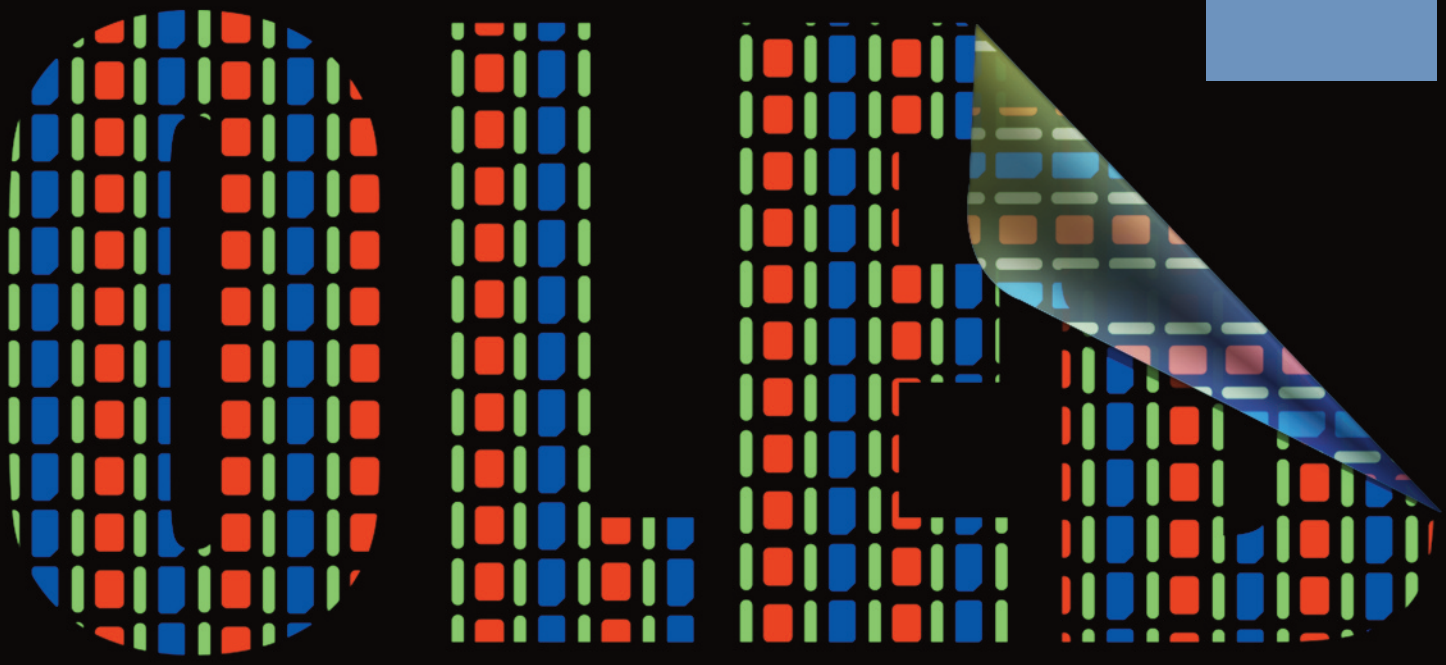
Goldman Sachs



Unfolding OLED

Pathways to a US$46bn market

Imagine a tablet that can be folded to the size of your phone. That technology is here. Organic light emitting diodes don't need a backlight, so can be manufactured into thinner, more flexible displays than LCDs. The demand from foldable devices, as well as the demand from Apple and Samsung for the displays on their next generation phones, will make OLED one of the fastest growing markets in the global tech hardware sector. By 2020, we expect sales to triple to US$46bn (32% CAGR) vs. US$15bn in 2016. We believe Samsung's market-leading position in mobile OLED is sustainable and the threat from Chinese OLED makers is at least 3-4 years away.

Giuni Lee
+82(2)3788-1177
giuni.lee@gs.com
Goldman Sachs (Asia) L.L.C., Seoul Branch

Daiki Takayama
+81(3)6437-9870
daiki.takayama@gs.com
Goldman Sachs Japan Co., Ltd.

Simona Jankowski, CFA
(415) 249-7437
simona.jankowski@gs.com
Goldman Sachs & Co. LLC

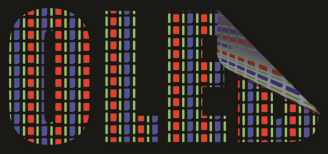
Brian Lee, CFA
(917) 343-3110
brian.k.lee@gs.com
Goldman Sachs & Co. LLC

Toshiya Hari
(646) 446-1759
toshiya.hari@gs.com
Goldman Sachs & Co. LLC

Satoru Ogawa
+81(3)6437-4061
satoru.ogawa@gs.com
Goldman Sachs Japan Co., Ltd.

Table of contents

Prices in this report are as of the July 11, 2017 close unless otherwise specified.



Unfolding OLED

The OLED market is on the cusp of inflection and we see a wide range of implications from this opportunity. See below for related reports:

Samsung Electronics (005930.KS): Less cyclical, more shareholder friendly; resume with Buy (add to CL)

South Korea: Technology: Hardware: Resuming 7 stocks; Buy Samsung Electronics (CL)/SK Hynix/SEMCO

Global: Technology: Semiconductors – Memory: DRAM & NAND update: introducing 2018 supply/demand estimates

Global Technology Hardware (Contributing analysts)

Asia

Giuni Lee
+82(2)3788-1177
giuni.lee@gs.com

Wei Chen
+886(2)2730-4185
wei.chen@gs.com

Masaru Sugiyama
+81(3)6437-4691
masaru.sugiyama@gs.com

Hideaki Mitani
+81(3)6437-9836
hideaki.mitani@gs.com

Daiki Takayama
+81(3)6437-9870
daiki.takayama@gs.com

Satoru Ogawa
+81(3)6437-4061
satoru.ogawa@gs.com

Donald Lu, Ph.D
+86(10)6627-3123
donald.lu@ghsl.cn

Nozomi Handa
+81(3)6437-9886
nozomi.handa@gs.com

US

Simona Jankowski, CFA
+1 (415) 249-7437
simona.jankowski@gs.com

Mark Delaney, CFA
+1 (212) 357-0535
mark.delaney@gs.com

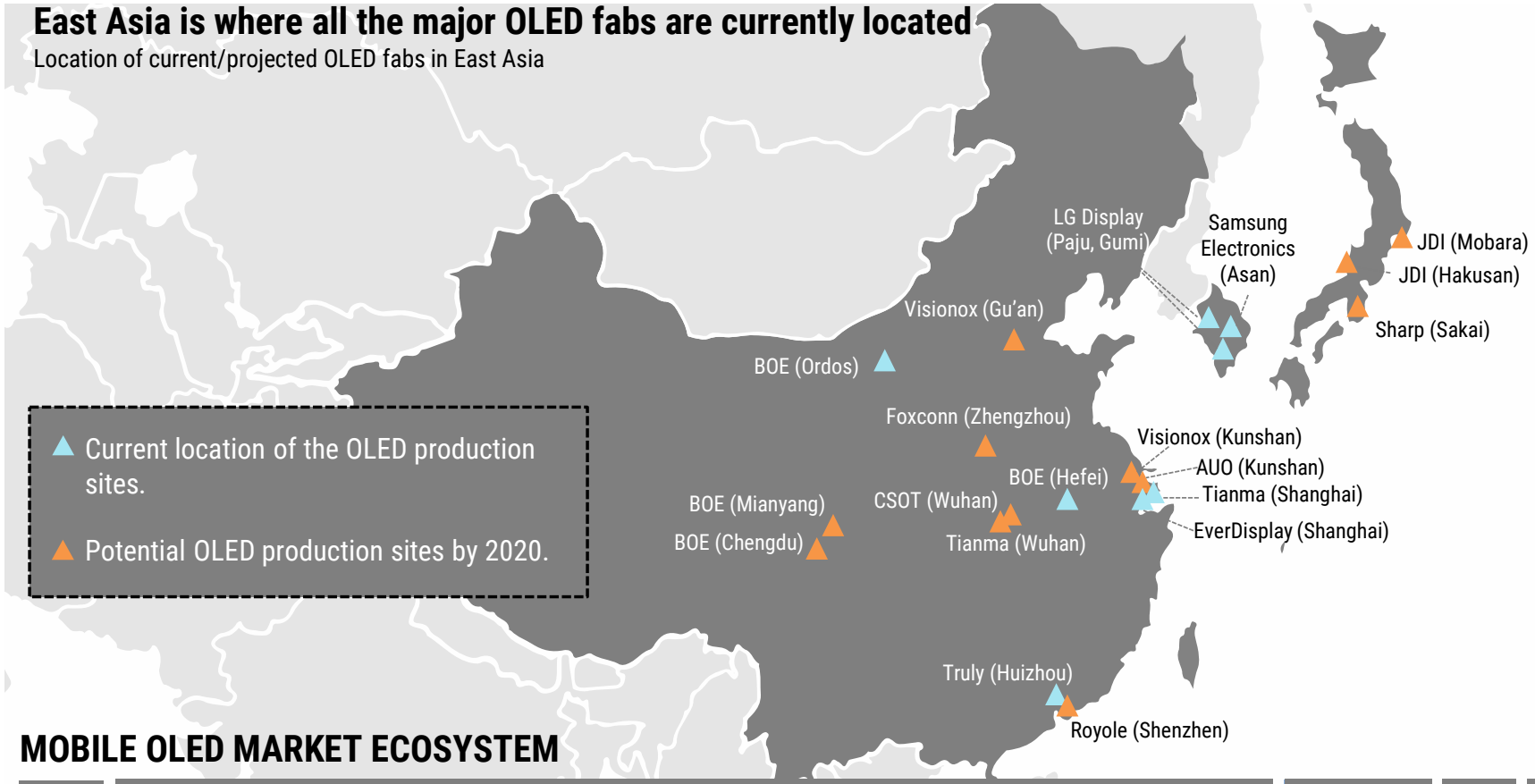
Brian Lee, CFA
+1 (917) 343-3110
brian.k.lee@gs.com

Toshiya Hari
+1 (646) 446-1759
toshiya.hari@gs.com

Doug Clark, CFA
+1 (415) 249-7453
doug.clark@gs.com

East Asia is where all the major OLED fabs are currently located

Location of current/projected OLED fabs in East Asia



MOBILE OLED MARKET ECOSYSTEM

	Korea		China	JP	TW
SUPPLY	Samsung Electronics (70% area shipment share in 2020E)	LG Display (10%)	BOE (4%) Tianma (3%) Visionox (2%) EverDisplay (2%) CSOT (1%) Truly (1%)	JDI (2%) Sharp (2%)	Foxconn (2%) AUO (1%)

DEMAND	SMARTPHONES		
	Samsung (34% of TAM in 2020E)	Apple 39%	China smartphones 22% (Oppo, Vivo, Gionee, etc.)
	TABLET PC		
	NOTEBOOK/PC AND MONITOR		
	VR/AR		

Source: Company data, Goldman Sachs Global Investment Research.

Portfolio Manager's Summary: Smart screens for smart devices

OLED: Our 5 key conclusions on the display of the future

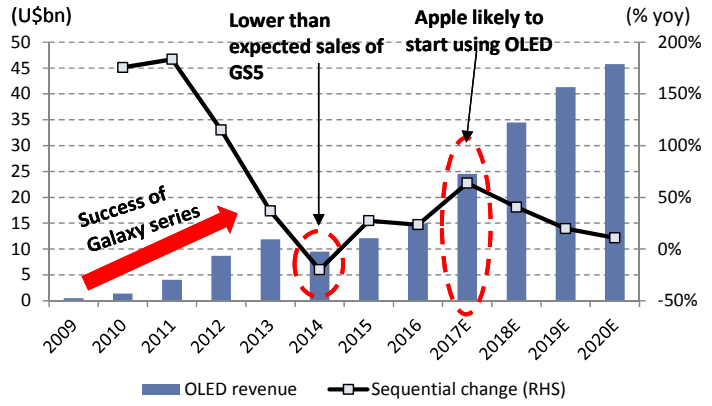
With applications extending from smartphones and TVs to automotive dashboards and tail lights, Organic Light Emitting Diodes (OLEDs) are solid-state emissive displays that generate their own light rather than depending on an external source (i.e., a backlight)[1]. Through the deep dive analysis presented in this report, we derive 5 key conclusions on how the market for this technology is set to evolve:

- **Global OLED supply/demand will be tight at least until 2019;**
- **The OLED market will triple into a US$46bn market by 2020.** Expanding at a 32% CAGR, OLEDs will be **one of the fastest growing and largest markets** in the global technology hardware sector;
- **Apple/China smartphones will drive market growth**, with OLEDs replacing existing Liquid Crystal Display (LCD) panels over the next couple of years. **Foldable OLED displays also have the potential to create significant growth opportunities and new applications from around 2020;**
- It will take **at least 3-4 years before Chinese OLED makers have a chance of increasing their industry presence.** Current OLED leader Samsung should therefore sustain its market-leading position over this period.
- **Global OLED capex will remain at a high level** through 2020.

Why now? OLED iPhone to lead the market take-off in 2017

While the OLED market has grown in tandem with expansion of Samsung Electronics' (SEC) smartphones over the past 7-8 years, we believe Apple will also start to use OLED screens in one of its iPhone models this year. Due to the high OLED ASP for the OLED iPhone (we expect the iPhone to use high-end OLEDs) we anticipate a significant expansion in the smartphone OLED total addressable market (TAM). On the back of this adoption, we estimate that the OLED panel market this year will grow by 64% yoy to reach ~US$25bn.

Exhibit 1: OLED iPhone to lead the market take-off in 2017
Global OLED industry revenue forecast



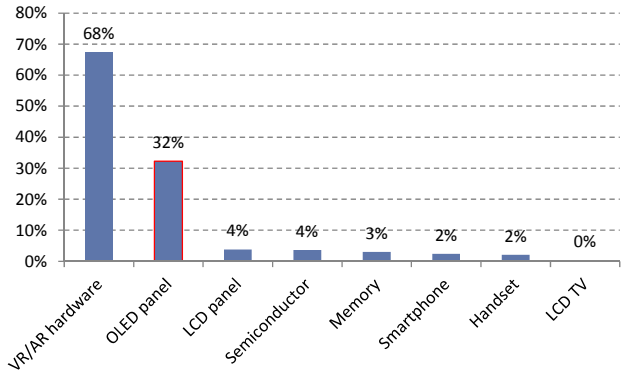
Source: Company data, Goldman Sachs Global Investment Research.

[1] Throughout this report, when mentioning OLED we refer to the mainstream active matrix (AM) OLED, which comprises almost the entire OLED market at present. See Appendix for a primer on OLED technology.

Why does OLED matter?: One of the fastest-growing and largest markets in global tech hardware

Given the muted growth expected in the traditional tech hardware space, OLED is one of the only tech sub-sectors in which we expect fast growth over the next several years. **We expect the US$$15bn market in 2016 to triple in size to US$46bn by 2020 (32% CAGR).** To put things in context, we forecast that by 2020 the OLED panel market will be larger than the combined VR/AR hardware and software markets in 2020 (GSe: US$38bn) and the DRAM market in 2016 (US$41bn).

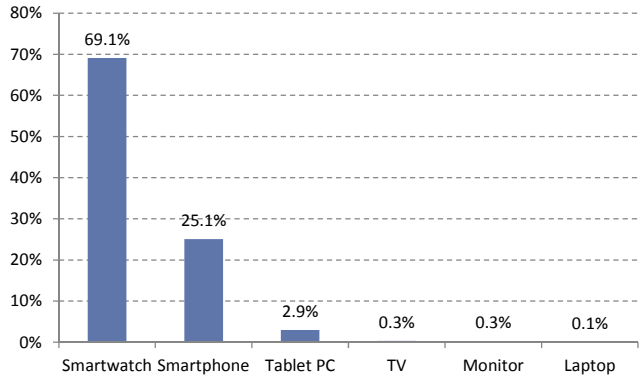
Exhibit 2: OLED – one of the fastest growing tech hardware subsectors
Major tech hardware sub-sector revenue CAGR (2016-2020E)



Note: Smartphone and handset based on 2016-2019E CAGR

Source: IHS, Gartner, Goldman Sachs Global Investment Research.

Exhibit 3: OLED has room to grow in many applications
OLED penetration in major applications (2016)

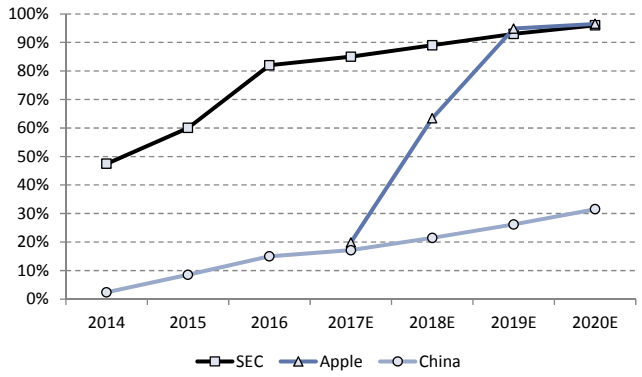


Source: IHS, Goldman Sachs Global Investment Research.

The growth path: Apple/China smartphones, then foldable displays

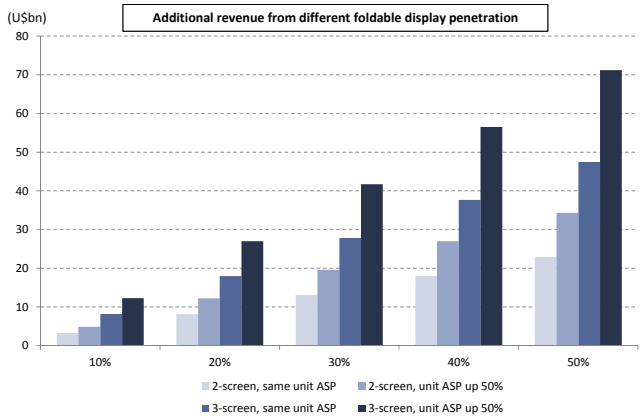
The main catalyst driving this growth during our forecast period is **higher smartphone OLED penetration** mainly driven by **Apple** and **Chinese smartphone makers.** Beyond 2020, an additional catalyst could be the **emergence of foldable displays**. Samsung targets commercialization of foldable displays in 2018 and mass production by 2019. We expect foldable displays will be a game changer in terms of smartphone and tablet/PC convergence and will enhance new applications including virtual/augmented reality (VR/AR). At this time, we emphasize that **foldable devices are no longer a far-off concept, but rather a product nearing realization for which the stock market should start considering the future impacts.**

Exhibit 4: We expect SEC, Apple, and Chinese smartphone makers to drive higher OLED penetration
OLED penetration by smartphone maker



Source: Company data, Goldman Sachs Global Investment Research.

Exhibit 5: We estimate that doubling/tripling of the smartphone screen size could lead to major market expansion
Market size simulation for the shift to 2-screens/3-screens with different ASP assumptions



Source: Goldman Sachs Global Investment Research.

Exhibit 6: Foldable OLED could enhance smartphone and Tablet/PC convergence and create new applications
Concept of foldable OLED

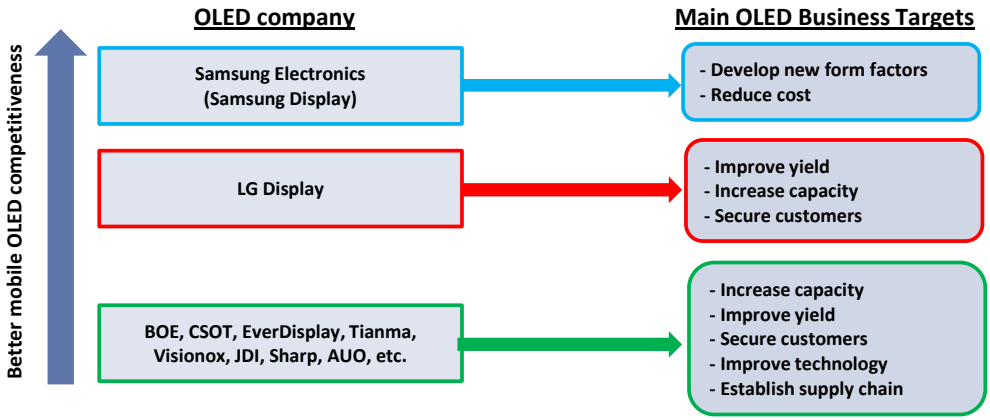
Note: This is for illustration purposes only.

Source: Goldman Sachs Global Investment Research.

How long can the OLED market leader's success continue?

We also highlight the competitive landscape in the mobile OLED space and examine whether OLED market leader Samsung Electronics (SEC; affiliate Samsung Display operates the OLED business, but earnings are consolidated into SEC, hence we refer to SEC throughout this report) will be able to maintain its lead in the industry amid the aggressive capacity expansions announced by Chinese display makers. **Our conclusion is that SEC's success in the mobile OLED industry will be sustainable** as smartphone makers will likely continue to source OLED panels from the company, any potential market disruption from the Chinese OLED makers is still at least 3-4 years away, and SEC already has a firm technology, cost, and supply chain advantage.

Exhibit 7: We believe SEC is best positioned in mobile OLED, followed by LGD
Mobile OLED competitiveness



Source: Goldman Sachs Global Investment Research.

How do we differ from the street?

Although we see no clear market consensus on the OLED industry outlook, we believe we are more bullish than the street on the whole, as we (1) reflect extra demand from foldable displays in our industry model, and (2) assume that OLED will be used in all new iPhone models released in 2018. We also believe tight supply/demand conditions will be sustained as we are confident that current market leader SEC will maintain its competitive advantage, while less confident on the execution ability of new OLED market entrants (mainly Chinese makers).

Key stock implications in the global technology sector

We consider OLED a disruptive technology that will reshape the supply chain in the global display industry. **Our bullish view on the OLED market** highlights (1) **Samsung Electronics (SEC)** as the sustainable leader, and (2) OLED-related material and equipment players as potential beneficiaries, including **Universal Display, Ulvac, Nikon, Canon Tokki, Tokyo Electron, Applied Materials, SEMCO, Samsung SDI, Nitto Denko, and touch sensor makers**. We also think **LG Electronics** would benefit if OLED TV demand takes off.

We see a more challenging path in the display industry for (1) LCD suppliers such as **Japan Display**, (2) LCD materials and components such as **Flexible Printed Circuit (FPC) boards**, mainly supplied by Japanese makers. For **LG Display**, we expect a mixed impact from both OLEDs and LCDs, but the initial cost burden for OLED as well as the LCD risk make us stay away from the stock.

We also believe OLEDs will accelerate further consolidation of smartphone makers dependent on the degree to which they can secure new technologies. **Apple, SEC and a few China brands** will further increase their product differentiation, in our view.

Exhibit 8: Several companies under our coverage have OLED exposure
Major OLED-related companies and products

Company name	Ticker	Rating	OLED-related product
Samsung Electronics	005930.KS	Buy*	OLED display
Ulvac	6728.T	Buy*	OLED evaporation equipment
Nikon	7731.T	Buy*	Lithography equipment
SEMCO	009150.KS	Buy	OLED RF-PCB
Apple	AAPL	Buy	OLED smartphone
Universal Display	OLED	Buy	OLED materials
Tokyo Electron	8035.T	Buy	Etchers, coaters
Samsung SDI	006400.KS	Neutral	OLED materials
LG Electronics	066570.KS	Neutral	OLED TVs
Applied Materials	AMAT	Neutral	CVD for encapsulation, evaporation tool
Corning	GLW	Neutral	Glass for OLED display
Hon Hai Precision	2317.TW	Neutral	OLED display
Canon	7751.T	Neutral	OLED evaporation equipment
Nitto Denko	6988.T	Neutral	OLED polarizer, ITO
Japan Display	6740.T	Neutral	OLED display
LG Display	034220.KS	Sell	OLED display
Nissha Printing	7915.T	Not Covered	Film touch sensor

Note: * denotes stock is on our regional Conviction List.

Source: Company data, Goldman Sachs Global Investment Research.

Unfolding OLED in numbers

GROWING AT A CRUISING SPEED

32%

The expected CAGR (2016-20) that makes OLED one of the **fastest growing** & **largest** markets in the global technology hardware sector. (p. 4, 5 & 18)

US$46bn

Estimated industry revenues by 2020 – **triple** the US$15bn in 2016. (p. 4, 5 & 18)

US$20bn

Expected global OLED capex to be reached in 2017, increasing close to 70% yoy. (p. 46)

TRENDING DEMAND

90% of global OLED revenue this year to be comprised of mobile OLED with **smartphones** the main driver. (p. 10 & 64)

APPLE: THE TAKE-OFF DRIVER

64% yoy growth expected for the OLED panel market this year driven by adoption of iPhone OLED screens. (p. 4)

DISRUPTING SUPPLY LEADERSHIP

2017 Samsung Electronics (SEC) likely the only supplier of OLED screens for iPhone this year, and will continue to be the major supplier for the next couple years. (p. 14)

3 - 4 years

Time needed for Chinese OLED makers to have a chance of increasing their industry presence, ensuring sustainable near-term success for SEC. (p. 4, 6, 41 & 43)

FOLDABLE DISPLAYS: THE NEXT KEY DRIVER

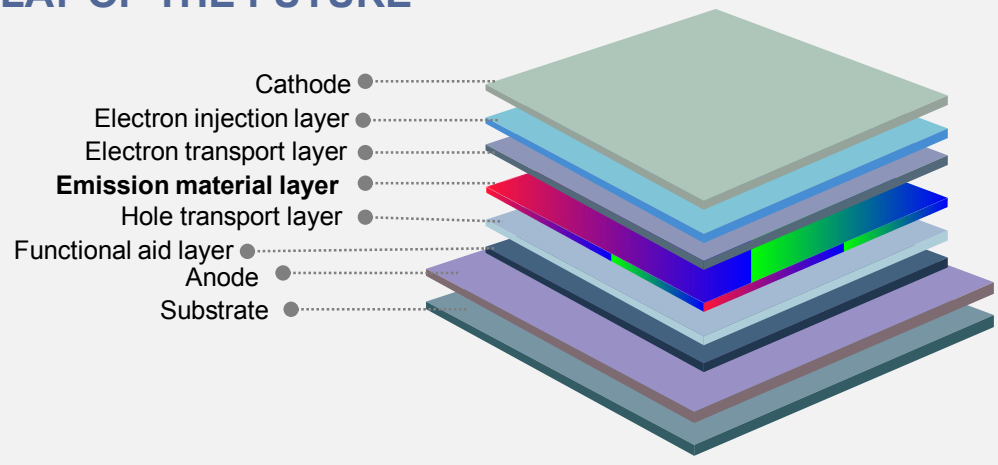
~13% of total smartphone OLED area demand in 2020 projected to come from **foldable displays**. (p. 28)

2x - 3x

Additional potential revenue size if foldable OLED leads to smartphone and tablet PC convergence post 2020. (p. 28 & 29)

OLED 101 - DISPLAY OF THE FUTURE

OLED can be used for many different applications. As OLED does not have a backlight, a flexible form or a transparent form is easier to achieve, which will reshape existing smartphones / enhance tablet/PC convergence.



