Eco-Efficiency Analysis Demonstrates the Environmental and Economic Benefits of Flexographic Printing Inks in Film Applications

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ABSTRACT

An Eco-Efficiency Analysis was conducted comparing three ink technologies used in the printing of low density polyethylene film, such as used to produce retail bags. Developed by BASF, the Eco-Efficiency Analysis compares the economic and environmental impacts that products and processes have over the course of their life-cycle. In the economic dimension materials, energy, waste, capital, labor and the cost of EHS programs are considered. The environmental impacts assessed are energy consumption, materials, land use, worker health effects, risk potential and emission to air and water. In this Eco-efficiency study a quantified output, or *customer benefit*, was defined as the production, use and disposal of 1000 m^2 of flexographic printed LDPE film. Three ink systems were evaluated; water base and solvent base which were thermally dried and a UV cured ink. The model assumed a 4-color CI flexographic printing press with each of the four stations applying 25% coverage of a solid color on the polyethylene film. Some of the processing variables considered were production speeds, applied wet and dry ink film weight, percent ink solids and energy to operate the printing equipment and cure the ink. The results show that the water-based ink system has a lower overall environmental impact, for relative inputs, in addition to lower life cycle costs. The UV ink had the highest cost impact, and the water ink the least. In four of the six environmental dimensions the solvent ink had a higher impact compared to the UV and water ink systems.

INTRODUCTION

Consumers continue to expect more from the packages that deliver and protect the products they consume. In response brand owners strive to innovate with new package designs, materials and user friendly features. Helping to fuel this is an interest in sustainability that continues to garner favor and attention in society, even with continuing energy and economic uncertainties. The concept, development and application of sustainable packaging have now touched all stakeholders in the value chain. Suppliers and package producers are diligently working to answer the need of this rapidly changing market.

Raw material selection is a vital component in producing products that meet the stringent demands of today's sustainable package. Skepticism is mounting with consumers as many products with eco-labels flood the shelves of stores. In response government, NGO's (non-government organizations) and trade organizations are adopting guidelines for marketing claims made on packaging. This year the Federal Trade Commission is adopting new guidelines on green marketing, the first such change in more than a decade.

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Market interest in environmental information on products that is credible, unbiased, verifiable, and covers the entire life cycle is growing. Life cycle assessment tools have become an important quantitative tool to validate the environmental impacts and claims of products and processes.

METHODS AND MATERIALS

Eco-Efficiency Methodology and Study Alternatives

An Eco-efficiency analysis (EEA) evaluates both the economic and environmental impacts that products and processes have over the course of their life-cycle[1]. The methodology was created by BASF, in partnership with an external consultant, and has since been further developed. BASF's EEA is based upon the ISO 14040 standard for life cycle analyses, however in addition to this standard, includes additional enhancements, which allow for the expedient review and decision-making at all business levels. Since its inception in 1996, BASF has completed nearly 400 analyses on a wide variety of products and processes. In particular, an EEA evaluates the environmental impact of the production, use, and disposal of a product or process in the areas of energy and resource consumption, emissions, toxicity and risk potential, and land use. The EEA also evaluates the life cycle costs associated with the product or process by calculating the costs related to materials, manufacturing, waste disposal, and energy.

The alternatives compared under this EEA study are summarized in Table 1, and consisted of water-based, solvent-based, and UV-cured printing inks. The Customer Benefit (CB), or defined level of output, for this study was defined as the production, use and disposal of 1,000 m^2 of 3 mil LDPE flexographic printed film with a 25% solid image coverage area as applied by each individual printing station on a 4-color CI (Central Impression) press.

The context of this EEA study compared three products competing in a consumer market with an incremental innovation level at a regional level over the course of an entire life cycle.

