Summary of Activities for a Life-Cycle Environmental Impact Evaluation *of* Tin-Lead and Lead-Free Solder

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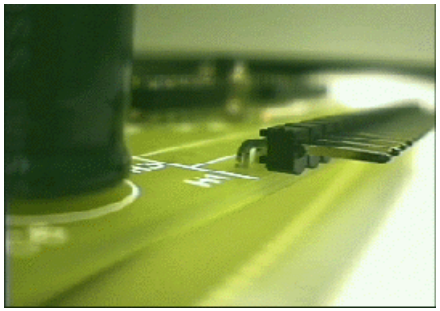
THE CENTER FOR CLEAN PRODUCTS AND CLEAN TECHNOLOGIES

EERC

UT Center for Clean Products and Clean Technologies (CCPCT)

- Mission
  - To develop, evaluate, and promote environmentally friendly products and technologies that minimize pollution at the source and contribute to long-term sustainable development
- Purpose
  - Assist producers and other stakeholders in cooperative efforts to design products and processes to reduce life-cycle environmental impacts
- Research in Electronics Sectors
  - Electronics, Printing, Automotive, Carpet
- Experience in LCA



Lead-Free Solder Partnership Goals

- Evaluate the relative environmental impacts of Sn/Pb solder and selected Pb-free alternative solders (LCA)
- Other Non-LCA specific goals:
  - Evaluate the effects of lead-free solders on recycling and reclamation at EOL
  - Assess the leachability of Pb-free solders and their potential environmental effects
- Identify issues that require additional research

Solders Selected for Evaluation

Wave Application Solders

- Sn/Pb (63 Sn/ 37 Pb)
- Sn/Cu (99.2 Sn/ 0.8 Cu)
- Sn/Ag/Cu (95.5 Sn/3.9 Ag/0.6 Cu)

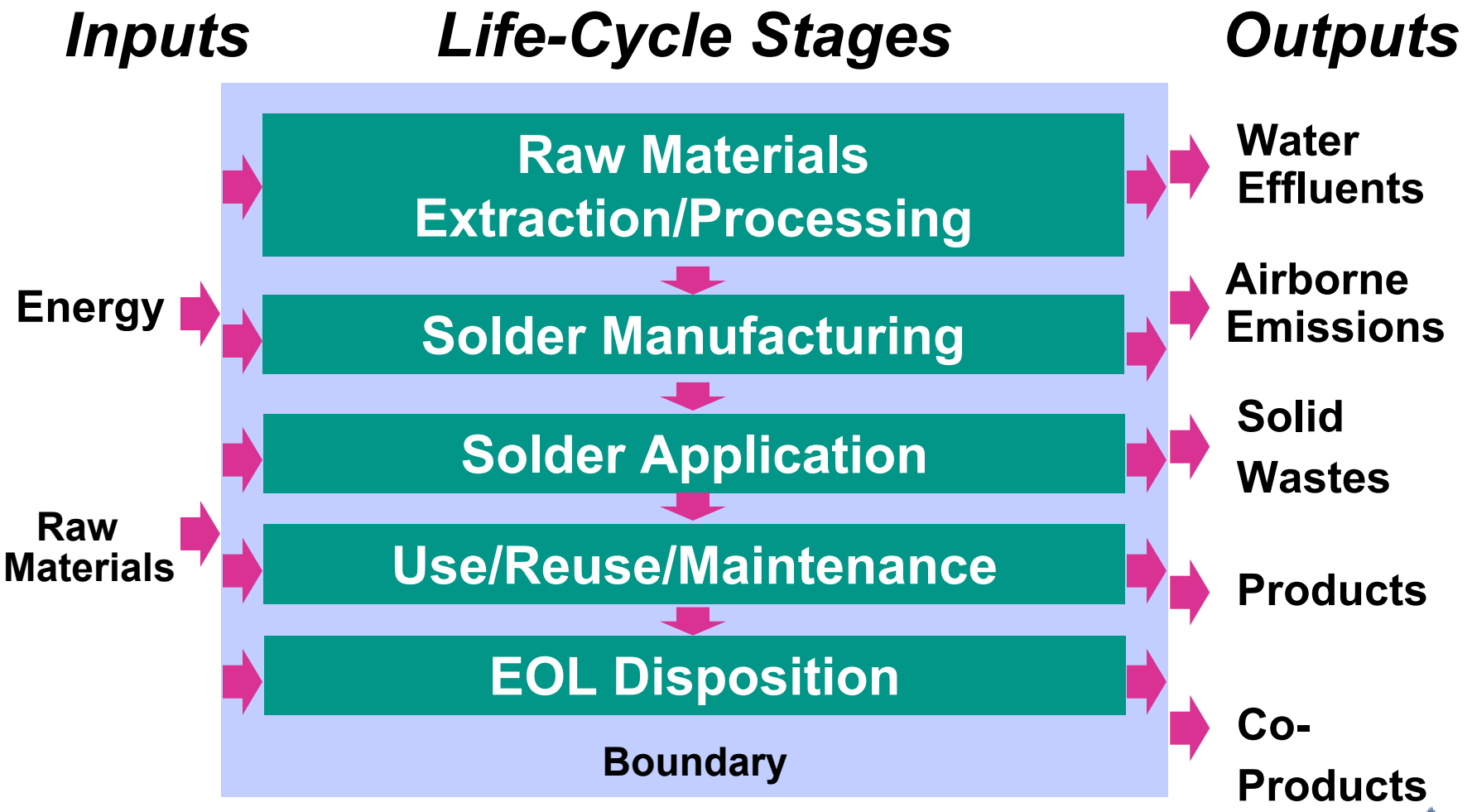
Reflow Application Solders

- Sn/Pb (63 Sn/ 37 Pb)
- Sn/Ag/Cu (95.5 Sn/3.9 Ag/0.6 Cu)
- Sn/Ag/Bi (42 Sn/1.0 Ag/57 Bi)
- SnAg/Cu/Bi (96 Sn/2.5 Ag/0.5 Cu/1.0 Bi)

