Reduction of Hazardous Substances in Electronics Manufacturing

TURI Continuing Education Conference
Norwood MA
November 3rd, 2010

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Market Segments / Product Examples

Device Monitors Programmers
Pumps & Infusion Technologies
Medical Capital Equipment

Guidance Systems
Communication Control
ID Systems

Lighting Devices
Power Controllers
HVAC Control Systems

Precision Automation Equipment
Micro Adhesive Dispensing
Semiconductor End-products

Medical | Computing & Data Storage | Aerospace & Defense | Energy | Industrial Controls | Test & Measurement | Semiconductor & Automation | Telecom

Servers and Server Products
High Reliability Computers
Disk Drives

Wind generators
Solar energy collectors
Power management

Optical Recognition Systems
Scientific Instrumentation
Telecom Test Equipment

Routers & Switches
Wireless Base Stations
Optical Networking

Driving Forces

- RoHS, REACH, and WEEE Directives passed by the EU and similar legislation emanating from around the world
  - RoHS restricts the use of Lead, Mercury, Hexavalent Chromium, Cadmium, and two chemical flame retardants
  - WEEE requires increased recycling of electronic waste and minimization of the burying and burning of the waste
- Companies have made the choice to become more environmentally friendly
- Influence from Non Government Organizations (NGOs) such as Greenpeace and consumers
- Difficulty in obtaining components that are not lead-free

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Impact of RoHS on Electronics Manufacturing

- Biggest Change in our Industry in More than three Decades
  - Lead has been used to assemble electronic products for over 50 years
- Surpasses the Thru Hole to SMT Transition and BGA Transition
- Need to Establish “Two Factories in One”
- Impacts the entire process from design, material acquisition, assembly, test, reliability, rework, field service returns, and end of life.

Customer Questions

- Will the price remain the same?
  - In most cases, “yes”
- Will the reliability of the product be equal to or better than a product assembled with lead?
  - In most cases, “yes”

Industry Research for Lead Free

- A tremendous amount of Pb-free research and development has taken place since the early 1990's and a central focus of the Benchmark conversion was to build on this work.
- National Center for Manufacturing Sciences (NCMS) 1999 Report
  - Considered 200 Pb-free alloys
  - Tested 32 Alloys – Recommended a Tin-Silver-Copper (SAC) Alloy
  - Alloy is consistent with the alloy used by the Japanese since the early 90's
- International Electronics Manufacturing Initiative (iNEMI)
  - Recommended Tin Silver Copper Alloy similar to NCMS
- IPC Solder Products Value Council – 2005 Report
  - Studied SAC alloys with Silver at 3.0%, 3.5%, and 3.9%
  - Concluded they were equivalent and recommended Silver at 3.0 or SAC305 which has become the standard for Lead Free
- Other consortiums include CALCE, iNEMI, New England Lead Free Electronics Consortium, HDPUG, Unovis, etc

Benchmark Electronics Lead Free Development

- Based on industry research
  - Minimized the risks in terms of assembling a reliable product, simplified the conversion, reduced the costs of the conversion, and ensured the conversion was consistent with emerging industry standards and practices.
- Conversion included the selection of cost effective test vehicles for the initial chemistry selection and validation, a larger more complex test vehicle.
- Participation in the New England Lead Free Electronics Consortium managed by the Toxics Use Reduction Institute (TURI) at the University of Massachusetts Lowell.

(http://www.turi.org/industry/research/supply_chain_program/electronics)

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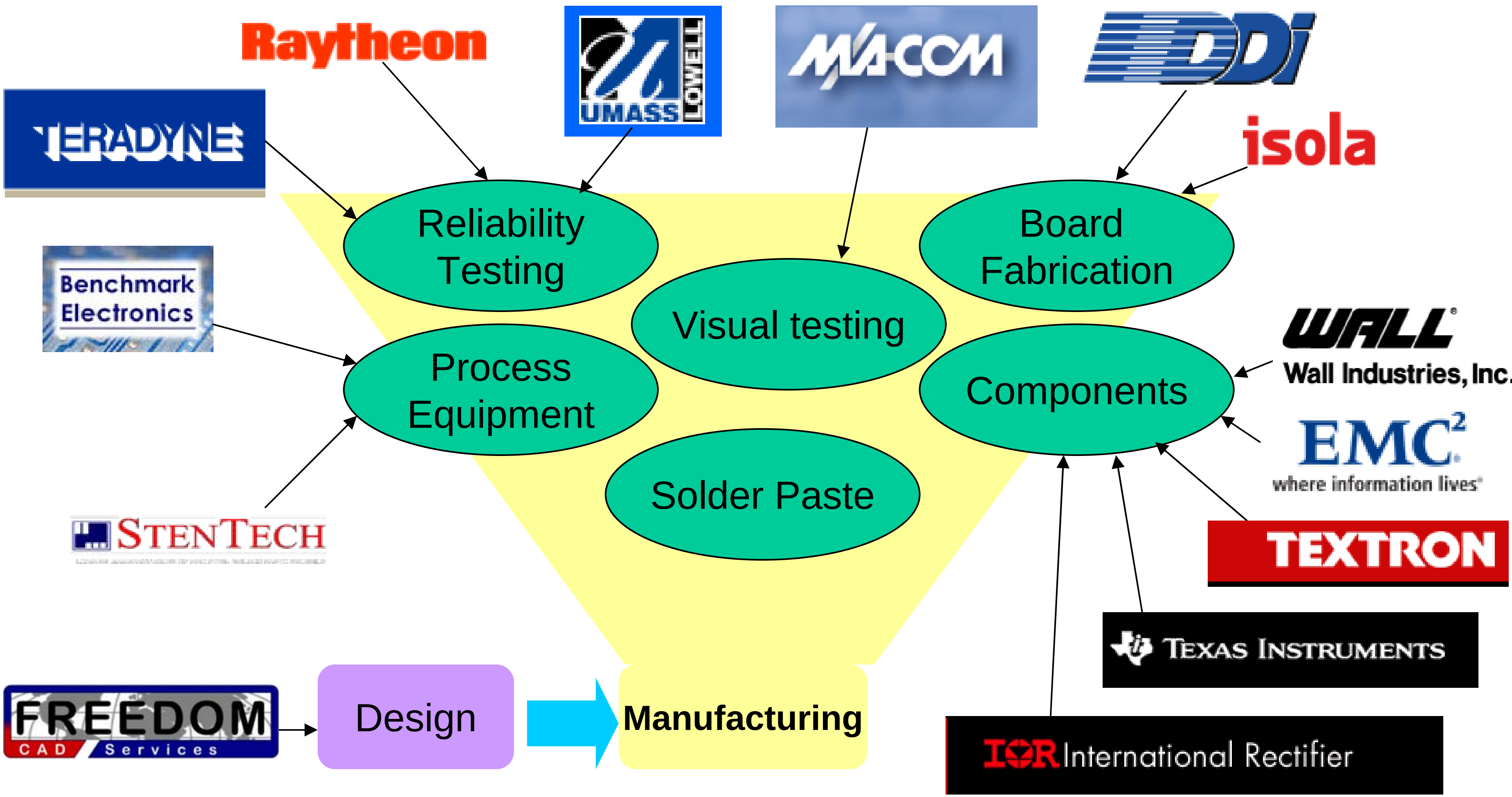
New England Lead Free Electronics Consortium Phase IV Members & Contributions

