Case Study of a Phthalates Alternative Assessment For Use in PVC-Jacketed Network Cable

PREPARED FOR

The United States Environmental Protection Agency (U.S. EPA)

Design for the Environment (DfE)

Alternatives for Certain Phthalates Partnership

May 2014

Flexible Vinyl Alliance

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- According to the United States Environmental Protection Agency (U.S. EPA), the Design for the Environment (DfE) "Alternatives for Certain Phthalates Partnership" is intended to "inform the substitution to safer alternatives by evaluating the hazard associated with functional alternatives and to provide other relevant information pertaining to alternative assessment, in keeping with DfE principles."

- DfE officials have stated, "Substitution that is *not* informed by the best available information and science can lead to *unintended and undesired consequences*"[1] (i.e. alternatives with similar or even fewer well-studied human health and environmental profiles as the targeted chemical; higher costs for the supply chain manufacturers and consumers).

- The U.S. EPA's Seven Key Principles to Ensure Value and Usefulness of Alternatives require evaluation of whether the alternatives: (1) are commercially available; (2) are technologically feasible; (3) provide the same or better value in cost and performance; (4) have an improved health and environmental profile; (5) provide economic and social benefits; (6) have the potential for lasting change; and (7) involve participation by interested stakeholders.[2]

- DfE currently has identified 96 phthalate alternatives for 74 applications in a matrix containing more than 7,100 possible evaluations that need to be completed to determine the suitability of phthalate alternatives for each of these applications. As currently constructed, this is a daunting task and is dramatically beyond the scope of any previous DfE alternatives assessments.

- The purpose of this white paper is to complete one evaluation in the DfE alternatives matrix. This evaluation requires undertaking the complex process of an informed and useful

[1] Lavoie ET, Heine LG, Holder H, Rossi MS, Lee II RE, Connor EA, Vrabel MA, Difiore DM, and Davies CL. Chemical Alternatives Assessment: Enabling Substitution to Safer Chemicals. Environmental Science & Technology 44:9248 (2010) (emphasis added), available at http://pubs.acs.org/doi/abs/10.1021/es1015789.

[2] Cited in DfE Alternatives, *supra* note 1 and found in Lavoie, *supra* note 2, at 9248.

alternative assessment using risk assessment, exposure evaluation and the U.S. EPA's Seven Principles. To avoid unintended and undesired consequences, as recognized by DfE, this alternative assessment requires far more than just an evaluation of the hazard profile of the phthalate in a particular application and its potential alternatives.

- This white paper evaluates the use of DIDP (diisodecyl phthalate) in PVC-jacketed network cables that are installed in commercial and residential buildings in vertical "riser" shafts, as well as in exposed office hook-up cables to computer and communications equipment. These network cables are essential to today's sophisticated wired and wireless communications systems and provide the backbone infrastructure to transmit data from source servers, data centers, and control monitoring equipment to desk computers, hand-held communication devices, head phones, and a host of other communications devices. These high-speed telecommunications cables connect us to instantaneous communication and data on the internet.

FIGURE 1
4-pair Category 6 Copper Communications Network Cable

- The network cable (copper or optical fiber) must meet stringent Underwriters Laboratories (UL), National Fire Protection Association (NFPA) and other building code requirements for fire safety (low smoke and low flame spread), must meet strict data transmission performance standards required to support the network and also be very durable.

- PVC is the preferred choice of materials for cable jackets and internal cable components because of its superior flame retardant attributes, outstanding durability and flexibility (with appropriate plasticizer additive selection), superior thermal stability, outstanding productivity and energy efficiency during cable manufacture and relatively low cost.

- Plasticizers provide flexibility, strength and other attributes to the PVC jacket covering the network cable and are critical to its functionality. Diisodecyl phthalate (DIDP) is currently the preferred plasticizer for network cable because of its superior contribution to the physical properties of PVC, including durability, low volatility, melt viscosity, thermal stability, increased production speed, resistance to mass loss or physical deterioration upon aging and low cost.

- Realistic exposure scenarios are critical to an informed, useful and risk-based alternative assessment. This white paper compares DIDP in the network cable jacket to an alternative candidate: a trimellitate plasticizer, tri-2-ethylhexyl trimellitate (TOTM or TEHTM).

    - DIDP has been tested extensively for more than 40 years. U.S. and European governmental agencies, including the European Commission in January 2014, have determined DIDP is safe for use in all of its current applications, including cable sheathing, because of its low hazard potential and low actual exposure based on recent biomonitoring data. DIDP is not carcinogenic, has low toxicity to both mammals and the environment, and is not classified as "toxic" under U.S. and European regulatory programs.

- TOTM presents low toxicity to mammals and is not classified as "toxic" under many regulatory programs; however it has not been tested in a chronic (lifetime) exposure study, and lacks biomonitoring data to determine actual exposure. Thus, the current risk assessment indicates DIDP should not warrant a full- or high-priority substitution evaluation under the U.S. EPA's Seven Principles of Alternative Assessment for its use in network cable.

- In addition to the risk assessment described above, this white paper completes the suitability assessment of the critical performance attributes of TOTM compared to DIDP in network cable jackets and reaches the following conclusions:
  - More TOTM is needed to manufacture network cable than DIDP because it is less efficient as a plasticizer (as measured by the physical performance characteristics of PVC such as tensile strength, elongation, hardness and flex modulus);
  - The higher amount of TOTM needed in network cable jacketing requires the use of more flame retardant to achieve the same cable fire safety ratings as those using DIDP;
  - Producing TOTM generates a significantly larger carbon footprint including the use of more processing energy and the generation of more wastewater than the production of DIDP;
  - TOTM is about 25 percent more expensive than DIDP.
- Overall, in applying the U.S. EPA's Seven Key Principles, TOTM does not present a better value in terms of performance, cost or an improved environmental and health profile over DIDP in network cable jacketing. Therefore, substitution in this end-use application is not justified.

