Resource Assessment for Livestock and Agro-Industrial Wastes – India

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The Global Methane Initiative

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EXECUTIVE SUMMARY

The Global Methane Initiative is an international partnership 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. It 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 mines. 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 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 India to identify and describe 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 sectors deemed to have the greatest potential for methane emission reductions are: dairy cattle, sugar and distilleries, fruit and vegetables, corn and cornstarch, and cassava starch (tapioca).

India has the world's largest milk-producer population of dairy animals, with more than 103 million dairy cattle and 80 million dairy buffalos in 2003. In 2009–2010, 109 million metric tons (MMT) of milk was produced by dairy cows and dairy buffalos in India. Uttar Pradesh, Punjab, Rajasthan, Madhya Pradesh, and Maharashtra are the major milk-producing states, accounting for more than half of the nation's milk production. The sector is comprised mainly of marginal and small farms. The most common manure management practices are land application and pit storage, and the manure is used as a fertilizer or directly as a fuel.

It is estimated that about 35 percent of the milk produced in India is processed. Most registered dairy plants have installed effluent wastewater treatment plants to meet the requirements of the Central Pollution Control Board. Because most plants already capture and flare the biogas, current baseline methane emissions in the milk-processing sector are very low. However, assuming that the biogas is used to generate electricity instead of simply being flared, there is an important potential for indirect emission reductions through fossil fuel replacement.

India is the world's largest sugar consumer and second largest sugar producer after Brazil. India produces about 350 MMT of sugarcane, 20 MMT of sugar, and 3.25 billion liters of ethanol per year. There are about 570 sugarcane mills (2005 data) and 285 distilleries (1999 data) in the country. Sugarcane is cultivated all over India, but the major clusters are in Maharashtra, Uttar Pradesh, and Tamil Nadu. The average wastewater chemical oxygen demand (COD) concentrations are 3,000 mg/L for sugarcane mill effluent and 110,000 to 190,000 mg/L for distillery vinasse. In both sugarcane mills and distilleries, the wastewater is treated either aerobically or anaerobically, which may include the use of aerobic lagoons, conventional anaerobic lagoons, anaerobic digestion, or a combination of the three.

India also is one of the main corn- and cassava-producing countries in the world. Currently, about 10 MMT of corn are produced throughout the country, of which 12 percent (1.2 MMT) is utilized for starch production. The major starch manufacturing plants are located in and around Ahmedabad (Gujarat), which contributes approximately 50 percent of India's total cornstarch production. The COD of cornstarch wastewater ranges between 10,000 and 20,000 mg/L. It is estimated that only about 14 percent of the cornstarch production in India treats wastewater in open lagoons with no biogas capture, while the other 86 percent of cornstarch production uses anaerobic wastewater treatment plants with biogas capture.

India has an annual production of around 6 to 8 MMT of cassava root and 100,000 metric tons (MT) of tapioca. The key production areas are concentrated primarily in the southern Indian states of Kerala, Tamil Nadu, and Andhra Pradesh. The average COD of tapioca plant wastewater ranges between 5,600 and 6,400 mg/L. About 25 percent of the small plants use open lagoons, while the other small plants discharge their waste directly into the environment. Small plants process less than 50 MT per month and represent two-thirds of all tapioca plants. All large plants treat their wastewater before discharge.

India produces the widest range of vegetables and fruits in the world. It is the second largest vegetable and third largest fruit producer. In 2008, the total vegetable and fruit production was about 79 million and 63 MMT, respectively. It is estimated than less than 2 percent of the total vegetables and fruits produced in the country are commercially processed, compared to nearly 70 percent in Brazil and 65 percent in United States. The COD levels of the fruit- and vegetable-processing effluents vary with the type of vegetable or fruit processed. On average, about 63 percent of the industry utilizes aerobic treatment processes, such as composting and activated sludge treatment; about 18 percent use anaerobic digestion processes with biogas use; and another 18 percent resort to discharge of untreated wastes.

Table ES-1 summarizes the findings of the RA in terms of potential methane emission reductions and fossil fuel replacement carbon offsets in India. The sector with the highest potential for methane reduction and carbon offsets is the dairy cattle sector (76 percent of the total reduction potential), followed by the distilleries (17 percent), sugarcane processing (3 percent), fruit and vegetable processing (2 percent), and cornstarch and tapioca production (2 percent) sectors. When fuel replacement offsets are considered, the milk-processing sector ranks third in total potential carbon emission reductions.

Table ES-1 – Summary of the Methane Emission Reduction Potential in the Livestock and Agro-Industrial Sector in India

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)
Dairy farms (milk production)	173,455	3,642,560	686,054	4,328,614
Distilleries	38,729	813,313	153,183	966,495
Dairy plants (milk processing)	N/A	N/A	456,297	456,297
Sugarcane mills	6,915	145,223	27,352	172,575
Fruit and vegetable processing	5,096	107,018	20,156	127,174
Cornstarch and tapioca production	4,858	102,016	19,214	121,230
TOTAL	229,054	4,810,130	905,959	5,716,089

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AD	Anaerobic digestion
AMBR	Anaerobic migrating blanket reactor
APMC	Agricultural produce market committees
ASBR	Anaerobic sequencing batch reactor
BDTC	Biogas Development and Training Centres
BOD	Biochemical oxygen demand
BMC	Bombay Municipal Corporation
CCAR	California Climate Action Registry
CDM	Clean Development Mechanism
CER	Certified emission reduction
CETP	Common effluent treatment plants
CPCB	Central Pollution Control Board
CH_4	Methane (chemical formula)
CO_2	Carbon dioxide (chemical formula)
COD	Chemical oxygen demand
CREP	Corporate Responsibility for Environmental Protection
crore	Unit equal to ten million
CSTR	Continuous stirred-tank reactor
DAF	Dissolved air floatation
ETP	Effluent treatment plant
FAO	United Nations Food and Agriculture Organization
FICCI	Federation of Indian Chambers of Commerce & Industry
GDP	Gross domestic product
GHG	Greenhouse gas
HRT	Hydraulic retention time
IFPRI	International Food Policy Research Institute
IIM	Indian Institute of Management
IPCC	Intergovernmental Panel on Climate Change
IINC	India's Initial National Communication to the United Nations Framework Convention on Climate Change
LPG	Liquefied petroleum gas
MCGM	Municipal Corporation of Greater Mumbai
MFP	Mega food parks
MNES	Ministry of Non-Conventional Energy Sources
MNRE	Ministry of New and Renewable Energy

MRU	Methane recovery and utilization
MT	Metric tons
MMPO	Milk and Milk Production Order
MMT	Million metric tons
$MMTCO_2e$	Million metric tons of carbon dioxide equivalent
$MTCO_2e$	Metric tons of carbon dioxide equivalent
NBMMP	National Biogas and Manure Management Program
NDDB	National Dairy Development Board
NMP	National Master Plan
RA	Resource assessment
Rs	Rupees
SO_2	Sulfur dioxide
TLWK	Ton of live weight kill
TOW	Mass of waste COD generated
TS	Total solids
TSS	Total suspended solids
UAFP	Upflow anaerobic filter process
UASB	Upflow anaerobic sludge blanket
UICA	Urban, Industrial & Commercial Applications
UNFCCC	United Nations Framework Convention on Climate Change
USDA	United States Department of Agriculture
U.S. EPA	United States Environmental Protection Agency
VS	Volatile solids
YSGKL	Yashwant Sahakari Glucose Karkhana Ltd.

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 made 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. GMI is focusing on a few key sources of methane, including agriculture, coal mining, landfills, and oil and gas systems.

The role of GMI 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 non-governmental 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 RA objectives are to:

- Identify and characterize methane reduction potential
- Develop country market opportunities
- Provide the location of resources and their ranking

The 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 India. 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.

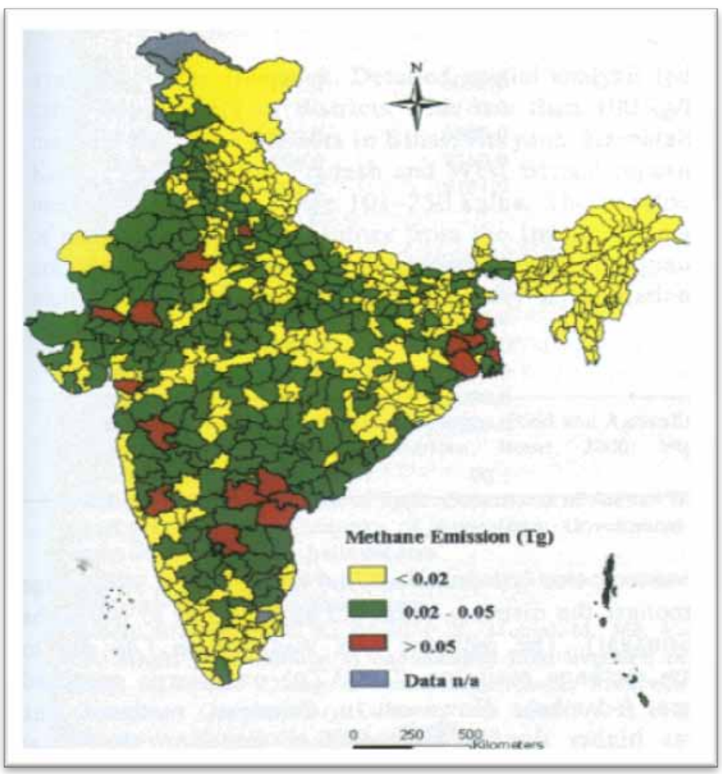
While there are other studies showing methane emissions from the sectors covered in this document, these studies usually consider population or production levels as the baseline for calculating the emissions. This RA, however, uses a different approach, recognizing that not all waste management operations (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 system (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 population and number of operations in the country. This fraction represents the number of animals that are assumed to be utilizing 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 GREENHOUSE GAS EMISSIONS IN INDIA

India's carbon dioxide (CO_2) emissions currently account for 55 percent of its total GHG emissions—compared to 90 percent in Japan, more than 80 percent in both the United States and Russia, more than 75 percent in both Brazil and Mexico, and about 70 percent in both China and Australia. Methane and nitrous oxide (N_2O) account for 23 and 22 percent of India's current GHG emissions, respectively. The largest source of India's total GHG emissions is agriculture. Though agricultural emissions of CO_2 comprise only 1 percent of the country's total CO_2 emissions, agriculture dominates emissions of other GHGs, accounting for 50 percent of India's methane (5 MMT) and a large share of N_2O emissions (0.31 million MT). The primary sources of agricultural GHG emissions are from the large and growing livestock population—estimated to increase to 625 million by 2020, resulting in the highest density of cattle in the world—and the cultivation of rice paddy. The district-level emissions of methane in India are illustrated in Figure 1.1.

Figure 1.1 – District-Level Methane Emissions in India (2003)

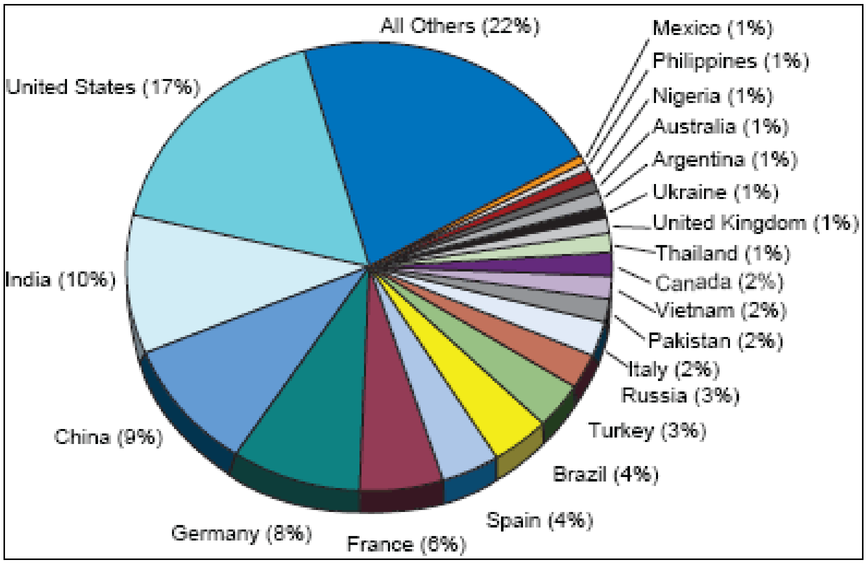


Source: Chhabra et al., 2009

1.2 METHANE EMISSIONS FROM LIVESTOCK WASTES

In 2005, livestock manure management globally contributed more than 230 million metric tons of carbon dioxide equivalents ($MMTCO_2e$) 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 is also a significant source of methane emissions. Figure 1.2 represents countries with significant methane emissions from livestock manure management.

Figure 1.2 – Estimated Global Methane Emissions From Livestock Manure Management (2005), Total = 234.57 MMTCO$_2$e

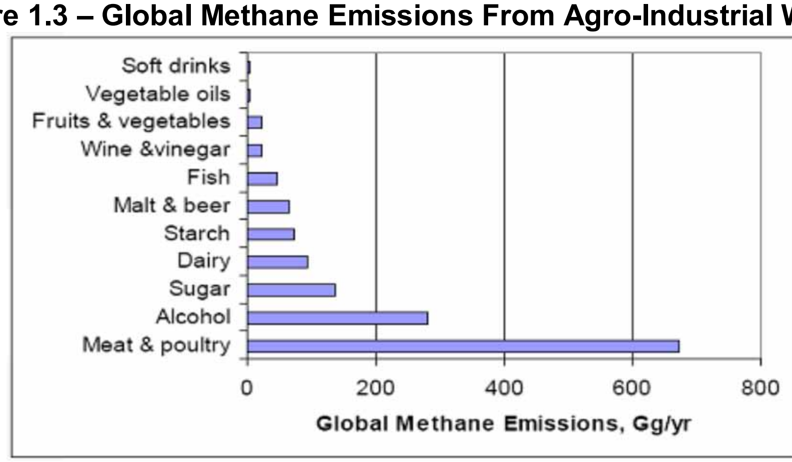


Source: Methane to Markets, 2008

1.3 METHANE EMISSIONS FROM AGRO-INDUSTRIAL WASTES

Wastes from agro-industrial activities are 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 1.3 shows global estimates of methane emissions from agro-industrial wastes.

Figure 1.3 – 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 (AD) systems.

Table 1.1 – Disposal Practices From Agro-Industrial Wastes

Sector	Region	% 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

1.4 ENERGY GENERATION POTENTIAL

A number of studies estimated the total potential in India for generating and capturing methane from livestock and agro-industrial waste for use as a fuel. One of the most comprehensive was the development of the National Master Plan (NMP) for Development of Waste-to-Energy in urban and industrial sectors by the Ministry of New and Renewable Energy (MNRE). This section summarizes the findings of the NMP for the sectors covered in this RA.

The NMP was developed by the Indian National Bio-Energy Board, Ministry of Non-Conventional Energy Sources (MNES). It covers the following sectors: 1) distilleries, 2) dairy farms and milk processing plants, 3) pulp and paper production, 4) poultry farms, 5) tanneries, 6) slaughterhouses, 7) cattle farms, 8) sugarcane processing, 9) cornstarch production, and 10) tapioca production.

The methane and energy generation potential estimated in the NMP are based on the total potential production levels assuming a maximum methane conversion factor (MCF), which corresponds to an open anaerobic lagoon. This differs from the methodology used in this RA, which uses actual waste management systems and the associated MCFs to estimate emissions. Hence, the estimates in this RA account for the range of waste management systems used at all scales in the agro-industrial rather than an assumption that all use open anaerobic lagoons. For the sectors covered in both reports, Table 1.2 compares the production levels used in the NMP and in the India RA, as well as the resulting methane generation potential and current baseline methane missions.

Table 1.2 – Comparison of the Findings of the NMP and the RA for the Sectors Covered in Both Reports

Sector	Total Production, MT product/yr (NMP)*	Production Using Open Lagoons, MT product/yr (RA)	Methane Generation Potential, MT CH_4/yr (NMP)[a]	Current Baseline Methane Emissions from Open Lagoons, MT CH_4/yr (RA)
Distilleries	4,020,000	146,701	656,329	38,729
Sugarcane processing	18,500,000	982,301	566,342	6,915
Cornstarch production	1,733,750	94,050	100,947	4,258
Tapioca production	817,600	16,667	29,877	600

[a] Assumes biogas contains 65% of methane, methane density of 0.67kg/m^3, and production 365 days/year.

Sources: **Indian Ministry of New and Renewable Energy, n.d.**
RA: See Chapters 3 and 4 of the RA for more details on each sector.

One of the main elements of the NMP is the development of a structured database containing the following information for each sector: 1) general details of the sector, 2) water consumption and raw materials used, 3) existing treatment systems, 4) quantity and quality of waste generated, and 5) details of the estimated bioenergy production potential.

Tables 1.3 through 1.6 present estimations of the total biogas and energy generation potential in the distilleries, sugarcane processing, tapioca and cornstarch production, and milk processing sectors in India from 2001 to 2007, as estimated in the NMP.

Table 1.3 – Potential for Biogas Energy Production from the Distilleries Sector

Alcohol Production (million m^3/year)	Spent Wash (vinase) (million m^3/year)	Potential Biogas Generation (million m^3/year)	Power (MW)
4.02	60.28	1,507.07	502

Table 1.4 – Potential for Biogas Energy Production from the Sugarcane Processing Sector

Sugar Production* (MMT/yr)	Press mud		Wastewater		Total Power (MW)
	Potential Biogas Generation (m^3/d)	Power (MW)	Potential Biogas Generation (m^3/d)	Power (MW)	
18.5	2,895,200	289	667,651	67	356

*2001–2002 production

Table 1.5 – Potential for Biogas Energy Production from the Tapioca and Cornstarch Production Sectors

	Starch Production (MT/day)	Wastewater (m^3/day)	Potential Biogas from Wastewater (m^3/day)	Solid Waste (MT/day)	Potential Biogas from Solid Waste (m^3/day)	Total Biogas (m^3/day)	Power (MW)
Tapioca	2,240	56,000	142,800	784	45,185	187,958	18.8
Corn	4,750	39,425	1,045	251,334	383,724	635,058	63

Table 1.6 – Potential for Biogas Energy Production from the Milk-Processing Sector

Total Milk Production (million m^3/year)	Milk Processed (million m^3/year)	COD (thousand MT/year)	Potential Biogas Generation (million m^3/year)	Power (MW)
112.4	35	420	215	62

Source: Indian Ministry of New and Renewable Energy, n.d.

2. BACKGROUND AND CRITERIA FOR SELECTION

Below is a description of the methodologies used in this RA.

2.1 METHODOLOGIES USED

The approach undertaken in this study is depicted in Figure 2.1 and is described below.

Figure 2.1 – Various Steps of Data Management

- **Primary data collection:** The primary data were collected through a survey questionnaire sent to the various industries in the sector and associations representing the industries. Questionnaire recipients were selected to provide a representative characterization of the current status of the sector. The survey on methane recovery and utilization (MRU) was carried out to determine the current status, barriers, and opportunities for recovering and utilizing methane.

- **Secondary data collection:** The secondary data were collected from a range of data sources, including national data; international data; data from scientific and technical reports; data from various sector organizations in India; and other documents, reports, and statistics. Information collected included general sector and subsector profile data, geographic extent of the sector, overview of the waste management practices, existing policies and regulations, and the annual production and population statistics. Information was also sought from various organizations and research and development institutions working in each sector.

- **Field visits:** Field visits were carried out in each sector to determine the waste management practices in the sector and to verify the information collected through other sources.

- **Structured discussions:** Apart from these data sources, additional data were obtained from structured discussions with technical experts, industry persons, government officials, and other sources in each of these sectors.

The data analysis of the methane potential in each sector was computed based on the current status update from the primary data. The waste management practice for some sectors was determined from secondary data sources. However, in certain sectors, such as the livestock sector, the waste management approach was region-specific and fragmented. The information on specific data was obtained from credible sources; however, in the event that data was not available, data from international organizations such as the Food and Agriculture Organization (FAO) and the Intergovernmental Panel on Climate Change (IPCC) were obtained. The subsectors and sectors were then compared and prioritized based on the methane emission potential. Mitigation options were suggested for these prioritized sectors. Barriers faced by some sectors for the implementation of MRU projects have also been projected where available.

The team employed the following approach to conduct the RA:

Step 1: The first step in the development of the India livestock and agro-industry RA involved constructing general profiles of the individual subsectors (or commodity groups), such as dairy or swine production or fruit processing. Each profile includes a list of operations within the subsector and the distribution of facilities by size and geographical 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, beef cattle, 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 those 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 utilize 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 utilized 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. Unfortunately, in India, the information about waste management practices is not always collected and compiled, or it may be incomplete or not readily accessible. Therefore, the team identified and directly contacted producer associations, local consultants, and business advisors and visited individual operations to obtain this information.

Step 5: The team then assessed the magnitudes of current methane emissions to identify those 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 perform direct discharge of 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 utilize available resources. This profiling exercise will aid in identifying the more 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 manure 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 *2006 IPCC Guidelines for National Greenhouse Gas Inventories* Tier 2 methods were used for estimating 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 follows using Equation 2.1:

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

where:

- $CH_{4\,(M)}$ = Estimated methane emissions from manure for livestock category M (kg CH_4 per year)
- $VS_{(M)}$ = Average daily volatile solids excretion rate for livestock category M (kg volatile solids per 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 (m^3 CH_4 per 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, %								
	Lagoons	Storage Tanks & 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 specifying 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
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 Agricultural Commodity Processing Waste-Related Emissions

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, poor quality, or other reasons. One example of solid organic wastes is the combination of wastewater and the solids removed by screening before wastewater treatment or direct disposal. This material may have relatively high moisture content and is commonly referred to as wet waste. Appendix B illustrates a typical wastewater treatment unit process sequence. The method for estimating methane emissions from wastewater is presented below.

2.2.2.1 Wastewater

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 method (Section 6.2.3.1) are an acceptable methodology for estimating methane emissions. This methodology utilizes COD and wastewater flow data. Using the Tier 2 method, the gross methane emissions for each waste category (W) and prior treatment system and discharge pathway (S) combination should be estimated using 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 per year)
- $TOW_{(W)}$ = Annual mass of waste W COD generated (kg per year)
- $S_{(W)}$ = Annual mass of waste W COD removed as settled solids (sludge) (kg per year)
- $EF_{(W,S)}$ = emission factor for waste W and existing treatment system and discharge pathway S (kg CH_4 per kg COD)
- $R_{(W)}$ = Mass of CH_4 recovered (kg per year)

As indicated above, the methane emission factor in Equation 2.2 is a function of the type of waste and existing treatment system and discharge pathway, and it is estimated using 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 per 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 selected from 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*	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

*Source: IPCC, 2006

If the annual mass of COD generated per year (TOW) is not known and the collection of the necessary data is not possible, the remaining option is to estimate using 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.

$$TOW_{(W)} = P_{(W)} \times W_{(W)} \times COD_{(W)} \qquad (2.4)$$

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

Table 2.5 – Examples of Industrial Wastewater Data

Industry	Typical Wastewater Generation Rate, m^3/metric ton	Range of Wastewater Generation Rates, m^3/metric ton	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 & 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 & vinegar	23	11–46	1.5	0.7–3.0

Source: Doorn et al., 1997

2.2.2.2 Solid Wastes

A variety of methods exist for disposing the solid wastes generated during the processing of agricultural commodities. These include: 1) land application, 2) composting, 3) placement in a landfill, and 4) open burning. In addition, solid wastes from meat and poultry processing, such as solids separated from wastewater by screening and dissolved air flotation, 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 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 2.6.

Table 2.6 – Types of Solid Waste Landfills and MCFs

Type of Site	MCF 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 on a VS 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

Again, based on limited data and best professional judgment, the MCF_{AD} (anaerobic digester methane conversion factor) values of 0.90 and 0.80 appear to be reasonable estimates, respectively, for heated and ambient temperature digesters for first-order estimates of methane production potential.

2.3 DESCRIPTION OF SPECIFIC CRITERIA FOR DETERMINING POTENTIAL SECTORS

The specific criteria to determine methane emission reduction potential and feasibility of AD systems include:

- **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.
- **Waste strength:** The wastewater generated has a high concentration of organic compounds, as measured in terms of its BOD and COD or both.
- **Geographic distribution:** There is a concentration of priority sectors in specific regions of the country, making centralized or comingling 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 India are dairy farms, sugarcane processing and distilleries, fruit and vegetable processing, tapioca and cornstarch production, and dairy processing.

3. SECTOR CHARACTERIZATION

3.1 INTRODUCTION

Agriculture in India is the means of livelihood for almost two-thirds of the work force in the country, with more than 600 million people involved in agriculture or agriculturally related activities. Agriculture and related activities contribute about 30 percent to the gross domestic product (GDP). With 168 million hectares of arable land, India ranks second only to the United States in the amount of arable land. Fifty-two percent of India is tillable land with varied climates.

