MSE 697
Design for Global Sustainability: Electronics

Purdue University
Tuskegee University

August 21, 2012
• Definition of global sustainability for electronics

How do we realistically measure what happens?
How do we frame the right questions?
What are the tradeoffs?
What data are not there? ...

We don’t know what this looks like yet.
We want to understand.
We want to eliminate barriers
We want to build bridges to industry, NGO’s, government, educators.
"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:

• the concept of needs, in particular the essential needs of the world's poor, to which overriding priority should be given; and

• the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs."

Sustainability: the Triple Bottom Line

Environmental Sustainability
- Available Natural Resources
- Ecosystem Health
- Climate Stability
- Water Quality, Biodiversity

Economic/Industrial Sustainability
- Energy Efficiency
- Subsidies/Incentives for Use of Natural Resources

Societal Sustainability
- Environmental Justice
- Natural Resources Stewardship Locally & Globally
- Education
- Access to food, clean water, shelter, health care
- Govt. stability
- Social justice
- Equity

Sustainable Electronics
- Profit
- Productivity
- Econ. Opportunity
- Econ. Growth
- Employment
- Manufacturing

Adapted from the 2002 University of Michigan Sustainability Assessment
Sustainability: the Triple Bottom Line

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Societal Sustainability
- Societal-Environmental
- Environmental Justice
- Natural Resources
- Stewardship Locally & Globally

Education
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- Manufacturing

Societal
- Economic-Societal
- Opportunity
- Fair Trade
- Workers’ Rights

Adapted from the 2002 University of Michigan Sustainability Assessment
Sustainability: the Triple Bottom Line

Adapted from the 2002 University of Michigan Sustainability Assessment
Sustainability

• Sustainable development:
  – meeting the needs of the present without compromising the ability of future generations to meet their own needs

• Economic – Societal - Environmental
• Sustainable for whom?
• Sustainable over what time?

• (Impact) X (number of people)
Sustainable Electronics – EPA Workshop 2012

• Business decisions are aligned with sustainability objectives
• All life cycle costs are internalized in the products
  “Externalities are impacts generated by one economic actor, which are felt by others, but the market doesn’t bring these impacts back to affect the actor that originated them.” Neva Goodwin
• Decisions are transparent
• Companies, consumers, and all people in the supply chain are accountable
• ICT enables smarter use of natural resources
Sustainable Electronics – EPA Workshop 2012

- All ICT hardware is manufactured in facilities with best-in-class health, safety, and environmental standards globally with employees earning a living wage, no forced labor, no forced overtime, no child labor, no discrimination, and workers have freedom of association
- No chemical or materials selection is made without an alternatives assessment, or the substance is on the “good” list
- Hazardous emissions to air, water, land are eliminated
- Resources are not wasted
- People and communities benefit
Maslow’s Hierarchy of Needs

- Sustainable for whom?
- Sustainable over what time?
<table>
<thead>
<tr>
<th>COMPONENT SUPPLIERS</th>
<th>ODM/ECMs</th>
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</table>

ChainLink research website
Simplified Supply Chain Map for an OEM

4.1B cell phone subscriptions worldwide in 2008
1.8B people on the internet
For a population of 6.9B
Environmental impact = population * (impact per person)

Impact to have needs met
  Food
  Shelter
  Water
  Safety
  Community
  …
Energy Return on Investment

Economics and Limits to Growth: What’s Sustainable?
Dennis Meadows
Washington, DC
October 6, 2009
Energy Return on Investment

Economics and Limits to Growth: What’s Sustainable?
Dennis Meadows
Washington, DC
October 6, 2009
The Reference Scenario

Economics and Limits to Growth: What’s Sustainable?
Dennis Meadows
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October 6, 2009

Original Report

Today

Industrial Output
Population
Pollution
Resources
Food
Dennis Meadows:
Main Points of His Speech

• Growth has continued until we are now past sustainable levels.
• The global society will change more over the next 20 years than in the past 100. Design policies for what is coming, not what has been.
• The main forces for change will be climate change and resource scarcity - especially fossil fuels and water.
• The end of growth does not result from total depletion, but from rising capital costs.
• The most important scarcity is the absence of a longer-term perspective.

Economics and Limits to Growth: What’s Sustainable?
Dennis Meadows
Washington, DC
October 6, 2009
iNEMI
(International Electronics Manufacturing Initiative)
An industry-led research and development consortium of major electronic firms, suppliers, industry associations and consortia, government agencies and universities.