FIGURE 2

Buffered Optical Fiber Communications Network Cable

What is Flexible Vinyl and How is it Used?

FLEXIBLE VINYL, ALSO KNOWN AS POLYVINYL CHLORIDE (PVC), is widely used in medical, automotive, flooring, wall covering and military applications, as well as in building and construction. A particularly large and important application is PVC-coated wire and cable, installed in homes, commercial buildings, hospitals and "cloud" internet server farms and data centers.

PVC: Flexible, Versatile, Safe, and Sustainable

PVC's ability to bend and twist without cracking is a safety feature that makes it particularly suitable for a large array of applications. The addition of plasticizers (such as phthalates) provides the required flexibility to insulate and sheath copper and optical fiber cables.

By varying the type of the plasticizers contained within PVC compound formulations, cable manufacturers are able to produce a wide range of sheathing thicknesses and properties to withstand the demands of harsh environments and mission-critical applications. The exact degree of flexibility can be altered to meet the mechanical and aging requirements of the end-application.

Beyond wire and cable, PVC is the most widely used plastic material in buildings for applications such as drinking water and waste water pipes, window frames, flooring and roofing foils and wall coverings. Like many other materials used in buildings including plastics, wood and textiles, PVC products will burn when exposed to enough heat. However, unlike some of these other materials, PVC products are naturally self-extinguishing. This means that if the ignition source is withdrawn, PVC will stop burning. Because of its high chlorine content, PVC products have burning characteristics that are quite favorable: they are difficult to ignite, their heat production is comparatively low, and they tend to char rather than generate flaming droplets.

There are many reasons to continue using PVC products in buildings, as they perform exceptionally well, both technically and economically, and provide significant margins of safety in terms of fire prevention. For these reasons, and others, it is important to recognize the challenges and potential unintended consequences of making plastic formulation changes such as alternatives to phthalate plasticizers, as is being suggested by the U.S. EPA in conducting the DfE Assessment.

DfE Alternatives to Certain Phthalates Project: Background and Perspectives

THE U.S. EPA IS CONDUCTING the "Alternatives to Certain Phthalates Partnership" project because the agency is concerned with certain phthalates' "toxicity and the evidence of pervasive human and environmental exposure to these chemicals."[3] The Partnership is intended to "inform the substitution to safer alternatives by evaluating the hazard associated with functional alternatives and to provide other relevant information pertaining to alternative assessment, in keeping with DfE principles."[4]

The U.S. EPA states, "a number of phthalates have been detected in biomonitoring surveys of human tissues, indicating widespread human exposure. Adverse effects on the development of the reproductive system in male laboratory animals are the most sensitive health outcomes from phthalate exposure. Several studies have shown associations between phthalate exposures and adverse human health effects, although no causal link has been established. Recent scientific attention has focused on whether the cumulative effect of several phthalates may multiply the reproductive effects in the organism exposed."[5]

The U.S. EPA is conducting a Design for the Environment (DfE) alternatives assessment to develop information that could be used:

- To encourage industry to move away from phthalates in a non-regulatory setting,
- To expand risk management efforts beyond whatever regulatory action might be taken under the Toxic Substances Control Act of 1976 (TSCA),
- To use as input to a regulatory action.

[3] *Alternatives to Certain Phthalates Partnership,* EPA.gov, http://www.epa.gov/oppt/dfe/pubs/projects/phthalates/ (last visited Mar. 25, 2014).
[4] *DfE Alternatives, supra* note 1.
[5] *Alternatives to Certain Phthalates Partnership, supra* note 4.

The alternatives assessment will build upon existing knowledge and will consider exposures to all human subpopulations, including children. Additionally, environmental exposures will be considered.

However, DfE officials have warned, "Substitution that is not informed by the best available information and science can lead to unintended and undesired consequences."[6] These consequences include companies and consumers: (1) switching to a poorly understood and potentially more hazardous substitute; and (2) repeatedly incurring unnecessary costs in moving from one alternative to another. Thus, the alternative assessment process must be designed for "informing substitution to safer alternatives and minimizing the likelihood of unintended consequences."[7]

To achieve these goals, DfE must use the U.S. EPA's Seven Key Principles to Ensure Value and Usefulness of Alternatives.[8] These principles require an evaluation and determination that the alternatives:

1. Are commercially available or likely to become commercially available,
2. Are technologically feasible to satisfy the same functional use as the replaced chemical after considering needed changes in engineering processes or manufacturing equipment,
3. Deliver the same or better value in costs and performance as the replaced material,
4. Have an improved health and safety profile to enable confident substitution,
5. Provide economic and social benefits,
6. Have the potential for lasting change, and
7. Involve the participation of interested stakeholders.

Thus, the U.S. EPA's Seven Key Principles place the burden on the proponents of the alternative material to show that these principles are met to effectuate a substitution.

In part I of its report, published in draft in December of 2012, the U.S. EPA DfE attempts to define 96 phthalate alternatives, with 74 application areas. This is an enormous proposition, entailing a need to provide data for over 7,100 discrete tabular boxes. The objective of this white paper is to perform an alternative assessment using the U.S. EPA's Seven Principles for just one of the 7,100 alternative application/combinations. This case study utilizes a commonly found, PVC-related application area that is a high market-value application, using large volumes of common phthalates: the aforementioned riser network communications cable.

