Analyzing the Business Case for UV-LED Curing
Part III: Interpreting Results

By Jennifer Heathcote

This article is the final installment in a three-part series designed to illustrate the process of conducting a business case analysis on UV-curing systems. If you have not yet read "Part I—Identifying Cash Flows" or "Part II—Executing Calculations," you may want to do so before continuing with Part III.

Return on Investment (ROI), Payback Period (PB) and Life Cycle Cost Analysis (LCCA) are analytical methods widely used to guide investment decision-making. Equations for each are provided in Figure 1. In general, ROI reflects the profitability of a project. PB is a measure of liquidity and LCCA assesses the total cost of ownership. All three equations, as well as typical cash flow variables used in the calculations, were covered in Part I. Part II presented a simple case study as a means of demonstrating how the tools are employed in practice. This third and final paper illustrates the benefit of performing a sensitivity analysis and offers additional insight into the case study results.

Sensitivity Analysis

The process of financial analysis should be both transparent and intellectually honest. Doing so will help ensure that the optimal investment decision is reached. Since the person conducting the business analysis has great liberty regarding how the study is executed as well as what is included and what is not, it is important to state all assumptions and operating conditions as well as the data used in the calculations. Defining all parameters and conditions aids the thought process, ensures transparency and helps expose any biases. It also provides the necessary backup to support investment decisions and address questions or challenges from colleagues, management or business advisors.

Ideally, actual values for the specific curing application as well as the intended installation facility should be used. This will always make the analysis more accurate. In cases where actual values are unknown, the alternative is to use best-guess estimates scrutinized with a sensitivity analysis. A sensitivity analysis consists of varying one or more of the values in a calculation as a means of gauging the impact on the results and exposing potential risk. It is often employed on variables that are more volatile or uncertain. A few examples of where it is often used include inflation in less stable economies; energy costs in resource-poor, politically unstable or increasingly regulated geographic locations; support or repair costs for newer and less familiar technologies;

Figure 1

Methods for evaluating and comparing investment opportunities

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

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

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

Table 1

Case study data from Part II

Costs	UV-Arc Lamp	UV-LED
Purchase and Installation	$43,250	$50,500
Annual Energy @ $0.08 per kWh	$6,389	$1,223
Annual Consumables	$1,150	$3,810

scrap rates; projected years of operation; and production downtime.

The primary objective of a sensitivity analysis is to determine the range of conditions that make the investment opportunity economically viable. It is also used to determine which cash flow variables have a negligible effect on the calculations as well as which have the greatest impact. All factors that significantly influence the financial outcome should be closely monitored and managed over the life of the investment in order to ensure that optimal value is achieved.

To demonstrate, a sensitivity analysis was conducted on the case study detailed in Part II. Five cash flow variables were evaluated, including (1) electricity rate, (2) discount rate, (3) purchase and installation cost of UV-LED curing system, (4) scrap and (5) HVAC energy. Discounted calculations for LCCA were run for all five variables while simple calculations for payback were run for everything except the discount rate. Please note that all parameters of analysis were identical to those presented in the Part II case study. For reference, the case study cash flow totals for purchase and installation, energy consumption and consumables are summarized in Table 1.

Electricity Rate

The case study assumed a nominal electricity rate of $0.08 per kWh for a facility operating in a suburb of Chicago, Ill. Electricity rates, however, vary by geographic location and can be as high as $0.40 per kWh in Hawaii. In order to better understand the impact of electricity costs on the LCCA and PB results, the rate was adjusted in $0.05 increments up to $0.40 per kWh. The incremental adjustment and range of analysis was arbitrary but reasonable. The primary goal was to better understand how a changing rate or a plant location affects the investment decision. It should be noted that the analysis was not extended to the HVAC cash flows that were evaluated separately. It should also be noted that the electricity rate analysis would favor the UV-LED system much more in cases where the UV-LED is only cycled ON as discrete product passes underneath the curing unit since this decreases the system's total energy demand. (See Tables 2 and 3.)

