THE MASSACHUSETTS
TOXICS USE REDUCTION INSTITUTE

Environmental, Health and Safety Issues in the Coated Wire and Cable Industry

Technical Report No. 51

April 2002

University of Massachusetts Lowell

ENVIRONMENTAL, HEALTH AND SAFETY ISSUES IN THE COATED WIRE AND CABLE INDUSTRY

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April 2002
Rev. 5/16/02

The Toxics Use Reduction Institute is a multi-disciplinary research, education, and policy center established by the Massachusetts Toxics Use Reduction Act of 1989. The Institute sponsors and conducts research, organizes education and training programs, and provides technical support to promote the reduction in the use of toxic chemicals or the generation of toxic chemical byproducts in industry and commerce. Further information can be obtained by writing the Toxics Use Reduction Institute, University of Massachusetts Lowell, One University Avenue, Lowell, Massachusetts 01854.

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Executive Summary

Environmental, health and safety concerns with the basic raw materials used in manufacturing coated wire and cable are driving innovation and change in the industry. These concerns include the life cycle impacts of heavy metals such as lead, brominated flame-retardants, and resin systems based on polyvinyl chloride. Seeking to help Massachusetts's wire and cable industry deal with the complex regulatory and technical issues, the Toxics Use Reduction Institute at UMASS Lowell contracted the preparation of this background report. The report examines the sector's main environmental, health and safety issues, European and United States (U.S.) regulatory drivers, and the state of new materials development. The report also outlines a set of research and technology diffusion recommendations for the Institute and is meant to serve as an introduction and reference point for those in industry, government and academia concerned with wire and cable industry environmental, health and safety issues.

This report focuses on those materials that are commonly used in wire and cable coatings. Two materials – polyethylene and polyvinyl chloride – receive substantial attention because these two resin systems dominate the U.S. wire and cable market and because there is substantial research and literature on them. Other resin systems that are or could be alternatives to polyethylene and polyvinyl chloride are noted, but with less detail. Costs are always a consideration in material selection – however the scope of this report is on environmental, health and safety issues. It does not include a review of raw material prices, trends, or volume related pricing strategies. Many of the substitute materials reviewed in this report are new to the market, are still under development, have a cost premium, and/or have limited processing windows. As a result, the technical barriers to these cleaner technologies should not be over simplified. Yet the high rate of new product introduction and significant research and development of substitute materials is a testimony to the sector's commitment to innovate and meet the demand for "greener" wire and cable products.

The wire and cable industry grew throughout the 1990's in response to the period's economic expansion and to meet the increased demand for wire and communications products. Shipments from U.S. wire and cable manufacturers of insulated products (excluding fiber-optic products) were nearly $12 billion in 1996 and $18 billion in 1999. The U.S. wire and cable industry is comprised of roughly 150-200 cable manufacturers, with the ten largest manufacturers making up roughly 50% of the market. The industry manufactures products for a host of markets including building wire, telephone and telegraph wire, cords, cord sets and appliance wire, power cable, coaxial and data wire, and magnet wire. Products are required to meet a set of application-specific performance standards including ultraviolet (U.V.) resistance, temperature (dry and wet), and flame retardancy.

The wire and cable industry uses a number of materials of concern, several of which are currently under European pressure for bans and material use restrictions. Materials used include lead, cadmium, and antimony compounds, halogenated flame-retardants, phthalates, and polyvinyl chloride. For example, the U.S. use of PVC in wire and cable for 1999 was estimated at 592 million pounds (CEH 2001, 580.1881 M). No nation-wide data is available on the wire

and cable use of the other chemicals. Table 1 below lists some of these materials used by the wire and cable industry in Massachusetts.

Table 1. Massachusetts Materials Use in Coated Wire and Cable

Chemical	Amount used by MA wire and cable industry (pounds)
Antimony and antimony compounds	2,532,131
Barium and barium compounds	20,225
Chromium and chromium compounds	71,2500
DEHP	240,240
Lead and lead compounds	3,480,500
Zinc and zinc compounds	469,011

Source: Toxics Use Reduction Institute, 1999 TURA data

Lead compounds in wire and cable have received the greatest attention due to two proposed European Union Directives (the Waste Electrical and Electronic Equipment Directive and the related Restriction of Hazardous Substances Directive) and lawsuits under California Proposition 65 rules. But the emerging focus on brominated flame-retardants, other heavy metals, PVC, and phthalate plasticizers points to the need for a comprehensive review of wire and cable raw materials throughout their life cycle.

Resin and additive manufacturers and wire and cable extruders have responded to customer demand and the emerging environmental, health and safety issues with numerous raw material and product innovations. The diversity of the wire and cable products and markets makes it difficult to find a single drop-in replacement for a material (e.g. alternatives to lead-based heat stabilizers) since any replacement must be formulated to meet the performance requirements for each application.

Most of the research and development has been on alternatives to lead stabilizers. Mixed-metal stabilizers, organotin and organic compounds are available alternatives. A new area of research involves alternative flame-retardants. Zinc borate, zinc stannate and zinc hydroxystannate, aluminum trihydrate, and magnesium hydroxide are some of the alternatives under testing. The growing focus on alternatives to PVC has led to an increase in the use of polyethylene and particularly cross-linked polyethylene in some applications. Fluoropolymers (e.g., Teflon) and polypropylene are also gaining a wider market share. Since the formulation of additives and resin systems is a key competitive advantage in the industry, there is limited public information on some of these innovations.

After evaluating the current state of the industry and the emerging clean technologies, this report proposes several strategies for research and technology diffusion in Massachusetts, such as development and testing of non-halogenated resins, use of lead-free stabilizers, and consideration of product stewardship, among others. The advantages and disadvantages of each strategy are outlined and recommendations for further basic research, testing, piloting and demonstration projects are included.

Addressing the various environmental, health and safety issues of coated wire and cable is not a simple and straightforward process. However, the process of developing and using cleaner alternatives has already begun, spurred by European legislative changes and customer demands. Several Massachusetts companies have reported success in developing alternatives to lead and halogens (e.g., AlphaGary, TeknorApex, Witco, Quabbin Wire). In this process TURI can continue to be actively involved in dialogue, research and educational initiatives that further help reduce toxics and promote the global competitiveness of Massachusetts coated wire and cable industry.

1. Introduction

This report provides background information on environmental, health and safety (EHS) issues facing the Massachusetts wire and cable industry. The report aims to serve as a basis for supporting research and development of cleaner technologies in the industry. The report outlines the main products, materials, processes, regulatory requirements and EHS impacts in the coated wire and cable sector[1].

In recent years, there has been a growing movement in Europe to control the end-of-life disposal of electrical equipment and electronics. Most of this equipment contains heavy metals, halogenated flame-retardants, and other hazardous and toxic materials that need to be handled properly to minimize their impact on the environment and human health. This movement culminated in the proposed EU Directives on Waste Electrical and Electronic Equipment (WEEE) (WEEE, 2000)[2].

The proposed WEEE Directive requires end-of-life equipment to be collected for recovery, recycling and re-use, placing main responsibility on the manufacturers of such equipment. The European Commission's draft text covers 11 categories of equipment, including large and small household appliances, telecommunication equipment, and radio and television equipment – so the scope of the directive is broad. The associated, but now separate, Restriction of Hazardous Substances Directive (RoHS) further bans the use of some toxic materials such as lead, cadmium, and some brominated flame-retardants. The Commission adopted the proposals on June 13, 2000. The parliamentary process is underway with a decision expected before 2003. The Directives, which may undergo further changes before being passed, are expected to come into effect by 2004 and as such may affect Massachusetts wire and cable industry export markets.

This report is part of the Toxics Use Reduction Institute's (TURI) effort to help Massachusetts manufacturers deal with regulations here in the US and abroad. TURI, located at the University of Massachusetts Lowell, focuses on education, public policy, and research and diffusion of environmentally safe and economically sound technology. This report was prepared based on a literature review, discussions with sector experts, and a focus group meeting sponsored by TURI and attended by approximately 30 representatives from the Massachusetts wire and cable industry (e.g., compounders, extruders, original equipment manufacturers (OEMs)). This report and the focus group are part of TURI's effort to involve the supply chain (e.g., polymer manufacturers and compounders, cable coating industry, and end users), standards setting organizations and government in the research and technology diffusion agenda setting process.

The report provides an overview of the following:

- various wire and cable products and markets,

[1] This report does not address the copper wire or fiber optics components of wire and cable products – which can have significant lifecycle impacts. It focuses on the resin jacketing and insulation component.

[2] The original WEEE Directive was split into two separate pieces – The Waste Electrical and Electronic Equipment Directive and the Restriction on Hazardous Substances Directive.

- key materials and additives as well as their function and properties,
- the process of manufacturing coated wire and cable products,
- main regulatory requirements concerning the industry (e.g., environmental, health and safety impacts along the life-cycle of coated wire and cable), and
- emerging cleaner technologies.

It concludes with recommendations for research and technology diffusion/transfer. Additional, technical information is provided in the appendices.

2. Wire and Cable Product Classification

The wire and cable industry has been growing at a steady rate over the past decade. Shipments from U.S. wire and cable manufacturers of insulated products (excluding fiber-optic products) were nearly $12 billion in 1996 and $18 billion in 1999 (Flame Retardant Industry Review 1999). It is estimated that there are 150-200 wire and cable manufacturers in the United States. The ten largest manufacturers are believed to make up about 50% of the U.S. market for insulated wire and cable (Graboski 1998). There are sixteen coated wire and cable manufacturers in Massachusetts that have reported under the Toxics Use Reduction Act in Massachusetts in 1999 (TURA data 1999). There are several main types of wire and cable products defined by their end use. The list below describes the main types and their U.S. market share ($) (Graboski 1998).

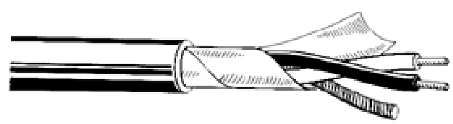
- **Building wire** – **23%** of U.S. insulated wire and cable shipment. Used to distribute electrical power to and within residential and non-residential buildings. Products are sold through home center and hardware retail chains, electrical distributors and to industrial customers and OEMs.
- **Telephone and telegraph wire** – **18%** of U.S. insulated wire and cable shipments. Twisted pair conductors that are jacketed with sheathing, waterproofing, foil wraps and metal. Used to connect subscriber premises to the telephone company. Products are sold to telecommunications system operators and through telecommunications distributors.
- **Cords, Cordsets, Appliance Wire, other** – **13%** of U.S. insulated wire and cable shipments. Two- or three-conductor cable insulated with rubber or plastic with a molded plug on one or both ends to transmit electrical energy to power equipment or electronic devices. Products are distributed through distributors, retailers, and to OEMs.
- **Power Cable** – **12%** of U.S. insulated wire and cable shipments. This is insulated wire and cable used to transmit and distribute electrical energy. Products are generally sold to the public utility sector.
- **Coaxial and antennae cable** – **12%** of U.S. insulated wire and cable shipments. Primary applications of this type of cable are broadcasting, cable television signal distribution and computer networking. Products are sold directly to Community Access Television (CATV) operators and through distributors.
- **Electronic and data wire** – **11%** of U.S. insulated wire and cable shipments. This type represents high-bandwidth twisted pair copper and fiber-optic cable. It is used to wire subscriber premises above ceilings and between floors to interconnect components. Growth has been driven by expansion of local and wide area networks. Plenum cable is a special application that will be discussed in greater detail further in the report.

- **Magnet Wire** – **11%** of U.S. insulated wire and cable shipments. Typical applications are electronic motors, generators, transformers, televisions, automobiles and small electrical appliances.

3. Wire and Cable Materials

Wire and cable products are critical to the modern economy. Their application is increasing with the growing use of computers, the Internet, cable television, and the increase in electrical power service worldwide. Wire and cable constructions range from the simple – such as building wire, to the complex – such as power cable and fiber optics. Each type of cable, however, has several common elements including the core (typically copper or fiber optic), insulation, and jacketing (see Figure 1).

Figure 1. Typical cable



One of the key components of a wire is its *insulation*. Its selection is determined by a number of factors such as stability and long life, dielectric properties, resistance to high temperature, resistance to moisture, mechanical strength, and flexibility. There is no single insulation that is ideal in every one of these areas. It is necessary to select a cable with the type of insulation, which fully meets the requirements of the application. *Jackets* cover and protect the enclosed wires or core against damage, chemical attack, fire and other harmful elements that may be present in the operating environment.

There are seven major types of materials used in coated wire and cable[3] (see list below). Each material type is reviewed in the following subsections.

(1) *resins* (thermoplastic and thermoset compounds) for insulation and jacketing;
(2) *plasticizers* to make the plastic flexible and easy to process (and impart other qualities such as impact resistance and abrasion resistance);
(3) *stabilizers* to provide heat resistance during manufacturing as well as visible light, UV-rays and heat resistance during product use;
(4) *flame retardants* to slow the spread of an accidental fire and reduce the amount of heat and smoke released;
(5) *fillers* to reduce formulation costs and improve insulation resistance;
(6) *lubricants* to improve the ease of processing; and
(7) *colorants* to give the desired color, which is crucial for identification purposes.

Table 2 and Table 3 present the basic materials used in the two most common wire and cable coatings – polyethylene and polyvinyl chloride. Table 2 outlines several polyethylene wire and cable formulations (polyethylene, cross linked polyethylene, and chlorinated polyethylene) for

[3] This report does not address the copper wire or fiber optics components of wire and cable products. It focuses on the jacketing and insulation of different types of cables. It also does not focus on some of the minor wire and cable ingredients such as curing agents or cross-linking agents.

power cable applications. Table 3 outlines typical polyvinyl chloride formulations for different applications. The types of materials used in a wire and cable depend largely on the specific resin system (e.g. thermoset polyethylene versus cross-linked polyethylene versus polyvinyl chloride) and the application (i.e., plenum rise communications wire versus high voltage power cable). When reviewing the formulations in Tables 2 and 3, note that:

- The formulations are presented in phr (parts per hundred resin) – a common way to present wire and cable formulations. To convert to weight percent, divide individual phr by total number of parts. Multiply this factor by 100 to get weight percent.
- The formulations are designed to meet Underwriter Laboratory (UL) test specifications.
- The formulations are generic and would require adjustments for specific applications.
- Some of the ingredients use trade names

Table 2 contains three different polyethylene formulations for a power cable. Power cable examples are used because the applications are most often flame retardant. The Underwriters Laboratory designation UL denotes "thermoset-insulated wire and cables". Wires marked "VW-1" comply with a vertical flame test. UL-94 references a test for flammability of plastic materials for parts in devices and appliances; V-0 is the highest flammability rating

Table 2. Various Polyethylene Power Cable Insulation Compositions

Source: Albemalre Web Site (http://www.albemarle.com/saytexfr_wire.htm)

Thermoplastic Chlorinated Polyethylene UL-44 VW-1		
Chlorinated Polyethylene (42%) (Resin)	90	phr
Medium Density Polyethylene (Resin)	30	phr
Washed Clay (Filler)	25	phr
N550 Carbon Black (Filler)	25	phr
Red Lead (Stabilizer)	9	phr
Epoxy Stabilizer (Stabilizer)	3	phr
Hydroquinone Antioxidant (Stabilizer)	2	phr
Saytex BT-93 (Brominated Flame Retardant)	30	phr
Sb2O3 (Flame Retardant)	15	phr

Thermoplastic Polyethylene UL-94 V-0 / UL-44 VW-1		
Polyethylene (Resin)	100	phr
Talc (Filler)	57.5	phr
Saytex 102 (Brominated Flame Retardant)	23	phr
Sb2O3 (Flame Retardant)	11.5	phr

Crosslinked Polyethylene UL-44 VW-1		
Low Density Polyethylene (Resin)	90	phr
EVA-LDPE (Resin)	10	phr
N550 Carbon Black (Filler)	25	phr
Saytex BT-93 (Brominated Flame Retardant)	30	phr
Sb2O3 (Flame Retardant)	12	phr
Phenolic Antioxidant (Stabilizer)	2	phr
MgO (Stabilizer)	2	phr
Vinyl Silane	1	phr
Calcium Stearate (lubricant)	1	phr
Teflon 6C	2	phr
Vul-Cup Peroxide	2	phr
TATM	1	phr

Table 3 depicts the material composition for different wire types. In general, the UL letter designations provide information on intended use, insulation type and insulation temperature rating. For example, T: thermoplastic insulation; H: 75°C temperature rating; HH: 90°C temperature rating W: moisture resistant; and N: nylon jacketing. Table 3 shows how composition changes for different wire types.

