Product Design for the Environment:
An Annotated Bibliography

Alon Dominitz, Chris Hendrickson

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Product Design for the Environment:

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Introduction:

This bibliography includes selected literature in the general areas of product design for the environment, design for recycling and reuse, and design for disassembly. Literature dealing with environmental effects of a products operation (for instance air pollution caused by automobiles) was excluded unless it was also relevant to the subjects covered here. Also excluded was literature having to do with designing for pollution control (Le. designing more efficient cars) unless that literature was relevant to the issues here (i.e. the effects of making cars lighter in order to make them more efficient).

This document consists of several sections. The first section, *Contacts*, is an alphabetized listing of groups and individuals doing research into the fields of design for disassembly, design for recyclability, or design for the environment. Where possible, addresses and/or telephone numbers have been included. Following this section are the sections *Periodicals*, a list of the most useful periodicals for information on these topics and *Important Works*, a listing of particularly significant, recent, and specific technical works. A work was chosen as important if it seemed to contain thorough data and a serious study of the problem. This is to distinguish from the majority of works available, which describe the problem eloquently but offer little information about the current state of the art in possible solutions. The next section, *Subject Indexes*, contains indexes of works pertaining to selected subjects. The last section is an annotated, alphabetized list of all works in this bibliography.

The bibliography was researched and written by Alon Dominitz during the summer of 1992 as part of the Engineering Design Research Center's Research Experience for Undergraduates program. Chris Hendrickson suggested and advised on this project References were provided by numerous people involved in other aspects of the Product Design for the Environment project, as well as local libraries, on-line databases, and CD-ROM databases For references obtained from people at Carnegie Mellon, the physical location of the reference has been included. The bibliography was compiled using RefBase™ and, subsequently RefCard™, both by Hyperglot Software. It is also available in electronic form. For more information, contact Sylvia Walters at EDRC (412-268-3372 orwalters@edrc.cmu.edu)

The Society of the Plastics Industry, Inc.
1275 K Street NW, Suite 400
Washington, DC 20005
202-371-5200
- SPI's Partnership Programs
202-371-5319
202-371-5679

WORLDESIGN Foundation
1142 Walker Rd.
Great Falls, VA 22066
703-759-0100

Corporations and Consortiums:

Inmetco/International Nickel Co.

Ellwood City, PA

412-758-5515

-provides hazardous waste management services for the specialty steel industry; produces nickel-chromium-iron products

Keystone Iron and Metal Co.

Pittsburgh, PA

412-462-1520

-Mary Lynn Thompson, Pres., also Pres. of local AISI chapter

-processes white goods and other metals (no autos)

Polymer Solutions, Inc.

Rick Noller, Director

10350 Olentangy River Rd.

PO Box 665

Worthington, OH 43085

614-885-9140, fax 614-885-4524

-a joint venture of GE Plastics and Fitch Richardson Smith

Polyurethanes Recycle & Recovery Council

355 Lexington Ave

New York, NY 100017

212-351-5425

Fax 212-697-0409

RSR Corporation

1111 W. Mockingbird Lane

Dallas, TX 75247

800-527-9452

-recycles automobile batteries

Government Research Laboratories and Individuals:

Alting, Leo Professor, PhD (author of "Life-Cycle Design of Industrial Products: A New Opportunity/ Challenge for Manufacturing Enterprises")
Institute of Manufacturing Engineering
Technical University of Denmark
Building 425, DK 2800 Lyngby, Denmark

Ashby, Michael F. (author of "Materials and the Environment")
Engineering Dept.
University of Cambridge
Cambrdige CB2 2PZ U.K.

Burke, Debra S., Kurt Beiter and Kos Ishii (authors of "Life-Cycle Design for Recycling")
Department of Mechanical Engineering
Ohio State University
206 W. 18th Ave
Columbus, OH 43210-1107

Risk Reduction Engineering Laboratory
Office of Research and Development
US Environmental Prevention Agency
Cincinnati, OH 46265

Sandia National Laboratories
Joan B. Woodard,
Director of Environmental and Manufacturing R&D Programs
Org. 6600
PO Box 5800
Albuquerque, NM 87185

Tompkins, David (co - author of "Automotive Interiors - Design for Recycling")
Himont Design Center
Wilmington, DE

Important Documents:

Arthur D. Little Inc. "Recycling State-of-the-Art for Scrapped Automobiles: Draft Final Report to American Iron and Steel Institute.". Arthur D. Little, Inc., 13 Nov., 1991. 30. (CMU-Rosy Chen)

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Design for Disassembly

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Curlee, Randall T. "Residue: Incentives and Barriers." *Materials and Society* v9 (1985): n1, 29-43.

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Annotated, Alphabetical Index:

ADRA (Automotive Dismantlers and Recyclers Association) Newsletter.

Key Words: recycling, automobile, reuse, design, engineer

Notes: ADRA is an advocacy group which, among other activities, produces publications *very relevant* to auto recycling.

Act 101 of 1988-The Municipal Waste Planning, Recycling, and Waste Reduction Act.

Commonwealth of Pennsylvania/ Dept. of Environmental Resources/ Bureau of Waste Management/ Division of Waste Minimization & Planning, September 26, 1991. (CMU-Green Engineering Lab)

Notes: includes graphs, charts, figures, etc.

Ainsworth, Susan J. "Plastics Recycling Ventures Attack Increasing Waste Problem." v68 July 9, 1990. n28, p19-22.

Key Words: Plastics, Recycling of waste materials, Industry profiles

Notes: ISSN 0009-2347

Abstract: Producers of resins and plastic products, Recyclers and end users are Recycling because it is good public relations. These efforts may help them deal with plastics legislation and the growing demand for Recycled products.

