected biogas would be used to generate electricity, replacing fuel oil.

Figure 4.1 – Distribution of Electricity Generation in Brazil (Total = 108,835,762 kW in 2008)



Source: ANEEL, 2008

Table 4.5 – Reductions in Carbon Dioxide Emissions by Use of Biogas to Generate Electricity in Place of Fossil Fuels

Fuel for Generating Electricity Replaced	CO_2 Emission Reduction
Hydro and nuclear	0 kg/kWh generated
Coal	1.02 kg/kWh generated
Natural gas	2.01 kg/m^3 CH_4 used
LPG	2.26 kg/m^3 CH_4 used
Distillate fuel oil	2.65 kg/m^3 CH_4 used

Source: Developed by Hall Associates

4.1.4 Summary

As illustrated by the equations presented in Section 2.2, the principal factor in the magnitude of methane emissions from livestock manures and agricultural commodity processing wastes is the waste management practice employed, which determines the MCF. As shown in Table 10.17 of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* and in Tables 2.2 and 2.6 of this report, anaerobic lagoons and landfills have the highest potential for emitting methane from these wastes. Thus, replacing those waste management practices with anaerobic digestion has the greatest potential for reducing methane emissions. While the reduction in methane emissions realized by replacing other waste management practices with anaerobic digestion will not be as significant, the methane captured will be a source of renewable energy with the ability to reduce fossil fuel consumption and the associated GHG emissions from sequestered carbon.

Table 4.6 summarizes the findings of the RA in terms of potential methane emission reductions and carbon offsets in Brazil. The sector with the highest potential for methane reduction and carbon offsets is the swine sector (64 percent of the potential), followed by distilleries (ethanol and cachaça, 20 percent), slaughterhouses (13 percent), cassava starch (1.9 percent), beverages (0.8 percent), and dairy cattle (0.6 percent).

Table 4.6 – Summary of Total Carbon Emission Reductions Identified in Brazil

Sector	Methane Emission Reductions ($MT\ CH_4/yr$)	Carbon Emission Reductions ($MT\ CO_2e/yr$)	Fuel Replacement Offsets ($MT\ CO_2e/yr$)	Total Carbon Emission Reductions ($MT\ CO_2e/yr$)
Swine	566,263	11,891,530	2,239,698	14,131,228
Distilleries (ethanol and cachaça)	174,370	3,661,771	689,673	4,351,444
Slaughterhouses (beef, swine, and poultry)	114,168	2,397,535	451,561	2,849,096
Cassava starch	17,102	359,136	67,641	426,778
Beverages (beer and carbonated beverages)	7,485	157,178	29,603	165,880
Dairy	4,989	104,767	19,732	124,500
Total	884,377	18,571,917	3,497,909	22,069,826

4.2 TECHNOLOGY OPTIONS

4.2.1 Methane Production

There are a variety of anaerobic digestion processes, which can be broadly categorized as either suspended or attached growth processes. The applicability of any specific process is determined primarily by physical characteristics of the waste or mixture of wastes that will be anaerobically digested. Attached growth processes are suitable for wastes with low concentrations of particulate matter. For wastes with higher concentrations of particulate matter, suspended growth processes generally are more suitable. The anaerobic digestion process options that are applicable to the various types of livestock manures and agricultural commodity processing wastes are discussed below.

Livestock manures: There are four anaerobic digestion reactor options for livestock manures: plug-flow, mixed, covered lagoon, and attached growth. The appropriate option or options are determined by the concentration of particulate matter, generally measured as TS concentration in the collected manure, type of manure, and climate as shown in Table 4.7. The TS concentration in the collected manure is determined by the method of collection—scraping or flushing—and the volume of water used in flushing manures.

Table 4.7 – Overview of Anaerobic Digestion Options for Livestock Manures

	Plug-Flow	Mixed	Covered Lagoon	Attached Growth
Influent TS concentration	11–13 percent	3–10	0.5–3	< 3
Manure type	Only dairy cattle	Dairy and swine	Dairy and swine	Dairy and swine
Required pretreatment	None	None	Removal of coarse fiber from dairy cattle manure	Removal of coarse fiber from dairy cattle manure
Climate	All	All	Temperate and warm	Temperate and warm

Source: U.S. EPA, 2004

As indicated in Table 4.7, use of covered lagoons and attached growth reactors to produce methane from dairy cattle manure requires removal of coarse fiber, usually by screening, before anaerobic digestion. For the attached growth option, screening of swine manure to remove hair and foreign matter, such as ear tags, is advisable. Covered lagoons and attached growth reactors operate at ambient temperature and thus are only suitable for temperate and warm climates. In temperate climates, there may be seasonal variation in the rate of methane production.

Agricultural commodity processing wastewater: As discussed above, agricultural commodity processing operations may generate either liquid wastewater, solid waste, or both. No single treatment process, except for the covered anaerobic lagoon, is suitable for all of these wastewaters, due to wide variation in physical and chemical characteristics. These characteristics can vary widely even for wastewater from the processing of a single commodity, reflecting differences in processing and sanitation practices. For example, some processing plants prevent solid wastes, to the extent possible, from entering the wastewater generated; others do not.

In addition, some plants employ wastewater pretreatment processes such as screening, gravitational settling, or dissolved air flotation (DAF) to remove particulate matter whereas others do not. Although the covered anaerobic lagoon has the advantages of universal applicability and simplicity of operation and maintenance, adequate land area must be available. If the volume of wastewater generated is low, co-digestion with livestock manure or wastewater treatment residuals may be a possibility. Other options for the anaerobic treatment of these wastewaters are briefly described below.

For wastewaters with high concentrations of particulate matter (total suspended solids) or extremely high concentrations of dissolved organic matter (BOD or COD), the complete mix, anaerobic contact, or anaerobic sequencing batch reactor (ASBR) processes are alternatives. These are typically operated at mesophilic (30 to 35°C) or thermophilic (50 to 55°C) temperatures.

As shown in Table 4.8, the anaerobic contact and ASBR processes operate at significantly shorter hydraulic retention times (HRTs) than the complete mix process. A shorter required HRT translates directly into a smaller required reactor volume and system footprint; however, operation of the anaerobic contact and ASBR processes is progressively more complex.

Table 4.8 – Typical Organic Loading rates for Anaerobic Suspended Growth Processes at 30°C

Process	Volumetric Organic Loading (kg COD/m³/Day)	Hydraulic Retention Time (Days)
Complete mix	1.0–5.0	15–30
Anaerobic contact	1.0–8.0	0.5–5
Anaerobic sequencing batch reactor	1.2–2.4	0.25–0.50

Source: Metcalf and Eddy, Inc., 2003

For wastewaters with low total suspended solids (TSS) concentrations or wastewaters with low TSS concentrations after screening or some other form of TSS reduction, such as dissolved air flotation, one of the anaerobic sludge blanket processes may be applicable. Included are basic upflow anaerobic sludge blanket (USAB), anaerobic baffled reactor, and anaerobic migrating blanket reactor (AMBR®) processes. The anaerobic sludge blanket processes allow for high volumetric COD loading rates due to the retention of a high microbial density in the granulated sludge blanket. Wastewaters that contain substances such as proteins and fats that adversely affect sludge granulation, cause foaming, or cause scum formation are problematic. Thus, use of anaerobic sludge blanket processes generally is limited to high-carbohydrate wastewaters.

Attached growth anaerobic processes are another option for agricultural commodity processing wastewaters with low TSS concentrations. Included are upflow packed-bed attached growth, upflow attached growth anaerobic expanded bed, attached growth anaerobic fluidized-bed, and downflow attached growth reactor processes. All have been used successfully in the anaerobic treatment of a variety of food and other agricultural commodity processing wastewaters, but are more operationally complex than the suspended growth and sludge blanket processes.

Agricultural commodity processing solid wastes: Generally, solid wastes from agricultural commodity processing are most amenable to co-digestion with livestock manure or wastewater treatment residuals in a mixed digester. Although it may be possible to anaerobically digest some of these wastes independently, it may be necessary to add nutrients (such as nitrogen or phosphorus) and a buffering compound to provide alkalinity and control pH.

4.2.2 Methane Use Options

Along with methane, carbon dioxide is a significant product of the anaerobic microbial decomposition of organic matter. Collectively the mixture of these two gases is known as biogas. (Typically, biogas also contains trace amounts of hydrogen sulfide, ammonia, and water vapor.) The energy content of biogas depends on the relative volumetric fractions of methane and carbon dioxide. Assuming the lower heating value of methane, 35,755 kilojoules per cubic meter, a typical biogas composition of 60 percent methane and 40 percent carbon dioxide has a lower heating value of 21,453 kilojoules per cubic meter. Thus, biogas has a lower energy density than conventional fuels.

