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CERAMICS AND THE ENVIRONMENT

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INTRODUCTION

It is an honor and a pleasure to have been invited by the meeting organizers to present this lecture on ceramics and the environment as part of the larger theme of the role of ceramics in a self-sustaining environment for this Second Forum of the Academy of Ceramics.

I wish to dedicate this presentation to the memory of a friend and colleague, Professor Malcolm G. McLaren, 1993-1996 President of the Advisory Board for Science of the Academy of Ceramics, whose sudden passing on April 12, 1996, left an enormous void in the world of ceramics.

Ceramics does indeed have a key role to play in a self-sustaining environment, both in terms of minimization of wastes in the ceramic industry as well as a reduction in environmental contamination, making use of the principles of industrial ecology. The role of ceramics is perhaps unique in that beyond being the products of an industry, subject to waste minimization techniques, ceramics is also an enabling technology, able to facilitate industrial ecology in virtually all technologies and industrial manufacturing processes. (A perfect example of the latter is provided by the Corning, Inc. ceramic catalytic converter substrate, being recognized at this meeting as a recipient of the 1996 International Ceramics Prize.)

Progress is being made in reducing industrial wastes and associated pollution in the ceramics and glass and other industries but the problems are complex with each material having a different set of problems. "Industrial Ecology" and "The Greening of Industrial Ecosystems" have recently emerged as conscious effort to assess the current situations and to propose means of achieving waste reduction and a cleaner environment.

As Laudice has pointed out, "Industrial ecology views industrial processes and products as part of larger ecological systems and seeks to design products and processes which are synergistic with and benign to the environment."[1] Recent studies by the U.S. National Academy of Engineering[2-4] have stressed the industrial ecology approach and, for example, have summarized: "....the reshaping of industrial systems for environmental success is based on efficient use of materials and energy, substitution of more abundant and environmentally preferable materials for those that are rare or environmentally problematic, reuse and recycling of products and materials, and control of waste and emissions"[2].

Steps towards "green products" and "green processes" have recently been taken in the ceramics and glass industries, as well as in the related electronics and automotive industries and examples of these are cited.[5] Even more recently, an integrated perspective has been provided for basic research needs for environmentally responsive technologies of the future,[6] including the chemical , automotive, electronics, energy and metals industries and highlights of this perspective will also be outlined.

INDUSTRIAL ECOLOGY – A DEFINITION AND PROSPECTIVE

Industrial ecology is the study of the flows of materials and energy in industrial and consumer activities, of the effects of these flows on the environment, and of the influences of economic, political, regulatory, and social factors on the flow, use, and transformation of resources.[2] The objective of industrial ecology is to understand better how we can integrate environmental concerns into our economic activities.[2] "This integration, an ongoing process, is necessary if we are to address current and future environmental concerns".[2]

Industrial ecology provides an integrated systems approach to managing the environmental effects of using energy, materials and capital in industrial ecosystems.[3] According to Frosch and Uenohara,[3] "to optimize resource use (and to minimize waste flows back to the environment), managers need a better understanding of the metabolism (use and transformation) of materials and energy in industrial ecosystems, better information about potential waste sources and uses, and improved mechanisms (market, incentives, and regulatory structures) that encourage systems optimization of materials and energy use."

INDUSTRIAL ECOSYSTEMS AND INDUSTRIAL METABOLISM

The global industrial ecosystem, which is the result of human economic activities, is a component of the more complex, finite, global natural ecosystem.[3] The natural ecosystem serves as a source of materials and energy for global economic activities. It also serves as a "sink" for discards from the economy, and as a sink, it absorbs, assimilates, and transforms the waste from human activities.[3]

The analogy between such industrial activities (indeed, the whole economic system) and the metabolism of biological organisms is obvious: An organism ingests energy-rich, low-entropy materials (food), to provide for its own maintenance and functions, as well as a surplus to permit growth or reproduction.[2] The process also necessarily involves excretion or exhalation of wastes outputs, consisting of degraded, high-entropy materials.[2] (In the vernacular of the best selling book by Taro Gomi, "Everyone Poops"[7]).

