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Improved Efficiency & Reliability for Data Center Servers Using Immersion Oil Cooling

ASQ RD Webinar

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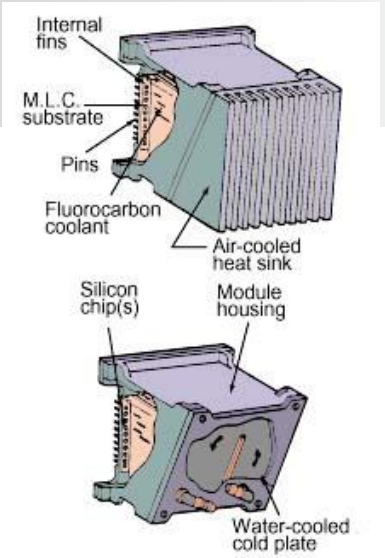
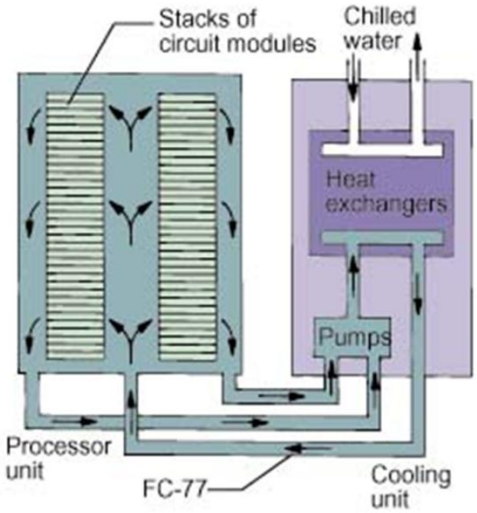
Agenda

- Immersion Oil Cooling Technology Overview
- Data Center Efficiency
- Cost & Size Benefits
- Technology Challenges
- Reliability Enhancements
- Summary

Liquid Immersion Cooling

- Not a new concept!
  - Direct liquid immersion cooling has been used within IBM for over 20 years to cool high powered chips on multi-chip substrates during electrical testing prior to final module assembly.
  - Early supercomputers relied on liquid cooling technologies.
    - Cray 2 supercomputer





http://www.electronics-cooling.com/1996/05/direct-liquid-immersion-cooling-for-high-power-density-microelectronics/

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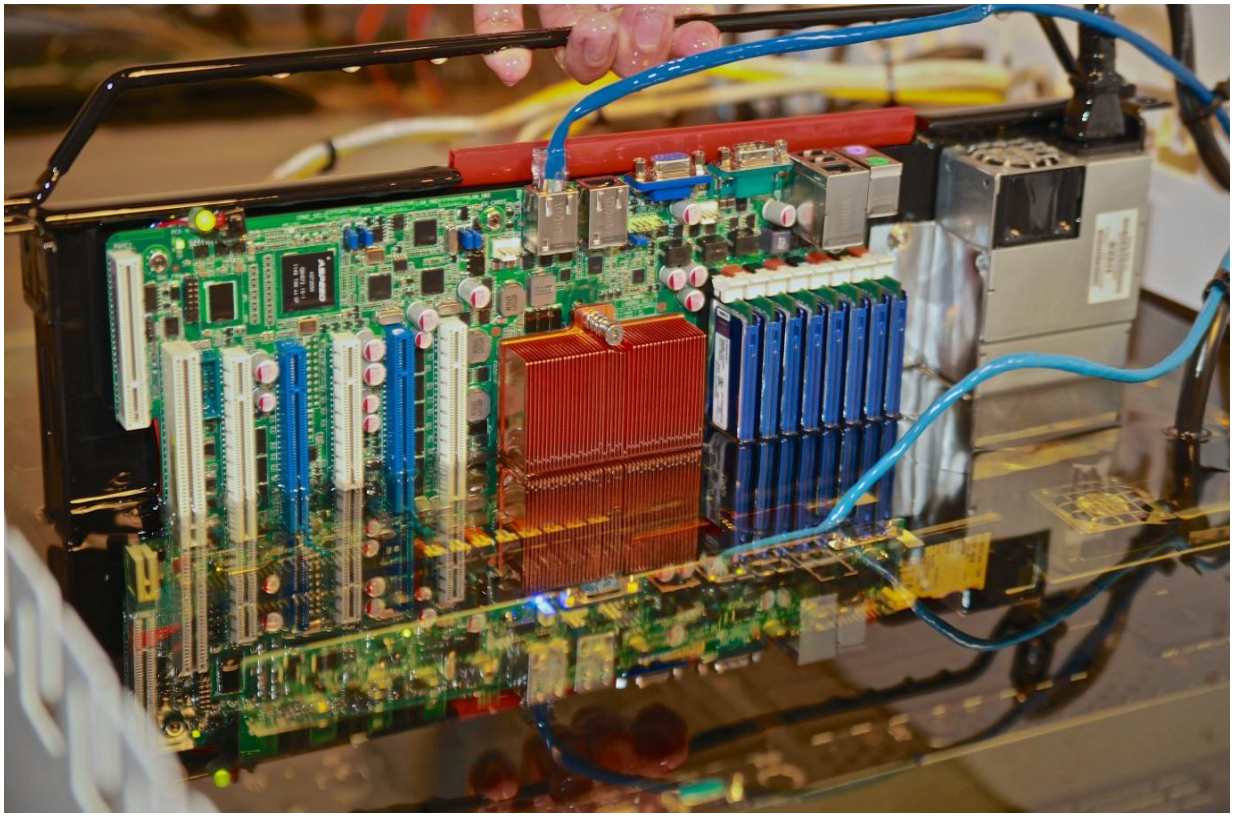
Liquid Immersion Cooling Example

- Liquid Submersion Blade Server
  - LiquidCool Solutions (Hardcore Computer) Supports High Frequency Trading with Liquid Submersion Cooled Computers
    - Released in 2010
  - 2012: LSS is the world's first rack-mounted total liquid submerged server. The system's patented liquid submersion cooling technology promises improvements in speed, performance, reliability and latency, while reducing environmental impact.

http://www.liquidcoolsolutions.com/

Cooling Using Dielectric Oil

1200X more effective at removing heat than air



Oil costs ~$500 per 55 gallon barrel, ~35C

Tanks, Not Racks

Tanks can dissipate 40kW of power or more

Business Value of Immersion Technology

Will redefine how data centers and servers will be built in the future

- Greatly reduced capital and operating expense vs. conventional data centers
- Data center can be built in non-traditional facilities, including transportable "pods"
  - No need for air conditioning, raised floors or chemical fire suppression
- No impact on software or network infrastructure
  - Retraining of support personnel not required
- A truly "green" solution
- Reliability Enhancements

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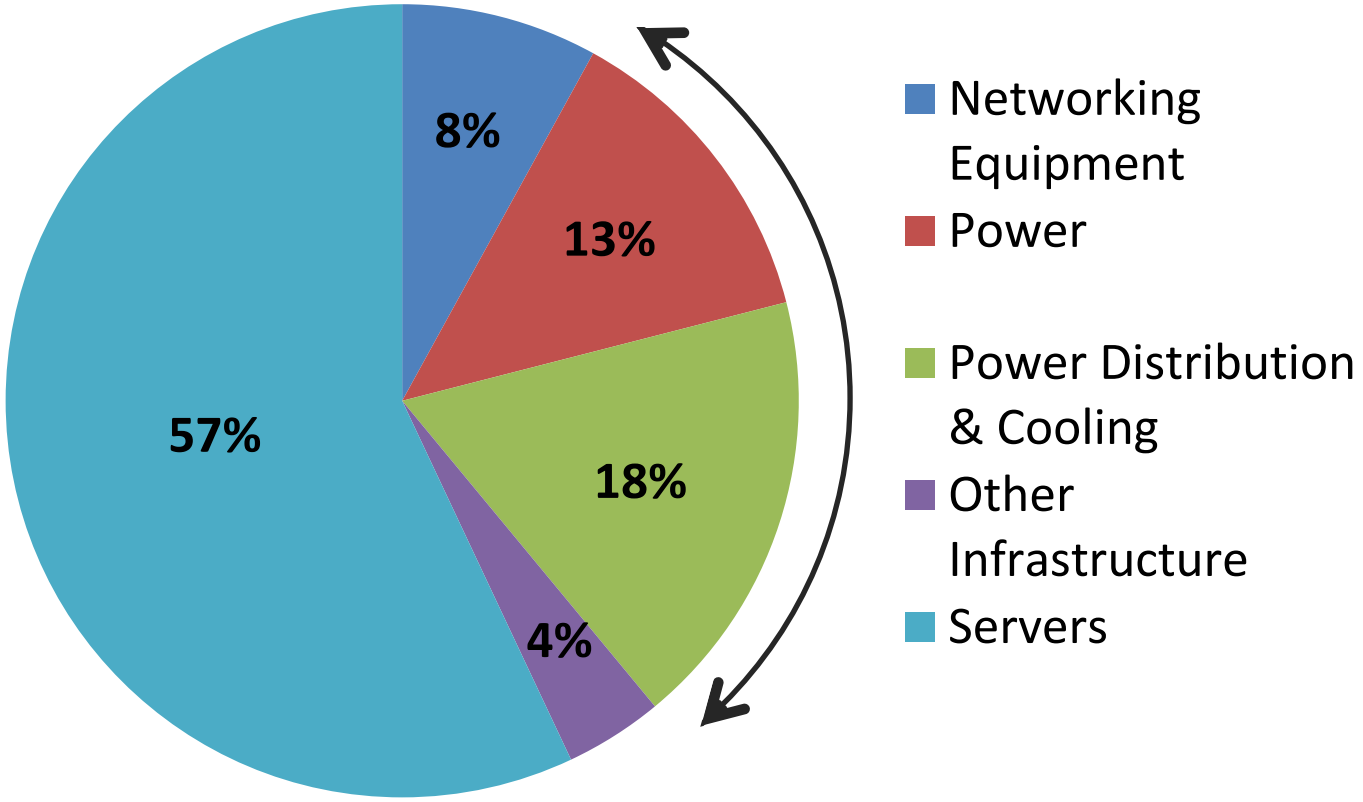
Typical Data Center Operating Costs Profile