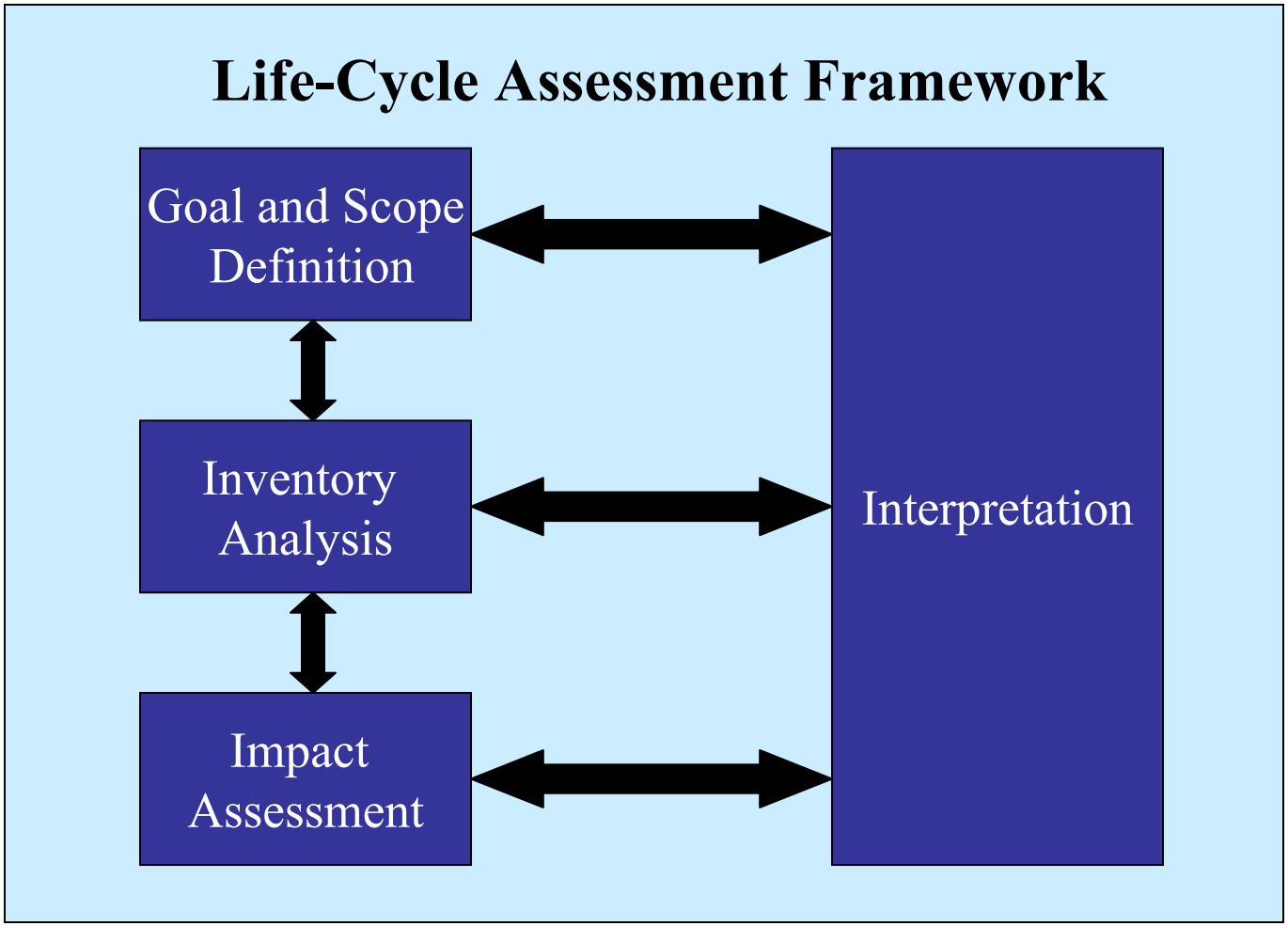
Project Contributors

- **Funding contributors**:
  - US EPA Design for the Environment, Agilent Technologies, Cookson Electronics, Delphi Delco, Hewlett-Packard, IBM, Intel, Pitney Bowes, Rockwell Collins, International SEMATECH, Thomson Multimedia,
- **Other contributors**:
  - Siemens, Kester, Omega Solder, Senju, AIM Solder, Noranda/ Micrometallics, Celestica, Hobi, Flextronics, Vitronics-Soltec, NEMI, Teradyne, Philips, U.S. Navy-Crane, U of Florida, Boliden, IPC

Life-Cycle Stages



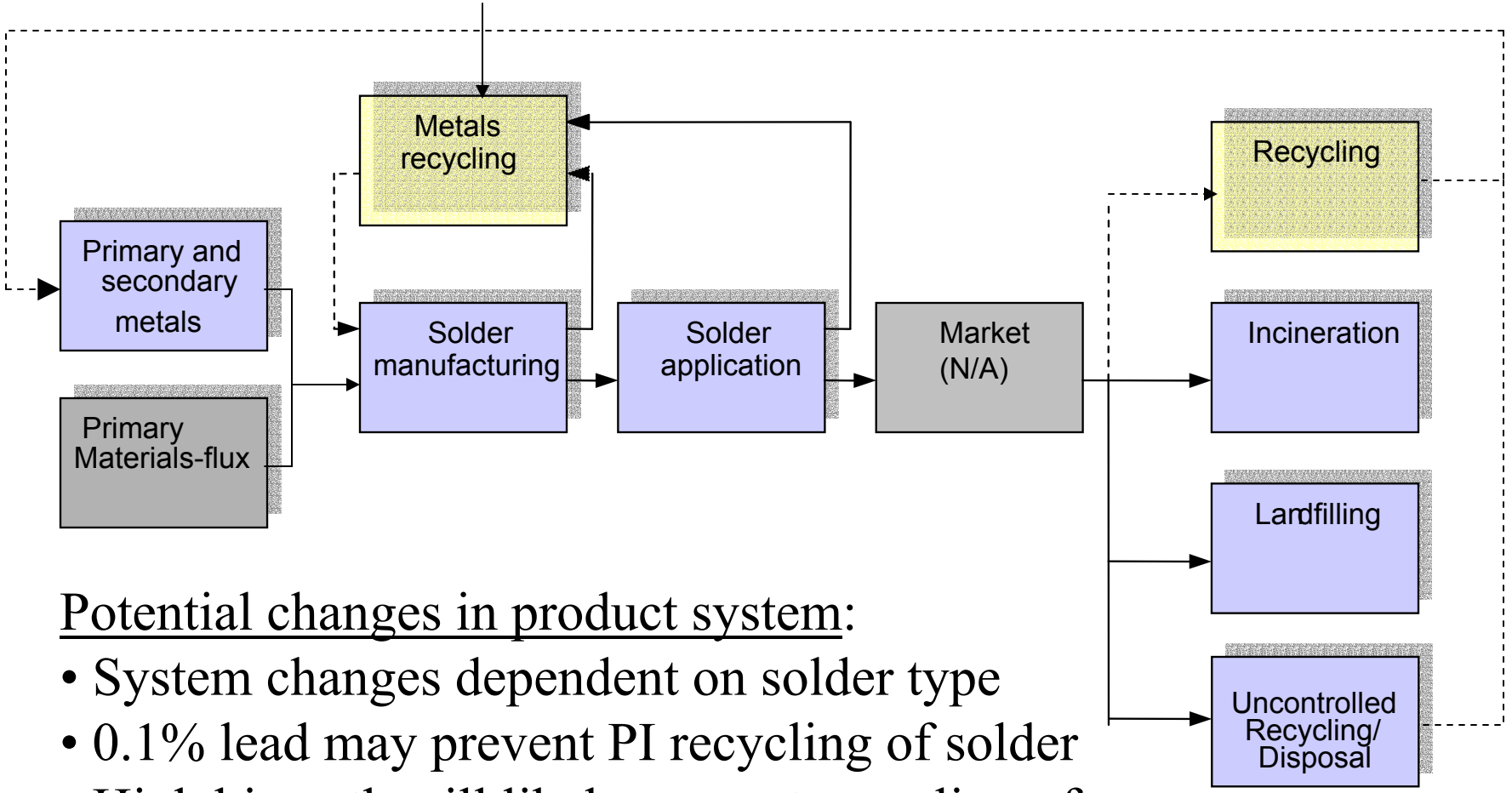
ISO 1404x Definition of LCA



Life-Cycle Impact Categories

- Resource consumption (renewable & non-renewable)
- Energy use
- Water use
- Landfill space use
- Global warming
- Ozone depletion
- Photochemical smog
- Acidification
- Local air quality (PM_{10})
- Water eutrophication
- Local water quality (BOD, TSS, pH)
- Chronic human health toxicity (occupational & public)
- Aesthetics (odor)
- Ecotoxicity (aquatic & terrestrial)

Lead-free Solder Product System



Potential changes in product system:

- System changes dependent on solder type
- 0.1% lead may prevent PI recycling of solder
- High bismuth will likely prevent recycling of EOL PWB scrap
- Economic factors key to recycling loops

Materials Extraction and Solder Manufacturing Stages

- Secondary (pre-existing) data sources for metal extraction and processing
  - data available for most metals (excepting bismuth)
  - limited time frame and budget
  - Existing data is being assessed for quality and accuracy
- Secondary data for fuels identified in other life-cycle stages
  - Solder manufacturing:
    - electricity, natural gas, heavy fuel oil (#6), LPG
  - Solder application:
    - electricity

Solder Manufacturing Stage

- Data aggregated from 5 companies
- Bar and paste data collected separately
- Major inputs:
  - Metals: primary vs. secondary
  - Energy: mix of power/fuels
  - flux (for paste): assumed same for each (differences appear in functional unit normalization)
- Outputs: not yet aggregated, likely not significant

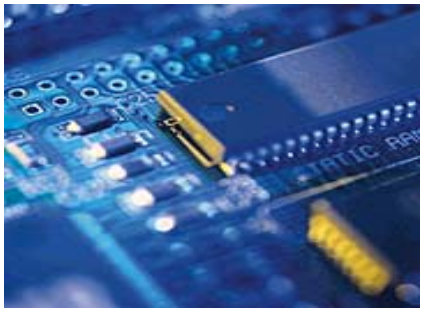
Solder Manufacturing Data - Energy

- Manufacturing energy inputs per unit of solder manufactured, by fuel type (MJ/kg solder):

Alloy	Electric	FO#6	LPG	Nat. gas	Kerosene	Total
Bar						
SnPb	6.37E-01	1.94E-01	4.57E-01	2.14E+00	1.20E-03	**3.43**
SAC	1.09E+00	1.94E-01	1.64E+00	3.20E+00	1.20E-03	**6.13**
SnCu	1.09E+00	1.94E-01	1.64E+00	3.20E+00	1.20E-03	**6.13**
Paste						
SnPb	1.31E+00	5.40E-01	1.10E-02	5.67E+00	3.34E-03	**7.54**
SAC	2.53E+00	5.40E-01	1.37E-02	5.38E+00	5.01E-03	**8.47**
SAB	2.53E+00	5.40E-01	1.37E-02	5.38E+00	5.01E-03	**8.47**
SACB	2.53E+00	5.40E-01	1.37E-02	5.38E+00	5.01E-03	**8.47**

