

CPMT IEEE COMPONENTS, PACKAGING, AND
MANUFACTURING TECHNOLOGY SOCIETY
Santa Clara Valley Chapter www.cpmt.org/scv


Santa Clara Valley Chapter

Halogen Free Electronics

Dan Donahoe
Michelle Poliskie

December 10, 2008

Santa Clara Valley Chapter




CPMT IEEE COMPONENTS, PACKAGING, AND
MANUFACTURING TECHNOLOGY SOCIETY
Santa Clara Valley Chapter www.cpmt.org/scv

Awareness of the Issues

- Perspectives:
 - Human survival depends on technology [1]
 - Material technology is new:
 - First thermosetting plastic, Bakelite, was patented in 1909 [3]
 - Nylon, a thermoplastic, was patented in 1938 [4]
 - A political will favoring environmental stewardship has developed worldwide
 - How does one define environmentally friendly, “halogen free”?
- Limits of knowledge:
 - Greenpeace argues the “Precautionary Principle” [2]:
 - Taking action to eliminate suspect chemicals before all evidence is collected, because scientific evidence may never be conclusive
 - This principle is key to Epidemiology, accredited to John Snow and the removal of a water pump handle during a cholera outbreak in 1854 [5].

2




CPMT IEEE COMPONENTS, PACKAGING, AND
MANUFACTURING TECHNOLOGY SOCIETY
Santa Clara Valley Chapter www.cpmt.org/scv

Environmental Issues

- Key events creating the environmental political arena:
 - Minamata disease 1956 resulted in the fatal mercury poisoning of ~2000 people in Japan
 - Rachel Carson's 1962 book Silent Spring raised concerns about pesticides
 - Greenpeace (1972) grew out of protests against nuclear weapon testing
 - Love Canal incident (1978)
 - Global warming [6, 7]

3




CPMT IEEE COMPONENTS, PACKAGING, AND
MANUFACTURING TECHNOLOGY SOCIETY
Santa Clara Valley Chapter www.cpmt.org/scv

Environmental Laws and Regulations

- United States Legislation:
 - Clean Air Act of 1963
 - Environmental Protection Agency (EPA) created in 1970
 - Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980
 - Created the "Superfund"
 - Law was passed in response to Love Canal
 - Emergency Planning and Community Right-to-Know Act of 1986 (EPCRA)
 - Source of the familiar Material Safety Data Sheet (MSDS)
- European Union Legislation:
 - Restriction on the Use of Certain of Hazardous Substances in Electrical and Electronic Equipment (RoHS) 2002/95/EC
 - Waste Electrical and Electronic Equipment (WEEE) 2002/96/EC
 - Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) EC/2006/1907
- Safety regulations based on standards
 - UL 1950 for IT and business equipment [46]

4




CPMT IEEE COMPONENTS, PACKAGING, AND
MANUFACTURING TECHNOLOGY SOCIETY
Santa Clara Valley Chapter www.cpmt.org/scv

Environmental Standards - Electronics

- Existing Standards:
 - Materials for Printed Boards and Other Interconnecting Structures IEC 61249-2-216
 - Halogen Free Copper Clad Laminate for Test Method JPCA-ES-01-20037
 - Specifications for Base Materials for Rigid and Multilayer Printed Boards IPC-4101B
 - Requirements for Solder Fluxes IPC-STD-004A9
- Pending Standards:
 - IPC/JEDEC J-STD-709, Definition of Maximum Limits on the Low-Halogen Bromine & Chlorine Used in Materials for Certain Electronics Components and Assemblies, Sept. 2008 Draft
 - Issues include levels (900 or 1000 ppm threshold for Br and Cl) and definition (article as in JIG Material Declaration, component as in IPC T-50 or homogeneous as in RoHS) [8, 9, 10]

5




CPMT IEEE COMPONENTS, PACKAGING, AND
MANUFACTURING TECHNOLOGY SOCIETY
Santa Clara Valley Chapter www.cpmt.org/scv

