PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
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# Environmental management for the future

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# Environmental management for the future

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The field of cleaner technology continues to represent the major new direction for environmental management. Defining cleaner technology or pollution prevention is difficult because the context for use is very diverse. However, a typical definition is 'All efforts closely related to or influencing manufacturing, that also reduce chemical loss or waste generation.' Other definitions are described in this paper, as well as a history of pollution prevention in the United States. Economics remain a major driving force for the development and use of pollution prevention alternatives in industries providing goods and services. The tools for achieving cleaner technology are discussed to better understand the challenges to industry in implementing cleaner technology concepts.

## 1. Introduction

The significant diversity of pollution prevention has a beneficial effect by realizing the great potential to improve manufacturing while reducing chemical loss or waste generation. However, this diversity has made it difficult to identify a simple definition of cleaner technology. In this paper the issues of definition will be discussed, as well as the tools and lessons learned from the past 10–20 years of pollution prevention. While the bulk of cleaner technology implementation has been in Europe and the United States, there have also been valid examples developed in numerous other countries (UNEP 1995). However, in the end, the definition of cleaner technology largely depends on the context (technical and political) in which the discussion occurs.

One strategy in defining cleaner technology is an all-inclusive approach. All changes which have a positive effect on some aspect of the environment are therefore 'cleaner technology'. This is a relatively easy approach and everyone can then relate to the new definition. The difficulty is that there is no specificity and the tendency to relabel environmental actions or approaches as cleaner technology means little fundamental change occurs. That is, the suite of technologies used for environmental compliance remains relatively constant and focused specifically on the regulations, which have been principally end-of-pipe techniques. There is an inertia that is difficult to overcome with the all-inclusive definition. Using the concept that there are technologic and economic limits to end-of-pipe approaches, defining these as cleaner technology simply means reaching the same limits and solutions. Thus the all-inclusive definition is not widely used in the United States.

A second approach has been to attempt the identification of specific processes or changes that constitute cleaner technology. This effort is very complex as the industrial process or the context can vary substantially. For example, an incineration process might not be viewed as pollution preventing, while use of a high-temperature oxidation process to harness the fuel value of a chemical stream as a direct process energy source is deemed pollution prevention. Needless to say, many hours were taken to debate these definitions. As an example of this Websters definition approach, the US Environmental Protection Agency definition of pollution prevention is as follows. 'The terms *industrial pollution prevention* and *pollution prevention* refer to the combination of industrial source reduction and toxic chemical use substitution. It does not include any recycling or treatment of pollutants, nor does it include substituting a non-toxic product made with non-toxic chemicals for a non-toxic product made with toxic chemicals.' However, the actual reality of pollution prevention practices that have led to successful reduction in environmental emissions is that 'recycle and reuse' programmes clearly do achieve these objectives. The recent benchmark study of pollution prevention in the United States discovered that the six best pollution prevention corporate programmes relied on recycle/reuse as well as source reduction (Business Roundtable 1994). Thus the difficulty of a strict process definition for cleaner technology is evident.

Another, possibly more powerful, definitional approach to cleaner technology is conceptual and thermodynamic. If one begins with any manufacturing process sequence, there are a series of chemical and energy inputs. At certain locations, some materials begin to diverge from the manufacturing sequence and will ultimately become wastes. These nodes (not often known precisely), where loss first occurs, offer the maximum potential for pollution prevention or the adoption of cleaner technology. That is, there are three general prevention principles that can be invoked at these loss nodes: (1) keep the chemicals and materials in the main manufacturing process; (2) establish a recycle mechanism to improve the overall use; and (3) use as a byproduct.

If one or more of these prevention strategies are not adopted, then these chemicals and materials will progress further toward waste streams (eventually to air, aquatic systems or land). In this progression, the entropy increases and chemical value decreases from the levels within the manufacturing process. At some point along this downward progression, cleaner technology options cease to be likely and pollution control techniques become the dominant options. That is, pollution control is needed to convert these waste chemicals into less or non-impacting materials. Thus pollution prevention is defined as those alternatives at or near the top of this waste generation progression, where the chemical and thermodynamic potential for prevention are highest. With this approach, each separate manufacturing case can have different pollution prevention alternatives, yet all share these principles of the relative location on this progression from in-process to waste dispersion.