OLED supply/demand tight globally at least until 2019

While we acknowledge the difficulty of forecasting the exact supply and demand for OLED displays, we have constructed a detailed supply/demand OLED model that reflects the guidance of the OLED supply chain companies with which we have held discussions, capacity announcements by the major OLED companies, as well as our view following the company visits and interviews we have conducted in the past several months. In this report, our analysis focuses more on mobile OLED (every OLED product except TVs) as we estimate that mobile applications will still comprise over 90% of global OLED revenue this year. We plan to undertake a detailed analysis of OLED TVs once the market size becomes more meaningful.

Conclusion: Global OLED supply/demand tight at least until 2019

Our bottom-up supply/demand model indicates that the global OLED market will be tight at least until 2019. Even in 2020, the oversupply ratio that we estimate is much lower than in 2014 when the industry saw considerable oversupply mainly due to lower-than-expected sales of SEC's Galaxy S5.

Exhibit 9: We expect global OLED supply/demand to be tight at least until 2019
Global OLED supply and demand model

	2009	2010	2011	2012	2013	2014	2015	2016	2017E	2018E	2019E	2020E
Total supply ('000 sqm)	**59**	**133**	**494**	**1,096**	**1,445**	**1,820**	**2,774**	**3,948**	**5,612**	**8,385**	**12,066**	**15,576**
Sequential change (%)		*127%*	*272%*	*122%*	*32%*	*26%*	*52%*	*42%*	*42%*	*49%*	*44%*	*29%*
Total demand ('000 sqm)	**55**	**142**	**470**	**1,034**	**1,382**	**1,641**	**2,607**	**3,996**	**5,609**	**8,331**	**11,564**	**14,635**
Sequential change (%)		*159%*	*230%*	*120%*	*34%*	*19%*	*59%*	*53%*	*40%*	*49%*	*39%*	*27%*
Over(under) supply ratio	**6%**	**-7%**	**5%**	**6%**	**5%**	**11%**	**6%**	**-1%**	**0%**	**1%**	**4%**	**6%**

Source: Company data, Goldman Sachs Global Investment Research.

Based solely on mobile OLED supply/demand, for which we include 1) non-Gen8 OLED capacity by suppliers in the supply numbers and 2) non-TV applications in the demand numbers, we still draw a similar conclusion that supply/demand will be constrained at least until 2019, and actually slightly more so than for the overall OLED market.

In the Appendix of this report (see page 58), we break down the details of supply and demand to show the assumptions behind our overall conclusions.

Exhibit 10: We expect global mobile OLED S/D to also be tight at least until 2019, more so than overall S/D
Global mobile OLED supply and demand model

	2009	2010	2011	2012	2013	2014	2015	2016	2017E	2018E	2019E	2020E
Mobile supply ('000 sqm)	**59**	**133**	**494**	**1,030**	**1,325**	**1,680**	**2,305**	**3,044**	**4,225**	**6,212**	**8,455**	**10,397**
Sequential change (%)		*127%*	*272%*	*108%*	*29%*	*27%*	*37%*	*32%*	*39%*	*47%*	*36%*	*23%*
Mobile demand ('000 sqm)	**55**	**142**	**470**	**1,034**	**1,378**	**1,576**	**2,315**	**3,330**	**4,378**	**6,341**	**8,252**	**9,857**
Sequential change (%)		*159%*	*230%*	*120%*	*33%*	*14%*	*47%*	*44%*	*31%*	*45%*	*30%*	*19%*
Over(under) supply ratio	**6%**	**-7%**	**5%**	**0%**	**-4%**	**7%**	**0%**	**-9%**	**-4%**	**-2%**	**2%**	**5%**

Source: Company data, Goldman Sachs Global Investment Research.

Why now?

iPhone a key catalyst for OLED take-off starting in 2017

We believe 2017 will be a breakthrough year for the OLED industry. We believe Apple will likely adopt an OLED screen in the 5.8" version of the three new iPhone models, contributing to higher OLED panel market revenue (see our May 11, 2017 report, *Apple Inc. (AAPL): The first $1,000 iPhone can drive meaningful upside; Buy* for more details).

We now expect OLED penetration in the iPhone to reach 20% in 2017 via its adoption in the display for one of the three new models we expect to be launched, and to further increase to 63% in 2018 on OLED adoption in all of the new models that will launch in 2018. We believe that SEC will be the sole supplier of the display at least for this year as: **1)** SEC is the only OLED maker that currently has enough capacity to serve a large customer such as Apple, and **2)** based on media reports such as the April 4, 2017 *Nikkei* that Apple has ordered OLED panels from SEC for the 2017 iPhone.

Exhibit 11: We estimate the iPhone OLED adoption rate could reach over 60% in 2018 while SEC maintains market share of above 90% in supplying the OLED display
Our estimates of OLED iPhone shipments and SEC's market share

	1Q17	2Q17E	3Q17E	4Q17E	1Q18E	2Q18E	3Q18E	4Q18E	1Q19E	2Q19E	3Q19E	4Q19E	2017E	2018E	2019E
iPhone shipment (mn units)	50.8	41.6	48.4	85.3	59.6	47.2	50.8	79.3	57.0	47.9	51.6	85.0	226.0	236.8	241.4
iPhone OLED adoption rate			17%	43%	43%	48%	65%	87%	89%	93%	95%	100%	20%	63%	95%
OLED iPhone shipment (mn units)			8.0	36.9	25.6	22.4	32.9	69.2	50.5	44.5	49.1	85.0	44.8	150.1	229.0
SEC's OLED screen market share in iPhone			100%	100%	100%	100%	90%	88%	85%	82%	80%	75%	100%	92%	80%
SEC's OLED screen shipment for iPhone (mn units)			8.0	36.9	25.6	22.4	29.6	60.9	42.9	36.5	39.3	63.8	44.8	138.5	182.4

Source: Company data, Goldman Sachs Global Investment Research.

Examining our 45mn OLED iPhone shipment estimate for 2017 from the supply side

We estimate that Apple will ship around 45mn OLED iPhones in 2017. This will heavily depend on the demand for the larger 5.8" screen OLED display and its new features, and we acknowledge that the shipment number could end up being different. From the supply side perspective, we nonetheless examine whether our estimate is reasonable.

1) Supply chain check indicates 40-50mn OLED iPhones could be shipped in 2017

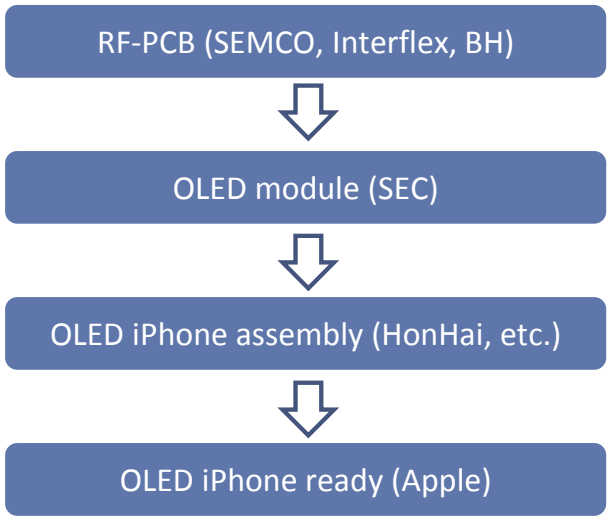
With SEC likely to be the sole supplier of the OLED display to Apple's new iPhone in 2017, we believe the supply chain for components such as the display RF-PCB (Rigid Flex PCB) for the OLED iPhone has shifted to Korean makers such as Samsung Electro-Mechanics (SEMCO), Interflex, and BH. According to our supply chain checks and discussions with these companies, we estimate that the three companies will divide the market share for the RF-PCB that will be used for the OLED iPhone, and that the combined shipments of OLED RF-PCBs for this year could reach around 70-90mn units. Taking into account the yield to make the OLED modules and assemble the phones as well as considering the lag time between panel shipments and final iPhone sales (some OLED screens produced in 4Q17 will likely be for OLED iPhone sales in 2018), we estimate shipments of OLED iPhones this year could feasibly reach around 40-50mn units.

Exhibit 12: Supply chain for the OLED iPhone has changed
Display FPCB and display supply chain of iPhone

	LCD iPhone	OLED iPhone
Display FPCB	Nippon Mektron	SEMCO, Interflex, BH
Display	LGD, JDI, Sharp	SEC (Samsung Display)

Source: Company data, Goldman Sachs Global Investment Research.

Exhibit 13: Korean companies expected to supply the PCBs for the OLED display
Supply chain process for the OLED iPhone



Source: Company data, Goldman Sachs Global Investment Research.

2) 40-50mn OLED screens in-line with SEC's expected capacity

We also examine if our estimate that Apple could ship around 40-50m units of the OLED iPhone in 2017 makes sense in terms of supplier capacity, which in this case is SEC's A3 fab capacity dedicated for production of flexible OLEDs, which we expect to be used in the next iPhone iteration.

Exhibit 15 shows our sensitivity analysis of producible OLED screens flexing various screen sizes and yield. Assuming a 70% yield, a little more conservative than the 80-90% yield seen in producing rigid OLED screens, we estimate that SEC can produce around 6-7mn 5.8" flexible OLED screens per quarter with 15K/month Gen-6 substrate capacity. We also estimate that SEC's A3 capacity used for iPhone OLED screen production could be around 60K-90K/month in 3Q17 (around 60K in the early part of the quarter and 90K as we reach the latter part of the quarter, based on our tracking of equipment order timing and supply chain checks).

In view of the above, we believe producible OLED screens for the iPhone in 3Q17 could reach roughly 30mn-40mn units, and adding the OLED screens produced in the early part of 4Q17, **we estimate SEC's capacity would be sufficient to supply the OLED screens needed if Apple were to ship 40-50mn OLED iPhones in 2017**.

Even assuming a lower yield of 60%, our sensitivity analysis indicates that producible screens in 3Q17 for the OLED iPhone would be around 25-35mn units, just enough to meet the 40-50mn demand when adding the OLED screens produced in the early part of 4Q17.

Exhibit 14: We estimate SEC would be able to produce around 6-7mn 5.8-inch flexible OLED screens per quarter with 15K/month substrate capacity
Producible OLED screens with 15K/month capacity

Screen size (inches)	5.0	5.5	5.8	6.0	6.2
Screens per Gen6 motherglass (MG)	280	216	204	187	176
Yield	70%	70%	70%	70%	70%
Screens per Gen6 MG (yield adjusted)	196	151	143	131	123
mn screens/month (with 15K capacity)	**2.9**	**2.3**	**2.1**	**2.0**	**1.8**
mn screens/quarter (with 15K capacity)	**8.8**	**6.8**	**6.4**	**5.9**	**5.5**
mn screens/year (with 15K capacity)	**35.3**	**27.2**	**25.7**	**23.6**	**22.2**

Source: Goldman Sachs Global Investment Research.

Exhibit 15: Different yield assumptions result in different numbers of producible screens
Producible OLED screens sensitivity analysis depending on screen size and yield (with 15K/month capacity)

(mn screens/qtr)		Screen size (inches)				
		5.0	**5.5**	**5.8**	**6.0**	**6.2**
Yield	**60%**	7.6	5.8	5.5	5.0	4.8
	70%	8.8	6.8	**6.4**	5.9	5.5
	80%	10.1	7.8	7.3	6.7	6.3

Source: Goldman Sachs Global Investment Research.

SEC likely to remain the major supplier for the OLED iPhone

SEC is currently the only OLED maker in the world with the capacity and experience to supply OLED panels for a full smartphone line-up, especially one with sales as large as the iPhone. We believe SEC will remain the major supplier of OLED screens for the iPhone for the next couple of years, after being the only supplier in 2017.

LGD likely to join as the second supplier

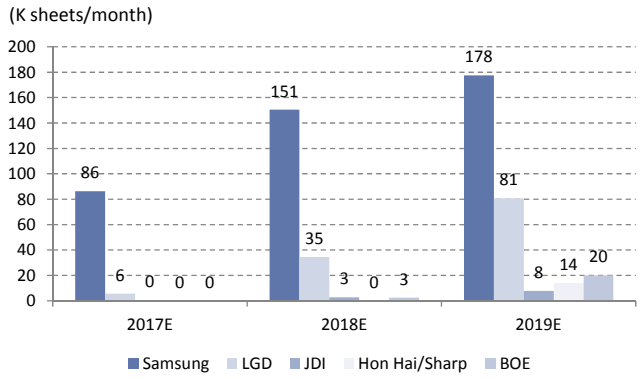
While we assume SEC will supply 100% of OLED screens for the iPhone in 2017, we estimate its market share will slightly decline to 92% in 2018 and to 80% in 2019. We believe that LG Display (LGD) will most likely become the second supplier of the OLED screens in 2018, especially as it prepares to ramp its Gen6 flexible OLED fab (E6) in 1H18 using the same vacuum evaporation tool that SEC employs. Given Apple's history of using multiple vendors to gain pricing power, we assume LGD will likely further increase market share in 2019, with a third vendor potentially also gaining a small share as well.

While we recognize the likelihood that SEC will lose its status as the sole supplier of OLED screens for Apple, we believe it will be difficult for other players to take significant share away given SEC's well advanced technology level in mobile OLED and the capacity advantage. We estimate that the only realistic threat to SEC in terms of capacity over the next couple years will be LGD. In our view, however, not until 2019 will LGD have enough scale to potentially take away meaningful share from SEC, and even then a technological gap could still remain.

SEC would have close to enough capacity even if all iPhones used OLED from 2018

We also take a look from Apple's perspective – how much capacity would be needed if all iPhones were to use OLED screens? We estimate that around 140K/month Gen6 OLED capacity would be needed to cover all iPhones shipped in a year (around 240mn units, based on our Apple estimates). We expect SEC to ramp up to 120K/month capacity at its A3 fab by end-2017, and believe this capacity could meet around 87% of the entire iPhone demand. We highlight that discontinuation of LCD iPhone sales and the sale of only OLED iPhones is an extreme case for 2018. Assuming legacy LCD models will continue to sell as well, SEC would likely be able to meet all of the OLED demand for Apple's OLED iPhones launched in 2018.

Exhibit 16: In terms of capacity, we believe only LGD has potential to become a meaningful second supplier for the OLED iPhone in the next couple of years
Average yearly Gen6 flexible OLED capacity for potential iPhone suppliers



Source: Goldman Sachs Global Investment Research.

Exhibit 17: SEC's A3 fab could meet almost all demand even if only OLED iPhones were sold from 2018
Gen 6 OLED capacity required to meet the entire iPhone demand and SEC's sufficiency ratio

	2018E	2019E
OLED iPhone unit assuming 100% penetration (mn units)	237	241
Producible screens with 15K/month capacity (mn units)	26	26
Capacity required for 100% OLED iPhone (K/month)	138	141
Samsung's estimated A3 fab capacity at end of previous year (K/month)	120	135
Sufficiency ratio	**87%**	**96%**

Source: Goldman Sachs Global Investment Research.

This page is intentionally left blank

Where's the market headed?

OLED market to triple to US$46bn by 2020

We expect **OLED industry revenue to triple in size to ~US$46bn in 2020, from US$15bn in 2016 (CAGR of 32%)**. The main driver of growth until last year was the success of SEC's flagship Galaxy smartphone series that used OLED panels, and the increasing penetration of OLED screens into SEC's lower-end smartphone models that followed. Companies like Oppo and Vivo started to use OLED screens in their main models from a couple of years ago and this also contributed to growth, in our view.

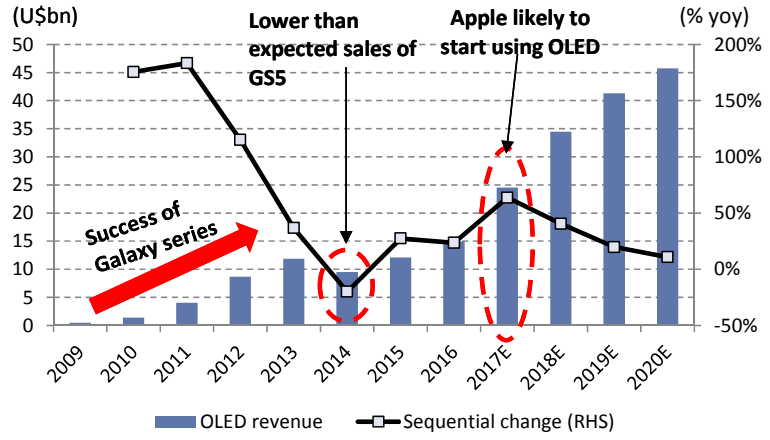
However starting from this year, in addition to the **1)** increased adoption of OLED screens in SEC's mass-tier models, we believe that **2)** Apple's adoption of OLED displays in the iPhone and **3)** increasing penetration of OLED in Chinese smartphones will combine to drive rapid market growth.

Exhibit 18: We expect the global OLED market to triple in size to ~US$46bn by 2020
Global OLED industry ASP and revenue

	2009	2010	2011	2012	2013	2014	2015	2016	2017E	2018E	2019E	2020E
Unit ASP (US$ per sq. cm)	0.9	1.0	0.9	0.8	0.9	0.6	0.5	0.4	0.4	0.4	0.4	0.3
Sequential change (%)		*6%*	*-14%*	*-2%*	*2%*	*-33%*	*-20%*	*-19%*	*17%*	*-5%*	*-14%*	*-12%*
OLED revenue (U$bn)	**0.5**	**1.4**	**4.0**	**8.7**	**11.9**	**9.5**	**12.1**	**15.0**	**24.6**	**34.6**	**41.4**	**45.9**
Sequential change (%)		*176%*	*183%*	*115%*	*37%*	*-20%*	*27%*	*24%*	*64%*	*40%*	*20%*	*11%*

Source: Company data, Goldman Sachs Global Investment Research.

Exhibit 19: OLED revenue to start to take off in 2017 with Apple likely to start using OLED in one of the iPhone models this year
Global OLED industry revenue forecast



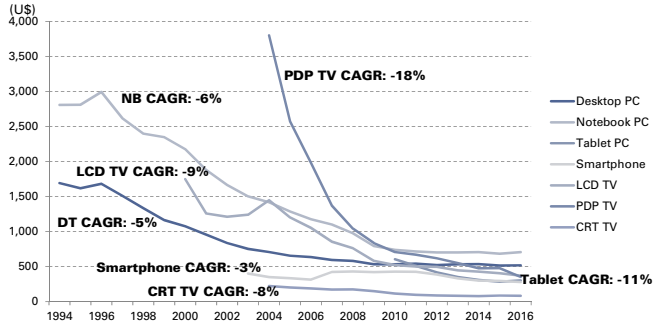
Source: Company data, Goldman Sachs Global Investment Research.

We consider a 10-20% annual decline in OLED ASP as the norm…

Looking back at the history of ASP decline for major tech products, we observe that major hardware devices such as LCD TVs, PCs, smartphones, and tablets have experienced an average 5-10% ASP decline per year (Exhibit 20). PDP TVs have seen an average ASP decline of 18%, but we believe that was a special case because this product lost out in the competition against LCD TVs to become the mainstream TV technology, and now has almost become obsolete.

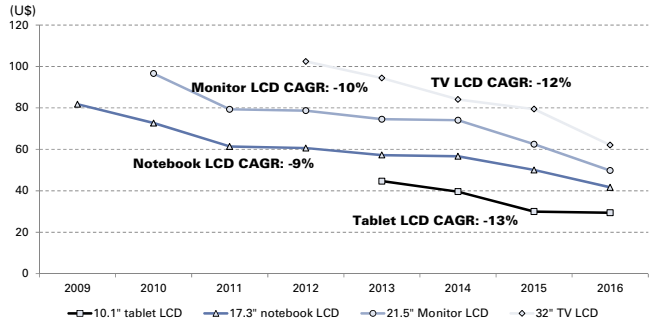
As OLED panels are components rather than hardware, we also examined how the LCD panel price has moved in the past few years. We found that the average annual price decline has been in the 10-15% range. Taking into account that LCD is a mature industry while OLED is still at a growth stage – meaning that a larger price decline could be seen to attract demand – our study into historical ASP declines for both hardware and the directly competing industry (LCD panels) suggests that an annual ASP decline of 10-20% could represent a normal range for OLED panels.

Exhibit 20: Major hardware devices have seen an average annual ASP decline of 5-10%
Historical ASP decline of major tech hardware products



Source: IHS, IDC, Gartner, Goldman Sachs Global Investment Research.

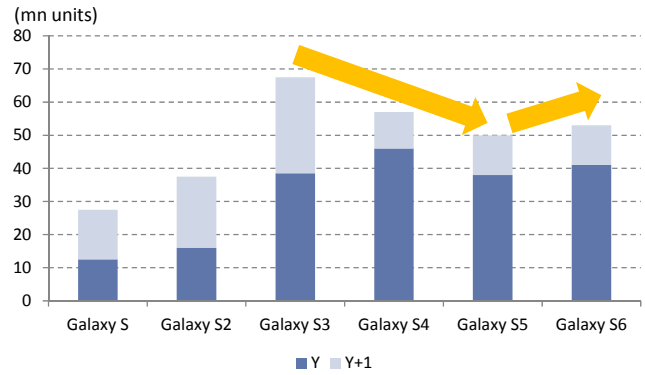
Exhibit 21: LCD panels have seen an average annual ASP decline of 10-15%
Historical ASP decline of major LCD panels



Source: IHS.

We believe an OLED price decline within this range was generally seen in the past few years based on conversations with supply chain companies, with the exception of 2012-2013 because **1)** the resolution of the OLED display in SEC's flagship Galaxy smartphone was upgraded (from WXGA to HD in Galaxy S III launched in 2012 and from HD to FHD in Galaxy S4 launched in 2013); and **2)** demand for those flagship smartphones was the highest ever (we estimate SEC's best-selling flagship smartphone to date is the Galaxy S III, followed by the Galaxy S4). Meanwhile, 2014 was the opposite of 2012-2013 as demand for the Galaxy S5 launched during the year failed to meet high expectations, and OLED panels accordingly suffered a steep ASP decline.

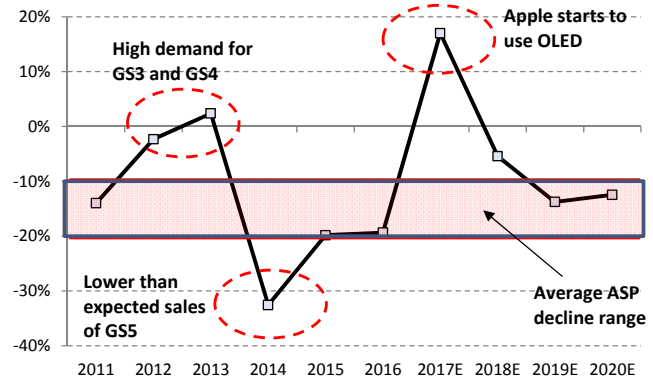
Exhibit 22: GS3 and GS4 were the most successful high-end models while GS5 failed to meet expectations
Combined shipments of each Galaxy S series in the launch year and one year after the launch year



Note: Y is the year of the launch and Y+1 is one year after the launch of each model; Galaxy S6 shipments include GS6 Edge and GS6 Edge Plus.

Source: Company data.

Exhibit 23: We estimate that a 10-20% annual ASP decline is the norm for OLED panels
OLED ASP forecast



Source: Company data, Goldman Sachs Global Investment Research.

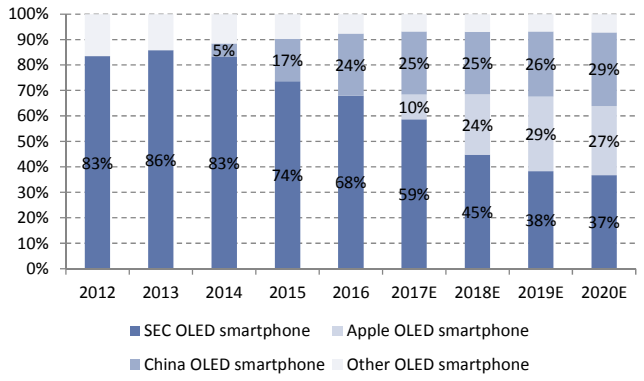
…but 2017 and 2018 will be different mainly due to iPhone impact

However we expect the mobile OLED market, as well as the overall OLED market, to see an OLED ASP increase in 2017. The main reason for this is that **1)** we expect Apple will start to use OLED displays with a much higher ASP than the industry average, and **2)** more companies will use screens with a wider aspect ratio of over 16:9 (such as the 18.5:9 used in the Galaxy S8) with a near bezel-less display, which also warrants higher ASP.

While we believe that the ASP of the OLED screen for the iPhone will be around 10-20% higher than the OLED screen used in SEC's high-end smartphones, we assume the portion of high-end products among its OLED smartphones for Apple will be 100%, while for SEC and the industry we expect this ratio to be much lower. This will improve the mix of the industry as higher price OLED screens for the iPhone will result in Apple contributing to a higher portion of OLED TAM, resulting in a higher yoy industry OLED ASP in 2017 and only a 5% yoy decline in 2018, per our estimates.

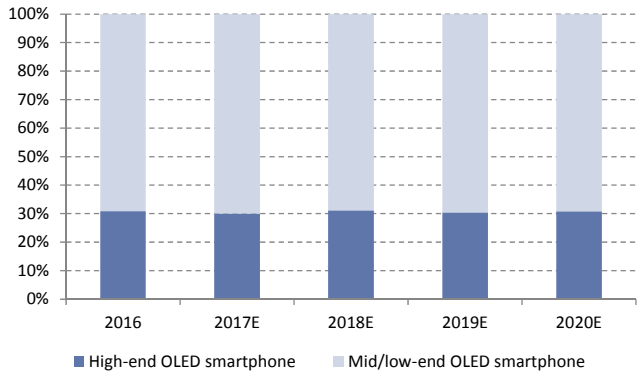
In addition, by using OLED displays with higher specifications such as wider aspect ratio and near bezel-less screens, both SEC and Chinese smartphone makers will employ screens that warrant higher ASP. This is another reason why we believe the industry will see an OLED ASP increase in 2017 and only a small ASP decline in 2018.

Exhibit 24: Although we expect Apple's OLED smartphone ratio to be smaller than SEC's…
Global unit share of OLED smartphone by company



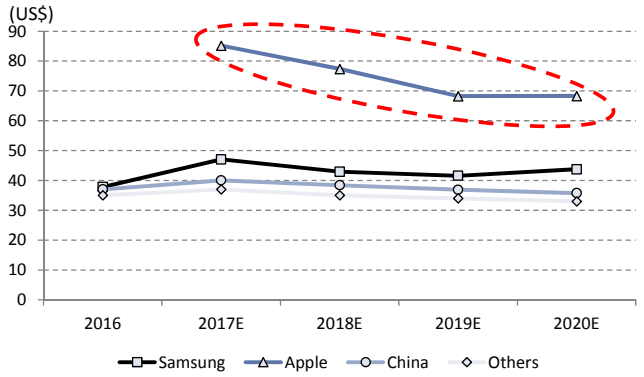
Source: Company data, Goldman Sachs Global Investment Research.