The results in Tables 2 and 3 illustrate that for this particular case study, a UV-LED curing system becomes much more attractive as the rate of electricity increases. For higher electricity rates, the discounted eight-year LCCA for a UV-arc system (which requires relatively more power to operate) increases more steeply than the discounted LCCA for a UV-LED curing system.

Similarly, the payback period to recover the investment of installing a UV-LED curing system on a new line as well as on a retrofit line becomes shorter at higher rates. In fact, the payback period to operate a UV-LED system on a newly installed line in a low-energy state at an electricity rate closer to $0.05 per kWh (as opposed to operating in a high-energy state at a rate closer to $0.40 per kWh) is reduced by 1.8 years (3.21-1.40).

In general, if the curing line is located in a geographic region with both a low cost of electricity and a stable cost of electricity, then the

Table 2

LCCA sensitivity analysis—electricity rate

Electricity Rate Per kWh	$0.05	$0.08	$0.10	$0.15	$0.20	$0.25	$0.30	$0.35	$0.40
LCCA of UV-Arc	$92,072	$96,677	$99,746	$107,420	$115,094	$122,767	$130,441	$138,115	$145,788
LCCA of UV-LED	$83,157	$86,140	$88,126	$93,095	$98,064	$103,033	$108,002	$112,971	$117,940
LED LCCA Savings	$8,915	$10,537	$11,620	$14,325	$17,030	$19,734	$22,439	$25,144	$27,848

Table 3

PB sensitivity analysis—electricity rate

Electricity Rate Per kWh	$0.05	$0.08	$0.10	$0.15	$0.20	$0.25	$0.30	$0.35	$0.40
Running Costs—Arc Lamp System and Ancillary Equipment	$5,680	$6,388	$6,861	$8,041	$9,221	$10,402	$11,582	$12,762	$13,942
Running Costs—UV-LED System and Ancillary Equipment	$764	$1,223	$1,529	$2,293	$3,057	$3,821	$4,586	$5,350	$6,114
Payback—UV-LED New Line	3.21	2.89	2.71	2.35	2.07	1.85	1.67	1.53	1.40
Payback—UV-LED Retrofit	22.38	20.15	18.90	16.35	14.41	12.88	11.65	10.63	9.77

decision of whether to use an LED or an arc system is less affected by cash flows due to electricity. The opposite is the case in geographic regions operating under high or unstable rates of electricity.

Discount Rate

The case study assumed a discount rate of 8% over an eight-year period. In order to demonstrate the impact of the discount rate on the LCCA calculations, a sensitivity analysis was conducted where the discount rate was adjusted from 5% to 40%. (See Table 4.) Please note that the PB calculations can also be discounted; however, for the sake of brevity, this was not done for this particular paper.

The discount rate is an interest rate that enables financial calculations spanning multiple years to factor into account the time value of money. Discount rates are different for each company and are based on a company's cost of equity, cost of debt and type of project. Higher discount rates have less impact on costs and benefits that occur later in the evaluation period. In other words, higher discount rates favor projects where the benefits are realized early and the costs are pushed into the future. Using too high of a discount rate, however, often results in the rejection of otherwise attractive longer term projects with upfront costs. Alternatively, using too low of a discount rate can lead to funding less lucrative investments.

Table 4 indicates that at lower discount rates, the net present value of operating the line for eight years with an LED-curing system is more cost-effective than operating it with an arc-lamp system. This is because the LED-curing system, when compared to the arc-lamp system, has a greater initial investment cost at the beginning of the eight-year study and lower operating costs in the future. At a discount rate of around 37%, the LCCA net present value is the same for both the arc- and LED-curing system. At rates above 37%, however, the arc-lamp system becomes more attractive since its numerically larger annual operating costs occurring in the future carry less weight.

