Analyzing the Business Case for UV-LED Curing Part I: Identifying Cash Flows

By Jennifer Heathcote

The benefits of UV-LED curing present a strong case for its use in industrial applications. As a result, a growing number of companies are using the technology or are considering it for future projects. In situations where both conventional and LED curing are viable options for a given UV formulation at the desired process speeds and under the constraints of the installation, a financial analysis is often used to determine which technology makes better economic sense.

Equations for three common methods of analysis, *Return on Investment (ROI), Payback Period (PB)* and *Life Cycle Cost Analysis (LCCA)*, are provided in Figure 1. ROI reflects the profitability of a project. PB is a measure of liquidity and LCCA assesses the total cost of ownership. While all three are evaluations of cash flow—the difference between inflows (receipts and savings) and outflows (capital costs and expenses)—each equation provides distinctly different insight.

ROI measures an investment's efficiency with the result expressed as either a ratio or as a percentage. It is calculated by dividing the benefit of an investment by its total cost. From a financial perspective, an investment should only be pursued if it has a positive ROI and there are no competing investment opportunities yielding a higher value.

Alternatively, the PB is the length of time required to recover the cost of an investment. It is calculated by dividing the total project costs by the annual cash inflows. In general, only short-term payback periods are desirable. However, the acceptable length of time is subjective and varies by industry and project. Among equally attractive opportunities, the investment with the shortest payback period is preferred.

Finally, the LCCA is used to determine the most cost-effective investment by calculating the total costs over the expected life of the equipment less any salvage value. LCCA focuses on all cash outflows related to an investment above and beyond the initial financial outlay. The venture with the lowest LCCA among equally desirable opportunities is typically the one that is pursued.

For short-term investment periods in which all transactions occur within a single year, executing the analysis is very straightforward. All respective

Figure 1

Methods for evaluating and comparing investment opportunities

$$\text{ROI} = \frac{\text{Gain from Investment} - \text{Cost of Investment}}{\text{Cost of Investment}}$$

$$\text{PB} = \frac{\text{Cost of Investment}}{\text{Annual Cash Inflows}}$$

$$\text{LCCA} = \sum \text{Costs} - \sum \text{Salvage Values}$$

cash flow values are simply plugged into the equations, and the results are tabulated for evaluation. In most cases, however, investment periods span multiple years. As a result, it is necessary to adjust cash flows that occur in different years to a common point in time.

Most multiyear methods begin the evaluation period when the first transaction takes place. This is considered the end of year zero and is effectively the present day. Subsequent cash flows are totaled within the year in which they occur and each year's total is individually discounted back to the present.

The process of discounting cash flows to the *Net Present Value (NPV)* is necessary due to the inherent time value of money. *An amount of money available today is worth more than the same amount of money available at any point in the future.* Money today can be invested and used to make a profit; whereas, any expected future cash flow carries risk and uncertainty which may make the actual amount at the time it occurs different than anticipated. As a result, future money must be discounted to the *NPV* so that cash flows spanning multiple years can be added together.

Whenever a cash flow analysis accounts for the time value of money, it is referred to as *discounted*. When the time value of money is ignored, the analysis is referred to as *simple*. Multiyear investment periods analyzed with *discounted* methods yield more accurate results and facilitate better investment decisions. However, *simple* methods are much quicker and easier to calculate. As a result, *simple* methods are often used for initial estimates.

ROI, PB and LCCA equations should be individually tailored to discrete investment opportunities and can either be simple or discounted. The person conducting the analysis has great liberty regarding how the analysis is executed as well as what is included and what is not. While the calculations themselves are not terribly difficult, the challenge lies in determining the input variables, collecting the actual data and correctly discounting everything to a common point in time. Since no two UV-curing applications, installations or situations are completely identical, the data and factors used for analysis will always be different.

In general, the more familiar one is with the subject matter or the greater one's experience in the respective field, the more the complexity can typically be reduced to simple calculations scratched on a note pad or on the back of a napkin. This is because experience teaches which factors carry more weight as well as which can be omitted without greatly affecting the results. For riskier, more complicated and less familiar endeavors, a much more thorough analysis involving many more variables further scrutinized with sensitivity analysis is sometimes required. An extended analysis has the benefit of increasing one's understanding of the investment being considered as well as strengthening one's confidence in the final results. It also helps illustrate where possible risks might lie.

