SANITATION and ENERGY

Sulabh International Academy of Environmental Sanitation and Public Health (SIAESPH), New Delhi, India

in collaboration with

Sulabh International Centre for Action Sociology (SICAS), New Delhi, India
FOREWORD

Half the population in countries of Asia, Africa and Latin America do not have access to sanitation, which is the foundation of health, dignity and development. Basic sanitation, education, hygienic waste disposal and energy consumption are important yardsticks for socio-cultural and techno-economic development of any society.

Higher utilization of energy signifies higher economic growth and development. However, globally, nations have been gravely affected by the scarcity of fossil fuels and high rise in oil prices. In an environment where alternative energy sources are not cost-effective, countries around the world are looking for cheaper ways of generating energy. In addition, the need for reducing green house gas emissions has led to a search for alternative sources of energy and technologies that mitigate the adverse effects of such emissions.

Wastes, including human, animal and biomass residues, which contribute to pollution of the environment, water and land, are an affordable source of renewable energy. Biomass residues can be converted into various non-solid fuel forms, while composting provides a simple process for converting organic solid wastes into manure. Human waste is a good substrate for bio-energy generation and has the additional advantages of improving of sanitation and production of bio-fertilizer. These illustrations of eco-friendly methods for production of energy can be practiced at domestic and commercial levels.

This publication on “Sanitation and Energy” provides an overview of sanitation and waste to energy conversion systems, and of technologies for producing and utilizing energy through conversion of human, animal and municipal wastes.

The publication will be useful resource for country governments and functionaries who are responsible for waste management, as well as those involved in promoting safe sanitation and generating energy from wastes.

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Preface

Sanitation, the hygienic means of preventing human contact with human and animal faeces, solid wastes, domestic wastewater (sewage, sullage, grey water), and industrial and agricultural wastes, is vital for improving health, alleviating poverty, protecting environment, enhancing economic progress, and increased productivity.

Sanitation is achievable through proper disposal and reduction, safe reuse and recycling of wastes. The safe and hygienic collection, treatment and disposal of human excreta or sewage can be achieved through engineering solutions (sewerage and wastewater treatment) and simple technologies (provision of latrines, septic tanks, etc). In the context of the poor, the technological responses required for enhancing access to sustainable sanitation are different from those available conventionally through centralized sewerage and waste disposal systems.

With the current focus on reversing the loss of resources and preventing environmental pollution by containing greenhouse gas (GHG) emissions to mitigate climate change, there is greater emphasis on improved sanitation and exploiting the potential of wastes for energy generation. Wastes are increasingly being seen as a resource for generating different forms of energy such as biogas, compressed biogas and pyrofuels.

Wastes are unwanted or discarded materials or substances because they are of no value at the place where generated. These can be in solid, liquid or gaseous forms and can arise from human habitats, agriculture and allied activities, industries and natural cycles. The wastes in urban or rural areas can be classified according to their type such as plastic, metal, e-waste, etc. or according to the point of generation such as domestic, commercial, industrial, agricultural, construction, food processing, biomedical, or nuclear waste. The wastes include municipal waste, biomass, human excreta or sewage and animal waste such as droppings or dung and abattoir waste. The physical, microbiological, biological or chemical hazards posed by different types of wastes to health highlight the importance of effective management of wastes for improving community health and the environment.

For converting waste to energy, information is needed on the types, quantity and quality of wastes generated and the percentage of combustible components in it that can be used for production of energy.
Three processes for conversion of waste to energy, namely i) bio-chemical pathways (anaerobic digestion); ii) thermo-chemical pathways, and iii) composting are appropriate. The choices to be made are location specific and depend on the quality and quantity of waste generated and available. Biogas is a commonly produced fuel from organic wastes by concerted action through the anaerobic pathway.

Municipal Solid Waste (MSW) can be converted to energy either by thermo-chemical or bio-chemical pathways, which can be adopted at different scales starting from household to community to medium and large scales. Large-scale plants have been introduced in industrialized countries for anaerobic digestion of municipal wastes. However, since several problems are associated with centralised waste management and sewage systems, the technologies for the two pathways are increasingly used at the decentralized levels. The decentralized and small-scale anaerobic digestion options provide a more suitable alternative in developing countries and have potential for commercial application in the future.

Solid wastes in developing countries contain high proportion of organic matter that has high moisture contents, making it unsuitable for thermo-chemical processes. The appropriate option for such biodegradable waste is to compost it to get valuable manure that can be used immediately in the vicinity for enriching soils and raising plants. Compost offsets the high-energy costs required for the manufacture of inorganic fertilizers.

The adoption of technologies for conversion of waste to energy requires consideration of local conditions, waste composition, and skills for adapting, managing and maintaining the technologies. Sulabh International Academy of Environmental Sanitation and Public Health (SIAES&PH) in collaboration with Sulabh International Centre for Action Sociology (SICAS) has brought out this publication on “Sanitation and Energy” with the aim to examine the sanitation and energy nexus; that is, how waste can be used as a resource for generating energy. This publication has been prepared to provide an overview of issues and technologies appropriate for local situations in developing countries. It covers various technologies used in different countries for conversion of human, animal and municipal wastes to energy at household, community/neighborhood and city/town levels. The descriptions include various energy forms derived from different wastes and how conversion of waste to energy contributes to effective waste management as well as safe and improved environmental sanitation.

The publication is organised in 13 Chapters covering comprehensively the conversion of waste to energy through the processes of ‘bio-chemical pathways (anaerobic digestion)’; ‘thermo-chemical pathways’, and ‘composting’.

Chapter 1 on ‘Waste, Health and Sanitation’ gives an overview of the different types of wastes and health hazards from them to highlight the importance of management of wastes for improving sanitation, community health and the environment.

Chapter 2 on ‘Waste to Energy’ describes the types, quantity and quality of wastes available in human habitats and presents the scope for recovering energy from wastes by the three pathways, viz. bio-chemical, thermo-chemical and composting.

When the biodegradable wastes have high moisture content, anaerobic digestion is a better option for generating biogas as a fuel. Chapter 3 on ‘Anaerobic Pathway: Biogas Production’ covers the processes and factors that control biogas production. The chemistry of biogas generation and the advantages of biogas technology provide the basis for assessing the biogas potential at a given site depending on the quantity of feed material available and make investment decisions.

Chapter 4 on ‘Bio-digester Models and their Adoption’ details out various bio-digester models, their operation and maintenance, and the scenario of biogas technology adoption in different countries. Different bio-digester models have evolved in different countries, particularly for small family adoption. These include Fixed-dome
digesters, Floating-drum digesters, Bag digesters, Plug Flow digesters, Covered Lagoon digesters, the Up-flow Anaerobic Sludge Blanket design, etc. The conditions under which different models are appropriate as well as the operation and maintenance requirements of the plants are issues which determine adoption of different technologies.

Chapter 5 on 'Energy from Human and Animal Waste' describes different types of feedstock for biogas production and the constraints relating to biomethanation. Different types of commonly available substrate/feedstock for biogas generation, their relevant characteristics and the constraints relating to biomethanation, that is, the economic and technical considerations such as the yield of methane from fermentation of a specific feedstock system, are covered in detail.

The technologies for 'Small-scale Biogas Generation from Municipal Waste' are presented in Chapter 6. Decentralized and small-scale anaerobic digesters that can be introduced locally to produce biogas from community wastes, vegetable market waste, food waste etc. are more suitable for developing countries as against developed countries where large-scale anaerobic digestion is the preferred option.

Chapter 7 on 'Energy from Municipal Solid Waste: Thermo-chemical Methods' describes how municipal solid waste can be converted to energy by thermo-chemical methods such as incineration, pyrolysis and gasification.

Chapter 8 on 'Composting of Waste and Utilization' provides appropriate options for composting biodegradable wastes and generate manure. This process is economically remunerative and can be practiced at any desired scale of operation.

Chapter 9 on 'Utilization of Energy from Waste' deals with the applications of biogas for purposes like cooking, lighting through mantle lamp and electricity generation. It also highlights the utilization of manure from biogas plants, use of biogas as a transport fuel by adopting Bio-CNG technology and the potential of other emerging technologies.

Chapter 10 on 'Technology Matrix' provides an easy reference by process, feedstock and various technologies for conversion of different kinds of wastes to energy. The selection of the appropriate process and technologies for a particular situation is based on several parameters and cost for construction as well as maintenance. This Chapter lists out technologies for conversion of different kinds of wastes to energy in three matrices by: 1) pathway, that is, a) Anaerobic digestion for biogas generation, b) Thermo-chemical treatment for energy production, and c) Composting; 2) feedstock and 3) type of technology. The matrices include description of the benefits of the technologies, their feedstock requirements and locations where used. After identifying the appropriate technologies, decision makers can get additional information on financial viability of the technologies in their locations.

Chapter 11 on 'Capacity Building: Problems and Prospects' covers issues relating to capacity building of professionals and practitioners in the sector. Experiences of development assistance have showed that provision for water, sanitation and energy is not only about infrastructure, but also about the local capacity to make appropriate choices regarding the technology and institutional forms for building and managing it.

The Chapter 12 on 'Regulatory Mechanisms for Municipal Solid Waste Management' provides an overview of the regulatory mechanisms and the organizational framework for municipal solid waste management to demonstrate the potential of conversion of waste to energy and support available from appropriate mechanisms, organizational structures and finances.

The Chapter 13 on 'Perspectives for Future Action' emphasizes the importance of cost-effective, adoptable, appropriate and eco-friendly renewable energy systems that generate energy from the un-wanted and polluting wastes in an integrated manner. On-going research and development for improved energy generation from the
wastes and the associated economic returns would not only contribute to sustainable development towards safe sanitation but also to achieving the Millennium Development Goal (MDG) 7 Targets.

The Publication has also documented the Indian experiences and practices in respect of Biogas Plants and Incinerator Technologies. This is annexed as Appendix-I and Appendix-II respectively.

For successful adoption of waste to energy strategies described, decisions and actions are required at several levels. Local authorities with responsibility for service provision need to make strategic decisions on how best to use their limited capacity and how to supplement this by appropriate mechanisms and devolution of responsibilities to all stakeholders. This publication is intended to document proven options for producing different forms of energy and can serve as a reference guide to local governments, functionaries and all those engaged in promoting safe sanitation and in generating energy from waste.

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Introduction

Urban settlements, where more than 50 percent of the global population lives, are engines of economic growth, and centres of human enterprise and socio-cultural diversities. The urban centres offer specialized education, health services, and several other opportunities for improving the quality of life. However, in practice, the urban settlements are overwhelmed by inadequate infrastructure and shelter, increasing environmental pollution, prevalence of poverty, social alienation and acute land pressures.

Sanitation
Around 2.2 million people, mostly children under five years of age, die every year from diarrhoeal diseases and cholera that are associated with contaminated water supply, poor sanitation and hygiene. The poor, especially women and children are the most affected in terms of health and security because of risks associated in use of open fields or public toilets in relatively isolated areas. Globally, 2.6 billion people or 38% of the world’s population (UNICEF and WHO, 2008) either have no organized system of sanitation or have access to very poorly maintained facilities. Access to safe and convenient sanitation facilities is vital for improving health, alleviating poverty and protecting the environment. It also has important bearings on productivity and economic progress of nations.

Sanitation, which commonly refers to the collecting and transferring of untreated sewage, does not only refer to the expansion of hygienic toilets and their long-term maintenance. The collection and safe disposal of grey water is an integral component of a functional wastewater management policy (ADB AWDO 2007). Sanitation, therefore, refers to the hygienic means of preventing human contact from the hazards of human and animal faeces, solid wastes, domestic wastewater (sewage, sullage and greywater), industrial wastes, and agricultural wastes to promote health. Epidemiological evidence suggests that sanitation is at least as effective in preventing diseases as improved water supply. Sanitation is not only about creating awareness about the benefits of attitudinal and hygienic behaviour changes, but also about protecting the environment and supporting sustainable development. Sanitation and environment are two sides of the same problem - one cannot be solved without solving the other.

Energy
The world’s growing population, with its desire for economic growth and a better quality of life, is raising the demand for energy. High-income countries, with 15 percent of the world’s population, use half the energy in the world, and have the highest per capita emissions of carbon dioxide. The global energy demand is projected to grow significantly by the year 2100. Some projections put the growth of energy demand during the 21st century to a factor of six, that is, a growth from about 400 exajoules (ej) in 2000 to 2400 in 2100. Of these, the global demand of electricity is expected to increase faster than direct use of fuels in the end-user applications. The infrastructure required to meet this demand will have long lasting consequences on GHG emissions.
Global efforts have been intensified for finding and promoting alternative sources of energy in order to reverse the loss of environmental resources, contain GHG emissions and limit ozone depleting substances to mitigate climate change. To achieve the Millennium Development Goal (MDG) target of 60% reduction in carbon emission by 2050, the contribution of renewable sources to the world’s primary energy supply (Figure A) has to be increased from the present level of about 10% to 30-40%. Similar steps are needed in the Indian context also (Figure B).

**Renewable Energy and Fuels**

The sun is the primary source of all types of energy resources - non-renewable (fossil fuels) and renewable sources. Humans initially met their energy needs from locally available renewable biomass fuels. The use of coal started at the end of eighteenth century. Subsequently, industrialized countries rapidly substituted (first transition) the use of low quality renewable biomass fuels with high quality fossil fuels (coal, petroleum, natural gas). The use of fossil fuels has increased more than fourfold since 1950 and has contributed to the accumulation of GHG such as carbon dioxide and methane.

The different types of renewable energy resources include wind, solar, hydropower, geothermal energy inside the Earth itself, biomass residues, energy crops and wastes. The energy conversion technologies include wind power, solar photovoltaic, solar thermal, concentrated solar power, photo-bioreactors, large hydro, mini and micro hydro, geo-thermal heat, geo-thermal power, bio-chemical conversion of biomass, thermo-chemical conversion of biomass, and conversion of waste to energy. These sources of energy, available in one or more forms across the globe, can be converted and delivered to the end users as electricity, heat, fuels, hydrogen, and as useful chemicals and materials. There is considerable potential to increase the contribution to primary energy supply from a mix of renewable energy technologies. Wind energy, particularly in the offshore, and biomass for electricity are the likeliest sources for major development in the next fifteen years. Currently, the renewable energy technologies are either marginal or uneconomical in competition with conventional fossil energy sources.

The search for alternative sources of energy and a renewed interest in urban wastes as a potential source of energy was precipitated during 1970s and 1980s, when nations were adversely affected by the high cost of oil and scarcity of low cost alternative fuels. More recently, some of the industrialized countries initiated the second transition in energy use (shift from non-renewable to renewable energy) due to the increase in oil prices globally and concern for emission of GHGs. In industrialized countries, this has contributed to a decrease in the share of low quality biomass fuels and an increase in the share of new-renewable energy sources (solar PV, wind power) in total power generation. In 2003, of the 8% net energy supply from renewable resources in the United States of America, 46% came from burning of biomass derived from wastes and crops. The scenario in developing countries is different with renewable biomass fuels contributing substantial portion of primary energy supply.

To illustrate, a range of technologies which contribute to global electricity demand are using fossil fuels, nuclear power, hydroelectric power and a relatively small amount of renewable energy. These include technologies for
conversion of waste to energy, which provide a means for addressing problems of sanitation. Novel and advanced long-range visionary as well as medium-range technology development programmes aim to address environmental concerns like GHG and Global Warming (GW) more effectively.

In spite of concerns about exhaustion of fossil fuels and environmental, social and political risks associated with extensive use of conventional fuels, the technologies that use fossil fuels remain commercially more competitive than technologies for alternative sources of energy, and hence are in greater demand for meeting energy needs.

**Waste to Energy Technologies: Problems and Prospects**
Increasingly, waste, that is, unwanted and discarded material or substance in solid, liquid or gaseous forms from the natural or human habitats, agriculture and allied activities, and industries is viewed as a resource for conversion to energy. While the potentials and prospects of harnessing energy and its net contribution from municipal and other wastes will be marginal, they will contribute substantially to reduction in emissions of GHGs and achieving environmental sanitation.

Waste to Energy technologies have been and are being developed in several highly industrialised countries where about 80% of energy requirements are for heating or cooling buildings and powering vehicles. In developing countries with tropical climates and less developed infrastructure, decentralized options for electricity and heat generation using renewable energy is an attractive option.

Renewable energy technologies are generally modular and can be used to meet energy needs of stand-alone applications for a building, an industrial plant or a settlement, or to cater to the larger needs of a national electrical grid or fuel network. In addition, renewable energy technologies can be used in various combinations such as hybrids with fossil-fuel based energy sources and with advanced storage systems to improve renewable resource availability. Such flexibility and standards are very important to safely and reliably interconnect power generated by renewable energy technologies to individual loads or buildings and to the electric grid. The countries of Asia and Africa can in the long term, significantly contribute to the production and use of renewable energies by introducing robust, commercially competitive and sustainable technologies. Despite the variations in composition of wastes in these countries, a sizeable proportion comprises combustible components that can be used as fuel in production of heat energy. The bio-degradable components in the waste can also be anaerobically digested to produce biogas.

In view of the above, there is substantial interest and enthusiasm among scientists and technocrats in the potential of generating energy from urban waste. Given the variations from site to site, before choosing technological options for waste management, a survey must be performed in terms of the quantity, type, characteristics and composition (both physical and chemical) of the waste.

**Role of Technologies and Strategies for Development**
The diversity of renewable energy sources offers a broad array of technological choices that can reduce carbon dioxide emissions. Analogous to crude oil, biomass can be converted to heat and electrical power, and can be used to produce fuels, hydrogen, chemicals, and intermediates. Herein, biomass refers to ‘biomass residues’ (municipal and agricultural wastes such as corn stover and rice hulls, forest residues, pulp and paper wastes, animal wastes) and fast-growing “energy crops”, chosen specifically for their rapid growth and efficient energy generation.

The shift from reliance on fossil fuels to renewable energy resources will require appropriate changes in the energy infrastructure. For example, significant changes are required in the electricity infrastructure to accommodate increased use of electricity generated from renewable sources. For renewable fuels used for transportation, significant changes may not be required to the design of vehicles and refueling infrastructure when the percentage of ethanol in the fuel mix (ethanol + gasoline) is up to 10%. However, modifications may be required for use of bio-oil and bio-diesel. Bio-refineries of the future could produce value added chemicals.
and materials together with fuels and/or power from non-conventional lower cost feedstock such as agricultural and forest residues, specially grown crops, and biomass derived from municipal solid waste, with no net carbon dioxide emissions. Bio-diesel use may continue to grow and replace the use of fossil fuels.

A recent assessment of potential bio-fuel resources concluded that by the mid 21st century, it would be technically possible to produce enough biomass to displace about one third of the current petroleum consumption. In this context, the role of waste to energy technologies is likely to be significant, even though the economic viability and marketability of such technologies are yet to be proved.

The technologies for production of renewable energy are at various stages of development, market penetration and readiness. In addition, the cost, performance and the experiences in use of renewable energy technologies are additional deterrents for a radical transition to renewable energy resources. However, the costs for the use of newer technologies for harvesting energy from urban waste, wind or solar radiation have to be considered in the context of the centuries taken in developing and operationalizing coal mines and the costs of ecological damage caused by their use. Given the present diversity in the stages of development of waste-to-energy technologies and their impacts on different economic, social and ecological sectors, it may not be judicious to leave their development only to market forces. National Governments, particularly those in developing countries need to provide research and development support and fiscal incentives for the development of a portfolio of renewable technologies. The composition of these portfolios will change because of market changes as well as continuous research and development.

The research challenges for waste to energy technologies are primarily to do with gaining better understanding of the contaminants, pre-cleaning and pre-treatments of waste streams, separation and recycling and over all environmental safety and performance. Future research and development efforts also need to contribute to a better understanding and management of bio-chemical and thermo-chemical conversion of biomass, development of sustainable agriculture and forest management systems that could provide biomass residues, and finally development of energy crops. Further, research is also required for developing devices that allow conversion of medium grade and low grade heat to electricity at economically attractive efficiencies, and for developing technologies for directly utilizing the thermal energy for various applications, simultaneously with electricity generation (for example, cogeneration and tri-generation). At the level of decentralized systems, public cooperation, public-private partnerships, policy support and other related issues have to be considered.

Thus, an integrated approach for tackling polluting wastes and the use of cost-effective and adoptable technologies can contribute to generation of renewable energy and can yield economic returns with sustained development. In fact, continued research and development would be the order of the day for improved and sustainable energy generation from wastes.
Waste, Health and Sanitation

Waste is defined as unwanted or undesired material or substance that is discarded because it is of no value at the place where it is generated. Any process or activity may generate waste in solid, liquid or gaseous forms, and it can be classified according to its type, such as plastic, metal, e-waste, etc. The wastes, irrespective of whether in urban or rural areas, can be from human habitats, agriculture and allied activities, industries and the environment. Wastes can be classified according to the point of generation such as domestic, commercial, industrial, agricultural, construction, food processing, bio-medical, and nuclear waste (Table 1.1.1).

**Table 1.1.1: Typical solid waste generation by sources, activities, locations and types of classification**

<table>
<thead>
<tr>
<th>Source</th>
<th>Activities/ Location</th>
<th>Types of solid wastes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>Single-family and multi-family dwellings, low, medium and high rise apartments</td>
<td>Food waste, rubbish, ashes, special wastes</td>
</tr>
<tr>
<td>Commercial</td>
<td>Stores, restaurants, markets, office buildings, hotels, print shops, auto repair shops, medical facilities and institutions, etc.</td>
<td>Food waste, rubbish, ashes, demolition and construction wastes, occasionally hazardous wastes</td>
</tr>
<tr>
<td>Municipal</td>
<td>As above (received at municipal disposal facilities)</td>
<td></td>
</tr>
<tr>
<td>Industrial</td>
<td>Construction, fabrication, demolition, light and heavy manufacturing, refineries, chemical plants, lumbering, mining, power plants, etc.</td>
<td>Food waste, rubbish, ashes, demolition and construction wastes, hazardous wastes and special wastes such as clinical waste, animal carcasses, livestock waste, radioactive waste</td>
</tr>
<tr>
<td>Treatment plant sites</td>
<td>Water, wastewaster and industrial treatment processes, etc.</td>
<td>Treatment plant wastes principally composed of residual sludge</td>
</tr>
<tr>
<td>Open areas</td>
<td>Streets, alleys, parks, vacant lots, playgrounds, beaches, highways, recreational areas, etc.</td>
<td>Special wastes (leaves, shrubs, plants), rubbish</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Field and row crops, orchards, vineyards, dairies, feedlots, farms, etc.</td>
<td>Spoiled food wastes, agricultural wastes, rubbish</td>
</tr>
</tbody>
</table>

*Source: EPD, 2000*

Waste poses several hazards in the form of physical, biological or chemical agents harmful to health. The management of waste from the different sources requires varying types of actions. Wastes from urban areas (residential, commercial and municipal disposal facilities), wastewater treatment plants, open areas, and from agricultural activities require different approaches from that required for industries. The waste from industries and other premises such as hospitals are expected to be managed at the point of generation to ensure that anything discarded is ultimately not hazardous to the environment. As for domestic wastes, the hygienic means of preventing human contact with such wastes can be through engineering solutions (sewerage and wastewater treatment), simple technologies (latrines, septic tanks) and through personal hygiene practices (hand washing with soap).
Currently, there is greater focus on reduction, reuse and recycling of waste. Both reduction and reuse focus on the point of generation. Reduction can be achieved by actions such as minimizing packaging, while reuse refers to the use of discarded materials by others who find them useful. This is achieved by sharing, selling or donating the materials rather than throwing. Recycling refers more to the treatment of waste that is already generated, specifically to conversion of waste to useable resources such as paper products from paper, or compost from biodegradable waste or energy.

The wastes that can be utilized for generation of energy can be classified as i) Municipal Solid Waste (MSW); ii) Human waste/excreta or sewage; iii) Animal waste in terms of droppings or dung as well as waste from abattoirs; and iv) Biomass.

1.01 Waste and Health
Globally, countries are facing problems of disposal of domestic wastes and effluents. However, the problems differ because of differences in the composition and quantities of waste in terms of non-degradable wastes such as plastics and electronic components and because of local conditions. In the developed countries where the per capita wastes are large, infrastructure generally exists for collection and management of both solid and liquid wastes. In developing countries where per capita waste is relatively low, urban local bodies face several challenges in providing adequate sanitation services and appropriate systems for urban waste collection and disposal. The challenges include: i) rapid urbanization that outstrips infrastructure provision; ii) inappropriateness of technologies introduced for sewage treatment and/or waste disposal; iii) inadequacy of funds; iv) non-availability of appropriate and affordable technologies; and v) inadequate capacity of those responsible for operation and management of the installed technologies. In addition, in the absence of affordable shelter and serviced land, the rapidly increasing urban population finds shelter on vacant and un-serviced land.

In the absence of adequate systems for management of both solid and liquid wastes, even in cities with the infrastructure to deal with municipal wastes, effluents are released into the surroundings. Waste management, where it exists, is still a linear system of collection and disposal, creating health and environmental hazards. In fact, uncontrolled land filling practices and associated problems of disposal of municipal solid waste in urban areas is a growing environmental and public health concern (Vasudevan and Soumitri, 2002). In rural areas, bio-wastes and animal wastes are added to other types of solid wastes. The situation is likely to be further aggravated unless steps are initiated to improve sanitation through innovative and appropriate technologies for safe management of municipal solid and liquid wastes and other human and animal wastes.

Municipal Solid Waste as a Health Hazard
In developing countries, the proportion of biodegradable waste in MSW is quite high due to the use of unprocessed foods/fresh vegetables and the small amount of recyclable materials. Most of the recyclable materials such as paper, cardboard, plastics and metal, are frequently recycled either by households or more often by rag pickers from the informal recycling sector. However, the rag pickers are exposed to health hazards. The biodegradable waste harbours various vectors like flies and rodents (Vasudevan et al., 2007). Flies propagate a variety of diseases and rats are responsible for the spread of plague. Further, a number of pathogenic viruses, bacteria, fungi and protozoa are supported by MSW (Table 1.1.2).

<table>
<thead>
<tr>
<th>Virus</th>
<th>Bacteria</th>
<th>Fungi</th>
<th>Protozoa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enterovirus</td>
<td>Arizona hinshawii</td>
<td>Aspergillus fumigatus</td>
<td>Acanthamoeba</td>
</tr>
<tr>
<td>Poliovirus</td>
<td>Citobacter sp.</td>
<td>Cryptococcus neoformans</td>
<td>Dentamoeba fragilis</td>
</tr>
<tr>
<td>Coxaschivirus</td>
<td>Escherichia coli</td>
<td>Epidermophyton sp</td>
<td>Entamoeba hystolitica</td>
</tr>
<tr>
<td>Echovirus</td>
<td>Klebsella sp.</td>
<td>Geotrichum candidum</td>
<td>Giardia lamblia</td>
</tr>
<tr>
<td>Myxovirus</td>
<td>Salmonella sp.</td>
<td>Microsporum sp</td>
<td>Isospora belli</td>
</tr>
<tr>
<td>Adenovirus</td>
<td>Serratia sp.</td>
<td>Phialophora richdss</td>
<td>Naegleria fowleri</td>
</tr>
<tr>
<td>Hepatitis A virus</td>
<td>Streptococcus sp.</td>
<td>Trichosporon cutaneum</td>
<td>Palantidium</td>
</tr>
<tr>
<td>Hepatitis E virus</td>
<td>Vibrio cholerae</td>
<td>Tricophyton sp</td>
<td>Sarcocystis sp</td>
</tr>
</tbody>
</table>

Source: Straub et al. 1993
Thus, the high proportion of biodegradable waste combined with the tropical climate requires frequent collection and removal of refuse from the collection points. In addition, non-degradable solid wastes such as discarded tyres, containers etc. that become receptacles of water or other liquids become breeding grounds for mosquitoes that cause malaria and dengue.

**Wastewater and Health Impact**
Different sources for wastewater generation are indicated schematically in Figure 1.1.1. Treatment of wastewater is neglected in developing countries mainly because of the high operation and maintenance costs of conventional technologies that are prohibitive. Semi treated or untreated sewage normally collected through covered or uncovered drains that finally lead to low land areas or nearby river of the town/city, cause major pollution of aquatic bodies and the environment. Besides, vectors such as mosquitoes and rodents, animals such as pigs and micro-organisms that are pathogenic to humans also thrive on stagnant water and wastes. Microbial contamination of water is the cause of many diseases (Vasudevan et al., 2007).

*Figure 1.1.1: Wastewater types*

Of the different types of wastewater shown above, rainwater is primarily clean except for contamination by atmospheric gases and airborne dust particles. However, once it flows on the ground, it carries the impurities that are already on the ground. In many areas, this surface runoff is directed into open drains carrying wastewater. Similarly, gray water or domestic sullage from kitchen and bath, is mixed with the sewage, wherever sewage collection systems exist. However, in most rural environments the sullage is just left on the roads and becomes a menace. In fact, in rural situations, sewage even when collected is often left to flow into the fields after primary settlement.

**1.02 Health and Sanitation**
Sanitation is a broad term that includes personal and domestic cleanliness, safe disposal of human wastes, sullage, wastewater and solid wastes, control of vectors of diseases, sewage treatment, water quality, water

*Figure 1.2.1: Population defecating in the open* *Figure 1.2.2: Population (in millions) without improved sanitation (2004)*

*Source: JMP, 2008*
availability, and drainage. Safe disposal of human wastes covers major part of sanitation. As described above, sanitation is a crucial stepping-stone to better health and offers the opportunity to save the lives of 2.2 million children a year and to protect the health of many others. It is fundamental for women’s dignity and important for economic development. Investments in sanitation protect investments made in sectors such as education and health, and bring measurable economic returns.

However, 2.6 billion people, including 1.2 billion who have no sanitation facilities at all, still lack access to improved sanitation (WHO/UNICEF 2008). 955 million in South Asia and 761 million in Eastern Asia are without having improved sanitation facility (Figures 1.2.1 and 1.2.2). In the International Year of Sanitation, special efforts were made to increase access of more people to sanitation.

Sanitation, which is more a social problem than a technical one, can be overcome if the technology is demonstrated to have sufficient economic returns and shown to bring real benefit to health. The trends in improving sanitation include: i) conversion of waste to energy, ii) eco-sanitation through separation of liquid waste from human excreta, and iii) decentralised systems for natural recycling of sewage and for conversion of solid waste to compost or biogas.

**Human Wastes and Diseases Transmission**

Human wastes contain full spectrum of pathogens that transmit from one person to another through various routes – as illustrated in Figures 1.2.3 and 1.2.4, causing infections and superimposed infections.

**Figure 1.2.3:** Transmission of Pathogens from human excreta
Classification of infections caused and control measures

There are several bacterial pathogens commonly found in human wastes causing diseases (Table 1.2.1):

### Table 1.2.1: Bacterial and Helminthic Pathogens in Human Faeces

<table>
<thead>
<tr>
<th>Bacteria</th>
<th>BACTERIAL Diseases</th>
<th>Reservoir</th>
</tr>
</thead>
<tbody>
<tr>
<td>Escherichia coli</td>
<td>Diarrhoea</td>
<td>Human</td>
</tr>
<tr>
<td>Salmonella typhi</td>
<td>Typhoid fever</td>
<td>Human</td>
</tr>
<tr>
<td>S. paratyphi</td>
<td>Paratyphoid fever</td>
<td>Human</td>
</tr>
<tr>
<td>Other salmonellae</td>
<td>Food poisoning &amp; other salmonelloses</td>
<td>Human</td>
</tr>
<tr>
<td>Shigella spp.</td>
<td>Bacillary dysentery</td>
<td>Human</td>
</tr>
<tr>
<td>Vibrio cholera</td>
<td>Cholera</td>
<td>Human</td>
</tr>
<tr>
<td>Other vibrios</td>
<td>Diarrhoea</td>
<td>Human</td>
</tr>
<tr>
<td>Camylobacter fetus</td>
<td>Diarrhoea</td>
<td>Animal &amp; Human</td>
</tr>
<tr>
<td>Yarsinia enterocolitica</td>
<td>Diarrhoea and Septicaemia</td>
<td>Animal &amp; Human</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Helminthis</th>
<th>Common Name</th>
<th>Diseases</th>
<th>Transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anoyolostoma duodenale</td>
<td>Hookworm</td>
<td>Hookworm</td>
<td>Human-soil-human</td>
</tr>
<tr>
<td>Acaris lumbricoides</td>
<td>Roundworm</td>
<td>Ascariasis</td>
<td>Human-human-soil</td>
</tr>
<tr>
<td>Taenia saginata</td>
<td>Beefworm</td>
<td>Taeniasis</td>
<td>Human-cow-human</td>
</tr>
<tr>
<td>T. solium</td>
<td>Pork tapeworm</td>
<td>Taeniasis</td>
<td>Human-pig-human</td>
</tr>
<tr>
<td>Trichuris trichiura</td>
<td>Whipworm</td>
<td>Trichuriasis</td>
<td>Human-soil-human</td>
</tr>
</tbody>
</table>

Source: Faechem et al, 1983

The infections caused by human excreta based pathogens have been categorized in six groups (Faechem et al, 1983) as given in Table 1.2.2. Five categories of the infections can be prevented through management of human waste, that is, through provision of toilets and treatment or proper disposal of the excreta. This highlights the significance of functional toilets for management of human waste and prevention of diseases.
Table 1.2.2: Human Waste related Transmission of Infections and Control

<table>
<thead>
<tr>
<th>S No.</th>
<th>Category and epidemiological features</th>
<th>Infections</th>
<th>Environmental transmission focus</th>
<th>Major Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Non-latent; low infective dose</td>
<td>Amoebiasis, Balantidiasis, Enterobiasis, Enteroviral infections Giardiasis, Hymenolepiasis, Infectious hepatitis, Rotavirus infection</td>
<td>Personal Domestic</td>
<td>Domestic water supply, Health education, Improved housing, Provision of toilets</td>
</tr>
<tr>
<td>II</td>
<td>Non-latent; medium or high infective dose; moderately persistent; able to multiply</td>
<td>Campylobacter, Cholera infection Pathogenic E.coli infection, Salmonellosis, Shigellosis, Typhoid Yersinia</td>
<td>Personal Domestic Water, Crop</td>
<td>Domestic water Supply, Health education, Improved housing, Provision of toilets. Treatment of excreta prior to discharge or reuse</td>
</tr>
<tr>
<td>III</td>
<td>Latent and persistent; no intermediate host</td>
<td>Ascariasis, Hookworm infection, Strongyloidiasis, Trichuriasis</td>
<td>Yard, Field, Crop</td>
<td>Provision of toilets. Treatment of excreta prior to land application</td>
</tr>
<tr>
<td>IV</td>
<td>Latent and persistent; cow or pig as intermediate host</td>
<td>Taeniasis</td>
<td>Yard, Field Fodder</td>
<td>Provision of toilets. Treatment of excreta prior to land application cooking, meat inspection</td>
</tr>
<tr>
<td>V</td>
<td>Latent and persistent; aquatic intermediate host</td>
<td>Clonorchiasis, Diphyllobothriasis Fascioliasis, Fasciolopsiasis Gastrodiscoidiasis, Heterophyiasis Metagonimiasis, Opsthorchiasis Schistosomiasis</td>
<td>Water</td>
<td>Provision of toilets. Treatment of excreta prior to discharge. Control of animal reservoirs. Control of intermediate hosts, Cooking of water plants and fish, Reducing water contact</td>
</tr>
<tr>
<td>VI</td>
<td>Spread by excreta-related insects</td>
<td>Bancroftian filariasis, transmitted by Culex pipiens. All the infections in I-V can be transmitted mechanically by flies and cockroaches</td>
<td>Various faecal contaminated sites in which insects breed</td>
<td>Identification and elimination of suitable insect breeding sites</td>
</tr>
</tbody>
</table>

Source: Faecem et al., 1983

1.03 Future Directions

There is now a greater focus on having decentralised systems for waste management and sanitation. Centralised solid waste management is practically not feasible for large urban areas for several reasons, including distances to which the waste would have to be carried, and availability of land required for centralized activities. Further, many local bodies are not financially or technically equipped for the purpose.

In terms of solid wastes in urban areas in less developed countries, the percentage of biodegradable wastes is higher than non-biodegradable or inert materials. Hence, the option of composting the waste at the household or cluster levels is feasible, especially if the technology options ensure absence of odour and the economic and health benefits are demonstrated to the community. In terms of human wastes, the separation of sewage from sullage at source can be an issue, but natural recycling of both sullage and sewage is possible for smaller decentralised systems. This can be achieved with hollow fibre membranes, use of plants for phyto remediation of wastewater and other modes where land is available.

Since many of the pathogens from the full spectrum in human excreta are eliminated under anaerobic conditions, anaerobic digestion offers the opportunity to generate energy while achieving sanitation. Currently, research for determining the effect of aerobic and anaerobic digestion, and technology innovations to achieve eco-sanitation by separation of gray water from excreta at the household and community levels are ongoing. This would enable quicker conversion of the wastes to usable resources such as bio-gas and manure. There is also an emphasis to link improved sanitation to economic activities and related improvements in the working conditions of those who work in the sector.
Waste to Energy

Wastes generated in human habitats, industrial processes, and agriculture and allied activities are hazards to human well-being and the environment if not treated and managed appropriately. Given the quantum and rate of waste generation in human settlements, it is essential to reduce, reuse and recycle the wastes. Lack of safe and hygienic disposal of human wastes affects community sanitation and health, results in high mortality and morbidity, and consequently has an effect on productivity. Therefore, both reduction in generation of wastes and their absorption or conversion through natural or controlled processes is essential to reduce its impact on humans and the environment; a part of the waste can be converted to energy.

The quantum of energy utilized is regarded as a yardstick of the socio-economic status of society. However, there is inadequate energy to meet the minimum needs of all people globally, and the fossil fuels cannot meet all the energy demand. People in many rural areas spend much of their time collecting firewood in the absence of easily accessible and affordable fuels. Countless worker-days are lost in such communities resulting in stagnation of progress and productivity. Locally appropriate means of energy generation can promote rural industries, agriculture, dairy and animal farming in a sustainable way. Therefore, it is essential to seriously consider the potential of garnering energy from waste by using appropriate technological options for different kinds, quality and quantity of wastes.

2.01 Waste Generation: Quantum and Quality

Municipal Solid Waste

Enormous amounts of solid wastes are generated globally. As shown in Figure 2.1.1, the per capita waste generated ranges between a low of 0.3 to 2.0 kilograms per capita per day. The composition of waste varies with

![Figure 2.1.1: Municipal solid waste generation for selected countries](image)

size of city, level of industrialisation, location, season and income group (Tables 2.1.1 to 2.1.3). Solid wastes from urban habitats comprise compostable vegetable matter and other materials such as paper, glass, plastics, metals and inerts. The composition of these municipal solid wastes depends on the level of economic development, socio-cultural and other parameters such as urbanization and the type of materials used and discarded affect the composition of waste.

