Submission for
Verification of Eco-Efficiency Analysis Under NSF Protocol P352, Part B

JONCRYL® Water-Based Polymers for Film Eco-Efficiency Analysis
May 2009

Submitted by:

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1. Purpose and Intent of this Submission

1.1. The purpose of this submission is to provide a written report of the methods and findings of BASF Corporation's "JONCRYL® Water-based Polymers for Film Eco-Efficiency Analysis", with the intent of having it verified under the requirements of NSF Protocol P352, Part B: Verification of Eco-Efficiency Analysis Studies.

2. Content of this Submission

2.1. This submission outlines the study goals, procedures, and results for the JONCRYL® Water-based Polymers for Film Eco-Efficiency Analysis (EEA) study, which was conducted in accordance with BASF Corporation's EEA (BASF EEA) methodology. This submission will provide a discussion of the basis of the eco-analysis preparation and certification work.

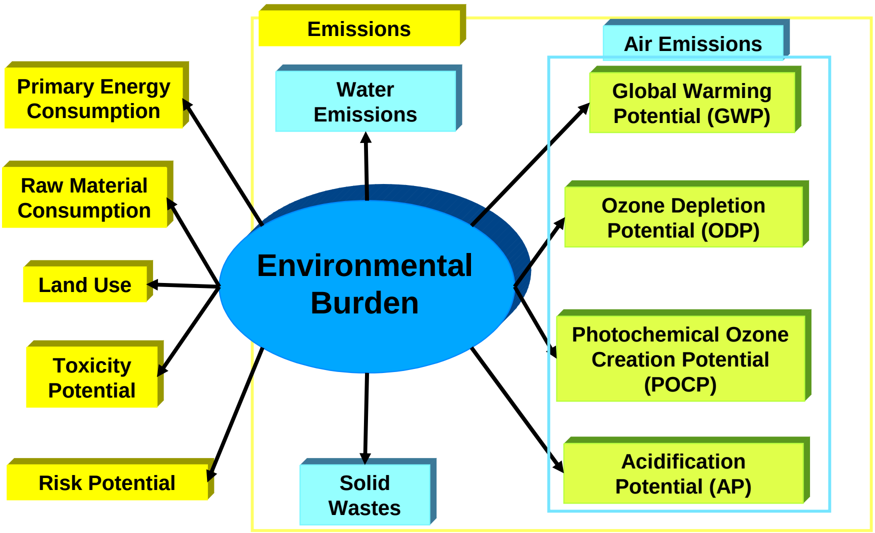
2.2. As required under NSF P352 Part B, along with this document, BASF is submitting the final computerized model programmed in Microsoft® Excel. The computerized model, together with this document, will aid in the final review and ensure that the data and critical review findings have been satisfactorily addressed.

3. BASF's EEA Methodology

3.1. *Methodology:* The JONCRYL® Water-based Polymers for Film Eco-Efficiency Analysis was performed by BASF according to the methodology validated by NSF International under the requirements of Protocol P352, Part A. More information on BASF's methodology and the NSF validation can be obtained at http://www.nsf.org/info/eco_efficiency/.

3.2. *Overview:* BASF EEA involves measuring the life cycle environmental impacts and life cycle costs for product alternatives for a defined level of output. At a minimum, BASF 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, at a minimum, materials, labor, manufacturing, waste disposal, and energy.

3.3. *Environmental Burden Metrics:* For BASF EEA environmental burden is characterized using eleven categories, at a minimum, including: primary energy consumption, raw material consumption, global warming potential (GWP), ozone depletion potential (ODP), acidification potential (AP), photochemical ozone creation potential (POCP), water emissions, solid waste, emissions, toxicity potential, risk potential, and land use. These are shown below. Metrics shown in yellow represent the six main categories of environmental burden that are used to construct the environmental footprint, burdens in blue represent all elements of the emissions category, and green show air emissions.



3.4. *Economic Metrics:* It is the intent of the BASF EEA methodology to assess the economics of products or processes over their life cycle and to determine an overall total cost of ownership for the customer benefit ($/CB). The approaches for calculating costs vary from study to study. When chemical products of manufacture are being compared, the sale price paid by the customer is used. When different production methods are compared, the relevant costs include the purchase and installation of capital equipment, depreciation, and operating costs. The costs incurred are summed and combined in appropriate units (e.g. dollar or EURO) without additional weighting of individual financial amounts. The BASF EEA methodology will incorporate:

- the real costs that occur in the process of creating and delivering the product to the consumer;
- the subsequent costs which may occur in the future (due to tax policy changes, for example); and
- costs having ecological aspect, such as the costs involved to treat wastewater generated during the manufacturing process.

4. Study Goals, Context and Target Audience

4.1. *Study Goals*: The specific goal defined for the JONCRYL® Water-based Polymers for Film Eco-Efficiency Analysis was to quantify the differences in environmental impact, and costs, of three different printing ink systems. This analysis treated the economic and environmental considerations independently but with equal importance. The intent was to parameterize the model such that all independent variables (e.g. printing machine) were sufficiently similar for all three alternatives, such that environmental differences could be evaluated based on specific composition and processing parameters (e.g. natural gas vs. electrical drying). Results of the EEA will be used as a basis for market differentiation between the alternatives. Additionally, the study results will be used to guide product development decisions that will results in more sustainable printing. The drivers of the study included R&D decisions, supporting process optimization and marketing efforts.

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4.2. *Context*: The context of this EEA study compared the life cycle for water-based, solvent-based, and UV-cured printing inks competing in a consumer market with an incremental innovation level at a regional level over the course of an entire life cycle. The study was competitive driven and required supplier and customer engagement. The study goals, target audience, and context for decision criteria used in this study are displayed in Figure 1.

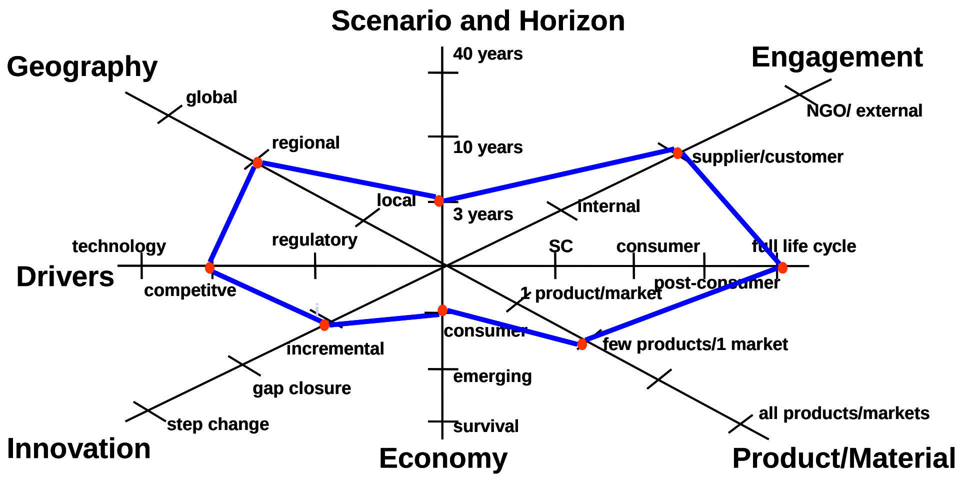


Figure 1. Diagram of study goals, target audience, and context for decision criteria for the JONCRYL® Water-based Polymers for Film Eco-Efficiency Analysis.

