LUMA

LIGHT ON WASTE

2020-2021 RESEARCH GRANT

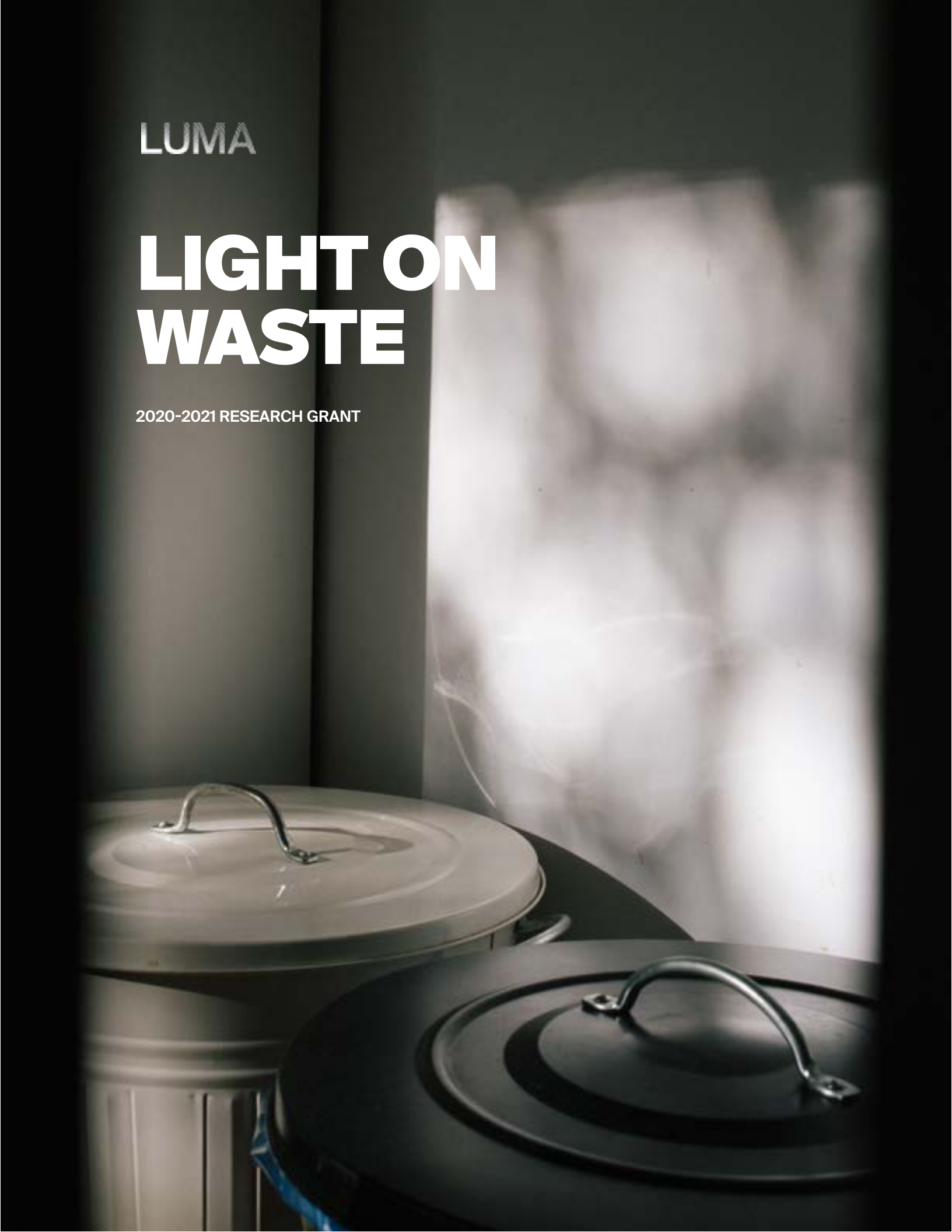


Table of Contents

Introduction

2020 GRANT SUBMISSION

As other industries in Construction & Design lead the charge in developing sustainable materials and processes, the lighting industry still has work to do.

Demanding *accountability* for the sustainable life cycle of luminaires.

At 25-80% more efficient than traditional lighting sources, LED lighting created a seismic shift in sustainable design. However, data on embodied energy, carbon impact, and waste stream is extremely limited. As a result, light fixture life cycle data and waste reduction processes are typically not required to meet building sustainability standards, code or policy.

As research shows, the embodied emissions of LED light fixtures have a significant impact on the overall carbon emissions of a building. A key challenge is the sourcing and production of typical light fixture components. Many standard elements, from LED chips to typical heatsinks, are comprised of finite resources. Additionally, material extraction is extremely energy intensive, and is often sourced in politically and economically unstable countries. Due to the unique nature of the materials, it can be challenging to recycle or re-use components, resulting in significant landfill waste.

It's time to close the finite resource loop. Light on Waste's goal is to lead the industry in creating the framework for a modular, up-cycled, and zero-waste LED light fixture.

THE TEAM

Michael Kim
SPONSOR

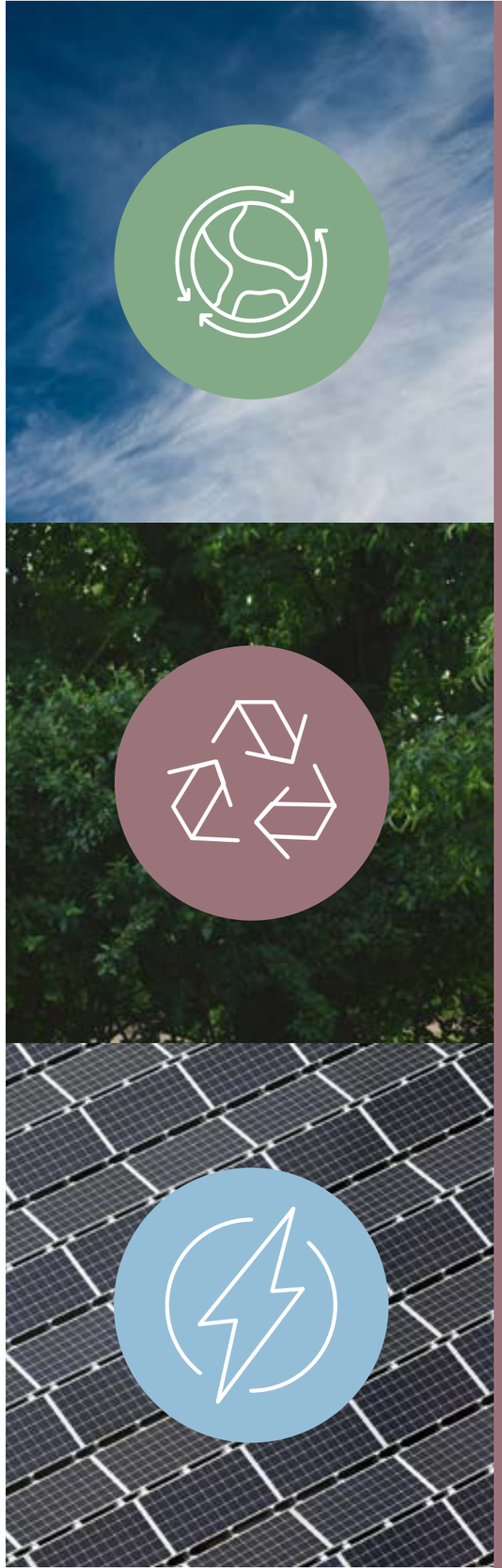
Brock Soderberg
ADVISOR

Christine Cornelius
HOUSING MATERIALS

Lauren Wilcox
WASTE STREAM + PACKAGING

Sara Duffy
ELECTRONICS

Colin Johnstone
SUSTAINABILITY RESOURCES



Initial Concept

2020 GRANT SUBMISSION

We strive to eliminate landfill waste and minimize our carbon footprint in all aspects of our lives. Our team cares deeply about the impact of our actions, from the products we specify to what we purchase and bring into our homes.

As designers, we want the industry we support to reflect both our individual missions and the mission of PAE and Luma. As we looked at the carbon impacts of lighting manufacturing, a seed was planted: how can our collective decisions create a positive impact on our planet?

By developing a product with interchangeable, sustainably sourced components, we will create a new framework for resilient luminaires.

As stewards of the planet, it is our responsibility to create a better future for all.

SECTION 1

Why Now?

Why Now?

THE STATE OF SUSTAINABLE BUILDING

Buildings construction is one of the heaviest consumers of natural resources and a high producer of carbon emissions.

In 2020, more than 11,000 scientists came together to declare a state of climate emergency due to troubling climate trends and a surge of natural disasters.[1] Globally, CO2 and methane levels are higher than they have been in 3.6 million years.[2] The fundamental root of the climate crisis has been attributed to the increasing overexploitation of the earth and its resources.[3] With that data in mind, the need to decarbonize the construction industry becomes apparent and urgent.

Buildings have traditionally been one of the heaviest consumers of natural resources and producers of carbon emissions worldwide. Building construction and operation have been shown to account for 39% of CO2 emissions and 36% of final energy use consumption.[4] In 2018, building-related construction generated 600 million tons of demolition debris.[5]

Globally, one billion square feet of buildings are demolished and replaced with new construction each year.

The construction & design industry is at a turning point in the transition to sustainable, low-impact building materials and processes. Sustainable building is becoming more commonplace, with the majority of new global construction anticipated to be green by the end of 2028. Circularity, carbon neutrality, and human-centered design are moving from the periphery of priorities to the forefront of design process and policy.

Light on Waste looks at the current state of the lighting industry by addressing five key components: policy and building standards, product materials, electronic components, shipping and packaging, and end-of-life treatment. This research will provide a framework to re-evaluate typical processes and move towards a decarbonized industry.

Key Components

A combination of local policy, construction regulations, and building sustainability standards (LEED, WELL, Living Building Certification [LBC]) provide guidelines for how a building can meet sustainability targets. Life Cycle Analysis (LCA) and Environmental Product Declarations (EPD) function as a starting point to increase the transparency and overall understanding of building material processes and products. As sustainability requirements have increased for other materials such as carpet and flooring, lighting and electronics receive allowances on certain components and have fewer requirements to meet sustainability criteria. With a precedent set for other materials, green building standards and codes can be re-evaluated to incorporate lighting and begin to address the missing pieces.

As technology in material science improves, the opportunities for new and alternative luminaire materials increases. Developments in sustainable sourcing, biomaterials, and material reuse all contribute to new opportunities to reduce the embodied emissions of light fixtures. Components that are typical in LED lighting, such as heat sinks and optical lenses, can be re-evaluated with an eye toward sustainability.

With a long-estimated lifespan and specific material requirements, the approach to LED and electronic carbon neutrality requires a more nuanced approach. Hazardous material restrictions, such as Restriction of Hazardous Substances (RoHS), lead the path in European construction guidelines, and can be applied globally for a more holistic approach. Modular systems, which allow for components to be interchanged as needed, allows for less waste and more flexibility for future building modifications. Recycling, reuse, and lighting-as-a-service (LaaS) are another way to address electronic waste and minimize the use of finite resources.

Shipping and packaging become equally as important when addressing the full life cycle of a luminaire. As shipping materials and transport are unavoidable, a sustainable approach requires a reimagining of how processes are defined, evaluated, and prioritized. Consumer power is shifting towards online commerce, which has resulted in an overall increase in shipping throughout the globe.[9] Due to this, the time is right to shift the paradigm and push forward new technologies. Alternative packaging materials, localized material production, and energy efficient transportation all contribute to reducing the overall carbon impact of a light fixture.

