



DUPONT NON-HALOGENATED FLAME RETARDANT POLYMERS for Electrical and Electronic Applications

**HOW TO MEET REGULATORY, ENVIRONMENTAL,
SAFETY AND PERFORMANCE CHALLENGES
IN ELECTRICAL AND ELECTRONIC COMPONENTS
WITH DUPONT NHFR POLYMERS**

**A WHITE PAPER GUIDE FOR
DESIGN ENGINEERS AND MATERIAL SPECIFIERS**

Executive Summary

The electrical and electronic (E&E) industry is under unprecedented regulatory pressure to improve product safety and performance, and to reduce the health and environmental impact of the plastics and elastomers used.

Tough legislation requires these materials to be halogen-free and flame-retardant (NHFR), produce low smoke emissions, and comply with the **WEEE** (Waste Electrical and Electronic Equipment) Directive, the EU **RoHS** (Restriction of Hazardous Substances in Electrical and Electronic Equipment) Directive, and the EU **REACH** Regulation, requiring the industry to manage the risks from chemicals, and progressively substitute the most dangerous.

In addition, E&E manufacturers must comply with a raft of new standards and tests, including **IEC 60335** for the safety of electrical appliances, **EN 45545** for testing the fire behavior of materials and components for trains, **UL 94** for the flammability of plastic materials in devices and appliances, and **UL 746** to evaluate the physical, electrical, flammability and thermal properties of polymeric materials for electrical equipment.

Key trends that also demand new solutions and better performing materials include *smart grids* designed to bring energy delivery systems into the 21st century, energy saving technologies like *photovoltaics* and *LED and OLED lighting systems*, and *substitution of PVC and Brominated Flame Retardants (BFRs)* with Non Halogen Flame Retardants (NHFR) materials in computers and mobile devices.

The trend to *miniaturization* demands materials that can be molded into more complex, thinner wall plastic constructions. *Auto engine downsizing* and encapsulation demands high temp hydrolysis-resistant materials for critical E&E applications.

The solutions to many of these urgent E&E market needs are provided by DuPont— the largest portfolio of high-performance fully compliant NHFR products for electrical components including DuPont™ **Crastin®** PBT resin, DuPont™ **Hytrel®** TPE resin, DuPont™ **Rynite®** PET resin and DuPont™ **Zytel®** PPA and PA66 polyamides — backed by DuPont know-how in processing, predictive engineering and Computer Aided Design.

Overview

Components manufactured by the electrical and electronic (E&E) industry must meet unprecedented regulatory, environmental, safety and performance challenges. That means the materials used in the design and construction of every E&E part made today must meet tougher demands than ever before. Many plastics and elastomers traditionally used in products such as LED lighting, connector systems, circuit breakers and other electrical components are less able to meet all these requirements, either because they are not regulation-compliant, or do not satisfy the latest high performance needs, or both.

This white paper takes a step-by-step guide through the regulatory framework and environmental issues confronting the industry, looks at the key emerging trends, outlines DuPont's materials and applications development expertise and helps engineers and specifiers select the DuPont products that will bring the greatest benefits to their application.

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1. The regulatory framework challenging the industry

The E&E industry is under regulatory pressure to improve product safety and performance, reduce the health and environmental impact of the plastics and elastomers used, and comply with end-of-life recycling requirements.

Organizations within the industry face several major challenges, most important being requirements for halogen-free, flame-retardance, low smoke emissions, and compliance with the WEEE (Waste Electrical and Electronic Equipment) Directive, the EU RoHS (Restriction of Hazardous Substances in Electrical and Electronic Equipment) Directive, and the four processes of the EU REACH regulation — the Registration, Evaluation, Authorization and Restriction of Chemicals

The **WEEE Directive** requires the end-of-life separation of halogen-containing materials, and aims to reduce the amount of waste electrical and electronic equipment going to landfill. It requires all manufacturers and producers to take responsibility for what happens to the products they sell at the end of the product's life.