Regardless of complexity, whenever critical factors are considered and the most accurate information is used, all fair and honest methods generally point toward the same course of action. On the other hand, when poor data is used, critical information is omitted or underlying assumptions are not clearly acknowledged, the outcome will often be extremely misleading even if the methodology is correct.

It is important to understand that ROI, PB and LCCA results are meant to be evaluated with respect to other opportunities, including the option of doing nothing. Unfortunately, the results are easily manipulated by altering or omitting certain input variables in order to yield a particularly desired numerical outcome for comparison to the alternatives. As a result, utmost caution should be used when assessing someone else's

Table 1

UV-curing line costs

Cost Component *Purchase, Installation, Operation, Maintenance*	**Conventional UV Curing**	**UV-LED**
(1) UV-curing system	✓	Higher
(2) UV shutters (pneumatic or electric)	Occasional	Eliminated
(3) UV cooling system (air or liquid)	✓	✓
(4) Exhaust fan and ducting to outside of facility	Occasional	Eliminated
(5) Makeup air (heated in winter, cooled in summer)	Occasional	Eliminated
(6) Mounting of lamphead / array	✓	✓
(7) Light shielding	✓	✓
(8) Communication to and from host machine	✓	✓
(9) Safety and equipment interlocks	✓	✓
(10) Warm-up and cooldown cycles	✓	Eliminated
(11) Spare parts and repair labor	✓	Lower
(12) Electricity for startup, operation, and shutdown	✓	Lower
(13) Natural gas for conditioned makeup air	Occasional	Eliminated
(14) Inks, coatings and adhesives	✓	Higher
(15) Financing	✓	✓
(16) Project management (time and staff resources)	✓	✓

calculations or results. If a promoter of a technology declines to share the input data used in the analysis or does not disclose the underlying assumptions, then the promoter's claims should be considered questionable. Overly optimistic or exceedingly pessimistic results may very well be accurate. However, they may also be a reflection of an individual person's biases or hidden agenda. Even with full disclosure, it is strongly recommended that the intended user and purchaser of the technology personally tailor the analysis directly to the application being considered for their facility.

The process of conducting an ROI, PB and LCCA analysis on the purchase, integration and operation of a UV-LED curing system will be explored in a three-part series of articles. The information is segmented into *identifying cash flows, executing calculations and interpreting results.* The overriding purpose of the articles is to demonstrate the method of analysis and is not meant to be a justification for or against using UV-LED curing in a specific application or in the broader sense.

Input Variables for ROI, PB and LCCA

The input variables for ROI, PB and LCCA calculations are all the costs, revenues and potential salvage values associated with the proposed investment or investments. This paper predominantly focuses on the costs detailed in Table 1 (page 11) that are directly related to purchasing, installing, operating and maintaining a UV curing line. While some of the costs are necessary with every system, others apply only in certain situations. It should be noted that Table 1 is limited to curing costs and does not reflect material handling equipment or systems required for the application of the ink, coating or adhesive. In addition, the descriptors in the UV-LED column are meant as a relative comparison to conventional technology.

Table 1 is not a fully comprehensive list as many applications will likely have other costs not specified. Some of these include pretreatment systems, chilled rollers or compressed air for shutter actuation. Systems that use forced air blowers for cooling may require an exhaust hood or enclosure to contain the heat and ozone emitted by conventional systems so that it can be properly exhausted. Some material formations may also require the use of a nitrogen chamber or blanket to counter oxygen inhibition. Many arc lamp systems, as well as longer length UV-LED curing systems, are often powered by higher voltage, three-phase, AC supplies. If the exact AC supply is not readily available at the installation site, then a voltage transformer must be purchased and installed. If any of these items are essential for the curing system and application being evaluated, they must be factored into the analysis.

UV Curing Systems, Shutters and Cooling (1, 2 and 3)

The purchase price of the UV-curing system is a key cash flow that significantly affects the ROI, PB and LCCA calculations. As a result, it is critical that real pricing from actual vendors be used. In general, the purchase price of UV-LED curing systems is often much greater than that of conventional UV-curing systems. However, the difference has recently narrowed for shorter length systems; systems used in slower material handling applications; and some air-cooled units.