Alting, Leo. "Life-Cycle Design of Industrial Products: A New Opportunity/ Challenge for Manufacturing Enterprises.". p23. (CMU-Green Engineering Lab)

Key Words: development, production, distribution, usage, recyclability, electronic products, plastic, EEC, disposal, recycling, design, assessment, environmental protection, working condition, resource optimization, life-cycle costs, manufacture, concurrent engineering, Computer Integrated Manufacturing (CIM), materials

"Are Resource Recovery Plants the Answer to Local Waste Problems?" *Public Utilities Fortnightly* v118 December 11, 1986. p53.

Arthur D. Little Inc. "Recycling State-of-the-Art for Scrapped Automobiles: Draft Final Report to American Iron and Steel Institute.". Arthur D. Little, Inc., November 13, 1991. p30. (CMU-Rosy Chen)

Notes: Includes articles relevant to this subject, diagrams, photos

Ayres, Robert U., Fancis C. McMichael and Samuel R. Rod. "Measuring Toxic Chemicals in the Environment: A Materials Balance Approach," *Toxic Chemicals, Health, and the Environment.* Eds. Lester B. Lave and Arthur C.Upton. Johns Hopkins University Press, 1987. p38-70. (CMU-Francis McMichael)

Notes: Includes bibliography

Abstract: Ayres, McMichael, and Rod introduce a basic framework for thinking about toxic chemicals in the environment: the materials (mass) balance framework. Activities do not create or destroy matter, but they can transfer it chemically and change its location. For inherently toxic substances, such as the heavy metals, the total mass must be monitored, with only secondary concern given to the precise chemical form. For organic compounds, such as those involving nitrogen, the precise chemical form is more important than the mass of released nitrogen. When used by chemical engineers for a plant or process, the materials balance framework is a rigorous tool. The authors advocate its use at a more aggregate level, such as a geographical region. They explore a historical reconstruction of deposition in the New York-New Jersey region and get strong results regarding the importance of industry versus consumer sources. While the materials balance framework is more art than science at a regional level, it appears to be a valuable tool in understanding the sources of chemicals an in suggesting control strategies.

Babyak, Richard J. "Design for Disassembly Focuses on Fastening." ***Appliance Manufacturer*** v39 1991. n6, p26-28.

Key Words: Appliance industry, Engineering, Fasteners

Bergstrom, Robin P. "Why Plastics Won't Go Away." *Production* v102 Oct., 1990. n10, p69-71.

Key Words: Waste disposal, Landfill, Recycling, Plastics, Containers, Problems

Abstract: In 1988, some 180 million tons of solid waste were generated. The number of landfills available in 1979 was 18, 500; in 1985, that number was about 9, 300. It is estimated that, by 1995, the number of landfills available will have fallen to 3, 000. The percentage of plastic in landfills, by volume, is 19.9%. Procter & Gamble (P&G) is a heavy user of plastic containers and a leader in the plastics recycling movement around the world. P&G's Ed Fox believes that, although the situation is serious both domestically and abroad, management is providing rational systems and policies are being put in place. Fox says that a rational solid waste management program needs to include 5 elements: 1. an intelligent reduction in the use of materials in product design, 2. recycling, 3. composting of organic materials, 4. incineration, and 5. landfills. Scientific studies have shown that material sent to landfills degrades very slowly-if at all. A degradable plastic is contrary to resource conservation in that degradable products become waste and cannot be reused.

Bergstrom, Robin P. "What's Ahead for Appliances." *Production* v104 Feb., 1992. n2, p28-34.

Key Words: Electrical, electronics, instrumentation, United States, Pollution Control

Abstract: The appliance industry is one in which domestic products are not in competition with foreign products, yet there are other concerns with which the industry must contend. The most serious concern is chlorofluorocarbons (CFC), which are destroying the ozone layer as they escape into the atmosphere. The appliance industry recognizes the dangers of CFCs, but will have problems discontinuing the use of CFC-base coolants because they are efficient, non-toxic, non-flammable and reliable. Moreover, the CFC alternatives so far all have one or more serious drawbacks. Another concern for industry is the problem of recycling old appliances which can no longer be repaired. Manufacturers must begin to design products which can be easily disassembled and recycled. The final concern is the question of a competitive global market. Along with globalization is the move toward product standardization. The two trends will change the appliance industry dramatically.

Bleviss, Deborah Lynn. *The New Oil Crisis and Fuel Economy Technologies: Preparing the Light Transportation Industry for the 1990's.* Quorum Books-New York. (CMU-Green Engineering Lab)
Key Words: plastics, materials, design

"Body-In-White Materials Systems: A Life Cycle Cost Comparison.". IBIS Associates, Apr., 1992. (CMU-Francis McMichael)
Key Words: design, recycling, reuse

Boley, Gary L. "Turning Waste into Watts." *Mechanical Engineering* v112 Dec., 1990. n12, p37-41.
Key Words: Recycling of waste materials, Energy, Electric power, Engineering & Engineers
Notes: ISSN 0025-6501
Includes Photograph; Illustration: Table
Abstract: At the Mid-Connecticut Resource Recovery facility, waste is processed to produce refuse-derived fuel (RDF), which is burned in boilers to produce steam that is used to generate electrical energy.

Bonsigmore, Patrick V., Bassam J. Jody and Edward Daniels. *Separation Techniques for Auto Shredder Residue.* (Argonne National Laboratory)
Key Words: Auto Shredder Residue
Abstract: Disposal of automobile shredder residue (ASR), remaining from the reclamation of steel from junked automobiles, promised to be an increasing environmental and economic concern. Argonne National Laboratory (ANL) is investigating alternative technology for recovering value from ASR while also, it is hoped, lessening disposal concerns. Of the ASR total, some 20% by weight consists of plastics. Preliminary work at ANL is being directed toward developing a protocol, both mechanical and chemical(solvent dissolution), to separate and recover polyurethane foam and the major thermoplastic fraction from ASR. Feasibility has been demonstrated in laboratory-size equipment.

