International Solid-State Lighting Alliance

SSL Industry Quarterly Report 2023-1

Editor: J. Norman Bardsley

Contents

1. Introduction:

One of the goals of this report is to discuss how the momentous events of 2022 are impacting the development and adoption of solid-state lighting (SSL). The most significant events include:

- The Russia-Ukraine conflict – The broad global reaction has led to a substantial interruption in the export of oil and gas from Russia, increasing the need for more efficient energy use. Rising energy costs have been a major contributor to inflation across the world, especially in Europe. Perhaps the broadest impact has been on the budgets of consumers but rising prices have also led to strains on the profitability of lighting companies. The higher cost of electricity has made it far more difficult to establish some new SSL applications, such as vertical farming and VUV treatment of viruses and bacteria, while the motivation to replace traditional forms of lighting has been strengthened.
- Continued impact of the COVID pandemic – lockdowns imposed in China and elsewhere have interrupted the supply of LED sources and lighting products. Since the government in China relaxed the restrictions on movement, the onset of COVID has increased and concern has switched to the availability of workers.
- Limited success of COP27 in combatting global warming - Current national commitments are likely to lead to an average temperature increase of 2.4%, far in excess of the 1.5% target set six years ago. No agreement was reached to reduce the use of fossil fuels. A British university research report concluded that about 40% of recent food price inflation was due to climate change.

These effects will be discussed in the context of concern about the potential slowing of the rate of global adoption of SSL and the need for further increases in the efficacy of lighting sources and systems.

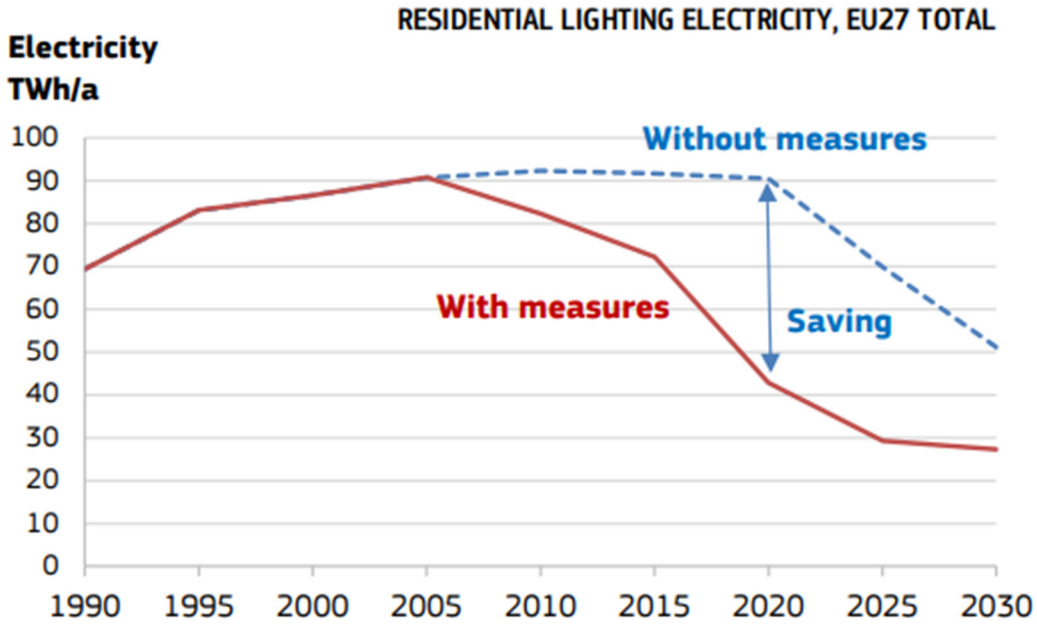
2. Energy Savings in Lighting

Although the introduction of SSL has led to significant energy savings, the demand for artificial light has increased and global consumption of electricity for lighting has changed little over the last twenty years, according to data collected by the International Energy Agency (IEA)and United Nations Environmental Protection Agency (UNEP). In 2005, 2650 terawatt hours (TWh) of electricity was used to create 135 petalumen hours (Plmh) of artificial light at average efficacy of 48 lm/W. By 2017/8 the demand had risen to 220 Plmh. with almost all the increase coming from economically developing countries. Although the average efficacy increased to 76 lm/W, the electricity consumption rose to 2900 TWh.

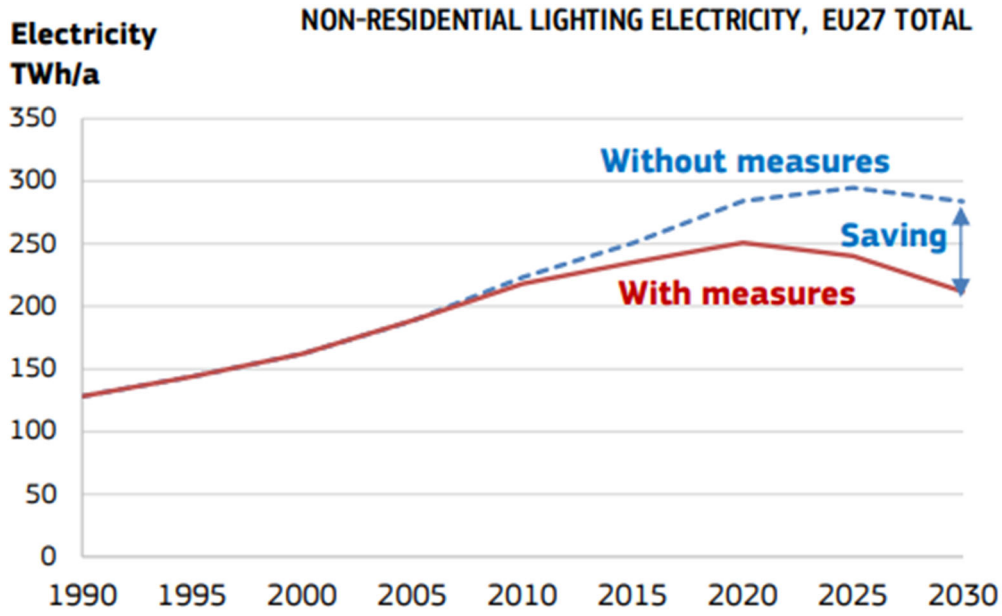
2.1 Europe

An analysis of trends in the electricity use for lighting in Europe was published by the European Commission in December 2022 as part of the “Ecodesign Impact Accounting

Annual Report 2021"[1]. They estimate that the average annual consumption for residential lighting fell from 521 kWh per household in 2005 to 379 kWh in 2015 and is expected to fall to 132 kWh in 2030. As shown in the chart below, they believe that these savings have been accelerated by regulations enforced in the European Union.

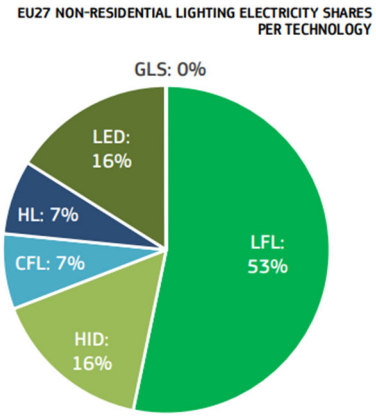


However, these gains have been offset by an increase in the use in the electricity used in non-residential applications.



[1]https://op.europa.eu/en/publication-detail/-/publication/392bc471-76ae-11ed-9887-01aa75ed71a1/language-en

These charts suggest that the total consumption rose from about 280 TWh in 2005 to 295 TWh in 2020.



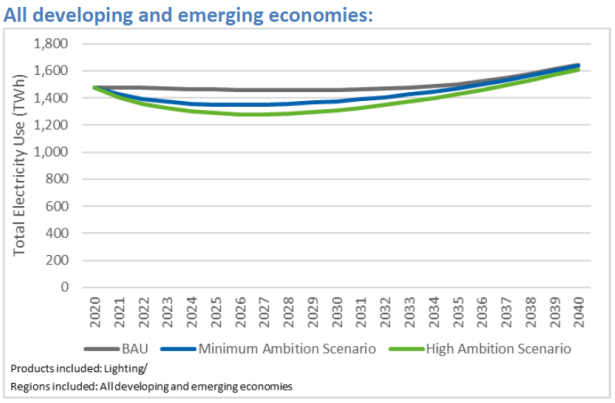
As shown in this pie-chart, around 85% of lighting electricity in Europe was consumed in the non-residential sector in 2020, of which 53% was by linear fluorescent lamps (LFL), 16% by high-intensity discharge lamps (HID), and the remainder by CFL, HL and LED. The major consumers are offices (20%), shops (15%), manufacturing areas (15%), road lighting (14%) and circulation areas in buildings (halls, corridors, stairs, toilets, etc., 10%).

2.2 Developing Economies

The table below shows the change in electricity used for lighting in the BRICS countries between 2010 and 2020, based on the Country Savings Assessments made by the UNEP United for Efficiency (U4E) program. The change in Gross Domestic Product is shown for comparison.

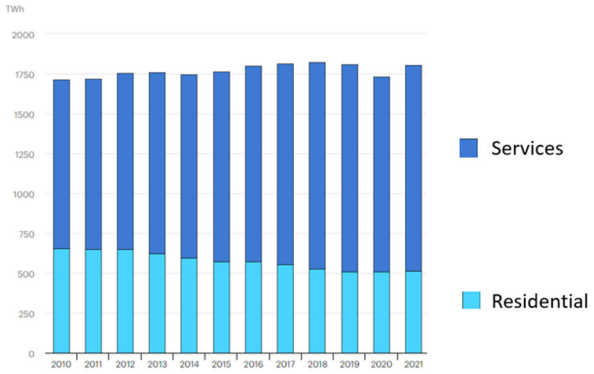
Country	TWh			GDP per capita		
	2010	2020	Ratio	2010	2020	Ratio
Brazil	72.7	65	0.89	10710	8921	0.83
China	550	1000	1.82	4428	9771	2.21
India	114	128	1.12	1475	2016	1.37
Russia	115	133	1.15	10442	11289	1.08
South Africa	24.7	34.5	1.4	7279	6340	0.87

In a 2019 report prepared for the UNEP, the demand for artificial light from 156 developing economies was predicted to rise by a further 50% from 134 Plmh in 2018 to 200 Plmh in 2040, requiring electricity use to rise from 1480 TWh to 1600 TWh.



In 2022 the IEA updated its tracking report on the electricity consumption for the residential and services sectors.

https://www.iea.org/reports/lighting

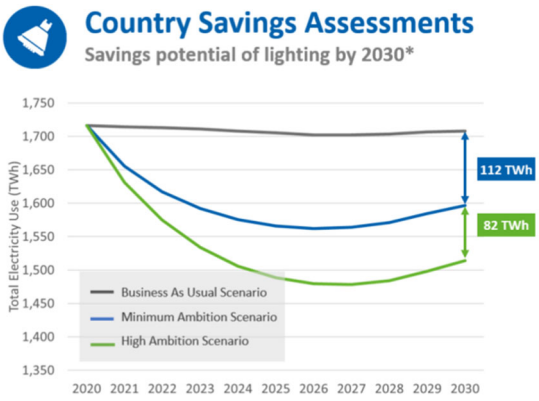


Between 2010 and 2021, electricity consumption for services grew from 1057 TWh to 1293 TWh, while that for residential use fell from 655 TWh to 512 TWh.

In July 2022 the UNEP United for Efficiency (U4E) program presented a technical brief based on its 156 Country Savings Assessments,

https://www.un.org/sites/un2.un.org/files/technical_brief_unep_u4e_efficient_lighting_and_appliances_in_asia_synergies_conference.pdf

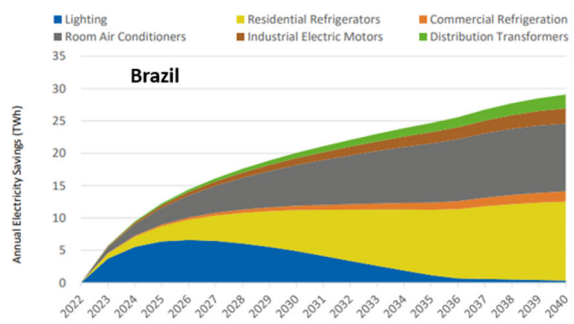
The report shows that over the next five years more ambitious programs could lead to significant energy savings for lighting, but that the growth in consumption may resume in later years. This demonstrates that there is a need for more long-term research in addition to measures to promote adoption.