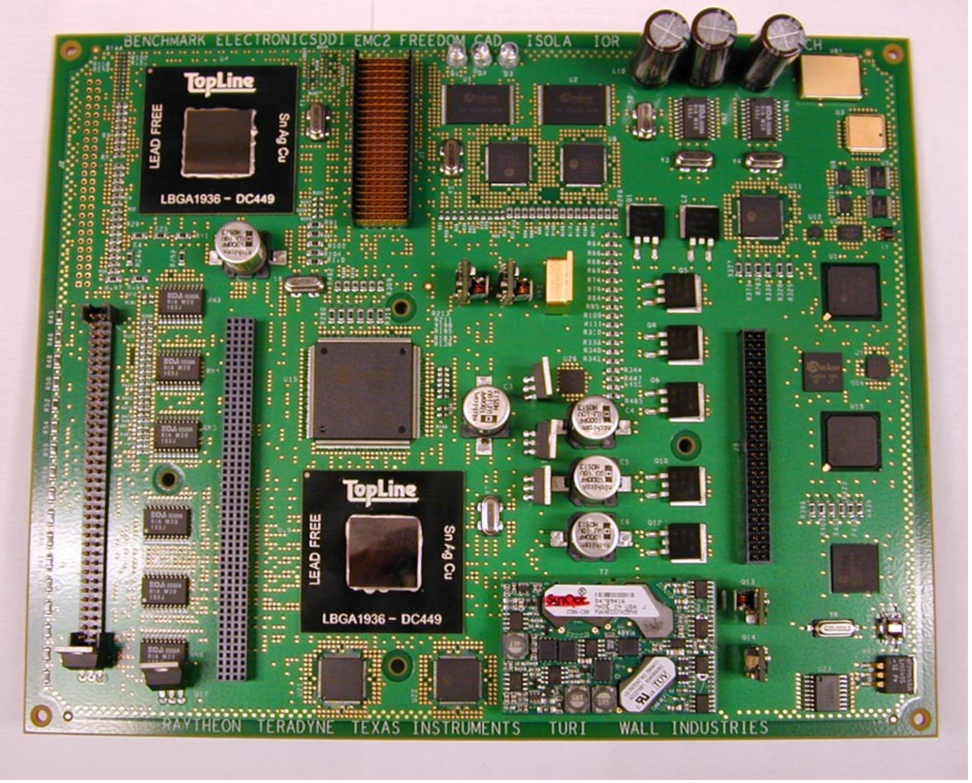


- Benchmark assembled the Phase III Test Vehicle in 2005 and the Phase IV Test Vehicle in 2007-2008
- Both test vehicles replicated real product

Phase III Test Vehicle	Phase IV Test Vehicle
▪16” by 18”	8” by 10”
▪.097” thick	.110” thick, 20 layers
▪Mixed Technology	Mixed Technology
▪Double Sided	Double Sided

- SnPb version assembled in parallel with Pb-free which allowed the direct comparison of assembly yields.
- Forced rework of BGA’s and Through Hole Devices
- Reliability testing via thermal cycling and vibration of SnPb and Pb-free in parallel to allow relative comparisons

New England Lead Free Electronics Consortium Phase IV Test Vehicle



- 8” by 10”
- .110” thick
- Double Sided SMT with Through Hole
- 20 layers including 2 oz copper
- Incorporated intentional DFM violations including an absence of thermal relief between through hole barrels and copper ground planes

Consortium Lessons Learned from Phase III and Phase IV Test Vehicles

- Pb-free SMT assembly yields equivalent to SnPb
- Phase IV through hole soldering yields were equivalent or better compared than SnPb
- Pb-free BGA rework acceptable – Good joints/No laminate damage
- Pb-free through hole rework acceptable for most components using a solder fountain although excessive copper dissolution was observed on some through hole reworks.
- Forced Convection and solder vacuuming used to remove through hole components to minimize copper dissolution

Phase III Test Vehicle:

- No statistical differences between SnPb and Pb-free identified during thermal cycling (0 to 100 C) and Highly Accelerated Life Testing (HALT)

Phase IV Test Vehicle:

- Temperature Cycling (-55 to 125 C) per IPC 9701
- Vibration
- Halogen free laminate failed around the 200th cycle (not Pb-free compatible)
- Isola 370 HR did not fail until around 1340 cycles (robust)
- Relative comparisons between SnPb and Pb-free solder joints being currently being determined

Papers have been presented on the Phase III and Phase IV cards and can be viewed at:

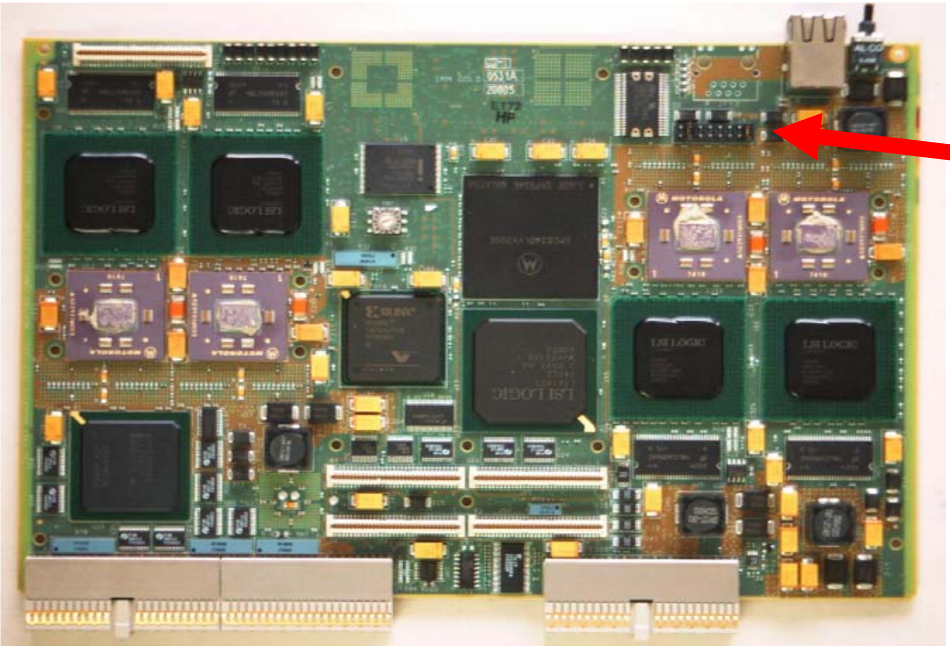
http://www.turi.org/industry/research/supply_chain_program/electronics

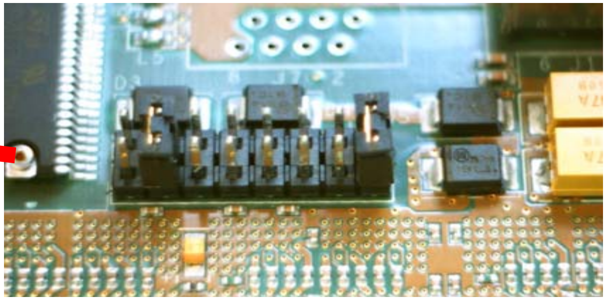
Limitations of Test Vehicles

Work very well for assessing solder joints but test vehicles incorporate numerous dummy components. Thermal or other issues with real components would not be detected.

Conversion of the Mercury Computer Inc, Maverick Medical Card from SnPb to Pb-free (2006)

- 9.2” by 7.5”, 16 layers including 7 power/ground, .084” thick
- Double Sided, Mixed Technology





14 Pin Through Hole Header Selected for Forced Through Hole Rework

Mercury Maverick - Key Findings

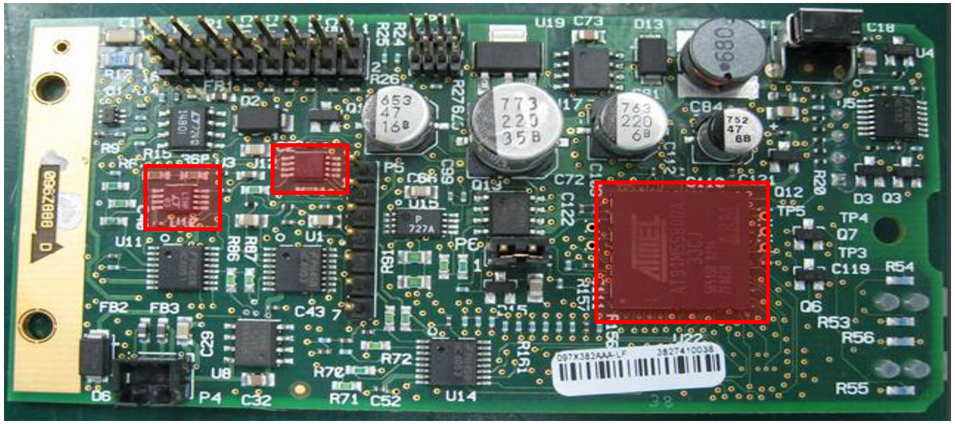
- Not all parts are available as RoHS-Compliant
- Temperature Rating of Some RoHS-Compliant Parts was too Low for Reflow
- Pb-free SMT and Through Hole Assembly and Electrical Test Yields Equivalent to SnPb
- BGA rework results were acceptable
- Through hole rework results were not acceptable on OSP boards - New Rework method developed.
- Thermal cycling confirmed the Pb-free version of the card met the customers reliability expectations

Brooks Instrument, LLC
Pb-free Qualification of a Real Product

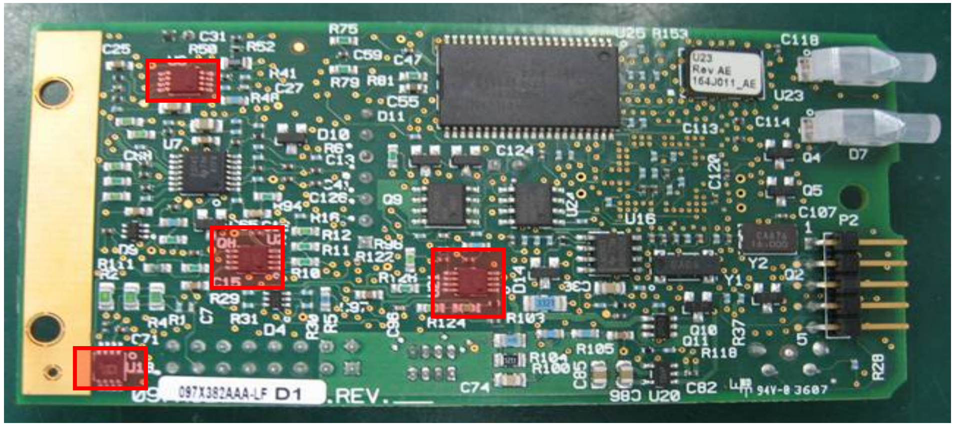
- Conducted by TURI, Benchmark Electronics, and Brooks Instrument
- The Smart II product was selected because was representative of the entire family of Brooks Instrument products. The product is considered high reliability with a 10-15 year life required in the field.
- Benchmark Electronics in Guadalajara, Mexico has been manufacturing Smart II product with tin-lead solder with an approximate production volume of 600 boards per month for about five years
- Complete 57 page report available at:

  http://www.turi.org/content/view/full/6051

Brooks Instrument LLC - Smart II Card
Double Sided SMT with Through Hole



Top View



Bottom View

- Product measures 3” by 1.6”
- .062” thick
- Red denotes location of conformal coating for enhanced Sn Whisker mitigation

