ENVIRONMENTAL, SOCIO-ECONOMIC, HEALTH AND OTHER POSITIVE IMPACTS OF BUILDING HOUSEHOLD BIOGAS PLANTS IN RURAL INDIA[⊗]

By

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I. INTRODUCTION

1.01. Over 75% of Indian population lives in rural areas, in about 600,000 villages, which mainly depend on agriculture and allied activities for their livelihood. India also has over 360 million bovine (cattle plus buffalo) population, majority of which lives in rural areas as domestic farm animals, forming the backbone of Indian agriculture and rural economy. The female bovine provides the milk, and the male cattle (bullocks) are used as draft animals for carrying out farming operations, like ploughing, levelling, thrashing, hauling of farm inputs and crops etc; short & medium distance transport of farm produced, other goods and the local villagers. In addition to this, the manure (dung) produced from bovine population in India is of great value to local communities, though often not given importance in terms of economic value, as at present it does not give direct cash benefits to majority of rural people. The size of Indian animal varies greatly from region to region and area to area with in the same region, and the majority of them are sent or left for grazing during the major part of the year during the day. Therefore, taking a safe value as 5 Kg dung/ bovine/ day, the average daily collectable quantity of dung in India would come to 1,800 million Kg/ day (360 million bovine population @ 5 kg per animal) or 1.8 million tones/ day[2].

1.02. Approximately 1/3rd (600 million kg/day) of total collectable bovine dung annually, is estimated to be made in to dried dung cakes by rural people- these dung cakes are used by rural women as cooking fuel. This is not only an inefficient way of using dung as fuel, which gives only 11% energy but also pollutes the local and the surrounding environment, and adds to the greenhouse gases (GHGs), which in terns contributes to the global warming and the climate change. At the same time cooking in the traditional and inefficient cook stoves (chulhas) in rural India also contributes to the drudgery of rural women, for example- time spent by them in the collection and cooking) as well as adversely effecting their health (respiratory, lungs & eye diseases etc). It has been estimated that burning of biomass (including dried manure) for cooking in the traditional stoves in rural India contributes to inhaling of smoke equivalent to smoking up to 20 packets or 200 nos. of cigarettes (@ 10 cigarettes per packet) by village women each day. Health of infant children (staying with mothers) as well as the adolescent girls (who also do cooking in rural homes) is also affected due to smoky kitchens in rural India.

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2. Average daily collectable quantity of dung in India as 1,800 million Kg/day (360 million bovine population @ 5 kg per animal) or 1.8 million tones/ day, has been estimated by the author for INSEDA. The author has also estimated that approx. 1/3rd (600 million kg/day) of total collectable bovine dung annually, is estimated to be made in to dried dung cakes by rural people- these dung cakes are used by rural women as cooking fuel.

1.03. Out of the balance of collectable bovine dung approximately 2/3rd (1,200 million kg/day or 1.2 million tone/day), the major portion (80% i.e. approx. 1,000 million kg dung/day or 1 million tone dung/ day) is estimated to be used for making organic manure in an inefficient manner. In fact this dung which is either left in the fields to dry or just dumped in heaps, is responsible for the release of methane (CH_4) to the atmosphere in the form of greenhouse gases (GHGs), that too with out given out any benefits to the people. This major percentage of dung also becomes responsible for the breading of flies and mosquitoes and creates pollution and public health problems. Moreover, bovine dung used at present for making organic manure in a traditional way also leads to major losses of beneficial nutrients by way of leaching and washing.

1.04. Balance of the left over manure out of the collectable bovine dung (200 million kg/ day) is estimated to be used for other miscellaneous activities, e.g. for building simple rural houses by mixing it with mud, as well as periodic plastering of walls and floors of houses in villages.

II. RECYCLING OF BOVINE MANURE THOUGH BIOGAS PLANTS IN INDIA

2.01. If biogas plants were used for recycling of this bio-degradable waste (dung) then apart from providing a clean & convenient domestic fuel for cooking as well as lighting rural houses, in the form of biogas,. If surplus biogas, which is essentially a mixture of methane (CH_4- 55-60%) and carbon dioxide (CO_2- 35-40%) gases, is available then it could be used for operating engine for mechanical operation. Biogas operated generators (gen-sets) could also be used for producing electricity in a decentralized manner, in remote and far-flung regions of the country, where transmission lines from the centralized power plant(s) and grids would never reach, and even if reached, it would not be cost effective and would require very high maintenance cost.

2.02. On the other hand, the digested liquid manure coming out of the biogas plants would provide an excellent organic manure in which all the useful nutrients remain preserved (due to decomposition in the enclosed digester of the biogas plant) for promoting environmentally sound eco-farming. Because the nutrient in the biogas digested liquefied manure gets mineralized, it is easily available to the crop. Moreover, the humus in the biogas digested manure, improves water-holding capacity of the soil, and acts like a soil-conditioner, improving its fertility and building-up micro-flora in the soil (which might have lost due to excessive use of chemical fertilizers & pesticides. Due to the residual effect of the biogas-digested manure on the soil, its positive impact could also be observed in the next 1-2 crops as well. As the biogas-digested manure provides all the plant food, minerals and micronutrients, it produces healthy crops, due to which the attack of insects and disease is reduced substantially. As the inherent strength of the plants (crops) is developed, it increases the capability and capacity of crops to fight back the diseases and also to withstand under worst stress conditions and water shortage, as compared to the chemical fertilizer based crops. If the farmers are not able to use the biogas plant digested liquid manure immediately, they could use this liquid for making excellent scientific compost along with other locally available biodegradable wastes. The digested liquid manure would also promote making of compost faster, and all the nutrients of the manure will remain preserved when composting rather than letting it dry- this compost could then be used during the crop seasons.

2.03. Some experiments[3] have also shown that crop seeds soaked in the biogas digested liquid manure for 24 hours, have comparatively better germination percentage, and tender seedlings are able to withstand stress conditions, with better chance of survival as compared to those germinated using the chemical fertilizers.

2.04. Thus it is clear that the potential of at least dual major well documented benefits, namely, generation of environmental benign fuel and organic manure from bovine dung, by recycling it through a biogas plant, is lost by either directly burning the same manure as dried dung cakes or using it directly for making organic manure, apart from creating negative environmental impact.

III. IMPLEMENTATION OF HOUSEHOLD BIOGAS PLANTS & EVD ACTIVITIES BY NGOS IN INDIA

3.01. India is one of the pioneer countries in the design and application of household biogas plants as well as large-scale implementation of this technology in rural areas. Systematic development and promotion of household (Hh) biogas technology is over 60 years old. The demonstration and limited extension phase of Hh plants was first initiated in India by KVIC (Khadi and Village Industries Commission), using their floating steel gasholder model in 1960. However, the implementation of Hh plants got impetus in India only after the Ministry of Non-Conventional Energy Sources (MNES), Government of India (GoI), launched a centrally sponsored scheme, known as the National Project on Biogas Development (NPBD), in 1981-82.