Table 3. Various Polyvinyl Chloride Insulation Compositions

UL Designation	T-TW	THW-THWN	NM-B	THH-THHN	Units
Temperature Rating	60°C	75°C	90°C	90°C	phr
Polyvinyl Chloride (Resin)	100	100	100	100	phr
DiIsoDecyl Phthalate (Plasticizer)	45	35			phr
Ditridecyl Phthalate (Plasticizer)		15	30	20	phr
Tri Octyl Trimellitate (Plasticizer)			15	35	phr
CaCO3 (Filler)	20	20		15	phr
Clay (Filler)	10	10	7	15	phr
Wax	0.5	0.3	0.5	0.3	phr
Bisphenol A (stabilizer)			0.2	0.3	phr
Sb2O3 (flame retardant)				3	phr
Tribasic lead sulfate (stabilizer)	4	5			phr
Basic lead sulfophthalate (stabilizer)			6	7	phr

Source: "Handbook of PVC formulating", edited by Edward J. Wickson, 1993 (Publisher: John Wiley & Sons).

3.1 Resins

Polyethylene and PVC are the principal resins used in the wire and cable industry. In Canada, for example, PVC makes up 60% of the market, polyethylene – 34% and numerous other resins comprise the remaining (6%). In U.S., however, polyethylene and its copolymers is the primary resin, followed by PVC, nylons, fluoropolymers and others. Table 4 presents data for the 2000 volume of thermoplastic resins used in wire and cable (BCC 2000, P-133R).

Table 4. Volume of US thermoplastic resins in wire and cable - 2000

Thermoplastic resin	Million lb.	Percent
Polyethylene and copolymers	578	46%
PVC	486	39%
Nylons	74	6%
Fluoropolymers	50	4%
Polypropylene	16	1%
Other	53	4%
Total	1257	100%

Source: BCC, Inc. 2000 P-133R

Table 5 presents the U.S. volume of polyethylene and PVC by application for 2000 (BCC 2000, P-133R). Either polyethylene or PVC is the leading resin system for every type of application. The building wire and cable market uses the greatest volume of polyethylene (212 million lb.), while the electric segment uses the greatest volume of PVC (165 million lb.) In total, polyethylene and PVC comprise 85% of the thermoplastic wire and cable resin market.

Table 5. Volume of Polyethylene and copolymers and PVC resins in U.S. wire and cable - 2000

Application	PVC (million lb.)	Polyethylene & CoPolymers (million lb.)	Polyethylene & Copolymers and PVC (percent of total pounds of thermoplastic)	Total Pounds of thermoplastics (million lb.)
Building	212	81	89%	329
Electric	73	165	85%	280
Telephone and Telegraph	73	48	89%	136
Fiber Optic Wire Cable	65	75	72%	194
Apparatus	26	54	88%	91
Power Distribution	21	96	93%	126
Magnetic	5	22	93%	29
Other	11	37	67%	72
TOTAL:	486	578	85%	1257

Source: BCC, Inc. 2000 P-133R

This section focuses mainly on these two resins and just briefly mentions other resins used for insulation and jacketing. Each selected resin for wire and cable needs to meet various performance requirements[4] (see list below).

- Temperature Range
- Flame resistance
- Abrasion resistance
- Ozone resistance
- UV resistance
- Solvent resistance
- Water resistance
- Heat resistance
- Electrical Properties (Insulation)
- Flexibility Tear/Impact Strength/Mechanical Strength

Polyethylene is a lightweight, water-resistant, chemically inert, and easy to strip resin. The different types of polyethylene used in the wire and cable industry include low-density (LDPE), linear low-density (LLDPE), medium-density (MDPE), high-density (HDPE), chlorinated polyethylene (CPE) and cross-linkable polyethylene (XLPE).

[4] Performance information for various resin systems can be found in reference texts (such as Gachter, R. and Muller, H., *Plastics Additives Handbook*) and at various web sites (such as www.iewc.com/Technical.htm).

Table 6. Polyethylene Types

Type	Notes
LDPE	Used in jacketing and insulation.
LLDPE	Has superior tensile strength and abrasion resistance
MDPE	When blended with LDPE, imparts stiffness and abrasion resistance
CPE	Contains 25% - 42% chlorine; used in jacketing due to toughness and flame retardancy
XLPE	Cross linked LDPE, usually with organic peroxides

Source: Albemalre Web Site (http://www.albemarle.com/saytexfr_wire.htm)

Polyethylene's low dielectric constant allows for low capacitance and low electrical loss making it the choice for audio, radio frequency, and high voltage applications. In terms of flexibility, PE can be rated stiff to very hard, depending on molecular weight and density. The resin has excellent moisture resistance and can be compounded to make it flame retardant. However, PE is less inherently flame retardant than other resin systems such as polyvinyl chloride and fluorinated ethylene-propylene. Therefore, polyethylene resins are often compounded (e.g., with brominated flame retardants, antimony oxide, etc.) to make them more flame retardant. PE is used in nearly all types of wire and cable products such as electronic, telephone and telegraph, power distribution, fiber optic, and building wire and cable products.

In Europe the market has accepted the use of non-halogen flame retardant PE and moisture-cured XLPE for insulation and jacketing in some flexible cords, appliance wires, building wire and many other end uses. The use of inexpensive aluminum trihydrate ($Al(OH)_3$) flame retardant additive is quite common. Calcium carbonate can also be used as a filler to provide a PE compound that is price-competitive with PVC compounds. Some companies, like IKEA of Sweden, have developed with their own specifications and converted appliance cords to non-halogenated PE alternatives.

Polyvinyl chloride (PVC) finds use in virtually all of the major types of wire and cable: low voltage building wire insulation and jacketing, low and medium voltage equipment cable jacketing, control cable jacketing, indoor telecommunications cable, automotive wire and flexible cords. It is an inherently flame and abrasion resistant material that is specially compounded for general-purpose applications at temperatures to 105 °C. It resists flames, oil, ozone, sunlight, and most solvents.

Wire and cable accounts for roughly 68% of PVC use in electrical products or about 592 million pounds in 1999 (CEH 2001, 158.1881 M). PVC's greatest uses are in building wire, and its second greatest use is in electronics and telecommunications.

Demand growth for PVC use in electrical applications will be negligible (~2%) according to the 2001 Chemical Economics Handbook (CEH 2001, 580.1881 N). The wire and cable industry will be impacted by several technological trends that can reduce the growth of polymer usage in general. For example, fiber-optic cable is replacing copper cable in many applications. Fiber-optic wire and cable requires less polymer than those made of copper because of reduced cable thickness. The proliferation of wireless communications technology, such as cellular, microwave and satellite communications, can reduce the need for premise wiring and, consequently, resin consumption. Even if these trends prove to have a minor impact on polymer usage, PVC growth in electrical uses is expected to be minimal because of competition from other polymers such as ethylene-propylene elastomers, thermoplastic elastomers and polyolefins. These trends are expected to keep growth in PVC consumption for electrical applications to about 2% per year through 2004 (CEH 2001, 580.1881).

PVC is typically used for cable inside buildings, due to its superior flexibility and flame retardant properties. Flame and smoke retardancy is critical in plenum space (above ceilings and/or below raised floors) of buildings, when air from this area is returned through ventilation systems to heating or air conditioning units and redistributed by fans throughout a building or plant. Currently PVC and FEP (fluoropolymers) are the two resins that can meet the strict fire safety requirements for plenum cables.

The principal technical characteristic that differentiates PVC and polyethylene (PE) wire and cable is the flame retardant qualities of PVC resin. Fire code specifications aim to ensure that insulation and jacketing materials are sufficiently flame resistant to delay the spread of fire long enough for people to safely evacuate a building. The presence of chlorine in the molecular structure of PVC resin, accompanied by synergists such as antimony trioxide, gives the material a much higher flame resistance than other thermoplastics such as PE. For this reason, PVC compounds are typically chosen as an inexpensive jacketing material in many interior wire and cable applications.

There are some reports of substitutions of other resin systems for PVC in the literature. For example, a 1997 report by Environment Canada reviewed the socio-economic and technical importance of products derived from the chlor-alkali industry, and options to reduce these products. Part of the report examined polyvinyl chloride in wire and cable products. The report noted an increase in the adoption of low- or zero-halogen PE resins in jacketing for new and replacement electrical and telecable installations in transit systems, shipboard systems, major commercial and institutional buildings and telephone switching stations (Environment Canada 1998). The report also noted:

- Switching from PVC-nylon insulation to moisture-cured cross-linked polyethylene (XLPE) in the NMD-90 residential building wire niche.
- In Europe, PVC has been replaced in a few wire and cable applications. The European market has accepted the use of non-halogen flame retardant PE and moisture-cured XLPE for insulation and jacketing in some flexible cords, appliance wires, and building wire uses .

Fluorinated ethylene-propylene (FEP) is a melt-processible copolymer of tetrafluorethylene and hexafluoropropylene. FEP has exceptional dielectric properties in addition to excellent chemical inertness, heat resistance, weather resistance, and toughness and flexibility. An example of FEP is Teflon (DuPont trademark). In the United States, the majority of FEP is supplied by DuPont, the only U.S. producer. The leading market for FEP is the manufacture of plenum wire and cable. More than 95% of the FEP that is employed in this market is used as primary insulation.

The remainder is used as a jacketing material. FEP will continue to experience good growth in this market sector because its superior electrical properties make it the preferred material for primary insulation in the rapidly growing data transmission segment of the plenum wire market (Chemical Economics Handbook, 2001).

Other resins: Small amounts of other materials are used as insulation and jacketing for wire and cable manufacturing. These typically include nylon, polypropylene, styrenics, acrylic, thermoplastic elastomers (such as EPDM), and other resins. Several of these materials are listed in Appendix A.

3.2 Plasticizers

Plasticizers make vinyl and other plastics flexible even at low temperatures and also provide mechanical properties, impact resistance and abrasion resistance. Their market is dominated by the PVC processing industry, which, according to different estimates, accounts for between 80 and 90% of demand (Wilson 2000). Polyethylene resins systems, for example, do not require plasticizers to increase flexibility.

Dioctyl phthalate (DOP or di-2-ethylhexylphthalate (DEHP)) is used in larger quantities in PVC than any other plasticizer. Both technically and commercially, DEHP is the reference point for assessment of other plasticizers. It is technically interchangeable to a large extent with the other major phthalates -- DIDP (diisodecyl phthalate) and diisononyl phthalate (DINP). DEHP's limitations include higher volatility and migration.

DIDP is much less volatile than DEHP, both in PVC processing and in end product service at elevated temperatures. It is the main plasticizer used in cables since it ensures conformance with a wider range of end use specifications than DEHP. However, it has lower plasticizing efficiency than DEHP and needs to be used at higher levels to give matching softness and requires higher temperatures when processed (Wilson 2000).

DINP is intermediate between DEHP and DIDP in all aspects of performance. It is the plasticizer that is most likely to be considered as a DEHP substitute either for commercial reasons or because users wish to avoid the health and safety questions associated with DEHP (see Section 7.2.5).

While there are numerous other types of plasticizers, there are few applications in the wire and cable industry. For example, adipates and sebacates confer far better cold flex and are usually classified functionally as low temperature plasticizers. But their high price tends to limit their use to special applications (e.g., military). Although still a small percent of the market, citrate and polyester plasticizers are currently emerging as viable substitutes for phthalates.

Advances in citrate technology and use are paving the way for their wider adoption. Morflex already has grades for plastic tubing and toys, and claims suitable citrates can be developed for virtually all flexible PVC markets, including wire and cable. Their cost is also expected to go down with improvements in the patented technology. Citric acid esters are made out of citric acid (made by fermentation from a biomass), which is biodegradable, as are other ingredients of the chemical. Also, citrates are approved by the U.S. Food and Drug Administration in current non-plastic uses such as coatings for tablets, fragrances, and cosmetic products like shampoos (Modern Plastics 2000).

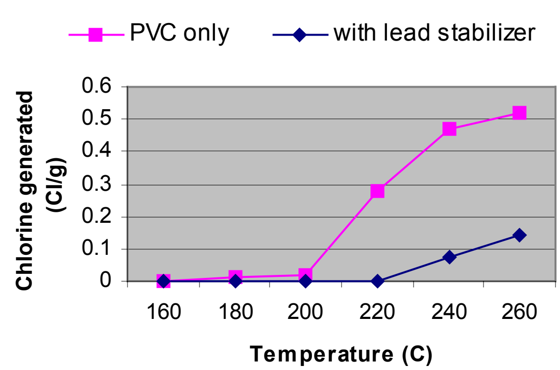
Another group of important phthalate alternatives is polyester plasticizers such as PX-811, a product developed by Japan's Asahi Denka Kyogo K.K., Tokyo. This plasticizer is claimed to outperform competing citrate plasticizers in key criteria, notable heat aging, oil extraction, and low-temperature performance. Its volatility is lower compared to citrates and this leads to lower in-plant emissions. Finally, the manufacturer claims that the material is significantly less costly than existing citrate plasticizers (about $1.50/lb) (Modern Plastics 2000).

Regardless of these developments, industry sources note that 85% of all flexible PVC worldwide still uses phthalates as plasticizers and there is no sign of a broad trend away from them.

3.3 Stabilizers

Stabilizers are added to guarantee heat resistance during manufacturing, and to elevate the resistance of products against external impacts like moisture, visible light, UV-rays and heat. PVC currently accounts for virtually all of the heat stabilizer consumption (99% of the world consumption) (Chemical Additives For Plastics 1999). Note that this figure does not include elastomerics.