In a different direction, cleaner technology can be defined operationally. That is, an effective programme in pollution prevention involves continual activities leading to manufacturing improvements that are cost-effective and reduce emission to the environment. Cleaner technology is defined more as a thought process than a strict definition of techniques and chemicals. This thought process is referred to as the roadmap and will be discussed later. The basic elements are: identifying quantities of chemical losses or wastes; determining origin of losses; developing technical alternatives for reduction; and selecting alternatives on the basis of economic feasibility. If one examines most cleaner technology activities that have occurred in manufacturing organizations, this thought process was followed, leading to successful changes. Thus these principles define cleaner technology.

The various definitions of pollution prevention help us understand the possible viewpoints that have sought to be labelled as the new approach for the environment. However, no effective definition can be 'whatever we wish'. Instead, certain characteristics seem to define cleaner technology in a way that reflects the need to rethink, reengineer and stimulate new concepts at the interface between manufacturing and environment. Without a strong goal for change in the pollution control approach to environmental compliance, there might not be a need for a definition of pollution prevention. Thus the first pollution prevention characteristic is the focus on manufacturing process changes that increase efficiency and lower chemical use. The second is changes which are cost-effective and thus the win–win strategy for acceptance. A third characteristic is the achievement of significant reuse potential. Finally, cleaner technology is not pollution control technology.

In Europe and the United States, the progress toward cleaner technology over the past 10–20 years involved a number of common stages. Most organizations with goals for pollution prevention appeared to go through these stages. The discovery of direct, often management-related, changes (referred to as good housekeeping options) that were cost-effective was a common first stage. Then innovative engineering solutions were developed for more difficult, but still cost-effective, improvements. Now a current stage for some firms involves research for the remaining chemical losses for which there are no clear technology alternatives that are cost-effective. Companies and countries vary in progression through these stages. Thus the techniques and emphasis of cleaner technology will vary with the degree to which results in this field have already been achieved.

## 2. History

No single dimension of environmental solutions has captured the imagination of engineers, scientists, policy-makers and the public like pollution prevention. In the space of ten years (1980–1990), the philosophical shift and the record of accomplishment have made cleaner production a fundamental means for environmental management. This decade began with pollution prevention origins in 1976–1979 when the 3M Corporation initiated the 3P programme and North Carolina adopted waste minimization as a state-wide priority for managing emissions from industry. By 1990, virtually all of the Fortune 1000 United States corporations had pollution prevention as the first emphasis in describing their approach to the environment. The shift from 20–50 years of conventional pollution control to a preventative approach was dramatic because of this reversal in priorities.

The adoption of pollution prevention as a clearly differentiated approach to environmental improvement began in United States industry and policy during the late 1970s. While examples of improved efficiency, and hence less waste, had existed since the start of the Industrial Revolution, the distinct explosion of successes in pollution prevention did not occur until the 1980s. Figure 1 is an approximate time line of this period (Overcash 1991, 1992). The early creation at the 3M Corporation of money saving innovations that reduced chemical losses to air, water or land was widely publicized (3M 1983). However, propagation into other large corporations was almost non-existent. The efforts through university research, state programmes (beginning in North Carolina) to illustrate the benefits of pollution prevention, led to a steady presentation of principles extending over the early to mid 1980s. In 1986–1988, the improved information regarding chemical losses to the environment as a