Table 2.1.1: Composition of municipal solid waste in Southeast Asian Nations

<table>
<thead>
<tr>
<th>Country</th>
<th>Organic waste</th>
<th>Paper cardboard</th>
<th>Plastic</th>
<th>Glass</th>
<th>Metal</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malaysia</td>
<td>62</td>
<td>7</td>
<td>12</td>
<td>3</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>Indonesia</td>
<td>62</td>
<td>6</td>
<td>10</td>
<td>9</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Vietnam</td>
<td>60</td>
<td>2</td>
<td>16</td>
<td>7</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>Cambodia</td>
<td>55</td>
<td>3</td>
<td>10</td>
<td>8</td>
<td>7</td>
<td>17</td>
</tr>
<tr>
<td>Myanmar</td>
<td>54</td>
<td>8</td>
<td>16</td>
<td>7</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>Thailand</td>
<td>48</td>
<td>15</td>
<td>14</td>
<td>5</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>Laos</td>
<td>46</td>
<td>6</td>
<td>10</td>
<td>8</td>
<td>12</td>
<td>21</td>
</tr>
<tr>
<td>Singapore</td>
<td>44</td>
<td>28</td>
<td>12</td>
<td>4</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Brunei</td>
<td>44</td>
<td>22</td>
<td>12</td>
<td>4</td>
<td>5</td>
<td>13</td>
</tr>
<tr>
<td>The Philippines</td>
<td>41</td>
<td>19</td>
<td>14</td>
<td>3</td>
<td>5</td>
<td>18</td>
</tr>
</tbody>
</table>


Table 2.1.2: Solid Waste quantity and composition in some Asian countries

<table>
<thead>
<tr>
<th>Country</th>
<th>GDP (PPP) per capita estimated for 2007 (USD)</th>
<th>Waste generation (kg/capita/day)</th>
<th>Composition (% wet weight basis)</th>
<th>Inert and other Biodegradable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bio-degradable</td>
<td>Paper</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>37,385</td>
<td>2.25</td>
<td>38</td>
<td>26</td>
</tr>
<tr>
<td>Japan</td>
<td>33,010</td>
<td>1.1</td>
<td>26</td>
<td>46</td>
</tr>
<tr>
<td>Singapore</td>
<td>31,165</td>
<td>1.1</td>
<td>44.4</td>
<td>28.3</td>
</tr>
<tr>
<td>Taiwan</td>
<td>31,040</td>
<td>0.67</td>
<td>31</td>
<td>26</td>
</tr>
<tr>
<td>South Korea</td>
<td>23,331</td>
<td>1.0</td>
<td>25</td>
<td>26</td>
</tr>
<tr>
<td>Malaysia</td>
<td>12,702</td>
<td>0.5–0.8</td>
<td>40</td>
<td>15</td>
</tr>
<tr>
<td>Thailand</td>
<td>9,426</td>
<td>1.1</td>
<td>48.6</td>
<td>14.6</td>
</tr>
<tr>
<td>China</td>
<td>8,854</td>
<td>0.8</td>
<td>35.8</td>
<td>3.7</td>
</tr>
<tr>
<td>Philippines</td>
<td>5,409</td>
<td>0.3–0.7</td>
<td>41.6</td>
<td>19.5</td>
</tr>
<tr>
<td>Indonesia</td>
<td>5,096</td>
<td>0.8–1.0</td>
<td>74</td>
<td>10</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td>5,047</td>
<td>0.2–0.9</td>
<td>76.4</td>
<td>10.6</td>
</tr>
<tr>
<td>India</td>
<td>3,794</td>
<td>0.3–0.6</td>
<td>42</td>
<td>6</td>
</tr>
<tr>
<td>Vietnam</td>
<td>3,502</td>
<td>0.55</td>
<td>58</td>
<td>4</td>
</tr>
<tr>
<td>Lao PDR</td>
<td>2,260</td>
<td>0.7</td>
<td>54.3</td>
<td>3.3</td>
</tr>
<tr>
<td>Nepal</td>
<td>1,760</td>
<td>0.2–0.5</td>
<td>80</td>
<td>7</td>
</tr>
</tbody>
</table>

Source: Shokdar, A.V., 2009
For example, India produces about 50 million tons of municipal solid waste annually, of which 30 to 55% is biodegradable (organic) matter, 40 to 55% is inert matter and 5 to 15% are recyclables. Paper, plastic, metals, wooden materials are present in low amounts because an informal system of separation at source and due to collection by rag pickers and others. The calorific value of the waste is therefore low (less than 1000 kcal/kg).

Table 2.1.3: Composition of Municipal Solid Waste in Indian Cities

<table>
<thead>
<tr>
<th>S No</th>
<th>Cities</th>
<th>Paper</th>
<th>Textile</th>
<th>Leather</th>
<th>Plastic</th>
<th>Metal</th>
<th>Glass</th>
<th>Ash, Fine earth &amp; others</th>
<th>Compostable matter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ahmedabad</td>
<td>6.0</td>
<td>1.0</td>
<td>-</td>
<td>3.0</td>
<td>-</td>
<td>-</td>
<td>50.0</td>
<td>40.0</td>
</tr>
<tr>
<td>2</td>
<td>Bangalore</td>
<td>8.0</td>
<td>5.0</td>
<td>-</td>
<td>6.0</td>
<td>3.0</td>
<td>6.0</td>
<td>27.0</td>
<td>45.0</td>
</tr>
<tr>
<td>3</td>
<td>Bhopal</td>
<td>10.0</td>
<td>5.0</td>
<td>2.0</td>
<td>2.0</td>
<td>-</td>
<td>1.0</td>
<td>35.0</td>
<td>45.0</td>
</tr>
<tr>
<td>4</td>
<td>Bombay</td>
<td>10.0</td>
<td>3.6</td>
<td>0.2</td>
<td>2.0</td>
<td>-</td>
<td>0.2</td>
<td>44.0</td>
<td>40.0</td>
</tr>
<tr>
<td>5</td>
<td>Calcutta</td>
<td>10.0</td>
<td>3.0</td>
<td>1.0</td>
<td>2.0</td>
<td>-</td>
<td>3.0</td>
<td>35.0</td>
<td>40.0</td>
</tr>
<tr>
<td>6</td>
<td>Coimbatore</td>
<td>5.0</td>
<td>9.0</td>
<td>-</td>
<td>8.0</td>
<td>-</td>
<td>-</td>
<td>50.0</td>
<td>35.0</td>
</tr>
<tr>
<td>7</td>
<td>Delhi</td>
<td>6.6</td>
<td>4.0</td>
<td>0.6</td>
<td>1.0</td>
<td>2.5</td>
<td>1.2</td>
<td>51.0</td>
<td>31.7</td>
</tr>
<tr>
<td>8</td>
<td>Hyderabad</td>
<td>7.0</td>
<td>1.7</td>
<td>-</td>
<td>1.5</td>
<td>-</td>
<td>-</td>
<td>50.0</td>
<td>40.0</td>
</tr>
<tr>
<td>9</td>
<td>Indore</td>
<td>5.0</td>
<td>2.0</td>
<td>-</td>
<td>1.3</td>
<td>-</td>
<td>-</td>
<td>49.0</td>
<td>43.0</td>
</tr>
<tr>
<td>10</td>
<td>Jaipur</td>
<td>6.0</td>
<td>2.0</td>
<td>-</td>
<td>1.0</td>
<td>-</td>
<td>2.0</td>
<td>47.0</td>
<td>42.0</td>
</tr>
<tr>
<td>11</td>
<td>Kanpur</td>
<td>5.0</td>
<td>1.0</td>
<td>5.0</td>
<td>1.0</td>
<td>-</td>
<td>-</td>
<td>52.5</td>
<td>40.0</td>
</tr>
<tr>
<td>12</td>
<td>Kochi</td>
<td>4.9</td>
<td>-</td>
<td>-</td>
<td>1.5</td>
<td>-</td>
<td>-</td>
<td>36.0</td>
<td>58.0</td>
</tr>
<tr>
<td>13</td>
<td>Lucknow</td>
<td>4.0</td>
<td>2.0</td>
<td>-</td>
<td>1.1</td>
<td>1.0</td>
<td>-</td>
<td>49.0</td>
<td>40.0</td>
</tr>
<tr>
<td>14</td>
<td>Ludhiana</td>
<td>3.0</td>
<td>5.0</td>
<td>-</td>
<td>4.0</td>
<td>-</td>
<td>-</td>
<td>30.0</td>
<td>40.0</td>
</tr>
<tr>
<td>15</td>
<td>Madras</td>
<td>10.0</td>
<td>5.0</td>
<td>5.0</td>
<td>3.0</td>
<td>-</td>
<td>-</td>
<td>33.0</td>
<td>44.0</td>
</tr>
<tr>
<td>16</td>
<td>Madurai</td>
<td>5.0</td>
<td>1.0</td>
<td>-</td>
<td>3.0</td>
<td>-</td>
<td>-</td>
<td>46.0</td>
<td>45.0</td>
</tr>
<tr>
<td>17</td>
<td>Nagpur</td>
<td>4.5</td>
<td>7.0</td>
<td>1.9</td>
<td>1.25</td>
<td>0.3</td>
<td>1.2</td>
<td>53.4</td>
<td>30.4</td>
</tr>
<tr>
<td>18</td>
<td>Patna</td>
<td>4.0</td>
<td>5.0</td>
<td>2.0</td>
<td>6.0</td>
<td>1.0</td>
<td>2.0</td>
<td>35.0</td>
<td>45.0</td>
</tr>
<tr>
<td>19</td>
<td>Pune</td>
<td>5.0</td>
<td>-</td>
<td>-</td>
<td>5.0</td>
<td>-</td>
<td>10.0</td>
<td>15.0</td>
<td>55.0</td>
</tr>
<tr>
<td>20</td>
<td>Surat</td>
<td>4.0</td>
<td>5.0</td>
<td>-</td>
<td>3.0</td>
<td>-</td>
<td>3.0</td>
<td>45.0</td>
<td>40.0</td>
</tr>
<tr>
<td>21</td>
<td>Vadodara</td>
<td>4.0</td>
<td>-</td>
<td>-</td>
<td>7.0</td>
<td>-</td>
<td>-</td>
<td>49.0</td>
<td>40.0</td>
</tr>
<tr>
<td>22</td>
<td>Varanasi</td>
<td>3.0</td>
<td>4.0</td>
<td>-</td>
<td>10.0</td>
<td>-</td>
<td>-</td>
<td>35.0</td>
<td>48.0</td>
</tr>
<tr>
<td>23</td>
<td>Visakhapatnam</td>
<td>3.0</td>
<td>2.0</td>
<td>-</td>
<td>5.0</td>
<td>-</td>
<td>5.0</td>
<td>50.0</td>
<td>35.0</td>
</tr>
<tr>
<td>Total (average)</td>
<td>5.7</td>
<td>3.5</td>
<td>0.8</td>
<td>3.9</td>
<td>2.1</td>
<td>2.1</td>
<td>40.3</td>
<td>41.80</td>
<td></td>
</tr>
</tbody>
</table>

Source: CPCB 1999

Human Waste

Provision of toilets is an essential and important means of human waste disposal; it is essential to incorporate it as a component of a functional wastewater management policy (ADB AWDO 2007). For operation and maintenance purposes, the most convenient option is the promotion of toilet construction at the household level. In urban situations, centralized sewage systems are built to collect domestic wastewater and treat it centrally. However, many problems are associated with the centralised systems, including large quantities of sewage effluents to be disposed off after secondary or tertiary treatment. In settlements where sewers have not been introduced, the options for deposition of human waste include septic tanks or the cheaper option of leach pit systems. In many cases, the waste from septic tanks is diverted to covered or uncovered drains that finally discharge into nearby water bodies or low-lying land, causing harm to the aquatic system, environment and community health.

In settlements with high population density and lack of space, community use toilets are an option, while for peri-urban areas and for floating population in markets, transport nodes and other public places, pay and use
public toilets are a viable option. Safe disposal of human wastes from public toilets is a major challenge that can be tackled through biogas generation. This enables complete recycling of human wastes and improved sanitation. Further, use of biogas for different purposes and safe use of biogas plant effluent for production of fertilizers can improve the quality of life of the poor in rural and urban slum areas. However, for both these options, care has to be taken to prevent ground water contamination. The decentralized systems and adoption of alternative and appropriate technologies requires financing, management skills, and above all – people’s participation.

Animal Wastes
Animal husbandry generates large amounts of animal wastes, particularly from cattle, pigs and poultry. The total quantity of waste generated depends on the number of animals, which may range from a few at the household level to a large number in dairies, poultry and pig farms. The per capita generation of wastes and the amount of biogas that can be produced from animal wastes (Table 2.1.4) has to be matched with the size of technology and corresponding energy demand.

Table 2.1.4: Biogas yield from common animal wastes

<table>
<thead>
<tr>
<th>SNo.</th>
<th>Animal</th>
<th>Availability of dung/droppings/manure (kg of fresh waste per animal)</th>
<th>Expected yield of biogas from animal waste (m³ per day per animal)</th>
<th>Expected yield of biogas from dung/dropping (m³ per ton of waste)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cattle</td>
<td>10-20</td>
<td>0.36-0.80</td>
<td>36-40</td>
</tr>
<tr>
<td>2</td>
<td>Pig</td>
<td>2-2.5</td>
<td>0.15-0.20</td>
<td>78</td>
</tr>
<tr>
<td>3</td>
<td>Poultry</td>
<td>0.16-0.20</td>
<td>0.01-0.012</td>
<td>62</td>
</tr>
</tbody>
</table>

Source: Mittal, K.M., 1996

Biomass Wastes
Plant biomass is a good source of energy and wood has been used as a fuel. The basic components present in all phyto biomass are carbohydrates and lignin that contain carbon, hydrogen and oxygen in combined forms. All plant biomass from agriculture, agro-forestry, forestry and the wildly growing weeds are hence suitable for conversion to energy. Plant biomass from parks, gardens and households and yard wastes get mixed in MSW depending on what reaches the municipal dumps.

Large quantities of biomass wastes are available as weeds and agro-residues or wastes such as bagasse, crop stalks, rice husk, and coconut shells that are generated in sugar mills and other industries. In addition, energy plantations are raised specifically for generating fuel wood, while aquatic plants such as water hyacinth and algae that have high doubling rates, provide high yields of wet biomass. Vegetable oils from seeds can be used for biodiesel production and algal biomass can be converted to oil or used for biogas generation.

In countries such as India, an estimated 600 million tons of agricultural residue is available annually. A biomass surplus of 140-170 million tons would be sufficient for sustaining a significant portion of power requirement in India. However, usability of biomass wastes depends on availability of labour for its collection and processing.

2.02 Generating Energy from Waste
The energy that can be derived from the wastes is essentially based on the combustible components, specifically on their carbon and hydrogen contents. The heat content per unit mass of the waste depends on the percentage of carbon and hydrogen, which burn to release energy.

Illustrative Chemical Reactions and the amount of energy liberated

\[
\begin{align*}
C + \frac{1}{2} O_2 & \rightarrow CO + \text{heat} \ (110.5 \text{ kJ}) \\
C + O_2 & \rightarrow CO_2 + \text{heat} \ (393.5 \text{ kJ}) \\
H_2 + \frac{1}{2}O_2 & \rightarrow H_2O \ (1) + \text{heat} \ (285.8\text{kJ}) \\
CH_4 + 2O_2 & \rightarrow CO_2 + 2H_2O \ (1) + \text{heat} \ (890.8\text{ kJ}) \\
C_3H_8 + 5O_2 & \rightarrow 3CO_2 + 4 H_2O \ (1) + \text{heat} \ (3535.6\text{ kJ})
\end{align*}
\]
An important aspect is that hydrogen and carbon are present in chemically combined forms in the wastes, and that some energy is used up in breaking these chemical bonds. Although dry biomass such as wood can release substantial heat (range of 16,000-20,000 KJ/Kg on complete combustion) irrespective of the plant origin, the moisture present in the biomass absorbs significant amount of the heat for its vaporisation. To this extent, the overall heat available on burning the waste is reduced depending on the moisture content, and hence the type of waste. Organic wastes such as kitchen and garden wastes have high moisture content compared to dry wood, while waste paper and paper products such as newspapers, magazines, books, and cardboards have relatively low moisture content, and plastic products have hardly any moisture.

2.03 Pathways for conversion of Waste to Energy
Essentially, there are two ways for conversion of waste to energy, that is, either through thermo-chemical pathways or bio-chemical pathways. Energy from waste can be harnessed through these pathways at different scales starting from household to community to medium and large scales. While the adoption of these technologies can be increased through decentralisation, urban local governments may find it more economical to operate on larger scales.

Biochemical (Anaerobic) pathways: Biomethanation
Biochemical pathways comprise anaerobic digestion (Biomethanation) of the biodegradable components such as cellulose, starch, vegetable oil and other biodegradable materials through complex fermentation processes occurring with the intervention of a consortium of bacteria. The biogas produced is used as a fuel directly or can be used to generate electric power. Biogas technology is best suited to convert the organic waste from agriculture, livestock, industries, municipalities and wastes from other human activities into energy and manure. The use of energy and manure can lead to socio-economic gains, better environment, and health as indicated in Figure 2.3.1.

![Figure 2.3.1: Use of Bio-methanization](image)

Biodegradable wastes such as animal or human excreta, unused agro-residues and other compostable organic matter such as kitchen, vegetable market and yard wastes are more amenable to anaerobic digestion and production of biogas with high (60%) methane content. In areas where such biodegradable wastes are available in large quantities, biogas production helps with waste recycling and production of energy and manure. Biogas is valued for its use as a source of energy and the spent slurry for its fertilizing properties (soil nutrients and conditioners). Chemical energy content of biogas can also be transformed into various other forms such as mechanical energy (for running machines), heat energy (for cooking), lighting and electricity, depending on the need and availability of the technologies.

Commercial electricity generation systems that use biogas typically consist of an internal combustion (IC) engine, a generator, a control system and an optional heat recovery system. IC engines designed to burn propane
or natural gas are easily converted to burn biogas by adjusting carburetion and ignition systems. Ongoing research and development is focusing on the use of micro turbines and fuel cells for converting biogas to electricity. Micro turbines are high-speed, small-scale (typically less than 100 kW) gas-driven turbine systems that produce electricity efficiently, have low emissions and require less maintenance. In addition, biogas can be enriched in methane content by suitable purification processes, compressed and used as vehicle fuel like Compressed Natural Gas (CNG). The technologies of biogas generation from different types of feedstock and details on application of biogas are discussed in the following Chapters.

**Thermo-chemical pathways**
Thermo-chemical pathways involve burning of the hydrogen and carbon compounds in the waste either completely or to form intermediate solid, liquid or gaseous fuels depending on the type of application desired. Better energy recovery can be achieved through pre-processing for segregation of the organic or combustible waste, using a number of methodologies.

Incineration, pyrolysis and gasification are some of the thermo-chemical pathways for energy generation. For municipal waste, incineration, especially after drying and pelletization (Refuse Derived Fuel) is useful and is being operated on large scales. The heat generated can be used as is and/or by conversion into mechanical or electric power. Figure 2.3.2 sums up various methods of energy recovery and the types of fuel and forms of energy that can be produced from Municipal wastes. Energy recovery can be accomplished with or without mechanical, manual or semi-mechanical processing of the waste prior to their conversion.

**Figure 2.3.2: Methods of Recovering Energy from Solid Wastes**

![Diagram showing methods of recovering energy from solid wastes]

**Composting Organic Wastes**
Solid waste from developing countries contain high proportion of organic matter that has high moisture content and attracts flies, mosquitoes, micro-organisms, rodents and other vectors posing health hazards. The low heat content makes it unsuitable for thermo-chemical processes. An appropriate option for solid waste management is therefore composting along with suitable disposal of non-compostable and non-recyclable material. Compost is a valuable manure that can be used immediately in the vicinity for enriching soils and raising plants. Even though energy in the form of fuel is not directly released in composting, there is an indirect energy saving in manure production.
production. This is because organic manure mixed with bio-inoculants can replace energy intensive chemical fertilizers resulting in overall energy conservation. Use of organic manure also benefits the environment and results in indirect energy saving due to saving of energy in pollutant removal and restoring the environment. The process of converting waste to compost and vermi-compost is discussed in detail in Chapter '8'.

Composting and vermi-composting are most appropriate at the household and community levels. Herein the community can segregate the wastes, recycle the non-decomposable wastes, and compost the biodegradable wastes. For municipalities that collect a large amount of waste, large scale composting options which require mechanisation, are appropriate. The leftover slurry after anaerobic digestion (for production of biogas) is also a good manure because the microbial action on bio-wastes produces valuable compost incorporating the macro and micronutrients available in the wastes.

2.04 Conclusion
It is seen that the quality and quantity of wastes widely differ depending on socio-cultural and economic aspects of the community. The options of biogas generation or composting are best adopted where biocompostible component and moisture content are high. For large quantities of dry wastes generated with non-biodegradables such as plastic, thermal pathways could be an option.
Anaerobic pathway: Biogas Production

Biogas is produced from organic wastes by concerted action of various groups of anaerobic bacteria. Constituents of biogas vary slightly depending on the nature of substrates. Biogas, which typically refers to the bio-fuel gas produced, is mainly composed of 50 to 70 per cent methane, 30 to 40 per cent carbon dioxide and low amounts of other gases as shown in Table 3.1.1.

<table>
<thead>
<tr>
<th>Constituents</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>50 – 70</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>30 – 40</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>5 – 10</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>1 – 2</td>
</tr>
<tr>
<td>Water vapour</td>
<td></td>
</tr>
<tr>
<td>Hydrogen sulphide</td>
<td>Traces</td>
</tr>
</tbody>
</table>

Source: Mittal, K.M. 1996

Biogas is about 20 percent lighter than air and has an ignition temperature in the range of 650°-750°C. The odourless and colourless gas burns with clear blue flame similar to that of LPG gas. Its calorific value is 20 to 26 Mega Joules (MJ) per cubic meter depending on the content of methane. It can be burnt with 60 percent efficiency in a conventional biogas stove. Biogas production is one of the most important benefits of anaerobic fermentation.

Biogas is a mixture of gases that can be produced from a variety of biodegradable wastes such as cow dung, kitchen wastes, leafy biomass, human wastes, sewage sludge, municipal solid waste, bio-degradable waste or any other biodegradable feedstock. Depending on where it is produced, biogas is also called: swamp gas/marsh gas/landfill gas/digester gas. The process of biogas production also provides manure that can be used for agricultural purpose.

Biogas is produced by the anaerobic digestion or fermentation of organic matter in a three-stage process when consortia of bacteria act upon bio-degradable materials under anaerobic conditions. As specific bacteria feed on certain organic materials, various reactions and interactions take place among the methanogens, non-methanogens and substrates fed into the digester as inputs. The complex three-stage process of breaking down of inputs or digestion (methanization) is described below.

**3.01 Microbiology and biochemistry of Biogas Generation**

Biogas generation from any waste is the result of microbial metabolic activities. There are three main classes of bacteria: i) the aerobic bacteria that require oxygen to grow, ii) the facultative anaerobic bacteria that can
metabolize and grow with or without oxygen, and iii) the obligate anaerobic bacteria that can grow only in the absence of oxygen. Anaerobic bacteria are involved in biogas generation. Biogas is produced through a series of biodegradative steps. The first stage called the fermentative or hydrolytic stage, which is achieved by fermentative bacteria that hydrolyze complex biopolymers into simpler organic acids, alcohols, and carbon dioxide. In the second acetogenic stage, bacteria called acetogenic bacteria, act upon long chain fatty acids, alcohols and produce acetic acids, carbon dioxide and hydrogen. In the third and final stage, the methanogens utilize hydrogen produced by the earlier groups and convert acetate and carbon dioxide into methane. The whole process can be outlined as at Box 3.1.1.

### Box 3.1.1: Process of Biogas production

<table>
<thead>
<tr>
<th>Hydrolytic stage</th>
<th>Acetogenic stage</th>
<th>Methanogenic stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic matters</td>
<td>Organic acids</td>
<td>Methane +</td>
</tr>
<tr>
<td></td>
<td>Carboxylic acids</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td></td>
<td>alcohols</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Acetic acid</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hydrogen,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Carboxylic acids</td>
<td></td>
</tr>
</tbody>
</table>

**Stage 1. Hydrolytic and Fermentative Stage**

The waste materials of plant and animal origin consist mainly of carbohydrates, lipids, proteins and inorganic materials. In this stage, fermentative bacteria hydrolyse complex biopolymers like cellulose, hemicelluloses, starch, proteins, fats, and lignin, into simpler compounds with the help of extracellular enzyme released by the bacteria. All these bacteria act upon complex biopolymers and produce acetate, butyrate, propionate, lactate, succinate, ethanol, hydrogen and carbon dioxide. For example, the cellulose consisting of polymerized glucose is broken down to dimeric, and then to monomeric sugar molecules (glucose) by cellulolytic bacteria. Consequently, this stage is also known as polymer breakdown stage. Various acids are produced by the acid forming bacteria with the help of enzymes. The acid-forming bacteria break down molecules with six atoms of carbon (glucose) into molecules with less number atoms of carbon (acids) which are in a more reduced state than glucose. The principal compounds produced in this process are acetic acid, propionic acid, butyric acid and ethanol.

**Stage 2. Acetogenic Stage**

In this stage, the acetogenic bacteria act upon the products of hydrolytic and fermentative stage and convert them into acetate, carbon dioxide and hydrogen under anaerobic conditions.

**Stage 3. Methanogenic Stage**

In the methanogenic stage, the acids produced in Stage 2 are processed by methanogenic bacteria to produce methane. There are many species of methanogens, which are obligate anaerobes and ultimately responsible for the production of biogas. These bacteria utilize acetate, carbon dioxide and hydrogen as substrates for their metabolism and produce methane. The growth of these bacteria is completely inhibited at 0.01 mg/l dissolved oxygen. The reaction that takes place in the process is called Methanization. The process of digestion under anaerobic condition generates many products, by-products and intermediate products before methane – the final product, is produced.

**Chemical Reactions in Methane Production**

\[
\begin{align*}
C_{14}H_{11}O_5 + H_2O & \rightarrow C_3H_6O_2 \\
C_{12}H_2O_5 & \rightarrow 2 \text{CH}_3\text{COOH} \\
C_{12}H_2O_5 & \rightarrow \text{CH}_3\text{CH}_2OH + 2\text{CO}_2 \\
\text{CH}_3\text{CH}_2OH & \rightarrow \text{CH}_3\text{COOH} + \text{CH}_4 \\
2\text{CH}_3\text{CH}_2OH + \text{CO}_2 & \rightarrow 2\text{CH}_4\text{COOH} + \text{CH}_4 \\
\text{CH}_3\text{COOH} & \rightarrow \text{CH}_4 + \text{CO}_2 \\
4\text{H}_2 + \text{CO}_2 & \rightarrow \text{CH}_4 + 2\text{H}_2\text{O}
\end{align*}
\]

**Source:** Mittal, K.M. 1996
Pathogen removal through Anaerobic Fermentation

An important advantage of anaerobic fermentation is the reduction of pathogens in effluent and digested sludge. More than fifty types of infections have been reported to be transmitted from human excreta, which contains bacterial pathogens and parasites that are transmitted through various routes from one person to another. Most of the pathogens are aerobic in nature, that is, they require oxygen for growth.

During biogas generation there is a remarkable reduction (up to 85%) of bio-chemical oxygen demand (BOD) in the effluent of biogas plant in comparison to its inlet value. In absolute terms, the BOD of effluent is around 125 mg/l. When human waste is used as feedstock, the reduction of pathogens varies from 85 to 100% depending on their nature. However, number of total faecal coliform count is still higher than the permissible limit for discharge into any water body. Such effluent contains good percentage of nitrogen, potash, phosphate and other micronutrients for plants. However, it has odour, yellowish colour, high BOD and pathogen counts, which limit its direct use for agriculture/ horticulture or safe discharge in water body. The sludge can be further processed suitably to produce valuable manure.

3.02 Factors controlling Biogas Production

Biogas is produced through a series of degradative steps carried out by different groups of bacteria. The metabolic activities of these bacteria are controlled by different factors that directly or indirectly influence biogas production. These include factors such as biogas potential of feedstock, design of digester, inoculum, nature of substrate, pH, temperature, loading rate, hydraulic retention time, Carbon/Nitrogen (C/N) ratio, and volatile fatty acids.

Temperature

Temperature is an important factor affecting biogas generation. A rise or fall in the optimum temperature reduces gas production. Based on tolerance of temperature, there are three groups of bacteria active at different temperature ranges: psychrophilic are active below 20°C, mesophilic at 20°-40°C, and thermophilic at above 40°C. Anaerobic bacteria belonging to the last two groups are active in biogas production. A majority of them are mesophilic growing optimally at temperatures of between 35°-37°C. When the ambient temperature goes down to 10°C, gas production virtually stops. Satisfactory gas production takes place in the mesophilic range, between 25° to 30°C. Proper insulation of digester helps in increasing gas production in the cold season. When the ambient temperature is 30°C or less, the average temperature within the dome remains about 4°C above the ambient temperature. In hot regions, it is relatively easy to shade the digester to keep it in the ideal range of temperature, but cold climates present more of a challenge. Certain species of thermophilic methanogens grow optimally between 63°-65°C.

Hydraulic Retention Time (HRT)

Retention time (also known as detention time) is the average period that a given quantity of input remains in the digester to be acted upon by the methanogens. In a cow dung plant, the retention time is calculated by dividing the total volume of the digester by the volume of inputs added daily. Selection of the Hydraulic Retention Time (HRT) depends on the temperature and type of substrate used. Up to 35°C, the higher the temperature, the lower the retention time needed. Normally, the HRT varies between 15-30 days, but can be maintained for up to 50 days. If the retention time is too short, the bacteria in the digester are “washed out” and the fermentation ceases. Conversely, when the retention time is high, there is an increase in gas production and the die-off rate of different pathogens. Under the climatic conditions of colder regions, a retention time of 50 to 60 days is desirable. Thus, a digester should have a volume of 50 to 60 times the slurry added daily. For a night soil biogas digester, a longer retention time (70-80 days) is needed so that the pathogens present in human faeces are destroyed. However, for a higher retention period, the cost of a digester increases as the volume increases. In a human excreta fed pilot plant, a study on biogas generation under different HRT has been carried out.

Loading rate

Loading rate is the amount of raw materials fed per unit volume of digester capacity per day. If the plant is overfed, acids will accumulate and methane production will be inhibited. Similarly, if the plant is underfed, the gas production will be low.
Nature of substrate/feed material
Quality of feed material is one of the important factors controlling gas production rate. In order to grow, bacteria require macronutrients like carbon, nitrogen, phosphate, potassium, oxygen and hydrogen and micronutrients such as iron, manganese, molybdenum, zinc, cobalt, selenium, tungsten, nickel etc. Normal feed material such as night soil and animal droppings contain all these nutrients. In industrial wastes, some of them may be lacking. They may contain toxic elements that inhibit biogas production. Contents of biodegradable materials in the feed materials are an important factor. The ratio of Chemical Oxygen Demand and Biological Oxygen Demand (COD/BOD ratio), which gives the proportion of total organics to bio-degradable organic matter, indicates the amount of waste which is biodegradable. Lower the ratio, the more is the expected biogas production. In the case of night soil, this ratio is around 2.4, making it biodegradable. More details of pH of substrate/feed material is placed below:

pH of substrate/feed materials
The optimum pH (a measure of acidity or alkalinity of a solution) required by methanogens is 7.0; but they can grow as well between pH of 6.5 to 7.5. The optimum biogas production in a single phase digester is achieved when the pH of input mixture in the digester is between 6 and 7. Methanogenic bacteria are very sensitive to the pH and do not thrive below pH by 6.5. Later, as the digestion process continues, concentration of NH₄⁺ increases the pH to above 8. When the methane production level is stabilized, the pH range remains buffered between 7.2 to 8.2.

The slurry in the digester usually has a buffering capacity due to carbondioxide-bicarbonate (CO₂-HCO₃⁻) and ammonia-ammonium (NH₄⁺-NH₃⁺) which balance the pH level. The pH of influent of human excreta based biogas plant is acidic (5.2 to 6.5). However, the pH of effluent comes to 7.2 to 7.4 when the digester is continuously or semi-continuously fed. The pH in a biogas digester is also a function of the retention time. In the initial period of fermentation, as large amounts of organic acids are produced by acid forming bacteria, the pH inside the digester can decrease to below 5. In addition, the pH of digester content drops drastically to even 4.5 when feeding is discontinued for a week or more. This inhibits or even stops the digestion or fermentation process, and consequently gas production. The problem mainly arises in household biogas plants. The remedy for such plant is to completely desludge and add fresh feed material and inoculums.

Inoculation
In a batch system, growth pattern of bacteria maintains hyperbolic curve where static growth rate occurs between 10-20 days. Before this, there is a growth phase and after it – die off phase. In the case of semi-continuous or continuous fed system, the start time of biogas production can be shortened by using active effluent sludge as inoculum that contain active methanogens and acetogens. When it is mixed with feed material, bacteria multiply and spread completely into the feed material. Once the inocula are mixed during start time of the digester feeding, further inoculation is not required. The percentage of such inoculum in feed material has effect on gas production. A 20-25% (by volume) of such inoculum gives optimum result of gas production.

Continuous feeding and design
Complete anaerobic digestion of cow dung takes about 8 weeks at normally warm temperatures. One third of the total biogas is produced in the first week, another quarter in the second week and the remainder of the biogas production is spread over the remaining 6 weeks. Gas production can be accelerated and made more consistent by continuously feeding the digester with small amounts of waste daily. This will also preserve the nitrogen level in the slurry for use as fertilizer. The higher the volatile solid content in a unit volume of fresh dung, higher the gas production. For example, a kilogramme of volatile solids in cow dung would yield about 0.25 cubic meters biogas.

Dilution and consistency of inputs
Before feeding the digester, the feed, especially fresh cattle dung, has to be mixed with water at the ratio of 1:1 on a unit volume basis (that is, same volume of water for a given volume of dung). However, if the dung is in dry form, the quantity of water has to be increased accordingly to arrive at the desired consistency of the inputs.
(for example ratio could vary from 1:1.25 to even 1:2). The dilution should be made to maintain the total solids from 7 to 10 percent. If the dung is too diluted, the solid particles will settle down in the digester and if it is too thick, the particles impede the flow of gas formed at the lower part of digester. In both cases, gas production will be less than the optimum. It is also necessary to remove inert materials such as stones from the inlet before feeding the slurry into the digester. Otherwise, the effective volume of the digester will decrease.

**Carbon/Nitrogen (C/N) Ratio**

Bacteria need both nitrogen and carbon for their metabolic activities. If there is too little nitrogen present, bacteria will be unable to produce the enzymes needed to utilize carbon. If there is too much nitrogen then it can inhibit the growth of the bacteria. The relationship between the amount of carbon and nitrogen present in organic materials is expressed in terms of the carbon/nitrogen (C/N) ratio. For optimum anaerobic digestion/biogas production, a C/N ratio of 25-30 of the feed material is required. If the C/N ratio is very high, the nitrogen will be consumed rapidly by the bacteria methanogens for meeting their protein requirements and they will no longer react on the left over carbon content of the material. As a result, gas production will be low. On the other hand, if the C/N ratio is very low, nitrogen will be liberated and accumulated in the form of ammonia (NH₃). This will increase the pH of the content in the digester. A pH of higher than 8.5 starts showing toxic effect on the methanogen population. While selecting a mixture of organic wastes as feed material, care must be taken to achieve C/N ratio close to the optimum. The C/N ratio of night soil varies from 8-10. However, its higher biodegradable content makes it suitable for biogas generation.

<table>
<thead>
<tr>
<th>Raw Materials</th>
<th>Carbon/Nitrogen Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human excreta</td>
<td>8-10</td>
</tr>
<tr>
<td>Chicken dung</td>
<td>10</td>
</tr>
<tr>
<td>Goat dung</td>
<td>12</td>
</tr>
<tr>
<td>Pig dung</td>
<td>18</td>
</tr>
<tr>
<td>Sheep dung</td>
<td>19</td>
</tr>
<tr>
<td>Cow dung/ Buffalo dung</td>
<td>24</td>
</tr>
</tbody>
</table>

*Source: Mittal, K.M. 1996*

Animal waste, particularly cattle dung, has an average C/N ratio of about 24. The plant materials such as straw and sawdust contain a higher percentage of carbon. The human excreta have a C/N ratio as low as 8. C/N ratio of some of the commonly used substrate materials are presented in Table 3.2.1.

Materials with high C/N ratio could be mixed with those of low ratio to bring the average ratio of the composite input to a desirable level. In China, as a means to balance C/N ratio, it is customary to load rice straw at the bottom of the digester upon which latrine waste is discharged.

**Mixing/Agitation/Stirring**

Biogas generation is the result of three degradative steps controlled by distinct groups of bacteria. The metabolic product of first group of bacteria becomes the substrate for the second group and so on. Proper mixing of digester content is necessary to make the substrate available to all the groups of bacteria. Some method of stirring the slurry in a digester is always advantageous, if not essential. Other advantages of mixing are: i) bacterial population density becomes uniform, and ii) scum formation at the top layer of feed material is broken and mixed uniformly. If not stirred, the slurry will tend to settle out and form a hard scum on the surface, which will prevent release of the biogas. This problem is much greater with vegetable waste than with manure, which tends to remain in suspension and have better contact with the bacteria as a result. Continuous feeding causes fewer problems in this direction, since the new charge will break up the surface and provide a rudimentary stirring action.
Toxic Substances
The substances that have adverse effect on micro-organisms are detrimental for biogas generation too. These substances are heavy metals, antibiotics, detergents, phenyl etc. Therefore, in a public toilet, for cleaning, there should be minimum use of these toxic substances.

3.03 Advantages of Biogas Technology
Biogas is a valuable source of energy from waste. It can be used for heating, lighting, power generation and as a transport fuel (see Chapter 9). Biogas recovery can improve profitability while improving environmental quality. It maximizes farm resources and may prove essential for livestock industry to remain competitive and environmentally sustainable. In addition, widespread use of biogas technology will create jobs related to the design, operation, and manufacture of energy recovery systems and lead to the advancement of agribusiness. The principal reasons a farmer or producer would consider installing a biogas system are:

On-Site Farm Energy
By recovering biogas and producing on-farm energy, livestock producers can reduce monthly energy purchases from electric and gas suppliers.

Reduced Odours
Biogas systems reduce offensive odours from overloaded or improperly managed manure storage facilities. These odours impair air quality and may be a nuisance to nearby communities. Biogas systems reduce these offensive odours because the volatile organic acids, the odour causing compounds, are consumed by biogas producing bacteria.

High Quality Fertilizer
In the process of anaerobic digestion, the organic nitrogen in the manure is largely converted to ammonium ions. Ammonium is the primary constituent of commercial fertilizer, which is readily utilized by plants.

Reduced Surface and Groundwater Contamination
Digester effluent is a more uniform and predictable product than untreated sewage. The higher ammonium content allows better crop production and the physical properties allow easier land application. Properly applied, digester effluent reduces the likelihood of surface or groundwater pollution.

Pathogen Reduction
Heated digesters reduce pathogen population dramatically in a few days. Lagoon digesters isolate pathogens and allow pathogen kill and die-off prior to entering storage for land application.

Apart from the well known and documented benefits of decentralized green fuel, saving of wood and forests, soil beneficiation due to application of digested sludge manure, more and more new facts are coming up, some of which are listed below:

- In a study carried out in Tamil Nadu (India), biogas from cow dung was found to be effective as a fumigant for control of pulse beetle. Earlier, the effectiveness of biogas as a fumigant for control of pests during storage of paddy was demonstrated (Mohan and Gopalan, 1992).

- Production of spirulina on sea water supplemented with effluents from pig waste fed biogas plant was successfully carried out by the Institute of Ecology, Xalapa, Veracruz, Mexico. This would open the scope of stripping nutrients from effluents from pig manure based biogas plants.

- The economic returns can be made more attractive by integrating heat recovery utilization, power generation, pisciculture (fish production) and aquaculture (algae and duckweed production), which in turn can support production of fish meal and poultry meal.
**Digested Sludge/Biogas Manure**

Although the focus here is on waste to energy, it is important to reiterate the potential of using the byproduct obtained from the biogas plants after the digestion of dung or other biomass for the generation of methane rich gas. Digested sludge/biogas manure supplies essential nutrients; enhances water holding capacity and soil aeration; accelerates root growth and inhibits weed seed germination. Dry biogas manure has 20-30% solids and micronutrients and its pH is 7 to 8. It may be noted that if biogas manure is sundried, then there will be loss of nutrients.

**Table 3.3.1: Nutrient status of different Organic Manures with Biogas Manure**

<table>
<thead>
<tr>
<th>Sno.</th>
<th>Manure</th>
<th>N %</th>
<th>P₂O₅ %</th>
<th>K₂O %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fresh Cattle Dung</td>
<td>0.3-0.4</td>
<td>0.1-0.2</td>
<td>0.1-0.3</td>
</tr>
<tr>
<td>2</td>
<td>Farmyard Manure</td>
<td>0.4-1.5</td>
<td>0.3-0.9</td>
<td>0.3-1.9</td>
</tr>
<tr>
<td>3</td>
<td>Compost</td>
<td>0.5-1.5</td>
<td>0.3-0.9</td>
<td>0.8-1.2</td>
</tr>
<tr>
<td>4</td>
<td>Poultry Manure</td>
<td>1.0-1.8</td>
<td>1.4-1.8</td>
<td>0.8-0.9</td>
</tr>
<tr>
<td>5</td>
<td>Cattle Urine</td>
<td>0.9-1.2</td>
<td>Trace</td>
<td>0.5-1.0</td>
</tr>
<tr>
<td>6</td>
<td>Paddy Straw</td>
<td>0.3-0.4</td>
<td>0.8-1.0</td>
<td>0.7-0.9</td>
</tr>
<tr>
<td>7</td>
<td>Wheat Straw</td>
<td>0.5-0.6</td>
<td>0.1-0.2</td>
<td>1.1-1.3</td>
</tr>
<tr>
<td>8</td>
<td>Biogas Manure</td>
<td>1.5-2.5</td>
<td>1.0-1.5</td>
<td>0.8-1.2</td>
</tr>
</tbody>
</table>

*Source: Vasudeo, G., undated*

The data in Table 3.3.1 shows that the nutrient contents of digested sludge (biogas manure) is higher in comparison to manure produced by natural process. For effective use of higher nutrients it is necessary to apply the biogas manure as it is produced. Application of biogas manure depends on the suitability of land, its location from biogas plants and cost of labour for application. In rural areas of China, biogas plants are constructed within homestead areas at a higher level. Digested sludge is continuously applied to surrounding croplands (owned by the commune members) by gravity flow. In locations where digested sludge is stored and dried, its nutrient contents decrease. Thus, apart from its advantages over chemical fertilizers, digested sludge has proven superiority in its nutrient content since the fermentation process reduces C/N ratio by removing some of the carbon, thus increasing the fertilizing effect.

### 3.04 Conclusion

Although biogas production technology is well established and it can greatly influence energy availability in rural areas, its full potential has not been realised.

