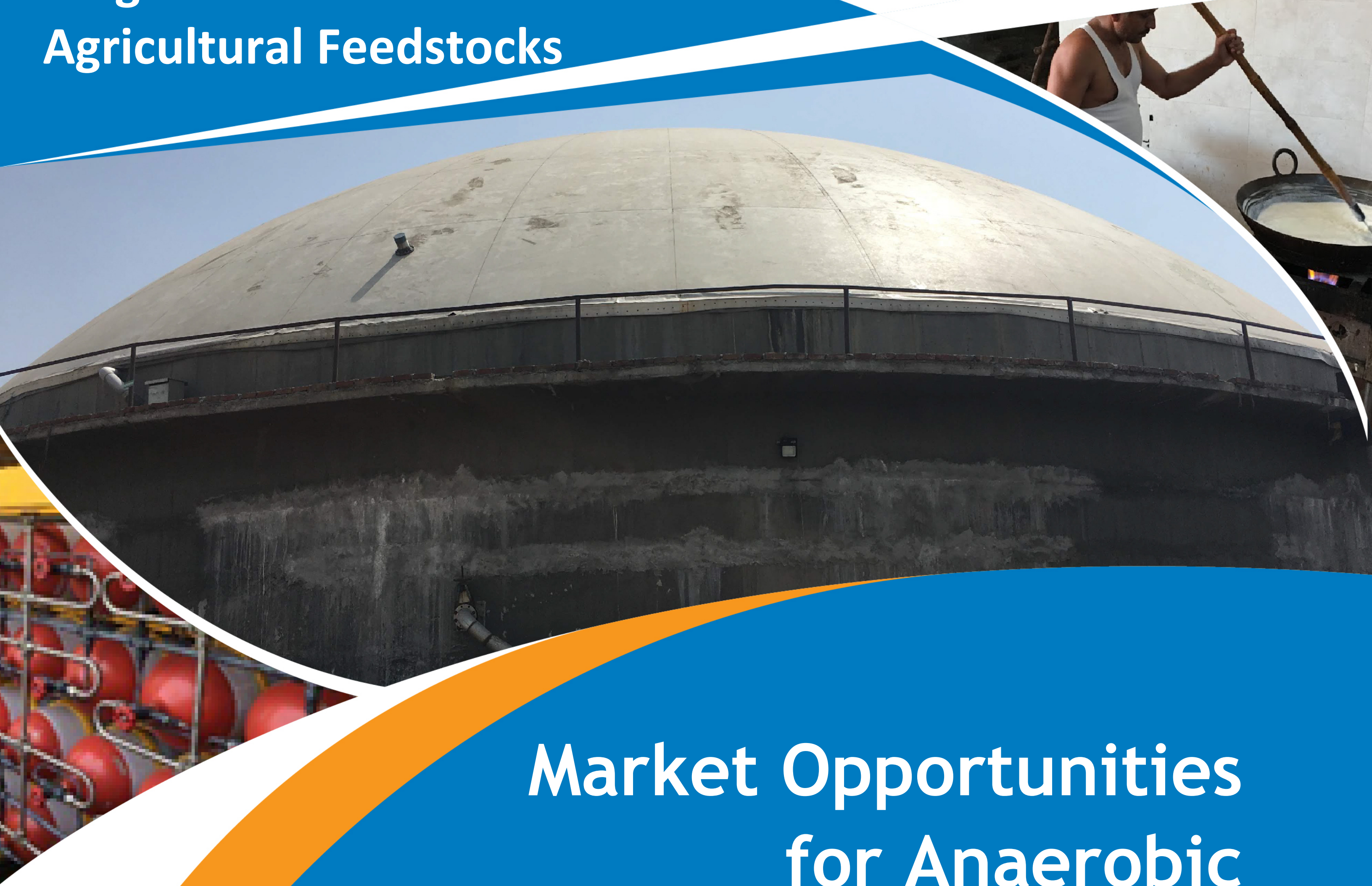
Section 3
Biogas Potential from Agricultural Feedstocks



Market Opportunities for Anaerobic Digestion of Livestock and Agro-Industrial Waste in India

Prepared for:

The Global Methane Initiative

3. Biogas Potential from Agricultural Feedstocks

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 agriculture-related activities. With 168 million hectares of arable land, India ranks second only to the United States in the amount of arable land. India has more than 500 million head of livestock and 700 million head of poultry (Government of India, 2014). With this level of agricultural activity, there is substantial amount of waste produced that could serve as feedstock for biogas production through anaerobic digestion (AD). Agricultural waste is produced from a wide range of subsectors, including crop production, livestock and milk production, and agro-based industries (paper and pulp production, sugarcane processing, distilleries, and other food and food processing industries).

In 2010, emissions of greenhouse gases (GHGs; excluding the land use and forestry sectors) in India were 2.7 billion metric tons of carbon dioxide equivalent (CO_2e). Nearly a quarter of these emissions were from agriculture, with an additional 5 percent from waste (including solid waste, wastewater, and waste incineration). Figure 1 presents national GHG emissions data for India.

The purpose of this section is to describe the availability of feedstocks for AD, as well as their associated methane reduction potential and biogas production potential. The goal of this overview is to help industry developers, financiers, and policymakers determine where to focus efforts on biogas development in India.