Although the principal objective of the anaerobic digestion of livestock manure and agricultural commodity processing wastes is to reduce methane emissions to the atmosphere, biogas has value as a renewable fuel. It can be used in place of a fossil fuel in stationary internal combustion engines or microturbines connected to generator sets or pumps and for water or space heating. Direct use for cooling or refrigeration is also a possibility.

Use of biogas in place of coal, natural gas, liquefied petroleum gas (LPG), or distillate or heavy fuel oil for water or space heating is the most attractive option—it is simple and existing boilers or furnaces can be modified to burn a lower-energy-density fuel. Conversion of a natural gas– or LPG-fueled boiler or furnace to biogas generally only requires replacement of the existing metal combustion assembly with a ceramic burner assembly with larger orifices. If there is seasonal variation in demand for water or space heating, biogas compression and storage should be considered if the cost of suitable storage can be justified.

Using biogas to fuel a modified natural gas internal combustion engine or microturbine to generate electricity is more complex. Livestock manures and most agricultural commodity processing wastes contain sulfur compounds, which are reduced to hydrogen sulfide during anaerobic digestion and partially desorbed. Thus, hydrogen sulfide, in trace amounts, is a common constituent of biogas and can cause serious corrosion problems in biogas-fueled internal combustion engines and microturbines. Hydrogen sulfide combines with the water produced during combustion to form sulfuric acid. Consequently, scrubbing to remove hydrogen sulfide may be necessary when biogas is used to generate electricity.

Using biogas to generate electricity also may require interconnection with the local electricity provider for periods when electricity demand exceeds biogas generation capacity, when generation capacity exceeds demand, or when generator shutdown for maintenance or repairs is necessary. One of the advantages of using biogas to generate electricity connected to the grid is the ability to use biogas as it is produced and use the local electricity grid to dispose of excess electrical energy when generation capacity exceeds onsite demand. Specifically in the case of Brazil, the National Agency of Electric Energy recently released a new resolution that encourages public utilities to purchase electricity from small biogas and biomass generation projects (< 5 MW). The generation of renewable energy in Brazil also has tax incentives related to transmission and distribution. Using biogas to generate electricity will reduce operating costs and provide a steady revenue stream for a farm.

When avoided methane emissions and associated carbon credits are considered, simply flaring biogas produced from the anaerobic digestion of livestock manures and agricultural commodity processing wastes is also an option—but only to the degree that replacing a methane-emitting waste management practice with anaerobic digestion reduces methane emissions. Although systems using biogas from anaerobic digestion as a boiler or furnace fuel or for generating electricity should have the ability to flare excess biogas, flaring should be considered an option only if biogas production greatly exceeds the opportunity for utilization.

4.3 COSTS AND POTENTIAL BENEFITS

The cost of anaerobically digesting livestock manures and agricultural commodity processing wastes and using the methane captured as a fuel depends on the type of digester constructed and the methane utilization option employed. The cost will also vary geographically, reflecting local financing, material, and labor costs. However, it can be assumed that capital cost will increase as the level of technology employed increases. For digestion, the covered anaerobic lagoon generally will require the lowest capital investment, with anaerobic sludge blanket and attached growth processes requiring the highest. As the complexity of the anaerobic digestion process increases, operating and maintenance costs also increase. For example, only basic management and operating skills are required for covered lagoon operation, whereas a more sophisticated level of understanding of process fundamentals is required for anaerobic sludge blanket and attached growth processes.

For captured methane utilization, the required capital investment will be lowest for flaring and highest for generating electricity. Based on past projects developed in the United States and Latin America, the cost of an engine-generator set will be at least 25 percent of total project cost, including the anaerobic digester. In addition, while the operating and maintenance costs for flaring are minimal, they can be substantial for generating electricity. For example, using captured biogas to generate electricity requires a continuous engine-generator set maintenance program and may include operation and maintenance of a process to remove hydrogen sulfide.

4.3.2 Potential Benefits

Anaerobic digestion of livestock manure and agricultural commodity processing wastes can generate revenue to at least offset and ideally exceed capital and operation and maintenance costs. There are three potential sources of revenue.

The first is the carbon credits that can be realized from reducing methane emissions by adding anaerobic digestion. MCFs, and therefore reduction in methane emissions and the accompanying carbon credits earned, are determined by the existing waste management system and vary from essentially 0 to 100 percent. Thus, carbon credits will be a significant source of revenue for some projects and nearly nothing for others.

The second potential source of revenue is from the use of captured biogas as a fuel. However, the revenue realized depends on the value of the form of energy replaced and its local cost. Because biogas has no market-determined monetary value, revenue is determined by the cost of the conventional source of energy it replaces. If low-cost hydropower-generated electricity is available, the revenue derived from using biogas may not justify the required capital investment and operating and maintenance costs. Another consideration is the ability to sell excess electricity to the local electricity provider and the price that would be paid. There may be a substantial difference between the value of electricity used on site and the value of electricity delivered to the local grid. The latter may not be adequate to justify the use of biogas to generate electricity. Ideally, it should be possible to deliver excess generation to the local grid during periods of low onsite demand and reclaim it during periods of high onsite demand under some type of a net metering contract.

The third potential source of revenue is from the carbon credits realized from the reduction in the fossil fuel carbon dioxide emissions when use of biogas reduces fossil fuel use. As with the revenue derived directly from using biogas as a fuel, the carbon credits generated depend on the fossil fuel replaced. When biogas is used to generate electricity, the magnitude of the reduction in fossil fuel-related carbon dioxide emissions will depend on the fuel mix used to generate the electricity replaced. Thus, the fuel mix will have to be determined to support the validity of the carbon credits claimed.

4.4 CENTRALIZED PROJECTS

Generally, small livestock production and agricultural commodity processing enterprises are not suitable candidates for anaerobic digestion to reduce methane emissions from their waste streams due to high capital and operating costs. The same is true for enterprises that only generate wastes seasonally. If all of the enterprises are located in a reasonably small geographic area, combining compatible wastes from two or more enterprises for anaerobic digestion at one of the waste sources or a centralized location is a possible option. Increasing project scale will reduce unit capital cost. However, operating costs will increase; centralized digestion will not always be a viable option if enough revenue cannot be generated to at least offset the increased operating costs.

There are two possible models for centralized anaerobic digestion projects. In the first model, digestion occurs at one of the sources of waste with the waste from the other generators transported to that site. In the model that typically is followed, wastes from one or more agricultural commodity processing operations are co-digested with livestock manure. In the second model, wastes from all sources are transported to a separate site for digestion. The combination of the geographic distribution of waste sources and the options for maximizing revenue from the captured methane should be the basis for determining which model should receive further consideration in the analysis of a specific situation.

For centralized anaerobic digestion projects, the feasibility analysis should begin with the determination of a project location that will minimize transportation requirements for the wastes to be anaerobically digested and for the effluent to be disposed of. The optimal digester location could be determined by trial and error, but constructing and applying a simple transportation model should be a more efficient approach. Although obtaining the optimal solution manually is possible, use of linear programming should be considered. This approach can identify and compare optimal locations with respect to minimizing transportation costs for a number of scenarios. For example, the transportation costs associated with locating the anaerobic digester at the largest waste generator versus a geographically central location can be delineated and compared.

Next, the revenue that will be generated from selling the carbon credits realized from reducing methane emissions and using the captured methane as a fuel should be estimated. The latter will depend on a number of factors including the location of the digester and opportunities to use the captured methane in place of conventional sources of energy. Generally, captured methane that can be used to meet onsite electricity or heating demand will have the greatest monetary value and produce the most revenue to at least offset and ideally exceed system capital and operation and maintenance costs. Thus, an energy-use profile for each source of waste in a possible centralized system should be developed to determine the potential for onsite methane use, the revenue that would be realized, and the allocation of this revenue among the waste sources.

Ideally, the digester location that minimizes transportation cost will be at the waste source with the highest onsite opportunity for methane utilization. This minimizes waste transportation cost while maximizing revenue. However, the digester location that minimizes transportation costs may not maximize revenue from methane utilization due to low onsite energy demand; alternative digester locations should be evaluated to identify the location that maximizes the difference between revenue generation from methane utilization and transportation cost. Again, using a simple transportation-type model to determine the optimal digester location is recommended. If the optimal location is not at one of the waste sources, additional analysis incorporating site acquisition costs will be necessary.