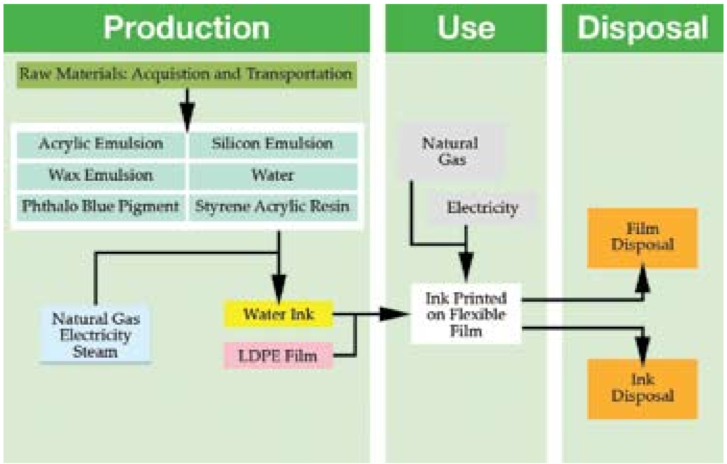
System Boundaries

The scope of any EEA is defined by its system boundar ies, which define the specific elements of production, use, and disposal that are considered as part of the analysis. The system boundaries for the three alternatives evaluated in this particular study are shown in Figure 1. The production, use, and disposal phases of the various printing inks differed slightly between the alternatives, therefore, the environmental and economic impact analysis focused on all three phases for each printing ink alternative.

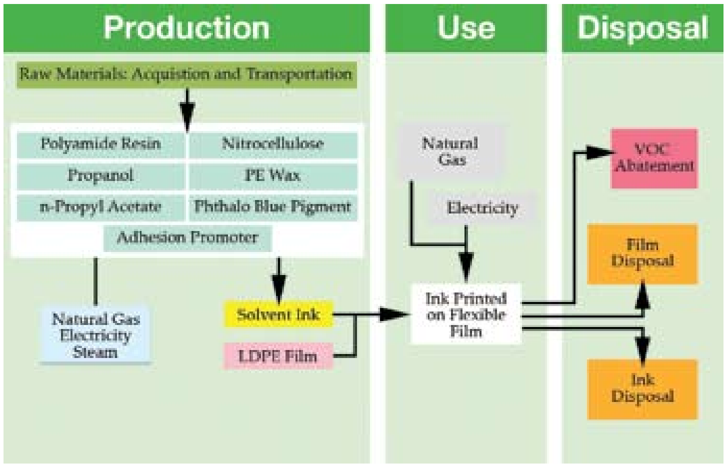
Table 1. *Summary of study alternatives*

Ink System	Description
Water	Styrene acrylic water-borne thermally cured
Solvent	LMW polyamide solvent-borne thermally cured
UV-Cured	Polyester acrylate UV-cured