4.3. *Target Audience*: The target audience for this study has been defined as ink and coating formulators, brand owners and converters.

5. Customer Benefit, Alternatives and System Boundaries

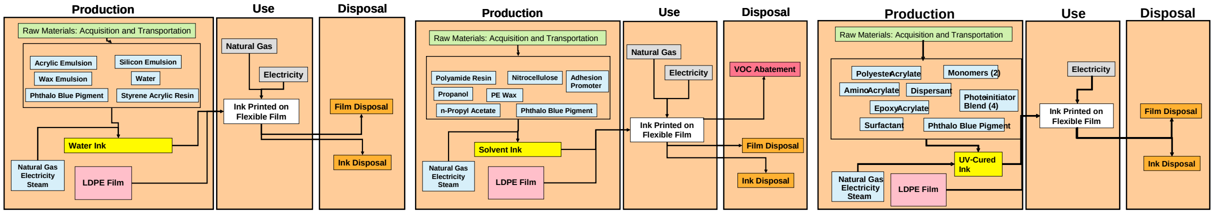
5.1. *Customer Benefit*: The defined level of output and basis of comparison, or Customer Benefit (CB), for the JONCRYL® Water-based Polymers for Film EEA, has been defined as the production, use, and disposal of 1,000 m^2 of 3 mil LDPE flexographic film with a 25% image coverage area. This particular CB was selected because it represented a typical amount of production that is often used as the basis of comparison within the ink industry.

5.2. *Alternatives*: The product alternatives compared under this EEA study are summarized in Table 1, and consisted of water-based, solvent-based, and UV-cured printing inks. These three alternatives represent the most commonly available technologies when selecting printing ink systems and represents the overwhelming majority of the market (>95%).

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

5.3. *System Boundaries*: The system boundaries define the specific elements of the production, use, and disposal phases that are considered as part of the analysis. The system boundaries for the three alternatives evaluated in the EEA study are shown in Figure 2. 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 the all three phases for each printing ink alternative. These particular system boundaries were selected because they encompass the entire life cycle of the printing process and include all relevant parameters and elements. The use and disposal phases were for those activities at the printer, and not at the consumer level. This is because it was determined that there would be no difference in function, use or disposal at the consumer level.



Water-Based *Solvent-Based* *UV-Cured*

Figure 2. System boundaries for the three alternatives.

6. Input Parameters and Assumptions

6.1. *Input Parameters*: A comprehensive list of input parameters were included for this study and considered all relevant operational characteristics for the three ink system alternatives. The ink formulations, processing variables, logistical & disposal and printing machine energy parameters are given in Tables 2 thru 5, respectively. Additionally, Table 6 provides parameters related to thermal oxidizer use. This list of parameters was developed utilizing standard operating parameters and best management practices for the ink industry.

6.1.1. *Ink Parameters:* The inks were parameterized based on common compositions for each of the three alternatives with the intent to have a printed dry weight of ink be at a level that is commonly applied within the printing industry. The formulations used for this study are confidential, but full formulations were disclosed to NSF International for the purposes of this verification. Table 2 provides sanitized ink formulations for the three alternatives. A single ink color was used for all three inks, blue, which ensured consistency between alternatives for this non-specific parameter. Specific parameters for the alternatives were based on the physical/chemical characteristic of the formulated ink and included: solids content, weight per gallon, and printed weight -dry and –wet (Table 3).

Table 2: Ink formulations for study alternatives.

Water		Solvent		UV-Cured	
Component	**% wt**	**Component**	**% wt**	**Component**	**% wt**
Blue Pigment	16	Blue Pigment	12	Blue Pigment	22
JONCRYL ECO 75	15	Polyamide	17	Laromer 9013	20
JONCRYL ECO 2124	57	nitrocellulose	3	Laromer PO 94F	15
Wax Emulsion	5	PE Wax	1	Laromer 8765	10
Silicon Emulsion	1	Adhesion Promoter	2	DPGDA	10
Water	6	nPropyl acetate	11	Laromer 8863	7
Total	**100**	nPropyl alcohol	54	Dispersants	4
		Total	**100**	Antioxidants	7
				TPO	2
				Esacure TZT	3
				Total	**100**

6.1.2. *Processing Parameters:* The processing parameters are shown in Table 3. The printing machine was based on a 4 station printer with 25% ink (image) coverage. There was nothing specific about the amount of image coverage chosen other than it was deemed to be a mid-point of the range of typical coverage amounts. The same LDPE film was used for all three alternatives along with the same web width (1.5 m). Web speed was specific for each alternative and was based on speeds common to the industry for respective printing machines. Production rate (m^2/min) was a calculated value based upon the web width and alternative specific web speed. It was assumed that the printing machines operate 4,000 hours per year.

Table 3: Summary of ink and processing parameters.

Ink Parameters	**Units**	**Water**	**Solvent**	**UV-Cured**
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 Parameters	**Units**	**Water**	**Solvent**	**UV-Cured**
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
Customer benefit printing area	m^2/CB	1,000	1,000	1,000

**EEA study was based on four station printing*

6.1.3. *Ink Consumption:* The wet ink usage amount (lbs/CB) was calculated from the printed weight - wet (g/m^2), the CB area of 1,000 m^2/CB and ink coverage (image)

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(%). See Table 4. Wet ink usage per hr then calculated from wet ink usage / CB based on web speed (m/min). The number of ink drums that are handled were calculated from the wet ink usage and production hours. It was assumed that the drums were staged using forklifts, so forklift operational time and costs were included. The same values for cost and forklift operational time were used for all three alternatives.

Table 4: Summary of logistical, disposal, and transportation information

Ink and Drum Usage	**Units**	**Water**	**Solvent**	**UV-Cured**
Wet ink usage / CB	lbs/CB	2.6	3.5	1.9
Wet ink usage / hr	lbs/hr	54	120	58
Drums Handled	#/yr	1,167	2,759	1,154
Labor – drum handling inbound	hrs/drum	0.33	0.33	0.33
Forklift Operational Time	hrs/drum	0.25	0.25	0.25
Forklift Operational Cost	$/hr	1.50	1.50	1.50
Forklift Labor Requirement	hrs/drum	0.25	0.25	0.25
Labor – drum handling outbound	hrs/drum	0.33	0.33	0.33
Waste Parameters				
Disposal Costs – Haz	$/drum	$225.00	$225.00	$225.00
Disposal Costs – Non-Haz	$/ton	$51.00	$51.00	$51.00
Hazardous-Spent Solvent	drums/yr	117	276	115
Scrap Film - Non-Hazardous	tons/yr	48	80	71
Transportation Parameters				
Transportation Distance	km/truck	200	200	200
Truck Fuel Consumption	MJ/tonne-km	2.2	2.2	2.2
Fuel From Weight of Truck	MJ/truck	8,944	7,638	9,680
Drums per Truck	drums/truck	88	80	88
Trucks per Year	trucks/year	13	34	13

6.1.4. *Waste Disposal:* The amount of hazardous waste and scrap film were calculated based on the amount of production, as shown in Table 4. A fixed scrap rate was set at 2% and costs for hazardous and non-hazardous waste disposal were based on US averages.