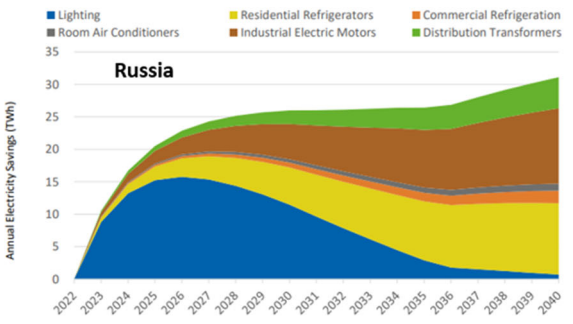


The U4E country assessments for lighting and several other applications were updated in 2022 and can be seen at

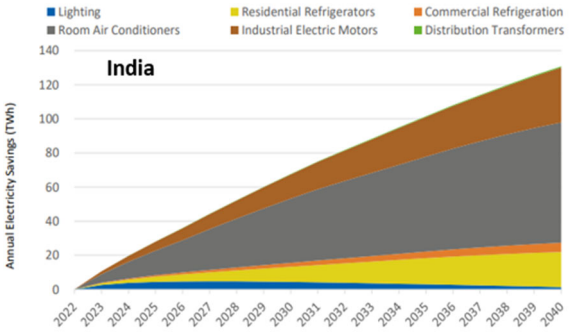
https://united4efficiency.org/countries/country-assessments/

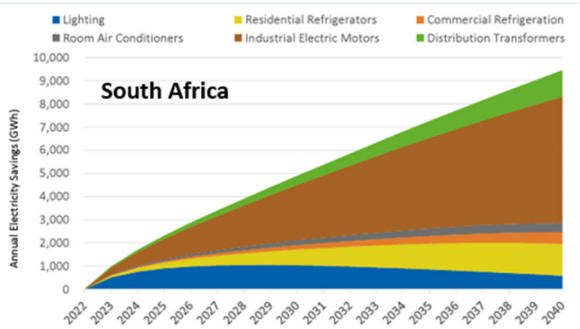
All five forecasts for the BRICS countries show that lighting is still the most fruitful area for additional short-term savings, as shown in the following charts for Brazil and Russia.





The forecast for India is surprising, with cumulative savings of 34 TWh by 2030 and 62 TWh by 2040. This seems very low, since the current annual consumption of traditional lights is about 150 TWh[2] and the 2016 U4E report predicted annual savings of 47 TWh in 2030. It is certainly reasonable to expect that the demand for lighting will grow substantially, but perhaps U4E believes that recently enacted policies are enough to cope with this growth. Further investigation by ELCOMA would be worthwhile.





The forecast for South Africa suggests that new savings will extend out further, perhaps suggesting that U4E believes that adoption of SSL will be slower than in other countries.

3. Adoption of SSL

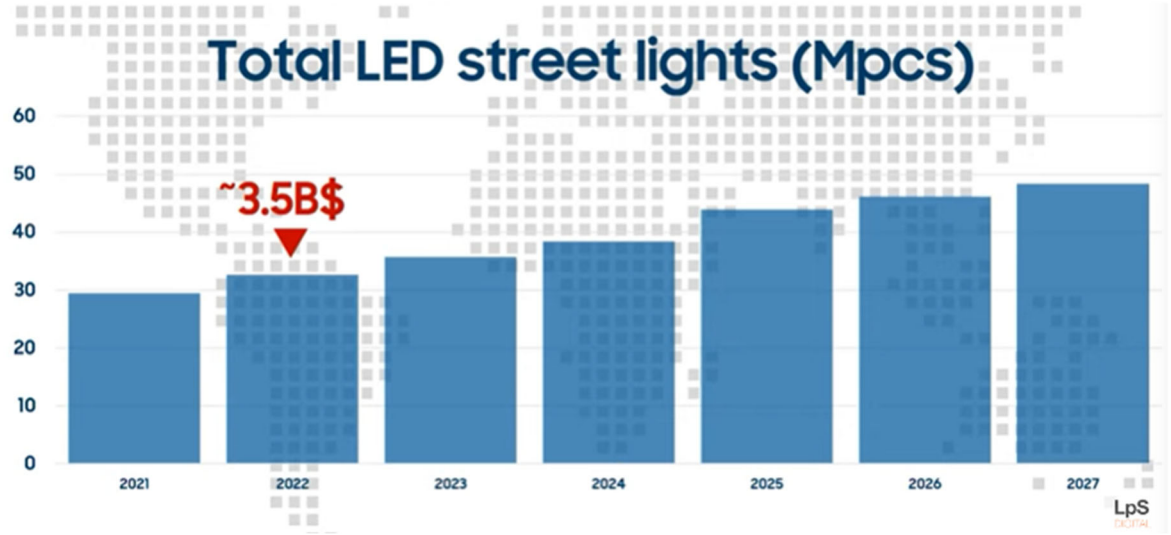
Perhaps the clearest evidence in 2022 of the impact that LED adoption can have on energy savings came from the request in December 2022 by President Zelensky of the Ukraine for 50 million LED bulbs. This would save around one gigawatt of power - reducing the shortfall at that time by about 40%. The EU immediately committed to sending 30M bulbs.

Although comprehensive data on the sale of LED lights in 2022 are not yet available, there are signs that LED adoption is stalling. Signify reported that LEDs accounted for 83% of their sales in the third quarter of 2022, the same fraction as in 2021. The market share for the whole of 2019 was 78%.

Data on the global installation of LED streetlights was presented at the LED Professional Symposium by Aleksandar Nastov of Samsung Semiconductors. As can be seen in the chart below, Samsung estimates that about 32M LED streetlights were sold in 2022 at a cost of ~$3.5B. This is less than had been anticipated in 2019 before the COVID pandemic, but

[2] Noor Ullslam, Muhammad Usman and Tariq Jamil, Energy Policy, volume 160, January 2022.

shows that a slow market growth has been resumed. If Samsung's forecast is achieved, over 80% of the global installed base will be replace by 2027.



3.1 India

An encouraging report regarding the adoption of SSL in India comes from a recent presentation from Surya Roshni. The following table shows the breakdown of revenues over the past five years for their Lighting and Consumer Durable business unit. Since the price of LEDs has fallen substantially in this period, the progress might seem even more impressive if expressed in unit volumes.

		FY 16-17		FY 18-19		FY 19-20		FY 20-21		FY 21-22	
Sr. No	**Product Name**	**Sales**	**EBITDA**	**Sales**	**EBITDA**	**Sales**	**EBITDA**	**Sales**	**EBITDA**	**Sales**	**EBITDA**
1	LED- Lighting	24%	18%	38%	14%	49%	11%	53%	12%	59%	11%
2	LED-EESL	11%	12%	21%	11%	8%	8%	1%	11%	-	-
	Total LED (1 + 2)	**35%**	**16%**	**60%**	**13%**	**56%**	**11%**	**54%**	**12%**	**59%**	**11%**
3	CFL (Peak Sale Rs. 374 Cr.)	10%	1%	2%	-	1%	-	-	-	-	-
4	Conventional	35%	10%	22%	4%	22%	3%	23%	9%	19%	1%
5	Consumer Durables	19%	7%	17%	7%	21%	7%	23%	8%	22%	6%
	Grand Total (1 to 5)	**100%**	**11%**	**100%**	**10%**	**100%**	**8%**	**100%**	**10%**	**100%**	**8%**

Indian cities are still experiencing difficulties in financing major projects to install LED streetlights. A plan to replace 485,000 lights was made in 2019 using the Shared Savings Model developed in collaboration with the International Finance Corporation. However, no progress had been made by the end of 2021 and the initial contract was cancelled. The city

leaders confirmed their support for the project in September 2022 and announced that the installation of smart LED lights would begin in the next two months.

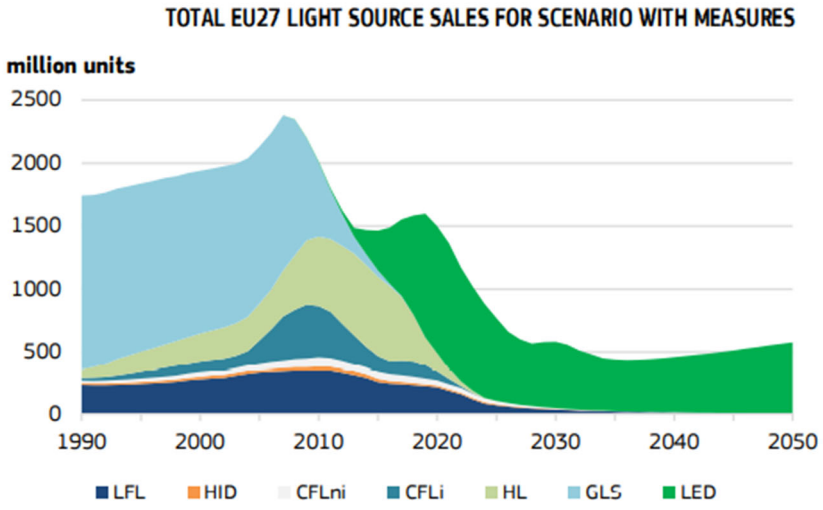
3.2 China

According to the annual report for 2022 from the China SSL Alliance (CSA), the total value of LED applications was RMB 569B, down 13% from 2021 and well below the 2019 figure of RMB 634B. The contribution from general lighting, as shown in the chart below, was 274B. CSA reported that "the export market is generally flat and still at a historical high. However, the domestic demand market has declined significantly, and small and medium-sized enterprises have been greatly impacted".

Looking back to 2021, another disturbing piece of news came from the Intelligence Research Group in Beijing. They reported that although China's landscape lighting market was up 27% year-on-year to 92B yuan, road lighting products were predominantly high-pressure sodium lamps (48%), followed by LEDs (30%). On a more positive note, they see a recent surge in the use of LED lamps in cars, with their market share growing from 3% in 2013 to 23% in recent years.

3.3 Europe

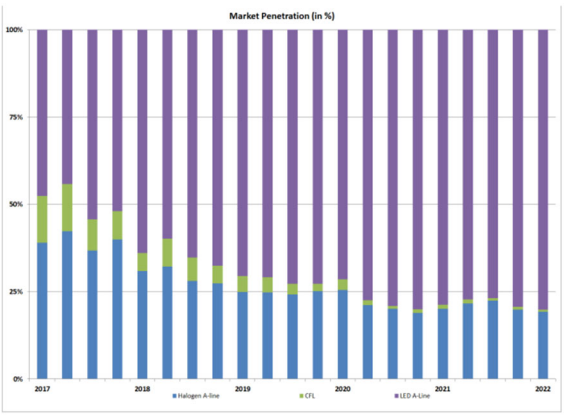
The next chart shows the evolution of lighting sales in Europe between 1990 and 2020 and the forecast until 2050 from the Ecodesign Annual Report for 2021.

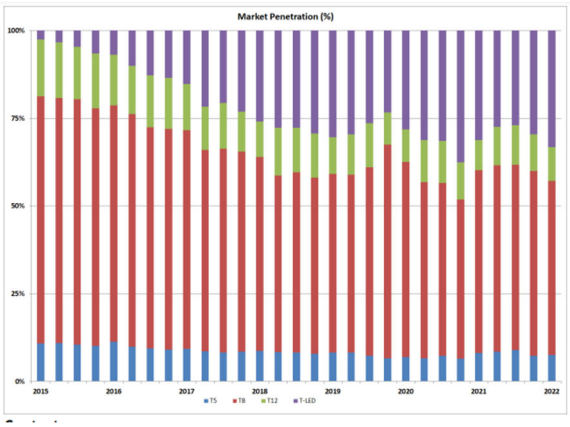


The longer lifetime of LEDs has already led to a substantial reduction in the total unit sales.

3.4 US

In the US, data on the market shares of various technologies in general service bulbs (A-lamps) and linear tubes (T-lamps) are published by the National Electrical Manufacturers Association (NEMA). The next two charts show the data from 2017 through 2022Q1, with bulbs on the left and tubes on the right.





Compact fluorescent lamps have been almost completely replaced by LEDs, but halogen bulbs still represent over 15% of sales. Penetration of LEDs into the tube market grew rapidly until 2019Q1 but has fluctuated since then and was still less than 30% in 2022Q1.

4. Supply Chain: Production and Exports of Chips and Packages

According to TrendForce, the global market for LED packages rose by 15% to $17.6B in 2021. The global leader Nichia is privately owned and does not release financial results publicly. Although Samsung does issue financial reports, the company is so diverse that it is difficult to extract data on their sales and profits from LED production.