Burke, Debra Sue, Kurt Beiter and Kos Ishii. "Life-cycle Design for Recyclability." *ASME DTM 92 Conference.* Dept. of Mechanical Engineering, Ohio State University, 1992. (CMU-Gieen Engineering Lab)

Abstract- This paper describes the development of a systematic method to enhance the recyclability of products in their early stages of design. The target industries include automotive, appliances, computers, and business equipment. The emphasis is on recycling of plastic materials used in their products. First, the paper gives a thorough background study on recycling and addresses the cost structure of recycling plastic parts. Then, we seek to relate the recycling cost drivers to design attributes such as material selection, method of fastening, geometry of parts, etc. The paper further describes the requirement for a system that evaluates a layout design for recyclability and helps engineers improve the design. This method parallels the Design for Assembly (DFA) systems and involves 1) representing designs for recyclability analysis, 2) describing general metrics for recycling costs, and 3) attributing cost drivers to various aspects of the candidate design.

"Carmakers Readying Push for Recycling; Big Three Car Manufacturers to Jointly Research & Develop Design for Disassembly Recycling Flan." *Plastics News* September 30,199L p4.

"Cars Ride Recyclability Road: U.S., Foreign Manufacturers Begin to Make Some Mileage; Chrysler Unveils Prototype Compact Auto Incorporating Innovative Features." *American Metals Market* July 8,1991.

Center for Plastics Recycling Research. *Technical Reports.* Center for Plastics Recycling Research/ Rutgers University, June 30,1991. (CMU-Green Engineering Lab)
Notes: Technical Reports numbers 1 through 62 dealing with plastics recycling

Charles, Dan. "Too Many Bottles Break the Bank." *New Scientist* April 18,1992. pl2-13.
Abstract: The US is gripped by recycling fever. But harsh economic reality is beginning to dent green idealism.

Constance, Joseph. "Can Durable Goods Be Designed for Disposability?" *Mechanical Engineering* June, 1992. p60-62.
Key Words: design, disassembly, recycling, Whirlpool, recycled

"Could Exxon's Future Slogan be 'Put a Diaper in Your Tank?'." *Environment Today* Sept., 1991. p14-15.
Key Words: pyrolysis, plastic, emissions, waste, reclamation

Crandall, Robert W. *Regulating the Automobile.* 1986.
Key Words: Automobiles Law and legislation United States. Automobile industry and trade Law and legislation United States.

Curlee, Randall T. *The Economic Feasibility of Recycling: A Case Study of Plastic Wastes.* Praeger/ New York. 1986 p186. (CMU-Eugene Monaco)
Key Words: reuse, design, automotive shredder Residue (ASR), incineration, pyrolysis, plastics
Notes: Includes thorough tables and charts, bibliography, index

Curlee, Randall T. "Plastic Wastes and the Market Penetration of Auto Shredders." *Technological Forecasting and Social Change* v28 1985. p29-42.
Key Words: recycling, auto shredder residue (ASR), plastics

Curlee, Randall T. "Residue: Incentives and Barriers." *Materials and Society* v9 1985. n1, p29-43.
Key Words: recycling, plastics, auto shredder residue (ASR)

Daniels, E. J., B. J. Jody, P. V. Bonsignor and E. L. Shomaker. "Automobile Shredder Residue: Process Developments for Recovery of Recyclable Constituents." *Proceedings of the 6th Annual International Conference on Solid Waste Management & Secondary Materials.* December 7, 1990. (CMU-Francis McMichael)
Notes: Includes bibliography
Argonne: 708-252-2000; Daniels: 5279

Derricott, R. and Seymour S. Chissick. *Rebuild.* Chichester; New York: Wiley, 1982. p286.
Key Words: Construction industry. Building.

Dudley, Joseph R. "Keeping Assemblies Together with Prevailing Torque." *Machine Design* v63 March 21, 1991. n6, p155-159.

Key Words: Fasteners, Preventive maintenance, Adhesives, Rotating, Friction, Polymers, Comparative analysis, Design engineering

Notes: Includes diagrams

Abstract: Some fasteners use prevailing torque to resist loosening. Prevailing torque is provided either by physical features that create interference or by chemical adhesives. Adhesive-locking fasteners have one feature that is superior to those that create prevailing torque mechanically. After the joint clamp load is broken, adhesive and capsule residue left in the threads creates interference, requiring further torque. Locking adhesives, however, are limited both by temperature and environmental conditions. Reusable prevailing torque fasteners lock by inducing frictional resistance between the mating threads. This frictional resistance can be caused by distortion of the male or female threads or a nylon insert, strip, or patch. Other types of prevailing torque locking fasteners are the polymer pellet, strip, or patch. The most commonly used polymer lock is the nylon patch.

"Eddy Current Separation: Time for a Repelling Idea; Eriez Magnetics: Developed Eddy Current Materials Separation Equipment." *Recycling Today* Sept., 1991. p84.

Eisenstien, Paul A. "Designers Take on 'Green' Concerns; Recyclable Plastics Seen as Priority." *Christian Science Monitor* November 29, 1990.

Key Words: Automobiles, Technology, Design, Plastics, Recycling of waste materials, Environment

Notes: Includes illustration

Abstract: As the so-called "Green revolution" takes hold, automobile designers are having to consider how their cars will disassemble and decompose, and whether or not the cars can be cost-effectively recycled.