In terms of sanitation, while human excreta linked biogas plants are technically possible, they may not be socially acceptable in all socio-cultural environments. The reasons for problems in social acceptance of biogas generated from human waste include:

- Misconceptions amongst people about biogas from human waste being unhygienic and dirty;
- Socio-cultural taboos associated with human excreta and use of biogas from such wastes for cooking and other purposes. This is a formidable deterrent to the introduction of biogas production units;
- Lack of awareness about extent of advantages of biogas technology and its contribution to improved health and sanitation.

The socio-cultural taboos associated with use of human waste for biogas could be overcome as values change with time, and with advancement of education and awareness among people. In addition, for wider acceptability, the real benefits in using excreta in terms of reduction in risks to public health have to be demonstrated and publicised.
Serious limitations in the use of biogas production units include: i) the availability of feedstock; ii) defects in construction, and iii) microbiological failure. A review of literature reveals numerous alternate feedstocks and their potential for biogas production. It is time that substrate-specific biocatalysts are made readily available to reduce the lag period of biomethanation during the start-up. Regular supply of inocula and quality control of marketable inocula will result in regulating the plant function.

Furthermore, designs to suit the microbial catalysts have been discussed for long but are yet to reach the field. It requires coordinated efforts of scientists, and engineers to overcome these limitations in order to translate this "high potential" technology to "high performing" technology.

To sum up, while biogas technology has definitely made its entry into agriculture and its acceptance and profitability is increasing, appropriate institutions will have to be established in the countries for making biogas programme sustainable. Support programmes for biogas technology are therefore strategic investment decisions for future markets of the world economy. Aspects related to current scenario on adoption of this technology are discussed in the next section.
Bio-digester Models and their Adoption

Description of different types of digesters has been presented in this Chapter. The physical size of biogas plant (digester) has to be matched with users need and/or availability of feed materials. Different sizes of biogas plants in use can be listed as follows:

a) Small size biogas plants which are constructed for domestic use, the physical size of such plants depends on the amount of dung available from cows and buffalos (generally found in use in rural areas of India, Nepal and Bangladesh).

b) Medium size biogas plants attached to institutional latrines such as in schools, etc.

c) Medium to large size biogas plants for use of gas by a number of families for cooking in rural areas (community biogas plant). Collection of dung, use of gas and distribution of manure are shared by community members.

d) Large size biogas plant for power generation attached to poultry farms located in rural and sub-urban areas. Management is less complicated in comparison to community biogas plant.

e) Large size biogas plant for power generation attached to industrial units such as agro-processing industries located in industrial and sub-urban areas.

f) Large size biogas plant for power generation attached to Sewage Treatment Plants (STPs) in urban areas or townships. More formal institutional mechanism and qualified workers are required for the management of such biogas plants and power generation units.

The above examples indicate that biogas technology has applicability both in rural and urban areas.

4.01 Bio-digester Models

The bio-digester is a physical structure, commonly known as the biogas plant. Since various chemical and microbiological reactions take place in the bio digester, it is also known as bio-reactor or anaerobic reactor. It optimizes naturally occurring anaerobic bacteria that decompose and treat the manure while producing biogas. Digesters are covered with an air-tight impermeable cover to trap the biogas for on-site energy use. The choice of which digester to use is driven by the topography of the place, climatic conditions, soil conditions, existing (or planned) manure handling system. It can be made of various construction materials and in different shapes and sizes. Construction of this structure forms a major part of the investment cost. There are various types of plants. Based on the feeding method, three types can be distinguished, namely; Batch plants, Continuous plants and Semi-batch plants.
Batch plants are filled and then emptied completely after a fixed retention time. Each design and each fermentation material is suitable for batch filling, but batch plants require high labour input. As a major disadvantage, their gas-output is not steady.

Continuous plants are fed and emptied continuously. They empty automatically through the overflow whenever new material is filled in. Therefore, the substrate must be fluid and homogeneous. Continuous plants are suitable for rural households as the necessary work fits well into the daily routine. Gas production is constant and higher than in batch plants. Today, nearly all biogas plants are operating on a continuous mode.

If straw and dung are to be digested together, a biogas plant can be operated on a semi batch basis. The slowly degrading straw-type material is fed in about twice a year as a batch load. Cow dung is added and removed regularly.

Different models have been evolved in different countries particularly for the small family sizes. Chinese fixed dome digester and the Indian floating cover biogas digester are shown in Figures 4.1.1 and 4.1.2.

**Figure 4.1.1:** An outline of fixed dome biogas digester

**Figure 4.1.2:** Floating drum Biogas Digester
The digestion process is the same in both digesters but the gas collection method is different in each. In the floating cover type, the water sealed cover of the digester rises as gas is produced and acts as a storage chamber. Whereas the fixed dome type of digester has a lower gas storage capacity, it requires good sealing if gas leakage is to be prevented. Some of the commonly used digester designs based on the above two basic designs are discussed below. In both cases, water at inlet level should be above that of the outlet.

**Fixed Dome Digester**

Fixed dome Chinese model biogas plant (also called drum less digester) was built in China as early as in 1936. It consists of an underground brick masonry compartment (fermentation chamber) with a dome on the top for gas storage (Figure 4.1.1). In this design, the fermentation chamber and gas holder are combined as one unit. This design eliminates the use of costlier mild steel gas holders that are susceptible to corrosion. The life of fixed dome type plant is longer as compared to KVIC plant (India) unless drums are made of noncorrosive material.

In India, fixed dome Janata model was developed by Planning Research and Action Division (PRAD) in Lucknow in 1978 based on field trials conducted at the Gobar Gas Research Stations Ajitmal (Uttar Pradesh, India). The main feature of this model is that the digester and the gas holder are integrated parts of the brick masonry structure. The digester is made of a shallow well having a dome shaped roof on it. The inlet and outlet chambers are connected with the digester through large chutes. These chambers are above the level of the junction of the dome and the cylindrical well. The gas pipe is fitted on the crown of the masonry dome.

In an effort to reduce the investment cost, Deenbandhu model was developed in 1984 by the Action for Food Production (AFPRO), New Delhi. This model is designed based on the principle of minimization of the surface area of a biogas plant to reduce its installation cost without sacrificing the functional efficiency. The design consists of two spheres of different diameters, joined at their bases. The structure thus formed acts as the digester or fermentation chamber, as well as the gas storage chamber. The digester is connected with the inlet pipe and outlet tank. The upper part above the normal slurry level of the outlet tank is designed to accommodate the slurry to be displaced from the digester with the generation and accumulation of biogas. The general layout of Deenbandhu biogas plant is at Figure 4.1.3.

**Figure 4.1.3:** Layout of Deenbandhu biogas Plant

Deenbandhu plants are made entirely of brick masonry with a spherical shaped gas holder at the top and a concave bottom. In addition to these designs developed particularly for household use in developing countries, there are other designs suitable for adoption in other specific conditions. In India, the Deenbandhu model proved to be 30% cheaper than Janata Model and about 45% cheaper than a KVIC plant of comparable size. Currently, this model is the cheapest among all the available models of biogas plant.
Sulabh Model Digester

It is indeed significant to mention at this juncture the efforts of Sulabh International Social Service Organisation, promoted by Dr. Bindeshwar Pathak, an eminent Action Sociologist, Founder, Sulabh Sanitation and Social Reform Movement, wherein, a fixed dome model biogas plant has been successfully designed and developed for the community toilet linked biogas digester for generating biogas from human excreta (Figure 4.1.4). The digester is a Reinforced Cement Concrete structure with arched bottom, domed top and vertical side walls. The outlet chamber is extended to form a displacement chamber.

Figure 4.1.4: Sulabh Biogas Digester with Displacement Chamber

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**Functional Parameters of the Human Excreta Fed Digester**

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Volume of feed material per user per day (excreta + ablution and flushing water + occasional cleaning water)</td>
<td>4 Litres</td>
</tr>
<tr>
<td>2</td>
<td>Volume of digested sludge per user per day</td>
<td>0.00021 cum</td>
</tr>
<tr>
<td>3</td>
<td>Average hydraulic retention time (HRT)</td>
<td>30 days</td>
</tr>
<tr>
<td>4</td>
<td>Cleaning (desludging) interval for half yearly digested sludge</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Expected average biogas production per user per day</td>
<td>30 litres</td>
</tr>
<tr>
<td>6</td>
<td>Pressure of biogas inside the digester normal (connected to floating gas holder) maximum (up to safety limit)</td>
<td>20 cm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>120 cm</td>
</tr>
<tr>
<td>7</td>
<td>Slurry level inside the digester</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Normal</td>
<td>1.0 meter below crown of the top dome</td>
</tr>
<tr>
<td></td>
<td>Maximum (highest)</td>
<td>0.2 meter below maximum slurry level</td>
</tr>
<tr>
<td>8</td>
<td>Diameter : depth ratio</td>
<td>1.5 : 1.0</td>
</tr>
<tr>
<td>9</td>
<td>Rise of top dome (h1)</td>
<td>D/5</td>
</tr>
<tr>
<td>10</td>
<td>Rise of bottom dome (h2)</td>
<td>D/2</td>
</tr>
<tr>
<td>11</td>
<td>Position of inlet pipe</td>
<td>H/3 below the top ring beam</td>
</tr>
<tr>
<td>12</td>
<td>Position of outlet pipe</td>
<td>middle height of the cylindrical wall</td>
</tr>
</tbody>
</table>

Gas storage space is provided under the dome for 50% gas storage. In this design inlet is located at 90° to the outlet. The extended outlet provides more space for the displaced liquid and reduces the variation in gas pressure to some extent while using biogas. Feed materials flow into digester under gravity without any manual handling. The daily gas production capacity of Sulabh digesters varies from 15 cum to 60 cum depending on the size of the digester and the number of users of the toilets. A type design of 15 cum biogas plant is shown at Figure 4.1.5. The rate of gas production is one cubic foot per user per day. Since anaerobic condition is maintained inside digester, most of the pathogens are eliminated. The percentage reduction of various bacterial and other pathogens at different Hydraulic Retention Times has been reported by many researchers. Survival of
Salmonella has been reported for up to one month and of Shigella for more than twenty days. Studies by the Sulabh Academy have shown that with increasing Hydraulic Retention Time, there is greater reduction of all the bacterial pathogens. The advantages of the digester system are:

- No manual handing of human excreta is required at any stage.
- Aesthetically and socially accepted.
- Technically appropriate and financially affordable.
- Operations and Maintenance costs are almost nil.
- Biogas is used for different purposes.
- Provides complete ecological sanitation at community level in addition to uses of biogas for different purposes.
- Treated effluent is safe to reuse or discharge into any water body. In drought prone areas treated effluent can be used for cleaning of floor of public toilets.

**Figure 4.1.5: Type Design of Sulabh Biogas Plant linked to Public Toilet (15 cum plant for 525 users)**

![Diagram of Sulabh Biogas Plant]

**Section Elevation**

**Bottom Plan**

**Top Plan**

*Source: SITTRAT, New Delhi*
As an extension to the above development, a simple and convenient technology has also been developed for effluent treatment. The SET (Sulabh Effluent Treatment) technology is based on sedimentation and filtration of effluent through sand and activated charcoal followed by exposure to ultraviolet rays (Figure 4.1.6). The schematic diagram is shown at Figure 4.1.7.

**Figure 4.1.6:** Sulabh Effluent Treatment System in Biogas Plant

![Sulabh Effluent Treatment System in Biogas Plant](image)

**Figure 4.1.7:** Schematic diagram of Sulabh Public Toilet linked Biogas Plant with SET Technology

![Schematic diagram of Sulabh Public Toilet linked Biogas Plant with SET Technology](image)

The system consists of an overhead sedimentation tank of 2000 liters capacity with conical shaped bottom fitted with valve. Effluent from outlet chamber of biogas plant is lifted to this tank and left for one and half hour to settle. It is passed through the sand filter column through Liquid Flow Meter (LFM). From sand column, effluent passes under gravity through an activated carbon column where carbon contact time is maintained for 5-6 minutes. Flow through the carbon column is upward. From this column it passes through U-V channel that helps eliminate bacteria and other pathogens. The treated effluent is colourless, odourless, pathogen free having...
BOD less than 10mg/l - quite safe for aquaculture, agriculture/ horticulture purposes or discharge into any water body without causing pollution. It can also be used for floor cleaning of public toilets in water scarcity areas.

**Floating Drum Digester**
The first known design of the floating gas-holder/dome bio-digester in India evolved in 1937, the floating drum biogas plant model popularly known as Gobar Gas plant was developed in 1954-56 by Jashubhai J. Patel. In 1962, Patel's design was approved by the Khadi and Village Industries Commission (KVIC) of India, and hence is known as the KVIC model. These were standardized in 1962 and are used widely currently. The digester chamber in the KVIC Model is a vertical pit made of brick masonry in cement mortar (Figures 4.1.2). A mild steel drum (gas holder) made of mild steel is inverted in the digester on a wedge shaped support to collect the biogas produced from the digester. This drum can move up and down along a guide pipe with the accumulation and disposal of gas, respectively. The weight of the drum applies pressure on the gas to make it flow through the pipeline to the point of use. Drums made of fibre glass or high density plastic (HDP) are also being used in place of mild steel drum that is subject to corrosion. Horizontal flow digester with floating gas holder is a variation of KVIC design suitable for areas where deep digging is not possible due to rocky terrain or due to high water table. In the floating drum models, as the gas collects, the drum floats and gas is at a pressure due to the weight of the gas holder unit in contact with the slurry underneath. Thus, there are two separate structures for gas production and collection. A typical design of the KVIC biogas plant is illustrated at Figure 4.1.8.

**Bag digester**
This design was developed in 1960s in Taiwan. It consists of a long cylinder made of PVC or red mud plastic, and combines the digestion chamber, settling tank and gas holder as one unit. The gas is stored above the digestion liquid. The biogas bag is supported so that the outlet of the bag is at level with the ground. The bag digester was developed to solve the problems experienced with brick and metal digesters. The plastic bag bio-digester could be successful only if PVC bag or Red Mud Plastic (RMP) is easily available, and welding facilities are available. The biogas bag digester was manufactured in Taipei and was propagated by the Institute of Natural Resources at the University of South Pacific, Fiji (UNESCO, 1982).

**Plug flow digester**
It consists of a trench (trench length has to be considerably greater than the width and depth) lined with concrete or an impermeable membrane. The reactor is covered with a flexible cover gas holder anchored to the ground. The first documented use of this type of design was in South Africa in 1957.

**Anaerobic filter**
This type of digester was developed in the 1950s to use relatively dilute and soluble wastes in water with low level of suspended solids. It is one of the earliest and simplest types of design developed to reduce the reactor volume. It consists of a column filled with a packing medium. A variety of non-biodegradable materials have been used as packing media for anaerobic filter reactors such as stones, plastic, mussel shells, reeds, and bamboo rings. The methane forming bacteria form a film on the large surface of the packing medium and are not carried out of the digester with the effluent. For this reason, these reactors are also known as "fixed film" or "retained film" digesters.

**Covered Lagoon Digester**
This type of digester is used in USA. Covered lagoons are used to treat and produce biogas from liquid manure with less than 3 percent solids. Generally, large lagoon volumes are required, preferably with depths greater than 12 feet. The typical volume of the required lagoon can be roughly estimated by multiplying the daily manure flush volume by 40 to 60 days. Covered lagoons for energy recovery are compatible with flush manure systems in warm climates. Covered lagoons may be used in cold climates for seasonal biogas recovery and odour control.
Figure 4.1.8: Typical design of the KVIC biogas plant

KVIC Biogas Plant 4 cum and above: Section

KVIC Biogas Plant Design Dimensions

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
<th>15</th>
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<tr>
<td>B</td>
<td>257</td>
<td>277</td>
<td>307</td>
<td>307</td>
<td>347</td>
<td>347</td>
<td>440</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>150</td>
<td>170</td>
<td>200</td>
<td>200</td>
<td>215</td>
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<tr>
<td>D</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>E</td>
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<td>23</td>
<td>23</td>
<td>23</td>
<td>23</td>
<td>23</td>
<td>40</td>
<td></td>
</tr>
</tbody>
</table>

General Layout of KVIC type biogas plant
Up-flow Anaerobic Sludge Blanket (UASB)

This UASB design was developed in 1980 in the Netherlands. It is similar to the anaerobic filter, in that, it involves a high concentration of immobilized bacteria in the reactor. However, the UASB reactors contain no packing medium. Instead, the methane forming bacteria are concentrated in the dense granules of sludge blanket that covers the lower part of the reactor. The feed liquid enters from the bottom of the reactor and biogas is produced while liquid flows up through the sludge blanket. Many full-scale UASB plants are in operation in Europe using wastewater from sugar beet processing and other dilute wastes that contain mainly soluble carbohydrates.

Bi-phasic Anaerobic Digestion System

The two-phase system consists of a solid phase reactor and methane phase reactor. In the solid phase, water is applied from the top of the waste using a drip or sprinkler irrigation system. The leachate is collected at the bottom of the solid phase using an under drain sump, and the leachate is then re-circulated through the solid waste bed until a desired level of volatile fatty acids is achieved in the leachate. At this point the leachate is transferred to the methane production reactor where the volatile fatty acids are converted to methane in a very short time (2–3 days). The overflow from the methane production reactor is then returned to the solid phase for re-circulation through the solid waste bed to replenish the volatile fatty acids concentration. The system works with a relatively small quantity of water (about 25% greater than the solid waste field capacity on weight basis) which is constantly re-circulated between solid phase and methane phase.

The two-phase system has several advantages over the traditional single phase systems. First, the total detention time in the two-phase system is considerably shorter than the detention time in the single phase system. The average duration of a two-phase system is 6–12 days compared to single phase system that lasts 30–50 days. Secondly, the gas conversion efficiency in two-phase system is also significantly higher than single-phase system. The gas conversion for the two-phase MSW system is 0.66–0.85 m³ of methane per kg of volatile solids consumed. This is compared with 0.22–0.48 m³ of methane/kg of volatile solids (VS) consumed for the single phase system. In addition, the methane concentration in the produced gas is higher in two-phase system than the single-phase system. The methane concentration in a two-phase system is 50–80% by volume compared to 40–60% for a single phase system (Chynoweth et al, 1993; Brummel et al, 1992; Pohland et al, 1975; Beccari et al, 1998; Ghosh et al, 1995).

For example, the system produces an average of 0.15 cubic meters of methane per kg of grass. The average methane concentration in the produced gas was 71%. The two phase system is especially useful for digesting municipal solid waste, biomass, etc.

Anaerobic digestion leads to significant pathogen destruction and two-phase operation allows for a lower pH in the acid phase that will further contribute to the destruction of pathogens. Thus, biphasic fermentation of MSW is an economically feasible technology that can be used to rapidly stabilize wastes for energy recovery and land application.

Size and models of the plant and its selection

Size: The Biogas Plants are being built in many sizes. Table 4.1.1 gives the feed requirement for popular sizes.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Size of biogas plant (m³ gas production capacity)</th>
<th>Pig droppings in kg (Ave. no. of pigs)</th>
<th>Poultry droppings in kg (Ave. no. of birds)</th>
<th>Fresh cattle manure in kg (Ave. no. of cattle)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>13.5 (6)</td>
<td>(18)100</td>
<td>25(2)</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>27 (12)</td>
<td>36 (200)</td>
<td>50 (4)</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>54 (24)</td>
<td>72 (400)</td>
<td>100 (8)</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>130 (60)</td>
<td>180 (1000)</td>
<td>250 (20)</td>
</tr>
<tr>
<td>5</td>
<td>30</td>
<td>390 (180)</td>
<td>540 (3000)</td>
<td>750 (60)</td>
</tr>
<tr>
<td>6</td>
<td>60</td>
<td>780 (360)</td>
<td>1080 (6000)</td>
<td>1500 (120)</td>
</tr>
</tbody>
</table>

Source: GATE, 1992
The smallest plant has 1m³/day capacity, which can produce roughly around 1 cubic meter of gas per day, which will be sufficient for preparation of food for two persons. The other common sizes are 2, 3, 4, 6, 8, 10, 15, 25, 35, 45, 60, 85 and 140m³/day capacity. These sizes can be classified into two groups. Plants ranging from size 1m³/day to 10m³/day are classified as family-size plants and those ranging from 15m³/day to 140m³/day are called as larger size plants. These can cater to the needs of institutions/community centres etc.

4.02 Operation and Maintenance of Biogas Plants
During operation and maintenance of biogas plants some problems arise. These can be overcome as follows:

Test for leakage
This is one of the major problems with digester made up of bricks. However, in digesters made from reinforced cement concrete, such problems do not generally arise. In a fixed dome digester any leakage can be detected in a simple way. Fix a manometer with gas outlet and fill the digester with water through inlet chamber. Take the reading of the pressure at both the arms of the manometer. After 24 hrs, the water column of manometer is checked for a drop in level. Drop in water column is an indication of gas leakage from the digester. Now the leak can be located by pouring soap water on all suspected locations. For any repair of dome, inside pressure of biogas should be released first. After locating the gas leakage point, it should be replastered with cement and sand.

Inoculation of digester
Human excreta rarely contain methanogenic bacteria. Therefore, for the gas production from human excreta, inoculums in the form of cow dung or digester effluent that contains methanogenic bacteria is required. Twenty per cent inoculum (by volume) is optimum for gas production. It is added only during the start-up of the digester.

Production of gas
Gas production starts after 8th day of inoculation. Initially it contains mainly carbondioxide. Gradually percentage of carbondioxide decreases and methane increases. After 20 days biogas production reaches stationary phase and percentage of methane in biogas and its rate of production becomes more or less constant.

Removal of water from gas pipe
Biogas contains moisture that accumulates in the gas pipe and sometimes blocks gas flow. Therefore, a moisture trap, where condensed moisture is stored, is fixed at the junction of delivery pipe. The moisture is released from the moisture trap once a week.

Scrubbing unwanted gases
Methane is the only combustible constituent of biogas, while gases such as carbondioxide and hydrogen sulphide reduce the calorific value of methane and are a health hazard when inhaled for long. Hence, to increase the calorific value of biogas, these gases have to be scrubbed off. If the volume of hydrogen sulphide is low, it can be removed through a cylindrical or conical scrubber filled with iron sponge or copper foil. The sulphur of hydrogen sulphide is trapped as a sulphide of iron or copper. Carbondioxide, especially for small scale operations, is removed by passing biogas through a solution of calcium hydroxide where carbondioxide forms calcium carbonate and precipitates. It can also be removed by passing it through high pressure water column to dissolve carbondioxide and form carbonic acid.

4.03 Digester Models in Different Countries
During the energy crisis of the 1970s, although there was interest in the biogas plants developed in India and China, they were found to be too small for the large farms in USA. Subsequently, based on the percentage of total solids in the manure, four types of anaerobic digesters were evolved – plug-flow type, slurry type, completely mixed and covered lagoon type.

The first farm based methane digester was commissioned in May 1972 in the periphery of Mt. Pleasant, Iowa (US Department of Energy, 1995) after a nearby town expanded to the border of the farm. The primary aim was to remove the odour from a hog production facility built during 1951-53. Initially, the lagoon in the farm was converted into an aerobic system where chemicals were used. When this did not solve the problem, decision was
made to introduce a system that would keep the manure odour free and allow the stabilized manure to be spread as per the farm’s schedule.

Although not exclusively an African model, the first documented use of the “Plug-flow” digester was from South Africa in 1957 (World Bank, 1986). Later studies have shown that for high solid concentrations, the plug-flow system produces more biogas compared to the completely mixed system. The two models that have been tried are: i) OLADE model (the Latin American Energy Organization), also known as OLADEGuatemala model (Ji Quin Ni) and ii) the Central American Industrial and Technological Research Institute (ICAITI) model, which is a horizontal digester that has been installed in Costa Rica, Guatemala, Honduras and El Salvador (Ji Quin Ni).

The system for collection of manure and the size of the farms are important determinants in selecting the digesters. If the manure is collected by a scraping mechanism, the solids would be much higher and a plug-flow system would be suitable. In a farm where the manure is hosed down with water, a covered anaerobic lagoon would be more suitable. The performance of many digesters has not been good. The problems and varied failure rates for the different type of the plants were ascribed to inadequate design or installation including lack of experienced contractors. Of the 39 plug-flow digesters installed, only 9 were operational, while of the 17 completely mixed digesters, 4 are operational; 7 out of 10 covered lagoon type digesters installed and all 5 slurry type digesters were operational (US Department of Energy, 1995).

The issues involved with larger facilities in agricultural farms and dairies, including the experience of methane recovery from animal manures generated in dairy, swine and poultry farms from the early 1970s to mid-1990s, are related more to technological constraints and return on investments. Although the methane recovery plants were primarily set up to mitigate environmental concerns like surface and ground water pollution, odour, GHG emission, air pollution and dust, it was soon realized that this system had the potential of turning the waste liability into a profit making venture. It further allowed growth in the business of livestock production in the face of declining commodity prices.

### 4.04 Scenario of Biogas Technology Adoption

**China**

With the energy policy target of China to achieve a renewable energy supply of 16% by 2020 from 7% in 2004, there is a change in the application of biogas technology for different bio-wastes. It is projected that biogas will contribute 24bn nm³ from all suitable biomass sources. Some of the biogas plants for municipal solid waste and food waste are based on the sophisticated imported technologies (Table 4.4.1).

**Table 4.4.1: Biogas plants for MSW and food waste under consideration in China**

<table>
<thead>
<tr>
<th>Location</th>
<th>Feedstock</th>
<th>Technology Developer</th>
<th>Capacity (MT/annum)</th>
<th>Cost (Euro)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beijing</td>
<td>Restaurant &amp; MSW, Manure</td>
<td>Linde Valorga Biomax</td>
<td>0.2</td>
<td>Inv. 18m Fee 13.5/t</td>
</tr>
<tr>
<td>Shanghai</td>
<td>Municipal wet waste</td>
<td>Valorga Biomax</td>
<td>0.18 to 0.29</td>
<td>Inv.30m Fee 17/t</td>
</tr>
<tr>
<td>Guangzhou</td>
<td>Municipal wet waste</td>
<td>Valorga Biomax</td>
<td>0.36</td>
<td>Inv 32</td>
</tr>
</tbody>
</table>

*Source: Zhao, Y, Ji, Rong et al. 2007*

China has extensive experience in the application of anaerobic fermentation technologies and has network of research centres and capacity to manufacture anaerobic digesters. The potential of domestic biogas plants in China has been estimated to be 150 million and the Ministry of Agriculture has set the objectives of increasing the number of domestic biogas plants to more than 27 million by 2010. China currently has a total of over 12 million household biogas digesters and over 1,500 industrial-scale biogas plants, which together produce over five billion cubic meters of biogas annually (Junfeng Li, Zhongying Wang and Jingli Shi, 2005). The numbers of domestic biogas plants in use has increased substantially because of the efforts of the Government of China to disseminate biogas technology. Some provinces of Guangxi, Sichuan, Yunnan and Guizhou have installed more
domestic biogas plants with more than 100,000 new digesters annually due to favourable financial support. The biogas plants being set up are based on the fixed dome hydraulic biogas plants design. However, there are biogas digesters with separate floating gas drum and with slurry recycle arrangement. During 1970s, China too had to deal with unsuccessful biogas plants due to the lack of proper design, poor quality of construction, lack of qualified masons and technicians, and due to the poor economy and institutional conditions. However, with improved institutional and financial support, active promotion, installation support, adequate quality control and training and post installation service, there is increased dissemination of biogas plants. The cost of biogas plants in China varies depending on the region of installation and on the various components. The details of the cost of an 8 cubic meters plant is at Table 4.4.2. Government subsidy and farmer users are the sources of finance.

### Table 4.4.2: Cost of biogas plant & related items in China (1 USD=6.82 Chinese Yuan)

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Biogas plant (8m³)</td>
<td>226</td>
</tr>
<tr>
<td>2. Kitchen remodelling</td>
<td>24</td>
</tr>
<tr>
<td>3. Toilet remodelling</td>
<td>39</td>
</tr>
<tr>
<td>4. Pen remodeling</td>
<td>230</td>
</tr>
<tr>
<td>Total</td>
<td>518</td>
</tr>
</tbody>
</table>

Source: Hu Qichun, 2006

### Box 4.4.1: Chicken wastes Based Biogas Plant in China

The Beijing Deqingyuan Chicken Farm Waste Utilization Plant (www.cleantechnica.com) seeks innovative ways to meet the energy and environmental requirements. Located in YanQing District, about 50 kilometers north of Beijing, the farm owns three million chickens, producing 220 tons of manure and 170 tons of wastewater each day. The farm’s new cogeneration system features an anaerobic digester system to treat the waste material, producing enough biogas to fuel two GE’s Jenbacher JMS 320 G5-B.I. gas engines. The plant has an installed electric capacity of more than 2 MW for use at the chicken farm. Additionally, the plant’s thermal output is used to support the chicken waste fermentation process and heat the chicken farm in the winter. Providing 14,600 MWh of electricity per year, the project is designed to help reduce suburban electricity shortages. The plant is the first of its type in China and could pave the way for similar applications in the future.

By using the biogas for power generation in place of previously used coal-fired power, the new project is expected to reduce the equivalent of about 95,000 tons of carbon dioxide per year, qualifying the project for the U.N. sanctioned Clean Development Mechanism (CDM) programme (www.arti-india.org).

### Taiwan

In 1975, the Taiwan Livestock Research Institute (TLRI) developed the first horizontal-type anaerobic fermenter using a bag of Red Mud Plastic in which hog wastes were treated (www.cag-net.org). After many years of improvement, a three-step treatment system that includes solid-liquid separation, anaerobic treatment and aerobic treatment, was developed. A 1:3 ratio of manure to washing water is suggested, which can easily be achieved with a flushing tank system. According to Hong (1985), the daily excreta of a 100 kg pig comes to around 5 liters and the total wastewater from one pig may be estimated as 20 liters. A HRT of 12-15 days is common for hog wastewater treatment (Sheen et al, 2008).

A tent-type fermenter should consist of no fewer than two digesters. The volume of the first digester is usually 1.2 times the daily wastewater. Both acidogenesis and sedimentation take place in this first digester. Most of the methanogenic reaction occurs in the rear digesters. Biogas may be collected for use as fuel. The excreta of each pig can generate 0.1-0.3m³ of biogas per day.

This system has been extended to hog farmers since 1987 and is considered most suitable for Taiwan’s conditions. According to the official data from 1993, out of the 9,108 hog farms that raised more than 200 pigs,
6,827 have installed waste treatment facilities. Tent-type anaerobic digesters have been adopted on more than 2,000 farms and a three-step wastewater treatment system has been adopted on more than 1,000 farms. After the three-step treatment, the BOD and suspended solids (SS) of treated water are both below 100 mg per liter, which meets national regulatory standards.

TLRI has also developed a manure-bed pig house that is suitable for pig farms located in protected water resource areas or for farmers raising less than 200 pigs (for which elaborate waste treatment facilities are not economical). While one-third of the pig bed is dug out into a 30 cm deep pit filled with rice husks or wood chips to absorb the pig excreta, the rest is left for feeding and other activities. The manure-bed piglets do not generate wastewater and hence cleaning is required only when the pigs are sold. The mixture of hog manure and rice husk or wood chips is made into compost. After one month of composting, the mature compost can be used as fertilizer for crops.

Nepal
The potential for biogas generation from cattle manure and from co-digestion of cattle manure and night soil in Nepal has been estimated to be 613 million cubic meters and 673 million cubic meters respectively. The biogas programme in Nepal started in 1955 with the introduction of the first biogas plant and it has a very successful record (Baigain, S. and Kellner, C., 2005). Biogas technology has been commercially introduced since the establishment of Gobar Gas Tatha Krishi Yantra Vikash (P) Ltd. in 1977 (Devkota, G.P., 1998).

In 1992, a non-governmental organisation based in Kathmandu decided to exploit natural resources to make small-scale changes with large impacts. Widespread promotion of domestic biogas plants was started in Nepal with the establishment of the Biogas Support Programme with Dutch and German support to tap the energy stored in cattle dung. The objective was to popularize biogas plants amongst farmers, particularly small farmers, and to evolve a structured programme for facilitating and controlling privatization of the sector for wider implementation. A differential subsidy regime was worked out to support the small farmers and to encourage the farmers in the hilly regions. Loan is provided to farmers for the financing of biogas plants (van Nes, W.J., 1993). The satisfactory functioning of the plants is indicated by the satisfactory repayments of loan.

The Biogas Support Programme has contributed significantly to the dissemination of biogas plants in different geographical regions of Terai Hills and remote hills (BSP, Nepal). Of 140,457 domestic biogas plants constructed in 66 Districts under the Biogas Support Programme (as of July 2005), 97% were operating well. 90% of the biogas produced was used for cooking while 10% was used for lighting (using mantle type biogas lamps), especially in hilly areas. Table 4.4.3 gives the financial support by the Government, including the plant cost and subsidy for different capacity plants. For the 4 and 6 cubic meters capacity plants in Terai and remote hilly districts, the subsidy rates are Rs. 6,500 and Rs. 12,500 respectively, whereas for 8 cubic meters plant, the rates for the two regions are Rs. 6,000 and Rs. 12,000 as compared to Rs. 9,000 for hills (BSP, Nepal). Some of the key factors under the Nepal biogas programme for maximizing the installations and functionality are adopting a uniform design, having quality control and monitoring, after sales service, awareness programmes, financial support in the form of government subsidy, micro-credit etc. As per an estimate of Winrock, 800,000 farmer households in Nepal are potential customers of microcredit for the installation of biogas plants. Significant effort is made by various organizations to mobilize the micro financing institutions to achieve the target of 200,000 additional installations by 2009 (Practical Action). In June 2005, the Biogas Support Programme won an Ashden Award for Sustainable Energy for “outstanding achievement in using sustainable energy to improve the quality of life and protecting the environment”.

An extensive programme called BEP (Biogas Extension Programme) has been supported by GATE/GTZ (German Appropriate Technology Exchange/Deutsche Gesellschaft fur Technische Zusammenarbeit GmbH) in developing countries using the model of Bremen Overseas Research and Development Association (BORDA), Germany (Ludwig Sasse, 1991). A Dutch aid organisation called SNV, which was involved in the Biogas Sector Partnership in Nepal is now replicating the project in Bangladesh, Cambodia, Vietnam and parts of Africa.
Table 4.4.3: Financial details for 6m³ capacity plants in Nepal (Hills)

<table>
<thead>
<tr>
<th>Year</th>
<th>Plant cost in Nepali Rupees</th>
<th>Subsidy in Nepali Rupees</th>
</tr>
</thead>
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<tr>
<td>2000-01</td>
<td>23,648</td>
<td>10,000</td>
</tr>
<tr>
<td>2001-02</td>
<td>23,673</td>
<td>9,500</td>
</tr>
<tr>
<td>2002-03</td>
<td>23,673</td>
<td>9,500</td>
</tr>
<tr>
<td>2003-04</td>
<td>23,298</td>
<td>8,500</td>
</tr>
<tr>
<td>2004-05</td>
<td>24,129</td>
<td>8,500</td>
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<tr>
<td>2005-06</td>
<td>24,621</td>
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<tr>
<td>2006-07</td>
<td>31,515</td>
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</tr>
<tr>
<td>2007-08</td>
<td>35,153</td>
<td>9,500</td>
</tr>
</tbody>
</table>

Source: NBPG, Government of Nepal

Bangladesh

With a total cattle population of 24.19 million, there is a potential to generate 8 million cubic meters of biogas in Bangladesh. The activity was initiated by Bangladesh Agricultural University and Bangladesh Council of Scientific and Industrial Research in the 1970s with the construction of the first family size biogas plant of 3 cubic meters capacity. Further with the initiation of the biogas production technology programme in 1999, 5,000 biogas digesters of varying capacity were installed in the same year. The cost of the plants varied between 3,000 to 12,000 Taka. The economic benefit of the biogas plants depended largely on the price of fuelwood, cost of construction and government subsidy.

With the formation of Infrastructure Development Company Ltd. (IDCOL), more than 7,000 biogas plants were set up under National Domestic Biogas and Manure Programme with support from the Government of Bangladesh and other multilateral organizations such as SNV Netherlands and KfW. It has been proposed to install a total of 60,000 domestic sized biogas plants with a fixed dome design during the period 2006-2009 (IDCOL Website). As in other Asian countries, the biogas is being used for cooking and lighting in rural households and the slurry is used as a good organic fertilizer or as fish feed. The capacity of the plants with cattle dung, night soil or with poultry droppings are in the range of 1.2, 1.6, 2.0, 2.4, 3.2 and 4.8 cubic meters gas production. The sizes are suitable for single household except for the 3.2 and 4.8 cubic meters plants. There is involvement of partner organizations for construction, financial support, for manufacturing and overall implementation. In addition to investment subsidy of 7000 Taka, there is a refinace to the extent of 80% of the loan to households at 6% interest rate.

A financial analysis carried out for an improved biogas plant with a capital cost of Taka 25,000 and life time of 15 years, indicates a financial internal rate of return (FIRR) of 17 percent (IDCOL & SNV, 2006). For successful implementation of the programme, in addition to awareness and training, strong emphasis is given to quality control during construction by employing trained masons, using approved construction materials, appliances, standard practices and to operation and maintenance through after sales services.

Sri Lanka

The origin of biogas plants in Sri Lanka goes back to the early 1970s with biomass fuels providing 45% of Sri Lanka’s energy (Mae-Wan Ho et al. 2006). 80% of the biogas is consumed for cooking food on fires and stoves (Munasinghe, undated). However, the Intermediate Technology Development Group (ITDG)/Intermediate Technology Sri Lanka (ITSL) found that poor design, lack of maintenance skills and insufficient capacity to deal with the problems led to only a third of the 5,000 biogas digesters of those installed in Sri Lanka since the 1970s were functional (ITDG 2005). To improve the success rate of the units on a national level, ITDG set-up demonstration units to help spread information, restored abandoned units and trained users to operate and maintain them. With further developments in the design and with feedstocks in addition to cow dung namely paddy straw, the Sri Lankan batch model developed by NERD (National Engineering Research and Development Centre) found its application with various farmers growing paddy. The biogas was mainly used for
lighting and cooking and there were efforts by the government and non-governmental organizations in spreading the awareness to the user community and in training of their officials. There were also favourable financial schemes in the form of subsidies by the Department of Animal production and Health and Energy Ministry. The favourable factors resulted in the increase in the number of functional biogas plants to about 76% in the case of the 350 biogas plants set up by ITDG. The plants were mainly of the domestic stand alone units. For wider replication and scale up, there is a need for proper financing support for setting up of biogas units, which cost about USD 350 per unit (ITDG 2005).

India

India has a vast potential of biogas. The combined population of cattle and buffaloes in India, as per livestock census of 2001 would yield 1000 million tons of cattle waste annually. Therefore, the biogas potential in the country is about ten million cubic meters per annum. The gas produced from cattle dung itself has a net heat value of 3.12 X 10^{14} kcal. Government of India has taken wide-ranging initiatives for the development and popularization of renewable energy sources.

A National Programme on Biogas Development (NPBD), which was launched in 1981, has been subsequently developed into a more comprehensive "National Biogas and Manure Management Programme" (NBMMP) under the Ministry of New and Renewable Energy (MNRE). The total potential of family size biogas plants under the Programme was estimated at more than 12 million biogas plants, while the cumulative achievement as on March 2007 was 0.39 million family-size biogas plants. The total number of community size (medium and large size) biogas plants installed under the Ministry’s programme was 3,902 in March 2002. More than 3380 community/institutional biogas plants and night-soil based biogas plants (NBP) have been installed all over the country with most reporting satisfactory performance levels. The family biogas plants in the country are estimated to be saving 3.96 million tons of fuel-wood per year. Besides, about 0.92 million tons of enriched organic manure are produced every year from these plants.

In addition, required infrastructure has been established in many cities for use of CNG in vehicles that can also be used for compressed bio-methane (Bio-CNG). There is considerable potential for generating compressed bio-methane in cattle sheds, dairies, community biogas plants, distilleries, sewage treatment plants, food processing industries etc. It can become a commercial venture to establish large size biogas plant and making compressed bio-methane filling station. Various Bio-CNG trial plants are operational at cattle-sheds at Jaipur, Rajkot and Ghaziabad. A pilot Bio-CNG production plant, solely based on sewage wastes, will be operational shortly at Okhla Sewage Treatment Plant, New Delhi.

Some of the Indian experiences of Biogas Plants are illustrated at Appendix I.

Thailand

The Government of Thailand has set the year 2011 as the target for generating 8% of the nation’s total energy, representing an estimated 1,900 MW from renewable energy sources compared to 1% of electricity generated from renewable sources in 2004 (Visvanathan). The objective is to strengthen energy security and sustainability by developing alternative sources of energy since Thailand relies substantially on crude oil imports. Biomass represents significant energy generating potential in Thailand since the country has high quantities of agricultural waste products, such as by-products from rice, oil palm, sugar and wood processing mills (The Energy for Environment Foundation). In addition, municipal waste is used by municipalities to produce biogas.

