Cross-Functional Environmental Initiatives: Addressing Restriction of Hazardous Substance (RoHS) Technical Challenges at Sun Microsystems

by

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Submitted to the Department of Civil and Environmental Engineering and the Sloan School of Management in Partial Fulfillment of the Requirements for the Degrees of

Master of Science in Civil and Environmental Engineering and
Master of Business Administration

In Conjunction with the Leaders for Manufacturing Program at the
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Abstract

The European Union (EU) passed the Restriction of Hazardous Substances (RoHS) Directive, effective January 2006, banning the sale of electronics equipment containing lead and five other hazardous substances into EU countries. The RoHS Directive is driving an accelerated transition to lead-free technology and products across the electronics industry. Lead is commonly used in component finishes and is a key material in the solder process used to attach components to printed circuit boards. Lead-free technical challenges include implementing significant changes in component plating and circuit board assembly. Although the industry has collaborated to produce viable technical options, various lead-free solutions have trade-offs among cost, reliability, and short-term availability.

Given regulatory deadlines and potential loss of EU sales, Sun and others in the electronics industry are impelled to make material and process changes based on less data and information than they would typically act on. Sun's RoHS technical team was staffed from the Central Engineering group and developed RoHS specifications that go beyond basic compliance in order to address known lead-free reliability issues. However, lead-free requirements included in RoHS technical specifications have significant supply chain implications with respect to cost, operations, and strategy in addition to reliability impact. The technical team has the capacity to address general lead-free technology and engineering challenges, but it is not staffed to conduct broader business impact analyses.

Industry supply base readiness varies widely; not all suppliers will meet RoHS deadlines and related Sun specifications. Product reliability and cost targets vary, but components and suppliers are common to a range of products. The technical team has experienced supplier and product group push-back in response to certain reliability-driven lead-free requirements. The question of whether Sun's reliability-driven requirements should be implemented uniformly across all products has been raised. In order to address this question and support informed decisions during the transition to lead-free, the team needed to consider the broader business and operations context as well as summarize and communicate relevant technical information. This involved thinking about the impact of RoHS specifications from an operations perspective, assessing relevant industry capability and trends, considering specification modifications or alternatives that would facilitate near term implementation, and considering alignment with longer term supply chain strategy.

Additionally, challenges facing the technical team highlight two ways in which the RoHS Directive is setting a precedent in the electronics industry. First, RoHS is an environmental initiative driving significant change across the industry value chain. This raises both tactical issues of how to coordinate and maintain industry consistency and efficiency, and strategic questions of when to collaborate vs. where competitive advantage may be gained. Second, within each company, RoHS impacts virtually all functional groups and cannot be implemented without broad coordination and effort. While this is similar to non-environmental cross-functional initiatives, most companies have not dedicated resources to environmental strategy and planning, nor have they integrated environmental issues into existing functions. Thus the capability to (a) strategically assess environmental activity as an investment with potential returns, (b) proactively drive tactical environmental programs, and (c) make meaningful progress on environmental and social issues is insufficient, contributing to the firefighting nature of RoHS activity and criticism of Corporate Social Responsibility (CSR) programs. The RoHS initiative illustrates the case for investing resources in forward looking corporate environmental planning and strategy.

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Chapter 1: Introduction and Overview of Project

The content in this thesis was developed during an internship at Sun Microsystems in Menlo Park, CA. The bulk of the work addressed specific technical challenges related to removing lead from Sun products in response to European Union legislation. Project results may help address near term lead-free transition challenges by considering implementation of reliability-driven lead-free requirements from an operations perspective. However, the thesis also considers the benefits of dedicating resources to develop Sun's corporate environmental strategy. Specifically, it outlines the need for internal capability to develop a critical forward looking value proposition to guide investment in corporate environmental and social activity, effectively drive cost-effective cross-functional environmental initiatives, and align corporate environmental strategy with Sun's broader strategy.

1.1 Project Description

Project Context

The European Union (EU) passed the Restriction of Hazardous Substances (RoHS) Directive, effective July 2006, banning the sale of electronics equipment containing lead(Pb) and five other hazardous substances into EU countries. The RoHS Directive is driving an accelerated transition to lead-free technology and products across the electronics industry. Sun's RoHS technical team has worked with industry consortia groups to develop lead-free standards and specifications that go beyond mere compliance in order to address reliability issues associated with the transition to new and unproven lead-free materials and technology.[1] Sun will rely on contract manufacturers and component suppliers to meet these reliability-driven lead-free requirements in order to maintain product quality.

Several key lead-free technical challenges have been resolved with the industry converging on common solutions. This thesis focuses on two technical issues where a potential gap between customer expectations and supplier activity remains:

1. *Tin whisker mitigation by component suppliers*: The term 'tin whisker' refers to the phenomena of needle-like growths of tin observed on components with pure tin plated lead

[1] The RoHS Directive bans five materials. This paper focuses on two technical challenges associated with the elimination of lead, thus the term lead-free is used throughout. Sun's RoHS initiative is addressing all banned materials.

frames[2]. Tin whiskers may grow long enough to bridge adjacent component leads and cause component failure or break off and cause failures as conductive debris.

2. *Solder joint reliability (SJR) testing by contract manufacturers*: Lead-free solder joints use a new solder alloy with a higher melting temperature; therefore, historical reliability data is not representative of the modified lead-free process.

Challenges and Supporting Informed Decisions

Regulatory deadlines and potential loss of EU sales are impelling Sun and others in the electronics industry to make material and process changes based on less data and information than they would typically act on. Thus far, the technical team has developed RoHS technical specifications with the goal that Sun's quality and reliability not be adversely impacted by the transition. Sun's RoHS specifications and supplier readiness efforts include reliability-driven requirements addressing both tin whiskers and solder joint reliability. Sun's RoHS Supplier Readiness team has implemented a comprehensive program to communicate Sun's requirements and monitor supplier progress.

However, lead-free requirements included in RoHS technical specifications have significant supply chain implications with respect to cost, operations, and strategy in addition to reliability impact. Despite Sun and industry-wide efforts to address remaining gaps, there will be a transition 'crunch time' with technical challenges[3] including component reliability and a lead-free solder learning curve. Industry supply base readiness varies widely; not all suppliers will meet basic RoHS compliance deadlines and even fewer will satisfy reliability-driven lead-free requirements. Although Sun's RoHS teams are working to identify and resolve supplier constraints, it is likely that Sun will be faced with situations where they will be forced to reconcile procurement and production demands with lead-free reliability concerns. This raises questions of business priorities, risk management, and product requirements that are much more involved than the reliability issues that the technical team has been asked to address. Specifically, the RoHS teams are facing the following questions:

1. Are Sun's reliability-driven lead-free requirements reasonable and consistent with industry practices? If not, what modifications could the technical team make to RoHS specifications

[2] The word lead refers to both the element lead and the component 'leads' or pins that are used to attach the component to the printed circuit board. When referring to the element, lead will be noted as lead(Pb) or used in a term such as lead-free.

[3] This paper covers technical related issues only. Significant logistics, IT, and communication challenges are also being

and supplier requirements?

2. Should these requirements be implemented and enforced uniformly across all Sun products? What information is needed to support product group decisions with respect to reliability-driven lead-free requirements? Is there a break between consumer and mid to high reliability products?

3. Can Sun benefit by being a smart follower without taking unacceptable reliability or compliance risks?

The internship focused on identifying and communicating relevant technical information, articulating reliability risks, quantifying risks where possible, and gathering non-technical market, supplier, and competitor information needed to answer these questions and support decisions on reliability-driven lead-free requirements.

Project Structure

In anticipation of the above questions the following topics were researched and summarized as they pertain to tin whisker mitigation and solder joint reliability testing requirements:

Risks of Not Meeting Reliability-Driven Requirements

Cost to Meet Reliability-Driven Requirements

- Supplier costs to meet reliability driven requirements (relative to bare minimum RoHS compliance costs).
- Transfer of costs to Sun and other OEMs.

Supplier Activity and Status

- Supplier ability to meet reliability driven requirements.
- Drivers of remaining technical gaps.

Competitor Strategy and Activity

- Consistency of Sun and competitor specifications.
- Implementation methods and status.

Where possible data has been compiled and quantified. However, due to the firefighting nature of industry and corporate RoHS efforts, in depth analysis on related costs, risks, and supply base

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addressed by Sun's RoHS teams.

status is largely absent. Therefore, the analysis and recommendations in this thesis are based on RoHS technical team assumptions, observations of industry trends, review of recent papers and conference proceedings, and most importantly, discussions with competitors, suppliers, and Sun managers.

Proactively Addressing Potential Component Shortages

Given initial findings on potential shortages of components that meet tin whisker mitigation requirements, the paper also evaluates two methods used by Sun competitors to proactively address potential shortages:

- HP has developed different tin whisker mitigation requirements for consumer products vs. mid to high reliability products.
- IBM has developed tin whisker mitigation requirements for components with large lead spacing vs. fine pitch components.

Each method was considered with respect to alleviation of potential component shortages, related reliability risks, implementation feasibility, and alignment with operations strategy.

Corporate Environmental Strategy

RoHS is the first of several environmental regulations that will drive significant industry change and corporate investment in cross-functional environmental initiatives. Additionally, there is a great deal of discussion and activity around sustainability and corporate responsibility. This thesis considers the business case to invest in development of a corporate environmental strategy by providing a framework to think about Sun's current position and opportunities to learn from industry first movers. It argues that rather than blindly playing catch-up, Sun should *develop a meaningful value proposition based on traditional business incentives to guide environmental strategy and investment.*

Examples from the RoHS Directive and competitor corporate social responsibility and sustainability programs are used to illustrate the:

- Need to supplement specialized environmental and compliance knowledge with an understanding of core strategy and operations.
- Benefits of aligning (1) tactical responses to environmental legislation with core operations, and (2) longer term environmental strategy with core strategy.

- Opportunity to reduce future costs and risks associated with regulatory-driven activity and improve returns on voluntary investment in Corporate Social Responsibility (CSR) activity or sustainability programs.

1.2 Overview of Remaining Chapters

Chapter 2 provides a brief overview of the electronics industry as it relates to RoHS implementation and corporate environmental strategy. Chapter 3 covers RoHS basics, non-technical implementation challenges, and two specific lead-free technical challenges, tin whiskers and solder joint reliability. Chapter 4 comments on Sun's Organizational structure and culture as it relates to RoHS and cross-functional initiatives. Background on project motivation and development is provided in Chapter 5.

Chapter 6 contains the meat of the internship project content, including detailed analyses and findings. Broader corporate environmental strategy issues are considered in Chapter 7. Finally, recommendations are summarized in Chapter 8.

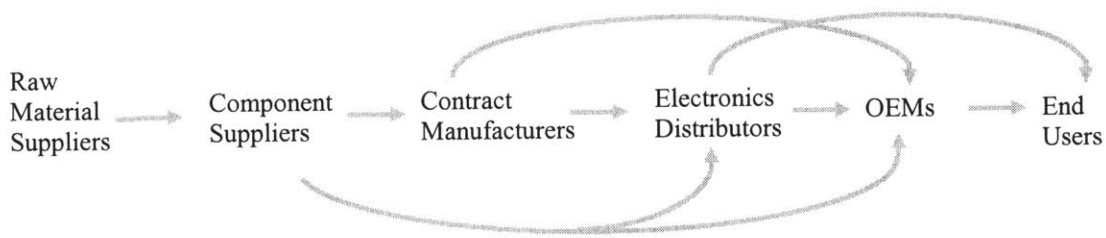
Chapter 2 Electronics Industry Context

This chapter provides a brief overview of the electronics industry as it relates to RoHS implementation and corporate environmental strategy.

2.1 Industry Complexity

Sun is part of a complex industry value chain that extends from raw material suppliers to end-market users.

Figure 1: Electronics Industry Value Chain[4]



The following factors contribute to industry value chain complexity and RoHS implementation challenges:

Global supply chains and markets: The industry is global from both a supply chain and end market perspective. Companies range from local manufacturers to multinational distributors and branded OEMs selling products globally.

Horizontal supply chain: The industry has evolved to be horizontally integrated with specialized component suppliers operating on one tier and contract manufacturers at another tier. The supply chain for a single product typically includes many suppliers and several supply tiers.

Standard Materials and Processes: Components from most suppliers can be utilized by most assemblers and contract manufacturers, i.e. the supply base utilizes standard, compatible materials and processes increasing procurement options and enabling industry competition and efficiency.

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[4] Based on Figure in Adexa report: The Electronics Supply Chain: Winning in a Virtual Environment

Rapid product innovation and market evolution: This industry has a high clockspeed.[5] Technology evolves rapidly to better meet customer needs and create new applications and markets.

Supply chain overlap between end users: End users range from consumer product and personal computer customers to military and aero / astro customers, with telecom, mission critical computing, and industrial customers dispersed between. Requirements for reliability, availability, and service (RAS) vary dramatically. However, suppliers and parts may be common across a range of end users.

Increasing cost pressure and limited technical resources: Despite demand for advanced technology and new generation products, cost pressure is increasing in almost all end user markets. Consumer markets drove the initial demand for low cost products, thus the need for cost-effective operations. However, cost pressure in mid to high reliability markets is also increasing. Cost pressure contributes to elimination of internal engineering and technical resources.

Commoditization and convergence of component supply chain: Technology and process control advances and competition have lead to commoditization of many component types, particularly passive components such as resistors and capacitors. Manufacturing quality and consistency have improved in low cost markets with consumer grade components increasingly satisfying mid to high reliability requirements. Although not all component suppliers meet high reliability customer needs, commodity component markets continue to converge with respect to end users. Basically, component suppliers can currently deliver high quality components at low cost due to industry experience and evolution.

Hardware redundancy and software capability:[6] Figure 2 shows that in addition to better component quality and consistency, increased hardware redundancy and software capability allow manufacturers to meet mid to high reliability product RAS requirements at lower costs. Hardware modularity and redundancy is driving greater part commonality across consumer and mid to high reliability products.

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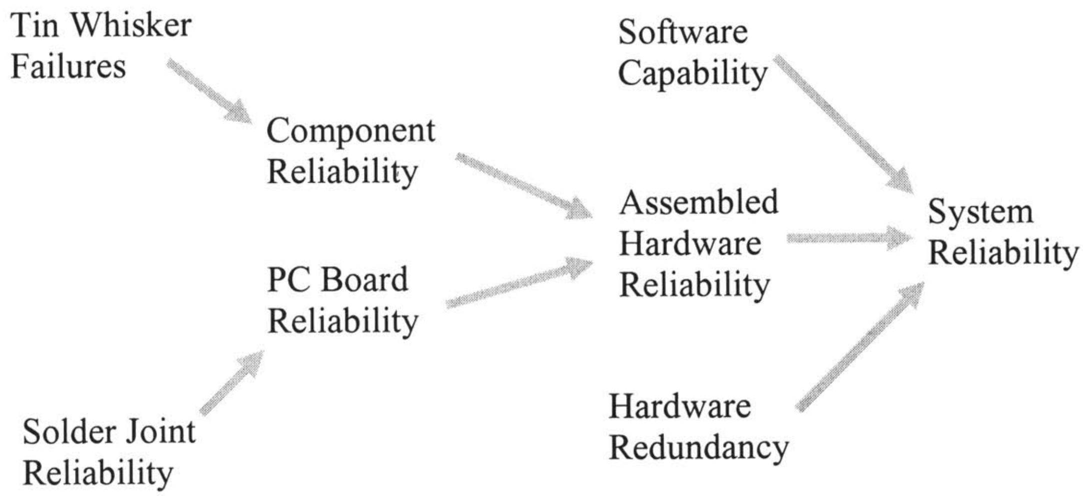
[5] The term 'clockspeed' is used by Charlie Fine to describe how quickly an industry evolves and changes in his book by the same name.

[6] Based on discussion with a Director in Sun's Procurement Strategy (PROST) group.

Figure 2: System Reliability Factors

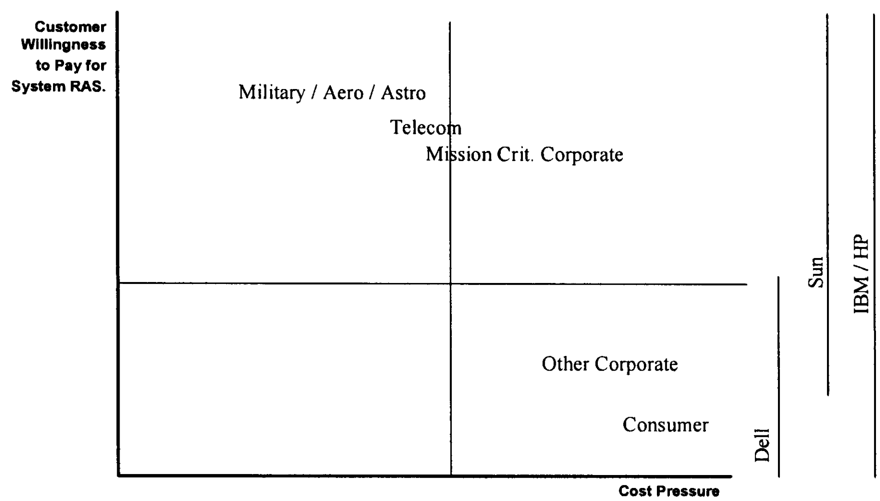


Competition among contract manufacturers (CMs): Cost pressure has also impacted contract manufacturers; however, the CM market segment is growing rapidly as CMs take on a broader scope of manufacturing and product development services. Bottom line cost is important, but recognition of total value provided allows CMs to differentiate on more than cost. Component supply chains are converging with respect to end user, but CMs develop capability to target specific end users and may increase margins by meeting mid to high reliability customer needs.

2.2 Sun Market Position

Industry evolution has forced large OEMs such as HP, IBM, Sun and Dell to adjust product and service offerings. As expected, there are both benefits and costs associated with spanning a wide range of end user markets. Figure 2 is a simplified illustration of Sun's position relative to their primary competitors. Competitor offerings are evolving. For example IBM is divesting consumer divisions and Dell is expanding into mid to high reliability markets. Sun currently spans the personal computer to high reliability markets with a focus on mid to high reliability markets.

Figure 3: Sun and Competitor Position Relative to End Markets Served



2.3 Key Industry Trends

This section outlines three trends related to RoHS implementation and broader environmental strategy.

Evolution from Hardware and System Sales to Solution and Service Provider: Historically, corporate customers were highly knowledgeable professionals who selected, installed, and maintained hardware and system options they wished to utilize at their organization. IBM, Sun and others began to expand their offerings to include more installation, customization, and maintenance services. OEM strategies vary, but there is an increasing focus on providing customized solutions and potentially data management and other business process services.

Utility Computing: Sun and industry competitors are taking steps to shift from selling products to providing services. Providing 'pay as you use' computing services, often referred to as utility computing based on similarities to electrical or water utility services, represents a major step in this shift from products to services. Utility computing would involve centralized computing capacity being accessed remotely by users eliminating the need for local processing and storage capability. The SunRay™ system[7] could be considered a precursor to larger, remote utility computing systems. According to Scott McNealy,[8] related technological challenges are being addressed and user acceptance and privacy concerns are likely to pose a more significant challenge.

Environmental Legislation in the Electronics Industry: Sun's former Environmental Health and Safety manager described the electronics industry as "having a target painted on its back" with respect to new environmental regulatory requirements.[9] RoHS is the first of many environmental regulations driving fundamental change in the electronics industry. Electronics waste or 'e-waste' is a very visible and growing wastestream produced by high profile branded companies. Regulatory trends include further materials / content restrictions and labeling, product end of life requirements, and energy efficiency standards. Basically, current regulatory trends require a response that is well beyond the scope of historical environmental compliance efforts. New legislation impacts materials selection, product design, supplier management, and customer relationships and cannot be managed by a traditional Environmental Health and Safety (EHS) group.

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[7] SunRays are desktop terminals that replace personal computers by allowing users to access a central on site server.
[8] Scott McNealy addressed Sun's summer interns on 8/17/04.
[9] 7/1/04 discussion with Sun's former Sun EHS Director

Chapter 3: Restriction of Hazardous Substances (RoHS) Background

This chapter will cover RoHS basics, non-technical implementation challenges, and two specific lead-free technical challenges, tin whiskers and solder joint reliability. None of these challenges are unique to Sun.

3.1 Legislation Basics

3.1.1 Legislation Content

The European Union (EU) enacted the Restriction of Hazardous Substances (RoHS) Directive in February of 2003. The Directive will be enforced in January of 2006. RoHS bans the sale of electrical and electronic equipment (EEE) in any EU nation if the product contains any of the following materials above the maximum concentration by weight (in parentheses):

- Lead (0.1%)
- Mercury (0.1%)
- Hexavalent Chromium (0.1%)
- Cadmium (0.01%)
- Certain Brominated flame retardants (0.1%)

The Directive includes several exemptions such as mercury in fluorescent lamps and lead in glass of cathode ray tubes. Some exceptions are intended to be permanent. A temporary exemption for lead in solder in server and storage arrays is in place until 2010. This exemption is intended to address lead-free solder reliability concerns and may be eliminated earlier if it is deemed that lead-free solder performance is acceptable.

Each of the 25 EU nations was tasked with passing a version of the Directive including details on enforcement, labeling, and reporting requirements by August 2004; however very few countries have done so to date.

3.1.2 RoHS Directive Motivation

The RoHS Directive is part of a broader legislative effort intended to address the health and environmental risks associated with waste electrical and electronic equipment (WEEE). Specifically lead and the other restricted materials were deemed to pose significant health and environmental risks if not handled and disposed of appropriately. Additionally, elimination of restricted materials was intended to facilitate recycling of end of life products. End of life or extended producer responsibility legislation was passed in parallel as the WEEE Directive.

3.1.3 Industry Opposition and Response

The RoHS Directive, particularly the restriction of lead, was opposed by many industry groups and companies. Enactment was delayed several times in response to questions raised by groups opposing RoHS. Opposition typically followed one of three themes:

1. Removing lead from electronic equipment posed insurmountable technical challenges.

2. The amount of lead contained in electrical and electronic equipment is not significant relative to other industries and wastestreams. Properly managed, the health and environmental risks posed by lead in electronics could be negligible.

3. The environmental benefits of removing lead from electrical and electronic equipment are questionable. At best, the cost-benefit from an environmental perspective of removing lead is low. Resources spent to remove lead could have greater environmental benefits elsewhere. At worst, substitute materials and processes will have a more severe environmental impact than existing practices using lead.

This thesis will not cover the validity of the opposing statements. However, in response to the first issue, although several lead-free solutions pose performance and reliability challenges, there are no 'showstoppers' from a technical standpoint.

The second and third issues are likely to be considered in future policy evaluation and discussion, but are moot with respect to RoHS enforcement and the industry transition to lead-free products. Potential loss of EU sales combined with similar lead-free legislation proposals in China and two U.S. states have provided sufficient motivation for the industry to take steps to meet RoHS requirements. No major industry player plans to ignore RoHS or continue to produce only lead containing products.[10] As Dave Love, Sun's RoHS technical team leader explains, "Folks, this train has left the station."

[10] Some companies will continue to provide lead containing parts for military customers or other customers outside of the EU. Military customers have expressed concern that lead containing parts will no longer be available and they will be forced to utilize lead-free parts.

3.2 Non-Technical Challenges[11]

Many individuals involved with RoHS implementation at Sun and other companies express the view that the technical challenges involved with RoHS are less challenging than other implementation challenges. *These challenges are not unique to Sun* and many of them are being addressed collaboratively through industry consortia and trade groups and partnerships. This section will briefly discuss some of these challenges to illustrate the complexity of RoHS as a cross-functional initiative.

3.2.1 Political

Ambiguity and Timing of Clarification: The scope of the RoHS Directive is narrow and the document itself is brief. However, lack of explanation of a few key terms present significant interpretation challenges. For example, the Directive specifies that any homogenous material meet the maximum concentration by weight restrictions. Depending on how you interpret 'homogenous material', the use of low concentrations of lead in component plating materials may be acceptable. Also, how a 'server' is defined will determine whether the server and storage array exemption for lead in solder would apply. These questions were raised soon after the Directive was enacted in February 2003. Clarification of some issues has been provided over the past year; however, the industry was forced to act on assumptions in order to meet RoHS deadlines. Sun's RoHS Program Management office and technical team made accurate assumptions for most issues, but outstanding questions made early stage communication and implementation difficult and risky.

Compliance Verification: Given that each EU nation was asked to "bring into force the laws, regulations and administrative provisions necessary to comply with this Directive"[12] and that most nations have not yet done so, companies do not know how they will verify compliance. This leaves many significant questions with respect to data management and reporting needs. Additionally, compliance reporting and verification requirements may vary by location. Again, the industry has been forced to act on assumptions in order to move forward with RoHS implementation.

Opposition and Delays – 'Cry Wolf' Response: As discussed in Section 3.1.3, RoHS legislation was delayed and opposed. This led many to wonder if the Directive would indeed be passed and enforced and may have slowed management response when the Directive was actually enacted.

[11] This section covers challenges that extend across the industry. Chapter 4 includes internal organizational challenges specific to Sun.
[12] Article 9 of the RoHS Directive.

The difficulty and political challenges associated with enactment of significant legislation are not surprising, but they do increase implementation risks and costs. One RoHS manager explained, "...lack of uniform implementation of the legislation and significant degree of legal ambiguity make it very difficult to assess how to comply."[13]

3.2.3 Supply Chain Management

Communicate Requirements to Multiple Tiers of Suppliers: The industry value chain is complex. Most electronic product supply chains involve hundreds of suppliers organized in multiple tiers. RoHS requirements must be communicated to all suppliers. Sun's contract manufacturers (CMs) and upper tier suppliers vary in their ability to manage and communicate with lower tier suppliers. Lower tier suppliers may be smaller firms with limited data management or technical resources. Processes to 'push' information to all suppliers (beyond CMs and upper tier suppliers) are not firmly established.

