Environmental Management Strategies

Towards Sets of Hazardous Waste Indicators

Essential Tools for Modern Industrial Management

Peter J. Peterson[1] and Åsa Granados[2]

[1]Institute for Environment and Development (LESTARI), Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor Darul Ehsan, Malaysia
[2]The Secretariat of the Basel Convention, Geneva Executive Centre, 15 Chemin des Anémones, 1219 Châtelaine (GE), Switzerland

Corresponding author: Professor Dr. Peter J. Peterson, Division of Life Sciences, King's College London, University of London, 150 Stamford Street, London SE1 8WA; e-mail: peter.peterson@virgin.net

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Abstract. Decision-makers require useful tools, such as indicators, to help them make environmentally sound decisions leading to effective management of hazardous wastes. Four hazardous waste indicators are being tested for such a purpose by several countries within the Sustainable Development Indicator Programme of the United Nations Commission for Sustainable Development. However, these indicators only address the 'downstream' end-of-pipe industrial situation.

More creative thinking is clearly needed to develop a wider range of indicators that not only reflects all aspects of industrial production that generates hazardous waste but considers socio-economic implications of the waste as well. Sets of useful and innovative indicators are proposed that could be applied to the emerging paradigm shift away from conventional end-of-pipe management actions and towards preventive strategies that are being increasingly adopted by industry often in association with local and national governments. A methodological and conceptual framework for the development of a core-set of hazardous waste indicators has been developed. Some of the indicator sets outlined quantify preventive waste management strategies (including indicators for cleaner production, hazardous waste reduction/minimization and life cycle analysis), whilst other sets address proactive strategies (including changes in production and consumption patterns, eco-efficiency, eco-intensity and resource productivity). Indicators for quantifying transport of hazardous wastes are also described.

It was concluded that a number of the indicators proposed could now be usefully implemented as management tools using existing industrial and economic data. As cleaner production technologies and waste minimization approaches are more widely deployed, and industry integrates environmental concerns at all levels of decision-making, it is expected that the necessary data for construction of the remaining indicators will soon become available.

Keywords: Hazardous wastes; indicators; management tools; industrial management; transport

Introduction

During the 1970's and 1980's, nations around the world became increasingly aware of the multiple impacts of industrialized society on human health and the environment (Davis and Hyfantis 1993). In 1989, increasing environmental concerns, and illegal dumping of hazardous wastes in developing countries by producers from industrialized countries, led to the adoption of the 'Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal' (UNEP 1989). It entered into force in 1992 and presently 123 countries and the European Economic Community are parties to it. The third meeting of the Conference of the Parties in 1995 adopted a decision to enhance the protection afforded to developing countries by prohibiting transboundary movements of hazardous wastes from States listed in the Convention's Annex VII (mainly OECD countries) to States not listed in Annex VII (mainly developing countries). However, some have argued that the Basel measures are a restriction on the international transfer of hazardous wastes for environmental reasons (Kummer 1995) whilst others argue forcefully that such an export ban is in contravention of basic General Agreement on Tariffs and Trade (GATT) rules (Guevara 1999).

Chapter 20 of Agenda 21 that deals with the environmentally sound management of hazardous wastes, recommended four programme initiatives that nations should adopt for more effective waste management (UN 1993). The development of indicators as useful tools to convert hazardous waste data into information for management also offers a mechanism to evaluate and quantify implementation of the Agenda 21 recommendations (UN 1993). Since then several indicators have been proposed by the Secretariate of the Basel Convention to the Commission for Sustainable Development. Four have been recommended to nations for testing as Sustainable Development Indicators (SDIs) (UN 1997b). They follow a Driving force-State-Response (DSR) model that is similar to the Organisation for Economic Co-operation and Development (OECD) Pressure-State-Response (PSR) approach (OECD 1994). The indicators recommended are:

- Generation of hazardous wastes (tonnes/year), a Pressure Indicator;
- Imports/exports of hazardous wastes (tonnes/year), a State Indicator;
- Area of land contaminated by hazardous wastes (km^2), a State Indicator;
- Expenditure on hazardous waste treatment (US$/year), a Response Indicator.

These indicators are Descriptive Indicators, for they provide useful information on 'status and trends'. However, the emerging global hazardous waste management regime is much wider and more complex than can be evaluated by reporting only on these four indicators (Peterson 1996). A wide range of additional indicators, that could be developed especially to help quantify the impacts of disposal of hazardous wastes to the environment and to human health, has been proposed (Granados and Peterson 1999). Consequently, environmental, ecosystem and human health impact indicators are not included in the present paper.

Indicators provide a means of giving data added value by converting them into information for direct use by decision-makers. This means that many indicators can be developed based on their links with, or analysis of, current and future policy issues. Different policy approaches involving management of hazardous wastes forms the basis for the indicator framework proposed in this paper.

That additional and new indicators are required arises from the increasing obligations of many nations to adopt Sustainable Development (SD) as an integral part of economic policy development. Preventive waste management policies are one component of SD. Such topics include, for example, hazardous waste reduction, hazardous waste minimization and cleaner production. Indicators are therefore required not only to report on hazardous waste production 'down-stream' and end-of-pipe abatement results, but also towards a reformulation and re-design of products and processes i.e. the adoption of preventive strategies 'up-stream' (Peterson 1996).

