CHAPTER 1. SCOPE AND BOUNDARIES

1.1 Purpose and Goals

1.1.1 Background

The Wire and Cable Project (WCP) is a voluntary, cooperative partnership among the following: the Design for the Environment (DfE) Program in the U.S. Environmental Protection Agency's (EPA's) Office of Pollution Prevention and Toxics (OPPT), the Toxics Use Reduction Institute (TURI) at the University of Massachusetts Lowell, individual wire and cable manufacturers, supply chain members (e.g., additive suppliers), and trade association members. OPPT established the DfE Program in 1992 to encourage businesses to incorporate environmental concerns into their business decisions. The EPA DfE Program promotes risk reduction, pollution prevention, energy efficiency, and other resource conserving measures through process choices at a facility level. DfE industry projects are cooperative, joint efforts that assist businesses in specific industries to identify and evaluate more environmentally sound products, processes, and technologies. The direction and focus of this project are determined by the project partners, while taking into consideration OPPT's goals.

The WCP partnership first developed partial life-cycle inventories (cradle-to-gate) of standard and alternative insulation and jacketing formulations for three selected cable products (Phase I):

1. Category 6, riser-rated communication wire (CMR)
2. Category 6, plenum-rated communication wire (CMP)
3. Non-metallic sheathed low-voltage power cable (NM-B)

These cable products have defined functionality and specifications, as described in Section 1.2.1.

The partnership then set out to objectively assess the complete environmental life-cycle impacts, including end-of-life (EOL) of the standard and alternative formulations for one or more of those three cable product types (Phase II).

The three product types were chosen because they 1) contain materials common to many cable applications; 2) contain materials of potential environmental concern, or materials for which stakeholders have expressed a desire to identify and evaluate alternatives; and 3) are believed to represent a significant amount of the wire and cable market. The project set out to evaluate alternative compositions that might meet, for example, lead-free, heavy metal-free, and/or zero-halogen specifications.[2,3] The goal is to determine whether the alternative products present environmentally preferable options.

The DfE WCP uses life-cycle assessment (LCA) as an environmental evaluation tool, which can be used to evaluate the environmental effects of a product, process, or activity. LCA is a comprehensive method for evaluating the full life cycle of the product system, from materials acquisition to manufacturing, use, and final disposition. As outlined in the ISO 14040 series, an LCA study has four major components: goal definition and scoping, life-cycle inventory (LCI), impact assessment, and

---

[2] These terms are used generically to describe categories of alternative cable constructions. For example, they are not linked with specific definitions that may delineate trace quantities of the materials intended to be absent.
[3] The initial goal was also to include decabromodiphenyl ether (decaBDE) and decaBDE-free cables; however, the cable types selected did not use decaBDE in the standard formulation, and therefore this was not included in the scope.

interpretation of results. The remainder of Chapter 1 represents the goal definition and scope, which includes the purpose of the WCP, background information on the need for the project, descriptions of the product systems being evaluated, and the boundaries the study used. Chapter 1 incorporates scoping as it is recommended in the LCA process (e.g., ISO, 2006a; ISO, 2006b; Curran, 1996; Fava *et al*., 1991).

1.1.2 Purpose

The DfE/TURI Wire and Cable Partnership set out to select and analyze three types of cable products for which alternatives to lead and other substances of concern could be considered. The goal was to evaluate the standard and alternative cable insulation and jacketing formulations for three product types from a life-cycle perspective in order to understand their environmental impacts. Specifically, this project aimed to compare the life-cycle impacts of the alternative resins, heat stabilizers, flame retardants, and plasticizers used in the baseline and alternative cables. It was understood that the results may show any of the substances or their alternatives to be preferable from certain perspectives. The results primarily will be useful in identifying the materials that have significant environmental impacts when compared to those with the alternative constructions, so that industry can make informed, balanced formulation decisions based on fire safety, electrical performance, and environmental impact.

The purpose of Phase I of this study was to collect materials extraction and manufacturing data for the standard and alternative compositions for all three of the cable types. During this phase, the life-cycle inventory data associated with the extraction/processing and the manufacturing of these materials was compiled. Under Phase II, the life-cycle inventory was developed, as appropriate, for the use and EOL stages of a selected cable type or types, and a life-cycle impact assessment was conducted for all life-cycle stages. The purpose of Phase II was to evaluate the life-cycle environmental impacts of the selected traditional and alternative cable formulations using LCA methodologies.

1.1.3 Previous research

The major resins used in CMR, CMP, and NM-B cables include polyvinyl chloride (PVC), polyethylene (PE), and perfluoropolymers (PFPs). Substantial research has been conducted on PVC and its life-cycle impacts; however, very little of the work has focused specifically on the use of PVC in wire and cable applications. The European Union recently completed a study that presents an overview of the publicly available information on PVC LCAs. Although the study found that detailed information does exist concerning the PVC life cycle from raw material extraction to PVC production, it concluded that a potentially relevant gap exists for the wire and cable compounding, use, and end-of-life phases. Williams *et al*., (2000) used the Chain Management of Materials and Products (CHAMP) methodology, which is based on life-cycle assessment, to compare the environmental impacts and options for recovery and recycling of Category 5 cables sheathed with PVC (assumed to be 100 percent pure) versus a low smoke zero halogen (LSZH) composition (50-67 percent aluminum trihydrate, 30-35 percent ethylene vinyl acetate copolymer, or EVA, 1 percent antioxidant). The study concluded that the copper conductor is the main contributor to the environmental impact of the systems studied. When the polymer sheaths alone are compared, PVC has slightly higher first-use environmental impacts, but it is slightly cheaper and has greater potential for recycling than the LSZH composition. This study, however, evaluated only cable formulations that meet European Category 5 standards, and did not account for additives in the PVC. It also did not evaluate the cable formulations that are required to meet the stricter U.S. standards for flame retardancy in plenum and riser applications. In addition, although information is available for the production of PE, no studies detailing its life cycle in wire and cable have been performed, and little to no life-cycle information is publicly available for PFPs, or fluorinated ethylene propylene (FEP), which is currently the most common PFP used in CMP cables. Monofluoroacetic acid (MFA), another PFP, can also be used as cable insulation. However, a current lack of adequate information regarding the production and use of MFA in the cable types examined prevents the WCP project from including it in this life-cycle assessment. EPA encourages further study of MFA so that it can be included in future assessments.

In a current study being done by DuPont (Krieger *et al*., 2007), plenum cable installations with either CMP cable or CMR cable in a steel conduit were compared. Based on their scope and assumptions, they found the required steel had the highest energy use and greenhouse gas emissions while the copper wire had the highest human toxicity impacts. The copper wire was shown to be a large contributor to most environmental impacts evaluated in their study. The study concludes that when comparing plenum space CMP and CMR/steel conduit alternatives, cabling material choices should be evaluated on whether they can reduce the use of copper or steel, thereby improving environmental performance of the cable installation. The Krieger study focused only on lead-free options for both CMP and CMR cables and did not focus on the comparisons of alternative constructions of similar cable installations (e.g., lead versus lead-free CMR in riser installations).

