A new paradigm for waste management

G.P.J. Dijkema a,*, M.A. Reuter b, E.V. Verhoef c

aDelft University of Technology, Department of Technology, Policy and Management, Jaffalaan 5, 2628 BX Delft, The Netherlands
bDelft University of Technology, Department of Earth Sciences, Mijnbouwstraat 120, 2628 RX Delft, The Netherlands
cDelft University of Technology, DIOC Infrastructures, Rotterdameweg 145, 2628 AL Delft, The Netherlands

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Abstract

The concept ‘waste’ was assessed, and redefined as ‘an emerged quality of a substance’. A substance or object is qualified as waste when it is not used to its full potential. Under this paradigm, any process can be used for the transformation of waste to remove this quality label, and the necessity of a systemic approach to the resource and waste management becomes obvious. Any substance, labelled waste or resource, is part of at least one material cycle. Material cycle modelling provides a convenient method of abstraction to present the system alternatives to decision-makers and emphasises the interdependence between the availability and fate of all atomic elements in primary production and waste management. The rearrangement and closing of material cycles, for example, opens the way to eliminate landfills of harmful residues and contributes to the conservation of resources. While the adoption of the new paradigm may lead to dramatic technological development, the consideration, appreciation and adoption of such integrated resource and waste systems by decision-makers must be adequately supported by the apt supply of accessible information on system structure, technology options and effects. To determine the scope of the decision support tool, four images of 2030’s waste infrastructure were constructed. Public awareness and attitude were identified as the main parameters that determine the future context, apart from technological development, resource scarcity and final abatement of waste processing residues. © 2000 Elsevier Science Ltd. All rights reserved.

1. Introduction

Generally once a week, household waste is collected in every municipality in Europe and transported to some waste processing facility or landfill-site. Usually, these activities are the responsibility of the community authorities, and the general public expects that processing and possibly landfill occurs responsibly under the existing legal framework. As a consequence, a local tax is levied to balance the public expenses incurred. Companies that generate industrial waste also expect proper processing after they have paid some fee to a privately owned waste management company, or when the public authorities levy a special tax. In both cases, the service ‘waste abatement’ is considered to be a public good that must be available to all on equal terms. Definitions of ‘infrastructure’ usually refer to the underlying foundation or framework of basic services, facilities and institutions, which is the foundation for growth and development of an area, community or a system [1]. Waste management is one of the public infrastructures that are based on a specific type of physical infrastructure to provide the goods or services, and in this respect it resembles the electricity, natural gas, and water sector.

An important similarity between the waste management sector and the other infrastructures is that this sector is also in transition. Firstly, it is changing from a completely publicly owned sector to a public-private sector where privately owned companies carry out increasingly larger parts. Secondly, its orientation and scale-of-operations is shifting from strictly regional or national to a truly international setting. As a consequence, decision-making on the design and management becomes increasingly complex. Meanwhile, environmental policy and sustainability demand for a continuous, if not dramatic improvement. We therefore seek to develop a decision-support-tool for the public and private sector alike to assist in the visualisation, understanding and evaluation of future waste infrastructure.

* Corresponding author. Tel.: +31-15-278-4839; fax: +31-15-278-3422.
E-mail address: g.p.j.dijkema@bpm.tudelft.nl (G.P.J. Dijkema).
In order to arrive at a some functional specification for such a tool, and to formulate related research objectives, we have (1) rethought the concept of waste, (2) assessed waste management technology, (3) technology and system development, (4) use material cycles as a concept for system modelling, (5) by means of a scenario-workshop constructed images of future waste infrastructure, (6) and addressed decision-making on waste infrastructure. Finally, conclusions have been drawn.

2. A new paradigm for waste management

‘Waste’ commonly has a negative connotation: one thinks of garbage, rubbish, or maybe even dangerous or toxic material. Waste is a substance that one would like to dispose of, and one is prepared to pay some fee for the service. Apart from household garbage, there are many substances and objects that are considered to be waste, particularly in the process industry and manufacturing business. A substance, however, is a waste only when it is experienced as or labelled as waste. A producer, for example, may consider unwanted by-products ‘prompt scrap’ or ‘production waste’, whilst others regard these a potential resource. Waste is a subjective concept, or rather a qualification of a particular substance or object, which does not vanish after disposal. The qualification, however, may change: what is considered waste today, can be a resource in the future. A more strategic notion, therefore, is that a substance or object is qualified as waste when it is not used to its full potential. Under this paradigm, any production process can be used for the transformation of waste, which vastly increases the alternatives for system design. In networks of industrial plants the waste of one plant can be the feedstock of another. Normally, in a transaction that concerns by-products neither of the two parties involved considers the substance flow a waste. If, however, the receiving party terminates its activity, the producer would immediately experience problems in disposing its by-products, and the substance would then be qualified as a waste product. Waste, therefore, is an emerged quality of a substance or object. Subsequent processing of any waste material causes the emerged quality to submerge again.