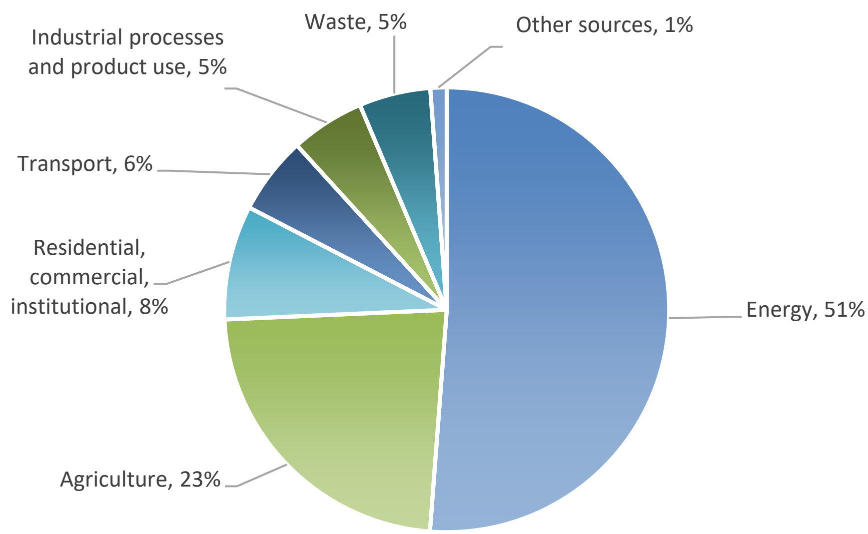


Figure 1. Total 2010 GHG Emissions in India by Sector (FAO, 2018)

3.1 Overview of Reviewed Agriculture Sectors

Subsectors of livestock production and agricultural commodity processing that had the greatest potential for biogas capture and use through AD were previously identified for India in the *Resource Assessment for Livestock and Agro-Industrial Wastes – India* (GMI, 2011). These subsectors included dairy farms, sugarcane processing, distilleries, fruit and vegetable processing, cornstarch production, tapioca production, and milk processing. The Global Methane Initiative (GMI) has included poultry manure and crop residues in this report based on increased interest in AD of poultry manure in India, primarily related to environmental concerns with poultry manure management and the air pollution and health impacts of burning crop residues, primarily rice paddy straw.

Table 1 below briefly describes each subsector included in this section and its primary geographic location. The remainder of this section includes a more detailed discussion of each of these subsectors.

Table 1. Main Subsectors with Potential for Methane Emission Reductions

Subsector	Agricultural Production	Primary States
Dairy Farms	67.5 million head of milk-producing cattle and 51.1 million head of milk-producing buffalo in 2012 (Government of India, 2014)	Uttar Pradesh, Madhya Pradesh, Rajasthan, West Bengal, Maharashtra
Poultry Farms	729 million head of poultry in 2012 (Government of India, 2014)	Andhra Pradesh (including Telangana), Tamil Nadu, Maharashtra
Milk Processing	165 million metric tons of milk produced in 2016–2017, 20 percent of which was processed (Government of India, Undated)	Uttar Pradesh, Rajasthan, Madhya Pradesh, Gujarat, Andhra Pradesh
Sugarcane Processing	348 million metric tons of sugarcane produced in 2014 (Government of India, 2018)	Maharashtra, Uttar Pradesh, Andhra Pradesh, Karnataka, Tamil Nadu, Gujarat
Distilleries	4.5 billion liters of alcohol produced	Maharashtra, Uttar Pradesh, Andhra Pradesh, Karnataka, Tamil Nadu, Gujarat
Fruit and Vegetable Processing	97 million metric tons of fruits and 184 million metric tons of vegetables produced in 2016–2017, 2 percent of which was processed (Government of India, 2018; USDA GAIN 2017b)	Karnataka, Maharashtra, Andhra Pradesh, Punjab, Gujarat
Cornstarch Processing	1.8 million metric tons of cornstarch from 24 million metric tons of corn (USDA GAIN 2017c)	Andhra Pradesh, Karnataka, Gujarat, Uttarakhand
Tapioca Processing	79 thousand metric tons of tapioca from 4.9 million metric tons of cassava produced in 2013–2014 (Government of India, 2018)	Kerala, Tamil Nadu, Andhra Pradesh
Crop Residues	178 million metric tons of surplus crop residue not used for other purposes (TIFAC, 2018)	Uttar Pradesh, Punjab, Maharashtra, Andhra Pradesh, Gujarat, Madhya Pradesh, Haryana, Telengana, Karnataka

Biogas Production Potential

AD systems can produce biogas and reduce methane gas emissions from the existing, or baseline, waste management system; and provide an opportunity to generate revenue from the produced biogas.

Biogas production and methane emission reduction potentials are defined as follows:

- **Biogas production potential** represents the amount of biogas that may be produced from AD systems.
- **Direct methane emission reduction potential** represents the methane emissions that may be avoided due to the use of AD systems. Direct emission reduction potential is reported here both in terms of CH_4 and CO_2e.
- **Indirect emission reduction potential** represents the CO_2e emissions that could be avoided if biogas were used as a fuel for electricity generation in place of fossil fuels.

Table 2 presents estimates of the potential methane emission reductions and biogas productions for the subsectors reviewed in this report. Default values from the *2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (IPCC 2006 Guidelines)* were used for the calculations when country-specific data were not available. Appendix A presents details of the calculations**.**

Table 2. Biogas Potential By Subsector

	Biogas Production Potential (million m³/yr)	Direct Methane Emission Reduction Potentials		Indirect Emission Reduction Potential
		CH_4 (thousand metric tons/yr)	CO_2e (thousand metric tons/yr)	CO_2e (thousand metric tons/yr)
Dairy Manure	5,137	324	8,096	12,788
Poultry Manure	929	3.3	81.4	1,573
Sugarcane Processing	328	122	3,062	554
Distilleries	125	8.8	220	212
Milk Processing	17	1.2	29	28
Fruit and Vegetable Processing	27	10	254	46
Cornstarch Processing	13	5	126	23
Tapioca Processing	0.3	0.1	2.9	0.5
Crop Residues	29,983	na	na	Na
Total	**38,538**	**359**	**8,975**	**15,224**

Notes:
1. Totals may not sum due to rounding.
2. Direct methane emission reduction potential was not calculated since the burning of crop residues does not produce methane and GMI lacked data on how the remainder of the surplus crops are disposed of.

While these industries may produce significant quantities of solid waste that could potentially be added to AD systems, these wastes were not included in developing the estimates shown in Table 2 due to lack of available data. However, the addition of these wastes may significantly increase the methane generation of the AD system.

Codigestion

Codigestion occurs when more than one type of organic waste is fed into an anaerobic digester. Codigestion typically is used to manage multiple waste streams and increase the volume of biogas produced. The wastes discussed above could be codigested resulting in higher methane production potentials than presented in Table 2.

