# The Impact of Lead-Free on PCB Design

Joseph Fjelstad
SiliconPipe, Inc.
San Jose, CA

# July 2006…

T minus 20 months and counting

# Outline

- Lead-free in perspective
- Environmental impact
- Technical Impact
- Getting ready
- Conclusions

# The good news…

…“all available scientific evidence indicates that the lead used in printed circuit board (PCB) manufacturing and electronic assembly produces no significant environmental or health hazards…”

From the IPC Lead-free Website

# Lead Levels in US Population vs Lead in Gasoline Over Time

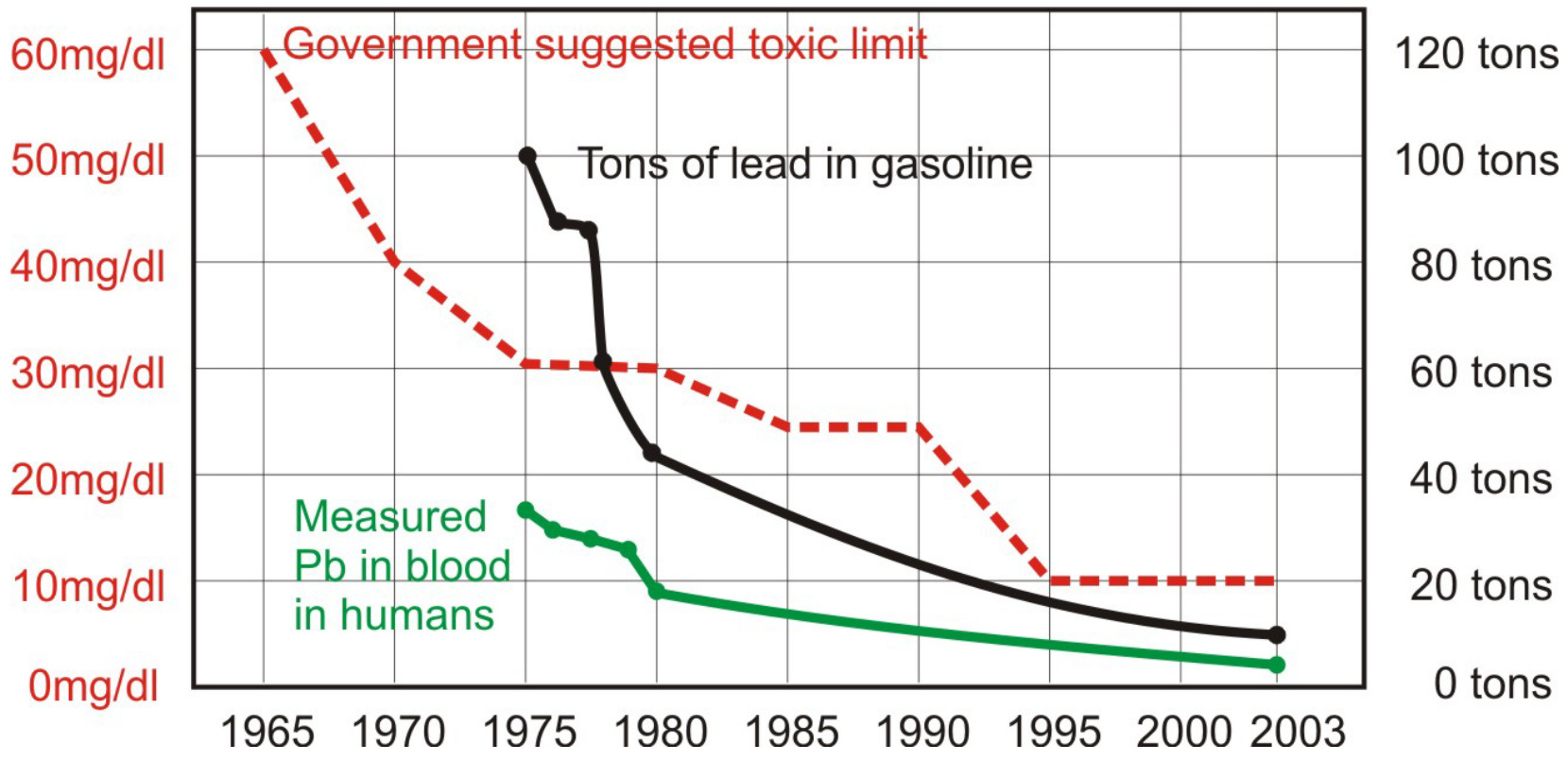



Chart created from data from “American Scientist” journal

# The bad news…

… “IPC believes the pressure to eliminate lead in electronic interconnections will continue in the future from both the legislative and competitive sides.”

From the IPC Lead-free Website

# Why lead-free?

- Concern over landfill content
  - ~4% of landfill waste is electronics and rising
- Short lifetime of consumer electronics (e.g. phone vs car)
- Limited electronics recycling infrastructure
- Easy target because of scare tactics based on paint and gas

However…

- Electronics only constitute <0.5% of all lead use
- Full lifecycle analysis makes lead appear a better choice
- Replacing lead with arguably less environmentally friendly metals
- All substitutes cost more than lead
- Lead use is not decreasing as the world uses more automotive batteries world wide every year
- More lead will be mined to get the extra silver

# Drivers of Leadfree Electronics I

## Legislation

- USA:
  - Discussion started during Carter administration
  - Reid Bill (proposed in1990, dropped after much`lobbying).
  - Various states contemplating action though most only concerns recycling.`
- Japan:
  - No lead ban as yet.
  - But landfil restrictions and recycling bill prompting activity.

# Drivers of Leadfree Electronics II

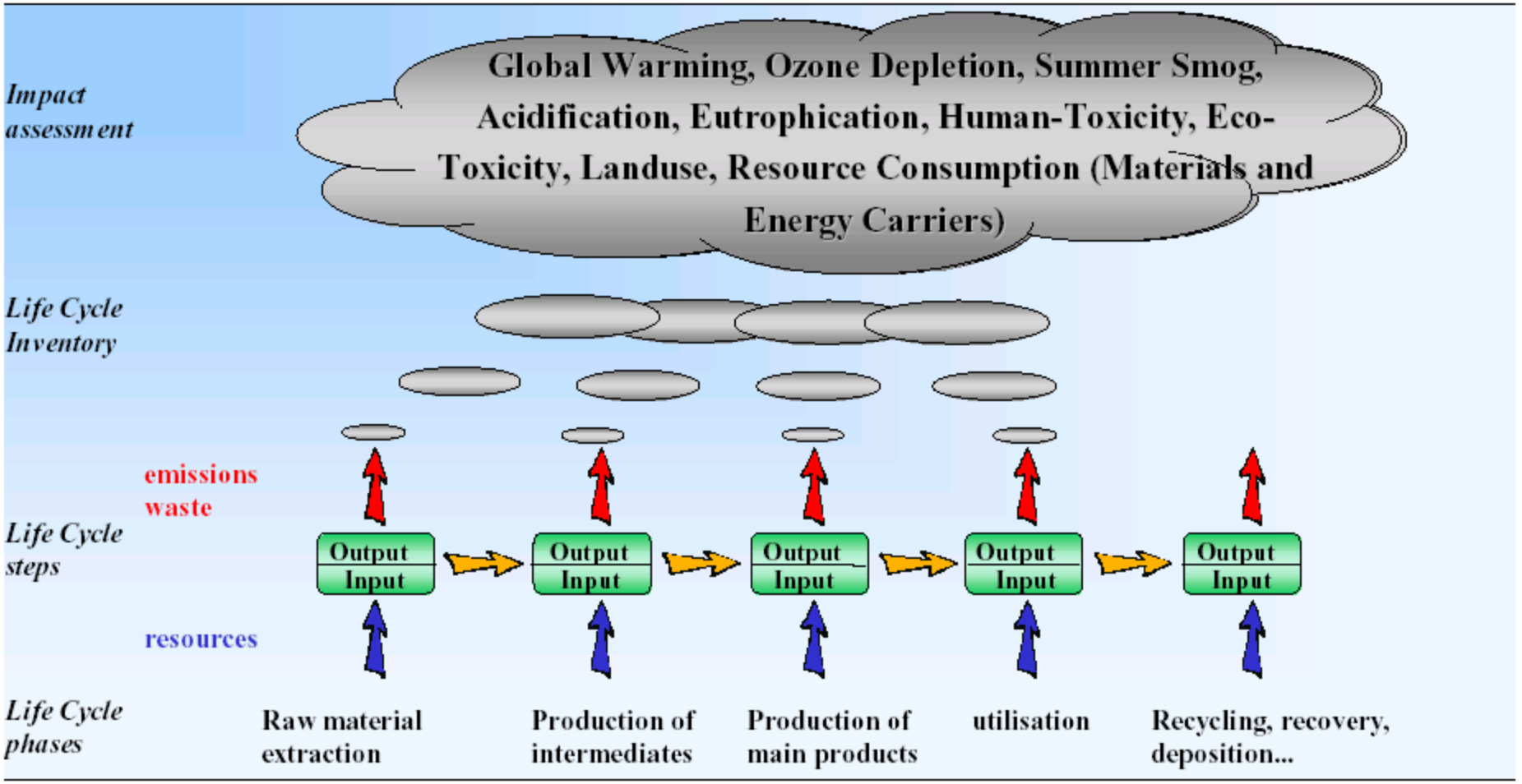
- Legislation
  - Europe
    EU: WEEE - Directive
- WEEE = (**W**aste **E**lectronic and **E**lectronic **E**quipment),

- RoHS - Directive (**R**eduction **o**f **H**arzadous **S**ubstances)
  - Orignal lead ban target was 01 Jan 2004 (first mentioned in 1998 draft);
  - Lots of protest but little practical lobbying (except tin industry?)
  - New RoHS directive adopted 13 Jun 2000,
  - Pb ban for electronics now 01 Jan 2006.