Lastly, the end-of-life treatment is essential to the overall carbon impact of a fixture. Both the function and ease of recyclability and reuse needs to be evaluated and established. Systems should be put in place to encourage the continued use of the product or materials.

Challenges and Setbacks

From design to production, construction to demolition, these limitations have prevented the lighting industry from establishing more sustainable practices:

- Global and local policy exclusions
- Minimal requirements in sustainable building standards and guidelines
- Increased financial impacts on manufacturers and contractors
- Lack of material production and life cycle transparency
- Industry acceptance of construction demolition and waste

Next Steps

The following key points are essential to create a sustainable framework:

- Encourage economic incentives
- Establish a precedent for alternative approaches
- Focus on circularity as an essential design element
- Educate on the impact of the building industry on the environment

SECTION 2

Terms and Definitions

LIVING BUILDING CHALLENGE:

An international sustainable building certification program created in 2006 by the non-profit International Living Future Institute

Terms and Definitions

GLOSSARY

Circularity: An economic and industrial system based on the reusability of products and raw materials and the recovery of natural resources.[10]

Closed Loop: An automatic control system in which an operation, process, or mechanism is regulated by feedback.[11]

Cradle-to-Cradle: Cradle-to-cradle design is a biomimetic approach to the design of products and systems that models human industry on nature's processes, where materials are viewed as nutrients circulating in healthy, safe metabolisms.[12]

Cradle to Grave: Extending throughout one's life, from birth to death.[13]

CRI: Color Rendering Index is the measurement of light in relation to how it affects the appearance of color.[14]

Declare: A product transparency disclosure that identifies where a product comes from, what it's made of, and where it goes at the end of its life.[15]

Holistic Regeneration: A process-oriented concept that uses whole systems thinking to create resilient and equitable systems that integrate the needs of society with the integrity of nature.[16]

Human Centered Design: A framework that integrates a set of practices to understand users—their needs, constraints, contexts, behaviors, and wants.[17]

IALD (International Association of Lighting Designers): An internationally recognized organization dedicated to supporting a network of 1,500 independent lighting design professionals and which strives to set the global standard for lighting design.[18]

IES (Illuminating Engineers Society): A lighting industry organization that seeks to improve the lighted environment by bringing together those with lighting knowledge and by translating that knowledge into actions that benefit the public.[19]

LAAS (Lighting as a Service): A method of delivering a lighting retrofit project without upfront capital expenses.[20]

LEED: (Leadership in Energy and Environmental Design): A green building rating system that provides a framework for healthy, highly efficient, and cost-saving green buildings. LEED certification is a globally recognized symbol of sustainability achievement and leadership.[21]

Living Building Challenge: An international sustainable building certification program created in 2006 by the non-profit International Living Future Institute.[23]

Life Cycle Assessment (LCA): A technique to assess environmental impacts associated with all the stages of a product's life.[22]

NEC (National Electrical Code): The benchmark for safe electrical design, installation, and inspection to protect people and property from electrical hazards.[23]

NEMA (National Electrical Manufacturers Association): A Standards Developing Organization made up of business leaders, electrical experts, engineers, scientists, and technicians.[24]

Red List: The Red List represents the "worst in class" materials, chemicals, and elements known to pose serious risks to human health and the greater ecosystem.[25]

PCA (Paris Climate Agreement): International treaty on climate change that aims to keep global warming below 2 degrees Celsius.[26]

RoHS (Restriction of Hazardous Substances): EU rules restricting the use of hazardous substances in electrical and electronic equipment to protect the environment and public health.[27]

UL (Underwriters' Laboratories): A global safety science leader that provides the expertise, insights, and services necessary to solve critical business challenges, such as safety, security, and sustainability goals.[28]

WELL: A performance-based system for measuring, certifying, and monitoring features of the built environment that impact human health and wellbeing, through air, water, nourishment, light, fitness, comfort, and mind.[29]

SECTION 3

—

Sustainability Standards, Codes and Policy

Sustainability Standards, Codes and Policy

WHAT DOES SUSTAINABLE LIGHTING LOOK LIKE?

IES AND IALD DEFINE SUSTAINABLE LIGHTING DESIGN AS:

> **“Meeting the qualitative needs of the visual environment with the least impact on the natural environment.”**

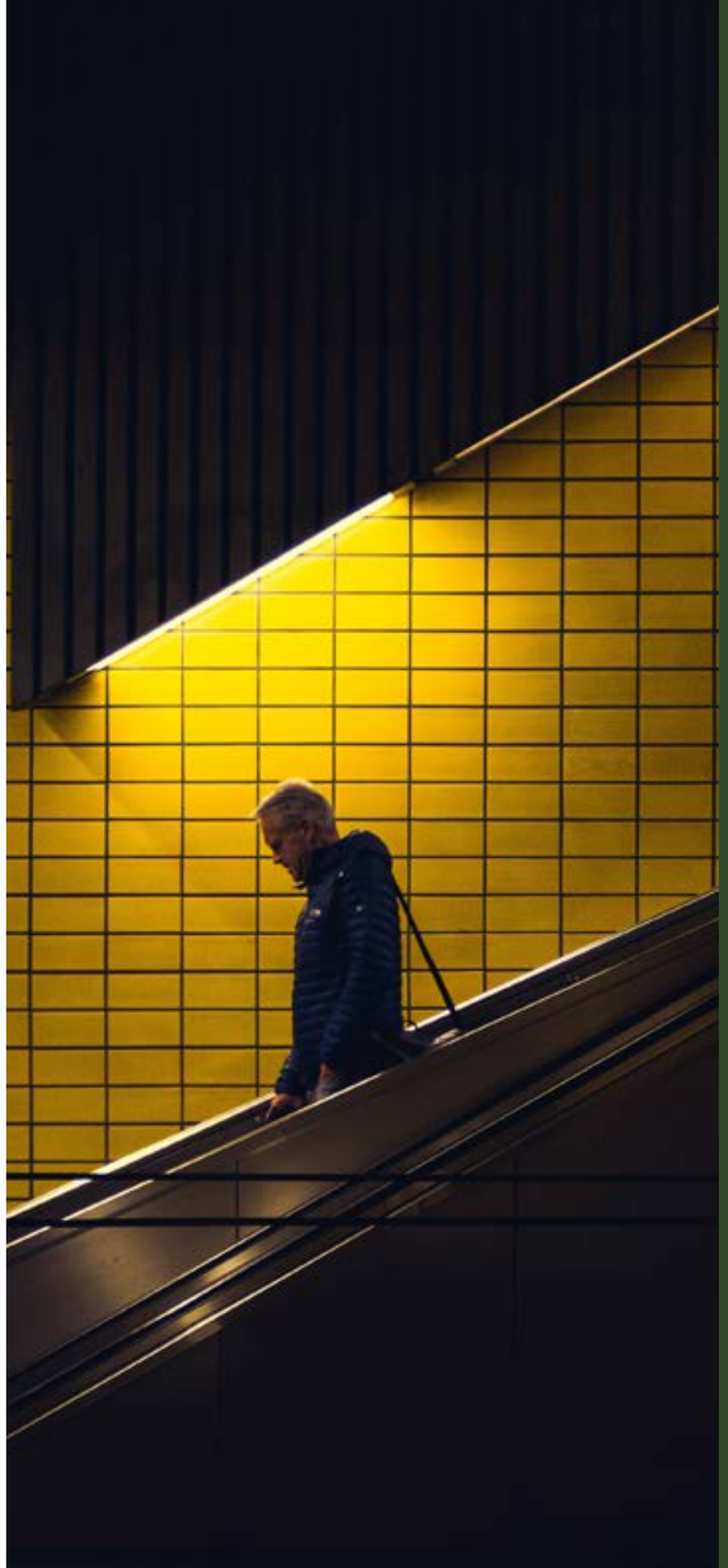
This approach links both the qualitative performance and the environmental impacts to create a sustainable lighting design; you can’t have one without the other. But how are these metrics measured as part of a holistic design approach?

Certifications and Standards

There is an increasing number of sustainability certifications and standards that can be used as a platform for inspiration and guidance. The three most recognizable sustainable building certifications are LEED, WELL, and the Living Building Challenge. At the forefront of the industry, these organizations have quantified ways in which buildings can be more sustainable.

Each certification focuses on a different aspect of sustainable design. LEED explores environmental impact, with a strong focus on operational emissions.[31] WELL encourages human centered design and includes qualifications that center on the health and physiological well-being of occupants.[32] LEED and WELL both include lighting performance guidelines, such as glare control, color rendering index (CRI), and lighting controls. The Living Building Challenge prioritizes net-positive, holistic regeneration, and includes specific building material life cycle requirements.[33] Each of these building standards require reduced energy load and encourages innovative design to meet challenging efficiency goals.

In addition to building certifications, there are also product specific certifications and product transparency documentation that can be obtained by manufacturers. Declare, an extension of the Living Building Challenge, aims for transparency and requires Red List free products. Manufacturers must document any material that comprises 0.01% of the weight of a fixture, which is a more stringent requirement than even Material



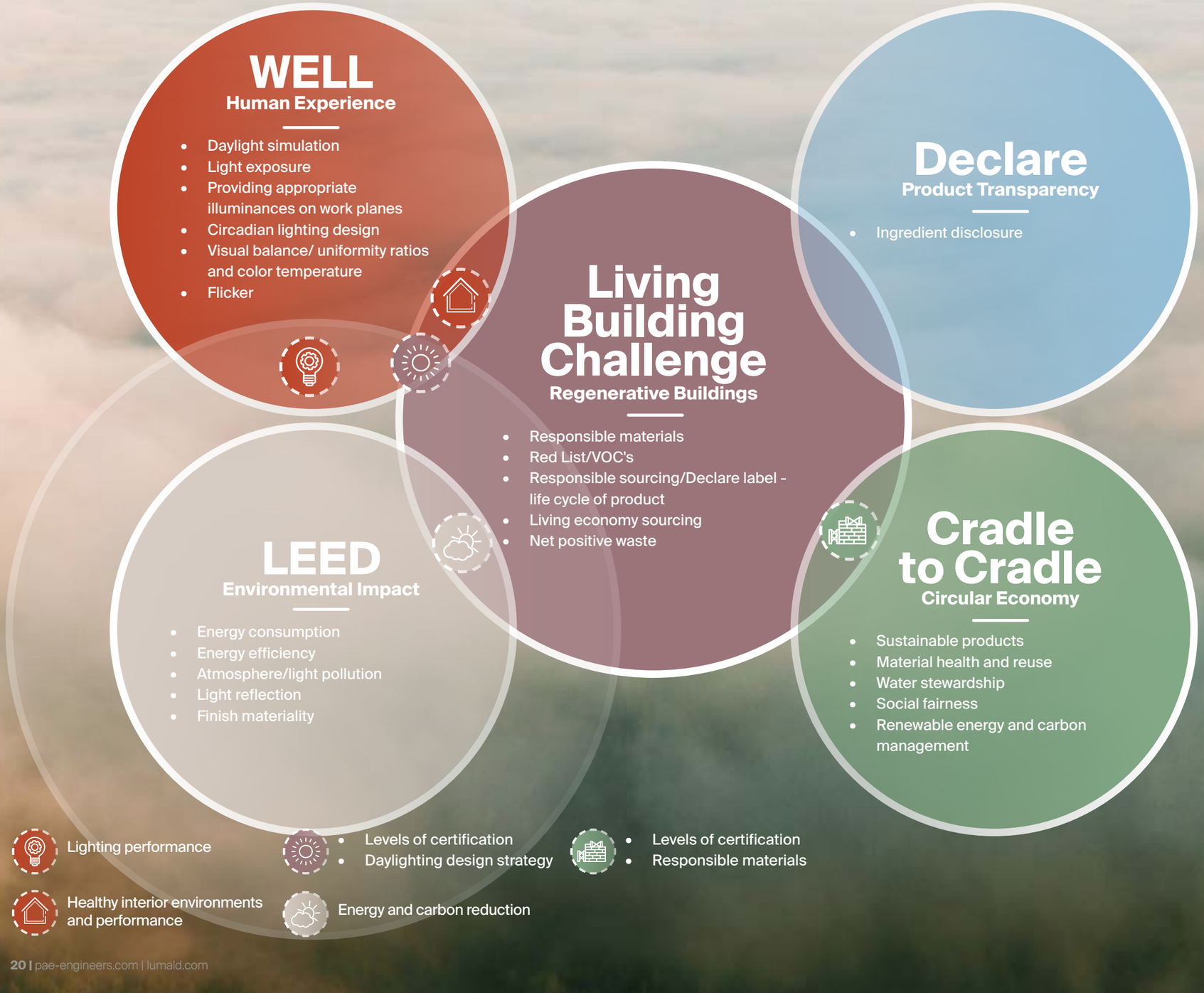
sheets.[34] A lesser-known product standard, Cradle to Cradle, pioneered the concept of circularity, and focuses on documenting the full life cycle of a product.[35] A Health Product Declaration (HPD) documents all product material that makes up at least 0.1% of the product. An HPD is purely informational and does not require any criteria to be met. It functions similarly to a nutritional label on food – it shows all material ingredients in order to be fully transparent in sourcing and content.

