“Pepsi and Coke”
(OLED vs QLED)
One year later what has changed

September 2018

We presented our view on Pepsi vs Coke last year: What has changed?

	OLED	True QLED
Colour volume	Very dark blacks but lower brightness	Very large (Higher brightness)
Lifetime (to significant color shift)	20,000 hours	40,000 hours
Power consumption (55-inch TV)	145 W avg (c. 2016) (650 nits peak)	70 W avg (c. 2022) (1400 nits peak)
Timing	Now	+ 5years
Backplane needed	High mobility Backplane IGZO or LTPS	High mobility backplane IGZO or LTPS
Deposition approach	Evaporation or IJP	IJP

1. Environment worse and 8K coming
2. QD options have changed
3. QDEF/QDOG supply chains firming up
4. QD OLED the Samsung bet. More desperation for Samsung
5. MicroLED now the bet for Taiwan Inc
6. OLED: LGD stepping on the gas
7. Printing is more proven
8. No one following Samsung, yet

Source: HCL pre-existing and market views. True QLED here means QDEL – electroluminescent QD

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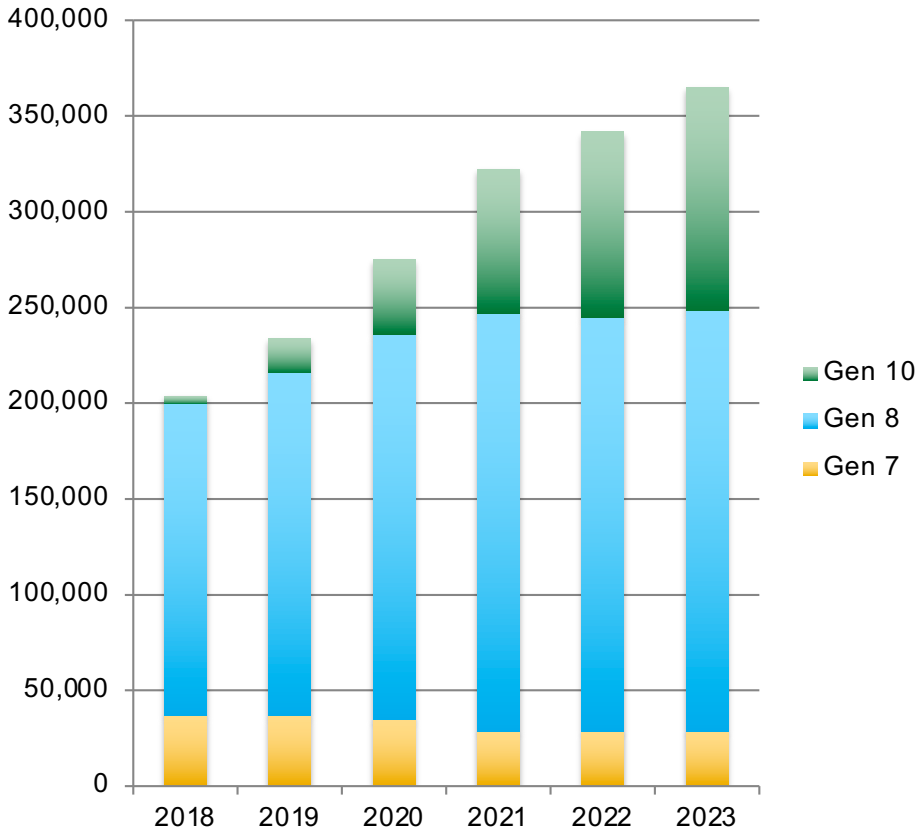
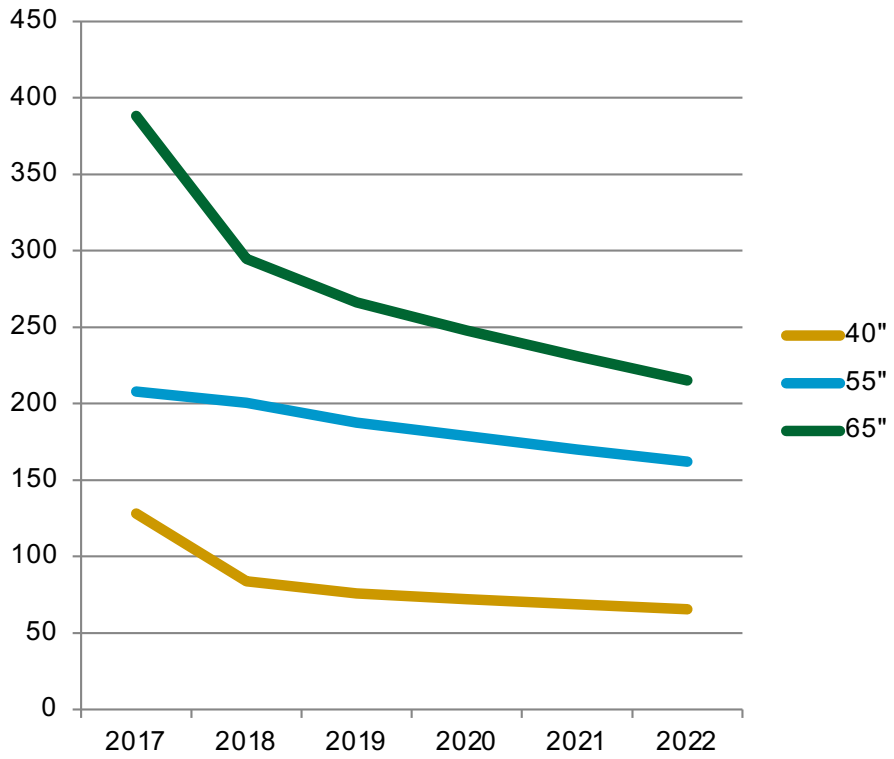
The environment is worse one year later. Gen 10 fabs beginning to ramp means downwards price pressure. 8K coming which may change the basis of competition