[6] Lavoie, *supra* note 2, at 9248.
[7] *Id.*
[8] Cited in *DfE Alternatives, supra* note 1 and found in Lavoie, *supra* note 2, at 9248.

CHAPTER 2

Varieties of Wire and Cable

THIS CHAPTER PROVIDES BACKGROUND on types of commonly employed wire and cable seen in today's market. The list below describes some of the wire and cable applications used in buildings, industrial facilities and consumer electronics:

BUILDING WIRE Used to distribute electrical power to and within residential and non-residential buildings. Products are sold through and to home centers, hardware retail chains, electrical distributors, industrial users, commercial users and OEMs.

CORDS, CORDSETS, APPLIANCE WIRE Two- or three-conductor cable insulated with thermoplastics that have a molded plug on one or both ends to transmit electrical energy to power equipment or electronic devices. Products are sold through distributors, retailers and directly to OEMs.

LOW VOLTAGE POWER CABLE Insulated wire and cable used to transmit and distribute electrical energy. Products are sold generally through distribution and electrical contractors.

COAXIAL AND WIRELESS ANTENNAE CABLE Primary applications for this type of cable are broadcasting, cable television signal distribution and wireless signal transmission. This is a rapidly growing application to support high broadband supply of data and video transmission to all mobile, hand-held devices. Products are sold through network providers.

DATA, VIDEO AND VOICE TRANSMISSION CABLES Twisted pair, coaxial copper conductors or optical fibers are insulated with materials to enhance the data and video transmission speed and bandwidth of network communications. These cables are predominantly sheathed with flame retardant and low smoke generating PVC compounds for safety, durability and flexibility. Products are sold through network system providers and integrators for communications, security and data transmission.

A Case Study: Riser Cable as Plasticized with DIDP or TOTM

NETWORK CABLES ARE THE ESSENTIAL BACKBONE of today's sophisticated wired and wireless communications systems. Every modern computer or hand-held communications device is dependent upon wire and cable as the backbone to transmit data from the source servers, data centers and control or monitoring equipment. Sophisticated wire and cable technology is still required for wireless transmitters, power re-charging and for personal electronic and media device peripherals such as headsets.

Network communications cables in commercial buildings are installed in both vertical shafts (called risers) and in horizontal spaces above the ceiling or below the floor. Communications networks are delivered from outside wire and cable designs into the base of commercial buildings. At these transition points, the copper or optical fiber cables are required to meet stringent code requirements for fire safety, along with data transmission standards required to support the network.

The primary path of network communications is initially provided to individual floors of buildings through isolated vertical shafts. Within these chimney-type shafts, wire and cable must meet strict, third-party verified fire safety performance testing requirements that prevent fire from expanding from floor-to-floor. Riser cables typically contain highly flame retardant, flexible PVC compounds in components such as outer cable sheaths and other internal components. Riser network communications cables are terminated in data centers or communications closets on each floor of a commercial building.

The cables that are used by individual business networks within buildings, from the data center to servers to desks, conference rooms and wireless transmitters are typically installed in the horizontal spaces above the ceiling or below the floors. These types of cables, due to their volume and proximity to people and egress corridors, must also meet stringent low smoke and low flame spread fire safety performance requirements to prevent the expansion of fire and to provide time and conditions for evacuation. Low smoke, flame retardant PVC is the preferred choice of materials for cable sheaths and internal cable components for these types of communications cables.

The purpose of this white paper is to describe the potential implications of phthalate substitutions in one of the more mainstream applications for plasticizers within a critical building communications application and contributing to the U.S. EPA's "Design for the Environment" project "Alternatives to Certain Phthalates Partnership". Riser network communications cable has been selected for the white paper to illustrate an example of the considerations and complexity required to achieve substitutions.

How is Riser Cable Made?

Achieving high-speed data and video transmission with physical and fire safety performance, is a complex engineering balance of cable design and material selection for each of the cable components. The basic properties of specialized plastic materials and the physical geometry of the cable components are what create the ability for an electronic signal, digital signal or light wave to be transmitted without any loss of information from the source to the computer hard drive or device.

Cable manufacturers create the designs for each component within the riser cable to minimize signal loss or crosstalk interference from outside sources. Materials such as polyethylene, with excellent dielectric properties, are used to insulate the copper conductors of a riser cable sufficiently to minimize transmission losses. Similarly, flame retardant PVC materials are used to buffer optical fibers to minimize light wave attenuation loss. Such losses are what ultimately slow the download or upload speed of data and video files from the server and computer.

While the core of riser cable is insulated to provide for high bandwidth and high-speed data transmission, the jacket (or sheath) of the cable is used both for physical strength and flexibility, as well as the primary barrier to minimize the spread of flame or generation of smoke in a developing fire hazard scenario. In a riser cable, the preferred jacket material is flame retardant PVC, to withstand the high heat, ignition and potential spread of intense flame from floor to floor in a building. The natural airflow and pressure drop in vertical shafts within a building are severe environments in the event of a fire. The unique properties of flexible and flame retardant PVC provide the inherent ignition barrier and generate char which prevents the exposure of flammable polyolefin or polyethylene core cable components to a flame source.