Figure 2: Heat Degradation of PVC



PVC resin begins to degrade at temperatures of roughly 160 °C via dehydrochlorination. Since PVC is generally processed at temperatures between 160 °C and 210 °C, stabilizers are necessary to manufacture PVC resin products such as wire and cable (see Figure 2). Figure 2 shows the PVC heat degradation relationship between chlorine generation and temperature (Mizuno et. al. 1999). There are four major types of primary heat stabilizers:

- Lead compounds
- Mixed metal salt blends
- Organotin compounds
- Organic compounds

Lead compounds are the predominant stabilizer in wire and cable worldwide as a result of its cost-effectiveness and excellent electrical insulation properties (e.g., for wet applications). PVC is the only plastic material in which lead is commonly used as a stabilizer. The compounds used include tribasic lead sulfate, dibasic lead phthalate, dibasic lead stearate, lead stearate, lead phosphite, carbonate lead derivatives, etc. One advantage of lead stabilizers is that the lead chloride produced during the stabilization process does not promote dehydrochlorination[5]. Lead stabilizers also give PVC excellent wet electrical characteristics. On a weight basis, lead compounds typically constitute 2-5% by weight of PVC wire insulation or jacketing.

Mixed metal salt blends are primarily used in flexible or semi-rigid PVC products. The most common are barium/zinc (Ba/Zn) and calcium/zinc (Ca/Zn) metal salts (Ba/Cd has been phased out due to cadmium toxicity concerns). Furukawa Inc. has developed an Al/Mg/Ca/Zn stabilizer. Mixed metal stabilizers are seen as potential replacements for lead in PVC wire and cable applications (see Section 8.1).

Organotin compounds are used primarily for rigid PVC applications. Sulfur-containing organotin compounds are currently the most efficient and most universally used heat stabilizer among all organotins. Organotin mercaptides (with at least one tin-sulfur bond) not only are able to react with hydrogen chloride but they also help impede autoxidation. The combination of these two functions gives the organotin mercaptides exceptional thermostabilizing properties, which are not exceeded by any other class of stabilizer. Organotin heat stabilizers are seen as potential replacements for lead in PVC wire and cable applications (Gachter and Muller 1993).

Organic compounds (completely metal-free) are a new entry in the market and the subject of intense development by the major heat stabilizer producers. Several types are being evaluated including organosulfide products and heterocyclic compounds. Although their usage is still very low, they could become a significant factor in the market in response to the pressures to replace cadmium, lead, barium and even zinc in heat stabilizers. There is a significant R&D effort to develop organic stabilizers at the expense of the metallic types (e.g., Witco, Morton and Ferro). By 2003 these stabilizers may account for 2% of total global market (Chemical Additives for Plastics 1999).

3.4 Fillers

Fillers are used in most resin systems (including PVC and polyethylene) to reduce formulation costs and improve the insulation's electrical resistance. Typical filler materials include precipitated calcium carbonates, ultra fine ground calcium carbonate and dolomite, fine ground, refined and micronised talcs, micas, silica, carbon black, china clays (kaolin) and wollastonite. "Filler" is a somewhat misleading term since it connotes that the material has no functional value. In fact, fillers are carefully chosen since they can significantly impact the resin system – by increasing tensile strength (carbon black), reducing costs (clays and talcs), and affecting electrical and other properties.

3.5 Flame retardants

Flame-retardants are used in wire and cable compounds to slow the spread of an accidental fire and reduce the amount of heat and smoke released. During combustion of wire and compound materials, free radicals are formed by pyrolysis. The radicals then combine with oxygen and a

[5] At the molecular level, dehydrochlorination causes the formation of double bonds, the cutting of molecular chains, and cross-linking, resulting in reduced processability, mechanical strength and electrical properties.

chain reaction ensues. Combustion is slowed or stopped when the oxygen -radicals chain reaction is interrupted. There are five major methods for making polymer systems fire retardant (Othmer 1985).

1. Raise the decomposition temperature of the polymer – generally by increasing polymer cross-linking density;
2. Reduce the fuel content of the system – e.g., by halogenating the polymer backbone, adding inert fillers, or employing organic systems;
3. Induce polymer flow – for thermoplastics interrupting the polymer backbone to reduce viscosity and promote dripping;
4. Induce selective decomposition pathways – e.g., use of phosphorous compounds in cellulose materials where phosphoric acid is generated, resulting in the loss of water and the retention of carbon as char which acts a physical heat and gas flame barrier; and
5. Mechanical/other means such as bonding non-flammable skins, employing sprinklers, etc.

The three primary classes of flame-retardants are halogenated compounds, inorganic compounds (including antimony), and phosphorous compounds. Chemically acting flame retardants (such as the halogenated bromine and chlorine systems) are very effective. Physically acting inorganic flame-retardants based on metal hydroxides and salts have a weaker effect. The performance of primary flame retardants such as chlorine, bromine and phosphorous is enhanced by additives such as antimony, zinc and other metal salts. Antimony oxide is typically used in flexible PVC wire and cable type products. Rigid PVC products are essentially flame retardant due to their chlorine content. Plasticized PVC (flexible) products contain large amounts of flammable plasticizers such as DIDP. For some applications, there is sufficient chlorine content in the PVC such that additional flame retardants are not required. However for applications that must meet more stringent flame tests, additional flame retardants are often used. (USAC 2001).

In general, flame retardants in the form of powder additives are mixed into the wire and cable compounds. They remain inert until high temperatures activate them – such as those generated by a fire. Table 7 estimates the volume and cost of flame-retardants used in wire and cable fabrication polymers. Cost estimates are for North America and are estimated average prices for the five major classes of flame-retardants.

Table 7: 1998 Volume of Flame Retardants in US Wire and Cable

Type	1998 Volume (million lbs)	Percent	Cost ($/lb)
Organic bromine compounds	9	9%	1.40
Organic chlorine compounds	1	1%	1.35
Phosphorous compounds	5	5%	1.35
Inorganic flame retardants	81	84%	
Alumina trihydrate	70	73%	0.25
Antimony trioxide	7	7%	1.90
Other inorganics	4	4%	
Total	96	100%	

Source: BCC 2000 (Volume) and TownsendTarnell (Cost)

3.5.1 Halogenated Flame Retardants

Halogenated flame-retardants include (1) bromine-containing flame retardants, (2) chlorine-containing flame retardants, and (3) halogen/antimony flame retardants.

Of chlorine and bromine the latter is more effective as a flame retardant since it has a weaker bonding to carbon, enabling it to interfere at a more favorable point in the combustion process. Bromine can be bound aliphatically or aromatically in flame retardants. Flame retardants with aromatically bound bromine have the highest market share. At moderate loadings they reduce the flammability of several polymeric materials used in wire and cable, such as polyolefins and neoprene rubber. Comparisons show that a UL-94 V0 fire rating is possible with 82% polyethylene, 12% decabromodiphenyl oxide, and 6% antimony oxide compound, whereas a 60% polyethylene, 27% chlorine, and 13% antimony oxide formulation yields a UL-94 V1 fire rating. Major brominated organic compounds used as wire cable flame retardants include decabromodiphenyl oxide (DBDPO), ethylene bis-tetrabromophthalimide, and tetradecabromodiphenoxy benzene (BCC 2000).

The chlorine present in PVC gives the cable a measure of inherent flame retardancy. However, additional flame-retardants are also usually added to such grades. Chlorinated flame retardants are used in plastics mainly in the form of chlorinated hydrocarbons or chlorinated cycloaliphatics. They are low cost and offer good light stability. To achieve the required flame retardancy, however, formulations with high amounts of the respective flame retardant are necessary. This can adversely affect the properties of the polymer (Gacher and Muller 1993). Therefore, a synergistic agent is often used. Antimony trioxide is such a widely used agent that produces a marked synergistic effect with halogen-containing compounds.

3.5.2 Inorganic Compounds

Very few inorganic compounds are suitable for use as flame retardants in plastics because they are usually too inert to be effective in the range of decomposition temperatures of plastics (between 150 and 400 °C). The most common types of inorganic flame retardants include alumina trihydrate (also known as aluminum hydroxide), antimony trioxide, and boron-containing compounds. One major disadvantage of inorganic flame retardants is hygroscopicity – non-halogens tend to pick up water and are sometimes compensated for by adding fillers such as clay which reduce water absorption. Pigmentation is also more difficult with non-halogenates.

Antimony Compounds. To be effective, antimony oxides must be converted to volatile species. This is typically accomplished when halogenated organics release halogen acids in the presence of fire temperatures. The halogen acids react with the antimony-containing materials in the condensed phase to promote char formation. The latter acts as a physical barrier to flame and inhibits the volatilization of flammable materials in the flame in sufficient volume to provide an inert gas blanket over the substrate, supplanting oxygen and reducing flame spread. Antimony halides also alter fire-temperature chemical reactions in the flame, making it more difficult for oxygen to combine with volatile flame byproducts. The most effective flame-retardant system for polyethylene is an antimony oxide and a low melting halogen combination.

Currently *aluminum hydroxide* (or also called alumina trihydrate ATH) is the most widely used inorganic flame retardant; it is low cost and easy to incorporate into plastics. When exposed to temperatures over 250°C, it forms water and alumina, with the evolution of water absorbing heat by cooling the flame, diluting the flammable gases and oxidant in the flame, and shielding the surface of the polymer against oxygen attack and thermal feedback. In wire and cable applications it is used in PVC, LDPE, EPDM and EVA. Recent studies have demonstrated that there are major advantages to using a *combination of ATH and zinc borate* in a variety of halogen-free polymer systems (combined filler and flame retardant functions, does not require halogens, does not produce toxic gases, low cost).

Magnesium hydroxide's main advantage over ATH is the higher decomposition temperature of 330-340 °C. Its main application is with polypropylene but it is also used in elastomeric cable compounds. Its main limitation is the tendency to agglomerate in polymers, affecting processability and performance.

Zinc borate is an effective and economical flame-retardant synergist of organic halogens in polymers. It has been demonstrated that the combination of zinc borate and ATH can be used as an effective flame retardant and smoke suppressant in halogen-free polymers such as EVA, polyethylene, EPDM, EEA, epoxy, and acrylics. Zinc borates have also found uses in PVC formulations. They have been shown to be effective flame/smoke suppressants when used as partial replacements for the antimony oxide that is normally used in a typical flexible PVC cable jacket, for example. For flexible vinyl and PVC plastisol formulations, a half to two-thirds of the antimony trioxide can be replaced by zinc borate without loss of flame retardancy.

Ultracarb[6] is a naturally occurring mixture of two mineral fillers and is similar to ATH. However, the filler can be processed at higher temperatures and is less expensive. Ultracarb is based on a proprietary mixture of huntite, $Mg_3Ca(CO_3)_4$ and hydromagnesite $Mg_3(CO_3)3(OH)_2.3H_2O$. Ultracarb has been widely used in wire and cable applications in materials such as PVC, PE, EEA, PP, EPDM and EVA.

3.5.3 Phosphorus-containing flame retardants

These flame retardants mainly influence the reactions taking place in the condensed phase. They are particularly effective in materials with high oxygen content, such as oxygen-containing plastics as well as cellulose and its derivatives.

The range of phosphorus-containing flame retardants is extraordinarily versatile, since in contrast to halogen compounds, it extends over several oxidation states. Phosphates, phosphate esters, phosphonates, phosphine oxides, elemental red phosphorus are all used as flame retardants. Often the phosphorus compounds also contain halogens, which increase the effectiveness of the flame retardant (e.g., chlorophosphates and chlorophosphonates). The two most important categories are the phosphate esters, extensively used in flexible PVC, and chlorinated phosphates, commonly used in polyurethane formulations (Gachter and Muller 1993).

[6] Manufactured by Microfine Minerals

3.6 Lubricants

Lubricants are added to improve the ease of processing. A typical lubricant for wire and cable manufacturing is *stearic acid* (added to PVC). Lubricants help provide a consistent, flawless surface finish and make it possible to produce long lengths of wire at high line speed.

3.7 Colorants

Colorants are added to wire and cable resins for identification purposes. Vinyl wire and cable compounds can be manufactured in virtually any color. There are two major types of colorants – *pigments* and *dyes.* A pigment is insoluble and is dispersed as discrete particles throughout a resin to achieve a color. Pigments can be either organic or inorganic compounds. A dye is soluble in the resin and always an organic based material. Light stability is an important factor when selecting a colorant.

Pigments are typically identified by their color families and to some extent their properties. Common inorganic types include lead, cadmium, lead chromate, titanium dioxide, zinc sulfide, iron oxides, cadmium oxides, ultramarines, mixed metal oxides, and carbon black. *Titanium dioxide* and *zinc sulfide* are white pigments which can be used in most resins. *Iron oxides* come in red, yellow, brown, and black. Their heat stability varies and they can be used in a variety of resins. *Lead chromates* and *lead chromate molybdates* include bright yellows and oranges. *Cadmium* comes in reds, yellows, oranges and maroons and is excellent for engineering resins. *Chromium oxides* are green and show very good heat and light fastness. *Ultramarines* come in blue, pink and violet shades and work in a wide range of resins. Alternatives to many of these "heavy metal" pigments are the "mixed-phase metal oxide" pigments (e.g., yellow *nickel titanates* and blue and green *cobalt aluminates*). Relatively new is a brilliant yellow *bismuth vanadate*. Orange version compounds have been developed as well. *Cerium sulfide* now is under commercialization for a range of reds. Organic pigments are also available in a wide range of colors. They, however, are more difficult to disperse than inorganic, which leads to possible loss in mechanical strength. The amount of colorants used in coated wire and cable is small and this makes it less of a priority for developing alternatives.

4. The Coated Wire and Cable Manufacturing Process

The manufacturing of coated wire and cable is a multi-stage process. Raw materials are combined in a series of manufacturing steps including resin and additive manufacturing, resin compounding, wire drawing (or fiber optic), extrusion, cabling, and jacketing.

Polymers and additives are combined together in a compounding operation to produce materials formulated to meet the various insulation or jacketing performance requirements (e.g., heat and light stability, smoke retardancy, or water resistance). Once the additives have been combined with the polymer resin, the resulting material typically goes through re-heating and cooling to produce small, hard pellets. These pellets are later re-melted in extrusion equipment to insulate or jacket wire and cable.

The core of the product is a metal (usually copper or aluminum) rod or fiber optic preform that is drawn down to a specified diameter. The process of "drawing" wire involves reducing the diameter of the core by pulling it through a converging set of dies until it reaches the specified size. Some products then require various drawn wires to be bundled together. Fiber optics use a different process involving an atmospheric controlled furnace to melt the preform and draw it to the specified diameter.

Plastic compound is then extruded over the core to provide jacketing or insulation. When plastic covers bare electric wire, the coating is called primary insulation. A secondary layer of plastic extruded over a wire or a group of wires is called a sheath or jacket. *Extrusion* is the process of melting, feeding, and pumping a polymeric compound through a die to shape it into its final form around the wire. Depending on the desired performance characteristics, the insulated wires are often combined, or cabled, in various configurations. A critical requirement is that the melt leaving the die is very uniform. Another critical requirement is that the line must be capable of running the wire or cable with uniform tension at a desired but constant speed without variation or drift. The lines are commonly designed for a range of different wires and cables (Rosato 1998).