As Ayres points out,[2] industrial metabolism is the whole integrated collection of physical processes that convert raw materials and energy, plus labor, into finished products and wastes in a (more or less) steady-state condition. This is shown in Figure 1, entitled "What is industrial metabolism?"

The supply side, by itself, is not self-regulating. The stabilizing controls are provided by its human component[2]. This human role has a direct (labor input) and indirect (consumer of output) aspect. The system is stabilized by balancing supply and demand for products and labor through the <u>price mechanism</u>. Thus, the economic system is, in essence, the metabolic regulating mechanism.[2]

Ayres also points out that the concept of industrial metabolism is equally applicable to nations or regions, as well as to manufacturing enterprises or firms.[2] The analogy is further useful in focusing attention on the "life cycle" or "materials cycle",[2] although natural earth cycles are

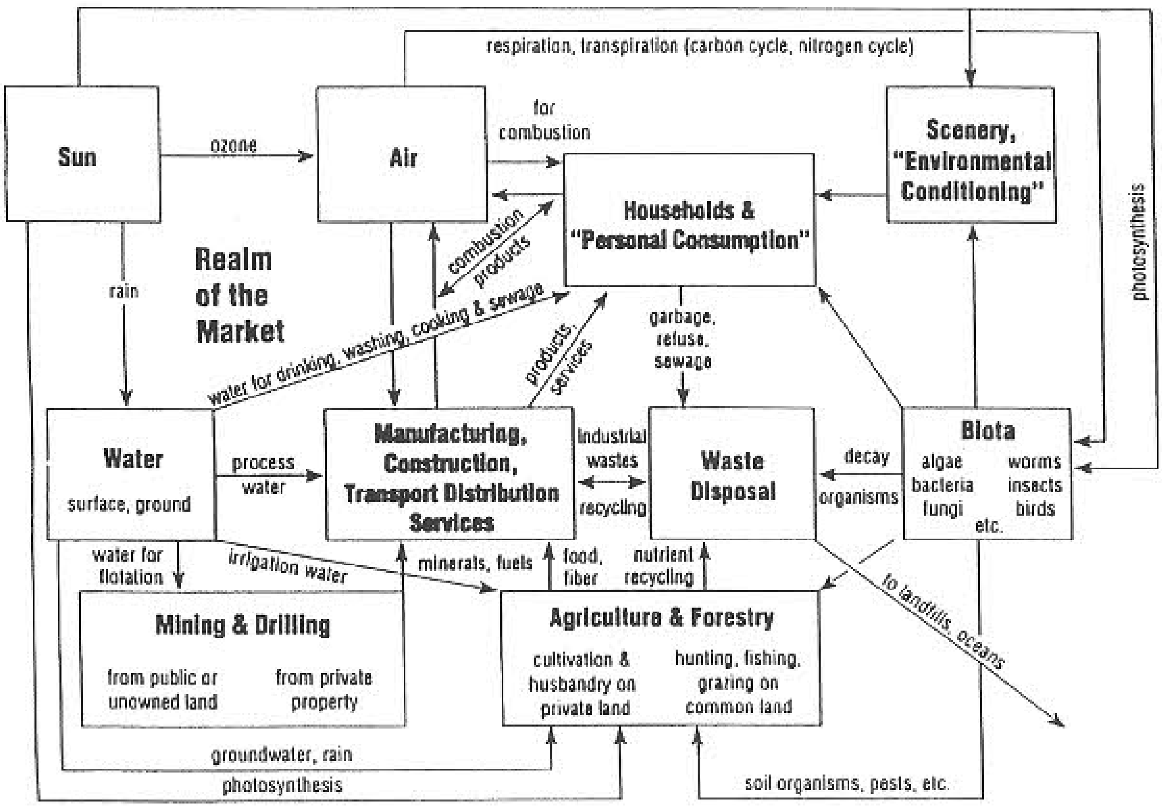


FIGURE 1 What is industrial metabolism?

closed, whereas industrial cycles are open, i.e., the industrial system does not generally recycle its "nutrients", but rather, high quality materials are extracted from the earth and returned to nature in degraded form.