Recycling of Waste Solder

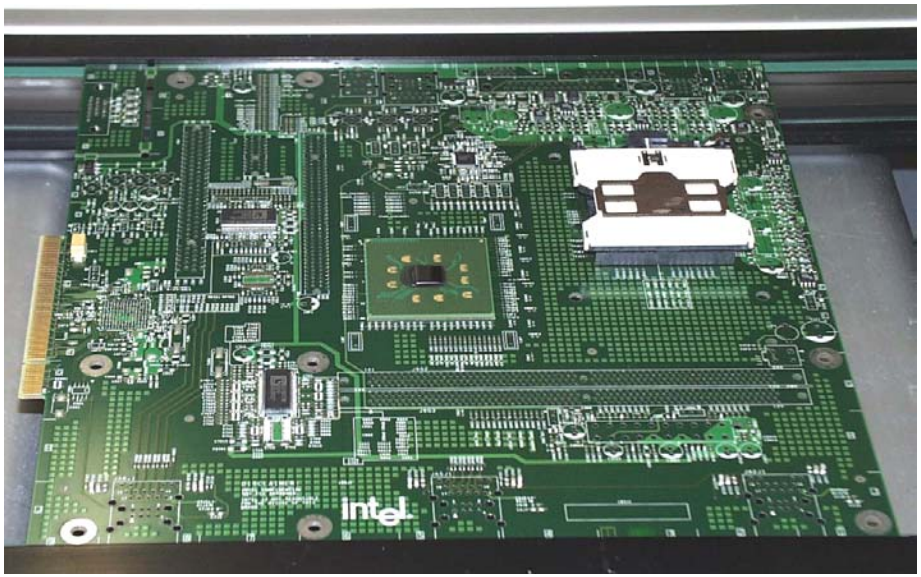
- Solder recycled through Sn or Pb smelting and refining process
  - Inputs include waste from solder manufacturing and application as well as materials from other industries
  - All metal content undergoes smelting and refining
  - Additional process steps required to separate lead-free metals (e.g. Ag, Bi)
- Lead limit of 0.1% Pb will present difficulties for lead solder recycling:
  - Feedstock segregation and sampling problems
  - Contamination of equipment equals high capital investment
  - Potential duration of changeover



Application of Solder LC Stage

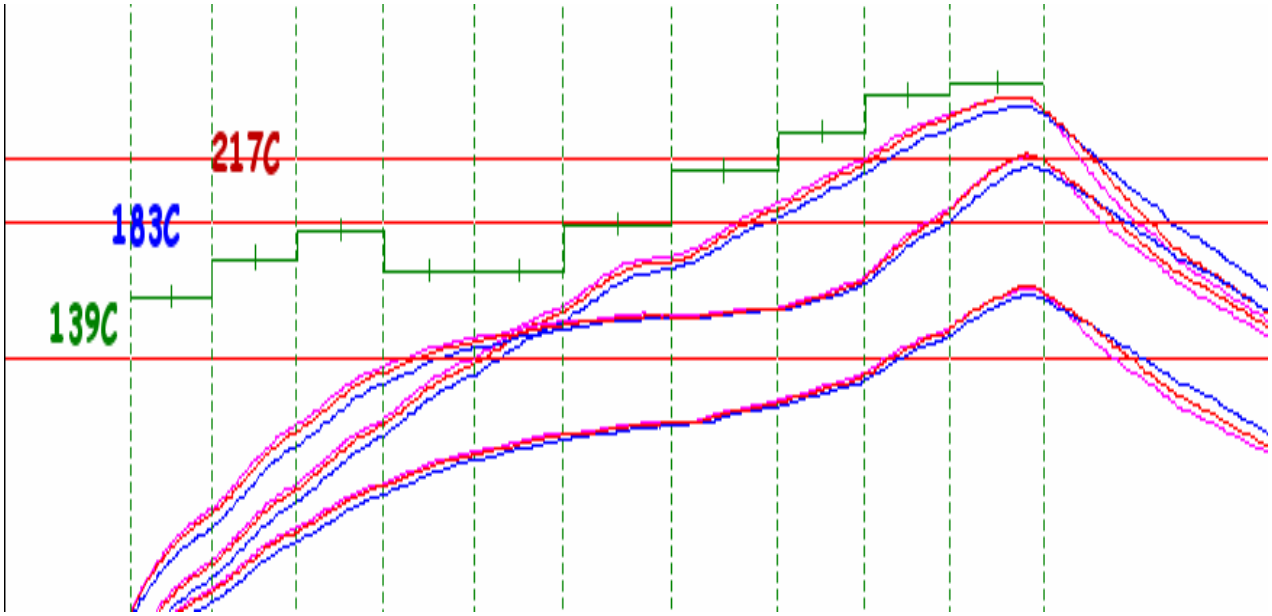
- Primary causes of environmental impacts
  - Energy consumption during assembly
  - Dross formation
  - Flux
- Conducted testing to determine reflow energy consumption (kW-h/g solder)
  - Steady-state operation
  - Throughput kept constant
  - Energy normalized by mass of solder (avg. 2.5 g/board)
- Wave solder testing to be conducted at Vitronics-Soltec in June

PWB Specs for Reflow Testing



PWB Type	Micro ATX Motherboard
Length	9.6 inches
Width	9.6 inches
Mass of Assembly	225 grams
Mass of Solder (est.)	2.5 grams/board

Reflow Test Profile Characteristics



Solder	Peak Temperature (range)	TAL (average)	δ Temp
Sn/Ag/Bi	160.2-170.1C	65 secs	9.9C
Sn/Pb	204.4-219.1C	51 secs	14.7C
Sn/Ag/Cu	235.2-248.8C	65 secs	13.6C

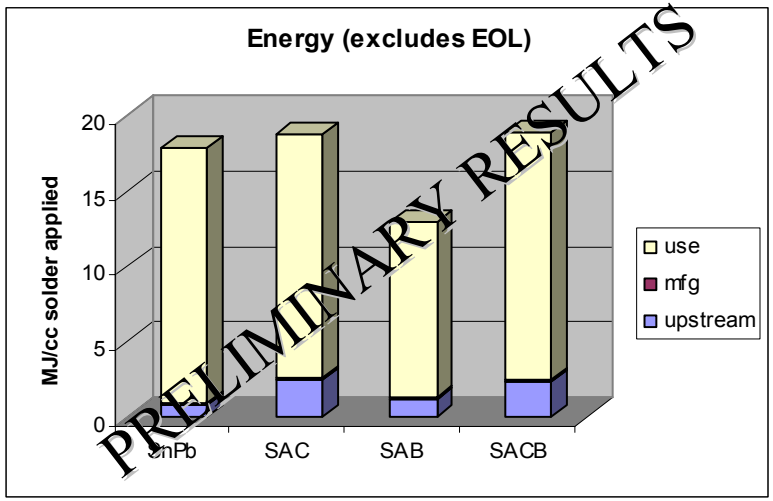
Solder Application Data

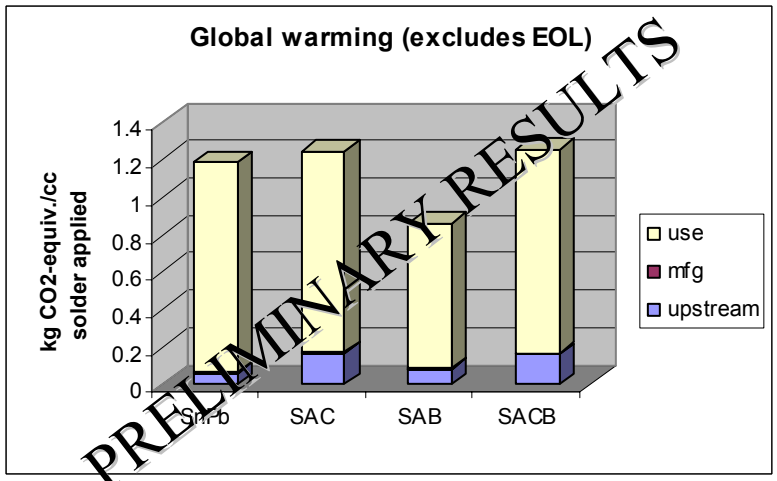
Energy Consumption during Reflow Testing