Determining Supplier Status and Part Availability: Similarly, Sun must evaluate each part included in a product Bill of Material (BOM) in order to determine if a RoHS compliant part will be available or if the product will need to be redesigned. Pulling this information from the supply base further highlights the lack of existing processes to communicate with lower tier suppliers. Perhaps more importantly, most suppliers have not yet fully evaluated their products with respect to RoHS compliance. An industry manager explains "....not all component suppliers are ready for the changeover. Customers are saying, 'We're buying 300 different products from you. Which ones are in compliance and which ones aren't?' And instead of giving a clear answer, some suppliers are saying, 'Were working on it.'"[14]

Enforcing Evolving Requirements: Sun has developed and communicated RoHS supplier specifications that are consistent with consortia group, i.e. competitor requirements and emerging standards. However, some of the requirements are subject to change as interpretation of legislation and lead-free technical understanding improves. Therefore, despite fixed RoHS deadlines, suppliers with limited resources dedicated to understanding RoHS issues may be reluctant to take action based on requirements that are perceived as interim.

3.2.2 Operations / Logistics

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[13] Steve Bush summary of roundtable debate

Data Management: In addition to supply chain complexity and communication challenges, RoHS poses significant data management challenges related to part numbering and material composition. No clear lead-free part numbering standard has emerged to facilitate lead-free part tracking and compliance verification. Comprehensive part and product material content information has not been communicated historically thus a standard reporting / material data transfer format does not exist. Information systems and reporting requirements must be modified in order to include materials / content data. Industry collaboration and development of data standards is imperative, but may also be too slow to meet implementation schedules.

Business Processes Stressed: Existing business processes such as product and process change notifications (PPCNs) and part and product requalification have been modified where necessary to handle RoHS related activity. However, the volume of RoHS related activity in the period leading up to January 2006 is much higher than typically experienced and is likely to stress established business processes and expose business process gaps or inefficiencies.

Transition Timing: Given that RoHS compliant parts and data are available, transition timing still poses significant challenges. For example, in order to requalify a system all lead-free parts must be available and qualified. This requires that all suppliers for a specific product make the transition simultaneously or a system is shipped using lead-free parts prior to system level qualification. On the other end, customer demand for RoHS compliant and lead-free products also varies widely. Transition timing will impact inventory decisions and costs. Predicting volumes of lead containing parts that will be used up to the transition point and flushing the supply chain to avoid procurement of obsolete parts will be difficult.

In summary, RoHS and lead-free implementation complexity and risk are amplified by significant non-technical challenges. Challenges span functional and hardware product groups and require a high degree of coordination with customers and suppliers who are in turn trying to coordinate with other OEMs. Companies are forced to predict regulatory requirements and act on assumptions. Industry collaboration and development of standards is imperative, but may not be effective due to aggressive implementation schedules and deadlines.

3.3 Technical Challenges

[14] From Rob Spiegel article titled *Lead Free Rules Create Havoc*

Finally, this section will discuss where lead is found in electronic products and describe the two technical issues, solder joint reliability and tin whiskers, which are considered in this document. This thesis does not attempt to contribute to the fundamental science underlying these technical issues, but rather how best to facilitate implementation and make informed decisions related to reliability risks and lead-free technical requirements. Therefore, the following summaries are supplemented by references to more detailed discussions of solder joint reliability and tin whiskers.

3.3.1 Lead in Electronics

All five of the restricted materials are used in electronic equipment and must be addressed in order to be RoHS compliant. However, lead is the most pervasive and difficult to remove. It is a key material in solder, printed circuit board finishes, and component plating. Lead is not used by accident; it provides desirable material properties at a low cost. The industry has collaborated to develop technical solutions and establish material and process standards. As mentioned previously, there are no showstoppers, but some lead-free solutions have performance and reliability issues. Lead-free solder joint reliability and tin whiskers are ongoing technical challenges.

3.3.2 Solder Joint Reliability (SJR)

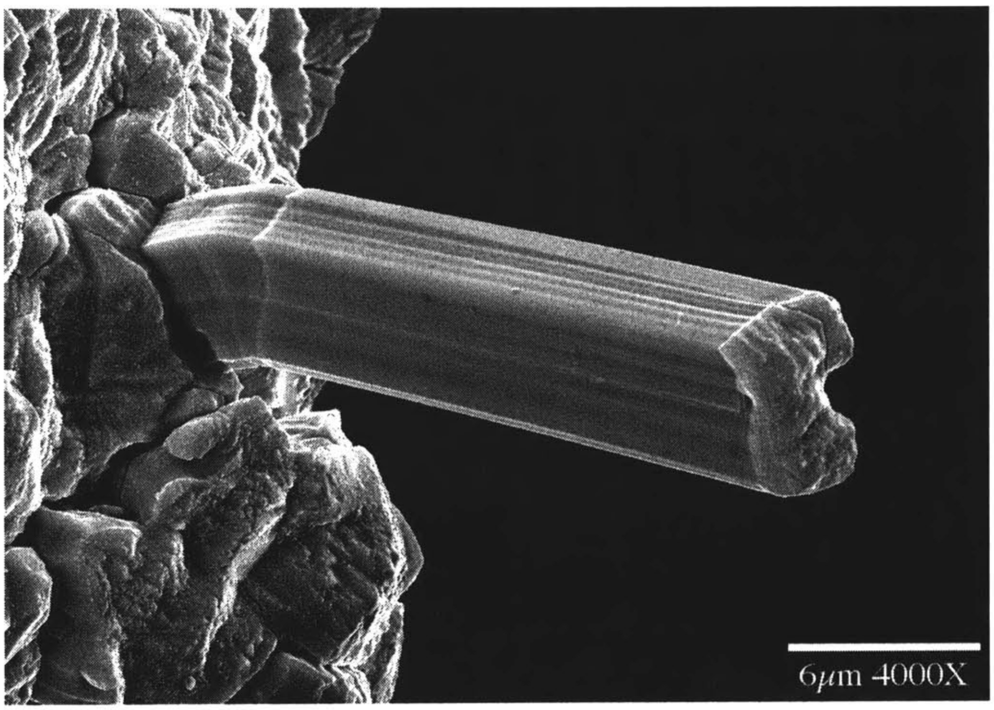
Historically a tin-lead(Pb) solder alloy has been used in product assembly across the electronics industry. This alloy has specific properties thus process control parameters. Tin-lead(Pb) solder processes have evolved over decades to provide a consistent, high quality assembly process. After extensive research and collaboration, the industry is converging on a standard tin – silver – copper (SAC) solder alloy that has the potential to meet or exceed existing tin-lead soldering performance and quality. However it is not a drop in replacement for tin-lead(Pb) solder. The SAC alloy requires not only a higher melting temperature, but also a tighter temperature range making process control more challenging than with tin-lead solder. Unlike tin-lead soldering processes, contract manufacturers do not have decades to troubleshoot and fine tune SAC alloy soldering processes. Thus the accelerated shift to high volume lead-free assembly involves process control challenges and learning curve effects are likely to impact yield and quality in the short term. The following resources have more information lead-free solder joint reliability:

Solder Joint Reliability: Theory and Applications, John Lau, Springer Publishing, 1991.
A Manufacturable Lead-Free Surface-Mount Process?, Jasbir Bath, Circuits Assembly, Jan. 2003.
NEMI's Lead-Free Alloy, Alan Rae and Carol Handwerker, Circuits Assembly, April 2004.

3.3.3 Tin Whiskers

Most component terminations or 'leads' are currently plated with a tin-lead(Pb) alloy that contains a small percentage of lead(Pb) (typically 3 to 40% by weight). Removing lead(Pb) from existing electroplating lines and *plating with pure tin is the most straightforward, inexpensive option to become lead-free* from supplier engineering resources, capital investment, and operating cost perspectives. However, pure tin electroplated finishes have a propensity to grow needle-like growths of tin referred to as 'tin whiskers'.

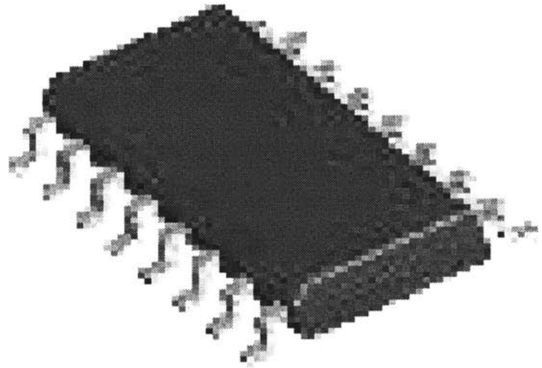
<u>**Figure 4:** Tin Whisker at 4000x</u>



Courtesy Peter Bush, SUNY Buffalo, ECTC Workshop, June 2004

Tin whiskers are a concern mainly for leaded components such as the one shown in Figure 5. Whiskers can cause reliability issues and component failure due to bridging and electrical shorting between adjacent leads or as debris if whiskers break off and cause electrical shorts or mechanical issues with other components. Tin whiskers may form within days of tin plating, but are more likely to grow over a period of months or years and have been known to cause failures over five years into product life.

Figure 5: Leaded Electrical Component

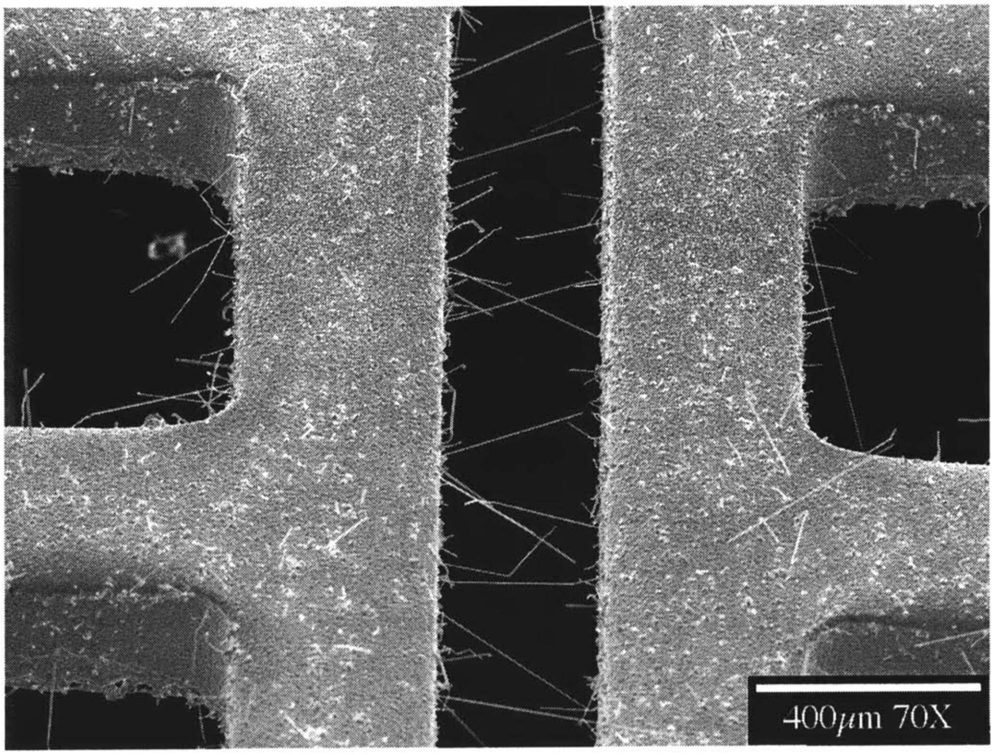


Tin whisker formation and growth mechanisms are not fully understood, but it has been shown that formation is a function of both plating material selection and process controls. In some cases whisker formation may vary widely from one 'identical' plating line to another based on plating bath chemistry, process controls, and material handling practices. Additionally, there is presently no accelerated test method to predict whether a specific plating line will produce components that form tin whiskers. Therefore, mitigation strategies for tin plated components include both plating recommendations and tin whisker testing requirements for every plating process to be qualified. A detailed discussion of tin whisker mitigation strategies is included in Chapter 5. The following articles are additional sources for tin whisker background information:

Tin Whiskers: Attributes and Mitigation, Brusse and Ewell, CARTS 2002 symposium

Avoiding Tin Whisker Reliability Problems, Galyon and Gedney, Circuits Assembly August 2004

Figure 6: Tin Whiskers Bridging Between Adjacent Leads



Courtesy Peter Bush, SUNY Buffalo, ECTC Workshop, June 2004

3.4 Summary of Challenges

In summary, there are significant technical and non-technical challenges related to the transition to lead-free electronics products. Timing and clarity of legislation has been lacking. Viable technical substitutes have been developed, but lead-free materials and processes may pose reliability challenges. Perhaps the most significant challenges involve data management, communication, and coordinating the transition across the value chain.

Chapter 4: Sun Organizational Structure and Culture as it Relates to RoHS and Cross-Functional Initiatives

4.1 Sun Organizational Structure

Sun has a matrix structure with Business Units (BUs) organized by product supported by functional groups such as Marketing, Human Resources and World Wide Operations (WWOPS). Within WWOPS, there is also a matrix structure with groups aligned with BU product groups supported by functional groups such as the Supplier Management and Operations Strategy group which includes Supplier Engineering and Procurement Strategy (PROST) subgroups.

Sun recently reorganized its Business Units (BUs) to form the Scalable Systems Group (SSG), Network Systems Group (NSG), and Network Storage Group (NWS). The SunRay™ desktop product is its own BU as well. Within SSG is a Central Engineering group which includes the Engineering Technology and Services group. The Engineering Technology and Services group manager has also taken over as the RoHS initiative leader.

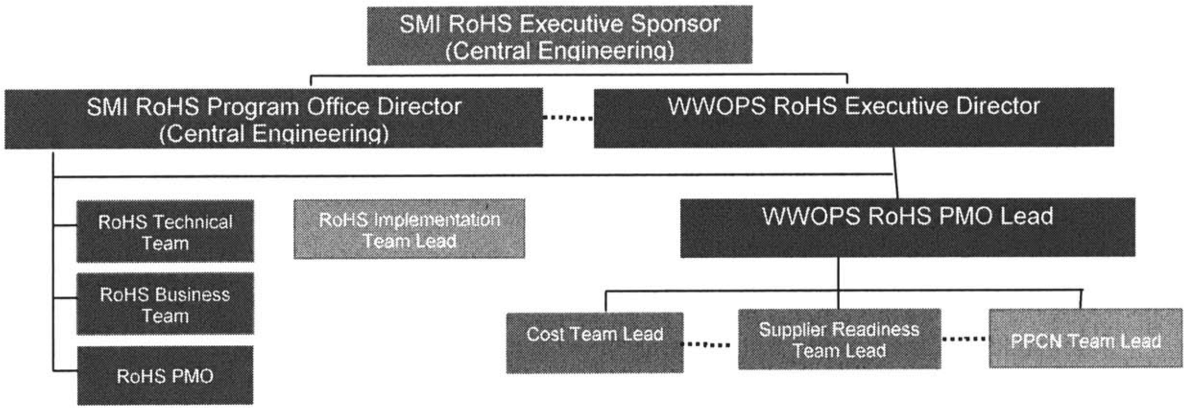
4.2 RoHS Program at Sun

The RoHS program structure (Figure 7) is yet another matrix with Implementation teams (I-teams) for each major product platform supported by the following functional teams:

- RoHS Business team
- RoHS Technical team
- WWOPS Supplier Readiness
- WWOPS Product and Process Change Notification (PPCN) team
- WWOPS Cost team
- Sun Services team

A RoHS Program Management Office (PMO) is tasked with coordinating Sun's RoHS efforts. PMO staffing has been impacted by company-wide layoffs and resource limitations. A Central Engineering manager is currently leading the PMO and broader RoHS initiative at Sun. The most active teams are the RoHS technical team, Supplier Readiness team and specific I-teams who have proactive, effective I-team leaders. Local effectiveness is mainly driven by individual capability and motivation.

Figure 7: RoHS Initiative Structure as of 12/2004



RoHS leadership is most closely aligned with the Central Engineering group and PROST groups based on the following:

- The RoHS technical team drove much of the early RoHS activity at Sun; they are staffed largely from the Central Engineering group.
- Senior level support was achieved by escalating RoHS resource allocation and visibility concerns through the Central Engineering group manager to the SSG manager.
- The Supplier Readiness team leadership is staffed from the WWOPS PROST group which is typically responsible for implementation of broad supplier related initiatives.

4.3 Environmental Health and Safety at Sun

4.3.1 Recent History and Philosophy

Sun's Environmental Health and Safety department consists of 2 full-time employees and 20 contract employees reporting to the EHS director. Sun utilizes an external environmental consulting firm to review EHS compliance at all Sun manufacturing sites every two to four years. The last review was conducted Fall 2003. Most EHS activity is effectively outsourced to contractors and consultants. Per a July, 2004 discussion with Sun's former EHS director:[15]

- The EHS director spends most of his time on policy and product related environmental issues. No other Sun personnel consider corporate environmental issues and strategy.

[15] The former EHS Director started in 1997 and retired in 2004. Sun's new EHS Director began shortly

- Sun's environmental activity has been based on legal obligations. Sun did not see opportunity to gain competitive advantage based on environmental performance or 'green' marketing.
- Sun does business with well-known and reputable suppliers and does not 'tell them how to do their business', i.e. Sun does not monitor suppliers' social or environmental performance.
- Contract staff spend over 90% of their time on workplace health and safety issues with the remainder of their time spent on environmental compliance activity. This split is driven by Sun's predominantly office setting.
- There are business incentives to design smaller and more energy efficient products; however, there is no formal effort to design Sun products with end of life in mind, i.e. no design for recyclability, reuse, disassembly, etc. program.
- Sun has an active product take-back policy and program in place where Sun will collect and dispose of any system replaced by a new Sun system. The program is managed by Sun Services and executed using contractors; it typically generates a profit based on system and part reuse and material recovery.
- As of the July, 2004 discussion, no one was leading Sun's WEEE initiative; the former EHS Director expected the existing take back and recycling program to be adequate.
- The former EHS Director considered tracking legislation and identifying executive level initiative sponsors as part of the EHS manager role, but did not closely follow RoHS progress once initial sponsors were identified.
- The EHS Director also spends time responding to customer surveys regarding Sun environmental policies and programs including product content questions.

Sun formerly published an internal EHS newsletter, Sun's Update Report on the Environment (S.U.R.E.). Newsletter contents included relevant regulatory updates, reports on Sun activity such as product recycling and energy conservation, and article excerpts and discussion on scientific topics such as anthropogenic climate change. Article excerpts seemed to present one side of a scientific argument based on EHS personnel personal views.

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afterwards.

4.3.2 Current Activity and Plans

A new EHS Director began in fall 2004. Another EHS professional also started on a part-time basis to lead Sun's WEEE initiative. Per an 11/2004 discussion, the new EHS Director expects the EHS department to be more active on environmental issues and felt that Sun's environmental activity will be driven by regulatory compliance, cost savings, and liability reductions. Potential activity discussed included:

- Get Sun certified per ISO 14001. Many of Sun's suppliers and most of Sun's customers are certified and certification would reduce future reporting efforts.
- Start an Environmental Council (cross-functional representation) to improve decision making on environmental issues.
- Set up infrastructure to respond to customer surveys and questionnaires.
- Implement a program to monitor suppliers' compliance with basic environmental regulations.
- Update Sun's internal and external websites on Product Stewardship with links to RoHS and WEEE.

The EHS department later published a summary of their revised plan for EHS department activity as given in Figure 8.

Figure 8: Draft Corporate Overview of EHS Department

Sun Corporate EHS- consists of Sun Environmental Office and Health and Safety Office.

Sun Environmental Office (SEO) will own architecting and championing Sun's philosophy of Sustainable Computing, Environmental Stewardship and Social Responsibility across Sun's business units and functions. SEO will proactively promote initiatives that economically position Sun as an industry leader and will monitor and manage Sun's response to industry and governmental guidelines and directives, internally and externally. SEO will collaborate with and leverage Sun's Public Policy, Corporate Communications and Business Conduct Offices.

- Sun/WR Policy & Standards
- Construction standards
- ISO 14001 Mgmt & reporting
-Community programs
- Business social assessments
- E-work and Transportation
- Product Supplier chain mgmt
- External Customer Inquiries

Sun Health and Safety Office (HSO) will own architecting and championing Sun's commitment to providing all employees and others utilizing Sun infrastructure, a safe and healthful work environment. HSO will proactively promote initiatives that economically provide Sun's business units and functions effective health and safety strategy, and tools. The HSO monitors and manages Sun's response to industry and governmental guidelines and directives. HSO will collaborate with and leverage Sun's Corporate Communications and Business Continuity Offices for crisis management and event response.

- Sun EHS Policy & Standards
- Business Unit Liaison
- Contractor Safety Oversight
- Community programs
- EHS Programs & Tools
- EHS Audits & Reporting
- External Customer Inquiries
- Web content mgmt

The overview covers many of the topics discussed previously and reiterates the EHS department's intentions to be more active with respect to corporate environmental issues. It does not however, discuss the value proposition driving future activity or consider cross-functional decision-making and initiative execution. In both discussion and the EHS overview, it seems that Sun will continue to view environmental performance as ancillary to core business strategy and operations. The goal seems to be to keep up with industry norms and avoid potentially negative impact such as negative publicity or non-compliance with regulations. Although there are plans to expand the scope of Sun's EHS activity, it seems that EHS activity continues to be viewed as risk management and cost of doing business vs. an investment with potential returns.

4.3.3 Executive Level Visibility

The EHS Director position is 4 levels removed from Scott McNealy, Sun's CEO. Obtaining executive level support and dedication of resources for environmental initiatives involves identifying the significant risks and 'right to do business' requirements that must be addressed, identifying appropriate managers, developing an escalation path to reach those managers, and communicating potentially negative consequences of not allocating resources to the issue at hand.

As mentioned in section 4.3.2, the EHS director is the only Sun employee with responsibility related to comprehensive environmental planning and strategy. Although the intent is to look longer term, the current focus is understandably dominated by immediate tactical demands to meet upcoming regulatory deadlines. Therefore, there is effectively no one in a position to critically assess Sun's long term environmental strategy and investment in related activity.

4.4 Organizational and Cultural Challenges - Impact on Cross-Functional Initiatives

4.4.1 Organizational Challenges

As described in Chapter 3, the industry-wide response to RoHS has a 'firefighting' nature driven largely by factors beyond any single organization's control. Even the most proactive, best-coordinated internal implementation effort would still face significant challenges. However, Sun's early RoHS efforts also experienced 'symptoms' of a lack of strategic planning and executive level visibility and support including severe budget and staffing constraints. This lack of visibility had two key drivers:

1. Initial efforts to designate executive level champions and a RoHS Steering Committee were significantly impacted by corporate reorganization.

2. The RoHS PMO and business team do not have representatives with the authority to allocate resources to RoHS activity.

Proactive follow on efforts to secure support and resources have been successful and the RoHS initiative has gained sufficient visibility and momentum. Sun seems to be positioned as well as most of their competitors with respect to RoHS implementation. Given the external challenges, and unprecedented complexity and magnitude of RoHS as a cross-functional environmental initiative, the effort should be viewed as a successful, functional program. However, firefighting has contributed to higher implementation costs and risks than necessary, and perhaps more importantly, no steps have been taken to improve implementation of future cross-functional environmental initiatives.

4.4.2 Comments on Sun Culture and Related Challenges

This thesis does not include a comprehensive discussion of Sun culture. This section includes a causal diagram as the basis of discussion for cross-functional project implementation and business process challenges observed during the LFM internship.[16] These challenges are most likely common to other innovation driven companies that grew quickly without significant cost pressure, but Sun's 'contrarian mind' culture seems to amplify the challenges.[17]

Figure 9: Rewarding Ideas or Innovation vs. Discipline or Attention to Business Processes (BP)

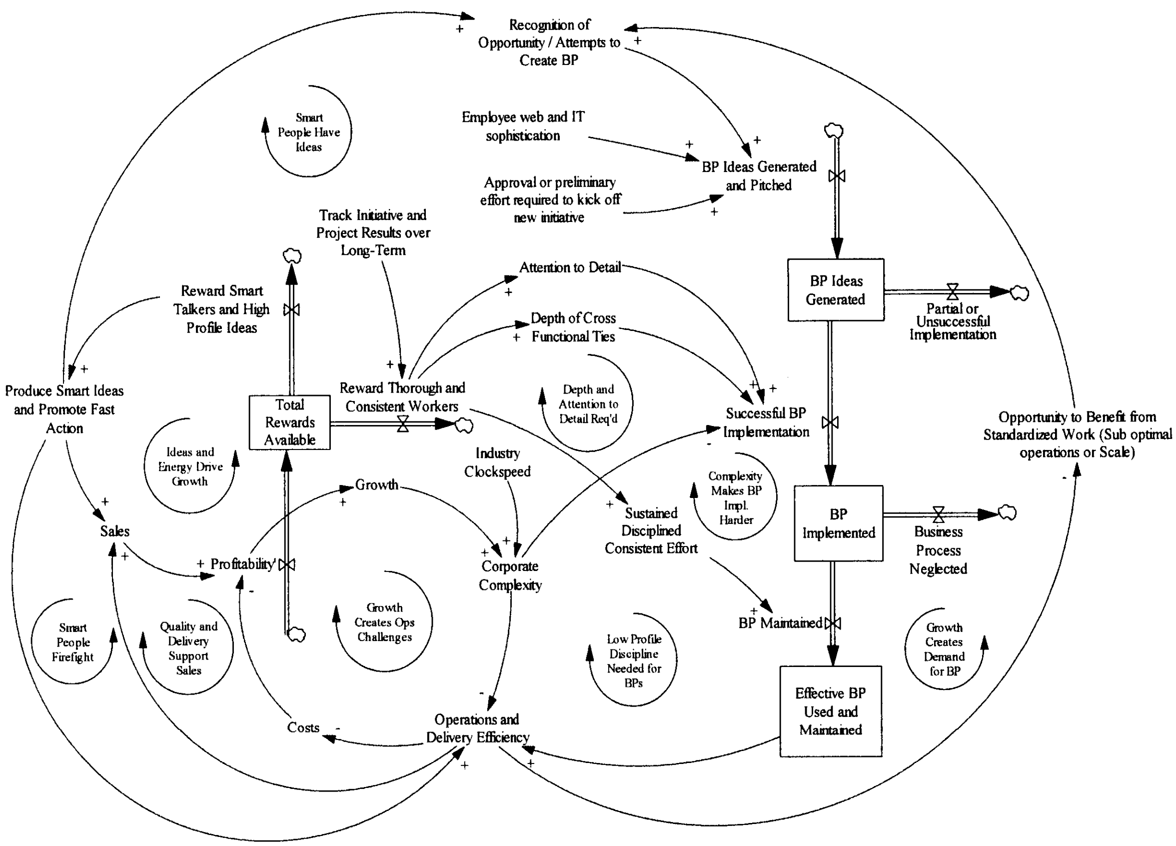

Figure 9 attempts to illustrate the dynamics that contribute both to Sun's strengths as an innovator and potential weaknesses with respect to business processes obsolescence or ineffectiveness. The main point illustrated by the diagram is that employee rewards may be distributed based on high profile ideas or as a result of thorough and consistent work. Both types of behavior may be

[16] Shion Hung discusses Sun's history and development and presents his perception of Sun culture in Section 3.2 of his 2004 LFM thesis, Software Content Delivery in an Outsourced Electronics Manufacturing Environment.
[17] Sun's internal website includes a contrarian minds section highlighting individual efforts and non-routine activity and contributions.

desirable depending on the situation, but a strong bias to one or the other is likely to negatively impact the balance between innovation and execution. Specifically:

Ideas and Energy Drive Growth: Innovative, high energy employees drove early sales and growth and were most likely rewarded based on high profile contributions. This type of contribution is needed to continue growth and evolution of a company, particularly in a high clockspeed industry. Rewarding high profile ideas and inventions will attract and encourage this type of employee. This type of activity is easy to recognize thus easy to reward.

