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Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

# 2020 LED Manufacturing Supply Chain

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# Disclaimer



This report was prepared for:

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# Comments

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# List of Acronyms and Abbreviations

| | |
|---|---|
| Btu | British Thermal Unit |
| DOE | Department of Energy |
| GUV | Germicidal Ultraviolet |
| HTS | Harmonized Tariff Schedule |
| LED | Light-Emitting Diode |
| NAFTA | North American Free Trade Agreement |
| NCM | Net Cost Method |
| PCB | Printed Circuit Board |
| RVC | Regional Value Content |
| SSL | Solid-State Lighting |
| SKU | Stock Keeping Unit |
| TLED | Tubular Light-Emitting Diodes |
| TVM | Transaction Value Method |
| USMCA | United States-Mexico-Canada Agreement |
| USTR | United States Trade Representative |

# Executive Summary

Over the last decade, the global lighting industry has seen a paradigm shift. Conventional lighting sources such as incandescent, fluorescent, and high-intensity discharge are being replaced by solid-state light-emitting diode (LED) technology, enabling energy savings with increased adoption. Due to improvements in scientific understanding and its underlying technology, LED lighting now outperforms many baseline technologies in energy efficiency, lifetime, versatility, and color quality. Furthermore, manufacturing advancements, increased demand, and the development of a global supply chain network have made LED lighting products cost-competitive to conventional technologies in most lighting applications.

The U.S. Department of Energy's (DOE) 2020 *Adoption of Light-Emitting Diodes in Common Lighting Applications* study showed that, as of 2018, LED penetration was 29.8% for indoor lighting and 51.4% for outdoor lighting in the United States. [1] Additionally, DOE's *Energy Savings Forecast of Solid-State Lighting in General Illumination Applications* forecasts that LED lighting will represent 84% of all lighting sales by 2035, resulting in annual primary energy savings of 4.8 quadrillion British thermal units (Btu). [2] The low costs of manufacturing overseas resulted in Asia being a manufacturing hub of LED and LED lighting products. However, there is also significant presence of LED lighting manufacturing in geographic locations beyond Asia, closer to the end-consumer.

This report aims to characterize the globalized manufacturing supply chain of LEDs and LED lighting products and investigate the economic impacts of this supply chain on the United States by addressing five research questions:

1. How is the manufacturing process structured for typical solid-state lighting (SSL) general illumination products?
2. What is the value added for a typical LED luminaire manufactured in the United States versus internationally?
3. What proportion of LED products are manufactured and assembled in the United States and internationally?
4. What is the impact of an economic event (e.g., tariffs) on the SSL manufacturing process and to the final consumer?
5. What are the domestic opportunities for SSL manufacturing in the global lighting supply chain?

To investigate these questions, this analysis used international trade data and market reports, and inputs from interviews with LED die, package, and lamp/luminaire manufacturers, as well as other industry stakeholders. Figure ES-1, Figure ES-2, and Figure ES-3 summarize the findings of the trade flow analysis. Major findings on the status of the global LED lighting supply chain include the following:

- Of the value added for a domestically manufactured LED luminaire, 89% can be attributable to the United States.
- With only a few exceptions, epitaxy and wafer fabrication are concentrated in Asia.
- China has a large manufacturing footprint for LED packaging, with many manufacturers that operate facilities for packaging in China. However, many other Asian countries have significant LED package manufacturing as well, including South Korea, Japan, Taiwan, Malaysia, and Vietnam.
- Most of the world's LED lamp production occurs in China. By value, 94% of all LED lamp imports to the United States were manufactured in China in 2019. Virtually no LED lamp manufacturing is taking place in the United States today.

- LED luminaire manufacturing differs significantly from LED lamp production in that there is still a worldwide distribution of manufacturing. By value, 58% and 21% of LED luminaire imports to the United States were manufactured in China and Mexico, respectively, in 2019.

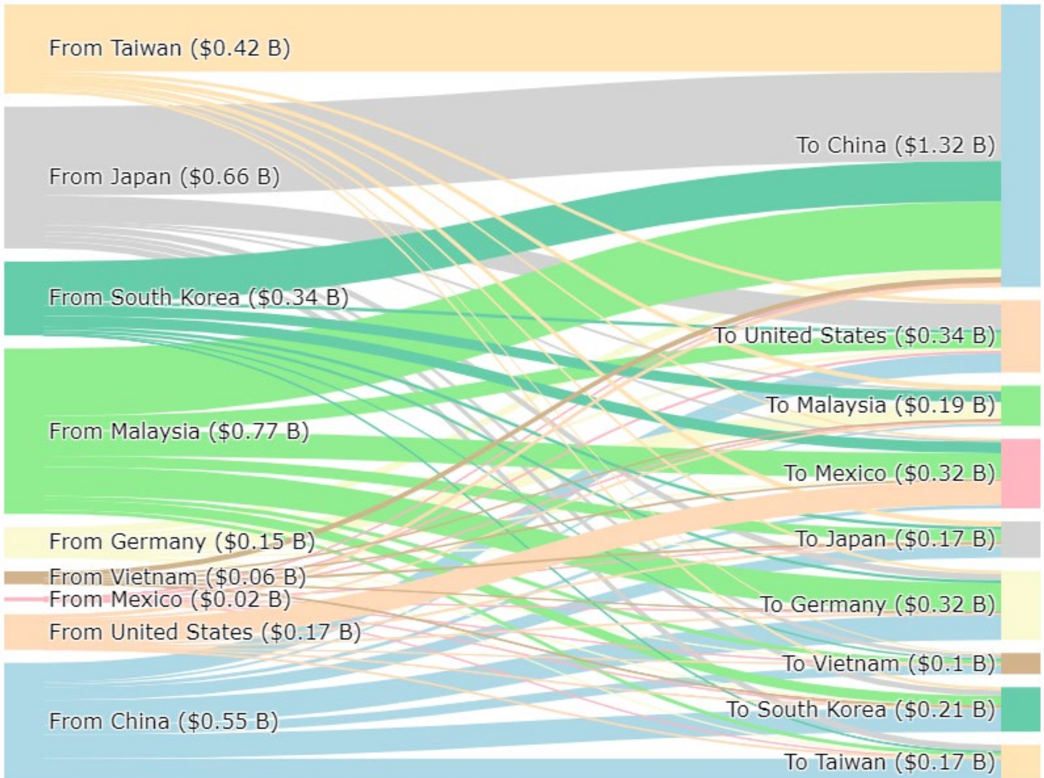


Figure ES-1. Trade flow of LED packages and die for lighting, 2019 [3] [4]. This data only includes exports to other countries and does not include LED packages manufactured for domestic consumption. The total global market for LED packages for general lighting in 2019 was $5.6 billion [4], and the total global exports from these nine countries were approximately $3.1 billion [3]. LED packages for general lighting applications were approximated from total LED package trade data based on global market share in 2019.

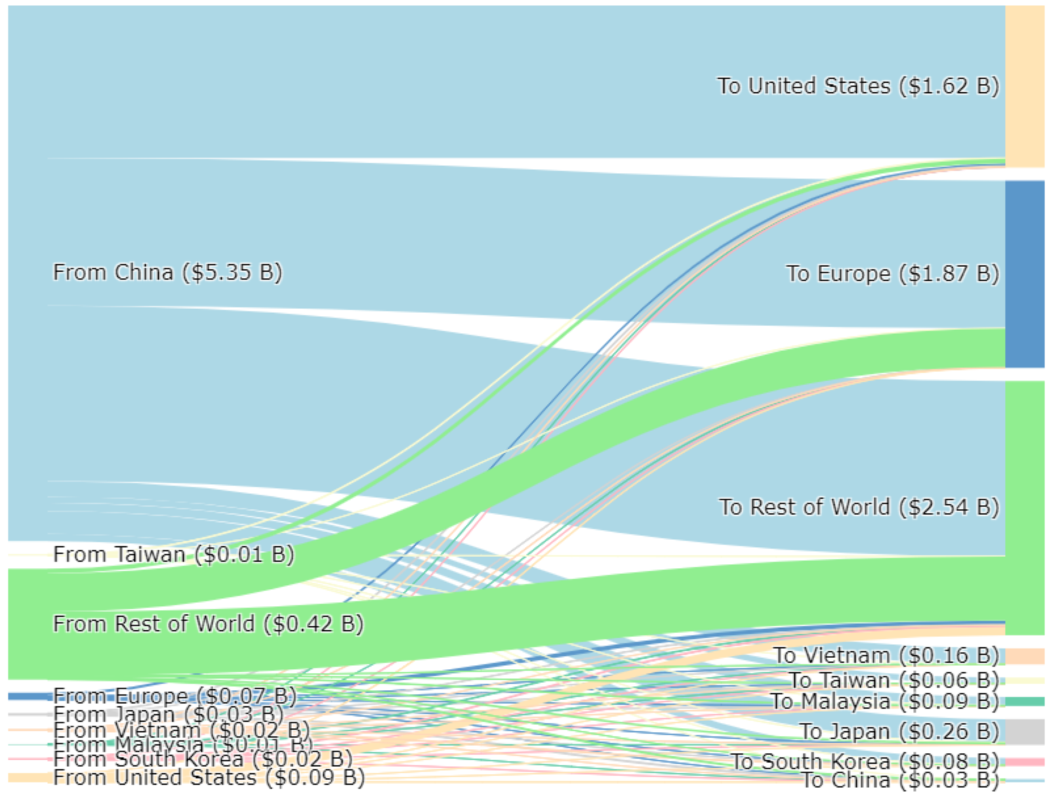


Figure ES-2. Global trade flow of LED lamps, 2019 [3]. This data only includes exports to other countries and does not include LED lamps manufactured for domestic consumption. The total global market for LED lamps for general lighting in 2019 was $10.6 billion [5] and the total global exports were approximately $6.7 billion [3].

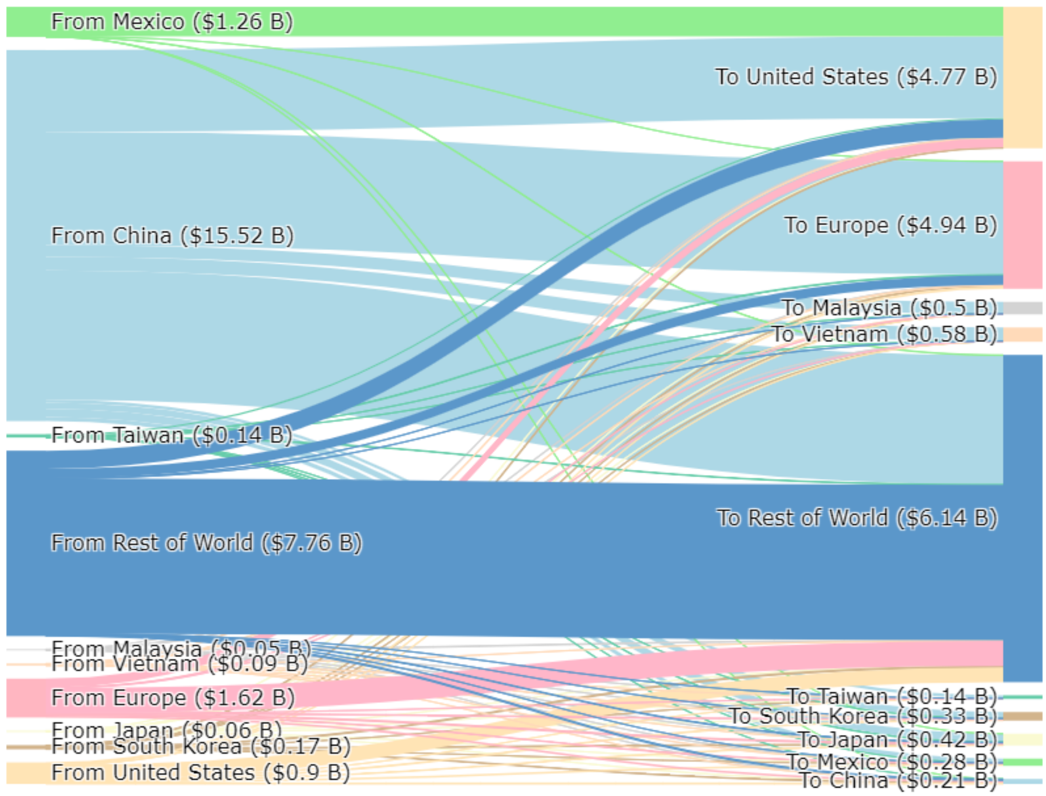


**Figure ES-3. Global trade flow of LED luminaires, 2019 [3]. This data only includes exports to other countries and does not include LED luminaires manufactured for domestic consumption. The total global market for LED luminaires for general lighting in 2019 was $50.6 billion [5] and the total global exports were approximately $27.6 billion [3]. LED luminaires were approximated from total lighting fixture trade data based on global LED market share in 2019.**