4.1 Production outside Mainland China

AMS-Osram has major manufacturing facilities in Malaysia. The merger between AMS and Osram has led to consolidation of their semiconductor manufacturing businesses, which now represent two thirds of their sales, serving the entire value chain of optical solutions. The other third is in lamps and systems. Total revenues in 2021 were close to 5B euros. In the first nine months of 2022, revenues for semiconductors fell by 9% to 2.40B euros. The reductions may be partially due to the sale of some business units. In their report for 2022Q3, the company stated that “Shipments for differentiated LED and imaging solutions in important markets remained at attractive levels during the quarter while demand trends in certain industrial markets started to reflect the unfavourable macro-economic momentum exiting the quarter.”

Epistar from Taiwan is another important supplier of LEDs, but it has recently become a subsidiary of Ennostar Inc. Ennostar has reported earnings results for the third quarter and nine months ended September 30, 2022. For the third quarter, the company reported sales of TWD 6,684M compared to TWD 10,329M a year ago. They suffered a net loss of TWD 358M compared to net income of TWD 1,296M a year ago. For the nine months, sales were TWD 23,011M compared to TWD 26,572M a year ago. Net income was down to TWD 790M million compared to TWD 1,737 million a year ago.

Turning now to the US, Cree has sold the units that focused upon the lighting industry but is expanding its manufacturing capabilities for silicon carbide technology providing power and radio frequency (RF) semiconductors. Wolfspeed’s product families include SiC materials,

power-switching devices and RF devices targeted for applications such as electric vehicles, fast charging inverters, power supplies, telecom and military and aerospace.

The growing demand for electric vehicles is driving a rapid increase in investment. The manufacturing capacity at Wolfspeed's existing factory in North Carolina is being expanded by 50%, but new plants in the Mohawk Valley in New York State and in Chatham County, North Carolina could lead to a 10-fold increase, with capital investment of over $5B.

4.2 Production in China

The China Solid-State Lighting Alliance (CSA) estimates that the overall output value in 2022 was about 675B yuan, a decrease of 13.2% from last year, of which the contribution of upstream epitaxial chips was 28.1 billion yuan, while packaging contributed 77.8 billion.

In 2022, the output value of the epitaxial chip production in mainland China was around 28B yuan, which is 8% lower than that in 2021. The total revenue of listed companies mainly engaged in LED chips totalled about 14.5B yuan, down ~2.2% from the same period last year. During the period, the expense ratio continued to rise, so the decline in the profits of leading companies was higher than the decline in revenue. The total profit in the first three quarters of 2022 was 1.1B yuan, a year-on-year decrease of 43%. Compared with the same period in 2019, the overall revenue and profit increased by 18% and 25%, respectively. In the first three quarters of 2022, the overall net profit of chip listed companies totalled 950 million yuan, a decrease of 41% from the same period last year.

Financial reports from some of the leading producers confirm these trends. The revenues of Sanan, the leading manufacturer of LED chips in China, rose by 48% between 2020 and 2021. However, revenues in the 3rd quarter of 2022 fell by 5% from those in the previous year and net income dropped by 86%. At their competitor HC Semitek, revenues in 3Q2022 fell by 39% year-over-year, while net income went from a profit of 48M yuan to a loss of 53M yuan.

In 2022, the output value of LED packaging in mainland China was expected to be 78B yuan, a decrease of 15% from last year. The revenue and profit of head packaging companies fell. In the first three quarters of 2022, the total revenue of listed LED companies in the packaging sector totalled 24.4B yuan, a year-on-year decrease of 10.5%, the total profit was 1.3B yuan, a year-on-year decrease of 38%, and the total net profit was 1.2B billion yuan, a year-on-year decrease of 40%.

Total sales of Mulinsen (MLS) in the first three quarters of 2022 were 12.2B yuan, down 9% from 13.4B yuan in the previous year. Operating profits fell by 56% from 1.14B yuan in 2021 to 498M in 2022. These figures include a major contribution from global sales of lamps and lighting fixtures.

Over this same 9-month period sales of Foshan NationStar Optoelectronics were 2.5B yuan, compared to CNY 2.85B yuan million a year ago. Net income was 110M yuan compared to 178M yuan a year ago.

Shenzhen Mason is another example of a medium size company that is experiencing falling sales and profits. For the 12 months ending in September 2022, revenues were 3.74B yuan, down from 4.18B in 2019. This resulted in a pre-tax loss of 549M yuan in the last 12 months, compared with a profit of 114M in 2019.

Despite its broader product range, Everlight has also suffered substantial reductions in sales and profits during 2022. For the quarter ending September 30, revenues were down by 28% to TWD 4778M from TWD 6621M in the previous year. Net operating income fell by 53% from TWD 750M to TWD 354M. For the first nine months of 2022 revenues were down 20% year-to-year to TWD 15,431M from TWD 19,265M. Net operating income fell by 39% from TWD 2069M to TWD 1258M.

The chip manufacturing and LED packaging arms of Signify have been spun off as Lumileds. Under private ownership, the new company has struggled financially but has recently emerged for bankruptcy and remains a strong competitor in international markets.

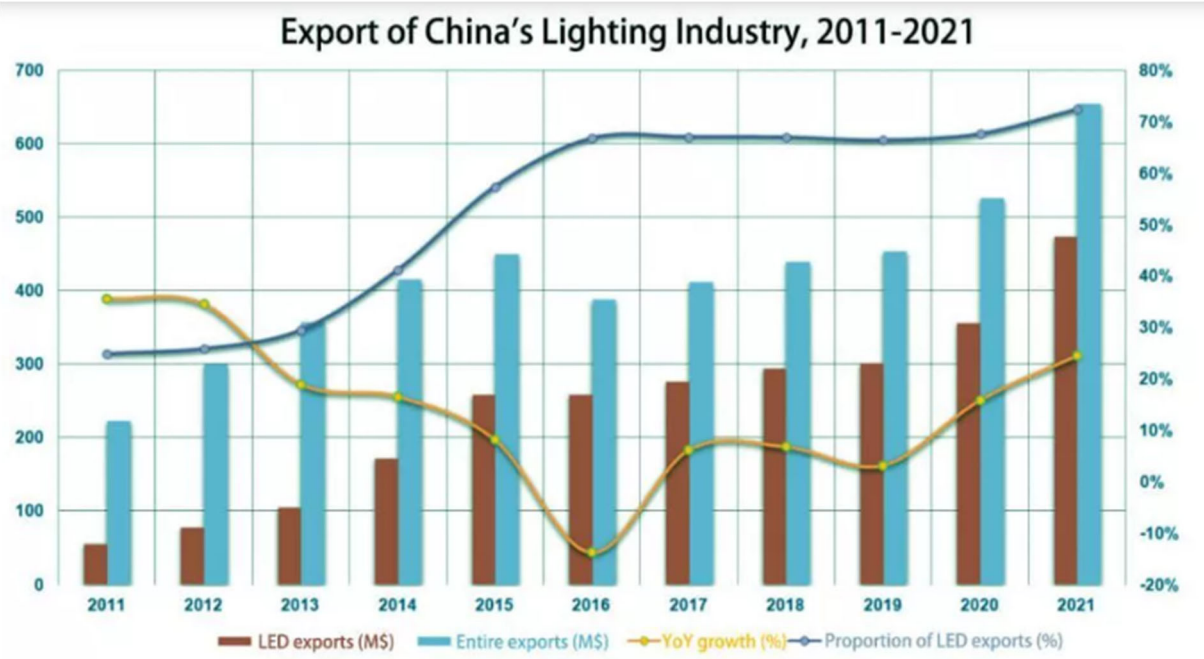
The recent surge in demand for UV LEDs also appears to have stalled. According to incomplete statistics from CSA Research, it is estimated that the market size of ultraviolet LED chip devices and modules was about 1.96B yuan in 2022 , a year-on-year decrease of about 10%.

4.3 Exports from China

Before discussing the situation in 2022, it is useful to look back over exports from China in the previous few years. Donne Yu of Darkless Lighting has provided an interesting report, based mainly on data from the China Association of the Lighting Industry (CALI).

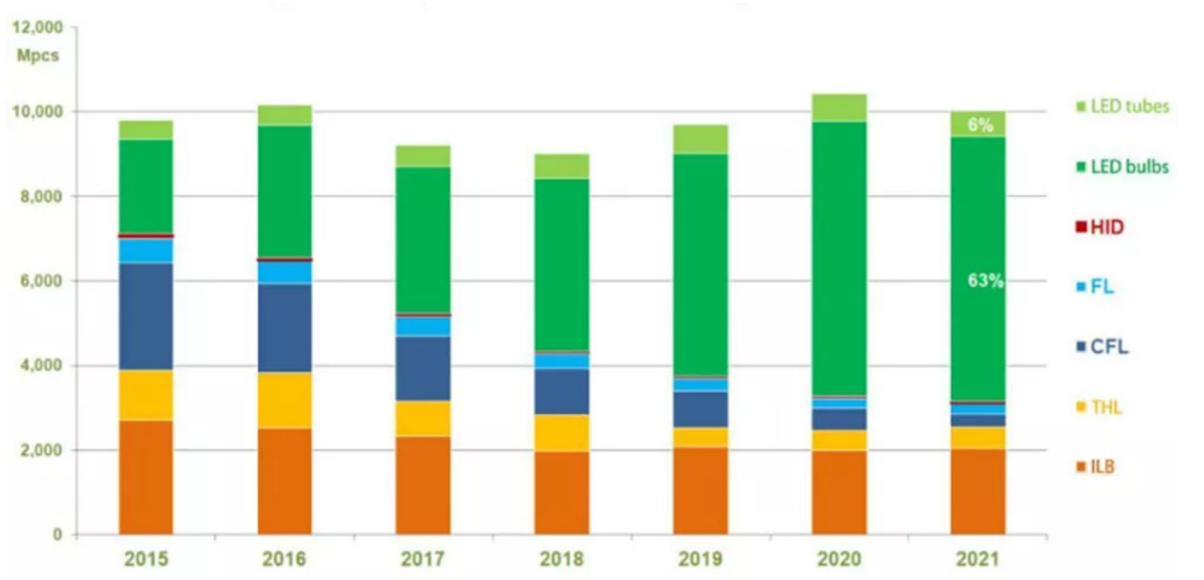
https://darklessled.com/2021-export-overview-of-chinas-led-lighting-industry/

The first chart shows that steady growth in the export of LEDs from China has led the expansion of their total lighting exports. However, the proportion of export revenues that came from LEDs remained at close to 70% between 2016 and 2020 before rising to 75% in 2021.

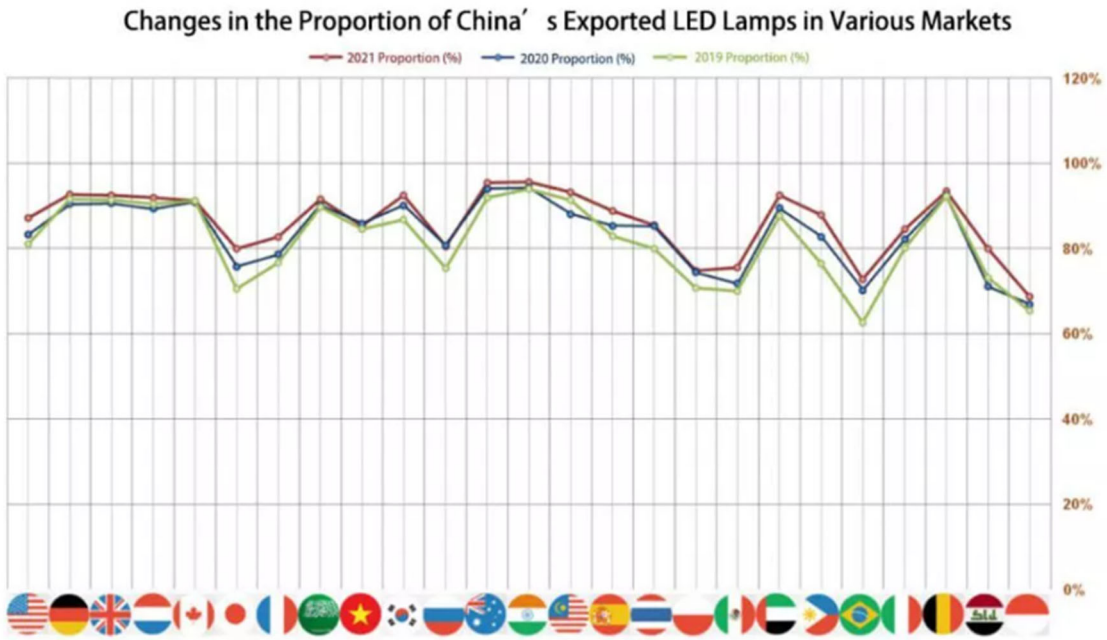


The increase in export revenues came mainly from the sale of lighting products rather than light sources, with products representing 77% of sales in 2021.

