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# Growth opportunities in OLED displays

## The truth and the hype

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# Agenda

## ■ Context

- OLED: Fact and Hype
  - Apple's recent moves
  - OLED technology is tricky
  - Cost parity: Fact or fiction
- Implications and growth opportunities

## Context

- OLED is now finally in growth mode: finally most of the technical and commercial pieces are in place to allow the technology to grow
  - Moreover Apple has just given OLED a massive push by negotiating contracts for the iPhone to move to AMOLED from 2018 (if not before)
- But the future of OLED is not the “complete conversion” of LCD to OLED since:
  - The industry cannot afford it
  - The OLED owners also own LCD fabs
  - Greenfield fabs (GF) are economically the same as conversions (once the opportunity cost of lost production is included) meaning it will be predominantly GF investment to provide OLED growth (since this allows for new optionality and new equipment)
- That being said, there are a number of innovation levers that do come with OLED that are not there with LCD
  - These may be the drivers for new futures for the display industry. Many of these are untested value propositions but they do represent new areas of potential product differentiation. Whether these new areas of product differentiation lead to changes in profit creation is unlikely without a change in behaviour
- In this presentation we seek to dig down into the truth and hype about OLED and highlight the likely winners and losers

# Agenda

- Context

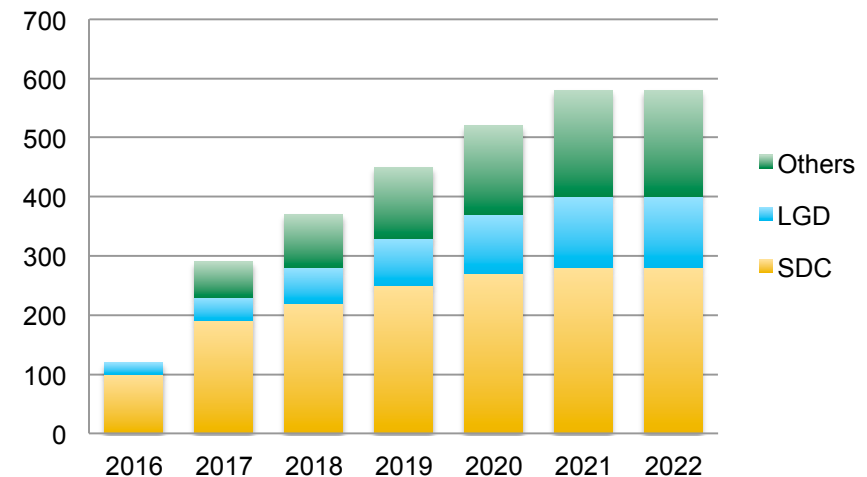
- OLED: Fact and Hype
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  - Cost parity: Fact or fiction

- Implications and growth opportunities

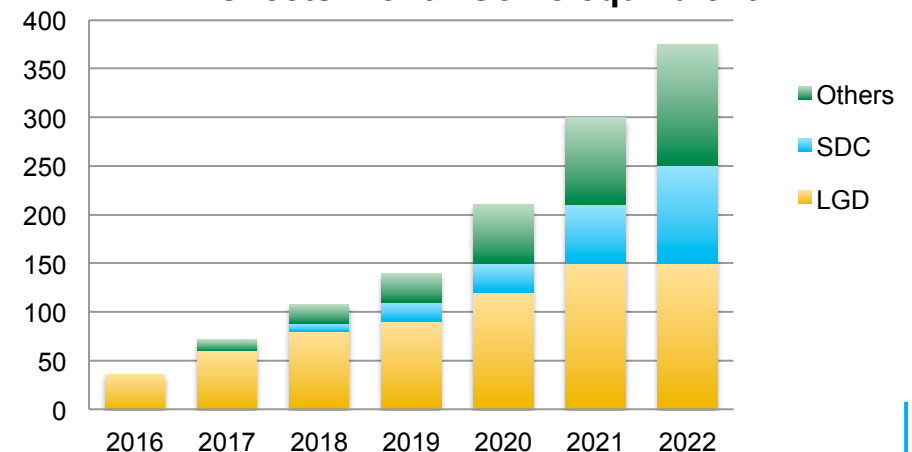
## OLED is currently in growth mode:

- After a long gestation period (of more than 20 years), OLED is now really in growth mode
  - Apple has pushed the market into a new round of capacity additions by seeking to move the iPhone to AMOLED by 2018
  - The Chinese display companies will jump to invest in AMOLED now based on this indicator of future Apple intent
- Moreover, after two rounds of products in the market with “flexible” displays, in the Galaxy EDGE range, there is more consumer acceptance of some of the innovative value propositions that OLED can provide
- We believe that equipment, materials and technology also explain some of the timing: they have reached a maturity that allow many players to consider market entry (despite the fact that OLED remains a tricky technology)