Cost of UV-LED Curing System

The purchase costs of UV-LED curing systems vary considerably. This is mostly due to the fact that systems are not completely identical. Some only include the array or head, while others also include the DC power supply

Table 4

LCCA sensitivity analysis—discount rate

Discount Rate	5%	8%	10%	15%	20%	25%	30%	35%	40%
LCCA of UV-Arc	$103,699	$96,680	$92,654	$84,389	$78,078	$73,171	$69,291	$66,177	$63,642
LCCA of UV-LED	$90,776	$86,140	$83,474	$77,985	$73,777	$70,495	$67,893	$65,801	$64,096
LED LCCA Savings	$12,923	$10,540	$9,180	$6,404	$4,301	$2,676	$1,398	$376	($454)

Table 5

LCCA sensitivity analysis—UV-LED system and installation costs

Cost of UV-LED System and Installation	$30,500	$40,500	$50,500	$60,500	$70,500	$80,500	$90,500	$100,500	$110,500
LCCA of UV-Arc	$96,680	$96,680	$96,680	$96,680	$96,680	$96,680	$96,680	$96,680	$96,680
LCCA of UV-LED	$64,098	$75,119	$86,140	$97,161	$108,182	$119,202	$130,223	$141,244	$152,265
LED LCCA Savings	$32,582	$21,561	$10,540	($481)	($11,502)	($22,522)	($33,543)	($44,564)	($55,585)

Table 6

PB sensitivity analysis—UV-LED system and installation costs

Cost of UV-LED System	$30,500	$40,500	$50,500	$60,500	$70,500	$80,500	$90,500	$100,500	$110,500
Payback—UV-LED New Line	(5.09)	(1.10)	2.89	6.88	10.87	14.86	18.85	22.85	26.84
Payback—UV-LED Retrofit	12.17	16.16	20.15	24.14	28.13	32.12	36.11	40.10	44.09

and integrated controls that range from the simple to the very complex. In addition, the type, wavelength and quantity of diodes; method of packaging the diodes; delivered peak irradiance; array form factor; cooling system; country of manufacture; and supplier's desired markup all contribute to the final purchase price.

Before starting any analysis, it is critical to first ensure that all curing systems being evaluated are truly capable of delivering the required curing results for the given application at the desired process speeds and setup. It is also important to make sure that the cash flows include all purchase and installation costs for all necessary components regardless of who is supplying them.

For the purposes of the sensitivity analysis, the cost of the UV-LED curing system refers to the total system cost and its installation regardless of whether the items are supplied by the curing system manufacturer, integrator or end-user. Tables 5 and 6 vary the UV-LED system cost from $30,500 to $110,500 in $10,000 increments. Since the value used for the Part II case study was $50,500, an investment of $100,500 (as shown in the table) could effectively represent two full units mounted on the same conveyor as well as a single system that is essentially twice the price. It should be noted that the cost of the arc-lamp system remained fixed for the analysis.

The results of the cost analysis are somewhat obvious. All else being equal, lower purchase and installation costs make a system more attractive. For this particular LCCA case study, the decision to use a UV-LED curing system makes strong financial sense up to an initial investment of about $60,064. This is the amount that makes the LCCA for an LED and an arc system under the parameters of the case study equal. For UV-LED investment costs greater than this amount, the arc-lamp system is the better choice.

From a PB perspective, the payback is immediate for UV-LED systems costing $43,250 or less. As the initial investment costs increase, the payback period becomes significantly longer. In fact, if two UV-LED curing systems are required to cure at the performance requirements of the case study or if the desired LED-curing system costs twice the one in the original case study, then the payback would be almost 22.85 years for a new line and 40.10 years for a retrofit. From a financial perspective, no one would rationally pursue such a project.

In general, as the overall pricing of UV-LED curing systems improves, investment decisions will more strongly favor their adoption. In the meantime, many projects already make financial sense and are being incorporated into manufacturing lines. Even some projects that are determined to be a bit risky or financially unattractive are being pursued for non-financial reasons. This often includes the desire to learn and develop new processes as a hedge against competitors as well as for applications where UV-LED curing provides process and functional capabilities that cannot be achieved with conventional curing.

Scrap Costs

One key data point that was not included in the case study was scrap costs. This was due to the fact that scrap costs vary dramatically based on the application and the facility, and the value that is used in the calculations has the potential to dramatically skew the financial results in both directions.