Solder	Unloaded (kW)	Loaded (kW)	% Total Energy Due to Loading	% Changed from baseline
SnPb	20.9	23.3	10.30%	---
SAC	22.2	25.2	11.90%	8.30%
SAB	15	15.7	4.50%	-32.50%

- Compares to 14.8 kW for Sn/Pb from NEMI (41% increase)
- Differences due to age of reflow equipment
- Retesting will be conducted to define range, cost, and environmental affects of equipment age

PRELIMINARY RESULTS





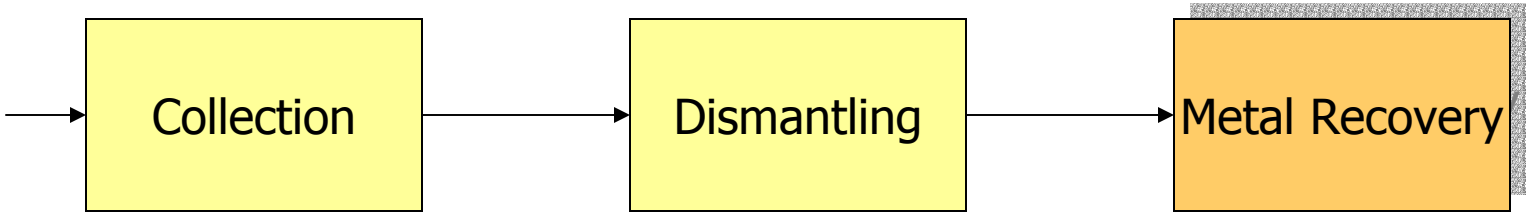
End-of-Life LC Stage

- Potential environmental impacts of electronics at end-of-life depend on disposition and location
  - Landfill (77%)
  - Incineration (14%)
  - Recycle or reclaim (4.5%)
  - Unregulated recycling/disposal (4.5%)
- Impacts for each method will be determined, weighted for actual disposition based on research
- Sensitivity analysis will be used to show spectrum of possible impacts

Impacts from Landfilling of WEEE

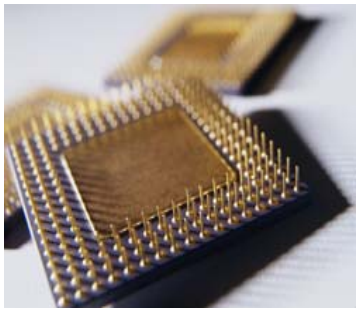
- Impacts will depend on several variables:
  - Location of landfilling (U.S. vs. other)
  - Leachability of solders
  - Fate and transport of metals through the environment and resulting human exposure
- Leachability testing is being conducted
  - 3 boards designs of varying surface area
  - PWB's assembled w/o components
  - TCLP, SPLP, and landfill leachate
  - Establish relationship between surface area and leachability

Recycling - Metal Recovery



- Initial metal recovery results based on 4 copper smelters:

Smelter	Tons of PWB/EEE waste processed per year
Boliden (Sweden)	30,000
Noranda (Canada)	50,000
Umicore (Belgium)	16,000
Norddeutsche Affinerie (Germany)	4,000



Recycling - Copper Smelting

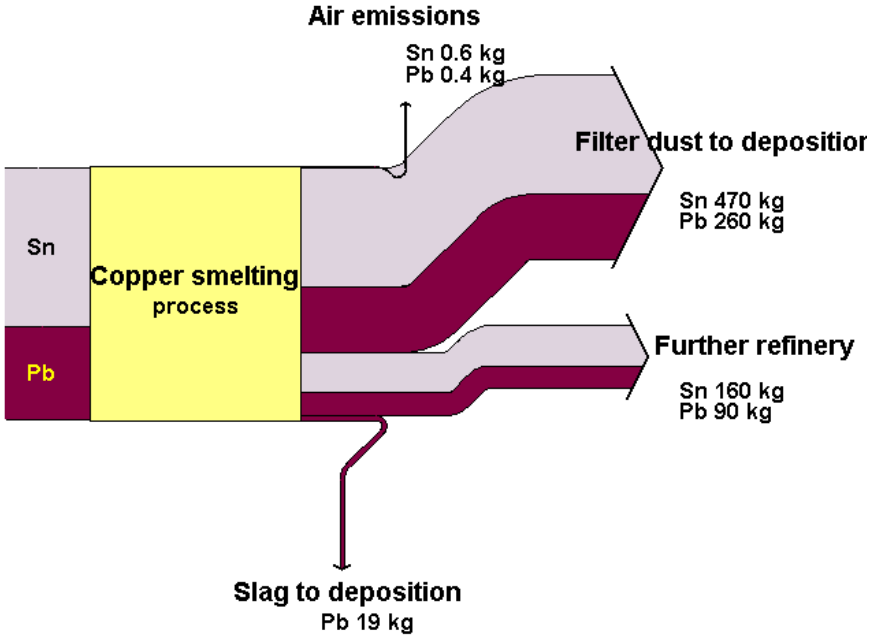
- Tin, lead and bismuth contained in PCBs are ”boiled” away in the process
- Most of the tin, lead and bismuth will be trapped as filter dust destined for

  -> deposition

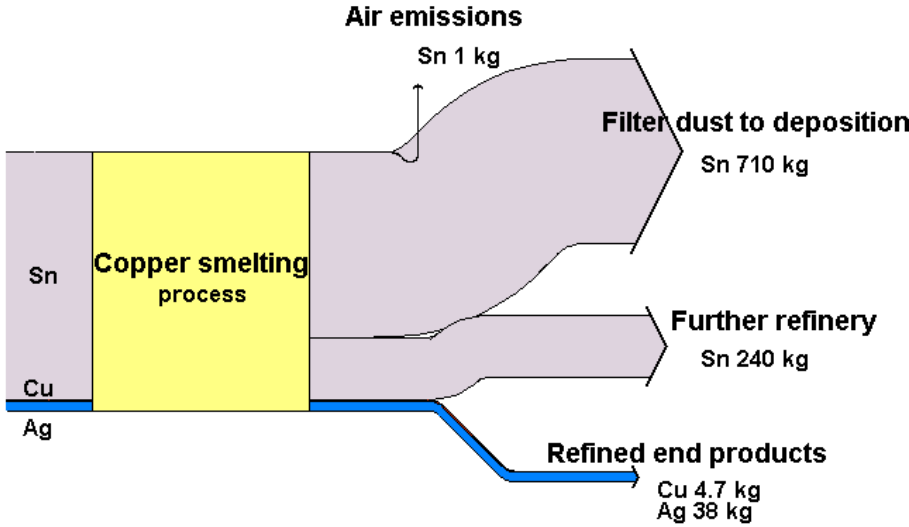
  -> further refinery
- Copper and silver are refined as end products
- Silver will increase the economic incentives for recycling PCBs
- Bismuth is considered a contaminant to the process and subsequent processes

Findings - smelting

Tin-lead (63 Sn/37 Pb)



Tin-silver-copper (95.5 Sn/4.0 Ag/0.5 Cu)



