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Analysis of lead/acid battery life cycle factors: their impact on society and the lead industry

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Abstract

The underlying theme of this paper is that society, globally, is undergoing a fundamental conceptual shift in the way it views the environment and the role of industry within it. There are views in certain quarters that this could result in the virtual elimination of the lead industry's entire product range. Despite these threats, it is argued that the prospects for the lead industry appear to be relatively favourable in a number of respects. The industry's future depends to a significant degree, however, upon its ability to argue its case in a number of key areas. It is contended, therefore, that if appropriate strategies and means are promulgated, the prospects of the industry would appear to be relatively healthy. But, for this to happen with optimal effectiveness, a conceptual change will be necessary within the industry. New strategies and tools will have to be developed. These will require a significantly more integrated, holistically based and 'reflexive' approach than previously. The main elements of such an approach are outlined. With reference to the authors' ongoing research into automotive lead/acid starting lighting ignition (SLI) batteries, the paper shows how the technique of in-depth life cycle assessment (LCA), appropriately adapted to the needs of the industry, will provide a crucial role in this new approach. It also shows how it may be used as an internal design and assessment tool to identify those stages in the battery life cycle that give rise to the greatest environmental burdens, and to assess the effects of changes in the cycle to those burdens. It is argued that the development of this approach requires the serious and urgent attention of the whole of the lead industry. Also to make the LCA tool fully effective, it must be based on a 'live' database that is produced, maintained and continually updated by the industry. © 1997 Elsevier Science S.A.

Keywords: Life cycle assessment; Lead/acid batteries; Environment; Reflexive approach; Database

1. Introduction

The lead industry faces an uncertain future. Working in an uncertain environment is not new to the industry. This uncertainty is, however, more profound and threatening than before. For example, Muth of Asarco, USA, in his paper [1] to the 11th International Lead Conference 1993, noted that 'recent attacks' on the lead industry had changed from being on the products and human exposures to 'attacks directed at lead markets'. He also suggested that whilst this was especially the case in the USA, it was occurring globally. Muth further contended that this was 'a totally different kind of confrontation and that [it would] make past challenges seem trivial in comparison.' Muth concluded that, in the USA, the government had started to adopt the attitude that 'lead is an indestructible toxic [substance] and should be left in the ground.' He contended that, as a result, practically all lead uses are susceptible to early elimination.

These statements raise the following questions of fundamental concern for the whole of the lead industry.

- Is Muth correct in this assessment?
- If it is the case, what are the underlying causes?
- How should the lead industry respond?
- Does the lead industry have any future?

The following sections of this paper examine these questions in some detail. The argument is made that Muth is correct in his contentions of there having been a shift in the nature of the attacks on the industry and that it could face the early elimination of its entire product range. Nevertheless, it is argued that, to a great extent, the industry holds within its grasp the keys to its own destiny.

The underlying theme of this paper is that industry

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needs to understand the changes that have occurred, what future changes are considered likely, and the reasons for their occurrence. It also shows that despite the apparent threats, the industry has a relatively strong position to defend. Therefore, if appropriate strategies and means to accomplish these strategies are promulgated, it could have a 'healthy' future. The study shows, however, that for this to happen with optimal effectiveness, a conceptual change will be necessary and new strategies and tools will have to be developed. With reference to the authors' own ongoing research project, an outline of the nature of such an integrated strategy and the specific tools that the authors consider should be used is given.

2. An industry under threat

Lead and its compounds are toxic. This is indisputable, but it is only a problem if such materials are able to enter body tissues. Unfortunately, lead's usage provides opportunities for the metal to escape into the environment and, thereby, to pollute it. Also the usage of lead in human society dates back thousands of years. Therefore, with this usage went its inevitable dissemination into the environment. In turn, this resulted in the uptake of lead into the tissues of living organisms. Indeed, there is evidence to suggest that all people living in the modern world have a biological burden of lead in their tissues and that it is at least partly anthropogenic in its origins.

As knowledge of the toxic and bioaccumulative nature of lead has developed, there has been a concomitant development of concern which has centred both on environmental and occupational exposures. In turn, it has led to a variety of initiatives and legislation aimed at reducing, or trying to eliminate, exposures.

In response to these developments, the industry has directed considerable efforts over the last few decades at reducing occupational and public exposures from emissions. This was brought about partly as a result of the more stringent regulation of the industry, but also because of its desire to be environmentally responsible. Considerable resources have also been spent on improving the environmental performance of existing process technology, and on developing and installing both clean-up and cleaner technologies.

As knowledge of the significance of the environmental burden from lead contamination developed, it became apparent that the vast majority of the environmental and human exposure came from three main contaminative uses, namely: (i) additives in petrol; (ii) additives in paint; (iii) lead pipes and lead-based solders used in pipes to convey drinking water. As a result, they are all now in decline. This has left the industry with a range of products that are relatively non-dissipative in nature. Nevertheless, concern about lead and the potential threats to the lead industry appear to be continuing unabated.

A substantial amount of research has been, and continues to be, conducted to identify both the extent and routes of environmental contamination as well as its consequent environmental and biological significance. This work has taken place at both national and international levels. Thus, a number of countries have attempted to assess the extent of soil contamination nationally. In the UK, for example, the Environment Agency (the regulatory authority) now has the duty to assess the extent of environmental pollution (including lead contamination) both nationally and regionally and to carry out regular reviews of the extent of this contamination. On an international level, the United Nations Economic Commission for Europe (UNECE) has formed a task force that has studied the problem of the dissemination of heavy metals in the environment. In 1995, it reported that there is now sufficient evidence to conclude that long-range transport and deposition of heavy metals (including lead) has occurred [2]. As a result of these findings, UNECE recommended for lead, mercury and cadmium that:

1. emissions should be reduced;
2. the principle of 'best available technology' and the precautionary principle should be applied;
3. restrictions should be placed on certain uses, and
4. substitution should be used as a principle.

Whilst all are of concern, the last recommendation is the most profound since it threatens the future of the entire lead industry. Thus, all lead products face the threat of substitution. There are numerous examples of other potentially threatening moves but probably the most potentially significant development has been the publication of a document entitled *A Common Strategy for International Chemical Control Work in Sweden* [3]. This document was jointly produced by a collection of Swedish regulatory authorities, viz., the National Chemicals Inspectorate, the Swedish Environmental Protection Agency, the National Board of Occupational Safety and Health. It details Sweden's national position on the control of chemicals and outlines measures and/or vehicles that it hopes could be used to impose their national policy at the international level.