Aside from LCA studies, there is substantial information on PVC, which is inherently flame retardant, durable, tough, and relatively heat resistant, thus making it a suitable material for wire and cable insulation and jacketing (Vinyl Inst., 2003). However, vinyl chloride, the monomer that is polymerized to form PVC, is classified by the EPA and the International Agency for Research on Cancer (IARC) as a known human carcinogen. Acute exposure can occur in workers who make or use vinyl chloride and is linked to vascular disturbances and central nervous system effects, including dizziness, drowsiness, and headaches (SRC, 2006). Advances in the PVC industry have been reported to reduce worker exposure to the monomer, but PVC's life-cycle impacts in wire and cable applications still warrant further evaluation, because dioxin and hydrogen chloride can form when PVC is heated above 250º C (e.g., incineration or accidental fires). Hydrogen chloride is a corrosive, toxic gas that can cause skin burns and severe respiratory damage. Dioxin has received significant attention because of its carcinogenicity.

Lead-based heat stabilizers are added to PVC for wire and cable applications because they provide long-term thermal stability and electrical resistance with low water absorption. Without heat stabilizers, PVC resins begin to degrade by dehydrochlorination at temperatures of 160ºC, which is below the PVC processing temperature (Mizuno *et al*., 1999). Although lead additives to PVC are cost- and performance-competitive, they have potential adverse health and environmental effects due to the known toxicity of lead. In looking at the life cycle of the lead compounds, releases of lead into the ambient or workplace environment may occur from the mining or processing of lead, or from recycling or disposing of products containing lead. Lead is a heavy metal that has been linked to developmental abnormalities in fetuses and children that ingest or absorb lead, primarily from paints or emissions from leaded gasoline. Small amounts of lead cause hypertension in adults and permanent mental dysfunction, and the Department of Health and Human Services has determined that lead acetate and lead phosphate may reasonably be anticipated to be carcinogens, based on animal studies. Further, lead is a toxic chemical that persists and bioaccumulates in the environment (DHHS, 1999). The toxic nature of lead has resulted in efforts around the globe to reduce its use.

Plasticizers are also added to PVC in order to make it flexible enough for use as cable jacketing. Phthalate compounds are the most commonly used plasticizers for PVC. These compounds have come under scrutiny because their chemical composition mimics natural hormones in humans and other animals. They have been shown to cause fetal death, malformations, and reproductive toxicity in laboratory animals (Shea, 2003; Wilson, 2004).

High density PE (HDPE) is used in CMR cable and does not require additives. It is unclear whether HDPE presents health and safety concerns during its production and use, though it is approved for use in food containers such as milk cartons and water bottles. When burned, HDPE releases the toxic gas carbon monoxide. In addition, the inherent fuel value of HDPE may encourage fire spread.

Fluoropolymers (polymers with atoms of fluorine) are used to insulate individual conductors (such as copper wire). The three primary fluoropolymers used for wire and cable insulation are FEP, polytetrafluoroethylene (PTFE), and polyvinylidene fluoride (PVDF). FEP is a common resin used to insulate wires in CMP cables because of its exceptional dielectric properties, flame and heat resistance, chemical inertness, durability, and flexibility. The polymer is also easily recycled at end of life. However, although FEP does not burn easily, it can emit toxic gases such as hydrogen fluoride (Wilson, 2004).

Perfluorooctanoic acid (PFOA), which is sometimes used as a polymerization aid in the production of FEP, also poses concerns. PFOA is a fully fluorinated organic compound produced synthetically or through the degradation or metabolism of other fluorochemical products. While PFOA may be used to manufacture FEP, it has not been detected in finished FEP products such as CMP cable (U.S. EPA, 2005a). Occupational exposure to PFOA as well as environmental release and fate, however, remain concerns. PFOA is present in low levels in the blood of the general U.S. population and in the environment, is highly persistent in the human body and in the environment, and has been found to cause developmental and other adverse effects in laboratory animals (U.S. EPA, 2005b). EPA released a preliminary risk assessment of potential developmental toxicity effects of PFOA in April 2003 and a draft risk assessment in January 2005 (U.S. EPA, 2005b). The draft risk assessment suggested that PFOA may be carcinogenic in male rats; however, EPA also identified uncertainty in the document and the need for further research.[4]

While EPA has obtained data on PFOA serum levels in workers and the general public, the pathways of human and environmental exposure to PFOA and the concentrations of PFOA in the environment are not well understood. Therefore, EPA has yet to determine whether PFOA poses an unreasonable risk to the public. Through its data gathering agreements with industry and other stakeholders, EPA continues to assess the potential risks posed by PFOA in order to determine what risk management steps may be appropriate, however, due to voluntary efforts on the part of industry stakeholders, it is less likely that further risk management steps will be necessary.[5]

---

[4] Specifically, EPA stated in the 2005 draft risk assessment of PFOA (U.S. EPA, 2005b), "PFOA may be best described as 'suggestive evidence of carcinogenicity, but not sufficient to assess human carcinogenic potential' under the draft 1999 EPA Guidelines for Carcinogen Risk Assessment." In 2006, three quarters of a Scientific Advisory Board (SAB) panel, whose role was to comment on the draft risk assessment, "judged that the weight-of-evidence conclusion for the potential of PFOA to cause cancer in humans was more aligned and consistent with the hazard descriptor of 'likely to be carcinogenic' as described in the Agency's cancer guidelines (i.e., 2003 EPA Guidelines for Carcinogen Risk Assessment)."

[5] For example, in 2006 EPA created the 2010/15 PFOA Stewardship Program. The participants include 8 major manufacturers of flouropolymers and telomers, who have committed to reduce facility emissions and product content of PFOA and related chemicals by 95 percent by 2010, and to work toward eliminating PFOA emissions and product content by 2015. Companies participating in the Stewardship Program are 3M/Dyneon, Arkema, Inc., AGC Chemicals/Asahi Glass, Ciba Specialty Chemicals, Clariant Corporation, Daikin, E.I. DuPont de Nemours and Company, and Solvay Solexis. As noted on the PFOA Stewardship Program website

1.1.4 Market trends

Currently, the U.S. electronics industry is facing significant legislative and market pressures to phase out heavy metals and other hazardous materials from use in electrical and electronic equipment. This applies to some wire and cable products. These pressures include initiatives in Europe and Japan that mandate the elimination of lead from electronic products, or that request manufacturers to eliminate these voluntarily. In Europe, effective July 2006, the Restriction of Hazardous Substances (RoHS) Directive effectively banned the use of lead and other selected toxic chemicals in most electrical and electronic equipment.[6] In Japan, following take back (recycling) legislation effective as of 2001, the Japan EPA and MITI (Ministry of International Trade and Industry) currently suggest the reduced use of lead to take place along with increased recycling. California Proposition 65 (Prop65), the Safe Drinking Water and Toxic Enforcement Act of 1986, requires the governor to publish an annual list of chemicals known by the state of California to cause cancer, birth defects, or other reproductive harm. Businesses are then required to notify Californians about significant amounts of these chemicals found in products they purchase, in their homes or workplaces, or that are released to the environment. A 2002 settlement between the wire and cable industry, which was represented by the National Electrical Manufacturers Association (NEMA), and the state of California required only "frequently handled" electrical cords with a lead content by weight of 0.03 percent (300 ppm) to be labeled by September 2003. An exemption was made for cords that are infrequently handled, such as building cable, plenum cable, and telecom power cable (NEMA, 2002). Consumer demand for lead-free products may also increase as the general public becomes increasingly aware of lead issues, in part due to EPA's successful efforts to eliminate exposures to lead in gasoline, paint, and dust/soil. These drivers are all helping to move the U.S. market toward lead-free products.