3.02. Multi-Model and Multi-Agency approach adopted under the NPBD, has ensured wide coverage throughout the country in which NGOs, especially INSEDA's members, played constructive role. India has achieved massive target of over 3.5 million household BG plants, till the close of the financial year 2003-04. Yet it is a drop in the ocean when considering revised potential of 20 million Hh plants[4], by INSEDA in year 2003 and present target and average implementation rate of 150,000- 200,000 units[5] annually under the NPBD, it could take 75-100 years to realize the total potential.

3.03. By March 31, 2004 there were over 50 NGO members of INSEDA who have together built over 150,000 household biogas plants under the NPBD[6].

3.04. The lessons learnt from the implementation of biogas programme for over 2 decades, had brought out the need for following integrated approach in the implementation of

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3. Field level experiments were conducted by INSEDA (Integrated Sustainable Energy and Ecological Development Association) member NGOs, which showed better germination percentage in the case of almost all the crops, sown after soaking their seed in the biogas digested slurry.

4. As per the official figure of the MNES, Govt. of India, the potential for family size BGPs is 12 million units, which was estimated by MNES for building an average size of 3-4 M^3 capacity plant, based on the bovine population in 1980. This official figure (potential) needs up ward revision (as estimated by INSEDA in this proposal), because on the one hand the bovine (cattle + buffalo) population have gone up in the last over 20 years, and on the other hand the majority of Hh biogas plants being built in India are of 2 M^3 capacity.

5 Unless specifically mentioned, through out this article, the simple rural household biogas plants refers to only one of the 4 popular Indian designs (namely KVIC, Janata, Deenbandhu and Grameen Bandhu models).

6. The development and implementation of low cost, Hh biogas plants by an NGO network (now members of INSEDA) in India and the lessons learned for empowering rural people in general and women in particular is of great significance, which is well documented and presented by the author in several conferences.

biogas plants with other renewable energy and ecological oriented activities, by treating each village as the micro-ecological unit for creating effective and measurable environment impact while ensuring people-centered developmental interventions. In view of this, in the last over 2 years, INSEDA in partnership with one of its grassroots member organization, Women's Action for Development (WAFD, has undertaken to promote and implement demonstration-cum-training, Eco-Village Development (EVD) programme in 12 villages, in one of the districts in Rajasthan (about 200 kM from Delhi). In each of these villages, four rural volunteers (2 male youth and 2 female) are formed in to one team, called as REEVOC (Rural Energy and Ecological Volunteers Corp), selected from within the target eco-villages. Thus in 12 selected villages (which were selected through a systematic process) there are a total of 12 such teams (or 12 REEVOCs), comprising a total of 48 volunteers (24 male youth and 24 women). The role of REEVOCs are to act as animators, awareness builders, motivators, educators, promoter and facilitators in the implementation of village level ecological and RE oriented, appropriate people-centered technology demonstrations as well as promotion of other related activities, with the ultimate aim of converting these villages in to sustainable energy based "Model Eco-Villages" in a foreseeable future, with focus on sustainable human development.

IV. ENVIRONMENTAL IMPACT OF BUILDING HOUSEHOLD BIOGAS PLANTS IN RURAL INDIA

4.01. Based on the practical experience gained by NGOs network in the last about two and half decades (25 years) it is clear that a 2 M^3 capacity[7] household (HH) biogas plant (BGP) is the most appropriate size for implementation in rural India. The reason for this is that this capacity BGP can easily meet the entire cooking needs of a rural family having an average of 6-8 members, and can also meet the lighting needs (one biogas lamp) for about four hours in the night. More over, a 2 M^3 capacity BGP requires an average of 50 kg fresh bovine dung (total solids-TS of 20%) every day for operating such plant, which is available from 3-5 farm bovine animals. It also requires about 50 liters of water to mix the bovine dung to make it in to liquid manure with 10% total solids (TS) for daily feeding in a 2 M^3 capacity HH biogas plant. Experience has shown that this quantity of dung (50 kg) and of water (50 liter) for mixing the dung to form a homogenous liquid manure of 100 liter (50 kg dung plus 50 liter water) for feeding in 2 M^3 capacity BGP would be comparatively available easily through out the year, to operate these plants at their optimum capacities in rural India. It is thus estimated that enough dung and space would be available with 20 million rural households (average size rural families) to build

7 In India, the capacity of simple rural household (HH) biogas plant means that this plant design is rated to generate/ produce that much Cubic Meter of biogas (if feed with the prescribed quantity of fresh bovine manure in kg and mixed with the same quantity of water to form an homogenous slurry for daily feeding in the plant) in 24 hours operation. This is because, in India, all the rural household biogas plants operate on the fresh bovine dung (less than 1% operate on manure from other animals or human excreta) and practically no plants operate on agricultural wastes or crop residues or other waste biomass of crop origin. As only animal manure is used as substrate, therefore, the effective digested volume (or capacity of the fermentation chamber) of these simple rural household biogas plants depend on the three HRTs (Hydraulic Retention Times) for which they are deigned- the HRT is decided by the three agro-climatic zones with in the country. For the hilly and mountain regions of India the HRT is fixed as 55 days; for the plains of northern India (which has 3 months of cold winter season) the HRT is fixed as 40 days, and for the southern and coastal regions of the country where the temperature variation is not much with no cold winters, the HRT is fixed as 30 days. This is the guidelines which are generally followed by the designers for the design of any new models of simple HH biogas plants for application in Indian rural areas.

20-million biogas plants of 2 M^3 capacities with out any problems in India. Therefore, a 2 M^3 capacity Hh plant, operating on bovine dung, has been taken as the most ideal size of BGP for the purpose of estimation of abatement of greenhouse gases (GHGs).

4.02. The 2 M^3 capacity plant refers to a simple design of semi-continuous flow hydraulic digester (SCFHD) household plant which when working under the ambient temperature and a defined HRT (hydraulic retention time) for the Indian conditions, would generate/ produce an average of 2 cubic meter (2 M^3 or 2000 liter) biogas per day (in 24 hours) when fed daily with 50 kg of bovine dung mixed with 50 liter of water for making it in to liquid manure with approximately 10% total solids (TS). When operated under optimum conditions, the 2 M^3 capacity biogas plant[8] would be the most ideal HH biogas unit under the Indian rural conditions, as it can provide energy for daily cooking of all the major meals (using 55-60% efficient biogas stove) for a family of 6-8 persons as well as can provide 4 hours per day of lighting from biogas lamp. This capacity plant requires on an average 50 kg of bovine dung per day[9]. While, the average biogas production per day would go up by 10-15% during the 3 months of summer season and go down by 10-15% in the 2 months of severe winter season, the over all daily average production of biogas (which comprises of 55-60% methane-CH_4 and 35-40% carbon dioxide-CO_2) on the annual basis would remain as 2 M^3 per day from the same quantity (50 kg) of fresh bovine dung. Thus, 2 M^3 capacity[10] biogas plants has been taken to work out the maximum potential of most appropriate and popular size household BGPs that could be built in rural India.

