

More sustainable WB binders and coatings from LIFE-WB BioPaint

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Abstract

The development of waterborne (WB) wood coatings is still hindered by a limited set of resin technologies, smaller than for solventborne (SB) products. In the EU-funded LIFE-WB BioPaint project, IVM Chemicals is piloting a new production technology that will make available for the first time as WB resins the same or better short oil alkyd polyols (ALK) used in the best SB 2K paints and varnishes. As initial examples, a low T_g and a high T_g resin were emulsified. Their use is demonstrated in a variety of clear and pigmented coatings for interiors, showing reduced VOC emissions and carbon footprint not only relative to SB analogues, but also to established WB options.

Introduction

We know by now that the current global economic model is not sustainable: we use up the yearly resources of the world by July and we are on a path to increase average temperatures by over 3°C, reduce livable land because of rising sea levels and increase frequency of the most destructive weather phenomena, all due to our emissions of heat-trapping compounds in the atmosphere [1]. We are all called to act rapidly to change what we do and how we do it to try and mitigate the impact of the disasters that are now clearly in our sight. That is, we must become, as individuals and as a society, sustainable. In particular, every industry and every company must look for ways to lower its environmental impact and ultimately to make its products be sustainable and carbon neutral over their lifetime.

In order to assess the sustainability of any product, it is necessary to understand the materials and processes used in making it, how the product is used, and how it is finally disposed of (Fig. 1). LCA (Life Cycle Assessment) analysis does just that, quantifying the various environmental inputs and outputs, including energy sources, human health impacts and ecosystems footprints.

How do coatings, and in particular those currently in use for industrial wood (the situation is different for other application areas), fit into this picture? They are made from mostly non-renewable resources, with processes that are relatively energy-intensive, contain several unhealthy compounds, and a good fraction of them (the volatile organic compounds, VOC, used as solvents, coalescents etc.) is lost in the atmosphere either during paint production or paint application processes, providing no function in the final coating yet causing significant air pollution.

Of the 3,3 million tonnes of paints used for wood coatings (2019 [2]), for furniture, fixtures, floorings etc., over 60% are SB, dissolved in 800 ktons of flammable and often toxic aromatics, acetates or ketones. Such VOCs also impact air quality, for example by triggering ozone formation at low elevations, and contribute to a large CO₂ footprint (CFP). The latter is estimated in 2,1 kg CO₂/kg of paint (kC/kg) by LCA (project results, cradle-to-gate value) for a typical white basecoat, a type of paint that is employed in greater quantities than most. Such value is expected to be a lower limit for the CFP of wood coatings, given the low relative CFP of mineral fillers, abundant in this type of paints, relative to the resins and solvents that would make up more of any clear coat.

In Europe, it is reported that up to 50% of the total over 8 million tonnes of VOC emissions (2018 [3]) derive from the coating sector in both industrial and construction applications. The industrial use of coatings is by far the greatest source of non-methane volatile organic compound pollution in the 33 countries of the EEA + UK.

