FLAT PANEL DISPLAYS

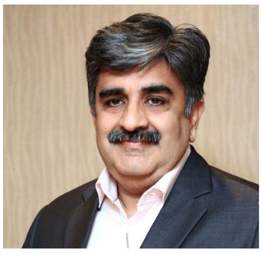
CREATION OF A DISPLAY INDUSTRY IN INDIA

ICEA
INDIA CELLULAR & ELECTRONICS ASSOCIATION

grantwood Technologies Pvt Ltd

Creation of a Display Industry in India

FOREWORD



MR PANKAJ MOHINDROO

CHAIRMAN

India Cellular & Electronics Association (ICEA)

Displays are the windows to the digital world of data. In the digital world, data is first created, then transmitted, processed, stored and finally visualized in a human readable form using displays.

The value-addition along this digital highway is driving the digital megatrends in information technology (IT) today, from data creation with IT software, social media, IOT devices or other sensors, data transmission through 5G communication networks, data processing with AI and data storage/retrieval over cloud-based data centres.

ICEA is proud to be associated with Grantwood Technologies for the formulation of the Report on the "Creation of the Display Industry in India".

We currently consume 7-8% of Global display market primarily in Mobile, TV and IT hardware products. Now with profound focus on Electronics manufacturing happening in India with scheme like PLI, the consumption of displays is going to increase multifold. There is no Display Fab in India as of now and is the right time that we focus on building this strategic industry in India.

Given the manufacturing plans for Mobile Phones, TV and IT hardware products for domestic as well as export we should aim to build a large Display industry with 25 -30% of global market share and create large value-addition in India. This industry would create a high-tech manufacturing ecosystem that can trigger Indian innovation in display-leveraged, high-tech, display centric consumer products of the future and in other adjacent industries, thereby creating direct and indirect domestic employment

It was only appropriate that at this point of the creation of the Display Industry in India, an important study is conducted to support our policy makers to evaluate the impact of this mammoth establishment on value addition, reduction of imports and maximization of exports with a massive employment creation, for the National Interest.

I note with satisfaction that this crisp, yet elaborative technical report undertaken by ICEA and Grantwood Technologies has truly revealed the immense possibilities for the Display manufacturing, for both the Public and the Private sectors. We are confident that study will support our policy makers in providing fiscal and non-fiscal support measures to the industry to achieve the glorious success envisaged.

CONTENT

Executive Summary

Displays are the windows to the digital world of data. In the digital world, data is (i) first created, (ii) then transmitted, (iii) processed, (iv) stored and (v) finally visualized in a human-readable form using displays. The value-addition along this digital highway is driving the digital megatrends in information technology (IT) today, from data creation with IT software, social media, IOT devices or other sensors, data transmission through 5G communication networks, data processing with AI (Artificial Intelligence) and data storage/retrieval over cloud-based data centers. These digital megatrends have spawned unicorn startups and billion-dollar companies with trillion-dollar economic potential capable of creating sustainable jobs, wealth and prosperity across nations. Data emerges from the digital highway into our physical world through displays. Display-centric products such as Smartphones, Tablets, Notebook PCs, Monitors, Televisions, Smart Watches, VR/AR (virtual reality and augmented reality) Headsets and Automobile Display Clusters, all connected ubiquitously to the digital highway, are some of the modern consumer-products that have leveraged the underlying display component products to revolutionize our physical world.

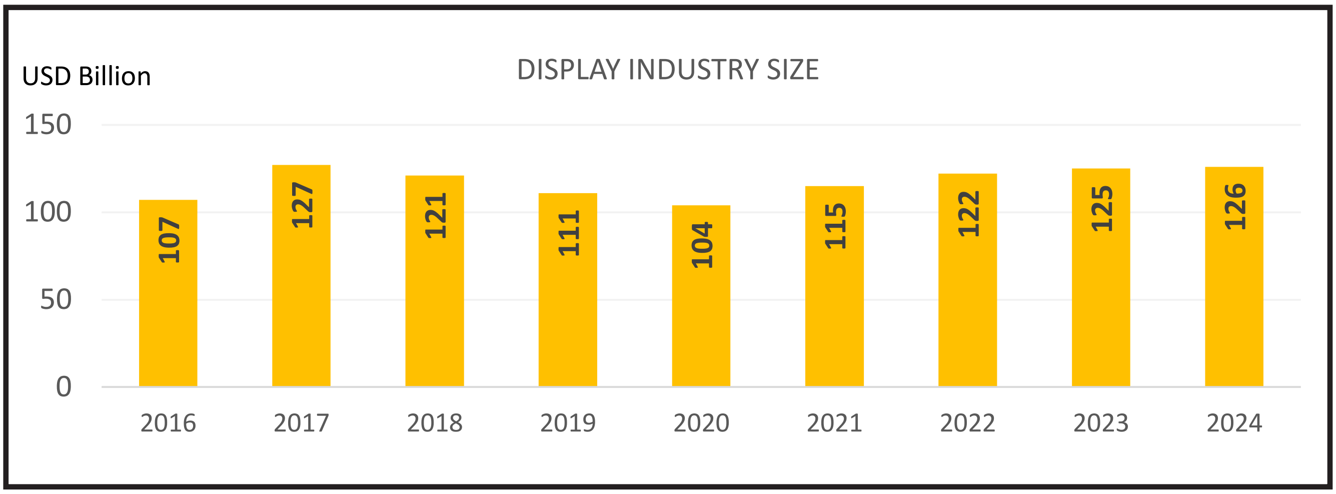


Figure 1.1: Global Display Industry (2016-2019 Actuals & 2020-2024 Forecast)
Ref: Ross Young, DSCC, SID 2020 Business Conference, August 2020

In this report, we will take a deeper dive into the Display Component industry and its future potential to create billion-dollar manufacturing industries in India with the potential to trigger leveraged trillion-dollar economies.

The global display industry has surpassed a hundred billion dollars (USD) in size while the display-leveraged consumer electronics hardware industry is currently driving a trillion dollar (USD) global economy. Figure 1.1 shows a recent report from a leading display industry analyst about the status of and forecast for the global display industry. In 2019, the display industry reported revenues of USD 111 billion, however, due to the worldwide economic impact of the pandemic the 2020 forecast has been revised down to projected revenues of USD 104 billion. However, the industry is expected to revive by 2024 to projected revenues of USD 126 billion. The display industry revenues are a consolidated total of several types of display-centric electronic hardware products, namely, Smart Phones, TVs, Notebooks, Tablets, Monitors, Automotive and others. Table 1.1 shows a breakdown of the number of display units shipped and the revenues attributable to each of these display product segments in the previous year 2019 and the forecast for the current year 2020. It can be seen from Table 1 that in 2019, the Mobile phones and TV product segments accounted for 66% of the industry revenues, Notebook and Monitor shipments accounted for 15% industry revenues and the remaining 19% of the industry revenues originated from Tablets, Automotive and other applications.

Products	2019 Actuals		2020 Actuals	
	Units (millions)	Revenues (billions)	Units (millions)	Revenues (billions)
Mobile phones	2,029	$ 44.2	1,745	$ 41.6
TVs	287	$ 28.5	273	$ 24.9
Notebooks	185	$ 7.7	201	$ 8.7
Tablets	180	$ 4.8	199	$ 5.2
Automotive	161	$ 7.8	133	$ 6.4
Monitors	150	$ 9.5	156	$ 9.7
Others		$ 8.5		$ 7.5
		$ 111		**$ 104**

Table 1.1: Breakdown of Global Display Shipments – 2019 vs 2020
Ref: Ross Young, DSCC, SID 2020 Business Conference, August 2020

In comparison, the Indian Global Display market is currently in its infancy with the Mobile, TV and IT hardwares' just about starting to get manufactured in a big way. But this is changing now with profoundly serious Electronics manufacturing happening in India. There is no Display Manufacturing activity in India as of now. All the Displays are imported into the country by the EMS and Contract manufacturers in India.

USD 18.9 B by 2025

The overall demand for Displays in India for 2020 was about 253 million Units valued at USD 5.4 B. Given the manufacturing plans for Mobile Phones, TV and IT hardware products, it is expected to grow at a heathy CAGR of 29.5% to 922 million units or USD 18.9 B by 2025.

$60 B DEMAND

The cumulative Indian market demand for Displays over the next 5 years is likely to be USD 60 B between 2021 to 2025.

The forecast for the Indian Display market is shown in Figure 1.2 & 1.3 below

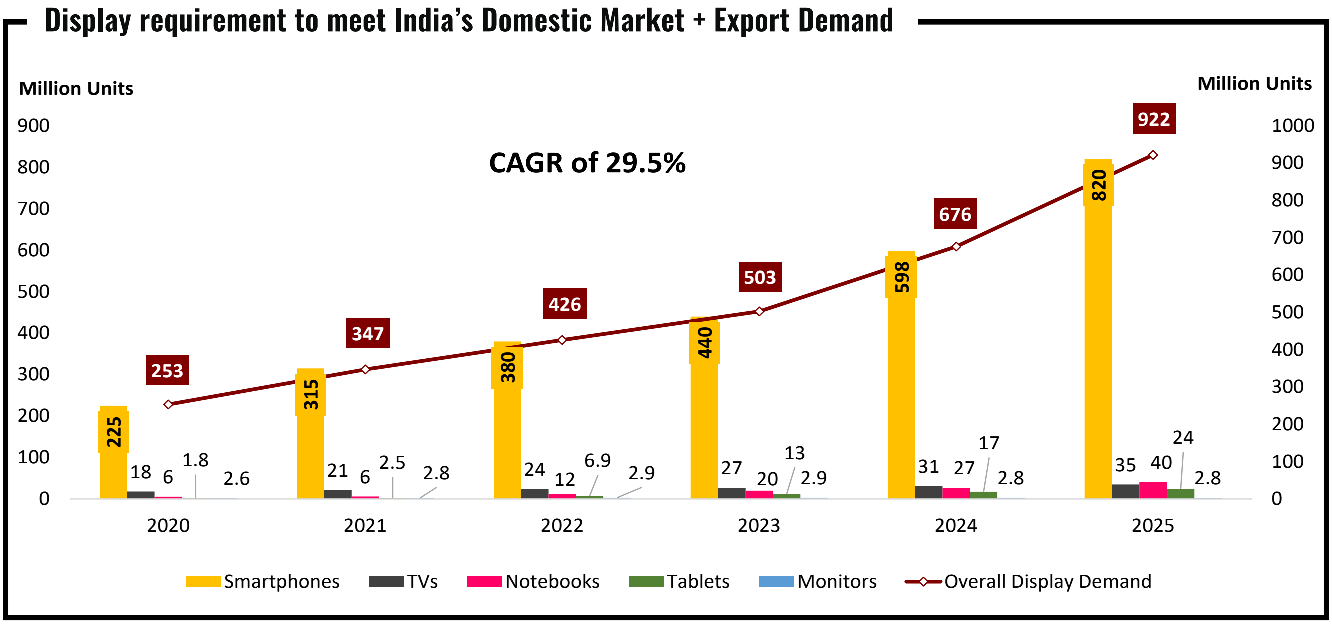


Figure 1.2: India Domestic Market + Exports Demand: Market Forecast
Source: India Cellular and Electronics Association Forecast, December 2020

***Note: Feature phone displays and automotive displays are not included.*

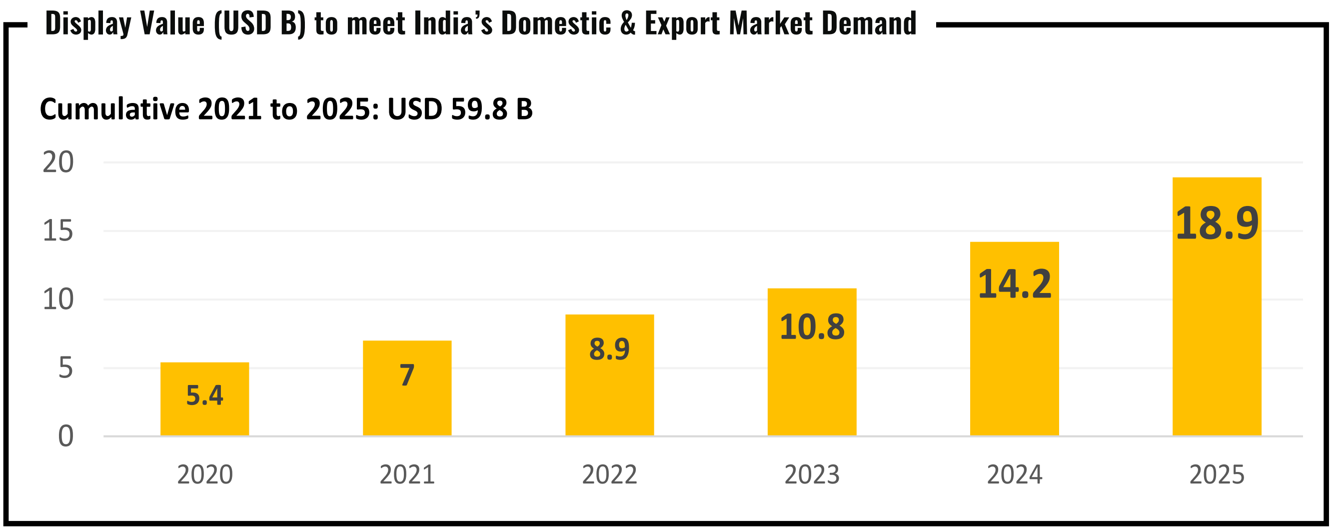


Figure 1.3: India Domestic Market + Exports Demand: Market Forecast
Source: India Cellular and Electronics Association Forecast, December 2020

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Benefits for India

Value-Addition

Create value-addition in India of greater than **USD11 billion** annually from Year 5.

Exports

Create new display export opportunities from India of up to **USD10 billion** by Year 5.

Imports

Eliminate the need for display component imports to satisfy domestic market demand.

Employment Creation

Create domestic employment, both direct and indirect, to the tune of **200,000 new, sustainable, high-tech, futuristic jobs.**

High-Tech Industry

Create a high-tech manufacturing ecosystem that can trigger Indian innovation in display-leveraged, high-tech, display-centric consumer products of the future and in other adjacent industries.

India – Display Manufacturing Plan

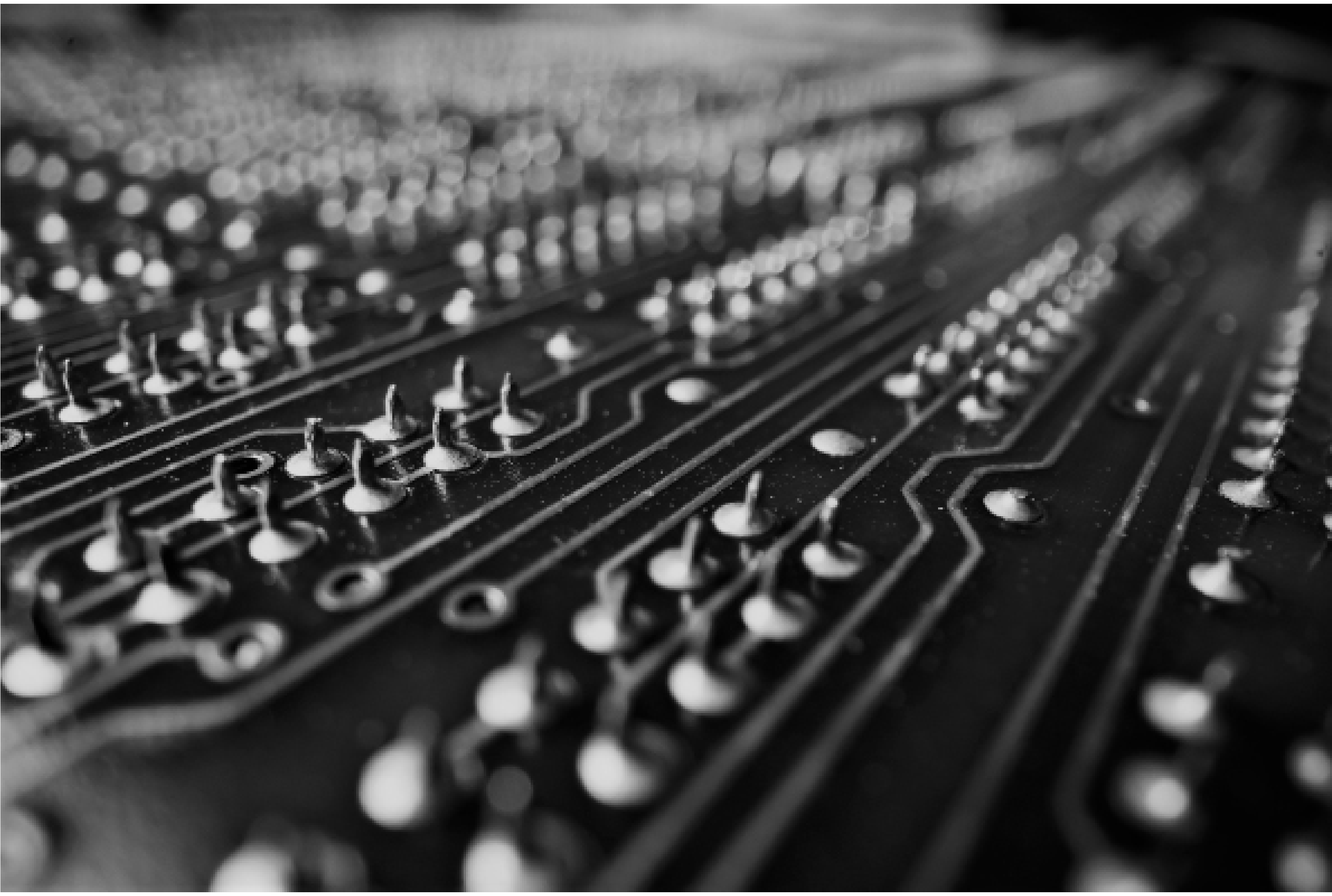
India, an established leader at the front-end of the data value-chain in information technology (IT) software, has now emerged as a leading consumer of display-centric hardware. The display component makes up at least 15% of the value of a display-centric hardware product like smartphones, tablets, TVs etc. In many cases, the display is the single largest unit cost item in a typical bill-of-materials listing. However, India does not currently have a local display manufacturing industry and all displays have to be imported from overseas suppliers. The demand for displays, consumed by an evolving local assembly manufacturing of display-centric products under the "Make-in-India" strategy, will substantially increase over the future years. As depicted in Figure 1.2 the display requirement to meet India's domestic market and export demand will grow at a CAGR of 29.5% in the time period 2020-2025. The cumulative cash outflows over the same 5-year period for displays adds up to USD60 billion as shown in Figure 1.3.