It also outlines three basic regulatory policies which if implemented internationally would have far reaching implications. These are as follows.

(i) *The precautionary and substitution principle* which would require anyone handling or importing a chemical (i.e., any lead compound and lead itself) to judge whether the same results could be achieved at a lower risk with a different product or in a different way. It would also require that if similar results could be achieved, then they must substitute the product.

(ii) *The duty of investigation principle* which would place the burden of proof on manufacturers of chemicals to establish the hazards of the chemical products themselves, rather than on the regulatory authorities.

(iii) *The 'polluter-pays' principle* which would require the manufacturers and importers of these chemicals to cover their own costs for compiling data concerning the impact of their chemicals on both health and the environment.

If any, or all, of these three principles were implemented internationally, both the cost overheads and the uncertainty on the industry would increase dramatically.

All of this provides evidence to support the claim of Muth [1] that attacks on the lead industry have shifted and now threaten the future of the whole market. It also gives strong support to his claim that the industry faces the threat of early substitution of its entire product range.

In addition, it is predicted that the lead industry will be increasingly threatened by societal demands for sustainable development. Ultimately, if humans are to have any long-term future, the technology of our society will need to be environmentally clean and societal development will have to be sustainable. Whilst it is likely to be some time before such objectives could be realized, the first governmental pressures on industry to develop strategies for sustainable development have begun to be exerted. Currently, the main source of this pressure is through Agenda 21 (which was one of the outcomes of the Rio Conference of June 1992). However, the obligations placed upon governments to develop action plans for industry were considerably whittled down from the original proposals, as a result of an effective lobbying effort by the International Chamber of Commerce [4]. Despite this, Agenda 21 still contains requirements, such as the international enforcement of the polluter-pays principle, that could prove somewhat onerous to industry. Agenda 21 is likely to be merely the first step in this pressure to move industry towards sustainability. Hence, the pressures on industry to develop strategies and means to achieve sustainability are expected to grow. The change to a sustainable society will require a world-wide shift in the conceptions of the roles of all members of society. Radical changes will have to occur across the whole of industry. In such a society, the production and usage of metals such as lead, might be extremely limited. Therefore, in the coming period, the whole of the metals industry will be subject to fundamental changes and over the long term could be virtually eliminated.

Despite these threats, in the short-to-medium term, the prospects for the lead industry appear to be favourable in several respects. For example, at present it seems likely that the power for the new generation of zero emission vehicles (ZEV) will come from fuel cell and lead/acid battery hybrid systems. Also, since the global usage of cars is predicted to show a sustained increase, the usage of lead for the production of automotive lead/acid starting lighting ignition (SLI) batteries is also expected to increase. Hence, it appears that the lead industry has (potentially at least) a strong position to defend. What it needs is appropriate strategies and tools to fight its case. The industry's challenge is to meet the increasing threats in a positive and proactive manner. It is an emergent field; those industries that are more effectively prepared are likely to fare better in the battles ahead.

The authors believe that the lead industry needs to appreciate that these potential threats and opportunities are themselves part of a wider process that is already occurring within industrialized society. Indeed, there is a growing body of opinion which has been arguing that industrialized society is undergoing a decisive transitional period. Therefore, the authors consider that the pressures to move towards a more sustainable society and the aforementioned threats to the lead industry are symptomatic of this wider process.

The authors contend that one of the most significant and influential theoretical contributions in this field is from Beck [5]. The latter has argued that industrial development is becoming increasingly characterized by two features. The first of these is that the axial principle of industrial society is shifting from the distribution of wealth and goods to a distribution of 'risks' [1]. He describes this new society as a 'risk society'. Beck contends that this society is still, and will continue to be, an industrial society. This is because, it is industry in conjunction with science that has been, and will continue to be, responsible for the creation of these risks. The second feature of this society, Beck argues, is that risk is becoming 'reflexive', i.e., that it is becoming its own theme. Thus, in the industrial society, the 'logic' of wealth production dominated the 'logic' of risk production. In the risk society, however, this relationship is reversed and the distribution of risk becomes the dominant theme [5]. The authors believe that the growth of the perceived threats to the lead industry provides strong evidence to support this claim. Thus, the perceived growth of the threats is thought to stem from an increasing domination of the perception of society, that the risks caused by the actions and products of industry need to be reduced and eventually eliminated.

The title of this paper refers to the impact of 'life cycle factors' on society and the lead industry. The term 'factors', refers to 'risks' in their broadest sense. Thus, it includes technical risks which can be evaluated from measurable environmental burdens that result from the processes involved at all stages of the life cycle of products. It also includes, however, the plurality of different 'public' risk perceptions which are influenced by aspects such as the degree of trust and the credibility of the risk causers [2]. The authors believe that since these 'factors' may be

[1] The term 'risk' in this context is defined by Beck [5] as a 'systematic way of dealing with hazards and insecurities induced and introduced by [the process of] modernisation itself'.

[2] The 'public' are here defined as those exposed to the risk in question. The 'public' may be divided through factors such as age, social class, occupation, gender, ethnicity, and degree of support for a particular position. Different 'publics' may be separated from each other by both physical (e.g., geographical) and/or social (e.g., cultural) differences. Within the various publics, there may also be a variety of divisions, differences and conflicts.

regarded as equivalent to risks they are also reflexive. Hence, they are becoming their own theme. Therefore, for the development of an integrated strategy and tools that will be successful in enabling the lead industry to meet the emerging environmental challenge, it will need to be reflexive as well. Thus, the strategy will need to consider their impacts both upon society and the lead industry, which is itself both a product of, and part of, that society.

3. Optimally meeting the environmental challenge

The previous section showed how the threats to the industry have broadened and, some such as the substitution principle, are now challenging its whole future. With the development of the substitution principle, industry will need to be able to clearly demonstrate the environmental burdens of all of its products throughout their life cycles, i.e., from their cradle (as raw materials) through to their grave (as waste). The authors contend that the traditional responses of the industry are unable to provide a proper and balanced consideration either to these life cycle factors or to the way in which they impact both on society in general and upon the lead industry itself. These shortcomings are expected to become increasingly apparent in the times ahead. Therefore, new strategies and tools are urgently needed.