In Figure 2, Frosch and Uenohara[3] further relate the finite global ecosystem to the growing economic subsystem (after Goodland). A growing population places greater demand on the environment, and industrial countries face the challenge of minimizing the environmental degradation to below sustainable levels.[2] According to Uenohara,[2] this will allow "developing countries to advance and developed nations to maintain living standards in environmentally sustainable ways". And technology is critical.

TECHNOLOGICAL ADVANCES PLAYS CRITICAL ROLE

As Frosch and Uenohara have stressed,[3] technological advance can play a critical role in transforming industrial ecosystems. While technological advance is sometimes referred to as an evolution, human artifacts such as technology do not evolve.[3] "They are pushed in different directions by the decisions of inventors, manufacturers, marketers, and users, people who have economic, social, and cultural- as well as practical-reasons to remake technology in ways that serve them best. As environmental concerns grow, environmental considerations will increasingly be integrated into technological innovation.[3] Wantanabe, for example, has shown that the substantial growth of the Japanese economy in the last 20 years, despite sharp energy constraints, was due to the substitution of technology for energy.[3]

Technological innovation has also lead to dramatic changes in the type and use of materials- especially ceramics and glasses - in the 20[th] century. Advances in materials technologies have contributed to "environmentally beneficial economic growth". "New processing technologies, more sophisticated materials, and improved product design have resulted in more efficient use of materials. This trend suggests that economic growth need not be accompanied by increased resource use."[3]

INDUSTRY CONTROLS FLOW OF MATERIALS AND ENERGY

As a principal producer of goods and services that fuel the economy, industry is in a position to control the flow of materials and energy, according to Frosch and Uenohara. "…..industry plays a critical role as an agent of environmental improvement. Industry has traditionally responded to environment demands by complying with regulations, controlling emissions from plants, and managing waste disposal. As society focuses on the environmental fate of obsolete products, the implications of product stewardship are growing in importance. Produce recycling and reuse and life cycle approaches are emerging industry practice."[3]

Flow rates of ceramic and glass materials are being lowered by more efficient use. Historically, materials have either been disposed of as waste, recycled, reused, or lost dissipately. Waste disposal is being increasingly regulated and recycling requirements are growing. In the U.S., recycling to manage solid wastes is growing, whereas in Japan and Germany, for example, recycling of entire appliances and durable goods is also occurring. "Cradle-to-grave" or "take-back" legislation is being enacted and methods such as "life cycle assessments" are being used to evaluate the environmental consequences of a "product, package, process or package."[4] For example, limited implementation of life cycle design considerations at Xerox Corp. saved $50 million in one year.