Some UV-LED curing systems are supplied as array-only configurations where the buyer or integrator is responsible for supplying the DC power supply, interface cable and connections, as well as the control signals. In other cases, the UV-LED equipment is supplied as a complete plug-and-play system that only requires host interface signaling. It is important to understand which configuration is quoted so that no costs are overlooked and left out of the calculations. The purchase price also needs to reflect the actual array or lamphead length, irradiance and energy density requirements of the application. Comparing two systems that aren't both capable of curing within the process constraints will skew the results and likely lead to poor investment decisions.

Many, though not all, conventional-arc systems employ the use of a shutter mechanism to block the UV light when the system is in standby mode. The cost of the shutter is typically included in the price of a UV system—although sometimes it is an optional add-on that can be supplied by the UV equipment manufacturer, integrator or end-user. It is necessary to know the shutter cost; who is supplying it; who is installing it; the common maintenance parts; and whether the actuation is electric or pneumatic. If compressed air is required to drive the shutter and is not currently available at the installation site, then it represents an installation cost as well as an operating expense. It is equally important to know the actuation time of the shutter mechanism as this has an impact on production cycle times. Since UV-LED curing systems are instant ON and instant OFF, shutters are not typically needed. Shutters are also not commonly used with microwave-curing systems.

The purchase, installation and operation of the UV-cooling system are also cash flows. Conventional

UV-curing systems typically employ forced air blowers or extraction fans ducted outside the building. Some also incorporate a liquid circulation system to cool the lamphead housing or utilize additional blowers or fans to cool shutters or other machine parts. Larger, industrial and multihead UV-LED curing systems are commonly cooled by refrigerated liquid circulation. As with the shutter mechanism, it is very important to know all the costs associated with the cooling system, including who is supplying it, who is installing it, and what is required for upkeep.

Before proceeding with ROI, PB and LCCA calculations, you should obtain purchase, installation and spare parts quotes for the UV system, shutter assembly, cooling system or systems, and the AC transformer to power the UV system, if one is needed. It is also necessary to obtain technical data sheets detailing the AC voltage and wattage requirements of each cost component as well as any recommended preventative maintenance schedules.

Exhaust Fans, Ducting and Make-up Air (4, 5 and 13)

Exhaust hoods, exhaust fans, ducting and makeup air factor into the purchase, installation and running costs of conventional UV-curing systems. In many cases, roof mounting or roof or wall penetration is required. In others, connecting the system to an existing HVAC infrastructure may be sufficient, or the equipment may simply be ducted up toward the ceiling without penetration. Whatever the case, applicable cash flows must be included in the analysis.

Makeup air systems are either all electric or a combination of electric and gas. Evaporative cooling makeup air systems also include a reservoir that requires a water supply line connection. The reservoir and external water lines should be drained and shut off in winter to avoid freezing. This, as well as filter changes, represent a maintenance task that should be included in the analysis.

Figure 2

Six-color screen press with 85-inch, UV-arc system

Consider the six-color screen press shown in Figure 2. It consists of six banks of 85-inch long, negatively air-cooled UV-arc systems. Each bank has two UV lamps that operate at either 300 or 400 watts per inch. The six banks of lampheads each have an exhaust fan whose stack penetrates the roof. The exhaust fans provide cooling to each of the banks, simultaneously removing heat and ozone. The cooling and exhaust requirements for the system in Figure 2 are 2,000 cfm for each of the six stacks resulting in a combined total exhaust of 12,000 cfm.

During installation, appropriately sized exhaust fans are purchased, installed and ducted to the UV systems in Figure 2 as well as outside the facility. In addition, the makeup air unit (either conditioned or non-conditioned) is sized to supply slightly more than 12,000 cfm into the plant during operation. This is necessary to maintain positive air pressure within the facility. Purchase, installation and maintenance for these items should factor into the cash flow analysis.

A key benefit of UV-LED curing is that the arrays do not produce significant heat or any ozone that must be exhausted outside the facility. As a result, conditioned plant makeup air that is heated in the winter and cooled in the summer is not necessary with LED technology. However, this benefit, is entirely lost on facilities which operate in temperate climates where unconditioned forced air fans are sufficient or in production facilities that simply elect not to condition the air.