The largest plant for conversion of waste to energy in Thailand is the Waste to Fertilizer and Energy Plant at Rayong Province, which is owned by Rayong Municipality (Juanga J.P., Adhikari R. et al, 2006). The Plant comprises two systems: a process that converts waste to biogas and fertilizer and a biogas-fired cogeneration process (power and heat generation). The Rayong plant uses MSW, food vegetables and fruit waste, and night soil waste as waste materials. The plant has a capacity to handle 60 tons of waste per day and has been designed for waste separation of recyclable and organic material. It has capacity of 25,550 tons of municipal waste per year and to treat organic waste by anaerobic digestion process to produce 5,800 tons of humus and 5,100 MW of
electricity per year. This plant shall serve the Municipality for 20 years of operation. The biogas holder will hold the raw methane gas produced from fermentation process and supply the gas to the gas turbine at constant pressure. Air blower regulates the variation between gas input and output, thus keeping the gas pressure inside the biogas holder at a constant level. Another plant is under construction at Chonburi province (owned by Chonburi Provincial Administrative Organization). There is one small-scale plant in Chiang Mai.

Latin American Countries
The Regional Biogas Programme of the Latin American Energy Organization (Organización Latinoamericana de Energía - OLADE) was launched in 1978. OLADE was born in the context of the international energy crisis of the early seventies, whose scope and repercussions were reviewed by the countries of Latin America and the Caribbean. In order to deal appropriately with this crisis, the countries began an intense process of political mobilization that culminated on November 2, 1973 with the signing of the Lima Agreement, the Constitution of this Organization, which has been ratified by 26 countries of Latin America and the Caribbean. These include twelve South American countries (Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Guyana, Paraguay, Peru, Surinam, Uruguay and Venezuela), seven Caribbean countries (Barbados, Cuba, Grenada, Haiti, Jamaica, Trinidad & Tobago and Dominican Republic), six Central American countries (Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua and Panama), and one North American country (Mexico). OLADE started the process of demonstration and diffusion of biogas technology at regional level in Latin American countries.

United States of America
Under the “Climate Change Action Plan” (1993) issued by the Government of United States of America, the US Environmental Protection Agency, the US Department of Energy and the US Department of Agriculture have jointly taken up a voluntary pollution prevention programme. The outreach programme called AgSTAR, is designed to reduce methane emission from livestock waste management operations by promoting methane recovery systems. The activities of the AgSTAR Programme have contributed to establishing of more than 111 operational digesters across the United States. The environmental and energy benefits in 2007 were approximately 215 million kWh equivalent of energy generation (http://www.epa.gov/agstar/accomplish.html). In addition, AgSTAR provides a host of information related to waste management and energy sector, conducts farm digester extension events, conferences and performance characterization for digesters.

Europe
There is rapid progress in the design and operation of biogas plants in countries of Europe, especially in Sweden, where a large percent of buses and cars run on a mixture of petrol and either biogas or natural gas. More than 60% of the national biogas production (1400GWh/year) is from sludge digestion at sewage treatment plants. In addition, Sweden has 20 energy plants that utilize a variety of organic wastes including household waste separated at source, animal manure, and wastes from food processing and slaughterhouses. The wastes are anaerobically digested to produce biogas, which is converted to a natural gas by removing hydrogen sulphide, moisture and carbon dioxide. The natural gas is useable as a motor vehicle fuel.

4.05 Conclusion
Different models of biodigesters have been adopted for varied feedstocks/substrate. The capacity of the digester is designed based on the availability of waste feedstock. The most popular size of biogas plants, particularly in developing countries is the small scale plant for households. For optimal functioning and efficient operation of the biogas plants, certain basic steps such as inoculation at the start-up, leakage testing, removal of accumulated moisture etc. are to be followed. The experiences of the different countries in terms of the difficulties in implementation of biogas programmes during the initial stages provide significant lessons for the successful transfer of a programme with adequate technical and financial resources and policy measures.
Energy from Human and Animal Wastes

Different types of commonly available feedstock for biogas generation are described in this Chapter.

5.01 Feedstocks/Substrates
Biomass residues can be converted to gaseous and liquid fuels, which are an alternate source of renewable and environment friendly energy especially useful for rural areas. Gaseous fuels are produced when biomass is microbiologically degraded or when biomass is partially combusted. The aim of the conversion processes is to get fuels with improved quality, specific energy content and transportability. The two most important parameters in the selection of particular plant feedstocks for biogas production are economy and the yield of methane from fermentation of the feedstock.

Animal waste is a popular feedstock for biogas production across the world. The production of methane from de-composting cattle manure was first established by Davy in the year 1808, and the potential of methane production from animal manure was recognized by the end of 19th century. In 1884, Gayon obtained 100 liters of methane per cubic meter of manure at controlled temperatures. Gradually, there was greater awareness in different countries about potential for different feedstocks with different names, such as livestock residues (droppings) in Europe, cattle manure (gobar) in India, Nepal, Pakistan and Bangladesh, and pig manure in China. Although a potent source for bio-methanation, slaughter house/abattoir waste is not generally included in the category of animal waste. Animal wastes generally used as feedstock in biogas plants and their potential for biogas production is given in Table 5.1.1.

Table 5.1.1: Potential Biogas Production from Different Feedstocks

<table>
<thead>
<tr>
<th>Feed Stock</th>
<th>Availability (kg/animal/day)</th>
<th>Gas yield (m³/day/animal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattle Waste</td>
<td>10</td>
<td>0.36</td>
</tr>
<tr>
<td>Buffalo Waste</td>
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<td>Piggery Waste</td>
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<td>Chicken Waste</td>
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<td>0.011</td>
</tr>
<tr>
<td>Human Excreta</td>
<td>0.4</td>
<td>0.030</td>
</tr>
</tbody>
</table>

Source: Mittal, K.M. 1996

Cattle dung
Dung is the most suitable feedstock for biogas plants because methane-producing bacteria are already present in the stomach of cattle. However, the gas production is lower and the proportion of methane is around 65% because of the pre-fermentation that occurs in the stomach. The homogenous consistency of dung is favourable for use in continuous plants when mixed with equal quantities of water. Fresh cattle dung has about 18-20%
solids that can easily be diluted with equal amount of water to bring down the total solids content to about 9-10%. This consistency is suitable for semi-continuous plug flow type, fixed dome or floating holder digesters. With a C/N ratio of 25:1 and in terms of nutrient balance, cattle dung is ideal for biological processing.

**Human excreta**

Night soil can be used in a biogas system. The toilet is drained directly into the system so that the night soil is fermented without pre-treatment. The amount of water accompanying the night soil should be minimized by ensuring that no water taps or other external sources drain into the toilet bowls, and cleaning/flushing should be limited to rinsing out with about 0.5 – 1.0 liter water.

Human excreta fed biogas plant systems, especially those linked with community toilet complexes, have a number of limitations related to quality, quantity and composition of the waste. Besides the limitations of space for construction of human excreta fed biogas plants in congested and busy areas and several others that relate to socio-cultural and health issues, other significant factors include (a) food and toilet habits of people vary and human excreta are associated with odour, psychological and religious taboos; (b) human excreta contain a full spectrum of pathogens that can cause health hazards if not carefully handled; (c) although there is not much variation in quantity of water used for personal cleaning, there is a wide variation in the frequency and quantity of water used for cleaning the pans and toilet floors; (d) variation in number of users leads to variation in loading rate of the digester; (e) with direct gravity feeding arrangement, the feeding of the digester is at best intermittent or semi-continuous depending upon the frequency of use; and (f) energy input in the form of heating, mixing, pumping etc. has to be kept to the minimum.

Thus, while there is no direct control over the concentration of the feed material, loading rate, hydraulic retention time, temperature etc., the design criteria for the plants have to consider all these, and the design parameters have to be flexible to accommodate the variations. Based on the above limitations in view, the additional criteria to be considered for night soil based biogas plants are (a) there should not be any direct handling of excreta; (b) aesthetically, waste should not be visible at any stage and it should be free from odour; (c) cleaning water should not be more than two liters per use; (d) disinfectants should not be used for cleaning the toilets; and (e) arrangements should be made for the drying of slurry before using it as manure.

**Pig dung and manure**

When pigs are kept in unpaved areas or pens, only the dung can be collected. It must be diluted with water to the requisite consistency for charging the digester. This could result in considerable amounts of sand being fed into the digester, unless it is allowed to settle in the mixing vessel. Once inside the digester, sand and soil accumulate at the bottom and have to be removed periodically.

**Goat dung**

For goats kept on unpaved floors, the situation is comparable to that described for pig dung. Most such systems are batch-fed versions into which the dung and an appropriate quantity of water are loaded without being premixed.

**Chicken droppings**

Chicken droppings can only be used if the chickens roost above a suitable dung collecting area of limited size. Chicken droppings can be fed into plants that are primarily filled with cow dung, though, there is a latent danger of high ammonia concentration with pure chicken dung. There are many well functioning biogas plants combined with egg or meat producing factories which are operated and maintained routinely. The proportion of methane in biogas from chicken droppings is up to 60%.

**Other wastes**

Besides the feedstocks from animals, agricultural residues like bran, oilseed cakes, vegetable and fruit wastes, mixed kitchen wastes, and sewage wastes can be alternate substrates. Anaerobic digestion of human wastes from toilet effluents is a process that occurs at very low solid concentration. Animal wastes are digested at 9-10 per cent solid concentration. For municipal waste, small scale systems for low (10%) and medium (10-16%) solid concentration are available. High solid systems digest matter at 16-40% solids, also referred to as “dry digestion” which occurs in landfills. Two stage digestion systems operate, separating the reaction of acidogenesis and methanogenesis. At the international level many anaerobic digestion processes are in operation, including some
that occur in the thermophilic range. These include conventional slurry digestion, (the RefCOM, the WMC, the Cal recovery, and the Waste Biogas processes), dry anaerobic digestion (the DRANCO, the VALOGRA and the BIOCEL processes) and two phase anaerobic digestion of solid wastes (the Hitachi, the IBVL and the Leach-Bed processes).

5.02 Issues and constraints of Biomethanation system

Biomethanation is regarded as the most viable system for harnessing energy from animal waste, particularly from fresh droppings. The system provides the dual benefit of bio-energy and quality bio-manure compared to traditional systems that provide fuel or compost. Biomethanation provides the highest benefits in terms of capturing methane within a limited period unlike an open dump-site or landfill of the material, or conversion to carbon dioxide through combustion. A dependable service network, including goods and services such as, availability of construction material, trained personnel for installation, spares and repair service are essential within a manageable distance for the success of biomethanation plants.

The objective, situation and scale of operation of biomethanation systems are significant determinants of success, and the main issues to be considered are (a) alternative technologies available for appropriate processing and disposal of the specific type and quantity of animal waste; (b) relative inputs and outputs of the system implemented; and (c) in case of institutional and other large plants, the scale of operation involved and overheads for management and administration.

There is substantial experience from family size biogas plants that have been installed in China and India (more than 8.0 and 3.9 million respectively) that can be consolidated. Further, it requires integration with other renewable energy forms like solar, biomass gasification and wind energy to maximize benefits, particularly at the community level.

To illustrate, there are several options that can be weighed for a household level biogas plant fed by cattle manure. A farmer owning 3 to 4 cattle would have the option of composting the cattle manure (dung) or making fuel cakes or running a biogas plant that can produce about 1-1.5 cubic meters biogas, which is sufficient for cooking frugal meals for a family of five. In addition, the farmer would get almost equivalent quantity of digested sludge manure, which is stabilized and has more readily available form of nitrogen compared to aerobically composted cattle dung. Thus instead of getting either fuel (in the form of cakes) or compost, the farmer gets both from the same feedstock. However, the construction of the biogas plant requires a capital investment. Therefore, the farmer has to consider affordability, including reduction in the cost. This can be achieved either by using standard materials that would last longer or by using suitable locally available construction material that may require reconstruction after some time. In either case, the water and air-tightness of the plant are crucial. One of the advantages of this scale of operation is the partial saving of cost on labour for construction and saving of operational costs due to participation of the family. However, the skills and willingness of the family have to be considered.

As the scale goes up, in addition to cost of administration and management, more mechanization is required for material handling at different stages, and higher level of skills are required for proper construction and for operation and maintenance. Depending on use of the biogas, additional cost would be incurred for the gas distribution pipeline or for conversion into motive power or electrical power. For the biogas plant at Haebowel, Ludhiana (For more details, see Indian case studies on Biogas Plants at Appendix I), the input cost was Rupees 136 million (USD 2.8 million) and the outputs include 9,000 cubic meters of biogas (converted to 1MW power) and 47 TPD digested sludge manure.

5.03 Conclusion

While biogas technology using some common feedstocks is already established at the field level, more work is needed for its adoption and for demonstrating its commercial viability. In addition, efforts are required for development of alternate feedstock and for improved bio-gas designs for faster processing at different scales of operation.
Municipal Waste: Small Scale Biogas Generation

As described earlier, urban areas in several countries of Asia, Africa and Latin America face the challenge of treating urban (Municipal) solid wastes (USW), especially at a small scale. Except for very few cities, waste treatment, recycling and disposal facilities are inadequate. Description of proto type studies on biogas generation by using municipal wastes has been presented in this Chapter to illustrate the trend in developing countries since it may be commercially applied in future.

In India, large scale systems are yet to take off and small scale systems are only beginning to show viability. Further, the type and extent of wastes generated in India has gradually changed during the last three decades. Wastes generated during the pre 1980s were predominantly organic, biodegradable and quite recyclable. Simple waste processing units (for example, composting and recycling) were adequate at that period. However, with the increased pace of development and globalization taking place, the amount of waste has increased and the nature of wastes has changed. There is a need for renewed thinking on how to manage and process these municipal solid wastes. Similarly, the process and mechanisms of waste generation and collection are also undergoing a rapid change driven both by the change in nature of waste being generated as well as increased levels of regulations that begin to play.

Urban wastes generated in India arise from a range of activities and may be grouped into that arising from domestic, trade and commercial activities, slums, street sweepings, institutional activities, large catteries, building activities, medical practice (biomedical wastes), scientific and research activities (bioethics bounded wastes), small and unregulated industrial activities, etc. There are a large number of poorly organized people associated with recycling and re-use of wastes, predominantly for economic reasons and only a few of them driven by environmental concerns.

Large systems, be it for processing or disposal, have become unwieldy and difficult to run although they fit into the larger scheme of responsibilities and activities of cities' governing systems. Small scale and decentralized processing have on the other hand become successful at various resident based organizations' initiatives and have even been run on commercial lines. There also has been successful emergence of many distributed systems for conversion of several components of USW namely, food wastes, soft garbage, etc. to biogas (energy and compost). Most of these have used older Gobar (cow dung) biogas plant designs or minor modifications of the overall process and design. Thus, there has been a gradual emergence of a consensus that, considering the ground realities of these cities, large systems would be difficult to manage and decentralized small scale waste treatment systems should also be tried in a big way. However, improved technologies have either not emerged or have not had the opportunity for appropriate field trials and adaptation.

In this context, the urban city systems are at cross-roads. As a consequence of a major ruling by the Supreme Court in 1999 and the Municipal Solid Waste (Management and Handling) Rules 2000 notified by the Ministry
of Environment and Forests (MoEF), gradually efforts are being made to control generation and collection of these wastes in urban areas. Many key laws and regulations on urban wastes have been enacted only recently and attempts are being made for their time bound implementation. As a result, it is possible to find the co-existence of both modern and dated waste management practices at adjacent locations. This must, therefore, be viewed as a society whose waste management practices are in transition and changes are expected to occur rapidly towards more regulated and cleaner practices.

6.01 Small scale Conversion Technologies

Small scale conversion of rural residues to biogas and compost has been attempted in India with and without admixtures with animal dung (Chanakya and Moletta 2004). The shortage of fuel-wood and national policy based promotion have triggered most research and development in this area. Similarly choking of water ways, mainly by water hyacinth had prompted new designs and processes for its use in anaerobic digesters (Srivastava et al. 1985; Sharma et al. 1999). A few of these successful efforts in the conversion of difficult feedstock as the above to biogas and compost have prompted the extension of this concept to the decentralized use of USW. In the mid-nineties, efforts of the Ministry of New and Renewable Energy, Government of India promoted conversion of USW to grid power with lots of incentives to industrial units as well (www.mnes.nic.in). This resulted in a large number of small and large industries setting up biomethanation plants for food and kitchen wastes using plant designs that were minor variants of the then popular Indian or KVIC biogas plant designs. There was little difficulty in operating such plants with food/kitchen wastes. However, the presence of herbaceous matter in the form of mature and fibrous vegetables and fruits, such as banana, leaves, intact fruits and flowers caused choking problems. Biogas technology for these plants was initially sourced from various locations. However, over a period of a few years many organizations have undertaken research and development and have built digesters that could accept food and kitchen wastes components typical to Indian urban locations. Based on available literature data and personal communications with the developers, five of the most promising process designs and comparisons that are being made, have been chosen, as seen in Table 6.1.1.

Food waste fed Khadi and Village Industries Commission (KVIC) type digester represents digestion of predominantly food with little kitchen/fibrous wastes and has been the earliest type. The designs and processes used by The Energy and Resources Institute (TERI), New Delhi, the solid-state stratified bed (SSB) (Figure 6.1.1) by Indian Institute of Science, and Nisargrana (biogas plant) by Bhabha Atomic Research Centre (BARC) represent three approaches to stage separation. A pre-treatment step is built into the design of a plug flow reactor (PFR) developed by ASTRA.

KVIC derived design

The fate of conventional biomass feedstocks with tendency to float has been described before in typical KVIC type digesters (Reddy and Rajabapaiah, 1981). The decomposition pattern of various biomass feedstocks has been studied and fractions remaining un-decomposed have been monitored (Chanakya and Moletta, 2004). Very little floating matter or sludge is found in food waste or blended kitchen waste fed anaerobic digesters. The concept of a slurry based biogas reactor is thus easily extended to this feedstock. With such feedstock, a large Volatile Fatty Acid (VFA) flux is typical where the acidogenic rate is about 8-10 times higher than

Figure 6.1.1: A Solid-state Bed Reactor and Gas storage device in foreground

Figure 6.1.2: Battery of 6 acidogenic reactors used by TERI’s 2-stage (TEAM) process
methanogenesis at typical operating temperatures in the range of 20°-30°C. This allows overall loading rates not exceeding 1-1.5 kg VS/m³/d after which VFA accumulation is found. Consequently, a large number of these plants have feed rates in this region. By far the most popular small plant design is based on this principle. The gas produced has most often been used as a substitute to LPG in the kitchen.

**TEAM process**
TERI enhanced acidogenesis-methanogenesis involves a batch operated acidogenic stage where digester liquid contents are recycled frequently during a 6d HRT. In the simplest mode of operation, 6 acidogenic batch digesters are employed (Figure 6.1.2). Liquid is recycled within each digester for a period of 6d to allow VFA accumulation and suppression of methanogenesis. After this liquid output is pumped to a locally developed UASB module. The residue is dried as manure. Each day one acidogenic reactor is emptied and recharged (www.mnes.nic.in) (Figure 6.1.3). Gas yields reported range from 130-260 l/kg TS depending upon the decomposability of the feedstock tried (Rajeshwari et al. 2001). Currently, these are operated at a daily feed rate of 50kg/each acidogenic reactor module.

**Figure 6.1.3:** Flow chart of the TEAM Process

**Nisargruna (BARC) process**
This process comprises a thermophilic acidogenic stage of 2d HRT and a simple CSTR type mesophilic methanogenic stage with a 6d HRT (Kale, 2004. Figure 6.1.4).

**Figure 6.1.4:** Nisargruna biogas plant (BARC)
The major feedstock tried in most of the locations using this process has been food and kitchen wastes arising from industrial type canteens. The heat energy to maintain thermophilic acidogenic stage is derived from the use of solar water heaters that provides hot water to create a slurry of the incoming food waste blended in a small 5-10HP blender. The use of a thermophilic acidogenic stage greatly reduces the SRT required for the acidogenic stage. After a 2d HRT, this is pumped to simple mesophilic CSTR based methanogenic stage. With food wastes the yields are reported to be in the range of 300-4001/kg TS fed. These have been tried in six locations at <1tpd scale generally employing food and kitchen wastes. The key factor is the use of a simple blender that slurries the waste and the use of a thermophilic acidogenic stage, which greatly hastens the digestion process. Currently these are being tried on more fibrous USW components.

**ASTRA Plug Flow Reactor**

ASTRA Plug Flow Reactor process combines a pre-treatment step along with a horizontal plug flow like digester. The primary feedstock, USW or rural solid wastes are allowed to undergo a rapid initial digestion under the digester liquid where the simple to digest fractions in USW and rural residue biomass are released quickly into the digester liquid. This kind of a pre-treatment built into the design of the reactor obviates any form of pre-processing of the feedstock, especially fibrous plant material. In this way issues of need for external energy and electrical power are obviated at the small scale. These digesters have been operated at various scales ranging from 0.03 to 1.0 tpd scales of operation. These digesters accept a feed rate of 2kg TS/m³/d producing about 0.5-1 m³ gas/m³ reactor/d (m³/m³/d) depending upon the constituent of USW used as feedstock (Chanakya and Jagdish, 1997; Table 6.1.1; Figure 6.1.5, 6.1.6 and 6.1.7).

An important aspect of this is that between 55-90% TS of rural residues and between 60-99% TS of USW components are converted to biogas in such reactors. Moist feedstocks in their existing state are fed without any pre-treatment. As a result there is very little need for daily water to be added with the feedstock. These have been in existence over for 15 years, and in field level operation for over 5 years in various forms. These have been operated in the field, that is, at small town levels for nearly 3 years. Like many of their large scale counterparts, these USW conversion plants have suffered from the absence of a reliable supply of segregated USW to demonstrate economic viability (TIDE, 2005).

**Figure 6.1.5:** Flow chart of ASTRA-plug flow Reactors

**Figure 6.1.6:** Sketch of a plug-flow reactor showing floating biomass and a submerged pre-treatment zone
Figure 6.1.7: A 3 X 60m³ Urban Solid Waste fed Plug Flow Reactor being operated in Karnataka, India

<table>
<thead>
<tr>
<th>Parameter and units</th>
<th>TERI</th>
<th>BARC</th>
<th>PFR</th>
<th>SSB</th>
<th>KVIC</th>
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<tr>
<td>Size of the reactors (m³)</td>
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<td>3-60</td>
<td>6</td>
<td>5-100</td>
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<td>K/FW</td>
<td>ssUSW</td>
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<tr>
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<td>N</td>
<td>N</td>
<td>So+Sh</td>
</tr>
<tr>
<td>Feed stock size reduction if any</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>Particle size permissible in feed (mm)</td>
<td>&lt;25</td>
<td>&lt;15</td>
<td>&lt;300</td>
<td>&lt;300</td>
<td>&lt;15</td>
</tr>
<tr>
<td>Daily Feed rate (kg fresh /m³/d)</td>
<td>50</td>
<td>20</td>
<td>12</td>
<td>12</td>
<td>10-12</td>
</tr>
<tr>
<td>Daily Feed rate (kg dry /m³/d)</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1.0-1.5</td>
</tr>
<tr>
<td>Total SRT (d)</td>
<td>6.66</td>
<td>8</td>
<td>35</td>
<td>35-40</td>
<td>35</td>
</tr>
<tr>
<td>Source of original inoculums</td>
<td>Cow</td>
<td>Dung</td>
<td>Slurry</td>
<td>Cow</td>
<td>Dung</td>
</tr>
<tr>
<td>Start-up time (days)</td>
<td>NA</td>
<td>30</td>
<td>15</td>
<td>15</td>
<td>NA</td>
</tr>
<tr>
<td>Aceticlastic rate (ml gas./hr/g or mL reactor)</td>
<td>NA</td>
<td>NA</td>
<td>14.96</td>
<td>14.9</td>
<td>0.5</td>
</tr>
<tr>
<td>H2-oxidative Methanogenic activity (ml/g or mL reactor)</td>
<td>NA</td>
<td>NA</td>
<td>5.8</td>
<td>5.8</td>
<td>0.5</td>
</tr>
<tr>
<td>Gas production rate (m³/m³/d)</td>
<td>2.5</td>
<td>NA</td>
<td>0.4-0.6</td>
<td>0.4-0.6</td>
<td>0.5-0.8</td>
</tr>
<tr>
<td>Specific gas yield fresh (m³/kg)</td>
<td>0.045</td>
<td>NA</td>
<td>0.05-0.08</td>
<td>0.08-0.1</td>
<td>0.05</td>
</tr>
<tr>
<td>Specific gas yield dry (m³/kg TS)</td>
<td>0.45</td>
<td>NA</td>
<td>0.5</td>
<td>0.35</td>
<td>0.4-0.5</td>
</tr>
<tr>
<td>VS conversion /transformation (%)</td>
<td>NA</td>
<td>NA</td>
<td>75-80</td>
<td>70-80</td>
<td>70-90</td>
</tr>
<tr>
<td>Methane content (%)</td>
<td>70-75</td>
<td>62-67</td>
<td>65-70</td>
<td>65-70</td>
<td>50-65</td>
</tr>
<tr>
<td>Gas storage</td>
<td>NA</td>
<td>Mild steel drum</td>
<td>Balloon</td>
<td>Mild steel drum</td>
<td>Mild steel /FI</td>
</tr>
<tr>
<td>Inlet</td>
<td>NA</td>
<td>Concrete pipe</td>
<td>Masonry</td>
<td>Masonry</td>
<td>Asbestos cement pipe</td>
</tr>
<tr>
<td>Outlet</td>
<td>NA</td>
<td>Concrete pipe</td>
<td>Masonry</td>
<td>Masonry</td>
<td>Asbestos cement pipe</td>
</tr>
<tr>
<td>Liquid recirculation if any</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
</tr>
</tbody>
</table>

[KVIC- Khadi and Village Industries Commission (Indian floating drum type); TERI- The Energy and Resources Institute; BARC- Bhabha Atomic Research Centre; SSB- Solid-state Stratified Bed; PFR-Plug Flow Reactor]
Solid-state Stratified Bed Process
This is another attempt to obviate the need for pre-processing rural and USW biomass components for anaerobic digestion in the small scale. This is derived from the two-step process based on the key principle that digested biomass itself can be used as an immobilized biofilm reactor. Instead of operating from two separate containers, the two stages are maintained as zones in transition from predominantly acidogenesis to methanogenesis. A small quantity of digester liquid is recycled once daily (manually) to keep the freshly fed upper layers in acidogenic stages and transferring VFA produced to methanogen colonized old biomass in the lower layers (Figures 6.1.1 and 6.1.8).

Figure 6.1.8: Flow chart for Solid Stratified Bed (SSB) Reactor

These are currently operated at pilot plant scale (30-50kg/d) with source segregated USW. The details of performance are presented in Table 6.1.1.

From the above, it may be seen that most research and development attempting development and field testing of USW based biogas plants for distributed applications in India appear to have derived designs and/or processes based on two stage processes or from the conventional Indian type floating-drum type biogas plants. The process, design and operation strategy have almost always attempted at anaerobic digesters capable of functioning in small-towns of India often without need for grid power and intensive process control or operating skills. These are two constraints that are accepted in these designs. It is also seen that most long duration research and development efforts accept the following important anaerobic fermentation properties of biomass (Chanakya et al, 2004):

- USW biomass feedstocks remain afloat at all stages of decomposition.
- Physical and chemical composition as well as availability of biomass residues vary significantly around the year.
- USW biomass exhibits a rapid initial decomposition accompanied by large VFA fluxes.
- Mechanical processing only improves material handling but does not significantly improve fermentation rates.
Three basic strategies in fermentation process and digester design (or combinations) have been used to handle these above mentioned obstacles. They are:

- Fermenting only treated (particle size reduction) food/kitchen waste with a large cooked food waste fraction in KVIC (CSTR) designs and thus escaping adverse physicochemical and microbiological conditions,
- Phase separation enabling separate handling of solids and liquids, and
- Pre-treatment of feedstock to partially or completely overcome the above obstacles.

A significant issue also exists in the use of biogas generated. While food waste generated biogas is used back in the kitchens that generate them, plants that generate biogas from segregated (or source segregated) USW still have to find economic operations. This is so because biogas plants built on waste treatment do not usually have a nearby outlet or user. These are too small to be viable as grid power generation systems (for example, in Chennai, India) where economic viability is poor even at 250KW scale. On the other hand, a few have tried using biogas in the recycling processes or in converting to transport fuel for transporting vehicles by using methane generated by anaerobic digestion. This technology is just emerging and efforts of the Ministry of New and Renewable Energy, Government of India are likely to make it viable at a sufficiently small scale. This being the case, economic viability would be very good. Other efforts by TIDE-IDECK, Bangalore to sell this gas to street side vendors and for farm machinery has not been very successful due to resource matching problems. Sale of biogas as LPG or Diesel substitute provides the best promise for economic viability.

6.02 Conclusion
Many of simple to use USW and food/kitchen waste based anaerobic digester designs are emerging for use in small towns of India and elsewhere as a result of concerted research and development as well as people's innovations. Attempts are also being made to use them in a decentralized manner in metropolises where local organizations and private institutions manage and operate them. These plants have the potential to function better than specifications provided for the earlier cattle dung based biogas plants and overcome the limitations posed by biomass constituents. In India, domestic and overall USW form excellent substrates for such digesters and hold good promise of success. Many are grid power independent. These small scale designs and processes are better poised to take off compared to the large centralized plants that are constrained by the absence of large tracts of uninhabited land, high costs of land, odour and related aesthetic problems, frequent power outages, etc. Many locations have proven technical feasibility of running waste to energy (biogas) plants but the system has not yet reached commercial maturity. Unless this happens soon, there would be poor incentives for waste to energy projects in the small scale.
Energy from Municipal Solid Waste: Thermo-chemical methods

7.01 Thermo-chemical Process

Although the composition of MSW varies from country to country, generally a sizeable fraction of it consists of combustible components, that is, materials that can serve as a fuel in the production of heat energy. The value of the waste for direct conversion depends primarily on its energy content. Chemical elements that make the greatest contribution to the heating value of waste are principally Carbon and Hydrogen. On the other hand, the fuel value of the waste is critically and most adversely affected by moisture content and the inclusion of non-combustible inert materials. Tables 7.1.1 and 7.1.2 illustrate composition of MSW and its chemical characteristics in Indian cities:

<table>
<thead>
<tr>
<th>Table 7.1.1: Distribution of Municipal Solid Waste in Indian Cities by Population (in Percentage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population Range (in millions)</td>
</tr>
<tr>
<td>---------------------------------</td>
</tr>
<tr>
<td>0.1 to 0.5</td>
</tr>
<tr>
<td>0.5 to 1.0</td>
</tr>
<tr>
<td>1.0 to 2.0</td>
</tr>
<tr>
<td>2.0 to 5.0</td>
</tr>
<tr>
<td>5.0 &amp; above</td>
</tr>
</tbody>
</table>

*Source: NEERI, 1995*

<table>
<thead>
<tr>
<th>Table 7.1.2: Chemical Characteristics of Municipal Solid Waste in Indian Cities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population range (in millions)</td>
</tr>
<tr>
<td>---------------------------------</td>
</tr>
<tr>
<td>0.1 to 0.5</td>
</tr>
<tr>
<td>0.5 to 1.0</td>
</tr>
<tr>
<td>1.0 to 2.0</td>
</tr>
<tr>
<td>2.0 to 5.0</td>
</tr>
<tr>
<td>5.0 &amp; above</td>
</tr>
</tbody>
</table>

*Source: NEERI, 1995*
Keeping the above in view, energy from waste can be derived through thermal or bio-chemical processes, each of which includes several options. Usually thermal techniques are costlier than the biological treatment techniques but much faster. MSW is not toxic or hazardous but is generated in thousands of tons per day. Hence, the treatment technique that destroys the waste faster is of value. These include:

a) Incineration,
b) Pyrolysis, and
c) Gasification.

7.02 Incineration
Incineration is the controlled burning of wastes to sterile ashes in properly designed and constructed furnaces with proper care for controlling air pollution. Incineration technique can be used for destroying a variety of wastes including municipal, medical and industrial wastes, sewage sludge, and residues from dumpsite cleanup. Incineration reduces the volume of MSW by about 90% and weight by about 70%. The first incineration unit was constructed in 1830 in the suburbs of New York City, while the first refuse-to-energy plant was established in 1896 at Hamburg in Germany.

Incineration is amongst the most preferred treatment method for MSW, biomedical waste and hazardous wastes, and is used widely for incineration of raw municipal solid waste throughout the world. In densely populated metropolitan cities that generate large volumes of waste, incineration enables volume reduction and generation of steam. In addition, it requires less space than other treatment methods such as landfill.

The composition of the waste materials in terms of combustibility, determines the successful incineration of the material as well as the fuel value of RDF. Many of the incineration plants procured by municipal authorities in developing countries did not function effectively or became defunct within months of their commissioning because of a mis-match between the technology and characteristics of the MSW.

An incineration system consists of a furnace, cooling equipment, air pollution control equipment and a stack. The furnace is fitted with waste and fuel feeding arrangements, refractory bricks inside and ash removal systems. Different types of furnaces used include rotary kiln, fluidized bed, cyclonic and grates type. Two significant disadvantages of incineration are: i) re-usable resources cannot be recovered because of direct combustion of raw waste, and ii) hazard of air pollution. Although some of the early incineration plants did not address the environmental concerns, many changes have been introduced in the technology to control pollution. Pollution is reduced through substantial investments for installation of air pollution control equipments, which effectively collect particulate matter, capture trace metals and organics, and neutralize acidic gases produced in the combustion chamber. The flue gas can be used for preheating air or for concentrating/drying the waste feed. Techniques adopted are cooling by spraying water, diluting with air or by recovering the heat through a boiler/generation of steam at 230°-370°C if the gas is discharged to air pollution control equipment, or at 470°-590°C if discharged to a refractory lined stack.

Details on some of the technologies for getting energy from waste by thermal pathways are described below:

7.03 Incinerator Technologies

Rotary Kiln
Rotary kilns, which are primarily installed for the incineration of municipal solid wastes and hazardous wastes, can also be used for all other wastes. The Rotary Kiln is an inclined, refractory lined cylinder that rotates about its horizontal axis. Waste is charged directly at the upper end of the kiln and agitated by the rotating motion of the kiln, normally in the range of 1 to 3 rpm. As the waste is subjected to this turbulence, it is washed by air to encourage combustion. The turbulence increases the particulate load of the flue gas resulting in the kiln system requiring more stringent air emission control than the other technologies, thereby increasing its overall cost. Thus, despite advantages of using rotary kilns, such as ease of operation on a continuous basis, flexibility for nature of waste and low unburned ash, they are not widely used due to their high capital and operating costs.
**Fluidized Bed Incinerator**

Fluidized bed incinerators are primarily used for MSW, liquids, sludge or shredded solid materials including soil. Fluidized bed incinerations have been proved highly efficient and are more environment friendly than other systems. These reactors operate at relatively lower temperatures than the other types. While conventional furnaces cannot burn MSW with more than 85% inert content efficiently and completely, fluidized bed incinerator can burn these wastes completely at a lower temperature of about 827°C (about 100°C lower than 927°C - the theoretical flame temperature). Complete combustion of the gases is ensured in the integrated combustion chamber with about 10 to 20% excess air.

The simplest fluidized bed incinerators consist of a vertical steel cylinder, usually refractory lined, with a sand bed on a supporting grid plate and air injection nozzles. When air is forced up through the bed, the bed fluidizes and expands to about twice its resting volume. The boiling action of fluidized bed promotes turbulence and mixing, and transfers heat to the waste that is injected into the reactor. Fluidized bed incinerators have high heat transfer efficiencies, high turbulences in both gas and solid phases, uniform temperature throughout the bed (variation less than 6°C) and the potential for in-situ acid gas neutralization by addition of lime, limestone or carbonate. The start-up after a shutdown is very easy as the heat loss (when the plant is not operational) is less than just 5°C/hr.

Fluidized bed incinerators can be either circulating or bubbling bed. In India, there are a few bubbling fluidized bed incinerators for burning industrial wastes and a few circulating fluidized beds for burning coal wastes/low grade coal.

**Spreader Stoker (Grates) Incinerator**

Spreader stoker (grates) incinerators are mostly used for the mass burning of MSW. They comprise moving grates that move like a conveyor belt at a slow and constant rate. The grate elements are designed to develop a relatively high-pressure drop under-fire air rate, which results in uniform air distribution over the entire surface. Air is supplied through the grate from one or more plenums under the grate.

**Heat Recovery and Power Generation**

The simplest method of recovering heat from MSW incineration is by incorporating waste heat boilers for the generation of hot water or steam. Steam can be used directly for industrial processes or to heat buildings or to produce mechanical/electrical energy with a steam turbine. The energy recovery from waste incineration plants not only cools the flue gas to temperatures that can be tolerated by air pollution control equipments, but also reduces the capital cost for air pollution control equipments because of the reduction in the volume of the flue gas to be 'cleaned'.

Boilers can either be introduced after the furnace or can be built as separate devices. The cooling water is passed under pressure into the pipes or tubes immersed in the stream of the hot flue gas or arranged in panels lining the furnace wall. The wall tubes are often welded together to form a continuous gas tight membrane or water wall enclosure. The boiler installation requires additional expenses and may require an experienced/licensed operator. Corrosion/erosion problems with the boiler tubes may arise during its operation.

On average, combustion of 2.5 to 5 kilogrammes of raw MSW (having a heat content of 10,000 to 5,000 kJ/kg) can produce 1kWH of electricity. The burning of MSW can result in problems such as corrosion (high temperature corrosion above 340°C and acid corrosion below 160°C) and fouling of the heat transfer surfaces (in boilers).

**Incinerators using Pure Oxygen (Oxygen lancing)**

In this type of incinerator, instead of injecting air that contains only 23.15% oxygen by weight, pure oxygen is injected for combustion. The use of enriched oxygen for combustion enables the burning of wastes with a very low calorific value, increases the efficiency and prevents or reduces the accumulation of un-burnt waste. The
other advantages are: i) increased capacity, ii) reduced CO, iii) reduced fuel consumption, iv) reduced particulate carry over, v) more efficient heat recovery, and vi) reduced off-gas volume. This allows the secondary chamber and off-gas systems to be more compact. The disadvantages are: i) increased NOx formation, ii) additional cost of oxygen, and iii) potential soot.

**Infrared Incinerators**

Organic compounds can be broken down to simpler, less harmful matter with near-infrared radiation. Temperature produced using electric energy can pyrolytically decompose the organic contaminants. Shirco Infrared System has developed a mobile thermal processing system that uses electrically powered silicon carbide rods to create high temperature that will combust the organic waste. Waste is fed through a furnace on a woven belt and exposed to high temperature. Air is blown into the system at specific locations to supply oxygen. Ash formed at the bottom of the chamber is collected and transported to an ash cooling system. Gases formed in the primary chamber are directed to a secondary chamber, where they are further heated to complete destruction. This system is commonly used for solids and soil containing organic waste. It is not recommended for liquid or slurry waste. The main disadvantage is that the volatile metals can cause problems of stack emission.

Some of the Indian experiences of Incinerator Technologies are illustrated at Appendix II.

**7.04 Pyrolysis (Non-Biological Gasification)**

Non-biological gasification processes are thermo-chemical in nature using which both bio-degradable and non-degradable combustible waste can be transformed. The percentage of energy recovery of non-biological gasification, known as pyrolysis, is therefore better than that of the biological systems. Pyrolysis is widely used in many industries, including for production of charcoal from wood/coke, and fuel gases from heavy petroleum fractions.

Pyrolysis involves heating of the waste to about 900°C (destructive distillation) in the absence of oxygen/air to break down the organic matter. This results in production of high heat content gases along with some solid residue (inerts, unburnt carbon, char, etc.) and liquid (tar, oil, acetic acid, acetone, methanol, etc.). The fuel gas consists primarily of hydrogen, methane, CO and carbon dioxide, and has a heat content of about 26,000kJ/m³. NOx formation is also less. Pyrolysis involves less turbulence than the rotary kiln and hence fewer particles are carried over. As it does not use air, the sizes of the downstream equipments such as fans/air pollution control devices and ducts can be small.

**Rapid Pyrolysis Systems**

The rate of heating in rapid pyrolysis systems is fast so that the time taken for the pyrolytic process is very short. Rapid pyrolysis can be achieved using a wide range of techniques such as microwaving, plasma heating, rapid heating in fluidized beds and high-pressurized drop tube furnaces. The rapid heating rate (above 500°C/sec) results in less char formation and more methanol formation than that from the slow pyrolysis (about 20°C/min) processes. Char from the rapid pyrolysis is more porous and more reactive than that from the slow process.

**Plasma Pyrolysis**

Plasma pyrolysis involves the creation of a sustained electrical arc by the passage of electric current through a gas, and it can be used to dispose off municipal and industrial wastes, soils with heavy metals, pesticides, medical wastes and ordinance by-products. Because of the high electrical resistive across the system, the significant heat that is generated strips away the electrons from gas molecules, resulting in an ionized gas stream or plasma. Plasma breaks down the wastes in milliseconds avoiding the formation of secondary products. In the ionized state, the gas is electrically conducting, can be confined by the electromagnetic fields and has an almost liquid like viscosity. The interior of the plasma vessel is hot (5000 to 14,000°C), dusty, and turbulent. As the waste materials are dropped into the vessel, they are dissociated into their molecular components.