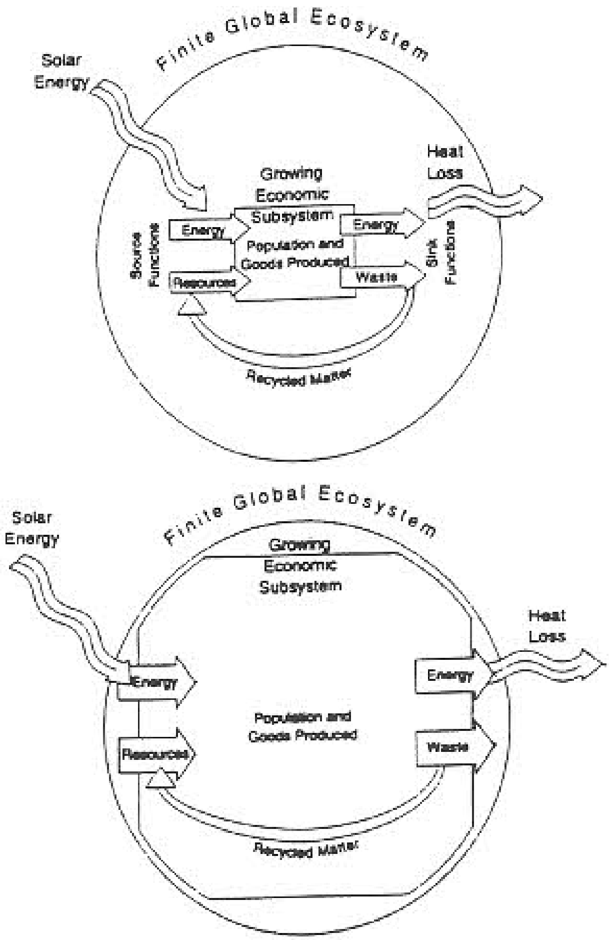


FIGURE 2 *The finite global ecosystem relative to the growing economic subsystem. SOURCE: Goodland (1991)*

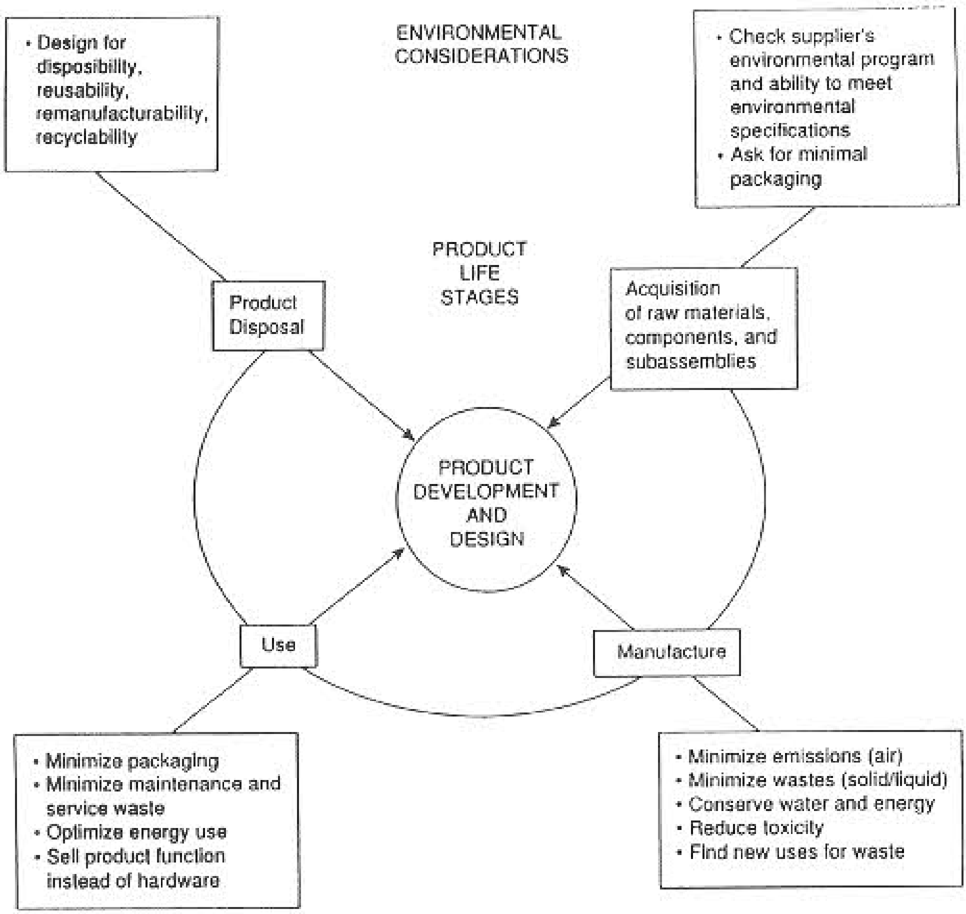


FIGURE 3 *Incorporating environmental considerations in product development and design.*

Figure 3 shows many of the factors and strategies to consider in improving the environmental life cycle attributes of products.[4]