In addition to certifications, standards are another voluntary metric in which manufacturers or organizations can create more sustainable products and processes. The International Standards Organization, or ISO, has developed the ISO 14000 family of standards that provide criteria for environmental management in businesses and organizations. This framework helps businesses develop a holistic system of operations that put a commitment to sustainable processes at the forefront. In order to meet the standard, a business needs to provide an environmental policy, outline environmental risks and opportunities, evaluate environmental impacts of their processes, determine future objectives and execution, document operational procedures, and more.[36] Awareness and interest in these standards is growing globally - there are currently more than 300,000 certifications to ISO 14001 in 171 countries.[37]

> **There are currently more than 300,000 certifications to ISO 14001 in 171 countries.**

Figure 1.

SUSTAINABILITY CERTIFICATION COMPARISON



“This field is a co-opetition, we are all playing in the same field.”

- Richard Garrett | ILFI

International Living Future Institute

Though each program incorporates unique and effective sustainability measures, no single building or product certification encompasses the full sustainable impact of producing a light fixture. For example, the Declare label includes Red List allowances due to limitations in the material economy, such as certain elements that are required for LED diodes.[38] Additionally, the certifications are often cost and time intensive, which is one of the key detractors from program participation.[63] An increasing number of owners and clients are choosing to design to meet sustainable criteria such as LEED, but not pursuing formal certification to avoid the additional cost. Similarly, some manufacturers will provide a “manufacturers letter” detailing their materials and processes as an alternative to pursing a product certification, such as an HPD or Declare label.[39]

The more complex the product or process, the more challenging it is to meet the criteria.

> **" The circular economy plays a definitive role here. It must expand if we are to reduce emissions across sectors as it is an essential component to achieving climate neutrality."**
>
> **- Patricia Espinosa**
> UN Climate Change Executive Secretary

Policies and Code

Regional, national, and international policies are extremely effective at realigning processes to achieve more sustainable goals. Unlike building or product standards, in which participation is elective, policies are typically mandated by elected governing bodies. Standards are often used as a starting point to establish policies or code requirements, as they provide clear guideliness from an established, external organization.

Sustainably focused policies require a governing body that is committed to environmental action. A well known policy in the United States is the Energy Independence and Security Act of 2007, which required a 25% greater efficiency in typical lamps. Additional regulation that expanded the existing law was established in 2017, which effectively eliminated the use of incandescent lamps for household or commercial use, as they are innately high energy consumers. However, in 2019, these new regulations were overturned by the Department of Energy under the Trump administration. This change shows how a nation's policies can easily change due to a shift in administration goals.

With a new administration, the United States is again realigning policy to address climate change and re-evaluate energy use as a nation. The Biden administration has introduced the “Build Back Better” infrastructure initative, which focuses on building a modern, sustainable infrastructure and an equitable clean energy future. Key carbon reduction initiatives include achieving a carbon pollution-free power sector by 2035, making dramatic investments in energy efficiency in buildings, and promoting environmental justice and equitable economy opportunity.[40] Building specific goals include completing 4 million energy efficient retrofits and building 1.5 million new affordable homes.

In addition to national policy, global initiatives bring climate issues to greater awareness and encourage holistic change to existing systems. The Paris Agreement is a landmark in the multilateral climate change process because, for the first time, a binding agreement brings all nations into a common cause to undertake ambitious efforts to combat climate change and adapt to its effects. With the Paris Agreement, countries established an enhanced transparency framework (ETF). Under ETF, starting in 2024, countries will report transparently on actions taken and progress made in climate change mitigation, adaptation measures and support provided or received. It also provides for international procedures for the review of the submitted reports.[41] Shifting to a circular economy is essential to achieving Paris Agreement goals.[42]

Policies are a starting point for change, and can be viewed as a principal of action and a guidepost for decision making. Building code requirements take that a step further, and are mandated for construction approval. An example of an effective, sustainable focused building code is California’s Title 24, which is designed to minimize energy consumption in both new construction and existing buildings.[43] The energy code is more stringent than the International Building Code, and is viewed as one of the most sustinable in the United States. The code is updated every three years, which results in further energy savings and a continuous improvement process. Each update is significant – the change between 2016 and 2019 codes are estimated to reduce residential energy use by about 53%, and reduce greenhouse gas emissions by 700,000 metric tons over three years.[44] For lighting specifically, the 2019 code reduced the allowed lighting power density by 29-37% over the 2016 code.[45]

In addition to strict lighting power density, Title 24 includes specific component and material limitations and energy saving control requirements.[46] This energy efficient code provides a foundation for other states, businesses, or building owners to see that code can make a significant impact on overall building emissions.

With a greater global understanding of the human impact on our climate crisis, further policies and code will be developed and implemented to help combat the challenge at hand. It is necessary to educate and bring attention to current omissions in the building industry to ensure that future policies have a greater impact.

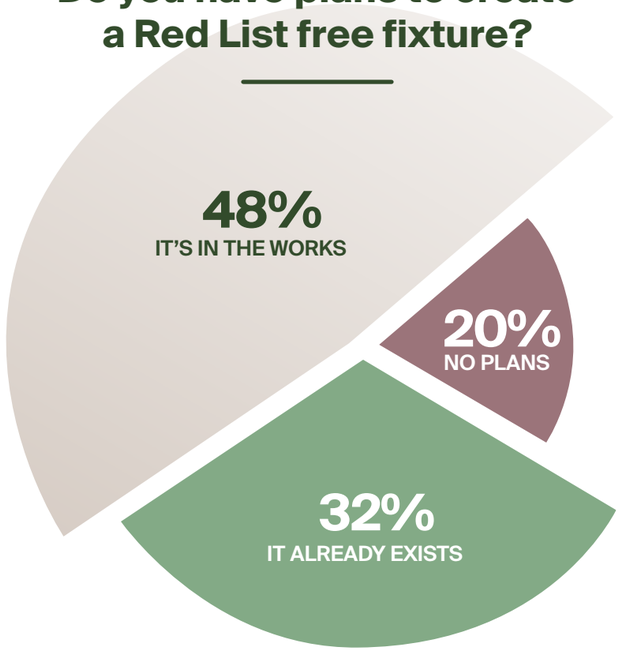
SECTION 3

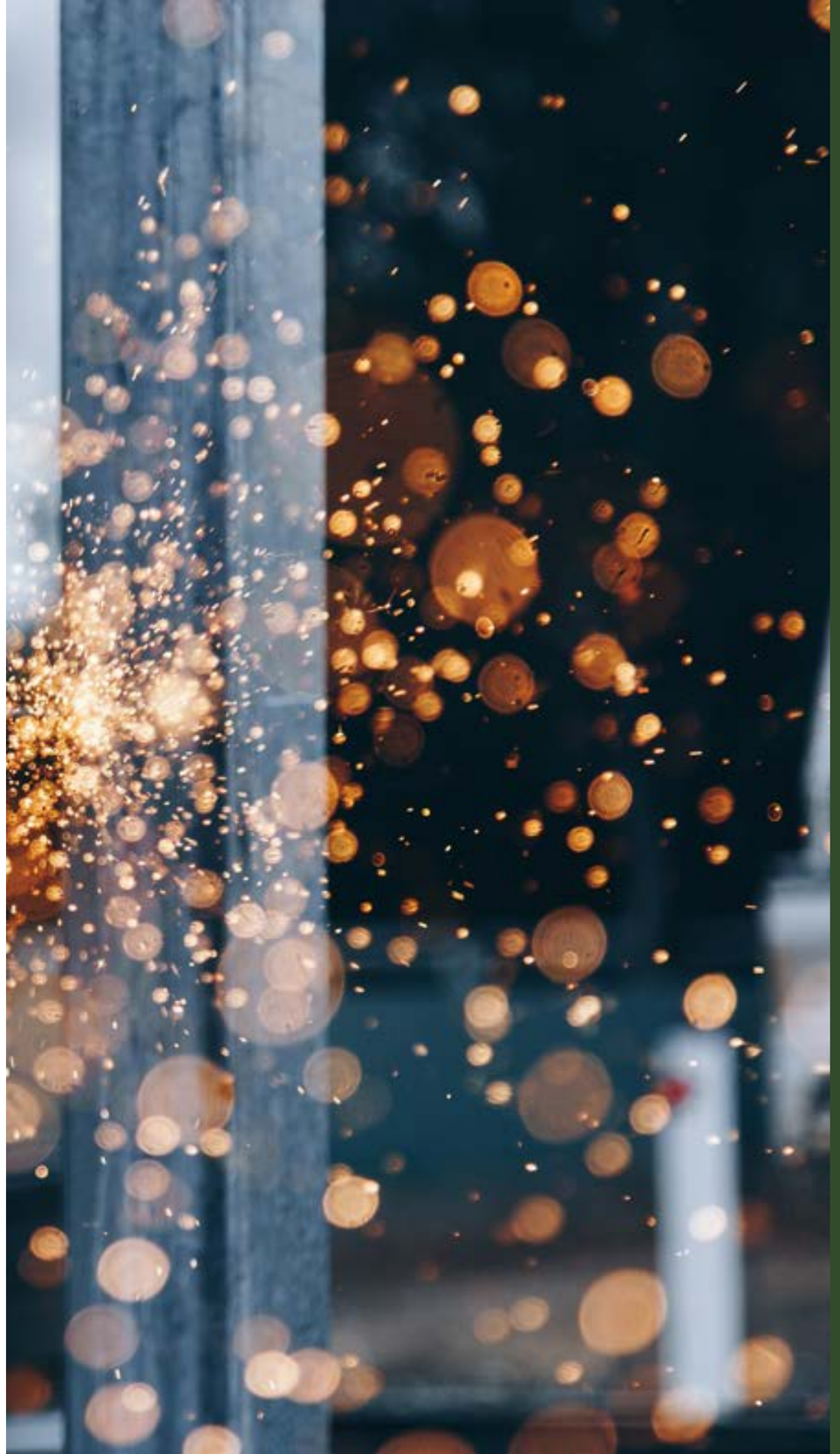
Where do Lighting Manufactures Fall on the Sustainability Spectrum?