Wire and cable coverings are tested in-line generally more than any other extruded product because they are rather inaccessible for many tests when wound on a reel. Spark testing is very common. The wire passes through a high-voltage field, and if there are any breaks, pinholes, or thin spots in the covering, a circuit is completed to the conductor and a signal of some type is produced. In addition, some measurements are made to ensure conformance to specifications (e.g., diameter, capacitance and eccentricity measurements). Finally the cable is wound onto reels and shipped to a job site or retailer.

5. Regulatory and Performance Aspects

This section is divided into two subsections – the first examining wire and cable fire safety aspects and the second reviewing environmental, health and safety issues. This section does not cover the accelerated service tests, nor the different electrical test performance requirements. While both of these areas are important in overall wire and cable performance, this report focuses on flammability issues because of the difficulty in meeting flammability performance requirements with non-halogenated materials.

5.1 Flammability Tests

Fire safety requirements are one of a host of performance requirements outlined in the U.S. National Electrical Code (NEC). The NEC, which is produced by the National Fire Protection Association (NFPA) is the reference standard used by electrical designers, contractors, installers, etc. to specify the performance standards for different wire or cable applications (e.g., flammability in plenum riser installations). Wire and cable manufacturers develop and test products using Underwriters Laboratories (UL) approved tests to ensure conformance with the NEC. The NEC does not specify which materials must be used in wire and cable construction.

The NEC only specifies the wire or cable's performance. These tests measure the performance of a complete cable construction, not just the jacketing material.

Flame retardancy in cable usage is the ability of the material to cease burning once the source of heat is removed. Several tests have been formulated to measure this properly. Appendix B outlines several of these tests including:

- Horizontal Flame Test (UL 44,83)
- All Wires Flame Test (UL 83)
- VW1 (Vertical-Wire Flame Test (UL 83)
- UL 1581 – Also referred as Vertical Tray Test (also known as IEEE 383)
- Vertical Tray Flame Test (UL 83, UL 1277)
- UL 1666 – Also referred to as a Riser Test.
- UL 910 – Also referred to as Steiner Tunnel Test

An example of a moderate flame test is the Horizontal Flame Test (UL-44, 83). The test involves applying a gas burner at 1,500°F to the sample for 30 seconds. The flame must not progress beyond a point 2" left or right of the point of application of the flame or ignite cotton on the floor of the test chamber by means of burning particles dripping from the cable. The most severe test a cable construction must pass to meet the National Electrical Code is the UL 910 – also referred to as Steiner Tunnel Test. A flame source is applied to a horizontally installed cable in a plenum environment for 20 min at a rate of 300,000 BTUs per hour. To pass the test, the flames must spread less than five feet and produce very little smoke.

Plenum cables deserve special attention since they usually have to pass the most stringent fire safety test – the UL 910 Steiner tunnel test. A recent report by NFPA revealed that there is a significant accumulation of sizable fire load in the plenum. Communications cables are the single largest contributor to plenum fire load due to the proliferation of telecommunication and computer networks. For example, plenum cable production has grown 46% annually during the period 1991 – 1998. Offices re-cable every three years on average and retired cable is usually left in the plenum. In 1991 there were approximately 5 billion feet of plenum cable in place. In 1997 the estimated length was 30 billion feet of plenum cable and by 2000 the estimated growth showed the potential of 45 billion feet (Moritz 1998). In 1998 the Technical Committee on Air Conditioning at the National Fire Protection Association proposed changes to NFPA 90A and NFPA 90B standards that will require the removal of all abandoned plenum cable (the final decision will be made in 2002). The intent of the proposed change in NFPA 90A is to control the fire-load in the plenum as the expected amount of smoke produced in the plenum is directly proportional to the fire-load in it.

The U.S. NEC differs from the electrical code in other countries.   One of the principle differences is the flame retardancy difference between the U.S. and the European Union. Generally, the United States has more stringent flammability requirements since wire and cable materials are required to pass tougher vertical flame tests. For some applications, such as plenum cables, there are few resin formulations other than those based on fluoropolymers and PVC that can meet the performance standards. Thus those products that meet fire protection requirements in Europe, may not meet the stricter US standards. As the industry looks to develop lead-free, bromine-free, and even halogen-free products, the conflicting standards force manufacturers and OEMs to decide to manufacture two different product lines or a single (and more costly) line that meets the most stringent global standard.

5.2 Environmental, health and safety issues and requirements.

This sub-section will outline the main environmental, health and safety issues and requirements that relate to wire and cable manufacturing, use and disposal. These are mostly associated with the impacts of cadmium, lead, brominated flame retardants, plasticizers, and PVC.

Proposed WEEE Directives: The proposed WEEE Directive requires end-of-life equipment to be collected for recovery, recycling and re-use, placing the main responsibility on the manufacturers of such equipment. The EC's draft text covers 11 categories of equipment, including large and small household appliances, telecommunication equipment, and radio and television equipment – so the scope of the directive is broad. The associated, but now separate, Restriction of Hazardous Substances Directive (RoHS) further bans the use of some toxic materials such as lead, cadmium, and some brominated flame-retardants. The commission adopted the proposal on June 13, 2000. A parliamentary process will has begun with decisions expected by the end of 2002. The Directives, which may undergo further changes before being passed, are expected to be implemented in 2004 and as such may affect Massachusetts wire and cable industry export markets.

Specified Home Appliances Recycling Law in Japan: This law was enacted in 1998 and was fully enforced in 2001. Scarcity of the final disposal site, increase of electrical and electronic equipment (EEE) in the waste stream and inadequacy of existing treatment plants to handle EEE were the main driving forces for the enactment of the law. The law was initiated by the Ministry of International Trade and Industry, and was further developed and finalized together with the Ministry of Health and Welfare and the Environmental Agency (Tojo 2000; Nikkei Weekly 1998). Under the program, manufacturers and importers of four large electrical home appliances are required to take-back the discarded products they manufactured and dismantle and recover the components and material that can be reused or recycled.

Proposition 65 in California: In November 1986, California voters approved an initiative to address growing concerns about exposures to toxic chemicals. That initiative became The Safe Drinking Water and Toxic Enforcement Act of 1986, better known by its original name: Proposition 65. The Act requires the Governor to publish a list of chemicals that are known to the State of California to cause cancer, birth defects or other reproductive harm. This list must be updated at least once a year. Businesses are required to provide clear and reasonable warnings prior to knowingly and intentionally exposing individuals to chemicals that have been listed in Proposition 65. Warnings are not required when the manufacturers can show that the California exposure occurs at a level that poses no significant risk of cancer. By Executive Order W-15-91, the Office of Environmental Health Hazard Assessment (OEHHA) was designated as the lead agency for the implementation of the Act. Currently many chemicals used in wire and cable are on this list and are used at levels that may trigger notification (e.g., lead and lead compounds, cadmium and cadmium compounds, antimony oxide and trioxide) (OEHHA 1999). For example, in 1999 the Mateel Environmental Justice Foundation (MEJF) sued Microsoft Corporation for violating the Proposition 65 in its marketing of PVC coated wire and cable. A series of lab tests revealed a sufficient amount of lead leaching from the wire and cable and other PVC-lead products during wire handling to require Prop 65 labeling. The case was settled and Microsoft was required to pay a civil penalty of $65,000, label its products or reformulate them to contain less than 300 ppm lead (0.03%) (Superior Court of the State of California 2001). Currently there are about 30 consumer product manufacturers that have been sued for not labeling lead-bearing PVC components such as wire and plastic housings.

***Concerns over PVC**:* The vinyl chloride industry is heavily regulated from an environmental, health and safety perspective. After its carcinogenicity was discovered, vinyl chloride monomer became one of just ten industrial substances to be controlled under the National Emission Standards for Hazardous Air Pollutants (NESHAP). There is also an OSHA standard for exposure to vinyl chloride in the workplace (1 ppm). Recently, however, chlorine (and as a result products such as PVC that involve chlorine in manufacture) has been under increasing attacks by Greenpeace and other organizations such as the International Joint Commission on the Great Lakes (IJC) and the American Public Health Association (APHA). The primary concerns are over dioxins, generated when PVC is heated above 250 °C (e.g., accidental fires or incineration).

In Europe, there has been an active debate about PVC. Environmental groups have raised issues about the environmental burden of PVC over its life-cycle, while industry has defended the benefits of using the material. In response to these pressures, the European PVC industry launched the “Voluntary Commitment of the PVC Industry” in March 2000. The program challenges participating PVC resin producers and their industry partners to reduce the environmental impact of PVC manufacture and expand options for waste management. (ECVM, 2000 and ECVM, 2001) The program has established commitments and specific targets in a number of areas, including, recycling programs and technologies, risk assessment research on phthalates, the elimination of cadmium stabilizers, and development of alternatives to lead stabilizers.

The EU has also been active in addressing the questions around PVC. In July of 2000, the European Commission published a “Green Paper on the Environmental issues of PVC” (ECC 2000) in order to present and assess the various environmental issues of the life cycle of PVC and to consider options to reduce those impacts. The paper was to “serve as a basis for a consultation with stakeholders in order to identify practical solutions to health and environmental issues raised by PVC.” (ECC 2000) In March 2001 the European Parliament issued a resolution on the EC’s PVC Green Paper. The resolution called on the EC to introduce substitution policies for PVC and legislation that would phase out cadmium and lead-based stabilizers (EU 2001). The resolution also called for compulsory marking of PVC products and for separate collection of PVC waste and indicated that incineration and landfill are unsustainable options for the disposal of PVC. At the same time, the EC voted for hard PVC waste to be diverted from incineration. In addition, the European Parliament is calling for the “polluter pays” principle to apply to PVC waste so that PVC producers are charged for any additional costs generated by the presence of PVC in waste. In the United States, the US EPA has not addressed PVC directly, but has spent two decades researching the health effects of dioxins and sources of exposure. In 1994, EPA published a draft of the *"Exposure and Human Health Reassessment of 2,3,7,8-Tetrachlorodibenzo-p-Dioxin (TCDD) and Related Compounds."* This report is commonly referred to as the EPA dioxin reassessment. The report, which concludes that “complex mixtures of dioxin and related compounds are highly potent, “likely” carcinogens,” (US EPA 2000) has been reviewed and commented on by the EPA’s Science Advisory Board, the public and many stakeholders. Additional information has been incorporated into the documents and they are available as working drafts (US EPA, 2000). The report estimates exposure and sources of dioxin, human health effects, and then integrates this information into a risk characterization of dioxin and dioxin-like compounds. EPA plans to release a “cross media dioxin strategy” along with the final reassessment that could recommend new limits on dioxin emissions.

***Heavy metals**: C*oncerns over the toxicity of cadmium, lead, chromium and other heavy metals led to some regulatory steps in Europe. Cadmium use as a pigment, stabilizer and for surface treatment is restricted by the EU Directive on “Chemical Products: Marketing and use of certain dangerous substances and preparations” (EU 76/769/EEC 2001). The Danish Environmental Agency has signed a statutory order prohibiting import and manufacture of many products containing lead. The phase-out dates depend on the use and type of product and vary from 2000 to 2003, with some uses, including electrical cable coating, allowed “until further notice.” (Danish EPA 2001). In the United States OSHA strictly regulates worker exposure to several heavy metals, including lead and cadmium.

***Phthalate plasticizers**:* Over the past several years, there has been growing concern regarding the potential health effects and human exposure of some phthalate plasticizers. While there are no phthalate regulatory restrictions in the U.S., there is a European ban on soft toys for young children. The European Commission is considering further restrictions, depending on the outcome of phthalate studies looking at exposure and health effects. As part of their “Community Strategy for Endocrine Disruptors,” the European Commission has published a list of suspected endocrine disruptors, which includes three phthalates: DEHP, BBP, and DBP (EC 2000).

In the U.S., the EPA has convened an advisory panel to develop a screening and testing protocol for suspected endocrine disruptors (U.S. EPA 2000). In addition, the National Toxicology Program Center for the Evaluation of Risks to Human Reproduction (NTP CERHR) completed an expert panel review of phthalates in 2000. The panel focused on available data for human exposure to these substances, and experimental evidence (animal studies) of reproductive and developmental toxicity. The panel assigned levels of concern to each substance: negligible, minimal, or low concern, concern, or serious concern. Of the seven different phthalates reviewed, the panel determined that for five (DINP, DIDP, BBP, DBP, and DNOP), there was low, minimal or negligible concern, for one (DEHP) concerns varied from minimal to serious depending on receptor and exposure, and for one (DNHP) there was insufficient data. In all cases, the higher concerns were for sensitive receptors, such as infants, children and pregnant women. (NTP CERHR 2000)

For DIDP, the predominant plasticizer in wire and cable, the panel expressed “minimal concern” for developmental and reproductive system effects for all receptors. For DEHP, there was “serious concern” for reproductive tract effects in male infants exposed via medical products during intensive medical procedures. There was also “concern” that the developing male reproductive tract could be adversely affected either by pre-natal exposure or by infant/toddler exposure. The concern for adult reproductive effects from DEHP exposure was “minimal.”

The NTP CERHR reports and scientific studies have led environmental groups to pressure manufacturers to eliminate the use of certain phthalate plasticizers in medical products and children's toys.

***Halogenated Flame Retardants**:* There are a number of European efforts underway to phase-out or limit the use of some brominated flame retardants, due to their suspected environmental and human health effects. Some of the brominated flame retardants are persistent, bioaccumulative, and toxic to humans and the aquatic environment. Swedish studies have shown that the concentration of PBDEs (poly brominated diphenylethers) in mother's milk has been rising exponentially since the 1970s. The EC RoHS Directive described above includes a phase-out of PBB (polybrominated biphenyl) and pentabrominated diphenylether (pentaDBE). Restrictions on two other polybrominated diphenylethers (octaBDE and decaBDE) have been postponed due to their fire safety benefits pending an EC risk assessment. However, in April 2002 the European Parliament amended the penta-BDE Directive, stating that "although the risk assessments for octaBDE and decaBDE are not yet complete, the marketing and use of these substances should be restricted, given that the current assessments have already established definite risks for human health and the environment." Denmark has initiated an Action Plan that aims at phasing out the most problematic brominated flame retardants. In the short term, the efforts include the substance groups PBBs and certain PBDEs. The Danish EPA is planning a major information campaign directed towards the Danish retailers launched in the autumn of 2001. In December 2000 the agency and the Danish Plastics Federation began a cooperative effort to identify the consumption of and the problems caused by brominated flame retardants in plastic goods. Projects are underway to develop and test alternatives (Danish EPAb 2001).

6. Life cycle impacts of coated wire and cable

Manufacturing of coated wire and cable is a complex, multi-stage process that is associated with various environmental, health and safety impacts. This section will address these impacts along the life-cycle of a typical PVC, lead-stabilized cable with phthalate plasticizers. The report also discusses the use of halogenated flame retardants, due to their presence in other plastics as well (e.g., PE). First the Massachusetts coated wire and cable use of these chemicals will be presented, followed by detailed discussion of each type of chemical and its associated impacts.

