Solid Waste Management: Rural (Farm) Waste: Identification of Green Business Potential in India

Preamble

India is an agriculture based economy and produces a huge quantity of agricultural residues such as straw and crop stubbles. Data from crop production estimates released by Ministry of Agriculture (MoA) in India indicate that sugarcane, rice and wheat are the most grown crops accounting for over 90% of the total crop production in the country. Since the area over which these crops are grown in the country is significant, the agri-residue in terms of surplus generated from these crops is also a substantial quantity.

Some part of agricultural residue which is generated after crop harvesting is over is consumed in traditional uses such as construction material for rural housing, domestic fuel for cooking etc. while the surplus is burned in open fields in the absence of affordable disposal alternatives. Burning of agricultural (agri-) biomass residue, or Crop Residue Burning (CRB) has been identified as a major health hazard. In addition to causing exposure to extremely high levels of Particulate Matter (PM) concentration to people in the immediate vicinity, it is also a major regional source of pollution, contributing between 12 and 60 percent of particulate matter (PM) concentrations, as per various source apportionment studies. Additionally, it causes loss of vital nutrients such as nitrogen, phosphorus, sulfur, and potassium from the topsoil, making the land less fertile and unviable for agriculture in the long run. Recently, the National Green Tribunal (NGT) banned such burning and declared such practice illegal and fineable. All stakeholders including general public have to think of novel and sustainable methods to utilize the idle, underutilized resources that are of important economic value to India. The time is ripe to look this so called waste as a resource as *Tom Szaky* rightly said "On looking at waste as an entirely modern, man-made idea, I stopped viewing waste as waste and instead started to see it as a commodity." The utilization of biomass resources also assumes importance due to the soaring crude price and depleting reserves of fossil fuels coupled with the rising environmental concern.

Straw often refers to the residues or by-productions of the harvesting crops. Increasing crop yields achieved year after year is also contributing to the increased straw yields. The main challenge to straw in biomass energy is to how to develop and manage the adequate, affordable and reliable energy in a sustainable manner for fuel's social, economic development and environmental protection. In countries like China, the government has attached high importance to the development and utilization of biomass as an energy resource and has conducted wide ranging research and development on the latest biomass energy conversion technologies as a part of the national programs. These programs achieved great results of straw as an energy has been obtained in direct combustion, biochemical and physico-chemical conversion, including improved stove, biogas, gasification and briquettes. These technologies are further commercialized and popularized by China through key policy initiatives such as medium and long term development plan of renewable energy. If India too can use this agri-residue resource efficiently, it can contribute significantly in addressing energy deficit of the rural India also; it can directly contribute to addressing the severe air pollution problems resulting due to burning of residue in open fields.

Efforts have to be made to increase the avenues for the alternate usage of paddy straw and other crop residue. For instance, paddy straw has a considerable calorific value, making it suitable for use as a fuel in biomass- based power plants. Similarly, it can be utilized for the preparation of biofuels, organic fertilizers, and for paper and cardboard industries. The strategy, broadly, is to assign a real economic and commercial value to the agricultural residue and making burning it an economic loss to the farmer.

India has one of the largest livestock population in the world which if accounted for generates significant volumes of cattle manure each year. The cattle manure including that is generated from poultry birds has the potential to generate significant volumes of compost which can be used for agricultural purposes. Also, the harvesting and utilization of this manure in biogas plants can serve to fulfill energy needs in rural areas.

Contents

Executive Summary 4

Chapters

1 Introduction 5
2 Growth Forecast 14
3 Technological Options 22
4 Business Opportunities & Estimates 25
5 Composting 34
6 Job Potential Estimates 39
7 Process Mapping 45
8 Occupational Mapping 48

References 55

Executive Summary

Rural India generates significant amount of solid waste per day which includes organic waste and recyclables. Rural solid waste primarily consist of Agricultural Residues (or Agri-Residues) and Animal Waste. Agricultural residues are classified in to two main categories: Crop Residues and Process Residues. The total amount of agri-residue generated from a particular crop can be estimated from of crop production, residue to crop ratio and dry matter fraction in the crop biomass. For most of the crops the dry matter fraction factor ranges from 0.8 to 0.88 (IARI, Jain et. al (2014)). A part of agricultural residues generated in the country are consumed in traditional uses such as construction material for rural housing, domestic fuel for cooking etc. The surplus that is generated is burned by farmers in open fields in the absence of affordable disposal alternatives. The crop residue generated in the field has to be made available to the user facilities. The supply chain involves collection, storage and transportation of residue from field to site for end-use. Agri-residues processing involves several key steps including baling, hauling, residue transportation and plant operation among others. India has skilled labor and substantial financial resources, which can be channeled into ramping up the collection of feedstock from crop residues; establishing collection infrastructure, and transporting and handling of large amounts of biomass.

Job related to agri-residue supply chain include jobs related to field collection of agri-residues, biomass densification and aggregation in biomass depots. Based on the secondary data research and interactions with stakeholders and technical experts, it is reflected that one person can handle an estimated 200 tons of agri-residues per year which form our base estimate of manpower requirement for aggregation of agri-residues. Estimated projections in the document indicate that there is a potential to generate 3.71 million jobs in agri-residue supply chain and processing by 2020 which may increase to 5.22 million jobs by 2030.

Animal waste include waste such as animal manures and slurries, used animal bedding materials among others and manure is a major residue generated in farms. India has one of the largest livestock population in the world. As per the 19th livestock census (2012), the number of milch animals (cows and buffaloes) has increased from 77 million (livestock census 2007) to 81 million (livestock census 2012) showing a growth of 4.51% with will also correspond to increase in dung availability. The cattle dung generated is expected to reach 1623.39 million tons (MT) by 2020 and 2171.92 MT by 2030. The corresponding data for cattle dung recovery is estimated at 572.11 MT by 2020 and 1176.97 MT by 2030. Dung production also depends on the type, sex and size of the animal. The projected job opportunities in animal waste are those related to cattle manure collection, aggregation and compost production. Estimated projections in the document indicate that there is a potential to generate 3.43 million jobs in cattle manure supply chain and processing which may increase to 7.06 million jobs by 2030 in the event that the demand is generated for cattle manure based products such as compost.

The job roles related to farm waste management sector were finalized in discussion with the industrial stakeholders and technical experts which are related to rural, agricultural, dairy and related areas. The job roles listed is a result of these comprehensive discussions and reflect the type of occupations that will be required in to realize the full potential of farm waste management sector.

Chapter 1
Introduction

- **Background**
- **Agri-residue & Agri-surplus generation in India**
- **Animal waste generation in India**
    - Cattle dung generation
    - Poultry waste generation

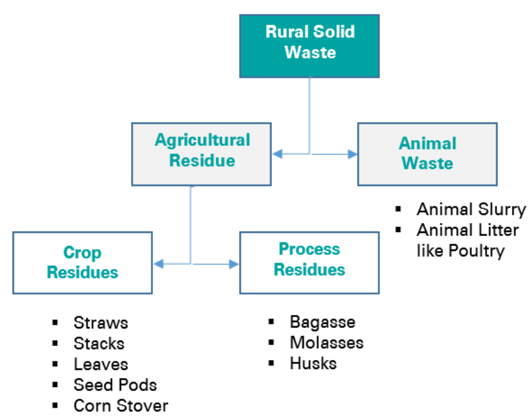
Background

India's population is expected to cross 1.4 billion by 2040 (*OECD Outlook, 2050*), coupled with high GDP growth, the demand for food will rise. Also, with its large rural population, agricultural growth in India will remain a key driver of poverty reduction. However, the vast majority of 90 million farm households have sub-optimal land holdings and are facing acute financial distress. There is, hence an urgent need for diversified farm economy that enhances farmers income sources viz., food production, fodder production and effective monetization and agriculture residues and manures for bioenergy products and compost production. Also, increase in farm yields with reduction in input costs through optimal use of organic manures and pesticides.

Rural India generates about 0.3 to 0.4 million metric tons of solid waste per day which includes organic waste and recyclables *(MNRE, 2015)*. Rural solid waste primarily consist of Agricultural Residues (or Agri-Residues) and Animal Waste. Agricultural residues are classified in to two main categories: Crop Residues and Process Residues. Crop residues include materials that are left in an agricultural field after the crop is harvested such as stalks, seed pods, straws, leaves etc.; Process Residues are the materials that are left after the crop is processed into a useable resource such as bagasse, husks and molasses. Animal waste includes waste such as animal manures and slurries, used animal bedding materials among others. Manure is a major residue generated in farms. Indian population of bovine animals is over 300 million, which annually generate manure of over 1,500 million tons (MT) (with 18% dry solids). The annual generation of Poultry manure is around 12 million tons (with 75% dry solids). Anaerobic treatment of manure would produce biogas and compost, which would reduce demand for fossil fuels & chemical fertilizers. In addition, farm yields will increase (due to increased availability of soil carbon & micro nutrients). In context of farm waste, the criticality is from environment pollution caused by burning crop residues on fields as well as health hazard from manure piles.

Rural solid waste is also classified based on the moisture content *i.e.,* as dry waste and wet residues. Dry residues include those parts of arable crops not to be used for the primary purpose of producing food, feed or fiber, used animal bedding and feathers while the wet residues include those wastes that have a high water content as collected. Due to high water content, is it energetically inefficient to use wet residues for combustion or gasification, and also, financially costly to transport. Preferably, wet residues are processed close to production through processes that can make use of biomass in an aqueous environment.

Classification of Rural Solid Wastes



Agri-Residue & Agri-Surplus Generation in India

There are large quantities of agriculture residues generated in farms from cultivation of grains, sugarcane, cotton, oilseeds and pulses. A portion of these agricultural residues are used as animal feed, albeit as inferior quality fodder. With focus on optimal productivity from dairy farms, there is an increasing shift towards high yielding forage crops, which is resulting in increased surplus of agriculture residues. The estimates for the year 2015 for various group of crops as published by Ministry of Agriculture and Farmers Welfare are listed in the Table below:

Estimates of Crop Production; Year 2015
(Source: Agriculture Statistics at a Glance (Ministry of Agriculture and Farmers Welfare))

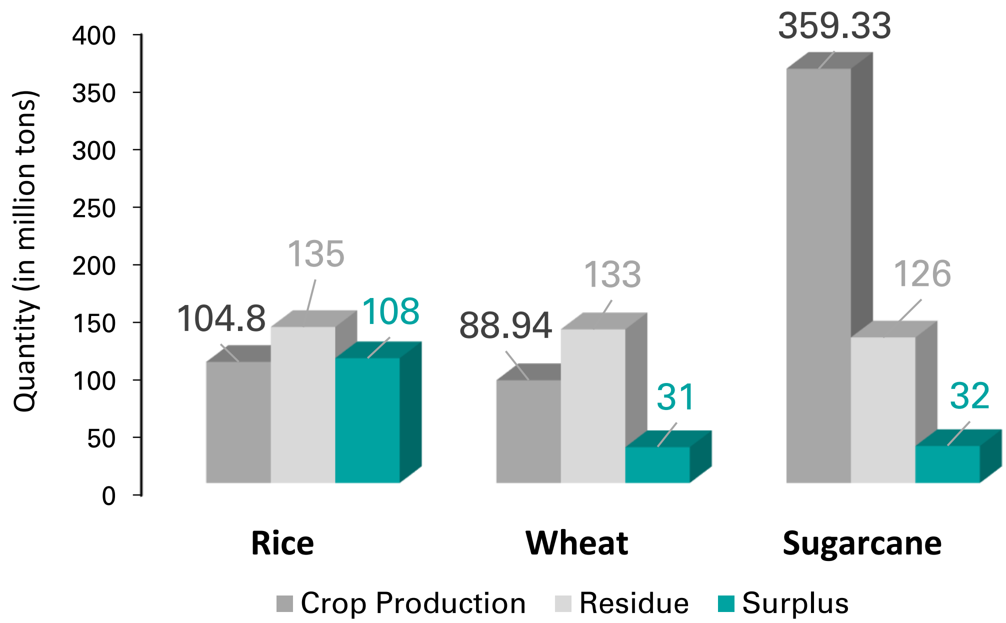
Group of Crops	Crops	Production (in million tons)	Production (in million tons)
Food Grains	Rice	104.8	104.80
	Wheat	88.94	88.94
	Coarse Cereals	41.75	41.75
	Pulses	17.2	17.20
	Total Food grains	252.68	252.68
Oil Seeds	Oil Seeds	26.68	26.68
Other Cash Crops	Sugarcane	359.33	359.33
($) Production in million bales of 170 kg each	Cotton ($)	35.48 million bales	6.03
(#) Production in million bales of 180 kgs each	Jute and Mesta (#)	11.45 million bales	2.06

The total amount of agri-residue generated from a particular crop can be estimated from of crop production, residue to crop ratio and dry matter fraction in the crop biomass. For most of the crops the dry matter fraction factor ranges from 0.8 to 0.88 (IARI, Jain et. al (2014)). A part of agricultural residues generated in the country are consumed in traditional uses such as construction material for rural housing, domestic fuel for cooking etc. The surplus that is generated is burned by farmers in open fields in the absence of affordable disposal alternatives. An IARI, 2014 study estimated a fraction of agri-residue that is burned for different crops which can be counted as surplus. The figures for residue to crop ratio for different crops and the corresponding residue and surplus estimated to be generated from different crops from the 2015 crop production estimates for different crops is estimated in the **Table** and **Graph** below:

Crops	Production figures (2015) (in million tons)	Residue to Crop Ratio	Dry Matter Fraction	Residue Generated (in million tons)	Agri-Surplus (Fraction burnt by farmer)	Surplus Generated (in million tons)
Rice	104.8	1.5	0.86	135	0.8	108
Wheat	88.94	1.7	0.88	133	0.23	31
Coarse Cereals	41.75	1.5	0.88	55	0.1	6
Pulses	17.2	1.5	0.8	21	0.1	2
Oil Seeds	26.68	3.0	0.8	64	0.1	6
Sugarcane	359.33	0.4	0.88	126	0.25	32
Cotton$	6.03	3.0	0.8	14	0.1	1
Jute and Mesta#	2.06	2.15	0.8	3	0.1	0
[$] Production in million bales of 170 kg each [#] Production in million bales of 180 kgs each				**552**		**186**
References: Based on Ministry of Agriculture and Farmers Welfare Statistics (MoA), 2015 Estimates; Jain et. al. (2014), IARI.				*Total Residue generated*		*Total Agri-Surplus generated*

Estimates for Crop Production, Residue and Surplus Generated for three key crops

(Based on Ministry of Agriculture Estimates, 2015)



Crop Residue: Open Burning versus Utilization

In many instances (e.g., cane trash, cotton stalks etc.) the residues are largely burnt in fields or used as cooking/heating, resulting in environment pollution. In a recent development, Delhi High Court has sought responses from four neighboring states on the burning of crop stubble, which spikes air pollution in the capital during winters. These can be effectively processed, employing advanced fermentation technologies, to produce sustainable end-products.