How do lighting manufactures navigate the best path towards sustainable lighting? The Light on Waste team conducted a survey and a series of interviews to see where manufacturers fell on the sustainable spectrum. The survey includes questions on the internal practices of sustainability within the business' employees and facilities, the sustainable impact of their products, and their goals looking forward. With hopes of learning more about current and future practices, this survey examines the value of sustainability across a range of manufacturers.

In reviewing the data, manufacturers are making strides to meet the rising demand for sustainable products and practices. There is still work to be done, with about 70% of manufacturers surveyed still in the early development phase of sustainable production.

Do you have plans to create a Red List free fixture?





If any, what sustainability practices does your company incorporate in its energy usage and manufacturing processes? i.e. solar panels, grey water filtration, etc.

- **30%** Recycling
- **21%** Energy Harvesting
- **12%** Daylight Harvesting
- **12%** Solar Power
- **9%** Local Sourcing
- **9%** Products
- **6%** None

How does your company encourage sustainability practices of its employees?

SECTION 4

Housing and Hardware

SECTION 4

Housing and Hardware

THE NUTS AND BOLTS

Luminaire housing encloses and protects the light source. It typically includes a frame, lens, hardware, mounting canopy, cables, heat sink, adhesive, and applied surface finishes.

Many of these elements come from finite material sources, require energy-intensive extraction or mining, and have limited recycling options. As the pace of construction continues to grow, the selection and sourcing of materials has an increasing impact on the embodied carbon emissions of a fixture.

Key challenges to both designers and manufacturers include a lack of viable alternative materials, high cost impacts of sustainably sourcing, and minimal transparency throughout the supply chain.

This report will look at a few frequently used housing materials to evaluate their current processes and potential possibilities.

Aluminum

Aluminum can be used for the housing frame, reflector, LED heat sink, hardware and more. On a typical linear fixture with extruded aluminum housing, aluminum makes up 54% of the fixture weight.[46] It is a preferred material due to its light weight, thermal conductivity, reflectance, and efficient fabrication processes.

Aluminum manufacturing, smelting, and refinement is harmful to the environment. It is an extremely energy-intensive process and emits significant quantities of CO2 and perfluorocarbon (PFC) gases.[12,16] As a result, the aluminum industry alone is responsible for around 1% of global greenhouse gas emissions.[17,13] Each ton of aluminum recycled avoids nine tons of CO2 equivalent emissions.[47]

A primary component of aluminum processing is bauxite, an aluminum-rich ore that covers 8% of the earth's surface. Bauxite mining results in negative environmental and social consequences, such as the contamination of water and local ecosystems, the destruction of land, and the displacement of local communities.[47] Bauxite exploitation poses severe and ongoing threats to communities in West Africa, Jamaica, Australia, India, and Brazil, among others. Since the 1980's, bauxite and alumina projects have been opposed by local communities that are affected by mining.[48]

Though the excavation and processing of aluminum is tough on humanity and the environment, it can be recycled continually without losing its characteristic properties. Recycling aluminum saves about 90% of the energy it takes to make virgin aluminum.[49] If recycling rates improve, this percentage increases.[50] To lower the carbon impact, it is necessary to utilize recycled aluminum in fixture design and encourage building owners, contractors, and manufacturers to develop clear recycling processes.

Hardware

CANOPY | Aluminum

CABLES/HARDWARE | Stainless Steel

Electronics

DRIVER | Circuit Board and Polycarbonate Housing

POWER CORD | Copper and PVC

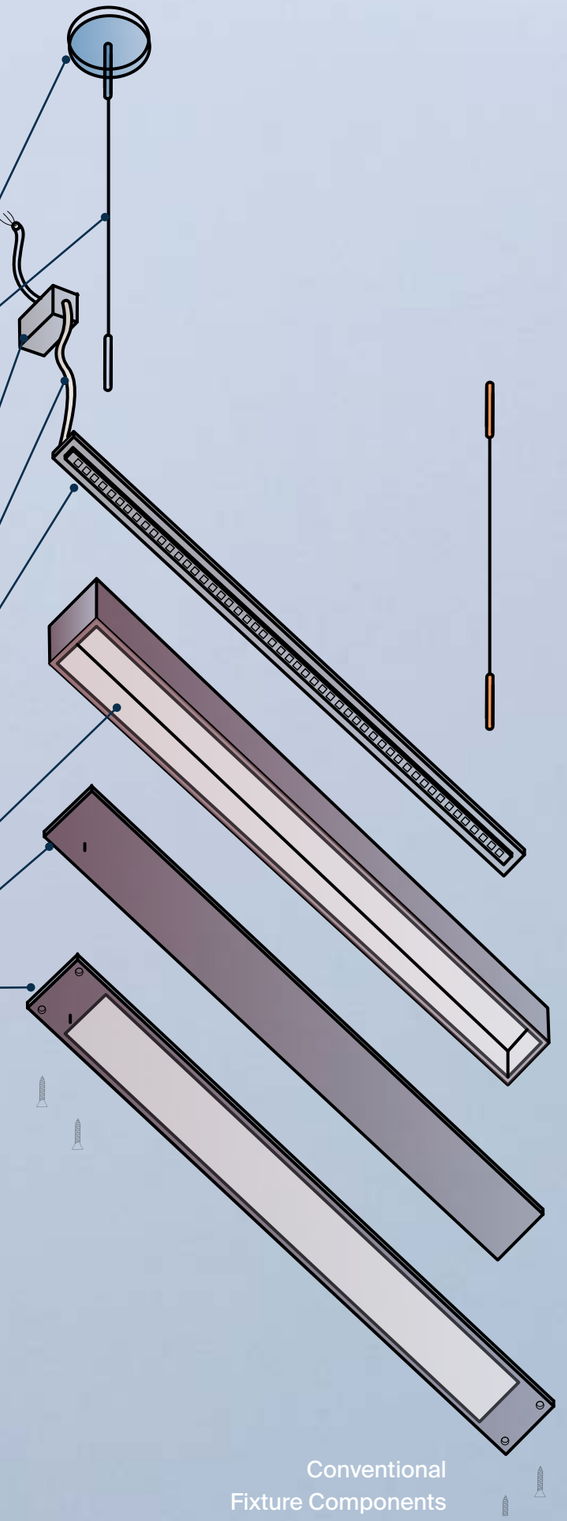
LED BOARD and HEAT SINK | Compound Semi-Conductor, Copper, Silicone, Aluminum

Housing

FIXTURE BODY | Aluminum and Powdercoat

LENS | Polycarbonate Acrylic

GASKET | Silicone



Conventional Fixture Components

50%

OF STAINLESS STEEL IS PRODUCED FROM RAW MATERIALS

21% ends up in the landfill after use.

Steel Sheet Metal

Steel sheet metal is used for rigid, durable components, such as reflectors, brackets, and hardware. Manufacturing sheet metal is an energy-intensive process that accounts for more global emissions than all road freight. In fact, steel manufacturing is the largest industrial consumer of coal.[51]

The process and machinery to create steel requires the use and exposure to a range of toxic chemicals such as silica dust, carbon monoxide, binder materials, and more. These chemicals pose a risk to both the environment and human health.[52] In 2014, the industry dumped 3 million pounds of chemicals into Pennsylvania waterways permitted by state and federal regulators.[53] In addition to polluting fresh water, metal fabrication relies on water usage to cool, process, wash, and dilute the material.

As a result, 75,000 gallons of water is used for each ton of steel produced. Additionally, sheet metal manufacturing produces significant non-degradable waste byproduct called slag, which can be harmful to the environment when not treated properly.

Thankfully, there are established processes to recycle steel and reuse its byproducts. Similar to aluminum, recycled steel of any grade can be repurposed without downcycling.[55] In the United States, 84.4% of slag is repurposed in the form of aggregate for civil and agriculture projects.[56] Slag is also shown to be beneficial to marine environment regeneration due to its high porosity, alkalinity and large surface area.[57]

Manufacturing can be re-evaluated to use fewer resources. There is opportunity for sustainable metalworking fluid systems by extending their use life or using gas-based minimum quantity lubrication (MQL) which reduces the use of large amounts of water by replacing them with air and vegetable oils.[58] Looking at the bigger picture, there is a significant effort to make steel production net-zero. Solutions include utilizing carbon capture and direct iron electrolysis; and replacing coal with hydrogen.[59] Though the effort has momentum, policy and infrastructure is needed to keep moving forward towards carbon neutral production.

“The production of 1 kg of PMMA (polymethyl methacrylate) requires approximately 2 kg of oil and releases 5.5 kg of CO2 into the ecosystem. ”

Coating and Finishing

Powder coating is the most used finish on metal components of a fixture. There are two types of powder coating: electrostatic (PES) and fluidized bed (PVC). PES is a multistep process that includes pre-treatment, polyester powder spray, and oven curing. Sustainable process options include infrared ovens and reverse osmosis. PVC submerges the metal in a bath of polyvinylchloride (PVC) powder. Studies show that the PES process is twice as high in environmental impact over PVC. As the more sustainable option, PVC could go one step further and use a more environmentally friendly product like polyethylene, which does not contain phthalates. Powdercoating can be less harmful than other painting processes - neither PES nor PVC powdercoating contain VOCs.[60]

Fixture Lens

The lens is the component that shields the LED diodes and light fixture from direct view. Acrylic plastics are often used as a lens for LED lighting fixtures, due to their diffusion capabilities and directional optical properties. Acrylic is a tough, transparent material with resistance to ultraviolet radiation and weathering. In lens manufacturing, virgin acrylic is most frequently used due to its high level of optical clarity.

> **Acrylic manufacturing is highly toxic and requires attentive storage and disposal practices. The process produces toxic fumes, generates rainwater acidification due to pollutants released, and can result in explosion if not handled properly. Recent legislation requires that acrylic production be carried out in closed environments to mitigate the spread of toxic fumes and neutralize before discharging into atmosphere.**

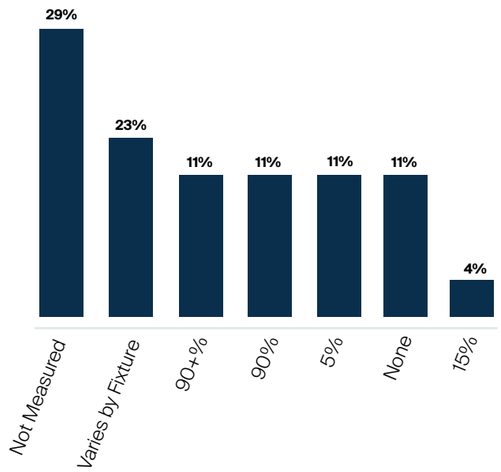
Acrylics are not easy to recycle and they contribute to fossil fuel depletion.[63] It should be noted that while acrylic is BPA free, polycarbonates, unless listed, are not.[64]

Due to it being a cost-effective, durable option with unique material properties, it can be difficult to find acrylic alternatives. Multiple manufacturers make 100% recycled acrylic sheets,[65] but manufacturers often find that recycled acrylic in lensing can “impact output characteristics” and “impede fixture efficiency.”[88] An alternate material can be found in cellulose plastics. They are made of a unique polymer from a renewable resource – softwood trees or cotton linters, not fossil fuels. Cellulose plastics can also biodegrade in soil and seawater, making it a very intriguing product for future use in lighting fixtures.[66]

Summary

Though the environmental impacts of the components listed above are significant, there are sustainable options and alternate approaches for all the housing components of a fixture. Light on Waste aims to push the industry in the direction of using 100% recycled aluminum, carbon neutral steel, and recycled or biodegradable lenses. This context helps generate design criteria for all designers, with the goal of furthering understanding the global impact of lighting specifications and having tools to better our planet.