Recent macroeconomic events also impacted the global supply chain for LED lighting. Most notably, in 2018 and 2019, the Section 301-China tariffs placed a 25% levy on LED packages and LED luminaires imported to the United States from China. The global supply chain was further disrupted by the COVID-19 pandemic. Major findings regarding these disruptions include the following:

- Because of the globalized production of LEDs and LED lighting products, the Section 301-China tariffs had varied impacts depending on the specific geographical manufacturing presence of each company.
- When LED package manufacturers sold their products originating in China into the U.S. market, 20%–100% of the tariff costs were passed on to customers as price increases, reflecting a 5%–25% price increase in line with the tariff value.
- LED luminaire manufacturers stated that Section 301-China tariffs drove production out of China. Manufacturers stated that in some cases they had migrated up to 40% of production lines from China into Malaysia and Vietnam.
- At this time, the impacts of the COVID-19 pandemic are still unfolding. Over the first 9 months of the pandemic, manufacturers stated there was both declining demand for commercial retrofit projects and localized supply disruptions. In contrast, the residential and outdoor lighting market demand had remained stable, according to industry feedback.

The trade analysis revealed that manufacturing of LED packages is dominated by five Asian countries while manufacturing of LED products is dominated by China. The majority of LED manufacturers have some manufacturing in China or countries with lower labor costs. Manufacturers also indicated there is little opportunity to bring manufacturing of LED die and LED packages to the United States. However, manufacturing potential in the United States remains for the LED luminaire market. In 2019, the total size of the North American LED luminaire market was estimated to be $11.6 billion, of which the United States is about $10.2 billion.[1] [6] [7] [8] [9] Accounting for 25% distributor markups, this represents approximately $8.14 billion in manufacturer assessed-value. In the same year, the United States imported $4.7 billion of LED luminaires, indicating the remaining market needs are fulfilled with LED luminaires manufactured domestically.

The following are opportunities for increased U.S. presence within the LED lighting supply chain:

- High-end LED luminaires, often with high variability in design, features, and customization
- LED luminaires that require fast lead times while maintaining lower inventories
- Niche market LED lighting products, such as UV and human-centric lighting
- Using additive manufacturing and 3D printing techniques, developing tools and molds, designing architectural luminaires, and fabricating luminaire components with fewer process steps or more automation.

Manufacturers indicated that further R&D is needed to support these opportunities and will be necessary to make these areas competitive in the United States.

[1] Estimated based on commercial building stock square footage for U.S., Canada, and Mexico

# Table of Contents

# List of Figures

# List of Tables

# 1 Introduction

Since their commercial introduction, light-emitting diode (LED) technology has enabled energy savings as lighting technology shifted from vacuum-based conventional lighting technologies—incandescent, fluorescent, and high-intensity discharge—to LED-based lighting. Due to improvements in scientific understanding and its underlying technology, LED lighting now outperforms many baseline technologies in energy efficiency, lifetime, versatility, and color quality. Furthermore, manufacturing advancements, increased demand, and the development of a global supply chain network have made LED lighting products cost-competitive to conventional technologies in most lighting applications.

The U.S. Department of Energy's (DOE) 2020 *Adoption of Light-Emitting Diodes in Common Lighting Applications* study showed that, as of 2018, LED penetration was 29.8% for indoor lighting and 51.4% for outdoor lighting in the United States. [1] Additionally, DOE's *Energy Savings Forecast of Solid-State Lighting in General Illumination Applications* forecasts that LED lighting will represent 84% of all lighting sales by 2035, resulting in annual primary energy savings of 4.8 quadrillion British thermal units (Btu). [2] The low costs of manufacturing overseas resulted in Asia being the primary manufacturing hub of LED and LED lighting products. However, there is also significant presence of LED lighting product manufacturing in geographic locations beyond Asia, closer to the end-consumer.

This report aims to characterize the globalized manufacturing supply chain of LEDs and LED lighting products and investigate the economic impacts of this supply chain on the United States by addressing five research questions:

1. How is the manufacturing process structured for typical solid-state lighting (SSL) general illumination products?

2. What is the value added for a typical LED luminaire manufactured in the United States versus internationally?

3. What proportion of LED products are manufactured and assembled in the United States and internationally?

4. What is the impact of an economic event (e.g., tariffs) on the SSL manufacturing process and to the final consumer?

5. What are the domestic opportunities for SSL manufacturing in the global lighting supply chain?

The LED lighting supply chain is made up of three principle stages of LED products: LED die, LED package, and LED lamp or luminaire. Figure 1-1 shows an example LED package containing an LED die. The LED die (also called an LED chip) is the light-emitting source within the LED package.

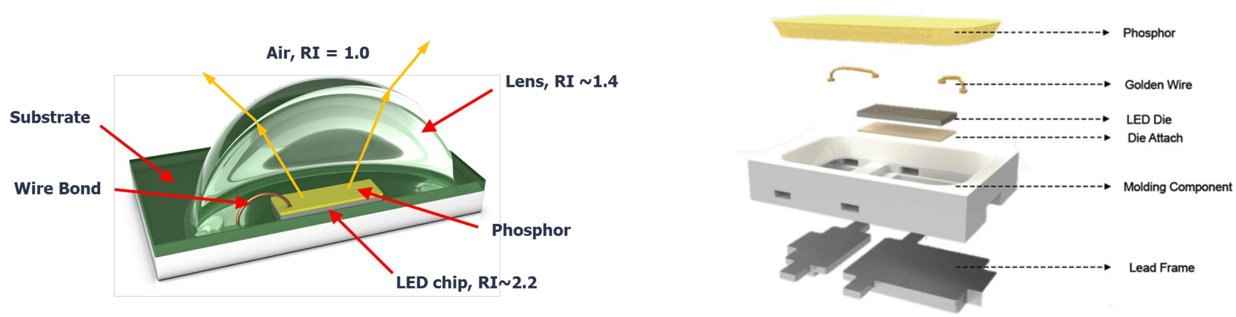


Figure 1-1. Schematic diagram of an LED package.

The LED die and package are upstream products within the LED lighting supply chain. LED packages are then mounted on printed circuit boards to serve as the light source for downstream lighting products. Assembled with several other subsystems, such as drivers, optics, and heatsink/housing, the LEDs are eventually assembled into a lamp or luminaire. Figure 1-2 shows a common LED lamp form factor, the A19 lamp, and a common commercial LED luminaire, the 2’ x 4’ troffer. LED lamps serve as screw-in, pin, or other general service lamp replacements and can be directly swapped with a conventional incandescent, fluorescent, or high-intensity discharge bulb. LED luminaires are far more integrated than LED lamps and are designed to replace the entire existing conventional lighting fixture, not just the bulb.

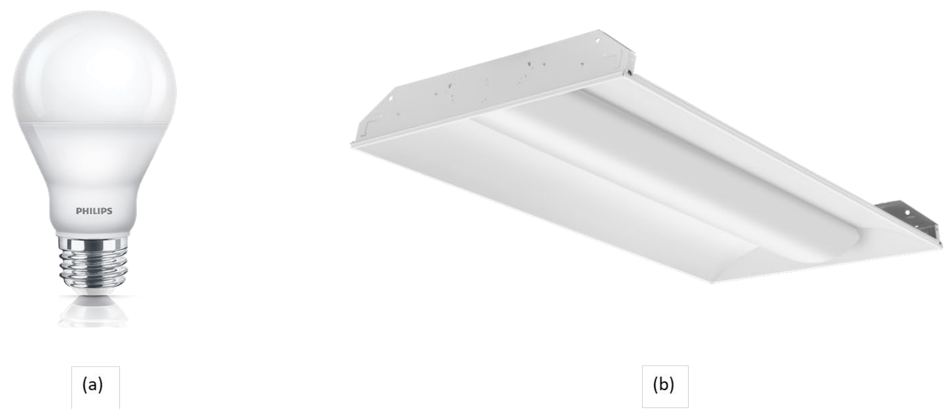


Figure 1-2. a) Philips A-Type LED lamp [10], b) Lithonia Lighting GT Series General-Purpose Recessed LED Troffer [11].

This report considers the how LED supply chains have shifted over the last decade in response to the rapid maturation of the LED lighting market. To examine the current global status of various steps of the supply chain, the study combined a number of data sources, including trade data, market reports, and interviews with LED die, package, and lamp/luminaire manufacturers. The report investigates which areas of the supply chain are generally offshore and identifies the key geographical and economic players involved in the supply chain that leads to the LED lighting end consumer in the United States. In doing so, the report seeks to define where the domestic manufacturing opportunities are from an economic and competitive feasibility perspective. Onshore manufacturing during any stage of the LED lighting supply chain could enable infrastructure development and provide long-term domestic manufacturing jobs and other benefits.

# 2 Structure of the LED Manufacturing Supply Chain

The manufacturing processes involved in the production of LEDs and LED lighting products can be broken up into discrete steps. These processes are supported by a supply of raw materials, manufacturing equipment, and testing equipment designed to ensure product quality. This combination of the manufacturing processes, equipment, materials, and testing constitute the manufacturing supply chain.

## 2.1 Stages of SSL Manufacturing and Current Process

Figure 2-1 outlines the current manufacturing process that leads to LED lamps and luminaires. The process links steps that contain three discrete products, each representing a tradeable good: the LED die, the LED package, and the LED luminaire (or LED lamp). Figure 2-1 is a schematic representation of the LED-based SSL manufacturing supply chain. The blue-shaded boxes and blue arrows describe the main manufacturing flow. The supporting elements of the supply chain are broken down into manufacturing equipment, materials, and test and measurement equipment. These supporting elements feed into the main manufacturing flow as indicated by the relevant arrows.