When contemplating an investment in an entirely new UV-LED line, the purchase and installation costs for exhaust fans, ducting and makeup air are eliminated. When considering a retrofit from arc to LED, however, the purchase and installation costs of these items will have occurred in the past and, therefore, do not represent any savings. Furthermore, the value of the existing capital equipment may or may not be fully depreciated on the company's books. If the items still have useful life, they can possibly be sold or used elsewhere. Otherwise, the items will need to be repurposed, idled, scrapped or written off. These are all cash flows that must be factored into the analysis.

The fuel for makeup air burners is either electricity or natural gas. Natural gas is more common as it is cleaner, cheaper and more efficient. By reviewing a recent utility statement or speaking with a utility representative, it is possible to determine a facility's natural gas rate in dollars per 1,000 cubic feet ($/1,000 ft^3). General estimates can also be found online. Costs due to electricity consumption are covered in a subsequent section.

Mounting, Shielding, Communication and Interlocks (6, 7, 8 and 9)

Mounting the lamphead or UV-LED array; shielding the stray UV light; integrating the communication between the UV-curing system and the host machine; and the installation of safety interlocks are all necessary integration tasks required for both conventional and UV-LED curing systems. The costs and associated installation labor will vary slightly between systems as well as between new lines and retrofits.

In calculating ROI, PB and LCCA for the comparison of new but different UV systems, it is often feasible to treat these cash flows as offsetting one another. This simplifies the calculations and reduces or eliminates the estimating time. If contemplating whether to install a new line in isolation or when considering a retrofit, these costs should always be factored into the calculations. Precisely detailing each and every cash flow in the analysis always leads to greater comprehension.

Conventional UV Warm-up and Cooldown (10)

Since UV-LED curing systems are instant ON and instant OFF, there is no need for the warm-up and cooldown cycles associated with conventional systems. This creates savings both in process time and in total energy consumption when compared to conventional UV curing. The significance of these savings, however, entirely depends on the application and will be greater for lines that start and stop the UV system more frequently.

It is important to know the warm-up and cooldown cycle times of the arc or microwave system being evaluated. A two- to five-minute startup cycle and a five-minute cooldown cycle are typical. However, it is important to use actual times for the systems being evaluated. For the stated values, the total cycle time results in seven to 10 minutes of production downtime each and every time the system is switched ON and OFF.

An additional characteristic of conventional UV systems is a very high peak in-rush current that occurs at startup. As will be discussed in the next section, monthly electricity demand charges reflect the maximum rate at which a facility consumes electric power over a single 15- or 30-minute period. Starting all UV systems simultaneously results in a high peak demand rate even if average electrical demand during normal operation is much less.

For example, the six-color screen press in Figure 2 operates on a 480-volt, three-phase AC Supply. During startup, each lamp experiences a 90-amp in-rush current that subsequently drops to 28 amps during normal operation. Staggering the startup of the six banks of UV systems will reduce this peak demand, but it will also increase the total time required for startup, resulting in lost production time.

Spare Parts and Repair Labor (11)

Table 2 lists common components for both conventional and UV-LED curing

Table 2

Spare parts for conventional and UV-LED curing systems

Conventional UV	UV-LED
Bulbs (500 to 2,000 hours)	Diodes (10,000 to 20,000 hours)
Borosilicate or quartz plates	Borosilicate or quartz plates
Filters (air and coolant)	Filters (air and coolant)
Reflectors	DC power supplies
Ignitors	Driver boards
Pipe fittings and tubing	Pipe fittings and tubing
Coolant for liquid cooled systems	Coolant for liquid cooled systems
O-rings for liquid cooled systems	O-rings for liquid cooled systems
Electronic ballasts, chokes, or transformers	
Shutter mechanics for arc units	
Machine parts adversely affected by ozone	
Magnetrons and screens for microwave units	
Exhaust ducting	

systems. Depending on the situation, it may be necessary to include the maintenance costs and repair labor for the ancillary equipment such as exhaust fans, chillers and makeup air systems. Included in all of these costs should be shipping charges and proper disposal fees. It is helpful to get spare parts quotes and suggested preventative maintenance schedules from all vendors before performing ROI, PB and LCCA calculations.