4.03 It is estimated that at least 1,000 million kg (1.0 million tone) of collectable dung would be available for feeding 2 M^3 capacity Hh biogas plants every day in India, as follows:

4.03.1 300 million kg (i.e. 50% of 600 million kg) would come from motivating those rural families who are currently burning dung cake as fuel, and

4.03.2 700 million kg (i.e. 70% of 1,000 million kg) would come from motivating those rural families who are currently converting bovine dung directly in to organic manure in a traditional and inefficient manner.

4.04. Thus, the total potential for building 2 M^3 capacity biogas plants by utilizing this 1,000 million kg collectable bovine dung every day would come to 20 million (1,000 million kg per day @ 50 kg of dung per 2 M^3 plant per day) biogas units.

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8. In India, a 2 M^3 capacity biogas plant would imply that this unit is rated to generate an average of 2 Cubic Meter (2,000 Liter) of biogas in 24 hours operation, when fed with 50 kg bovine dung mixed with 50 liters of water. This is found to be the most practical and understandable way to convince the rural masses who are the main beneficiary of this technology. As against this, the commonly accepted norm in many countries is to refer the capacity of biogas plants in terms of the digester volume; and moreover, most international journals and papers use the digester volume to refer the capacity of a biogas unit. This important aspect has to be kept in view while reading, understanding and comparing this paper with documents on biogas plants from other countries.

9. On an average 3-5 medium size bovine (cattle and buffalo) animals would produce 50 kg of fresh dung every day- the number of animals required to produce this quantity of dung would depend on the size and quantity of feed given to bovine, according to which they would produce dung.

10. Effective digester volume (capacity of fermentation chamber) of a 2 M^3 capacity Indian Hh biogas plant (for operation on fresh bovine dung) for the hilly region of the country would be 5.5 CuM; for the plains of northern India it would be 4 CuM and for the southern and coastal regions it would generally be 3 CuM. However, under normal conditions the digester volume of Indian design of fixed done rural Hh BG units for all the plain regions (northern, southern or coastal regions) are kept as 4 CuM for practical reasons under the field conditions.

V. ABATING OF GHG GAS EMISSION BY BUILDING HH BIOGAS PLANTS IN RURAL INDIA

5.01. There is a large potential of abating/ offsetting greenhouse gases (GHGs) emission to the atmosphere by building household biogas plants in rural India, covering about 600,000 villages in a decentralized manner, using animal dung (manure) from the domestic farm animals. Since the bovine (cattle and buffalo) dung is available in plenty in rural India and almost all these 600,000 villages have some bovine population, therefore the majority of household plants are operated on bovine dung, and the rural people are aware of its importance as well as various usages in their daily lives. In fact the bovine population has been the integral part of the lives of rural people in India for centuries- both female and mail of the species playing key roles in the socio-economic well being of the rural people.

5.02. Inefficient utilization of the large quantity of dung which is not being utilized in an appropriate manner in these villages and is creating other types of problems and GHG emission, contributing to global warming and climate change.

5.03. Out of all the dung available from the domestic farm animals in India, the quantity of dung available from the bovine population and its present utilization in India is fairly well documented. Therefore, the environmental impact of present utilization of bovine dung in India is estimated with a view to analyze and suggest alternate method of recycling it through the large-scale decentralized implementation of simple household biogas plants, which could be built and serviced by rural artisans and easily operated and maintained by rural families after appropriate training to these groups.

5.04. Therefore, by installing 20 million household (Hh) biogas plants of 2 M^3 capacity, the 1,000 million kg (1.00 million tone) of fresh bovine dung per day could be recycled and utilized in an efficient manner. This 1.00 million tone dung is either (i) presently being used as fuel by burning of dried dung cake (refer paragraph no. 4.03.1) or (ii) being dumped in heaps or in open pits in rural India for making organic manure (refer paragraph no. 4.03.2) and is responsible for directly releasing greenhouse gases (GHGs) in the form of carbon dioxide (CO_2) and methane (CH_4) in to the atmosphere, which would be offset/ abated.

5.05. Calculations for abatement of the amount/ quantity of two key greenhouse gases (GHGs) emission (carbon dioxide-CO_2 & methane-CH_4) from bovine dung available for building 2 M^3 Hh BG plants in rural India are given in the subsequent paragraphs.

5.06. Abating/ offsetting of carbon dioxide (CO_2) emission

5.06.1 Fresh bovine dung has 80% moisture and 20% dry matter (total solids-TS); therefore, 50 kg dung (fed daily in a 2 M^3 capacity biogas plant) would be equivalent to 10 kg (50 Kg x 0.2) of dried dung.

5.06.2 1 kg dry dung (as dung cake) when burnt directly would produce an average of 2.5 kg of carbon dioxide (CO_2) emission[11]- i.e. 2.5 kg CO_2 emission per kg dry dung.

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11. No data and information could be found for the emission of carbon dioxide (CO_2) from direct burning of bovine dry dung, in from of dung cake. Therefore, based on the CO_2 emission from coal and charcoal (which is 3.10 kg of CO_2/ kg), the author has taken a safer figure of the CO_2 emission from burning of bovine dung cake as 2.50

5.06.3 Thus, 10 kg dry dung (equivalent of 50 kg fresh bovine dung), when burnt directly in open stove, would produce 25 kg of CO_2 (2.5 kg CO_2/kg of dry dung X 10 kg).

5.06.4 However, the biogas produced in a biogas plant, is mainly the mixture of methane- CH_4 (average of 60%) and carbon dioxide- CO_2 (average of 40%). Therefore, by recycling of 10 kg of dry dung (in the form of 50 kg of fresh dung) through a 2 M^3 capacity plant would prevent release of about 40% of CO_2 per kg of dry dung, which is converted in to biogas through microbial activities under anaerobic (in the absence of oxygen) environment inside the biogas plant**12**. This would mean a 2-M^3 HhBGP would efficiently recycle 10 kg of CO_2 per 10 kg dry bovine dung every day (40% of 25 kg of CO_2).

5.06.5 In other wards a Hh Indian model BGP of any capacity would abates/ offsets 1 kg CO_2/ kg dry bovine dung every day, by efficiently recycling it as compared to the direct burning of the same quantity (1 kg dry dung) in the form of dung cake as cooking fuel.

5.06.6 From the above, it is clear that by recycling 50 kg fresh dung with 20% TS (equivalent to 10 kg of dry dung) through a 2 M^3 capacity standard Indian household biogas unit one can prevent direct emission of 10 kg of CO_2 (25 kg x 0.4) per day in to the atmosphere, there by reducing GHG emission by 40% of CO_2, as compared to when the same quantity of dung is burnt directly as dung cake for cooking purpose.

5.06.7 Out of the 600 million kg fresh dung that is being currently burnt as dung cake in a traditional and inefficient manner, it is estimated to utilize 50% or 300 million kg per day (equivalent of 60 million kg of dry dung per day) for biogas production- refer paragraph nos. 4.03.1. This quantity would be 30% of the total of 1,000 million kg (1.00 million tones) of fresh bovine dung required per day for operating 20 million HH biogas plants of 2 M^3 capacity- refer paragraph nos. 4.04 & 5.04.