Because of the high temperature, the plasma pyrolysis plant is able to treat combustible materials, biological waste, and a significant part of non-combustible materials such as glass, metal, construction waste, etc. It ensures
complete destruction of chemicals and biologically active substances such as viruses and bacteria, drugs, pesticides and other toxic substances. The process does not produce smoke, but a clean burnable gas and residue, and glass like substances. However, the volatile metals may vaporize and be carried out of the unit with the gas stream. About 98% of the energy value can be recovered as electric power. For 1000 tons/day waste processing capacity, the cost of Plasma-Pyrolysis-Vitrification system is about USD 100 million whereas for incineration it is about USD 200 million.

**Pyrolytic Thermal Depolymerization**

Thermal Depolymerization (TDP) is a process for the reduction of complex organic materials (usually waste products of various sorts such as biomass and plastic) into light crude oil. Under pressure and heat, long chain polymers of hydrogen, oxygen and carbon decompose into short-chain petroleum hydrocarbons.

At present, plastic waste that cannot be recycled represents about 8-9% of domestic waste in Europe. In countries like India also, this is gradually becoming a significant component of the municipal solid waste. The diversion of these waste streams would alleviate the pressure on domestic land fill sites and improve the urban environment. Energy recovery from plastic waste can make a major contribution to energy production. It is estimated that if all of Europe’s plastic waste that are not recyclable were turned to energy, it will be equivalent to 17 million tons of coal.

Technology that converts plastic wastes back to the starting materials or useful decomposition products are promising development in plastic recycling. Present technological systems use melting vessels, autoclaves, tube reactors, fluidized beds, stirred reactors, cascades of stirred reactors and rotary kilns (Hornung et al.). For energy production pyrolysis units are coupled with a thermal plant. The pyrolysis fractions can be used as pre-cleaned feed support for the combined power plant. Such plants are operational in many developed countries (Hornung et al.).

### 7.05 Gasification

Low heat content fuel gases are produced when the waste material is partially burnt at a temperature of 650 to 850°C (providing less than the stoichiometric oxygen requirement). This is called gasification. This is a self-sustaining process if the waste has enough heat content. The fuel gases can be burnt off or can be tapped and used later on for burning. The fuel gas consists of mostly CO (about 20%), hydrogen (about 15%), methane (about 2%) and carbon dioxide (about 20%). Energy content of the fuel gas is about 5-6MJ/m³ (if air is used for partial combustion) or about 13MJ/m³ if oxygen is used instead of air.

This is a promising technology as the fuel gas can be used. In the cases where the fuel gas is directly burnt off, the combustion efficiency is much higher than in an incineration unit. The emission of NOₓ and particulate matter are usually lower than that from incinerators. In addition, the sizes of the downstream equipments are relatively smaller. The existing incinerators having two chambers can be easily operated in an efficient way by maintaining the starved air mode (gasification) in the primary chamber and excess air mode (complete oxidation) in the secondary chamber. Most of the biomedical waste incinerators in India have two chambers and are effectively operated.

### 7.06 Issues related to Thermal Processing

**Thermal Characteristics of MSW**

It is necessary to assess the thermal characteristics of a waste to decide on the feasibility for opting for thermal processing. Parameters, including the heat content (kJ/kg of dry MSW), moisture content (kg/kg of MSW), inert content (kg/kg of MSW), temperature for volatilization, ignition temperature, and ash fusion temperature help to rank the waste in term of its incinerability. For self-sustaining combustion, heat content of the waste
needs to be a minimum of 2500 kcal/kg (about 5000 Btu/lb). When heat content of the MSW is below 1500 kcal/kg, it is not recommended for incineration.

Moisture content plays a crucial role in the suitability of the incineration process. If the moisture content is about 20% (by weight), then, about 50% of the heat generated goes for drying the moist waste. If the moisture content is about 50% (by weight), then about 80% of the heat generated is utilised in drying. Consequently, self-sustaining combustion becomes very difficult. Similarly, temperature reduces with increase in the inert content of the MSW. All these make it less attractive for direct incineration. The other characteristics of MSW, which are useful are given below with data for India by way of illustration:

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk Density</td>
<td>300 to 520 kg/m³</td>
</tr>
<tr>
<td>Temperature for Volatilization</td>
<td>177 to 260°C</td>
</tr>
<tr>
<td>Ignition Temperature</td>
<td>about 316°C</td>
</tr>
<tr>
<td>Ignition Temperature of Carbon (Bed residue)</td>
<td>700°C</td>
</tr>
<tr>
<td>Initial Deformation: 1075°C (reducing environment)</td>
<td>1130°C (oxidizing environment)</td>
</tr>
<tr>
<td>Softening: 1250°C (reducing environment)</td>
<td>1280°C (oxidizing environment)</td>
</tr>
<tr>
<td>Fluid: 1360°C (reducing environment)</td>
<td>1420°C (oxidizing environment)</td>
</tr>
<tr>
<td>Specific Heat of MSW Combustion Products</td>
<td>0.26 kCal/kg°C</td>
</tr>
<tr>
<td>Thermal Conductivity of MSW</td>
<td>0.0059 to 0.0153 Cal/cm/s/°C</td>
</tr>
<tr>
<td>Temperature Coefficient of Resistivity for MSW</td>
<td>-0.0172 to -0.0322</td>
</tr>
<tr>
<td>Electrical Conductivity of MSW</td>
<td>0.056 to 0.441 (10⁶ Ohms)</td>
</tr>
</tbody>
</table>

The comparison of the thermal properties of MSW from different cities is difficult because MSW characteristics are never consistent. The characteristics vary across cities and within the city during different seasons. Every truckload of MSW is usually different from the next. Making such variations not only pose a challenge for designing thermal systems for MSW treatment, but also require blending of the MSW to get a uniform feed for thermal treatment units.

**Waste Preparation and Feeding**

*Mass Firing*

This can be practiced only when the waste feed characteristics do not change considerably over time. Also mass firing "as received" may not be possible if the waste feeding does not meet minimum thermal requirements. Drying the waste and/or removing the inert materials or blending may be required. Sometimes the furnace type may not allow feeding the waste as such (example: Fluidized Bed Incineration units can not burn heavy and bulky wastes). However, firing "as received" may be possible in most of the developed nations as their MSW is usually rich in heat content and low in inert and moisture contents.

*Refuse Derived Fuel*

Refuse-derived fuel (RDF) is produced by processing MSW to produce either a combustible product or to increase the fuel value of the waste. The RDF process involves processing waste using screens, shredders and separators to recover recyclable materials and to remove incombustible materials such as dirt, glass, metals, and very wet organics. The normal sequence of RDF preparation is shredding municipal waste to a finer size to make RDF more consistent in size, air classifying/screening, magnetic separation, and sometimes eddy current separation for nonferrous metal recovery. Usually air classification (density separation) is used for screening. Then the burnable fraction of the waste is shredded (usually in a Hammer Mill) and then made into pellets (using die) or briquettes by pressing. The pellets are made with or without a binding agent, and can be transported easily or can be stored for several months without any disintegration. The heat content of RDF is largely uniform, and it can be burnt to produce power or can be used along with conventional fuels for industrial operations. Many variations of the process have been developed, each of which has certain advantages. Manual operation for material recovery sometimes precedes the operation, particularly in the developing countries.
Environmental Issues

Burning of Plastics
MSW often contains some plastics that reach the incineration unit. Although there is general opposition against burning plastics, it is primarily the burning of chlorinated plastics (such as PVC) that is dangerous. Hence, the removal of PVC at source is highly recommended. The burning of chlorinated plastics generates dioxins/furans (which are carcinogenic) and HCl. In general, plastics other than PVC increase the heat content of the waste without posing any additional difficulties. In India, less than 11% of the plastics in MSW are chlorinated, about 55% are polyolefines, about 20% polystyrenes and 14% are other plastics. The burning of polystyrene may emit dense smoke and odour, while polyolefin may melt and drip through the grates. However, polyethylene and polyurethane speed up combustion.

Ash from the Thermal Processes
Two types of ashes, namely bottom ash and fly ash are generated in an incineration unit:

Bottom ash is the un-burnt and inflammable part of waste, which can include large quantities of metals, glass and un-burnt organics. Bottom ash from MSW incineration facilities may contain considerable concentrations of Zinc (Zn), Lead (Pb), Copper (Cu), Nickel (Ni), etc. Presence of mercury (Hg) is unlikely because it evaporates at 800-1000°C.

Ash density is usually less than one, though bottom ash from Fluidized bed incineration units can have a density of 1.43 to 1.80 due to the presence of sand fines. Bottom ash can be used for road base construction and for making building blocks after mixing with fly ash, hydrated lime and portland cement. Bottom ash from hazardous waste incinerators is to be disposed in sealed landfills.

Fly ash is the material that is removed by equipment installed for air pollution control from the flue gases, and comprises micron and submicron particulates. Increase in the efficiency of air pollution control systems results in removal of more fly ash from the flue gas. Electrostatic precipitator and fabric filter are commonly used for the removal of fly ash, and have a removal efficiency higher than 99%. Current trends favour fabric filter since it has higher fine-particle control efficiency (important in control of metal emissions). There is a correlation between the amount of fly ash entrained in the effluent gas and the distribution and amount of over-fire and under-fire air supply and the type of the grates employed. Proper operation will ensure that large amount of fly ash is not entrained in the gas stream.

Disposal of ash is a problem for many incinerator operators. If the combustion process is not complete, the fly ash will be sooty. Fly ash requires careful handling to avoid fugitive dust emission, which is harmful to workers and the surrounding environment. About 50% of fly ash particles that are smaller than 5.5 μm can result in transfer of toxic metals into the human bloodstream by inhalation, deposition and absorption. Another concern is of groundwater contamination by the heavy metal content of the fly ash, which has higher concentration of heavy metals (that volatilize easily) than in the bottom ash.

7.07 Conclusion
Energy from municipal solid waste can be generated from the processes of Thermo-Chemical method and the main issues are analyzed on the following categories:

Technical
Comparing the biological, chemical and thermal treatment options in developing countries such as India, the biological processing options get higher priority. However, biological processes are slow and require larger space. In addition, external parameters like weather and temperature affect the processes. In this context thermal systems could be useful. Of the thermal processes, incineration is the most popular one even today. However, incineration of MSW may give rise to a number of complaints, especially atmospheric emissions, the most controversial emission being dioxins and furans. To control the toxic emissions, the incinerator should be properly designed and operated and appropriate air pollution control equipment should be installed and operated.
Manufacture of RDF is promising in locations where markets for RDF are available. Combustion of the RDF from MSW is technically sound and is capable of generating power. RDF may be fired along with the conventional fuels like coal without any ill effects for generating heat. If the power generation plant is at a distance from the RDF plant, firing as RDF pellets/briquettes is suitable because they can be transported easily and stored for many months. However, if it is possible to burn the processed waste at the RDF plant, then the portion for burning need not be pelletized or briquetted.

Operation of the thermal treatment systems involves higher cost, and relatively higher degree of expertise. In addition, there are chances of accidents and fire as high temperature and high pressure are involved. Hence, the usage of thermal techniques in a decentralized way is to be carefully planned and assessed on a case-to-case basis. Rather than many small thermal systems operating inefficiently damaging the environment, it is better to have a few larger environment friendly systems operating efficiently.

Of the various thermal processes, gasification looks attractive and promising as it can destruct the waste giving some heat containing fuel gas. It is not as complex as pyrolysis and not as costly as wet air oxidation. The processing is self-sustaining if the heat content is high enough. It is recommended to operate the existing incineration units (especially the ones with multiple chambers) in the starved air mode (gasification) first and then in the excess air mode for complete oxidation of the gasified products. It is possible to find out the mode in which the unit is working, by simply increasing the combustion air supply. If the furnace temperature increases with this increase in air supply, the unit is in the starved air mode (gasification). On the other hand, if the temperature decreases, it is in the excess air mode. This is based on the fact that at the stoichiometric air, the temperature is the highest.

**Environmental**

The development of energy from waste can play a vital role in a country’s economy by reducing oil imports and sustaining fossil fuel reserves. It would also contribute to meeting international obligations to reduce the emission of greenhouse gases, in particular carbon dioxide, by replacing fossil fuel as a source of energy. Therefore, it is desirable that Governments in developing countries provide fiscal incentive for generated energy such as heat and electricity from waste.

The two key issues to be resolved for the acceptance for energy from waste are i) whether energy from waste would act as a disincentive to materials recovery and recycling? and ii) Whether incineration, pyrolysis and other thermal processes would pose a risk to public health?

On the first issue, evidence from Europe indicates that high recycling can be sustained alongside generation of energy from waste. The issue of health impact has implicated energy from waste in UK and Europe for decades. Emissions of dioxins and the hazardous nature of solid residues have been of particular concern and as such energy from waste operations need to be stringently regulated industrial processes. It is acknowledged that if energy from waste is integrated into a balanced waste management strategy, public health concerns could be addressed adequately. Epidemiological studies and public health risk assessment have shown no link between emissions from modern well designed and well operated energy from waste facility, and any adverse impacts in the surrounding areas.
Composting of Waste and Utilization

Urban (Municipal) Solid Waste (USW) management is one of the most challenging tasks faced by most of the developing countries. There has been a progressive decline in the standard of services with respect to collection, storing and disposal of household wastes. In many cities, nearly half of solid waste generated remains unattended and gives rise to insanitary conditions, increase in morbidity due to microbial and parasitic infections. Periodic out-breaks of food borne, water borne, and vector borne diseases occur in almost all cities. Since landfill sites are also not properly designed, lined and treated, the contamination of underground and air pollution have also been noticed. It is imperative that effective techniques are adopted for efficient management of USW, keeping in view the environmental aspects, hygiene and sanitation. It has been observed that in developing countries percentage of biodegradable waste is higher than in the developed countries. Consequently, technologies tackling the problem will also differ. In addition, lack of financial resources, inadequate workers, fragmentation of administrative responsibility and non-involvement and lack of awareness of the community are the basic constraints for inadequate and unsatisfactory levels of services. Given the current scenario, the public has to be made aware and participate in the waste disposal system. Composting of the degradable part of the waste is an easy and economical option, which can be practiced at any desired scale. Composting also leads to energy saving as it replaces energy intensive chemical fertilizers.

8.01 Composition and Classification of Municipal solid waste
In developing countries like India, USW containing paper, plastic, metals, wooden materials etc. are in low amounts as these are picked up/separated at source by rag pickers and others. The calorific value of waste is as low as less than 1000 k cal/kg and not suitable for thermal technologies. A typical composition of municipal solid wastes in India is shown in Tables 8.1.1 and 8.1.2.

<table>
<thead>
<tr>
<th>Waste Components</th>
<th>% Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaves, Fruits, Vegetables, Meat, Fish, Food, Waste</td>
<td>37.8</td>
</tr>
<tr>
<td>Plastics of all kind including poly layer cartons</td>
<td>19.8</td>
</tr>
</tbody>
</table>
### Table 8.1.2: Classification of Municipal solid waste

<table>
<thead>
<tr>
<th>S No.</th>
<th>Items present in the waste</th>
<th>% content</th>
<th>TPD Qty. based out of 300 TPD MSW</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>Easily compostable:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Food waste, leafy matter, fruit &amp; vegetables, waste flowers</td>
<td>29.6</td>
<td>88.8</td>
</tr>
<tr>
<td></td>
<td>Fish, meat, bones</td>
<td>1.6</td>
<td>4.8</td>
</tr>
<tr>
<td></td>
<td>Green grassy matter</td>
<td>3.3</td>
<td>9.9</td>
</tr>
<tr>
<td></td>
<td>Soft paper, tissue paper</td>
<td>3.3</td>
<td>9.9</td>
</tr>
<tr>
<td></td>
<td><strong>Sub-total</strong></td>
<td><strong>37.8</strong></td>
<td><strong>113.4</strong></td>
</tr>
<tr>
<td>B.</td>
<td>Combustibles/long term degradation:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Corrugated boxes, jute rags, cotton waste</td>
<td>6.8</td>
<td>20.4</td>
</tr>
<tr>
<td></td>
<td>Bamboo baskets, hardboard, card board</td>
<td>3.5</td>
<td>10.5</td>
</tr>
<tr>
<td></td>
<td>Coconut shells, Banana stumps</td>
<td>3.4</td>
<td>10.2</td>
</tr>
<tr>
<td></td>
<td>Tree twigs, palm leaves, frawns &amp; dry grass</td>
<td>3.3</td>
<td>9.9</td>
</tr>
<tr>
<td></td>
<td>Wooden materials</td>
<td>2.5</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td><strong>Sub-total</strong></td>
<td><strong>19.5</strong></td>
<td><strong>58.5</strong></td>
</tr>
<tr>
<td>C.</td>
<td>Recyclables/Combustible:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Synthetic textiles</td>
<td>3.8</td>
<td>11.4</td>
</tr>
<tr>
<td></td>
<td>Plastic film, bags</td>
<td>5.4</td>
<td>16.2</td>
</tr>
<tr>
<td></td>
<td>Hard plastic, mugs, cans, buckets</td>
<td>2.8</td>
<td>8.4</td>
</tr>
<tr>
<td></td>
<td>Tetra packs, poly Aluminum, poly paper pouches</td>
<td>1.8</td>
<td>5.4</td>
</tr>
<tr>
<td></td>
<td>Rubber and leather</td>
<td>2.4</td>
<td>7.2</td>
</tr>
<tr>
<td></td>
<td>Glass</td>
<td>1.8</td>
<td>5.4</td>
</tr>
<tr>
<td></td>
<td>Ferrous metal &amp; other metals</td>
<td>1.8</td>
<td>5.4</td>
</tr>
<tr>
<td></td>
<td><strong>Sub-total</strong></td>
<td><strong>19.8</strong></td>
<td><strong>59.4</strong></td>
</tr>
<tr>
<td>D.</td>
<td>Other Materials:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stone, bricks, debris, soil, silt ceramics</td>
<td>13.5</td>
<td>40.5</td>
</tr>
<tr>
<td></td>
<td>Miscellaneous (diapers, Sanitary napkins, bandages, feather, hair)</td>
<td>9.4</td>
<td>28.2</td>
</tr>
<tr>
<td></td>
<td><strong>Sub-total</strong></td>
<td><strong>22.9</strong></td>
<td><strong>68.7</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Grand-total</strong></td>
<td><strong>100.00</strong></td>
<td><strong>300.00</strong></td>
</tr>
</tbody>
</table>

**8.02 Composting of Municipal Solid Waste**

For processing, treatment and disposal of municipal solid waste, various technologies are available. It is for the urban local body (ULB) to choose any one or combination of technologies to suit their local situation so as to meet the criteria, statutory standards for different end products, emission, discharge etc. Various technologies for generating bio-energy from wastes have been discussed in the previous Chapters. However, composting and vermi-composting are most easily applicable and replicable. This is because wastes contain high proportion of organic matters along with high moisture contents. The garbage has low combustible material and hence not suitable for direct incineration. Naturally composting appears to be the most preferred option of solid waste management (SWM).

Also given the rapidly declining per-capita land availability, the only means of meeting the rising food requirement due to burgeoning population in developing countries is through increased soil productivity, health and quality, without detriment to environment and sustainability. For effective management and improvement of soil quality, fertility and productivity, adequate organic carbon needs to be added to the soil matrix. This can be achieved if proper composting of bio-degradable segment of SWM is conducted by ULBs through public-private participation and the compost is applied to plants. Addition of organic matter would also improve the use and efficiency of added plant nutrients (manure and water) by 20-25 percent. Other benefits of compost are as follows:

- Maintaining soil organic carbon around 1% in soil will improve biological cycle involving microorganisms, soil flora and fauna.
- Making available the entire macro and micro-nutrients in adequate amounts for achieving better yields.
• Improving physical, chemical and biological conditions of the soil leading to proper balance of air and water in soil system.
• Enhancing nutrient response ratio, keeping in view soil-water-plant continuum.
• Eco-friendly approach for better soil health without any green-house effect.
• Prevent warming up of atmosphere by controlling the release of CO₂, CH₄, etc.

**Composting Process**

For effective and efficient composting, the C/N ratio of organic segment of waste is vital. Since mainly microorganisms are involved in the process of conversion of various organic compounds, the proportion of carbonaceous and nitrigenous segments determines their effectiveness. A C/N ratio in the range of 25:35 to 1 has been reported as optimal by various scientists. In case the ratio is high, the decomposition rate slows down even if other conditions are favourable. The organic wastes fall into the following categories. It may be noted that the second category has higher C/N ratio.

• **Easily Compostable:** Food wastes, leafy matter, fruit and vegetable waste, fish, meat, green grass from parks, soft paper, etc.
• **Long-term Degradable Waste:** Cotton waste, corrugated boxes, bamboo baskets, coconut shell, banana stumps, tree twigs, palm leaves, flowers, wooden materials, etc. having high lignin contents.

The segregated garbage having around 40-50 per cent of bio-degradable segment and around 50 per cent moisture is placed in heaps or windrows. Whether it is under aerobic or anaerobic conditions, the decomposition is performed by the micro-organisms. It has been found that aerobic composting is definitely better as compared to anaerobic one. The aerobic process is performed by mesophilic and thermophilic micro-organisms. Within a week, temperature inside heap reaches to 60°-70°C. At this temperature the contaminants including weed-seeds, pathogens and other biologically hazardous materials such as residues of organic, organo-metallic compounds degrade. The process is fast and is completed in six to eight weeks.

The biodegradable material undergoes intensive decomposition by different groups of heterotrophic micro-organisms, namely bacteria, fungi, actinomycetes and protozoa. The role of cellulolytic and lignolytic micro-organisms in decomposition of crop, horticultural and household wastes is of prime importance.

The bacteria under aerobic conditions utilize oxygen, decompose organic matters and assimilate some of the carbon, nitrogen, phosphorus, sulphur and other nutrients for synthesis of their cell protoplasm. In the process, production of CO₂, humus substances and release of plant nutrients take place. Under field conditions, aerobic decomposition of organic matter is a continuous natural process and there is hardly any problem such as foul odour.

In brief, composting is a microbiological conversion process of biodegradable segment of USW leading to the decomposition of organic particles to a final product like humus. Microflora like bacteria, fungi and actinomycetes and certain macrofauna are responsible for this bio-conversion process. The quality of organic manure produced would naturally be dependent on the composition of organic waste and the process involved in its bio-conversion. In the absence of waste segregation at source, it is possible that organic manure may contain the heavy metals and toxic/hazardous substances, etc. Segregation at source and before composting should be conducted.

**Microbial activities**

The fungi and acid forming bacteria are activated during initial mesophilic stage and multiply at fast rate. Their activities are high under optimum moisture and aerobic conditions at a temperature of 37°C but it starts declining as the temperature rises above 40°C sharply. At that temperature the thermophilic microorganisms, which are effective in the degradation of organic bio-polymers can thrive. Mesophilic bacteria that flourish during limited time degrade carbohydrates and biopolymers. Actinomycetes degrade starch actively and also decompose it to water soluble fractions. They are quite active in decomposing cellulose fraction even at thermophilic stage.
The mesophilic fungi present in the compost are mostly saprophytic that are replaced by thermophilic fungi as the temperature rises. As the temperature drops to 40°C these mesophilic fungi reappear again. Since temperature is variable in the heap (lower at the crest and higher at the middle to bottom) the mesophilic fungi continue to work at the outer layer of heap and again start their activity when the conditions are favourable. The phases that can be distinguished in the composting or stabilization process according to temperature pattern are shown in Box 8.2.1.

**Box 8.2.1: Phase of bio-composting as per temperature pattern**

- **Latent Phase**
  - Which corresponds to the time necessary for the microorganisms to acclimatize and colonize in the compost heap

- **Growth Phase**
  - Which is characterised by the rise of biologically produced temperature to mesophilic level

- **Thermophilic Phase**
  - In which the temperature rises to the highest level 63°C-65°C. This is the phase where waste stabilization and pathogens destruction are most effective

- **Bio-stabilisation Phase**
  - Where the temperature decreases to mesophilic and subsequently ambient levels

- **Secondary Fermentation**
  - A secondary fermentation takes place, which is slow and favours humification, that is, the transformation of some complex organics to humic colloids closely associated with minerals like iron, calcium, etc., and finally to humus

- **Humus**
  - Organic manure like organic fertilizer/soil enricher is recovered

Thus, composting process harnesses the natural forces of decomposition to secure the conversion of organic waste into manure. During the process of decomposition of the organic matters by the micro-organisms the temperature rises to about 65°C-70°C within 7-8 days. This is due to anabolic activities of microbes that are exothermic in nature. At such high temperature mesophilic bacteria present in the wastes are killed. Further anaerobic condition is created inside heap resulting in formation of hydrogen sulphide gas causing pungent odour. Therefore it is advisable to churn the waste heap once in a week. It helps maintain mesophilic temperature inside and aerobic condition inside waste heap. Addition of thermophilic bacteria as inoculums enhances the degradation of wastes particularly at the bottom and middle layers of the heap, where temperature rises. After 3-4 times of churning of wastes upside down, the final churning should be done at longer time interval. It helps elimination of most of the mesophilic bacteria that are mostly pathogens. Thus the final compost is almost free from pathogens. Parasites such as Ascaris eggs, cysts of Entamoeba histolytica and Lookunorms eggs are also destroyed at this high temperature. Since the heaps are placed as windrows in an open environment, care must be taken that the decomposing material does not get too dry or wet in summer or rainy seasons, respectively. Optimum moisture content should be around 65%. Higher moisture content causes anaerobic condition while lower results in drying up of waste, resulting in low activity of mesophilic micro-organisms.

After 6-8 weeks the composted material is spread on an open platform so that the moisture level reaches 15-20 percent. This composted “Humus” type of material is to be passed through 4mm sieve and then packed in the bags, ready for farmers to apply in the field.
Factors affecting Composting
There are largely five main factors that influence the composting process: i) Composition of organic waste and its particle size of organic material; ii) Addition/application of inoculants; iii) Moisture content; iv) Aeration; and v) Temperature. In fact, optimization of all factors for efficient decomposition is vital for the conversion of bio-degradable matter and its stabilization as humus by micro-organisms.

Composition of Organic Waste
A higher C/N ratio of organic wastes may lead to slower decomposition rate. Addition of nitrogen source such as legume residues and aquatic weeds (Water hyacinth), slaughter-house waste, green leaves etc. can enhance microbial activity. C/N ratio between 26-30, nitrogen around 0.5 - 0.8% and pH between 6.5 - 7.6 are optimum parameters for effective composting.

Particle Size
Composting process can be accelerated, if the organic waste is shredded into smaller pieces. This increases surface areas of the substrate for microbial growth. Normally less than 5 cm sizes are most easily decomposed. The ultimate product would naturally be obtained early and the end product would be of good quality.

Moisture
The optimum moisture level of the organic waste for aerobic decomposition should be kept around 50 per cent. However, if the material contains higher amount of fibrous/lignin, the moisture level should be maintained at 60-80 per cent. During aerobic composting high moisture content should be avoided as it causes anaerobic conditions. If moisture level drops below 40 per cent the required nutrition for the survival and effective conversion by the micro-organisms is not available and there is a considerable reduction in bacterial activity.

Aeration
Composting process is entirely dependent on the air supply mechanism. Under aerobic condition, decomposition rate is 10-20 times faster than under limited oxygen concentration. In anaerobic condition methane and hydrogen sulphide gases are formed causing foul smell. Therefore, oxygen level in the pile heap is maintained within the windrow through turning and mixing at regular interval of 7-10 days.

Temperature
The temperature within a composting yard windrows determines the rate at which many of the biological processes are taking place and is, therefore an important parameter for sanitization, degradation and stabilization of organic matters. The inoculums added for composting contain both mesophilic and thermophilic bacteria. Initially mesophilic bacteria act upon waste materials and decompose. During the process heat is generated. The temperature rises more than 40°C to 70°C. The activities of such bacteria decrease and at such elevated temperature thermophilic bacteria start growing. Regular churning of wastes serves dual purpose - providing oxygen to aerobic bacteria and maintaining low temperature of the waste heaps.

However, high temperature up to 70°C in the core windrows middle pile is essential for destruction of pathogenic organisms, weed seeds, degradation of organic based pesticides etc. However, it inhibits the mesophilic microbial growth. This generally occurs within 7-8 days of composting. Decomposition is faster in the thermophilic stage, but this temperature should not be kept for a longer period. Most of the findings reveal that optimum temperature is 60°C to 70°C for an oxidation of organic material into carbondioxide and water. The rise in temperature would be governed by C/N ratio, moisture present, microbial activity, size of the heap and of course aerobic conditions created by turning/stirring etc.

The temperature at which decomposition rate is maximum is between 30°-40°C by mesophilic organisms. Temperature below 20°C further lowers down the decomposition rate.

Inoculants
Even though the microbes are present in the biodegradable materials under natural condition, addition of inoculants along with fresh cow dung slurry has been found to speed up the composting process. Addition of
inoculants enhances the process of composting and decomposition. Whenever the C/N ratio is too high, addition of nitrogen would naturally enhance the microbial activity. Microbial population and species diversity involved in degradation of complex components such as celluloses, hemicelluloses, lignin, vary from $10^4$-10$^7$ cells/g. Addition of microbes has been found to be quite effective and the whole process of composting is completed within 6-8 weeks. There are several mixed cultures of cellulolytic and hydrolytic bacterial strains used as inoculums for composting. However, these are not readily available. In the absence of such mixed culture, compost from vegetable wastes along with cow-dung can be used as inoculums.

**Production of leachate, odours and control**

a) Organic residues and waste are normally composed of celluloses, hemicelluloses, proteins, fatty matters and are therefore, susceptible to putrefaction. If allowed to remain under anaerobic conditions foul odour is released, in case high water and moisture contains blackish leachate is released. Because of high BOD and pathogen counts, release of soluble organic acids, salts etc., there is a danger of polluting the underground water by leachate.

b) To overcome this, the waste must be kept on a slope but not more than 1% of the platform and waste heap around 2 meters. By turning in 7-10 days, the leachate is ploughed back into the waste.

c) As per MSW Rules 2000, stocking of waste is mandatory at the cemented platform with proper design, size and slope to channel leachate in a tank and then reuse in composting cycle after proper treatment.

d) Aesthetics and ecological considerations must be taken into account all around.

**Large Scale Composting**

The bio-degradable waste is placed at the compost pad, which is constructed by using reinforced concrete and the joints are sealed by asphaltic concrete or soil cement in order to prevent ground water contamination. The compost pad (pavement) should have strength to bear the load of at least 30 to 40 tones/m². The construction material and size of pad should be designed considering the techno-economic aspects.

Self-propelled windrow turner may also be used for turning of waste, aeration of materials. It reduces the composting pad area by at least 30 percent. Tractor mounted attachment for handling and turning the waste is preferred, as it is cheaper to run and maintain. At least 35 per cent of the composting plant should be covered with proper roof to enable at least 30 days of decomposition under roof to prevent the wetting of material from possible rainfall and hampering the operations.

The bio-degradable waste is treated with the microbial inoculants in the form of either mixed culture of bacteria or compost/cow-dung and proper moisture is maintained in the windrow. After one week the temperature is recorded and as soon as it reaches 65°C, it is taken that microbial decomposition by thermophilic micro-organisms is being performed. In 7-10 days, this material is turned upside down in order to make oxygen available to microbes and lower the temperature inside heap.

**Compost Refinement**

The well-composted material is placed on a platform for moisture reduction and for getting the organic manure well matured. Thereafter, it is enriched as per the requirement of cropping system and the demand of the user. Well-decomposed material is passed through sieve of 35 mm and 14 mm. Finally, the well cured and stabilized material must pass through 4-6 mm sieve and then only compost is ready for marketing. The finished product should be dark brown with earthy smell, fragile, easy flow, rich in carbon content and nutrients.

**Compost Quality**

- It is vital that organic fertilizer produced at the compost plant is of good quality; hence it is necessary that all compost plants of 100 TPD and above should have quality control laboratory. They should be free from the pathogens, parasites, weed seeds and other contaminants. The compost quality should be tested by batch regularly and each bag should have quality code printed.
- Production of compost of different quality with due enrichment should be prepared for different crops including plantation crops, medicinal aromatic crops, horticultural crops and other cropping systems.
Table 8.2.1: Standards for Compost/Organic Fertilizer

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Parameters</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Moisture per cent by weight</td>
<td>15.0 - 25.0</td>
</tr>
<tr>
<td>2</td>
<td>Colour</td>
<td>Dark brown to black</td>
</tr>
<tr>
<td>3</td>
<td>Odour</td>
<td>Absence of foul odour</td>
</tr>
<tr>
<td>4</td>
<td>Particle size</td>
<td>Min. 90% material should pass through 4.0 mm IS Sieve</td>
</tr>
<tr>
<td>5</td>
<td>Bulk Density (g/cm³)</td>
<td>0.7 - 0.9</td>
</tr>
<tr>
<td>6</td>
<td>Total Organic Carbon% by weight min.</td>
<td>16.0</td>
</tr>
<tr>
<td>7</td>
<td>Total Nitrogen (as N) % by weight min.</td>
<td>0.5</td>
</tr>
<tr>
<td>8</td>
<td>Total Phosphate (as P₂O₅)% by weight min.</td>
<td>0.5</td>
</tr>
<tr>
<td>9</td>
<td>Total Potash (as K₂O)% by weight min.</td>
<td>1.0</td>
</tr>
<tr>
<td>10</td>
<td>C/N Ratio</td>
<td>20:1 or less</td>
</tr>
<tr>
<td>11</td>
<td>pH</td>
<td>6.5-7.5</td>
</tr>
<tr>
<td>12</td>
<td>Conductivity (as dSm⁻¹) not more than</td>
<td>4.0</td>
</tr>
<tr>
<td>13</td>
<td>Pathogens</td>
<td>Nil</td>
</tr>
</tbody>
</table>

Note: The compost/organic fertilizer from integrated MSW plant will meet all the above specifications.

Key factors for Compost Plant Setting

- Only segregated bio-degradable segment be used for composting.
- Regular removal of rejects from the compost plant is ensured by the ULB.
- Composting technique must be systematically followed by the concerned persons for achieving the desired quality of compost.
- Tipping area of compost plant should be prevented from ground water pollution.
- Thirty five percent of composting land should be covered to prevent wetting of decomposed material by rain.
- Every compost plant of 100 TPD and above should have a laboratory for the preparation of the desired type and quality of inoculants and a quality control testing.
- Every compost plant should have a weighbridge for weighing the organic waste being received.
- Green plantation should be done on the periphery of compost plant.
- The design and structure of the compost plant should be as per specifications laid by respective governments.
- Compost Plant should be at least 1 Km away from the proposed residential area.

8.03 Vermi Composting

Vermi-composting involves the stabilization of organic solid waste through earthworms that convert the material into worm castings. Vermi-composting is the result of combined activity of micro-organisms and earthworms. Microbial decomposition of bio-degradable organic matter occurs through extracellular enzymatic activities (primary decomposition) whereas decomposition in earthworm occurs in alimentary tract by micro-organisms inhabiting the gut (secondary decomposition). Microbes such as fungi, actinomycetes, protozoa etc. are reported to inhabit the gut of earthworms. Ingested feed substrates are subjected to grinding in the anterior part of the worms gut (gizzard) resulting in particle size reduction.

This technology has been used for agricultural waste and its adoption to municipal solid waste is of recent origin. The worm species that are commonly considered are Pheretima sp, Eisenia sp and Perionyx excavatus sp. These worms are known to survive in the moisture range of 20-80% and the temperature range of 20°C-40°C. The worms do not survive in pure organic substrates containing more that 40% fermentable organic substances. Hence, fresh waste is commonly mixed with partially or fully stabilised waste before it is subjected to vermi-composting. The worms are known to be adversely affected by high concentrations of such heavy metals, as Cd (Cadmium), Cr (Chromium), Pb (Lead) and Zn (Zinc). Due to the constraints of the temperature, moisture,
fermentable organic substances (FOS) and heavy metals use of vermi-composting on municipal scale has not been successful. However, use of this method for wastes from individual houses, housing colonies etc. where the waste is mainly organic in nature and where the quantities are less and can be manually handled, is common.

The vermi-compost is relatively more stabilised and harmonises with soil system without any ill effects. Unfavourable conditions such as particle size of biomass, extent of its decomposition, very large temperature increase, anaerobic conditions, toxicity of decomposition products etc. influence activity of worms.

**Method of Composting**

- **Size of pit:** Optimum size of pits is of 3 m (length) x 1 m (width) x 2 m (deep) but can be longer depending upon the requirements. Pits may be dug under the shade of a tree.
- **Bed Preparation:** A layer of 15-20 cm thick loamy soil should be provided at the bottom of pit.
- **Inoculation of earthworm:** About 1000-2000 earthworms are introduced into the pit.
- **Organic Layering:** Digested organic waste is then layered with dry leaves to about 5 cm.
- **Organic Layering:** Organic waste is layered to a thickness of 5 centimetres along with adequate moisture (50-60 per cent), every 3-4 days. Soft mixing is performed without disturbing the vermi-bed underneath. This is done until the compost pit is nearly full. This is then left to compost wetting as needed.
- **Harvesting of Vermi-compost:** When maturing is complete, the moisture content is brought down so that the worms migrate into the vermi-bed and the compost is harvested from the upper layer.

**Nutrient Contents**

Nutrient content of vermi compost is more as compared to compost from city waste and has N, P$_2$O$_5$ and K$_2$O around 1.9%, 3.0% and 0.8% respectively. The phosphorus enriched vermi compost contains P$_2$O$_5$ between 2 to 4%.

**Advantages of Vermi Compost**

- Productive conversion of organic waste.
- Improves physical, chemical and biological content of the soil and ensures better crop productivity.
- Because of earthworms, the soil pathogens are destroyed and beneficial micro-organisms flourish. Thus soil quality and soil health are improved.
- For organic farming and growing high value low volume crops, it is being recommended.

**8.04 Limitations of Conventional and Vermi Composting Processes**

- It requires longer time – not less than 70-75 days.
- Space requirement is huge due to longer time period required.
- Churning of waste upside down is required at least once a week.
- Manual handling of wastes is required – a source of health hazards.
- Mechanical handling of wastes makes the system economically unaffordable.

**8.05 Sulabh Approach to Bio-degradable Waste Treatment**

The technology developed by Sulabh International, viz., Sulabh Thermophilic Aerobic Composter (STAC) (Figure 8.5.1) requires only 10 to 12 days to make compost from any bio-degradable wastes without any manual handling during composting. It is based on thermophilic aerobic method. The technology does not require recurring expenditure.

The structure is made of a G.I. sheet having double wall filled with glass wool to make insulate and partitioned with perforated plates into three chambers.
Waste is put in upper two chambers after pulverization. Initially some thermophilic bacteria as inoculums are put inside the plant along with waste materials. Inside temperature of plant rises to 60-65 degree Celsius within 48 hours, at such temperature thermophilic bacteria acts quickly to degrade wastes. At high temperature, pathogenic bacteria die off and thermophilic start growing, that degrade wastes quickly. Aeration is provided through compressor twice a day for 3-4 minutes. After biodegradation, liquid is collected in bottom chamber that can be easily taken out and used for agricultural/horticultural purposes. It is also reused as inoculums of thermophilic bacteria. The degraded wastes taken out from the plant is put into pits till further use. Manure that contains 30-35% moisture can be directly used for agriculture/landfill purposes or it can be dried, granulated and stored till further use. The technology requires much less space. The compost generated is pathogen free. It functions at low temperatures also.

Utilities of STAC technology
- Organic solid waste can be efficiently converted into manure and soil conditioner having direct/indirect economic return;
- It will control diseases transmitted from wastes, as at high temperature, pathogens are eliminated from the waste;
- Due to reduction in volume, carriage cost of wastes to disposal site as well as area needed for landfills will be drastically reduced; and
- spread of weeds from wastes will also be controlled.

The technology is more suited at household level, for multi-story buildings, for fruit and vegetable markets, hostels, housing colonies, hilly areas etc. The compost can be readily used for agricultural purposes, and reduces health hazards.

Use of STAC Technology in Dharmshala, Himachal Pradesh, India
A project for 2 tons of municipal wastes is under implementation in Makloreganj, Dharmshala in the State of Himachal Pradesh, India. Composting is being carried out through STAC technology. There are 20 such STAC
plants (Figure 8.5.2) operated in batches. Waste materials after segregation at the plant site are pulvarised in small pieces and put into plant. There is provision of aeration through compressor. Degraded materials are taken out and put into pits. There are 4 such pits at the sites. Compost from the pits are taken out and used for agriculture purpose when ever required. The liquid part collected after degradation is used for agriculture/horticulture and also as inoculums for the next batch of operation of the plant, thereby, ground water pollution from leachets does not arise.

