

# Subjects in and Approaches for Life Cycle Design

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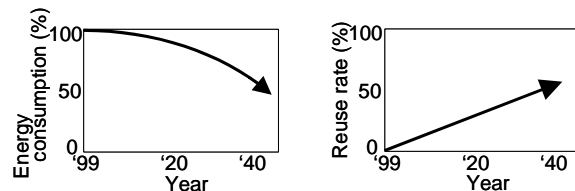
## Abstract

*In order to solve environmental issues, it is necessary to realize a sustainable development society. This can only be accomplished by achieving a circulating-society through a change in both material flow and a reduction in energy consumption. "Life-cycle design" is an important approach that is expected to have a significant positive effect on tackling/solving this difficult issue. However, there are certain fundamental reasons why environmental issues are difficult to solve. In this paper, we begin by discussing the issues which make it difficult to solve environmental problems. Based on this discussion, we proceed to present an approach essential to arrive at a timely solution. Examples of our current achievements are introduced and important future problems and approaches to be taken are discussed.*

## 1. Introduction

Environmental degradation, including global warming, water and soil pollution, ozone layer depletion, and exhaustion of natural resources, is progressing rapidly. Although accurate estimations of the trends and impacts of these phenomena are difficult, the effects are expected to become significant and serious for humans within several decades. For example, if the following are not realized within 20-50 years, the world could be seriously damaged.

- A 30 - 70% reduction in energy consumption per capita



**A drastic improvement is necessary!**

Fig.1 Examples of material & energy consumption reduction

- A 20 - 50% reuse rate of virgin materials (maximize the reuse rate of materials and parts).

If this forecast is correct, radical improvement, as shown in the Fig. 1 examples, is required very shortly. This can only be accomplished by achieving a sustainable-society through a change in both material flow and a reduction in energy consumption.

Even though we aware that the time frame in which this must be accomplished is very short, to date, the implementation of countermeasures to address this issue by society has been too slow and the scale of such measures too small. More effective and drastic countermeasures must be executed with a very high degree of urgency. A significant step toward achieving this goal involves drastically changing the life-cycle of industrial products and the flow and consumption of materials and energy in order to establish a sustainable society.

When addressing this issue, there a number of fundamental reasons why environmental problems are difficult to solve. The environmental issue has a very complex set of

characteristics which include social, cultural, technological, and economic factors. Consequently, the environmental issue is one of the most difficult problems that the human race has ever faced.

Environmental problems are basically attributable to excessive consumption of materials and energy, as well as the irrecoverable flow of materials. Therefore, in order to solve these issues and realize a “sustainable society” model before irrecoverable damage occurs, drastic reductions must be realized in energy and material consumption and the cycle of material flow in society must be changed significantly so as to become a closed cycle. In order to achieve this, diverse and radical changes are required in the processes of production, use, maintenance, reuse and recycling, and disposal, so as to minimize environmental impact and natural resource consumption. This is not an easy task. Although these problems cannot be solved through technological advances alone, without technological breakthroughs, no solution will be satisfactorily effective.

“Life-cycle design” is an important approach that is expected to have a significant positive effect on tackling/solving this difficult issue. Although many problems must be solved in order to realize this, the authors regard “life-cycle design” as an orthodox approach to providing an effective and concrete counter-measure.

In this paper, the authors initiate the discussion by focusing on the issues that represent obstacles to solving environmental problems.

## **1. Characteristics of environmental issues and specific subjects to be addressed**

The reasons why the environmental issue is difficult to solve can be summarized as follows:

- (1) Environmental degradation progresses very slowly,
- (2) There is a long time interval between the event that causes an environmental problem and the appearance of the resulting damage,
- (3) There are many contributing factors, and the relationships and interactions between individual factors are very complicated and have yet to be explained clearly.
- (4) The social economy, in particular market mechanisms, makes finding a solution difficult.

The problem is then a highly intensive “concurrent engineering” issue. Therefore, the latest, most sophisticated manufacturing

engineering systems, system technologies, and information technologies must be fully utilized. To this end, “life-cycle design” is a powerful candidate for providing a solution to this problem.

Life-cycle design is defined as the design and management of a product throughout the product’s life-cycle, including the circulation of materials, energy, money and value, and information and knowledge. Therefore, broad-perspective activities for executing production, use, maintenance, reuse and disposal in a manner that minimizes environment impact and the consumption of natural resources are included in, or related to, “life-cycle design”.