An accurate prediction of the useful life of the UV-LED curing system can be a bit difficult. The individual UV-LED diodes are solid-state technology and have an extremely long life, ranging from 10,000 to 20,000 hours or more. In reality, the actual life is often compromised when less suitable, less efficient and cheaper diodes are used; the diodes are not packaged or cooled correctly; air-cooled systems are run in extreme ambient conditions; systems are abused during operation; the coolant is not filtered sufficiently; different coolant formulations are mixed; or the array pushes or exceeds the limits of the diode's rated UV output. As a result, some UV-LED curing systems may last less than 10,000 hours.

If failures occur, UV-LED systems built on a modular structure can be repaired in the field. If modules are not used, it is often difficult—if not impossible—to repair the UV-LED array. If a UV-LED array cannot be repaired and only lasts a few thousand hours before failure, then an entirely new array must be purchased in order to get the system back up and running. In general, the economics of shorter life UV-LED curing systems are not very attractive in comparison to conventional curing systems because the UV-LED array effectively becomes an expensive spare part.

In some applications, a maintenance benefit with UV-LED curing relates to the negative impact of ozone on machine parts. Conventional UV-curing systems emit various amounts of ozone that can corrode metals within the material handling equipment. This may simply be a cosmetic issue that has no impact on the performance of the line. However, it may require that certain machine parts be periodically repaired or replaced. Since UV-LED curing systems do not emit ozone, this issue is not a factor.

One final maintenance issue is relevant to both UV-LED curing and conventional curing. Whenever a curing line stops, either the LED system must be turned OFF or the conventional system must be turned OFF or switched to standby. If this is not done, any heat-sensitive materials underneath the light source (such as plastic parts, paper media, films or conveyor belts) will begin to warp and may even melt. The damage is typically reduced with UV-LED curing, but it can still occur. If the damage is significant, then the parts being processed will need to be scrapped and any affected machine parts will need to be cleaned, repaired or replaced. Properly installing both safety interlocks and interfacing the UV system with the host machine can help prevent this from occurring.

Electricity Calculations (12)

In general, electricity consumption often proves to be a savings with UV-LED when compared to arc or microwave. However, this fact is entirely dependent on the application. For example, in high-speed lines where the part being cured is underneath the UV source for shorter periods of time, the UV system must incorporate a much larger quantity of UV-LED diodes that emit much greater irradiance in order to deliver the required energy density and counter oxygen inhibition during the short exposure period. Alternatively, multiple arrays can be used to increase the total exposure window. As a result, the potential electricity usage for UV-LED curing systems on higher speed lines today can be closer to that of conventional UV-curing systems.

Electricity rates vary significantly by country and within regions of a single country. In general, the rates are determined by supply and demand; type of power generation; fuel prices; transmission; government subsidies; government and industry regulation; taxes; rate schedules; and local weather patterns. By reviewing a recent utility statement or speaking with a utility representative, it is possible to determine a viable electricity rate for the calculations. General estimates for regional electricity rates can also be found online. However, published estimates will likely not capture additional fees, penalties, rate schedules or usage discounts specific to a facility.

When reviewing a utility statement, it is helpful to understand the language and cost elements influencing commercial electricity billing as well as charges billed in addition to the base rate. Some of these include:

- **Watt**—unit of power equivalent to a Joule per second. (1 Watt = 1 Joule / second).
- **Demand**—rate of energy usage expressed in kilowatts (kW).
- **Electricity Rate**—cost per unit of electricity expressed in dollars per kilowatt hour ($/kWh).
- **Total Energy Usage**—aggregate power consumption used by a facility over a billing period expressed in kilowatt-hours (kWh).
- **Peak Demand**—highest rate of usage over a 15- or 30-minute period. It is reported in kilowatts (kW) or KVA Demand which is kilowatts (kW) divided by the Power Factor (PF).

- **Power Factor**—real power (kW) divided by apparent power (kVA). It is a measure of how effectively electrical power is being used. A value of one means that voltage and current are perfectly in phase; however, values between 0.80 and 0.95 are more typical. The lower a facility's power factor, the higher the corresponding electricity bill. Utility providers typically have a minimum acceptable power factor. Anything less results in billing penalties.
- **Ratchet Charges**—minimum electricity charge designed to discourage high peak demand. These charges are typically 50-80 percent of the highest billing demand incurred in the preceding 12-month period.
- **Fuel Adjustment Charge**—line item in a utility bill that reflects the actual cost of materials such as coal or natural gas burned to produce electricity.