Environmentally Conscious Manufacturing Magazine

Notes: contact: Joan B. Woodard

Published for Department of Energy

E.P.A. *Current Projects.* US EPA-Pollution Prevention Research Branch. (CMU-Eugene Monaco)

Key Words: pollution, recycling, hazardous waste, solid

Notes: Describes current EPA projects. Includes names & phone numbers of participants.

Publisher: Risk Reduction Engineering Laboratory

Fisher, M. "Recovery and Recycling of Post-Consumer Automotive Plastics in the United States: CSWS Initiatives.". C.S.W.S.-Council for Solid Waste Solutions, Apr., 1992.

Notes: Paper presented at Davos Recycle '92, International Forum and Exposition, Davos, Switzerland

Includes tables, diagrams, and figures of:

Table 1: North American Automobile Recycling Infrastructure

Table 2: Shredder Residue

the by-product of the present automobile recycling industry

Table 3: Profiles of Participating Dismantlers

Table 4: Specific project tasks performed by the transportation coordinator

Table 5: Plastics sales to the United States and Canadian Transportation Market (cars, vans and light trucks)

Figure 1: Material flow (between dismantlers, reclaimers, and resin manufacturers)

Table showing times to dismantle specific items using specific methods

Table 7: examples of parts contamination

Table 9: Estimated cost to recover plastic parts base on % dismantled and % sold

Forcucci, Francesco and David Tompkins. "Automotive Interiors-Design for Recyclability.". S.A.E. International Congress and Exposition, 1990. p41-46. (CMU-Green Engineering Lab, U Pitt)

Key Words: Automobiles-Furnishings, Polyolefins-Recycling, Materials-Recycling, Engineering, Polypropylenes, Interiors, Recyclability, Disassembly, Processing Technologies

Abstract: New developments in polyolefin-base materials have created a family of polypropylene products with a wide range of physical properties, including the ability to be easily recycled. When utilized by automotive and product designers as part of a "design for disassembly" strategy, these compatible materials will yield large subassemblies that can be reclaimed with a minimum of handling.

Franklin Associates Ltd. *Resource and Environmental Profile Analysis of Polyethylene and Unbleached Paper Grocery Bags: Final Report*. The Council for Solid Waste Solutions, June, 1990. pp30. (CMU-Navin Chandra)

Key Words: Packaging, recyclability, plastics, materials, energy requirements, environmental emissions, incineration impacts, landfill impacts, solid waste

Notes: A hefty report with many useful figures, charts, diagrams. Includes bibliography. THIS IS AN IMPORTANT DOCUMENT

Green Engineering: Designing Products for Environmental Compatibility. Springer Verlag, 1992. (CMU-Green Engineering Lab)

Key Words: recyclability, reuse, design, environment, life-cycle analysis, planning

Notes: A collection of papers and citations dealing with the subject of design with the environment. Some documents include equations, figures, diagrams, tables, bibliography.

AN IMPORTANT DOCUMENT

Key Words: design, recycling, reuse, environment, plastics, materials, engineering, process, solid waste

Hanson, David. "Plastics Industry Maps Major Recycling Plan." *Chemical & Engineering News* v69 8. n14, p25-26.

Key Words: Plastics, Recycling of waste materials, Industry profiles, Strategic planning, Environmental cleanup

Notes: The US plastics industry's Blueprint for Plastics Recycling is a major national commitment to a postconsumer plastics recycling plan.

Haynsworth, H. C. and Tim R. Lyons. "Remanufacturing by Design, the Missing Link." *Production & Inventory Management* v28 1987. n2, p24-29.

Key Words: Manufacturing, Used equipment, Rehabilitation, Component parts, Trends

Hecht, Norman L. "Design Principles in Resource Recovery Engineering." 1983.

Key Words: recycling (Waste, etc.). Organic wastes

Hendrickson, Chris and Francis McMichael. "Editorial: Product Design for the Environment." *Environmental Science & Technology* v26 1992. n5, p844.

Key Words: solid wastes, recyclability, manufacturing, automobiles

Henstock, Michael E. *Design for Recyclability.* Institute of Metals (on behalf of The Materials Forum), 1988. p264. (CMU-Library)

Key Words: Waste materials, Metals, Recycling

Notes: Full of graphs, figures, and tables.

Excellent book dealing exclusively with this subject.

THIS IS AN IMPORTANT BOOK

Herman, Robert, Siamak A. Ardenakani and Jesse H. Ausubel. *Dematerialization* Eds. Jesse H. Ausubel and Hedy E. Sladovich. National Academy Press, 1989. p50.

International Consortium on Auto Recycling. The Japan Research Institute, Ltd., Apr., 1992. (CMU-Francis McMichael)
Key Words: automobile shredder residue (ASR), fluff, reuse, design, environment

Ishii, Kos and Sudipto Mukherjee. "Post Manufacturing Issues in Life-Cycle Design." *ASME Wisconsin Annual 92 Meeting*. Dept. of Mechanical Engineering, Ohio State University, 1992. (CMU-Green Engineering Lab)
Key Words: serviceability, recyclability, cost, design, Service Mode Analysis (SMA), design compatibility analysis (DCA)
Notes: The paper uses specific examples to illustrate these [analysis] techniques. Includes bibliography.

Kennedy, Melissa. "Plastics Group Drives Auto Industry Toward Recycling." *Machine Design* v64 May 7, 1992. n9, p14-16.
Key Words: transportation equipment industry, United States
Abstract: Predicting plastics' increasingly important role in the manufacture of automobiles, the Partnership for Plastics Progress' Automotive Group will develop the infrastructure to recover, recycle, and dispose of post-consumer automotive waste. A pilot study conducted by Cambridge Reports/Research International concluded that future automobile programs should include design for disassembly. Also, plastics should be marked for identification, and the industry needs more reclaimers that can process plastics. Argonne National Laboratory is developing a program to separate plastics and other recyclable materials from the nonmetalic material left over from recycled cars and trucks. Technology for breaking down the polymeric materials into their original chemical state is also gaining ground. Methods include the processes of hydrolysis, methanolysis, and pyrolysis. Current and future recovery efforts for automotive plastics in the US center on such parts as: 1. automotive batteries, 2. reaction injection molding parts, 3. radiator caps, and 4. automotive sheet molding composite scrap.

