FEATURED M&A REPORT

Display Industry

RCL Tech M&A Trends - June 2020

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Scope of the Report

It is becoming clear that at an R&D level, the technology challenges of Micro-LEDs have been solved and the technology has already moved into pilot production – for small form factor displays through to large commercial displays. The attributes of Micro-LED displays seem to be sufficient to disrupt the Display industry in a way that OLED technology promised but has never completely achieved. LCD is still the dominant display technology by any measure. It is also clear that the field of AR and Near Eye displays required for AR is set to be a significant market, and while touched on in this report, it will be the focus of a separate report in the future. While Korea, Japan and China dominate in the manufacture of displays, new technologies are generated, developed and financed globally. This will give rise to a wave of M&A consolidations in the near future as the display industry which, usually progresses through incremental changes, is open to the adoption of discontinuous technology change, in the search for market share and profitability.

We will look cover the technical aspects in greater detail in a separate report. However, our understanding of the market, verified by discussions with key members in the display industry, visits to photonics and optics conferences and various display reports and news published in recent years, is that the Display market offers multibillion-dollar opportunities across its supply chain technologies.

This report covers:

1. Currently available technologies
2. The history of displays
3. Market
4. Ecosystem
5. Manufacturing
6. Investment / M&A
7. Our view of the future

Overview of Key Display Types

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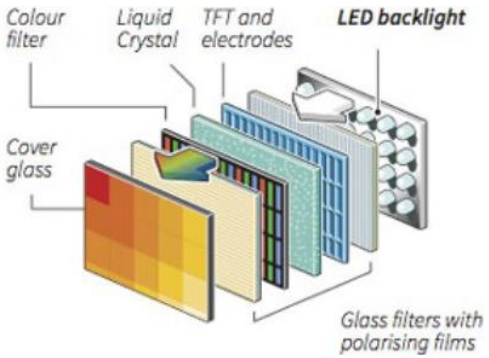
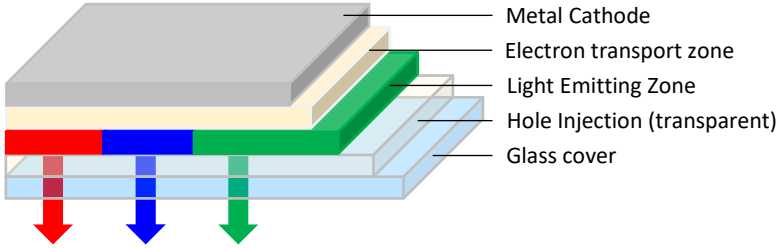
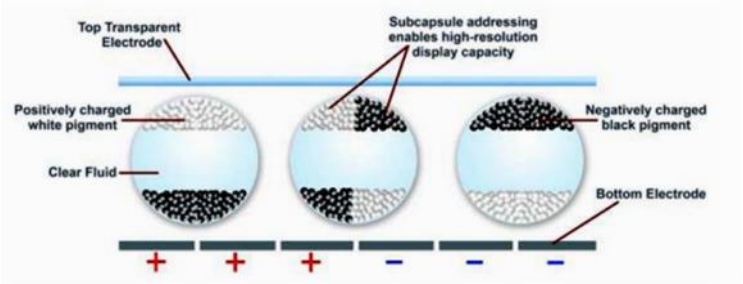
	Backlight Displays		Self-Emissive Displays	Reflective Displays
Diagram				
Variations	LCD Plasma TVs	Mini-LED QLED	OLED / AMOLED Micro-LED	Electrophoretic Displays Electronic Ink
Description	▪ White light produced from a backplane is "filtered" using electrically-controlled liquid crystals ▪ Light able to pass through the liquid crystals then goes through a colour filter to give colour to the sub-pixel		▪ Current flows through from "Metal Cathode" to "Hole Injection" ▪ Red, blue or green light is produced in "Light Emitting Zone" and shines through the "Hole Injection" zone and glass cover to give colour to sub-pixel	▪ Balls with freely moving negative and positive particles (white or black) are held inside a layer ▪ Electrode in the back layer determines changes charge to repel or attract charged particles ▪ The colour particle repelled by the electrode cause white or black to be seen (mixing charge gives grey)
Applications	*Older generation TVs* *Computer monitors* *Laptops* *Tablets* *Old phones*		*New TVs* *Smart Phones* *AR/VR Headsets*	*E-book readers* *Watches* *Electronic Shelf Labels*

The Evolution of Displays

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Shift to Asian manufacturing dominance

Cathode Ray Tube television dominated the display market for many decades following commercialisation in 1934

CRT
1934 – 1990s

LCD
1964 - present

- First developed in 1964
- Penetrated market due to portability and power efficiency
- Cost and performance enhancement driven mainly by Japan
- Plasma TVs suffered catastrophic market collapse due to image burn-in issues
- Innovations continued but speed refresh rate, daylight visibility, and achieving panel sizes >65'' remained problematic
- Problems allowed OLED and inorganic LED array displays to garner interest

OLED
2004 - present

- First OLED technology developed in 1987
- First OLED TV in 2004
- Success in large flat panel displays and then small displays for smartphones propelled OLED to market dominance
- Benefits included: high resolution, low-weight, high blackness levels, power efficiency and fast response times
- The technology also held the promise of foldable displays, leading companies such as LG to remain OLED-focused
- As display fabrication plants have converted to make larger OLED displays production costs have risen to unprofitable levels
- Further compounding the issue are reports of image burn-in resulting from maximising image brightness

LCD Resurgence
2015 - present

- LCD now making a return with QLED and mini-LED
- QLED introduced in 2015 by Samsung to rival OLED
- The technology involves adding a "Quantum Dot" layer to an LCD display to achieve better colours and brightness
- Mini-LED massively increases the number of LEDs in the backplane to better alter brightness levels in specific areas on the screen

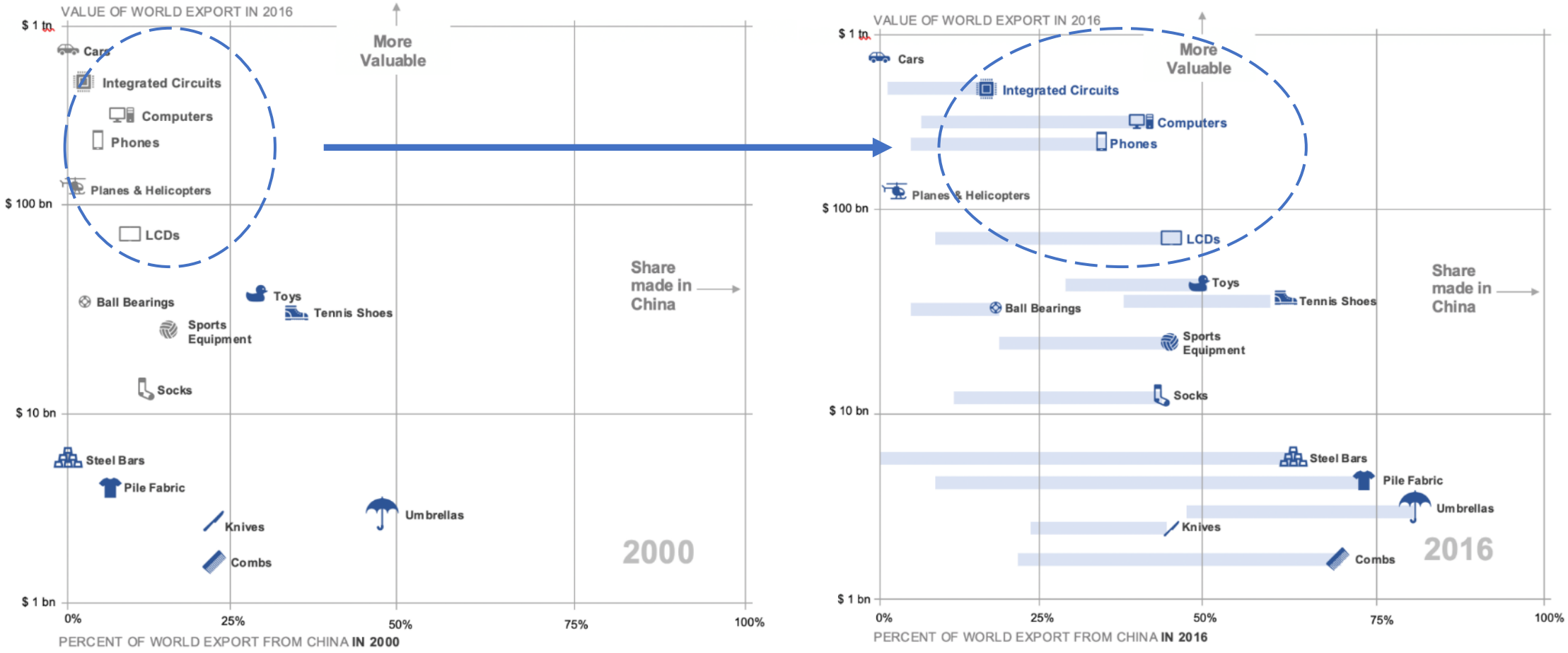
Micro-LED
Present

- Technology developed in 2000, however, has not been commercialised yet
- Micro-LED displays have the potential to deliver "better-than-sight" colour performance, high response speed, ultra-high resolution, optimal power efficiency and cost-effective manufacturing