A growing number of original equipment manufacturers (OEMs), particularly in the electronics and automobile industries, have introduced supplier materials declarations. These declarations, composed of lists of materials the OEMs want to restrict in their products, typically include materials found in wire and cable products, such as lead, cadmium, brominated flame retardants, and hexavalent chromium. Wire and cable components, however, have not been the initial target of materials declarations and restrictions by the OEMs. Several OEMs, including those in the High Packaging User Group (Dell, Hewlett-Packard, IBM, and Nokia), are even conducting tests to verify supplier compliance. In addition, Underwriters Laboratories Inc. (UL) and other testing houses have introduced compliance programs to assist all the channel partners with declarations. Because multinational OEMs want to make a class of products that can be sold anywhere in the world, rather than different products that comply with the requirements of various countries, they base their policies on the most restrictive worldwide standards. Many Japanese OEMs have been the most aggressive in restricting materials, in part to gain marketing advantage for the sale of their products (Harriman *et al*., 2003). A number of the leading electronics manufacturers in Japan–Sony-Europe, Sharp, Electrolux, and Ricoh of Japan–have PVC phaseout policies. Many auto manufacturers, including Toyota, Honda, and Nissan, also have goals to replace PVC with polyolefins[7] in order to increase the recyclability of plastic parts in vehicles at their end of life (Rossi *et al*., 2005).

(http://www.epa.gov/oppt/pfoa/pubs/pfoastewardship.htm), many of these companies have already exceeded their 2010 goals and have moved on the 2015 goal of elimination of PFOA emissions and product content.

[6] RoHS does allow *de minimis* levels of lead (maximum concentrations of up to 0.1%.of lead in electrical and electronic equipment); however, lead stabilizers in the cables being analyzed are used in amounts greater than 0.1%.

[7] Polyolefins are a family of polymers such as polyethylene and polypropylene, which are made from olefin monomers. Olefin is the common name for the class of compounds known as alkenes, which contain double bonded carbons and include unsaturated aliphatic hydrocarbons, among which are ethylene, propylene, and butylene.

In addition to the OEM requirements, several European Eco-labels, such as the German Blue Angel and the Nordic Swan, act as market drivers. These labels prohibit the use of lead, hexavalent chromium, cadmium, and certain brominated flame retardants. In addition, some government and non-governmental organizations (e.g., Silicon Valley Toxics Coalition, Healthy Building Network) promote the purchase of products free of hazardous substances (Harriman *et al*., 2003).

Communications network cables in the U.S. have had to meet stringent NFPA (National Fire Protection Association) National Electrical Code® (NEC) fire performance requirements for the past 30 years. Network cables installed in vertical shafts (CMR) are highly flame retardant. Network cables installed in horizontal plenum spaces (CMP) must both be highly flame retardant and meet requirements for low smoke generation. An effort is also currently underway to further raise the standards for fire safety, requiring cables installed in concealed spaces to be "limited combustible" (LC). LC cables would be required to have higher flame retardancy and less smoke production than CMP cables. Fluoropolymer compounds would be one of the few jacketing materials currently available that would meet LC performance requirements. For the latest revision of the NEC in 2008, the decision was made not to include the LC designation.

Primarily as a consequence of distinct fire performance hierarchies, communication network cable markets differ considerably between the U.S. and Europe. Approximately 75 percent of the U.S. communications network cable market is CMP-rated cable (~6.0B ft/yr), and 15 percent is CMR-rated cable (~1.2B ft/yr). The U.S. market has changed substantially in recent years, as several cable manufacturers have introduced lead-free cables that meet Cat 6 CMR and Cat 6 CMP standards. In Europe, where cable fire performance standards are not as stringent as the U.S. NFPA NEC standards, 95 percent of the network cables (~5.0B ft/yr) currently meet the criteria for lower than CMR/Riser fire performance (CRU, 2002). (Typically, these European network cables are jacketed with either PVC or halogen-free compounds [e.g., polyolefins] and insulated with PE.)

The annual market for NM-B-rated cable is estimated at 800 million to 1 billion pounds (6.6 to 8.3 billion feet).[8] While some companies are converting to lead-free PVC insulation and jacketing, currently a relatively low percentage of the total annual market consists of alternative compositions, such as lead-free, heavy metal-free, and/or zero-halogen (Sims, 2007).

It should be noted that for many applications, alternatives do not always exist to the materials of potential concern that will satisfy performance requirements. For example, no commercial zero-halogen alternatives are available for CMP applications.

1.1.5 Need for the project

The wire and cable industry manufactures a wide range of products that support a multitude of applications. Many wire insulation and cable jacketing compositions contain materials, such as lead, halogenated compounds, and other ingredients, that impart electrical insulation and fire performance properties, but that have been identified as materials of potential environmental concern or as materials for which industry stakeholders have expressed a desire to identify and evaluate alternatives. In some applications, lead and other heavy metals have been removed from cable constructions, whereas other applications continue to use such materials. For example, European legislation has driven these changes for electronics and automotive applications; however, such changes have not been made for other

[8] Using an average net weight of 83 lbs/1,000 ft (0.083 lbs per foot for 12-gauge 2-conductor copper NM-B with ground wire).

applications (e.g., low-voltage power cable) where such drivers are not present. Alternative constructions such as halogen-free jacketing (e.g., polyolefin-based polymer system) are available for some applications (i.e., subway systems and other locations where acid emissions from halogenated compounds are unacceptable). However, they have not been widely used, primarily due to their higher relative cost, the lack of market drivers, and their inability to meet all the requirements of the more demanding applications (Wilson, 2004).

Products that pose fewer environmental impacts are of interest to many wire and cable companies and their customers, if performance and cost requirements can be met. The DfE/TURI Partnership has generated information on the environmental impacts of traditional and alternative cable constructions in order to help companies make environmentally sound product and material choices. While some changes have been made in certain wire and cable sectors, the WCP believes that developing and providing sound environmental data using a life-cycle assessment approach could assist those and other sectors to pursue environmentally preferable alternatives. Because of the large quantity of cable put into commerce every year, choosing environmentally preferable materials could have a broad impact on public health and the environment.

Quantitative environmental life-cycle analysis of the traditional and alternative formulations is needed, given the current interest in lead-free cables in the United States and halogen-free cable materials in certain overseas markets, the potential environmental concerns that lead- and halogen-containing additives pose, and the fact that the relative life-cycle environmental impacts of alternative formulations have not yet been determined. This project offers the opportunity to mitigate current and future risks by assisting the wire and cable industry in identifying cable jacketing and wire insulation formulations that are less toxic and that pose fewer risks over their life cycles.