A different picture is seen when one looks at the export volume in number of pieces. The fraction of LEDs rose from about 30% in 2015 to 70% in 2021. The relative price of LEDs has fallen substantially and the average is now close to that of traditional technologies.



The next chart shows the market share of LEDs sent to various countries in 2019 (green), 2020 (blue) and 2021 (purple). The share is over 60% everywhere.



These numbers show that although LEDs clearly dominate the market, there is still much work to be done to replace inefficient conventional lights.

The data for 2020 and 2021 shows that the lighting industry in China coped well with the onset of COVID. The export value of LED lighting products in 2021 was USD 47.4 billion, up 33% year on year and up 57% over 2019. However, most of that increase came through rising prices.

Preliminary results confirm that 2022 was more difficult for the industry in China. CALI reported that from January to October 2022, China's total export of lighting products was US$52 billion, a slight decrease of 1.7% year-on-year, which was generally weaker than the overall export market.

The classroom lighting continued to be hot in China. According to incomplete statistics from CSA Research, as of the end of December, there were about 800 classroom lighting bidding projects nationwide, with a total amount of over 3.5 billion yuan.

Mini-LED direct display applications continue to expand. At present, Mini-LED displays have been widely used in conferences, high-end indoor commercial displays, command centers, live event broadcasts, home theaters, education and other scenarios, and with the development of technology, the scope of application continues to expand. According to incomplete statistics from CSA Research, the amount of investment projects in the Mini/Micro-LED field exceeded 27 billion yuan in 2022, and the scope of participation in the industry chain investing in Mini-LED expanded.

LED has become one of the mainstream technologies for car lights. In 2022, the demand for LED automotive LEDs will rise against the trend, becoming one of the most eye-catching segments in the LED application segment. According to TrendForce data, the penetration rate of global LED headlights has exceeded 60% in 2021, and the penetration rate in new

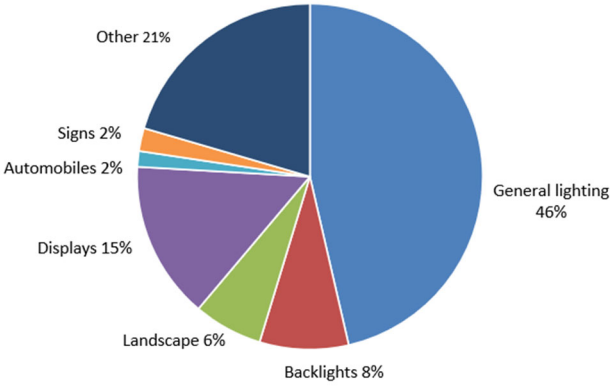
energy vehicles is as high as 90%, which is expected to increase to 72% and 92% respectively in 2022.

5. LED Lamps and Light Fixtures

In this section we will review the status of the production and sale of LED products in general lighting in several major regions.

5.1 China

The China Solid-State Lighting Alliance (CSA) has estimated that in 2022 the revenues to Chinese companies from downstream applications of LEDs were 569B yuan, down by 13% from 2021. The distribution by application area is shown in this pie chart.



According to CSA, the total revenue of listed LED companies in the application sector was 51B in the first three quarters of 2022, a decrease of 4.2% from the same period last year. However, expenses were tightly controlled and profits rose to 4.0B yuan, an increase of 11.7% from the same period last year. In terms of specific segments, revenues of the display application and general lighting sectors decreased slightly by 1.9% and 2.6% year-on-year respectively, while profits increased by 28.2% and 12.6% year-on-year respectively. Beyond the listed companies, small and medium-sized enterprises in the application field are facing greater difficulties.

As noted above, the revenues of MLS, a leading global supplier of LED lighting products, rose in 2021 by 7.3% to 18.5B yuan. But in the first nine months of 2022, revenues were down by 9.3% to 12.0B yuan, while net income fell by 58% to 394M yuan. Zhejiang Yanon has been struggling for longer with revenues declining each year from 2019 to 2021. In the first nine months of 2022, revenue was 2.9B yuan compared to 3.2B yuan a year ago. Net income was 130M yuan compared to 342M yuan a year ago. One company that has increased sales substantially is Foshan Electrical. Their revenues increased in 2021 by 27.5% to 4.73B yuan. For the first nine months of 2022, revenues almost doubled from 3.25B yuan to 6.4B yuan.

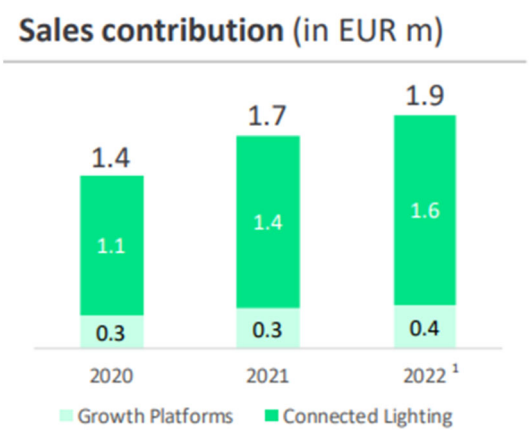
A desire for a more reliable source of chips and packages is leading to further consolidation in the industry. According to CSA “BOE has subscribed for shares of HC Semitek to become its largest shareholder. Hisense Vision has increased its holdings in Qianzhao Optoelectronics, and the trend of strong alliances between the upstream and downstream of the industry chain is clear.”

5.2 Europe

The strong position of Osram in the downstream market has shrunk significantly following the sale of LEDVANCE and the merger with AMS. Only one third of the revenues of the combined company come from lamps and lighting systems. In the first nine months of 2022, those revenues were down by a further 11% to 1.25B. These sales are spread over

three regions. During the first half of 2022, the geographic distribution was 39% in Europe and the Middle-east (EMEA), 34% in the Americas and 27% in Asia/Pacific.

Following the divestiture of its chip and packaging business, Signify has strengthened its commitment to lighting systems. Its revenues grew by 5.5% to 6.9B Euros in 2021 and net income rose by 21% to 407M euros. The gains continued into the first three months of 2022, with sales rising by 14% to 5.5B euros and net income up by 90% to 447M euros. Sales of connected lighting systems now provide about a quarter of their revenues, as seen in this chart. Horticultural lighting makes a smaller contribution, despite the acquisition of Fluence.



Revenues also rose at Zumtobel in FY 2021, by 10% from 1.04B euros to 1.15B euros, while net income remained steady at $46M. Further gains were made in the 6 months from May to October of 2022, with revenues rising by 11% to 628M euros and income up by 47% to 33M euros.

Fagerhult is another example of a medium-sized European company that has recovered well from the pandemic, by focusing on sustainable lighting systems. They have dealt well with the supply chain challenges and now see steady improvements from the supply chain. Although they have had to increase the price of their services, they have been able to offer renovation projects with shorter payback periods, partly due to the rising cost of electricity for their customers. In the first 9 months of 2022 their revenues were up by 14% to 6.0B Swedish krona (SEK), which is equivalent to US$570M. Operating profit rose by 6% to 579M SEK.

5.3 USA

The lighting industry in the US has experienced many changes of ownership in the past few years. Cree divested its lighting business and has changed its own name to Wolfspeed. Sylvania Lighting Solutions was sold by Osram to Wesco. Cooper Lighting was adopted by Eaton and then Signify. Hubbell is still a major supplier of lighting, but its financial reports provide little detailed information on its business segments.

Revenues at Acuity Brands, the largest US lighting company, rose by 16% to $4.0B in fiscal year 2022, which ended on August 31, 2022. Net income was up by 25% to $384M. Acuity is less dependent on imports from Asia than most of its competitors. It operates 18 manufacturing facilities, including six facilities in the United States, seven facilities in Mexico, two facilities in Europe, and three in Canada.

The risks that are faced by small companies with a small number of critical customers are illustrated by the recent experience of Orion Energy Systems, which is based in Wisconsin and has a 260,000 square foot manufacturing facility in Manitowoc. In the year ending in March 2022 their revenues grew by 6% to $124M and their gross operating profit increased

from $30M to $34M. However, due to delays in major projects, their revenues in the next 6 months fell by 50% to $36M and operating profits were down by 62% to 8M. The company expects to be well on the way to recovery by the end of this fiscal year in March 2023. To soften the potential impact of fluctuations in the lighting market, Orion has acquired Voltrek which designs, installs and services electric vehicle charging stations.

5.4 India

The leading lighting companies in India have shown steady increases in sales over the past 30 months, but profits have varied from one company to another. The following table shows the revenues and before-tax profits for three of the companies which publish financial results for business units that are dominated by lighting. The fiscal years in India end on March 31st and the first two columns of data give results for the fiscal years 2020-21 and 2021-22. The next column is for the 12 months between October 2021 and October 2022. All amounts are in crores.

Company	Business Unit	Annual revenues			Calendar Quarterly revenues				
		2020-1	2021-2	Last	3Q2021	4Q2021	1Q2022	2Q2022	3Q2022
Crompton Greaves	Lighting products	987	1055	1142	288	311	301	261	269
Havells	Lighting and fixtures	1085	1371	1575	354	408	399	371	397
Surya Roshni	Lighting & consumer durables	1233	1332	1514	342	372	404	355	383
Company	Business Unit	Annual pre-tax profit			Calendar Quarterly pre-tax profit				
		2020-1	2021-2	Last	3Q2021	4Q2021	1Q2022	2Q2022	3Q2022
Crompton Greaves	Lighting products	116.1	116.1	112.4	26.3	32.6	34.3	25.2	20.3
Havells	Lighting and fixtures	204,1	257.6	266.7	77.3	86.9	61.7	61.1	57
Surya Roshni	Lighting & consumer durables	96.2	79.7	88.1	21	21.4	27.4	15.1	24.2

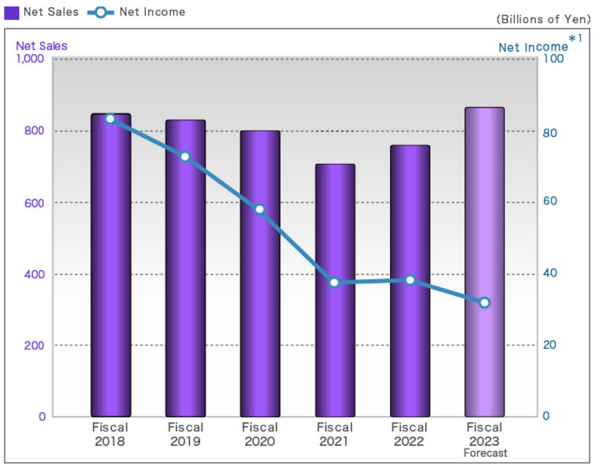
6. Special Applications

Although general lighting remains an important application area for solid-state lighting, pricing pressures have led many companies to look for alternative markets. The rise in the cost of electricity has slowed the growth of agricultural and disinfection markets, but new markets are opening up in automotive and display applications.

6.1 Automotive Lighting

Estimates of the size of the automotive lighting market by 12 market research companies vary from US$20B to US$35B, with predicted growth rates ranging from 3.2% to 9.5%. There is even more uncertainty about the LED share, with guesses from $6B to $20B.

The evolution of the automotive lighting market over the past five years can also be seen in the revenues of global leader, Koito, as shown in this chart. Although revenues have recovered, net income has fallen by more than 50%.



The Visibility Systems Business Group of Valeo also reported higher sales in the first nine months of FY2023, with revenues rising to €1.32B from €1.13B in the corresponding period of FY2022. However, this underperformed global automotive production by 8 percentage points, reflecting an unfavourable product mix (lower electronics content) in Europe and China due to the electronic component crisis and an unfavourable customer mix in Japan and China.

Hella reported revenues from lighting of €2.9B in the year ending May 31, 2022. In the following 6 months, revenue rose by 27% to €1.8B as the automobile industry solved its problems regarding semiconductor components and customer demand grew. Growth was strong for heavy vehicles, such as buses and trucks. The demand for replacement lamps was particularly high in Mexico, Turkey and the US. Due to the particularly strong demand for innovative body lighting in the Chinese market, HELLA has joined hands with BHA to set up a third lighting factory in China, that will be called the Beijing BHA Hella Lighting Changzhou Factory.