Unfortunately, it would never be possible to create a perfect system that had zero losses to the environment at all stages in the product's life cycle and on all occasions. Nevertheless, it will be possible systematically to design products, their modes of use, recycling and disposal in such a way that the environmental burdens are minimized and reduced to levels that are competitive and may even outperform potential rivals throughout their life cycles. To achieve this, a significantly more integrated and holistic approach needs to be adopted than in the past.

The authors contend that in the immediate-to-medium term, the biggest threats to the industry will be from attempts at substitution, from demands for lower emission limits, and from views that lead is a dirty and polluting substance. Thus, an approach needs to be adopted which will ensure that these of threats are addressed. This approach can be detailed as follows.

1. To meet the threats of substitution, the approach needs to develop means to compare, most effectively, the environmental burdens associated with lead and lead products with (i) so called 'environmentally friendlier' substitutes, and (ii) services that are currently supplied by other means but which the industry believes its products should replace (e.g., replacing petrol-driven vehicles with lead/acid powered ZEVs).
2. To meet the demands for lower emission limits, the approach needs to assess the accuracy and adequacy of the currently accepted techniques for measuring plant emissions and their dispersion in the environment.
3. The approach must also adopt more effective means to improve both the image of lead and the trust of the public in the industry.

The authors' justification for adopting these three strands comprises the next section of the paper.

4. Developing means to promote the case for lead and argue most effectively against its substitution

Demand for primary lead is expected to remain relatively constant for at least the next ten years. By contrast, estimates of the demand for secondary lead predict that it will increase from about 52% of all lead (1995 level) to between 59 to 63% by 2005. Pugh and Breeze [6] have also estimated that consumption of lead for batteries will increase from 66 to 73% over the same period. On the other hand, dissipative uses are expected to continue to decline at a rapid rate and the other non-dissipative uses (such as cable sheathing) are expected to remain relatively constant over the same period. Thus, it is expected that the lead industry will grow over the next ten years due to an expansion of the secondary-lead business, but that this growth will be increasingly dominated by batteries. Since battery recycling rates are already between 80 to 90% [7], this expansion will, presumably, have to be achieved by an increased recycling of lead from other sources. The industry is also currently pinning much of its future hopes on being able to provide a convincing argument that lead/acid batteries will be the best option, both practically and economically, for powering the new generation of ZEVs. Whilst it has been argued that it will not be a dramatic market driver for the next ten years, it is essential that the industry starts to prepare its environmental case.

These trends and the aforementioned threats indicate that the future of the industry hangs upon its ability to argue effectively its case in a number of key potential battle areas. There is the real danger, if inadequate comparisons are made, that the lead industry could lose out in arguments over substitution when its position environmentally is significantly stronger than it had realized. Thus, it is clear that it needs to adopt the most effective means available to argue its environmental case.

To make effective comparisons between different materials and their substitutes, one needs to have a uniform basis. The authors contend that the most effective means to carry out these comparisons is through the technique of in-depth life cycle assessment (LCA). The crucial advantage of this technique over other methods of assessment is that it adopts the stance that, to make effective comparisons, one has to evaluate the material and energy burdens that arise from the products from their cradle (as raw materials) right through to their grave (as disposed waste). This evaluation includes all of the stages of the life cycle and also all of the significant co-product, by-product and waste-product streams. LCA is able to provide a balanced assessment of the contribution of all of the individual stages to the life cycle, because it measures them against a functional unit that is specified for the study in question.

The authors have commenced an LCA of the environmental burdens of the service provided by automotive batteries. This choice was made purely on the basis of the growing domination of automotive batteries and the magnitude of the potential threat their loss would pose to the business. The technique is equally valid, however, for all products. Accordingly, it needs to be applied to all products that it intends to defend.

Such an approach represents a significant change in the way the lead and other industries conduct comparisons. In the past, where comparisons between lead and its competitors have been made, they have not considered all of the stages of the life cycle. Nevertheless, since the technique of LCA is gaining in acceptance, it is probably only a matter of time before it is applied, if not by the industry itself then by its competitors. The industry needs to be the first into the arena so that it can be fully prepared to argue its position from a more informed basis.

LCAs consist of several interrelated phases (Fig. 1) [8]. The most time-consuming phase is likely to be that of data collection. High-quality data are essential and some of them may only be obtainable by on-site measurements, interviews or investigations into company records. Also, this collection needs to carried out for all involved enterprises in the product's life cycle. After collection and processing, the data must be evaluated. A variety of different evaluation techniques may be applied. Currently, one of the most popular is to aggregate the data of the environmental inputs and outputs (i.e. burdens) according to their potential environmental impacts for the whole of the product's life cycle. This is, however, only one of many different potential ways in which the data may be processed. For instance, it would be equally possible to aggregate the data for each stage rather than for the whole life cycle. There is also a variety of ways in which these aggregated data may then be processed. For example, one method is to normalize each impact in relation to a specified reference such as an environmental threshold below which no environmental affects or biological effects are detectable. Alternatively, the data could simply be evaluated in relation to a specific set of values.

Even though LCA is now becoming accepted as the most effective means to carry out comparisons of relative environmental burdens, there are some controversies concerning certain aspects of its methodologies, as well as areas that require further research and development. This is largely because it is still a relatively new concept and is still under development. In time, the majority of these deficiencies are likely to be remedied. Nevertheless, there are certain aspects of the assessment and valuation stages of the process that are likely to remain contentious. Despite these criticisms, the authors still contend that the technique of LCA, appropriately applied to the needs of the industry, provides the best means currently available to carry out these assessments.

The complete life cycle of lead/acid automotive batteries is presented in Fig. 2. Since data will need to be collected from all of these stages, it can be seen that the co-operation of all involved businesses will be required. This will be worthwhile since the technique of LCA, when applied to any product, will enable:

1. the industry to assess the overall environmental burdens associated with that product;
2. the stages in the life cycle giving rise to the greatest environmental burdens to be identified;
3. effective comparisons with potential substitutes and/or alternative systems to be made, and
4. the effect of changes to the stages of the product's life cycle to be predicted.

LCA can also be applied to measure and assess the environmental burdens associated with each of the individual processes that together comprise each stage of the life cycle. Such in-depth LCAs turn the technique into a powerful tool for designing away environmental burdens.