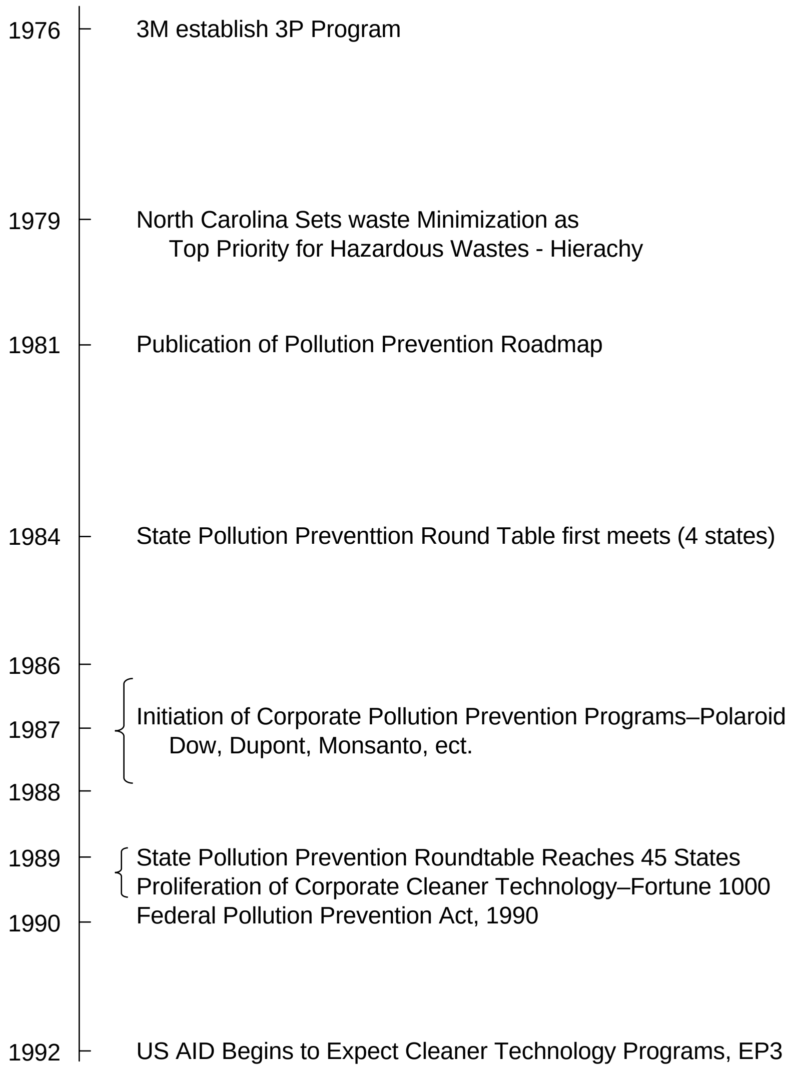


Figure 1. General historical sequence for growth of cleaner technology in the United States.

part of the US EPA Toxic Release Inventory (TRI) Programme precipitated action. A number of CEOs in large corporations challenged their companies, in a very public fashion, to reduce these chemical losses. As the autocatalytic effect spread to other companies and whole industry associations or sectors, the policy of priority for pollution prevention took shape in the United States. The outcome has been impressive, not necessarily uniform, by achieving a philosophical shift to cleaner manufacturing. These events were even more impressive when it is recognized that virtually all of the individual changes to manufacturing have been cost-effective (a generally held rule of a two year payback on capital investment). In addition, the majority of large corporate programmes occurred prior to a regulatory requirement for pollution prevention. Thus pollution prevention was the largest example of voluntary programmes and has allowed less dependency by the US EPA on command and control approaches. However, a danger exists that prescriptive requirements in cleaner technology will lead back to another command and control system.

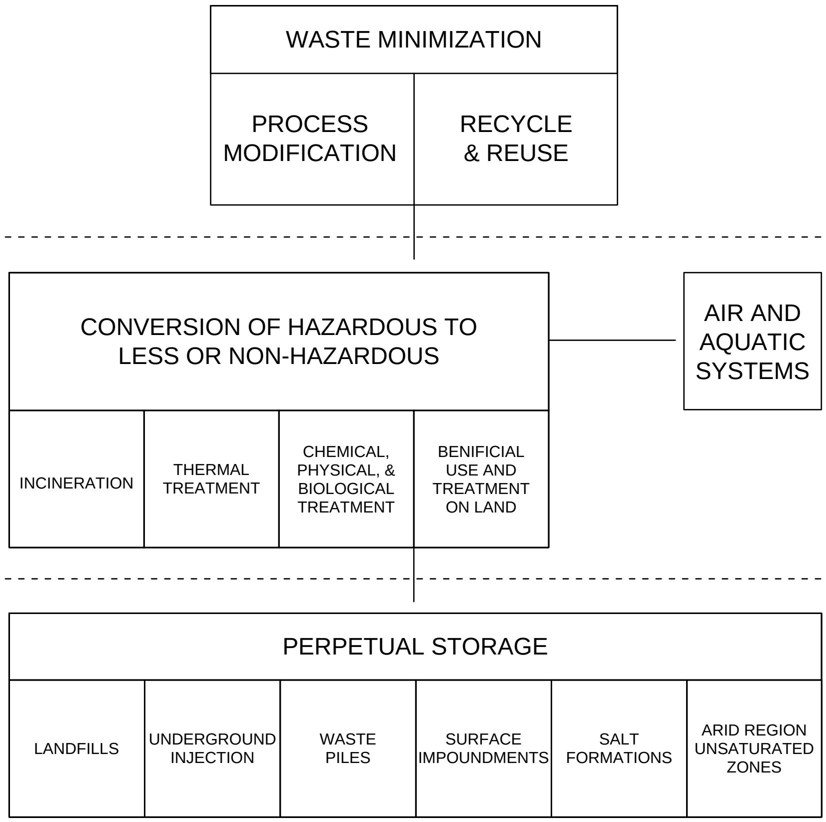


Figure 2. Overview of pollution prevention and industrial manufacturing (cleaner production).

