

THE PRODUCTION OF PVC CABLES: PAST AND FUTURE OF THE VALUE CHAIN

**SAFETY, ENVIRONMENT, PERFORMANCE,
COST-EFFECTIVENESS**

Summary

Several plastics are now used as insulation and sheathing for electric cables or as sheathing for telecommunication cables.

Among these, the plastic material most used, but also able to ensure the best cost/performance ratio, high sustainability and recyclability, is PVC (PolyVinyl Chloride).

The strengths of PVC can be summarised as follows:

- good electrical and insulating properties
- low ignitability, flammability and flame propagation due to the presence of chlorine, which breaks off the combustion process by scavenging free radicals and by surface charring.
(the low flammability can be improved by formulations that can contribute to slow down flame propagation and by intumescence of the surfaces subjected to the action of fire)
- durability, the ability to maintain its performance over time
- easy to be processed (processability)
- low production costs
- sustainability, as confirmed by LCA
- possibility to be recycled in other applications.

In particular, regarding the advantages of PVC in fire prevention it is useful to highlight that:

- the presence of the halogen component in the polymer chain makes ignition of PVC articles difficult. This characteristic can also be enhanced through the addition of certain flame-retardants and/or fireproof substances
- due to the difficulty to catch fire, and thanks to its limited contribution in terms of heat release, PVC is generally not considered to be a determining factor that leads to the development of fire
- PVC does not produce flaming droplets
- PVC releases HCl gas, which is detected due to its odor even at concentrations well below its level of concern to human health. This helps in the detection of the fire before it has developed and has become beyond control, therefore ensuring an early warning to escape on time or intervene to fight the fire.

This last point is very important because there is a broad and unfounded perception that during a fire, PVC cables develop more toxic gases compared to the alternative materials. Studies have shown that this assumption is not correct, as for example demonstrated by the findings of the investigation on the fire that happened at the airport in Düsseldorf in 1996.

Regarding the sustainability of the formulations used to produce PVC cables, it is important to consider how the whole PVC value chain has endeavoured over the last 10-20 years to make not only the production but also the products more sustainable. The Voluntary Commitments of the European PVC industry, Vinyl 2010 and VinylPlus, allowed to develop a new generation of PVC formulations free of substances of concern. and to develop recycling technologies, such as Vinyloop, which allow reuse of the recycled material in high performance applications.

1 . introduction

1.1 The history

The first cable for transmission of electrical energy has been used in Europe in 1890 to supply power to the lamps for street lighting.

The early cables were insulated with gutta-percha, a rubber insulating material that was substituted with dielectric laminated paper and oil which allowed the construction of cables for medium voltage.

A 1900 publication describes the requirements for a cable: "Water Resistant over 100 years, flexible and extensible, so resistant to voltage that the thinner insulating layer with a dielectric constant of approximately that of air is sufficient".

It is curious to note that these requirements have remained the same even today, and in fact even now represent a target for manufacturers of cables.

It is not a coincidence that the first cables were economically satisfactory and of good quality so that the old cables, with lined paper and oil have shown to be able to achieve a useful life of 50 years or more.

In the '30s the development of chemistry has led to the use of polymers as insulator for cables, and numerous experiments have been made with various plastics, many of which have proved to be technically suitable for insulating electrical cables.

1.2 The European industry of electrical cables

The European cable industry sector is converting about 2% of the total polymer demand.

The main polymers used in the cables are polyvinyl chloride (PVC) and polyethylene (PE). Rubber is used alternatively, but in limited quantities.

The economic crisis naturally affected the EU demand for cables: Demand expressed in terms of raw materials processed into cables dropped from approximately 1.5 million tons in 2007 to 1.1 million tons in 2011. A slight demand increase is expected for the next few years, but it will however remain well below the level of 2007.

As an indication, today in the EU-27 there are over 350 cable manufacturing facilities and Italy is the country that, with 20%, has most processing plants.

This is also confirmed by the fact that Italy continues to be, together with Germany, the European country with the highest demand for polymers for cables, estimated at about 15% of the total EU-28.

1.3 PVC cables

As previously mentioned, PVC remains a material of choice in cables because of its many strengths that are detailed in later chapters, and which can be summarised in:

- good electrical properties and insulation to a wide range of temperatures
- an inherent fire safety thanks to its low ignitability, low flammability, low (or inhibition of) flame propagation and moderate heat release
- excellent durability with an expected long time in use
- easy processability
- cost efficiency
- recyclability.

Furthermore it can be stated that :

- PVC cables comply with the limits accepted for smoke opacity
- smoke acidity is considered a problem only for some special applications, and has never been found the determining factor in terms of threat to people
- the acidic smoke due to the presence of gaseous HCl allows an early detection of fire, thereby providing an early warning for evacuation or for fighting the fire.

2 . Socio-economic impact of the industry PVC cables in Europe

At the end of the '90s, in Europe, 65% of the cables was made of PVC, with a PVC consumption calculated in 2000 of about 770,000 tons , with the following breakdown of the applications :

Application	type	tons
power cables in B&C and E&E equipment	insulation LV	228.000
	sheating LV	258.000
	insulation MV	7.500
	sheating MV	30.500
	insulation HV	7.500
Telecommunication	insulation	76.000
	sheating	76.000
Automotive		68.500
Mine		7.500
Others		15.000

A further audit carried out in 2008 showed for the PVC used in cable a decrease both in percentage, estimated at around 55%, or in quantity, estimated at about 690,000 tonnes.

In 2009, cables accounted for 7% of the total sales of PVC polymer in Western Europe with a market share still greater than the main competitor, PE, with its various types: LDPE, linear PE, XLPE, HFPE and HFFR.

In 2015, the consumption of PVC in cables was still estimated higher, even if only slightly, than PE, with a market share close to 50%. The comparison between the various PVC and PE formulations indicates that :

1. PVC is used for energy and telecommunications systems at low or medium voltage
2. PE is used in telecommunication cables
3. XLPE (cross-linked PE) is mainly used for medium and high power transmission, but also for low power in case LSFOH (low smoke zero halogen fume) is required.

3. Flammability of materials

3.1 The fire behavior of materials

The behavior of a material to fire depends on some parameters and the related performance of the material itself.

The development of any fire also when PVC is involved from the ignition of the material to the release of fire effluents, is a complex process, which can be represented by the following diagram, also applicable to a wide range of

materials.

It shows that the "heat from a source of ignition" applied to the PVC solid material leads to a "thermal degradation" and a "thermal oxidation".

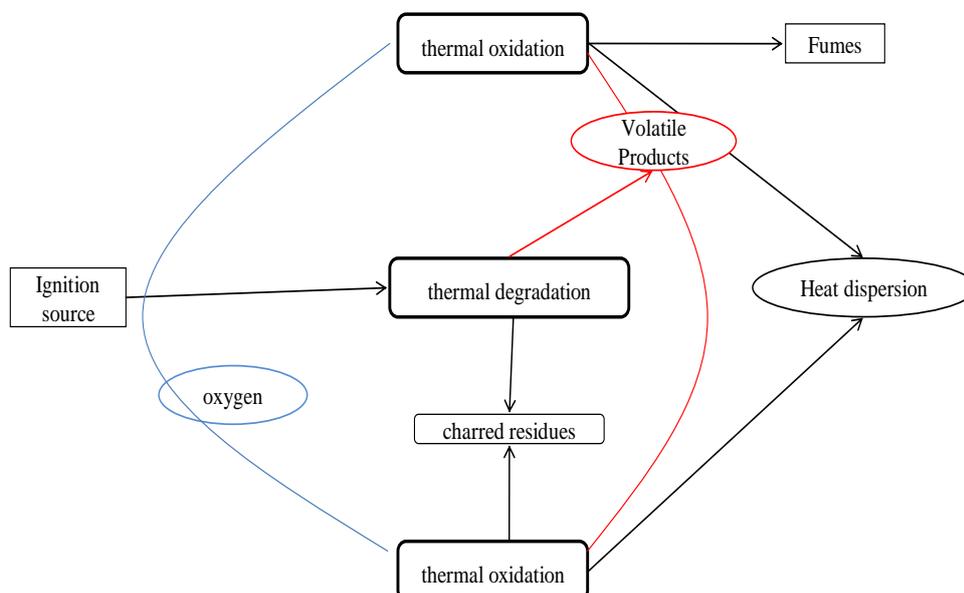
The "thermal degradation" produces gases (volatile products) which are mixed with the hot air and, when the oxygen concentration is within the flammability limits and the temperature above the ignition temperature, react through a process of "thermo oxidation in the gas phase" with the development of flames and fumes.