# Environmental impact

# Life Cycle Analysis

*Life Cycle Approach as basis for modelling systems*

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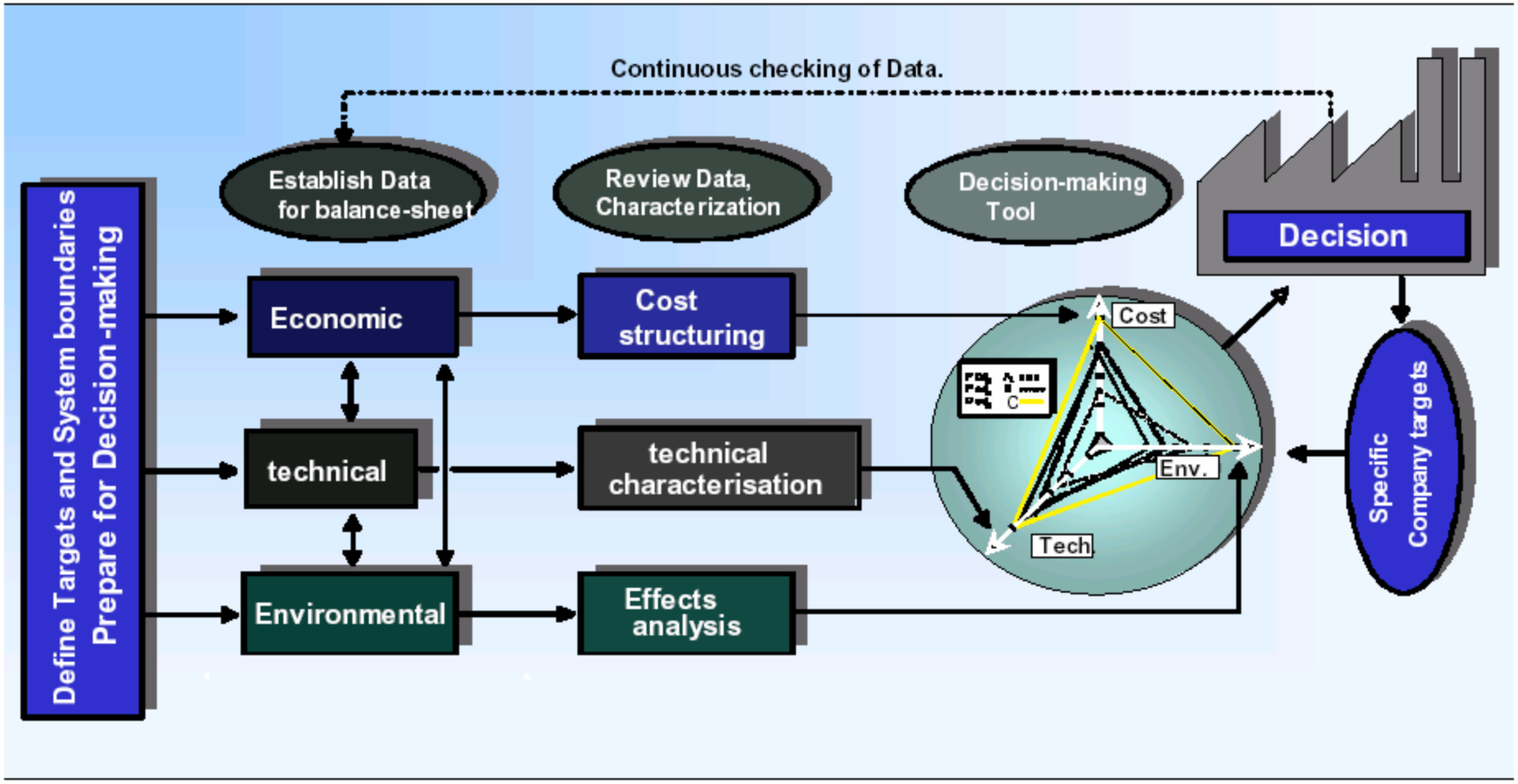
# Life-Cycle Engineering - A Tool for Decision-Making

*transformation from detail knowledge to system knowledge*





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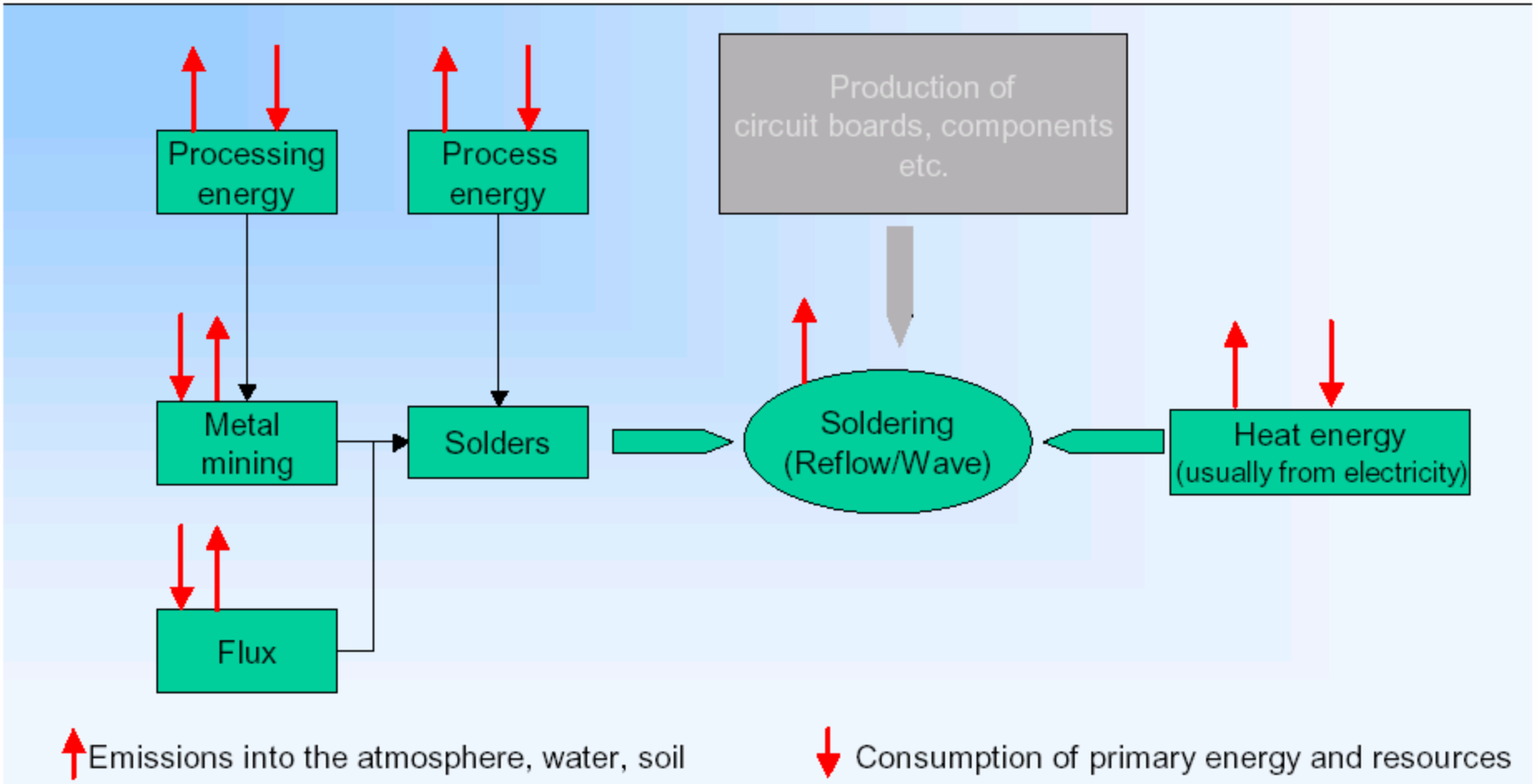
# Industrial Soldering

*sources of environmental effects*

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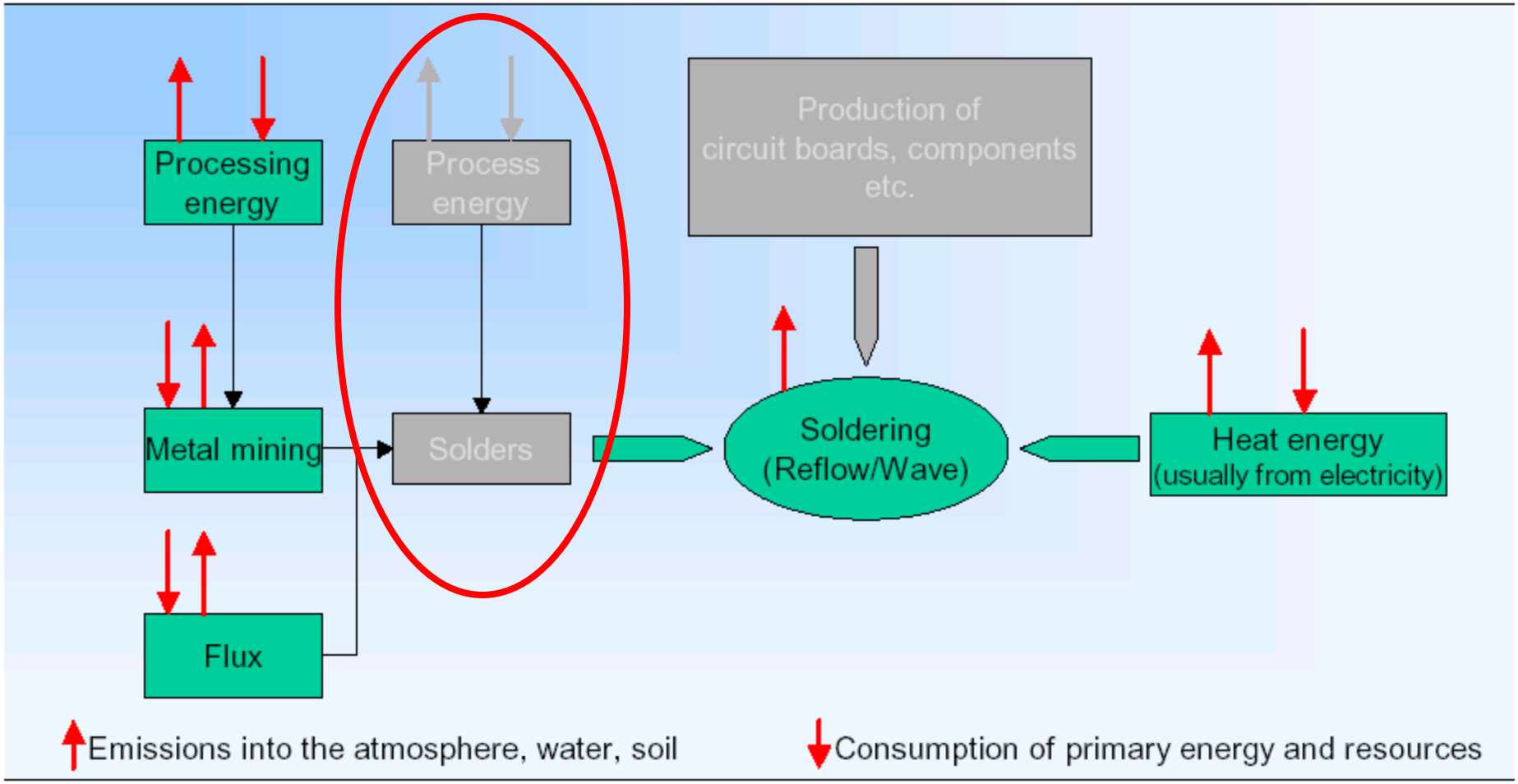
# Soldering with- and without Lead.

