

SMART CITIES

Bright LEDs could spell the end of dark skies

Outdoor LED lighting projects can save energy, but they can also make light pollution worse.

The Milky Way as seen from the South Rim of the Grand Canyon.

ADAM SCHMID/GETTY IMAGES

by **Shel Evergreen**
August 17, 2022

Late one evening in June of 2016, John Barentine stood alone at Mather Point, an iconic and rarely empty overlook at Grand Canyon National Park. The moon slid away, leaving the darkness of a crisp, clear sky. The stars that make up our galaxy seemed to align overhead. The inky chasm of the ancient canyon spread out below, and he marveled at a feeling of being unmoored in time and space.

An astronomer who worked for the International Dark-Sky Association (IDA), Barentine had a special reason to revel in the scene. With his help, the park had recently been given provisional status as an International Dark Sky Park, a designation given to public land that exhibits “exceptional” starry nights. Few publicly accessible places on Earth experience this kind of pristine darkness. Indeed, the view is quite different 200 miles away in Tucson. There, photons from the city’s lights scatter in the sky, forming an obscuring dome of light called sky glow—a feature now common to major cities.

Scientists have known for years that such light pollution is growing and can harm both humans and wildlife. In people, increased exposure to light at night

disrupts sleep cycles and has been linked to cancer and cardiovascular disease, according to a [2016 report](#) by the American Medical Association. Meanwhile, the ecological impacts of light pollution span the globe. It can affect the reproduction patterns of male crickets, causing them to chirp during the daytime instead of at night, when they typically call mates. [Baby sea turtles](#), which have evolved to evade predators by rushing to the ocean upon hatching, can be disoriented by lights near the shore. Owls lose their stealthy advantage over prey. Even trees can struggle, holding onto leaves longer and budding earlier than they should because the brightness of their surroundings gives them incorrect information on the time of year.

Astronomers, policymakers, and lighting professionals are all working to find ways to reduce light pollution. Many of them advocate installing light-emitting diodes, or LEDs, in outdoor fixtures such as city streetlights. Watt for watt, LED streetlights are now comparable in efficiency to traditional sodium vapor streetlights—and are in some cases more efficient. But the crucial difference is that they are better at directing light to a targeted area, which means less light and energy are needed overall to achieve the desired illumination.

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Several major cities across the globe, including Paris, New York, and Shanghai, have already adopted LEDs widely to save energy and money. But a growing body of research suggests that switching to LEDs is not the straightforward panacea some might expect. In many cases, LED installations have worsened light pollution. Steering a path toward reducing the problem requires more than just buying some energy-efficient fixtures. Cities must develop dark-sky-friendly policies, and lighting professionals need to design and manufacture products that enable those policies to succeed. And they must start doing so now, say many light pollution experts, including Karolina Zielinska-Dabkowska, an assistant professor of architecture at Gdańsk University of Technology in Poland. LEDs already make up more than half of global lighting sales, according to the International Energy Agency. The high initial investment and durability of modern LEDs mean cities need to get the transition right the first time or potentially face decades of consequences.

Zielinska-Dabkowska may understand the potential and drawbacks of using LEDs better than anyone. In the 2000s, she worked for various lighting companies on high-profile projects, including the Tribute in Light memorial in New York City. The striking installation shoots two beams of light into the sky to echo the two World Trade Center towers lost on 9/11. Soon after it was completed in 2002, the tribute turned out to be trapping migrating birds in its hypnotizing beams.

The piece is now switched off at times to allow birds to disperse, but light pollution ultimately became an issue Zielinska-Dabkowska could not ignore, and she wrapped research on solutions into her work. “I wanted to make a change,” she says.

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There are four main elements of light pollution, Zielinska-Dabkowska says. The most recognizable is sky glow, which can affect migrating birds hundreds of miles away. Another is light trespass, the photons that cross boundary lines. They can creep in through windows and can affect sleep and circadian rhythms. Glare, meanwhile, is a change in contrast—the sort that happens when you walk from a highly lit area into a darker one, forcing your eyes to adjust. Lastly, and most significant, she says, is over-illumination—lighting things up much more than necessary.

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LEDs have the potential to combat all four of these problems. The bulbs can, for example, be installed in “smart” housings that can be remotely tuned and programmed. “You can control LEDs,” Zielinska-Dabkowska says. “You can dim them down to 0%.”