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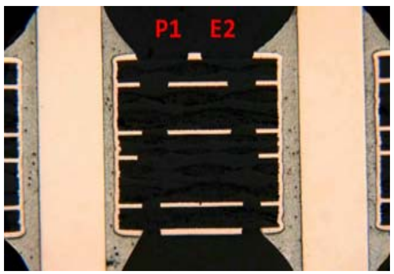
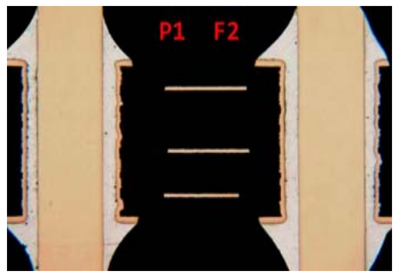
Brooks Smart II Cross Sections After Assembly - Acceptable

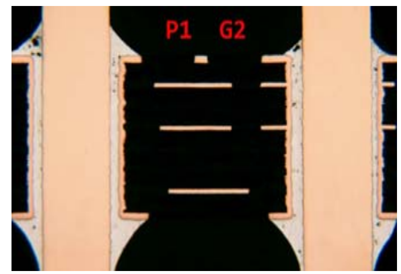
TSOP

SnPB No Clean | Pb-free OA | Pb-free No Clean

Through Hole Header

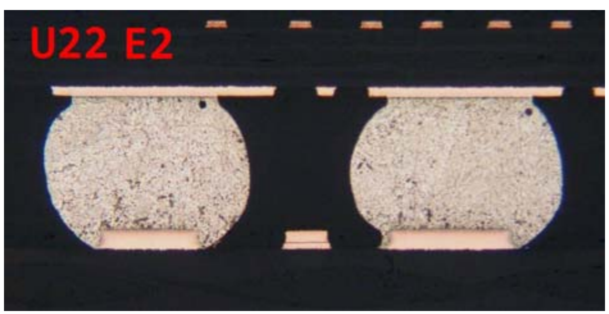


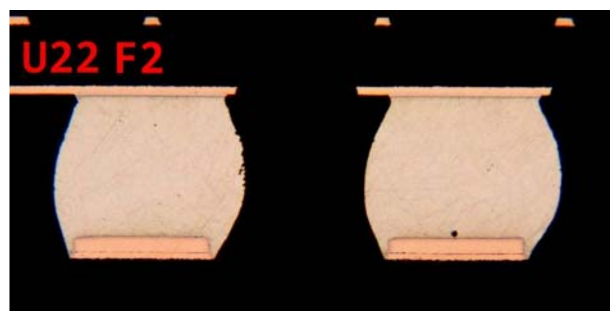




SnPb No Clean | Pb-free OA | Pb-free No Clean

BGA





SnPb No Clean | Pb-free OA

Brooks Smart II – Lessons Learned

- In almost all cases, RoHS compliant components were available for the Smart II design that had the appropriate temperature rating of 260 °C and incorporated generally accepted tin whisker mitigation guidelines. These parts were not always available during similar studies performed several years earlier.

- Based on the limited sample size, the defect levels for tin-lead and lead-free could be considered roughly equivalent.

- Visual inspections, X-Ray analysis, and cross-sections confirmed that the lead-free joints met IPC 610-D Class 3 criteria. There was no evidence of thermal degradation to the printed circuit board or components after assembly.

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Brooks Smart II – Lessons Learned (cont)

- Forced rework on BGA’s, through-hole components, and SMT lead frame components were successful, although there was evidence of thermal degradation on a through-hole component that was reworked by hand.
- The lead-free cards passed ion chromatography testing, but this testing indicated that there may be an opportunity to improve bare board cleanliness and handling during assembly to provide a further level of robustness against electrochemical failures.
- There were no lead-free or tin-lead solder joint failures during thermal cycling for reliability.
- Tin whiskers were not observed during any tin whisker testing, and all cards passed functional testing conducted during these tests.
- Vibration testing indicated that the lead-free and tin-lead cards were equivalent in their robustness.

Customer A Pb-free Qualification of Product A (2010)

- **Overall Objective:** Provide cost effective Pb-free product with reliability metrics equal to or better than SnPb
  - Product A is a network communication products that is currently exempt from the RoHS Directive
  - Compliance is expected to be required by 2014 at the earliest

However,

- SnPb components are becoming more difficult to source.
- Pb-free is more environmentally friendly than SnPb and Customer A is interested in offering such products to their customers

Therefore,

- Customer A is targeting 2012 for conversion

Additional Pb-free Preparation by Customer A

- Continuous involvement with HDPUG along with independent studies to identify the solder joint reliability impacts for specific component package styles
- Components subjected to extensive thermal cycling

    -20 C to 80 C for 7000+ cycles

    - 0 to 100 C for 6000+ cycles

- Failure analysis work was performed after cycle completion to determine root cause for component failures. The results of this testing helped determine high risk component types and high risk solder joint types. These package styles are avoided where possible.

HDP USER GROUP INTERNATIONAL, INC.