Kobe, Gerry and Christopher A. Sawyer. "Plastic vs. Steel." *Automotive Industries* Sept., 1991. p26-32.
Notes: Discusses recyclability of materials as a factor of total automobile cost.

"Leading-Edge Engineers Design for Recycling." *Machine Design* v63 January 24, 1991. n2.

Key Words: Design engineering, Recycling, Product Design, Trends, Appliance industry, Plastics industry, Automobile industry

Abstract: Some manufacturers are already beginning to design for recycling. BMW, for example, recently unveiled a special $55000 model with doors, side panels, and other components made of recyclable thermoplastic. Designing products that disassemble easily into components made of reusable materials is another way to encourage recycling. In appliance engineering, design for recycling means substituting new refrigerants for chlorofluorocarbons (CFC). It also means increasing energy efficiency by 60% by 1993, but new refrigerants tend to be less efficient than CFCs. Many designers refuse to specify recycled materials because they do not believe they are as good as new materials. Therefore, most material suppliers still put most of their development effort into producing new materials. Experts in materials marketing feel that consumer awareness of the environment will force recycling, and they are preparing for increased demand for recycled goods.

Leaversuch, Robert D. "Is Industry Serious About Solid Waste Recovery?" *Modern Plastics* v65 June, 1988. n6, p65-76.

Key Words: Waste disposal, Plastics, Recycling, Resource recovery, Landfill

Leaversuch, Robert D. "Auto-Part Recycling is a Top Industry Priority." *Modern Plastics* v69 Mar., 1992. n3, p37-38.

Key Words: Pollution control, chemical industry, includes rubber & plastics, transportation equipment industry, recycling

Abstract: General Motors, Ford, Chrysler, and the Society of the Plastics Industry are launching parallel initiatives to make US vehicles of the late 1990's more recyclable than current models. The consortium will orchestrate an industry wide effort to recapture materials that evade existing recycling systems. A broad group of suppliers, recyclers, and trade groups representing all materials used in automobiles will meet in March 1992. Manufacturers are supporting auto recycling because it is backed by the US public and because landfill costs are rising. About 1/4 of the content by weight of the 10 million vehicles retired annually in the US becomes auto shredder residue (ASR), which is disposed of in landfills. Extending the reclaim of plastics used in autos will not be easy because of a coding system of acronyms for over 120 thermoplastics and thermosets. Immediate measures are needed to reduce the volume of automotive shredder residue and increase in-plant scrap reuse.

Lightman, Sam. *Integration Puts Plastics Recycler on Top of The Heap.* Hewlett-Packard Co, Cupertino, CA, 1986. p22-24.

Key Words: Plastics Recycling, Industrial Management Machinery, Computer Aided Manufacturing, Information Systems

Abstract; Where it can be found: llman Industries' 33-acre plastics recycling complex in Johnsonville, S. C. In the early 80s, Wellman decided to upgrade the reporting system to a real-time manufacturing information management system. The company contacted Industrial Computer Corp. (ICC), Atlanta, to design and implement the finished goods portion of the operation. Hewlett-Packard Co. s HP 1000 was selected as the central processing unit around which the system would grow. Bar coding in particular was critical to the success of the system.

'Limbach, Bonnie Merrill. *Plastics and the Environment: Progress and Commitment.* Society of the Plastics Industry, Inc., 1991. p 125. (CMU-Green Engineering Lab)

Key Words: recycling, reuse, solid waste, conservation, energy, pollution prevention/control, waste-to-energy

Lodge, George C and Jeffrey F. Rayport. "Knee-deep and Rising: America's Recycling Crisis." *Harvard Business Review* Oct., 1991. pl28-139.

Key Words: business, education

Notes: Includes case studies, diagrams

"Made on Earth II: The New Reality-Several Articles on Design for the Environment." *Innovation* v11 1992. n3.

Key Words: Design, Industry, Recycling, Environment, Reuse, Reduce

Notes: Special issue of the Journal of the Industrial Designers Society of America (IDS A)

Abstract: The deterioration of the Earth's environment is a critical quality of life issue and designers can be a pan of the solution. The articles in this publication provide designers with information on how to minimally affect the environment, furthering the Foundation's goals and addressing one of the priorities articulated in its Design Agenda.

contact: WORLDESIGN Institute

Mattikalli, Raju S. and Pradeep K. Khosla. "Determining the assembly sequence from a 3-D model: EDRC Report #24-16-89.". Carnegie Mellon University. Engineering Design Research Center., 1989. (CMU-Library)

Key Words: Engineering design, Computer-aided design. Computer arithmetic.

Notes: Includes references

OCLC No. 20456608

Date Added 891018

Abstract: "Geometric modeling systems are rapidly replacing manual drafting techniques for defining the geometry of mechanical parts and assemblies. This makes possible the development of a variety of software tools to aid the designer in effective representation and evaluation of mechanical systems and assemblies (MSAs). The long term goal of our research is to address the question: Can the given MSA be assembled automatically with the given facilities? In order to accomplish our goal we need to develop techniques to model the Mechanical System/Assembly (MSA) and the available facilities. In this paper, we address the first part of our goals and develop a methodology to automatically determine the assembly sequence from a 3-D geometric modeler description of the assembly. Our approach consists of automatically determining a set of assembly operations, through a disassembly procedure, that lead to the given assembly (MSA). We use the Noodles Solid Modeler, developed at Carnegie Mellon, to describe the assembly. We have implemented our algorithm to determine the disassembly sequence on a SUN workstation in C language. We also describe our initial implementation through an example."