The city of Tucson implemented smart lighting controls in its streetlights in 2016, replacing 18,000 sodium lights with shielded LEDs to help prevent light from escaping upward. A 2018 study on which Barentine was lead author found that Tucson’s [sky glow](#) decreased by 7% after the transition. The “color temperature” of those lights—a measure the industry uses to describe the warmth or coolness of their tone—is a moderate 3,000 K. But that color temperature now exceeds the IDA guidelines for outdoor lighting, which were released last year; researchers agree a warmer temperature of 2,200 K is a better cutoff. Bluer, cooler-toned lights with higher Kelvin ratings have shown the clearest evidence of disruption to the circadian rhythms of people and animals, which causes a cascade of health and environmental impacts.

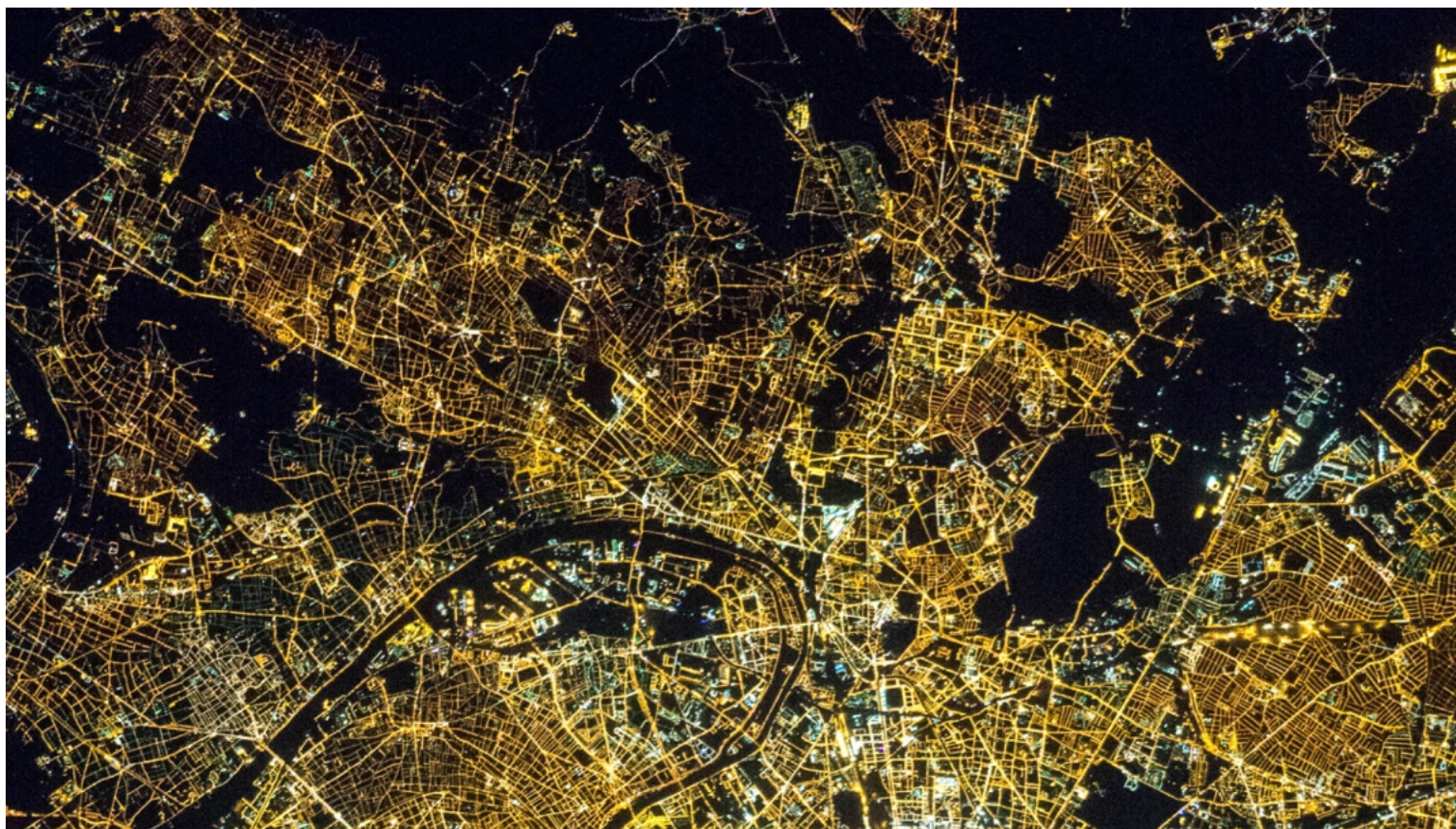
The switch to LEDs has been habitually lauded as an environmental win, but experts say they are often used to extremes. One problem, says Pete Strasser, a Tucson resident and technical director at the IDA, is the excessive use of bright white LED lighting in cities such as [Los Angeles](#), which has boasted about its ability to make streets brighter. “We hear that people feel a lot safer with the white light,” Ed Ebrahimian, then director of LA’s street lighting, said in a 2014