The **RoHS Directive** aims to increase recycling and/or reuse of electrical and electronic equipment, and requires the substitution of heavy metals such as lead, mercury, cadmium and hexavalent chromium and traditional flame-retardants with safer alternatives.

The **REACH Regulation** places responsibility on the industry to manage the risks from chemicals, provide safety information on the properties of their chemical substances to allow safe handling, and register the information in a central European Chemical Agency database. It also calls for the progressive substitution of the most dangerous chemicals when suitable alternatives have been identified, and applies the concept of "No data, no market".

2. Environmental and safety issues facing the industry

The increase in environmental awareness around the world, linked to environmental issues and human health and safety, has also driven new standards and regulations, some of which impact the E&E industry. Today, materials suppliers and component manufacturers must comply with several essential requirements, most important of which are:

- **IEC 60335** — a standard published by IEC (International Electrotechnical Commission), specifying requirements for the safety of electrical appliances for household and similar purposes, including electrical heat pumps, air conditioners and dehumidifiers. It also covers appliances not intended for normal household use, operated in shops, light industry and farms, that may be a source of danger to the public.
- **EN 45545** — a European Standard prepared by CEN (European Committee for Standardization) specifying requirements for the fire testing and behavior of materials and components for trains. Aimed at improving fire safety on trains, it defines tests for flame spread, smoke density and toxicity, heat release, the burning behavior of electro-technical components, and fire protection requirements for electrical equipment, among others.
- **UL 94** — a standard for tests of flammability of plastic materials for parts in devices and appliances. Developed by Underwriters Laboratory Inc., it serves as a preliminary indication of the acceptability of polymeric materials with respect to flammability for a particular application — for example, thinner wall structures. Tests include assessment of factors such as ease of ignition, burning rate, flame spread, fuel contribution, intensity of burning, and products of combustion.
- **UL 746 (A, B and C)** — a three-part standard to evaluate the physical, electrical, flammability, thermal and other properties of polymeric materials under consideration for electrical equipment, and provide guidance for the material manufacturer, the molder, the end-product manufacturer, safety engineers and other interested parties.

Exacting requirements

These test standards have become particularly relevant in view of many well-publicized incidents of electrical fires such as those generated by electric motors used in tumble driers and washing machines. As a result, the safety and environmental requirements for plastic and elastomeric materials used by the industry have become much more exacting, and have driven the demand for non-halogenated, fire-retardant (NHFR) materials.

Customers within the industry continue to seek new solutions that will not only comply with the directives, but also maintain or improve on the properties of the widely used thermoplastic or thermoset materials used today. Many of these materials are no longer fully compliant with the latest regulations, being difficult to recycle, and linked to unhealthy emissions.

Electrical market OEMs looking for alternatives to halogens as flame retardants for health, safety and recycling reasons are now focusing their efforts on developing efficient new regulation-compliant products without compromising on performance, safety and cost. Therefore, material requirements for critical applications such as contactors, circuit breakers, coil bobbins, motors, relays and transformers have become much tougher:

- Parts must meet demanding electrical and mechanical requirements under harsh conditions such as high temperature and moisture.
- Materials must provide safer and cost-effective solutions.
- Today's market requirements demand environmentally friendly, halogen-free, low smoke, low acidity and recyclable materials that comply with the directives and standards mentioned above.

The future now

Companies manufacturing E&E products today that will need to be recycled in 10+ years time must think now of the key requirements, and look for thermoset replacement with conforming NHFR polymers to reduce the environmental impact of less compliant products, or risk raising serious issues of compliance in the next 10-15 years.

3. Key emerging trends in electrical and electronic markets

- *Smart grids* — significant investment in smart electrical grids designed to bring energy delivery systems into the 21st century demand new solutions and create new opportunities for the industry. These include smart meters (see *Figure 1*) to measure electrical consumption in residential, commercial and industrial facilities.



Figure 1: DuPont™ Rynite® FR is the material of choice for smart meter applications, offering an excellent balance of mechanical properties and dimensional stability, suitable for heavy-duty applications demanding resistance to extreme weather conditions.