Ideal feedstocks for codigestion are those that have a high biogas yield. Since it will impact the amount and nature of the feedstock to be digested, the following considerations need to be evaluated when determining if codigestion is an option:

- Volume of additional feedstock
- Impact of additional feedstock
- Potential for the introduction of toxic substances that will suppress biogas production
- Ability to utilize the additional biogas produced
- Possible need for pre-processing of the additional waste
- Need for additional digester effluent disposal
- Ability to secure a long-term contract with the supplier guaranteeing minimum volume, quality, and fees of feedstock.

3.2 Dairy Manure

Sector Description

India is the largest producer of milk in the world, with a population of milk-producing buffalo, cattle, and goats of more than 180 million head. According to the 19th Livestock Census (Government of India, 2014), India has 67.5 million milch (milk producing) cattle, including both dry and in-milk females, and 51.1 million milch buffalo. These animals are concentrated in several states. More than 50 percent of India's dairy cattle population is concentrated in Uttar Pradesh, Madhya Pradesh, Rajasthan, West Bengal, Maharashtra, and Bihar. Uttar Pradesh, Rajasthan, and Andhra Pradesh (including Telangana) together have 50 percent of India's dairy buffalo population. Figure 2 presents a map of the top dairy-producing states, shown in dark blue, from the combination of dairy and buffalo.

As seen in Figure 3, the top 10 states with the greatest dairy cattle populations account for over three-quarters of dairy cattle in India.

Figure 2. Main Dairy-Producing States

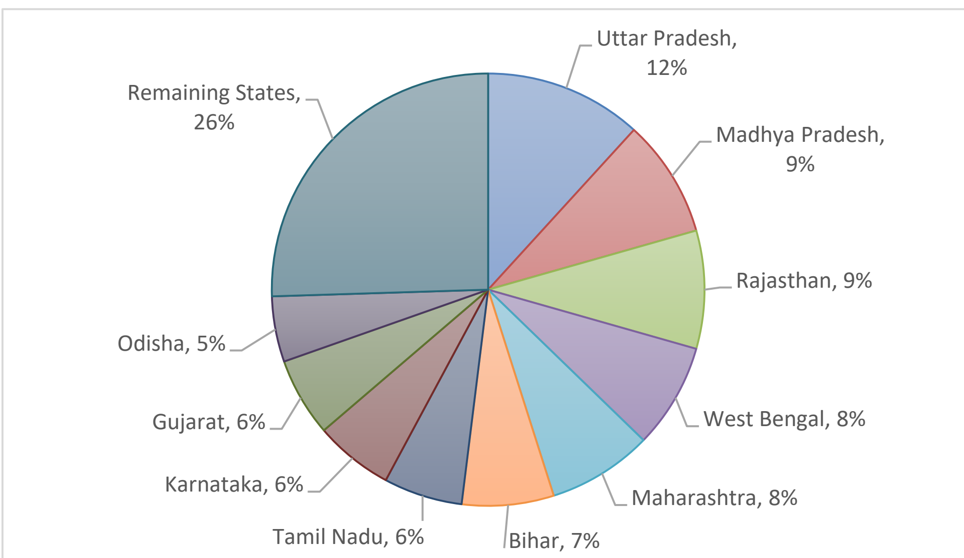


Figure 3. Dairy Cattle Population from the 19th Livestock Census (Government of India, 2014)

Manure Management

Based on assumptions in the *IPCC 2006 Guidelines*, 51 percent of dairy manure (both cattle and buffalo) in India is burnt for fuel, 27 percent is left on pasture, 19 percent is spread daily, 1 percent is managed in liquid slurry systems, and the remaining 1 percent is managed in AD systems.

Biogas Production Potential

For the assessment, GMI assumed that 50 percent of dairy manure managed on systems other than pasture could be treated using AD, based on expert judgment. Table 3 presents the biogas production and methane emission reduction potentials for dairy manure. Default values from the *IPCC 2006 Guidelines* were used to calculate the values included in the table. Appendix A presents details of the calculations.

Table 3. Biogas Production and Direct Methane Emission Reduction Potential for Dairy Manure in India

Potentials	Value
Biogas Production Potential (million m^3/yr)	5,137
Direct Methane Reduction Potential (thousand metric tons CH_4/yr)	324
Direct Methane Reduction Potential (thousand metric tons CO_2e/yr)	8,096
Indirect Emission Reduction Potential (thousand metric tons CO2e/yr)	12,788

3.3 Poultry Manure

Sector Description

Poultry production is one of the fastest-growing agricultural sectors in India. Between 2007 and 2012, the population of poultry animals in India increased by 12 percent from 648 to 729 million head.

Chickens or fowls (including laying hens and broilers) make up the majority of poultry in India. The remaining poultry (ducks, turkeys, and others), make up about 5 percent of the population.

India's primary poultry-producing states, Andhra Pradesh (including Telangana), Tamil Nadu, and Maharashtra, contain nearly 50 percent of the country's total poultry population. Figure 4 presents a map with the main poultry-production states shown in dark blue. Figure 5 presents the top 10 poultry-producing states and their populations.

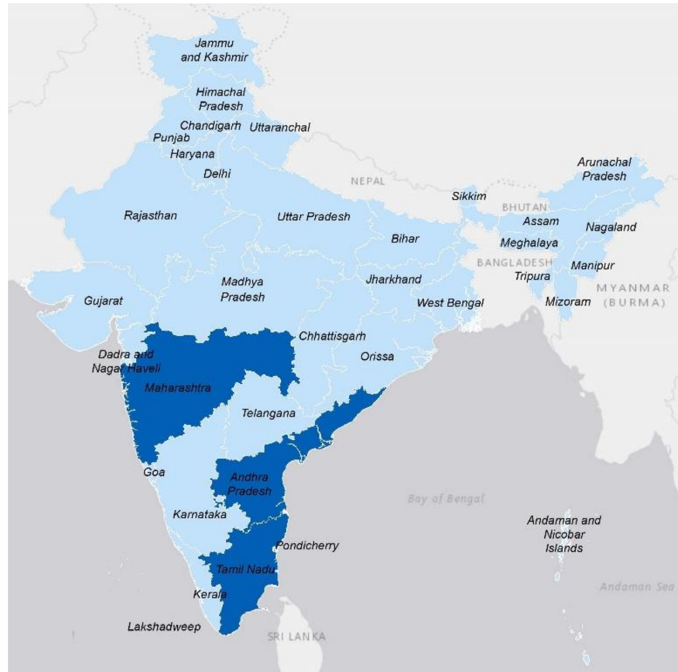


Figure 4. Main Poultry-Producing States

Manure Management

The production and development of poultry produces waste, which is called "litter" and includes manure, eggshells, feathers, and feed. This waste does not typically include any bedding material because it is generally not used in India. Relatively few poultry farms use any type of anaerobic treatment. At most poultry farms (and likely all large poultry farms), the litter is typically removed from the animal housing every six months and composted for use as fertilizer.