UV-LED curing systems have the ability to reduce scrap costs relative to conventional curing. This is because UV-LED curing systems are instant ON/OFF which eliminates the need to run product beneath the UV source during the UV system's warm-up period. With conventional curing, any product run before the UV system is at the desired power level must be scrapped. Secondly, UV-LED curing systems transmit less infrared energy to the cure surface. While damage to heat-sensitive products and materials can still occur, it is less likely—especially if jams or line stops are interlocked so that the UV-LED curing system turns OFF when incidents occur.

While it may not be possible to eliminate all scrap with UV-LED, the analysis assumed there would generally be more scrap with the arc lamp system. As a result, in order to evaluate the significance, a sensitivity analysis was performed where the "additional" annual scrap costs of the arc system were varied, while the scrap costs for the UV-LED line were held fixed. The increased annual costs were varied from $500 for minimal scrap on a low-production cost product or well-run line up to $64,000 for a product requiring very expensive raw materials and a high image quality or a poorly maintained line that produces significant jams or curing issues. (See Tables 7 and 8.)

If scrap represents a large operating cost which can be reduced or eliminated through UV-LED curing, then the use of a UV-LED curing system becomes significantly more attractive. Over the eight-year LCCA study, depending on the actual cost of scrap, the LED-curing system has the potential to generate between $13,413 and $378,325 in savings as shown in Table 7. The ability to eliminate or reduce scrap also has the potential to significantly reduce the payback period for both a new line and a retrofit line. (See Table 8.)

Both tables demonstrate that scrap is a key variable that drastically influences the financial results. Overestimating or underestimating its value, as well as omitting it from calculations, can lead to poor investment decisions. If the actual amount of scrap is uncertain, it is always better to make more

Table 7

LCCA sensitivity analysis—arc system scrap

Cost of Scrap	$500	$1,000	$2,000	$4,000	$8,000	$16,000	$32,000	$64,000
LCCA of UV-Arc	$99,553	$102,427	$108,173	$119,666	$142,653	$188,626	$280,572	$464,465
LCCA of UV-LED	$86,140	$86,140	$86,140	$86,140	$86,140	$86,140	$86,140	$86,140
LED LCCA Savings	$13,413	$16,287	$22,033	$33,526	$56,513	$102,486	$194,432	$378,325

Table 8

PB sensitivity analysis—arc system scrap

Cost of Scrap	$500	$1,000	$2,000	$4,000	$8,000	$16,000	$32,000	$64,000
Payback—UV-LED New Line	2.41	2.07	1.61	1.11	0.69	0.39	0.21	0.11
Payback—UV-LED Retrofit	16.80	14.40	11.21	7.76	4.81	2.73	1.46	0.76

Table 9

LCCA sensitivity analysis—HVAC

HVAC Costs	$0	$4,500	$5,500	$6,500	$7,500	$8,500	$9,500	$10,500	$11,500
LCCA of UV-Arc	$67,420	$96,676	$103,178	$109,679	$116,181	$122,682	$129,183	$135,685	$142,186
LCCA of UV-LED	$86,140	$86,140	$86,140	$86,140	$86,140	$86,140	$86,140	$86,140	$86,140
LED LCCA Savings	($18,720)	$10,536	$17,038	$23,539	$30,041	$36,542	$43,043	$49,545	$56,046

conservative estimates and perform a sensitivity analysis.

HVAC Energy Costs

One of the more attractive benefits of UV-LED curing is the elimination of exhaust. Conventional systems require exhaust to remove heat and ozone. In many cases, the UV units are exhausted outside the facility. The consequence is that the exhausted air must be replaced. Depending on the facility and geographic location, the makeup air is often heated in the winter and cooled in the summer at a considerable cost. The actual costs of conditioning the air vary depending on environmental conditions as well as the use of electric, natural gas and evaporative methods.

The sensitivity analysis evaluated the impact of heating, ventilating and air conditioning (HVAC) the facility in which the arc-lamp system was installed. The calculations were run for a temperate climate that requires no HVAC ($0), the case study of Part II ($4,500), as well as seven additional scenarios where the HVAC costs were increased in $1,000 increments up to $11,500 annually. (See Table 9.)