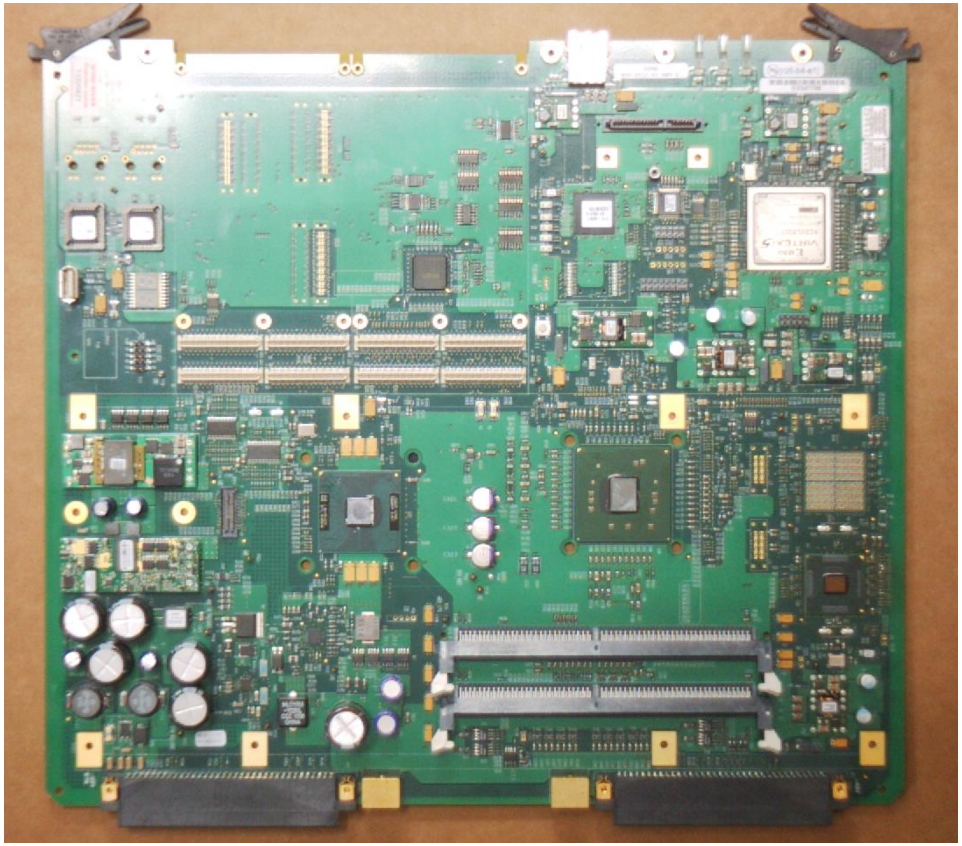
Product A - Field Requirements

- 25 Year Life
- Central Office Conditions
- Temperatures between -5 C and 50 C.
- Relative Humidity as high as 90%
- Vibration conditions ranging from transportation profiles to Zone 4 Earthquake environment
- Required to be assembled under IPC-610 Class 3 visual and X-Ray criteria which is the highest performance criteria.

<u>Key metric:</u>

SnPb version of the product has been operating reliably in the field under these conditions for 20 plus years

Product A - Topside View

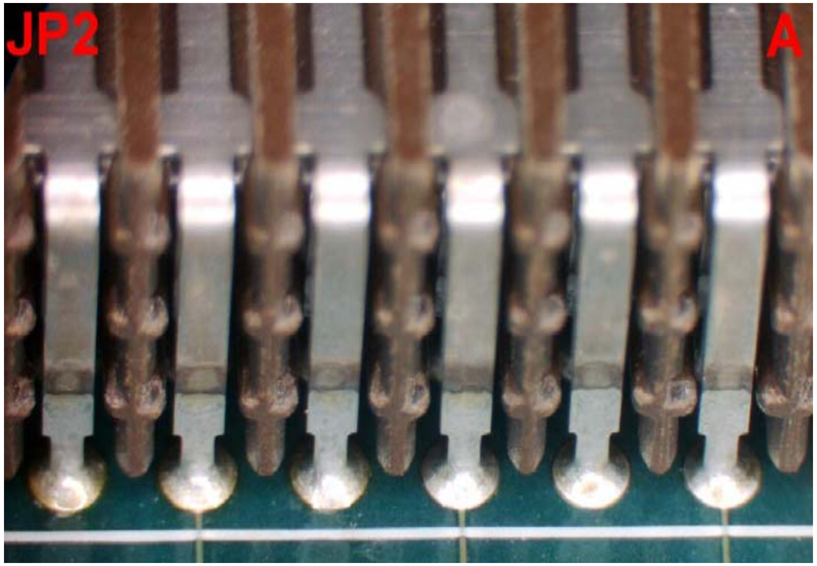


- Isola PolyClad 370HR
- 12.800" by 14.432"
- .090" Thick, 18 layers
- 1893 components
- Total pin count = 10,859
- Surface Mount = 9,641
- Through-Hole = 1,218

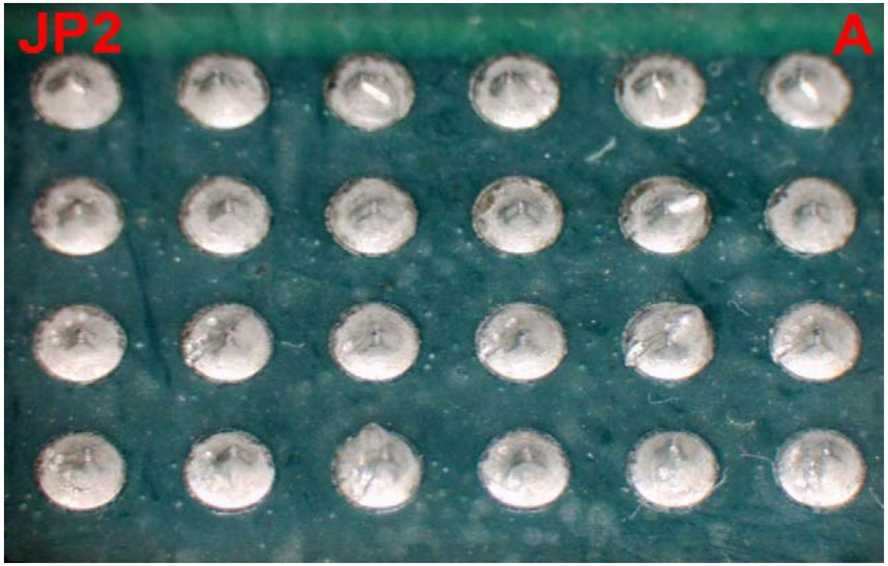
Summary of SMT Visual Inspection for Product A After Assembly

- All solder joints met IPC 610 Class 3 criteria with the exception of the surface mount display at location DS6 which had insufficient fillet heights on several pins. This was a component wetting issue.
- There was no evidence of thermal degradation to any of the SMT components or the printed circuit board laminate
- The Dye and Pry results show the joints to be very strong with almost all pads separating from the PC board laminate.