Department of Energy video on LED streetlights. Light pollution experts say this feeling of safety seems to stem from fact that one can see a greater range of colors under white light, which gives the sensation that one can see better.

Artificial light grew by an estimated 49% globally between 1992 and 2017—and as much as 400% in some regions.

Tracking the global extent of light pollution is challenging. Researchers have mainly relied on low-resolution satellite sensors and a radiometer suite aboard the Suomi National Polar-orbiting Partnership satellite, says Alejandro Sánchez de Miguel, an astrophysics postdoc at the Complutense University of Madrid. The instrument provides higher-resolution images, but its infrared sensors exclude wavelengths found in many LEDs. “The more blue light a light has, the less light the satellites see,” says Sánchez de Miguel. “We are color-blind, and we are thinking that everything is red.” Last year, he and his colleagues found that previous studies had probably lowballed global light emissions. Their study estimated that artificial light had grown by at least 49% around the planet between 1992 and 2017, and as much as 400% in some regions.

The adoption of cool white LEDs—alongside factors like increasing population and electrification—is likely responsible for some of this growth. The attraction is understandable. They are cheaper and more efficient than warm LEDs, Zielinska-Dabkowska explains.





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Paris, the "City of Light," viewed from the International Space Station.

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But flipping the switch on light pollution involves more than changing colors.

Even LEDs that look warm in tone still have a [spike of blue](#) that signals daylight in our brains, Zielinska-Dabkowska says. And different species display diverse responses to light, according to [a study](#) published in 2021 in the journal *Integrative & Comparative Biology*. For example, photoreceptors are more red-sensitive in freshwater species of the teleost fish than in marine species—a distinction that illustrates the complexity of responses to light even among similar animals. The study cautioned that efforts to deal with light pollution are “accumulating faster than our basic knowledge of sensory systems.” Picking a single hue, even a warmer one, and blasting it into the night will likely have significant repercussions, says Valentina Alaasam, a PhD candidate at the University of Nevada, Reno, and lead author of the study. “Everything that affects species interactions winds up affecting evolution and species distribution,” she says. “Animals that can cope better with the city and with lights are moving into cities, and animals that can’t cope are moving out.” She says it’s a problem that has gotten really big, really fast.

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Barentine says the color can’t be taken in isolation from other aspects like shielding, brightness, distribution, and timing. For example, he says, dark-sky-friendly lighting might have cooler-toned light at a lower intensity, ultimately still resulting in less blue light emission.

For light pollution researchers, the key hurdle to overcome is no longer technology but communication. “The biggest obstacle that we have to making more progress in this realm is a lack of awareness and education on the part of people that are in municipal government,” says Barentine, who now works on dark-sky policies as an independent consultant.

Career civil servants like city administrators or engineers, he says, are most often the people who make day-to-day decisions or recommendations in municipal governments, rather than elected officials. “My perception is that a lot of their information comes from the lighting industry, for better or worse,” Barentine says. Until recently, those companies were at odds with light pollution researchers, Barentine says. “There was just tremendous skepticism within the lighting manufacturing industry,” he says, adding that he thinks there was an intrinsic belief that the issue was simple: light is good and darkness is bad.

Barentine says he makes sure to communicate to the lighting industry that his work is about “dark sky,” not “dark ground.” The IDA has worked with industry since the 1980s, he says: “Our message, in so many words, was ‘If you follow our principles that reduce light pollution, you won’t sell any less lighting than you sell now; you’ll be selling different lighting.’”

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Still, the advent of white LEDs that promised perfect illumination and the boom that followed led to a misalignment of goals, whether real or perceived. Lighting professionals and researchers continued to speak about light in fundamentally different ways.

