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An optimized model for waste management using the concept of industrial symbiosis

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Abstract – *Managing of industrial waste is a challenging issue faced by many industries. Recovery, reuse and recycling of industrial residuals, often dismissed as wastes, are common in industrialized countries due to lower associated costs. In this paper alternative waste management models are developed using the principles of industrial symbiosis for effective management of waste in a pipe manufacturing company so that by-products can be reused for different processes in industry. Cost benefit analysis of different models is done and optimum model is identified for implementation.*

I. Introduction

Waste, by definition, is something that the producer no longer needs and therefore discards. In many industrial economies, the traditional approach to waste has been to dispose of it as cheaply as possible, without much concern as to what happens once the waste leaves the producer's premises. This attitude is now changing as greater environmental awareness is reflected in more stringent waste management legislation and a genuine desire on the part of industry to improve environmental performance and meet customers' expectations.
The environmental risks associated with poor waste management are well known and understood. For example, poorly planned and managed landfills will create a significant neighbourhood nuisance, and where landfill gas and leachate are not properly treated there will be a serious threat to the safety of local residents. Old, closed dumps and landfills are likely to be contaminated land which may be difficult or dangerous to remediate and redevelop. Even improperly managed recycling and composting facilities can be a source of serious air, water and soil pollution. Waste producers carry their share of responsibility to guarantee that such polluting incidents do not occur. What is often overlooked by manufacturers is that waste is not only a potential source of environmental damage, but also represents a waste of their resources – raw materials, energy, water, etc. These wastage of resources will lead to increase in manufacturing costs and reduction of their profit. Here comes the importance of the waste management as it helps to manage the waste with reduced environmental impact and better profitability. There is a Waste Hierarchy available for the management options and this seeks to rank waste management options. The waste hierarchy mainly consist 6 levels with prevention, minimization or reduction, reuse, recycling, energy recovery and landfill. Waste producers are urged to "move their wastes up the hierarchy", for example by recycling instead of landfilling. Some governments have introduced economic instruments, such as taxes on landfill and incineration, to help facilitate this movement. By reducing, reusing and recycling waste, manufacturers can cut costs considerably, create a cleaner and safer working environment and perhaps even improve the quality and safety of their product.

The concepts of industrial symbiosis can be used while designing waste management models for manufacturing facilities. Industrial symbiosis (IS) describes a relationship between two or more firms where the unwanted by-products of one firm are used as a resource by another (Graedel & Allenby, 2010). It mimics biological systems by using by-products of the industrial metabolismwhich would otherwise be discarded as waste as useful resources for other firms. The focus on product and resource recycling and reuse helps to create closed loop systems which produce less waste and require fewer inputs of natural resources and energy.

Recovery, reuse and recycling of industrial residuals, often dismissed as wastes, are common in India and other industrializing countries largely due to lower associated costs. Some wastes are reused within the facility where they are generated, others are reused directly by nearby industrial facilities, and some are recycled via the formal and informal recycling markets. Direct inter-firm reuse is the cornerstone of the phenomenon termed industrial symbiosis, where firms cooperate in the exchange of material and energy resources.

This paper focuses on a study conducted at a pipe manufacturing facility with considerable amount of waste generation. In current scenario the company is losing a significant amount of money due to this high amount of waste generation and its improper management. They are also landfilling a major part of the waste which can create environmental problems in the long run. In this case the complete prevention of waste generation is not possible because it is inherent to the manufacturing process. The direct minimization is also not economically feasible as it requires the replacement of machinery. So we have to focus on minimization with reuse and recycling opportunities.

The aim is to develop an optimized waste management model which helps to recover resources through reuse and recycling with reduced environmental impacts and increased economic benefits.

2. LITERATURE REVIEW

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 labour and other inputs for producing goods. India's formal manufacturing sector accounted for 16% of its GDP in 2006 [1]. There has been a significant rise in the export of these goods from 0.5% of world exports in 1980 to 0.9% in 2006 [1]. Thousands of small scale and bigger industrial units simply dump their waste, more often toxic and hazardous, in open spaces and nearby water sources. Over the last three decades, many cases of serious and permanent damage to environment by these industries have come to the fore. Rapid industrialization has resulted in the generation of huge quantity of wastes, both solid and liquid, in industrial sectors such as sugar, Plastic, pulp and paper, fruit and food processing, sago/starch, distilleries, dairies, tanneries, slaughterhouses, poultries, etc. Despite requirements for pollution control measures, these wastes are generally dumped on land or discharged into water bodies, without adequate treatment, and thus become a large source of environmental pollution and health hazard[3].