A **product** sustainability depends on

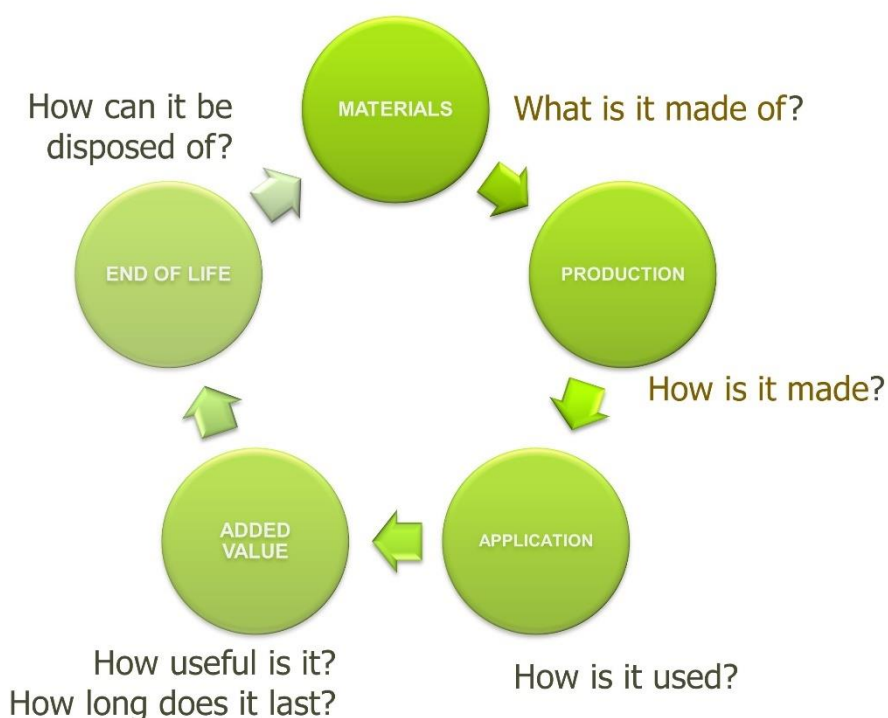


Figure 1. Sustainability of products in a circular economy model

Why not to eliminate or reduce the use of coatings, then? That would not be a solution at all, either! Indeed, coatings have a large positive effect on the durability of coated materials and items, and, hence, an overall positive environmental impact. Accordingly, the use of coatings is estimated to increase in the future.

That is particularly true for wood coatings: wood (along with its derivatives such as cellulose) is an ideal sustainable material, biorenewable and biodegradable. As a matter of fact, it is starting to replace plastics in single use items, and steel and cement in construction. However, wood is also susceptible to damage from mechanical and chemical attacks; hence, it tends to benefit the most, among solid materials, from the protection provided by coatings.

More sustainable wood coatings are clearly and urgently needed.

Scope

For a long time, IVM Chemicals has made greater sustainability one of its core objectives. The integrated resin and paint production plant in Parona, Italy, opened around 2000, is still cutting-edge for emission control and energy efficiency (Fig. 2). Moreover, we have a strong tradition of research aimed at environmental footprint improvement: IVM was the first to introduce paints designed to avoid low-altitude ozone formation, styrene-free oxy-radical polyesters [4], and high quality 2K polyurethanes (PU) at very high biorenewable content.



Figure 2. IVM Chemicals Parona integrated resin and paint production site

IVM Chemicals is notable in having the rare capability to produce both coatings and binders, unsaturated polyesters (UPE) and ALK. Such synergy was already exploited in LIFE-BioPaint, a previous EU-funded project, to design new biorenewable UV-curable UPE, to use them in UV-curable coatings of the highest quality and lowest environmental impact, formulating the latter in a specifically designed and built innovative production line (For more info on this project, please see <https://www.ivm-lifebiopaint.com/>)

The obvious next target for a sustainable make-over are SB coatings. By switching from solvent to water as the carrying medium for the resins, the associated atmospheric VOC emissions and all impacts of production and transport of the organic solvents are avoided.

Existing alternatives to SB coatings are WB paints based on acrylic emulsions and PU dispersions. However, they constitute no more than about 25% of the market for industrial wood coatings because of outstanding quality issues with chemical and mechanical resistance, look and feel. Moreover, they still have a CFP estimated in 1.7 kC/kp (project results, cradle-to-gate value) for the equivalent of the white basecoat evaluated in the SB case, despite a small impact in this regard of its resins made from petrochemicals. They also include toxic material such as acrylic acid and isocyanate monomers. Although biobased WB low-molecular weight (MW) long-oil ALK are also available, they are not suitable for most industrial applications because of quality issues and slow drying speed. The development of novel WB paint technologies with lower CFP and VOC appears to be necessary.

The hypothesis was made that, if new WB coatings contained the same binders as the gold standard SB 2K PU, they would yield the same great performance. Such SB 2K PU are based on high quality high-MW short-oil hydroxy-functional ALK. An LCA of the same type of white basecoat whose evaluation is mentioned above, made this time with the WB version of the ALK used in the SB analogue (that is, with standard biorenewable content) yields a CFP of 1.6 kC/kp (project results, cradle-to-gate value; by comparison, the SB equivalent value is 2,1 kC/kp). Better yet, IVM already developed more biorenewable versions of such resins,

now only available as SB materials: if turned into WB resins, the CFP of the relative coatings would be even lower than the cited value. Moreover, as mentioned earlier, we expect this type of coating to provide the lower limit for CFP change among wood coating types, any clearcoat being more impacted by resin change and solvent decrease.