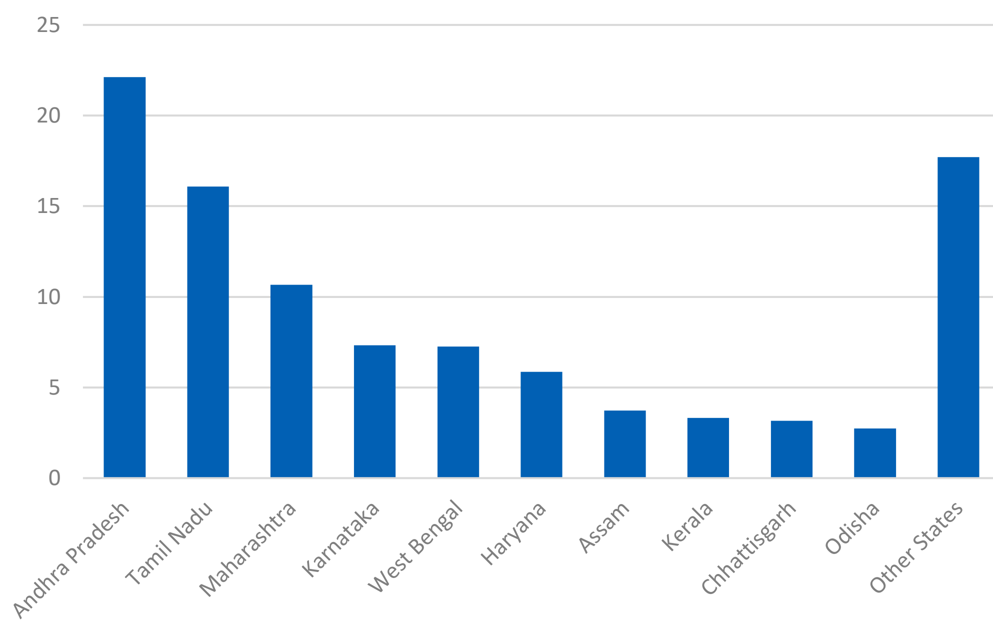


**Figure 5. Poultry Population by State (percent)
(Government of India, 2014)**

Biogas Production Potential

AD of poultry manure can be a challenge due to the moisture and nitrogen content of the waste, and the presence of a significant amount of grit. Also, poultry manure typically has relatively low methane emissions and low methane production potential compared to other types of manure. This is especially true when the poultry manure is mixed with other materials (such as feathers) and not removed from the animal housing frequently.

However, due to negative environmental impacts of poultry manure in India, there is interest in using AD for poultry manure management. Multiple Indian poultry farmers have installed AD systems. Some of these systems modified existing manure handling and management practices. For example, the Radu Sakku Agro Farm in Karlam village in the state of Andhra Pradesh installed conveyor belts to remove manure daily from the poultry housing; this manure was then transported to an AD system (Srinivas, 2013).

For this assessment, GMI assumed that 50 percent of poultry manure could be treated using AD, based on expert judgment. Table 4 presents the biogas production and methane emission reduction potentials for poultry manure. Default values from the *IPCC 2006 Guidelines* were used to calculate these numbers. Appendix A presents details of the calculations.

Table 4. Biogas Production and Direct Methane Emission Reduction Potential for Poultry Manure in India

Potentials	Value
Biogas Production Potential (million m^3/yr)	929
Direct Methane Reduction Potential (thousand metric tons CH_4/yr)	3.3
Direct Methane Reduction Potential (thousand metric tons CO_2e/yr)	81.4
Indirect Emission Reduction Potential (thousand metric tons CO2e/yr)	1,573

3.4 Sugarcane Processing

Sector Description

India is the largest consumer and second-largest producer of sugar worldwide with sugarcane grown across India. Uttar Pradesh, Maharashtra, Andhra Pradesh, Karnataka, Gujrat, and Tamil Nadu are the primary sugar-producing regions, as shown in Figure 6.

Sugar processing facilities tend to be located near major sugarcane-producing areas to minimize transportation costs. As a result, Uttar Pradesh, Maharashtra, Karnataka, and Tamil Nadu have the highest amount of both sugarcane area and sugarcane production (VSI, 2018). As presented in Figure 7, these states make up nearly 85 percent of sugarcane production in India. Based on expert judgment, an estimated 75 percent of sugarcane is processed in sugar mills, while the remaining 25 percent is used to produce jaggery, an unrefined sugar product, which produces no wastewater.

Figure 6. Main Sugar-Producing States

In the 2011–2012 processing season, 529 sugar factories were operational in India and processed 257 million metric tons of sugarcane, producing 26 million metric tons of sugar (VSI, 2018). As of 2014, the amount of sugarcane processed was over 350 million metric tons.