8.06 Composting and Conservation of Energy
Composting indirectly helps in conserving energy. This is so as bio-organic fertilizer is ideal for improvement of soil properties in terms of (1) porosity for ease of ploughing and crop root expansion, (2) moderating of bulk density to improve both sandy as well as clay soils, and (3) better transmission ability in the soil for conservation of water and nutrients, for temperature regulation and higher microbial activity. The higher biological activity helps in breakdown of toxic chemical residues. It further,

• promotes beneficial micro-organisms in the root rhizosphere.
• improves soil health by converting residual organic matter into humified substances; helps in solubilising unavailable mineral nutrients into readily available form; and contributes directly by addition of humic components into the soil.
• helps in suppression of plant root disease through pro-biotic effects.
• provides resistance to plant leaves against sucking insects.
• absorbs nutrients from chemical fertilizers and releases slowly for long-term feeding of crops, thereby increasing the fertilizer usage efficiency.
• helps to increase enzymatic activity in plants to detoxify pesticide residues and also increase quality of the produce.
• helps in reclamation of salt affected degraded soils through multiple actions in the soil.

8.07 Adoption of Composting Technology
In adopting composting, the following are important to consider:

• Segregation of garbage at source and supply point, so as to avoid any contaminant toxic elements in the final product.
• Technical, physical and financial support by all stakeholders (city dwellers, ULBs, State/Provincial Governments, Central Government and the Private entrepreneurs) is vital.
• Composting technology has to be adopted rigorously and systematically, that is, placing the biodegradable segment in windrows, treating it with inoculants, maintaining adequate moisture and temperature, turning after every 7-10 days.
• No compromise should be made at the cost of quality of manure. The farmer must be provided with full package of practices of the cropping system at an affordable price for both organic farming and integrated nutrient management.
• Government (Central and State/Provincial) may grant incentive price share, may be to the extent of say 40% of the total minimum price rate.
• No taxation on solid urban waste management, including well composted manure, machinery equipment, etc. and land lease for about 30 years (revenue free), water and electricity charges at agricultural rate.
• Basket approach may be adopted by the fertilizer companies (in the ratio of 50:50) for transport charges. Co-marketing is vital for furthering its use and efficiency.
• Back-up research and development is essential for formulating the package of practices for all crops including high value low volume crops, forestry and others. The Agricultural Universities should be granted adequate allocation for exhibiting the fruits of research on farmer's field.
Utilization of Energy from Waste

As seen from the previous Chapters, gaseous, liquid and solid fuels can be generated from different kinds of wastes. Where wastes are organic and biodegradable and are moist and soft like animal wastes they can be digested anaerobically to produce biogas, which can be burnt to release heat, for a variety of applications. In the case of biomass which is relatively dry as with woody wastes or dry chicken manure and also waste plastics it may be possible to directly burn them to produce heat which can be used for warming of premises or produce electricity. Alternatively gaseous and liquid fuels may be obtained by gasification or pyrolysis. The fuels generated can be used in further applications. Scope exists to apply these techniques at domestic, community, and on large scales for cities as described below. The various end uses of wastes mentioned in this Chapter include cooking, lighting, power generation, transport fuel (CNG).

9.01 Applications of Biogas from Human and Animal wastes

As already described in the previous Chapters, animal wastes including human, are a good feedstock for biogas generation. Typically biogas contains about 60 to 65% methane, 35 to 40% carbon dioxide, about 1% hydrogen sulphide and rest nitrogen, hydrogen, carbon monoxide etc. Methane is the only combustible constituent in biogas that is utilized for getting different forms of energy. A thousand cubic feet (30m³) of biogas is equivalent to 600 cubic feet of natural gas, 6.4 gallons of butane, 5.2 gallons of gasoline or 4.6 gallons of diesel oil.

### Characteristics of methane

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molecular weight</td>
<td>16.04</td>
</tr>
<tr>
<td>Boiling point at 1 atm</td>
<td>-164.0°C</td>
</tr>
<tr>
<td>Freezing point at 1 atm</td>
<td>-182.5°C</td>
</tr>
<tr>
<td>Density at 0°C 1 atm</td>
<td>0.7172 kg/m³</td>
</tr>
<tr>
<td>Critical temperature</td>
<td>-82.5°C</td>
</tr>
<tr>
<td>Critical pressure</td>
<td>4.628MN/m³</td>
</tr>
<tr>
<td>Heat capacity Cp at 15°C, 1 atm</td>
<td>2.219 KJ/Kg°C</td>
</tr>
<tr>
<td>Ratio Cp/Cv</td>
<td>1.307</td>
</tr>
<tr>
<td>Flammable limits in air</td>
<td>5.3 - 14% by volume</td>
</tr>
<tr>
<td>Calorific value at 15°C</td>
<td>37.71 MJ/m³</td>
</tr>
</tbody>
</table>
Biogas can be used in different ways depending on the scale of operation, requirements such as cooking, pumping water, generating electrical power and using other utilities like refrigerator. Some applications and requirement of biogas for popular uses are listed in the Table 9.1.1. For these appliances, the biogas is delivered at a pressure of 7.5 – 15 cm water column.

**Table 9.1.1: Biogas consumption in different applications**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Appliance</th>
<th>Consumption in liters per cubic feet/hr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Burner</td>
<td>227(8) 453(16) 680(24) 906(32) 1133(40)</td>
</tr>
<tr>
<td>2</td>
<td>Mantle type lamps</td>
<td>113-142 (4-5) single mantle</td>
</tr>
<tr>
<td>3</td>
<td>Electrical Power</td>
<td>0.75m³ biogas is equivalent to 1 kWh. that is 1.333 kWh is produced from 1m³ biogas</td>
</tr>
</tbody>
</table>

*Source: Ramarao et al, 1988*

**Use for Cooking**

Biogas, which has a calorific value of 20 - 26 MJ/m³ depending on methane content in the biogas, can be used efficiently for cooking (Figure 9.1.1, 9.1.2 and 9.1.3). It burns with a blue flame and without any soot and odour. In rural areas where cow dung and wood burning are the only source of fuel, biogas is a boon. Depending upon the size, a cooking burner consumes 8-25 cubic feet of biogas per hour.

**Figure 9.1.1: Use of Biogas for Cooking**

While 5 kg of fresh dung can generate 16 MJ heat on burning and give net heat of about 1.3 MJ in an open stove/chullah at 8% efficiency, the same amount of dung on digestion will yield approximately 0.20 cum of biogas having thermal value of 5MJ. Further, since the gas is utilized in gas burners at 60% efficiency, the net heat value recovered for cooking is 3MJ. Thus, not only is the net available heat through conversion into biogas nearly 2.5 times higher than that of burning dung cake in open stove/chullah, but also there is the additional benefit of using the spent slurry from the digester as compost. In addition, unlike the smoke emitted on burning of cow dung, biogas burns without emitting smoke.

**Figure 9.1.2: Sketch of Biogas Burner for Cooking Purpose**

**Figure 9.1.3: Biogas burner for cooking purpose**
Use of biogas for Lighting through Mantle Lamp

Biogas can be utilized for mantle lamp lighting (Figure 9.1.4). A mantle lamp consumes 3 to 4 ft³ biogas per hour. Its illumination capacity is equivalent to 40 watt bulb at 220 volt.

Figure 9.1.4: Use of Biogas for Lighting through Mantle Lamp

Use of biogas for Electricity Generation

Biogas can be used for generating power (Figure 9.1.5) through dual fuel generator coupled to alternator. The engine requires modifications to enable the entry of biogas with intake air and an automatic regulator to control diesel supply, which is required for the initial stage. The mixing of biogas with intake air and its entry into the engine is achieved by providing a mixing chamber below the air cleaner. Since the self-ignition temperature of biogas is high at 651°C, the temperature achieved with conventional compression ratio is not sufficient to initiate its combustion and hence diesel is supplied. Thereafter, biogas is injected into the engine through an air mixing chamber to provide it with additional fuel. At optimum conditions, up to 80% diesel can be saved, depending upon the percentage of methane in biogas.

The consumption of biogas by dual fuel genset is 15 cubic feet/BHP/hr. 60 cubic meters of biogas can run a 10 KVA genset for 8 hours a day producing about 65 units of power. The consumption of diesel varies with load also. The controlled trial with 10 KVA (12 BHP) genset showed 73.0% diesel saving at full load and 76.5% at half load. However, based on the recent R&D on genset, there are engines which do not require diesel to operate and can run on 100% biogas. Thus recurring expenditure on diesel has been totally saved.

Figure 9.1.5: Electricity from biogas
**Use of biogas for body warming**

The use of biogas in winter for body warming is important particularly for slum and rural areas. In a simple device, biogas is passed through a small hole in a flattened galvanised iron pot, covered with small pieces of stones. Biogas spreads over the stone pieces and burns when ignited, providing a source of warmth to the surroundings.

**Manure Production**

One of the important resources recovered from biogas technology is the use of slurry as manure. It contains good percentage of plant macro-nutrients (N.P.K) and many micronutrients. The content of plant nutrients in effluent and sludge are discussed in other Chapters.

**9.02 Benefits of Sulabh Biogas Plant linked to Public Toilet**

One thousand cubic feet of biogas is produced from a toilet complex used by 1000 persons daily. In other words, one cubic foot of gas is generated per user per day. Biogas from human waste contains methane, carbondioxide, hydrogen sulphide, nitrogen, hydrogen, carbon monoxide, etc. Biogas is being used for cooking, lighting lamps and electricity generation for local neighbourhood of the toilet complex. The water discharged from the public toilets contains phosphate, nitrogen and potash. This effluent after treatment through SET technology is made free from any odour and colour. It can be used for agriculture/horticulture or safe discharge in any water body without causing any health or environmental risk. It would be beneficial to implement biogas technology in all the public toilets in slums, housing colonies, high-rise buildings, etc. The public toilet linked with biogas plant benefits economically, when located at busy market places, hospital areas, railway stations, etc in the town/city. All the public toilet complexes in a town/city, when taken together, is always economically sustainable.

The use of water in biogas technologies from individual houses or public toilets is limited to only 1.5 to 2 liters of water per use to flush; whereas in conventional system it requires minimum 10 liters of water per use for flushing. Thus the most precious thing, the potable water, of around 6000 MGD can be saved if calculated with single use per day for 700 million people with no access to improved sanitation. The extent of actual potable water conserved is much more by using the technologies promoted by Sulabh. In addition, enormous amount of treated waste water is recycled for uses other than drinking purposes.

The use of public toilet on pay and use not only generate income but also provide economic stability of the system. The user charges, in general, are about Rs.1 to Rs.2 (2 to 4 US cents) per use. If a toilet has 1000 users a day, calculated income of the order of Rs.1000 to Rs.2000 (USD20 to 40 approx.) per day per toilet is generated. However, women, children, disabled persons are exempted from such charge. One can imagine the extent of actual income that can be generated for all types of uses in a toilet and from all the Public Toilets in the city/town and the country as a whole. People use public toilet for defecation and bathing by paying money, while the raw material for biogas production is available free of cost. A restaurant can be run using biogas generated from the digester. It will help reduce cost of cooking gas to a great extent.

Health is wealth. The food we consume, grown from chemical fertilizers affect insidiously the health system. This technology is also of great value as it produces fertilizer which promotes agriculture.

Digested sludge from night soil based biogas plant can efficiently be utilized for increased productivity of agriculture as it contains good percentage of nitrogen, phosphate, potash and several micro-nutrients for plant growth. It is much better than any chemical fertilizer as it improves soil texture also and sets as soil conditioner as well. From two pit pour flush toilet technology. 40 kgs of fertilizer is obtained per annum per person. If calculated for 700 million people (having no access to safe sanitation in India) @ 40 kgs., the production of manure works out to approx. 28 million tons per annum and the cost of which is around US$ 3 billion. While on one hand, the system helps to minimize the use of chemical fertilizers, on the other, it can raise agricultural productivity. Globally, there has been enormous demand for use of bio-fertilizer in agriculture and horticulture. Also, the gases emitted get dispersed into the soil through the holes in pit lining and do not contribute to climate change.
With the availability of on-site safe disposal toilet systems, the concept of open defecation-free towns/cities is fast growing. The system evolved for the operation and maintenance of the public toilets for community use has proved a boon to the local governments and Urban Local Bodies (ULBs) in their endeavour to keep a clean and improved environment in the cities and towns.

Sulabh Sanitation System also works in an environment where temperatures are at subzero levels and generation of biogas from public toilets pose a major technical problem. In Kabul, Afghanistan, sanitation coverage is very low and there is no sewer system. A major breakthrough was achieved for the local body by Sulabh International, which constructed five public toilets linked with biogas plants. In these biogas plants, the temperature largely remains constant because they are made underground. Consequently, there is constant gas production throughout the year, including during winters when atmospheric temperature goes below 0°C up to minus 25°C (Figures 9.2.1 and 9.2.2).

Thus, Sulabh Sanitation Technologies provide both social and economic benefits. Around 10 million people all over India have benefitted with household toilets which are being used successfully. The Sulabh system of Pay & Use public toilets have been implemented by several local bodies spread all over India covering around 7000 such toilets, constructed and well maintained. The biggest Sulabh public toilet has been constructed at Shirdi, in the district of Nasik of Maharashtra State, India, having 120 WCs, 108 bathrooms, 28 special toilets (separate for ladies and gents) and 5,000 lockers for the convenience of the pilgrims.

The people have accepted and are fully satisfied with its performance. The Government of India, State Governments, various National and International Agencies like UNICEF, World Bank, UNDP, WHO, UN-HABITAT, etc. have accepted the design, advocating its use and are propagating for construction of such toilets in India and other developing countries in South-East Asia, Latin America, Africa etc. Also, the national and international print and TV media have also helped a lot in disseminating the Twin Pit Toilets as the Most Appropriate Technological and Affordable Option for the disposal of human excreta and appreciated the methodology adopted for Social Marketing and delivery to the beneficiaries.

Sulabh International Social Service Organisation has established practical solutions to the problem of sanitation to the developing countries by providing appropriate, affordable, eco-friendly and acceptable technologies with focus on social transformation.
9.03 Use of Biogas as Transport Fuel

Generally, biogas is primarily used for cooking. This can be greatly enhanced where bigger plants are in operation, for example, institutional biogas plants, cattle sheds, dairy farms or community biogas plants. To tap the full potential of biogas and commercialize its use, biogas is enriched and stored in transportable cylinders. The basic difference between biogas and natural gas is the difference in the methane content. If the methane level in biogas is increased by suitable purification or enrichment method, it can meet all the applications where natural gas is used. In addition, self-ignition temperature of biogas is high as compared to other motor fuels, thereby reducing the probability of a fire or explosion in the event of fuel leakage. It is possible to upgrade the quality of biogas by enriching its methane content up to the natural gas level. The complete technology can be divided into two stages, namely the enrichment and compression stages.

Enrichment and compression of biogas makes it easy to use it away from the biogas plant or at any remote location. For example, after methane enrichment and compression it can be bottled as Bio-CNG (Figure 9.3.1).

The enriched and compressed biogas can be used in transportation, for example, in three wheelers, buses, cars, vans, tractors etc (Figure 9.3.2). It can also be used in stationary engines to generate motive power for a rural industry, for example, flour mill, or water lifting pump for irrigation. Enriched and compressed biogas is lighter than air, so it escapes into the atmosphere in the event of leakage and therefore avoids the puddling characteristics inherent in petrol/diesel.

**Fig 9.3.1:** Biogas purification and bottling (Experimental Set-up)

**Enrichment stage**
The presence of incombustible gases like CO₂, H₂S and water vapour reduce the calorific value of biogas and make it uneconomical to compress and transport. Therefore, the incombustible gases are removed before compression. Biogas that has been upgraded to biomethane (90% methane gas) by removing the H₂S, moisture, and CO₂ can be used as a fuel for vehicles.

**Compression stage**
Compressing biogas reduces the requirement for storage, concentrates energy content and increases the pressure to the level needed to overcome resistance to gas flow. Sometimes the production pressure of a biogas...
source does not match the pressure requirements of the gas utilization equipment. Compression can eliminate the mismatch of pressures and guarantee efficient operation of the equipment. Enriched biogas reduces the cost of compression and produces a gas with a high heating value, making it more suitable for uses in internal combustion engines and automobile engines. In addition, since production of such fuel typically exceeds immediate on-site demand, the biomethane can be stored for future use, either as compressed biomethane or liquefied biomethane.

Liquefaction of biogas is not possible under normal temperature and pressure (critical temperature for biogas liquefaction is -82.1°C and 4.75 MPa pressure). Therefore, it is filled in cylinders only after compression. Bottling not only eliminates plant bound applications of biogas and pipeline supply network but also creates opportunities for employment and income generation.

Compressed biogas has several advantages similar to CNG as described here. Firstly, popularity of natural gas as vehicle fuel has increased and the CNG technology in vehicles is well established. CNG has a much higher octane number and lower cetane number, which makes it a superior fuel than petrol. It is more economical as compared to petrol or diesel due to its lower production cost. CNG does not contain any lead or benzene thus eliminating lead fouling of spark plugs and lead or benzene pollution. Further, the operation and maintenance costs of natural gas vehicles are lower than of petrol fueled vehicles. Greenhouse gases emissions from CNG fuel are about 25% lower than petrol.

9.04 Direct Combustion of Solid Wastes
Sun dried dung cake is the most common form in which animal dung is used in rural areas for cooking. Others convert dung to manure. Biogas plants facilitate the use of dung both as fuel (biogas) and manure (digested sludge). In urban areas too, dried municipal wastes and dung are used as fuel. In the case of chicken and other manures, direct combustion for steam or power generation is possible. Municipal wastes are dried and burnt directly or after pelletizing (RDF) to generate steam or electricity.

9.05 Conclusion
There are many ways in which energy from wastes can be utilized. The requirement of alternate energy in developing countries is enormous. Several government agencies, non-government organizations and institutions are involved in generation and utilization of biogas from specific feed materials - cow dung, other animal wastes or human wastes. The design of biogas plants varies according to the feed materials used. Most biogas plants, particularly in rural areas, are cattle dung based. However, due to adoption of mechanical farming, the population of cattle is decreasing and affecting the availability of required feed materials for biogas plants. This has resulted in non-functioning of many biogas plants. On the other hand, both biomass and kitchen wastes are discarded without any economical use. The available biomass can be utilized with animal dung to generate biogas. For this purpose suitable pre-treatment of raw materials is required before it is put into digester with semi-degraded cow dung. Further attempts are required to optimize the process design to work the system at lower HRT to reduce the cost of the system and make the biogas technology an economical alternative for applications such as power generation and bio-CNG for transport.
Technology Matrix

The Technology Matrix provides a ready reference to available technologies in actual practice in the area of sanitation and energy and their application for processing of various materials as practiced in different countries.

The Technologies are classified under three sections, viz.:

1. “Anaerobic Digestion” for biogas generation.
2. “Thermo-chemical Treatment” for energy production; and
3. “Composting”.

The thermo-chemical treatment section is further categorized into incineration, pyrolysis and gasification. The matrix contains notings on selected technologies in terms of:

1. process,
2. brief description,
3. benefits,
4. limitations,
5. cost indication,
6. feed-stock compatibility,
7. country of origin,
8. area of application, and
9. opportunity for adoption/up-scaling.

The technologies (or their variant), which are presented in the Matrix, are in use in developing as well as some developed countries. It is expected that the matrix would provide information support to the planners and decision makers in the local governments/municipal governments, enabling them to converge on appropriate technology options. In short, the matrix is a tool, which is expected to help in making informed choices for technology selection.

10.01 How to use the Technology Matrix

- Prospective user (particularly, planners and decision makers in the local/municipal government) should first get prepared a comprehensive report about the sanitation and energy situation in the concerned town/locality. The report should also indicate the priorities of the town or community and the goal of the local body.
- Indication of long term priorities: (a) centralized vs. decentralized systems – whether majority of the population would like to practice decentralized systems of sanitation and waste management or prefer centralized system, (b) whether sanitation or harnessing energy has higher priority, (c) how much the
population would like to get involved with these activities, e.g., segregation of waste material at source and cooperation with doorstep collection in a disciplined manner, and (d) whether stand alone systems or integrated systems would be preferred.

- Goal of the city/local government: in accordance with the will of the people and affordability of the city, long term goals must be clearly evolved and stated on a time scale, say in 5, 10, 15 and 20 years.
- The above exercise would give an insight into the existing situation as well as the planned deliverables on a time scale.
- The next step would be a scan through the matrix to shortlist 3 or 4 technologies and the required size (size is very important for designing the actual system and to calculate cost).
- Then the selected 3-4 technologies need to be deliberated in detail by the local government or their consultants and at the same time inputs should be taken from the citizens.
- Finally, one or a combination of more than one technology on integrated mode may emerge as the choice for implementation through this participative planning process.
- It must be remembered that only those technologies should be considered which have been proven in actual practice.
- The applicable laws of the land should also be kept in consideration.

10.02 Technologies by Pathways
In the context of energy and sanitation, anaerobic digestion provides both – energy in the form of biogas and a means of sanitation through processing of the bio-degradable material.

Anaerobic digestion:
Anaerobic digestion is a process in which bio-degradable material is acted upon by a host of microbes in the absence of free oxygen resulting into the production of biogas, which is a mixture of methane, carbon dioxide and other gases in trace amounts. It is a complex 3-stage biological process – (i) hydrolysis of the complex molecules, (ii) formation of volatile fatty acids in the acidogenic phase and (iii) formation of methane in the methanogenic phase.

Initially only mono-phasic digester was used. However, later modifications took note of the different environments preferred by the different microbial consortia leading to the development of bi-phasic digesters (acidic phase followed by Upflow Anaerobic Filter digester, Upflow Anaerobic Sludge Blanket digester etc.). Bi-phasic digesters are faster. They can also be useful for digesting mixed bio-degradable waste, fresh bio-mass etc. followed by methanation of the liquid obtained.

Temperature is another variant leading to three categories of digestion: mesophilic (25°-35°C), thermophilic (45°-55°C) and psychrophilic (upto 15°C). The last named is not common. Thermophilic digestion is considerably faster but highly sensitive to temperature fluctuation and additional heat is required to compensate for heat loss and to keep the temperature in this range. Methane, the major constituent, is combustible and biogas is used to generate energy in different forms for different types of applications such as cooking and heating, motive power for pumping, transport, etc. and electrical power.

From the point of digester configuration, three basic variants have emerged for mono-phasic systems: fixed dome type, floating dome (holder) type and flexible bag type. Bi-phasic digesters have different configurations – often a mix of fixed structures with gas collection under a floating holder or in a flexi-bag. Each variant has some advantages and disadvantages.

Thermo-chemical Treatment
Incineration or ‘mass burn’ has been a popular technology across the industrialized nations. However, in the last two decades there has been a steady trend to replace this with other systems of waste processing. One of the major reasons is the growing concern about the health hazards from emissions and the elaborate arrangements to scrub and contain the emissions, which has sharply pushed the cost (investment as well as operation) upwards, making it the most expensive way for waste processing/disposal. The advantage of least land requirement is also being debated due to the requirement of significant ash disposal. Of the thermal systems, the technology of RDF is showing potential in combination with biological system for taking care of the bio-degradable waste.
Composting
It is one of the most popular technologies, practiced by the farmers across the world over since centuries. However, there have been rapid developments in the last 5-6 decades. Composting of municipal solid waste along with other urban waste, has emerged as an important interest area. Compost or organic manure is increasingly regarded as an essential supplement for chemical fertilizer. More than a dozen composting technologies have been developed, which can be broadly categorized as: aerobic windrow composting, anaerobic trench (pit) composting, in-vessel aerobic composting and vermi-composting. In this case, the planner/decision maker has to look at the quantum of waste, availability of land, constraints like proximity to habitation, market demand and availability of funds for construction as well as operation and maintenance.

### Table 10.2.1: Anaerobic Digestion for Biogas Generation

<table>
<thead>
<tr>
<th>Name of technology/ system</th>
<th>Technology</th>
<th>Benefits</th>
<th>Limitations</th>
<th>Cost</th>
<th>Feedstock compatibility</th>
<th>Country of origin</th>
<th>Area of Application (Rural/ Urban)</th>
<th>Opportunity for adaptation/ up-scaling</th>
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<tr>
<td>Fixed dome digesters - three most popular models: Chinese, 'Janata' and 'Deendhanbu' There are other models like 'Chak', 'Borda' etc.</td>
<td>These are relatively small plants with capacity to produce up to 10 m³ biogas per day. They are used mostly for households and small farms. Fixed dome plants consist of an underground brick masonry compartment (fermentation chamber) with a dome on the top for gas storage combined as a single unit.</td>
<td>Comparatively lower root, particularly, Deendhanbu model. Thermal insulation effect due to underground structure. Less adverse effect in winter or summer. Leakage of the compost in the bottom, a very common complaint. Very good skill required for making leak proof dome. Slurry formation on top of the slurry, hindering passage of gas.</td>
<td>Low cost due to simple structure and brick masonry.</td>
<td>Low cost due to use of local materials and voluntary labour.</td>
<td>Mostly used in the rural settings for swine and cattle manure mixed with kitchen waste. China (first model in 1936), researched and standardised by the Biogas Institute at Chengdu.</td>
<td>Predominantly rural.</td>
<td>Standardised version has huge potential for adoption as well as adaptation in China and other countries. Up-scaling would be difficult.</td>
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<tr>
<td>(a) Chinese model</td>
<td>Although confined to China, this model has the largest number of installations across the world (more than 8 million). It was taken up as a movement at commune level. Provides biogas for use in kitchen and digested slurry for the agricultural field.</td>
<td>Leakage of gas dome was rampant in the initial phase. Later improvements have been brought about.</td>
<td>Low cost due to brick masonry.</td>
<td>Mostly used for cattle manure (called 'ghobari' in India) and other animal manure.</td>
<td>India, Gobar Gas Research Station, Ajramal, India.</td>
<td>Predominantly rural.</td>
<td>Has some potential but the 'Deendhanbu' model is becoming more popular over a period of time. Up-scaling would be difficult unless concrete is used.</td>
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<td>(b) 'Janata' model (Indias)</td>
<td>Has similarity with the Chinese model, except that the middle portion is cylindrical with vertical section. Installed in huge numbers.</td>
<td>Leakage of dome</td>
<td>Low cost due to brick masonry.</td>
<td>Mostly used for cattle manure (called 'ghobari' in India) and other animal manure.</td>
<td>India, developed by APFRO (Action for Food Production).</td>
<td>Predominantly rural.</td>
<td>Good potential for adaptation. Up-scaling would be difficult due to structural constraints.</td>
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<tr>
<td>(c) 'Deendhanbu' model (Indian)</td>
<td>Has similarity with the Chinese model.</td>
<td>Leakage of dome</td>
<td>Lower cost (about 30%) compared to 'Janata' model.</td>
<td>Cattle manure and other animal manure.</td>
<td>India, developed in 1954-56 by Mr. Ishahbhala J. Patel. The design was adapted, improved and promoted by Khadi and Village Industries Commission (KVIC), India.</td>
<td>Predominantly rural.</td>
<td>The small digester is popular in rural areas. Large digesters have been used for community level application and for large dairy and pig farms. Vegetable market wastes have also been used in India. Floating holder design is used extensively throughout the world. Adaptation exercises have been carried out by various institutes with modifications to make the design suitable for different leafy biomass. Tablets have also been linked. KVIC designs have been standardized up to 140 m³ gas capacity. Battery of 85 m³ and 140 m³ has been successfully used for community projects in India. Attentions have also been made for thermal insulation.</td>
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<tr>
<td>Technology</td>
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<td>Public toilet linked biogas plant (on-site system)</td>
<td>The Sulabh Model biogas plant has been designed for biogas generation from human wastes from public/community toilets. The digester is fed with underground concrete structure with liquid displacement chamber for inside biogas storage. For the safe reuse of effluent of human wastes biogas plant, a device (as mentioned below) has been developed.</td>
<td>This system is suitable for high as well as low solid sewage without the need for de-watering etc. Very useful for unpowered areas. Instead of being a disposal facility, the waste material generates biogas and rich digested slurry. The system has been extensively used in India and in Kabul, (Afghanistan) where biogas is being used for cooking, lighting and electricity generation. There is no chance of gas leakage due to R.C.C. structure.</td>
<td>The digesters are designed for a liter per capita water use for cleaning and flushing. More suitable for poor flush toilets. Higher quantity of human wastes resulting in over-dilution of human wastes resulting in decrease in biogas production.</td>
<td>The cost is relatively high because of concrete structure. However, operation and maintenance cost is much lower due to concrete structure of the dome and displacement chamber.</td>
<td>Human waste (faeces, urine, and flush water). Other biodegradable wastes like animal wastes, kitchen wastes, fruit and vegetable wastes can also be used for biogas generation along with human wastes.</td>
<td>India, developed by Sulabh International Social Service Organization, New Delhi.</td>
<td>Suitable for urban, peri-urban and rural areas, for public toilets, group of toilets, housing colonies, high rise buildings, hospitals, restaurants etc.</td>
<td>There is ample scope for adaptation and up-scaling of this system in unpowered areas. It is also suitable for low ambient temperature areas. Due to concrete and underground structure variation in atmospheric temperature has least effect on biogas generation.</td>
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<td>Sulabh Effluent Treatment Technology (on-site system)</td>
<td>Sulabh Effluent Treatment (SET) is a convenient technology for on site treatment of effluent of biogas plant. It is based on sedimentation and filtration of effluent through sand and activated carbon bed followed by exposure to ultraviolet rays.</td>
<td>The treated effluent from SET technology is colourless, odourless, pathogen free, having BOD less than 10mg/lt. Quite safe for aquaculture, agriculture, horticulture purposes or discharge safely in any water body without causing any health risk or pollution. Its is suitable for public/community toilet linked biogas plants or for decentralized treatment of sewage.</td>
<td>It is low cost. Operation and maintenance cost is much lower.</td>
<td>Effluent from human excreta based biogas plants or sewage for its safe reuse for different purposes.</td>
<td>India, developed by Sulabh International Social Service Organisation, New Delhi.</td>
<td>Suitable for urban, peri-urban and rural areas. Useful for decentralized treatment of human wastes for its safe reuse for different useful purposes. More useful for water scarcity areas.</td>
<td>Good potential for application for decentralized treatment of human wastes/ sewage.</td>
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<td>Bag digester</td>
<td>The digester is made of plastic bag, containing a long cylinder made of PVC or red mud plastic. With further R&amp;D a three step system incorporating solid-liquid separation, anaerobic fermentation followed by aerobic stabilization has been developed.</td>
<td>Light weight, low cost and very small gestation period. Availability of suitable membrane for making the digester. Puncture from any sharp object. Need for good technicians for any repair work.</td>
<td>Relatively low cost where the membrane is available.</td>
<td>Animal waste.</td>
<td>India</td>
<td>Digesters developed in Taiwan in 1985 by Taolan livestock Research Institute (TLRI).</td>
<td>Predominantly rural as these digesters are suitable for animal manure.</td>
<td>Due to light weight, small gestation period and low cost, this is becoming popular. It has tremendous potential for up-scaling as well as modular expansion.</td>
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<td>Plug flow digester</td>
<td>It comprises a long narrow (typically a 5 length: 1 width ratio) trench like tank made of reinforced concrete; steel or fibreglass with a gas tight flexible cover (like bag digester) to capture the biogas. These digesters can operate at mesophilic or thermophilic temperature. The plug flow digester has no internal agitation and can be loaded with thick manure of 11–14% total solids such as, straw manure with little bedding and no sand.</td>
<td>For high solid concentrations, the system produces more biogas compared to the completely mixed system. Long gestation period due to the simple arrangement.</td>
<td>Availability of suitable membrane for making the top cover of the digester. Relatively low cost where the membrane is available.</td>
<td>Animal manure.</td>
<td>South Africa in 1957.</td>
<td>Used in large dairy farms in USA. Other models include: OLACE- Guatemala model; and ICATT model in Costa Rica, Guatemala, Honduras and El Salvador.</td>
<td>This design is amenable for modular application. Hence up-scaling can be done in a battery of modular units.</td>
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<td>Name of technology/system</td>
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| Covered lagoon digester  | A covered lagoon digester is a large anaerobic lagoon (not a manure storage pond or basin) with high dilution factor. Typically covered lagoons with depth of 3-4 meters are used with flush manure management systems that discharge manure at 0.5 to 2% solids. The in-ground, earth or lined lagoon is covered with a flexible or floating gas tight cover. They are considered ambient temperature digesters. Retention time is usually 30-45 days or longer. In climates that have elevated year round temperatures, such as southern and western U.S., these digesters can produce stable, reduced odour, nutrient rich effluent for application on fields and crops: pathogen and weed seed reduction and produce biogas for farm energy use. | Covered lagoons for energy recovery are compatible with flush manure systems in warm climate and may be used in cold climate for seasonal biogas recovery and odour control. The effluent is applied on farmland. | Land requirement is high. Digestion may not be complete (lack of direct contact). | Relatively inexpensive. | Animal manure. | USA. | USA. |

**Anaerobic filter** (also known as "fixed film" or "retained film" digester)

A fixed film digester vessel is filled with an inert medium or packing that provides a very large surface area for microbial growth. The wastewaters passes through the media and anaerobic microbes attach themselves on the surface, creating a thin layer (biofilm). These microbes then continue to grow by removing nutrients from the wastewater as it flows by. Unlike the suspended growth digesters, the microbes are not washed out with hydraulic flow. Hence these digesters have smaller volumes, shorter retention times and must be loaded with a feedstock that will readily flow through the media without clogging (typically high BOD, low suspended solids, industrial waste water). Three to five day retention times are typical. Part of the biogas can be used to heat the digester for Thermophilic operation, when gas production is much higher.

Good for waste water from distillery, sugar and other food processing industry etc. where the very high BOD waste water is efficiently treated in a short period in relatively small digesters. With particulate waste, they can be treated in a bi phasic system, where the material is allowed to get hydrolyzed in acidogenic phase and the resulting liquid is passed through the anaerobic filter (such as UAF).

Not suitable for waste with high solids and high suspended particles such as animal manure. Maintenance and replacement of the packing material.

High cost, but due to high volume of biogas production, the system is economical for the industry.

Biodegradable waste water with high BOD and low suspended solids.

Predominantly industrial waste water.

These are normally large facilities, operated commercially.
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<tr>
<td>Up flow anaerobic sludge blanket (UASB)</td>
<td>The Up flow anaerobic sludge blanket is similar to the anaerobic filter. It involves a high concentration of immobilized bacteria in the reactor. The UASB reactors contain no packing medium. Instead, the methane forming bacteria are concentrated in the dense granules of sludge blanket that covers the lower part of the reactor. The feed liquid enters from the bottom of the reactor. Biogas is produced while the liquid flows up through the sludge blanket. This is similar to anaerobic filter involving high concentration of immobilized bacteria.</td>
<td>This is useful for sewage treatment and also wastewater from processing industry (example, sugar beet) and other dilute wastewaters. With particulate waste, they can be treated in a bi-phasic system, where the material is allowed to get hydrolyzed in acidogenic phase and the resulting liquid is passed through the anaerobic filter (such as UAF).</td>
<td>Formation of good granules in the sludge blanket. High cost but comparatively less than fully stirred digesters. Liquid wastes – wastewater with high BOD and less suspended solids.</td>
<td>The Up flow anaerobic sludge blanket design was developed in the late 1970's by Prof. G. Lettinga, Wageningen University, the Netherlands.</td>
<td>Many full-scale UASB plants are in operation in Europe, China, India etc. using waste water from food processing industry, sewage and other soluble waste waters.</td>
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<td>Rural/ Urban</td>
<td>Already digesters upto 8000 m² have been built, while upto 2000 m² site have become common.</td>
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<td>Digester for sewage sludge digestion (STP)</td>
<td>There are single phase digesters which are normally fed by concentrated sludge produced by activated sludge process (anoxic), which is then anaerobically digested to produce biogas. The biogas is upgraded by removing the hydrogen sulphide (higher percentage is produced from human waste) and moisture to make it suitable for engines. During the past decade, the UASB process is being increasingly used in STP because of the lower cost, particularly O&amp;M cost.</td>
<td>Largely located at sewage waste treatment plants and more than 60% of the national biogas production (1400 GWh/year) is produced in digesters for sludge digestion. Sweden has 10 energy plants that utilize a variety of organic wastes. The biogas generated is usable as fuel in motor vehicles. Sweden has thousands of biogas buses and cars running on a mixture of petrol and other biogas or natural gas.</td>
<td>ASP followed by anaerobic digestion is cost intensive and energy intensive.</td>
<td>UASB is relatively lower cost. Domestic sewage. Some mix of non-toxic industrial waste may be allowed provided the overall BOD load is maintained in a workable range.</td>
<td>Sweden</td>
<td>System being adopted in European countries.</td>
<td></td>
<td>Huge opportunity in view of increasing urban population across the world. As per the present state of development, modular UASB facilities appear to be the best suited because population increase can also be addressed conveniently.</td>
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<td>TEAM Process</td>
<td>Six acidogenic digesters degrade solid waste with recycling within each digester. Liquid is pumped to UASB model for biogas generation.</td>
<td>Same as biphase digesters. Large scale applications yet to be tested.</td>
<td>Medium cost</td>
<td>Solid wastes</td>
<td>The Energy and Resources Institute (TERI), India</td>
<td>Hotel and restaurant waste, fruit and vegetable market waste, municipal solid waste etc.</td>
<td>Appears to have good potential.</td>
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<td>Modified UASB technology</td>
<td>Modified UASB technology for municipal and other biodegradable solid waste. Useful for food and market waste. Large scale applications yet to be tested.</td>
<td>Medium cost</td>
<td>Municipal solid wastes, canteen wastes, food processing waste, domestic waste, house waste etc.</td>
<td>Medium cost</td>
<td>India, Malleshwaram Engineers Pvt. Ltd.</td>
<td>Urban and Industrial waste</td>
<td>There is scope for up-scaling from the present capacity of about 20 TPD.</td>
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<td>Country of origin (Rural/ Urban)</td>
<td>Area of Application (Rural/ Urban)</td>
<td>Opportunity for demonstration/ up-scaling</td>
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<td>Nisarguna (BARC) process</td>
<td>The process comprises a thermophilic anaerobic stage and a simple mesophilic methanogenic stage. This biogas digester is operated in thermophilic stage heated by solar water heating in the first stage. The second mesophilic stage is in a simple digester for biogas production. Fibrous USW components can be degraded by this process.</td>
<td>Large scale applications yet to be tested.</td>
<td>Food and kitchen wastes from industrial type canteens.</td>
<td>Developed by BARC, India</td>
<td>Rural/ Urban</td>
<td>India</td>
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<td>ASTRA plug flow reactor</td>
<td>This has a pre-treatment step combined with a horizontal plug flow biogas digester. The feedstock is digested in the first phase. The liquid obtained is digested in the second phase. This kind of pre-treatment built into the design of the reactor obviates any form of pre-processing of the feedstock, especially fibrous plant material. In this system, need for external energy and electrical power are obviated at the small scale.</td>
<td>An important aspect of the system is that the rural residues and USW components are converted to biogas in such reactors. Main feed stocks in their existing state are fed without any pre-treatment. As a result there is very little need for daily water to be added with the feed stock. These have been in existence for over 15 years, in field level operation for over 5 years in various farms and at small town level for nearly 3 years.</td>
<td>Urban/Rural solid waste</td>
<td>Developed by ASTRA, SSC, Bangalore, India</td>
<td>India</td>
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<td>Large scale bio-digesters</td>
<td>At the international level many patented anaerobic digestion processes are in operation, including those occurring in the thermophilic range. These include: Conventional Slurry Digestion (the RERCOM, the WMC, the Cal recovery and the Waste Biogas processes); Dry Anaerobic Digestion – DRANCO, VALORGA and BIOCIL processes. Two-phase Anaerobic Digestion of Solid Wastes (the Hitachi, the IRBL and the Leach Bed processes).</td>
<td>These are generally designed for large amounts of wastes and for centralised and mechanised operations.</td>
<td>Expensive, especially for developing economies.</td>
<td>High</td>
<td>Municipal solid wastes, farm and agro waste.</td>
<td>Different countries</td>
<td>Municipal, farm and Industrial</td>
<td>Good potential provided cost can be reduced.</td>
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<td>Sanitary landfilling with extraction of methane and energy generation</td>
<td>Municipal solid waste is landfilled in a scientifically designed fill area, which has multi-layer bottom and side liners for containment of pollution from leachate generated over time. Compaction and levelling followed by daily cover is the routine. Gas wells are built for extraction of the landfill gas. Leachate collection and treatment is arranged. When the fill is complete, an elaborate multi-layer cover is placed, which prevents seepage of rain water but allows movement of gas under the cover. Methane is generated for 15-20 years, depending upon the waste quality, climate size and depth of the fill etc. The methane is normally used for production of electrical power or supplied through pipes.</td>
<td>Segregation of waste is not required. All kinds of waste can be landfilled. However, biomedical, toxic and hazardous waste is not allowed in these municipal landfills. Hazardous waste landfills have to maintain a much more stringent containment norm and operational practice.</td>
<td>Land requirement is much higher. There is no scope of recycling/ resource recovery, so natural resources are not saved.</td>
<td>Modern landfill is expensive.</td>
<td>Municipal solid waste</td>
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<tr>
<td>Name of technology/system</td>
<td>Brief Description</td>
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<td>Spreader Stoker (Grates) Incinerator</td>
<td>The incinerator has travelling grates that move at a slow, constant rate much as a conveyer belt. The grate elements are designed to develop a relatively high-pressure drop under fire air rate, which results in a uniform air distribution over the entire surface. Air is supplied through the grate from one or more under-grate plenums.</td>
<td>Used for mass burning of MSW.</td>
<td>Municipal Solid Waste</td>
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<td>Rotary Kiln</td>
<td>Rotary Kiln is an inclined, horizontal refractory lined cylinder that rotates about its horizontal axis. Waste is charged directly into the kiln at the upper end. Air in excess of the stoichiometric requirement is usually provided. The waste is agitated in the kiln by the rotating motion of the kiln, usually in the range of 1 to 3 rpm. At the waste is subjected to this turbulence, it is washed by the air, which encourages combustion. The kiln system requires more extensive air emission control than the other types.</td>
<td>rotary kilns have various advantages like ease of operation on a continuous basis, flexibility for nature of waste and low unburnt ash. These are not widely used due to their high capital and operating costs.</td>
<td>Municipal solid wastes, hazardous wastes and any kind of wastes.</td>
<td>In India municipal waste converted to RDF is burnt</td>
<td>Operational all over the world, particularly in European countries.</td>
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<td>Fluidized Bed Incinerator (FBI)</td>
<td>In its simplest form, fluidized bed incinerator consists of a vertical steel cylinder, usually refractory lined, with a sand bed on a supporting grid plate and air injection nozzles. When air is forced up through the bed, the bed fluidizes and expands to about twice its resting volume. The fluidizing action of fluidized bed promotes turbulence, mixing and transfers heat to the waste that is injected into the reactor. Complete combustion of the gases is ensured in the integrated combustion chamber. FBI can either be circulating or bubbling bed. FBI can burn MSW completely at relatively lower temperature.</td>
<td>Fluidized bed incinerators have high heat transfer efficiencies, high turbulence in both gas and solid phases, uniform temperature throughout the bed and the potential for in situ acid gas neutralization by lime, limestone or carbonate addition. The start-up after a shutdown is very easy as the heat loss is minimal. These can burn any kind of waste and have been proved to be highly efficient and are more environment friendly than other systems.</td>
<td>Municipal Solid Waste, liquids, sludge or shredded solid materials including coal.</td>
<td>In India, there are a few bubbling FBI incineration units for burning industrial wastes and a few circulating fluidized beds for burning coal wastes/low grade coal.</td>
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<td>Inincinerators using Pure Oxygen (Oxygen Lancing)</td>
<td>In this type of incinerator, instead of injecting air that contains only 23.31% Oxygen by weight, pure oxygen is injected for combustion. In this way it is possible to burn waste with a very low calorific value.</td>
<td>The use of enriched oxygen for combustion increases the efficiency and prevents or reduces the accumulation of unburnt waste. The advantages are increased capacity; reduced CO2; reduced fuel consumption; reduced particulate carry over; more efficient heat recovery, and reduced off gas volume. This allows the secondary chamber and off gas systems to be more compact.</td>
<td>Municipal Solid Waste</td>
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<td>Infrared Incinerators</td>
<td>A mobile thermal processing system that uses electrically powered silicon carbide rods to create high temperature that will combust the organic waste. Waste is fed through a furnace on a woven belt and exposed to high temperature. Air is blown into the system at specific locations to supply oxygen. Ash formed at the bottom of the chamber is collected and transported to an ash cooling system. Gases formed in the primary chamber are directed to a secondary chamber, where they are further heated to complete destruction.</td>
<td>This system is commonly used for solids and soil containing organic waste. It is not recommended for liquid or slurry waste. The main disadvantage is that the volatile metals can cause stack emission problems.</td>
<td>Solids, Organic Waste</td>
<td></td>
<td>Japan and other countries</td>
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<td>Name of Technology/System</td>
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<td>Feedstock Compatibility</td>
<td>Area of Application (Rural/Urban)</td>
<td>Opportunity for Adaptation/Up-scaling</td>
<td></td>
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</tr>
<tr>
<td>Rapid Pyrolysis System</td>
<td>Pyrolysis can be achieved by a wide range of techniques like microwave, plasma heating, rapid heating in fluidized beds and high-pressurized drum tube furnaces, etc. Rapid heating rate results in less char formation and more methane formation than that from the slow pyrolysis processes.</td>
<td>Char from the rapid pyrolysis is more porous and more reactive than that from the slow process. Especially useful for thermal depolymerisation of plastic waste. Gases can also be burnt for electricity generation.</td>
<td>Plastic wastes</td>
<td>Developed countries</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Plasma Pyrolysis</td>
<td>Plasma technology involves the creation of a sustained electrical arc by the passage of electric current through a gas. Significant heat is generated which serves to strip away the electrons from the gas molecules, resulting in an ionized gas stream or plasma. In the ionized state, the gas is electrically conducted, and can be confined by the electromagnetic fields and has an almost liquid like viscosity. The interior of the plasma vessel is hot, dusty, and turbulent. The plasma is confined by the vessel, they are dissociated into their molecular components. Plasma breaks down the wastes in milliseconds, avoiding the formation of secondary products.</td>
<td>Because of the high temperature, the plant is able to treat not only combustible materials like biomass and biological waste, but also a significant part of non-combustible materials such as glass, metal, construction waste, etc. It ensures complete destruction of chemicals and biologically active substances such as viruses and bacteria, drugs, pesticides and other toxic substances. It does not produce smoke, but a clean burnable gas and residue, glass like substances. Nevertheless, the volatile metals may vaporize and be carried out of the unit with gas stream. About 88% of the energy value can be recovered as electric power.</td>
<td>Municipal and Industrial wastes, soils with heavy metals, pesticides, glass, metal, construction waste, medical wastes and ordnance by-products.</td>
<td>So far there is no field level plant operating on municipal solid waste.</td>
<td>Developed countries use this technology for electricity generation.</td>
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</tr>
<tr>
<td>Pyrolytic Thermal Depolymerization</td>
<td>Thermal Depolymerisation is a process for reduction of complex organic materials into light crude oil. It mimics the natural geological processes involved in the production of fossil fuels. Under pressure and heat, long chain polymers of hydrogen, oxygen and carbon decompose into short-chain petroleum hydrocarbons.</td>
<td>Energy and material recovery from plastic waste can make a contribution to its production. The pyrolysis fractions can be used as pre-cleaned feed support for the combined power plant.</td>
<td>Organic materials usually of waste products such as biomass, plastic, etc.</td>
<td>Developed countries, especially European countries use this technology for polymer recycling.</td>
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</tbody>
</table>