Damage due to Fires

- In 2003, residential fires in the United States alone caused 2,740 deaths and 13,230 injuries [18]
- An example of fire losses due to lack of fire retardants
 - A fire in The Station nightclub in West Warwick, Rhode Island on 20 Feb. 2003 claimed 100 lives and injured hundreds more

6



CPMT IEEE COMPONENTS, PACKAGING, AND
MANUFACTURING TECHNOLOGY SOCIETY
Santa Clara Valley Chapter www.cpmt.org/scv

Greenpeace Audit of PCs

- Greenpeace published an inspection of 5 laptops in 2006 [17]
 - Brands: Acer, Apple, Dell, HP, Sony
 - Substances tested: Pb, Hg, hexavalent chromium (Cr⁺⁶), brominated flame retardants (BFRs), polybrominated flame retardants (PBDEs), tetrabromobisphenol A (TBBPA), polyvinyl chloride (PVC)
- Lead was reported in solder of one brand of laptop
- PVC was found on wires in several models
- Bromine was found in 25% of all components and materials
- High concentrations (greater than RoHS limits of 0.1%) of PBDEs (TBBPA, decaBDE, monaBDE) were detected

7




CPMT IEEE COMPONENTS, PACKAGING, AND
MANUFACTURING TECHNOLOGY SOCIETY
Santa Clara Valley Chapter www.cpmt.org/scv


Verification of Compliance

- How do regulators verify compliance with halogen-free electronics requirements?
 - Taking a parallel with RoHS, little government enforcement has occurred
- IPC Certificate of Compliance [16]

8



**IEEE COMPONENTS, PACKAGING, AND
MANUFACTURING TECHNOLOGY SOCIETY**
Santa Clara Valley Chapter
www.cpmt.org/scv




IPC/JEDEC J-STD-709 Sept. 2008 Draft*

General Presence of Bromine and Chlorine in Electronics


Part Type	Potential Halogen Use
Mechanical Plastic Parts (thermoplastics)	BFRs/CFRs used in certain flame retardants ABS, HIPS, PC, PS, Polyimide (PI) and PBT resins
Cables	BFRs used in cable/wire insulation material PVC used in cable/wire jacketing and overmold
Printed Circuit Boards	BFRs added or reacted into FR-4 and other epoxy resins. Certain solder masks, cover coat, and conformal coatings also contain halogens. Chlorinated organic materials are used in the commercial manufacture of epoxy resins and sodium chloride is a byproduct from this process.
Electronic Components	BFRs added or reacted into FR-4 and other epoxy resins, mold compounds, plastic packages, thermal interface materials, die attach, underfills. Certain solder masks, cover coats and conformal coatings also contain halogens.
Connectors	BFRs used in certain flame-rated PBT and PA resins
Films, Adhesives, Tapes	PVC used in certain magnetic tapes (is this right?) Certain polymers containing bromine for optical properties Polymers containing chlorine or chlorine residuals in certain adhesives
Vibration dampening parts	PVC used in shock absorbing or vibration dampening resins
Soldering pastes/fluxes	Br and Cl used in certain fluxes to improve soldering. While process chemicals such as flux are not within the scope of this standard, any solder flux residue that is part of the electronic product is within the scope of this standard.

* Table taken verbatim from draft standard.

9



**IEEE COMPONENTS, PACKAGING, AND
MANUFACTURING TECHNOLOGY SOCIETY**
Santa Clara Valley Chapter
www.cpmt.org/scv



Why are Halogens Bad?

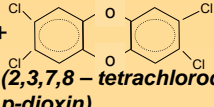
Q: People eat table salt (Na⁺ Cl⁻), why are halogens bad?