To produce high performance communications cables, precision controls are required. Most cable components, including insulated copper conductors, buffered optical fibers and the outer jacket, are produced by melting specialized plastic pellets. The melted plastic is extruded onto copper or optical fibers at very precise thicknesses and cooled with water in a trough or by spray. Such precision control requires that the plastic material melts and flows and that rheology is sufficiently created within the material formulation. In addition the physical, transmission and safety performance requirements of the finished cable must be met. These performance requirements are largely dictated by the balance of plasticizers, heat stabilizers, flame retardants and smoke suppressants in the vinyl compound. The correct balance is complex and challenging to achieve. The substitution of any of the materials in the formulation, such as DIDP phthalate plasticizer, will typically require changes to other raw materials or their weight balance in order to maintain the processability, fire safety, transmission and physical performance of the riser cable.

The Durability and Use of Riser Cable

Riser cable is the physical transfer point of data and video signals that have been transported externally into a computer or server network within a building. With multi-floor buildings and multiple tenants who maintain their own communications networks, the riser cable brings signals through copper or optical fiber cables from "the street" or satellite antennae to the network data center or communications closet on each floor. This cable is the initial internal cable that must maintain sufficient fire safety performance.

These cables begin and end at termination racks that distribute the signal to the server or network. Connections at the termination racks can severely strain the cables. Flexible PVC is the preferred jacket solution for these important combined physical and performance properties.

Riser cables tend to be installed primarily at the construction phase of a building or during major renovations. As the backbone of a building, they are often used throughout the life of the structure. Therefore, long-term aging and thermal stability (riser shafts are not air conditioned) need to be factored into the material formulations and raw material selection process. This, too, is an engineering demand for the plasticizers contained in flexible PVC.

Performance Standards Verification and Independent Safety Listings of Cables

Due to the criticality of network communications cable, there are many important performance certification standards that have been developed for both copper and optical fiber cables. In the U.S., ANSI approved standards have been generated by industry bodies such as the Telecommunications Industry Association (TIA), as well as by service providers like AT&T and Verizon. International standards are evolving rapidly, requiring many cable designs to be further enhanced with more complex geometries and components. For example, HDMI cables for data, video, television and gaming platforms have been created to achieve the high definition of modern display monitors. No longer is a coaxial or simple twisted pair cable design sufficient.

So that network providers and individual cloud computing data centers can supply the bandwidth and services required, cables must achieve third-party verified certifications to different levels of performance standards. Equally important, cables are also required to be third-party tested, listed and certified to meet the requirements of legally mandated fire, life and safety codes by national and local jurisdictions. The important fire, life and safety requirements for building materials and components including cables are established by authorities such as the National Fire Protection Association (NFPA) and maintained within NFPA Codes and Standards. For wire and cable and electrical components, the NFPA National Electrical Code® is legally adopted by state and local jurisdictions on three-year revision cycles and mandates the performance requirements in different sections or environments of a building, including riser shafts.

Third-party verification and safety certification listings are performed by organizations such as Underwriters Laboratories, Inc. (UL) and Intertek Testing Services / Engineering Testing Laboratories (ITS / ETL). Tests are costly and include both initial product listing evaluations, as well as continuous random monitoring of product performance and safety throughout the commercial life of a product. Any change to the geometric design or the internal material components of a product such as a wire and cable requires new listing certifications and ongoing random follow-up performance testing.

For a typical riser cable, the initial third-party safety listing and performance verification costs for a cable manufacturer can approach $20,000 - $30,000 per cable. The random follow-up testing is approximately $5,000 per year for each cable listing.

The Impact of Reformulation

Specialty materials manufacturers with research and development capabilities are continuously looking for the better engineering balance of properties offered by newer material technologies. Improvements for the cable manufacturer can be achieved through new cable designs or processing efficiencies. In addition, every material compound manufacturer in the world needs to meet a variety of global hazardous substance and sustainability requirements in the evolution of their product portfolios.

While this is a costly endeavor, each new development project is based on a value proposition to enhance performance, safety, health and environmental benefits. This is the nature of continuous improvement and innovation.

However, changes to material formulations or cable designs must be based on scientific evaluations, inclusive of real risk scenarios. Any substitution is a costly endeavor, from both a research and development investment as well as for product re-certification. It is inappropriate to force raw material substitution without peer-reviewed scientific data on the real hazard to health and environmental sustainability, inclusive of the exposure scenario. This must apply equally to both the incumbent materials, as well as the suggested substitute material. To have anecdotal lists of substances of concern based on inappropriate exposure or application information could have unintended consequences in several other human life and safety impacts of the mandated re-designs.

Over the past two decades, the wire and cable industry has methodically and successfully replaced lead-based stabilizers in plastic compounds with adequate metal hydrate substitutes, as a result of well-understood exposure health issues, primarily to the employees of the material manufacturers themselves. This came at a high cost to the material and cable manufacturers, but the complex engineering balance of performance, fire safety, environmental sustainability and commercial factors were successfully met. While this is an example of replacing one minor, yet challenging ingredient within wire and cable jacket and insulation compounds (typically less than 2% of the compound composition), these heat stabilizers are necessary to enable the material to withstand the melt temperatures of the extrusion process to produce the cable.

Plasticizers, on the other hand, are major ingredients (typically 25 to 50% of the finished compound) that enable the material to remain fully functional over the 10 to 50 years of the intended life of the product. Plasticizers are often used in synergistic and compatible combinations to accomplish the desired end-use performance requirements. As such, substituting plasticizers demands an extremely thorough, complex and long-term assessment process that typically occurs when the product performance requirements are enhanced.

Each plasticizer should be assessed based on its own risk factors, inclusive of the hazard and application exposure. It is certainly inappropriate to cast a wide net over all phthalate plasticizers based on an individual grade used in materials for a specific application. For example, it is not appropriate to require a substitution of a certain phthalate grade used in baby accessories or toys that can be mouthed, if it can be safely used in a riser wire and cable that is installed in an isolated riser shaft in a building.