Burning of residues in boilers is another way through which the agricultural residues are utilized in India however, it is observed that except in case of co-generation plants (which are located at source of agri-residues generation), the economics are increasingly against such small biomass power plant since high costs are associated with processing stages of agriculture residues such as baling, handling and transport. Another factor which affects the utilization of residues in boilers is far more competitive feed-in tariffs offered by solar-PV Power plants. Another effective way for higher value realization from agriculture residues (lingo-cellulosic biomass) can also be achieved through processing in 2nd Generation Bio-Refineries. Employing advanced Bio-Technologies, such residues can be processed to Bio-CNG, Bio-Ethanol or 'Drop-In Fuels', with Compost being a Co-Product. Bio-CNG is a co-product and approximately 166 kilograms of Bio-CNG is produced per ton of cellulosic ethanol processed. Bio CNG finds an easy application as LPG replacement in community kitchens or transport applications.

At lower value realization but, perhaps, bulk application they can be briquetted or pelletized. This would reduce demand for fossil fuels & chemical fertilizers. In addition, farmer incomes will increase & there will be enhanced 'non-farm' jobs creation in rural areas. This approach is being captured in "National Bioenergy Mission" that India is preparing, to update the earlier National Biofuels Mission.

Indian Energy Demand (IEA, 2016)

India's oil demand in the three months of the financial year that began April 1 grew at the fastest pace for any first quarter period in the past 10 years. The country consumed 48.5 million tons of oil products in the quarter, an increase of 7.8 percent from the same period a year ago, according to the oil ministry's Petroleum Planning and Analysis Cell. That's the fastest since the first quarter of the year ended March 2007, when growth was 8.4 percent. Diesel consumption expanded 4.7 percent to 20.1 million tons and gasoline use increased 10 percent to 5.9 million tons.

The International Energy Agency expects India to lead the world in oil demand and surpass Japan as the world's third-largest oil user this year. It will be the fastest-growing crude consumer in the world through 2040, Paris-based IEA estimates, and adding 6 million barrels a day of demand, compared with 4.8 million for China.

The growth in consumption has a cyclical element to it with the first quarter being slower than the other three in a year. In the previous three quarters demand climbed at least 11 percent. The country consumed 15.6 million tons of oil products in June, an increase of 6.2 percent from the same month a year earlier. Diesel consumption rose 1.5 percent to 6.4 million tons and gasoline sales climbed 4.4 percent to 1.8 million tons. The monthly growth in diesel sales was the slowest since July 2015 and that in gasoline since November 2014.

Cellulosic Ethanol & Bio-CNG Market Prospects

India’s current oil demand is over 4.3 million barrels/ day (bpd), having risen @ 11% in past 3 quarters & forecasted to rise @ 7.5% in 2016 (IEA) by 400,000 bpd in 2016 (Energy Aspects). ASEAN, Africa & Latin America are bound to see increases in Oil demand, which will offset reductions in OECD countries (on a/c of natural/shale gas, EV’s & EE in thermal applications). By 2019, when Oil demand climbs beyond 100 million bpd, the current OECD reserves of 3 billion barrels will no longer be able to depress market prices, as they would have depleted to “strategic reserves” levels. India’s Petrol sales in last quarter was 5.9 million tons, registering increase of 10%. This trend is likely to increase with environmental issues being raised on Diesel cars. Consequently, Petrol demand in 2019 could be close to 30 million tons/year. “Petrol Cracks” (difference between refined Product prices & Crude Oil price) around 18 to 20 a barrel in last 4 quarters, could also increase from “demand – supply” dynamics. 20% ethanol blending will require 6 million tons (equivalent to 100 number of 60,000 tons/year 2G Bio-Refineries). From above facts, it would be reasonable to assume that Cellulosic Ethanol & Bio-CNG market prices, in 2019, would be market competitive with that of Petroleum Products (produced from imported Crude Oil).

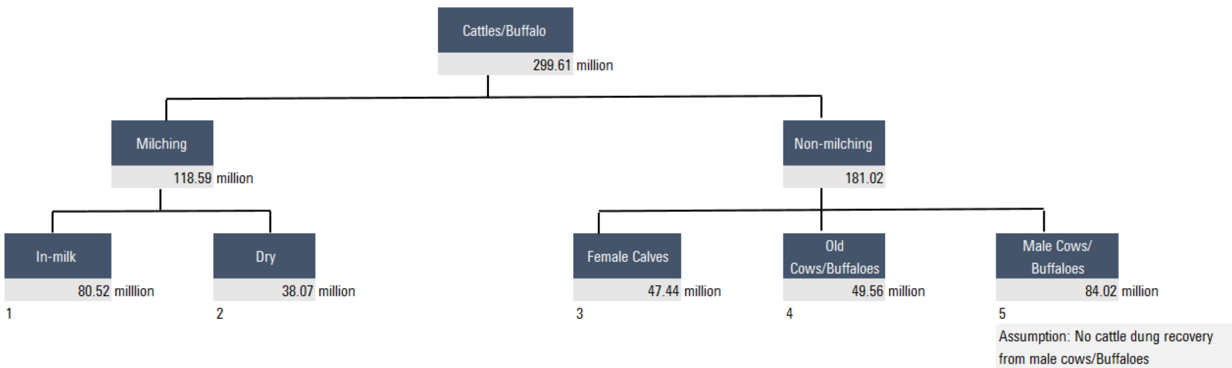
Animal Waste Generation in India

Cattle Dung generation

India has one of the largest livestock population in the world. As per the 19th livestock census (2012), the number of milch animals (cows and buffaloes) has increased from 77 million (livestock census 2007) to 81 million (livestock census 2012) showing a growth of 4.51% with will also correspond to increase in dung availability. Dung production also depends on the type, sex and size of the animal. Based on the 19th Livestock census, the number of the cattle's / buffalo under mulching and non-milching is listed in the Table and represented in the flowchart below:

Flowchart indicating Cattle numbers against Cattles/Buffaloes

(Reference: Based on data from 19th Livestock Census)



Milching (In-milk)	Milching (Dry)
All numbers in million	
80.52	38.07
Total Milching	**118.59**

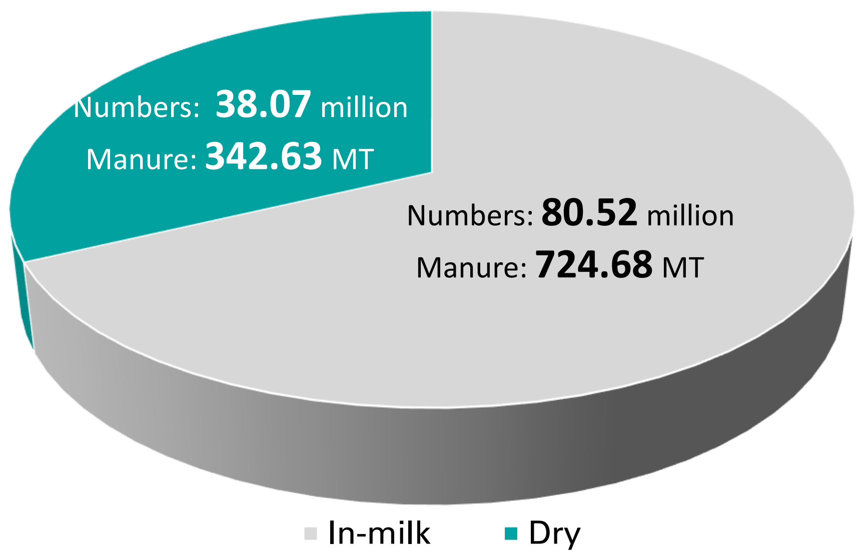
Female Calves	Old Cows/ Buffaloes	Male Cows/ Buffaloes
All numbers in million		
47.44	49.56	84.02
Total Non-milching		**181.02**

Reference/Assumption:

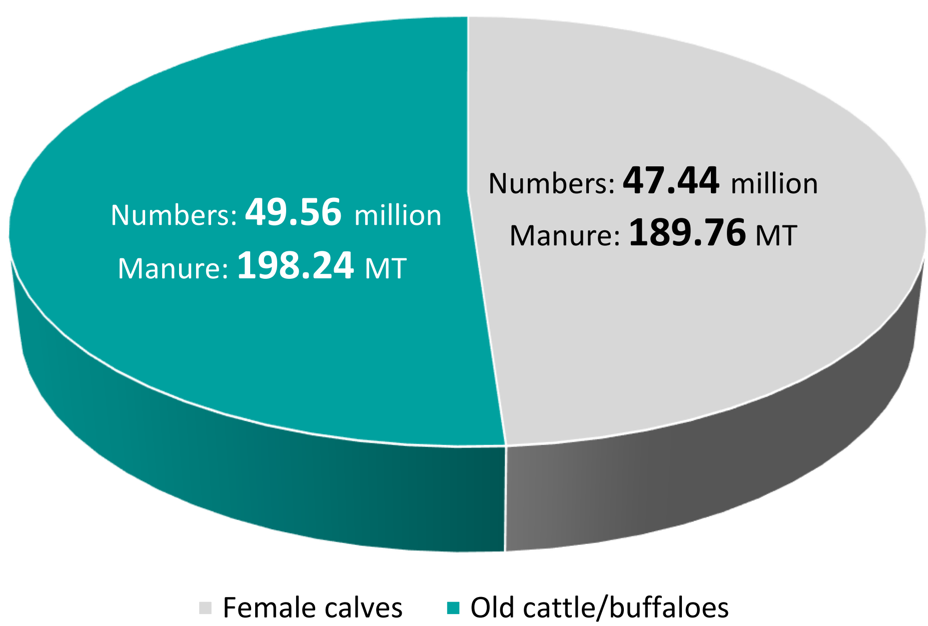
- *Milching Cattle:* These are those which are typically in the age group of 3 to 7 years (out of a typical age of 12 years). *Milching Cattle (in-milk):* These are those that are producing milk i.e., when they are giving birth to calves and correspondingly producing milk; *Milching Cattle (dry):* Represent those that are in between lactation periods. The goal is to keep milching cows in lactation for over 300 days per year; *Non-milching cattle:* These are female calves and old cows (Post milking Phase).
- Population of Calves (0-2 years old) could perhaps be taken as 40% of milching cows (3 to 7 years).
- The reference flow chart and numbers above are based on 19th Livestock Census (Chapter 3, Salient Features and Table 3.1 (Total Livestock).

Assuming that dairy industry would adopt improved animal feed standards, the average annual dung produced per Indian dairy milching cow / buffalo could be taken as 9 tons per year per animal (18% dry solids) up to 2020 which is estimated to increase to 11 tons per animal per annum by 2030. Animals which are not yielding milk (non-milching), are given inadequate feed and, consequently, dung production is much lesser which is assumed at 4 tons per year per animal with 18% dry matter. Based on these considerations the expected manure production from different categories of cattle's / buffaloes is represented in the **figure** below:

Estimates of manure production from milching cattle (Year 2012)



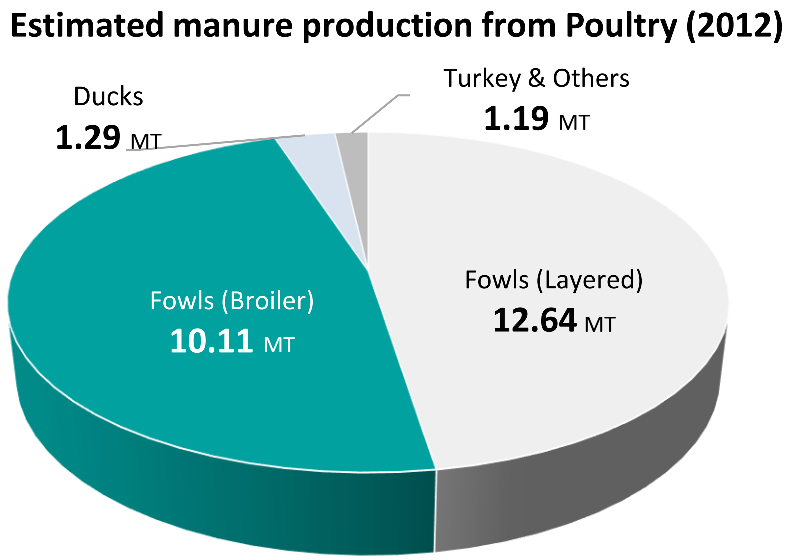
Estimates of manure production from non-milching cattle (Year 2012)



- *Assumption: No cattle dung recovery is estimated from male cows / buffaloes*

Poultry Manure Generation

Poultry manure or a Poultry fertilizer or litter as fertilizer is basically a mix of droppings of chicken or birds like pigeon, ducks and turkey. They are generally hotter as compared to other organic fertilizers like those of cow and horse. They need to be composted first or else they have the tendency to burn plants. As per Livestock Census 2012, India has about 729.2 million poultry numbers comprising of fowls, ducks, turkey and others. The estimated poultry manure production as per these numbers is about 25.23 million tons (in 2012) with 75% dry matter.



Reference/Assumption:

- As per FAO Estimates (Poultry Waste Management in Developing Countries); *Layer Chicken* (per 1000) produces 120 Kgs of manure per day, *Meat Chicken* (per 1000) produces 80 kgs of manure per day. *Turkey* (per 1000) produces 200-300 kgs of Manure per day. *Ducks* (per 1000) produces 150 kgs of Manure per day.

Poultry Manure Utilization and Nutrition Content

The poultry manure is not being effectively utilized at present even though it can be used as a very good fertilizer rich in Nitrogen and Phosphorus and micronutrients such as Copper (Cu) and Zinc (Zn). FAO estimates on the nutrient content of chicken manure and litter is indicated in the **Table** below:

Poultry Type	Nitrogen	Phosphorus (as phosphorus pentoxide)	Copper	Zinc
Layer Chicken Manure	13.5	10.5	0.01	0.07
Meat Chicken Manure	13.0	8.0	0.01	0.04
Broiler Litter	35.5	34.5	0.26	0.36
Reference: Food and Agriculture Organization of United Nations (FAO)				

The nutritional elements of Poultry manure fertilizer are very effective in increasing the productivity and rapid growth of farms e.g. farms that produce vegetables. It is preferred to use manure after within 120 days of the harvesting of crops. Similarly it is preferable not to use fresh manure because it may contain certain bacteria which are harmful for human health and may cause diseases. It is therefore suggest that the manure should be used after it is composted because composting not only enhances the nutrients but also avoids the risks of exposure to different diseases. The composting procedure involves 3 to 4 weeks after which the manure is used as a fertilizer in gardens and for crops. As per a study estimate, the fertilizer value of one ton of dried cage poultry manure is equivalent to 100 kg urea, 150kg super phosphate, 50 kg potash, 125kg calcium carbonate, 30 kg sulphur, 12 kg sodium chloride, 10kg magnesium sulphate, 5kg ferrous sulphate, 1kg manganese sulphate, zinc sulphate and other trace minerals.

In some countries, Farmers with farms close to poultry farms use poultry manure regularly for their crops, with good returns. The poultry manure can be pelletized and packed in 5-25 kg capacity bags, as in the case of developed countries, for use in home gardens and nurseries. As per FAO Estimates, fowls (in thousand) produce about 100 kgs of poultry manure per day. The corresponding figures (per thousand) Ducks and Turkeys are 150 kgs and 250 kgs per day. The above estimates are taken into consideration for projecting the increase in poultry numbers and the poultry manure production.