This broader concept invokes a more integrated systemic approach to management of hazardous wastes and a re-orientation of the macro-economic driving mechanisms of material consumption. Changes in consumption and production patterns that optimize resource use and minimize environmental and human health impacts from production patterns and waste generation are becoming a major international issue (OECD 1997a, OECD 1999). Indeed such broad objectives were proposed in Chapter 4 of Agenda 21 (UN 1993).

This paper highlights several areas where key indicator development as part of the policy-making process could contribute to more effective management of hazardous wastes within a dynamic industrial framework. This initiative is in line with the recent decision of the 5th Meeting of the Conference of the parties to the Basel Convention (UNEP 1999), to explore the possibility of formally developing indicators of hazardous wastes, that could facilitate national and international decision-making. Such initiatives would be reported at its 6th Meeting in 2002.

Indicators for quantifying infectious hospital waste, radioactive waste, or wastes that arise from normal discharges from ships are not discussed, as they are covered by other international control systems. These include the MARPOL 73/78 Convention (IMO 1983), the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matters as Amended (1994), and the Code of Practice on the International Transboundary Movement of Radioactive Waste (IAEA 1990), and the Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management (IAEA 1997).

1 Identification of Hazardous Waste

Development of indicators to quantify and monitor hazardous waste management, including generation, movement and disposal, has to be based on accepted definitions of such waste. National definitions vary widely and nations accordingly monitor different types of waste in different ways and to a different extent to comply with the legal and regulatory framework of the nation (UN 1994). The terminology can include 'special wastes, 'scheduled wastes', 'listed wastes', 'dangerous wastes', 'wastes that are hard to dispose of', etc. The Basel Convention has not adopted a single definition of hazardous waste (UN 1997a). Rather the convention takes a broad view that there are 45 categories of waste that are presumed to be hazardous – 18 of them are waste streams and 27 other wastes that contain hazardous constituents. However, to be classified as hazardous, these categories of waste need to exhibit one or more hazardous characteristics. Because of the uncertainties of the definitions in the Convention, it has proved necessary to develop a list of wastes that are hazardous, and wastes that are not, subject to the Convention (SBC 1998).

What constitutes hazardous waste lies at the heart of nationally declared statistics. For example, the USA defines 450 materials as hazardous, Germany 85 and Japan a mere 8 out of 23,000 compounds in use (Jeraratnam 1994). In the European Community, 236 entries of hazardous wastes have been reported as complying with Annex III of the EC Directive on Hazardous Waste 91/689/EEC (Haigh 1996). Annex III of the Basel Convention includes the 13 hazardous characteristics used, and the criteria for developing the characteristics. These range from explosive, flammable liquids and solids through to toxic and ecotoxic substances (UNEP 1989).

Even within European Union country compilations of hazardous waste data may not be consistent. For example, Sweden and Portugal report statistical data based on EC regulations while Austria has yet to classify its hazardous waste under European regulations (SBC 1999). The UK has gone beyond the EC Directive on hazardous waste and Decision 94/904/EC which sets out an EC list of hazardous waste. They have set out criteria by which waste, not on the EC hazardous waste list but which possesses one or more of a limited number of hazardous waste properties, is also recorded as being hazardous. Germany, because of its adoption of recent legislation has not yet been able to relate quantities of hazardous waste generated under their National Acts with the Basel reporting requirements (SBC 1999).

The lack of standard classifications and definitions of hazardous waste in some countries coupled with the complexity of many waste streams and composition variation over time has exacerbated the problem of collecting reliable data. Nevertheless, governments, industrial waste producers and waste contractors are being encouraged to invest in the provision of information and data in order to comply with the environmentally sound management of hazardous wastes as called for in Agenda 21 (UN 1993). Not surprisingly, progress with the development of relevant indicators has been slow in some countries.

A further difficulty in the definition of what are hazardous wastes lies in the definition of 'waste', i.e. a material that has been discarded as worthless. However, the Basel Convention was drafted to cover two kinds of processes, that is, wastes for final disposal (i.e. 'useless' wastes), and wastes intended for recovery operations (i.e. secondary raw materials as 'useful' products). Indeed the single term 'disposal' includes both processes. Hazardous wastes, however, have a commercial value and can be considered as goods (Kummer 1995). If they are used for recycling they have a positive value, and if they are for disposal they have a negative economic value, i.e. the holder pays for their disposal

The establishment of indicators for quantifying hazardous wastes and associated issues within an organizational framework must therefore consider the four conventional hazardous waste indicators adopted by the CSD for testing, as well as the development of additional indicators that reflect all of the industrial production processes and concerns.

2 Sets of Hazardous Waste Indicators

For ease of description in this paper, hazardous waste indicators are grouped and developed within two conceptual policy subsets based either, on the traditional preventive hazardous waste management strategy, or the more recent proactive paradigm including changes in consumption and production patterns. The essential elements for indicator construction are arranged within a hierarchical step-wise framework that describes each of the two policy subsets (**Fig. 1**). The different concepts of pollution prevention and environmental and human health protection that have been adopted, or proposed, by industrial organizations, governments, the UN and OECD over the past several decades are shown in the figure. Each of the subsets starts with relatively simple voluntary actions and concludes with more complex integrated policy concepts.