A: Reactive starting reagents and decomposition products from halogenated polymers and flame retardants are caustic (using PVC as an example)

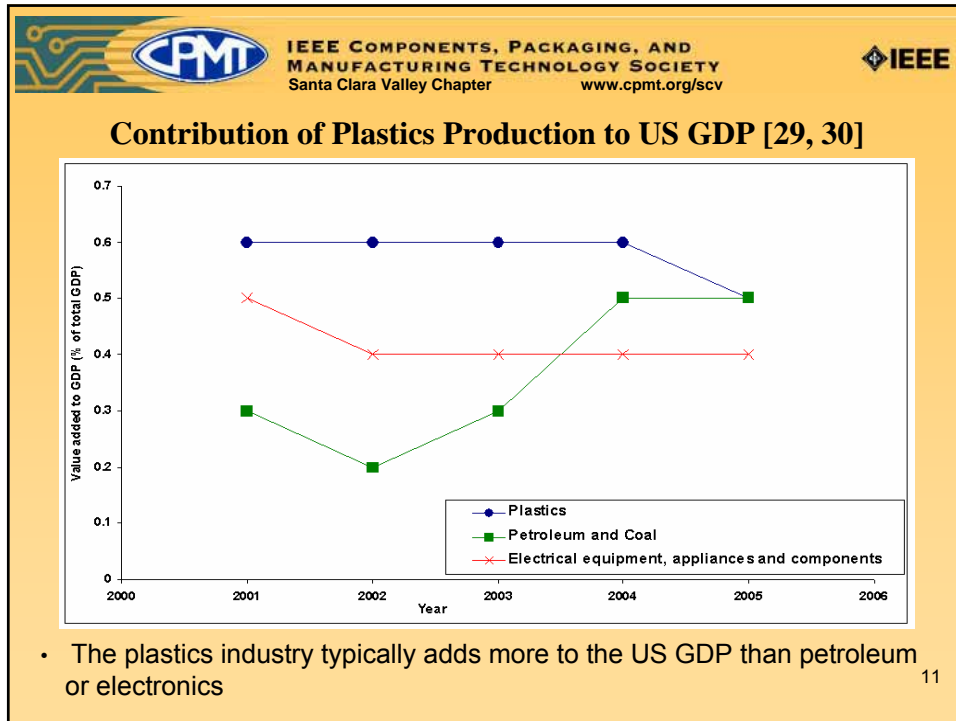
$$\text{CH}_2=\text{CHCl} \xrightarrow{\text{polymerize}} \{\text{CH}(\text{Cl})-\text{CH}_2\}_n$$

(vinyl chloride)
OSHA TWA = 5 molar ppm with
an A1 Carcinogen Rating [26]

$\xrightarrow{\text{combustion}}$

$\text{HCl} + \text{CO}_2 +$


(2,3,7,8-tetrachlorodibenzo-p-dioxin)
OSHA TWA: 200 ppm [28]



11

Petrochemical By-Products are Starting Materials for Thermoplastics

Hydrocarbon Type	Chemistry [31]
Paraffins	C_nH_{2n+2}
Naphthenes	Cyclohexanes: C_nH_{2n}
Aromatics	Cyclohexenes

Paraffins $\xrightarrow{\text{filtering}}$ **Small chain alkanes** $\xrightarrow{\text{cracking}}$ **alkenes + alkanes** $\xrightarrow{\text{polymerization}}$ **Polyethylene**


$CH_3-CH_2-CH_2-CH_3$

CH_3-CH_3
 $CH_2=CH_2$


$\{CH_2-CH_2\}_n$

- Oil-refining by-products result in the production of commodity plastics such as polyethylene (represented above), polyvinyl chloride and polystyrene

12




**IEEE COMPONENTS, PACKAGING, AND
MANUFACTURING TECHNOLOGY SOCIETY**
Santa Clara Valley Chapter www.cpmt.org/scv




Why are Flame Retardants Necessary?