Smart People Firefight and Deliver: Prior to implementation of functioning business processes (whether in start-up or transition and rapid growth phases), significant individual and one-time efforts are often needed to execute and meet customer needs from an operations perspective. The same type of innovative, high energy employee will be able to make this type of effort.

Quality and Delivery Support Sales: If operations enable product delivery and customer satisfaction, sales, profitability, and growth will increase.

Growth Creates Ops Challenges: As a company grows and becomes more complex or as an industry matures and becomes more cost sensitive, individual and one-time efforts are likely to be insufficient to meet customer demands cost effectively.

Growth Creates Demand for BPs: Operations delivery and efficiency might suffer if business processes are not established. This may contribute to higher costs and lower profitability.

Smart People Have Ideas: High energy, innovative employees are likely to recognize that business processes are needed and develop and communicate proposals. Sun has been described as 'open talent market' in which employees can develop an idea, convince management to endorse it, and recruit others to work on it. This empowerment lends itself to high energy, innovative employees generating many ideas and business processes. Additionally, many of Sun's employees are technologically savvy, thus they can produce software programs and tools locally without relying on limited centralized resources.

Depth and Attention to Detail Required: While smart ideas, presentations, programs, and draft business processes are abundant at Sun, many of the initiatives do not seem to be fully coordinated or implemented across business and functional groups often leading to redundant or obsolete processes and programs. For example, while attempting to develop an internship project, the author identified several areas of supplier communication and part data management that could be improved. However, in almost every case, the issue had been addressed previously, and a seemingly sound solution or proposal had been generated and communicated, yet implementation had not occurred or was only partially completed.

Low Profile Discipline Required: When business processes and programs are effectively implemented, they must be maintained and updated to continue to support the company as it evolves. The author found several on-line resources that were structured to maintain important information or data, yet many of them had not been maintained consistently over time or across business groups. Thus the information was not available when needed and efforts to partially maintain databases and tools were effectively wasted.

Complexity Makes BP Implementation Harder: As a company grows as rapidly as Sun has, it is not surprising that business processes become outdated and obsolete. Markets, technology, and the industry value chain are evolving and becoming more complex. Processes and programs may not evolve as the work that needs to be done changes rapidly. Updating of processes may fall behind as employees focus on day to day demands, particularly if rewards are biased towards high profile problem solvers.[18]

Attempting to formalize or standardize all repetitive work and data management in this type of dynamic setting is not reasonable, yet the ability to execute, i.e., operations effectiveness, depends on maintaining a balance between innovation and flexibility vs. standardization and process. During the author's internship, Sun's internal website published accounts of Scott McNealy visits to employees "quietly doing a good job" indicating that this apparent bias towards high profile inventors is recognized. Further acknowledgement of disciplined efforts to thoroughly establish and maintain business processes should improve Sun's ability to drive cross-functional initiatives.

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[18] Nelson Repenning and John Sterman article titled, *Nobody Ever Gets Credit for Fixing Problems that Never Happened: Creating and Sustaining Process Improvement* provides an in depth discussion of dynamics leading to firefighting activity at the expense of proactive disciplined execution.

Chapter 5 RoHS Technical Team Challenges and Project Motivation

This chapter provides background on internship project motivation and development. Sections 5.1 through 5.3 cover technical team challenges and context. Section 5.4 outlines broader challenges addressed in Chapter 7 of this thesis, and Section 5.5 describes the project approach and methodology.

5.1 Overview of Technical Team Challenges

As discussed previously, regulatory deadlines and potential loss of EU sales are impelling Sun and others in the electronics industry to make material and process changes based on less data and information than they would typically act on. Sun's RoHS technical team was staffed from the Engineering Technology and Services group (formerly the Central Engineering group) and developed RoHS specifications that go beyond basic compliance in order to address known lead-free reliability issues. However, lead-free requirements included in RoHS technical specifications have significant supply chain implications with respect to cost, operations, and strategy in addition to reliability impact. This raises questions of business priorities, risk management, and product requirements that are much more involved than the reliability issues that the technical team has been asked to address. Specifically, the following questions were raised:

1. Are Sun's reliability-driven lead-free requirements reasonable and consistent with industry practices? If not, what modifications could the technical team make to RoHS specifications and supplier requirements?

2. Should these requirements be implemented and enforced uniformly across all Sun products? What information is needed to support product group decisions with respect to reliability-driven lead-free requirements? Is there a break between consumer and mid to high reliability products?

3. Can Sun benefit by being a smart follower without taking unacceptable reliability or compliance risks?

The internship focused on identifying and communicating relevant technical information, articulating reliability risks, quantifying risks where possible, and gathering non-technical market, supplier, and competitor information needed to support decisions on reliability-driven lead-free requirements.

5.2 Development of Reliability-Driven Lead-Free Requirements

As discussed in Section 2.1, the electronics industry utilizes compatible materials and standard processes to enable flexibility and compatibility across the supply base. Development of vertically integrated manufacturing capability using non-standard materials is possible over the long-term, but near term industry efficiency depends on development of standard, compatible lead-free materials and processes. Therefore, collaboration among competitors and across the value chain has been necessary to develop new lead-free alternatives and establish standards with respect to materials and processes.

5.2.1 Industry Collaboration

Information Sharing: Some companies have been more proactive with respect to lead-free technology development. Companies such as IBM and Texas Instruments invested heavily in lead-free research and development over the past decade. However, these companies have published most of their findings and do not expect to gain significant competitive advantage or develop proprietary processes.[19]

Consortia Groups: Several industry groups are addressing RoHS and lead-free challenges. These groups focus on both technical and operations / implementation challenges. The International National Electronics Manufacturing Initiative, Inc (iNEMI) organization is one of the major consortia groups actively addressing lead-free issues. iNEMI has a number of subgroups including the following:[20]

1. *Tin Whisker Modeling Group*: This group is trying to gain a basic understanding of the tin whisker phenomena. They hope to understand formation and growth mechanics and develop the ability to prevent or control tin whiskers.
2. *Tin Whisker Accelerated Test Group*: There is currently no accepted accelerated tin whisker test method. The goal of this group is to develop a standard test method to detect inclination of a particular metallurgy or plating line to grow tin whiskers. The group plans to work with IPC and JEDEC to have the method published as a standard.

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[19] Texas Instruments has patented some of their work related to component plating processes that do not utilize lead or tin.
[20] More information on RoHS related NEMI work can be found at www.nemi.org.

3. *Tin Whisker User Group*: This group consists of ten large manufacturing companies working to develop standard tin whisker mitigation recommendations for immediate use given that RoHS deadlines are driving the lead-free transition prior to development of a complete understanding of and ability to prevent tin whiskers. Mitigation recommendations include both preferred component plating materials and processes, and tin whisker testing standards. The iNEMI User group recommendations are directed toward mid to high reliability applications.

4. *Lead-Free Assembly Group:* This group developed recommendations and assembly standards for the standard lead-free solder alloy, tin – silver – copper (SAC), that is being widely adopted throughout the industry. They conducted research reviews, collaborated with other groups, and performed original research to evaluate the reliability and manufacturability of the recommended alloy. The group concluded their work and is no longer active.

5. *RoHS Transition Group:* This group is addressing many of the logistical and data standards / reporting challenges posed by RoHS. Subgroups include Assembly Process Specifications, Component and Board Marking, Component Supply Chain Readiness, and Materials Declaration.

Sun is involved with all of the iNEMI groups and is currently most active in the Tin Whisker User group which includes representatives from Sun, IBM, HP, Celestica, Tyco, Freescale, Cisco, Alcatel, Lucent, Storage Tek, and Delphi. This group and other iNEMI subgroups communicate and collaborate with similar lead-free focused consortia groups and industry partnerships such as the Japan Electronics and Information Technology Association (JEITA), and University of Maryland's Computer Aided Life Cycle Engineering (CALCE) Electronics and Systems Center. The iNEMI group is working with industry standards groups such as IPC, the Association Connecting Electronics Industries, and JEDEC, the Solid State Technology Association.[21] Sun and iNEMI representatives also take part in lead-free conferences and other information sharing forums.

5.2.2 Reliability-Driven Lead-Free Recommendations

[21] Per Sun RoHS technical team member Heidi Reynolds, IPC addresses printed circuit board level standards, and JEDEC addresses component level standards.

This section will describe Sun's requirements for tin whisker mitigation and solder joint reliability testing.[22]

Tin Whisker Mitigation

Sun has adopted tin whisker mitigation requirements consistent with iNEMI User group recommendations. Tin whisker mitigation recommendations have evolved over the past few years and will continue to evolve as tin whisker research and understanding advance. However, given RoHS deadlines and qualification testing durations, suppliers must act on the latest guidelines if they are to meet reliability-driven requirements prior to RoHS deadlines.

As mentioned previously, iNEMI tin whisker mitigation recommendations and Sun specifications consist of (a) preferred component plating material(s) and processes, and (b) tin whisker testing for all plating using tin.

Component Plating: The most common component plating options endorsed by iNEMI include:

1. *Preplated nickel – palladium – gold lead frames*: Lead frames are preplated, typically by an outside facility. Tin whisker issues are eliminated by a shift to a non-tin plating thus tin whisker testing is not required for this option.

2. *Matte tin electroplating with nickel underlayer*: This option would add new nickel plating lines and remove lead from existing tin-lead(Pb) plating baths to plate pure tin over nickel.

3. *Matte tin electroplating followed by a heat treatment step*: This option would remove lead from existing tin-lead(Pb) plating baths to plate pure tin followed by a heat treatment step consisting of heating components to 150°F for 1 hour within 24 hours of initial tin plating.

Tin Whisker Testing: Tin whisker test conditions and durations, and qualification requirements recommended by iNEMI are under review by JEDEC for adoption into standard test methods and qualification criteria. iNEMI's proposed tests take approximately 6 months and require an investment in engineering resources, test equipment, and sample material. Components are examined following the test period to determine if whiskers of 'failure' lengths have formed.

[22] Sun's RoHS specifications address other lead-free reliability issues in addition to the two issues addressed in this thesis. Specifications also include more explicit descriptions of tin whisker mitigation requirements.

Component suppliers must submit material or process changes and tin whisker testing data through Sun's Product and Process Change Notification (PPCN) process to approve RoHS related changes.

Solder Joint Reliability (SJR) Testing Requirements

As explained in section 3.3.2, the industry is converging on a standard tin – silver – copper (SAC) solder alloy that has the potential to meet or exceed existing tin-lead soldering performance and quality. However, the shift to high volume lead-free production poses process control challenges and learning curve effects are likely to impact yield and quality in the short term.

In anticipation of the lead-free transition, Sun collaborated with Cisco and others to coauthor SJR testing guidelines that were adopted by IPC as IPC-9701, Performance Test Methods and Qualification Requirements for Surface Mount Solder Attachments. This standard outlines the design of a daisy chain test board that allows testing of every solder joint geometry that will be utilized in a product. The test is likely to be designed to cover multiple products since many of the joints will be common across products manufactured in the same facility.

This level of testing has not been required by Sun or competitors prior to RoHS. However, decades of tin-lead solder process and reliability data are available. Thus current SJR estimates are based on historical tin lead solder joint data. With the introduction of new and unproven lead-free soldering processes, this data may not reflect actual solder joint reliability, particularly during the transition and learning period.

5.2.3 Sun RoHS Technical Team Assumptions on Consortia Partners

Members of Sun's RoHS technical team are actively involved in consortia groups and communicate with their counterparts at competitor organizations regularly. The technical team was correct in assuming that other consortia group members were adopting material and process standards consistent with consortia group recommendations. However, further research and *interviews with employees from competing firms* found that specific RoHS supplier requirements varied with respect to application of consortia group recommendations. Basically, specific consortia group members considered business impact and context and adjusted tin whisker mitigation requirements in order to balance anticipated supply base capability and reliability risk. Sections 6.2.6 and 6.2.7 of this thesis cover this topic in detail and address how Sun might benefit from being a smart follower.

5.3 Supplier and Sun Manager Response

This section will describe preliminary supplier response to the reliability-driven lead-free requirements outlined in the previous section. It will also discuss specific cases of internal responses that raised questions of how to apply these requirements across product groups that range from consumer to high reliability.

5.3.1 Preliminary Supplier Response and Push-back

Sun's RoHS technical team created a RoHS Supplier Scorecard and began to communicate Sun's RoHS requirements to major suppliers as early as November, 2003. This scorecard included information to gauge supplier status with respect to (a) achieving RoHS compliance and (b) meeting reliability-driven lead-free requirements. Supplier response and status varied widely. Some suppliers were aware of RoHS requirements and were already taking steps consistent with Sun's requirements. Others were not familiar with RoHS and had not begun planning or implementation. Most suppliers were familiar with RoHS compliance requirements, but had not yet developed detailed implementation plans or an understanding of lead-free reliability risks. As suppliers began to tackle RoHS requirements, Sun's technical team members observed supplier push-back on tin whisker mitigation and SJR testing requirements. Specifically:

- Many component suppliers planned to utilize pure matte tin component plating and have not conducted tin whisker testing.
- Some contract manufacturers had not initiated SJR testing programs that met IPC-9701 intent or did not wish to share the results.

Sun's RoHS Supplier Readiness team has taken over RoHS Supplier Scorecard responsibilities and update supplier status as companies progress. The Supplier Readiness team expects all of Sun's core suppliers to be RoHS compliant. However, initial concerns on lead-free reliability raised during preliminary supplier communication are still significant. A more detailed review of supplier response and status was part of this project and is included in Section 6.2.1.

5.3.2 Internal Response and Push-back

An internal June 2004 conference call with RoHS technical team members, RoHS Supplier Readiness team members, and the appropriate WWOPS manager, covered Samsung Computer Division's response to Sun's request for solder joint reliability testing. The Samsung Computer Division indicated that they did not feel that the investment in SJR testing per IPC-9701 was reasonable given the low volumes of 'low end' product currently being produced by the Computer Division for Sun. The result of the meeting was to:

1. Withdraw Sun's demand for SJR testing.
2. Request to see results of any testing they may have already conducted or planned to conduct.
3. Advise the Samsung division that their non-compliance with SJR testing requirements would handicap them with respect to future business with Sun.

This outcome seemed reasonable given the situation, time constraints, and available information. As discussed previously, the RoHS technical team is not staffed to conduct business impact analyses or make risk decisions that account for product requirements and supplier management strategy. However, relaxing Sun requirements on a discretionary basis raises several issues with respect to lead-free reliability risk communication, impact on RoHS implementation, and WWOPS ability to differentiate between suppliers based on satisfaction of specific lead-free requirements.

Similarly, WWOPS managers in Sun's Network Systems Group (NSG) have asked for time to review Sun's RoHS specifications prior to signing off on them, citing questions of whether "...some of the testing and requirements in this specification may be excessive for our needs in NSG. Meeting some of these requirements could result in excessive cost to our programs and make us uncompetitive...."[23] Again this request for time to review requirements is reasonable given that reliability-driven requirements appear to have cost and reliability trade-offs.

The broader question raised by these discussions is whether Sun's reliability-driven lead-free requirements are reasonable and should be applied uniformly across all of Sun's products or whether requirements should be modified based on product reliability requirements. Basically, are there "two Suns", one selling consumer products with lesser RAS requirements and the other selling mid to high reliability products, and if so, where is the line between them?

Given that this issue is relevant to many suppliers and most hardware products at Sun, a more thorough review and analysis was conducted to support better-informed decisions. Results of this review and analysis were presented in an Executive White Paper and discussed in Chapter 6.

[23] Sun internal email sent to Sun's RoHS technical team leader in November, 2004.

5.4 Broader Strategic Issues Illustrated by RoHS

As discussed in the previous section, development and implementation of RoHS driven reliability standards across Sun raises strategic as well as tactical issues including the following:

1. Should reliability-driven requirements be implemented uniformly across all product groups? If not, where do you draw the line between consumer and higher reliability products?

2. RoHS is the first of several environmental regulations that will drive industry change. When should Sun collaborate? What should be considered competitive?

3. The electronics industry is a high profile target for 'green' legislation. How can Sun reduce related costs and risks? Facilitate tactical implementation efforts? Can they position themselves to be a smart follower?

4. Additionally, the electronics and other industries are currently awash with voluntary corporate social responsibility (CSR) and sustainability initiatives. What activity should Sun invest in? Can they gain competitive advantage? Again, how can they benefit as a smart follower?

All of these questions indicate that corporate environmental activity is no longer purely a tactical effort that can be 'outsourced' to consultants and EHS departments staffed with environmental specialists. EHS departments historically manage compliance-focused initiatives as ancillary projects. RoHS and other legislation as well as voluntary 'sustainability' activity have a significant impact across all of Sun's hardware products and functional groups.

The EHS department is not structured or adequately staffed to: (a) evaluate strategic impact, alternatives, and investments, or (b) proactively plan and manage the coordinated implementation effort required for initiatives of this magnitude and complexity. Specialized environmental and compliance knowledge must be supplemented by an understanding of an organization's core strategy and operations. The RoHS Directive has illustrated the lack of corporate environmental planning and strategy at Sun and across the electronics industry. In summary, RoHS has highlighted significant opportunities to reduce future costs and risks associated with regulatory-driven activity and improve returns on voluntary investment in environmental activity or sustainability programs. .

5.5 Project Approach / Methodology

This section will outline the project approach and briefly describe how research and analyses were conducted.

5.5.1 Project Structure

Based on the challenges outlined in previous sections, information was gathered to support informed business decisions with respect to reliability-driven lead-free requirements. Chapter 6 includes findings on the following:

Risks of Not Meeting Reliability-Driven Requirements (including sample calculations)

Cost to Meet Reliability-Driven Requirements

- Supplier costs to meet reliability driven requirements (relative to bare minimum RoHS compliance costs).
- Transfer of costs to Sun and other OEMs.

Supplier Activity and Capability

- Supplier ability to meet reliability driven requirements.
- Drivers of remaining technical gaps.

Competitor Strategy and Activity

- Consistency of Sun and competitor specifications.
- Implementation methods and status.

Evaluation of Competitor Methods to Proactively Address Potential Component Shortages

Findings are used to assess whether Sun should implement and enforce RoHS specifications uniformly across all hardware products or consider modifying requirements for specific product lines.

Chapter 7 considers the broader issue of corporate environmental strategy drawing upon the RoHS initiative to illustrate the opportunity to reduce future risk and costs and improve return on investment in environmental planning and activity.

5.5.2 Research and Implementation Methods

Sun references on Risk Management and Risk Decisions were reviewed to ensure that the project structure was consistent with Sun's risk management practices.[24] Target information and project structure was reviewed with members of Sun's RoHS Technical, Supplier Readiness, and Product I-teams. Where possible data has been compiled and quantified. However, due to the firefighting nature of industry and corporate RoHS efforts, in depth analysis on related costs, risks, and supply base status is largely absent. Therefore, the analysis and recommendations in Section 6 are based on RoHS technical team assumptions, observations of industry trends, and discussions with competitors, suppliers, and Sun managers.

Interviews were conducted with a range of Sun employees from the RoHS initiative, Worldwide Operations (WWOPS), and the Environmental Health and Safety (EHS) department. Industry publications, conference proceedings, and interviews with suppliers and competitors were also used extensively. Statistical analysis was used to estimate the reliability impact of specific lead-free solutions at the component level. Sun's existing system level reliability estimation methods were utilized to consider the impact of component reliability on system performance. Data analysis was used to assess the supply chain impact of various technical options. Ongoing communication with the technical team and a white paper were used to share findings.

[24] Sun document, "A Guide to Risk Management" published in March 2004 by Mike Ward and Mike Belch was reviewed.

Chapter 6 Project Results

This chapter opens with a Summary of Findings related to tin whisker mitigation and solder joint reliability testing followed by detailed analyses and findings. This chapter includes most of the content from the white paper utilized to communicated findings at Sun. Broader corporate environmental strategy questions are addressed in Chapter 7. Recommendations are given in Chapter 8.

6.1 Summary of Findings

This section summarizes tin whisker mitigation and solder joint reliability and solder joint reliability testing findings separately. As mentioned previously, tin whisker mitigation is a component supplier issue while solder joint reliability testing is an assembly or contract manufacturer issue.

6.1.1 Tin Whisker Mitigation by Component Suppliers[25]

Key points from this summary are expressed in the table located in Appendix A.

Reliability Risk

- Reliability risk due to tin whiskers is not clear; tin whisker formation mechanisms are not fully understood. There is currently no accepted accelerated tin whisker test method.

- Despite unknowns, tin whisker reliability risk is deemed high enough to warrant significant industry investment in mitigation strategies. Sun's RoHS technical team has collaborated with competitors via consortia groups to develop specifications that go beyond compliance to address tin whisker reliability concerns.

- Per RoHS technical team best estimates, tin whiskers may increase the probability of component failure by 0.4% (over 80 FITs[26]) for components plated with pure tin. Tin whisker mitigation may reduce related component failures up to 90% depending on the mitigation strategy and product life considered.

- Component FIT rate increases were used to estimate system level reliability for one of Sun's mid

[25] Tin whisker mitigation practices as recommended by consortia groups and specified by Sun are a combination of (a) preferred component plating material(s) other than pure tin, and (b) testing for tin whiskers. Tin whisker testing must be performed for each plating line to be qualified.
[26] A FIT refers to Failure in Time which is a measurement of probability of failure.

range servers. Using components plated with pure tin (i.e. compliant, but no tin whisker mitigation) increased annual downtime 2x – 15x higher than estimates for existing systems. Use of a recommended mitigation strategy reduced the impact on annual downtime to only 0.1x to 5x higher than existing.

Cost Impact

- Component suppliers face trade-offs between cost and expected reliability. Cost impact varies based on existing supplier operations and the mitigation strategy selected.
- The up front cost to meet reliability-driven requirements is small relative to total RoHS compliance costs; however there may be sustained increases in operating costs due to plating materials, cycle times, and energy consumption.
- Cost is only one of several key factors contributing to supply base strategy and readiness.
- Cost increases are likely to be absorbed by suppliers or reflected in future pricing vs. direct customer charges or immediate pricing adjustments. Component market dynamics and competition will continue to be the primary driver in component pricing.

Supplier Activity and Status

- Supplier readiness varies widely. Not all component suppliers will meet tin whisker mitigation requirements thus *there may be shortages of components that meet Sun's current reliability-driven requirements.*
- Component suppliers who understand tin whisker issues typically take a direction consistent with consortia group recommendations for high reliability products, matching Sun requirements.
- Low margin and smaller component suppliers may not take steps to satisfy tin whisker mitigation requirements based on the following combination of factors:
  - Opinion on the significance of tin whisker impact on product reliability varies widely. Industry consortia group recommendations for tin whisker mitigation continue to evolve and take time to work up the supply chain. Recommendations may be perceived as interim.

- Implementation requires dedicated engineering resources and investment in equipment and testing. Component suppliers facing severe cost pressure are not likely to have available resources.
- Customers have taken a firm 'no cost increase' position offering limited relief from cost competitive markets, thus little incentive to invest beyond basic compliance.
- Components used in high reliability products may be common to consumer markets and customers who are willing to accept components of unknown reliability, i.e. no tin whisker mitigation requirements. Consumer sales volumes may dictate tin whisker strategy.

- Proactive component suppliers who satisfy tin whisker mitigation requirements may have a short-term advantage as Sun and their competitors attempt to source from a diminished supplier pool. Suppliers seem to view this as an opportunity to increase market share rather than raise pricing.

