GC3 Green Chemistry & Commerce Council
Moving Business Toward Safer Alternatives

GC3 Webinar Series

September 11, 2013

Successful Industry Collaborations for Evaluating the Performance of Safer Chemical Alternatives

Greg Morose, Research Manager, Toxics Use Reduction Institute

Webinar Discussion Instructions

- Due to the number of participants on the Webinar, all lines will be muted.
- If you wish to ask a question, please type your question in the Q&A box located in the drop down control panel at the top of the screen
- All questions will be answered at the end of the presentation.

Successful Industry Collaborations for Evaluating the Performance of Safer Chemical Alternatives

Greg Morose
Research Manager, Toxics Use Reduction Institute
Research Professor, University of Massachusetts Lowell

Webinar Agenda

- Alternatives Assessment Overview
- Example 1: Lead-free electronics
- Example 2: Hex chrome free coatings
- Results/Benefits/Lessons Learned

What is Alternatives Assessment?

A <u>process</u> for <u>identifying</u> and <u>comparing</u> potential chemical, material, product, or other alternatives that can be used as substitutes to replace chemicals of high concern.

Goals

- Reduce risk by reducing hazard
- Move from problems to solutions
- Avoid regrettable substitutions
- Encourage transparency, common language, and documentation to communicate among stakeholders

Alternatives Assessment

EHS	Cost/ Financial	Technical/ Performance
Is it safer?	Is it affordable?	Will it work?
• Flammability? • Human toxicity? • Animal toxicity? • Ozone depletion? • Persistence? • Bioacummulative? • Etc.	• Materials? • Regulatory compliance? • Insurance? • Training? • Equipment? • Utilities/energy? • Etc.	• Process changes? • Equipment changes? • Material compatibility? • Product quality? • Produce longevity? • Customer specifications? • Etc.

TURI Conditions for Industry Collaboration

1. Use of a toxic chemical(s) of concern is pervasive in an industry sector
2. Toxic chemical is not used for competitive advantage (pre-competitive)
3. Strong market and/or regulatory drivers to reduce the use of the toxic chemical
4. Significant research required to switch to the use of safer alternatives
5. Time and cost intensive for companies to individually conduct research
6. Independent third party available to manage and coordinate the effort
7. Voluntary participation by government, academic, and industry collaborators
8. Participants provide either in-kind contributions (production equipment, technical expertise, materials, supplies, testing, etc.) or direct funding
9. Intent of participants is to adopt the safer alternative solutions identified
10. All results made public so that other companies can adopt solutions identified

Project Example 1: Lead-free Electronics 2001 – 2011

Project Example 2: Hex Chrome-free Coatings 2012 - ??

TURI Project: Lead-free Electronics

Toxic Chemical of Concern	Lead: acute & chronic health effects
Industry	Electronics products: sales of about $1 trillion each year
Use	Solder, solder paste, board surface finish, component surface finish
Volume	80 – 90 million pounds used globally on an annual basis
Driver	EU Directive: Restriction on the Use of Certain Hazardous Substances (RoHS)
Research Required	Technical performance of alternatives for assembly, rework, and long term reliability
Collaborative Research Approach	Formation of the New England Lead-free Electronics Consortium

Lead Basics – Inherent Properties

- Low melting temperature
- Conducts electricity
- Very ductile (malleable)
- Slow to corrode
- Relatively abundant and inexpensive
- High density
- Attenuation of radiation and sound
- Lead alloys and lead compounds have other useful properties