**Small panel OLED capacity ramp (estimate),  
k sheets/month Gen 6**



**Large panel OLED capacity expansion (estimate)  
k sheets/month Gen 8 equivalent**



Source: HCL estimates

This is one of the biggest bubbles of capacity expansion that we have seen for a long time:



## FPD Industry Key Metrics

Key Industry Metrics Weather Forecast				
Metric	2014	2015	2016	
<b>Macro Economics</b>				Slowing Chinese economy, excessively low oil prices, and weak currencies create headwinds that affect the FPD market
<b>FPD Maker Financials</b>				Expect most panel makers to be "in the red" all of 2016 due to excessively low panel prices
<b>Capacity Expansion</b>				High investment levels despite weak financial outlook
<b>Equipment Market</b>				Chinese capacity additions and leading brand's AMOLED ramp creating best equipment market since 2011
<b>Supply/Demand</b>				Concern of endemic oversupply for both large-area & small medium displays
<b>Fab Utilization</b>				Utilization is a wild card that will vary by maker, but if not reduced, it will prolong the oversupply
<b>AMOLED SM</b>				Expect continued success of small-medium AMOLED by leading brands
<b>AMOLED TV</b>				Leading AMOLED TV manufacturer expanding capacity and developing partnerships with more brands
<b>Overall</b>				"It is the best of times, it is the worst of times" depending on your perspective

Source: IHS

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Upturn Balanced Downturn, oversupply

- But we must see this bubble of capacity optimism in a fairly otherwise bleak picture based on being at the bottom of the crystal cycle
- The leaders are investing now to be ready for the next pricing upswing and the Apple move just reinforces this

## Apple has fundamentally provided the impetus for this phase of growth:

Exhibit 21  
Apple iPhone OLED Adoption Scenario Analysis

<i>(in million units)</i>	Scenario	2014	2015	2016E	2017E	2018E	2019E
Samsung		100	180	225	270	297	327
YoY			80%	25%	20%	10%	10%
Apple	Full adoption (2018)	-	-	-	-	115	240
	Partial adoption (2018)	-	-	-	-	50	120
Samsung + Apple	Full adoption (2018)	100	180	225	270	412	567
	<i>iPhone as % of total</i>	-	-	-	-	23%	40%
	Partial adoption (2018)	100	180	225	270	347	447
	<i>iPhone as % of total</i>	-	-	-	-	10%	20%
OLED Mobile Demand (IHS)		174	264	339	402	510	602

Source: IHS Display Search, Company disclosure, Bernstein estimates and analysis

- Up until now around half of the Samsung range of phones has been AMOLED (though a higher portion of handsets released since the beginning of 2015) and we might expect this to be driven a little higher
- Apple's conversion (here shown in part or total) almost doubles the demand for small panel OLED screens
- Apple's motivations may be several: OLED now really is a comparable product in terms of front of screen performance to LCD, and OLED opens up the options for future product innovations, that may include being flexible, but are also thinner and lighter

## We expect the trickle down of Apple's move to be far reaching:

### Potentially makes LTPS LCD less valuable

- There were 6 LTPS Gen 6 fabs planned for China: expect to see these plans withdrawn or modified. Apple purchases 50% of all LTPS
- Current LTPS facilities may be converted to some degree to small panel AMOLED facilities but this conversion (remove the cell shop and put in sMOLED deposition instead) is not so straightforward. Nearly all of the AMOLED capacity in the industry has been greenfield OLED capacity

### Others will also scramble into OLED

- The Chinese players had pulled back on massive investment announcements into OLED but we should expect to see these again
- JDI has already announced plans to be in the OLED market by 2017-8
- There have been discussions on AUO being influenced to play in the small panel OLED market also. Expect GVO and EDO to invest
- Foxconn backing Sharp to make a play in OLED