RECYCLING OF MATERIALS

Recycling has long been an integral part of several industries, such as steel, aluminum, and the glass industry (cullet). Steel scrap recycling is as old as the steel industry itself. Similarly, nearly 75 per cent by weight of a discarded automobile is recycled by well established processes. The remaining 25 per cent, however, which amounts to about 600 pounds per car, ends up as waste (known in the industry as "fluff") and is buried in landfills. (Fluff consists of about 30-40% plastics, 15-20% fluids, 15-20% glass, and 10-20% other materials.[2,3])

Table 1 Kind and amount of industrial waste used in cement industry of Japan (1990)

Category	Kind of industrial waste	Amount of industrial waste (t)
Oil or solvent	Reclaimed oil, waste oil	141,347
Acid or alkali soil	Waste clay Others	37,892 3,000
	Subtotal	40,892
Rubber or plastics	Used tire Others	101,038 100
	Subtotal	101,138
Wood	Wood waste	6,670
Slag	Blast furnace slag Copper slag Molding sand Debris Others	12,790,713 1,232,726 168,501 1,600,476 230,884
	Subtotal	16,023,300
Ash	Coal ash	2,020,975
Sludge	Organic sludge Inorganic sludge	19,942 289,306
	Subtotal	309,248
Gypsum as by-product	Chemical gypsum Desulfurization gypsum	875,561 1,424,148
	Subtotal	2,299,709
Soot or dust	Dust	477,970
Others	Remainder of animal and plant origin Waste from construction Others	196 6,164 118,991
	Subtotal	125,351
		21,546,600

(after Uchikawa)

Research is needed on converting shredder fluff into reusable materials so that it might be reused and not buried in landfills. In this regard, the cement industry provides one possible use of fluff.[3]

Indeed, the cement industry is increasingly providing an effective means of recycling many industrial waste products beyond automotive fluff. Calcium- bearing wastes, clay alternative products and iron-oxide-rich wastes are examples of materials that can be recycled in cement kilns, as well as mud, sand, and slag.[3] Blast furnace cement, and fly ash cement are examples of newer products make from wastes.

Uchikawa[8] has provided quantitative information on the broad range of industrial wastes used in the cement industry of Japan (Table 1). He also has shown an example of a flow chart of industrial waste recycling of raw materials and fuel in cement production (Figure 4). Uchikawa has also shown an example of the quantity of industrial waste used in cement plants in Japan, as fuel and raw materials (Figure 5). Further use of industrial wastes is predicted "for meeting the social demand"[8] and in order to ensure more timely and even greater use of industrial wastes, new administrative, tax and financial incentives are urged.