1.1.6 Targeted audience and use of the study

The wire and cable industry is expected to be the primary user of the study results. The study is intended to provide the industry with an objective analysis that evaluates the life-cycle environmental impacts of selected cable products. Scientific verification of the relative environmental impacts will allow industry to consider environmental concerns along with traditionally evaluated parameters of safety, cost, and performance, and to potentially enhance efforts to manufacture products and design processes that reduce the environmental footprint, including energy consumption, releases of hazardous chemicals, and risks to health and the environment. Given the results, the industry can then evaluate material or process improvements based on the comparison of the alternative insulation and jacketing formulations. This study is designed to provide the wire and cable industry with information needed to identify the origin of impacts, throughout the life cycle, of both the traditional and alternative insulation and jacketing formulations. This information could lead to improvement in the cables' environmental attributes. The study results will also enable the wire and cable industry to make environmentally informed choices about alternatives when assessing and implementing improvements, such as changes in product, process, and activity design; raw material use; industrial processing; consumer use; and waste management.

Identification of impacts from the cables' life cycle can also encourage industry to implement pollution prevention options, such as development and demonstration projects, and technical assistance and training. The wire and cable industry can use the tools and data in this study to evaluate the health, environmental, and energy implications of the technologies. With this evaluation, the U.S. wire and cable industry may be more prepared to meet the demands of extended product responsibility that are growing in popularity in the global marketplace, to help guide public policy towards informed solutions that are environmentally preferable based on scientific study, and to be better able to meet the competitive challenges of the world market. In addition, the inventory data, results, and model in this study provide baseline data upon which other alternative cable formulations can potentially be evaluated. This allows for more expedited LCA studies, which are growing in popularity by industry and may be demanded by OEMs or international organizations.

We expect that the wire and cable industry will use the information generated in this study of the life-cycle environmental impacts of the standard insulation and jacketing formulations, and the alternative formulations, to select the formulations that meet the safety and transmission performance requirements of the end-use application, that pose fewer risks to public health, and that have the least impact on the environment.

1.2 Product Systems

1.2.1 Functional unit

In an LCA, product systems are evaluated on a functionally equivalent basis. The functional unit normalizes data based on equivalent use to provide a reference for relating process inputs and outputs to the inventory and impact assessment across alternatives. The product systems evaluated in Phase I of this project are standard and alternative (i.e., lead-free and zero-halogen) wire insulation and cable jacketing formulations, as used in telecommunication and low-voltage power cable installations in the United States. Each of the three cable types is evaluated in separate analyses, as each type has a different functionality. The functional unit for each cable type is the insulation and jacketing used in one kilometer of linear length of cable, which would be used to transmit a signal that meets certain UL performance requirements and fire safety specifications for the product types listed in Table 1-1. Most telecommunications network cables are expected to achieve a minimum service life of 10 to 15 years. NM-B cables are generally replaced after 25 to 40 years of service, depending on the installation conditions. During remodeling, NM-B cables are typically replaced only if they are disturbed.

Table 1-1

Wire & Cable Products Selected for Separate Analyses of Alternative Insulation and Jacketing Constructions

Wire and Cable Product	Application type	Specifications (standards)[b]
Riser communication cable (CMR)	Telecommunication (Category 6)[a]	UL-444, Article 800 NEC, TIA-568-B.2-1, and ICEA S-80-576
Plenum communication cable (CMP)	Telecommunication (Category 6)[a]	UL-444, Article 800 NEC, TIA-568-B.2-1, and ICEA S-80-576
Non-metallic-sheathed cable (NM-B)	Low-voltage power cable	UL-719, Article 334 NEC

[a] Telecommunications Industry Association/Electronic Industries Alliance (TIA/EIA) (specifies data transmission performance category).

[b] UL=Underwriters Laboratories; NEC=National Electrical Code® (addresses flammability performance); ICEA = Insulated Cable Engineers Association (specifies physical, mechanical performance of insulation/jacket/finished product).

1.2.2 Cable systems and alternatives

A cable product generally consists of a wire conductor covered by insulation, and a jacket that encases the insulated wire(s). The insulation of NM-B and the jacketing of CMR, CMP, and NM-B cables are compounded with other materials, such as heat stabilizers and flame retardants, to meet performance specifications. Figure 1-1 shows the general process flow of manufacturing a cable.

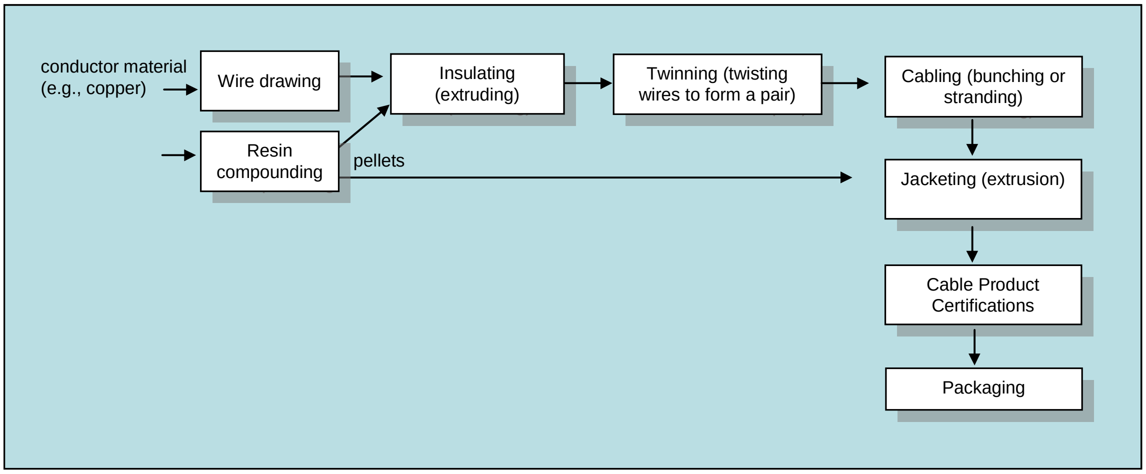

Figure 1-1. General Manufacturing Process Diagram for Cable

Project partners assisted in identifying alternative constructions to the cable products for inclusion in Phase I. We set out to evaluate as many lead-free and halogen-free alternatives for each cable type as possible. Given the data that were provided, Table 1-2 lists the general characteristics and makeup of each alternative included in Phase I this analysis.

The general makeup of each cable type is summarized in the pie charts in Figures 1-2, through 1-6. These constructions are from primary input data provided by the cable manufacturers and cable resin compounders that participated in this partnership. For CMR and CMP cable, the weight percentages for the baseline and lead-free constructions are only slightly different (Figures 1-2 through 1-5). Data received on the entire cable construction for the halogen-free CMR cables were not adequate to depict in a pie chart. Similarly, for NM-B cables, adequate data were not received for the lead-free cable to determine the component breakdown; however, industry partners of the WCP estimated the general makeup of baseline (Figure 1-6) and lead-free cables to be approximately the same. In each case, the cables were defined as having equivalent copper gauge wires, however, averaging primary copper input data from multiple companies resulted in the values being slightly different. This could be partially a function of different material efficiencies within different facilities. Thus, the cables as defined by the functional unit, are assumed to have the same amount of copper for each alternative within a cable type, and thus are excluded from the comparative analysis.

