

# How to Sustainable Create Recyclable Packaging Through the Use of Electron Beam Curable Inks In the Printing Process

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## Abstract

This document relates to the process of creation a Recyclable packaging through all the conversion process from the raw material till the final packaging, and specifically how the use of Electron Beam curable inks in the printing process (either Flexographic or Offset printing) can help in achieving this Recyclable packaging in the most sustainable way.

## EB PRINTING TECHNOLOGY - BASICS

Radiation induced in situ polymerization reactions offer significant advantages over conventional thermal processes. Biggest advantage is the usage of 100% reactive and compliant chemistry and thus no thermal drying at all. Since the introduction of electron beam equipment in the mid-sixties, polymer chemists were intrigued by the ability of the electrons to initiate free-radical polymerization reactions without the addition of any photo initiators or photosensitizers<sup>1</sup>. Immediate applications were sought in packaging using the free radical initiated chemistries, using functional groups like acrylate esters. EB curing was preferred due to the following reasons:

- No VOC
- High degree of conversion. (Low migration) Food packaging
- No photo-initiator or other additives
- No to low odor important for Food packaging
- Excellent physical properties like scuff and abrasion, COF, Gloss
- High production speeds
- Good quality control through NIST traceable dosimeter techniques and closed loop control electronics.

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<sup>1</sup>Comexi; <sup>2</sup>Energy Sciences Inc.

- Lowest Power Consumption than any curing\drying options.
- Coolest curing temperatures important for thermally labile films like heat shrink films or PE.

The development of 150-300 kV electron beam equipment in the late seventies and early eighties was considered a breakthrough in the curing technology especially for curing offset lithography inks on paper board substrates used for semi-rigid food packaging applications like liquids and frozen foods.

However, electron beam processing technology in spite of all its advantages remained a niche application and could not penetrate the flexible food packaging, the fastest growing segment in food packaging.

The reasons attributed to this restricted growth in flexible food packaging of the 150-300kV EB equipment were as follows:

- EB equipment was quite large and expensive especially for cost sensitive applications like flexible food packaging
- Flexible food packaging utilized a significant number of polymeric films.

The 150+kV EB equipment damaged some of these polymeric films rendering the final package not functional.

There was significant development to address these limitations of the EB equipment of the past to make it a curing unit of choice moving forward for these broader markets.

Let us review the fundamentals of EB equipment. As shown in Fig 1 is a cross-section of the EB accelerator.

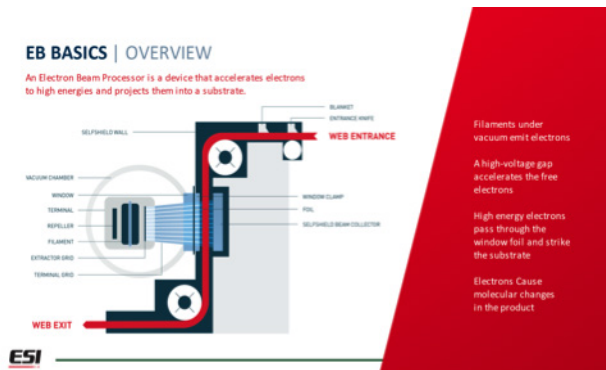


Fig 1. EB BASICS

As shown, electrons are created in a vacuum where tungsten filaments are heated to very high temperatures (2400 K) which is the thermionic emission temperature of tungsten. At these temperatures' electrons are boiling from the filament, then by applying positive voltage these electrons are extracted and then accelerated to almost the speed of light. These electrons then come out of the vacuum chamber passing a thin Titanium foil supported on a copper window body. They then strike a moving web printed and or coated in an inert nitrogen environment and initiates a free radical polymerization reaction, instantaneously curing the coating and or ink.

Significant development in the window body and foil area was done to introduce these low voltage EB equipment (70-125kV range) in early 2000, like the EZCure<sup>2,3</sup>. These low voltage EB units addressed some of these issues, of the higher voltage EB machines as shown in Figures 2 and 3.



Fig 2. The New low voltage EB unit addressed the size issue of the older 150-200 kV EB unit

**100 kV vs. 150 kV  
Depth: Dose. Laminating Adhesive**

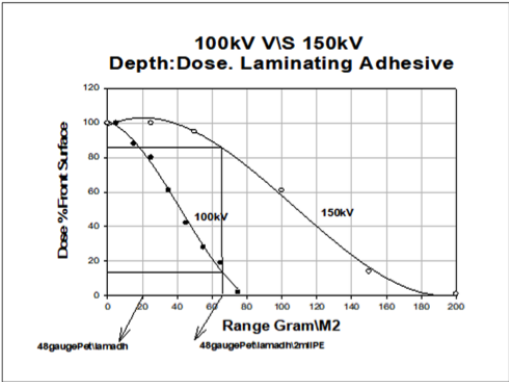


Fig 3. The low voltage EB equipment operating at 100 kV reduces penetration in the substrate for the EB adhesive application allowing heat seal ability required in downstream processing

These low voltage EB machines have been well accepted especially in packaging in particular food packaging for the following applications as seen below:

**APPLICATIONS OF Low Voltage EB IN PACKAGING**

**EB Curing of Coatings (replacing laminates)**

**EB Curing of Inks**

- EB Offset Inks
- EB CI-Flexo Inks (Surface print OR Reverse Print)
- EB curing digital inks

**EB X-linking of Films**

- MDO | OPE Films
- VSP Films
- High Barrier / POF Shrink Bags

**EB Curing of**

- Laminating
- Adhesives



Recently market needs for packaging are driven towards sustainability and recyclability. Again, electron beam curing becomes the curing unit of choice to make packages recyclable meeting the mandates of a circular economy as shown in Figure 4. At the same time reducing VOC and carbon footprint by using 100% solids EB offset inks or 90% solids EB flexo inks.