The design and assessment capabilities of LCA could also be multi-dimensional. To date, LCAs have tended to be used to catalogue and assess the environmental burdens of products from their cradle through to their grave. One of the strengths of LCA, however, is that it could also set its frame of reference to whatever is considered to be of relevance. Thus, the lead industry, as a whole, needs to be able to identify and design away the overall environmental

I. Planning *(= goal definition and scoping)*

Objectives
Definition of product and choice alternatives
System boundary (space, time, product chain)
Choice of environmental parameters
Choice of method for aggregation and evaluation
Strategy for data collection

II. Screening

A preliminary execution of the phases III - VI
Adjustment of plan

III. Data collection and data treatment *(= inventory analysis)*

Measurements
Interviews
Search in literature and handbooks
Theoretical calculations
Search in databases
Qualified estimation
Data addition

IV. Evaluation *(= impact assessment)*

Classification of data into impact categories
Aggregation of data in relation to their potential environmental impacts
Normalisation of data in relation to a specified reference
Evaluation of data in relation to a specific set of values

V. Adjustment of alternatives *(=.improvement analysis)*

Sensitivity analysis
Improvement priority and feasibility assessment

VI. Possible reiteration of phases III - V

Note: This is not a definitive list. Elements may be added or removed.
The process is also expected to be iterative.

[Modified from: Pedersen B, Krüger A S (Eds.)] [8]

Fig. 1. Probable phases for the life cycle assessments.

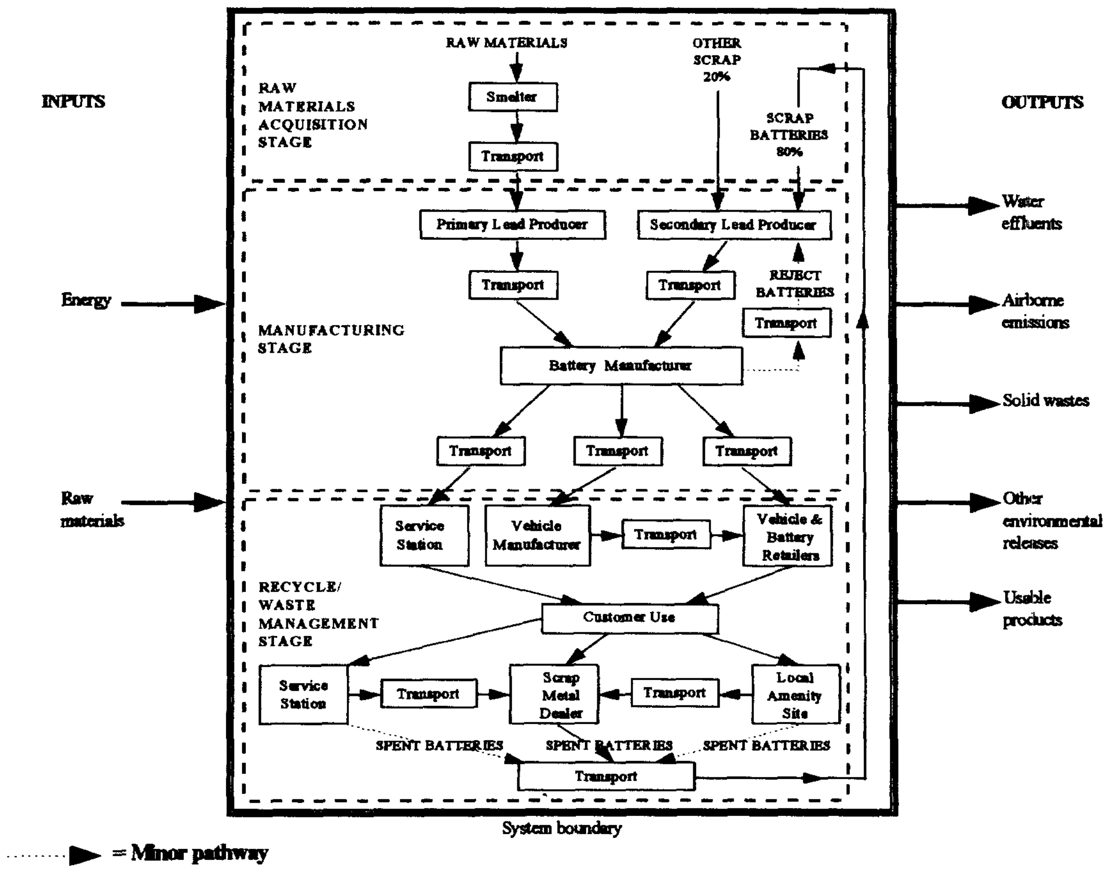

Fig. 2. A summary of the main stages in the life cycle of the UK automotive battery.

burdens of it products. It should be noted, however, that life cycles involve distinct stages and some of these are under the remit of different businesses. The authors' research project should prove that it is also possible to set the technique's frame of reference to individual businesses, i.e., to produce a gate-to-gate type of analysis.

Another potential benefit if LCA is that, since it assesses all environmental burdens including energy consumption, it may also be used as a powerful tool for increasing the efficiency of resource and energy utilization of individual businesses. Thus, it could also lead to significant cost savings.

Once LCA has been established as a design and assessment tool, it will enable the industry to evaluate its environmental position and provide it with a baseline for environmental improvement. It will also enable it to obtain and maintain a powerful environmental defence for its products. Furthermore, it could also become a key tool in a pro-active campaign by the industry against substitution and for the securing of new markets. In the latter context, it is the authors' current intention to use the LCA data on the automotive battery to carry out a theoretical assessment of the likely burdens that will be associated with ZEVs powered by lead/acid batteries. This assessment could be used either as a baseline to be improved upon, or it could be used to strengthen the industry's environmental case. It could also be employed to compare lead/acid-powered ZEVs with substitute products or systems for providing personal transportation with zero environmental emissions during use.