- *Reducing energy consumption* — one of the key challenges to the global environment. Solar energy is one of the renewable energy sources with the highest potential for growth. The challenge is for the photovoltaic industry to decrease the cost of solar energy in order to be competitive with the electricity grid today.
- *Evolution of LED and OLED lighting systems* — Light Emitting Diodes (LEDs) and Organic Light Emitting Diodes (OLEDs) are energy efficient alternatives to traditional incandescent, halogen and compact fluorescent lamps (CFLs) (see Figure 2). They consume less power, are mercury-free, emit less UV and IR light and are capable of significantly longer lifespan. The LED lighting market is projected to grow by over 12x during the next decade, driven by government and environmental policies. In addition, European Union Directive 20008/89/EC requires all road vehicles manufactured after August 2012 to be equipped with daytime running lights (mainly LED type), a practice that is increasingly mandated worldwide.

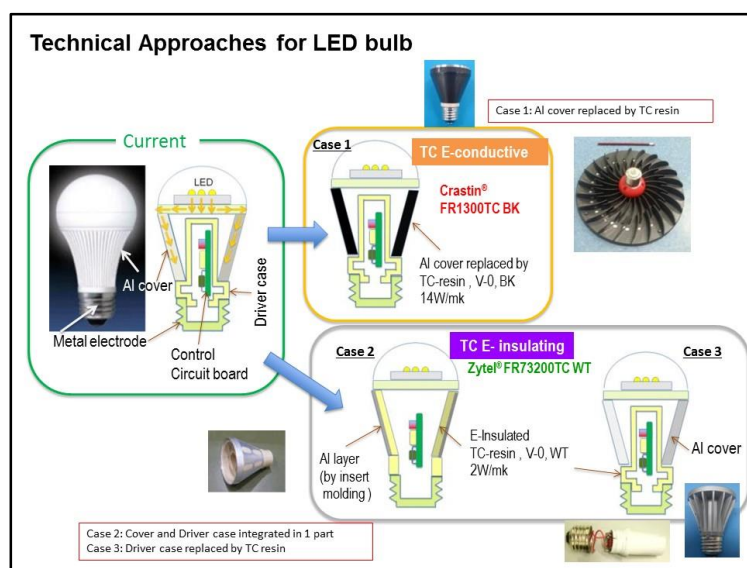


Figure 2: DuPont™ Crastin® PBT and Zytel® PPA and PA66 resins for LED applications including reflex/mixing chambers, heat sink, housing/fixture/electrical chamber and lens.

- *Material transition in the computer world* — the world's leading manufacturers of mobile devices, laptops, tablets and desktop computers are substituting extensively used polyvinyl chloride (PVC) and brominated flame retardants (BFRs) with non-halogenated flame retardant materials.
- *Lightweighting and miniaturization* — the trend to smaller and lighter devices is driving the trend to miniaturization and to more complex, thinner wall plastic constructions. Tiny one-size-fits-all USB Type-C connectors (see Figure 3) are expected to replace Type A and B connectors as the universal port for all devices including desktops, laptops and mobile phones. Automotive connectors have become 4-5 times smaller in little over three years and now number typically 700 in the average family car.



Figure 3: Evolution in miniaturization of USB connectors. Latest universal Type-C connector is encapsulated with halogen free DuPont™ Zytel® HTN polyamide, offering excellent flow rates, superior dimensional stability and low dielectric constant specifically, enabling wall thickness as little as 0.18mm.

- *Tougher under-hood environments for E&E components* — auto engine downsizing, more encapsulation and increasingly confined engine compartments are creating hotter and more hostile operating environments for many critical E&E applications, demanding high temperature and hydrolysis resistant materials.
- *Faster productivity* — demands for faster production turnaround favor materials with acknowledged UL flammability ratings and Electrical Insulation System (EIS) homologation.