- roadmaps the needs of the global electronics industry, identifies gaps in the technology infrastructure, and establishes implementation projects to eliminate these gaps (both business and technical).

- works with government, universities and funding agencies to set priorities for R&D initiatives.

- has been instrumental in providing the reliability and manufacturing knowledge necessary for the world-wide conversion to Pb-free electronics and continues to serve that role as replacement materials for electronics systems continue to be required due to environmental or human health bans or material shortages.
iNEMI Board of Directors

Chairman: Nasser Grayeli, Intel Corporation
Marc Benowitz, Alcatel-Lucent
Ravi Bhatkal, Cookson Electronics
William Chen, ASE
Byung Joon (BJ) Han, STATS ChipPAC Ltd.
Kim Hyland, Cisco
Sundar Kamath, Sanmina-SCI
Kevin Keller, Delphi Electronics & Safety
Mark Morizio, IBM
Jean-Luc Pelissier, CBA Group LLC

Ex-Officio Board Members:
Bill Bader, iNEMI
James Olthoff, National Institute of Standards and Technology
Robert C. (Bob) Pfahl Jr., iNEMI
### MANUFACTURING TECHNOLOGIES
- Board Assembly
- Final Assembly
- Test, Inspection & Measurement

### COMPONENT / SUBSYSTEM TECHNOLOGIES
- Electronic Connectors
- Energy Storage & Conversion Systems
- Interconnect Substrates – Ceramic
- Interconnect PCB - Organic
- Large-Area Flexible Electronics
- Mass Data Storage
- MEMS / Sensors*
- Optoelectronics
- Packaging & Component Substrates
- Passive Components
- Photovoltaics
- RF Components & Subsystems
- Semiconductor Technology
- Solid State Illumination

### BUSINESS PROCESSES / TECHNOLOGIES
- Information Management

### DESIGN TECHNOLOGIES
- Environmentally Conscious Electronics
- Modeling, Simulation & Design Tools
- Thermal Management

### Table 2. The 2011 iNEMI Roadmap covers 21 technology and business process areas, contrasting trends with anticipated product needs. TWGs are composed of experts from OEMs, EMS providers, suppliers, government agencies, universities and related consortia/trade associations.

iNEMI coordinates with other roadmapping organizations to synchronize timelines, agree on and refine product sector definitions, identify common elements, facilitate cross-functional groups, and coordinate roadmapping schedules. Direct links with other roadmaps and other organizations include: ITRS (semiconductors), IPC (interconnection substrates), the Optoelectronics Industry Development Association (OIDA, optoelectronics and optical storage), the Information Storage Industry Consortium (INSIC, magnetic and optical storage), the Supply Chain Council (SCC, product lifecycle information management), the International Microelectronics and Packaging Society (IMAPS, ceramic substrates), the Surface Mount Technology Association (SMTA, board assembly), MEMS Industry Group (MIG, MEMS), and IEEE's Components, Packaging & Manufacturing Technology (CPMT) Society.

### 2011 Roadmap Facts & Figures

**Content:**
- 1800 pages of information
- 27 chapters covering 6 product sectors and 21 technology areas

**Contributors:**
- 575 individuals
- 310 organizations from 18 countries
### iNEMI Assembly Project Participants

**OEMs/EMS**
- Agilent
- Alcatel Canada
- Celestica
- Compaq
- Delphi
- IBM
- Intel
- Kodak
- Lucent
- Motorola
- Sanmina-SCI
- Solectron
- StorageTek

**Solder Suppliers**
- Alpha Metals
- Heraeus
- Indium
- Johnson Mfg.
- Kester

**Govt. & Other**
- NIST
- SUNY/IEEC
- ITRI (US)
- IPC

**Components**
- ChipPac
- Intel
- Motorola
- Texas Instruments
- FCI USA Electronics

**Equipment**
- BTU
- DEK
- Orbotech
- Teradyne
- Universal
- Vitronics-Soltec
Example of Solder Joint Microstructure:
169 CSP, LF-LF, -40 °C to +125 °C

Sn-3.9Ag-0.6Cu

Solder consists of tin dendrites separated by Cu-Sn and Ag-Sn intermetallics.
Example of Solder Joint Microstructure:
169 CSP, LF-LF, -40 °C to +125 °C