*Relevant processes with a focus on the environmental effects*

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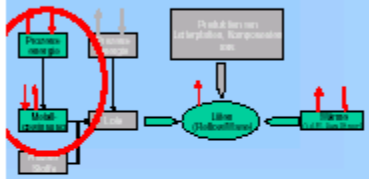
# Influence of the Solder Composition

*comparison of different solder pastes*



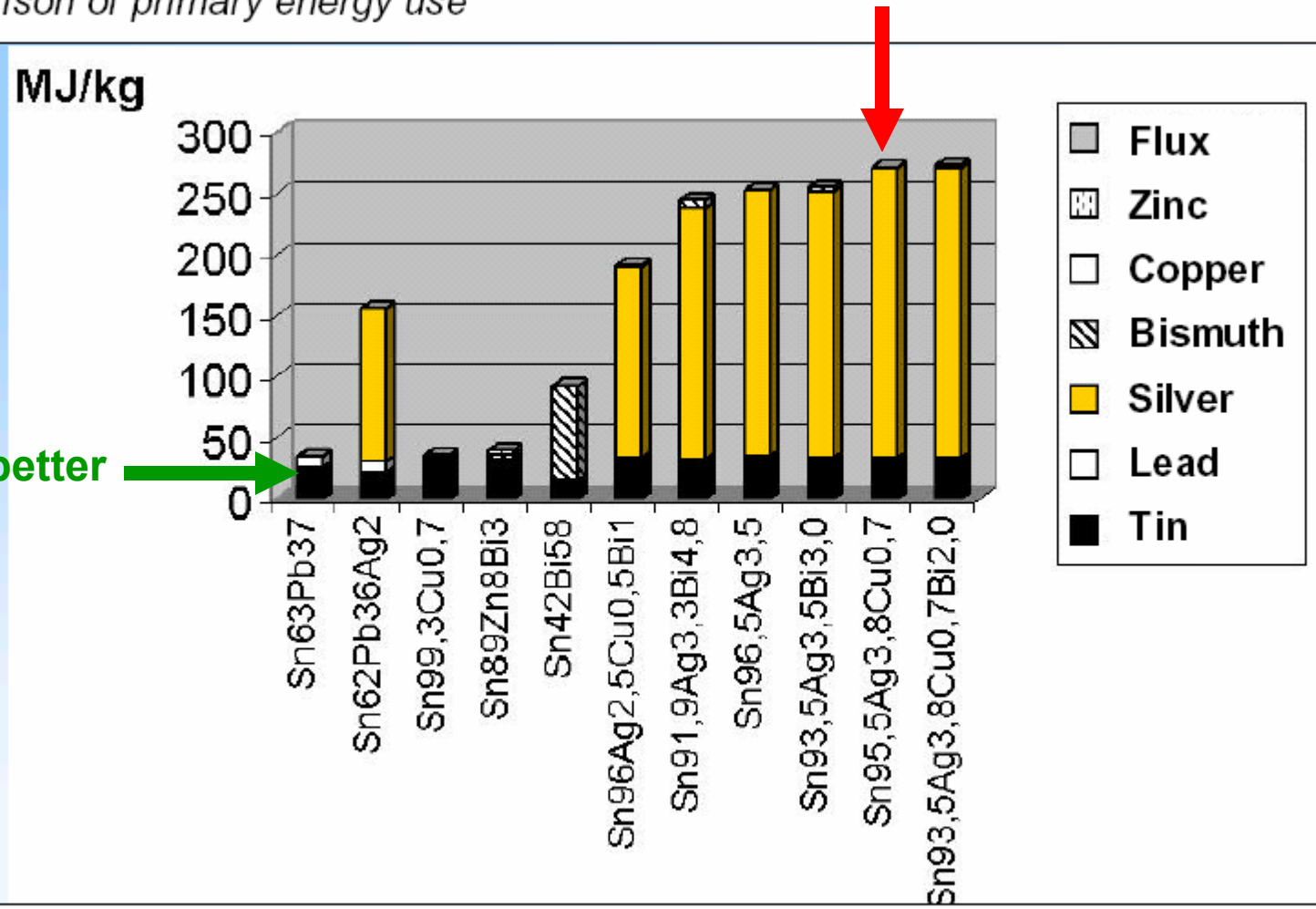
Investigated solders / pastes:

Lead Solders:
- SnPb37
- SnPb36Ag2

Lead-free solders:
- Sn93,5-Ag3,5-Bi3
- Sn95,5-Ag3,8-Cu0,7
- Sn91,9-Ag3,3-Bi4,8
- Sn96-Ag2,5-Cu0,5-Bi1
- Sn42-Bi58
- Sn96,5-Ag3,5
- Sn99,3-Cu0,7
- Sn89-Zn8-Bi3

# Influence of the Solder Composition

*Comparison of primary energy use*

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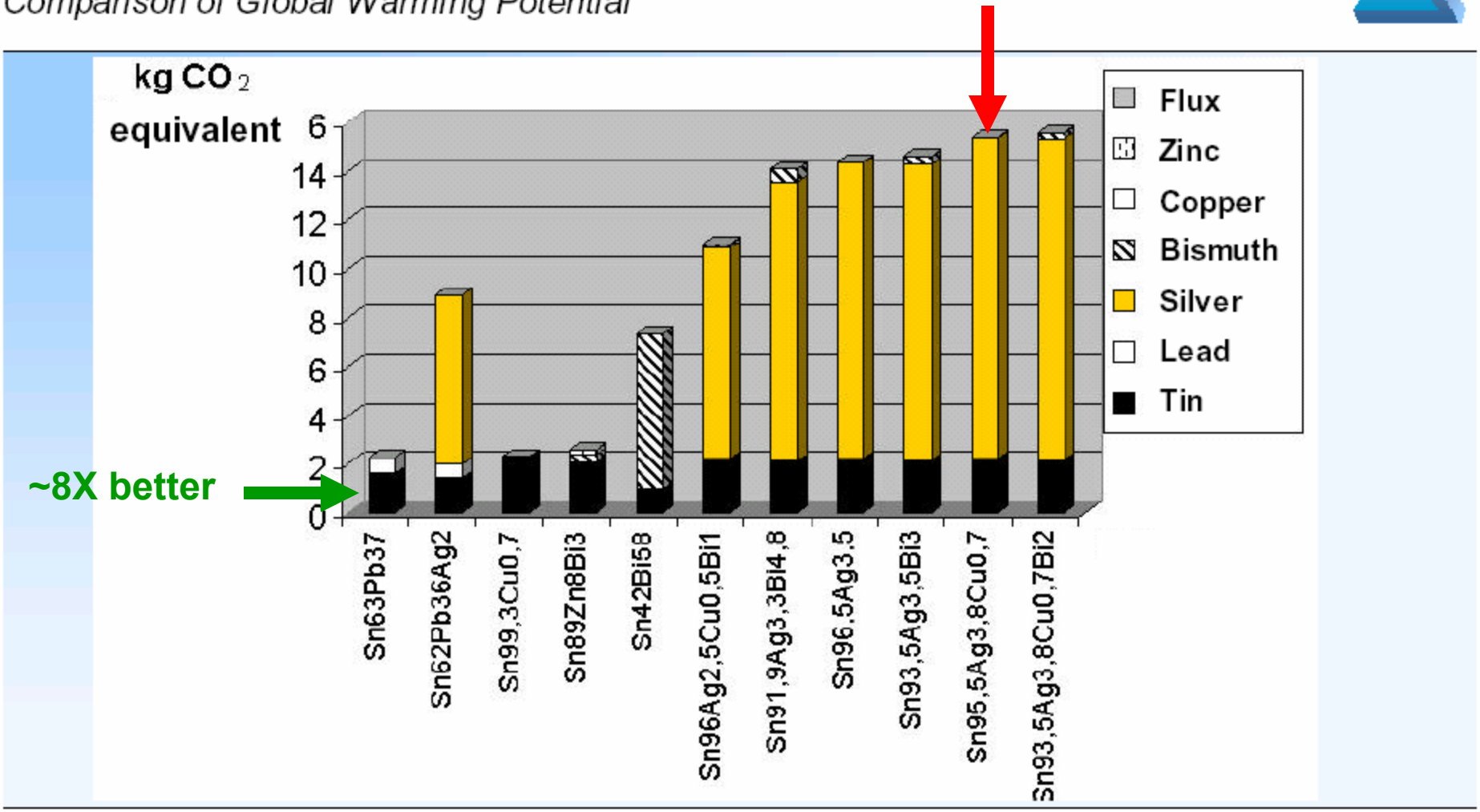
# Influence of the Solder Composition