Based on Boliden's smelting process and the current economic situation

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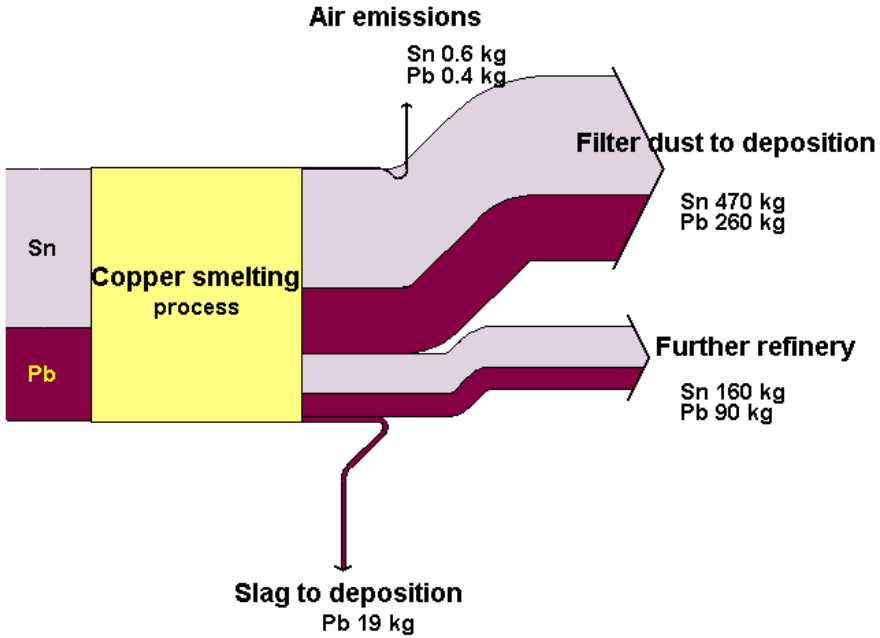
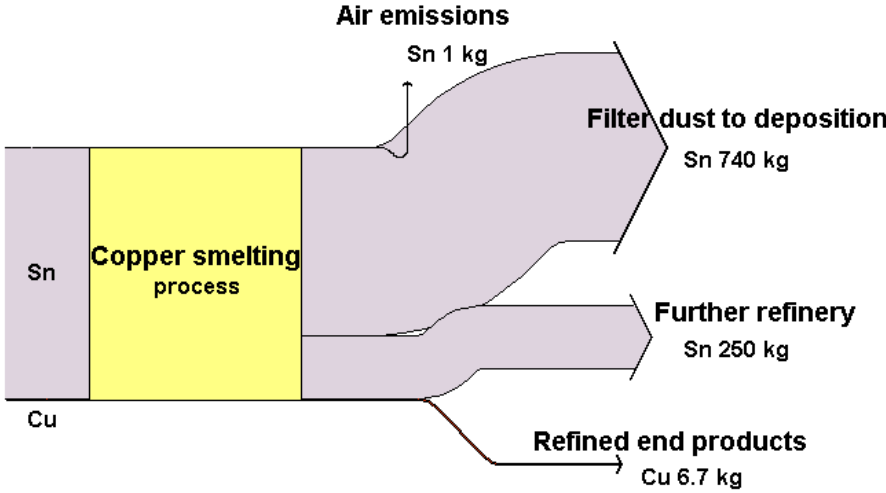


Tin-copper (99.3 Sn/0.7 Cu)



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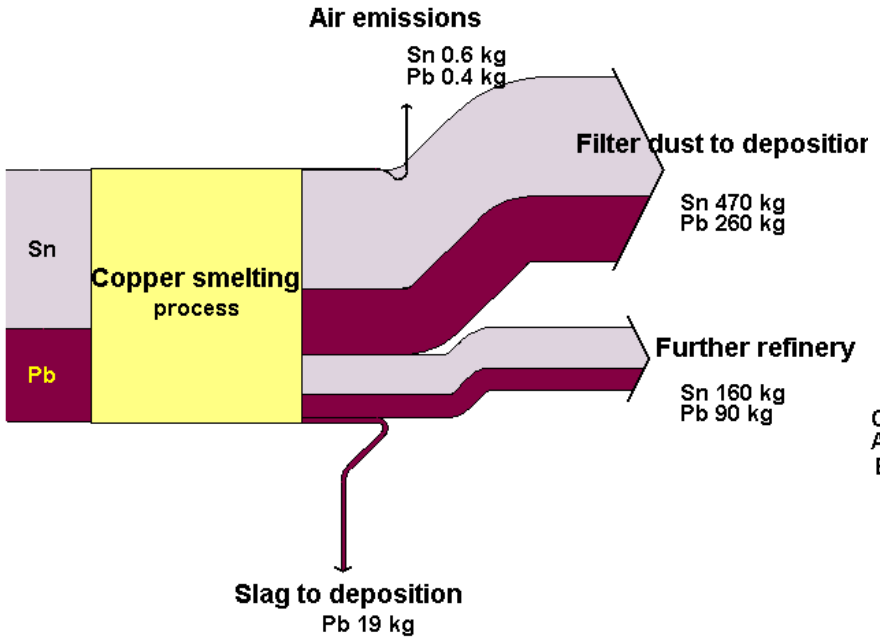

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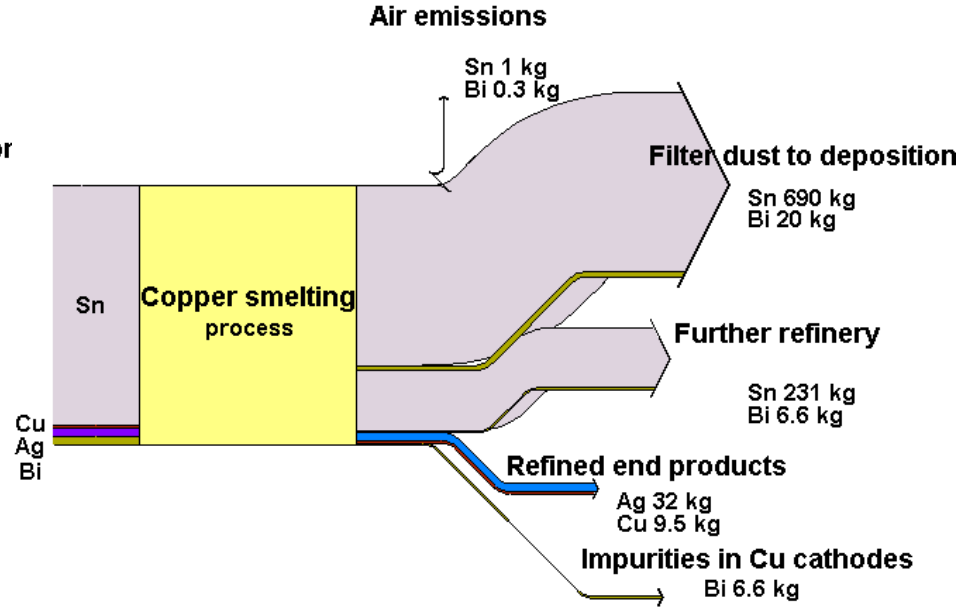
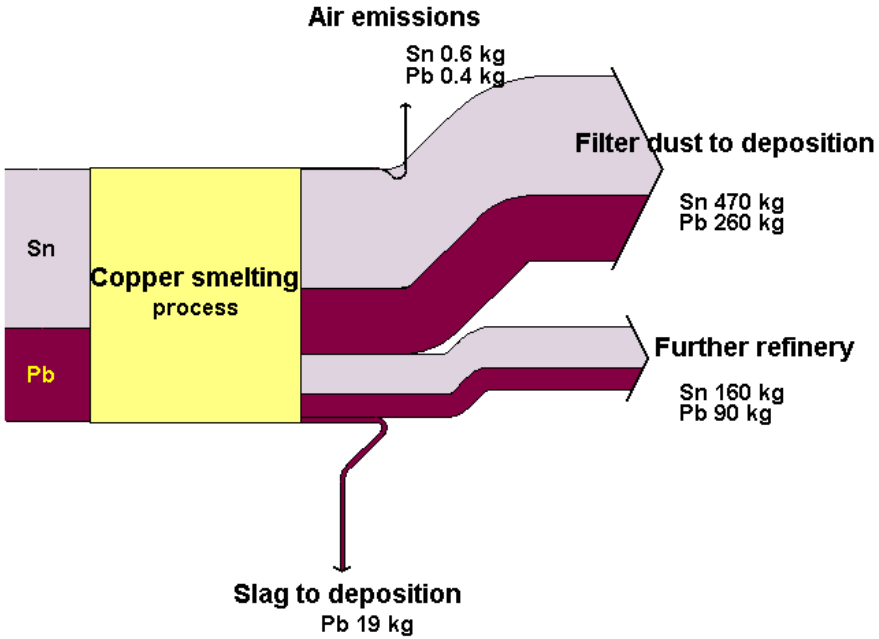
Tin-silver-copper-bismuth (92.3 Sn/3.4 Ag/1.0 Cu/3.3 Bi)



Source: Kindesjo, 2002

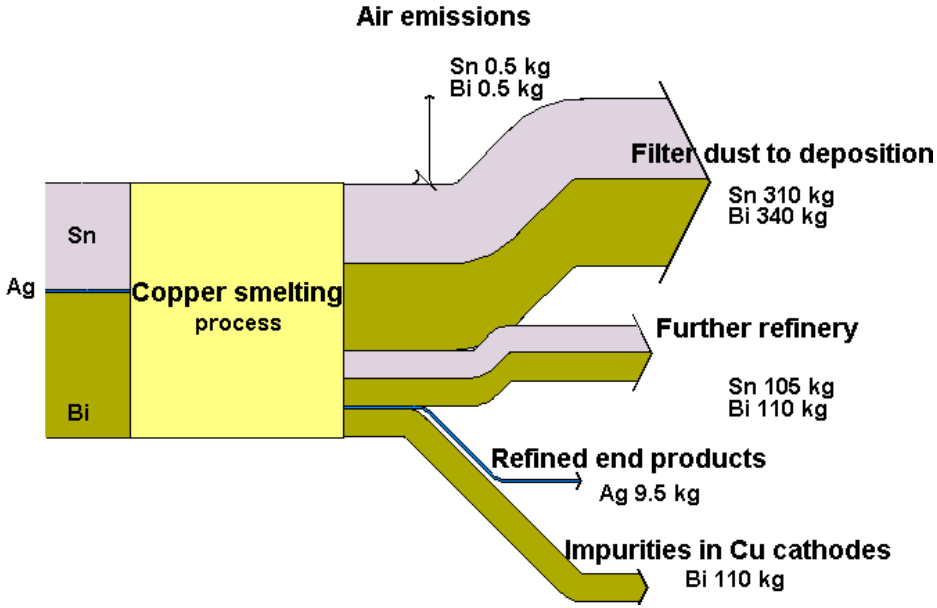
Findings - smelting

Tin-lead (63 Sn/37 Pb)