In order to calculate the cost of energy consumption for all items related to a UV-curing system, the wattage of each component; the respective ON time for the evaluation period (typically a year); as well as the electricity rate and power factor should be determined. The analysis should include all components associated with the line, including (but not limited to) the UV system, liquid circulation chillers, exhaust fans, blowers, compressors and makeup air system.

The formula in Figure 3 can be used to calculate the total electricity cost. However, it does not reflect any additional charges stemming from high peak demand or other billing and delivery fees. It should be noted that whenever a facility's power factor is above the electric supplier's minimum requirement, the power factor correction is not necessary and falls out of the equation.

Figure 3

Formula to calculate the total electricity cost for a UV-curing system

$$\text{Energy Cost} = \text{Electricity Rate} \cdot \sum \left(\text{Wattage} \cdot \frac{\text{Target PF}}{\text{Existing PF}} \cdot \text{Usage}\right) \cdot \text{Tax Rate}$$

Where: Energy cost is in dollars ($)
Electricity rate is in dollars per kilowatt hour ($/kWh)
Wattage of components is in kilowatts (kW)
PF is unit-less
Usage is in hours (h)
Tax Rate is unit-less

For conventional UV-curing systems, the demand wattage varies during startup, operation, standby and shutdown. A precise analysis would identify these wattage levels and respective time durations separately and then calculate the corresponding energy costs. A simplified analysis would assume that the UV-curing system is always at a fixed wattage when it is ON and ignore the startup, standby and shutdown cycles. Since UV-LED curing systems instantly switch from OFF to the desired power level, it is only necessary to know the power level wattage and ON time when calculating the energy costs.

The operating power level of both a conventional and a UV-LED curing system determines the effective wattage. Lower power levels for a given system require less energy. Using the full wattage on the UV-rating plate for a system that is always run at 70 percent power would produce misleading results. Finally, since UV-LED arrays run on DC power, it is important to make sure that the AC wattage of the DC power supply or full control unit is used for the calculation.

Inks, Coatings and Adhesives (14)

Today, the costs of UV-LED inks, coatings and adhesives are often more than the conventional counterparts. These consumable costs impact operating expenses and should be included in the equations in order to determine whether any differences are significant. It is important to get actual pricing from vendors and have an understanding of annual material consumption requirements for the application being evaluated. If both conventional and UV-LED curing lines exist in a facility and each requires a different formulation, it will be necessary to stock and manage both sets.

Financing (15)

Many UV systems are purchased outright. If not, the costs of financing a new or retrofit line should also be included in the analysis. Fortunately, interest rates remain at all-time lows. However, financing may not be readily available for all manufacturers. Whatever the situation, if the equipment is to be leased or financed on credit, the associated costs for securing funding and paying interest should be included in the analysis.

Project Management (16)

All too often, project management costs and internal technical support labor are left out of the investment analysis. However, this minimizes the role that a facility's executive team, engineering staff and project managers play in coordinating and supervising the purchase and installation of new equipment. Depending on the application and the nature of the project, the time and labor needed to qualify the capabilities of the curing system, ink, coating or adhesive and manage the overall selection, purchasing, installation and training processes can be significant, especially with new and less prevalent technology such as UV-LED curing. In addition, the time, energy and resources required to certify new equipment for use in food packaging, medical applications and for printing color and image-sensitive consumer product labels are also cash flows that must be considered.

Final Comments

Before proceeding with ROI, PB and LCCA calculations on the purchase, integration and operation of a UV-LED curing system, it is important to first identify the cash flows discussed in this paper and collect the respective data. The data should reflect the actual values specific to the facility and its geographic location as well as the exact UV-curing systems being evaluated.

Using more accurate information will always lead to more tangible results and facilitate better investment decisions. An extended analysis, while more time consuming, has the benefit of increasing one's understanding of the investment being considered as well as strengthening one's confidence in the final results. It also helps illustrate where possible risks may lie.

The next installment of this paper will present an actual case study and demonstrate the methods for executing ROI, PB and LCCA calculations. The third and final paper will explain how to interpret the results and perform a sensitivity analysis.

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