Chapter 2
Growth Forecast

- **Growth in Agri-residues**
- **Growth in Animal Waste**
    - Growth in Cattle Dung Manure
    - Growth in Poultry Manure

Growth in Agri-Residues

India is an agrarian economy and a wide range of crops are cultivated in its different agri-ecological regions. Although, crops such as rice, wheat, maize, millets, sugarcane, fiber crops, pulses and oil seeds are widely cultivated in India, rice and wheat are the pre-dominant crops, together accounting for 41 percent of the cropped area, while pulses, oil seeds, and other commercial crops account for 13.8 percent, 15.9 percent and 10.2 percent, respectively.

Several studies such as UNEP-DTU were done to project the quantity of crops that are likely to be produced in India by 2020 & 2030. The projected crop estimates for each of these studies are along the similar ranges. Estimates from one of such studies on area, crop projections done by Purohit and Fisher (2014) is used to project the surplus that is likely to be generated by 2020 and 2030. Table below presents a study by *Purohit and Fischer (2014) which* projected the area and productivity data for the years 2020–21 and 2030–31 based on the Ministry of Agriculture data from 1950–51 to 2011–12 which is also represented in the Table below:

Table for Projections for Production and Area under different crops in India up to 2030/31

(Source: Purohit and Fisher, 2014 estimates)

Crops	Economic Produce	Area (in million hectares)			Crop Production (in million tons)		
		2010/11	2020/21	2030/31	2010/11	2020/21	2030/31
Rice	Food Grains	42.9	48.1	50.3	96	109.9	123.2
Wheat	Food Grains	29.1	33.7	36.6	87	108.2	121.1
Jowar (Sweet Sorghum)	Food Grains	7.4	5.2	3.4	7	6	5.7
Bajra	Food Grains	9.6	9.3	8.8	10.4	11.4	12.3
Maize	Food Grains	8.6	8.4	9	21.7	24.8	28.3
Other Cereals	Food Grains	2.9	2.1	1.5	4.6	3.9	3.8
Gram	Food Grains	9.2	8.9	8.7	8.2	8.4	8.6
Tur (Arhar)	Food Grains	4.4	4.4	4.7	2.9	3.1	3.3
Lentil (Masur)	Food Grains	1.6	1.7	1.9	0.9	1.2	1.4
Other Pulses	Food Grains	11.2	12.8	13.2	6.2	6.3	6.8
Groundnut	Oil Seeds	5.9	6	6.1	8.3	8.9	9.6
Rapeseed and Mustard	Oil Seeds	6.9	7.2	7.9	8.2	9.6	11
Other Oilseeds	Oil Seeds	14.5	16.7	18.6	16	19.3	22.4
Cotton	Fiber	11.2	11.9	12.6	5.6	6.1	6.4
Jute and Mesta	Fiber	0.9	1	1	1.9	2.3	2.5
Sugarcane	Sugar	4.9	5.1	5.6	342.4	406.4	459.3
Total		**171.2**	**182.5**	**189.9**	**627.3**	**735.8**	**825.7**

Based on the Residue to Crop Ratio and Dry Matter Fraction discussed in the **Chapter 1** the corresponding residue and surplus generated for the years 2010 and projected by the 2020 and 2030 are calculated considering the projections made by Purohit and Fisher (2015) study. These calculations for the individual years are represented in the following Tables and represented in the graph thereafter.

Tables for Agri-residue surplus projections based on crop production data

2010

Crops	Production figures (2010) (in million tons)	Residue to Crop Ratio	Dry Matter Fraction	Residue Generated (in million tons)	Agri-Surplus (Fraction burnt by farmer)	Surplus Generated (in million tons)	Agri-Residues Utilized by Farmers (in million tons)
Rice	96	1.5	0.86	124	0.8	99	25
Wheat	87	1.7	0.88	130	0.23	30	100
Coarse Cereals	43.7	1.5	0.88	58	0.1	6	52
Pulses	10	1.5	0.8	12	0.1	1	11
Oil Seeds	32.5	3	0.8	78	0.1	8	70
Sugarcane	342.4	0.4	0.88	121	0.25	30	90
Cotton ($)	5.6	3	0.8	14	0.1	1	13
Jute and Mesta (#)	1.9	2.15	0.8	3	0.1	0	3
				540 *Total Residue Generated*		**176** *Total Surplus Generated*	**364** *Agri-residues Utilized*

2020

Crops	Production Figures (2020) (in million tons)	Residue to Crop Ratio	Dry Matter Fraction	Residue Generated (in million tons)	Agri-Surplus (Fraction burnt by farmer)	Surplus Generated (in million tons)	Agri-Residues Utilized by Farmers (in million tons)
Rice	109.9	1.5	0.86	142	0.8	113	28
Wheat	108.2	1.7	0.88	162	0.23	37	125
Coarse Cereals	46.1	1.5	0.88	61	0.1	6	55
Pulses	10.6	1.5	0.8	13	0.1	1	11
Oil Seeds	37.8	3	0.8	91	0.1	9	82
Sugarcane	406.4	0.4	0.88	143	0.25	36	107
Cotton ($)	6.1	3	0.8	14	0.1	1	13
Jute and Mesta (#)	2.3	2.15	0.8	3	0.1	0	3
				629 *Total Residue Generated*		**205** *Total Surplus Generated*	**424** *Agri-residues utilized*

2030							
Crops	**Production figures** (2030) (in million tons)	**Residue to Crop Ratio**	**Dry Matter Fraction**	**Residue Generated** (in million tons)	**Agri-Surplus (Fraction burnt by farmer)**	**Surplus Generated** (in million tons)	**Agri-Residues utilized by Farmers** (in million tons)
Rice	123.2	1.5	0.86	159	0.8	127	32
Wheat	121.1	1.7	0.88	181	0.23	42	139
Coarse Cereals	50.1	1.5	0.88	66	0.1	7	60
Pulses	11.5	1.5	0.8	14	0.1	1	12
Oil Seeds	43	3	0.8	103	0.1	10	93
Sugarcane	459.3	0.4	0.88	162	0.25	40	121
Cotton ($)	6.4	3	0.8	14	0.1	1	13
Jute and Mesta (#)	2.5	2.15	0.8	3	0.1	0	3
				703 *Total Residue Generated*		**229** *Total Surplus Generated*	**473** *Agri-residues utilized*

Summarized Table for Total Residue and Surplus generated

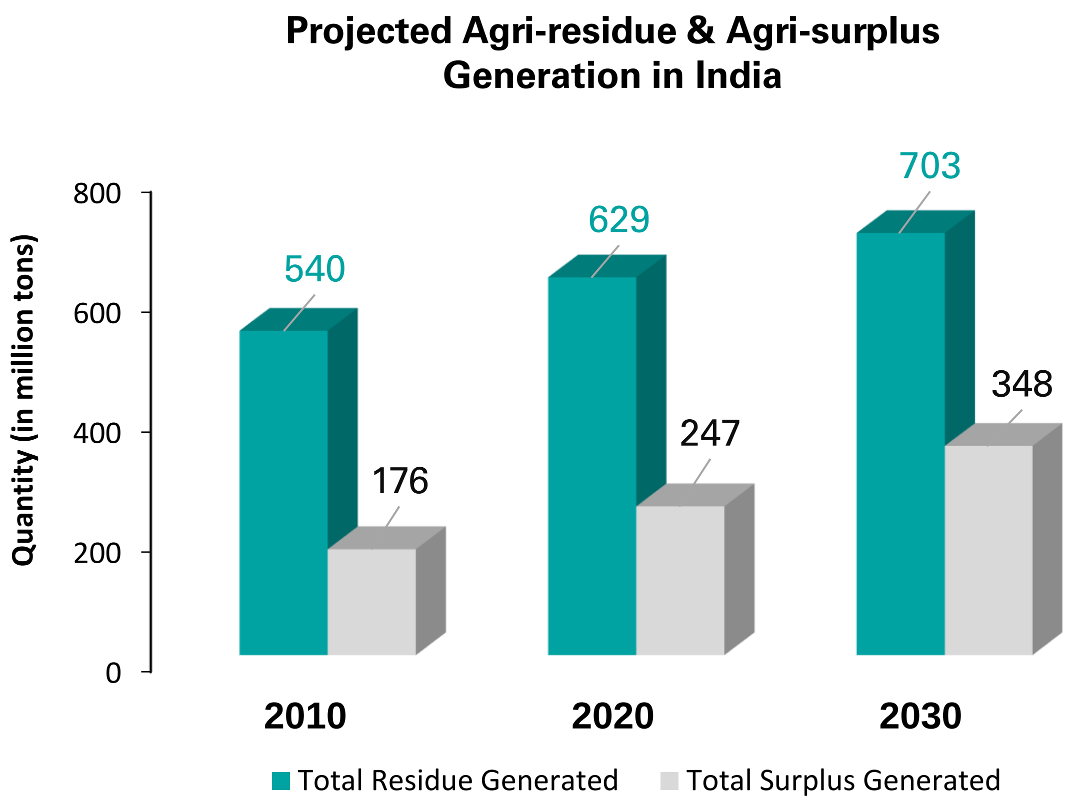
Year	Total Residue Generated (in million tons)	Total Surplus Generated [1] (in million tons)	Agri-residues utilized by Farmers (in million tons)
2010	540	176	364
2020	629	205	424
2030	703	229	473

Reference/Assumption:

- [1] Decline in inefficient use of agri-surplus (cattle feed, cooking/heating fuel etc.) will result in increase in the quantity of agri-residues which is currently utilized by farmers. Assuming that the agri-surplus will increase by a factor of 0.10 by (Year 2020) and 0.25 by (Year 2030)

Year	Total Residue Generated (in million tons)	Total Surplus Generated (in million tons) [2]	Agri-residues utilized by Farmers (in million tons)
2010	540	176	364
2020	629	247	382
2030	703	348	355

[2] *Increased Agri-surplus Quantity*


Projected Agri-residue & Agri-surplus Generation in India
Quantity (in million tons)
800
600
400
200
0
540
176
629
247
703
348
2010
2020
2030
Total Residue Generated
Total Surplus Generated

Growth in Animal Waste

Growth in Cattle Dung Manure

As per the 19th livestock census (2012), the number of animals in milk, cows and buffaloes have increased from 77 million (livestock census 2007) to 81 million (livestock census 2012) showing a growth of 4.51%. The increase in number of milch animals (in-milk and dry), cows and buffaloes is from 111.09 million to 118.59 million showing a growth of 6.75%. Based on the interactions with technical experts in the field of agriculture and dairy industry it was suggested that average weight of Indian milching cattle is in the range of 350 to 450 kgs. Considering average weight of Indian milching Cattle/Buffalo to be around 400 kgs, based on the FAO estimates, the manure production in per animal will be around 25 kgs per day (~9 tons/annum/animal). Assuming that due to increase in the quality of feed as well as cattle/farm management techniques by 2030, the average manure production in (kgs/day/animal) is estimated to increase to ~ 30 kgs per animal per day (~11 tons/annum/animal) for milching animals.

For the non-milching animals such as female calves the corresponding manure production is estimated at 4 tons/annum per animal which is about 40% to that of the milching animals. The volume of cattle dung produced for non milching female calves is less since for the first 6-8 months they remain on liquid feed and do not take external feed. Similar estimates of 4 tons/annum per animal are considered for old cows and buffaloes due to the poor feed provided to them.

Based on the data from 18th and 19th livestock census, the corresponding annual growth rate (AGR) (in terms of %) increase in the number of cattle/buffalo's and poultry numbers is calculated. These AGR rates form the basis on projected estimates of animal and poultry manure generation for 2020 and 2030. These calculations for the individual years are represented in the following Tables and represented in the graph thereafter.

Year	**Numbers** (in million)	**Cattle Dung Manure Produced** (in million tons)	**Cattle Dung Recovered** (in million tons)	**Dry Matter in the Recovered Cattle Dung** (in million tons)
Milching (In-milk)				
2012	80.52	724.68		
2020		778.53	311.41	56.05
2030		1040.73	624.44	112.40
Milching (dry)				
2012	38.07	342.63		
2020		412.92	165.17	29.73
2030		637.27	382.36	68.82
Non-milching (female calves)				
2012	47.44	189.76		
2020		211.25	84.5	15.21
2030		241.56	144.94	26.09
Non-milching (old cows and buffaloes)				
2012	49.56	198.24		
2020		220.69	11.03	1.99
2030		252.36	25.24	4.54

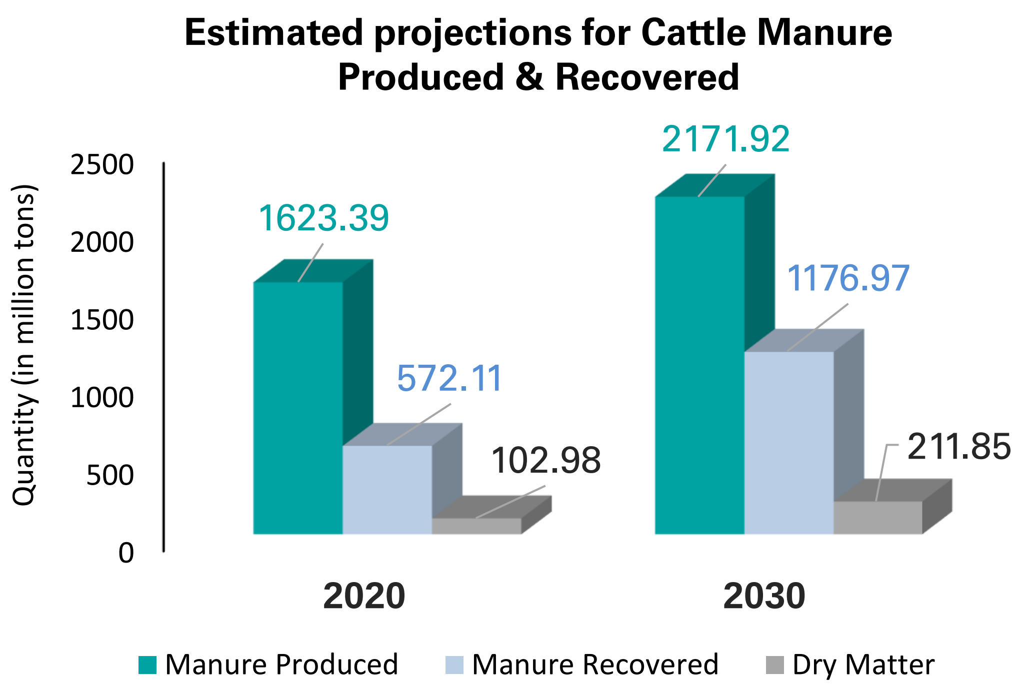
References/Assumption:

- *The increase in cattle numbers is expected to be nominal up to 2020 and 2030. However, due to the expected increase in high yielding cattle's, cattle dung manure and milk production is expected to increase.*