Gen 10 fabs coming (m^2 000s)



Average prices for 40 (2K), 55, 65 TV



Source: IHS Q1 2018

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The QD options are changing in emphasis: QD-OLED now hot and QDCFR may stay in the kitchen longer

	QDEF	QDOG	QDCFR	Hybrid OLED-QD (Colour by blue)	QDEL	QD on Chip
Embodiment description	QD material between two layers of film	QD material coated on LGP replacement	QD material replaces CF dots on front plane (CF)	Blue OLED with QD CF	Electrical emission of the QDs	QD material on LED chip in BLU
Pros	Drop in film Takes advantage of current industry No conversion cost	Relatively straightforward replacement of LGP film	Potential for premium displays Display player gains ASP up	Premium display High brightness. Avoids need for in cell polarisation. No BLU so thin	Premium display High brightness	Very small amounts of QD material
Cons	Cost of barrier film Film is not so simple to make	Custom shaped glass plates for each project, Corning value price	Technically some challenge (polarisation, front fluorescence, light optics)	Just as costly as OLED for a new fab (probably).	Just as costly as OLED for a new fab (probably)	QDs need to be very robust to flux and heat
Demand driver and market related issues	Demand is end user determined based also on supply of film and pricing	Potentially constrained by Corning SKU management	Will reflect conversion of CF fabs in chunks due to new equipment	Will be the same type level of investment as OLED	Will be the same type level of investment as OLED	Supply of appropriate LEDs/pricing/supply chain dynamics
My summary	Primary demand driver for the QDEF industry	Glass supplier driven business but has product complexity issues	Allows for premium OLED like displays if technical problems are done	Medium term strategy perhaps by Samsung	Longer term strategy perhaps by Samsung	The wild card bet that could change the game as uses much less material