Water-Based



Solvent-Based



UV-Cured

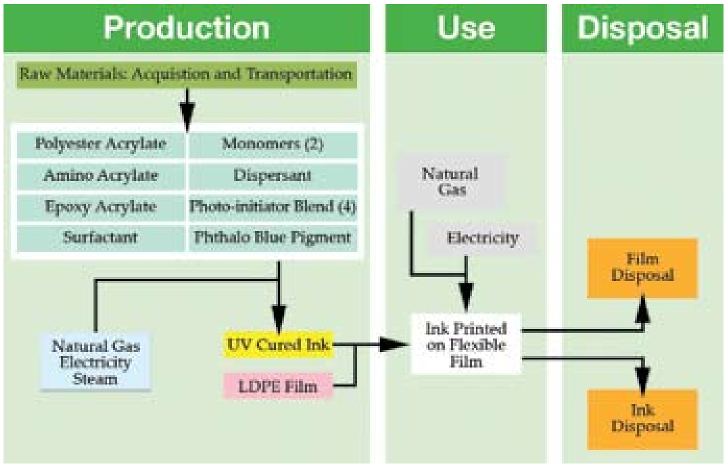


Figure 1. *System boundaries for the three alternatives.*

Environmental and Cost Categories

The environmental and economic aspects are deemed and weighted equally important in an eco-efficiency analysis. As briefly mentioned earlier, environmental impact is characterized using eleven categories, including: primary energy consumption, raw material consumption, global warming potential (GWP), ozone depletion potential (ODP), acidification potential (AP), smog creation potential, water emissions, solid waste generation, toxicity potential, risk potential, and land use. Primary energy consumption includes the cumulative energy utilized during production, use, and disposal as well as the energy content remaining in the products. All forms of energy are converted back to their primary energy sources, measured in MJ/CB, and include: crude oil, natural gas, anthracite, lignite, uranium ore, water power, biomass and others. The individual energy values are summed to obtain the total primary energy consumption. Additionally, key raw materials consumed in a process are calculated in terms of kg/CB with a cut-off criterion being < 0.1%. These values are weighted with a factor that reflects the demand and exploitable reserves of the raw materials so that the lower the reserves of a raw material and the higher the rate of consumption, the scarcer that material is and therefore the higher the weighting factor it is assigned.

The amount of air emissions were weighted with a factor reflecting their potency regarding the global warming, acidification, smog creation, and ozone depletion potentials. The air emissions for each major greenhouse gas were adjusted for the 100-year GWP as defined by the Intergovernmental Panel on Climate Change (IPCC)[2]. Water emissions are assessed through a critical volumes approach, which considers both the total amount of emissions to water, as well as the environmental toxicity of the chemicals being emitted. Critical volumes (CV) are calculated as the ratio of the amount of chemical emitted to the Maximum Emission Concentration threshold limits For example, an emission of 200 mg NH4-N with an MEC threshold value 10 mg/L results in a critical volume of 20 L (CV = 200 mg/10 mg/L). The individual critical volumes are then summed for each emission to water in order to obtain an overall impact (L/CB). The solid waste emissions account for all materials generated and disposed of in a landfill, therefore materials that are recycled or reused are not counted as solid waste. Wastes are categorized as municipal, hazardous, construction, and mining, with a weighting factor applied to each type to account for impact. The impacts are then summed to obtain an overall impact amount in kg/CB. The weighting factors are 1, 5, 0.2, and 0.4 for each waste category, respectively, and are based on costs for landfill which reflect the degree of potential environmental impact for each.

Furthermore, even though land is considered to be a finite resource, most life cycle analyses do not include an evaluation of land use patterns. BASF's EEA, however, allows for the consideration of land use as an environmental impact category based on the degree of land development needed to fulfill the customer benefit. Land use has five categories according to the degree of development that is needed. These categories include: i) No Development – untouched ecosystems, forests, lakes, rivers, wetlands; ii) Partially Developed – organic agriculture, green land, fallow, heterogeneous agriculture; iii) Developed – conventional agriculture, modified areas; iv) Covered – long-term paved areas, industrial areas, landfills, areas with buildings on them; and v) Covered and Divided – long-term paved areas that divide ecosystem areas, transportation areas such as streets, rail tracks, canals. The land use results are calculated based on the total amount of land used (m^2/CB) with weighting factors applied to categories iii – v to reflect the higher potential impact for these land uses.

The toxicity potential was assessed not only for the components of the finished printing inks, but for the entire pre-chain of chemicals used to manufacture the components as well. The result is an assessment of life-cycle toxicity potential. The entire method for performing the analysis of toxicity potential is described in Saling *et al.* (2002)[1] and is based upon the Hazardous Materials Regulations (R-phrases). A total score for toxicity potential is calculated and then weighted. From the standpoint of the final consumer the use phase is the most important so it is weighted at 70% of the total score while the production phase is weighted at 20% and disposal at 10%.

The risk potential covers the physical hazardous during the production, use, and disposal phases and also considers the risk of explosion, flammability, storage accidents, worker illness and injury rates, malfunctions in product filling/packaging, transportation accidents, and any other risk deemed relevant to the study. For this analysis risk potential was characterized based on working accidents, fatal working accidents, and working diseases.

