Industrial Symbiosis and Residual Recovery in the Nanjangud Industrial Area
Photograph on cover: An industrial waste recovery facility
by Ariana Bain

Printed and distributed by

Resource Optimization Initiative (ROI),
No. 66, 1st Floor, 1st Cross, Domlur Layout,
Bangalore – 560 037
www.roi-online.org

March 2010
Abstract

The recovery, reuse, and recycling of industrial residuals, often dismissed as wastes, are common in India and other industrializing countries. Some wastes are reused within the facility where they are generated; others are reused by nearby industrial facilities, or recycled via the largely informal recycling markets. Industrial symbiosis describes direct reuse of wastes by firms in relative geographic proximity. This study examines the material flows in a diverse industrial area – Nanjangud, a town near Mysore in the State of Karnataka in South India, and characterizes the recovery, reuse, and recycling of industrial residuals. It quantifies waste materials generated by 42 companies, accounting for materials that remain at generating facilities, materials that are directly traded across facilities and those that are either recycled via the informal market or disposed. The examined industries generate 897,210 metric tons of waste residuals annually, of which 99.5% is recovered for reuse or recycling, with 81% reused within the generating facilities. One company, a sugar refinery, processes most of this amount. Geographic analysis show that over 90% of residuals exiting facility gates wind up at destinations within 20km of the industrial area. Two-thirds of this goes directly to other economic actors (manufacturing facilities and farmers) for reuse. This study distinguishes how particular types of materials are reused in different ways, the geographic extent of symbiotic activities and the important role of the informal sector in industrial waste management in developing regions. It also highlights potential ways to expand the existing industrial symbiotic network to incorporate the recovery of two materials (non hazardous ash and plastic) that are currently underused.
Acknowledgements

We thank the Karnataka Pollution Control Board for its co-operation and support, especially Former Chairman Dr. H.C. Sharatchandra, Current Chairman Mr. A.S. Sadashivaiah, and Chief Environmental Officer Mr. M.D.N Simha at the Bangalore Office. We also thank Senior Environmental Officer Mr. Nandakumar S, Regional Officer Mr. B.M. Prakash, and Assistant Environmental Officer Mr. Gurudeva Prakash G.M. at the Mysore Office for providing guidance, arranging for interviews, and organizing an awareness program to inform involved industries about the findings of this investigation. We also thank all the managers of the companies interviewed for generously sharing their time and providing detailed information about their operations. This work was supported in part by the Center for Industrial Ecology and Tropical Resources Institute at Yale University.
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Introduction

Manufacturing activities are on the rise in India and other parts of the developing world owing to the concentration of population and the relatively low cost of labor and other inputs for producing goods. India’s formal manufacturing sector accounted for 16% of its GDP in 2006 (Winters and Yusuf 2007). In countries such as India, limited wealth and a large population contribute to resource scarcity, making thriftiness and reuse of materials common practices. Since time immemorial a high priority is placed on the recycling of wastes (industrial and domestic) that can cycle back into society. In this report we focus on three methods of industrial waste recovery (from disposal): (i) reuse within the facility where they are generated, (ii) through direct reuse among nearby firms (industrial symbiosis), and (iii) through informal recycling markets. This report highlights industrial materials that are currently disposed and enables us to recommend environmentally sustainable options for their diversion to more productive uses.

Direct inter-firm reuse of waste is the cornerstone of the phenomenon termed industrial symbiosis (IS), where a group of firms in relative geographic proximity cooperate on resource management issues. Industrial symbiosis falls within the field of industrial ecology. One of the central themes of industrial ecology is that industrial systems would be more sustainable if they were organized and managed with some of the insights we have gained from observing biological ecosystems. A systems view is a critical conceptual foundation of industrial ecology – suggesting that it is not enough to think about ways to reduce the environmental impacts of using a particular product, but that we must think about the entire physical and social system that creates demand for the product, and ways of systemically altering impacts. Industrial ecology arose in the 1990s as a new discipline that places emphasis on the sustainability of energy and material flows. It allows focus on energy and materials utilization at the facility level, across firms, or even, at the regional and global levels. Figure 1 highlights that the goal of industrial ecology is sustainability. Industrial ecology, with its focus on energy and material flows, provides tangible strategies for policy-makers and industrialists to implement concepts of sustainability.

Complex networks of symbiotic industries, also known as industrial ecosystems, are thought to exist in many industrial regions, but may not yet be recognized (Chertow, 2007). Much more common are bilateral exchanges among firms, which are also referred to as ‘kernels’ of symbiosis (Chertow, 2007), green twinning or by-product synergies. Industrial symbiosis can be considered as a critical factor in the sustainability of industrial regions because it promotes a collective approach to reduce environmental damage with both private and public benefits.
This study applies material flow analysis (MFA), a core methodology of industrial ecology, to an economically diverse area – Nanjangud Industrial Area, a town close to Mysore in the State of Karnataka in South India – to quantify the generation of wastes and their final disposition by different strategies. MFA is based on the law of conservation of mass and energy. It is used to quantify the flow of materials (raw materials, products, wastes) into and out of a defined system. In this study we applied MFA to individual facilities to understand the generation of wastes and the movement of these materials among facilities and out of the industrial area. The study area consisted of two adjacent industrial estates populated by over 60 independent facilities spanning a size range from micro and small-scale industries to large multinational firms. These industries produce a wide range of goods that includes pharmaceuticals, food, automotive parts, and electronic items among others. The analysis assesses the potential for further eco-industrial development.

This report proceeds with a literature review on the nature of recycling and industrial symbiosis, including previous research in these areas from India and across the world. This literature review helps place the current investigation in the context of industrial symbiosis around the world and helps in identifying means to improve the industrial symbiotic network at Nanjangud. Then the research framework and methods used in this investigation are presented, followed by results of the case study and implications of the findings. We conclude with significance of the present study and recommendations to improve the recovery of residuals in Nanjangud by expanding the existing industrial symbiotic network.


Literature Review

This section describes published studies on waste generation, recovery, and recycling, the informal recycling market and industrial symbiosis. It then elaborates on previous attempts to characterize and implement industrial symbiosis in India.