5.06.8 Therefore, by installing 6 million (300 million kg/ 50 kg dung/plant), 2 M^3 capacity Hh biogas plants in India, the offsetting (abatement) of total CO_2 emission (as compared to burning of dung cakes) from bovine manure would be 60 million kg (2.50 kg CO_2 x 60 million kg dry dung x 40% of CO_2 in the mixture of biogas) every day- i.e. 60 million kg CO_2 per day- refer paragraph nos. 5.06.2 & 5.06.5.

5.06.9 Thus, to sum up, by recycling 300 million kg per day fresh bovine manure (currently being burnt as dung cake in rural households) by installing 6 million, 2 M^3 capacity standard household biogas plants in India, the abatement of carbon dioxide (CO_2) as greenhouse gas, would be as under:

- Annual abatement of approx 20,000 million kg (60 million kg x 330 days of average annual operation of BGPs) - or say 20 million tones of carbon dioxide (CO_2) abatement annually.

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kg CO_2/ kg dry weight- this is only to highlight the relative benefit (in terms of total quantity of CO_2 abatement) by using biogas plant for generating/ producing energy (fuel) for cooking in the rural houses of India. In any case, this assumed carbon dioxide (CO_2) figure is not going to affect the final emission figure from bovine manure, because the methane (CH_4) being more potent and aggressive greenhouse gas (GHG), only the CO_2 equivalent of methane (CH_4) emission (refer paragraph 5.07 for the calculation of methane emission from bovine dung) has been taken in to account in the final calculations for determining the environmental impact of building household BGPs in rural India.

12. Bovine dung converted in to biogas is much more efficient to burn as cooking fuel using a specially designed 60% efficient biogas stove, as compared to burning as fuel for cooking in the form of dung cakes with 11-12% efficiency in existing traditional cooking stoves used in Indian villages. Even if a very efficient biomass stove of 20-25% (not common in rural India) is used for burning dung cake as fuel still it would still be appropriate to recycle it through a biogas plant to prevent about 40% of CO_2 going directly in to atmosphere.

- The total abatement in 10 years would be 200,000 million kg (20,000 million kg x 10 year average useful working life of these biogas plants) - or say 200 million tone of carbon dioxide (CO_2) abatement in 10 years.

5.07. **Abating/offsetting of methane (CH_4) emission**

5.07.1 Bovine dung when allowed to decompose in a traditional manner (while making organic manure by either dumping in heaps or in open pits in the backyard of rural houses) in Indian villages would release (emit) methane (CH_4) to the atmosphere.

5.07.2 As per the estimate from the Danish Farm[13], liquid manure (which is about 7% total solids-TS[14]) from cattle dung, when left in the open field, releases 3.6 kg of methane (CH_4) per cubic meter (M^3) of liquid manure.

5.07.3 Whereas, the bovine (cattle and buffalo) manure collected in India has approx. 20% TS, therefore this would be equivalent to 2.86 M^3 (20/ 7) - say almost 3 times that of the liquid manure having 7% TS.

5.07.4 From the above calculations we get the 1 M^3 fresh liquid cattle manure (7% TS) equivalent to 0.35 M^3 (7/ 20) of semi-solid fresh bovine manure (20% TS), as collected each day in rural India.

5.07.5 Methane (CH_4) is much more potent and aggressive greenhouse gas (GHG) and remains in the atmosphere for a far longer period, as compared to CO_2- the CH_4 is 19 times more potent than CO_2. Due to this the greenhouse gas (GHG) characteristic of 1 kg of methane (CH_4) is equivalent to 19 kg of carbon dioxide (CO_2).

5.07.6 From the above (paragraph nos. 5.07.2 & 5.07.4), the methane released to atmosphere from the semi-solid (20% TS) fresh bovine manure (dung) in India, would be 10.2857 kg CH_4/ M^3 {(3.60 kg methane (CH_4)/ M^3 liquid manure)/ (0.35 M^3/ M^3 liquid manure)} - say 10.30 kg CH_4/ M^3 from semi-solid bovine manure in India.

5.07.7 Therefore, the carbon dioxide (CO_2) equivalent of methane (as GHG) from 1 cubic meter (M^3) of manure (20% TS) would be 195.70 kg (10.30 kg methane x 19) - say 200 kg CO_2/ M^3 of bovine (cattle and buffalo) manure.

5.0.7.8 Calculation of methane (CH_4) emission and its equivalent (as GHG) value in terms of carbon dioxide (CO_2) under paragraph 5.07.7 is given in terms of 1 cubic meter (M^3) of bovine dung (20% TS). Therefore, this value of CO_2 has to be calculated in terms of 1 kg of bovine dung for practical purposes and subsequent use.

5.07.9 For calculating CH_4 emission (in terms of CO_2 equivalent (as GHG) from 1 kg of bovine dung (i.e. CO_2 emission in kg per kg of bovine manure) it is assumed (for all practical purposes) that the weight of 1 M^3 (1,000 liter) volume of fresh bovine manure (20% TS) would be equivalent to 1,000 kg of fresh bovine dung.

5.07.10 Thus, 10.30 kg of methane/ 1,000 kg = 0.0103 kg CH_4/ kg bovine dung (refer paragraph 5.07.6 & 5.07.9). This in terms of CO_2 equivalent would be 0.1957 (19 x 0.0103) kg CO_2/ kg of dung. Or say 0.20 kg of CO_2/ kg fresh bovine dung.

5.07.11 Therefore, to sum up the above calculations, it can be said that 1 kg of fresh (semi-solid) bovine manure (dung) would emit 0.0103 kg methane (or 0.0103 kg CH_4/ kg

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13. Calculation by the Danish Energy Agency is based upon liquid manure, where the fresh manure (dung), urine & water from the stable, are processed together; thus its total solids (TS) content is about 7 % for cattle manure.

14. Name of the Report: Biogas Plant Cooperation- From Idea to Reality. Official figure from the Danish Energy Agency Report: 1995.

dung) to the atmosphere- which in terms of CO_2 equivalent of GHG would be 0.20 kg of CO_2 / kg fresh bovine dung - refer paragraph 5.07.10.

5.08. **Abatement/ offsetting of greenhouse gas (in terms of methane) by building 20 million 2 M^3 capacity household biogas plant in rural India**

5.08.1 The calculations under paragraph 5.06 shows the relative environmental benefit due to the abatement of carbon dioxide (CO_2) from bovine manure when the same quantity currently being burnt as 'Dung Cake", were to recycled through biogas plants. Whereas, the calculations under paragraph 5.07 shows the relative environmental benefit due to the abatement of methane (CH_4) emission from bovine manure, when the same quantity currently being used for decomposition as manure in a traditional and unscientific manner by farmers (either in their backyard or by leaving unexposed in their agricultural fields), were to recycle through biogas plants.

5.08.2 However, as the burning of bovine manure in the form of dried dung cake produces carbon dioxide (CO_2), as calculated under paragraph 5.06, would normally be considered as carbon neutral, as it is biomass, which is recycled through bovine stomach in a short cycle and therefore renewable[15].