The five major product categories for display demand in India are smartphone, TVs, notebooks, tablets and monitors. The fastest growing segment is the smartphone display segment. To meet the display demand in various categories and keeping technology adoption rate and price sensitivity in consideration, the display manufacturing plan for India should focus on two types of display fabs, namely, (i) Gen 6 fabs for smartphone displays; and (ii) Gen 8.5 fabs for all other product categories. Table 1.1 shows such a manufacturing plan for the display market demand forecast for India.

Display Manufacturing Plan for India					2025 Panel Capacity (Sheets per Month) Gen 6	Gen 8.5
				Operating Efficiency -->	85%	85%
Product Category	Product Size (in)	2025 Quantity (millions)	Panels per Sheet	Process Yield	1500mm x 1850mm	2200mm x 2500mm
Smartphones - Case 1	6	820	250	85%	380K	
Smartphones - Case 2	5.5	820	300	85%	320K	
TVs - Case 1	55	35	6	90%		640K
TVs - Case 2	47	35	8	90%		480K
Notebooks	15.6	40	75	90%		60K
Tablets - Case 1	10.1	24	75	85%	40K	
Tablets - Case 2	10.1	24	170	85%		20K
Monitors	19	2.8	50	90%		6K
Total				Total Panel Capacity -->	360K to 420K	560K to 730K

Table 1.2: Recommended Plan for Display Panel Manufacturing in India (2021-2025)

The key factors that drive the sizing of a display factory are mother glass size, product size, panels per sheet, process yield and operating efficiency. For example, in order to manufacture 820 million smartphone displays per year of 6-in diagonal size in Gen 6 fabs, approximately 380,000 (or 380K) MG sheets per month will be required to be processed at 85% yield and 85% operating efficiency. As an additional example, in order to manufacture 35 million TV displays per year of 55-in diagonal size in Gen 8.5 fabs, approximately 640,000 (640K) MG sheets per month will be required to be processed at 90% yield and 85% operating efficiency. In summary, the manufacturing plan for India covering the product categories and quantities outlined in the Figure 1.2, requires Gen 6 fabs with a cumulative capacity of 360K to 420K sheets per month and Gen 8.5 fabs with a cumulative capacity of 560K to 730K sheets per month. Assuming that a Gen 6 fab is sized at 60K sheets per month and a Gen 8.5 fab is sized at 120K sheets per month, then India needs six Gen 6 fabs and 5 Gen 8.5 fabs.



Recommendations for India

The creation of a display industry will require the confluence of capital, knowhow and market-pull. India is already a leading consumer of displays, hence there is already a strong domestic market-pull. The challenge for India is to bring together capital and knowhow to trigger the growth of a domestic display industry. A display manufacturing industry can be created in India through private-public partnerships (PPP) under private sector leadership, as discussed below.

The Role of Private Sector

01

The display industry must be operated under the leadership of private sector companies.

02

Several private sector corporations are necessary to establish a healthy domestic competition in the display value chain (including display makers and supply chain providers).

03

Private sector corporations interested in leading the India display industry as display makers must have strong balance sheets since the investments and the cash flows are large.

04

Such display makers must have management teams that have gained extensive hands-on experience from previous involvement in the global display industry.

05

The private sector companies that are interested in being display makers or Tier-1 suppliers to the display makers must establish multi-year business plans addressing:

a. Supply Chain Management and Cost Reduction Plan
b. Capital investment Plan
c. Marketing Plan
d. Knowhow Acquisition Plan
e. Research and Development Plan
f. IP licensing plan.

06

The business plans proposed by private sector companies for consideration of government support must address the need for two types of display fabs (Gen 6 and Gen 8), as discussed in earlier sections of this report, needed to address the high-growth area of high-performance displays needed for smartphones and the more mature displays needed for TVs, laptops, monitors and tablets.

The Role of Public Sector

A coherent national policy is required to mobilize private sector companies to bring together capital and knowhow to establish state-of-the-art display fabs. The national policy can extend government support of up to USD20 billion, as noted earlier, towards providing financial incentives to display makers and display supply chain companies who agree to make substantial investments under the private-public partnerships. Such incentives may be directed and leveraged towards the following types of support for private companies.

01 Infrastructure Support

a. Land, water and electricity
b. Building
c. Transportation and housing

02 Capital Investment Support for

a. Investment in new display fabs and display module manufacturing plants
b. Acquisition of used fabs

03 Other Financial Support

a. Equity participation
b. Loans &/or loan guarantees
c. Production linked incentives

04 Tax Benefits

05 Research & Development credits to private sector companies

06

Set up a national R&D center for display technology development (Gen 4 or Gen 5.5 fab) that can create new IP in state-of-the-art technologies which can be made available to the display industry.

2.Evolution of Displays & Display-Centric Products

Karl Ferdinand Braun, a German electrical engineer and physicist, made significant contributions to the birth of radio and television technologies. He shared the 1909 Nobel Prize with Guglielmo Marconi (an Italian inventor and a pioneer in wireless communication) for "contributions to the development of wireless telegraphy". In 1897, Braun had built the first cathode-ray tube (CRT). CRT, the first electronic hardware for visualizing information, became the basis for the subsequent invention of the television (CRT-TV). Some of the key contributors to the birth of CRT-TV during that pre-commercial era were Philo Farnsworth (USA), John Baird (Scotland) and Vladimir Zworykin (Russia). The groundbreaking contributions of these pioneers resulted in the arrival of the commercial television products to market. The first commercial television products, based on CRT displays, were introduced to the market in 1934 and carried only black and white TV program content. This was followed by color television products, also based on CRT displays, which entered the market in 1954. The CRT-TV industry grew into a billion-dollar global industry over the next few decades. By 1995, some 160 million CRTs were being manufactured and shipped to the global CRT-TV market. Until the late 1990s, the CRT-TV industry enjoyed a monopoly status and had very few rivals that could come close in either performance or cost.

In the 1990s, customer preferences began shifting to flat screens and larger screen sizes in their CRT-TV products and leading suppliers tried to meet these demands with innovative solutions. However, the CRT-TV had an inherent scaling limitation when screen sizes had to be increased. With increasing screen sizes, the bulk and weight of the underlying CRT components also had to increase. The quantity and weight of glass required for structural integrity in larger CRT-TV products (to prevent implosions) increased as well. The state-of-the-art CRT television products introduced by Sony in 1998, namely, the 27-inch, 32-inch and 36-inch FD Trinitron WEGA flat-screen models, weighed 100 lbs., 165 lbs., and 190 lbs., respectively. Due to these limitations, the television market began to gradually migrate to the newly maturing flat panel display options which were of thinner profile and lightweight. The era of CRT-TVs eventually began to come to an end. The life of the CRT-TV and the industry it supported lasted over sixty years before being disrupted by the emergence of commercially viable flat panel display product options. The golden age of the CRT-TV and the CRT display industry that it helped create lasted well into the 21st century prior to its demise.

In the meanwhile, the information technology (IT) revolution had begun in the early 1980s triggered by the semiconductor industry and the availability of cost-effective computing power. Personal computers (PC), such as the IBM PC, HP, Compaq, Dell and Apple II models, were early examples of desktop personal computer models that came with separate but connected CRT monitors for displays. These desktop personal computer products began to be adopted by business customers as tools for office productivity enhancement (such as word processing, spreadsheets, presentations, etc) and inter-office communications (such as email). Although the Compaq Portable PC and Apple MacIntosh PC were the first portable PCs to be introduced into the market in 1983 and 1984, respectively, with small built-in bulky display screens, they failed to gain any market traction. These early "portable" PC models were bulky and heavy to be truly portable and lacked the appropriate input/output peripherals needed for portability. Meanwhile, the steady advances in computing power using Intel microprocessors, the mass-market adoption of the Microsoft operating system and the introduction of a graphical user interface system (including

the mouse) by Apple began to create a mass-market appeal for portable PCs and increased the demand for mobile PC products outside the office environment. In order to meet customer preferences, the mobile PC industry began looking for a non-CRT display solution for their product designs. During the mid-1980s, several leading corporations of that era began to develop the building-block manufacturing technologies capable of producing thin, flat and power-efficient display panels that could be powered by portable battery power. In 1989, IBM and Toshiba formed a joint venture in Japan (called DTI) for the production of a new class of display panels which combined thin-film transistors (TFT) and liquid crystal (LC) light valves on glass substrates. This new class of displays, which came to be known as TFT-LCD displays, entered the market for use in Notebook PCs in the early 1990s and remains today as the primary display of choice for modern Notebook PCs. In 2019, as noted in Table 1.1, the display industry shipped out 185 million display units for use in Notebook PCs.

Figure 2.1 shows a recent twenty-year history of the global display industry categorized by the type of underlying display technologies. This figure provides a 2010 snapshot of industry progress from 1998 and a future forecast of the global display industry until 2017. By 2000, there were two main display technologies in production, namely LCD and CRT, that accounted for a substantial portion of the display industry revenues exceeding USD40 billion. They represented two different classes of display technologies, namely, non-emissive (LCD) and emissive (CRT) displays. The LCD displays required external light sources in combination with LC light valves whereas the CRT displays directly emitted light from phosphors coated on their emitting surfaces. In general, emissive displays exhibit superior contrast ratios, an intrinsic display attribute demanded by customers, compared to non-emissive displays since a non-emitting pixel of an emissive display is truly black when it is not turned on. Thus, CRT displays (circa 2000) delivered superior image quality than their LCD counterparts. However, customers were becoming familiar with flat panel LCD displays in their Notebook PCs and liked the thin and lightweight designs of the resulting display-centric products. The market needed displays with superior contrast ratios while being thin and lightweight. The race was on to develop new display technologies that could deliver these features simultaneously.

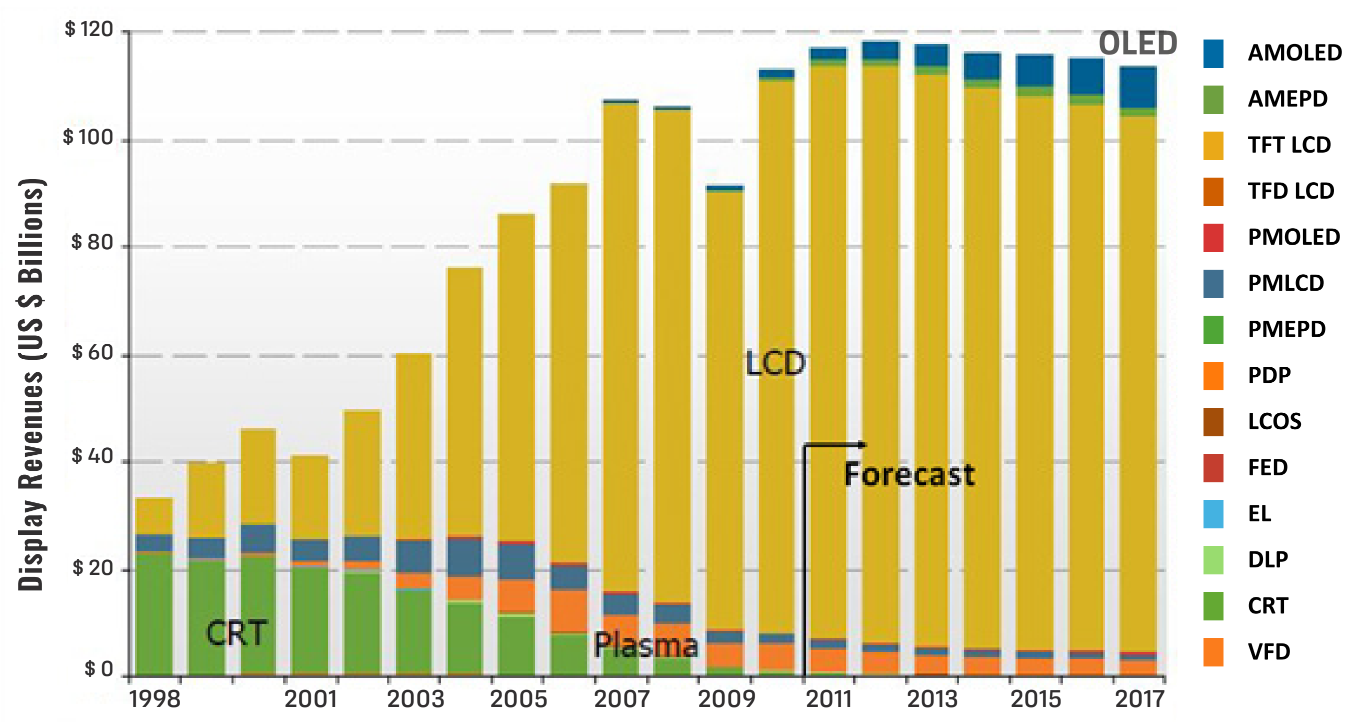
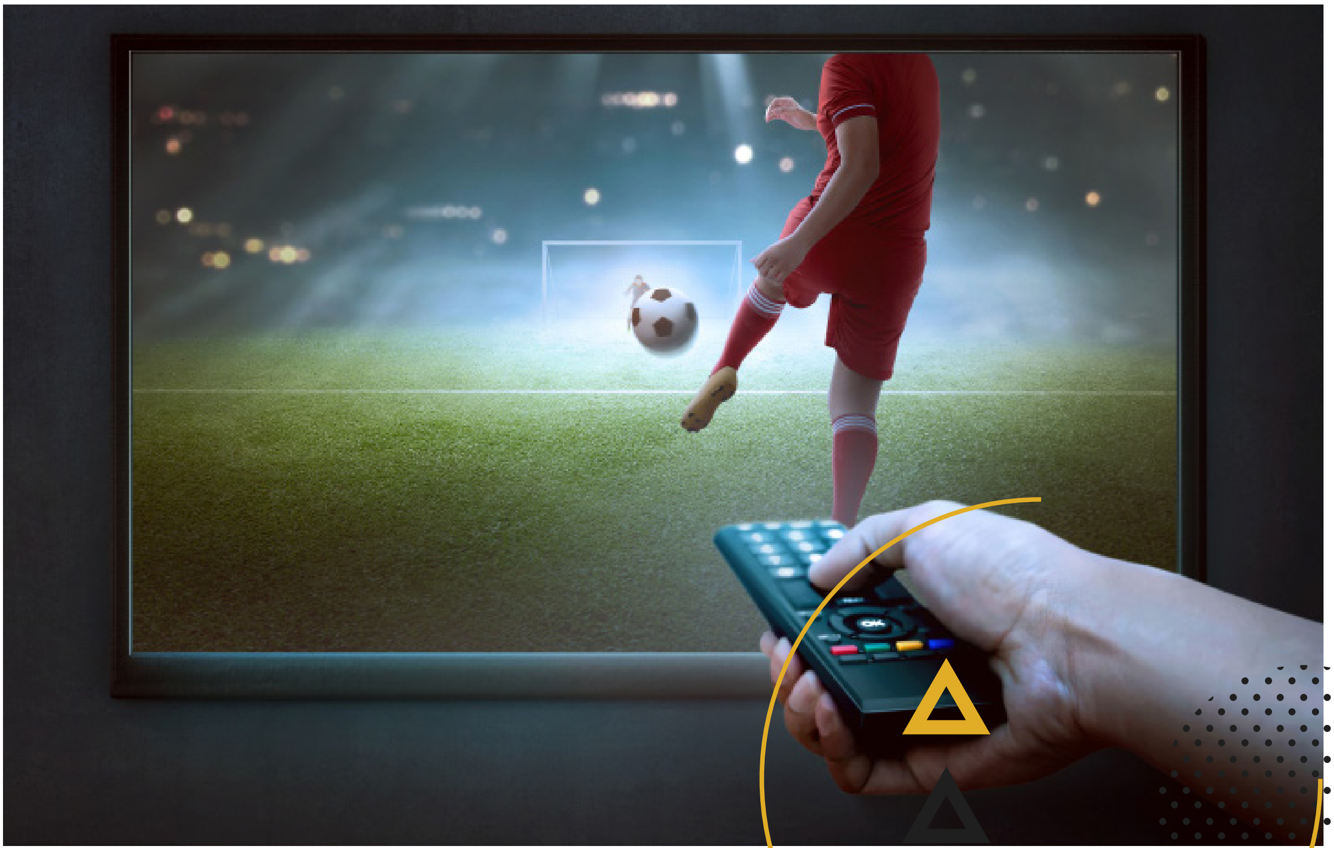


Figure 2.1: History of the Flat Panel Display Industry
Source: DisplaySearch, Quarterly Worldwide FPD Shipment and Forecast Report (2010)

Several promising display technology solutions, as shown in the legend of Figure 2.1, were developed as alternate flat panel display options. Only a few of these options shown were capable of being scalable or usable over a wide variety of applications. **The two most promising options were the OLED and PDP displays.**

i. **Organic Light Emitting Diode (OLED),**

a self-emissive light-emitting device consisting of thin layers of functional organic materials sandwiched between two electrodes and driven by an electrical current, was invented in 1987. The passive-matrix OLED display (PMOLED) was introduced into the display market in 1998 as a substitute for low-information content displays that were being used in mobile phone sub-displays and automotive applications, a relatively small market segment. The active-matrix OLED display (AMOLED) was first demonstrated in 1999 by the combination of TFT backplanes used in TFT-LCD displays and OLED devices deposited over them. They entered mass-production in 2002 and were first commercialized in 2003 for digital still camera and mobile phone applications. The first AMOLED displays for use in TVs was developed in 2006 and introduced to the market in 2012. AMOLED displays were self-emissive displays that exhibited excellent characteristics of an emissive display technology while being thin and lightweight.



ii. **Plasma Display Panel (PDP),**

also a self-emissive display technology, is based on an invention in 1964 of a light-emitting device where each of the pixels can emit light from a phosphor coating that can be energized on demand by ionized gases (plasma) driven by an electric field. Although PDP monochrome display products were used during the 1970s and 1980s in a variety of low-information content information panel applications, the first full color PDP display was demonstrated only in 1994. PDP displays were also self-emissive displays that exhibited excellent characteristics of an emissive display technology while being flat. By 2000, PDP display technology had entered the TV market mainly driven by large CRT-TV manufacturers who saw their business under threat from the emerging flat panel LCD industry. It was found that, due to intrinsic design rule limitations, PDP displays could be manufactured only in large sizes (such as > 60-in TVs) with relative ease but could not be produced in a cost-effective manner when scaled down towards the display sizes (32-in to 42-in) where the prevailing CRT-TV market was at that time.