4. DuPont: The industry's widest portfolio of NHFR material solutions

DuPont offers the industry's largest portfolio of pre-UL-approved electrical insulation systems (EIS) and fully compliant state-of-the-art materials and solutions for electrical components to help customers stay ahead of the latest E&E industry trends. The company's NHFR materials are seeing widespread use in E&E applications such as insulating elements and housings for circuit breakers, contactors, transformers and motors. They meet current standards and regulatory requirements without compromising on performance.

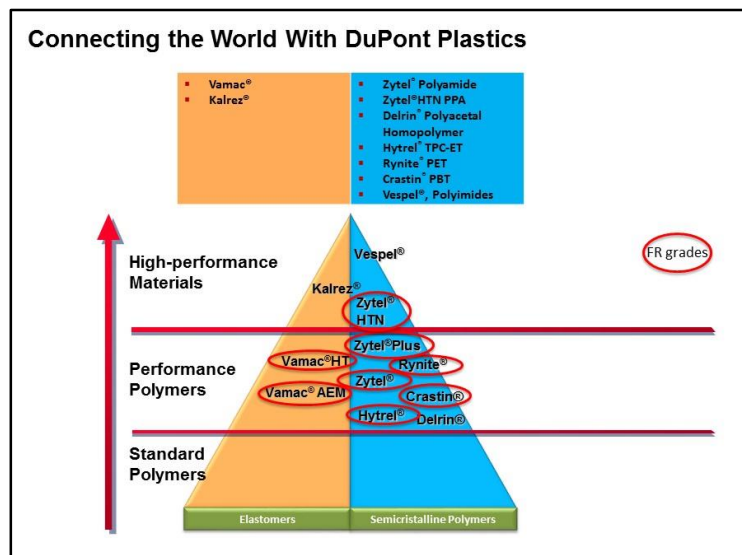


Figure 4: DuPont offers the largest portfolio of NHFR materials solutions to help the E&E industry comply with all important regulatory, environmental, recycling and safety requirements.

DuPont offers an unusual choice to E&E designers by tailoring materials to the specific application rather than proposing a one-size-fits-all solution, with the goal of increasing performance and processing efficiency while lowering costs. Material specifiers and designers can select bespoke grades from the following key product families:

5. DuPont™ Crastin® polybutylene terephthalate (PBT)

Crastin® NHFR is a new generation of non-halogenated flame retardant PBT grades, offering excellent electrical insulation properties and electric strength plus a balance of stiffness, toughness, dimensional stability, heat and moisture resistance and surface finish that make them particularly well-suited for connectors, electrical components, circuit breakers and distribution boxes.

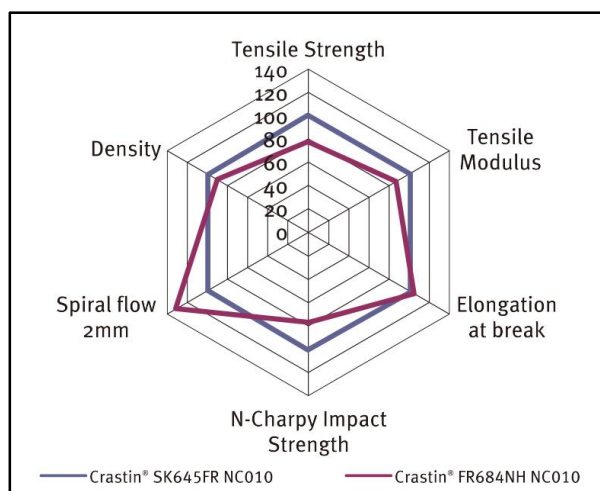


Figure 5. New non-halogenated DuPont™ Crastin® provides lower density, higher flow and higher CTI of 450-500V than halogenated PBT, with minimal loss of mechanical properties.