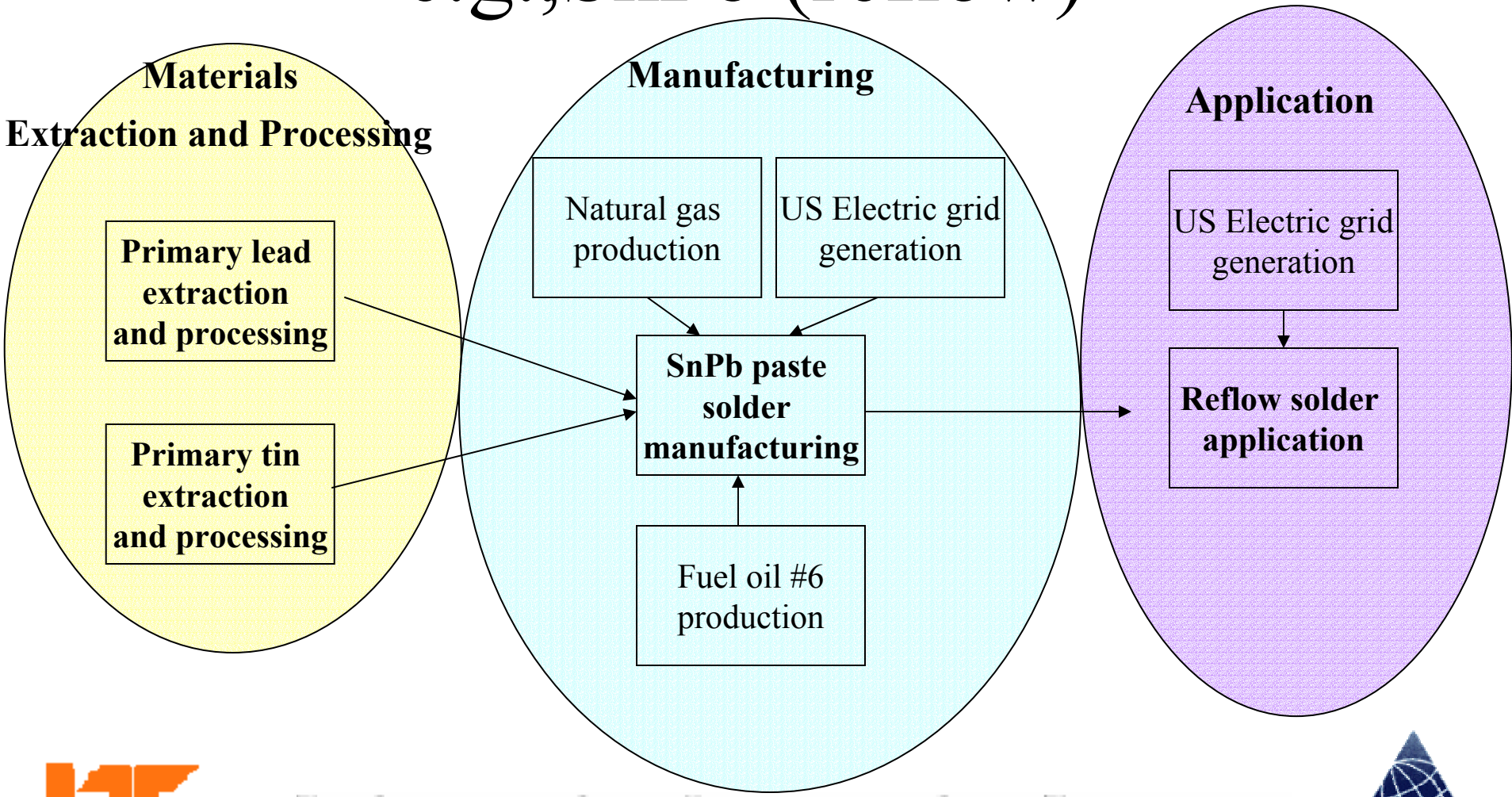
Based on Boliden's smelting process and the current economic situation

Tin-silver-bismuth (42 Sn/1.0 Aq/57 Bi)

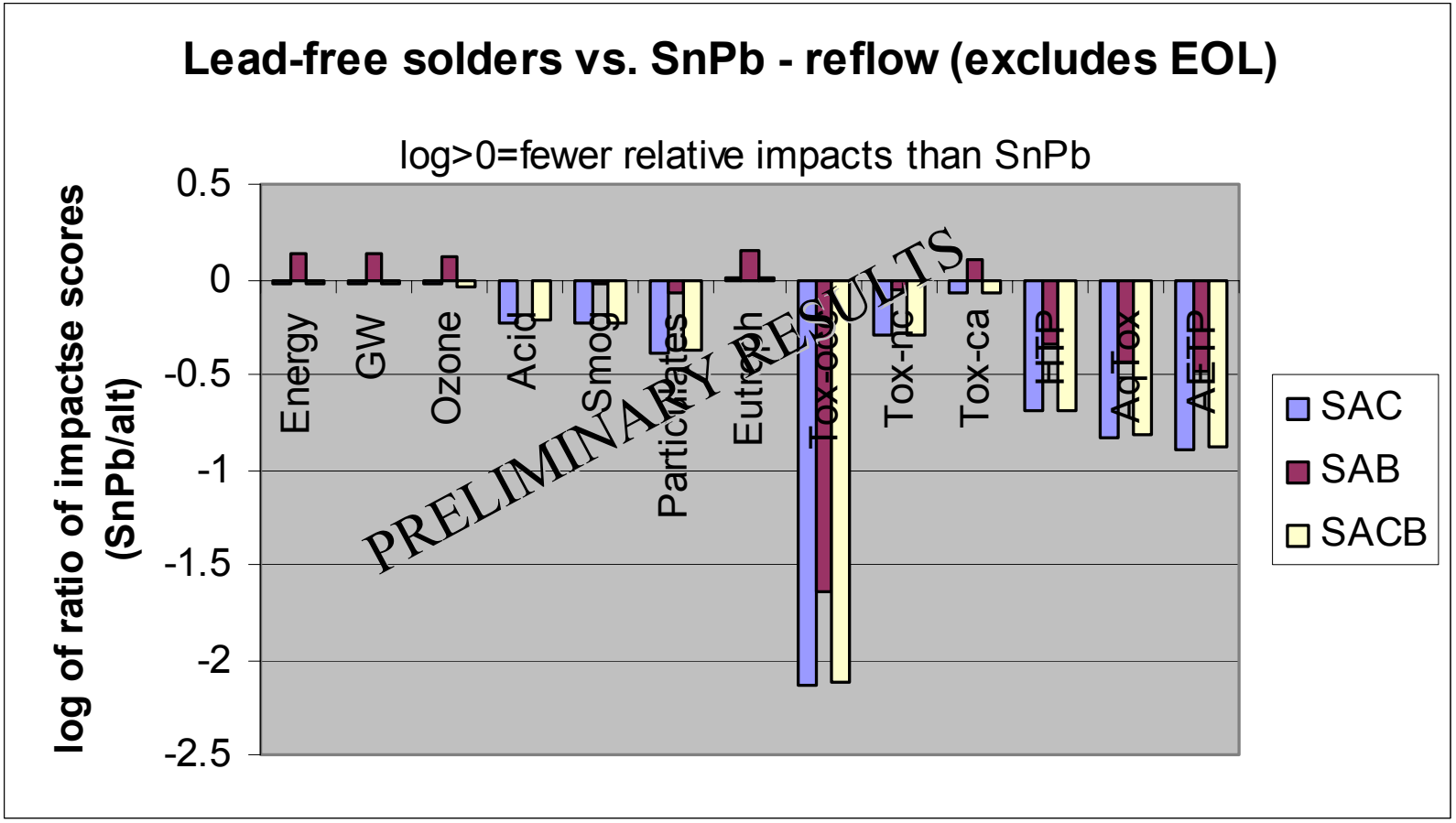


Source: Kindesjo, 2002

Processes in Preliminary Results: e.g.,SnPb (reflow)