McCosh, Dan. "Recycling the Car." *Popular Science* Dec., 1990. p107.

Notes: Includes breakdown of typical car by weight of materials.

Graphs: Weight of the average American car as efforts to improve fuel economy take effect (decreasing)

Consumption of plastics in the auto industry in the same period of time (increasing)

Abstract: General report on recycling of automobiles.

Menges, G., S. V. Eysmondt, A. Feldhaus and H. Offergeld. *Recycling the Plastics Content of Cars: Yes, But How?*. 1988.

Key Words: Plastic Recycling

Notes: Use of plastics is outlined. Also the problem plastic parts cause is discussed. Ways of recovering and recycling the plastics are included.

Navinchandra, D. "Design for Environmentability.". ASME Design Theory and Methodology Conference, American Society of Mechanical Engineers, 1991. (CMU-Green Engineering Lab)

Abstract: There is a growing interest in making products environmentally more compatible. While there is a need to make products and processes less toxic, we have to try to achieve environmental friendliness without compromising product quality. This approach to design has come to be called Green Engineering Design. The aim is to identify, develop, and exploit new technologies that can bolster productivity without costing the environment. The idea is to inject concerns about environmental friendliness into the design process, where the assessment of environmental friendliness is based on a life-cycle view of the product. This includes the product's manufacturing process, distribution, use, and final disposal. Our approach to green engineering design has two parts: (1) the development of special green indicators-measures of environmental compatibility, and (2) tools that use the green indicators to help designers assess, compare, and make design decisions.

"Need Plastic Lumber? Here's Who to Call." *Plastics News* December 16, 1991. p11-27.

Notes: List of plastics recyclers, plastic lumber producers, by alphabetical order and by state.

Noller, Rick. "Environmentally Responsible Product Design.". Polymer Solutions, Inc., 1991.

Key Words: Source Reduction, Design for Recyclability, Design for disassembly, tactics, fastening methods and feasibility for disassembly

Abstract: Five years ago, nobody foresaw that today we would be seriously discussing environmentally responsible design and design for disassembly. Five years from now, it is entirely possible that today's product designers will be managers in charge of disassembling and recycling the products they designed. The design community must participate in the drive for recycling of plastics, or it is doomed to failure. Source reduction, design for recyclability through design for disassembly, and specification of recycled materials are the ways in which we must drive industry-even society-toward environmentally responsible design.

O'Connell, C. E. "Remarks of C.E. O'Connel, President, the Society of the Plastics Industry, Inc.". June 10, 1987. (CMU-Green Engineering Lab)

Notes: Speech dealing with Degradable Plastics made by C.E. O'Connel. Provides general information on the subject.

Society of Automotive Engineers. *Plastics in Automobile Bumper Systems and Exterior Panels.* 1990. (Warrendale, PA)
Key Words: Plastics in automobiles Congresses. Automobiles Materials Congresses.

"Plastics Recycling: An Overview.". Plastics Recycling Foundation, Center for Plastics Recycling Research, NJ Commission on Science and Technology, Council for Solid Waste Solutions. (CMU-Green Engineering Lab)
Notes: Includes Plastics in a Multi-Material Collection/ Sortation Program for Non-Rural, Single-Family Homes

"Plastics Recycling: From Vision to Reality.". Plastics Recycling Foundation, Center for Plastics Recycling Research, NJ Commission on Science and Technology, Council for Solid Waste Solutions. (CMU-Green Engineering Lab)
Key Words: economics, solid waste

Pollock, Cynthia. "Mining Urban Wastes: The Potential for Recycling: Woldwatch Paper 76." *Worldwatch Papers.* Worldwatch Institute, Apr., 1987. p57. (CMU-Rosy Chen)
Key Words: garbage, solid waste, recycling
Notes: ISBN 0-916468-77-1
Includes data tables, references

Polymer Solutions Inc. "Design for Disassembly." *Industry Week* v240 June 17,1991. n12, p44-46.
Key Words: Product Design, Product development, Recycling, Design engineering
Notes: Short but important article.

"Recycling Cars: Mass Destruction." *Economist* November 10, 1990. p82-89.
Key Words: Automobiles, Recycling, Automobile industry, Product design, Trends

Recycling Markets and Operations Directory-Region 5: Pittsburgh (Southern PA). PA Dept. of Environmental Resources, Bureau of Waste Management, December 7, 1990. (CMU-Green Engineering Lab)
Notes: Includes information about Pittsburgh-area recyclers and recycled materials buyers.

"Recycling Mixed Plastics: New Markets.". Council for Solid Waste Solutions, Plastics Recycling Foundation. (CMU-Green Engineering Lab)
Notes: Describes developing markets for recycled materials.

Regan, James G. "Voest-Alpine, Mercedes Eye Auto Recycling Plant.".
Notes: Very short article. Not very specific.
Abstract: Voest-Alpine, AG, the Austrian steelmaker, and Mercedes-Benz AG are aiming to establish a vehicle dismantling plant in Europe that will enable virtually all of a car's metal and non-metal parts to be recycled.

Regan, James G. "German Car Men See Green." *American Metals Market* v99 April 4, 1991. n64.
Notes: Short article. Not very specific. Good general background on this subject.
Abstract: The auto industry has decided to "establish its own recycling policies and avoid government intervention." German car manufacturers have spent 500 million deutschemarks ($297 million) on environmental research, $178 for each car sold in Germany (a misleading statistic, since the results apply to cars not sold in germany as well). By the end of 1993, the German government is expected to insist that automakers have in place adequate facilities to recycle the two million vehicles per year sold in western Germany alone.