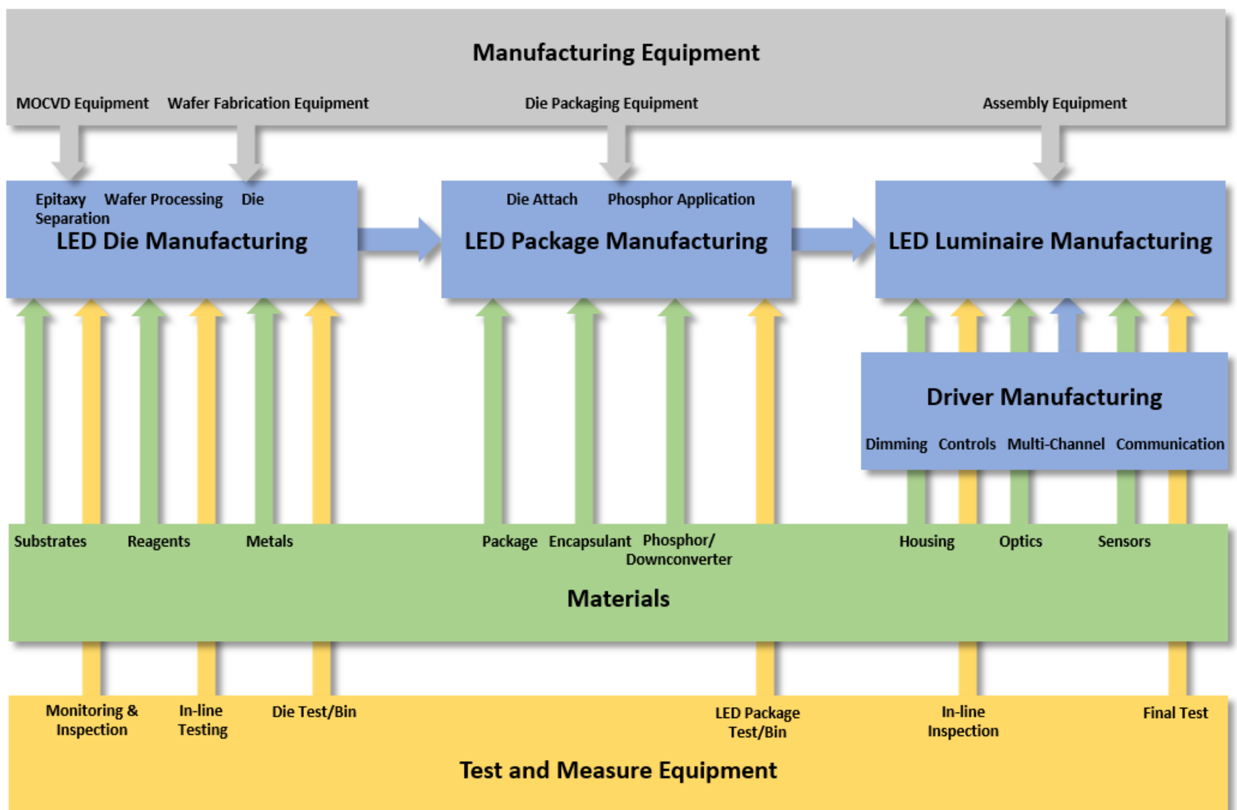


Figure 2-1. LED lighting supply chain.

The manufacturing process for LED lighting begins with LED die manufacturing, which consists of growing the LED wafer by metal organic chemical vapor deposition, processing the LED wafer by mostly conventional semiconductor processes, and separating the LED wafer into individual LED chips. Next, the LED die/chip is typically mounted into LED packages, including depositing phosphor material to convert the blue LED emission to white light. Finally, the LED packages are mounted onto a printed circuit board and integrated into the end luminaire or lamp product. End products, such as luminaires, are integrated products that contain mounted LED packages, a driver, heat sink, optics, and a general housing structure with specific form factors by end use.

## 2.2 Global LED Lighting Supply Chain

LED and LED lighting manufacturing are global enterprises with a globalized supply chain and customer base. Since the commercial introduction of LED lamps and luminaires more than a decade ago, the LED lighting industry has matured, and the supply chain has evolved.

In the early days of LED adoption, the leading companies involved in the LED lighting industry were often vertically integrated and involved in a number of the processes described in Section 2.1. to provide the necessary performance level and cost structure for market success. As the market has matured, the various pieces of the LED lighting supply chain have become disaggregated; different companies have developed expertise in specific areas of manufacturing. For example, as the LED die and package manufacturing has become most commoditized, the advantage of being vertically integrated has lessened, allowing for more entrants to compete since the technical know-how required to develop high performance LED lighting fixtures has eased with the proliferation of commodity LED packages. Thus, the global LED lighting industry has achieved greater manufacturing efficiency, which is reflected in the marked increase in product volume and the factors of magnitude decrease in cost. Most LED die and package manufacturers are no longer directly involved in manufacturing LED lamps and luminaires, and vice versa.

Table 2-1 highlights the global nature of SSL manufacturing by listing some of the key companies involved in the manufacturing of LED-based SSL products in each major geographic region. The number of companies that manufacture LEDs, LED lamps, and LED luminaires grown significantly to fill the varying form factors, end-use applications, and needs of customers worldwide, and therefore this list is not an exhaustive survey of all manufacturers, but a compilation of prominent companies.

**Table 2-1. Prominent Manufacturers in the LED Supply Chain – Die, Package, and Luminaire**

| Supply Chain Stage | North America | Europe | Asia |
|---|---|---|---|
| **LED Die & Package** | Lumileds<br>Cree (Smart Global Holdings) | OSRAM Opto Semiconductors | Nichia<br>Seoul Semiconductor<br>Mulinsen (MLS)<br>Sanan Optoelectronics<br>Samsung<br>LG Innotek<br>Everlight<br>Epistar<br>Lextar<br>Bridgelux<br>HC Semitek<br>Luminus Devices<br>Lumens<br>Citizen<br>Stanley<br>Toyoda Gosei<br>Nationstar<br>LITE-ON<br>Kingbright<br>Shenzhen Jufei<br>Edison Opto<br>Unity Opto<br>Shenzen Refond Opto<br>Hongli Opto<br>Jiangsu Aucksun<br>Shenzhen ChangFan<br>Changelight<br>Shenzhen Manson |
| **LED Luminaire**[1] | Acuity Brands<br>GE Current<br>Hubbell Lighting<br>Cree Lighting<br>Eaton<br>Finelite<br>Ecosense Lighting<br>Lighting Science<br>Maxlite<br>Energy Focus<br>Green Creative<br>Feit Electric<br>ETC<br>Fluence<br>E-conolight<br>Soltech | Signify<br>Zumtobel<br>TCP<br>Coelux<br>Regent Lighting<br>Trilux<br>Halla<br>Siteco | LEDVance<br>Leedarson<br>LG<br>Sharp<br>Panasonic<br>NVC International<br>HPWinner<br>Opple Lighting<br>Kingsun<br>Yankon Lighting<br>MatrixLED<br>Foshan Electrical Lighting<br>Xiamen Topstar Lighting<br>PAK Corp<br>Sengled Optoelectronics<br>MinebeaMitsumi |

1. There are a large number of LED lamp and luminaire manufacturers. The manufacturers listed above are just an example of large brand name manufacturers.

With few notable exceptions, epitaxy and wafer fabrication is geographically concentrated in Asia. Because of the highly protected intellectual property associated with this stage of the SSL supply chain, particularly with epitaxial growth of LED wafers, many manufacturers historically based these activities near their company's headquarters or home country. The processes involved in this stage of LED manufacturing are highly guarded because they involve much of a business' innovation, research, and patents. As the overall maturity of the industry has increased, this sensitivity to trade secret has lessened, leading to more epitaxial growth shifting to Asia since most LED manufacturers are capable of producing an acceptable level of performance for LED die. As Table 2-1 shows, only two domestic LED manufacturers operate in the United States, with the rest of the market primarily concentrated in Asia.

In contrast to the intellectual property-sensitive wafer fabrication, LED packaging has historically been centered in Asia. The packaging process is more labor-intensive and the benefits of reduced labor cost structures in Asia have made it a competitive marketplace for packaging. Specifically, due to economies of scale, existing infrastructure benefits, and cheap labor and know-how, China has emerged as the primary geographical center of LED packaging processes for many LED manufacturers. (The convergence of the global LED package marketplace in China and its impacts are further discussed in Section 5.) Aside from the concentration of LED package manufacturing in China, many other Asian countries have significant LED package manufacturing, including South Korea, Japan, Taiwan, Malaysia, and Vietnam.

Lamp and luminaire manufacturing has a different geographical distribution as compared to the upstream segments of the supply chain (LED die and packages). In the early 2010s, LED lamp manufacturing emerged in North America, Europe, and Asia. As customer awareness of the advantages of LED products increased and regulatory bodies and utility incentive and rebate programs helped drive LED adoption, the market volume of LED lamps has grown exponentially. LED lamps have become increasingly commoditized as a result. For example, the price of the A19 general service lamp designed to replace incandescent bulbs has declined 94% since 2010, with current prices at approximately $3 per lamp based on web-scraped distributor prices, albeit with lower lifetimes than the products originally on the market in 2010. The total installed stock of A-type LED lamps has reached 1.1 billion units in the United States. [1]

With the increasing commoditization of LED lamps in various form factors, the market has responded by shifting to accommodate increasing downward price pressure. Specifically, the LED lamp market has concentrated the production of LED lamps in China due to the same advantages that drew the LED package market into the country: cheap labor, vast manufacturing infrastructure, availability of raw materials, and government subsidies. As a result, the vast majority of LED lamp manufacturing occurs in China, where it is exported to European and North American markets. LED lamps represent a highly commoditized product with little performance variability between products of the same form factor. Most metrics for LED lamps are comparable, with similar ranges of efficacies, color quality, and lifetimes for each lamp form factor.

LED luminaire manufacturing differs significantly from LED lamp production in that there is still a worldwide distribution of manufacturing. While the LED lamp has become a commodity product with many manufacturers in a race to the bottom, most LED luminaire form factors have retained a significant amount of value and provide a unique benefit to localized manufacturing. First, luminaires are fully integrated lighting products that require significant physical volume considerations when shipping across countries or long distances, adding significantly to shipping costs. Second, LED luminaires remain highly customizable, often with manufacturers providing tens of thousands of stock keeping units (SKUs) for a single end-use application.[2] LED luminaire manufacturing represents an opportunity for continued U.S. manufacturing to supply the North American market.

As the LED lighting market continues to evolve and mature, the inherent market demand in the United States provides significant opportunity for potential domestic manufacturing and growth, particularly in the luminaire market. The complexity of lighting continues to deepen as scientific understanding progresses. Further improvements in LED luminaire design may enable additional opportunities for LED luminaires when it

[2] End-use application refers to general lighting end uses such as downlights or high-bay lights.

comes to providing features (e.g. optical distribution control) or performance improvements (e.g. lighting application efficiency) in ways that conventional or LED lamps cannot compete. As such, the LED luminaire market represents an opportunity to retain manufacturing onshore and provide the greatest value to the end consumer and the U.S. economy.

# 3 LED Luminaire Value Added Analysis

Value added analysis is used to determine the effects of a globalized supply chain on technologically advanced products, such as LEDs and LED lighting. In traditional manufacturing, large companies have historically designed and manufactured their products in-house, often using components and supply chains based within the company (if not within the economy or country itself). However, the supply chain of many modern technologies, including LED lighting products, has been widely distributed across companies, countries, and even continents. Within the supply chain of a single product, each constituent component manufacturer or material supplier purchases inputs, such as materials and upstream components, then adds value. These subcomponents and materials are then used as costs in the next stage of production.

This value added analysis focused on a typical 2' x 4' LED troffer, as LED troffers represent one of the most common commercial LED luminaire installations. To break down the value added of a typical commercial LED luminaire, the 2' x 4' LED troffer was analyzed using known cost variables. This analysis assumes a commodity level 2' x 4' LED center basket troffer with average performance (approximately 4000 lumen output at 3000 K, with a CRI of 80).