Life Cycle Analysis (LCA) and recycling are placed on the border between the two subsets, for they can be seen as either, preventive (Section 2.1) or, proactive (Section 2.2) in concept. For ease of discussion they are presented in the Preventive Approach subset. Indicators that can be used to describe and evaluate the transport of hazardous wastes are

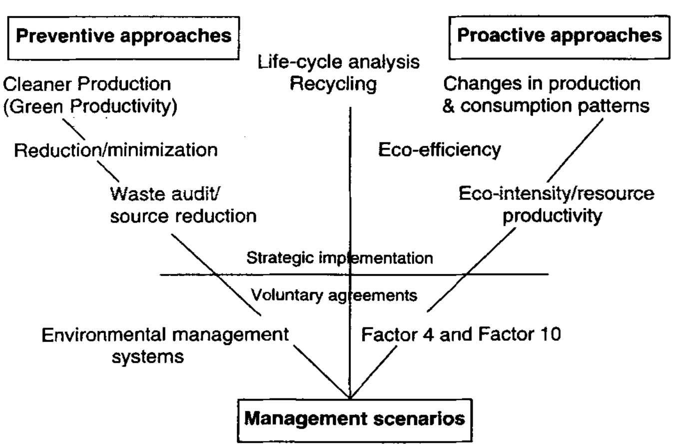

Fig. 1: Framework for selecting hazardous waste indicators within an industrial management action plan

described collectively in Section 2.3 as transport is involved to varying degrees in both the Preventive and Proactive approaches to hazardous waste management.

2.1 Preventive waste management

One of the most important new goals of technological policies within the last decade or two has been the shift towards prevention of releases of potentially hazardous materials into the environment (TSO 1998). Proponents of the precautionary principle approach, following its adoption as Principle 15 of the Rio Declaration on Environment and Development (UN 1993), stress the need for action to be taken in advance of establishing causal-links between releases of hazardous materials and observed harmful effects (Dethlefsen et al. 1993, Bro-Rasmussen 1999). Others argue that the precautionary principle is a controversial principle and has no place in science (Gray 1990). Irrespective of point of view, the adoption of the precautionary principle approach, with its potential for hazardous waste minimization, recycling, cleaner production etc. has been shown to be of economic benefit to a great many industries (Dorfman et al. 1993). It is clear that development of indicators will need to be an ongoing progressive process.

2.1.1 Environment management systems

Several self-regulatory (voluntary) codes of conduct, guidelines, principles, statements, policies, etc. have been advanced by industrial organizations that address hazardous waste issues and their environmental and health objectives. These include industry initiatives, e.g. the Chemical Industries Association Responsible Care®, third party initiatives, e.g. the International Organization for Standardization (ISO) series of environmental management standards, and the European Union's Eco-Management and Audit Scheme (EMAS) (ILO 1999).

The primary objective of Responsible Care® is to improve industry performance concerning the health and safety of employees, the community and the environment (Stevenson 1999). This has recently been extended to include product stewardship, a code of practice that takes into account all health, safety and environmental aspects of a product during its life-cycle. Another important recent initiative has been the development of a responsible care management system comparable with EMAS and the international environmental management standard, ISO 14000.

ISO 9001 as the lead quality management system standard, and ISO 14001 as the standard for environmental management systems, are being adopted world-wide. An indicator based on assignment of ISO 14001 to industries would provide a measure of how many industries are controlling their operations to particular voluntary quality standards. Indicators could also be used to describe the strengths and weaknesses in the organization's management, i.e. breaches of legislation, complaints, corrective actions completed, etc. However, the assignment of ISO 14001 is a reflection of good practice, it does not mean that the product is 'safe' and that the industry's environmental performance has actually been assessed (Krut and Gleckman 1998).

EMAS is the European Union's voluntary commitment scheme to provide recognition for companies that have established a programme of positive action to protect the environment (EC 1993). As with ISO 14001, EMAS has been criticized for insufficient attention being paid to ensuring environmental improvements. It should be noted that safety and health are not specifically included in EMAS and ISO 14001. They therefore contrast with the wider Responsible Care® programme.

In addition to the chemical industry initiatives and environmental management systems and standards, there are environmental agreements between national governments and industry. These latter agreements cover those commitments undertaken by firms and sector associations that are the result of negotiations with public authorities and/or explicitly recognized by authorities (EEA 1997). A useful example is the voluntary participation by industries in the U.S. Environmental Protection Agency's (EPA) 33/50 Program (EPA 1999). The overall aim being to reduce the releases and transfers of 17 toxic chemicals (using the Toxics Release Inventory) by 33% by 1992 and by 50% by 1995 compared with a 1988 base year. This approach identified the goals while letting industry determine the most effective route for reaching the goals. This approach has similarities with the Factor 4 and Factor 10 voluntary approaches discussed later in Section 2.2.

Voluntary agreements between companies and local/state/ national authorities in many countries, including energy efficiency have also been detailed (OECD 1997b, ILO 1999). These voluntary initiatives encourage companies to shift from hazardous waste treatment methods to cleaner production and other SD strategies. Indeed in all States of the European Union some environmental agreements have been concluded for hazardous wastes (Dröll 1998).

The setting of goals and targets and the development of indicators as policy tools to quantify goal attainment, following adoption of voluntary agreements, are further useful approaches. Voluntary goal attainment may be industry specific, medium-specific, or cross-sectoral. Indicators reflecting voluntary schemes include:

- Numbers of EMAS accredited enterprises (numbers/year, or as % of numbers of enterprises);
- Numbers of third-party verifications of EMAS accredited (numbers/year);
- Numbers of companies awarded ISO 14001 certification (numbers/year);
- Numbers of customers and suppliers along the supply chain (product stewardship) awarded ISO 14001 certificates (numbers/year, or as %);
- Numbers of companies certified by the U.S. EPA 33/50 program, (or as % of companies);
- Numbers of guidance documents produced relevant to voluntary industrial initiatives and best practices (number/enterprise/year);
- Numbers of training courses held relevant to voluntary industrial initiatives and best practices, (numbers held/ enterprise/year, or as numbers of applicants trained).