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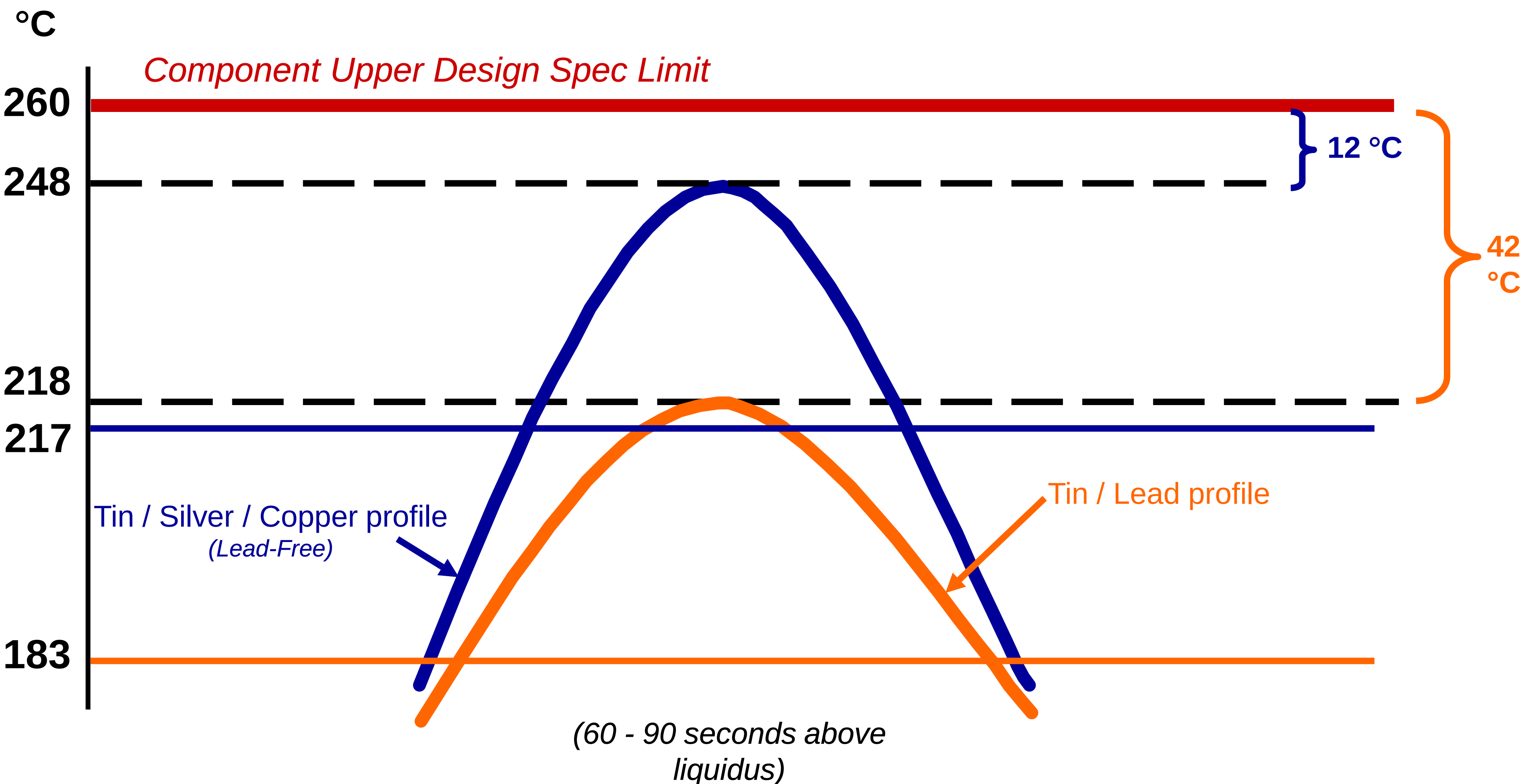
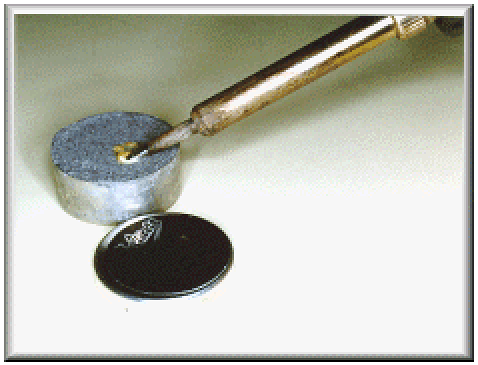
Alternatives Have Tighter Processing Window



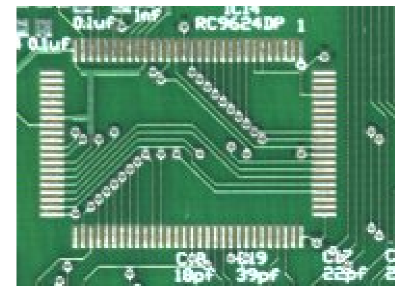
Higher thermal stresses to components and boards.

Lead-free Electronics Industry Challenges

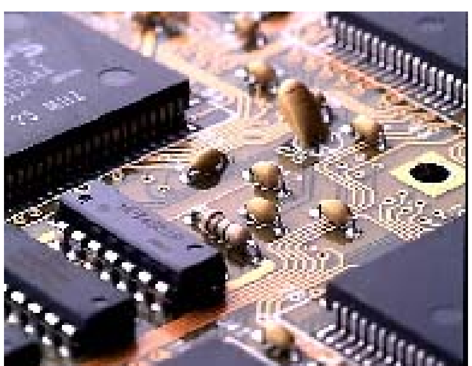
1. Which lead-free solders?



2. Which lead-free board finishes?



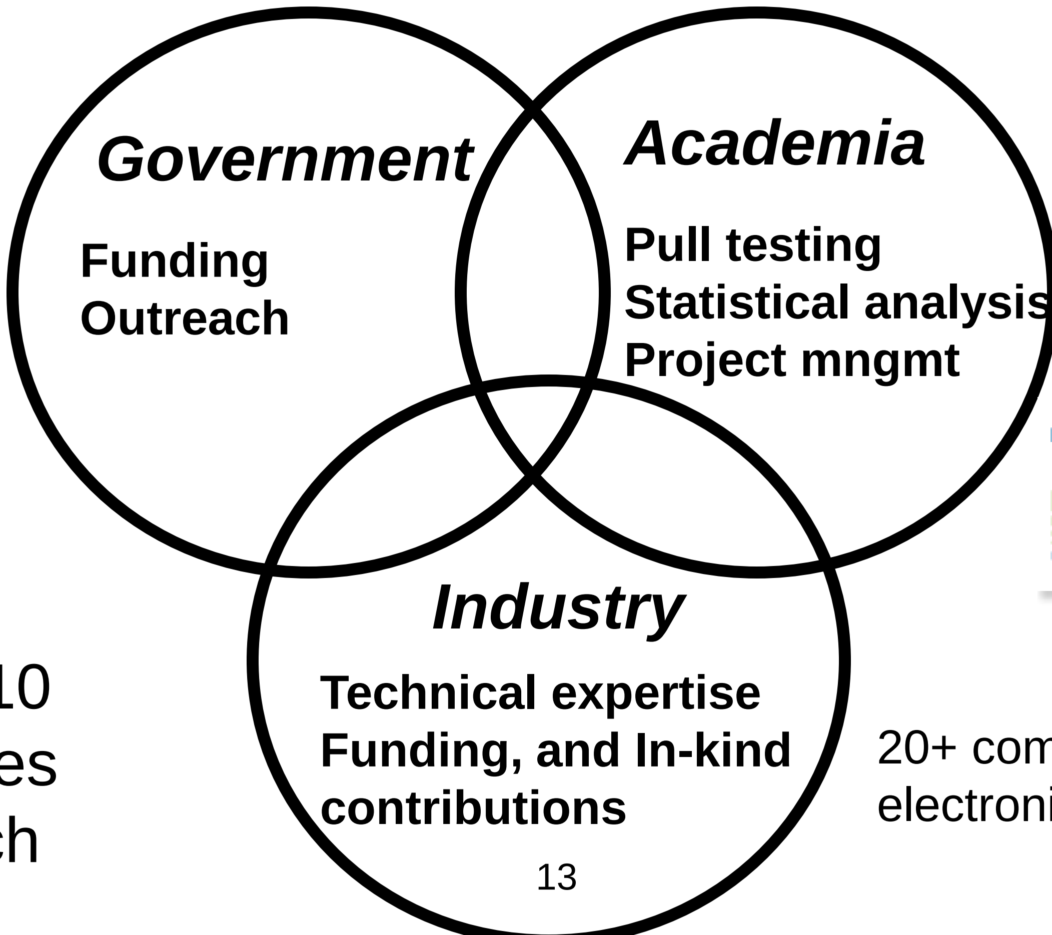
3. Which lead-free component finishes?