5. Evaluating the accuracy and adequacy of the currently accepted techniques for measuring plant emissions and their dispersion in the environment

It is probable that the lead industry will increasingly need to be able to justify the quantities, character and exit routes for all of its emissions to all of the environmental media. Therefore, it is essential that the entire planning-sampling-analysis-reporting chains and any modelling techniques that may be used to measure and assess the emissions, provide an accurate indication of actuality. The national regulators of the industry generally insist that standard methods (such as those of the British Standards Institute) are used and that those who carry out the measurements operate to some form of quality assurance system (such as British Standard for a Quality System *BS5750*). This ensures some consistency and standardization of data gathering and analysis techniques; the overall aim being to try to ensure a certain level of reliability and accuracy in the data. All standards will inevitably, however, contain various compromises. These will affect the final quality of the data. In some cases, this may lead to results that are misleading. Since the lead industry will also be judged on its environmental emissions, it is essential that any compromises that are made do not lead to such erroneous and/or exaggerated results. Indeed it is the belief of the authors, that this problem may exist with some of the currently adopted methods for measuring and modelling emissions from lead refining and recycling operations. Hence, there is the need for a comprehensive and critical evaluation of all of the measurement and modelling techniques that are used. Where deficiencies are found, appropriate changes will have to be instigated. Any such changes will need to be adopted internationally to ensure that a level playing-field is maintained.

6. Improving the public image of lead

The authors contend that a key aim of the industry should be to try to ensure that lead products in non-dissipative uses are removed from the threat of substitution for the foreseeable future. This will only happen if the industry can convincingly demonstrate its environmental credentials. The LCA technique will provide the best vehicle for this. Due to its dirty image, however, it is likely to still face discrimination. Therefore, challenging the attitudes of society to lead needs to be a core component of any integrated strategy. This needs to include the education of society of the environmental credentials and benefits of lead over other materials. Obviously, the future is uncertain. Therefore, the industry needs to take an active part in the debate over how this uncertainty is managed and communicated. All industries are vulnerable to environmental challenges. The 1995 Brent Spar affair is testament to this. Shell, the owners of the Brent Spar oil platform, had intended to dump it in the North Sea and had carried out a thorough appraisal. Despite this, public pressure forced them into a humiliating reversal of their plans. This happened despite the fact that the evidence of those who opposed the plan was flawed. Events such as this show the power of public pressure over industry. All industry needs to learn from incidents such as this.

The authors believe that one of the greatest potential dangers for all industry stems from the tendency for a disparity to exist between how the public perceives the environmental impacts of industry and its products and that of the 'experts' in industry. The former tends to be strongly influenced by factors such as trust and the credibility of those responsible for managing the risk, whilst the latter tend to base their judgements upon quantitative risk assessments. The authors believe that the Brent Spar affair provides a case study of the potential consequences of failing to bridge this disparity. Thus, all industry needs to take active steps to bridge it. In the case of the lead industry, the poor public image that it has unfortunately inherited could make it especially susceptible to such dangers. Since these threats appear also to be becoming reflexive (i.e. their own theme), the industry will need to adopt approaches that fully take this into account. Therefore, new forms of communication will need to be developed that will be based more on interactive dialogue than the traditional 'top down' type of approach (whereby the experts impart their knowledge to the public). This is a developing field in risk communication. The industry needs to ensure that it is actively involved in its development.

7. Early findings of research into the life cycle of automotive batteries

7.1. Introduction

The LCA technique is both a technical and a broadly based (i.e., holistic) approach. This is because it uses data derived from technically based investigations that pertain to different stages of the life cycle and enable them to be compared in a balanced and useful manner. Because it is holistic, however, one cannot accurately and reliably assess where the greatest environmental burdens are in the life-cycle until all of the stages have been evaluated and the quality of the data used in each stage has been fully verified. For this reason, no attempt has been made in this paper to make assertions with respect to the significance of the environmental burdens of the stages so far assessed to the overall burdens of the whole life cycle.

Thus, a basic premise of LCA is that one cannot prejudge the significance of the burdens of any individual stage until the whole life cycle has been considered. Unfortunately, due to the toxic nature of lead, its historical legacy, and the perceived problems of emissions from the various handling, processing and manufacturing processes, the attention of the industry has tended to be focused upon certain stages in the life cycle. Hence, attempts to limit environmental burdens within the industry have also tended to be concentrated upon these certain stages. The authors consider that, as a result of this, the resources of the industry have been inefficiently allocated. This is because the most efficient way of directing resources to reduce the overall environmental impact of a product, would be to focus them chiefly on those stages and/or individual processes in the life cycle with the greatest burdens. For example, it has been shown that for many products the greatest energy burden is associated with the use stage of the life cycle. If this is the case with automotive batteries, the most efficient and beneficial place to target investment to reduce the energy burdens would be into research to reduce the energy associated with their use. The authors consider that such an approach may seem somewhat counter-intuitive, since there is a natural tendency to believe that stages such as smelting and refining would have the greatest energy burdens. This is quite understandable since they consume large quantities of fossil fuels and/or electricity. What matters most in reducing the environmental burdens, however, is not the amount of energy used per tonne of product smelted or refined, but the energy consumption per functional unit at that stage in the life cycle compared with that of the other stages. Nevertheless, as far as individual businesses are concerned, there may be economic considerations that could still make it a top priority to reduce energy consumption at that stage. Thus, as was previously explained, the LCA technique may also be applied in a gate-to-gate type of mode (i.e., applied to the activities of a single plant or business within the life cycle). When thus used, it may indicate that, as far as an individual company is concerned, the most efficient means to reduce the environmental burdens is still to address that stage.

Two key concepts need to be appreciated. These are as follows.

1. Reductions in the environmental burdens from any stage in the life cycle benefit the whole industry since they improve the environmental credentials of the product and strengthen the industry's case in its fight to prevent substitution.
2. The process will need to be iterative. Databases must be built and developed and then maintained. This is because the life cycle will be subject to continual change and development. Only if it is kept up to date and contains data of appropriate accuracy will the technique remain a powerful design and assessment tool. Since the life cycle will undergo continual development, the priorities for action to reduce the environmental burdens will also change with time.

7.2. Choice of transport stage for initial data collection and analysis

For the outlined reasons above, it should not be assumed that the environmental burdens associated with any individual stage of the life cycle are relatively insignificant until all of the data for the whole life cycle have been collected and assessed. The initial stage of the authors' LCA research has focused on the transport stage as, arguably, it is one of the most difficult stages to assess reliably. Hence, it is likely to be one of the most time-consuming. This is because (i) there are many hauliers involved and many individual journeys and (ii) journey patterns vary from driver to driver. This is a particular problem with the recycle/waste management stage because there is considerable variation in the number of hauliers, the size of the trucks used, their utility, and the lengths and road conditions of the journeys taken.