Through Hole Inspection for Product A



Edge Connector – Location JP2



Edge Connector – Location JP2
Bottom View

The card edge (JP1 and JP2) through hole soldering was excellent with close to 100% solder fill and good top side wetting. The bottom side flux residue is a hard amber material which is moderately heavy in areas. The material is benign and only a cosmetic issue.

Product A Reliability Testing

- Customer A ran an entire chassis of 15 Product A Pb-free assemblies through an accelerated thermal cycling test.

- Thermal cycling was performed at the minimum and maximum thermal profiles for central office extremes which is -5 to +50C (55 degree delta)

- Test Specifics: Thermal Cycle Count = 5900 cycles

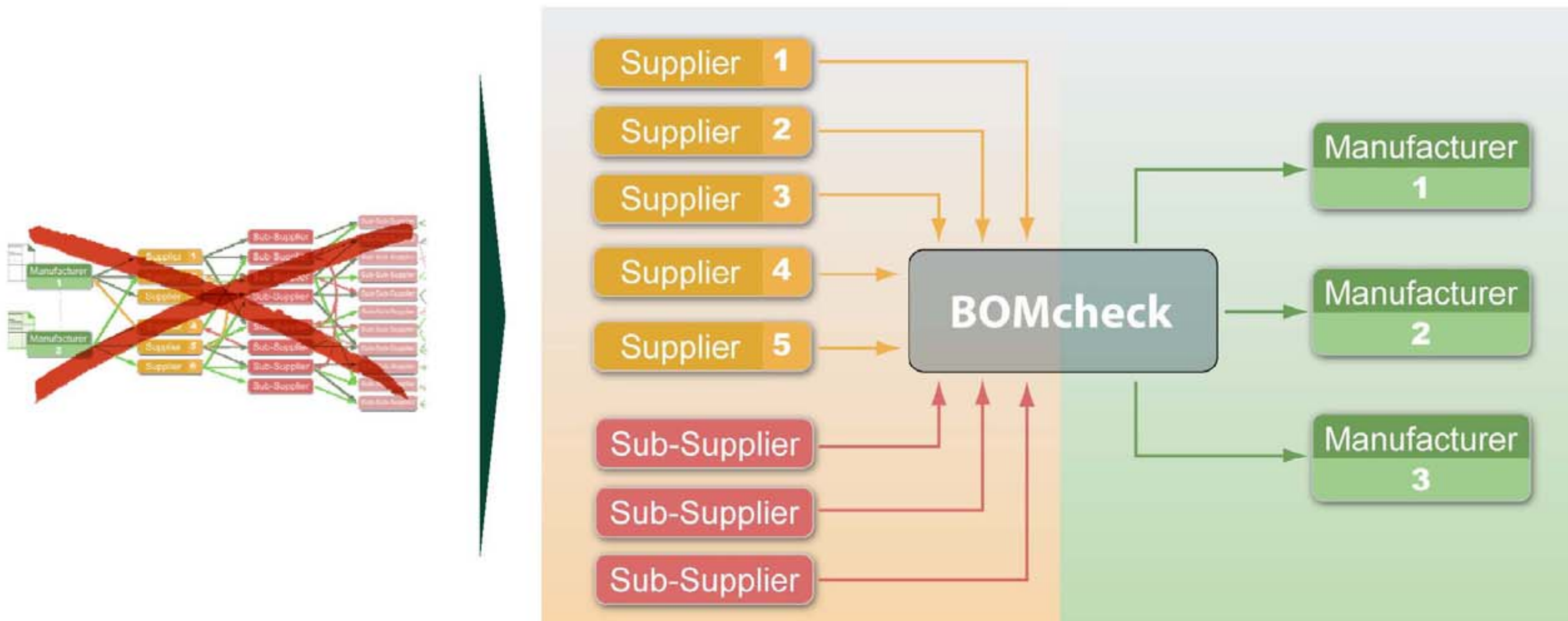
Test Results

No Pb-free solder joint failures occurred

LEAD FREE Pb SOLDER COMPATIBLE

Gathering Data – the Path to Full Material Disclosure

- Responsibility for component/material verification depends on the manufacturing services agreement (MSA)
- Benchmark asks suppliers to join BOMcheck or answer surveys when new REACH SVHC candidate lists are released approximately every 6 months
- IPC 175X preferred format for non-BOMcheck responses



REACH = **R**egistration, **E**valuation, **A**uthorization and Restriction of **Ch**emical Substances / SVHC = **S**ubstances of **V**ery **H**igh **C**oncern

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Companies That Have Embraced BOMcheck

Benchmark
electronics

The Current Environment is Challenging

- Many customers have their own restricted chemicals lists beyond what is legally required based on their markets
- List of substance restrictions is ever changing
- Dealing with the technical issues sometimes means that you have to share information with your competitors
- Many different drivers to new legislation and regulations, both political and Non Government Organization (NGO) driven

HP Breaking Green Promises – No More Excuses!

Feature story - July 28, 2009

Greenpeace activists climbed to the top of HP's global headquarters and painted the message "Hazardous Products" in big, bold letters on the roof. The message, applied using non-toxic children's finger-paint, covered over 11,500 square ft., or the size of two and half basketball courts.

Greenpeace Gives HP, Apple More Green Points

Greenpeace might have waited about a month, and saved itself the paint.

It was in late August that Greenpeace trespassed on **Hewlett Packard's** Palo Alto, Calif.-headquarters to paint the words "hazardous product" on the roof - an attack on HP's failure to meet deadlines to reduce polychlorinated biphenyls (PVC) and brominated flame retardants (BFRs) in their products.