Waste generation, recovery, and recycling

Waste generation has been a nearly inevitable by-product of industrial production and human consumption of materials. There has been growing concern to reduce waste generation and to recover waste materials for reuse or recycling. These options range from reusing waste in the same process, burning it to recover energy or recycling the waste to make a different product. The waste management hierarchy is an ordered set of preferred strategies that can be used to reduce the amount of waste being disposed (Graedel and Allenby, 1995). The hierarchy has been incorporated into national waste legislation and policy in several countries (European Union, 1989; Department of the Environment, U.K., 1994; 1995) and is considered to be a simple guideline for extracting maximum embedded value from waste material (Figure 2).

Figure 2: Waste Hierarchy (Source: Waste aware business, Wordpress, 2009)

The hierarchy has five strategies, generally ordered in decreasing preference as follows: (i) waste minimization, (ii) reuse, (iii) material recycling, (iv) energy recovery, and (v) waste disposal (Price and Joseph, 2000). The decreasing preference of this hierarchy is based on the principle of preserving the “embedded utility” equivalent to the total amount of water, energy, and materials needed to produce it, including resources used for raw material extraction and product manufacturing. If a product is landfilled, these resources are lost along with all the energy and emissions associated with their production. For example, material recycling conserves more embedded utility when compared to strategies that only recover energy from
materials. According to this hierarchy disposal of waste is the least preferred strategy because the embedded utility of materials is lost. Therefore, higher levels of the hierarchy are more environmentally benign than the lower levels in most cases; with burying waste in the ground as the least desirable approach to waste management. Additionally, material reuse offers another advantage when it comes to climate change considerations. The decomposition of organic waste in landfills releases methane, a very potent greenhouse gas (GHG), so diverting these materials from landfills through reuse and recycling avoids significant increases in GHG emissions.

Various factors drive the demand for reusing waste materials in industrializing economies. These include differences in the economic value of: (i) primary (raw) material and secondary material (waste/residual), (ii) technology for extraction of primary material (iii) technology for substitution of secondary material for primary material, and (iv) market structure in developing countries (Bower, 1978; van Beukering, 1994). In addition, energy savings based on the reuse of materials are very important in developing economies (Powell, 1983; Krivtsov et al., 2004; Pimenteira et al., 2004), for example, energy savings over virgin production range from 60% for paper (Krivtsov et al., 2004) to 96% for aluminium (Pimenteira et al., 2004).

In developing regions, the informal/unorganized sector is usually the most important domain within which materials are recycled. The structure of the informal recycling sector in developing countries is complex (van Beukering, 1994; Choudhary, 2003; Agarwal et al., 2005). It can be viewed as having five to six ‘layers’ starting with residential consumers and industries producing recyclable wastes and ending in industries that re-process these materials (Figure 3). Informal recycling can have several negative consequences: (i) unregulated pollution caused by reprocessing units, (ii) economic exploitation of an “unskilled” workforce, (iii) improper or unverified records of the amount of material flowing through enterprises, (iv) threats to human health from unprotected activities of the workers, and (v) tax evasion by economic actors dealing with these residuals. On the other hand, the number of people involved in informal recycling networks in urban areas is very high: approximately 90,000 people were estimated to work in the informal recycling market in New Delhi (Agarwal et al., 2005) when its total population was about 14 million. The low cost associated with informal recycling also implies that large volumes of materials can be economically recycled for reuse in the economy.
**Industrial symbiosis**

The field of industrial ecology marks its formal beginning with the publication of a 1989 article titled “Strategies for Manufacturing” in which the authors suggested that industries would be more sustainable if they were organized and managed with insights we have gained from observing biological ecosystems. In biological systems, resources - carbon, energy, water, minerals and other elements - are continuously cycled and taken up by a variety of organisms through food web linkages; similarly industries could reorganize themselves such that the waste of one industry becomes the input for another (Frosch and Gallopoulos, 1989). A complex network of industries in Kalundborg, Denmark that practiced this concept, termed industrial symbiosis (IS), gained worldwide attention in the same year (Gertler and Ehrenfeld, 1994) (Figure 4) and thus the concepts of industrial symbiosis and eco-industrial networks grew in popularity.
Three types of symbiotic transactions can occur among industries: (i) utilizing waste as raw material inputs from others (by-product exchanges) (ii) sharing utilities or access to services (such as energy or waste treatment) (iii) cooperating on issues of common interest such as emergency planning, training or sustainability planning (Chertow et al., 2008). Industrial symbiosis offers an analytical framework for understanding how groups of firms cooperate in the pursuit of competitive advantage by managing their resources in a sustainable manner.

Eco-industrial parks that facilitate cyclic flows of materials across industries have been initiated in Asia, North America, Europe and Australia (Gibbs et al., 2005, Chertow, 2007). The attempts in the West met mixed success (Gibbs, 2003), with more significant results in East Asia (Zhu et al., 2007; Shi et al., 2010). The Chinese, for example, have implemented a national “Law of the Circular Economy” in which eco-industrial parks are a key feature. In 2007, the government designated 27 trial EIPs and in 2008, three of these were selected as national demonstration EIPs including the Tianjin Economic-Technological Development Area (TEDA) (Shi et al., 2010). Current investigations on the functioning of these parks have suggested that strategies for industrial sustainability are more successful when existing spontaneously evolved “kernels” of symbiotic exchanges are encouraged to expand into wider networks rather than being initiated from scratch (Schwarz and Steininger, 1997; Korhonen, 2002; Baas and Boons, 2004; Desrochers, 2004; Jacobsen and Anderberg, 2005; Chertow, 2007; Gibbs and Deutz, 2007).
In developed countries, economic and regulatory factors are thought to be the main drivers of industrial symbiosis (van Berkel, 2006), with communication and trust among firm managers being important “soft” enablers of these relationships (Cohen-Rosenthal, 2000; Christensen, 2004). Industrial symbiosis occurs most commonly among industrial actors in heavy process industries who must comply with existing norms and regulations (van Berkel, 2006). Chertow’s taxonomy of material exchanges includes reuse within firms, among co-located firms, among firms in a broader region, and with a virtually defined geographic boundary (Chertow, 2000). Several authors emphasize the necessity of extending the geographic boundaries for consideration of waste reuse beyond the formal boundaries of industrial park or estate because materials are more likely to find uses among diverse industries in a larger area (Sterr and Ott, 2004). While the literature in this field has grown significantly in the last few years, there remain relatively few studies about existing industrial symbiosis in developing countries, and even fewer examining the role of the informal sector in these activities.