Among Chinese companies, Hongli Zhihui's LED automotive LED business is growing steadily. Revenue in the first half of 2022 was 284M yuan, a year-on-year increase of 4.8%, accounting for 15.8% of total revenue, and a gross profit margin of 15.1%. At Foshan Lighting the revenue of the automotive lighting business in the first half of 2022 was 788M yuan, a year-on-year increase of 460%, accounting for 18% of revenue from 3.9% in the same period last year; the gross profit margin was 17%, an increase of 1% from the same period last year.

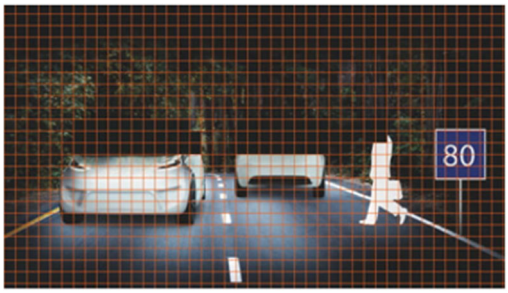
LED suppliers are competing aggressively in this market segment. Lumileds inherited the automotive business of Philips and supplies traditional lights as well as LEDs. Approximately 40% of the revenues of AMS/Osram come from automotive applications. Chinese chip manufacturers such as Sanan, HC Semitek and Jucan Optoelectronics are all paying more attention to automotive applications.

However, the relatively high cost of LEDs is still retarding growth in high-volume markets, especially in China. As seen in the chart in section 5, CSA estimates that automotive lamps represent only 2% of the revenues from all lighting applications.

Interest in segmented lamps is growing in the high-end of the market, both for headlamps and tail lights. Infinion Technologies has just introduced a light engine for headlights using Nichia's micro-LED technology and an integrated LED driver IC that can drive 16,384 micro-

LEDs individually using pulse-width modulation (PWM) control. The driver provides extensive diagnostics and high-speed video and control interfaces, while the optical system gives a four-times wider field-of-view with significantly higher light output than previous products. The system can warn drivers of hazards by highlighting people or objects on or by the side of the road. It can also project markings on the road to guide the driver through a construction site or intersection. In addition, functions such as the glare-free high beam or bending light work precisely and smoothly.

In the EVIYOS project, AMS-Osram developed a similar system with arrays of up to 25,600 micro-LEDs, each of which can be controlled independently with the aid of forward-looking sensors. This simulation illustrates how the system can be used to avoid glare in the eyes of both pedestrians and oncoming drivers.

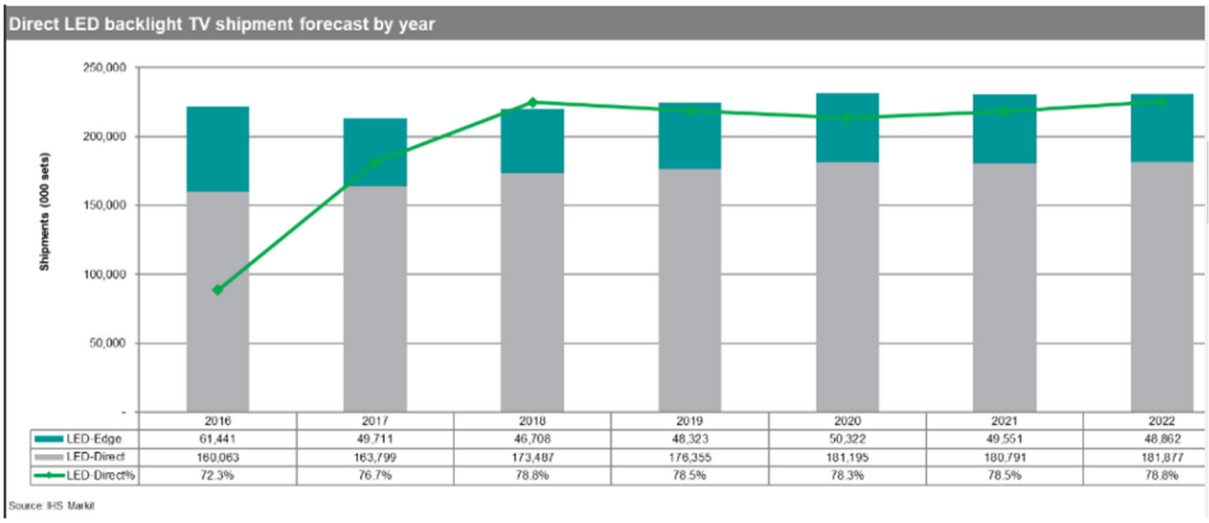


Dynamic multi-pixel taillights using organic LEDs on flexible substrates are available from OLEDWorks and were demonstrated at CES 2023 in Las Vegas. The systems were developed in conjunction with Corning Incorporated, Valeo, STMicroelectronics and Audi. The figure below shows the technology installed in an Audi A-8 car.

Yeolight has showed prototype OLED taillight systems with up to 1434 segments at a recent Automotive Lighting Exhibition in Shanghai.

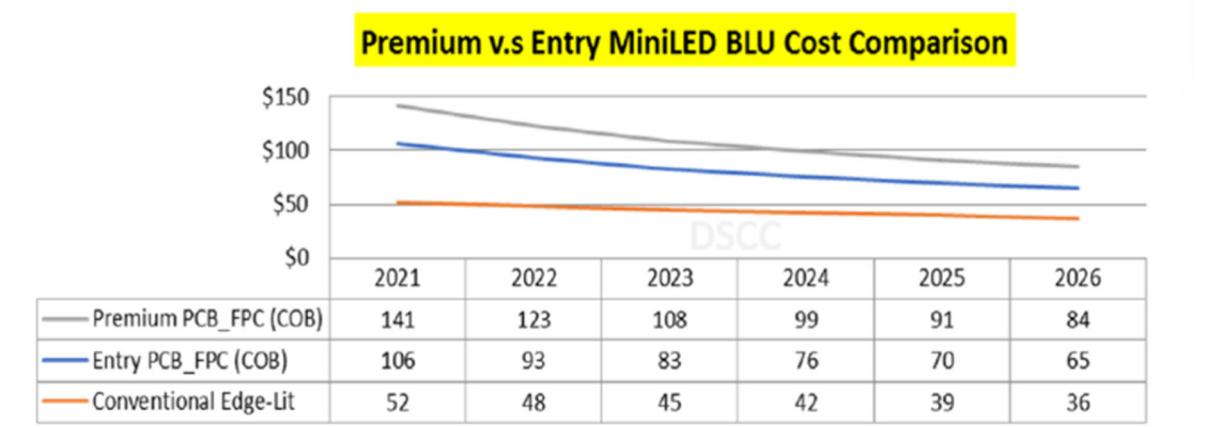
6.2 Inorganic LEDs in Displays

The replacement of fluorescent tubes by LEDs in liquid crystal display (LCD) backlights led to a rapid growth in chip manufacturing around 2010. The LEDs can be placed around the edge of the panel or spread across the back. Edge lighting allows for the construction of thinner backlights, but is less adaptable for local dimming. The next chart from a 2019 report by Omdia shows the trend of sales of TV backlights in recent years, with edge-lit versions taking about one quarter of the market.



Liquid crystal displays have been losing market share in the high-end TV market to OLEDs that offer better colour and deeper blacks. LCD manufacturers have reacted by extending local dimming. The panel is divided into many zones, each lit by a mini-LED that can be controlled independently. The size of these mini-LEDs is typically 0.1-1mm.

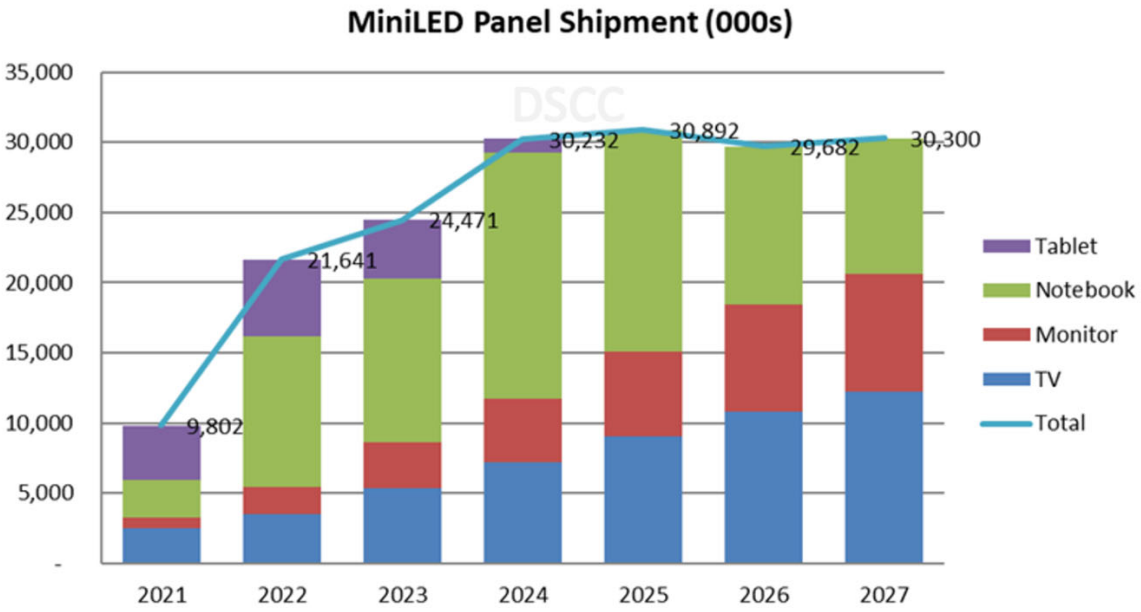
Although some mini-LED displays use thousands of LED chips, the cost is much higher than with a conventional edge-lit BLU, as shown in the next table from Display Supply Chain Consultants (DSCC). So panel makers are also offering entry-level mini-LED solutions with fewer LED chips and dimming zones.



	2021	2022	2023	2024	2025	2026
Premium PCB_FPC (COB)	141	123	108	99	91	84
Entry PCB_FPC (COB)	106	93	83	76	70	65
Conventional Edge-Lit	52	48	45	42	39	36

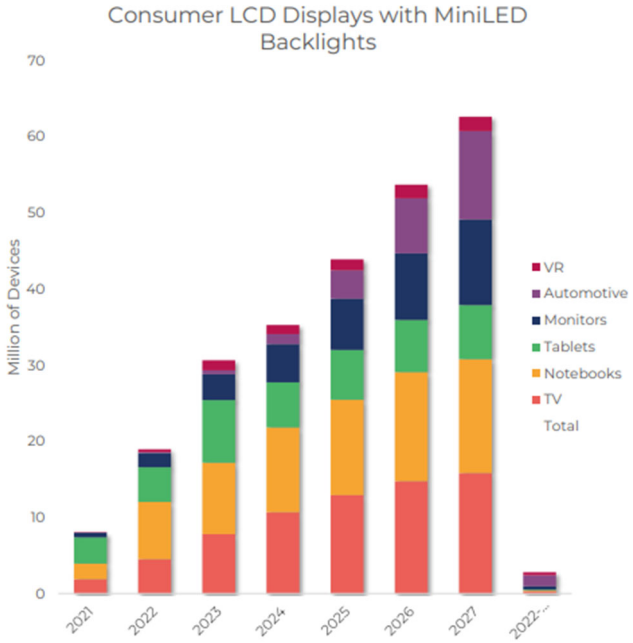
Source: DSCC

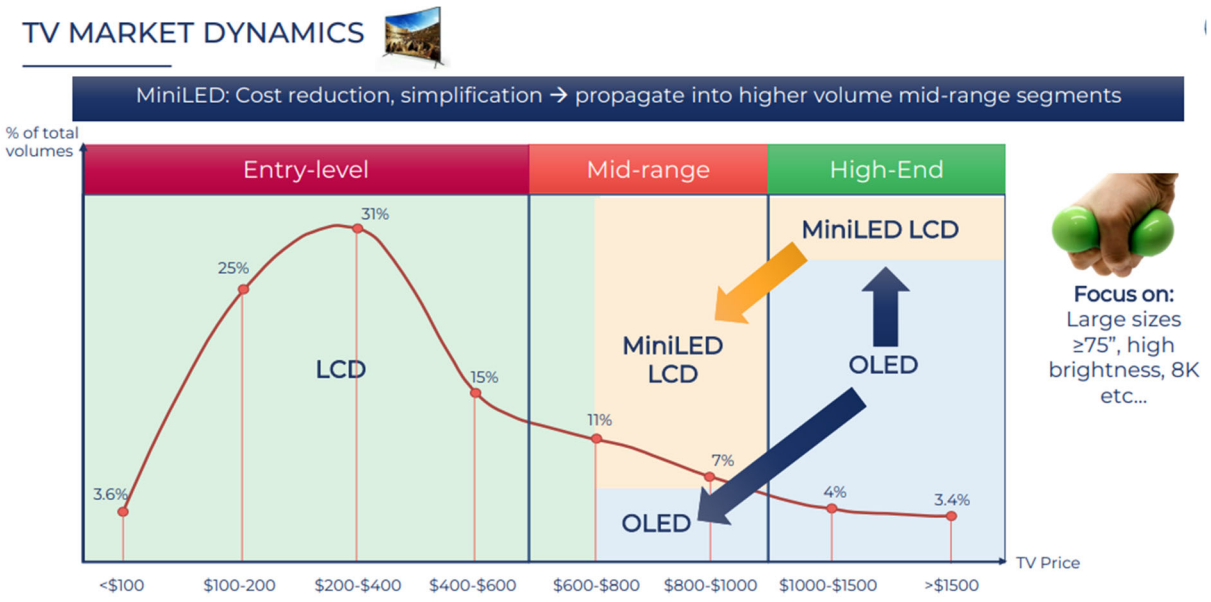
The next chart showed DSCC's latest forecast of shipments of mini—LED displays. The market has grown rapidly but may saturate in 2024, with penetration rates of about 5% for TV and notebook displays.



