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ENLIGHTEN AND INSPIRE

LED Tubes Versus Integrated LED Fixtures

Introduction

For nearly all lighting applications of the past century, light fixtures and light sources were manufactured as separate products. The short service life of incandescent bulbs and fluorescent tubes meant that ease of replacement was crucial, and these products fit that requirement. As LEDs became commercially viable, they transformed lighting with both increased energy efficiency and long service life. Lighting became less like other household or maintenance facility supplies, no longer requiring a small stockpile of replacements waiting to replace a failed bulb or tube, and more like a furnace or roofing, which could be installed and let be for many years.

The advent of the integrated LED fixture, which takes advantage of the versatile form factors of LEDs and the unprecedented retreat of large incumbent lamp manufacturers, has, for the first time since the days of Thomas Edison, fundamentally challenged the mutual dependence of fixtures and lamps in the lighting industry. With it have come aesthetically flexible lighting options, nearly infinite design and color tuning options, and smartphone compatibility. Joining the myriad of other LED products, they have become influential in the drive against greenhouse gas emissions through energy consumption reductions. However, these fixtures come with issues that are becoming increasingly evident, jeopardizing the financial and sustainability potential of LED lighting.

Technological Trends

As LEDs became commercially viable in the context of their much more versatile form factors during the latter part of the first decade of the 21st century, fixture manufacturers commenced integrating them directly into their products. The additional space for hardware afforded by this integration enabled them to not only present additional design potential but also achieve a higher lumen output, a fully managed heat dissipation system and additional lighting controls. However, innovations in LED as well as communications, electronics and software technologies have led high-quality LED tubes to catch up with and match the capabilities of integrated fixtures while still retaining their ease of installation and operability over the past few years.

Over the past decades, LED lighting technology, built upon semiconductor wafers, has been following the Haitz Law[1], which predicts that for every 10 years, the cost per lumen falls by a factor of 10 and the amount of light generated per LED package increases by a factor of 20. In other words, within 5 years, cost per lumen per LED would likely drop by approximately 70%. Even if we assume LEDs comprise only 30% of an LED lamp's cost today and the cost of the rest of the 70% components fall only by a conservative 20% due to larger production scale, better designs and improved production processes, cost per lumen for LED lamps would drop 35% in 5 years. Therefore, the rate of efficiency advancements for LEDs remains a strong motivator for lighting upgrades. **Tube-based troffers grant facilities the ability to retrofit existing**

troffers with the latest lamps, without having to replace the entire fixture. Current estimates place the maximum achievable efficacy for LED lights at between 200 and 250 lumens/watt, approximately 50 to 100% more efficient than the prevailing LED lamp efficiency today.[2] Therefore, simply based on efficiency improvement, LED lighting still has plenty room to go within the next 5 to 10 years.

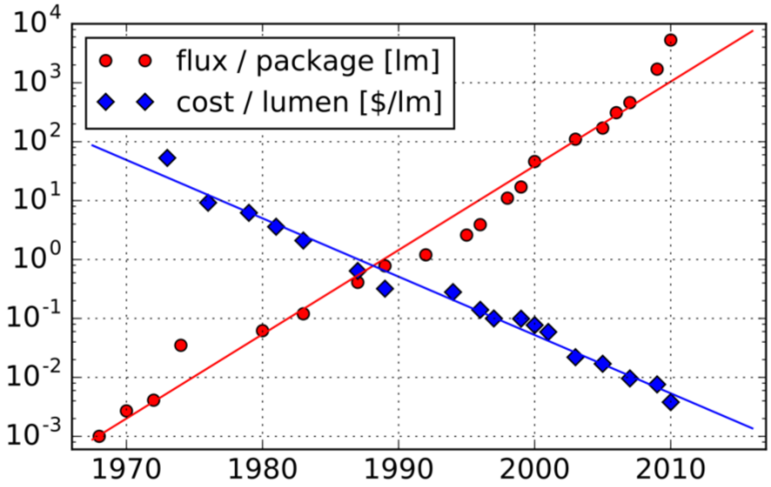


Fig. 1: Illustration of Haitz's Law

In addition to following Haitz's Law, LED lamps and fixtures are also incorporating growing arrays of exponential technologies involving electronics (following Moore's Law[3], which predicts that the number of transistors, or processing speed, of an integrated circuit doubles every 18 to 24 months), software, sensors and the cloud that contribute to the Internet of Things (IoT)—a system of interrelated and interconnected devices. Therefore, **conservatively, every five years, LED lighting would come with much-expanded functionalities and intelligences that generate additional and unseen economic, environmental and human benefits** that organizations could capitalize on, cost-effectively. Such flexibility of upgrades is crucial for organizations to stay competitive in their building performances in the age of IoT.