Management of Industrial Solid Waste (ISW) is not the responsibility of local bodies. Industries generating solid waste have to manage such waste by themselves and are required to seek authorizations from respective State Pollution Control Boards (SPCBs) under relevant rules. In most of the cases the rules works based of polluter pays principle and this forces the industries to formulate adequate waste management models to handle the waste generated [2].

The three R's are commonly used terms in waste management; they stand for "reduce, reuse, and recycle". As waste generation rates have risen, processing costs increased, and available landfill space decreased, the three R`s have become a central tenet in sustainable waste management efforts [7, 20, 22]. The concept of waste reduction, or waste minimization, involves redesigning products or changing societal patterns of consumption, use, and waste generation to prevent the creation of waste and minimize the toxicity of waste that is produced [12]. Reduction can also be achieved in many cases through reducing consumption of products, goods, and services. The most effective way to reduce waste is by not creating it in the first place, and so reduction is placed at the top of waste hierarchies [3]. In many instances, reduction can be achieved through the reuse of products. Efforts to take action to reduce waste before waste is actually produced can also be termed pre-cycling [14].

It is sometimes possible to use a product more than once in its same form for the same purpose; this is known as reuse. Examples include using single-sided paper for notes, reusing disposable shopping bags, or using boxes as storage containers [18]. Reusing products displaces the need to buy other products thus preventing the generation of waste. Minimizing waste through reduction and reuse offers several advantages including: saving the use of natural resources to form new products and the wastes produced in the manufacturing processes; reducing waste generated from product disposal; and reducing costs associated with waste disposal [3]. Not all waste products can be displaced and even reusable products will eventually need to be replaced. It is inevitable that waste will be created as a by-product of daily human living [19], but in many cases it is possible for this waste to be diverted and recycled into valuable new materials. Glass, plastic and paper products are commonly collected and reformed into new materials and products. Recycling products offer many of the benefits of waste reduction efforts (displacing new material usage, reducing waste generated and the costs associated with disposal) but recycling requires energy and the input of some new materials, thus placing it lower on the waste hierarchy (Fig. 1) than reduction and reuse [18].

Fig. 1 - Waste Hierarchy

2.1 INDUSTRIAL SYMBIOSIS

In countries such as India, limited wealth and a large population contribute to resource scarcity, making thriftiness and reuse of materials common practices. As such, a high priority is placed on the recovery, reuse, and recycling of industrial process wastes that can cycle back into manufacturing processes. This is where the importance of concepts of industrial symbiosis comes in. Industrial symbiosis (IS) describes a relationship between two or more firms where the unwanted by-products of one firm are used as a resource by another [8]. Chertow defines IS as requiring a minimum of three separate entities exchanging at least two different resources. This definition differs significantly in that it does not recognize one-way linear exchanges as examples of IS [16].

Industrial symbiosis mimics biological systems by using by-products of the industrial metabolism which would otherwise be discarded as waste as useful resources for other firms. The focus on product and resource recycling and reuse helps to create closed loop systems which produce less waste and require fewer inputs of natural resources and energy. There are five different categories of industrial symbiosis (Table 1) which are classified according to the spatial scale of the relationships of the firms involved, or the nature of the products being exchanged [8].

Category 1	Occurs through waste exchanges where recovered materials are sold or donated to another firm.
Category 2	Involves the exchange of materials within a single facility, firm or organization, but between different processes.
Category 3	Co-located firms in a defined industrial area exchange materials and resources
Category 4	Firms in relative proximity to each other engage in the exchange of materials and resources
Category 5	Firms organized across a broad spatial region exchange materials and resources