In all of the above mentioned indicator schemes, traditional hazardous waste indicators represent only one of the many types of output.

2.1.2 Waste audits and source reduction

Preventive actions can be seen as both a technological strategy and an economic one. Hazardous waste auditing involves especially a methodological examination of a facility's technological procedures and practices highlighting identification and quantification of all waste streams. In practice, economic resources may limit waste audits to a priority analysis of major streams by volume (Shen 1999). Nevertheless auditing is a precursor of hazardous waste reduction.

Hazardous waste audits again look inwards towards the production of waste as an activity-oriented goal. The audit may also evaluate how well the facility conforms with good environmental practice and how it complies with internal policies and legal requirements (ICC 1991). Indictors for other more specific audits, such as liability audits, energy audits, etc. although adopting standard methodology lie outside this paper.

Indicators that could be used to reflect hazardous waste audits include:

- Audit results on waste streams and generation points (characterization and quantification);
- Establishment of environmental effects of waste streams (site and impact);
- Strategies to prevent hazardous waste impacts being adopted following audits (numbers and outcomes/year);
- Input materials measured in hazardous waste streams (quantities and as % of waste stream);
- Establishment of hazardous waste streams that fall under environmental regulations (number and quantities);
- Compliance of waste stream discharge limits with present legislation (number of non-compliances and as %);
- Consistency of audit results with corporation goals (% of goal attainment);
- Costs of hazardous waste disposal ($ total and as % capital and operating costs).

2.1.3 Hazardous waste reduction and minimization

Various hazardous waste reduction and minimization approaches have been developed as efforts to 'prevent waste generation'. Hazardous waste reduction is the near-term practical option. It may be achieved through improved plant housekeeping and process control through a waste audit procedure (Feates and Barratt 1995, UNEP 1996) as discussed in the earlier Section. Current use of the term hazardous waste minimization on the other hand, includes any source reduction activity that results in reductions in total volumes or quantities of hazardous waste, or the reduction of toxicity of hazardous wastes, or both (UN 1994). Recycling is, strictly speaking, not a minimization technique but is often included for practical reasons (UNEP 1991). Consequently hazardous waste minimization is not the same as hazardous waste reduction.

A useful indicator that quantifies a reduction in hazardous waste releases has been reported by the UK Chemical Industries Association (CIA 1998). A 95% reduction in discharges of Red List Substances (27 substances and groups of substances of concern agreed at the series of North Sea Conferences) has been reported for 1997 (20 tonnes) compared with 1990 values. Another indicator that could reflect hazardous waste reduction, would report hazardous waste disposed of by method, rather than quantify hazardous wastes generated. In these cases the indicators, would be State Indicators, including:

- Discharges of Red List substances (tonnes/year);
- Hazardous waste disposed of by method (as tonnes/year, or %, to landfill, incineration, energy recovery etc.);
- Hazardous waste disposed of compared with the previous year (tonnes/year and as %).

More restricted sets of indicators related to disposal off-site arise from the CIAs UK list of indicators of performance (CIA 1998). The sets of indicators could be:

- Hazardous waste disposed off-site by method (as tonnes/year, or %, recycled, incinerated, for energy recovery etc.);
- Hazardous waste disposed off-site vs. on-site disposal (tonnes/year and as %);
- Costs of hazardous waste disposal off-site vs. on-site treatment costs ($).

Hazardous waste minimization is recognized by many organizations as good business practice for it reduces waste at source, re-uses materials in the production process and recovers and recycles waste rather than sending it to landfill. This is a much wider waste prevention policy than included within the short-term hazardous waste reduction approach. State Indicators for hazardous waste minimization could be:

- Hazardous waste *diverted* from waste disposal facility (tonnes/year or as %);
- Transport of hazardous waste *avoided* (tonnes/year or as %);
- Primary *recovery* of hazardous waste materials for reuse (tonnes/year or as %);
- Secondary *recovery* of hazardous waste materials for energy recovery (tonnes/year or as %).

This group of four indicators can be used to reflect differences in waste policies between related enterprises, that report comparable generation data, but where one enterprise recycles and the other does not. For example, differences between the enterprises would be easily seen by comparing the values for the indicators for 'hazardous waste generation' with those for 'primary recovery of hazardous material for re-use' and/or 'secondary recovery'. Furthermore, the enterprise(s) recycling hazardous waste could also attract further attention by reporting indicators that reflect 'amount of hazardous waste *diverted* from disposal' along with 'transportation of wastes *avoided*'. Economic indicators reporting 'cost savings could also be developed that would further distinguish between efficient and less-efficient enterprises.

Hazardous waste minimization indicators described above have emphasized the chemical, physical and environmental parameters associated with such wastes. But further relevant Performance Indicators can be established that reflect economic concerns. These could be used either singly, or in combination with other environmental indicators (Burritt 1996) but how such indicators can be developed has not received much attention.