**EB Curing is the Solution to Today's Market Challenges**

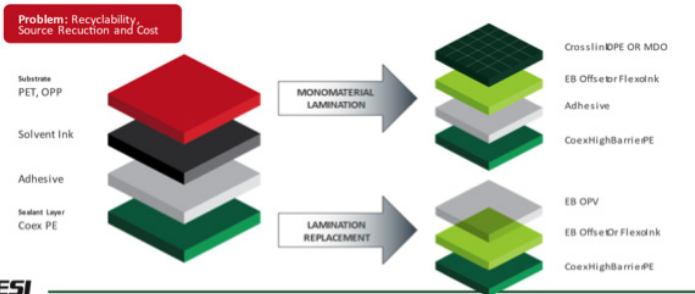


Fig 4.

**EB PRINTING PRESSES**

Flexible Packaging can be printed in different technologies, mainly in Offset, Rotogravure and Flexography, but regarding Electron Beam inks, then the choice is restricted at this moment to Flexography or Offset printing.

**Flexo Printing Presses:**

Flexo printing is a process where the ink is transferred to the substrate in a liquid form from a fountain roller (Anilox) through a printing form (plate). The way the ink goes from the Anilox to the Plate and finally to the substrate is thanks to the different surface tension of the Anilox-Plate-Substrate, and in any case the ink has to have a liquid state to be able to flow from one element to the next.

Traditionally the inks are thinned out by the addition of a diluent (water or solvent) that is evaporated when the inks reach the substrate, allowing the inks to become solid and fixed to the substrate. In general, the Solvent based or Water based inks have about 60 to 65% of diluent that needs to be evaporated, so this means that the Flexo machines require a powerful drying system able to blow hot air onto the substrate to dry and fix the inks.

Inks are applied in different stations (decks) for each different color, and to go from one station to the next, they must be dried so the next ink can be applied onto. The different decks can be In-Line or around a Central Drum (CI).

In a traditional In-Line Flexo machine, there is a powerful drying after each deck, so the inks are totally dried before the next one is applied.

In a traditional CI machine, there are two drying zones, one first zone which is called intercolor drying, where the inks are applied, and where a first drying is made, just to allow the trapping of the different colors, and a second zone, which is called final drying where there is the final and total drying of the inks. These drying zones are equipped with high volume fans and heating sources, as it is typical to blow around 10.000Nm<sup>3</sup>/h (6.500 SCFM) in both zones, at temperatures of 60 to 80°C (140°F – 180°F).

In the case of Electron Beam Curing Inks, as explained before, there is no drying of the inks, but a curing reaction, and as the inks are applied one after the other and the curing reaction takes place at the end of the application, all the inks are cured at the same time. This makes it not possible to be used in an In-Line machine, as the movement of the web from one station to the next would damage the ink on the substrate as the substrate has to go through different rollers. In a CI machine this problem does not exist as all decks are located around a common cylinder (the Central Drum) and the substrate is all the time fixed to this cylinder not having any contact with any other roller. So, when referring to an Electron Beam Flexo machine it's always a CI press machine.

The inks still have a small part of diluent that is always below 20%. Depending on the technology can be solvent (GELFLEX EB inks) or water (WETFLEX EB inks) which is evaporated with a small quantity of air, without any heating, and only with the intercolor drying.

The main difference between a traditional Flexo and a EB Flexo press, is that the second one does not require the final drying tunnel, does not require a heating source, and does not require powerful fans. Instead of all this equipment the machines are equipped with an Electron Beam generator that will irradiate the printed substrate with electrons in an inert atmosphere, so just creating the chemical reaction that

will anchor the ink onto the substrate. In addition to the Electron Beam generator a nitrogen supply to create this inert atmosphere is required.

Other differences can be found in the press architecture like the higher viscosity inking system to properly operate with the EB curing inks. These inks are typically having much higher viscosity than their water based or solvent based homonymous.

Fig 5 shows a homonymous. COMEXI F2 press equipped with the Electron Beam generator.



*Fig 5. F2-EB machine*

### **Offset Printing Presses:**

Offset printing is a process where the ink is transferred to the substrate in a paste form from a lithographic aluminum plate through a blanket. The process of imaging the plate gives to it the properties that the imaged areas accept ink and reject water, while the non-imaged areas reject ink and accept water. The blanket will only take the ink from the plate, and so only transfers the image to the substrate.

As mentioned, the inks are pasty (non-liquid), and they arrive at the plate by means of a train of rollers that laminate the ink to deliver the appropriate thickness for printing. These inks are 100% solid content having not any diluent, so it means that the offset inks do not need any type of drying. Therefore, in the case of Electron Beam Offset inks, only the Electron Beam Generator and the Nitrogen for the inertization are required.

Traditionally Offset presses have been In-Line and only used for printing on absorbent materials like paper (commercial printing) or board (card boxes), because the inks have no drying properties, and so the anchorage onto a plastic film was difficult. Thanks to the Electron Beam inks, that are cured and fixed onto the

substrate by means of a chemical reaction, the use on plastic film becomes possible opening some decades ago the door to Labeling and Flexible packaging.

Due to the high viscosity of the offset inks, when applying the ink into a plastic film, the Central Drum configuration becomes a key advantage in terms of quality, registration and easy to run. It's especially relevant with thin materials.

Fig 6 shows an Offset CI evolution machine from Comexi, it's a Central Drum press that prints using EB inks. Such a machine has up to 8 decks organized around a Central Drum (it can also have 7 offset decks + 1 Flexo deck for OPV or opaque white) and an Electron Beam generator at the end of the Central Drum where all the inks and OPV are cured at the same time, with no need of any type of air drying.