Some examples of existing technologies that are related to “life-cycle design” include:

- Product design and development of materials, processes and facilities aimed at conserving energy and natural resources and reducing the circulation of resources.
- Development of new materials or manufacturing processes that does not involve harmful or environmentally hazardous materials.
- Development of information systems for administrating the maintenance of constructions such as buildings, and road.
- Process, facility and system for recycling end-of-life artifacts.
- Conversion of industrial products, which can be regarded as a material object, to a conveyor of a “service”.
- Activities toward encouraging consensus among various layers in society with respect to the more reasonable sharing of the cost of realizing sustainability.

These activities are positively promoted at progressive companies because such policies are expected to result in business advantages in the long run. These activities are regarded as bringing not only a reduction in environmental load, but also an improvement in the product’s image through longer life and reduced life-cycle cost due to lower running and maintenance costs, etc.

However, the prevalent “attitude” toward the environment at present is not sufficiently aggressive to solve the issue on the society scale. In order to build a truly circulating society, it is necessary to realize a social system that adopts a much higher level life-cycle design based on the new concept of material flow. In such a system, all products and parts must be reused “in full” as long as effective functions and applications remain.

In order to realize the full circulation of artifacts such as

consumer durables, it is necessary to simultaneously achieve both high-quality circulation (high recycling rate and most efficient utilization of products with low energy consumption and no pollution) in order to reduce environmental impact, and a reduction in circulation cost. For this purpose, the following are necessary or effective countermeasures:

- (1) Upgradability and longer life design.
- (2) High-level reuse of parts and materials.
- (3) Perfect closed-loop material flow to prevent leakage throughout the life cycle of products.

As mentioned before, the problem is a highly intensive "concurrent engineering" issue. Therefore, system technologies, and information technologies must be fully utilized. The relevant important approaches that should be adopted are summarized as follows:

- (1) Designing the product such that the product can be handled easily at various steps during its life time.
- (2) Preparing product information and process information for the maintenance, reuse and recycling of products.
- (3) Developing collection and processing systems that utilize information for a product's maintenance, reuse, and recycling, and constructing an information system that supports the process.

A number of recent application examples in this field are introduced in the following chapter.

### **3.Design technologies and information systems related to realization of circulating society**

#### **3.1 Recyclability Evaluation Method[1]**

Recycling of industrial products at end-of-life is an urgent problem that has significant influence on society. Due to the shortage of dumping sites and pollution problems, recently in Japan, legislation has been passed to promote recycling such as the Home Appliance Recycling Act.

In order to realize good quality and efficient recycling of end-of-life products, it is essential to design the product so that it is easy to recycle. The Recyclability Evaluation Method (REM) was developed to support such designing process.

This method was developed so that not only ease of disassembling, but also recycle processing can be assessed in a quantitative manner. A practical design evaluation method was

realized based on the development of an evaluation scheme. An automatic estimation function of the recycling process, a process model, a well-organized recycle process database, and convenient calculation software were prepared, and its accuracy and applicability was tested. The evaluation method is outlined below.

To begin with, the most popular recycling methods in use five to ten years from now were presumed and adopted because products currently being designed will come to the end of their life in five or ten years time.

In order to obtain an accurate evaluation from simple input information, an internal estimation system was developed. Elemental data is substituted into this detailed process plan, and cost estimation and recyclability index calculation are made. The output information is composed of various indices useful for go/no go judgement, identification of weaknesses and improvement effect, etc.

The accuracy of the method was tested and it was found that the error in the disassembly operation time of individual parts for various products is within  $\pm 20\%$ .

This method has been applied to many products including home appliances, AV products, information equipment and industrial machinery, within and outside of Hitachi, and in all cases produced excellent results. Used in combination with other methods, i.e., the Assemblability Evaluation Method (AEM) [2] and the Assembly Reliability Evaluation Method (AREM)[3], a comprehensive design evaluation support system that covers broad life-cycle processes is realized.

#### **3.2 Information system for circulating and recycling manufactured products**

As key-technologies for a circulating society which will take the place of the present "large production-consumption-disposal" society, prototype information systems were developed. Advanced reuse and correct processing of end-of-life industrial products by exchanging recycling information between users, manufacturers, recyclers, etc., will be realized, thus realization of circulating economy society based on more appropriate, efficient material saving and right recycle processing are supported.

