

# NSF Assessment of Environmental Issues in Electronics Manufacturing

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February 15, 2001

# NSF Study on Environmentally Benign Manufacturing (EBM)

- 18 month study
  - 52 site visits within Japan, Europe, and US
  - workshop in DC (July, 2000)
  - final draft report (Jan, 2001)
- Managed by WTEC at Loyola University, Baltimore
- Directed by NSF (Delcie Durham with the assistance of A.F. Thomson and K. Rajurkar)

# EBM Panel Mission

- ✓ Advance understanding of EBM
- ✓ Establish baseline and document best practices;
  - policy, practice, and motivation
  - infrastructure and technology,
  - methodologies and metrics,
  - goals and assessments
  - research
- ✓ Identify research opportunities
- ✓ Promote international cooperation

# EBM Panelists

- Timothy Gutowski (Chair)
- Cynthia Murphy (Co-chair)
- David Allen
- Diana Bauer
- Bert Bras
- Thomas Piwonka
- Paul Sheng
- John Sutherland
- Deborah Thurston
- Egon Wolff
- Delcie Durham (NSF)
- Fred Thompson (NSF)

# Focus Areas

- ✓ Metal Processing
- ✓ Polymer Processing
  - thermoplastics and thermosets,
  - composites
- ✓ Applications
  - automobiles
  - electronics

# Environmentally Benign Manufacturing (EBM)

Environmentally benign manufacturing is involved with the technologies, the operational practices, the analytical methods and strategies for sustainable production within the industrial ecology framework. (Sheng, Durham, Wellek)

- ✓ Specifically addresses the development and implementation of benign materials processing to meet the challenges of sustainable materials flow in a use and reuse environment
- ✓ It also addresses systems consideration of re-manufacturing, reuse, and recycling in total waste-stream management.

# Sites Visited: Japan

- Fuji Xerox
- Hitachi PERL
- Horiba, Ltd.
- Kubota
- MITI/Mechanical Eng. Lab.
- MITI/AIST/NIMC
- Nagoya University
- NEC Corporation
- Nippon Steel Corporation
- NIRE
- New Earth Conference & Exhibition
- NRIM
- PVC Industrial Association
- Sony Corporation
- Toyo Seikan Kaisha
- Toyota Motor Corporation
- University of Tokyo
- Institute for Industrial Science

# Sites Visited: Europe

Belgium, Denmark, Netherlands, Germany, Sweden,  
Switzerland

- Corus Holland
- DaimlerChrysler
- Denmark Tech. U.
- EC Environmental Directorate
- EC Research and Technical Development
- Excello
- Fraunhofer, Aachen
- Fraunhofer, Berlin
- Fraunhofer, Stuttgart
- ICAST
- IVF
- MIREC
- Siemens
- TU Aachen
- TU Berlin
- TU Delft (Ministry of Environment, Lucent Tech., Phillips)
- Univ. of Stuttgart
- Volvo

# Sites Visited: U. S.

- Applied Materials
- Caterpillar
- CERP
- Chaparral Steel/Cement
- DaimlerChrysler
- DRI
- DuPont
- Federal Mogul
- Ford
- GM
- IBM
- Interface
- Johnson Controls
- MBA Polymers
- Metrics Workshop
- Micro Metallics
- NCMS

# Highlights by Study Region



## US

- Focus on toxic releases and risk minimization
- Industrial response to environmental concerns highly variable
- Infrastructure is a free-enterprise activity
- Emphasis on tying to cost and business strategies

## European Union

- Focus on take-back, land-fill minimization, and control of toxic materials
- Taxation of emissions, energy, and consumption
- Regulation of products and industries rather than medium (air, water, soil)

## Japan

- Focus on solid waste, energy, and CO<sub>2</sub> emissions
- DFE, LCA, EBM part of concurrent engineering
- Material and energy inventories a priority
- High level of industry and public awareness

