# ENVIS

## Urban Municipal Waste Management Newsletter

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NSWAI ENVIS

**National Solid Waste Association of India**

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### *FROM THE EDITOR'S DESK*

*A world which is on the rapid path of development has led to an increasing waste generating World. It has also posed a challenge not only with respect to treating and disposing properly but also to see this as an opportunity to derive useful products from it. Solid wastes may seem to be the most ordinary forms of wastes, but they could be responsible for many problems such as spread of diseases and emission of green house gases. All these years, solid waste disposal was a neglected issue as these wastes were simply dumped on land in the outskirts of the city. This gave rise to problems like odors, flies, mosquitoes, groundwater pollution, emission of landfill gases etc. Many of these problem areas could be addressed with the implementation 'Sanitary landfill'.*

*With the severe energy crises in the World today, an attempt has been initiated to produce energy from solid wastes. This started with the concept of Biomethane production on the lines of the older practice of 'Gobar Gas' production. Later, newer concepts like fuel alcohol production, bio-hydrogen have also started coming up.*

*Micro-organisms are the agents which bring about the conversion of these wastes into useful products like fuel gases, fuel alcohol and also compost which can be used as manure. The gases produced in landfills due to decomposition by anaerobic organisms also can be used as a source of energy. The major problem today in producing energy from waste is the cost factor. Efforts are being made to produce genetically modified organisms which will produce energy from wastes more efficiently and at least cost.*

*We live in a world where Solid Waste is no more a waste, but a storehouse of precious potential products. We can look forward to major breakthroughs in the field of Solid waste management using micro-organisms. This newsletter deals with '**Applications of Microbiology in Solid Waste Management'.***

## APPLICATIONS OF MICROBIOLOGY IN SOLID WASTE MANAGEMENT

Micro organisms are omnipresent and are responsible for many good as well as bad things in our biosphere. They are present even in waste materials. These micro organisms carry out various biochemical processes to degrade waste materials. This process may be aerobic or anaerobic. Solid waste decomposition is carried out by bacteria which decompose complex organic materials to simple water soluble organic compounds. These are then converted to $CO_2$ and $H_2O$ aerobically , or to $CH_4$ anaerobically.

Fungi are mostly aerobic and feed on decaying organic matter. Soil fungi play a vital role in stabilizing solid wastes in composting and landfilling processes by decomposing plant tissues like cellulose and lignin. Protozoa are predators on bacteria. They are found wherever bacteria are prevalent. Thus they help to maintain the equilibria of microbial flora in solid waste disposal systems.

## Composting:

Composting is the aerobic and thermophilic decomposition of organic matter present in the waste, by micro-organisms. The organic matter is transformed into a stable humus-like substance which can be used as a manure and soil conditioner, during this process. The decomposition is performed primarily by facultative and obligate aerobic bacteria, yeasts and fungi, helped in the cooler initial and ending phases by a number of larger organisms, such as springtails, ants, nematodes and oligochaete worms. The bacteria involved are those which have the capacity to degrade complex carbohydrates like cellulose, lignins as well as lipids. Many different materials are suitable for composting organisms. Some materials contain high amounts of carbon in the form of cellulose which the bacteria need for their energy. Air spaces should be left in the compost because to decompose the organisms need oxygen. Other materials contain nitrogen in the form of protein, which provide nutrients for the energy exchanges.

For an optimum composting operation, the following control parameters are usually adhered to:

1. *Volume*: In the process of composting, the waste volume is first reduced by about 30 to 60%
2. *Temperature*: The reactions taking place during decomposition generate heat and hence compost temperature rises during this process. Hence the temperature has to be regulated. It should be maintained at 40$^{o}$C to 50$^{o}$C. ( If the temperature goes beyond 66$^{o}$C the biological activity will be reduced.)
3. *pH*: 4.5 to 9.5 (It is better to maintain the pH below 8.5 to minimize the loss of nitrogen in the form of ammonia as gas.)
4. *Moisture*: 40 to 70 % (The optimum value is about 55%).
5. *Particle size*: 0.63 to 2.54 cm.
6. *Air:* 0.5 to 0.8 m$^3$ /day/kg of volatile compost solids.
7. *Carbon to Nitrogen ratio*: 35:1 to 50:1.
8. *Carbon to phosphorous ratio*: 100:1.