6.1.5. *Transportation Logistics:* The environmental impacts for transporting drums were determined as part of this study (Table 4). A transportation distance of 200 km was used, and represents a general distance that drums are shipped from ink manufacturer to the printer. Impacts were evaluated based on diesel usage.

6.1.6. *Energy:* The environmental burden of the inks included both the raw material consumption and the energy consumption during production of the three ink alternatives. The electricity and natural gas consumption values were based on a central impression printing machine from Windmöller & Hölscher (see Table 5). It was a 4 station printing press that is designed to run water and solvent based inks, and can modified to run UV-cured inks. Technical specification data on energy consumption, and other parameters, was provided by the equipment manufacturer. Drive power (kWh) was calculated from the web speed parameters and, therefore, the solvent had the highest driver power because it had the highest web speed. Electricity usage was specific for each alternative, in that no usage is required for Water and Solvent alternatives during Main (final) – Drying because for these alternatives natural gas is the energy source. Likewise, there is no natural gas consumption for the UV-Cured alternative because only electricity is utilized for this ink technology.

Table 5: Summary of energy parameters for printing machine.
Based on 4-station central impression machine from W&H.

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	-

6.2. *Thermal Oxidizer*: Environmental impacts and cost of operating a thermal oxidizer (TO) were included for the Solvent alternative (Table 6). Thermal oxidizers are the most common method of VOC abatement for solvent inks within the printing industry and parameterization was based upon typical operating characteristics for solvent based inks. Parameterization and calculations for the TO were based on data from the U.S. EPA and Institute of Clean Air Companies[1,2]. Specific assumptions were as follows: (1) TO is operated continuously (i.e. no ramp-up period); (2) incoming waste stream to TO is vapors only, and no liquids are diverted prior to TO; (3) 35% of the energy is recovered from the process and is credited back to printing process (4) assumes 4,000 hrs/yr of operation. Energy consumed in by the TO was calculated in according with the U.S. EPA and ICAC equations and are shown in Box 1.

Box 1: Energy consumed in the RTO can be determined by performing a heat balance as follows:

QT = QI + Qcc + QRL – QVOC

Where:
QI: Heat used to raise temperature of FI (BTU/hr)
Qcc : Heat used to raise temperature of FCC (BTU/hr)
QRL: Radiation Heat loss from RTO (BTU/hr)
QVOC: Heat Release from oxidation of VOCs (BTU/hr)
QI = FI X 1.10 x (TO – TI)
QCC = FCC X 1.10 X (TO – TA)
QVOC = VOC X HC X (% Dest / 100)
Where:
FI: Process air (SCFM)
FCC: Combustion air (SCFM)
TI: RTO inlet air temperature (oF)
TA: Ambient or Combustion air temperature (oF)
TO: Average RTO outlet temperature (oF)
1.10: 60 (min/hr) x 0.075 (lb/ft3, density of air at standard conditions) x 0.245 (Btu/deg F – lb, specific heat of air), where 0.245 is the average heat capacity of air over the temperature range.
VOC: lbs/hr of VOC to the oxidizer
HC: Weighted Average for Heat of Combustion of VOCs
% Dest: Guaranteed VOC Destruction Rate
Since FI, FCC, TI, TO and TA can all be determined by data supplied with proposal, QI and QCC can be determined.

Source: ICAC, 2002

Table 6: Manufacturing and operational parameters for thermal oxidizer.

Parameter	Unit	Value
Film Manufacturing Process		
Process air flow	SCFM	4,590
Process air temperature	^{0}F	110
VOC Loading	lbs/hr	96
Heat of combustion of VOCs	BTU/lb	12,256
Thermal Oxidizer		
Oxidizer surface area	ft^2	900
Thermal efficiency	%	95
Combustion temperature	^{0}F	1,800
VOC destruction efficiency	%	98
Combustion air	SCFM	450
Temperature out of TO	^{0}F	350
General Parameters		
Ambient air temperature	^{0}F	68

6.3. *Costs:* The economic analysis for the JONCRYL® Water-based Polymers for Film EEA considered material, energy, manufacturing, and waste disposal costs. Specifically, the analysis took into account the costs of the ink, film, electricity, natural gas, production labor, drum handling, logistics, hazardous and non-hazardous waste disposal, and, if appropriate, thermal oxidizer costs. Any life-cycle costs that have not been listed were assumed to be equivalent for all three alternatives and therefore were not included in the analysis. The life-cycle cost data was acquired from numerous sources. The natural gas and electricity energy costs were obtained from Bloomberg (as of July 21st, 2008), the diesel fuel price was assumed to be an average, and the labor rates, which are fully-absorbed rates that include salary and benefits, are typical for the industry. The ink and film selling prices were calculated as a 20% premium of the NAPIM 2007 prices. The study also considered the forklift operational cost, which includes operations, maintenance and fuel as well as the industry average for hazardous and non-hazardous waste disposal costs. The Disposal costs of $225.00 per drum for hazardous waste and $51.00 ton for non-hazardous waste were used for all three alternatives and are average disposal rates. It was assumed that 10% of the total amount of ink used was disposed of as hazardous spent solvent waste, with a 3% scrap rate of the film. The values were based on standard operating parameters and best management practices for the ink industry. While it is recognized that the use of these inks on the same printing press could potentially result in different process efficiencies (and thus raw materials and energy consumed and waste generation), it was decided for this analysis to keep the values the same for the three ink alternatives. For the thermal oxidizer, energy costs were calculated using ink formulation specific data, while indirect costs were assumed to be 60% of direct annual costs, based on USEPA 2002.

6.4. *Further Assumptions*: The EEA assumed that there were no differences in film scrap rates during the production of each alternative and that the printing equipment is up-and-running, therefore no capital investment was considered. Additionally, ink costs were calculated based on the raw material costs plus and equal percentage mark-up and the film cost was based on the film type and average pricing.

Relevant to the Toxicity Potential in the production phase, the safety standards associated with various technologies for manufacturing of the inks as well as for the use of diesel fuel were deemed as low and thus a weighting factor of 1.0 was applied.

7. Data Sources

7.1. The 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 and for truck usage and energy. Life cycle inventory data for these eco-profiles were from several data 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. A summary of the eco-profiles is provided in Table 7.

Table 7: Summary of eco-profiles used in this EEA.