*Comparison of Global Warming Potential*





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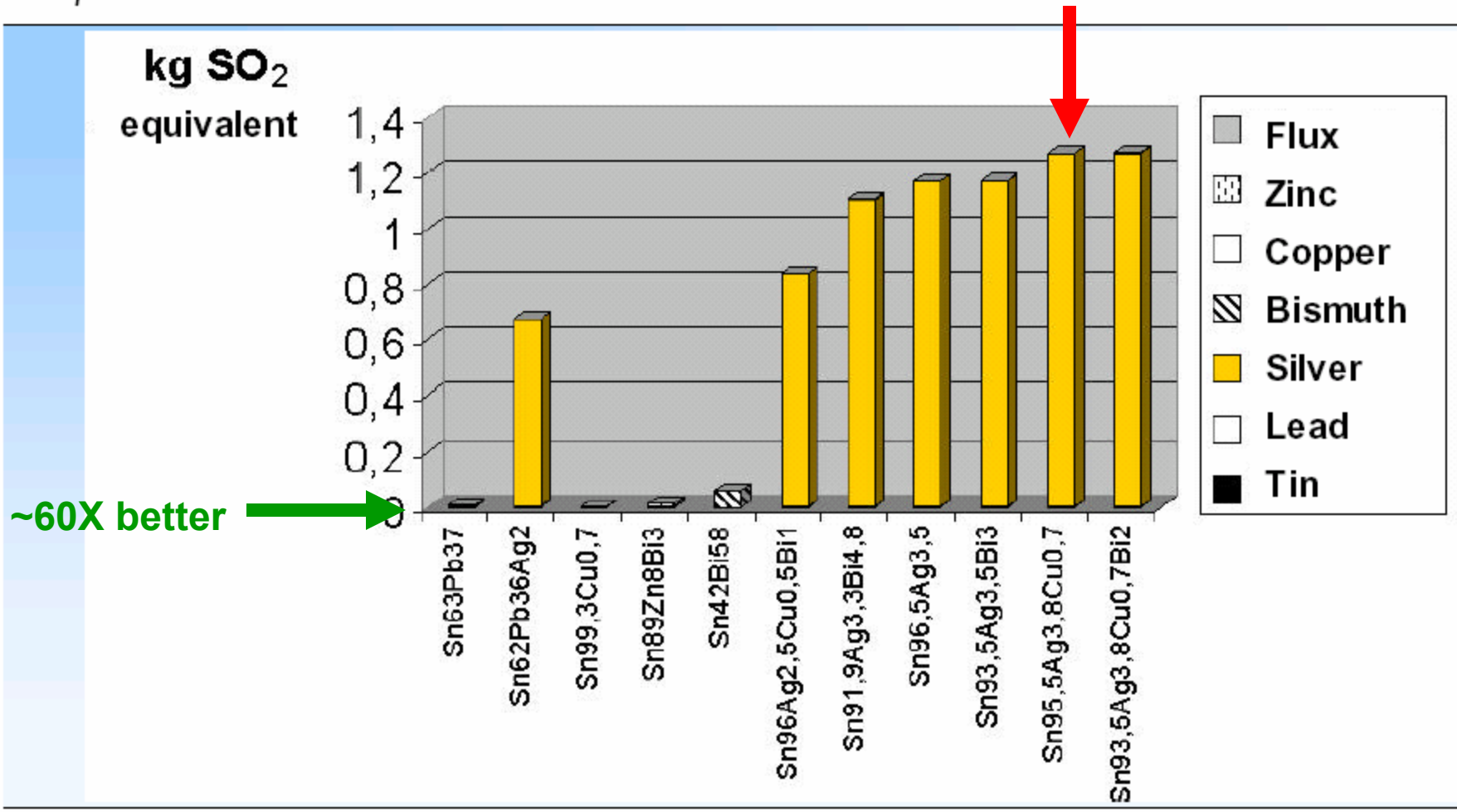
# Influence of the Solder Composition

*Comparison of Acidification Potential*

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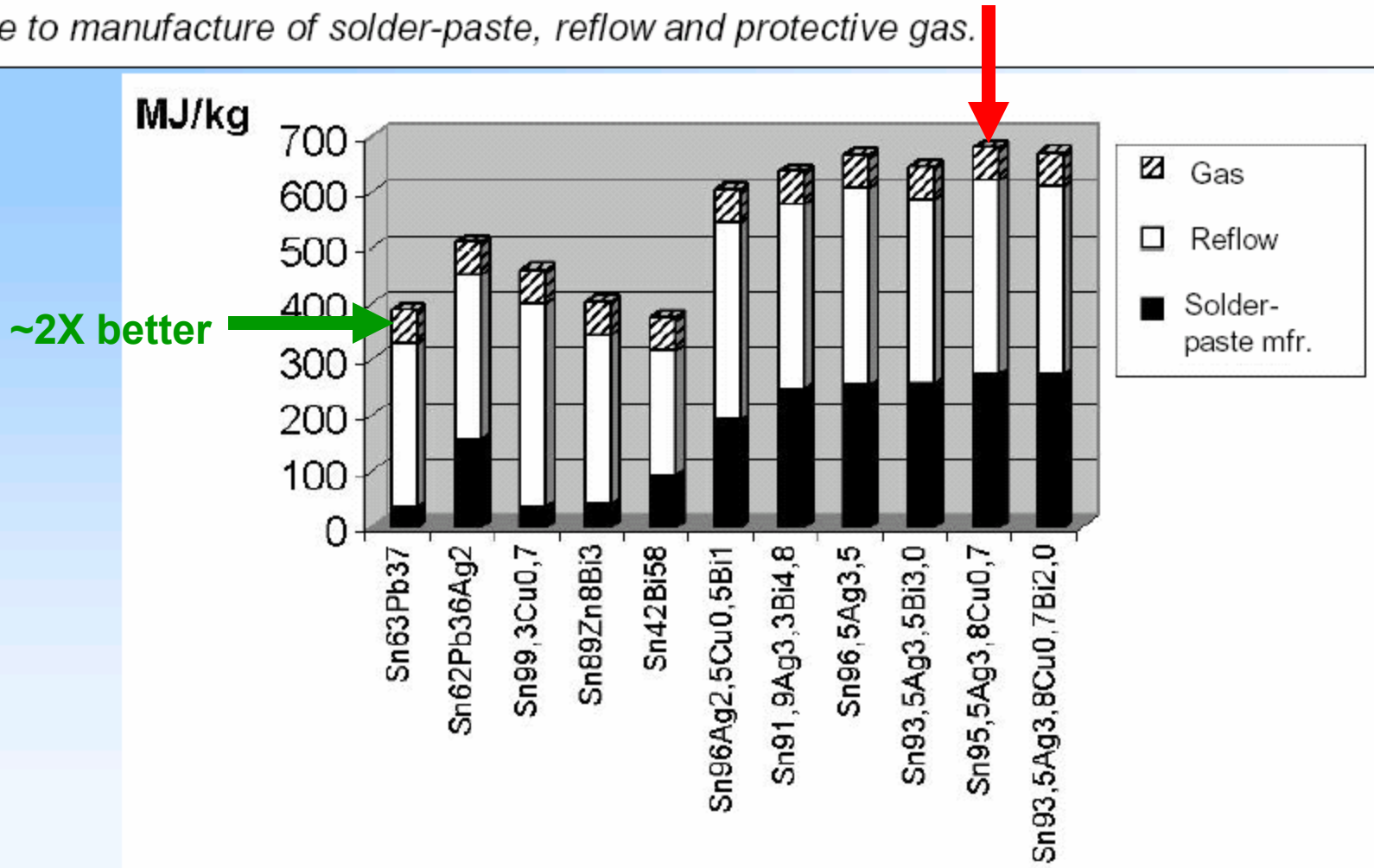
# Primary Energy Consumption

*Due to manufacture of solder-paste, reflow and protective gas.*

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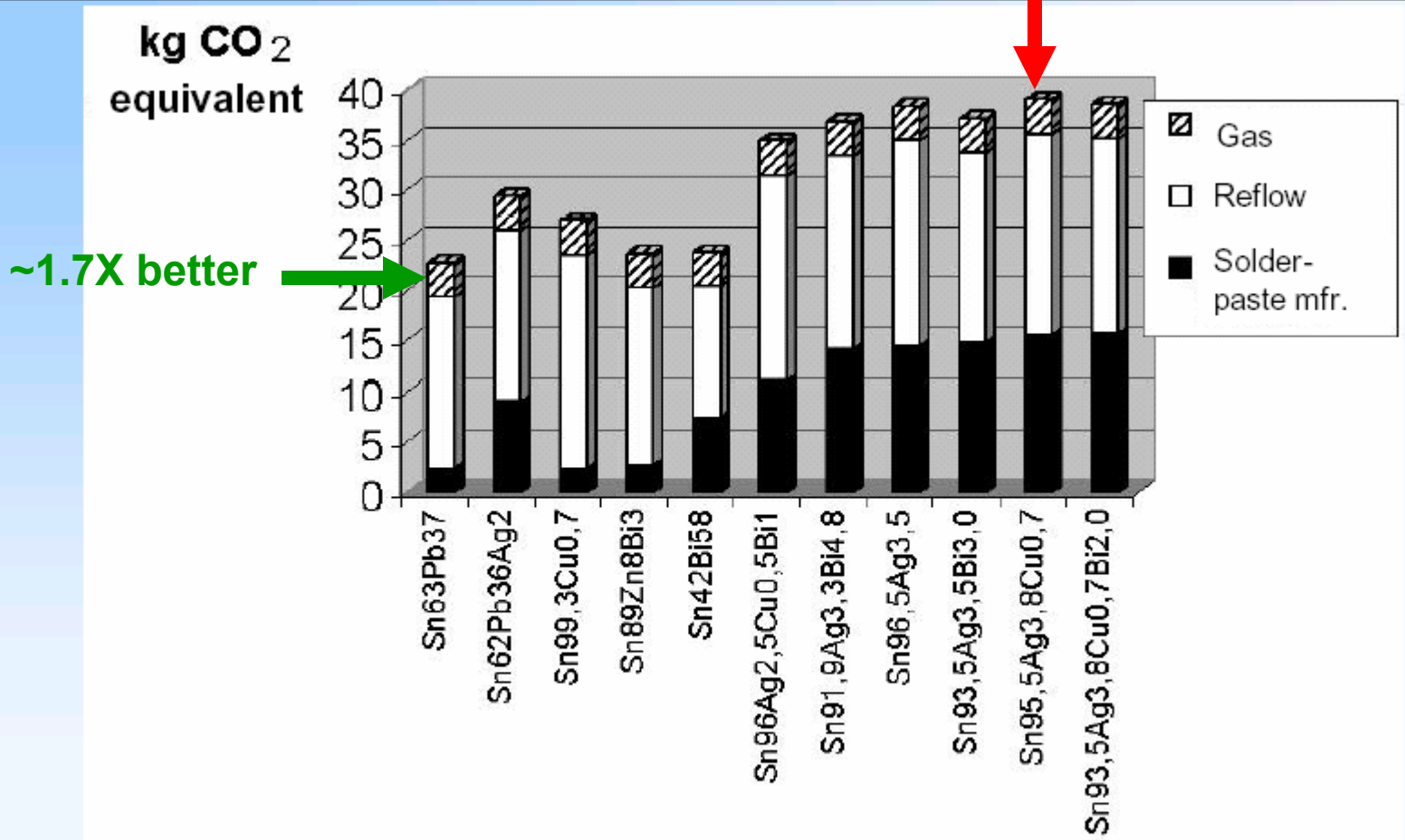
# Global Warming Potential

