COLOR KINETICS

Color Science

Color science for professional LED lighting

a Signify brand

A new look at the science (and art) behind professional lighting

Color science serves as an underlying technical foundation for the entire lighting industry. It establishes a consistent way of thinking about light—how it is created, controlled, and delivered in real-world implementations. A core understanding of the science of color is critical to lighting professionals, who must be able to specify the right light—color, technology, luminaire, and more—clearly and accurately. Only then can they achieve their unique vision, whether designing lighting for a home or an iconic architectural gem.

Photography: Themorningglory | Dreamstime.com

The impact of LED lighting on color science

Our understanding of how color is perceived and measured has changed over time, based on new discoveries, new color models, and evolving light sources.

As with any disruptive digital technology, the introduction and market dominance of LED lighting renders many of the old ways of thinking about color obsolete. It also introduces extraordinary new capabilities, exciting opportunities, and new applications that were unthinkable, unaffordable, or impossible just a decade ago.

But the move to LED technology also creates confusion. Lighting professionals now have to deal with new underlying approaches to color that go beyond the familiar RGB—including RGBA, RGBW, and other multi-channel luminaires. They have to stay in sync with evolving standards. And they have to choose from a broad array of system components—including luminaires, controllers, and sensors.

As a visionary that helped lead the LED lighting revolution, Color Kinetics has a unique perspective on color science and deep knowledge of all aspects of lighting. We created **Color Science** to provide lighting professionals of all types with a brief, easy-to-read guide that delivers:

- an overview of core color science concepts
- an exploration of how color science is changing in the LED era
- an overview of Color Kinetics technologies that maximize performance and consistency
- general guidance for specific lighting scenarios

Traditional Color Science

How is color perceived and measured? Man-made light is created for humans to perceive, appreciate, and benefit from—at home, work, and in public spaces. How we interpret and understand color involves the human eye and brain, which translate light into color perception. Light receptors within our eyes transmit messages to the brain, which produces the traditional, familiar sensations of color. That's the simple description—the more detailed version is even more remarkable.

Why is color so complicated?

Color is not inherent in objects—our eyes only perceive color in reflected light. This fact reveals some of the core complications of color and light, since light will vary depending on the surface that reflects it. And our physical perception and interpretation of light varies from person to person. In short, perception of light and color are subjective, not absolute.

How is color perceived?

A full exploration of the complicated (and truly amazing) biological origins of color perception is beyond the scope of this brief guide. But these facts are important to know:

- Since people have different percentages of red, green, and blue cones, they may perceive color—and differentiate hue—slightly differently. Since color perception is, ultimately, a construct of the brain, the signals to the brain will vary, making it impossible to compare color images that different people see.
- Cultural differences and personal preferences affect color perception.
- Some people (8% male, 1% female) experience some form of color perception impairment.[1]
- Blue-heavy white light sources have a higher perceived brightness,
- The reflectance of the object (e.g., a wall) also impacts color perception, since it affects the amount of light/color that actually reaches the eyes, receptors.
- A MacAdam ellipse is the term used to describe the point at which a color difference becomes just perceptible to the average person viewing in a laboratory setting.
- At very low light levels, people cannot perceive any color—only black and white, a phenomenon known as scotopic vision.
- Color light has a significant effect on the human sleep/wake cycle.
- Perception of light changes as the eye ages, creating the need for light sources to change and adapt to accommodate aging, as well as personal preferences.
- Color synesthesia is a condition where a person perceives letters or numbers as inherently colored. Or chromesthesia, where sounds can trigger the perception of color.

Color preference

Researchers have been exploring color preference to identify why people tend to prefer certain lighting sources and colors. As it turns out, many people tend to prefer lighting sources that have a larger gamut in the red area, causing slight oversaturation in the red range vs. daylight. Does this mean that lighting designers should specify more red? Ultimately, that's a personal decision, one that weighs inherently subjective color preferences vs. staying realistic (e.g., close to daylight)—without distorting any individual color rendering.

1. National Eye Institute (NEI), Facts About Color Blindness, February, 2015.

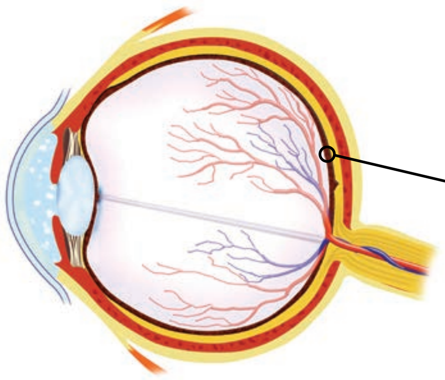
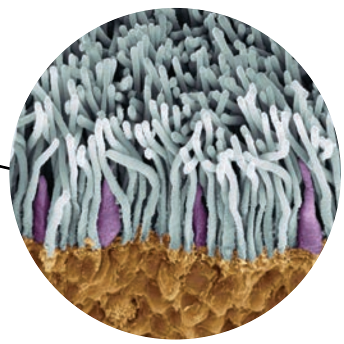


Illustration: Mkkans | Dreamstime.com



850x scanning electron micrograph (SEM) of rods (gray) and cones (purple). Color added for clarity.