Exhibit 25: …SEC has a higher mix of mid/low-end OLED smartphones…
SEC's OLED smartphone mix



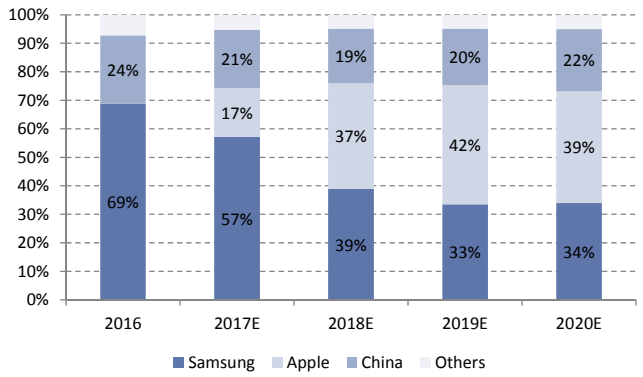
Source: Company data, Goldman Sachs Global Investment Research.

Exhibit 26: …while Apple's OLED smartphones will likely all be high-end, warranting higher OLED panel ASP…
OLED panel ASP comparison by customer



Source: Company data, Goldman Sachs Global Investment Research.

Exhibit 27: …resulting in a higher OLED TAM portion for Apple and acting as a tailwind to industry ASP
Smartphone OLED revenue TAM portion by customer



Source: Company data, Goldman Sachs Global Investment Research.

Case Study: iPhone display changes have been positive for suppliers' pricing and margins in the past

Based on our outlook for Apple changing the screen from LCD to OLED in one of its iPhone models this year to have a positive impact on industry OLED ASP, we examined past cases of transformation in iPhone's display to gauge the impact on suppliers' pricing and margins.

The iPhone has undergone two major display upgrades in the past five years: 1) In 2H12, the iPhone 5 started to use in-cell technology for the display, and at the same time the size of the display was enlarged to 4.0" from the 3.5" used in the iPhone 4S launched the previous year; 2) In 2H14, iPhone 6 and iPhone 6 Plus featured display size increases to 4.7"/5.5" respectively from 4.0" used in the previous model.

For both cases, the price of the display increased 10-30% compared to the previous model. In addition, as the major display suppliers for the LCD iPhone have been LGD, JDI, and Sharp, we attempted to assess how the companies' gross margins changed post the launch of iPhones with major display upgrades.

As illustrated in Exhibit 29, after the launch of the iPhone 5 in 2H12, the gross margins for both LGD and JDI gradually improved. Following the launch of the iPhone 6 and iPhone 6 Plus in 2H14, the gross margin for JDI improved but LGD's gross margin improved only briefly before starting to fall from early 2015. We believe that the different direction for gross margins in the iPhone 6 case reflected TV panel prices starting to fall sharply from early 2015, and at that time LGD's iPhone panel sales exposure was around 15% while TV panel sales exposure was 40%, making its margin more dependent on TV panel pricing. On the other hand, JDI's iPhone panel sales exposure was 40-50%, hence the positive gross margin movement, in our view.

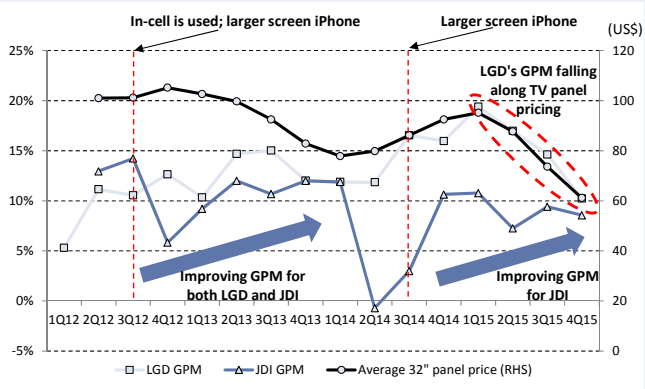
Although different factors such as forex movement may also have played a part in these margin trends, our finding is that the major display upgrades for the iPhone have been positive for suppliers' pricing and margins in the past. Should a similar trend play out going forward, this could bode well for SEC's OLED ASP and margins as the company will likely be the sole supplier of the display for 2017.

Exhibit 28: Major iPhone display upgrades have resulted in higher pricing for the display…
Major iPhone display change and pricing

Product	Release date	Pixel per Inch	Display technology change	Display size change	Display cost
iPhone 4S	Oct. 2011	330	no change	no change	$35-$40
iPhone 5	Sep. 2012	326	In-cell	3.5" -> 4.0"	~$45
iPhone 5S	Sep. 2013	326	no change	no change	~$40
iPhone 6	Sep. 2014	326	no change	4.0" -> 4.7"	~$45
iPhone 6 Plus	Sep. 2014	401	no change	4.0" -> 5.5"	$50-$55

Source: Company data, IHS, Goldman Sachs Global Investment Research.

Exhibit 29: …as well as favorable margins for the display suppliers
iPhone display change timing and LGD/JDI gross margins



Source: Company data, IHS.

This page is intentionally left blank

What's next for technology?

Foldable displays – the main driver post-2020

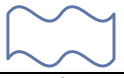
Foldable displays the next step in the flexible OLED roadmap

OLED displays chiefly come in two forms - **flat (rigid) and flexible**. Flexible displays comprise curved, bended, foldable, and rollable forms that allow the shape of the display to be altered, as opposed to a flat (rigid) display which cannot be bent or curved.

The only OLED maker currently producing both rigid and flexible OLEDs at scale is SEC, which uses its A2 fab mainly for the former and its A3 fab for the latter. The company has designed smartphones that use flexible OLED displays with different forms and curvatures, and currently is in the bended stage of its flexible display roadmap (Exhibit 32).

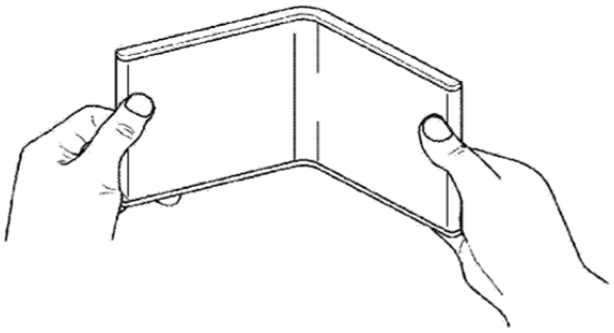
SEC has filed several patents related to foldable and rollable devices in the past few years. We believe the company is preparing for the commercial launch of foldable displays as the next step along the flexible OLED roadmap, to be followed by a stretchable/rollable display.

Exhibit 30: SEC is currently in the bended display stage, while the next likely steps are foldable displays and then rollable displays
SEC's flexible display roadmap

Type of OLED display	Flat (Rigid)	Curved	Bended	Foldable	Stretchable/Rollable
Rigid or Flexible	Rigid	Flexible			
Illustration of design					
Product example	Galaxy S7	Galaxy Round	Galaxy S7 edge	N/A	N/A

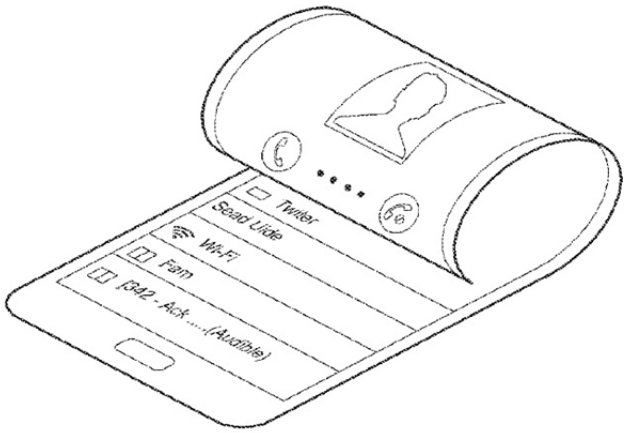
Source: Company data.

Exhibit 31: A device could be folded using foldable display to reduce size and enhance mobility through device convergence…
Example of SEC's foldable device patent application



Source: United States Patent and Trademark Office.

Exhibit 32: ..or could be rolled like paper using a stretchable/rollable display to also enhance mobility
Example of SEC's rollable device patent



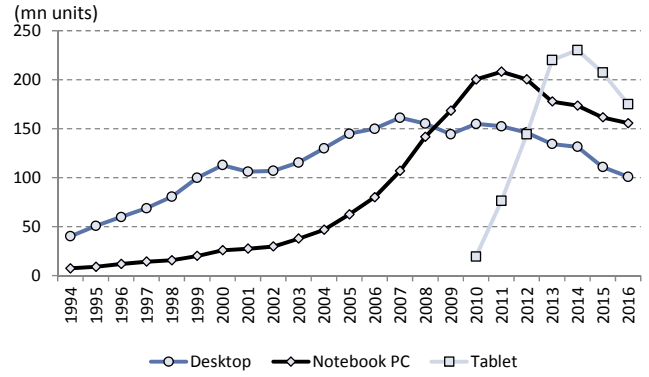
Source: United States Patent and Trademark Office.

Foldable device for better mobility with device convergence

We believe a key reason for developing a foldable device is the potential form factor options that could enhance mobility via the convergence of devices.

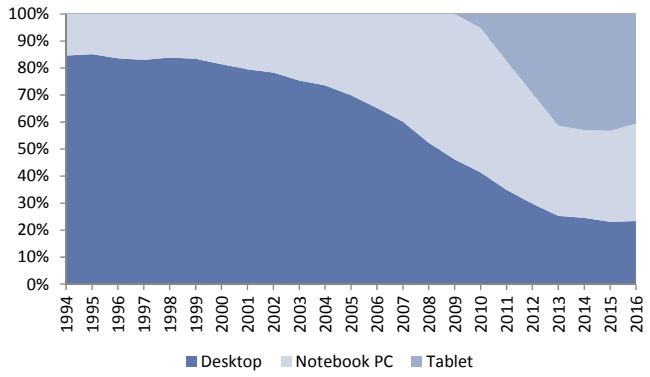
Historical shipment trends of computing devices show that the shipment share of desktop PCs has been declining sharply since early 2000s at the expense of an increasing share for notebook PCs, while both desktop/notebook PC shipment shares have declined since 2009 as more people have opted for tablet PCs. This historical trend indicates to us that user demand for better portability (i.e., preference for devices that are easy to carry around) has been one of the main drivers of product cycles.

Exhibit 33: Launch of devices with better mobility…
Computing devices unit shipment trend



Source: Gartner, Goldman Sachs Global Investment Research

Exhibit 34: …has led to better shipment share
Computing devices shipment share trend

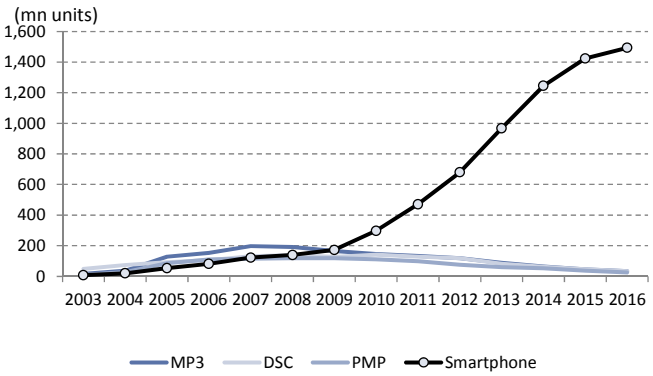


Source: Gartner, Goldman Sachs Global Investment Research

Shipments of portable devices such as MP3 players, digital still cameras, and PMP players were all significantly impacted by the launch of smartphones as listening to music, taking photos, and watching a video all became possible with a single device. The convergence of functions has led to smartphones becoming an "all-in-one" solution for various portable devices.

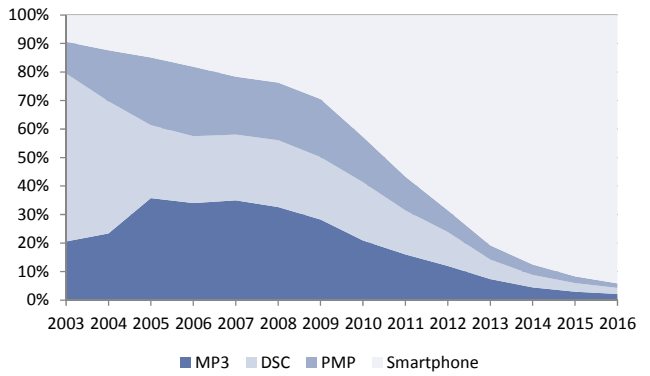
We believe foldable displays could play a key role in driving device convergence and mobility. For example, a single foldable device could be used for both content consumption (functioning as a smartphone/tablet PC) and content creation (functioning as a tablet PC/notebook PC).

Exhibit 35: Launch of smartphones…
Portable devices unit shipment trend



Source: Gartner, Goldman Sachs Global Investment Research.

Exhibit 36: …has combined functions into a single device
Portable devices shipment share trend



Source: Gartner, Goldman Sachs Global Investment Research.

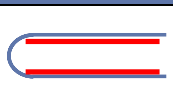
Fewer technical barriers to a 2-screen foldable display, but 3-screen display likely more practical

We see a greater possibility that the initial form of foldable display will be the infold C-type foldable display, which features two screens inside the device when folded. Since such a design would be relatively thin as the display needs to be folded only once, we believe the technical hurdles to manufacturing would be lower than with other types of foldable display.

Folding the device outwards so that two display screens would be located outside the device when folded (outfold C-type), or folding the device more than once to offer the possibility of three screens (G-type or S-type) will in our view be commercialized later due to the relative technical difficulty, in particular the challenge of having to fold the components more than one time.

That said, as our scenario analysis below suggests, we acknowledge that for a better aspect ratio for both smartphone and tablet usage with the foldable device, G-type or S-type foldable displays offering three screens may be a more suitable option. (Exhibits 38-41).

Exhibit 37: We expect a 2-screen foldable display first, followed by 3-screen
Types of foldable display

Type of foldable display	C type		G type	S type
Illustration of design				
Display location	Inside	Outside	Inside	In & outside
No. of folding	1 time	1 time	2 time	2 time
Direction of folding	1 way	1 way	1 way	2 ways
No. of screens	2 screens	2 screens	3 screens	3 screens
Thickness	Low	High	Medium	High
Difficulty	Low	High	Medium	High

Source: Company data, IHS.

Display tech not the highest hurdle for a foldable device

According to our supply chain checks, the current technology level of foldable display under development allows for folding/unfolding over 200,000 times. Durability should not be a problem assuming an average smartphone life cycle of 2 years, as the display could be folded and unfolded ~274 times a day and still withstand a 2-year cycle.

Rather than the technology hurdle of the foldable display itself, we believe the current difficulties in commercializing a foldable device are:

1. Developing reliable components in addition to the display that are compatible with each other and can be folded numerous times without losing functionality,
2. Bringing the high cost down, and
3. Adding additional functions to the device to justify the high ASP and creating commercial demand for the device.

Thickness could also be a problem from an aesthetic perspective but something that consumers might have to accept for the sake of functionality as any type of foldable device will likely be thicker than the current smartphones in use.

Scenario analysis on the size of foldable display

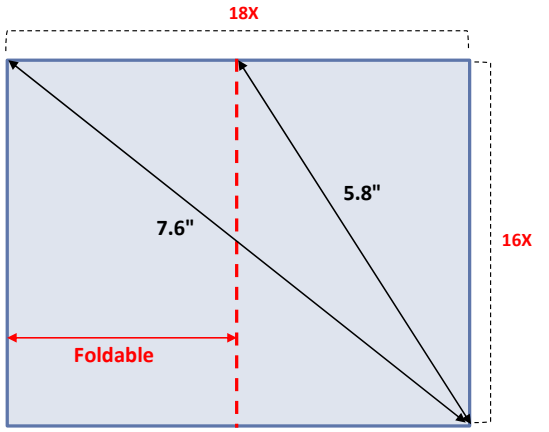
While we have limited visibility regarding the display size, aspect ratio, or the number of folds for the first foldable devices that will be launched in the market post 2020, we examine different scenarios for these factors based on a 16:9 smartphone or tablet screen. In this exercise, we disregard the size of the hinge that connects the screens for simplicity, but acknowledge that the actual display size could vary depending on the size of the hinge.

We examine two cases:

- Transforming 2-3 smartphone screens into a single tablet screen,
- Transforming a single tablet screen into 2-3 smartphone screens.

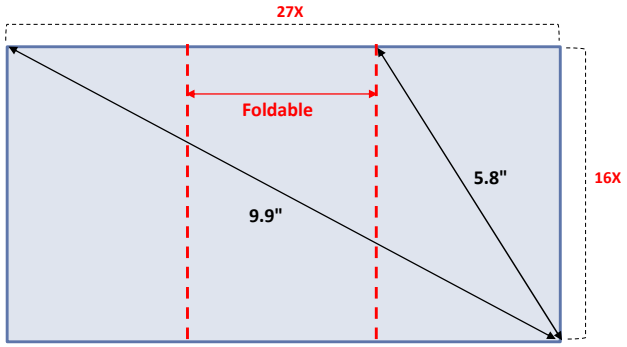
Our exercise indicates that a 2-screen foldable display (unfolding two smartphone screens to a single tablet screen or folding a tablet screen to two smartphone screens) would result in an aspect ratio that is almost square (Exhibits 38, 40). On the other hand, unfolding smartphone screens or folding a tablet screen to create a 3-screen foldable display would result in a much more practical screen size and aspect ratio. **Therefore while a 2-screen (single-fold) foldable display may be easier to produce, we believe the ultimate target for a foldable display is likely to be a 3-screen (double-fold) display due to its practicality.**

Exhibit 38: Unfolding two 5.8" smartphone screens with a 16:9 aspect ratio results in a 7.6" tablet screen that is almost square
Unfolding two 5.8" smartphone screens to a tablet screen



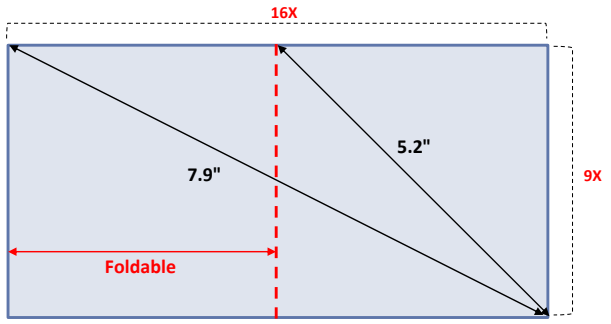
Source: Goldman Sachs Global Investment Research.

Exhibit 39: Unfolding three 5.8" smartphone screens with a 16:9 aspect ratio results in a 9.9" tablet screen with a 27:16 aspect ratio
Unfolding three 5.8" smartphone screens to a tablet screen



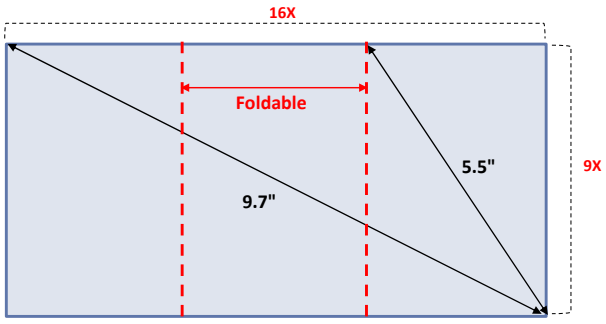
Source: Goldman Sachs Global Investment Research.

Exhibit 40: Folding one 7.9" tablet screen with a 16:9 aspect ratio results in two 5.2" smartphone screens that are almost square
Folding one 7.9" tablet screen to two smartphone screens



Source: Goldman Sachs Global Investment Research.

Exhibit 41: Folding one 9.7" tablet screen with a 16:9 aspect ratio results in three 5.5" smartphone screens with a 16:27 aspect ratio
Folding one 9.7" tablet screen to three smartphone screens



Source: Goldman Sachs Global Investment Research.

Reflecting foldable displays in our numbers: Smartphone penetration 3-4% by 2020

We assume that initial production of foldable displays will start in 2018, but that it will take several more months before production on a larger scale begins in 2019. Since we believe SEC will likely be the first to commercialize foldable displays, we would expect its internal mobile division to be the first customer. We accordingly estimate less than 1% penetration for foldable smartphones within SEC's smartphone units in 2018. We assume other smartphone makers will begin testing foldable displays in their devices starting from 2019, and by 2020 we forecast that global foldable smartphone penetration will reach 3-4%, or around 59mn units, still a relatively small part of the industry.

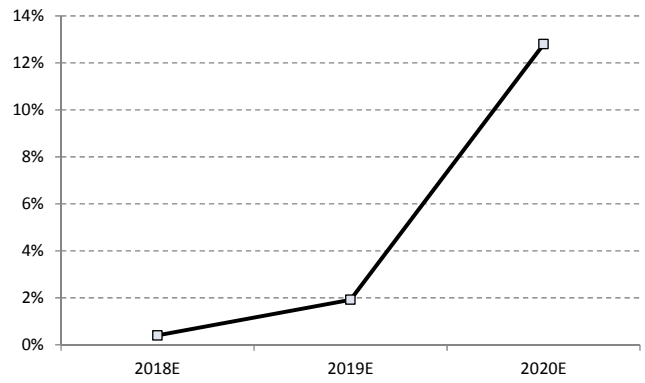
In calculating the extra area demand from foldable displays, we assume foldable displays will be C-type (as shown in Exhibit 37), which we see as the first stage due to the lower technological barriers than for G-type or S-type. This means that the screen size for foldable smartphone units is around double our assumption for average smartphone screen area per unit. Based on this assumption, we project OLED area demand from foldable displays in 2020 to be around 1.08mn sqm, or ~13% of total smartphone OLED area demand.

Exhibit 42: We expect global foldable smartphone penetration to reach 3-4% by 2020, mainly led by SEC
Assumptions for foldable smartphone demand

	2018E	2019E	2020E
Samsung foldable smartphone penetration (%)	0.4%	2.0%	8.8%
Samsung foldable smartphone (mn units)	1.3	6.5	29.3
Others foldable smartphone penetration (%)		0.1%	2.6%
Others foldable smartphone (mn units)		1.1	30.1
Global foldable smartphone (mn units)	**1.3**	**7.6**	**59.3**
Global foldable smartphone penetration (%)	**0.1%**	**0.4%**	**3.4%**
Foldable smartphone OLED area demand ('000 sqm)	22	136	1,083
Extra OLED demand from foldable ('000 sqm)	**11**	**68**	**541**

Source: Goldman Sachs Global Investment Research.

Exhibit 43: We expect foldable smartphone area demand will explain around 13% of total smartphone OLED area demand by 2020
Foldable smartphone area demand penetration



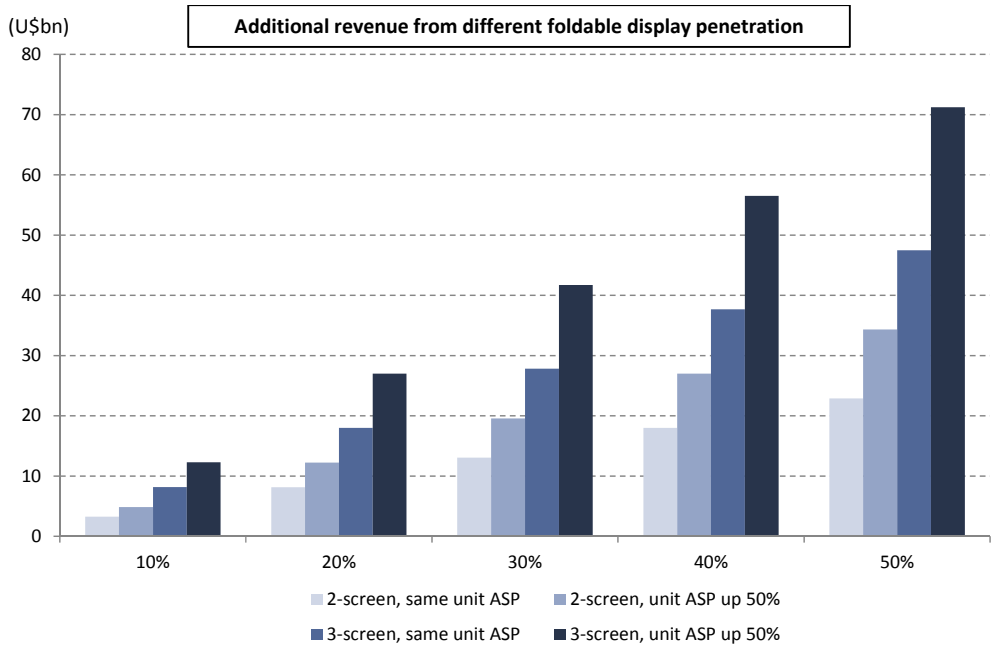
Source: Goldman Sachs Global Investment Research.

Key demand driver post-2020

We expect foldable OLED screens to transition to a phase of broader penetration from 2020. Although likely only a small portion of the industry in 2020, we see good prospects for the expansion of OLED in new applications such as VR/AR devices (nearly all VR/AR headsets already use OLED) and automotive displays.

Even assuming no ASP change for foldable OLED beyond 2020, our simulation suggests that 50% penetration of 2-screen foldable displays could create another US$23bn market, while 50% penetration of 3-screen foldable display could generate incremental revenue of US$47bn. If the ASP of foldable displays were to rise, there could be even greater market potential. We therefore believe foldable displays have the potential to become one of the key demand drivers of OLED post-2020.

Exhibit 44: We estimate that doubling/tripling of smartphone screen size could lead to a major market expansion
Market size simulation for the shift to 2-screens/3-screens with different ASP assumptions



Source: Goldman Sachs Global Investment Research.

This page is intentionally left blank

What are the risks?

Risks to our OLED market forecast

We highlight five main risks to our OLED market forecast, both to the upside and downside.

1. **Faster/slower pace of OLED display adoption in iPhones and China smartphones:** As the OLED penetration for SEC's smartphones is already high, the pace of OLED adoption in Apple and China smartphones could be a key swing factor for OLED demand.
2. **Faster/slower pace of entrance by new suppliers:** While SEC is the clear leader of the OLED market with more than 90% market share, a faster/slower OLED capacity ramp especially from Chinese OLED makers could disrupt OLED supply/demand and affect pricing.
3. **More/fewer applications for flexible (foldable) displays:** Flexible displays are currently mainly used for smartphones, but the pace of expansion into other applications such as VR/AR, automotive, and commercial displays could affect overall demand. The pace of foldable display penetration will also be one of the key demand factors post-2020.
4. **Stronger/weaker competition from other display technologies:** While OLED has many advantages, other display technologies such as micro-LED and QLED (Quantum Dot Light Emitting Diodes) have their own advantages and are being developed by several display makers. Stronger/weaker competition from these technologies could alter the trajectory of OLED market growth. While micro-LED is widely known to be brighter and more energy efficient than OLED, it is currently at the trial production stage of technology development and we have seen no cases of a major commercial product adopting the technology thus far. For QLED, the main advantages include lower cost and brighter image, but we have seen no prototypes to date and thus we believe it will likely take several years to enhance the technology.
5. **Faster/slower pace of cost reduction:** We believe that the cost to produce a rigid OLED panel for smartphones is close to or slightly higher than the cost to produce a similar size LTPS LCD panel. Depending on the pace of cost reduction, there could be more/less demand for OLED panels, especially for the rigid type as the form factor is not entirely different from existing flat panel displays such as LCD.

Who is best placed to compete?

Mobile OLED competitive landscape – will SEC's success continue?