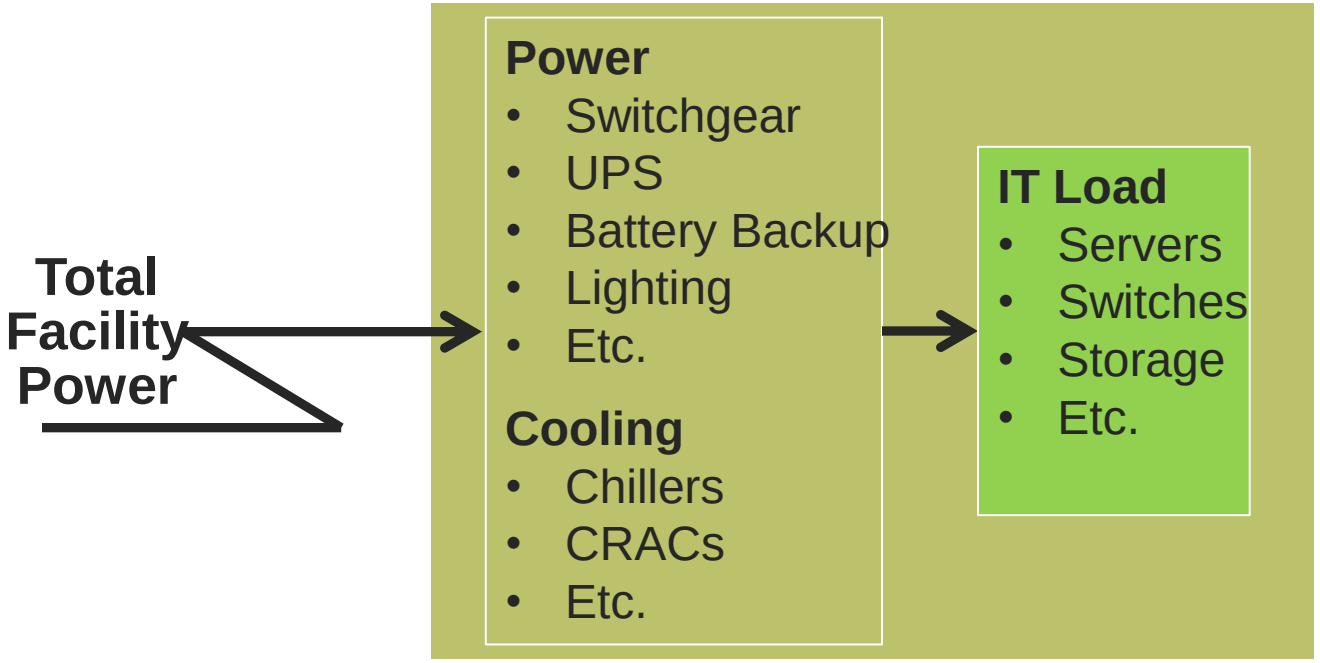
Power costs represent 25-40% of monthly operating expenses



3 yr. Server; 10 yr. Infrastructure Amortization

Power Usage Efficiency (PUE)

Any energy expended other than that to drive the IT Load contributes to inefficiency



$$PUE = \frac{\text{Total Facility Power}}{\text{IT Load}}$$

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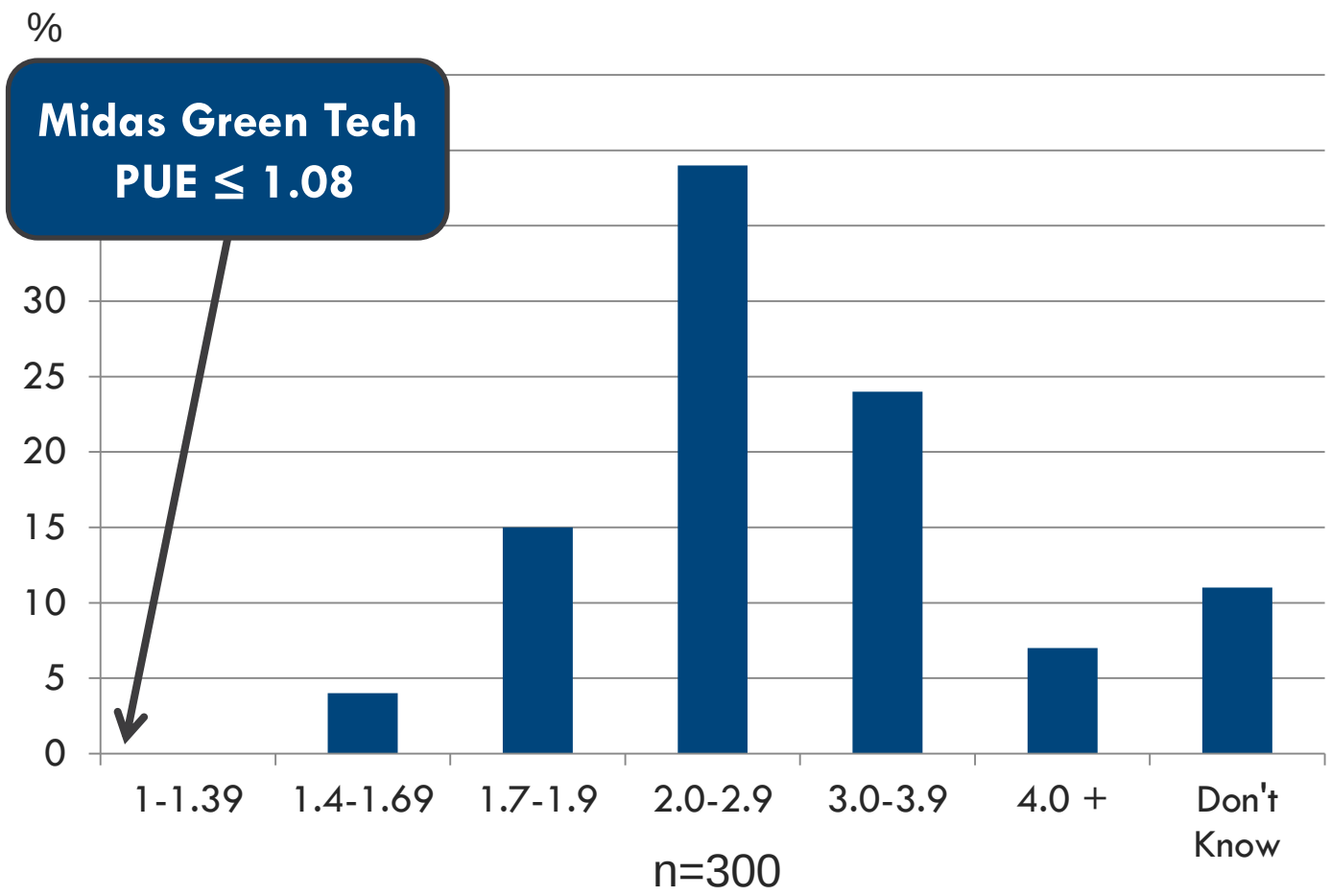
Industry PUE Profile

Average PUE:

- Per Uptime Institute: 1.8
- Per EPA Energy Star Program: 1.91



Source: Digital Realty Trust 2012 Survey

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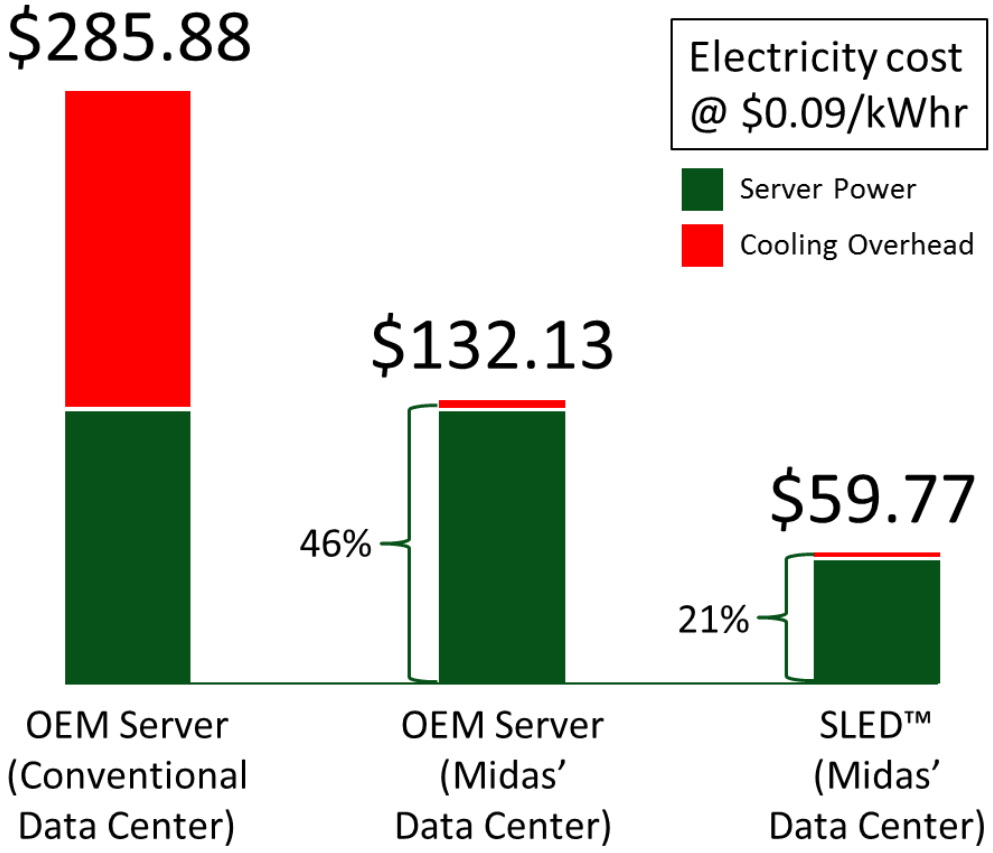
Huge Energy and Cost Savings

Fan-less, ultra-efficient data center

Per Server Monthly Electricity Cost



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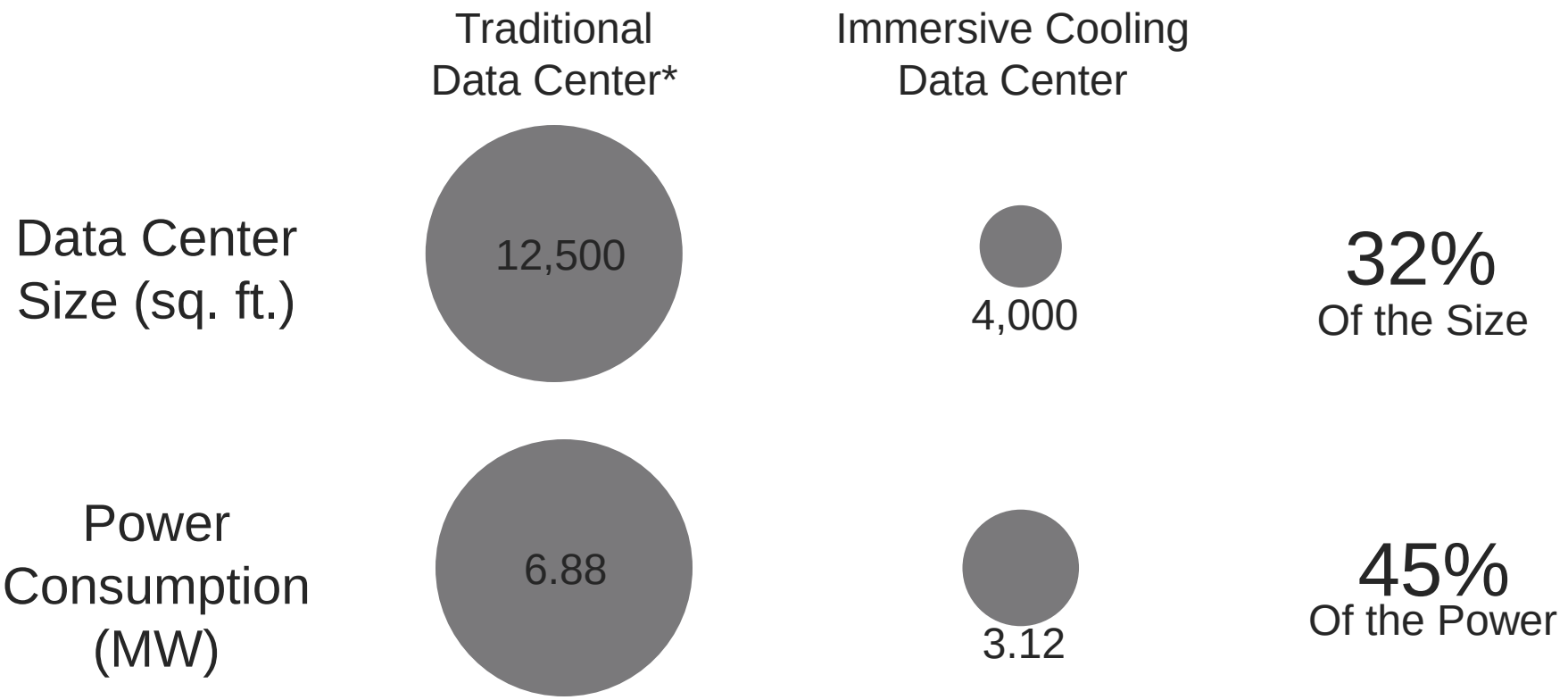
Traditional Data Center vs. Immersion Cooled Data Center