Shift to Asian manufacturing dominance

China's Role in the Asian Dominance of Displays

- Chinese (and Taiwanese) manufacturing capability dramatically expanded from 2000 to 2016 across most export areas
- High-tech exports saw this increase most prominently, rising from a diminutive share to significant positions
- China's growing manufacturing capability, combined with that from the Japanese and South Koreans, has led to an Asian frenzy in the Display Industry



Source: Forbes

Flat Panel Display Market

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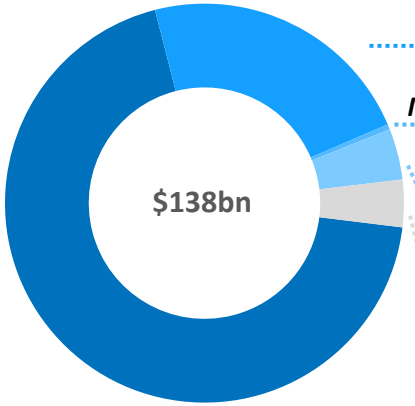
Display Industry Breakdown by Technology, 2019[1,2,3,4]



OLED $31.0bn

Micro-LED $0.6bn

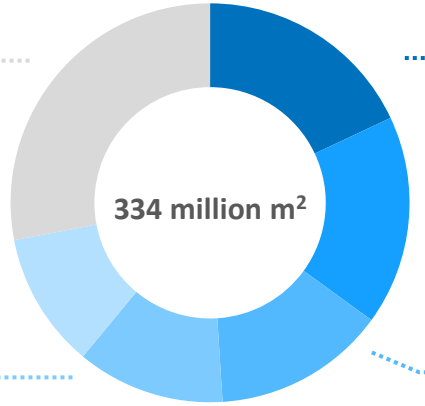
Direct-View LED $5.7bn

Other $5.3bn

LCD $95.1bn

	Large/medium Displays	Small Displays	Micro-displays	Automotive
				
Uses	*TV* *Monitors* *Laptops* *Signage*	*Smartphones* *Tablets/Phablets*	*AR/VR* *Smart Watches*	*Car Dashboards / Other Internal Displays*
Drivers	▪ Growth of the premium TV market ▪ UHD, 4K, 8K availability ▪ Improved colour / brightness / contrast	▪ Higher pixel densities ▪ Availability of flexible displays ▪ Power efficiency improvements	▪ Very high pixel densities ▪ Mass adoption of wearables ▪ Improved front- and back-end of AR/VR glasses	▪ Digital transformation of the auto industry (e.g. driver assistance systems) ▪ Growth of premium car markets

Market Share by Display Area Manufactured, 2019[5]



Other 28%

BOE 18%

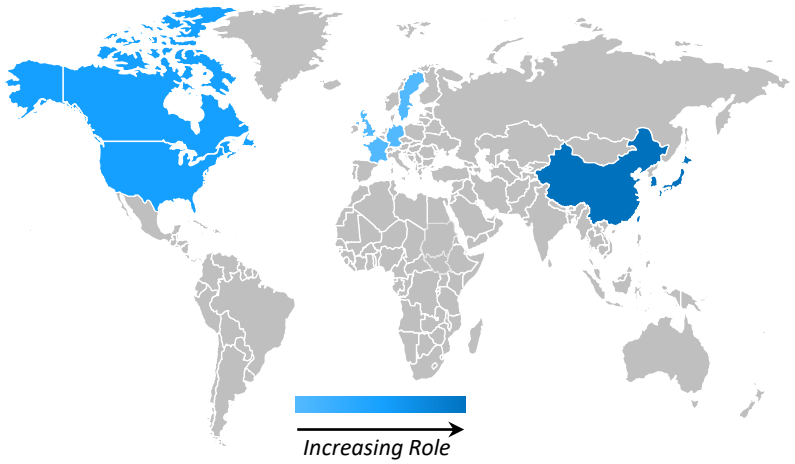
LG 17%

AUO 11%

SAMSUNG 12%

INNOLUX 14%

Key Countries Involved in Display Technology Innovation



Key Takeaways

- **LCD dominates** the display industry due to massive volume production for mid-market displays, e.g. common TVs and monitors
- **LCD** is also **still widely used** in low and mid-market **smartphones** equating to **~50%** of all **smartphone display revenue,** although OLED adoption is rising (Samsung dominating smartphone OLED market with >90% market share)[6]
- China is the largest display manufacturing country by area produced – previously South Korea (through Samsung and LG)

Source: [1] Markets and Markets, [2] OLED-Info, [3] Medium, [4] Sixteen-Nine, [5] IHS Markit, [6] The Investor

TVs: A Key Driver of Display Technology

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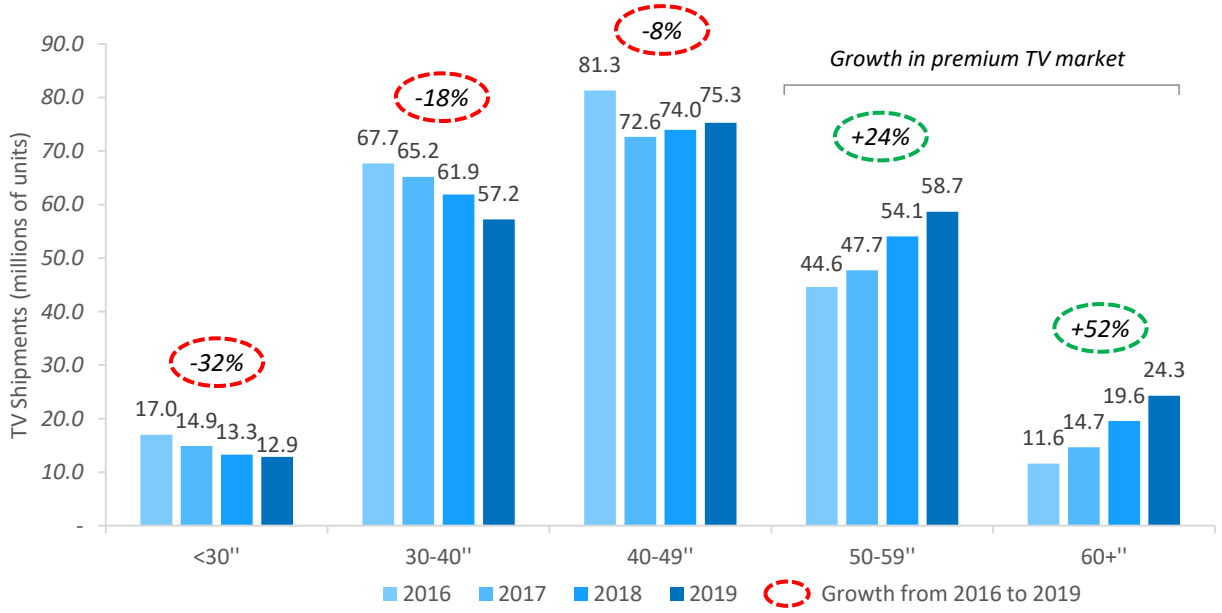
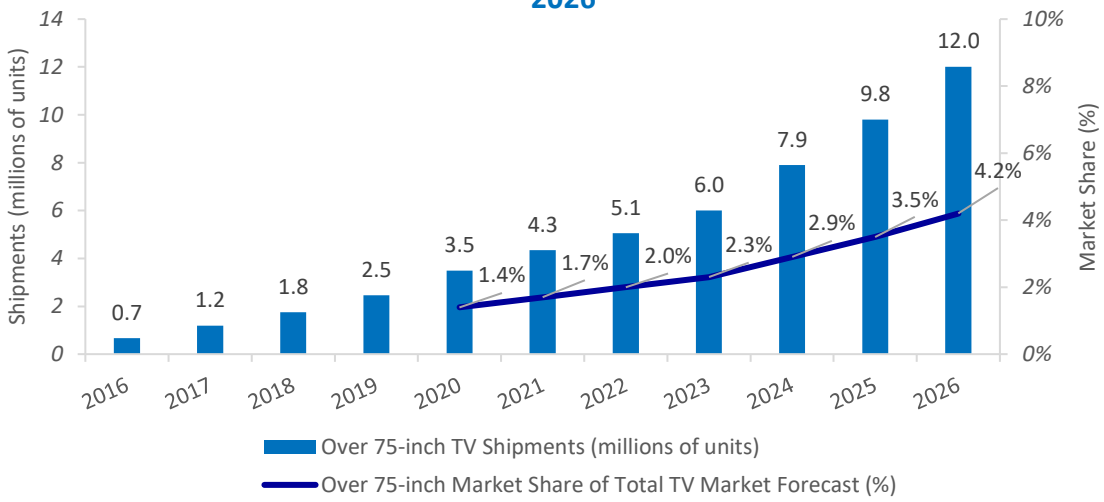
TV Shipments by Size (millions of units)[1]