From an economic standpoint, life cycle costs are evaluated for the following categories: capital investment, labor, supply chain, wastes, energy, raw materials, and environmental health and safety (EHS) programs. Raw material costs were based on the purchase price of the ink, films, and if necessary, the thermal oxidizer. The ink costs were calculated based on the raw material costs in addition to an equal percentage mark-up and the film cost was based on the type of film used and average pricing. The costs for energy were based on prices for electricity and natural gas. As mentioned earlier, the production, use, and disposal phases were all considered during this study, including the production labor, drum handling and logistics, and solid waste disposal costs. Particularly, in the use phase, the model assumed a 4-color CI flexographic printing press with each of the four stations applying 25% coverage of a

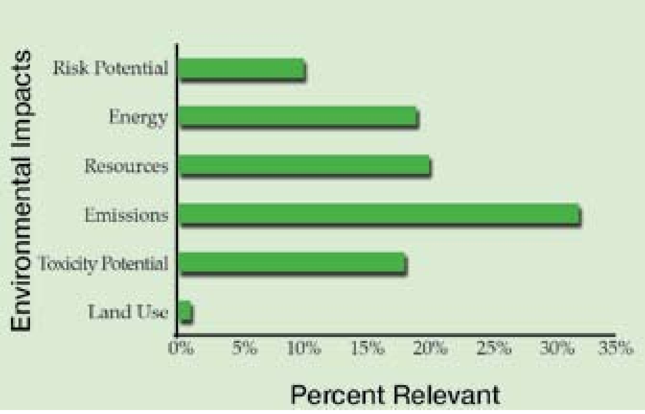


Figure 2. *Relevance Factors.*

Table 2. *Summary of ink and processing parameters*

	Units	Water	Solvent	UV-Cured
Ink Variables				
Color		cyan	cyan	cyan
Solids	%	42%	33%	100%
Weight per gallon	lb	8.4	7.9	9.1
Dry film thickness	microns	2.0	2.2	3.2
Printed weight – wet	g/m^2	4.8	6.4	3.5
Printed weight – dry	g/m^2	2.0	2.1	3.5
Processing Variables				
Per print station*	#	1	1	1
Ink coverage (image)	%	25%	25%	25%
Web width	m	1.5	1.5	1.5
Web speed	m/min	227	378	333
Production rate	m^2/min	341	567	500
Production hours	hrs/yr	4,000	4,000	4,000
(CB) Customer Benefit of printed product =	1,000	1,000	1,000	
* four stations were printing in the model				
Ink Consumption				
Wet ink usage / CB	lbs/CB	2.6	3.5	1.9
Wet ink usage / hr	lbs/hr	54	120	58

Table 3. *Summary of energy parameters*

Energy	Units	Water	Solvent	UV-Cured
Electricity				
Drive power	kWh	108	180	159
Inter-station – Drying	kWh	-	-	130
Inter-station – Blower	kWh	12	12	-
Main (final) – Drying	kWh	-	-	65
Main (final) – Blower	kWh	18	18	-
Inter-station cooling – UV lamps	kWh	-	-	24
Main cooling – UV lamps	kWh	-	-	36
Natural Gas				
Inter-station – Drying	MBTU/hr	0.76	0.64	-
Main (final) – Drying	MBTU/hr	1.14	0.96	-
Total	MBTU/hr	1.9	1.6	-
Total	MJ/CB	98	50	-

solid color. The press was configured to print and dry/cure all three ink systems.

Environmental Footprint and EEA Portfolio

BASF's EEA methodology assesses environmental burdens and economic costs independently then aggregates and normalizes both to obtain an environmental footprint and eco-efficiency portfolio. In order to calculate the footprint and portfolio, two weighting factors are applied: a relevance factor and societal weighting factor. The relevance factor reflects the level to which the emission (or energy consumption) contributes to the total emissions (or energy consumption) in North America, whereas the societal factor accounts for the value society attaches to the reduction of the individual environmental impacts. The relevance factors are updated regularly and the values are obtained primarily from the US EPA's toxic release and water release inventories. Public opinion polling, performed by an independent firm, is used to establish the societal weighting factors.