Identical Processing Capacity Comparison
(10,000 servers)

*Assumes PUE of 1.8
and Dell PowerEdge R520 servers

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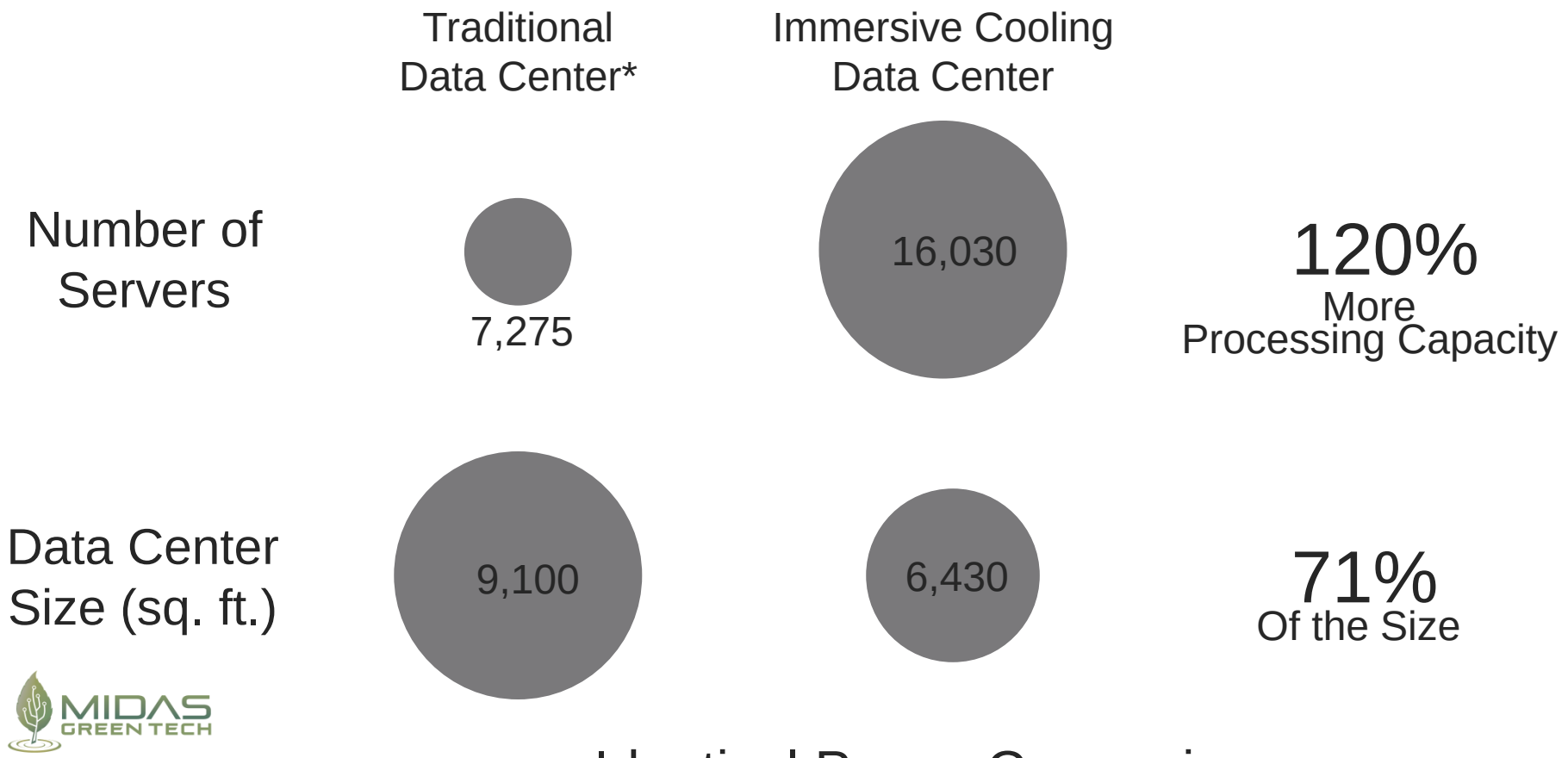
Traditional Data Center vs. Immersion Cooled Data Center



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Identical Power Comparison
(5 MW)

*Assumes PUE of 1.8
and Dell PowerEdge R520 servers

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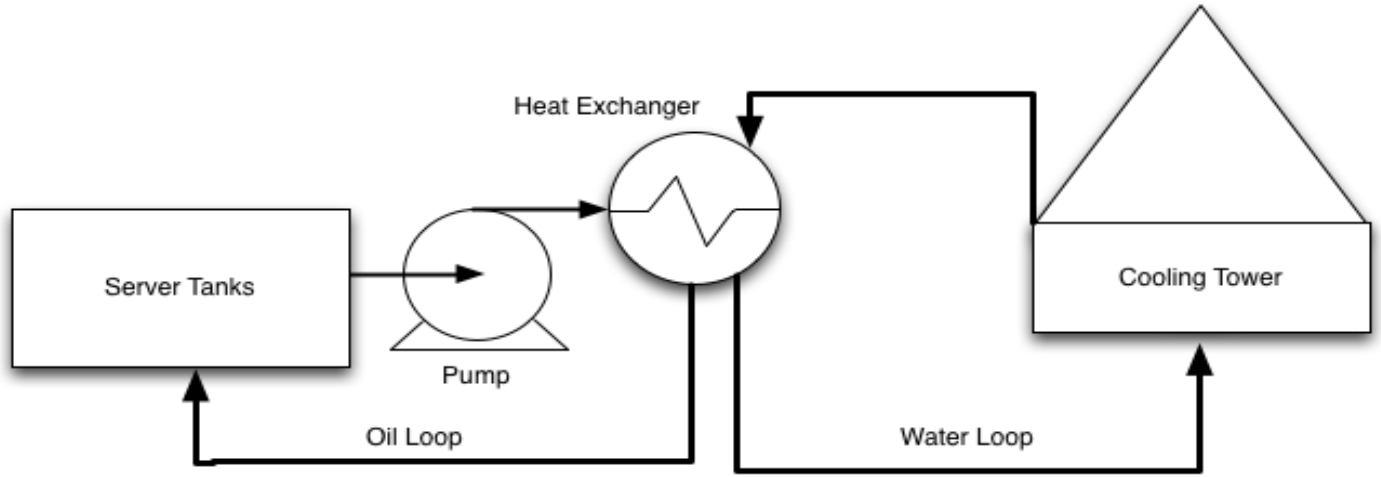
Oil Cooling System Components Schematic

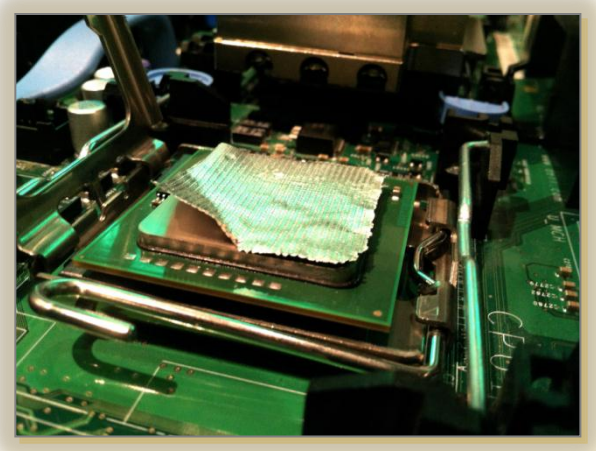
- Simpler than typical air cooling system
- Improvements in the instrumentation and reporting in progress