5.08.3 However, as can be seen from the calculation of methane emission (refer paragraph 5.07) from bovine manure that by recycling it through biogas plants (as compared to the decomposition of manure in a traditional way in Indian villages) would provide substantial gain in terms of abatement of methane (CH_4), which is comparatively a more potent greenhouse gas- GHG than CO_2. Therefore, it has been analyzed further and detail calculations have been given in the subsequent paragraphs.

5.08.4 Out of the 1,000 million kg (refer paragraph 1.03) fresh bovine dung that is being currently converted directly in to organic manure in a traditional and inefficient manner, it is proposed to utilize 700 million kg per day (equivalent to 140 million kg of_dry dung per day) for biogas production- refer paragraph no. 4.03.2. This would be 70% of the total of 1,000 million kg (1.00 million tones) of fresh bovine dung per day required for operating 20 million household biogas plants of 2 M^3 capacity- refer paragraph no. 5.04.

5.08.5 By installing 14 million, 2 M^3 capacity HH biogas plants (700 million kg dung per day @ 50 kg dung per HH biogas plant/ day) in India, the methane (CH_4) emission from 700 million kg fresh bovine dung per day[16], which is a very potent greenhouse gas (GHG), would be abated- refer paragraph nos. 4.03.2, 4.04 & 5.08.4.

5.08.6 Quantity of methane (CH_4) abated by efficient recycling and utilization of this 700 million kg (0.700 million tone) fresh dung through 2 M^3 capacity Hh plants, is calculated below:

a). A 2 M^3 capacity Indian HH plant requires daily feeding of 50 kg of fresh bovine dung to generate an average of 2 M^3 biogas every day in 24 hours[17].

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15. In spite of knowing that there is a relative gain (due to efficient burning and conservation of nutrient) by recycling the same quantity of dung through biogas plants, normally, it is not considered as gain in terms of greenhouse gas (GHG) emission. Due to this, it has not been analyzed further or used for detail calculations in this paper by the author.

16. The 700 million kg (0.70 million tone) of fresh bovine dung (or 140 million kg of dry dung), which is currently being decomposed in an efficient manner per day, and in this process releasing methane (CH_4) emission, which is a very potent greenhouse gas (GHG) in the atmosphere would be abated.

17. This average biogas generation is on an annual basis when the BGP is operating at ambient temperature, taking in to account the seasonal variation of gas production, more in summer season & less in winter season.

b). 50 kg of fresh bovine dung would release 0.515 kg methane (0.0103 kg CH_4/ kg fresh dung x 50 kg fresh dung)- or say 0.50 kg methane (CH_4), which is approx. equivalent to 10 kg (0.2 CO_2/ kg x 50 kg) of carbon dioxide (CO_2) to the atmosphere- refer paragraph 5.07.11.

c). In other words, a 2 M^3 capacity standard Indian household plant fed every day with 50 kg of fresh bovine dung would abate methane (CH_4) equivalent of 10 kg/ day of carbon dioxide (CO_2), which was earlier release to the atmosphere.

d). This comes to 0.01 kg methane (CH_4) per kg (0.50 kg methane/ 50 kg fresh dung) of fresh bovine manure- which is equivalent to approx. 0.20 kg carbon dioxide (CO_2)/ kg (0.01 kg CH_4 x 19 = 0.19 kg) of fresh dung.

e). Therefore, 700 million kg fresh dung when allowed to decompose in an unscientific manner in rural areas, would release 7 million kg (700 million kg x 0.01 kg CH_4/ kg fresh dung) of methane (CH_4), as GHG to the atmosphere.

f). 7 million kg of methane (CH_4) as greenhouse gas would be equivalent to approx 140 million kg (700 million kg dung x 0.20 kg CO_2/ kg fresh dung) of carbon dioxide (CO_2)- refer paragraph 5.08.6 (d).

5.08.7 Similarly, the quantity/ amount of methane (CH_4) offset/ abated by efficient recycling and utilization of this 300 million kg (0.300 million tone) fresh bovine dung through 2 M^3 capacity household biogas plants, which is currently being burnt as dung cake, is calculated below:

a). Out of the 600 million kg fresh dung that is currently being burnt as dung cake in a traditional and inefficient manner, it is estimated to utilize 300 million kg/ day (or 60 million kg of dry dung/ day)**18** for biogas production- refer paragraph nos. 4.03.1.

b). Thus, by installing 6 million (300 million kg/ 50 kg dung/ plant), 2 M^3 capacity Hh biogas plants in India, the abatement of total CO_2 emission (as compared to burning of dung cakes) from bovine manure would be 60 million kg (2.50 kg CO_2 x 60 million kg dry dung x 40% of CO_2 in the mixture of biogas) every day- i.e. 60 million kg CO_2 per day- refer paragraph nos. 5.06.2 & 5.06.3.

5.08.8 Therefore, 20 million household plants of 2 M^3 capacity in India, would abate 200 million kg CO_2 per day (or 0.20 million tones of CO_2 equivalent/ day) by utilization of 1,000 million kg dung per day. Out of this 70% would be mobilized from dung which is currently being utilized for making traditional manure and balance of 30% would be mobilized from dung which is currently being burnt as dried dung cake in an inefficient manner, as per break-up given below:

a). 140 million kg of carbon dioxide (CO_2) per day or 0.14 million tones of CO_2 equivalent/day, from recycling of 700 million kg (from 14 million HH plants) of fresh bovine dung being currently used as organic manure by decomposing in a traditional and unscientific manner in Indian villages; and

b). 60 million kg of carbon dioxide (CO_2) per day or 0.06 million tones of CO_2 /day, from recycling of 300 million kg (from 6 million HH plants) of fresh bovine dung being currently burnt as dried dung cake directly in traditional cook stoves in an inefficient manner in Indian villages.

18. This would be 30% of the total of 1,000 million kg (1.00 million tone) of fresh bovine dung per day required for 20 million household biogas plants of 2 M^3 capacity- refer paragraph nos. 4.04 & 5.04.

5.08.9 From the calculation in paragraph 5.08.8, a practical value of approximately 200 million kg (or 0.20 million tones)**19** equivalent of CO_2 per day can be abated by building 20 million HH biogas plants of 2 M^3 capacity in rural India.

5.08.10 Thus, as a thumb rule one can say that one simple Indian household biogas plants of 2 M^3 capacity, would abate 0.01 tone equivalent of CO_2 per day

5.08.11 Assuming that the average working days for these BGPs is 330 days per year, then the quantity of emission abated by these 20 million BGPs would be equivalent to 66 million tone (0.20 million tone x 330 days/ year) of carbon dioxide (CO_2) equivalent of emission per year - refer paragraph no. 5.08.6, 5.08.7, 5.08.9 and 5.08.10.

5.08.10 Average useful working life (UWL) of Indian household biogas plants is over 20 years**20**. But for mobilizing/ securing funds from the International 'CARBON MARKET', using CDM (Clean development Mechanism), a much safer and practical useful working life (UWL) of these plants has to be taken as only 10 years**21**.