Model Parameters

The assumptions and inputs in this study were modeled and from manufacturer equipment specifications, and not collected from a live printing run. The ink, processing and energy parameters utilized for this study are given in Tables 2 and 3 respectively. A general assumption was made that the printed film scrap made during production was the same for all three ink scenarios.

Life Cycle Inventory Data

Environmental impacts for the production, use, and disposal of the three alternative printing ink systems were calculated from eco-profiles (a.k.a. life cycle inventories) for the individual components. Life cycle

Table 4. *Life cycle costs*

Item Costs	Units	Water	Solvent	UV-Cured
Material				
Ink Cost	$/CB	$22.70	$41.54	$63.91
Film Cost	$/CB	$290.00	$290.00	$290.00
Total Material Costs	**$/CB**	**$313**	**$332**	**$354**
Energy				
Electricity Cost	$/CB	$0.63	$0.58	$1.29
Natural Gas Cost	$/CB	$0.10	$0.05	-
Total Energy Costs	**$/CB**	**$0.73**	**$0.63**	**$1.29**
Manufacturing				
Production Labor	$/CB	$4.26	$2.56	$2.90
Drum Handling and Logistics	$/CB	$0.50	$0.71	$0.34
Total Manufacturing Costs	**$/CB**	**$4.76**	**$3.26**	**$3.24**
Waste				
Hazardous Costs	$/CB	$0.52	$0.73	$0.35
Non-Hazardous Costs	$/CB	$0.05	$0.05	$0.05
Total Waste Costs	**$/CB**	**$0.56**	**$0.78**	**$0.40**
Thermal Oxidizer				
	$/CB	-	$1.24	-
Total	**$/CB**	**$318.75**	**$337.45**	**$358.84**

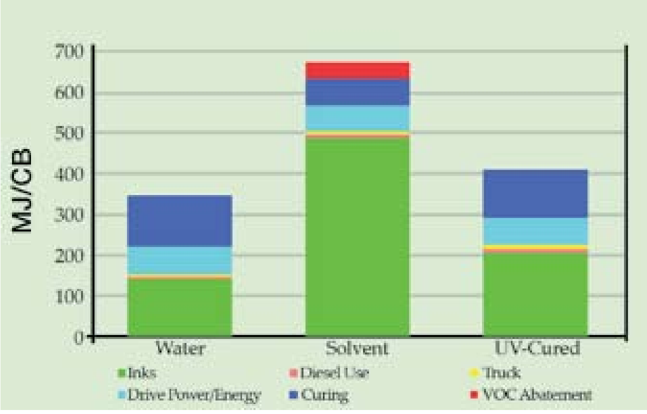


Figure 3. *Primary energy consumption.*

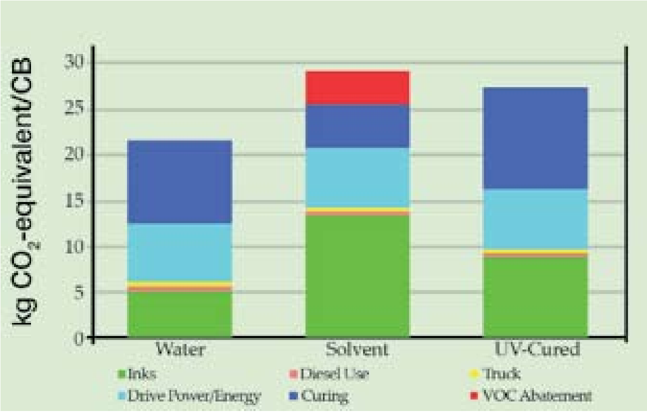


Figure 4. *Global warming potential.*

inventory data for these eco-profiles were from several sources, including BASF specific production sites, and the quality of these data was considered medium-high to high. None of the eco-profile data was considered to be of low data quality. The energy production mix was based on the Midwestern United States (MI, IN, OH, KY, WV), and analysis indicated results did not change significantly for other US regions.

A sensitivity analysis of the results indicates that the most relevant impacts of this study included the energy consumption, resource consumption, air emissions, and water emissions. More specifically, from an air emission standpoint, the global warming potential (GWP) and acidification potential (AP) were found to have the highest relevance on the results.