4. What process modifications?

New England Lead-free Electronics Consortium

$1.5 million total in direct funding and in-kind contributions



2001 – 2010
Four Phases
of Research

20+ companies in the electronics industry

Electronics Assembly Process

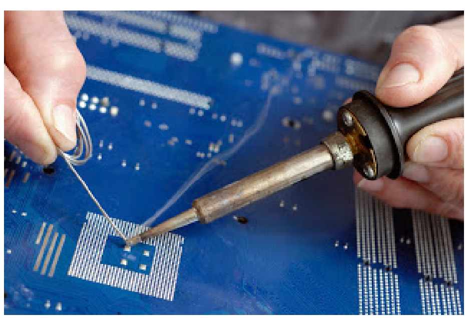
Solder Paste Printing

Component Pick & Placement

SMT Reflow Oven

THT Soldering

X-ray & Optical Inspection



Repair/rework

THT Soldering: Process Variables

Flux Process Variables
Flux type
Flux speed
Aperture opening time
Pressure
Nozzle diameter
Nozzle to board gap
Frequency (how fast the plunger is moving up and down)

Preheat Process Variables
Target temperature
Temperature delta across board
Preheat type
Preheat duration
% Power
Preheat area
Certain lamps on/off

Soldering Process Variables
Solder pot temperature
Dwell time
Wait time before dwell
Drag speed
Speed solder is pulled from board
Board drop speed to nozzle
Nozzle to board gap
Nozzle sizes
Nozzle design
Height of solder in nozzle
Solder alloy
Solder flush cycle

26 Process Variables

Factors and Levels

A factor is an independent variable that is an input to a process.

A level is a variable that constitutes different levels of a factor.

Type of Factor	Factor	Levels
Attribute data	Flux type	Vendor A, Vendor B, etc.
Continuous data	Solder Pot Temp. (degrees C)	290, 300, 310, 320, etc.

Six Sigma - DMAIC

Define

- ❑ Initiate the Project
- ❑ Define the Process
- ❑ Determine Customer Requirements
- ❑ Define Key Process Output Variables

Measure

- ❑ Understand the Process
- ❑ Evaluate Risks on Process Inputs
- ❑ Develop and Evaluate Measurement Systems
- ❑ Measure Current Process Performance

Analyze

- ❑ Analyze Data to Prioritize Key Input Variables
- ❑ Identify Waste

Improve

- ❑ Verify Critical Inputs Using Planned Experiments
- ❑ Design Improvements
- ❑ Pilot New Process (Implement)

Control

- ❑ Finalize the Control System
- ❑ Verify Long Term Capability

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Six Sigma Approach

Problem Statement

- Need to switch from lead based solders to lead-free solder materials in electronics products.

Goal

- Successfully use lead-free solder materials to achieve equivalent or better solder performance for product manufacture, repair, and longevity.

Key Process Outputs

- Manufacture: Defects per unit
- Rework: Copper dissolution
- Longevity/Reliability: Cycles to failure

Key Process Inputs

- Reflow profile, solder paste, print speed, surface finish, component finish, laminate material, etc.