**Industrial symbiosis in India**

Although industries in India may have been practicing industrial symbiosis for years, formal research of this phenomenon is new. The few studies on industrial symbiosis have examined ways to plan and implement eco-industrial parks (Singhal and Kapur, 2002; Saraswat, 2008). Previous industrial symbiosis studies have revealed some existing ‘kernels’ of symbiosis and suggested changes in policy to monitor pollution and waste management at the estate level, rather than at the facility level, and to encourage co-operative approaches to solve these problems (Singhal and Kapur, 2002; Unnikrishnan et al., 2004; Saraswat, 2008).

The Naroda by-product exchange network is the foremost example of research on eco-industrial development in India (vonHauff and Wilderer, 2000; Lowe, 2001; Unnikrishnan et al., 2004; Saraswat, 2008). The Naroda industrial estate contains around 700 companies in a 30 km² region in Ahmedabad, Gujarat. In December 1998, research funded by the German Ministry for Education and Research surveyed 477 of these industries to suggest potentially beneficial industrial symbiosis initiatives (Lowe, 2001). These included: (i) converting spent acid containing high concentrations of H₂SO₄ to commercial grade FeSO₄, (ii) selling sun dried chemical gypsum to cement manufacturers, therefore replacing the need for disposal, (iii) reducing the hazardous content of iron sludge produced by dye manufacturing industries, so that it can be used by brick manufacturers, and (iv) converting approximately 100 tons per month of industrial food waste to biogas (vonHauff and Wilderer, 2000). More than a decade later, however, activities other than a common effluent treatment plant are still in the planning stages. Another planned pilot project in Naroda is aimed at creating a ‘waste exchange bank’ to facilitate future exchange of residuals across companies (Gopichandran, 2008; Express News Service, 2009).
Another study by the National Institute of Industrial Engineering, Mumbai, at the Taloja Industrial Estate, Raigad District, Maharashtra, revealed two existing by-product exchanges: (i) scrubbed tailgas from a petrochemical industry sold to another petrochemical industry for the manufacture of maleic anhydride, (ii) brewery wastes sent to a neighboring chicken farm for use as poultry feed (Unnikrishnan et al., 2004). The same study also identified six other potential avenues for symbiotic exchanges involving chemical solvents used by industries in this estate (Unnikrishnan et al., 2004), however, no reports of progress beyond this stage have been found.

Yet another industrial estate - The Narela industrial estate in New Delhi was designed to utilize cooperative solutions to minimize environmental and economic costs. This estate was constructed with a common effluent treatment plant (CETP) for irrigation of a green belt around the industrial estate, common guest houses, common storage facilities, and common worker tenements (Indian Express, 1998). Management issues not only extended the construction period of this estate (from 1978 to 1998) but also resulted in under-allotment of industrial sites within the estate and inefficient operation of common facilities leading to sub-optimal functioning (Indian Express, 1998). This case alludes to the administrative challenges facing successful operation of cooperative strategies such as industrial symbiosis in India.

The German Development Agency (GTZ) has recently initiated efforts to promote eco-industrial developments in India, with efforts focused in Andhra Pradesh. An international conference on Eco-Industrial Parks was held in Hyderabad, Andhra Pradesh in July 2009. Their efforts will promote EID training among manufacturers in existing estates and provide technical support to new industrial estates in Andhra Pradesh; industrial estates in Nacharam and Mallapur have been chosen as pilot estates (GTZ, 2009).

These efforts demonstrate that while there may be many regions with active symbiotic “kernels” and an ongoing interest in promoting eco-industrial development, the implementation or expansion of these networks has been a major challenge. In addition, the informal sector has not been included in these initiatives despite its predominance in developing economies, and is a topic that was included in this study.
Methods

This study applies material flow analysis (MFA) to an economically diverse industrial area in Nanjangud, South India to quantify the generation and disposition of industrial wastes. MFA focuses on the input, consumption, storage, and output of materials through a defined system. This defined system could be an individual industrial facility, an industrial area, or a country.

MFA results can identify materials that are currently disposed, suggest potential alternative uses, and assess resource efficiency improvements within a system (Graedel and Allenby, 1995). MFA research in India, also called Resource Flow Mapping, has informed waste and wastewater reuse and recycling in several industrial regions in India such as: textile industries in Tirupur, cast iron foundries in Haora, and leather industries along the river Palar in Tamil Nadu (Erkman and Ramaswamy, 2003).

This study compares waste generation, recovery, and disposal. We apply the term recovery to activities that collect matter fit for disposal and divert it to other processes where it has a productive use, i.e. reuse and recycling of waste (van Beukering, 1994; Graedel and Allenby, 1995). Recycling typically involves the physical transformation of materials, whereas reuse usually does not. Within this broad definition of recovery we examine three main activities: (i) materials that remain within the facility where the residual is generated, (ii) direct transfer of residuals across parties, either through purchase or exchange (predominantly recognized as industrial symbiosis), and (iii) materials traded through the informal recycling sector. We broaden the definition of industrial symbiosis to include firm-farmer and firm-informal small enterprise exchanges in addition to the inter-firm exchanges that typically characterize symbiosis studies in industrialized nations.