A more optimistic prediction was given by Eric Virey of Yole Developpement in a presentation for TechBlick in November 2022. This analysis includes contributions from automotive and virtual reality applications. They report that preferred die sizes are around 200 x 200 µm for tablets and notebooks and 150 x 500 µm for TV screens.

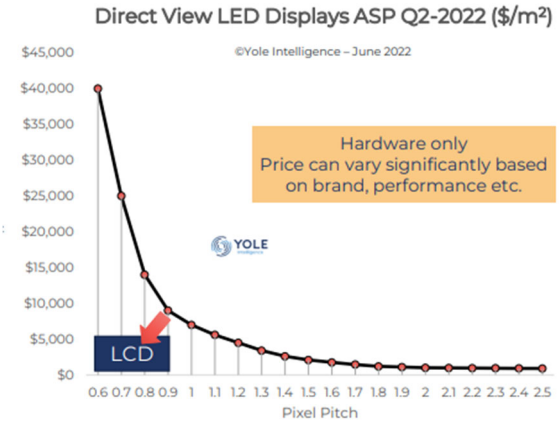
In the chart below, Virey illustrated how mini-LEDs could influence the competition between LCD and OLED technologies in TVs at various price levels. The chart does not show the impact of quantum dots, which are also used to improve the image quality in high end displays.



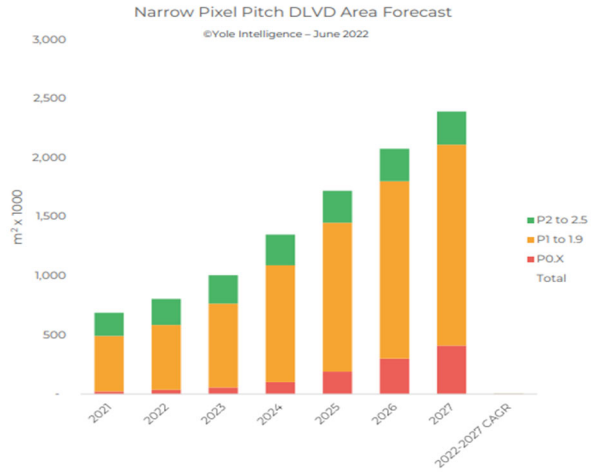


Most current displays are very inefficient, with efficacies of less than 10 lm/W. In LCD's, less than 10% of the light created in the LEDs emerges towards the viewer. Higher efficiency can be obtained using direct view LED displays, which contain an LED in every subpixel. The intensity of the light of each colour from each pixel is then controlled at the source rather than with liquid crystal modulators or colour filters.

Efficacies of over 30 lm/W have been obtained in direct-view outdoor displays with large pixels. However, the efficacy decreases as the pixel size is reduced, as is discussed in the next section. More significantly, as shown here, the cost per square metre rises sharply as the pixel size is reduced and seems prohibitive for most customers of high-resolution indoor displays.

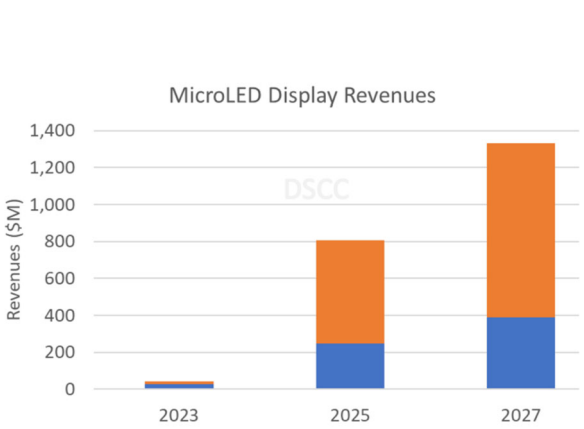


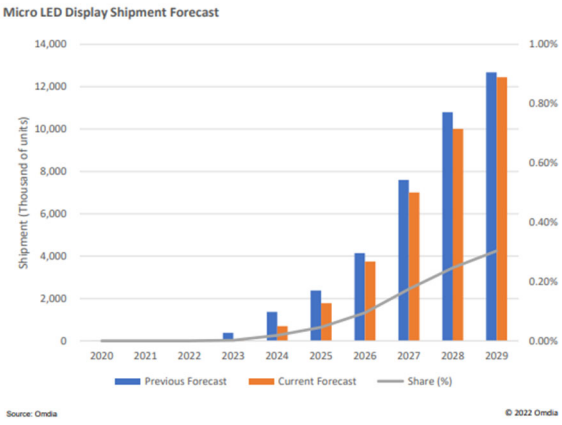
The next chart shows the forecast from Yole of the short-term market for direct view displays with relatively small pixel sizes. The most popular pixel dimensions are expected to be those between 1mm and 2mm.



Many in the industry believe that the solution is to reduce the size of each pixel to a few micrometres. Some of the research that is needed to accomplish this is described in the next section.

It is perhaps too early to make reliable forecasts of the market for micro-LED displays, but brave predictions of revenues from DSCC and unit shipments from Omnia.





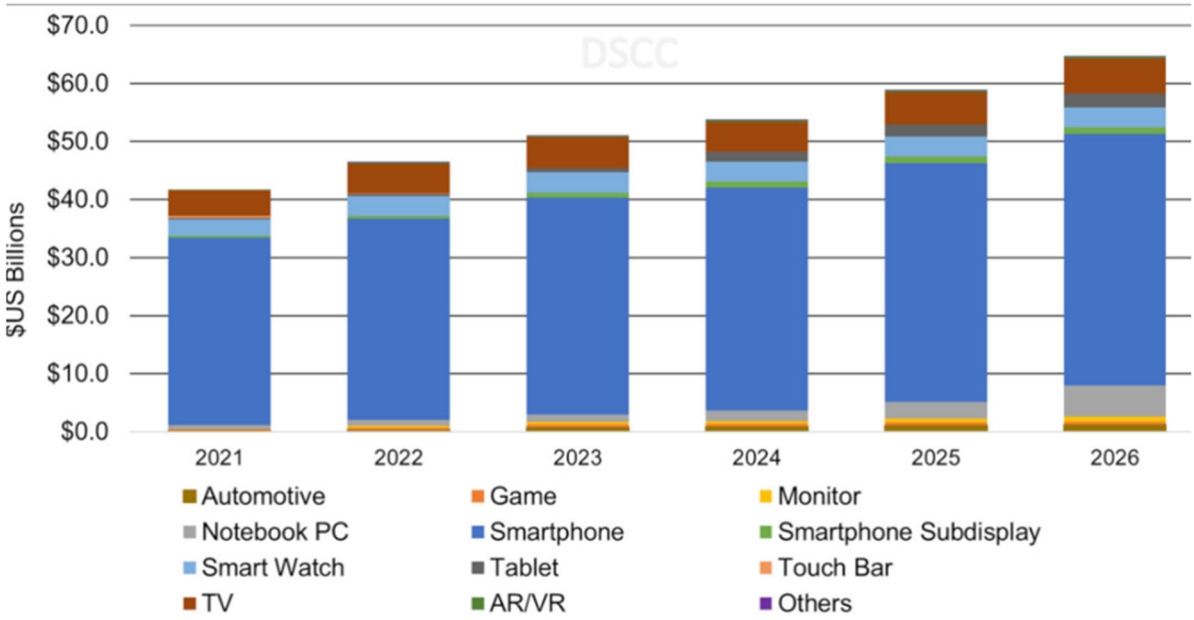
These developments have led chip companies such as Sanan Optoelectronics, Huacan Optoelectronics, Zhaochi, Jucan Optoelectronics, and Qianzhao Optoelectronics to plan mini /micro-LED capacity expansion. According to CSA, the investment of LED chip companies in the mini/micro-LED field will exceed 10B yuan in 2022. AMS-Osram announced that it will ramp-up production of micro-LEDs at its new 8-inch wafer fab in Malaysia in 2024. Seoul Semiconductor believes that its WICOP technology will help it to lead in the production of micro-LEDs.

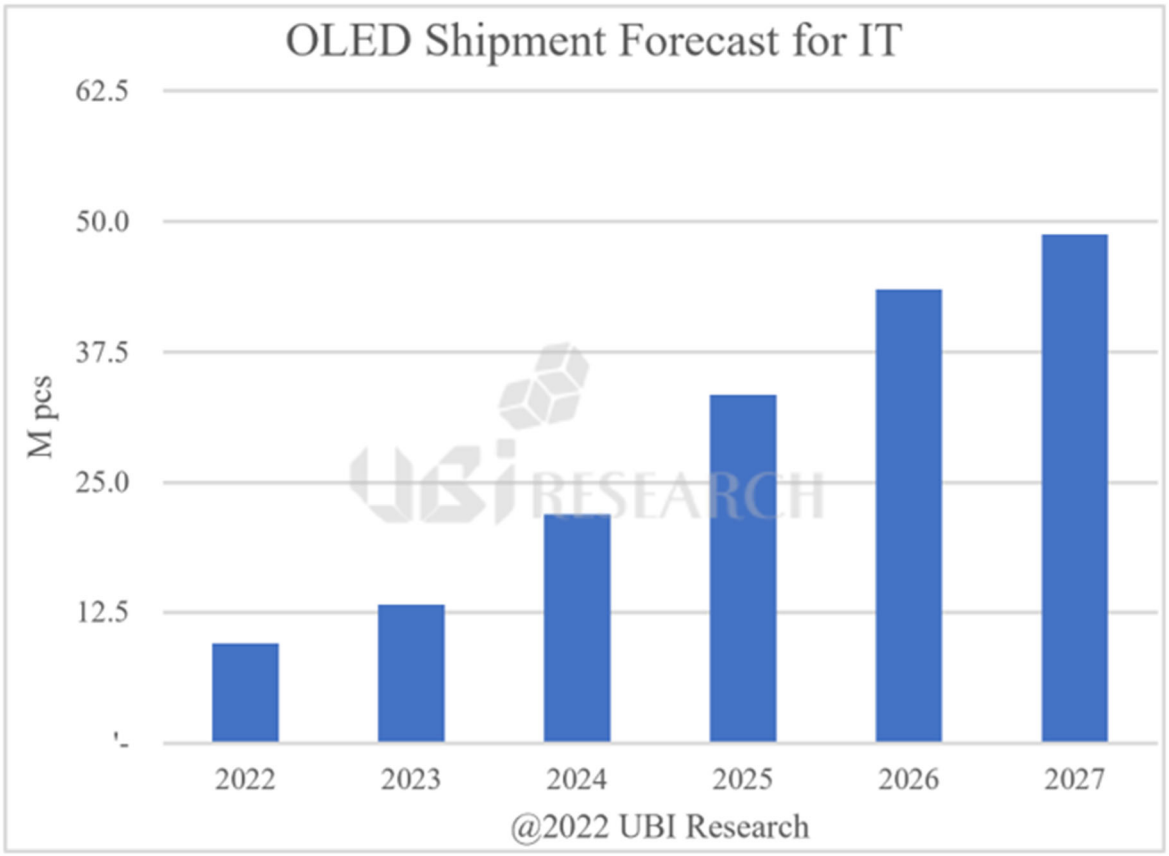
6.3 Organic LEDs in Displays

Direct view displays have already captured a substantial share of the high-end market in the form of OLED displays. Although the intensity of the light created in each sub-pixel is controlled independently, much of this light is still blocked by polarizers, colour filters or quantum dots that are inserted to improve the contrast and colour quality. Source efficacy is good for green and red pixels, due to the introduction of phosphorescent emitters, but inefficient fluorescent emitters are used for blue, due to their longer operating lifetime.