- *Increase in cattle dung manure is estimated at 0.90 % AGR (Milching In-milk); 2.36% AGR; 1.35 % (Non-milching (Female Calves)); 1.35% (Non-milching (old cows / buffalo)).*
- *Estimates Cattle Dung Production (2020): Considering average weight of Indian milching Cattle/Buffalo to be around 400 kgs, based on the FAO estimates, the manure production in (kgs/day/animal) will be ~ 25 kgs per day (~9 tons/annum/animal). Assuming that due to increase in the quality of feed as well as cattle/farm management techniques by 2030, the average manure production in (kgs/day/animal) will increase to ~30 kgs per animal per day (~11 tons/annum/animal).*
- *Dung Recovery Estimates from Milching (In-Milk): 40% from milking animals (up to 2020) and 60% (up to 2030).*
- *Dung Recovery Estimates from Milching (Dry): 40% from milking animals (up to 2020) and 60% (up to 2030).*
- *Dung Recovery Estimates from Non-milching (Female Calves): 40% (up to 2020) and 60% (up to 2030).*
- *Manure recovery is estimated at 5% (up to 2020 and 10% up to 2030) for Non-milching (Old cows and buffaloes)*
- *Dry matter in the recovered cattle dung: 18% dry solids.*
- *Population of Calves (0-2 years old) is taken as 40% of milching cows (3 to 7 years).*
- *Animal dung produced per dairy Cow/Buffalo (in tons) = 4 tons/annum per animal (40% of the milching animals).*
- *Old female cows (balance female cows) would have to be fed whether in farm households or gaushalas. Considering manure production (linked to reduced animal feed) of less than 40% of manure produced by a milching cow.*

Summarized Table for Cattle Manure

Year	Cattle Dung Manure Produced (in million tons)	Cattle Dung Recovered (in million tons)	Dry Matter in recovered Cattle Dung (in million tons)
2020	1623.39	572.11	102.98
2030	2171.92	1176.97	211.85



Growth in Poultry Manure

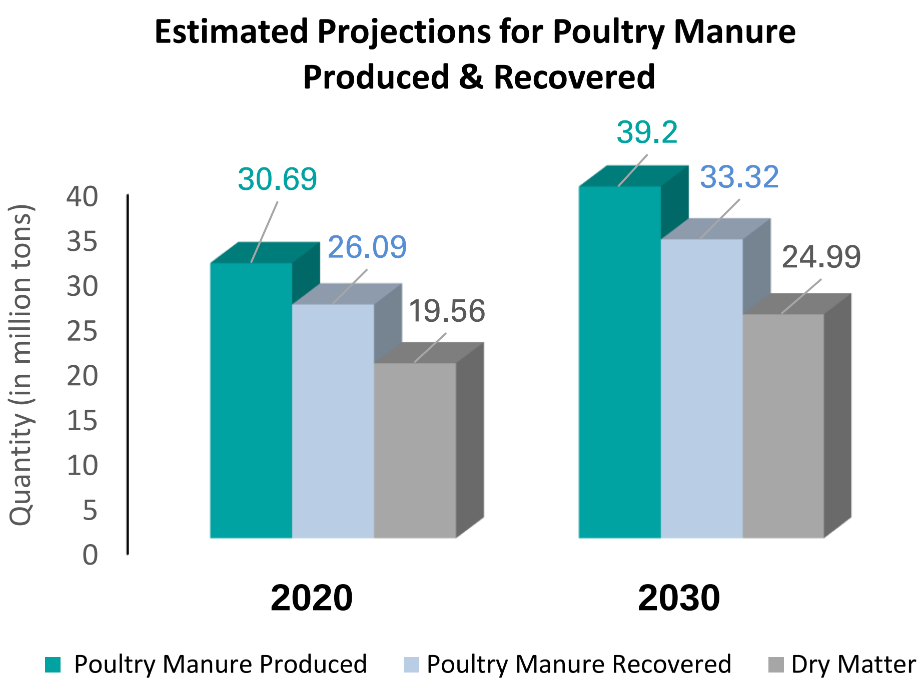
As per the 19th livestock census (2012), the overall poultry population in the country has increased by 12.39% from 648.8 million (livestock census 2007) to 729.2 million (livestock census 2012). The increase in the number of fowls is from 617.7 million to 692.6 million (increase of 12.13%) and the increase in the number of Turkeys and others (excluding Ducks) is from 3.45 million to 13.02 million (increase of 277.3 %). The number of Ducks showed a decline and has decreased from 27.6 million to 23.5 million (decrease of 14.85%). The corresponding percentages of fowls, Ducks and Turkeys (& others) in the total population is 95%, 3.2% and 1.8% respectively. For projecting the growth of poultry manure and numbers these percentages in the total poultry population are taken into consideration.

As per FAO Estimates, fowls (in thousand) produce about 100 kgs of poultry manure per day. The corresponding figures (per thousand) Ducks and Turkeys are 150 kgs and 250 kgs per day. The above estimates are taken into consideration for projecting the increase in poultry numbers and the poultry manure production. The projections are shown in the figure below:

Projections for Poultry Manure from various Poultry Types
(Based on 19th Livestock Census Figures & FAO Estimates)

Year	Fowls (Broiler)	Fowls (Layered)	Ducks	Turkey & Others	Total Poultry Manure	Poultry manure recovered $	Dry matter from poultry manure #
	(All quantities in million tons)						
2012	10.11	12.64	1.29	1.19	25.23	21.45	16.08
2020	12.30	15.38	1.57	1.45	30.69	26.09	19.56
2030	15.71	19.64	2.00	1.85	39.20	33.32	24.99

$ Considering 85% recovery from farms
# Considering 75% dry matter in the poultry manure



Chapter 3
Technological Options

Technological Options

Based on the nature and quality of end products required from rural waste, multiple technological options are available. These adoption of these options also helps in effective management of rural waste generated in huge quantities in a country like India where significant number of livelihoods options are based on agricultural economy. The various technological that can be adopted for management of rural waste are discussed as below:-

Briquetting: Briquetting is a process where some type of raw material is compressed under high pressure to form a round or square briquette that can be used for heating purpose. If the raw material is wood waste or agri-waste, the lignin content is liberated under this very high pressure thus binding the material into a briquette with high density. During the compression of the material, temperatures rise sufficiently to make the raw material liberate various adhesives that will assist in keeping the particles together in the compressed shape. However, to make this process successful, the moisture content of the raw material must be in the range 6 - 16 %. The high temperature also causes the moisture in the raw material to evaporate. At a very high moisture contents, steam pockets may build up during the process thus leading to expansion which will demolish the briquette. As the optimum moisture content for briquetting purposes varies with the raw material, we know from experience that the recommended water content is from min. 6% to max. 16%. The ideal moisture content for most wood-based material is 10-12%.

Pellet Making: This is the process provided for creating feed pellets from agricultural residue material having substantially no food value, such as corn stove. The agricultural residue material is harvested and baled for transport to a storage and processing site. The baled agricultural residue material is then shredded and ground, and one or more chemical agents are added to polymerize the fiber (lignin-carbohydrate) matrix of the agricultural residue material.

Biomass Gasification: It is a process of converting solid biomass fuel into a gaseous combustible gas (called producer gas) through a sequence of thermo-chemical reactions. The gas is a low-heating value fuel, with a calorific value between 1000- 1200 kcal/Nm^3 (kilo calorie per normal m^3). Almost 2.5-3.0 Nm^3 of gas can be obtained through gasification of about 1 kg of air-dried biomass.

Biofuel Production (Fermentation): Agricultural crops and residues are the main sources of feed stocks for energy to displace fossil fuels. A wide range of materials such as grains, crop residue, and cellulosic crops are used for the production of bio-fuel. These products are processes further to generate liquid fuel such as ethanol and diesel fuel through fermentation process.

Biomethanation (Biogas Production): Biomethanation is an anaerobic process in which organic material is microbiologically converted into bio-gas. Biogas is a fuel gas consisting of a mixture of methane (CH_4) and carbon dioxide (CO_2), produced through microbial processes under anaerobic conditions from a variety of organic material like animal, agricultural, industrial and domestic wastes. Biogas is an attractive option for cooking energy and for motive power, with value addition being provided in the form of fertilizers from the slurry from biogas plants. Microbial conversion of agricultural, industrial and domestic wastes has been a common practice for the last half century. The conversion results in utilizing all biomass wastes as a valuable resource and producing a fuel gas called biogas which can be used for cooking, lighting and power generation. Biogas systems have in recent years become an attractive option for decentralized rural development as it produces a cheap fuel and good quality, rich manure. It also provides an effective and convenient way for disposing night soil, generates social benefits in terms of reduction of drudgery, time and effort for fuel-wood collection and cooking by women and children and overcoming the ill effects of smoke filled kitchens and making available time for gainful activities.

Bio-char: Bio-char is charcoal used as a soil amendment. Like most charcoal, bio-char is made from biomass via pyrolysis. Bio-char offers a strong link between the three Rio conventions as it simultaneously addresses climate change, soil degradation and biodiversity. Bio-char is under research as an approach to carbon sequestration to produce negative carbon dioxide emissions. Bio-char thus has the potential to help mitigate climate change via carbon sequestration. Independently, bio-char can increase soil fertility of acidic soils (low pH soils), increase agricultural productivity, and provide protection against some foliar and soil-borne diseases.

Composting: Composting is the natural process of 'rotting' or decomposition of organic matter by microorganisms under controlled conditions. Raw organic materials such as crop residues, animal wastes, food garbage, some municipal wastes and suitable industrial wastes, enhance their suitability for application to the soil as a fertilizing resource, after having undergone composting. (Refer Chapter 5 for details).

Chapter 4
Business Opportunities and Estimates

- **Business Opportunities based on end-use applications of biomass**
- **Estimations related to Business Case:**
  - Biomass Aggregation & Storage
  - Estimating the size of biomass storage yard

Business Opportunities based on the end-use applications of the biomass

Biomass has a lot of business opportunities based on the end-use application and capitalizing on these options cane generate potential revenue options which can sustain rural livelihoods and generate large number of jobs in the sector. Some of these opportunities are presented in the **Table** below:

End-Usage Options	Process/Activities	Revenue Opportunities (Business)
Production of Agri-Briquettes and Maintaining/ Operating Biomass Storage Depots	▪ Collection and Transport ▪ Storage ▪ Crushing ▪ Drying ▪ Briquetting ▪ Cooling ▪ Sales & Revenue ▪ Warehousing and Supply Chain Operations (These serve as intermediate long term storages of high calorific value energy	Option for Selling it to: - Power Plants (Gasifier Based) - Industries - Usage as Fuel (As per Market Rates 1 Ton of Agri-briquette Cost INR 5000-6000)
		Options:- - Sell densified biomass briquette's to industries, bio-refineries, sugar industries, building industries etc.; as well as village community cooking centers, schools etc.
Production of Manure/Compost* (including compost produced from 2G Bio-refinery) (Technology: Composting/ Vermicomposting)	▪ Collection ▪ Segregation ▪ Preparation of Compost Pits ▪ Earthworm Farming ▪ Feed Preparation ▪ Manure Sieving and Processing ▪ Sales & Revenue *Note:* Certification can be sought by compost manufacturers, terming the product as Organic Fertilizer (clause 14-18) of Fertilizer Control Order. However, most compost producers, especially biogas plant operators, prefer not to go through the rigors of seeking and maintaining certification under Fertilizer (Control) Order.	Options: - Manure can be sold to Forest Department, Nurseries, Schools - Selling material recycled during segregation - The compost produced in 2G bio-refinery can be certified as organic fertilizer. In a biogas plant, digester effluent would need to be further treated to remove suspended solids below < 50 ppm, to comply with the norms of the Pollution Control Boards. The separated solids (around 30% dry solids) are then subjected to aerobic digestion to produce compost. The compost, so produced (with dry solids>75%) could be sold as "manure" and if so, it would not fall under Fertilizer (Control) Order 1985 and subsequent amendments. - Estimate: Generation of compost (with 75% dry matter) would be 40,000 tons/year linked to the production of 60,000 tons of cellulosic ethanol/year with feed stock of agriculture residues.

Biogas Production (including wastewater streams generated from bio-refinery plants) **(Biomethanation)**	▪ Setting up of Bio-gas plant ▪ Operation and Maintenance ▪ Manure Management	Options: - Potential usage as a fuel and the manure generated can be sold. - The volume of wastewater streams of the 2nd generation bio-refinery is approx. 200 KL/hour for plant rated 7.5 tons cellulosic ethanol/hour. This wastewater can be treated anaerobically to produce biogas. *(Bharathiraja et. al. 2014).*
Biofuel Production (Bioethanol) / Ligno-cellulosic Biomass	▪ Collection and Transport ▪ Analysis and Testing of Feed (m/c) ▪ Process Stages (Dewatering, Thickening, Filtering, Drying, Disruption, Oil Extraction, Purification) ▪ Sales to Petrochemical companies for Blending	Options: - Supply Chain Management and Supply to Bio-Refineries - Sell the products for petrochemical industries for blending targets - Estimated generation of 2G Ethanol from lingo-cellulosic biomass is 250 liters/ton of dry lingo-cellulosic biomass. TIFAC constituted committee anticipated that more than 120 million tons of dry matter by 2030 which translates to 30 billion liters owe year of 2G ethanol potential. This can be used to meet gasoline blending targets which can be integrated into clean cooking solutions.
Production of Building Materials	▪ Purchase/ Procurement and Collection ▪ Cleaning ▪ Drying ▪ Hammer Mill ▪ Cooling ▪ Cutting ▪ Packing and Dispatch	Options: - Sell them as Green Building Materials Insulation Coatings.
Production of Bio-Char	▪ Slow pyrolysis (heating in the absence of oxygen) of biomass	Options: - Sell for end-use in agriculture. - Rich is carbon is an efficient soil additive.
Production of Green Power (Gasifier)	▪ Gasification Process **Process:** Gasification is a thermo-chemical process in which gas is formed due to partial combustion of crop residues. The main problem in biomass gasification for power generation is the purification of gas for removal of impurities. The crop residues can be used in the gasifiers for 'producer gas' generation. In some states, gasifiers of more than 1 MW capacity have been installed for generation of 'producer gas', which is fed into	Options: Power generated can be sold.

	the engines coupled with alternators for electricity generation.	

(*) Giving the compost a local name (such as Poshak & Pushti, adopted Malavalli Power Plant) rather than terming it as "Organic Fertilizer" can meet marketing objectives. Such an approach needs compost to be tested by local agriculture universities (periodically) as well as in onsite lab (through daily testing). Also, program for effective "extension activities" can be undertaken by the compost producer under guidance from agriculture universities.

Ethanol from Ligno-cellulosic biomass. Ethanol derived from renewable Ligno-cellulosic biomass of non-edible variety has been identified globally as the future solution for meeting the energy demand. Apart from fuel and energy, biomass can also be the source of large number of derivatives. Ethanol from Ligno-cellulosic biomass is a complex technology; it has been noted that extensive research efforts are underway by industry and academia in making this technology technically and economically viable in near future.

Estimations related to Business Cases

Biomass Aggregation and Storage: Crop Residue Densification Plant

The series of steps starting from agri-surplus collection from fields up to storage as densified biomass is depicted in the figure below:

1	2	3	4	5	6
Collection from fields	Densification	Primary Storage	Transport	De-baling and densification	Storage in Depot

Densification Technology, which converts loose crop residues into densified biofuel holds great promise for expediting the efficient use of crop residues. First, the technology can improve the physical property of the crop residue to facilitate collection, transportation and storage. Second, densification technology can increase energy density and subsequently produce high energy conversion efficiency. Finally, the crop residue densified biofuel has many demand sectors including residential, commercial and industrial

Estimations

Estimating Raw material supply to Biomass Densification Plant (Biomass Briquetting Plant)

Available amount of crop residues for densified biofuel is be calculated based on the following equation:

$$Q_a = \frac{fr \times Qt}{Aj} A_{sp}$$

fr = Percentage of remaining crop residue after removal of other uses. fr *is* usually set to a typical value of 30% (Jiang *et al.*, 2012);

Q_t = Total amount of crop residue generated in the concerned area

A_{sp} = Collection area of crop residue for every sub-plant.