While these alternate technologies (PDP and OLED) were emerging into the market, the LCD displays were eroding the market share of CRT displays in applications such as the desktop monitors and TVs. It can be seen from Figure 2.1 that the LCD industry continued to grow in size driven by the market demand for cost-effective TVs and investments by LCD manufacturers in larger, more productive factories. In the past decade beginning in 2010, the advances made in LCD technologies and their product presence across all display-centric applications resulted in the demise of the CRT and PDP industries. Meanwhile, OLED display technology reached manufacturing maturity by 2010 and was ready to compete with the LCD industry. Currently, there are only two dominant technologies used by the display industry, namely, LCD and OLED. The rest of this report will therefore solely focus on LCD and OLED display technologies and products.

3. Display-Centric Products "The Market-Pull"

The emergence of the Flat Panel Display (FPD) industry can be divided into three eras when the dominant market applications of that period (also known as "Market-Pull" or "Killer App") provided the high demand and the business rationale for capital inflows which resulted in the construction of display production facilities and the necessary supply chain infrastructure. In addition to the market-pull with "Killer App" display-centric products, the display industry requires the availability of capital and knowhow to establish a sustainable infrastructure to grow and reinvent itself continuously.

a) Display Metrics
"The Figures-of-Merit"

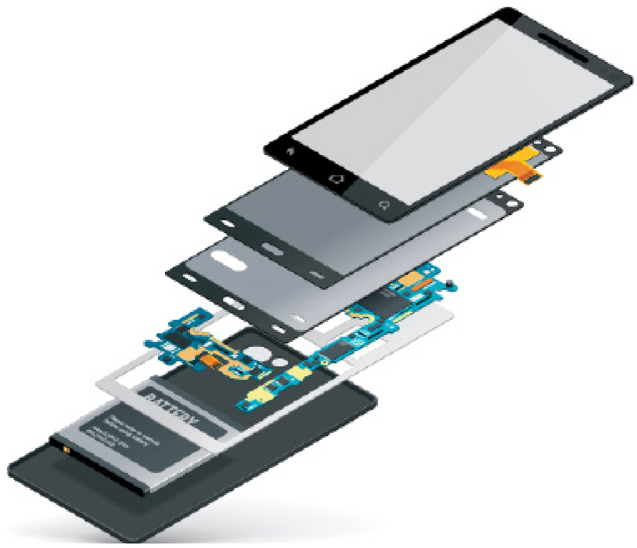
Consumers have come to expect a certain set of "intrinsic" attributes (or "Figures-of-Merit") from commercial direct-view display technologies. Such figures-of-merit allow the proper comparison of any technology over contemporary display technologies. These intrinsic attributes are listed below:

i. Higher resolution (in "Pixels Per Inch" or "PPI")
ii. Higher brightness (in units of **"cd/m^2"** or "nits")
iii. Higher contrast ratio ("brightest pixel" to "dimmest pixel" ratio under ambient illumination)
iv. Wider viewing angle
v. Lower power consumption
vi. Larger color gamut
vii. Faster response time

Over the years, while new display technologies have always vied for market acceptance and market share by improving one or more of the above intrinsic display attributes through innovative solutions, substantial industry growth has only occurred when such display technologies have also delivered certain "enabling" attributes that made new display-centric products possible for the high-volume consumer market. A few such enabling attributes are:

i. Lightweight
ii. Thin profile
iii. Flexible

As an example, the weight and bulkiness of the CRT display did not provide a suitable display-centric product solution for the emerging portable personal computer market. This paved the way for the emerging flat panel LCD display panel technology to enter the prevailing display market and provide a solution that met the market demand of that time. Even though the CRT displays of that era had superior intrinsic attributes compared to then available LCD display panels, the enabling attributes of lightweight and thin profile were decisive factors driving customer acceptance.

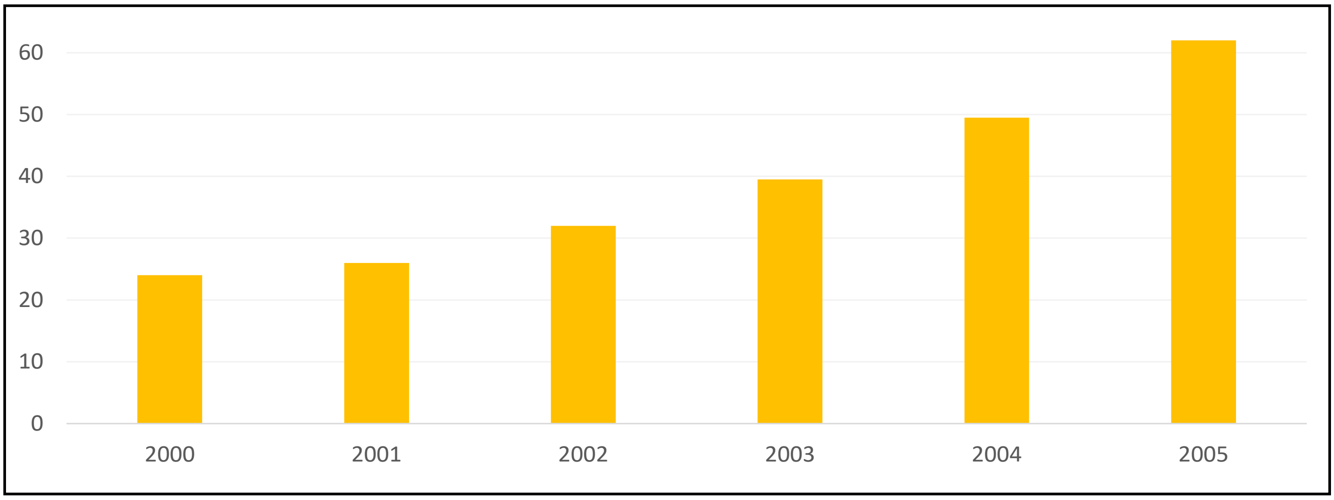


b) The 1st Killer App
"Notebook PCs"

In the decade beginning in 1990, mobile personal computers (also known as Mobile PC or Notebook PC or Laptop PC) provided the market-pull that resulted in the birth of the FPD industry. The Notebook PC products can be referred to as the "1st Killer App" since they created the high-volume, high-growth business platform for the launch of a new technology called TFT-LCD displays. The TFT-LCD display panels had thin profiles, capable of low-power operation and were lightweight. The TFT-LCD displays provided a solution for a new emerging Notebook PC industry where the incumbent CRT displays were inadequate to meet customer preferences. The first decade of the TFT-LCD display industry established it as the standard for flat panel display screens and fostered the supply-chain ecosystem for the TFT-LCD manufacturing tools and display materials. In this period, the TFT-LCD display industry moved up the "learning curve" on the factory floors by increasing productivity and yield while moving down the "cost curve" through investments in cost-effective, new-generation display fabs. The FPD industry revenues, substantially based on TFT-LCD panels for the Notebook PC market, had reached USD 20 billion in size within a decade from its first product launch. By the year 2000, the TFT-LCD manufacturing knowhow had become mature enough to take on the CRT industry in other entrenched applications such as desktop monitors and TVs.

Figure 3.1: Growth of the Flat Panel Display Industry (2000-2005)

FPD Revenues (USD Bn)



c) The 2nd Killer App
"Desktop Monitors & Televisions"

The second era of the FPD industry growth, in the period from 2000 was driven by customer preferences for the replacement of CRT-based desktop monitors and the demand for increasingly larger LCD TVs ("the 2nd Killer App"). This phase of growth resulted in the total displacement of the CRT and PDP displays from the market.

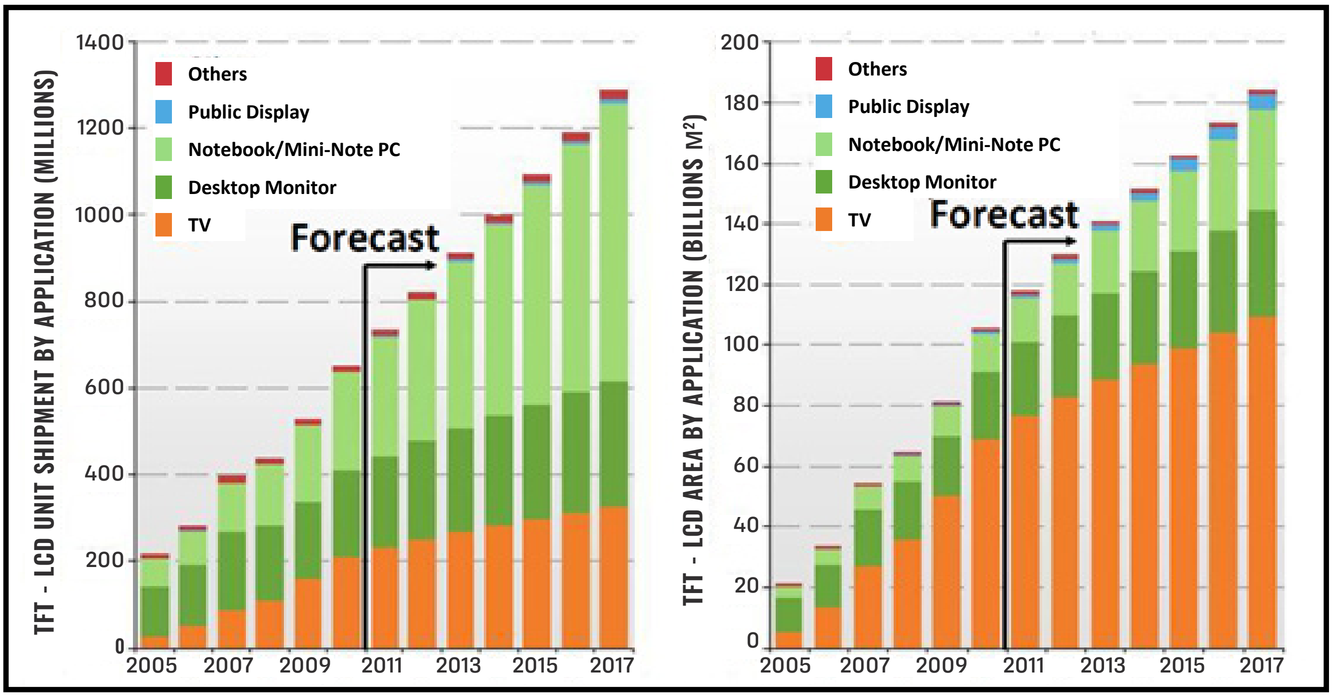
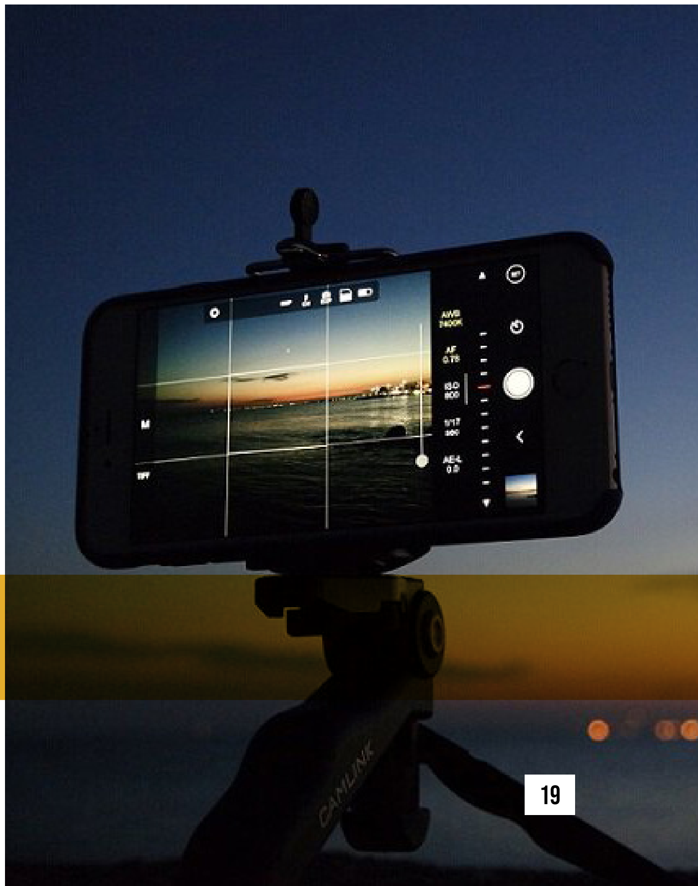


Figure 3.2: Growth of the FPD Industry (2005-2010) and Forecast for 2010-2017
Ref: DisplaySearch - Quarterly Worldwide FPD Shipment and Forecast Report 2010

Figure 3.2 shows an industry forecast made by a leading market research firm (Display Search) in 2010. This figure shows the growth of LCD display industry by both product shipments and display area for each of the major market segments, namely, Notebook PCs, Desktop Monitors and TVs. It can be seen that there was growth in all market segments as customer preferences for flat panel display products became the new standard. It is notable that the emergence and the extent of growth of the smartphone display market was not anticipated in 2010, hence it is prominently absent from the 2010 forecast. The smartphone application created a new market segment for displays and this is discussed in the next section



d) The 3rd Killer App
"Smartphones"

The convergence of high-bandwidth, ultra-fast wireless technologies capable of streaming large information content everywhere and the ready availability of cost-effective computing power for microprocessors and memories for processing such content into human-readable images anywhere and everywhere is driving the consumer market towards a new class of display-centric products. The smartphone is an example of this new class of "connected" display-centric consumer products which can be called as the "3rd Killer App". Smartphones require displays that can handle multi-media content (movies, videos, gaming, pictures, messages, email, etc.), be available in the 5-in to 7-in format and be flexible to allow new degrees of freedom in product design. Such requirements drive intrinsic display attributes to have 400 PPI resolution, fast response times, display peak brightness to be readable in outdoor conditions and low power consumption so that the time between battery charges is extended. Among all other flat panel display options, AMOLED displays were found to have most of these intrinsic and enabling display attributes and had reached sufficient manufacturing maturity to be an ideal fit for the new smartphone applications. As AMOLED display production costs decreased with increasing production experience, they started eroding the market share of equivalent LCD displays in smartphone applications. The AMOLED display industry, spearheaded by the Samsung Galaxy smartphones, had grown into a USD10 billion industry by 2015. With Apple iPhones also adopting AMOLED displays in 2018, the AMOLED display industry has further grown as shown below.

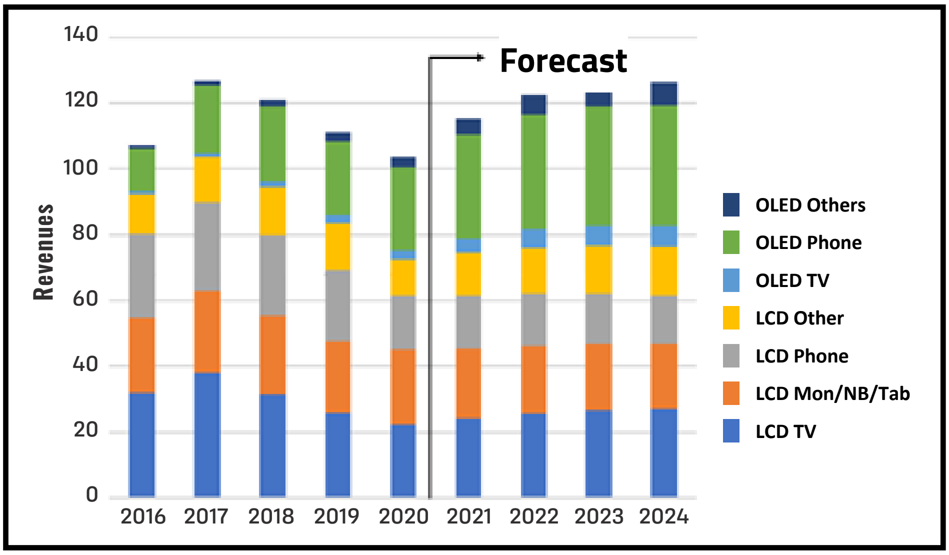


Figure 3.3: The Display Market and Trends by Technology and Applications (2020)
Ref: Robert O'Brien, DSCC, SID 2020, August 2020

Figure 3.3 shows the recent (August 2020) display industry market trend (from 2016) and the forecast (until 2024) from a leading market research firm (DSCC). They predict that the display industry will grow into a USD125 billion size in 2024 with LCD display revenues accounting for about USD75 billion and OLED displays for the remaining USD50 billion. The AMOLED display industry is expected to grow from its current USD30 billion size to greater than USD50 billion size, mainly powered by the growth of smartphones.

The development and emergence of flexible AMOLED display technology that allows bendable, foldable and rollable display-centric product designs provides another vector of new growth opportunity. Flexible display products are likely to contain foldable or rollable AMOLED displays in the future. Two of the major display manufacturers (Samsung and LG Display) have already announced their intention to focus all their future development and manufacturing on AMOLED displays and stop further development activities in TFT-LCD products, as the enabling display attribute of flexibility is only available with AMOLED displays. Many of the attributes of flexible AMOLED displays developed for smartphones are likely to permeate to all other product segments just as LCD displays did around the beginning of this century.