What percentage of recycled content is in your fixtures?



Does your company have a plan to reduce overall carbon emissions of your products?

SECTION 5

Electronics

Electronics

HARNESSING THE ENERGY

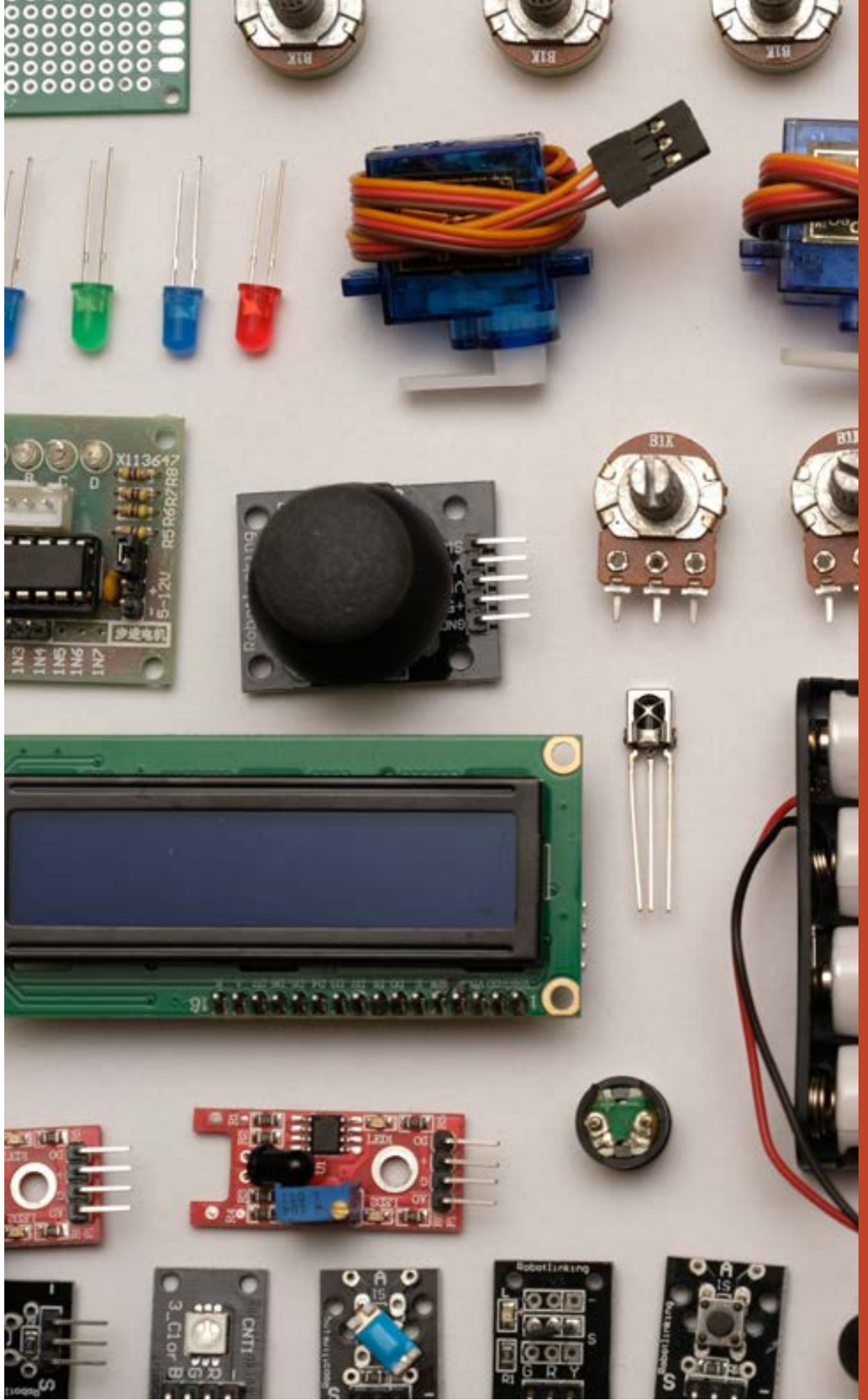
The advent of LED lighting created a huge shift in the design and manufacturing of luminaires. Over the last 10 years, LED market share has shifted from 1% to 46% of total global sales, growing to an anticipated 87% in 2030.

This is a huge accomplishment in terms of operational energy efficiency. However, LED sources and power supplies are manufactured with finite material sources, typically include environmentally harmful components, and are challenging to recycle or reuse. Additionally, there is inconsistent or unavailable data on the embodied emissions of the sourcing, manufacturing, and shipping of LED components. This makes the overall environmental impact difficult to quantify, document, or regulate.

Mineral and Metals

There are no clear alternatives to the mined minerals required to build diodes, semi-conductors, and electronic housing. LED production requires a combination of gallium, arsenic, indium, phosphorous, aluminum, copper, lead, zinc, rare-earth elements, and more.[68] These materials are chemically combined to create unique compounds that can be used to refine the color temperature, wavelength, performance, and quality of an LED light source. For example, aluminum can be added to the gallium arsenic compound Gas to create a red light output, and indium can be added to increase lifespan, lumen output, and efficiency.[69] As technology develops, the chemical make-up of LEDs and other electronics change, further complicating documentation and supply of the material makeup of a light source.

These minerals and metals are produced globally, either through mining or as a byproduct of material processes. The supply chain is extensive – starting at the mine, it moves through traders, exporters, smelters, refiners, and alloy producers before reaching component manufacturers.[70]



As an example, this section will look at gallium, a required component of LEDs and semiconductors that is generated by processing mined materials. There is no domestic gallium production in the United States, and more than half of the imports come from China.[71] Due to the complexity of the supply chain and import process, it is challenging to create clear regulation on how the material is produced, recycled or disposed. Additionally, it requires a potentially unstable dependency on international trade.

When gallium is combined with other metals to create high performance alloys, it requires specific technology to separate the compound back to its original components. As a result, less than 1% of discarded gallium products are recycled and reused.[72] As the globe increases its dependence on gallium, new technologies are needed to effectively recycle and reuse this finite material source.

Gallium represents just a small portion of the material required to create an LED and its components - these same challenges affect all parts of the LED supply chain. When recycling or reusing is not possible, it is essential to encourage healthy, sustainable sourcing. The Responsible Minerals Initiative has developed standards for smelters to limit their social and environmental impacts and provides third party assessments to help monitor the supply chain.[73] This initiative focuses on conflict minerals, including tin, tungsten, tantalum, and gold, which are often mined in areas of armed conflict, forced labor, and human rights abuses. Recently, the EU passed a regulation that requires responsible sourcing of imported conflict minerals, with the goal of putting an “end to the exploitation and abuse of local communities.”[74] These initiatives are just a starting point - they lay the groundwork to help balance and improve the sustainable and social impact of a complex industry.

Due to a lack of available information, manufacturers are not required to document the life cycle of their lighting components to meet most sustainability program requirements. Though LED lighting and power supplies are produced primarily in Asia and shipped worldwide, there is not a global standard that mandates sourcing, manufacturing, and shipping transparency.

EXTRACTION

1. LEAD
MINED IN ZHANGJIAKOU, CHINA

2. RARE EARTH MINERALS AND METALS
GALLIUM, ARSENIC, PHOSPOR, LEAD, NICKEL, TIN, ZINC, INDIUM, MANGANESE, PHOSPHATE ROCK, SELENIUM
MINED IN CHINA

3. BAUXITE
MINED IN AUSTRALIA

4. GLASS: SODA ASH
MINED IN KENYA

5. IRON ORE
MINED IN SWEDEN

6. COPPER WIRE
MINED IN CHILE

7. PVC COATING
ETHELYNE FROM OIL
MINED IN USA

8. SILICA
MINED IN USA
MN, WI, IL, IN, IA, FL

PROCESSING

9. LED HEATSINK MATERIAL
PROCESSED IN CHINA

10. LED SEMICONDUCTOR MATERIAL
PROCESSED IN TAIWAN

11. WIRES
PROCESSED IN JAPAN

MANUFACTURING

12. FIXTURE MANUFACTURING
COMPONENTS COMBINED AND MANUFACTURED IN US

JOB SITE

13. JOB SITE
EXAMPLE IN US

Automobiles | **40%**
Trucks | **34%**
Aviation | **11%**
Marine | **11%**
Railways | **4%**

Due to a lack of available information, manufacturers are not required to document the life cycle of their lighting components to meet most sustainability program requirements.

Hazardous and Red List Materials

Some minerals and materials in LED lighting, such as lead and mercury, are hazardous or harmful to human health. Compliance requirements, such as the EU based Restriction of Hazardous Substances (RoHS), limit the use of hazardous materials in electronics.[75] Though this is not required in products outside of the EU, other governing bodies or manufacturers can apply the standards to improve overall product safety.

More in-depth sustainable product programs, such as the Living Building Challenge Declare label, require strict transparency of lighting materials, and limit toxic or hazardous materials for Red List approval. A key example of a frequently used Red List material is PVC (polyvinylchloride), which coats wires as an insulator and is found in most electronic products. It is a known human carcinogen, and releases toxins during manufacturing and disposal.[76] There are some halogen-free alternatives available, but they are more expensive, challenging to source, and have limited industry interest.[77]

When the use of hazardous or Red List materials is unavoidable, manufacturers can limit their use through strategic products and spatial lighting design. For example, an efficient optical lens can minimize the number of LEDs and components, and strategic LED board placement can shorten the wiring within a fixture. Thoughtful housing design techniques, such as increased air flow for thermal management, can increase the lifespan of electronics. In building design, Power Over Ethernet (PoE) allows for the lighting power and communications network to be distributed over the same wires, limiting the number of wires and power supplies needed.[78] Wireless systems offer control communication through radio waves and eliminate all hardwiring except for the central processor to the building electrical system.

More than 10 billion LED units have been sold globally to date.[67] Additionally, the Global Lighting Challenge, which was introduced at the Paris 2015 Climate Change Conference, aims to deploy 10 billion more LED replacement lamps by 2030.[79] These statistics are often lauded in relation to operational energy savings, but what is the embodied emission impact?