7.3. Early findings

The authors have investigated the transport of scrap automotive batteries to Britannia Refined Metals' battery-breaking plant (CX Plant) at Northfleet in Kent, UK, see Table 1. Their early findings are shown and discussed below.

Using these data in conjunction with the PEMS 3 database and the LCA tool, the major environmental burdens resulting from such transportation movements were identified [9], see Table 2.

As a demonstration of the capabilities of LCA as a

Table 1
Deliveries of scrap batteries to the Britannia Refined Metals battery-breaking plant (CX Plant) at Northfleet, Kent, UK [a]

Distance (km)		Total mass delivered (tonnes)				% By mass of scrap SLI transported			% Proportion of total mass delivered
Band	Median	Small truck [b]	Medium truck [b]	Large truck [b]	Total mass	Small truck [b]	Medium truck [b]	Large truck [b]	
1–80	40	541.23	8464.67	5091.51	14097.40	3.84	60.04	36.12	54.90
81–160	120	62.67	2751.29	203.95	3017.91	2.08	91.17	6.76	11.75
161–240	200	13.17	320.79	1277.93	1611.89	0.82	19.90	79.28	6.28
241–320	280	281.84	1982.31	2948.04	5212.19	5.41	38.03	56.56	20.30
321–400	360	2.20	56.04	404.94	463.18	0.47	12.10	87.43	1.80
401–480	440	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
481–560	520	1.76	10.82	158.83	171.41	1.03	6.31	92.66	0.67
561–640	600	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
641–720	680	0.00	8.42	305.11	313.53	0.00	2.69	97.31	1.22
721–800	760	0.00	31.79	723.79	755.58	0.00	4.21	95.79	2.94
801–880	840	0.00	15.80	20.43	36.23	0.00	43.61	56.39	0.14
881–960	920	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
961–1140	1000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Grand total (tonnes) 25679.30

[a] The data used in this assessment cover a representative period of battery shipments to the plant. Journey distances were estimated for trucks travelling along a mixture of urban and rural roads. Motorways and primary roads were chosen where available.

[b] The nominal capacities for the small, medium and large trucks were those used in the PEMS 3 database, i.e., 3.6, 16 and 30 tonnes, respectively. The database assumes that the 3.6 tonne trucks use gasoline fuel.

Table 2
Inventory of environmental burdens resulting from the delivery of scrap automotive batteries to the Britannia Refined Metals battery-breaking plant (CX Plant) at Northfleet, Kent, UK [a]

Distance (km)	Environmental burdens associated with the transportation of scrap automotive batteries to the battery breaking plant/1000 kg of batteries delivered						
	Total energy consumption (MJ)	Fossil fuel reserve depletion (kg)	CO_2 (kg)	NO_x (kg)	SO_2 (kg)	VOC (kg)	Dust (kg)
40	51.34	1.13	3.44	0.067	0.013	0.0122	0.0043
120	30.05	0.71	2.025	0.042	0.0088	0.00450	0.0026
200	19.37	0.44	1.31	0.26	0.0049	0.0040	0.0017
280	112.98	2.86	7.53	0.15	0.028	0.025	0.00917
360	9.36	0.21	0.63	0.013	0.0024	0.0020	0.00085
440	0	0	0	0	0	0	0
520	5.08	0.12	0.34	0.0068	0.0012	0.0011	0.00044
600	0	0	0	0	0	0	0
680	11.03	0.25	0.75	0.015	0.0027	0.0023	0.0010
760	31.86	0.70	2.17	0.043	0.0079	0.0067	0.0029
840	1.67	0.037	0.11	0.0023	0.00046	0.00030	0.00015
920	0	0	0	0	0	0	0
1000	0	0	0	0	0	0	0
Total	272.74	6.45	18.31	0.37	0.070	0.058	0.023

[a] VOCs are volatile organic compounds.
Note: the variations in the environmental burdens within each category with distance are due to the combined effects of the differences in the relative proportions of the total mass of scrap batteries transported by small, medium and large trucks and the relative proportions of the total mass delivered from each of the distance bands. As shown in Table 1.
There were no data for the distance bands of 440, 600, 920 and 1000 km. Therefore, the environmental burdens associated with them are zero.

design and assessment tool, the effect upon the environmental burdens of the following, plausible 'what if' scenarios were considered:

Scenario I using only small trucks for the transportation;
Scenario II using only medium-sized trucks for the transportation;
Scenario III using only large trucks for the transportation;
Scenario IV using large vehicles for all truck movements that are further than 160 km from the battery-breaking plant and retaining the same mix of vehicles sizes where the transport distance is less than or equal to

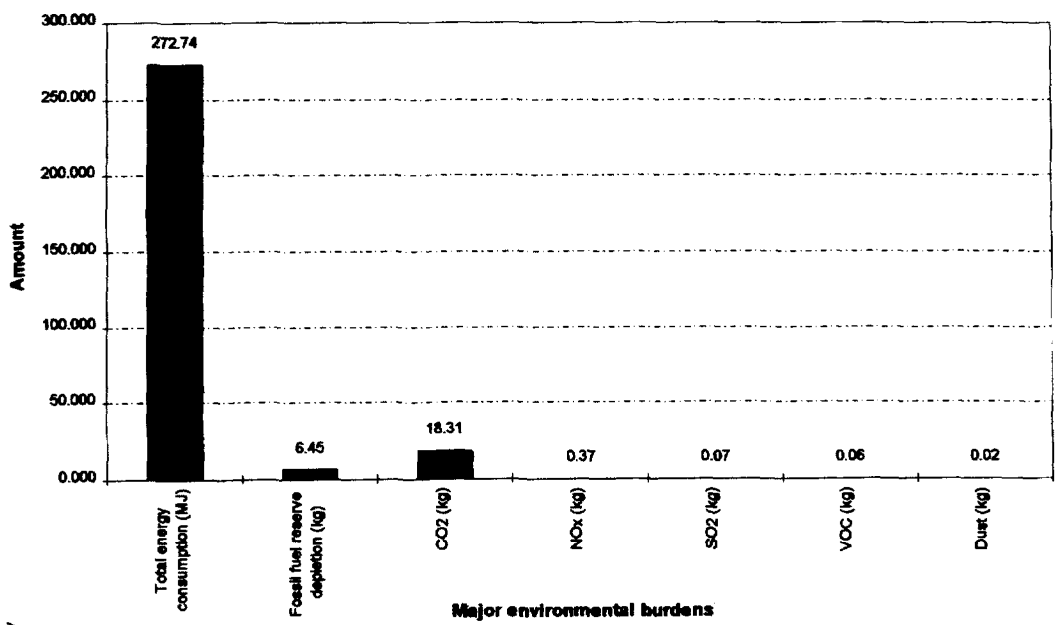

Fig. 3. The main environmental burdens currently resulting from the transportation of scrap automotive batteries to the Britannia Refined Metal battery-breaking plant (CX Plant) at Northfleet, Kent, UK.