For all cable types, the conductor makes up between 52 and 70 percent of the weight of the cable for a given linear length of the cable. The percent mass that is insulation ranges from 10 to 21 percent of the cables, and jacketing ranges from 19 to 34 percent. Separators (also referred to as spacers or crosswebs) or other components constitute between 2 and 4 percent.

Table 1-2

Wire & Cable Product Alternatives

Alternative	Insulation	Jacketing	Functional Unit (kg/km cable)[d]
CMR baseline[a]	HDPE	Compounded PVC (lead-based heat stabilizer)	20.1
CMR lead-free[a]	HDPE	Compounded PVC (non-lead heat stabilizer)	21.8
CMR zero-halogen[a]	HDPE	Non-PVC[b] (non-lead heat stabilizer)	64.5
CMP baseline[a]	FEP	Compounded PVC (lead-based heat stabilizer)	22.8
CMP lead-free[a]	FEP	Compounded PVC (non-lead heat stabilizer)	22.9
NM-B baseline[c]	Compounded PVC (lead-based heat stabilizer)	Compounded PVC (lead-based heat stabilizer)	e
NM-B lead-free[c]	Compounded PVC (non-lead heat stabilizer)	Compounded PVC (non-lead heat stabilizer)	e

[a] Conductors are unshielded twisted pairs, 8 conductors in 4 pairs; 23-gauge bare copper.

[b] Proprietary.

[c] Conductors are 12-gauge, 2-conductor copper with ground wire.

[d] Functional unit conversions are based on primary data received for insulation and jacketing (see in Chapter 2).

[e] NM-B leaded and lead-free cables have approximately the same mass per length; the values are not reported to protect confidentiality.

Note: CMR = riser-rate communication cable; CMP = plenum-rated communication cable; HDPE = high density polyethylene; FEP = fluorinated ethylene propylene; PVC = polyvinyl chloride.

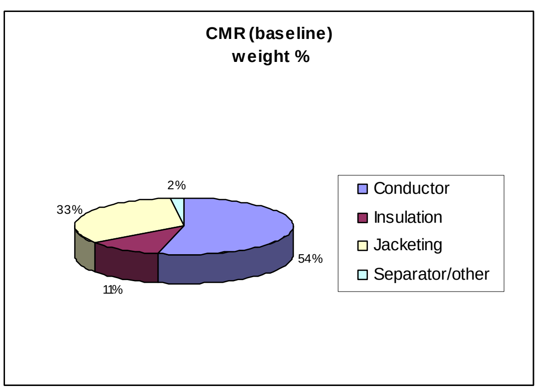

Figure 1-2. CMR Baseline Cable Component Breakdown

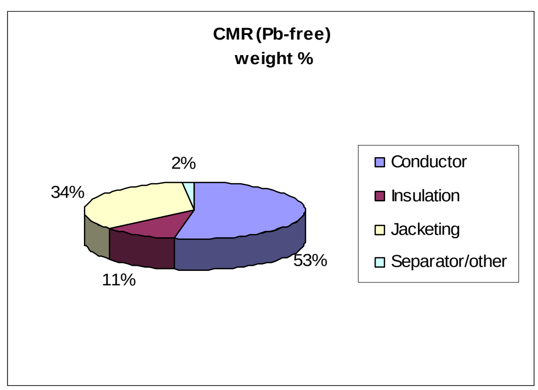

Figure 1-3. CMR Pb-free Cable Component Breakdown

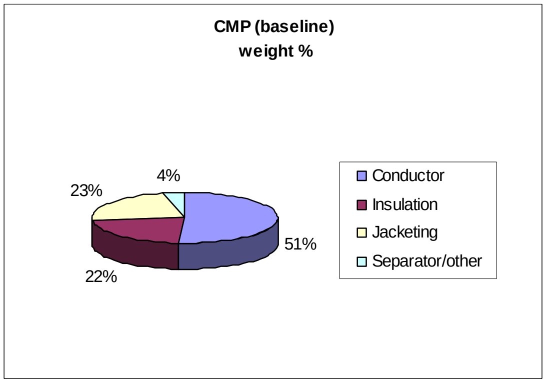

Figure 1-4. CMP Baseline Cable Component Breakdown

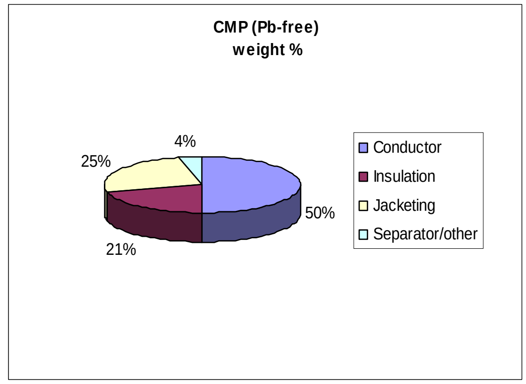

Fig 1-5. CMP lead-free Cable Component Breakdown

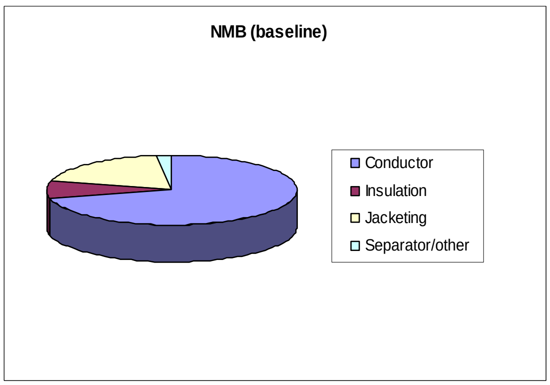

Figure 1-6. NM-B Cable Component Breakdown (percentages not shown; proprietary)

The focus of the comparative LCAs in this report is on the insulation, jacketing, and separator/ crossweb resins, as well as any compounded materials contained within the resins. Each cable type uses equivalent amounts of copper conductor per unit length of cable, and thus the conductor is excluded from the comparison of alternatives within each cable type.

1.3 Assessment Boundaries

1.3.1 Life-cycle assessment (LCA)

LCAs evaluate the life-cycle environmental impacts from each of the following major life-cycle stages:

- Raw materials extraction/acquisition
- Materials processing
- Product manufacture
- Product use
- Final disposition/end-of-life

Figure 1-7 briefly describes each of these stages for a wire and cable product system. The inputs (e.g., resources and energy) and outputs (e.g., product and waste) within each life-cycle stage, as well as the interaction between each stage (e.g., transportation), are evaluated to determine the environmental impacts.