Problem Solving Approach

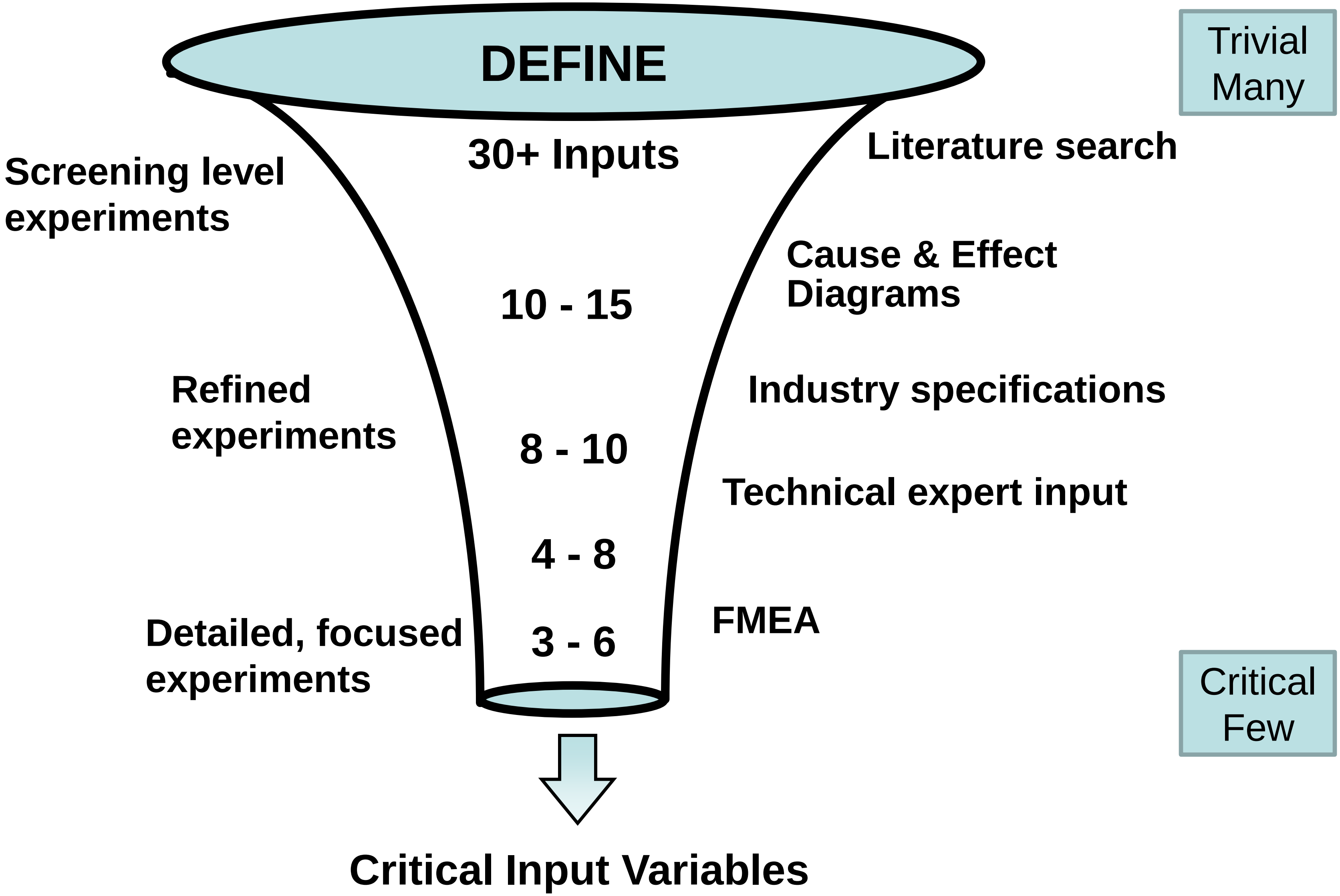
The Outputs (Y's) are determined by the Inputs (X's). If we know enough about our X's we can accurately predict Y.

$$Y = f(x_1, x_2, x_3, \ldots, x_k)$$

Solder joint integrity = (reflow profile, solder paste, print speed, surface finish, component finish, laminate material, etc.)

- Y1: Defects per unit (assembly)
- Y2: Copper dissolution (rework)
- Y3: Cycles to failure (reliability)

Determine Critical Inputs



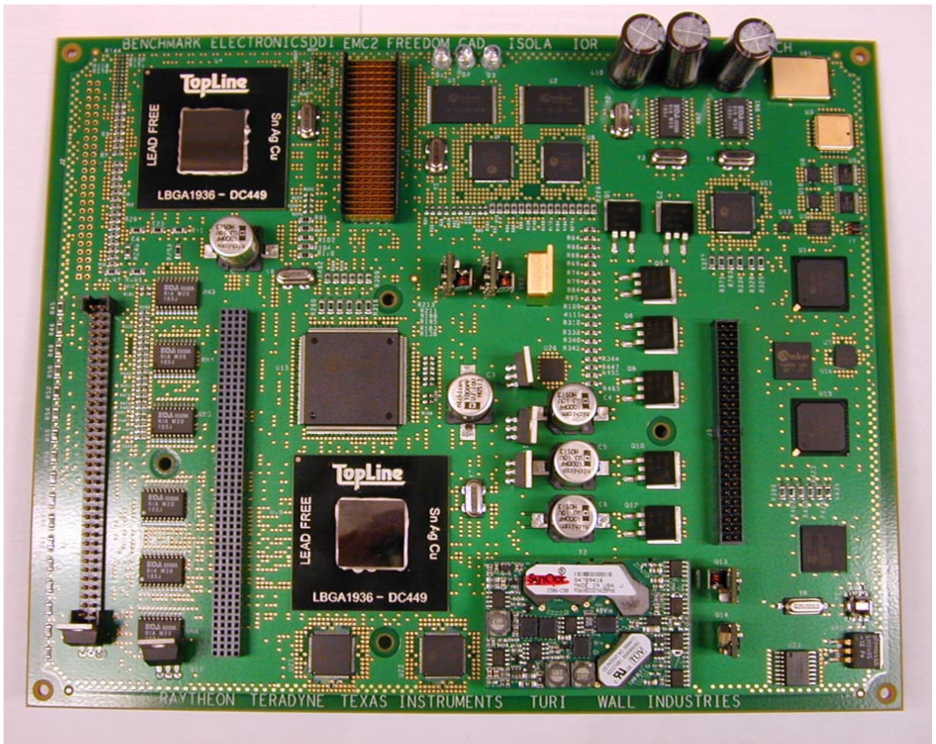
Research Overview

Phase	Test Vehicle (Experimental Printed Circuit Board)	Factors Investigated	Results
Phase One 2001 - 2002	Experimental Board: Single layer, single sided, surface mount components only, low component density.	LF solder alloys (3) Thermal profiles (2) Reflow environments (2) Surface finishes (2)	• Lead-free soldering with equal or less defects than lead soldering is possible with experimental boards. • After thermal cycling, the strength of lead-free solder joints is comparable to lead solder joints for experimental boards. • Decision to focus on tin/silver/copper alloy and a ramp to peak thermal profile for reflow processes.
Phase Two 2002 - 2004	Experimental Board: Single layer, single sided, surface mount components only, low component density.	LF Solder Alloys (1) Thermal profiles (1) Reflow environment (2) Surface finishes (5)	• Decision to focus on air only atmosphere for reflow environment. • Decision to focus on 3 printed circuit board surface finishes: ENIG, OSP, and Immersion silver.