Cost accounting for waste minimization includes not only the costs of waste handling and disposal, and process efficiency gains, but also indirect benefits such as market advantage of being perceived as an environmentally responsible organization (Girardi 1996). Measuring cost avoided by implementing waste minimization systems, such as avoiding future penalties for non-compliance with legislation and regulations and precautionary actions to avoid contingent liabilities arising from the need to remediate hazardous waste sites, provides tangible reasons for identifying such costs. Consequently, there is room for the development of financial indicators of performance of hazardous waste minimization. These could be called Operational Performance Indicators. Environmental Performance Indicators too could be used to illustrate and recognize the organization's environmental performance record, and Management Performance Indicators to evaluate its good business performance based on annual financial reports. Such comparative Performance Indicators could reflect an industry's competitive edge and could be used to further consolidate and extend their market position (Hölz 1999).

2.1.4 Cleaner production

The emphasis on prevention has encouraged new approaches to technological processes in industry characterized by the United Nations Environment Programme's (UNEP) Division of Technology, Industry and Economics Cleaner Production activities (UNEP 1994, 1998). Cleaner production can be described as the application of an integrated, preventive environmental strategy to processes and products in order to reduce risks to humans and the environment (Kummer 1995, UNEP 1996). It is more than just hazardous waste minimization. Cleaner production techniques, such as those promoted through the United Nations Industrial Development Organization (UNIDO) – UNEP National Cleaner Production Centres, include reducing the quantity and toxicity of hazardous wastes and emissions, and substituting for toxic and dangerous materials. In addition, one of the aims of cleaner production is to reduce the costs of raw materials and energy and thus make the process in question more attractive economically. Indeed, cleaner production has often been described as a profitable environmental management option.

The introduction of Cleaner Production activities into industrial processes calls for broad policy development irrespective of whether environmental protection or macro-economic policies aimed at SD are being implemented. Consequently, an indicator that reflects direct benefits to the organization, as well as efficiency gains, would reflect introduction of management strategies. Indicators could be developed that reflect a commitment to cleaner production concepts. These Response Indicators can reflect policy approaches: at private sector, government or international organization levels:

Private Sector

- Corporate policy development (e.g. numbers, or %, of organizations/industries adopting cleaner production programmes by sector);

- Operational performance outcomes (e.g. the number of organizations/industries modifying production processes to take into account public statements on environment, legal or social objectives);
- Accountability for hazardous waste management (e.g. numbers or organizations/industries identifying and accounting for hazardous waste disposal costs as a reflection of cultural change within the organization);

Government
- Number of new regulatory approaches adopted (e.g. introduction of legally binding reporting requirements for hazardous waste arisings);
- Number of cleaner production demonstration campaigns undertaken nationally;
- Number of cleaner production projects adopted and verified nationally;

International
- Establishment of cleaner production centres for strengthening national capabilities (e.g. numbers of cleaner production centres established nationally and internationally)
- Access to information on cleaner production (e.g. numbers of national electronic inventory/tracking and information systems developed at the national level);
- Training of people in cleaner production techniques (number/year).

This group of Response Indicators that can reflect hazardous waste policy approaches does not represent quantitative numbers for use by decision-makers for measuring progress towards meeting targets, or of use for regulatory controls. Rather they report on organizational 'score keeping'. They are in effect First Generation Response Indicators. Nevertheless this group of indicators can be useful, for the data are usually available and provide a local 'foot print' of organizational actions designed to meet public concerns.

The Green Productivity Programme, established by the Asian Productivity Organization in 1994 for countries in the region (APO 1999), embodies the major elements of the Cleaner Production Programme. It shifts the emphasis away from 'end-of-pipe' pollution control strategies to cost-effective preventive scenarios. Consequently the environmental management tools, techniques and technologies are similar. As the waste prevention and Green Productivity options are similar to those for the generic Cleaner Production Programme, no new indicators are described.

2.1.5 Life-cycle analysis

The life-cycle analysis (LCA) approach, defined by ISO 14040, takes a 'cradle-to-grave' perspective of a product's numerous steps from the inputs (raw material and fuel) to outputs (solid, liquid and gaseous releases) and final disposal, including assessments of both environmental and human health issues (Owens 1997). LCA is usually used interchangeably with life cycle assessment. The approach includes both an inventory component and an assessment, or interpretation of the inventory results. Consequently LCA can be considered as a preventive approach to hazardous waste management and is listed in Section 2.1. If the LCA also includes a future component, i.e. life-cycle improvement analysis, which would include changes in product, processes and activity design, consumer use, etc. then it could be considered in Section 2.2 of the paper dealing with proactive approaches. This is why LCA is located on the boundary between Sections 2.1 and 2.2 in Fig. 1.

As LCA covers a whole range of steps, a wide range of indicators can be considered. These can be used to reflect a product that is 'environmentally superior' using the LCA to compare and score overall environmental and human health impacts. Trade-offs would have to be analyzed and cost-benefit analysis undertaken. In essence, LCA indicators can be used for making relative comparisons between alternatives. However, comparisons between alternatives can only be properly compared if they perform identical functions i.e. production of the same product or 'like product' (Boustead and Chaffee 1998).

The value of the LCA is not just confined to overall comparisons between different technologies. It can be used to identify 'hot spots' in the production system where the impacts to the environment, or to human health, are especially significant. It can highlight the most important points at which to take action. The LCA in effect evaluates not only all of the emissions, or quantities of hazardous waste generated, but can be extended further to cover the whole material and energy supply chain associated with the industry, or product (Shen 1999). The LCA also recognizes the value of recyclability of hazardous waste materials as reflected in ISO 14041.