RESULTS

Costs

The results of the life cycle cost analysis found that UV-Cured ink systems have the highest costs and the alternative with the lowest life cycle cost is the conventional water system. From Table 4, it can be seen that the film cost is the overwhelming driver of the total cost of each alternative.

Primary Energy Consumption

Energy consumption measured over the entire life cycle show that water-based printing ink systems are the most advantageous alternative with regard to this particular environmental assessment measurement, using 345 MJ of energy per customer benefit. This is followed by the UV-Cured alternative, which uses 409 MJ of energy per customer benefit over the entire life cycle. The least favorable alternative over the entire life cycle, from an overall energy consumption standpoint, is the solvent based ink system, which uses about 676 MJ of energy per customer benefit.

Furthermore, it can be seen from Figure 3 that the key driver for energy consumption for each alternative is the ink formulation. This can be attributed directly to the oil and gas consumption required to produce the inks.

Global Warming Potential (GWP)

The highest carbon footprint occurred in the solvent-based printing ink alternative, with a measurement of over 29.2 kg of CO_2 equivalents per customer benefit followed by the UV-cured system, with 27.3 kg of CO_2 per customer benefit. The lowest carbon footprint with respect to the other alternatives results for the water-based printing ink system, which has an emission of 21.6 kg of CO_2 equivalents per customer benefit. The result is about 26% reduction in the carbon footprint for the water-based alternative when compared to solvent-based, and about 6.5% reduction when compared to UV-cured.

The main contributors to the GWP of each alternative include the CO_2 emitted during the ink formulation, drive power, and curing stages. Additionally, the solvent-based ink system contains a VOC abatement stage that has a measurable impact on GWP, which contributes to the fact that it is the least desirable alternative from a carbon footprint standpoint..

Ozone Depletion Potential (ODP)

Both the water and solvent-based ink systems results in a very minimal ozone depletion potential, measured at 1.05 mg CFC equivalents per CB. The UV-cured alternative on the other hand, has the potential to emit ozone depleting chemicals at the level of 9.69 mg CFC equivalents per customer benefit. The results indicate that main contributors to the ODP of each alternative can be attributed to the level of chlorofluorocarbons (CFC's) emitted during the ink formulation stage.

Acidification Potential (AP)

It can be seen from Figure 5 that overall, the water-based ink system has the lowest acidification potential over the entire life cycle, with emissions of 194 g of SO_2 equivalents per customer benefit. The UV-cured option has the highest value, with 270 g of SO_2 equivalent emissions per customer benefit, due in large part to the significant impact from the curing stage, which contributes 127 g of SO_2 equivalents per customer benefit. Additionally, the solvent-based system has an acidification potential of 231 g of SO_2 equivalents per customer benefit, which falls between the other alternatives.

The ink formulation, drive power, and curing stages are all key drivers for the acidification potential of each of the alternatives studied, which can primarily be attributed to the NO_x and SO_x emitted during each stage. In addition, the NO_x and SO_x emitted during the VOC abatement stage of the solvent-based ink system also have a measurable impact on AP, contributing to the fact that it is a less desirable alternative, from an acidification standpoint, compared to the water-based system.

Photochemical Ozone Creation Potential (Smog)

The lowest emissions for ground level ozone formation potential occur in the water-based ink system alternative, with 4.80 g of ethene equivalents emitted per customer benefit. The UV-cured alternative follows with the second highest level of emissions, 5.98 g of ethene equivalents per customer benefit, and the largest photochemical ozone creation potential occurs in the solvent-based ink system, with a measurement of 9.03 g of ethene equivalents per customer benefit. Similar as was the case for ozone depletion potential, it is the ink formulation in particular that by far contributes the most to potential smog formation. This is specifically attributable to the methane and non methane-VOC's released during the ink production process.