*Fig 6. Offset EB machine*

## SUSTAINABILITY TRENDS

According to **The Global Risks Report 2021**<sup>4</sup> published by The World Economic Forum, the majority of the Top Global Risks we will face in the coming years will be related to climate change, to Biodiversity loss, to Weather.... Top Risks that in some way can be considered as a result of human action regarding pollution.

More in detail, as we can see in Fig 7, fourth of the Top 5 Risks by likelihood are “**Extreme Weather**”, “**Climate action Failure**”, “**Human Environmental damage**” and “**Biodiversity loss**”, while when analyzed by Impact, still 3 of them are within the Top 5, “**Climate action Failure**”, “**Biodiversity loss**” and “**Natural Resource Crisis**” (Fig 8), so it is not just that it is probably to happen, but that when it will happen will have a big impact...

## Top Risks

by likelihood

- 1 Extreme weather
- 2 Climate action failure
- 3 Human environmental damage
- 4 Infectious diseases
- 5 Biodiversity loss
- 6 Digital power concentration
- 7 Digital inequality
- 8 Interstate relations fracture
- 9 Cybersecurity failure
- 10 Livelihood crises

## Top Risks

by impact

- 1 Infectious diseases
- 2 Climate action failure
- 3 Weapons of mass destruction
- 4 Biodiversity loss
- 5 Natural resource crises
- 6 Human environmental damage
- 7 Livelihood crises
- 8 Extreme weather
- 9 Debt crises
- 10 IT infrastructure breakdown

Fig 7. Top Global Risks Range

And this is not just something new, we can see in fig 8 and 9 that the evolution of the Top Global Risks during the past years has been in the sense to add every year more and more risks related to human action on the climate or related to pollution.

Top Global Risks by Likelihood



Fig 8. Top Global Risks by Likelihood





Source: World Economic Forum Global Risks Perception Survey 2020

Fig 9. Top Global Risks by Impact

If we continue with the same report, and we focus on climate-related matters, we can also see the evolution of the Global Emissions and how it relates to the Warming Goals, and its uncoupling can easily explain this perception for the Global Risks. In Fig 10 we can see the evolution within this century, and we can observe that despite of the recession in 2008, and the last recession due to COVID-19 crisis, the tendency of the Global Emissions and the Warming Goals are totally uncoupled.

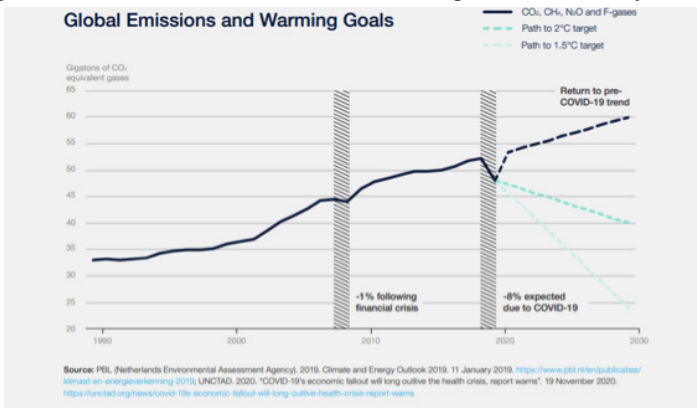


Fig 10. Global Emissions and Warming Goals evolution

So, it is clear that humankind has to do something related to these risks and to this Global Warming, and this is creating a stream within the society to move against one of the players that is seen as one of the main contributors to this global warming and to this pollution, which is the Flexible Packaging, and more concretely the Flexible Packaging which is made by Plastic. And this stream is not just in the society, but we can see also in governments, and moving into the different layers of

the Flexible Packaging Industry, starting with Brand Owners and going down to the Converters and Plastic producers.

We see governments restricting or even banning the use of single use plastics, or taxing the use of non-recycled plastic, the use of solvents or the emissions of VOCs or CO<sub>2</sub>. We can find declarations of the main Brand Owners (Nestlé, P&G, Unilever...) in the sense that all the plastic used in their packaging will be either Recyclable or Reusable by 2025 or 2030 at the latest...

But this is not enough, there is still another important aspect that needs to be addressed, which is the energy consumption and the VOCs emission, which at the end relates to the CO<sub>2</sub> footprint of our packaging. When we want to change the tendency of Global Warming by reducing CO<sub>2</sub> emissions, solvent use has a direct effect on it, even if most of the converters are equipped with abatement equipment that convert the VOCs into CO<sub>2</sub> by burning the solvent.

All these actions will move down to the producers, and they have already started, so the major trends in the Flexible packaging industry are today:

- **Plastic Reduction**
- **Plastic Recyclability**
- **Use of Recycled Plastic**
- **Solvent Use Reduction**
- **Energy Reduction**

In this paper we will see how the use of Energy Curable inks, and more specific Electron Beam curable inks plays an important role in these 5 tendencies.

## **RECYCLABLE FLEXIBLE PACKAGING**

Packaging is recyclable if it can be collected, sorted, reprocessed, and ultimately reused in manufacturing or making another item.

A Packaging will be recyclable if the circularity can be completed in the majority of communities where an item is sold.

The plastic recycling rate shows that the recyclability today is dominated by three types of plastics. (HDPE, LDPE, PET)

- HDPE recycled is mainly sourced by tubes, and bottles i.e.: chemicals, milk.
- PET recycled mainly from beverage bottles and trays.
- LDPE from flexible films, agriculture, wrapping, etc...

As we can learn from *HDPE & PP MARKET IN EUROPE: STATE OF PLAY*<sup>5</sup> from Plastic Recyclers Europe Publications -an organization representing the voice of the European plastics recyclers who reprocess plastic waste into high-quality material destined for the production of new articles-, the main reason that laminated

plastics used in flexible packaging are not recycled is due technical difficulties to separate the different types of polymers.