PbSn eutectic

SAC Sn-3.9Ag-0.6Cu
## NEMI Pb-Free Assembly Project: ATC Relative Performance

### -40 to +125

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<th>Component</th>
<th>SnPb - SnPb</th>
<th>SnPb - LF</th>
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<td>208 CSP</td>
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<td>0</td>
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<td>208 CSP - JEITA alloy</td>
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<tr>
<td>256 PBGA</td>
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### 0 to 100

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<tr>
<td>256 Ceramic BGA</td>
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<td>-</td>
<td>+</td>
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---

0 equivalent to SnPb-SnPb benchmark (95% confidence bounds)

- statistically worse than SnPb-SnPb benchmark

+ statistically better than SnPb-SnPb benchmark
169 CSP Lifetime Analyses: What are the Acceleration Factors for Sn-Ag-Cu?

0 °C to 100 °C cycling

-40 °C to +125 °C cycling

<table>
<thead>
<tr>
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<table>
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<tr>
<td>$\beta$</td>
<td>6.6</td>
<td>11.3</td>
<td>7.7</td>
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</table>
Figure 5 BGA-225 Pbfree versus SnPb test results for the “Manufactured” test vehicles (170C Tg)
Figure 16 TSOP-50 Pbfree versus SnPb test results for “Manufactured” test vehicles (170°C Tg)
Morphology of Fillet Lifting

Through-Hole Lead

Solder Fillet

Separation during Cooling

Through-Hole Lead on Board

NCMS Lead-Free Solder Project and collaboration between NIST and Tsung-Yu Pan, Ford
Large Semiconductor Component (PBGA313)

- processed by iNEMI Consortium
- would like to understand behavior

Reflow @ 205 ºC
Primary solid phases: (Sn) + η + ε

Reflow @ 225 ºC
Primary solid phase: η

No solid stable
Reflow @ 240 ºC
Ag$_3$Sn Plate Formation:
Darrel Frear, Freescale
iNEMI Advanced Pb-free Assembly & Rework Development Project

Program Chairs: Jerry Gleason, Hewlett Packard, Charlie Reynolds, IBM

Assembly Team Leader: Matthew Kelly, IBM

Rework Team Leaders: Jasbir Bath, Solectron and Quyen Chu, Jabil Circuits

Reliability Team Leader: Patrick Roubaud, HP

Logistics & Procurement Leader: Ken Lyjak, IBM

Project Report Coordinator: Ken Lyjak, IBM

iNEMI Project Consultant: Ron Gedney

Four important findings have emerged:

1. There are no major impediments to Pb-free SMT reflow processes for IPC Class 2 printed circuit assembly. Monitor paste composition and tendency for void formation – poorly controlled. Self-alignment properties of solder weaker for Pb-free – only cosmetic right now but monitor.

2. The accelerated thermal cycle (ATC) thermal fatigue life of Pb-free solder joints appears to be longer than the control SnPb assemblies. A caveat to this is that acceleration factors on ATC testing have not been established for Pb-free solders.

3. Large Pb-free assemblies can only withstand ~50% of the mechanical bend force and deflection when compared to tin-lead (SnPb) assemblies. The latter implies that more care needs to be taken in handling throughout the manufacturing process, including adequate fixtures for In Circuit Tests (ICT). Maybe also mounting issues for high reliability applications.
4. The reliability of reworked area array components (BGAs, etc.) was poorer than that of as-assembled / nonreworked assemblies, and the rework processes adversely impacted adjacent component solder joints (collateral damage) through secondary reflow effects. If this problem is not solved, area array components spacing may have to increase to ensure reliability if hot gas rework on an adjacent site is performed.

To improve the Pb-free rework process, a project proposal is being written to make needed improvements for hot gas rework of area array components. Solectron, Celestica and Jabil Circuit are working together with input from HP and IBM to define the specific improvements needed. Rework for pin through hole (PTH) also needs to be developed. Another important area needing development is laminates and fabricator processes that can withstand 5X reflow at 260 °C. Also, the laminates need to be more tolerant to bend forces.
Stakeholders get together to discuss the future
- Showed they could make a change
Lowered exposure to Pb for workers in manufacturing
Allowed to sell products in Europe
Lowered the amount in landfills in Europe and US
Eliminated shoddy manufacturers
  - 30% of EU electronics are not RoHS compliant
Companies selling processing equipment benefited because old equipment would not operate

Adverse effects
More Ag is being used
More Sn being used – cassiterite
Increased the electronics shipped to the third world
a strict subset of the dynamic gains. However to get the dynamic gains one generally has to introduce into a model non-competitive features, which means that static model is not necessarily a conservative estimate of the gains. It is possibly an incorrect estimate, especially for individual countries. Saying “the static gains are just the measurable component of the total gains” is logically different from saying “under a different model one gets much higher estimates of the global gains, but that model is incompatible with the model that produced the static gains.”