Composting may be carried out naturally under controlled conditions or in mechanized composting plants. In natural systems, the garbage is mixed with a nutrient source and filler, which permits air to enter the pile. The moisture content of the mixture is maintained at 50%. It is kept in windrows having a depth of about 2.5 m. The mixture is turned over twice a week. Within about 4 – 6 weeks, the temperature falls, the color darkens and a musty odor develops. This indicates completion of the process. With mechanical systems, the composting time is reduced to half of that required in natural systems because of continuous aeration and mixing. Aeration is required because decomposition with a lack of air encourages growth of anaerobic microbes, which produce methane and disagreeable odorous gases.

The mechanical composting process usually consists of the following steps:

***1. Waste preparation:***

The solid waste is placed on slow moving conveyer belts. Materials like corrugated paper are handpicked and then ferrous materials are removed by magnetic separation. Thus the materials which are not easily biodegradable are separated. The waste is then ground in hammer mills and converted to pulp. Then it is mixed with nutrient source, water and fillers. Nutrient sources like sewage sludge, night soil or animal manure is used. Wood chips or ground corn cobs may be used as fillers. Water is added to maintain 50 % moisture. Many Indian compost cycles does not include fillers material and other nutrient sources.

Figure 1: Domestic composting bin

Figure 2: Compost heap kept warm as the exothermic action of bacteria decompose organic matter

***2. Digestion:***

The mixture is placed in the windrows for 4 to 6 weeks, while turning once or twice a week. The waste is decomposed by thermophilic micro-organisms during this period, and warmth is produced by exothermic action of micro-organisms. The material is allowed to stabilize for another 2 to 5 weeks.

In Western Europe, Japan, Israel, and some third world countries which use waste for land reclamation, many composting plants have been operating for several years. India has made considerable progress in organizing compost plants in cities like Baroda, Kolkata, Nagpur, Delhi, Banglore and Ahmedabad. Mechanical compost plants are encouraged in our country by the government as a national programme. Also, composting is done on domestic scale in many farms and households. The National Research Development Corporation is now in a position to offer the Indian know-how to other countries. The agricultural research institutes of our country are developing the technology to produce blue-green algae coated granulated compost.

## Sanitary landfill:

Landfilling is the most economical method of solid waste disposal in many countries. Disposing solid waste in open dumps in a low lying area is one of the oldest practices of disposal. This unsanitary dumping of waste results in water pollution, bad odors, blowing papers, fires, flies, rats etc.. These problems can be reduced by covering the wastes with a layer of soil at the end of each day. This method is used in sanitary landfill. Care is taken to avoid off gases, bad odors, poisonous leachetes, etc..

In a sanitary landfill, complex organic wastes are slowly degraded or decomposed by the soil micro-organisms, primarily by aerobic or facultative bacteria and fungi. Since air cannot enter through a compacted landfill, the aerobic bacteria decompose the organic solid waste by utilizing whatever oxygen is present inside the landfill. Then, decomposition by anaerobic micro-organisms begins, which accounts for degradation of most of the solid waste present in the landfill. The water soluble organic acids generated in this process enter the water media and diffuse through the landfill soils. The bacteria and fungi present in the soils aerobically metabolise these organic acids into $CO_2$ and water.