6.1 Wire and Cable Materials Use in Massachusetts

Table 8 presents the amounts of materials used by the Massachusetts coated wire and cable industry during the period 1995-99 and reported under the state's Toxics Use Reduction Act. The table shows that barium and chromium are used in very small amounts, lead and antimony are used in the largest volumes, zinc compounds and DEHP have seen the greatest percent increase since 1995[7]. The industry has simultaneously reported increases in production levels under the EPA Toxics Release Inventory over this period. In 1999 fifteen facilities reported the use of antimony and antimony compounds; only one facility reported barium compounds, DEHP

[7] These changes have not been adjusted for the changes in production level, so changes in chemical use might be due to increases or decreases in economic activity. For a more detailed analysis of toxic chemical trends in the MA wire and cable industry, see "TURA Data Review: Cable and Wire Industry Sector", TURI publication MP22, 2002.

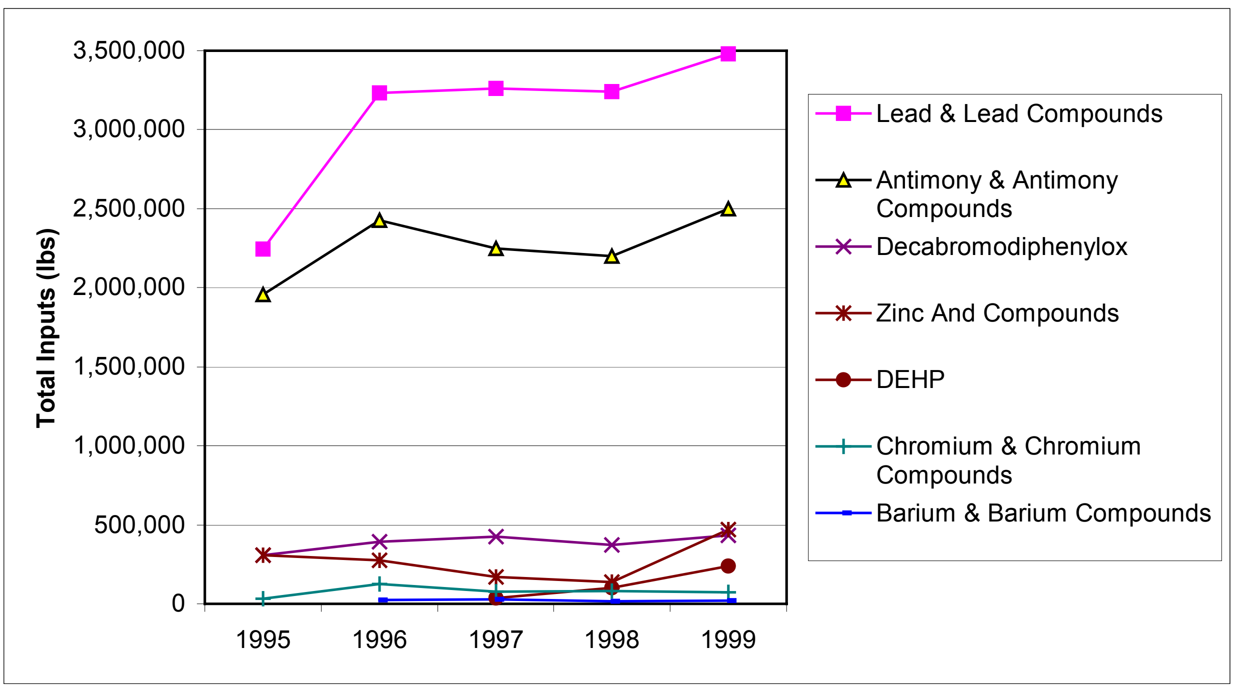
was reported by three facilities; lead or lead compounds – by fourteen facilities; and zinc and compounds – by four facilities. The last column in Table 8 presents the number of companies SIC 3357 reporting each year since 1995. Lesser amounts of nickel, toluene, methyl ethyl ketone, methanol, cupric nitrate, nitric acid, and caprolactam dust and vapor were also reported (all less than 80,000 lbs each in 1999). Figure 3 represents the data from Table 8 in a graphical format.

Table 8: 1999 Chemical use by Massachusetts coated wire and cable industry (SIC 3357)

Year	Antimony & Antimony Compounds	Barium & Barium Compounds	Chromium & Chromium Compounds	Decabromodi phenylox	DEHP	Lead & Lead Compounds	Zinc Compounds	Number of reporting companies
1995	1,955,913		32,047	307,645		2,244,418	308,774	17
1996	2,428,494	22,914	126,803	393,200		3,232,647	276,814	18
1997	2,247,108	26,442	76,036	423,482	35,047	3,262,796	171,874	21
1998	2,201,431	17,940	81,050	371,069	100,852	3,241,298	138,831	21
1999	2,532,131	20,225	71,250	433,919	240,240	3,480,500	469,011	16
95-99 % change	28%		122%	41%		55%	52%	
97-99 % change	11%	-24%	-6%	2%	585%	7%	173%	
Notes	increased	shrinking	'97-'99 shrinking	'95-97 big increase	increasing	1995-96 change	98-99 big increase	

Source: TURA data 1995-1999

Figure 3. TURA Material Inputs - MA Coated Wire And Cable Industry SIC 3357



Source: TURA data 1995-1999

6.2 Brief Assessment of Materials with the Greatest EH&S Impacts.

The significance of the EHS impacts associated with coated wire and cable manufacturing is summarized in Table 9 below, with each chemical discussed further in the section. Low, medium and high refers to a subjective assessment of the impact significance based on available scientific data (US EPA Air Toxics 2001, EPA IRIS 2000).

Table 9: Summary of Wire and Cable Environmental, Health and Safety Impacts

Materials/products/ processes	CAS no.	Impacts		Notes[8]
		Environmental	Health and Safety	
Vinyl chloride monomer	75-01-4	High	High	Proven carcinogen, global warming, acidification.
Lead and lead compounds	7439-92-1	High	High	Persistent, bioaccumulative, and toxic; slows a child's cognitive development.
DEHP	117-81-7	Low	Medium	High degree of uncertainty regarding EHS.
DIDP and DINP		Low	Low	Lower impacts compared to DEHP
PBDEs		High	High	Impacts different for different PBDEs: disrupt thyroid hormones, neuro-developmental toxicity, high degree of uncertainty regarding EHS
Antimony trioxide	1309-64-4	Medium	Medium/High	Probable carcinogen (IARC)
Cadmium and compounds	7440-43-9	High	High	Proven carcinogen; toxic, persistent and bioaccumulative
Zinc and zinc compounds	7440-66-6	Medium	Low	Aquatic toxicity; bioaccumulates.
Dioxin (a group of chemicals)		High	High	Proven carcinogen; toxic, persistent and bioaccumulative.

The following subsections describe in a greater detail the EHS impacts of these chemicals

6.2.1 Lead Compounds

While the lead compounds impart necessary properties to the wire and cable coatings, their presence can be environmentally detrimental. Not too many years ago it was common practice to burn wire removed from buildings to recover and sell the copper. Such a practice produces smoke from the PVC that would not only be acidic and potentially toxic, but also a source of lead toxicity.

[8] All chemicals in this table are listed in California Proposition 65.

Lead (Pb) is a persistent, bioaccumulative and toxic chemical. In high concentrations it can cause brain damage, kidney damage, and gastrointestinal distress. Long-term exposure affects the blood, central nervous system, blood pressure, kidneys, and vitamin D metabolism. In children it causes slowed cognitive development, reduced growth and other effects (U.S. EPA 2000).

In cable insulation and jacketing lead is bound to the PVC-matrix, therefore most of it remains in the product and emissions during product use have been thought to be negligible[9]. More important are the impacts during refining, accidental fire and during disposal. Since it is difficult to recycle wire and cable, virgin material is typically used, which leads to emissions from refining and manufacturing. Accidental fires and incineration of waste scrap from wire and cable leads to the release of lead and other heavy metals and toxic substances. In the case of landfill, especially under acidic conditions, leaching of lead is possible into the soil and ground water.

6.2.2 Halogenated Flame Retardants

The use of halogenated chemicals as flame retardants is currently under pressure in Europe due to their potentially significant environmental and human health effects. One group of flame-retardants is reviewed here - polybrominated diphenyl ethers (PBDEs). Major brominated organic compounds used as wire and cable flame retardants include decabromodiphenyl oxide (decaBDE), ethylene bis-tetrabromophthalimide, and tetradecabromodiphenoxy benzene (BCC 2000). Swedish time trend studies reveal that the levels of PBDE in the environment have been increasing since the 1970s. While there seems to be a decrease in the levels of brominated flame retardants in the aquatic system, levels in human breast milk are increasing exponentially, doubling every five years. OctaBDE have been measured in indoor air of premises containing flame-retarded electronic apparatus such as computers and television receivers. Elevated blood concentrations of octaBDE have recently also been shown in occupational categories handling computers, for example. OctaBB concerns include liver and reproductive toxicity. In the USA, decaBDE has been found in human fatty tissue from a normal population. These chemicals show effects mainly on the liver but also on the thyroid and reproduction (teratogenic effects).

Generally speaking, there is much scientific uncertainty regarding the adverse impact of PBDEs on human health as research is relatively new and limited. Preliminary data suggest that the effects of PBDEs, PCBs and dioxins on thyroid hormone disruption and enzyme induction may be additive. Similarities to PCBs suggest that PBDEs may affect fetal brain and nervous system development resulting in learning and motor deficits in newborns; animal studies in this area have recently begun. Sources of information on brominated flame retardants include web sites run by the IPC Association Connecting Electronics Industries (www.halogenfree.org), the Bromine Science and Environment Forum (www.bsef.com) and the Environmental Finance Center (www.greenstart.org/efc9/bfrs/background.htm).

6.2.3 Antimony Compounds

Antimony trioxide can cause irritation of the respiratory tract. Symptoms can include sore throat and cough. Ingestion causes irritation to the mouth, nose and stomach. Other symptoms include salivation, cough, metallic taste, nausea, vomiting, bloody diarrhea, dizziness, irritability, and

[9] However, recent findings of Proposition 65 in California show potential exposure (see Section 6.2).

muscular pains. It may cause the heart to beat irregularly or stop. It irritates skin and symptoms include redness, itching, and pain. Antimony trioxide causes irritation, redness, and pain of eyes when in contact. Prolonged or repeated exposure may damage the liver and the heart muscle. Prolonged skin contact may cause irritation, dermatitis, itching, and pimple eruptions. There is an association between antimony trioxide production and an increased incidence of lung cancer. Persons with pre-existing skin disorders, impaired respiratory function, or heart disorders (or disease) may be more susceptible to the effects of the substance (ToxFAQs 1993). When released into the soil, this material is not expected to leach into groundwater. The International Agency for Research on Cancer classifies antimony as probable carcinogen (category 2B). It is currently on the California Proposition 65 list.

6.2.4 Cadmium

Exposure to cadmium happens mostly in the workplace where cadmium products are made. Incineration of scrap cable or leaching from landfilled scrap wire and cable can release cadmium in the air and water. Cadmium is a toxic, bioaccumulative heavy metal. It damages the lungs, can cause kidney disease, and may irritate the digestive tract. Cadmium has been found in at least 388 of 1,300 National Priorities List sites identified by the Environmental Protection Agency. The US National Toxicology Program has determined that cadmium and cadmium compounds are known to be carcinogens (NTP 2001).

6.2.5 Phthalate Plasticizers

DIDP (diisodecyl phthalate) and DINP (diisononyl phthalate) are both somewhat less toxic than DEHP and are currently not reportable under TURA. In 1999, three wire and cable manufacturers in Massachusetts reported the use of DEHP. DIDP is the main plasticizer used in cables. There is considerable research underway in both Europe and the US around the health effects and exposure potential of various phthalates. Phthalates can leach from the plastics and some of them have been identified as suspected endocrine disrupters and suspected reproductive toxicants. The International Agency for Research on Cancer (IARC) recently downgraded the classification of the carcinogenicity of DEHP from Group 2B (possibly carcinogenic to humans) to Group 3 (not classifiable as to carcinogenicity). As stated in section 5.2, the most concern is focused on DEHP, sensitive receptors (e.g., children) and uses where the potential for exposure is high (e.g., medical devices and teething toys).

6.2.6 Zinc and zinc compounds

Exposure to high levels of zinc occurs mostly from eating food, drinking water, or breathing workplace air that is contaminated. Such exposure to zinc can be harmful. However, zinc is an essential element for our bodies, so too little zinc can also be harmful. This chemical has been found in at least 801 of 1,416 National Priorities List sites identified by the Environmental Protection Agency.

Eating large amounts of zinc, even for a short time, can cause stomach cramps, nausea, and vomiting. Taken longer, it can cause anemia, pancreas damage, and lower levels of high density lipoprotein cholesterol (the good form of cholesterol). Breathing large amounts of zinc (as dust or fumes) can cause a specific short-term disease called metal fume fever. This is believed to be an immune response affecting the lungs and body temperature. We do not know the long-term effects of breathing high levels of zinc. The Department of Health and Human Services, the International Agency for Research on Cancer, and the Environmental Protection Agency (EPA) have not classified zinc for carcinogenicity (ToxFAQ 1995).

Zinc and zinc compounds (in the form of fumes or dusts) are currently listed under section 313 of the Emergency Planning and Community Right-to-Know Act of 1986 (EPCRA). This decision is based on evidence that zinc ion can become available from zinc oxide through several mechanisms and that zinc ion is highly toxic to aquatic organisms and has a high potential to bioaccumulate (EPA 1995).

6.2.7 PVC, Vinyl Chloride, Hydrogen Chloride and Dioxin

The life-cycle of PVC represents a potential source of dioxins. There is considerable disagreement as to how large this source is, with some suggesting that it is "possibly the largest single material source of dioxin," (Thornton, 1997) and others stating that emissions are well controlled during manufacture, and that PVC is not a significant contributor to dioxin formation during waste incineration. As part of their Dioxin Reassessment, EPA has looked extensively at sources of dioxins. This information, which has been compiled into a database, shows the largest source of dioxin emissions to be waste incineration (US EPA, 2001). While the relatively low emissions from the manufacture of ethylene dichloride and vinyl chloride (EDC/VC) are fully attributable to PVC, PVC materials could be a source of dioxin at other points during its lifecycle. Wire and cable coatings, in particular, could potentially contribute to several sources included in the EPA inventory: manufacture of EDC/VC, secondary copper smelting, scrap electric wire recovery, and waste incineration. Dioxins cause cancer in humans, according to the World Health Organization. They are also linked to numerous non-cancer health impacts including reproductive disorders, birth defects, impaired neurological development, immune system suppression, and diabetes. The following sections provide additional information on the three main PVC life-cycle stages: manufacture, use and disposal.

Manufacture – PVC begins with the manufacture of elemental chlorine gas by the energy intensive electrolysis of salt. The chlorine is then reacted with ethylene to produce ethylene dichloride (EDC). EDC is then converted into vinyl chloride monomer (VCM), which is then polymerized to form pure PVC plastic. The latter is then mixed with various additives to make PVC-compounds for wire and cable. It is unlikely that dioxins are formed during wire and cable extrusion since most processing operations occur at <200 °C[10]. The PVC industry has made tremendous strides in reducing worker exposure to vinyl chloride monomer by developing a closed loop polymerization process and reducing the amount of residual monomer in PVC resin. Vinyl monomer is a highly toxic material that causes liver cancer and adversely affects the central nervous system, respiratory and lymphatic systems, among others. Currently the OSHA standard for exposure to vinyl chloride monomer is 1 ppm (8-hour time-weighed average).