Understanding current practices in the reuse and recycling of materials is critical to future industrial research and planning in India. This study addresses the research questions:

i. How can the recovery of non-hazardous industrial process residuals be systematically quantified, mapped, and characterized in India?

ii. Do residual exchanges occur across facilities in an industrial cluster in India, and if so, what is their significance relative to other recovery methods?

iii. Of the remaining wastes produced by industries, how much does the informal recycling market recover and how much is disposed?

iv. How can companies and governments pursue additional opportunities for eco-industrial development?
Data collection and analysis
The study characterized energy, water, and residual material flows in two adjacent industrial estates in Nanjangud (Thandya Industrial Estate and KIADB Industrial Estate, Nanjangud). Nanjangud is a town approximately 20km from Mysore (Figure 5), the closest city (population 800,000), in the South Indian state of Karnataka. These two industrial estates are collectively referred to as the Nanjangud Industrial Area (NIA) in this report. NIA is home to over 60 industrial facilities in diverse industries, from small scale enterprises to large domestically owned companies and subsidiaries of multinational corporations. Most of the industries in these two estates are members of the Nanjangud Industrial Association. All of the facilities interviewed are either members of the Nanjangud Industrial Association, or are located within one of the two estates.

Figure 5: Nanjangud, South India

Structured interviews with managers from 42 NIA facilities provided data from the 2007-08 financial year. Two of the authors (Ariana Bain and Megha Shenoy) collected the following data from each facility: (i) quantities of raw materials, water, and energy consumed, (ii) quantities of products, waste, and energy generated. All facilities are subject to a zero liquid effluent discharge policy, so only non-water outputs leave individual facility gates in the NIA system. Where possible, self reported data from companies were verified through follow-up interviews with the reported recipients. Environmental audit reports submitted by each company to the Karnataka State Pollution Control Board (KSPCB) for the 2006-07 financial year provided additional data verification. These environmental audits contain information on types and quantities of waste, chemical contents and quantity of wastewater and gaseous pollutants emitted at each of these industries. Facilities
report non-hazardous residuals to the KSPCB, but the KSPCB does not regulate or track them systematically.

From the initial interview data, scrap dealers and biomass residue suppliers associated with the industrial facilities were identified and interviewed. Dealer and supplier interviews involved 5 scrap collection agents and 5 biomass residue suppliers located within a 40 km radius of the industrial estates.
Results

Overall flows of industrial waste
NIA facilities generate 897,210 metric tons (t) of waste annually. Companies report recovering or sending 893,120 t (99.5%) for reuse or recycling, and disposing 4,090 t either at the generating facilities or offsite. Of the 893,120 t of recovered residuals, the generating facilities reuse 81% (724,630 t) onsite, while 19% leave the gates of generating facilities (Figure 6). Of the materials sent offsite, facilities directly transfer 67% of the materials (113,650 t) to other parties who utilize the by-products as-is, however 45,260 t (27%) of non-hazardous ash reported as transferred for direct reuse could not be verified. The informal recycling market receives 9,580 t (6%) of the waste materials sent offsite (or 1% of all residuals generated).

Figure 6: Final disposition of all wastes generated by NIA facilities

Residual material data were divided into five functional aggregation categories as follows: (i) Biomass: Bagasse, (ii) Biomass: Other, (iii) Food Residue, (iv) Non-Hazardous Ash, and (v) Non-Hazardous Gas. A total of 817,360 tons (or 91% of all waste generated within the system) are bio-based materials corresponding to the first three categories. For biomass, the categories are split into bagasse, a fibrous by-product of sugar cane processing, and other material. The category Biomass: Other consists of residues with little nutritional, but high energy value, such as paddy husk. Food residues include high nutritional and low energy value material including molasses, sludge from effluent treatment plants (ETPs), and coffee grounds. The remainder includes spent acid, metal, plastic scraps, and carbon dioxide gas that are aggregated into a single category “All Others” unless otherwise noted. Recovery and disposal of all residuals by type are detailed in Table 1.
### Table 1: Overall recovery, reuse, and recycling of residuals at NIA (metric tons/year)

<table>
<thead>
<tr>
<th></th>
<th>Total Mass of Residuals</th>
<th>Total Recovered</th>
<th>Reused Within Facility</th>
<th>Informal Market Recycling</th>
<th>Symbiotic Exchange</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass: Bagasse</td>
<td>508780</td>
<td>508780</td>
<td>508780</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Biomass: Other</td>
<td>16970</td>
<td>16970</td>
<td>12900</td>
<td>0</td>
<td>4070</td>
</tr>
<tr>
<td>Food Residues</td>
<td>296360</td>
<td>296360</td>
<td>188370</td>
<td>0</td>
<td>107990</td>
</tr>
<tr>
<td>Non-Hazardous Ash</td>
<td>49790</td>
<td>49790</td>
<td>4520</td>
<td>0</td>
<td>45270</td>
</tr>
<tr>
<td>Non-Hazardous Gas</td>
<td>2250</td>
<td>2250</td>
<td>1440</td>
<td>0</td>
<td>810</td>
</tr>
<tr>
<td>All others</td>
<td>23060</td>
<td>18970</td>
<td>8620</td>
<td>9580</td>
<td>770</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>897210</strong></td>
<td><strong>893120</strong></td>
<td><strong>724630</strong></td>
<td><strong>9580</strong></td>
<td><strong>158910</strong></td>
</tr>
</tbody>
</table>

**Recovery of residuals within generating facilities**

98% of the 724,630 tons of industrial waste that are reused or recycled at the facilities where they are generated are biomass and food residues. Nearly all biomass residues are recovered for onsite energy generation: 99% are combusted to generate steam, electricity, or both through cogeneration. When Biomass: Bagasse, which is the dominant material, is excluded, on-site reuse accounts for 56% rather than 81% of final material disposition. Of 296,360 tons of food-grade residues, industrial or ancillary processes reuse 64%. For example, land application absorbs a large portion of non-hazardous sludge from several onsite ETPs. Generating facilities report disposing or storing very few residuals (3,340 t) including: plastic (1,990 t), hazardous ash (210 t), hazardous sludge from effluent treatment plants (550 t), hazardous chemicals (610 t).

**Recovery of residuals among NIA facilities**

NIA facilities interact with each other in a number of ways. Facilities buy, sell, and trade primary products and by-products, borrow raw materials on a returnable basis, and offer other types of non-material based cooperation.