Table 1 - The five categories of industrial symbiosis

In the IS context, production processes exchanging wastes for primary inputs correspond to natural organisms exchanging resources for services. Two production processes, A and B, implement a symbiotic relationship when at least one waste produced by the former is used to replace at least one primary input required by the latter [7]. In such a case, the process B receives one resource (waste) from process A in return for a service provided (B is disposing wastes for A). Accordingly, IS can be conceptualized as a form of mutualistic symbiosis, since the relationship provides both the processes with environmental and economic benefits. In particular, from the environmental point of view, the amount of wastes disposed of in the landfill is reduced for process A, whereas the amount of primary inputs purchased from conventional sources is reduced for process B. Moreover, from the economical point of view, process A benefits from reduction in waste disposal costs whereas process B benefits from reduction in primary input purchase costs [4].
Literature has addressed the IS approach from technical, economical, and social point of view.
Two different cases of IS relationships can be recognized from the technical point of view: i) pure substitution between waste and primary input; ii) impure substitution between waste and primary input. Pure substitution occurs if a waste can be directly used in place of a primary input without any treatment process (Fig. 2a). In the case of impure substitution, wastes need to be treated before being used as inputs, i.e. some physical-chemical characteristics of the wastes have to be changed [7]. Hence, treatment processes making wastes suitable to be used as primary inputs have to be introduced. In carrying out this treatment, such processes may require additional primary inputs and energy and may generate additional wastes, in turn generating environmental impact (Fig. 2b). However, the waste exchange is considered an IS process only if such an additional environmental impact is lower than the avoided one due to symbiotic exchange.
Hence, although the need to treat wastes, the overall environmental benefits of IS relationships are positive

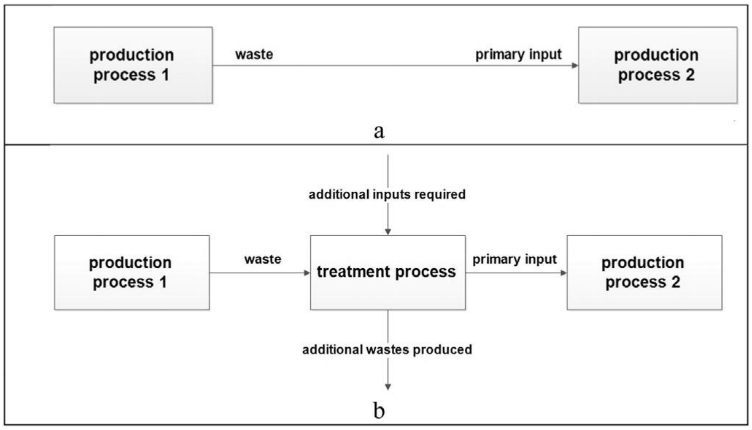

Fig. 2- IS relationship with pure substitution between wastes and primary input (a) and IS relationship with impure substitution between wastes and primary input (b)

3. WASTE MANAGEMENT MODELS USING THE CONCEPT OF INDUSTRIAL SYMBIOSIS

The concepts of industrial symbiosis is very useful while developing waste management models. In most of cases we can reuse some part of the waste either through pure substitution or impure substitution. In the case of pure substitution there is no additional treatment required to the waste before using it as an input to another process on other hand in the case of impure substitution additional treatment is required to the waste before using it as an input. We only consider IS models with positive environmental benefits so the models developed with the concepts of IS will be always environmentally feasible

Looking in-depth into technical production efficiency of IS models, When IS is implemented among processes belonging to an industrial system, the amount of wastes disposed of in the landfill as well as of inputs purchased from outside may be reduced. In such a case, some performance of the system can be enhanced. Let us consider an industrial system composed by two production processes, A and B. For the sake of simplicity, let us assume that each process produces only one output (O(A) and O(B), respectively), requiring only one primary input (I(A) and I(B)) and producing only one waste (W(A) and W(B)) (Fig. 3).

Let us assume that the system is perfectly efficient from technical point of view, i.e. that no inputs or wastes can be reduced at equal produced output (technical production efficiency of the system is equal to one). In particular, the amount of I(A) required and W(A) generated are directly proportional to the amount of O(A) produced. Similarly, the amount of I(B) required and W(B) generated are directly proportional to amount of O(B) produced. In such a system, there is no substitutability among productive factors, i.e. the current combination of required inputs and produced wastes is the only one able to produce the current amount of outputs. Hence, the efficient production frontier is composed by only one point, denoting the current status of the system in the space Fig.3 (the number of dimensions is equal to the total number of inputs required and wastes produced by the system). Let us assume now that feasibility conditions to replace I(B) with W(A) arise. Moreover, let us assume that one unit of W(A) is technically able to replace T units of I(B). Hence, Q units of waste produced by process A can be potentially used to replace TxQ units of input required by process B (Fig. 3b).