[10] Although experts hold differing opinions on the formation of dioxin, they do agree on essential "ingredients": a carbon surface or structure, organic or inorganic chlorine, copper or iron metal, an oxidizing atmosphere, and, ideally, a temperature range of 250-450 ^{o}C (H. Huang).

Use – the main risks during use come from accidental fires. Although PVC coatings are designed to be fire-resistant, once they burn they can generate gases such as CO, CO_2, dioxins and hydrogen chloride gas. Many of these gases are the same as those produced by burning other plastics, wood and coal and are highly hazardous and present both acute and chronic health hazards to building occupants, fire fighters and surrounding communities (Hurst and Jones 1985). Hydrogen chloride gas is a corrosive, highly toxic gas that can cause skin burns and severe long-term respiratory damage. It also contributes to acidification and global warming.

In electrical fires, wire sheathing is often the first material to burn. Several prominent subway fires in recent years have led to new regulations regarding wire and cable in those applications. For example, a fire in London Underground resulted in a total ban of halogenated cables there, and a fire in the New York City subway system led to new requirements for low-smoke sheathings in certain city applications.

Disposal – After its use, PVC wire and cable can be incinerated, disposed in landfills, or in some cases, recycled. In terms of waste incineration, it is clear that chlorinated substances in the feedstock are an essential component for the formation of dioxins, however there is conflicting evidence about whether the chlorine content of waste feedstock has a significant impact on dioxin emissions. Evidence indicates that for commercial scale incinerators, combustion conditions (flue gas temperature and residence time, combustion efficiency, etc.) are the dominant factor in determining stack emissions. For uncontrolled combustion (e.g., backyard burning and accidental fires) the chlorine content of waste feedstock may have more impact on dioxin emissions. Incineration of waste wire and cable is no longer allowed in Europe, since it leads to the release of heavy metals and dioxins in the air.

Except for the space taken up, land filling pure PVC is not usually a problem. In fact, most landfill liners are made of PVC. The presence of additives, however, (which is the case of wire and cable products) can make the waste materials hazardous. Electrical wires are commonly shredded to recover the metals, leaving the PVC material, known as “fluff”. Some, but not all “fluff” passes the EPA Toxicity Characteristic Leachate Procedure, forcing some of the material to be handled as hazardous waste, making it expensive to dispose of (Environmental Building News 1994).

Scrap created during manufacturing or installation as well as end-of-life wire and cable can be collected and recycled. For this purpose all of the various materials – metal, plastic and others – must be separated. The wires are typically chopped, and the vinyl is then separated from the metal through electrostatic separation, which uses electrical charges to extract the metal from the plastic. Once separated, the vinyl is shredded and recycled into second generation products, such as sound-deadening panel for car doors. The presence of various additives, which may generate toxic gases and release heavy metals, presents a potential barrier to recycling.. In addition, it may seriously damage recycling equipment. The processing of PVC releases hydrochloric acid in the machinery, and it can corrode the chrome plating of recycling equipment (Environmental Building News 1994). As a result of possible European regulatory initiatives, new recycling processes for waste PVC-coated wire and cable are being developed by the vinyl industry. For example, a joint venture in Italy called Vinyloop® will be chemically recycling PVC into "precipitated PVC compounds".

7. Available or Emerging Cleaner Technologies

The complexity of wire and cable applications makes it difficult to find one option to address the various environmental, health and safety issues. Therefore, the emerging technologies are organized in three categories, according to the possible strategy: (a) lead-free wire and cable; (b) low impact flame retardants for wire and cable; and (c) PVC-free wire and cable. The section reviews these strategies, outlining a number of cleaner technologies and emphasizing the EHS trade-offs of substitute technologies.

7.1 Lead-free wire and cable

PVC is the only plastic resin system in which lead is commonly used – various lead compounds are used as heat stabilizers. Therefore, most of the lead-free alternatives discussed in this section relate to PVC-cables.

The main alternatives to lead in wire and cable currently are:

a) ***calcium/zinc soaps*** (with heat resistance up to 100 °C). If exposure to higher temperatures may occur, substitution of lead by Ca/Zn system is technically feasible if special Ca/Zn compounds are applied. One potential solution is Ca/Zn with epoxidized soybean oil as a co-stabilizer. Such compounds are more sensitive than Pb-systems and therefore require a more precise dosage and processing. Some processing parameters need to be adjusted because the floating properties of Ca/Zn differ from those of Pb-systems. The additional cost is estimated at 50-200 per cent of the cable price, which in a complex installation maybe equivalent to a relative cost increase of 10-20%. Lead-free harnesses for cables stabilized by a Ca/Zn-system were introduced on the market in Toyota cars in 1997-98 (Okopol Institute 2000).
b) ***barium/zinc combinations*** are less preferable because of the moderate toxicity of barium to humans, but have a wider "processing widow" than Ca-Zn.
c) ***organotin derivatives*** are another option but currently no reliable information exists about their behavior in the environment and effects on human health; for example, organotins used in marine coatings are known to be bioaccumulative in marine environments.
d) stabilizers based on ***magnesium-aluminum carbonates*** are not well examined but it is unlikely that they will have high toxicity.
e) **o*rganic compounds*** (completely metal-free) are a new entry in the market and the subject of intense development by the major heat stabilizer producers. Several types are being evaluated including organosulfide products and heterocyclic compounds. Although their usage is still very low, they could become a significant factor in the market as response to the pressures to replace cadmium, lead, barium and even zinc in heat stabilizers.

Table 10 summarizes the main alternatives to lead and the trade-offs of their use. This is an area of evolving research with some uncertainties and controversies.

Table 10: Environmental profiles of various PVC stabilizer systems

Criteria	Variants	Pb	Ca/Zn	Ba/Zn	Organotins	Mg-Al
Emissions during winning		Pb emissions due to separation and extraction from the ores	Cd accompanies zinc ores; Cd emissions during winning	Cd accompanies zinc ores; Cd emissions during winning		
Toxicity		Pb toxic to humans and ecosystems	Non-toxic to humans and ecosystems	Ba is moderately toxic to humans	Not well examined (but some concerns raised)	Not well examined but unlikely
Emissions during product use		Bound to matrix	Bound to matrix	Bound to matrix	Bound to matrix, but emissions from new products (especially soft PVC)	
Dispo-sal	Re-cycling	Dispersion of Pb into recycling products			Sulfur containing organotins hamper recycling (formation of insoluble sulfides with Cd, Pb, Zn)	
	Process output via SLF/SHF[11] without recycling	Emissions of Pb from thermal processes Potential emissions from landfill			Tinoxide emissions from thermal processes. Emission from landfill not well examined	

Source: Okopol Institute, 'Lead as stabilizer in plastics', 2000, p. 23.

An increasing number of companies are developing lead-free formulations. For example, in 1992 the American Telephone and Telegraph Company (now Avaya, Inc.) filed a European patent application for lead-free stabilized polyvinyl chloride for communication cabling. The stabilization system consists of ***organotin constituent (organotin maleate or mercaptide) in combination with a calcium-zinc stearate mixture***. The system exhibits good electrical resistance (generally comparable to that of a lead-stabilized system). The calcium-zinc mixture provides a sacrificial function to prevent the formation of tin chloride, which would affect adversely the electrical properties of the insulated conductor (European Patent, 1992).

The International Tin Research Institute (ITRI) has developed several formulations where lead is replaced with ***organotin*** type stabilizer (see Section 7.2 on low impact flame-retardants). Table 11 lists an example of one such formulation.

[11] Shredder heavy fraction (SHF)/Shredder light fraction (SLF).

Table 11. Lead-free PVC formulation for wire and cable

Chemical	Amount
PVC	100 parts
Plasticiser	50 parts
Stabilizer (organotin type)	1.5 parts
Epoxidized soybean oil	3 parts
Processing aid (stearate type)	0.7 parts
Filler (ATH)	45-50 parts
Synergist[12]	0-5 parts

Source: International Tin Research Institute (ITRI), 'Zinc Stannates in Flexible PVC', Technical bulletin No. 1, http://www.itri.co.uk/index.htm, 2000.

Witco Vinyl Additives in Germany, a business unit of Crompton Corp, Greenwich, Connecticut, has developed an ***organic based stabilizer*** (OBS). Its primary market is pipe but marketing manager Manfred Willert says versions are being developed for wire and cable, though it may take 2-3 years before they are commercialized. This fully organic formulation differs from other PVC stabilizers by limiting crosslinking and thus minimizing viscosity and yielding a process window that officials report to be as broad as that of lead. Although the company does not disclose details about the material's composition, the marketing manager says that it is a new technology based on a nitrogen cyclic compound. OBS is a primary stabilizer and not a co-stabilizer as with phosphates and other organic compounds. The material is reported to be nontoxic and has been tested in Sweden and Germany. OBS carries a price premium over lead of 5% based on German marks per meter of pipe, and costs 1% more than tin stabilizers. The company, however, is hoping that with the growing demand the price will go down (Modern Plastics 2001).

TeknorApex has also developed lead-free compounds for wire and cable. The latest innovation in their product line is the development of the **Fireguard 910 NL Series**, which, like many other Teknor wire and cable compounds, is free of the lead-based additives. The seven compounds in the series process at the same high rates as established Fireguard plenum-cable products, exhibit similarly high levels of end-use performance, and cost only slightly more (Wigotsky 2001). They exceed all applicable performance specified in UL Subjects 13, 1424, and 444 while exhibiting heat stabilization comparable to their lead-containing counterparts.

AlphaGary (USA) has developed ***PVC-based lead- and cadmium-free stabilizer*** for their standard jacket and insulation materials for energy/power cables and LAN cables (which meet tray, IEC 332.1 and .3, riser and plenum fire performance testing standards). The company responded to increasing pressures from Europe, Proposition 65 and the Denmark Consumer Initiative for alternative materials. The resulting jacketing and insulation will enhance the disposal and recycling capability of cables removed from service (AlphaGary, 2001).

Furukawa Electric (Japan) has developed ***Al/Mg/Ca/Zn-based stabilizer for PVC***, used in sheaths for electrical power cables. The company claims that the non-lead-stabilized formulations are equal or better than the lead-stabilized PVC in terms of static and dynamic

[12] For proprietary reasons the type of synergist is often not disclosed.

thermal stability; electrical properties; mechanical properties; tinting, and processability. Resulting power wire products were also confirmed to be equivalent to products using conventional lead stabilizers in terms of both initial properties and reliability in the long-term tests for resistance to weather and water immersion. Furukawa has been marketing the non-lead stabilized PVC sheathed wire under the "Eco-Ace" name and claims that it is applicable to any of the electric power, telecommunications and vinyl cord applications using PVC insulation or sheathing (Mizuno et.al. 1999).

Akcros Chemicals (Denmark) has added ***Interlite® 6088/12*** to its range of CaZn-based stabilizer systems for PVC cables. The product was designed to provide improved color, color hold and good stabilizing and processing properties for PVC cables. The company says that the new product, while meeting these criteria, also meets the requirements of high-speed extrusion. The lubricant system has been adapted to allow high extrusion speeds of up to 1200 m/min for cable insulation of 1.5-2.5 mm. Akcros says that their product ***Interlite ZG 6067/3*** was developed particularly for formulations containing phosphorus-based plasticizers. The development work involved Akzo Nobel's Phosflex® range of plasticizers and the company argues that it has gained experience in combining CaZn-based systems with Phosflex, as well as flame retardants, such as zinc borate and aluminum trihydrate. In some cases, Akcros claims, the newly developed Interlite ZG 6067/3 is better than current lead system.

7.2 Low impact flame retardants for wire and cable

The International Tin Research Institute (ITRI) in the United Kingdom has been working primarily on lead-free soldering and other uses of lead in electronics. It has developed several formulations that use organotin type stabilizers and ***zinc hydroxystannate*** (ZHS) and ***zinc stannate*** (ZS). The latter two are used as low cost inorganic fillers. These "coated fillers" have been shown to exhibit significantly enhanced flame-retardant and smoke-suppressant properties, compared with simple mixtures of the individual components, when evaluated in halogen-containing polymer formulations, such as PVC. Thus ZHS and ZS are effective flame-retardant synergists in flexible PVC formulations and can be used as total or partial replacements for antimony trioxide. They have several advantages over Sb_2O_3 and other flame retardants additives, such as lower toxicity, safer and easier to handle, combined flame retardancy and smoke suppression, high performance at low additional levels, and synergy with inorganic fillers (ITRI 2000).

The use of inexpensive ***aluminum trihydrate*** (ATH) or $Al(OH)_3$ flame retardant additive is a quite common alternative for use with PE. Calcium carbonate can also be used as filler to provide a PE compound that is price-competitive with PVC compound. Some companies, like IKEA of Sweden, have developed their own specifications and converted appliance cords to non-halogenated PE alternatives.

Zinc borate is an effective and economical fire-retardant synergist of organic halogens in polymers. It has been demonstrated that the combination of zinc borate and ATH can be used as an effective flame retardant and smoke suppressant in halogen-free polymers such as EVA, polyethylene, EPDM, EEA, epoxy, and acrylics. Zinc borates have also found uses in PVC formulations. They have been shown to be effective flame/smoke suppressants when used as partial replacements for the antimony oxide that is normally used in a typical flexible PVC cable jacket, for example. For flexible vinyl and PVC plastisol formulations, a half to two-thirds of the antimony trioxide can be replaced by zinc borate without loss of flame retardancy. If a small decrease in flame retardancy can be tolerated, all of the antimony trioxide can be replaced with zinc borate, leading to smoke reductions of up to 65%. The flame retardancy can be increased and smoke formation decreased by adding ammonium octamolybdate to the borate-containing formulations.

Another alternative is ***magnesium hydroxide;*** the main advantage over ATH is the higher decomposition temperature 330-340 °C. Its main application is with polypropylene but it is also used in elastomeric cable compounds. Its main limitation is the tendency to agglomerate in polymers, affecting processability and performance.

Ultracarb[13] is a naturally occurring mixture of two mineral fillers and is similar to ATH. However, the filler can be processed at higher temperatures and is less expensive. Ultracarb is based on a proprietary mixture of huntite, $Mg_3Ca(CO_3)_4$ and hydromagnesite $Mg_3(CO_3)_3(OH)_2.3H_2O$. Ultracarb has been widely used in wire and cable applications in materials such as PVC, PE, EEA, PP, EPDM and EVA. The suppliers maintain that Ultracarb can help in the elimination of antimony from PVC compounds. For applications where high fire performance antimony-free compounds are required with low smoke and low acid fume characteristics, Microfine recommends a blend of Ultracarb, zinc borate and precipitated calcium carbonate.

Furukawa Electric has recently developed an indoor cable conduit that does not contain any halogenated flame-retardant, and is going to bring the product into the marketplace under the trade name of ***"Eco PLAFLEKY-PFS***". The conduit does not emit any dioxins and halogen gases when combusted and is recyclable (the flame-retardant is based on metal hydroxide). The company has filed a patent for the flame-retardant. The cable will be launched into the marketplace on May 20, 2001, and was expected to be available on the market by 2002 (Furukawa Electric 2001).