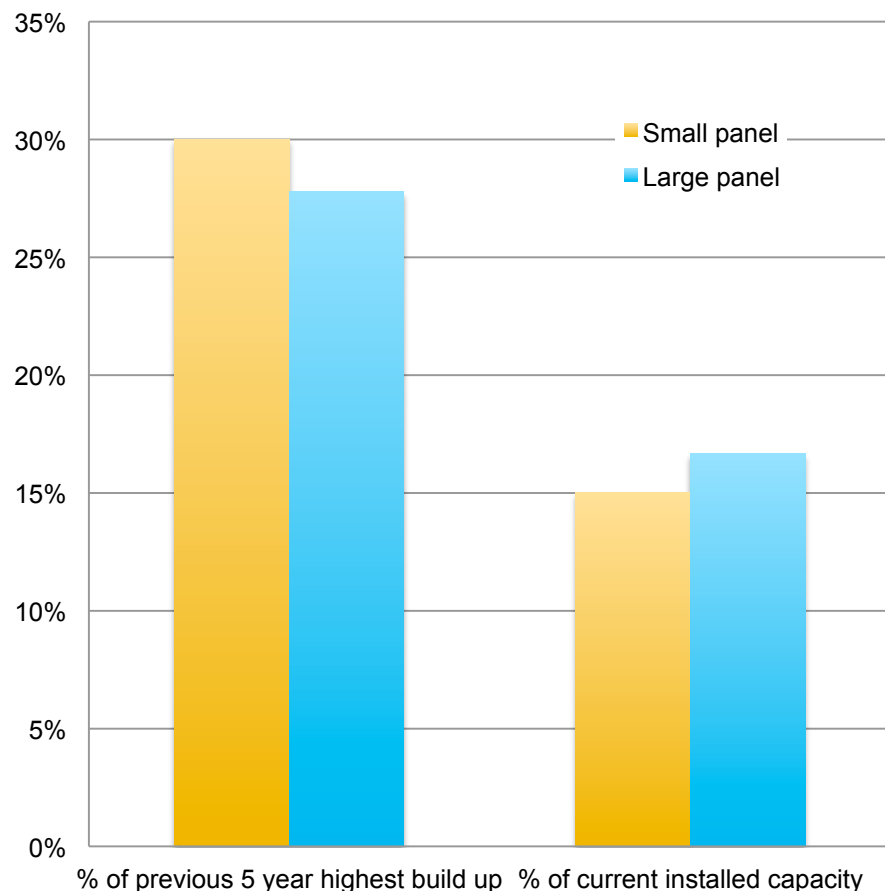
### Smaller companies with no OLED play will be put under pressure

- Companies like CPT selling one fab and closing another. CPT had been implementing a strong innovation story, including work on flexibles and coatable IGZO
- Not clear on the impact on Hannstar
- Smaller players in China may also be put under pressure. May be some more consolidation
- Impact on Innolux not yet clear



But let us put this all in context: this is not the complete conversion to OLED that the OLED converts have always sought after:

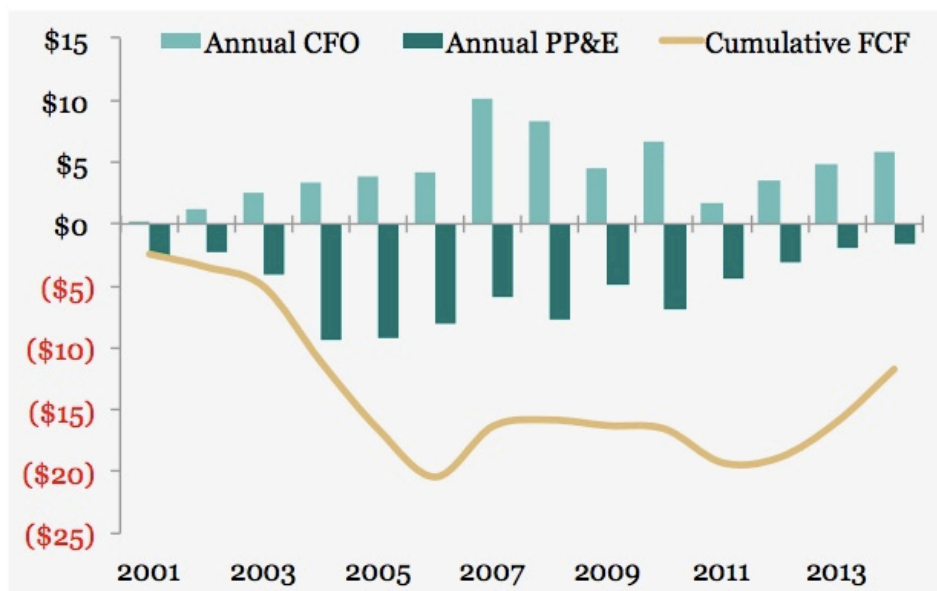
### % substitution metrics (of the incremental capacity by 2022)



- We actually envisage an incremental capacity investment of about 15% of the current TFT-LCD total to be taken up with OLED by 2022 representing about 30% of the previous period of the highest speed of capacity investment
  - In other words this is a rapid build up of capacity but not commensurate with the fastest ramp which was the first part of last decade
- The true OLED believers have always talked about an OLED conversion (perhaps similar to the displacement of CRT by LCD)
- Their beliefs however, have always been predicated on the notion that an OLED is just like an LCD and fabs can easily be converted. Moreover, that OLED is cheaper and simpler. All of these are fallacies. The capital markets know this
- OLED conversion will be limited by what the industry can afford and by portfolio decisions of leading players

## A key part of this story is that the industry cannot afford the conversion:

Taiwanese AMLCD Industry Results (USD billions)