# R & D Activities - Relative Competitiveness

<u>Activity</u>	<u>Japan</u>	<u>US</u>	<u>Europe</u>
<b>Relevant Basic Research (&gt;5 years out)</b>			
Polymers	◆ ◆	◆ ◆ ◆	◆ ◆
Electronics	◆ ◆	◆ ◆ ◆	◆
Metals	◆ ◆ ◆	◆	◆ ◆
Automotive/Transportation	◆ ◆	◆	◆ ◆ ◆
Systems	◆ ◆	◆	◆ ◆ ◆
<b>Applied R&amp;D (≤ 5 years out)</b>			
Polymers	◆	◆ ◆ ◆	◆ ◆
Electronics	◆ ◆ ◆	◆ ◆	◆ ◆
Metals	◆ ◆ ◆	◆	◆ ◆
Automotive/ Transportation	◆ ◆ ◆	◆	◆ ◆ ◆
Systems	◆ ◆	◆	◆ ◆ ◆

# Industrial Activities - Relative Competitiveness

<u>Activity</u>	<u>Japan</u>	<u>US</u>	<u>Europe</u>
ISO 14000 Certification	❖❖❖❖	❖	❖❖❖
Water conservation	❖❖	❖❖❖	❖
Energy conservation/ $CO_2$ emissions	❖❖❖❖	❖❖	❖❖
Decreased releases to air and water	❖	❖❖❖	❖❖
Decreased solid waste /post-industrial recycling	❖❖❖❖	❖❖	❖❖❖
Post-consumer recycling	❖❖	❖	❖❖❖❖
Material and energy inventories	❖❖❖	❖	❖❖
Alternative material development	❖❖	❖	❖❖❖
Supply chain involvement	❖❖	❖	❖❖
EBM as a business strategy	❖❖❖❖	❖❖	❖❖❖
Life-cycle activities	❖❖	❖❖	❖❖

# Government Activities - Relative Competitiveness

<u>Activity</u>	<u>Japan</u>	<u>US</u>	<u>Europe</u>
Take-back legislation	◆◆	—	◆◆◆◆
Landfill bans	◆◆	◆	◆◆◆
Material bans	◆	◆	◆◆
LCA tool and database development	◆◆◆	◆◆	◆◆◆◆
Recycling infrastructure	◆◆	◆	◆◆◆
Economic incentives	◆◆	◆	◆◆◆
Regulate by medium	◆	◆◆	◆
Cooperative/joint efforts with industry	◆◆	◆	◆◆◆◆
Financial and legal liability	◆	◆◆◆◆	◆

# Preliminary Findings of EBM Study

## Future needs:

- ✓ Products designed for re-use
- ✓ Better reprocessing technologies
- ✓ Introduction of EBM as part of being "lean" rather than new
- ✓ Integration of financial and environmental systems
- ✓ Re-use / life prediction modeling
- ✓ Accounting system for the "value" of EBM in processing and design selection

# State of International Environmental Performance Standards

- The International Electrotechnical Commission (IEC) is concerned with the following issues related to environmental standards in the area telecommunications technology and **electronic equipment** :
  - ✓ the primitive state of LCA
  - ✓ pollution prevention (especially solder cleaning and DI water)
  - ✓ environmental impact assessments
  - ✓ design for disassembly (including joining technologies and decorative surface finishes / paints)

Laudise and Graedel (1998), *Manufacturing, The Ecology of Industry*, NAE Press

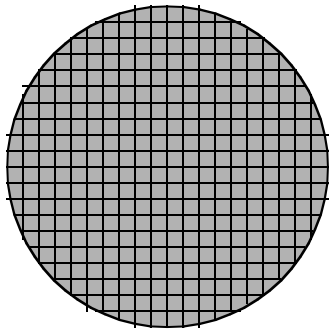
# Electronics - Overview of EBM Findings

- The electronics industry tends to be proactive (worldwide) and is a leader in the areas of
  - Life-cycle Assessment (LCA)
  - Design for Environment (DFE)
  - End-of-Life Management (ELM)
- An industry culture of minimization, cost-reduction, and increased efficiency are all compatible with EBM

# Electronics - Overview of EBM Findings, Cont'd

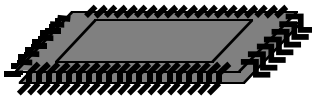
- Accustomed to inserting and integrating new designs, technologies, and equipment
  - Average product life span of 18 to 24 months
  - Complete capital equipment turn-over every 5 years
- Expert at managing and analyzing large amounts of data (legacy of quality movement)