Reisch, Marc. "Independent Waste Recycler Sees Growth in Plastics." *Chemical & Engineering News* v69 July 8, 1991. n27, p23-24.
Key Words: Company profiles, Recycling of waste materials, Plastics, Resource Technologies Inc
Notes: ISSN 0009-2347
Abstract: Resource Recycling Technologies, a Vestal, NY-based company generates its profit through the recycling of consumer-generated waste. With the addition of a plastics recycling division, the company is well on its way to becoming an integrated waste processing company.

Rousseau, M. and A. Melin. "Processing of Non-Magnetic Fractions from Shredded Automobile Scrap: A Review." *Resources, Conservation, and Recycling* v2 1989. n2, p139-159.
Key Words: scrap metal, reprocessing, automobile materials, nonferrous metals recovery, separation, shredded automobile scrap, reclamation, design & manufacture
Notes: Shredded automobile scrap has become an important source for the recovery of nonferrous metals. The nonferrous metals are recovered and separated at low cost and under controlled conditions in a few industrial plants. The separation of the nonmagnetic fraction from nonmetals is conducted generally with techniques used in materials beneficiation (screening, heavy medium separation in drums or hydrocyclones). The aluminum is remelted to a salable alloy. The lead, copper, and zinc are normally separated from each other by pyrometallurgy, taking advantage of their different melting points. The metal-bearing phases have to be remelted and/or recycled in lead and zinc plants. Industrial applications using the above mentioned techniques in Europe are reviewed. New processes and developments are based on dense media separation in magnetic fields, automatic sorting and eddy-current separation. These are applicable in a few specific cases only.

Rubinger, Bruce and Simon Prenskey. "Computer-Based Resource Accounting Model for Generating Aggregate Resource Impacts of Alternative Automobile Technologies.". Washington DC: Office of the Assistant Secretary for Systems Development and Technology
Key Words: design

Russell, Paul G. "Solid Waste Disposal-Resource Recovery Projects." *International Business Lawyer* June, 1984. p275-278.

Saechtling, Hansjurgen. *International Plastics Handbook: for the Technologist, Engineer, and User*. 1987.
Key Words: Plastics Handbooks, manuals

Samuelson, Robert J. "Opinion: The End is Not at Hand." *Newsweek* June 1, 1992. p43.
Notes: Synopsis: Our environmental rhetoric is overblown. The planet will survive.

Saxton, James C. and Robert U. Ayres. "Materials-Process Production Model." *Mineral Materials Modeling*. Ed. William A. Vogely. Resources for the Future, Dec., 1975. p178.

Schroeder, Michael. "Tinfoil Lizzies." *Business Week* January 29, 1990. p41.

Key Words: transportation equipment industry, metals & metalworking industry

Abstract: Automobile executives have long believed that aluminum's high price outweighed its advantages over steel. Aluminum Co. of America (Alcoa) even created an auto recycling plan in the mid-1970's to win over automakers. Alcoa was willing to give manufacturers of aluminum-laden cars a certificate redeemable for cash when the worn-out autos were returned. Starting in 1982, Alcoa teamed with Audi to design a new manufacturing process for building autos with aluminum structural components, or space frames. By 1992, Alcoa will be able to supply customized space frames to European automakers, radically speeding up new model introductions. Ford Motor Co. and Reynolds Metals Co. are building a prototype aluminum car, but, until the aluminum industry slows down the swings in prices, there will be no move to use aluminum on a wholesale commercial basis. While producers have made significant gains in improving steel's corrosion resistance and in making thinner gauge steel stronger, lighter materials are the future. Even steel executives admit that aluminum and plastics will continue to corrode their dominant market share.

Schwartz, Seymour S. and Sidney H. Goodman. *Plastics materials and processes*. 1982.

Key Words: Plastics.

"Scrap Dealers Join Research Effort to Recycle Electricals." *The Engineer* June 20, 1991. p40.

Notes: Describes efforts by the Centre for Exploitation of Science and Technology (Cest) to coordinate research in both the electrical/ electronics sector and the scrap reprocessing sectors in Europe.

-Project Leader Dr. Jonathan Williams

Sharp, M. L. and R. H. G. McClure. "The Practicality of Aluminum for Automotive Body Structure.". p11. (CMU-Eugene Monaco)

Key Words: emissions, automobile

Notes: Includes bibliography

Shilke, Neil A. and Steve M. Rohde. "An Automotive Systems Approach." *Automotive Engineering* v97 Feb., 1989. n2, p165-170.

Notes: Incudes figures.

Abstract: A systems approach which integrates aspects of product definition, design, manufacturing, and use is required to engineer complex systems using today's computer-aided tools and rapidly-advancing analytical techniques.

Society of Automotive Engineers (SAE). "Plastics in Automobile Bumper Systems and Exterior panels." *SAE International Congress & Exposition*. Warrendale, PA: Society of Automotive Engineers, 1990. (Detroit, Mich.)
Key Words: Plastics in automobiles-Congresses. Automobiles-Materials-Congresses.

Society of Automotive Engineers (SAE). "Plastics in Automobile Instrument Panels, Trim and Seating." *SAE International Congress and Exposition*. Warrendale, PA: Society of Automotive Engineers, 1990. (Detroit, Mich.)
Key Words: Plastics in automobiles-Congresses. Automobiles-Materials-Congresses.