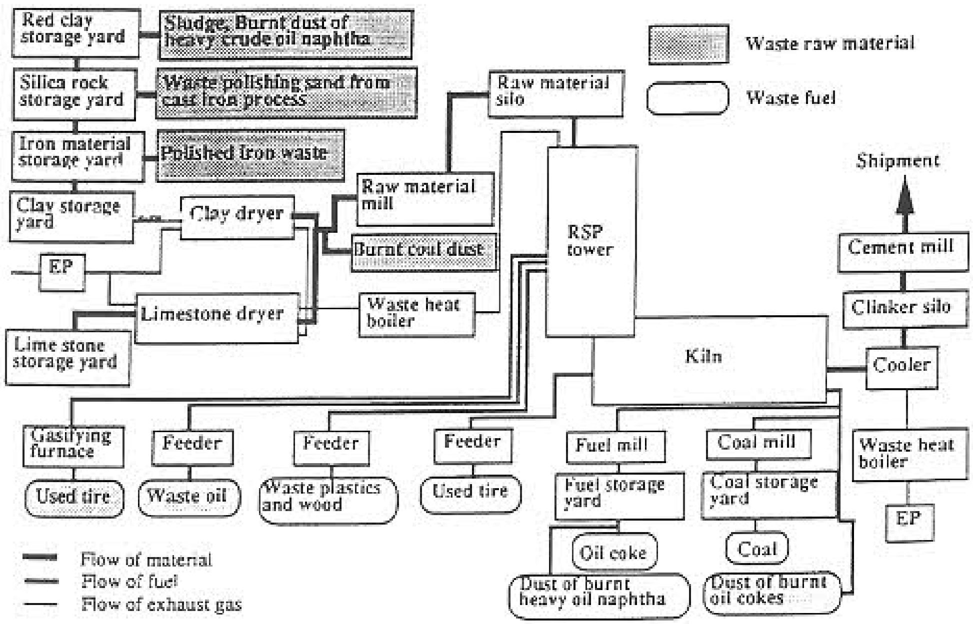


Fig. 4 An example of the flowchart of industrial waste recycling and utilizing processes (after Uchikawa)

Fig. 5 An example of the amount of industrial waste used in cement plant

(after Uchikawa)

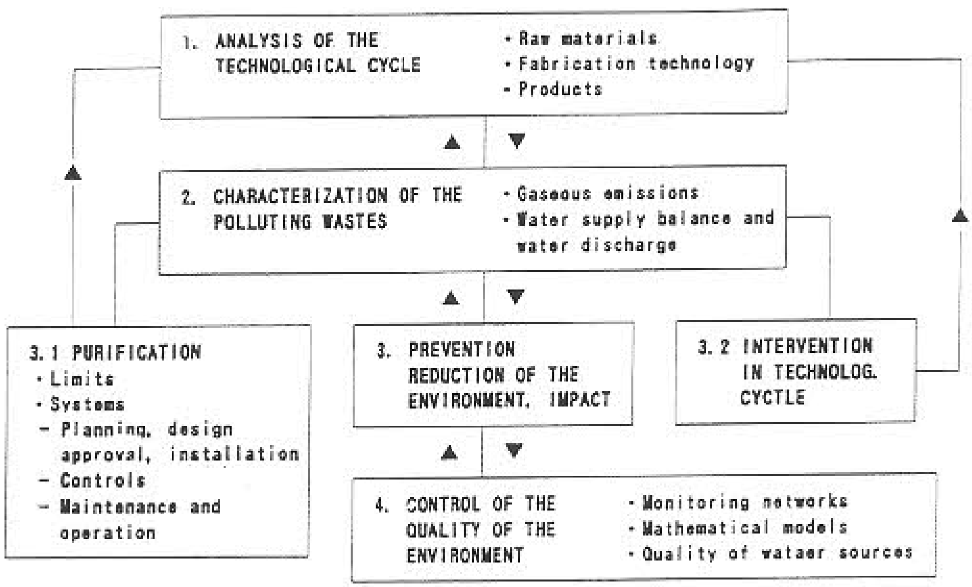
In an interesting use of city waste incinerator ash, Kambara[9] has recently described the triaxial mixing and sintering of incinerator ash with cullet from bottle glass waste and mud from water supply and drainage, to create ash-cullet-mud derived paving brick (230x115x60 mm. or 9x4.5x2.4 in).

WASTES AS RAW MATERIALS

"Post consumer waste, industrial scrap, and unwanted by- products from manufacturing operations should not be viewed as wastes. Rather, they are raw materials that are often significantly under-used. One of the research challenges of the emerging discipline of ceramic industrial ecology will be to identify productive uses for [ceramic and glass] materials that are currently regarded as wastes .... ."[2]

As cited by Allen and Behmanesh,[2] more than 12 billion tons of industrial waste and 0.2 billion tons of municipal solid waste are generated annually in the U.S. alone. This compares to an annual output of 300 million tons per year of the top 50 commodity chemicals.

Fig. 6 INDUSTRIAL POLLUTION APPROACH TO PREVENTION



(after Palmonari et al)

The extent to which industrial wastes could serve as raw materials, however, depends on both the mass of the waste stream and the concentration of resources in the wastes. The value of the resource is proportional to the level of dilution at which it is present in the raw material. Resources present at high concentrations can be recovered economically, but very low concentrations can only be recovered at high cost.[2] While this relationship has been well developed for many metals as well as some chemicals and organic compounds, it has yet to be quantified for ceramics. However, similar opportunities are believed to exist to recycle ceramic wastes as raw materials, e.g., whitewares, electrical porcelains, refractories and glasses. While some are recycled, most are now disposed of in landfills.