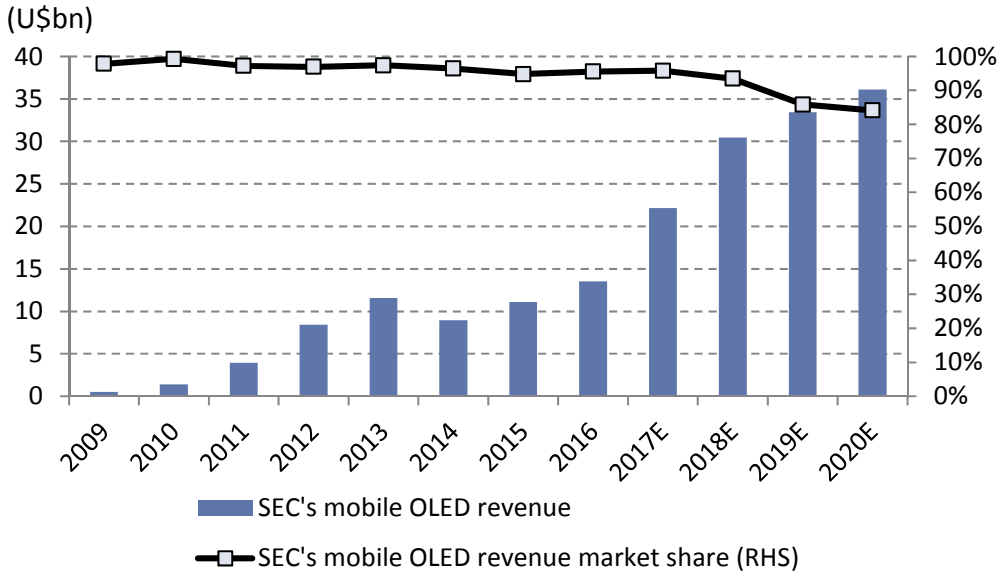
SEC is the clear market leader in mobile OLED currently

In the mobile OLED space, SEC is currently the clear leader in terms of every aspect of competition - capacity, market share, technology. We estimate that its revenue market share was higher than 95% in 2016, and that its market share this year will remain high and potentially rise slightly on the back of being the sole supplier of this year's OLED iPhone.

While we believe it would be premature to worry about SEC losing market share given its current market dominance and better positioning than competitors in meeting business targets, in the following sections we attempt to answer the two key questions - one from the demand side and one from the supply side - to see how sustainable SEC's success can be:

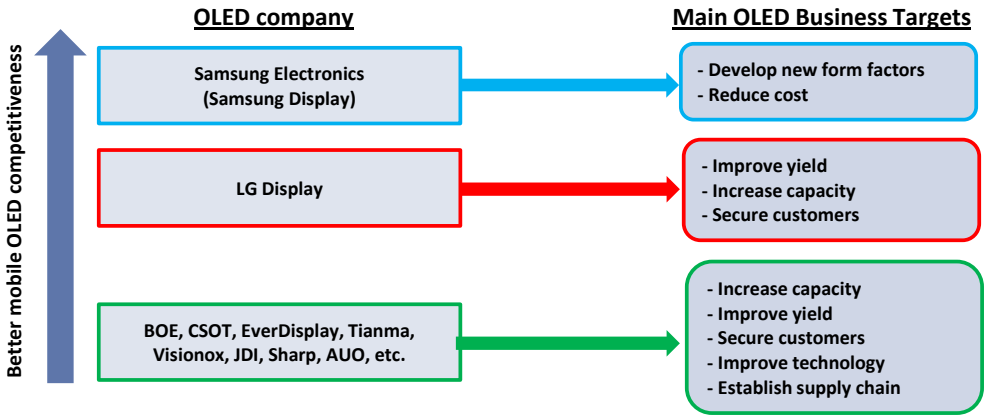
- **Will smartphone makers continue to demand OLED from SEC?**
- **How soon will the Chinese OLED makers disrupt the market?**

Exhibit 45: We expect SEC's mobile OLED revenue to continue to grow
SEC' mobile OLED revenue and market share



Source: Company data, Goldman Sachs Global Investment Research.

Exhibit 46: We believe SEC is best positioned in mobile OLED, followed by LGD
Mobile OLED competitiveness



Source: Goldman Sachs Global Investment Research.

Key demand question: Will smartphone makers continue to demand OLED from SEC?

SEC's OLED revenue used to be centered on supplying its own mobile division due to the success of Galaxy flagship smartphones as well as the limited external supply capacity of the display division. As SEC continued to increase OLED capacity – notably by ramping its A3 fab starting in 2015 – it was able to gradually expand sales to external customers. We estimate that the portion of sales to external customers in 2017 will exceed 40%, mainly on the back of Apple demand.

Will SEC continue to demand OLED from its own display division? Yes
We expect SEC's mobile division will continue to source OLED panels from its own display division even if there are several options for an OLED vendor (the company has historically co-developed technologies via cooperation between divisions). The question is whether an alternative source of OLED panels might exist for other smartphone makers such as Apple and Chinese players.

Will Apple continue to demand OLED from SEC? Yes, though some share could be given to other makers such as LGD
For Apple, as mentioned earlier in the report, we recognize SEC could lose some share given Apple's history of using multiple vendors, but believe it will be hard for other players to take significant share away due to the technology and capacity gap between SEC and other OLED players. Apple is widely acknowledged for placing importance on product quality, but especially more so in displays – the highest bill of material cost. Apple has even designated the marketing term "Retina Display" just for the display, in our view as a means of emphasizing the quality of this component. Chinese display makers have no track record of entering Apple's supply chain, likely due to this high quality standard approach by Apple, as most lack a strong low temperature poly-silicon (LTPS) technology. We believe OLED may present a similar case as LTPS technology is also important for mobile OLED quality.

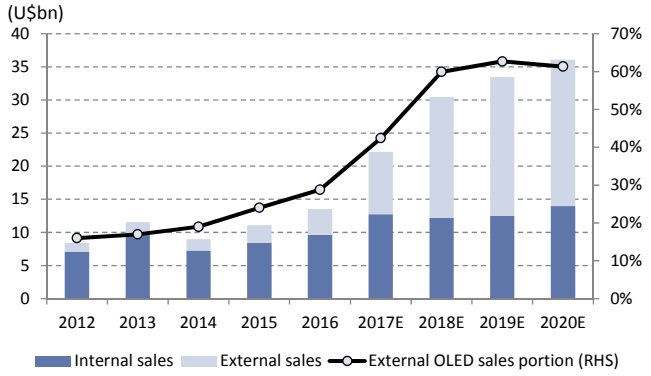
Will Chinese smartphone makers continue to demand OLED from SEC? Yes, though low-end OLED panels could be increasingly procured from domestic OLED players

We believe Chinese smartphone makers are most sensitive about technology, sufficient supply and price, and service and quality when deciding procurement of OLED display, based on their past approach to sourcing display components.

- **Technology**: SEC has been mass producing quad high-definition (QHD) OLED panels since 2014 while Chinese OLED makers are still producing HD and full HD (FHD) OLED panels only in a small scale, indicating a gap in technology;
- **Sufficient supply and price**: Lower prices from Chinese OLED makers starting in 2019-2020 could be a risk. However, we expect only SEC and LGD will have sufficient volume to supply a high-selling smartphone model at least until 2020;
- **Service and quality**: In some past cases, a smartphone maker has attempted to use OLED panels made by a Chinese maker, but not too long after switched back to SEC – potentially because of large gap in service and panel quality.

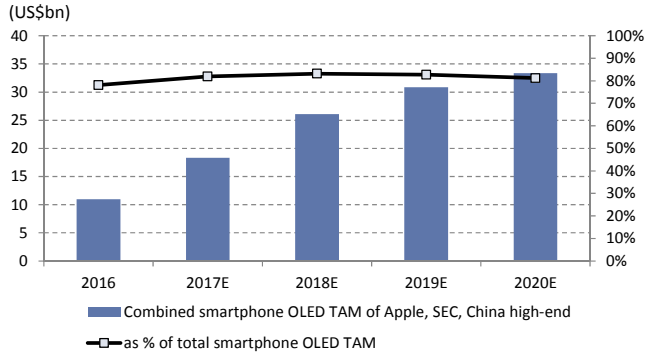
We therefore believe that SEC, and to a lesser extent LGD, will have the advantage in supplying OLED panels to Chinese smartphone makers for at least the next few years. Even if Chinese smartphone makers were to start using cheaper OLED displays from domestic suppliers for their mid/low-end smartphones, we believe SEC would still be in a position to supply OLED to **1)** SEC's mobile division, **2**) Apple, and **3)** Chinese high-end smartphones (we assume ~30% of the market throughout the forecasting period to calculate the TAM in our worst case scenario). For these three customers, we project the combined TAM in each year of our forecast period could comprise over 80% of total industry smartphone OLED revenue.

Exhibit 47: We believe SEC's OLED sales to external customers will exceed 40% starting in 2017 on the back of Apple demand, providing a balanced source of revenue
SEC's OLED sales mix by customer



Source: Company data, Goldman Sachs Global Investment Research.

Exhibit 48: We estimate the smartphone OLED TAM for SEC would still be at least 80%+ of industry smartphone OLED revenue even in a worst case scenario
Combined smartphone OLED TAM of Apple, SEC, and Chinese high-end smartphones



Source: Company data, Goldman Sachs Global Investment Research.

Key supply question: How soon will Chinese OLED makers disrupt the market?

Several Chinese companies such as BOE, Tianma, Visionox, and EverDisplay have announced plans to enter the OLED market and invest in production facilities. Since most companies with aggressive plans to enter this potentially high-growth market have yet to show any meaningful results, the key questions for us are whether they can make a tangible impact, and how long it might take for them to disrupt the market. Below, we examine a few cases across different tech sub-sectors in a bid to answer these questions.

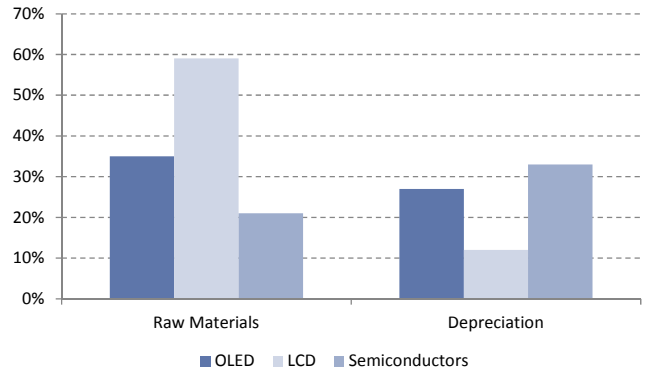
OLED cost structure bears more resemblance to semiconductors than LCD

A comparison of cost structures for OLED, LCD, and semiconductors reveals that both OLED and semis have a higher fixed cost portion, while LCD incurs higher variable costs. We believe this is due to the higher raw material cost for LCD, which uses high cost components such as the backlight unit. However, both OLED and semiconductors tend to be more capital intensive than LCD, with the depreciation cost portion typically around 30% compared to 10-15% for LCD in general over the past couple of years.

We believe that this low fixed-cost portion makes it difficult for LCD makers to differentiate their margins. Margins will differ substantially only when there are company-specific incidents, such as the earthquake in Taiwan impacting Innolux's margin in 1H16, and SEC's unsuccessful attempt to change its LCD manufacturing process impacting its margin also in 1H16.

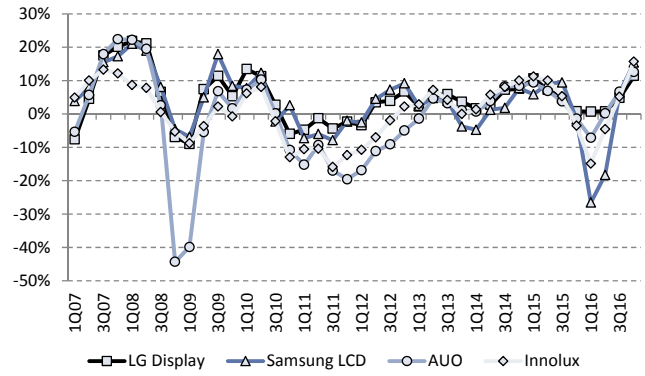
Overall, our key findings from comparing the different industries are that **1) OLED's cost structure is more akin to semiconductors than to LCD**, and **2) maintaining cost competitiveness in LCD is difficult due to the low portion of fixed costs.**

Exhibit 49: Generally, the cost structure of OLED is more akin to semiconductors than LCD
Illustrative cost structure comparison



Source: Goldman Sachs Global Investment Research.

Exhibit 50: LCD makers generally do not have differentiated margins
LCD operating margin comparison



Source: Company data.

It took a long time for Chinese players to make an impact even in the LCD industry

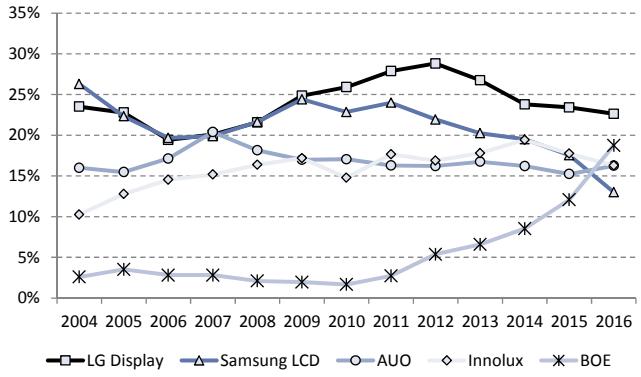
SEC entered the LCD market in 1991, starting mass production in 1995 and achieving over 10% market share in large-size LCDs in 1997. In the case of the current leading Chinese LCD maker BOE, after entering the business in 2003 it took 12 years for the company to attain over 10% market share. BOE's recent rapid rise in LCD market share was also helped by the LCD industry leaders LGD and SEC both reducing their LCD capex weightings in order to focus more on OLED. Therefore, **even in the LCD industry, where maintaining cost competitiveness is difficult, it took a long time for Chinese players to make an impact.**

Exhibit 51: It took BOE 12 years from launching the business to make an impact in the LCD industry
LCD milestone comparison (BOE vs. SEC)

	BOE	SEC
Launch of LCD business	2003	1991
Mass production start	2005	1995
Large size LCD m/s over 10%	2015	1997

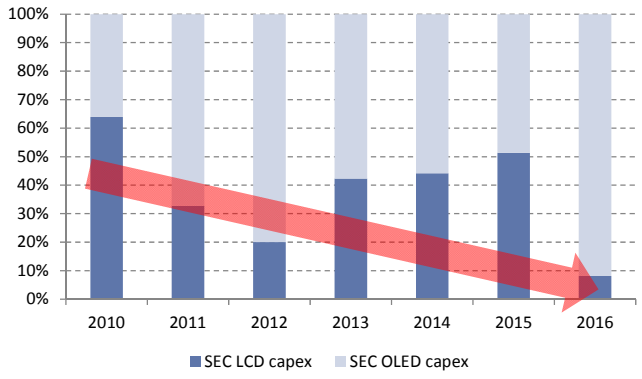
Source: Company data.

Exhibit 52: Not until the Korean makers shifted their focus to OLED did BOE see its LCD market share rise
LCD market share trend



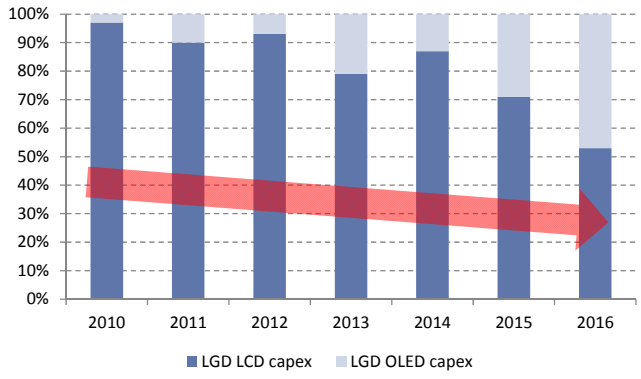
Source: IHS.

Exhibit 53: SEC reducing focus on LCD…
SEC display capex mix



Source: Company data.

Exhibit 54: …LGD too
LGD display capex mix



Source: Company data.

Limited impact yet from China in semis, where cost structure is similar to OLED

Next we examine two cases for semiconductors, an industry with a similar cost structure to OLED.

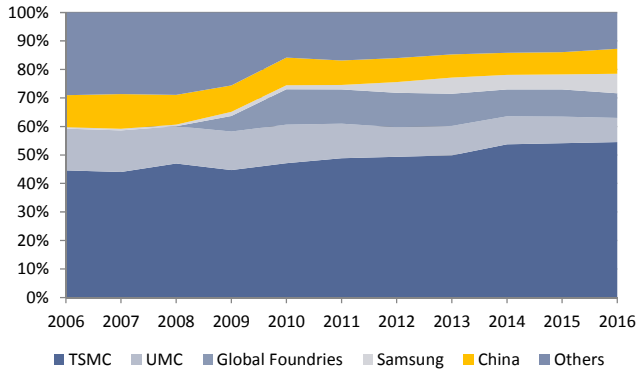
1) Foundry industry

The foundry industry is still dominated by TSMC, which has more than 50% market share (as of 2016), and the China presence is small with the combined 2016 market share of Chinese foundry companies at less than 10%. A decade ago, the combined market share of Chinese foundry companies was actually higher than 10%, but they lost share while TSMC gained ~10pp share. Also, China's leading foundry player SMIC's operating margin has been well below the margin of the global leader TSMC (generally 25-40pp lower than TSMC for the past 10+ years).

Read-across for OLED: Since OLED has a similar cost structure to semiconductors in having a high deprecation cost portion, early entrants to the industry that are able to complete depreciation will have more of a cost advantage than late entrants. This cost advantage also gives leeway for incumbents to spend more on R&D, raising the potential to improve technological expertise and accumulate intangibles.

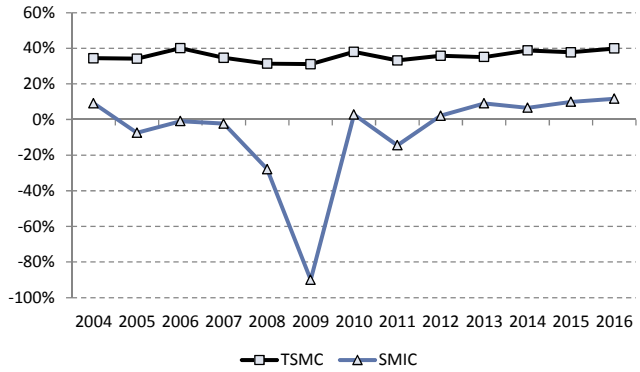
We believe that SEC's A1 fab and most lines in its A2 fab have completed depreciation, and that A3 fab deprecation will likely be almost over by the time Chinese OLED makers enter the market with mass production capability. We therefore believe **SEC will likely continue to sustain its major cost advantage over Chinese OLED players**.

Exhibit 55: As late entrants to the foundry market, Chinese makers have struggled to gain market share…
Foundry market share trend



Source: Gartner.

Exhibit 56: …as well as improve margin
OPM comparison between TSMC and SMIC



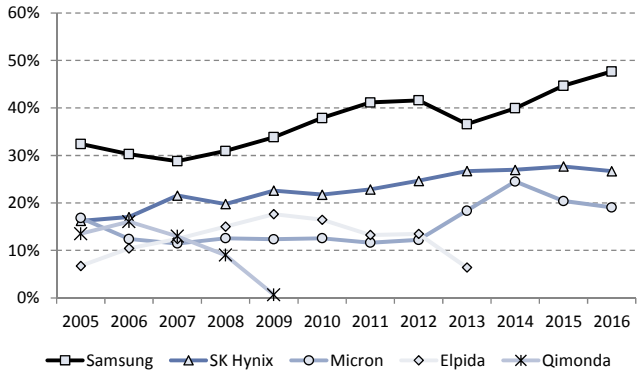
Source: Company data.

2) DRAM industry

The DRAM industry is dominated by a handful of players that have been in the market for a long time, and Chinese players have yet to enter the market. Due to the high cost weighting of depreciation and low weighting of raw materials, the margin difference between the DRAM maker with the highest margin and the one with the lowest has been much wider than the LCD industry (Exhibit 58).

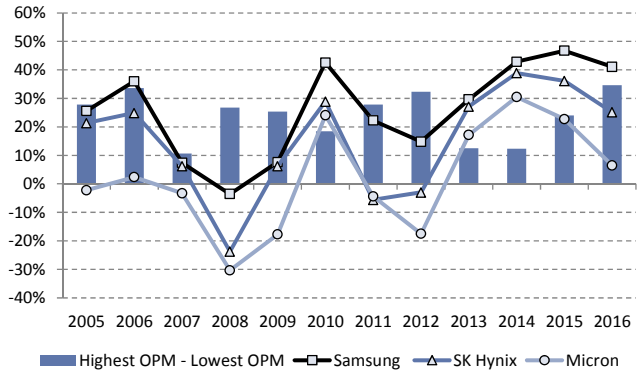
As such, we believe it would also be difficult for any new entrant to disrupt the DRAM market, as is the case in the foundry industry.

Exhibit 57: DRAM industry is dominated by few players
DRAM market share trend



Source: Company data.

Exhibit 58: Margin delta between the companies with highest and lowest margin is much larger than LCD
OPM of major DRAM makers and margin delta



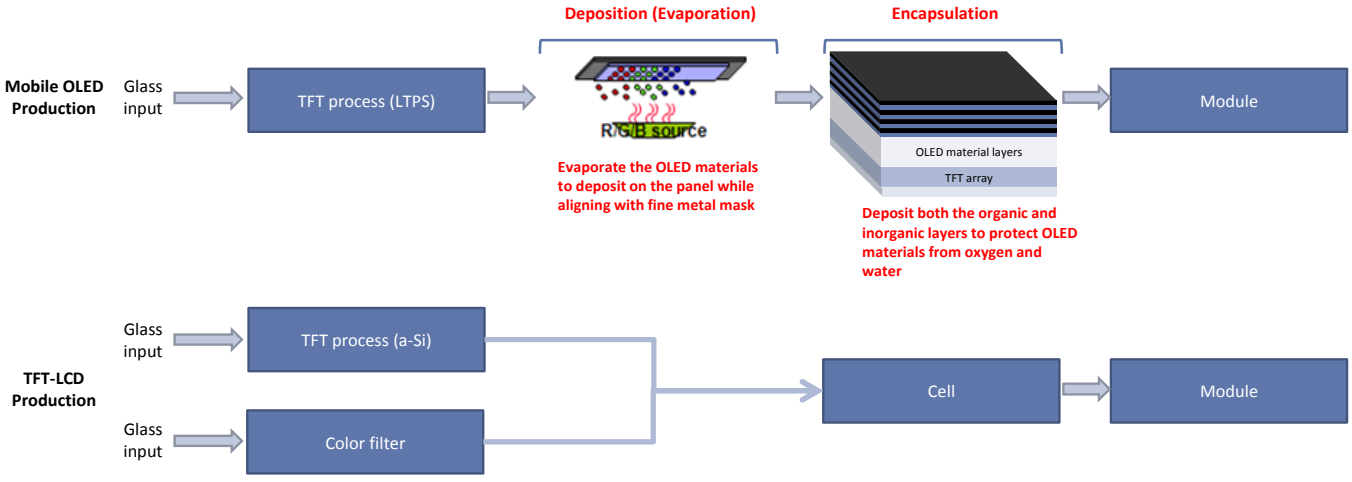
Source: Company data.

"Analog" aspect of OLED bodes well for leading players

The vacuum evaporation and encapsulation processes of OLED require optimization of materials/processes through working with suppliers to find the right recipe.

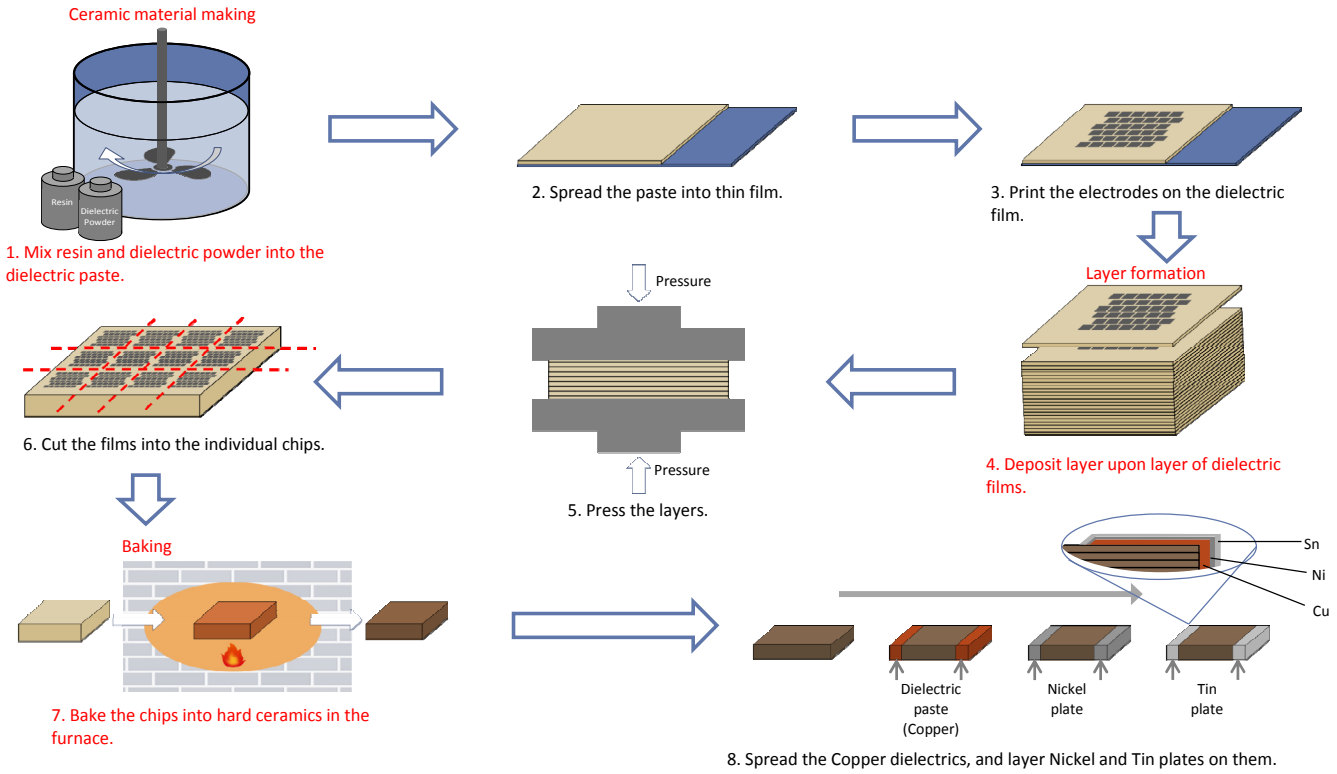
Simply spending large sums will not work if processes are not optimized. We think this makes the process more "analog" in nature than LCD (i.e., more dependent upon the processes and materials). The multi-layer ceramic capacitor (MLCC) manufacturing process is also "analog", especially in terms of making the ceramic material and baking the chips in the furnace. We believe this "analog" aspect of the process has provided advantages for the leading players in MLCC such as Murata, and thus the OLED process could also bode well for the early entrants in achieving higher yields and gaining the technological advantage.

Exhibit 59: Vacuum evaporation and encapsulation processes of OLED makes it an "analog" process
Mobile OLED and LCD manufacturing process



Source: Goldman Sachs Global Investment Research.