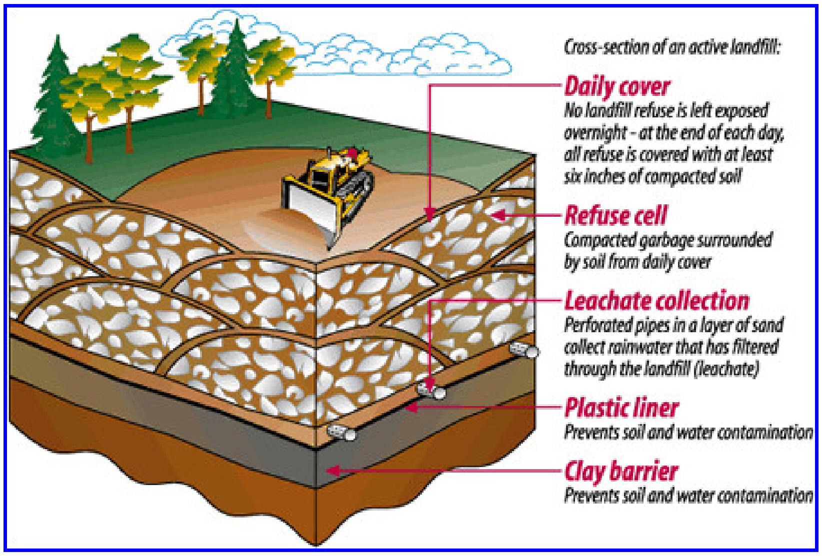


Figure 3: Sanitary Landfill

Occasionally, anaerobic methane bacteria like *Methanosarcina* and *Methanobacterium* accumulate in landfill systems and generate appreciable quantities of methane gas. Methane constitutes about 50-60% of the gas generated in sanitary landfills. A portion of this gas may be utilized by aerobic bacteria as it diffuses through the landfill. However, most of the methane escapes to the atmosphere causing potential fire hazards and increase in levels of green- house gases. Carbon dioxide is also present in the landfill gas and may dissolve in the surrounding water to form carbonic acid, or diffuse into the air leading to green house gas emissions.

These gases produced in the sanitary landfills by the anaerobic digestion of organic waste are generally vented to the atmosphere gravel packed seams or wells. In some landfills, the escaping gases are burnt off with the help of burners installed at top of the vents. Methane may be harnessed as a source of energy.

## Biomethanation:

Solid wastes can be used for production of Biogas. Biogas comprises of 68% methane, 31% $CO_2$, 1% nitrogen and gives calorific value of 5871 kcal/cu.M. Calorific value of biogas is 80% that of methane gas and depends on its $CO_2$ contents. Biogas forms a combustible mixture in range of 6% to 15% concentration in air.

The waste used as substrate must contain adequate quantities of required nutrients. The C:N ratio should be below 40:1. Phosphorous, nitrogen, and trace elements should be added to the substrate if needed. The pH should be around 7.

Several hundred species of bacteria are involved in the anaerobic digestion and biogas production. These bacteria can be divided into the following four groups:

1) *Hydrolytic and fermentative bacteria:* This group includes both obligate and facultative anaerobes, and their concentration may go upto $10^8$ - $10^9$ cells /mL. These bacteria hydrolyse and ferment the organic materials e.g. cellulose, starch, sugars, proteins, lipids etc and produce organic acids, $CO_2$ and $H_2$. They utilize small amounts of $O_2$ present and create anaerobic conditions. Some examples of bacteria degrading complex carbohydrates like cellulose are *Cytophaga* and *Sporocytophaga.* These degrade cellulose into simpler molecules under aerobic conditions. But usually only 50 % of the polysaccharides present in the waste may be digested.

2) *Syntrophic $H_2$ producing bacteria:* This group is also called obligate $H_2$ producing or obligate proton reducing bacteria since the oxidize NADH by reducing $H^+$ to $H_2$ and thereby produce hydrogen. These bacteria breakdown organic acids having more than 2 carbon atoms in their chain to produce acetate, $CO_2$ and $H_2$. However, they are able to grow freely and produce $H_2$ only under low $H_2$ partial pressure, which is maintained by methanogens. The anaerobic digesters have about 4 x $10^6$ cells/ mL of this group. Examples of these bacteria are *Syntrophomonas wolfei*, and *S. wolinii*.