PRELIMINARY LCA Results



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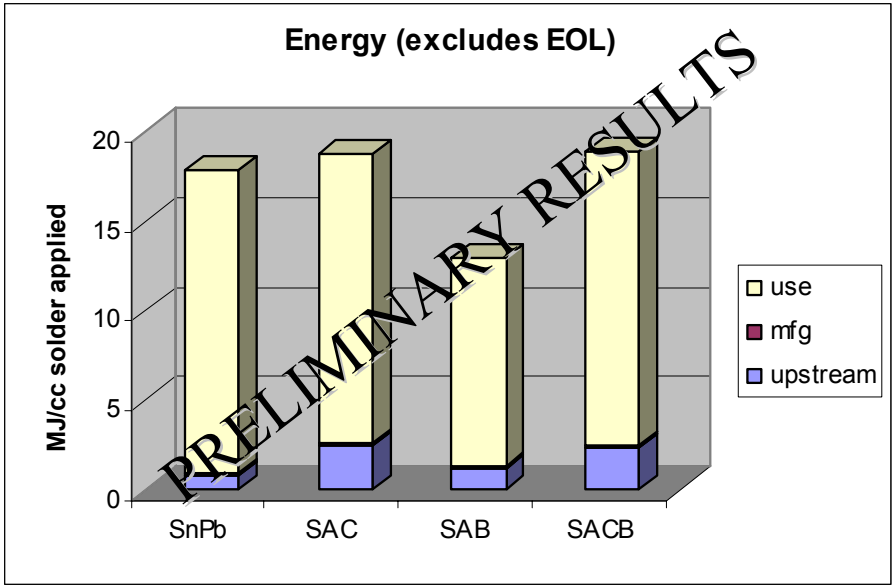

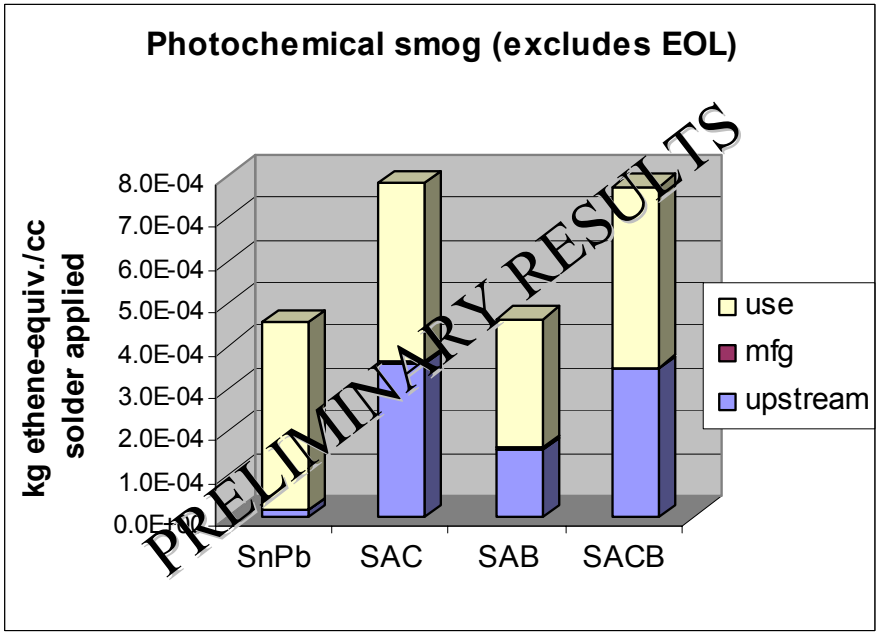

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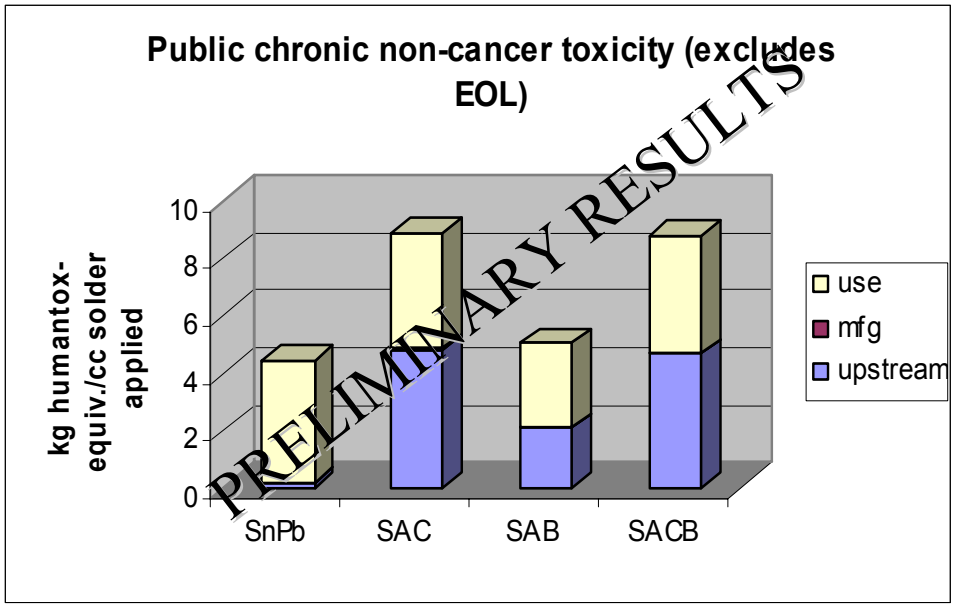
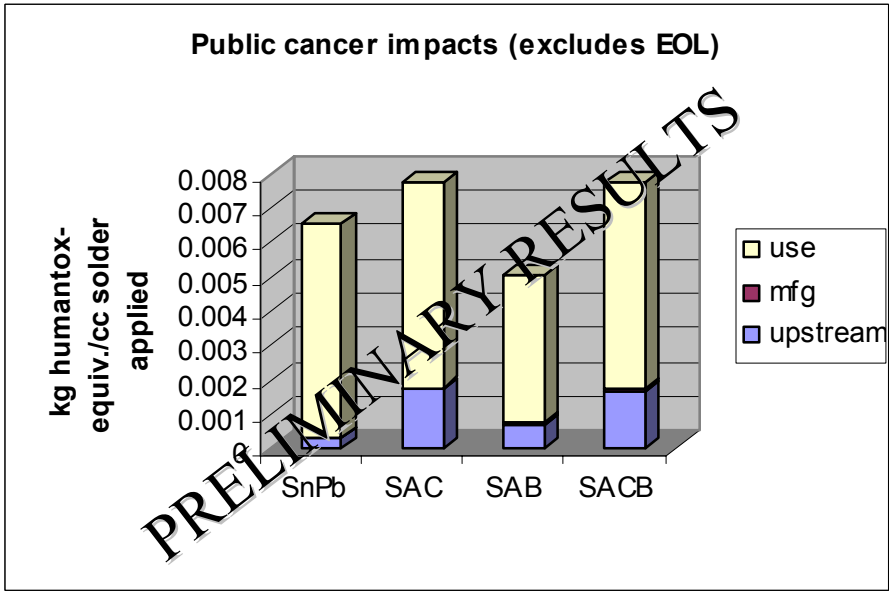
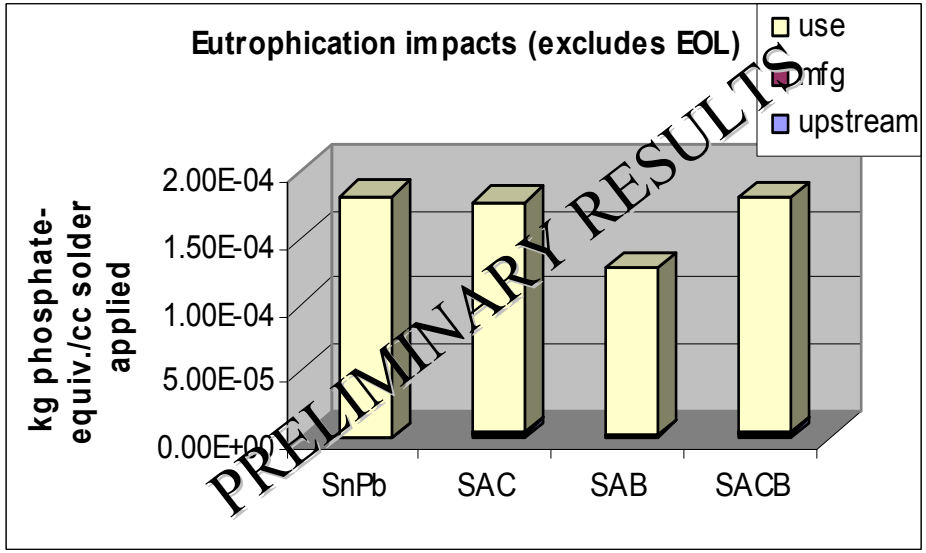