In one case study recently reported,[4] Corning, Inc., has found an alternative to disposal: glass furnaces demolition wastes have been recycled as glass raw material. For furnaces that have been used to melt lead glass or have used hazardous components such as arsenic, the cost of landfill is several times higher than recycling, and there is a strong economic incentive to reprocess such furnace rubble.

OTHER CASE HISTORIES FOR REUSING, REDUCING, OR RECYCLING WASTE

Environmental waste is commonly associated with materials destined for landfills or water treatment facilities or emitted into the atmosphere.[4] Yet, it can be reduced, reused or recycled.

Waste minimization, or pollution prevention, is a commonly reported action. For example, Palmonari and colleagues[10] have reported on 20 years experience with the large (25-30% of world production) Italian ceramic floor and wall tile industry in industrial ecology and the environmental impact of this industry and its approach to prevent or reduce environmental pollution (c.f., Figure 6). This has included limits for gaseous emissions; purification systems for gaseous emissions ; specific flow rates from kilns; reductions in fuel consumption (a one-third decrease from 1980 to 1991 while production was being increased by more than 25%); decreases in water consumption in the tile technological cycle (double firing cycle-dry milling); removal of boron in wastewaters; etc. Finally, a European Commission product trademark, called "Ecolabel" (c.f. Figure 7) -instituted by the CEC in 1993, is in the process of being implemented for the (Italian) ceramic floor and wall tile industry.

Ecolabel is a voluntary trademark of ecological quality, which promotes the conception, production, sale and use of products having as little negative impact as possible on the environment during their entire life cycle ("from cradle to grave").[10]

Additional case histories of waste reduction exist. For example, one example relates to the 3M Corporation, a major manufacturer and user of chemicals. Principally from employee suggestions, 3M has greatly decreased air pollution, water pollution and sludge and solid waste for a total savings of $537 million (from 1975 to 1991).[4]

The modern automobile is also being (re) designed for recycling.[2] As previously mentioned, autos are already among the most widely recycled products with 75% of vehicle materials being recycled. (Aluminum beverage containers have a recycling rate of about 60%). Lead-acid vehicle batteries have achieved 95% lead recycle rates. There has also been progress in dealing with chlorofluoro-carbons, coolants, tires, oils, and other materials. A major new focus, however, is the recycling of the non-metallic components of the auto body and power train.[2]

Fig. 7 Trademark of Ecological Quality for PRODUCTS (CEC Reg. No. 880/92) (after Palmonari et al)

As mentioned, each car that is dismantled and shredded yields an average of 600 pounds of non-metallic residue, called fluff, all of which is currently being landfilled. A Vehicle Recycling Partnership has been established – in the U.S. among General Motors, Ford and Chrysler – to focus on automobile recycling. Three groups will focus on Design (to facilitate recycling by developing material selection and design guidelines); Disassembly (to focus on creating an infrastructure based on separation of materials at the disassembly stage – e.g., the marking of plastic parts); and Shredder Residue (to improve the recycling rate of current designs, that will dominate disposal for the next 20 years, to reduce the total environmental impact of shredder residue by resource recovery or secondary uses).[2]

Another case study relates to AT&T and "Greening of the Telephone".[2] AT&T is conducting a demonstration project called Green Product Realization to provide a basis for a more comprehensive "green" design program. This demonstration project will be used as a learning experience to generate feedback about the relevancy and utility of potential design for environment guidelines and tools and to explore all elements of a system for delivering "green" products to customers.[2] This effort seeks to link industrial ecology concepts to specific industrial practices.