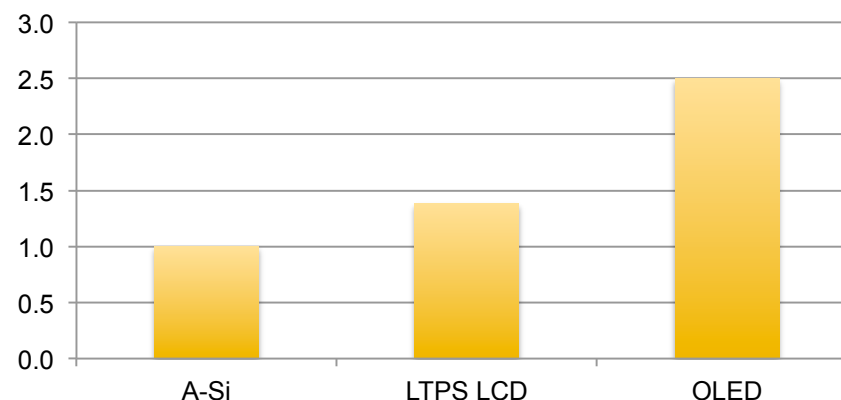


Free-cash flow (FCF) is cash-flow from operations minus capex (PP&E).

Source: public disclosures; SEC rates and our analysis

- This is our 2014-2015 analysis of the free cash flow of the Taiwanese LCD industry: cumulatively \$15bn down since 2001. Taiwan at least does not have the money to invest
- And OLED is an expensive technology, at almost 2.5x the cost of a-Si to implement

## Multiple of the cost of an a-Si fab for other types new greenfield (equipment + building)



## Cost of rededication is broadly similar according to LGD\*

- IGZO rededication: Array capacity loss of 22-40% according to LGD. Neutral for CVD, additional equipment required for PVD. CF capability required is similar as in LCD
- Replacement of the cell shop with OLED patterning Expensive and new equipment risk. Likely to lead to line rebalancing
- LGD believes that this is an 18 month process
- Loss of lost production makes this balanced against green field cost

...and part of the problem is that OLED is a very tricky technology:

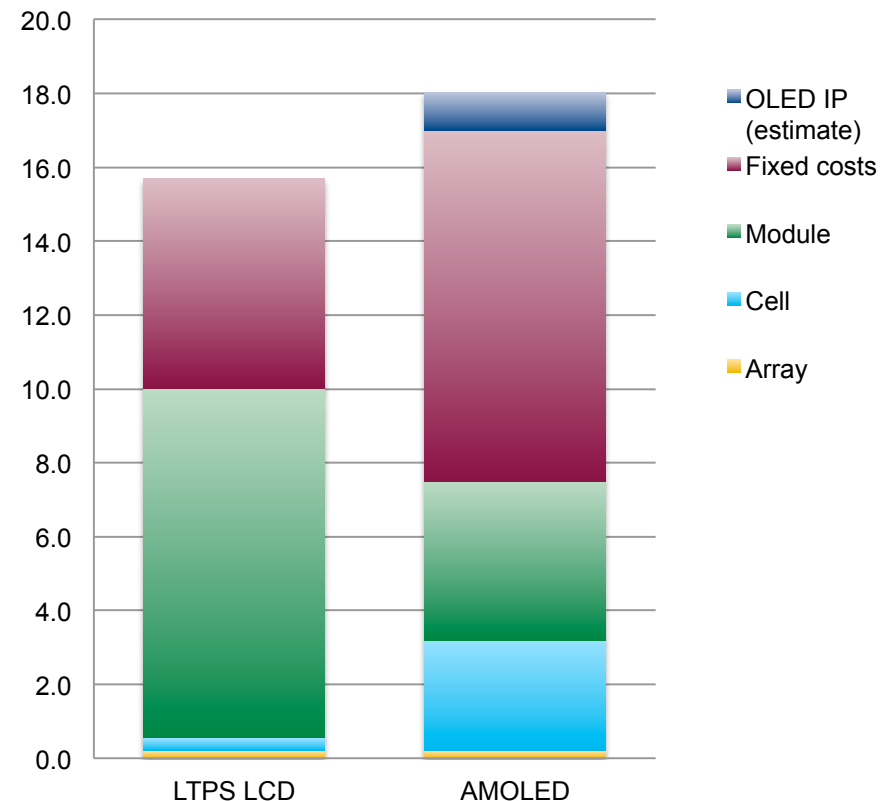
	A-Si	LTPS	Oxide based OLED	LTPS based OLED	Comments
Backplane	Simple	Hard	Hard	Hard	LTPS has laser & cost issues; Oxide has physics challenges
Front plane	Simple	Simple	Hard	Hard	OLED patterning with FMM in challenging
Know how needed	Low	Mid-High	High	High	Learning issues for LTPS, oxide and patterning
Availability of tools and materials	High	High	Mid	Mid	Some of the materials and tools have been locked down by Samsung
Yield risk*	Low	Mid-High	High	High	OLED could have low yields for new entrants