5.08.11 Thus, to sum up, by recycling 1,000 million kg per day of fresh bovine dung (which is currently being utilized either for making organic manure in a traditional manner or being burnt as dung cake in rural areas) by installing 20 million HH biogas plants of 2 M^3 capacity in India, the abatement of methane (CH_4) emission, as greenhouse gas (GHS) in terms of carbon dioxide (CO_2) equivalent, would be as under:

a). Annual abatement of approximately 66,000 million kg (200 million kg x 330 days of average annual operation of BGPs) - or 66 million tones of carbon dioxide (CO_2) abatement annually.

b). The total abatement in 10 years would be 660 million tones (66 million tones x 10 year average useful working life of these biogas plants)- or say abatement of greenhouse gas to the atmosphere, amounting to 660 million tones of carbon dioxide (CO_2) during the 'Useful Working Life- ULF' of 10 years of these Hh biogas units.

5.08.12 In addition, these HH biogas plants (BGPs) would also become instrumental in promoting ecological agriculture, using enriched organic manure from BGPs, contributing to overall positive environmental impact, promoting empowerment of rural people as well as facilitating people centered, sustainable development.

VI. EXPECTED BENEFIT AND IMPACT OF THE PROGRAMME IN RURAL INDIA

6.01. Any technological oriented programme implemented in the rural areas of the developing countries should be analyzed for its socio-economic implications to ensure that it would fulfill the development goals, by promoting process oriented, sustainable human development (SHD) of the target communities, particularly the poor, marginalized, landless rural labourers and other weaker sections of the society, more specifically focused on the women's empowerment. This would more than justify the introduction &

19. Potency of methane as a GHG (in terms of carbon dioxide) ranges between 19 and 20 times of CO_2, but for the calculation in this paper, the author has taken a safer value of CH_4 equivalent to only 19 times of CO_2.

20. This is based on the building and operation of fixed dome household biogas plants by NGO network of INSEDA members for about two and a half decades.

21. This is due to the involvement of a large number of household BGPs, spread though out the country, and not all of them could be expected to perform at the optimum level for the entire 20 years. In view of these practical field level realities, the useful working life (UWL) of the BGPs under this programme has been taken as only 10 years.

implementation of any technological programme, developed outside the rural environment of the developing countries.

6.02. In view of the above, based on the experience of implementing biogas development programme[22], some of the important benefits and positive impacts of the BGP programme on the lives of rural people in India- such as social, economical, health, employment generation- are also enumerates in the subsequent paragraphs:

6.03 **<u>Socio-economic impact and local employment generation in rural India</u>**

6.03.1 <u>Social impact</u>

a). Following positive social impact is created by the implementation of household BGPs in India:

- Removing drudgery of rural women in the collection of firewood,
- Provision of clean and convenient cooking fuel to women at their door-step,
- Saving in time of cooking,
- Saving in time for cleaning cooking vessels as no soot is formed,
- Fetching lesser quantity of water for cleaning of utensils & washing kitchen,
- Smoke-free kitchen and soot-free walls of the kitchen and the areas surrounding the cooking area,
- More time available to rural women to take rest during the day as the time spent in collecting the firewood and cooking would be substantially reduced.
- Adolescent girls who normally required to stay at home and help their mothers to assist in the domestic chores including cooking, could have time to be sent to schools, and
- Availability of more time with the rural women is utilized by them for carrying out other more productive (socially and economically) activities,

b). To sum up- implementation of HH biogas plants creates positive social impact on the life of rural women, contributing to their empowerment.

6.05.2 <u>Economic impact</u>

a). Following economic impact is created by the implementation of household biogas programme:

- Construction of the fixed models, about 30% of their cost goes towards providing wages to the local labour, in the form of skilled (local artisans), semi-skilled and unskilled labourers, who generally work as a daily wage earners. It also generates employment and self-employment to trained local people in providing post-plant implementation services to the plant owners.
- Digested liquid manure coming out of the biogas plant after recycling is used either directly or after drying it or by converting it in to compost along with other biodegradable waste biomass and used as manure in the farmers' field. This enable them to save money, which is other wise, spent for the purchase of costly inorganic fertilizers.
- Improvement in crop yield with reduced cash outflow increase their net economic benefits, also improving micro-flora of the soil and building the soil structure and texture, conserves natural resources, which would gradually lead to their economic sustainability, using available local resources.

22. This is based on the experience of the INSEDA member NGOs in the past about 25 years.

b). To sum up, the implementation of household biogas plants creates positive economic impact on the life of rural people.

6.05.3 Generation of local rural employment by building/ constructing household BGP

a). Building of one popular Indian model fixed dome BGP (namely Deenbandhu model), 40 days HRT, 2 M^3 capacity generates employment for skilled, semi-skilled and unskilled persons as follows:

- Skilled rural people (Artisans/Master Masons) 22 man days
- Semi-skilled rural people 11 man days
- Un-skilled rural people 10 man days

b). From Therefore, construction of 10,000 fixed dome BGPs (Deenbandhu model), 40 days HRT, 2 M^3 capacity/ year, would generate employment for skilled, semi-skilled & unskilled persons annually, as follows:

- Skilled rural people (Artisans/Master Masons) 220.000 man days
- Semi-skilled rural people 110.000 man days
- Un-skilled rural people 100.000 man days

c). Therefore, by building/ constructing of 20 million fixed dome unit (as per current potential) of 2 M^3 capacity (40 days HRT) household BGP (Deenbandhu model), would generate employment for skilled, semi-skilled & unskilled persons as follows:

- Skilled rural people (Artisans/Master Masons) 440 million man days
- Semi-skilled rural people 220 million man days
- Un-skilled rural people 200 million man days

VII. IMPACT OF THE PROGRAMME ON THE HEALTH IN RURAL INDIA

7.01. A large-scale, systematic implementation of household biogas programme in rural areas would be instrumental in creating positive impact on public health and more specifically on the health of rural women, as given below:

7.01.1 Impact on public health-

- Presently, bovine dung, which is not made in to dung cakes for using as cooking fuel, is normally left outside the houses of the families for getting decomposed in an un-scientific manner. This becomes the breading ground for flies and mosquitoes, causing diseases. Biogas plants would effectively recycle this dung which would create positive impact on the health of the rural people, and
- The dung, which is normally left unattended in heaps, creates foul smells and creates nuisance and during the rainy seasons they are spread in the village streets and could cause pollution and public health problems. This problem would be effectively tackled by recycling the dung through biogas plants.

7.01.2 Impact on the health of the women and her family- following negative effect on rural women and her family, would be automatically addressed and very positive impact created in the lives of rural women by large-scale implementation of household biogas plants in villages:

- The health of the women of the rural household are affected the most due to the traditional ways of cooking. It is estimated that while cooking on the traditional biomass cook stoves, a rural woman daily inhales as much smoke as smoking of 10 packets of cigarettes every day. This causes both, eye, lungs and respiratory diseases as well as cancer, which could be prevented by using biogas for cooking,

- Adolescent girls and the infants who normally remain with their mothers at the time of cooking also get affected with the smoke & soot formed during cooking,
- As the kitchens in Indian rural houses are built very close to the living places therefore, the smoke also spreads to other rooms of the houses, especially those belonging to the rural poor, therefore to certain extent the health of entire family also gets affected, and
- With this physically exhausting routine it is understandable, why rural women are not interested in activities such as literacy & education, then viewing them as further burden on their overworked days. Neither do they have motivation for taking any initiative.