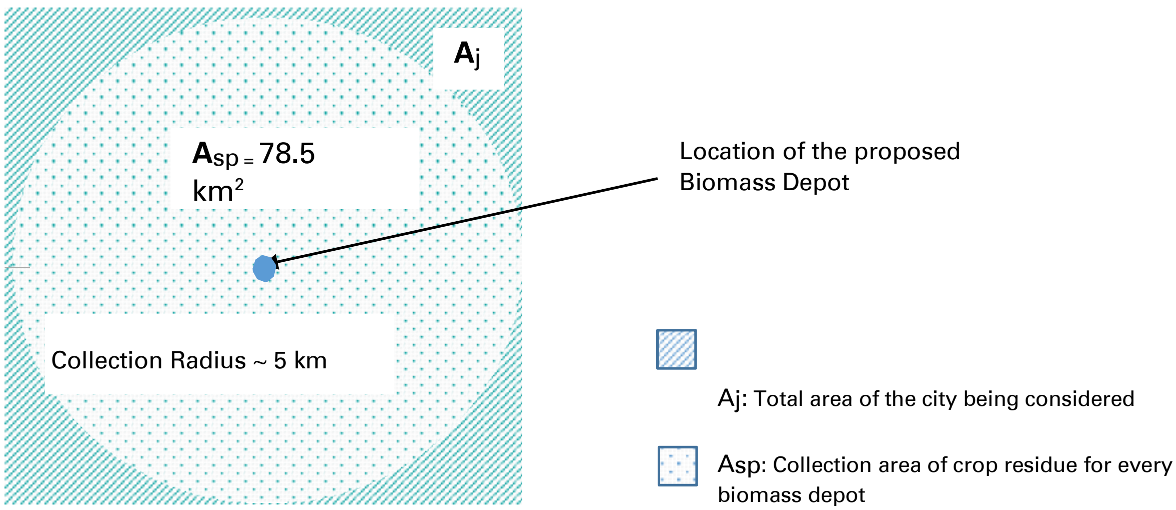
A_j = Total area of the city being considered.

Considerations:

Due to the looseness of crop residues, the transportation cost would be very high if the round trip collection radius distance from the field to sub-plot location is too large. On the other hand, the supply of raw material will be insufficient if the collection radius is too small.

The collection radius is dependent on several parameters such as capacity of production equipment set, conversion ratio of raw material to densified biofuel. Several studies have estimated the optimal collection radius of about 5 km. which will translate into an A_{sp} of (~78.5 km^2).

Typical Case:



Considering an area (A_j) of 10 km × 10 km~ 100 km^2 (=10,000 hectares) which is cultivating wheat crop (residue to crop ratio: 1.6). As per the 2015-16 data of Department of Agriculture, the yield wheat crop (yield/hectare) was 2872 kg/hectare. The corresponding generation of crop residues from this crop will be =1.6 × 2872 × 90,000 = 45952 tons (Q_t). (Similarly, the crop residues generation from a particular area can be calculated based the nature of crop planted in a season and the corresponding yield)

The available amount of crop residues for biomass densification plant (including moisture) is calculated based on the equation mentioned above:

$$\mathbf{Q_a} = 0.3 \times 45952 \times 78.5 / 900 \sim 1200 \text{ tons}$$

The agricultural residues from wheat typically contain about 12-14% moisture content (Chen et al. 2009). So the estimated amount of the available crop residue biomass for the densification plant will be

$$\mathbf{Q_a} = 1200 \times 0.87 = 1044 \text{ tons of dry matter.}$$

The dried biomass can be densified and stored as biomass briquettes. The various types of devices that can be used for biomass densification include mechanical piston press, screw press, hydraulic press and roller press.

Table below gives the parameters for various types of straw briquetting machines

Types	Motor Power (kW)	Productivity (kg/h)	Power Consumption (kWh/ton)	Density of briquette (kg/m³)	Moisture content of raw material
Screw	11	100-200	60-80	1100-1300	6-10%
Screw	15	130-150	60-80	1100-1300	6-10%
Screw	7.5	~110	100	1100-1300	~12%
Piston	7.5	60 - 100	65	900-1300	6-12%
Hydraulic Piston	18.5	300-500	71	800-1200	7-14%

Reference: These are taken as reference case from China, Zeng et. al. 2009.

Assuming that there is a briquetting plant with 10 hydraulic piston press (capacity: 500 kg/h) for making biomass briquettes which are operating 8 hours per day

Briquettes produced per month (based on 25 days of operation per month for each press) = 25 × 8 × 500 × 10 = 1000 tons of briquettes (with average density of 800 – 1200 kg/m³ can be produced).

Economics of the Briquetting Plant:

Revenue earned from biomass briquette in market based on the present market rate of $80 per ton
= 80 × 1000 = $ 80,000 per month = ₹ 5520000

Overview of Typical Expenses

Power consumption = 71 × 1000 = 71000 kWh (Refer above Table for Reference). Considering power cost per unit in Rural areas at ₹ 4 per unit = 4 × 71000 = ₹ 284000

Raw Material Cost = Farmers can be paid (Say ₹1 per kg based on per ton of biomass that they can provide to the biomass densification plants. The cost of transportation can be reimbursed to the farmer within reasonable limits = 1 × 1000 × 1000 = ₹ 1000000

Manpower Cost: Assuming that 1 skilled operator and 1 helper will be responsible for operation of 3 briquetting machine the total manpower requirements for operating 10 machines (capacity 500 kg/h) is about 6.

Based on the minimum wages the manpower cost is estimated as below:
Skilled persons: 3
Unskilled: 6 (3 helpers + 3 others viz., security)

Skilled Labor	3 × 11000 × 12	₹ 396000
Unskilled Labor	6 × 9500 × 12	₹ 684000
Total Manpower Cost		₹ 1080000

Initial one time capital investment will be required for machinery and land for setting up the plant.

Fuel Briquetting Plant having capacity of 750 kgs/hr. will require 1000 m² of area *(Source: National Small Industries Corporation, NSIC).*

POLICY INTERVENTIONS FOR PROMOTING BIOMASS USAGE IN CHINA

To support the efficient utilization of crop residues, some regulations and laws have been established in China. In 2005, the Renewable Energy Law of China was promulgated, which regulates the promotion, application, price management, and economic incentives of renewable energy from biomass materials. The law clearly indicates that the enterprises operating gas pipe line networks and heat pipeline networks should accept biomass energy into the net- works if the gas and heat produced with biomass resources conform to the gas and heat pipeline networks.

In 2007, the Medium and Long- Term Development Plan for Renewable Energy in China presented the development prospective of densified biofuel as follows (a) By **2010**, 500 pilot rural areas using densified biofuel will be established. The annual consumption of densified biofuel will reach 1 million tons. Densified biofuel will mainly be used as living energy for local rural residents. (b) By **2020**, densified biofuel becomes a widely used form of high quality fuel and its annual consumption will reach 50 million tons. The production pattern of densified biofuel can be divided into the small scale in rural areas and large scale in suitable areas. The former will be mainly used as living energy for local rural residents, whereas the latter will be used as commercial fuel for urban residents and industrial users. In 2011, the Implementation Program of Crop- Residue Utilization during the Twelfth Five-Year Plan of China was promulgated by the National Development and Reform Commission of China, Ministry of Agriculture of China, and Ministry of Finance of China. It is clearly proposed in this program that the densified biofuel from crop residue will be developed as a priority field. In combining with new country side construction products, crop-residue densified biofuel projects used by rural residents will be conducted, and a high- efficiency commercial operation model will be explored with the aim of large-scale application in China.

Estimating the size of biomass storage yard (Depot)

Sizing Criteria for Biomass Depots:

The sizing of the biomass depot for supplying biomass to bio-refineries is constructed is primarily based on annual stocking requirement.

Annual stocking requirement: this is determined by Agri-residues generation (harvesting) period. In case of cotton and castor stalks (or cane trash) this period is 180 days and hence stocking requirement of 150 days consumption of biomass bales. In case of paddy straw, the window is between 40-50 days i.e., stocking requirement is for 280 days consumption of biomass bales.

Straw management cannot be tackled in Isolation: CII Agro Tech, 2016

Maligned paddy straw can be given back to the soil using appropriate mechanisms instead of burning in open fields which causes pollution. There are other uses as well - straw from wheat and rice can be combined to grow button mushrooms.

'Size of stubble left behind critical': "The size of the stubble left after cutting must not be more than 10cm and machines applied must be used properly for this to happen. Germany is using Strip Till, where animal excreta is used to manage the residue." As a rule, we need a chain of methods to manage straw and farmers' education also plays a role.

Four Methods of Straw Management: CII- Agro Tech 2016

Collection of straw to make bales is a solution like animal fodder etc. Mulching is an option for menthe, turmeric, potato and it leads to water saving. Happy seeder has been promoted since 2006, but requires farmers to be aware of limitations under which it works. "PAU Happy Seeder is an option for farmers to explore. Tractor-operated loose straw chopper is also an option"

In situ retention as mulch in flat fields is also another method for better management of straw. He added that use of machines was a deterrent especially as farmers had the option of burning.

Agri-Residues for Green Remediation of Mining Sites (USEPA, 2012)

Through EPA funding, the University of Oklahoma constructed a passive treatment system for seepage from abandoned underground lead and zinc mines at the Tar Creek Superfund Site in Oklahoma. The system encompassed oxidation/re-aeration ponds, surface flow wetlands, vertical-flow/sulfate-reducing biochemical reactors, and horizontal flow limestone beds. Approximately 90% of each biochemical reactor consisted of agricultural and forestry waste products.

To accelerate oxidation in the ponds, **off-grid renewable energy systems** were integrated into the system's design.

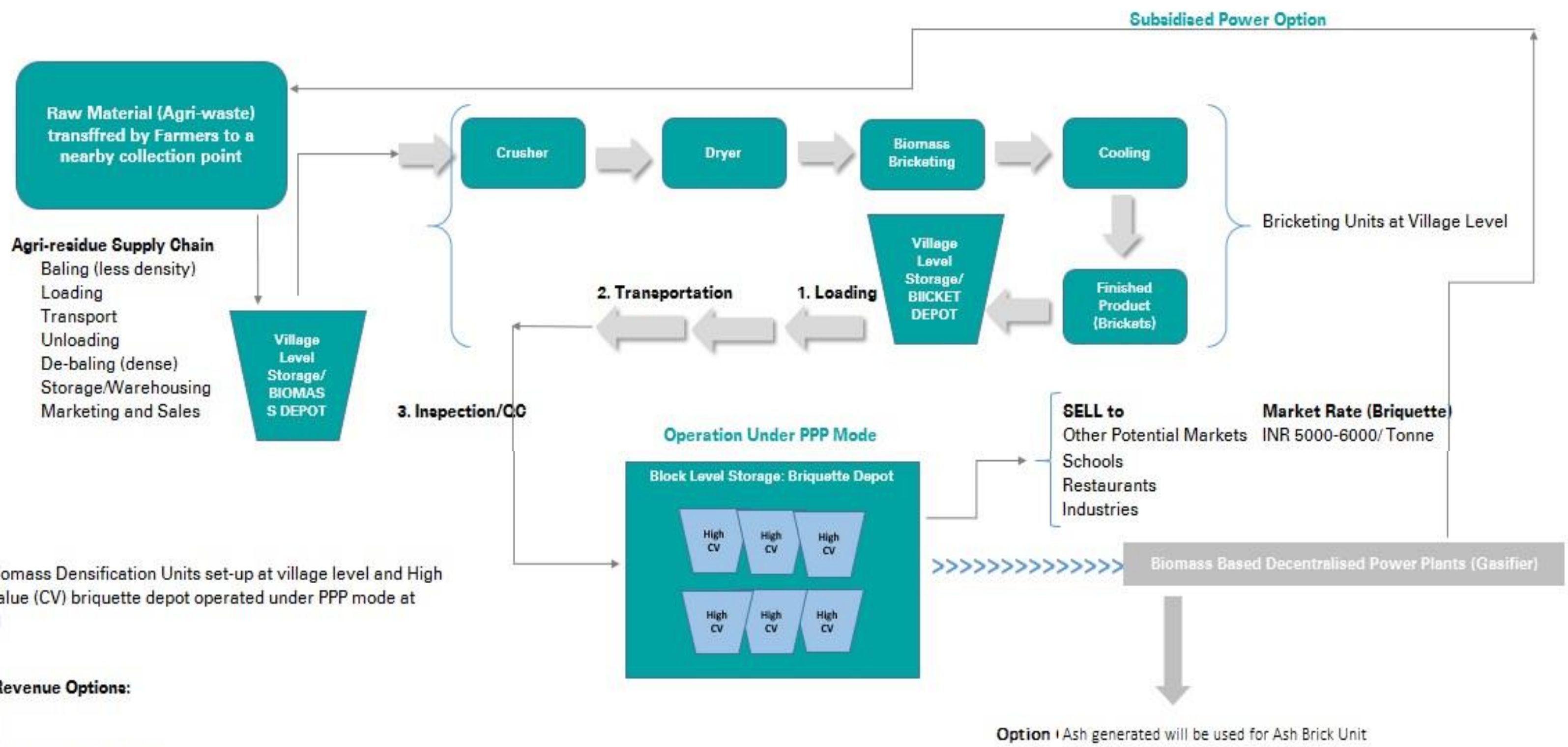
Sizing of Biomass Depots: this would be function of availability of land parcels (even agriculture land on lease) and distance from the site (bio-refinery). Estimates suggest that optimal depot size is 2 hectares (20,000 m^2) from perspective of leasing land parcels as well as adequacy of storage area (11,250 m^2) in 3 tiers for biomass bales. An estimated 37,500 biomass bales of size (1.5 m × 0.6 m × 0.6 m), having bulk density of 400 kg/m^3 which would amount to 8000 tons/depot. The depot size of 20,000 m^2 also caters for area required for compost yard (about 1000 tons/year).Assuming 30 days composting cycle time (accelerated through enzyme/microbe additives) & 10 operational months, around 200 m^2 will be required for compost vats, sieving and bagging area (to produce 100 tons/2000 bags of compost per operational month).

Estimation of Depot Manpower: Depot size of 20,000 m^2 also caters for area required for security gate/office, tractor-trolley parking area, weighbridge, laboratory, Agri-residues de-baling /cleaning/high density baling, Roads for movement of material handling equipment, Bio-CNG prime mover and bed trolley parking area, mobile rakers.

Estimating the number of Depots: For a bio-refinery with a rated capacity 7.5 tons/hour cellulosic ethanol, the stocking requirement, for paddy straw would be 315,000 tons (280 days storage) will require 40 depots. In case of cotton + castor stalk, the stocking requirement would be 210,000 tons (150 days storage), requiring 27 depots. In case of Cane Trash, the stocking requirement would be 170,000 tons (150 days storage), requiring 22 depots.