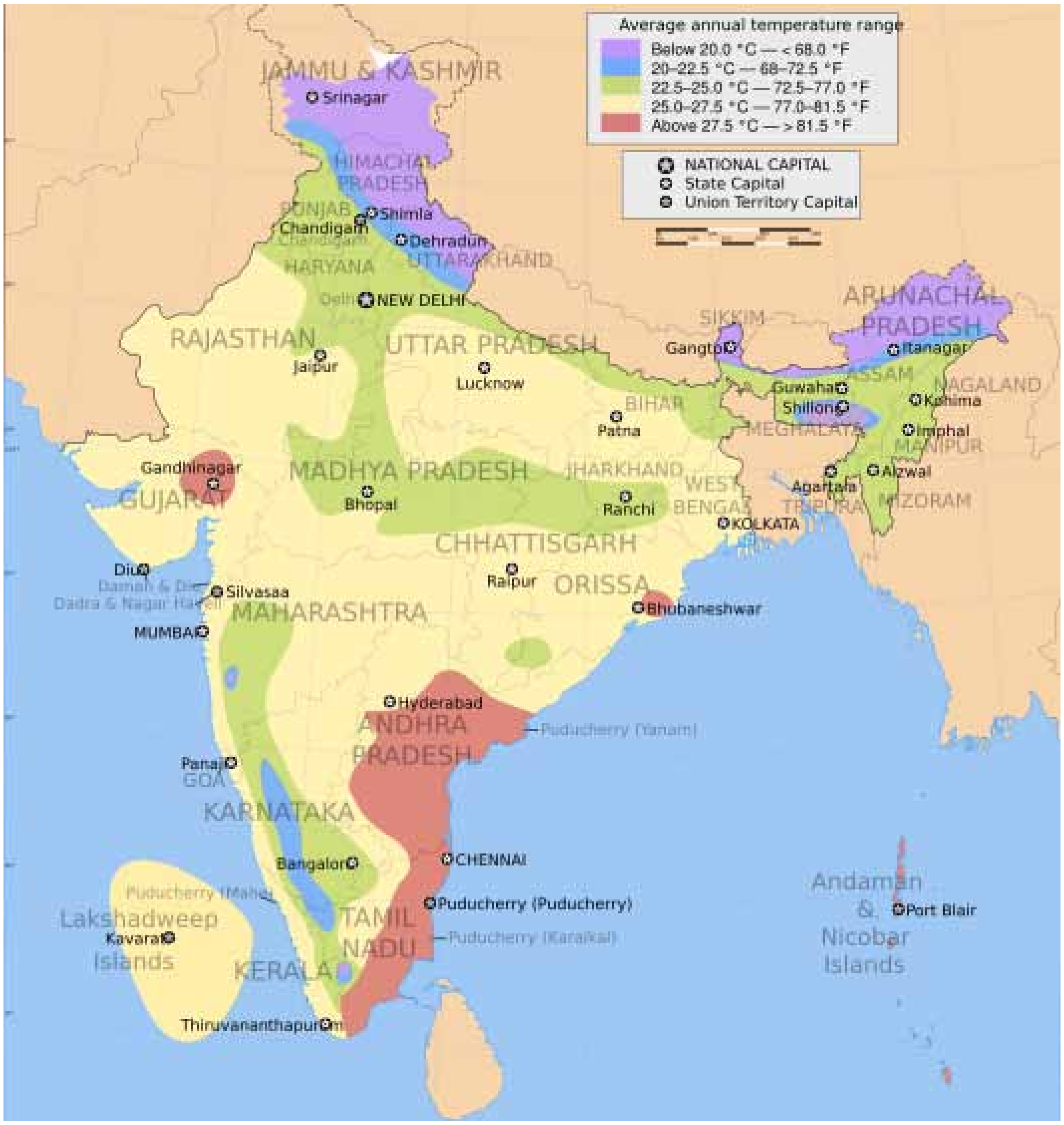
A wide range of subsectors are included directly or indirectly under the agriculture sector. These include crop production, livestock and milk production, and agro-based industries (paper and pulp production, sugarcane processing, distilleries, and other food and food-processing industries). A map of India is provided in Figure 3.1 as a reference to locate states and regions mentioned in the report.

Figure 3.1 – Map of India's States and Regions

Source: Indian Community of Geneva, n.d.

Because methane production is temperature-dependent, temperature is an important consideration in evaluating locations for potential methane capture. In India, the annual average temperature ranges between 6°C and 27°C (Figure 3.2).

Figure 3.2 – Average Annual Temperature in India



Source: Easy India Tours, n.d.

3.2 SUBSECTORS WITH POTENTIAL FOR METHANE EMISSION REDUCTION

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

The important subsectors of the livestock production and agricultural commodity processing sectors in India, as identified in this RA, are summarized in Table 3.1. These subsectors include dairy farms, sugarcane processing and distilleries, fruit and vegetable processing, cornstarch production, tapioca production, slaughterhouses, and milk processing. A more detailed discussion of each of the important subsectors is provided in Sections 3.3 through 3.11.

Table 3.1 – Main Subsectors with Potential for Methane Emission Reduction

Subsector	Size (production/year)	Geographic Location
Dairy farms	103 million dairy cattle, 80 million dairy buffalo in 2003	Uttar Pradesh, Punjab, Rajasthan, Madhya Pradesh and Maharashtra are the major milk producing states, accounting for more than half the production
Sugarcane mills and distilleries	348 MMT of sugarcane; 3.25 million m^3 of ethanol	Major clusters of sugarcane cultivation are found in Maharashtra and Uttar Pradesh
Fruit and vegetable processing	79 MMT vegetables, 63 MMT fruits in 2008	Andhra Pradesh (Mango, Tomato), Uttar Pradesh (Mango, Potato) Gujarat (Onion, Potato, Banana, Mango), Maharashtra (Grapes, Mango, Banana), Karnataka (Citrus, Grapes, Mango), Tamil Nadu (Guava, Banana, Mango), West Bengal (Cabbage, Potato, Mango), Himachal Pradesh and Jammu and Kashmir (Apple, Pear, Plum, Peach)
Cornstarch production	660,000 MT of cornstarch from 1.2 MMT of corn (12 percent of the total corn production)	The region of Ahmedabad (Gujarat) contributes about 50 percent of the total production
Tapioca production	6.18 MMT of cassava roots; 100,000 MT of tapioca	Kerala, Tamil Nadu, and Andhra Pradesh
Slaughterhouses	6.5 MMT meat in 2007 (2.5 percent of the world's production)	The major meat production centers are located in Aurangabad, Nanded, Mumbai, and Satara in Maharashtra; Goa; Medak district in Andhra Pradesh; Derabassi in Punjab; Aligarh, Unnao, and Ghaziabad in Uttar Pradesh; and Cochin in Kerala
Dairy processing	109 MMT of milk in 2008	10 states together constitute more than 80 percent of the overall milk production in the country

3.3 LIVESTOCK SECTOR

India has a very large livestock population of 485 million animals.[1] At the current livestock population growth rate, India will have the densest cattle population in the world by 2020.[2] The distribution of the livestock category in 2003 (as shown in Table 3.2) was as follows: cattle (185 million, 38 percent); goats (124 million, 26 percent); buffalos (98 million, 20 percent); sheep (61 million, 13 percent); and swine (13 million, 3 percent). Figure 3.3 shows the population of cattle, buffalo, and goats in some key states.

Table 3.2 – Livestock Population in India by Category (1977–2003)

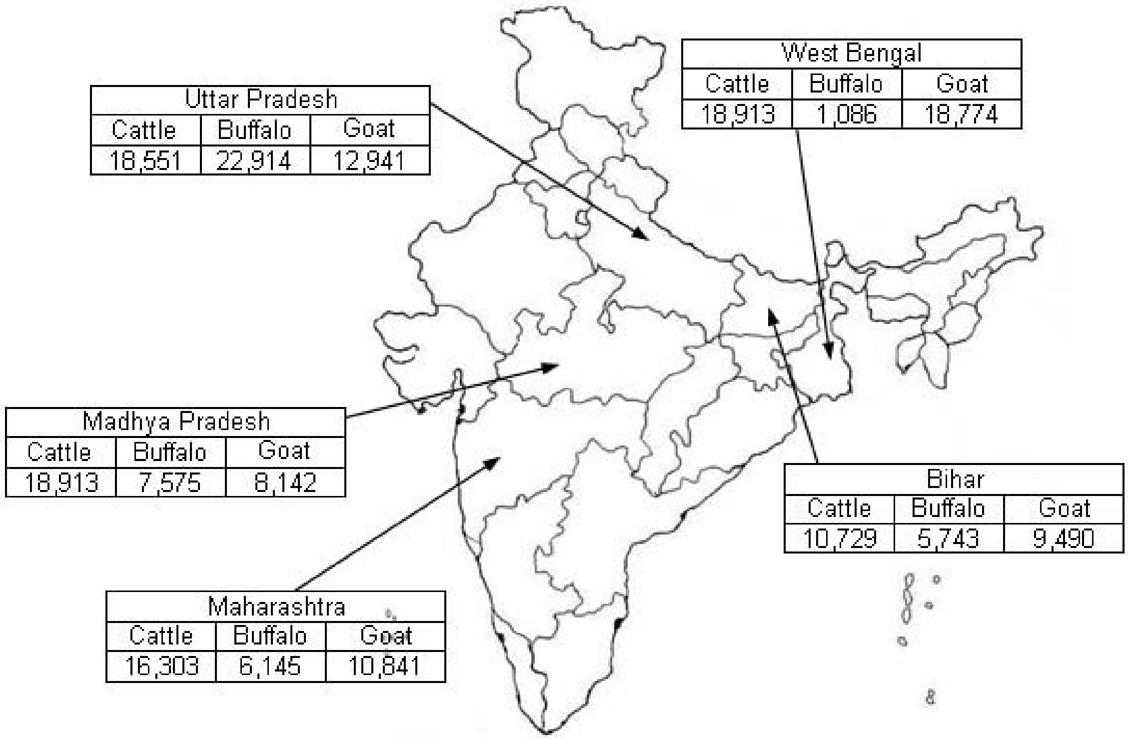
Species	Number of Animals (Millions)					
	1977	1982	1987	1992	1997	2003
Cattle, including adult females	180.0	192.5	199.7	204.6	198.9	185.2
Adult female cattle	54.6	59.2	62.1	64.4	64.4	64.5
Buffalo, including adult females	62.0	69.8	76.0	84.2	89.9	97.9
Adult female buffalo	31.3	32.5	39.1	43.8	46.8	51.0
Total cattle and buffalo	242.0	262.2	275.7	288.8	288.8	283.1
Sheep	41.0	48.8	45.7	50.8	57.5	61.5
Goats	75.6	95.3	110.2	115.3	122.7	124.4
Horses and Ponies	0.9	0.9	0.8	0.8	0.8	0.8
Camels	1.1	1.1	1.0	1.0	0.9	0.6
Pigs	7.6	10.1	10.6	12.8	13.3	13.5
Mules	0.1	0.1	0.2	0.2	0.2	0.2
Donkeys	1.0	1.0	1.0	1.0	0.9	0.7
Yaks	0.1	0.1	0.0	0.1	0.1	0.1
Mithun*	NA	NA	NA	0.2	0.2	0.3
Total Livestock	369.4	419.6	445.2	470.9	485.4	485.0
Poultry**	159.2	207.7	275.3	307.1	347.6	489.0

NA: Not Available
*Mithun (or *Bos frontalis*) is a breed of cattle found in Burma, Bhutan, Bangladesh, and northern India. The breed is used for fieldwork or meat.
**Includes chickens, ducks, turkeys, and other birds.

Source: National Dairy Development Board (NDDB), 2010

[1] *NDDB, 2010*
[2] *ICAR, 1999*

Figure 3.3 – Population of Cattle, Buffalo, and Goats in Some Key States (in thousands)



Both the national economy and socioeconomic growth of the country are supported by the livestock sector. Livestock production has been a life -sustaining practice during catastrophic events such as flood or draught. It contributes about 6.8 percent of the GDP and 33 percent of the agriculture subsector GDP.

3.4 DAIRY CATTLE

3.4.1 Description of Size, Scale, and Geographic Location of Operations

India is the world's largest milk producer, with approximately 103 million dairy cattle and 80 million dairy buffalos in 2003, as shown in Table 3.3. In 2008, India produced 109 MMT of milk.[3] India's milk production has continuously increased because of its growing livestock population, better feedstock, and better breeds. According to 2009–2010 data from the U.S. Department of Agriculture (USDA), milk production in India is growing at an annual rate of 4 percent. The USDA report suggests that strong milk prices along with rising domestic demand for a variety of milk products, supported by the growth of the Indian economy, are the primary factors driving increased production.[4] Milk consumption has kept pace with the increasing supply. However, milk productivity in India has remained low compared to other countries[5,]

[3] *FAOSTAT, 2010*
[4] *Press Trust of India Ltd., 2008*
[5]*Macdonald, 2006*

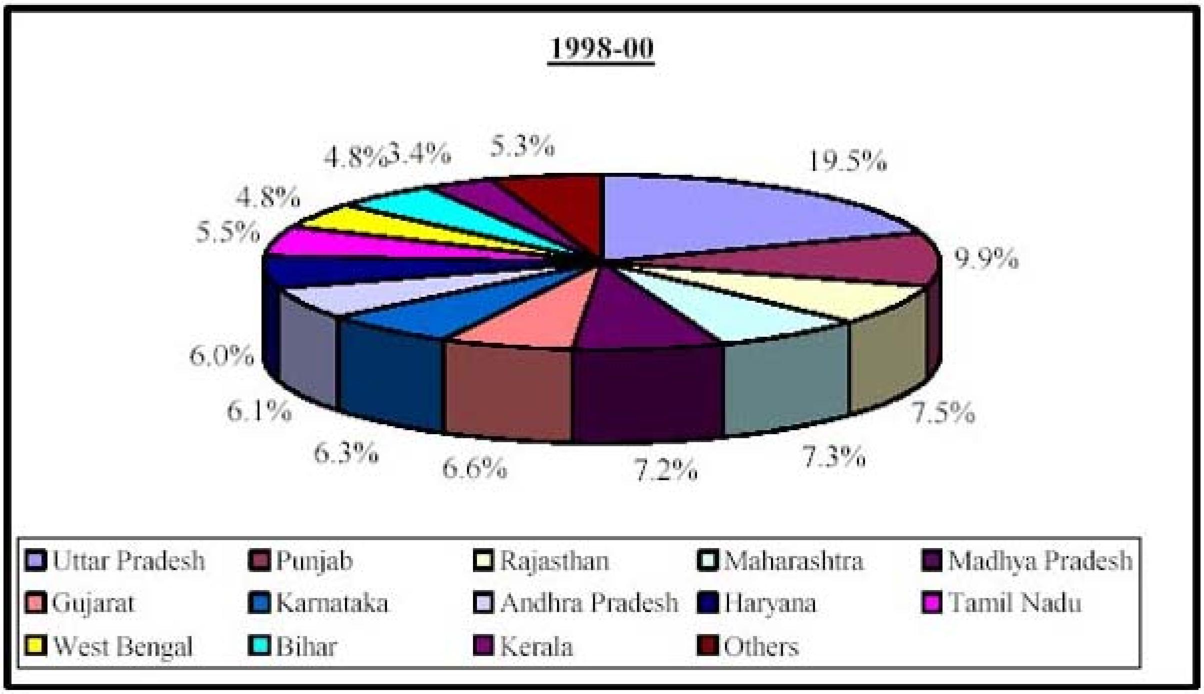
Table 3.3 – Dairy and Non-Dairy Cattle and Buffalo Population (2003)

Livestock category	Population (Millions)
Dairy cattle	102.70
Non-dairy cattle (indigenous)	77.53
Non-dairy cattle (exotic)	4.91
Dairy buffalo	80.03
Non-dairy buffalo	17.88
Total dairy cattle and dairy buffalo	182.73

Source: Chhabra et al., 2009

Uttar Pradesh, Punjab, Rajasthan, Madhya Pradesh, and Maharashtra are the major milk producing states, accounting for more than half of the nation's milk production (Figure 3.4).

Figure 3.4 – Share of Milk Production in India by State (1998–2000)



Source: NDDB, 2003

Dairy operations in India can be classified based on land ownership as follows: large, medium, semi-medium, small, marginal, and landless. Marginal and small operations account for 59 percent of India's dairy cows and 60 percent of its dairy buffalos (Table 3.4). Thus, semi-medium, medium, and large operations account for only 40 percent of the Indian dairy herd.

Table 3.4 – Distribution of Cattle and Buffalo According to Land Ownership Categories (1991–1992)

Land Ownership Category	Cattle		Buffalos	
	Male Population (millions)	Female Population (millions)	Male Population (millions)	Female Population (millions)
Marginal	38.2	36.6	8.7	24.4
Small	28.3	23.1	5.3	16.2
Semi-medium	24.2	20.7	5.1	15.6
Medium	17.4	15.1	3.8	12.2
Large	4.7	4.7	1.1	3.7
All classes	112.8	100.3	24.0	72.0

Source: FAO, 2003a

Table 3.5 presents the state distribution of small, medium and large dairies in India. Individual household farms are not included in this table because of the dispersed nature of these farms and the lack of data on these farms.

Table 3.5 – Distribution of Dairy Farms Based on Herd Size

Name of State	Small	Medium	Large
Andhra Pradesh	18	17	4
Assam	2	-	-
Bihar	4	1	-
Chandighar	-	1	-
Chattisghar	1	3	3
Delhi	2	8	1
Goa	7	2	-
Gujarat	23	15	2
Haryana	40	10	2
Jharkhand	3	4	2
Karnataka	42	16	1
Kerela	4	4	2
Madhya Pradesh	3	7	0
Maharashtra	42	49	25
Meghalaya	2	-	1
Punjab	25	22	1
Rajasthan	11	4	3
Tamil Nadu	27	10	1
Uttar Pradesh	26	23	7
Uttranchal	9	2	4
West Bengal	4	1	1
Total	295	202	60

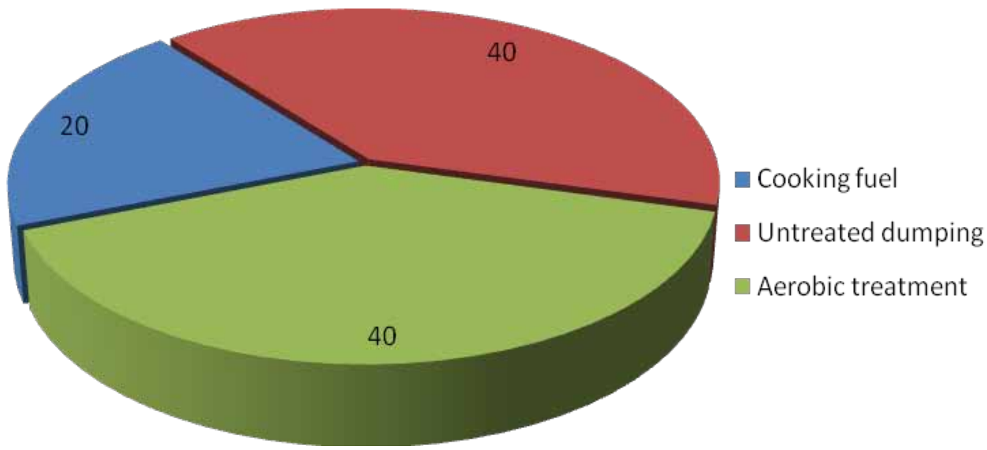
Source: Dairy India, 2007

3.4.2 Description of Waste Characteristics, Handling, and Management

The different categories of waste generated at dairy farms include animal manure, wastewater containing proteins and fats, wasted feed, and bedding, with animal manure and wastewater making up the largest portion. The Federation of Indian Chambers of Commerce & Industry (FICCI) published information about very large dairy farms with 145,000 to 200,000 animals. Depending on the number of animals, these farms produce 15 to 100 MT of manure per day, 15 to 100 m^3 of wastewater per day, and 25 kg to 1500 kg of other wastes such as wasted feed and bedding per day.

The most common manure management practice is composting (40 percent), followed by storage in pits or piles (40 percent). About 20 percent of manure is sun dried for use as a cooking or heating fuel (Figure 3.5).

Figure 3.5 – Overview of Manure Management Practices in India



Source: FICCI, 2010

A field survey of the Indian dairy industry was conducted in 2002–2003 by the Indian Institute of Management (IIM) and the International Food Policy and Research Institute (IFPRI). Table 3.6 summarizes method of disposal by size of farm across the northern and western regions of India. FAO provided the following description of the data:

> "For the dairy farmers sampled throughout the zones, manure was used as an organic fertilizer or as fuel. As the size of operations increased, the percent use as a fertilizer increased and the percent use as a fuel decreased. Seventy percent of the small farmers used manure as fuel while only 16 percent of the commercial farmers use it as fuel. This is not surprising as it may be one of the main sources of fuel for small farmers, and large farmers may rely on another source for fuel. As the size of farms increased, so did the percentage of households storing manure in a pit. This is perhaps an indication of manure surplus and/or a desire to use it as fertilizer when needed by the plants."[6]

[6] *FAO, 2003b*

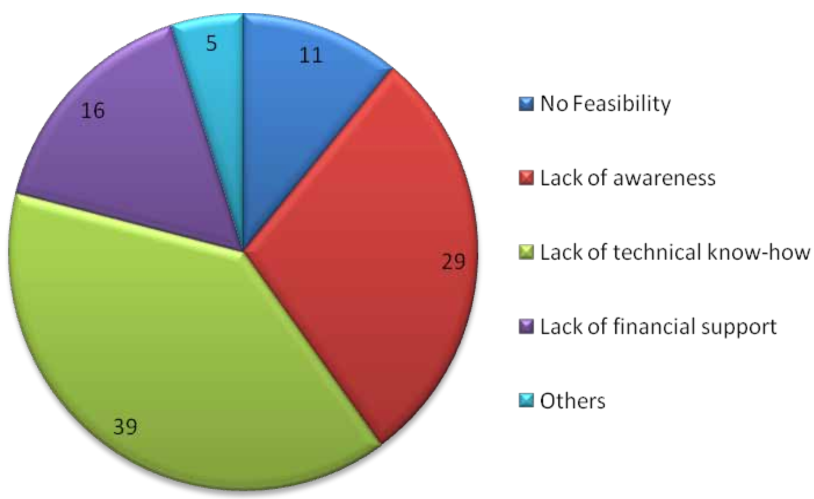
Table 3.6 – Distribution of Farms by Method of Disposal of Dairy Manure in India (2002)

Region	Farm size	Manure Use (% of farms)		Disposal Location (% of farms)	
		Organic Fertilizer	Fuel	Open Farm Field	Manure Pit
North zone	Small	30	70	90	10
	Medium	55	45	87	13
	Large	68	32	84	16
	Commercial	84	16	78	22
	All	72	28	86	14
West zone	Small	82	18	85	15
	Medium	85	15	80	20
	Large	87	13	78	22
	Commercial	95	5	76	24
	All	86	14	81	19

Source: FAO, 2003b

To date, methane recovery projects have not been common on Indian dairy farms. Figure 3.6 shows the barriers to implementing MRU projects in the dairy sector in India.

Figure 3.6 – Barriers to Implementing MRU Projects in the Dairy Sector in India



Source: FICCI, 2010

3.5 MILK PROCESSING

Milk-processing plants in India have wastewater treatment systems (often anaerobic digesters such as upflow anaerobic sludge blanket [UASB] reactors) to meet the regulatory requirements of the Central Pollution Control Board (CPCB). Therefore, while the overall biogas generation and subsequent potential for energy generation is high, current baseline emission levels are low given that most plants already treat their wastewater streams. It is in this context that this milk-processing section has been prepared.

3.5.1 Description of Size, Scale of Operations, and Geographic Location

India is one of the largest milk producers in the world, and milk processing has emerged as a key industry in the country. Table 3.7 provides a historic overview of the growth of the sector and indicates that milk production has shown a significant increase over the past three decades. India's buffalo, cow, and goat milk production increased from 31.5 in 1980 to about 97 MMT in 2005 and 109 MMT in 2008.

Table 3.7 – Trends in Annual Production of Buffalo, Cow, and Goat Milk (metric tons)

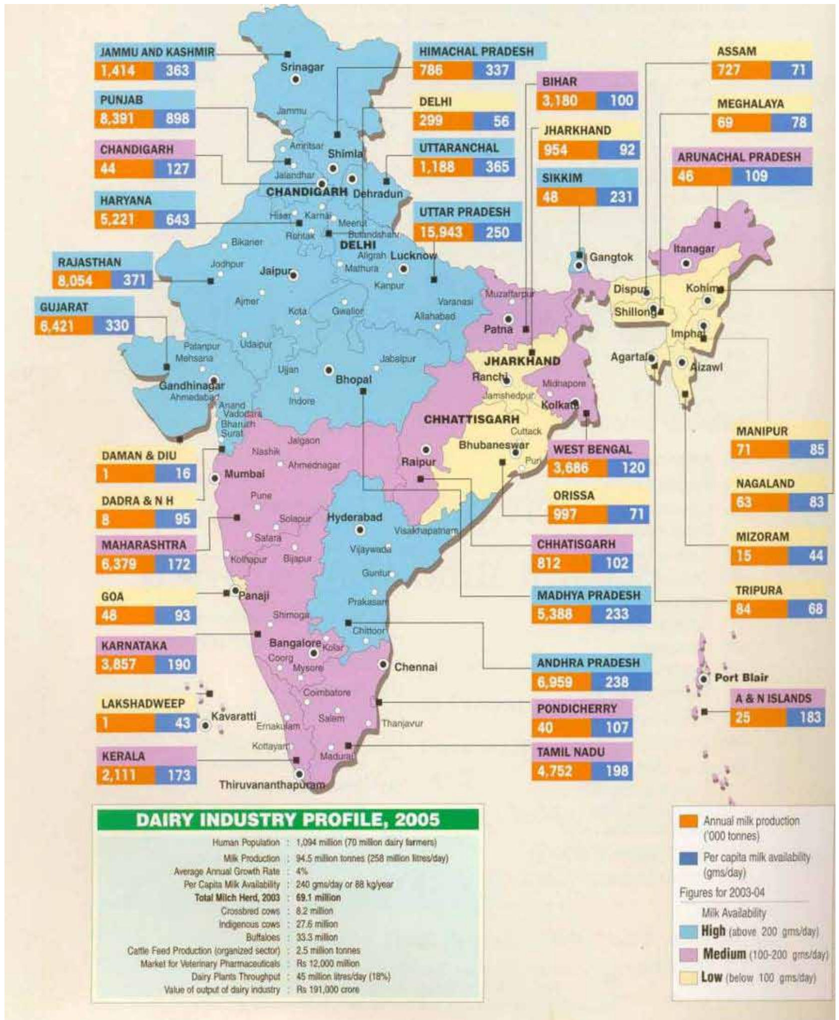
	1980	1990	2000	2004	2008
Buffalo milk	17,358,000	29,057,000	43,428,000	50,178,000	60,900,000
Cow milk	13,255,000	22,240,000	32,967,000	37,344,000	44,100,000
Goat milk	947,000	2,381,000	3,266,000	3,537,000	4,000,000
Total	31,560,000	53,678,000	79,661,000	91,059,000	109,000,000

Source: FAOSTAT, 2010

While there has been a significant increase in overall milk production, the 2007–2008 National Dairy Plan estimated that the demand for milk is likely to be on the order of 172 MMT in 2021–2022. Therefore, the sector must grow at a rate of approximately 4 percent per year to keep pace with increasing demand.