For riser wire and cable, lead-free fire resistant PVC and the other cable materials such as polyethylene or polyester are well understood for their risk assessment. To force substitution through a general discussion on phthalates could have severe and unknown impacts on cost, availability, fire safety and long-term durability. These substitutions should be individually assessed in each individual application to determine the real science-based benefit to performance, human, environmental, health and fire safety.

DIDP Plasticizer is Proven Safe in Wire and Cable

In a general sense, the substitution of DIDP (diisodecyl phthalate) with TOTM (tri-2-ethylhexyl trimellitate, also abbreviated as TEHTM) in flame resistant PVC can be done, while maintaining the complex engineering balance described above. However, these formulations have to be adjusted for other components, such as flame retardants, because TOTM is less efficient; more is required to achieve the same properties. Because TOTM is flammable, this means that flame retardants must be added at higher levels than in DIDP-plasticized compounds.

This assessment calls into question whether the finished compound is better, safer or more beneficial using TOTM plasticizer when compared to the original that uses DIDP. Also, do the added costs of these new formulations provide the necessary value proposition and benefit to be commercially viable while meeting the intent of substitution efforts?

The Safety of Incumbent Phthalates

PLASTICIZERS ARE SUBSTANCES USED TO MAKE INHERENTLY BRITTLE materials soft and flexible. This is not a new concept; various materials have been used to make hard things soft and bendable for thousands of years. For example, water has been used to soften clay since the early evolution of man, and oils have been used for centuries to plasticize pitch for waterproofing boats.

Modern plasticizers are substances which, when combined with PVC and other polymers, create a whole new world of physical properties for high performing applications and uses that bring a myriad of benefits to everyday life. Plasticizers are not chemically bound to PVC, but are incorporated into the plastic matrix during processing to allow the matrix to flex. Today, over 90 percent of all plasticizers consumed are employed in flexible PVC applications, largely for the building and construction, automotive and wire and cable markets.

Globally, approximately seven million tons of plasticizers are consumed every year, of which U.S. consumption accounts for approximately 800,000 tons and European consumption accounts for approximately 1.4 million tons. The U.S. plasticizer market is dominated by phthalates, with approximately 500,000 tons of the total U.S. consumption. Higher molecular weight phthalates (such as DINP, DIDP, DPHP) account for approximately 45% of total plasticizer use in the U.S. The European plasticizer market has shifted toward high molecular weight phthalates (often referred to as high phthalates) more quickly, which today represent just over 55% of total plasticizers consumed in Europe.[9]

Plasticizers are colorless and odorless liquids that cannot be treated as additives like pigments or fillers. They comprise 10% to over 50% of flexible vinyl material formulations and are, therefore, major functional components that determine and improve the physical properties of PVC.

[9] CEH, 2013.

Typically, these plasticizers are esters that have low vapor pressure and good heat stability. Most of them are chemically inert. There have been over 10,000 esters suggested, with over 300 different commercial launches, of which less than 50 are in commercial use.[10] They can be divided in two wide application categories, based on their performance features:

- General purpose plasticizers are suited to a very wide range of applications and processing techniques where they bring an optimized balance of cost, versatility, and performance.

- Specialty plasticizers impart one or more special properties that cannot be obtained by the use of a general purpose plasticizer alone. They are suited to a narrow range of applications and are produced in smaller quantities than general purpose plasticizers.

General Purpose Plasticizers

It is precisely for their low cost, high permanence, and versatility that phthalates such as diisononyl phthalate (DINP), diisodecyl phthalate (DIDP) and dipropylheptyl phthalate (DPHP) are used as general purpose plasticizers in a wide variety of applications. These plasticizers process efficiently, improving PVC melt viscosity and increasing production speeds, resulting in better workability and reduced out-of-service or broken equipment. They are commonly selected by product manufacturers because of their low volatility and durability and because they offer the best balance between cost and performance. General purpose phthalates are vital for energy cables used in buildings and for power distribution wiring buried underground which must remain flexible even at low temperatures.

Specialty Plasticizers

For more stringent cable operating conditions, such as oil extraction resistance, high temperature resistance or fire resistance, general purpose high phthalates can be blended with or replaced by specialty plasticizers such as di-tridecyl phthalates (DTDP), trimellitates (TOTM or TINTM), phosphate esters or polymeric plasticizers.

Di-tridecyl phthalates, linear undecyl phthalates or trimellitate plasticizers have become the first choice for very high-temperature resistant applications such as the wiring used near automobile engines.

Phosphate ester plasticizers are commonly used in applications where additional flame-retardant and smoke-suppressant properties are important.

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[10] Godwin, 2012.

Polymeric plasticizers are ideal for use in cables where oil resistance is necessary or when plastic materials other than PVC are susceptible to stress cracking when in contact with flexible PVC cables.

Performance Considerations

Tables 1 and 2 highlight the important performance considerations for comparing plasticizers for use in wire and cable applications. Apart from cost, some of the most important criteria are: efficiency (amount of plasticizer required to achieve the desired softness), low temperature performance (retention of flexibility at low temperatures), processing (time and temperature required to incorporate plasticizer into the PVC resin and for the finished product to be made) and UL aging (performance in Underwriters Laboratories testing).