A typical LED troffer product has the manufacturing cost breakdown shown in Figure 3-1. The LED light engine costs include the cost of LED packages and printed circuit boards (PCBs). The overhead included in the cost refers to factory overhead consisting of labor, manufacturing, equipment depreciation, documentation, in-line and compliance testing, shipping, and distribution. In addition to the costs of the luminaire, there are manufacturer markups, as well an additional channel margin of approximately 20% to 30%. [12]

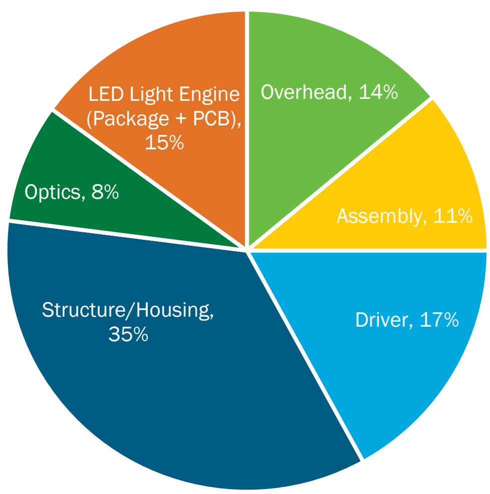


Figure 3-1. Cost breakdown for LED troffers. Source: Stakeholder and industry feedback. The costs associated with an LED troffer are estimated as follows in order of largest to smallest: structure/housing (35%), driver (17%), LED lighting engine (15%), overhead (14%), assembly (11%), and optics (8%). The overheard included in this cost refers to factory overhead. The cost of the LED Light engine (15%) can be further broken down to the cost of LED packages (5%) and the PCB (10%).

Since their market introduction, LED package costs have dropped tremendously and are no longer a large portion of the total product cost. In 2014, LED packages constituted up to 33% of the cost of an LED luminaire. [13] Massive economies of scale, global competition, and in some cases, oversupply of LED packages have led to commoditization of some common package form factors and brought the costs for LED packages down dramatically. In current LED luminaires, the proportion of luminaire costs associated with LED packages range from 3% to 9% depending on form factor and end-use application. [12] For LED troffers, about 5% of the total product cost is associated with the cost for LED packages, with an additional 10% associated with the PCB.

Table 3-1 shows the cost breakdown and estimated manufacturing value added for a typical 2' x 4' LED troffer assembled in the United States. The gross margins correspond to an estimated typical gross margin of various global publicly traded companies that supply each part.[3] It can be assumed with reasonable confidence that the driver, PCBs, and LED packages are sourced from overseas markets, with Asia being the most likely source. Interviews with manufacturers indicated that the assembly and structural components of an LED luminaire assembled in the United States would be domestically sourced. For a typical 2' x 4' LED troffer assembled in the United States, approximately 75% of the value added from manufacturing is to the U.S. economy and 25% of the value added from manufacturing can be attributable to foreign economies.

**Table 3-1. Estimated Manufacturing Value Added of a Typical 2' x 4' LED Troffer, Assembled in the United States**

| | Cost Breakdown | Estimated Cost ($) | Estimated Gross Margin | Domestically Sourced? | Domestic Value Added ($) | Foreign Value Added ($) |
|---|---|---|---|---|---|---|
| Factory Overhead | 14% | 6 | 23% | Yes | 1 | - |
| Assembly | 11% | 5 | 23% | Yes | 1 | - |
| Driver | 17% | 7 | 18% | No | - | 1 |
| Structure/Housing | 35% | 15 | 23% | Yes | 3 | - |
| Optics | 8% | 3 | 26% | Yes | 1 | - |
| LED Light Engine | 15% | 6 | 15% | No | - | 1 |
| | | | | **Manufacturing Value Added* ($)** | **7** | **2** |
| | | | | | **75%** | **25%** |

*Values may not add due to rounding.

Moving beyond the manufacturing stage of the luminaire, there is additional value added from the manufacturer "markup" or gross margin on the product. Interviews with manufacturers indicated that for a typical 2' x 4' LED troffer, an average 25% markup can be expected. This accounts for the value added from the engineering, design, and profit to shareholders. Table 3-2 shows the estimated total value added of a typical 2' x 4' LED troffer assembled in the United States. Approximately 89% of the total value added is attributable to the U.S. economy and 11% of the total value added can be attributable to foreign economies.

**Table 3-2. Estimated Total Value Added of a Typical 2' x 4' LED Troffer, Assembled in the United States**

| | United States | Foreign Countries |
|---|---|---|
| Engineering, Design, and Profits* | 10 | 0 |
| Manufacturing Inputs and Assembly | 7 | 2 |
| **Total Value Added ($)**** | **17** | **2** |
| | **89%** | **11%** |

*This accounts for a 25% markup on 2'x4' LED Troffers by manufacturers, which is attributable to the engineering, design, and profits to shareholders.
** There is additional value added from wholesale, distribution, and retail that is not shown here. This additional value added would be attributable to the country of final sale.

[3] Value added can be estimated by subtracting material costs from the total sales price. However, because corporations do not separate material costs from labor costs in their reporting of cost of goods sold, a rough estimate of the value added can be obtained from gross profit. The more a corporation outsources manufacturing, the smaller difference between gross profit and value added. [30]

Table 3-3 shows the same cost breakdown with estimated manufacturing value added for a typical 2' x 4' LED troffer assembled in Mexico. In this instance, the troffer is assembled in Mexico by a U.S. company and the value added results differ significantly compared to those assembled in the United States. In this case, all of the manufacturing value added can be attributed to Mexico, with no manufacturing value added attributable to the United States. It is significant to note that aside from the United States, Mexico is a major manufacturing hub for LED luminaires sold in the United States.

**Table 3-3. Estimated Manufacturing Value Added of a Typical 2' x 4' LED Troffer, Assembled in Mexico**

| | Cost Breakdown | Estimated Cost ($) | Estimated Gross Margin | Domestically Sourced? | Domestic Value Added ($) | Foreign Value Added ($) |
|---|---|---|---|---|---|---|
| Factory Overhead | 14% | 6 | 23% | No | - | 1 |
| Assembly | 11% | 5 | 23% | No | - | 1 |
| Driver | 17% | 7 | 18% | No | - | 1 |
| Structure/Housing | 35% | 15 | 23% | No | - | 3 |
| Optics | 8% | 3 | 20% | No | - | 1 |
| LED Light Engine | 15% | 6 | 15% | No | - | 1 |
| | | | | Manufacturing Value Added* ($) | 0 | 9 |
| | | | | | 0% | 100% |

*Values may not add due to rounding.

However, the additional value added from the engineering, design, and profit to shareholders is still maintained in the United States, as seen in Table 3-4. For a typical 2' x 4' LED troffer assembled in Mexico by a U.S. based company, approximately 55% of the total value added is to the U.S. economy and 45% of the total value added can be attributable to foreign economies.

**Table 3-4. Estimated Total Value Added of a Typical 2' x 4' LED Troffer, Assembled in Mexico**

| | United States | Foreign Countries |
|---|---|---|
| Engineering, Design, and Profits* | 10 | 0 |
| Manufacturing Inputs and Assembly | 0 | 9 |
| **Total Value Added ($)**** | **10** | **9** |
| | **55%** | **45%** |

*This accounts for a 25% markup on 2'x4' LED Troffers by manufacturers, which is attributable to the engineering, design, and profits to shareholders.
** There is additional value added from wholesale, distribution, and retail that is not shown here. This additional value added would be attributable to the country of final sale.

This value added analysis indicates that while the majority of the value added for a typical 2' x 4' LED troffer can be attributed to the country in which the product is designed and the company is based, a significant portion of the value added can be attributable to the economy in which the luminaire is manufactured, with most of this value coming from the overhead, assembly, and structural components. Manufacturers indicated that structural components of luminaires are generally sourced close to the location of assembly. Furthermore, the large costs associated with the structural components showcase a strong opportunity for the United States to retain or bring back the manufacturing of LED luminaires onshore and provide high quality products, quick turnarounds, and minimize the logistical burdens associated with shipping large luminaires. A recent study has shown that the costs of internationally shipping large volume luminaires (such as troffers) is high enough to negate much of the cost savings associated with manufacturing these luminaires overseas. [14] However, as shipping costs often scale with weight, volume, or both, specific form-factors may have different advantages when considering manufacturing overseas versus domestically.

The cost breakdown for luminaires can vary significantly depending on the application and end use. For example, products with inherently high light output requirements, such as area/roadway luminaires or high-bay luminaires, may have significantly higher costs associated with components that are often manufactured overseas, such as LED packages and drivers.

# 4 LED Lighting Trade Analysis

## 4.1 Determining Country of Origin

When determining the official country of origin of a LED or LED lighting product for trade purposes, the total assessed value of the finished good relative to the constituent components that make up the product must be determined. For the U.S. lighting market, Mexico is one of the largest hubs of LED luminaire manufacturing for lighting products, with only China contributing more to U.S. imports. In addition, LED luminaires manufactured in the United States or Mexico for the U.S. lighting market typically contain LED components manufactured in China or other Asian countries. For these reasons, North American lighting manufacturers indicated the importance of trade flow between Mexico and the United States and determining the country of origin.

Country of origin refers to whether a lighting product assembled in Mexico constitutes a "made in Mexico" product, even if most of the components originate in other Asian countries. The country of origin issue was of particular interest in the United States when the Section 301-China tariffs went into effect in 2018 and 2019; these tariffs levied a 25% tariff on all LED packages from China beginning in July 2018 and a 10% tariff on LED luminaires from China beginning in September 2018. The 10% tariff on LED luminaires was increased to 25% in May 2019.

Beyond LED packages and luminaires directly imported to the United States from China, there were effects on LED lighting products made elsewhere. Many North American manufacturers assemble in locations such as Monterrey, Mexico, and ship products to be sold in the United States. If these products contain components from China, they potentially (depending on how much the final value of the product is from Chinese components) face tariffs when they enter the United States.

There are two ways to officially determine the country of origin of lamps and luminaires. Of key interest is how the former North American Free Trade Agreement (NAFTA) and its successor, the United States-Mexico-Canada Agreement (USMCA), treat LED lighting products and determine the country of origin tag. For a discussion on how LEDs are treated within the NAFTA and USMCA framework, see Appendix A. While there are some exceptions to the rule throughout NAFTA and USMCA, both agreements use the same methods to calculate regional value content (RVC) and the thresholds to determine country of origin. [15] RVC is a calculated value used to determine the country from a good originates based on a percentage of originating content value. USMCA and NAFTA allow two methods to calculate this content value: the transaction value method (TVM) and the net cost method (NCM). The TVM calculates the RVC based on the total transacted value of the imported good, while the NCM uses the net cost to produce the good. Both NAFTA and USMCA set threshold values of 60% for the TVM and 50% for the NCM; if a good's RVC is higher than the threshold value for either of these calculations after having been transformed within a country, the good is considered as originating from that country. The calculation methods for each method can be seen below:

$$\boldsymbol{Transaction\ Value\ Method}:$$

$$RVC = \frac{(Transaction\ Value\ of\ the\ good -\ Value\ of\ Non\ Originating\ Materials)}{Transaction\ Value\ of\ the\ good}\ x\ 100$$

$$\boldsymbol{Net\ Cost\ Method}:$$

$$RVC = \frac{(Net\ Cost\ of\ the\ good -\ Value\ of\ Non\ Originating\ Materials)}{Net\ Cost\ of\ the\ good}\ x\ 100$$

Although some manufacturers indicated industry concern regarding the new USMCA deal prior to the final deal's announcement, LEDs and LED lighting products are treated the same under USMCA as under NAFTA, allowing continuity between the two trade agreements for lighting manufacturers that operate in the North American market. These two calculation methods for determining country of origin are the standard to determine if lighting products assembled in Mexico with Chinese components would be subject to tariffs when entering the United States.

For the trade data analyzed in the following sections 4.4 and 4.5, the country of origin was determined using either of the RVC methods above. For example, a luminaire assembled in Mexico may have a significant number of components sourced from China but could be imported into the United States as a product of Mexico if the RVC threshold is met. In this case, the total value of the luminaire would be counted as an import from Mexico.