There are big differences in the plastic packaging recycling rates depending on the type of plastic and the local capabilities for collecting, sorting and recycling. In Fig 11 we see the evolution of the Plastic Containers and Plastic Waste management in USA according to *Facts and Figures about Materials, Waste and Recycling*<sup>6</sup> from EPA (United States Environmental Protection Agency).

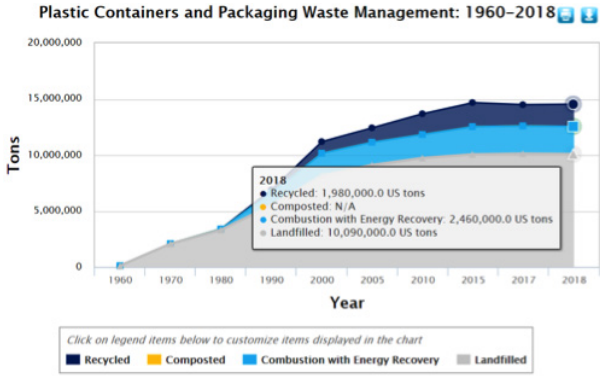


Fig 11. Plastic Containers and Packaging Waste Management evolution

And in Fig 12 we can see the recycling rate of post-consumer waste in Europe in 2018, where only 2 countries are over 40%, while all the other countries are between 20% to 40%, so there is still a great job to be done. This, and other graphics can be found in *Plastics - the Facts 2020*<sup>7</sup> from Plastics Europe, association of plastics manufacturers, and in *Plastic waste and recycling in the EU: facts and figures*<sup>8</sup> from the European Parliament.

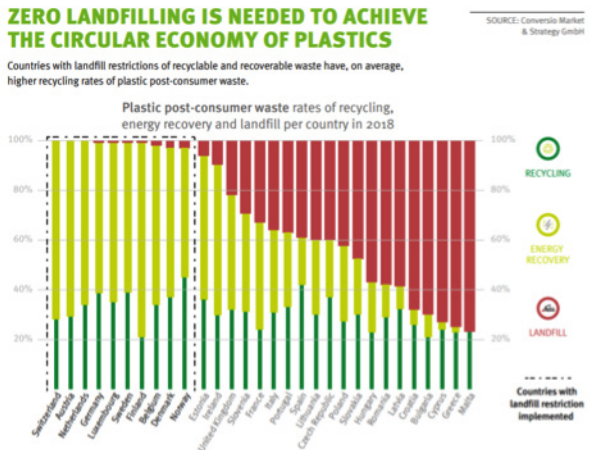


Fig 12. Plastic Post-consumer waste recycling rate

Market pressure and government pressure is pushing flexible packaging to a circular economy, where changes in the whole supply chain will be needed.

To increase the recyclability rates for flexible packaging will be needed actions in the whole supply chain of the products, meaning:

- Improvement on design of packaging to facilitate the recyclability
- Improvement on the collection and sorting of the flexible packaging.
- Increase of the capabilities to reprocess the flexible packaging and converting in new pellets to be reintroduced in the film extrusion lines.

Regarding the improvement of design of packaging, some guidelines have been created, example of Recyclclass<sup>9</sup> or Ceflex<sup>10</sup>, where main rules are:

- **Use monofil laminated PE/PE or PP/PP**
- **Focus on monolayer surface print, PE or PP**
- **Total percentage PE or PP >90%**
- **Avoid mixed structures PAPER/PLASTIC or ALU/PLASTIC**
- **Avoid incompatible combinations with PA, PVDC...**
- **For barrier use compatible layers AlOx, SiOx, EVOH or metallized**
- **Reduce layers and total thickness**
- **Total density <1g/cm<sup>3</sup>**
- **Minimize lamination adhesives <5% OF TOTAL WEIGHT**
- **Total inks + coatings up to max. 5%**
- **Designs with lighter colors better than darker**
- **Spouts, zippers and complements use same material as film.**

To follow those recommendations will need some efforts, especially for the multilayer structures with combinations of different layers for (PET, Bopp, PE, PA, ALU, etc..) to be replaced by monofilm.

Actually, the major part of the new developments for recyclable flexible packaging are moving to monofilm full PE because it is the easiest polymer to recycle.

The combination of different types of PE (LLDPE, LDPE, HDPE, BOPE, MDO PE...) will be necessary to keep some of the packaging requirements, like optical, mechanical properties, sealing performance, surface protection, etc...

In terms of barrier properties can be combined with barrier layers like EVOH and still recyclable depending on the percentage versus total thickness.

In terms of surface resistance, the replacement of typical layers PET or Bopp by PE will be limiting some performance of the packaging and thus limiting the viability of this replacement.

In this document we are studying how the EB curing can improve the surface protection of the monofilm full PE flexible packaging to reduce those limitations and consequently increase the performance in the filling lines or pouch making machines to make it more feasible for a wider range of applications.

**CASE STUDY: REPLACEMENT OF A LAMINATED NON-RECYCLABLE PET+PE STRUCTURE BY MONOMATERIAL EB PRINTED.**

Current non-recyclable structure of PET+PE (Structure A)

One of the most typical structures for flexible packaging until the date is laminated PET + LDPE (Structure A in fig 13), which is widely used for pouch making in many different kinds of products.

The PET usually is 12microns thin layer that is reverse printed and laminated to a sealing layer of LDPE, and the use of these two different materials makes it difficult if not impossible to Recycle the final packaging.

- PET is required to give mechanical and surface properties to the final product, mainly:
  - Mechanical Consistency to the package
  - Mechanical Resistance to scratch, abrasion... protection of the ink layer
  - Optical properties (clarity, glossy...)
  - Thermal Resistance when sealing
  - Barrier properties against Oxygen and Water
- PE is required to give barrier resistance to water and sealability to form the package (Pouch)

In fig 13 we can see two different approaches to make the same final product with a recyclable solution, both using ONLY PE material, either a laminated monomaterial structure of full PE (Structure B) or a monofilm PE structure (Structure C).