A "thermal oxidation" occurs also within the solid matrix and for this reason is called "in condensed phase" and produces not only a charred residue but also other volatile compounds that react with oxygen through the "gas phase" thermal oxidation.

The scheme is of general application, but some stages of the cycle, such as the charring and thermal oxidation in the condensed phase typical of PVC, may be absent or not significant with many other materials; this is depending on the type of material and on the conditions of combustion.

The combustion proceeds until the material is completely consumed if the heat transmitted from the flame is sufficient to maintain its thermal degradation rate above the minimum value required to feed the flame itself, otherwise the flame goes out when the heat source is removed.

So, to start a combustion process 3 components are necessary, combined with two requirements.



Components:

The fuel - its intrinsic (chemical structure, morphology, physico-chemical properties) and extrinsic (surface, geometry, dimensions) characteristics influence the development of the combustion.

The oxygen - required to permit the chemical reaction of oxidation of the fuel and must be in sufficient quantity in the environment where the fire develops.

The energy – it is transferred to the fuel through radiation, spark or flame. For a sustained flaming, the intensity and life time of the ignition source as well as the distance from the material are to be considered.

Requirements:

Stoichiometric Requirement - is the proper ratio between the substance that catches fire and the oxygen that acts as oxidizing. It is referred to as the "equivalence ratio".

Power Requirement – it must exceed the energy level of activation of the combustion process; this energy can be given by providing heat to reach the self-ignition temperature or through an external ignition source.

If the heat generated by the reactions of thermal oxidation in the gas phase and in condensed phase is sufficient to support the combustion process itself, it can feed itself also when the heat brought by the ignition source has become negligible or has disappeared.

3.2 Terminology and parameters involved

The following table lists the main terms used to describe fire ignition and propagation of the flame until the extinction of the fire, and the terminology with which they are usually defined (sourced or adapted from ISO 13943):

Flammability: ability of a material or product to burn with a flame under specified conditions

Ignition: initiation of combustion

Flash over: transition to a state of total surface involvement in a fire of combustible materials within an enclosure

Flame propagation or flame spread: propagation of a flame front

Speed of flame propagation or flame spread rate: distance travelled by a flame front during its

propagation, divided by the time of travel, under specified conditions (unit: m.s⁻¹)

Flaming debris or burning debris: material other than droplets separating from a burning item and continuing to flame, during a fire or fire test

Flaming droplets or burning droplets: flaming molten or flaming liquefied drops which fall from a burning material and continue to burn

Heat release: thermal energy produced by combustion (unit: J)

Heat release rate: rate of thermal energy production generated by combustion (unit: W)

Smoke production: amount of smoke which is produced in a fire or fire test. The smoke production is determinate through the measurement of two parameters:

TSP, total smoke production, expressed with the unit of measurement of " m² "

SPR, smoke production rate, expressed with the unit of measurement of " m² / second "

Smoke opacity: ratio of incident light intensity to transmitted light intensity through smoke, under specified conditions (opacity of smoke is the reciprocal of transmittance)

(Optical) density of smoke: measure of the attenuation of a light beam passing through smoke expressed as the logarithm to the base 10 of the opacity of smoke

Toxic hazard: potential for harm resulting from exposure to toxic combustion products, such as asphyxiants and irritants

Asphyxiant: toxicant that causes hypoxia, which can result in central nervous system depression or cardiovascular effects, such as carbon monoxide (CO) and hydrogen cyanide (HCN).

Irritant: gas or aerosol that stimulates nerve receptors in the eyes, nose, mouth, throat and respiratory tract, causing varying degrees of discomfort and pain with the initiation of numerous physiological defense responses, such as reflex eye closure, tear production, coughing, and bronchoconstriction. Typical irritants are acidic species (e.g. HCl, HBr, HF, NO_x, SO₂), acrolein, formaldehyde.

Oxygen Index (OI) or Limiting Oxygen Index (LOI): minimum volume fraction of oxygen in a mixture of oxygen and other gases, at 23°C, that

will just support flaming combustion of a material under specified test conditions (unit: %).

Thermal decomposition: process whereby the action of heat or elevated temperature on an item causes changes to the chemical composition

Thermal degradation: process whereby the action of heat or elevated temperature on an item causes a deterioration of one or more properties, e.g. physical, mechanical or electrical properties (This is different from thermal decomposition)

Thermo-oxidative decomposition: process whereby heat exposure, for example via a temperature increase, in the presence of an oxidant (such as O₂), leads to chemical structure changes.

The relationship between these parameters and the PVC and the fire behavior of PVC is hereinafter explained and clarified.

3.3 Fire and its dangers

Fire is an uncontrolled thermal process that always develops because of the concurrent occurrence of three factors:

- a combustible material
- oxygen in the air
- a sufficient heat source such as a cigarette, an open flame or a short circuit

The fire leads to the following effects and threats:
thermal effect: materials combustion and heat release causing e.g. skin, eye and respiratory tract burns

toxic effect: development of an incapacitating atmosphere due to the release of toxicants and the depletion of oxygen, which leads to troubles of consciousness, asphyxiation and possibly death
traumatic effect: smoke and flames causing panic and a syndrome of "psychological aggression".

In addition to the effects they have on people and property, large fires have negative effects on the environment due to the release of gases and soot, their dispersion in the atmosphere and their deposition on the ground, with potential water and soil contamination.

These environmentally hazardous substances essentially are soot particles containing polycyclic aromatic hydrocarbons (PAHs) and volatile organic compounds (VOC). These substances

have a longer term effect compared to other toxic gases released from the burning materials, such as CO (carbon monoxide), HCN (hydrogen cyanide), HCl (hydrochloric acid), acrolein.

It is important to emphasize that the environmental impact of HCl is very limited as evidenced by a report by the Analysis and Research Swedish Institute, that says: "*HCl is unique among common fire gases in that its concentration in the gas phase decays by reacting rapidly with most construction surfaces, which limits its transportation (...).*"

The data suggest that HCl is unlikely to have significant impacts on vegetation within the fire plume zone (...)."

Even if PVC was accused of emitting dioxins in case of fire, as mentioned, e.g. in the Düsseldorf Airport fire investigation report 1996, the analysis showed that the danger due to PAH is much higher than that due to dioxins.

This has been confirmed by experts such as Prof. Rotard, Environmental Agency of Germany (German Environmental Agency, UBA), who said at a conference in Cologne in 1996: "*To summarise, the cancer risk due to PAH's in fire residues and combustion gases must be regarded as far higher than the risk related to dioxins.*"

It is also important to remember that all fires involving organic materials (plastics, wood, paper, cardboard, plant material, wool, foodstuff, textile, etc.) emit mixtures of toxic gases in which CO is always present and generally predominates.

4. The advantages of PVC in fire prevention

4.1 The behavior of PVC during a fire

Ignition and flammability

If the necessary factors (fuel - oxygen - heat) occur in the specific proportions, the start of the thermal degradation, and therefore uncontrolled fire can happen.

PVC behaviour: the presence of the halogen component in the molecules of the polymer makes it difficult for the PVC material to catch fire.

For instance, the Oxygen Index (OI) of rigid PVC is 50%. It ranges from 21 to 36% for PVC-P (plasticised PVC) and is only 17% for typical PE (reference "Flammability Handbook of Plastics". C

J Hilado. 4th ed. Technomic. 1990). OI may be slightly lower than 21 for PVC-P, depending on the plasticiser content. This means that burning PVC requires a higher oxygen concentration than PE for instance, combustion of which can therefore occur in presence of oxygen below its natural concentration in the air (21%).

Flame spread

Combustion increases the temperature of the materials located close where the fire has started; the materials ignite when they reach their ignition temperature. At this point the fire starts spreading. *PVC behaviour: the combined factors of high oxygen index and charring (see below) make it hard to have a sustained flaming of PVC in the absence of an external heat source. As another consequence, its contribution in terms of heat release is limited.*

Flaming droplets

The combustion destroys the structure of the burning material and particles thereof may fall as:

- flaming droplets
- burning debris or embers
- inert debris, such as ash and charred material

PVC behaviour: PVC does not produce flaming droplets or burning debris. Consequently, discontinuous flame propagation to another material located below is avoided.

Charring

Most of the burning products produce powdered ash, but some materials retain their solid structure and form a solid layer of carbonaceous residues that protects the surface from fire.