Use of the term 'pollution prevention' is common in the United States, but is actually one of many synonyms or terms used to describe similar concepts. These include: waste minimization; cleaner production; waste reduction; clean technology; source reduction; environmentally benign synthesis; environmentally conscious manufacturing; industrial ecology; and sustainability. Use of a particular terminology is usually linked to the forum in which the debate is occurring and hence these terms have subtle differences, but share the major emphasis on prevention. That is, all of these descriptors refer to the intuitive perspective that it is advantageous to manage chemical losses or wastes generated from the top of a hierarchy for waste management (figure 2).

## 3. Pollution prevention principles

The hierarchy for waste management has been reconstructed numerous times by authors in the cleaner production field, but still retains the same basic fundamental principles. The first point in time, and potentially the most thermodynamically or economically effective opportunity for reducing impact on the environment, is to prevent or reuse wastes. These wastes are chemical losses from the vast diversity of industrial conversions that occur between chemicals in the natural state found around the world and the state of those chemicals in the products or services which reflect the gross domestic product of the all countries. Preventing chemical and material

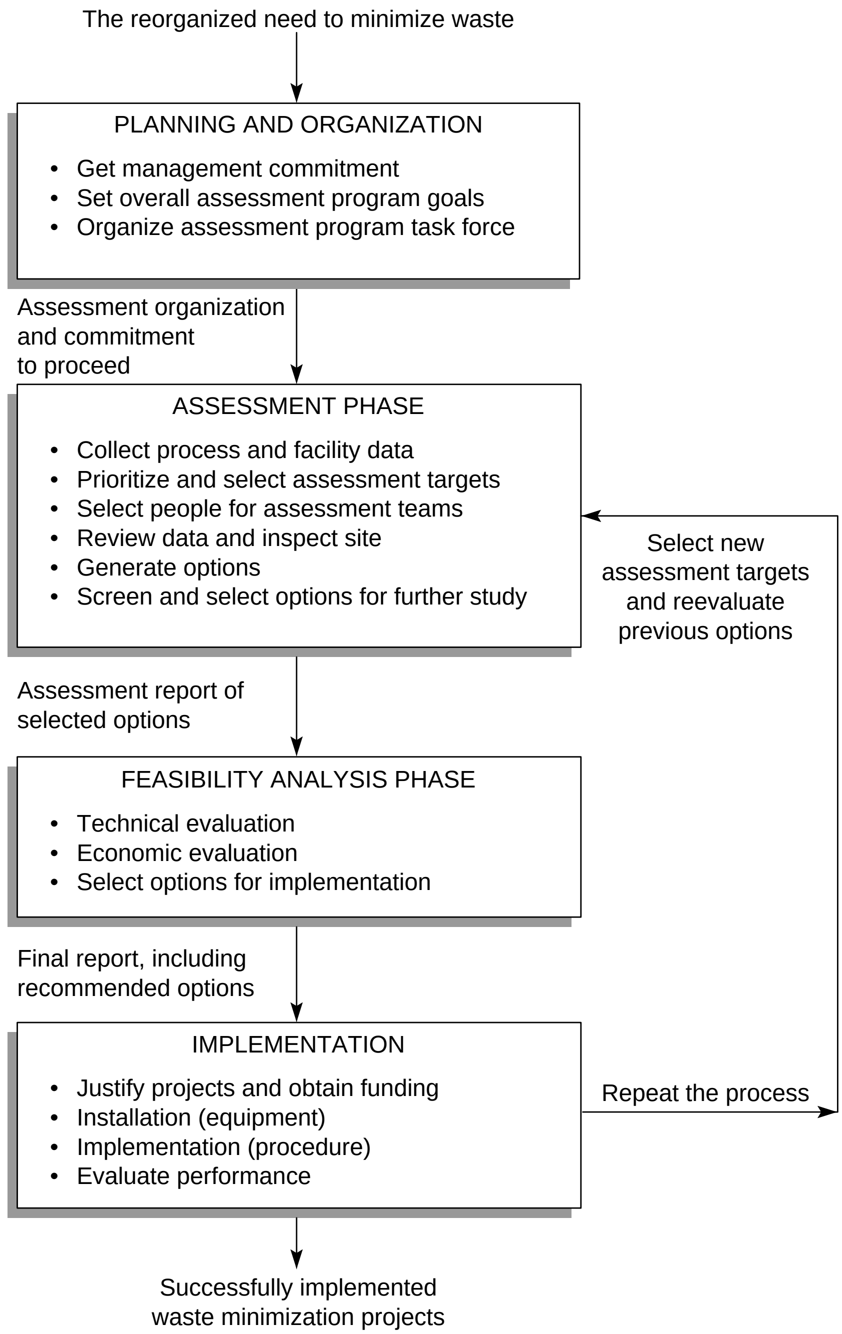


Figure 3. The waste minimization assessment procedure.

losses reduces waste and the magnitude of the remainder of the waste management hierarchy (figure 2).

Wastes can never be reduced to zero in conjunction with the industrial conversions described above. Thus, the next level of the waste management hierarchy is aimed at converting to less or non-hazardous constituents (figure 2). This is pollu-