About a decade of research at IVM R&D labs revealed that the novel application of screw extrusion, a mainstay of thermoplastic processing, affords a stable WB version of the target ALK and confirmed the possibility to employ such resins in high quality wood coatings.



Figure 3. Logo of LIFE-Waterborne BioPaint project

The good people at the LIFE Programme, the main EU financing tool for environmental and climate progress, agreed with us on the potential value of this new technology and of the resins and coatings that could be thus produced, and funded the LIFE-WB BioPaint project we are presenting here.

LIFE- WB BioPaint runs September 2020 - July 2024. It is close to conclusion at the time of writing.

Objectives

The overall objective of LIFE WB BioPaint is to pilot an innovative process for production of novel WB resins and the paints using them. They will be nearly VOC-free, non-hazardous, with better mechanical properties than benchmarks, at comparable cost.

Based on research work lasted over ten years, we established that screw-extrusion is a superior technology for emulsification of high-MW hydrophobic polymers. Therefore, within this project we designed and built a prototype pilot line and ancillary systems able to disperse in water:

- the high-quality high-MW hydroxy-functional ALK now used as binders in the best SB 2K PU paints and
- UV-curable UPE, particularly the biobased ones developed within the LIFE-BioPaint project

These emulsions are being used to formulate advanced paints not otherwise possible, that are being tested in a wide variety of final coating applications for maximum environmental improvement.

The paints using such WB resins would be able to fill application niches now using

- traditional SB 2K PU paints, reducing VOC emissions, CFP and dangerous chemicals
- UV or oxidatively-cured SB paints applied by spray or curtain coating, reducing VOC emissions, CFP and dangerous chemicals
- WB paints now made from petrochemical materials, increasing biorenewable content
- WB paints made from dangerous components such as acrylic acid, reducing health and environmental risks.

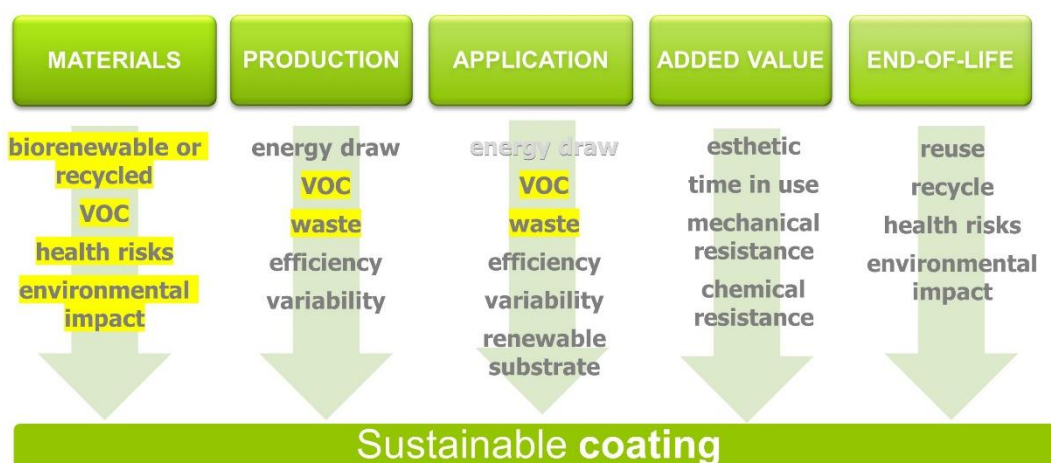


Figure 4. LIFE-Waterborne BioPaint contributions to sustainability

Expanding from the general analysis of a product sustainability to the specific details for a coating (Fig. 4), we can see that the “Application” stage is much improved by greater use of WB coatings, since VOC emissions are going to be mostly avoided at the application sites. Since such sites are globally distributed, the related improvement in air quality would be also widespread. In addition, the reduction in organic solvent use will yield emission improvements both at the resins and paint “Production” site and upstream where component “Materials” are produced. Further environmental advantages at this stage will derive from the increased use of more sustainable starting materials and the reduction in noxious components. Energy consumption at the application sites is, unfortunately, going to increase on average, since water evaporation requires more heat for a longer time than the equivalent evaporation of organic solvents. The precise environmental impact cradle-to-grave, in particular CFP, will depend on the energy source, on whether it is renewable or fossil. However, we expect that there will be always a significant improvement, growing in size as the energy source mix becomes ever more low-carbon.