Over 75-inch TV Market Shipments and Market Share Forecast, 2016 - 2026[2]



1. TV demand for smaller sizes declining – higher-end "premium" TVs have shown unhindered growth
2. Prices for TVs up to 55'' have become accessible to the average consumer but 60+'' prices remain prohibitively high for most, particularly 75'' and above
3. Display manufacturers pre-empting market move to larger TVs through fabrication plant upgrades

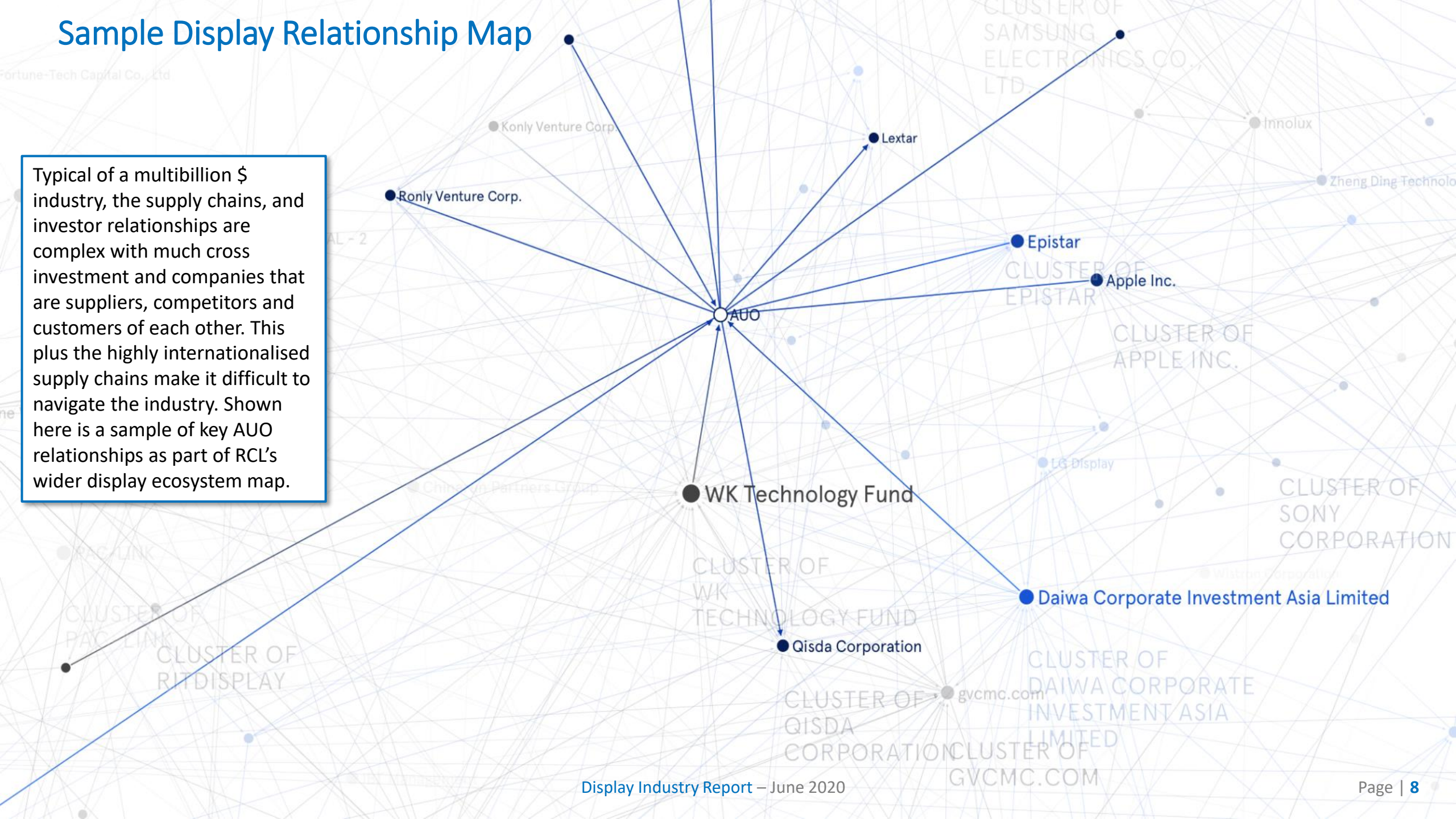
Is there a limit to display sizes?

- As display size increases, manufacturing cost increases at an exponential rate (see slide 12)
- There has been a major drive to work around this for several years
- At CES 2020, Samsung unveiled a solution aptly named "The Wall": a giant TV made using a modular design
- The modularity theoretically enables devices of any size to be manufactured without prohibitively high costs
- This ability to modularise the design seems obvious but is difficult to achieve in practice, as the human eye tends to notice joints in displays, such as those seen in large wall advertising
- The price of this product is still ludicrously high; however, it marks a significant breakthrough with the potential to usher in a new era of displays
- In the long-term power issues may become the limiting factor for size

Sources: [1] Applied Materials, [2] IHS Markit

Sample Display Relationship Map

Typical of a multibillion $ industry, the supply chains, and investor relationships are complex with much cross investment and companies that are suppliers, competitors and customers of each other. This plus the highly internationalised supply chains make it difficult to navigate the industry. Shown here is a sample of key AUO relationships as part of RCL's wider display ecosystem map.



Flat Panel Display Manufacturing

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- The manufacturing process for displays is comparable in complexity to the manufacturing process for electronic products using Silicon Semiconductors
- While silicon semiconductors have millions of transistors crammed into less than $1cm^2$, displays have millions of semiconductors spread over $1m^2$. Uniformity becomes a significant consideration, as does mechanical integrity and differential thermal expansion over the myriad dissimilar materials needed. This is further compounded by the need to maintain optical performance.
- To date the 100s of Millions of transistors required by displays have been formed using aSi. This has in turn been supplanted by LTPS and IGZO as better able to meet the conflicting physical requirements. Recently Organic Semiconductors have advanced sufficiently to surpass the performance of these technologies in high volume, as well as offering significantly reduced manufacturing cost and processing temperate. This latter aspect enables displays to be manufactured not just on glass but lower weight and more robust plastic substrates.
- Fabrication plants cost staggering amounts. Samsung, for instance, announced it plans to spend $11bn developing a new technology and plant for the production of self-illuminating QLED displays by 2025[1]

Array

- Two separate glass substrates are used to create the colour filter (CF) and thin-film transistor (TFT)
- The array patterns are formed using specialist large area photolithography processes (Mycronic dominate technology for display photomask production)
- Both are created by depositing the colour filter/transistor materials onto the substrate typically using vacuum deposition processes
- Materials are precisely etched (chemically dissolved) to remove unwanted coverage with micron-level precision
- Processes are repeated several times to build correct layers or patterns

Cell

- A hardwearing base of polyimide coating is applied for physical and chemical stability
- Liquid crystal is poured onto the substrate and brushed to orientate the crystals
- The colour filter is sealed to the TFT by heating it
- Glass is cut to achieve desired display sections sizes