Milk production in India is highly geographically concentrated. Figure 3.7 shows the distribution of milk production across India.

Figure 3.7 – Dairy Map of India



Source: Dairy India, 2007

Table 3.8 clearly highlights that there are regions of concentrated milk production in the country. Just 10 states constitute greater than 80 percent of the overall milk production.

Table 3.8 – States With the Highest Milk Production (2005)

Rank	State	Milk Production (MMT)	Percentage Share of Milk Production
1	Uttar Pradesh	15.94	18.1
2	Punjab	8.39	9.5
3	Rajasthan	8.05	9.1
4	Andhra Pradesh	6.96	7.9
5	Gujarat	6.42	7.3
6	Maharashtra	6.38	7.2
7	Madhya Pradesh	5.39	6.1
8	Haryana	5.22	5.9
9	Tamil Nadu	4.75	5.4
10	Karnataka	3.86	4.4
	Total (top 10 states)	71.36	80.9

Source: Dairy India, 2007

To determine the processing capacity of the dairy processing plants across the states, Dairy India Yearbook (2007) performed a data analysis. These data show that approximately 60 percent of the plants can be classified as medium-sized plants and approximately 30 percent as large, as shown in Table 3.9. In addition, these data show that the majority of plants are located in Maharashtra and Uttar Pradesh.

Table 3.9 – Geographic Distribution of Milk-Processing Plants Based on Processing Capacity

Name of State	Small (Capacity <10,000 liters/day)	Medium (Capacity 10,001–100,000 liters/day)	Large (Capacity >100,000 liters/day)
Andaman and Nicobar	1	0	-
Andhra Pradesh	7	20	7
Arunachal Pradesh	–	0	0
Assam	–	2	0
Bihar	2	7	4
Chandighar	–	1	1
Chattisghar	2	1	–
Delhi	–	0	5
Goa	–	2	0
Gujarat	1	17	16
Haryana	1	10	7
Himachal Pradesh	–	2	1
Jammu and Kashmir	–	4	–
Jharkhand	–	3	–
Karnataka	–	8	4
Kerela	–	9	1
Madhya Pradesh	2	3	4
Maharashtra	12	84	39
Punjab	1	17	15
Rajasthan	1	21	6
Sikkim	2	0	–
Tamil Nadu	4	12	17
Tripur	–	1	–
Uttar Pradesh	5	82	30
Uttranchal	–	2	–
West Bengal	–	7	6
Total	42	316	163

Source: Dairy India, 2007

Market estimates suggest that about 35 percent of the milk produced in India is processed. Of the processed milk, about 13 percent falls within the organized sector and 22 percent within the unorganized sector. This analysis was focused on the organized sector (comprising registered dairy plants in the private, cooperative, and government sectors). Table 3.10 summarizes the number of dairy plants that are registered under the Milk and Milk Production Order (MMPO) of 1992. These data indicate that private and cooperative dairies make up the most significant number of milk-processing plants in the country.

Table 3.10 – Number of Dairy Plants Registered Under MMPO (as of March 31, 2006)

Ownership	Number of Plants	Capacity (thousands of liters/day)
Cooperative	246	36,569
Private	493	46,085
Others	50	15,396
Total	789	98,050

Source: Dairy India, 2007

Milk and dairy product processing

In addition to pasteurized fluid milk, dairy processing plants may also produce other dairy products including milk powder, butter, ghee (clarified butter), cream, various cheeses, casein, condensed milk, and other dairy products based on demand (both seasonal and regional). Milk consists primarily of water (83 to 87 percent), with the balance made up of fat, protein, lactose, and non-fat matter (as total solids). Therefore, most of the products manufactured require removal of water or standardization of the milk fat content during processing.[7] The processing of whole milk requires chilling, clarification, and pasteurization prior to packaging, storage, and distribution.

Water is utilized in milk-processing plants for cleaning equipment, chilling, and during processing. Water also is used for cooling but is segregated from the water used for milk processing and is directly reused. In general, the ratio of fresh water used to milk processed is around 1:1, and the amount of wastewater generated is usually is 75 to 85 percent of water used, depending on the products produced.[8]

3.5.2 Description of Waste Characteristics, Handling, and Management

Wastewater from plants manufacturing dairy products will have higher concentrations of organic compounds than the wastewater from plants only producing fluid milk. In addition, the volume and characteristics of wastewater from plants producing dairy products, such as butter and cheese, will vary depending on the product or combination of products being produced and the plant design and operational practices. Thus, concentrations of BOD, COD, and nitrogen and phosphorus are high. High concentrations of oil and grease and suspended solids also are common, as are wide fluctuations in flow rate and pH throughout the day. Typical wastewater characteristics of a milk-processing unit are provided in Table 3.11.

Table 3.11 – Wastewater Characteristics of a Typical Milk-Processing Unit

Operation	pH	BOD, ppm	COD, ppm	Suspended Solids (SS), ppm	Fat, ppm	Kg BOD/m^3 Milk Production
Milk storage tank washing	4.2 – 10.7	511 – 5,034	1,142 – 11,167	243 – 6,757	-	0.08 – 0.76
Case and crate washing	5.8 – 6.0	226 – 3,170	890 – 5,234	180 – 899	0.25 – 0.085	0.04 – 0.53
Plant washing	10.7	184 – 731	1,183 – 1,250	42 – 1,025	–	0.06 – 0.24

[7] *Indian Ministry of New and Renewable Energy, n.d.*
[8] *Based on our discussion with representatives from a sample of large dairy plants in the country.*

Operation	pH	BOD, ppm	COD, ppm	Suspended Solids (SS), ppm	Fat, ppm	Kg BOD/m³ Milk Production
Processing tank washing	2.9 – 6.0	55 – 360	121 – 832	36 – 332	–	0.01 – 0.06
Raw milk reception dock	6.1 – 9.4	245 – 3,810	411 – 4,522	162 – 2,127	0.05	0.17 – 2.54
Milk processing	6.7 – 10.7	731 – 1,100	1,250 – 3,045	380 – 1,025	-	0.18 – 0.28
Butter production	6.0 – 7.3	810 – 11,595	2,751 – 4.749	46 – 533	–	0.27 – 0.53
Ghee production	5.0 – 6.3	800 – 4,500	3.480 – 13,780	107 – 2,175	0.20 – 2.20	0.20 – 1.13
Cheese production	3.7 – 4.2	8,333 – 50,000	19,504 – 96,000	1,106 – 2,718	0.10 – 0.30	3.33 – 20.32
Casein production	3.5 – 4.4	26,571 – 27,429	64,800 – 79,192	284 – 1,047	0.1	2.66 – 2.74
Powdered milk production	4.1 – 6.3	2,027 – 5,999	4,48 – 10,854	154 – 349	–	0.43 – 1.26
Integrated dairy	5.6 – 6.8	1,654 – 4,953	3800 – 8,631	89 – 4,953	–	5.51 – 16.5

Source: CPCB, n.d.

The environmental regulations of the CPCB require treatment of wastewater before it is discharged. To meet these requirements, most registered dairy plants have installed effluent treatment plants (ETPs) to remove the high levels of suspended solids and associated organic and nitrogenous compounds.

In a standard wastewater treatment process (using anaerobic digestion), applicable to a milk-processing plant, the effluent from the plant is first subjected to primary treatment, which involves removing the suspended matter and floating masses. The effluent is then directed into equalization tanks to dampen the variations in flow and acidify the effluent. After acid formation, the effluent enters an anaerobic digester. Most Indian dairies flare the biogas that is generated. The treated wastewater is either discharged or used in-house for gardening/horticulture.

3.5.3 Case Study

Mahanand Dairy is one of the largest cow milk-processing and distributing plants in India. Mahanand Dairy is at the forefront of any breakthrough or advances in milk production and dairy technology in India. It is a dairy cooperative that processes, packages, and markets 600,000 liters of milk per day through 722 milk distributors. Mahanand Dairy has plants all over Maharashtra and is headquartered in Mumbai. The dairy also produces dairy products such as flavored milk, lassi, misti dahi, dahi, srikhand, ghee, paneer, peda, and ice cream.

The processing of milk and milk products in Mahanand Dairy results in 800 m^3 of effluent wastewater per day and 46 MT of wastewater treatment residuals annually on average. The dairy has operated an anaerobic/aerobic activated sludge wastewater treatment plant since 1996. The wastewater is screened and then goes into a fat removal unit. The wastewater is stored in an equalization tank until it enters the UASB reactor. It is treated anaerobically in the UASB, and then the UASB effluent is polished aerobically with activated sludge. Finally, the effluent is treated using activated sludge. The final step is secondary clarification before discharge. The biogas generated by the UASB reactor is sent to an engine-generator set, which burns 25-30 m^3 of biogas per hour to produce electricity and heat. The resulting wastewater treatment residuals are dried in sludge-drying beds. In addition to MRU projects, Mahanand Dairy has state-of-the-art solar panels that power a hot water boiler.

3.6 SUGARCANE MILLS AND DISTILLERIES

This section discusses both sugarcane processing mills and distilleries (both stand-alone plants as well as integrated plants, where relevant). The molasses produced as the byproduct of raw sugarcane refining is the major feedstock for ethanol production at distilleries, which is why the two industries are grouped together in this report. Although there are stand-alone distilleries, the combination of sugarcane mills and distilleries is common.

3.6.1 Description of Size, Scale of Operations, and Geographic Location

Sugarcane processing mills and distilleries are two of the largest components of India's agro-industry. India has been called the original home of sugar and the sugarcane sector. India is the largest sugar consumer and the second largest sugar producer in the world. India produces traditional cane sugar sweeteners equivalent to approximately 19.55 MMT raw value. Sugarcane cultivation in India has increased only slightly over the last decade, as shown in Table 3.12. However, it is expected to increase more significantly in the future due to improved varieties of sugarcane and technological advances.

Table 3.12 – Productivity and Land Indicators of Sugarcane Production in India

Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Area harvested (ha)	3940	4100	4228	4300	4430	4230	4000	3660	4200	4500	4650	4721
Production (MMT)	262	296	299	296	300	282	236	237	281	315	325	330
Average yield (MT/ha)	66.5	72.1	70.8	68.7	67.7	66.7	59.1	64.8	67.0	70.1	69.9	70.0

Kostka et al., 2009

There were 571 sugarcane processing plants in India as of March 31, 2005, compared to 138 in 1950–1951. In 1999, there were 285 distilleries in India producing 2.7 billion liters of alcohol and generating 40 billion liters of wastewater each year. In 2004, there were 319 distilleries producing 3.25 billion liters of alcohol and generating 40.4 billion liters of wastewater annually.[9]

Sugarcane is cultivated all over India, with major clusters in Maharashtra, Uttar Pradesh, and Tamil Nadu. Figure 3.8 shows the spatial distribution of Indian sugarcane production. Sugarcane mills and distilleries in India are located in or near the major sugarcane-producing areas to minimize raw cane and molasses transportation costs

[9] *Mohana et al., 2009*

Figure 3.8 – Sugarcane Producing States of India

Source: Vasantdada Sugar Institute, n.d.

3.6.2 Description of Waste Characteristics, Handling, and Management

The waste products from sugarcane mills include bagasse (residue from the sugarcane crushing), press mud (soil and other foreign material separated by juice clarification), and wastewater (from washings).

Water is used for cleaning equipment and facilities. The representative characteristics of sugarcane mill wastewaters are presented in Table 3.13. These characteristics are based on the results of two surveys conducted by the Institute of Economic Growth at 60 sugarcane mills during 1994–1995 and 120 mills during 1996–1999.

Table 3.13 – Typical Characteristics of Sugarcane Mill Wastewater

Parameter	Mean	Maximum	Minimum
BOD (mg/L)	995	6,300	35
COD (mg/L)	3,071	31,800	170
SS (mg/L)	1,001	65,000	63

Source: Murty, 2001

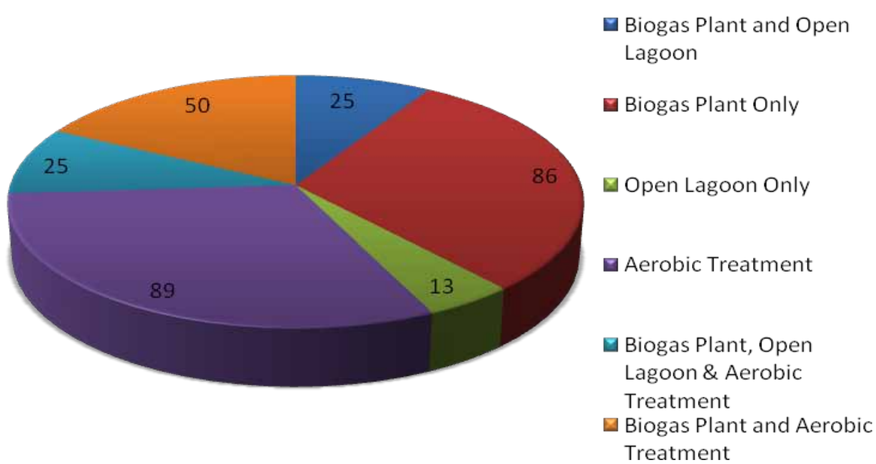
Typical physical and chemical characteristics of wastewater from Indian molasses-based distilleries, which is also known as spent wash, vinasse, or distillery slops, are summarized in Table 3.14. This wastewater also has dark brown color, which makes discharge to surface waters after treatment problematic.

Table 3.14 – Typical Physical and Chemical Characteristics of Untreated Distillery Spent Wash

Parameters	Value for Untreated Spent Wash
pH	3.0–4.5
BOD_5 (mg/L)	50,000–60,000
COD (mg/L)	110,000–190,000
Total solids (TS) (mg/L)	110,000–190,000
Total volatile solids (TVS) (mg/L))	80,000–120,000
Total suspended solids (TSS) (mg/L))	13,000–15,000
Total dissolved solids (TDS) (mg/L))	90,000–150,000
Chlorides (mg/L)	8,000–8,500
Phenols (mg/L)	8,000–10,000
Sulphates (mg/L)	7,500–9,000
Phosphate (mg/L)	2,500–2,700
Total nitrogen (mg/L)	5,000–7,000

As shown in Figure 3.9, a variety of processes are used in India for the treatment of sugarcane mill and distillery wastewaters. Included are combinations of anaerobic and aerobic wastewater treatment processes.

Figure 3.9 – Overview of Waste Management Practices in Sugarcane Processing and Distilleries



Source: FICCI, 2010

3.6.2.1 ANAEROBIC TREATMENT

Because of its high BOD concentration and a favorable BOD:N:P ratio of 100:2.4:1, distillery spent wash is especially suitable for anaerobic treatment prior to land application for disposal, or as a pretreatment process prior to aerobic treatment if surface water discharge is the only wastewater disposal option. Conventional anaerobic lagoons (Figure 3.10) are the simplest choice for distillery spent wash treatment but are significant sources of methane emissions.

As shown in Figure 3-9, use of anaerobic digestion under controlled conditions (biogas plants) for treatment of distillery spent wash is far more common in India than treatment in conventional anaerobic lagoons. However, there is some discharge of biogas plant spent wash effluent to conventional anaerobic lagoons, where some methane will be formed and emitted. Both continuously stirred-tank reactors (CSTRs) and UASB reactors are commonly used.

Figure 3.10 – Anaerobic Lagoon in a Distillery in India

Source: FICCI, 2010

3.6.2.2. AEROBIC TREATMENT

As also shown in Figure 3.9, aerobic treatment of distillery spent wash both solely and in combination with anaerobic treatment is common in India. Combining anaerobic and aerobic processes is a common approach for treating high-strength wastewater, especially when surface water discharge is the only disposal option. The advantage of this combination is that there is a reduction in the energy required for aerobic treatment, which translates directly into reduced carbon dioxide emissions because less fossil fuel is required to generate the necessary electricity. It also reduces the mass of treatment residuals generated and requiring stabilization and disposal. Figure 3.11 shows the composting of press mud at a distillery in India.

Anaerobic treatment of spent wash decreases the COD concentration to 20,000 mg/L, assuming an untreated spent wash COD concentration of 100,000 mg/L and a treatment efficiency of 80 percent during anaerobic treatment, which is the primary treatment step. A subsequent aerobic treatment system process, such as activated sludge treatment, will help with the further reduction of COD and will also lighten the color of the effluent to some extent. After anaerobic treatment, composting of spent wash and press mud is a common treatment option for distilleries connected to a sugarcane processing mill. Figure 3.11 shows the composting of press mud and spent wash at a distillery in India.

Figure 3.11 – Composting of Spent Wash in a Distillery in India

Source: FICCI, 2010

3.6.2.3 BIOGAS UTILIZATION

At about 50 percent of the sugarcane mills and distilleries that utilize anaerobic wastewater treatment under controlled conditions, the captured biogas is used directly as a boiler fuel to generate process heat. The remaining operations use cogeneration to produce both process heat and electricity. The payback period for capture and utilization projects averages 4 to 5 years.

High costs are still a large factor associated with the implementation of both of the aforementioned AD technologies. Though the technologies have been deployed all over India and are available to Indian distilleries, there is no direct regulation mandating the reduction of methane emissions. Because of this, several distilleries continue with traditional practices, such as conventional anaerobic lagoons, which result in methane emissions. Costs are an especially critical factor at cooperative distilleries run by farmers.

However, because of the implementation of Corporate Responsibility for Environmental Protection (CREP) guidelines in several distilleries, distilleries should be able to identify the potential of MRU projects and the benefits, such as attaining energy self sufficiency. Distilleries integrated with sugarcane plants may have the potential to benefit from burning both methane and bagasse in boilers. This would avoid dependency on coal and result in a reduction of both methane and CO_2 emissions. Distilleries may also be encouraged to implement MRUs by partly financing such projects through the Clean Development Mechanism (CDM) of the United Nations Framework Convention on Climate Change (UNFCCC).

3.7 CORNSTARCH AND TAPIOCA PRODUCTION

Starch is a commodity that can be extracted from a number of crops, including corn and cassava, and is used to manufacture a variety of food and non-food products. In the non-food category, the demand for starch is high in the pharmaceutical, textile, paper, and packaging industries. While native starch has industrial uses, modified starches have a broader range of applications and are therefore more effective for industrial use.

The growth of the starch industry in India has been driven by population growth and the increase in disposable income. Government policies, including subsidies in the form of land, power, and water, are also likely to influence the growth of the industry. This assessment focuses on the two largest sectors in the Indian starch industry: corn and cassava.

3.7.1 Cornstarch

3.7.1.1 DESCRIPTION OF SIZE, SCALE OF OPERATIONS, AND GEOGRAPHIC LOCATION

Before it dries, cornstarch forms a viscous, opaque paste with a cereal flavor. It is widely used for thickening sauces, gravies, puddings, and pie fillings. In addition, cornstarch has numerous uses in the baking industry (e.g., for making cakes and cookies), as well as in the ice cream industry. Cornstarch also has applications in the paper industry where it is used as a surface-sizing agent, binder, and paper-coating agent. Cornstarch also has multiple applications in the textile industry.

Currently, about 10 MMT of corn are produced in India, with 12 percent (1.2 MMT) utilized for starch production. A number of processing plants are involved in producing the entire range of products. In addition to cornstarch, there are other value-added products such as modified starch and byproducts of the wet milling process (e.g., dextrose monohydrate, dextrose anhydrous, glucose syrup, sorbitol).

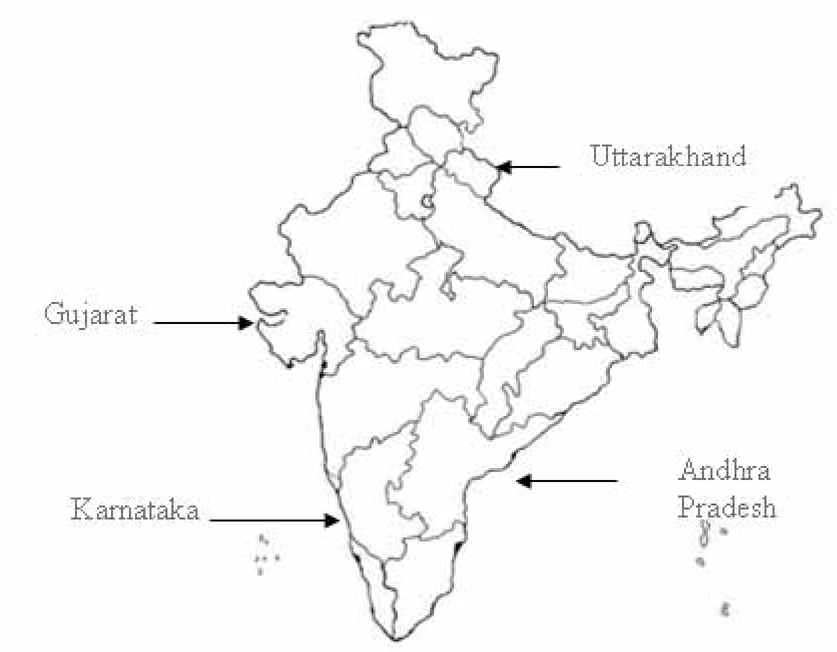
The major starch manufacturing plants are located in and around Ahmedabad (Gujarat). These plants contribute about 50 percent of the total starch production. It should be noted that approximately 40 percent of the cornstarch in India is produced from plants for which there is no readily available data. The largest cornstarch manufacturing plants in India are listed in Table 3.15 and the states where Indian cornstarch production is concentrated are shown in Figure 3.12.

Table 3.15 – Main Starch Production Plants in India

Name	Head Office/Key Location	Estimated Capacity (MT/year)
Anil Starch	Ahmedabad, Gujarat	95,961
Bharat Starch Industries Ltd	Pondicherry	30,059
Gujarat Ambuja Ltd	Ahmedabad Gujarat	32,692
Riddhi Siddhi	Ahmedabad Gujarat	65,126
Sahyadri Starch & Chemicals (P) Ltd	Bangalore, Karnataka	12,147
Sukhjit Starch & Chemicals Ltd.,	Phagwara, Punjab	57,365
Tirupati Starch & Chemicals Ltd.,	Indore, Madhya Pradesh	20,405
Universal Starch Chem Ltd	Dhule, Maharashtra	53,104
Sayaji Industries Ltd	Ahmedabad, Gujarat	113,166
Vensa Biotech	Samalkot, Andhra Pradesh	40,000
Others		679,975
TOTAL		1,200,000

Source: Ministry of New and Renewable Energy, n.d.

Figure 3.12 – Key States Producing Cornstarch



Corn contains about 70 percent starch, with the other components being protein, fiber, and fat. The objective of the corn milling process is to separate the corn kernel into its different parts. Cornstarch is produced by the wet milling process, which involves grinding softened corn and separating corn oil seeds (germs), gluten (proteins), fiber (husk), and finally pure starch. In this process, corn kernels are soaked/seeped after cleaning to remove any foreign matter. The soaked/steeped corn is then sent to special disc disintegrator mill for degermination. The degerminated material is then subjected to separators to separate starch from gluten.

According to a study by MNRE, every metric ton of corn processed yields 0.55 MT of starch. The total production of cornstarch in the country is about 660,000 MT produced from 1.2 MMT of corn. The main steps in a typical production process for corn wet milling are briefly described below.[10]

Cleaning**:** The basic raw material for wet milling is shelled dent corn delivered in bulk. Cleaning ensures that foreign materials are removed from the corn before steeping.

Steeping: Steeping is a controlled fermentation process with sulfur dioxide (SO_2), and it is carried out in a continuous counter-current process where the cleaned corn is processed in a battery of large steeping tanks (steeps), where the corn is soaked in hot water for up to 50 hours. The corn kernels swell to more than double their original size, and the moisture content increases to around 45 percent.

Steep water evaporation**:** Following the steeping process, the steep water generated is drained from the kernels and condensed on a multi-stage evaporator. Most organic acids

[10] *Adapted from Ministry of New and Renewable Energy, n.d.*

formed during the concentrated fermentation are volatile and evaporate with the water. The condensate from the first evaporator stage will therefore be discharged after the heat is recovered for preheating the feed steep water.

Spent steep liquor, containing 6 to 7 percent dry matter, is continually drawn off for subsequent concentration. The steep water is evaporated to an auto-sterile product—a valuable nutrient in the fermentation industry—or concentrated to approximate 48 percent dry matter and mixed and dried with the fiber fraction.

***SO_2 plant*:** Sulfurous acid is used for steeping to soften the corn kernels and to control microbiological activity throughout the process. The SO_2 is prepared by burning sulfur and absorbing the gas formed in water. The absorption takes place in water spray in the absorption towers. The sulfurous acid is collected in intermediate storage tanks. SO_2 may also be supplied in steel cylinders under pressure.

***Germ separation*:** Softened kernels are broken up in attrition mills to loosen the hull and break the bonds between germ and endosperm. Water is added to assist the wet milling. Oil constitutes one-half of the weight of the germ at this stage, and the germ is easy to separate by centrifugal force. The lightweight germs are separated from the ground slurry by hydrocyclones to remove the prime germ. To complete the separation, the product stream with remaining germs is reground by a second milling operation followed by a second hydrocyclone separation, which effectively removes residual germ. The germs are repeatedly washed to remove the starch. Process wash water is added at the last stage.