4. Display Technologies
"The Building Blocks"

Flat panel displays are fabricated by the integration of its building-block technologies, namely, TFT backplane, LCD panel or OLED panel frontplane and the assembly of module components. There are several technology choices within each of these building-block categories and the combination of technology choices is selected to ensure that the display can meet or exceed the technical requirements demanded by the display-centric end product. In this section of the report, each of these technology building-blocks will be described in further detail.

a) TFT Backplane

The thin film transistor (TFT), whose typical device cross-section is shown in Figure 4.1A, is the basic element of the TFT backplane that is used in the pixel areas of all commercial LCD display panels. The TFT device is constructed on insulating glass substrates by the sequential deposition, patterning and etching of the dissimilar thin-film layers made of insulator, semiconductor, metal or other functional materials. The device shown in Figure 4.1A is known as a bottom gate TFT since the gate layer lies under the rest of the device structure. The silicon nitride layer (SiNx), situated above the gate contact, is also known as the gate dielectric. The channel layer above the gate dielectric, which is comprised of an hydrogenated amorphous silicon (a-Si:H) film, exhibits semiconductor-like properties because the silicon dangling bonds are passivated by the incorporation of hydrogen (approximately 10% to 20%) in the films. The TFT device has three terminal contacts, namely, the source (S), the gate (G) and the drain (D). To aid in the ohmic contact behavior of source and drain contacts to the channel region, a highly doped (n+ a-Si:H) layer is

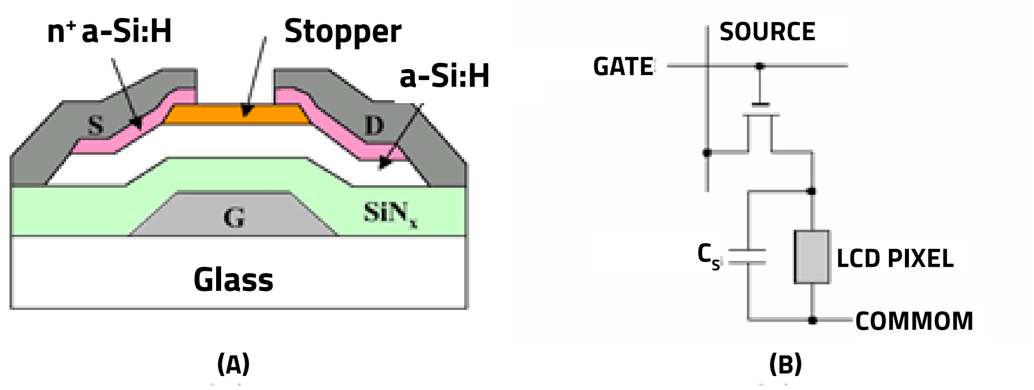


Figure 4.1: Typical Structure (A) and Function (B) of an a-Si:H TFT in the LCD Pixel Location

utilized in the contact regions. In order to predictably control the thickness (and therefore its device properties) of the channel region above the gate across the glass substrate area, an etch stop layer (Stopper) is typically used. The current transport from the source to the drain (called drain current) is controlled by the amount of voltage applied at the gate. The TFT device is turned ON to charge a pixel capacitor connected to the drain contact at each LCD pixel during the frame refresh cycle, as shown in Figure 4.1B. If the leakage current (or OFF current) is several orders of magnitude smaller than the ON current, then the pixel capacitor can hold that charge until the next frame refresh time.

The source, drain and gate layers are deposited using a sputtering method while the gate dielectric (SiNx), channel layer (a-Si:H) and the highly doped source/drain contact layers (n+ a-Si:H) are deposited by a plasma-enhanced chemical vapor deposition (PECVD) method at 350C substrate temperatures (hence, suitable for use with glass substrates). Over the three decades of the flat panel display industry, the equipment technology for these deposition methods have become very mature for production and can be scaled to large glass substrates. Other associated patterning processes for photoresist coating, photoresist exposure with large area steppers and layer removal with either wet or dry processes have also become very mature for large glass substrate production.

An intrinsic figure-of-merit of the TFT device chosen for use in a TFT backplane for displays is known as mobility. For example, the mobility of a-Si:H TFT device is about **0.5 cm^2/V.sec**, a relatively low number compared to the mobility of a standard semiconductors like crystalline silicon. Low mobility TFT technologies have limitations when used in large displays or high-resolution displays due to the requirement for high refresh rates. Over the past two decades, the technical capabilities of the basic a-Si:H TFT technology has been sufficient for use in notebook PCs, desktop monitors and TV applications of that era. However, as the market demand continues towards "Connected, Multi-Megapixel" display-centric products in recent years, new TFT technologies with higher mobilities are becoming a necessity.

Table 4.1 shows a comparison of the three major TFT technologies currently available for use as mature production technologies to the display industry. Besides the original a-Si:H TFT technology, Low Temperature Polysilicon (LTPS) TFT and Amorphous Oxide Semiconductor (AOS) TFT technologies were developed in the mid-1990s and mid-2000s, respectively. The mobility of LTPS-TFT devices was greater than 80 cm^2/V.sec, this being a substantial improvement over the mobility of prevailing a-Si:H TFT devices. Although LTPS-TFT backplanes were originally developed for the purpose of column and row driver integration directly on to the display glass using TFT circuits, the ideal application for LTPS-TFT technology was first demonstrated in 1999 with the development of the AMOLED display. AMOLED displays require excellent threshold voltage stability for the drive transistor attached to the OLED device, a requirement that the LTPS-TFT device was able to provide but the equivalent a-Si:H TFT device was not able to provide due to inherent instability mechanisms. Hence, LTPS-TFT backplanes became the technology of choice for AMOLED displays used in smartphones.

Description	A-Si:H TFT	LTPS TFT	Oxide TFT
Mobility	~0.5 cm^2/V.sec	~80 cm^2/V.sec	~10 cm^2/V.sec
TFT-Gate Structure	Bottom	Top	Bottom
TFT-Type	NMOS	NMOS/PMOS	NMOS
Off Current	~pA	~pA with LDD	<pA
Stability	Good	Excellent	Good
Transparency	Opaque	Opaque	Transparent
Number of Masks	4 to 5 (NMOS)	8+ (CMOS)	7 (NMOS)
Application	**LCD Displays** Notebook PC Monitor TV	**AMOLED Displays** Smartphone **LCD Displays** Smartphone	**LCD Displays** Premium TV **AMOLED Displays** TV

Table 4.1: Comparison of Prevailing TFT Device Technologies

The process for the fabrication of LTPS-TFT backplanes is more complex than that required for the fabrication of a-Si:H-TFT backplanes. Three additional process steps are required, namely, excimer laser annealing (ELA), ion doping and rapid thermal annealing (RTA). The number of masks required increases to eight or more for constructing CMOS circuits. The maximum glass substrate size for LTPS-TFT manufacturing is limited to 1500mm x 1800mm (Gen 6) due to limitations of the ELA process. The preferred device structure for LTPS-TFT backplanes uses the top gate architecture. These types of TFT backplanes are currently used for both high-resolution AMOLED and LCD displays used in smartphones.

In comparison with a-Si:H-TFT or LTPS-TFT devices, the Oxide TFT or AOS-TFT devices have intermediate mobilities of around 10 cm^2/V.sec The process for the fabrication of AOS-TFT backplanes is less complex than for LTPS-TFT backplanes but more like a-Si:H-TFT backplanes except that the active channel material is based on Indium-Gallium-Zinc-Oxide (IGZO) materials. This type of TFT backplanes, which have no scaling limitations and can offer comparable economies-of-scale in manufacturing as a-Si:H-TFT backplanes, is currently used with high-resolution large displays requiring high data refresh rates.

b) LCD Panel Frontplane

The typical device cross-section and the top view of an LCD panel are shown in Figure 4.2 (A) and (B), respectively. The LCD panel consists of two pieces of glass substrates, namely, the TFT backplane glass and the color filter glass, that are separated by a small, well-defined gap (approximately 10m). The liquid crystal (LC) material is filled in this gap. The LC material is designed to have intrinsic properties where its optical transparency is modified in a predictable manner when an electric field is applied across the gap. In other words, the LCD panel is a light valve whose transparency can be controlled by an electric field. The color filter substrate contains a patterned array of red, green and blue transmissive materials that form island regions designed to align with equivalent transmissive pixel regions on the TFT backplane substrate when the two substrates are aligned together and overlaid upon each other with the specified gap discussed above. The space between the color filter islands is patterned with an opaque material (commonly known as black matrix) to prevent non-pixel area light from leaking through the LCD panel structure.

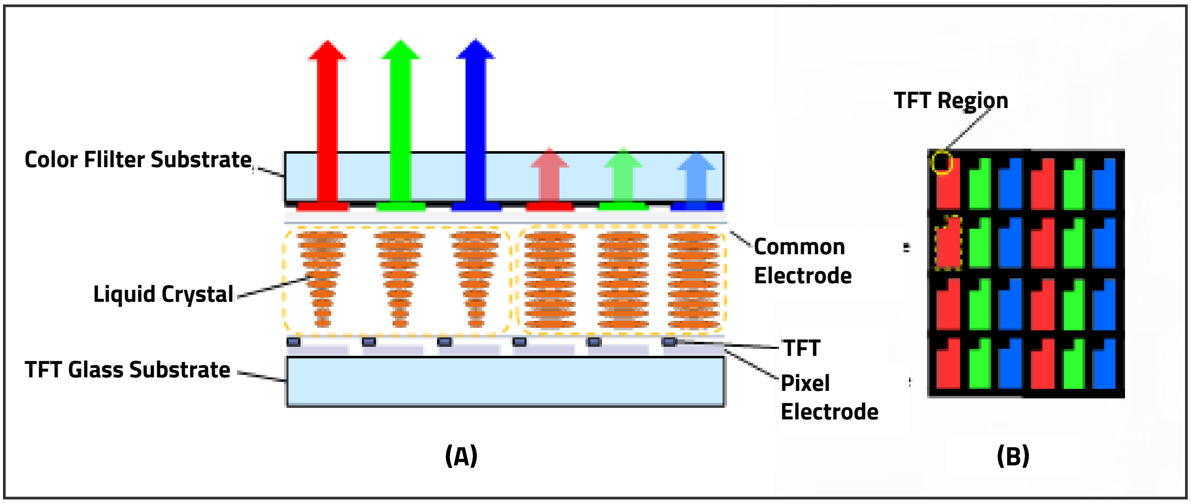


Figure 4.2: Typical TFT-LCD Panel – (A) Cross-Sectional View and (B) Top View

Each of the two substrate surfaces, namely, that of the TFT backplane and the color filter glass surfaces, are covered with a final transparent conducting layer which can function as independent electrodes. The electric field can be applied across the LC-filled gap using these electrodes. The electrode layer on the color filter glass is not patterned and serves as a common electrode while the electrode layer on the TFT backplane substrate is patterned over each of the display pixel areas and serves as the pixel electrode. Figure 4.2 (B) shows the top view of the LCD panel (from the color filter glass side of the LCD panel) and the pixel layout when overlaid on the TFT backplane substrate. The TFT circuits are opaque and situated in one corner of the otherwise transmissive color filter regions of the display pixel zones. The TFT backplanes and color filter substrates are manufactured in the cleanroom floors of a display fab on large mother glass substrates. The LC-materials are dispensed at all of the pixel regions on the TFT backplane substrate, the TFT substrate and color filter substrate are aligned, attached together with the specified gap and sealed with UV adhesives in the peripheral regions of each the panels before being cut into product-sized LCD panels. The LCD panels are then shipped to LCD module assembly factories that are located elsewhere.

c) OLED Panel Frontplane

There are two different AMOLED panel technologies being used in the display industry currently. The device structure of an AMOLED display panel used in smartphones is shown in Figure 4.3(A) while the device structure of an AMOLED display panel used in OLED TVs is shown in Figure 4.3(B). Except for the underlying device physics, these two display technologies are not similar. Therefore, even though the TFT backplane technologies may be common for LCD and AMOLED applications, the AMOLED panel frontplane technologies are divergent for smartphone and TV applications.

Figure 4.3(A) shows that the LTPS-TFT backplane technology is required for AMOLED panels that are used in smartphone applications. The OLED device structure consists of several functional layers of organic thin films deposited over the pixel area contact electrodes (anodes) of the LTPS-TFT substrate, as shown in Figure 4.3(A). These functional organic layers are the hole injection layer (HIL), the hole transport layer (HTL), the emission layer (EML), the hole blocking layer (HBL), the electron transport layer (ETL) and the electron injection layer (EIL). An uniform cathode is deposited over the organic layer structure. When an electric field is applied across the anode and the cathode, the OLED device emits light from the EML layer. The EML layer usually consists of a host material and a dopant material and the wavelength of light emission is dependent on the properties of the materials selected and used in the EML layer. The primary display colors of red (R), green (G) and blue (B) emission are created by the appropriate selection of the host and dopant materials incorporated in the respective EML layer. All organic films and the cathode are deposited under vacuum conditions and the R, G, B pixel areas are patterned by the use of fine metal masks (FMM) in order to create an array of self-emissive pixels. The AMOLED device design for smartphone applications uses a single stack OLED device as shown inFigure 4.3(A). Furthermore, in order to narrow the emission spectrum and obtain purer primary colors, the OLED device design resorts to a top emission structure. In other words, the emitting light exists through a semi-transparent cathode. State-of-the-art AMOLED panels use thin film encapsulation over the cathode layer and therefore, the encapsulation must also be transparent and optically engineered for best light extraction efficiency.

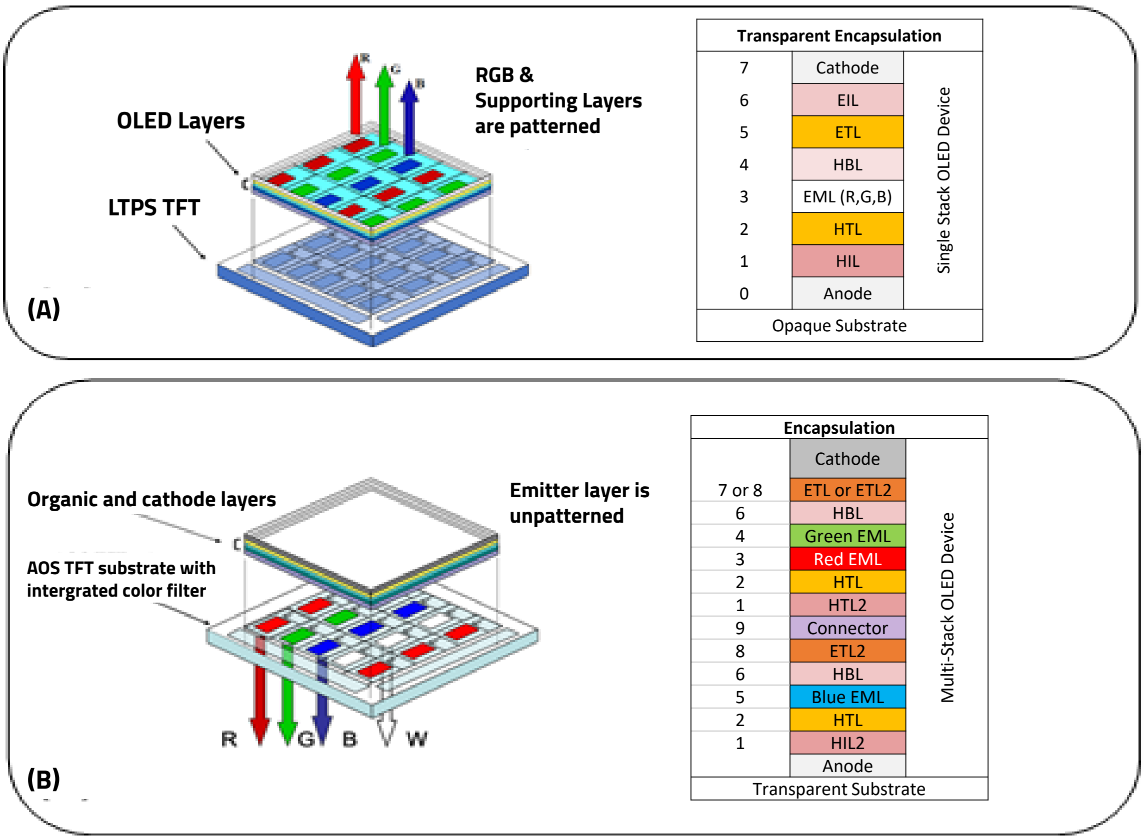


Figure 4.3: Typical Structures of AMOLED Display Panels for (A) Smartphones and (B) TVs

Figure 4.3(B), in contrast, shows the AMOLED panel cross-section intended for use in OLED TVs. The OLED devices are the multi-stack type with several units of light emitting EML layers contributing to increased light emission through the display pixels. This multi-stack OLED device is more suitable for TV application where high brightness, long lifetime performance is required. The lifetime of the OLED multi-stack device increases as the number of stacks increases. In order to achieve high brightness and long lifetime, the tradeoff parameter is the voltage drop across the device stack. In practice, the emission of the OLED multi-stack structure is engineered to match the color filter transmission characteristics of the color filters incorporated on the TFT backplane substrate. The TFT backplane technology for OLED TVs utilizes the AOS-TFT (oxide TFT) type. This TFT backplane technology is scaleable in manufacturing to large area substrates and has higher mobility to match the current driving needs of the OLED device pixel. The AMOLED panel frontplane further differs from normal TVs in that it operates using a 4-pixel design, namely, R,G,B and White pixels. The use of the white pixel improves power efficiency in the OLED TV and the color rendering is accomplished with these four primary colors. The AMOLED technology for OLED TVs is therefore called the White OLED technology, resulting from the use of the white pixels.