APPENDIX A: IPCC METHODOLOGY FOR SOLID WASTE AND LEAKAGES

Solid Wastes

A variety of methods are possible for the disposal of solids wastes generated during the processing of agricultural commodities. Included are: 1) land application, 2) composting, 3) placement in a landfill, and 4) open burning. In addition, disposal of solid wastes from meat and poultry processing, such as solids separated from wastewater by screening and DAF, may be disposed of by rendering.

If country and waste sector specific values for B_o are not available, the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* default value of 0.25 kg CH_4 per kg COD for wastewater, based on stoichiometry, should be used. The use of this default value for the solid wastes from agricultural commodity processing is based in the assumption that the organic compounds in these wastes will degrade as rapidly as the wastewater organic fraction.

Because the mechanisms responsible for the degradation of these wastes are similar to those of livestock manure following land application, the appropriate MCF value for manure disposal by daily spreading listed in Table 10.17 of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* should be used. For composting, the IPCC default value of 4 g CH_4 per kg of wet waste should be used. When agricultural commodity processing wastes are disposed of in landfills, the applicable MCF depends on the type of landfill as shown in Table A.1.

Table A.1 – Types of Solid Waste Landfills and Methane Conversion Factors

Type of Site	Methane Conversion Factor Default Value
Managed—anaerobic[1]	1.0
Managed—semi-anaerobic[2]	0.5
Unmanaged[3]—deep (>5m waste) and/or high water table	0.8
Unmanaged[4]—shallow (<5m waste)	0.4
Uncategorized solid waste disposal sites[5]	0.6

[1]**Anaerobic managed solid waste disposal sites.** Controlled placement of waste with one or more of the following: cover material, mechanical compacting, leveling
[2]**Semi-anaerobic managed solid waste disposal sites.** Controlled placement of wastes with all of the following structures for introducing air into the waste layer: permeable cover material, leachate drainage system, pondage regulation, and gas ventilation.
[3]**Unmanaged solid waste disposal sites—deep and/or with a high water table.** All sites not meeting the criteria of managed sites with depths greater than 5 m and/or a high water table near ground level.
[4]**Unmanaged solid waste disposal sites.** All sites not meeting the criteria of managed sites with depths less than 5 m.
[5]**Uncategorized solid waste disposal sites.** Uncategorized solid waste disposal sites.

For disposal of agricultural commodity processing solid wastes by open burning, the IPCC default value of 6.5 kg of methane per metric ton of waste should be used.

For all four disposal options, the commodity specific rate of solid waste generation must be known. In addition, information about the concentration of COD in the solid waste, on a wet weight basis, is necessary for all but the composting disposal option. However, COD concentration generally has not been used as a parameter for agricultural commodity processing solid waste characterization. The alternative is to use published values from studies of methane production potential on a volume or mass of methane produced per unit mass of wet waste, or volatile solids added basis as a first-order estimate for B_o for the waste under consideration. If the COD concentration in the solid waste is known, the methane emissions resulting from land application and landfill disposal with the appropriate MCF is calculated using Equation 2.6:

$$CH_{4\,(SW)} = TOW_{(SW)} \times B_o \times MCF_{(SW,\,D)} \qquad (2.6)$$

where: $CH_{4(SW)}$ = Annual methane emissions from agricultural commodity processing waste SW (kg CH_4 per year)

$TOW_{(SW)}$ = Annual mass of solid waste SW COD generated (kg per year)

$MCF_{(SW,\,D)}$ = Methane conversion factor for solid waste W and existing disposal practice S (decimal)

Leakage and Combustion Related Emissions

The reduction in methane emissions realized when anaerobic digestion is incorporated into an existing livestock manure or agricultural commodity processing waste management system will be somewhat reduced by leakage and combustion related emissions.

There is very little information regarding methane leakage from anaerobic digestion systems although some leakage probably occurs from all systems and should be incorporated into estimates net methane emissions reductions. The *2006 IPCC Guidelines for National Greenhouse Gas Inventories* provides no guidance, with an MCF default value of 0-100 percent. Thus, the use of the *2008 California Climate Action Registry* (CCAR) default collection efficiency value of 85 percent in the following equation is recommended unless a higher value can be justified by supporting documentation.

$$LK_{(P)} = \left(\frac{CH_{4\,(P)}}{0.85} - CH_{4\,(P)} \right) \times 0.67\ \text{kg/m}^3$$

where: $LK_{(P)}$ = Project methane leakage (kg/year)

$CH_{4\,(P)}$ = Estimated methane production potential from manure or agricultural commodity processing wastes or both (kg/year)

0.85 = Default methane capture efficiency (decimal)

Because no combustion process is 100 percent efficient and all captured methane should be disposed of by combustion, combustion related methane emissions also should be accounted for in estimating a project's net methane emission reduction. Unless higher combustion efficiency values can be justified by supporting documentation, the default values listed in Table A.2 should be used.

Table A.2 Default Values for Methane Combustion Efficiencies, decimal

Combustion process	Default value
Open flare	0.96
Enclosed flare	0.995
Lean burn internal combustion engine	0.936
Rich burn internal combustion engine	0.995
Boiler	0.98

Source: CCAR, 2008

Methane emissions associated with each combustion process utilized should be based on the fraction of estimated methane production that will be captured and calculated as follows:

$$CE_{(P)} = \left[(CH_{4\,(P)} - LK_{(P)}) \times (1 - C_{eff}) \right]$$

where: $CE_{(P)}$ = Combustion related emissions (kg CH_4 per year)

$CH_{4\,(P)}$ = Estimated production potential (kg CH_4 per year)

C_{eff} = Combustion efficiency (decimal)

Fossil Fuel Use Related Emissions

An anaerobic digestion project may result in increased fossil fuel use such as use of gasoline or diesel fuel for manure transport to a centralized anaerobic digestion facility or transport of another waste to a facility for co-digestion. The resulting increase in carbon dioxide emissions also should be accounted for using the default values for fossil fuel use related carbon dioxide emission rates, as shown in Table A.3.

Table A.3 Default Values for Carbon Dioxide Factors for Gasoline and Diesel Fuel Use for Transportation

Fuel	CO_2 emission factor, kg/l
Gasoline	2.38
Diesel	2.75

Source: Regional Greenhouse Gas Initiative, Inc., 2007

Estimate the carbon dioxide emissions resulting from increased fossil fuel use due to transportation as follows.

$$FF_{(P)} = \frac{\left(FF_{(Use)} \times C_{factor}\right)}{21}$$

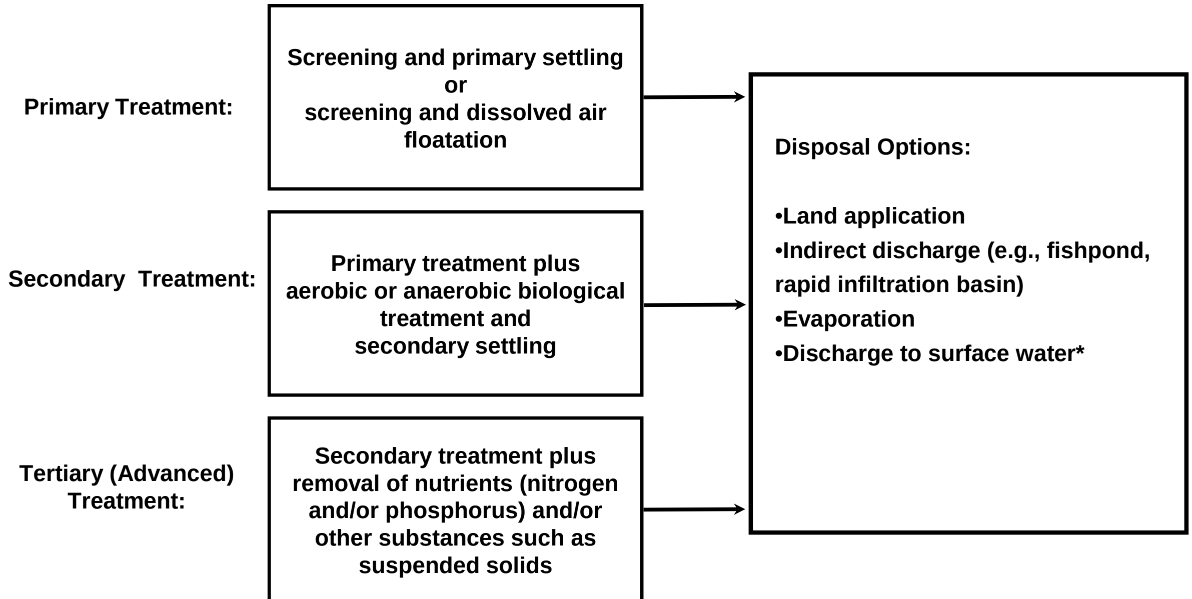
where: $FF_{(P)}$ = Fossil fuel related carbon dioxide emissions on a methane equivalent basis (kg CH_4 per year)

$FF_{(U)}$ = Additional fossil fuel use (L/yr)

E_{factor} = Emission factor (kg CO_2/L)

21 = GWP of methane as compared to carbon dioxide (kg CO_2/kg CH_4)

APPENDIX B: TYPICAL WASTEWATER TREATMENT UNIT PROCESS SEQUENCE



*According to applicable discharge standards

APPENDIX C: ADDITIONAL SECTOR INFORMATION

This appendix discusses sectors not included in Chapter 3 either because they have a low potential for methane emissions or because there was not enough information on their specific waste management practices. These sectors include beef cattle, poultry, corn starch, orange juice processing, and milk processing.