Estimating the number of mobile rakers/balers (per Depot): Assuming coverage of 6 hectares/day and collection of 30 tons/day (or 1500 tons over 50 days) from each set of balers, for paddy straw, each depot will require 6 sets of rakers/balers. In case of cotton and castor stalks (or cane trash) with a rated capacity of 30 tons/day (or 4500 tons over 150 days), each depot will require 2 sets of rakers/balers.

Model : Agro-waste to Biomass Briquette



MODEL: Biomass Densification Units set-up at village level and High Calorific Value (CV) briquette depot operated under PPP mode at Block level

Potential Revenue Options:

Option A:
Subsidised Power to the Village
Option B:
Village has a common pool earned by selling brickets to the Silo Farm
Option C:
Ash generated will be used for Ash Brick Unit

Chapter 5
Composting

- **Composting**
  - Vermi-composting
  - Agri-waste to manure Process
- **Technologies for Composting Business**
- **Economics of Composting Business**

Composting

Composting is the natural process of 'rotting' or decomposition of organic matter by microorganisms under controlled conditions. Raw organic materials such as crop residues, animal wastes, food garbage, some municipal wastes and suitable industrial wastes, enhance their suitability for application to the soil as a fertilizing resource, after having undergone composting. Composting is a biological process that is optimized when the starting carbon to nitrogen ratio is in the range of 30:1 and the moisture and oxygen levels and temperatures are closely managed and monitored.

Compost is a rich source of organic matter. Soil organic matter plays an important role in sustaining soil fertility, and hence in sustainable agricultural production. In addition to being a source of plant nutrient, it improves the physico-chemical and biological properties of the soil. As a result of these improvements, the soil: (i) becomes more resistant to stresses such as drought, diseases and toxicity; (ii) helps the crop in improved uptake of plant nutrients; and (iii) possesses an active nutrient cycling capacity because of vigorous microbial activity. These advantages manifest themselves in reduced cropping risks, higher yields and lower outlays on inorganic fertilizers for farmers.

Composting may be divided into two categories by the nature of the decomposition process. In anaerobic composting, decomposition occurs where oxygen (O) is absent or in limited supply. Under this method, anaerobic micro-organisms dominate and develop intermediate compounds including methane, organic acids, hydrogen sulphide and other substances. In the absence of O, these compounds accumulate and are not metabolized further. Many of these compounds have strong odors and some present phytotoxicity. As anaerobic composting is a low-temperature process, it leaves weed seeds and pathogens intact. Moreover, the process usually takes longer than aerobic composting. These drawbacks often offset the merits of this process, *viz.*, little work involved and fewer nutrients lost during the process.

Vermicomposting

It is the product or process of composting using various worms, usually red wigglers, white worms, and other earthworms, to create a heterogeneous mixture of decomposing vegetable or food waste, bedding materials, and vermicast, also called worm castings, worm humus or worm manure, is the end-product of the breakdown of organic matter by an earthworm. These castings have been shown to contain reduced levels of contaminants and a higher saturation of nutrients than do organic materials before vermicomposting. Containing water-soluble nutrients, vermicompost is an excellent, nutrient-rich organic fertilizer and soil conditioner. This process of producing vermicompost is called *vermicomposting*. While vermicomposting is generally known as a nutrient rich source of organic compost used in farming and small scale sustainable, organic farming, the process of vermicasting is undergoing research as a treatment for organic waste in sewage and wastewater plants around the world.

Agri-Waste to Manure Process

Primary Segregation	Uploading / Stage 1 Secondary Segregation	Zero Waste Management Centre / Stage 2 Secondary Segregation	Composting Process	Compost Beds	Revenue Potential Options
At Farm / Household Level	Wet items are Segregated before it is transferred to common facility	Segregation	Windrow Aerated Windrow	Manure Sieving Manure Processing	Sale and Purchase agreements with forest departments, nurseries etc.

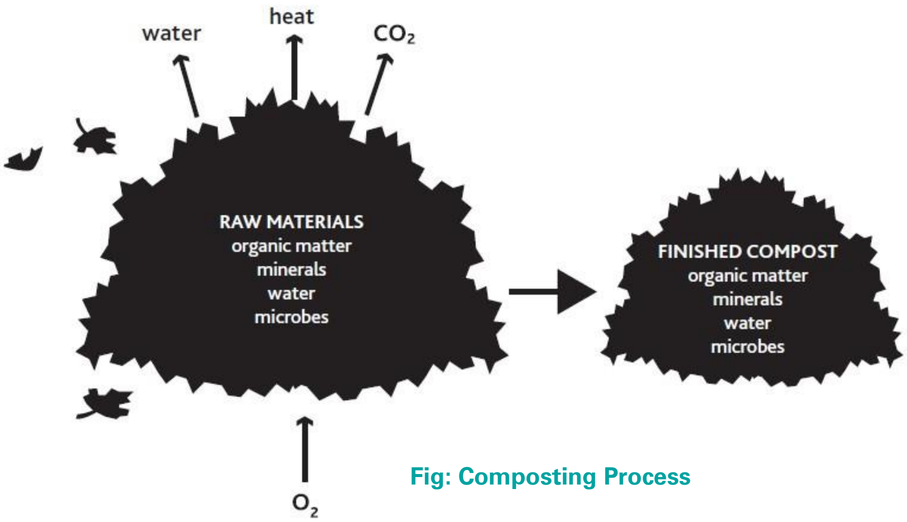


Fig: Composting Process

Technologies for Composting Business

Composting Technologies and systems for the actual composting phases are described in the **Table** below:

Technology	Description
Windrow	Outdoor composting in piles that rely on mechanical aeration, typically with a compost windrow turner, to optimize the composting process. Windrow facilities with straddle turners (a turner which goes over the top of the pile) are limited in pile height by the height of the turner. Other turner technologies, e.g., elevating face, perform the turning function from the side and therefore pile height is less of a constraint. To optimize the windrow composting process, pile height typically is limited to 3 to 4 meters. Organics to be composted are either premixed prior to being formed into a windrow, or are layered (e.g., typically on a bed of ground yard trimmings, wood chips or sawdust) and then mixed with the turner. To control release of odors when the food scraps in the organics are "fresh," some windrow facility managers create the windrows and then wait for a few days or a week before the first pile turning. In some cases, the windrows are covered with a layer of ground yard trimmings, which acts as a bio-filter during this initial stage. In a windrow, temperature control and oxygen levels are managed via mechanical agitation. Pile temperature and oxygen level need to be taken by a site operator with hand-held monitoring tools. Pile turning introduces oxygen, accelerates physical degradation of feed-stocks and provides an opportunity to adjust the moisture content to the optimum level. Many windrow turners have a watering attachment, which enables moisture to be added to the pile while turning. Generally speaking, the total composting time can be managed by the aggressiveness of the turning regime. More frequent turning breaks particles down more quickly, and provides an opportunity to optimize composting conditions, thus accelerating the composting process. This enables a windrow composting facility to increase its annual throughput capacity.

Enclosed Aerated Windrow	An aerated windrow is essentially a hybrid between a windrow and an aerated static pile. It uses both forced air (to more directly control oxygen levels and temperatures) and pile agitation, which accelerates the physical breakdown of composting materials and thus the composting process. Facilities using aerated windrows typically house them in a building, where the composting hall floor has aeration trenches covered by grates. Process air is directed to a bio-filter outside of the building. Few, if any, facilities solely use aerated windrows by themselves to compost the SSO stream. Typically, aerated windrows are used after initial processing in rotary drums (typically three-day retention time in the drums) or with in-vessel containers.
Aerated Static Pile	Aerated static pile composting is comprised of forcing (positive) or pulling (negative) air through a trapezoidal compost pile. Agitation only occurs when piles are combined or moved to a different area for curing. To better manage odors, piles often are covered with a layer of finished compost or wood chips, which then are incorporated when the piles are moved. The aerated static pile composting method was developed in the early 1970s primarily for composting municipal sewage sludge. For bio-solids, a bulking agent is needed to provide pile porosity to enhance the flow of air and control temperatures. Wood chips were determined to be the optimum bulking agent (although over the years, there has been some experimentation with shredded tires); these are recovered through screening and recycled back into the initial pile mix. One advantage of aerated static pile composting is the ability to capture the process air for odor treatment (typically through a bio-filter). Outdoor aerated static pile operations need to use negative aeration (pulling air down through the pile) in order to direct it to an odor control system. Indoor aerated static piles can use positive aeration, with building air removed and treated through an odor control system.
Rotary Drums	Rotary drums (also called digesters) are included in this section because a number of the solid waste composting systems in North America utilize a drum as the first stage of composting. Rotary drums are not, in and of themselves, a composting technology. They must be used in tandem with another composting method. Rotary drums are popular because they serve several purposes: blending, size reduction without shredding, and screening. Over the three day retention time, the composting process is initiated, providing some degradation of feed-stocks, particularly food waste. Air is fed into the drum to aerate the material; process air typically is treated through a bio-filter. As material exits the drum, it passes through a screen, removing contaminants. Proponents of drums over mechanical shredding of composting feed-stocks cite a better ability to sort contaminants, especially plastic, as it has not been reduced to small pieces that can keep passing through screening systems. In Bangalore, Rotary Drums are used for composting the daily dump.
Anaerobic Digestion	Anaerobic digestion (AD) is the biological breakdown of organic materials in the absence of oxygen. In the process, biogas containing methane and carbon dioxide is produced. This biogas can be used as a fuel to generate energy. The material remaining after digestion is a partially stabilized organic material, which can then be aerobically cured and used as compost. Anaerobic Digestion Equipment: Proprietary equipment with a pulping system to pulverize or machinate the in feed materials into a consistent size feedstock for the anaerobic digestion chamber or silo. Vendors offer

	Systems of various throughput capacities, with abilities to directly inject liquids (e.g., manures, sludge's, etc.). One and two stage anaerobic digestion systems are available, where the solids are pressed from the liquids and processed in a separate system. All facilities processing SSO treat process air through a bio-filter. Materials typically are premixed before being loaded in the silos; all curing of materials are done in a separate structure (open-sided or enclosed). At some installations, aeration is provided in the curing phase.

Economics of Composting Business

Compost Yards: They are used for preparation of compost from separated solids from biogas plant effluent. Separated solid from biogas plant effluent (about 30% dry solids) will be composted. There will be custom built vats, compost shifters, vibratory sieves, bagging system etc. to produce assured quality compost estimated to be 2000 No × 50 Kg bags per month.

Roof mounted Solar PV Plant: (200 KW, 300,000 KW/year) will function as captive power plant depot cum compost yard adopting net metering scheme. Some power will also be supplied to school or other community centers in nearby village as part of community support activity.

Economics: The capital cost ranges shown below are per throughput ton assuming a minimum of 50,000 throughput tonnes per year.

Composting Technique	Economics
Windrowing	$40 - 60 per throughput ton
Enclosed Windrowing	$100 - $150 per throughout ton
Anaerobic Digestion	$500-$700 per throughput ton

Note: "throughput" is the maximum rate of production

Chapter 6
Job Potential Estimates

- **Job Projections for Agri-residues**
- **Job Projections for Animal Waste**
  - Cattle Dung Manure
  - Poultry Manure

Estimating Job Potential for Farm Waste Management

Job Projections for Agri-residues

The crop residue generated in the field has to be made available to the user facilities which utilize agri-residues for making final products. The supply chain for agri—residues involve collection, storage and transportation of residue from field to site for end-use, collectively these activities are called as aggregation. Aggregation involves processing of agri-residues which involve several key steps such as baling, hauling, residue transportation and plant operation among others. India has skilled labor and substantial financial resources, which can be channeled into ramping up the collection of feedstock from crop residues; establishing collection infrastructure, and transporting and handling of large amounts of biomass. The bulky nature or low energy density of agricultural residues possesses problems in handling, storage, transportation and conversion processes. Since biomass transportation cost is a function of the quantity of available biomass in a region and the transportation distance, it is desirable to ensure availability of adequate crop residue in the vicinity of facilities, industries etc. where agri-residues are processed to make finished goods.

Biomass needs to be stored to ensure long term biomass availability for implementation of economically viable bio-based energy projects. Biomass can be stored in Biomass storage depot which need to be built and maintained for comprehensive inventories of biomass preferably in States which have high biomass availability per unit area which in turn is linked to the number of jobs in the region.

Estimating Jobs: Job related to agri-residue supply chain include jobs related to field collection of agri-residues, biomass densification and aggregation in biomass depots. Based on the secondary data research and interactions with stakeholders and technical experts, it is reflected that one person can handle an estimated 200 tons of agri-residues per year which form our base estimate of manpower requirement for aggregation of agri-residues. Considering the factor of 200 tons/person/annum, the number of potential job opportunities are estimated based on the agri-surplus projections for 2020 and 2030. These job estimates are mentioned in the following Tables.