3) *Methanogenic Bacteria:* This group of bacteria converts acetate and $CO_2$ + $H_2$ into methane. Thus methanogens remove the $H_2$ produced by obligate $H_2$ producing bacteria, thereby lowering the $H_2$ partial pressure and enabling the latter to continue producing $H_2$. Methanogenic bacteria are the strictest possible anaerobes known. They may occur upto $10^6$ to $10^8$ cells/ mL in the digester.

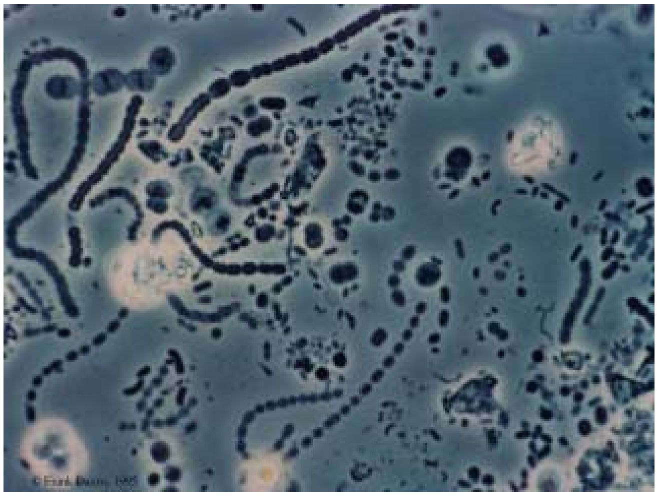

Figure 4: *Methanosarcina*

These belong to the new kingdom called Archaebacteria and oxidize $H_2$ by reducing $CO_2$ to obtain energy. Examples of methanogenic bacteria are *Methanosarcina barkeri, Methanobacterium omelianski,* etc..

4) *Acetogenic bacteria:* These bacteia oxidize $H_2$ by reducing $CO_2$ to acetic acid, which is then used by methanogens to generate methane , $CO_2$ and $H_2$. Thus acetogenic bacteria remove $H_2$ and enable the obligate $H_2$ producing bacteria to continue their function. Eg .*Acetobacterium* ferments hexoses quantitatively to acetate as a consequence of its ability to synthesize acetate from $CO_2$. It is capable of anaerobic chemoautotrophic growth with $H_2$ and $CO_2$. The mechanism of ATP synthesis is not known, but is probably respiratory.

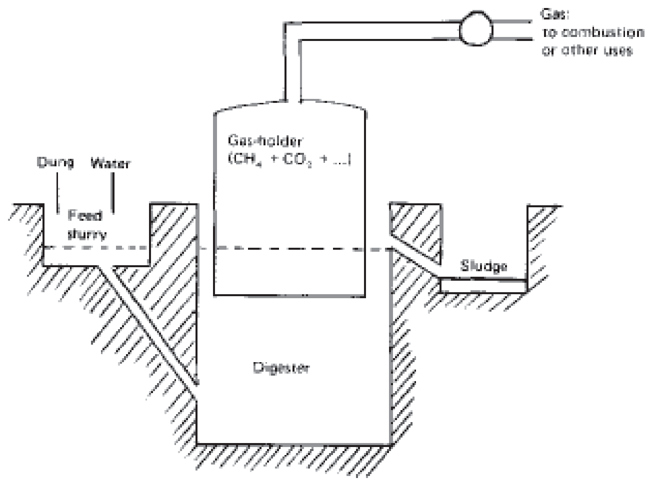


Figure 5: Schematic of a Biomethanation Plant

Biogas production from wastes is given more and more importance because it couples degradation of wastes to energy production and not energy consumption.