INPUTS	LIFE-CYCLE STAGES	OUTPUTS
	RAW MATERIALS EXTRACTION / ACQUISITION Activities related to the acquisition of natural resources, including mining non-renewable material, harvesting biomass, and transporting raw materials to processing facilities.	
Materials	**MATERIALS PROCESSING** Processing natural resources by reaction, separation, purification, and alteration steps in preparation for the manufacturing stage; and transporting processed materials to product manufacturing facilities.	Wastes
Energy	**PRODUCT MANUFACTURE** Processing materials to compound and extrude wire and cable.	
Resources	**PRODUCT USE, MAINTENANCE, REPAIR** Use of wire and cable in buildings and telecommunication applications.	Products
	FINAL DISPOSITION / END-OF-LIFE At the end of their useful life, the wire and cables are retired individually or as part of other equipment or products. If the wire and cable can feasibly be reused and recycled, the cable can be transported to an appropriate facility where the conductor can be separated from the insulation for materials recovery. Materials that are not recoverable are transported to appropriate facilities and treated (if required or necessary) and/or disposed of.	
	Product System Boundary	

Figure 1-7. Life-cycle Stages of Wire and Cable Alternatives

As defined by the Society of Environmental Toxicology and Chemistry (SETAC), the four major components of an LCA are (1) goal definition and scoping, (2) inventory analysis, (3) impact assessment, and (4) improvement assessment. More recently, the international standard ISO 14040: Environmental Management—Lifecycle Assessment—Principles and Framework has defined the four major components of an LCA as (1) goal and scope, (2) inventory analysis, (3) impact assessment, and (4) interpretation of results. The SETAC and International Organization for Standardization (ISO) frameworks are essentially synonymous with respect to the first three components, but differ somewhat with respect to the fourth component: improvement assessment or life-cycle interpretation. Improvement assessment is the systematic evaluation of opportunities for reducing the environmental impacts of a product, process, or activity. Interpretation is the phase of LCA in which the findings from the inventory analyses and the impact assessment are combined, consistent with the defined goal and scope, in order to reach conclusions and recommendations.

The goals and scope of this LCA for wire and cable insulation and jacketing are the subject of Chapter 1. The inventory analysis and impact assessment are included in Chapters 2 and 3, respectively. Chapter 4 summarizes the results; however, much of the life-cycle interpretation, which is the last step of an LCA as recommended in ISO 14040, is left to the wire and cable industry. The life-cycle inventory (LCI) and life-cycle impact assessment (LCIA) strategies are briefly described below.

The LCI involves quantifying raw material and fuel inputs, and solid, liquid, and gaseous emissions and effluents. The approach to the LCI in this study involved defining product materials, developing bills of materials (BOM) for the products, and obtaining inventory data for major processes within each life-cycle stage. Section 1.4 provides additional details of the LCI data-gathering activities.

The LCIA involves translating the environmental burdens identified in the LCI into environmental impacts. LCIA is typically a quantitative process involving characterizing burdens and assessing their effects on human and ecological health, as well as other effects, such as smog formation and global warming. Further details of the LCIA impact categories appear in Section 1.3.5. This project used an LCIA methodology that was used in the most recent DfE LCA, entitled *Lead-Free Solders: A Life-cycle Assessment* (Geibig and Socolof, 2005), which was based on the methodology used in DfE's Computer Display Project (Socolof *et al.*, 2001).

1.3.2 Life-cycle stages and unit processes

In a comprehensive cradle-to-grave analysis, the product system includes five life-cycle stages: (1) raw materials extraction/acquisition; (2) materials processing; (3) product manufacture; (4) product use, maintenance, and repair; and (5) final disposition/end-of-life (EOL). Also included are the activities that are required to affect movement between the stages (e.g., transportation). The first two stages (materials extraction and materials processing) are represented as one "upstream" life-cycle stage throughout this report, as available data are aggregated as such.

Figure 1-8 depicts the major processes within the life cycles of the cables that are modeled in this study. Each of these unit processes has its own inventory of inputs and outputs. In the upstream stages, resins and additive materials for the insulation and jacketing are included. The extent to which additive materials are included depends on decision rules, which are discussed in Section 1.4.2. Because each cable alternative uses the same type and quantity of conductor material, this LCA does not include upstream stages of the copper conductors. The differences between the cable alternatives are in the insulation or jacketing, and thus those components of the wire and cable products are the focus of this comparative LCA.

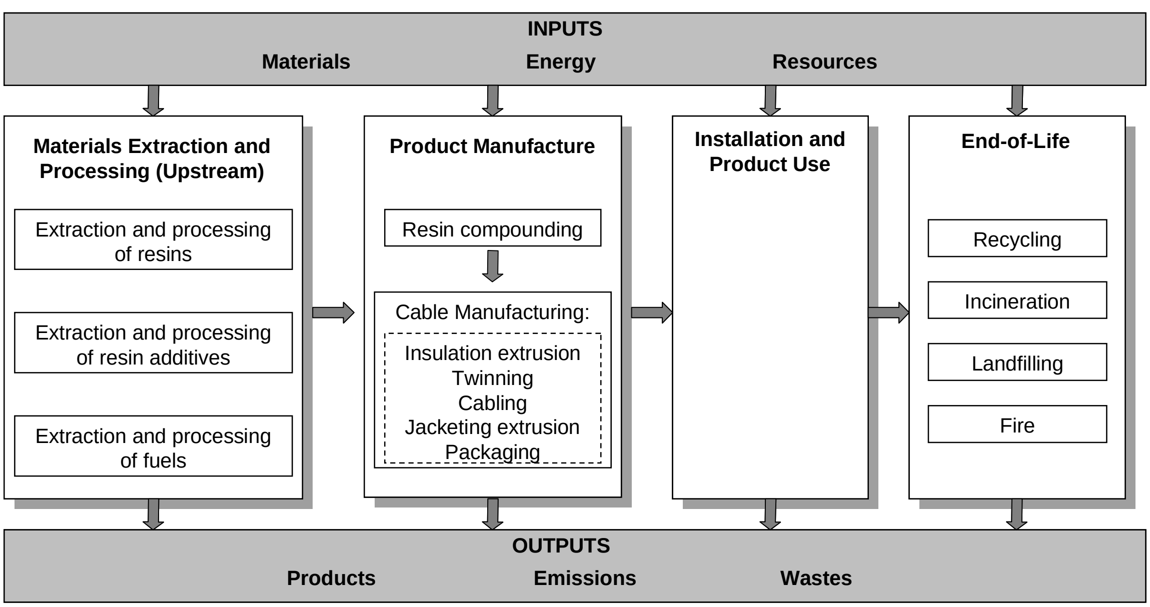

Figure 1-8. Wire and Cable Life-cycle Conceptual Model

The manufacturing stage includes compounding and extrusion processes, and any assembly processes associated with manufacturing a cable (see Figure 1-1). The installation and use of the cables is consistent between alternatives, and thus does not need to be included in a comparative analysis. If service lifetimes during use of the cables differ between alternatives, then the amount of cable produced would be scaled so that each alternative would have equivalent functional units. However, lifetimes for cables being compared were consistent.