Number of Jobs for "Field Collection" of Agri-Residues

Year	Total Surplus Generated (in million tons)	Number of Jobs in Field Collection of Agri-Residues
2010	176	880000
2020	247	1235000
2030	348	1740000

Number of Jobs for "Biomass Densification"

Year	Total Surplus Generated (in million tons)	Number of Jobs in Cleaned Biomass Densification
2010	176	880000
2020	247	1235000
2030	348	1740000

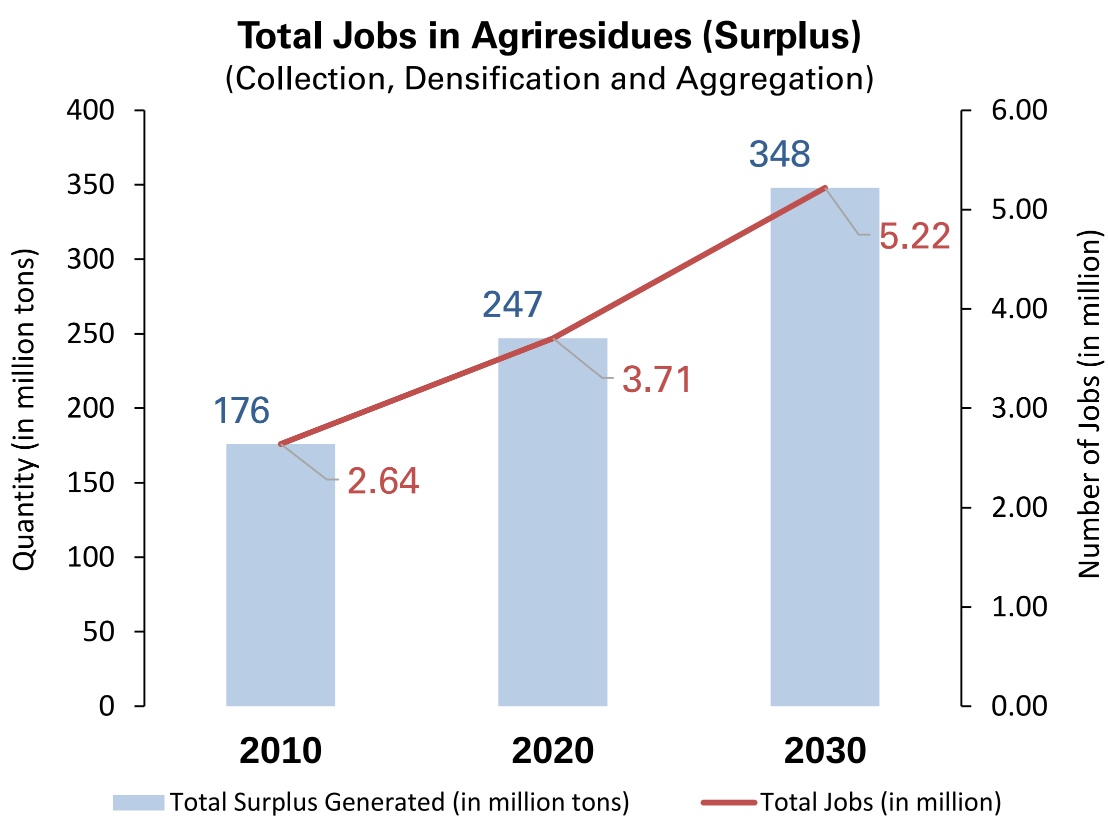
Number of Jobs for "Aggregation in Biomass Depots"

Year	Total Surplus Generated (in million tons)	Number of Jobs for Aggregation in Biomass Depots
2010	176	880000
2020	247	1235000
2030	348	1740000

The total number of jobs in agri-residue supply chain will be a sum of all the three steps mentioned in the Table above viz., field collection, densification and aggregation in biomass depots. These are reflected in the Table and graph below:

Total Jobs in Agri-residue aggregation

Year	Total Surplus Generated (in million tons)	Total Jobs (in million)
2010	176	2.64
2020	247	3.71
2030	348	5.22



Job Projections for Animal Waste

Jobs in Cattle Manure collection, aggregation and compost production and retailing

As per the growth projections described in Chapter 2, the cattle dung generated is expected to reach 1623.39 million tons (MT) by 2020 and 2171.92 MT by 2030. The corresponding data for cattle dung recovery is estimated at 572.11 MT by 2020 and 1176.97 MT by 2030. Based on the secondary data research and interactions with stakeholders, technical and dairy experts, it was reflected that one person can handle an estimated 200 tons of cattle dung/manure per year which form our base estimate of manpower requirement. Considering the factor of 200 tons/person/annum, the number of potential job opportunities are estimated based on the cattle dung recovery estimates for 2020 and 2030. The projected job opportunities in animal waste are those related to cattle manure collection, aggregation and compost production. These are described in the following Tables:

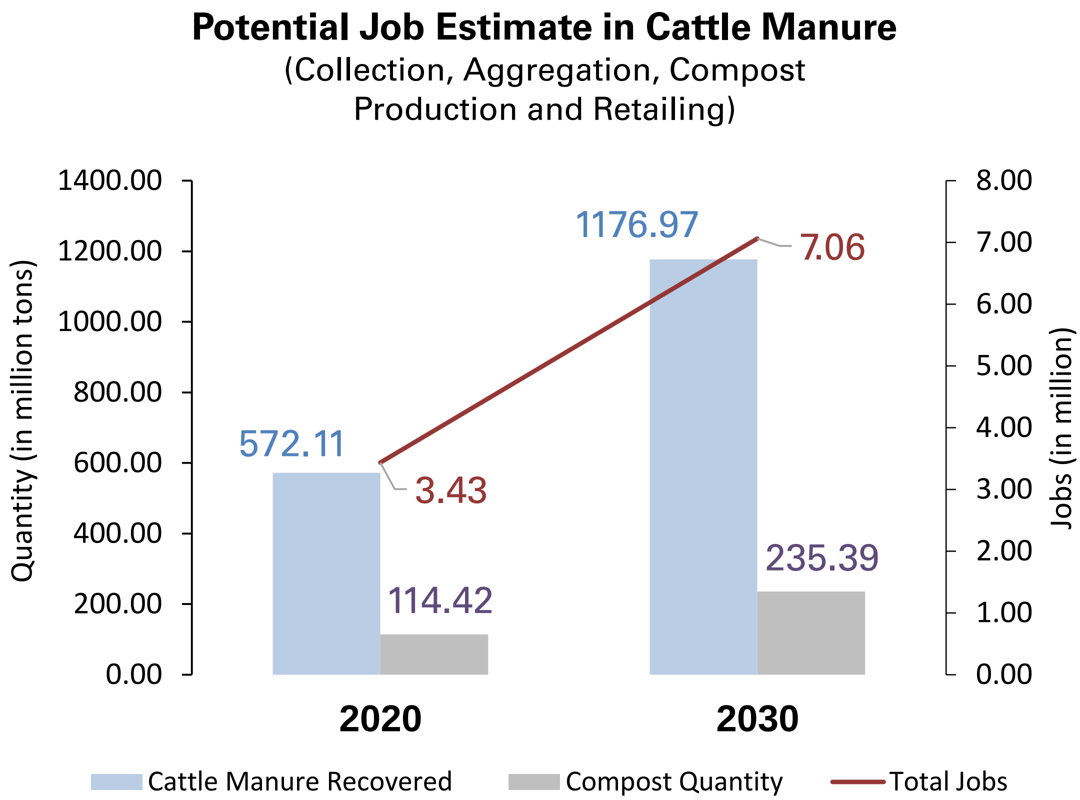
Total Cattle Dung recovered & Quantity of Compost produced

Year	**Cattle Dung Recovered** (in million tons)	**Cattle Dung available for Biogas Production** (in million tons)	**Cattle Dung available for producing Compost** (in million tons)	**Quantity of Compost Produced** (in million tons)	**Quantity of compost generated after Biogas Production** (in million tons)	**Total Compost Quantity** (in million tons)
2020	572.11	114.42	457.69	91.54	22.88	114.42
2030	1176.97	235.39	941.58	188.32	47.08	235.39

Total Jobs in Cattle Manure Aggregation & Supply Chain

Year	**Number of Jobs in Cattle Manure Collection and Aggregation**$ (in million)	**Number of Jobs in Compost Production, Distribution & Retailing** # (in million)	**Total Jobs** (in million)
2020	2.86	0.57	3.43
2030	5.88	1.18	7.06

$ Manure Collection and Aggregation: 200 tons/person/year
# Compost Production, Distribution & Retailing: 200 tons/person/year



Jobs in Poultry Manure aggregation and compost processing

The projected estimates for recovery of poultry manure and the quantity of compost produced in 2020 and 2030 are provided in the table below. The jobs are related to poultry manure collection, aggregation and compost production. An estimated factor of 100 tons per person per year based on stakeholder consultations is taken to calculate the total number of jobs.

Year	Poultry Manure Produced (in million tons)	Poultry Manure Recovered (in million tons)	Compost Quantity from Biogas Plant (in million tons)
2012	25.23	21.45	4.29
2020	30.69	26.09	5.22
2030	39.2	33.32	6.66

Number of Jobs in Poultry Manure Collection and Delivery to Biogas Plant

Year	Number of Jobs (in millions)
2012	0.2145
2020	0.2609
2030	0.3332

Number of Jobs for Poultry Manure Collection and Transport of Separated Solids from Digester Effluent

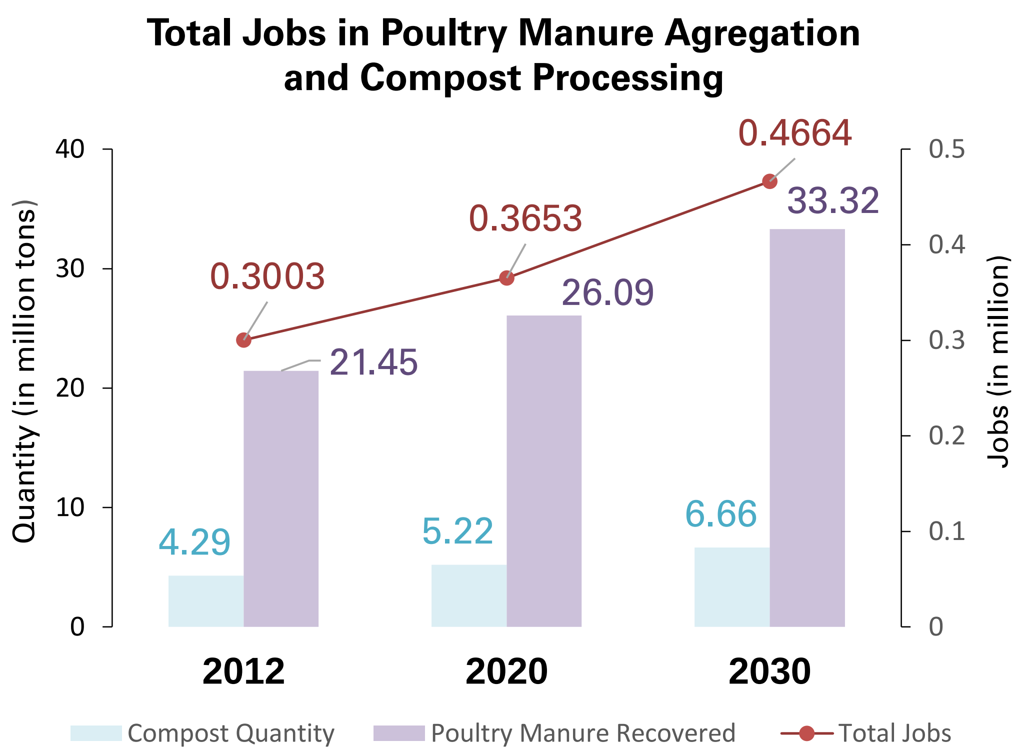
Year	Number of Jobs (in millions)
2012	0.0429
2020	0.0522
2030	0.0666

Number of Jobs for Composting, Bagging, Distribution and Retailing

Year	Number of Jobs (in millions)
2012	0.0429
2020	0.0522
2030	0.0666

Estimate/Assumption:

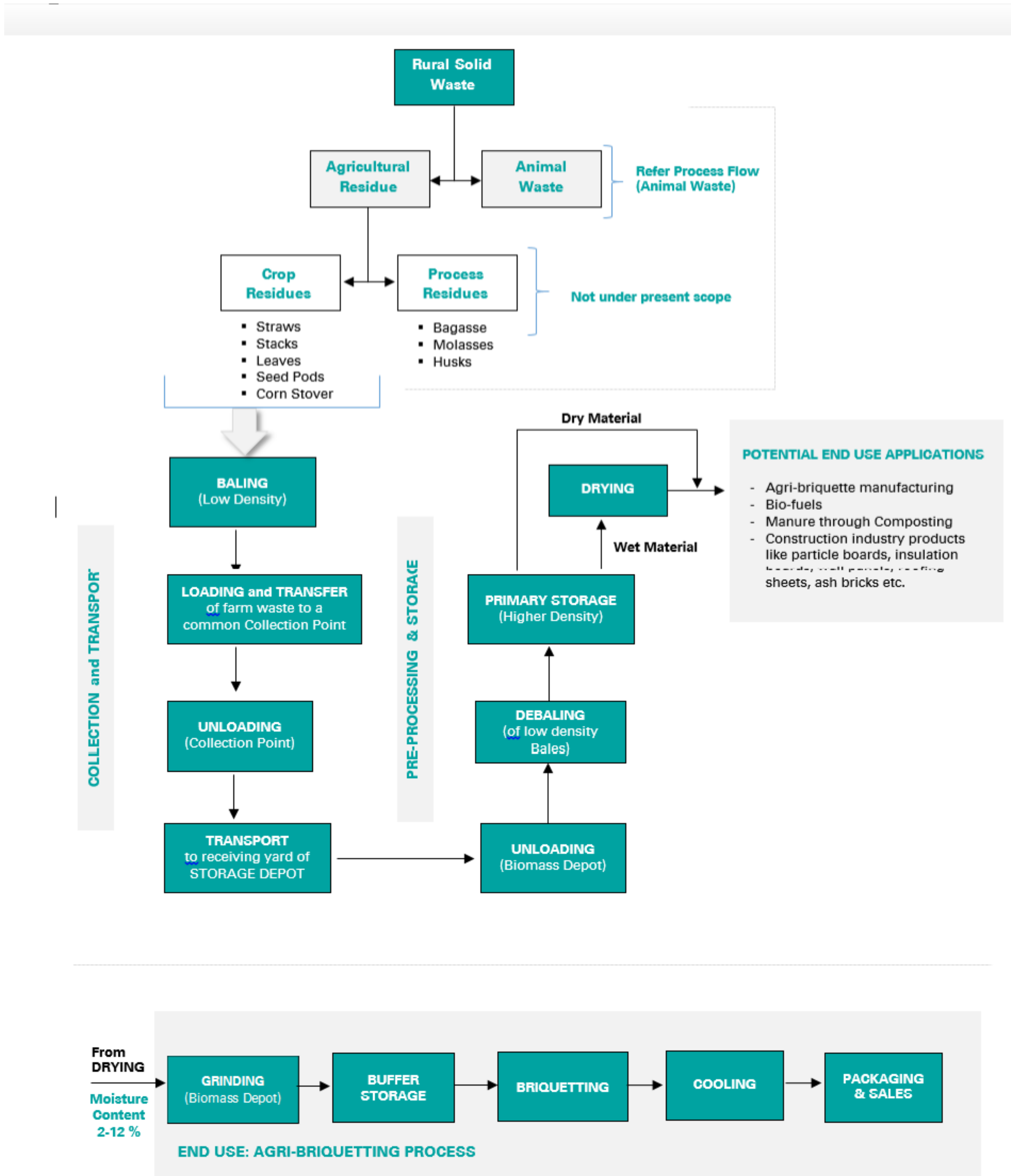
- # Manpower Requirement: Poultry Manure Collection / Delivery to Biogas Plant & Collection / Transport of separated solids from digester effluent: 1 person per 100 tons/year.
- Composting/ Bagging / Distribution and Retailing: 1 person per 100 tons/year



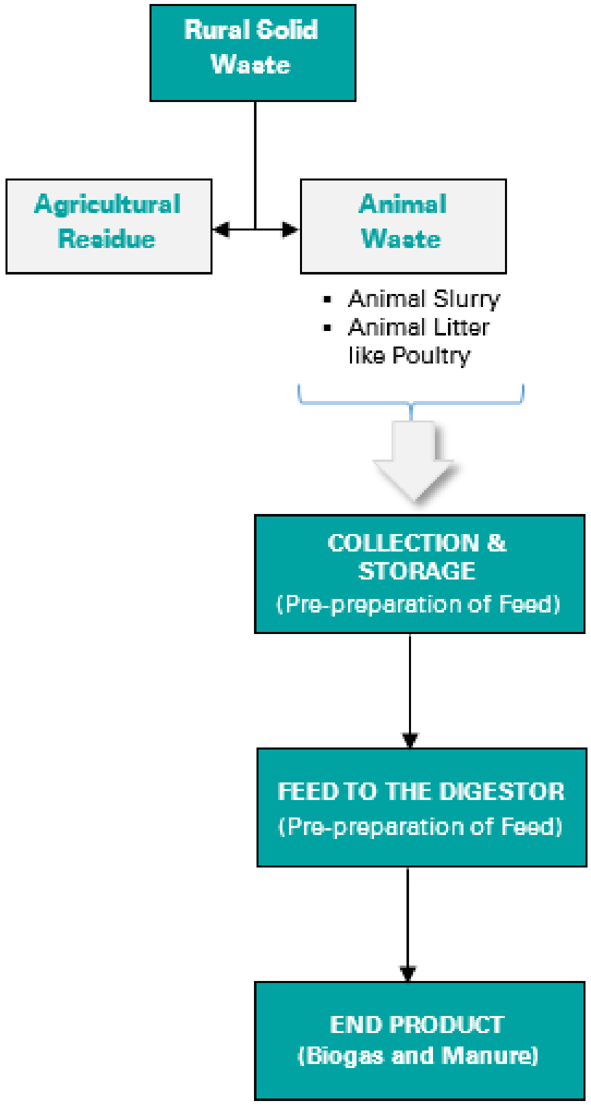
Chapter 7
Process Mapping

- **Process Map: Agri-residues**
- **Process Map: Animal waste**

Process Map (Agri-Residues)



Process Map (Animal Waste)



Chapter 8
Occupational Mapping

- **List of key Occupational Job Roles & NSQF Levels**
- **Occupational Map (OM)**
  - OM-Customer Relationship
  - OM-Supply Chain (Aggregation): Farm Waste
  - OM-Operations & Quality
  - OM-Finance & Human Resources

The job roles related to farm waste management sector were finalized in discussion with the industrial stakeholders and technical experts which are related to rural, agricultural, dairy and related areas. The job roles listed is a result of these comprehensive discussions and reflect the type of occupations that will be required in to realize the full potential of farm waste management sector. Wherever possible, reasonable assumptions were also taken to reflect number of jobs that are presented in the earlier chapters. Table below and flowchart thereafter lists key occupational job roles that were identified along with their NSQF levels.