- One of the reasons that OLED has taken so long is that it is fundamentally a very difficult technology, both in terms of the backplane technology (where LTPS has challenges in shot-to-shot uniformity of the laser, scalability and cost issues, while oxide is not much simpler. Moreover the backplane needs multiple transistors to give stable current drive performance) but also the FMM (or other) patterning technique in the front-plane
- Without an industry standards body to share platforms for tools and materials (and in fact Samsung trying to lock down its own access to these), learning is much slower for other players
- Moreover, OLED displays now are expected to have integrated touch: this further increases the technical challenge

While Samsung is now crowing about (near) cost parity with LCD, we have to remember how long it took to get to this point:

- Samsung have always maintained that OLED should be cheaper than LCD
  - No back-light unit
  - Reduced polarisers and optical films
  - No CF (if RGB is used)
- Samsung now are touting that they have finally reached this point and from here on in then OLED should be cheaper to produce
- However, this has taken Samsung over 10 years to get to this point with a cumulative > 500m displays: will take others quite some time to have the same learning experience both in terms of the patterning of the OLED layers but also in appropriate circuit design for LTPS-based OLED
- We believe many serious OLED players may have to make IP payments that Samsung may avoid

**Manufacturing cost LTPS LCD vs OLED (estimated)  
for capable player, 5 inch FHD, USD**



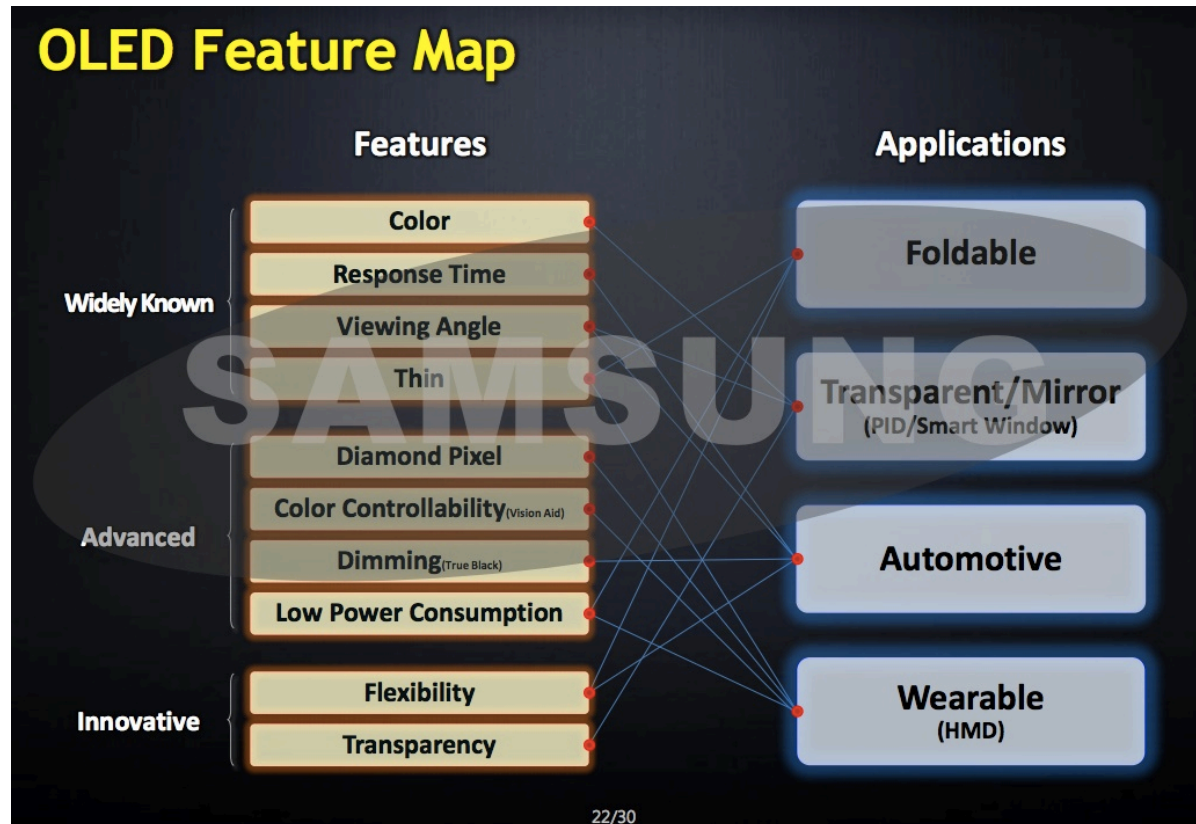
## While the idea of mass conversion might look exciting for some, what we will see is modest adoption:

- Conversion of the whole small panel industry to OLED would cost around \$150-180bn in new capex
  - The industry spends at peak around \$12bn per year on capex at most (across small and large panel) with the bulk very much concentrated in spend from BOE, SDC and LGD
  - Would take the industry 15 years to replace just the small panel LCD capacity: that is assuming that they spent nothing on LCD improvements or large panel at the same time
- And we have this feeling that people will find implementing AMOLED more difficult than they imagine
  - FMM evaporation is an art and Samsung control the IP for some of the pixel games that can help give apparent higher resolution
  - We wonder whether some players will put down the first chunk of capacity only to find that yield takes longer than they hope to come up
- We do have to remember that the leaders in AMOLED also own LCD fabs: pushing hard on the conversion only eats the “rest of their lunch” elsewhere. All players will want to optimise their total portfolios: and up to now only Samsung has been profitable in OLED

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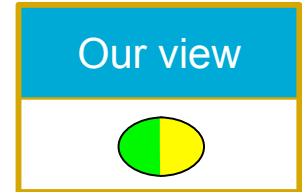
OLED provides growth opportunities from 5 new drivers of innovation:



- 1 Flexible, foldable, rollable
- 2 Other form factor innovations
- 3 Transparent and mirror applications
- 4 Colour gamut options battle against LCD
- 5 Stronger performance trajectory



## Issue 1: Flexibles, foldables and bendables and new 3D value propositions



- With the Galaxy EDGE phones, the market has seen (and quite liked) the notions of incremental moves into flexible displays. The EDGE models have sold at about 1/3 of the total Galaxy range
- Frankly, not all of the rollable ideas appeal to us as consumer value propositions, but 3D flexible/conformable displays for automotive integrated dashboards really make sense (The BMW picture here goes somewhat in the direction, but with a conformal OLED so much more would be possible)
  - As the automotive world moves toward autonomous vehicles that become entertainment pods then flex OLED could have a big role
- Not all of the innovations are yet clear here, but flexibles, foldables and bendables provide a new lever of innovation that is much more strongly delivered with OLED than with LCD





## Issue 2: Other form factor innovations

Our view

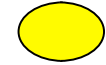


- However, stronger than 3D/Flex and foldable innovations are the basic step changes driven by OLED on PI (Poly Imide)
  - Lighter weight
  - Less breakable
  - Narrower bezels (Display right to the edge as shown below, this is possible with LTPS LCD as shown in the picture but also part of the proposition of OLED)
  - Freeform displays (such as the above picture, also a function of LTPS, but easier to implement in OLED)
- These basic functions are beginning to be understood and we think could support OLED adoption more strongly



## Issue 3: Transparent and mirror implementations

Our view



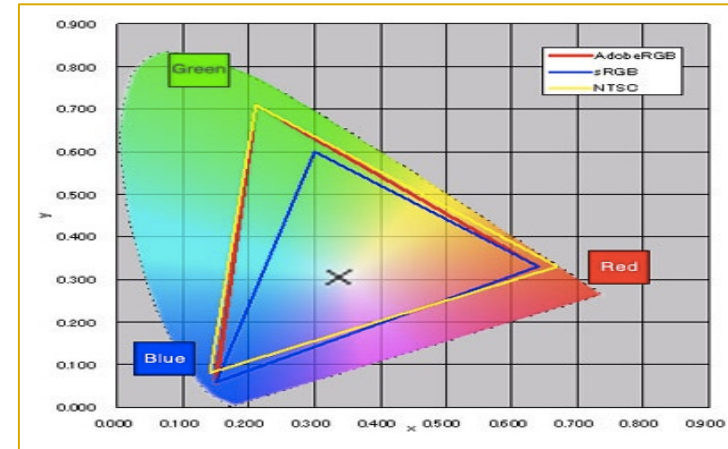
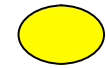
- Samsung and LGD have put continued weight into the notion of transparent OLED and mirror OLED as potential innovations
- The whole transparent category so far has been a very weak value proposition, with failed attempts by Samsung to establish a major new market in retail: transparent LCDs simply had too many issues with transparency and colour gamut
- While there may be some new design freedoms for TVs that might be interesting, overall we find this category to be not yet proven