Research Overview

Phase	Test Vehicle (Experimental Printed Circuit Board)	Factors Investigated	Results
Phase Three 2004 - 2007	Production Like Board: 20 layers, double sided, surface mount and through hole components, high component density.	LF Solder Alloys (1) Thermal profiles (1) Reflow environment (1) Surface finishes (3) Laminate materials (2)	• Lead-free soldering with equal or less defects than lead soldering is possible for production like boards. • Decision to use Isola HR370 laminate material as baseline lead-free laminate material for upcoming experiments.
Phase Four 2008 - 2011	Production Like Board: 20 layers, double sided, surface mount and through hole components, high component density.	LF Solder paste alloys (1) THT solder materials (2) Thermal profiles (1) Reflow environment (1) Surface finishes, including one with nanomaterials (4) Laminate materials including halogen and non-halogen (2)	• Successful single and double rework efforts are possible with lead-free materials that can achieve Class 3 standards without signs of thermal degradation. • Long-term reliability results of lead free materials were mixed for the various component types investigated. • The halogen-free laminate materials had early failures during thermal cycling and require reformulation before additional reliability testing.

Test Vehicle (Phase IV)



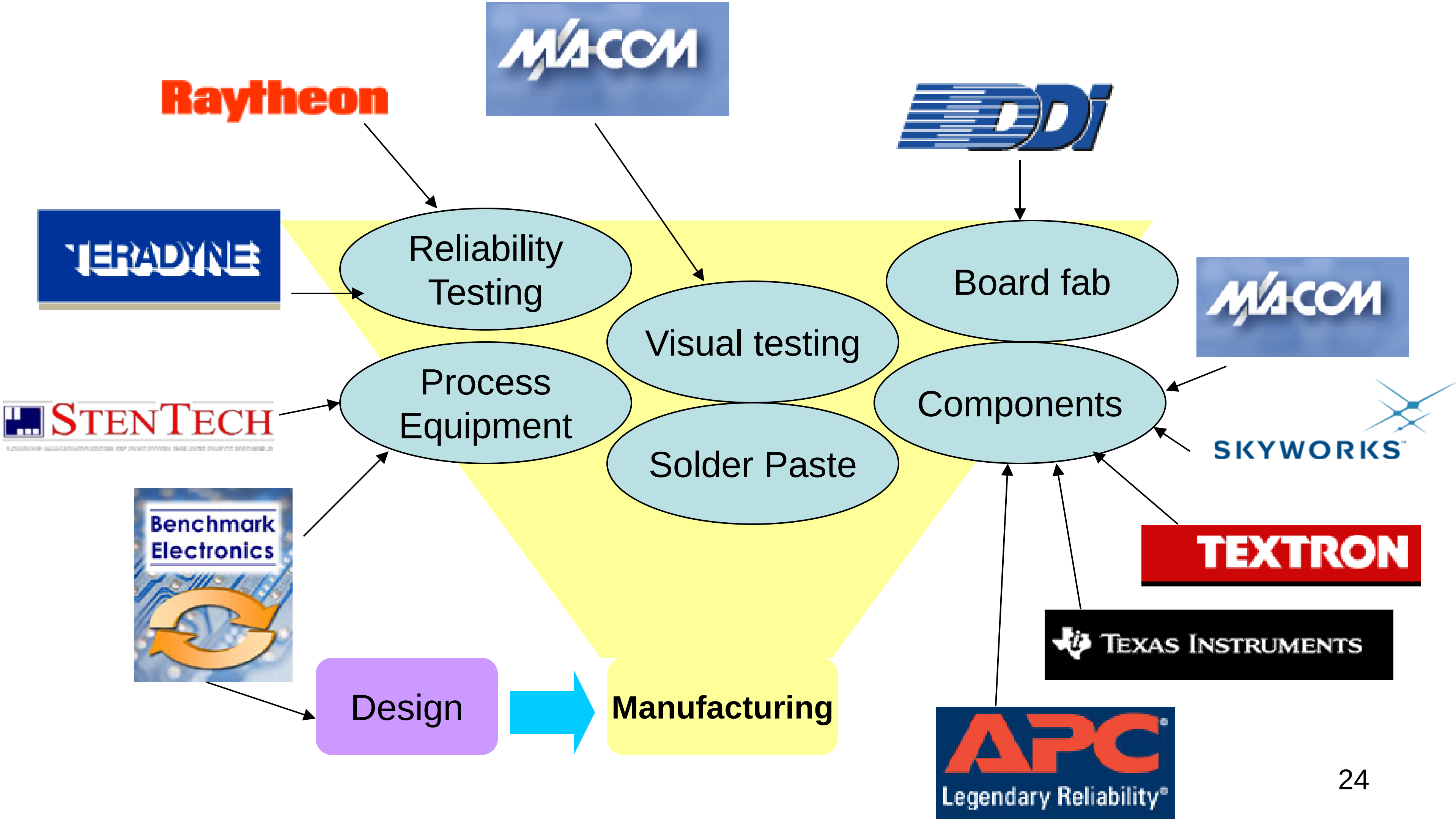
Test Vehicle

- 8” wide x 10” long
- 20 layers
- 0.110 inches thick
- 907 components per test vehicle