Photography: Steve Gschmeissner

Rods and cones comprise the key types of photoreceptor cells in the retina of the eye. **Rod cells** function in less intense light. Critical to peripheral vision and night vision, rods are concentrated at the outer edges of the retina. There are more than 90 million rod cells in the human eye. **Cone cells** are responsible for color vision and function best in relatively bright light. There are about six to seven million cones, concentrated towards the macula of the eye.

How is color measured?

When the world was lit only by the sun, there was no real need to measure or quantify color. Light was simply light and colors were perceived by the world in a similar manner, though with the inherent variations created by perception and preference. With the advent of electric light sources (from incandescent to fluorescent to LED) came the need to quantify and accurately measure that light output[1] —and to compare different light sources.

Here are just some of the ways that light is measured via scientific quantification:

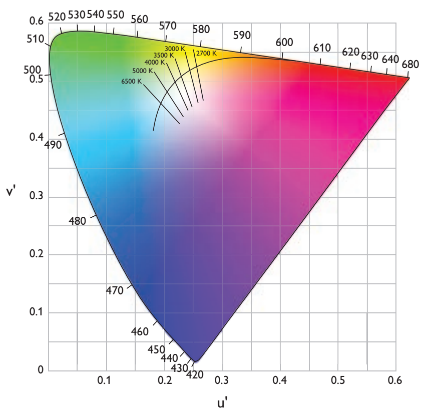
Lumen output: A traditional form of measurement

The specification most commonly used for evaluating and comparing the performance of conventional lighting is lumen output. However, complete and accurate definitions of lumens and related terms are often technical and complex—and misunderstood. Lumen measurements should not be the only measurement considered when comparing light sources.

Correlated Color Temperature (CCT): A fundamental representation of white light

The CIE[2] 1960 color space shows a range of color temperatures, measured in degrees K (Kelvin) along the black-body curve, from red to orange to yellow to white to blue. This progression is similar to the way a piece of iron changes color when heated in a blacksmith's forge.[3]

CCT provides a basis for identifying the quality of light by assigning a color temperature to that light. This approach works well with incandescent bulbs, which use a filament that is heated until it emits light—so the temperature of the filament is also the color temperature of the light. However, CCT doesn't take into account human biology and perception of light. It simply compares the color of heated tungsten to the color appearance of a light source—making it functionally obsolete in an LED context.



1 **Light output** is the informal term for how much light a luminaire produces. The more technical term for data describing the visible light produced by a light source is **photometrics.**

2 International Commission of Illumination, known as the **CIE** from its French title, the Commission Internatonale de l'Eclairage, an organization "devoted to worldwide cooperation and exchange of information on all matters relating to the science and art of light and lighting, color and vision, and image technology."

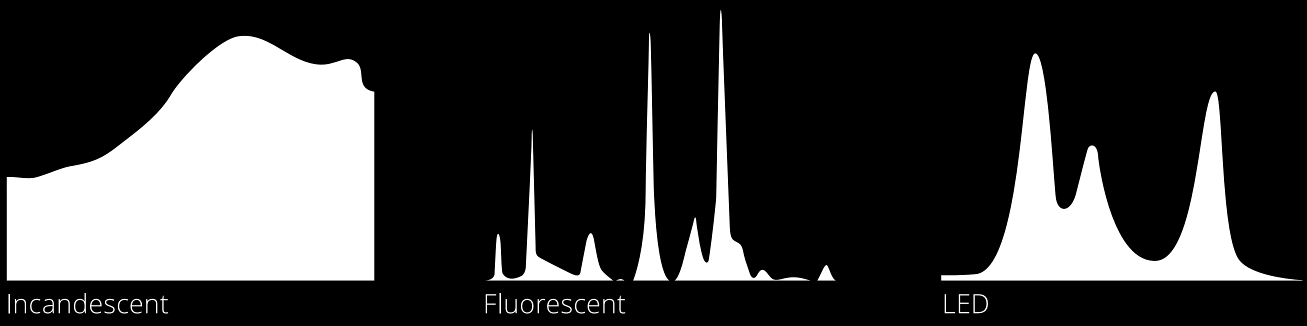
3 In fact, the **black body** is a theoretical object that absorbs all electromagnetic radiation that falls on it. Because it reflects no light, it appears black. And though no perfect black bodies exist, certain metals offer approximations.