Competitor Strategy and Activity

- Sun's main competitors and some customers are part of consortia groups working to understand tin whiskers and develop mitigation and testing standards. Sun's tin whisker mitigation requirements are consistent with consortia group recommendations for mid to high reliability requirements.
- HP and IBM deviate in their application of consortia group recommendations in order to proactively address potential component shortages as follows:
  - HP differentiates based on product reliability requirements with dual tin whisker mitigation standards for consumer vs. mid to high reliability products. Specifically, HP consumer product groups are given the authority to accept components with pure tin finishes and no tin whisker testing.
  - IBM differentiates based on component lead spacing with dual tin whisker mitigation standards for wide vs. fine pitch[27] components. Components with lead pitch greater than 1mm can be plated with pure tin and do not require tin whisker testing.
- Dell is planning to follow consortia group recommendations and has not formally taken steps

[27] Pitch refers to the center to center distance between component leads (pins). When considering the clear spacing between leads, the diameter of the lead must be subtracted. A conservative rule of thumb is that clear spacing = ½ pitch.

to address potential component shortages.[28]

Evaluation of Methods to Proactively Address Component Shortages

The HP and IBM approaches were evaluated for use at Sun based on reliability implications, implementation feasibility, alignment with operations strategy, and alleviation of potential component shortages. The IBM approach is preferred and could significantly reduce RoHS implementation challenges related to component suppliers.

- If Sun is willing to accept tin whisker reliability risks for consumer products, the HP dual standard for consumer vs. mid to high reliability products is an option. However, there are significant drawbacks associated with this approach including:
  - Many parts and suppliers are common across consumer and mid to high reliability products. Implementation would be difficult and costly due to part proliferation and inventory tracking.
  - Per Sun's Procurement Strategy (PROST) group, cost pressure in mid to high reliability products is driving even greater part commonality and modularity.
  - Most suppliers will not maintain multiple lines for the same component, thus there still may be shortages of low margin components that meet tin whisker mitigation requirements.
- If Sun is willing to accept the risk of tin whiskers growing and potentially breaking off of wide pitch components, the IBM dual standard for wide vs. fine pitch components is an option. This option seems feasible based on the following:
  - Empirical observations of tin whisker growth lengths indicate that the probability of a whisker bridging between leads of a wide pitch component are minimal.[29]
  - A single set of specifications could apply to all products and component suppliers facilitating implementation. Component suppliers who meet tin whisker mitigation requirements could be given preference.

[28] 11/04 email discussions with Dave McCarron, Dell Lead Free Program Director and Scott O'Connell, Dell Environmental Affairs manager.
[29] 12/04 email discussion with George Galyon, IBM RoHS Team Leader.

- Analysis of a Sun Uniboard[30] showed that leaded components with nominal pitch < 1mm are integrated circuits. Typically, Sun's IC suppliers are taking steps to meet tin whisker mitigation requirements. Thus, this method should effectively address potential component shortages.

Tin Whisker Mitigation Related Recommendations

1. Modify Sun's RoHS specifications to accept matte tin plated components with no tin whisker testing if pitch is greater than 1 mm. Give preference to component suppliers who meet tin whisker mitigation requirements.

2. Given implementation of the first recommendations, enforce tin whisker mitigation requirements uniformly across Sun products.[31]

6.1.1 Solder Joint Reliability Testing by Contract Manufacturers

Reliability Risk

1. Lead-free soldering processes have the potential to meet or exceed tin-lead solder performance and reliability. However, the rapid shift to full-scale production using unproven lead-free materials and processes will lead to learning curve bumps and transition challenges.

Supplier Activity and Cost Impact

2. The cost to conduct solder joint reliability testing ranges from $100k to $250k per product line depending on product complexity.[32]

3. Suppliers who have traditionally had good quality and proactively planned for the transition to lead-free have most likely independently initiated solder joint reliability testing programs and expect investments to pay off in terms of a smoother transition.

4. Completion of solder joint reliability testing per IPC-9701 or equivalent standards is not a hard prerequisite for lead-free capability. It is, however, *a strong signal that a company has been planning for the transition and is likely to have fewer yield and quality issues during the transition.*

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[30] Sun's Uniboard is a large printed circuit board used in a range of Sun products.
[31] SunRay™ products may be an exception if part commonality is low.

Solder Joint Reliability Testing Related Recommendations

1. Modify Sun's specifications to request solder joint reliability testing per IPC-9701 *or equal*, i.e. continue to encourage suppliers who have independently developed alternative SJR testing programs to submit information.

2. Select and / or leverage well prepared contract manufacturers who best satisfy SJR testing requirements in order to avoid hidden transition costs related to lead-free learning curve impacts.

6.2 Tin Whisker Mitigation by Component Suppliers

This section presents detailed findings on tin whisker mitigation.

6.2.1 Tin Whisker Mitigation Options and Supplier Activity (6.2.1)

Sun is one of the ten large manufacturers in the International National Electronics Manufacturing Initiative, Inc. (iNEMI) Tin Whisker User consortia group working to develop standard tin whisker mitigation recommendations for immediate use in the absence of a complete understanding of and ability to prevent tin whiskers. The iNEMI User group recommendations are directed toward mid to high reliability applications. Tin whisker mitigation recommendations have evolved over the past few years and will continue to evolve as tin whisker research advances. *However, given RoHS deadlines and qualification testing durations, suppliers must act on the latest guidelines if they are to meet high reliability requirements prior to RoHS deadlines.*

As mentioned previously, iNEMI tin whisker mitigation recommendations and Sun specifications consist of (a) preferred component plating material(s) and processes, and (b) tin whisker testing for all plating using tin. Tin whisker test conditions and durations, and qualification requirements recommended by iNEMI are under review by JEDEC for adoption into standard test methods and qualification criteria. iNEMI's proposed tests take approximately 6 months and require an investment in engineering resources, test equipment, and sample material. Components are examined following the test period to determine if whiskers of 'failure' lengths have formed.

The most common component plating options endorsed by iNEMI include:

1. Preplated nickel – palladium – gold lead frames: Tin whisker issues are eliminated by a shift to non-tin plating thus tin whisker testing is not required for this option. Some suppliers such

[32] SJR testing costs based on Sun RoHS technical team leader's experience and recent estimates.

as Texas Instruments and Cypress Semiconductor have taken this approach. In both cases the decision predated RoHS implementation and was driven by cost reductions based on elimination of in-house plating processes and subsequently improved cycle times. Lower margin component suppliers do not appear to have cost structures that support similar decisions.[33] However, more suppliers may take this approach if tin whisker related reliability issues prove to be significant following the lead-free transition.

2. Matte tin electroplating with nickel underlayer: This option would utilize tin plating baths in place of existing tin-lead(Pb) plating lines and add new nickel plating lines to plate pure tin over nickel. Agere, Tyco and a few other large component suppliers have conducted their own research and committed to nickel underplating. However, capital costs for nickel plating lines are significant and installation may be complicated by existing plant footprint and layout. Sun's technical team prefers this option when using tin plating based on preliminary reliability studies and expects good tin whisker testing results given this plating process, but a limited number of suppliers have taken this direction to date.

3. Matte tin electroplating followed by a heat treatment step: This option would utilize tin plating baths in place of existing tin-lead(Pb) plating lines to plate pure tin followed by a heat treatment step consisting of heating components to 150°F for 1 hour within 24 hours of initial tin plating. Most facilities could perform the heat treatment step using existing equipment. Research data for this option vary widely and it appears to require very good process control to realize whisker reduction benefits. However, it is endorsed by iNEMI and acceptable per Sun specifications if accompanied by acceptable tin whisker testing results. This option is popular with many suppliers based on simple and inexpensive implementation. Sun's technical team is concerned that suppliers taking this direction without a good understanding of other process variables that impact tin whisker formation may have poor results and fail tin whisker testing criteria.

6.2.2 Tin Whisker Impact on Component Reliability[34]

As mentioned previously, tin whisker formation and growth mechanisms are not fully understood and an accelerated test method has not been established. Research results to date are inconsistent and often conflicting making a statistically significant quantification of tin whisker impact on

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[33] Low value component suppliers may not realize similar cost savings due to reduced cycle time and lower inventory holding costs.

[34] All component reliability data is shown as FIT rate deltas associated with tin whisker failures to avoid publication of absolute reliability data. Technical team assumptions related to tin whisker reliability impact

component reliability impossible at this point.[35] However, given that decisions on tin whisker mitigation strategies must be made prior to statistically accurate data being available, this section presents tin whisker impact on component reliability for various mitigation strategies *based on the technical team's best estimates*. Component failure due to bridging was considered; failures due to tin whiskers breaking off and causing failures elsewhere is assumed to be negligible for this analysis. The range of uncertainty around 'best estimate' numbers is intentionally broad; inconsistent data and the significance of process variability both contribute to the magnitude of the error envelope. The following tin plating options were considered:[36]

1. Matte tin (not currently accepted)
2. Matte tin w/heat treatment (currently accepted w/test data)
3. Matte tin over nickel underlayer (currently accepted w/test data)

The technical team estimated and plotted the probability of critical tin whisker growth, P_W (probability that a 'failure' length tin whisker forms on a component) over time for each tin plating option with an uncertainty envelope showing the range around the best estimate. Probability of failure due to tin whiskers, P_{ij} was then calculated as follows:

$$P_{ij} = P_W * P_F * (1 - P_T)$$

where:

i = Tin plating option

j = Component life

P_W = Probability that a whisker long enough to potentially cause a short between leads has formed (based on technical team estimates)

P_F = Probability that a failure length whisker will cause a component shorting failure

P_T = Probability that tin whisker testing per current iNEMI recommendations would identify and eliminate a plating process producing components that form tin whiskers

A value of 0.01 was used for P_F, assuming that 1% of the components that form long whiskers actually cause a component failure. This should be a function of component geometry (wider pitch components have a lower probability of tin whisker bridging failures) and application voltage, but

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are based on consortia group or publicly available studies.

[35] Per a 10/04 email from Andrew Kostic, Engineering Fellow with Northrup Grumman Product Integrity Engineering, "....no one has a valid model for whisker growth. Different companies perform the same experiments on identical samples from the same plating lot and get different results. If there were enough statistics from a large number of applications, it would be possible to come up with an adequate distribution that would fit the general case. Right now there is not enough information to develop meaningful statistics."

[36] All plating options assume a copper lead frame.

based on the level of uncertainty in the whisker formation probabilities this value was assumed to be constant for all leaded components.

P_T was assumed to be 0.5, signifying that tin whisker testing of 6 month duration can screen out 50% of the whisker prone plating lines. Again, this value could vary based on the mitigation strategy's propensity to slow whisker growth, but that level of detail is not appropriate given the accuracy of whisker formation assumptions.

Component failure rates based on best estimate tin whisker formation numbers for all options are shown on Figure 10. Figures 11, 12, and 13 show best estimate, upper bound, and lower bound failure rates for matte tin, matte tin with heat treatment and testing, matte tin with Nickel underlayer and testing, respectively.

Figure 10: Component Failure Rates Due to Tin Whiskers - Best Estimates for 3 Plating Options

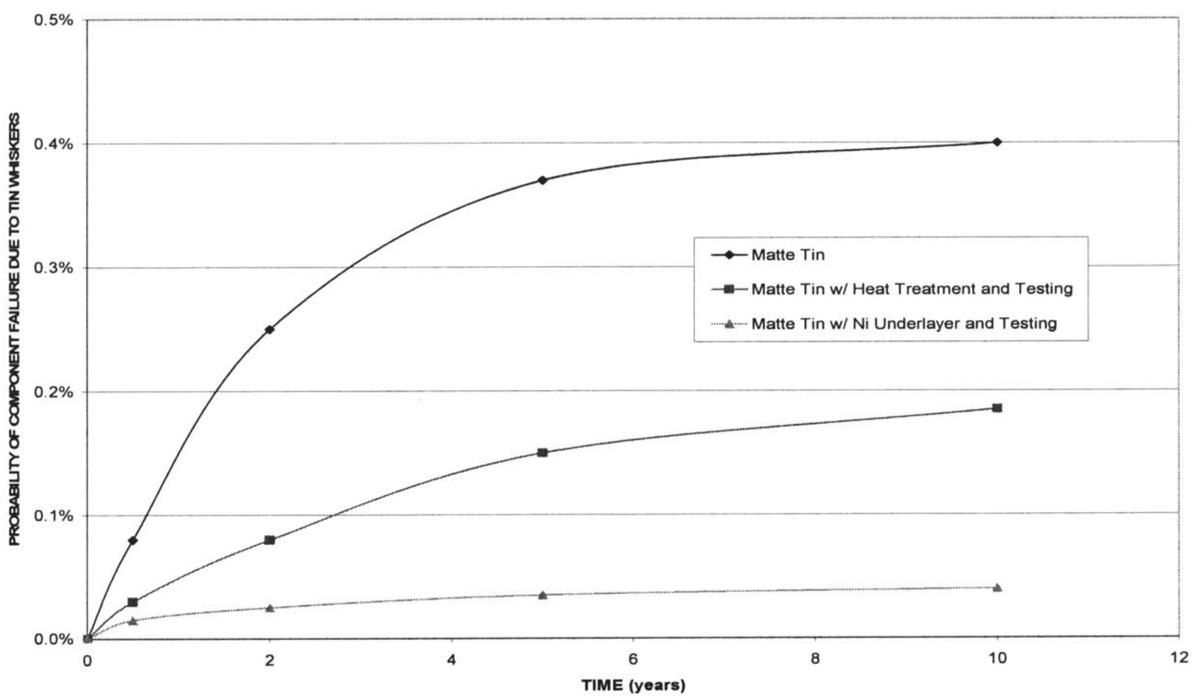


Figure 11: Component Failure Rates Due to Tin Whiskers - Matte Tin

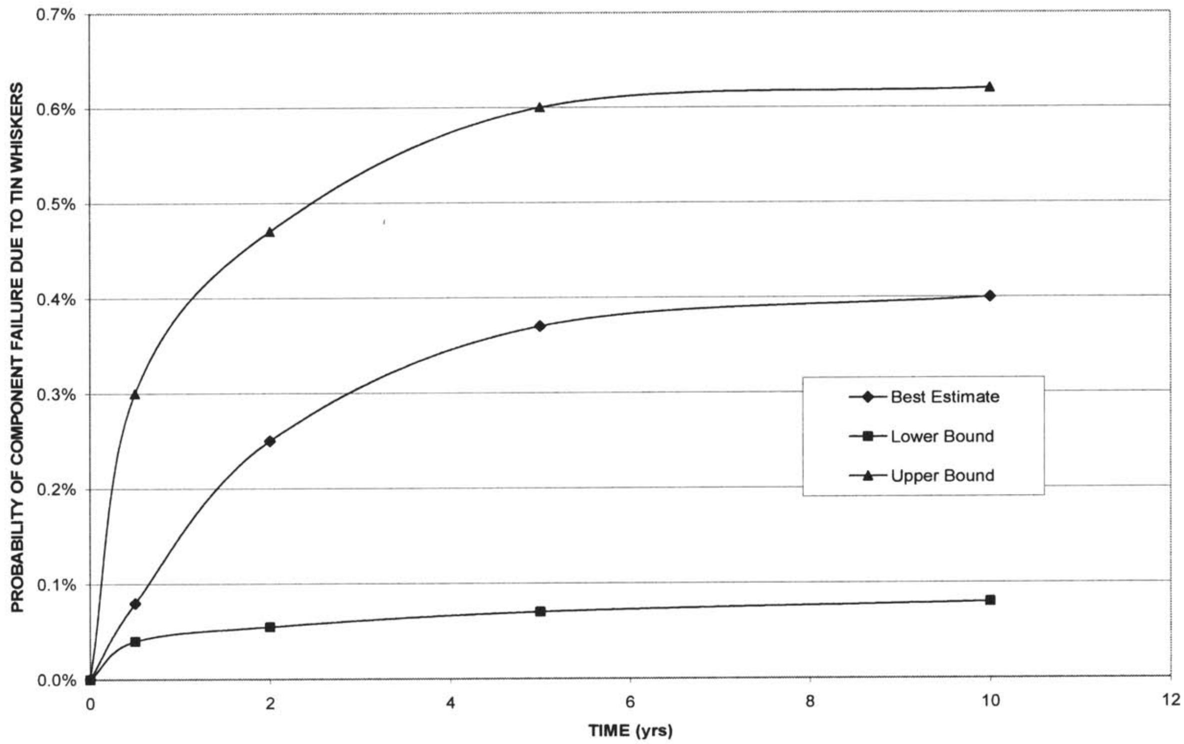


Figure 12: Component Failure Rates Due to Tin Whiskers - Matte Tin w/Heat Treatment + Test

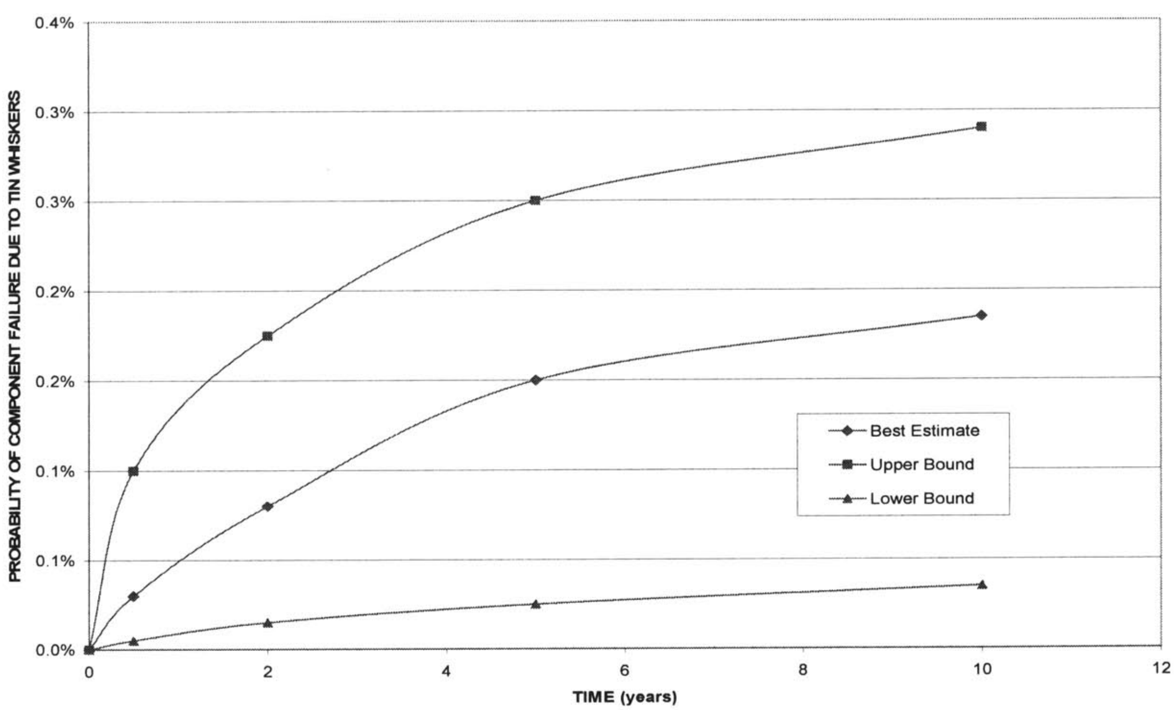
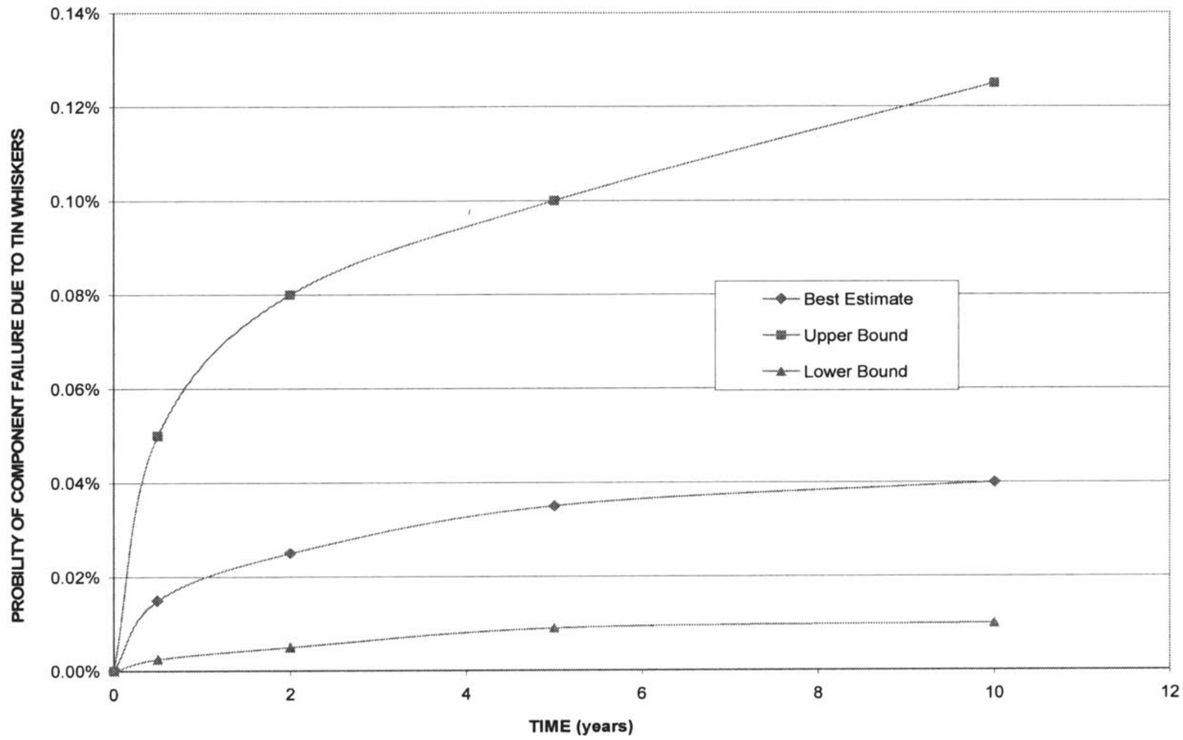


Figure 13: Component Failure Rates Due to Tin Whiskers - Matte Tin w/Ni Underlayer + Test



FIT rate deltas are the increase in component failure rate due to tin whiskers assuming that existing failure modes and baseline FIT rates remain unchanged. FIT rate deltas were estimated using P_{ij} for 0.5, 2, and 5 years as shown in the following table. For example, a matte tin plated component failure probability will increase 57 FITs within two years of being plated.

Table 1: FIT Rate Deltas – Tin Whisker Impact on Component Reliability

Mitigation Option	0.5-yr Component Life		2 – yr Component Life		5 – yr Component Life	
	Best Estimate	Range	Best Estimate	Range	Best Estimate	Range
Matte Tin (no mitigation)	18	10 - 70	57	13 - 110	84	16 - 140
Matte Tin w/Heat Treatment (No Test)	14	2 - 50	37	7 - 80	68	11 - 120
Matte Tin w/Ni Underlayer (No Test)	7	1 - 25	11	2 - 37	16	4 - 50
Matte Tin w/Heat Treatment + Test	7	1 - 25	18	3 - 40	34	6 - 60
Matte Tin w/Ni Underlayer + Test	3	1 - 10	6	1 - 18	8	2 – 23

6.2.3 Tin Whisker Impact on System Reliability[37]

FIT rate deltas were applied to component data inputs in an existing system reliability model to consider the impact of increased component failure due to tin whiskers on system level reliability.[38] The system selected was the Sun V490 server (A52-JTG4-16GRB). The reliability models assume a constant component failure rate or component MTBF. Therefore, although tin whisker related failures will increase over time, the 2-year component life FIT rate deltas were used for system level reliability impact estimates.

Table 2 shows system level impact relative to estimates of existing system reliability when tin whisker FIT rate deltas are applied to all leaded components. Table 3 shows system level impact relative to estimates of existing system reliability when tin whisker FIT rate deltas are applied only to fine pitch components. This case assumes that all passive components such as resistors and capacitors are wide pitch components and will not be prone to tin whisker failures. Again, this analysis considers bridging failures only; failures due to whiskers growing on one component, breaking off, and causing failure on a different (finer pitch) component are considered negligible.

Table 2: System Level Reliability Impact – Tin Whisker FIT Rate Deltas Applied to All Leaded Components

	% Difference Relative to Existing System			
	Availability	**Annual Downtime**	**Mean Time to Repair – MTTR**	**Mean Time Between Service Interruptions - MTBSI**
Matte Tin (best estimate)	-0.26%	1546%	-41%	-94%
Matte Tin w/Heat Treatment (best estimate)	-0.17%	1004%	-40%	-91%
Matte tin w/Heat Treatment + Testing (best estimate)	-0.08%	489%	-36%	-83%
Matte tin w/Nickel Underlayer (best estimate)	-0.05%	299%	-32%	-75%
Matte Tin w/Nickel Underlayer + Testing (best estimate)	-0.03%	163%	-26%	-62%

[37] All system level data is shown relative to existing system reliability estimates to avoid publication of absolute data where %Difference = (New Value – Existing Value) / Existing Value

[38] System level reliability estimate for the V490 server were completed by David Wonnacott and Roy Andrada using FIT rate deltas given in Table 1.