Exhibit 60: Ceramic material making, layer formation, and baking processes of MLCC makes it an "analog" process
MLCC manufacturing process



Source: Goldman Sachs Global Investment Research.

Our answer to the key supply question: We think it will take at least 3-4 years before Chinese OLED makers may potentially disrupt the market

We summarize key points below:

- In the semiconductor industry, where cost structure is similar to OLED, **it is difficult for a new entrant to disrupt the market as the incumbents have a cost advantage**, mainly resulting from a high portion of fixed costs, as well as better technological expertise and intangible assets.
- Even in the LCD industry, where maintaining cost competitiveness is more difficult, **it took 12 years before Chinese players made an impact** in the market.
- The "analog" aspect of OLED manufacturing could be comparable to the MLCC production process, where optimization of the process by finding the right recipe is important, and just spending a lot of capital without securing the right solution may not work.

We conclude that it will take several years before Chinese OLED makers are in position to disrupt the OLED market. This is supported by our discussions with companies in the supply chain that have supplied both SEC and China, which indicated it could potentially take at least 3-4 years.

Strong and exclusive supply chain of SEC another advantage

We believe another advantage for SEC's sustainable success is that it has a strong supply chain, and an exclusive one for some of the important equipment/components. SEC has

worked with numerous companies in both Korea and overseas since the initial stage of OLED development, and has established a strong supply chain that shares the know-how of OLED production.

SEC has also established joint ventures with partner companies to source materials (i.e., SU Materials, the JV with Ube Industries), has affiliates such as Samsung SDI that provide essential materials for OLED production, and has invested in material/equipment companies for stable sourcing. Since several companies in the supply chain have proprietary technology that was developed together with SEC, we believe that SEC will continue to work together with those companies and leverage their know-how as it seeks to widen the OLED technology gap.

Exhibit 61: SEC's OLED equipment supply chain

Process	Equipment	SEC
Polyimide curing	Batch furnace	Terasemicon, Viatron
Crystallization	ELA	AP Systems, Coherent
TFT formation	PECVD	Applied Materials, SFA Engineering
	Sputter	Ulvac
	Stepper/scanner	Canon, Nikon
	Dry etcher	Wonik IPS, ICD
RGB patterning	Evaporator	Canon Tokki
Encapsulation	Glass encap	AP Systems
	Thin-film encap	Kateeva, Applied Materials
Glass detachment	LLO	AP Systems
Back-end	Logistics	SFA Engineering, Toptec, Daifuku, Shibaura Mechatronics
	Laser cutting	Rorze Systems, Toptec
	Testing equipment	Rorze Systems, HB Technology
	Scriber	SFA Engineering

Source: Company data

Exhibit 62: SEC's OLED material/component supply chain

Materials and Components	Companies
HTL/HIL	Duksan Neolux, Doosan
ETL/EIL	Samsung SDI, LG Chem, Tosoh
p-dopant, n-dopant	Samsung SDI (Novaled)
Phosphorescent Red (Host)	Dow Chemical, Duksan Neolux
Phosphorescent Red (Dopant)	Universal Display
Phosphorescent Green (Host)	Samsung SDI, Universal Display, Nippon Steel & Sumitomo Metal
Phosphorescent Green (Dopant)	Universal Display
Fluorescent Blue (Host)	Idemitsu Kosan, Dow Chemical, SFC
Fluorescent Blue (Dopant)	Idemitsu Kosan, SFC
Shadowmask	Dai Nippon Printing
OLED polarizer	Sumitomo Chemical, Nitto Denko, Samsung SDI
OLED driver IC	Samsung LSI
Liquid polyimide	SU Materials
OLED thin glass process	Soulbrain, Chemtronics
Touch sensor	Sumitomo Chemical (Dongwoo Fine-Chem), Alps Electric, Nissha Printing
Glass for OLED display	Corning
OLED display RF-PCB	SEMCO, Interflex, BH
Cover polyimide	Kolon Industries, SKC, Sumitomo Chemical, Mitsubishi Chemical
ITO film	Nitto Denko
OLED etchant/gas	Soulbrain, SK Materials, ENF Technology

Source: Company data

Key winners: SEC, OLED equipment/material/component makers

We expect **SEC** to maintain its leading position in the mobile OLED industry as smartphone makers will likely continue to source OLED panels from the company, the market disruption potential from the Chinese OLED makers is still at least 3-4 years away, and SEC already has a firm technology, cost, and supply chain advantage.

The OLED supply chain that produces the equipment and material/components should also benefit from the OLED market take-off, as both the OLED market leader seeks to widen the gap and the followers who want to bridge the gap will continue to spend large amounts of capital to capture a larger portion of the TAM that we expect to grow rapidly.

For LGD, we think the company may need more time as it was relatively late in entering the mobile OLED market. However on the positive side, it is the only company in the world mass producing OLED TV panels, and is behind SEC alone in terms of experience and technology in mobile OLED, which we believe puts the company in a better position than others in catching up. The single vendor risk for smartphone makers could also help LGD, as a potential bottleneck in production due to limited OLED supply and limited bargaining power could increase customer demand to source from other OLED vendors besides SEC, provided the quality of the OLED panel is sufficient.

Exhibit 63: SEC is the clear leader in the mobile OLED space, followed by LGD
OLED mass production timing comparison

	SEC	LGD	BOE	Chinese 2nd-tier
First rigid OLED mass production	2007	2011	2016	2015
First flexible OLED MP in scale	2012	2017E	2019E	2020E
First flexible OLED MP in Gen6 fab	2015	2017E	2019E	2020E

Source: Company data, Goldman Sachs Global Investment Research.

This page is intentionally left blank

Who's investing?

Global OLED capex – high level of spending expected through 2020

We expect global OLED capex to reach around US$20bn in 2017, increasing close to 70% yoy. The largest portion of capex will likely come from Korea, as we believe the Korean OLED makers such as SEC and LGD will conduct record OLED capex this year.

We expect **SEC** to continue to ramp its A3 fab to expand capacity for mainly Apple smartphones, and to also start investing in 1) a new fab for additional customers especially in China, 2) foldable display preparations, and 3) high resolution panels for applications such as VR/AR usage.

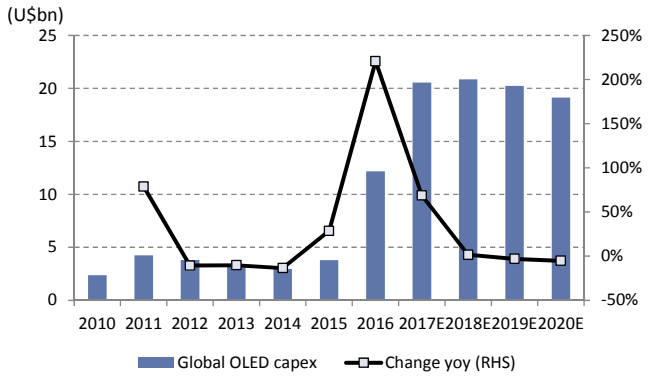
For LGD, the company is investing in additional capacity for its Gen8 OLED TV line, and also preparing to ramp its first Gen6 mobile OLED line in Gumi (E5). It will also be spending capital to prepare for the ramp-up of another Gen6 line in Paju (E6). We also expect LGD to announce capacity plans for its new P10 fab in the next few weeks. While we believe that LGD will include a Gen6 mobile OLED line, it will likely add another line to produce either large LCDs or large OLEDs. No matter the decision it makes regarding LCD or OLED, we believe that its long-term strategy is to focus on OLED, and even if it decides to produce LCD first, it could eventually convert the capacity into OLED.

For Chinese OLED makers, we expect BOE and Tianma to be high capex spenders as the former invests in its first Gen6 fab in Chengdu (B7), and the latter prepares to ramp its first Gen6 fab in Wuhan.

High capex activity is unlikely in Taiwan or Japan as the current focus is more toward LCD or R&D activities in OLED, but we will closely monitor any change in their investment activities.

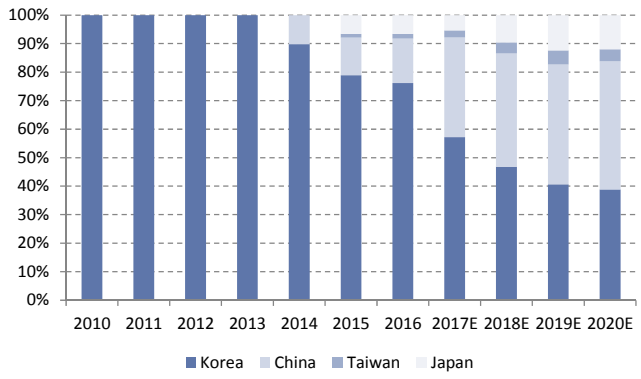
We expect the combined capex from Korean OLED makers to gradually decline starting from next year, while China OLED capex continues to increase slightly each year. We forecast that China OLED capex will be higher than Korea OLED capex by 2019, and reach close to half of global OLED capex by 2020.

Exhibit 64: We expect a high level of OLED capex through 2020
Global OLED capex forecast



Source: Company data, Goldman Sachs Global Investment Research.

Exhibit 65: Capex by Chinese OLED makers to exceed Korea OLED capex by 2019
Global OLED capex weightings by economy



Source: Company data, Goldman Sachs Global Investment Research.

Who will be affected?

Key stock implications in the global technology sector

OLED a disruptive technology with positive/negative implications

We believe OLED will be a disruptive technology that reshapes the supply chain of the display industry. Taking a bullish view on the OLED market, we highlight (1) **Samsung** as the sustainable industry leader, and (2) OLED related material and equipment players (such as **Universal Display, Ulvac, Nikon, Canon Tokki, Tokyo Electron, Applied Materials, SEMCO, Samsung SDI, Nitto Denko, and touch sensor makers)** as potential beneficiaries. We also think **LG Electronics** would benefit if OLED TV demand takes off.

Companies with an LCD focus may find the path more challenging, including (1) LCD suppliers such as **Japan Display**, (2) LCD materials and components (such as FPC: Flexible Print Circuit boards) mainly supplied by Japanese makers). For **LG Display**, we see a mixed impact from OLEDs and LCDs, but the initial cost burden for OLED as well as LCD risk make us stay away from the stock.

We also think OLED could accelerate consolidation of smartphone makers, depending on the degree to which they can secure new technologies. **Apple, Samsung and a few China brands** will further increase their product differentiation, in our view.

Individual company comments

Covered by Daiki Takayama, Asia Tech Hardware analyst

Samsung Electronics (005930. KS, Buy, on CL): OLED gaining importance as new earnings driver

OLED impact: We forecast SEC's OLED sales will expand sharply from W15.7tn in 2016 to W25.5tn in 2017E driven by the iPhone and further increase to W41.5tn in 2020E. As a result, we estimate that the OLED OP weighting will increase to 17% in 2020E from 9% in 2016, and that OLED OP will exceed W10tn in 2020E.

Stock view: We expect the valuation gap between Samsung and global peers to narrow further against a backdrop of (1) strong earnings potential for OLEDs, where we expect Samsung to maintain competitiveness and, in future, to breathe new life into its products via foldable displays; (2) higher shareholder returns; and (3) an upward shift in the margin range for memory. We resume coverage of SEC at Buy (on CL) with a 12-month target price of W3.35mn (see our July 14, 2017 report *Samsung Electronics (005930.KS): Less cyclical, more shareholder friendly; resume with Buy (add to CL)*).

Covered by Giuni Lee, Asia Pacific Technology analyst

Samsung Electro-Mechanics (009150.KS, Buy): New entrant in the OLED chain

OLED impact: We believe that SEMCO will benefit from SEC's likely status as the sole supplier of OLED displays to Apple starting this year, as the supply chain for display FPCBs has also shifted to Korean suppliers such as SEMCO. By providing RF-PCBs for OLED panel production to SEC, the company's exposure to OLED should reach around 5% of sales in 2017E and 6% in 2018E.

Stock view: We are positive on the stock in all business aspects as we believe: 1) the tight market situation in MLCCs will lead to margin expansion, 2) increasing dual camera adoption by major smartphone makers will drive SEMCO's camera module business's top-line growth, and 3) RF-PCB sales growth from entering the OLED iPhone supply chain will lead to a turnaround in the company's PCB/package business. We resume coverage at Buy with a 12-month target price of W125,000 (see our July 14, 2017 industry report *South Korea: Technology: Hardware: Resuming 7 stocks; Buy Samsung Electronics (CL)/SK Hynix/SEMCO* for more details).

Covered by Giuni Lee

LG Display (034220.KS, Sell): Number two mobile OLED player

OLED impact: We expect the company to rapidly increase its OLED sales weighting due to its involvement in both the TV and mobile OLED panel businesses. We project LGD's OLED sales will reach over W9tn by 2020, up from ~W1.4tn in 2016, but at the expense of declining LCD sales. We estimate LGD's OLED sales weighting will reach 32% by 2020E versus 5% in 2016.

Stock view: We expect LGD to continue to be the leading player in the OLED TV panel space, but as one of the main LCD screen suppliers for the iPhone expect it to lose some market share in 2017/2018E as the iPhone display transitions from LCD to OLED. In addition to seeing sizeable losses from OLED, we believe that China LCD capacity will likely cap the LCD business margin as well. We resume coverage at Sell with a 12-month target price of W30,000 (see our industry report for more details).

Covered by Giuni Lee

Samsung SDI (006400.KS, Neutral): Key OLED material provider

OLED impact: We believe that SDI is poised to benefit from OLED market growth in two major ways: 1) Growth in its OLED materials business, and 2) increased equity-method income from Samsung Display Corp. (SDC). While it mainly supplies green host materials to SDC, it has a track record of supplying other OLED materials such as Electron Transport Layers (ETLs) and Pixel Defining Layers (PDLs) that are important materials in the OLED production process. The company is also preparing for the expansion of the OLED polarizer business, which should enable it to further expand its OLED-related business. We expect SDI's OLED material sales to be around 3% of total sales in 2017E.

Stock view: While we believe SDI's electronic materials business will remain the main source of profits for the company, earnings growth is likely to come from both the turnaround of the small-sized LiB business and the reduction of losses in its large-sized LiB business. We believe this is a process that will take time as larger scale is needed. We resume coverage at Neutral with a 12-month target price of W170,000. (See our industry report for more details).

Covered by Giuni Lee

LG Electronics (066570.KS, Neutral): Waiting for the OLED TV boom

OLED impact: We believe that LGE will see a higher portion of sales from OLED TVs going forward as the pioneer of the product, and this will likely help the company to capture a higher overall TV ASP premium than the industry as OLED TVs are sold at a higher price than a comparable LCD TV. However, in order for LGE to deliver a meaningfully higher ASP and margin from higher OLED TV sales, the pricing of OLED TVs may need to come down further as a big gap in terms of pricing still exists. We expect LGE's OLED TV revenue to reach 25% of the company's TV revenue, or 6% of total company revenue, by 2019E from 13%/3% respectively in 2016.

Stock view: While we continue to expect LGE's TV and appliances to drive stable company earnings, we do not have confidence yet of a full smartphone turnaround and we believe it is too early for its vehicle component business to contribute meaningfully to earnings. Given limited upside in the already high margins for both TV and appliances, we will need to see additional catalysts to turn more constructive on the stock. We thus resume coverage at Neutral with a 12-month target price of W79,000. (See our industry report for more details).

Covered by Simona Jankowski, US Hardware & Communication Technology analyst

Apple (AAPL, Buy): The first OLED iPhone can drive meaningful upside

OLED impact: The next iPhone is shaping up to be the most anticipated iPhone since the launch of the iPhone 6 in September 2014, driven by a major redesign marking the 10-year anniversary of the flagship device. In 2017, we expect Apple to add a new member to the family (we call it "iPhone 8") with a larger, 5.8" screen. While nothing has been confirmed

at this stage (as is typical ahead of an Apple product launch), multiple news outlets (including Bloomberg) have reported that the iPhone 8 will include a nearly edge-to-edge OLED display that will result in a larger display size than the iPhone 7 Plus, packed into a form factor more similar to the iPhone 7 (only 15% larger). Combined with this and other significant improvements in iPhone 8, including a 3D sensing driven augmented reality experience, we expect the phone to drive meaningful upside for Apple in FY18 (Sep). We expect the iPhone 8 to account for 58% of 2017 iPhone model volumes during the first four quarters post-launch, with 45mn units shipped in 2HCY17. Importantly, given the significantly higher price of iPhone 8 (potentially starting at $999), we expect iPhone ASPs to increase 16% in FY18 to reach $763. Please see our May 11, 2017 report, *Apple Inc. (AAPL): The first $1,000 iPhone can drive meaningful upside; Buy* for more details.

Stock view: We maintain our Buy rating on Apple. We are more bullish on iPhone 8 as the supply chain provides mounting evidence that it may be significantly more innovative than its two predecessors with capabilities like augmented reality/3D sensing and we expect a stronger product cycle with higher ASPs in FY18. Further, with over US$230bn in cash overseas, Apple would be the top beneficiary from repatriation, which it could deploy for accelerated buybacks and potentially M&A to accelerate its content strategy.

Covered by Wei Chen, Asia Pacific Technology analyst

Hon Hai Precision (2317.TW, Neutral): A potential technology enabler

OLED impact: Hon Hai is the largest shareholder of Sharp (~45% ownership as of 2016), and we believe Sharp will likely lead the OLED investment strategy instead of Hon Hai due to its technology expertise. We estimate the OLED fab will take 1-1.5 years to build and at least several months to achieve satisfactory yield. As such, if Sharp decides to build out capacity for OLED after seeing success from the pilot lines, the earliest timeline it could supply OLED panels to iPhone would be in 2H19E. In such a scenario, Sharp could potentially join the supply chain as a third source after Samsung and LG Display. On the topline, Hon Hai would not be able to recognize any potential Sharp revenue as the accounting treatment is based on the equity method (not the consolidated method).

Stock view: We stay Neutral. Our current Hon Hai model does not assume any OLED display contribution. Also, no meaningful capex has been executed from Hon Hai and Sharp besides the pilot lines to date.

Covered by Toshiya Hari, US Semiconductor & Semiconductor Capital Equipment analyst

Applied Materials (AMAT, Neutral): Beneficiary of strong OLED capex; all eyes on new products

OLED impact: AMAT, which has dominant market share in the CVD (chemical vapor deposition) equipment market, derives ~10% of total revenue from OLED (12% from total displays). We forecast AMAT's Display and Adjacent Markets segment revenue to grow 29%/21% in CY17/18 before declining 3% in CY19. All eyes will be on the company's new products (one of which we believe is an evaporation tool), which we expect to grow AMAT's served available market by 3x. Depending on the rate/magnitude of success with its new products, there could be upside to our CY18/CY19 estimates. For context, one evaporation system which provides 15k of monthly OLED substrate capacity can sell for $150-$200mn vs. $2.1bn in CY18 Display and Adjacent Markets segment revenue (GSe).

Stock view: While we continue to view the outlook for Semi and FPD capex positively, we maintain our Neutral rating on AMAT as we await signs of further share gains and/or gross margin expansion.

Covered by Brian Lee, US Clean Energy analyst

Universal Display (OLED, Buy): Pure play volume leverage driven by industry-leading IP and emissive materials portfolio

OLED impact: As the sole source supplier of phosphorescent red and green emitter material that is required for OLED displays and owing to its strong IP position, we expect

Universal Display to remain a pure-play on the theme. 100% of revenue is derived from the OLED market with the opportunity to increase the served addressable market if blue phosphorescent material can be commercialized, although this is not currently included in our estimates.

Stock view: We remain Buy-rated. We expect an estimated 32% CAGR through 2020 in the broader OLED display market to drive a ~40%/66% revenue/EPS CAGR for Universal Display owing to: (1) the most pure play leverage to growth in OLED adoption; (2) a material and royalty/license revenue model with approximately 72.5% and 97% gross margins, respectively, and (3) the development of new OEMs entering the space (Apple, BOE, etc.).

Covered by Doug Clark, US Hardware & Communication Technology analyst

Corning (GLW, Neutral): Effectively hedged in the transition from LCD to OLED

OLED impact: Corning is the world's largest supplier of glass substrate for electronic devices. Corning's largest end market is LCD TVs, while small form factor devices (e.g. smartphones) represent about 7% of glass demand. **We view the transition to OLED devices as largely neutral for Corning**, especially when considering small form-factor devices are a minority of its sales exposure. On one hand, plastic or flexible OLED devices contain less glass substrate layers in the final panel; thus removing potential content for Corning. However, the manufacturing process of OLED thin-film encapsulation, polyimide (PI) substrate requires high performance glass products produced by companies like Corning. More specifically, Corning's Lotus glass is used by Samsung in the production of the Galaxy S8 and S8+. In other words, Corning is hedged in the transition to OLED as long as share shifts or technology innovation do not change its leading competitive positioning of specialty glass products. Finally, we do see some long term risk for Corning's cover glass business from foldable or flexible displays. If foldable devices use plastic covers instead of cover glass, this could cannibalize Corning's Gorilla Glass business (8% of 2016 sales). Regardless, Corning's Gorilla Glass business is likely to be more influenced by the shift to double-sided glass smartphones (such as in the upcoming iPhone), which doubles cover glass content per phone.

Stock view: We remain Neutral-rated on GLW. We believe glass fundamentals remain healthy, largely driven by rational glass pricing and expanding TV screen sizes. We also see positives from diversifications and growth in Corning's Optical business (33% of sales) and its Gorilla Glass business (8% of sales, poised to benefit from double sided glass iPhone). That said, we think these are largely factored into premium valuation, especially with headwinds from FX coming in 2018E.

Covered by Satoru Ogawa, Japan Hardware & Semiconductor analyst

Ulvac (6728.T; Buy, on CL): Beneficiary of OLED upcycle, with further upside

OLED impact: We expect Ulvac to see significant benefits 1) as OLED will create further demand for their core PVD (sputtering) equipment (70% global market share), and 2) OLED brings incremental topline growth opportunities through product portfolio expansion (i.e., evaporation tools). In FY6/17 we expect Ulvac's OLED related equipment sales to more than triple yoy and account for 20% of sales. Further, we believe high OLED equipment sales will continue on the back of sustained capex. We also see incremental upside if one of the company's customers for evaporation tools successfully enters the mass production phase and begins capacity ramp-up (we assume the ASP of evaporation tools is ~$100mn vs total OLED sales of $400mn in FY6/17).

Stock view: We are Buy-rated (on CL) on Ulvac, our top pick in the Japan equipment sector. We acknowledge some investors are concerned on the sustainability of FPD capex but we believe technology innovation like OLED and ongoing competition between panel makers will keep capex at a high level. Moreover, on the back of strong execution by the current management, we see Ulvac expanding its OP margin from 9.3% in FY6/16 to 15.8% in FY6/19. Despite high market share, attractive business opportunities and strong

execution, the stock trades at a discount versus peers (FY6/18E EV/EBITDA 6.6X vs sector avg. 8.2X).

Covered by Satoru Ogawa

Nikon (7731.T; Buy, on CL): Beneficiary of increasing OLED penetration

OLED impact: Nikon is one of the global leaders in FPD lithography equipment which accounts for 60% of its operating profits. Generally speaking, OLED production requires more lithography process steps, and thus higher penetration of OLED is positive for equipment demand. Currently rival Canon is gaining share with Samsung by offering a bundled product of evaporation tool (Canon has 90% share) and lithography. However, we assume no further share losses in the near term given, 1) OLED ramp-up by Chinese panel makers, where Nikon has higher share, and 2) increasing demand for high resolution panels (i.e. ppi500~), where Nikon is solid.

Stock view: We are Buy-rated (on CL) on Nikon as we believe the market is still underestimating the value of its FPD equipment business. As management appears keen on reforming the company, we expect a successful turnaround in sluggish businesses (loss making semi lithography and the struggling camera business). With this, we expect investors to focus on the strong-growth FPD business with its high margin (40% operating margin)/high share (45% share in FY3/18E). Our SOTP valuation factors in such strong growth in FPD equipment.

Covered by Satoru Ogawa

Canon (7751.T, Neutral): Clear OLED enabler but impact to earnings isn't material

OLED impact: Canon Tokki, a wholly owned subsidiary of Canon, is the leading global supplier of vacuum deposition equipment, a key system used in the process of OLED production. Canon Tokki's equipment has a dominant share globally with key customers including Korean panel makers. We project Canon Tokki's revenue to double from ¥60bn in FY12/16 to ¥120bn in FY12/18E on the back of robust OLED investments.

Stock view: While we view the contribution of OLED business positively, we remain Neutral on Canon, with over 90% of its earnings derived from non-OLED related businesses such as office equipment, cameras, and medical technology.

Tokyo Electron (8035.T, Buy): Benefits from strong OLED capex on top of solid semiconductor business

OLED impact: Tokyo Electron (TEL) generated 9% of its revenue and 3% of its operating profit from FPD equipment in FY3/17. TEL's mainstay products in FPD are plasma etch/ash systems and coater developers. We believe TEL possesses a product portfolio well placed to benefit from increasing investments in both FPD and semiconductors. While we have no exact numbers on OLED-related equipment we think the scale is relatively small at present but that incremental investment from China could provide upside going forward.

Stock view: We are Buy-rated on TEL for 1) margin improvements in key products such as etchers, 2) shareholder return policy approaching top level amongst global peers, and 3) compelling valuation (FY3/19E P/E 14.5X vs. SPE peer average 17X).

Covered by Daiki Takayama

Nitto Denko (6988.T, Neutral): OLED expansion has a greater impact than the loss of LCD polarizing film for iPhone

OLED impact: Nitto Denko is a key supplier in film (polarizing/ITO film) and adhesive technologies in displays for electronic devices. A technological shift from LCD to OLED displays will represent a volume decline for polarizing film for iPhone (only 1 film required for OLED v. 2 films in LCD). However, we expect the value per device to increase on aggregate as the aforementioned negative will be offset by (1) increased adoption of ITO film in film touch sensors (both standard and force touch sensors), (2) selection of a higher value polarizing film (thinner, anti-reflective properties), and (3) incremental adoption of

adhesive and optical films. Although we expect Nitto Denko will not be able to gain high market share for the iPhone 8 in higher-value polarizing film due to Sumitomo Chemical share gains, it should still increase value per device driven by factors (1) and (2).

Stock view: While we expect the optical business to maintain strong momentum in 1H3/18, we believe this is fully captured in the FY3/18E P/E of 22.4X, which in our view also reflects expectations for the medical business. We remain Neutral.

Covered by Daiki Takayama

JDI (6740.T, Neutral): Big restructuring is needed before they decide clear strategy to OLED business

OLED impact: JDI is the leading supplier of small LTPS LCDs mainly for the iPhone and China smartphones (smartphone applications were 82% of total sales in FY3/17). JDI is now facing a significant risk of losing iPhone LCD business in 2017-2018 on the shift to OLED iPhones. It may be forced to reduce fixed costs and conduct restructuring before shifting focus to OLED. We believe JDI is far behind Korea makers in OLED technology (vapor deposition) but also has unique OLED technology (the printing method, which is cheaper but not high resolution, targeting non-smart phone applications). We will closely monitor what kind of strategy is possible for JDI, including potential cash injection from others.

Stock view: Our Neutral rating reflects a low FY3/18E P/B of 0.4X. We remain on the sidelines until we get clear visibility on the company's growth strategies.