These systems have been developed with the support of the Ministry of International Trade and Industry, the Inverse Manufacturing Forum, the Mechanical Systems Foundation,

and the Manufacturing Science and Technology Center, and with the cooperation of various companies.

**(1) Inverse Manufacturing Ecological Information System[4]**

The goal of this system is to make the recycling process more economically feasible. The purpose of this prototype system is to test the technological feasibility of data exchange between manufacturers and recyclers, to make recycling of products easier and to conduct more appropriate, efficient and low-cost recycling processes.

By utilizing this pilot system, the possibilities and problems to be solved were confirmed. The developed technology will be practically available after reliability testing and development of various application systems. However, it is expected to contribute to the establishment of high-grade economical recycling.

**(2) Inverse Manufacturing Information System[5]**

The goal of this system is to establish the circulation manner for not only manufacturing and recycling but the entire product related activities. This prototype data exchange system connects various industries and these industries and the consumer. In order to accelerate recycling/reusing in the inverse manufacturing society, we have included a function that offers necessary life-cycle information to everyone in society. An upgrade service and maintenance as well as product and recycling that satisfy the consumers' needs are provided. In addition, information exchange through the Internet of the demand and offer of parts for reuse, use and recycle, etc. was realized. Figure 3 shows the basic functions of the product user, manufacturer, distributor, etc., and information flow between them.

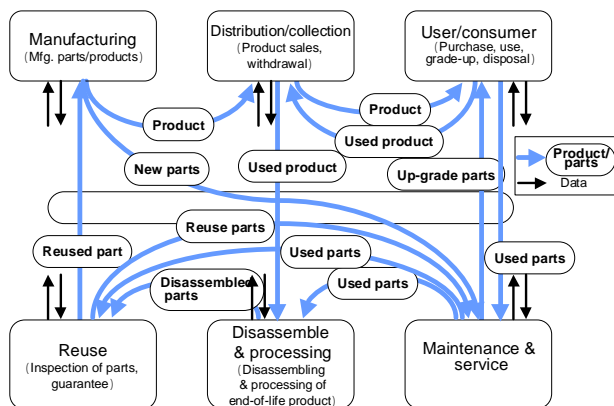


Fig.2 Information flow in the Inverse Manufacturing Information System

**4. Necessary Policy and Future Problems**

Currently, life-cycle design addresses a portion of the environmental issues. Many major subjects remain to be addressed. As mentioned in chapter 2, environmental issues are usually not regarded as very high priority issues by either manufacturers or consumers due to the nature of the problems. As a result, countermeasures tend to be put off and delayed.

**4.1 Problems to be considered**

The following problems must be considered in order to achieve a circulating society:

- (1) Due to complicated relationships and interactions between individual factors, it is difficult to define a quantitative target value for the countermeasures.
- (2) Individual countermeasures of various sections interfere with each other, and as a result each countermeasure policy is limited. Bottom-up type countermeasures are not effective in this situation.
- (3) Environmental issues are inter-generational. However, the generation that has to live with any damage does not have the opportunity to influence relevant decisions or policies at the time these are made.
- (4) In the market, the value placed on "environment", "materials", and "energy" is too low compared to the cost of human labor.
- (5) Investment and expenses for the environment might tentatively cause economic recession. Conventionally, consumers tend to buy conveniences or amusements for the present. If consumers have to spend money on the environment and natural resource preservation, this will reduce their short-term satisfaction, and hence reduce the consumers' desire to buy and in turn industry will worry about the effect on the economy. It is important but difficult to accomplish the social *transition* from a conventional social structure to a less material and energy

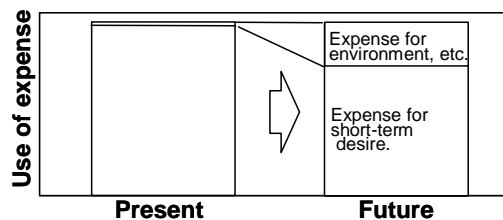


Fig. 3 ECP reduces short-term desire of consumers

dependent structure “without decelerating the economy.”

(6) Consensus has not yet been made who should endure the burden of environmental issues. Eventually, the consumer and society should (by including it in the price, or through a deposit system). But are consumers willing to pay for this added expense? *The problem becomes how to divide our resources or wealth* in order to satisfy our needs and desires.

(7) The solution must satisfy national differences. The countermeasures must be considered in a way to overcome these conditions.