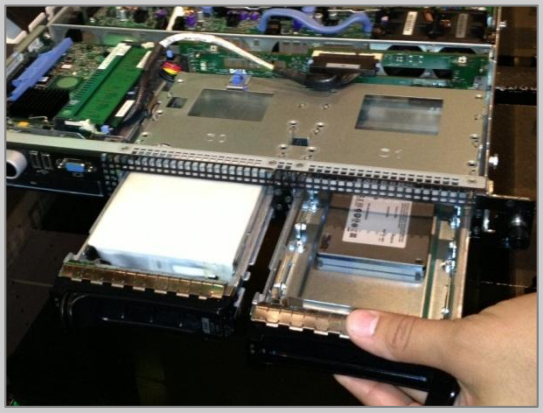
Preparation: Works With Any OEM Server

Prep takes less than 10 minutes

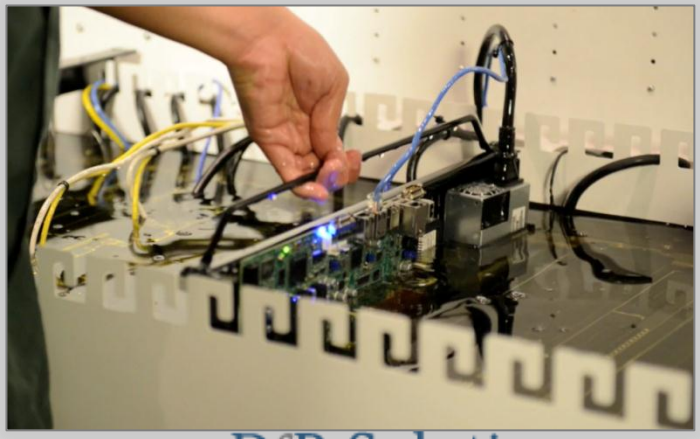
Remove fans



Replace thermal paste



Use sealed or solid-state drives



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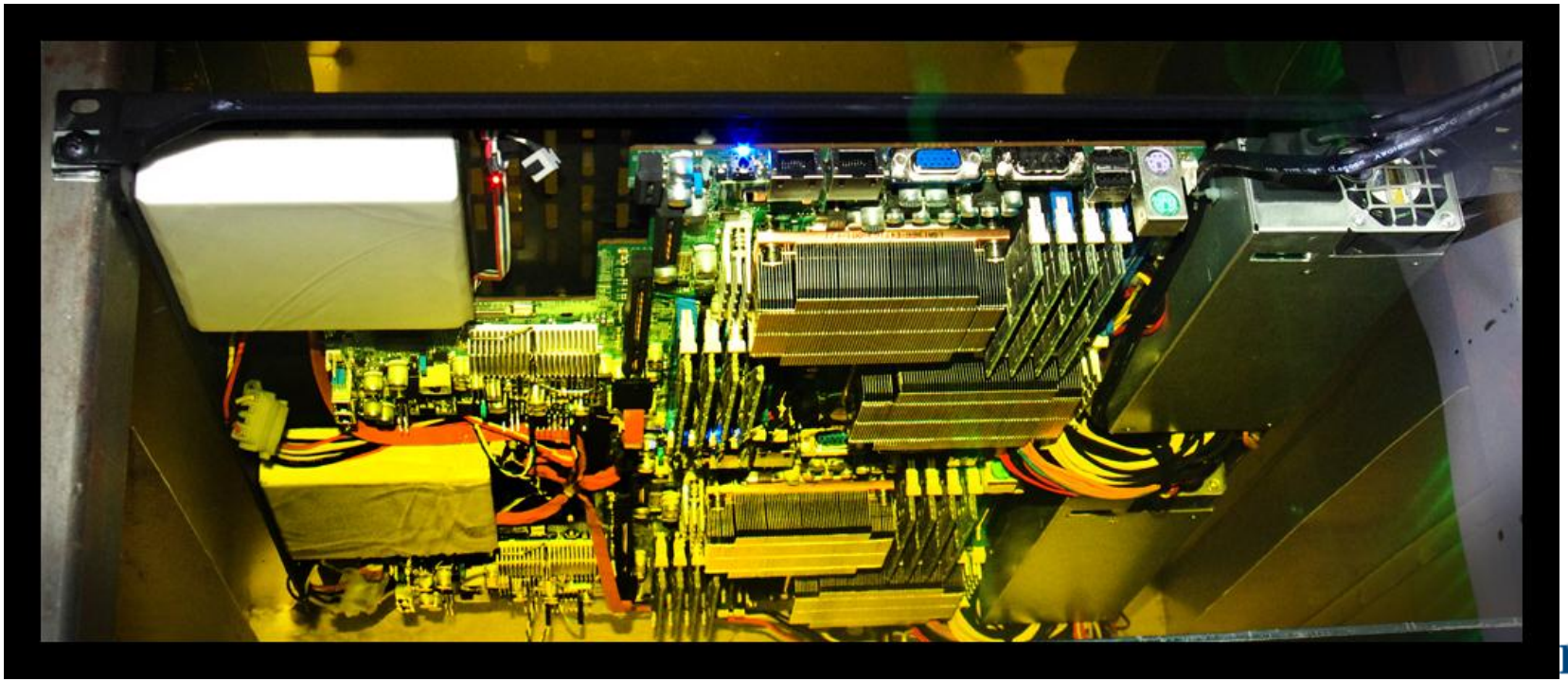
Server Maintenance

- If you do get thermal paste into the system, it can be easily filtered by temporarily replacing the catch screen in the pump module with a 2 um filter.
  - The thermal paste dissolves in the oil, making it cloudy.

- How do you work on a server in immersion oil cooling?
  - Pull the server out, wait for it to drain
  - Keep a paper towel nearby

Optimized Design

- The SLED: custom server design takes optimal advantage of the cooling technology
  - Based on experience gained from more than 18 months of experience operating an immersion cooled data center

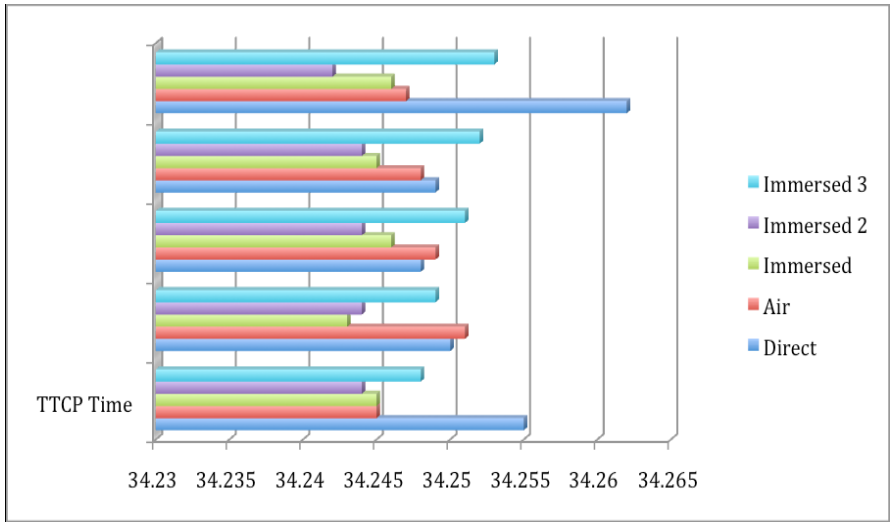


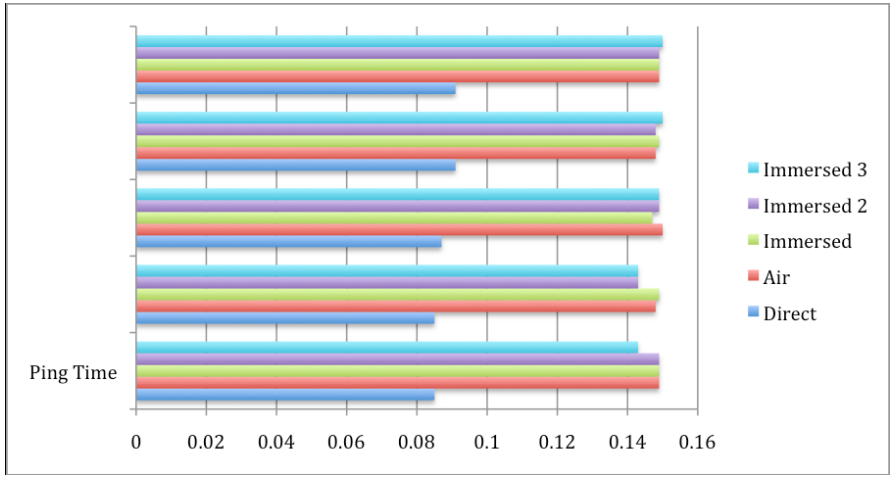
Immersion Technology Challenges

- Skepticism from OEMs
  - This is changing--Intel's recent positive report
  - SuperMicro Computer is developing SKUs for immersion boards
    - http://www.datacenterknowledge.com/archives/2012/03/22/submerged-supermicro-servers-accelerated-by-gpus/
  - Network gear manufacturers are lagging behind server vendors
- Disk Arrays
  - Current hard disks leak, and the oil crashes the heads
  - Solid State Drives (SSDs) are expensive
  - Waiting to test the new Western Digital helium filled drives when they ship next year, hermetically sealed
    - http://www.hgst.com/press-room/2012/hgst-announces-radically-new-helium-filled-hard-disk-drive-platform

Immersion Technology Challenges

- Proving technology
- Impact on optical components
  - TTCP transfer times and ping times are very similar crossing the switch network, regardless of whether the optical interfaces are immersed
  - In all cases, no pings were lost
    - Coolant immersion does not appear to adversely affect the error rate on the links.





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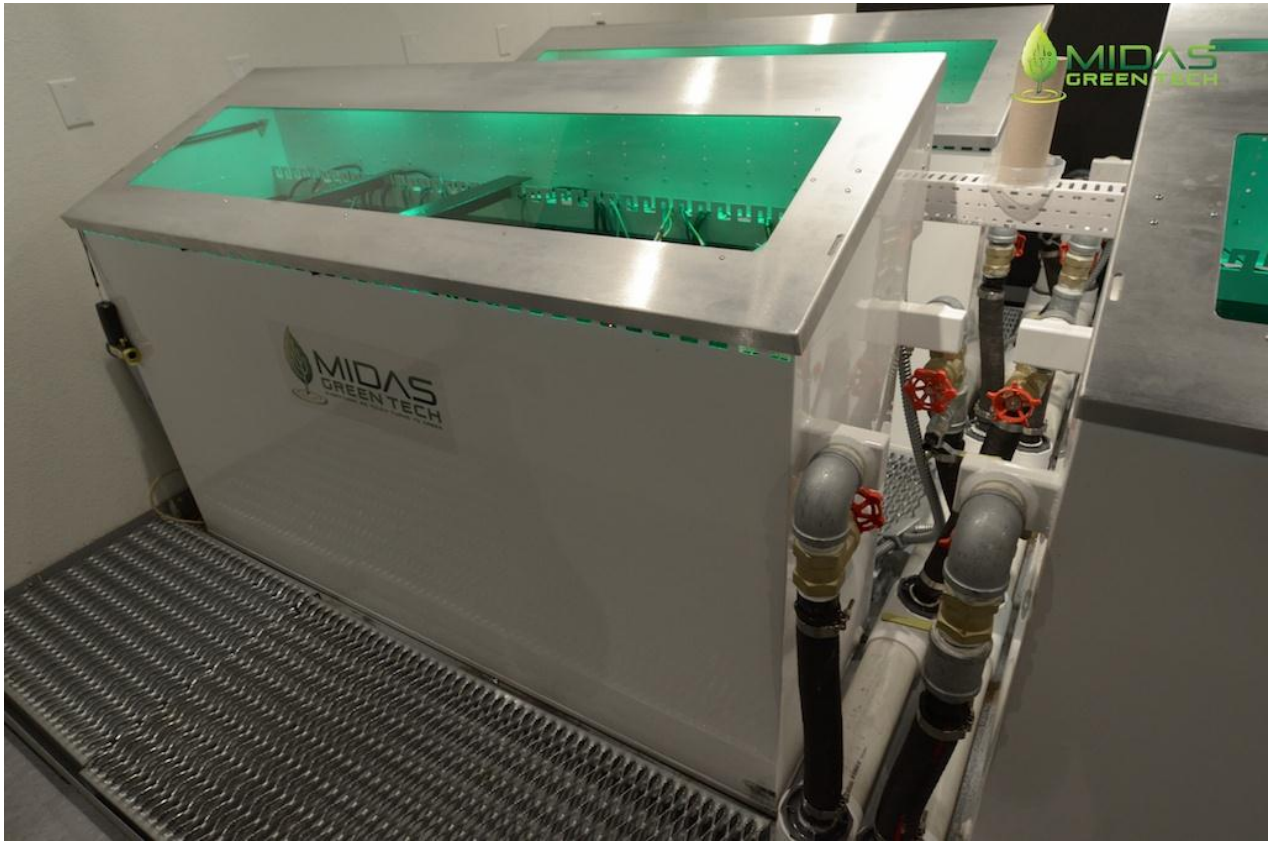
Immersion Technology Challenges