7.3 PVC-free wire and cable

One significant trend away from PVC is the increasing adoption of ***low- or zero-halogen PE*** resins in jacketing for new and replacement electrical and telecommunications cable installations in transit systems, shipboard systems, major commercial and institutional buildings and telephone switching stations. A second development is the switch from PVC-nylon insulation to ***moisture-cured XLPE*** in the NMD-90 residential building wire niche. In Europe PVC has been replaced in a few wire and cable applications. The market has accepted the use of non-halogen flame retardant PE and moisture-cured XLPE for insulation and jacketing in some flexible cords, appliance wires, building wire and many other end uses (Environment Canada 1998). Recent innovations in XLPE technology include irradiation or e -beam curing technology to manufacture halogen-free insulated wire.

[13] Manufactured by Microfine Minerals

Thermoplastic or cross-linked PE resin with no flame retardant will burn easily in a fire. It is possible to load PE or XLPE with flame retardant additives to various degrees which will give the compound certain flame retardant properties, some comparable to that of PVC. A common halogenated flame retardant system includes the use of decabromodiphenyloxide ("decabrome") combined with antimony oxide. Common inorganic flame-retardants include aluminum trihydrate and magnesium hydroxide. Flame retardant PE or XLPE can be compounded to meet or exceed PVC in limiting oxygen index tests, but may have limited performance when compared to PVC in actual fire conditions. High levels of flame retardant additives may adversely affect the processability and some of the physical properties of the compound, such as melt index, tensile strength, elongation and flexural modulus. According to the Electro Federation of Canada, "PE-based resins with equivalent flame resistant properties to PVC are available at higher costs and lower all around performance". A US-based compound supplier, however, argued that a compromise in some specifications may be required if PVC is to be replaced in some high performance applications (Environment Canada 1998). Overall, this is an area of active research. Currently, however, no non-halogen resin can meet the strict U.S. fire requirements for plenum applications (FEP and PVC are the two major resins used).

7.4 Alternative colorants

Alternatives to many of the "heavy metal" pigments are the "mixed-phase metal oxide" pigments (e.g., yellow ***nickel titanates*** and blue and green ***cobalt aluminates***). Relatively new is a brilliant yellow ***bismuth vanadate***. Orange version compounds have been developed as well. ***Cerium sulfide*** now is under commercialization for a range of reds. Organic pigments are also available in a wide range or colors. They, however, are more difficult to disperse than inorganic, which leads to possible loss in mechanical strength.

8. Research and Technology Diffusion Recommendations

As manufacturers seek out non-halogen wire and cable, the diversity of industry products and applications makes it difficult to find one simple solution. A substitution for lead or halogenated flame-retardants for example, would have to be carried out on a case-by-case basis involving extensive testing. The efforts by the European Union to ban lead in electronics and similar efforts to restrict halogenated flame-retardants and PVC have led many Massachusetts firms to modify their products accordingly. The threat of Chinese firms, which compete on cost for existing technology, provides another incentive for Massachusetts manufacturers of resins, additives and coated wire and cable to innovate. Such innovations are more difficult for low cost producers (such as those found in China) to appropriate and make it possible for Massachusetts firms not only to retain their European markets, but also to develop a position in the newer "green wire" niche markets in the US.

Firms interviewed for this report are carrying on active research in a host of areas, including lead substitutes for PVC wire, low impact flame-retardants and non-PVC based resins.

- In the lead substitute areas, mixed-metal stabilizers, organotin and organic compounds are viable alternatives for many applications.

- Among low impact flame-retardants, zinc borate, zinc stannate and zinc hydroxystannate, aluminum trihydrate, and magnesium hydroxide are some of the alternatives under testing.
- Non-PVC resins include cross-linked polyethylene, fluoropolymers (e.g., Teflon), and polypropylene.

Cost appears to be the main barrier in many of these research efforts – including both the cost of the alternative resins/additives and the switching expenses. However, it is expected that as demand for such products continues to grow, the cost will go down. In fact, in the early 90s the cost of Ca/Zn stabilizers was $4/lb; today it is about $1/lb. Other barriers include performance and processability. Performance is of concern in plenum cable and even more in wet applications, where the UL 83 test is applied. Processability is more of an issue when mixed metals are used as a substitute to lead ('cocktail of materials' vs. single material). Table 12 presents some of the available "green wire" alternatives by product type. Due to proprietary concerns, some companies have not provided detailed information regarding specific formulations.

Table 12. Available alternatives by product type

Type of cable	Lead-free	Low impact flame retardants	PVC-free
Building wire	*TeknorApex (*plenum) *AlphaGary* (plenum)	*Furukawa* (indoors) based on metal hydroxide to be used with PE.	Moisture-cured XLPE; PE for jacketing; FEP (plenum);
Telephone and telegraph	*Avaya;* *Furukawa Electric* (Al/Mg/Ca/Zn-PVC stabil.) *AlphaGary*		PE switch board
Cords, cordsets and appliance wire	Polyolefins (cars) *Furukawa Electric* (Al/Mg/Ca/Zn- PVC stabil.) *ITRI* (PVC with organotin stabilizer) *AlphaGary*	*ITRI* (PVC cable with zinc hydroxystannate and zinc stannate coated on the surface of inorganic filler – ultracarb, ATH)	Moisture-cured XLPE Polyolefins (cars) Polyurethane (jacketing)
Power cable	*AlphaGary* *Furukawa* (Al/Mg/Ca/Zn-based stabilizer for PVC)		PE; XLPE; EPDM; PVC/nylon
Coaxial & antennae cable	*AlphaGary*		PE
Electronic and data wire	*AlphaGary*		PE; BLPE; LDPE & MDPE
Magnet wire			
Not specified application	*Witco* (organic based stabilizer for PVC) *TeknorApex*; *Akcros Chemicals* (CaZn stabilizer system for PVC cables)	*ITRI* (PVC cable with zinc hydrosystannate and zinc stannate coated on the surface of inorganic filler – Ultracarb, ATH)	

8.1 Recommendations

On June 22, 2001, the Toxics Use Reduction Institute conducted a focus group meeting entitled "Environmental Challenges in the Coated Wire and Cable Industry" (see meeting summary in Appendix C). The meeting was attended by approximately 30 persons representing firms throughout the coated wire and cable supply chain (additive suppliers, compounders, extruders, and customers). During the discussion, participants recommended to TURI a number of activities that the Institute might sponsor and support. These recommendations are excerpted in the bulleted list below.

- *Regulatory/Environmental Information:* Provide information on the various standards, requirements and regulations that could affect Massachusetts coated wire and cable manufacturers. Attendees stated that they do not have easy access to such information and would like to know if their products are acceptable in Europe, Japan, California, etc. Such information would include up-to-date information on Proposition 65 requirements and court cases related to coated wire and cable.
- *Materials Environmental, Health and Safety Information:* Participants requested information on the 'safety factors' for the different chemicals used in their products. They were also interested in tools for understanding how to analyze potential materials in order to select materials with lowest risk. Some requested assistance in understanding and prioritizing the relative hazards of alternatives.
- *Total Cost Assessment:* Some participants requested assistance in estimating the total cost of using lead, PVC, brominated flame-retardants. According to the participants, disposal costs and OSHA costs are not always taken into account when considering alternatives.
- *Similar Meetings:* Participants were very interested in TURI bringing firms from the supply-chain group together about six months following the first meeting to discuss issues and share information.

In addition to the recommendations from the focus group meeting, there are several other strategies that TURI could pursue to aid Massachusetts firms in meeting EU and Japanese electronics requirements:

- *Testing/Materials Evaluation*: The coated wire and cable industry is keenly interested in new materials development. TURI could explore the possibility of working with research institutions, such as the Institute of Plastics Innovations at UMASS Lowell, to set up test procedures, prototype lines and other tools that would allow Massachusetts firms to develop and test different alternatives.
- *Information Development*: Many in the coated wire and cable extrusion industry have only recently become aware of the various pressures to modify some of the basic materials used in their products. These manufacturers are in need of basic information concerning regulatory standards, leading material options, and case studies of firms that have successfully developed substitute products.
- *Demonstration Project*: TURI could target one of its demonstration grants to a wire and cable extruder that has successfully modified its products to the evolving demands of the European market. Such a demonstration site would provide other wire and cable

manufactures with an opportunity to learn first hand about the firm's technology changes, processing issues, cost factors, etc.

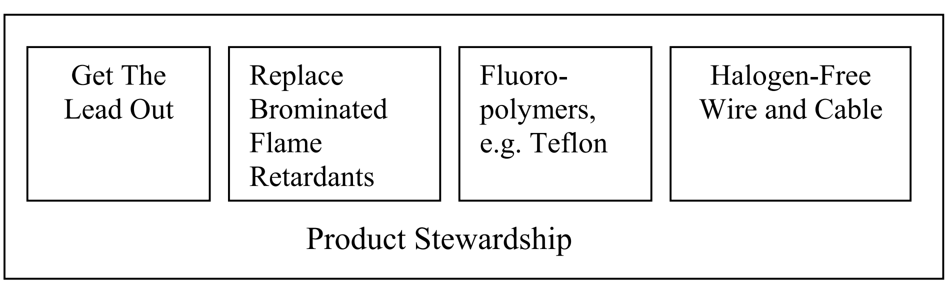
- *Electronics Manufacturer Workshop*: Many Massachusetts firms that include coated wire and cable components in their products are likely unaware of the environmental issues of these components. The workshop would target such manufacturing firms and highlight the issues in an effort to keep Massachusetts manufacturers competitive and in touch with the sector's evolving requirements.
- *Telecom Sector Research*: Based on brief discussions with a few telecommunications sector experts, it appears that many of the newer telecommunication and Internet hardware firms have not developed environmental management capabilities to deal with issues such as lead-free electronic equipment or the evolving European efforts to limit or ban certain materials. This research project would provide a baseline of the environmental management activities (or lack thereof) of telecommunications and Internet hardware companies in the Commonwealth and recommend a strategy for building such capacity.

8.2 Technology Innovation Approaches

Based on the literature review, focus group meeting, and discussions with sector experts, the efforts of the coated wire and cable industry to "green" their products can be organized into four approaches. These approaches are presented in Figure 4 and outlined in a greater detail below.

Each of the four approaches includes elements of product stewardship (therefore the figure shows product stewardship encompassing all approaches). Product Stewardship is a principle that directs all participants in the life cycle of a product to take responsibility for the impacts to human health and the natural environmental that result from the production, use and disposal of the product. The primary actors in the life cycle of a product typically include manufacturers, retailers, consumers and government (Product Stewardship Institute). Manufacturing coated wire and cable uses many valuable materials. Any attempt to modify the current technology should include a focus on long-term product stewardship, including recovery and reuse of metals, plastics and other materials.

Figure 4. Approaches for "Greening " Coated Wire and Cable



Without question, there is no simple method for "greening" coated wire and cable. All substitutions require a detailed analysis of replacement materials and are bound by the performance requirements of the specific application. Furthermore, strategies that eliminate one material (e.g. PVC) may introduce new materials (e.g. brominated retardants) with different life-cycle impacts – including bioaccumulation, toxicity, recyclability, etc. Additional research is necessary to help manufacturers use the most benign material for the specific application.

Approach 1: **Get The Lead Out**

Advantages

- Keep market share in Europe and Japan
- Proactive with concerned customers
- Potential cost savings from end-of-life assets recovery
- Avoid future liabilities
- Works in most applications; exception - wet applications.
- In most cases cost is low to moderate (see Table 13);

Disadvantages

- Complexity of processing
- Cannot meet wet applications requirements (UL 83).
- Introduce other materials which may have impacts that have not been sufficiently studied (e.g., barium, tin)
- Cost increase - switching cost (e.g., capital expenditures, operators' training, materials costs)
- Issues associated with PVC unresolved.

Table 13. Cable applications: Lead to Non-lead

Style	Description	Transition	Cost Effect
SPT - 1, 2, 3	Appliances	Fairly easy	Low
TW, THW	Building wire, outdoor flexible cords	Very difficult	Moderate
THHN, THWN	Industrial / residential building wire	Very difficult	Moderate
ST, SJT	300 / 600 volt flexible cords	Fairly easy	Low
STW, SJTW	300 / 600 volt flexible cords (outdoor)	Very difficult	Low
CM, CMR	Communications: tray / riser	More difficult	Low
CMP	Communications: plenum	More difficult	Moderate
UL 758	Fixed applicance wire	Difficult	Moderate
Vinyl TPE	Booster, audio	Difficult	Moderate
SEO, SJEO	Service entrance	Fairly easy	Moderate

Source: AlphaGary. For Style definitions one can use the National Electric Code (www.nfpa.org/nec) or review Underwriters Laboratories, Inc. wire and cable marking guides (www.ul.com/regulators/guides.html).

Approach 2: **Replace Brominated Flame Retardants**

Advantages

- Keep market share in Europe
- Avoid future liabilities
- Avoid life cycle impacts associated with brominated flame retardants – including during recovery
- Applications where it can work include indoor building wire, cords and appliance wire

Disadvantages

- Issues associated with PVC not resolved
- Introduce other materials which may have impacts that have not been sufficiently studied
- May not work for plenum cables
- Cost

Approach 3: **Fluoropolymers (e.g., Teflon)**

Advantages

- Keep market share in Europe
- Proactive with concerned customers
- Eliminates some potential life cycle hazards (e.g., brominated flame retardants, lead, phthalates, dioxins)
- Avoid future liabilities
- Application where it can work: leading market is plenum wire and cable; can be used in many other applications.

Disadvantages

- Higher cost of Teflon
- May not work for wet applications
- If it starts burning will generate highly toxic HF

Approach 4: **Halogen-free coated wire and cable**

Advantages

- Keep market share in Europe and Japan
- Proactive with concerned customers (e.g. OEMs such as Lucent)
- Eliminates life cycle hazards related to PVC additives (e.g., lead, phthalates, dioxin)
- Potential cost savings from end-of-life assets recovery
- Avoid future liabilities
- Applications where it can work: building wire, telephone and telegraph, electronic and data wire, cords and appliances, automobile wire.

Disadvantages

- Probably not going to work for everything in terms of technology and cost.
- Higher cost of materials (e.g., PE) and switching costs
- May not be recyclable (e.g., XLPE)
- May need larger amounts of halogen-free flame retardants

- Introduces other materials (such as other flame retardants or other resins) for which we have insufficient information regarding lifecycle impacts.

Addressing the various environmental, health and safety issues of coated wire and cable is not a simple and straightforward process. The complexity of the products and the stringent performance standards make it difficult to find a single ‘greener’ alternative. The cost of such alternatives is the main barrier, followed by performance and processability in some applications. However, as new standards and regulations address the life cycle impacts of lead, brominated flame-retardants, and PVC, and the demand for alternatives continues to grow, the cost of these alternatives is expected to decrease significantly. The process of developing and using alternatives has already begun, spurred by European legislative changes and customer demands. Several Massachusetts companies have reported success in developing alternatives to lead and halogens (e.g., AlphaGary, TeknorApex, Witco, Quabbin Wire). In this process TURI can continue to be actively involved in dialogue, research and educational initiatives that further help reduce toxics and promote the global competitiveness of Massachusetts coated wire and cable industry.