Therefore, the responsibility assumed by the present generation must be taken very seriously.

#### 4.2 Approaches to be adopted

To ensure that the activities of the present generation are undertaken with sufficient urgency, the following principles must be considered:

(1) Target setting and achieving social consensus

Prepare reasonable arrangements to **enduce** society (consumer) and private enterprises to become completely environment oriented.

(2) Arouse public opinion and awareness in order to initiate/accelerate policy change by industry. Here, governments and social opinion leaders such as university professors should take the lead.

(3) Technological advancement toward realizing a sustainable society must be considered together with corresponding political, legal and economic incentives or circumstances.

(1) Leadership by government is essential.

A pioneer in this field once insisted that “Environmental issues are a kind of war. The government (not municipal government only) should take the lead.” This statement certainly expresses the nature of this issue. As this issue is getting much more important as national strategy, the active leadership of the government is required.

Influencing governmental policy through closer research ties with the international community is very important.

Based on the above mentioned concept, the countermeasures should be deployed more concretely in the following order:

(1) Target setting and establishing social consensus

To begin with, a major social movement must be initiated. Here, the behavior of society must be modified according to an

accepted social model.

It is considered essential to establish “quantitative targets” for society. The push toward environmental consciousness and the development of policy without a realistic target has not only less meaning but may even lead to a misleading impression of the progress of environmentalization. Although it is very difficult to provide accurate target values, an example of a realistic system may be a value reached by a consensus of 80% of relevant specialists. The specialist may be obligated to reach this consensus, and keep the public adequately informed and educated. As the target will affect the strategy to be adopted, target setting will be very important. Even if the accuracy may be not enough, agreeable tentative figures should be proposed by concentrating the best knowledge and wisdom available at the time, and based on this consensus, determination of betterment target, the technology improvement target, and total system design of the circulating society to be achieved should be proposed. This is the most important subject.

(2) Contrivance to move industrial enterprises is required.

Industrial enterprises are entities that offer product choices to consumers, and actually introduce products into society. As such, from an environmental perspective, industry has a tremendous responsibility. However, the ability of industry to realize the desired reform is limited by the fact that companies must earn a profit and reward their stockholders. Furthermore, industries are concerned that:

- Consumers do not necessarily appreciate enterprise initiatives based on long-term goals.
- Consumers often behave differently to their stated opinions, basing product preference on factors other than environmental consciousness.
- There is no apparent social target, and it is usually difficult for individual enterprises to set their own goals.

Therefore, the following steps must be taken to move industry by establishing a positive relationship between the enterprises that offer product choices and the consumers who are willing to support such enterprises through positively purchasing environmentally conscious products. In order to stimulate

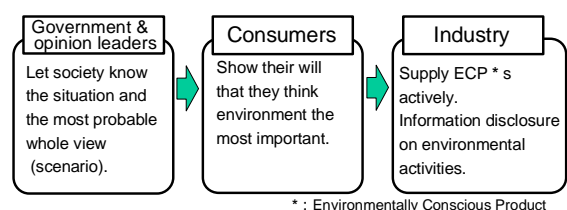


Fig.4 Steps to move the society

industry to act in an urgent manner by assigning a higher priority to the long term benefits, the following (Fig.4) must (eventually) be realized in order:

- (a) The majority of consumers must adopt an environmentally conscious way of life and way of thinking. Product purchasing and offers that satisfy personal environmental considerations should be given the highest priority, thus supporting enterprises with the most progressive environmental image.
- (b) A very persuasive explanation of the future forecast on environmental issues and governmental and industry policy must be given in order to instill a personal will for change in consumers.
- (c) Government, specialists and opinion leaders should adopt a “best efforts” policy to clearly show and explain to consumers the future forecast and target to be achieved, as well as establish a “grand design” for the sustainable society.

At the same time, it should be emphasized that even for industry, the soft-landing approach of earlier action must be regarded as preferable to the forced catastrophic change that will be imposed if the situation continues unchecked. The authors would like to ask specialists from universities and public research organizations to speak out and take the lead much more in reforming social opinion.

Although the present generation must adopt an extremely drastic change in lifestyle and also economic expenditure in order to solve the environmental issue, a firm social consensus with respect to recognition of the situation and the efforts aimed at solving the issue will be realized.