Fig 13. Case study - Pouch structures

In the following pages we will analyze both solutions B and C to evaluate how the use of EB inks and varnishes, and the EB radiation itself impacts not only in making possible the recyclability of the final packages, but also in reducing the CO2 footprint of said packaging.

### **First Alternative Packaging, FULL PE laminated (Structure B)**

In this case the PET is replaced by PE film BOPE or MDO PE to achieve better optical properties than regular PE, the film is printed in reverse with EB inks and the EB radiation will also partially crosslink the PE depending on the electron beam dosing.

Therefore, the PET properties must be transferred to the BOPE or the MDO PE, some of them are already there, but some other are missing like the Oxygen barrier and Thermal resistance when making the Pouch.

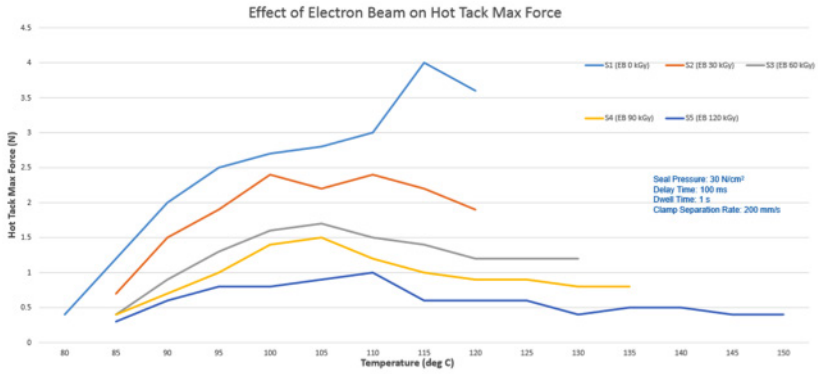
The property of Oxygen barrier is transferred to the Internal layer of COEX PE, and the Thermal resistance is increased when the BOPE or MDO PE is exposed to the EB radiation at the same time the inks are cured.

The ability to modify the surface properties in some films with the Electron Beam radiation, by increasing the temperature resistance makes it possible to modify the melting temperature, so even having the same material (PE) in the external side or internal side, the melting temperature of the external side will be higher, so facilitating the sealing performance required for the packaging creation.

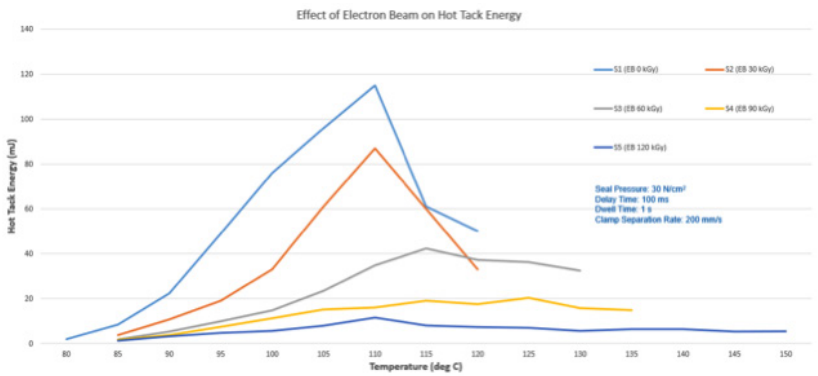
This partial crosslink will provide additional external resistance in comparison to non-treated PE, that will be demonstrated in this following example:

Example analyzed (fig 14, 15, 16 and 17):

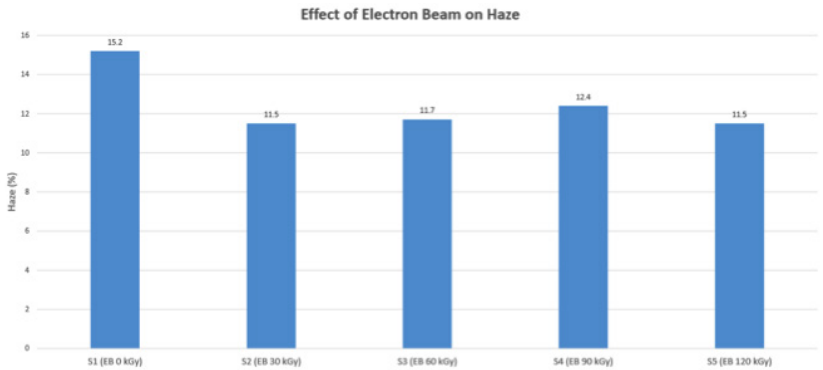
- Top Layer BOPE Film Thickness 25 microns
- EB Conditions: 125 kV providing complete penetration
  - Sample S1 0 kGy Control
  - Sample S2 30 kGy
  - Sample S3 60 kGy
  - Sample S4 90 kGy
  - Sample S5 120 kGy
- Films tested for Sealing, Hot Tack, Haze and Dart Impact Strength



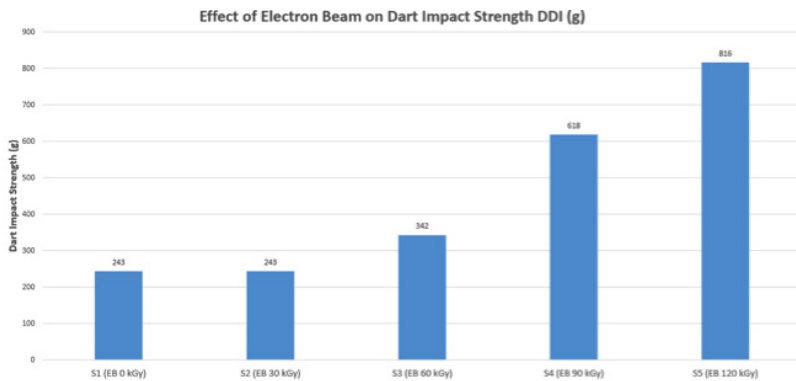
**Fig 14. EB effect on Hot Tack Max Force**