Table 1[11] shows the relative performance of four plasticizers with "10" representing the best performance and green highlight representing better performance in the DIDP-TOTM comparison. DEHP (di-2-ethylhexyl phthalate), for example, is best with respect to cost, efficiency, and processing; however, it would only be suitable for lower temperature rated wire and cable uses and provides no advantage in low temperature flexibility performance. TOTM, on the other hand, performs best for higher temperature wire and cable applications but is more expensive and has disadvantages in efficiency, low temperature flexibility and processing. DIDP is widely used in wire and cable applications because it is economical, is more efficient and processes better than the specialty plasticizers such as DUP (di-undecyl phthalate, a predominately linear C11 phthalate ester) and TOTM. DIDP can also be used to meet a number of the UL rating requirements except for those requiring the highest temperature conditions.

TABLE 1

Plasticizer	Cost	Efficiency	Low Temp.	Processing	UL Aging
DEHP	10	10	5	10	4
DIDP	10	7	5	7	7
DUP	7	6	10	5	9
TOTM	7	6	4	6	10

An overview of the performance of various commercial plasticizers in high temperature aging tests to meet UL requirements is shown in Table 2. The table shows that as the wall thickness of the cable jacket decreases and the aging temperature increases, higher molecular

[11] Table 1 prepared and reviewed by technical experts from Flexible Vinyl Alliance member companies.

weight plasticizers are required to ensure that the physical performance requirements of the jacket are retained (e.g., tensile strength or low temperature flexibility). As the chain length of the alcohols increase, the higher temperature performance of the cable jacketing compound improves. For the di-phthalate esters, improved thermal performance is achieved using DINP (di-isononyl phthalate, a C9 phthalate ester) => DIDP/DPHP (C10 phthalates, DPHP is dipropylheptyl phthalate) => DUP (linear C11) => DTDP (di-isotridecyl phthalate, a C13 phthalate ester). For the highest temperature applications, tri-ester trimellitates such as TOTM or TINTM (trei-isononyl tremelliate) are required.[12]

TABLE 2

Wall thickness (mil)	Test temperatures for 7-day aging, deg C			
	100	113	121	136
8	DIDP, DPHP	DUP	DUP	TOTM, TINTM
15	DIDP, DPHP	911P, DUP	DUP, DIDP/DTDP	DUP/TOTM
30	DINP, DIDP, DPHP	DIDP	DIDP	DTDP/TINTM
60	DINP, DIDP, DPHP	DIDP, DPHP	DIDP, DPHP	DUP, DTDP

Adapted from Godwin and Krauskopf, 2008

Safety Profile of Incumbent DIDP Phthalate in Riser Cable

DIDP has been extensively tested to determine its potential impact on human health and the environment. These test results have been reviewed by regulatory authorities and experts in the U.S. and Europe.[13] Scientific assessments have determined that DIDP is safe for use in its current applications due to its low hazard potential and expected low exposures.

Importantly, in January 2014, the European Commission completed its review of a comprehensive, 368-page evaluation of DIDP and DINP by the European Chemical Hazard Agency. The Commission concluded that there is "no unacceptable risk" from the use of DIDP (and DINP) in articles, including cable sheathing, that are not mouthing toys and childcare arti-

[12] Godwin and Krauskopf, 2008.
[13] NTP-CERHE, 2003, and ECHA, 2013.

cles.[14] The Commission further concluded, "in light of the absence of any further risks from the uses of DINP and DIDP, the evaluation of potential substitutes has been less pertinent."[15]

Results of a 2008 Korean study indicate that DIDP is not carcinogenic.[16] The National Toxicology Program Center for Evaluation of Risks to Human Reproduction (NTP CERHR) in 2003 concluded that there was evidence of developmental effects in rats but that there was minimal or negligible concern for humans.[17] Related phthalate products have also been declared safe in Australia by the Department of Health.[18]

In addition, a recent study by researchers from the U.S. EPA found that exposure to DIDP was unlikely to result in anti-androgenic effects.[19] DIDP also has low environmental toxicity and may be safely handled, having been determined to be low hazard for skin and eye irritation and sensitization. Biomonitoring data shows that human exposures to DIDP are several orders of magnitude lower than those levels found to cause adverse effects in animals.[20]

Using the U.S. EPA DfE criteria, the following hazard assessment for DIDP is expected:[21]

Design for the Environment Criteria - Hazard Ratings: Diisodecyl phthalate (DIDP)														
Human toxicity											**Ecotox**		**Fate**	
C	**M**	**R**	**D**	**AT**	**RD**	**N**	**SnS**	**SnR**	**IrS**	**IrE**	**AA**	**CA**	**P**	**B**
L	**L**	**L**	**M**	**L**	**L**	*L*	**L**	*L*	**vL**	**L**	**L**	**L**	**L**	**L**

Developmental (D) – Listed under CA Proposition 65 (M or H using DfE criteria), but assessed as M based on animal data and lack of anti-androgenic effects.

Additionally, all end points except for two are rated with bold letters to indicate that a large amount of test data on DIDP exists. Low hazard concerns for neurotoxicity (N) and respiratory sensitization (SnR) are expected based on read-across data from other phthalate esters.

14 European Commission (EC): *Phthalates entry 52 – Commission conclusions on the review clause and next steps* (January 15, 2014) at 4, available at http://ec.europa.eu/enterprise/sectors/chemicals/files/reach/entry-52_en.pdf, based on review of European Chemicals Agency (ECHA): *Evaluation of new scientific evidence concerning DINP and DIDP* (August 2013) at 4, available at http://echa.europa.eu/documents/10162/31b4067e-de40-4044-93e8-9c9ff1960715.