Eco-Profile	Source, Year	Comments
Printing Ink – Water		
Blue Pigment	BASF Avg., 2005	Same for all three alternatives
JONCRYL ECO 75	BASF Avg., 2008	
JONCRYL ECO 2124	BASF Avg., 2008	
Wax	BASF Avg., 2008	
Emulsion	G.B. Avg., 1996	Most recent available
Water	BASF, 1995	
Printing Ink – Solvent		
Blue Pigment	BASF Avg., 2005	Same for all three alternatives
Polyamide	BASF, 2008	
nitrocellulose	DE Avg., 1998	Most recent available
Wax	BASF Avg., 1999	
Emulsion	BASF Avg., 2008	
nPropyl acetate	G.B. Avg., 1996	Most recent available
nPropyl alcohol	BASF Avg., 2001	
Printing Ink – UV-Cured		
Blue Pigment	BASF Avg., 2005	Same for all three alternatives
Laromer 9013	BASF Avg., 2008	
Laromer PO 94F	BASF Avg., 1999	Most reliable profile available
Laromer 8765	BASF, 2008	
DPGDA	BASF Avg., 2003	
Laromer 8863	BASF Avg., 1999	Most reliable profile available
Dispersants	DE Avg., 2004	
Antioxidants	DE Avg., 1996	Most recent available
TPO	BASF Avg., 2005	
Esacure TZT	DE Avg., 1996	Most reliable profile available
Diesel Use – US	U.S. Avg., 1996	Most reliable profile available
Truck 16t	U.S. Avg., 1996	Most reliable profile available
Electricity use - ECAR	ECAR, 1996	The energy production mix was based on the Eastern United States (MI, IN, OH, KY, WV), and analysis indicated results did not change significantly for other US regions
Natural gas use - ECAR	ECAR, 1996	
BASF data sources are internal data, while the others are external to BASF. Internal data is confidential to BASF; however, full disclosure was provided to NSF International for verification purposes.		

8. Eco-efficiency Analysis Results and Discussion

8.1. *Environmental Impact Results*: The environmental impact results for the JONCRYL® Water-based Polymers for Film EEA are generated as defined in Section 6 of the BASF EEA methodology, which has been validated by NSF International under the requirements of Protocol P352 Part A.

8.1.1. *Primary energy consumption*: Energy consumption, measured over the entire life cycle, shows that the water-based printing ink system is the most advantageous alternative with regard to this particular environmental assessment measurement, using 344 MJ of energy per customer benefit. This is equivalent to a 49% reduction in energy consumption relative to the alternative with the highest level of primary energy consumption, the solvent-based alternative. The water based alternative 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 675 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.

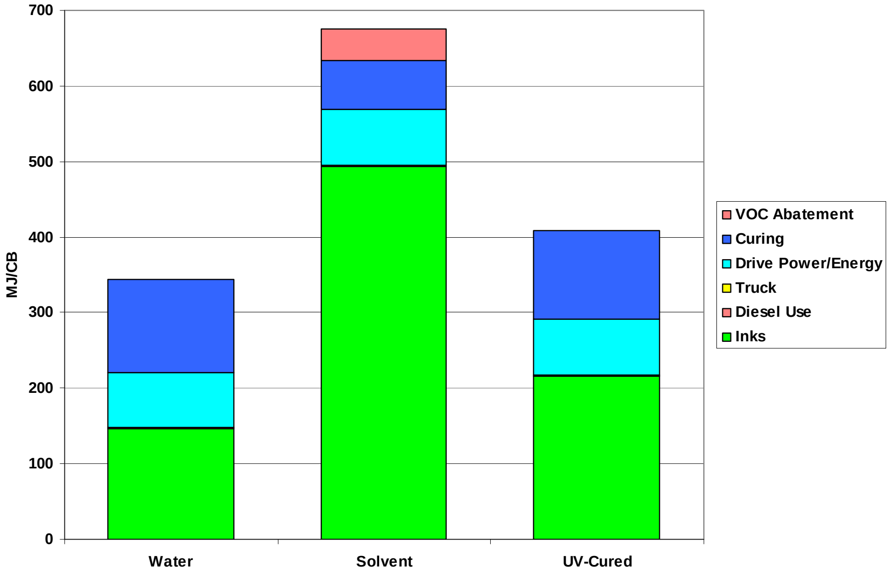

Figure 3. Primary energy consumption.

8.1.2. *Raw material consumption*: It is clear from Figure 4 that the solvent-based alternative consumes the largest amount of fossil fuels (coal, oil, natural gas, and lignite) over the life cycle relative to the other alternatives. The largest reduction of fossil fuel consumption compared to the solvent-based ink system occurs for the conventional water-based alternative, which amounts to nearly a 53% savings. 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.

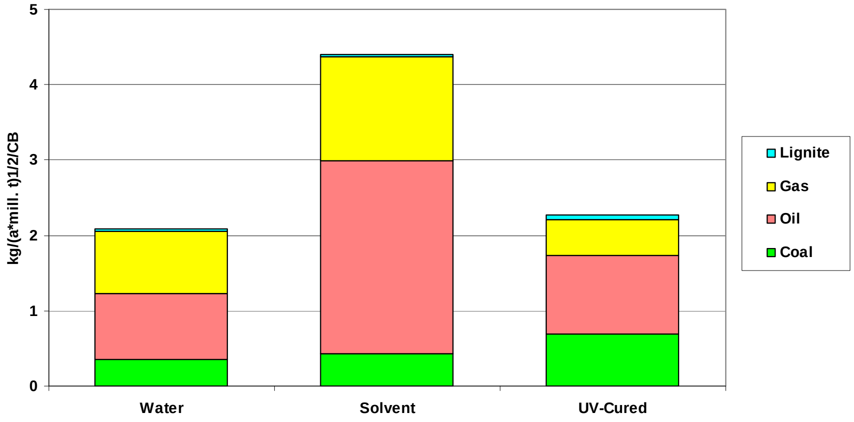

Figure 4. Fossil fuel consumption.

8.1.3. *Air Emissions*:

8.1.3.1. *Global warming potential (GWP)*: The highest carbon footprint occurred in the solvent-based printing ink alternative, with a measurement of nearly 29.1 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, resulted for the conventional water-based printing ink system, which results in the emission of 21.5 kg of CO_2 equivalents per customer benefit. This results in about a 26% reduction in the carbon footprint for the water-based alternative when compared to solvent-based, and over 21% reduction when compared to the UV-cured option. As displayed in Figure 5, 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.

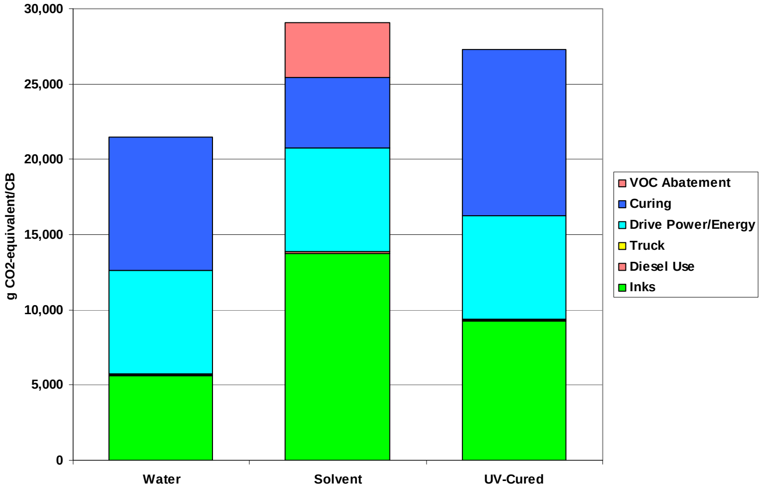

Figure 5. Global warming potential.