Color-Rendering Index (CRI): How well a light source renders colors

Another key traditional measure of light and color is the color rendering index (again, devised by CIE), which measures the ability of a light source to reproduce the colors of standardized color samples—designated R1 to R8, with R9 (a saturated deep red color) often added. The color rendering score rates the faithfulness to the reference source—with a CRI of 100 being the highest fidelity compared to the reference source. For example, incandescent light sources have a CRI rating of 100. And color rendering under sunlight changes based on the time of day and weather conditions.

As with other traditional color measurement methods, CRI presents problematic issues when characterizing LED sources. For example, CRI cannot effectively predict the color quality of white-light LEDs. And different sources with the same CRI value render colors very differently.

For example, consider spectral power distribution. The three curves below show wavelength content of three types of light—incandescent, fluorescent, and LED. While all three types of light create the same hue of white on a white wall, colored objects will render quite differently under each. CRI attempts to quantify source color rendering differences.



Understanding the foundation

It's helpful for today's lighting professionals to understand color perception, including the basic physiological details of how humans experience and understand color. We've highlighted some of them here, but there are many other, more detailed resources online. And a working knowledge the various methods of color measurement is also important, since these concepts are central to how light is characterized, quantified, and specified. CRI, CCT, and many more—these acronyms are part of the specialized vernacular of the lighting industry.

Color Science in the LED Era

Traditional color science created a rational way for lighting designers and others to quantify the light output and describe specific color qualities of conventional incandescent lighting sources. CCT, CRI, and other measurements served as an accurate paradigm for defining light within that context. But as we've seen, the old standards are not ideal for the LED world. The accepted standards and their associated terminology will not go away (at least immediately) but will be supplemented by other, more precise ways of quantifying color—and differentiating between different light sources.

As it often does, digital disruption (LED lighting) has inspired a parallel effort toward standardization. At some point in the future, our industry will adopt a standardized way of evaluating light source color rendition. Groundbreaking efforts, including Color Quality Scale (CQS), Gamut Area Index (GAI)—and now IES's TM-30—can be seen as important steps toward the goal of standardization. But the day-to-day reality for today's lighting professionals is that they have many alternatives available when choosing how to achieve their creative vision. Knowing these alternatives—and their particular strengths—is critical.

Lighting design is all about choices.

For lighting designers, the initial choice is between the three main varieties of light—white, color, or color-changing effects. This choice then leads to a second level of decisions—what type of light source to use to create that light. Before choosing a specific luminaire, form factor, or vendor, lighting professionals face a core decision about what type of light source will work best for their application.

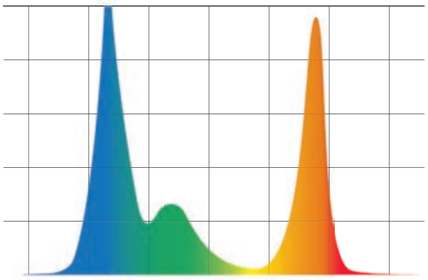
RGB, and beyond

For want of a better word, there are multiple **approaches** to color available now—which, ultimately, is good news for lighting professionals, who can tailor their choice to the specific needs of an application. In the past, designers had to use what was available, which meant RGB luminaires. But new options also trigger the need for careful decision making—backed by an understanding of the options.

Options from **Color Kinetics** include:

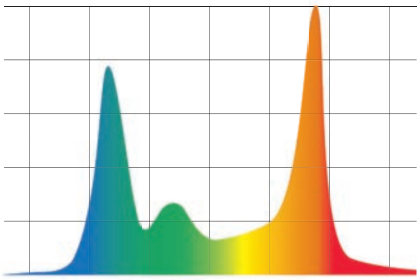
RGB

RGB luminaires were the prevailing standard in color-changing installations for many years. Now luminaires combining red, green, and blue LEDs remain an option that allows a workable three-channel approach to creating color for a defined range of applications. It remains the default option for many luminaires, and gives lighting professionals a simple way to match legacy implementations—allowing for incremental addition vs. replacing all of the current luminaires.