Matte Tin (lower bound)	-0.05%	315%	-32%	-76%
Matte Tin (upper bound)	-0.49%	2979%	-42%	-97%

Table 3: System Level Reliability Impact – Tin Whisker FIT Rate Deltas Applied to Fine Pitch Components

% Difference Relative to Existing System

	Availability	**Annual Downtime**	**Mean Time to Repair – MTTR**	**Mean Time Between Service Interruptions - MTBSI**
Matte Tin (best estimate)	-0.02%	91%	-19%	-48%
Matte Tin w/Heat Treatment (best estimate)	-0.01%	59%	-14%	-37%
Matte tin w/Heat Treatment + Testing (best estimate)	-0.005%	29%	-9%	-22%
Matte tin w/Nickel Underlayer (best estimate)	-0.003%	18%	-6%	-15%
Matte Tin w/Nickel Underlayer and Testing (best estimate)	-0.002%	10%	-3%	-9%
Matte Tin (lower bound)	-0.003%	21%	-7%	-17%
Matte Tin (upper bound)	-0.03%	176%	-27%	-64%

As expected the impact on system level reliability varies widely given the two sets of assumptions and input data. Estimates may be refined as better component reliability models are developed. At this point, the two data sets may be viewed as best and worst case estimates. It is likely that actual impact will be closer to the estimates where FIT rate deltas were applied to fine pitch components only.

6.2.4 Component Availability Challenges

Over the past year, Sun's RoHS technical team has communicated lead-free technical requirements to major suppliers and found that supplier response and readiness varies widely. Some suppliers are well prepared and are proactively addressing lead-free reliability issues in addition to basic RoHS compliance. Other suppliers have not begun preparation and risk losing large fractions of their customer base. Most are somewhere in between. It seems that momentum to adopt preferred plating and testing practices is growing, but many suppliers are still ramping up RoHS efforts so it is unclear what percentage of the component supply base will be RoHS compliant and further satisfy tin whisker mitigation requirements.

Many component suppliers in higher margin markets have invested resources and taken steps consistent with consortia group recommendations for high reliability markets based on their risk tolerance and customer demands (TI, Intel, AMD, Cypress). Additionally, some larger component suppliers in lower margin markets have dedicated central resources and taken a more proactive approach in anticipation of increased market share (Tyco). However, many smaller or low margin component suppliers have not yet taken an approach that will satisfy tin whisker mitigation requirements[39] due to the combination of the following factors:

- Reliability risks due to tin whiskers are not clear. Opinion on the significance of tin whisker impact on product reliability varies widely and is not likely to be substantiated until multiple years of field data are available or an understanding of formation and growth mechanics is gained.

- Industry consortia group recommendations for tin whisker mitigation continue to evolve and take time to work up the supply chain. Recommendations may be perceived as interim and suppliers are hesitant to invest in processes that may not be congruent with the final tin whisker solution.

- Management and engineering resources have not been available or assigned to understand lead-free technical issues. Without a good understanding of tin whisker issues planning and capital investment in equipment and testing necessary to meet high reliability requirements is unlikely.

- Components used in high reliability products may be common to consumer markets and customers who are not specifying tin whisker mitigation practices. Consumer product sales volumes may dominate and drive lead-free technical activity (or lack thereof).

- Customers have taken a firm 'no cost increase' position offering limited relief from cost

[39] Per John Quist of Cypress Semiconductor as of 11/04, none of his high volume, low margin suppliers had converted to NiPdAu yet. Many larger component suppliers are doing tin whisker testing, but others are pushing back and asking for compensation.

competitive markets, thus there is little incentive to invest beyond basic compliance.

Sun's reliability-driven technical requirements have been integrated into the Process and Product Change Notification (PPCN) and Approved Vendor List (AVL) review (scrub) processes. A RoHS Supplier Scorecard has been developed for Sun's major suppliers; the scorecard reflects which suppliers are best prepared. However, Sun's competitors are performing the same type of part list scrubbing and scorecard activity and will most likely identify the same diminished pool of preferred suppliers. Given that less than 100% of the industry supply base will be RoHS compliant, and that significantly less than 100% of the supply base will satisfy tin whisker mitigation requirements, Sun and others may face component availability challenges during the RoHS transition period (assuming that technical specifications are enforced). In addition to the obvious challenge of having no lead-free alternative for a specific part, Sun should consider the impact of component shortages due to the diminished pool of suppliers who satisfy tin whisker mitigation requirements.

6.2.5 Tin Whisker Mitigation Costs

Companies considering the business case to meet RoHS requirements have not typically completed a quantitative analysis due to industry momentum, customer demands, and the obvious motivation of potential loss of EU sales. It seems that most suppliers are in firefighting mode to become RoHS compliant and cost data for various tin whisker options either has not been generated or not shared. A qualitative discussion and rough estimates of supplier cost impact is given below and summarized in Appendix A.

Preplated nickel – palladium – gold lead frames: In most cases preplated frames must be purchased from an outside supplier at a significantly higher cost than tin-lead plated frames. Some semiconductor suppliers have taken this approach prior to RoHS based on cycle time and inventory cost reductions associated with outsourcing the plating step. Lower margin suppliers are not currently taking this approach.

Matte tin with nickel underlayer: Addition of nickel plating lines may require significant capital investment ($250K to $1000K).[40] Cycle time and operating costs will be higher based on the additional process step.

[40] Cost estimates from Sun RoHS Technical Team Leader, based on a manual plating line and automated nickel plating system.

Matte tin followed by a heat treatment step: Existing ovens may be utilized if they provide sufficient process control. New furnaces may be required with capital costs ranging from \$60K to \$120K.[41] Operating costs (energy) and cycle times will increase slightly based on the additional process step.

Matte tin: Existing tin-lead plating lines can be used to plate pure tin with minimal capital investment and no impact on operating costs.

Tin Whisker Testing: Tin whisker testing requires investment in test equipment and engineering resources. Cost impact depends on the number of plating lines to be qualified.

As mentioned previously, many higher margin and larger component suppliers plan to satisfy tin whisker mitigation requirements. These suppliers claim that alternative plating options and tin whisker testing costs are significant, but feel they are warranted based on tin whisker risks. They also recognize that price increases will not be openly absorbed by customers. Proactive suppliers hope to gain market share and expect RoHS costs to be absorbed or reflected in future pricing based on market conditions. Tin whisker mitigation costs may be more significant relative to lower margin supplier cost structures, but supplier pushback and limited activity seem to be driven by the combination of factors listed in the previous section in addition to direct cost impact. Component price increases are more likely to be driven by availability issues and other market dynamics than transfer of direct RoHS costs.

6.2.6 Competitor Activity Related to Tin Whisker Mitigation

Participants in the International National Electronics Manufacturing Initiative (iNEMI) User group working to develop tin whisker mitigation recommendations and standard tests for high reliability products include IBM, HP, Celestica, Tyco, Freescale, Cisco, Alcatel, Lucent, Storage Tek, and Delphi. Sun's RoHS specifications are consistent with NEMI recommendations for tin whisker mitigation, including component plating and testing practices. Dell, HP, and IBM requirements are also largely consistent with respect to material and process requirements; however, HP and IBM vary in their application of tin whisker mitigation requirements. Competitor tin whisker mitigation positions are as follows:

Dell: Per Dell's Lead-Free Program Director,[42] they plan to follow iNEMI recommendations for plating and tin whisker testing. Since it is a component level issue, they plan to be

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[41] Cost estimates from Sun RoHS Technical Team Leader based on installation of 6 or 10 zone furnace.

[42] 11/04 email discussions with Dave McCarron, Dell Lead Free Program Director and Scott O'Connell, Dell

consistent across all of their system level products. However follow up questions with environmental staff indicated they may "allow flexibility in this area based on risk" but did not clarify further. Per an LFM 2003 thesis Dell's broader quality program is administered consistently across consumer and server products.[43] Dell's consortia related activity has been focused on logistics challenges thus far.

HP: HP has developed a dual standard approach based on product reliability requirements.[44] Based on anticipated component availability challenges, they allow *consumer* product groups to independently review and accept matte tin plated components with no further processing (i.e. no nickel underlayer or heat treatment step) or tin whisker testing. Products classified as *price performance* and *high reliability* will adhere to requirements that are more restrictive than iNEMI recommendations for plating and tin whisker testing. Specifically, HP will accept matte tin components with a nickel underlayer and acceptable testing results, but does not currently accept matte tin components that have been heat treated based on their opinion that heat treated components do not provide sufficient tin whisker mitigation. HP is working to address significant procurement and operations challenges inherent in implementing this dual standard for component reliability.

IBM:[45] Per IBM's RoHS Team Leader, IBM has developed a dual standard approach based on component lead spacing.[46] IBM's plating requirements are similar to iNEMI and Sun plating requirements with the following exceptions: IBM accepts tin-bismuth plating, matte tin over Alloy 42, and matte tin over copper with no further processing (i.e. no nickel underlayer or heat treatment step) for components with lead pitches greater than or equal to 1mm. Although IBM lists additional less common plating options that may be proposed and reviewed on a case by case basis for specific applications, they basically follow iNEMI plating recommendations for components with lead pitches less than 1mm. However, despite their participation in iNEMI groups developing test methods and criteria, IBM does not require tin whisker testing for any components. According to Dr. Galyon, IBM may modify their requirements to be consistent with iNEMI recommendations, but do not currently require test data. This position

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Environmental Affairs manager.

[43] 11/04 discussion with Steve Schiveley on his 2003 LFM thesis at Dell: Reducing the Cost of Quality Through Increased Product Reliability and Reduced Process Variability.

[44] 11/04 discussion with Greg Henshall, HP RoHS manager.

[45] 12/04 email discussion with Dr. George Galyon, IBM Senior Technical Staff member / RoHS Team Leader, and IBM Engineering specifications forwarded by Dr. Galyon

[46] IBM has separate specifications for 'Server and Storage Purchased Electronic Components' and 'Electrical and Electronic Equipment for IBM Products', but the plating options are identical for both specifications.

varies from many competitors and suppliers; most suppliers who plan to utilize preferred plating options also plan to submit tin whisker test data.

In summary, both HP and IBM have taken steps to proactively address potential shortages of components that meet tin whisker mitigation requirements. Additionally, IBM does not currently require tin whisker testing. Dell seems to be taking an approach very similar to Sun's current position but it is not yet clear how they will allow 'flexibility' in meeting tin whisker mitigation requirements.

6.2.7 Evaluation of Methods to Proactively Address Component Shortages

As discussed in previous sections, Sun competitors have recognized the same potential shortages of components that meet tin whisker mitigation requirements and have adopted two methods to proactively address shortages. IBM has less stringent requirements for wide pitch vs. fine pitch components and HP differentiates based on consumer vs. mid to high reliability products.

Table 4 considers each method with respect to alleviation of potential component shortages, related reliability risks, implementation feasibility, and alignment with operations strategy.

Table 4: Evaluation of HP and IBM Methods to Proactively Address Potential Component Shortages

	HP dual standard for consumer vs. mid to high reliability products.	**IBM dual standard for wide vs. fine pitch components.**
Reliability Implications	Reasonable: Consumer products are accepting components of unknown reliability which seems reasonable given the uncertainty of tin whisker impact and challenges of meeting tin whisker mitigation requirements. If reliability impact is higher than expected, consumer product specifications can be modified accordingly.	Reasonable: Empirical observations of maximum tin whisker lengths indicate that the chance of failure due to bridging in wide pitch components is low.[47] However, this approach accepts the risk of whiskers growing on a wide pitch component, breaking off, and creating problems on other components. This risk has not been quantified to date.

[47] Galyon and Gedney, Avoiding Tin Whisker Reliability Problems, p.30

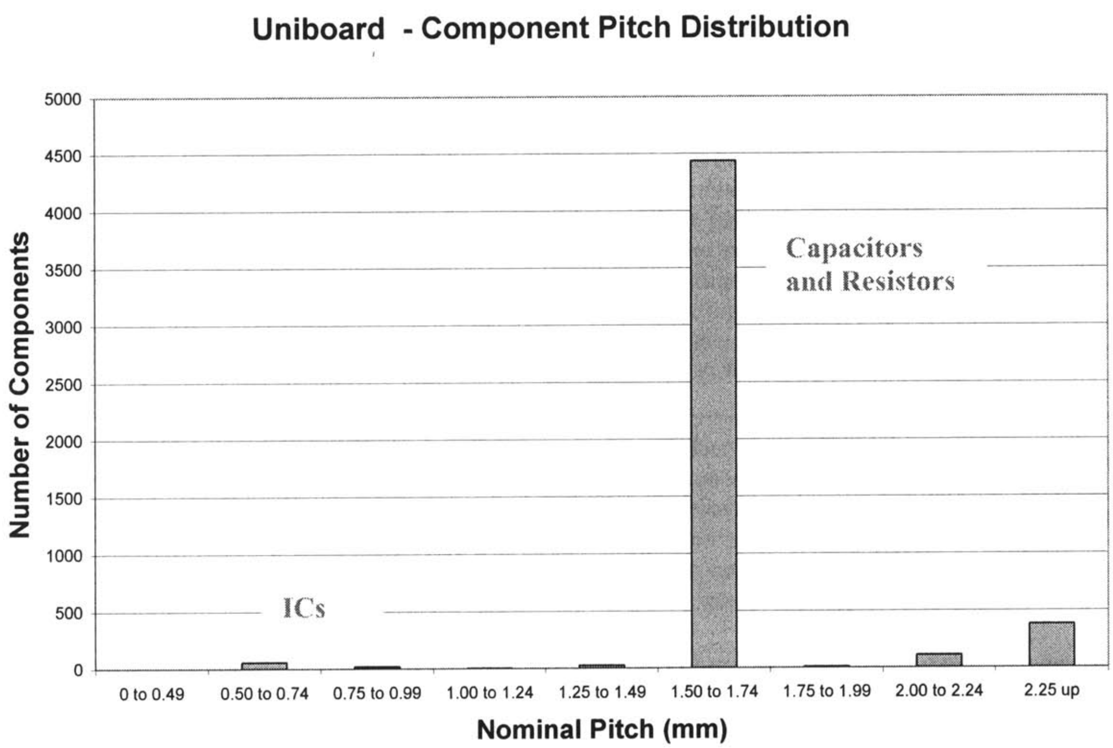
Implementation Feasibility	Poor: Many parts and suppliers are common across consumer to mid and high reliability products making this option very difficult to implement. Additionally, physical separation and tracking of parts that meet mitigation requirements vs. similar parts that do not would be a significant challenge.	Feasible: Sun could modify specifications and use one set for all suppliers. Suppliers of wide pitch components who meet tin whisker mitigation requirements should be given preference to reduce 'break off' failure risks. Balancing this issue with other procurement and supplier selection criteria will require communication and training. Otherwise implementation should be straightforward.
Alignment w/ Operations Strategy	Poor: Cost pressure and increasing hardware redundancy in the mid to high reliability markets is driving increasing part commonality and modularity across consumer and higher reliability products.[48] Developing different specifications for similar or identical parts will increase costs (part proliferation, inventory management, etc.)	Feasible: This approach should be consistent with procurement trends and strategy.
Alleviation of Component Shortages	Unclear: This approach should alleviate potential component shortages. However, finding low margin components that meet high reliability tin whisker mitigation requirements may remain a challenge.	Good: Analysis of a common Sun printed circuit board showed that most low margin components (including most capacitors and resistors) have a nominal pitch greater than 1mm. If this board is representative of Sun products, this approach should alleviate component shortages.
Bottom Line	Not Feasible: This option creates significant operating challenges and is not aligned with Sun's longer term procurement strategy.	Feasible: This option should alleviate potential component shortages and makes sense from an operations perspective. The main drawback is the potential reliability impact of tin whiskers as debris. Giving preference to wide pitch component suppliers who meet mitigation requirements would reduce this risk.

The Bill of Materials for a Sun Uniboard[49] was used to collect data for all components on the board. Data were sorted by component type and lead spacing. Figure 14 illustrates the distribution of component lead pitch for all soldered components on the board. This analysis showed that all components with a nominal pitch < 1mm are integrated circuits (ICs). As mentioned previously, IC suppliers are typically taking steps to meet tin whisker mitigation requirements. Low margin component suppliers who are less likely to meet reliability-driven requirements include most of the passive components with nominal pitch greater than 1mm. Modifying specifications to accept

[48] 9/04 discussion with Sun procurement strategy (PROST) manager.
[49] A Uniboard is a Sun designed printed circuit board used in a range of Sun products.

matte tin components with no tin whisker testing for components with a nominal pitch > 1mm should effectively alleviate potential component shortages.

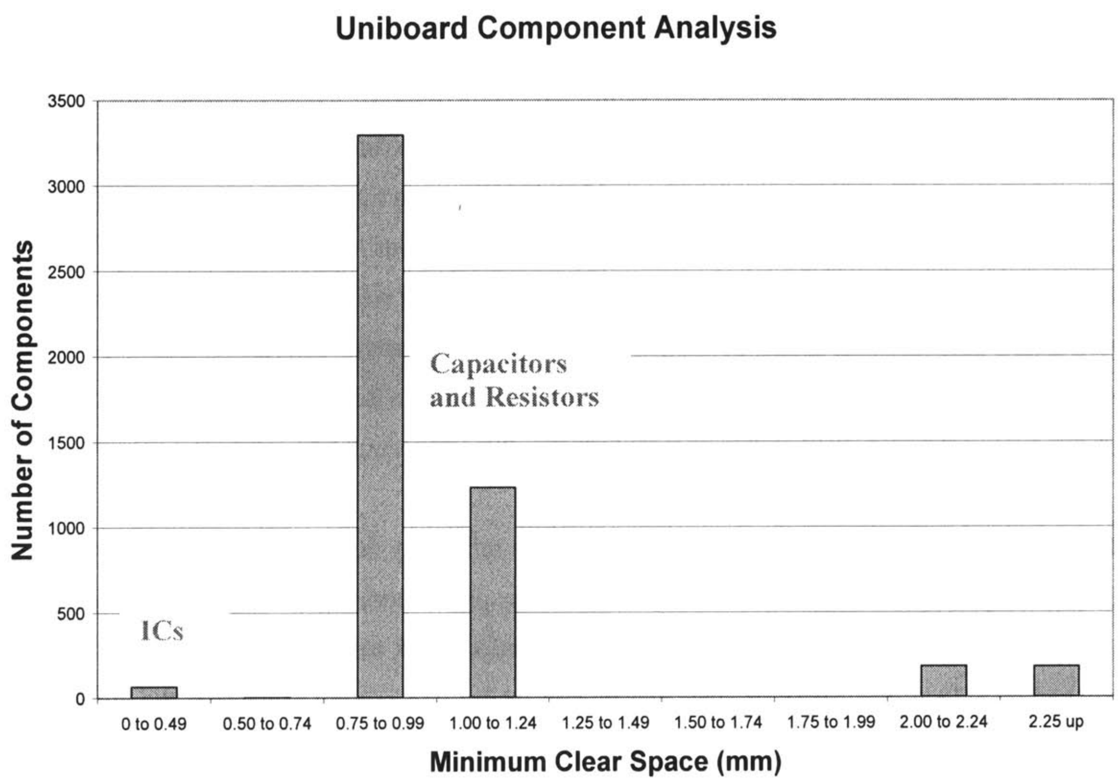
Figure 14: Distribution of Component Lead Pitch for a Sun Uniboard[50]



It should be noted that nominal pitch refers to the distance from the center of one lead to the center of the adjacent lead. The clear space between the leads, i.e. the distance a tin whisker must span to bridge between leads, is the nominal pitch less the average lead diameter. A conservative rule of thumb is clear space between leads equals ½ pitch. However, lead diameter data was gathered for each component in order to calculate actual clear space between leads. Figure 15 shows the distribution of Uniboard components based on minimum clear space.

[50] SMT capacitors and resistors with end terminals were assumed to have two leads with a pitch equal to the length of the component minus the width of one terminal.

Figure 15: Distribution of Component Minimum Clear Space Between Leads for a Sun Uniboard[51]



Many of the common capacitor and resistor package types have a minimum clear space of 0.9mm. IBM specifications refer to lead / pin pitch > 1mm implying that nominal pitch may be used to determine if components must meet high reliability tin whisker mitigation requirements. Sun may want to consider also specifying a minimum actual clear space (i.e. > 0.75 mm) in addition to nominal pitch > 1mm to avoid confusion and provide both standards for suppliers.

6.3 Solder Joint Reliability Testing and Contract Manufacturers

6.3.1 Lead-Free Solderability and Solder Joint Reliability (SJR) Testing Requirements

The industry is converging on a standard tin – silver – copper (SAC) solder alloy, solder paste, and ball grit array (BGA) material that has the potential to meet or exceed existing tin-lead solder joint performance and quality. However, the shift to high volume lead-free production poses process control challenges and learning curve effects which are likely to impact yield and quality in the

[51] SMT capacitors and resistors with end terminals were assumed to have two leads with a pitch equal to the length of the component minus the width of both terminals, i.e. clear space equals the minimum distance between terminals.

short term. Specifically, the SAC alloy requires not only a higher melting temperature, but also a tighter temperature range making process control more challenging than with tin-lead solder.

Decades of tin-lead solder process and reliability data are available. Current solder joint reliability estimates are based on historical tin lead solder joint data. With the introduction of new and unproven lead-free soldering processes, Sun and competitors are requesting that manufacturers conduct SJR testing per the IPC-9701 standard. This standard outlines the design of a daisy chain test board that allows testing of every solder joint geometry that will be utilized in products. IPC-9701 is a new standard and is still being adopted across the industry. Therefore, Sun's technical team will review supplier reliability testing programs and data to determine if test results provide equivalent reliability information even if not based on the IPC standard.

SJR testing is critical during the lead-free transition as reliability depends not only on material selection and joint geometry, but also assembly process parameters (thermal profile, solvent/carrier used, stenciling, etc.) that may vary by supplier or location. SJR testing requirements are likely to be relaxed once lead-free solder process quality and control are established across the industry.

6.3.2 Supplier Response and Cost Impact

Cost estimates to conduct SJR testing per IPC-9701 range from $100,000 to $250,000 depending on product complexity. Similar to tin whisker issues, supplier readiness and response varies. Some of Sun's suppliers have pushed back against SJR testing and feel that solder joint reliability testing should remain at their discretion and new requirements should not be implemented based on the transition to lead-free assembly. Suppliers who have not already begun testing are not likely to have data that meet RoHS qualification timelines. Alternatively, manufacturer's who have been the most proactive and organized in their preparation for high volume lead-free circuit board assembly typically independently initiated solder joint reliability testing in order to facilitate their transition to lead-free assembly. Sun's RoHS Supplier Scorecard may be used to identify contract manufacturers with acceptable SJR testing programs.

Timely completion of SJR testing is not a binary data point that will indicate whether a supplier will or will not be capable of lead-free production in time to meet RoHS deadlines; some suppliers will make process modifications and be RoHS compliant without completing SJR testing that meets IPC-9701 intent. However, *completion of SJR testing is a strong signal that a company has been planning for the transition to a new and unproven technology and is likely to have fewer yield* *and quality issues*. Additionally, some of Sun's customers are asking for this data to use in reliability models. Many suppliers expect the upfront investment in reliability testing to pay off in the form of a smoother transition and do not expect customer prices to increase as a result of testing requirements. Additionally, while SJR testing costs are not immaterial, engineering resource allocation and management understanding of RoHS challenges seem to be a far more significant roadblock to meeting high reliability technical requirements than additional direct costs.

Chapter 7 Corporate Environmental Strategy

Managers should look at environmental problems as business issues. They should make environmental investments for the same reasons they make other investments; because they expect them to deliver positive returns or reduce risks. [52]

- Forest Reinhardt

This chapter will make the case for Sun's investment in developing a corporate environmental strategy (CES). It will start with a discussion of why this is important now, then present a framework to gauge Sun's current position and trajectory and think critically about the best path forward. Sun-specific analysis and recommendations are included in Section 7.3. The RoHS initiative will be used to illustrate points where relevant.

7.1 Magnitude and Relevance: Why Environmental Strategy Now?

This section will explain why environmental strategy and compliance can no longer be delegated to narrowly-focused consultants or compartmentalized Environmental Health and Safety (EHS) departments. Two main trends driving this transition are:

1. Recent product-focused environmental legislation requires a more cross-functional, integrated response in order to minimize firefighting risk and costs.

2. The growing focus on business' role in sustainable development and related customer demands requires managers to consider business risks and opportunities associated with Corporate Social Responsibility (CSR) activity and sustainability programs that go beyond regulatory driven activity.

7.1.1 Legislative Trends

As outlined in section 2.3, recent legislative trends in the electronics industry require responses of greater magnitude and complexity than in the past. Electronics waste or 'e-waste' is a very visible and growing wastestream produced by high profile branded companies. RoHS is the first of many product-focused environmental regulations that will drive fundamental change in the industry.

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[52] From article titled Bringing the Environment Down to Earth published in the July / August 1999 Harvard Business Review, p. 149

The tactical effort required to achieve RoHS compliance could be compared to the effort required for Y2K with added political ambiguity and product technology challenges. Industry-wide compliance costs will reach millions of dollars with single organizations dedicating significant resources across a range of functional groups and product teams. The European Union has drafted or enacted the most significant environmental legislation thus far; however, many countries and states are following with similar legislation that reinforces EU regulations.

Historically, environmental regulations have focused on 'end of pipe' controls and disposal methods for manufacturing facility emissions and wastes including air, water, and solid waste streams. Recent trends have moved 'upstream' to focus on the impact of products not only during the manufacturing stage, but during the use and disposal phases as well. The three major types of product-focused regulatory trends observed in the electronics industry are discussed here.

Materials Reporting and Restrictions

As research on the long-term health and ecological effects of materials used in production increases, more materials are identified as potentially harmful. In addition to manufacturing emissions controls, recent legislation has focused on disclosing and /or eliminating the use of the most toxic or harmful materials in products or manufacturing processes. Materials reporting requirements or restrictions have been imposed for specific compounds or elements such as arsenic, polychlorinated biphenyls (PCBs), and now lead(Pb) and the other RoHS restricted materials.

This 'upstream' approach is typically more efficient than end of pipe controls from both the cost and environmental / health impact perspective if good alternative materials are available. However, as discussed in Sections 3.2 and 3.3, the RoHS initiative has illustrated that finding suitable replacements for key materials involves significant technical, operations, and communication challenges. Internally, all hardware products and functional groups are impacted and must be engaged in order to make a successful lead-free transition. Externally, collaboration across a complex value chain is difficult with outstanding data organization and transfer challenges threatening to drive implementation costs even higher.