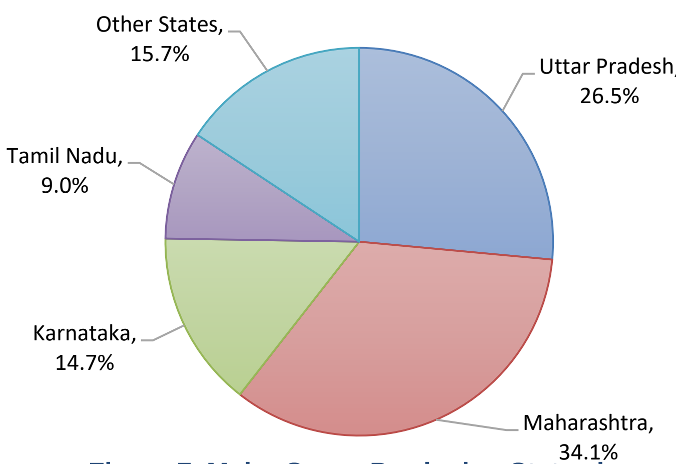


Figure 7. Major Sugar-Producing States by Percent of Production (VSI, 2018)

Wastewater Treatment

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). Based on the IPCC methodology, wastewater emissions are related to the chemical oxygen demand (COD) content of wastewater. Typical sugarcane mill wastewater has a COD that can be as high 32,000 mg/L; however, on average, the COD is closer to 3,000 mg/L (GMI, 2011). For this assessment, GMI used the IPCC default COD of 3,200 mg/L.

Based on information collected during the development of the 2011 Resource Assessment for India, sugarcane processing facilities commonly use a combination of aerobic and anaerobic treatments. Aerobic treatment is the most common management practice, followed by AD. An additional 17 percent of facilities combine aerobic treatment with AD.

Biogas Production Potential

For this assessment, GMI assumed that 5 percent of sugar processing wastewater is managed in open lagoons that could be converted to AD systems (as determined from information collected for the 2011 India Resource Assessment). Table 5 presents the biogas production and methane emission reduction potentials. Appendix A presents details of the calculations.

Table 5. Direct Methane Reduction and Methane Production Potential for Sugar Processing in India

Potentials	Value
Biogas Production Potential (million m^3/yr)	328
Direct Methane Reduction Potential (thousand metric tons CH_4/yr)	122
Direct Methane Reduction Potential (thousand metric tons CO_2e/yr)	3,062
Indirect Emission Reduction Potential (thousand metric tons CO2e/yr)	554

3.5 Distilleries

Sector Description

There are 330 distilleries in India that produce 4.5 billion liters of alcohol annually (USDA GAIN, 2017a). Molasses produced as the byproduct of sugarcane refining is the major feedstock for distilleries. As a result, distilleries are often, but not always, integrated with sugarcane processing mills. A minor number of distilleries use grain as a feedstock (ENVIS Centre, Undated).

Distilleries are typically located in or near the major sugarcane-producing areas in India to minimize raw cane and molasses transportation costs. As a result, similar to sugarcane processing facilities, distilleries are primarily located in Maharashtra, Uttar Pradesh, and Tamil Nadu. The main producing states are shown in dark blue in Figure 8.

Figure 8. Main Alcohol-Producing States

Wastewater Treatment

Major sources of wastewater for molasses-based distilleries include process waste streams like spent wash, fermented sludge, and spent lees. Non-process waste streams that produce significant quantities of wastewater include cooling water, waste wash water, boiler blowdown, and bottling plant wastewater (ENVIS Centre, Undated). Nearly 12–15 L of wastewater is produced per liter of alcohol generated, and COD can range from 80,000 to 160,000 mg/L (ENVIS Centre, Undated).

Based on expert opinion, more than 90 percent of distilleries in India already treat their wastewater with AD systems. In distilleries without AD, incineration is another common method of waste disposal.

Biogas Production Potential

Approximately 5 percent of distillery wastewater in India is currently managed in aerobic systems. For this assessment, GMI assumed that the wastewater managed in aerobic systems could instead be managed using AD systems. Table 6 presents the biogas production and methane emission reduction potentials. Appendix A presents details of the calculations.

Table 6. Biogas Production and Direct Methane Emission Reduction Potential for Distilleries in India

Potentials	Value
Biogas Production Potential (million m^3/yr)	125
Direct Methane Reduction Potential (thousand metric tons CH_4/yr)	8.8
Direct Methane Reduction Potential (thousand metric tons CO_2e/yr)	220
Indirect Emission Reduction Potential (thousand metric tons CO2e/yr)	212

3.6 Milk Processing

Sector Description

India is the world's largest milk producer with more than 165 million metric tons of milk produced in the 2016–2017 market year (Government of India, Undated). Figure 9 presents a map of the main milk-producing states, shown in dark blue, which mainly track the location of dairy cattle discussed in Section 2.1. Figure 10 presents the top 10 milk-producing states in 2017, which accounted for greater than 80 percent of production.

India's milk production has been continuously increasing due to its growing livestock population, better feedstocks, and better breeds of cattle. In the 2016–2017 market year, Uttar Pradesh, Rajasthan, Madhya Pradesh, Gujarat, and Andhra Pradesh were the major milk-producing states, accounting for greater than 50 percent of the nation's milk production. Figure 11 (Government of India, Undated) shows the increase in milk production in India over 30 years.

Figure 9. Main Milk-Producing States

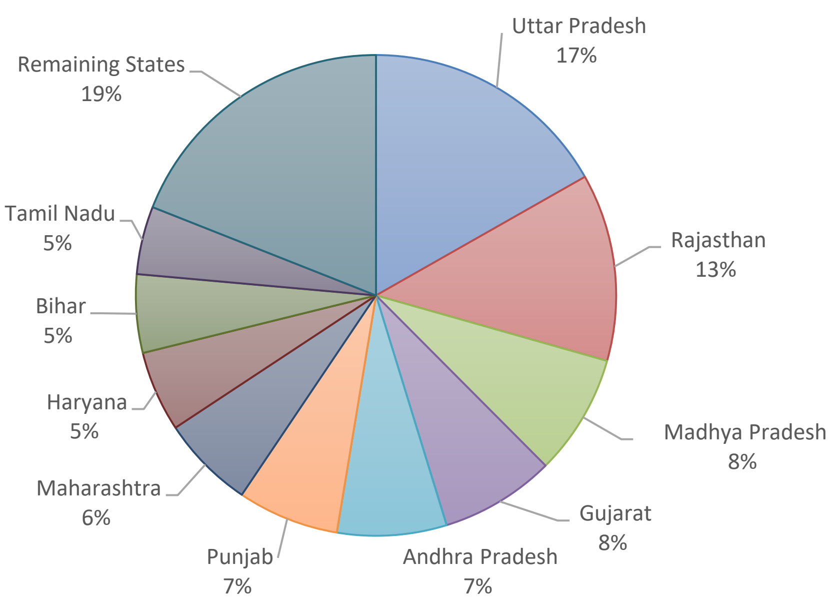


Figure 10. Milk Production for the 2016–2017 Market Year (National Dairy Development Board, 2017)