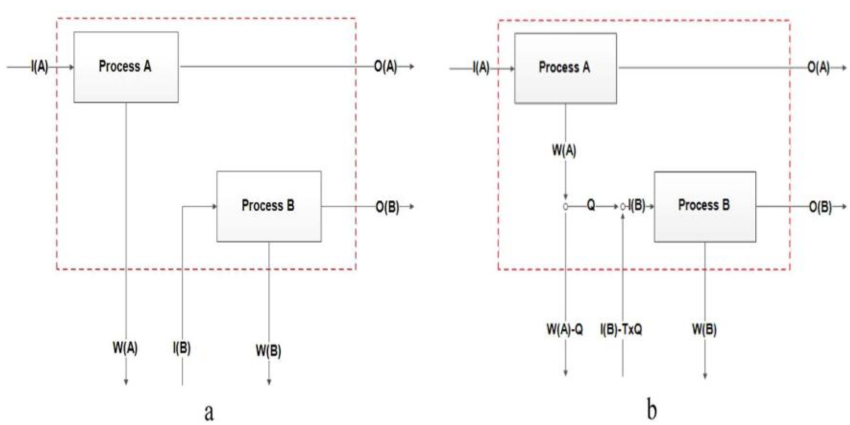

Fig. 3 - Industrial system composed by two production processes, when IS does not occur (a) and when IS occurs (b).

From the Figure (Fig. 3) if we consider the process A and process B as a single system the total input given to the system was I(A)+I(B) and the total output from the system was O(A)+O(B) for the system without industrial symbiosis (Fig. 3a). After implementing IS exchanges between process A and B the required amount of input is reduced to I(A)+I(B)- TxQ for the same amount of output O(A)+O(B). So it is clear that in the case of pure substitution the IS models are technically efficient. In the case of impure substitution we have to compare the reduction in required input for the process B with additional input requirements for the waste treatment process. If we look in to the environmental benefits, In firstsystem without industrial symbiosis (Fig. 5a) the amount of waste that have to be landfilled was W(A)+W(B) but when we consider the system with IS exchanges it is reduced to W(A)-Q+W(B).From this we can infer that in the case of pure substitution the IS models always have positive environmental benefits. But In the case of impure substitution comparisons should be done between the additional wastes generated during treatment and the total amount of waste that have to be landfilled. From the economical point of view the pure substitution is always profitable as it reduces the utilization of raw materials. On other hand in the case of impure substitution detailed economic analysis has to be done to calculate the cost and benefits of the IS exchanges because it requires resources like labour, machinery, Electricity etc. for the treatment process.

4. CASE STUDY

This study was conducted at a PVC pipe manufacturing company located in Kollam district of Kerala state. The company produces PVC water pipes, Conduit pipes and pipe fitting. There was a considerable amount of waste generation due to the nature of the process and management of the waste was one of the big problems faced by the company for a long time. It is found that a major portion of the waste is dumped to the backyard of the company. In long run this will definitely create environmental problems. Even though PVC is considered as a non-hazardous industrial waste studies from the literature review shows that it can create serious environmental problems like soil pollution and ground water contamination if improperly landfilled. More over the company is losing a considerable amount of money due to improper waste management. So the aim was to develop a waste management model that can minimize environmental impact and also economically beneficial for the company

4.1. DATA COLLECTION

The data about the amount of waste that is getting generated in the company was collected and it is found that around 10% of their total production gets converted into waste (Fig. 4)

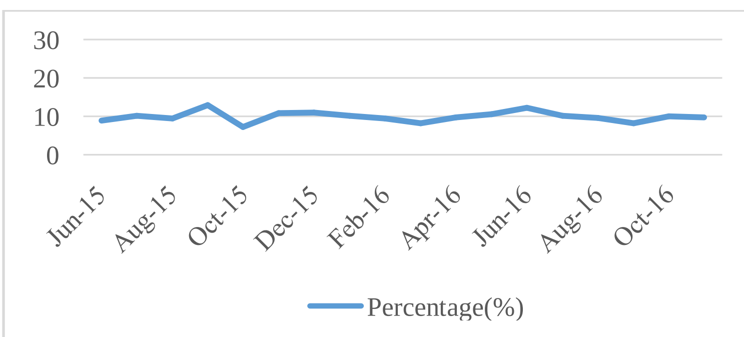

Fig. 4- Percentage of waste generated

From the initial data collection it is identified that there are manly 3 types of waste is generated within the company. They are