Nissha Printing (7915.T, Not Covered): Key beneficiary of OLED iPhone trend

OLED impact: Nissha is the global market leader in film touch sensors for smartphones and tablets. It is the only company that can mass produce GF DITO (Glass/Film Double-sided ITO) touch sensors and we believe the market expects the company to have a 100% market share in both the standard (XY-axis) sensors and force touch (Z-axis) sensors in the OLED iPhone in 2H2017. Film touch sensors are the required standard for the OLED iPhone and other flexible/foldable devices given glass and embedded alternatives lack flexibility.

Exhibit 66: Ratings, 12-month target prices, methodologies, and key risks for companies in our coverage
Major OLED-related companies

Ticker	Name	Rating		Price (7/11)	Target Price	Methodology	Risks
Korea companies							
005930.KS	Samsung Electronics	Buy*	KRW	2,450,000	3,350,000	SOTP applying 25% discount (its lowest historical level relative to peers)	Significant deterioration in memory supply-demand balance, sharp contraction in smartphone margins, and OLED supply bottlenecks
009150.KS	SEMCO	Buy	KRW	102,000	125,000	SOTP	Stronger than expected industry MLCC supply increase, slower than expected dual camera adoption by SEC, and weaker than expected demand for smartphones
006400.KS	Samsung SDI	Neutral	KRW	176,500	170,000	SOTP	Higher/lower cylindrical and polymer battery sales, faster/slower revenue growth in xEV battery, and higher/lower ECM margin
066570.KS	LG Electronics	Neutral	KRW	71,500	79,000	SOTP (based on 2018E divisional EBITDA)	Higher-/lower-than-expected smartphone sales, OLED TV demand, higher-/lower-than-expected H&A margins
034220.KS	LG Display	Sell	KRW	37,000	30,000	P/B-ROE correlation based on three year historical average	Slower-than-expected LCD supply growth, stronger-than-expected demand for OLED TV, and faster-than-expected ramp up in mobile OLED
Japan companies							
6728.T	Ulvac	Buy*	JPY	5,620	6,800	Blend: 85% FY6/18E EV/GCI vs. CROCI/WACC & 15% M&A methodology	Sharp development cost growth, OLED investment delays, deterioration in LCD market conditions
8035.T	Tokyo Electron	Buy	JPY	15,670	16,700	FY3/18 EV/GCI vs. CROCI/WACC	Deterioration in macroeconomic conditions, deterioration in market prices, and excessive focus on changes in quarterly earnings
6988.T	Nitto Denko	Neutral	JPY	9,814	8,950	FY3/18-19E avg. EV/GCI vs. CROCI/WACC	Greater than expected swings in smartphone production, forex volatility
7731.T	Nikon	Buy*	JPY	1,865	2,300	SOTP based on EV/DACF sector applied to FY3/18-19E avg. DACF	China's FPD investment, drop in FPD lithography market share, strong yen
7751.T	Canon	Neutral	JPY	3,769	3,560	FY12/17 target dividend yield of 4.5%	Changes in office quipment demand, forex, and dividend policy
6740.T	Japan Display	Neutral	JPY	203	230	FY3/18E EV/EBITDA of 2.4x	Sudden swings in smartphone production, yield improvement/deterioration, weaker/stronger yen
Taiwan companies							
2317.TW	Hon Hai	Neutral	TWD	119	98	FY17E sector avg. PB/ROE	Execution from other ODMs and order allocation within Apple, market share of Chinese OEMs
US companies							
AAPL	Apple	Buy	USD	146	170	15x CY18E EPS of $11.38	Product cycle execution, end demand, and a slower pace of innovation
OLED	Universal Display	Buy	USD	109	140	DCF, 15% COE	Delayed OLED capacity ramp, unfavorable litigation, slow OLED adoption
GLW	Corning	Neutral	USD	30	29	17x normalised EPS estimate	End demand volatility, traction with new products, forex volatility, competition
AMAT	Applied Materials	Neutral	USD	45	49	14x normalized EPS estimate	Memory supply/demand, timing of China capex, competition

Note: * denotes stock is on our Conviction List. Closing prices are as of July 11, 2017.

Source: Company data, Goldman Sachs Global Investment Research.

Exhibit 67: 12-m target price history for Korean names

Samsung Electronics (005930.KS)	
Date of report	Target price (W)
24-Jan-17	1,950,000
6-Jan-17	1,880,000
16-Dec-16	1,850,000
27-Oct-16	1,750,000
11-Oct-16	1,700,000
7-Oct-16	1,750,000
19-Sep-16	1,650,000
28-Jul-16	1,550,000
7-Jul-16	1,500,000
15-Jun-16	1,400,000
29-Apr-16	1,350,000
7-Apr-16	1,300,000
28-Jan-16	1,250,000
20-Jan-16	1,300,000
30-Oct-15	1,400,000
7-Oct-15	1,350,000
20-Sep-15	1,300,000
31-Jul-15	1,400,000
2-Jul-15	1,450,000
21-May-15	1,550,000
6-May-15	1,600,000

SK Hynix (000660.KS)	
Date of report	Target price (W)
30-Jan-17	65,000
16-Dec-16	54,000
20-Oct-16	50,000
18-Sep-16	43,000
28-Jun-16	35,000
26-Apr-16	32,000
30-Mar-16	33,000
26-Jan-16	34,000
20-Jan-16	36,000
22-Oct-15	50,000
11-Oct-15	53,000
23-Jul-15	57,000
5-May-15	60,000
28-Jan-15	55,000

LG Display (034220.KS)	
Date of report	Target price (W)
24-Jan-17	23,000
21-Nov-16	22,000

LG Electronics (066570.KS)	
Date of report	Target price (W)
25-Jan-17	53,000
6-Jan-17	50,000
16-Dec-16	51,000
21-Nov-16	50,000

Samsung SDI (006400.KS)	
Date of report	Target price (W)
24-Jan-17	105,000
16-Dec-16	100,000
28-Oct-16	95,000
20-Oct-16	100,000
19-Sep-16	105,000
29-Jul-16	110,000
15-Jun-16	120,000
26-Jan-16	110,000
20-Jan-16	120,000
31-Oct-15	110,000
31-Jul-15	120,000
19-Jul-15	130,000
29-Apr-15	140,000
11-Feb-15	150,000

Samsung Electro-Mechanics (009150.KS)	
Date of report	Target price (W)
25-Jan-17	54,000
16-Dec-16	50,000
27-Oct-16	48,000
20-Oct-16	50,000
19-Sep-16	52,000
22-Jul-16	49,000
15-Jun-16	50,000
26-Apr-16	51,000
7-Apr-16	53,000
29-Jan-16	55,000
20-Jan-16	57,000
30-Oct-15	60,000
28-Jul-15	55,000
2-Jul-15	57,000
6-May-15	70,000
30-Jan-15	60,000

Samsung SDS (018260.KS)	
Date of report	Target price (W)
23-Jan-17	144,000
16-Dec-16	145,000
29-Jul-16	156,000
4-Jul-16	146,000
22-Jan-16	250,000
20-Jan-16	260,000
31-Jul-15	250,000

Source: Datastream, Goldman Sachs Global Investment Research.

This page is intentionally left blank

Appendix

Details of our OLED supply and demand model

OLED Supply: Led by SEC, followed by LGD and China

We expect global OLED supply will continue to be led by SEC, on the back of its existing OLED fabs as well as capacity expansion plans. At the same time, we believe that LGD and Chinese OLED makers will be aggressive in ramping capacity as they try to catch up to SEC. For Japanese and Taiwanese OLED makers, we think capacity expansion will likely be less aggressive due to a lack of financial resources and a continued focus on LCD.

Samsung Electronics

SEC is currently producing OLED displays in its Gen4.5 A1 fab, Gen5.5 A2 fab, and Gen6 A3 fab. These fabs produce only mobile displays (non-TV displays) as SEC is not conducting R&D on OLED TV anymore after shifting its TV strategy to focus on Quantum Dot TV. While A2 is mainly where rigid OLEDs are produced for its own mobile division and Chinese smartphone customers, we expect most of the A3 capacity will supply the OLED screen for the upcoming new iPhone.

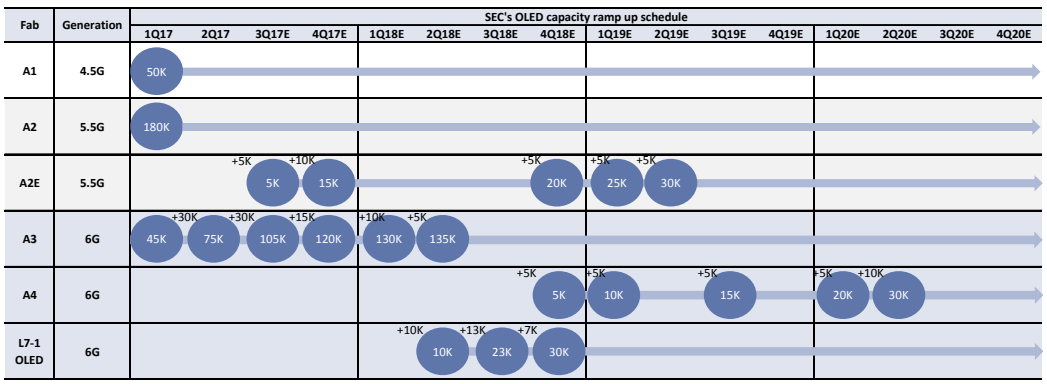
Given that SEC is the only OLED maker with sufficient capacity to meet the demand of a customer's flagship model, we expect the company to continue to expand capacity as the smartphone industry sees more companies trying to adopt OLED as the main display. We believe SEC has several possible options to expand capacity, for instance by converting its L7-1 LCD fab into an OLED fab, increasing the capacity of its A2 fab (A2E), and also building another Gen6 fab (A4) to meet rapidly rising demand.

Exhibit 68: SEC has by far the largest OLED capacity in the world
Samsung Electronics' current and future OLED fabs and capacity projection

Company	Fab	Generation	Rigid/Flexible	Application	Total OLED Capacity (as of end-1Q17)
Samsung Electronics	A1	Gen4.5	Rigid	Mobile	50K/month
Samsung Electronics	A2	Gen5.5	Rigid and Flexible	Mobile	180K/month
Samsung Electronics	A3	Gen6	Flexible	Mobile	45K/month
Samsung Electronics	A4	Gen6	Flexible	Mobile	Mass production expected from 2H18
Samsung Electronics	L7-1 OLED	Gen6	Flexible	Mobile	Mass production expected from 1H18

Source: Company data, Goldman Sachs Global Investment Research.

Exhibit 69: We expect Samsung to continue to expand its mobile OLED capacity
GS projection of SEC's OLED capacity expansion plan



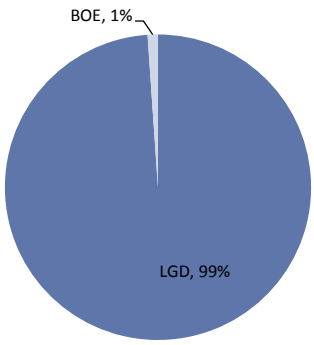
Source: Company data, Goldman Sachs Global Investment Research.

LG Display

LGD is currently producing OLED displays in its Gen4.5 E2 line and Gen8 E3 and E4 lines. E2 is where flexible OLED (also referred to by LGD as plastic OLED or POLED) is produced mainly for the Apple Watch. It has also produced OLED screens for LG Electronics (LGE)'s smartphones in the past albeit on a small scale. E3 and E4 are lines using oxide backplane to produce OLED TV screens, from which the majority of LGD's current OLED sales are derived (~70% of OLED sales as of 2016).

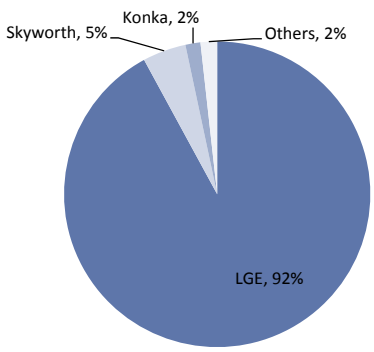
LGD is currently aggressively expanding OLED capacity for both mobile and TV. As its main mobile customers LGE and Apple are both preparing to launch a smartphone with OLED screen starting from 2H17, LGD is planning to ramp two Gen6 flexible OLED lines named E5 and E6. We expect E5 to start mass production in 3Q17 and E6 mass production to begin in 2Q18. LGD is the only company that produces OLED TV screens after SEC changed its TV strategy. As its major shareholder and captive customer LGE is the company that has most of the market share in OLED TVs, LGD's TV OLED screen capacity depends on demand from a limited number of customers. We expect LGD to increase its E4 capacity by another 26K/month to reach a total of 60K/month capacity for TV OLED screens by 4Q17.

Exhibit 70: LGD is dominant in OLED TV displays…
OLED TV display area market share (2017E)



Source: Goldman Sachs Global Investment Research.

Exhibit 71: …while LGE is dominant in OLED TV
OLED TV unit market share (2016)



Source: IHS

We currently assume LGD will first build a Gen6 flexible OLED line in P10 starting mass production in 1H18, and then a Gen 10.5 TV OLED line starting mass production in1H20 could follow. As the OLED TV market is still at a very early stage and LGD is the only producer of such screens, we believe it has more time to decide on its OLED TV screen capacity.

Exhibit 72: We expect LGD to expand OLED capacity for both mobile and TV aggressively
LG display's current and future OLED fabs/lines and capacity projection

Company	Fab/Line	Generation	Rigid/Flexible	Application	Total OLED Capacity (as of end-1Q17)
LG Display	E2	Gen4.5	Flexible	Mobile	20K/month
LG Display	E3	Gen8	Rigid	TV	8K/month
LG Display	E4	Gen8	Rigid	TV	26K/month
LG Display	E5	Gen6	Flexible	Mobile	Mass production expected from 2H17
LG Display	E6	Gen6	Flexible	Mobile	Mass production expected from 1H18
LG Display	P10	Gen6	Flexible	Mobile	Mass production expected from 1H18
LG Display	P10	Gen10.5	Rigid	TV	Mass production expected from 1H20

Source: Company data, Goldman Sachs Global Investment Research.

Chinese OLED makers

There are several Chinese players trying to establish a presence in the OLED market. However there are currently a limited number of companies who are actually producing OLED screens that are used in commercial products, and the capacity expansion plans of the Chinese OLED makers could easily change depending on the production yield and market demand. As such, visibility on supply is lower than for the leading Korean OLED makers.

BOE Technology is the most ambitious Chinese maker based on the plans it has announced. BOE is different from most other Chinese OLED makers; like LGD, it has plans to enter both the mobile OLED and the OLED TV markets. While it already has a Gen5.5 fab in Ordos (B6), it is planning to build additional fabs for mobile OLED production such as Gen6 fabs in Chengdu (B7) and Mianyang (B11). It is also testing white OLED technology at its Gen8 Hefei fab (B5) for OLED TV display production, which could become another source of OLED TV screens besides LGD in the future if yield were to improve significantly.

Exhibit 73: BOE – aggressive in expanding both mobile and TV OLED capacity
BOE's current and future OLED fabs and capacity projection

Company	Fab	Generation	Rigid/Flexible	Application	Total OLED Capacity estimated by end-2020
BOE	Hefei B5	Gen8	Rigid	TV	28K/month
BOE	Ordos B6	Gen5.5	Rigid	Mobile	4K/month
BOE	Chengdu B7	Gen6	Rigid and Flexible	Mobile	45K/month
BOE	Mianyang B11	Gen6	Flexible	Mobile	20K/month

Source: Company data, Goldman Sachs Global Investment Research.

Tianma and **Visionox** are two major Chinese players trying to gain a foothold in the mobile OLED market. Tianma has a history of supplying LTPS panels to most of the main local smartphone makers. Since backplane technology is one of the important factors for OLED production, we believe the company has an advantage over other Chinese OLED makers in this regard. Visionox is known for its experience in producing PM OLED, and is trying to enter the current mainstream AM OLED market.

Exhibit 74: Tianma and Visionox expected to become important Chinese OLED makers
Tianma and Visionx current and future OLED fabs and capacity projection

Company	Fab	Generation	Rigid/Flexible	Application	Total OLED Capacity estimated by end-2020
Tianma	Shanghai	Gen5.5	Rigid and Flexible	Mobile	12K/month
Tianma	Wuhan	Gen6	Rigid and Flexible	Mobile	33K/month
Visionox	Kunshan	Gen5.5	Rigid and Flexible	Mobile	26K/month
Visionox	Gu'an	Gen6	Flexible	Mobile	15K/month

Source: Company data, Goldman Sachs Global Investment Research.

EverDisplay is the current leading Chinese OLED supplier. Its OLED screens from the Gen4.5 Shanghai fab are supplied to local smartphone makers such as Huawei and Xiaomi. However, we believe its market share will likely decline as more aggressive players such as BOE expand capacity. Other notable OLED makers such as **China Star (CSOT)**, **Truly**, and **Royole** may also participate in the race to expand presence in the industry.

Taiwanese and Japanese OLED makers

AU Optronics (AUO) currently has around 7.5K/month OLED capacity (motherglass basis) at its Gen4.5 Singapore fab, which is mainly used to provide OLED screens for Chinese whitebox makers. The company has mentioned in the past that it is not planning to invest high capex into OLED, and that it will develop OLED for applications besides smartphones such as wearables and automotive.

Hon Hai is investing in OLED through **Sharp**, which currently is conducting R&D activities at its Sakai fab. After attaining satisfactory results at the pilot line, we believe that Hon Hai/Sharp could build an OLED mass production plant in China. Mass production at the Sakai fab is also a possibility and we assume production there starting from 2H19.

As we expect **Japan Display (JDI)** to lose market share in this year's iPhone due to OLED screen adoption, the company may have to pick up the pace in OLED mass production. While it is currently conducting R&D, its recent financial struggles may make it difficult for the company to aggressively invest in OLED. We expect the company to try to ramp OLED capacity at its Mobara fab and Hakusan fab.

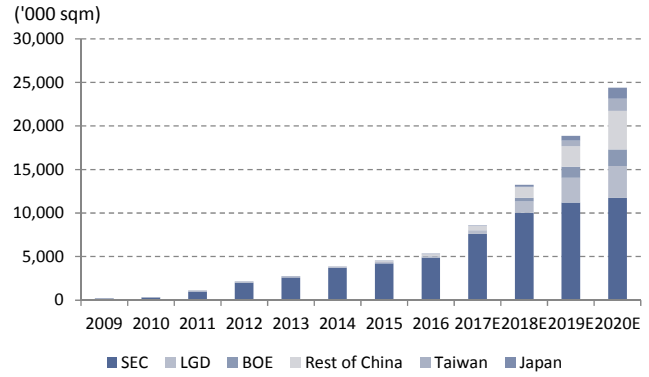
JOLED was established by JDI, Sony, and Panasonic, and focuses on developing mid/large size OLED screens for tablets, notebooks, and TVs. The company focuses on R&D for an inkjet printing method of production to lower the production cost, but the technology is well behind the current vacuum evaporation method used for OLED material deposition.

Growing capacity from China unlikely to translate into actual output

Actual output is much more important than capacity especially for a capital intensive industry at a high-growth stage like OLED, as companies with higher yield/utilization have a competitive advantage. While we estimate that Chinese OLED makers will be aggressive in adding OLED capacity at least for the next three years, the added capacity will likely not translate into actual output in our view. This is mainly due to:

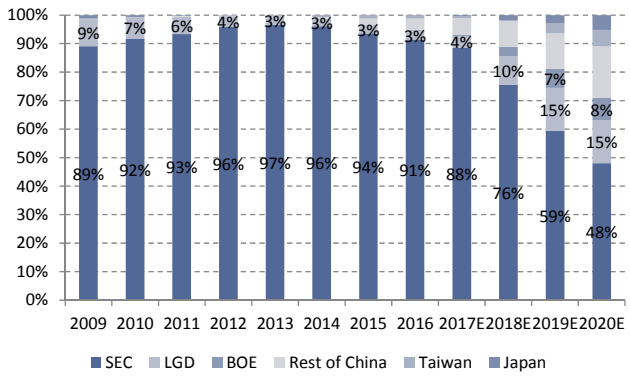
1) **The low yield** that every new entrant will experience, just as both SEC and LGD saw at their respective early stages of OLED production, and
2) **The lack of customer reference** as most of the set makers will continue to be dependent on SEC, the dominant player in the mobile OLED market, and to a lesser extent LGD. We believe any new entrants would have to offer a competitive price to set makers even assuming the quality of the OLED display is on par with the market leaders in order to take away market share. In our view, this is unlikely to happen for some time mainly because of the lack of core technologies and experience in producing OLED screens.

Exhibit 75: Mobile OLED capacity to be led by SEC, but growth coming from China
Mobile OLED area capacity



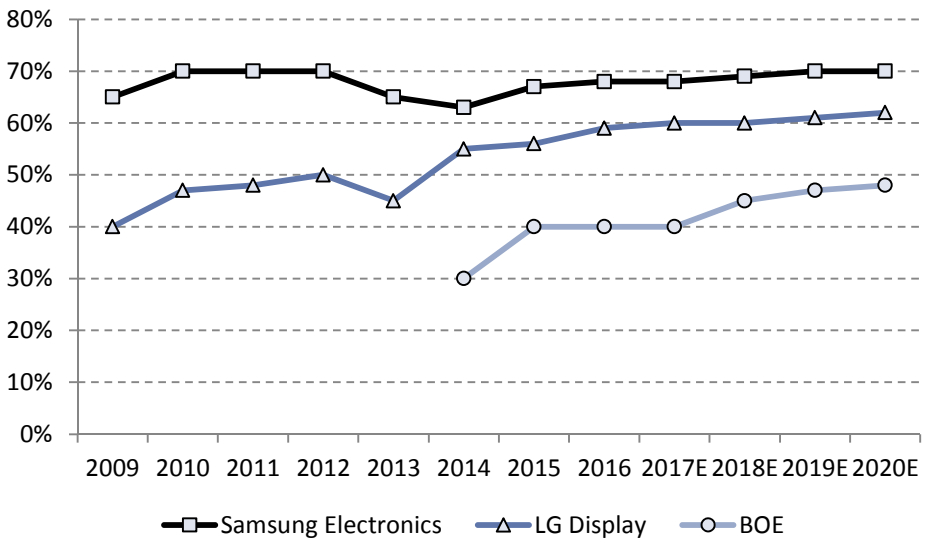
Source: Company data, Goldman Sachs Global Investment Research.

Exhibit 76: We expect SEC's mobile OLED area capacity share to decline to 48% by 2020…
Mobile OLED area capacity share



Source: Company data, Goldman Sachs Global Investment Research.

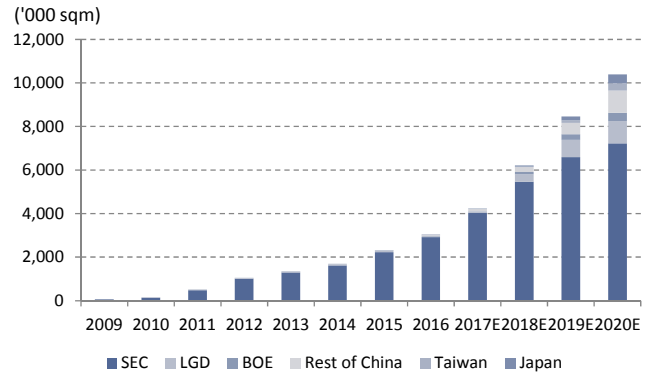
Exhibit 77: …but as we estimate new market entrants such as BOE to have much lower yield than the market leaders like SEC…
Blended yield and glass efficiency comparison



Note: Above numbers are company average yield multiplied by glass efficiency

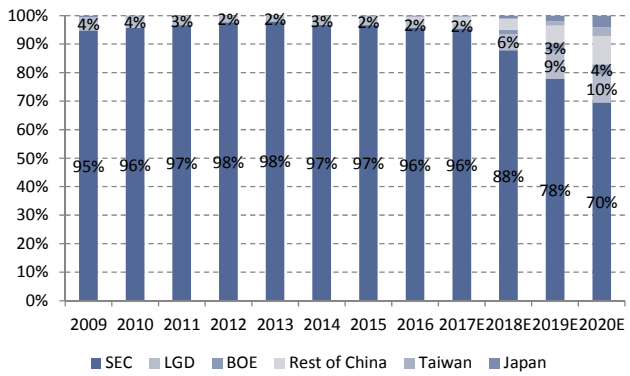
Source: Goldman Sachs Global Investment Research.

Exhibit 78: …we expect SEC to be positioned much stronger in terms of actual output…
Mobile OLED area output



Source: Company data, Goldman Sachs Global Investment Research.

Exhibit 79: …and project a 70% share in mobile OLED in terms of actual output in 2020, much higher than the 48% capacity share
Mobile OLED area output share



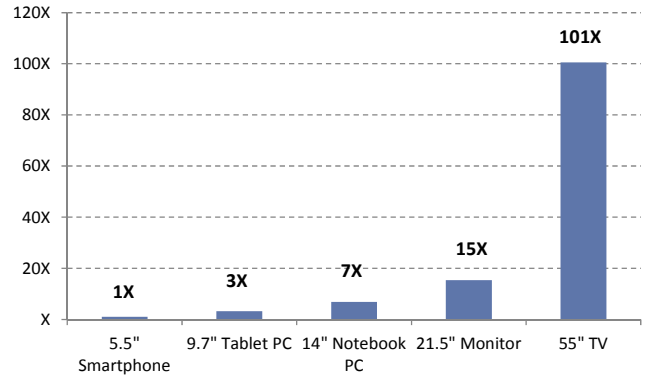
Source: Company data, Goldman Sachs Global Investment Research.

OLED Demand: Smartphones the main driver

We breakdown OLED demand into different applications such as **smartphones, tablet PCs, notebooks, monitors, TVs, and VR/AR**.

For total OLED area demand, we expect smartphones to be the main driver, comprising 73% of area demand in 2016 and still accounting for 58% of total OLED area demand by 2020. At the same time, we expect the TV OLED area demand weighting to rise to 33% by 2020 from 17% in 2016, mainly due to the much larger area size compared to other products (a 55" TV has an area ~100X larger than a 5.5" smartphone).

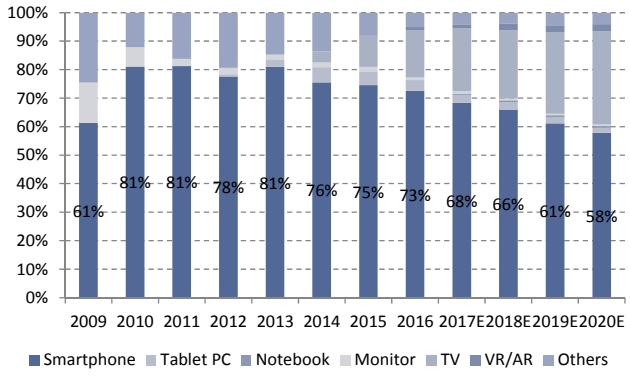
Exhibit 80: As TV area is much larger than other products…
Area comparison between different products



Note: Based on 1X = area of 5.5" smartphone

Source: Goldman Sachs Global Investment Research.