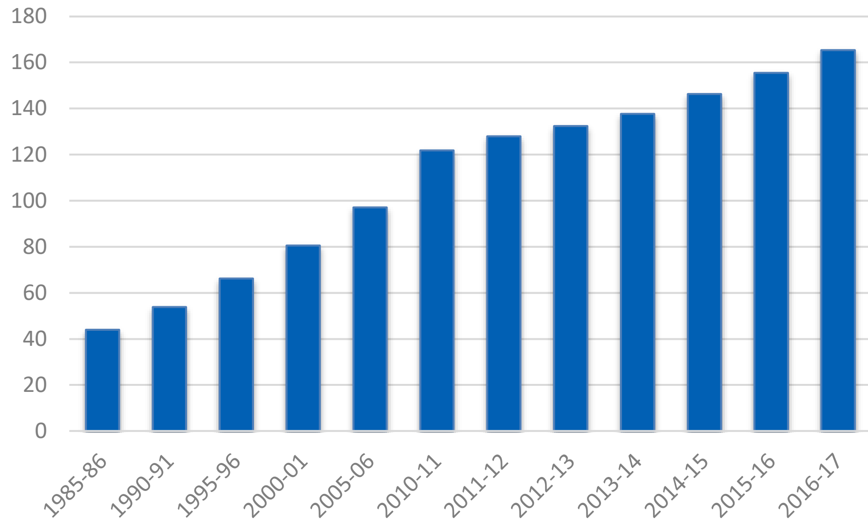


Figure 11. Milk Production in India in Million Metric Tons (DAHDF, 2017)

Wastewater Treatment

About 20 percent of milk produced in India is processed (Mehrotra et al., 2016). Water is used in milk-processing plants for cleaning equipment and chilling, and during processing. Water used for cooling is reused and segregated from the water used for milk processing. In general, the ratio of fresh water used for milk processing is around 1:1, and the amount of wastewater generated is usually 75 to 85 percent of the water used, depending on the dairy product. Based on the IPCC methodology, methane emissions from wastewater are based on the amount of COD content. The COD at milk processing plants in India typically ranges from 1,000 to 4,500 mg/L (Mehrotra et al., 2016).

Milk-processing plants in India have wastewater treatment systems that meet the regulatory requirements of the Central Pollution Control Board and remove high levels of suspended solids and organic material. Most milk processing wastewater is managed using aerobic treatment. Few AD systems treat dairy processing waste.

Biogas Production Potential

For this assessment, GMI assumed that 5 percent of the wastewater from milk-processing facilities could be managed using AD systems, based on expert judgment. Table 7 presents the biogas production and methane emission reduction potentials. Appendix A presents details of the calculations.

Table 7. Biogas Production and Direct Methane Reduction Potential for Milk Processing in India

Potentials	Value
Biogas Production Potential (million m^3/yr)	17
Direct Methane Reduction Potential (thousand metric tons CH_4/yr)	1.2
Direct Methane Reduction Potential (thousand metric tons CO_2e/yr)	29
Indirect Emission Reduction Potential (thousand metric tons CO2e/yr)	28

3.7 Fruit and Vegetable Processing

Sector Description

In the 2014–2015 market year, an estimated 97.4 million metric tons of fruits and 184.4 million metric tons of vegetables were produced in India (Government of India, 2018). An estimated 2 percent of the fruit and vegetable production is processed (USDA GAIN, 2017b). Typical processed products include fruit pulps, juices, pickles, dehydrated and curried vegetables, dried fruits, and processed mushrooms (USDA GAIN, 2017b).

Figure 12 highlights the main states producing fruits and vegetables in India, and Table 8 presents the fruit and vegetable produced in these states.

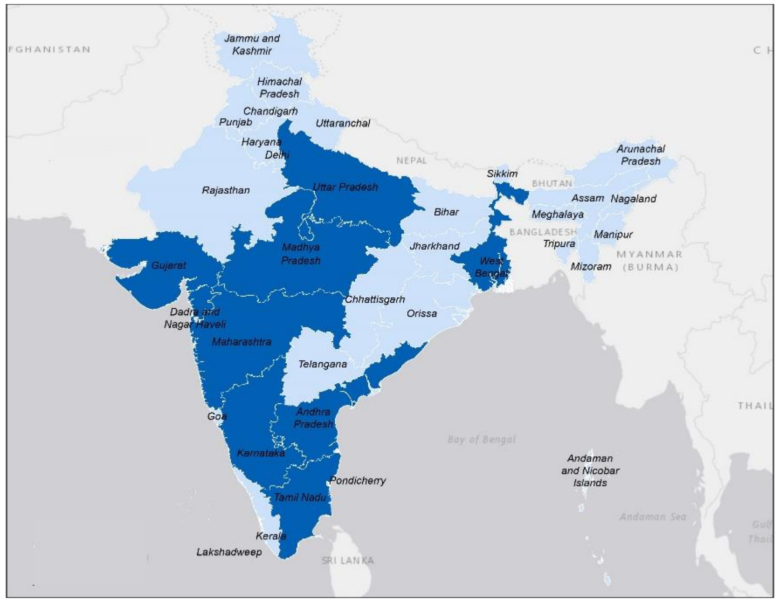


Figure 12. Main Fruit and Vegetable-Producing States

Table 8. Major Indian States Contributing to Fruit and Vegetable Production

State	Fruit/Vegetable Production
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
Madhya Pradesh	Temperate fruits, apple, pear, plum, peach

Source: Government of India, 2017.

Wastewater Treatment

Fruit and vegetable processing produces a significant amount of liquid waste with high concentrations of organic matter. While wastewater type and composition vary by type of product, processes that may contribute to wastewater production at food processing facilities include washing, husking, desilking, blanching, cutting, peeling, slicing, clipping, screening, and grading.