Source: HCL, Palomaki consulting

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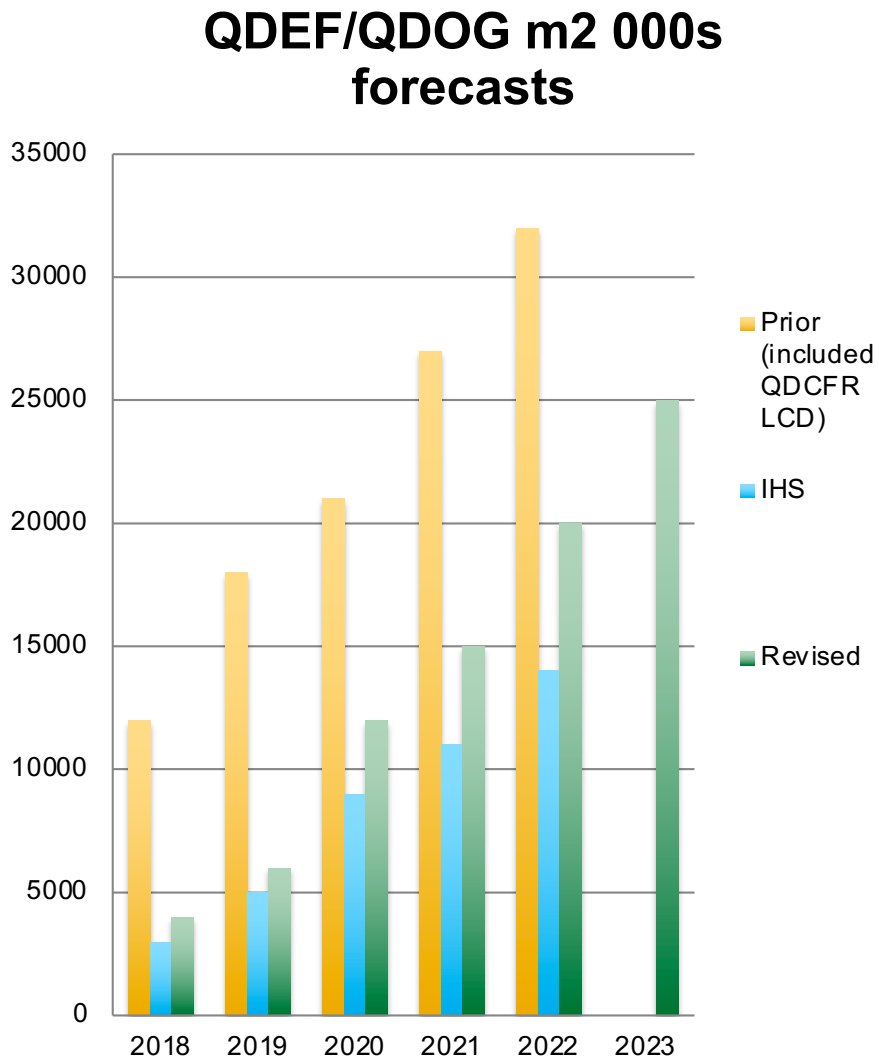
QDEF/QDOG supply chains firming up but volumes might be lower than we previously thought: this is really only in that we now recognise more competing approaches