- Water pipe waste (Wp Waste)
- Conduit pipe waste (Cp waste)
- Flushing compound waste (Fc Waste)

Data about the quantity of these 3 wastes are collected and the results are as shown in figure (Fig. 5)

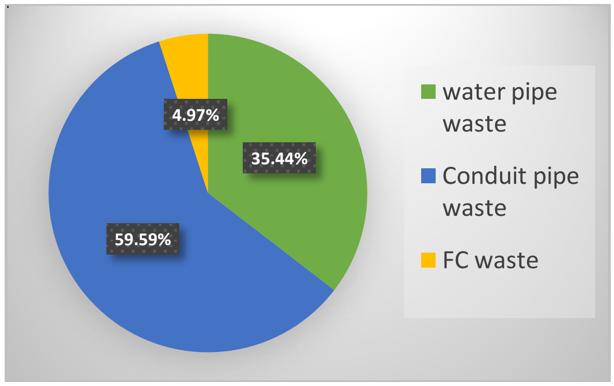

Fig. 5- Percentage contribution of different type of waste generated to total waste generated

4.2. MODEL BUILDING AND ANALYSIS

The main advantage of first stage PVC wastes are they can be recycled completely recycled and can be used for raw materials for other products. The different alternative methods which can be used to recycle and reuse the PVC wastes are identified and using this a total of 12 EIO (Enterprise Input Output) models ware developed. As we aim to reduce environmental impact of the waste disposal we should only considered the models with positive environmental benefits. So using the concept of industrial symbiosis we have eliminated 5 models with landfilling option. This step is to ensure that all of the models will be environmentally feasible

4.3 COST BENEFIT ANALYSIS

After eliminating the models with negative environmental benefits to find a better model in terms of economic aspects a cost benefit analysis is conducted. For this the first model (Fig. 6) is set as basis for the comparison

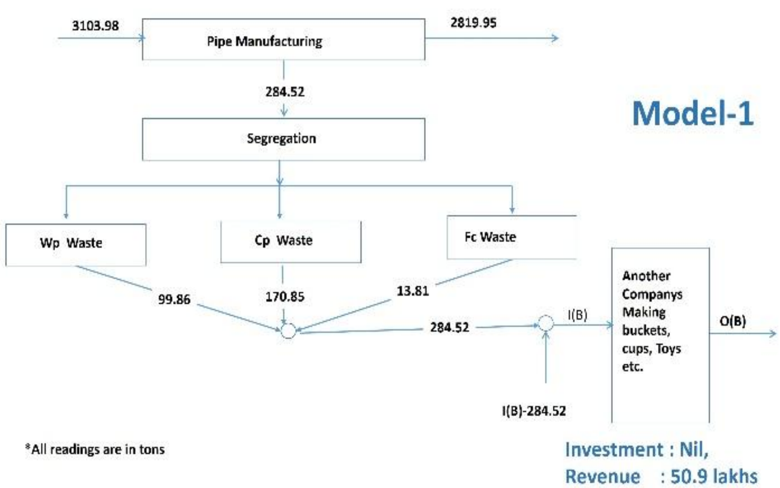

Fig. 6- Model 1

This is because the basic model does not require any fixed investment as in this model the waste is directly selling outside without any treatment. So from the point of view of the company it is a pure substitution case of IS exchange. For the cost benefit analysis this paper uses DPP (Discounted Payback Period) method as normal payback period does not considers the time value of money.DPP of all 6 models with respect to the first model is calculated using following equations.

$$\text{Discounted Cash Inflow} = \frac{\text{Actual Cash Inflow}}{(1 + i)^n}$$

$$\text{Discounted Payback Period} = A + \frac{B}{C}$$

Where,

A = Last period with a negative discounted cumulative cash flow

B = Absolute value of discounted cumulative cash flow at the end of the period A
C = Discounted cash flow during the period after A
The results of the DPP calculations for different models are as shown in table 2

Model Name	Description	Discounted Payback Period (years)
Model 1	Sell the waste outside without any treatment	NIL
Model 2	Segregate - crush - sell outside	4.21
Model 3	Segregate – grind - use as raw material remaining sell outside	4.01
Model 4	Segregate – grind - use as raw material - crush and sell outside	2.58
Model 5	Segregate - Bend remaining sell outside	2.8
Model 6	Segregate - Bend remaining crush and sell outside	2.06
Model 7	Segregate – Bend – Grind – Use as raw material- remaining crush and sell outside	1.32

Table 2- DPP of different models with respect to the first one

4.4. RESULTS

Frome the cost benefit analysis it is evident that model 7 (Fig. 7) is better in terms of returns to the company.