## Fuel alchohol production:

The feasibility of using ethanol as fuel for spark ignition automobile engines, boilers, gas turbines, utility fuel cells is well established. Ethanol is currently produced from corn starch derived sugars or from sugars of molasses but producing alcohol using costly sugars and spending energy to produce it will not be an attractive proposition. Hence technology to produce ethanol from wastes is being developed. Ethanol is basically produced from waste containing high levels of cellulose. The cellulose is first converted to into glucose and other fermentable sugars, which are then converted to into alcohol using yeast.

The current process is based on the following three micro-organisms:

1) *Trichoderma reisei* which is an anaerobic fungus producing cellulose and converts cellulose into glucose

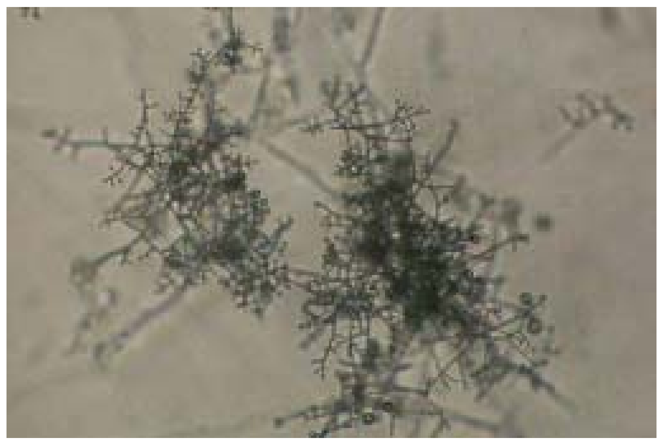

Figure 6: *Trichoderma spp.*

2) *Sacchromyces cerevisiae* which ferments hexoses to produce alchohol

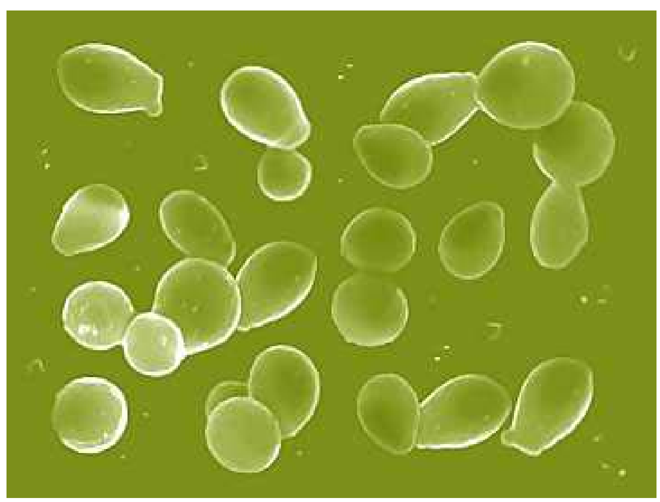

Figure 7: *Saccromyces cereviseae*

3) Recombinant *E.coli* which converts pentoses since yeasts do not utilize pentoses. The organisms which utilize pentoses, like *E.coli* and *Klebsiella oxytoca* are poor producers of ethanol. The genes encoding pyruvate

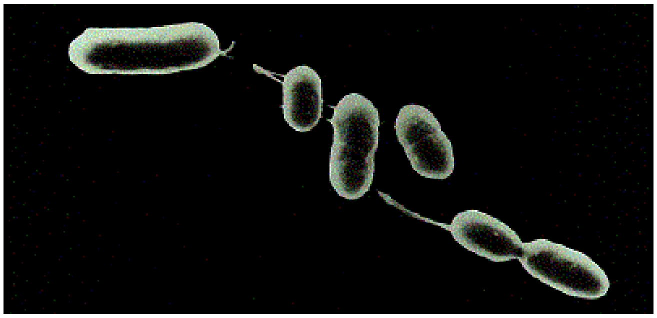

Figure 8: *Zymomonas mobilis*

decarboxylase and acetaldehyde dehydrogenase have been transferred from *Zymomonas mobilis* into *E.coli* and *K. oxytoca.*

4) If all these functions were performed by a single organism with high production rates, the cost of production will be markedly reduced.