What Greenpeace didn't know was that HP was about to come out with a nearly BFR and PVC-free notebook, the **ProBook 5310m**, which launched in mid-September.

Staying Ahead of the Curve

- Suppliers are responsible for the chemicals they use in their products
- Full material disclosure reduces the number of resources required to manage environmental compliance
- Full material disclosure allows manufacturers to have a bigger picture of their supply chain risk
- Full material disclosure allows manufacturers to assign a lower risk level to suppliers once CE marking is required

Protecting Interests

- Full material disclosure through automated systems streamlines communication while improving data integrity
- Full material disclosure does not relieve the obligation for suppliers to provide certificates of conformance to requirements for RoHS
- Full material disclosure CAN be done in a way that protects intellectual property rights through legal agreements

Full Material Disclosure is the Foundation

Maintaining Product Integrity

- Tin Lead and Lead Free products must be built in the same factories
- Reality of producing Tin Lead and Pb free product requires diligence, controls and visual management throughout the entire manufacturing process.
- Failure to deploy controls can result in a RoHS misconduct. As noted in the Online EE Times dated 10/15/07, "Vendor admits to RoHS misconduct", "cross contamination usually results from a company's running of both RoHS and non-RoHS Manufacturing lines".

Maintaining Product Integrity (cont)

- Add an “LF” or “Lead Free” suffix to any product converting to Lead Free
- Add “LF” to every component used in the assembly of this product

<u>For example:</u>

  - Assembly “8675309” becomes “8675309-LF”
  - Resistor “004” used on this assembly becomes “004-LF”

- Since many component suppliers change the part from Tin / Lead to Lead Free without changing the part number, the Benchmark “LF” suffix ensures everyone involved with assembly, test, and repair knows that it is a Lead Free product

Material Process Control

- Details of the SMT Manufacturing controls include Pb-free process controls, visual management and XRF verification of components, process materials, assemblies and due diligence.

- Material integrity and opportunities for cross contamination with the tin/lead SMT assembly process.

- XRF verification data capture along with systems and traceability required which is an integral part of due diligence.

- Lastly, failure data of the XRF non conformances to date. The data will verify the effectiveness of the XRF controls and validation of supplier non compliant product by commodity and banned substances detected.

Material Process Control

- The immediate goal is to create a method to identify, segregate and store material through the entire manufacturing process including receiving, stockroom, manufacturing floor and field returns.
- The first step of a manufacturing compliance process is the control of material given the varied stages of compliance between suppliers and commodities.
- Several methods can be implemented such as part number identification or signs. Many part number identification strategies have been used in the industry including adding prefixes, suffixes to existing part numbers or changing part number schemes with specific identifiers detailing compliance or new dedicated compliance part numbers.
- Upon deployment of the part number identification, the material must be marked or labeled with the compliance part number.

Visual Management

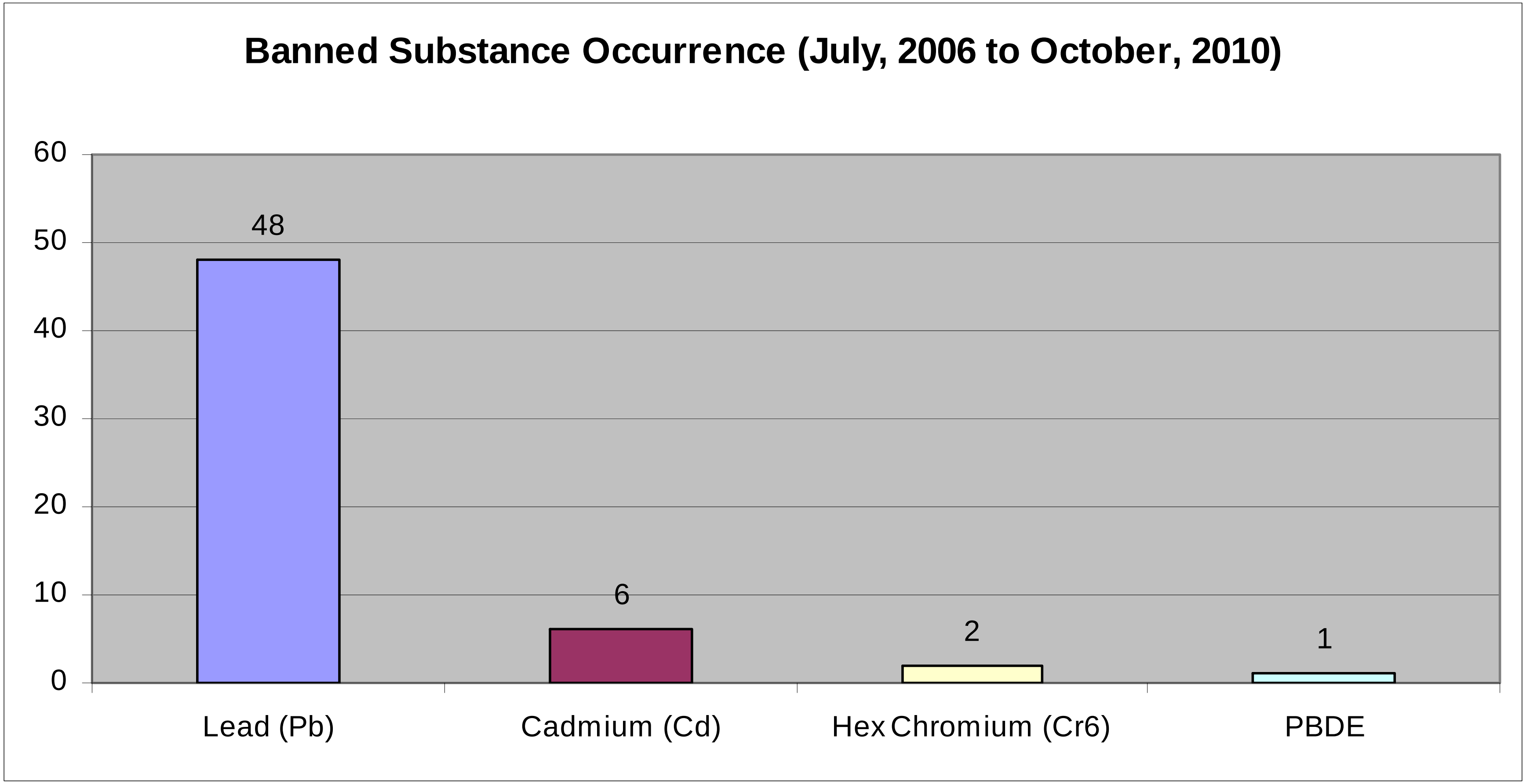
Components in the Stockroom

Screen Printer (Assembly)