BEEF CATTLE

Beef cattle represent 69 percent of the total Brazilian livestock, excluding poultry. Currently, the country is the second largest cattle producer worldwide, only behind India, and the largest beef exporter, exporting 12.9 percent of the total beef production in the country. The main importers of the Brazilian beef include Russia, Hong Kong, Venezuela, the United States, Egypt, Iran, and the UK, among approximately 140 countries in total generating total revenue of US$2.3 billion. Although the production is spread out, 34.2 percent of the beef herd of Brazil is concentrated in the Midwest region, in the states of Mato Grosso, Mato Grosso do Sul, and Goiás. In 2007, the beef cattle population in Brazil was estimated to be about 206 million head, resulting in the total production of 8.8 million metric tons of beef meat.

Although beef production represents a large share of the total livestock production in the country, it does not represent a significant source of methane capture and reduction. Weather conditions and land availability allow the great majority of the beef cattle production to be done extensively in pasture, where manure is not collected or treated, so methane emissions are very low. It is estimated that 2.7 million head of beef cattle were raised in confined operations, which represents only 1.5 percent of the total beef cattle herd of the country. Even in beef feedlot operations, manure is usually left to decay on the floor of the feedlot pens during the whole confinement period. When scraped, manure is usually applied on the cropland as fertilizer. Some feedlots may have manure ponds to store the runoff during the rainy season; however, feedlots usually operate with lower capacity or do not operate during this period, once pasture is abundant. There is no standard manure management practice in place for beef feedlots in the country and, since the beef cattle production works with tight margins, producers tend to keep the facilities as simple as possible.

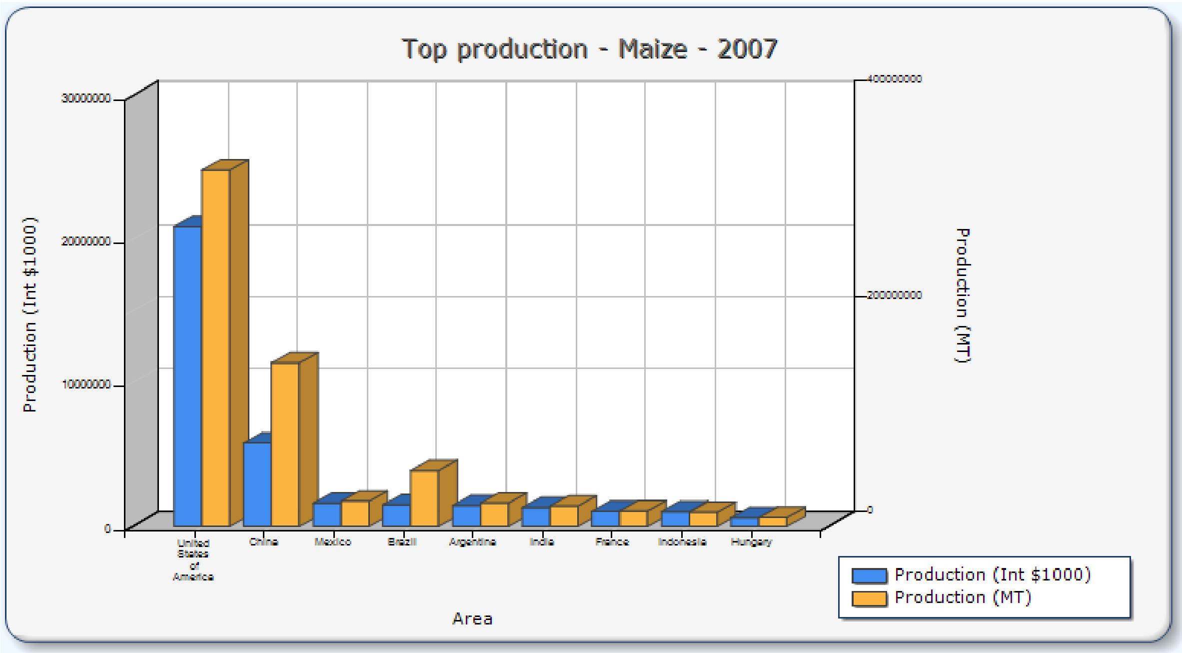
POULTRY

In the case of broiler production, manure is managed as a solid and combined with the bedding material (straw, rice hulls, sugarcane bagasse, etc.), with no extra water addition. Usually, the bedding material is used for several animal lots (three to six). When removed, it is composted before being applied or sold as fertilizer. Therefore, methane emissions from poultry manure are very limited and have almost no opportunity for reduction.

CORN STARCH

Brazil is the fourth largest producer of corn worldwide, behind the United States, China, and Mexico, having achieved a production of over 59 million metric tons in 2008 (IBGE) (Figure C.1).

Figure C.1 – Top Corn Producers Worldwide in 2007



Source: FAO

Starch has been manufactured from corn commercially for more than 100 years. In the early days of the industry, only starch was recovered; all the other components of the kernel were discarded. Toward the end of the 19th century, the corn millers began to realize that the non-starch fraction of corn had value as an animal feed. Later, a process for separating germ and recovering the corn oil was developed. Improved methods for steeping the corn permitted evaporation of the steepwater and recovery of the solubles as part of the animal feed. By the beginning of the 20th century, practically the entire corn kernel was being recovered, including a large fraction of the solubles (Bensing and Brown, no date).

Corn has several applications in different Brazilian industry sectors. According to ABIMILHO (no date), as shown in Table C.1, 77 percent of the total Brazilian corn production is directly consumed by the livestock industry, mainly poultry and swine. In the 2007 harvest, 9 percent of the corn production was consumed by the corn milling industry, 2 percent was used for human consumption, and about 11 percent was exported.

Table C.1 – Estimated Corn Consumption in Brazil by Industry Sector, 2007

Industry Sectors	Consumption 2007**	
Poultry	20,515	45%
Swine	12,022	26%
Cattle	2,374	5%
Other livestock	673	1%
Industrial consumption	4,369	9%
Human consumption	705	2%
Losses/seeds	349	1%
Export	5,000	11%
Total	**46,007**	**100%**

**Estimated.

Source: ABIMILHO, 2010

Brazilian starch production is dominated by three global companies (Corn Products, Cargill, and National Starch) and one local company (Adram), as shown in Table C.2. Together, these four companies account for more than 95 percent of Brazilian corn starch production, mainly at six manufacturing facilities. The production is located in the states of São Paulo, Minas Gerais, Paraná, Pernambuco, and Santa Catarina. Given the production concentration, the availability of information on production of this industry sector is very limited.

In 2009, Brazil is estimated to have produced 550 thousand metric tons of corn starch and 700 thousand metric tons of other sugars, such as dextrose and maltose, totaling 1.25 million metric tons.

Table C.2 – Corn Starch Production in Brazil

Company	Main Production Facility Location	Estimated Milling Capacity (tons of corn/day)
Corn Products	Mogi Guaçu, SP	3,000
	Balsa Nova, PR	1,200
	Cabo de Santo Agostinho, PE	800
Cargill	Uberlândia, MG	2,000
National Starch	Trombudo Central, SC	200
Adram	Faxinal, PR	800
Others		300
TOTAL		**8,300**

Source: ABAM

Some corn is consumed by the dry milling industry, resulting in low-aggregated-value products for human consumption, such as corn flour. Corn dry milling does not generate significant amounts of wastewater.

However, the fraction of the corn consumed by the wet milling process—which results in products such as starches for human consumption and industrial applications, sugars, and ethanol—generates large amounts of wastewater. According to ABIMILHO, about 1.2 million metric tons of corn were consumed in Brazil by wet millers in 2006, which corresponds to about 2 percent of the total Brazilian corn production.