Extended Producer Responsibility

As discussed previously, the electronics industry generates many products with short life spans. Products are replaced often due to obsolescence and newer generation models, subsequently generating a large visible waste stream. Extended Producer Responsibility (EPR), also referred to as End of Life or Extended Producer Liability (EPL), legislation is intended to address the impact products have at the end of their useful life. EPR legislation typically involves making producers financially responsible for collection and disposal of products they manufacture. Ideally, the transfer of end of life costs from consumers to producers would drive the design of more durable, reusable, modular, recyclable products in order to reduce end of life disposal costs. Additionally, if it is more expensive to handle and dispose of hazardous materials, it should also drive reductions in the use of those materials. Of course, the end of life costs must be significant enough to drive changes in product design for EPR legislation to effectively reduce the volume and impact of the electronics waste stream.[53]

Figure 16: Impact of EPL Legislation on Product Development

	Dispose	**Recycle**	**Reuse**
Material Selection	▪ Non-Hazardous ▪ Non-toxic ▪ Acceptable for Landfill/Incineration	▪ High Salvage Value ▪ Can be Recycled ▪ Cost to Recycle not Prohibitive	▪ Durable ▪ Repairable
Product Design	▪ Design to Long-term Customer Needs ▪ Minimize Material Use / Mass ▪ Better Durability ▪ Compatibility with Future Models	▪ Deconstructable – simple design ▪ Minimize permanent connections (glue) ▪ Minimize number of parts ▪ Label components	▪ Modular design ▪ Standardized Components ▪ Compatibility with Future Models ▪ Expandable ▪ Upgradeable

This type of legislation may or may not be tied to recycling requirements. The European Union passed EPR legislation as the Waste Electrical and Electronic Equipment (WEEE) Directive. The WEEE Directive requires producers to finance or conduct recovery of a target percentage of products, sets recycling targets, and makes the producer responsible for final disposal. This Directive will drive the expansion and / or development of collection, disassembly, and recycling infrastructure. If end of life costs are significant, it will also drive broad product development modifications to reduce end of life costs, hence environmental impact as shown in Figure 16. Design for environment (DfE) programs similar to current programs often referred to as DFX where 'X' may refer to manufacturing, supply chain, quality, etc. may be implemented at more

[53] A presentation by the thesis author and teammates for MIT's Industrial Ecology course postulated that the use of EPR legislation in combination with increased landfill, incineration, and other disposal fees may provide market incentives that drive product innovation and reduced environmental impact.

companies in greater detail and depth than in the past. This will require cross-functional understanding of environmental impact and add criteria to already complex design processes.

One advantage of EPR regulations is that they can be implemented similarly across industries and countries. Once implemented, innovative firms will integrate end of life costs into their cost structure and modify product design accordingly in order to reduce costs with little governmental intervention.

<u>Life Cycle Performance / Use Impact</u>

Life cycle performance analysis can include the environmental impact of products from raw material and manufacturing through product use and disposal. However, this type of exhaustive analysis is time consuming and expensive and typically only used to support strategic decisions such as material selection or public policy assessment. Although it is likely to expand in the future, current 'life cycle' legislation addresses the environmental impact of products during their useful life. Regulations typically involve fuel consumption, energy efficiency, or emissions; for electronics products, energy efficiency is the most relevant goal. The European Union is developing legislation to address eco-efficiency of Energy Using Products (EuP) that includes an energy efficiency component requiring energy efficiency reporting and efficiency targets. In most cases the electronics industry already has strong incentives to improve energy efficiency, but environmental legislation may drive further improvements and provide better information to intermediate customers and consumers who actually incur the energy costs.

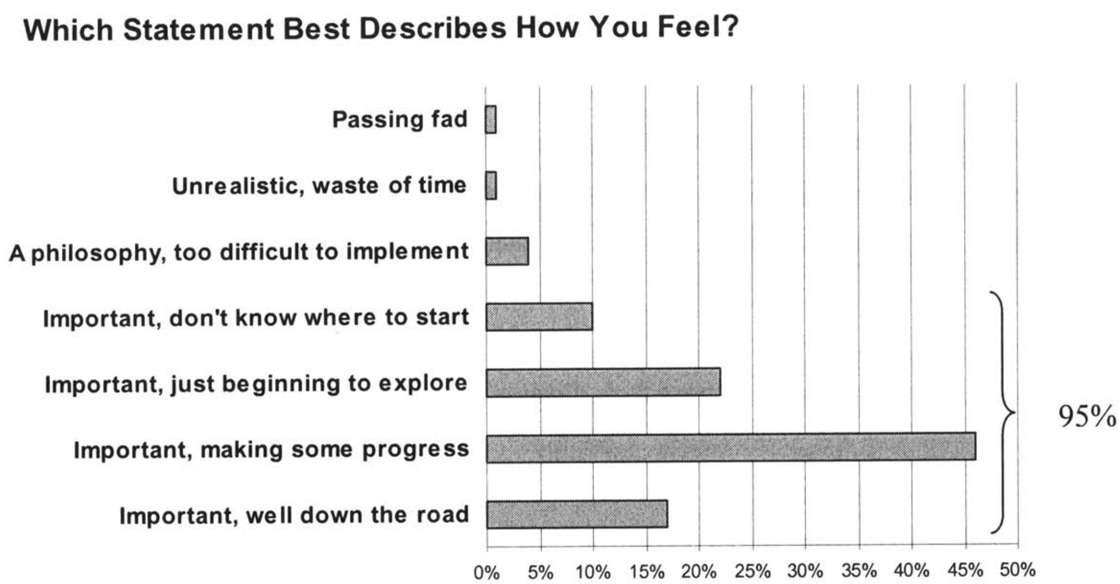
In summary, regulatory trends are shifting from dictatorial end of pipe regulations to a broader focus on product content and performance. Compliance and associated costs are no longer ancillary to core business strategy and operations and product groups. The EHS department cannot independently drive any of the implementation programs required to meet recent EU Directives. Regulation drive product redesign, impact product costs, influence supply chain and operations strategy, and require a comprehensive implementation plan and a high level of cross-functional coordination further complicated by the need for industry standards and development of end of life infrastructure.

7.1.2 Sustainability Buzz

Sustainable development and broader corporate social responsibility (CSR) ideas are becoming common topics in business settings. Company mission statements and visions, corporate dialogue, and board room discussions increasingly include sustainability topics. Companies are reporting their efforts and CEOs sign Annual Sustainability Report cover letters. Managers participate in, and sponsor training and task forces to address sustainability issues, and management consultants have sprouted sustainability groups. As Clive Crook stated in a January 2005 interview published in the Economist, "Most multinationals now have a senior executive, often with a staff at his disposal, explicitly charged with developing and coordinating the CSR function. In some cases, these executives have been recruited from NGOs. There are executive education programmes in CSR, business-school chairs in CSR, CSR professional organizations, CSR websites, CSR newsletters and much, much more."

A 1998 Arthur D. Little (ADL) survey [54] of North American and European business executives reported that 95% of respondents felt that sustainable development is an important management topic and 85% indicated that efforts to address sustainability at their firms have been initiated.

Figure 17: ADL Survey of 481 Executive Respondents in North America and European Companies.



One of the largest sustainability coalitions, the World Business Council for Sustainable Development (WBCSD) has 175 member companies from more than 35 countries and 20 major industrial sectors with a stated commitment to sustainable development via the three pillars of economic growth, ecological balance, and social progress and the belief that the pursuit of sustainable development is good for business and business is good for sustainable development.[55] A multitude of business and NGO coalitions, the United Nations, and World Bank have also developed sustainability positions and programs.

7.1.3 Customer Requests

Growing awareness of sustainability topics and environmental impact has led to related customer requirements and requests for information. Sun routinely receives surveys and audits from customers regarding environmental practices and performance. Customers range from large telecom companies to government departments. In some cases countries including the United States are passing environmental guidelines for electronics procurement that apply to multiple departments within the government. Typically the surveys and audits cover environmental management processes and product content. Many organizations are developing lists of materials that are prohibited or limited for use in procurement agreements. The lists are typically a compilation of materials restricted or controlled in all markets that the firm operates or sells in. The lists may also contain materials that are expensive to handle or dispose of due to environmental and health risks or materials that the customer expects to be restricted in the future. Organizations may use the list or audit in a binary approval process such as Sun's Approved Vendor List (AVL) or give preference or a higher ranking to suppliers who best meet the material restrictions.

7.1.4 Corporate Environmental Activity - Collaboration or Competitive Advantage

As discussed in Section 2.1, the use of standard materials and assembly technology is important in the vertically disintegrated electronics industry, i.e., there are strong incentives to collaborate to maintain industry standards and supply chain consistency. It is not clear that customers will pay more for better environmental performance, but they do seem to expect suppliers to meet a basic threshold with respect to environmental management systems and performance. Thus far, it seems that Sun and other OEMs must meet industry norms in order to be considered by some customers, but do not expect customers to base purchasing decisions on performance above those norms. However, there are both immediate and longer term opportunities to gain competitive advantage with respect to environmental performance. In some cases, the advantage may be the ability to effectively structure and drive environmental initiatives; in other cases, core business strategy and operations may be aligned with environmental goals.

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[54] Figure copied from 2002 Sarah Roberts Arthur D. Little presentation to OIKOS, titled "The Role of Strategic Consultancies in Promoting Corporate Sustainability."
[55] Information taken from the WBCSD website www.wbcsd.org.

Ability to Drive Cross-Functional Environmental Initiatives

RoHS compliance and lead-free technology is not typically viewed as competitive; RoHS implementation is mainly viewed as a cost to be minimized or risk to be mitigated. However, the ability of a large organization in a rapidly evolving industry to plan and execute cross-functional and supply chain initiatives, environmental or other, is obviously a source of competitive advantage. All three of the regulatory trends discussed require complex cross-functional responses thus a company's ability to identify and structure environmental initiatives is increasingly important, and the competitive impact of a company's ability to execute complex cross-functional programs is amplified.

Adapting Design Processes to Create Value from End of Life Products

EPR legislation should create opportunities for companies to compete on end of life product strategy and operations. If a company can modify its product development processes to eliminate hazardous materials that are expensive to dispose of, reduce the labor required to disassemble and recycle a product, or design a product such that modular parts are reusable, it can dramatically reduce end of life costs. Companies with flexible product development processes will require less effort and cost to integrate 'design for end of life' criteria into the process. Again, existing competitive advantage may be amplified by environmental initiatives.

Leveraging Technology Development and Product Design Expertise

In some cases, legislation pushes companies further in a direction that already makes sense from a financial perspective. For example, there are already strong incentives to design energy efficient systems that generate less heat, and to reduce the size, thus material demands, of most electrical parts and systems. Regulatory requirements may drive further improvements and reward companies with the best performance by potentially increasing relative cost to competitors to meet the requirements.

Minimizing Supply Chain Risk

Downstream electronics companies see environmental and social performance of suppliers as a reputation risk with the quintessential example being Nike's negative publicity due to its suppliers' labor practices. Many companies have initiated efforts to monitor supplier performance on these issues; given that most suppliers serve a range of customers, they are facing a multitude of audit and survey formats. A collaborative effort including IBM, Dell, Solectron, Sanmina SCI, Jabil, Celestica, and Flextronics, and led by HP recently published a Supplier Code of Conduct intended to establish a standard set of expectations and reporting format for supplier environmental, social, and employee health issues. Thus minimizing reputation risk related to supplier may be a collaborative effort.

Meeting Customer Needs

Environmental legislation impacts customers who purchase Sun products for resale in a larger system or application; these customers are likely to expect their suppliers to manage implementation and compliance just as Sun expects their suppliers to do so. Thus there does seem to be an opportunity for OEMs and EMs to differentiate themselves with respect to facilitating and potentially managing RoHS transition activity and other complex compliance efforts for customers.

Pushing Legislation Based on Relative Implementation Costs

Companies that develop a proactive corporate environmental strategy and feel that they are better positioned, whether based on environmental-specific capability or broader business process or technology strengths, to meet environmental legislation may push for earlier or more extensive regulations. In some cases, these companies see opportunities to align environmental activity with core business activity; in other cases, they expect to have lower implementation and compliance costs relative to their competitors so although their costs may increase, they will have a comparative advantage.

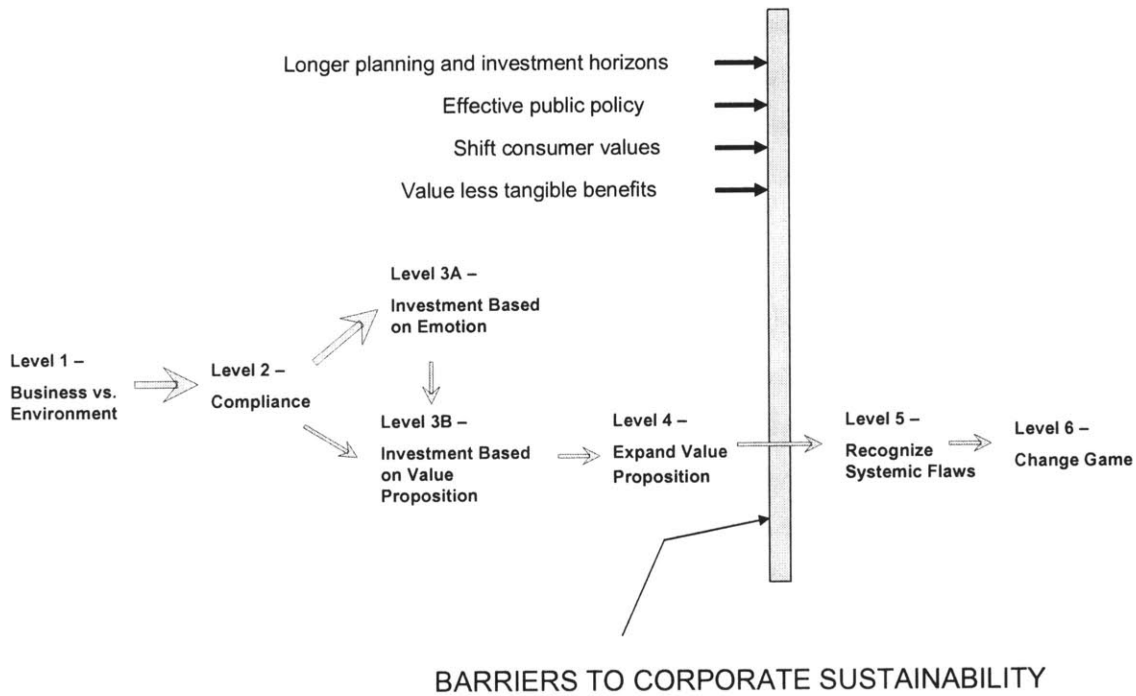
In summary, there are significant incentives for companies in the electronics industry to collaborate to maintain or improve value chain efficiency and supplier monitoring. However environmental performance is increasingly a source of competitive advantage. Sections 7.2.4 and 7.2.5 include discussion on additional benefits and potential competitive advantage related to environmental performance and CSR programs.

7.2 The Evolution of Corporate Environmental Thinking

7.2.1 Introduction of Framework

The author developed the following 'Corporate Environmental Strategy' framework to help companies recognize their current position, consciously develop an environmental strategy, and potentially understand how they can realistically evolve towards sustainable operations in a manner that does not conflict with traditional business objectives.[56] The framework presented here describes 6 stages or levels of thought with respect to how for-profit firms think about the environmental impact of their products and operations, and their role in the natural and societal systems that support the economic system they operate in.

Figure 18: Corporate Environmental Strategy Evolution



Levels 1 through 4 are relevant to Sun and most other organizations at this point. Levels 5 and 6 are included to complete the framework and address concerns that evolution to level 4 does not lead to long term environmental solutions and sustainable development goals. Sun is currently at Level 2 with the goal of leapfrogging to Level 3B. Section 7.3 discusses their current trajectory towards Level 3A and the steps necessary to redirect efforts towards Levels 3B and 4.

Level 1: Enemies - Business vs. Environment: Companies at this level oppose or ignore environmental regulations, make no investment in related activity, and see no alignment between business and environmental objectives. Most organizations in developed countries have evolved past this phase.

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[56] Ideas expressed in the framework are a result of attending sustainability conferences, reviewing related literature, assessing corporate environmental programs, and discussing related challenges with industry

Level 2: Compliance – Meet Legal Obligations: Most companies meet their legal obligations and maintain their right to do business with respect to environmental regulations. Environmental activity is viewed as a cost to do business to be managed by EHS professionals whether they are located with external consultants or specialized EHS departments. Improving environmental performance beyond compliance is not typically viewed as necessary or productive. Recently, many companies have begun to question this position and evolve, in theory if not practice, to the following phases. Most companies take an approach consistent with Level 3A, but some are developing the capability and discipline to reach Level 3B.

Level 3A: Find Religion – CSR Programs Based on Emotion and Good Intentions: Increasingly, business people are questioning the role of business as it relates to broader environmental systems and social well-being. Business is well positioned to take meaningful action on a range of environmental and social challenges. In some cases, environmental and social goals are aligned with business objectives. However, for companies at this level activity is often based on emotion, NGO pressure, or a 'bullet point' business case[57] rather than a meaningful value proposition. Although the company may benefit from 'green marketing' or employee motivation and may eventually evolve to Level 3B, companies at this level are more likely to experience poor returns on investment, a loss of momentum and credibility for CSR type activity, and only superficial gains with respect to environmental and social impact. The Economist published a series of articles in January 2005 detailing the pitfalls of companies at this level.[58]

Level 3B: Back to Business - Investment Based on a Value Proposition: Companies at this level recognize that there can be alignment of environmental and social goals with business objectives thus potentially significant opportunities to create and capture value by viewing 'beyond compliance' environmental and CSR activity as an investment. As with any strategic initiative or investment, a value proposition must be developed to justify capital outlays and dedication of resources. The value proposition must consider industry and organizational factors as they relate to the company's ability to realize attractive returns on investment in

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managers and classmates.

[57] The author uses the term " 'bullet point' business case" in reference to the common abbreviated summary of CSR benefits found in many corporate presentations and annual reports on sustainability programs and the lack of in depth or company/industry – specific analysis behind the summary.

[58] The author found that much of the content in the Economist articles was consistent with content in Level 3A. However, other assumptions and conclusions from the same articles are not consistent with the author's

environmental and social activity. Companies at this level recognize potential benefits such as reduced manufacturing costs, reduced risk and future liabilities, and improved ability to implement regulatory-driven cross-functional environmental initiatives. For a company to reach this level, they must dedicate management resources in order to develop and communicate an appropriate value proposition. There is no business reason for a company to not be at this level other than severely limited resources or a myopic focus on short term results.

Level 4: Recognize Less Tangible Benefits – Expand the Value Proposition: Evolution to this level is difficult, but the benefits are potentially significant. Companies at this level recognize that returns on investment in 'beyond compliance' environmental and social activity may be in a less tangible form than reduced costs. This type of benefit is difficult to isolate and quantify, but may be far more significant than the more visible waste reduction and cash flow benefits. Benefits include enhanced corporate reputation and easier access to capital, easier recruitment of new employees, better retention, motivation, and productivity of existing employees, improved risk management, better product design and process efficiency, and potential alignment with core strategic initiatives such as the transition from product to service. Isolation and quantification of less tangible benefits is difficult and may lead back to 'bullet point' business case challenges.[59]

Level 5: Economic Theory vs. Reality - Recognize Systemic Flaws: If all companies developed corporate environmental strategies that allowed them to evolve to Level 4 behavior, we would see dramatic improvements in environmental and financial performance. However, companies would still need to evolve further to do more than slow the negative effects of an expanding, unsustainable system. Systemic flaws (economic, political, social) prevent business incentives from being fully aligned with environmental goals and society well-being. Human inability to understand, predict, and satisfactorily manipulate complex systems, increasing focus on short-term results, and business ability to influence public policy and societal values all contribute to the misalignment of incentives.

Level 6: Change the Game – Influence government and consumers to address systemic flaws:

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position as described in Levels 5 and 6.

[59] The author did not do so for this thesis, but feels that system dynamics can be used to evaluate the magnitude, drivers, and interrelation of less tangible benefits.

In order to be competitive for-profit companies must pursue traditional business goals, focusing on environmental performance only when it makes sense from a business perspective. However, business is uniquely positioned to work with government and consumers to address systemic flaws. Mature, successful companies or new companies with disruptive business models or technology may evolve to level 4, then consider how they might influence public policy or consumer values to improve the alignment of business goals with environmental and social well-being.

Operating in The Existing System: Levels 1 through 4

Sustainability and CSR buzz and corporate activity is increasing. This trend has the potential to lead to dramatic gains with respect to preservation of natural resources and systems, and society well-being. Due to the magnitude and complexity of the challenges being considered, this trend also has the potential to lead to poorly defined goals and incoherent corporate programs, poor return on investment, loss of credibility, and ultimately, dismissal as an irrelevant fad. Given the gravity of the challenges and current trajectory, the latter would certainly be viewed as tragic in retrospect. Levels 1 through 4 include information on how companies might develop a cohesive and profitable corporate environmental strategy and avoid this loss of momentum and position themselves to facilitate the shift towards a more sustainable economic system.

7.2.1 *Level 1*: Business and Environment are Enemies

At this level, the perception is that doing what is good for the environment is contradictory to what is good for business. Diversion of capital or management resources to address environmental issues is viewed as a cost with no meaningful return, a distraction from the core business of the organization. 'Environmentalists' are most likely viewed as liberal, unreasonable and out of touch with the reality of business and the economy. Regulatory-driven environmental controls are opposed, potentially based on claims that associated costs hurt competitiveness and job creation.

Who's Here

Most organizations have matured past this base level. Organizations in developed countries are largely compliant with current environmental regulations, conscious of the benefits of waste reduction and energy efficiency basics, and at least publicly, less opposed to environmental controls than in the past. Organizations and entrepreneurs in less developed countries typically face capital and technology or knowledge transfer limitations that prevent them from leapfrogging over heavily polluting practices to more efficient technology, but many are aware that this is a possibility, that gross uncontrolled pollution is not a prerequisite for development.

Corporate funded lobbyists still seek less stringent environmental regulations, but the argument that sound environmental policy and reasonable environmental controls dampen economic development and growth has been scaled back. This type of argument is typically only used in two situations. First, it is used by industries or organizations that are least able to innovate or adapt to changing requirements, i.e., companies where compliance costs are highest relative to competitors, and industries where compliance costs may accelerate disruption by a competing technology (such as the displacement of coal based energy production). Second, this argument may be used in developing countries facing capital and technology or knowledge transfer constraints. In developed countries, competing organizations or alternative technologies are likely to render the argument irrelevant in the long term as the organization or industry least able to adapt is likely to be susceptible to broader competitive challenges. The question of how developing countries might follow a less destructive economic and industrial development path is very relevant, but beyond the scope of this thesis.

Benefits of Being in This Stage

In the short term, operating in this stage reduces immediate investment of resources to install modern efficient equipment, control pollution, and reduce environmental impact. Management and capital resources are free to be deployed on other strategic and tactical issues. If the majority of the organizations in an industry are in this stage, they may wield significant enough political power to prevent increased regulation and environmental requirements.[60]

Pitfalls of Being in This Stage

Companies remaining in this stage may be there due to operational, technology, and capital constraints or an inability to adapt, both of which are likely to become competitive liabilities as other organizations, industries and stakeholders evolve further. Further, access to capital may be constrained based on environmental practices and liabilities, ability to influence future environmental policy may be limited relative to more proactive competitors, and community or consumer backlash and negative publicity is a distinct possibility if environmental performance is deemed to be unacceptable.

[60] Companies who argue for self regulation and market solutions may fall into this group if they do not address environmental issues. However, more evolved companies who effectively address environmental impact may also argue for less restrictive legislation and more market based regulations.

Misconceptions and Barriers to Evolution Past this Stage

Companies may remain in this stage if environmental regulations (1) do not exist or are not enforced, (2) are perceived to be overly restrictive or inefficient with respect to environmental benefit relative to implementation cost, or (3) impact a company or industry significantly relative to competitors. Most companies in the US transitioned from Level 1 to Level 2 as environmental legislation was passed during the 1960s and 70s. Companies and industries that are less able to adapt have opposed legislation and face potentially painful and costly transition periods. A decline in traditional industries and jobs may create strong political opposition to environmental legislation even if it is not responsible for the decline. As discussed in Section 7.1 public policy is evolving with the intent of allowing business to innovate and compete to meet environmental goals efficiently, i.e. good public policy generates the same environmental benefits at lower cost with less opposition. As outlines in Section 3.1.3, the RoHS Directive has been criticized and opposition may be partially due to questionable environmental gains relative to implementation costs.

7.2.2 *Level 2:* Compliance – Meet Legal Obligations

Companies at this level are compliant with environmental regulations. They maintain their legal right to do business and manage environmental impact responsibly as dictated by public policy. Environmental activity is viewed as a cost of doing business to be managed by EHS professionals whether they are located with external consultants or ancillary internal departments. Improving environmental performance beyond compliance is not typically viewed as necessary or productive. In many cases, it has never been considered as a potential source of financial returns or competitive advantage. EHS departments are likely to be structured as cost centers with limited visibility or influence across functional or product groups and limited contact with senior management.

Who's Here

As mentioned in the previous section, most companies in developed countries have evolved past level 1 and are compliant with current environmental regulations. Many companies have begun to consider their role in addressing beyond compliance environmental and social issues and may have articulated a commitment to evolve further putting them at Level 3A, but in reality, most corporate investment and activity is still regulatory-driven. As Figure 18 shows, most companies evolve towards Level 3A, but some consciously jump to Level 3B.