Overall, the resulting impacts can be visualized as in Fig. 5.

Process Innovation

The development work was carried out on high quality high-MW short-oil hydroxy-functional ALK. It was never possible to emulsify some of them with conventional processes, despite collaborations with the best in the field. In particular, viscosity goes through a peak during the

emulsion formation of such magnitude as to make it impossible to proceed with stirrers or similar devices.

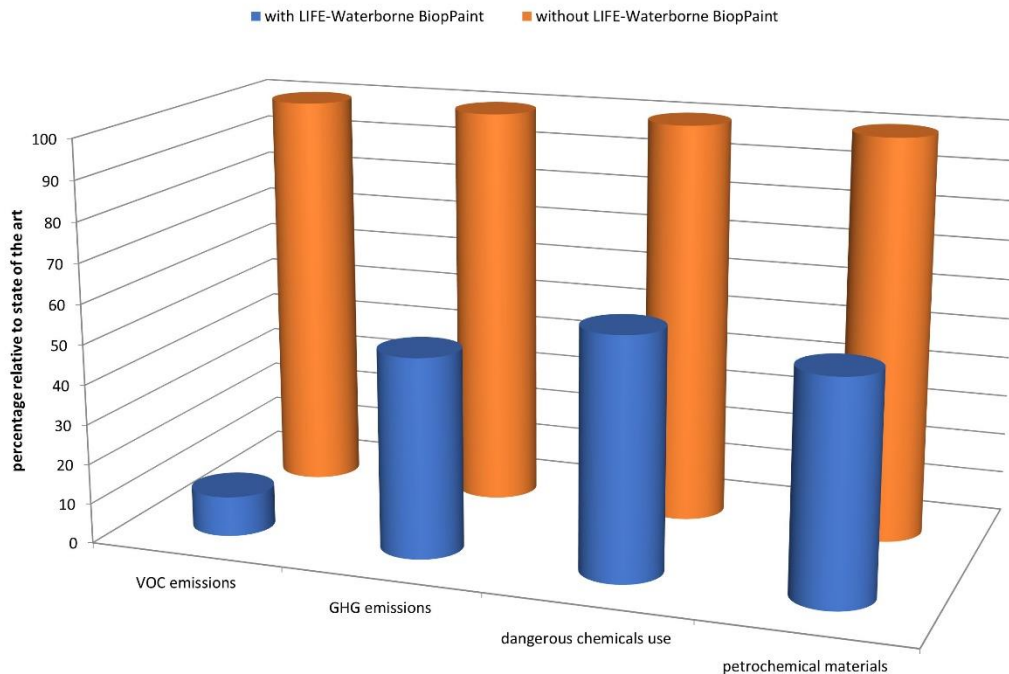


Figure 5. Expected environmentally significant impacts at 5 years from project end.

However, the process conditions within a screw extruder overcome this problem; enormous shear forces are applied to very small volumes where the ratio of components can be precisely controlled. Moreover, an extruder can also be conceptualized as a linear-flow reactor with the possibility to control the temperature almost analogically along the transit, going rapidly from the relatively high temperature (over 100°C) required to pump high MW ALK to a temperature where the material can be safely handled (below 40°C) without any thermal shock. High pressure avoids water boiling even at temperatures above 100°C for initial contact with the hot resin. It is possible to add different material inputs at different stages, diluting gradually and changing the reaction conditions within. Hence, pH can be also tuned separately at different stages, crucial for dispersibility and stability.