Thus the conversion of cellulose to ethanol involves the following four steps:

1) Production of cellulase
2) Hydrolysis of cellulose
3) Hexose fermentation
4) Pentose fermentation

The hexoses are obtained from hydrolysis of cellulose in the form of glucose and cellobiose. Hemicellulose digestion gives rise to pentoses. The cellulosic biomass must be first suitably pretreated eg. A brief exposure to high temperature in combination with acid or ammonia and/or explosive decompression, to make the cellulose available for digestion by cellulase.

The areas of further improvement to reduce cost of production are:

1) Pretreatment
2) Biological conversion

Biological conversion can be improved by the following approaches:

1) By making efficient ethanol producers like yeast and *Zymomonas mobilis* more capable of utilizing substrate.
2) By increasing the ethanol producing ability of organisms which have ability to utilize cellulose or hemicellulose, eg. thermophilic bacteria.

It is expected that in near future, enzymatic hydrolysis and fermentation of cellulose containing wastes to obtain ethanol would become an economically viable activity.

## Ethanol recovery:

Recovery of ethanol from fermentation broth is by distillation, which exploits the difference in boiling points of ethanol (87ºC) and water (100ºC). As a result, when water –ethanol mixture having <95% ethanol is heated, the vapour has greater concentration of ethanol than the liquid phase. Thus the dilute ethanol:water mixture can be repeatedly distilled to obtain more concentrated ethanol solution(upto 95%).

In future, research must be carried out along the following lines, to improve the production of ethanol from waste:

1) To increase the substrate utilization ability of excellent ethanol producers like yeast and *Z. mobilis.*
2) To enhance alcohol tolerance of yeast so that it can survive and function in the digester at higher concentrations of alcohol.
3) To increase the ethanol production ability of bacteria capable of utilizing cellulose, hemicellulose, pentoses etc..
4) More efficient and cheaper methods of ethanol recovery.

## Biohydrogen:

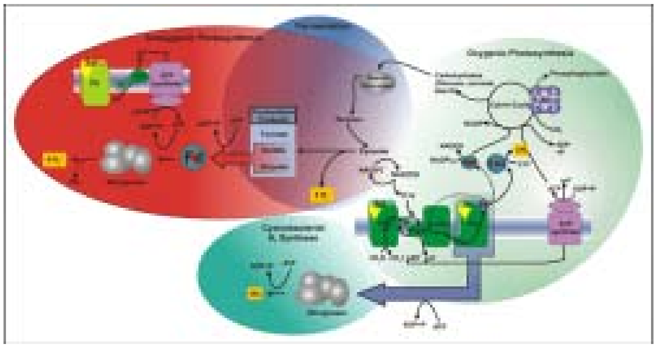

Figure 9: Biohydrogen production

Hydrogen has several attractive features to be used as a fuel. It has high energy to mass ratio. Its combustion yields only water vapour. It can be stored as a metal hydride which makes it safe, portable and usable as a transport fuel. It can be produced using renewable energy sources. When $H_2$ is generated by biological means, it is called biohydrogen. It can be produced by anaerobic bacteria like *Clostridium butyricum* using waste biodegradable organic material as substrate.