Benefits of Being in This Stage

Companies in this stage maintain their legal right to do business and reduce environmental related liabilities and future risk. They allow public policy to judge the level of environmental protection necessary, do not dedicate resources to non-essential environmental planning and activity, and avoid potential pitfalls of Level 3A activity. This is a conservative, defensible position for most companies.

Pitfalls of Being in This Stage

Companies who continue to view corporate environmental activity as a cost and delegate responsibility to specialized EHS consultants or departments are subject to the following pitfalls:

- Limited capability to anticipate, plan, and drive complex, cross-functional responses to product focused environmental legislation leading to increased costs and compliance risks.
- Poor competitive position relative to more proactive competitors who influence legislation based on their strategic position and capabilities, i.e., if competitors perceive a gap between their ability to meet regulatory requirements, they may push legislation further to widen the gap and leverage their relative cost advantage.
- Limited ability to recognize high ROI opportunities related to proactive, 'beyond compliance' environmental activity. If environmental activity is perceived as a cost of doing business to be managed by EHS specialists who do not focus on or understand core strategy and operations, positive NPV projects will be ignored.

In summary, companies in this position are not equipped to meet upcoming legislation in a cost effective manner, and competitors who are better positioned may push legislation to amplify this comparative advantage. Further, companies who consider environmental related activity purely as a cost are forgoing potential returns where environmental goals and business objectives are aligned.

Misconceptions and Barriers to Evolution Past this Stage

The primary barrier to evolution beyond basic compliance is the perception that environmental activity is a cost to be minimized vs. an investment opportunity with potentially attractive returns. Companies at this level have not dedicated management resources to consider the alignment of environmental goals with business objectives. Severe cost pressures, short term planning, or a myopic focus on core business strategy may prevent the dedication of management and capital resources required to realize returns, i.e., alternatives must be assessed and investments made to yield returns. Companies struggling with basic business strategy and operations are not likely to have the bandwidth to consider this type of strategic investment; as Peter Drucker put it, "*To be good to the environment, one must already know how to be very good at production.*"

Additionally, some companies may subscribe to popular economist arguments that business objectives are fully aligned with social and environmental welfare given free market pricing of goods. Mainstream economic theory indicates that while public policy may be required to address externalities, business provides the most social benefit by pursuing traditional goals. The author believes the assumptions underlying this argument and the disconnect between economic theory and reality require further attention. A brief discussion of these topics is included in Section 7.2.6.

7.2.3 *Level 3A*: Find Religion – CSR Programs Based on Emotion and Good Intentions

Increasingly, business people are questioning the role of business as it relates to broader environmental systems and social well-being, recognizing that business is well positioned to take meaningful action on a range of environmental and social challenges. Although there may be cases where environmental and social goals are aligned with business objectives, *companies at this level do not base activity and investment on a comprehensive value proposition.* Alternatively, activity is often based on emotion, executive special interests, NGO pressure, or a generic 'bullet point' business case [61] rather than an in depth business analysis.

> "*The business case for implementation is often built on individual conviction or motivational case examples, rather than being grounded in solid theory with associated frameworks, guidelines, and tools.*" [62]

CSR activity and sustainability programs may cover a broad range of environmental and social goals and involve investment of resources by many organizational groups within a company. Philanthropic activity is often lumped in with other CSR activity, and goals other than traditional business objectives[63] are often cited as the basis of investment, further complicating overall CSR strategy and justification. Individuals responsible for managing CSR activity and sustainability programs are often EHS specialists or environmentalists recruited from NGOs; these individuals

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[61] The author uses the term " 'bullet point' business case" in reference to the common abbreviated summary of CSR benefits found in many corporate presentations on sustainability programs and the lack of in depth or company or industry – specific analysis behind the summary. Often this abbreviated business case makes the blanket assumption that what is good for the environment is good for business which may or may not be true.
[62] Farrukh et al, p. 527
[63] Intermediate goals related to environmental impact and social well-being may be aligned with business

most likely have a great deal of passion for the topic, but may lack business experience and understanding of core strategy and operations. As Bob Willard explains in *The Sustainability Advantage*, "Most environmentalists know less about accounting than accountants know about the environment." [64]

Who's Here

As mentioned in Section 7.1.2, the topic of environmental sustainability has entered the thoughts and language of most companies and executives. However, sustainability is a complex topic, introduced into the private sector fairly recently. Most companies are still trying to make sense of what sustainability means for them, how it fits within their competitive strategy and operations. Most corporate CSR and 'beyond compliance' environmental activity currently seems to lack a coherent strategy or sound value proposition, thus fall into this level of thinking.

Benefits of Being in This Stage

Companies at this level may be in an awareness or sensemaking phase and potentially evolve to Level 3B. In the meantime, companies may benefit from 'green marketing' and improved recruiting based on public perception of sustainability type efforts. Employees at all levels may be positively motivated as long as they feel their efforts make a difference.

Pitfalls of Being in This Stage

Common pitfalls of indiscriminate investment in CSR activity have been well documented as of late. The Economist published a series of articles in January 2005 detailing negative impact of CSR activity on companies operating at this level.[65] The following excerpts from a Michael Porter interview on CSR cover many of the pitfalls inherent to subjective investment in CSR activity.[66]

> *My major criticism is that the field of corporate social responsibility (CSR) has become a religion filled with priests, in which there is no need for evidence or theory. Too many academics and business managers are satisfied with the 'good feeling' as argument. Much corporate philanthropy is driven by top management's personal beliefs.*

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objectives, but the relationship is often not assessed in depth or cited as the basis for investment.

[64] From *The Sustainability Advantage* by Bob Willard, p. 12

[65] The author found that much of the content in the Economist articles was consistent with content in this thesis section. However, other assumptions and conclusions from the same articles are not consistent with the author's position as described in Levels 5 through 7.

[66] The Michael Porter interview was published by the European Business Forum (EBF) at www.ebfonline.com

My concern is that companies are reacting to pressure rather than having their own affirmative strategies. The giving is not integrated into strategic thinking, and quite a few corporate leaders are not sure that the money they spend is well spent. If we want to make sure that companies – not leaving it to individual leaders – are to maintain an interest in corporate social initiatives we have to provide the rationale for them as to why they should be doing it. If companies are just being good and donating a lot of money to social initiatives then they will be wasting shareholders' money. That is not sustainable in the long-run, and shareholders will quickly lose interest. Giving money away is easy, but if that is all it is going to create cynicism – among shareholders, managers and employees.

- Michael Porter

Companies who invest in CSR and beyond compliance activity on any basis other than a critical business value proposition risk the following:

- Poor return on investment and a subsequent loss of momentum and credibility for CSR type activity.
- Superficial environmental gains or improvement "at the margin" [67] or as Economist writer Clive Crook stated, "*For most conventionally organized public companies – which means almost all of the big ones – CSR is little more than a cosmetic treatment.*" [68]
- Potential backlash, internally or publicly, if corporate activity is perceived to be hypocritical relative to CSR statements, or if CSR and sustainability activity is viewed as superficial.

In summary, indiscriminate investment in CSR activity and sustainability programs will, at best, lead to increased learning and awareness of business impact on the environment and society and eventually progress to disciplined programs with more substantial benefits. At worst, it may distract attention from complex and significant environmental and social challenges, delay meaningful activity, waste business resources, and create cynicism, both inside and outside of the company.

Misconceptions and Barriers to Evolution Past this Stage

CSR advocacy at this level can take several forms; each type may or may not evolve to a more productive level:

[67] This phrase is used by Kate Parrot in her MIT Engineering Systems Design (ESD) doctoral thesis draft proposal.
[68] January 2005 Economist article titled The Good Company

1. *Uninformed Enthusiasm*: As discussed in Section 7.1.2, there are a multitude of resources, opinions, and case studies on sustainability and corporate social responsibility. As individuals and companies become more aware of environmental and social issues, they may wish to make a difference and take action without assessing how sustainability relates specifically to their company or situation. This may lead to an ineffective blend of generic CSR activity and investment. Early awareness level efforts often mislabel philanthropy or office recycling and waste reduction programs as sustainability solutions. This may not be a barrier if thinking and activity evolve past this level, but ineffectiveness and mislabeling may delay more meaningful activity, create cynicism, and waste company resources.

2. *Altruism*: Some advocates would prefer to ignore the underlying economic system and traditional business incentives, insisting that businesses should base their strategies and operations on a broader set of objectives including environmental and social goals. The author feels that as long as the incumbent economic system is dominant, companies are forced to behave based on traditional business incentives. Certainly there are business reasons to invest in CSR activity, but they should be assessed and framed as such. Thus, while this position may be appealing, it is not realistic and may be more interesting from a system reform vs. a corporate strategy perspective.

3. *Lean and Green*: In some cases, CSR advocates make the assumption that what is good for the environment is unfailingly good for business, and vice versa. In reality, after the low hanging 'win – win' opportunities are exhausted, there are many cases where business objectives are *not* consistent with environmental sustainability. If a company is willing to consider a longer investment horizon, alignment improves, but is still not likely to be fully consistent. Again, it is not realistic to expect companies to ignore traditional financial incentives in order to pursue alternative social or environmental goals as long as companies are measured and rewarded based on financial objectives. These types of efforts are likely to lose momentum and be abandoned in a competitive for profit setting.

4. *Overwhelming Complexity*: CSR advocates with a more mature perspective may struggle as the question of sustainability leads to broader questions of economic theory and business' role relative to social and natural systems. Obviously this is a complex, emotional topic, not immediately digested or distilled into manageable tactical level concepts, and not easily integrated into business strategy. If a company tries to understand and directly address a vast array of social and environmental issues simultaneously it will be difficult to develop a cohesive, actionable corporate environmental strategy.

Perhaps most importantly, even companies who understand that CSR investments and sustainability programs must be congruent with traditional business objectives *have not dedicated sufficient management resources* to collaborate with EHS specialists to develop a meaningful value proposition. Investments made based on good intentions and emotion, managed by non-business people, with little consideration of core strategy and capabilities are not likely to generate satisfactory or even measurable financial returns. As explained by Porter, this type of investment will not be sustained in a competitive for profit setting.

7.2.4 *Level 3B*: Back to Business – Investment Based on a Value Proposition

Companies at this level base activity and investment in CSR and sustainability programs on a critical value proposition. These companies recognize bottom line financial benefits and positive NPV opportunities instead of viewing compliance activity as a cost of doing business or 'beyond compliance' activity as a moral obligation. CSR advocates at this level may be passionate about making a difference on social and environmental issues or simply seeking means to increase returns; either way, activity is based on traditional financial analysis and expected returns.

> *"I used to see this area of corporate social philanthropy as the last thing on my agenda ten years ago, but now I agree that social and economic issues are intertwined. ……corporate social responsibility is becoming an ever more important field for business. Today's companies ought to invest in corporate social responsibility as part of their business strategy to become more competitive."* [69]
>
> *- Michael Porter*

Companies at this level have allocated management resources to consider what issues are most pertinent to their industry and organization, to assess where business objectives and environmental goals are aligned, and to develop and manage effective programs based on the value proposition. By taking this position, companies make the implicit assumption that business should improve environmental performance in the case where goals are aligned, and public policy, not business, must address misalignment of economic incentives and environmental goals.

<u>Who's Here</u>

A few companies at Level 2 aspire to be at Level 3B, but their behavior indicates that they still treat both regulatory-driven and beyond compliance activity as a cost rather than a business

[69] From Michael Porter interview published by the European Business Forum (EBF) at www.ebfonline.com

opportunity. Many companies at Level 3A cite business benefits to justify related activity, but are most likely operating from the 'bullet-point business case' mentioned previously. Specific companies, particularly smaller or newer organizations with more flexibility or innovative business models, have made progress on integrating CSR and sustainability into their core strategy and operations, but it seems that the number of companies effectively operating at Level 3B is small relative to the number at Level 3A.

Benefits of Being in This Stage

Former IBM executive Bob Willard wrote *The Sustainability Advantage*, one of the few publications that attempts to quantify the financial benefits of CSR and sustainability activity. He asks, "Suppose the company stopped treating the Environmental affairs office as a cost center and started treating it as a Sustainable Development Profit Center?" [70] Some potential benefits and factors cited by Willard and others that clearly influence the value proposition include:

- Anticipating global legislative trends and developing cross-functional capability to meet regulations efficiently, thus reducing compliance costs and risks.
- Realizing operating and end of life cost savings by investing in programs to improve energy and water use efficiency and eliminate waste, and reducing recycling and disposal costs through better product design and production efficiency.
- Protecting or enhancing brand, meeting customer requirements for environmental and social performance, and potentially improving sales due to 'green' marketing effects.

In summary, companies at this level recognize that investment in product development and manufacturing may yield environmental benefits and cost or risk reductions, and allow the company to better meet customer requests.

Pitfalls of Being in This Stage

Level 2 barriers include extreme short term focus or capital constraints and myopic focus on core strategy. There is no business reason for a healthy organization with reasonable planning horizons and discount rates to not evolve past Level 2 towards Level 4. Some pitfalls include potential backlash if public relations claims regarding sustainability and CSR exceed actual activity. Another drawback involves the degree of alignment of environmental goals and business objectives; if alignment is poor or the value proposition undervalues the benefits of CSR and

[70] Bob Willard, from The Sustainability Advantage, p.16

sustainability programs, environmental gains may remain superficial, momentum may decline, and future opportunities to both reduce environmental impact and improve business performance may be ignored.

Misconceptions and Barriers to Evolution Past this Stage

The evolution from Level 3B to Level 4 does not involve a dramatic change in perspective or objectives. Potential benefits in Level 3B could actually be expanded to include Level 4; however, Level 4 has been delineated based on specific challenges related to (1) appropriate valuation of benefits, (2) isolating and quantifying some of the most significant yet less tangible benefits of CSR and sustainability activity, and (3) determining what type and level of investment generates the best results.

For example, it is generally accepted that a company with a strong mission that includes factors such as improving environmental performance or contributing to social well-being has an advantage with respect to recruiting and retaining employees. However, understanding how much of this is attributable to CSR activity, quantifying how much the benefit is worth, and assessing what level and type of investment in CSR is necessary to generate such a benefit is difficult.

Additionally, specific CSR activities and related benefits have dynamic, interrelated, and non-linear relationships. For example, brand may contribute to ease of recruiting which may improve product development capability which may lead back to brand strength, but other factors may negate, for example, the product development improvement and reduce the brand benefit of CSR activity. Positive dynamics may be significantly improved due to CSR and sustainability programs, but understanding where the best leverage points are and what level of investment is justified is difficult. Also, benefits of CSR are often broad and cross-functional while the investment that generated the benefit is likely to be borne by a specific organizational group, i.e., organizational structure, cost accounting system, and divisional incentives may discourage local investment even if it benefits the broader organization.

7.2.5 *Level 4*: Recognize Less Tangible Benefits – Expand the Value Proposition

Companies at this level think similarly to those at level 3B. They view CSR and sustainability programs as strategic investments to be made based on a sound value proposition. However, their perception of potential benefits of CSR and sustainability activity is broader, considers a longer investment horizon, and includes less tangible benefits that may not typically be included in a traditional financial analysis.

> *"Based on available literature, it can be seen that sustainability initiatives can bring about benefits such as financial gains, enhanced corporate reputation, improved government relations, increased technology and innovation skills, increased risk management skills, brand loyalty, employee loyalty, and last but not least, increased ease of recruitment."* [71]

These less tangible benefits may have exceptionally high returns relative to the more visible waste reduction and efficiency type benefits, but are not easily included in a value proposition due to the following challenges:

1. Benefits are difficult to isolate. Similar to a successful cohesive operations strategy like that of Southwest Airlines, it is difficult to understand the impact of a specific factor in a complex dynamic system.

2. Benefits are difficult to quantify. Benefits such as employee motivation or improved risk management are difficult to quantify. They are undoubtedly important benefits whose magnitude may be more significant than more visible waste reduction and cost savings type benefits, but putting values on the benefits is difficult.

3. The magnitude and type of CSR investment must be determined. Given that it is difficult to isolate and quantify benefits, it is also hard to understand what activity drove the benefits, i.e., where the leverage points are and what level of investment is necessary to kick off or enable positive dynamics. For a company to reach this level, the value proposition requires an understanding of the complex dynamics leading to business benefits. [72]

It may help to think of corporate investment in CSR and sustainability activity in parallel to investment in quality. Initially, external forces, whether market demand for reliable products or safety and environmental regulations, drive investment. However, as corporate capability and thinking matures, it becomes apparent that there is value to be gained by exceeding minimum standards. Improving quality creates a range of benefits beyond the obvious cost reductions

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[71] Farrukh et al, p.530

[72] While a system dynamics model was not generated for this thesis, the author feels that system dynamics can be used to evaluate the magnitude, drivers, and dynamic interrelation of less tangible benefits in order to develop a coherent corporate environmental strategy and meaningful value proposition.

associated with rework and warranty expenses. Isolating and quantifying the value is difficult, but it is obvious that some level of investment is justified.

Who's Here

Many companies cite these less tangible benefits as the basis for investment in CSR and sustainability activity. However, it isn't clear that any large corporations have developed a clear investment strategy based on a detailed value proposition.

Pitfalls of Being in This Stage

The pitfalls of being in this stage include the same pitfalls of level 3B. Additionally, given that it is difficult to quantify benefits and understand what type and level of investment yields the best returns, companies at this level are susceptible to the 'bullet point' business case pitfall. Also, as with most business models, a number of factors contribute to a whole that is greater than the sum of the parts, i.e. investment may not kick off positive dynamics and yield returns as expected if companies do not understand what is driving creation of benefits.

Benefits of Being in This Stage

Potential benefits from Level 3B are expanded to include the following: [73]

- Enhanced corporate reputation and easier access to capital.
- Easier hiring of the best talent, higher retention of top talent, and increased employee motivation, productivity, and morale.
- Improved risk management such as ability to achieve environmental compliance and maintain the right to operate, lower materials availability and cost fluctuation risk, reduced remediation liabilities, reduced risk related to negative publicity, and reduced supplier risk when partnering with suppliers who meet EHS goals.
- Potential alignment with core strategy and operations. For example, in most cases transitioning from selling a product to providing a service not only generates a desirable cash flow, but also creates incentives for the service provider to extend hardware life and improve operating efficiency in order to lower total cost of ownership. Marketing the environmental benefits may improve consumer acceptance and service provider revenues.

[73] Content in this section draws heavily from *The Sustainability Advantage: Seven Business Case Benefits of a Triple Bottom Line* by Bob Willard.

- Increased opportunity for product and process innovation. Similar to the implementation of safety programs in construction, process improvements are common during detailed re-evaluation for safety or environmental impact. Innovation in product development may be spurred by DFE programs. For example, companies who wish to reduce disassembly time (to lower recycling costs) may also improve assembly processes.

While there are difficult challenges in developing a sound value proposition around these and other less defined benefits, potential benefits may be significant depending on the industry and organization. Companies who are able to realize less tangible benefits may create competitive advantage and very tangible bottom line benefits.

Fundamental System Change: Levels 5 and 6

Companies at levels 3B and 4 take the position that business should pursue business objectives, leaving public policy to better align business goals with broader goals based on societal values. If all companies developed corporate environmental strategies that allowed them to evolve to Level 4 behavior, we would see dramatic improvements in environmental and financial performance. This type of progress is necessary and valuable. However, companies would still need to evolve further to do more than slow the negative effects of an expanding, unsustainable system. Essentially, getting to level 4 buys time and potentially positions companies to evolve to levels 5 and 6.

Companies in level 5 evolve to recognize systemic flaws (economic, political, social) that drive business incentives that are starkly misaligned with long term environmental goals and social well-being. Companies who attempt to address public policy and societal issues directly are likely to fall victim to the pitfalls of level 3A, superficial improvement and a loss of momentum and business credibility on CSR and sustainability issues. However, at level 6 these companies or new organizations position themselves to create and potentially capture value by influencing public policy and consumer values to address the systemic flaws contributing to unsustainable behavior, i.e., companies can change the game and incentive structure in which they operate.

7.2.6 *Level 5*: Recognize Systemic Flaws Leading to Unsustainable Behavior[74]

Mainstream economic theory, as taught in leading MBA programs and cited in the January 2005 Economist articles criticizing CSR activity, tells us that (1) public policy should address environmental externalities such as pollution (through taxes, assignment of property rights, etc.), and (2) market pricing should reflect resource scarcity and drive efficiency, material substitution, and innovation - thus natural resource depletion should not be considered a limit to society well-being or economic growth. The author would argue that there is undeniable evidence that prevalent economic thought is not consistent with reality with respect to environmental impact and social well-being.

Symptoms and Evidence

Environmental: There are a multitude of sources that might be cited to outline dramatic and in some cases irreversible anthropogenic impact on the environment, natural systems, and societal well-being. Although there have been meaningful gains with respect to emissions control and remediation of polluted sites, the overall impact continues to be decidedly negative.

> *"....the loss of living systems is accelerating worldwide, despite huge capital spending on environmental cleanup by industrial nations and responsible corporations....its as if you are intent on cleaning your house, which is situated on a floodplain whose river is rising. Cleaning house is an admirable activity, but not an appropriate response to the immediate problem."*
>
> - unknown

Frank Dixon of Innovest Strategic Advisors summarizes negative environmental impact including the following: [75]

- 50% of forests cleared
- 50% of wetlands gone
- Accelerating biodiversity losses
- Global warming exacerbated by greenhouse gas emissions
- Topsoil erosion, salination of soil, and aquifer depletion ongoing
- Every major ocean fishery at its limit or in decline
- Dispersing 80,000 synthetic chemicals into the land, air and water

Social: Despite a higher standard of living (as measured by Gross Domestic Product (GDP) or Gross National Product (GNP) per capita) from an economic perspective, it seems that societal well-being is also not perfectly aligned with western economic efficiency and growth. There is certainly evidence that increasing GDP per capita to a level that allows people to meet basic needs

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[74] This section draws heavily from presentations and articles by Frank Dixon of Innovest Strategic Advisors.

improves social well-being. Many questions have been raised, however, on whether GDP per capita growth is an appropriate metric once the basic needs threshold has been reached.

"Over the last 50 years, we in the west have enjoyed unparalleled economic growth. We have better homes, cars, holidays, jobs, education, and above all, health. According to standard economic theory, this should have made us happier. But surveys show otherwise. When Britons or Americans are asked how happy they are, they report no improvement over the last 50 years. More people suffer from depression, and crime - another indicator of dissatisfaction - is also much higher.

These facts challenge many of the priorities we have set for ourselves both as societies and as individuals. The truth is that we are in a situation previously unknown to man. When most people exist near the breadline, material progress does indeed make them happier. People in the rich world (above, say, $20,000 a head per year) are happier than people in poorer countries, and people in poor countries do become happier as they become richer. But when material discomfort has been banished, extra income becomes much less important than our relationships with each other: with family, with friends and in the community. The danger is that we sacrifice relationships too much in pursuit of higher income".

- Richard Layard

Social pressure and turmoil are increasing around the world, driven by population growth, a widening gap between rich and poor and other factors. Social distress is evident even in prosperous regions. Americans, for example, medicate themselves with food (two thirds are overweight, one third are obese), television (four hours per day on average), and anti-depressant drugs (rapidly growing use).

- Frank Dixon

In a nation of that was proud of hard work, strong families, close-knit communities and our faith in God, too many of us now tend to worship self-indulgence and consumption. Human identity is no longer defined by what one does, but by what one owns.

But we have discovered that owning things and consuming things does not satisfy our longing for meaning. We have learned that piling up materials goods cannot fill the emptiness of lives which have no confidence or purpose.

- Jimmy Carter, 1979

[75] From Frank Dixon April 13, 2004 presentation to Harvard Business School students.

Relevant Economic System Flaws

While some are more commonly acknowledged than others, the systemic flaws summarized here are observed and discussed in mainstream economics. However, economic solutions have not been broadly implemented and the flaws continue to contribute to the misalignment of business incentives and environmental goals.

Externalities: Some activities impose costs that are not reflected in the market or borne by the party performing the activity. For example, uncontrolled air or water emissions from a manufacturing facility or mining operation may negatively impact air and water quality; the cost of this impact may include degradation of natural systems and negative impact on wildlife and human health. This cost is external to the manufacturing company, that is, their operations, thus their cost accounting and pricing of goods does not reflect the pollution costs. The concept of externalities is not new; introductory economics courses typically cover the problem of externalities and discuss theoretical solutions. Taxing pollution is a common concept for reducing pollutant emissions, allocating pollution 'credits' to industrial facilities and allowing them to sell or trade credits may provide more economically efficient emissions reductions. Ronald Coase won the Nobel Prize in Economics in 1991 for showing that assigning property rights to either the polluter or the 'pollutee' should yield an economically efficient agreement to internalize external costs. However, while externalities and economic solutions are readily understood in theory, straightforward, effective implementation has been slow and in some cases infeasible. In the case of pollution controls, a region is typically willing to ignore the external effects until the costs (degradation of natural systems and impact on human health) are highly visible. At this point, emissions controls have been achieved largely through dictatorial regulations and monitoring rather than market based strategies such as emissions credit trading programs.[76] The following example from Sloan's core microeconomics curriculum was used to explain the Coase theorem.[77]

> <u>Problem</u>: Factory discharges Air Emissions that Impact a Neighboring Dairy Farm.
>
> <u>Given</u>: Economic Impact of Pollution to Farmer = \$X,
> Cost for Factory to Eliminate Pollution = \$Y
>
> <u>Solution</u>: Per the Coase Theorem, if the farmer is legally granted the right to Clean Air, OR if the factory is legally granted the right to pollute, market forces should cause the farmer and factory manager to negotiate an economically efficient agreement.

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[76] A commonly cited emissions credit trading programs was successfully implemented in the US to reduce industrial sulfur dioxide emissions.