Summary of advantages:

- Industry-leading high CTI (comparative tracking index) of 450-500V.
- More stable dielectric strength than polyamides at high temperature.
- Lower density and superior flow qualities than halogenated PBT; similar easy processing on conventional injection molding machines.
- High flow enables complex shapes with thinner walls (as thin as 0.8mm), miniaturization and high design flexibility.
- Free of PHAs, BPA, red phosphorus, bromine, chlorine and antimony, fulfils RoHS, WEEE and REACH requirements.
- Complies with UL, IEC, VDE and other electrical industry safety standards, including UL 746 RTI approval at 130°C at 0.8mm, UL 94 flammability approval V0 at 0.8mm, GWFI (Glow Wire Flammability Index) 960°C, and GWIT (Glow Wire Ignition Temperature) 750°C at 0.8mm — enables long-term performance at higher temperatures.

6. DuPont™ Hytrel® thermoplastic polyester elastomer (TPC-ET)

Hytrel® TPC-ET balances the flexibility of high performance elastomers with the strength and processability of thermoplastics, combining resilience, heat and chemical resistance and durability to outperform typical flexible PVC compounds in tensile strength, elongation, and low temperature toughness (see Figure 6).

Outperforming PVC			
Property	Hytrel® ^a	PVC ^b	Test Method
Tensile strength, psi (MPa)	5800 (40)	2500-3500 (17-24)	ASTM-D-638
Elongation, %	500	250-350	ASTM-D-638
Brittle point, °C	<-70	-10 to -30	ASTM-D-746
Specific gravity	1.20	1.30-1.41	ASTM-D-792

a: Hytrel® 55555HS

b: Typical flexible PVC compounds for wire & cable

Figure 6: Halogen-free, RoHS compliant DuPont™ Hytrel® TPC-ET outperforms typical flexible PVC compounds in tensile strength, elongation and low temperature toughness.

In consumer electronics, Hytrel® is specified for applications such as laptop B-cover frame sealing, hard disk drive brackets and computer feet (see Figure 7).



Figure 7: Flexible DuPont™ Hytrel® is used for laptop components such as laptop B-cover frame sealing, hard disk drive (HDD) brackets and computer feet.

Parts made with Hytrel® can flex in multiple directions cycle after cycle, long after rubber would break. It is an excellent choice when innovative new designs require creation of unique parts with multiple performance characteristics, since it can be processed using many thermoplastic methods.

Summary of advantages:

- All Hytrel® TPC-ET materials are completely halogen free.
- Processable on standard thermoplastic lines, and suitable for injection molding.
- Flammability performance from UL94 V-2 to V-0, some grades offer Limited Oxygen Index (LOI) of >40%.
- Low temperature flexibility (-70°C) and high temperature rating (125°C) better than PP, PE, and PVC for longer life.

- Halogen-free Hytrel® contains no plasticisers, lead or other heavy metals, is RoHS-compliant and readily recycled.

7. DuPont™ Rynite® polyethylene terephthalate (PET)

Stiff UV-resistant Rynite® resin unites the best properties of reinforced PET to bring enhanced durability and electronic performance to coil forms, electrical encapsulation, solenoids, smart meters, photovoltaic parts (see Figure 8), solar junction boxes, switches and other critical components, in replacement of die-cast metals and thermosets. Outstanding flow characteristics enable easy filling of complex thin-walled molds, design freedom and miniaturization of parts.



Figure 8: UV resistant DuPont™ Rynite® brings durable, strong and cost-effective properties to photovoltaic solar junction boxes, module frames and mounting structure components.

Summary of advantages:

- Higher strength, stiffness and durability than most plastics.
- Outstanding electrical insulating performance.
- A lighter, easier to work and more cost-effective solution than metal.
- High structural and dimensional stability, high RTI (Relative Thermal Index) and HDT (Heat Deflection Temperature or Deformation Temperature under load).
- High UV, electrical and chemical resistance.
- Can outperform thermosets as material of choice for many applications.
- Suitable for heavy duty applications demanding resistance to extreme weather conditions.

8. DuPont™ Zytel® PPA and PA66 polyamide resins



Figure 9: The new generation of DuPont™ Zytel® NHFR nylon resins offer best-in-class high temperature performance (RTI UL746), industry-leading high CTI, flame retardance in thin-wall constructions, excellent surface finish and high flow for connectors, circuit breakers and thousands of other electrical and electronic components.