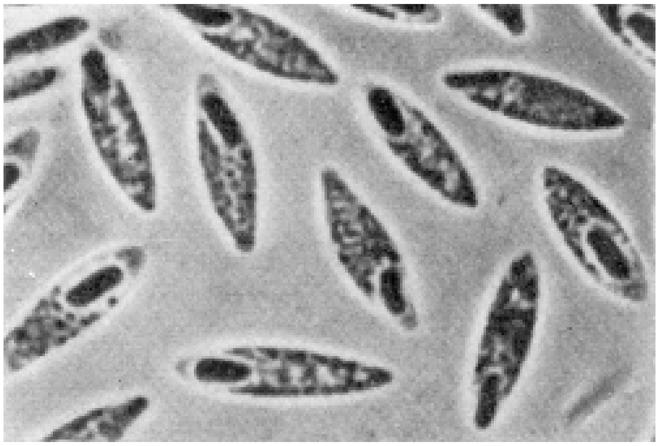

Figure 10: *Clostridium butyricum*

Anaerobic bacteria oxidize the substrate by reducing $NAD^+$ to NADH. But for continued substrate oxidation it is essential to remove NADH from the cell environment and regenerate $NAD^+$. The electrons from NADH are transferred to $H^+$ ions to produce $H_2$ gas, thereby regenerating $NAD^+$. The reaction is catalysed by enzyme hydrogenase. If $H_2$-producing bacteria are grown in absence of $H_2$-utilizing bacteria, $H_2$ accumulates and can be collected, and used as a fuel.

## Bioplastics:

Figure 11: Bioplastics and their degradation

Plastic is one of the few new chemical materials which pose environmental problem. Polyethylene, polypropinyl chloride, polystyrene is largely used in the manufacture of plastics. These chemicals are resistant to and persist in soil environment for a long time. There has been an intense research activity for making biodegradable plastic. Modification of existing material, chemical copolymerization of known biodegradable material, use of biopolymers for making plastics etc.. are the different approaches which are being tried.

'Bioceta' is a new biodegradable plastic which is cellulose diacetate- based product. It has been developed by Rhone Poulenc's Belgium subsidiary, Tubiz plastics. Bioceta uses additives which both plasticize and accelerate degradation by micro-organisms.

Polymers obtained from growth of micro-organisms are likely to replace currently used plastics atleast in some fields. Poly beta-hydroxybutyrate and polylactic acid are the biological origin materials which may be used as plastics.

## Conclusion:

Micro-organisms allow us clean up waste in an environment friendly and hygienic manner. They produce soil manures by decomposing waste. These are safer to use than chemical fertilizers from the environment point of view. They enable us to produce energy from waste and harness it. This is extremely useful in today's energy crisis. They not only degrade waste material, but also help us to produce environment friendly material. Thus they play a vital role in management of solid waste generated from urban areas.

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**We would appreciate your feedback on this newsletter and welcome you all to contribute articles, news or in any other form pertaining to the Waste Management issues, for publishing in our subsequent newsletters.**

## Upcoming Events

**World Future Energy Summit**
19-21 January 2009
Abu-Dhabi, United Arab Emirates
Web: *http://www.worldfutureenergysummit.com*

**8th International Electronics Recycling Congress**
21-23 January 2009
Salzburg, Austria
Web: *http://www.icm.ch*

**5th Waste Management Finance Forum**
22-23 January 2009
London, UK
Web: *http://www.euromoneyenergy.com*

**9th International Exhibition & Conference on Municipal Services, Urban Development and Public Works**
29-31 January 2009
Mumbai, India
Web: *http://www.municipalika.com*

**9th International Automobile Recycling Congress**
11-13 March 2009
Munich, Germany
Web: *http://www.icm.ch*

**Cooperation for Waste Issues – The 6th International Conference on Solid Waste, Sewage and Air Emissions Management**
8-9 April 2009
Kharkiv, Ukraine
Web: *http://www.waste.com.ua/cooperation*

**BIR Spring Convention**
24-27 May 2009
Dubai, United Arab Emirates
Web: *http://www.bir.org*

**WasteExpo 2009**
8-11 June 2009
Las Vegas, Nevada, USA
Web: *http://www.wasteexpo.com*

**Futuresource**
9-11 June 2009
London, UK
Web: *http://www.futuresourceuk.com*

**METALRICICLO 2009**
2-4 September 2009
Montichiari, Italy
Web: *http://www.metalriciclo.com*

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