Larger manufacturers have the resources to introduce sustainable manufacturing and sourcing processes. However, the overall market pressure does not exist to encourage smaller manufacturers to spend their resources transitioning to sustainable production. A more universal approach addresses the full life cycle, with a focus on recycling or reuse at end of life. Examples of growing initiatives include LaaS (Lighting as a Service), manufacturer recycling or upcycling programs, and government-based recycling policies.[80]

LaaS treats lighting as a subscription service, with the owner paying a recurring service fee rather than purchasing lights as part of their initial construction investment.[81] Maintenance, upkeep, and end of life treatment is typically included in the service, and the fixtures are monitored and updated to meet consistent efficiency energy usage goals.[82] As a result, both the embodied and operational emissions can be reduced using this service-based system.

Sustainably minded manufacturers design their fixtures to be easily recyclable and make it as easy as possible to do so. Modular based design allows for components to be separated and sent to designated recycling facilities. For example, the aluminum heatsink can detach from the LEDs, and the lens can separate from the silicone gasket. Committed manufacturers, such as Goldeneye, will accept shipments of old fixtures to recycle main components.[83] In the European Union (EU), Signify has partnered with Collection and Recycling Service Organizations (CRSOs) to facilitate the recycle and reuse of lamps – through their treatment process, more than 80% of extracted materials can be re-used.[84]

This process was instigated to meet the requirements of WEEE (Waste of Electrical and Electronic Equipment), an EU based policy that mandates the treatment, recovery, and recycling of electronic components.[85] This shows that sustainably focused policy can result in a direct response from manufacturers and designers and grow the capabilities of the lighting industry.

Summary

There are no clear market alternatives to LEDs and their required electronic or material components. To create a low waste, circular approach to lighting production, a policy-centered framework needs to be developed to encourage healthy, transparent production and holistic recycling and reuse processes.

SECTION 6

Shipping & Packaging

Shipping & Packaging

THE FULL PACKAGE

A sustainable lighting industry cannot focus exclusively on the fixture alone. It transcends beyond, taking into consideration each segment of a product's life, from how it gets to its destination to the condition in which it arrives.

Light on Waste views shipping and packaging as an extension of a fixture, and considers materiality, transportation efficiency, and emissions. Currently, there are no universal sustainable shipping standards - shipping companies and ports approach the issue of environmentally friendly shipping in different ways[86].

This variation in outlook can be an issue for retailers who are looking to streamline their processes in a monetarily conscious way. As consumer understanding grows, the shipping industry is no longer able to justify excessive packaging for the sake of speed and profit.

82.2 million tons of packaging waste was created in 2018[62]

What makes a package?

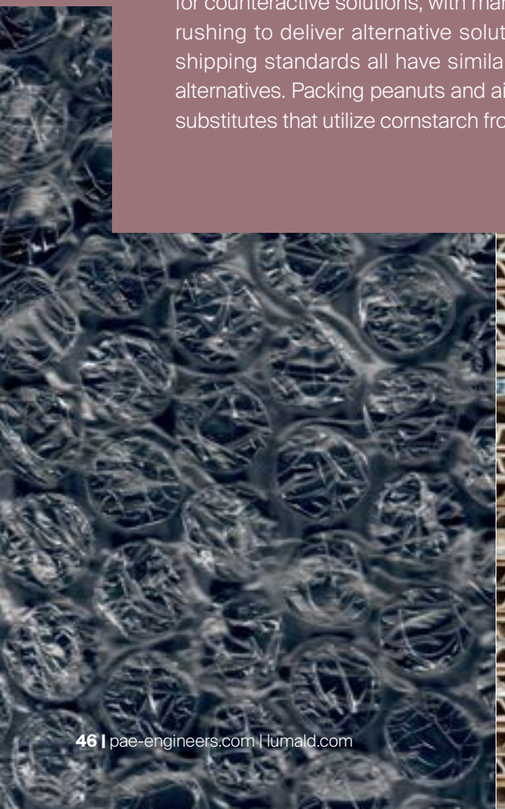
The EPA defines containers and packaging as, “products that are assumed to be discarded the same year the product they contained are purchased.”[87] 83% of surveyed manufacturers are making the effort to source packaging locally.[88] This habit keeps business in the local economy and lowers emissions. While these efforts are important to manufacturers, 82.2 million tons of packaging waste was still generated in 2018. [62]

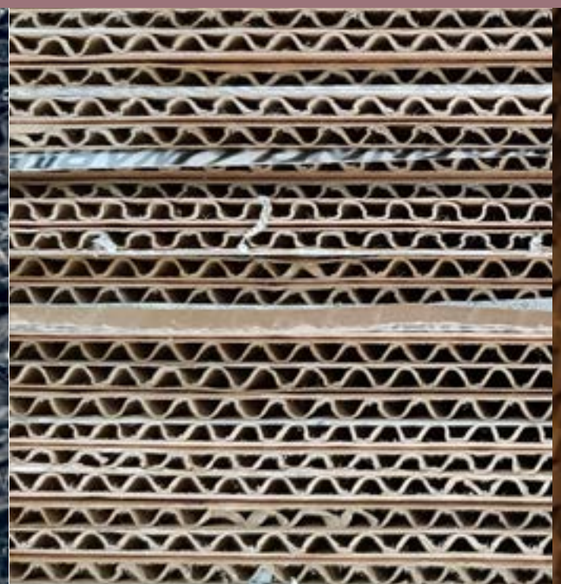
Only 9% of plastic is recycled properly.[69]

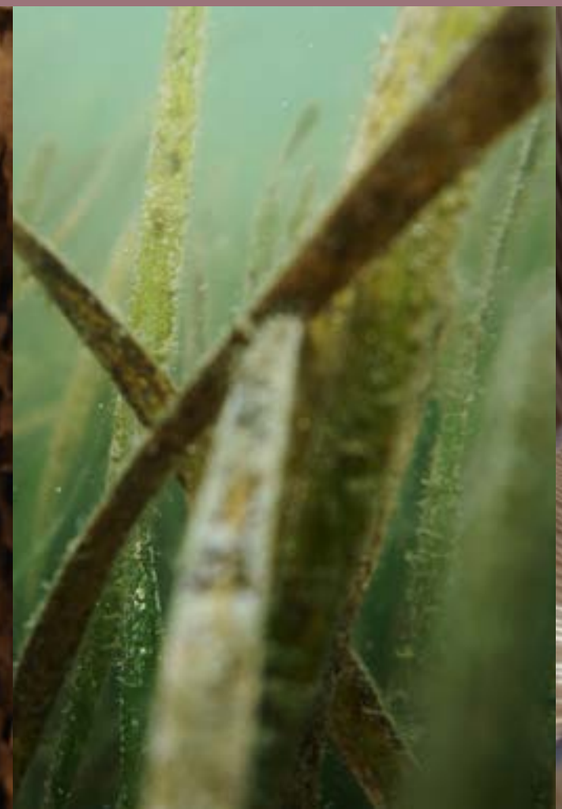
The most used shipping material, plastic, is an inexpensive and lightweight human innovation that comes at a hefty environmental price. With over 9.2 billion tons of plastic being produced, only 9% has been recycled properly.[69] This neglectful habit has created an immense need for counteractive solutions, with many companies rushing to deliver alternative solutions. Current shipping standards all have similar eco-friendly alternatives. Packing peanuts and air pillows have substitutes that utilize cornstarch from agricultural waste. Cardboard boxes are being revitalized to avoid environmentally harmful inks and adhesives while being simultaneously sourced from certified and sustainably managed forests.[86] Mushroom packaging, a non-fuel-based filler and biomaterial, takes biodegradable materiality a step further. 73% of surveyed manufacturers expressed concern regarding inconvenience, cost or durability when asked about the implementation of sustainable packing products.[37] On the contrary, studies show that mycelium-based packaging is almost identical in form, function, and cost to plastic, with the added ability to decompose. Similarly, seaweed-based products, such as kelp bioplastics, have the added feature of absorbing CO_2[86].

While identifying areas in the supply chain where environmentally harmful products can be reduced, reused, or eliminated is essential, the gap ultimately lies in demand. Modifying industry awareness as a whole and aiding change management is fundamental to the positive longevity of the lighting industry.

of surveyed manufacturers expressed concern regarding inconvenience, cost or durability when asked about the implementation of sustainable packing products.[88]







Thinking Outside the Box

The international system of goods movement is integral to life in the 21st century. With the rapid growth of e-commerce and almost instantaneous delivery options, it creates immense issues in terms of carbon emissions and infiltrates consumer mindsets into thinking instant is a necessity. Boat shipments equate to four percent of all human-caused carbon emissions, and a large ship emits approximately four ounces of CO2 to transport two tons of cargo in just one mile[89]. Surprisingly, this is one of the most efficient methods of conventional transport. Ships emit half as much carbon as a train, one-fifth of a truck or one-fifteenth of an airplane to complete the same task. Moving in the direction of cleaner fuels is a large task but shifting the conversation to addressing "last-mile" issues has a vast range of possible solutions[90]. Last-mile delivery accounts for 53% of the total cost of shipping and as its name suggests, refers to the final steps in the delivery process. This phase of delivery is the most time-consuming, high effort, and costly part of the process. With innovative technologies, consumer education, and industry collaboration, large steps can be made towards greener industry standards.[91]

> **Last-mile delivery accounts for 53% of the total cost of shipping.[38]**

Data and Analytics

Keeping data at the forefront will allow for real-time insight into industry preferences and purchasing patterns to innovate and optimize inventory.[67] Optimizing delivery routes to the final jobsite through delivery management software provides the most efficient routes and ensures a lower carbon footprint. Additionally, innovative packaging techniques reduce material use, transportation costs and jobsite recycling—all while protecting the products themselves.

Unique Asset Use

Implementing sustainable transportation alternatives such as hybrid or all electric vehicle fleets and centralized delivery boxes are all ways to reduce delivery emissions. Taking this concept a step further, rethinking asset use companywide is an impactful mindset shift. Consider repurposing or sharing vehicle fleets and infrastructure while investing in green technology and evolving regulations that support these approaches.