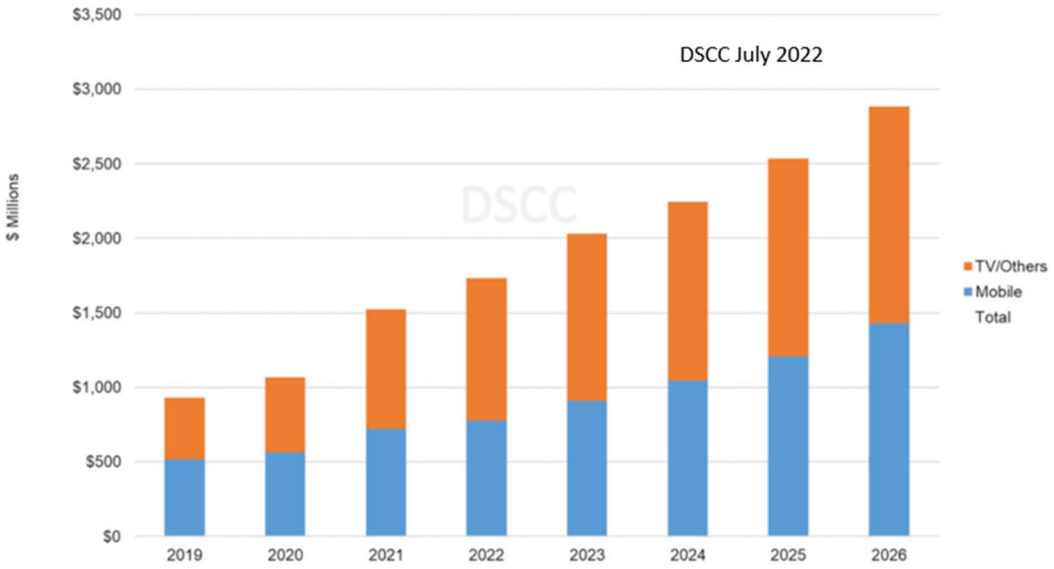
Search for a stable efficient blue has been underway for at least a decade. New approaches such as thermally activated delayed fluorescence (TADF), hyper-fluorescence (HF), electroluminescent quantum dots and perovskites, have been studied in many laboratories but have not yet reached the target efficacy and lifetime. Universal Display Consortium has just confirmed that it expects to be in production of phosphorescent blue emitters in 2024.

The market for OLED materials and OLED displays is tracked closely by DSCC, Omdia and UBI Research. The next chart shows DSCC's forecast of the sales of OLED displays through 2026. Although smart phones and TVs have been the most important segments, the most rapid future growth is expected to come from personal computers, such as notebooks and tablets, as confirmed in the following chart from UBI.

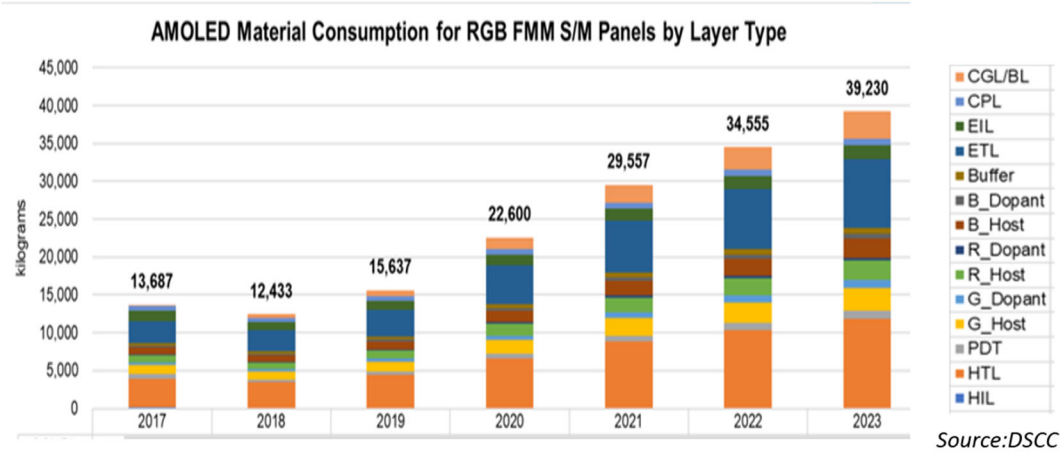




The heart of an OLED display is a stack of organic molecules that convert electrical current into light. The market for OLED materials is shown in the next chart, with almost equal contributions from small and large screen applications. These stacks contain many layers to control the flow of electrons and holes between the electrodes and to create red, green and blue light.

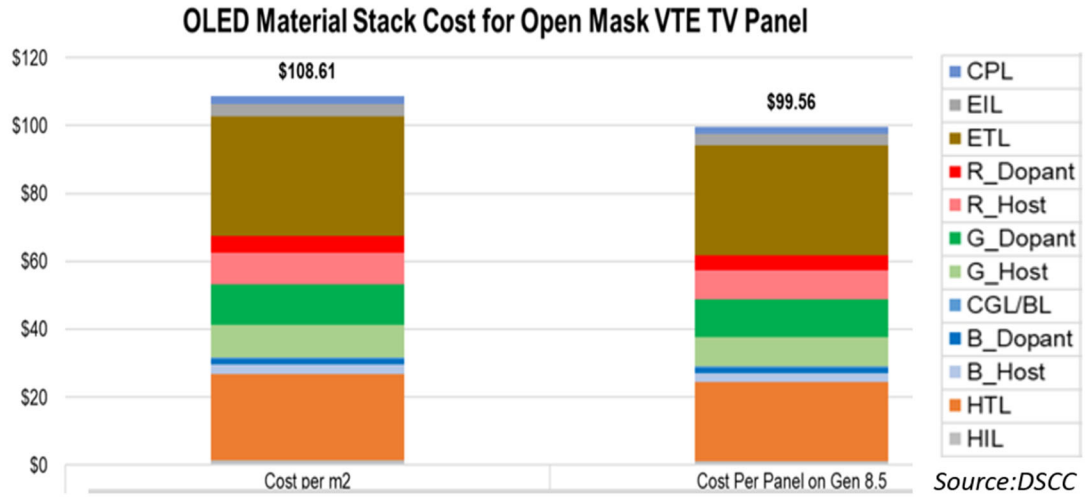


The next slide shows the sales volumes of the many different materials that make up the stack of OLED displays in mobile phones.



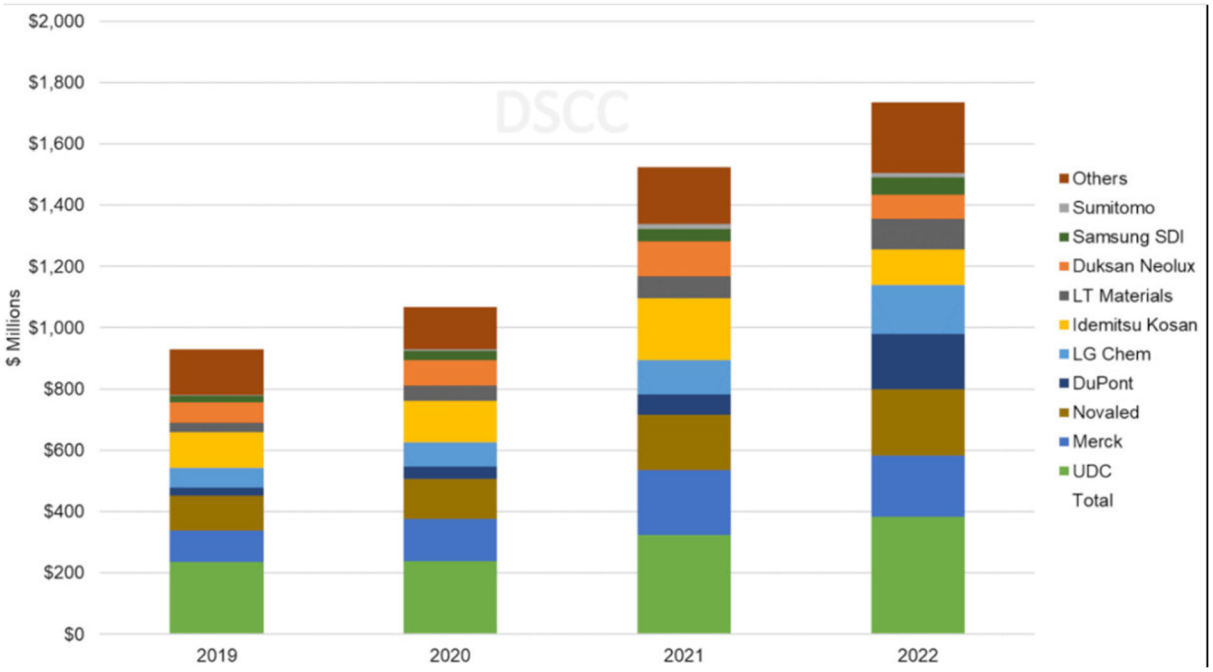
Source:DSCC

The cost of the various materials in a single OLED TV is shown in the next chart.



Source:DSCC

Although almost all OLED displays are manufactured in Asia, US and European companies are among the major suppliers of materials, as shown below.



7. Opportunities for Further Efficiency Improvements

The need for reduced electricity use and the growing interest in new applications are both providing opportunities for further research. This is recognized by the Ministry of Science and Technology in China. CSA has provided the following list of new projects that began in 2022

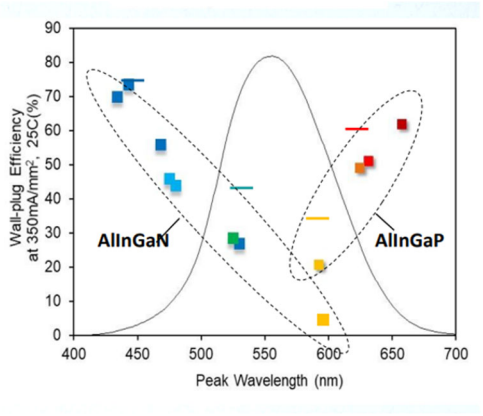
serial number	project name
1	Key Technology of High Pixel Density Micro-LED Microdisplay for AR Applications
2	Research on Key Technology of High Brightness Micro-LED Projection Display
3	Research on key technologies of flexible Micro-LED display
4	Key technologies of InGaN-based long-wavelength LEDs
5	LED technology and its demonstration application for the needs of efficient planting in modern agriculture
6	Development of LED technology and special system for reproductive health medical needs
7	Key technologies for the industrialization of high-power deep ultraviolet AlGaN-based LED luminescent materials and devices
8	High-sensitivity wide-bandgap semiconductor ultraviolet detector and multi-element imaging technology
9	Development and application demonstration of deep ultraviolet LED modules and equipment for public health and other fields
10	Key technologies of AlGaN-based deep ultraviolet LEDs, ultraviolet laser materials and devices with wavelengths shorter than 250 nanometers

Source: Compiled by CSA Research

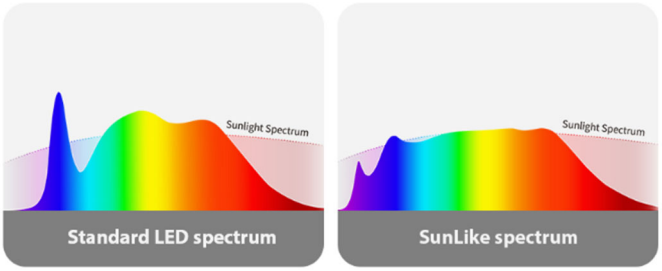
In the remainder of this section, some of the opportunities to increase LED system efficiency are described.

7.1 Higher Efficacy at all Wavelengths

Blue LEDs are extremely efficient, but progress is still needed at other wavelengths, even within the visible range. Oleg Shchekin of Lumileds recently summarized the status in this figure. The efficacy of AlInGaN chips falls rapidly as the wavelength is increased from 450nm, whereas AlInGaP provides high efficacy only above 600nm. So almost all commercial sources of white light combine blue LEDs with phosphors or quantum dots to convert part of the light to higher wavelengths. The horizontal bars in the figure denote the efficacy that would be needed for green, yellow and red emitters to replace the phosphors.