*Due to manufacture of solder-paste, reflow and protective gas.*

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# Acidification Potential

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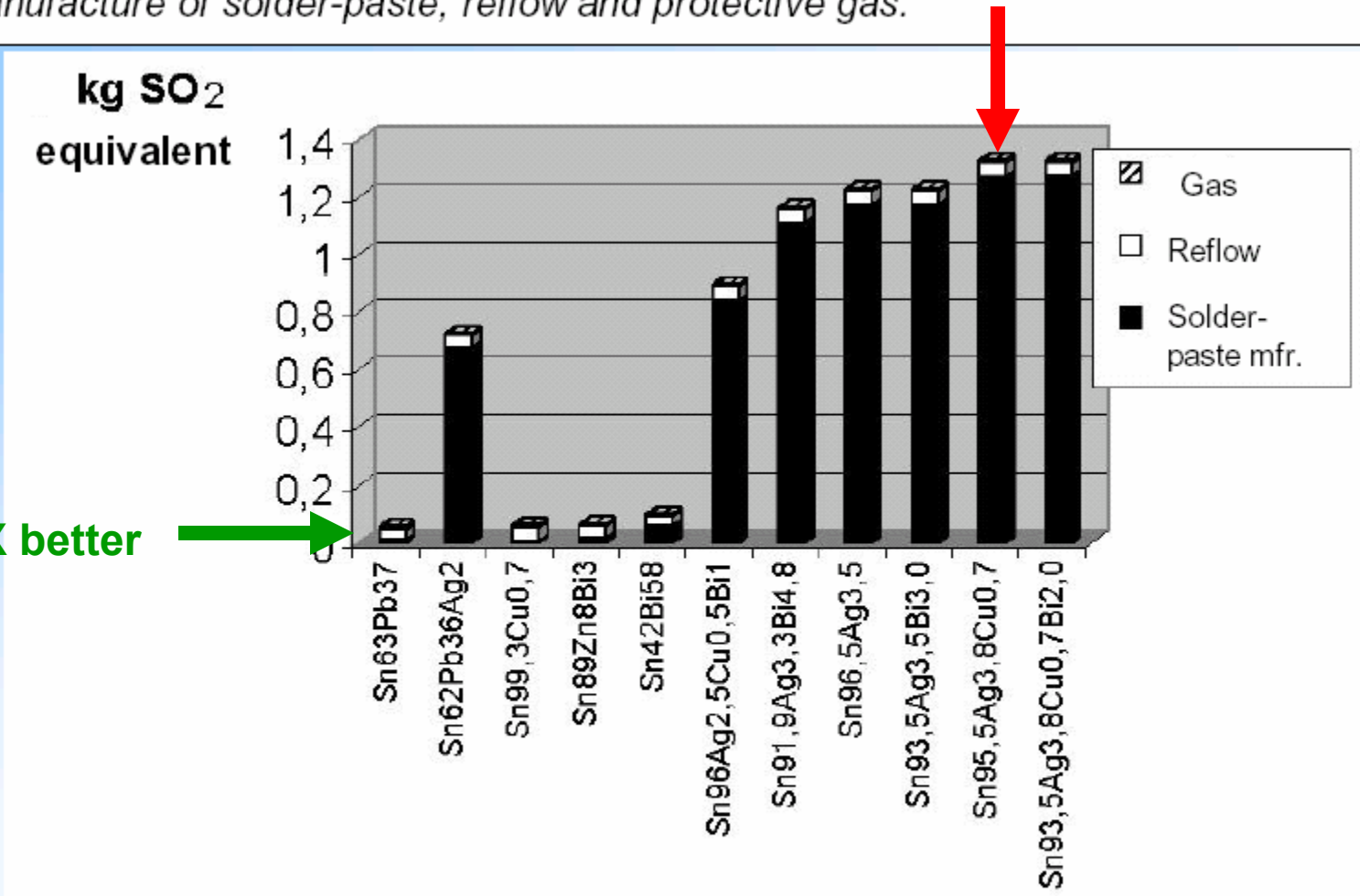


**~11X better**


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# Technical impact

# First the good news…

**The sun will rise tomorrow**

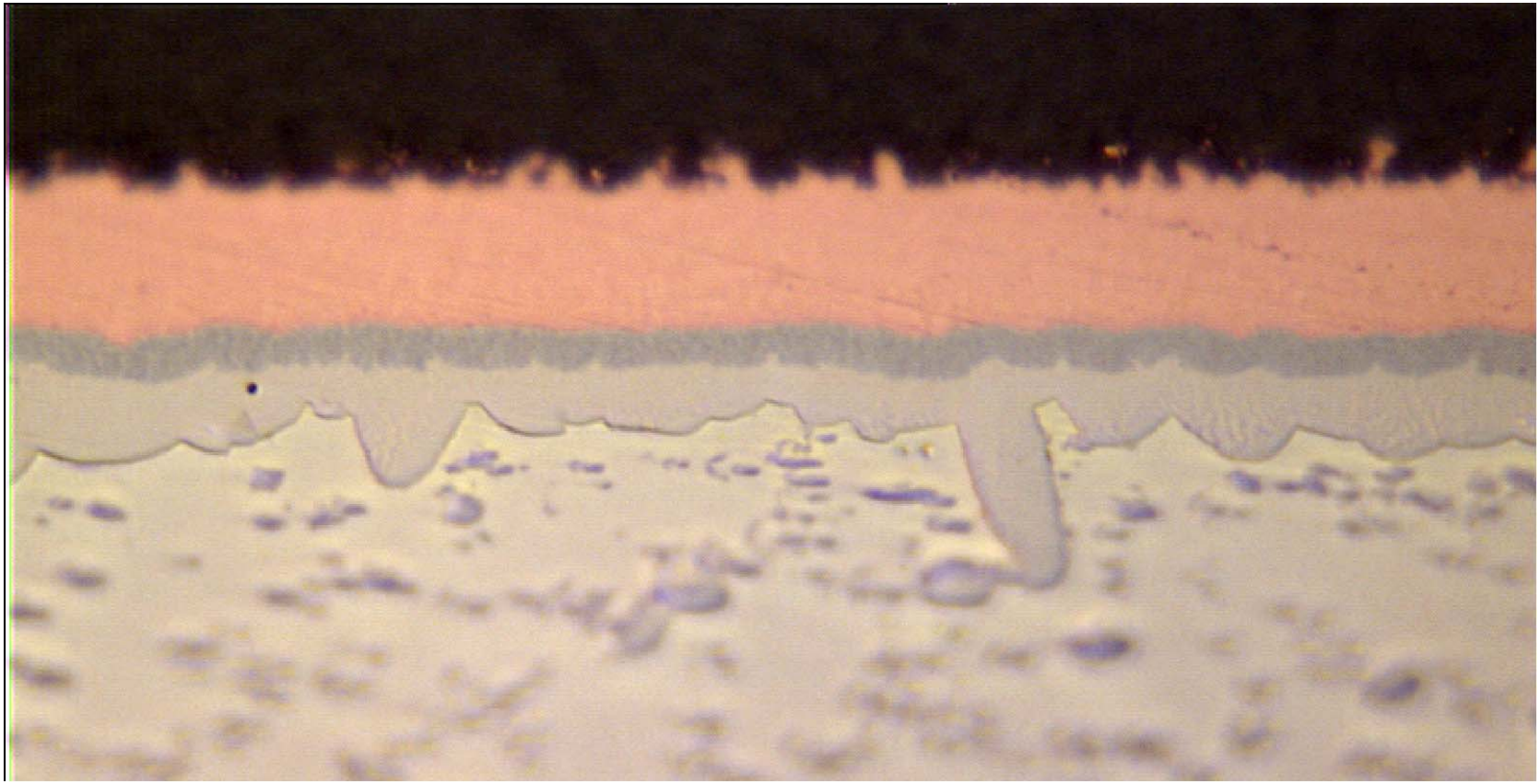
# Now the bad news…

"…apparently no commonly used solderable surface coating is consistently immune to embrittlement problems."

"…Transitioning to Pb-free soldering the industry seems to be facing significant risks of solder joint fragility associated with all the commonly used solder pad surface finishes."