Transportation of wire and cable materials for alternative constructions is expected to be the same for all plastic pellets and cables, and does not have any regional or global differences. Therefore, transportation was not included in this comparative analysis for transport between compounding facilities, cable manufacturing facilities, installation sites, and EOL disposition. Transportation is included when secondary data sets used for materials extraction and processing already have transportation aggregated into the data set.

1.3.3 Spatial and temporal boundaries

Geographic boundaries are used in an LCA to show where impacts are likely to occur for each life-cycle stage. This is important for assessing the impacts of things such as transportation impacts between life-cycle stages. Raw materials acquisition and material processing for materials used in the manufacture of the cables are conducted throughout the world. Product manufacturing also occurs worldwide. CMR-rated cable products are sold in numerous markets around the world, whereas the CMP-rated cable products and low-voltage power cables are more limited to the North American market. This study, however, focused on the use of these cables for telecommunications and low-voltage power cable applications in the United States. The EOL evaluation also focused on cables that reach the ends of their lives in the United States. However, due to limited data availability, data from other countries were used when available.

While the geographic boundaries show where impacts might occur for various life-cycle stages, traditional LCAs do not provide actual spatial relationships of impacts. That is, particular impacts cannot be attributed to a specific location. Rather, impacts are generally presented on a regional or global scale.

This study addresses impacts from cables that were manufactured between the years 2005 and 2006. Installation and use of the cables would occur shortly thereafter; however, EOL disposition would occur after the 10- to 15-year-service life for CMP and CMR cables, and after the 25- to 40- year NM-B service life. Given the lack of temporal specificity in an LCA, EOL impacts are assumed to be based on current EOL technologies and conditions, despite the potential changes that might occur during the product’s service life. Thus, we assumed that any parameters that may change with time (e.g., availability of landfill space, recycling rates, recycling technologies) would be similar to current conditions, and would remain constant throughout the lifespan of the product system. Note that the inherent uncertainty in this assumption is greater when the product lifespan is longer.

1.3.4 General exclusions

Impacts from the infrastructure needed to support the manufacturing facilities are beyond the scope of this study (e.g., general maintenance of manufacturing plants). Given that the copper wire is equivalent, by definition, across alternatives, the mining and production of copper and the copper drawing process were not evaluated in the study.

1.3.5 Impact categories

In the LCIA phase of an LCA, several different impact categories can be evaluated among the alternatives. This study evaluates the following:

- Non-renewable materials use/depletion
- energy use
- landfill space use
- global warming (global climate change)
- stratospheric ozone depletion
- photochemical smog
- air acidification
- air particulates
- water eutrophication (nutrient enrichment)
- potential chronic non-cancer human toxicity – occupational
- potential cancer human toxicity – occupational
- potential chronic non-cancer toxicity – public
- potential cancer human toxicity – public
- potential aquatic ecotoxicity

The methodologies for each category are based on those used in previous DfE LCAs and are common to many LCAs. The toxicity-based categories use a methodology developed for DfE in a previous LCA (for computer displays), and has also been used in the DfE solder LCA. All the methodologies are detailed in Chapter 3.

1.4 Data Collection Scope

This section describes the data categories that were evaluated in the WCP LCI, the decision rules used to determine which materials would be eliminated from consideration, and data collection methods. It also describes procedures for allocating inputs and outputs from a process to the product of interest (i.e., a cable) when the process is used in the manufacture, recycle, or disposal of more than one product type at the same facility. Finally, it describes the data management and analysis software used for the project, and methods for maintaining overall data quality and critical review.

1.4.1 Data categories

Table 1-3 describes the data categories for which inventory data were collected, including material and energy inputs; and emissions, wastes, and product outputs. In general, inventory data are normalized to either (1) the mass of an input or output per functional unit, or (2) energy input (e.g., megajoules, MJ) per functional unit. As discussed in Section 1.2, the functional unit is a unit length of a particular cable for a given service life.

Data that reflect production for one year of continuous processes are scaled to one functional unit. Thus, excessive material or energy associated with startups, shutdowns, and changeovers are assumed to be distributed over time. Consequently, any environmental and exposure modeling associated with the impact assessment reflects continuous emissions such that equilibrium concentrations may be assumed. If the reporting year was given as less than one year for any inventory item, the analysis was adjusted as appropriate to the functional unit. Data were also collected on the final disposition of emissions outputs, such as whether outputs are recycled, treated, and/or disposed of. This information was used to help determine which impacts are calculated for a particular inventory item.

Table 1-3

LCI Data Categories

Data Category	Description
Inputs: Material and resource flows (kg per functional unit)	
Primary material flows	*Actual materials that make up the final product for a particular process.*
Ancillary (process) material flows	*Materials that are used in the processing of a product for a particular process. May be renewable or non-renewable resources.*
Natural resource flows	*Materials extracted from the ground that are non-renewable (i.e., stock, resources such as coal), or renewable (i.e., flow resources such as water or limestone).*
Inputs: Energy flows (MJ per functional unit)	
Energy flows	*Process energy, pre-combustion energy (i.e., energy expended to extract, process, refine, and deliver a usable fuel for combustion), and when available, transportation energy are included. Energy can be renewable or non-renewable. The energy flows modeled in this analysis are generally from non-renewable sources.*
Outputs: Emissions, wastes (kg per functional unit)	
Emissions to air	*Mass of a product or material that is considered a pollutant within each life-cycle stage. Air outputs represent actual gaseous or particulate releases to the environment from a point or diffuse source, after passing through emission control devices, if applicable.*
Emissions to water	*Mass of a product or material that is considered a pollutant within each life-cycle stage. Water outputs represent actual discharges to either surface or groundwater from point or diffuse sources, after passing through any water treatment devices.*
Emissions to soil	*Mass of chemical constituents that are considered pollutants and emitted to soil within each life-cycle stage. Soil emissions represent actual or modeled discharges to soil from point or diffuse sources.*
Wastes/deposited goods	*Mass of a solid or hazardous waste landfill or deep well. Could include hazardous, non-hazardous, and radioactive wastes. Represents solid or liquid outputs that are deposited in a landfill or sent for treatment (e.g., incineration, composting), recovery, or recycling processes.*
Outputs: Products (kg or number of components per functional unit)	
Primary products	*Material or component outputs from a process that are received as inputs by a subsequent unit process within the product life cycle.*
Co-products	*Material outputs from a process that can be used, either with or without further processing, and that are not used as part of the final functional unit product.*

1.4.2 Decision rules

Given the enormous amount of data involved in inventorying all of the input and output flows for a product system, LCA practitioners typically employ decision rules to make the data collection manageable and representative of the product system and its impacts.

In this project, decision rules were used to determine which upstream processes to include. In considering upstream materials, a combination of several factors were considered, including availability of existing data and manufacturers' willingness to participate. Decision rules are also used to determine whether material flows are excluded from a particular process. This was determined once all the inventory data were collected for each process in the product systems.