Module Assembly

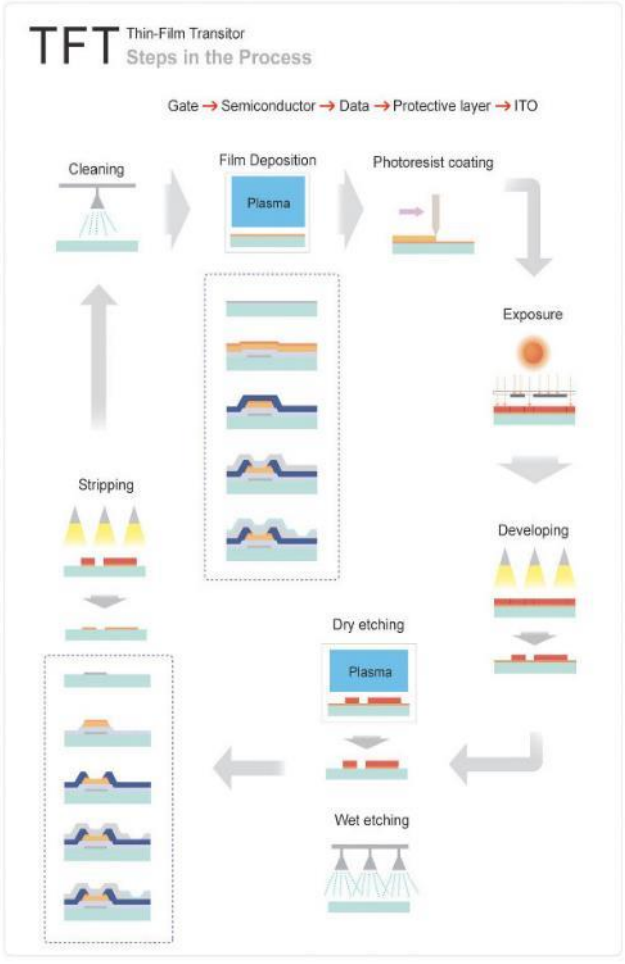
- The last step is to attach the electronics that drive the transistors to turn the pixels on/off
- After this the casing is put on and sealed

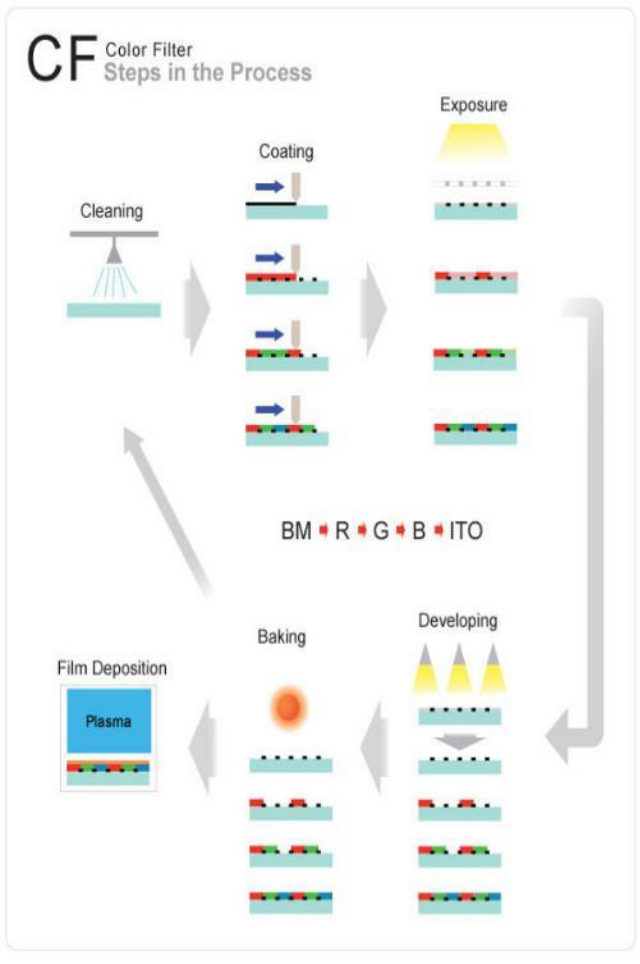
Sources: [1] CNET

Flat Panel Display Manufacturing

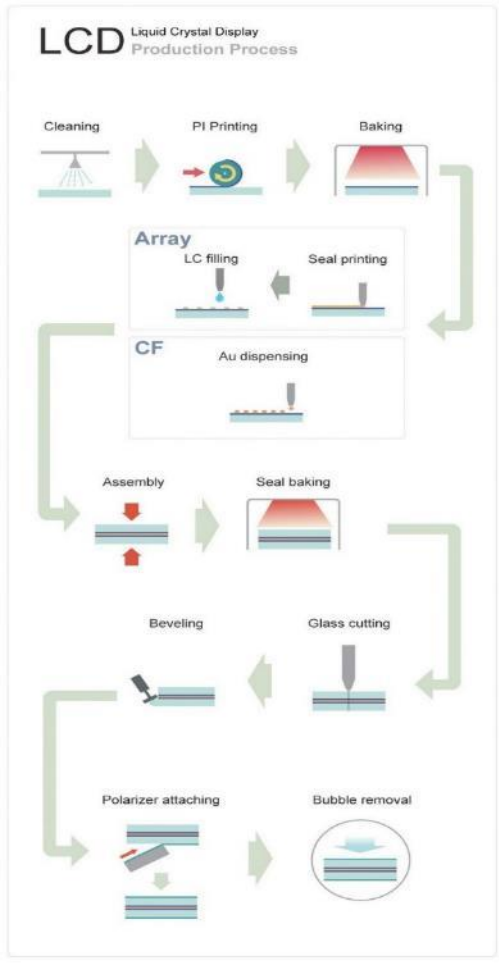
Outlined below is the manufacturing process of LCD – the most common fabrication method in the Display Industry
Please see https://www.auo.com/en-global/TFT-LCD_process_animation/index/ for a diagrammatic explanation of the material below