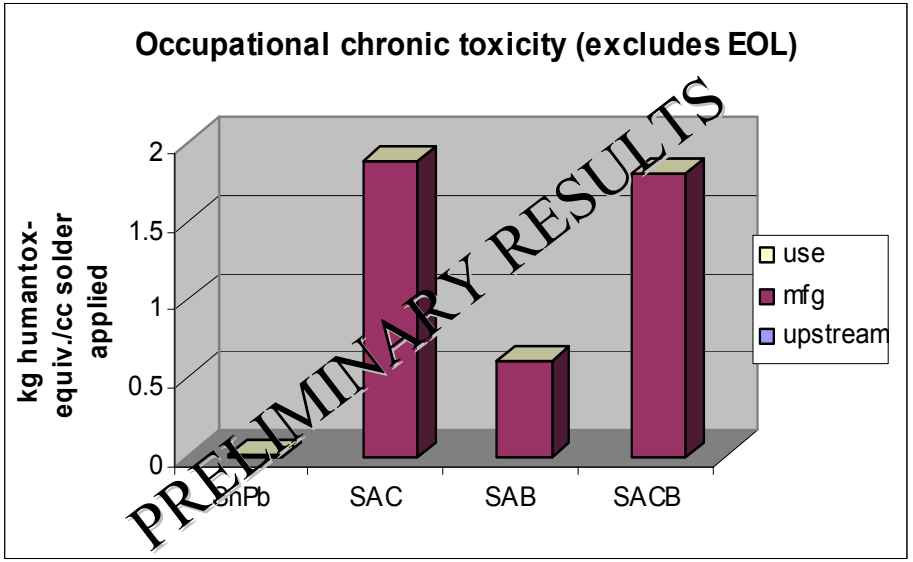


- Driven by SO_2 from electricity during application and/or SO_2 from silver mining/processing
- Without SO_2, electricity from application still dominates, e.g., SnPb: As (34%), Be (32%), NOx (10%), Cd (5%)

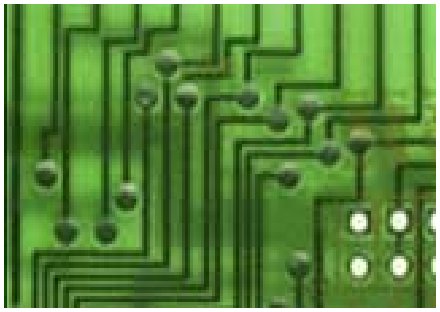
- Driven by NOx, methane (default relative cancer toxicity) from electricity during application; plus dust for silver-bearing alloys

PRELIMINARY LCA Results





- Occupational impacts currently only for manufacturing stage



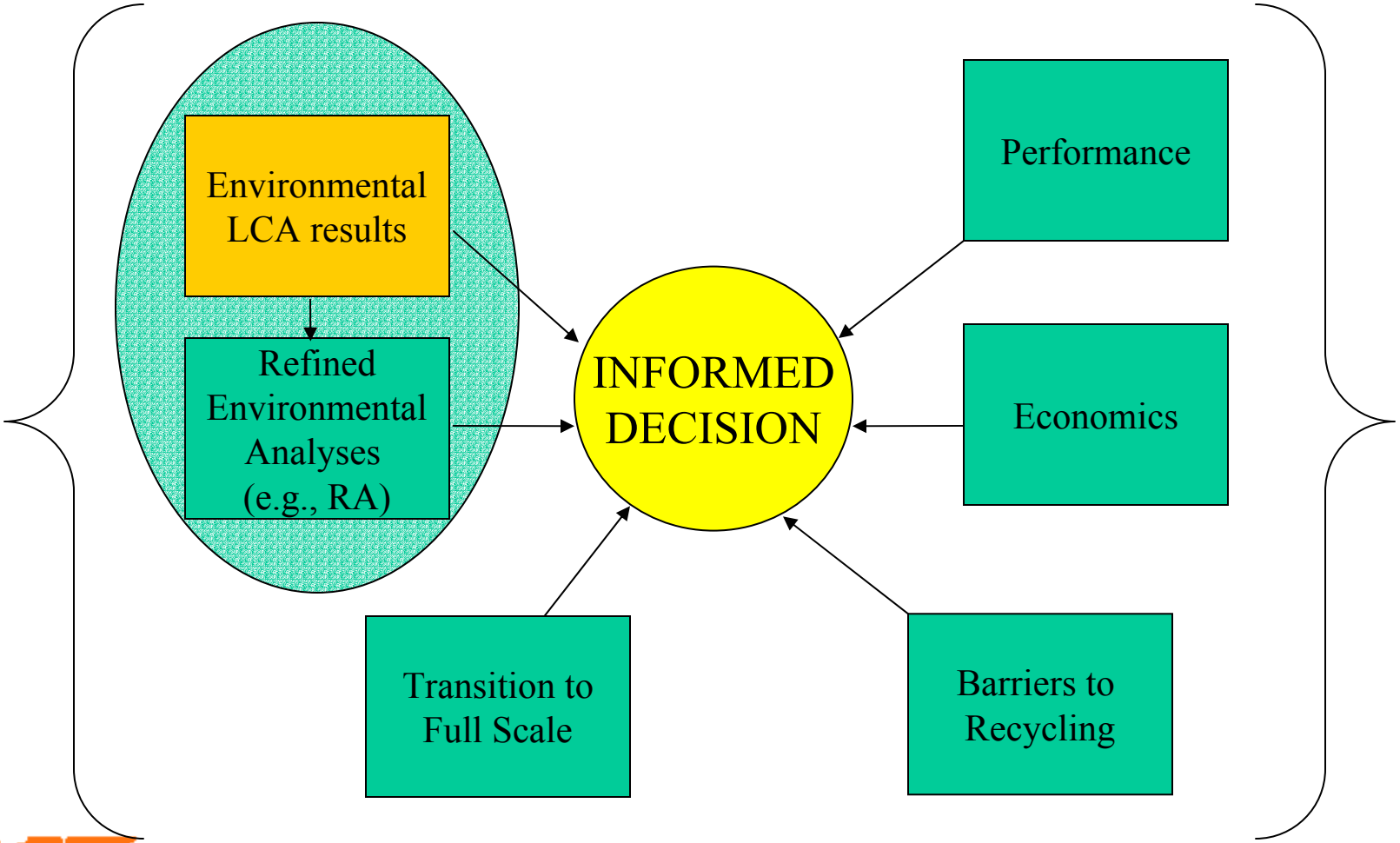
What the study will show

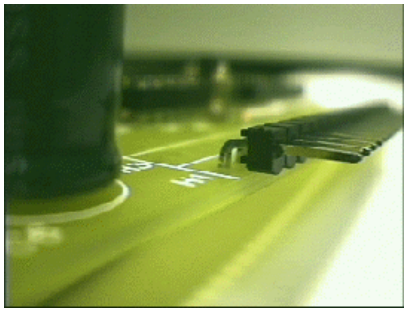
- LCA
  - Relative contribution of each solder to impacts in different impact categories
  - Life-cycle stage, process, or specific inventory item that contributes greatest to the life-cycle impacts
  - Relative toxicity of the metals and their associated potential or impacts
- Other research
  - Leachability testing results of solder alternatives in this study
  - Discuss issues of concern (e.g., recycling limitations such as Bi contamination or equipment life)

What this study does not address

- Excludes performance and economic considerations
- Does not address non-quantified impacts such as Bi in recycling
- Does not address the impacts occurring during transition time to full production of lead-frees
- Assumes releases to the environment are surrogates for exposure; e.g., does not address fate and transport of materials released to the environment

Factors in Making an Informed Solder Selection





Project Schedule

- Draft LCA Reflow– July 2003
- Draft LCA Wave– Aug 2003
- Draft Final LCA – Oct 2003