Significant value addition is created at the AMOLED panel frontplane since all the key device elements are integrated at the display fab and not at the module assembly factory. For flexible AMOLED smartphone applications, the TFT backplanes are manufactured on top of high temperature polyimide (PI) and after the OLED frontplane devices are fabricated over the TFT backplanes, the entire device is lifted off from the rigid glass carrier substrates and attached to surrogate substrates matching the product design needs.

d) Display Module

A display module contains an assembly of the display panel integrated with optical, mechanical and electronic subcomponents. As an example, Figure 4.4 shows some of the additional components needed to convert an LCD panel into an LCD module. The LCD panel requires an external broadband light source, such as the LED backlight assembly, for its operation and this light source is attached behind the TFT as shown in the figure below. The backlight provides only unpolarised light whereas the LC-material only works with linearly polarized light. Hence polarizer films are required between the backlight assembly and at the exit of the color filter substrate. Only the linearly polarized light comes through the LCD panel, the rest of the light is absorbed or rejected by the polarizers. In practical designs, only about 5% of the light exiting the LED backlight assembly contributes to the brightness of an LCD display product.

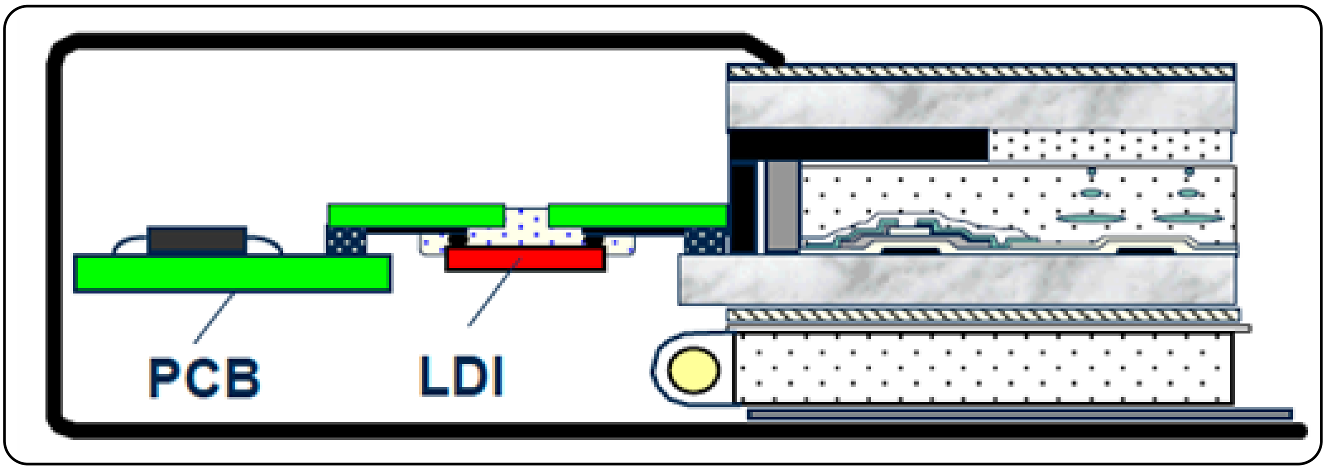


Figure 4.4: Conversion of an LCD Panel into an LCD Module
Ref: Dr. S.T.Shin, Former CTO/Samsung Display, IWPSD 2017 Display Tutorial, New Delhi, India

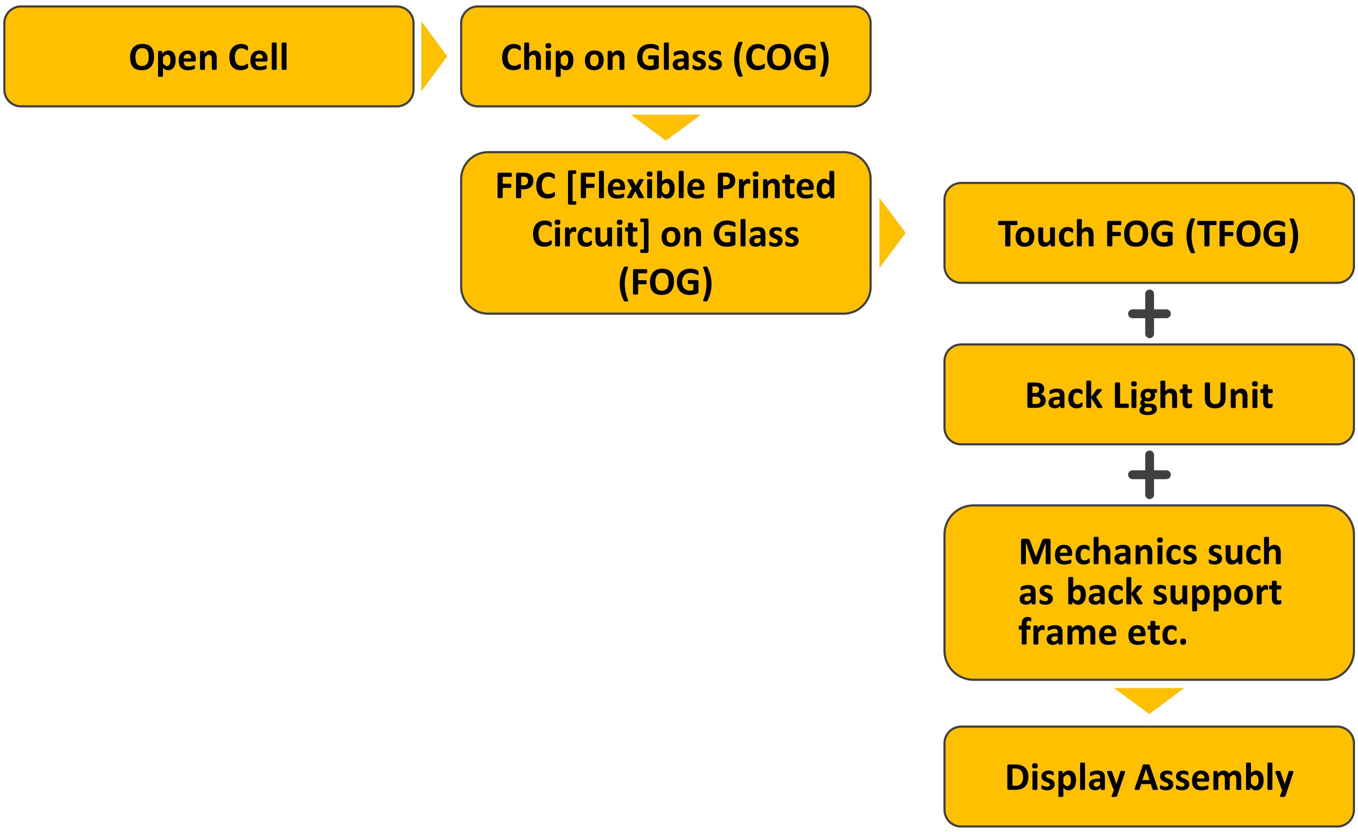
For reference, LCD Display Assembly of a Smartphone is considered. Its' Bill-of-materials (BOM) contains the following items:

a) Touch Panel, b) LCD In-cell, c) BEF- Brightness Enhancement Film, d) Diffuser- Light Controller, e) LGP- Light Guide Plate (Distribution of light through screen), f) Reflector, g) LED backlight assembly, h) Polarizers, i) LCD Driver IC (LDI) mounted on an FPC, j) Mechanics such as back support frame etc., k) Flexible printed Circuit/PCB (Needed for rendering display functions & will usually be supplied as part of a display module kit)

For display designs using touch panels, such touch panel assemblies are attached on color filter glass substrate side of the LCD module. Also to note, the back support frame provides strength, protection and structural stability to the fragile LCM display assembly and also saves it from dust, moisture, etc.

The assembly process for conversion of an AMOLED panel into an AMOLED module is more or less the same as shown in the figure above, except that LED backlight assembly is eliminated as the display is self-emissive and the linear polarizers are therefore not required. However, a circular polarizer must be attached to the surface of the AMOLED display to increase its ambient contrast ratio. The electronics assembly to the AMOLED module is similar to that shown above, except that the Display Driver IC (DDI) has completely different functionality than that of the LCD display and is designed with a different architecture.

A flow chart is mentioned below, describes the various steps for the formulation of the Smartphone's LCD Display Assembly and Figure 4.5 depicts the illustrative figures of the LCD Display Assembly.



a) b)

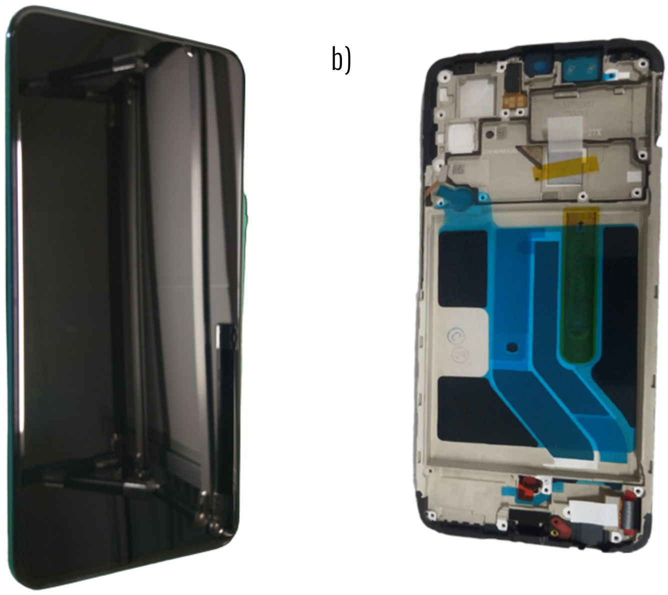


Figure 4.5: a) Display Assembly Front View and b) Display Assembly Rear View

e) Advancements in LCD/OLED Display Technologies

Over the past two decades, LCD and OLED display technologies have made steady advances in their underlying technologies in order to provide product differentiation to customers and to compete for market share. The following is a list of key technologies that have improved the intrinsic or enabling display attributes of either the LCD or the OLED display technologies.

- The introduction of LED backlights reduced the power consumption in LCD displays and allowed for thinner LCD display modules. Such TFT-LCD displays, when used in TV applications, were mislabeled in the market as LED TV. In other words, LED-TVs are actually LCD-TVs with a better backlight.

- Introduction of quantum dot (QD) materials into advanced LED backlight assemblies increased the color gamut of TFT-LCD displays. In the market, these displays are commonly branded as QLED products. In other words, QLED products are display products equipped with a sophisticated LED backlight assembly

- Improvements in liquid crystal materials (IPS and VA types) led to the improved wide-viewing angle properties of TFT-LCD displays

- Incorporation of phosphorescent OLED emission materials to increase the external quantum efficiency of red and green OLED pixels and to reduce power consumption in AMOLED display panels

- Introduction of top emission OLED device structures and microcavity effects to achieve narrower emission spectrum and larger color gamut in AMOLED display panels

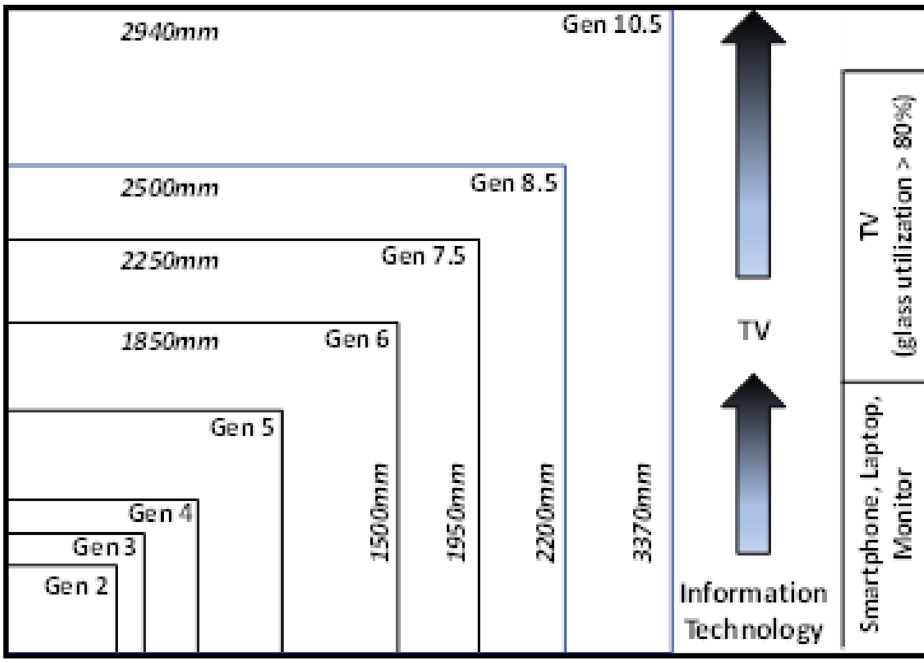
- Increasing the manufacturing capability of fine metal mask (FMM) color patterning process to deliver ~500 ppi AMOLED panels for the smartphone market

- Invention, development and the commercialization of multi-stack OLED devices for use in high-brightness, long-life TV applications that resulted in OLED TV products
- Development and commercialization of higher mobility AOS-TFT backplanes for the manufacture of premium TV display products (ultra-large LCD-TVs and OLED TVs)
- Development and commercialization of LTPS-TFT backplanes on high temperature polyimides to result in flexible AMOLED display panels

5. Display Manufacturing
"Economies-of-Scale"

There are two major types of full-color display technologies in mass production currently, namely, LCDs and OLEDs. Both of these types of displays are constructed on large glass substrates ("Mother Glass" or "MG"). Display panels are manufactured on large glass substrates in mega-scale display factories ("Display Fabs") in high-volume production. The capacity of each of these display fabs is measured in units of MG sheets per month (or simply referred to in units of "Sheets per Month" or "SPM"). The steady market-pull for increasingly larger display-centric consumer television products over the past two decades at acceptable price points has driven the display industry to invest in increasingly larger generation display fabs that use up to Gen 10.5 (2940mm X 3370mm) mother glass substrates.

Figure 5.1 shows the migration of glass substrate to larger sizes over the past two decades. Larger glass yields more panel count and therefore more products for sale. The display industry has thus far operated based on the principle of "economies-of-scale". When the substrate size increases, the investment cost in display fabs increases but the panel count for MG substrate also increases. The industry experience is that the final product costs are lowered by the migration to larger substrate size due to the larger number of products that can be manufactured and monetized. Therefore, it is important to predict the global display market trends carefully, determine the optimum glass size for the manufacture of the most popular products and ensure that display fabs are able to deliver continuous reduction in manufacturing costs over its operating lifetime. A significant portion of the investment goes into the manufacture of TFT backplanes, so the factory must be built with sufficient flexibility to allow for it to adopt new technologies as they evolve.



Display Size	Gen 6	Gen 7.5	Gen 8.5	Gen 10.5
75-in				6
65-in				8
55-in			6	
52-in			6	
47-in		6	8	
42-in		8		
32-in	8	12	18	
26-in	12	18	24	
19-in	24		50	
14-in	40		98	
7-in	180		360	
6-in	250		510	
5-in	360		720	

Figure 5.1: Mother Glass Size and Panel Count Optimization

The most optimum solution for the TV market is Gen 8.5 or higher since the panel count can be 6 or 8 for the 47-in to 55-in TVs, respectively. Ultra large TVs (60-in to 70-in class) will require Gen 10.5 size display fabs. Smartphones with 2K or higher pixel counts require LTPS-TFT backplanes and these fabs are limited to Gen 6 size, whether the products are intended for LCD or AMOLED displays. All other product categories, namely, notebook PCs and monitors, are manufactured in fabs that are between Gen 6 and Gen 8.5 in size.

It requires large capital investments and several months to construct a display fab, move-in all the necessary manufacturing equipment for its operation and optimize the manufacturing process before beginning mass production status. The mass production milestone is loosely defined as the time when the display fab can create added value and generate cash from its operations after accounting for its fixed costs and variable costs encountered during production. This depends on several parameters such as product yield, factory loading (a measure of factory capacity in MG starts per month), direct bill-of-materials (BOM) costs, costs of indirect materials, direct and indirect labor costs and depreciation schedule. The time to the mass production milestone takes 18 to 24 months for LCD fabs and up to 30 months for AMOLED fabs even for experienced companies with manufacturing knowhow. New manufacturers entering the display industry without the benefit of manufacturing knowhow are expected to take a longer time. Once the investments are decided and the fab built, the display technology options that can be delivered to the customer are substantially frozen. In the display industry, the technology cycle is considered to be about five years. Hence, display manufacturers typically use the following guidelines to manage the factory economics and investment decisions:

Guidelines to manage the Factory Economics and Investment Decisions

01

The business plan is made for an eight (8) year factory life

02

The capital investments are amortized over a four (4) or five (5) year period on an accelerated, straight line basis.

03

The factory must achieve breakeven in its 3rd year of operation

04

The factory must start generating cash in its 4th year of operation

05

The factory must create new cash flows and sufficient cash flows necessary for investments in the next display fab incorporating newer technologies and for sustenance during the low periods of the supply-demand pricing cycles.

06

Ex-factory product pricing typically includes module manufacturing cost whether it is manufactured by an affiliated business unit at a different location or outsourced to a 3rd party.

07

Ex-factory transfer pricing may exclude R&D, IP management and SG&A costs if the final commercial sale is recognized at the parent company level.

Each display maker typically owns multiple display fabs with separate product streams addressing different market segments. If this is the case, then the appropriate R&D, IP management and SG&A costs must be added on to the ex-factory product pricing at the display business unit level. All display businesses must allocate sufficient R&D and IP management funds in their business plans before computing the added value of their fabs at either the ex-factory market pricing or at the market pricing levels. The display business, like any other commodity business, is subject to the vagaries of supply and demand. Hence, the business plan should account for price erosion over the period of the fab life and cost reduction over the same period.

A key factor in managing display fab operating costs is supply chain management. The display maker who invests and operates the display fab must bring together hundreds of other supply chain businesses who deliver direct and indirect materials or other goods and services to the display fab. The display maker must also bring together skilled personnel to the fab location in order to improve yield and productivity of the fabs. In the next section, the elements of the display supply chain are reviewed in further detail.