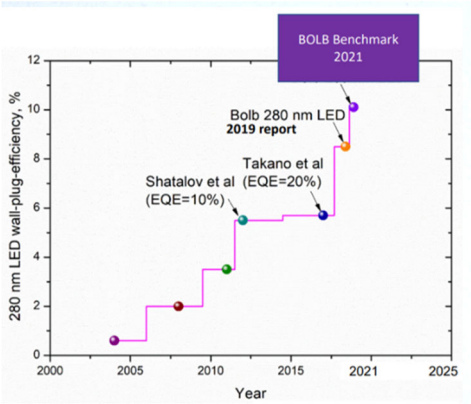


The effect of the lower efficiency at higher wavelengths can be seen in the relative performance of the "sunlike" LEDs which have been introduced to reduce the blue peak in the spectrum of white light, as shown in the next figures from Seoul Semiconductor.



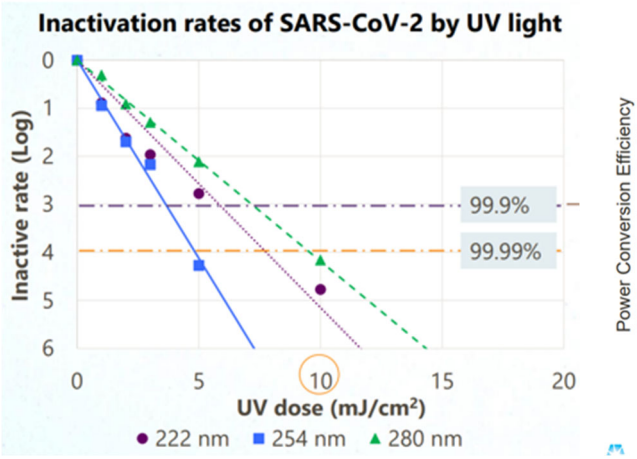
Although many benefits are claimed for sun-like spectra, they usually come with a significant reduction in energy efficiency. According to data sheets downloaded in January 2023, the efficacy of the sunlike 3030 LEDs from Seoul Semiconductor is 139 lm/W at a current of 65 mA, while other LEDs give over 220 lm/W at the same current. A similar efficiency loss is seen in the Optisolis products from Nichia.

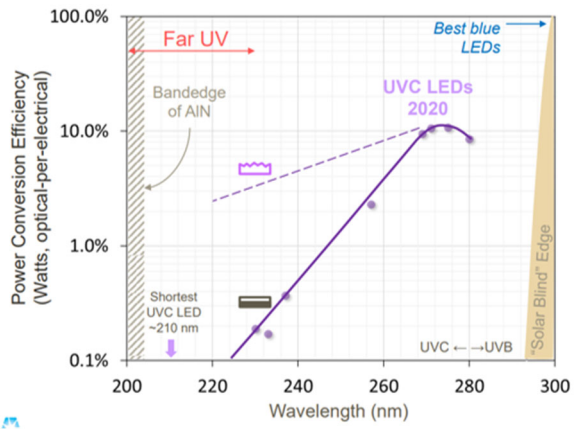
The growth of interest in deactivation of viruses has stimulated research into LEDs in the deep UV region around 280nm. The wall-plug efficiency of most widely available LEDs is below 5%, but recent laboratory studies have suggested that much higher values may be possible, as shown in this figure from Bolb.



CSA reports that similar results have been obtained in laboratories in China. A radiant flux of 22.9mW has been achieved at 40mA and current density 16A/cm^2), corresponding to a wall plug efficiency of 10.1%.

Many authors have suggested that the risk of damage to human eyes and skin can be reduced by using wavelengths around 222nm. The radiation is absorbed harmlessly in the outermost layers which are cast off regularly, rather than penetrating more deeply and causing permanent damage. The figure from Yamaguchi University below (on the left) shows that such radiation is effective. However, as shown in the figure on the right from Michael Krames of Arkessa, the efficiency of LED sources is even lower at these wavelengths.





7.2 Higher Efficacy at all Intensities

The efficacy of LEDs is very sensitive to current density, typically peaking around 10 A/cm^2. The current needs to be high enough to produce electrons and holes but not so high that the resulting excitons interact and decay non-radiatively. Higher currents also raise the junction temperature which leads to further losses. This table from Lumileds shows the result for white light created both by phosphor conversion and colour-mixed emitters.

3000K/90CRI efficacy with state-of-the-art LED performance

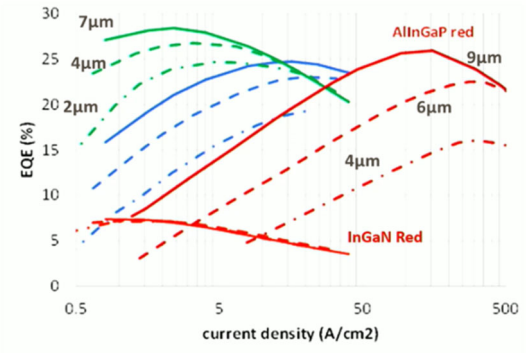
J (A/cm²)	Tj (°C)	PC-LED efficacy (lm/W)	CM-LED efficacy (lm/W)
10	25 °C	167	145
20	55 °C	134	109
35	85 °C	124	79
70	85 °C	83	48

If one needs high intensity from a single package, one solution is to use large LEDs such as the 7mmx7mm packages from Cree Lighting. The XHP70.3 LEDs can give over 1800 lumens from 12.5W, with an efficacy of around 150 lm/W.

7.3 MicroLEDs

The last few years have brought a surge of interest in micro-LEDs, mainly from the display industry. Most displays are very inefficient, with only around than 5% of the light created within the display emerging towards the viewers. OLEDs promised a significant improvement, but this has come mainly in the form of better pictures rather than energy savings. Large area direct view LED displays, in which light is created only when and where it is needed, can be much more efficient when used in outdoor billboards with large pixels. However, when the same technology is used for higher resolution displays for high quality video presentation, the efficiency drops dramatically. So, it will be interesting to see whether the predictions of energy savings from micro-LED displays can be realized.

One challenge is that the efficacy of LEDs drops as the size is reduced. This figure from Lumileds shows the external quantum efficiency of LEDs as a function of chip size and current density. As with larger LEDs, InGaN chips seem better at low current density and for blue and green emission while AlInGaP chips at have advantages in the red. The efficiency falls rapidly for both technologies as the size is reduced below 10 µm.

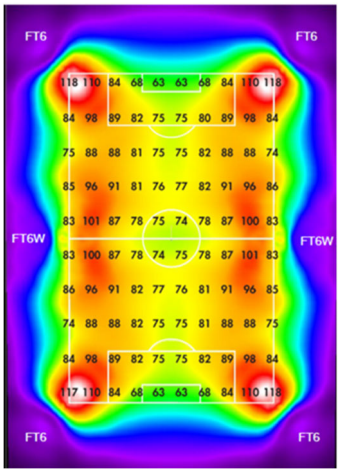


The main cause of the problem seems to be defects near the edges of the chips. While many researchers are studying ways to mitigate these effects with traditional structures, others believe that radically new designs are needed, such as nanorods.

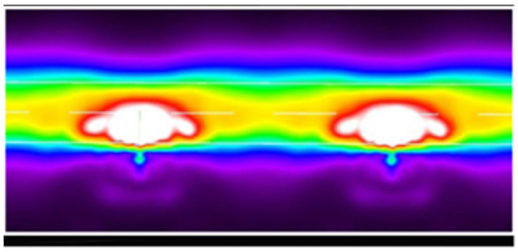
7.4 Better Control of the Direction of Emitted Light

Beyond the development of more effective LEDs, much can be gained for many applications by more effective use of the light, for example through greater control of the direction of the emitted light. This is particularly important in outdoor applications, where misdirected light can be hazardous as well as a waste of energy. Even in areas that need to be well lit, better spatial control can lead to significant savings as well as avoidance of glare.

As an example, the figure from LEDiL on the right shows the spatial distribution of light from the floodlights in a football stadium. Substantial light reaches all parts of the playing area while avoiding glare in the goalkeeper's eyes. This system represented an improvement over previous models, but still only 44% of the emitted light reaches the pitch.



The situation can be even worse for streetlights, as shown in the figure below, again showing a state-of-the art system from LEDiL.



More effective lighting with greater energy savings could come from dynamic control of the spatial distribution. As discussed above, this is being used in automobile headlamps to reduce glare. Several years ago, Osram experimented with a similar system for indoor applications, called OmniPoint, but this technology is still in its infancy.

7.5 More Effective Temporal Control

The trend towards more work being done at home has increased the motivation to deploy systems for automatic control of the lights in offices. However, the development of effective occupancy controls has proved to be more difficult than expected, particularly since the majority of systems depend on motion detection. Similar problems have occurred in systems for parking lots, but there have been some very successful applications in warehouses, where the combination of LED installation, increased use of daylight and occupancy controls has led to energy savings of over 90%.

8. Proposed Efficiency Standards and Regulations

The European Union (EU) has introduced a new series of energy efficiency labels, with ratings between A (best) and G (worst). The basic efficacy levels for omni-directional light sources are shown in this table. The efficacy levels for directional lamps are reduced by 15%.

Energy efficiency class	Total mains efficacy η_{TM} (lm/W)
A	$210 \leq \eta_{TM}$
B	$185 \leq \eta_{TM} < 210$
C	$160 \leq \eta_{TM} < 185$
D	$135 \leq \eta_{TM} < 160$
E	$110 \leq \eta_{TM} < 135$
F	$85 \leq \eta_{TM} < 110$
G	$\eta_{TM} < 85$

The information from each label is published on the internet at

https://eprel.ec.europa.eu/screen/product/lightsources

The list includes over 270,000 models. The site shows the distribution of the ratings for various selections of entries. The distribution (%) for directional and non-directional lamps as of February 6, 2023 is shown here. More than half of all lamps are in the lowest two classes. The EU clearly believes that further efficiency gains can be made.

Class	A	B	C	D	E	F	G
	%	%	%	%	%	%	%
Non-directional	0.4	0.7	5	14.8	24.5	35.9	18.8
Directional	0.4	3.1	9.5	10.6	20.6	36.5	19.4
All	0.4	1.3	6.1	13.7	23.5	36	19

In the US, the Department of Energy (DOE) has recommended a new rule that would more than double the efficacy requirement for most general service lamps to around 120 lm/W, effectively moving the market away from compact fluorescent (CFL) replacements for traditional incandescent and halogen lamps. However, it seems unlikely that such a regulation will be approved by congress in the next two years.

A similar effort is underway in South Africa. The Department of Trade, Industry, and Competition (DTIC) has formulated new regulations imposing an efficacy minimum of 90 lm/W that would also ban the sale of halogen and CFL bulbs. The proposed rules were put out for public comment in 2021, but do not appear to have been officially proposed by the government.

Concern about the environmental impact has led to consideration of bans on all fluorescent lamps that contain mercury. Although the text of the Minamata Convention (MC) on the restriction of mercury was first approved in 2013 and ratified by 137 parties in 2017, implementation for lighting has been very slow, partly due to resistance by the Lighting Industry Associations in Europe and Japan. The MC COP4 meeting in 2022 postponed a decision regarding linear fluorescent tubes until COP5 in November 2023, after consideration of a potential global ban in 2027.

Following pressure from Africa, the EU Commission in December 2021 adopted regulations under the RoHS Directive effectively banning fluorescent lighting for sale in the EU by September 2023. On a cumulative basis between 2023 and 2035, the much-delayed decision to phase-out these mercury-containing lamps is expected to save approximately €18.2 billion, as well as 190 TWh of electricity and 1.8 metric tonnes of toxic mercury.

In the US, despite the reluctance of the Federal Government to restrict trade, individual states are considering legislation. Regulations have been introduced in Vermont and California that would ban most sales of fluorescent tubes beginning in 2024.

The Clean Lighting Coalition has conducted a series of studies to show that the replacement of mercury-containing lamps has economic benefit to consumers in addition to the impact on health. This table shows their analysis for Brazil of the total cost of replacement for bulbs and tubes, including operating costs as well as the initial purchase price.

	Unit	CFL	LED lamp	LFL tube	LED Tube
Purchase Price	BRL	11	8	15	30
Power consumption	Watt	15	9	36	20
Annual cost of operation	BRL	14	9	91	52
Annual CO2 emission	kg	3.3	2	24	13

The rationale should become even stronger with every increase in the cost of electricity.

9. Summary

Faced with the growing challenges of climate change and with the amelioration of the effects of the COVID pandemic, 2023 brings opportunities for the lighting community to reaffirm and strengthen efforts to save more energy while increasing the benefits of solid-state lighting. This must take place across the globe and involve the reinforcement of local economies and national security as well as greater international collaboration.