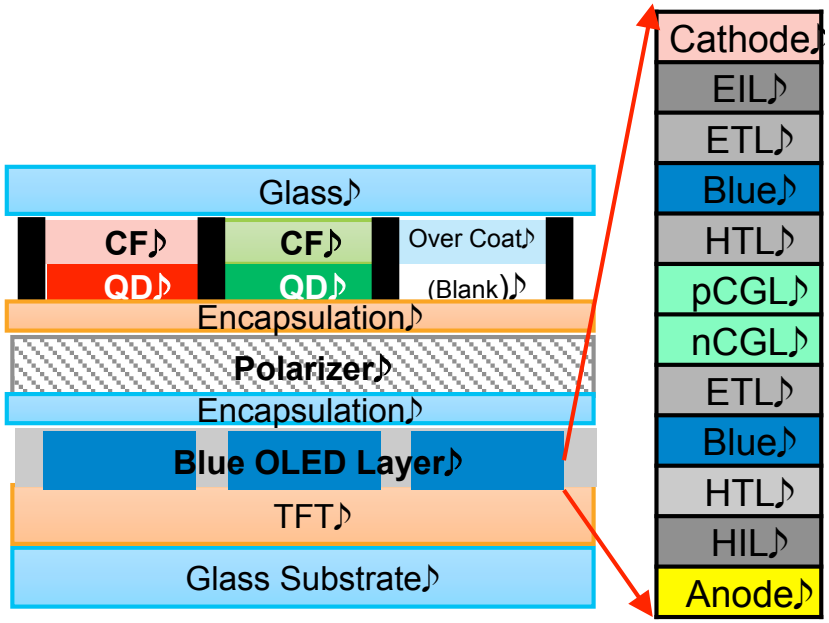
Brands	Samsung	TCL	Hisense	
Film suppliers	Shinhwa	Hitachi Chemical	SKC Hitech	Kolon & KDX & Wah Hong
Barrier film	Kolon			
Dot suppliers	Hansol	Nanosys		

- In general, we are bullish on WCG and our previous forecasts reflected that
- With Samsung putting the weight of their support into QD-OLED hybrids we still believe in this but perhaps at a lower level (we are recognising more competing approaches including phosphors)



Source: IHS, HCL
IHS numbers property of IHS

4 Samsung now focusing on the QD-OLED bet:



Actual status
with 2~3 tandem blue OLED layer♪

- Samsung now moving as fast as they can on QD-OLED
  - Evaporators from Tokki and IJP from Kateeva according to DSCC
- Current architecture however, seems to still include a CF (according to IHS) though we imagine this to be a transitionary measure to help to extinguish blue light through green dots
- Samsung starting at Gen 8 but we would expect them to consider moving to Gen 10 very rapidly if the technology is proven
  - We would also expect the CF to be removed and attempts to reduce the number of layers in the OLED stack
- Samsung's Achilles heel may be grasp of oxide for large panel

Source: IHS, DSCC
Graphic property of IHS

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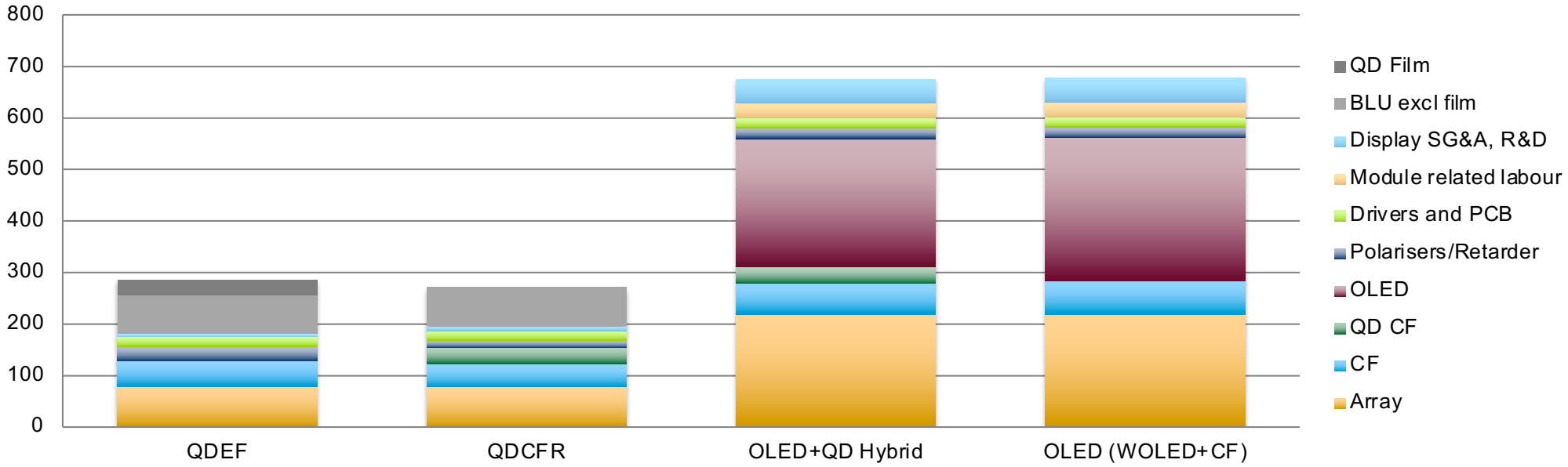
…which may not be cost advantaged over WOLED:

Costs and pricing of potential QD implementations, for illustration, 55” 4K Yield assumption makes a big difference for right hand two cases

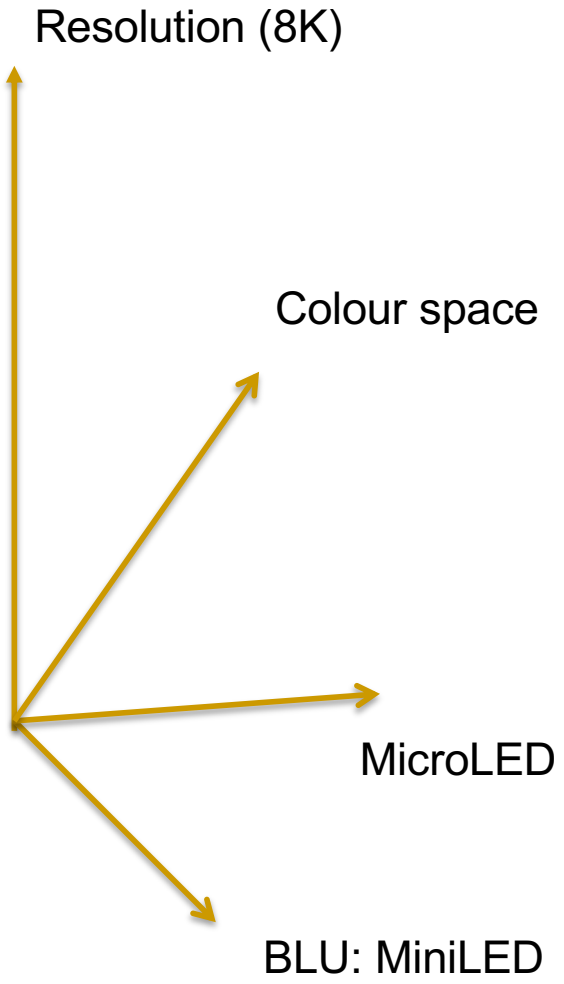


- Current industry finds the quenching of blue light especially with green non-Cd QDs particularly difficult: hence the need for a CF
- Samsung cost may actually be higher than WOLED, since yield may well be worse

Source: HCL
Pre-existing and market views

4 …and at the same time Samsung all the more desperate to regain position against LGE

Axes of competition



- Samsung corporately is getting more and more desperate about trying to rebuild its position in premium TV
  - The challenge is the fundamental display technology innovations take quite a while (monolithic MicroLED, QD-OLED)
  - SDC in particular may try many other things in desperation: MiniLED lit 8K? MicroLED through tiled approaches?
  - Try again with QDOG?
- The aim of this presentation is to try to simplify: the reality is that there are many choices based on technology and different value chain ideas