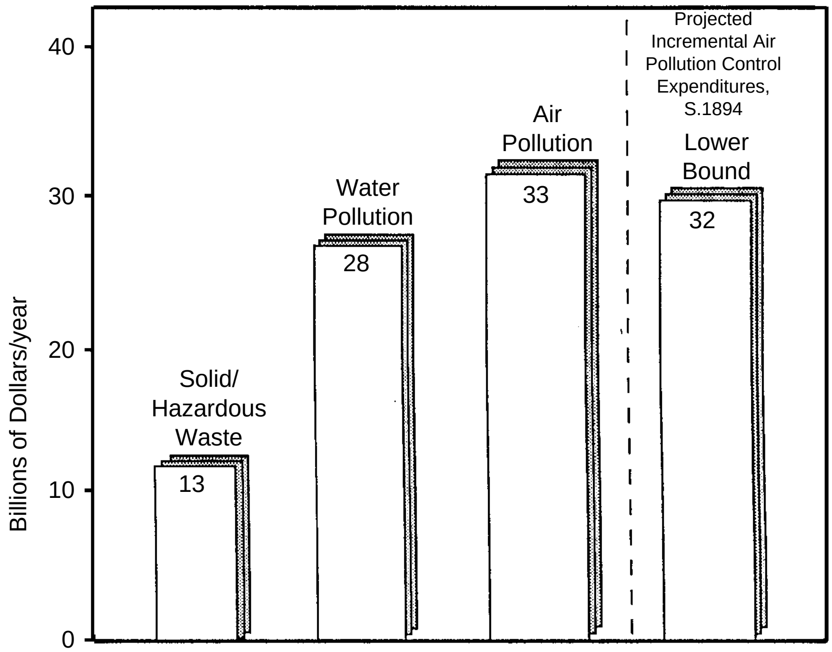


Figure 4. National environmental expenditure.

tion control and was the predominant means of environmental protection prior to the shift to cleaner technologies. It may in fact still be the predominant technology for environmental protection, but is no longer viewed as preferable. Unfortunately, these treatment techniques, as with other conversions in chemical states, also produce wastes, or residues (figure 2). Landfills and underground injection are the dominant approaches for residue management in the United States. The increased costs of pollution control and residue management levels of this hierarchy can stimulate pollution prevention. The creation of this hierarchy was an important step in defining the whole concept of cleaner technology.

However, conceptual development of the hierarchy and the need to focus on the preventative and reuse elements were not sufficient to achieve progress and general understanding of the pollution prevention field. A methodology for achieving cleaner technology was needed. This roadmap, figure 3 (Overcash & Miller 1981), was first developed in 1981 from studies of the small literature of pollution prevention successes. In essence, the roadmap identified the generic concepts needed to implement cleaner production. Following the logic or thought process in figure 3 has repeatedly led firms to discover pollution prevention alternatives that are technically and economically feasible. In retrospect, this roadmap is very similar to the solutions of other manufacturing goals such as total quality management (TQM), continuous process improvement (CPI) and safety. However, with a formal set of procedures (figure 3), the transferability of pollution prevention occurred across all types of industry and countries.