8.1.3.2. *Photochemical ozone creation potential (smog)*: The lowest emissions for ground level ozone formation potential occur in the water-based ink system, with 4.7 g of ethene equivalents emitted per customer benefit. The UV-cured alternative follows with emissions of 5.9 g of ethene equivalents per customer benefit. The largest photochemical ozone creation potential occurs in the solvent-based ink system, with a measurement of 9.2 g of ethene equivalents per customer benefit. Figure 6 indicates that 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.

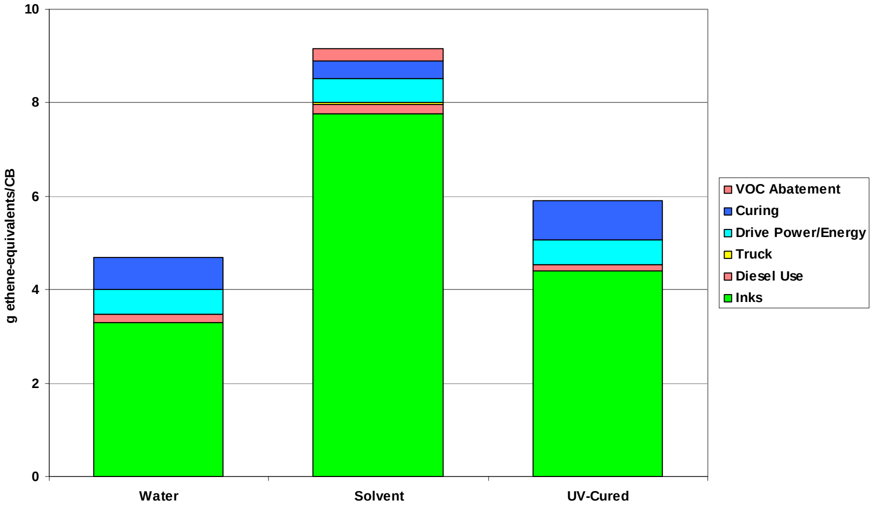

Figure 6. Photochemical ozone creation potential.

8.1.3.3. *Ozone depletion potential (ODP)*: The water-based as well as the solvent-based ink systems result in a very minimal ozone depletion potential, measured at 1.0-1.05 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 9.7 mg CFC equivalents per customer benefit. Similar as was the case for photochemical ozone creation potential, the results indicate that main contributors to the ODP of each alternative can be attributed to the emissions during the ink formulation stage, in this case, particularly the level of chlorofluorocarbons (CFC's) emitted.

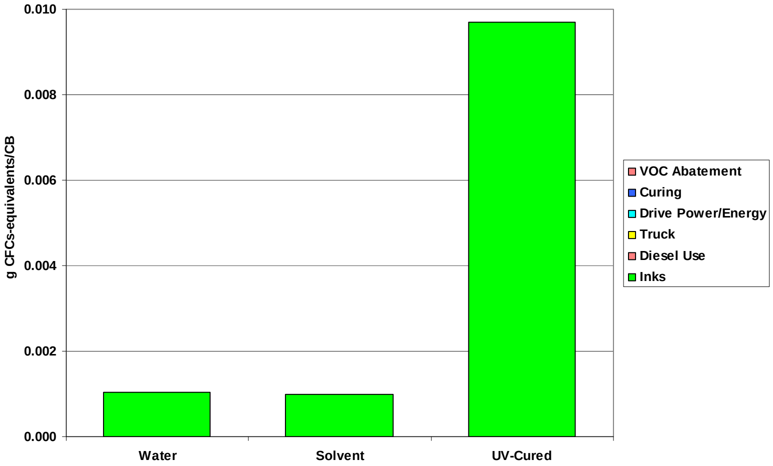

Figure 7. Ozone depletion potential.

8.1.3.4. *Acidification potential (AP)*: It can be seen from Figure 8 that overall, the conventional 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, a 28% decrease relative to the UV-cured option, which has the highest emission potential (270 g of SO_2 equivalent emissions per customer benefit). The high AP for the UV-cured alternative is 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 230 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.

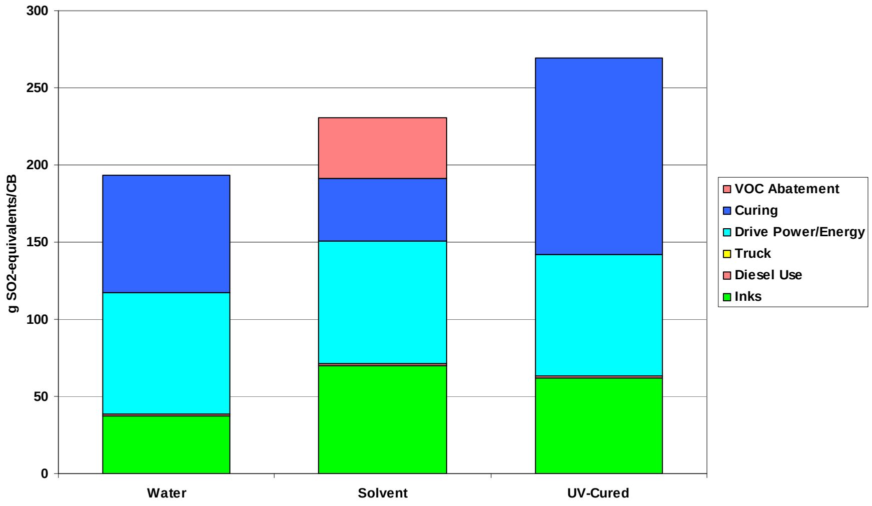

Figure 8. Acid rain potential.

8.1.4. *Water emissions*: Figure 9 displays that relative to the alternatives, the solvent-based ink system has the lowest critical waste water volume (6,531 L/CB), followed by the UV-cured (7,203 L/CB), and lastly the water-based alternative, which has a critical waste water volume of 7,544 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.

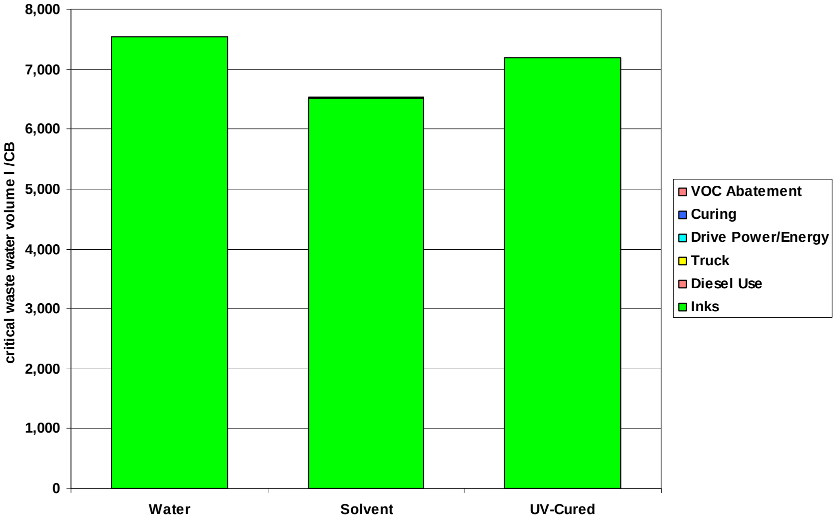

Figure 9. Water emissions.