## 4.2 Harmonized Tariff Schedule Codes for LED Products

The Harmonized System is a hierarchical structure that describes all trade goods for duty and reporting purposes across countries. This report identified four Harmonized Tariff Schedule (HTS) codes of goods with descriptions specific to LEDs or lighting that were determined to impact the manufacture and sale of LEDs and LED lighting products within the United States. With the exception of HTS code 8541.40.20, which reaches the HTS-8 level of granularity, all identified categories are at the HTS-6 level, which is consistent across all trading partners (i.e., all countries use the same HTS codes up to the detail of six digits). Individual countries often extend those codes for further classification—for example, the United States classifies products down to the HTS-10 level. [16]

In addition to the descriptions provided by each HTS level, the analysis examined rulings decided by the U.S. Customs and Border Protection related to tariff classifications. These rulings are often requested by persons or businesses that plan to import a particular good to the United States and require clarity on how the good fits into the existing HTS. [17] The analysis determined that, among the products that are inputs to fabricating and manufacturing LEDs, packages [18] on tapes and reels [19] are considered in HTS code 8541.40.20, "Light-emitting diodes (LED's)," while LED boards [20] and chips on board [21] are not. Once LED packages are transformed into modules, they are classified under HTS code 9405. [22]

## 4.3 Data Sources and Methodology

The data used to conduct the LED trade flow analysis was gathered from the United Nations International Trade Centre Trade Map website,[4] which aggregates data from different sources, including the United Nations Comtrade Database and individual countries' trade statistics. [3]

For this analysis, trade flows were broken into three categories of goods representing different stages of the LED lighting supply chain: LED packages, LED lamps, and lighting fixtures and luminaires. Specific HTS codes were identified (seen in Table 4-1) that covered the products traded.

**Table 4-1. HTS Codes and Corresponding LED Lighting Manufacturing Stages**

| HTS Code | Description | Production Stage |
|---|---|---|
| 8539.50[1] | Light-emitting diode (LED) lamps[1] | LED lamps |
| 8541.40.XX[2] | Light-emitting diodes (LED's) | LED packages and die |
| 9405.10[3] | Chandeliers and other electric ceiling or wall lighting fittings, excluding those of a kind used for lighting public open spaces or thoroughfares | Lighting fixtures/luminaires[3] |
| 9405.40[3] | Other electric lamps and lighting fittings | |

1. HTS code 8539.50 for LED lamps refers to LED replacement lamps designed for use in general service lighting [23]

[4] Website: https://www.trademap.org/

2. Countries in the analysis were not harmonized on the level of LED packages. The following codes were used to gather data on individual countries: China – 8541.40.10; United States – 8541.40.2000; Taiwan – 8541.40.29009, 8541.40.21908; Japan – 8541.40.010 (Imports Only), 8541.40.910 (Exports Only).
3. HTS codes 9405.10 and 9405.40 are not specific to LED source products. However, additional data from market reports were used to estimate the proportion of trade in each geographical zone attributable to LED lighting products (luminaires).

The trade analysis was developed using data from multiple sources, including import and export data between selected countries. There are some discrepancies in the data between what Country A reports exporting to Country B and what Country B reports importing from Country A. The Trade Map website lists several reasons why this is the case. Some prominent reasons include differences in trade systems and time lag (between when a product is exported and when it is received at the importing country). [24]

Additionally, Malaysia and South Korea did not self-report LED package data. In these instances, their exports were estimated using reported imports from trade partner countries or using the average export values from the other countries within the sample.

For HTS codes 9405.10 and 9405.40, the international trade data available is not specific to LED lighting products; rather, it encompasses all lighting fixtures and luminaires, including conventional technologies such as incandescent, fluorescent, and high-intensity discharge. Combined with data available through market reports, the total size of the lighting market, including total LED versus non-LED, is known for North America, Europe, and Asia. [6] [7] [8] [9] The raw trade flow data using the 9405.10 and 9405.40 HTS codes can be broken down further to calculate the estimated proportion of LED lighting trade flows by using this market data (about 66% in 2019), thereby producing an estimate of LED trade flows for each region.

Similarly, for HTS code 8541.40, the international trade data available is not specific to LED packages for general illumination lighting; rather, it encompasses all LED packages used in applications including displays, mobile phones, automobiles, signs, mini-LEDs, lighting, and all others. To estimate LED packages used in general illumination lighting only, the analysis applied the known LED package market share for general lighting (about 36% in 2019) to the raw trade flow data for code 8539.50. [4]

## 4.4 LED and LED Lighting Trade Flow Analysis

The results of the LED and LED lighting trade analysis in this study is based on trade data spanning a range from 2015-2019, with a primary focus on 2019. An analysis conducted by the Clean Energy Manufacturing Analysis Center (CEMAC) provides a historical view of LED package trade flows in 2014.[5]

LED die and package exports are concentrated in a small handful of countries. Figure 4-1 illustrates the flow of LED packages between nine countries of interest: Taiwan, Japan, South Korea, Malaysia, Germany, Vietnam, Mexico, China, and the United States. The figure shows how Asian countries dominate LED production, with five countries exporting between $0.34 and $0.77 billion worth of LEDs. Of the $3.1 billion in exports from these countries in 2019, China imported about 42% ($1.32 billion), which aligns with the expectations of global LED manufacturing companies. Intellectual property-sensitive epitaxial growth and wafer fabrication of LED die is more geographically distributed based on a company's home country or the location of company infrastructure, expertise, or partnerships. During the next stage of the LED supply chain—when LED die are packaged into LED packages—many manufacturers indicated they have LED packaging facilities in China. One large contributing factor is that LED packaging is one of the most labor-intensive parts of the supply chain. While Southeast Asia is a large hub of manufacturing for LED packages, export of LED packages from the United States to these eight countries is minimal, only reaching $170 million in 2019. The United States imports LED die and packages predominantly from three countries with 35% coming from Japan, 26% from China, and 20% from Malaysia (Figure 4-2).

[5] See *Benchmarks of Global Clean Energy Manufacturing,* CEMAC: https://www.nrel.gov/docs/fy17osti/65619.pdf

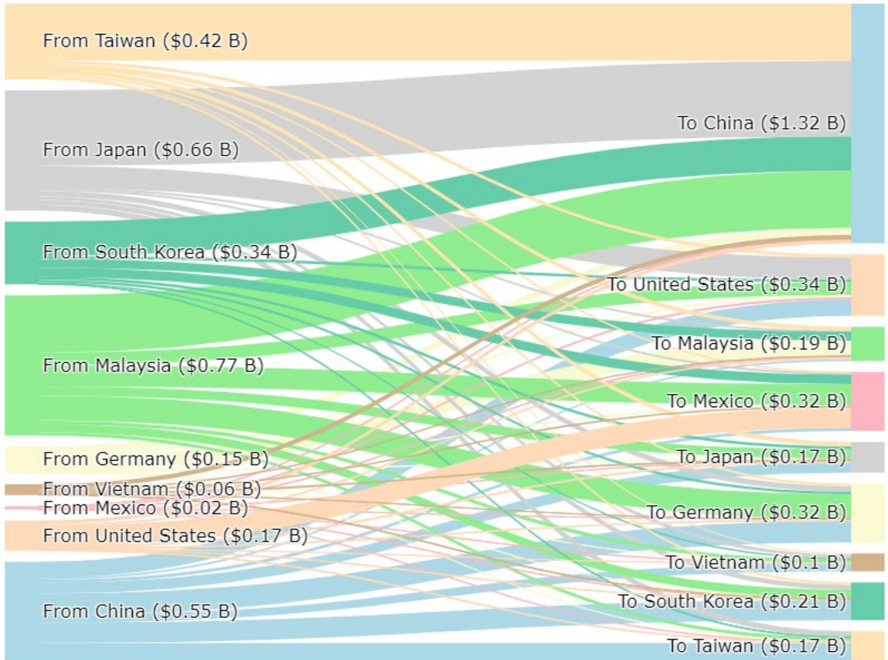


**Figure 4-1. Trade flow of LED packages and die for lighting, 2019 [3] [4]. This data only includes exports to other countries and does not include LED packages manufactured for domestic consumption. The total global market for LED packages for general lighting in 2019 was $5.6 billion [4], and the total global exports between these nine countries were approximately $3.1 billion [3]. LED packages for general lighting applications were approximated from total LED package trade data based on global market share in 2019.**

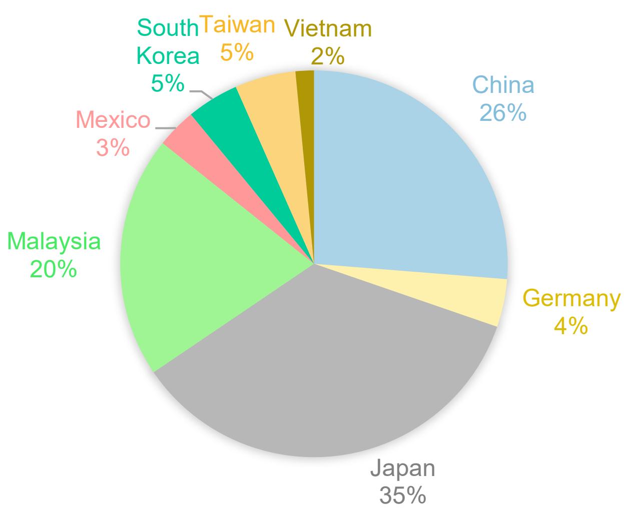


**Figure 4-2. U.S. imports of LED packages and die, 2019 [3]. In 2019, the United States imported a total of $340 million from the 8 other countries of interest listed (these countries account for the vast majority of LED die and package production globally). The United States predominantly imports LED die and packages from Japan, China, and Malaysia.**

Figure 4-3 captures worldwide LED package and die exports from 2017 to 2019 for the same nine countries. This figure shows the top Asian exporters—China, Japan, Malaysia, South Korea, and Taiwan—all exporting between $300 million and $900 million per year from 2017 to 2019. Those same countries saw decreases in worldwide exports over this time period, with China and Taiwan seeing the greatest decreases ($319 million and $198 million, respectively). The decrease in global LED package and die exports from 2018 to 2019 is the result of an oversupply of LED packages in 2018 due to increased production capacity in China and also a slowdown in the global LED lighting market that occurred in 2019. The steep drop in exports from China led to Malaysia becoming the top exporter in 2018 and 2019. Multiple manufacturers indicated they had ramped up production in Malaysia for several reasons, including the increasing cost of labor in China. They also stated the Section 301-China tariffs accelerated this product shift from China to Malaysia.