Incentive-Based Change

Developing "choice architecture" or incentive-based changes that aid client budgets encourages consumers to choose the more sustainable solution. Consumer education regarding shipment consolidation options, like "bulk pack", encourages the sustainable delivery conversation from a project's infancy. [67]

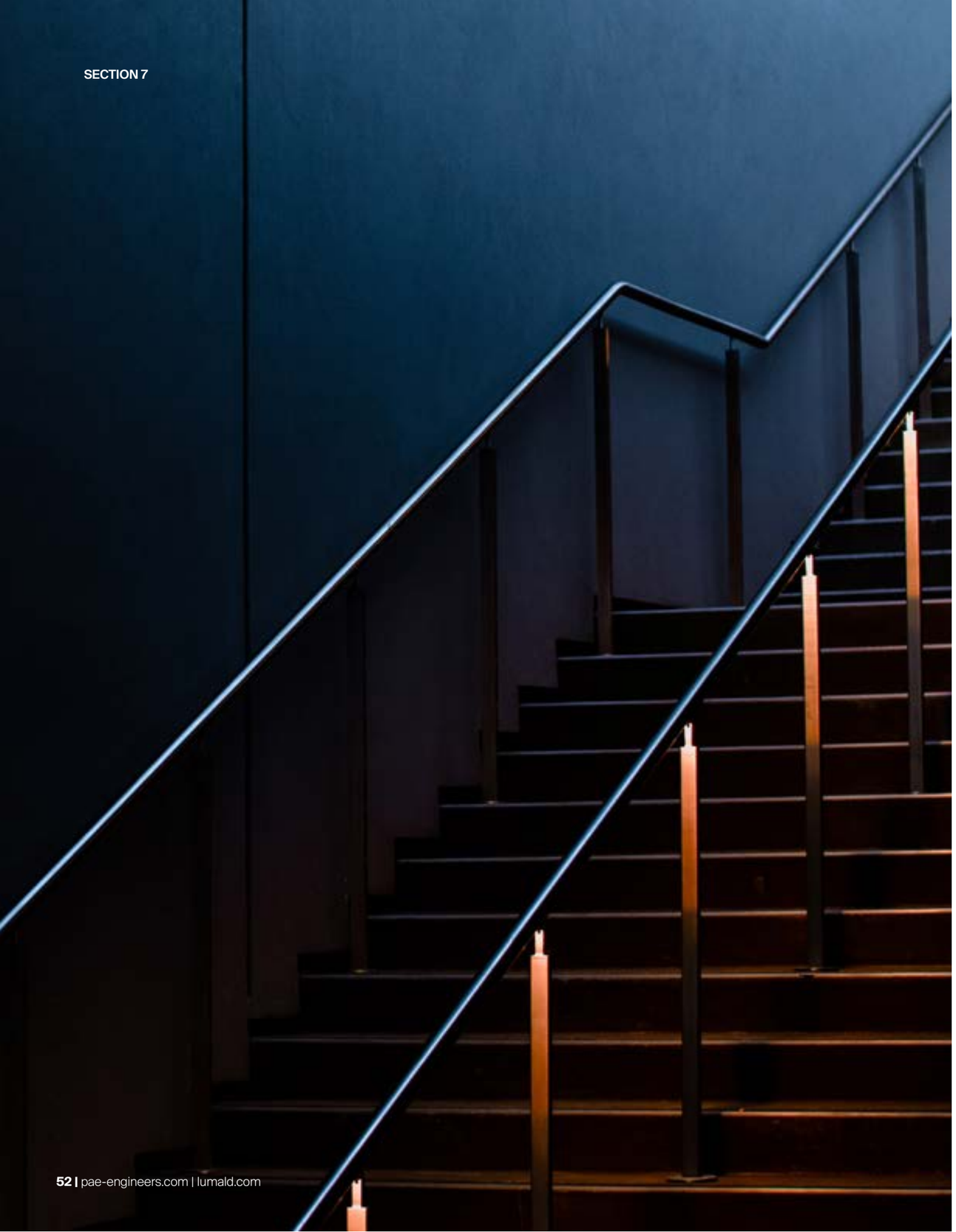
Summary

It would be an understatement to say that environmental concerns are influencing an urgent need for sustainable solutions. Whether shipped by land, air or sea, carbon emissions and waste accumulation are an unfortunate byproduct of the lighting industry. With no existing universal shipping or packaging standards, the final step from manufacturing line to jobsite is often overlooked and undervalued. Extending the sustainability conversation past a fixture's green performance factors to include package materiality and transportation efficiency will help close the industry gap. Solutions surrounding biomaterial, asset sharing, and client education can and should find their rightful and critical place in the lighting industry.

> **Boat shipments equate to four percent of all human-caused carbon emissions and a large ship emits approximately four ounces of CO2 to transport two tons of cargo in just one mile.[89]**

SECTION 7

Conclusion



Conclusion

EVER EVOLVING

The latest IPCC report, released August 2021, explains that without immediate action in reducing carbon and greenhouse gas emissions the chances of continued unreversible damage to our planet is inevitable.[92] “This report is a reality check” says IPPC Co-Chair Valerie Masson-Delmotte. Human activity is responsible for about 1.1C of warming from 1850-1900. Building construction and operation has traditionally been one of the heaviest consumers of natural resources and producers of carbon emissions worldwide.

> **Light on Waste developed to shed light on industry shortcomings, explore new design and production methods, and to lead the creation of an industry framework for a more sustainable trade.**

This research honed in on industry gaps by breaking down all elements that go into the design and production of a light fixture. Each part of the process, from external sustainability guidelines to well-established production and material requirements, comes with its own set of clear challenges. In digging deeper, we can find examples and opportunities for potential solutions. Each existing sustainability program incorporates their own unique and effective sustainability measures, but no single certification encompasses the full sustainable impact of a light fixture. Additionally, while policy exists, enaction and participation is dependent on local government or a voluntary merit system. Housing and hardware challenges include a lack of viable alternative materials, the cost impacts of sustainable sourcing, and minimal transparency throughout the supply chain. Similarly, LED sources and power supplies are manufactured with finite mineral and metal sources, environmentally harmful materials, and inconsistent or unavailable life cycle information. Lasty, with no existing universal shipping or packaging standards, the final step from manufacturing line to jobsite is often overlooked. While solutions surrounding biomaterial, asset sharing and client education exist to offset those numbers, they rely on full industry priority and participation to make a meaningful impact.

Light on Waste originated with the idea that as stewards of the planet, it is our responsibility to create a better future for all. The intended result was to create a tangible light fixture with interchangeable, sustainably sourced components. Through our expansive research and analysis of collected data, Light on Waste recognized its original outcome could be more impactful by refocusing efforts on the bigger picture. With that realization, the goal shifted focus from creating a single, sustainable product to developing an industry-wide design framework. Light on Waste’s enlightened goal is to create a more sustainable day-to-day design process while also pushing for policy upgrade and holistic industry change.

REFERENCES

1. William J Ripple, Christopher Wolf, Thomas M Newsome, Jillian W Gregg, Timothy M Lenton, Ignacio Palomo, Jasper A J Eikelboom, Beverly E Law, Saleemul Huq, Philip B Duffy, Johan Rockström, World Scientists' Warning of a Climate Emergency 2021, *BioScience*, Volume 71, Issue 9, September 2021, Pages 894–898, https://doi.org/10.1093/biosci/biab079
2. Stein, Theo. "Despite Pandemic SHUTDOWNS, Carbon Dioxide and Methane Surged in 2020." Welcome to NOAA Research, Welcome to NOAA Research, 28 Apr. 2021, research.noaa.gov/article/ArtMID/587/ArticleID/2742/Despite-pandemic-shutdowns-carbon-dioxide-and-methane-surged-in-2020.
3. Rockstrom, Johan, et al. "Planetary Boundaries: Exploring the Safe Operating Space ..." *Stockholm Resilience*, Resilience Alliance, 2009, www.stockholmresilience.org/download/18.8615c78125078c8d3380002197/ES-2009-3180.pdf.
4. Benjamin, Heather. "2018 Global Status Report Shows Potential for Emissions Reduction." *U.S. Green Building Council*, U.S. Green Building Council, 10 Dec. 2018, www.usgbc.org/articles/2018-global-status-report-shows-potential-emissions-reduction.
5. "Construction and Demolition Debris: Material-Specific Data." *EPA*, Environmental Protection Agency, 28 Oct. 2020, www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/construction-and-demolition-debris-material.
6. Merlino, Kathryn Rogers. "WASTE: Construction and Demolition Debris." *Building Reuse: Sustainabililty, Preservation, and the Value of Design,* University of Washington Press, 2018, pp. 69–77.
7. Jones, Stephen A., editor. Dodge Data and Analytics, 2018, pp. 4–4, *SmartMarket Report: World Green Building Trends 2018.*
8. Chua, Jasmin Malik. "Online Shopping Has Boomed in the Pandemic. but What about All the Packaging?" *Vox*, Vox, 8 Jan. 2021, www.vox.com/the-goods/22214017/online-shopping-pandemic-packaging-ecommerce-waste-plastic.
9. "Was Ist Zirkularität? Definition Und Erklärung DER KREISLAUFWIRTSCHAFT." *BlackSatino*, blacksatino.eu/en/circular-thinking-is-in-our-dna/what-is-circularity/.
10. "Closed Loop." *Merriam-Webster*, Merriam-Webster, www.merriam-webster.com/dictionary/closed%20loop.
11. *Resources - Cradle to CRADLE Products Innovation Institute*, www.c2ccertified.org/resources/collection-page/cradle-to-cradle-certified-resources-public.
12. "Cradle-to-Grave Definition & Meaning." Dictionary.com, Dictionary.com, 2021, www.dictionary.com/browse/cradle-to-grave.
13. Staff, Waveform. "What Is CRI? The Ultimate Guide to the Color Rendering Index." *Waveform Lighting*, Waveform Lighting, 17 Jan. 2018, www.waveformlighting.com/tech/what-is-cri-color-rendering-index.
14. "About Declare." *International Living Future Institute*, 3 May 2021, living-future.org/declare/declare-about/.
15. Lyle, John Tillman. Design for *Human Ecosystems: Landscape, Land Use, and Natural Resources.* Island, 1999.
16. "Human-Centered Design: Design Defined." *InVision*, www.invisionapp.com/design-defined/human-centered-design/.
17. "About IALD." *International Association of Lighting Designers*, www.iald.org/About/About-the-IALD.
18. "History." *Illuminating Engineering Society,* www.ies.org/about/history/.
19. "What Is Lighting as a Service?" *FSG Electric & Lighting*, 14 May 2021, fsg.com/what-is-lighting-as-a-service/.
20. "What Is LEED?" *U.S. Green Building Council,* www.usgbc.org/help/what-leed.
21. "Life Cycle Assessment." *Life Cycle Assessment - an Overview | ScienceDirect Topics*, www.sciencedirect.com/topics/earth-and-planetary-sciences/life-cycle-assessment.
22. "NFPA 70®." *NFPA 70®: National Electrical Code®*, www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=70.
23. "About." *NEMA*, www.nema.org/about.
24. "Living-Future.org." *International Living Future Institute*, 6 Aug. 2021, living-future.org/.
25. "The Paris Agreement." *Unfccc.int*, unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement.
26. "RoHS Directive." *Environment*, ec.europa.eu/environment/topics/waste-and-recycling/rohs-directive_en.
27. "About UI." *UL*, www.ul.com/about.
28. *International Well BUILDING INSTITUTE*, www.wellcertified.com/about-iwbi/.
29. "Part 1: Basics of SUSTAINABLE LIGHTING." *Consulting - Specifying Engineer,* 1 Apr. 2010, www.csemag.com/articles/part-1-basics-of-sustainable-lighting/.
30. "Why LEED." *Why LEED Certification* | U.S. Green Building Council, www.usgbc.org/leed/why-leed.
31. "About IWBI." *International Well BUILDING INSTITUTE*, 2020, www.wellcertified.com/about-iwbi/.
32. "Living Building Challenge 4.0 Basics." *International Living Future Institute,* 24 Aug. 2021, living-future.org/lbc/basics4-0/.
33. "About Declare." *International Living Future Institute,* 30 Aug. 2021, living-future.org/declare/declare-about/.
34. "What Is Cradle to Cradle Certified?" *What Is Cradle to Cradle Certified®? - Get Certified - Cradle to CRADLE Products Innovation Institute,* www.c2ccertified.org/get-certified/product-certification.
35. Gatley, Neill. "What Are the ISO 14001 Requirements?" *British Assessment Bureau,* 16 June 2021, www.british-assessment.co.uk/insights/what-are-the-iso-14001-requirements/.
36. *Introduction to ISO 14001:2015.* International Organization for Standardization, 2015, www.iso.org/files/live/sites/isoorg/files/store/en/PUB100371.pdf.
37. Merlino, Kathryn Rogers. "WASTE: Construction and Demolition Debris." *Building Reuse: Sustainabililty, Preservation, and the Value of Design,* University of Washington Press, 2018, pp. 69–77.
38. Cornelius Christine, Duffy Sara, Wilcox Lauren, Johnstone Colin, et al. "Manufacturer Sustainability Survey." *Sustainability Survey, Luma Lighting Design,* 1 Feb. 2021, docs.google.com/forms/d/1cyxQuOziVR9JOocf4eBI2DMnCSL3Q7G_tjvnDJeox8w/edit
39. Roos, Scott. *Specifying Sustainable Luminaires*. 25 August 2021, Acuity CEU Presentation.
40. "The Biden Plan to Build a Modern, Sustainable Infrastructure and an Equitable Clean Energy Future." *Joe Biden for President: Official Campaign Website,* 5 August. 2020, joebiden.com/clean-energy/.
41. "The Paris Climate Agreement." *Unfccc.int.* United Nations Climate Change. unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement.
42. "Shifting to a Circular Economy Essential to Achieving Paris Agreement Goals." *Unfccc.int,* United Nations Climate Change, 15 Apr. 2021, unfccc.int/news/shifting-to-a-circular-economy-essential-to-achieving-paris-agreement-goals.
43. California Energy Commission. "Building Energy Efficiency Standards - Title 24." *California Energy Commission, California Energy Commission,* www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards.
44. *2019 Building Energy Efficiency Standards Frequently Asked Questions. California Energy Commission,* Mar. 2020, www.energy.ca.gov/sites/default/files/2020-03/Title_24_2019_Building_Standards_FAQ_ada.pdf.
45. *What's New in the 2019 Code? Nonresidential Lighting.* UC Davis California Lighting Technology Center, 29 Jan. 2019, cltc.ucdavis.edu/sites/default/files/files/publication/Whats-New-2019-T24-Non-Residential-Final.pdf.
46. California Energy Commission. "Building Energy Efficiency Standards - Title 24." *California Energy Commission,* California Energy Commission, www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards.
47. "Environmental Product Declaration - Lincor DI C 5000-830 L12 LDE ASQ1 SR." Zumbobel Lighting , Nov. 2017.
48. "Aluminum Industry." *EPA*, Environmental Protection Agency, June 2021, www.epa.gov/f-gas-partnership-programs/aluminum-industry#sources.
49. "Source of Greenhouse Gas Emissions." *EPA*, Environmental Protection Agency, July 2021, www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.
50. Samarendra Das & Felix Padel, Battles over Bauxite in East India: The Khondalite Mountains of Khondistan, 23 August 2010. http://www.savingiceland.org/2010/08/battles-over-bauxite-in-east-india-the-khondalite-mountains-of-khondistan/
51. NAT/Friends of the Earth Brazil, Aluminium Value Chain, 2011.
52. Calma, Justine. "Aluminum Is Recycling's New Best Friend, but It's Complicated." The Verge, The Verge, 12 Sept. 2019, www.