# Materials and Environmental Concerns - Integrated Circuits



Wafer fabrication

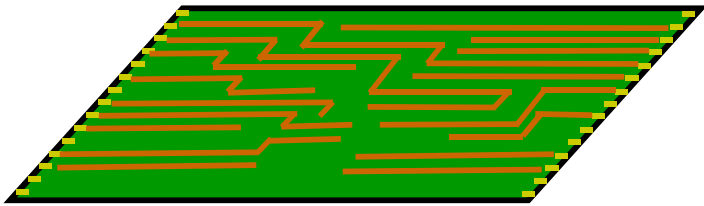
Product materials: Si, SiO<sub>2</sub>, Al, ± Cu  
EBM Issues: Water, energy, gas emissions  
(especially PFCs - perfluoro compounds)



Chip packaging

Product materials:  
Polymers, Ceramics, Ni/Au alloys, Cu, Au  
EBM Issues: Energy, metal-bearing liquid waste,  
flame retardants, material waste

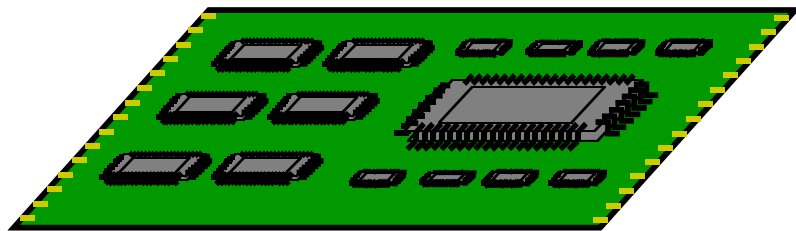
# Materials and Environmental Concerns - Printed Wiring Boards



PWB fabrication

Product materials: Ceramic, epoxy-glass, or other polymers; Cu, Pd, Pb, Au

EBM Issues: Water, energy, flame retardants, Pb finishes, plating solutions

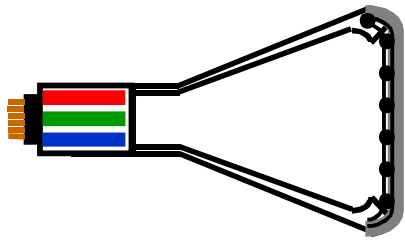


PWB (board-level) assembly

Product materials: Pb/Sn

EBM Issues: Energy, Pb

# Materials and Environmental Concerns - Computer System



CRT

Product materials: Glass, Pb,  
phosphors, steel, Al, Cu  
EBM Issues: Energy, Pb



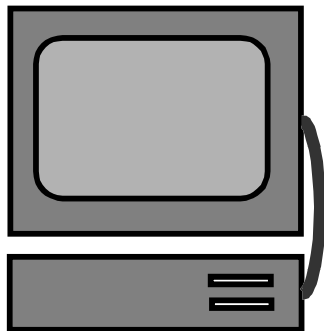
Batteries

Product materials: NiCd  
EBM Issues: Cd, life/efficiency



Storage Media

Product materials: Al or glass, Ni, Mg  
EBM Issues: recyclability



Final Assembly

Product materials: Al or glass, Ni, Mg  
EBM Issues: recyclability

# Japan - Findings

- ✓ Highly responsive to activities in Europe
  - Elimination of halogenated flame retardants
  - Pb-free solders
- ✓ **ISO 14000** certification is a focus
- ✓ New recycling law to require recycling of selected appliances starting April, 2001. Computers are expected to follow.
- ✓ Using alternative PWB technologies (microvias) that are inherently less water, energy, and material intensive processes while providing better performance
- ✓ Sites visited: **Hitachi, Sony**

# Europe - Findings

- ✓ Take-back legislation and WEEE (Waste Electrical and Electronic Equipment) Directive
  - Recycling
  - Material alternatives (Pb and non-brominated FRs)
- ✓ Dutch have a well-developed infrastructure for collecting and recycling computers
  - Glass and metals are re-introduced into the material stream
  - Plastic is incinerated
- ✓ "Green" products offered in parallel with conventional, but with a price differential
- ✓ Sites visited: MIREC, Siemens