Polymer Type	Chemical Structure	Flammability (ASTM D635) (ipm) [33]	Millions of Metric Tons of Production in 1993 [32]	Important for electronics production?
Polyethylene	$[-CH_2-CH_2-]_n$	1.0	24.7	
Poly(vinyl chloride)	$\{CH(Cl)-CH_2\}_n$	Self-extinguishing	14.8	✓
Polypropylene	$\{CH(CH_3)-CH_2\}_n$	0.7-1.0	12.5	
Polystyrene	$-CH(C_6H_5)-CH_2-)_n$	1.0-1.5	7.5	
Phenolic and Cresylic Polymers (e.g. Bakelite)	Structure Omitted: Crosslinked Aromatic Rings	Self-extinguishing	2.6	✓

• Some of the highest production polymers exhibit the highest flammability 13



**IEEE COMPONENTS, PACKAGING, AND
MANUFACTURING TECHNOLOGY SOCIETY**
Santa Clara Valley Chapter www.cpmt.org/scv





Components of Polymer Formulations [34, 35]

- **Processing Reagents**
 - Plasticizers (~64 wt%)
 - Blowing Agents
 - Antistatic Agents
 - Heat Stabilizers
- **Environmental Stabilizers**
 - Flame Retardants (~15 wt%)
 - UV stabilizers
 - Antioxidants
- **Pigments/Colorants**
- **Fillers**
- **Reagents**
 - Cross-linking agents
 - Unreacted starting materials

}

~ 50 wt%


• Additives comprise a large percentage of the total weight of polymer formulations, but relative concentrations vary based on the base resin 14


IEEE COMPONENTS, PACKAGING, AND MANUFACTURING TECHNOLOGY SOCIETY
 Santa Clara Valley Chapter www.cpmt.org/scv


Classification of Flame Retardants [36]


Flame Retardants

Additive



Def: compounded into the formulation

Reactive




Def: covalently bonded to the polymer structure

Organic
(e.g., phosphorous, halogenated)

Typically inhibit reactions through reaction with gaseous by-products



Inorganic
(e.g., talc, antimony trioxide)

1. Typically synergists
2. Reduce the need for large quantities of flame retardants
3. Primarily work by forming a protective layer or emitting a gas that eliminates the presence of O₂




Classification is an issue for *China and California RoHS, IEC 61249-2-21, JPCA-ES-01-1999, California Proposition 65* compliance

15



IEEE COMPONENTS, PACKAGING, AND MANUFACTURING TECHNOLOGY SOCIETY
 Santa Clara Valley Chapter www.cpmt.org/scv


Attributes of Flame Retardants [38]


1. Cost
2. Changes in Physical Properties
 - High conc. (≥ 40 wt%) of halogenated FR required, resulting in changes in color, mechanical properties, etc.
3. Efficacy of the chemical reactions




Iodine $r = 1.33 \text{ \AA}$
electron affinity = -295.2 kJ/mol



Bromine $r = 1.14 \text{ \AA}$
electron affinity = -324.5 kJ/mol

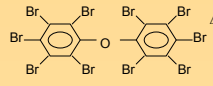


Chlorine $r = 0.99 \text{ \AA}$
electron affinity = -348.7 kJ/mol



Fluorine $r = 0.64 \text{ \AA}$
electron affinity = -327.8 kJ/mol

Decreasing Flame Retardant Efficacy [37] →
4. Compatibility with Polymer Matrix
5. Disassociation temperature for desired operation conditions



 $\xrightarrow{\Delta = 300-315 \text{ }^\circ\text{C}}$

HBr + other product


- Choose a compound which will release HBr before ignition (must look at the combustion temperature of the polymer matrix)
 - Therefore, decabromodiphenyl ether is typically compounded into polyethylene

83% Br by mass

16



CPMT
IEEE COMPONENTS, PACKAGING, AND
MANUFACTURING TECHNOLOGY SOCIETY
Santa Clara Valley Chapter
www.cpmt.org/scv



The Combustion Process Described as a Reaction


$$\text{Fuel} + \text{O}_2 \xrightarrow{\text{Free radical reactions}} \text{gaseous products} + \text{char}$$

(e.g., polymer)


To stop the depolymerization (free radical) reaction:

- Remove reactants and thermal energy
 - free radicals from the polymer chain
 - fuel
 - oxygen


17



CPMT
IEEE COMPONENTS, PACKAGING, AND
MANUFACTURING TECHNOLOGY SOCIETY
Santa Clara Valley Chapter
www.cpmt.org/scv



Mechanisms for Flame Retardants

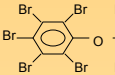
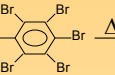


1. Flame retardants (e.g., Hexamine Cobalt (III) Chloride) react to form inert gas (e.g., CO₂, N₂) reducing the concentration of oxygen [39]

$$6\text{Co}(\text{NH}_3)_6\text{Cl}_3 \rightarrow 6\text{CoCl}_2 + \text{N}_2(\text{g}) + 6\text{NH}_4\text{Cl} + 28\text{NH}_3(\text{g})$$

$$\text{Fuel} + \text{O}_2 \xrightarrow{\text{X}} \text{CO}_2 + \text{CO} + \text{H}_2\text{O}$$

2. Inhibit gaseous phase free radical chemistry that occurs during combustion [39]



 $\xrightarrow{\Delta}$

HBr + other products

$$\text{HBr} + \text{OH}^\bullet \rightarrow \text{H}_2\text{O} + \text{Br}^\bullet$$

$$\text{HBr} + 0.5\text{O}_2 \rightarrow \text{OH}^\bullet + \text{Br}^\bullet$$

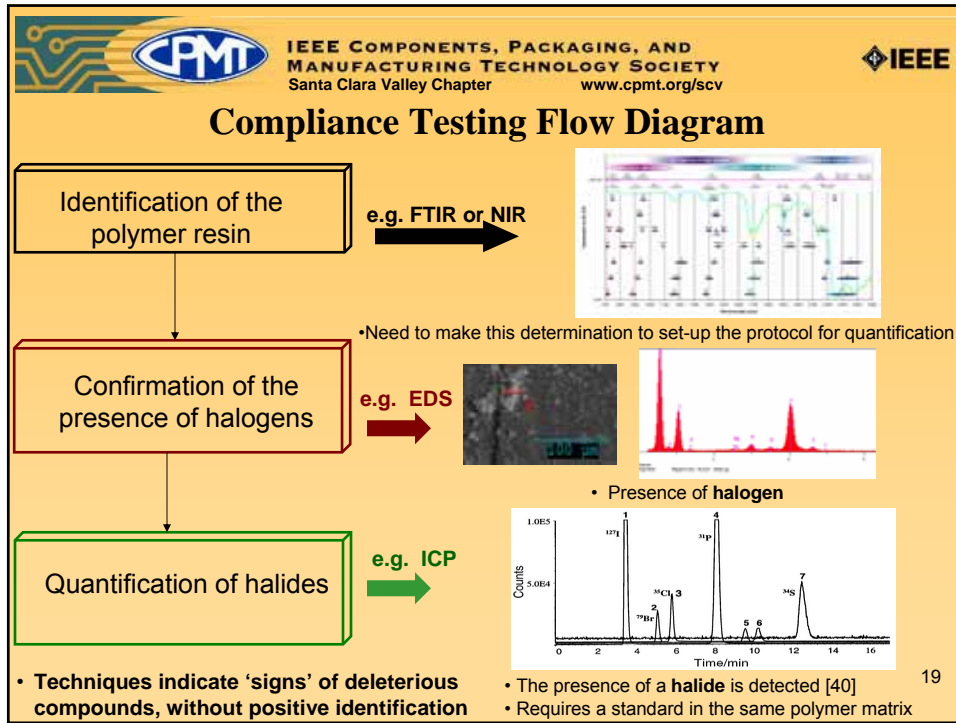
$$\text{HBr} + \text{CH}_3^\bullet \rightarrow \text{CH}_4 + \text{Br}^\bullet$$

$$\text{H}^\bullet + \text{Br}^\bullet + \text{H}_2 \rightarrow \text{HBr} + \text{H}_2$$