Financial Considerations

Aesthetics

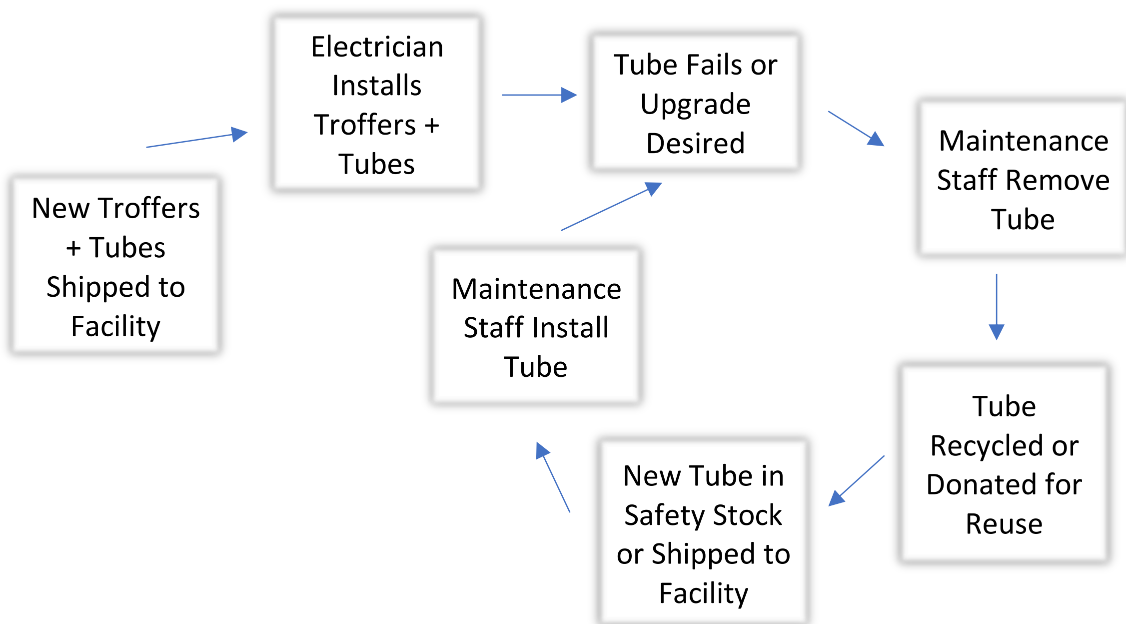
With luck, no integrated fixture will have to be changed for at least 5 or even 10 years. However, while that may be a benefit, chances are high that not all the fixtures will fail at the same time. It's far more likely that some lights, in areas where usage is higher, will stop working before others. In the past, with traditional fluorescent tubes, the solution was to simply order more tubes and replace the ones that had burned out. Unfortunately, integrated fixtures don't offer that option due to their all-in-one design—the entire fixture will need to be replaced. **Lighting companies don't habitually maintain stock of their entire line for more than a few years, so replacing a fixture with the same design and color temperature will likely pose a challenge. Whereas the lamps in tube-based fixtures are easily replaced to match the existing lighting while simultaneously upgrading their performance, without replacing the troffer or fixture.**

Life-Cycle Cost Analysis Overview

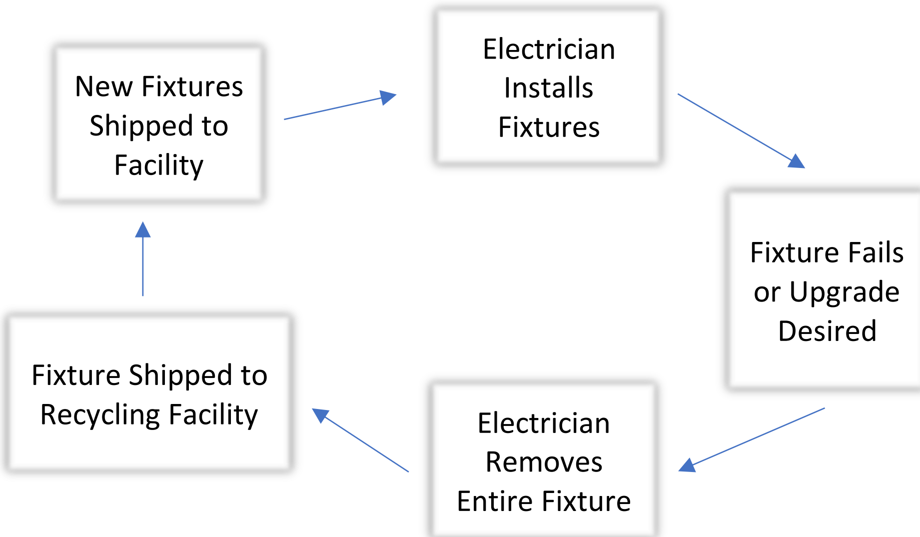
An effective evaluation of lighting options requires the use of a life-cycle cost analysis, which takes into account not only the initial cost of installation, but also all the future costs associated with the particular product.