List of Key Occupational Job Roles & NSQF Levels

Job Role Title	NSQF Level
Entrepreneur /GM (Integrated Farm Waste Management)	8
Customer Relationship	
Manager (CRM)	7
Executive (Online Support)	5 - 6
Executive (Tele-calling)	5 - 6
Supply Chain (Aggregation): Farm Waste	
Procurement Manager (Crop Residues)	6-7
Entrepreneur (Crop Residue Supply)	5-4
Contractor (Transport)	3
Loader	1-2
Baler	1-2
Driver	1-2
Operations & Quality	
Entrepreneur (Biomass Depot)	7
Executive (Biomass Depot)	5
Operator (Biomass Depot)	4
Baler	1 - 2
Raker	1 - 2
Helper (Biomass Depot / Compost Plant/ Chipping/ Shredder/Sieving/Cooling) etc.	1 - 2
Entrepreneur (Compost Yard)	6
Supervisor (Compost Plant)	4 - 5
Operator (Compost Plant)	3
Entrepreneur (Agri-pellets)	6
Technical Assistant (Raw Material /Pellet Quality)	4 - 5
Operator (Pellet mill)	3
Finance & Human Resources	
Manager (HR/Admin/Sales)	6
Executive (Sales/Finance/Marketing)	4 - 5

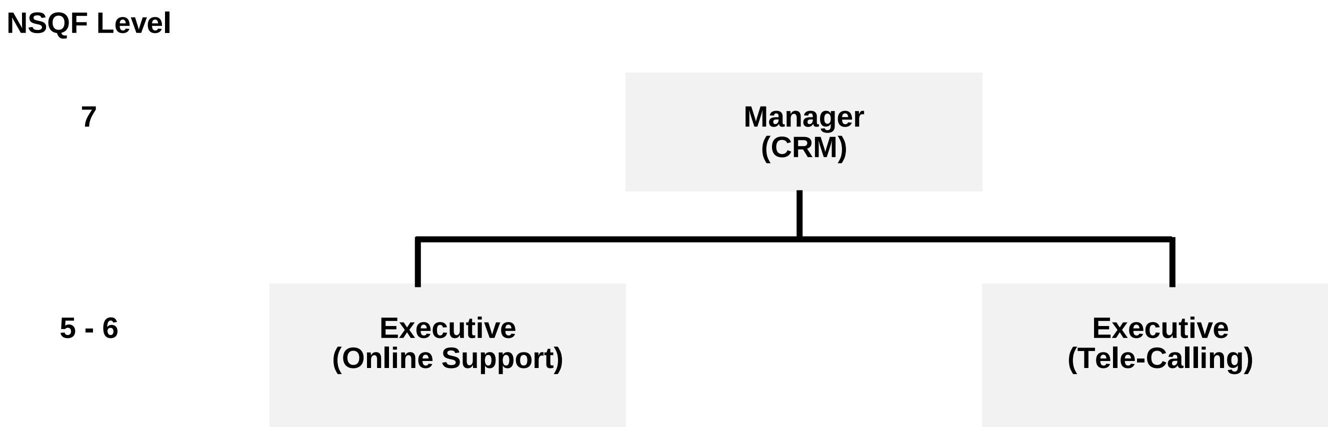
Occupational Map

Representative Occupational Map for Farm Waste Management Business

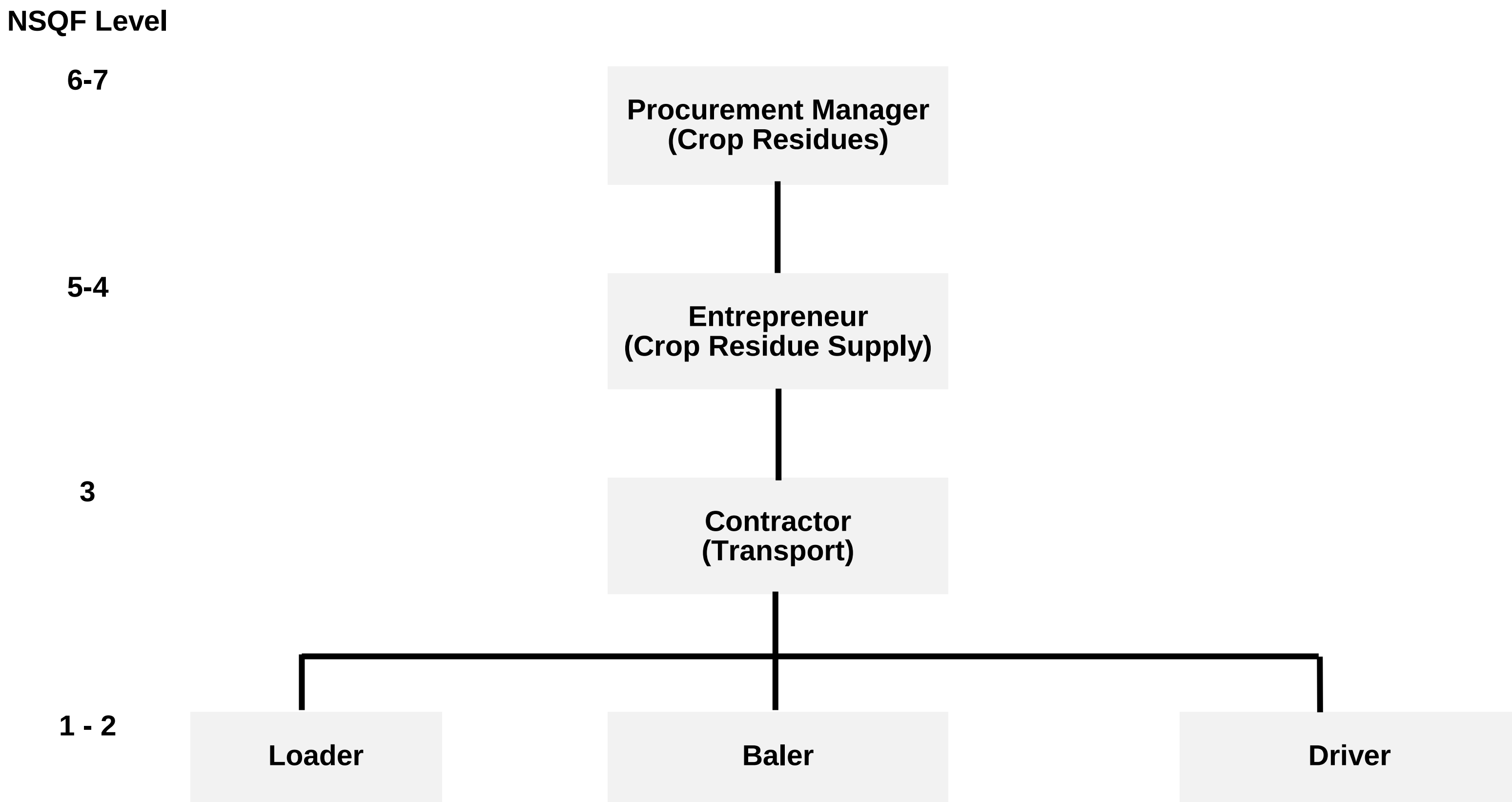
Entrepreneur /General Manager –
Integrated Farm Waste Management Business

A.	B.	C.	D.
Customer Relationship	**Supply Chain (Aggregation): Farm Waste**	**Operations & Quality**	**Finance & Human Resources**

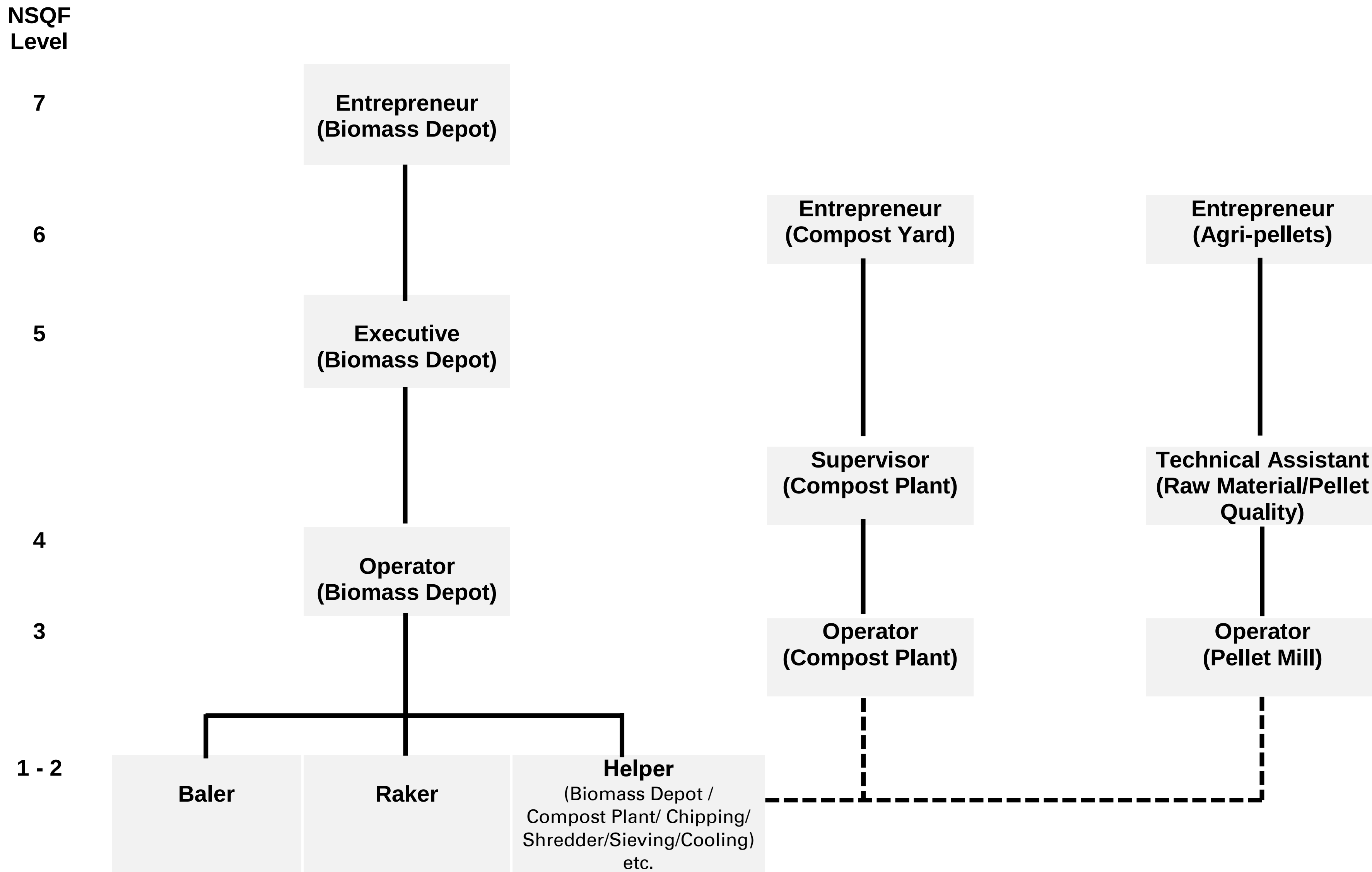
A. Occupational Map: Customer Relationship



B. Occupational Map: Supply Chain (Aggregation): Farm Waste



C. Occupational Map: Operations and Quality



D. Occupational Map: Finance & Human Resources

NSQF Level	
6	Manager (HR/Admin/Sales)
4 - 5	Executive (Sales / Finance/ Marketing)

References

1. Biomass 2020, Opportunities, Challenges and Solutions; 2011 Report.
2. UNEP-DTU Report; Promoting Low Carbon Transport in India: Biofuel Roadmap for India, 2015.
3. Vision 2030 Document; Indian Veterinary Research Institute; 2011.
4. Statistical Estimates on the Production of Food Grains; Department of Agriculture, Cooperation and Farmers Welfare, Directorate of Economics and Statistics; 2016.
5. Ministry of New and Renewable Energy. (2014–2015), *Annual report*, Government of India.
6. Planning Commission Report. (2014). *Reports of the task force on waste to energy* (Vol-I) (in the context of Integrated MSW management).
7. Crop Residues Management with Conservation Agriculture: Potential, Constraints and Policy Needs; IARI; 2012.
8. Zeng et. al. (2007); Utilization of straw in biomass energy in China; Renewable and Sustainable Energy Reviews; 11(2007) 976-987.
9. Chen et. al. (2009); Renewable energy from agri-residues in China: Solid biofuels and biomass briquetting technology; Renewable and Sustainable Energy Reviews; 13(2009) 2689-2695.
10. Hiloidhari et. al. (2014); Bioenergy potential from crop residue biomass in India; Renewable and Sustainable Energy Reviews; 32 (2014) 504-512.
11. Awalgaonkar et. al. (2014); Assessment of surplus energy residues for biomass briquetting in India; ResearchGate.
12. Feng et. al. (2013); The economic feasibility of a crop residue densification plant; Renewable and Sustainable Energy Reviews; 24 (2013) 172-180.
13. Tripathi et. al. (1998); A Techno-economic evaluation of biomass briquetting in India; Biomass and Bioenergy; 14 (1998) 479-488.
14. Panwar et. al. (2011); Biomass residue briquetting and characterization; Journal of Energy Engineering; 137(2) (2011) 108-114.
15. Bharathiraja et. al. (2014); Biofuels from sewage sludge-A review; International journal of ChemTech Research; Vol. 6(9)(2014); 4417-4427.