### Gasification

- **Gasification** is a self-sustaining process if the waste is having enough heat content. The fuel gases produced can be burnt off or can be tapped and used later on for burning.
- **Benefits**:
  - This is a promising technology as the fuel gas can be used. In the cases where the fuel gas is directly burnt off, the combustion efficiency is much higher than in an incineration unit. The emission of NOx and particulate matter are usually lower than that from incinerators. The sizes of the downstream equipments are relatively smaller. The existing incinerators having two chambers can be easily operated in an efficient way by maintaining the starved air mode (gasification) in the primary chamber and excess air mode (complete oxidation) in the secondary chamber. Most of the biomedical waste incinerators in India are having two chambers and can be effectively operated.
- **Limitations**:
  - Municipal solid waste, woody biomass, bio-medical waste, etc
- **Cost**:
  - Operational in several countries excluding India

### Refuse Derived Fuel (RDF)

- **Refuse Derived Fuel (RDF)**: The RDF process involves processing waste using screens, shredders and separators to recover recyclable materials and to remove incombustible materials such as dirt, glass, metals, and very wet organics. The normal sequence of RDF preparation is shredding municipal waste to a fixed size to make RDF more consistent in size, air classifying/screening, magnetic separation, and sometimes eddy current separation for nonferrous metal recovery. Air classification is used for screening. The burnable fraction of the waste is shredded and made into pellets or briquettes by pressing.
- **Benefits**:
  - The pellet from wastewater are made with or without a binding agent, and can be transported easily and can be stored for several months without any disintegration. The fuel content of RDF is largely uniform, and it can be burnt to produce power or can be used along with conventional fuels for industrial operations. Many variations of the process have been developed, each of which has certain advantages.
  - Works well only with segregated dry and combustible waste.
  - Comparatively less expensive than other thermal systems.
- **Feedstock Compatibility**: Municipal waste
- **Area of Application (Rural/Urban)**: Municipal waste
- **Opportunity for Adaptation/Up-scaling**: India and other developing countries
<table>
<thead>
<tr>
<th>Technology</th>
<th>Name of technology/ system</th>
<th>Brief Description</th>
<th>Benefits</th>
<th>Limitations</th>
<th>Cost</th>
<th>Feedstock compatibility</th>
<th>Country of origin</th>
<th>Area of Application (Rural/ Urban)</th>
<th>Opportunity for adaptation/ up-scaling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerobic composting</td>
<td>1</td>
<td>Composting is a microbial conversion process of biodegradable segment of municipal solid waste leading to decomposition of organic particles to humus like final product. Microflora like bacteria, fungi and actinomyces and certain macroflora are responsible for this bio-conversion process. The quality of organic manure produced would be dependent on the composition of input organic waste and the process involved in its bio-conversion. Composting process seeks to harness the natural forces of decomposition to secure the conversion of organic waste into manure.</td>
<td>Composting of the degradable part of the waste is an easy and economical option, which can be practiced at any desired scale. Composting leads to energy saving as it replaces energy intensive chemical fertilizers.</td>
<td>Presence of contaminants, particularly heavy metals in the incoming waste, market demand and price.</td>
<td>Medium investment and operational cost for quality compost and good environmental care. Inexpensive if quality is not considered or environmental considerations are not taken into account.</td>
<td>Biodegradable materials, like municipal solid waste, garden and kitchen waste, agro waste etc</td>
<td>India (Indure process)</td>
<td>Operational across the world.</td>
<td>Tremendous scope of application. Up-scaling upto 500 TPD has been done. Battery of modular plants of 500 TPD unit capacity can be designed for any quantum subject to availability of land, waste and market.</td>
</tr>
<tr>
<td>Vermi-composting</td>
<td>2</td>
<td>Vermi-composting is the result of the combined activity of microorganisms and earthworms. Microbial decomposition of biodegradable organic matter occurs through extracellular enzymatic activities whereas decomposition in earthworm occurs in alimentary tract by microorganisms inhabiting the gut.</td>
<td>Vermi-composting is easily applicable and replicable. Suitable for small scale processing of a variety of biomass wastes. This technology has been used for agricultural waste and its adoption to municipal solid waste of recent origin. The vermi-compost is relatively more stabilised and harmonises with soil system without any ill effects.</td>
<td>Predators like ants, rats, birds etc. Temperature above 40°C.</td>
<td>Medium to low cost depending upon the quality and environmental goals.</td>
<td>Any kind of biomass</td>
<td>Practiced in many countries</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** The above technologies have to be sustained by suitable capacity building and regulatory mechanisms.
### 10.03: Technology by Feedstock/Waste

**Table 10.3.1: Technology by Feedstock/Waste**

<table>
<thead>
<tr>
<th>Feedstock/Waste</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>All biodegradable wastes</td>
<td>Anaerobic filter/“fixed film” or “retained film” digester</td>
</tr>
<tr>
<td>Animal manure</td>
<td>Plug flow digester</td>
</tr>
<tr>
<td>Animal waste</td>
<td>Bag digester</td>
</tr>
<tr>
<td>Animal: Cattle manure</td>
<td>Biogas induced Mixing Arrangement Technology (BIMA)</td>
</tr>
<tr>
<td>Animal: dairy, poultry piggery wastes</td>
<td>Fixed dome bio-digester/drumless digester</td>
</tr>
<tr>
<td>Any kind of biomass</td>
<td>Aerobic composting (in windrows and pits)</td>
</tr>
<tr>
<td>Any kind of biomass</td>
<td>Vermi-composting</td>
</tr>
<tr>
<td>Biodegradable wastes mix including human waste</td>
<td>Biotech process</td>
</tr>
<tr>
<td>Cattle sheds, dairies, distilleries, sewage treatment plants,</td>
<td>Biogas bottling units - BIO-CNG technology</td>
</tr>
<tr>
<td>food processing industries, biogas plants</td>
<td></td>
</tr>
<tr>
<td>Food: Industrial scale food and kitchen wastes</td>
<td>Nisargruna (BARC) process</td>
</tr>
<tr>
<td>Household waste, animal manure, food processing</td>
<td>Digester for sludge digestion</td>
</tr>
<tr>
<td>wastes and slaughterhouse wastes.</td>
<td></td>
</tr>
<tr>
<td>Human waste from public toilets</td>
<td>Biogas digester with system for effluent treatment</td>
</tr>
<tr>
<td>Kitchen and food waste (waste grain flour, spoilt grain, overripe or misshapen</td>
<td>Portable biogas plant</td>
</tr>
<tr>
<td>fruit, non-edible seeds, fruits and rhizomes, green leaves, kitchen waste,</td>
<td></td>
</tr>
<tr>
<td>leftover food, etc.)</td>
<td></td>
</tr>
<tr>
<td>Liquid wastes</td>
<td>Covered lagoon digester</td>
</tr>
<tr>
<td>Liquid wastes</td>
<td>Up flow anaerobic sludge blanket (UASB)</td>
</tr>
<tr>
<td>Municipal solid waste</td>
<td>Incinerators using pure oxygen (Oxygen Lancings)</td>
</tr>
<tr>
<td>Municipal solid waste</td>
<td>Spread Stocker (Grates) Incinerator</td>
</tr>
<tr>
<td>Municipal solid waste &amp; biomass which are lignocellulosic in nature</td>
<td>Bi-phasic Anaerobic Digestion System</td>
</tr>
<tr>
<td>Municipal solid waste, liquids, sludge or shredded solid materials including</td>
<td>Fluidized Bed Incinerator (FBI)</td>
</tr>
<tr>
<td>soil.</td>
<td></td>
</tr>
<tr>
<td>Municipal solid waste, woody biomass, bio-medical waste, etc.</td>
<td>Gasification</td>
</tr>
<tr>
<td>Municipal solid wastes</td>
<td>Large scale bio-digesters</td>
</tr>
<tr>
<td>Municipal solid wastes, hazardous wastes and any kind of wastes.</td>
<td>Rotary Kiln</td>
</tr>
<tr>
<td>Municipal waste</td>
<td>Refuse derived fuel (RDF)</td>
</tr>
<tr>
<td>Organic materials usually of waste products such as biomass, plastic, etc.</td>
<td>Pyrolytic Thermal Depolymerisation</td>
</tr>
<tr>
<td>Plasma Pyrolysis</td>
<td>Municipal and industrial wastes, soils with heavy metals, pesticides, glass, metal, construction</td>
</tr>
<tr>
<td></td>
<td>waste, medical wastes and ordinance by-products</td>
</tr>
<tr>
<td>Plastic wastes</td>
<td>Rapid Pyrolysis System</td>
</tr>
<tr>
<td>Solid wastes</td>
<td>TEAM Process</td>
</tr>
<tr>
<td>Solids, organic waste</td>
<td>Infrared Incinerators</td>
</tr>
<tr>
<td>Un-decomposed biomass</td>
<td>KVIC design</td>
</tr>
<tr>
<td>Urban/rural solid waste</td>
<td>ASTRA plug flow reactor</td>
</tr>
</tbody>
</table>
### 10.04: Technology by Process

#### Table 10.4.1: Technology by Feedstock and process

<table>
<thead>
<tr>
<th>Technology / Process</th>
<th>Feed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anaerobic filter/“fixed film” or “retained film” digester</td>
<td>All biodegradable wastes</td>
</tr>
<tr>
<td>Bag digester</td>
<td>Animal waste</td>
</tr>
<tr>
<td>Bio-digesters of large scale</td>
<td>Municipal solid wastes</td>
</tr>
<tr>
<td>Biogas bottling units - BIO-CNG technology</td>
<td>Cattle sheds, dairies, distilleries, sewage treatment plants, food processing industries, biogas plants</td>
</tr>
<tr>
<td>Biogas digester with system for effluent treatment</td>
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<tr>
<td>Biogas induced Mixing Arrangement Technology (BIMA)</td>
<td>Cattle manure</td>
</tr>
<tr>
<td>Biotech process</td>
<td>Mix of biodegradable wastes including human waste</td>
</tr>
<tr>
<td>Bi-phasic Anaerobic Digestion System</td>
<td>Municipal solid waste &amp; biomass which are lignocellulosic in nature</td>
</tr>
<tr>
<td>Covered lagoon digester</td>
<td>Liquid wastes</td>
</tr>
<tr>
<td>Digester for sludge digestion</td>
<td>Waste from households; food processing units and slaughterhouses and animal manure</td>
</tr>
<tr>
<td>Fixed dome bio-digester/ drumless digester</td>
<td>All types of waste, especially useful for pig waste, poultry waste and dairy wastes</td>
</tr>
<tr>
<td>Floating Dome Digester (KVIC design)</td>
<td>Un-decomposed biomass</td>
</tr>
<tr>
<td>Floating gas-holder/ dome bio-digester</td>
<td>All types of biodegradable wastes; especially animal waste</td>
</tr>
<tr>
<td>Nisagruna (BARC) process</td>
<td>Industrial scale food and kitchen wastes</td>
</tr>
<tr>
<td>Plug flow digester</td>
<td>Animal manure</td>
</tr>
<tr>
<td>Plug flow reactor of ASTRA</td>
<td>Urban/ rural solid waste</td>
</tr>
<tr>
<td>Portable biogas plant</td>
<td>Kitchen and food waste (spoilt grain, grain flour, overripe/ misshapen fruit, non-edible seeds, fruits, rhizomes, green leaves, leftover food, etc)</td>
</tr>
<tr>
<td>TEAM Process</td>
<td>Solid wastes</td>
</tr>
<tr>
<td>Up flow anaerobic sludge blanket (UASB)</td>
<td>Liquid wastes</td>
</tr>
<tr>
<td>Aerobic composting (in windrows &amp; pits)</td>
<td>Any kind of biomass</td>
</tr>
<tr>
<td>Vermi-composting</td>
<td></td>
</tr>
<tr>
<td>Fluidized Bed Incinerator (FBI)</td>
<td>Municipal solid waste, liquids, sludge or shredded solid materials including soil</td>
</tr>
<tr>
<td>Gasification</td>
<td>Municipal solid waste, woody biomass, bio-medical waste, etc</td>
</tr>
<tr>
<td>Infrared Incinerators</td>
<td>Solids, organic waste</td>
</tr>
<tr>
<td>Oxygen Lanc ing (incinerators using pure oxygen)</td>
<td>Municipal solid waste</td>
</tr>
<tr>
<td>Plasma Pyrolysis</td>
<td>Municipal and industrial wastes, soils with heavy metals, pesticides, glass, metal, construction waste, medical wastes and ordinance by-products</td>
</tr>
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<td>Pyrolytic Thermal Depolymerisation</td>
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</tr>
<tr>
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<td>Rotary Kiln</td>
<td>Municipal solid wastes, hazardous wastes and any kind of wastes.</td>
</tr>
<tr>
<td>Spreader Stocker (Grates) Incinerator</td>
<td>Municipal solid waste</td>
</tr>
</tbody>
</table>
Capacity Building: Problems and Prospects

The paradigm shift in sanitation has not yet made structural inroads into the professional and university educational system. Sanitation is failing in sustainability and in serving the world’s poor. The current sanitation paradigm delivers neither equity nor sustainability. Although there are alternative solutions, they are neither fully developed nor fully legitimised. The educational system remains fixed on the old paradigm and is failing to adapt to changes in approaches arising from new knowledge and contexts. Training continues to treat sanitation systems as a means for removal of faeces and urine (and the grey water that bears them) rather than as a resource.

The failure in support for the new sanitation paradigm can be observed in the discourses on sanitation, research, development interventions, and documentation. Most institutions continue to offer curricula for centralised sewered sanitation and end of pipe wastewater treatment and disposal and the discourses do not accord users of sanitation systems any status in the decision making process. Thus, young sanitation engineers continue supporting the single solution uncritically. The users are objectified and their ideas and preferences are largely ignored. Users of sanitation systems are only considered as recipients of public relation campaigns aimed at 'changing behaviour', enforcing payment or use norms and for stimulating compliance. The potential users of products that can be generated through recycling of these wastes are neglected. All these are leading to inappropriate and expensive solutions that are not sustainable. These are failures in the education system which accepts the older approaches, without any challenge.

There is an urgent need for a change in approach to sanitation education for professionals and academics. The approach needs to consider holistic solutions that address all dimensions of sustainability, including health, socio-technical aspects, natural resource management, agriculture, micro and macro economics and institutional aspects. This has to be complemented by enabling access to knowledge. Further, although participatory and inter-disciplinary planning approaches have been in use for several years, the basic framework for education and training in sanitation remains narrowly focused on the technical aspects. Consequently, neither students nor scholars are learning skills for introducing the process approach to development.

11.01 Need for capacity building
With the focus on environmental sustainability, specifically conservation of water, reduction in environmental pollution and recycling of grey-water, the context in which decisions have to be made for planning and management of sanitation services has changed. The context changes include the need for enabling access of the poor to sustainable water and sanitation services in locations without adequate infrastructure, in very densely built up areas, areas of water scarcity, and in environmentally fragile areas. In addition, since citywide services,
especially in areas where the poor live are often of inferior quality because of a combination of bad planning and design, sub-standard operation and inadequate maintenance, local sanitation problems are often solved by solutions that result in untreated wastes polluting water sources. All these require technological responses that are different from those used conventionally for disposal of waste and for sewerage.

In urban areas with large deficiencies in sanitation services, the options for enabling access to informal settlements and in peri-urban areas are usually small scale interventions for which there is a wide range of technologies to choose from. The selection and adoption of the technologies most appropriate to local circumstances requires technical and managerial skills for supporting (where appropriate) community-managed and small-scale private sector-managed options. It also requires improved governance, participation of communities, and skills for adopting, managing and maintaining alternative technologies. The need for these skills is rarely recognized in the staffing or structures of both the utility and local authorities.

It requires raising awareness about the suitable technological options in a specific environmental and socio-cultural context, their implications in terms of investments and other requirements, operation and maintenance and in terms of efficiency and effectiveness. In many settings, it is also about local possibilities for partnership between government agencies, private enterprises, community organizations and local NGOs. Hence, competent, capable, representative community organizations able to engage with government and to help develop solutions are important. It needs to include procedures for an adequate information to households, provisions for capacity building at all levels, and a re-orientation of supply agencies to allow consumer demand to guide investment programmes (Katz and Sara, 1997).

The lack of local capacity has been widely recognized for many years. Experiences since the early 1950s show that efficient provision for water and sanitation services, and energy is not only about infrastructure but also about local capacity to make appropriate choices about the technology used and the institutional forms for installing, operating and managing it. This includes a local capacity to innovate when conventional methods do not work. Some of the reasons put forward include the poor quality of existing training and the difficulty that practitioners have in specifying the capacity building that is needed, the failure to identify the skills required in staff for an effective institution and a lack of vision of the role of the institution itself. Another reason is the greater weightage given to length of service rather than to competence of local government staff when considering promotion. Consequently, the requirements for enhancing capacity of actors involved in sanitation services have changed. Capacity building is essential at different levels for:

- Strategic planning, assessing of alternative available technologies to make a suitable choice for the local context;
- Technological capabilities including technology transfer;
- Enabling institutions to initiate programmes for introducing renewable energy technologies;
- Developing human resources for effective and efficient management of institutions; and
- Skills at the operational level.

These issues have to be addressed in professional training institutions, Governments, utilities and amongst citizens. In addition, there is a growing consensus that in order to achieve improved sanitation services those who work in the sector need to be more accountable to lower income groups. The World Bank notes that service delivery to low-income groups can be improved by putting poor people at the centre of service provision - by enabling them to monitor and discipline service providers, by amplifying their voice in policymaking, and by strengthening the incentives for providers to serve the poor (World Bank 2003).
The framework in Figure 11.1.1 focuses on the relations between ‘client/citizens’, ‘providers’ and ‘the state’ and emphasizes the role of negotiation in ensuring that services are responsive to the needs of the citizens, including the poor, and that the level of improvement depends on the influence that the citizens/clients can bring to bear on the service provider, either directly or via the government. It distinguishes between two routes of accountability: the short route whereby those lacking access to sanitation services and energy exert an influence directly on the provider, and the long route whereby they influence politicians and policy-makers, who in turn influence the providers. By placing the influence of the citizens/clients at the centre, the framework provides a useful collective measure for determining locally appropriate solutions. Hence, capacity building needs to address issues related to technology as well as to skills for participatory decision-making and management.

11.02 Strategic planning and choosing a suitable technological option
A strategic approach would entail a holistic approach to sanitation and tackling of the problem with multi-pronged actions. This would include creating greater awareness about the consequences of poor sanitation, means of tackling the problems, developing capacity of the responsible organisations/utilities and institutions covering large tracts of land, encouraging small-scale private sector involvement, and area/community-based initiatives.

The main challenge is to find the technical and organizational solutions that fit best with local circumstances and possibilities, strategise expansion over time as per actual demand and revenues increase, and facilitate community participation and cooperation between stakeholders. This calls for a dynamic planning and expansion process for specific training to encompass stakeholder participation, option identification and strategy selection.

It is assumed that the local authority is responsible for service delivery and must therefore, provide and manage the services itself - which results in strategies and plans that are far beyond the authority’s local competence and
capacity. However, in other circumstances, the assumption is that the local authority is unable to carry out this function and the private sector should take on the task; in both cases, problems arise if the decision is not made from sound understanding of the problems and the choices available and the capacity is not put in place to ensure the chosen strategy is effective. A wide range of implementation modalities are possible but an appropriate and participatory planning process is essential, which includes ensuring that the appropriate people have the knowledge and capacity to make strategic decisions.

At the local authority level, it is often assumed that provision of sanitation services in secondary urban centres, peri-urban and rural areas is more difficult than for large cities because of weaker local government, fewer economies of scale for infrastructure and less capacity to manage and pay. The multidisciplinary and managerial complexity of solutions is further aggravated because of the small engineering or works department, with limited or no planning and management experience, and no dedicated structures to address water, sanitation and energy issues. In addition, the poor working conditions make it difficult to attract well-qualified and experienced staff to secondary urban centres and there is limited access to in-service training.

However, in the context of adopting environmentally appropriate technologies for sanitation, secondary towns, peri-urban and rural areas and institutions with large tracts of land have several advantages because the scale of interventions is often more manageable. Within Governments, the different offices or departments of government are more willing to work with each other and to share information. The relationships between citizens and the organisations/utilities are closer or less conflicting, there may be informal accountability measures and there is greater willingness to accept partnerships with community organizations and local NGOs. On the other hand, retaining good staff in these areas is problematic both because of the attractions of more urbanised areas as well as the frustration of not being able to do the job due to lack of resources, lack of access to information and lack of recognition.

The problem requires coordinated action at national and local levels, and a strategic planning and flexible approach to sanitation services. National planning has to be linked to local planning to allow solutions and actions appropriate to each locality with the framework of national support, assistance and monitoring. Capacity-building components should be more clearly articulated for projects and programmes, requiring monitoring of specified outcomes, impacts and indicators, and can be complemented with incentives for successful outcomes over a given period. Experience suggests that appropriate information and communication for sensitization are necessary for consumers together with appropriate facilities and management system.

11.03 Skills for technology assessment and transfer
There are clearly many areas where training of local authority/utility staff is needed. However, this is unlikely to be either sustainable or successful if carried out without reference to larger strategic planning systems of both the developing urban centres/local authorities and the national government. The appropriate technologies and their functioning etc. can be studied/observed by potential adopters of the technologies.

Twinning or facilitating the linkages between local authorities is another strategy to facilitate peer-to-peer exchange of good practices where “those with something to learn” are partnered with “those with something to teach”. Training needs for local authority staff is not restricted to technical personnel and capacity building should be targeted at the management level in charge of urban centres. They are the ones to establish the enabling environment and the framework for action. The final choice of strategies and technical solutions to the problem will be made at this level and they should include pro-poor, gender aware and stakeholder participation strategies. The governance decisions create the enabling environment for the local authority staff, the private sector and the community to act.

11.04 Enabling institutions to initiate capacity building programmes
Adoption of service standards and guidelines provide a basis against which formal training, education or professional qualifications can be delivered and monitored. There is considerable knowledge about sanitation
services, including the strategies, technologies and methods for implementation and maintenance. However, as the different contexts do not allow standard solutions, strategies for sanitation services are more complex and span disciplines and address institutional, management, financial, social and technical aspects, which do not fit easily into conventional engineering approaches.

In addition, while a great deal of information is available on sanitation service provision, much of it is not readily accessible to those that need it. Nor is it used in the curricula of education programmes that include engineering solutions, especially for piped systems but rarely include community-based solutions, small-scale technology, social skills and tools, and the financial and management options. Given the pivotal role that these operatives play, a cadre of personnel with formal training in sanitation can complement engineers responsible for the infrastructure. The technical staff for day-to-day operations of wastewater plants and sanitation services require standardized training and certification.

Efforts have been made to assemble the knowledge in various toolkits and it would be useful to assess the impact and accessibility of these tools. The World Bank Rural Water Supply and Sanitation Toolkit provides some guidance for addressing capacity building in developing urban centres where conditions are similar to rural communities. However, the complexity of linking these responses to other types of water supply and sanitation system, integrating solutions and providing for the long-term capacity-building support is rarely addressed in the sanitation documentation. "Upgrading Urban Communities: A Resource for Practitioners" has many examples of how to do it and gives case studies that include some capacity building; there is also a "Practitioners Companion on Provision of Water and Sanitation services to the Urban Poor".

Community organizations often have knowledge and capacity that is not adequately tapped. In many places, there is a long history of community organizations managing the services with appropriate systems. The use of participatory approaches recognizes this potential for communities to contribute in various ways to the planning, design, implementation and management of sanitation services. However, to be successful, this requires a local authority capacity to manage the process and the understanding, often lacking, that the local authority is to service the community and not the other way round. The capacity of the local authority to maximize the benefits of community knowledge and commitment, particularly taking into account gender differences is still weak.

The experiences in sanitation services for Asia and Africa need to be better packaged and be more accessible for local adaptation at different levels. The lack of access to information and experience has to be addressed with a variety of strategies. Coverage of technologies appropriate across the world has limited use due to lack of local relevance. The knowledge is often there but is not being applied. When anchored in local capacity-building institutions, this knowledge can be adapted to the appropriated social, cultural and environmental context. There is a range of complementary solutions to this including:

- National technical support structures to assist local authorities,
- Strengthening of centres of knowledge such as training centres, universities and research institutions in the field of growing urban centres (as practiced in Pakistan) and professional engagement and knowledge sharing about technologies that work in developing urban centres,
- Twinning local authorities to share knowledge and experiences. This would be appropriate where partnerships between community organizations and sanitation service providers are successful,
- Improved physical electronic access to well-structured information, and
- The formation and strengthening of training networks, which might involve numerous disciplines and attract participation from public, private and civil society organizations, and provide opportunities for colleagues to work together to build internal capacity.

**Human resources for effective and efficient management**

Most sanitation solutions for growing urban centres are small scale and involve greater stakeholder participation in technology selection, implementation, management, payment strategies, operation and maintenance. They are
also demanding in terms of management support from the local authority requiring a mix of disciplinary skills and complexity of decision-making.

Empirical evidence shows that technical and scientific personnel lack sufficient knowledge about overall sanitation management and use. While important scientific and technological advances have been made for monitoring and managing in the institutional and managerial sphere, sanitation problem will not be solved by improved technologies alone. Research focused on effective institutional structures and management techniques is required. Local authorities with responsibility for service provision need to make strategic decisions on how best to use their limited capacity and how to supplement this by training, expansion and devolution of responsibility to stakeholders or the private sector. Capacity building needs to be supported and sustained through local institutions whether they are universities, training institutions or private consultants. This requires improved anchoring of knowledge and information at resource centres within the country and as close to local action as possible.

Addressing the lack of capacity at the level of developing urban centres may take a combination of routes. The establishment of a functional technical support structure can give special advice to urban development centres on design, financing, management, and operation and maintenance, gaining advantages of scale and reducing the need for recruitment of expensive personnel at the local level. This may be achieved through government structures, utilities, and franchise agreements with NGOs or the private sector. Given that in most developing urban centres, it is not possible to develop the full technical competence and broad capacities, more centralized support structures can be both effective and acceptable and may vary from support with design and implementation to more targeted interventions for improving operation and maintenance, and addressing weaknesses in the local authority.

Clearly, the capacity requirements for local authorities of developing urban centres to effectively deliver sanitation services may be beyond their reach and alternative strategies appropriate to national realities may be considered. Their capacity needs may be reduced by allowing, authorizing or contracting others to provide the necessary services. Experience with large-scale private sector involvement suggests that they are not appropriate solutions for growing urban centres as they may not be adequately supervised by the local authority and the financial basis may not be large enough to attract their interest. However, the experiences of liberalization of service delivery that allows small-scale private sector involvement suggest that it is a successful and effective means to increase coverage and service improvement over time. The importance of small-scale providers such as handcarts, and septic tank and latrine-emptying services is obvious from the demand in informal settlements as well as newly developed areas in peri-urban locations. The informal nature of small-scale private sector operators affects the level of service (when legal they can produce a service equal or better than the utility) but does provide an opportunity to address capacity building, regulation or certification.

**Skills at the operational level**

Low and many middle-income nations may not have systems for capacity-building support or programme for training of technical staff responsible for sanitation services. Simple wastewater treatment facilities are often managed and staffed by junior personnel who are directly responsible for the quality of services delivered and the performance of waste management systems. The strategy for building skills of these personnel is by building on existing systems and structures. One example is how using experience from the Canadian Water and Wastewater Association in northern Ghana (Box 11.4.1) and South Africa. Zimbabwe established a formal training programme for wastewater operators (Box 11.4.2). The programme is also available in a distance-learning format and suitable for adoption by other countries in the region.

An important skill is to enable participation of citizens in decision-making. Citizens 'participate' in government to get them to do something or change the way things are done. Participatory governance implies more participation within the relationships between citizens and government. It goes beyond increasing the scope for
**Ghana**

**Box 11.4.1:** International Intervention and National Technical Support for Optimizing Service Delivery

Recognizing the performance problems with existing water and sanitation systems in developing urban centres, Ghana requested support from the Canadian International Development Agency (CIDA) to improve waste system management, operation and maintenance by implementing the District Capacity Building Project in northern Ghana.

It soon became obvious that building capacity at the district level was a necessary but not sufficient condition to obtain properly functioning water supply systems and District Capacity Building Project decided to complement these activities with developing urban centre initiatives directed to water boards, operators and the community itself. The purpose of this initiative was to progressively build on acquired awareness, skills, empowerment and dialogue in order to improve administrative, managerial, operational and financial systems performance in a sustainable way. These local activities were supplemented by regional initiatives to provide the necessary enabling environment. Issues tackled at regional level were outstanding government loans to developing urban centre systems, required policy changes, bye-laws and clearly defining roles and responsibilities at all levels.

**Source:** Susana Sandoz

The process, which is called the optimization Model, addresses primarily the software aspects of the system, empowering stakeholders to focus on what they can do themselves. One of the main strategies takes the form of topical two or three-day workshops followed by two or three-day visits to each urban centre to put the learning into practice. Training is delivered by local training institutions.

Clusters of developing urban centres were selected around a larger urban centre where a better qualified operator existed who was selected to act as mentor. An advantage of this approach is experience sharing among clusters of urban centres, as well as the possibility of joint provision of services like preventive maintenance to all centres in a cluster by private sector providers.

After 18 months implementation, real sustainable advances have been observed in stakeholders’ attitudinal changes, increased dialogue and cooperation, a better gender balance and more effective staff. The systems are now reducing their water losses, are more financially stable, administrative procedures are in place and service to customers has substantially increased. Eight female system operators are working well and the role of women in decision-making role has increased.

**Zimbabwe**

**Box 11.4.2:** Capacity building - Experiences with water and wastewater operators in Zimbabwe

The work of water and waste-water operators is key to health, environmental sustainability, and economic development and indeed contributing to meeting the MDGs. Yet in parts of Zimbabwe, these cadres have been invisible in terms of defined career path, skills development and recognition of their trade. Prior to 1993, training for these operators was offered on an ad hoc basis by the City of Harare. Even then, this training was not institutionalized within the local authority activities but driven by a motivated individual.

Recognizing the inherent weakness of this approach to training, local authorities through the engineers forum approached the Institute of Water and Sanitation Development for support in training water and wastewater operators. The training was then formalized and offered with a three-year progressive system starting with Operators Part I and moving through to Part 3.

After several years of implementation, the Institute worked towards registration of the course with the Ministry of Higher Education following national standards and regulation. Currently in line with other trades offered at tertiary institutions, the water and wastewater operators course offers a national certificate and national diploma. There are plans to start a higher national diploma that will see these students moving from their specialization to general management of water resources. This will be particularly relevant for plant supervisors and managers.

**Useful lessons**

The course has been a learning curve for the institute, the local authorities and even for the Ministry of Higher Education.

- Adaptation of materials: A lot of materials were initially received from the Canadian Association of Water and Wastewater and these were then adapted.
- Career development: The students value what they see as career development and as such are willing to pay for their own education. Due to economic difficulties, local authorities withdrew the tuition support they used to give to students but instead of a decrease in enrolment, there has been a steady increase.
- Skill level: The registration of the course with Ministry of Higher Education opened an opportunity for raising the entry qualification and thus directly improving management of treatment plants.
- Inclusive course: The course is open to the plant operators working with private sector, urban and rural local authorities.
- Self-instruction: The design of self-learning with specific contact points and examinations makes the courses cheaper and affordable.
- The future: The Institute is considering the registration of water and waste-water operators as a trade so that these often invisible cadres have a voice that can be used in bargaining for improved working conditions and can be eligible for reimbursements of tuition, as with other registered trades.

**Source:** Noma Nesen
participation in a specific neighbourhood or a single development programme or project. A review of
community participation within municipalities found that in general, municipal authorities are staffed by
administrators and technical professionals, especially in public works departments who find community
participation irrelevant. Municipal officials have an incomplete knowledge of the potential of and limitations to
participatory approaches, and often lack the skills and resources needed to do so. They also do not appreciate the
difficulties in establishing effective partnerships with community organizations.

Table 11.4.1: Contexts in which good governance can be pursued

<table>
<thead>
<tr>
<th>Resources available to local government</th>
<th>The quality of local government/governance</th>
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<tbody>
<tr>
<td></td>
<td>Accountable local government structures</td>
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<tr>
<td>For relatively well resourced, local government institutions with the needed technical competence</td>
<td>Local government can be the channel through which external funding for sanitation is channelled; whether or not it is the main provider or it oversees and supports private sector or community provision</td>
</tr>
<tr>
<td>For poorly resourced local governments lacking funding, a strong local revenue base and technical capacity</td>
<td>Need for a strong focus on capacity building for local government and support for its partnerships with civil society and local private sector service providers (including informal providers)</td>
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</table>

The interest in good governance is in part related to dissatisfaction with the shortcomings of many actors
responsible for sanitation services and partly to the search for more effective development strategies. Governance
as a concept recognizes that power also exists outside the formal authorities and institutions of government, and
it involves new relationships between citizens and governments. The term ‘governance’ is used for one aspect of
this citizen-government relationship. It encompasses the institutions and processes, both formal and informal,
which provide for the interaction of the state with a range of other stakeholders affected by the activities of
government. Thus, the search for achieving greater effectiveness is obvious from the deficiencies in provision for
sanitation services and energy, and government as well as several other institutions and organizations and
multiple actors involved in the sector, and citizens as well as citizen organizations.

Governance issues include developing the capacity within institutions and organisations to address deficiencies
in sanitation services. Table 11.4.1 illustrates the way by highlighting how very different the local governance
decisions and how national governments, and international agencies can promote better governance. It
highlights how this varies, depending on the quality of local government. Perhaps the most important point to
remember here is that support for community provision should be seen not as an alternative to better local
governance but a powerful way of supporting it.

11.05 Policies for Implementation
Capacity for decision-making and for action is required at several levels. This includes not only implementing
programmes that may emphasize community or stakeholder capacity but also political awareness and political
will that is built from knowledge; also managerial capacity to design and manage the implementation and
subsequent operation and maintenance and the technical competence of staff for installation, operation and
maintenance. The key actions can be listed as:

- Awareness of the importance of sanitation among decision-makers to influence prioritization and
  resource allocation at the local authority level.
- Raise awareness within the local authority, collaborating agencies, teachers, community and its leaders
  and other civic groups about a range of sanitation issues such as service level, technology, financing,
  management and maintenance; and on hygiene issues such as sanitation, hand washing and
  environmental sanitation.
- Develop capacity within the utility to understand the problems, potential solutions, then pros and cons,
implement the plans and sustain support for the services, and manage alternative technologies. This requires strategic planning and commitment to the solutions.

- Develop collaborative mechanisms with other agencies such as the local authority, NGOs, health and the private sector that are working in the sector.
- Develop routes for communicating effectively with the community.
- Develop capacity within the community to take on specific management responsibilities for sanitation services.