Emulsification within the screw extruder can be schematized thus:

1. hot (>100°C) resin input, already comprising dissolved emulsifier
2. neutralization stage: basic water added, water-in-resin emulsion formed
3. some time for reaction allowed, emulsification pH reached
4. emulsion inversion stage: water is added, viscosity peak is reached and passed as the resin-in-water emulsion forms
5. dilution: more water is added, pH can be adjusted and buffered for stability

In order to run the pilot line within IVM's resin production department, we had one big engineering problem to overcome: a SB resin production site is, of course, subject to ATEX restriction, since the possibility that an accident leads to the formation of an explosive atmosphere is always present. On the other hand, extruders that comply with such restrictions,

although possible, are less flexible than we desired and hugely expensive. We settled on an elegant design by Hysytech Srl including an extruder from F.lli Maris, both from Turin, Italy (Fig. 6).

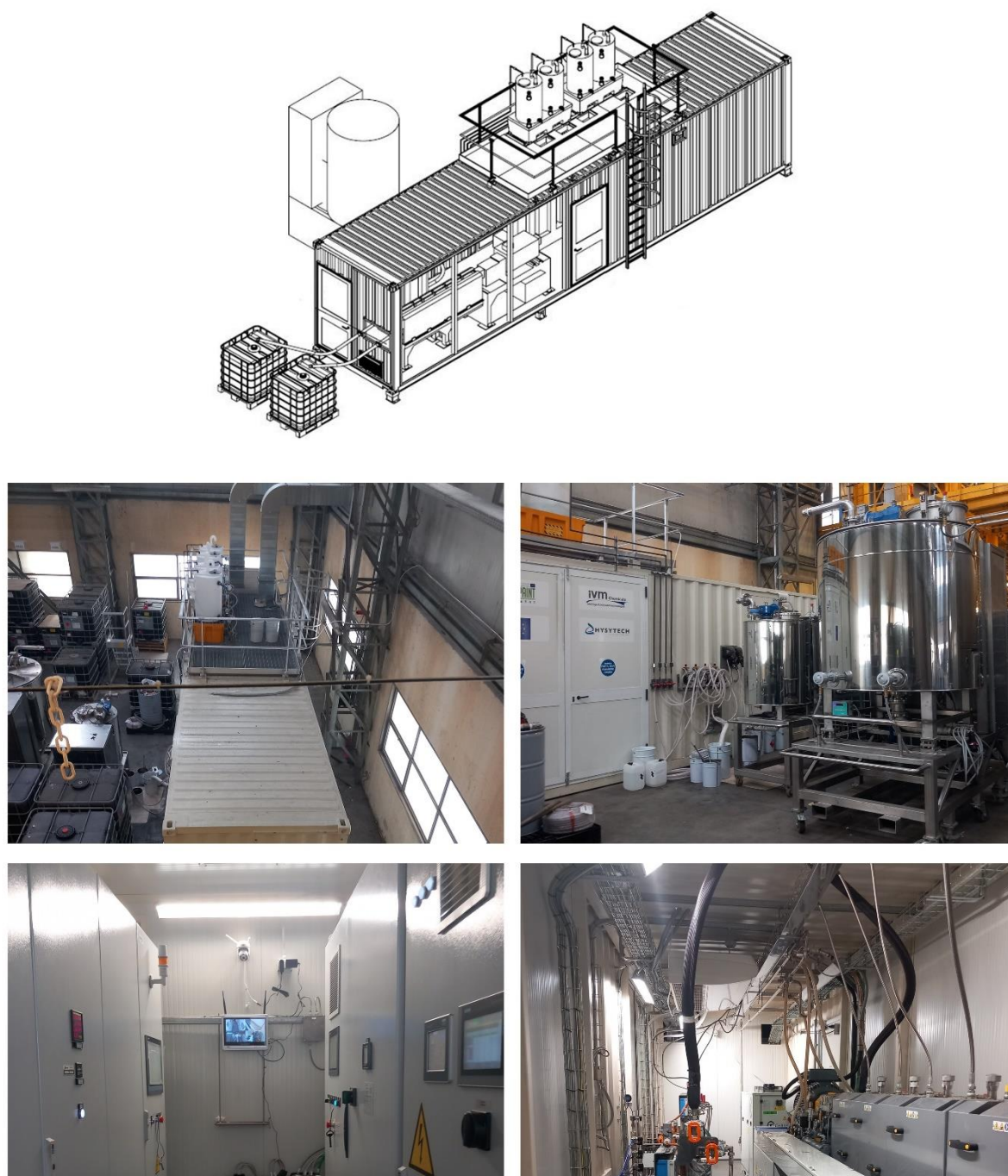


Figure 6. Drawing and images of emulsification extruder line

Using a model that was already within that company's portfolio for installation of small chemical production units or labs in extreme conditions, the whole line, including the extruder itself, the dosing units, the temperature regulation system and all the control electronics, is arranged within a 12 m long container that is kept in overpressure. All the wall sections can be taken off to be able to work more easily on the line for maintenance, but the day-to-day work takes place without the operators having to physically access the line. Input and output

of materials and products occurs outside, , with cameras to permit monitoring of the systems inside the container. Line operations, including monitoring of the redundant safety features can be carried out locally or remotely thanks to the computer control system (Fig.7).



Figure7. Emulsification line control system examples

Product Innovation

It was mentioned above that the emulsifier is pre-dissolved in the resin before it is injected in the extruder. Selection of the surfactant agent that acts as the interphase between water and resin is crucial to emulsion stability, particle size and resistance to hydrophilic agents of the final coatings. In our experiments, after testing several surfactant systems varying in chemical nature and hydrophile/lipophile balance (HLB) we have been able to establish that the main emulsifying agent must be non-ionic, that it must have $HLB > 15$ and have a lipophilic section of great compatibility with polyester resins. It appears also that a high MW for the emulsifier is a consequence of these constraints.

Using an emulsifying surfactant of this type, we have established emulsion formulations and procedures for a low T_g (-7°C) ALK and a higher T_g (13°C) one. The pH of stability falls between 7 and 8, emulsion size is about 300 nm (measured with a NanoFlex by Microtrac). At the time of writing, it is possible to discuss some of the results obtained with the higher T_g ALK, employed in formulations made for various applications and compared directly to the most relevant current WB product.