Performance Indicators that describe elements of the LCA could include:

Inputs
- Raw material extraction efficiency;
- Energy transfer efficiency for materials delivery and process steps;
- Energy utilization efficiency for materials processing and fabrication;
- Water use, recovery and reuse efficiency.

Products
- Raw materials use per product;
- Energy efficiency per production process (energy consumed/unit of product, or /unit of economic activity);
- Safety performance during manufacture;
- Recycling/re-use of product

Emissions/wastes
- Emissions from processes during manufacture;
- Hazardous waste arisings from each stage of production;
- Hazardous waste disposal by media;
- Transfrontier movement of hazardous wastes as % of production.

Costs
- $ cost of hazardous waste treatment/cost of industrial product/year;
- $ saved/kg hazardous waste reduced/year;
- $ saved/$ spent on changes to production processes/year;
- $ saved/industrial activity, or through-put/year;
- $ saved in reduced liability costs arising from reduction in hazardous waste generated.

It is important to mention that, irrespective of the indicator used to quantify emissions and hazardous wastes, a toxicity score is needed. This would include hazardous properties of the waste and as well as its possible effects on the environment and human health. The development of hazardous waste Impact Indicators that includes discussions of toxicity scores, has been discussed in an earlier publication (Granados and Peterson 1999).

2.2 Proactive approaches to hazardous waste management

Proactive approaches are not based on reactive preventive actions that focus on the identification and reduction of hazardous waste generation as discussed in Section 2.1. Rather, the approach moves further upstream from addressing the industrial process and its end-of-pipe concept to the 'prime' cause of hazardous waste, namely human demand. The proactive strategy therefore addresses changes in production and consumption patterns, resource productivity and including eco-intensity issues. It is therefore much more a socio-economic strategy rather than a technical one (Hirschhorn et al. 1993).

2.2.1 Factor 4 and Factor 10

Factor 4 and Factor 10 are two voluntary strategies aimed at improving national efficiency (Gee and Moll 1998). The starting point of the Factor 4 approach is that production of national resources can be economically improved by a factor of 4 in 20-30 years (Weizsäcker et al. 1997). Factor 10 on the other hand, is based on an estimation of by how much, industrialized countries should reduce carbon dioxide emissions and the use of materials in around 50 years, to reach SD. It really addresses the absolute use of nature (Factor 10 Club 1997). As Factor 4 and Factor 10 have as their aim to progressively improve national eco-efficiency no separate indicators have been proposed as eco-efficiency is discussed below.

2.2.2 Eco-intensity and resource productivity

Resource Productivity Indicators, or perhaps they are better described as Resource Efficiency Indicators include:

- Hazardous waste generation/unit of production (tonnes/m^3);
- Hazardous waste generation/unit of product/industry;
- Hazardous waste generation/unit of product/cost of goods;
- Hazardous waste generation/value of specific industry turnover.

None of the indicators mentioned, reflect toxicity of the hazardous waste, or its real impact on the environment, or other risks produced by the waste. Furthermore, the impact of the hazardous wastes generated may, by their intrinsic properties brought about by changes to the production processes, interact with different environmental media, or their relative weights may have changed.

Although useful indicators may well be developed, it will be difficult to analyze the elements associated with sustainably produced goods without further research and agreement on what measures to evaluate. Perhaps hazardous waste generated/selected product consumed/per capita could be a useful indicator to develop?

Quantifying the intensity of material use with economic data provides a further useful approach. This linking of accounting information with production processes (Girardi 1996) in its simplest form can be represented as:

$W_{HI} = W_H \div$ GNP per capita

Where

W_{HI} is the hazardous waste intensity
W_H is the amount of hazardous waste (tonnes)
GNP per capita is expressed as US$1,000 GNP

Clearly the primary aim must be to reduce the value of W_{HI}. Values for hazardous waste intensity for Japan, Australia, US, UK, Poland and Hungary have been reported as 0.6, 1.7, 6.6, 7.6, 20.7 and 21.6 (kg/US$1,000 GNP) respectively (Jackson 1993). Opportunities for a reduction in hazardous waste intensities exist in various developing countries. However, as changes in intensity can be influenced by either, economic activity or, hazardous waste production general conclusions are hard to make. These two factors are, nevertheless, amenable to technological influences.

More detailed indicators for reporting hazardous waste intensity can be developed using data for specific waste streams and costs associated with those wastes at a particular site rather than using country-wide GNP. Such actions can be expressed in monetary terms but it may not be possible to put a monetary value on other, equally important aspects such as regulatory compliance, and community relations (Feates and Barratt 1995).

Eco-intensity and its inverse, *resource productivity*, are the two generic indicators monitoring progress towards achieving 'more service outputs with less resource input' (Gee and Moll 1998). Thus:

Eco-intensity = use of nature ÷ welfare
Resource productivity = welfare ÷ use of nature

However, these are relative indicators that need to be supplemented by:

- *Absolute reductions* in resource flows which are necessary to remain with the carrying capacities of the earth;
- In addition *equitable access* to resources by current and future generations is required for SD.