theverge.com/2019/9/12/20862775/aluminum-recycling-water-tech-plastic-manufacturing-cocacola-pepsi-apple.

53. UK Parliament Select Committee on Science and Technology, Aluminium: A Truly Sustainable Material, January 2008. http://www.publications.parliament.uk/pa/ld200708/ldselect/ldsctech/163/8012207.html

54. IEA. “Iron and Steel Technology ROADMAP – ANALYSIS.” *IEA*, Oct. 2020, www.iea.org/reports/iron-and-steel-technology-roadmap.

55. IARC Working Group on the Evaluation of Carcinogenic Risks to Humans. “Occupational Exposures during Iron and Steel Founding.” *Chemical Agents and Related Occupations*., U.S. National Library of Medicine, 1 Jan. 2012, *www.ncbi.nlm.nih.gov/books/NBK304429/*.

56. Reed, Christopher. “How the Steel Industry Uses Billions of Gallons of Pennsylvania Water.” *How The Steel Industry Uses Billions Of Gallons Of Pennsylvania Water,* 90.5 WESA, 30 Sept. 2016, www.wesa.fm/economy-business/2016-09-30/how-the-steel-industry-uses-billions-of-gallons-of-pennsylvania-water.

57. 9 Steel Industry Raw Materials and Wastes.” *Studies in Environmental Science,* Elsevier, 14 Apr. 2008, www.sciencedirect.com/science/article/abs/pii/S0166111608707465?via%3Dihub.

58. “Steel Production & Environmental Impact.” *Greenspec*, www.greenspec.co.uk/building-design/steel-products-and-environmental-impact/.

59. M;, Guo J;Bao Y;Wang. “Steel Slag in China: Treatment, Recycling, and Management.” *Waste Management* (New York, N.Y.), U.S. National Library of Medicine, Aug. 2018, pubmed.ncbi.nlm.nih.gov/32559918/.

60. Kardys, Gary. “High Performance Slag Materials – a Steel Industry Byproduct.” *High Performance Slag Materials – A Steel Industry Byproduct | Engineering360,* Jan. 2018, insights.globalspec.com/article/7809/high-performance-slag-materials-a-steel-industry-byproduct.

61. Skerlos, Steven. “Current Advances in Sustainable Metalworking Fluids Research.” Https://Cfpub.epa.gov/ncer_abstracts/Index.cfm/Fuseaction/Display.pubFullText/publication_id/44530, Inderscience Enterprises Ltd, 2008.

62. Delasalle, Faustine. “This Is How the Steel Industry Is Forging a Path to Net-Zero.” *World Economic Forum*, May 2021, www.weforum.org/agenda/2021/05/green-steel-forging-a-path-to-net-zero/.

63. Kellens, Karel. “Environmental Comparison of Metal Coating Processes.” *Science Direct*, 2015, www.sciencedirect.com/science/article/pii/S221282711500493X.

64. Totaro, Antonella Ilaria. “The Unsustainable Prevalence of Plexiglass.” *Materia Rinnovabile,* 7 Aug. 2020, www.renewablematter.eu/articles/article/the-unsustainable-prevalence-of-plexiglass.

65. Dorman, Evelyn S, and Chris Cavette. “Acrylic Plastic.” *How Products Are Made,* www.madehow.com/Volume-2/Acrylic-Plastic.html.

66. Richard Campbell, and Peter M. "Eco-Friendly Alternatives to Acrylic (Plexiglass) - 2020 Guide." Ubuntu Manual. 09 Nov. 2020. Web. 04 Dec. 2020.

67. “Acrylic, Everything You Need to Know!” *Max Plastics*, 21 May 2021, maxplastics.com/acrylic-everything-you-need-to-know/.

68. “Why Green Cast.” *Green Cast Recycled Acrylic*, www.greencastus.com/why-green-cast-2/.

69. “Biodegradability of Cellulose Acetate.” *Biodegradability of Cellulose Acetate Daicel Corporation*, www.daicel.com/cell_ac/en/cellulose/ca_biodegradable.html.

70. IEA. “Lighting – Analysis.” *IEA*, 1 June 2020, www.iea.org/reports/lighting.

71. Wilburn, D.R., 2012, Byproduct metals and rare-earth elements used in the production of light-emitting diodes—Overview of principal sources of supply and material requirements for selected markets: U.S. Geological Survey Scientific Investigations Report 2012–5215, 15 p. http://pubs.usgs.gov/sir/2012/5215

72. *Understanding Compound Semiconductor Materials in LEDS*. Marktech Optoelectronics, 16 Jan. 2021, marktechopto.com/technical-articles/understanding-compound-semiconductor-materials-in-leds/.

73. “Conflict Minerals.” *Signify*, 2021, www.signify.com/global/contact/suppliers/sustainability/our-programs/conflict-minerals.

74. “Gallium, Mineral Commodity Summaries.” *US Geological Survey,* USGS, Jan. 2021, pubs.usgs.gov/periodicals/mcs2021/mcs2021-gallium.pdf.

75. Foley, N.K., Jaskula, B.W., Kimball, B.E., and Schulte, R.F., 2017, Gallium, chap. H of Schulz, K.J., DeYoung, J.H., Jr., Seal, R.R., II, and Bradley, D.C., eds., Critical mineral resources of the United States—Economic and environmental geology and prospects for future supply: U.S. Geological Survey Professional Paper 1802, p. H1–H35, https://doi.org/10.3133/pp1802H.

76. “Responsible Minerals Initiative.” *Responsible Minerals Initiative,* 2021, www.responsiblemineralsinitiative.org/.

77. “Conflict Minerals Regulation Explained.” *European Commission,* 21 Dec. 2020, ec.europa.eu/trade/policy/in-focus/conflict-minerals-regulation/regulation-explained/.

78. “RoHS Guide.” RoHS Compliance FAQ, www.rohsguide.com/rohs-faq.htm.

79. “The Red List.” *International Living Future Institute,* 24 Aug. 2021, living-future.org/declare/declare-about/red-list.

80. Patterson, Caleb. “LightArt + Graypants Sustainability Conversation.” Phone Interview. 3 December 2020.

81. “What Is Power over Ethernet (PoE)?” *Cisco*, Cisco, 13 Sept. 2021, www.cisco.com/c/en/us/solutions/enterprise-networks/what-is-power-over-ethernet.html.

82. “Global Lighting Challenge Launched at cop21.” *Global Lighting Challenge Launched at COP21 | Global Lighting Challenge,* 2015, www.globallightingchallenge.org/Latest/GlobalLightingChallengeLaunchedatCOP21/.

83. Halper, Mark. “Lighting as a Service Poised to Deliver the Circular Economy.” LEDs Magazine, 29 May 2018.

84. “Light as a Service.” *Signify,* www.signify.com/en-us/lighting-services/managed-services/light-as-a-service.

85. Halper, Mark. “Lighting as a Service Makes It Easier to Raise Money for Other Things, Even in 2019.” *LEDs Magazine,* 12 Sept. 2018, www.ledsmagazine.com/architectural-lighting/indoor-lighting/article/16695783/lighting-as-a-service-makes-it-easier-to-raise-money-for-other-things-even-in-2019-magazine.

86. “Recyclable.” *Goldeneye*®, Inc., goldeneyelighting.com/recyclable.

87. “Collection and Recycling.” *Signify*, www.signify.com/global/sustainability/product-compliance/collection-and-recycling.

88. “RoHS Guide.” WEEE Compliance Regulations, www.rohsguide.com/rohs-weee.htm.

89. “Ecovative Design.” *Ecovative Design*, ecovativedesign.com/.

90. “Green Shipping & Eco-Friendly Shipping Solutions: Easyship Blog.” *Easyship*, www.easyship.com/blog/green-shipping.

91. “Containers and Packaging: Product-Specific Data.” *EPA,* Environmental Protection Agency, Jan. 2021, www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/containers-and-packaging-product-specific-data.

92. Marine Environment Protection Committee (MEPC), 68th session, 11 to 15 May 2015. (n.d.). Retrieved December 05, 2020, from https://www.imo.org/en/MediaCentre/MeetingSummaries/Pages/MEPC-68th-session.aspx

93. Andre Pharand, Andre. “The Sustainable Last Mile.” Accenture, 27 Mar. 2021, www.accenture.com/us-en/insights/consulting/sustainable-last-mile-delivery.

94. “Climate Change Widespread, Rapid, and Intensifying.” *IPCC*, IPCC Press Office, 9 Aug. 2021, www.ipcc.ch/2021/08/09/ar6-wg1-20210809-pr/.