PVC behaviour: when burning, PVC produces a carbonaceous layer thanks to the presence of chlorine and its high oxygen index (see above). This structure forms a thermal barrier that protects the underlying part. The protective properties can be enhanced by intumescence (expansion of the char layer) induced by specific additives used for e.g. critical applications where resistance to fire is required.

Gas and smoke

The incapacitating impacts of smoke are due to loss of visibility and toxicity:

- reduced light and low visibility that may slow down movement or even preclude a safe evacuation
- effects of irritating or toxic gas that can impact cognitive and motor-skilled reactions of people, lead to incapacitation and ultimately death. Most casualties occur because people have inhaled a lethal amount of carbon monoxide (CO).

Smoke (obscuration and toxicity) is one component of fire effluents to be considered at the same level as heat and radiant energy in terms of tenability. The time to compromised tenability for individuals is the shortest of four distinct times estimated from consideration of asphyxiant fire gases, irritant fire gases, heat and visual obscuration.

Under some conditions, smoke can be corrosive, but this effect is generally of minor importance compared to the total damage caused by the fire itself (heat) or by the means used to fight it (e.g. water).

PVC behaviour: as any organic materials, PVC releases CO in variable quantities. The release of HCl gas is detected due to its odor even at concentrations well below its level of concern to human health. This helps in the detection of the fire before it has developed and has become beyond control, therefore ensuring an early warning to escape on time or intervene to fight the fire. Recent studies have shown that in typical fire scenarios, the release of HCl has never been the determining factor compromising tenability (Ref.: Guillaume E., Didieux F., Thiry A., Belliver A.. Real-scale fire tests of one-room apartments with regard to tenability assessment. Fire Safety Journal, vol. 70, pp. 81-97, 2014).

As mentioned above it can be concluded that:

- PVC has a low ignitability, low flammability and a low combustion heat
- thanks to the presence of a halogen in its composition, PVC does not contribute to the propagation of flames; this capacity is further improved by the addition of suitable additives such as flame retardants (see below)
- PVC stops burning when the heat source is removed
- PVC chars and does not produce burning droplets that can spread the fire
- the emission of HCl gas at the beginning of the fire acts as an early "warning" before the development of the fire, contrary to CO, which is odorless.

4.2 The flame retardant additives

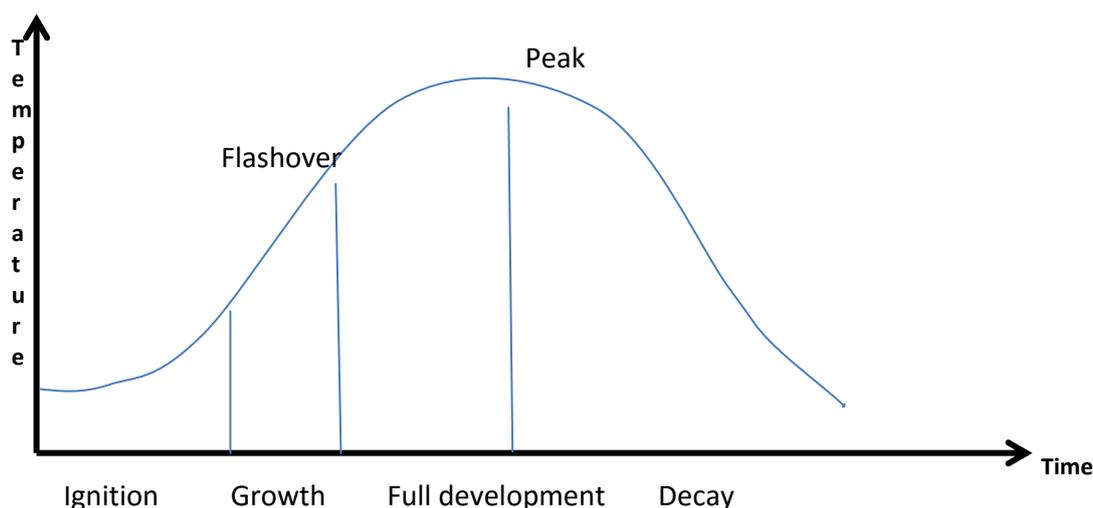
According to a universally recognized scheme (see ISO 834-1 and EN 1363-1), the development of a fire occurs through four main stages that refer to the temperature profile due to the combustion of materials in a close environment:

1st stage: ignition and start of the combustion.

2nd stage: slow development until the Flashover, which is the moment when the accumulated gases ignite, resulting in a rapid temperature increase and fire development.

3rd stage: peak of temperature and fire involving the whole environment.

4th stage: decay due to the reduction of the combustible material, available oxygen or an external intervention that dramatically lowers the temperature of the environment.



The flame retardant additives are active only in the first two stages of fire development.

According to the definitions listed in ISO 13943, the family of flame retardant additives can be subdivided into Fire-Retardant and Flame-Retardant.

Flame retardant: substance added, or a treatment applied, to a material in order to suppress or delay the appearance of a flame and/or reduce the flame spread rate

Fire retardant: substance added, or a treatment applied, to a material in order to delay ignition or to reduce the rate of combustion

The use of flame retardant(s) or fire retardant(s) does not necessarily suppress fire or terminate combustion

Note that there are additives that have both flame retardant and fire retardant properties.

4.2.1 The fire retardant

PVC

It is universally acknowledged that the halogenated organic compounds are extremely effective in improving fire behavior. The halogens present in organic compounds inhibit the

combustion because they develop a series of reactions directly in the gas phase that have as effect the removal of the radicals O^{\bullet} e H^{\bullet} that are constituents of the flame.

The halogenated compounds RX under the effect of heating decompose, forming R^{\bullet} e X^{\bullet} and, through a re-combination reaction, HX. The hydrogen halide (HX) reacts and neutralizes

radicals such as O^{\bullet} and H^{\bullet} that have an extremely high reactivity and are the main responsible for the pyrolysis of organic materials and therefore the spread of fire.

Therefore, PVC can be considered as a fire retardant because it contains chlorine.

Antimony Trioxide (Sb_2O_3)

The efficiency as fire retardant of halogenated organic compounds is significantly increased thanks to the synergic effect of Antimony Trioxide (Sb_2O_3). Acting as a sort of "catalyst", Antimony Trioxide promotes the break of carbon-halogen bond (CX bond) and the formation of halogenated compounds of antimony (characterized by X-Sb and Sb-O-X bonds) and H-Cl extremely effective in the removal of free radicals in the gas phase and therefore particularly repressive of flame propagation.

It was observed that the effect of Sb_2O_3 is particularly effective when only few phr (parts per 100 parts of PVC polymer) are introduced in the formulation (from 2 to 3.5 phr). It is also noted that even if more than this level of additive is added, the flame retardant behavior is not proportionally reflecting the content of the Sb_2O_3 . 7 phr can be considered as the threshold beyond which the

addition of Sb_2O_3 in formulation produces no more effect on the flame retardant performance.

Chlorinated-paraffin (medium chain)

In the formulations of PVC the halogen content can be increased by introducing as secondary plasticizer chlorinated paraffin up to its maximum level of compatibility. The chlorinated paraffin introduces the halogen chlorine as a flame retardant and at the same time partially contributes to modify the characteristics of hardness and flexibility of the material. The paraffin contained in this secondary plasticiser, however, increases the content of fuel present in the material, so the chlorine paraffin can be considered to be effective only if used for replacing other plasticisers that burn more easily.

Conclusion: the combination of PVC, chlorine-paraffin, antimony trioxide allows producing materials with characteristics of high fire resistance capable of satisfying the requirements of the majority of the reference standards in use until today.

4.2.2 The flame retardant

Magnesium Hydroxide

At high temperature ($> 300^\circ \text{C}$) the magnesium hydroxide decomposes with a dehydrating endothermic reaction.

Therefore, it ensures:

- cooling of the substrate resulting in a slowing down of the pyrolysis reaction of the polymer
- formation of water which, in the vapor phase, reduces the concentration of O_2 (oxidizing) in the gas phase
- formation of MgO that forms a protective thin layer on the polymer surface and that (even if with limited effect) slows down the heat and matter exchange because of its impermeability to gases and fumes.

Aluminium tri- hydrate

At temperatures $> 190^\circ \text{C}$ Aluminium tri-hydrate develops an dehydrating endothermic reaction entirely similar to those described for magnesium hydroxide.