The wet milling process separates corn into its four basic components: starch, germ, fiber, and protein. This process has five basic steps. First, the incoming corn is inspected and cleaned. Then it is steeped for 30 to 40 hours to begin breaking the starch and protein bonds. The next step involves a coarse grind to separate the germ from the rest of the kernel. The remaining slurry consisting of fiber, starch and protein is finely ground and screened to separate the fiber from the starch and protein. The starch is separated from the remaining slurry in hydrocyclones. The starch then can be converted to syrup or made into several other products through a fermentation process (Corn Refiners Association, 2002).

Wet corn milling may be a large source of liquid waste. Water used for washing solubles from the starch is disposed of in the sewers. These solubles, amounting to about 2 percent of the corn, must be removed to obtain the best quality starch and syrup products (Bensing and Brown, no date). For every metric ton of corn processed, 1.8 to 2.2 cubic meters of water are used in direct contact with the corn or its components (Brown and Van Meer, 1978). However, over time the quantity of wastewater produced was reduced by recycling process waters, and recovering solubles as a byproduct (Bensing and Brown, no date). Due to the lack of data from the local industry, in this report it will be conservatively estimated that the lower value of added water (1.8 cubic meters per metric ton of processed corn) equals the amount of generated wastewater.

The only waterborne waste from the wet starch process is the condensate resulting from the evaporation of steepwater. The condensate contains volatiles, which are formed during the steeping process and vaporized during evaporation.

The sources of other liquid wastes vary within the wet milling industry, depending on the products made and the processes used. Typically, in addition to the volatiles, the waste stream might contain filtrates from the preparation of modified starches, with dissolved chemicals used for modification, and some soluble carbohydrate formed during the process. Another source of waste is the impurities removed during the refining of corn syrups and dextrose (Bensing and Brown, no date).

The overall efficiency of the corn wet milling process is high, using close to 100 percent of the input material. However, trace amounts of end products such as syrups, sugar, and starch are found in the wastewater. The contribution of each of the waste sources varies considerably on a time basis, but the general composition indicates that the concentrated raw waste stream is made up of about 35 percent from the corn syrup channel, 25 percent from volatiles in the steepwater channel, 20 percent from the dry starch channel, 15 percent from steepwater entrainment, and 5 percent from the dextrose channel (Brown and Van Meer, 1978). In the Brown and Van Meer study, the COD concentration in the raw wastewater from a wet corn milling plant was 2,500 milligrams per liter and, by correlation, 25 to 30 percent of the COD value corresponds to BOD_5. Therefore, from a wastewater standpoint, the information obtained from literature indicates that 1.79 cubic meters of wastewater are generated per ton of processed corn, with an average COD concentration of 2,500 milligrams per liter and a BOD_5 of 750 milligrams per liter.

According to information informally collected from some cornstarch production sites, given the proximity to urban concentrations, the majority of the production units use aerobic lagoons with forced aeration as the primary wastewater treatment. Apparently, anaerobic digesters (reactors) are commonly used to treat the resulting sludge from the aerobic lagoons, and the use of the biogas is also common. Therefore, the potential for methane emission reduction from the Brazilian cornstarch industry can be considered low.

ORANGE JUICE

Citrus became commercialized in the Americas in the late 1800s. In the early to mid-1900s, the principal producing states were Florida, Texas, and California in the United States. Following a devastating freeze in Florida in 1962, a group of Florida businessmen began to establish citrus groves and later a processing industry around São Paulo, Brazil. This industry grew rapidly; after being sold to the Brazilians, it soon surpassed Florida in production by the mid-1980s (FAO, no date).

The orange juice industry in Brazil quickly reached a technological level equivalent to that of most advanced countries in the sector. In the 1980s, Brazil became the world's largest producer of oranges. Most of Brazil's oranges are located in the state of São Paulo and are used by the juice industry and exported to many countries as juice (CitrusBR, no date). More than 30 percent of the world orange production is in located in Brazil.

According to Christian Lohbauer, President of the Brazilian Association of Citrus Juice Exporters (CitrusBR), Brazil accounts for 80 percent of world exports of orange juice. There is no other economic sector in which the country has world position more absolute than in the export of citrus juices (Lohbauer, 2009). More than 97 percent of all the orange juice produced in the country is exported.

The USDA Agricultural Trade Office (ATO)/São Paulo estimates the Brazilian orange crop for marketing year 2009/10 (July–June) to be 16.6 million metric tons, or 407 million 40.8-kilogram boxes, with 28.5 percent for domestic consumption. The equivalent production of frozen concentrated orange juice is estimated to be 1.24 million metric tons (USDA Foreign Agricultural Service, 2009). The production of orange juice consumes about 71 percent of the total Brazilian orange production (USDA Foreign Agricultural Service, 2009).

During the last two decades, 15 companies were consolidated into four large companies, which today hold more than 95 percent of the country's orange juice exports: Citrosuco Fischer, Citrovita Votorantim, Louis Dreyfus Commodities, and Sucocítrico Cutrale (Lohbauer, 2009). In 2005, 98 percent of the orange juice production took place in 10 plants, mostly in the northern area of the state of São Paulo (CETESB, 2005). Recent research indicates that approximately 20 plants are now used to produce orange juice in Brazil. The wastewater generated from orange juice production has a high organic fraction. Table C.3 shows average values of a few parameters for wastewaters from Brazilian orange juice production plants. The weighted average shows concentrations of 3,994 and 2,282 milligrams per liter, respectively, for COD and BOD. The average flow rate is 0.8 cubic meters per metric ton of processed oranges. One factor that can affect biological treatment is the presence of d-limonene, a bacteriostat that inhibits bacterial growth, in the wastewater.

Table C.3 – Average Characteristics of Untreated and Treated Wastewater From Four Brazilian Orange Juice Production Plants

Wastewater	Facility 1		Facility 2		Facility 3		Facility 4	
Parameter	**Raw**	**Treated**	**Raw**	**Treated**	**Raw**	**Treated**	**Raw**	**Treated**
COD (mg/L)	5,050	418	5,544	102	5,209	743	3,034	145
BOD (mg/L)	2,582	121	2,883	47	3,167	386	1,753	36
pH	6.2	7.8	6.3	8.7	6.7	7.7	8.9	8.2
Flow rate (m^3/h)	68	68	29	29	147	149	241	249
Organic load (kg BOD/h)	827	1	90	11	463	84	440	8
Boxes processed per day	52,549		17,173		88,385		197,389	
Orange processing (t/day)	2,144		701		3,606		8,053	
Average flow rate (m^3/t of orange)	0.8		1.0		1.0		0.7	

Source: CETESB, 2005

There are several sources of wastewater in the citrus juice process—both directly associated with fruit processing (e.g., washing, crushing, or bagasse milling) and indirect (e.g., equipment washing).

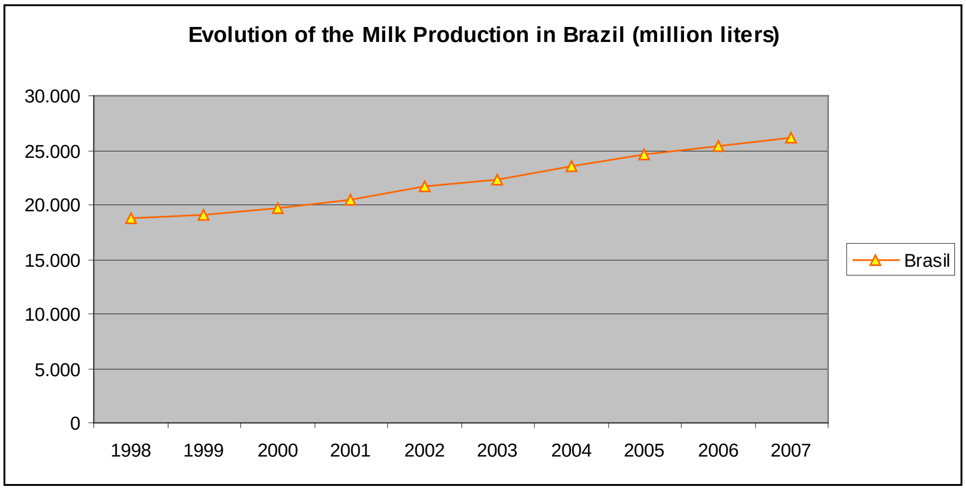
Usually, the citrus industry uses biological treatment, generally activated sludge and lagoons. Large lagoons can cause a nuisance to the neighborhood, resulting from poor design or improper operation, creating areas of oxygen depletion and emission of hydrogen sulfide (CETESB, 2005). According to the literature, the great majority of the industry uses lagoons with forced aeration (activated sludge) as the primary treatment. Anaerobic reactors are also used as primary treatment and for sludge treatment, and the capture and use of biogas as an energy source is common practice. The use of open anaerobic lagoons can still be found at a few plants.