- Impact on RF components?
- Performance Impacts?
  - None detected yet
  - Trials underway
  - Image of Ethernet switch which has been running immersed since January 2011

Reliability Enhancements

Minimizes Common Operational Issues:

- Overheating
- Temperature swings
- Server fan failures
- Dust
- Air quality
- Corrosion



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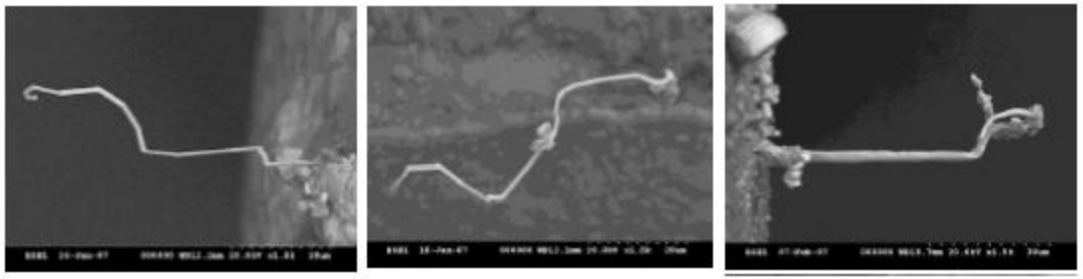
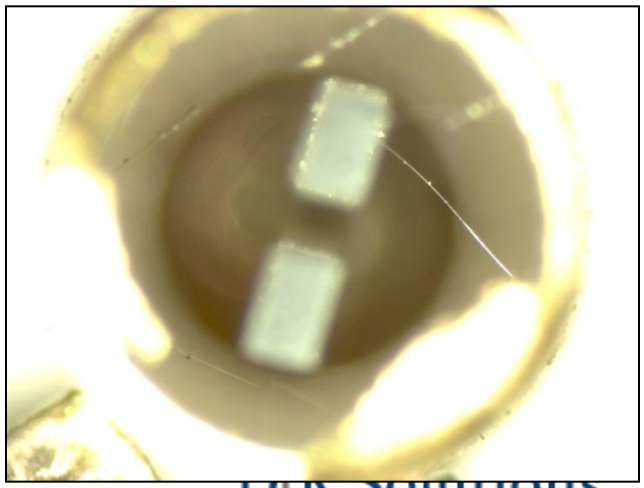
Reliability Enhancements

- Tin Whisker Mitigation
  - Arcing
- Reduction in Corrosion & Electrochemical Migration
  - Corrosive exposure reduction
  - Moisture reduction
- Environmental contaminant reduction
  - Dust, debris, particulates
- More stable and even thermal environment
  - No hot spots

Tin Whiskers

- Tin whiskers are hair-like single crystal metallic filaments that grow from tin films.
- Their unpredictability is the greatest concern.
- The Aerospace and Defense industries consider tin whiskers the, “greatest reliability risk associated with Pb-free electronics”.
  - Manhattan project phase 2 report





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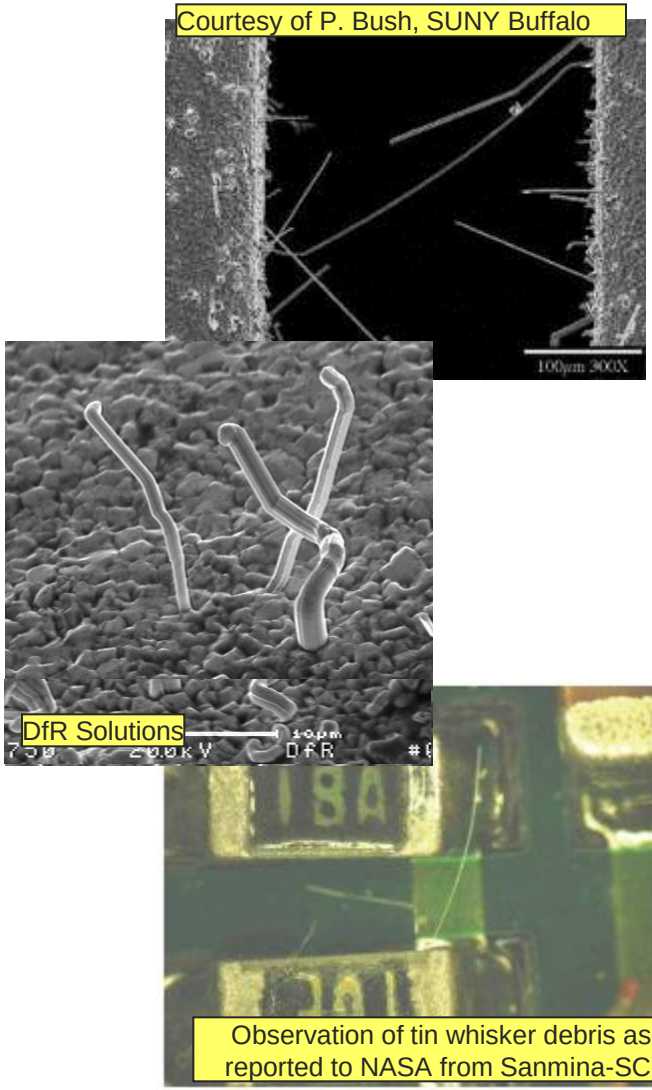
What are the potential failure modes?

- Direct Contact
  - Causes an electrical short (arcing)
  - Requires growth of sufficient length and in the correct orientation
- Electromagnetic (EM) Radiation
  - Emits or receives EM signal and noise at higher frequencies
  - Deterioration of signal for frequencies above 6 GHz independent of whisker length
- Debris
  - Whisker breaks off and shorts two leads (primarily during handling)
- These can be mitigated by immersion oil



Response to Tin Whisker Risk

- Biggest challenges are high reliability applications with high volumes and strong cost pressures
  - Examples: **Enterprise servers,** external defibrillators, first-responder radios, industrial process monitoring, etc.

- Every mitigation must be looked at closely in regards to need and cost (led by GEIA)
  - Requires a clear understanding of why and when tin whiskers occur

Why Worry about Contamination and Cleanliness?

- Believed to be one of the
- primary drivers of field issues in electronics today
  - Induces corrosion and metal migration (electrochemical migration – ECM)

- Intermittent behavior lends itself to no-fault-found (NFF) returns
  - Driven by self-healing behavior
  - Difficult to diagnosis
- Pervasive
  - Failure modes observed on batteries, LCDs, PCBAs, wiring, switches, etc.
- Will continue to get worse

Future of Contamination / Cleanliness

- Continued reductions in pitch between conductors will make future packaging more susceptible
- Increased use of leadless packages (QFN, land grid array, etc.) results in reduction in standoff
  - Will reduce efficiency of cleaning, which may lead to increased concentration of contaminants
- Increased product sales into countries with polluted and tropical environments (East Asia, South Asia, etc.)
  - ECM occurrence very sensitive to ambient humidity conditions
- Pb-Free and smaller bond pads
  - Require more aggressive flux formulations

What is ECM?

- One definition
  - Movement of metal through an electrolytic solution under an applied electric field between insulated conductors
- Electrochemical migration can occur on or in almost all electronic packaging
  - Die surface
  - Epoxy encapsulant
  - Printed board
  - Passive components
  - Etc.

ECM Drivers

- Temperature
- Moisture
- Contamination
- Voltage/Electrical Field

- Temperature, moisture, and contamination aspects can all be reduced and/or eliminated with immersion cooling

Sources of Contaminants

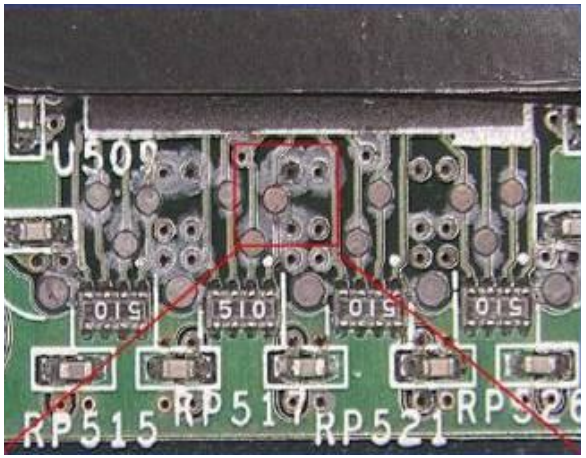
- Printed board fabrication process
  - Insufficiently cured polymers
- Rinse water
- Fluxes
- Handling
- **Storage and use environment**

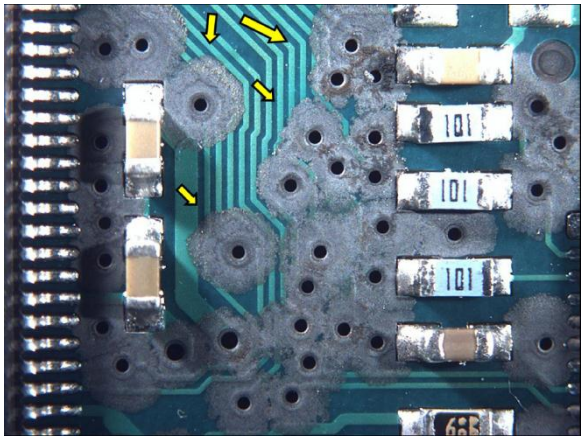
Contaminants: Handling / Storage / Environment

- Handling
  - Salts from human contact (KCl and NaCl)
- Storage
  - Cleaning chemicals
  - Outgassing
  - Polymeric materials
- Use Environment
  - Dust, Debris
  - Moisture, Evaporated sea water
  - Industrial pollutants
- Filtered oil prevents these from accumulating on electronics

Influence of Pollutants: Creepage Corrosion

- Recent field issues with printed circuit boards (PCBs) plated with immersion silver
  - Sulfur-based creepage corrosion
- Failures in customer locations with elevated levels of sulfur-based gases
  - Rubber manufacturing
  - Sewage/waste-water treatment plants
  - Vehicle exhaust fumes (exit / entrance ramps)
  - Petroleum refineries
  - Coal-generation power plants
  - Paper mills
  - Landfills
  - Large-scale farms
  - Automotive modeling studios
  - Swamps
- Immersion oil would prevent this exposure!