Design for Recyclability and Reuse of Automotive Plastics. Society of Automotive Engineers (SAE), Inc., Feb., 1991. p63. (CMU-library)
Key Words: energy recovery, life cycle, Automotive Materials, Plastics, Recycling, Waste Utilization, Polymers-Recovery, Energy Engineering, Recyclability, Reaction injection Molded, Processing Technologies, Scrap Recovery
Notes: Standard No. 156091131X (pbk.)

Abstract: Design for Recyclability and Reuse of Automotive Plastics (SP-867) consists of papers from two sessions of the SAE International Congress. Papers in the "Plastics-Design for Recyclability" session discuss how designers may enhance the recycling of plastic components and promote aggressive reclamation of plastic materials. The session on "Reuse of Polyurethane RIM Materials" focuses on the recycling options for thermoset polyurethane and polyurea polymers made by the Reaction Injection Molded (RIM) process.

The volume contains eight papers presented at the meeting. Subjects covered include 1) RIM parts and life cycle energy-ecobalance recycling RIM thermosets, 2) RIM scrap recycling by compression molding, 3) thermal process recycling of RIM polyurea elastomers, 4) energy recovery, 5) automotive interior design for recyclability, 6) plastic beverage bottle recycling, 7) and auto shredder residue separation.

THIS IS AN IMPORTANT DOCUMENT

Thayer, Ann M. "Solid Waste Concerns Spur Plastic Recycling Efforts." *Chemical & Engineering News* v67 January 30, 1989. n5, p7-15.

Key Words: Waste materials, Plastics, Landfill, Recycling of waste materials, Research & development, R&D, Cost control

Abstract: The management of solid waste is reaching a crisis in the US and worldwide. With plastics taking up 30% of the volume of municipal solid waste and costs of landfilling and incineration rising rapidly, waste reduction efforts are focusing on development of plastics recycling technology.

"The Great Search for Substitutes." *Modern Plastics* Sept., 1990. p89-151.

Notes: Describes the search for additive substitutes which are designed to replace environmentally harmful additives.

Tilton, John E. "Materials Substitution: The Role of Technology." *International Institute for Applied Systems Analysis: Diffusion of Technologies and Social Behavior*. Ed. Grubler Nakicenovic. Springer Verlag, 1991.

Vasilash, Gary S. "There's More Than One Way to Skin a Car." *Production* v101 Jan., 1989. n1, p60-64.

Key Words: Automobile industry, Plastics, Component parts, Applications, Advantages

Abstract: A new automotive industry trend is the increased use of plastics in the skin of cars. However, since companies are extremely efficient in steel, speculation exists as to who will benefit from using plastic bodies for production vehicles. Plastics are popular for exterior trim, bumpers, and fascias. Fenders, doors, and quarter panels are vertical segments that are being made of plastic by certain manufacturers. The coefficient of linear expansion of materials is greater for plastics than for steel, which creates a special problem for doors. Using plastics on horizontal body panels is more difficult since they lend themselves to steel. Ford Motor Co. has undertaken a low-investment vehicle program that uses structural and nonstructural fiber-reinforced plastics and thermoplastic components. From a production standpoint, plastics provide the capability to run just-in-time whereas steel parts tend to create inventory holdovers. Design freedom is another benefit of the use of plastic.

Venta, E. R. and A. M. Wolky. *Energy and Labor Cost of Gasoline Engine Remanufacturing*. Argonne National Laboratory for US DOE Sept., 1978. p41. (CMU-Rosy Chen)

Notes: Includes thorough data tables, some diagrams.

Abstract: This report represents a detailed estimate of the labor and energy, by fuel type, required by the U.S. economy to remanufacture gasoline-fueled automobile and truck engines. The estimate was obtained by combining data provided by several remanufacturers with the results of input-output analysis. A rough estimate of the labor and energy required to manufacture new engines is also given. These estimates suggest that remanufactured engines require 50% of the energy and 67% of the labor that new engines require.

Wolfe, Paris R. "BMW Takes Leadership Role in Automotive Recycling." *Recycling Today* September 15, 1991. p48.

Key Words: Design for Disassembly, Reuse

Notes: Graph: costs for disposing auto shredder fluff have skyrocketed in Germany, motivating research by companies like BMW.

Abstract: Compared with any other post-consumer product, the automobile has the highest recycling rate. Present estimates say 75 percent of a car is recovered for recycling. However, its visibility as the largest source of obsolete scrap has made it a target of recycling attention. To control the effects of recycling on its business, BMW has take steps which could change the scrap industry.

Wolfe, Thomas J. "Realistic Recycling. (The Changing Directions of Environmental Law in the 1990's)." *Federal Bar News & Journal* v37 Feb., 1990. p90-94.

Notes: Describes trends in environmental regulations and rulings

Wolff, Michael E. "Practice 'Aggressive Incrementalism'." *Research-Technology Management* v31 July, 1988. n4, p8-10.

Key Words: R&D, Design engineering, Comparative analysis, Product development

Wolf, Roland. *Thesis: Reprocessing of ABS Automobile Parts Performance and Economy.* University of Lowell, 1991. p702.

Key Words: Engineering, materials science, plastics technology, environmental sciences

Abstract: The garbage situation in Western Europe forces new solutions in waste disposal. Used cars are one reason for this escalating problem. Right now most materials of a car are recycled, but plastics still are landfilled. One of the many possibilities to recycle is via reprocessing and reuse, but its realization will depend on the performance and economics of reprocessed plastics. In this study Flexural Modulus, HDT, Impact Strength (unnotched and notched) and Elongation and Break were investigated for ABS derived from used BMW cars and from commercially available repelletized used ABS. The recycled material was tested unwashed, washed, and reextruded. With some restrictions the results exhibit an acceptable performance and a good economics for the reprocessed chip material and repelletized pellets. To sum up there is a positive future for the reuse of ASS automotive parts combined with a decrease in material costs.