6. The Display Supply Chain “The Infrastructure”

The display manufacturing supply chain consists of suppliers of patterning materials, functional materials, optical materials, process equipment, metrology tools, subcomponents for module assembly, display driver ICs, factory automation, cleanroom and auxiliary equipment either for LCD or AMOLED display production. At the apex of the display supply chain is the “display maker”, the business entity that integrates the goods and services delivered by the supply chain for conversion to TFT backplanes and to OLED or LCD panel frontplanes and further takes the responsibility to deliver OLED or LCD display modules for use by the “set maker”. The set maker, who is the end customer to the display fab, manufactures and delivers display-centric products to the market.

The major capital equipment suppliers provide PECVD equipment and sputtering equipment for thin film deposition, lithography, etching and numerous auxiliary process and metrology tools to the display fabs. Some examples of these types of equipment are shown below.

Figure 6.1: AKT PECVD System used for a-Si:H Deposition
Ref: Applied Materials (www.appliedmaterials.com)

Figure 6.1 shows an AKT PECVD system that is commonly used for the deposition of amorphous silicon (the channel material used in TFT devices for LCD displays and as the source material for the formation of polysilicon in LTPS-TFT devices for OLED displays), doped amorphous silicon (for source and drain contact regions), silicon oxide (dielectric), silicon nitride or silicon oxynitride dielectric films to manufacture TFT backplanes. The proprietary in-situ cleaning process cycle incorporated in these AKT tools allows particle-free manufacturing on large glass substrates (up to Gen 10.5 size) at good productivity. Figure 6.2 shows an ULVAC in-line sputtering equipment commonly used for the deposition of gate, source and drain layers to manufacture TFT backplanes.

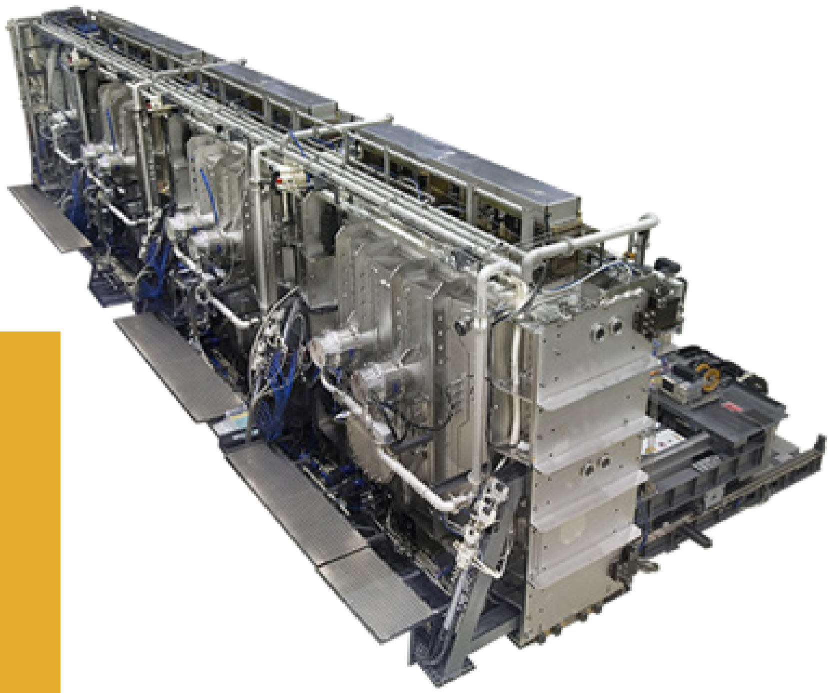
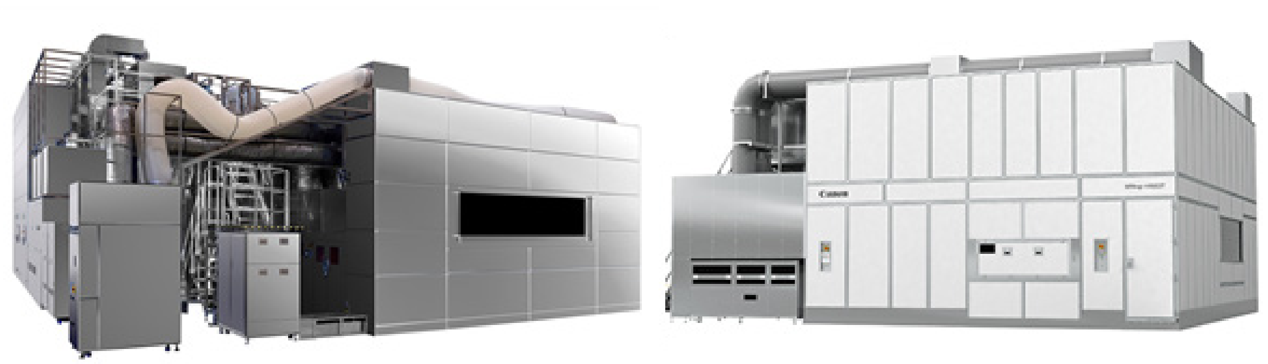


Figure 6.2: ULVAC In-line Sputtering System used for Gate/Source/Drain Metallization
Ref: ULVAC Japan (www.ulvac.co.jp)

Figure 6.3 shows an AKT PVD system that is used for the deposition of IGZO channel material in oxide-TFT backplanes.

Figure 6.3: AKT PVD system used for IGZO deposition
Ref: Applied Materials (www.appliedmaterials.com)

Figure 6.4 shows a Canon lithography equipment used commonly in display fabs to expose large glass substrates coated with photoresist to make high-resolution TFT patterns. These sophisticated exposure tools are capable of delivering feature resolutions of 2 micron with +/-0.5 micron overlay accuracy across the entire mother glass substrate (up to Gen 10.5 size) with a single exposure.



(A) (B)

Figure 6.4: FPD Lithography Systems from (A) Nikon and (B) Canon
Ref: https://global.canon/product/indtech/ and www.nikon.com

The specialized expertise and technologies for the construction and maintenance, of these above tools and of numerous other tools used in the inspection and repair process steps, are only available with equipment suppliers and it is imperative that they also work in partnership with the display makers. The equipment required for display fabs must be assembled in a factory with a cleanroom environment where cleanroom protocols are observed, prepared for shipment in cleanroom compatible packaging and then reassembled in the display fab cleanroom floor. It is important therefore for these capital equipment providers to have presence and be co-located in geographic clusters near display fabs to provide expertise during the entire life of the display fab.

The display fabs require several consumables to be delivered to its operations on a continuous basis. The mother glass substrate is one of the major consumables required in display fabs. The glass substrate must be of high-quality with specified properties and free of particle contamination. The glass substrate maker usually sets up a dedicated glass manufacturing plant at the display fab location in order to minimize handling and transportation to the display fab site. In state-of-the-art Gen 10.5 display fabs, the glass substrates are delivered directly to the connected display fabs using automation under clean conditions. The colocation of glass substrate manufacturing with display fabs completely eliminates the need for handling and transportation of glass substrates. A strategic relationship must exist between the display maker and the glass maker for this to happen.

Many global companies are involved in the supply of direct materials (consumables that are incorporated in the product) to the display industry. Some of the important companies involved in the display supply chain are Merck (LC and OLED materials), Corning/Asahi Glass/NEG (glass substrates), UDC (phosphorescent OLED dopants and hosts), 3M (light management films), ULVAC Materials (sputtering targets), LG Chemicals/Samsung Cheil (several LCD and OLED materials) and DNP/Toppan (fine metal masks for OLED patterning). There are hundreds of other medium and small size companies also involved in the display fab supply chain. Some of these supplies are needed on a continuous basis while others can be scheduled deliveries based on a rolling horizon forecast provided by the display maker. Many of these suppliers of display consumables usually establish

local operations in the countries where large investments in display fabs are made and a market-pull is created for them to justify their colocation in the geographical clusters near the display fabs.

Several indirect materials (mainly liquids and gases) must be delivered to the various process tools in a display fab. If gases and liquids are required on a continuous basis, they are integrated into the cleanroom design and piped in from a centralized site to the point of use. There are several consumables companies, such as Linde/Air Products/Air Liquide (process gases, liquid nitrogen), that must also set up local operations in the vicinity of the display fabs.

The building, plant and machinery required for display fabs are provided by specialized engineering firms that have expertise in the design and construction of large ballroom-style cleanroom facilities with integrated auxiliary equipment for the delivery of power and utilities to each of the process tools and air handling systems for establishing a particle free cleanroom environment. The design of the display fab is driven by inputs from the display maker regarding the full process flow, the number of tools needed of each kind, the footprint of process tools used in the factory and the utilities required for each of these tools for their operation. The construction of these display fabs containing specialized process equipment requires skilled personnel. It takes about 12 to 18 months to construct and commission a factory before the process equipment can move-in. Furthermore, additional skilled personnel are required at the display fab site for providing continuous support (on a 24/7 basis) when operations begin.

In summary, the manufacture of displays in display fabs creates the environment where several supply chain providers of equipment, consumables and services come together under a common mission and establish their local ecosystem around the display fabs. This creates a supply chain infrastructure that attracts skilled personnel to the towns and cities around the display fabs. The display fab creates thousands of high-tech jobs and attracts several more indirect jobs that provide goods and services in the display supply chain. The local governments and municipalities must also gear up to provide land, water, power and transportation services to the display fab infrastructure under commercially attractive terms. The creation of a display industry infrastructure requires substantial amounts of upfront capital for investments and sufficient working capital for sustaining continuous production operations.

7. Creating a Display Industry Infrastructure

"Capital, Knowhow & Market-Pull"

By the year 2000, a decade after FPD mass production began in Japan, it had globalized to Korea and Taiwan, as shown in Figure 7.1 and the reasons are further discussed next.

The FPD industry requires capital, knowhow and a strong market-pull for its initial creation and for sustained growth to keep up with market trends. The early market-pull was the surge in demand for flat display screens to be used in notebook PCs. The IBM-Toshiba joint venture in Japan pooled the necessary resources together to serve the notebook PCs. A few years later, Japan began going through the bubble-economy crisis and many leading corporations in Japan could not free-up sufficient capital for new investments to keep up with the growth of the FPD manufacturing capacity. During this period, Korea was able to raise capital and technology knowhow through early collaborations with Western European and Japanese companies that also needed flat panel displays for their notebook PC products (that could not be readily provided through the IBM-Toshiba joint venture) and these conditions provided the spark for the Korean display industry to grow. Taiwan was able to raise sufficient capital during the 1997-98 Korean financial crisis, team with Japanese companies as their knowhow partners, raise the necessary capital to also enter the FPD business. By then, the display manufacturing industry had been globalized into the three main East Asian countries, namely, Japan, Korea and Taiwan and the competition among these nation-based display makers resulting in improved technologies and lower costs for the end customers. Leading Japanese display companies began outsourcing the low-value labor intensive display module manufacturing businesses to their subsidiaries and partners in China in order to compete with Korean and Taiwan manufacturing costs. The first era of the FPD industry growth, the period up to 2005, saw the globalization and continuous growth of the display industry in Asia. Each of the three governments, both federal and local, in Korea, Taiwan and Japan provided substantial benefits and incentives to attract display factories to their regions.

Many global companies in the supply chain with specialized display solutions, examples being Corning, Applied Materials, ULVAC, Tokyo Electron, Merck, 3M, saw their display businesses grow substantially during these early years and began establishing regional operations to support the display industry infrastructure in each of the countries. Each of them was also offered substantial incentives to relocate their local manufacturing operations to support the display makers in their countries and regions. The display industry flowed across national boundaries to wherever there was a confluence of capital and knowhow and display makers could create economies-of-scale at each of their factories. The majority of these display makers were based in Japan, Korea and Taiwan during the three-decade period prior to 2010. This period also the consolidation of the flat panel industry around LCD and OLED technologies.

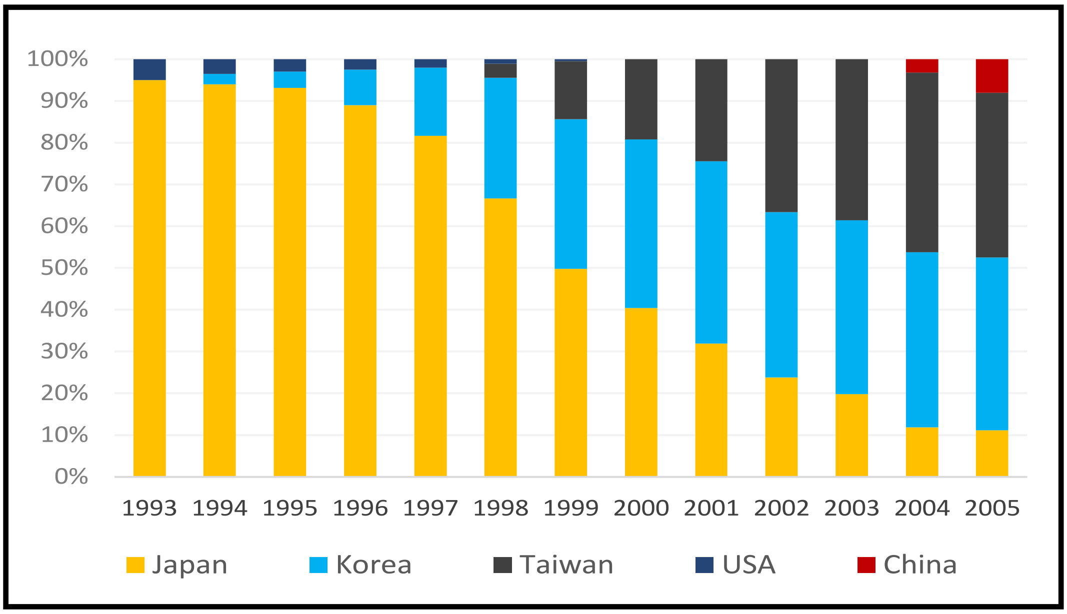


Figure 7.1: Growth of the Display Industry Infrastructure in Asia
Ref: Prof. Jeffrey Hart, National Research Council, Washington DC (2008)

After 2010, the Chinese government, both central and provincial, mobilized a substantial amount of capital, created favorable policies and offered incentives for their local companies to invest substantially in its display manufacturing capacity. Several new display fabs began to be constructed beginning in 2013 and China has now emerged as a global powerhouse in the display industry. Table 7.1 shows the country wise distribution of display fabs that are in mass production status at the time of this report.

Display Fabs (>=Gen 6) in Mass Production (2020)					
Country	Gen 6 Class	Gen 8 Class	Gen 10 Class	Total	Major companies
Japan	3	1	0	4	JDI, Sharp
Korea	4	2	0	6	Samsung, LGD
Taiwan	2	3	0	5	AUO, Innolux
China	5	17	2	24	BOE, CEC, CSOT, HKC, Visionox, Tianma, Samsung, LGD & AUO
Total	14	23	2	39	Source: Mizuho/August 2020

Table 7.1: Display Fabs (>=Gen 6) in Mass Production in 2020
Ref: Y. Nakane, Mizuho, SID 2020 Business Conference, August 2020

It can be clearly seen from the table above that the amount of display manufacturing capacity and the number of fabs (Gen 6 or larger size) in China have surpassed all other previous investments that had been made in Japan, Korea and Taiwan combined. It can also be seen from Table 7.1 that leading display companies from Korea and Taiwan were also attracted to set up display fabs in China. China has several Gen 8 class fabs in operation now which manufacture TFT-LCD display products using the traditional a-Si:H TFT backplane. China has reached manufacturing maturity in this technology in most of their display fabs. However, Chinese companies are still on the learning curve on the new value-added OLED technologies needed for smartphones and TVs. In anticipation of the Chinese dominance in the older technologies due to these investments, Korean companies have moved on to new flexible OLED and OLED TV technologies that are needed for new market growth areas in smartphones and premium TV segments. As Chinese display fabs came online, all the major global companies in the supply chain also moved to China to set up their operations in the vicinity of the display fabs. New display companies came into being in China during the last decade and their product shipments fulfill both domestic and export requirements of China. The growth in the China display industry has benefited all the supply chain companies as their businesses expanded with increased consumption of goods and services by the Chinese display makers. But it has also adversely impacted the Taiwan and Japan display industries, as seen in Table 7.2 below.

Table 7.2 shows the country wise distribution of display fabs under construction or under conversion to new technologies and expected to reach mass production within the next five years. It can be clearly seen that no new fab investments are planned in either Taiwan or Japan. All new investment announcements are in Korea and China, where there is either capital or knowhow or both. Korea leads the display industry in next-generation OLED technologies for smartphones and TVs and their technologies are aligned with the new vector of market growth, namely, smartphones and premium TVs.

Display Fabs (>=Gen 6) Under Construction or Conversion (2021-24)					
Country	**Gen 6 Class**	**Gen 8 Class**	**Gen 10 Class**	**Total**	**Backplane/Frontplane Investment Trends**
Japan	0	0	0	0	
Korea	1	2	0	3	Flex OLED & Oxide/OLED
Taiwan	0	0	0	0	
China	8	3	2	13	Flex OLED, Oxide/LCD & Oxide/OLED
Total	9	5	2	16	Source: Mizuho/August 2020

Table 7.2: Display Fabs (>=Gen 6) Under Construction or Conversion (2021-24)

Ref: Y. Nakane, Mizuho, SID 2020 Business Conference, August 2020

In summary, the creation and growth of the display industry are governed by macroeconomic factors such as the availability of capital, favorable national and local government policies, knowhow and a substantial market pull for the products. National governments are best positioned to craft attractive business policies for an emerging industry, mobilize resources and align their local businesses to participate. Knowhow flows to where display fabs are created as experience personnel and supply chain companies move to the new centers of capital.

8. The Competitive Edge "Research & Development"

The display industry is a technology business. As in any other technology business, intellectual property (IP) is an important asset of the company that can help it remain relevant and competitive. Therefore, every business in the display value chain, from the supply chain providers to display makers and users, must engage in their own multi-year, in-house research and development program that can generate new IP for product differentiation and business sustenance. As noted in earlier sections of this report, the modern display industry is more than three decades old. During this period, several thousands of patents have already been issued in the field of displays through research and development across the industry value chain and invaluable unpatented knowhow has been accumulated by the industry through manufacturing practice.