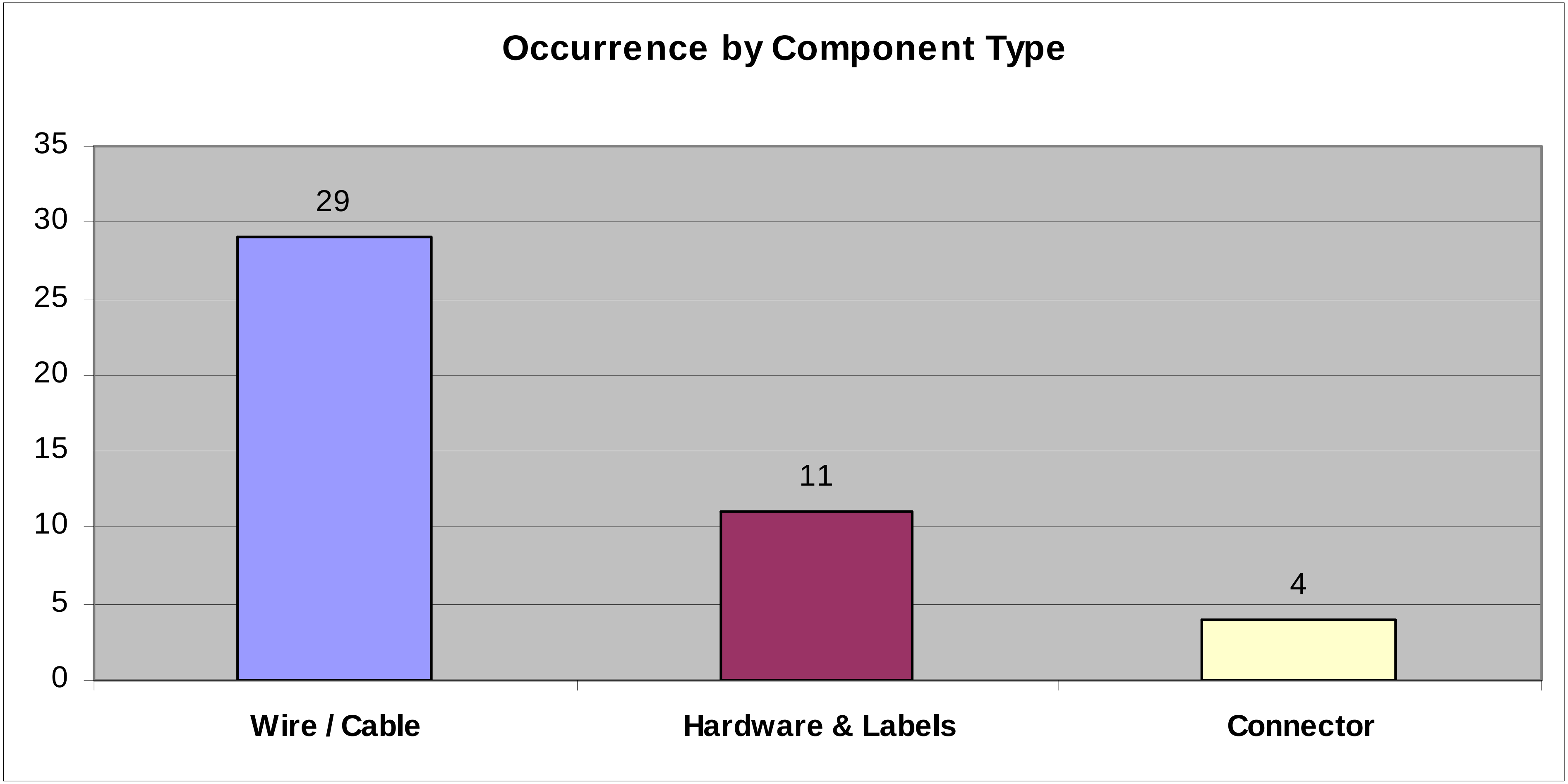
XRF Due Diligence Verification – "Trust But Verify"

- A due diligence verification program utilizing XRF technology (X-ray fluorescence analysis) should be implemented, to substantiate compliance. The deployment will provide a method for the first line of detection while collecting verification data for the compliance assurance system.
- The XRF screening program should verify key points of the process including:
  - Incoming receipt of material
  - Stockroom
  - Manufacturing process
  - Manufacturing materials
  - Completed product prior to shipment

Banned Substance Violations – Detected With XRF



Banned Substance Violations Occurrence by Component Type



Reduction of Hazardous Substances in Electronics Manufacturing - Overall Summary

• Since 2005, Benchmark Electronics has reduced the use of Lead by approximately 50% and the use of Mercury, Hexavalent Chromium, Cadmium, PBDE, and PBE by approximately 95%.

•Direct result of RoHS and / or customer's desire to be Pb-free (RoHS Compliant) and applicable conversions in the supply chain.

Additional Work

- Tin Whiskers are of concern because they can grow and cause electrical shorts and product failure
- With the transition to Lead Free, most component leads are coated with 100% Tin
- Benchmark Electronics, EMC Inc, TURI, and CALCE (University of Maryland) are investigating a new surface finish comprised of nano particles of silver dispersed in a polyaniline.
  - Eliminates the risk of Tin Whiskers
  - Reduces energy consumption, metal consumption, and waste discharge by > 95% as compared with 100% Tin
- Results will be presented at the IPC (www.ipc.org) Tin Whisker Conference December 7th in Chicago IL

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Thank You!

The authors would like to thank Greg Morose of TURI and the entire New England Lead Free Electronics Consortium for their contributions

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Be green