3. Inhibit ignition by acting as a thermal sink to lower the temperature of the polymer (e.g., metal hydroxides, aluminum trihydroxide (ATH)) [39]

$$2 \text{Al}(\text{OH})_3 \rightarrow \text{Al}_2\text{O}_3 + 3\text{H}_2\text{O} \quad \Delta H = 1050 \text{ kJ/kg}$$

18



Compliance Testing Instruments



Technique	Standards
Energy Dispersive Spectroscopy (EDS)	None known
Fourier Transform Infrared Spectroscopy (FTIR)	None known
X-ray Fluorescence (XRF)	None known
Inductively coupled plasma mass spectroscopy (ICP-MS)	J-STD-004A

>1000 ppm for a single halogen

>500 ppm for a single halide

• Compliance testing standards will be dictated by the concentration limits set by legislation

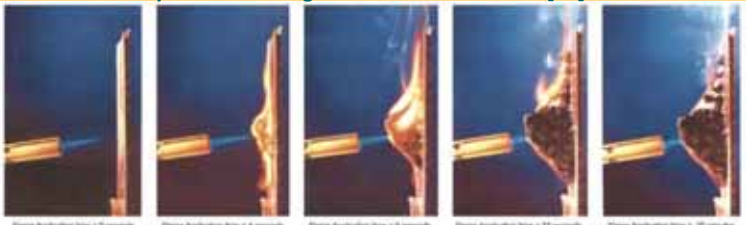
20


IEEE COMPONENTS, PACKAGING, AND MANUFACTURING TECHNOLOGY SOCIETY
 Santa Clara Valley Chapter www.cpmt.org/scv




The Future of Flame Retardants

1. **Inorganic Compounds [41]**
 - Future target for regulation
2. **Switch to other types of polymers**
 - Thermoplastic Elastomers (TPE) to replace PVC [42]
 - Still require flame retardants
3. **Nanocomposites**
4. **Reactive Organic Compounds**
 - Polymerize upon application of heat
 - Form biologically benign by-products

Example: Technologies from JJI Industries [41]



21


IEEE COMPONENTS, PACKAGING, AND MANUFACTURING TECHNOLOGY SOCIETY
 Santa Clara Valley Chapter www.cpmt.org/scv


Antimony Chemistry: Greenpeace's New Initiative

Stibnite ores

Lead and arsenic impurities ↘ ↓ Mining, purification


Antimony metal + Oxygen

↓

Sb_2O_3

- No known regulations for antimony
- **Arsenic** is typically found as an impurity to flame retardants in concentrations of [43,44]:
 - 430 mg/kg in mattress materials
 - 0.014 mg/kg-day has caused skin lesions when it occurs in drinking water

22




CPMT IEEE COMPONENTS, PACKAGING, AND MANUFACTURING TECHNOLOGY SOCIETY
Santa Clara Valley Chapter www.cpmt.org/scv

Conclusions – in the Form of Questions

- Are there substitute non-halogen materials?
 - Yes, manufacturers are working to supply substitute materials [21, 24]
- This substitution of materials is similar to implementation issues raised with RoHS [23]
 - Were there surprise problems with RoHS? Yes [25]
- Will the environmental community continue to impose new requirements?
- Does “non-halogen” guarantee health and safety?
 - What new problems may be introduced by introducing alternate materials?

23




CPMT IEEE COMPONENTS, PACKAGING, AND MANUFACTURING TECHNOLOGY SOCIETY
Santa Clara Valley Chapter www.cpmt.org/scv