Preliminary treatment of wastewater may include screening and grit removal, which is typically followed by pH adjustment and aerobic treatment. Although aerobic biological treatment is the most common practice, variable flow rates and concentrations of organic compounds result in operational problems and variations in effluent quality. As a result, anaerobic processes are becoming the preferred approach for treating fruit and vegetable processing wastewater in India. Of the 18 percent of wastewater being managed in anaerobic systems, it is estimated that half is managed in open lagoons (GMI, 2011).

Biogas Production Potential

For this assessment, GMI assumed that the 9 percent of wastewater managed in open lagoons could be replaced with and managed using AD systems, based on expert judgement. Wastewater that is managed in open lagoons typically has the greatest potential for reducing methane emissions. Table 9 presents the biogas production and methane emission reduction potentials. Appendix A presents details of the calculations.

Table 9. Biogas Production and Direct Methane Emission Reduction Potential for Fruit and Vegetable Processing in India

Potentials	Value
Biogas Production Potential (million m^3/yr)	27
Direct Methane Reduction Potential (thousand metric tons CH_4/yr)	10
Direct Methane Reduction Potential (thousand metric tons CO_2e/yr)	254
Indirect Emission Reduction Potential (thousand metric tons CO2e/yr)	46

3.8 Cornstarch Production

Sector Description

The growth of the starch industry in India has been driven by population growth and the increase in disposable income. Corn is one of the primary sources of starch in India. Cornstarch is widely used in foods, but also has applications in the paper and textile industries.

India produced 24 million metric tons of corn during the 2016–2017 market year, and 1.8 million metric tons of that is used for starch production (USDA GAIN, 2017c). Cornstarch production is concentrated in Andhra Pradesh, Karnataka, Gujarat, and Uttarakhand, as highlighted in Figure 13.

Figure 13. Main Cornstarch-Producing States

Wastewater Treatment

Cornstarch processing begins with cleaning and steeping, a controlled fermentation process where the corn is soaked in hot water. Kernels are then separated and dried, and oil is extracted from the corn and refined. Significant quantities of liquid and solid wastes are produced in the processing of cornstarch; and the major sources of liquid waste include steeping, separation, and fiber drying. For every metric ton of corn processed, an estimated 8.3 m^3 of wastewater is generated (GMI, 2011). Table 10 presents typical characteristics of cornstarch processing wastewater. Based on information collected for the previous India resource assessment, 14 percent of cornstarch processing wastewater in India is treated in open lagoons.

Table 10. Characteristics of Wastewater from Cornstarch Plants

Characteristic	Typical Range
pH (s.u.)	4–5
BOD (mg/L)	4,000–12,650
COD (mg/L)	10,000–20,000
TSS (mg/L)	5,600–11,000
TDS (mg/L)	4,000–6,000

BOD = biochemical oxygen demand, TDS = total dissolved solids, TSS = total suspended solids.
Source: GMI, 2011.

Biogas Production Potential

For this assessment, GMI assumed that the 14 percent of cornstarch processing wastewater managed in open lagoons could be managed using AD systems, based on expert judgement. Table 11 presents the biogas production and methane emission reduction potentials. Appendix A presents details of the calculations.

Table 11. Biogas Production and Direct Methane Emission Reduction Potential for Cornstarch Production in India

Potentials	Value
Biogas Production Potential (million m^3/yr)	13
Direct Methane Reduction Potential (thousand metric tons CH_4/yr)	5
Direct Methane Reduction Potential (thousand metric tons CO_2e/yr)	126
Indirect Emission Reduction Potential (thousand metric tons CO2e/yr)	23

3.9 Tapioca Production

Sector Description

India is one of the world's major producers of cassava, an important root crop and a source of tapioca starch. While cassava is cultivated in 13 states in India, the key production areas are concentrated primarily in Tamil Nadu, but some production also occurs in the southern Indian states of Kerala and Andhra Pradesh (GMI, 2011). Figure 14 presents a map of the main tapioca-producing states, shown in dark blue.

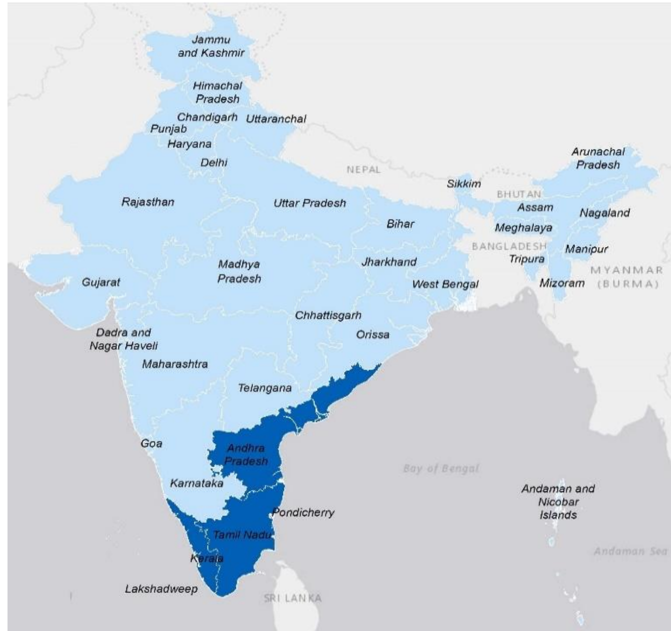


Figure 14. Main Tapioca-Producing States

Wastewater Treatment

Tapioca processing begins with washing and peeling. The tubers are then rasped, screened to separate pulp, dewatered, dried, and then pulverized and packaged for sale. Depending on the stage of the manufacturing process, wastewater characteristics will differ. Table 12 shows typical characteristics of combined tapioca processing wastewater.

Table 12. Characteristics of Wastewater from Tapioca Plants

Characteristic	Typical Range
pH (s.u.)	4.5–5.6
BOD (mg/L)	4,600–5,200
COD (mg/L)	5,631–6,409
TSS (mg/L)	565–640
TDS (mg/L)	3,435–3,660

Source: GMI, 2011.