The diagrams below of a total lighting upgrade demonstrate the cycle cutoff of tube-based fixtures using Type B tubes[4] after the troffer is installed, contrasted with the cycle of replacing the entire integrated fixture.

Tube-Based Fixture:



Integrated Fixture:



Assuming a comparable quality of product (5-year warranty integrated fixture and 10-year warranty tubes), the initial cost is greater for integrated fixtures. A two-foot by four-foot troffer ($52) with three top-of-the-line (with a 10-year warranty) 11W 1,540-lumen tubes ($11 each) comes out to $85, while an integrated fixture with similar design and performance ratings is $90.

Example replacement cost table per fixture (as of October 2019):

	Replacement Cost	Replacement Labor Cost	Total Replacement Cost
Tube-Based Fixture	$11 to $33	$~0	**$~11 to $33**
Integrated Fixture	$60 to $100	$30	**$90 to $130**

Initial installation costs are roughly equal assuming either a new build or renovation where new lighting fixtures are required. The maintenance costs would be equivalent only assuming a zero-failure rate, but failures do happen and will happen. When failures occur, replacement of a tube does not require a licensed electrician and does not require the removal of the entire fixture. Failures in a tube-based fixture therefore cost significantly less than replacing a whole integrated LED fixture. In other words, **when an individual or group of diodes or the driver does fail, in an integrated fixture the repair costs equal the cost of a new fixture from both product and labor perspectives, whereas with tube-based LEDs, it's simply a matter of changing the tube.** All told, integrated fixtures could cost 3 to 10 times more than tube-based fixtures during a 5 to 10-year period.

End of serviceable life costs are where the two options emphatically differ. Integrated fixtures, by design, are intended to be fitted and forgotten. LEDs are known for their long life and low maintenance with warranty coverage on tubes up to 10 years.[5] Warranties for integrated fixtures generally cap out at 5 years. **It's also exceedingly rare for warranties to cover installation costs, which won't have much of an impact when replacing a single tube but far more of an impact when replacing an entire fixture.** This drives the cost to replace an integrated fixture far above the entire trio of tubes, ~$90 per fixture (in addition to the cost of a licensed electrician to remove the old fixture and install a new one).

In addition, the serviceable life of the design for an integrated fixture is only as long as the life of the LEDs and the power supply electronics (i.e. drivers) themselves, since the fixture is one with the lamp. The primary benefit of a tube-based system, outside of the significant savings on replacements over time, is its interoperability with new more efficient tubes (for the life of the troffer), which could bring additional energy savings and capabilities to the lighting system.

Environmental

According to the "2019 Advancing Net Zero Status Report" from the World Green Building Council, approximately 40% of energy-related global greenhouse gas emissions are generated by commercial, residential, and industrial buildings.[6] And according to the US Department of Energy, lighting accounts for more than 20% of the energy used by commercial buildings.[7] For any organization looking to reduce its environmental impact, lighting is the place to start. Note that there are significant pitfalls to not taking a life-cycle approach.

A life-cycle assessment calculates the environmental impact of a product by taking into account all the stages of a product's life from raw material extraction all the way to end of life and disposal or recycling. It's easy to take a reduction in energy efficiency at face-value and disregard the other factors that dictate environmental impact.

Product comparison for existing fixture replacement or upgrade:

	Acuity brands Lithonia lay-in troffer with prismatic lens	Energy Focus 500D Single replacement	Energy Focus 500D Full replacement
Lumens/Watts	3,980 lumens/29w	1,540 lumens/11w	4,620 lumens/33w
Price	$60	$11	$33
Metal weight	6,804 grams (steel)	172 grams (aluminum)	516 grams (aluminum)
Plastic weight	816 grams	76 grams	228 grams
Driver(s) weight	295 grams	50 grams	150 grams
LED backing weight	140 grams	20 grams	60 grams

Environmental Impact of Replacement Less Transport and Recycling:

	Acuity brands Lithonia lay-in troffer with prismatic lens	Energy Focus 500D Single replacement	Energy Focus 500D Full replacement
Lumens/Watts	3,980 lumens/29w	1,540 lumens/11w	4,620 lumens/33w
Price	$60	$11	$33
Metal	12,928 grams CO_2e	2,064 grams CO_2e	6,192 grams CO_2e
Plastic	5,141 grams CO_2e	479 grams CO_2e	1,436 grams CO_2e
Total Impact	18,069 grams CO_2e	2,543 grams CO_2e	7,628 grams CO_2e