P. Mazurkiewicz , ISTFA 2006

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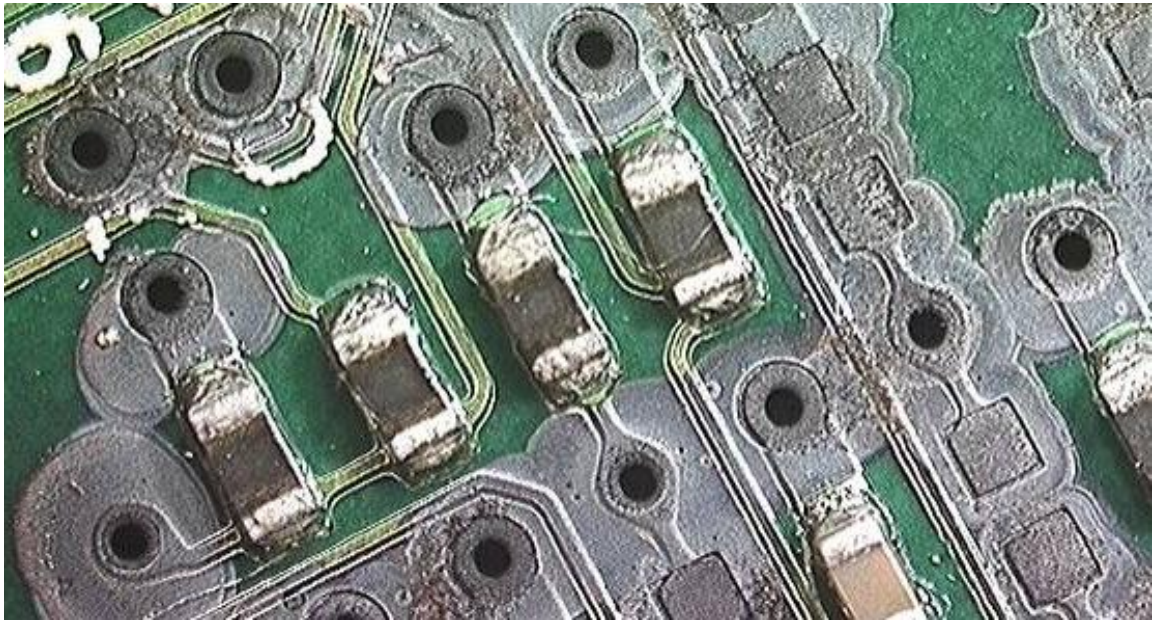
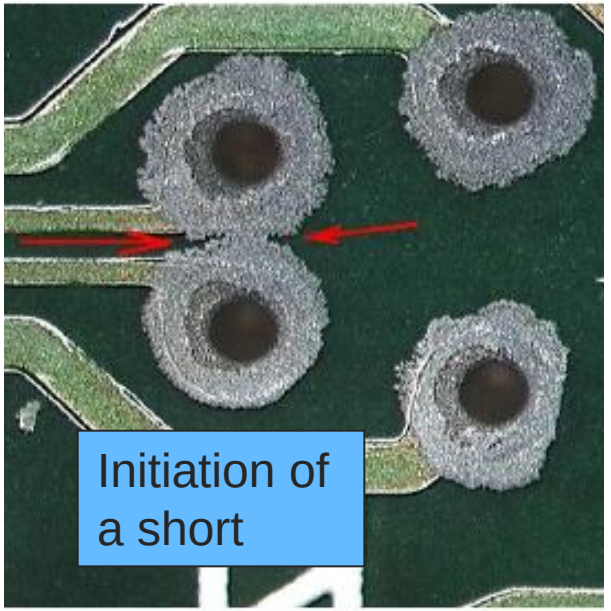
Creepage Corrosion Failure of ImAg

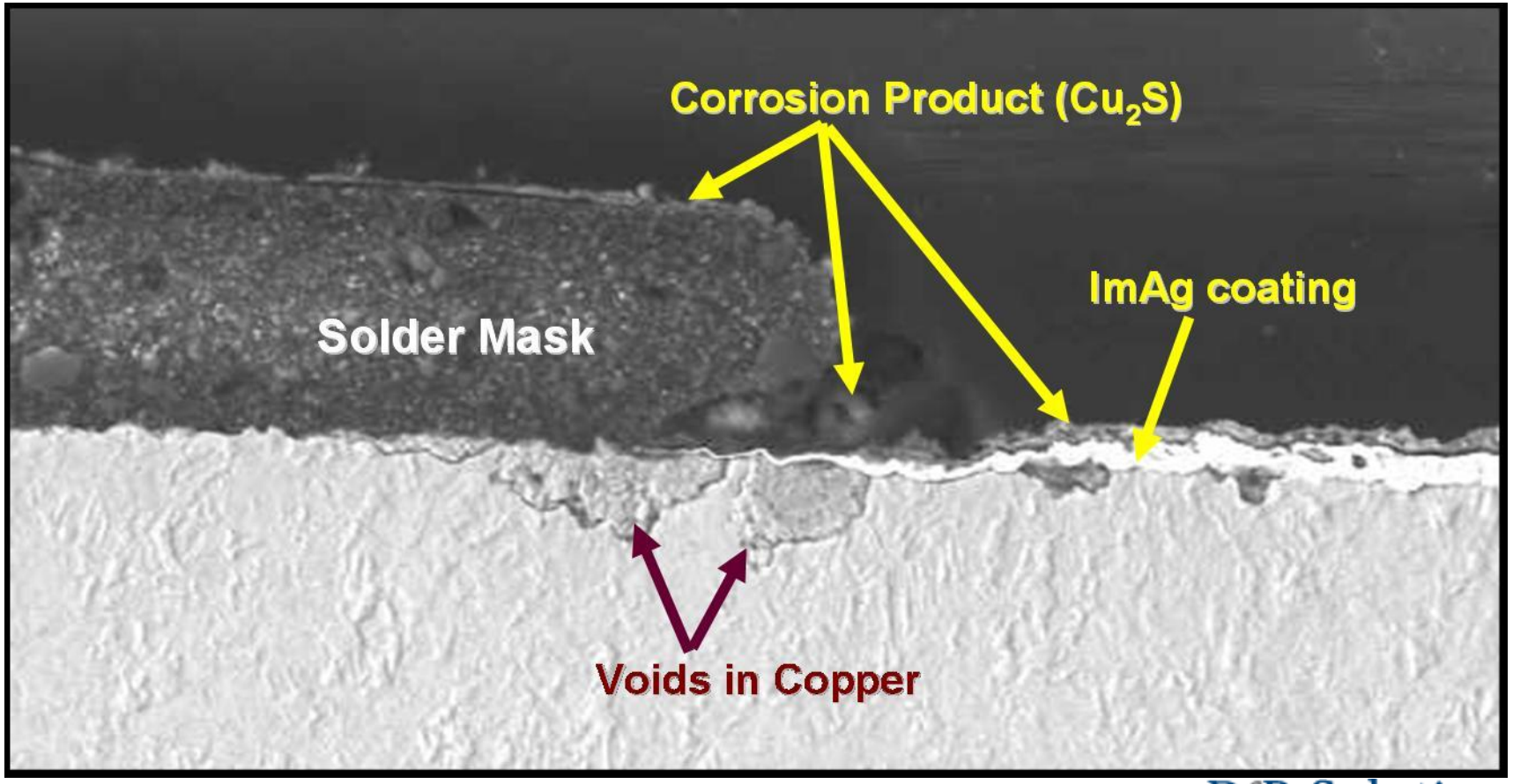




- Corrosion product is semi-conductive (resistance of about 1Mohm).
- Resistance decreases as humidity increases.
- Traces sensitive to leakage current trigger the system failure.
- Visual inspection required to identify failures (most are CNDs).

Creepage Corrosion Mechanism

- Exposed Cu was consumed to form copper sulfide that could cause electrical shorts.



Industrial Pollutants (Sulfur-Based)

SO2

- MFG Test
  - 100ppb, 200ppb
- Average annual outdoor
  - 2-20ppb (USA)
  - 25-100ppb (Asia)
- 24 hour
  - ~150ppb (NAAQS / Telcordia)
  - 150-600ppb (Industrial-USA)
  - 100-1500ppb (Asia)
- May not be critical for sulfidation of silver
  - Rate independent of SO2 concentration

H2S

- MFG Test
  - 10ppb, 100ppb, 200ppb
- Average annual outdoor/indoor
  - 0.05 to 0.8ppb
- 24 hour (outdoors)
  - 8 to 100ppb (State Regs)
- 24 hour (indoors)
  - 500 to 20,000 ppb
- May be more critical

	Clean room	Controlled environment	Rural	Urban with heavy traffic or industrial	Adjacent to industrial	Inside industrial
SO2	100 ug/m^3 38 ppb	100 38	100 38	1000 380	10000 3800	40000 15300
H2S	1.5 0.6	10 4	10 4	500 200	10000 4075	70000 28500

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IEC 60721-3-3

Pollutants: Not Always in Industrial Settings

Drywall Sulfur Fumes Blamed for A.C. & Electrical Equipment failures

- **Chinese Drywall Cited in Building Woes**
  - The drywall is emitting sulfur-based gases that are corroding air-conditioner coils, computer wiring and metal picture frames.
- **Drywall blamed for A.C. failures**
  - Air-conditioning coils have turned black, along with wiring, piping and even silver jewelry.
  - "We have definitely identified that a combination of sulfide gases are the cause of the corrosion," said Robert P. DeMott, managing principal of Environ.
  - "Foul odors reported by people living in the homes may also be caused by the combination of sulfur gases being released from the drywall,
- **Chinese drywall class action lawsuit**
  - LEE COUNTY, Fla. - The Lawsuit was filed against Knauf Plasterboard Tianjin Co., LTD, The Knauf Group, Rothchilt International Limited and the Banner Supply Company.
  - Known as "Chinese Drywall", it was manufactured oversees and was made from waste materials. As a result, it emits sulfur compounds that corrode copper wiring and other metals found in homes.