# United States - Findings

- ✓ Responding to activities in Europe
  - Take-back
  - Pb-free solder
  - Non-brominated flame retardants
- ✓ Emphasis on metrics and supply chain management
- ✓ Recycling activities in partnership with OEMs (HP, IBM) or sponsored by government agencies (DoC, DoE, and DoD)
- ✓ Focus on recycling rather than incineration of plastic
- ✓ Sites visited: IBM, Applied Materials, DuPont (electronic materials), MBA polymers, Micro Metallics

# Challenges - Pb-free Solder

- ✓ Pb-free solders require higher temperatures
  - Need capacitors and resistors that can withstand increased temperatures
  - Need substrates that withstand increased temperatures
  - More energy intensive and lower yield (higher waste)
- ✓ More complex alloys
  - More difficult to maintain uniform composition
  - May be more difficult to recycle or disassemble to allow recycling of boards

# Challenges - Pb-free Solder, Cont'd

- ✓ Unclear that Pb-free solders are actually more environmentally friendly
  - material extraction
  - increased processing difficulties
  - ease of recycling
- ✓ Best solution may be completely new attachment technologies (e.g., adhesive flip-chip)

# End of Life Management

- ✓ Interest being driven by
  - Take back legislation in Europe
  - Material bans in Europe (Pb, halogenated FRs)
  - Landfill bans and labeling laws in US (e.g., CRTs, Hg)
  - Leasing agreements (increased producer responsibility)
- ✓ Reuse
  - Limited to systems less than 36 - 60 months old
  - Component harvesting economic only in tight markets
- ✓ Three primary materials commodities / issues
  - Plastics / separation, contamination, high cost-to-value ratio
  - Glass / Pb and FPDs
  - Metals / decreasing volume, especially precious metals

# US Activities

## Professional associations and consortiums

- IEEE - ISEE - focus on LCA, DFE, EOL
- IPC - PWBs, interconnect, packaging, ESH
- NEMI - systems level issues, policy, roadmaps
- EIA (focused on industry-wide DFE and on unified responses to policy and legislation - esp. WEEE)
- MCC (roadmaps, PWBs, electronics recycling, software)
- SIA / SEMATECH (roadmaps, semiconductor fabrication, equipment, ESH as a major thrust area)
- NCMS - process and materials, technology development and evaluations

# US Activities Cont'd

## Government programs

- NSF - EBM Center (ICs), EBM panel
- DARPA - ECM Program - focus on PWBs including bio-laminate, fully-additive circuitry, permanent resists
- EPA - DfE Program- PWB z-axis metallization, computer displays
- DoE, DoD, DoC, EPA - Electronics recycling

# Funding Opportunities for EBM

- ✓ Unsolicited Research Proposals to Materials Processing and Manufacturing Program (1467) for February 1 and October 1 deadlines each year.
- ✓ New announcement: **NSF/EPA Technologies for a Sustainable Environment (NSF 01-??)** - totally new section for green design and manufacturing, industrial ecology for sustainable product realization - WATCH for this announcement within next few days
- ✓ Small Grants for Exploratory Research - MUST be high risk, high potential - truly unusual approach or concept. Contact: **ddurham@nsf.gov**

# Lead-free solder: current and past awards from NSF

- **FRG: Modeling of Microstructure Evolution & Thermomechanical Fatigue in Lead-Free Solder Joints** #0081796 K. N. Subramanian, Michigan State
- **New Technology for the Environment: Environmentally-Conscious, Economically-Feasible Electronics Manufacturing** #0086726 Mark A. Palmer, Virginia Commonwealth
- **RUI: Modeling Formation of Microstructure of Intermetallic Compounds During Soldering.** #0080176 Alexander Umantsev, Saint Xavier
- **Design of Interfacial Microstructures and Creep Resistant Lead-Free Solders for Electronic Interconnects** #9813919
- **Instability of the Wetting Tip in Lead-Free Solder Reactions** #9705195 and #9320769
- **Development and Evaluation of Lead-Free Solders for Electronic Applications** #9523447 and #9201834 Morris E. Fine, Gautam Ghosh, Semyon Vaynman, Northwestern University

found on: <https://www.fastlane.nsf.gov/a6/A6AwardSearch.htm>