Capacity building is required for facilitating partnerships with communities and the customers who support to assess, choose, and introduce alternative ways for solving their sanitation problems and to take-up the roles and responsibilities that may be attributed to them.

- Ensure the capacity in the utility to engage with the low-income community, to manage and implement diverse options.
- Train staff in participatory techniques, engage staff with social skills, allocate resources and develop a work plan for dealing with services to low-income communities.

Developing urban centres need a flexible approach that allows adaptation to changing circumstances and new information. This flexibility is all the more important for urban centres that have rapidly growing population and changing economies. The adaptive approach to strategic planning recognizes the gradual broadening of the knowledge base and a demand-based and incentive-driven strategy. Whatever is considered the 'right' approach to addressing the sanitation problems of growing urban centres, the capacity to make decisions and take action starts at the simplest level of awareness.

11.06 International Cooperation
The global crisis in access to sanitation is an issue that the international community has pledged to address through the UN Millennium Declaration, specifically by halving the proportion of people who did not have access to safe drinking water and sanitation. However, this target poses considerable financial and technical challenges in those countries that do not have the required financial resources and administrative or technical capacity.

While access to water and sanitation depends on several local and international dynamics, international cooperation is often seen as relevant only in terms of development assistance. The focus needs to change to protection of shared resources and reduction in environmental pollution through multi-pronged approaches.
Regulatory Mechanisms for Municipal Solid Waste Management

India is currently facing a municipal solid waste management dilemma. In spite of a detailed and stringent legislation in place, open dumping is the most widespread form of waste disposal throughout the country. It thrives because of the mistaken belief that it is the easiest and cheapest disposal method to use and because of insufficient will and allocation of resources to improve the prevailing disposal practices.

The deposition of wastes along roadsides and on riverbanks and on marginal lands and then ‘hopping’ it will go away is both naïve and dangerous. It is inevitable that chemical and biological contaminants in waste will pollute the surrounding natural environment and find their way back to humans to affect health and quality of life. The traditional thinking in the minds of many waste managers whose municipalities practice open dumping is that it is acceptable because they cannot do anything else.

It is estimated that about 115,000 MT of Municipal Solid Waste (MSW) is generated daily in the country. Per capita waste generation in cities varies from 0.2 kg to 0.6 kg per day depending upon the size of population. As per an assessment, per capita yearly waste generation is increasing by about 1.3%. With growth of urban population ranging between 3 to 3.5% per annum, the annual increase in overall quantity of solid waste generated in the cities is assessed at about 5%. The collection efficiency ranges between 70 to 90% in major metro cities, whereas in several smaller cities it is below 50%.

It is estimated that Urban Local Bodies (ULBs) spend about Rs.500 to Rs.1500 per ton on solid waste collection, transportation, treatment and disposal. About 60-70% of this amount is spent on street sweeping, 30% on transportation and less than 5% on final disposal of waste, which shows that hardly any attention is given to scientific and safe disposal of waste. Landfill sites have not yet been identified by many municipalities and in several municipalities, the landfill sites have been exhausted and the respective local bodies do not have resources to acquire new land. Due to lack of disposal sites, the collection efficiency has been affected.

The enormity and complexity of problems requires coordinated and concerted efforts of all role players, public, private and Government. The planning, policy supports and regulation mechanisms laid by the policy makers in India are presented herein below:

12.01 Model Municipal Laws, Regulations on MSW and related Acts

Model Municipal law
Keeping in view, the Constitution (74th Amendment) Act, 1992 which delegates a set of responsibilities and functions to the ULBs, Ministry of Urban Development initiated the urban reform agenda. This agenda has
been supplemented with the formulation of the Model Municipal Law, which intends to assist urban local bodies in the areas of accounting reforms, resource mobilization, levy of user charges and entry of private sector participation. Ward committees have to be constituted and they have to be consulted/involved in the decision making process with regard to provision of basic amenities.

The Model Municipal Law has specific provisions on financial management of municipalities, municipal revenue, urban environmental infrastructure/services and regulatory jurisdiction. The Model Municipal Law developed by the Ministry is based on a set of Policy postulates that offer guidelines for State Governments to adapt to their specific conditions. The Model Municipal Law has been circulated to all State Governments for follow up action/implementation.

Consequent to the 74th Constitutional Amendment Act, the States are expected to devolve responsibility, powers and resources upon the Urban Local Bodies (ULBs) as envisaged in the Twelfth Schedule of the Constitution. This has brought in its wake the need to strengthen the accounting and reporting systems in these civic bodies.

**Regulations on MSW and related Acts**

In addition to a comprehensive legislation on MSW by the centre and the Municipal Solid Wastes (Management and Handling) Rules, 2000, a few states have notified specific legislation on solid wastes management. A few Municipal Corporations have also made rules way back in the 1950s to manage wastes.

**Municipal Solid Wastes (Management and Handling) Rules, 2000**

A set of rules entitled Municipal Solid Waste (Management and Handling) rules were notified for the scientific management of municipal solid wastes, ensuring proper collection, segregation, transportation, processing and disposal of municipal solid wastes and to upgrade existing facilities to arrest contamination of soil and ground water.

**Salient Features**

These rules lay out procedures for waste collection, segregation, storage, transportation, processing and disposal. Further these mandate that all cities set up suitable waste treatment and disposal facilities by December 31, 2001 or earlier. These rules also specify standards for compost quality, leachate control, and management and closure of landfill sites. Table 12.1.1 gives the broad outline of the rules.

Rule 2 specifies that the rules are applicable to every municipal authority that is responsible for collection, segregation, storage, transportation, processing and disposal of municipal solid wastes. In order to facilitate quick understanding of the rules, terms used in the rules have all been defined in Rule-3.

**Table 12.1.1: Outline of the Rules, Schedules and Forms**

<table>
<thead>
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<th>Rule</th>
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<td>2</td>
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<td>Responsibility of municipal authority</td>
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<td>4</td>
<td>5</td>
<td>Responsibility of the State Government and the Union Territory Administration</td>
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<tr>
<td>5</td>
<td>6</td>
<td>Responsibility of the Central Pollution Control Board and the State Board or the Committee</td>
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<td>6</td>
<td>7</td>
<td>Management of municipal solid waste</td>
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<td>Annual reports</td>
</tr>
<tr>
<td>8</td>
<td>9</td>
<td>Accidents Reporting</td>
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</tbody>
</table>
Management of municipal solid wastes as outlined in Rule-7:

1. Any municipal solid waste generated in a city or a town, shall be managed and handled in accordance with the compliance criteria and the procedure laid down in Schedule-II of the rules and is reproduced in Table 12.1.2.

2. The waste processing and disposal facilities to be set up by the municipal authority on their own or through an operator of a facility shall meet the specifications and standards as specified in Schedules III and IV.

### Table 12.1.2: Schedule-II, Management of Municipal Solid Wastes

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<tr>
<th>No</th>
<th>Parameters</th>
<th>Compliance criteria</th>
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| 1  | Collection of municipal solid wastes            | 1. Littering of municipal solid waste shall be prohibited in cities, towns and in urban areas notified by the State Governments. To prohibit littering and facilitate compliance, the following steps shall be taken by the municipal authority, namely:  
   a) Organising house-to-house collection of municipal solid wastes through any of the methods, like community bin collection (central bin), house-to-house collection, collection on regular pre-informed timings and scheduling by using bell ringing of musical vehicle (without exceeding permissible noise levels);  
   b) Devising collection of waste from slums and squatter areas or localities including hotels, restaurants, office complexes and commercial areas;  
   c) Wastes from slaughter houses, meat and fish markets, fruits and vegetable markets, which are biodegradable in nature, shall be managed to make use of such wastes;  
   d) Bio-medical wastes and industrial wastes shall not be mixed with municipal solid wastes and such wastes shall follow the rules separately specified for the purpose;  
   e) Collected waste from residential and other areas shall be transferred to community bin by hand-driven containerised carts or other small vehicles;  
   f) Horticultural and construction or demolition wastes or debris shall be separately collected and disposed following proper norms. Similarly, wastes generated at dairies shall be regulated in accordance with the State laws;  
   g) Waste (garbage, dry leaves) shall not be burnt;  
   h) Stray animals shall not be allowed to move around waste storage facilities or at any other place in the city or town and shall be managed in accordance with the State laws.  
2. The municipal authority shall notify waste collection schedule and the likely method to be adopted for public benefit in a city or town.  
   It shall be the responsibility of generator of wastes to avoid littering and ensure delivery of wastes in accordance with the collection and segregation system to be notified by the municipal authority as per Para 1(2) of this Schedule. |
| 2  | Segregation of municipal solid waste            | In order to encourage the citizens, municipal authority shall organise awareness programmes for segregation of wastes and shall promote recycling or reuse of segregated materials.  
   The municipal authority shall undertake phased programme to ensure community participation in waste segregation. For this purpose, regular meetings at quarterly intervals shall be arranged by the municipal authorities with representatives of local resident welfare associations and non-governmental organizations. |
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| 3  | Storage of municipal solid wastes  | Municipal authorities shall establish and maintain storage facilities in such a manner as they do not create unhygienic and insanitary conditions around it. Following criteria shall be taken into account while establishing and maintaining storage facilities, namely:  
   a) Storage facilities shall be created and established by taking into account quantities of waste generation in a given area and the population densities. A storage facility shall be so placed that it is accessible to users;  
   b) Storage facilities to be set up by municipal authorities or any other agency shall be so designed that wastes stored are not exposed to open atmosphere and shall be aesthetically acceptable and user-friendly;  
   c) Storage facilities or 'bins' shall have 'easy to operate' design for handling, transfer and transportation of waste. Bins for storage of bio-degradable wastes shall be painted green, those for storage of recyclable wastes shall be painted white and those for storage of other wastes shall be painted black;  
   d) Manual handling of waste shall be prohibited. If unavoidable due to constraints, manual handling shall be carried out under proper precaution with due care for safety of workers. |
| 4  | Transportation of municipal solid wastes | Vehicles used for transportation of wastes shall be covered. Waste should not be visible to public, nor exposed to open environment preventing their scattering. The following criteria shall be met, namely:  
   a) The storage facilities set up by municipal authorities shall be daily attended for clearing of wastes.  
   b) The bins or containers wherever placed shall be cleaned before they start overflowing;  
   c) Transportation vehicles shall be so designed that multiple handling of wastes, prior to final disposal, is avoided. |
| 5  | Processing of municipal solid wastes | Municipal authorities shall adopt suitable technology or combination of such technologies to make use of wastes to minimize burden on landfill sites. Following criteria shall be adopted, namely:  
   a) The biodegradable wastes shall be processed by composting, vermicomposting, anaerobic digestion or any other appropriate biological processing for stabilization of wastes. It shall be ensured that compost or any other end product shall comply with standards as specified in Schedule-IV;  
   b) Mixed waste containing recoverable resources shall follow the route of recycling. Incineration with or without energy recovery including pelletization can also be used for processing wastes in specific cases. Municipal authority or the operator of a facility wishing to use other state-of-the-art technologies shall approach the Central Pollution Control Board to get the standards laid down before applying for grant of authorisation. |
| 6  | Disposal of municipal solid wastes  | Land filling shall be restricted to non-biodegradable, inert waste and other waste that are not suitable either for recycling or for biological processing. Land filling shall also be carried out for residues of waste processing facilities as well as pre-processing rejects from waste processing facilities. Land filling of mixed waste shall be avoided unless the same is found unsuitable for waste processing. Under unavoidable circumstances or till installation of alternate facilities, land-filling shall be done following proper norms. Landfill sites shall meet the specifications as given in Schedule -III. |
12.02 Acts and Rules notified by Indian States
The States of Delhi, Himachal Pradesh, and a few others have notified State specific legislations to regulate MSW.

The Delhi Plastic Bag (Manufacture, Sales and Usage) and Non-Biodegradable Garbage (control) Act, 2000
The Act was enacted to prevent contamination of foodstuffs carried in recycled plastic bags, reduce the use of plastic bags, throwing or depositing non-biodegradable garbage in public drains, roads and places open to public view in the National Capital Territory of Delhi and for matters connected therewith or incidental thereto.

The Himachal Pradesh Non-Biodegradable Garbage (Control) Act, 1995
The Act was promulgated to prevent throwing or depositing non-biodegradable garbage in public drains, roads and places open to public view in the State of Himachal Pradesh and for matters connected therewith or incidental thereto.

12.03 Institutional and Organizational Set-up
The management of municipal solid waste is one of the most important obligatory functions of the urban local bodies, which is closely associated with urban environmental conditions. The 74th constitutional amendment gives constitutional recognition for local self-government institutions specifying the powers and responsibilities. Therefore, the time has come, when all the concerned authorities should make concerted efforts to control and mitigate the problem of municipal solid waste.

Solid Waste Management (SWM) is a part of public health and sanitation and according to Indian Constitution, it falls under State list. Since this activity is non-exclusive, non-rivalled and essential, the responsibility for providing the service lies in the public domain. As this activity is of local nature, it is entrusted to the Urban Local Bodies. The Urban Local Body undertakes the task of solid waste service delivery, with its own staff, equipment and funds. In a few cases, part of the said work is contracted to private enterprises.

Very few Urban Local Bodies in the country have prepared long term action plans for effective Solid Waste Management in their respective cities. For obtaining a long term economic solution, planning of the system on long term sustainable basis is very essential.

12.04 Role of Authorities

Role of Municipalities/ULBs
Every municipal authority, for the territorial area of the municipality, is responsible for the implementation of the provisions of the MSW rules, including the timetable drawn up in schedule-I, and for any infrastructure development for collection, storage, segregation, transportation, processing and disposal of municipal solid wastes. The municipal authority or the operator of a facility is required to make an application in Form-I of the rules for grant of authorization for setting up waste processing and disposal facility, including landfills, from the State Board or the Committee. The aim is to comply with the implementation programme laid down in Schedule I of the rules and to meet the specifications and standards specified.

The municipal authorities are also required to furnish its annual report in Form-II:

1. to the Secretary-in-charge of the Department of Urban Development of the concerned State or as the case may be of the Union Territory, in case of a metropolitan city; or
2. to the District Magistrate or the Deputy Commissioner concerned in case of all other towns and cities, with a copy to the State Board or the Committee on or before the 30th day of June every year.

Role of State Governments
The Secretary-in-charge of the Department of Urban Development of the State or the Union territory, has the overall responsibility for the enforcement of the MSW rules in the metropolitan cities and the District Magistrate/the Deputy Commissioner, of the concerned district.
Role of State Pollution Control Boards/Committees

1. The State Boards/Committees are required to monitor the compliance of the standards regarding ground water, ambient air, leachate quality and the compost quality including incineration standards as specified.

2. The State Board/Committee, on receipt of application from the municipal authority or the operator of a facility in Form I, for grant of authorization for setting up waste processing and disposal facility including landfills, will examine the proposal taking into consideration the views of other agencies like the State Urban Development Department, the Town and Country Planning Department, Air Port or Air Base Authority, the Ground Water Board or any such other agency prior to issuing the authorization.

3. The State Board/Committee will issue authorization in Form-III to the municipal authority or an operator of a facility within forty-five days stipulating compliance criteria and standards as specified in Schedules II, III and IV including such other conditions, as may be necessary. The authorization shall be valid for a given period and after the validity is over, a fresh authorization shall be required.

4. The State Boards/Committees are required to prepare and submit to the Central Pollution Control Board an annual report with regard to the implementation of these rules by the 15th of September every year in Form-IV.

Role of Central Government

The Central Pollution Control Board co-ordinates with the State Boards and the Committees with particular reference to implementation and review of standards and guidelines and compilation of monitoring data. The CPCB also prepares the consolidated annual review report on management of municipal solid wastes and forwards it to the Central Government along with its recommendations before the 15th of December every year.

Role of Citizens, NGOs and CBOs

The informal sector plays a critical role in waste management and exists as a parallel system to the formal waste management process. The sector is labour intensive and includes rag pickers, Itinerant Waste Buyers (IWBs) and small recycling enterprises. Further promotion and development of recycling groups is also a means of upgrading living and working conditions of rag pickers.

Experience in India is, that citizens and NGOs can play an important role in municipal solid waste management. Another innovative approach being tried by cities is the involvement of local business/trade associations in cost sharing and monitoring of these services.

NGOs/CBOs are increasingly supporting the incorporation of micro-enterprises and informal waste recycling groups. In Ahmedabad, the Self-Employed Women’s Association (SEWA) has played an important role in helping organize women rag pickers.

12.05 Conclusion

Some of the measures that would facilitate sustainable management of Municipal Solid Waste are as follows:

by Government

- Fiscal concessions and subsidies may be considered in the management of solid waste, for example, transport vehicles carrying MSW be exempted from excise, sales tax etc.
- Custom and excise duty exemption for plant and machinery used for processing plant be considered.
- Organic manure be granted subsidy like chemical fertilizers.
- All out efforts be made to implement the MSW rules, 2000.
- Supply power at agricultural sector rates to MSW processing plants.
- Tax holiday for companies setting up MSW disposal facilities be considered.

by Urban Local Bodies

- The 74th amendment to the constitution should be given effect and Ward Committees should be constituted.
• Adequate land should be earmarked/allotted at the planning stage by ULBs for setting up sanitary landfills, compost plant and for expansion.
• Improve Resource Base and Institute Income from SWM Service delivery.
• Commercial Orientation.
• Partnerships.

by Financial Institutions
• Evolve low interest loan schemes. Attractive low interest rates and long duration loan schemes should be evolved and be given infrastructure status. NGOs and private parties should be encouraged to partake of these loans for establishing and maintaining MSW systems.
• Evolve Policy framework. While supporting infrastructural projects, like housing, industrial estates, shopping complexes etc., special emphasis on systems being installed for SW disposal, should be ensured.
Perspectives for Future Action

With a long history of development and abundant research in the energy sector, the critical question facing Governments is – what should be the road map for meeting energy needs of the future more sustainably?

Rapid growth in the energy sector depends upon its availability and affordability of the consumers. The pricing of energy has a critical role in efficient utilization of energy. With the sharp increase in prices of coal and petroleum products in the 1970s, the challenges in the sector in terms of identifying affordable energy resources were addressed seriously. More recently, there is growing concern about increasing energy efficiency for savings in costs as well as for reduction in carbon emissions.

Globally, Governments need to play an important role in containing the growth of per capita emissions to a sustainable level while not compromising the objectives of inclusive and sustainable growth. The challenge can be met by expanding domestic supply, promoting demand management and energy conservation, and by encouraging use of alternative energy sources. It is necessary to identify local solutions and evolve appropriate policies and practices for sustainable energy production and utilization.

The thrust in achieving the above should be on deriving energy from wastes, its sustainable disposal and thereby promoting safe sanitation particularly. The uses of unwanted wastes from municipal, animal and human sources are an efficient renewable energy source, and are economical and consistent with optimal utilization. To the extent possible, these can be used in place of existing expensive fossil fuels, nuclear power and hydroelectric power that have been contributing to environmental degradation.

The approaches should be simple, adoptable and affordable. The two pathways of conversion of waste to energy, namely, anaerobic and thermo chemical digestion, and the option of composting waste that has low combustible content (and is not suitable for the anaerobic and thermo chemical processes), provide appropriate means for treating waste and availing energy.

In case of biogas generation from digestible wastes, many countries have installed a large number of family size cattle-manure-fed biogas plants. However, a lot more needs to be done to consolidate the efforts and reach a larger population. Such measures can be taken in an integrated manner to harness more than one form of renewable energy, for example, solar, wind, biomass gasification, and micro-hydel. At a decentralised or community level, the financial and managerial issues are very important and these have even greater collective benefits that could change the environments of the settlements. This scenario holds true for most countries.

In large farms and dairies, waste to energy technology can provide different types and levels of benefits, as has been experienced in European and American farms. At this level of operation, there is potential for further research to improve the outputs and in turn, improve the returns from the investments. Unlike some frontline
developments in the case of high strength industrial waste waters, technology interventions for achieving comparable reaction rate and volumetric efficiencies in farms with comparatively higher animal droppings have been limited. In addition, many developing countries, even those with tropical climate, have not taken advantage of the simplest technologies for conversion of waste to energy.

Thus, a well-defined road map would include emphasis on consolidation and integration with other renewable energy forms for maximization of benefits, particularly at community level in the countries where the family size facilities have reached a sizable population. At the same time, in view of the constraints faced in operation and maintenance of community level biogas plants, institutional or some support mechanism has to be introduced and validated through actual application and long-term monitoring. On the other hand, countries where a programme for conversion of waste to energy is nascent, can use the experiences to date for making decisions on how to best utilize the available resources or for mobilising support for introducing alternative means for managing their waste.

Although biogas production technology has established major influence on the energy scenario, care should be taken to realize its full potential. Comparing the biological, chemical and thermal treatment options, the biological processing option gets a priority. The usage of thermal techniques in a decentralized way is to be carefully planned and assessed on a case-to-case basis in view of its high operational costs and degree of expertise required. Composting of the degradable waste is an easy and economical option, leads to energy saving and can be practiced at any desired scale. Vermi-composting has numerous advantages of productive conversion of organic waste, improving physical, chemical and biological content of the soil and ensures better crop productivity.

At a larger scale, such as for farms or dairy/poultry based units, there is scope for optimizing the core technology, and combining it with other forms like solar, wind, dry biomass based gasification etc. to improve techno-economic viability.

Another important dimension is the possibility of harnessing Clean Development Mechanism benefits and creating dependable trading platforms. In the case of small family size plants, a mechanism to “bundle” the small units into viable size trading entities would help the sector in a big way and may provide an additional support along with Government subsidy. It can even provide an alternative, depending upon the policy of the Government to have a two-way impact in terms of: i) viable bio-energy and bio-manure for the large number of farm families and their villages; and ii) benefits by mitigation of GHG.

The development of energy from waste could play a vital role in country’s economic self sufficiency by reducing oil imports and sustaining fossil fuel reserves. It would also help in reducing the emission of green house gases, in particular, carbon dioxide by replacing fossil fuel as a source of energy. It is desirable that the country governments at various levels of operation facilitate some of the following measures for sustainable energy management from wastes:

- White Paper on use of alternative energy sources, especially on conversion of waste to energy;
- Incentives for adopting and using technologies that reduce and recycle waste in terms of fiscal concessions, tax holidays and subsidies;
- Duty exemptions for plant and machinery;
- Supply power at concessional rates;
- Earmarking adequate land for introduction of alternative options for waste management and for plants for conversion of waste to energy;
- Promoting partnerships that optimally utilise available resources, capacities and knowledge;
- Encouraging NGOs and the Private Sector for promoting/adopting approaches and processes that reduce and recycle waste; and
- Evolving low interest loan schemes and appropriate policy framework.
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Biogas plants: Indian Case Studies

Some of the Indian experiences on Biogas Plants:

Nisargruna Biogas Plant
Bhabha Atomic Research Centre (BARC) has designed this plant, which is a modification of the floating holder KVIC plant and is claimed to be able to process different types of waste materials, like animal waste, abattoir waste, waste from kitchen, fruit and vegetable markets etc. For waste requiring size reduction, the plant has a mixer/pulper. To enhance the process the design has a solar heated thermophilic (55°-60°C) aerobic pre-digester. Following this the material is put into the anaerobic digester, which has a floating dome as its cover. The digested sludge is put into manure pits for drying whereas the effluent is recycled. The retention time is 10-12 days and the methane content is 70-75% compared to 30 days and 50-55% for the conventional biogas plant (MNES, 2006).

Biomethanation of Kitchen Wastes at ARTI, Pune
Appropriate Rural Technology Institute (www.arti-india.org) is a Pune based NGO in India. ARTI has developed a compact biogas plant that uses waste food rather than dung/manure as feedstock to supply biogas for cooking. ARTI developed a compact biogas system that uses starchy or sugary feedstock (waste grain flour, spoilt grain, overripe or misshapen fruit, non-edible seeds, fruits and rhizomes, green leaves, kitchen waste, leftover food, etc). Just 2 kg of such feedstock produces about 500g of methane and the reaction is completed within 24 hours.

Figure I.1: Biogas based on Food Waste
The conventional biogas systems, using cattle dung, sewerage, etc. use about 40 kg feedstock to produce the same quantity of methane, and require about 40 days for completing the reaction. Thus, from the point of view of conversion of feedstock into methane, the system developed by ARTI (Figure 1.1) is 20 times as efficient as the conventional system, and from the point of view of reaction time, it is 40 times as efficient. Thus, overall, the new system is 800 times as efficient as the conventional biogas system.

The plant is sufficiently compact to be used by urban households and about 2000 are currently in use in urban and rural households in the Maharashtra State. A few have been installed in other parts of India and elsewhere in the world.

**Bio-methanation plant based on cattle dung at Haebowal (Ludhiana)**

The Biogas Induced Mixing Arrangement (BIMA) technology of Austrian origin is used for the large cattle manure digester at Haebowal. The city of Ludhiana has large number of dairies producing about 2500 TPD of cattle manure. More than half of this was being dumped in the open or flushed into the drain leading to problems of sanitation and GHG emission. To mitigate this problem, a demonstration project was set up by the Punjab Energy Development Agency (PEDA) at the Haebowal dairy complex at the outskirts of Ludhiana (Figure 1.2), one of the two sites to which the scattered dairies have been shifted. The input capacity of the plant is 235 TPD from which over 9000 m³ biogas and 47 tons per day of dried organic manure is obtained. The biogas is converted into electrical power (one MW).

The designed retention time is 27 days, volatile solids loading rate is 30 TPD and efficiency of the BIMA digesters is claimed to be 55%. The plant was commissioned in October 2004. The total cost of the project was Indian Rupees 136.6 million, 50% of which was borne by PEDA and 50% by the Government of India through the Ministry of New and Renewable Energy/National Bio-energy Board (MNES, 1996).

The cattle manure is collected by a contractor and the power generated is sold to the State. The digested sludge manure is sold to the farmers. Water conservation is practiced by using the treated effluent as make-up water. The plant has a number of benefits – better utilization of the cattle manure resulting in resource recovery (power and manure) and prospect of value addition in the form of CDM benefits resulting from 80% reduction in GHG emission.

**Figure 1.2: MW Power Project based on Cattle Dung at Haebowal Dairy Complex, Ludhiana**

**Biomethanation Plant from Abattoir Solid Wastes at Rudraram, Andhra Pradesh**

A project for demonstration of biomethanation technology for energy recovery from slaughterhouse wastes and their treatment has been installed at M/s Al kabeer, Rudraram, Medak in Andhra Pradesh. The solid wastes are collected in a dissolution tank, which is equipped with a mixer to completely mix the wastes. The produced biogas is stored in a gas-holder (Figure 1.3) and is further used for thermal energy application in the abattoir. Biogas Induced Mixing Arrangement (BIMA) Technology, patented by M/s. Entec, Austria has been used for Anaerobic Digestion of Wastes.
The plant is fed by raw feed @ 60 tons/day and biogas production is 2600 m³/day. Apart from this, bio-fertilizer production is 7 tons/day at the site (70% solids). Total cost of the project is Rs. 37.5 million of which 50% has been borne by M/s Al kabeer Exports Ltd. (AKEL) and the rest by National Bio-energy Board (NBB)/ Ministry of New and Renewable Energy, Government of India.

**Biomethanation Plant based on Domestic Sewage, Bhubaneswar, Orissa**

Regional Research Laboratory (RRL), Bhubaneswar has a campus generating substantial amount of domestic wastewater, which is required to be treated in order to maintain a clean environment. In view of this, RRL installed a 0.4 MLD (Million liters per Day) Sewage Treatment cum Biogas Plant based on anaerobic fixed film technology developed by Nagpur Environmental Engineering Research Institute (NEERI), Nagpur.

The plant (Figure I.4) is installed on an area of 400 m². The sewage in the reactors is biodegraded through microbial action of bacteria and biogas with 75-80% methane is produced which is collected in the 10 m³ capacity biogas holder. The high rate biomethanation process is based on high mean cell residence time (MCRT) independent of HRT. In conventional anaerobic reactors, the MCRT is rarely greater than twice the HRT while the fixed film process can achieve MCRT more than 10 times the HRT. The biogas generated from sewage treatment is used for heating or illumination purposes. The treated effluent is used over-lapping for irrigation of horticulture plantation. The total cost of the project was Rs. 23,41,700. The plant was constructed as a model unit without any commercial purpose; hence generation of any revenue was not envisaged.

**Biomethanation of Mixed Wastes, Vijayawada, Andhra Pradesh**

In any vegetable/fruit market, large quantities of biodegradable wastes are produced because of damage, bruising, rotting of produce. At present, part of these wastes are disposed off usually only by feeding stray cattle. In view of the above, a demonstration project for biomethanation of 20 tones mixed wastes per day, generating of 150 kW of electricity and rich bio-manure was installed by Vijayawada Municipal Corporation at Vijayawada, Andhra Pradesh (A.P.). The project has been set up with the aim to demonstrate biomethanation of mixed wastes. The
mixed wastes consist of 16 tones of vegetable market waste from the Rythu bazaars (Market Yard) and 4 tones of slaughterhouse waste from the Kabela (Slaughterhouse) daily. Biogas generated from this waste is 1615 m³/day and Bio-manure produced is 0.67 tones/day. Total cost of the project is Rs. 28.3 million. (Figure 1.5 and 1.6).

**Biomethanation Plant based on Vegetable Market Wastes, Tamil Nadu**
The Koyambedu Wholesale Market Complex is one of the projects evolved by the Chennai Metropolitan Development Authority (CMDA) to facilitate trading of perishable items like vegetables, fruits and flowers. It has developed over an area of 60 acres with good infrastructural facilities to attract traders and consumers. This Market complex being one of the largest in Asia generates large quantity of organic wastes. About 80 tones of wastes are generated per day at present. The waste collected from the vegetable market is brought to the existing transfer station where packing material and silts are removed. The waste is transferred to the feeding hopper of the conveyor and transferred through the conveyor for size reduction. The waste is delivered into the shredder to reduce the wastes to uniform size of around 15-20 mm and the unit can process about 4 tones/h. The plant that is based on “Biogas Induced Mixing Arrangement”, BIMA Digester, utilizes the vegetable wastes, where stabilization takes place with the production of biogas. The produced biogas, after removal of hydrogen sulphide, is used as fuel to produce electricity. A 230 KW, 100% biogas engine imported from M/s Deutz Germany is installed for generation of electricity. The plant’s waste handling capacity is 30 tons/day and Biogas production is 2500 m³/day. Total cost of the project is about Rs. 50 million.

**Biogas generation for Integrated Waste Management, Kerala**
Since biogas can be generated from any kind of biodegradable waste, biogas technique can be used for integrated waste management. For example, an NGO, BIOTECH-Kerala in South India, which has specialised in propagating family size biogas unit throughout Kerala state, is now propagating use of the technology for treating a mix of biodegradable waste.

They have portable biogas plant for the family level (Figure 1.7). They are also using the system for digesting vegetable market waste (Figure 1.8), and have established a 3 KW electric power plant from market waste at Pathanapuram Gram Panchayat in the Kollam district.

**Biogas Engines Installed at Kanpur and Varanasi, Uttar Pradesh**
The Uttar Pradesh Water Supply and Sewerage Board, India has set up Sewage Treatment Plants in different cities under the River Ganga Action Plan for treating municipal wastewater. Two sewage treatment plants of 5 mld capacity are based on UASB technology at Jajmou, Kanpur and one 8 mld capacity plant based on Activated Sludge Process (ASP) is located at Bhagawanpur, Banaras Hindu University (BHU), Varanasi, where biogas generated is being used in dual fuel engines for generation of power required in the treatment plants. Biogas generation at these plants are 150 and 371 m³/day respectively. Three engines of 70 KVA are used at Varanasi
and one engine of 40 KVA is used at Kanpur. All the engines are made by DFG Kirloskar Cummins. These plants are generating power for 4-6 hrs daily since commissioning.

**Figure 1.7**: Portable Biogas Plant

**Figure 1.8**: Biogas Plant for digesting Vegetable Market Waste

**Biogas-based Power Generation Plant at Surat, Gujarat**
Surat Municipal Corporation, Surat installed six sewage treatment plants (STPs) at Surat city that are functioning satisfactorily since October, 2003. Out of these, four plants have sludge digesters wherein biogas is also being generated. The average biogas generation is about 100-120m$^3$/h from each digester at Anjana STP.
There are three conventional anaerobic sludge digesters installed at Anjana STP that currently generate 4200-1320 m$^3$/day of biogas. To minimize H$_2$S, the biogas is passed through a twin tower chemical scrubber consisting of a packed bed tower supplemented by a venturi-jet column. This scrubber is designed to scrub the biogas to reduce the H$_2$S level to 100 ppm at the outlet of the scrubber. The capacity of the installed Biogas engine generator set is 6234 kWh/day and is capable of operating with a wide variety of gases including natural gas, sewage gas, landfill gas etc. as fuel with minimal adjustments. The electrical efficiency of this engine generator set is 35.4% at full load. This process, besides waste minimization, reduces release of green house gases into atmosphere and works as a cost effective and financially viable model saving on energy bills.
Incinerator Technologies: Indian experiences

In India a few gasifiers are in operation, but they are mostly for burning biomass such as agro-residues, saw mill dust, forest wastes. But, it may be possible to gasify MSW after drying, removing the inert and shredding for size reduction.

When most of the developed nations turned to incineration (for instance: Switzerland: >80%, Denmark: >70%, Sweden: > 55%, France: > 40%) for the disposal of MSW, in India, incineration was never a popular method for the treatment of MSW. Some of the Indian experiences are presented herein to understand the techno-economics and operation and maintenance issues (Vasudevan and Soumitri).

Timarpur Incineration Plant, New Delhi
The first large-scale MSW incineration plant was constructed at Timarpur, New Delhi in 1987. It is a unique plant in its own right. It is of interest to analyze the details of this plant. It is a “twin plant” having a capacity of 300 tons/day (i.e. 150 X 2). It was installed at a cost of Rs. 250 million by M/s Volund Miljotechnik, Denmark. The main features of the plant are as follows:

| Capacity: | 300 tons/day of MSW fired as received (mass burning) |
| Furnace type: | multiple chamber (a combination of three reciprocating grates and Rotary kiln at the end of the grates) |
| Auxiliary fuel: | Light Diesel Oil (LDO), 4 burners |
| Combustion temperature: | 1050°C |
| Heat recovery: | Water tube Boilers and pre-heating of combustion air (20°C to 200°C) |
| Air pollution control: | Electrostatic precipitator (ESP), 2 Nos. |
| Stack: | 60 m tall, 1 No. |
| Power generation: | 3.75 MW |
| Turbine: | Impulse type |
| Cost of electricity produced: | 58 paise/kWH (in the year 1987) |

Though the project was looked upon with lots of hope and expectation but it did not yield the expected results. The plant was out of operation after about six months of commissioning. However, the routine maintenance was carried out.

Operational difficulties of the Plant
During the operation of the plant, there were two major problems, viz. difficulty in maintaining combustion and failure of the ash handling system.

The plant was designed for a MSW having a calorific value of 1463 kcal/kg. But in actual operation, it was realized that usually, the heat content of the Delhi MSW was only 660 to 750 kcal/kg. This created many
difficulties. As it could not sustain combustion, there was a need of large quantities of auxiliary fuel and hence the combustion air. But the burners and the air supply arrangements could not cope up with the load. The high inert content of the MSW caused the failure of the ash handling system. The operational difficulties and the failures were mainly due to the difference between the design assumptions and the actual field scenario. To put back the Timarpur plant in operation, the heat content of the MSW must be increased (by drying before firing into the furnace and by removing much of the inert portion) and enhancing the ash handling capacity of the plant.

Depending on the new heat content achieved (after drying and removing the inert), the additional heat required for sustainable combustion (that may have to be supplied as auxiliary fuel) may be calculated. The capacity of the burners and the combustion air supply may also have to be looked into.

Refuse Derived Fuel Plants in India
Of the several RDF plants in operation in India, the plants in Hyderabad and Mumbai are described below:

Golconda, Hyderabad
The RDF plant at Golconda, Hyderabad was commissioned in the year 1999. It was set up by the Andhra Pradesh Technology Development and Promotion Centre (APTDC) and Selco International Ltd. The city of Hyderabad generates about 2200 tones of MSW a day. Of this, about 1400 tons/day goes to the dumping ground at Auto Nagar and the remaining 800 tones/day goes to the Gandham Guda (Golconda) dumping ground. The RDF plant adjacent to this dumping ground can receive about 1000 tones of MSW a day reducing the pressure on the Gandham Guda dumping ground. The details of this RDF plant are given below:

<table>
<thead>
<tr>
<th>Plant capacity:</th>
<th>2x500=1000 tons/day (but receiving only 700 tons/day at present).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant Cost:</td>
<td>about Rs. 110 million (land cost not included)</td>
</tr>
<tr>
<td>Plant area:</td>
<td>about 10 acres</td>
</tr>
<tr>
<td>Waste Preparation:</td>
<td>Drying using solar energy manual + air classification (density separation) + magnetic separation (to separate ferrous metals)</td>
</tr>
<tr>
<td>Waste Segregation:</td>
<td>Segregated portion goes for land dumping.</td>
</tr>
<tr>
<td>Shredding:</td>
<td>by Hammer Mill about 210 tons/day (i.e. about 30% of the raw MSW) as Fluff, Briquettes and Pellets.</td>
</tr>
<tr>
<td>RDF production:</td>
<td>2 types (60 mm dia. and 90 mm dia.) no binding agent used now. (Previously, Calcium Oxide)</td>
</tr>
<tr>
<td>Pellets:</td>
<td>Powder was used as the binding agent, but discontinued later on due to the lowering of the ash fusion temperature)</td>
</tr>
<tr>
<td>Briquettes:</td>
<td>about 50 tons/day; selling price is about Rs. 1000/per ton; solid mostly to Steel roll mills and boilers</td>
</tr>
<tr>
<td>Power consumption:</td>
<td>about 60 units/tons of briquettes produced</td>
</tr>
<tr>
<td>Mass Power:</td>
<td>about 30 People</td>
</tr>
</tbody>
</table>

The RDF produced is to be used for producing power (about 6.60 MW). A power plant (with air cooled condenser) is to be set up at Silar Nagar (about 40 km from the RDF plant) at a cost of Rs. 280 million (including the land cost). Power evacuation is to the grid (33 kV line). RDF will have to be transported to the power Plant.

Deonar, Mumbai
The RDF plant at Deonar, Mumbai was set up in early 1990s by Department of Science and Technology and CMS Energy Systems. It could successfully demonstrate that it is possible to make fuel from MSW with indigenous equipments. However, the plant is not operational now.
Abbreviations

**ASP**  Activated Sludge Process
**ASTRA**  Application of Science and Technology to Rural Areas (recently renamed as Centre for Sustainable Technologies)
**BIMA**  Biogas Induced Mixing Arrangement
**BOD**  Biochemical Oxygen Demand
**CDM**  Clean Development Mechanism
**CNG**  Compressed Natural Gas
**C/N Ratio**  Carbon/Nitrogen Ratio
**COD**  Chemical Oxygen Demand
**CSTR**  Complete Stirred Tank Reactors
**FBI**  Fluidized Bed Incinerator
**FOS**  Fermentable Organic Substance
**GHG**  Green House Gas
**GI**  Galvanized Iron
**GW**  Global Warming
**HDP**  High Density Plastic
**HRT**  Hydraulic Retention Time
**IC**  Internal Combustion
**LFM**  Liquid Flow Meter
**MCRT**  Mean Cell Residence Time
**MDG**  Millennium Development Goal
**MSW**  Municipal Solid Waste
**NBMMP**  National Biogas and Manure Management Programme
**NBP**  Night Soil-based Biogas Plant
**NPBD**  National Programme on Biogas Development
**PFR**  Plug Flow Reactor
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
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<tr>
<td>pH</td>
<td>Measure of acidity/alkalinity</td>
</tr>
<tr>
<td>PPP</td>
<td>Public-Private-Partnership</td>
</tr>
<tr>
<td>RDF</td>
<td>Refuse Derived Fuel</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>Research and Development</td>
</tr>
<tr>
<td>RMP</td>
<td>Red Mud Plastic</td>
</tr>
<tr>
<td>SET</td>
<td>Sulabhe Effluent Treatment</td>
</tr>
<tr>
<td>SS</td>
<td>Suspended Solids</td>
</tr>
<tr>
<td>SSB</td>
<td>Solid-state Stratified Bed</td>
</tr>
<tr>
<td>STP</td>
<td>Sewage Treatment Plant</td>
</tr>
<tr>
<td>SWM</td>
<td>Solid Waste Management</td>
</tr>
<tr>
<td>TDP</td>
<td>Thermal Depolymerisation Process</td>
</tr>
<tr>
<td>UASB</td>
<td>Up-flow Anaerobic Sludge Blanket</td>
</tr>
<tr>
<td>ULB</td>
<td>Urban Local Body</td>
</tr>
<tr>
<td>USW</td>
<td>Urban Solid Waste</td>
</tr>
<tr>
<td>VFA</td>
<td>Volatile Fatty Acids</td>
</tr>
<tr>
<td>VS</td>
<td>Volatile Solids</td>
</tr>
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</table>