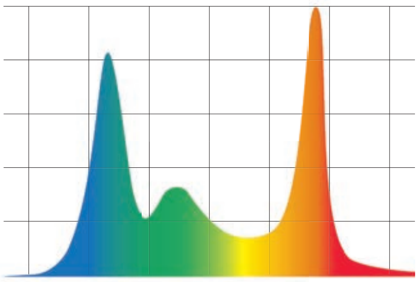
RGBA

Luminaires with red, green, blue, and amber LEDs expand the available range of colors to include warmer tones such as rich gold, yellow, and orange shades. The fourth channel enables creation of amber, a color that is impossible to achieve via color mixing of RGB channels alone. Whites will appear as the same color on a white surface, no matter what colors created it. But when viewing colored objects under the source, the differences become clear.



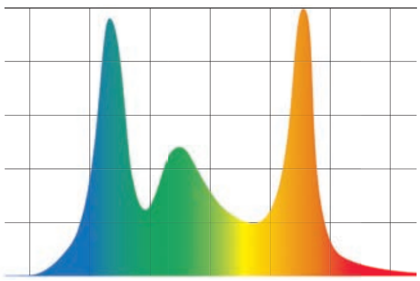
RGBW

Adding a separate white LED creates better-quality whites compared to RGB, but lacks the ability to make amber tones. It also enables saturated reds, and a full range of pastels—as well as creation of white and diverse color light in the same luminaire.



IntelliHue

Our advanced approach to color control and mixing produces an enhanced spectrum of precisely controllable light, including high-quality white, millions of saturated colors, and pastels, all in the same precisely controllable luminaire. By combining carefully selected channels of LED light sources, IntelliHue enables high-quality dynamic color and white light from the same luminaire.



As we'll see in the next section, these approaches give lighting specifiers options that can match the specific demands of their application—and achieve their creative visions.

Specific lighting scenarios

Turning Science into Reality

How to choose the right type of luminaire to achieve your creative vision

The expanding range of implementations now possible with LED lighting creates challenges and opportunities for today's lighting professionals. What type of lighting is right for a specific job? Will it meet the expectations for color, brightness, and consistency?

Here are just a few real-world scenarios—indoor and outdoor—and our recommendations for the suggested type of Color Kinetics luminaire.

Photography: Roland Nagy

Lighting a wood wall with white and color light

The challenge:
To achieve a natural-looking wood surface, as well as combining white and color-changing effects.

The recommendation:
IntelliHue luminaires

Because:
IntelliHue excels at combining high-quality white and color light in the same luminaire.

Photography: Photology1971

Lighting a white wall with color-changing light only

The challenge:
To provide even illumination with saturated colors, as well as complete mixing of the source on the wall.

The recommendation:
RGB luminaires

Because:
If no white light is needed, standard RGB lighting will suffice.


Photography: Redshift Photography

Lighting a white wall with color-changing light part of the time, and white light at other times

The challenge:
To address the issues raised by a white wall (which will reflect light and contribute to general illumination), to provide the highest output with high-quality white light, and to provide saturated color effects.

The recommendation:
IntelliHue luminaires

Because:
Since high-quality white light is needed, IntellHue is a better option than RGB.

Photography: Trevor Palin

Lighting up a white wall—and adding fire effects or a specific orange/yellow brand color

The challenge:
To achieve natural, realistic fire effects, and to create the desired atmosphere

The recommendation:
RGBA luminaires

Because:
Fire effects and orange/yellow tones are exactly the colors where RGBA excels.

Photography: Trevor Palin

Lighting a pink marble building that has to match daylight viewing conditions

The challenge:
To make viewing in daylight or at night indistinguishable.

The recommendation:
IntelliHue luminaires

Because:
IntelliHue's tunable white light can most closely match daylight's rendering of colors, while most other sources do not have the same spectral content (and color rendering) as daylight.

Photography: Gary Blakeley

Lighting cement or concrete with white and color light

The challenge:
To provide even illumination and the highest output on white surfaces, to provide high-output saturated effects, and to streamline programming for a large installation.

The recommendation:
IntelliHue luminaires

Because:
Since it integrates white and color, IntelliHue will provide exceptional results with light of both types.

Photography: Eduard Hueber

Lighting a cement structure with fire effects or a specific orange color

The challenge:
To bring a natural and realistic look to fire effects, and to add amber colors that no other luminaire is capable of generating.

The recommendation:
RGBA luminaires

Because:
RGBA provides great fire effects and orange/yellow tones, outdoors or indoors.