Zinc borate ($2\text{ZnO } 3\text{B}_2\text{O}_3 \cdot 3.5\text{H}_2\text{O}$)

At temperatures $> 300^\circ \text{C}$, zinc borate hydrate releases water of crystallization through an endothermic reaction that produces:

- cooling of the substrate resulting in slow pyrolysis reactions of the polymer

- the release of crystallization water that, as steam, dilutes the O_2 content in the gas phase
- the effect of heat also produces a compact layer of B_2O_3 , glassy and hard, on the surface of the material, having a thermal insulation effect and reducing the polymer - oxygen exchange surface and the emission of airborne particulate from the surface
- finally, even if with less significant effect, in case of mixture with other organic halides, the zinc borate decomposes and reacts with halogens to form ZnX_2 , ZnX , H_3BO_3 , BX_3 ($\text{X} = \text{Cl}$ or Br) that are able to cover the surface of the charred material decreasing the exchange with air.

4.2.3 The additive flame retardants that are also fire retardants

Additives containing phosphorus - Phosphate esters

The additives containing phosphorus can act both in the gas phase and in the condensed phase depending on the thermal behavior of the same additives (volatility of the phosphate esters or of its degradation substances).

In the gas phase phosphorus is oxidized (P_2O_{10} , P_2O_5) and catalyzes the recombination of radicals O^\bullet e H^\bullet extinguishing the flame.

In condensed phase there is production of phosphoric and poly-phosphoric acid that modify the degradation processes on the surface of the polymer, accelerating the reaction of carbonization. In this way, it forms a carbon compact layer that, as in the case of the zinc borate, produces a thermal insulation effect, reduces the polymer-oxygen exchange surface and the emission of airborne particulates from the surface.

Zinc stannate and zinc hydroxy stannate

At temperatures $> 300^\circ \text{C}$ the zinc stannate decomposes forming oxides of Sn and Zn. The oxides of tin react with halogens producing in the gas phase a series of halogenated substances very similar to those observed in the case of antimony. Differently from Sb_2O_3 , however Zinc stannate is a flame retardant which can be effective even without the synergic effect of halogens, but in this case, the Sn oxides alone are, however, less effective.

Zinc stannate, like all the additives based on Zn, is effective in the condensed phase because it produces a protective charred material.

4.2.4 Possible innovations

Among the systems that give a protection to the surface of the burning material, those that have some interest are the nano-composites polymer-silicates which are an hybrid between an organic phase (the polymer) and an inorganic phase (the silicate) dispersed in the polymer matrix at the nano level. In the presence of an heat source the nanocomposites lead to the formation of a thermally stable coating on the surface of the polymer which isolates it from the heat source or the flame.

There is also a growing interest towards all those natural minerals that have the properties of flame retardants, as for example mixtures of calcium and magnesium carbonates and magnesium hydrates.

These mineral mixtures, in the presence of heat, decompose with an endothermic reaction and have substantially the same behavior as the other flame retardants described above.

5. Application areas , performance and characteristic of PVC cables

As previously shown, PVC can be used successfully for the realization of any type of electric and data transmission cables and can be used as insulation and/or sheathing in various fields:

- classic electric cables for power transmission at low and medium voltage for homes and offices
- telephone cables
- coaxial cable tv/computer/hifi
- cables for cars
- battery cables and robotics
- data transmission cables, LAN and IT.

All this is due to its excellent versatility, which can meet the different characteristics and technical performance. Following the main technical characteristic of PVC materials compared with the other competitor materials in the cable sector are listed:

Processability - easy to extrude also with different types of screw and technology; the rheology can be controlled; excellent productivity in terms of meters per hour of extruded cable with benefits on plant productivity and therefore on

production costs.

Resistant to temperature - very wide range from -40 ° to 125 ° in the automotive industry, thanks to the use of different plasticizers and stabilisers.

Resistant to atmospheric agents - good resistance to UV rays also with standard formulations.

Resistant to hydrocarbons - for example, oil and gasoline.

Self-extinguishing - unlike most polymers, the flexible PVC (as of course the rigid PVC) is for its specific characteristics also a flame retardant without adding significant quantity of mineral fillers or additives; this is not the case for the other polymers competitors.

Fire resistant - PVC can provide excellent behavior in term of resistance to the fire and to the fire development both in terms of oxygen index that temperature.

Insulation - PVC presents inherently high values of the insulation coefficient that can be improved further adding mineral fillers.

Recyclability or reuse - increasing amounts of PVC cables are recycled, thanks to synergy with copper recovery systems. Via techniques of grinding and/or solubilization, the recovered PVC is reused in molding and extrusion sectors. This is not possible with other types of cables such as, for example, HFFR cables.

Co-extrusion - can be co-extruded producing a multi-layer cable that makes possible to achieve an excellent cost/performance ratio.

Other properties of PVC cables are the same of the other PVC applications and in particular include an excellent flexibility, transparency, easy to be colored and lightness.

6. The reaction to fire classification of cables according to the CPR

Since 2006, the cable industry has been subject to a European classification system supporting a cable market throughout Europe using similar

standards. This system was initially introduced under the European Directive 89/106/EEC, commonly called CPD (Construction Product Directive).

Commission Decision 2006/751/EC included in the CPD the Fire Classification of cables "Euroclasses of reaction- to-fire performance for power, control and communication cables", introducing either a classification or an uniform nomenclature at European level and enabling

their marketing throughout Europe on the basis of similar standards.

In 2011, with the publication of Regulation 305/2011/EU, the CPD has been transformed into the CPR, (Construction Product Regulation). In this way there is no more need for transposition of the classification by the individual Member States but instead it will enter directly into force simultaneously across Europe.

Classes of reaction to fire performance for electric cables

Class	Test method(s)	Classification criteria	Additional classification
A_{ca}	EN ISO 1716	PCS ≤ 2,0 MJ/kg ⁽¹⁾	
B1_{ca}	EN 50399 (30 kW flame source) <i>and</i>	FS ≤ 1,75 m <i>and</i> THR _{1200s} ≤ 10 MJ <i>and</i> Peak HRR ≤ 20 kW <i>and</i> FIGRA ≤ 120 Ws ⁻¹	Smoke production ⁽²⁾⁽⁵⁾ <i>and</i> Flaming droplets/particles ⁽³⁾ <i>and</i> Acidity (pH <i>and</i> conductivity) ⁽⁴⁾
	EN 60332-1-2	H ≤ 425 mm	
B2_{ca}	EN 50399 (20,5 kW flame source) <i>and</i>	FS ≤ 1,5 m; <i>and</i> THR _{1200s} ≤ 15 MJ; <i>and</i> Peak HRR ≤ 30 kW; <i>and</i> FIGRA ≤ 150 Ws ⁻¹	Smoke production ⁽²⁾⁽⁶⁾ <i>and</i> Flaming droplets/particles ⁽³⁾ <i>and</i> Acidity (pH <i>and</i> conductivity) ⁽⁴⁾
	EN 60332-1-2	H ≤ 425 mm	
C_{ca}	EN 50399 (20,5 kW flame source) <i>and</i>	FS ≤ 2,0 m; <i>and</i> THR _{1200s} ≤ 30 MJ; <i>and</i> Peak HRR ≤ 60 kW; <i>and</i> FIGRA ≤ 300 Ws ⁻¹	Smoke production ⁽²⁾⁽⁶⁾ <i>and</i> Flaming droplets/particles ⁽³⁾ <i>and</i> Acidity (pH <i>and</i> conductivity) ⁽⁴⁾
	EN 60332-1-2	H ≤ 425 mm	
D_{ca}	EN 50399 (20,5 kW flame source) <i>and</i>	THR _{1200s} ≤ 70 MJ; <i>and</i> Peak HRR ≤ 400 kW; <i>and</i> FIGRA ≤ 1 300 Ws ⁻¹	Smoke production ⁽²⁾⁽⁶⁾ <i>and</i> Flaming droplets/particles ⁽³⁾ <i>and</i> Acidity (pH <i>and</i> conductivity) ⁽⁴⁾
	EN 60332-1-2	H ≤ 425 mm	
E_{ca}	EN 60332-1-2	H ≤ 425 mm	
F_{ca}	EN 60332-1-2	H > 425 mm	

(1) For the product as a whole, excluding metallic materials, and for any external component (i.e. sheath) of the product.