Carbon calculations based on:
http://www.dartmouth.edu/~cushman/books/Numbers/Chap1-Materials.pdf
CO2e for each, assuming identical sourcing and logistics pathways:
Steel (1.9 grams CO_2e per gram)
Aluminum (12 grams CO_2e per gram)
Polycarbonate (6.3 grams CO_2e per gram)

While eliminating the lamps of traditional tube-based fixtures slightly reduces the inputs required in manufacturing, it significantly magnifies the issue of waste at end of life. An average LED tube with aluminum heatsink weighs approximately 312 grams; with three lamps in a fixture, the total weight of material is approximately 936 grams. This is the material that would be replaced should an upgrade be desired or a lamp fail. The troffer to accommodate these lamps weighs approximately 9,525 grams but will not need to be replaced. A comparable integrated fixture weighs between 6,985 grams and 15,876 grams, depending on design and brand. Should a failure occur, or an efficiency upgrade be desired, the **integrated fixture requires the discarding of between 7 times (for flat panels) and 50 times (for more heavily designed luminaires) the weight of the material of a comparable tube-based fixture**. The emissions generated during the transport and processing of this additional material for recycling must not be overlooked when considering environmental impact.

Recycling is unquestioningly preferable to sending the material to a landfill, but not all recycling processes are created equal. Integrated fixtures are comprised primarily of sheet metal and polycarbonate, which have quite different environmental implications at their end of life. Metals like steel and aluminum can be recycled repeatedly without degrading their properties, but the process still requires a significant input of energy. Plastics, like polycarbonate, are usually downcycled – that is, when plastics are recycled, they are used to make a lower-quality form of plastic and cannot be formed into the same product more than once – or incinerated, which release dangerous dioxins (a persistent environmental pollutant) into the air.

Many organizations are likely to take advantage of the efficiency improvements of LEDs over time and retrofit their facilities before the lamp's end of life. In this case, with tube-based LEDs, the old lamps can be moved easily and cost-effectively to areas of the facility that still have fluorescent tubes or donated to organizations for reuse in underprivileged areas.

Conclusion

After more than 10 years of commercialization, LED lighting is now entering mainstream markets. There is no doubt that LED lighting is the optimal lighting choice today (and for the foreseeable future) for the vast majority of general lighting applications, particularly in commercial buildings.

In recent years, integrated fixtures had become the preferred choice for new building construction due to their aesthetics and control capabilities that designers and architects found attractive to specify in new building designs. However, when compared with LED tube-based troffers over the long term, integrated fixtures, as analyzed above, represent a far more costly, environmentally unfriendly and inflexible form of lighting. As LED lighting technology continues to evolve rapidly in terms of both energy efficiency and connectivity, the exponential emergence of IoT technologies will only accelerate improved functionality and intelligences of LED lighting. This will further shorten the replacement cycles of LED lamps and fixtures.

Organizations intending to progress sustainably must take into account the future implications of actions they take today by considering the entire lifecycle of the products they choose. LED lamps, which can be replaced much more quickly and inexpensively and generate far less environmental waste, are now incorporating dimming, color tuning, connectivity and control capabilities previously only available in integrated fixtures, at a fraction of the cost. One doesn't have to accept increased maintenance headaches for functionality, nor replace an entire fixture when a diode fails, or upgrade an entire fixture for increased energy efficiency. LED lamps offer a much more affordable and smart option to keep buildings and facilities up-to-date with the most compelling and impactful LED lighting technologies.

Sources

[1] https://www.nature.com/articles/nphoton.2006.78

[2] https://www.dial.de/en/blog/article/efficiency-of-ledsthe-highest-luminous-efficacy-of-a-white-led/

[3] https://www.britannica.com/technology/Moores-law

[4] There are currently four options available for wiring LED tubes. Type-B LED tubes offer the optimal balance of efficiency and ease of installation for most applications.

	Ballast Compatible (A)	Direct Wire (B)	Remote Driver (C)	Hybrid (A+B)
Cost	Low	Low	High	High
Efficiency	Low	High	High	Low
Maintenance	High	Low	Medium	Medium
Capability	Ballast dependent	High	High	Medium

[5] https://www.energyfocus.com/company/terms-and-conditions/energy-focus-10-year-warranty/

[6] https://www.worldgbc.org/news-media/advancing-net-zero-status-report-2019-publication

[7] https://www.nrel.gov/docs/fy14osti/60197.pdf

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