Exhibit 81: …TV OLED area demand to grow significantly although smartphone to still comprise the largest portion
OLED area demand breakdown by applications

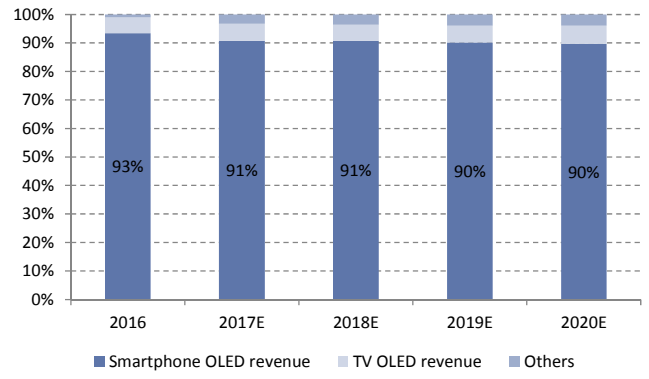


Source: Company data, IHS, Gartner, Goldman Sachs Global Investment Research.

However from the industry revenue perspective, we expect smartphones to comprise at least 90% of the OLED market during our forecasting period, as we estimate that the ASP/area for smartphone OLED is at least 4-5X higher than that of TV OLED.

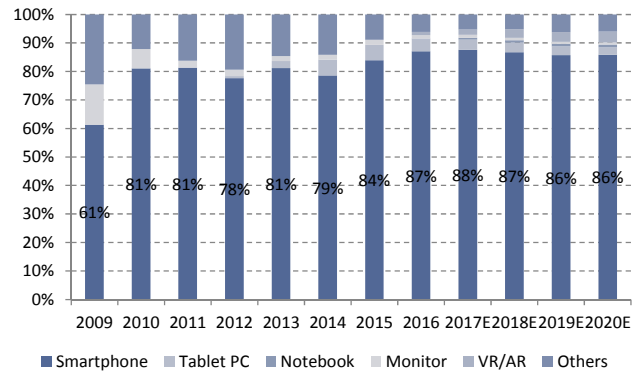
As mobile OLED is much more significant in terms of revenue we examine the mobile OLED area demand breakdown by application. We expect smartphones to remain the main driver in the mobile space, comprising 85-90% of mobile OLED area demand throughout our current forecast period.

Exhibit 82: We expect OLED displays for smartphones to comprise at least 90% of the total OLED market
OLED revenue breakdown by application



Source: Company data, Goldman Sachs Global Investment Research.

Exhibit 83: Smartphone is the main driver for mobile OLED demand
Mobile OLED area demand breakdown by application

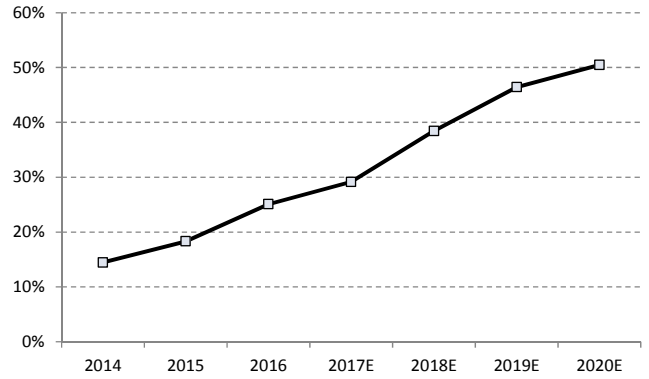


Source: Company data, IHS, Gartner, Goldman Sachs Global Investment Research.

Smartphones

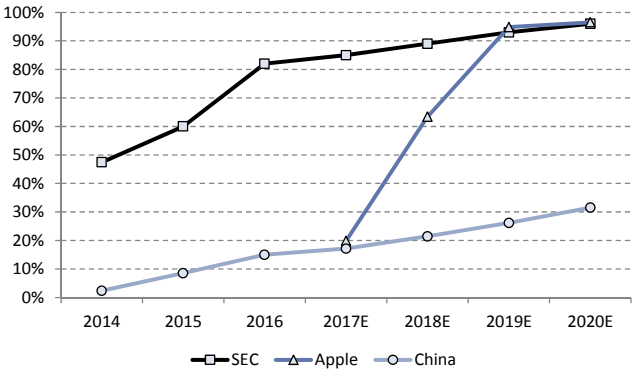
We expect smartphone to be the main demand driver of the OLED market on the back of our projection that **OLED penetration in smartphone will double to 50% by 2020 from 25% in 2016**. We believe that **1) SEC's internal demand** from its mobile division, **2) Apple's adoption of OLED display** starting this year's iPhone, and **3) increasing adoption of OLED in Chinese smartphones** will be the core drivers for the rise in OLED penetration.

Exhibit 84: We expect OLED penetration in smartphones to double to 50% by 2020
Global smartphone OLED penetration



Source: Company data, Goldman Sachs Global Investment Research.

Exhibit 85: We expect SEC, Apple, and Chinese smartphone makers to drive higher OLED penetration
OLED penetration by smartphone maker



Source: Company data, Goldman Sachs Global Investment Research.

SEC already has a high OLED penetration in its smartphones as it has been using OLED for all of its flagship smartphones since launching the Galaxy smartphone brand in 2010. Looking at the displays it has used in its flagship phones, the trends are **1) using more**

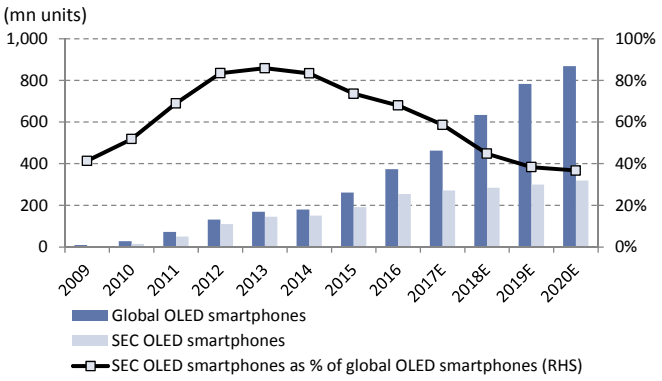
flexible OLED, and **2) using larger OLED screen size**. For example the latest flagships GS8 and GS8+ both use flexible OLED screen, and the display size is the largest ever at around 6" for both. We believe these trends will support OLED revenue and area demand from SEC smartphones, although SEC's OLED smartphone weighting within global OLED smartphones will likely decline due to increasing OLED smartphone shipments from Apple and China. Assuming use of more OLED screens for its mid-range and low-end smartphones, we expect OLED penetration in SEC's smartphones to rise to 96% by 2020 from 82% in 2016.

Exhibit 86: Since launching the Galaxy smartphone brand in 2010, SEC has used OLED as the main display in its flagship smartphones
SEC's major flagship smartphones using OLED display

Launch date	Model	Display type	Display size (inch)	Resolution	Pixels per inch
June 2010	Galaxy S	Rigid OLED	4	480x800 (WVGA)	233
April 2011	Galaxy S II	Rigid OLED	4.3	480x800 (WVGA)	217
October 2011	Galaxy Note	Rigid OLED	5.3	800x1280 (WXGA)	285
May 2012	Galaxy S III	Rigid OLED	4.8	720x1280 (HD)	306
September 2012	Galaxy Note II	Rigid OLED	5.5	720x1280 (HD)	267
April 2013	Galaxy S4	Rigid OLED	5	1080x1920 (FHD)	441
September 2013	Galaxy Note 3	Rigid OLED	5.7	1080x1920 (FHD)	386
October 2013	Galaxy Round	Flexible OLED	5.7	1080x1920 (FHD)	386
April 2014	Galaxy S5	Rigid OLED	5.1	1080x1920 (FHD)	432
October 2014	Galaxy Note 4	Rigid OLED	5.7	1440x2560 (QHD)	515
November 2014	Galaxy Note Edge	Flexible OLED	5.6	1600x2560 (WQXGA)	524
April 2015	Galaxy S6	Rigid OLED	5.1	1440x2560 (QHD)	577
April 2015	Galaxy S6 edge	Flexible OLED	5.1	1440x2560 (QHD)	577
August 2015	Galaxy Note5	Rigid OLED	5.7	1440x2560 (QHD)	518
August 2015	Galaxy S6 edge+	Flexible OLED	5.7	1440x2560 (QHD)	518
March 2016	Galaxy S7	Rigid OLED	5.1	1440x2560 (QHD)	577
March 2016	Galaxy S7 edge	Flexible OLED	5.5	1440x2560 (QHD)	534
April 2017	Galaxy S8	Flexible OLED	5.8	1440x2960 (QHD)	570
April 2017	Galaxy S8+	Flexible OLED	6.2	1440x2960 (QHD)	529

Source: Company data.

Exhibit 87: SEC OLED smartphones as % of global OLED smartphones to fall due to increasing portion of OLED smartphones from Apple and China
SEC OLED smartphone as % of global OLED smartphones



Source: Company data, Goldman Sachs Global Investment Research.

Apple has traditionally used TFT-LCD as the main display since the first iPhone was released in 2007. However this will likely change starting this year as we believe Apple will adopt OLED in one of the new iPhone models expected to launch later this year. (Please refer to the report *Faster than Light: OLED goes mainstream* published on May 23, 2016 for more details).

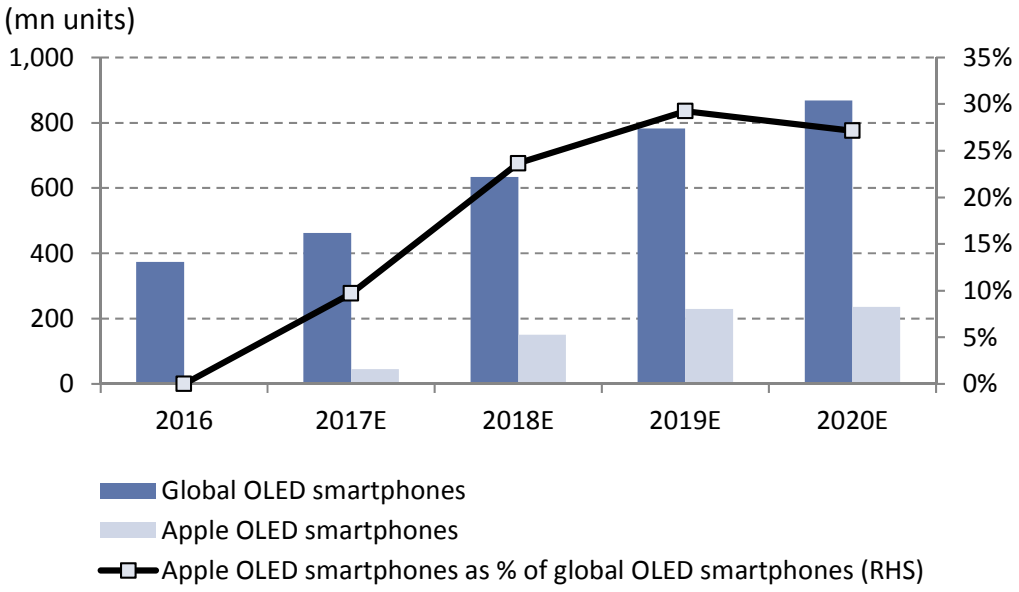
We believe there are several advantages of OLED versus LCD that provides the motivation to do so, such as a lighter and thinner form factor and faster response time. As we expect Apple to start to use OLED in all of its new iPhones starting next year, we believe the OLED penetration in Apple's smartphones will rapidly rise to 97% by 2020 from 20% in 2017.

Exhibit 88: OLED has many advantages over LCD such as faster response time and more freedom for a flexible/foldable form factor, as backlight is not required
Key advantages and disadvantage of OLED vs. LCD

Advantages of OLED vs. LCD	Disadvantages of OLED vs. LCD
Faster response time	Higher unit cost as most fabs not fully depreciated
More freedom for flexible/foldable form factor	Lower life time
Thinner body as backlight is not required	Burn-in images
Lighter weight	
Better color reproduction	
Wider viewing angle	

Source: Goldman Sachs Global Investment Research.

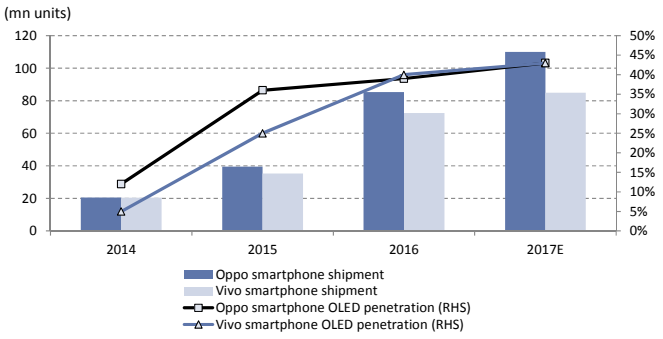
Exhibit 89: We expect Apple OLED smartphones to reach approximately 1/4 of global OLED smartphones in 2018 as we assume all new iPhones next year will use OLED
Apple OLED smartphone as % of global OLED smartphones



Source: Company data, Goldman Sachs Global Investment Research.

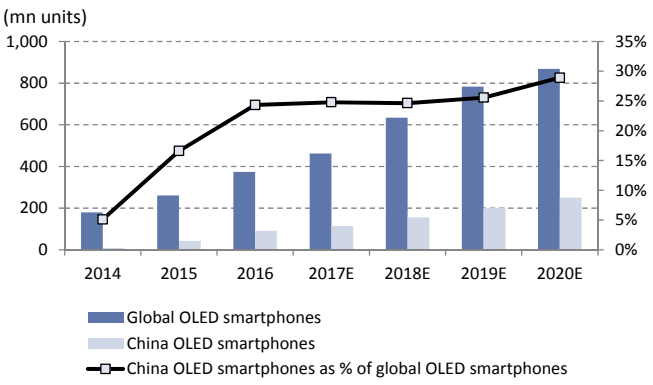
For **Chinese smartphone** makers, companies such as **Oppo** and **Vivo** have achieved shipment growth, with the early adoption of OLED screens to differentiate the hardware being one of the main reasons, in our view. We expect an increasing number of companies to try to follow the strategy of Oppo and Vivo to imitate their success. Key "innovator" Apple starting to use OLED could also motivate Chinese companies to increase usage. We therefore expect OLED penetration in Chinese smartphones to double to 31% by 2020 from 15% in 2016.

Exhibit 90: We believe the aggressive adoption of OLED was one of the main reasons for Oppo and Vivo's success
Oppo and Vivo's smartphone shipment and smartphone OLED penetration



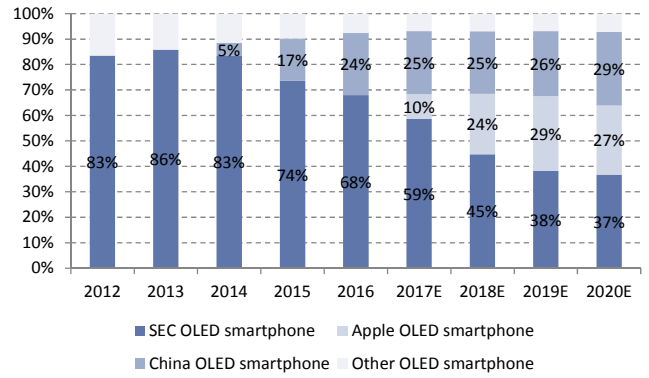
Source: Company data, Gartner, IHS, Goldman Sachs Global Investment Research.

Exhibit 91: We expect China OLED smartphones as % of global OLED smartphones to continue to rise mainly due to more players trying to differentiate the hardware
China OLED smartphone as % of global OLED smartphone



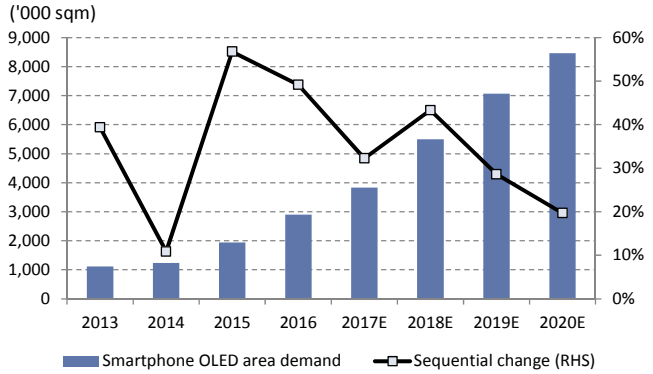
Source: Company data, Goldman Sachs Global Investment Research.

Exhibit 92: By 2020, we expect the global OLED smartphone shipment will not be heavily dependent on a single company
Global unit share of OLED smartphone by company



Source: Company data, Goldman Sachs Global Investment Research.

Exhibit 93: We expect smartphone OLED area demand to continue to grow on the back of larger screen size and higher OLED penetration in smartphones
Smartphone OLED area demand

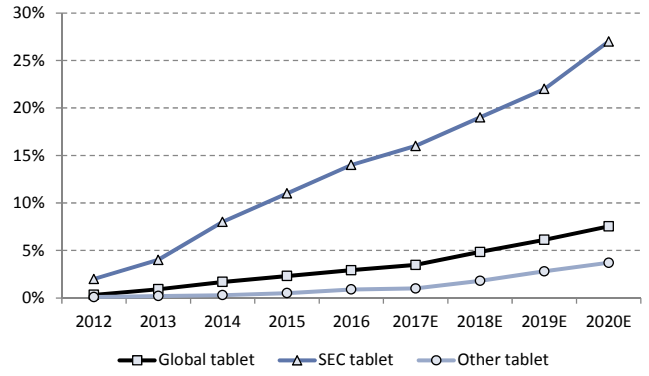


Source: Company data, Goldman Sachs Global Investment Research.

Tablet PC

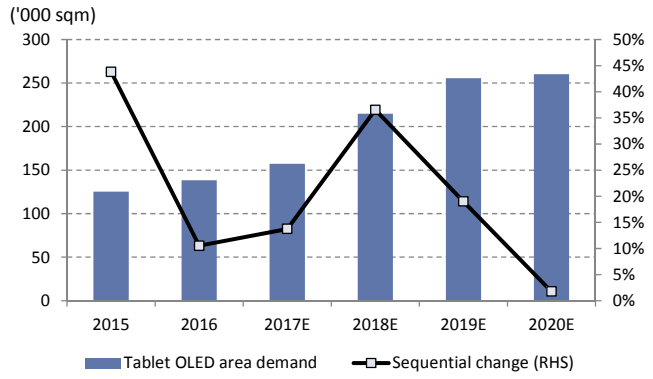
The first tablet to use an OLED screen was SEC's Galaxy Tab 7.7 released late 2011 in Korea. A few other models from other companies have also adopted OLED screens, such as the Toshiba Excite 7.7, but SEC has been the only company creating meaningful OLED demand from tablets. We believe the reason for the slow adoption has been primarily the high cost of OLED panels as well as the limited supply for other applications besides smartphones. We expect OLED penetration in tablet PCs to rise to around 8% by 2020 from 3% in 2016, mainly led by OLED penetration in SEC tablets rising to 27% from 14% during the same period. Due to the limited visibility and the tight supply situation, we assume the iPad will not use OLED screens during our forecasting period, but assuming Apple adopts OLED in half of its tablets, we estimate that global OLED penetration in tablet PCs could be higher than 20% by 2020.

Exhibit 94: Tablet OLED penetration mainly led by SEC
Tablet OLED penetration



Source: Company data, Goldman Sachs Global Investment Research.

Exhibit 95: We do not expect a significant OLED area demand contribution from tablets
Tablet OLED area demand



Source: Company data, Goldman Sachs Global Investment Research.

Notebook PCs and Monitors

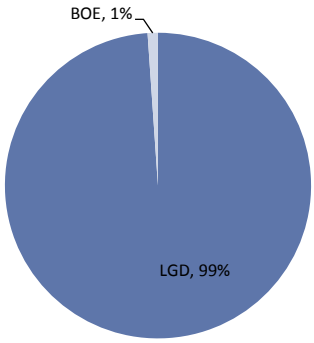
For both notebook PCs and monitors, the use of OLED displays has been limited due to the higher cost and the burn-in effect. As OLED displays do not use a backlight as a source of light, but rather consist of organic materials that emit light, displaying the same image for a long time creates an after-image on the screen known as a burn-in. For OLED, each pixel is driven independently and the lifetime of the OLED emitter is limited. Differences in image retention will occur as a much-used pixel will not be as bright as a pixel that has not been driven significantly.

As notebook PCs and monitors are often used for displaying the same screen for a long time (usually a white screen for Internet usage and Word processing), they tend to be more susceptible to burn-in than smartphones. We expect **OLED penetration for both notebook PCs and monitors to remain low at around 1%** during our forecast period, while we recognize there could be some niche demand for OLED screens for gaming purposes and also for high-end medical monitors.

TVs

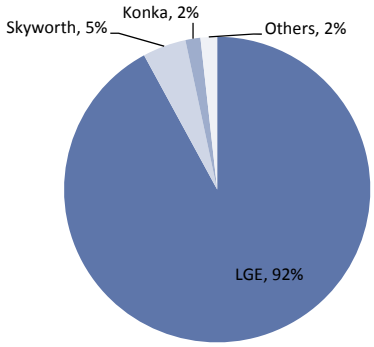
While LGD is the only commercial supplier of TV OLED panels currently and this should continue to be the case for the next few years, the OLED TV market that has been dominated by LGE is starting to see more participants. As all of these entrants procure LGD's OLED panels, we believe LGD's TV OLED capacity is a good indicator of demand. Reflecting our TV OLED capacity forecast for LGD and considering the still much higher price points compared to LCDs, we expect OLED penetration in TVs to remain low. However due to the positioning in the premium segment and the larger average size than LCD TVs, we expect TV OLED to contribute meaningfully to global OLED area demand.

Exhibit 96: LGD is dominant in TV OLED display…
TV OLED display area market share (2017E)



Source: Goldman Sachs Global Investment Research.

Exhibit 97: …while LGE is dominant in OLED TV
OLED TV unit market share (2016)



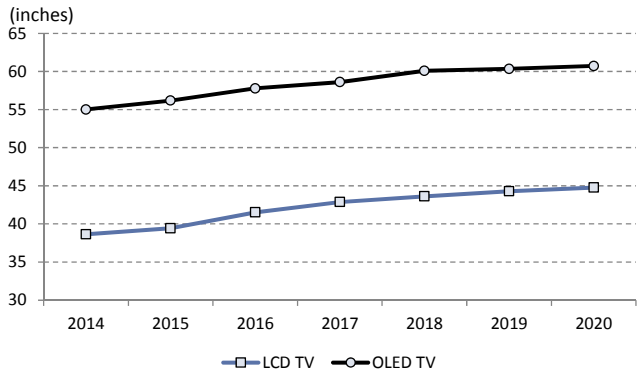
Source: IHS

Exhibit 98: More OLED TV brands entering the market
List of key companies that have launched or are planning to launch OLED TV

	Company	Launch year	Country
Launched	LG Electronics	2013	Korea
	Skyworth	2014	China
	Changhong	2015	China
	Konka	2015	China
	Panasonic	2015	Japan
	Philips	2016	Netherlands
	Loewe	2016	Germany
	Sony	2017	Japan
Planning to launch	Bang & Olufsen		Denmark
	Toshiba		Japan

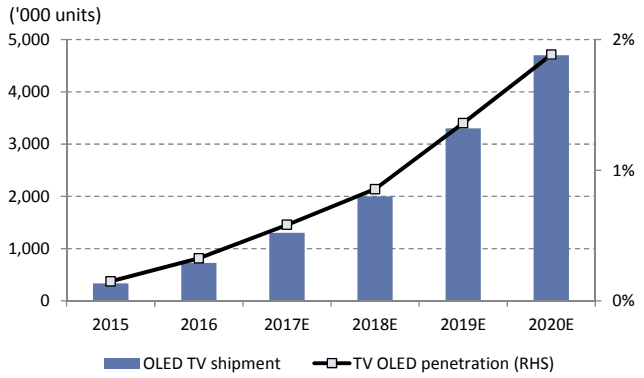
Source: Company data.

Exhibit 99: Average size of OLED TV much higher than LCD TV
Industry average TV size



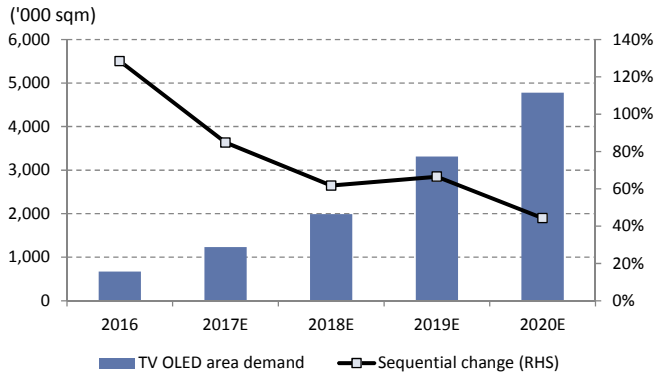
Source: IHS.

Exhibit 100: We expect OLED penetration in TV to remain below 2% by 2020…
OLED TV shipment and penetration



Source: Company data, IHS, Goldman Sachs Global Investment Research.

Exhibit 101: …but area demand to grow significantly on the premium positioning and larger screen size
TV OLED area demand



Source: Company data, IHS, Goldman Sachs Global Investment Research.

VR/AR

Faster response time, lighter weight, wider viewing angle, and better color reproduction are some of the advantages that OLED can offer compared to other displays for better performance using head-mounted devices (HMD) for virtual reality (VR) and augmented reality (AR). Not having a backlight also helps achieve a higher transparency for transparent displays, which could especially be advantageous for AR. Since most if not all of the commercial VR devices sold in the market are using OLED displays at present, we therefore assume that VR/AR will continue to see 100% penetration of OLED displays.

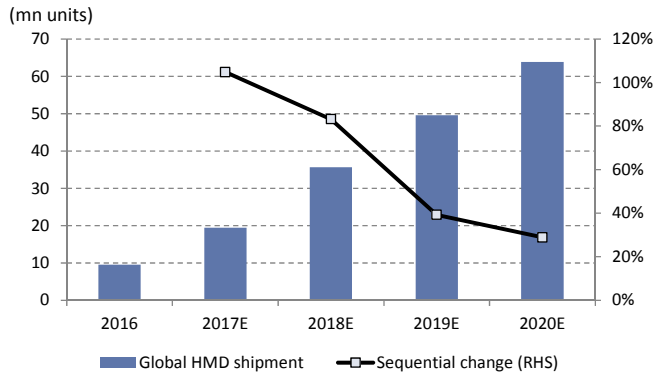
Slide-on HMDs such as SEC's Gear VR operate with the smartphone inserted and snapped to the front of the HMD, as the smartphone acts as both the display and processor of the VR device. We therefore do not include OLED screen demand from slide-on HMDs to avoid double counting area demand.

As higher display resolution will help enhance the VR/AR viewing experience, OLED makers including SEC are trying to work with the supply chain to improve the resolution of the display. While the current resolution level attained with stable yield by SEC is Quad

High Definition (QHD) and for others are still FHD or HD, we believe that a resolution of UHD or higher is required to reduce the tiredness and dizziness of VR/AR.