15 *Id.*

16 Cho, 2008 and 2010.

17 NTP CERHR, 2003.

18 NICNAS, 2013.

19 Hannas, 2012.

20 Kranzler, 2013.

21 Robust summaries of the important toxicology endpoints may be found at the ECHA website, CAS# 68515-49-1 at http://echa.europa.eu/web/guest/information-on-chemicals/registered-substances.

The Functional Importance of Phthalates In the Context of Safety Performance in End-Use Applications

THERE IS A LIMITED RANGE OF ALTERNATIVE PLASTICIZERS that can, first, meet the physical property requirements of a riser cable jacketing compound, and second, are within reasonable cost differential relative to the incumbents. For the purposes of this analysis, substitutes deemed unacceptable for physical properties have been eliminated; substitutes carrying a cost penalty of greater than 50% in the final product have also been eliminated.

Multivariate analysis, incorporating a number of safety attributes, involves weighting the importance of various endpoints. Assigning an even weight as a default is still an assignment of weighting. A sensitivity analysis can been done varying the weighting of major hazard endpoints.

Riser cable insulation and jackets can contain as many as 15 ingredients in the compound. As a major ingredient along with the PVC resin, the role of the plasticizer goes well beyond its primary function of softening the PVC compound to the desired level. Some of the more important functions are:

1. Compoundability

The plasticizer plays a significant role as compatibilizer with the many minor ingredients necessary to give the finished compound its ultimate performance in the end use application. Two or more functional additives may be incompatible with each other or with the base PVC resin, but are amalgamated successfully by the chemistry offered by the phthalate ester plasticizer. The successful dispersion of all the ingredients is necessary to provide for a uniform mixture in which there are undetectable variations in composition from sample to sample.

2. Processability

Smooth and efficient coating of wire conductors is necessary where just the right amount of adhesion to the conductor, tolerable shrinkage of the compound upon cooling and optimal rate of application to the wire through the extruder are accomplished. With some alternatives, rate of application becomes a limiting factor rendering the end product uneconomical to manufacture. Alternative plasticizers must also provide the cable jacket surface finish required for efficient installation of the cable in a building. This needs to be accounted for during an alternatives assessment.

3. Durability

A critical application attribute for riser cables is service life and they are expected to last the life of the building, typically several decades. Any alternative must be assessed for its ability to last as long as the incumbent phthalate esters based compounds under the end use application conditions. The plasticizer must resist degradation from oxidation, moisture absorption or biological attack in order to survive decades of installation in dark and damp locations subjected to extreme fluctuations in temperature.

4. Fire performance

In the unfortunate event of a building fire, each building component including wire insulation and jacketing must provide enough fire resistance so the building occupants can escape safely and allow enough time for fire fighters to extinguish combustion. A number of additives included in the plastic compound assure these important functions. Fire retardants that reduce heat release and flame spread, smoke suppressants that minimize smoke generation and char formers that intumesce or carbonize to control flammability are a few of the compound ingredients that are typically required. The plasticizer must allow each of these special additives to perform their intended function.

As explained above, weighting of each of these factors in an alternative assessment can influence the result. Alternatives must not result in a regrettable substitution whereby, for the sake of replacing a phthalate ester, the alternative is incapable of functioning under all the demands of the application as well as the original material.

Alternatives to Incumbent Phthalates

POTENTIAL ALTERNATIVES TO INCUMBENT PHTHALATES fall into several categories including, trimellitates, terephthalates, sebacates, adipates, citrates, succinates, benzoates, phosphates, polymeric plasticizers and others.

According to the U.S. EPA DfE, 96 plasticizers have been identified as potential alternatives to incumbent phthalates. Equivalency claims of some of these alternatives are not well considered and need to be evaluated in end-use applications to ensure they meet the intended performance specifications.

In the example of riser cable, alternative plasticizers fall into two distinct categories:

- alternatives that perform well in the application but are more expensive

- alternatives that do not perform well and will not meet the end-use application requirements

In this white paper, trimellitate plasticizers demonstrate an example of a successful, but more costly, substitution. There are also several families of alternatives that exist and cannot meet this end-use application due to performance deficiencies.

Phthalates are multipurpose plasticizers that can be used in broad applications. Many alternatives have a more narrow application bandwidth and need to be fully evaluated for performance in intended applications. In the case of riser cable, the critical properties include service temperature, flammability, thermal stability, volume resistivity, loss of mass and retention of physical properties on aging including tensile and elongation.

The balance of this white paper will explore the scientific assessment of replacing riser cable flame resistant PVC jacket materials that historically have used DIDP plasticizer with a non-phthalate substitute, tris (octyl) trimellitate (TOTM).

Trimellitate Plasticizers (TOTM)

- Trimellitate esters are more expensive than phthalate esters on a pound for pound basis (usually about 25% more expensive).

- Trimellitate esters are less efficient than phthalate esters, as plasticizers, so more is needed in a formulation to achieve the same properties in a PVC compound. Efficiency can be quantified as a function of PVC durometer hardness for equal parts of plasticizer added. In other words, if a trimellitate is 10% less efficient than DIDP, it needs to be used at 10% higher levels to achieve the same hardness.

- The required higher usage level of a trimellitate ester changes the PVC compound formulation sufficiently to have an adverse affect on its fire resistance properties (fuel load). A higher loading of flame retardants are added to maintain the same fire resistance achieved with cable jacketing compounds that contain DIDP.

- The manufacturing process of trimellitate esters has a significantly larger carbon footprint: to produce 1 mole of a phthalate ester, 2 moles of alcohol are required whereas production of 1 mole of a trimellitate ester requires 3 moles of alcohol. The trimellitate ester manufacturing process is also slower compared to a phthalate ester manufacturing process (due to reaction kinetics) and leads to increased power usage during production.