## Issue 4: Colour gamut and role of colour performance against LCD

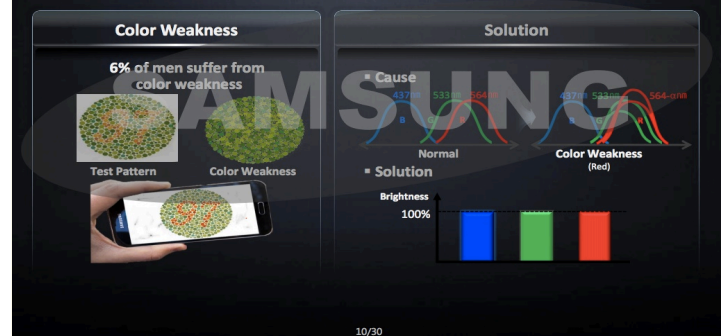
- OLED has come from the point of having a distorted colour space (shifted too much into the green to accommodate the stronger green emitters) to being a strong match to LCD
  - Integration of QD materials into OLED emitters could mean further expansion of the colour capabilities of OLED
- Meanwhile, LCD will not remain stationery: as QD film implementations improve the colour performance of LCDs with a drop in film (or light bar) implementations
- Beyond this, Samsung for one are beginning to talk about the manipulation of colour (say for those that are colour blind/deficient) to improve those users' experience
  - This is possible with LCD (and QD LCD) too
- Users will benefit from a technology race to improve colour performance of displays

Our view



### Advanced Performance ... Vision Aid

Providing vision aid to color weakness



## Issue 5: Stronger performance *trajectory*

Our view



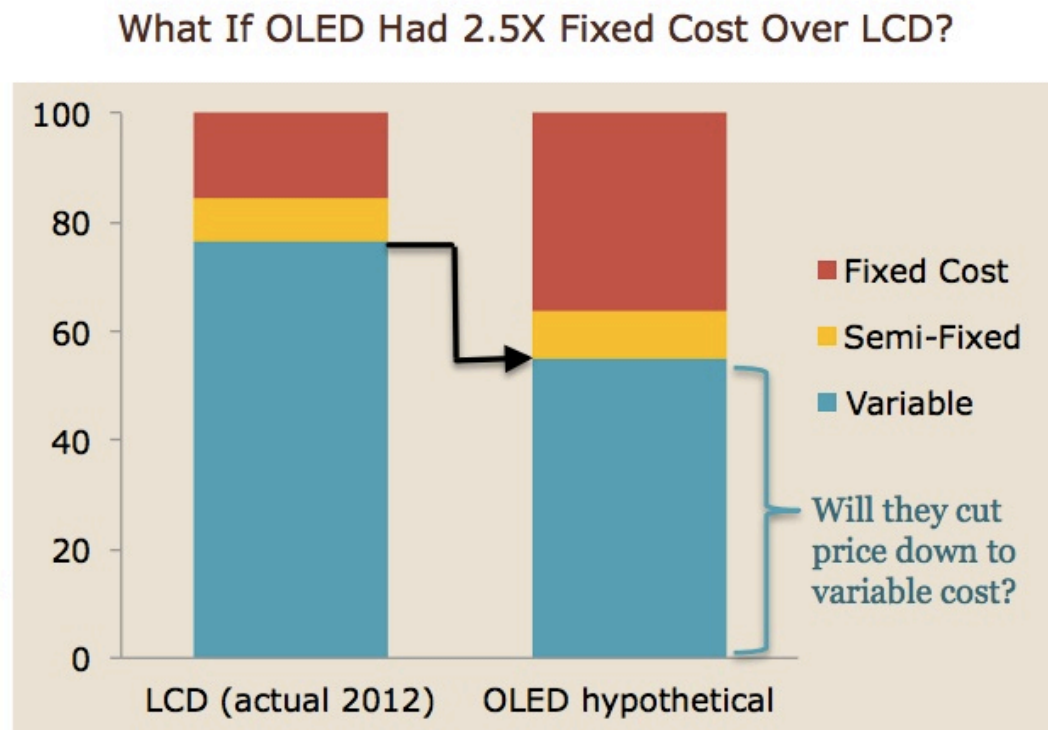
### ***Performance increase of Galaxy phones in just 6 years (Source: DisplayMate)***

	S1	S2	S3	S4	S5	S6	S7
PPI	223	207	306	441	432	577	577
PPI of subpixels	188	207	246	355	347	464	464
Brightness (Nits)	305	289	224	287	351	348	414
Contrast in High Ambient light	69	61	45	65	78	76	90
Power efficiency (W)	2.5	1.8	1.3	1.5	1.5	1.2	1.45
Regularity of the gamma*	1.13	1.18	1.08	1.10	1.10	1.07	1.09
Brightness decrease : Viewing angle	28%	26%	28%	22%	22%	27%	28%

- Finally, despite our holding a modest view of the conversion of the display industry to OLED, we do recognise that OLED is already matched (or in places superior) in performance on colour, contrast, viewing performance and other performance metrics compared to LCD *in mass production displays*
  - However, it is a substantially younger technology
  - Theoretically then there is more performance that we can eek out in OLED along many parameters as we seek to push up display performance