**Fig 15. EB effect on Hot Tack Energy**



**Fig 16. EB effect on Haze**



*Fig 17. EB effect on Dart Impact Strength*

From this example, we can easily see the effect of the EB radiation in this BOPE film in terms of Heat Resistance, Optical and mechanical properties, so making it useful for the indicated purpose:

- Heat resistance of PE films is increasing with higher dose of EB irradiation.
- At 60 kGy the hot tack is dropped to quite a low level.
- At 90 + kGy the films do not hot tack anymore indicating heat resistance is quite high.
- Between 0 and 120 kGy difference in seal initiation temperatures is about 18 C.
- Films turn more transparent haze drops and some mechanical property improvement with EB dose
- MD film shrinkage reduces with EB dose, better for printing.
- PE films after EB treatment increase in temperature resistance, better mechanical properties.

Once we know how to modify the properties of the external PE layer for a laminated full PE packaging, we can also test the laminated structure itself, to see if it performs the required properties for the final packaging.

To make this analysis we made a Recyclability & Packaging Study with a real structure:

- 25-micron BOPE EB treated Film at 90 kGy was laminated to 80-micron PE film using PU solventless adhesive
- The EB treated laminate was shredded, chopped and re-pelletized to be used in making blown films in combination with 50% virgin LLDPE.

and the findings were:

- The above laminate consisting of EB treated top film providing 18 C higher temperature resistance than the non EB treated laminate performs better on VFFS machines.



- The EB treated laminate could be blown back into films, the only difference was haze was higher than the non-EB treated laminate.
- Slight decrease in tensile elongation at break of the EB treated laminate versus non EB treated.

So, as a result of this study, and regarding the alternative Structure B, we can conclude that:

- **EB treated laminate provides higher temperature resistance than non EB treated laminate.**
- **EB treated laminate performs better on packaging lines than the non-EB treated laminate.**
- **EB treated laminate can be recycled following the EU RecyClass protocols**
- **Printing with EB cure inks (Flexo or offset) and EB crosslink the film can be an option to make PE\PE recyclable similar material laminates.**

### **Second Alternative Packaging, MONOLAYER PE (Structure C)**

If the packaging can be made in a single material it becomes more recyclable, in addition when this package can be made on a single film layer (avoiding lamination) it becomes an overall process more sustainable and recyclable.

In this case, we need to transfer all the properties of the PET layer to the PE monolayer, and to do so we should move to a COEX PE that will give us all the required properties except the Thermal resistance, which will be given by the Overprint EB Varnish.

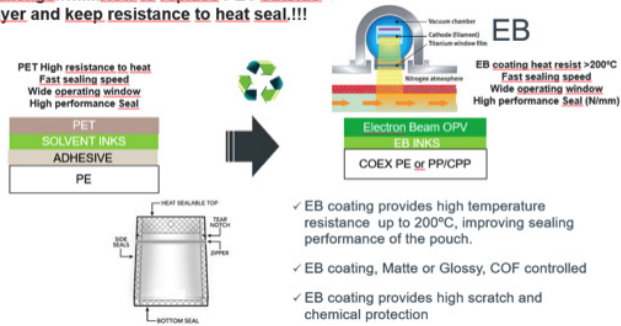
The greater resistance and the enhanced finishing qualities of the Electron Beam varnishes provide the facility to print on the external surface of the packaging without the need of having a layer of film that protects the inks from scratching, wear, and other degradation that the packaging can have during its life.

Also, one can combine matte gloss and/or EB varnishes like tactile on the last decks of either CIFlexo or CI offset to provide shelf appeal and aesthetics to the package. In addition, the monolayer PE approach could be easier to recycle. The EB coatings\ink either Flexo or offset can be deinked using a caustic bath following the APR procedures <https://plasticsrecycling.org/apr-design-guide/test-methods>. Initial lab work has shown this to be a possibility. Scale-up of the deinking process is ongoing. The EB curing can be restricted by controlling the voltage to the inks\coatings and not allowing penetration into the film and crosslinking it again aiding in the recycling process.

The heat resistance of EB varnishes is typically 200°C – 250°C (390°F – 490°F), similar to a PET layer that is substituted, for this reason this solution will provide high performance in the sealing process, as we can see in fig 18.

# Recyclable Monomaterial Surface Printed

**Challenge!!!!.....How to replace PET outside layer and keep resistance to heat seal!!!**



*Fig 18. COEX PE Monolayer PET replacement*

## Sustainability & Carbon FootPrint Comparison

We have seen two alternative solutions where thanks to the use of Electron Beam inks we can convert a traditional non-recyclable packaging, into a monomaterial recyclable packaging.

But recyclability is not the only impact we have with these alternative structures and the use of Electron Beam inks, in both solutions Structure B and Structure C we will have positive impact in terms of sustainability because:

- Recyclable solution
- PE has reduced Carbon footprint compared to PET
- Solventfree printing (Offset EB and Flexo Wetflex EB), Solvent reduction (Flexo Gelflex EB)
- Energy reduction (no required high energy for drying and solvent recovery)
- Waste reduction (EB inks can optimize waste by extended gamut process higher capabilities)

In addition, Structure C:

- Single sourcing for the film.
- Monofilm solution eliminates the process of lamination.
- Combining matte/gloss EB varnish in the printing process improves shelf appeal.
- Slitting process can be done in-line with printing machine in a single process.
- Deinking of EB inks/coatings and controlled depth of EB penetration into the film to cure inks and coatings can facilitate recyclability.