References

1. Donahoe, D. and Poliskie, M., Economics and the Engineering Career, IEEE GOLD/CPMT Santa Clara Section, April 2006.
2. Greenpeace, Guide to Greener Electronics, Version 5, Sept. 2007, <http://www.greenpeace.org> (23 Nov. 2008).
3. Bakeland, L., Condensation Product and Method of Making Same, US Patent 9428097, Dec. 1909.
4. Carothers, Linear Polyamines and their Production, US Patent 2130523, W., 20 Sept. 1938.
5. Paneth, N., Assessing the Contributions of John Snow to Epidemiology, Epidemiology, Vol. 15, No. 4, September 2004, pp. 514-516.
6. Pachauri, R., Intergovernmental Panel on Climate Change, Nobel Lecture, 10 Dec. 2007.
7. U.S Environmental Protection Agency, State of Knowledge, <http://www.epa.gov/climatechange/science/stateofknowledge.html> (28 Nov. 2008)
8. European Union, Restriction on the Use of Certain Hazardous Substances in Electrical and Electronic Material, 2002/95/EC, 12 Feb. 2003.
9. IPC, Terms and Definitions for Interconnecting and Packaging Circuit Elements, IPC T50.

24




CPMT IEEE COMPONENTS, PACKAGING, AND MANUFACTURING TECHNOLOGY SOCIETY
 Santa Clara Valley Chapter www.cpmt.org/scv

References

10. European Chemical Agency, ECHA, Guidance on Requirements for Substances in Articles, 2008.
11. Dowds, S., Legitimate Legislation? From Lead to Halogen, SMT, Oct, 2008.
12. Poon, C., Long, A., Wang, J., Halogen-Free Debate on Solder Paste: IPC Classification and Application, NPECON Shanghai, 8 April 2008.
13. IPC 4-33a, Definition of Maximum Limits on the Low-Halogens Bromine & Chlorine for Certain Electronic Components and Assemblies, Final Draft for Industry Review, IPC/JEDEC J-STD=709 September 2008.
14. IPC, Test Method for Total Halogen Content in Base Materials, IPC-TM-650 Test Methods Manual, Number 2.3.41m April 2006.
15. ASTM F2617, Standard Test Method for Identification and Quantification of Bromine, Chlorine, Chromium, Mercury and Lead in Polymeric Material Using Energy Dispersive X-Ray Spectrometry, 15 August 2008.
16. IPC 1752 Materials Declaration
17. Brigden, K. and Santillo, D., Toxic Chemicals in Computers Exposed, Technical Note 05/06, Greenpeace, September 2006.

25




CPMT IEEE COMPONENTS, PACKAGING, AND MANUFACTURING TECHNOLOGY SOCIETY
 Santa Clara Valley Chapter www.cpmt.org/scv


References

18. Hua, I., Kuo, Y., Dorie, B., Quantifying Brominated Flame Retardant Content and Emissions in Polymers, Materials Research Society Symposium Proceedings, Vol. 993, 2007.
19. Greenpeace, Why BFRs and PVC Should Be Phased Out of Electronic Devices, <http://www.greenpeace.org> (9 July 2008).
20. Brinkley, A., Kirby, J., Wadehra, I., Life Cycle Inventory of PVC: Manufacturing and Fabrication Processes, Proceedings of the 1996 Electronics and Environment, ISEE-1996, pp. 94-101.
21. Tisdale, S. and Krabbenhoft, R., iNEMI Halogen-Free Project Phase 1 Review, 26 September 2006.
22. Lee, F., Halogen Free Materials Manufacturing and Supply Chain Challenges, Intel Halogen Free Symposium, 16 January 2008.
23. Donahoe, D. and Fasching-James, A. RoHS: 1 of 6, ASME Santa Clara Valley Section, 20 April 2006.
24. Halogen-Free Subcommittee (4-33), IPC White Paper and Technical Report on the Use of Halogenated Flame Retardants In Printed Circuit Boards and Assemblies, IPC-WP/TR-584A, April 2003.
25. ASHRAE TC 9.9, Particulate and Gaseous Contamination in Datacom Environments (in press).