***Germ drying*:** Surface water then is removed from the germ using a tapered screw press. The dewatered and clean germ is then fed into a rotary steam tube bundle dryer and dried to approximate 4 percent moisture. Low moisture content improves shelf life of the germ. The remaining fibers are removed from the dried germ by a pneumatic separator and transported to the fiber silo. Finally, the germ is pneumatically transported to a germ silo, ready for bagging or further processing.

***Corn/corn oil*:** Mechanical presses and solvent extraction are used to extract the crude oil from the germ. The oil then is refined and filtered. A typical yield per metric ton of corn is 27 kg corn oil. During refining, free fatty acids and phospholipids are removed. The finished oil is used in food, as cooking oil, or as raw material for margarine.

***Fine grinding and screening*:** After germ separation, the mill flow is finely ground in impact or attrition mills to release starch and gluten from the endosperm cell walls (fibers). The degerminated mill starch leaving the fine mill is pumped to the first stage of a fiber washing system, where starch and gluten is screened off. The hull and larger fibers are washed free from adhering starch and gluten (insoluble protein) on screens, countercurrent to process wash water added at the last stage. The last fiber washing stage has a slightly courser screen for pre-dewatering the fiber prior to a tapered screw press. The “throughs” (fine fiber) of the screen are separately dewatered on a rotating screen.

***Fiber drying*:** The dewatered fibers from the dewatering press may be mixed with concentrated steep water and dried in a rotary steam tube bundle dryer to about 12 percent moisture. The dried fiber is disintegrated in a hammer mill and pneumatically transported to a silo ready for bagging. Drying is facilitated by powder recycling.

***Starch and gluten primary separation*:** Crude starch milk from the dewatering screen ahead of the fine mill and from the first stage fiber washing are combined. The crude starch milk contains starch, gluten, and solubles. It is fed to a primary separator via a safety strainer and degritting cyclone. The difference in density makes it possible to use centrifugal force for continuous separation. Gluten enters into the overflow and starch enters the underflow.

***Gluten concentration and dewatering*:** The primary separator overflow, containing mostly protein and solubles, is concentrated on a nozzle-type continuous centrifugal separator. The overflow from the gluten separator is used as process water. The underflow, which is mainly protein and a small amount of starch, is discharged to the gluten dewatering section. The gluten stream contains at least 60 percent protein. Process water from the gluten concentrator and gluten filter is collected and used for washing germs and fiber and for steeping.

***Gluten drying*:** The gluten slurry is dewatered on a vacuum belt filter. The filter belt is continuously washed with high-pressure filtrate. The dewatered gluten is dried in a rotary steam tube bundle dryer to approximately 10 percent moisture and then disintegrated in a hammer mill. Drying is facilitated by powder recycling. The fiber fraction is pneumatically transported to the fiber silo, ready for bagging.

***Starch refining*:** Washing with fresh clean water refines the crude starch milk. With hydrocyclones it is feasible to reduce fiber and solubles, including soluble protein, to low levels with a minimum of fresh water. To save water, the wash is done countercurrent (i.e., the incoming fresh water is used on the very last step, and the overflow is reused for dilution on the previous step). By using multi-stage hydrocyclones, all soluble materials and fine cell residues are removed in a water-saving process. The refined starch milk contains an almost 100 percent pure starch slurred in pure water. The overflow of the first washing stage contains mainly protein, some starch and other impurities, which are recycled to the primary separator.

The starch is separated through the use of a hydrocyclone and a centrifuge. Although some impurities go with the starch in the underflow, larger particles are removed by using a sieve.

***Starch dewatering/ drying*:** The purified starch milk is sent via an overhead tank and discharged to a peeler centrifuge for dewatering. The peeler filtrate is recycled to the primary separator or to the starch refining. The dewatered starch is peeled off in batches and discharged by gravity to the moist starch hopper. From the moist starch hopper, the starch is fed by a metering screw conveyor into a flash dryer and dried in hot air. The dried starch is pneumatically transported to a starch silo, ready for screening and bagging. The moisture content of cornstarch after drying is normally 12-13 percent. Before delivery the starch is screened on a fine sieve to remove any scale that might have formed.

***Starch modification*:** Most starch is used for industrial purposes and is modified to meet the end-use requirements. By applying different reaction conditions—such as temperature and pH—and strict process controls, specialty starch products (termed as modified starch) with unique properties are made commercially. Modified starch retains its original granule form and thereby resembles the native (unmodified) starch in appearance, but the modification improves the quality of the starch.

3.7.1.2 DESCRIPTION OF WASTE CHARACTERISTICS, HANDLING, AND MANAGEMENT

As is evident from the production process, the cornstarch industry produces significant quantities of liquid, as well as solid wastes. In most of the manufacturing plants, the waste recovery process involves salvaging byproducts such as glucose monohydrate, gluten, and fiber. The quantity and composition of the liquid and solid wastes are discussed below.

The steps in the manufacturing process that are major sources of liquid waste include steeping, germ separation, and fiber drying. It has been estimated that around 8.3 m^3 of wastewater is generated for every metric ton of corn processed.[11] The total quantity of wastewater generated from this industry in India is about 28,000 m^3 per day, based on an average of 3,370 MT of corn processed per day.

The analysis of the wastewater from cornstarch plants indicates a BOD of 4,000 to 12,650 mg per liter and a COD in the range of 10,000 to 20,000 mg per liter. The wastewater is also acidic in nature and contains a variety of carbohydrates and lactic acid. Table 3.16 details typical wastewater characteristics.

Table 3.16 – Characteristics of the Wastewater from Cornstarch Plants

Characteristics	Values
pH	4 – 5
BOD	4,000 – 12,650 mg/L
COD	10,000 – 20,000 mg/L
TSS	5,600 – 11,000 mg/L
TDS	4,000 – 6,000 mg/L

Source: CPCB, n.d.

Solid wastes generated from the cornstarch production process are primarily in the form of corn husk and oil cake. In most cases, the solid waste is disposed of by various methods, and only a limited quantity is used as animal feed. About 17 MT of corn husk and 5 MT of oil cake are produced for every 100 MT of corn processed. Using these approximate values, the total amount of solid waste generated from the Indian cornstarch industry is estimated to be around 0.26 MMT annually (consisting of 0.20 MMT of husk and 0.06 MMT of oil cake).

The chemical composition of the solid waste produced from cornstarch plants is shown in Table 3.17.

Table 3.17 – Characteristics of the Solid Waste from Cornstarch Plants

Residues	Crude Protein (%)	Fiber (%)	Lignin (%)	Ash (%)
Stover	4.3	74.6	6.6	5.8
Husk	5.8	62.5	4.5	2.7
Cob	2.4	86.1	8.6	1.9
Bran	10.2	63.5	4.1	2.2

Source: FAOSTAT, 2010

[11] *Ministry of New and Renewable Energy, n.d.*

To estimate potential methane reduction in the cornstarch industry, we identified the various waste management systems currently in use to treat both the wastewater and the solid waste. Table 3.18 provides an overview of the approaches currently in place in the various cornstarch manufacturing plants in India. As indicated in Table 3.18, it is estimated that 25 percent of the other large and 50 percent of the other medium and small plants use conventional anaerobic lagoons or storage tanks, which are sources of methane emissions.

Table 3.18 – Current Waste Management Systems in Various Cornstarch Plants

Name	% of Total Production	Current Waste Management System
Anil Starch	43	Anaerobic wastewater treatment with methane capture
Bharat Starch Industries, Ltd.		UASB with methane capture
Gujarat Ambuja Proteins, Ltd.		Anaerobic wastewater treatment with methane capture
Riddhi Siddhi		Anaerobic wastewater treatment with methane capture
Sahyadri Starch & Chemicals (P) Ltd.		Anaerobic wastewater treatment with methane capture
Sukhjit Starch & Chemicals Ltd.		Anaerobic wastewater treatment with methane capture
Tirupati Starch & Chem Ltd.		NA
Universal Starch & Chemicals Ltd.		Wastewater treatment plant with biodigestion
Sayaji Industries Ltd		Anaerobic plant followed by aerobic plant and tertiary plant
Vensa Biotech		Anaerobic treatment of wastewater and solid wastes with methane capture
Other large plants	57	Assume 75% with existing wastewater treatment systems have anaerobic unit processes with methane capture
Other medium and small plants		Assume 50% with existing wastewater treatment systems have anaerobic unit processes with methane capture

Source: Ministry of New and Renewable Energy, n.d.

3.7.1.3 *CASE STUDY*

Yashwant Sahakari Glucose Karkhana Ltd. (YSGKL) is a cooperative starch and glucose production unit with maize as the raw material. The wastewater generated in each step of the wet milling process has a high concentration of particulate and soluble organic matter with the latter including the lactic acid produced during steeping. YSGKL generates about 500 m^3 of wastewater per day with an average COD concentration of 20,000 mg per L. The wastewater from each processing step is combined in a flow equalization tank, which is followed anaerobic and then aerobic treatment before discharge. Currently, the captured biogas is being flared for disposal but use in a 600 kW engine-generator set is planned.

3.7.2 Cassava/Tapioca

3.7.2.1 DESCRIPTION OF SIZE, SCALE OF OPERATIONS, AND GEOGRAPHIC LOCATION

Cassava is an important root crop, and India is one of the world's major producers, along with Brazil, Indonesia, Thailand, Nigeria, and Zaire. While the crop can be cultivated throughout the year with irrigation, its importance stems from the fact that it has the flexibility and adaptability to withstand adverse soil and drought conditions. India has an annual cassava production of about 6.18 MMT from 0.235 million hectares under cultivation.[12] Projections indicate that cassava production is expected to reach 7.44 MMT by 2020.[13]

One of key uses of cassava is as a source of starch such as tapioca. The term cassava is usually used to denote the tubers, whereas tapioca is used to denote processed products of cassava. In India, however, the entire cassava plant is also referred by the term tapioca. Tapioca is used in the food-processing industry (including the manufacture of sago used in infant/baby food), as well as in the textile, paper, and pharmaceutical industries. Starch derivatives include corrugated gum starch, carboxyl methyl starch, acid-modified starch, cationic starch, and pre-gelatinized starch.

Tapioca production is seasonal and time sensitive. While the cassava tuber is available from July to April, the maximum quantity of raw material is available from November to February, during which time the starch content of the tubers is at its peak. The crushing activity therefore reaches its peak during this period. While the extraction of starch is a straightforward process, the roots of the cassava plant must be processed within 24 hours after harvesting the crop to ensure a high quality product.

Around 100,000 MT of tapioca are produced in India every year. The key starch-producing clusters (with around 600 plants) are in the Salem and Namakkal districts of Tamil Nadu. The production capacity of these plants is in the range of 0.6–600 MT per month. Approximately one-tenth of the plants produce more than 100 MT of starch per month, and two thirds of the plants produce less than 50 MT of starch per month.[14]

The manufacture of starch is carried out in four types of establishments:

- Cottage industries (producing 50 to 60 kg of crude starch per employee per day)
- Small-scale plants (processing 5 to 50 MT of tubers per day)
- Medium-scale plants (processing 50 to 100 MT of tubers per day)
- Large-scale plants (processing more than 100 MT of tubers per day)

While cassava is cultivated in 13 states in India, the key production areas are concentrated primarily in the southern Indian states of Kerala, Tamil Nadu, and Andhra Pradesh. While Kerala has historically been the key cassava-growing state in the country, the states of Tamil Nadu and Andhra Pradesh have witnessed remarkable growth in recent years. In Kerala, cassava is cultivated predominantly as a staple food crop. In the states of Andhra Pradesh

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[12] *Edison, 2002*
[13] *Sudhandhiran, 2001*
[14] *Ministry of New and Renewable Energy, n.d.*

and Tamil Nadu, it is used as an industrial crop. Starches (such as sago) are produced from cassava in more than 900 small- and medium-scale plants and at least two large-scale plants in Tamil Nadu. In Andhra Pradesh, one large-scale and about 35 small-scale plants process cassava for starch and sago production. Figure 3.13 depicts the key tapioca producing states in India.

Figure 3.13 – Main States Producing Tapioca

The manufacturing process for tapioca production consists of the following steps:[15]

Washing and peeling: The tubers are washed and peeled. This is done by mechanical scrubbing using a perforated drum partially immersed in a water bath. The roots are propelled forward by a series of paddle arms or a spiral brush attached to a central rotating shaft. A countercurrent flow of water through the bath ensures continuous removal of soil. In certain cases, high-pressure water spraying from nozzles may also act on the roots. The combined action of the high-pressure water jets and abrasions of the tubers against the drum walls and against each other removes most of the epidermis.

***Rasping*:** The washed tubers are "rasped" to disintegrate the cellular structure and rupture the cell walls. This releases the starch from other insoluble matter. The "rasper" consists of a rotating drum (40 to 50 cm in diameter and 30 to 50 cm length) with longitudinal sawtooth blades. Following the preliminary rasping, the coarse pulp is reground in a secondary rasp with finer blades having a greater number of teeth per unit length of blade and then returned for rescreening. While a rasping effect of about 85 percent is achieved at the first rasping, the overall rasping effect is raised to 90 percent after secondary rasping.

***Screening*:** This separates the rasped pulp into two components—specifically, waste fibrous material (known as *tippi*) and starch milk. A series of vibrating screens with increasing fineness (80, 150, and 260 mm mesh) are used, aided by water showers, to separate starch

[15] Adapted from *Ministry of New and Renewable Energy, n.d.*

from the fibrous matter. Alternatively, sieve bands (DSM screens) with three to six stages in a series can also be used. Another effective device for separating starch from cellulose fiber is the jet ejector, or the continuous perforated basket centrifuge. A process of sedimentation using primary and secondary sedimentation tanks is also undertaken.

***Dewatering*:** The starch separated from the fibrous material is then dewatered mechanically using a rotary vacuum filter or a disc centrifuge. Dilute starch may be concentrated at rates of 70 m^3 per hour to obtain cakes with 22 to 25 percent solids. The process wastewater will have 1,000 to 2,000 mg per L of suspended starch particulate.

***Drying*:** The damp starch is dried to remove the moisture. Tray dryers, rotary dryers, belt and tunnel dryers, and flash or pneumatic dryers are used for starch drying. The final product has a moisture content of 10 to 12 percent.

***Finishing*:** The dried material is then pulverized, sifted, and packaged for sale.

3.7.2.2 DESCRIPTION OF WASTE CHARACTERISTICS, HANDLING, AND MANAGEMENT

Water is required primarily for two stages of tapioca manufacturing: washing and screening. During the washing stage, water is required for washing the tubers before peeling to remove the soil and dirt remaining on the surface of the roots. In the screening stage, water is required to separate free starch from the fibrous pulp. In addition to these two stages, water is also required during the rasping operation, albeit in limited quantity. The quantity of water consumption in the starch industry is estimated to be between 36 and 40 m^3 per metric ton of output.[16]

Wastewater from the starch manufacturing process is generated during tuber washing (accounting for about 10 percent of the wastewater generated) and also during the sedimentation process (accounting for about 90 percent of the wastewater generated). The amount of wastewater generated ranges from 28 to 32 m^3 per metric ton of starch produced.[17]

The characteristics of the wastewater differ depending on the stage of the manufacturing process. The characteristics of the combined wastewater are presented in Table 3.19.

Table 3.19 – Characteristics of Wastewater from Tapioca Plants

Characteristics	Values
pH	4.5 – 5.6
BOD	4,600 – 5,200 mg/L
COD	5,631 – 6,409 mg/L
TSS	565 – 640 mg/L
TDS	3,435 – 3,660 mg/L

Source: Sagoserve, 1996

[16] *Ministry of New and Renewable Energy, n.d.*
[17] *Ministry of New and Renewable Energy, n.d.*

The two major sources of solid waste are the peelings and the screenings of starch slurry before sedimentation (i.e., *tippi*). The peelings and sun-dried *tippi* are used primarily as a cattle feed.

With regard to waste management systems, it has been noted by MNRE in their National Master Plan for Development of Waste to Energy in India that a significant number of tapioca plants in the state of Tamil Nadu are small-scale plants (approximately two-thirds of the plants manufacture less than 50 MT of output per month). MNRE has also noted that these plants have been discharging waste into the environment and are facing potential regulatory action. Larger plants such as Varalakshmi Starch Industries (P) Ltd. have invested in effluent treatment systems to generate biogas from wastewater in its plant in Salem, Tamil Nadu.

For the purpose of this study, it was assumed that 25 percent of the small plants (less than 50 MT per month), which represent two-thirds of the plants, use open lagoons, while the other small plants directly discharge waste into the environment. It is also assumed that large plants capture biogas during treatment.

Table 3.20 lists waste-to-energy projects in the starch manufacturing subsector. This information was obtained from MNRE and shows which plants currently are operating anaerobic digesters (as of 31 March 2009). The list includes projects that have received funding from MNRE; projects that have not received support from MNRE and projects that are under consideration for support by MNRE are not been included in the list.

Table 3.20 – List of Existing Waste-to-Energy Projects in the Starch Industry

Name and Location	Type	Capacity	Year of Commissioning
Biogas plant based on Starch Industry Wastes at Vensa Biotek, Samalkot, A.P.	Corn	0.70 MWeq (8,000 m^3 biogas/day)	1999–2000
Power generation from starch industry solid waste at M/s Vensa Biotek Ltd., E.G. District, Samalkot, A.P.	Corn	4.00 MW	2003–2004
Biomethanation plant based on starch industry waste at Anil Starch, Ahmedabad, Gujarat.	Corn	0.45 MWeq (4,800 m^3 biogas/day)	2001–2002
Starch industry waste-based biomethanation project by M/s Riddhi Siddhi Gluco Biols, Ltd., Riddhi Siddhi Nagar, Village – Juna Paddaar, Becharjee Road, Virmgam, Distt. Ahmedabad, Gujarat	Corn	0.458 MWeq. (5,500 m^3 biogas/day)	2007–2008
Starch industry waste-based biogas-to-power (through 100% biogas engine) project by M/s Sayaji Industry Ltd., Ahmedabad, Gujarat	Corn	1.00 MW	2008–2009
Starch industry waste-based biomethanation project by M/s Riddhi Siddhi Gluco Boils Pvt. Ltd., Gokak, Karnataka	Corn	2.00 MWeq. (24,000 m^3 biogas/day)	2007–2008
Starch industry waste-based biomethanation project by M/s Riddhi Siddhi Gluco Boils Pvt. Ltd., Gokak, Karnataka	Corn	1.00 MWeq. (12,000 m^3 biogas/day)	2008–2009
Biogas generation project at Universal Starch-Chem Ltd., Dhule, Maharashtra	Corn	0.90 MWeq. (10,000 m^3 biogas/day)	2001–2002
Starch industry waste-based biomethanation project by M/s Sukhjit Starch & Chemicals Ltd., Phagwara, Punjab	Corn	0.458 MWeq (5,500 m^3 biogas/day	2006–2007

Name and Location	Type	Capacity	Year of Commissioning
Power generation project based on biogas from Sago Industry Waste at Varalakshmi Starch Industry Ltd., Salem, Tamilnadu	Corn	0.20 MW	2001–2002
Biogas generation project for tapioca processing industry wastewater at Varalakshmi Starch Industry Ltd., Salem, TN.	Cassava and corn	0.50 MWeq (6000 m^3 biogas/day)	2002–2003
Starch industry waste based biomethanation project by M/s Varalakshmi Starch Industries Pvt. Ltd., Salem, T.N.	Cassava and corn	1.00 MWeq. (12,000 biogas m^3/day)	2006–2007
Starch industry liquid waste-based biomethanation project by M/s Varalakshmi Co., Mallur, Salem, Distt. Namakkal	Cassava and corn	0.75 MWeq (9,000 m^3 biogas/day)	2008–2009
Tapioca industry liquid waste-based biomethanation project by M/s Spac Tapioca Products (India) Ltd., Poonachi Bhavani TK , Erode, Tamilnadu	Cassava	1.00 MWeq (12,000 m^3 biogas/day)	2008–2009
Starch industry liquid waste-based biomethanation project by M/s Riddhi Siddhi Gluco Biols, Udham Singh Nagar, Uttarakhand	Corn	1.52 MWeq (18,300 m^3 biogas/day)	2007–2008
Starch industry liquid waste-based biomethanation project by M/s Gujarat Ambuja Exports Ltd., Udham Singh Nagar	Corn	1.08 MWeq (12,960 m^3 biogas/day)	2008–2009

Source: Kishore and Pant, n.d.

The list of projects above demonstrates that methane from starch plants can be successfully captured and used. The list also demonstrates the potential benefits for starch manufacturing plants that do not currently have waste treatment systems for capturing methane.

3.8 FOOD PROCESSING

The food processing sector includes all the subsectors related to the food crop, produce, and livestock sectors. In general, food processing encompasses all activities that transform raw agricultural commodities into products that are intended for human consumption. For the purpose of this report, however, the food-processing subsectors of fruits and vegetables, edible oils, and grain processing are considered. These subsectors represent more than two-thirds of the food-processing sector in India.

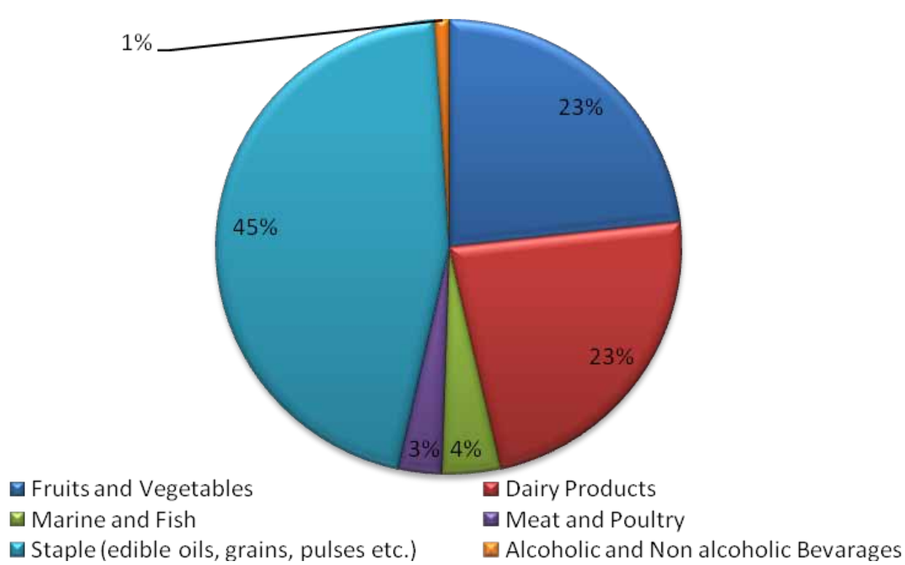
India is among the leading food producers in the world, having the second largest arable land area. The diverse agro-climatic conditions in the country are favorable for the production of a wide variety of crops. Though the food-processing sector in India is one of the largest in the world, it is highly unorganized. A large percentage of production (49 percent) in the food-processing sector comes from the unorganized fraction (Figure 3.14).

Figure 3.14 – Segment-wise Share of Production in the Food-Processing Sector

Source: Indian Brand Equity Foundation (IBEF), 2008

From 2004 to 2007, the number of registered, operating food processing plants increased from 24,000 to 25,725.[18] Food processing currently contributes 14 percent to manufacturing GDP, with an annual product value of 2.8 trillion rupees. About 70 percent of India's expenditures for food and beverages are for fruits and vegetables and staples (Figure 3.15) of which two-thirds are for processed products.

Figure 3.15 – Percentage Distribution of Spending of Each Subsector in the Food-Processing Sector



Source: Ministry of Food Processing Industries, Government of India (MOFPI), n.d.

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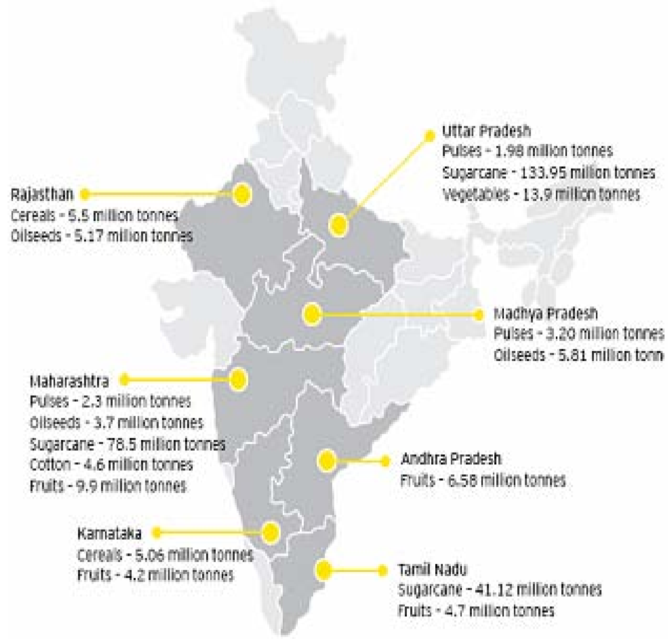
[18] *FICCI, (2008).*

The industries from the food-processing sector are mainly based in Andhra Pradesh, Rajasthan, Uttar Pradesh, Madhya Pradesh, Tamil Nadu, Karnataka, and Maharashtra (see Figure 3.16). There are several agricultural produce market committees (APMCs) established in each state to facilitate marketing of the agricultural produce.

Figure 3.16 – The Productivity of Major Agricultural States in India



Source: Ministry of Agriculture, Government of India

Correspondingly, there are many regional clusters formed for many food commodities. There are about 358 clusters identified in the country. These clusters include:

- Fruit and vegetable processing clusters in Pune (Maharashtra) and all of Bihar
- Petha clusters in Agra (Uttar Pradesh)
- Mango clusters in Chittoor (Andhra Pradesh) and Krishnagiri (Tamil Nadu)
- Chikki clusters in Lonavala (Maharashtra)
- Rice milling clusters in Punjab, Haryana

The key producing regions are shown in Figure 3.16. The food processing industry produces large amounts of biodegradable waste. However, only the fruit and vegetable sector produces a significant amount of liquid waste and is therefore a potential sector for methane emission reduction. The other sectors that were evaluated but not found to have potential for signification methane emission reductions (edible oil and grain processing) are described in the appendices.