3. Waste management technology

A typical waste management system comprises collection, transportation, pre-treatment, processing, and final abatement of residues. Various types of waste can be collected separately (Fig. 1). Transport can be to some local or regional pre-treatment facility, or directly to some regional or national processing facility, such as a waste incineration plant. Local or regional pre-treatment may include compressing, sorting, separation, drying, storage and so on. Today, waste processing often yields some valuable product, such as electricity, compost or synthetic crude oil [2]. Unavoidably, however, part of the waste yields residue, which more often than not must be classified ‘hazardous waste’. Additional processing before final disposal of such residues is often mandatory, and transportation or handling restrictions may apply.

In this context, waste management has been dominated by linear thinking: waste is an inevitable end product that has to be disposed of in such a manner that the impacts on the environment are minimised.

4. Technology development

Technology development for waste management has largely been focused on the transformation of particular types of waste. The Dutch Waste Management Council (AOO), for example, has presented a selection of promising waste disposal techniques (Table 1) [3].

Such a listing convey two messages to policy-makers:

1. Waste is an inevitable end product of industrial activities and consumption
2. One can rest assured that a lot is already being done

While the list appears to be rather extensive, it is of course far from complete, as in the selection presented two criteria were used:

- the techniques (are expected to) achieve improved performance compared to present waste disposal techniques (quality of emissions, residues, costs, and process reliability)
- the techniques will be commercially applicable within the next 10 years.

The major categories are the options found for combustible waste, non-combustible waste, etc. This illustrates the focus on single technologies rather than waste management systems. As a consequence, usually one waste problem is solved at a time, and more often than not a new waste problem emerges, because most treatment techniques yield residues. A municipal waste incinerator, for example, produces flue dusts that contain Zn, Pb, Hg, Cd, Na, and K, etc., which poses a problem. A similar situation exists in recycling technology, where recycling systems only have recently emerged. We conjecture therefore that a great many opportunities are yet to be explored in technology development for waste management. At present, integral resource management, for example, is addressed almost exclusively by academics (e.g. [4]), while in policy development waste management per se prevails.
Fig. 1. A typical waste management system: collection of organic waste (GFT), municipal solid waste (MSW), and mixed plastic waste (MPW); other waste streams (Waste X).

### Table 1

Selected waste disposal techniques [3]

<table>
<thead>
<tr>
<th>Waste stream</th>
<th>Waste disposal technique</th>
<th>Costs (remarks)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Combustible wastes</strong></td>
<td>Roaster incineration</td>
<td>F 225,-/ton (quality ashes)</td>
</tr>
<tr>
<td></td>
<td>Fluid bed incineration</td>
<td>F ??,-/ton (limited scope waste)</td>
</tr>
<tr>
<td></td>
<td>Pyrolysis-incineration</td>
<td>F 300,-/ton, (quality of ashes, reliability)</td>
</tr>
<tr>
<td></td>
<td>Pyrolysis-gasification</td>
<td>F 270–300,-/ton (reliability)</td>
</tr>
<tr>
<td></td>
<td>Separation–composting–incineration</td>
<td>F 250,-/ton (applicability streams)</td>
</tr>
<tr>
<td></td>
<td>(Wet and dry) separation–digesting–incineration</td>
<td>F 250,-/ton (wet)</td>
</tr>
<tr>
<td></td>
<td>Separation–digesting–pyrolysis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Separation–digesting–gasification</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Separation–digesting–incinerization in a cement plant</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Selective separation–incineration</td>
<td>F 240,-/ton</td>
</tr>
<tr>
<td><strong>Non-combustible wastes</strong></td>
<td>Landfill</td>
<td>F 135,-/ton–&gt; F 175,-/ton</td>
</tr>
<tr>
<td><strong>Partially combustible waste streams</strong></td>
<td>Pyrolysis and co-incineration in a coal power plant</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pyrolysis and co-incineration in a powdered coal power plant</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Incineration in a fluid bed furnace</td>
<td>F ??,-/ton (quality ashes)</td>
</tr>
<tr>
<td></td>
<td>Gasification</td>
<td>F 30–40/ton (cleaning flue gas?)</td>
</tr>
<tr>
<td><strong>Plastics</strong></td>
<td>Gasification</td>
<td>F 300,-/ton costs</td>
</tr>
<tr>
<td></td>
<td>Feedstock Recycling</td>
<td>F 265,-/ton (200 + 210 t/a vacuum residue)</td>
</tr>
<tr>
<td><strong>Organic wastes</strong></td>
<td>Composting</td>
<td>F 100,-/ton</td>
</tr>
<tr>
<td></td>
<td>Digesting</td>
<td>F 120,-/ton</td>
</tr>
</tbody>
</table>
As stated above waste must only be considered an emerging attribute of a resource. This paradigm is not an entirely new one, as in many industries some processing of a waste becomes economically and ecologically feasible, and the substance or object previously labelled ‘waste’ changes into a ‘resource’. In the development of the petrochemical industry, for example, this has been an ongoing process. The production of ethylene out of naphtha, for example, can only be profitable if the other products of this cracking operation, notably propylene, C4s and aromatics, can also be sold at a reasonable price. The design and optimisation of naphtha crackers therefore is aimed at maximisation the yield of valuable products, while at the same time minimising the production of waste-gases that can only be used as fuel.