Array

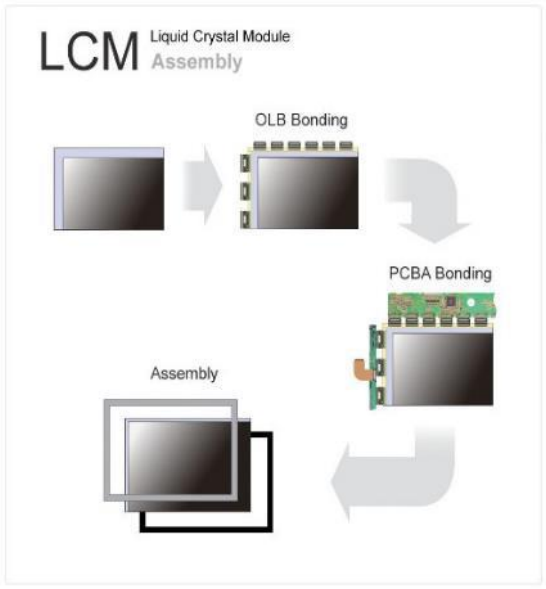




Cell

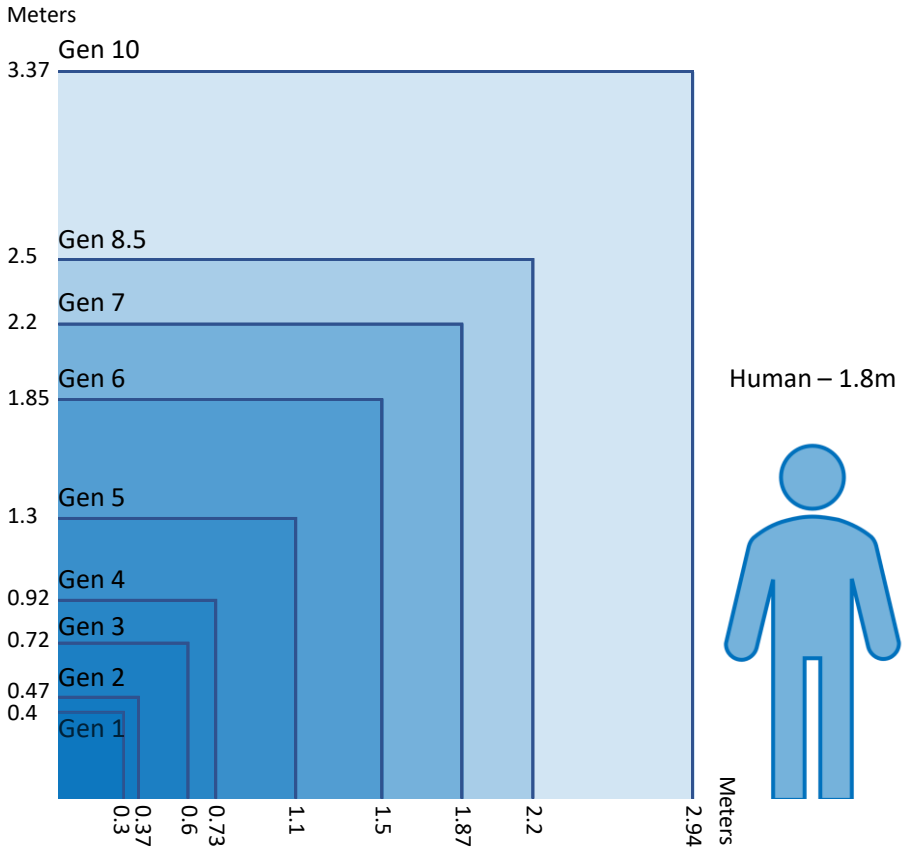


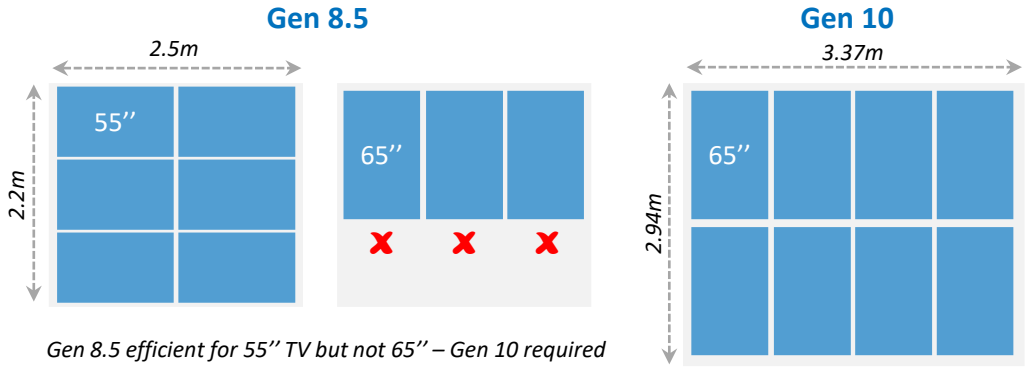
Module Assembly



Fabrication Plants: The Cost Behind Displays

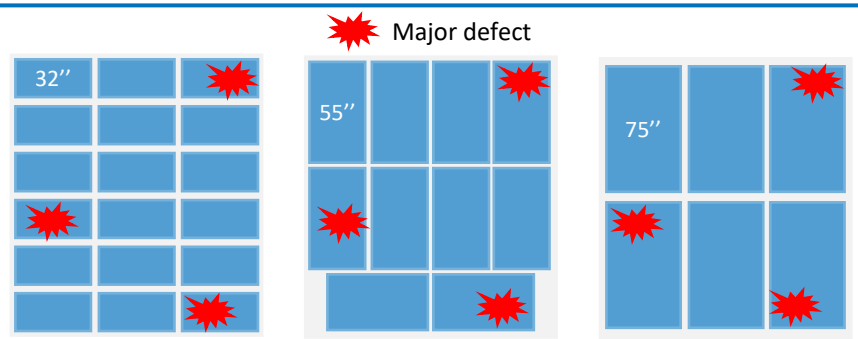
- Display fabrication plants are defined by the substrate glass size *(see diagram below)*
- Costs increase dramatically for building higher gen fabs
- Similarly to Gen 8.5, other generation fabrication plants are available in .5 versions; these offer slight differences in substrate size
- The size variation between fabs allows "cut" optimisation for different screen sizes *(see diagram on the right)*





Gen 8.5 efficient for 55'' TV but not 65'' – Gen 10 required

Why do large screen TVs cost so much?



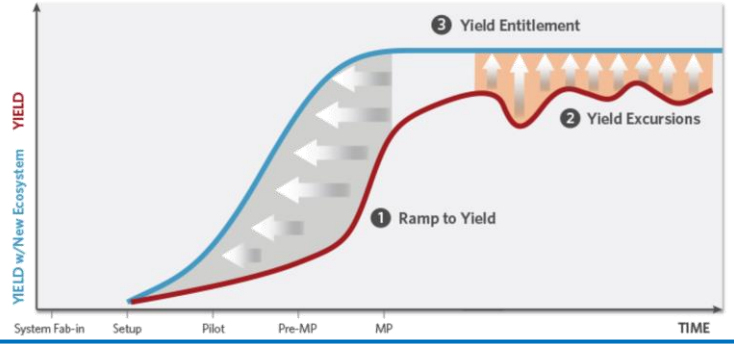
3/18 wasted
83% yield

3/10 wasted
70% yield

3/6 wasted
50% yield

- Higher (and therefore more expensive) gen fabs process larger display sizes, however, the number of major defects per unit area remains the same as of that for lower gen fabs
- **As display sizes increase, yield per substrate glass used drops significantly**
- **Manufacturers increase price points accordingly to compensate for this yield drop** (and higher fab plant costs) – consumers see this in the massive increase in price for large TVs

- Another problem for fabs is the yield issue they experience
- Yield excursions are common in the lifecycle of display fabrication plants (see chart on the right)
- Manufacturers push for better equipment to counter this
- Applied Materials, for instance, has improved its flat panel display manufacturing equipment offering to cater for highly advanced Gen 10+ fabs, aiming to help manufacturers reach the "Yield Entitlement" line
- Attaining maximum yield is the objective for higher gen fabs which already bear high operational costs



Display Start-up Investment

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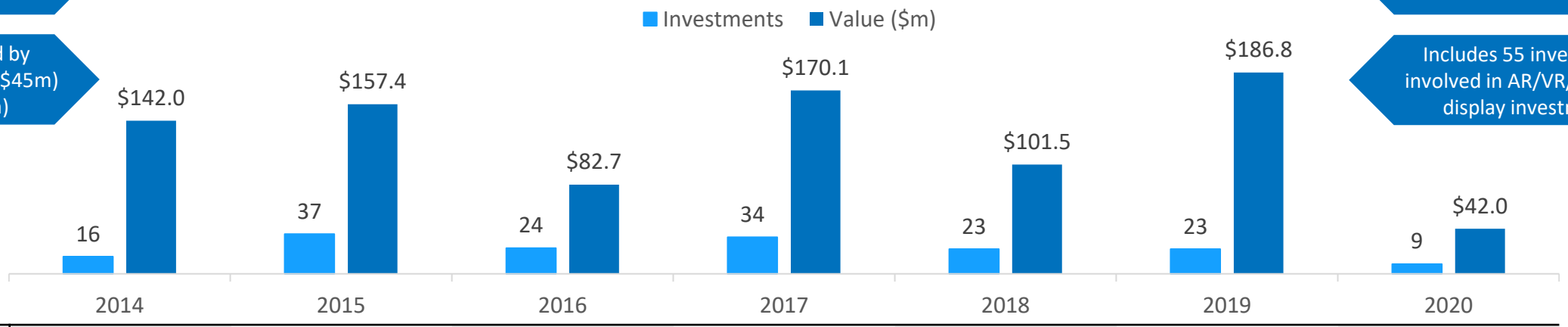
5 LED-specific investments

2019 deals dominated by Playnitride ($52m), Leia ($45m) and MIRROR ($34m)

42 transactions of undisclosed value

Includes 55 investments involved in AR/VR/wearable display investments

Display-Focused Investments, 2014-2020 YTD ($m)[1]



Sample Investors

2014	2015	2016	2017	2018	2019	2020
SAMSUNG, VENVEST CAPITAL, wellingtonpartners	ATI, BASF The Chemical Company, LUX+	DeepWork CAPITAL, GRAYCLIFF PARTNERS, wellingtonpartners	APPLIED MATERIALS, Google, Phoenix Venture Partners	intel Capital, 北极光创投 northern light VENTURE CAPITAL, Qualcomm ventures	investiere venture capital, Lenovo, SAMSUNG	APEX VENTURES, DAKTRONICS, i5 invest

Although many relevant transactions are of undisclosed value officially, micro-LED-specific start-ups are said to have raised **>$800m**, with at least **$100m raised in 2019** alone[1]. Apple has reportedly spent **$1.5-2bn on micro-LED technology**