3.8.1 FRUITS AND VEGETABLES

3.8.1.1 DESCRIPTION OF SIZE, SCALE OF OPERATIONS, AND GEOGRAPHIC LOCATION

India produces the widest range of fruits and vegetables in the world. It is the second largest vegetable producer and third largest fruit producer, accounting for 8.4 percent of the world's production.[19] Fruit production in India registered a growth of 3.9 percent from 2000 to 2005, whereas the fruit-processing sector grew several times faster, at 20 percent over the same period. Table 3.21 presents a summary of the fruit and vegetable production in 2008.

Table 3.21 – Fruit and Vegetable Production in India

Fruit	Production in 2008 (MT/yr)
Bananas	23,204,800
Mangoes, mangosteens, guavas	13,649,400
Fruit, fresh (not elsewhere classified)	6,862,000
Oranges	4,396,700
Fruit, tropical fresh nes	3,575,900
Papayas	2,685,900
Lemons and limes	2,429,000
Apples	2,001,400
Grapes	1,677,100
Pineapples	1,305,800
Pears	200,000
Grapefruit (including pomelos)	187,000
Plums and sloes	160,000
Citrus fruit (not elsewhere classified)	156,000
Peaches and nectarines	150,000
Figs	10,500
Apricots	10,000
Cherries	8,000
Berries (not elsewhere classified)	1,400
Stone fruit (not elsewhere classified)	1,400
Total fruit	**62,672,300**
Vegetables	Production in 2008 (MT/yr)
Vegetables, fresh (not elsewhere classified)	29,117,400
Tomatoes	10,260,600
Eggplants	8,450,200
Dry onions	8,178,300
Cabbages and other brassicas	5,283,200
Cauliflower and broccoli	5,014,500
Pumpkin, squash, and gourds	3,500,000
Okra	3,497,200
Green peas	2,292,700
Lettuce and chicory	790,000
Other melons (including cantaloupes)	645,000
Garlic	645,000
Green beans	420,000
Carrots and turnips	350,000

[19] *FICCI, 2010*

Fruit	Production in 2008 (MT/yr)
Watermelons	255,000
Cucumbers and gherkins	120,000
Green chilis and peppers	51,000
Mushrooms and truffles	16,000
Total vegetables	**78,886,100**
Total fruit and vegetables	**141,558,400**

Source: FAOSTAT, 2010

The total land area being cultivated for fruit is estimated at 4.18 million hectares. The total land area being cultivated for vegetables is estimated at 7.59 million hectares. However, less than two percent of the total vegetables and fruits produced in the country are commercially processed, compared to nearly 70 percent in Brazil and 65 percent in the United States. About 20 percent of fruits and vegetables processed in India are exported. Fruit exports have registered a growth of 16 percent in volume and 25 percent in value in 2005–2006. Mango and mango-based products alone constitute 50 percent of the exports.

The total capacity of the fruit and vegetable processing industry has increased from 1.1 MMT in January 1993 to 2.5 MMT in January 2007.[20] Major states in India contributing to fruit and vegetable production are

- Andhra Pradesh (mango, tomato, chilis, turmeric)
- Uttar Pradesh (mango, potato)
- Gujarat (onion, potato, banana, mango)
- Maharashtra (grapes, mango, banana)
- Karnataka (citrus fruits, grapes, mango)
- Tamil Nadu (guava, banana, mango)
- West Bengal (brinjal, cabbage, potato, mango)
- Himachal Pradesh and Jammu and Kashmir (temperate fruits, apple, pear, plum, peach)

The principal products in the fruit and vegetable segment are fruit pulps and juices; fruit–based, ready-to-serve beverages; canned fruits and vegetables; jams; squashes; pickles; chutneys; dried fruits and vegetables; fruit juice concentrates; and dehydrated vegetables. The various operations involved in fruit and vegetable processing are washing, husking, desilking, blanching, cutting, peeling, slicing, clipping, screening, grading, and inspection. These processes are employed as required.

3.8.1.2 DESCRIPTION OF WASTE CHARACTERISTICS, HANDLING, AND MANAGEMENT

Food processors may generate wastewaters with totally different physical and chemical characteristics. These wastewaters can contain high organic loads, concentrations of carbohydrates, cleansing and blanching agents, salt, and suspended solids such as fibers and soil particles. They may also contain pesticide residues washed from the raw materials. The BOD and COD concentrations in these wastewaters vary with the type of fruit or vegetable processed. They may be as high as 1,000 mg per liter BOD and 2,000 mg per liter COD for potato processing wastewater.

[20] *D&B, 2008*

The fruit and vegetable industry typically generates large volumes of solid waste comprising leaves, trimmings, stems, peels, pods, husks, cobs, silk, and defective processed vegetables. The waste generated is 43 percent of the total quantity processed. The main solid wastes are organic materials, including discarded fruits and vegetables.

Wastewater from the fruit and vegetable subsector can have high concentrations of organic matter, and it is amenable to secondary biological treatment. Preliminary treatment of wastewater includes screening (or sieving to recover pulp) and grit removal, if necessary. This is followed by pH adjustment and aerobic treatment. Although aerobic biological treatment has been a common practice, variable flow rates and concentrations of organic compounds result in operational problems and variations in effluent quality. Another problem with aerobic treatment of fruit and vegetable processing wastewater is the quantity of biosolids generated. Finally, high-energy costs can result in wastewater being aerated less than required, resulting in the formation of anaerobic conditions and methane emissions.

Because of the problems with aerobic treatment noted above, anaerobic processes have become the preferred approach for treating fruit and vegetable processing wastewater in India and elsewhere. In addition, anaerobic processes offer the potential of producing a usable form of energy for boiler fuel or for generating electricity. The potential methane production from various types of fruit and vegetable processing wastes are presented in Table 3.22.

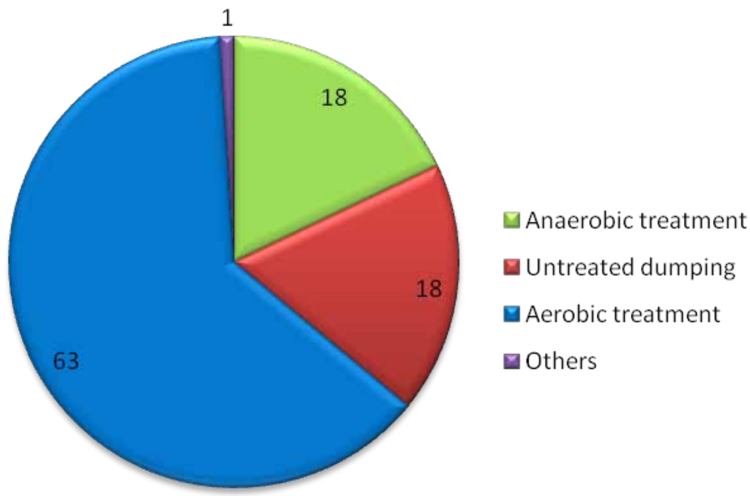
Table 3.22 – Methane Yield Potential From Some of the Fruit and Vegetable Waste

Waste	Methane Yield (m^3/kg VS added)
Spinach	0.316
Strawberry slurry	0.261
Apple pulp	0.308
Pineapple pressings	0.335
Carrot waste	0.417
Papaya fruit processing waste	0.357
Green pea slurry	0.31
Banana	0.529
Mixture of fruit and vegetable waste	0.51
Apricot	0.286
Fruit wastes	0.37
Potato	0.426
Tomato processing waste	0.42

Source: Rajeswari,2009.

The characteristics of the wastewater and solid wastes generated by fruit and vegetable processing reflect the commodity being processed and the nature of the process. Constituents include peelings and pulp (8 to 25 percent); seeds (34 to 50 percent); and water, including brine (10 to 20 percent). Figure 3.17 shows the distribution of wastewater management practices in the Indian fruit and vegetable processing sector.

Figure 3.17 – Waste Management Practices in Fruit and Vegetable Processing Plants



Source: FICCI, 2010

Although those fruit and vegetable processing operations that are utilizing anaerobic waste treatment processes have found them to be beneficial, inadequate policy incentives, including lack of funding, remain barriers to more extensive adoption. Another barrier is the seasonable nature of at least some segments of the industry.

There are several options available for anaerobic wastewater treatment. The UASB reactor is seen as a most effective anaerobic treatment system for fruit and vegetable processing wastewater, providing an 85 to 95 percent reduction in COD concentration. There are also reports of hybrid reactors being used in this subsector. These combine the merits of UASB and fixed film reactors. Hybrid reactors have the advantage of being less sensitive to variations in flow and loading rates. However, they have yet to be used commercially in India.

3.8.1.3 Case study

Mother Dairy Fruits and Vegetables, Pvt. Ltd. is one of the renowned brands in India, not only for dairy products but also for fruit juices, pulp and concentrate, and vegetables. The fruit segment of Mother Dairy's business is marketed under the brand name Safal. This brand is marketed throughout northern India with the production unit at the NDDB campus at Mumbai.

This plant processes tropical fruits, with mango being the most commonly processed. Mango constitutes 65 to 70 percent of the plant's operation in the months of May, June, and July. Other processed fruits include tomatoes (December to February), pomegranates (September to January), bananas (November and December), guavas (November and December), and amlas (November and December). The unit processes mango fruit for 90 to 110 days per year and other fruits for 60 to 70 days. It also packs organic bananas and amlas, as required. The plant has the capacity to process 10,000 MT of fruit per year and currently processes 7,000 MT per year. The fruit is unloaded from the trucks and then sent for sorting and grading prior to primary washing. The fruit is disinfected during primary washing and then processed through secondary washing with water. Next, the fruit is mechanically peeled and the juice is extracted. Once the juice is extracted, it is clarified, filtered, sterilized, cooled, and then packaged in containers.

The solid waste from the plant includes mainly peels, fibers, pulp, seeds, and debris. Mango solid waste is approximately 40 to 45 percent of the total processed weight of the fruit, pomegranate is 40 to 45 percent, banana is 50 percent, guava is 20 to 25 percent, amla is 5 percent and tomato is 5 percent. The solid waste generated is on average about 25 to 35 tons per day during the operating season and is sent to the Bombay Municipal Corporation (BMC) landfill sites for dumping under contract with a private BMC-approved service provider. The NDDB currently transports the generated solid waste via trucks, which carry 3.5 MT per trip; each trip costs 2,500 rupees (Rs). Currently, the plant is spending a substantial amount of money to safely dispose the solid fruit waste.

The liquid waste generated includes the wash water, which has a relatively low BOD concentration and is treated aerobically using the activated sludge treatment process. The onsite wastewater treatment plant has been operating since 1991.

Although there is huge potential for MRU projects in this industry and sector, this plant only operates seasonally, which makes anaerobic digestion more difficult. On average, the plant operates 125 to 150 days per year. The capital investment for AD technology for this plant may not only help in recovering the solid waste disposal costs, but may also generate revenues either through energy savings or through the sale of products such as compost.

4. POTENTIAL FOR METHANE EMISSION REDUCTIONS

This section presents an estimate of the potential for reducing GHGs emissions from livestock manure and agricultural commodity processing wastes though the use of anaerobic digestion. Anaerobic digesters reduce GHG emissions in two ways. First, they directly reduce methane emissions by capturing and burning methane that otherwise would escape from the waste management system into the atmosphere. Second, they indirectly reduce carbon dioxide, methane, and nitrous oxide emissions by using captured biogas to displace fossil fuels that would otherwise be used to provide thermal energy or electricity. Section 4.1 explains the potential methane emission reductions 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 on 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 physically feasible because of the lack of necessary land. Section 4.2 briefly describes types of AD technologies, methane utilization options, costs and benefits, and centralized projects. Appendix D provides more information regarding emissions avoided when wet wastes are sent to landfills, as well as emissions from leakages and waste transportation in projects with comingled substrates.

4.1 METHANE EMISSION REDUCTIONS

AD projects for both manure and agricultural commodity processing wastes may produce more methane than currently is being emitted from 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 system where manure was applied daily to cropland or pasture would produce significantly more methane than the baseline system. As such, the direct methane emission reductions from a digester correspond 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 reductions, as explained in Section 4.1.3, are 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 using Equation 2.1 and the MCF for the baseline manure management system used at the operation, as show in Equation 4.1:

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

where: $CH_{4\,(M,P)}$ = Estimated methane production potential from manure (kg/year)
$VS_{(M)}$ = Daily volatile solids excretion rate for livestock category M (kg dry matter per 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 per kg volatile solids excreted)
MCF_{AD} = methane conversion factor for anaerobic digestion (decimal)

Table 4.1 shows the estimated GHG emission reduction potential for dairy farm operations in India. When the indirect emission reductions are considered, the potential reductions are more than 4.3 $MMTCO_2e$ per year.

Table 4.1 – Methane and Carbon Emission Reductions From Manure

	Dairy Cattle and Buffalo – Solid Storage	Dairy Cattle and Buffalo – Cooking Fuel	Assumptions
H (#)	23,316,348	11,658,174	• Assumes biogas is used to replace coal and generate electricity. • Consider only medium to large farms (32%). • Assumes 40% of manure is piled up or dumped in pits (solid storage) and 20% is burned for fuel (cooking fuel).
VS (kg/head-day)	2.6	2.6	
B_o (m^3 CH_4/kg VS)	0.13	0.13	
MCF	0.04	0.1	
CH_4 (MT/yr)	77,091	96,364	
CO_2 ($MTCO_2e$/yr)	1,618,916	2,023,644	
Indirect emission reduction ($MTCO_2e$/yr)	392,415	490,518	
Total CO_2 ($MTCO_2e$/yr)	2,011,330	2,514,163	

4.1.2 Direct Emission Reductions from Digestion of Agricultural Commodity Processing Wastes

The methane production potential from agricultural commodity wastes is estimated using Equations 2.2 and 2.3 and the MCF for the baseline waste management system used at the operation, as shown in Equations 4.2 and 4.3:

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

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

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

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

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

Based on limited data and best professional judgment, the MCF_{AD} value of 0.80 is used to estimate the methane production potential of ambient temperature digesters. When the W and COD values were not available, IPCC default values were used.

Table 4.2 shows the estimated GHG emission reduction potential for the six major agro-industrial subsectors in India. For the milk-processing sector, it is assumed that there are no baseline methane emissions, as most dairy plants already have ETPs with biogas capture. However, assuming that the captured biogas is used to generate electricity instead of being simply flared, indirect emission reductions through fuel replacement amount to more than 1 MMT CO_2e per year. For the rest of the remaining subsectors, where both direct and indirect emission reductions are considered, the potential GHG reductions range from 14,973 metric tons carbon dioxide equivalent ($MTCO_2$e) per year for tapioca to 966,495 $MTCO_2$e per year for distilleries.

Table 4.2 – Methane and Carbon Emission Reductions from Agro-Industrial Waste

	Milk Processing	Distilleries	Sugarcane	Fruits and Vegetables	Cornstarch	Tapioca	Assumptions
P (MT/year)	30,520,000	146,701	982,301	254,805	94,050	16,667	Biogas use: Assumes biogas is used to replace coal and generate electricity. Milk processing: Assumes 80% would be used to replace fuel oil. Distilleries and Sugar: Assumes only 5% uses open lagoons. Fruit and Vegetables: Assumes only 9% uses open lagoons. Cornstarch and Tapioca: Assumes ~14% (corn) and ~17% (tapioca) use open lagoons.
W (m^3/MT)	7	12	11	20	8.3	30	
COD (kg/m^3)	2.7	110	3.2	5	15	6	
B_0 (kg CH_4/kgCOD)	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	
CH_4 reduction (MT CH_4/year)	N/A	38,729	6,915	5,096	4,258	600	
CO_2 reduction ($MTCO_2$e/year)	N/A	813,313	145,223	107,018	89,416	12,600	
Indirect emission reductions ($MTCO_2$e/yr)	587,241	197,142	35,201	25,941	21,674	3,054	
Total CO_2 reductions ($MTCO_2$e/yr)	587,241	1,010,454	180,425	132,959	11,090	15,654	

4.1.3 Indirect GHG Emissions Reductions

The use of AD systems has the financial advantage of potentially offsetting energy costs at the production facility. Biogas can be used to generate electricity or supplant or eliminate the use of fossil fuels. Using biogas energy also reduces carbon emissions from the fossil fuels that are displaced by using the recovered biogas. The degree of emission reduction depends on how the biogas is used.

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 India, the generation sector is comprised of thermal plants (60 percent), hydroelectric plants (34 percent), and nuclear plants (6 percent). The principal fuels used by the thermal plants are coal, fuel oil, and natural gas. Many thermal plants in India are dual fuel, which allows them to use either natural gas or fuel oil. Currently, fuel oil is used most often for both the base and peak loads. Table 4.3 shows the associated carbon emissions reduction rate if biogas reduces the use of various fossil fuels for generating electricity.

Table 4.3 – 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
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: Hall Associates, 2010

Reduction in carbon dioxide emissions from fossil fuels by the use of biogas to generate electricity was estimated based on the potential of capturing biogas through the use of anaerobic treatment or digestion to reduce methane emissions and its use to generate electricity. For this resource assessment, it was assumed that use of the captured biogas would reduce the use of coal to generate electricity.

4.1.4 Summary

As indicated by the variables in the equations presented in Section 2.2, the principal factor responsible for determining the magnitude of methane emissions from livestock manure 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 4.4 summarizes the findings of the RA in terms of potential methane emission reductions and carbon offsets in India. The subsector with the highest potential for methane reduction and carbon offsets in India is the dairy cattle sector, followed by the distilleries, sugarcane, fruit and vegetable processing, and cornstarch and tapioca subsectors. Milk processing is not included in the summary because, as previously noted, most milk-processing plants already have treatment in place with low methane emissions.

Table 4.4 – Summary of Total Carbon Emission Reductions Identified in India

Sector	Methane Emission Reductions (MT CH_4/yr)	Carbon Emission Reductions ($MTCO_2e$/yr)	Fuel Replacement Offsets ($MTCO_2e$/yr)	Total Carbon Emission Reductions ($MTCO_2e$/yr)
Dairy cattle	173, 500	3,642,600	882,900	4,525,500
Distilleries	38,700	813,300	197,100	1,010,500
Sugarcane processing	N/A	N/A	587,200	587,200
Fruit and vegetable processing	6,900	145,200	35,200	180,400
Cornstarch and tapioca production	5,000	107,000	25,900	133,000
TOTAL	4,900	102,000	24,700	26,700

4.2 TECHNOLOGY OPTIONS

4.2.1 Methane Production

There are a variety of AD processes, which can be broadly categorized as either suspended or attached growth processes. The applicability of any specific process is determined primarily by the 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 AD process options that are applicable to the various types of livestock manure and agricultural commodity processing wastes are discussed below.

Livestock manure: For livestock manure, there are four AD reactor options: 1) plug-flow, 2) mixed, 3) covered lagoon, and 4) attached growth. The appropriate option or options are determined by the concentration of particulate matter, generally measured as TS concentration in the collected manure; the type of manure; and the climate, as shown in Table 4.5. The TS concentration in the collected manure is determined by the method of collection—mechanical (scraping) or hydraulic (flushing)—and the volume of water used for hydraulically collected manure.

Table 4.5 – Overview of Anaerobic Digestion Options for Livestock Manure

	Plug-Flow	Mixed	Covered Lagoon	Attached Growth
Influent TS concentration	11–13 %	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. Environmental Protection Agency, 2004

As indicated in Table 4.6, the use of covered lagoons and attached growth reactors for methane production from livestock manure requires removal of coarse fiber, usually by screening, before anaerobic digestion. 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 because of the wide variation in physical and chemical characteristics. Even the physical and chemical characteristics of wastewater from the processing of a single commodity can vary widely, reflecting differences in processing and sanitation practices. For example, to the extent possible, some processing plants prevent solid wastes from entering the wastewater generated, whereas others do not.

In addition, some plants employ primary wastewater pretreatment processes such as screening, gravitational settling, or dissolved air floatation (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 (TSS) or extremely high concentrations of dissolved organic matter (measured as 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 4.6, 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 4.6 – Typical Organic Loading Rates for Anaerobic Suspended Growth Processes at 30°C

Process	Volumetric Organic Loading, kg COD/m^3-day	Hydraulic Retention Time, days
Complete mix	1.0–5.0	15–30
Anaerobic contact	1.0–8.0	0.5–5
ASBR	1.2–2.4	0.25–0.50

Source: Metcalf and Eddy, Inc., 2003

For wastewaters with low TSS concentrations, or wastewaters with low TSS concentrations after screening or some other form of TSS reduction (e.g., DAF), one of the anaerobic sludge blanket processes may be applicable. Included are the: 1) basic UASB, 2) anaerobic baffled reactor, and 3) 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 or cause foaming or scum formation are problematic. Thus, use of anaerobic sludge blanket processes generally is limited to high-carbohydrate wastewaters.

Attached growth anaerobic processes represent another option for agricultural commodity processing wastewaters with low TSS concentrations. Included are the:1) upflow packed-bed attached growth, 2) upflow attached growth anaerobic expanded bed, 3) attached growth anaerobic fluidized bed, and 4) 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, the addition of nutrients, such as nitrogen or phosphorus, and a buffering compound to provide alkalinity and control pH may be necessary.

4.2.2 Methane Use Options

In addition to methane, carbon dioxide is also significant product of the anaerobic microbial decomposition of organic matter. Collectively the mixture of these two gases commonly 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 kJ per m^3, a typical biogas composition of 60 percent methane and 40 percent carbon dioxide has a lower heating value of 21,453 kJ per m^3. Thus, biogas has a low energy density compared to 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 because it is simple and the possibility exists of utilizing existing boilers or furnaces modified to burn a lower energy density fuel. Conversion of a natural gas- or LPG-fueled boiler or furnace to a biogas-fueled boiler or furnace generally only requires replacing 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 is an option that 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 manure 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 shut down 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 India, MNRE is promoting an initiative that aims to supply at least 8 percent of the total national energy consumption through renewable energy systems by 2016. India has developed several tariff rates to support new electricity generation projects. The use of biogas to generate electricity not only will reduce farm operating costs, but will also provide a steady revenue stream for the farm.

When avoided methane emissions and associated carbon credits are considered, simply flaring biogas produced from the anaerobic digestion of livestock manure and agricultural commodity processing wastes also can be considered an option. However, this can be considered only to the degree that replacing the current methane-emitting waste management practice with anaerobic digestion reduces methane emissions. Although systems utilizing 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 costs of anaerobically digesting livestock manure and agricultural commodity processing wastes and utilizing the methane captured as a fuel depends on the type of digester constructed and the methane utilization option employed. In addition, these costs will vary geographically, reflecting local financing, material, and labor costs. However, it can be assumed that capital costs 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 AD 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 for flaring will be the lowest, and generating electricity the will be highest. 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 biogas hydrogen sulfide removal process.

4.3.1 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 the reduction of methane emissions by the addition of 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 the biogas captured 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, the revenue realized from its use as a substitute for a conventional source of energy is determined by the cost of the conventional source of energy replaced. If low-cost, hydropower-generated electricity is available, the revenue derived from using biogas to generate electricity may not justify the required capital investment and operating and maintenance costs. Another factor that must be considered in evaluating the use of biogas to generate electricity 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, the ability to deliver excess generation to the local grid during periods of low onsite demand and the subsequent ability to reclaim it during periods of high onsite demand under some type of a net metering contract should exist.

The third potential source of revenue is from the carbon credits realized from the reduction in carbon dioxide emissions when using 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. In using biogas 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 geographical area, combining compatible wastes from two or more enterprises for anaerobic digestion located at one of the waste sources or a centralized location is a possible option. By increasing project scale, unit capital costs will be reduced. However, operating costs will increase, and centralized digestion will not always be a viable option if the ability to generate adequate revenue to at least offset the increased operating costs is lacking.

There are two possible models for centralized AD 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 AD projects, the feasibility analysis should begin with determining a project location that will minimize transportation requirements for the wastes to be anaerobically digested and for the effluent to be disposed. 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. With this approach, optimal locations with respect to minimizing transportation costs for a number of scenarios can be obtained and compared. 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 the sale of carbon credits realized from reducing methane emissions and utilizing 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.