Versatile Zytel® HTN PPA and PA66 NHFR nylon resins represent the E&E industry's broadest portfolio of non-halogenated flame retardant engineering polymers. Several Zytel® NH grades have lower density and better tracking resistance than comparable halogen-containing products, resulting in lightweighting and cost advantages, and parts that can serve in more demanding electrical applications (see Figure 10). They cover a wide range of E&E performance needs from stiffness to heat resistance.

Typical applications include hand-held consumer electronics, such as thinner, lighter frames, spines and housings for laptops and mobile phones, new USB Type-C connectors, relays, circuit breakers, actuators, bobbins, LED components, heat sinks, battery casings, motor housings, and terminal blocks.

General Properties (Competition vs. DuPont NH Offerings)

		GR30% LCP	GM40% LCP	GR40% Halogen FR PA46	GR30% Standard	GR30% High Flow	GR35% Super High Flow	GR45% Low Warpage High Flow
Items	Units				FR52G30NH	FR52G30NHF	FR52G35NHF	FR52G45NHLW
Tensile Strength	MPa	156	118	159	150	155	138	149
Elongation	%	1.7	1.5	2.2	2.1	2.2	1.9	1.3
Flexural Strength	MPa	225	164	-	238	-	204	200
Flexural Modulus	MPa	15000	10100	14500	8900	10000	10800	14000
N-Charpy Impact	KJ/m2	14	3.1	14.5	8	7.2	7.4	7.6
Density	g/cm3	1.61	1.71	1.77	1.44	1.44	1.51	1.63
Flammability		V0(0.4mm)	V0(0.4mm)	V0(0.2mm)	V0(0.4mm)	V0(0.4mm)	V0(0.4mm)	V0(0.4mm)
Shrinkage MD	%	0.1	0.23	-	0.3	0.3	0.39	0.47
Shrinkage TD	%	0.5	0.63	-	1	1	1.36	0.93

Figure 10: Zytel® NHFR grades offer several processing and performance advantages versus competitive polyamide products, including significantly lower density which translates into lower weight and as much as 10% lower cost of the part.

Summary of advantages:

- Zytel® resins contain no elemental phosphorus, heavy metals or antimony.
- Excellent flow rates, superior dimensional stability and low dielectric constant specifically for moulding USB Type-C connectors.
- High flow, low melt viscosity, lower density enables wall thickness as little as 0.18mm — less than 2 sheets of paper.
- Zytel® HTN is available as glass-reinforced flame retardant V-0 lubricated PPA resins.
- Better electrical properties — higher CTI than conventional halogenated FR V-0 resins.

9. Selecting DuPont materials by application

Following is a guide to the best high-performance DuPont material for your application. In some cases, one product has been tailored to a specific application; in others, one or more products have been developed to offer a choice.

Electrical and electronic applications:

Product	UL 94 V0 (mm)	LOI (%)	GWIT (°C) (mm)	GWFI (°C) (mm)	RTI Electr (°C) (mm)	CTI UL Class (V)	Electronic Connectors	Industrial circuit breakers	Fuse switchers	Terminal blocks	Contacts	Railways- automation and control	EIS systems	Motors	Lighting	Smart Meters	Photovoltaics (JB, Inverters)	Switches & Relays	Microswitches	Wall plates, Plugs and Sockets	Batteries	Appliance Switches & Connectors	Plugs+Terminal Blocks	Micro Circuit Breakers
Zytel Glass Reinforced	0.5	32	725 (1.0)	960 (1.0)	160 (0.75)	0 (600)																		
Zytel Non Reinforced	0.4	35	775 (0.75)	960 (0.75)	130 (0.75)	0 (600)																		
Zytel HTN Standard	0.4	40	725 (0.75)	960 (0.75)	140 (0.75)	0 (600)																		
Zytel HTN High Flow	0.4		725 (0.75)	960 (0.75)	140 (0.75)	0 (600)																		
Crastin	0.75		750 (0.75)	960 (0.75)	130 (0.75)	1 (500)																		
Rynite FR533NH	0.4		775 (0.75)	960 (0.75)	155 (0.75)	2 (250-400)																		
	Suitable																							
	Possible																							

Figure 11: Guide to DuPont NHFR products by electrical/electronic application.