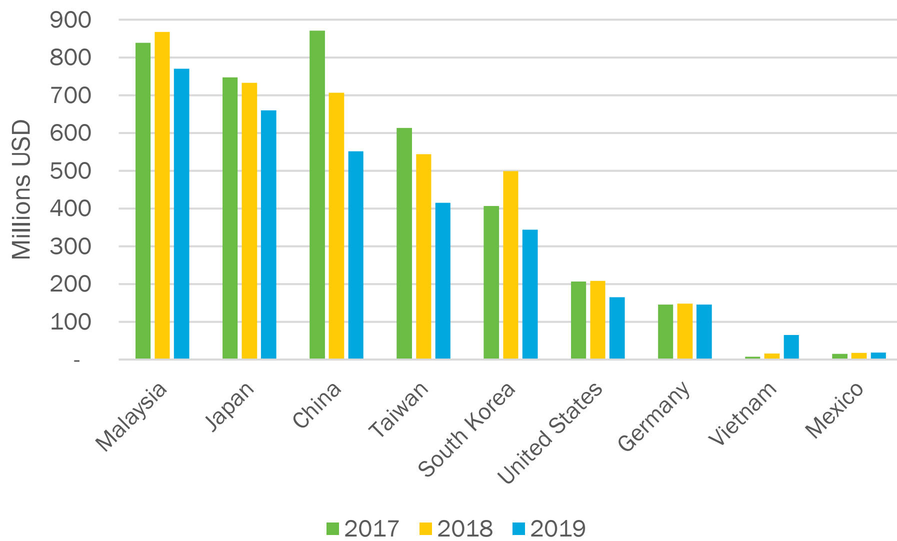


Figure 4-3. LED package and die exports by country, 2017–2019 ($ M). The top Asian exporters—China, Japan, Malaysia, South Korea, and Taiwan—all exported between $300 million and $900 million per year from 2017 to 2019. The decrease in global LED package and die exports from 2018 to 2019 is the result of an oversupply of LED packages in 2018 due to increased production capacity in China and also a slowdown in the global LED lighting market that occurred in 2019. [3]

Figure 4-4 shows the next stage of the value chain for LEDs. LED lamp production is dominated by China, which exported a total of $5.35 billion in 2019, about 80% of total global exports for that year. For comparison, the United States only exported around $92 million in 2019, or around 2% of China's value. LED lighting manufacturers also described these same trends during interviews. Nearly the entire LED lamp market, consisting of general service lamps, other screw-in replacement lamps, and tubular-LEDs (TLEDs), is manufactured in China.

LED lamp imports are dominated by the United States and Europe with 56% of LED lamp exports from China being shipped to the United States and Europe. In 2019, the United States imported $1.6 billion in LED lamps, 94% of which came from China (Figure 4-5).

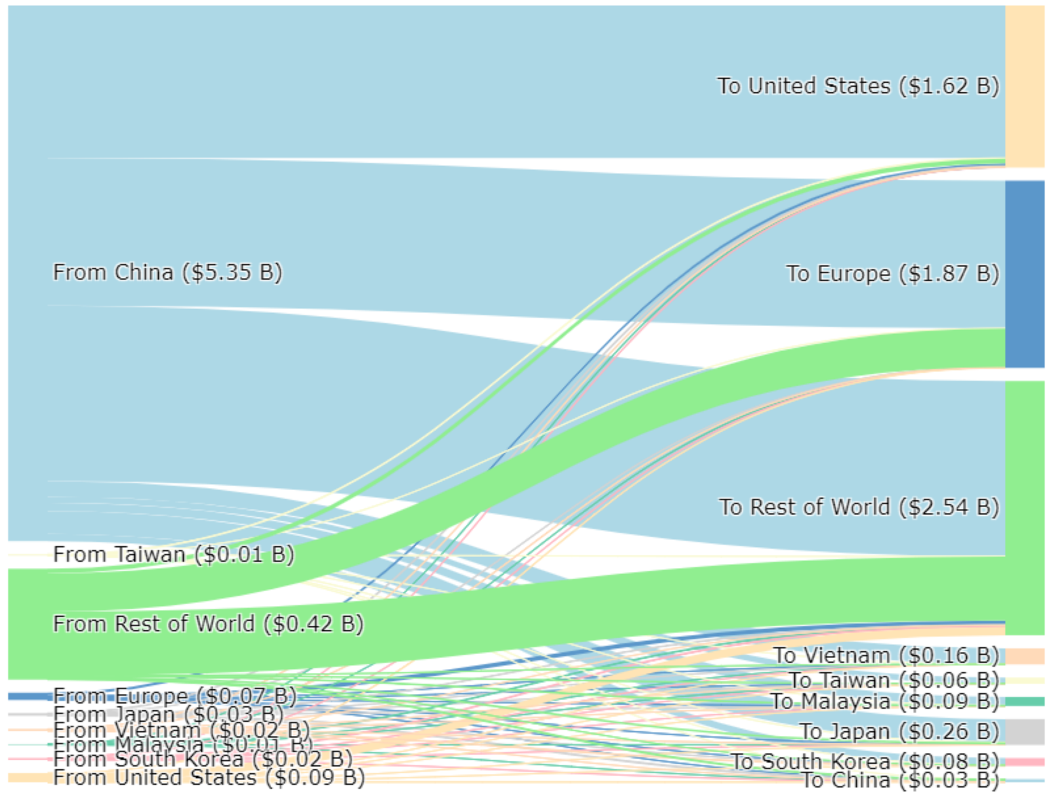


Figure 4-4. Global trade flow of LED lamps, 2019 [3]. This data only includes exports to other countries and does not include LED lamps manufactured for domestic consumption. The total global market for LED lamps for general lighting in 2019 was $10.6 billion [5] and the total global exports were approximately $6.7 billion [3].

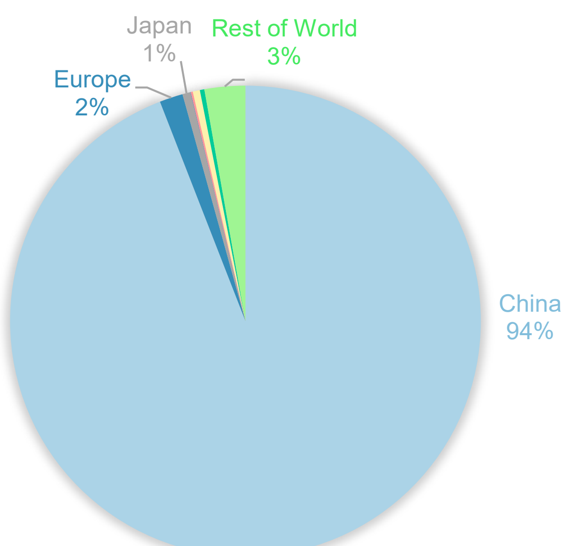


Figure 4-5. U.S. Imports of LED Lamps, 2019 [3]. In 2019, the United States imported a total of $1.62 billion of LED lamps. Of this $1.62 billion of LED lamp imports, 94% of this trade was from LED lamps manufactured in China.

The last stage in this trade flow analysis covers LED luminaires. The trade flows of LED luminaires resemble those of LED lamps: China is the main exporter and the United States and Europe are the major importers. China exported more than $15.5 billion in LED luminaires globally in 2019, $3.4 billion of which went to the United States. The United States also imported nearly $1.25 billion from Mexico to bring total U.S. imports from this sample to $4.77 billion. Mexico exports LED luminaires almost exclusively to the United States, further highlighting the importance of this trade partnership and Mexico's geographic importance in the U.S. lighting market. Overall, the United States imports around 58% of LED luminaries from China and 21% from Mexico (Figure 4-7). Due to the large physical volume of LED luminaires, the transportation costs to ship LED luminaires are significant, particularly for long distances overseas and across the globe.

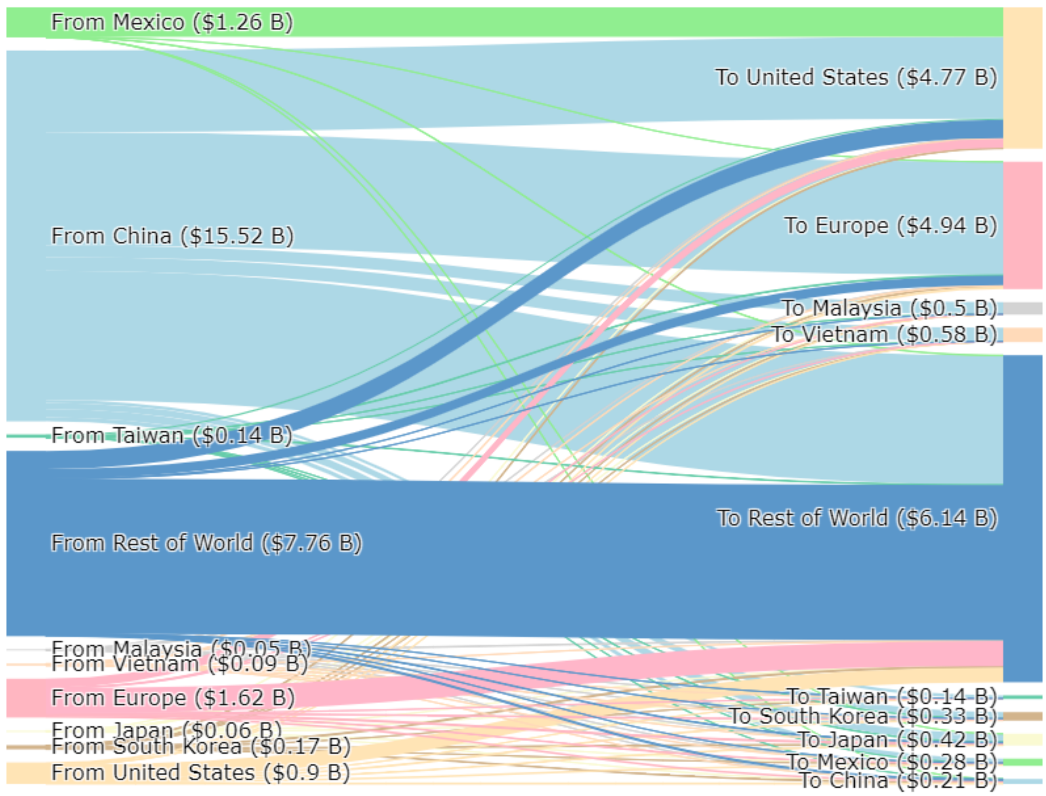


Figure 4-6. Global trade flow of LED luminaires, 2019 [3]. This data only includes exports to other countries and does not include LED luminaires manufactured for domestic consumption. The total global market for LED luminaires for general lighting in 2019 was $50.6 billion [5] and the total global exports were approximately $27.6 billion [3]. LED luminaires were approximated from total lighting fixture trade data based on global LED market share in 2019.

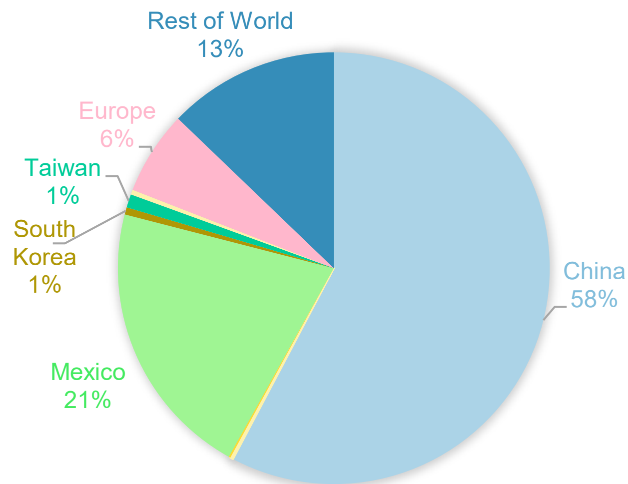


Figure 4-7. U.S. Imports of LED Luminaires, 2019 [3]. In 2019, the United States imported a total of $4.77 billion of LED luminaires. Of this $4.77 billion of LED luminaire imports, $3.4 billion (58%) came from China and $1.25 billion (21%) came from Mexico.

While Taiwan, Malaysia, South Korea, and Japan were significant exporters of LED packages (as Figure 4-1 shows), they do not have as big of a role in LED production further down the value chain. Interviews with LED luminaire manufacturers indicated a large proportion of LED luminaires are still manufactured in China due to cost of labor and materials and the industrial infrastructure. In particular, the more commodity-level luminaires, with high volumes and low variation in design (high volume, low SKU), are often manufactured in China and brought into the United States. However, the lower volume, higher variation luminaires (low volume, high SKU) are more likely to be assembled close to their end market, such as Mexico or even the United States. A significant amount of LED luminaires sold in the United States are assembled in either the United States or Mexico, with varying levels of components being sourced abroad (LED packages, LED modules, drivers, optics).