Patents and unpatented knowhow, which are the assets of any display value chain company, provide the individual display businesses with the necessary freedom to deliver each of their commercial products to global markets without the fear of being slapped with lawsuits by others for patent violations. The patents underlying each of the commercially available products must therefore be valid in the countries where products are finally sold to consumers. The life of patents in most jurisdictions is twenty years from the effective date of the patent grant. Therefore, all patents will expire in course of time. The lack of patents and knowhow poses an additional barrier for new entrants to the display industry. Although patent licenses on background technology can be obtained from third parties for an appropriate payment and an agreement to pay running royalties during the life of licensed patents, the acquisition of new patents and knowhow requires a commitment to in-house research and development activities and through manufacturing practice by the manufacturer. Sustained research and development can lead to new IP and the ability to cross-license such IP with others to reduce the running royalty burden or create new products. In the display industry, research and development provides a competitive edge.

9. Rationale for Creating a Display Industry in India

a) India – Market Demand

India, an established leader at the front-end of the data value-chain in information technology (IT) software, has now emerged as a leading consumer of display-centric hardware. The display component (hereafter referred to as "display") makes up at least 15% of the value of a display-centric hardware product and in many cases, the display is the single largest unit cost item in a typical bill-of-materials listing. However, India does not currently have a local display manufacturing industry and all displays have to be imported from overseas suppliers. The demand for displays, consumed by an evolving local assembly manufacturing of display-centric products under the "Make-in-India" strategy, will substantially increase over the future years.

In order to estimate the annual value of display imports into India for use in the top five product categories during the period from 2021 to 2025, the following conservative assumptions are used.

TVs:

(i) the average customer price point for TV displays in India will be USD85; (ii) the product size will migrate from 39-inch diagonal in 2021 to approximately 50-inch diagonal in 2025 and customers will expect improved display attributes at the same price point.

Tablets:

(i) the average customer price point for tablet displays in India will be USD50; and (ii) the display diagonal size will remain at 10.1-in but customers will expect improved display attributes at the same price point.

Notebooks:

(i) the average customer price point for notebook displays in India will be USD65; and (ii) the display diagonal size will remain at 15.6-in but customers will expect improved display attributes at the same price point.

Monitors:

(i) the average customer price point for desktop monitors in India will be USD50; and (ii) the display diagonal size will remain 19-in but customers will expect improved display attributes at the same price point.

Smartphones:

(i) the value of the bill-of-materials (BOM) in a smartphone assembly is 75% of the product price; (ii) the display component is 15% of the BOM cost; (iii) the average customer price point for smartphones in India will be USD130 and remain constant at that value until 2025; (iv) the product size will migrate from 5.5-in diagonal in 2021 to 6-in diagonal in 2025; and (v) the display resolution will be Full HD or higher.

India display requirement can be looked from 2 different scenario's as given below:

- Scenario 1 : India's Domestic Demand
- Scenario 2 : India Domestic and Exports Demand arising out of the 'Make-in-India' which has attracted a series of global players to make in India and export to the world.

Using the above assumptions, our estimate of the India demand is summarized below in the 4 charts given below.

In Scenario 1(Domestic requirement only), The requirement of Display Panels to meet the Indian domestic market requirement is likely to increase from 188 million units in 2020 to 367 million units in 2025, growing at a CAGR of 13.3%, driven largely by Mobile phone requirement as shown below in Figure 9.1:

Scenario 1: Display Requirement to meet India's Domestic Market Demand

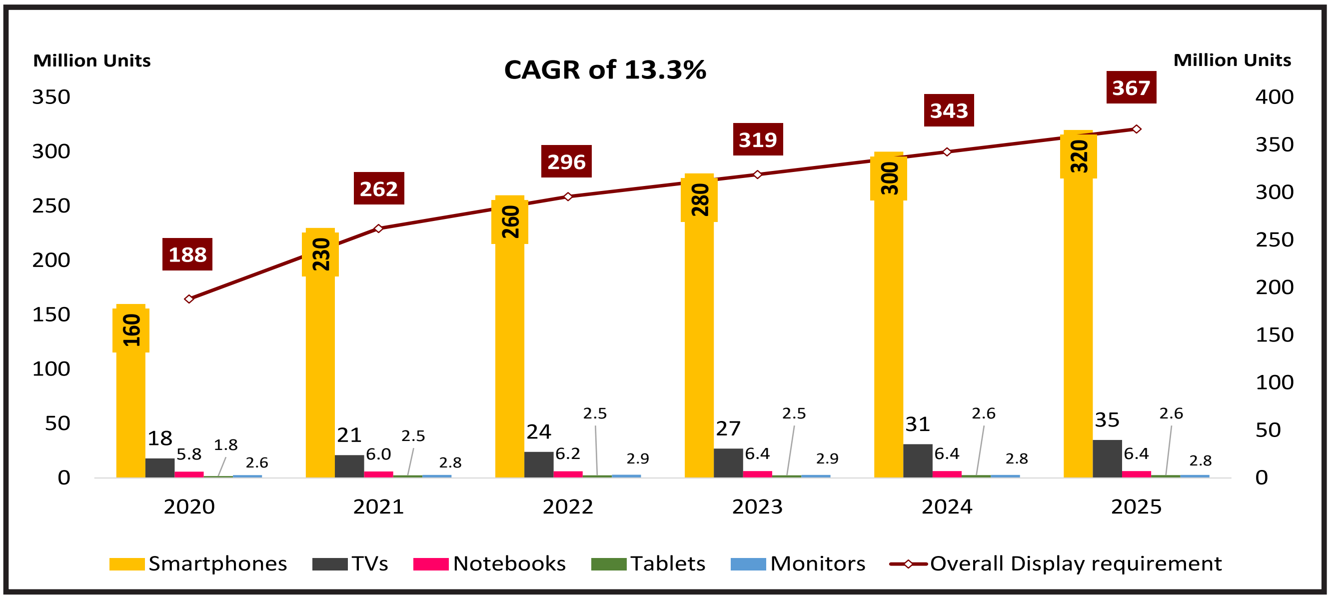


Figure 9.1: SCENARIO-1 ("India Domestic Demand"): Market Forecast
Source: India Cellular and Electronics Association Forecast, December 2020

Note: Feature phone displays and automotive displays are not included.

In Scenario 2 (Domestic + Exports requirements), The requirement of Display Panels to meet both the Indian domestic market + The Exports requirement is likely to increase from 253 million units in 2020 to 922 million units in 2025, growing at a strong CAGR of 29.5%. The additional growth is essentially from a strong growth in exports as envisaged in NPE 2019 for the Mobile sector. The additional momentum in requirement is driven by:

1. For substantial growth in demand for smartphone displays (up to 500 million units in 2025); and
2. For a modest growth in demand for Notebook and Tablet displays as shown below in Figure 9.2

Scenario 2: Display Requirement to meet India's Domestic Market + Exports Demand

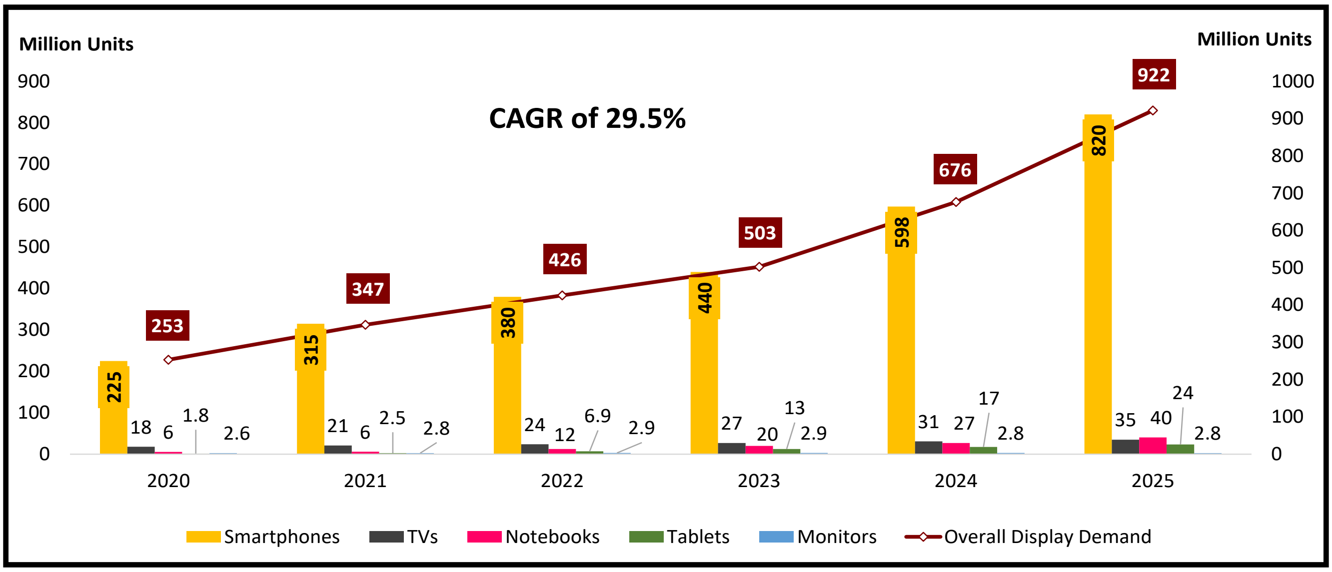


Figure 9.2: SCENARIO-2 ("India Domestic Market + Exports Demand"): Market Forecast
Source: India Cellular and Electronics Association Forecast, December 2020

Note: Feature phone displays and automotive displays are not included.

In Value terms, the Display market in Scenario 1 (Domestic requirement only) is likely to grow at 13.3 CAGR for the next 5 years to reach USD 8.3 B in 2025 from USD 4.5 B in 2020. In Scenario 2 (Domestic + Exports requirements) this is like to grow at 28.4% CAGR for the next 5 years to reach USD 18.9 B in 2025 from USD 5.4 B in 2020.

In other words, the India Display Market is likely to be a USD 35.4 B cumulatively between 2021 to 2025 in Scenario 1 (Domestic requirement only) and it is likely to be USD 59.8 B cumulatively between 2021 to 2025 in Scenario 2 (Domestic + Exports requirements) as shown in Figure 9.3.

Scenario 1: Cumulative 2021 to 2025: USD 35.4 B
Scenario 2: Cumulative 2021 to 2025: USD 59.8 B

Display Demand in India (Value in USD B)

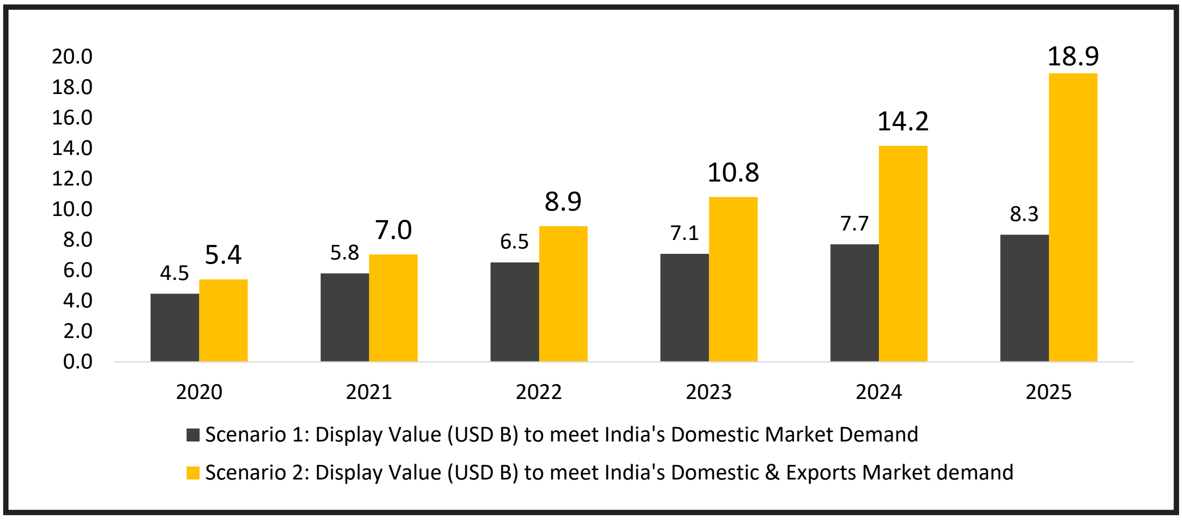


Figure 9.3: India Display Market Value Forecast in USD B
Source: India Cellular and Electronics Association Forecast, December 2020

***Note: Feature phone displays and automotive displays are not included.**

In terms of Segments, the top two product categories driving these display imports are smartphones and TVs. In the absence of a display manufacturing industry in India. Displays contribute to 15% or higher value in smartphone BOMs, 30% or higher value in TV BOMs and similar contributions in the BOMs of notebooks, tablets and monitors. The Product wise Display Demand is shown below for both the above-mentioned scenarios in Figure 9.4:

Segment wise Display Demand in Value USD B – 2020 to 2025

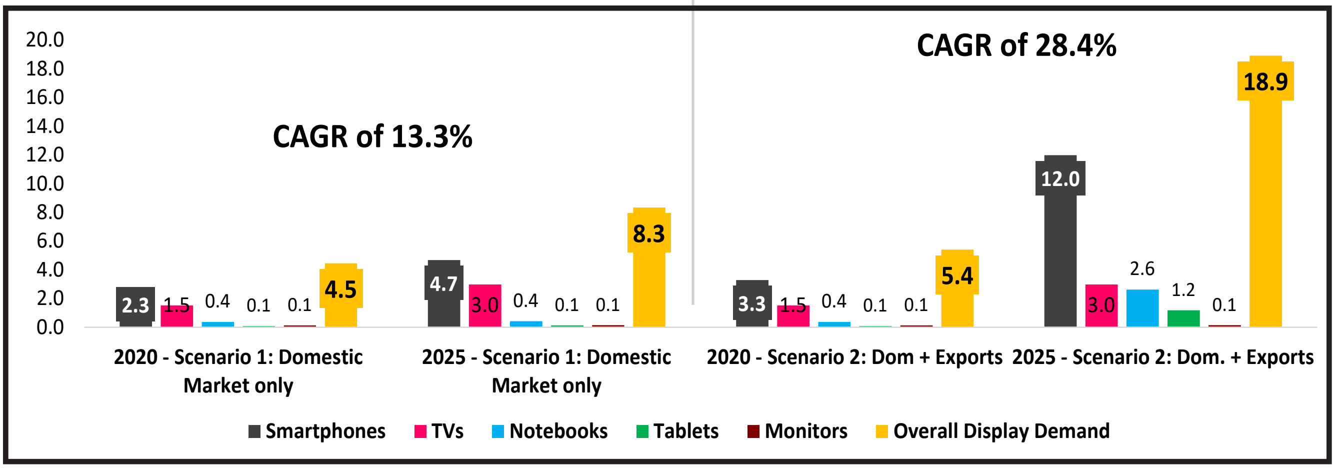


Figure 9.4: India Display Market Segment wise Value Forecast in USD B
Source: India Cellular and Electronics Association Forecast, December 2020

***Note: Feature phone displays and automotive displays are not included.**

b)
Benefits for India

Table 9.1 provides a concise summary of a 5-year plan for the creation of a display manufacturing industry in India under the Scenario-2 investment assumptions (discussed earlier in Section 9 of this report) and the benefits it can bring to the country from a macro-economic point-of-view.

A: Display Cash Outflows w/o Domestic Display Industry	Cumulative Display Value (USD billions)				
	2021	2022	2023	2024	2025
SCENARIO-2 : Domestic Demand + Export Opportunity	$ 7.0	$ 15.9	$ 26.7	$ 40.9	$ 59.8
SCENARIO-1 : Domestic Demand Only	$ 5.8	$ 12.3	$ 19.4	$ 27.1	$ 35.4
B: Value Creation Plan with Domestic Display Industry	**Annual Display Value (USD billions)**				
	2021	2022	2023	2024	2025
DEMAND					
Total Display Demand in All "Make-in-India" Products	$ 7.0	$ 8.9	$ 10.8	$ 14.2	$ 18.9
Display Demand for Domestic Consumption Only	$ 5.8	$ 6.5	$ 7.1	$ 7.7	$ 8.3
Display Demand in Export-Oriented Consumer Products	$ 1.2	$ 2.4	$ 3.7	$ 6.5	$ 10.6
SUPPLY					
SCENARIO-2 India Manufacturing Capacity Ramp-Up	0%	0%	20%	50%	80%
Revenues from India Display Manufacturing	$ -	$ -	$ 2.2	$ 7.1	$ 15.1
Foreign Cash Outflows from Supply Shortfalls	$ (7.0)	$ (8.9)	$ (8.6)	$ (7.1)	$ (3.8)
Value Creation in India	$ (7.0)	$ (8.9)	$ (6.5)	$ -	$ 11.4

Table 9.1: Benefits Resulting from the Creation of an India Display Manufacturing Industry

01

India already has a strong market-pull for display-centric consumer products and the cumulative cash outflows (Scenario-1) over a 5-year period (2021-2025) for domestic display consumption adds up to USD 35 billion.

02

India is now implementing a "Make-in-India" plan for display-centric consumer products for both domestic consumption and for export markets. The cumulative cash outflows (Scenario-2) over the same 5-year period for displays adds up to USD 60 billion.

03

In the absence of a local display manufacturing industry, these cash outflows will continue for the foreseeable future. If the displays are imported as components, integrated into the "Make-in-India" display-centric products and then subsequently exported as an integrated product, the cash outflows are offset by cash inflows. Hence for the purposes of estimating the true cash outflow, only Scenario-1 (domestic consumption) is considered for the purpose of justifying the investments required by India for the creation of a display manufacturing industry. In Section 9 of this report, we calculated the net present value (NPV) for Scenario-1 cash outflows to be USD 25 billion.