While the professor mentioned that transaction costs might prevent an agreement, there was no other discussion of implementation challenges, actual implementation examples and results, or alternative solutions. However, in order for assignment of property rights to be a feasible solution, the following must be true:

- Transaction costs (including legal fees) are negligible.
- Impact on the farmer (X) is measurable, isolated and attributed to factory.
- Cost to reduce emissions (Y) is known.
- No other entities are impacted.
- No other future users of the land are impacted.
- 'Clean' air is defined.
- The parties are acting under the same legal system.

Each one of these assumptions creates significant implementation challenges, even for this simple example. The persistence of negative environmental externalities, even in mature industrial economies, indicates that theoretical solutions have not been implemented successfully.

Assumptions of Perfect Knowledge: One of the underlying assumptions of mainstream economic theory is that given reasonable levels of information, free market pricing of goods will reflect long-term issues such as resource scarcity. Thus markets will resolve resource depletion issues by sending price signals that will spur innovation in the form of development of substitutes and efficiency gains. Further, some economists would argue that pursuit of economic goals is the best means of improving social well-being.[78] While the author would not encourage business to pursue goals unrelated to business performance, this rationale fails to consider the limits of human cognitive ability as it relates to assumptions of market knowledge. Specifically, it assumes that humans are capable of understanding, predicting, and manipulating the behavior of complex systems, social or natural, over the long term.

The introductory chapter of John Sterman's text, *Business Dynamics, Systems Thinking and Modeling for a Complex World*, provides an in depth discussion of human ability to learn in and comprehend complex systems. "....people generally adopt an event-based, open-loop view of causality, ignore feedback processes, fail to appreciate time delays between action and response,

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[77] Based on Professor Joseph Doyle's Microeconomics Fall 2003 lecture slides.

[78] The article *Profit and the Public Good* in the January 2005 Economist makes the argument that if government addresses environmental externalities, the market's invisible hand, guided by self-interested consumers and profit-seeking firms, will advance the public's interest.

and in the reporting of information do not understand stocks and flows and are insensitive to non-linearities that may alter the strengths of different feedback loops as a system evolves." [79]

- *Delayed feedback is not easily processed*: Humans survived and evolved based on our ability to react to visible events in real time, thus we are 'hard wired' to think about direct actions and reactions in the short term. In reality, particularly with natural systems, feedback such as chronic illness or global warming is delayed or less obvious. Those taking actions that contribute to long term phenomenon are not likely to receive feedback or link results to the initial action.

- *Complex systems are unconsciously simplified*: Human cognitive ability is limited, mental models do not represent complex realities. We are designed to react to short term threats and cannot grasp complexity beyond a certain degree, thus we make simplifying assumptions in order to understand and react to our surroundings in the near term. In reality, most of our actions have unintended effects that we may or may not link to the action causing the effect. For example, chlorofluorocarbons (CFCs) were used for decades before they were linked to ozone depletion. Current phenomena such as declining and malformed frog populations in seemingly unpolluted regions of the world indicate that there is a pollutant or natural system decline that we do not understand.[80]

- *Assumed linearity*: We assume that most causal relationships are linear, i.e. one more pound of phosphorus emitted to a river will have the same impact as the previous. In reality, most natural systems have a natural carrying capacity that may allow them to buffer changes up until a tipping point, after which reaction, such as algae blooms and dissolved oxygen deficits, may be rapid and dramatic. Another example of assumed linearity was Thomas Jefferson's prediction that it would take 100 generations for Americans to populate the areas that Lewis and Clark had explored. It took less than five. It seems reasonable to assume that Jefferson's cognitive abilities were well above average, yet he dramatically underestimated population growth and development rates.

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[79] From Sterman *Business Dynamics* text p. 27
[80] The Minnesota Pollution Control Agency website describes the issues, "...frog populations around the world have showed increasing signs of stress in recent years. Some species have disappeared, and others are no longer found where they used to be. An increase in deformities may be a sign that something is wrong. Scientists are concerned about what's happening to the frogs, because the health of frogs is closely linked to the health of the environment. Frogs are sensitive to pollution, because they live at the meeting of two environments -- land and water -- and they can easily absorb pollutants through their skin."

- *Judgmental Errors and Bias*: Decision research cited by Sterman was summarized, "People suffer from overconfidence in their judgments (underestimating uncertainty), wishful thinking (assessing desired outcomes as more likely than undesired outcomes), and the illusion of control (believing one can influence the outcome of random events)." [81]

In summary, the assumption of perfect or even reasonably comprehensive information is limited by human cognitive ability. We are 'hard wired' to process simple cause and effect information in real time. Further, our ability to recognize our limits is restricted due to simplified mental models and judgment biases.

Finite Natural Resources: Of the primary macroeconomic models used in western economics, none consider limits to growth based on finite natural resources. Labor, capital, and technology are viewed as inputs that may constrain economic growth, but natural resources are assumed to be infinite or replaceable.[82] Further, the primary metrics used to measure economic growth and well-being are largely a measure of exchange and consumption of man-made material goods and do not consider natural resource stocks.

> *"Under the current system of national accounting, a country could exhaust its mineral resources, cut down its forests, erode its soils, pollute its aquifers, and hunt its wildlife and fisheries to extinction, but measured income (GDP) would not be affected as these assets disappeared..."*
>
> \- *Robert Repetto, WRI economist*

Investment Horizon (short-termism): For several reasons, business strategy is heavily weighted towards short term performance. Quarterly and annual financial reports often drive behavior and business plans seldom consider more than 5 years. Standard financial analysis using significant discount rates or short payback periods effectively ignores the value of assets in the future. Benefits of CSR and sustainability programs (positive cash flows) as well as negative environmental impacts such as resource depletion and pollution may be delayed, thus effectively ignored in financial analysis biased towards the short term.

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[81] From Sterman text *Business Dynamics, Systems Thinking and Modeling for a Complex World*, p. 31

[82] In the introductory chapter of *Natural Capitalism, Creating the Next Industrial Revolution* the authors discuss the context in which the current economic system was developed – low density populations drew from vast, seemingly endless natural resources stocks; production and the ability to meet basic needs was limited by labor and productivity. Thus macro models based on labor, capital, and technology were reasonable. However, this context evolved due to productivity gains (division of labor and industrialization) and population increases to our current situation where natural resources are being rapidly depleted and unemployment is more likely to be a challenge than labor shortages, i.e., the position of labor and natural resources has been reversed, but our economic model has not adjusted to reflect this fundamental change.

Relevant Political System Flaws

It seems reasonable that business should address issues of business and government should address issues of social well-being including consideration of business impact on the environment and society. When business attempts to address issues not related to traditional business goals, they risk the pitfalls described in Level 3A. The article *The Ethics of Business* in the January 2005 Economist states, "It is indeed desirable to establish a clear division of duties between business and government, which are accountable to their electorates, should decide matters of public policy. Managers, who are accountable to their shareholders, should run their businesses." However, systemic flaws in the political system limit the ability of government to effectively address the negative environmental and social impact of business.

Political 'Investment Horizon' (short-termism): Politicians face the same imperfect information and short-term incentives challenges as business. Term limits and re-election concerns reduce incentives to consider policy effects over the long-term. In many cases, political leaders have been reduced to responding to near term pressures. Additionally, it is typically politically infeasible for a political candidate or elected official to acknowledge complexity or uncertainty and address long term challenges such as resource depletion or degradation of natural systems at the expense of visible, short-term constituent desires such as economic health and stock market performance.

Campaign Financing and Lobbying: If business is to stick with business objectives, and government is to implement policy that provides for social well-being, it is obviously a problem that business, whether through lobbyists or campaign funding, is able to exercise such a powerful influence on public policy. Business is incented to maximize profits which may or may not be consistent with improving social well-being depending on consumer values and the rules established through public policy, yet business plays a significant role in determining the rules set by government.

Societal System Flaws

Richard Layard explains how human (and animal) happiness is tied to status, i.e., we judge ourselves relative to others.

> *".....we cannot just wish away the pervasiveness of status comparisons; the desire for status is wired into our genes. Studies of monkeys show how it works: when a male monkey is moved from*

a group where he is top into a group where his status is lower, his brain experiences a sharp fall in serotonin - "the neurotransmitter most clearly associated with happiness".

- *Richard Layard*

Given that we are 'hard wired' to compare ourselves to others, it seems reasonable that exposure to a broader range of people and cultures would negatively impact most people's perception of themselves relative to others.

"....And there is another consideration: If we work harder and raise our standard of living, we first appreciate it but then we get used to it. Research shows that people do not adequately foresee this process of habituation, or fully realise that once they have experienced a superior lifestyle they will feel they have to continue it. They will in effect become addicted to it".

- *Richard Layard*

This phenomenon may be unavoidable, but setting economic and standard of living metrics based on material consumption can only exacerbate the problem. Additionally, advertising may amplify the desire for perception of material goods as a source of status.

"Being focused on maximizing sales and earnings, companies view citizens primarily as consumers of goods and services. Advertising is used to create a perceived need and prompt a purchase. This is frequently done by taking advantage of human needs for self esteem, love and connection to others. Advertisements often use strong emotional appeals to imply purchasing a product will meet these non-material needs.

A common and intended consequence of advertising is that consumers feel inadequate without the product. Widespread use of this type of advertising creates a pervasive sense of emptiness and low self esteem in society. Emotionally false advertising does not tell consumers that non-material needs are met through activities such as being a good spouse, parent and neighbor, doing fulfilling work or being in nature, since firms don't make money on this. Conventional advertising is one of the most destructive influences in society. It is a root cause of increasing compulsive behavior and depression. (The destructiveness of advertising is not obvious to many because, from childhood, we are steeped in an advertising culture that equates success with material prosperity.)"

- *Frank Dixon*

Marketing strategy often includes meeting 'latent' needs of customers, but discussion of the potentially negative impacts of influencing customer perceptions and societal values is largely absent.

In summary, economists argue that pricing reflects societal values and material scarcity, and externalities can be addressed through public policy, i.e., the economic system is sound and fully relevant in its current state. However economic theory does not acknowledge that (1) human cognitive ability is not sufficient to allow us to successfully predict and manipulate the behavior and value of natural system in the long term, (2) economic solutions that are not implementable are not solutions, and (3) business is capable of influencing government and consumer perceptions of need thus biasing economic goals and societal values towards growth and material consumption.

7.2.7 *Level 6:* Change the Game / Break Down Systemic Barriers

Given that (1) the best corporate environmental strategy in the existing system is to invest in CSR and sustainability activity based on a sound business value proposition, and (2) due to systemic flaws, this strategy is not likely to lead to sustainable operations and society well-being, what is the next level?

> *The uncomfortable fact is that the business case is still weak in many areas, because markets have not yet worked out how to value human, social, and natural forms of capital appropriately. Where such market weaknesses become clear, business will need to work with governments and other stakeholders to change markets, whether through regulation or – increasingly – taxes and fiscal instruments.*
>
> - John Elkington and Oliver Dudok van Heel [83]

It seems obvious that businesses in a competitive environment must pursue business objectives and activity that contribute to meeting business goals or they will decline and cease to exist as an organization. However, government and society, partially due to the influence of business, are not creating economic incentives for business to be sustainable. The straightforward answer is that business must partner with government and positively influence customers to better align economic incentives with environmental goals and social well-being.

> *Economic, social and political systems that do not hold firms fully accountable essentially force companies to be irresponsible and unsustainable. This occurs because any firm attempting to fully mitigate impacts in a competitive market would probably put itself out of business (costs would become too high relative to competitors). Many well-intentioned firms make huge strides in the right direction, but can only go so far in a system that does not hold them fully responsible.*

[83] From the foreword of *The Sustainability Advantage* by Bob Willard

Sustainability can only be achieved through the coordinated action of many different stakeholder groups. Business cannot do it alone. However, since business is such a large part of the problem, it must be a large part of the solution. To achieve sustainability, business leadership must rise to a new level. Visionary, proactive leaders must work aggressively with others to remedy system flaws.

- Frank Dixon

While this is a straightforward concept, implementation is difficult. If companies are facing short-term competitive pressure and struggling with formation and execution of traditional business strategy it is not likely that they will have the capacity to understand and address systemic economic and political flaws. However, very successful companies or new players entering an industry may have the capacity to change the game. In doing so, they may force entire industries to evolve with them. Dell Inc., arguably one of the most dominant companies in the electronics industry, is led by Michael Dell. Mr. Dell answered a student question during the Leaders for Manufacturing plant tour regarding Dell's environmental strategy and performance by stating that Dell will pursue activity that makes sense from a business perspective and provide leadership on environmental issues by contributing to public education. Thus Dell plans to operate based on a sound business proposition in the existing system, but influence consumer values to strengthen incentives to improve environmental performance. Another example of a successful company seeking to address systemic flaws was explained by Mike Rion, former Director of Corporate Responsibility at Cummins Engine Company, during a Leaders for Manufacturing seminar. At that time Cummins had a policy that they would not contribute funds to industry groups or lobbyists to advocate positions that benefit the company or industry, but are not deemed to benefit broader society, i.e., they try to allow unbiased public policy decisions. Both of these examples are from established companies who evolved through various phases. Alternatively, new companies with a disruptive business model or technology may displace existing companies; the strategy and operations of the new companies may allow much better alignment of business and environmental incentives. For example, Zipcar founder Robin Chase explains that although her company's services reduce private ownership and use of automobiles thus environmental impact, the business is focused primarily on meeting customer needs. The environmental benefits are not due to a parallel effort, but rather inherent to the core business model.

7.3 Relevance to Sun

Sun's COO, Jonathan Schwartz, has indicated that Sun should be 'better positioned' with respect to environmental activity and performance. Sun's previous corporate environmental strategy could be described as minimalist or consciously conservative with respect to investing in environmental related activity. Their current strategy could be described as indiscriminate investment in 'catch-up' activity.[84]

Current Position and Trajectory

Sun has expressed the desire to be a smart follower and base CSR and sustainability investment on legal obligations and a value proposition. However, the EHS department is not structured nor staffed to efficiently manage tactical compliance initiatives or develop a value proposition and coherent corporate environmental strategy. Currently, most of its activity is compliance related putting Sun at Level 2, with a trajectory towards Level 3A.[85] However, Sun is in the position where it can critically assess competitor activity and programs in order to develop its own strategy. In order to do so, sufficient management resources must be dedicated to consider the payback of the competitor activity that Sun plans to emulate. Otherwise, Sun will be subject to the same pitfalls other companies have experienced rather than benefiting from acting as a smart follower. Additionally, Sun has struggled to establish cross-functional efforts to address recent directives effectively and has no structure or resources in place to improve future initiatives.

Recommendations

Rather than blindly playing catch-up, Sun should take steps to align (1) tactical responses to environmental legislation with core operations, and (2) longer term environmental strategy with core strategy. The underlying assumption is that a coherent Corporate Environmental Strategy (CES) should be developed based on a value proposition. Chapter 8 includes specific recommendations to help Sun move towards levels 3B and 4.

[84] Sun's EHS employee efforts are primarily and necessarily focused on RoHS and WEEE compliance efforts.

[85] Sun has programs providing commuting options and employee wellness support based on expected motivation and productivity benefits.

Chapter 8 Summary and Recommendations

This chapter includes recommendations based on project findings and earlier chapters. Tactical recommendations are made for specific technical issues and RoHS implementation in Section 8.1. Section 8.2 includes recommendations for development of a corporate environmental strategy based on a value proposition.

8.1 Facilitating RoHS Implementation

8.1.1 Recommendations for RoHS Teams

Sun's RoHS technical team has developed lead-free requirements with the goal that Sun's quality and reliability not be adversely impacted by the accelerated transition to new and unproven lead-free materials and technologies. The RoHS technical team feels that reliability driven requirements such as tin whisker mitigation and SJR testing are reasonable and necessary for Sun's mid to high reliability products. Sun's broader RoHS team is working to establish systems and resources to support the transition. Reliability-driven requirements have been integrated into Sun specifications and WWOPS RoHS Supplier Readiness efforts including the PPCN process andAVL part review (scrub). Requirements have been communicated to suppliers and supplier status is measured through the RoHS Supplier Scorecard program.

However, the industry is in firefighting mode; supplier readiness varies and continues to evolve, and it is difficult to predict what percentage of the supply base will satisfy high reliability lead-free requirements. There will be technical transition 'bumps' for everyone in the industry including a lead-free manufacturing process learning curve, tin whisker related component reliability risks, and potential shortages of components that provide adequate tin whisker mitigation requirements. Given cost and reliability trade-offs and significant implementation challenges, *Sun's RoHS team* should consider the following:

- <u>Modify tin whisker mitigation requirements to proactively address potential component shortages:</u> Modify Sun's specifications to allow wide pitch components to use matte tin plating without further mitigation or tin whisker testing, i.e., adopt the IBM approach for components with lead pitch > 1mm. Continue to ask for plating and testing information and give preference to suppliers meeting requirements in order to minimize reliability risks associated with tin whiskers breaking off of a wide pitch component and causing failures elsewhere.

- <u>Clarify Solder Joint Reliability testing requirements</u>: Modify Sun's specifications to require solder joint reliability testing per IPC-9701 or equal to encourage suppliers who have independently developed adequate SJR testing programs to submit information.

8.1.2 Recommendations for Product Groups

Meeting RoHS compliance deadlines is a significant challenge that will require coordination across the electronics industry and involvement across each organization. Further work to minimize the reliability impact of the lead-free transition may be led by specialized RoHS teams, but will require input and understanding by all Sun product and operations groups. *Product teams* should take the following steps to reduce risk and unforeseen costs during the lead-free transition.

- Enforce Sun specifications for tin whisker mitigation uniformly across products and suppliers.[86] Tin whisker component and system level reliability risks may be significant. Waiving tin whisker mitigation requirements equates to accepting components of unknown long-term reliability and may lead to higher cost of defects. If Sun modifies its tin whisker mitigation requirements based on component pitch, component supplier readiness challenges and potential component shortages should be greatly reduced. Given this modification, relaxing requirements on a discretionary basis for specific products or product groups does not seem justified given associated reliability risks, cost impact, implementation challenges, and long term procurement strategy. Sun should enforce tin whisker mitigation requirements uniformly across product groups and suppliers.

- Select and/or leverage well prepared contract manufacturers to reduce lead-free learning curve impacts. Well-prepared contract manufacturers have most likely established solder joint reliability testing programs that meet the intent of IPC-9701. Utilizing one of the more proactive suppliers will significantly reduce RoHS challenges and transition risks. Sun's RoHS supplier scorecard identifies suppliers best prepared for lead-free product design and qualification, full-scale lead-free manufacturing and component supplier management. The Chicago workstation product team integrated RoHS criteria such as SJR testing status and component supplier management plans into their supplier selection process.

- Recognize that RoHS requires an investment of resources; build time and resources into product plans. Upfront planning and coordination will reduce firefighting costs and transition risks. RoHS is likely to impact product development schedules and drive redesign of existing products where lead-free parts are not available or do not meet reliability-driven requirements. Sun's central

[86] SunRay products may be an exception if part commonality challenges are not significant.

RoHS team has developed processes and resources to support Sun's transition,[87] but they are not staffed to drive all product transitions. In addition to leveraging supplier strengths, product teams should plan to be engaged on RoHS issues.

In summary, the lead-free transition introduces significant reliability risks and trade-offs among cost, reliability, and component availability. There are specific steps that Sun's RoHS team can take to facilitate the transition, but product groups must understand key technical issues and enforce Sun's reliability-driven requirements in order to further reduce lead-free reliability impact.

8.2 Invest in Development of Corporate Environmental Strategy

Sun is compliant with existing environmental legislation and is working to meet regulatory deadlines associated with recent EU Directives. They have not yet invested significantly in CSR or sustainability programs, but have plans to do so in the near future. They are currently in the position where they can consciously bypass the pitfalls of Level 3A and evolve to Level 3B; however given current plans and resources, it seems that activity could be described as 'catch up' potentially leading to:

- Limited capability to anticipate, plan, and drive complex, cross-functional responses to product focused environmental legislation leading to increased costs and compliance risks.
- Poor competitive position relative to more proactive competitors who influence legislation based on their strategic position and capabilities.
- Indiscriminate investment in CSR and sustainability activity and subsequent poor return on investment or missed opportunities.

In order to avoid the pitfalls of Level 3A and move towards Levels 3B and 4, Sun should consider the following recommendations to develop a coherent, actionable Corporate Environmental Strategy (CES):

1. <u>Dedicated management resources</u>: Sun should assign at least one full time person with an operations or product development background and a good understanding of broader strategy and organizational capabilities. Broadly, the manager should be responsible for developing

[87] Sun's reliability-driven technical requirements have been integrated into the PPCN process and AVL scrub effort (covers Sun's top 120 suppliers and 70% of the AVL). Results can be used to check if parts are RoHS compliant and meet tin whisker mitigation requirements.

Sun's corporate environmental strategy and underlying value proposition. Specific responsibilities should include:

- Track relevant legislation and interface with Sun's external facing public policy group.
- Benchmark industry activity including competitor programs and consortia group activity.
- Communicate strategic and tactical needs to executive level management.
- Coordinate with marketing groups to understand customer requirements for environmental and social performance.
- Coordinate with supplier management groups to understand supplier capability and risk.
- Prioritize and structure regulatory-driven initiatives, obtain executive support, procure resources, structure cross-functional programs, and monitor progress.
- Consider investment opportunities related to both easily measured and less tangible financial benefits.

2. Leverage EHS specialists: The CES manager is not likely to have specialized or detailed EHS knowledge, but may be paired with Sun's EHS employees to provide specialized knowledge and input on the value proposition and CES.

3. Executive Support: The CES manager should have a clear line of communication to senior management. While routine updates and issues may be handled independently, the CES manager must be able to raise resource issues and strategy topics when necessary.

4. Investment Accountability: While isolation and quantification of benefits may be difficult, the CES managers should be held accountable for returns on investment in environmental activity. This return might be as straightforward as maintaining the right to sell products into EU countries (as with RoHS) or it may involve considering less tangible benefits. Even if a financial analysis is imperfect, environmental activity should be critiqued and based on positive NPV expectations. [88]

5. EHS Newsletter: Sun previously published a newsletter; this practice could be valuable in providing regulatory updates, highlighting related industry trends and risks, increasing cross-functional awareness of environmental initiatives, and communicating expectations and accomplishments. While environmental issues may tend to generate opinions or an emotional

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[88] The author feels that system dynamics may be valuable in assessing less tangible benefits of environmental activity and developing an actionable value proposition and corporate environmental strategy.

response, the newsletter should not be utilized to express management opinion on environmental issues.

6. Alignment with Utility Model: The CES manager should consider alignment of environmental strategy with core strategy. Specifically, a shift to selling computing capacity, i.e. the utility model, should dramatically reduce environmental impact as the total cost of ownership, including capacity upgrade, operating, and disposal costs, is internalized. In a seminar with summer interns, Scott McNealy mentioned that consumer acceptance may be complicated by privacy concerns. Sun might consider whether marketing the environmental benefits would accelerate consumer acceptance as well as the more obvious benefits of reducing regulatory burdens associated with EPR and product take back and disposal logistics.

In summary, this type of action should help Sun realize the benefits associated with viewing environmental activity as a source of competitive advantage and basing corporate environmental strategy on a sound value proposition.

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Appendix A: Tin Whisker Summary

	Ni-Pd-Au Pre-plated	Matte Tin w/Ni Underlayer + Testing	Matte Tin w/Heat Treatment + Testing	Matte Tin w/ no Mitigation
Component Reliability Impact	No tin whiskers.	Preferred option for tin plating. Sun anticipates good tin whisker testing results and field reliability.	Acceptable option for tin plating, but supplier understanding and process controls may impact effectiveness.	Accepting matte tin components with notesting equates to accepting components of unknown reliability.
Supplier Cost Impact (related to tin whisker mitigation only)	Purchasing preplated Ni-Pd-Au lead frames is considered infeasible by some suppliers. No tin whisker testing required for this option.	Addition of nickel plating lines may be significant (250k to 1000k per plating line). Operating costs slightly higher. Cycle time impact. Tin whisker testing requires investment in test equipment, samples, and engineering resources.	Existing ovens may be utilized significantly reducing capital costs. Operating costs (energy) slightly higher. Cycle time impact. Tin whisker testing requires investment in test equipment, samples, and engineering resources.	Remove lead (Pb) from existing tin-lead(Pb) plating lines. Capital investment is minimal and operating costs not impacted.
Supplier Activity	Some semiconductor suppliers have taken this approach based on cycle time reduction from elimination of the plating process. May become more popular if tin whisker reliability impacts prove to be significant for alternatives of this solution.	Some large suppliers (Tyco, Agere) have taken this approach. More suppliers may follow their lead, but it seems less popular than the heat treatment option among suppliers who wish to satisfy high reliability requirements.	Many suppliers have taken or plan to take this approach in order to satisfy high reliability requirements.	Default position of many component suppliers, particularly if they do not have engineering resources dedicated to lead-free. As RoHS deadlines approach and iNEMI recommendations make it up the supply chain more suppliers will attempt to use the heat treatment option.
Component Availability Challenges	Most components will not be available in Ni-Pd-Au.	Limited availability, but increasing.	Moderate availability. Suppliers taking this approach should grow rapidly, but test data may be inadequate.	Availability challenges would be greatly relieved by accepting matte tin w/no other mitigation.
Competitor Position (HP, Dell, IBM, Sun)	All competitors accept Ni-Pd-Au component plating.	All competitors accept Ni underlayer. IBM does not require tin whisker testing.	HP does not accept heat treatment for mid to high reliability applications. All others accept this option. IBM does not require tin whisker testing.	IBM accepts matte tin for components with pitch >1 mm. HP gives consumer product groups discretion to review and accept matte tin. Sun and Dell do not currently accept matte tin.