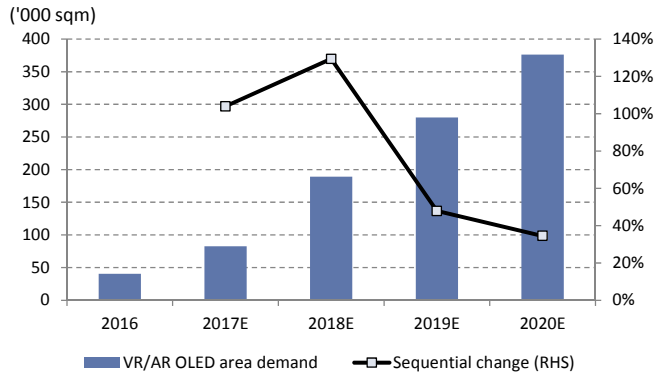
According to the Korea Economic Daily (June 21, 2017), SEC is currently developing the "next generation Gear VR" in the form of a discrete HMD that has an OLED display with a resolution over 2,000ppi. As the current HMDs in the market have displays with pixel density of around 500ppi, the successful development of such displays could greatly reduce the dizziness and potentially help boost OLED demand coming from VR/AR, in our view.

Exhibit 102: We believe the HMD market for VR/AR to grow at a rapid pace…
Global HMD shipment



Source: Company data, Goldman Sachs Global Investment Research.

Exhibit 103: …and have the potential to become the third largest factor of OLED area demand after smartphone and TV
VR/AR OLED area demand

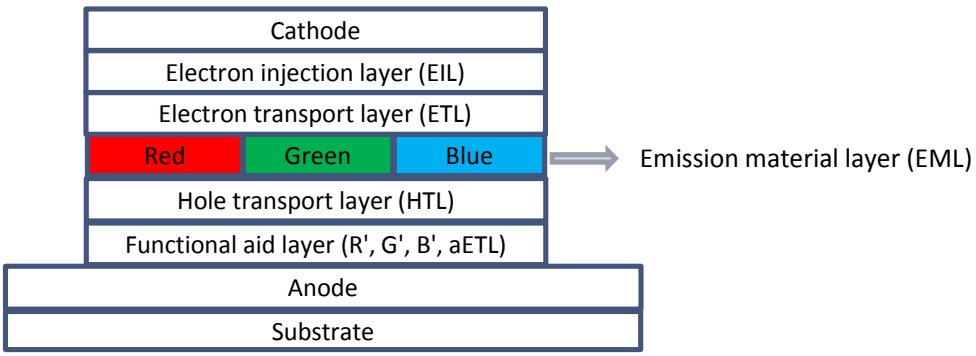


Source: Company data, Goldman Sachs Global Investment Research.

OLED – the display of the future

Organic light emitting diodes (OLEDs) are solid-state emissive displays that generate their own light rather than depending on an external source. OLED displays stack cathode organic materials (where the light generation occurs) and anode layers on top of a substrate that contains circuitry and is able to conduct electricity. When the current flows through the stacked layers, the electrons and holes are paired to help generate light in the emission material layer (EML). OLED displays can be generally classified into passive matrix (PM) OLED and active matrix (AM) OLED.

Exhibit 104: OLED does not depend on an external source to generate light
OLED structure



Source: Company data.

Due to its many advantages compared to Liquid Crystal Display (LCD), the current mainstream technology, OLED is widely regarded as the display of the future with potential to be used for many different applications. In terms of advantages:

- Since OLED does not require a backlight, **a flexible or transparent form is easier to achieve**. The flexible form, for instance, offers the opportunity to reshape existing smartphones and enhance tablet/PC convergence.
- **A faster response time and wider viewing angle** in our view makes OLED the best option for VR/AR usage and automotive applications such as dashboards and head-up displays (HUDs).
- **The form factor of OLED** helps meet demand for increased mobility in daily lives not only by making the device lighter and thinner, but also by creating more room inside the device for higher battery content.

OLED also has some secondary characteristics that are lacking relative to LCD such as a lower lifetime, higher unit cost, and burn-in images.

Exhibit 105: OLED has many advantages over LCD such as faster response time and more freedom for a flexible/foldable form factor as a backlight is not required
Key advantages and disadvantages of OLED vs. LCD

Advantages of OLED vs. LCD	Disadvantages of OLED vs. LCD
Faster response time	Higher unit cost as most fabs not fully depreciated
More freedom for flexible/foldable form factor	Lower life time
Thinner body as backlight is not required	Burn-in images
Lighter weight	
Better color reproduction	
Wider viewing angle	

Source: Goldman Sachs Global Investment Research.

Mindcraft: Our Thematic Deep Dives

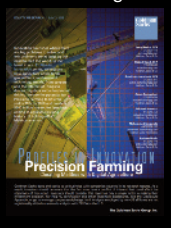
Innovation & Disruption

Virtual Reality

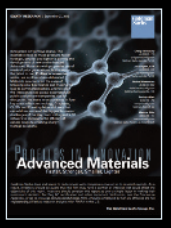
Drones

Factory of the Future

Precision Farming



Advanced Materials



Artificial Intelligence

Space

5G

Cars

Rise of the Asian Consumer

Chinese Consumer

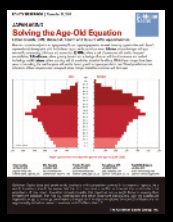
Chinese Millennials

Chinese Tourist Boom

China E+Commerce

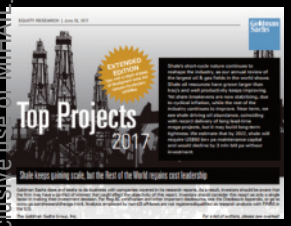
China Banks

Japan Aging



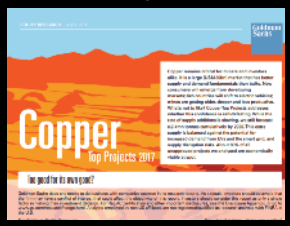
Old China Commodities

Top Oil & Gas Projects



Reforming China Energy

Copper: Too good for its own good?



New Old China: 4R's Beyond 2016

The Future of Finance

Future of Finance

Blockchain

Asia Digital Banking

The Low Carbon Economy

Tech in the Driver's Seat

The Great Battery Race

China's Environment

China's Battery Challenge

Low Carbon China

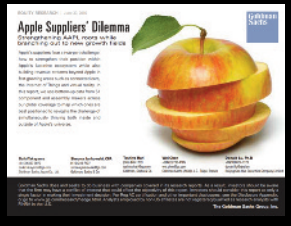
Music's Return to Growth

Opportunity

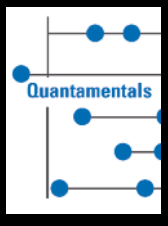
Risk

Creating Tomorrow's Greater Bay

Apple Suppliers' Dilemma

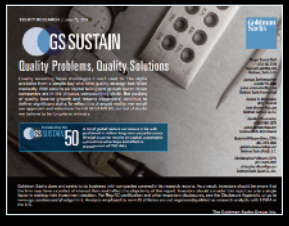


Asian Quantamentals



SUSTAIN

Quality problems, quality solutions



Credit

Mapping Out China's Credit Market

Disclosure Appendix

Reg AC

We, Daiki Takayama, Giuni Lee, Simona Jankowski, CFA, Brian Lee, CFA, Toshiya Hari and Satoru Ogawa, hereby certify that all of the views expressed in this report accurately reflect our personal views about the subject company or companies and its or their securities. We also certify that no part of our compensation was, is or will be, directly or indirectly, related to the specific recommendations or views expressed in this report.

Unless otherwise stated, the individuals listed on the cover page of this report are analysts in Goldman Sachs' Global Investment Research division.

GS Factor Profile

The Goldman Sachs Factor Profile provides investment context for a stock by comparing key attributes to the market (i.e. our coverage universe) and its sector peers. The four key attributes depicted are: Growth, Financial Returns, Multiple (e.g. valuation) and Integrated (a composite of Growth, Financial Returns and Multiple). Growth, Financial Returns and Multiple are calculated by using normalized ranks for specific metrics for each stock. The normalized ranks for the metrics are then averaged and converted into percentiles for the relevant attribute. The precise calculation of each metric may vary depending on the fiscal year, industry and region, but the standard approach is as follows:

Growth is based on a stock's forward-looking sales growth, EBITDA growth and EPS growth (for financial stocks, only EPS and sales growth), with a higher percentile indicating a higher growth company. **Financial Returns** is based on a stock's forward-looking ROE, ROCE and CROCI (for financial stocks, only ROE), with a higher percentile indicating a company with higher financial returns. **Multiple** is based on a stock's forward-looking P/E, P/B, price/dividend (P/D), EV/EBITDA, EV/FCF and EV/Debt Adjusted Cash Flow (DACF) (for financial stocks, only P/E, P/B and P/D), with a higher percentile indicating a stock trading at a higher multiple. The **Integrated** percentile is calculated as the average of the Growth percentile, Financial Returns percentile and (100% - Multiple percentile).

Financial Returns and Multiple use the Goldman Sachs analyst forecasts at the fiscal year-end at least three quarters in the future. Growth uses inputs for the fiscal year at least seven quarters in the future compared with the year at least three quarters in the future (on a per-share basis for all metrics).

For a more detailed description of how we calculate the GS Factor Profile, please contact your GS representative.

Quantum

Quantum is Goldman Sachs' proprietary database providing access to detailed financial statement histories, forecasts and ratios. It can be used for in-depth analysis of a single company, or to make comparisons between companies in different sectors and markets.

GS SUSTAIN

GS SUSTAIN is a global investment strategy aimed at long-term, long-only performance with a low turnover of ideas. The GS SUSTAIN focus list includes leaders our analysis shows to be well positioned to deliver long term outperformance through sustained competitive advantage and superior returns on capital relative to their global industry peers. Leaders are identified based on quantifiable analysis of three aspects of corporate performance: cash return on cash invested, industry positioning and management quality (the effectiveness of companies' management of the environmental, social and governance issues facing their industry).

Disclosures

Coverage group(s) of stocks by primary analyst(s)

Daiki Takayama: Japan-Electronic Components. Simona Jankowski, CFA: America-Consumer Hardware & Mobility, America-IT Hardware, America-Telecom Equipment. Brian Lee, CFA: America-Clean Energy, America-Solar Energy. Toshiya Hari: America-Semiconductor Capital Equipment, America-Semiconductors. Satoru Ogawa: Japan-Precision, Japan-SPE.

America-Clean Energy: Acuity Brands Inc., Clean Harbors Inc., Covanta Holding, Cree Inc., Mueller Water Products Inc., Silver Spring Networks Inc., Universal Display Corp., Veeco Instruments Inc., Watts Water Technologies Inc., Xylem Inc..

America-Consumer Hardware & Mobility: Apple Inc., BlackBerry Ltd., BlackBerry Ltd., Corning Inc., Garmin Ltd., GoPro Inc., Qualcomm Inc..

America-IT Hardware: 3D Systems Corp., Aerohive Networks Inc., Arista Networks Inc., Brocade Communications Systems, CDW Corp., Cisco Systems Inc., F5 Networks Inc., Hewlett Packard Enterprise Co., HP Inc., Motorola Solutions Inc., NetApp Inc., Nutanix Inc., Presidio Inc., Pure Storage Inc., Stratasys Ltd., Xerox Corp., Zebra Technologies Corp..

America-Semiconductor Capital Equipment: Applied Materials Inc., Entegris Inc., Keysight Technologies Inc., KLA-Tencor Corp., Lam Research Corp., Teradyne Inc., Versum Materials Inc..

America-Semiconductors: Advanced Micro Devices Inc., Analog Devices Inc., Broadcom Ltd., Integrated Device Technology Inc., Intel Corp., Maxim Integrated Products, Nvidia Corp., NXP Semiconductors NV, Qorvo Inc., Skyworks Solutions Inc., Texas Instruments Inc., Xilinx Corp..

America-Solar Energy: 8point3 Energy Partners, First Solar Inc., Pattern Energy Group, SolarEdge Technologies Inc., SunPower Corp., Sunrun Inc., TerraForm Global Inc., TerraForm Power Inc., Vivint Solar Inc..

America-Telecom Equipment: Acacia Communications Inc., ADTRAN Inc., ARRIS International Plc, Ciena Corp., Finisar Corp., Infinera Corp., Juniper Networks Inc., Lumentum Holdings.

Japan-Electronic Components: Alps Electric, Hirose Electric, Ibiden, IRISO Electronics, Japan Aviation Electronics Industry, Japan Display Inc., Kyocera, Mabuchi Motor, MinebeaMitsumi Inc., Murata Mfg., NGK Insulators, NGK Spark Plug, Nichicon, Nidec, Nippon Ceramic, Nitto Denko, Pacific Industrial, Shinko Electric Industries, Taiyo Yuden, TDK.

Japan-Precision: Brother Industries, Canon, Casio Computer, Citizen Watch, FUJIFILM Holdings, HOYA, Konica Minolta, Ricoh, Seiko Epson.

Japan-SPE: Advantest, Disco, Hitachi Kokusai Electric, Nikon, SCREEN Holdings, Sumco, Tokyo Electron, Ulvac.

Company-specific regulatory disclosures

Compendium report: please see disclosures at http://www.gs.com/research/hedge.html. Disclosures applicable to the companies included in this compendium can be found in the latest relevant published research

Distribution of ratings/investment banking relationships

Goldman Sachs Investment Research global Equity coverage universe

	Rating Distribution			Investment Banking Relationships		
	Buy	Hold	Sell	Buy	Hold	Sell
Global	32%	54%	14%	65%	56%	49%

As of July 1, 2017, Goldman Sachs Global Investment Research had investment ratings on 2,753 equity securities. Goldman Sachs assigns stocks as Buys and Sells on various regional Investment Lists; stocks not so assigned are deemed Neutral. Such assignments equate to Buy, Hold and Sell for the purposes of the above disclosure required by the FINRA Rules. See 'Ratings, Coverage groups and views and related definitions' below. The Investment Banking Relationships chart reflects the percentage of subject companies within each rating category for whom Goldman Sachs has provided investment banking services within the previous twelve months.

Price target and rating history chart(s)

Compendium report: please see disclosures at http://www.gs.com/research/hedge.html. Disclosures applicable to the companies included in this compendium can be found in the latest relevant published research

Regulatory disclosures

Disclosures required by United States laws and regulations

See company-specific regulatory disclosures above for any of the following disclosures required as to companies referred to in this report: manager or co-manager in a pending transaction; 1% or other ownership; compensation for certain services; types of client relationships; managed/co-managed public offerings in prior periods; directorships; for equity securities, market making and/or specialist role. Goldman Sachs trades or may trade as a principal in debt securities (or in related derivatives) of issuers discussed in this report.

The following are additional required disclosures: **Ownership and material conflicts of interest:** Goldman Sachs policy prohibits its analysts, professionals reporting to analysts and members of their households from owning securities of any company in the analyst's area of coverage. **Analyst compensation:** Analysts are paid in part based on the profitability of Goldman Sachs, which includes investment banking revenues. **Analyst as officer or director:** Goldman Sachs policy generally prohibits its analysts, persons reporting to analysts or members of their households from serving as an officer, director or advisor of any company in the analyst's area of coverage. **Non-U.S. Analysts:** Non-U.S. analysts may not be associated persons of Goldman, Sachs & Co. and therefore may not be subject to FINRA Rule 2241 or FINRA Rule 2242 restrictions on communications with subject company, public appearances and trading securities held by the analysts.

Distribution of ratings: See the distribution of ratings disclosure above. **Price chart:** See the price chart, with changes of ratings and price targets in prior periods, above, or, if electronic format or if with respect to multiple companies which are the subject of this report, on the Goldman Sachs website at http://www.gs.com/research/hedge.html.

Additional disclosures required under the laws and regulations of jurisdictions other than the United States

The following disclosures are those required by the jurisdiction indicated, except to the extent already made above pursuant to United States laws and regulations. **Australia:** Goldman Sachs Australia Pty Ltd and its affiliates are not authorised deposit-taking institutions (as that term is defined in the Banking Act 1959 (Cth)) in Australia and do not provide banking services, nor carry on a banking business, in Australia. This research, and any access to it, is intended only for "wholesale clients" within the meaning of the Australian Corporations Act, unless otherwise agreed by Goldman Sachs. In producing research reports, members of the Global Investment Research Division of Goldman Sachs Australia may attend site visits and other meetings hosted by the issuers the subject of its research reports. In some instances the costs of such site visits or meetings may be met in part or in whole by the issuers concerned if Goldman Sachs Australia considers it is appropriate and reasonable in the specific circumstances relating to the site visit or meeting. **Brazil:** Disclosure information in relation to CVM Instruction 483 is available at http://www.gs.com/worldwide/brazil/area/gir/index.html. Where applicable, the Brazil-registered analyst primarily responsible for the content of this research report, as defined in Article 16 of CVM Instruction 483, is the first author named at the beginning of this report, unless indicated otherwise at the end of the text. **Canada:** Goldman Sachs Canada Inc. is an affiliate of The Goldman Sachs Group Inc. and therefore is included in the company specific disclosures relating to Goldman Sachs (as defined above). Goldman Sachs Canada Inc. has approved of, and agreed to take responsibility for, this research report in Canada if and to the extent that Goldman Sachs Canada Inc. disseminates this research report to its clients. **Hong Kong:** Further information on the securities of covered companies referred to in this research may be obtained on request from Goldman Sachs (Asia) L.L.C. **India:** Further information on the subject company or companies referred to in this research may be obtained from Goldman Sachs (India) Securities Private Limited, Research Analyst - SEBI Registration Number INH000001493, 951-A, Rational House, Appasaheb Marathe Marg, Prabhadevi, Mumbai 400 025, India, Corporate Identity Number U74140MH2006FTC160634, Phone +91 22 6616 9000, Fax +91 22 6616 9001. Goldman Sachs may beneficially own 1% or more of the securities (as such term is defined in clause 2 (h) the Indian Securities Contracts (Regulation) Act, 1956) of the subject company or companies referred to in this research report. **Japan:** See below. **Korea:** Further information on the subject company or companies referred to in this research may be obtained from Goldman Sachs (Asia) L.L.C., Seoul Branch. **New Zealand:** Goldman Sachs New Zealand Limited and its affiliates are neither "registered banks" nor "deposit takers" (as defined in the Reserve Bank of New Zealand Act 1989) in New Zealand. This research, and any access to it, is intended for "wholesale clients" (as defined in the Financial Advisers Act 2008) unless otherwise agreed by Goldman Sachs. **Russia:** Research reports distributed in the Russian Federation are not advertising as defined in the Russian legislation, but are information and analysis not having product promotion as their main purpose and do not provide appraisal within the meaning of the Russian legislation on appraisal activity. **Singapore:** Further information on the covered companies referred to in this research may be obtained from Goldman Sachs (Singapore) Pte. (Company Number: 198602165W). **Taiwan:** This material is for reference only and must not be reprinted without permission. Investors should carefully consider their own investment risk. Investment results are the responsibility of the individual investor. **United Kingdom:** Persons who would be categorized as retail clients in the United Kingdom, as such term is defined in the rules of the Financial Conduct Authority, should read this research in conjunction with prior Goldman Sachs research on the covered companies referred to herein and should refer to the risk warnings that have been sent to them by Goldman Sachs International. A copy of these risks warnings, and a glossary of certain financial terms used in this report, are available from Goldman Sachs International on request.

European Union: Disclosure information in relation to Article 4 (1) (d) and Article 6 (2) of the European Commission Directive 2003/125/EC is available at http://www.gs.com/disclosures/europeanpolicy.html which states the European Policy for Managing Conflicts of Interest in Connection with Investment Research.

Japan: Goldman Sachs Japan Co., Ltd. is a Financial Instrument Dealer registered with the Kanto Financial Bureau under registration number Kinsho 69, and a member of Japan Securities Dealers Association, Financial Futures Association of Japan and Type II Financial Instruments Firms Association. Sales and purchase of equities are subject to commission pre-determined with clients plus consumption tax. See company-specific

disclosures as to any applicable disclosures required by Japanese stock exchanges, the Japanese Securities Dealers Association or the Japanese Securities Finance Company.

Ratings, coverage groups and views and related definitions

Buy (B), Neutral (N), Sell (S) -Analysts recommend stocks as Buys or Sells for inclusion on various regional Investment Lists. Being assigned a Buy or Sell on an Investment List is determined by a stock's total return potential relative to its coverage. Any stock not assigned as a Buy or a Sell on an Investment List with an active rating (i.e., a stock that is not Rating Suspended, Not Rated, Coverage Suspended or Not Covered), is deemed Neutral. Each regional Investment Review Committee manages various regional Investment Lists to a global guideline of 25%-35% of stocks as Buy and 10%-15% of stocks as Sell; however, the distribution of Buys and Sells in any particular analyst's coverage group may vary as determined by the regional Investment Review Committee. Additionally, each Investment Review Committee manages Regional Conviction lists, which represent investment recommendations focused on the size of the total return potential and/or the likelihood of the realization of the return across their respective areas of coverage. The addition or removal of stocks from such Conviction lists do not represent a change in the analysts' investment rating for such stocks.

Total return potential represents the upside or downside differential between the current share price and the price target, including all paid or anticipated dividends, expected during the time horizon associated with the price target. Price targets are required for all covered stocks. The total return potential, price target and associated time horizon are stated in each report adding or reiterating an Investment List membership.

Coverage groups and views: A list of all stocks in each coverage group is available by primary analyst, stock and coverage group at http://www.gs.com/research/hedge.html. The analyst assigns one of the following coverage views which represents the analyst's investment outlook on the coverage group relative to the group's historical fundamentals and/or valuation. **Attractive (A).** The investment outlook over the following 12 months is favorable relative to the coverage group's historical fundamentals and/or valuation. **Neutral (N).** The investment outlook over the following 12 months is neutral relative to the coverage group's historical fundamentals and/or valuation. **Cautious (C).** The investment outlook over the following 12 months is unfavorable relative to the coverage group's historical fundamentals and/or valuation.

Not Rated (NR). The investment rating and target price have been removed pursuant to Goldman Sachs policy when Goldman Sachs is acting in an advisory capacity in a merger or strategic transaction involving this company and in certain other circumstances. **Rating Suspended (RS).** Goldman Sachs Research has suspended the investment rating and price target for this stock, because there is not a sufficient fundamental basis for determining, or there are legal, regulatory or policy constraints around publishing, an investment rating or target. The previous investment rating and price target, if any, are no longer in effect for this stock and should not be relied upon. **Coverage Suspended (CS).** Goldman Sachs has suspended coverage of this company. **Not Covered (NC).** Goldman Sachs does not cover this company. **Not Available or Not Applicable (NA).** The information is not available for display or is not applicable. **Not Meaningful (NM).** The information is not meaningful and is therefore excluded.

Global product; distributing entities

The Global Investment Research Division of Goldman Sachs produces and distributes research products for clients of Goldman Sachs on a global basis. Analysts based in Goldman Sachs offices around the world produce equity research on industries and companies, and research on macroeconomics, currencies, commodities and portfolio strategy. This research is disseminated in Australia by Goldman Sachs Australia Pty Ltd (ABN 21 006 797 897); in Brazil by Goldman Sachs do Brasil Corretora de Títulos e Valores Mobiliários S.A.; in Canada by either Goldman Sachs Canada Inc. or Goldman, Sachs & Co.; in Hong Kong by Goldman Sachs (Asia) L.L.C.; in India by Goldman Sachs (India) Securities Private Ltd.; in Japan by Goldman Sachs Japan Co., Ltd.; in the Republic of Korea by Goldman Sachs (Asia) L.L.C., Seoul Branch; in New Zealand by Goldman Sachs New Zealand Limited; in Russia by OOO Goldman Sachs; in Singapore by Goldman Sachs (Singapore) Pte. (Company Number: 198602165W); and in the United States of America by Goldman, Sachs & Co. Goldman Sachs International has approved this research in connection with its distribution in the United Kingdom and European Union.

European Union: Goldman Sachs International authorised by the Prudential Regulation Authority and regulated by the Financial Conduct Authority and the Prudential Regulation Authority, has approved this research in connection with its distribution in the European Union and United Kingdom; Goldman Sachs AG and Goldman Sachs International Zweigniederlassung Frankfurt, regulated by the Bundesanstalt für Finanzdienstleistungsaufsicht, may also distribute research in Germany.

General disclosures

This research is for our clients only. Other than disclosures relating to Goldman Sachs, this research is based on current public information that we consider reliable, but we do not represent it is accurate or complete, and it should not be relied on as such. The information, opinions, estimates and forecasts contained herein are as of the date hereof and are subject to change without prior notification. We seek to update our research as appropriate, but various regulations may prevent us from doing so. Other than certain industry reports published on a periodic basis, the large majority of reports are published at irregular intervals as appropriate in the analyst's judgment.

Goldman Sachs conducts a global full-service, integrated investment banking, investment management, and brokerage business. We have investment banking and other business relationships with a substantial percentage of the companies covered by our Global Investment Research Division. Goldman, Sachs & Co., the United States broker dealer, is a member of SIPC (http://www.sipc.org).

Our salespeople, traders, and other professionals may provide oral or written market commentary or trading strategies to our clients and principal trading desks that reflect opinions that are contrary to the opinions expressed in this research. Our asset management area, principal trading desks and investing businesses may make investment decisions that are inconsistent with the recommendations or views expressed in this research.

The analysts named in this report may have from time to time discussed with our clients, including Goldman Sachs salespersons and traders, or may discuss in this report, trading strategies that reference catalysts or events that may have a near-term impact on the market price of the equity securities discussed in this report, which impact may be directionally counter to the analyst's published price target expectations for such stocks. Any such trading strategies are distinct from and do not affect the analyst's fundamental equity rating for such stocks, which rating reflects a stock's return potential relative to its coverage group as described herein.

We and our affiliates, officers, directors, and employees, excluding equity and credit analysts, will from time to time have long or short positions in, act as principal in, and buy or sell, the securities or derivatives, if any, referred to in this research.

The views attributed to third party presenters at Goldman Sachs arranged conferences, including individuals from other parts of Goldman Sachs, do not necessarily reflect those of Global Investment Research and are not an official view of Goldman Sachs.

Any third party referenced herein, including any salespeople, traders and other professionals or members of their household, may have positions in the products mentioned that are inconsistent with the views expressed by analysts named in this report.

This research is not an offer to sell or the solicitation of an offer to buy any security in any jurisdiction where such an offer or solicitation would be illegal. It does not constitute a personal recommendation or take into account the particular investment objectives, financial situations, or needs of individual clients. Clients should consider whether any advice or recommendation in this research is suitable for their particular circumstances and, if appropriate, seek professional advice, including tax advice. The price and value of investments referred to in this research and the income from them

may fluctuate. Past performance is not a guide to future performance, future returns are not guaranteed, and a loss of original capital may occur. Fluctuations in exchange rates could have adverse effects on the value or price of, or income derived from, certain investments.

Certain transactions, including those involving futures, options, and other derivatives, give rise to substantial risk and are not suitable for all investors. Investors should review current options disclosure documents which are available from Goldman Sachs sales representatives or at http://www.theocc.com/about/publications/character-risks.jsp. Transaction costs may be significant in option strategies calling for multiple purchase and sales of options such as spreads. Supporting documentation will be supplied upon request.

All research reports are disseminated and available to all clients simultaneously through electronic publication to our internal client websites. Not all research content is redistributed to our clients or available to third-party aggregators, nor is Goldman Sachs responsible for the redistribution of our research by third party aggregators. For research, models or other data available on a particular security, please contact your sales representative or go to http://360.gs.com.

Disclosure information is also available at http://www.gs.com/research/hedge.html or from Research Compliance, 200 West Street, New York, NY 10282.