Using the European Environment Agency's typology of indicators, Eco-intensity Indicators lie within Type C category, i.e. "are we improving" (Gee and Moll 1998). They can be constructed from two Descriptive Indicators (Type A). A Type C indicator for hazardous waste would be a combination of an Outputs Approach (i.e. hazardous waste generation) with the Process Approach (technology used). Examples would include:

- Hazardous waste generated/numbers of people exposed to the waste at landfill sites/year;
- Hazardous waste generated/output of goods/employee/year.
- Hazardous waste generated/energy input/product.

2.2.3 Eco-efficiency

Eco-efficiency is a strategy aimed at de-coupling resource use and pollutant release from economic activity (Gee and Moll 1998). It is attained by "the delivery of competitively-priced goods and services, that satisfy human needs and brings quality of life, while progressively reducing ecological impacts and resource intensity throughout the life cycle, to a level at least in line with the Earth's estimated carrying capacity" (WBCSD 1993). Its general idea is to 'produce more with less'. Eco-efficiency has been promoted by its originator, the World Business Council for Sustainable Development (Lehni 1998) and more recently by the OECD (OECD 1997a, Michaelis 1998). The OECD has stated that as much emphasis should be placed on improving resource efficiency as has been traditionally placed on improving labour productivity (OECD 1997a). Most of the eco-efficiency improvements proposed have been concerned with the input side. Eco-efficiency also depends on the value of the outputs as well, although it has received less attention.

Development of eco-efficiency indicators is designed to bring about innovation in human and corporate behaviour, changes to industrial technology including use of new materials, an absence of government subsidies, and new ways of thinking nationally and internationally. Eco-efficiency is a relative concept and sets itself no absolute targets. In the related Factor 4 and Factor 10 targets (discussed earlier), levels of emissions and wastes are used as decision criteria. The concept of eco-efficiency continues to evolve. It has recently been enlarged to include the social dimension, i.e. 'the production, delivery of competitively priced goods and services, coupled with the achievement of environmental and social goals (Planès and Sanches 1998). It is also being further enlarged to cover other fields as well, such as agriculture, services and governments (OECD 1997a). Eco-efficiency is then in reality a conceptual component of SD.

2.2.4 Resources and consumption clusters

Hazardous wastes are generated at all stages of human activities. Its composition and amount depends largely on production and consumption patterns. Chapter 4 of Agenda 21 recommended that in order to achieve sustainable production and consumption patterns, one of the major activities has to be 'managing the generation of wastes' (UN 1993). Policy-makers, therefore, are concerned with (1) indicators of resource use and environmental, health and social impacts, and (2) indicators that reflect consumer and producer choices (UN 1998). Such indicators concerned with the material balance approach complement the more traditional approaches to policy development (Adriaanse et al. 1997). In the first case, approaches to minimize change resulting from resource use predominate. But increasingly policy approaches are aimed at changing consumer demand and satisfying demand with less resource input and hazardous waste output. In effect changing not only materials use and manufacturing processes but also product design and the creation of totally new products and concepts. In addition, the decision to produce particular goods will be increasingly influenced by the disposal potential of the wastes produced (Pushchak and Rocha 1998).

In this newer paradigm, inventiveness and innovation for hazardous waste avoidance replaces material inputs as crucial ingredients to process development. The policy challenges have direct linkages to the promotion of SD. They include:

- To progressively dematerialize consumption, i.e. to reduce material use per capita;
- To decrease intensities of material use in production and consumption;
- To reduce the negative environmental and health effects of resource use;
- To decrease energy consumption per capita.

Indicators that reflect changes in production and consumption patterns are wider than the concept of eco-efficiency (mentioned earlier) for eco-efficiency does not offer a sufficiently comprehensive framework for the determination of which consumption trends are unsustainable and how changing these trends can best be managed (OECD 1997a).

Indicators for monitoring trends in consumption and production patterns are becoming increasingly important in the policy-making process (UN 1998). However, much work is needed on the development and policy relevance of such indicators especially in terms of hazardous waste management. On the consumption side, indicators could, for example, report:

- Market share of more sustainably produced goods and services (%);
- Total 'material requirement' of an industrial sector (annual flows/capita);
- Reduction in materials use (tonnes/capita/year).

Similarly, policies that encourage the transfer of environmentally sound technologies to developing countries and indicators that quantify such a process, are also important. In terms of hazardous waste management, further indicators could reflect:

- Material input flows avoided through changes to material use (recycling, re-use, re-build);
- Hazardous wastes avoided through adoption of 'environmentally friendly' industrial processes;
- Hazardous waste generation as % of market share of more sustainably produced goods and services.

2.3 Transport of hazardous wastes

Transportation of hazardous wastes is relevant to both the preventive and proactive approaches. Hazardous wastes may be treated or stored on-site. More likely it will be transported to off-site locations for storage, or as part of a waste exchange process, or for treatment by local/national facilities, or exported/imported, or disposed to landfill, or dumped illegally, or incinerated for energy recovery, or for non-calorific reasons (SBC 1998). Indicators for off-site handling by commercial waste hauliers and disposers, relate especially to the requirement for environmental and human health protection arising from collection, transport, treatment, storage and disposal. All of these transport-related issues are especially sensitive politically and raise substantial public reaction.