Source: HCL in discussion with Paul Gray

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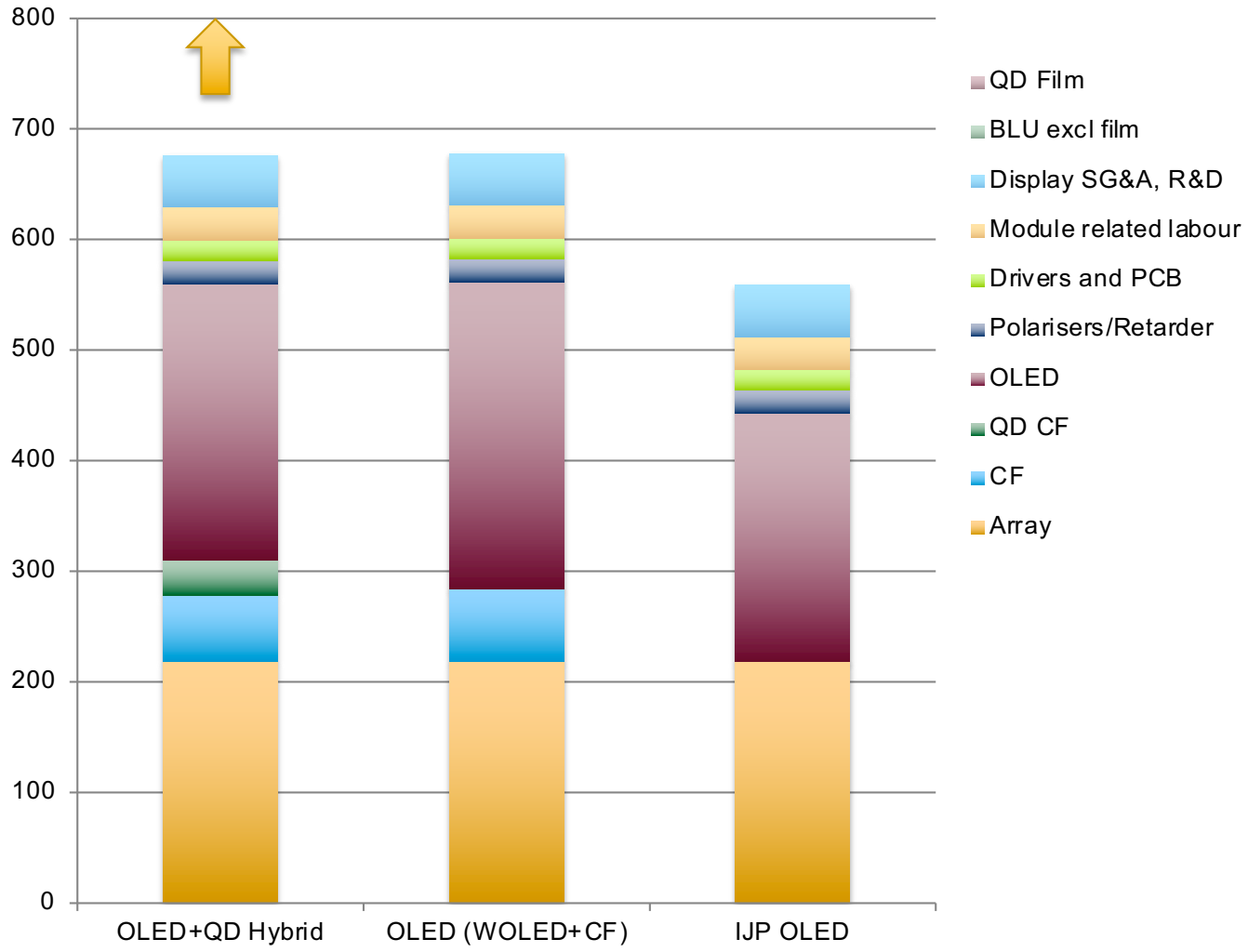
While at the same time LGD may make the move to IJP OLED