Once this paradigm is accepted, the necessity of an integrated resource system is obvious. It immediately follows that under this paradigm, waste management and production form a single system. If decisions are made on either of them, the consequences for the complete system must be visualised and taken into account. The new paradigm thus forms the foundation of a movement towards a cyclic economy that resembles the way nature’s ecosystems are build up: a network of integrated processes that form cycles. The holistic approach towards industrial ecosystems [5] and industrial ecology [6] use this analogy to capture and build upon it a strategy for sustainable development. We use the concept of material cycles to effectuate this strategy for a waste infrastructure.

5. Material cycles

The problem of continued resource availability and the abatement of waste processing residues requires radical rethinking of the way waste is treated. In order to stimulate a more symbiotic realisation of industrial activities and waste treatment, the waste management infrastructure must not be treated in isolation from the systems that generate waste. Rather the two must be combined in the concept of material cycles [4,7]. ‘Waste’ is considered an attribute only of a physical resource that is similar to the attribute ‘primary’ of other resources. Materials flow through production and waste management systems alike, cycles back and forth and forms the connection between industrial and waste management activities.

One of the waste infrastructure characteristics is that it deals with great many different entities, whereas all other infrastructures must only deal with a single principal entity (electricity, natural gas, water, and bytes). ‘Waste’ is really an aggregate term for a large variety of materials. Therefore it relates to the availability and fate of all atomic elements, which can be modelled as multiple interconnected material cycles, e.g. copper, zinc and tin.

The cycles of metals in industry already are complex. Most valuable metals are recycled, but usually to a lower grade. The recycling of steel, for example, is well known. At present, however, in the automobile industry steel corrosion-protection often is realised by galvanising it with zinc. Before recycling the metal to the oxysteel furnaces, the zinc must be removed; otherwise it would destroy the furnace. The by-product zinc finds its way to zinc producers, as well as the Zn-containing flue dust. The result is a coupling of the copper, zinc, tin and iron material cycles. Decisions on the exploitation of copper, therefore, can have a strong impact on the supply of zinc and tin, while vice versa recycling initiatives on copper influence the feasibility of new exploitation ventures. When one considers the complete network of systems that use primary and secondary resources (or waste), some problems in the management of material cycles that manifest themselves in the processing of waste actually can require a solution in the primary production system. In addition, both primary production and waste processing includes chemical transformations, additions, and physical separation. The concept of material cycles offers a convenient method of abstraction to model the broad spectrum of technologies involved, as the material cycles concept enables a shift in focus- from single linear technologies to interconnected systems.

The infrastructure design problem includes the selection between a great many technology alternatives for each part of a waste management system. A decision support tool allows visualisation of the effects of particular design decisions on the performance of the complete resource–waste infrastructure. One option indicated in Fig. 1, for example, is the combination or separation of facilities for collection and transport, local pre-treatment or processing. In addition, the material cycle approach offers a way to present ‘non-conventional’ technological options to decision-makers in the waste management sector. Finally, it serves to demonstrate that there exists a myriad of system configuration options (Table 2) when the selection of technologies or subsystems is considered a degree-of-freedom, as well as the creation of connection with the resource production system.