Monday,January 12, 2009 As of 12:00 PM
THE WALL STREET JOURNAL.

news-press.com
Fort Myers, Florida • Southwest Florida

Copper Corroded by Sulfur flumes

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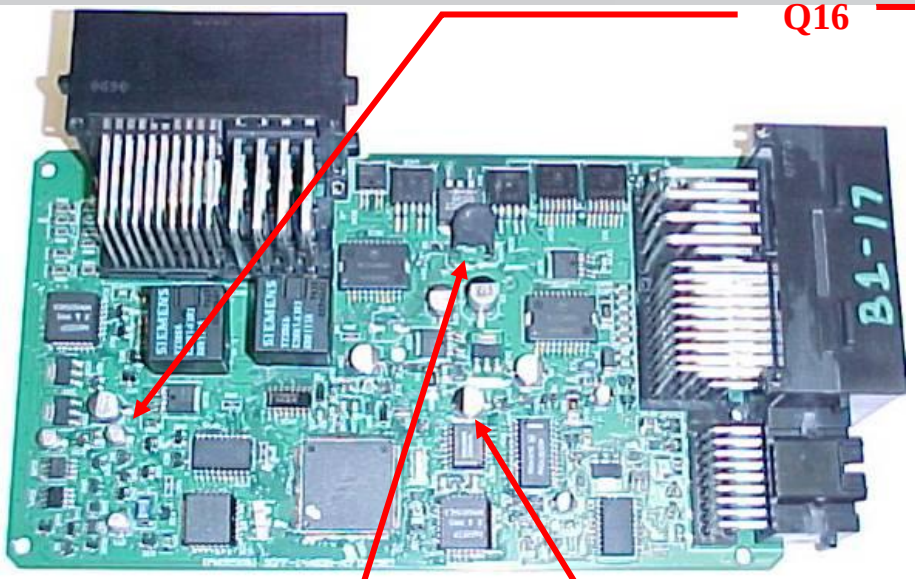
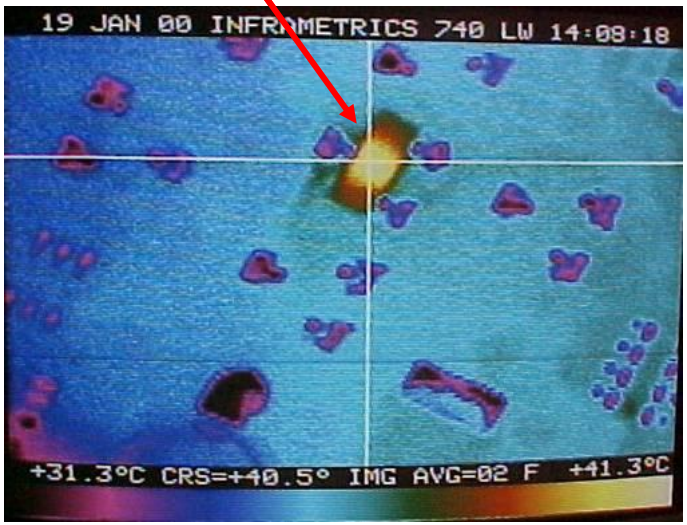
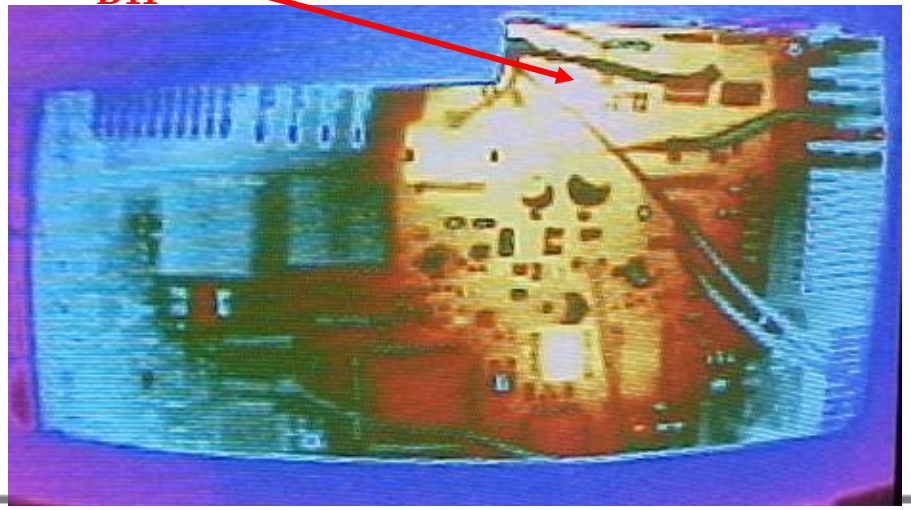
Infra-Red Thermal Evaluation







Thermal Anomalies Detected

- Q16 producing heat when is it supposed to be in an off state - sneak circuit detected
- D11 detected a hot spot that exceeded thermal limit

Expect hot spot reduction and improved thermal uniformity using immersion oil cooling

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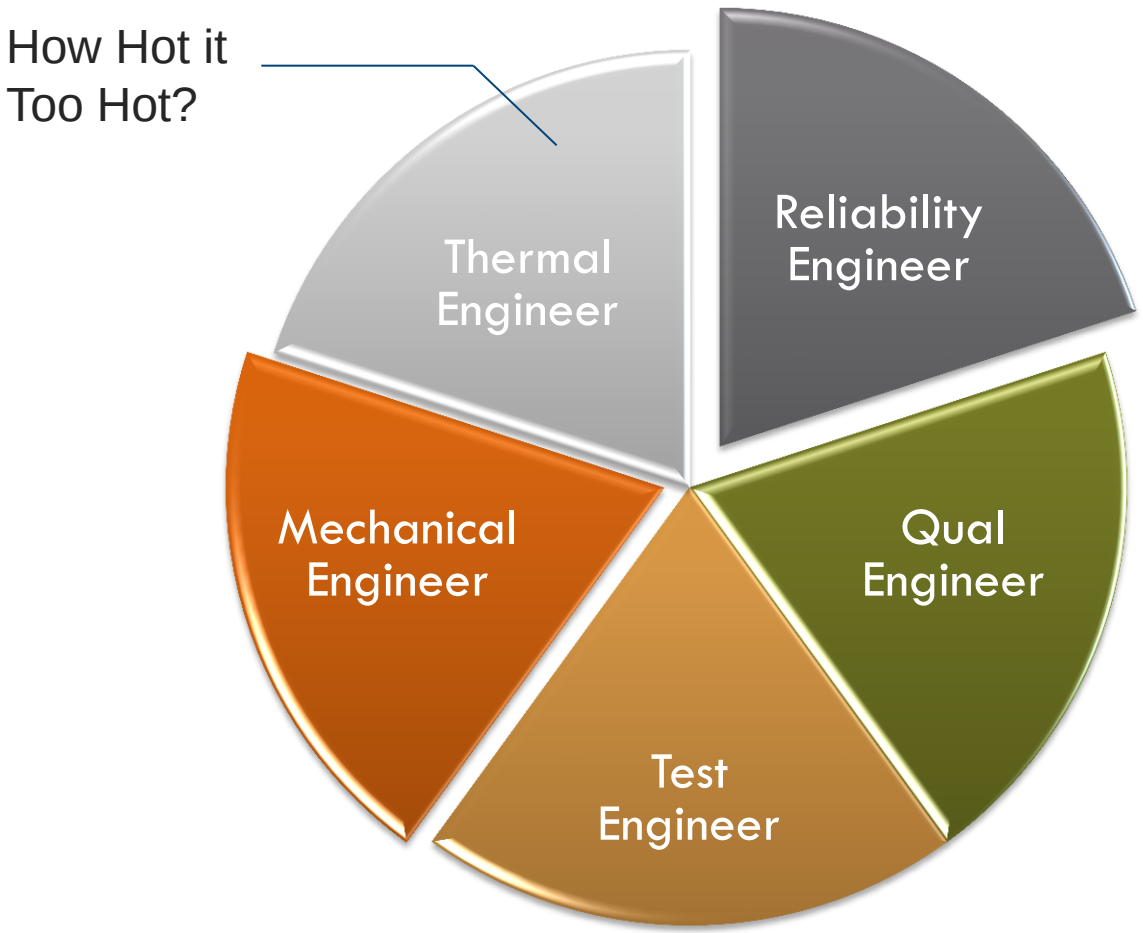
Software Reliability Modeling & Prediction Tool



- PCB Design
- Temp Cycling
- Vibration
- Shock
- Bending
- In Circuit Test
- DFMEA
- Thermal Derating
- Failure Rate

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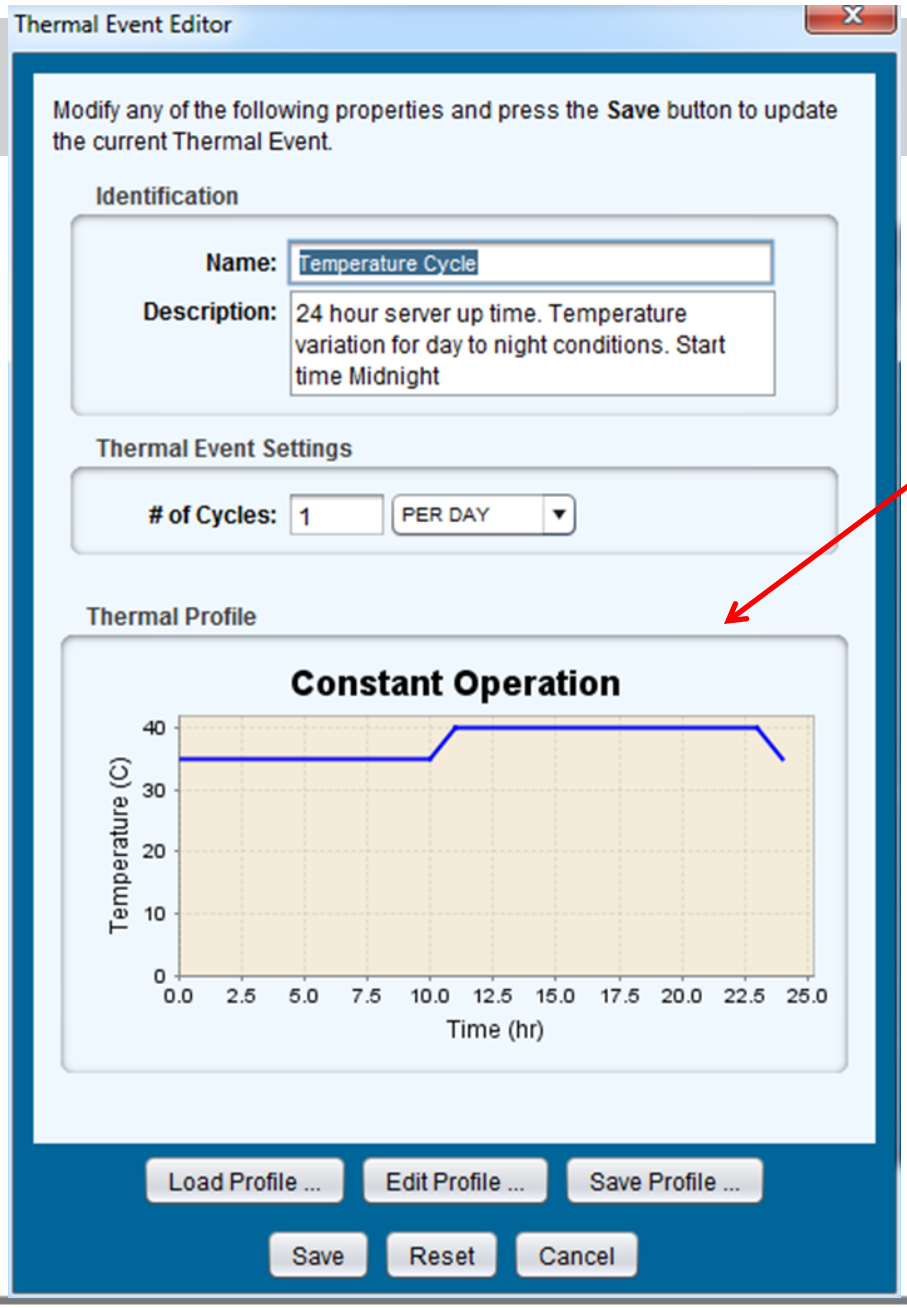
Thermal Modeling & Prediction



- Create Thermal Environment for a typical, air-cooled data center
- Create 2nd environment for immersion oil cooled data center
- Compare
- Correlate to longer term actual data