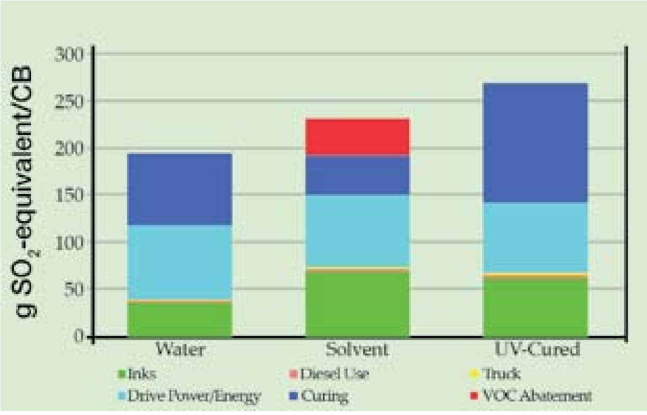


Figure 5. *Acid rain potential.*

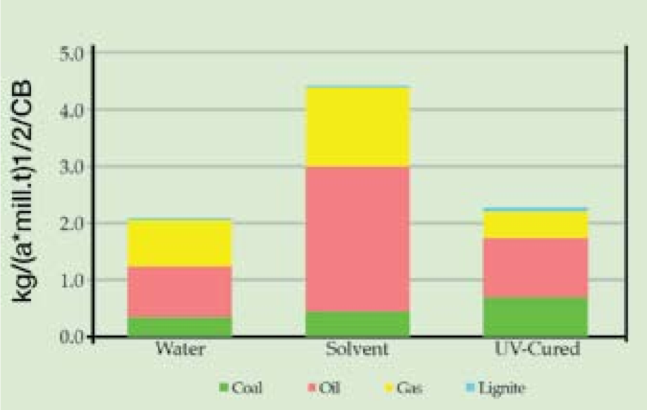


Figure 6. *Fossil fuel consumption.*

Water Emissions

Relative to the alternatives, the solvent-based ink system has the lowest critical waste water volume (6,533 L/CB), followed by the UV-cured alternative (7,204 L/CB), and lastly the water-based alternative, which has a critical waste water volume of about 7,545 L/CB. Again, it is the ink formulation processes that by far contribute the most to the critical waste water volume, particularly by way of chemical oxygen demand, ammonium-n, and chlorine.

Solid Waste Generation

The water-based ink systems can reduce the amount of solid waste generation by nearly 46% compared to the UV-cured alternative and over a 13% reduction compared to the solvent-based alternative. The results specifically indicate that the chemical, mining, and municipal waste disposals during the ink production phase are the most significant contributors to the generation of solid waste over the production, use, and disposal phases of each of the printing ink systems.