- The trimellitate ester manufacturing process generates more wastewater compared to the phthalate ester manufacturing process. In producing one mole of trimellitate ester, two moles of water are generated compared to a phthalate ester that generates only one mole of water. The water generated in the manufacturing process requires treatment (usually through a biological waste treatment system) because of dissolved organics.

Assessing Risk

WHEN EVALUATING RISK, both exposure and potential hazard must be considered. And in some cases, a judgment call must be made: Is it safer to have low exposure to a high hazard compound, or high exposure to a low hazard compound? These decisions have to be made in conjunction with the other technical, performance, cost and environmental issues previously discussed.

DIDP, as described earlier, is of low toxicity, both to mammals and to the environment. It is not classified as being "toxic" by a number of global regulatory bodies. It has been thoroughly tested.

TOTM is also of low toxicity to mammals and also is not classified as being "toxic" according to a number of regulatory bodies. However, TOTM does not have a chronic (lifetime) exposure study, which would allow for a more thorough toxicity comparison to be made between the two plasticizers.

Using the U.S. EPA DfE criteria, the following hazard assessment of TOTM is expected:[22]

Design for the Environment Criteria - Hazard Ratings: Triethylhexyl trimellitate (TOTM)														
Human toxicity											Ecotox		Fate	
C	M	R	D	AT	RD	N	SnS	SnR	IrS	IrE	AA	CA	P	B
dg	*L*	L	M	L	L	dg	L	dg	L	L	L	L	M	L

Mutagenicity in vivo - older study, Klimisch 4

Developmental - spermatocyte and sertoli cell effects at 300 mg/kg, NOAEL 100 mg/kg in OECD 421, but no effect on reproduction. OECD 414 NOAEL 1000 mg/kg with a few transient aereoli in males at higher doses.

Determination of risk must also consider exposure or exposure potential. Both DIDP and TOTM are relatively "large" molecules with low vapor pressures, significantly limiting the pos-

[22] For robust summaries of the toxicology data for TOTM see the ECHA website, CAS# 3319-31-1 at http://echa.europa.eu/web/guest/information-on-chemicals/registered-substances. Also see p. 46-68 in a 2010 summary by the US CPSC at https://www.cpsc.gov/PageFiles/126546/phthalsub.pdf.

sibility of inhalation exposure. Potential exposures from other sources have not been definitively characterized. However, due to the recent emergence of biomonitoring data, "actual" exposures to the general public can be more clearly defined, including all sources, not just the wire and cable application in this white paper. Actual exposures to DIDP are extremely low (mean: < 1 ug/kg/day; 95th % < 5 ug/kg/day), using data from the CDC NHANES studies of thousands of people in the U.S.

In the case of TOTM, biomonitoring data are not available, so there is no way to quantify actual exposures at this time.

In determining risk, several agencies around the world calculate "health based exposure guidance values." Both the U.S. Consumer Product Safety Commission and the European Food Safety Authority have developed allowable daily intakes (ADI)/tolerable daily intakes (TDI) for DIDP based on the available toxicity data and accounting for sensitive populations, including children. These two authorities concluded that based on available data, the ADI/TDI for DIDP is 150 ug/kg/day. This value is orders of magnitude higher than what actual exposures are for DIDP, indicating that DIDP, overall, poses minimal risks to humans.

Indeed, most recently, the European Commission concluded in January 2014 that the use of DIDP (and DINP) in articles, including cable sheathing, that are not mouthing toys or childcare articles presents "no unacceptable risk."[23] This European Commission conclusion is based on the Commission's review of a 368-page comprehensive evaluation of DIDP and DINP by the European Chemical Hazard Agency.

[23] ECHA *Evaluation of New Scientific Evidence Concerning DINP and DIDP, supra* note 10, at 4.

Conclusions

THIS WHITE PAPER HAS EXPLAINED the complex technical and scientific considerations that determine the appropriate choice for the plasticizers used in plastic compounds to produce communications network cable and a potential substitution decision. DIDP is the predominant plasticizer currently used in this application. For this white paper, over 90 non-phthalate potential substitutes were initially screened. Based on engineering judgment and industry experience over many decades, TOTM was selected for this alternative assessment as the most suitable and feasible potential non-phthalate substitute that would meet the myriad of demanding performance requirements for network cable.

When the U.S. EPA's Seven Key Principles to Ensure Value and Usefulness of Alternatives are applied, TOTM does not merit replacing DIDP in materials used for network cable. A material solution containing TOTM presents a lower total value relative to incumbent materials that contain DIDP, in terms of both cost and performance. More TOTM is needed than DIDP to achieve equivalent physical performance, more flame retardants are needed when TOTM is used and TOTM costs up to 25% more than DIDP.

Likewise, TOTM does not present improved health or environmental performance, has not been studied nearly as much as DIDP and has a significantly higher carbon footprint. Thus, under the U.S. EPA's Seven Key Principles, substitution of TOTM for DIDP in materials for riser communications network cable is not warranted.

About the Flexible Vinyl Alliance

THE FLEXIBLE VINYL ALLIANCE is a coalition of trade organizations, materials suppliers, compounders, formulators, molders and fabricators established in 2009. FVA provides messaging and advocacy on the proven safety, economy and utility of flexible PVC, a material used in a wide range of health care, recreational, military, automotive, building, flooring, wire and cable, construction and packaging applications.

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Flexible Vinyl Alliance

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