The driving forces for adoption of cleaner technology also include major economic factors. These are related to both the rapidly increasing cost of compliance with the regulations for managing wastes that are generated by industry and the economics of significant process improvement. Figure 4 illustrates the national annual expen-





PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Table 1. *Summary of nine US industrial case studies in pollution prevention*
(Source: M. Overcash, original research for this project paper, November 1991.)

| industry catagory of the plant | process change | capital cost (to nearest $500) | annual savings (to nearest $500) | % of savings from improved efficiency |
|---|---|---|---|---|
| fine chemicals | heat recovery | 7 500 | 5 000 | 50 |
| chemical mfg. | vapour loss reduction | 5 000 | 275 000 | 100 |
| food canning | steam recapture | 15 000 | 45 000 | 100 |
| brewing | waste as fertilizer | 88 000 | 88 000 | 0 |
| textile mfg. | effluent heat reduction | 100 000 | 50 000 | 100 |
| furniture mfg. | hazardous waste reuse | 1 500 000 | 905 000 | 0 |
| textile printing | solvent recovery | 7 500 | 90 000 | 100 |
| metal finishing | spray paint loss reduction | 874 000 | 642 000 | 33 |
| small appliance mfg. | solvent recycling and substitution | 3 000 | 20 500 | 85 |

ditures by United States industry to comply with the environmental laws governing air, water and land (US Department of Commerce 1987). In 1987, when pollution prevention was beginning to grow rapidly, these costs were about $75 billion per year. In 1990, the amendments to the Clean Air Act alone added an estimated $32 billion per year. These are large costs and the trend was for escalating expenditures as successive waves of environmental law amendments were developed. Within companies, costs of 20% of the total manufacturing expenditures for environmental compliance occurred. Current estimates of total sales spent on environmental compliance are in the range of 4–6%. Pollution prevention is aimed at avoiding these costs and the escalating trends through future decades. However, the experience with the cost benefits of pollution prevention has shown that regulatory cost avoidance is often exceeded substantially by the cost improvement through greater process efficiency. Ten randomly selected pollution prevention economic studies, with sufficient information to differentiate the origin of savings, were studied (Bendavid-Val *et al.* 1992) (table 1). In a significant number of cases the dominant fraction of the cost savings occurred from process improvement, rather than avoidance of environmental compliance costs. Thus, the driving forces for pollution prevention may often originate in opportunities to improve manufacturing through a new framework for analysis, namely the environmental emissions.

## 4. Conclusions

Pollution prevention or cleaner technology represents significant change in the means by which industry has demonstrated a commitment to environmental protec-





PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

tion. While strict definitions are not feasible, pollution prevention can generally be differentiated from pollution control by the emphasis on cost-effective manufacturing improvement. The problem of defining cleaner technology stems from the problem of changing scientific and engineering attitudes towards environmental improvement. In a sense, pollution prevention has enlisted a new dimension of expertise and individuals, those with responsibility for processes, chemicals, materials, products and the losses to the environment. The rapid growth of successful implementation in this field, now emerging into a significant area of research, has demonstrated significant creativity and a win/win scenario.

For the opportunity to formulate this paper, I thank Professor Roland Clift. In addition, appreciation is given to the research and industrial community of Europe and the United States who shared their perceptions of the cleaner technology field with the author.

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### *Discussion*

A. Kelly (*Cambridge University, UK*). Professor Overcash has made a valiant attempt to quantify the environmental impact of certain measures. He mentioned governments always trying to maximize the quantity (GDP/population). This quotient has very little connection with environmental impact, because in all developed countries the material input and to some extent the energy input per unit of GDP per head of population is falling. With traditional materials, e.g. steel, it is falling quite fast (Kelly 1994). What is needed is the generation of an agreed unit of environmental impact, so that meaningful audits independently of monetary values may be carried out.

M. Overcash. The in-country use of steel or energy may be further complicated by importing materials made elsewhere and hence a global life-cycle approach might be a useful means to evaluate environmental issues.

A. Wagner (*Kilburn, London, UK*). I disagree with the view of Professor Overcash that corporations have been the catalyst to preventing pollution. He seems to have ignored the role of environmental campaigning groups in leading the movement towards less destructive technologies.

M. Overcash. Environmental groups have led a general appeal for the environment; however, the targeted success of cleaner production has largely been from corporations. This has been widely acknowledged in the US, where the goals and actions by industry have been more visible.

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