MILK PRODUCTION AND PROCESSING

Organized milk production in Brazil began after 1929. In the 1950s and 1960s, technological advances in roads, equipment, and packaging enhanced Brazil's milk production industry. Major changes during the 1970s through the 1990s (including the formation of MERCOSUR, the end of government intervention in the price of milk, and stabilization of the economy) led to the increased production of milk in Brazil (CETESB, 2008).

Brazil—which became the world's sixth largest milk producer in 2001—was traditionally a net importer of dairy products but became a net exporter in 2005, with the value of exports exceeding imports by US$8.90 million. From 1998 to 2007, Brazilian milk production increased from less than 20 million to over 25 million liters per year (Figure C.2). Milk production was estimated by the USDA to reach 30.34 billion liters in 2009 (USDA Foreign Agricultural Service, 2009). At 130 liters per capita per year in 2005, though, domestic consumption was still below the World Health Organization's recommended rate of 175 liters per capita per year (CETESB, 2008).

Figure C.2 – Evolution of Milk Production in Brazil, 1998–2007

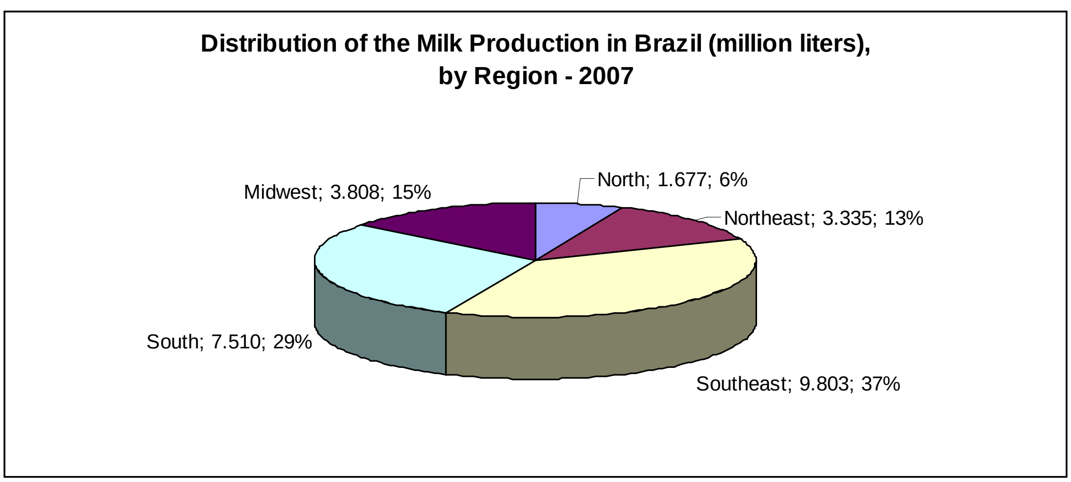


Source: IBGE, 2008

Whether Brazil continues to increase its net exports of milk will depend not only on production growth, but also the increase in in domestic consumption. Reduced income inequality and the growth in the size of the Brazilian middle class should aid the growth in the domestic consumption of dairy products. Growth in domestic consumption will be due to a combination of an increase in fluid milk consumption by lower-income families and cheese consumption by middle-income families.

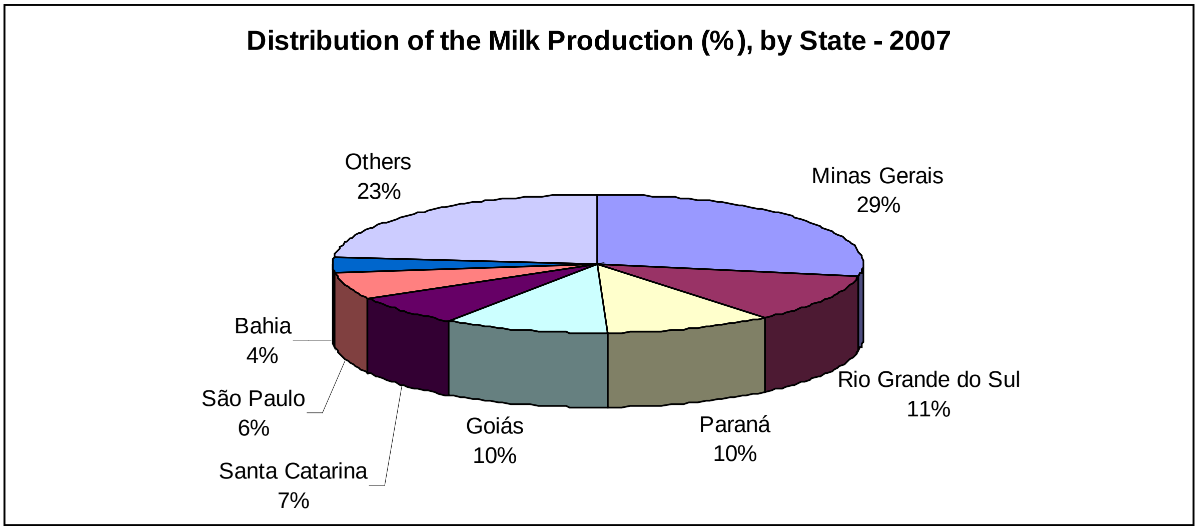
Milk production takes place in 1,219 dairy farms distributed all over Brazil. As shown in Figure C.3, the Southeast region is the country's largest milk producer in Brazil, with 37 percent of the country's production, followed by the South region with 29 percent, the Midwest with 15 percent, the Northeast with 13 percent, and the North with 6 percent. On a state level, Minas Gerais produces 29 percent of the total production in Brazil (Figure C.4). Average production is 1,700 kilograms per cow per year (RERC, 2009).

Figure C.3 – Milk Production in Brazil by Region, 2007



Source: IBGE, 2008

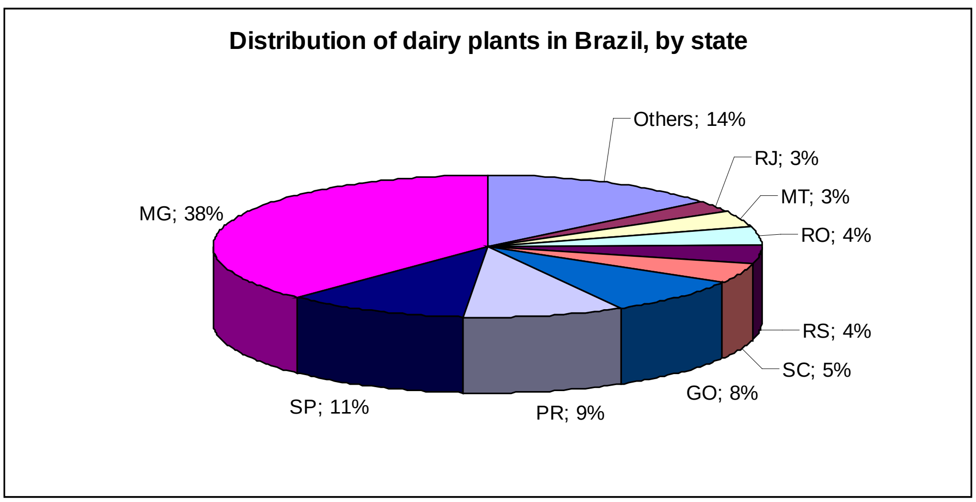
Figure C.4 – Milk Production in Brazil by State, 2007



Source: IBGE, 2008

The distribution of milk processing plants follows a similar pattern, with Minas Gerais being home to 38 percent of the plants (Figure C.5).