7.02. In view of the above, the installation and use of biogas plants for cooking, under the proposed programme would create positive impact on the public health as well as the heath of the rural woman and her entire family, as given above.

VIII. IMPACT OF PROGRAMME ON CHECKING MIGERATION FROM RURAL TO URBAN AREAS

8.01. A large-scale, systematic implementation of household biogas programme in rural areas would be instrumental in checking migration from the villages to the urban centers in search of employment, as given below:

8.01.1 Implementation of household biogas programme is expected to generate employment & self-employment in the form of post-plant implementation services to the plant owners by the appropriately trained local artisans, un-employed rural youth and rural entrepreneurs, through regular follow-up service, maintenance and repairs of plants, after a large number of plants are built in a particular area and region.

8.01.2 With awareness, motivation, training and demonstration undertaken on the efficient use of organic manure and scientific composting using biogas digested slurry, the change over to ecological farming will take place, which would save their cash going out of the villages for the purchase of seeds, fertilizers, pesticides and other external inputs and will also promote more seasonal employment from the agricultural activities.

8.01.3 The eco-farming is being promoted by some of the NGO members of INSEDA, which could be geared-up in a bigger scale with a large number of biogas plants implemented in cluster of villages. Slowly but gradually the urban consumers of food products are getting aware about the benefits of the organic food, which would also create good market for such eco-product, thus promoting economic self-sufficiency with in villages.

8.01.4 Due to more economic activities generated with in the villages, the number of local people, especially the daily wage earners would stay back in their villages, thus checking the migration to urban centers in search of jobs.

IX. IMPACT OF PROGRAMME ON THE MICRO-ENVIRONMENT IN RURAL AREAS OF INDIA

9.01. Saturating each village by installing biogas plants as per the potential in the selected villages and in the surrounding villages, the biomass, either in the form of trees, shrubs and the harvested crop residues, would be saved from burning as fuel for cooking, would prevent release of greenhouse gases (GHGs).

9.02. Rural people could be motivated and trained to convert the major part of the biomass available form the harvested agricultural crops as well as dung from bovine and other domestic farm animals could be converted in to enriched compost (scientifically produced organic manure), which would be returned to the farmers field for crop production. This would create positive environmental impact at the micro level.

9.03. From the calculations under paragraphs 5.06 & 5.07 we get the figures for the abatement of carbon dioxide (CO_2) and methane (CH_4) emission from bovine dung, by recycling it through biogas plant. However, the burning of manure in the form of dried dung cake could be considered as carbon neutral, as it is biomass, which is recycled through bovine stomach in a short cycle and treated as renewable. Therefore, in spite of knowing that there is a relative gain (due to efficient burning and conservation of nutrient) by recycling the same quantity of dung through biogas plant, it has not been considered as gain in terms of greenhouse emission.

9.04. However, as can be seen from the calculation of methane emission (paragraph no. 5.07) from bovine manure (dung), recycling the same quantity of dung through biogas plant provides substantial gain in terms of abating greenhouse gas (GHG), as compared to the decomposition of manure in a traditional way in Indian villages. Thus, this very positive environmental impact alone justifies building of plant for the efficient recycling of bovine manure for two important outputs of socio-economic consequences for the empowerment of rural community in general and rural women in particular.

X. BUILDING HOUSEHOLD BIOGAS PLANTS UNDER THE SPONSORSHIP OF CARBON MARKET

10.01. Several models of household biogas plants are being built in India, but the most popular amongst them, at present are the fixed dome models, which are comparatively cheaper as compared to the floating gasholder models. Therefore, majority of plants being built in rural India are the fixed dome models and the INSEDA members are only building fixed dome models for the last about two and half decades. However, any programme for large-scale implementation of household biogas plant in villages in India, should follow multi-model approach for extension, to ensure flexibility, as in some cases and regions it would be desirable and appropriate to construct even the floating gasholder models.

10.02. Criteria for including the different biogas models would be that the technology is well tested and mature to ensure that they are technically foolproof and generate employment and self-employment in programme areas/regions, during construction as well as, by providing service, maintenance & repairs, after these plants are built.

10.03. The table-1 gives the quantity of abatement of methane (CH_4) emission as greenhouse gas (per day, annually and the useful working life of the plant) in terms of equivalent carbon dioxide (CO_2) for 5 different sizes (1, 2, 3, 4 & 6 M^3 capacities BGPs) household biogas plants in India, as well as the present cost in US dollars (US$) for the abatement of GHG in the 'Carbon Market'.

10.04. The table-2 gives the total abatement of methane (CH_4) emission as greenhouse gas (GHG) in terms of equivalent carbon dioxide (CO_2) by installing different number (1,000 to 200,000 household plants of 2 M^3 capacity) in rural India, as well as their *total cash value in US$* in the 'Carbon Market'.

XI. RECOMMENDATIONS FOR BUILDING HOUSEHOLD BIOGAS PLANTS FOR CREATING POSITIVE SOCI0-ECONOMIC, HEALTH AND ENVIRONMENTAL IMPACT AND FOR EPOWERING OF UN-SERVED RURAL PEOPLE OF INDIA THROUGH NORTH-SOUTH NGO PARNERSHIP BY MOBILIZING FUNDS UNDER THE INTERNATIONAL CARBON MARKET

11.01. Calculations in paragraphs 5.06, 5.07 & 5.08, convincingly show the positive environmental impact by installing all the 20 million household biogas plants of 2-M^3 capacity (as per the present potential) in rural India. This alone justifies support of international community for building of biogas plants in India for the efficient recycling of bovine manure for providing two other important benefits (clean and convenient cooking fuel and the enriched organic manure) of socio-economic consequences for the rural community in general and the empowerment of rural women in particular. Therefore needs to be strongly supported by global community.

11.02 Such a North-South NGO partnership programme for the systematic implementation of the Hh biogas plants would be an important vehicle for the improvement of the socio-economic status and quality of life of the rural people from the south, as against only as a means for balancing the 'GHG' emission for the countries from the North.

11.03 Ideal way to implement the BG programme would be to integrate it with other RE technologies for meeting the entire energy needs, e.g. cooking, lighting and power generation needs of a rural community, as well as dove-tail it with the existing ecological development programme of NGOs, by treating each village as the smallest unit for sustainable development for empowering the rural community. Such a demonstration-cum-training project, namely "Sustainable Energy based Eco-Village Development (EVD)", is being already being implemented by INSEDA in partnership with one of its grassroots member NGO in 12 villages in Bharatpur district of Rajasthan, during the last 2 years, with the ultimate goal of gradually converting their villages in to "Model Eco-Villages" in a foreseeable future, with focus on sustainable human development. Later on, such EVD villages would be used as demonstration-cum-training units for awareness, motivation and capacity building of NGOs, CBOs and other developmental agencies for promoting such model with them, in their area of operation.