Sources: [1] Crunchbase

Sample M&A in the Display Industry

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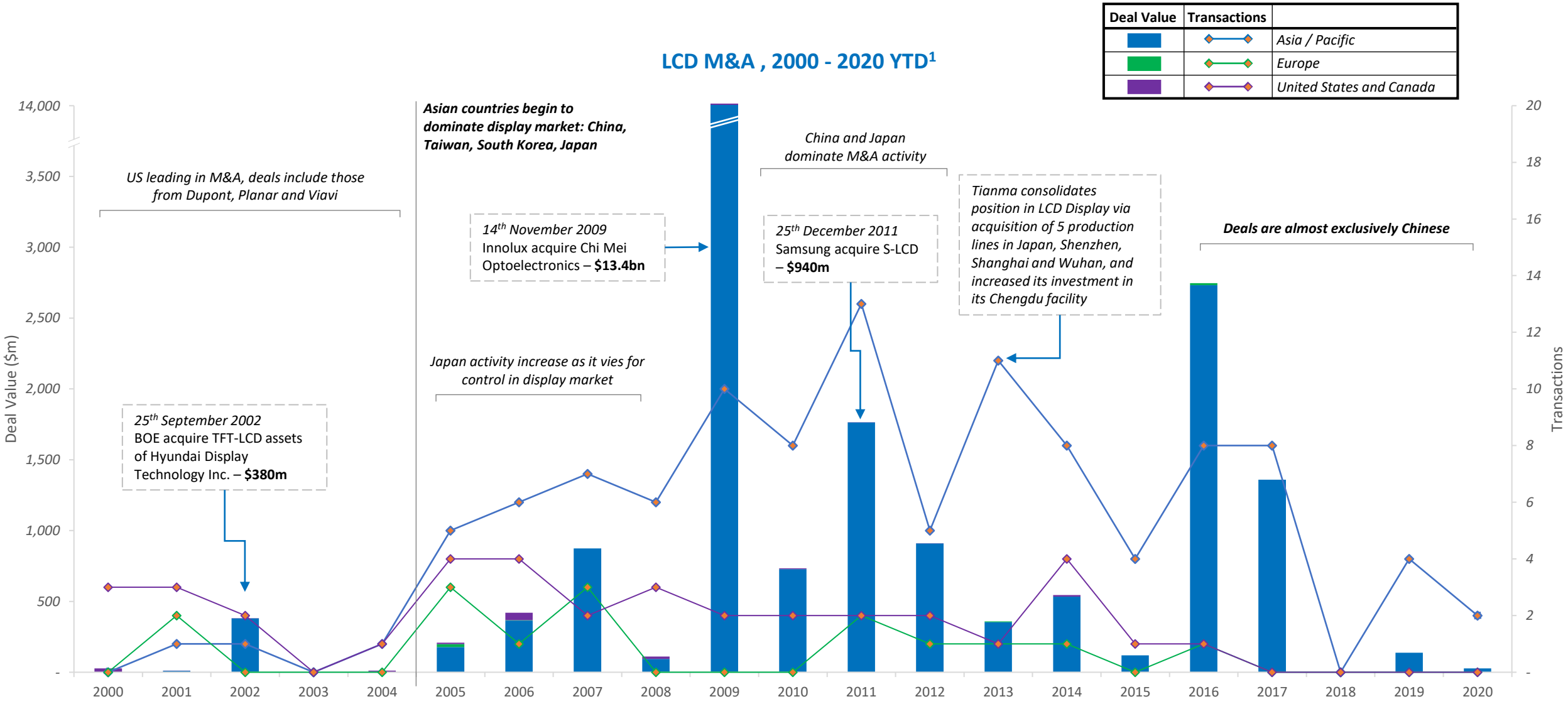
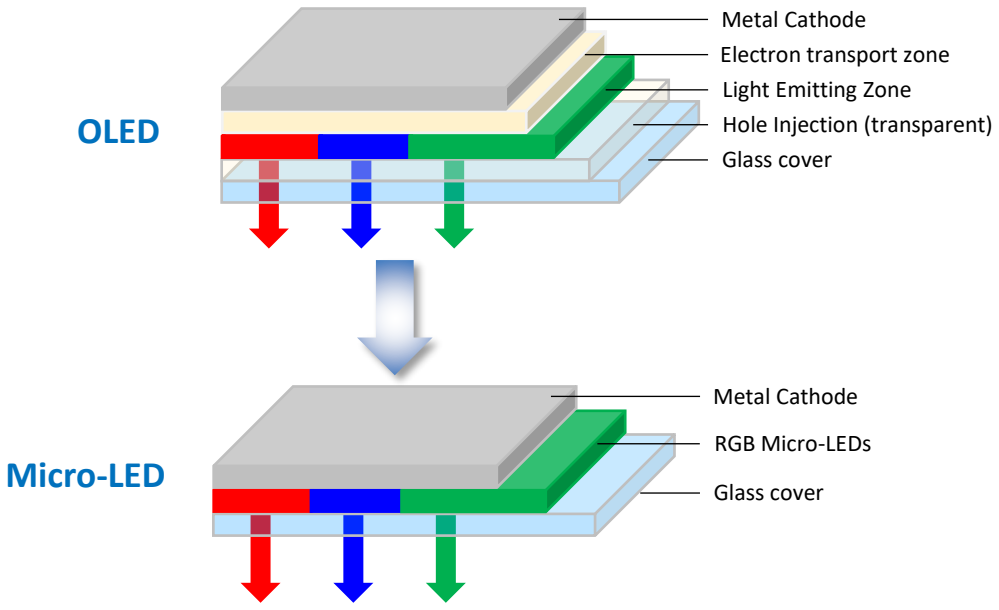


Sources: [1] S&P Capital IQ

The Future of Displays

- Despite the popularity of various legacy display types, the most promising types moving forward are mini- and micro-LED displays
- The potential of micro-LED displays are explained below and in the following slides
- Mini-LED is likely to become significantly more popular as Apple is preparing to release the new iPad and MacBook later this year or beginning of 2021



Benefits of Micro-LED over OLED

- Lower power
- Higher brightness
- Colour saturation
- Chemical stability
- Simpler design

While it will take many years to displace the existing technologies, micro-LED is expected to dominate in many areas, starting with displays greater than 75” but eventually migrating to many other areas of the Display industry.

With the large flows of capital into micro-LED technology and its clear advantages over OLED, the Display market is clearly primed for disruption. OLED will likely remain strong in areas where it has gained a significant market share e.g. premium smartphones. Conversely, in nascent markets such as AR, micro-LED will be the optimum choice.
A critical driver for this change is the problem of image burn-in associated with OLED displays, which has heavily impacted the large display arena. This has been evident in recent electronics conferences where micro-LED TVs (and other displays) have grown significantly in number.