## ...but we do have to wonder whether different fixed-variable economics will lead to deeper losses in the OLED industry:







- Samsung are particularly interested in this OLED game, since they have believed that the economics of the industry could set up an industry structure and profits similar to the DRAM industry
- This will only work if the OLED market can be maintained in some sort of tight supply scenario: if the OLED industry moves to oversupply (as looks likely) then this could mean pricing down to variable cost
  - Pricing down to variable cost for OLED could mean bigger losses than for LCD
- The question is whether OLED is indeed a new economic game, or whether established pricing behaviours of all current firms will destroy value in OLED as they did in LCD









Plots a hypothetical 100 units of product cost contribution for AMLCD in 2012 and a hypothetical case of AMOLED with 2.5 times more fixed cost.



## Winners and losers by areas of technology:








	Area
Leading display firms	
Smaller display companies	
Glass	
Polarisers	
Drivers	
Backlight integrators	








	Area
Optical films companies	
LED companies	
Liquid crystal	
Plastic substrate providers	
Device makers	
Equipment players	

- There are only a small number of winners: largely the big display firms, the OLED equipment companies, the plastic substrate providers
- Many of the companies who supply LCD specific technologies (such as the whole of the backlight unit, plus polariser makers, LC makers and those LED companies supplying LEDs for display backlights) will be hit



## Winners and losers by company:

	Impact
SDC	
LGD	
BOE	
Sharp	
AUO	
Innolux	
Corning, Asahi, NEG	

	Impact
Merck	
3M	
Coretronic, Heesung, Forhouse etc	
Samsung LED, LG Innotek	
Novatek, Renesas and Himax	
Nitto Denko, LG Chem BenQ materials, Optimax	
Kateeva, AMAT Tokki, Coherent etc	

- The Korean majors and BOE may be among those that have the best opportunity to benefit from OLED. The Taiwanese LCD majors are perhaps among the weakest positioned. Sharp better positioned through its deal with Foxconn. The equipment makers will also do well
- Samsung display overall seems to be the winner in this conversion and any of the materials players for LCD will see some reductions in volumes



## Summary

- OLED is now in growth mode: Apple has pushed the technology into prime time, though more of the pieces are becoming available for others to try to compete
- That being said, this is not the complete conversion option that the OLED camp would like to advocate despite Samsung crowing about getting to cost parity and Apple's recent moves
- What it will do is create a short term stampede into OLED, though the longer term picture will depend on the ability of these OLED newbies to manufacture OLED at appropriate yields and cost. AMOLED is a difficult technology with challenges at the TFT level (either through the physics of the interface for oxide or the challenges with laser anneal for LTPS) and the patterning level (FMM a challenging technology to get right at very high resolution)
- OLED will create winners and losers: The winners will be the small number of display firms that will succeed in the technology (especially SDC), and the equipment industry in the short term. Losers will be all of the businesses that support purchased materials for LCD, especially those in LEDs, optical films etc but also for Corning as TFE replaces the need for another layer of glass
- However, despite this modest conversion outlook, we do have to admit that OLED is important as it extends and opens new innovation axes for the display industry. An open question is whether the economic profile of the display industry, which is to destroy value by pricing down to fill fabs will be any different in OLED than in LCD



## Our offerings:

<b>Growth strategy</b> <ul style="list-style-type: none"><li>• Market entry strategy</li><li>• Business unit strategy</li><li>• Growth strategies for new technologies</li></ul>	<b>Performance improvement</b> <ul style="list-style-type: none"><li>• Product portfolio management</li><li>• Pricing strategy</li><li>• Cost reduction</li></ul>	<b>Equipment and Capex</b> <ul style="list-style-type: none"><li>• LCD/OLED factory capex decisions</li><li>• Strategies for equipment makers</li></ul>	<b>Sourcing strategy (Purchasing)</b> <ul style="list-style-type: none"><li>• Sourcing strategies, especially LCD and medical detectors</li><li>• Make/buy decisions</li></ul>
<b>Technology strategy and technology assessment</b> <ul style="list-style-type: none"><li>• Market and commercial strategies for new technology businesses</li><li>• Market tracking services for corporates monitoring technology</li></ul>	<b>Partnering and alliances</b> <ul style="list-style-type: none"><li>• M&amp;A candidates and assessments</li><li>• Alliance formation support</li><li>• Post merger integration planning</li></ul>	<b>Professional advisory and business planning</b> <ul style="list-style-type: none"><li>• Specialist insights for bankers, equity investors and other consultancies</li><li>• Reviews of business plans and models (Strategic audits)</li></ul>	<b>Strategies for materials providers</b> <ul style="list-style-type: none"><li>• Strategy support for materials providers in the FPD, SSL, and PV markets</li><li>• IP and pricing plans</li></ul>