Many tapioca plants are small and likely use open lagoons or do not treat their wastewater. Large plants are more likely to have anaerobic treatment for their waste. Based on information collected for the previous India resource assessment, GMI estimated that approximately 17 percent of tapioca processing wastewater is managed in open lagoons (GMI, 2011).

Biogas Production Potential

For this assessment, GMI assumed that the 17 percent of tapioca processing wastewater managed in open lagoons could be managed using AD systems based on expert judgement. Table 13 presents the biogas production and methane emission reduction potentials. Appendix A presents details of the calculations.

Table 13. Biogas Production and Direct Methane Reduction Potential for Tapioca Production in India

Potentials	Value
Biogas Production Potential (million m^3/yr)	0.3
Direct Methane Reduction Potential (thousand metric tons CH_4/yr)	0.12
Direct Methane Reduction Potential (thousand metric tons CO_2e/yr)	2.9
Indirect Emission Reduction Potential (thousand metric tons CO2e/yr)	0.5

3.10 Crop Residues

Sector Description

Figure 15. Main Major Crop Producing States

India has 140 million hectares (TIFAC, 2018) of land under crop cultivation with a large variety of crops being grown. A substantial amount of crop residues is generated post-harvest. These residues are mainly used for animal feed, thatch for roofing, soil mulch and manure, and as a source of energy for rural households and industrial use. However, a large portion of the crop residues (referred here as surplus crop residue) is not utilized, and sometimes burned to clear fields for sowing the next crop. It is estimated that about 683 million tons of crop residue is produced annually from 11 major crops grown in India. The total annual surplus crop residues is estimated to be approximately 178 million tons. While burning the crop residues does not generate methane, it does have a substantial impact on air quality due to emissions of particulate matter. Crop burning in Punjab and Haryana impacts the air quality not just in the states where it is burned, but as far away as New Delhi, which is about 250 kilometers away. These crop residues are a potential feedstock for biogas projects.

The availability of major crops in India by state is provided in Table 14. The annual production of crop residues and surplus quantities of key crops is shown in Table 15. The States of Uttar Pradesh, Punjab, Maharashtra, Andhra Pradesh, Karnataka, Gujarat, Madhya Pradesh, Rajasthan, Haryana, West Bengal, and Tamil Nadu, highlighted in Figure 15, are the primary major crop (and crop residue) producing states.

Table 14. Availability of Major Crops of India by State

Crop Type	States
Rice	Uttar Pradesh, Punjab, West Bengal
Wheat	Uttar Pradesh, Punjab, Haryana
Bajra	Rajasthan, Gujarat, Maharashtra
Jowar	Maharashtra, Karnataka, Madhya Pradesh, Andhra Pradesh
Sugarcane	Uttar Pradesh, Maharashtra, Karnataka
Cotton	Maharashtra, Uttar Pradesh, Andhra Pradesh
Groundnut	Gujarat, Tamil Nadu, Andhra Pradesh
Oilseeds	Madhya Pradesh, Rajasthan, Andhra Pradesh, Karnataka, Maharashtra

Table 15. Crop-Wide Total Dry and Surplus Biomass

Methane Potentials	Dry Biomass (million tons)	Surplus Biomass (million tons)
Rice	225.5	43.9
Wheat	145.5	25.1
Maize	27.9	6.0
Sugarcane	119.2	41.6
Gram	26.5	8.7
Tur	9.2	1.8
Soybean	27.8	10.0
Rapeseed and Mustard	17.1	5.2
Cotton	66.6	29.7
Groundnut	12.9	3.9
Castor	4.6	3.0
All Crops	**682.6**	**178.7**

Note: Dry biomass refers to moisture-free content; totals do not sum due to rounding.

As shown in Figure 16, the States of Uttar Pradesh, Punjab, Maharashtra, Andhra Pradesh, Gujarat, Madhya Pradesh, Haryana, Telangana, Tamil Nadu, and Karnataka contribute about 87 percent of total surplus crop residue production in the country.

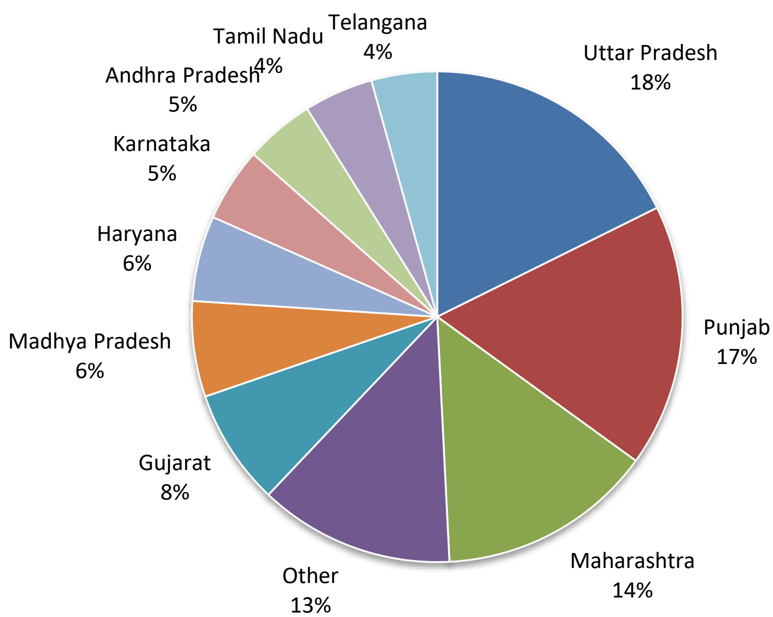


Figure 16. Major Crop Residue-Producing States by Percent of Surplus Production

Biogas Production Potential

For the assessment, GMI assumed that 25 percent of total surplus crop residues could be treated using AD, based on expert judgment. Table 16 presents the biogas production potential for crop residues. Methane emission reduction potential was not calculated since the burning of crop residues does not produce methane and GMI lacked data on how the remainder of the surplus crops are disposed of.

Table 16. Biogas Production and Direct Methane Production Potential for Crop Residues in India

Potentials	Value
Biogas Production Potential (million m^3/yr)	29,938

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