In total, 11 symbiotic interactions across NIA facilities were uncovered and verified (Figure 7). Ten of these are material transactions among facilities within NIA, and one is electricity sharing. In addition, the authors recorded 17 instances of residual transfer from facilities within NIA to other parties outside this boundary for reuse. In total, 113,650 t of waste materials were verified as directly reused by others (see Table 2).
Four symbiotic transactions involve materials other than biomass residues: carbon dioxide, spent acid, non-hazardous ash, and granite polishing residues. The carbon dioxide trade was a case of intentional co-location as the distillery, a bottling facility, and a carbon dioxide compressor share a single industrial compound, material inputs into each other’s processes, and security services. Spent acid from an aromatic chemical manufacturer neutralizes the alkaline effluent from an adjacent textile facility before the neutralized effluent is used to irrigate a small onsite sugar cane plantation (a co-product that is then sold to the sugar refinery). The ash reused within NIA is used by a neighbouring facility during construction and staging. The granite polishing residues are given for free to local construction projects as foundation materials with the incentive that it saves the producing company money on disposal costs. In addition to materials exchanges, a distillery in the NIA system generates 10 MW of electricity from a methane digester run on paddy husk and exports electricity to a neighbouring facility as needed during power cuts via a direct, non-grid-tied connection. Of the verified symbiotic transfers, 95% are food residues returned to an industrial process, while 4% are biomass residues used as fuel.

**Table 2**: Mass of residuals exiting NIA generating facilities that are in symbiotic exchanges (metric tons)

<table>
<thead>
<tr>
<th>Residual category</th>
<th>Mass of residuals exiting generating facilities</th>
<th>Mass of residuals in symbiotic exchange</th>
<th>Verified mass exchanged</th>
<th>Unverified mass exchanged</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass: Other</td>
<td>4070</td>
<td>4070</td>
<td>4070</td>
<td>0</td>
</tr>
<tr>
<td>Food Residue</td>
<td>107990</td>
<td>107990</td>
<td>107990</td>
<td>0</td>
</tr>
<tr>
<td>Non-Hazardous Ash</td>
<td>45270</td>
<td>45270</td>
<td>10</td>
<td>45260</td>
</tr>
<tr>
<td>Non-Hazardous Gas</td>
<td>810</td>
<td>810</td>
<td>810</td>
<td>0</td>
</tr>
<tr>
<td>Spent Acid</td>
<td>7</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>All other residuals</td>
<td>11080</td>
<td>770</td>
<td>770</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>169230</strong></td>
<td><strong>158910</strong></td>
<td><strong>113650</strong></td>
<td><strong>45260</strong></td>
</tr>
</tbody>
</table>

*Totals may not agree due to rounding*

Figure 7 maps the symbiotic exchanges originating from NIA facilities. One highly symbiotic facility, an oil processor receives residuals directly from other facilities as its main inputs and trades or sells all of its own by-products directly to other facilities. The two other central companies, a sugar refinery and a distillery, produce 100,155 t or 88% of all verified symbiotically exchanged materials in the NIA system.
Recovery of Non-hazardous ash

Apart from biomass residues used for energy recovery and food residues for processing, the largest waste stream from the system is 49,790 t of non-hazardous ash. Companies report a number of different uses for the non-hazardous ash: application as fertilizer, addition to cement bricks, incorporation into incense sticks as pulverized carbon, and for levelling uneven land. Data verification was difficult because the informal actors were reluctant to provide interviews. Two interviews with cement brick manufacturers suggested that, though they have in the past, neither currently takes ash because of a public perception that brick strength is reduced by adding it. This perception is based on the darker colour of brick manufactured by the addition of ash from biomass combustion. Additional cement brick manufacturers were contacted for interviews, but they either stated that they no longer took the residual, or they declined to comment. Farmers in the surrounding area were the largest reported recipients of ash, applying it as a supplementary fertilizer. A follow-up study conducted field interviews with a random sample of farmers in the region around the NIA (n=90); only 24% of respondents confirmed receiving and using ash from NIA facilities. These responses suggest that some
portion of this material is not ultimately beneficially recovered. Our recommendations to overcome these hurdles associated with the recovery of non-hazardous ash are on Page 18.

**Informal market recycling**

While the bulk of material is reused within generating facilities or reused directly within 20 km of NIA, 9,580 t of “All Other” materials are recycled through the informal market. The major materials (by mass) that make up this stream are listed in Figure 8. More than 99% of glass, metals (ferrous and non-ferrous), paper, rubber, waste oil, and wood are reportedly recycled through the informal market. The bulk of textile residues are reused within generating facilities, with some informal market recycling.

Plastic material is the major anomaly. Facilities report recycling 3% of plastic waste, and store or dispose the remainder while awaiting new regulations governing their final disposition. Our recommendations, to recovery this plastic waste, are included in Page 18.

**Figure 8:** Recycling of major materials in “All Others” residual category (metric tons)

Five informal scrap dealers who purchase residuals from NIA facilities were interviewed. Scrap dealers tend to purchase all unused or untraded waste produced by a firm and transport the materials to their own facilities where they are separated. A large portion of these residuals are profitably recycled, but some components have
little resale value and, ultimately, are not profitably recycled. Only one scrap dealer provided complete material balance information; the data revealed that he disposes as much as 40% of the residuals collected. Many of the scrap dealers are individuals operating without government regulation, so the recycling that does occur is usually conducted informally and at a small scale often without sufficient human protection (personal observation) and with significant material and energy losses (van Beukering, 1994). However, informal recycling may provide significant economic benefits to participants and promote the recycling of otherwise unrecoverable materials.
Recommendations to improve industrial symbiosis

**Improve recovery of non-hazardous ash**

This study found that facilities in NIA have already tried ways to recover non-hazardous ash, but have come across certain hurdles in promoting its reuse, owing to the lack of certification of the strength of bricks that contain ash. We suggest a three step approach to overcome these hurdles:

**Step 1: Form working groups for streamlining ash recovery:** A working group that include members of (i) facilities that produce the non-hazardous ash, (ii) cement brick manufacturers within NIA, (iii) researchers from reputed engineering colleges in Mysore should be constituted. The working group should meet and discuss hurdles that they came across in previous attempts to recover ash, in addition to planning activities outlined in step 2 and 3 given below.