Indicator groupings that can help quantify control of hazardous waste movements include:

- Trade and transboundary movements of hazardous waste for treatment, recovery, recycling, disposal (tonnes/year);
- Hazardous waste transported by mode of transport (tonnes/km);
- Net hazardous waste transported for off-site disposal (after on-site treatment, recycling etc.);
- Hazardous waste trade balance (import/export as tonnes/year);
- Costs of transporting wastes off-site and legal liability ($);
- Operating costs for waste handling and disposal ($);
- National registration/licencing systems developed to report and quantify transport of hazardous wastes (numbers of licences issued/year; number of licences revoked/year);
- Network of collection and transfer stations established for efficient movement of wastes (number of stations/tonnes hazardous waste transported);
- Establishment of movement documents to accompany transport of hazardous wastes to encourage disposal close to the source of generation (number of movements/year/per capita or per GDP);
- Changes to existing, or development of new legislative/regulatory frameworks and requirements for regulatory permits for hazardous waste movements (number of new laws passed);
- Development of legislation for the transfer of legal liability for hazardous waste from producers to the collector/haulier/disposer;
- Establishment of emergency response procedures to address spills and/or accidents during hazardous waste transportation (number of facilities);
- Promotion of public awareness of the dangers of illegal dumping of hazardous wastes (number of campaigns and effectiveness).

Clearly there are a number of policy challenges associated with hazardous waste transportation. Mainly they involve a shift towards more eco-efficient procedures. This will also reduce the need for transportation of hazardous waste to off-site disposal/re-cycling/re-use.

3 Conclusion and Future Outlook

This paper should be seen as a 'thought starter' pointing to the need for further work especially to establish indicators that monitor the effectiveness of industrial policy development and to establish broad trends in goal attainment. Goals and environmental quality objectives could reflect either, better environmental and human health protection without jeopardizing continuing rises in human welfare in developing countries, and for reporting on further cost-effectiveness of industrial processes.

The need for simple as well as more sophisticated indicators that translate qualitative and quantitative data into understandable information for decision-makers, politicians and the community has never been greater. Indicators that measure the scope, strength and effectiveness of policies and legislation are certainly required. Indicators are also powerful communication tools and as such are components of a national and international forum for discussing the complex issues of hazardous wastes. Hazardous waste indicators, such as the four currently being tested by the UNCSD (UN 1997b), can provide useful information along traditional lines. But a new preventive and proactive industrial strategy is developing that requires a wider range of indicators than could be used to monitor and evaluate hazardous waste issues considered in their widest context

Indicators that reflect a reduction in hazardous waste generation arising from reductions in the use of materials and energy clearly relate to industrial efficiency gains. For example, a modification of production processes, that substitutes less hazardous materials for hazardous ones, can enable the organization not only to profit economically from the changes of process and materials management, but also enables savings to be made from a lessening of the controls needed to protect workers safety, their health and the environment.

The development of useful indicators reflecting aspects of hazardous waste should not be seen as a trivial task. They must be matched to their purpose. The wide range of indicators outlined in this paper is intended to serve a variety of purposes. The data needs for the various indicator constructions will consequently be different depending upon the purpose of the indicator, e.g. to monitor the technological process, or to evaluate the management policy adopted nationally and internationally. Indicator design has to be carefully documented and open to scrutiny and discussion. Indicators also have to be accepted not only at the enterprise level but also nationally and internationally by scientists and industrialists as well as by politicians and the public.

In most cases the major problem will be to obtain sufficient data, in a consistent and comparable form, across all hazardous waste issues. Differences of measurement technique, data definitions, sampling regimes, and the statistical factors that affect data quality and comparability across national boundaries all have to be addressed. Quality control of the indicators themselves will have to be introduced, to ensure that indicators reflecting comparable issues are not inconsistent. Such issues are not new, they affect all attempts at indicator development, especially where national and international comparisons are required.

We have outlined indicators that could be used to address and report on hazardous waste issues within an industrial management framework. Selection of a core set of hazardous waste indicators within an industrial management strategy involving economic, social and technological elements, will have to be based on the consultative process involving all stakeholders. It is clear that diverse sets of indicators will develop over time in order to address a wide audience comprising politicians, the public, industrialists, investment analysts, experts, etc. Inter-disciplinary work is clearly required for better indicator constructions that track progress in new cross-cutting initiatives including, for example, extended producer responsibility, sustainable product policies, full-cost accounting of hazardous waste generation, etc.

Many developing countries are at different levels of industrialization as well as of indicator development and use. Several countries of Asia and the Pacific Basin, despite being within a fast growing region, have no survey or inventory of hazardous waste generation (Cirillo et al. 1994) and little experience in developing and using indicators (UN 1997c) let alone hazardous waste indicators. Initiatives are underway in several countries of the region to address these deficiencies with regard to indicator development (Peterson1997a,b, UN 1997c, Peterson et al. 1999). The establishment of Regional Training Centres for Implementation of the Basel Convention, in China, Indonesia, and more recently in India and associated training programmes is a further significant step forward for countries of the Asia-Pacific region. Comparable regional and sub-regional centres have also been established in Africa, Eastern Europe and Latin and Central America.

Collection and assembly of data for indicator development is an expensive and time-consuming process, yet small by comparison with the social and institutional costs of clean-up of uncontrolled discharges of hazardous waste into the environment. Increased public concern of the potential impacts of current and newly emerging industries and associated hazardous waste on the environment and human health especially in developing countries can be used as motivation for effective indicator development and their use for measuring progress towards SD.

Overall, the wide variety of industrial processes that leads to the generation of hazardous wastes in all its forms, and the wide variety of indicators that are called for, provide the overarching driving force for further significant indicator development.

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