RCL's View on the Future of Displays

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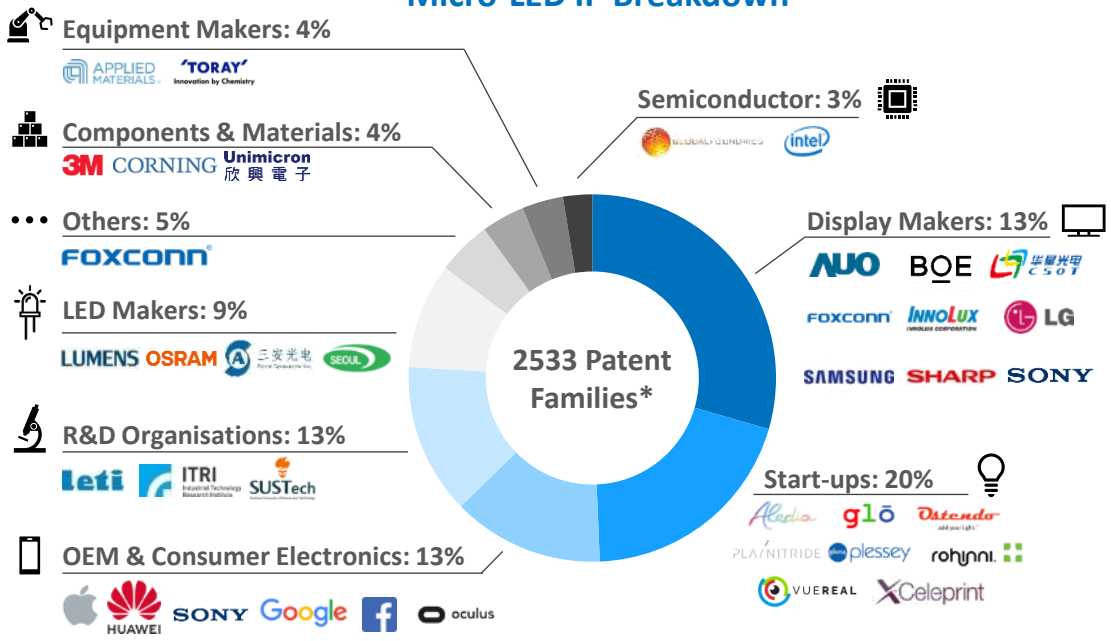
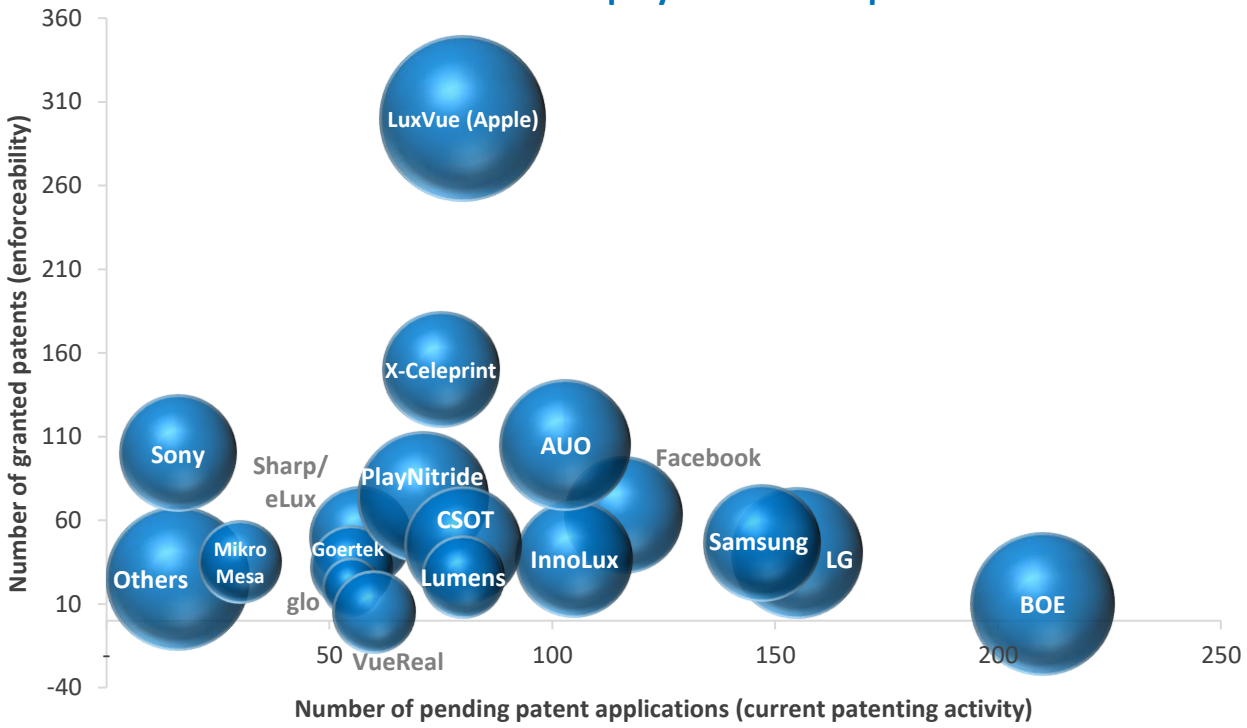
Micro-LED IP Breakdown[1]



* Total number of patent families is 2453 but some patents are co-assigned to more than one organisation

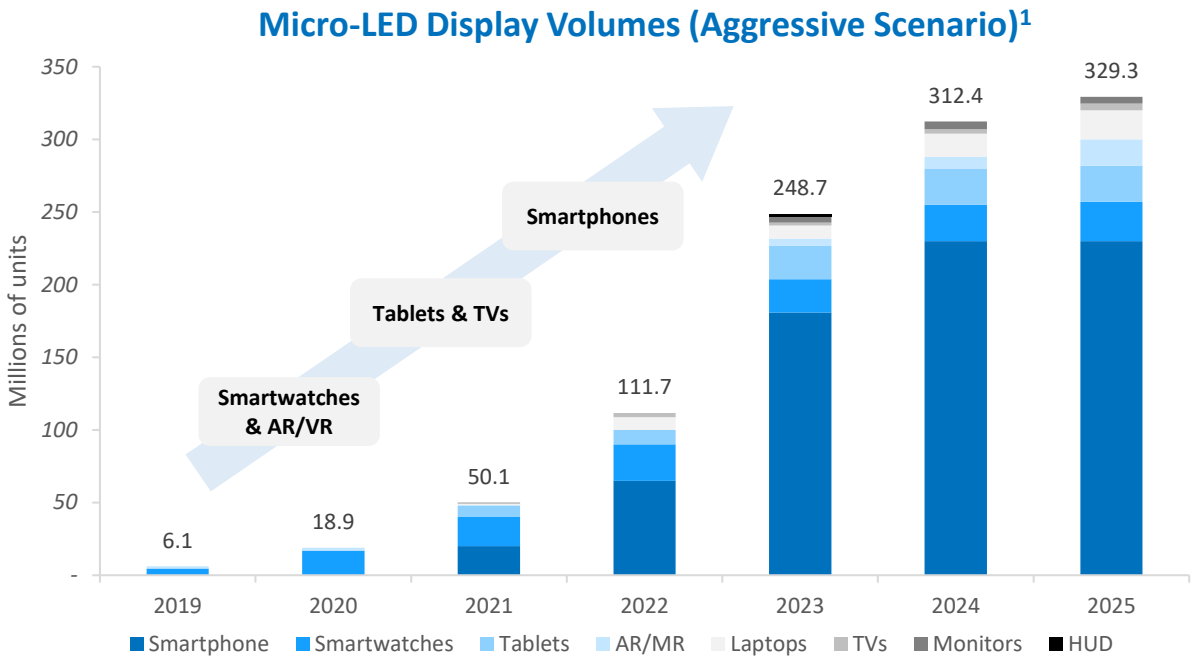
Micro-LED Display IP Leadership[1]

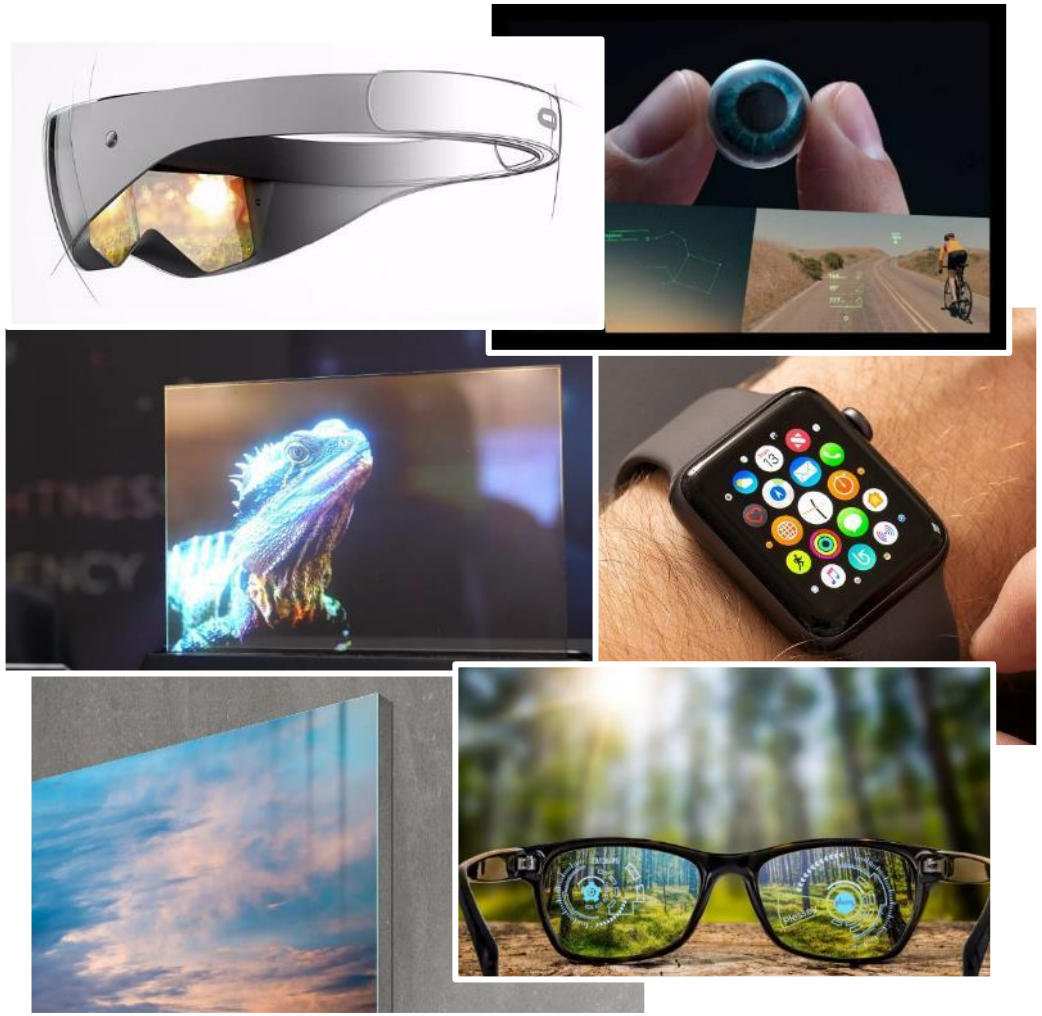


- Micro-LED spending ~$4.8bn[2]
- Apple itself contributing $1.8bn[2] through LuxVue acquisition and R&D expenditure – highlighted through their May and October 2019 patent filings
- Large consumer electronics companies keen to commercialise micro-LED displays
- The competition drive has gone beyond technological benefits of the technology; it now is a play to maintain a competitive edge