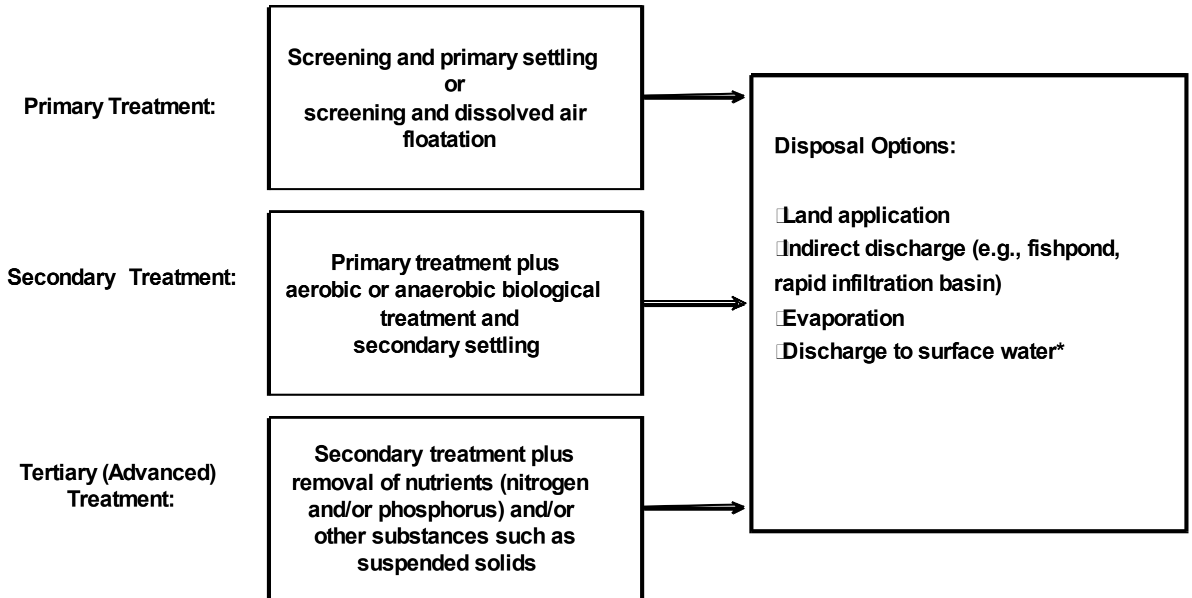
Ideally, the digester location that minimizes transportation costs will be at the waste source with the highest onsite opportunity for methane utilization. Thus, waste transportation costs will be minimized while revenue will be maximized. However, the digester location that minimizes transportation costs may not maximize revenue from methane utilization due to low onsite energy demand. Thus, alternative digester locations should be evaluated to identify the location that maximizes the difference between revenue generated from methane utilization and transportation costs. 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: ABOUT THE FEDERATION OF INDIAN CHAMBERS OF COMMERCE & INDUSTRY (FICCI)

Established in 1927, FICCI is the largest and oldest apex business organization in India. Its history is closely interwoven with India's struggle for independence and its subsequent emergence as one of the most rapidly growing economies globally. FICCI plays a leading role in policy debates that are at the forefront of social, economic, and political change. Through its 400 professionals, FICCI is active in 52 sectors of the economy. FICCI's stand on policy issues is sought out by think tanks, governments, and academia. Its publications are widely read for their in-depth research and policy prescriptions. FICCI has joint business councils with 79 countries around the world.

A non-government, not-for-profit organization, FICCI has direct membership from private as well as public sectors, including small and medium enterprises and multi-national corporations. As an apex chamber, over 350 chambers of commerce and industry are our members; thus, FICCI is the voice of India's business and industry. FICCI works closely with the government on policy issues, enhancing efficiency and competitiveness, and expanding business opportunities for industry through a range of specialized services and global linkages. It also provides a platform for sector-specific consensus building and networking. Partnerships with over 350 chambers from across the country carry forward its initiatives in inclusive development, which encompass areas such as health, education, livelihood, governance, and skill development.

With eight offices in India and overseas offices in the United Kingdom, United States, Singapore, and other countries. as well as institutional partnerships with 211 counterpart organizations, FICCI serves as the first port of call for Indian industry and the international business community.



*According to applicable discharge standards

APPENDIX C: ADDITIONAL SECTOR INFORMATION

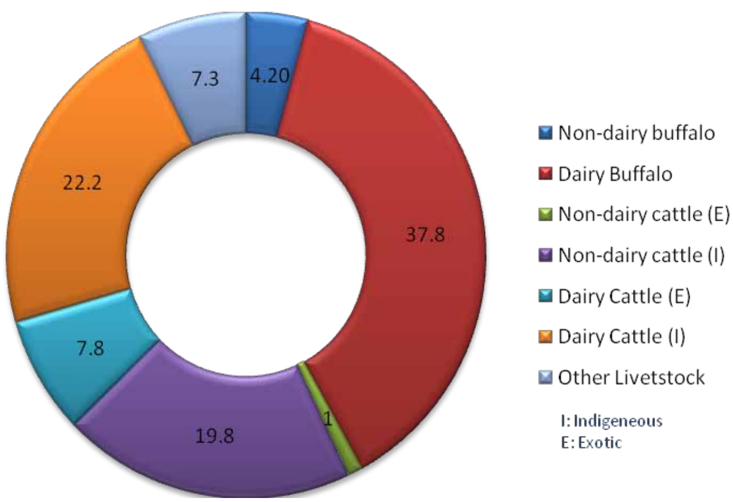
The following section provides further details on the sectors included in Chapter 3. It also presents information on other sectors not included in Chapter 3 because of their limited potential for methane emission reductions. These sectors include slaughterhouses, poultry, grain processing, and edible oil.

C.1. DAIRY CATTLE

Results from previous studies

Though this sector is huge, and it substantially contributes to the GDP of the nation, waste management in the sector is still at an early stage. The sector produces highly organic waste, which generates methane emissions and contributes an overwhelming percentage to overall methane emissions in the agriculture sector. The methane emissions from each category of the livestock sector are presented in Figure C.1.

Figure C.1 – Livestock Sector Contribution to Methane Emissions (Percent)[1]



Source: Chhabra et al., 2009

The total estimated methane emissions (including enteric fermentation and manure management) from Indian livestock was 11.75 Teragrams (Tg) in 2003. The figure adopted in the study is in accordance with the India's Initial National Communication to the United Nations Framework Convention on Climate Change (IINC) method of methane emission estimation.[21] Enteric fermentation constitutes a major part of the total methane emissions, accounting for approximately 91 percent, or 10.65 Tg of the total, while manure management of livestock accounts for only 9 percent, or 1.09 Tg. Cattle and buffalo are the major source of methane emissions (10.9 Tg) compared to emissions from other livestock (0.86 Tg). Livestock contributes about 18 percent of the global GHG emissions and as much as 37 percent of anthropogenic methane (see Figure 3.2.1 and Table 3.2.2).

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[21] *IPCC, 1996*

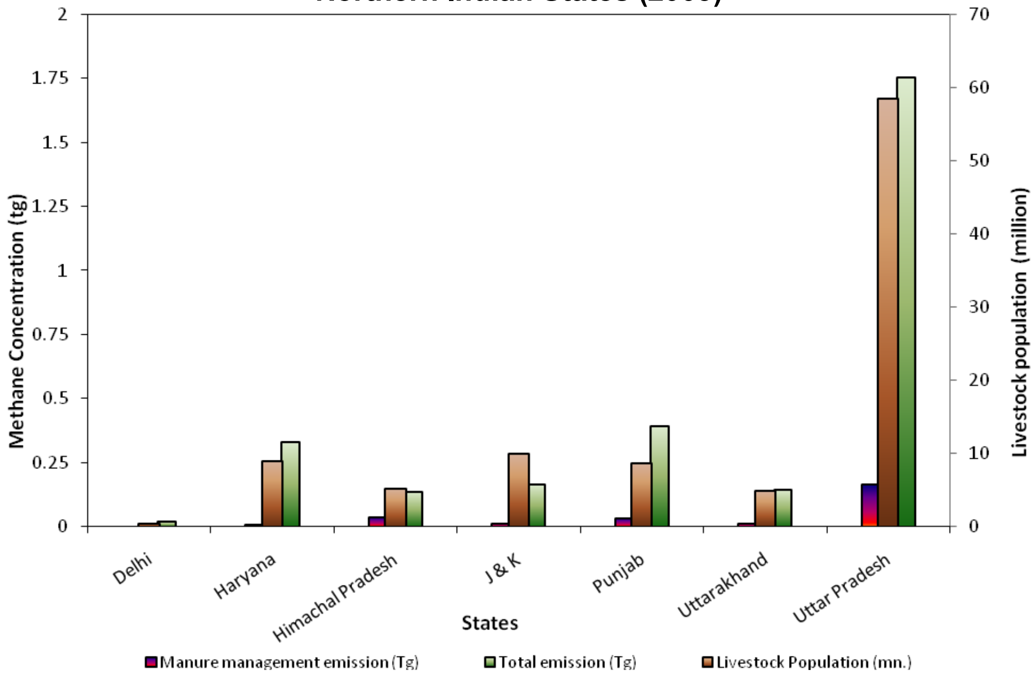
The methane emissions from manure management and enteric fermentation for different categories of livestock in India are presented in Table C.1. All the figures presented are for the base year 2003.

Table C.1 – Methane Emissions From Enteric Fermentation and Manure Management and Percentage Contribution of Each Category to Total Methane Emissions (2003)

Livestock Category	Population (Millions)	Enteric Fermentation (Tg)	Manure Management (Tg)	Total Emissions (Tg)	Percentage Contribution
Dairy cattle					
Indigenous	82.96	2.32	0.289	2.61	22.20
Exotic	19.74	0.84	0.074	0.92	7.83
Sub-total	102.70	3.17	0.363	3.54	30.03
Non-dairy cattle (indigenous)					
Below 1 yr	9.85	0.09	0.012	0.102	0.87
1-3 yrs	12.00	0.27	0.034	0.304	2.59
Adults	55.68	1.76	0.162	1.922	16.36
Sub-total	77.53	2.12	0.208	2.33	19.78
Non-dairy cattle (exotic)					
Below 1 yr	1.90	0.02	0.002	0.022	0.19
1-3 yrs	1.14	0.03	0.003	0.033	0.28
Adults	1.87	0.06	0.004	0.064	0.54
Sub-total	4.91	0.11	0.01	0.12	1.04
Dairy buffalo	80.03	4.06	0.371	4.441	37.78
Non-dairy buffalo					
Below 1 yr	7.37	0.06	0.013	0.073	0.62
1-3 yrs	3.83	0.08	0.014	0.094	0.79
Adults	6.68	0.29	0.028	0.318	2.70
Sub-total	17.88	0.44	0.055	0.490	4.17
Sheep	61.40	0.23	0.010	0.240	2.04
Goat	124.35	0.45	0.020	0.470	3.99
Horse and pony	0.75	0.01	0.001	0.011	0.09
Mule and donkey	0.65	0.02	0.002	0.022	0.19
Camel	0.63	0.03	0.001	0.031	0.26
Pig	13.52	0.01	0.060	0.070	0.59
Sub-total	201.3	0.77	0.094	0.860	7.30
Total	485.00	10.65	1.09	11.75	

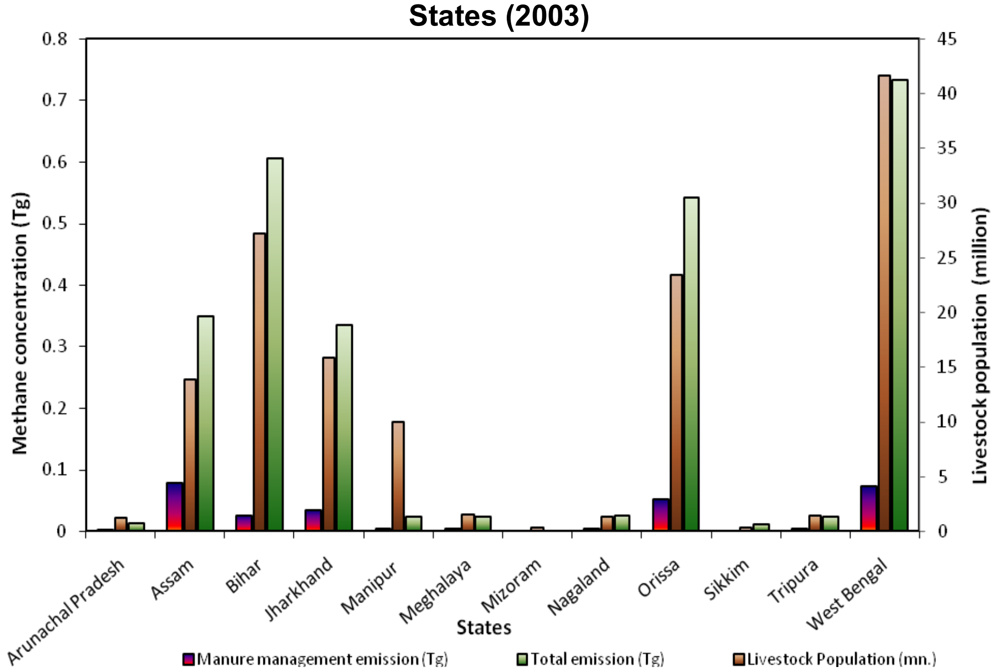
Source: Chhabra et al., 2009

The methane emissions from enteric fermentation and manure management for different regions in India are presented in the figures that follow. All the data presented are for the base year 2003. Figure C.2 depicts the methane emissions from northern Indian states, with Uttar Pradesh having the highest livestock population and corresponding methane emissions followed by Punjab and Haryana. Jammu and Kashmir, which have higher livestock populations, nevertheless emit much less methane because of the cooler climate. The case is well supported by similar trends in Himachal Pradesh and Uttarakhand. **Figure C.2 – Methane Emissions From the Livestock Sector in Northern Indian States (2003)**



Source: Chhabra et al., 2009

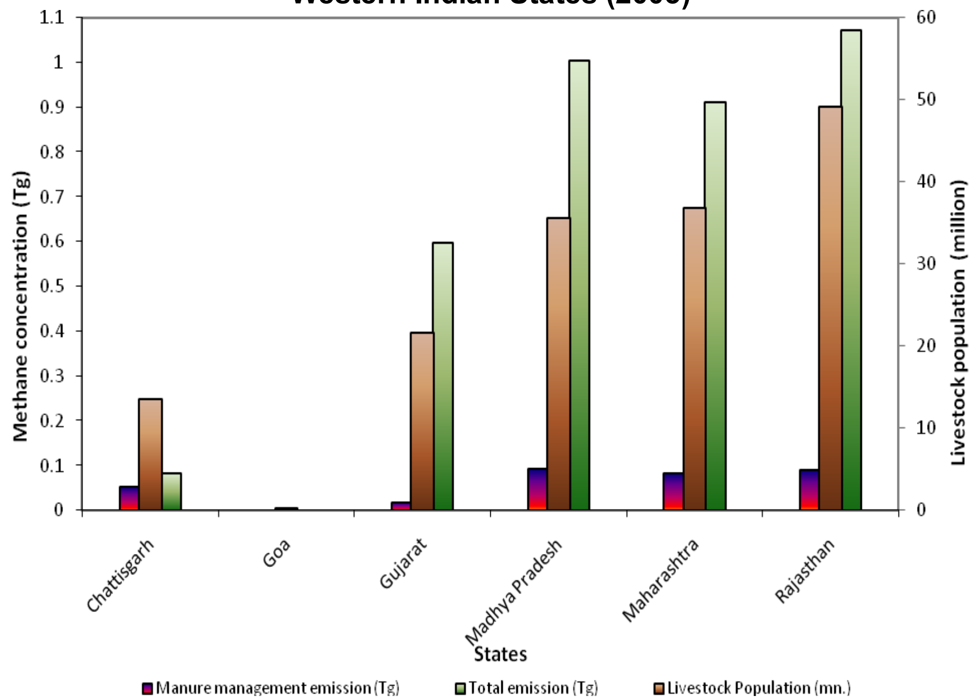
Figure C.3 – Methane Emissions From the Livestock Sector in Northeastern Indian States (2003)



Source: Chhabra et al., 2009

The northeastern region of India comprises several states, and most of the states have low human and livestock population densities. In addition, because of the cooler climate in these states, methane emissions are much lower than other regions. The methane emissions from manure management in the state of Assam are high, however, and would serve as an interesting case study in the northeast region.

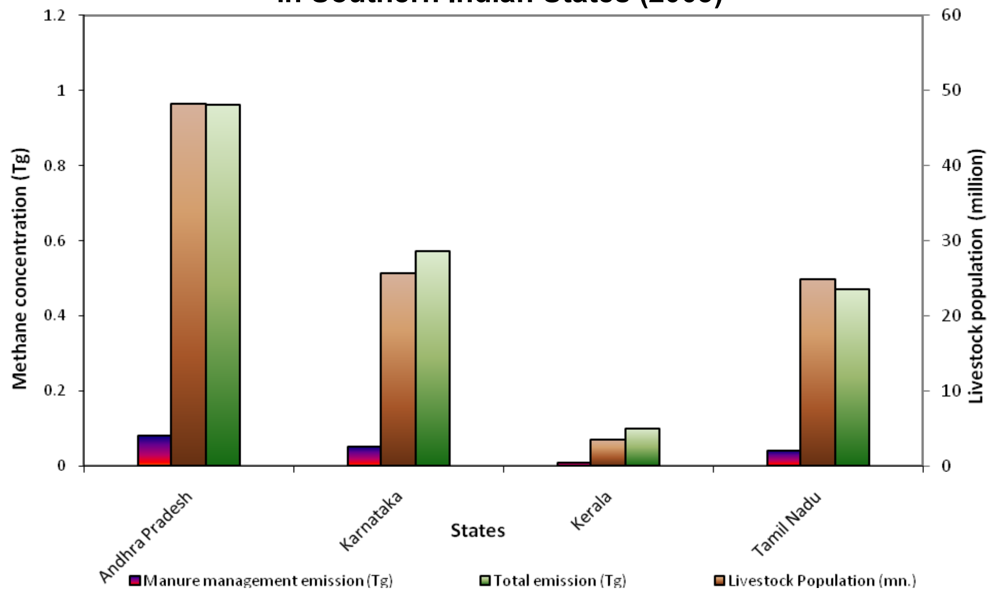
Figure C.4 – Methane Emissions From the Livestock Sector in Western Indian States (2003)



Source: Chhabra et al., 2009

The western region of India holds the distinction of being the largest methane emitter in the country. The reasons for this include a higher livestock population and much warmer environment compared to other regions. Rajasthan and Uttar Pradesh in the northern western region are the highest methane emitters in India. Both the states have correspondingly higher livestock population and warmer climates. Chattisgarh, interestingly, has high manure management-related emissions although it is in the eastern region. Manure management emissions in Chattisgarh constitute about 75 percent of the total methane emissions and contradicting the overall Indian trend. This state would also serve as a useful case study in the western region for improving manure management practices.

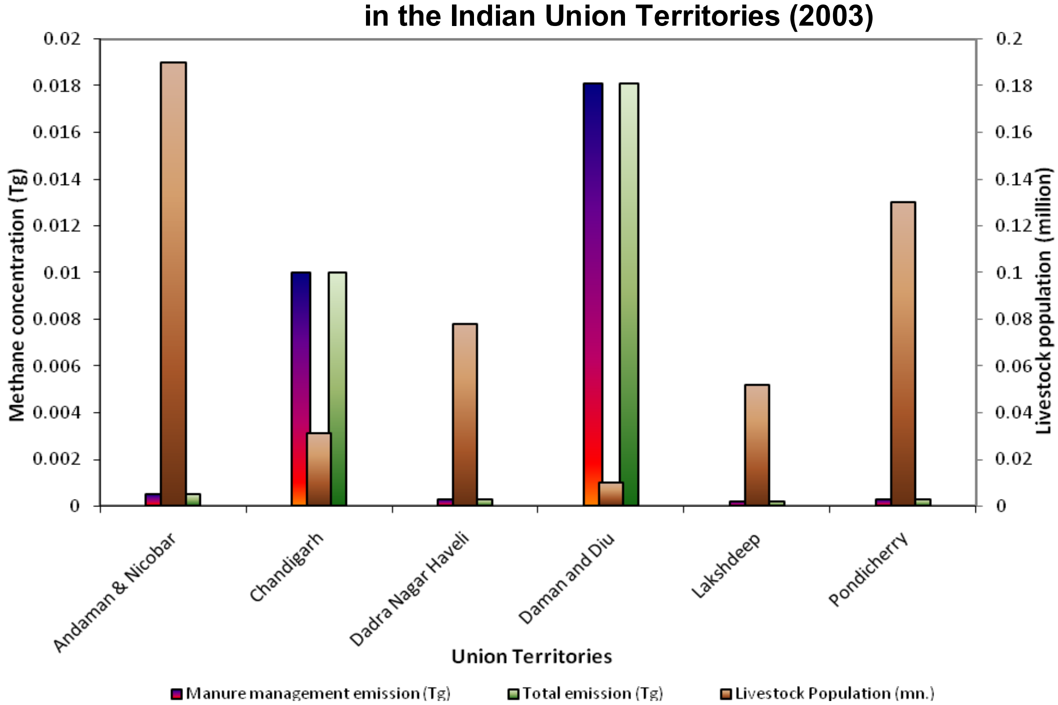
Figure C.5 – Methane Emissions From the Livestock Sector in Southern Indian States (2003)



Source: Chhabra et al., 2009

Methane emissions in the southern region are low compared to other regions of India, even though the livestock population is high in these states. In the southern region, Kerala emits the least amount of methane, and Andhra Pradesh emits the most.

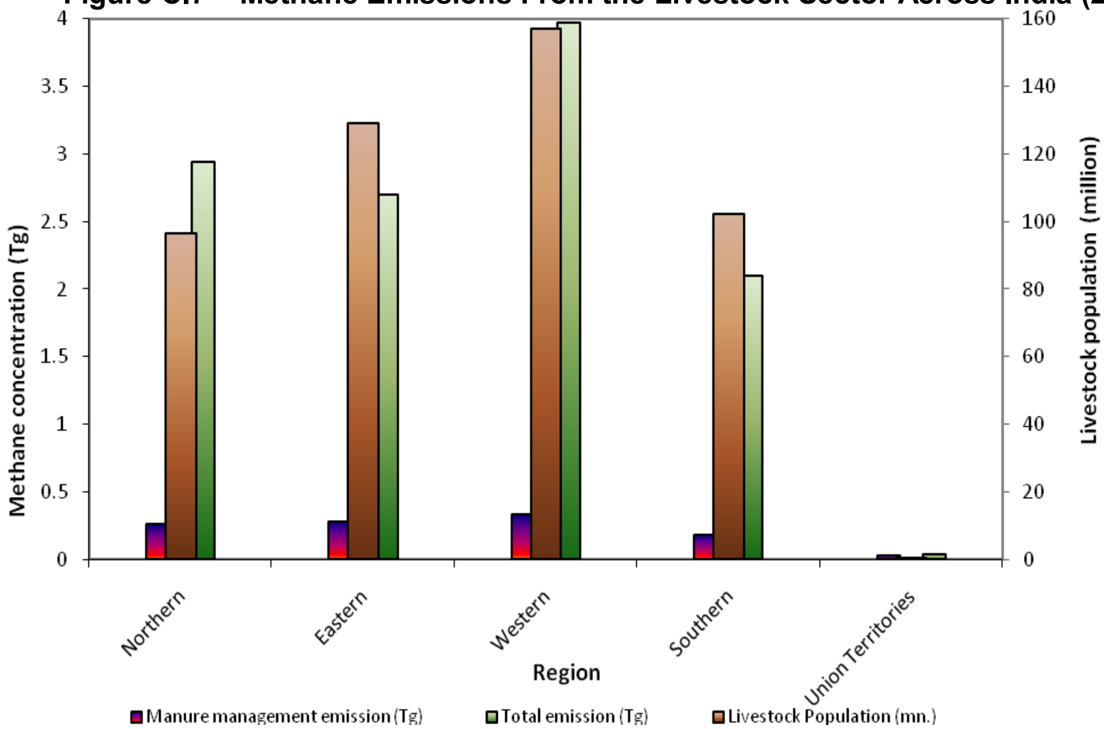
Figure C.6 – Methane Emissions From the Livestock Sector in the Indian Union Territories (2003)



Source: Chhabra et al., 2009

Methane emissions in the Union Territories are of particular note, not because of the volume of methane emitted or the high livestock population, but rather because of the source of the methane emissions. Methane emissions from manure management practices are especially high Daman and Diu and Chandigarh, possibly due to inefficient traditional manure management practices in these union territories. The Union Territories could also serve as a case study for MRU projects if done as demonstration projects. In Daman and Diu and Chandigarh, methane emissions clearly deviate from over the rest of India, with manure management accounting for almost all of the methane emissions.

Figure C.7 – Methane Emissions From the Livestock Sector Across India (2003)



Source: Chhabra et al., 2009

As shown in Figure C.4, manure management practices contribute the highest concentration of methane emissions in the western region, followed by the eastern and northern regions. This is directly proportional to the livestock populations in these regions. Interestingly, the southern region, which is hotter than the other regions all year round, results in lower methane emissions than the other regions, even though it has a higher livestock population than the northern region. This suggests that the southern region has better manure management and other animal management practices, effectively reducing methane emissions.