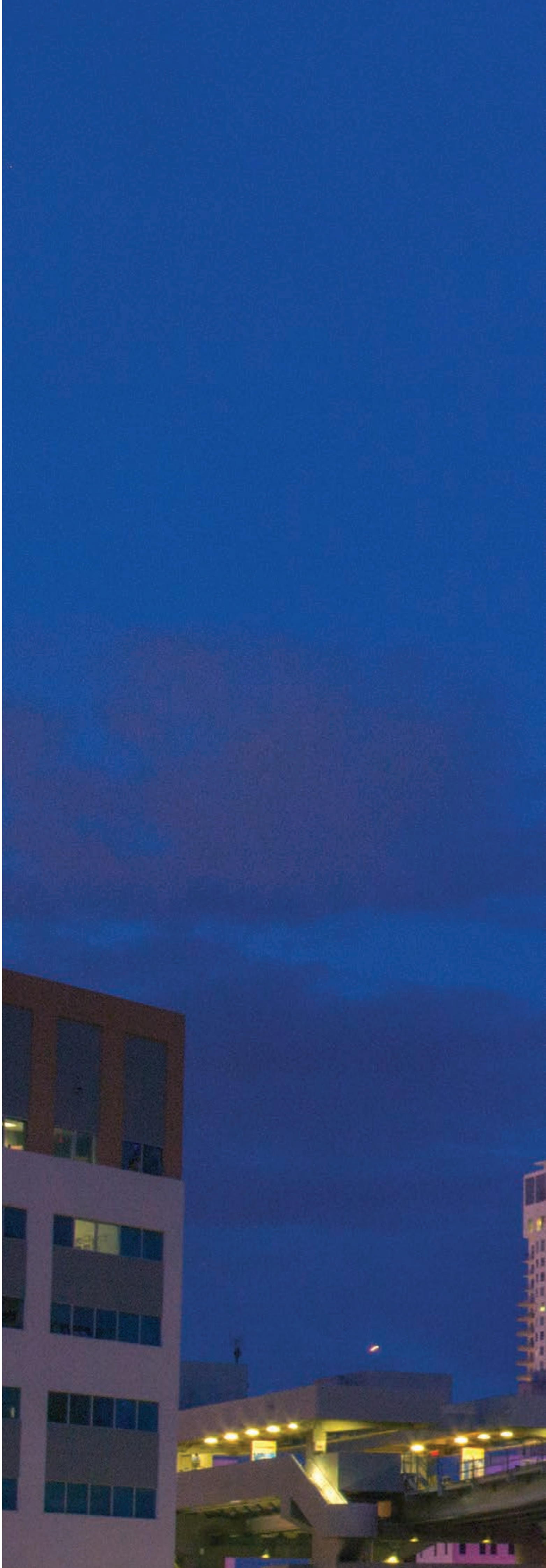
Photography: Joby Benoit

Lighting a metal structure with only color-changing effects

The challenge:
To achieve high output and high uniformity, to speed commissioning.

The recommendation:
RGB luminaires

Because:
If only color-changing light is needed, standard RGB lighting will work well in this outdoor application.



Photography: New York Focus

What matters in professional lighting?

Our series of guides explores key topics in professional lighting—color science, light, quality, optics, and more.

It’s part of our commitment to passing on our deep technical knowledge and decades of expertise to help you achieve your vision.

Color Science

Color science serves as an underlying technical foundation for the entire lighting industry. It establishes a consistent way of thinking about light—how it is created, controlled, and delivered in real-world implementations. A core understanding of the science of color is critical to lighting professionals, who must be able to specify the right light—color, technology, luminaire, and more—clearly and accurately.

Light Matters

Traditional methods of evaluating light focused on lumen output, which was defined by the output capabilities of a light source, such as an incandescent lamp. The advent of LED lighting changed all that, since lumens were no longer the best measurement of a luminaire's capabilities. We explore some of the new ways lighting can be evaluated in the age of LEDs.

Quality Matters

What does quality mean to you?

The answer depends on what you do within the lighting industry. Quality has different meanings for building and site owners/managers, lighting designers, and installers.

We delve into the needs of each of these groups as we take a holistic approach to quality, one that begins and ends with the customer.

Optics Matter

It's safe to say that few lighting designers, building owners/managers, or other lighting professionals have ever seen the optical system housed inside an LED luminaire. But the optical system, or optics, play a vital, but often hidden role in performance, efficiency, and more. The right optics within a luminaire make a big difference in the final results—for both interior and exterior applications.

Control Matters

Controlling light used to be simple. It was on or off.

Then came dimming, which raised or lowered the intensity of light. The invention of LED luminaires added another dimension, color—and new capabilities, such as the digitalization of lighting, including the ability to zone dimming and control the spectral content of color-changing light.

Sustainability Matters

By raising efficiency to new heights, our solutions help our customers do more with less energy. And since we design our solutions for long, useful lives, they create less waste. So, our customers get great results, year after year. All with less impact on the planet.

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