SMT Components:
Resistors, BGAs, microBGAs, PQFN, TSSOP, PQFP, MLF, Transformer

THT Components:
Connectors, LEDs, capacitors, DC/DC Convertors, TO220

New England Lead-free Consortium – Phase III



Consortium Communication

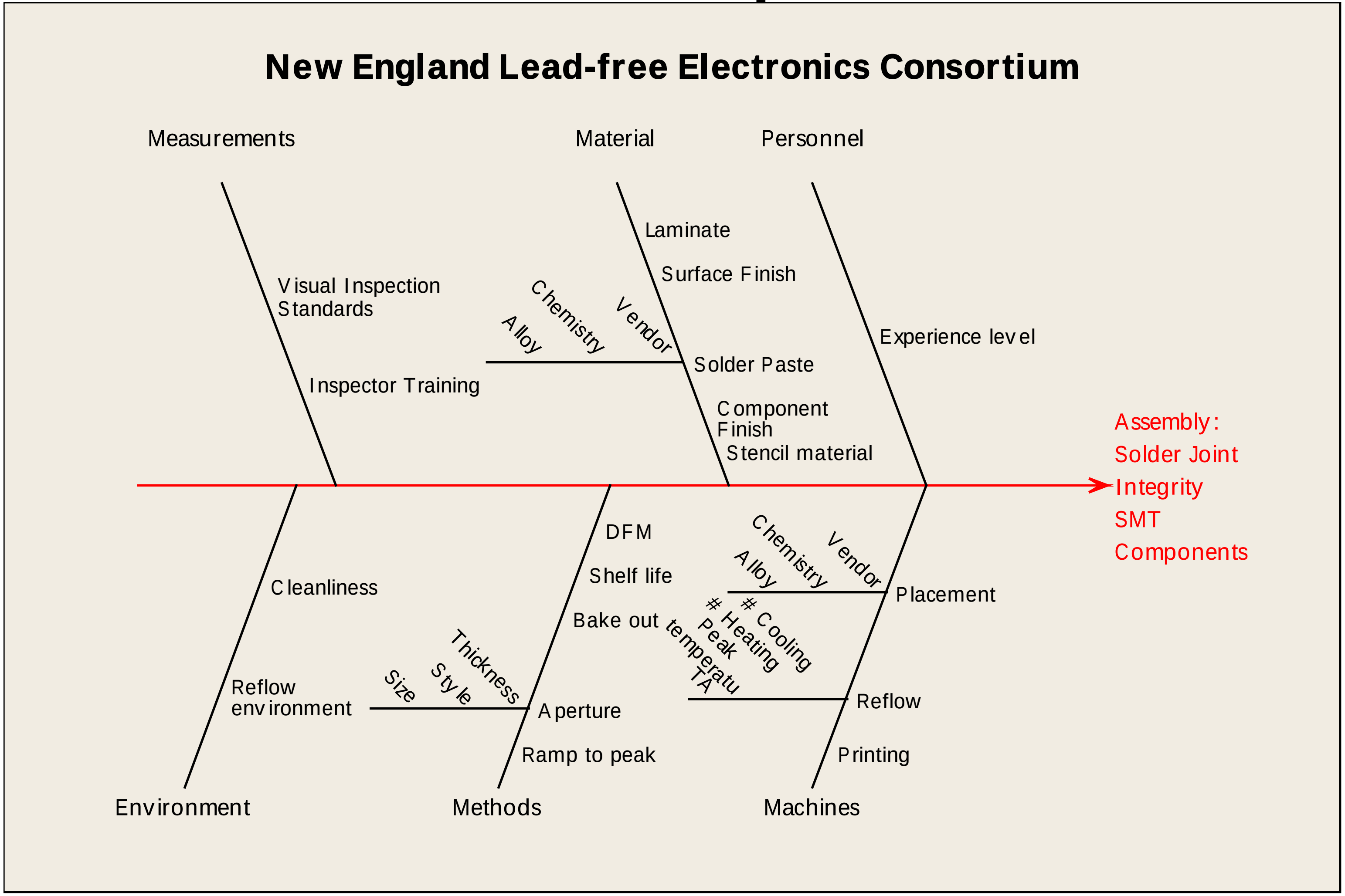
- Bimonthly consortium meetings
- Distribution of meeting materials and meeting minutes
- Workgroup documentation and presentation of results for specific issues (i.e. FMEA, board design, rework, etc.)
- Surveys, Workshops
- Develop papers for submission to electronics publications and electronics conferences
- Presentation at major electronics conferences
- Maintain consortium website