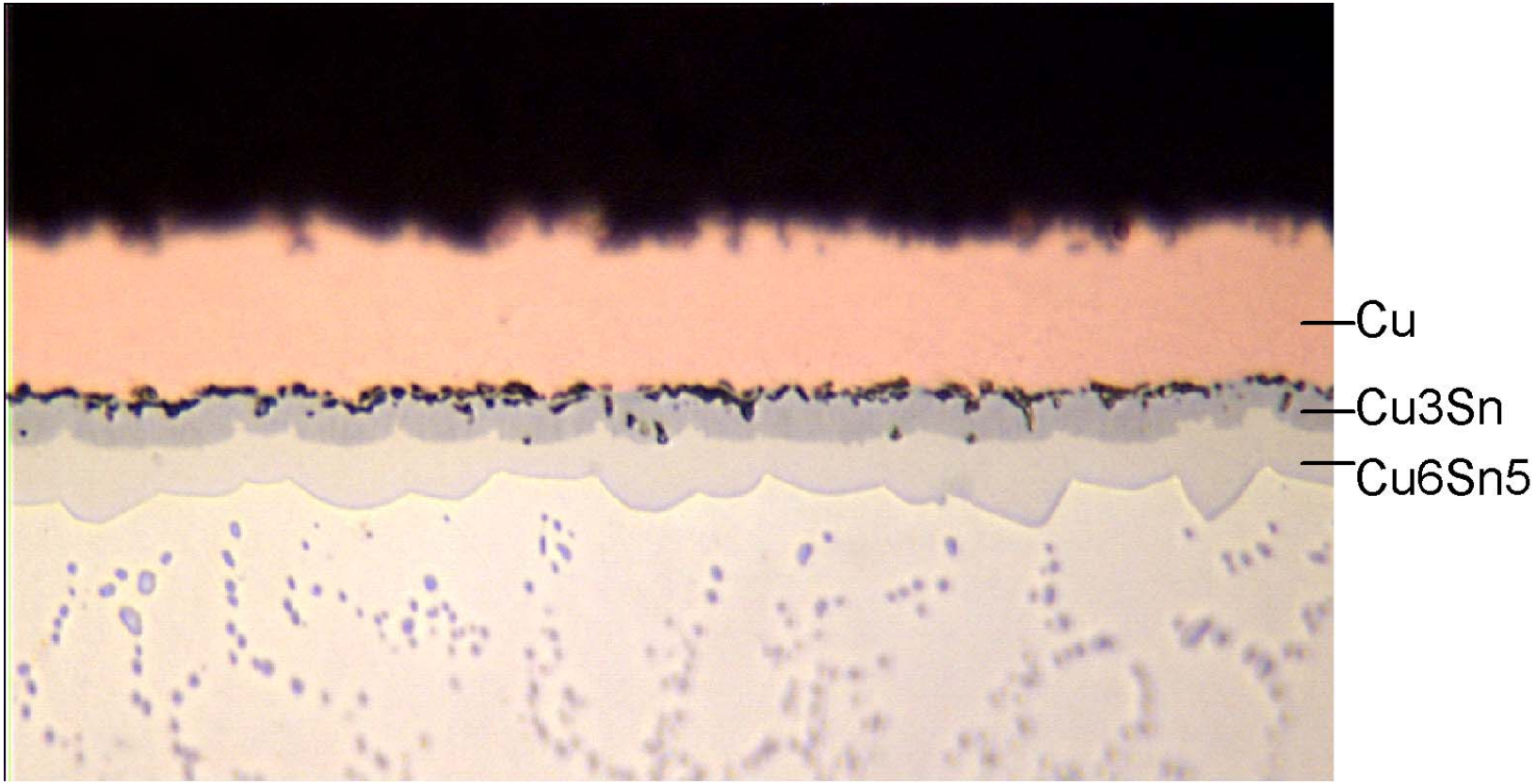
White Paper… **"FRAGILITY OF Pb-FREE SOLDER JOINTS"**
Peter Borgesen and Donald W. Henderson
August 20, 2004

# Traditional Solder Interface



**Source: “Fragility Of Pb-free Solder Joints”**

# SAC Alloy Interface




**Source: “Fragility Of Pb-free Solder Joints”**

# It doesn't take long…

"Extensive voiding was observed after only moderate aging (20-40 days at 100°C) making it an obvious practical concern, at least for products facing elevated operating temperatures and mechanical shock or vibrations in service."

White Paper… **"FRAGILITY OF Pb-FREE SOLDER JOINTS"**
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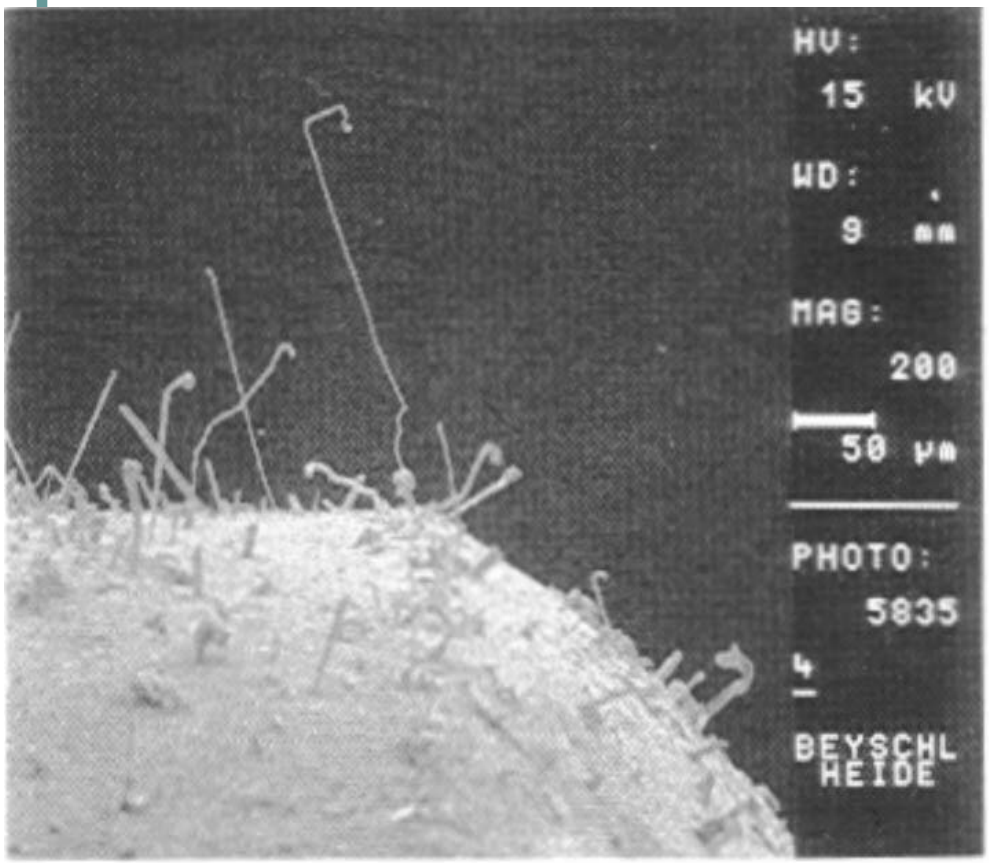
# Reality of lead-free assembly

- There is no drop in replacement for Sn63/Pb 37
- Higher processing temperatures are required
  - $20^0$ C to $40^0$C higher
- Narrower reflow process window
  - Between liquidus and peak (was $40^0$C → now $20^0$C)
- There are many lead-free patents Alloy patent issues are now resolved by cross-licensing between major suppliers
- The right finish choice for lead-free??
  - OSP?...HASL… ENIG?... Ag?… Sn…?
- What about tin whiskers?

Source: Cookson

# What about Tin-Whiskers?



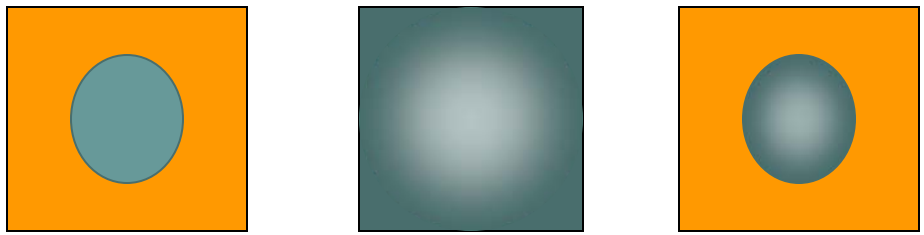

- Appear to be caused by compressive stress.
- Possible solutions...
- - Hot tin leads
- - Use lower tin solders
- - Remelt to create stress-free tin surfaces



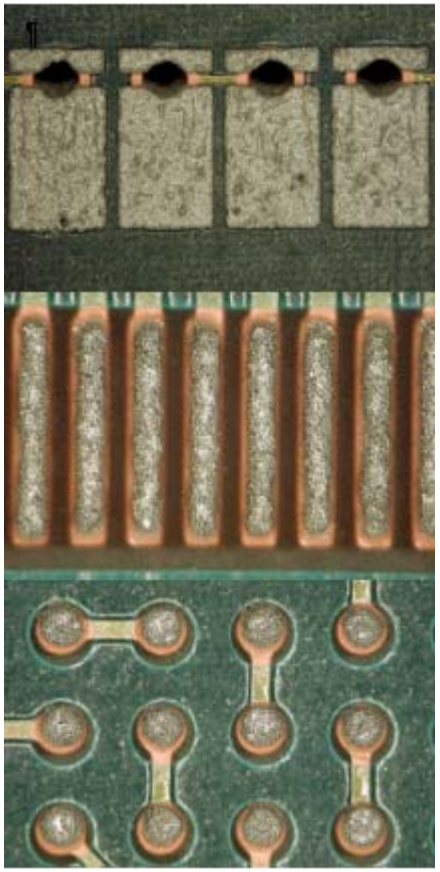
Source: Cookson

# Printing paste

- No major issues
- No rapid stencil wear
- Lead-free solders do not spread during reflow