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10. Appendices

Appendix A: Alternative resins

Chlorosulfonated polyethylene (CSPE) is better known as Hypalon (a DuPont trademark). Used as a 105°C rated motor lead wire insulation, but is primarily a jacketing compound. It has excellent tear and impact strength, excellent abrasion, ozone, oil, and chemical resistance and good weathering properties. The material also has low moisture absorption, excellent resistance to flame and heat, and good dielectric properties.

Polypropylene is similar in electrical properties to polyethylene. It is primarily used for insulation. Polypropylene provides excellent heat and abrasion resistance. Stiffer than polyethylene, it is valued for use in manufacturing miniature components and thin wall insulation. UL maximum temperature ratings may be 60°C or 105°C.

ETFE Tefzel (DuPont trade name) is a 150°C material, has very good electrical properties, chemical inertness, high flex life and exceptional impact strength. It can withstand an unusual amount of physical abuse and is self-extinguishing.

Halar (Ausimont Corporation trademark) has a specific gravity of 1.68, the lowest of any fluorocarbon. Its dielectric constant and dissipation factor at 1 MHz are 2.6 and 0.013 respectively. Halar chars, but does not melt or burn when exposed to direct flame, and immediately extinguishes on flame removal. Its other electrical, mechanical, thermal and chemical properties are almost identical with Tefzel's. The temperature rating is -70°C to 150°C.

Teflon (DuPont trademark) has excellent electrical properties, temperature range and chemical resistance. It is not suitable where subjected to nuclear radiation and does not have good high voltage characteristics. FEP Teflon is extrudable in a manner similar to PVC and polyethylene. This means that long wire and cable lengths are available. It has a service temperature of 200 °C. TFE Teflon is extrudable in a hydraulic ram type process. Lengths are limited due to amount of material in the ram, thickness of the insulation, and preform size. TFE must be extruded over a silver or nickel-coated wire. The cost of Teflon is approximately 8 to 10 times more per pound than PVC compounds.

PFA is the latest addition to DuPont's Teflon resins. Like the others it has outstanding electrical properties, high operating temperature (250 °C), resistance to virtually all chemicals and flame resistance. The cost of Teflon is approximately 8 to 10 times more per pound than PVC compounds.

TPR (Thermoplastic rubber) has properties similar to those of vulcanized (thermosetting) rubbers. The advantage is that processed like thermoplastics, it is extruded over the conductor. Like many conventional rubber materials, TPR is highly resistant to oils, chemicals, ozone and other environmental factors. It has low water absorption and excellent electrical properties, and is very flexible with good abrasion resistance.

Silicone is a very soft insulation which has a typical temperature range from –80 °C to 250 °C. It has excellent electrical properties plus ozone resistance, low moisture absorption, weather resistance and radiation resistance. It typically has low mechanical strength and poor scuff resistance. While silicone rubber burns slowly, it forms a non-conductive ash, which, in some cases, can maintain the integrity of the electrical circuit.

EPR (Ethylene Propylene Rubber) is a chemically cross-linked, thermosetting high temperature rubber insulation. It has excellent electrical properties combined with outstanding thermal stability and flexibility. Its resistance to compression, cutting, impact, tearing and abrasion is good. EPR is not attacked by acids, alkalis and many organic solvents. It is also highly moisture resistant. It has temperature ratings up to 150°C.

SBR (Styrene Butadiene Rubber) is flexible and offers good heat and moisture resistance at an economical cost. It must be jacketed for mechanical and chemical protection. Suitable for 75°C maximum temperature ratings.

EPDM (ethylene-propylene diene elastomer) is chemically cross-linked elastomer with excellent flexibility at high and low temperatures (150 C to –55 C), good insulation resistance and dielectric strength as well as excellent abrasion resistance and mechanical properties.

Polyurethane is used primarily as cable jacket material. It has excellent oxidation, oil, and ozone resistance. Some formations also have good flame resistance. It has outstanding “memory” properties, making it an ideal jacket material for retractive cords. Since it is very expensive it is used only when other jacket materials do not meet the required specifications.

FEP (Fluorinated ethylene propylene) has properties similar to extruded polytetrafluoroethylene, but will melt at soldering temperatures. It is rated at 200°C and is, therefore, considered a high-temperature insulation. Although FEP is inherently flame resistant, when FEP burns, it is known to produce highly toxic HF gas.

Appendix B: UL Flame Tests

a) *Horizontal Flame Test (UL 44,83)*
A moderate flame test conducted on a horizontal sample in a special enclosure. A Tirrill gas burner with a 1500 °F is applied to the sample for 30 seconds. The flame must not progress beyond a point 2” left or right of the point of application of the flame or ignite cotton on the floor of the test chamber by means of burning particles dripping from the cable.

b) *All Wires Flame Test (UL 83)*
A vertical flame test in an enclosure using a Tirrill gas burner with a 1500 °F flame. A paper flag is positioned on the sample, 10 inches above the point at which the flame touches the specimen. The flame is applied for 15 seconds, removed for 15 seconds, and then re-applied for 15 seconds. The total number of flame applications is five. The sample shall be considered unsatisfactory if more than 25% of the paper bag is burned away or flaming or glowing particles ignite the cotton base of the enclosure or, if after the last application of flame, the sample continues to burn for longer than 60 seconds.

c) *VW1 (Vertical-Wire Flame Test (UL 83)*
Very similar to All Wire Flame Test except that after the flame application, the flame is not reapplied after 15 seconds if the sample is still burning, but only when flame is extinguished. If the sample burns longer than 60 seconds after any application, this constitutes a failure.

d) *UL 1581 – Also referred as Vertical Tray Test (also known as IEEE 383)*
A stringent test usually applied to jacketed cables lashed to a vertical metal ladder type tray 8 feet high. The combustion source is a ribbon burner, flame temperature 1500 °F with a heat source of 70,000 BTUs per hour. The burn time is 20 min and the cable is required to not propagate the flame to the top of the tray, a distance of travel of the flame of 6 feet from the point of application.

e) *Vertical Tray Flame Test (UL 83, UL 1277)*
Based upon the IEEE test with minor modifications such as flame temperature 1600-1750 °F.

f) *UL 1666 – Also referred to as a Riser Test*. A flame source is applied to a vertically installed cable in a shat for 30 min at the rate of 527,500 BTUs per hour. To pass the test the cable cannot propagate flames higher than 12 feet, which in real fire condition would prevent the spread of a fire from one floor to the next.

g) *UL 910 – referred also as Steiner Tunnel Test*, and the most stringent fire test a cable construction must pass to meet the National Electrical Code. A flame source is applied to a horizontally installed cable in a plenum environment for 20 min at a rate of 300,000 BTUs per hour. To pass the test, the flames must spread less than five feet and produce very little smoke.

Appendix C: Focus Group Summary

Meeting Summary

Wire and Cable Focus Group

"Environmental Challenges in the Coated Wire and Cable Industry"
held at Quinsigamond Community College, Worcester, MA
June 22, 2001
Sponsored by MA Toxics Use Reduction Institute (TURI) at UMass Lowell

On June 22, 2001, a group of approximately 30 representatives from the wire and cable supply chain gathered to hear about and discuss research and technology options that will assist their industry in meeting increasingly stringent international environmental, health and safety standards. The latter include the proposed EU Directive on the Waste Electronic and Electrical Equipment (WEEE Directive), the increasing focus in the US on lead and PBT's (Persistent, Bioaccumulative Toxics), California "Prop 65," and European efforts to phase-out PVC and some halogenated flame-retardants.

TURI's objective is to assist the sizable Massachusetts coated wire and cable industry in reducing toxics use while keeping the industry globally competitive. The focus group was convened to provide recommendations to the Institute for fostering research, development and diffusion of alternatives to some of the toxic substances and other materials of concern currently used. Alternatives must be environmentally and economically sound throughout the life-cycle of the wire and cable products.

Because any product material changes impact the entire supply chain, the focus group included wire and cable fabricators (13), resin compounders (6), additive suppliers (5) and OEM's (end users) (3). The agenda began with presentations about emerging international requirements, materials and their environmental health and safety concerns, and technology issues and options for wire and cable products, additives and resins. The meeting ended with a facilitated discussion around issues of concern to participants, including their information and research needs.

The following is a brief summary of the meeting's presentations and discussion.

Overview and Welcome

Liz Harriman (TURI) opened the focus group meeting by welcoming the attendees from the Massachusetts coated wire and cable industry. The focus group objectives were reviewed:

- Provide background information on the issues and industry
- Give an update on the emerging global scene
- Hear supply chain issues and perspectives
- Review technology options and needs
- Provide input on TURA Program research and technology diffusion plan (e.g., information products, demonstration grants, research, supply chain discussions, etc.)

EH&S Issues and Drivers

Vesela Veleva (Greiner Environmental) set the stage by briefly presenting the main environmental, health and safety challenges and requirements that the industry is facing currently. These included the proposed EU WEEE Directives (Waste Electrical and Electronic Equipment and the Restriction on the Use of Hazardous Substances), California Proposition 65, Specified Home Appliances Recycling Law in Japan, and concerns over PVC, heavy metals, phthalate plasticizers, and halogenated flame retardants. (See attached presentation)

Industry Supply Chain Perspectives: Additive Supplier

Peter Gallagher (Baerlocher USA) presented information about the current use of lead (30,000,000 lb) and non-lead (1,900,000 lb) stabilizers. The reason industry uses lead as a heat stabilizer is that it is cost effective, efficient, imparts excellent weather characteristics and electrical properties. However, there are growing concerns about its chronic and acute toxicity that are pushing ahead the research on alternative stabilizers. There are different forms of lead that have been used, which exhibit different toxicity. Mixed metal stabilizers have been developed as alternative (e.g., Ca-Zn). Europe is currently leading in this direction, using 69% of these stabilizers; North America is second using 23%. Some of the key challenges facing the use of such alternatives involve:

- Cost (the greatest challenge; alternatives are about twice as expensive);
- Reduced performance in heat stability
- Significant changes in formulation required to achieve similar wet electrical properties

In the case of mixed metals we have a ‘cocktail’ of materials versus a single material, therefore the complexity of processing increases. Although the cost difference is still large it is quickly going down. For example, in the early 90s alternative heat stabilizers used to cost $4/lb. Today their cost is $1/lb. When we talk about cost, we include both the cost of raw materials and the cost of processing. Wet applications (UL 83) remain one of the biggest concerns. The test takes 6 months and therefore coming up with an alternative is likely to take more time. Manufacturers are likely to implement alternatives in the less demanding jacketing applications first, followed by insulation applications.

Industry Supply Chain Perspectives: Compounder

Dave Kiddoo (AlphaGary) first briefly informed the audience about the NFPA conference held the previous couple of days. The process of harmonization of fire safety tests is still ongoing. There are provisions for the European Union to adopt the U.S. hierarchy of fire safety. He highlighted the technology gap between current transmission performance vs. meeting fire safety requirements vs. environmental requirements. Special emphasis was given to cable recyclability and recovering the materials. In the upcoming National Electrical Code there will be provisions for removing abandoned cable – currently estimated at more than 45 billion feet. Looking to the future, it makes sense to have products with value at their end-of-life. In his presentation Dave Kiddoo discussed the use of alternatives to lead for different applications and the level of difficulty and costs associated with such a transition. He stressed the need for a balanced approach to meeting the performance, safety and environmental requirements. (See attached presentation)

Industry Supply Chain Perspectives: OEM (End-User)
Tony George (Lucent Technologies) presented the position of the OEMs for whom the cost, quality and availability are the three most important criteria for selecting a cable. The EU is pushing toward using non-halogen telecommunication cables. Lucent is committed to designing products that are globally acceptable and therefore is currently in the process of finding non-halogen alternatives to PVC cables and those containing brominated flame retardants. Plenum applications in the United States are the most difficult. Currently only FEP and PVC cables can meet the fire safety requirements. Neither is halogen-free. Presently Lucent has 40-50% of its products halogen-free and its goal is to become 100% halogen-free. In some cases the transition is easy, in others – more difficult and involves higher cost. (See attached presentation)

Facilitated Discussion
Following the presentations, the meeting continued with an open discussion, facilitated by Tim Greiner (Greiner Environmental), where the participants raised the following concerns/issues:

- Chinese imports of low cost coated wire and cable products with high lead content – risk both for Massachusetts companies trying to keep their market share, and for the state trying to reduce toxic waste. Wire and cable fabricators are worried that as they switch to higher cost non-lead coating formulations, importers might label their products as such, but use lower cost lead stabilizers. There was a proposal to introduce some type of legislation that requires testing of products before they are imported in the United States. European Union has already such legislation in place.
- A supplier shared their experience with one customer that made the transition to lead-free products. Originally pressured by OSHA, the company started a program to replace all lead. They first identified several alternative stabilizer packages and gradually shifted production to use these instead of lead. Currently the company is 95% lead-free. Large costs involved. They had no problems with wet applications. The major challenge was processability. Equipment operating parameters must be modified.
- There are three main challenges to introducing halogen-free products: cost, processability and physical properties (performance).
- An equipment manufacturer (who purchases coated wire and cable) raised the issue of disposal costs, which are currently not considered when comparing alternatives. With the introduction of take-back policies, equipment manufacturers need to take these costs in account. They want to evaluate the total life-cycle cost of the product.
- Several participants raised questions about California's Proposition 65 – what it means for the coated wire and cable industry and how TURI and OTA can help them stay informed about recent changes and requirements.
- One of the questions raised addressed the different forms of lead – is there a difference between lead sulfate, lead stearate, etc. It is important for the industry to know which one is less toxic.
- The Office of Technical Assistance for Toxics Use Reduction (OTA) couldn't be at the meeting, but wanted participants to know that they are working on getting a project with UMASS Amherst polymer science faculty started that would focus on substitutes for lead in wire and cable coating. For more information on that project, contact Ken Soltys at OTA (617)-626-1082.
- A wire company shared their experience with some European customers, who require the completion of extensive questionnaires that address product recyclability.

- All participants agreed that one way TURI can be of particular help is in prioritizing the different alternatives in regard to their toxicity.
- The discussion revealed that all R&D efforts to develop alternatives are currently proprietary. Often companies along the supply chain collaborate on such projects to share both the costs and the benefits.

The focus group discussion led to the following **recommendations/suggestions** on how TURI can help the Massachusetts coated wire and cable industry to both reduce the use of toxics and stay competitive:

- Provide web-based information on the various standards and regulations worldwide. Currently, companies do not have access to such information and would like to know if their products are acceptable in Europe, Japan, etc.
- Provide up-to-date information on Proposition 65 requirements and court cases related to coated wire and cable. The industry would like information on the 'safety factors' for the different chemicals used in their products.
- Assist the industry in understanding and prioritizing the relative hazards of alternatives and also the different lead compounds. Currently manufacturers just intuitively choose one alternative over another.
- Help the coated wire and cable industry estimate the total cost of using lead, PVC, and brominated flame retardants. Currently disposal costs and OSHA costs are not taken into account when considering alternatives.
- Get the supply-chain group together again to discuss issues and share information.