Contributions for Four Phases

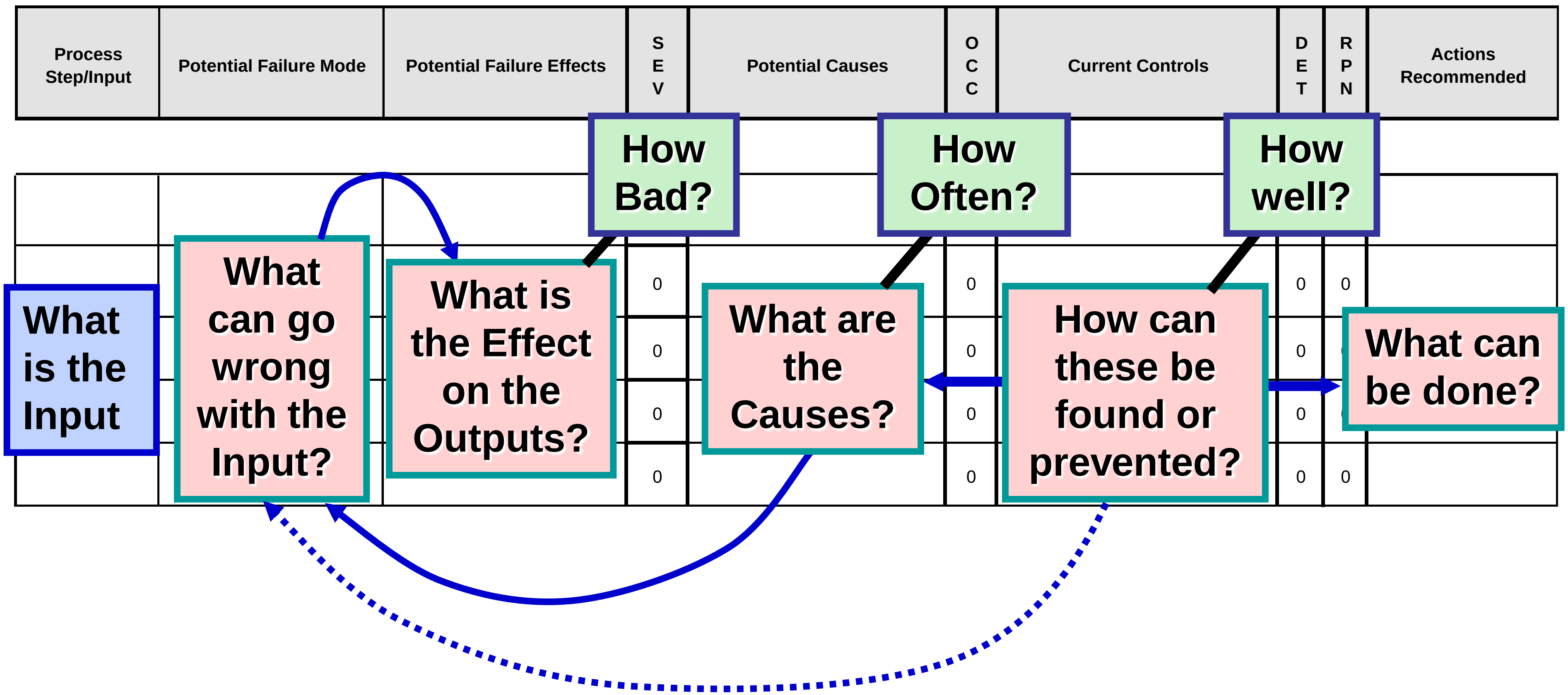
Contributions
Production equipment and technical support
Analysis and project management
U.S. EPA funding
Engineering support
Testing, inspection, and support
Components and materials

TOTAL VALUE: > $1.5 million

Cause and Effect Diagram Example



Failure Mode and Effects Analysis (FMEA)



Risk Priority Number (RPN)

- The RPN is an output of FMEA
- The RPN is used assist in the prioritization of items in the FMEA based on three characteristics
  - Severity of the Effects
  - Occurrence of the Causes
  - Detection capabilities of current Controls

RPN = Severity X Occurrence X Detection

Effects | Causes | Controls

Design of Experiments

Lead-free Test Vehicles, Boards 1 – 8 (illustrative only)

Board	SMT Solder Paste	Through Hole Solder	Surface Finish	PWB Laminate
1	Tin/lead	Tin/lead	ENIG	High Tg FR4
2	Tin/lead	Tin/lead	ENIG	High Tg FR4
3	Tin/lead	SAC305	LF HASL	High Tg FR4
4	Tin/lead	SAC305	LF HASL	High Tg FR4
5	SAC305 NC-1	Tin/Copper	OSP	Halogen free FR4
6	SAC305 NC-1	Tin/Copper	OSP	Halogen free FR4
7	SAC305 NC-1	SAC305	Nanofinish	Halogen free FR4
8	SAC305 NC-1	SAC305	Nanofinish	Halogen free FR4

Hex Chrome – Uses in Defense/Aerospace Applications

- Sealants
- Primers
- Conversion coatings

Health Effects:
- IARC Group 1 (carcinogenic to humans)
- Mutagen and developmental toxicant
- Long term inhalation can cause lung cancer, and can also result in perforation of the nasal septum and asthma.

Driver for Change:
Defense Federal Acquisition Regulation Supplement (DFARS) , May 2011

Sealant Research Overview

Research Phase	Timeframe	Purpose	Materials Evaluated
Phase I	2012	Screening level information for sealant performance	4 sealants 2 conversion coatings 2 aluminum alloys 2 primers 2 fastener types With & without topcoat
Phase II	2013	• DFARs compliance for sealants • Sealant removal evaluation	6 sealants
Phase III	2014	Totally hex chrome free stack-up: conversion coating, sealant, primer, & topcoat	To be determined

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Contributors to Phase I Research

Government

Aviation & Missile Command Safety Office

U.S. AIR FORCE

NAVAIR
NAVAL AIR SYSTEMS COMMAND

NASA

OTA
OFFICE OF TECHNICAL ASSISTANCE & TECHNOLOGY

Industry

LOCKHEED MARTIN

NORTHROP GRUMMAN

METALAST INTERNATIONAL, INC.