In the following section, we can see a Carbon Footprint analysis of 100.000m<sup>2</sup> (110.000ft<sup>2</sup>) flexible packaging order, to demonstrate the reduction of the same, not only by the recyclability of the packaging, but also for the direct CO<sub>2</sub> reduction resulting from the use of Electron Beam inks, and the reduction of processes in the case of Structure C where we can eliminate a further process of lamination and slitting while making the full converting process in one and only printing line.

In the tables 1 to 3 we will find the comparison analysis for these Structures A, B and C:

- The Orange-color cells show the productivity and consumption parameters of specific solutions.
- The Blue-color cells show specific Emission Factors depending on the specific film supplied and energy data.
- Recycling credit factor should be evaluated in each case, depending on recycled content (PCR) and depending on the specific Life Cycle Assessment for the product and local capabilities on collecting, sorting and recycling the packaging. In this example case used 0,6 credit factor meaning 40% reduction in the case of recycling capabilities.

This analysis will only compare main process differences: film, inks and energy, other differences in the process are estimated not relevant for this comparison.

**GENERAL**

SKU's Order size m2	10.000	CASE A	CASE B	CASE C
Substrate width	mm	1.000	1.000	1.000
Print run length	mts / job	10.000	10.000	10.000
Machine run speed average	m / min	250	250	250
Avg total change-over time	min	40,0	40,0	40,0
Printing time per job	min	40	40	40
Time per job	min	80	80	80

**PRINTING SUBSTRATE**

Substrate density kg/m3	Kg / m3	1.400	940	940
Substrate thickness µm	µm	12	25	105
Waste average (setup + others)	m / job	1.000	1.000	1.000
Total m2 per print run	m2 / job	11.200	11.200	11.000
Total Weight of substrate	Kg / job	188	263	1.086
CO2 emission factor	Kg Co2eq/unit	5,4	2,2	2,1
Recycling credit factor		no recycl.	0,6	0,6
<b>Kg Co2eq by film printed per job</b>	<b>Kg Co2eq/job</b>	<b>1.016</b>	<b>347</b>	<b>1.368</b>

**LAMINATING SUBSTRATE**

		CASE A	CASE B	CASE C
Substrate density kg/m3	Kg / m3	930	930	
Substrate thickness µm	µm	90	80	
Waste average (setup + others)	m / job	200	200	
Total m2 per print run	m2 / job	11.200	11.200	
Total Weight of substrate	Kg / job	937	833	
CO2 emission factor	Kg Co2eq/unit	2,1	2,1	
Recycling credit factor		no recycl.	0,6	
<b>Kg Co2eq by Lam. Substrate per job</b>	<b>Kg Co2eq/job</b>	<b>1.969</b>	<b>1.050</b>	<b>0</b>

**SUBSTRATES**

		CASE A	CASE B	CASE C
<b>Kg Co2eq by substrates per job</b>	<b>Kg Co2eq/job</b>	<b>2.985</b>	<b>1.397</b>	<b>1.368</b>

*Table 1. Substrate parameters*

In this example the PET has a huge impact in the equivalent emissions compared to PE, when the packaging can be recycled shows the difference is high.

INKS		CASE A	CASE B	CASE C
Color Ink Coverage of yearly production	%	150%	150%	150%
Color ink wet gramage for solid 100%	g/m2	1,5	1,0	1,0
C02 emission factor	Kg Co2eq/unit	2,2	2,2	2,2
<b>Kg Co2eq by ink per job</b>	<b>Kg Co2eq/job</b>	<b>55</b>	<b>37</b>	<b>36</b>
Coating				
Coating coverage avg.	%			100%
Coat. wet gramage	g / m2			2,00
C02 emission factor	Kg Co2eq/unit			2,2
<b>Kg Co2eq by coating per job</b>	<b>Kg Co2eq/job</b>	<b>0</b>	<b>0</b>	<b>48</b>
Solvents				
Added solvent during printing	%	35%		
Solvent conversion factor	liter / kg	114%		
Added solvents	lts / m2	0,0009		
C02 emission factor	Kg Co2eq/unit	1,9		
<b>Kg Co2eq by solvent per job</b>	<b>Kg Co2eq/job</b>	<b>19</b>	<b>0</b>	<b>0</b>
Waste ink				
% wasted ink		10%	1%	1%
<b>Kg Co2eq by inks and solvents per job</b>	<b>Kg Co2eq/job</b>	<b>74</b>	<b>37</b>	<b>85</b>
LAMINATION ADHESIVE		CASE A	CASE B	CASE C
Adhesive gramage avg	g/m2	2,5	2,5	
C02 emission factor	Kg Co2eq/unit	2,1	2,1	
<b>Kg Co2eq by Lam. Adhesive per job</b>	<b>Kg Co2eq/job</b>	<b>59</b>	<b>59</b>	<b>0</b>
INKS & ADHESIVES		CASE A	CASE B	CASE C
<b>Kg Co2eq by Inks &amp; Adhesives per job</b>	<b>Kg Co2eq/job</b>	<b>133</b>	<b>96</b>	<b>85</b>

Table 2. Inks, Coating, Solvents and Adhesive parameters

The impact of the inks and adhesives are not much relevant in this study, only 4 to 5% of the total Material and Energy impact.