**Step 2: Test strength of cement bricks with and without ash:** The cement brick manufacturers should use the non-hazardous ash produced by NIA facilities to manufacture sample bricks whose strength (flexion and tension resistance) should be tested by engineering college researchers. The engineering college can then certify the tested strength of bricks with and without non-hazardous ash.

**Step 3: Use cement bricks with hazardous ash in facilities within NIA:** Once the strength of the bricks with ash is certified, NIA facilities that produce the non-hazardous ash can use these bricks for construction. This exercise will serve to showcase these bricks to potential customers.

If this attempt fails to convince customers about the strength of bricks with non-hazardous ash, the cement brick manufactures can consider using known dyes such as Iron (III) oxide (red oxide), others available in the market to mask the dark colour of the bricks.

**Improve recovery of waste plastic**

Around 2000 t of waste plastic is generated by NIA facilities. Only 3% (60 t) of this plastic waste is recycled, the remaining is stored at the site of generating facilities. There are two options for recovering this type of plastic that are already available throughout India:

i. produce a polymer blend that can be used in the construction of roads,

ii. use as a fuel in cement kilns
Further studies are needed to assess the environmental, social and economic costs and benefits associated with these two processes. Government agencies such as the Karnataka State Pollution Control Board should investigate these options, before a suitable strategy is recommended to the industries. Details about these strategies are given below:

**Waste plastic in roads**
Littered plastic bags, PET bottles and thin film grade plastics can be used to create a polymer blend that is used to construct roads. Currently the company K. K. Plastic Waste Management Pvt. Ltd., Bangalore is using this technology to convert plastic waste (free from other wastes) into a bitumen modifier that is used to construct roads. This bitumen modifier made from plastic waste is cheaper than others currently available in the market. The emissions from the conversion process should comply with the Air (Prevention and Control of Pollution) Act, 1981 and the Water (Prevention and Control of Pollution) Act, 1974 (Department of Environment India, 1974, 1981). Contact details of K. K. Plastic Waste Management Pvt. Ltd. are provided in Appendix 1.

**Waste plastic in cement kilns**
Waste plastic can be used for co-processing in cement kilns. Co-processing involves the substitution of industrial ‘waste’ materials as fuels or as raw materials in cement kilns, dryers and captive power plants, depending on the composition and calorific value of the ‘waste’.

Two large cement manufacturers in India viz. Ambuja Cement, and ACC Ltd. are currently co-processing plastic waste in their cement kilns. Air emissions from co-processing should comply with Air (Prevention and Control of Pollution) Act, 1981 (Department of Environment India, 1983).

Ambuja Cement does not have plants in South India. ACC Limited has three plants in the states of Karnataka and Tamil Nadu in proximity to Nanjangud (Table 3). ACC requires that samples of the materials be sent to their labs for assessing the feasibility of co-processing them in cement kilns. Contact details and necessary forms for sending waste samples for testing to ACC Ltd. are attached in Appendix 2.
Table 3: Location of ACC Ltd. cement plants in proximity to Nanjangud

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Location of ACC plant</th>
<th>Address and Phone Number</th>
<th>Route</th>
<th>Road distance from Nanjangud (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Madukkarai</td>
<td>Madukkarai Cement Works</td>
<td>NH 67</td>
<td>186</td>
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<td></td>
<td></td>
<td>P.O. Madukkarai</td>
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<td></td>
<td>District Coimbatore</td>
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<td></td>
<td>Tamil Nadu</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Phone: 91-422-822282/449</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Thondebhavi</td>
<td>Thondebhavi Cement Works</td>
<td>SH 17</td>
<td>219</td>
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<td></td>
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<td>Madugiri Road</td>
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<td>Thondebhavi</td>
<td>SH 33 &amp; SH 17</td>
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<td>Gauribidannur Taluk</td>
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<td>Dist Chikballapur 561 213</td>
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<td>Karnataka</td>
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<tr>
<td></td>
<td></td>
<td>Phone: 91-8155-288802</td>
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<td></td>
</tr>
<tr>
<td>3</td>
<td>Kudithini</td>
<td>Kudithini Cement Works</td>
<td>SH 17 &amp; SH 19</td>
<td>382</td>
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<td>Kurugodu Road</td>
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<td>Karnataka</td>
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<td></td>
<td></td>
<td>Phone: +91 839 2210522</td>
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We recommend that NIA facilities request the Karnataka State Pollution Control board to recommend a suitable strategy for recovery of plastic waste generated at NIA.
Discussion

Three major patterns emerge from the MFA that deserve some attention: (i) the nearly complete recovery of waste through industrial symbiosis and facility-level reuse, (ii) the unconscious self-organization of industrial symbiosis amongst NIA facilities, and (iii) the distinctions between reuse through industrial symbiosis and recycling through informal markets.

Waste recovery

Companies in Nanjangud exhibit an almost complete recovery (99.5%) of all the waste materials that they generate. Even when the sugar refinery that dominates the material flows in the region is removed, the recovery rate remains very high (96%). This suggests that the companies in NIA find it in their best economic interest to find productive uses for any wastes that they generate, either within their own facilities or by sending it to other economic actors.

Many of the industries in the region are based on processing agricultural products and thus generate organic residues from their production. These materials are easily recovered because they are not hazardous and have high calorific and nutritive content. The biomass residues used for energy generation in NIA tend to remain at the facilities where they are generated, or are purchased from specialist suppliers/agents. Three facilities produce electricity in grid-tied power plants, taking advantage of the Karnataka State Electricity Supply Act (1991) that encourages independent production in order to ease the burden on generating capacities at state utilities (Sakri et al., 2006). All use majority biomass feed stocks, and use supplemental coal to supply sufficient energy density to reduce incomplete combustion. Biomass residues are easily combustible in boilers designed for coal. However, the energy efficiency of the boilers may be lower when fuelled by biomass because it is less energetically dense per unit volume.