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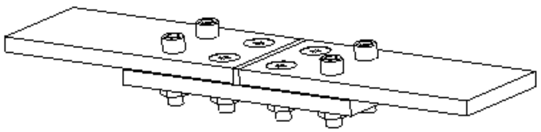
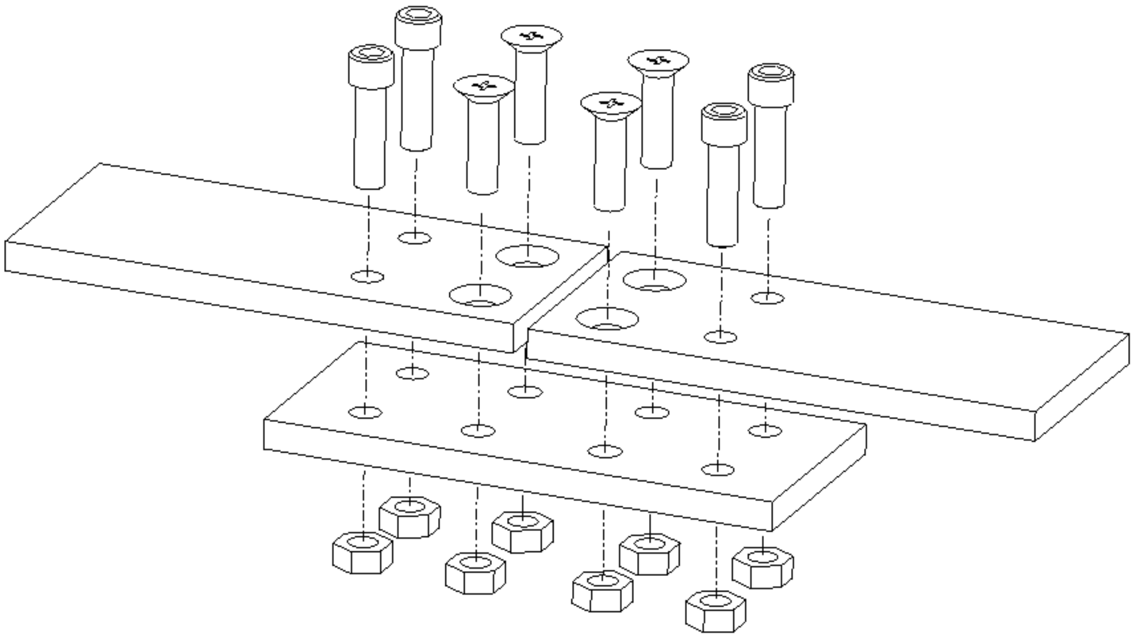
Test Vehicle Assembly Drawing

Aluminum plates: 2” x 4.5” x 0.25” (alloys 6061 and 7075)





8 stainless steel fasteners (4 with countersunk heads, and 4 with socket heads)

Lead-free Electronics:
Results, Benefits, and Lessons Learned

Collaborative Research Results

Successful Research Results	Demonstrated that electronics assembly & rework with lead-free materials can be done with equal or fewer defects than lead.
Adoption of Safer Materials	Consortium members were able to initiated their own lead-free electronics programs. For example, Benchmark Electronics has now manufactured approximately 9 million lead-free printed circuit boards to date.
Outreach	Published and presented the results of research efforts widely, including more than 40 papers, articles, and presentations for national and international professional conferences and technical journals.

University Member Benefits

Forged collaborative relationships between university and regional businesses that have led to additional UML research projects.

Increased university faculty experience in applied science and engineering.

Hands on laboratory efforts for real world learning and research experience.

Faculty/Student presentations at industry conferences.

Government Member Benefits

Government

Reduced the use of a toxic material (lead) which leads to a safer occupational setting and an improved environment.

Improved the competitive position of local businesses by addressing industry challenges in a proactive and efficient manner.

Industry Member Benefits

Industry

Ability to have input and influence on consortium efforts (e.g. material selection, supplier selection, testing strategies, etc.).

Access to cutting edge research and analysis.

Ability to share the costs to address a major industry challenge.

Forum provided to share ideas and receive advice from industry peers.

Ability to derive competitive advantage for early preparedness.

Individual: Become a knowledge leader within organization.

TURI Collaborations: Key Success Factors

- **Standards**: Adopt relevant standards when feasible (performance, testing, inspection, etc.). Deviate from relevant standards when necessary (with justification).
- **Methodology**: Use Six Sigma DMAIC process and tools as appropriate.
- **Value**: Want value received from participation in consortium to be greater than the cost of participation
- **Transparency**: All members involved in decisions. Evaluation results are documented and become publicly available.
- **Balance:** Identify intersection/overlap of research interests among participants. Don't allow individual participants to dominate the direction of the group.
- **Responsiveness:** Timely response to participant inquiries and concerns.
- **Communication**: Not too much (be respectful of people's time), and not too little (keep them informed of major decisions and milestones).
- **Detailed analysis:** Work out details with assigned subgroups, and present results and decisions to entire group.

The audio recording and slides shown during this presentation will be available to GC3 Members on the GC3 Website:
http://www.greenchemistryandcommerce.org

Non- GC3 Member Attendees who would like to view these slides please contact Sarah Shields at sarah_shields@uml.edu

Upcoming GC3 Webinars

Successes and Lessons from a Serial Green Chemistry Innovator

-Kaichang Li, Professor, Oregon State University
-Tuesday, September 17, 2013
-2pm Eastern/11am Pacific

Accelerating Commercialization of Green Chemistry Technologies at GreenCentre Canada

-Rui Resendes, Executive Director, GreenCentre Canada
-Tuesday, October 8, 2013
-2pm Eastern/11am Pacific