**Notes**

3. **Dirty** industries. Just between you and me, shouldn’t the World Bank be encouraging more migration of the dirty industries to the IDCs? I can think of three reasons:

1. The measurement of the costs of health impairing pollution depends on the foregone earnings from increased morbidity and mortality. From this point of view a given amount of health impairing pollution should be done in the country with the lowest cost, which will be the country with the lowest wages. I think the economic logic behind dumping a load of toxic waste in the lowest wage country is impeccable and we should face up to that.

2. The costs of pollution are likely to be non-linear as the initial increments of pollution probably have very low cost. I’ve always thought that underpopulated countries in Africa are vastly under-polluted, their air quality is probably vastly inefficiently low compared to Los Angeles or Mexico City. Only the lamentable fact that so much pollution is generated by non-tradable industries (transport, electrical generation) and that the unit transport costs of solid waste are so high prevent world welfare enhancing trade in air pollution and waste.

3. The demand for a clean environment for aesthetic and health reasons is likely to have very high income elasticity. The concern over an agent that causes a one in a million chance of getting prostate cancer is obviously going to be much higher in a country where people survive to get prostate cancer than in a country where under 5 mortality is 200 per thousand. Also, much of the concern over industrial atmospheric discharge is about visibility impairing particulates. These discharges may have very little direct health impact. Clearly trade in goods that embody aesthetic pollution concerns could be welfare enhancing, while production is mobile the consumption of pretty air is non-tradable.

The problem with the arguments against all of these proposals for more pollution in IDCs [intrinsic rights to certain goods, moral reasons, social concerns, lack of adequate markets, etc.] could be turned around and used more or less effectively against every Bank proposal for liberalization.
An Imperial Legacy? An Exploration of the Environmental Impact of Ancient Metal Mining and Smelting in Southern Jordan

F. B. Pyatt*

Department of Life Sciences, The Nottingham Trent University, Clifton Lane, Nottingham NG11 8NS, U.K.

G. Gilmore

School of Geography and Environmental Sciences, Nene University College, Northampton NN2 7AH, U.K.

J. P. Grattan

Institute of Geography and Earth Sciences, The University of Wales, Aberystwyth SY23 3DB, U.K.

C. O. Hunt

Department of Geographical and Environmental Sciences, University of Huddersfield, Huddersfield HD1 3DH, U.K.

S. McLaren

Department of Geography, University of Leicester, Leicester LE1 7RH, U.K.
An Imperial Legacy? An Exploration of the Environmental Impact of Ancient Metal Mining and Smelting in Southern Jordan

F. B. Pyatt*

Extensive wastes from the copper mining and smelting activities of the Nabatean, Roman and Byzantine periods in the Wadi Faynan in the southern Jordanian desert continue to exert a profound influence upon the environment, mainly through processes of bioaccumulation. It is suggested that in antiquity both producers and consumers (plants and animals) would have similarly been subjected to enhanced bioaccumulation of potentially toxic heavy metals such as lead and copper, whose consequences are explored in this account.

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J. P. Grattan

Institute of Geography and Earth Sciences, The University of Wales, Aberystwyth SY23 3DB, U.K.

C. O. Hunt

Department of Geographical and Environmental Sciences, University of Huddersfield, Huddersfield HD1 3DH, U.K.

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Department of Geographical and Environmental Studies, University College, Aberystwyth, U.K.

S. McLaren

Department of Geography, University of Lancaster, U.K.

(Gilbertson et al., 1997). Small wonder then that in Romano-Byzantine times the mines of Phaino were seen as a place to send recalcitrant criminals. Eusebius of Caesarea in his “Martyrs of Palestine” describes such a scene; “they demanded that he should be sent away to the mines, and not just any mines but to that of Phaino where even a condemned murderer is hardly able to live a few days”.

Purdue University