Self-organized industrial symbiosis

The results indicate that NIA facilities have unconsciously self-organized into a symbiotic network with 11 transfers of residuals across facilities within NIA and 17 more originating from NIA facilities to others outside it. In addition, 8 NIA facilities receive wastes as material inputs, such as paper manufacturers that purchase waste paper for recycling, while 16 NIA facilities combust residual biomass to generate energy. The revelation of such a complex network of inter-firm linkages supports the assertion that such networks exist throughout the world (Chertow, 2007).

Industrial symbiosis in the NIA exists in the absence of a regulatory framework for non-hazardous waste disposal and a culture in which repeated reuse and recycling of materials has been the norm. This differs from many eco-industrial networks in
industrialized countries, which were primarily seen as driven by a combination of regulatory restrictions, most often on waste disposal, and economic considerations.

**Distinctions between industrial symbiosis and informal recycling**

Based on the magnitude, by mass, of different residual treatments, our data suggest that priorities for residual management strategies in this region are: (i) on-site reuse, (ii) by-product exchange, (iii) informal market recycling, and (iv) disposal. These preferences are probably due to a number of factors including the market value of the residual, cost savings on raw materials or on waste disposal, transaction costs, brand reputation, and convenience as well as less tangible factors such as existing social networks and cultural norms.

Informal scrap dealers frequently purchase waste with properties similar to fungible commodities, those with relatively uniform publicized values and sales markets outside the local area, such as glass, plastic, paper, and rubber. Conversely, firms commonly symbiotically trade materials that lack a standardized monetary value or market, such as food residues. Symbiotic reuse of industrial residuals has the advantage of low transportation costs and related emissions by virtue of being reused within a relatively small geographic region (94% of materials within 20km in this case). In addition, exchanges among formal entities enable verification of information about residual management.

**Future of industrial symbiosis in India**

The present study reveals high levels of residual recovery through industrial symbiosis in the Nanjangud Industrial Area. The results highlight the significance of self-organized symbiotic exchanges among firms in the absence of regulatory pressures. The study identifies opportunities for expanding symbiosis in the cluster and distinguishes different opportunities for symbiosis and informal recycling. Finally, it shows the need for considering the role of informal actors in a symbiotic network, in order to address issues of social equity. Strengthening the existing inter-firm network in NIA by encouraging additional connections between NIA facilities and new enterprises or individuals, either formal or informal, can improve the residual handling process and allow participating facilities to realize the benefits of agglomerated waste streams, particularly for non-hazardous ash and waste plastic.

In order to follow this approach, and to strengthen and expand the industrial symbiotic network in Nanjangud an awareness program on “Industrial Ecology and Eco-Industrial Networking” was organized by the Karnataka Pollution Control Board in collaboration with the Yale Center for Industrial Ecology and the Resource Optimization Initiative, Bangalore. This program was organized in Mysore on the National Pollution Prevention Day – 3rd December 2009. The program was open to the public and industrial managers from the Nanjangud Industrial Area were specifically invited. The program consisted of a presentation titled “Industrial
One promising phenomenon on which symbiosis might be developed are the common effluent treatment plants (CETP) and common toxic disposal facilities that are commonplace in many Indian industrial parks. Having avenues such as these, in which managers already meet and discuss issues with economic and environmental relevance provides a natural place for other issues of collaboration to be addressed. Industrial associations that manage these common facilities can undertake activities to include encouraging waste exchange among facilities and other co-operative solutions to reduce environmental damage due to industries.

Eco-industrial development in India is difficult to assess since the majority of symbiotic transactions between industries are not reported or recorded. Studies similar to this one, which first characterize existing symbiotic relationships, and then identify further opportunities, including important actors to be engaged, could be utilized in other regions. Additionally, MFA can serve as a core method to comprehensively characterize and map waste flows, and quantify the relative magnitudes of residual treatment strategies across industrial areas. Future studies could also illustrate the economic, environmental, and social benefits of industrial symbiosis and encourage its development.

**Conclusion**

This study found extremely high rates of material and energy recovery in the Nanjangud Industrial Area. Companies in the uncovered network reuse their own by-products, share by-products with other local companies, and engage with local informal recycling markets. Whether such high recovery rates would be found in industrial districts throughout India remains unclear. The sugar refinery produces 87% of the total residuals recovered; other configurations of industrial companies may not have this sort of lead player. Further analysis could calculate the environmental and economic lifecycle costs and benefits of the system. The high levels of symbiosis and recycling found reflect that these resources are valuable and that actors in both the formal and informal sectors capture and recycle these materials; however, in order to draw more generalized conclusions from this paper, comparable analyses are necessary. As an early study of this kind in India, these results can build a foundation for a broader body of knowledge covering symbiosis, reuse, and recycling practices in India.
References


Appendix 1

Contact details of K. K. Plastic Waste Management Pvt. Ltd.
<http://www.kkplasticroads.com/company.htm>

Address:
K. K. Plastic Waste Management Pvt. Ltd.,
No. 50, Y.V. Annaiah Road, Opp. Post Office,
Yelachenahalli, Krishnadevaraya Nagar II Stage,
Kanakapura Road, Bangalore - 560 078

Telephone : +91-80-4057 5594, 4094 7005

Contact persons:
Mr. Ahmed Khan
Managing Director
Mobile: +91-98450 78600

Mr. Rasool Khan
Director
Mobile: +91-9880 045811, +91-9886505811
Email: kkpwm@hotmail.com
Appendix 2

Contact details of ACC Ltd.
<http://www.acclimited.com/newsite/index.asp>

Send enquiries for ACC plants in Western and Southern India to: rajivkumar.bimalchand@acclimited.com

Address:
Corporate Office
ACC Limited,
Cement House
121, Maharishi Karve Road
Mumbai - 400 020
India

Tel: 91-22-66654321
Fax: 91-22-66317440

Regional Office
Southern & West Region (Pune)
313, Connaught Place,
Third Floor, Bund Garden Road,
Pune - 411 001, India