WB wood coating products can be 1K or 2K, pigmented or clear, for industrial applications (with oven/forced air drying) or for use by craftsmen (with ambient drying), used as sealers or topcoats. The novel emulsions yield sealers with good pigment dispersion and greater filling power than acrylic resins. Table 1 shows results of use in several different topcoats, where several different performance vectors are vitally important.

In every case, the need for the addition of coalescents, VOC or otherwise, is much decreased or eliminated altogether. Indeed, it was noted that these WB ALK show excellent coalescence on their own even at cold ambient temperatures and they also tend to improve the coalescence of accompanying acrylic emulsions or PUD, acting themselves as coalescing agents. Gloss is generally higher, wood color is brought out more brilliantly, transparency is improved, pigment dispersion and covering power tends to be better, yielding “whiter” whites than acrylic resins do. The last point can be also exploited to reduce the amount of TiO₂ in some products: this whitest of pigments is both the most expensive and the one with the worst environmental impact, including CFP, among similar materials.

	% solids	% alkyd		drying speed	resistance to liquids	notes
		emulsion on formula	solids on tot binder			
2K clear topcoat for industry	37,03	0	0	= (in oven)	>	more glossy, less grey
	37,51	50	69			
2K white topcoat for industry	46,59	0	0	= (in oven)	=	more glossy whiter
	46,87	9	20			
2K clear self-sealer	26,96	0	0	= (at RT)	=	more glossy, less grey, fuller
	26,93	62	100			
2K clear topcoat max resistance	28,52	0	0	= (at RT)	<	similar scratch resistance
	28,35	40	71			
1K clear topcoat	31,99	0	0	< (at RT)	<	needs most work
	31,80	38	55			
2K white topcoat, minimal cost	46,59	0	0	< (at RT)	=	more glossy needs less TiO ₂
	46,54	45	100			

Table 1. Formulation and performance of WB topcoats with new WB ALK vs. WB Std

LCA and sustainability analysis

To try and assess sustainability properly for the results of this project we need to compare the paints and varnishes made with the new emulsified ALK with their SB analogues made with the same ALK and with analogues made with the current WB resins. ISO 14044:2006 spells out that, for a comparative LCA assertion to be valid, the products or processes involved must be analyzed using the same functional unit, system boundaries, performance parameters, inputs and outputs assessments etc. Therefore, we have been very careful to change as little as possible any aspect of the products being compared to be able to assess only the impact of the new resins, even to the cost of providing only a lower limit of the possible sustainability improvements. The products were assessed at equal performance and at ratio of main component types (resin, pigments, mineral fillers, solvents) as similar as possible. Our assessment is always just cradle-to-gate since each wood coating product can be and is used in many ways for coating many different possible objects and surfaces.