Table 9 illustrates that a facility's HVAC costs are a vital factor in determining whether an LED or an arc-lamp system makes better economic sense. In temperate climates where HVAC is not necessary, an arc-lamp may often be the better financial choice; however, as HVAC costs increase, the UV-LED system becomes more economically viable. For the case study, the UV-LED curing system has a life-cycle cost that is $18,720 greater than the arc-lamp system when HVAC is not required, but for annual HVAC costs of $11,500, the life-cycle costs of the LED system are $56,046 less than the conventional system.

The HVAC factor also applies to the payback period as presented in Table 10. Where HVAC costs are nonexistent or low, the payback period for installing a UV-LED curing system on a new line under the conditions of the case study is 3.64 years. It increases to 25.32 years if the LED system is used to replace a functioning conventional system on an existing line. As HVAC costs for the case study increase, the payback period decreases

Table 10

PB sensitivity analysis—HVAC

HVAC Costs	$0	$4,500	$5,500	$6,500	$7,500	$8,500	$9,500	$10,500	$11,500
Running Costs—Arc Lamp System and Ancillary Equipment	$1,888	$6,388	$7,388	$8,388	$9,388	$10,388	$11,388	$12,388	$13,388
Running Costs—UV-LED System and Ancillary Equipment	$1,223	$1,223	$1,223	$1,223	$1,223	$1,223	$1,223	$1,223	$1,223
Payback—UV-LED New Line	3.64	2.89	2.07	1.61	1.32	1.11	0.97	0.85	0.76
Payback—UV-LED Retrofit	25.32	20.15	14.41	11.21	9.17	7.76	6.73	5.94	5.31

to 0.76 years for a new installation and 5.31 years for a replacement.

Downtime

The examples in this paper focused on LCCA and PB. A sensitivity analysis should also be performed on the ROI. For example, it might be assumed that a new machine with a UV-LED curing system will always run at full capacity. In practice, however, it may not be possible to secure all of the UV-LED ink colors necessary to run every job or it may be time-consuming to run samples and get customer approvals for each new ink color.

If the production volume in a particular facility is high and there are numerous lines, it may be possible to shift jobs that only require currently available or currently approved inks to the LED line. However, if a facility does not have this flexibility, it may not be possible to always run the UV-LED decorating line at full capacity all the time. This will impact the ROI. The degree of impact can and should be evaluated with a sensitivity analysis.

Final Comments

The purpose of this three-part series was not meant to be an argument for or against any particular type of UV-curing system, especially since the values used in the examples do not readily lend themselves to every scenario. Instead, the sole intent was to demonstrate common methods of business case analysis and to show that the data used in the calculations significantly impacts the results and, ultimately, the investment decision. Hopefully, the papers also serve to encourage readers to run their own calculations and scrutinize others' results by demonstrating that it is vitally important that calculations only use data specific to the application and installation site and that ROI, PB and LCCA claims only carry weight if they are reported with stated assumptions and clearly defined input data. Furthermore, performing a sensitivity analysis will always strengthen one's confidence in the numerical results and can also be used to expose potential risk and errors due to preconceived biases.

While the overriding financial benefit of any investment should be the driving factor, there are situations where UV-LED technology may be pursued even when the economics are not very appealing. This would include cases where UV-LED technology offers process capabilities that cannot be achieved with conventional systems as well as the desire to install a pilot, low-capacity or hybrid line in order to learn more about the technology and develop processes for the future. In some cases, the decision to use a UV-LED curing system is heavily influenced by current or pending regulatory mandates. On the other hand, there are also situations where facilities have already made significant investments in a particular type of curing system. This may lead them to stick with existing technology for the purposes of standardization.

In the end, the decision of which curing technology to use is a combination of analytical and subjective factors. Different facilities operating under very similar conditions can often reach drastically different investment decisions based on their respective risk tolerance and their decision-making methodology. Lab and field trials; evaluations of exiting installations and case studies; availability of formulations; relationships with suppliers; analytical business case specific to the application and facility; and the consideration of relevant subjective factors are all tools designed to minimize risk and aid the decision-making process. As long as a thorough analysis is pursued in a transparent and intellectually honest manner, then the correct investment decision for a particular facility should ultimately be achieved.

—Jennifer Heathcote is a member of the RadTech NA board.