(2) **s1** = TSP₁₂₀₀ ≤ 50 m² *and* Peak SPR ≤ 0,25 m²/s
s1a = **s1** *and* transmittance in accordance with EN 61034-2 ≥ 80 %
s1b = **s1** *and* transmittance in accordance with EN 61034-2 ≥ 60 % < 80 %
s2 = TSP₁₂₀₀ ≤ 400 m² *and* Peak SPR ≤ 1,5 m²/s
s3 = not **s1** or **s2**

(3) **d0** = No flaming droplets/particles within 1 200 s; **d1** = No flaming droplets/particles persisting longer than 10 s within 1 200 s; **d2** = not **d0** or **d1**.

(4) EN 60754-2: **a1** = conductivity < 2,5 μS/mm *and* pH > 4,3; **a2** = conductivity < 10 μS/mm *and* pH > 4,3; **a3** = not **a1** or **a2**.

(5) The smoke class declared for class B1_{ca} cables must originate from the EN 50399 test (30 kW flame source).

(6) The smoke class declared for class B2_{ca}, C_{ca}, D_{ca} cables must originate from the EN 50399 test (20,5 kW flame source).

The decision 2006/751/EC has been recently repealed by the Delegated Regulation 2016/364 on the "Classification of the reaction to fire performance of construction products pursuant to Regulation (EU) No 305/2011 of the European Parliament and of the Council".

The CPR, aims at ensuring that the construction products placed on the market were designed or manufactured in such a way that the work of construction in which they are integrated fulfills certain requirements considered essential for the safety, health and other needs of the users.

It harmonises classification of building materials, analytical methods for classification, evaluation and reporting of performance through:

- Common technical specifications
- homogeneous certificates of conformity
- homogeneous application of CE Marking.

The CPR provides the basis for the harmonisation of systems of classification relating to the "reaction to fire" for all types of products, including specific ones such as floorings, linear pipe insulation products and cables.

The CPR Regulation 305/2011/EU improved and simplified the CPD Directive 89/106/EEC with an

automatic entry into force in the Member States, starting from 1 July 2013 (2017 for cables).

The Delegated regulation 2016/364 only defines the fire performance classes applicable to cables. Minimum classification requirements for cables, depending on the type of application and the location of installation, remain the responsibility of national authorities.

The definition of minimum classification is related to the implementation of the following four conditions:

- the establishment of the Reference Authority at National level.
- National Rules that indicate which class is applicable to which application.
- issuing of the Standard that has to be published on the Official European Union (European Official Journal).
- National Authorities have to define the body that as Third Party has the responsibility to certify the products.

The process requires time considering the necessity of several consultations at various levels, the preparation of a number of documents and the validation of supporting standards.

In the following table are reported the standards that were issued, or are going to be issued, for evaluating the behavior of cable in case of fire.

STANDARDS FOR THE EVALUATION OF THE FIRE BEHAVIOR OF CABLES	
The reaction to fire is now being verified by the standard EN 50399 which addresses heat release and heat release rate. Other three additional aspects are addressed in separate standards: smoke production, flaming droplet/particles, acidity. In addition to EN 50399, the other standards necessary for completing the assessment process and for CE marking are given hereunder:	
Product standard	EN 50575
Classification standard	EN 13501-6
European test standards	EN ISO 1716 (heat release) EN 60332-1-2 (flame propagation) EN 61034-2 (smoke density) EN 60754-2 (fumes acidity)
The European cable classification is made using the standard EN 13501-6 and must be marked on the CE marking. The CE marking is based on the harmonized standard EN 50575 and is mandatory from 1 July 2017.	
The fire resistance of the cable can be defined by the retention time of the expected performance in presence of fire. Also in this case it will need to have the same procedures as for the reaction.	
Product standard (unprotected cables)	EN 50577
Classification standard	EN 13501-2
European test standards	EN 50200 (emergency circuits) EN 50489-4-16 (integrity of cables for telecommunications) EN 50 opt (for optical cables)

Note: With regard to the measurement of smoke acidity from cables (EN 60754), the following tests are available and used:

- EN 50267 – 2 – 1
- EN 50267 – 2 – 2

Both for the test use the same equipment (described in EN 50267-1) and the substantial difference between the two tests consists:

- For EN 50267-2-1 the test temperature is raised at a constant rate in 40 minutes up to 800°C
- For EN 50267-2-2 the material is placed instantaneously at a temperature of 935°C.

The CPR as amended by the delegated regulation 2016/364 defines that EN 60754-2 (replacing EN 50267-2-2) has to be used. It is important to evaluate in depth whether the chosen test is the most suitable to correctly analyze the development of HCl during the phases where a fire develops.

7. Fire Reaction Classes and CE marking

The classification of electrical cables used as energy, control and communication cables is carried out in accordance with EN 13501-6 and the harmonized standard EN 50575.

The CE marking under the Construction Products Regulation (CPR) has a very different meaning from what it had in the CPD: it attests to the existence of a harmonized way through which the product is evaluated by means of test or calculation and production control. With the CE marking, the performance class of the product used in the constructions is also declared.

"Declaration of Performance - DoP" (replacing the Declaration of Conformity): The EC marking is a result of the performance declaration and it must coexist with the product identity card with all the essential features and declarations. The statement always accompanies the product.

The cornerstone of this regulation is the new meaning of the marking that is supported by the "Performance Statement - DoP" without which the CE marking cannot be affixed. These two elements (DoP + CE) are mandatory.

Contrary to what the CPD provided, the performance statement is a self-contained document, separate from the label, which always accompanies the product. In summary, the

fundamental aim of the European Commission is to ensure that accurate and reliable information is provided. The EC marking does not directly demonstrate any suitability for the use of the construction product, which must be evaluated by the user or the supervising authority on the basis of the declared performance and in comparison with the requirements. In carrying out the work, the performance statement therefore becomes a better aid for the builder and control authorities. The performance statement becomes a document that "leaves track".

The requirements for the CE marking are as follows:

Essential Features	Points contained in this and other European standards relating to the essential characteristics	Regulatory Classes
Reactions to fire	4.1	Aca B1ca B2ca Cca Dca Eca Fca
Release of dangerous substances (*)	4.2	

(*) On this subject we remind what is stated in the technical product specification EN 50575: 2016 and that national regulations may require verification and declaration of release and / or content of hazardous substances.

The same rule states that there are no harmonized European test methods to that effect and therefore reference is made to the individual national laws where they exist.

Depending on the reaction to fire classes, a production control system must be applied. The control is carried out using 3 different compliance systems: 1+, 3 and 4.

Example of AVCP system:

Product	Intended use	Levels or classes of performance	AVCP system(s)
Power, control and communication cable	For uses subject to regulations on reaction to fire	A _{ca} B1 _{ca} B2 _{ca} C _{ca}	1+
		D _{ca} E _{ca}	3
	For uses subject to regulations on dangerous substances	F _{ca}	4
			3
System 1+: See Regulation (EU) No. 305/2011 (CPR) Annex V, 1.1 as amended. System 3: See Regulation (EU) No. 305/2011 (CPR) Annex V, 1.4 as amended. System 4: See Regulation (EU) No. 305/2011 (CPR) Annex V, 1.5 as amended.			

The DoP and the label are written in accordance with EN 50575:

Example of DoP

DECLARATION OF PERFORMANCE

No. to be given by the manufacturer

1. Unique identification code of the product-type:
.....**To be given by the manufacturer**
2. Type, batch or serial number or any other element allowing identification of the construction product as required under Article 11(4): **To be given by the manufacturer**
3. Intended use or uses of the construction product, in accordance with the applicable harmonized technical specification, as foreseen by the manufacturer
4. Name, registered trade name or registered trade mark and contact address of the manufacturer as required under Article 11(5)
5. Where applicable, name and contact address of the authorized representative whose mandate covers the tasks specified in Article 12(2)
6. System or systems of assessment and verification of constancy of performance of the construction product as set out CPR, Annex V: System 1+
7. In case of the declaration performance concerning a construction product covered by a harmonized standard
8. Declared performance

<i>Essential characteristics</i>	<i>Performance</i>	<i>Harmonized technical specification</i>
Reaction to fire	B2, -s1, d1, a1	EN 50575:2014
Dangerous substances		

9. The performance of the product identified in points 1 and 2 is in conformity with the declared performance in point 8.
10. This declaration of performance is issued under the sole responsibility of the manufacturer identified in point 4. Signed for and on behalf of the manufacturer by:

(name and function) ... (place and date of issue) ...
(signature)

CE marking and labeling

The CE marking symbol shall be in accordance with the general principles set out in Article 30 of Regulation (EC) No. 765/2008 and shall be affixed visibly, legibly and indelibly to the product labels

affixed to the reels, coils or drums of the power, control and communication cables.