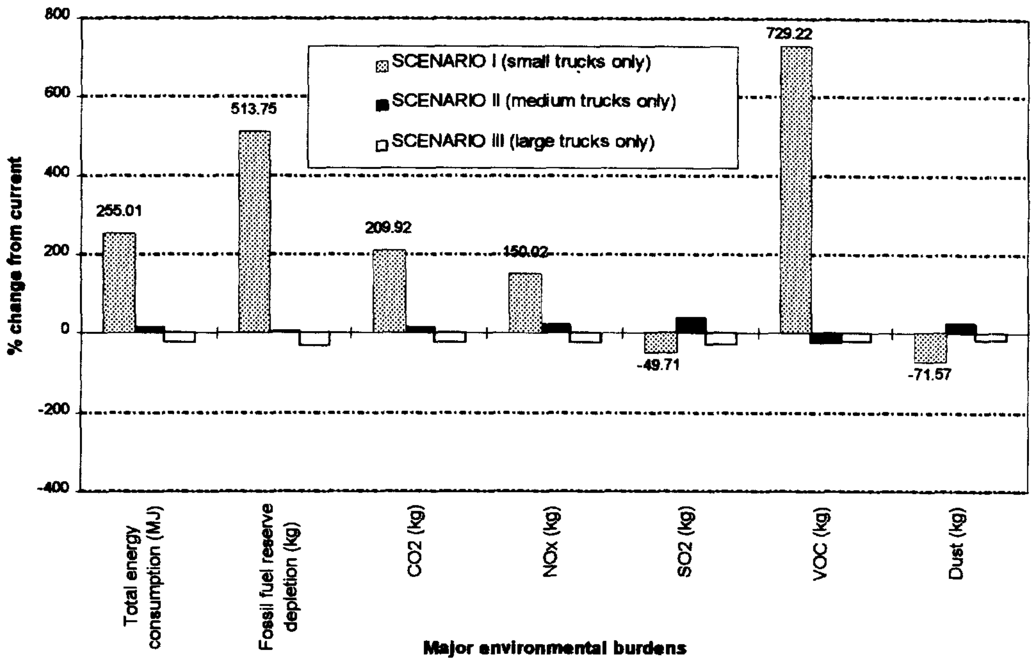

Fig. 4. Comparison of the relative affects on the environmental burdens of scenarios I, II, and III with the current situation.

160 km. (Scenario IV is essentially a compromise between the current situation and Scenario III.)

All of these scenarios represent choices that individual businesses and/or the whole industry may decide to consider. This could occur pro-actively or could be enforced upon the industry (as a result of the aforementioned societal pressures to improve environmental performance). The findings of each of the scenarios are summarized below.

The main environmental burdens arising from the current arrangement are illustrated in Fig. 3 [3].

7.3.1. Scenario I (Fig. 4)

Using only small gasoline-fuelled trucks would lead to significant reductions in SO_2 and dust emissions compared with the current situation. Therefore, the implementation of this scenario should reduce the SO_2 emissions arising from this transport stage. In all of the other major categories, however, it would lead to much greater environmental burdens. In the case of VOC emissions and fossil-fuel reserve depletion, it would lead to substantial increases (i.e., >700 and $>500\%$, respectively) [4]. Recently, there has been a growth in concerns about the effects of SO_2 on the environment and about the health effects of particulate emissions (i.e., dusts) from diesel vehicles. Since this scenario should lead to a reduction in these emissions, there would be an advantage in implementing it with regards to these two burdens. At present, however, the environmental and health concerns over VOCs, NO_x and CO_2 still probably outweigh the potential benefits of the SO_2 and dust emission reductions. Scenario I would also have the disadvantage of leading to increased running costs due to its increased rate of total energy consumption and fossil-fuel reserve requirements.

7.3.2. Scenario II (Fig. 4)

The use of only medium-sized trucks would lead to an increase in the environmental burdens in all of the major categories except for VOCs. Thus, there would be no particular advantage of such an approach unless the prime need was to decrease VOC emissions. If that was the main priority, then this scenario would be the approach to adopt since it would also result in only small increases in the rate of total energy consumption and fossil-fuel reserve depletion. This would also mean that it would only lead to a slight increase in running costs. Unfortunately, it does

[3] The data presented here and the scenarios chosen are intended to illustrate some of the basic assessment capabilities of LCA. Actual company data for the Britannia Refined Metals facility at Northfleet in Kent, UK, have been used. The environmental burdens resulting from the current transport of scrap automotive batteries to the plant have been identified and quantified using the PEMS 3 LCA solftware program and database. Thus, the reliability of the findings shown here is dependent both upon the company data and the PEMS 3 database. Whilst the authors are confident of the accuracy and reliability of the company data they have not, however, been able to assess the reliability and accuracy of the PEMS 3 transport database. Since these data are intended to be illustrative, however, possible inaccuracies in the PEMS 3 database will not affect the validity of the general assertions made in this paper. Nevertheless, if it to become a reliable design and assessment tool it will be necessary to evaluate the reliability and accuracy of all databases that are used.

[4] VOC emissions are emissions of volatile organic compounds. These are mainly but not exclusively hydrocarbons.