10. How DuPont adds value to the industry

The singular objective of DuPont in developing materials for the E&E industry is to create competitive advantage for its customers through sustainable and innovative solutions in design, materials and processing:

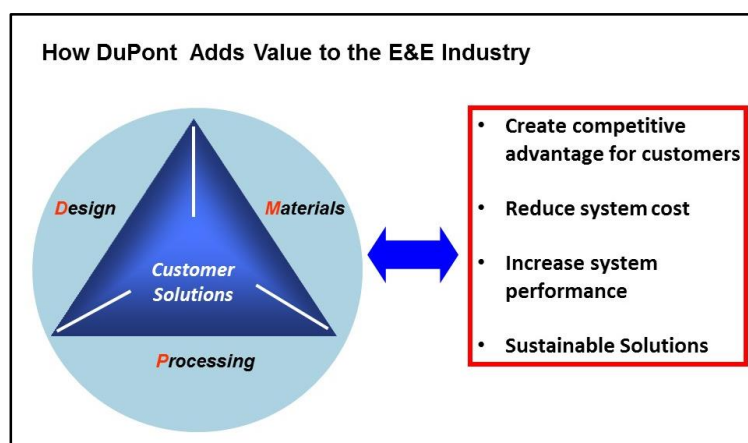


Figure 12: Three key ways DuPont adds value to E&E customer products.

- **Design** – by working together with customers to optimize possibilities.
- **Materials** – by creating new formulations when new properties are required.
- **Processing** – by working together with customers to optimize process efficiency with DuPont products.

Extensive know-how

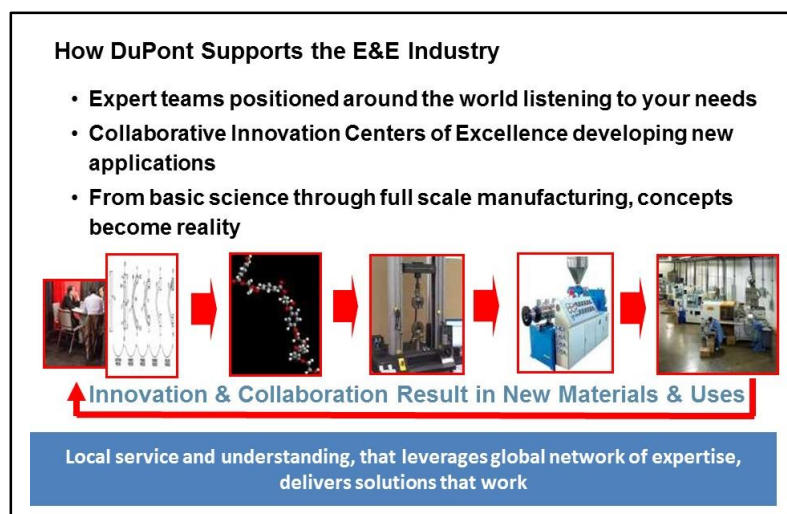


Figure 13. DuPont expertise, widest portfolio of polymer products and solutions, expert teams and Innovation Centers of Excellence are available to customers around the world.

To support the customer, DuPont combines its extensive applications development know-how in the industry with an impressive worldwide technical support network using basic science through to full-scale manufacturing. The result? Concepts become reality.

DuPont support for customers is achieved via:

- Expert teams positioned in 34 locations around the world listening to your needs.
- Collaborative Innovation Centers of Excellence developing new applications.
- Computer Aided Engineering and Design (CAE/CAD), on-site technical support, tool and customized gate design, mold flow simulation, etc.
- Local service and understanding that leverages the global network of expertise, delivers solutions that work by enhancing customer's product performance, improving sustainability and reducing total system cost at competitive price.