The CE marking shall be followed by:

- The last two digits of the year in which it was first affixed;
- the name and the registered address of the manufacturer, or the identifying mark allowing identification of the name and address of the manufacturer easily and without ambiguity;
- the unique identification code of the product-type;
- the reference number of the declaration performance;
- the class of the performance declared;
- the dated reference to the harmonized technical specification applied;
- the identification number of the notified body;
- the intended use as laid down in the applied harmonized technical specification.

Example of CE marking information on the product label for products subject to AVCP system 3:

<ul style="list-style-type: none"> • CE marking, consisting of the “CE”-symbol • Identification number of the product certification body
<ul style="list-style-type: none"> • Name and the registered address of the manufacturer, or identifying mark • Last two digits of the year in which the marking was first affixed • Reference number of the DoP (to be given by the manufacturer)
<ul style="list-style-type: none"> • No. of European Standard applied, as referenced in OJEU • Unique identification code of the product type (to be given by the manufacturer) • Intended use of the product ad laid down in the European Standard applied • Class of performance

The CE symbol must be affixed visibly and indelibly followed by the number of the notified body. The label can be attached to the coil or other types of packaging

Fire-reaction classes of cables made entirely or partly in PVC may be as follows:

B1ca, B2ca, Cca, Dca, Eca, Fca.

The classes show a different fire behaviour and this is highlighted and determined by the tests provided by the product standard.

Each class therefore defines a fire behaviour that is matched to the final application usage depending on the type of building where the electrical wires will be installed.

The requirement for specific end-use classes is not governed by European standards or regulations, but by specific provisions issued by national competent bodies, such as ministries, fire brigades, law enforcement agencies.

In the European market there will be cables with fire reaction classes that will be used for different situations that may vary from country to country.

There is also a secondary classification level always dictated by standard EN 13501-6 for which each class provides three subclasses for additional parameters relating to:

s= smoke

d = droplets

a = acidity

With the possibility of three levels of behaviour for each additional feature.

Each class therefore has three subclasses with three levels of different behaviour.

Each Member State can prescribe a specific combination, or allow use of cables classified with or without subclasses, so CE label can also be issued to cables that only report the class without subclasses.

The most important document remains the DoP, which will allow the designer and the user to get acquainted with the behaviour of the cable and its classifications.

8. LCA of PVC cables: energy consumption and CO₂ emissions

In 2005, the University of Catalonia conducted a Life Cycle Assessment study in which the energy consumption and CO₂ emissions of the main materials used in the insulation in electrical cables were compared:

"Estimate of energy consumption and CO₂ emissions associated with the production, use and final disposal of PVC, XLPE and PE cables"

Authors: Baldasano Recio, Jemenez Guerrero Parra Navaez, Goncalves Ageito

The choice of these two parameters was motivated by the importance of the Kyoto Protocol with its limitation of emissions of greenhouse gases, especially CO₂, and the promotion of an

ever greater energy efficiency.

The analysis took into consideration, studied and compared energy consumption and CO₂ emissions due to the production, use, recycling and final disposal of low voltage and single-pole electrical cables with copper conductor and insulant comprising just one material, normally used in domestic electrical installations.

For comparison with the PVC cables, the products selected were cables with cross-linked XLPE and PE with mineral charge HFPE (Halogen Free PE). The cross-linked polyethylene cable considered had a PVC coating, as it was noted that single-pole XLPE cables without a coating in different materials were not commonly available on the market.

Cables with dimensions allowing a maximum admissible voltage as close as possible to the one for the PVC cable were considered, pursuant to the provisions of the Low-voltage Electrotechnical Regulations; in both cases, these are cables with a rated section of 25 mm², admitting a maximum intensity of 96 A, 11% higher than the standard case.

For PVC and HFPE the case where the insulation contains 25% recycled material was also evaluated, although at present the use of recycled raw materials is not usual. Cross-linked polyethylene XLPE is not usually submitted to recycling processes because of its structure, and this option has therefore not been considered.

The functional unit, defined as the reference unit, was 1 metre linear cable having the same maximum electrical intensity, and then a section of the insulation different depending on the type of insulating material used. In fact, with similar diameter of the conductor the intensity value electricity flowing in the conductor depends on the capacity of the insulating material used for the insulation.

The assessment of the Life Cycle was made for 5 different types of copper single-pole cables:

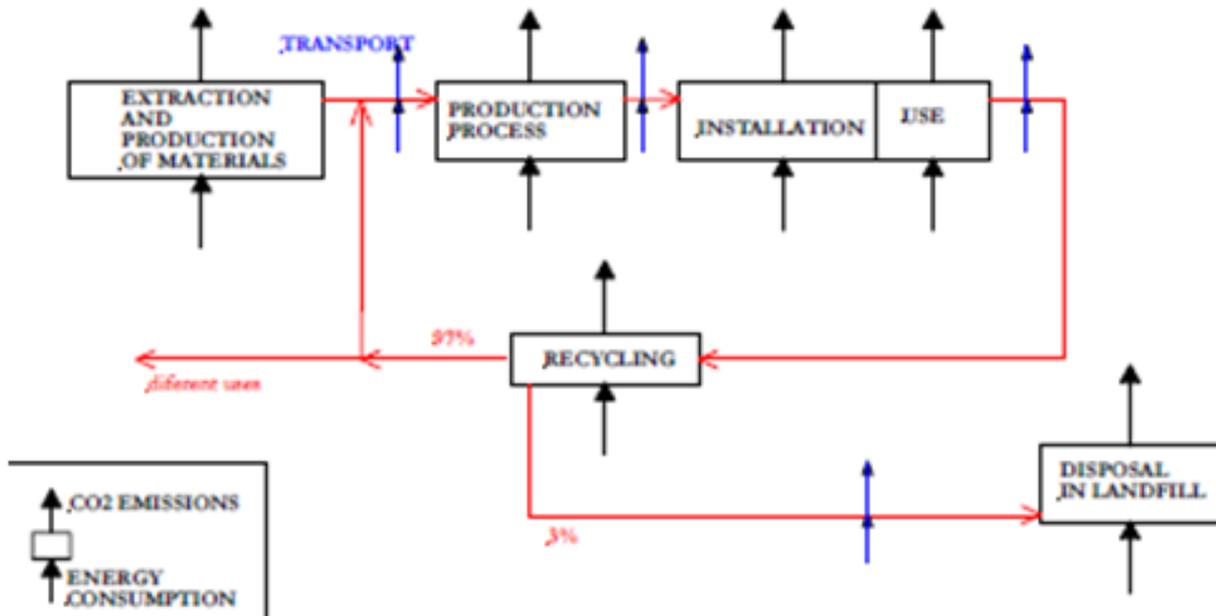
- PVC cable with 86 A maximum current and section of 35 mm²
- PVC cable with 86 A of current intensity and maximum section of 35 mm² with 25% of recycled material
- XLPE cable with 96 A maximum current and section 25 mm²
- HFPE cable with 96 A maximum current and

section 25 mm²

- HFPE cable with 96 A maximum current and section 25 mm² with 25% recycled material

As said, the methodology used in this work was based on the energy consumption and related carbon dioxide emissions in each of the stages of the life cycle of the functional unit: the extraction

and production of raw materials, transportation to manufacturing facilities, production of the cable, transportation and installation, use, transport to recycling and recycling, transportation and disposal in landfills, as shown below :



An in-use life of 50 years was assumed, and the energy losses (Joule effect) during the 50 years

were calculated on the basis of the relation $Q = I^2 \times R \times t$, where Q = the energy lost, I = intensity electric, R = resistance of the conductor and t = time in use.

A summary of results is shown in the following Table:

1 m of unipolar cable	Nominal cross section (mm ²)	Weight (kg m ⁻¹)	Conductor diameter (mm)	External diameter (mm)	Thickness of insulation (mm)	PVC cover (mm)	Energy consumption (kWh m ⁻¹)	CO ₂ emissions (kg CO ₂ m ⁻¹)	% variation of energy consumption respect to new PVC cable	% variation of CO ₂ emissions respect to new PVC cable
PVC (25% recycled)	35	0,5	8,3	13,5	2,6	no	144	65	-0,1	-0,1
PVC	35	0,5	8,3	13,5	2,6	no	145	65	0,0	0,0
Halogen free PE (25% recycled)	25	0,3	6,6	9,0	1,2	no	198	88	37	35
Halogen free PE	25	0,3	6,6	9,0	1,2	no	198	88	37	35
XLPE	25	0,3	6,6	11,2	0,9	2,8	199	88	37	36

Energy consumption, CO₂ emissions and main characteristics of the cables taken as basis to the LCA.