8.1.5. *Solid waste generation*: The conventional water-based ink system 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 in Figure 10 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.

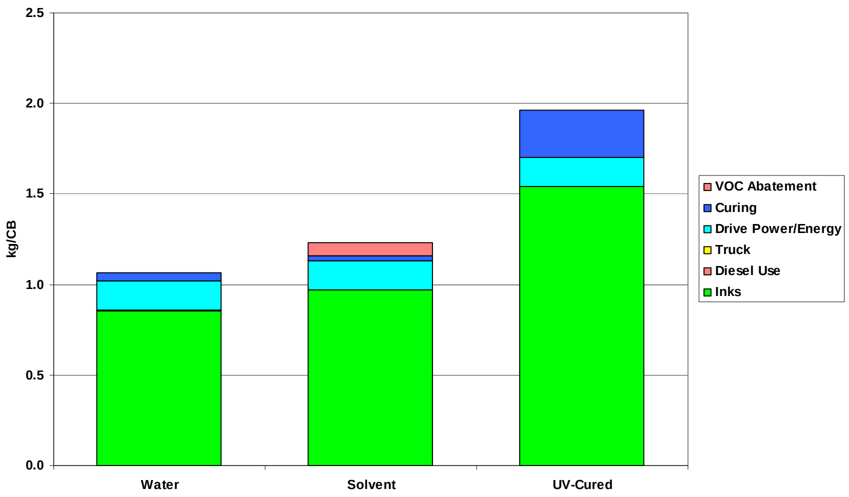

Figure 10. Solid waste generation.

8.1.6. *Land use*: As displayed in Figure 11, the water-based ink system is the most favorable alternative for land use, while the solvent-based uses the most amount of land over the entire life cycle. The results are primarily driven by the area of conventional agricultural used to produce the various ink systems. The water-based inks results in a reduction of land use by over 60% relative to the solvent alternative and over a 27% reduction compared to the UV-cured system. The diesel use related to drum transportation as well as the ink formulations are the two key drivers to land use impacts.

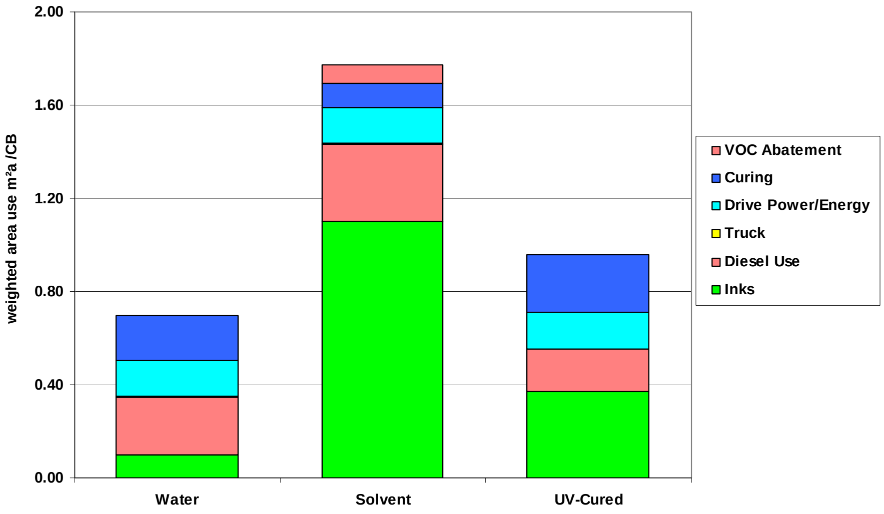

Figure 11. Land use.

8.1.7. *Toxicity potential*: Analyzing the overall toxicity potential regarding the life cycle of printing inks, as displayed in Figure 12, 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.

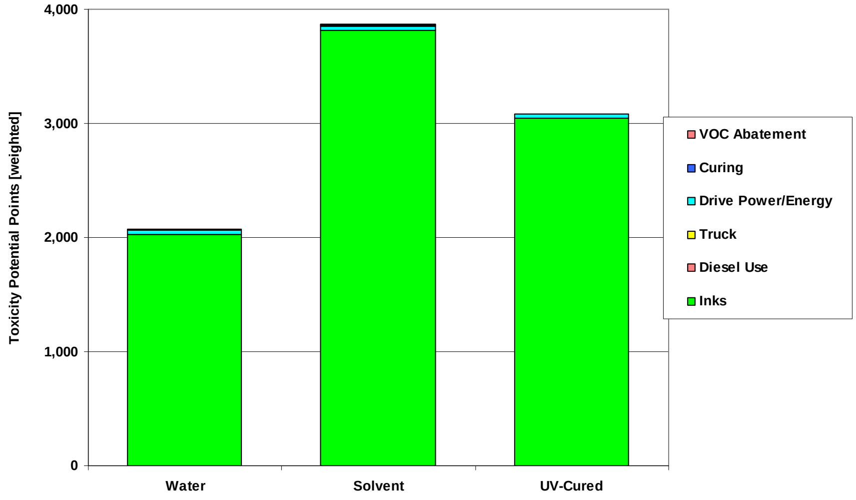

Figure 12. Toxicity potential.

8.1.8. *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 13. 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 13 that 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.

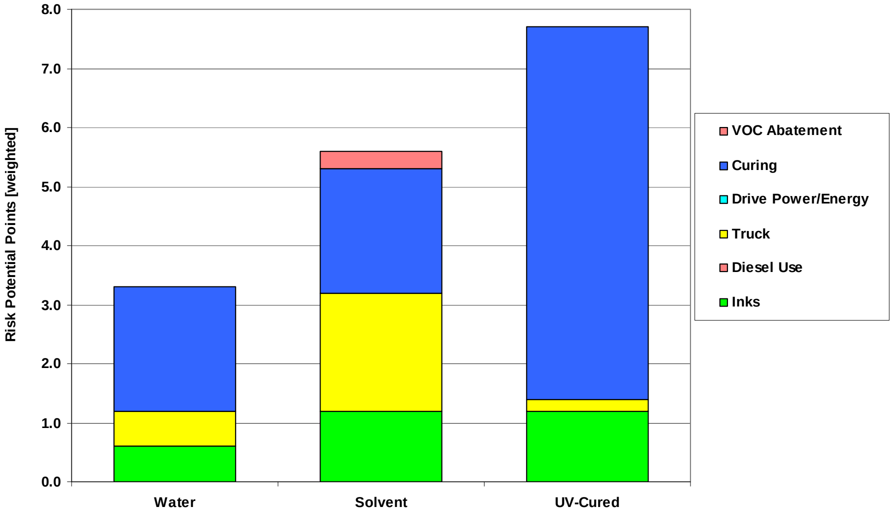

Figure 13. Risk potential.