6. Images of 2030-waste infrastructures

Since the tool to be developed must support decision-makers in this context of infrastructure-in-transition, scenario techniques were used to construct four images of a future waste infrastructure (Table 3) and to establish important context parameters [8]. Garbage Land represents a society where environmental issues have no priority, while in a Green Archipel these are part of everyday life. A society that resembles the techno-dream image is completely confident that a technical solution can be engineered for any problem. Finally, in Opportunia problems and solutions come and go, and the people continue to behave opportunistically, no matter what happens.
The four images must be considered extreme realisations of the development of waste management infrastructure. Public awareness and attitude were identified as the main context-parameters. These influence the behaviour of individuals via ethics and social codes, e.g. with respect to consumption, the separation of waste, the acceptance of fees levied. Technology sets the scope for what is possible. By responding to technological development, resource scarcity, abatement toxic residues, etc., the public, however, determines both the context for technology and its continued acceptance. Information plays a pivotal role and largely influences decisions of individuals or organisations.

7. Waste infrastructure decision-making

The realisation of an integrated resource-waste management system can have unexpected consequences, and can present tough problems for decision-makers. In the pulp and paper industry, for example, Scandinavian countries are key players. Careful reforestation programmes are executed to sustain this production, and large pine forests are present in Norway, Sweden and Finland. These trees, however, need a long time to grow tall, whilst in a country such as Brazil, Eucalyptus trees grow approximately 30 m in only 7 years whilst providing good fibres for paper production. Brazil therefore appears to be an attractive location for a paper plant, both from an economic and from an ecological point of view. The forests in Scandinavia can then be reserved for timber production. In a global perspective, however, location of a pulp and paper plant in Norway operated on Brazil-Eucalyptus may represent the environmentally best solution, because of the presence of low-cost and environment-friendly energy (hydropower), the mandatory use of best available, clean technology, and strict enforcement of stringent environmental legislation. In contrast, transport costs and environmental impacts may prove to represent only a fraction of the total costs and impacts, respectively.

Complex systems often are represented by a configuration of subsystems at a single aggregation level, for
example complete facilities as depicted in Fig. 1. In decision-making on waste management systems, more often than not alternatives at this level are considered, where subsystems such as a separation facility are replaced 1:1 by another. Possibilities that are offered by the formation of new subsystems by rearranging their respective elements are not considered. A material-cycle approach can bring new incentives forward. In the base metal industry, for example, such an approach is starting to pay off, due to low metal prices! One primary zinc producer, for example, has terminated its end-of-pipe solution, forfeits 20% of its net zinc recovery. A by-product now remains, however, which is a feedstock to another zinc producer where, due to legislation, a move had been made from primary resource to 50% secondary material. Both companies benefit from the change in the overall system design, which was enabled by considering the complete material cycle, and by sharing resources the survival of both plants is ensured. More of such options become available when it is considered, to relocate parts of facilities, or to swap parts of the business. In the aluminium cycle, for example, the primary steps of extraction can be located at the mine, while some intermediate steps for the production of primary aluminium grades can be integrated with waste management systems, rather than designing a separate system for primary aluminium production and one for aluminium recycling.

8. Conclusions

Once the paradigm is accepted that waste is only a temporary attribute of a resource, the total current waste management system for a large part can be labelled an end-of-pipe system. In reality, the infrastructure design problem includes the selection between a great many technology alternatives for each part of a material cycle, be it primary production or waste management. The development of new technology will allow us to keep all metals and inorganic material in their respective material cycles. A decision support tool allows visualization of the effects of particular design decisions on the performance of the complete resource-waste infrastructure and must allow identification of ‘loose ends’, such as residues generated.

On a technical level, integrated resource management presents novel problems as to the modelling and visualization of complex, interconnected materials cycles. To implement prototype integrated resource systems, careful decision-making processes need to be designed in order to strike a balance between the interest of all parties involved. Scenarios for 2030’s waste infrastructure provide the scope for the decision support tool.

The material cycle approach offers a way to present ‘non-conventional’ technological options to decision-makers in the waste management sector, and it serves to demonstrate that there exists a myriad of system configuration options when the selection of technologies or subsystems is considered a degree-of-freedom, as well as the creation of connection with the resource production system.

The ultimate challenge in the construction of a support tool is to improve the decision process, which must be realised by the supply of information on system alternatives, and by the apt representation of the many opportunities for improved process system design in an integrated resource industry and waste infrastructure.

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References