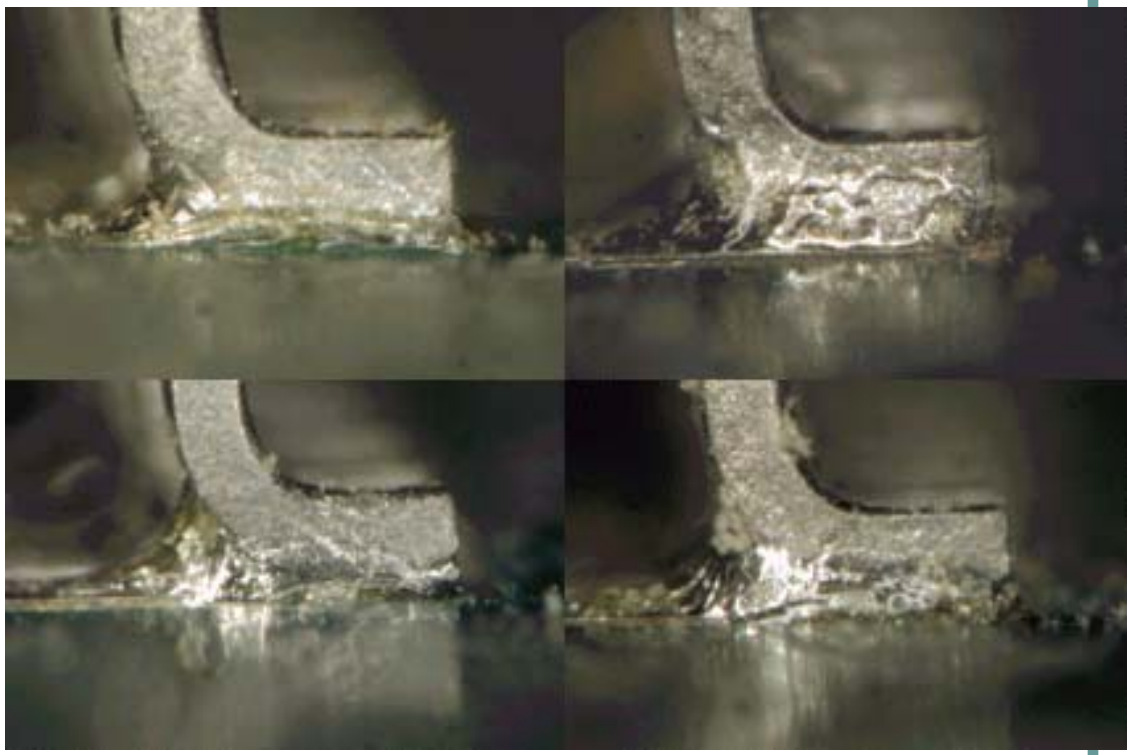
As Printed | Pb-Sn | Lead-free



Source: Cookson

# Joint appearance

- Fillet appearance is not the same as tin-lead – less wetting and spreading
- Surface finish is not the same as tin-lead because of crystal formation on cooling
- Many suppliers use IPC610 inspection criteria and can pass with lead free solders

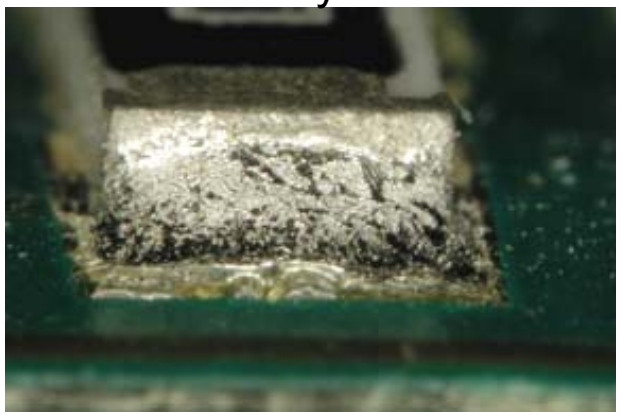


Source: Cookson

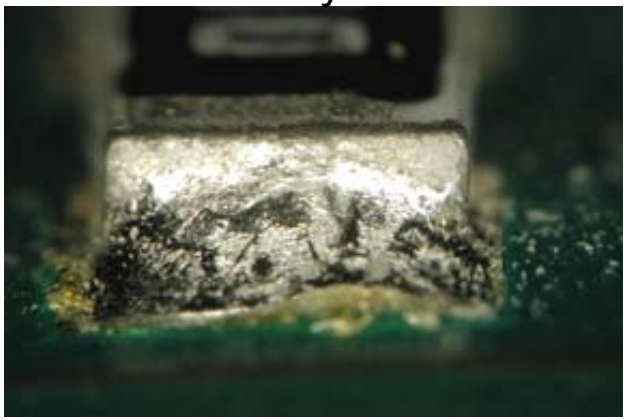
# Typical Visual Degradation of Solder Joints

## Images of R1206 solder joints after AATS exposure for SAC405-I-Ag

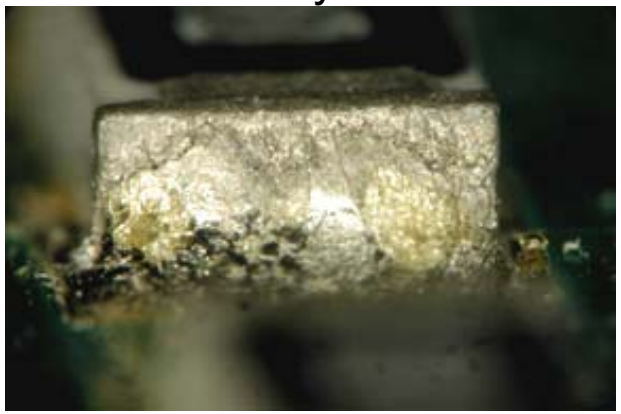
100 Cycles



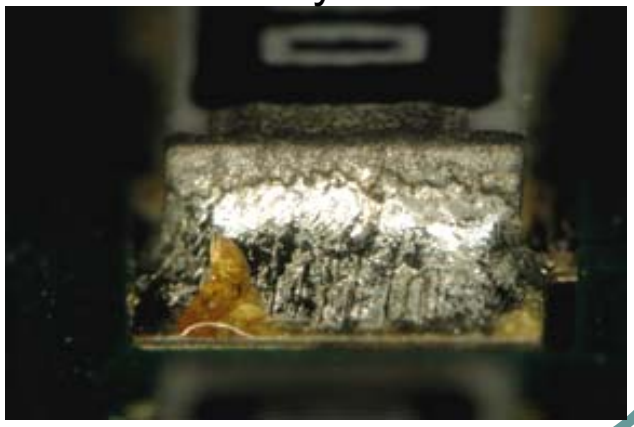
200 Cycles



600 Cycles



1008 Cycles



Source: Cookson

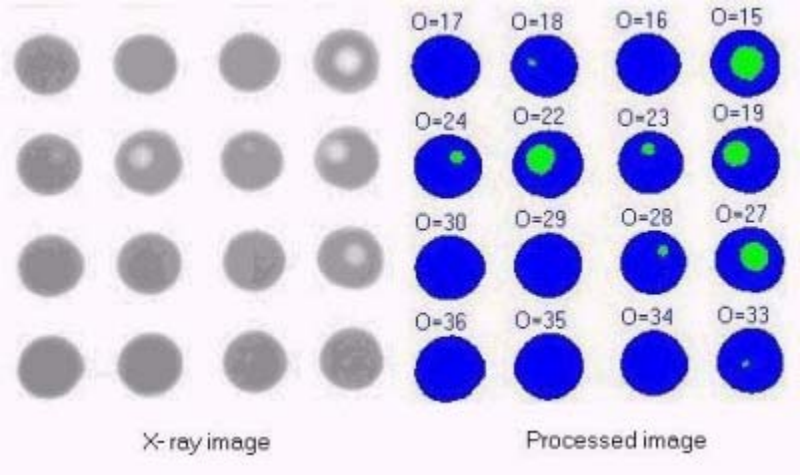
# Through-hole Fillet Lifting

- Caused by solder fillet cooling before the board; the board contracts away from the fillet as some solder on the board side is still pasty
- Reportedly made worse by lead-tin board coatings
- Avoid by using lead-free components and rapid cooling

Source: Cookson

# Voids

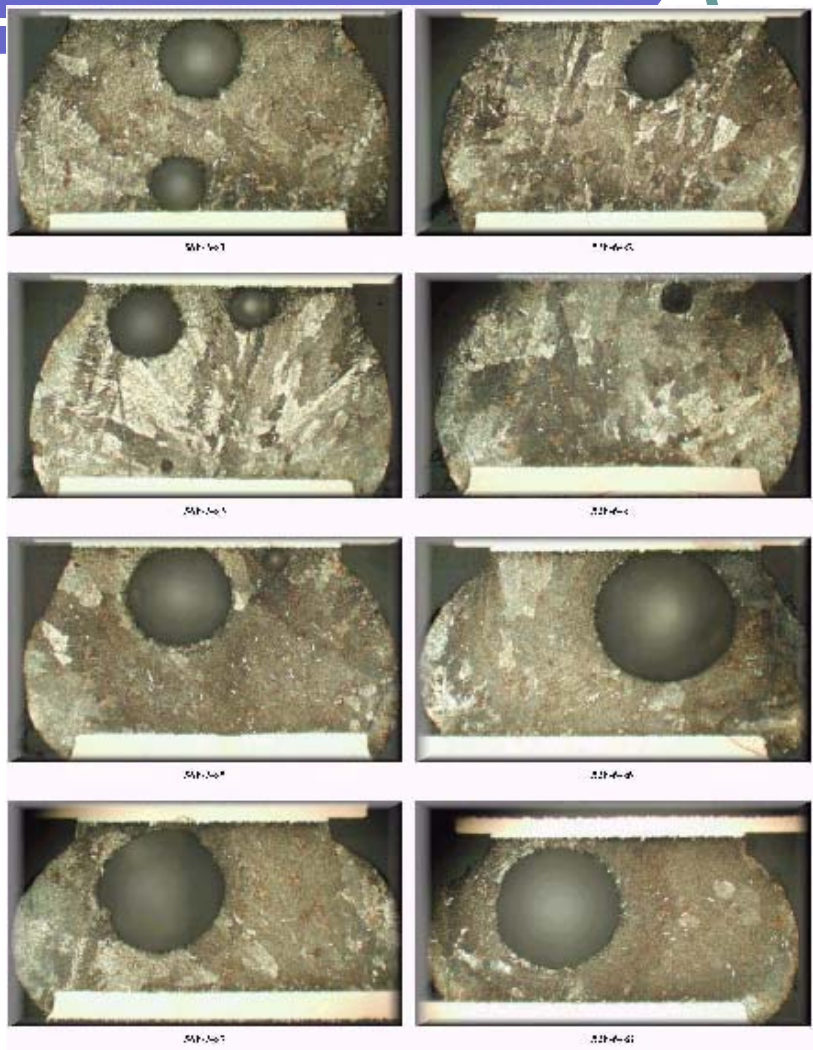
- Found with **ALL** lead-free solders
- Occur at the interface between solder and pad
- SAC305 gives lowest voiding
- Flux design and process control are critical
- Not a reliability issue…..until 0.5mm pitch