Green Product Realization seeks to develop the full-stream capability for minimizing the adverse life- cycle environmental impacts of manufactured products through their entire life cycle. To speed the development and application of "green" design principles, and to investigate the environmental implications of the entire lifecycle of a product, a simple product was selected for the demonstration project: the telephone.[2]

TOTAL QUALITY MANAGEMENT

Environmental protection is a critical element of an industry's operation. Thus environmental issues are increasingly being considered alongside traditional manufacturing criteria such as cost, quality, and performance.[5] Companies with total quality management (TQM) programs are using them to achieve environmental goals. TQM has made quality the responsibility of everyone in the company, not just the internal quality group. Similarly, environmental responsibilities in can be instilled across the board ceramic and glass industries using TQM programs.[4]

SOME NEXT STEPS

To advance and strengthen ceramic and glass corporate environmental practice, several next steps can be taken.[4]

1. Communicate the results of environmental initiatives to prompt others to act.
2. Develop metrics to gauge and improve environmental performance
3. Integrate waste flow and material information databases to aid recovery of useful information in waste streams.
4. Identify and catalog obvious, proven techniques that enhance environmental performance.
5. Integrate environmental concerns into educational curricula to produce environmental professionals and an environmentally literate work force, and
6. Develop future scenarios to guide the development of alternative long-range strategies for various industry sectors.

RESEARCH DIRECTIONS

There is a dearth of scientific and engineering research in the field of industrial ecology that needs to be addressed in the longer term.[4] Research is needed in four key areas:

1. Technical, scientific, or engineering opportunities
2. Data evaluation, rationalization, and collection, e.g., for waste streams and materials
3. Environmental concerns and modern production frameworks and structure (e.g., research is needed to determine how the processes and structure of industrial production can be modified to take into account environmental factors).
4. Incentives and barriers to corporate environmental action.[4]

In addition to the above, an integrated perspective of academic, industrial and governmental researchers has very recently been provided for the basic research needs for environmentally responsive technologies of the future, including the automotive, chemical, electronics, energy and metals industries.[6] While not directly focused on the ceramic industry, this January 1996 workshop nonetheless identifies major findings and research opportunities for each of the above industries that are equally applicable to the ceramics and glass industry. Additionally, several of the industries do have a ceramics and glass component,[6] e.g.,

- Automotive Industry: research is needed to develop applications for used foundry sands, used in metals casting and representing the largest volume of solid waste generated in the auto industry (1.5M tons per year).
- Increasing use of glass in autos, since glass manufacturing is the largest per-vehicle energy consuming process and is an environmental concern.
- Auto recycling generates 2.5M tons per year of shredder residue (a large portion of which is glass) – fluff- currently land filled and requires an ecological solution.

- Chemical Industry: basic research in a large number of areas can contribute to the development of evolutionary and revolutionary cleaner chemical technologies, including chemical synthesis, process science and materials technologies.
- Electronics Industry: Creative environmental technology solutions are required for production manufacturing, process assessment and recycling of electronic materials, a multi-billion dollar industry.
- Energy Industry: Environmentally driven technology needs exist for the industry, especially regarding air quality, waste management and risk assessment.
- Metals Industry: an aggregate of industries that utilize a variety of processes, fabrication techniques and recycling systems that have similar environmental concerns. There are a wealth of potential basic science opportunities in support of the goal of zero harmful emissions and total recyclability

MINIMIZING WASTES IN CERAMICS VIA INDUSTRIAL ECOLOGY

All of the aforementioned industrial ecology practices and imperatives apply to the ceramics and glass industry where there are numerous opportunities to reuse, recycle and reduce wastes. Waste minimization and pollution prevention, along with energy conservation, must be the watchwords as we approach and enter the next century.

As Laudise stated in his Orton lecture on Industrial Ecology: A Key to Green Processing and Green Design: "A new ethic which begins with the education of scientists and engineers and extends through industrial, regulatory, accounting and management activities will be required."[1]

The NAE approach to industrial ecology is summarized in the following statement: "...the reshaping of industrial systems for environmental and economic success is based on

- efficient use of materials and energy
- substitution of more abundant and economically preferable materials for those that are rare or environmentally problematic
- reuse and recycling of products and materials, and
- control of waste and emissions".[2]

This approach is widely applicable to ceramics and glasses.

Acknowledgment

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