In addition, a grand design must be constructed. In such a design, an action plan must be included. As environmental issues are influenced by many factors, and as countermeasures must be promoted by many sections in a cooperative manner, a system design approach is essential.

In a system design approach, the following are important:

- (1) A quantitative target should be set.
- (2) Top-down assignment, not bottom-up determination, is preferable.
- (3) Planning and evaluation is the essence of the work. This is a major point; environmental projects are, fundamentally, very different in nature from usual development projects.
- (4) In such projects, when making proposals, members are requested to at all times adopt an overall view in order to

achieve the optimum global solution. Specialists must spend most of their time performing coordination work. For this kind of project, a system engineering approach is required and for this purpose competent system engineers from private companies would be most effective. Therefore, the participation of private-sector systems engineers must be encouraged even in government planning projects.

As mentioned in chapter 2, the reason why the environmental issue is so difficult to solve is because it includes social, cultural, technological, and economic factors. The economic questions that must be answered are:

- (1) How to move from a material and energy dependent economy to a much less material and energy dependent economy without decelerating economic growth?
- (2) Market prices of materials and energy are too low compared to labor costs. How to increase the value and market price of energy and virgin materials and maintain a good balance with human labor cost?
- (3) How to create a new business model which is less dependent on material and energy consumption? A simple shift to information- and service-oriented business generates too much cheap and low quality recycled materials, and is not a solution for the society.

Needless to say, the environmental issues cannot be solved within any one country. The concepts of “Factor 10” and “Factor 4” are valuable. However, international compensation between developed countries and developing countries that depend on natural resource production must be carried out.

## References

- [1] To be presented at EcoDesign '01.
- [2] Ohashi, T.; Development of Producibility Evaluation Method; PEM, Trans. JSME, Vol.67 No.655-C, pp.888-895.
- [3] Suzuki, T., et al.; Assembly Reliability Evaluation Method, Proc. 00 Int. Conf. DFMA,
- [4] Ohashi, T., et.al.; Proceedings Ecological Information System, EcoDesign '99, pp.143-147, Fe. 1999.
- [5] Sugimoto, Y., et. al.,; Study on inverse manufacturing recycling information system (in Japanese), Proceedings of EcoDesign '00 Japan Symp., pp.238-239, Dec. '00.

Additional considerations (added in 2002):

1. The importance of adult environmental education

The importance of education in teaching environmental issues to young generations is broadly argued. Logic suggests that young generations are free from a way of life that depends on excessive consumption of material and energy, while it is difficult to educate adults who are accustomed to such a lifestyle. However, we have to consider the contradiction contained in this logic. It is important to consider the following.

- (1) Adults largely decide what to buy and how to spend money in society. They tend to give priority to their own desires over the social rights of their descendants.
- (2) Young generations will continue the trend of misusing environmental resources that should be maintained for future generations until real sustainability is realized. Therefore, as they get older they will face more serious environmental conditions than the ones they experienced as children. This will lead to difficulties for future generations in that they will be required to address environmental conditions that they did not actually create.
- (3) If adults force young generations to do what they themselves will not undertake, it will result in ethical problems.

Therefore, although it is important to provide environmental education to younger generations, it is also essential at the same time to provide sufficient environmental education to adults. If it is necessary to provide very firm motivation to guarantee necessary efforts to act for future generations, how can this be achieved? Perhaps the only possibility is to rely on parental affection for children and grandchildren.

2. A simple shift to information- and service-oriented business will result in another problem

Due to technological limits, the quality of recycled materials is not as good as new materials. Market needs for out-of-date products, parts and materials might thus disappear. Because of this, continued recycling under present market conditions will only result in a large amount of useless recycled materials. A fundamental solution would be to create a market price adjustment mechanism for new and recycled materials. This could be accomplished through the enactment of an environmental taxation system. Such a system would also be effective in maintaining a balance between human labor cost and material and energy cost.

3. Providing satisfaction without using large amounts of material and energy

In order to solve environmental problems, North-South relationships must be overcome. This will be a very difficult problem to solve. It is true that a very large number of people living today face great hardship with respect to their daily living conditions. Such people are hardly in a position to give serious consideration to future generations. The only idea we can propose to address this issue is to utilize the five steps of desire concept developed by A. H. Maslow. Perhaps the progress that needs to be realized will be based on equality in the rate of improvement in individual countries. This might offer the only possibility for achieving equality in terms of satisfaction obtained through improvement in living conditions.