## 4.5 Status of U.S. Imports of LED Packages, Lamps, and Luminaires

Over the past 5 years, U.S. imports of LED packages have decreased from a high of $553 million in 2016 to a low of just over $368 million in 2019. Figure 4-8 shows how this decrease is driven by declining imports from China, whose imports to the United States have decreased almost 60% over the 5-year period. Over the same timeframe, imports from the rest of the world have remained relatively stable, decreasing less than 10% from $301 million in 2016 to $278 million in 2019. In 2018, the Section 301-China tariff of 25% went into effect for LED packages. As mentioned previously, the declining trend of LED package imports is likely the result of an oversupply of LED packages in 2018 due to increased production capacity in China and also a slowdown in the global LED lighting market that occurred in 2019.

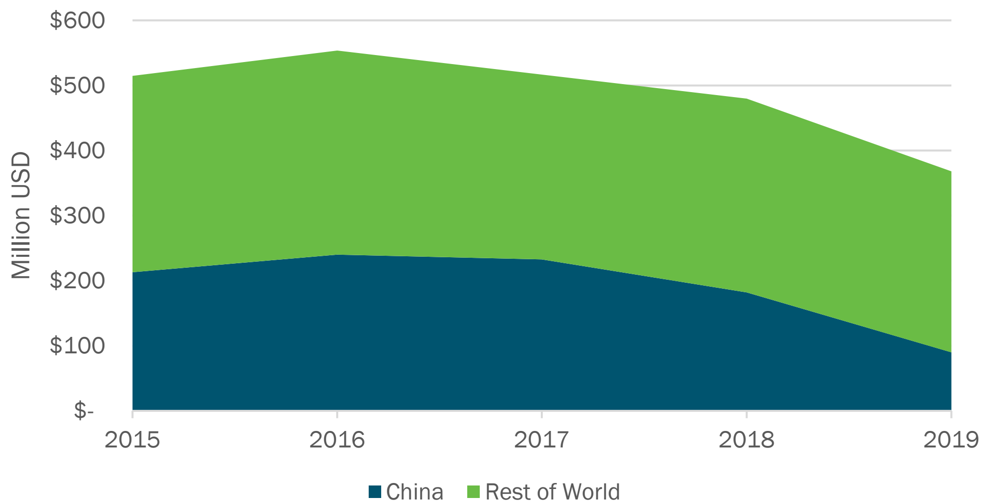


**Figure 4-8. U.S. Imports of LED packages, 2015–2019 ($ M) [3]. U.S. imports of LED packages have decreased from a high of $553 million in 2016 to a low of just over $368 million in 2019. This decrease is driven by declining imports from China, whose imports to the United States have decreased almost 60% over the 5-year period, while imports from the rest of world have remained stable over the same 5-year period.**

Despite declines in yearly trade value to the United States, China remained the United States' largest trading partner for LED packages from 2015 to 2019; the United States imported $958 million worth of LED packages from China in that timeframe. In 2019, the continued decrease in Chinese imports made Japan the largest current trading partner, despite slight declines (13%) in Japanese exports since 2015. Figure 4-9 shows the total cumulative imports from selected countries in Asia from 2015-2019, with the United States importing between $0.4 billion and $0.7 billion in LED packages from each Japan and Malaysia.

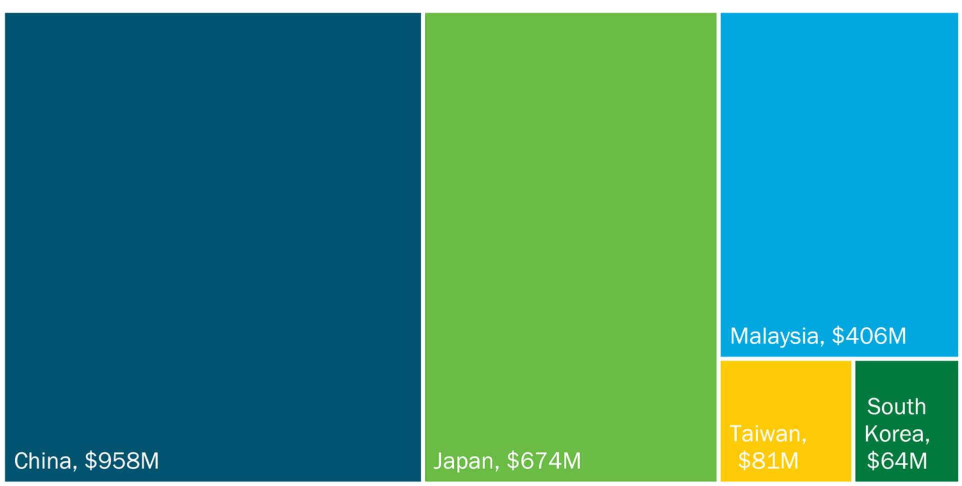


**Figure 4-9. Cumulative U.S. imports of LED packages, 2015–2019 ($ M) [3]. Despite declines in yearly trade value to the United States, China remained the United States' largest trading partner for LED packages from 2015 to 2019 on a cumulative basis.**

While U.S. imports of LED packages have decreased in recent years, imports of LED lamps have increased. In 2017, the United States imported $1.6 billion of LED lamps, which grew to $2.1 billion in 2019. This indicates the United States is producing less LED products and importing more finished products from abroad. As Figure 4-10 shows, this increase in imported LED lamps is almost exclusively due to increased imports from China, which makes up 94% of U.S. imports of LED lamps. LED lamp trade data only extends back to 2017, as the HTS code 8539.50 was delineated beginning in 2017. The LED lamp imports shown in Figure 4-10 were not subject to the Section 301-China tariffs. Trade talks between the United States and China led to the cancellation of the 25% tariffs scheduled to go into effect.

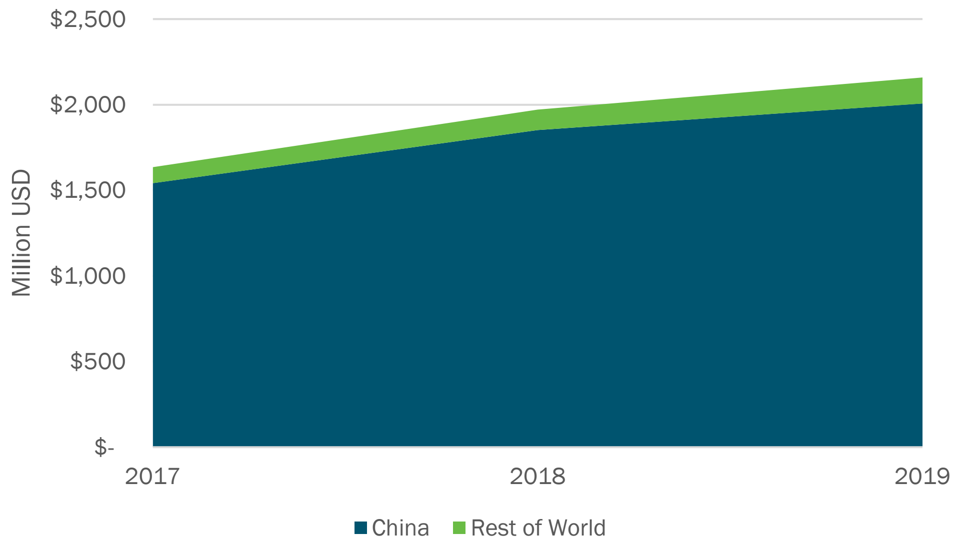


**Figure 4-10. U.S. Imports of LED lamps, 2017–2019 ($ M) ) [3]. Imports of LED lamps into the United States have been increasing. In 2017, the United States imported $1.6 billion of LED lamps. By 2019, the United States imported $2.1 billion of LED lamps. This increase of LED lamp imports is nearly exclusively due to increased imports from China.**

Figure 4-11 shows that fluctuations in yearly imports of LED luminaires to the United States since 2017 have tracked closely to imports from China. Both total U.S. imports and imports from China saw a yearly increase from 2017 to 2018 and a yearly decrease from 2018 to 2019. While U.S. imports of LED luminaires are not dominated by China in the same way as LED lamps, Chinese exports still make up 58% of U.S. imports. Imports from the rest of the world remained relatively stable.

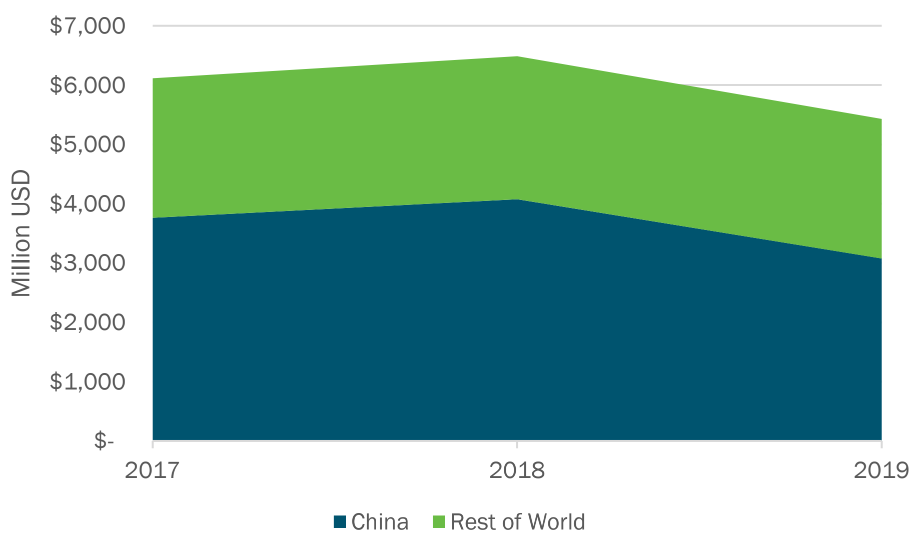


**Figure 4-11. U.S. Imports of LED luminaires, 2017–2019 ($ M) [3] [6] [7] [8] [9]. While U.S. imports of LED luminaires are not dominated by China in the same way as LED lamps, Chinese exports still make up 58% of U.S. imports. Fluctuations in total yearly imports of LED luminaires to the United States since 2017 have tracked closely to U.S. imports from China.**

# 5 Impact of Economic and Supply Chain Disruptions

A globalized supply chain network is effective for producing high volumes of LEDs and LED lighting products. However, this network of cross-border trade flows is vulnerable to macroeconomic events often outside the control of any one company or industry. Two large macroeconomic events examined in this report are the Section 301-China tariffs and the COVID-19 pandemic. These macroeconomic events revealed vulnerabilities in the LED lighting supply chain for many industry stakeholders and proved to be major hurdles for LED and lighting companies to overcome to create a more resilient and robust supply chain.

## 5.1 Section 301-China Tariffs

In August 2017, the office of the United States Trade Representative (USTR) initiated an investigation under Section 301 of the Trade Act of 1974 into the government of China's acts, policies, and practices related to technology transfer, intellectual property, and innovation. As a result of the investigation, on June 20, 2018, the USTR announced a 25% tariff on specific goods originating in China, effective July 6, 2018. Of the items included in List 1 was HTS code 8541.40.20, corresponding to LED packages. [25] On July 17, 2018, the USTR announced a 10% tariff on traded goods published in List 3 of the tariff action documents. HTS codes 9405.10 and 9405.40, corresponding to electric lighting fixtures, were included in the List 3 round of tariffs that went into effect on September 24, 2018. The goods, including LED luminaires, in List 3 underwent a tariff increase from 10% to 25% in May 2019. [26] List 4 of the tariffs included the HTS code 8539.50, and a 25% tariff was scheduled to go into effect in late 2019. However, the scheduled 25% tariff on LED lamps never went into effect. [27]

The extent of the impact resulting from the Section 301-China tariffs varied by company depending on the geographical manufacturing location, the stage in the supply chain in which the company operates, and the customer base. For example, many LED die and package manufacturers stated that even though they operate facilities in China, their LEDs are sold as intermediate components to lamp and luminaire manufacturers located in China, Southeast Asia, or Mexico. Many of these manufacturers indicated the United States is a small portion of their global customer base relative to Europe, Asia, and the rest of the world.