11.04 Therefore, supporting the implementation of Hh biogas plants in rural India could be an excellent partnership programme, beneficial to both, developed as well as the developing countries. For the developed and industrialized countries it would provide a good option for meeting the environmental goals and also getting the carbon credit in their respective countries. At the same time, it could also become a powerful tool/ instrument for bringing about positive change and impact in the lives of the local people from the developing countries as well as empowering rural communities, especially the women. This it would be a truly 'North-South partnership programme'. By supporting the implementation of household biogas plants in rural India though the "North-South NGO Partnership", the groups in the industrialised countries would also fulfil the aims, objectives and vision of KYOTO PROTOCOL for sponsoring appropriate project for the reduction of the greenhouse gas emission in the developing countries, using the "Clean Development Mechanism- CDM".

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Table- 1

ABATEMENT OF METHANE EMISSION- CH_4 (IN TERMS OF CARBON DIOXIDE- CO_2) FROM DIFFERENT CAPACITIES INDIAN HOUSEHOLD BIOGAS PLANTS

(Average Useful working Life of the standard Indian household biogas plant is taken as 10-years)

Sl. No.	Rated capacity (in terms of daily biogas production in 24 hours) of standard Indian household BGPs	Daily requirement of fresh dung (manure)	Daily feeding of manure slurry in BGP	Av. daily production of biogas (taking annual average)		Daily qty. of abatement of methane (CH_4)	Daily qty. of abatement of CO_2 equivalent of methane (CH_4)	Annual quantity of abatement of carbon dioxide (CO_2) equivalent of methane (CH_4) emission	Total abatement of CO_2 equivalent of CH_4 emission during the 10-year useful working life of Indian Hh BGP		Cash value (US dollars) of abatement of CH_4 emission in terms of CO_2 equivalent during the 10 year useful working life of Indian Hh BGP
	M^3	Kg	Liter	M^3	Liters	Kg of methane (CH_4)- @ 0.0108 kg/kg	Kg of carbon dioxide (CO_2) @ O.2 kg/kg	Kg	Kg	MT (Metric Tone)	@ US$ 10.00/Tone of CO_2 equivalent of CH_4 abated
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)
						(c) x 0.0108	(c) X 0.2	(h) X 330 days/year	(i) X 10 years	(j)/1,000	(k)x 10 USD
1.	1 M^3	25	50	1	1,000	0.27	5	1650	16500	16.5	165
2.	2 M^3	50	100	2	2,000	0.54	10	3300	33000	33	330
3.	3 M^3	75	150	3	3,000	0.81	15	4950	49500	49.5	495
4.	4 M^3	100	200	4	4,000	1.08	20	6600	66000	66	660
5.	6 M^3	150	300	6	6,000	1.62	30	9900	99000	99	990

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Table- 2

Cost of abatement of carbon dioxide (CO_2) equivalent of methane (CH_4) emission from bovine manure (dung) by building different numbers of 2 M^3 capacity household biogas plant in India

(Average useful working life of the standard Indian household biogas plant is taken as 10 years)

SL. No.	2 M^3 (cubic meter) capacity, standard model of Indian household biogas plant (IHh BGP)										
	Proposed number of IHh BGP constructed annually in India	Daily requirement of fresh dung (manure)	Daily feeding of manure slurry in BGP	Average daily production of biogas (taking annual average)		Daily abatement of methane (CH_4) emission	Daily abatement of the CO_2 equivalent of CH_4 emission	Annual abatement of CO_2 equivalent of Methane (CH_4) emission	Total abatement of CO_2 equivalent of CH_4 emission during the 10-year useful working life (UWL) of Indian Hh BGPs		Value (US Dollars) of abatement of CO_2 equivalent of CH_4 emission during the 10-year UW life of Indian Hh BGPs
	No.	Kg	Liter	M^3	Liters	(CH_4) @ 0.0108 Kg/Kg	Kg of CO_2 @ O.2 Kg/Kg	Kg	Kg	MT (Metric Tone)	Amount (cash value) in US$ (@ US$ 10.00/Tone of CO_2)
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)
		(b) X 50	(b) X 100	(b) X 2	(b) X 2,000	(c) x 0.0108	(c) X 0.2	(h) X 330 days/year	(i) X 10 years	(j)/1,000	(k)x 10 USD
1.	1,000	50,000	100,000	2,000	2,000,000	540	10,000	3,300,000	33,000,000	33,000	330,000
2.	2,000	100,000	200,000	4,000	4,000,000	1,080	20,000	6,600,000	66,000,000	66,000	660,000
3.	3,000	150,000	300,000	6,000	6,000,000	1,620	30,000	9,900,000	99,000,000	99,000	660,000
4.	4,000	200,000	400,000	8,000	8,000,000	2,160	40,000	13,200,000	132,000,000	132,000	1,320,000
5.	5,000	250,000	500,000	10,000	10,000,000	2,700	50,000	16,500,000	165,000,000	165,000	1,650,000
6.	7,500	375,000	750,000	15,000	15,000,000	4,050	75,000	24,750,000	247,500,000	247,500	2,475,000
7.	10,000	500,000	1,000,000	20,000	20,000,000	5,400	100,000	33,000,000	330,000,000	330,000	3,300,000
8.	15,000	750,000	1,500,000	30,000	30,000,000	8,100	150,000	49,500,000	495,000,000	495,000	4,950,000
9.	20,000	1,000,000	2,000,000	40,000	40,000,000	10,800	200,000	66,000,000	660,000,000	660,000	6,600,000
10.	25,000	1,250,000	2,500,000	50,000	50,000,000	13,500	250,000	82,500,000	825,000,000	825,000	8,250,000
11.	30,000	1,500,000	3,000,000	60,000	60,000,000	16,200	300,000	99,000,000	990,000,000	990,000	9,900,000
12.	40,000	2,000,000	4,000,000	80,000	80,000,000	21,600	400,000	132,000,000	1,320,000,000	1,320,000	13,200,000
13.	50,000	2,500,000	5,000,000	100,000	100,000,000	27,000	500,000	165,000,000	1,650,000,000	1,650,000	16,500,000
14.	75,000	3,750,000	7,500,000	150,000	150,000,000	40,500	750,000	247,500,000	2,475,000,000	2,475,000	24,750,000
15.	100,000	5,000,000	10,000,000	200,000	200,000,000	54,000	1,000,000	330,000,000	3,300,000,000	3,300,000	33,000,000
16.	125,000	6,250,000	12,500,000	250,000	250,000,000	67,500	1,250,000	412,500,000	4,125,000,000	4,125,000	41,250,000
17.	150,000	7,500,000	15,000,000	300,000	300,000,000	81,000	1,500,000	495,000,000	4,950,000,000	4,950,000	49,500,000
18.	200,000	10,000,000	20,000,000	400,000	400,000,000	108,000	2,000,000	660,000,000	6,600,000,000	6,600,000	66,000,000

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