In every case assessed, core processes were relatively unimportant, accounting for less than 10% of any calculated impact (see Fig. 8 for an example). The most important inputs were always the raw materials, considered at whatever level of preparation they are received by IVM production (again, see Fig. 8 for an example).

Among core processes, energy and water consumption are always overwhelmingly the main drivers of impacts like CFP, hence they remain a priority for the pursuit of greater efficiency. Transport is always a minor contributor, showing up in a significant way only for one material, TiO₂, procured from China in these examples; such material must be minimized regardless of origin because it has a very impactful production process for CFP (4,8 kg CO₂/kg of material, the highest of any material input), waste generation and toxic materials use.

We compared, as described above, three white basecoats: SB, WB std, and the new WB from the project. TiO₂, despite being a relatively minor component in percentage, was always the greatest single source of environmental impacts, between $\frac{1}{3}$ and $\frac{1}{2}$ of the overall impact of all component materials. In this case, CFP was 2,1 vs. 1,7 vs. 1,6 kC/kp, respectively. The relatively small difference between the SB and WB products is due to the large contribution of TiO₂ partially hiding the other factors. The surprisingly small improvement in CFP in going from WB std to new WB products is the result of relatively larger CFP impacts assessed for biorenewable materials like oils and fatty acids than for petrochemicals like acrylic acid. Indeed, oils suffer from being charged, in the databases used for LCA, with a large land-use-change impact, since some, like castor oil used in our case, still are often cultivated on fields subtracted from forests or derive from substitution of food production. Procurement of these materials through supply chains certified via schemes like ISCC-plus [5], that start from the impact of the growing field, would reduce greatly such impacts, and the overall LCA, accordingly.

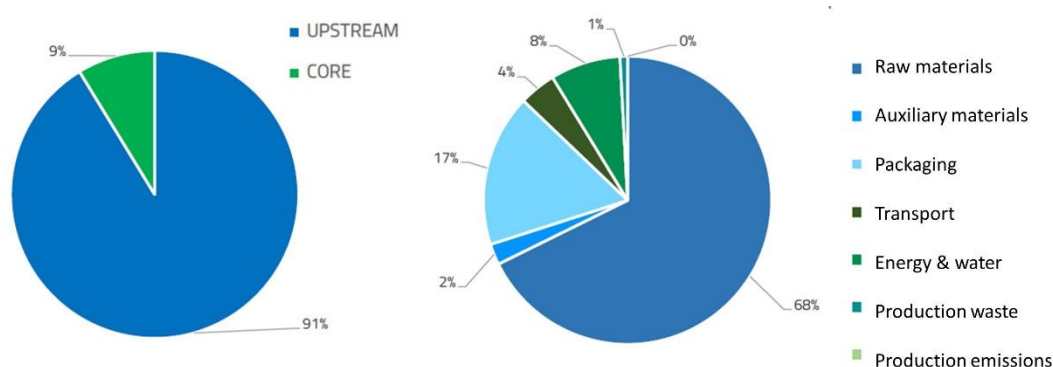


Figure 8. Global Warming Potential of different inputs for innovative white basecoat

We also compared clear topcoats as SB or new WB varieties, separating best the impact of VOC solvents from that of the polymeric resin (that is the same in the two cases). Therefore, the difference calculated between 2,4 and 1,4 kC/kp for SB or new WB products precisely reflects the contribution of volatile organic solvents.

For more information on the LIFE-WB BioPaint project and to keep up-to-date on its progress and the latest results, please go to <https://www.ivm-lifebiopaint-wb.com/>

References

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- 5) See <https://www.iscc-system.org/> for more on this sustainability certification.