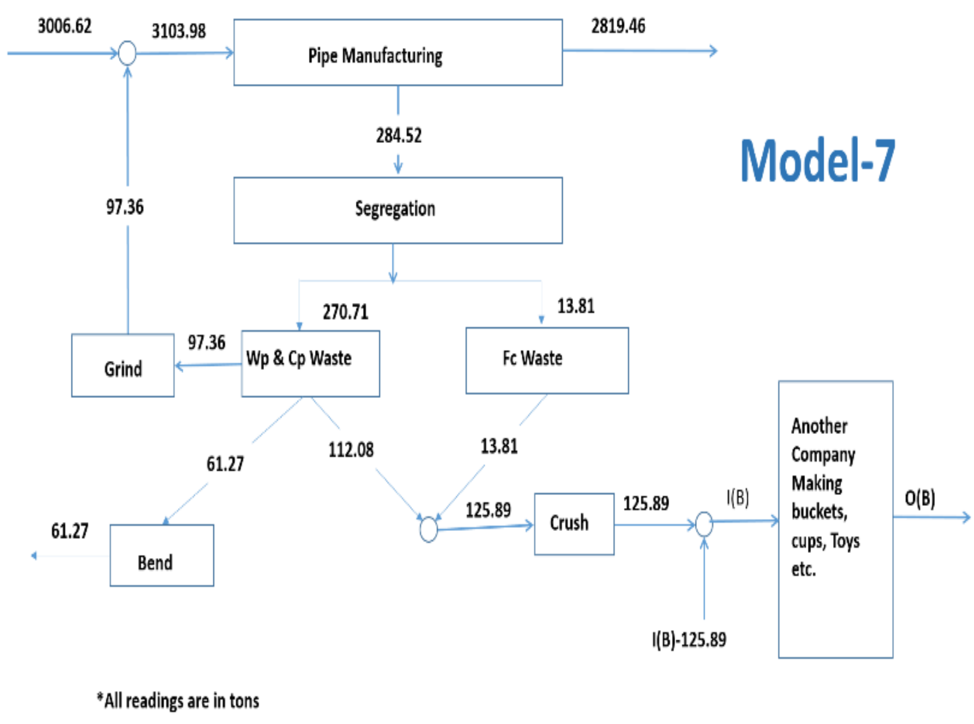

Fig. 6- Model 7

The model does not have any IS exchanges with landfill so the model also has positive environmental benefits. Using this model company can save 97.36 tons of raw material as well as it can produce about 61.27 tons of bend per year from the waste itself. This model can also save 125.89 tons of raw materials used by other companies in the IS network the details about different costs and revenues from this model is as shown in table 3.

Particulars	Value in Rs./year
Total Fixed investment for 1st year	68.46 lakh
Variable cost per year	39.52 lakh
Current revenue	50.9 lakh
Total revenue	127.15 lakh
Additional revenue	76.1 lakh
Cash inflow per year	36.58 lakh

Table 3- Costs and revenue details for Model 7

As we can see from the results even though the models requires a fixed investment of 68.46 lakh it was able to generate an additional revenue of 127.15 lakh which results in 36.58 lakh of additional cash inflow per year. The model has a DPP of 1.32 years that means it can return the fixed investment in just 1.32 years. This makes this model beneficial for the company from an economical point of view.

5. CONCLUSION

From the results of the case study we can conclude that Optimized models for waste management can be developed with the concept of industrial symbiosis. Properly designed IS exchanges between the processeswill help the systems to work with increased technical and economic efficiency as well as with positive environmental benefits it reduces the amount of waste that have to be landfilled and incinerated by reusing and recycling. It also reduces the wastage of resources like raw materials, machine hours etc. and thus by saving manufactures money. To facilitate the IS exchanges between companies a proper IS network should be designed. The IS networks can be designed and implemented easily in industrial parks to make them more eco-friendly. Every time pure substitution will not work but the results of our study shows that even with impure substitution the IS exchanges can be profitable. To maintain proper waste management it is necessary to developCollaborative waste management practices between related companies and governments should be able to guide and supportthese efforts.

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