Tel: 91-20-66271000 / 66271040
Fax: 91-20-66271090

Guidelines for sending solid and sludge samples for analysis to ACC Ltd. are given below.
GUIDELINES FOR SENDING SOLID AND SLUDGE SAMPLES FOR ANALYSIS

Kindly send us 1 kg (well sealed & labeled) waste sample of each of your industrial wastes with the following considerations:

1. The waste samples should be sent along with cover letter (attached as Annexure I), clearly mentioning the names of the samples.
2. The waste sample must be representative.
3. The waste samples should be contained in 2-3 layers of polythene cover. The hard copy of the waste sample label (attached as Annex II) should be placed between the layers of the polythene.
4. The waste samples must be accompanied by the Waste Profile Form (attached as Annexure III)

Kindly send a hard copy of the forms with your samples to the following address:

Mr. Arnab Nandi / Mr. Kasi Viswanath
AFR Laboratory
ACC Madukkarai Cement Works
P.O. Madukkarai
Pin - 641 105
District Coimbatore
Tamil Nadu

Please also send soft copies of all the filled up forms to the following e-mail ids:

arnab.nandi@acclimited.com
kasiviswanath.yannamani@acclimited.com
pradeep.kaduskar@acclimited.com
sharmistha.nandi@acclimited.com
sarika.saxena@acclimited.com
Mr. Arnab Nandi / Mr. Kasi Viswanath

AFR Laboratory
ACC Madukkarai Cement Works
P.O. Madukkarai
Pin - 641 105
District Coimbatore
Tamil Nadu

TIN of ACC Madukkarai: 33261920015

Dear Sir

Subject: Samples of Waste Materials to ACC Limited for Evaluation

This is to inform you, that we M/s.____________ Limited are sending the following samples of waste materials generated at our unit, to ACC TSS for evaluating their co-processing feasibility.

<table>
<thead>
<tr>
<th>S. No</th>
<th>Name of waste</th>
<th>Waste samples are properly labeled (Y/N)</th>
<th>Waste Profile Form accompanied (Y/N)</th>
<th>Waste Generation Process Form accompanied (Y/N)</th>
<th>Quantity of waste samples dispatched</th>
</tr>
</thead>
<tbody>
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</tbody>
</table>

Please find table below containing the details of the sample dispatch:

<table>
<thead>
<tr>
<th>Mode of Dispatch</th>
<th>Dispatcher’s Name &amp; Contact No.</th>
<th>Date of Dispatch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tbody>
</table>
Waste Generation Process Details

• Name of the Waste: ____________________

• Name of the Waste: ____________________

• Name of the Waste: ____________________
<table>
<thead>
<tr>
<th><strong>WASTE SAMPLE LABEL</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Name of the Waste</strong></td>
</tr>
<tr>
<td><strong>Name of the Industry</strong></td>
</tr>
<tr>
<td><strong>Address</strong></td>
</tr>
<tr>
<td><strong>Contact Person &amp; No.</strong></td>
</tr>
<tr>
<td><strong>Nature</strong></td>
</tr>
</tbody>
</table>

Revised on 10.09.09

Rev No: 01
Appendix 3

Articles covering the Awareness program on “Industrial Ecology and Eco-Industrial Networking


Develop green belts, KSPCB chief tells units in NIA


MYSORE: The Karnataka State Pollution Control Board (KSPCB) chairman A S. Sadashivaiah has called upon industries in the Nanjangud Industrial Area (NIA) to focus on developing green belts in and around their units in order to improve the plant cover and enhance the natural beauty.

Speaking at the National Pollution Prevention Day organized by the board here on Thursday, Mr. Sadashivaiah said, "The performance of the units in the NIA in pollution control: air quality and river quality control has been largely satisfactory. Water quality of the Kaveri river conforms to Class 'C' standards which is suitable for domestic water supply after preliminary treatment. Now, the industries should focus on adopting the best available manufacturing techniques and creating green belts."

Major industries such as the TVS Motor Company, Nestle India, and Reid and Taylor are located in Nanjangud.

An awareness programme on "Industrial ecology and eco-industrial networking" in collaboration with the Centre for Industrial Ecology (CIE), Yale University, U.S., and the Resource Optimization Initiative (ROI), Bangalore, was organized.

Wesleyan Ashton from Yale University dwell on industrial ecology and international best practices on application of industrial ecology in business, and Megha Shetty, of ROI spoke on building eco-industrial networks in the NIA.

"As the Kaveri flows in close proximity to the NIA, we have imposed a rule that all industries have to treat their effluents and reuse it and the excess can be diverted for green belts and agriculture," Mr. Sadashivaiah said.

Whenever problems had been noticed, the board had taken action to address the issues and take preventive measures, he said. Also, penal action had been taken against erring units. "We have adopted the carrot and stick policy for effective enforcement," he explained.

He also stressed on the importance of the reduction of carbon dioxide emissions.

He said that solid wastes and hazardous wastes should be properly managed. Industrial ecology took a systematic approach in understanding the sustainability of materials and energy and water flows within the system, he said.
‘Adding greenery is crucial’

Industries must do their bit to save environment; KSPCB Chairman

MYSRRE: Stressed on the fact that it is imperative for the industry to focus on developing green patches and conserve natural resources and reduce carbon dioxide emissions. He was speaking after inaugurating an awareness programme on industrial ecology and eco-industrial networking organized as part of National Pollution Prevention Day at the Regional Museum of Natural History here on Thursday. The board is planning to plant more plants in and around industries by taking the help of forest department by next year.

The event not only improved the environment but also gave an aesthetic touch to the surroundings. He explained how the KSPCB has zeroed in on green initiatives to reduce their carbon footprint to save the environment.

Karnataka State Pollution Control Board (KSPCB) honorary chairman S. Sadashivakale called upon the industries to bring in a holistic change by adopting the latest available manufacturing techniques to conserve natural resources and reduce carbon dioxide emissions.

He was speaking after inaugurating an awareness programme on industrial ecology and eco-industrial networking organized as part of National Pollution Prevention Day at the Regional Museum of Natural History here on Thursday. The board is planning to plant more plants in and around industries by taking the help of forest department by next year.

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