Source: Cookson

# Voids… why?

- Surface tension is higher than Sn-Pb, flux residues can not escape
- Reduced by tight control of reflow and solder paste printing



Source: Cookson

# Getting ready…

# Numerous Issues

- Component selection
- PCB material selection
- Solderable finish selection
- Electrical testing concerns
- Surface mount process concerns
- Rework and repair concerns
- Reliability factors

# Component Selection Checks

- Materials used in component construction
  - Need temperature rating of 220C for 90 sec with 260C max.
  - Choose finish: (e.g. ENIG, Sn, Ag, Pd, etc.)
  - Evaluate and choose suppliers with required capabilities
  - Check JEDEC moisture sensitivity level
  - Verify component performance
  - Verify finish solderability
  - Establish ID protocol for marking lead free components
- Logistics
  - Identify & segregate or purge temperature sensitive materials,
  - Inventory control/segregation lead/lead-free finishes
  - Disposition components that can not be converted
  - Assure document changes are correct
  - Develop timeline for implementation of required changes

After Barmuta

# Failure modes during assembly

- Active Components
  - Popcorning
- Passive Components
  - Loss of electrolyte
  - Thermal shock cracking
  - CTE mismatch related failures

# Popcorning… What is it?

- Delamination and failure of packaging due to expansion of trapped moisture
  - Moisture can be present as liquid in voids
- Initial rack growth followed by catastrophic failure
- Bake out is challenging
  - Little moisture required to generate the saturated vapor pressures required for popcorning
- Ideally components would pass JEDEC Level 1 but most components need to be de-rated 2 or 3 levels

# PCB Materials Concerns

- Concerns of lead free exceed concerns of surface finish
  - The temperatures associate with lead free soldering can damage and reduce the reliability of base materials.
- The designer should seek directly the advise of laminate suppliers to ensure they will be designing with materials that meet the manufacturing demands of the product they are designing

# PCB Materials Concerns

Some questions to ask…

- How many reflow cycles at the higher that will the material be able to withstand?
  - Multiple cycles can have an additive effect on the material
- What is the glass transition temperature of the material?
  - Higher temperature reflow processes demand higher temperature resins
- What is the z-axis expansion rate of the material?
  - Can impact PTH reliability
- What is the decomposition temperature of the laminate?
  - Materials are rated to withstand high temperatures for limited times
  - Extreme temperatures can break chemical bonds, and weaken material

# Board Design Checks

**Laminate:**

- Is the glass transition temperature rating more than 170ºC?
- Reason· CTE: Z axis expansion, via and PTH reliability, thru hole copper plating thickness & potential delamination.

**Final finishes:**

- Is the finish capable of multiple reflow cycles?
- Reason: Some finishes degrade more rapidly at lead-free assembly temperatures and solderability and solder joint reliability may be reduced.

# Board Design Checks

**Circuit Panelization**

- Will the board layout on the panel be affected by the higher temperatures?
- Reason: The number of support points may need to be increased (e.g. for route and retain assemblies) New or alternative board retention strategies may be needed.

**Board marking**

- Will the board have a lead-free designation mark or marking?
- Reason: Some certification markings will likely be required for ID purposes it must be legible following processing.

# Failure modes during assembly

- **Cosmetic "failure"**
  - Discoloration
- **Performance failure**
  - Barrel Cracking
  - Delamination

Source: Cookson

# PCB Finishes for Lead-free

- **Hot Air Solder Level (HASL) Coatings**
  - Advantages – Pure metal alloy should work with most Pb-Free alloy choices. Should wet faster than other finishes
  - Concerns – Non uniform deposits, Delamination or warpage due to higher processing temperatures. Entrainment of chemicals into PCB.
- **Immersion Metal Finishes – (e.g. Tin,  Silver)**
  - Advantages – Simple process, uniform height
  - Concerns – Coating thinness and durability, Non uniformity. Formation of non-solderable alloys, Oxidation

# PCB Finishes for Lead-free

- **Electroless NiAu**
  - Advantages – Simple process, Uniform finish, Good shelf life, Compatible with many alloys
  - Concerns – Black pad failure mechanisms not fully explained .
- **Organic Solderability Proctectants (OSPs)**
  - Advantages – Simple process, Uniform finish, Good solderability, Low cost
  - Concerns – Limited shelf life, Durability in multi solder cycle assembly

# Electrical Testing Concerns

- **Baked on Flux Residues…**
  - Possible interference with electrical pin contact
- **Board Warpage…**
  - Non planarity can make testing a problem
- **Finish Choice…**
  - OSP thickness must be pierced at bare board test

# Surface Mount Readiness Checks

- **Lead Free Solder Paste:**
  - Select alloy, select flux , select vendors, develop test matrix
- **Stencil Print Evaluation**
  - Check print ability, working life, placement life, print speed, separation, stencil clean: printer, stencil and board, determine required changes, incorporate changes
    · Stencil Clean: printer, stencil and board, determine required changes, incorporate changes
- **Dispensing Equipment**
  - Evaluate equipment, determine  quality identify changes needed and incorporate changes
- **Reflow Equipment**
  - Characterize zone settings for chose paste (or pastes),  all anticipated board types, all anticipated board finishes and anticipated component types.
  - Check thermal profile and dwell times. Verify max temperature and cooling ramp down. Higher temperatures affecting board warpage, fixturing, component compatibility. Determine optimum recipes, incorporate changes.

After Barmuta

# Surface Mount Readiness Checks

- **Solderability:**
  - Wetting, solder joint appearance and acceptability. Increased voiding and defects
- **Visual Inspection AOI:**
  - verify inspection criteria for solder joints relative to their appearance and implement  any needed changes
- **Equipment Effected:**
  - Reflow: Higher temperatures, transport system, fixturing, ventilation, maintenance, upgrades, vapor phase, nitrogen. Stencils: apertures
- **Moisture Sensitive Components:**
  - Shorter exposure times ratings, baking
- **Inventory control/segregation Lead/Lead Free**
- **Waste and Reclaim**
- **Document changes**

After Barmuta

# Lead-free Equipment Corrosion

- Unmodified wave solder equipment will be corroded
- Specialized coating materials are available on new equipment or as retrofits

Affects all stainless steel alloys after less than 6 months

Source: Cookson

# Rework & Repair

- **Need to avoid cross-contamination of solders**
  - >0.5% Pb will cause reliability issues
- **Hand-soldering of Pb-free alloys requires training**
  - Freeze behavior is different than eutectic
  - It isn't a major issue – most plumbing solder is now Sn-Ag
  - Need to selectively apply heat to only the areas that need rework
- **Sn-Ag is probably the universal rework material**
  - Available in wire
  - No disastrous intermetallics

Source: Cookson

# Reliability has many factors

| Reliability | | | | |
|---|---|---|---|---|
| **Mechanical** | **Electrical** | **Thermal** | **Radiation** | **Altitude** |
| **Cause** | **Cause** | **Cause** | **Cause** | **Cause** |
| Mechanical shock vibration, drop, twist | High humidity, voltage, current, contamination, power cycling | High temperature storage, thermal cycling & shock, high operating temperature | Alpha particles, beta or gamma Ultra violet | Pressure, temperature, condensation |
| **Effect** | **Effect** | **Effect** | **Effect** | **Effect** |
| Solder joint failure, interface degradation, physical damage | Corrosion, electromigration, Degraded interfaces | Intermetallic growth, solder joint fatigue, popcorning | Data loss, embrittlement, discoloration | Deformation, embrittlement, corrosion |

After: Nokia

# Conclusions

- The legislative mandate for lead-free solder is still moving ahead, however, only 17% of the global manufacturing is converted because full conversion will run into the tens of billions of dollars.
- Most design issues are tied to material choice and finish
- Primary alloy look to be a SAC alloy (Sn96Ag3.5Cu0.5)
- The process window for lead-free is smaller and the fragility is a big concern
- Lead-tin eutectic will likely continue to be used but there is concern over the compatibility with finishes
- Recycling makes more sense than lead free
- California just passed law allowing consumers to turn over old cell phones to recyclers at no charge.

# Next Time…

- Seek the truth
- Do your homework
- Avoid “group think”

# The Signs of Groupthink…

- Examining few alternatives
- Not seeking expert or outside opinions
- Being highly selective in gathering information
- An illusion of invulnerability
- Strong belief in the group's inherent morality
- Rationalizing poor decisions
- Pressure to conform within the group; members withhold criticisms
- Pressure to protect the group from negative views or information
- Overt external or internal pressure to come to a decision
- Individual group members look to each other to confirm theories

# Next Time…

- Seek the truth
- Do your homework
- Avoid “group think”
- Educate yourself and your customer
- Be a devil’s advocate
- If suspect legislation is being proposed, challenge the legislators to provide evidence of need before submitting to it
- Seek the truth…

# The truth is out there…