Sources: [1] Yole, [2] Compound Semiconductor

RCL's View on the Future of Displays





- Micro-displays are thought to initially impact the micro-device market, then progress to the tablets and TVs (Samsung already catalysed the process with "The Wall"), and finally enter the high-end smartphone market where OLED dominates
- Samsung's breakthrough with "The Wall" defined the start of a new epoch in the evolution of display technology, as consumer electronics manufacturers begin to adopt micro-LED for a broader range of display types

Sources: [1] Yole

Notable Companies

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Category	Company	Country	Founded	Description
R&D	ITRI	Taiwan	1973	ITRI develops products aimed at Smart Living, Quality Health and Sustainable Environment - including collaborating with companies to produce micro-LED displays
Materials and Process	SmartKem	United Kingdom	2008	SmartKem Limited develops organic thin film transistor for mini-LED displays
Process Equipment	Aixtron	Germany	1983	AIXTRON provides deposition equipment to the semiconductor industry
	Applied Materials	United States	1967	Applied Materials provides manufacturing equipment, services, and software to the semiconductor, display, and related industries
	Mycronic	Sweden	1970	Mycronic develops equipment for the electronics industry
	PlayNitride	Taiwan	2014	PlayNitride develops micro-LED technology
	Veeco	United States	1945	Veeco Instruments develops semiconductor and thin film process equipment primarily to make electronic devices
	VueReal	Canada	2016	VueReal develops mass transfer technologies for micro-LED displays
LED	Epistar	Taiwan	1996	EPISTAR Corporation engages in the development of LED epiwafers and chips
	Sanan	China	2000	Sanan Optoelectronics develops LED epitaxial wafers and chips, compound solar cells, compound semiconductors, semiconductor and communication chips, and sapphire substrates
Display Technology Solutions	Corning	United States	1851	Corning engages in display technologies, optical communications, environmental technologies, specialty materials, and life sciences businesses
	ELK	South Korea	1999	ELK offers advanced backlight, touch panel and other display technologies
	Flexium Interconnect	Taiwan	1997	Flexium Interconnect develops flexible printed circuit (FPC) boards

Notable Companies (cont'd)

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Category	Company	Country	Founded	Description
Display Technology Solutions	Hon Hai Precision Industry	Taiwan	1974	Hon Hai Precision Industry (Foxconn) provides various technology solutions and technology contract manufacturing
	Mflex	United States	1984	Multi-Fineline Electronix engages in the development of flexible printed circuit boards and related component assemblies for the electronics industry
	Nichia	Japan	1956	Nichia's products include light emitting diodes (LEDs); laser diodes; optical semiconductor devices; phosphors; fine chemicals, such as electronic and pharmaceutical materials
	Unimicron	Taiwan	1990	Unimicron Technology Corporation develops printed circuit boards, HDIs, FPCs, RFs, and IC carriers
	Unity Opto	Taiwan	1993	Unity Opto Technology operates in the LED and lighting industry
	Universal Display Corporation	United States	1985	Universal Display Corporation engages in the commercialisation of OLED technologies and materials for use in display and solid-state lighting applications
Display Manufacturer	Apple	United States	1977	Apple manufactures and markets smartphones, personal computers, tablets, wearables, and accessories
	AUO	Taiwan	1996	AU Optronics develops thin film transistor liquid crystal displays and other flat panel displays
	BOE Technology	China	1993	BOE operates in three core businesses are Interface Devices, Smart IoT Systems and Smart Medicine & Engineering Integration
	Eink	Taiwan	1992	E Ink develops electronic paper display panels
	Innolux	Taiwan	2003	Innolux develops TFT-LCD panels, modules, and monitors of liquid crystal displays (LCD), color filters, and low temperature poly-silicon TFT-LCDs
	Konka	China	1980	Konka is engaged in electronics manufacturing focusing on TV, refrigerators, washing machines, audio, other digital products, and home applicances
	LG Electronics Inc.	South Korea	1958	LG Electronics manufactures and sells home appliances and air solutions

Notable Companies (cont'd)

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Category	Company	Country	Founded	Description
Display Manufacturer	Samsung	South Korea	1938	Samsung Electronics Co., Ltd. engages in the consumer electronics, information technology and mobile communications, and device solutions
	TCL Technology Group Corporation	China	1981	TCL develops various electronics and electrical equipment, focusing on mobile, TV and audio divisions
	Tianma	China	1983	Tianma Microelectronics manufactures LCD and LCM products
	Visionox	China	1996	Visionox Technology develops OLED display products
Driver Electronics	Macroblock	Taiwan	1999	Macroblock supplies LED drivers for display, backlighting, and lighting applications
	Micrel	United States	1978	Micrel develops analog, mixed-signal, and digital semiconductor devices
	Novatek Microelectronics	Taiwan	1997	Novatek Microelectronics develops integrated circuit chips for speech, communication, computer peripheral, LCD driver IC system, embedded MCU, DSP, and system applications
	Texas Instruments	United States	1930	Texas Instruments develops semiconductor and computer technology for cellular handsets, digital signal processors and analog semiconductors

Notable Companies (cont'd)

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Category	Company	Country	Founded	Description
	Aledia	France	2011	Aledia develops and manufactures an LED display technology based on a unique 3D architecture using gallium-nitride (GaN)-on-silicon nanowires (WireLED™)
	MicroOLED	France	2007	MicroOLED designs and develops high-performance OLED micro-displays for near-to-eye applications
	OLiGHTEK	China	2008	OLiGHTEK develops high definition AMOLED (Active Matrix-Organic Light Emitting Diode) technology and micro-displays
Near Eye Displays	Plessey	United Kingdom	2000	Plessey Semiconductors develops optoelectronic technology solutions
	Seeya	China	2016	Develops OLED micro-displays
	Tooz	Germany	2018	Tooz Technologies develops smart glasses which enable its customers to read situation specific information
	WaveOptics	United Kingdom	2012	WaveOptics manufactures augmented reality display technology

RCL Background

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Renevo Capital Limited (RCL) is focused on delivering corporate finance advisory services to the "digital stack“: all the way from fundamental Materials, Processing, Electronics, Photonics and Semiconductor Industries, to Communications, Software, and Internet Services. Our technical strengths and expertise generate the most value to companies with high growth potential in technologically advanced industries, who are looking to capitalise on their potential.

Renevo has core teams based in the thee three key technology markets, Europe, North America, and Asia. Our international focus and local connections are effectively employed throughout all of our activities.

Mike Powell is the Managing Director and Partner of RCL. Mike focuses on the TMT and Advanced Materials sectors. He has 15 years experience advising companies internationally on M&A, financing, and corporate strategy. He is extremely well-connected across Europe, North America and Asia. Mike's speciality is photonics and efficiency technologies, bringing 30 years of senior level experience in leading, advising, managing and negotiating corporate projects and transactions for both private and public companies.

Mike began his professional career as a defence contractor with GEC Marconi. He then entered a period of serial entrepreneurship by founding, funding, growing and ultimately selling three businesses: IOC International PLC, K2 Optronics Inc and Pelikon Ltd.

He managed IOC as CEO from start-up to its subsequent float on the London AIM stock exchange in 1997 until 2000. He subsequently sold it to NASDAQ quoted SDLI before moving to the Bay Area to found K2 Optronics, which he later sold to Emcore. In 2002, Mike returned to the UK and joined the founding team of Pelikon as CEO. In 2008 he sold Pelikon to NASDAQ listed MFLEX.

Mike has a degree in Physics from Imperial College and is a keen athlete, competing regularly in triathlons. He is also a level 2 qualified Triathlon coach.

Disclaimer

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