8.1.9. *Environmental fingerprint*: The results of this EEA find that the water-based ink systems have lower overall environmental impacts. The relative impact for all six of the environmental categories is shown in the environmental fingerprint (Figure 14). 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.

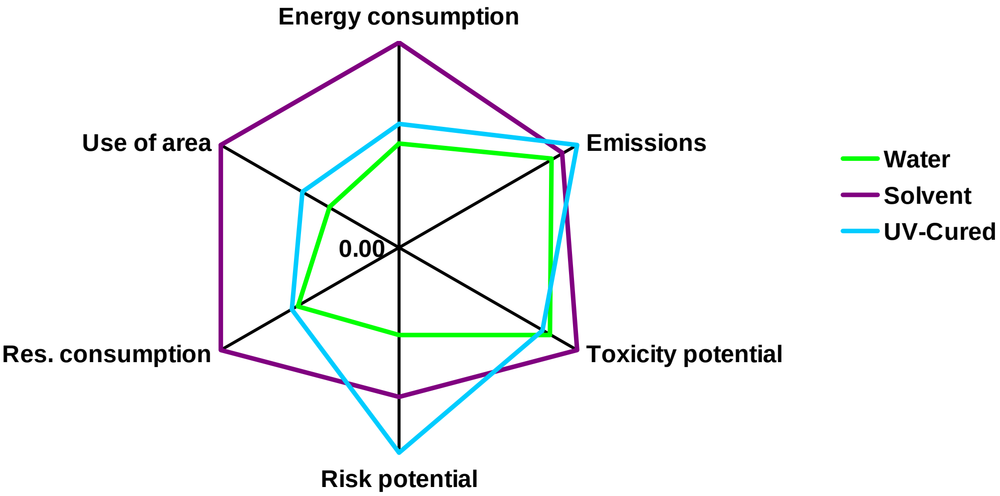

Figure 14. Environmental fingerprint.

8.2. *Economic Cost Results*: The life cycle cost data for the JONCRYL® Water-based Polymers for Film EEA are generated as defined in Section 7 of the BASF EEA methodology, which has been validated by NSF International under the requirements of Protocol P352 Part A. The results of the life cycle cost analysis found that UV-Cured ink systems have the highest life cycle costs and the alternative with the lowest life cycle cost is the conventional water system. From Table 8 and Figure 15, it can clearly be seen that the film cost is the overwhelming driver of the total cost of each alternative.

Table 8: Life cycle costs

Item Costs	Units	Conventional 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**

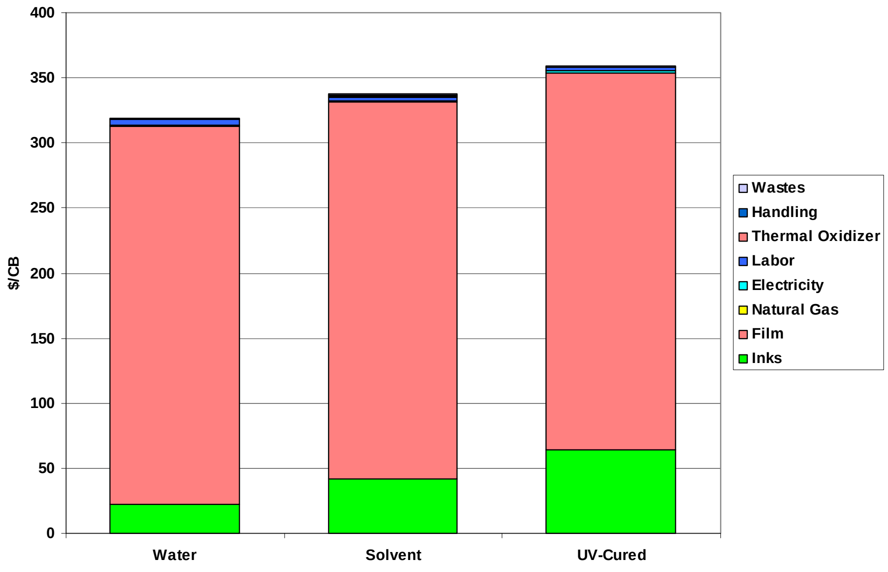

Figure 15. Life cycle costs.

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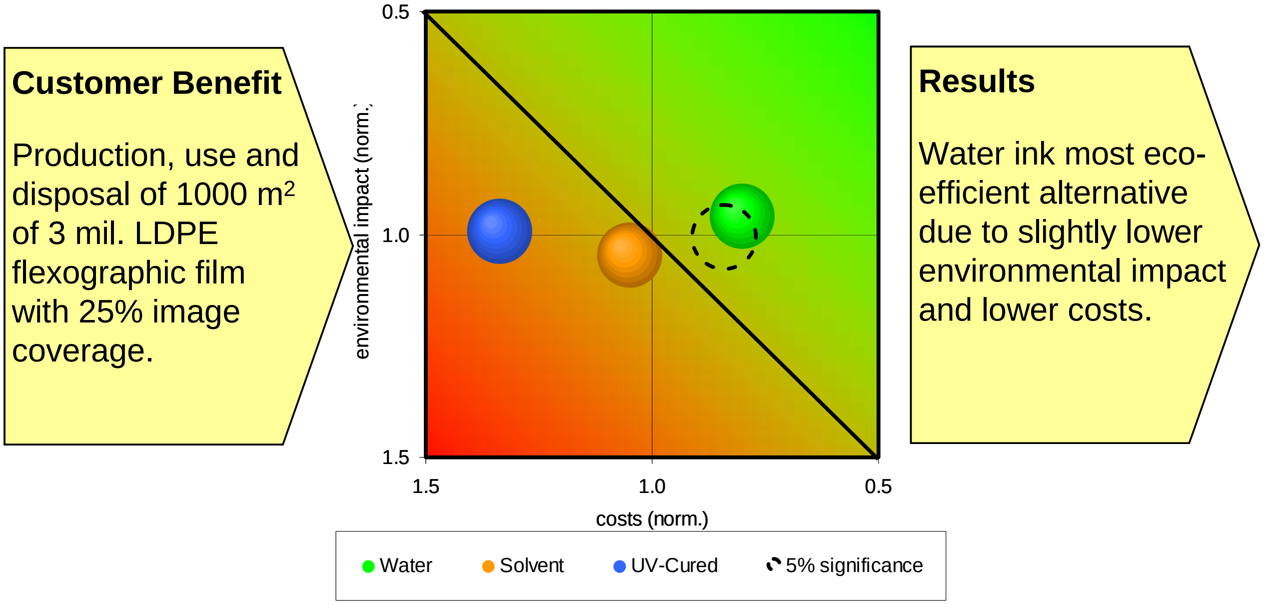
8.3. *Eco-Efficiency Analysis Portfolio*: The Eco-efficiency analysis portfolio for the JONCRYL® Water-based Polymers for Film EEA has been generated as defined in Section 9.5 of the BASF EEA methodology, which has been validated by NSF International under the requirements of Protocol P352 Part A. Utilizing relevance and calculation factors, the relative importance of each of the individual environmental impact categories are used to determine and translate the fingerprint results to the positions of the alternatives on the portfolio. Figure 16 displays the eco-efficiency portfolio, which shows the results when all six individual environmental categories are combined into a single relative environmental impact. 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.