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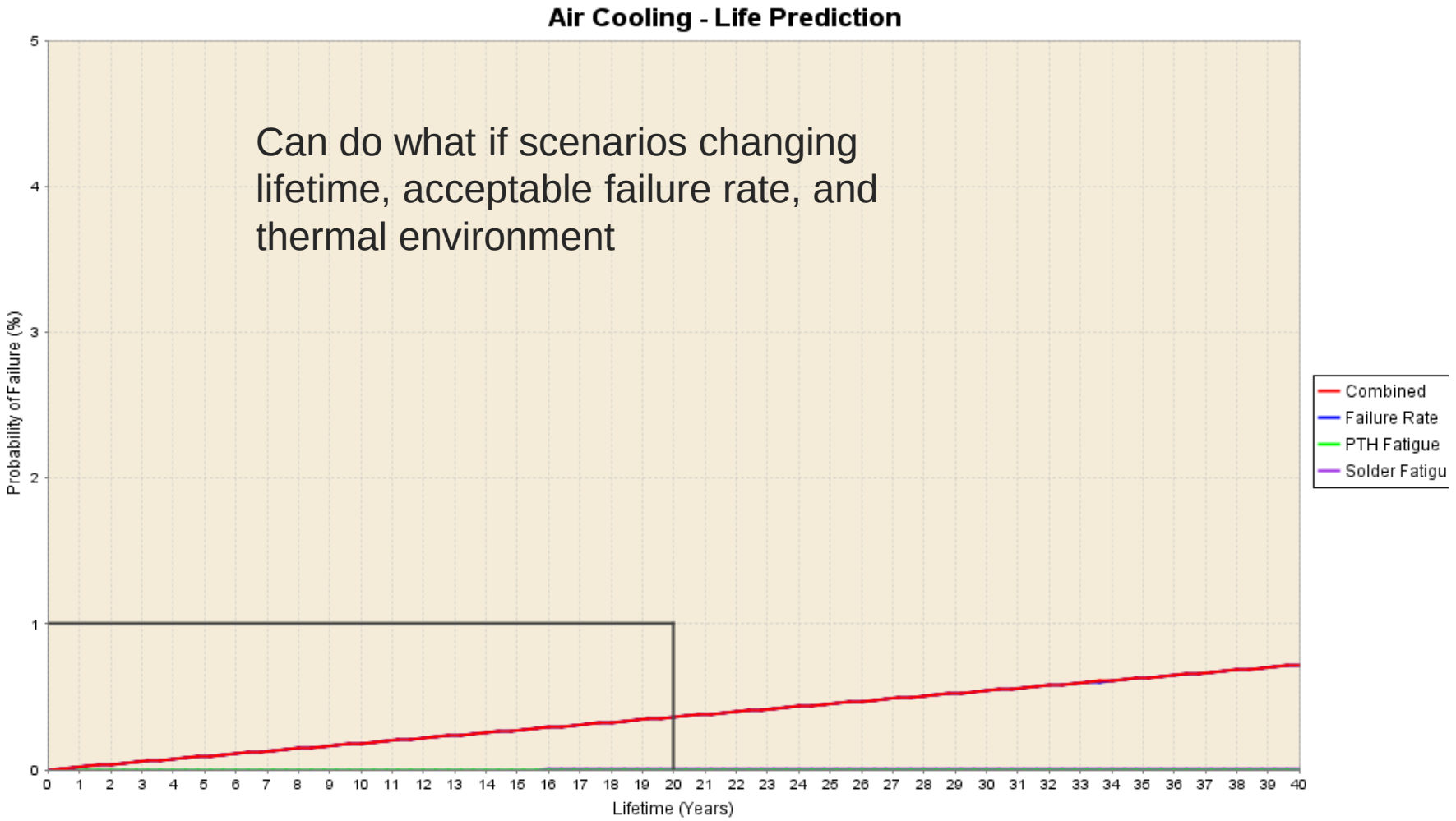
Thermal Modeling & Prediction Life Curves



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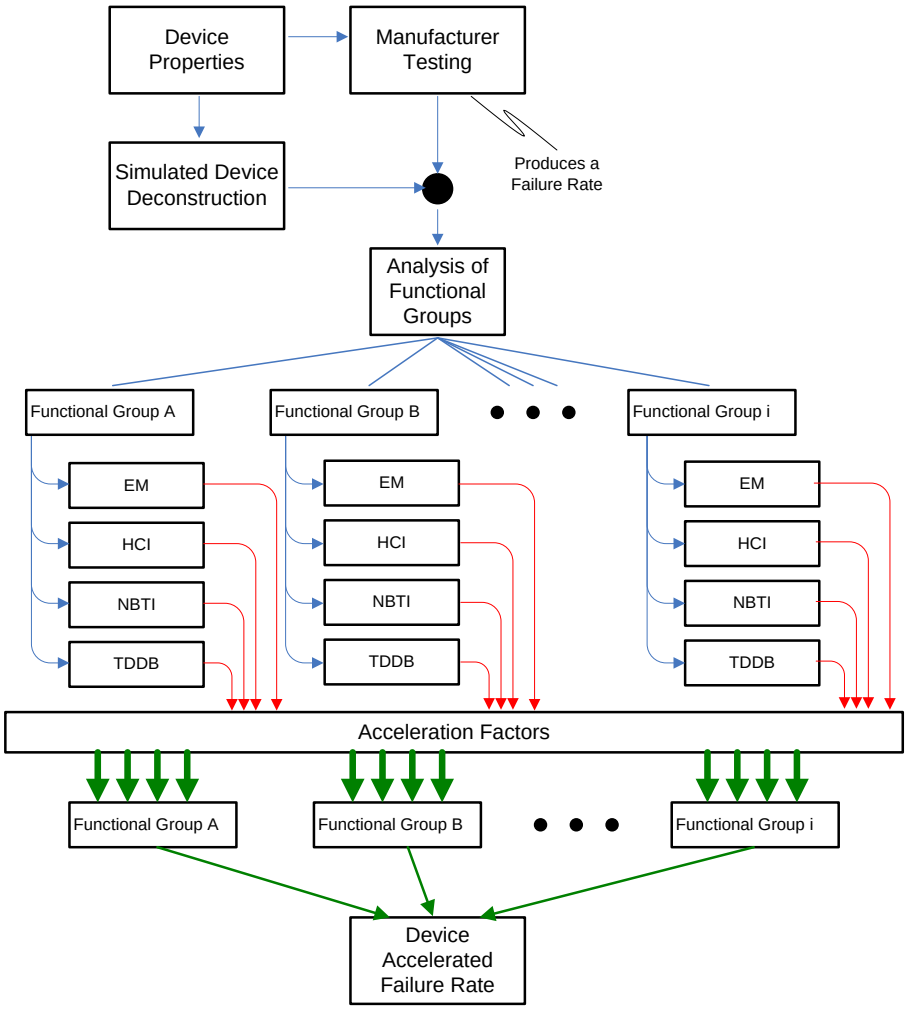
ICs – Lifetime Prediction & Impact of Temperature



- Models the simultaneous degradation behaviors of multiple failure mechanisms on integrated circuit devices
- Devised from published research literature, technological publications, and accepted degradation models from:
  - NASA\JPL
  - University of Maryland
  - Semiconductor Reliability Community
- Easy to use software solution by multiple engineering disciplines

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Industry Evaluation – Intel Experience

- Intel tests oil immersion to cool servers
  - "If you are going to add a significant amount of capacity and have systems with a lot of density and don't have good air flow in your data center, this is worth looking at," said Mike Patterson, a senior thermal architect for data centers at Intel who supervised the test.
  - "We asked a lot of tough questions and they had pretty good answers for all of them so we put a pilot together," said Patterson. "There's almost an emotional reaction [against oil immersion] at first, so people say they would never do that, but when they see the potential [energy] savings, they see there's something there," he said.

Industry Evaluation – Intel Experience

- With all this in mind, Intel plans to start developing motherboards optimized for immersion cooling. Various OEMs involved in server hardware are expected to create modified designs with oil immersion in mind as well. In the future, this technology might even make it to the consumer level in a more official way.
- Intel also found that no computer components — processors, hard drives etc. – were damaged from the yearlong immersion in mineral oil.

http://green.blogs.nytimes.com/2012/09/06/cooling-a-computer-server-with-mineral-oil/

Technology Summary

Midas is the only commercial data center using this technology

- Immersion cooling technology has been used previously in the computing and electric power industries
- More than 600,000 hours of server time logged by customers including one of the largest grocery chains in Texas and Texas Multicore
- Virtually unlimited heat density and scalability
- Using highly effective enviro-friendly fluid for cooling greatly improves server reliability
- Will be vital for “hot” CPUs currently in development
- Dramatically reduced carbon footprint

DfR Solutions

Summary

- Immersion oil cooling offers significant environmental, cost, performance, and reliability advantages.
  - Reduces potential for failure in:
    - Tin Whisker Mitigation via arcing
    - Corrosion & Electrochemical Migration (ECM)
    - Moisture reduction
    - Environmental contaminant reduction
    - Provides stable and even thermal environment

Speaker Biography

- Cheryl Tulkoff has over 22 years of experience in electronics manufacturing with an emphasis on failure analysis and reliability. She has worked throughout the electronics manufacturing life cycle beginning with semiconductor fabrication processes, into printed circuit board fabrication and assembly, through functional and reliability testing, and culminating in the analysis and evaluation of field returns. She has also managed no clean and RoHS-compliant conversion programs and has developed and managed comprehensive reliability programs.

- Cheryl earned her Bachelor of Mechanical Engineering degree from Georgia Tech. She is a published author, experienced public speaker and trainer and a Senior member of both ASQ and IEEE. She holds leadership positions in the IEEE Central Texas Chapter, IEEE WIE (Women In Engineering), and IEEE ASTR (Accelerated Stress Testing and Reliability) sections. She chaired the annual IEEE ASTR workshop for four years and is also an ASQ Certified Reliability Engineer.

- She has a strong passion for pre-college STEM (Science, Technology, Engineering, and Math) outreach and volunteers with several organizations that specialize in encouraging pre-college students to pursue careers in these fields.

Co-Speaker Biography

- Chris Boyd, Chief Technology Officer, Midas Green Technology, LLC. Chris Boyd has 20+ years' experience in the telecommunications industry as a network operator, system engineer, and technical trainer. He is the co-founder of Midas Green Technology, LLC, a managed hosting provider which deploys a new server immersion cooling technology for commercial users.

- Chris is a recognized technologist and is a frequently requested consultant for data center, hosting and telecommunications companies. Chris has extensive experience developing and implementing leading innovative technology solutions in network management, performance management and patents for packet telephony routing. Chris is also treasurer of the Electric Frontier Foundation - Austin, working to ensure the internet remains a "level playing"
- field for the end user.

- Chris received a degree from UT Dallas in May, 1989 with areas of specialization in communication, computer science, and management.

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- Connect with me in LinkedIn as well!
- See the server dunking videos at http://www.midasgreentech.com/svlg/