Policies and Programs Related to MRU in the Livestock Sector

This section briefly describes the existing regulations and policies of the government of India that directly or indirectly affect waste management practices in the dairy sector.

a. *THE* NATIONAL BIOGAS AND MANURE MANAGEMENT PROGRAM (NBMMP)

The Central Sector Scheme of the National Biogas Program, which mainly focuses on setting up family-type biogas plants, was implemented in 1981–1982. NBMMP provides subsidies; turn-key job fees linked with 3 years of free maintenance; financial support for repairing old, nonfunctional plants; training for users, masons, entrepreneurs, and others; publicity and extension; service charges or staff support; state-level Biogas Development and Training Centres (BDTC); fixed amount of support to institutional biogas plants; and financial support to institutions for cattle dung-based power generation plants. A total of 3.93 million family-type biogas plants have been established in the country, with an estimated potential for 12 million plants.[22]

b. INTENSIVE DAIRY DEVELOPMENT PROGRAM

It was recommended by evaluation studies that the Central Sector Scheme be modified to become the Intensive Dairy Development Program. The program was launched during the 8th Plan period and is being continued during the 11th Five-Year Plan period with an outlay of Rs. 29.99 crore for 2008–2009. So far, 84 projects with an outlay of 480.05 crore have been sanctioned in 25 states and one Union Territory. A total of Rs. 330.35 crore have been released to various state governments up through March 31, 2008, and 206 districts have been covered. The Central Sector Scheme has benefited about 15.07 lakh farm families and organized about 24,808 village-level Dairy Cooperative Societies up through March 31, 2008.[23]

c. BIOGAS-BASED DISTRIBUTED/GRID POWER GENERATION PROGRAM

The MNRE started a scheme, "Biogas-Based Distributed/Grid Power Generation Program," in January 2006, with the purpose of promoting biogas-based power generation, especially in the small capacity range, based on the availability of a large quantity of wastes (e.g., animal, forestry, agro/food processing, kitchen). The program is implemented through nodal departments/agencies of the states/Union Territories, Khadi and Village Industries Commission (KVIC), institutions, and non-governmental organizations. Projects can be undertaken by any village-level organization, institution, private entrepreneurs, or other entity in rural areas, as well as areas covered under the Remote Village Electrification (RVE) program of MNRE, except for the industries and commercial establishments covered under Urban, Industrial & Commercial Applications (UICA) programs for sale of electricity to individual/community/grid on mutually agreeable terms.[24]

Apart from these initiatives, MNRE has various national-level R&D programs for improving waste utilization and conversion of waste into energy.[25] The biogas program is integrated into each initiative the MNRE has taken regarding renewable energy development. The government of India provides subsidies and financial assistance to waste-to-energy projects, especially for households.[26]

[22] *Ministry of New and Renewable Energy, n.d.*
[23] *Government of India, (n.d).*
[24] *Ministry of New and Renewable Energy, n.d.*
[25] *Ministry of New and Renewable Energy, n.d.*
[26] *Ministry of New and Renewable Energy, n.d.*

The above-mentioned schemes are for family-type or farm-based biogas plants. These are specific programs that deal with biogas recovery and utilization in the dairy sector. There are other programs that have an indirect effect on the waste management practices of the dairy industry. The government implemented four such schemes during 2007–2008.

d. STRENGTHENING INFRASTRUCTURE FOR QUALITY AND CLEAN MILK PRODUCTION

A new centrally sponsored scheme was launched in October 2003, with the main objective of improving the quality of raw milk produced at the village level in the country. Under this scheme, assistance is provided for training farmers on good milking practices. The scheme is being implemented on a 100-percent grant-in-aid basis to District Co-op Milk Union and State Co-op Milk Federation through the state governments/Union Territories for training farmers, purchasing detergents and stainless steel utensils, and strengthening existing laboratory facilities. There is 75-percent financial assistance provided for setting up milk chilling facilities (i.e., bulk milk coolers) at the village level. Since its inception, 130 projects at a total cost of Rs. 194.93 crore with a central share of Rs 159.08 crore have been approved up through March 31, 2008. A total sum of Rs. 100.57 crore as central share has been released to the concerned state governments for implementation of approved project activities up March 31, 2008. The scheme has benefited 4,170,000 farmers through training and by installing 15.56 lakh litre capacity bulk milk coolers to facilitate marketing of milk and keeping its quality intact as of March 31, 2008.[27]

e. ASSISTANCE TO COOPERATIVE

The scheme aims at revitalizing the suffering dairy cooperative unions at the district level and cooperative federations at the state level. NDDB is the implementing agency and is releasing central grants. The scheme is being continued during the 11th Five-Year Plan period with a tentative outlay of Rs. 50 crore. Since its inception in 1999–2000, 32 rehabilitation proposals from milk unions in 12 states (i.e., Madhya Pradesh, Chhattisgarh, Karnataka, Uttar Pradesh, Haryana, Kerala, Maharashtra, Assam, Nagaland, Punjab, West Bengal, and Tamil Nadu) at a total cost of Rs. 197.37 crore, with a central share of Rs. 98.68 crore, have been approved up through March 31, 2008. A total of Rs. 79.19 crore, including Rs. 5.05 crore in 2007–2008, have been released up through March 31, 2008. An amount of Rs. 7.00 crore has been provided for continuing the scheme during 2008–2009, of which a total of Rs. 2.19 crore has been released to the concerned milk unions, including a new project approved for Saharanpur Milk Union in Uttar Pradesh, up through May 31, 2008.[28]

f. DAIRY/POULTRY VENTURE CAPITAL FUND

To bring about structural changes in the unorganized sector, measures such as milk processing at the village level, marketing pasteurized milk in a cost-effective manner, and upgrading traditional technology, a new scheme called the Dairy/Poultry Venture Capital Fund was initiated in the 10th Five-Year Plan period. Assistance under the scheme is provided to the rural/urban beneficiaries; including agriculture farmers/individual entrepreneurs and groups of all sections of unorganized as well as organized sectors, including cooperatives and non-governmental organizations from any part of the country.

[27] *Government of India, (n.d.)*.
[28] *Government of India, (n.d.).*

The scheme was approved in December 2004 with a total outlay of Rs. 25.00 crore. It is being implemented through the National Bank for Agriculture and Rural Development (NABARD), and the funds are released to NABARD to be maintained as a revolving fund. Since its inception, a total of Rs. 77.99 crore have been released to NABARD up through March 31, 2008. There is a budget provision of Rs. 40.00 crore for implementing the scheme during 2008–2009, of which Rs. 20.00 crore have been released up through June 30, 2008.[29]

g. MILK AND MILK PRODUCT ORDER–1992 (MMPO)

The government of India notified the MMPO on June 1992. As per the provisions of this order, any person/dairy plant handling more than 10,000 liters per day of milk or 500 MT of milk solids per year needs to be registered with the registering authority appointed by the Central Government. The order was amended from time to time, as per the decision of the Milk and Milk Product Advisory Board and as per a request of state governments. In pursuance of the Cabinet decision dated February 22, 2002, this Department amended MMPO–1992 through Milk and Milk Product (Amendment) Order 2002, SO No. 335(E), dated March 26, 2002, where the provisions of assigning regional milk production limits were eliminated. The power of granting registration to the plants having up to 2.00 lakh liters per day processing capacity, where all the activities of the plant occur within a state, has been delegated to concerned State Registering Authority.[30]

h. FRAMEWORK FOR PROGRAMMATIC CDM (CDM-POA) FOR DECENTRALIZED BIOGAS PLANTS (MEDIUM- AND LARGE–SCALE) BY MNRE[31]

MNRE has taken an initiative to develop a framework for programmatic CDM projects in India. This framework addresses, among other renewable energy technologies, decentralized, medium-, and large-scale biogas plants, which shall be taken up as a CDM-PoA project with UNFCCC to issue certified emission reductions (CERs).

C.2 SUGARCANE MILLS AND DISTILLERIES

Policies and Programs Related to MRU in the Sugar and Distillery Sector

CPCB, in consultation with industrial associations, experts in respective fields, state pollution control boards (SPCBs), and Ministry of Environments & Forests (MoEF), has issued a specific timeline-driven action plan for 17 major categories of industry. The program is called "Corporate Responsibility for Environmental Protection" (CREP, 2003). As per the guidelines, zero discharge with any combination of the following measures:

- Compost with press mud/agricultural residue/municipal waste
- Concentration and drying/incineration
- Treatment of spent wash through biomethanation followed by two-stage secondary treatment and dilution of the treated effluent with process water for irrigation

[29] *Kaur, n.d.*
[30] *Government of India, 1992*
[31] *Ministry of New and Renewable Energy, n.d.*

A performance study of some distilleries was carried out from 2002–2006. Industries were pursued to implement CREP recommendations through state boards, as well as by issue of directions and through task force meetings. The time-targeted action plan under CREP and status of its implementation are presented in Table C.2.[32]

Table C.2 – Status of Compliance by the Distilleries as Per CREP Guidelines

CREP Action Points	Status (as of December 2006)
All distilleries will achieve zero discharge in surface water bodies and 100% utilization of spent wash by December, 2005.	Information on compliance received from 233 distilleries, of which information from 17 distilleries was incomplete. 101 distilleries achieved 100% utilization of spent wash. 34 others achieved 50 to 75%. 22 distilleries are closed.
Proposal for stand-alone new distilleries and expansion of existing distilleries without achieving zero discharge in surface water/ground water will not be considered by MoEF/ SPCB.	Being followed by SPCBs/MoEF

Although there has been a good amount of progress and improvement in the status since then, it is evident that the Indian distilleries are lagging far behind in achieving the zero discharge goal.

C.3 SLAUGHTERHOUSES

This section will cover both private and municipal slaughterhouses.

C.3.1 Size of the sector

Despite being the highest producer of milk in the world and having a large population of small and large ruminants, India's share in world meat production is less than 2.5 percent, as shown in Table C.3.

Table C.3 – India's Share in World Meat Production (2007) (in MT)

Item	India	World	% Share
Buffalo	1,498,266	3,322,166	45.1%
Cattle	1,282,349	59,851,860	2.1%
Chicken	2,240,000	75,826,354	3.0%
Duck	72,800	3,583,809	2.0%
Goat	543,000	4,828,237	11.2%
Others	140,000	1,238,594	11.3%
Pig	497,000	99,211,931	0.5%
Sheep	234,456	8,303,867	2.8%
Total	6,507,871	256,166,818	2.5%

Source: FAOSTAT

With rising incomes, the share of high-value food products in the food basket of people increases. In the case of India, sustained rises in per capita income, together with urbanization, are resulting in increased demand for animal food products (i.e., meat). The

[32] *CPCB, 2010*

rising demand has been accompanied by an increase in domestic supply. Meat products have an annual growth rate of 10 percent, whereas the growth rate of eggs and broilers are 16 and 20 percent, respectively.

According to FAO, the number of cattle being slaughtered has been slowly declining, while that of buffalos is gradually increasing. In terms of number of animals slaughtered, goats are by far the most preferred animals for slaughter, primarily due to their availability in large numbers compared to buffalos and sheep. (See Table C.4)

Table C.4 – Number of Animals Slaughtered for Meat

Type	2004	2005	2006	2007
Chicken (*1,000)	1,750,000	2,000,000	2,100,000	2,352,000
Duck (*1,000)	50,000	52,000	54,000	56,000
Buffalo	10,799,000	10,876,000	10,869,000	10,857,000
Cattle	12,985,000	12,950,001	12,510,001	12,449,999
Goat	53,868,000	54,110,000	54,200,004	54,300,000
Pig	14,200,000	14,200,000	14,200,000	14,200,000
Sheep	18,928,000	19,110,000	19,322,000	19,538,000

Source: FAOSTAT, 2010

According to the Ministry of Food Processing, government of India, the estimated production of meat (including poultry meat) in the country was more than 6.5 MMT during 2007–2008. Per capita consumption is also increasing—from 870 grams in 2000 to an expected 2 kg by 2009.

India is the sixth largest exporter of bovine meat in the world, annually exporting more than 500,000 MT, of which the major share is buffalo meat. There is strong international demand for Indian buffalo meat due to its lean character and nearly organic nature.

C.3.2 Structure of the Sector and Geographic Location

Most of the production of meat and meat products continues to be in the unorganized sector. There are 5,521 registered and 25,776 unregistered slaughterhouses in the country. Small slaughterhouses are generally not registered. Whether a slaughterhouse is registered depends to a large degree on the enforcement of the municipalities/municipal corporations. Among the registered slaughterhouses, 2,999 are in Karnataka, and among the unregistered slaughterhouses, 21,063 are in West Bengal. There is a large potential for setting up modern slaughter facilities and developing cold chains in the meat and poultry processing sector. The major meat production centers are located in Aurangabad, Nanded, Mumbai, and Satara in Maharastra; Goa; Medak district in Andhra Pradesh; Derabassi in Punjab; Aligarh, Unnao, and Ghaziabad in Uttar Pradesh; and Cochin in Kerala.

Figure C.8 – Location of Major Meat Production Centers

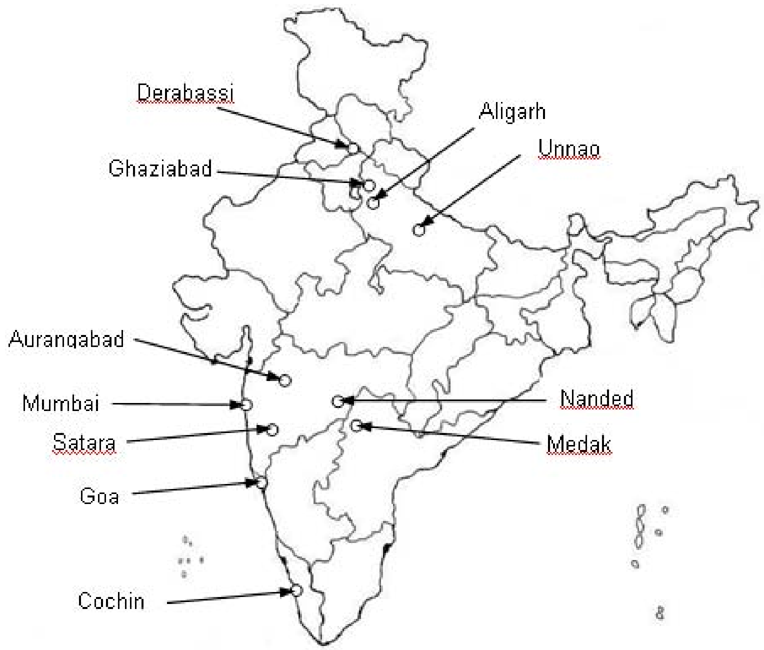


Table C.5 presents the number of registered and unregistered slaughterhouses per Indian state.

Table C.5 – Number of Slaughterhouses Per State

State	Registered	Unregistered	State	Registered	Unregistered
Andhra Pradesh	214	270	Nagaland	0	0
Arunachal Pradesh	2	0	Orissa	63	2177
Assam	0	0	Punjab	91	0
Bihar	42	0	Rajasthan	744	1597
Chhattisgarh	26	9	Sikkim	1	0
Goa	1	0	Tamil Nadu	123	0
Gujarat	38	0	Tripura	0	0
Haryana	34	0	Uttarakhand	0	0
Himachal Pradesh	37	53	Uttar Pradesh	317	0
Jammu & Kashmir	1	0	West Bengal	11	21063
Jharkhand	0	0	A & N Islands	0	0
Karnataka	2999	0	Chandigarh	1	0
Kerala	0	0	Dadra & Nagar Haveli	0	0
Madhya Pradesh	175	23	Daman & Diu	0	0
Maharashtra	338	0	Delhi	1	0
Manipur	0	1	Lakshadweep	1	25
Meghalaya	0	0	Pondicherry	260	552
Mizoram	0	0			

Source: FAO 2006

C.3.3 Scale of Operations

Slaughterhouses can be classified based on the type of animals slaughtered:

- Large animal (i.e., cattle, buffalo, and veal) slaughterhouses
- Goat and sheep slaughterhouse
- Pig slaughterhouses
- Poultry slaughterhouses

To assess the variations in pollution load with respect to number of animals slaughtered, bovine and goat and sheep slaughterhouses can be further classified into following categories:

- Large-scale – more than 200 bovines per day or more than 1,000 goat and/or sheep per day
- Medium-scale – more than 50 and up to 200 bovines or more than 300 and up to 1,000 goat and/or sheep per day
- Small-scale - less than 50 bovines and/or less than 300 goat and/or sheep per day

Large-scale slaughterhouses are located mainly in big cities, while the small-scale slaughterhouses are scattered all over the country and are unorganized.

C.3.4 Operational/Production Process

To avoid glycogen depletion, which generally occurs during transit, animals are given sufficient rest, fodder, and water approximately 24 hours before they are slaughtered. They are then inspected by veterinarians, known as the ante mortem health inspection, and the nonconforming animals are rejected for slaughtering. The various steps in the process are provided below:

Lairage: To flush out internal pathogenic micro-organisms. After the ante mortem health inspection, the animals are given a sufficient quantity of water but no fodder for 12 hours prior to their slaughtering. However, only a small number of slaughterhouses have lairage facilities.

Slaughtering: Large animals are slaughtered as per the Islamic rites by halal method. In the majority of plants, a stunning facility is not available, and the animal is pushed on the floor for slaughtering and bleeding.

Goats and sheep are slaughtered either by halal or jhatka methods as per the needs of consumers. The animal is stunned with the help of an electric stunner in mechanized slaughterhouses, whereas in manual slaughterhouses stunning is not practiced before slaughtering.

Dressing: The dressing operation consists of removal of horns, legs, head trimming; demasking; flaying of abdomen and chest; and removal of hide or skin.

Evisceration: In this process, edible and inedible offal are segregated. While the edible offal are cleaned with water and sold, the inedible portions are disposed of as solid waste. In mechanized slaughterhouses, dressing and evisceration is carried out in hung position with the help of equipment.

In case of pigs, stunning, scalding, and dehairing are carried out prior to evisceration. A brief description of each the processes are provided below:

Stunning: The animal is stunned with an electronic instrument. Subsequently, sticking is done and body is hoisted on a rail to ensure complete bleeding.

Scalding: The carcass is dipped into hot water at 60ºC for 5 minutes to relax the muscles and make the dehairing operation easier.

Dehairing: The animal is transferred to a mechanical dehairing machine. The final dehairing is done manually or by using gas burner. Thereafter, the dehaired carcasses are washed. In manual slaughtering, stunning is not practiced and dehairing is done manually.

C.3.5 Waste Characteristics and Management Systems

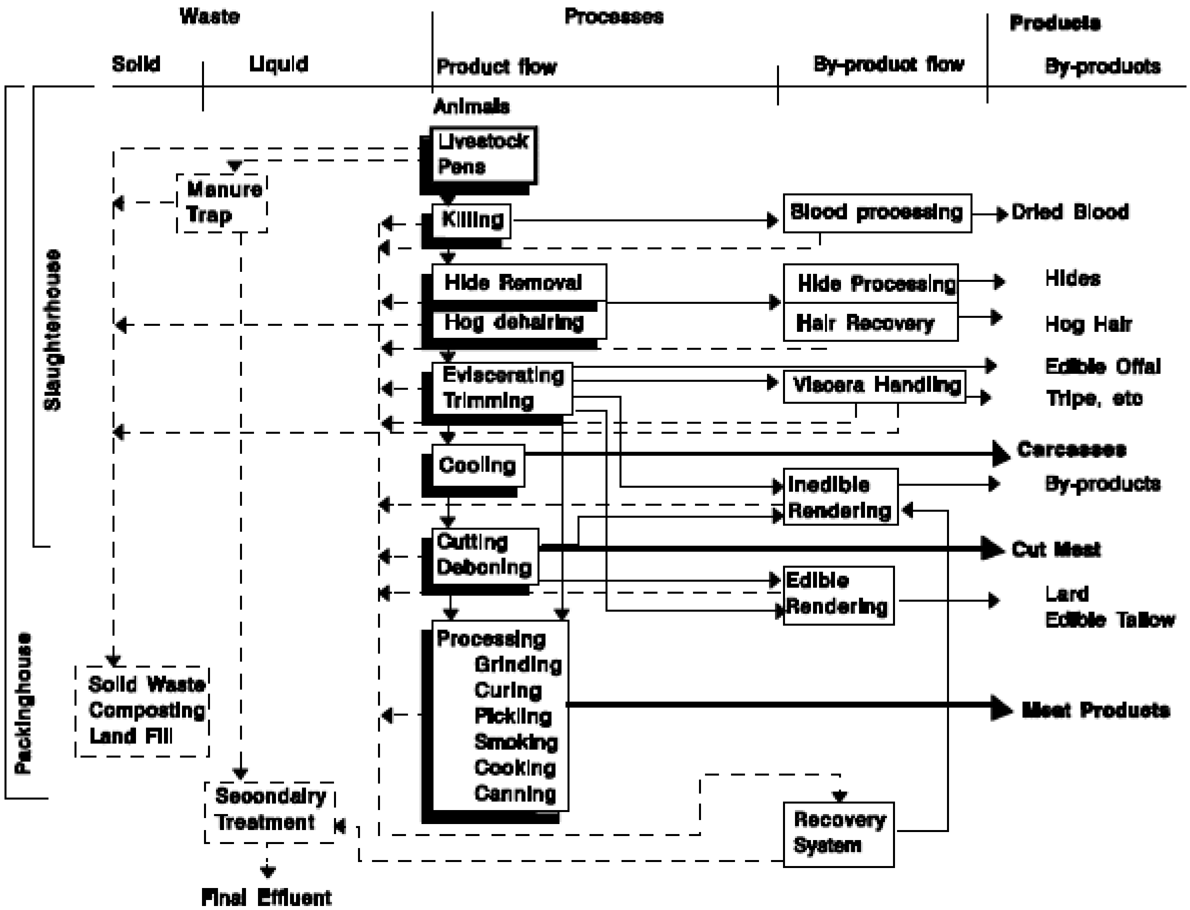
Waste Generation

In the slaughter process, the following byproducts and waste products are generated:

- Manure – contents of rumen and intestines
- Edible products – such as blood and liver
- Inedible products – such as hair, bones, feathers
- Fat – recovered from the wastewater by means of fat separators
- Wastewater

The following diagram shows the waste generation stages in meat processing, including slaughtering.

Figure C.9 – Waste Generation in Meat Processing



Source: Verheijen, Wiersema, Pol and De Wit, (1996)

Solid Waste Generated

The average amount of solid waste generated from bovine slaughterhouses is 275 kg per metric ton of live weight kill (TLWK), which is equivalent to 27.5 percent of the animal weight. In the case of goats and sheep, the average solid waste generation amounts to 170 kg/TLWK, which is 17 percent of the weight of the animals. Solid waste generated from pig slaughtering is up to 4 percent of the animal weight. (See Table C.6)

Table C.6 – Solid Waste Generation

Animal	Quantity of Solid Waste		
	Kg/head	Kg/TLWK	% Weight of Animal
Bovine	83	275	27.5
Goat/sheep	2.5	170	17
Pig	2.3	40	4

Source: CPCB, n.d.

Slaughterhouse waste contains mostly biodegradable matter. Characteristics of solid wastes from goat and sheep slaughtering are provided in Table C.7.

Table C.7 – Characteristics of Slaughterhouse Waste

Parameters	Value
Moisture %	69.45
Total solids %	30.55
Volatile solids %	87.95
Fixed solids %	12.05
Organic carbon %	23.32
Total nitrogen %	2.71
Phosphorus mg/g	4.19
Potassium mg/g	6.9

Source: CPCB, n.d.

The solid waste generated from slaughterhouses can therefore be classified into two categories (i.e., vegetable matter and animal matter) (Table C.8). The wastes need to be segregated so that they can be properly treated.

Table C.8 – Classification of Solid Waste

Category	Constituents of Waste
Type I	Vegetable matter such as rumen, stomach, and intestine contents; dung; agricultural residues, etc.
Type II	Animal matter such as inedible offal, tissues, meat trimmings, waste, and condemned meat, bones

Water Consumption in Slaughterhouses

Large bovine slaughterhouses use more water per unit compared to medium and small plants because of higher hygienic requirements. Goat, sheep, and pig slaughterhouses use more water per unit compared to bovine slaughterhouses because of additional water requirements for intestine cleanings and dehairing. This is illustrated in Table C.9.

Table C.9 – Water Consumption and Wastewater Generation

Animal Slaughtered	Category	Fresh Water Consumption (m^3/TLWK)	Wastewater Generation (m^3/TLWK)
Bovines	Large	1.5	1.4
	Medium	0.5	0.5
	Small	1.0	1.0
Goat/ Sheep	All	3.0	3.0
Pig	All	7.1	6.1
Chicken	All	17.0	14.8

Source: CPCB, 1992

Wastewater Generation in Slaughterhouses

The effluent generation from animal holding, paunch tank, lairage, abattoir, drying chamber, and rendering plant is about 1,300 to 1,400 m^3/day for the processing of 1,500 to 1,600 sheep or goats or 500 to 800 buffalos, whereas the process hall generates between 200 to 300 m^3/day. The quality and quantity of effluent generated from various unit processes varies from one abattoir to another. The major processes from which wastewater is generated are as follows:

From Lairage: The process of lairage discharges large quantities of animal washing water. In general, the lairage waste contains dung materials and the washing water. The wastewater is pumped into a paunch tank, where the liquid content of paunch and dung material are filtered and pumped into the ETP collection sump for treatment. About 100 to 150 m^3/d of wastewater is generated for lairage for the processing of 1,500 to 1,600 sheep or goats or 500 to 800 buffalos.

From Abattoir and Process: Most of the blooded effluents generated from abattoir are from animal slaughtering, head removal, legs and horn removal, and carcass processing, as well as the floor washings. Effluents are also generated from handwashing, sterilizing plants, floor washing, and table and conveyer washings. The abattoir process generates approximately 600 to 800 m^3/day of effluent. The process hall generates only unblooded effluents, which can be treated separately.

From Rendering Plant and Decanter: The rendering plant generates about 100 to 150 m^3 of effluent/day, whereas the decanter generates around 80 m^3/day of glue water. The collection pit of bones, legs, liver, head, and paunch also generates liquid effluents in the rendering plant.

Wastewater Characteristics

Effluents from slaughterhouses are usually heavily polluted with solids, floatable matter (fat), blood, manure, and a large variety of proteinaceous compounds. The composition depends very much on the type of production and facilities. The BOD and solid concentrations in the plant effluent depend on in-plant control of water use, byproducts recovery, waste separation at the source, and plant management.

The COD to BOD ratio of typical slaughterhouse wastewater ranges between 2 to 2.5. Because of this, anaerobic digestion of the wastewater seems to be a viable option. Baseline data for calculating average biogas energy potential of slaughterhouse wastewater is presented in Table C.10.

Table C.10 – Baseline Data for Slaughterhouse Wastewater

Parameter	Value
BOD (mg/L)	3,750
COD (mg/L)	7,000
BOD removal efficiency (%)	85 to 90
COD removal efficiency (%)	65
Specific biogas yield (m^3/kg of COD removed)	0.5

Source: Ministry of New and Renewable Energy, 2004

Although there are 5,520 registered slaughterhouses in India, most of them are small. For the purpose of assessing methane capture and potential for electricity generation, AD plants can be set up in about 200 slaughterhouses. This would result in capturing 500,000 m^3 of methane per day and would generated 84 MW of electricity.

Waste Management System

Regarding existing waste management systems, the large slaughterhouses (which are government owned) treat the wastewater by ETPs, which have activated sludge treatment systems. The solid wastes are landfilled. In the case of large, privately owned slaughterhouses like M/s Al Kabeer Export Limited, the wastewater is subjected to biomethanation, while the solid waste is either composted or landfilled.