To illustrate and quantify the communication gap, Catherine Pérez Vega, a doctoral candidate at the Leibniz Institute of Freshwater Ecology and Inland Fisheries in Berlin who works with Zielinska-Dabkowska, led a systematic review of more than 200 studies of artificial light at night. The results, published in the journal *Sustainability* earlier this year, found a disconnect between researchers and professionals such as lighting architects, urban lighting designers, and electrical illumination engineers. In some cases, the two groups were essentially speaking different languages. For example, those studying artificial light use a metric called “irradiance” to talk about brightness, while those in the lighting industry go with a different measure, called “illuminance.” In a list of 19 physical measurements of light, only one term has the same level of usage—and it is rarely used by either group.

“I think [the review] has stimulated a conversation in this field that is a long time in coming,” Barentine says. “We are beginning to realize that even though we have similar goals—and I think we do—we often talk past one another.”

Arizona, with its dozens of observatories and arid desert skies, is a major hub for astronomy research. As a result, Tucson has been relatively successful in its dark-sky endeavors. But the priorities are different in other cities. Pittsburgh, for example, also has observatories nearby, but to some people, light pollution can seem an insignificant concern compared with other issues the city is tackling, such as air pollution, food deserts, and road maintenance. Even so, Diane Turnshek, a physics lecturer and assistant professor at Carnegie Mellon University (CMU), thinks it shouldn’t be hard to address.

Turnshek spent many nights under the stars while studying astronomy at the University of Arizona in the 1970s. Decades later, she briefly returned to join the Mars Desert Research Station, a NASA laboratory for learning how to live in a harsh, isolated, Mars-like environment.

Inspired once again by the desert's starry skies, Turnshek became a vocal dark-sky advocate when she returned to Pittsburgh. But she struggled to be heard. Lighting professionals, in her experience, have “zero” idea light pollution is even a research field. “We’re not even talking in the same units,” she says, pointing to Pérez Vega’s study. “There’s no overlap.”

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Earlier this year, Pittsburgh was slated to begin work on a [streetlight upgrade](#). But Turnshek says the process has been opaque. An earlier description of the project said the city intended to add 15,000 new LEDs, something that Turnshek worried would lead to over-illumination.

The latest city estimate is that 3,000 to 15,000 new LED lights will be needed, says Angie Martinez, a senior manager in Pittsburgh’s Department of Mobility and Infrastructure. But the first task for the winning consultant will be a citywide streetlight inventory that addresses the current state of individual streetlights, as well as their overall distribution. “The challenge of taking on a project of this magnitude is that it just gets really complex,” Martinez says. “We can’t just assume that every single light in the city of Pittsburgh is in the most optimal location.” It’s possible, she says, that there may end up being fewer total streetlights.



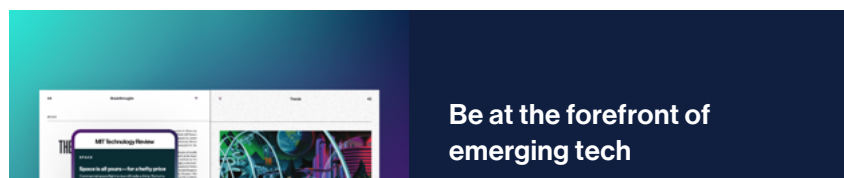


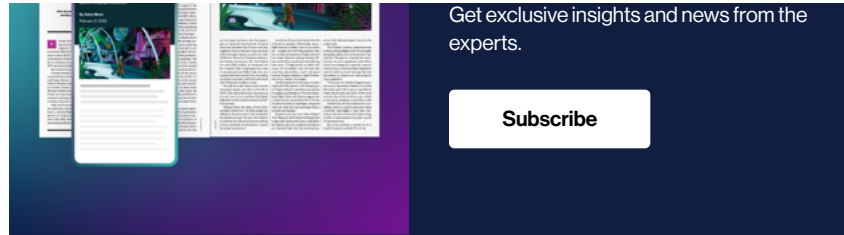
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NASA

Specifications in the current proposal provide a starting point for planning, including a color temperature cutoff of 3,000 K in line with Pittsburgh’s dark-sky ordinance, which passed last fall. However, Martinez says that is the maximum, and as they look for consultants, they’ll be taking into account which ones show dark-sky expertise. The city is also considering—budget and infrastructure permitting—a “network lighting management system,” a kind of “smart” lighting that would allow them to control lighting levels and know when there is an outage.

Martinez says there will be citywide engagement and updates on the status as critical milestones are reached. “We’re in the evaluation period right now,” she says, adding that the next milestone is authorization of a new contract. She acknowledges there is some “passionate interest in street lighting,” and that she too is anxious to see the project come to fruition: “Just because things seem to go quiet doesn’t mean work is not being done.”