The decision rule process began by assessing the materials used in cable production for the following attributes:

1. *The mass contribution of each material.* With a greater mass of materials and resources consumed, the potential for a material to have a significant environmental impact increases.
2. *Materials that are of known or suspected environmental significance (e.g., toxic).* To the extent feasible, the process considers materials or components known or suspected to exhibit an environmental hazard.
3. *Materials known or suspected to have a large contribution to the system's energy requirements.* Because many environmental impacts can be associated with energy consumption, priorities were given to including materials or processes that are known or suspected to consume large amounts of energy.
4. *Materials that are physically or functionally unique to one alternative over another.* The physical or functional uniqueness of a material or component could be identified by chemical makeup or by size.

Materials that are greater than one percent of the total mass of material required to manufacture the product were considered for inclusion in the scope. Attempts were made to include all materials greater than five percent by weight. Materials between one percent and five percent by mass were subject to inclusion based on other decision rules or data availability (as approved by the WCP Core Group, described in Section 1.4.7). Materials of known or suspected environmental or energy significance were also included, regardless of their mass contribution. Materials that are physically or functionally unique to a cable product alternative over the baseline construction, as determined by the Core Group, are also considered if they would have otherwise been eliminated based on the mass cutoff.

1.4.3 Data collection and data sources

Data were collected from both primary and secondary sources. Primary data are directly accessible, plant-specific, measured, modeled, or estimated data generated for the particular project at hand. Secondary data are from literature sources, LCI databases, or other LCAs, but may not be specific to the product of interest. Table 1-4 lists the types of data (primary or secondary) collected for each life-cycle stage in the WCP LCI. If both primary and secondary data are lacking, various assumptions and modeling serve as defaults.

Table 1-4

Data Types by Life-cycle Stage

Life-cycle stage	Data types	Scope
Upstream (materials extraction and processing)	Secondary data; possibly primary data	Greater emphasis
Product manufacturing	Primary data or secondary data for industry averages	Greater emphasis
Installation and use	None	Excluded since it is equivalent among alternatives
Final disposition (recycling and/or disposal)	Primary and secondary data	Moderate emphasis
Packaging, transportation, distribution	None	Excluded because it is assumed to be equivalent among alternatives

1.4.4 Allocation procedures

An allocation procedure is required when a process within a system shares a common management structure with other products produced. In the WCP LCI, allocation procedures may be required when processes or services associated with the functional unit are used in more than one product line at the same facility. Inputs and outputs are allocated among the product lines to avoid overestimating the environmental burdens associated with the product under evaluation.

The International Organization for Standardization (ISO) recommends that wherever possible, allocation should be avoided or minimized. This may be achieved by subdividing the unit process into two or more subprocesses, some of which can be excluded from the system under study. For example, if a manufacturer produces only one type of cable, no allocation would be necessary from that manufacturer. However, if the manufacturer produces multiple cables products, the flows would need to be allocated to the one cable of interest. As suggested by ISO, if sub-processes within the facility can be identified that distinguish between the cables being manufactured, the sub-processes manufacturing the cables that are not of interest can be eliminated from the analysis, thus reducing allocation procedures. Where disaggregation into subprocesses was not possible, inventory data for utilities and services common to several processes were allocated to reflect the relative use of the service. For example, fuel inputs and emission outputs from electric utility generation were allocated to a cable according to the actual or estimated electricity consumed during the applicable process.

1.4.5 Data management and analysis software

The data collected in this study were obtained either from data forms developed for this project, from existing databases, or from primary or secondary data collected by Abt Associates, Inc. All data were then transferred to spreadsheets, which were then imported into a commercially available LCA tool: GaBi4–The Software System for Life Cycle Engineering [PE Europe GmbH and IKP University of Stuttgart, 2003]. This software tool stores and organizes life-cycle inventory data and calculates life-cycle impacts for a product profile. It is designed to allow flexibility in conducting life-cycle design and life-cycle assessment functions, and provides the means to organize inventory data, investigate alternative scenarios, evaluate impacts, and assess data quality. Impact methods developed by the University of

Tennessee under grants from DfE were also incorporated into the GaBi4 tool as appropriate for this project.

1.4.6 Data quality

LCI data quality can be evaluated based on the following data quality indicators (DQIs): (1) the source type (i.e., primary or secondary data sources), (2) the method in which the data were obtained (i.e., measured, calculated, estimated), and (3) the time period for which the data are representative. LCI DQIs are discussed further in Life-Cycle Assessment Data Quality: A Conceptual Framework (SETAC, 1994). Data quality for each life-cycle stage is summarized below.

For the primary data collected in this project, we asked participating companies to report the method in which their data were obtained and the time period for which the data are representative. Data from 2005-2006 were sought. The time period of secondary data and methods in which the data were originally obtained were also recorded, where available. Secondary data were expected to be from earlier time periods.

Anomalies and missing data are common hurdles in any data collecting exercise. Anomalies are extreme values within a given data set. Any anomaly identified during the course of this project that is germane to project results was highlighted for the project team and investigated to determine its source (e.g., mis-reported values). If the anomaly could be traced to an event inherently related to the process, it was left in the data set. If, however, the anomaly could not be accounted for, it was removed from the data set.

We attempted to account for missing data by replacing it hierarchically. That is, if specific primary data were missing, secondary data were used. Where neither primary nor secondary data were available, we made assumptions, and in cases where there was potentially large uncertainty with an assumption, we conducted an uncertainty analysis based on those assumptions. In the cases where no data were found or reasonable assumptions could be made, these deficiencies were reported. Any proprietary information required for the assessment is subject to confidentiality agreements between Abt Associates, Inc. and the participating company. Proprietary data are presented as aggregated data from a minimum of three companies to avoid revealing the source of the data.

1.4.7 Critical review

Critical review is a technique used to verify whether an LCA has met the requirements of the study for methodology, data, and reporting, as defined in the goal definition and scoping phase. A critical review process was maintained in the WCP LCA to help ensure that the following criteria were met:

- The methods used to carry out assessments are consistent with the EPA, SETAC, and ISO assessment guidelines.
- The methods used to carry out assessments are scientifically and technically valid within the LCA framework.
- The data used are appropriate and reasonable in relation to the goals of the study.
- The interpretations reflect the limitations identified and the goals of the study.
- The study results are transparent and consistent.

This review process conforms to the recommendations in ISO 14040.

A project Core Group of representatives from industry, academia, and government provided critical reviews of the project assessments. The Core Group served as the project Steering Committee, and was responsible for approving all major scoping assumptions and decisions. It provided technical guidance and reviews of all major project deliverables including the final LCA report. In addition to Core Group review, the report was also reviewed by several EPA staff, including those with LCA and risk assessment expertise.

Comments on the review drafts were collected, logged into a comment-response log, and shared with all reviewers. Meetings to discuss and/or resolve comments were conducted and the final responses and actions taken were entered into the comment-response long and provided to the reviewers with the final report. An independent LCA expert was identified within EPA, who was tasked with conducting a review of the methods and findings of this study. Supplied with this document, in accordance with Section 7.3.2 of ISO 14040, is a review statement from the authors of the study, comments of the expert LCA practitioner, and responses to the recommendations made by this practitioner.