Figure C.5 – Distribution of Dairy Plants in Brazil by State



GO: Goiás; MG: Minas Gerais; MS: Mato Grosso do Sul; MT: Mato Grosso; PR: Paraná; RS: Rio Grande do Sul; SC: Santa Catarina; SP: São Paolo

Source: SIGSIF, 2008

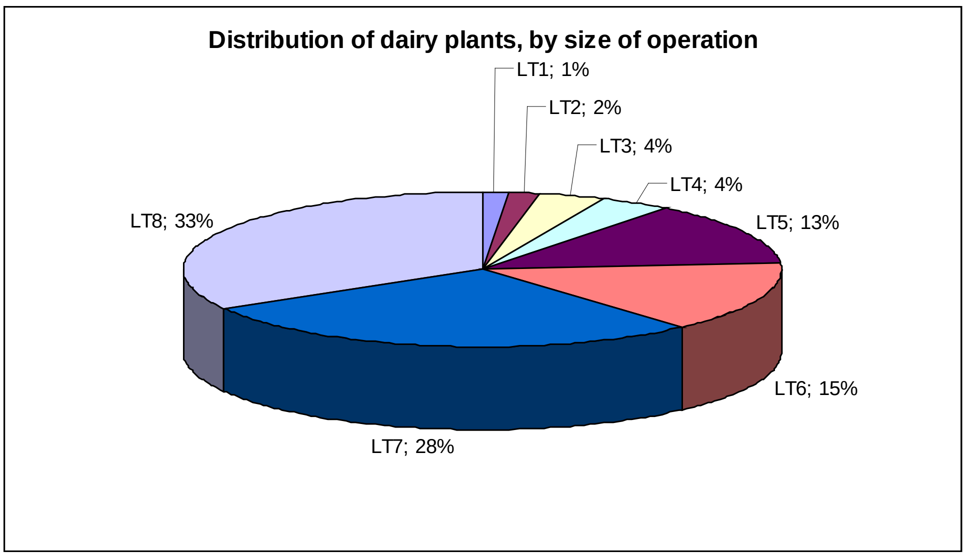
Based on the classification system used by the Department of Inspection of Animal Origin Products (Table C.4), 76 percent of the 1,219 milk-processing plants in Brazil have a processing capacity of less than 20,000 liters per day and only 7 percent have a capacity of more than 100,000 liters per day.

Table C.4 – Classification of Dairy Plants in Brazil

Class	Parameters
LT1	More than 500,000 liters/day
LT2	300,000 to 500,000 liters/day
LT3	100,000 to 300,000 liters/day
LT4	50,000 to 100,000 liters/day
LT5	20,000 to 50,000 liters/day
LT6	10,000 to 20,000 liters/day
LT7	5,000 to 10,000 liters/day
LT8	up to 5,000 liters/day

Source: DIPOA, n.d

Figure C.6 – Distribution of Dairy Plants in Brazil, by Size and by State



Source: SIGSIF, 2008

Milk processing wastewater is characterized by high concentrations of BOD, COD, fats, nitrogen, and phosphorus, with the milk itself responsible for 90 to 94 percent of the BOD and COD. Typically, the sources of the wastewater are (CETESB, 2008):

- Cleaning and sanitizing tank trucks and plant and equipment.
- Spills and leaks.
- Disposal of byproducts such as whey.
- Disposal of spoiled or contaminated product.

The characteristics of milk processing wastewaters depend heavily on the products being produced (e.g., pasteurized milk, powdered milk, cream, butter, or some combination thereof) as well as management practices. Brião and Granhen Tavares found that dairy plants generate 0.67 cubic meters of wastewater per cubic meter of processed milk, on average, but this value seems low. Depending on the product mix, the volumetric coefficient ranges from 1 to 6 cubic meters of wastewater per cubic meter of processed milk, according to CETESB. This range coincides with references made by Brião, which indicate a COD range from 1.3 to 3.2 milligrams per liter. Some representative physical and chemical characteristics for England and Wales and Brazil are compared in Table C.5. Brião and Granhen Tavares (2007) indicated that average COD concentration should be about 2,500 milligrams per liter.

Table C.5 – Milk Processing Wastewater Characteristics

Parameters	Ranges	
	(1)	(2)
Volatile suspended solids	24 - 5,700 mg/L	100 – 1,000 mg/L
Total suspended solids	135 – 8,500 mg/L	100 – 2,000 mg/L
COD	500 – 4,500 mg/L	6,000 mg/L
BOD_5	450 – 4,790 mg/L	4,000 mg/L
pH	5.3 – 9.4	1 – 12
Temperature	12 – 40 ºC	20 – 30 ºC

Sources:

(1) Environment Agency of England and Wales, 2000 & European Commission – Integrated Pollution Prevention and Control, 2006

(2) Brazilian Association of the Chemical Industry (ABIQ)

Source: CETESB, 2005

Typically, processing wastewaters are treated as follows:

- Pretreatment by skimming to remove floating fat particles.
- Primary treatment involving chemical coagulation/flocculation followed by DAF to remove suspended solids.
- Secondary biological treatment, which can be an aerobic process such as activated sludge or an anaerobic process such as a conventional anaerobic lagoon or a UASB reactor.

According to CETESB (2001), only 18 anaerobic wastewater treatment units were built at Brazilian milk processing plants in 2001. Thus, the amount of biogas collected is very small in comparison with other sectors.

Thirty-eight percent of the milk processing plants in Brazil are located in the state of Minas Gerais, which is the source of 29 percent of Brazilian milk production. Eighty percent of these have processing capacity of less than 20,000 liters per day and do not treat their wastewater, mainly due to scarce financial and technological resources (Prado, 2008). In this report, we assumed that only milk processing plants with a processing capacity greater than 20,000 liters per day have some form of wastewater treatment. As shown in Table C.6, such plants, Class LT 1 through LT 5 plants, process 17,431 million liters per year, which is 84 percent of Brazil's milk production.

Table C.6 – Milk Processing in Brazil by Plant Class.

Class	Parameters (million liters/year)
LT1	4,344
LT2	3,468
LT3	4,928
LT4	1,789
LT5	2,902
LT6	1,299
LT7	1,263
LT8	741
Total	20,732

Source: SIGSIF; Elaboration: LOGICarbon

APPENDIX D: GLOSSARY

Acetogenesis—The formation of acetate (CH_3COOH) from carbon dioxide and hydrogen. Many methanogens grow and form methane from acetate.

Acidogenesis—The formation of primarily short-chain volatile acids such as acetic, proprionic, butyric, valeric, and caproic from simple soluble compounds produced during hydrolysis.

Activated Sludge Process—A biological wastewater treatment process in which a mixture of wastewater and activated sludge (biosolids) is agitated and aerated. The activated sludge is subsequently separated from the treated wastewater by sedimentation and wasted or returned to the process as needed.

Advanced Waste Treatment—Any physical, chemical or biological treatment process used to accomplish a degree of treatment greater than achieved by secondary treatment.

Aerated Pond or Lagoon—A wastewater treatment pond or lagoon in which mechanical or diffused aeration is used to supplement the oxygen supplied by diffusion from the atmosphere.

Aerobic—Requiring the presence of free elemental oxygen.

Aerobic Bacteria—Bacteria that require free elemental oxygen to sustain life.

Aerobic Digestion— The degradation of organic matter including manure by the action of microorganisms in the presence of free elemental oxygen.

Aerobic Waste Treatment—Waste treatment brought about through the action of microorganisms in the presence of air or elemental oxygen. The activated sludge process is an aerobic waste treatment process.

Anaerobic—Requiring the absence of air or free elemental oxygen.

Anaerobic Bacteria—Bacteria that grow only in the absence of free elemental oxygen.

Anaerobic Contact Process—Any anaerobic process in which biomass is separated from the effluent and returned to a complete mix or contact reactor so that the solids retention time (SRT) is longer than the hydraulic retention time (HRT).

Anaerobic Digester—A tank or other vessel for the decomposition of organic matter under anaerobic conditions.

Anaerobic Digestion—The degradation of organic matter including manure by the action of microorganisms in the absence of free elemental oxygen.

Anaerobic Pond or Lagoon—An open treatment or stabilization structure that involves retention under anaerobic conditions.

Anaerobic Sequencing Batch Reactor (ASBR) Process—A batch anaerobic digestion process that consists of the repetition of following four steps: 1) feed, 2) mix, 3) settle, and 4) decant/effluent withdrawal.

Anaerobic Waste Treatment—Waste stabilization brought about through the action of microorganisms in the absence of air or elemental oxygen. Usually refers to waste treatment by methane fermentation. Anaerobic digestion is an anaerobic waste treatment process.

Attached Film Digester—An anaerobic digester in which the microorganisms responsible for waste stabilization and biogas production are attached to inert media.

Bacteria—A group of universally distributed and normally unicellular microorganisms lacking chlorophyll.

Bagasse—Fibrous residue remaining after sugarcane stalks are crushed to extract their juice.

Biochemical Oxygen Demand (BOD)—A measure of the quantity of oxygen utilized in the biochemical oxidation of organic matter in a specified time and at a specified temperature. It is not related to the oxygen requirements in chemical combustion, being determined entirely by the availability of the material as biological food and by the amount if oxygen utilized by the microorganisms during oxidation.

Biogas—A mixture of methane and carbon dioxide produced by the bacterial decomposition of organic wastes and used as a fuel.

Biological Treatment Processes—There are two general types of biological waste treatment processes: suspended and attached growth. Suspended growth processes generally involve mixing to enhance contact between the microbial population and the wastewater constituents. Suspended growth processes can be either aerobic or anaerobic. The activated sludge process is an example of suspended growth wastewater treatment process.