26




**IEEE COMPONENTS, PACKAGING, AND
MANUFACTURING TECHNOLOGY SOCIETY**
Santa Clara Valley Chapter www.cpmt.org/scv




References

26. Linde Gas LLC "MSDS Vinyl Chloride"
http://www.orcbs.msu.edu/msds/LINDE_MSDS/pdf/155.pdf (5 Dec 2008)
27. European Flame Retardants Association "How do they work?" 2006
<http://www.flameretardants.eu/Content/Default.asp?PageID=130> (5 Dec 2008)
28. National Institute of Standards and Technology "MSDS 2,3,7,8-Tetrachlorodibenzo-p-dioxin" Feb 4, 2005 <https://srms.nist.gov/msds/3063-MSDS.pdf?CFID=16952439&CFTOKEN=ff2c50c13c37d139-17C39C7B-E5FF-835A-04823752DE1905DA&jsessionid=b430792e4a6f52805f19> (5 Dec 2008)
29. Howells, T.F.; Barefoot, K.B. "Annual Industry Accounts "May 2007 <http://www.bea.gov> (24 Nov 2008)
30. Howells, T.F.; Barefoot, K.B. "Annual Industry Accounts "May 2005 <http://www.bea.gov> (24 Nov 2008)
31. Cleveland, C.J. "Hydrocarbon Chemistry" Occupational Safety & Health Administration Feb 4, 2007 http://www.eoearth.org/article/Hydrocarbon_chemistry (6 Dec 2008)
32. Bower, D. Introduction to Polymer Physics, Cambridge University Press, 2002.
33. Shackelford, J.F. Alexander, W. "Chemical Properties of Materials" Materials Science and Engineering Handbook CRC Press 2001.

27




**IEEE COMPONENTS, PACKAGING, AND
MANUFACTURING TECHNOLOGY SOCIETY**
Santa Clara Valley Chapter www.cpmt.org/scv




References

34. R. Liepins and E. M. Pearcet, *Environmental Health Perspectives*, vol 17, 1976, pp 55.
35. Walton, D; Lorimer, P., *Polymers*, Oxford ,2000.
36. Environmental Protection Agency Section 2.0 Types of Chemical Flame Retardants
<http://www.epa.gov/dfe/pubs/flameret/altrep-v1/altrep-v1a-sec2.pdf> (25 Sept 2008)
37. Zumdahl, S., *Chemistry* ,D.C. Heath and Company, 1989.
38. Groshart, C.P. and Wassenburg, W.B.A. Lanne, R.W.P.M. "Chemical Study on Brominated Flame-retardants" Directoraat-Generall Rijkswaterstaat ,Feb 14, 2007
<http://www.rws.nl/rws/rikz/thema/ikc/rapport2000/rikz2000017.pdf> (5 Dec 2008)
39. European Chemical Industry Council "How do flame retardants work?" 2006
<http://www.noharm.org/goingGreen> (24 Sept 2008)
40. Royal Society of Chemistry 2001, <http://www.rsc.org/ej/JA/2001/b103577k/b103577k-f4.gif> (5 Dec 2008)

28



**IEEE COMPONENTS, PACKAGING, AND
MANUFACTURING TECHNOLOGY SOCIETY**
Santa Clara Valley Chapter www.cpmc.org/scv



References

41. JJI Technologies "Environmentally Friendly Non-halogen Plastic Compound" www.JJI-Technologies.com (30 Aug 2008).
42. Anthony, G and Pfeiffer, J. *Wire Journal International* 2004, vol. 37, pp. 64.
43. International Antimony Oxide Industry Association Newsletter Volume 1 Issue 3 October 2002 <http://www.iaoia.org/newsletters/IAOIA-Newsletter-Oct2002.PDF> (5 Dec 2008).
44. EFRA Antimony Trioxide Fact Sheet , January 2006 http://www.iaoia.org/newsletters/EFRA_Fact_Sheet_ATO_Jan_2006.pdf (5 Dec 2008).
45. Blackburn, G., UL-1950: an IEC-950-based US Standard for Information Technology Equipment Including Electrical Business Equipment, *IEEE Transactions on Industry Applications*, Vol. 28, Issue 1, Jan/Feb 1992, pp. 228-232.

29