PRINTING ENERGY		CASE A	CASE B	CASE C
Machine load average in production	kWh	90	90	90
C02 emission factor	Kg Co2eq/unit	0,287	0,287	0,287
<b>Kg Co2eq by Energy per job</b>	<b>Kg Co2eq/job</b>	<b>26</b>	<b>26</b>	<b>26</b>
Gas consumption per hour (m3)	m3 / hour	18		
C02 emission factor	Kg Co2eq/unit	0,210		
<b>Kg Co2eq by Gas per job</b>	<b>Kg Co2eq/job</b>	<b>44</b>	<b>0</b>	<b>0</b>
N2 consumption per printing hour (m3)	m3 / hour		75	75
C02 emission factor	Kg Co2eq/unit		0,430	0,430
<b>Kg Co2eq by N2 per job</b>	<b>Kg Co2eq/job</b>	<b>0</b>	<b>38</b>	<b>38</b>
<b>Kg Co2eq by Energy printing per job</b>	<b>Kg Co2eq/job</b>	<b>70</b>	<b>64</b>	<b>64</b>
LAMINATING PROCESS		CASE A	CASE B	CASE C
Machine run speed average	m / min	300	300	
Avg total change-over time	min	25,0	25,0	
Lamination time per job	min	33	33	
Time per job	min	58	58	
LAMINATION ENERGY		CASE A	CASE B	CASE C
Machine load average in production	kWh	35	35	
C02 emission factor	Kg Co2eq/unit	0,287	0,287	
<b>Kg Co2eq by Lam. Energy per job</b>	<b>Kg Co2eq/job</b>	<b>8</b>	<b>8</b>	<b>0</b>
SLITTING PROCESS		CASE A	CASE B	CASE C
Machine run speed average	m / min	350	350	
Avg total change-over time	min	10,0	10,0	
Slitting time per job	min	29	29	
Time per job	min	39	39	
SLITTING ENERGY		CASE A	CASE B	CASE C
Machine load average in production	kWh	12	12	
C02 emission factor	Kg Co2eq/unit	0,287	0,287	
<b>Kg Co2eq by Slit. Energy per job</b>	<b>Kg Co2eq/job</b>	<b>2</b>	<b>2</b>	<b>0</b>
ENERGY		0	0	0
<b>Kg Co2eq by Energy per job</b>	<b>Kg Co2eq/job</b>	<b>80</b>	<b>74</b>	<b>64</b>

Table 3. Energy consumption

In terms of Energy consumption, there is more efficiency and a carbon footprint reduction when using EB inks. In addition, when printing Surface, the reduction of post processes like lamination or slitting significantly impact on the overall end product.

In the Structure C it saves many more resources (not detailed here), reduces complexity and delivery time (no waiting time between processes).

In Fig 19 we have added all the different CO<sub>2</sub> conversions, and made the comparison regarding Carbon footprint reduction for Structure B and Structure C. In the best case we achieve a reduction of 1,68Tn of CO<sub>2</sub>eq of emissions in a single order of 10.000m<sup>2</sup> [110.000ft<sup>2</sup>].

**CO2 REDUCTION A-C: -1.680 Kg CO2eq**

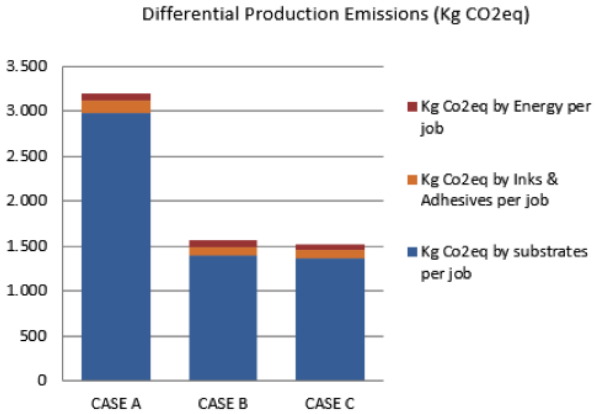
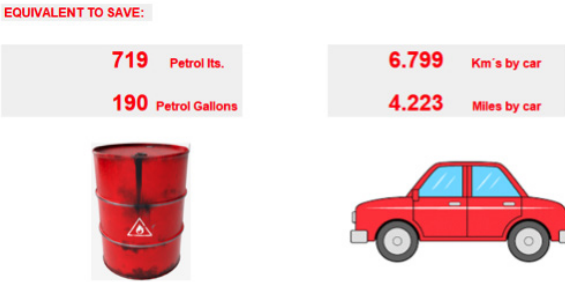


Fig 19. CO<sub>2</sub> reduction

In Fig 20 we have converted these CO<sub>2</sub> emissions to a more understandable concepts, so those emission savings can be equivalent to:



<https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator>

Fig 20. CO<sub>2</sub> reduction equivalence

## CONCLUSIONS

The exposed above demonstrates that the use of Electron Beam curable inks in the printing process (either Flexographic or Offset printing) helps in achieving a Recyclable packaging in a more sustainable way.

More specifically the following has been proved:

Thanks to Electron Beam full PE recyclable laminated structures can be created due to the ability to modify the surface properties, by increasing the temperature resistance of the outer layer so facilitating the sealing performance required for the packaging conversion.

Thanks to Electron Beam full PE recyclable monolayer structures can be created due the greater resistance and the enhanced finishing qualities of the Electron Beam varnishes so facilitating the sealing performance required for the packaging conversion.

In addition, in both solutions full PE laminated or monolayer have positive impact in terms of sustainability because:

- Recyclable solution
- PE has reduced Carbon footprint compared to PET
- Solventfree printing (Offset EB and Flexo Wetflex EB), Solvent reduction (Flexo Gelflex EB)
- Energy reduction (no required high energy for drying and solvent recovery)
- Waste reduction (EB inks can optimize waste by extended gamut process higher capabilities)
- Single sourcing for the film when monolayer.
- Monofilm solution eliminates the process of lamination.
- Slitting process can be done in-line with printing machine in a single process.

In Global the potential savings in emissions can be up to 1,68Tn of CO<sub>2</sub>eq in a single order of 10.000m<sup>2</sup>. [110.000Ft<sup>2</sup>]

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