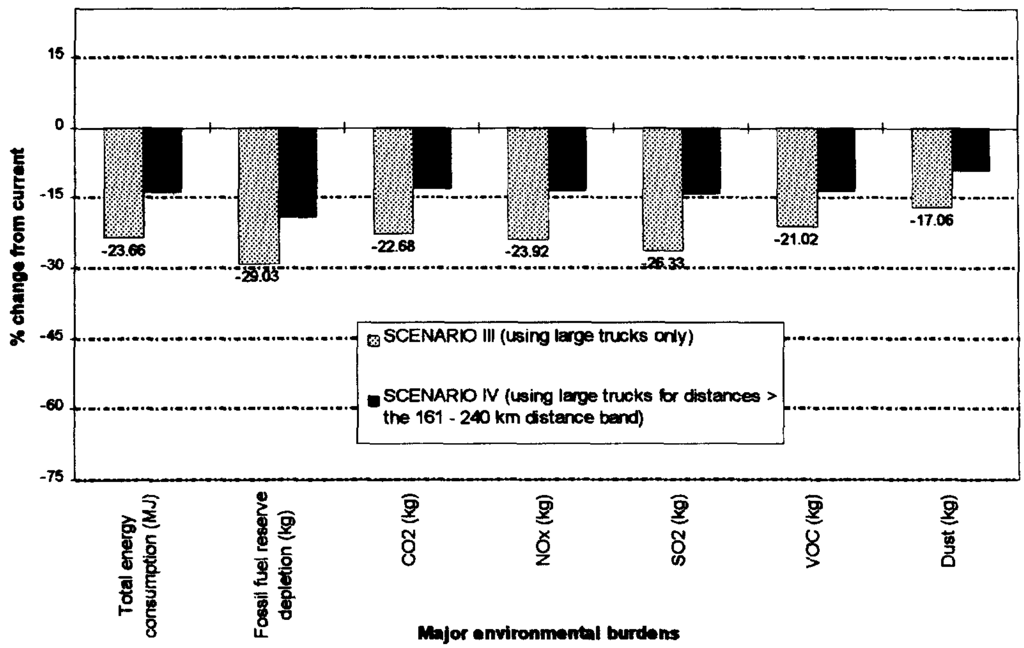

Fig. 5. Comparison of the relative affects on the environmental burdens of scenarios III and IV with the current situation.

have the disadvantage, however, of giving rise to the greatest increases in SO_2 and dust emissions of all of the scenarios.

7.3.3. Scenarios II, III and IV: (Figs. 4 and 5)

Scenario III would provide the greatest reductions in all major categories except for VOCs where scenario II would be slightly better. It would also be better than the compromise scenario (i.e., scenario IV) in all categories. Therefore, unless VOC emissions were the main priority, scenario III would be the best approach to adopt for both environmental and health reasons. Also, due to the fact that both the rate of total energy consumption and the rate of fossil-fuel reserve depletion would be less, the running costs would also be reduced.

These scenarios demonstrate that where there are reductions in all burdens, it is relatively easy to determine whether the option is an environmental improvement. Where it is better in some categories but worse in others, (as in some of the scenarios above), value judgements will have to be made to decide which burdens are the most important. Such judgements will be influenced by demands from national governments, industry regulators and from the pressure of public opinion. All of these are interrelated and are expected to evolve as a result of the changing concerns of society.

These simple comparisons are currently restricted to the transportation stage, since that is the only area where data have been collected and assessed. The authors' aim is to produce a tool which will allow 'what if' scenarios to be applied across all of the different stages of the life cycle. Once developed, the tool will make it be possible to reliably measure the environmental burdens arising from the life cycle of the automotive battery and to evaluate the overall environmental benefits of any changes to the life cycle. Such assessments will not be possible until the whole life cycle has been assessed.

Environmental burdens may also be evaluated by aggregating inventory data (such as that in Table 2) into categories according to their potential environmental impact. For example, individual burdens could be assessed according to factors such as their: (i) global warming potential; (ii) ozone depletion potential, and (iii) human toxicity, etc.

It should be noted, however, that different burdens generally have more than one environmental impact and also the relative contributions to the impact varies according to both the burden concerned and its location. Therefore, burdens are sometimes assigned different weightings and then their combined effects are calculated.

This form of impact assessment is considered to be contentious and is expected to remain so. Despite this, the authors believe that such an approach would provide the lead industry with a valuable vehicle for arguing its environmental case in terms that are understandable to all concerned parties. It would also help the industry (and society in general) to choose their priorities when trying to decide which environmental burdens are the most important to reduce.

8. Concluding comments

This paper has argued that not only have the threats facing the industry intensified, but that they have also become more fundamental. This has occurred as a result of profound societal changes which are certain to continue.

The industry has much to lose. Its future rests, however, to a significant extent within its own grasp. Nevertheless, to successfully meet the new challenges will require a significant change in the manner in which it conceives the threats that are facing it. Full commitment and practical support for a much more integrated form of approach, that employs LCA and systematically evaluates all of the techniques for measuring and characterising emissions, is needed.

The industry has already demonstrated that it can work pro-actively. For example, many companies have adopted their own exposure indicator limits for their workers that are lower than statutory requirements. This pro-activity now needs to be extended to a full commitment to a more integrated approach. LCA will provide a highly effective and key tool in this approach, but its effectiveness could be limited by an unwillingness of different businesses within the life cycle to share their data and information. This should not be insurmountable since it should be possible to develop appropriate confidentiality agreements to ensure that the data cannot be used as a tool for discrimination between different suppliers and customers. An active commitment to set up and maintain a 'live' (i.e., continually updated) database within the industry is vital. The industry will have to do this itself since the evidence points to the fact that the onus of establishing the environmental credentials of products will be placed increasingly on the industry itself. The better the quality and the more in-depth the data, the better the LCA will become as a tool to fight the environmental battles, and the better it will be as a design and assessment tool. The authors' research project will provide the basis for this database but it will only be directly applicable to the UK automotive battery life cycle. Also once it is complete, it will be up to the industry to continue its development and keep it up to date. Thus, as an urgent priority, the industry internationally needs actively to commence the collection of data in a form that is suitable for the creation of LCA-type databases for all of the products it intends to defend. This commitment will also need to be actively sustained.

The perception of the industry that it is under threat is also part of the problem. It needs to try to work co-operatively to try to develop new forms of communication that will develop trust and consensus with the global community. This will not be easy. Nevertheless, the industry has everything to gain as well as lose from the success or failure of this process.

Finally, it needs to be noted that the integrated strategy which has been outlined in this paper has been developed by the authors to enable the industry to meet the current environmental challenges and those likely in the short-to-medium term. In addition, the industry needs to ensure that is aware of the more long-term challenges and that these will evolve with time. Thus, the integrated strategy outlined herein will need to evolve simultaneously and pro-actively with the changes that will occur in society. If the strategies do so, they should ensure that the industry continues to be fully prepared to meet any challenges that face it.

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