Customer Benefit

Production, use and disposal of 1000 m^2 of 3 mil. LDPE flexographic film with 25% image coverage.

Results

Water ink most eco-efficient alternative due to slightly lower environmental impact and lower costs.

Figure 16. Eco-Efficiency portfolio.

9. Data Quality Assessment

9.1. *Data Quality Statement*: The data used for parameterization of the EEA was sufficient with most parameters of high data quality, which means the data was specific to this study context and goals. Moderate data is where industry average values or assumptions predominate the value. No critical uncertainties were identified within the parameters and assumptions that could have a significant effect on the results and conclusions. Table 9 provides a summary of the data quality for the EEA.

Table 9: Data quality evaluation for EEA parameters.

Parameter	Quality Statement	Comments
Ink Parameters		
Formulations	High	Known formulations for all three alternatives. Some averaging in eco-profiles, but mostly production/site specific values. Many eco-profiles were developed specifically for this study and are based on current technologies.
Color	High	The same color was used for all three alternatives for known pigment.
Printed dry/wet weights	High	Calculated values from processing parameters
Processing Parameters		
Ink coverage (image)	High	25% coverage is a reasonable value for this study context
Web speed/width	High	Specific to each alternative, with solvent fastest and water slowest
Production rate/hours	High	Typical industry production values.
Ink and Drum Usage		
Wet ink usage	High	Calculated amounts from alternative specific parameters
Drums handled	High	Calculated amounts from alternative specific parameters
Forklift operations	Moderate	Assumed value is reasonable given study context and goals.
Inbound/Outbound labor	Moderate	Assumed value is reasonable given study context and goals.
Waste Parameters		
Spent solvent and scrap rate	Moderate	Assumed values are reasonable given study context and goals.
Transportation Parameters		
Distance and fuel consumption	Moderate	Assumed values are reasonable given study context and goals.
Energy Consumption		
Printing press	High	Based on technical specifications for a W&H printing press that is capable of processing water, solvent and UV-cured inks.
Thermal Oxidizer	Moderate	Parameters were based on average TO configurations, equations were of high quality as developed by US EPA and ICAC.
Costs		
Utility Prices	Moderate	Current prices for region of study.
Labor Rates	Moderate	Average values for fully-loaded labor rates to include salary and benefits.
Ink Selling Price	Moderate	Based on industry average data plus 20% up-charge (NAPIM, 2007)
Thermal Oxidizer	Moderate	Energy costs were calculated using ink formulation specific data, while indirect costs were assumed to be 60% of direct annual costs, based on USEPA 2002.
Forklift Operational Cost	Moderate	Industry average values.

10. Sensitivity and Uncertainty Analysis

10.1. *Sensitivity and Uncertainty Considerations:* A sensitivity analysis of the results indicates that the impacts of this study with the highest relevance factors were 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. This is expected, and consistent, for technologies that utilize more electricity than natural gas; which was the case for this study where one alternative in particular, UV-Cured, had electricity as its only source of energy. The calculation factors indicate

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which environmental impact categories were having the largest affect on the outcome on the portfolio. The impacts with highest calculation factors were the same as those with the highest relevance factors, with is often the case, and the input parameters that were related to these impact categories have sufficient data quality to support a conclusion that this study has a low uncertainty.

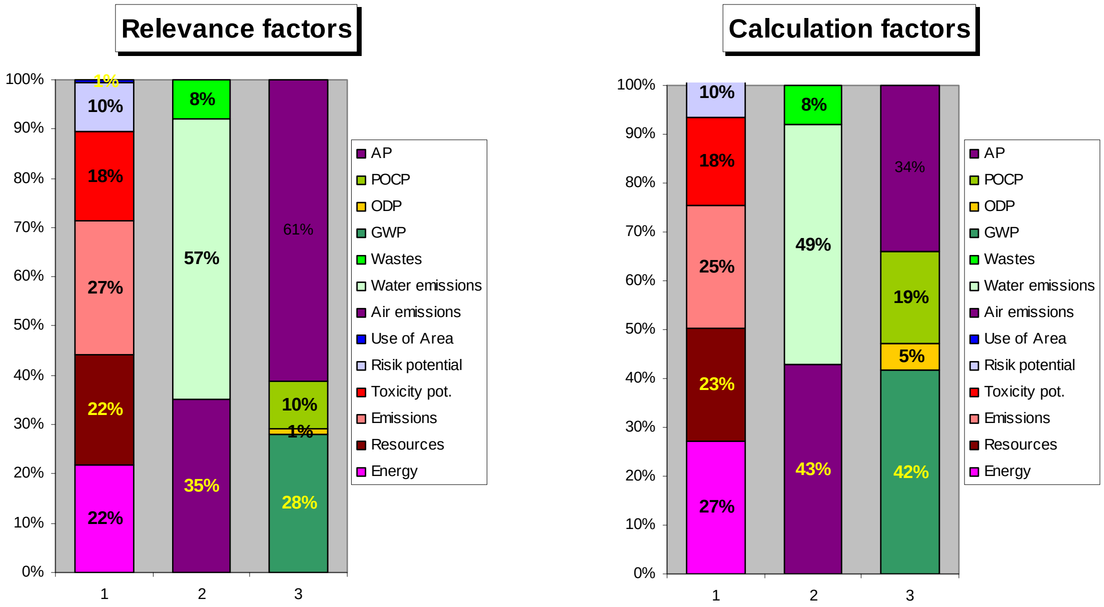

Figure 17. Relevance and calculation factors that are used in the sensitivity and uncertainty analyses.

10.2. *Critical Uncertainties:* There were no significant critical uncertainties from this study that would limit the findings or interpretations of this study. The data quality, relevance and sensitivity of the study support the use of the input parameters and assumptions as appropriate and justified.

11. Limitations of EEA Study Results

11.1. *Limitations*: These Eco-efficiency analysis results and its conclusions are based on the specific comparison of the production, use, and disposal, for the described customer benefit, alternatives and system boundaries. Transfer of these results and conclusions to other production methods or products is expressly prohibited. In particular, partial results may not be communicated so as to alter the meaning, nor may arbitrary generalizations be made regarding the results and conclusions.

12. References

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[1] EPA Air Pollution Control Cost Manual, 6th ed. January 2002. United States Environmental Protection Agency. Office of Air Quality Planning and Standards. Research Triangle Park, North Carolina 27711. EPA/452/B-02-001.

[2] ICAC Guidance Method for Estimation of Gas Consumption in a Regenerative Thermal Oxidizer. Institute of Clean Air Companies. July 2002.