As shown in the table below, for all the cables under evaluation, the most important phase of the life cycle is the use phase that is approximately

95% of the total energy consumed and CO₂ emissions.

Energy consumption (kWh m ⁻¹)	PVC	PVC (25% recycled)	XLPE	Halogen free PE	Halogen free PE (25% recycled)
Extraction and production of materials	2,3	2,2	1,7	1,3	1,3
Transport to production	0,0	0,0	0,0	0,0	0,0
Production	0,2	0,2	0,1	0,1	0,1
Transport to installation	0,0	0,0	0,0	0,0	0,0
Use	141,6	141,6	196,4	196,4	196,4
Transport to recycling	0,0	0,0	0,0	0,0	0,0
Recycling	0,4	0,4	0,3	0,3	0,3
Transport to landfill	0,0	0,0	0,0	0,0	0,0
Disposal in landfill	0,0	0,0	0,0	0,0	0,0
TOTAL	144,5	144,4	198,6	198,2	198,1

CO ₂ Emissions (kg CO ₂ m ⁻¹)	PVC	PVC (25% recycled)	XLPE	Halogen free PE	Halogen free PE (25% recycled)
Extraction and production of materials	1,7	1,7	0,5	0,4	0,4
Transport to production	0,0	0,0	0,0	0,0	0,0
Production	0,1	0,1	0,0	0,0	0,0
Transport to installation	0,0	0,0	0,0	0,0	0,0
Use	62,7	62,7	87,0	87,0	87,0
Transport to recycling	0,0	0,0	0,0	0,0	0,0
Recycling	0,1	0,1	0,1	0,1	0,1
Transport to landfill	0,0	0,0	0,0	0,0	0,0
Disposal in landfill	0,0	0,0	0,0	0,0	0,0
TOTAL	64,6	64,6	87,7	87,5	87,5

In conclusion, the study showed that:

- the cable that has the best results in terms of energy consumption and CO₂ emission is insulated with PVC
- the worst result is that cable insulated with XLPE with approximately 37 % more energy consumption
- the use of 25% recycled material in insulation, both in PVC and in HFPE, does not substantially affect the reduction of energy consumption
- the contribution to energy consumption and CO₂ emissions is almost entirely concentrated in the use phase.

9. PVC cables, Reach and a “Quality and Sustainability” Label

Assessing the impact that chemicals can have on health and the environment is one of the most important issues faced by both industry and national and international bodies.

The European Regulation REACH was enacted to protect human health and the environment through a systematic evaluation of substances.

The REACH Regulation requires that all substances placed on the EU market are not only

registered but also evaluated, and, if hazardous, potentially subjected to restrictions or requiring specific authorization on the basis of the intended use. This Regulation constitutes a guarantee for consumers but also for the industry, because it provides a rigorous and structured process to assess substances.

It is also clear that the use of PVC products, made with formulations in line with REACH, must be considered safe and sustainable in terms of environmental impact and human health, with full transparency and traceability of the individual components.

Today there are on the market PVC articles that have followed and/or applied in advance the objectives of REACH, ensuring the use of substances that are considered "not dangerous" and that in any case should not require any special precautions for their use.

In particular, some Italian companies, members of the PVC Forum Italian, producing PVC compound for power cables have adhered to a Mark of “Quality and Sustainability” called "Green PVC Compounds". Logo and membership criteria provided by the Regulations are following showed:

GREEN PVC COMPOUNDS VOLUNTARY LABEL: LOGO AND CRITERIA



The use of this voluntary “Quality and Sustainability” Label is only allowed to PVC compounds meeting the following criteria:

Formulations: are not intentionally added

- stabilisers or other additives based on lead as well as other heavy metals such as Cd, Hg, Cr VI;
- phthalate plasticizers such as DEHP, BBP, DBP and DIBP;
- substances defined SVHC (substances of very high concern) in accordance with the REACH Regulation and included in the candidate list;

The guaranteed limit for the substances not intentionally added and/or the impurities present in the raw materials are:

- Lead an heavy metal = 100 ppm (0,01% weight of the heavy metal);
- DEHP, DBP, BBP, DIBP and other SVHC = 1000 ppm (0,1% weight of the substance);
- The compliance with the above limits for the substances inserted in the Candidate List (SVHC) is guarantees after 6 months after the official inclusion in the list;

quality: compounds are guaranteed as suitable to manufacture products complying with technical performance provided for each application and the production plant is certified ISO 9000.

environment: the company producing compounds in line with the label has obtained the ISO 14000 certification or, waiting to be certified, has joined the Federchimica Responsible Care® program. May be permitted to use the Label to companies that have began the path of ISO 14000 certification, in the face of proof that have actually started this certification path.

production: in addition to comply with all current regulations, the plant shall implement all necessary actions to minimize the amount of waste to be sent to landfills and to ensure the safety of the workers.

The new PVC cable formulations

The PVC used in electrical and transmission cables is a plasticized PVC formulation, of which and indicative composition is summarized below:

- PVC polymer : 100
- Filler : 0-50
- Plasticizer : 30-60
- Other additives : 3-10

Note: data in phr = parts per 100 parts of PVC polymer

The formulations have been and are updated and improved over time. For many years the PVC value chain, through the well-known Voluntary Programs (Vinyl 2010 and VinylPlus) and the Reach Regulation, has been engaged in the research and development of new formulations in order to ensure maximum safety and protection of environment and the health of users and consumers. See below for some examples:

old formulation	new formulation
PVC	PVC
CaCO ₃	CaCO ₃
MgCO ₃	MgCO ₃
DEHP	DIDP
Chlorine-paraffine medium chain	Chlorine-paraffine medium chain
Sb ₂ O ₃	Sb ₂ O ₃
-	ESBO
Lead stabilisers	Calcium based (or calcium/zinc or calcium/organic) stabilisers

The new formulations, thanks to the absence of heavy metals, increase the possibility for mechanical reuse of the material at the end of life and hence a reduction of the quantity and hazardousness of solid waste produced during incineration.

Even the users of electrical cables can now look at the new PVC (that could be called PVC 2.0) as a material that provides a high level of environmental sustainability coupled with high performance.

New developments have allowed formulation to further improve the performance characteristics of fire resistance of PVC cables allowing to obtain:

- reducing release of halogenated gases
- smoke emissions of lower density, and opacity
- LOI (see par 3.2) values greater than 36 %

All this is making even more PVC a material highly suitable for use in the cable industry.

10. The recycling of PVC cables

We can divide the recycling of cables at the end of life in two different streams :

- a) cables subject to one of both European regulations : the WEEE (Waste from Electrical and Electronic Equipment), and ELV legislation (End of Life Vehicles) Directives. In these cases there is a general obligation to recover and recycle at end of life electrical and electronic equipment and vehicles sent to demolition, although without an explicit obligation for "cables".
- b) cables not subject to the above rules and regulations, such as the cables used for the transport of energy and for communications: this cable waste is recycled by recycling schemes substantially supported by private initiatives.

Through the first voluntary program Vinyl 2010, confirmed with the second voluntary program VinylPlus, the European PVC industry has set the

objective of promoting the recycling of PVC articles. To encourage the recycling of PVC in Europe an organisation called Recovinyl was created, with the aim to develop and support the collection and recycling schemes including for cables .