Meeting market trends with innovative solutions

Recent commercialized developments at DuPont that have enabled customers to meet many of the latest market trends *and* comply with non-halogen, flame retardant and recycling requirements include:

Reducing energy consumption

- *Smart grids* — **DuPont™ Rynite® FR** is the material of choice for smart meter applications, offering an excellent balance of mechanical properties and dimensional stability, suitable for heavy-duty applications demanding resistance to extreme weather conditions.
- *Solar power* — specialized grades of **Rynite® PET UV** resistant resins bring a high degree of stiffness and weather resistance to lightweight structural photovoltaic applications.
- *Evolution of LED and OLED lighting systems* — **Crastin®** PBT and **Zytel®** PA66 and HTN PPA resins are specified for reflex/mixing chamber, heat sink, housing/fixture/electrical chamber and lens components.

Safety

- *EIS capabilities* — DuPont offers more than 400 safe, pre-approved **electrical insulating system** (*EIS) combinations to help customers speed up product launch time to market by as much as 18 months, and reduce total product testing cost by as much as \$80,000.

*Open and closed EIS are groups of materials that through extensive testing are recognized as well suited to electrical applications at a given temperature or class, and at a specified material thickness.

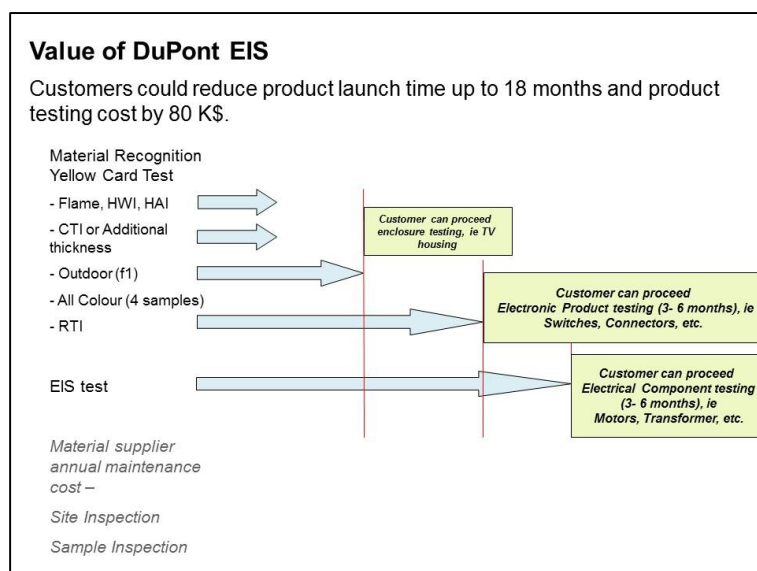


Figure 14: Over 400 DuPont EIS combinations can help customers to dramatically reduce typical launch times, and save significantly on product testing costs.

Lightweighting and miniaturization

- *Ultra light, thin and small components* — High flow and low density **Zytel®**, HTN and **Crastin®** polymers enable lighter, dimensionally stable moldings as thin as 0.18mm.
- *Material transition in the computer world* — **Zytel®** HTN PPA is used for covers, housings and new USB Type-C mobile phone connectors. **Hytrel®** is used for tablet covers, overmolded grips and protective edges.
- *Tougher under-hood environments for E&E components* — automotive connectors of **Zytel®**, HTN and **Crastin®** provide high temperature and hydrolysis resistant performance.

** Halogen-free or non-halogenated when used herein means that halogen is not an intended ingredient of our product.*

NOTES

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The data provided should not be used to establish specification limits or used alone as the basis of design; they are not intended to substitute for any testing you may need to conduct to determine for yourself the suitability of a specific material for your particular purposes. Since DuPont cannot anticipate all variations in actual end-use and disposal conditions, DuPont does not guarantee results, makes no warranties and assumes no liability in connection with any use of this information. All such information is given and accepted at the buyer's risk. It is intended for use by persons having technical skill, at their own discretion and risk. Nothing in this publication is to be considered as a license to operate under or a recommendation to infringe any patent.

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