04

Instead, If the country were to set aside approximately USD 20 billion (less than the NPV of USD 25 billion noted earlier) during 2021 to promote investments in a domestic display manufacturing industry, it can help to stem future cash outflows (during and beyond the current 5-Year period shown in the table) and furthermore result in significant value creation in India from display manufacturing activities. The investment funds needed for this outcome should ideally result from private-public partnerships in a manner similar to previous such experiences that resulted in the creation of display industries in other countries (for example, China).

In Section B of Table 9.1, where annual cash outflows are shown for display consumption in India during the same 5-Year period from 2021 to 2025, it can be seen that if a domestic display industry were to be created through private-public investments with sufficient manufacturing capacity to meet the Scenario-2 market demand, then the country can: (i) break even in Year 4 (2024) and (ii) create positive cash flows in Year 5 (2025). The key benefits to the nation, both tangible and intangible, from the presence of an Indian display component manufacturing industry are:

Value-Addition

Create value-addition in India of greater than **USD11 billion** annually from Year 5.

Exports

Create new display export opportunities from India of up to **USD10 billion** by Year 5.

Imports

Eliminate the need for display component imports to satisfy domestic market demand.

Employment Creation

Create domestic employment, both direct and indirect, to the tune of **200,000 new, sustainable, high-tech, futuristic jobs.**

High-Tech Industry

Create a high-tech manufacturing ecosystem that can trigger Indian innovation in display-leveraged, high-tech, display-centric consumer products of the future and in other adjacent industries.

c)

India – Display Manufacturing Plan

As discussed earlier in this section, the five major product categories are smartphone, TVs, notebooks, tablets and monitors. The fastest growing segment is the smartphone display segment. The display attributes, both intrinsic and enabling, required for smartphone applications are driving the display industry towards the manufacture of flexible OLED frontplanes on LTPS-TFT backplanes. It is expected that the India market will follow these global trends within the next five years and transition from LCD displays to OLED displays. If the pixel resolution about 350 ppi, it will be necessary to use LTPS-TFT backplanes even for LCD displays intended for smartphones. As an additional consideration, the production technologies for LTPS-TFT backplanes are limited to Gen 6 mother glass size. Since the Scenario-2 demand is strongly driven by smartphone displays for export markets, the India display industry must become proficient at the state-of-the-art technologies required for the manufacture of flexible OLED displays. All other product categories needed by the price sensitive India market, namely, TVs, notebooks, tablets and monitors will use LCD displays as the manufacturing technology of choice. In summary, the display manufacturing plan for India should focus on two types of display fabs, namely, (i) Gen 6 fabs for smartphone displays; and (ii) Gen 8.5 fabs for all other product categories. Table 9.2 shows such a manufacturing plan for the Scenario-2 market demand forecast for India.

SCENARIO 2: "Make-in-India"					2025 Panel Capacity (Sheets per Month)	
					Gen 6	Gen 8.5
				Operating Efficiency -->	85%	85%
Product Category	**Product Size (in)**	**2025 Quantity (millions)**	**Panels per Sheet**	**Process Yield**	**1500mm x 1850mm**	**2200mm x 2500mm**
Smartphones - Case 1	6	820	250	85%	380K	
Smartphones - Case 2	5.5	820	300	85%	320K	
TVs - Case 1	55	35	6	90%		640K
TVs - Case 2	47	35	8	90%		480K
Notebooks	15.6	40	75	90%		60K
Tablets - Case 1	10.1	24	75	85%	40K	
Tablets - Case 2	10.1	24	170	85%		20K
Monitors	19	2.8	50	90%		6K
Total				**Total Panel Capacity -->**	**360K to 420K**	**560K to 730K**

Table 9.2: Recommended Plan for Display Panel Manufacturing in India (2021-2025)

The key factors that drive the sizing of a display factory are mother glass size, product size, panels per sheet, process yield and operating efficiency. For example, in order to manufacture 820 million smartphone displays per year of 6-in diagonal size in Gen 6 fabs, approximately 380,000 (or 380K) MG sheets per month will be required to be processed at 85% yield and 85% operating efficiency. As an additional example, in order to manufacture 35 million TV displays per year of 55-in diagonal size in Gen 8.5 fabs, approximately 640,000 (640K) MG sheets per month will be required to be processed at 90% yield and 85% operating efficiency. In summary, the manufacturing plan for India covering the product categories and quantities outlined in the Scenario-2 option, requires Gen 6 fabs with a cumulative capacity of 360K to 420K sheets per month and Gen 8.5 fabs with a cumulative capacity of 560K to 730K sheets per month. Assuming that a Gen 6 fab is sized at 60K sheets per month and a Gen 8.5 fab is sized at 120K sheets per month, then India needs six Gen 6 fabs and 5 Gen 8.5 fabs.

10. Recommendations for In

The creation of a display industry will require the confluence of capital, knowhow and market-pull. India is already a leading consumer of displays, hence there is already a strong domestic market-pull. The challenge for India is to bring together capital and knowhow to trigger the growth of a domestic display industry. A display manufacturing industry can be created in India through private-public partnerships (PPP) under private sector leadership, as discussed below.

The Role of Private Sector

01

The display industry must be operated under the leadership of private sector companies.

02

Several private sector corporations are necessary to establish a healthy domestic competition in the display value chain (including display makers and supply chain providers).

03

Private sector corporations interested in leading the India display industry as display makers must have strong balance sheets since the investments and the cash flows are large.

04

Such display makers must have management teams that have gained extensive hands-on experience from previous involvement in the global display industry.

05

The private sector companies that are interested in being display makers or Tier-1 suppliers to the display makers must establish multi-year business plans addressing:

a. Supply Chain Management and Cost Reduction Plan
b. Capital investment Plan
c. Marketing Plan
d. Knowhow Acquisition Plan
e. Research and Development Plan
f. IP licensing plan.

06

The business plans proposed by private sector companies for consideration of government support must address the need for two types of display fabs (Gen 6 and Gen 8), as discussed in earlier sections of this report, needed to address the high-growth area of high-performance displays needed for smartphones and the more mature displays needed for TVs, laptops, monitors and tablets.

ndia

The Role of Public Sector

A coherent national policy is required to mobilize private sector companies to bring together capital and knowhow to establish state-of-the-art display fabs. The national policy can extend government support of up to USD20 billion, as noted earlier, towards providing financial incentives to display makers and display supply chain companies who agree to make substantial investments under the private-public partnerships. Such incentives may be directed and leveraged towards the following types of support for private companies.

01 Infrastructure Support

a. Land, water and electricity
b. Building
c. Transportation and housing

02 Capital Investment Support for

a. Investment in new display fabs and display module manufacturing plants
b. Acquisition of used fabs

03 Other Financial Support

a. Equity participation
b. Loans &/or loan guarantees
c. Production linked incentives

04 Tax Benefits

05 Research & Development credits to private sector companies

06 Set up a national R&D center for display technology development (Gen 4 or Gen 5.5 fab) that can create new IP in state-of-the-art technologies which can be made available to the display industry.

About the Authors

G. Rajeswaran, Ph.D.

Fellow/Society for Information Display
Professor of Practice/Indian Institute of Technology Madras, Chennai, India
Director & CEO/Grantwood Technologies Inc, Rochester, New York, USA.

In 2013, Dr. Rajeswaran ("Raj") was elected as a Fellow of the Society for Information Display "for pioneering contributions to the development, manufacturing and commercialization of AMOLED displays".

In 1999, Raj demonstrated the world's first AMOLED display on LTPS-TFT backplanes while at the Kodak Research Laboratory in Rochester/New York. Subsequently, he was responsible for the establishment in 2001 of the world's first AMOLED display manufacturing joint venture between Kodak and Sanyo ("SK Display") in Japan. At Kodak, Raj held leadership positions as the VP of Kodak's Display Business Unit and as the Director of AMOLED display manufacturing technology. In 2001, Raj moved to Japan to serve SK Display and Kodak Japan in a leadership role to commercialize AMOLED displays. During his 7-year tenure in Japan, he led the teams that delivered the first commercial AMOLED displays to the market and developed many of the underlying production technologies that make modern AMOLED smartphone displays and OLED TVs possible. Between 2004 to 2007, he established the Kodak AMOLED technology collaborations with display industry leaders in Korea and Taiwan that triggered the growth of the AMOLED display industry (>USD25 billion in 2019).

In 2014, Raj founded the Grantwood group of companies to develop and commercialize next-generation technologies. Grantwood Technologies Pvt Ltd, a start-up established in 2018 in New Delhi by the Grantwood group, is currently engaged in a joint development program with the Indian Institute of Technology Madras ("IIT Madras") to demonstrate building-block technologies for cost-effective, state-of-the-art, next-generation AMOLED displays. Raj, who is actively involved as a Principal Investigator in the AMOLED project, also holds an appointment as a Professor of Practice in the electrical engineering department at IIT Madras.

Amitava Majumdar, Ph.D.

CTO/Grantwood Technologies Pvt Ltd, New Delhi, India
Program Manager/Grantwood-IITM AMOLED Program, Chennai, India

Dr. Amitava Majumdar ("Amitava") brings three decades of product development, manufacturing process development and technology commercialization experiences in the fields of xerography, storage media, photovoltaics, LED and OLED technologies. He has extensive experience in collaborations and relationship management with global suppliers and customers (from Japan, Europe and USA) for enabling the manufacture of state-of-the-art, high-tech products in India. Prior to joining Grantwood Technologies Pvt. Ltd, Amitava has held leadership positions as Vice President at Vikram Solar, as Vice President at Moser Baer India and at Xerox India. Amitava received the M.Tech. and Ph.D degrees from IIT Kharagpur.

Anjali Kapur, MBA

Head of Business Development
Grantwood Technologies Pvt Ltd, New Delhi, India
anjali.kapur@grantwoodindia.com

Ms. Anjali Kapur ("Anjali") brings more than 15 years of hands-on experience in the fields of corporate strategy and corporate finance. Prior to joining Grantwood Technologies Pvt Ltd, she has worked with DLF, McKinsey, Moser Baer India and Jubilant in different roles. From 2018 since joining Grantwood, Anjali has been engaged in the analysis of the business forecast and market trends in the global display industry and of the display business opportunities in the India region. Anjali received her MBA degree in Finance and Marketing.

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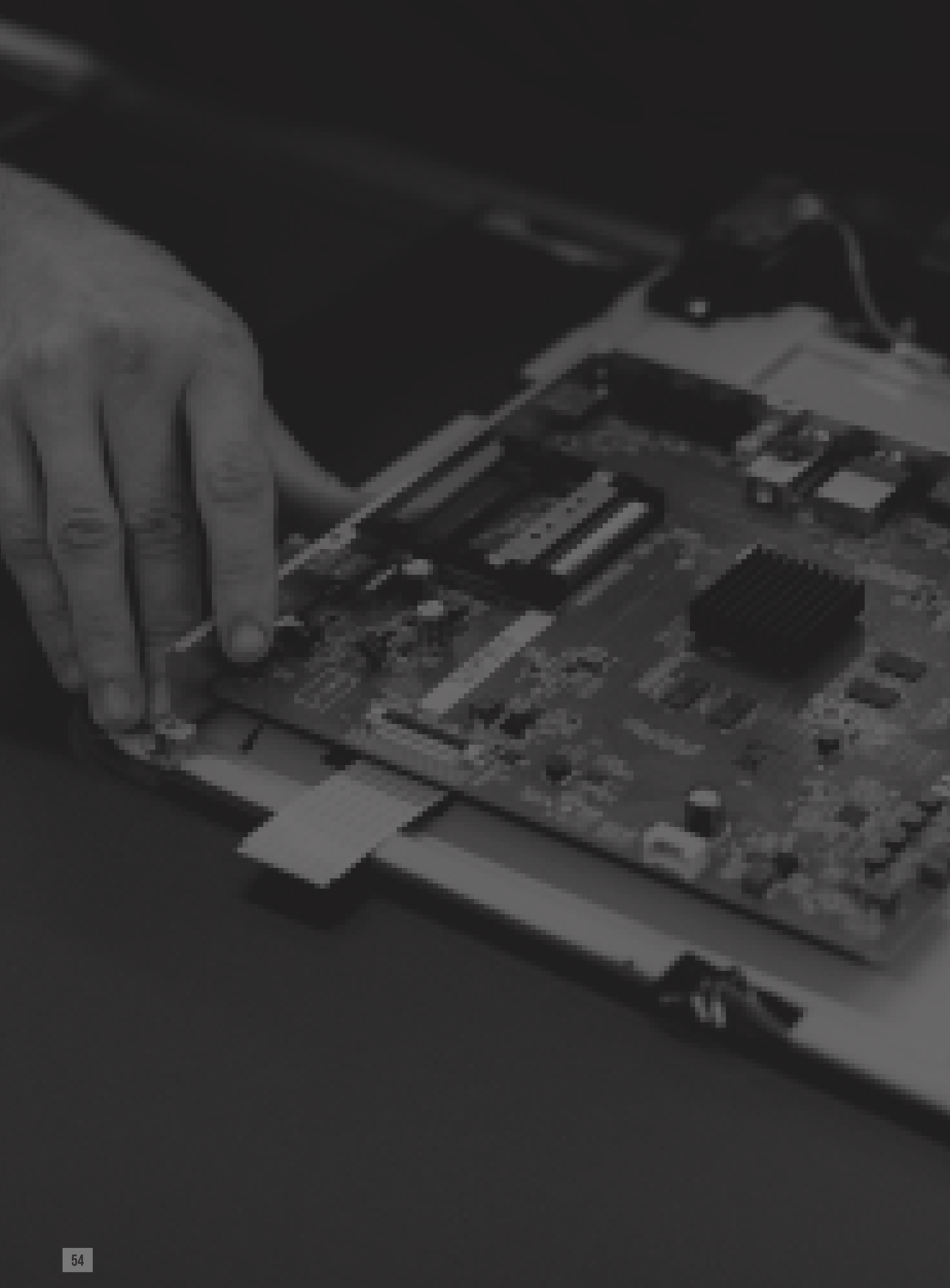

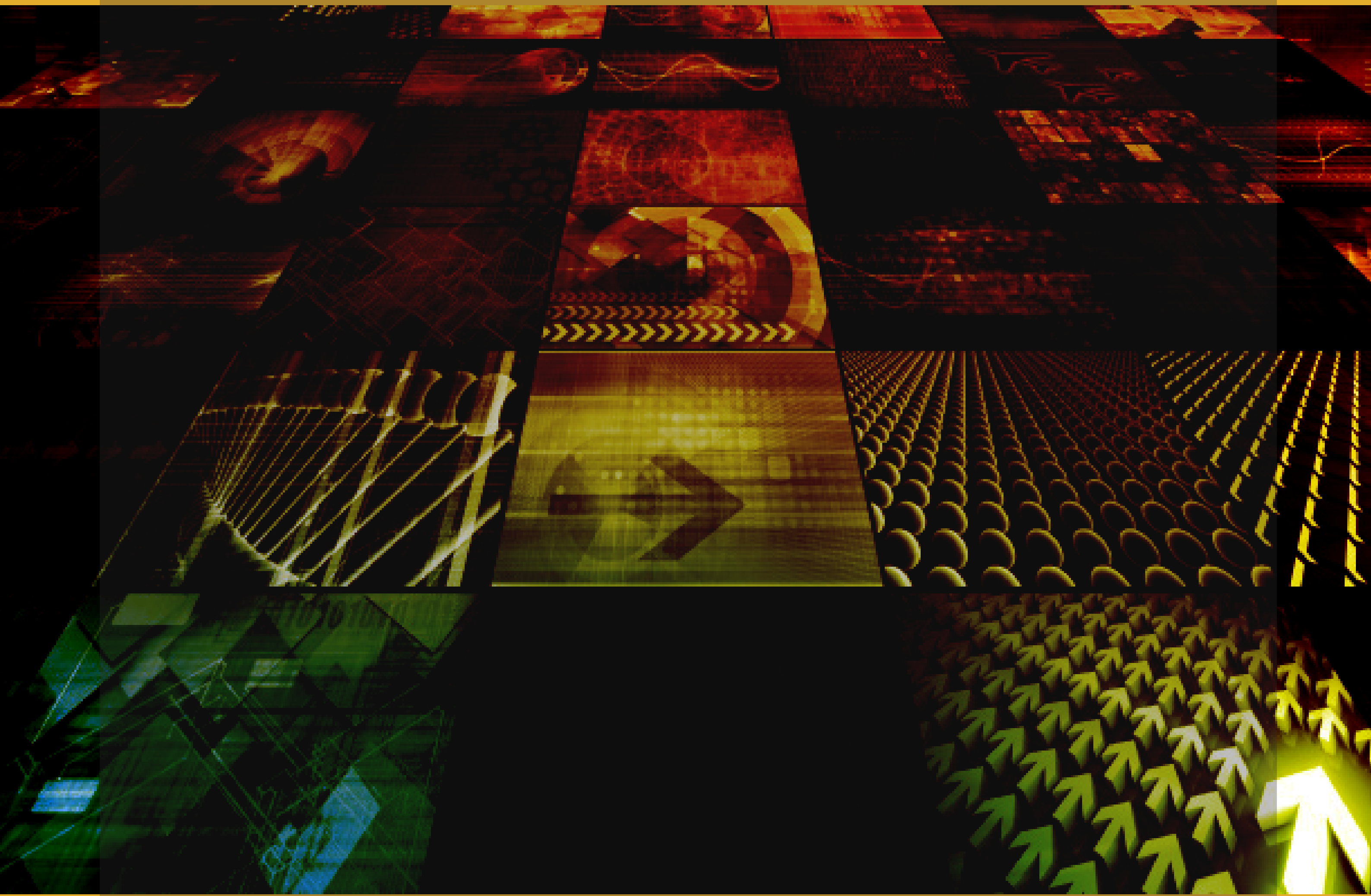

India Cellular & Electronics Association

9th Floor|Le-Meridian Commercial Tower|18 Windsor Place | New Delhi-110001

Grantwood Technologies Private Limited

Eros Corporate Towers|Level 15|Nehru Place| New Delhi-110019