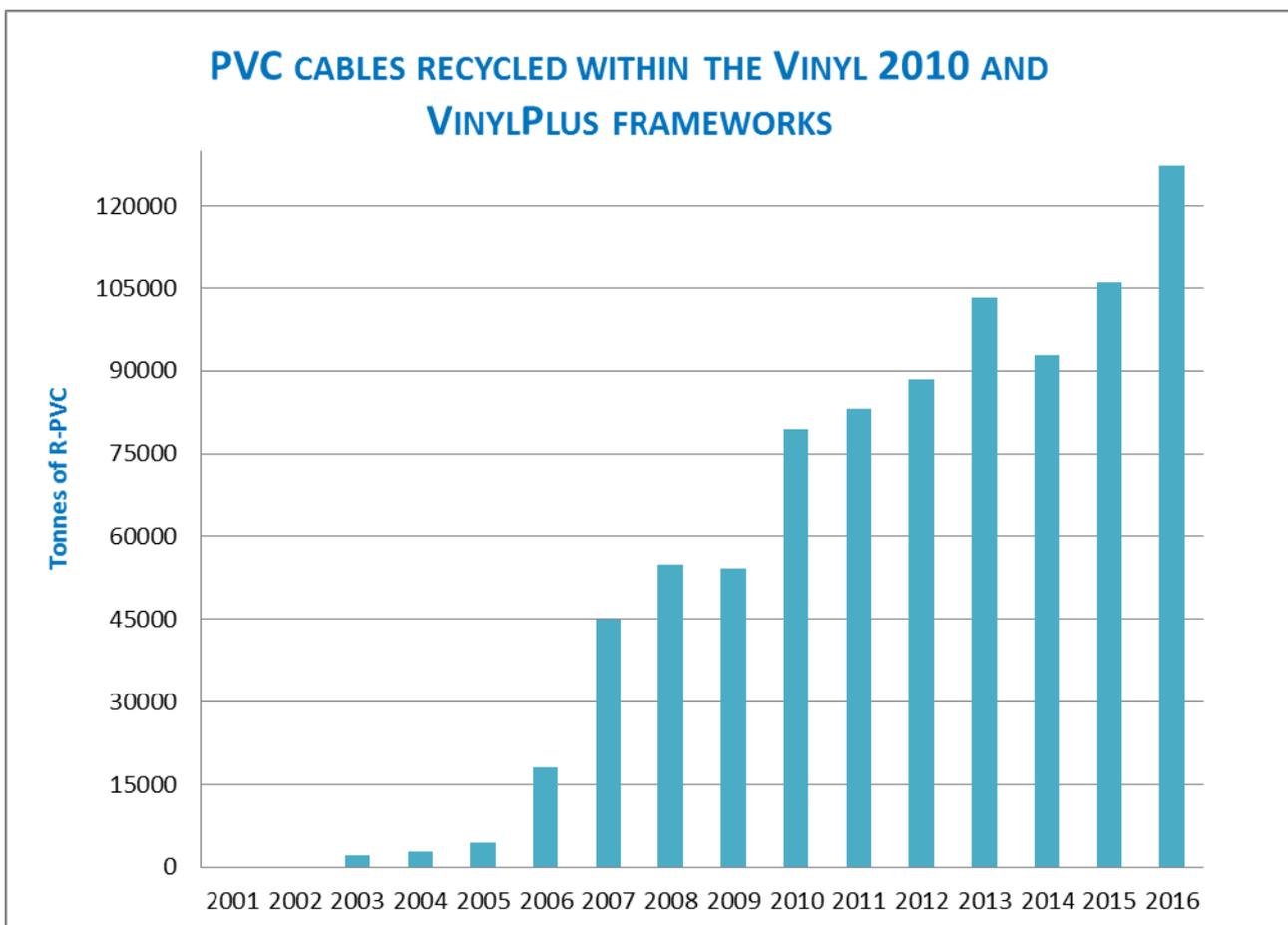
It is important to highlight the contribution that recycling of PVC cables gave to the achievement of the objectives of the European industry, because the amount of recycled cables in 2012, accounted by Recovinyl was almost 25% of the total amount of recycled PVC in the same year.

An estimation based on historical sales in all cable applications and average product lifetimes amounts to more than 330,000 tons of PVC cable waste available by 2020.

The cables at the end of the life cycle are recovered by recyclers that, through a process of peeling, are separating the conductor (copper) from the sheathing and insulation (the plastic materials).

The copper is recovered and recycled in the foundry.

The following diagram shows the trend of the recycling of PVC cables since 2006 when Recovinyl has started its activities in this area:



To be recycled, the sheathing and the insulation of electrical cables, or the single sheathing of telephone cables, after being separated from the conductor, is subjected to a mechanical process of micronisation and the micronised PVC is sold on the market to be used in suitable applications for the production of new products.

Alongside the traditional mechanical recycling of PVC cables insulation and sheathing, a more sophisticated process, called Vinyloop[®], has been operating since 2003.

Vinyloop[®] : an innovative recycling process

The sheathing and insulation of PVC cables at the end-of- life, even if mixed with other materials such as copper residues, fibers, polyester , rubber or other plastic materials, can be recycled through the Vinyloop[®] process.

This process allows the selective recycling of PVC composite products in high value application, thereby avoiding landfill or incineration and giving new life to resources that would otherwise remain unused or used in low value applications.

The Vinyloop[®] process is based on the principle of selective dissolution, through the use of a special chemical solvent, that brings in solution only the PVC fraction in order to obtain a PVC compound with the original components of the formulation used for the production of articles that are recycled.

This process is divided into several stages:

Dissolution: a suitable solvent, used in a closed loop, allows to dissolve the PVC fraction, separating it from the other components of the article.

Filtration: the residual contamination still present in the solution (solvent + PVC) is removed in two consecutive stages :

⇒ a first filtration using a traditional mechanical filter

⇒ then passing through a decanting centrifuge that removes the last contaminants

Precipitation: the solution (solvent + PVC) is conveyed into a tank where steam is injected at high temperature to allow the solvent evaporation and the consequent precipitation of the PVC in an aqueous solution (slurry). The evaporated solvent, once condensed, is sent to a storage tank for closed loop reuse in the dissolution phase.

Drying: after recovery of the water present in the slurry, PVC is conveyed to a dryer for removing

the residual water.

The sophisticated technology allows to obtain a regenerated PVC compound, free from external contamination, which has characteristics comparable to those of a virgin compound (in terms of quality level and consistency) and is suitable to be used as raw material in various applications.

The Vinyloop[®] process keeps the physico-chemical properties of the starting polymer unchanged and consequently the products manufactured with PVC -R[®] Vinyloop can be easily recycled.

The Vinyloop Ferrara S.p.a. – started as a partnerships between SolVin (a joint venture Solvay - BASF) and Serge Ferrari SA; SolVin subsequently transferred its part of the ownership to INOVYN, the JV between SolVin and Ineos Chlor Vinyls. It manages the first plant in the world which operates according to the new technology resulting from the above-mentioned patent. The plant is able to treat approximately 10,000 tons per year of post-consumer PVC composite waste.

A recent study on the Environmental Footprint of Vinyloop[®], subjected to critical evaluation by the independent testing and certification organization DEKRA Industrial GmbH, has assessed the environmental impact of recycled product, comparing one kg of PVC -R[®] VinyLoop with one kilogram of virgin PVC compound.

The results of the study show that the Environmental Footprint of Primary Energy Demand (Primary Energy Demand - PED) of PVC -R VinyLoop is 46% lower than virgin PVC compound produced in the traditional way. The Global Warming Potential (GWP 100a) is 39% less and the water consumption is reduced by 72%.

Conclusions

PVC belongs to the class of organic materials that give the best performance in case of fire thanks to the presence of a halogen in its polymeric chain:

- PVC is difficult to ignite;
- PVC moderately releases heat;
- PVC hardly contributes to the propagation of flames;
- PVC carbonizes and does not melt, and therefore does not form burning droplets or burning debris that may spread the fire
- PVC stops burning when the heat source is removed; it is a self-extinguishing material

These characteristics can further be improved by the addition of suitable additives..

The PVC formulations used in wire coating have helped to further improve its fire behavior performance; in particular the development of new and innovative formulations has allowed further improvement of the fire performance of PVC cables, such as a low development of halogen gases and smoke emission at lower density and opacity, and permitting to reach LOI values greater than 36% which is the maximum value obtainable with the usual plasticized PVC formulations.

The emission of HCl gas from burning PVC at the beginning of the fire acts as an early "warning" before the development of the fire, contrary to CO, which is odorless. Such immediate detection occurs at a very low concentration of HCl and well

below the threshold limit considered dangerous for the human health. Overall, HCl in fire effluents is less dangerous than CO, which is an odorless asphyxiant that can quickly lead to paralysis and death.

The PVC recovered from the cables at the end of life is recycled through techniques of grinding and/or selective solubilisation with subsequent filtration to ensure that the PVC recovered can be reused using molding or extrusion technology. Instead it is extremely difficult, if not almost impossible, to recycle the cables produced with the alternative plastic materials .

Last but not least, PVC is a material easy to work that allows to get cables having excellent flexibility, lightness, easy to color and excellent resistance to weathering, UV and hydrocarbons.

In conclusion, the choice to produce and use PVC cables allows to obtain cables with high performance and optimal isolation coefficient, with a high fire resistance to which it must be added a high "sustainability" linked to lower energy consumption and lower CO₂ emissions, all at highly competitive costs compared to competing materials.