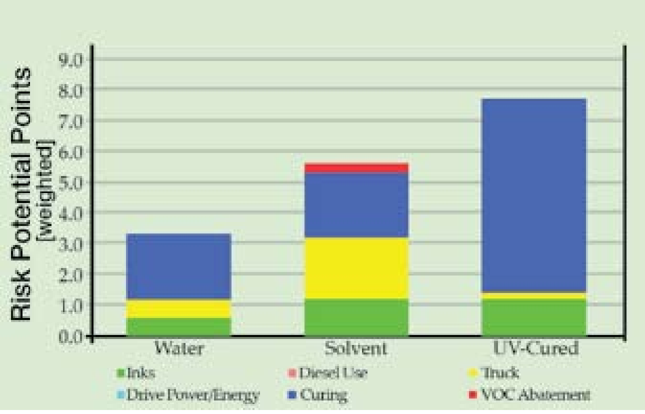


Figure 7. *Risk potential.*

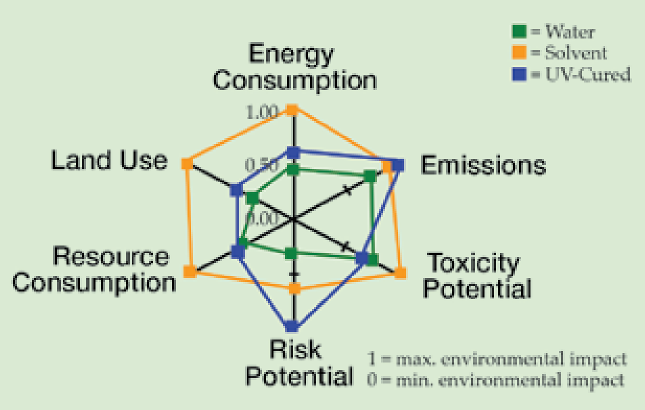


Figure 8. *Relative environmental fingerprint.*

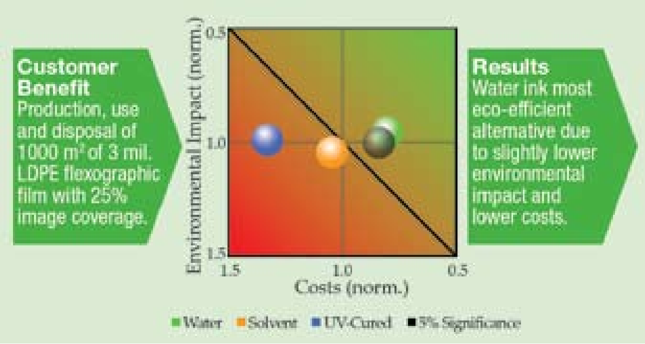


Figure 9. *Eco-Efficiency portfolio.*

Raw Material Consumption

The water-based printing ink system uses the least amount of fossil fuels (coal, oil, natural gas, and lignite) relative to the two other alternatives, although the UV-cured and water-based inks consume only a slightly greater amount, as is shown in Figure 6. It is clear from the figure that the solvent-based alternative consumes the largest amount of fossil fuels over the life cycle. The total reduction of fossil fuel consumption for the water-based compared to solvent-based inks amounts to nearly 53%. The key drivers for the fossil fuel consumption are mainly attributable to the significant oil, gas, and coal consumption rates required specifically during the ink production phase of each ink system.

Toxicity Potential

Analyzing the overall toxicity potential regarding the life cycle of printing inks finds that, as would be expected, water-based ink systems have the lowest toxicity potential, followed by UV-cured, and solvent-based systems with the highest potential, due primarily to the inherent toxicity of the solvent production and its precursors. It was found that the production, use, and disposal of a water-based ink results in a reduction of toxicity potential by over 46% compared to the solvent alternative and nearly a 33% reduction relative to the UV-cured system.

Risk Potential

The lowest risk for worker accidents, fire and explosion hazards, and transportation during the production, use and disposal of 1,000 m^2 of LDPE flexographic film results for the water-based ink system, followed by the solvent-based and UV-cured alternatives, as is shown in Figure 7. In fact, the water-based ink results in a reduction of risk potential by over 57% relative to the UV-cured alternative and more than a 41% reduction compared to the solvent system.

It is also clear from Figure 7 that the electricity used during the curing phase is a key driver for the each alternative, whereas the inherent risk involved in the transportation and ink production result in contributions of varying degrees to the final results of the various ink systems.

CONCLUSIONS

The results of this analysis find that the water-based ink systems have lower overall environmental impacts, for relative inputs in addition to lower life cycle costs. The relative impact for all six of the environmental categories is shown in the environmental fingerprint (Figure 8). It can be clearly seen that the water-based alternative results in the minimum environmental impact relative to the other options in five of the six environmental impact categories. The exception is in toxicity potential, where it lies between the solvent-based and UV-cured alternatives.

Figure 9 displays the eco-efficiency portfolio, which shows the study when all six individual environmental categories from the study are combined into a single relative environmental impact adjusted using the weighting factors described above. Because environmental impact and cost are equally important, the most eco-efficient alterative is the one with the largest perpendicular distance above the diagonal line and the results from this study find that water-based ink system is the most eco-efficient alternative due to its slightly lower environmental impact and lower costs relative to the solvent-based and UV-cured alternatives.

BASF's Eco-efficiency Analysis continues to be a valuable tool for suppliers, manufacturers and end-users to make informed and educated decisions about raw material selections for printed products.

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The results of this study were verified in a third party review by NSF International.
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