While they aren't meeting with light pollution experts right now, Martinez says the ones they met with during the last proposal round—Stephen Quick and Diane Turnshek of CMU— were “instrumental” in adopting the dark-sky ordinance.

In recent months, Zielinska-Dabkowska says, her “baby” has been the first Responsible Outdoor Light at Night Conference, an international gathering of more than 300 lighting professionals and light pollution researchers held virtually in May. Barentine was among the speakers. “It’s a sign that all of this is really coming along, both as a research subject but also something that attracts the interest of practitioners in outdoor lighting,” he says of the conference.

There is more work to be done, though. The IDA recently released a report summarizing the current state of light pollution research. The [18-page report](#) includes a list of knowledge gaps to be addressed in several areas, including the overall effectiveness of government policies on light pollution. Another is how much light pollution comes from sources other than city streetlights, which a 2020 study found accounted for only 13% of Tucson’s light pollution. It is not clear what makes up the rest, but Barentine suspects the next biggest source in the US and Europe is commercial lighting, such as flashy outdoor LED signs and parking lot lighting.

Working with companies to reduce light emissions can be challenging, says Clayton Trevillyan, Tucson’s chief building officer. “If there is a source of light inside the building, technically it’s not regulated by the outdoor lighting code, even if it is emitting light outside,” Trevillyan says. In some cases, he says, in order to get around the city’s restrictions, businesses have suspended illuminated signs inside buildings but aimed them outside.

Light pollution experts generally say there is no substantial evidence that more light amounts to greater safety.

For cities trying to implement a lighting ordinance, Trevillyan says, the biggest roadblocks they’ll face are “irrelevant” arguments, specifically claims that reducing the brightness of outdoor lighting will cut down on advertising revenue and make the city more vulnerable to crime. The key to successfully enforcing the dark-sky rules, he says, is to educate the public and refuse to give in to people seeking exceptions or exploiting loopholes.

Light pollution experts generally say there is no substantial evidence that more light amounts to greater safety. In Tucson, for example, Barentine says, neither traffic accidents nor crime appeared to increase after the city started dimming its streetlights at night and restricting outdoor lighting in 2017. Last year, researchers at the University of Pennsylvania analyzed [crime rates](#) alongside 300,000 streetlight outages over an eight-year period. They concluded there is “little evidence” of any impact on crime rates on the affected streets—in fact, perpetrators seemed to seek out better-lit adjacent streets. Barentine says there is some evidence that “strategically placed lighting” can help decrease traffic collisions. “Beyond that, things get murky pretty quickly,” he says.

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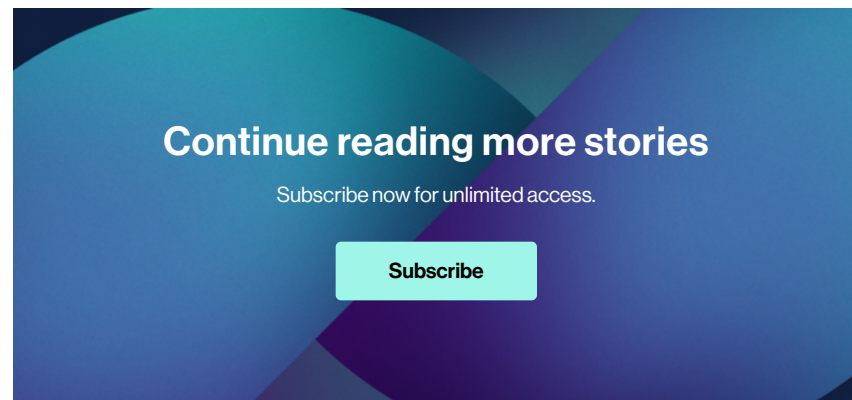
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Still, the perception of security is a factor that cities need to take seriously, Barentine says. For example, a study published in the journal [Remote Sensing](#) earlier this year found that people in various neighborhoods of Dalian, China, felt safer in consistent levels of warm light, something easily achieved with controlled LED lighting.

Many light pollution experts say LEDs simply need to be used to their full potential to avoid over-illuminating the skies. Responsible lighting doesn't seem to disadvantage anyone, but there's a mysticism about the night to overcome, Barentine says: “At the end of the day, there's a real, entrenched human fear of the dark.”

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