However, when LED package manufacturers sold their products originating in China into the U.S. market, they indicated that in most cases some of the tariff's cost was passed on to their customers. Following the implementation of the tariffs in 2018, U.S. customers for LED packages from China generally faced a price increase between 5% and 25%. In some cases, manufacturers indicated the full value of the tariff was passed on to their U.S. customers as a 25% price increase.

Downstream manufacturers also faced similar concerns. Several manufacturers indicated that nearly all of their luminaires were manufactured in China. Due to the tariffs placed on these goods, there was a significant shift in their production from China to Vietnam and Malaysia (in some cases up to 40%). Many manufacturers stated there were already plans to move out of China prior to the implementation of the tariffs because of increasing labor costs and the uncertainty that impending tariffs caused for their business planning. The tariffs between China and the United States accelerated this migration into Vietnam, Malaysia and other South East Asian countries for many of the global manufacturers; however, a large proportion of manufacturing continues to take place in China.

A major unintended consequence of the Section 301-China tariffs was that the tariffs on intermediate components (e.g., light engines) often resulted in shifting their manufacturing and production out of the United States and into Mexico. In addition, LED drivers are commonly manufactured in Mexico using components from China and then brought into the U.S. for final assembly; this avoids the Section-301 China tariffs because a tariff classification shift occurs. Further, manufacturers stated there was actually no sizeable shift to manufacture LED luminaires in the United States because of the tariffs, but did confirm a significant LED luminaire manufacturing and assembly presence remains in the United States. For a full discussion on domestic LED supply chain opportunities, see Section 6.

## 5.2 COVID-19 Pandemic

The full extent of the impact from the COVID-19 pandemic is still uncertain. Over the first 6–9 months of the pandemic, manufacturers reported substantial impacts to the supply chain including supply shortages and delays, decreased demand and sales, and both inventory surpluses and shortages (depending on the product line and manufacturer).

Supply chain impacts were generally seen early in the pandemic. Many manufacturing plants in China were shut down or forced to reduce staff and operation significantly, causing shortages in LED packages, driver components, and materials. These shortages had a ripple effect throughout the LED industry, affecting plants in other countries and exposing vulnerabilities in the global LED supply chain. A few months later, countries including Malaysia, Mexico, and the United States saw similar shutdowns and decreased manufacturing capacity. Simultaneously, the impending arrival of COVID-19 caused an initial spike in lighting product demand as many lighting projects were accelerated in anticipation of shutdowns. As a result, manufacturers struggled to keep up and saw product manufacturing delays from 4–8 weeks or more and significant backorders.

The supply chain impacts from COVID-19 also showed the resiliency that comes from having a diversified supply chain. Single-source manufacturers were hit the hardest and struggled to stay operational. On the other hand, manufacturers that were double/triple sourced from various geographic regions were well-insulated against the impacts of supply shortages. Many manufacturers had diversified suppliers already to avoid business risk while others were forced to make swift changes in anticipation of future shutdowns. However, some manufacturers with multiple sourcing options still reported difficulties as the pandemic spread. In addition, manufacturers with more complex supply chains faced more difficulties than others.

As the pandemic went on, challenges shifted from supply chain issues and shortages to decrease demand and surpluses. Many manufacturers cited a decreased demand of lighting products as the greatest challenge they are currently facing due to the pandemic. Quarterly earnings for publicly traded LED lighting manufacturers dropped substantially. Most saw around 30% decreases, with ranges from 10% to 50% earnings losses varying by region and market sector. With the shutdown of many commercial facilities and building construction delays, the commercial lighting industry saw the greatest declines in demand. Lighting manufacturers in the United States stated that many commercial retrofit projects were delayed or halted, reducing the immediate demand for their commercial luminaires. In response to the declines in sales, manufacturers also reported inventory surpluses for certain products. In particular, high-volume general lighting products have lower sales and higher inventories relative to customized and specialty lighting products. Automotive lighting showed declines that mirrored the slowdown of automobile sales. In contrast, manufacturers indicated that residential and outdoor lighting demand remained flat or even increased slightly. As shutdowns caused more people to stay home, residential lighting sales grew. Less people commuting on the roadways also allowed cities to make street lighting upgrades more easily. In addition, some niche sectors such as home improvement retailers and public schools have continued to do lighting retrofits. With more students learning from home, schools were able to save money for capital improvements and make renovations without disrupting classes.

# 6 Domestic Supply Chain Opportunities

The LED lighting trade analysis in Section 4 showed that the manufacturing of upstream LED packages is dominated by five Asian countries while manufacturing of LED lighting products is dominated by China. The majority of LED manufacturers, even U.S.-based manufacturers, have moved some manufacturing to China or countries with lower labor costs over the last decade or more, while other US companies never had domestic manufacturing. Manufacturers also indicated there is little opportunity to bring back manufacturing of early-stage LED components (chips, die) and LED packages to the United States. However, manufacturing potential in the United States remains for high-end LED luminaires, specialty and emerging lighting technologies, products with high variability (customization), and products with fast lead time requirements. Additive manufacturing/3D printing has the potential to streamline certain manufacturing processes to make U.S. manufacturing more competitive. For example, stakeholders indicated that additive manufacturing (3D printing) is being implemented for certain designing and prototyping needs, as well as to create tools for production lines. Many manufacturers cautioned that significant improvements in cost and throughput are still needed before additive manufacturing techniques can be implemented on a larger scale.

In 2019, the total size of the North American LED luminaire market was estimated to be $11.6 billion, of which the United States is about $10.2 billion.[6] [6] [7] [8] [9] Accounting for 25% distributor markups, this represents approximately $8.14 billion in manufacturer assessed-value. In the same year, the United States imported $4.7 billion of LED luminaires, indicating the remaining market needs are fulfilled with LED luminaires manufactured domestically.

## 6.1 Economic Barriers

In 2019, the United States accounted for less than 1% of total global exports of LED packages, lamps, and luminaires of major countries. Significant economic barriers limit the growth potential of U.S. LED manufacturing. First, general LED lighting products, such as LED lamps, are highly commoditized and manufacturer profit margins are razor thin. Accordingly, manufacturing for these products has been dominated by China because of their low labor costs and substantial government subsidies for production equipment and facilities. For these reasons and the high cost of labor and real estate in the United States, shifting manufacturing of LED components, packages, and lamps to the United States in the future is unlikely without significant advances in factory automation for LED wafer fabrication. Further, manufacturers with substantial capital investments in production equipment and facilities in other countries have little motivation to build new facilities in the United States. As discussed in Section 5, the Section 301-China tariff has driven shifts in assembly manufacturing from the United States to Mexico to avoid tariffs on LED components/packages imported from China. Historically, U.S. manufacturers involved in upstream components (LED die and packages) have kept some manufacturing in the United States to protect intellectual property rights, such as epitaxy and wafer fabrication processes, though manufacturers have indicated they are in the process of moving these stages offshore as well, as the process know-how becomes less of a differentiator now that the technology has matured.

## 6.2 Domestic Lighting Opportunities

China dominates LED die and package manufacturing due to several key advantages: cheap labor, government incentives, manufacturing infrastructure, and the availability of raw materials. The United States has little opportunity to compete with China and other Asian countries on commoditized high-volume and low-margin lighting products and LED packages, which are labor-intensive.

Despite significant growth in Mexico manufacturing, U.S. manufacturing can still play a role in high-end luminaire and emerging lighting technology markets. Domestic manufacturing is driven by highly specialized

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[6] Estimated based on commercial building stock square footage for U.S., Canada, and Mexico

and customized lighting products and the need for fast lead times in certain products. The United States is a global participant in manufacturing architectural lighting, automotive lighting, high-bay and stadium lighting, and lighting system design, among others. U.S. specialty manufacturers can deliver domestic orders quickly and offer highly customized designs not possible in large factories overseas. Architectural-grade lighting products in the United States are almost solely manufactured domestically, though components are often sourced outside the United States.

Emerging niche lighting markets could be opportunities for growing U.S. manufacturing. Germicidal ultraviolet (GUV) lighting has been growing during the COVID-19 pandemic with the increased need to disinfect air and surfaces. Currently, there are several GUV LED start-up companies in the United States that could bolster domestic LED manufacturing. Human-centric lighting design using connected lighting systems and color-tunable LED lighting products (RGBA lighting) are other emerging opportunities.

## 6.3 Advanced Manufacturing Opportunities

Though 3D printing has existed for many years, recent technological developments and equipment cost reductions have made it more commonplace in manufacturing for many industries. In the SSL industry, additive manufacturing and 3D printing is an emerging manufacturing technology that has shown the potential to reduce manufacturing costs of luminaires in prototyping, developing tools and molds, developing decorative or customized luminaire designs, and fabricating luminaire components with less material and fewer process steps. It can also offer benefits to manufacturers including lower operating costs, less inventory storage, and faster lead times for products.

Many manufacturers indicated that additive manufacturing and increased automation in LED manufacturing could make manufacturing in the United States a more viable option in the future, though many challenges remain. The high volumes required in the lighting industry and the ease of manufacturing most luminaire components using traditional techniques make additive manufacturing a less attractive option considering the return on investment for 3D printing.

Manufacturers indicated that 3D printing capabilities and printable materials are currently not adequate for manufacturing needs today and more R&D is needed. 3D printing is generally used in limited applications in the LED industry and significant improvements in the technology are needed for it to be used in mainstream manufacturing. Material capabilities are limited (especially for optics and thermal management), equipment sizing is limited for large luminaires and to realize high throughput, capital cost and operating cost are too high, and printing speeds are too slow. Manufacturers indicated that significant advances in speed and cost reduction (10 times current levels in each speed and cost reduction) will be necessary to make additive manufacturing competitive for LED luminaires. For more information on R&D opportunities in additive manufacturing, refer to the 2020 DOE SSL Manufacturing Status & Opportunities Report.

# Appendix A: LEDs in NAFTA Compared to USMCA

Annex 401 of NAFTA specifies rules of origin based on product category. [28] Table A - 1 lists the HTS codes, descriptions, and threshold values.

**Table A - 1 HTS Codes and RVC Thresholds in NAFTA**

| HTS Code | Description | RVC Threshold |
|---|---|---|
| 8539.50 | Light-emitting diode (LED) lamps | No product-specific rule of origin |
| 8541.40.20 | Light-emitting diodes (LED's) | No RVC threshold values |
| 9405.10 | Chandeliers and other electric ceiling or wall lighting fittings, excluding those of a kind used for lighting public open spaces or thoroughfares | No RVC threshold values (unless changed from subheading 9405.91 through 9405.99) |
| 9405.40 | Other electric lamps and lighting fittings | |

Apart from product category changes from 9405.91–9405.99 and 9405.10–9405.40, no RVC thresholds were assigned to LEDs or LED components under NAFTA. This remains the case under USMCA, which removed the specific subheading caveat for sections 9405.10–9405.40.

NAFTA also notes that LEDs that qualify as originating from a NAFTA country and undergo further production outside that country will maintain their origination status after being reimported as long as the further production did not change the subheading to outside of that group. This guideline was also carried through to the USMCA. [29]

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