Case Study

The Deonar abattoir owned by the Municipal Corporation of Greater Mumbai (MCGM) slaughters about 1.5 million sheep and goats, 131,000 horned cattle (including buffalos), and 50,000 pigs per year. The daily average slaughter rate is 5,000 sheep and goats, 350 horned cattle, and 150 pigs. The process generates an average of 500 m^3/day of effluent, comprising floor washings, blood, and other animal tissues. The effluents are treated in an ETP with an activated sludge treatment system and a capacity of 1,300 m^3 per day. The solid waste from the slaughtering complex—37 MT per day—is transported to Deonar landfill.

C.4 POULTRY

Poultry rearing has always been an integral component of livestock production systems in India. The concept of a composite farming production system with crop, livestock, fish, and poultry production has been practiced for centuries in India. However, poultry production in India has taken a quantum leap in the last four decades, emerging from an entirely unorganized and unscientific farming practice to a commercial production system with state-of-the-art technological interventions.

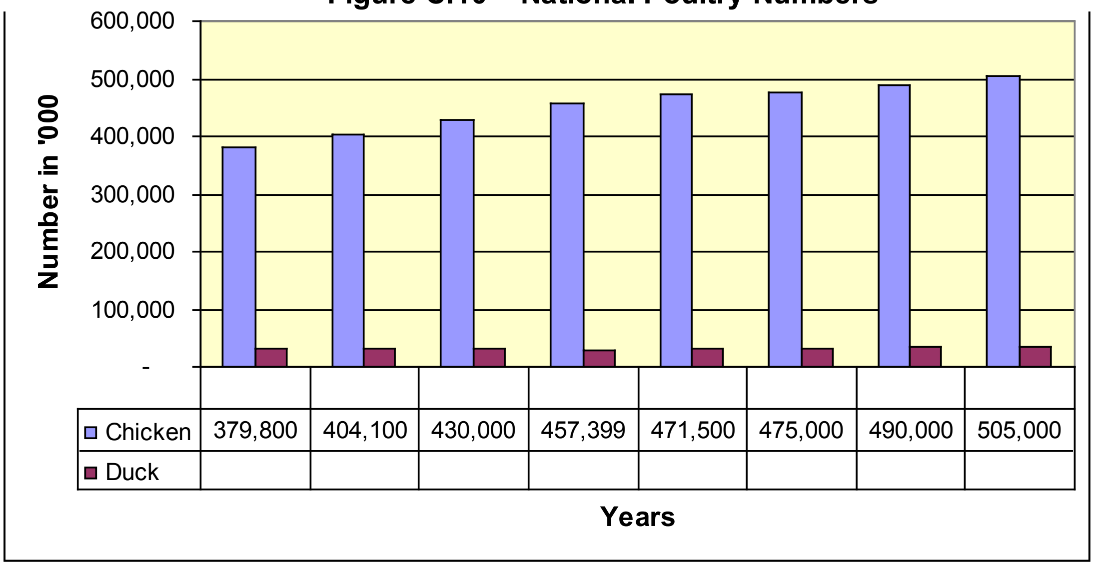
The poultry sector, in addition to providing direct or indirect employment to nearly 3 million people, is a potent tool for subsidiary income generation for many landless and marginal farmers and also provides nutritional security, especially to the rural poor. Furthermore, landless laborers derive more than 50 percent of their income from livestock, especially from poultry.

C.4.1 Sector Profile

A. SIZE OF THE SECTOR

The poultry industry in India represents a major success story. What was largely a backyard venture before the 1960s has been transformed into a vibrant agribusiness with an annual turnover of Rs 30,000 crores. It is one of the fastest growing segments of the agricultural sector in India today. The poultry industry in the country has grown at a rate of 11 percent per year, compared to the country's GDP growth rate of 9 percent (1991–2006) and agricultural growth rate of 2 percent. Figure C.10 shows the growth in the number of chickens and ducks from 2000 to 2007.

Figure C.10 – National Poultry Numbers



Source: FAOSTAT, 2010

India is now the world's third largest egg producer and the eighteenth largest producer of broilers. A combination of factors is driving this expansion—growth in per capita income, a growing urban population, and falling real poultry prices. Table C.11 shows growth in the production of eggs and meat in the subsector from 1995–1996 to 2004–2005.

Table C.11 – Growth in Production of Eggs and Poultry Meat (1995–1996 to 2004–2005)

Year	Egg Production		Poultry Meat (thousands of MT)		
	USDA (million eggs)	GoI (million eggs)	FAO	USDA	GoI
1995–96	28,000	27,198	624	590	-
1996–97	29,100	27,496	714	610	-
1997–98	32,000	28,689	648	630	-
1998–99	34,000	29,476	763	670	361.81
1999–2000	35,000	30,447	875	690	382.30

Year	Egg Production		Poultry Meat (thousands of MT)		
	USDA (million eggs)	GoI (million eggs)	FAO	USDA	GoI
2000–01		36,631	1136	710	363.06
2001–02		38,729	1307	1250	393.51
2002–03		39,823	1460	1400	439.05
2003–04		40,403	1662	1600	507
2004–05		45,201	1715		507
2005–06		51,000[33]	2000[34]		537
Growth per year	6.24	6.18	14	14.09	6.50

Source: FAO, 2006

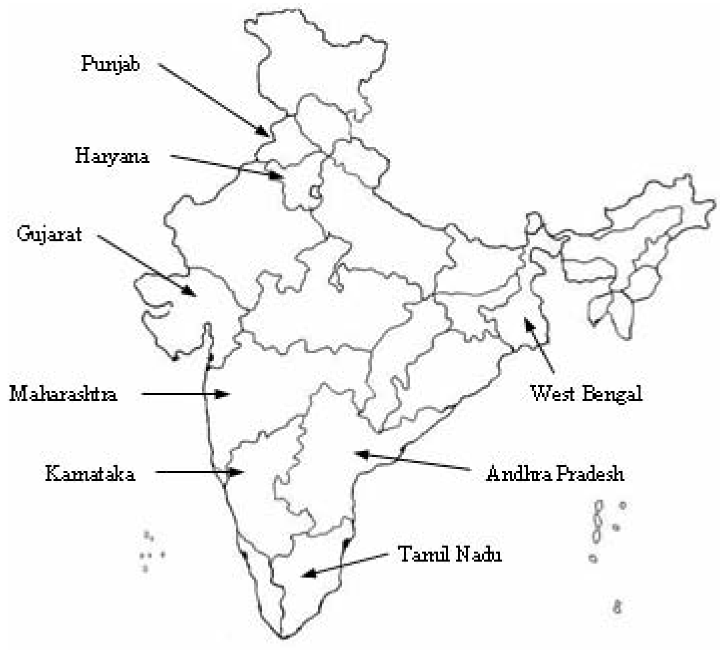
It should be noted that meat is the most important product in the poultry sector, having a 66.7 percent share of poultry output (in value terms). Poultry is the largest source of meat in India today. Its share in total meat consumption is 28 percent, as against 14 percent 10 years ago. It has outpaced its two competitors—beef and veal and buffalo meat. High mutton prices, religious restrictions on beef and pork, and the limited availability of fish outside of coastal regions have all helped to make poultry meat the most preferred and most consumed meat in India. Expanding domestic production and increasing integration have pushed poultry meat prices downward and stimulated its consumption.

B. GEOGRAPHIC LOCATION

The poultry industry in the country is characterized by its regional variation. Eight states account for bulk of egg production in India—Andhra Pradesh, Gujarat, Haryana, Karnataka, Maharashtra, Punjab, Tamil Nadu, and West Bengal. Andhra Pradesh is the largest egg-producing state, accounting for nearly 40 percent of the total egg production in the country. Following Andhra Pradesh is Tamil Nadu, whose share in countrywide production increased from 11.21 percent in 1997–1998 to 13.46 percent in 2005–2006 (See Figure C.11).

[33] Department of Animal Husbandry, 2008.
[34] Department of Animal Husbandry, 2008.

Figure C.11 – Largest Egg-Producing States in India



One district of Tamil Nadu—Namakkal—alone accounts for more than 30 percent of the total broiler production. The rest of the production is scattered across the country, mainly in the southern and western regions. Although a major portion of poultry production is concentrated in clusters, this is one of the most concentrated districts in India. There are several reasons that may account for this concentration, including the presence of an egg powder plant and availability of feed mills nearby. Per capita egg and chicken meat availability is also highest in the southern states, followed by the northern and western states, and is lowest in the eastern and central states. The cost of production is also lowest in the southern region for both eggs and meat, largely because of:

- Vertical integration in the sector
- Lower variation in temperature in the southern states
- Easy availability of medicines, vaccines, and veterinary services
- The fact that the poultry revolution was started in the south

Though the distribution of poultry production is much greater in rural versus urban areas, the markets are predominantly urban. As per the Indian Poultry Industry Yearbook, 1997, there are 3,786 farms in the country; the statewide distribution is presented in Table C.16.

C.4.2 Operational/Production Process

There are three main phases in the poultry industry: production, development, and processing/marketing. The poultry plants supporting these phases are commonly known as hatcheries/breeding farms (layer and broiler), farms (layer and broiler farms), and processing industry, respectively. The main products of the poultry industry are eggs, broilers, layers, processed eggs, and chicken meat.

C.4.3 Waste Characteristics and Management Systems

Table C.12 shows the types and quantity of wastes generated during various stages in the poultry industry.

Table C.12 – Waste Generated in Different Phases

S.N.	Phase	Corresponding Poultry Unit	Amount of Waste Generated	Main Waste Source/Stream	Contents of Waste
1	Production	Breeding farm/hatchery	1. 11 kg/ 1,000 chicks produced 2. 225 – 275 kg/ 1,000 parent birds/day	1. Hatching 2. Poultry litter	1. Eggshells, unhatched eggs, dead birds, etc. 2. Droppings, feathers, bedding material, waste feed, etc.
2	Development	Layer and Broiler Farms	180 kg/1000 layers/day 225-275 kg/1000 broilers/day	Poultry litter	Poultry droppings, feathers, bedding material, waste feed, etc.

The fresh litter from poultry farming in India is estimated to be 50,000 MT per day and 16.69 MMT per year. (See Table C.13)

Table C.13 – Estimated Production of Litter (x 10,000)

Chicken	Fresh MT/day	Fresh MT/year*	Dried MT/year*
Desi birds – Adult	1.408	511.94	170.61
Desi chicks (20 weeks age) – egg/meat	0.671	220.66	73.59
Exotic birds – adult (cock & hen)	1.243	451.66	150.37
Exotic chicks – for egg production (20 weeks age)	0.594	197.34	65.78
Exotic chicks – for meat production(up to 6 weeks age on litter)	0.957	260.92	87.01
* Fresh MT/year: assume 2 weeks down time per flock (no litter) * Dried MT/year: dried 25% to 35% moisture.			

Source: CPCB, 2009

Table C.14 presents the characteristics of poultry droppings as found from a study on recovery of energy from poultry waste, Institute of Agro-Tech Research, New Delhi.

Table C.14 – Characteristics of Poultry Droppings (bird weight 900–1,800g)

BOD(kg/ day)	TS (kg/ day)	SS (kg/day)	Nitrogen (% by weight)		Phosphate (% by weight)		Potassium Oxide (% by weight)		Carbohydrate (% by weight)	
			Solid	Liquid	Solid	Liquid	Solid	Liquid	Solid	Liquid
0.155	0.055	0.023	1.4	0.5	0.9	-	-	0.5	30.0	NA

The physical composition of fresh poultry manure is provided in Table C.15.

Table C.15 – Physical Composition of Poultry Manure

Parameter	Value
Moisture	75–80%
Volatile solids	15–16%
Ash content	5–7%
Avg. particle density	1.8
Bulk density	1,100 kg/m^3
Calorific value (based on 75% moisture)	3,200 KJ/kg of wet manure

The available waste is utilized as a fertilizer. The poultry droppings are very rich in plant nutrients. The quality and composition of the droppings depend on the method used for collecting droppings. Two important ways of collecting poultry droppings include:

- Deep Litter System: In this system, a bedding of rice straw (chopped in small pieces), rice husk, or saw dust is spread on the floor in the poultry farms. This system is used for broiler chicken farms.

- Slatted Floor and Cage System: In this system, the excreta remains deposited either on the floor or on the dropping boards under the perches below the cages. This system is used for layer chicken farms.

With the deep litter system, over the life cycle of the birds, the litter that they drop gets mixed and compacted with the husk. At the end of the cycle, local farmers come and buy this compacted litter-husk mixture at a rate which roughly offsets the cost incurred by the farm to buy the husk. The farmers use the material as fertilizer for fields.

With the slatted floor and cage system, the cages are open below and the litter falls in an evacuation in the ground, which is roughly 4 to 6 feet deep. It accumulates over days. When it dries, local farmers collect portions of the litter for use in their fields as manure.

C.4.4 Potential Biogas and Energy Generation

The biogas potential is estimated based on the following assumptions:

Poultry litter generated per bird (layer/broiler)	= 100 gm/bird/ day
Moisture content	= 40% (60% dry solids)
VS content	= 50% dry solids
VS utilized for biogas generation	= 40 - 45%
Biogas produced	= 0.8 m^3/kg of VS destroyed

As per the Indian Poultry Industry Year Book, 1997, there are 3,786 farms generating 4,564,862 kg of waste per day. Biogas generation potential of more than 70 percent of individual farms is less than 100 m^3/day; the total biogas potential of all the farms in the country is 438,227 m^3/day. This equates to capturing 243,459 m^3 of methane per day. The total bio-energy potential of this sector is estimated to be 55 MW (2001–2002), and it will be necessary to form a cluster of nearby farms in the same district to feed a common biomethanation facility at many locations across the country, as a majority of the farms are small and scattered.

Table C.16 presents the number of poultry farms and an estimate of their energy potential per state.**Table C.16 – Distribution of Poultry Farms and Potential Energy Generation, by State**

S.N.	State	No. of Farms	Flock Strength	Total Waste Generated (kg/day)	Biogas Potential (m^3/day)
1	Andhra Pradesh	664	13,619,300	1,362,480	130,798
2	Maharashtra	329	6,066,500	605,650	58,142
3	Haryana	390	5,446,900	543,990	52,223
4	Punjab	327	4,458,600	445,360	42,755
5	Karnataka	371	3,552,550	355,255	34,104
6	Tamil Nadu	327	3,507,600	350,760	33,673
7	Gujarat	211	2,393,999	239,400	22,982
8	Madhya Pradesh	170	1,575,000	156,700	15,043
9	Uttar Pradesh	165	861,150	86,115	8,267
10	Goa	67	521,625	52,163	5,008
11	Orissa	92	506,000	50,600	4,858
12	Chandigarh	30	503,500	50,350	4,834
13	Jammu & Kashmir	86	501,050	50,105	4,810
14	Kerala	210	493,050	49,305	4,733
15	Delhi	23	462,000	46,200	4,435
16	Rajasthan	45	364,200	36,420	3,496
17	West Bengal	122	362,550	36,255	3,480
18	Assam	28	228,000	22,800	2,189
19	Himachal Pradesh	32	136,550	13,655	1,311
20	Bihar	24	38,700	3,870	372
21	Andaman & Nicobar	31	28,350	2,835	272
22	Sikkim	8	14,750	1,475	142
23	Manipur	17	7,550	755	72
24	Meghalaya	8	5,900	590	57
25	Mizoram	1	4,700	470	45
	Total	3,786	45,673,124	4,564,862	438,227

Source: Indian Poultry Industry Yearbook

C.5 EDIBLE OIL SECTOR

C.5.1 Sector Profile

Edible oils are generally derived from various oil seed sources, including sunflower, soybean, corn, peanut, and rapeseed, and other vegetable sources. India accounts for 8.8 percent of world oilseed production. With oilseed production of about 22 MMT and oil production of about 7 MMT, India is the world's fourth largest edible oil economy. It is the world's largest producer of castor seed, the second largest producer of groundnut, and the third largest producer of rapeseed and cottonseed.[35] Major oilseed producing states in India include

[35] *India Image, (n.d.).*

Gujarat, Rajasthan, Madhya Pradesh, Maharashtra, Andhra Pradesh, Karnataka, and Tamil Nadu. According to estimates, there are approximately 150,000 oil crushing plants, 785 solvent extraction plants, 950 refineries (independent and attached with vanaspati solvent extraction plant), and 222 vanaspati plants.[36]

C.5.2 Production Process

The oilseed processing sector is largely concentrated in the cottage industries dominated by ghnis and kolus (animal-operated oil expellers).

C.5.3 Waste Characterization and Management

The quality and quantity of waste generated in this industry depends on the process involved and the efficiency of the system in minimizing the losses of raw materials and product. Solid wastes are generated, such as soil and organic material from the bleaching plants in the refining section and discarded oilseed waste. Wastewater characteristics are summarized in Table C.17.[37]

Table C.17: Wastewater Characteristics in the Different Processes of the Edible Oil Industry

Unit Name	pH	BOD (mg/L)	COD (mg/L)	TSS (mg/L)	Oil and Grease (mg/L)
Solvent extraction	6.5–9	180–1,083	485–2,740	79–1,352	5–30
Refinery	8–10	1,375–6,570	2,500–10,500	100–5,800	150–1,900
Hydrogenation	6.6–7.5	1,200–3,800	2,700–8,800	350–1,325	410–1,300

The degree of treatment required depends on the local conditions. Typically, the first stage entails the use of physical processes to recover free oils and fats. The most commonly used processes are fat traps, tilted plate separators, and DAF plants. Centrifuges and electrofloatation systems are occasionally used. Further treatment stages include flow and load balancing, pH control, chemical treatment, biological treatment, and sludge dewatering. In aerobic treatment, an activated sludge process is commonly followed.[38] However, anaerobic treatment can also be helpful, as the BOD and COD levels of the wastes from the edible oil industry are high. As indicated in Figure 3.4.4 for fruit- and vegetable-processing industries, the solid waste generated in the edible oil sector is also usually dumped in open landfills.

C.5.4 Technological Options

The technology options for the edible oil sector in anaerobic digestion are similar to the fruit and vegetable sector.

[36] *Directorate of Vanaspati, (n.d.).*
[37] *Andra Pradesh Pollution Control Board, (n.d.)*
[38] *Erickson, (1990).*

C.6 GRAIN PROCESSING SECTOR

C.6.1 Sector Profile

India is self-reliant in grain production, with an annual output of about 217 MMT in 2006–2007. India is the second largest producer of wheat and rice in the world, with a 20 percent share. All major grains, such as paddy, wheat, corn, barley, millets like jowar (great millet), bajra (pearl millet), and ragi (finger millet) are produced in the country. The states in India rich in grain production are Punjab (wheat, rice), Haryana (wheat, rice), Uttar Pradesh (wheat, rice, pulses), Rajasthan (millets, wheat, pulses), Madhya Pradesh (wheat, rice, pulses), Maharastra (wheat), Karnataka (corn), Andhra Pradesh (corn), and West Bengal (rice).

More than 65 percent of the wheat is converted into wheat products by the organized and unorganized sectors. Rice is consumed primarily in the form of polished rice, parched rice, and flaked rice. With a share of 40 percent, grain processing is the largest component of the food sector.[39] Wheat and rice together constitute the staple diet of the country. Total rice-milling capacity in the country is 186 MMT. There are about 516 large flour mills in the country, as well as about 10,000 pulse mills.[40] The rice-milling industry prevails mainly in states such as Uttar Pradesh, Uttrakhand, Punjab, Haryana, Orissa, West Bengal, Andhra Pradesh, Tamil Nadu, Bihar, Assam, and Karnataka. These states produce both basmati and non-basmati rice varieties.[41]

C.6.2 Production Process

Rice-, wheat-, and pulse-processing mills form a part of the grain-processing industry. Primary processing constitutes 96 percent, with the remaining accounted for by the secondary and tertiary sectors. Primary processing involves removing the husk and outer coating of the grains using a manual or mechanized process, followed by cleaning, grading, and packing. The secondary and tertiary sectors involve further processing of the grains for value-added products.

C.6.3 Waste Characteristics and Management

The solid waste generated during grain processing comprises mainly rejected grains, husk, and straw. Currently, the waste generated is being used in industries as an energy source in the boiler because it has high calorific value. However, large quantities of waste, especially straw, are left in the agricultural fields, which results in anaerobic digestion and subsequent methane emissions. In addition, some of the waste is also burned, resulting in carbon dioxide emissions. Apart from these wastes mentioned, wastewater is generated from straw wash.

The solid waste, such as straw, can be given away as cattle feed or burned inside a boiler, and the wastewater can be efficiently treated anaerobically. The rice husk having a high calorific value, produced after rice processing, is used as source of energy for boilers in many industries. The waste stream from raw wheat straw wash has a COD as high as 7,000 mg/L, making anaerobic treatment suitable.[42]

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[39] *Government of India, 2009*
[40] *Government of India, 2009*
[41] *Government of India, 2003.*
[42] *UNFCCC, n.d..*

C.6.4 Technological Options

Reactors such as UASB, upflow anaerobic filter process (UAFP), and anaerobic fluidized-bed are used in this sector and therefore serve as the technological options.

C.6.5 Policies and Programs in the Food-Processing Sector

The Ministry of Food Processing has been actively working on schemes to improve the food-processing sector. Some of these measures, schemes, and programs are detailed below.

a. SCHEME FOR TECHNOLOGY UPGRADING/EXPANSION/MODERNIZATION/ESTABLISHMENT OF FOOD PROCESSING INDUSTRIES

The scheme for technology upgrading/expansion/modernization/establishment of food-processing industries is aimed at creating and upgrading existing processing capabilities. The scheme provides 25 percent of the cost of plant and machinery and technical civil works subject to a maximum of Rs. 50 lakhs in general areas and 33.33 percent up to Rs. 75 lakhs in difficult areas. This scheme is continued from the 10th Five-Year Plan without any modifications in the pattern of assistance.

While in the 10th Five-Year Plan, the applications for assistance were processed by the Ministry of Food Processing in the 11th Five-Year Plan period, the processing and disbursal of grants has been decentralized through banks/financial institutions to provide wider coverage for food-processing industries in the country and simultaneously decentralize the procedures for appraisal, assistance, and monitoring. Decentralization has increased the number of cases, improved the viability of food-processing plants, and facilitated better monitoring of implementation. It also aimed at bringing the services of the government closer to the citizens, streamlining the existing procedures and increasing the reach and availability of assistance to larger sections of society. It marks an important step toward implementing the e-governance initiative of the government.

b. SCHEME FOR INFRASTRUCTURE DEVELOPMENT

The scheme has three components: mega food parks, integrated cold chain, and setting up/modernization of abattoirs. In its meeting held on September, 11, 2008, the Cabinet approved the establishment of 30 mega food parks (MFP) under the Infrastructure Development Scheme for MFPs during the 11th Five-Year Plan period. Ten MFPs have been approved for development in the first phase. The MFPs will be established at identified locations on the basis of cluster mapping and where there are infrastructure gaps.

c. RESEARCH AND DEVELOPMENT SCHEME

The research and development scheme of the Ministry of Food Processing includes activities in the following areas:

- Developing value-added processes for food products.
- Utilizing waste from food processing.
- Developing a process for extracting natural food colorants.

- Developing value-added products from guar gum.
- Developing weaning foods.
- Developing rapid testing kits for early detection of microbial spoilage.
- Establishing minimal processing technology for fruits, vegetables, and mushrooms; preserving food products; and standardizing shidal processing.

C.6.6 Costs and Potential Benefits

As previously mentioned, the food-processing sector in India is highly fragmented. There are many small-scale plants that cannot afford investing in waste management technology. Hence, there are limited waste management initiatives in these industries. However, the potential for MRU projects in these subsectors is high, as the wastewater is highly organic. Initiatives such as common effluent treatment plants (CETP) for food-processing industries would not only help in reducing costs, but also maximize benefits. The various cost elements include, in the case of individual plants, identifying technologies appropriate for MRU for this sector and implementing the technology. The value of the remaining lifetime of the existing wastewater treatment system (after depreciation) should also be included in the costs elements. Because the technologies suited for this sector include UASB, UAFB, and anaerobic fluidized bed reactor, substantial capital costs would be involved. Recurring costs like operations and maintenance expenses would also be major cost elements. If the CETP is being implemented apart from the aforementioned costs, land costs and other relevant costs would also be one of the major elements. The CDM projects for waste management in this sector are also less than the potential of this sector. Thus, the industry should look forward to the opportunity to partially finance the waste management projects through carbon markets.

APPENDIX D: GLOSSARY

Acetogenesis—The formation of acetate (CH_3CO_2) 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 process used to accomplish a degree of treatment greater than that 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 example of 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 micro-organisms lacking chlorophyll.

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.

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 2-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 clarifier, called an upflow clarifier, uses floatation rather than sedimentation to remove solids.

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

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

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

Covered Lagoon Digester—A pond or lagoon operated for the anaerobic stabilization of organic wastes, including manure, 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 manure.

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 (e.g.,with or without free oxygen).

Facultative Bacteria—Bacteria that 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 5 days at 20°C.

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

Human Sewage (Domestic Wastewater)—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°C 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- and acetoclastic-type substrates and methyl..

Municipal Wastewater—Wastewater treated in a municipal (publicly owned) treatment plant and containing 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 anaerobic stabilization of organic wastes, including manure, 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.

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 or 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.

Vanaspati—Indian; purified hydrogenated vegetable oil; similar to margarine and usually fortified with vitamins A and D. Also used to prepare ghee (vanaspati ghee).

Volatile Solids—Materials, generally organic, that can be driven off by heating, usually to 550°C; nonvolatile 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 primary and secondary treatment processes.

*Appendix B illustrates the typical wastewater treatment process.

APPENDIX E: BIBLIOGRAPHY

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