Attached growth processes are characterized by the development of a microbial population attached to a natural or artificial media when exposed to wastewater constituents. The trickling filter is an example of an attached growth wastewater treatment process. Attached growth processes also can be either aerobic or anaerobic.

Cachaca—Liquor made from fermented sugarcane. Also called Aguardiente.

Cassava—Crop grown in tropical climates. When extracted, its starch is known as tapioca.

Cesspool—A lined or partially lined underground pit into which wastewater is discharged and from which the liquid seeps into the surrounding soil. Sometimes called a leaching cesspool.

Chemical Oxygen Demand (COD)—A quantitative measure of the amount of oxygen required for the chemical oxidation of carbonaceous (organic) material in wastewater using inorganic dichromate or permanganate salts as oxidants in a two-hour test.

Chemical Unit Processes—Processes that remove dissolved and suspended wastewater constituents by chemically induced coagulation and precipitation or oxidation. An example is the addition of alum or lime to remove phosphorus by precipitation in tertiary treatment.

Clarifier—Any large circular or rectangular sedimentation tank used to remove settleable solids from water or wastewater. A special type of clarifiers, called upflow clarifiers, use floatation rather than sedimentation to remove solids.

Complete Mix Digester—A controlled temperature, constant volume, mechanically or hydraulically mixed vessel operated for the stabilization of organic wastes including manures anaerobically with the capture of biogas generated as a product of waste stabilization.

Compost—The production of the microbial oxidation of organic wastes including livestock manures at an elevated temperature.

Composting—The process of stabilizing organic wastes including livestock manures by microbial oxidation with the conservation of microbial heat production to elevate process temperature.

Covered Lagoon Digester—A pond or lagoon operated for the stabilization of organic wastes including manures anaerobically and fitted with an impermeable cover to capture the biogas generated as the product of waste stabilization.

Digester—A tank or other vessel for the aerobic or anaerobic decomposition of organic matter present in biosolids or other concentrated forms of organic matter including livestock manures.

Dissolved Air Floatation (DAF)—A separation process in which air bubbles emerging from a supersaturated solution become attached to suspended solids in the liquid undergoing treatment and flat them up to the surface for removal by skimming.

Effluent—The discharge from a waste treatment or stabilization unit process.

Evaporation Pond—A pond or lagoon used for the disposal of wastewater by evaporation.

Facultative—Having the ability to live under different conditions; for example with or without free oxygen.

Facultative Bacteria—Bacteria, which can carry out metabolic activities including reproduction in the presence or absence of free elemental oxygen.

Facultative Pond or Lagoon—A natural or constructed pond or lagoon with an aerobic upper section and an anaerobic bottom section so that both aerobic and anaerobic processes occur simultaneously.

Five-Day BOD—That part of oxygen demand usually associated with biochemical oxidation of carbonaceous material with in five days at 20°C.

Greenhouse Gas (GHG)—A gas present in the atmosphere, which is transparent to incoming solar radiation but absorbs the infrared radiation reflected form the earth's surface. The principal greenhouse gases are carbon dioxide, methane, and CFCs.

Human Sewage (Domestic Wastewater) – Human sewage is wastewater that contains human urine and feces. It also usually contains wastewater from bathing and washing of dishes, kitchen utensils, clothing, etc. and may include food preparation wastes. It may be discharged directly, treated on-site prior to discharge, or transported by a collection system for direct discharge or treatment in a centralized wastewater treatment plant followed by discharge. Human sewage also is known as domestic wastewater.

Hydraulic Retention Time (HRT)—The volume of a reactor divided by the volumetric flow rate.

Hydrolysis—The reduction of insoluble organic and complex soluble organic compounds to simple soluble organic compounds.

Influent—Wastewater flowing into a unit waste treatment or stabilization process.

Lagoon—Any large holding or detention structure, usually with earthen dikes, used to contain wastewater while sedimentation and biological oxidation or reduction occurs.

Liquid Manure—Manure having a total solids (dry matter) content not exceeding 5 percent.

Manure—The mixture of the fecal and urinary excretions of livestock, which may or may not contain bedding material.

Mesophilic Digestion—Digestion by biological action at 27 to 38 °C.

Methane—A colorless, odorless, flammable gaseous hydrocarbon that is a production of the anaerobic, microbial decomposition of organic matter.

Methanogenesis—The formation of methane from CO_2-type, methyl, and acetoclastic type substrates.

Municipal Wastewater—Wastewater treated in a municipal (publicly owned) treatment plant and can contain domestic, commercial and industrial wastewaters.

Organic Matter—Chemical substances of animal or vegetable origin, or more correctly, containing carbon and hydrogen.

Oxidation Pond—A relatively shallow body of wastewater contained in an earthen basin of controlled shape, in which biological oxidation of organic matter is effected by the natural or artificially accelerated transfer of oxygen.

Physical Unit Processes—Processes that remove particulate matter in wastewater. Screening and gravity separation to remove particulate matter are examples of physical unit processes. These processes are used for primary treatment and following secondary and tertiary treatment processes. A typical example of the use of physical unit processes in a wastewater treatment system is primary settling followed by the activated sludge treatment process, which is then followed by secondary settling before final effluent discharge.

Plug-Flow—Flow in which fluid particles are discharged from a tank or pipe in the same order in which they entered it. The particles retain their discrete identities and remain in the tank for a time equal to the theoretical retention time.

Plug-Flow Digester—A controlled temperature, constant volume, unmixed vessel operated for the stabilization of organic wastes including manures anaerobically with the capture of biogas generated as a product of waste stabilization.

Primary Treatment*—(1) The first major treatment in a wastewater treatment facility, usually sedimentation but not biological oxidation. (2) The removal of a substantial amount of suspended matter but little or no colloidal and dissolved matter. (3) Wastewater treatment processes usually consisting of clarification with or without chemical treatment to accomplish solid-liquid separation.

Psychrophilic Digestion—Digestion by biological action below 27 °C.

Raw Wastewater—Wastewater before it receives any treatment.

Secondary Treatment*—(1) Generally, a level of treatment that produces removal efficiencies for BOD and suspended solids of at least 85 percent. (2) Sometimes used interchangeably with the concept of biological wastewater treatment, particularly the activated sludge process. Commonly applied to treatment that consists chiefly of clarification followed by a biological process, with separate sludge collection and handling.

Solids Retention Time (SRT)—The average time in which solids including the population of active microbial biomass remain in a reactor.

Septic Tank—An underground vessel for treating wastewater by a combination of settling and anaerobic digestion. Effluent usually is disposed of by leaching. Settled solids are removed periodically for further treatment or disposal.

Settling Pond—An earthen basin in which wastewater containing settleable solids is retained to remove a part of suspended matter by gravity. Also called a settling or sedimentation basin and settling tanks or basins perform the same function.

Stabilization—Reduction in the concentration of putrescible material by either an aerobic or anaerobic process. Both aerobic and anaerobic digestion are examples of waste stabilization processes.

Suspended Solids—(1) Insoluble solids that either float on the surface of, are in suspension in, water, wastewater, or other liquids. (2) Solid organic or inorganic particles (colloidal, dispersed, coagulated, flocculated) physically held in suspension by agitation or flow. (3) The quantity of material removed from wastewater in a laboratory test, as prescribed in “Standard methods for the Examination of Water and Wastewater” and referred to as nonfilterable residue.

Tertiary Treatment*—The treatment of wastewater beyond the secondary or biological stage. Term normally implies the removal of nutrients, such as nitrogen and phosphorus, and a high percentage of suspended solids. Term now being replaced by preferable term, advanced waste treatment.

Thermophilic Digestion—Digestion carried on at a temperature approaching or within the thermophilic range, generally between 43 °C and 60 °C.

Total Solids—The sum of dissolved and suspended solid constituents in water or wastewater.

Treatment—The use of physical, chemical, or biological processes to remove one or more undesirable constituents from a waste.

Upflow Anaerobic Sludge Blanket (UASB) Reactor—An upflow anaerobic reactor in which influent flows upward through a blanket of flocculated sludge that has become granulated.

Vinasse—Wastewater with a high organic content generated via ethanol production through sugar juice or final molasses fermentation.

Volatile Solids—Materials, generally organic, which can be driven off by heating, usually to 550°C; non-volatile inorganic solids (ash) remain.

Wastewater—The spent or used water of a community or industry, which contains dissolved and suspended matter.

Wastewater Treatment System*—A sequence of unit processes designed to produce a final effluent that satisfies standards for discharge to surface or ground waters. Typically will include the combination of a primary and secondary treatment processes.

*Appendix B illustrates the typical wastewater treatment process.

APPENDIX E: BIBLIOGRAPHY

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