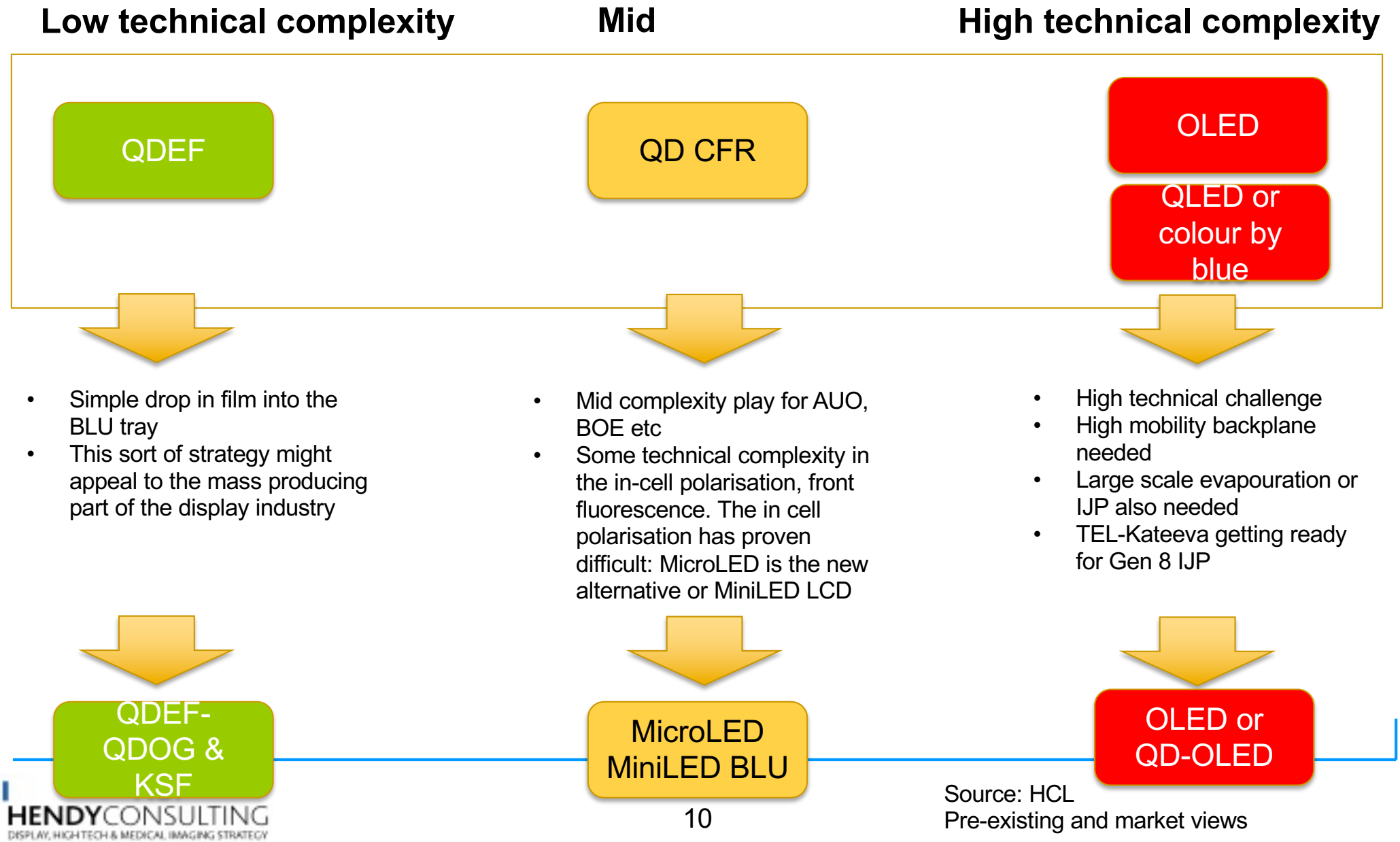
Cost at module level 55” 4K USD per piece



- IJP can generate large cost savings:
  - Reduced cleaning cycles
  - Reduced cost of masks (open masks and CF masks)
  - No CF cost materials, CF capex or CF shop
  - Reduced use of OLED materials
- The performance of the IJP OLED top emission and QD-OLED solution may not be too dissimilar

Source: HCL
Pre-existing and market views

5 And Taiwan Inc plus others very interested in MicroLED



Source: HCL
Pre-existing and market views

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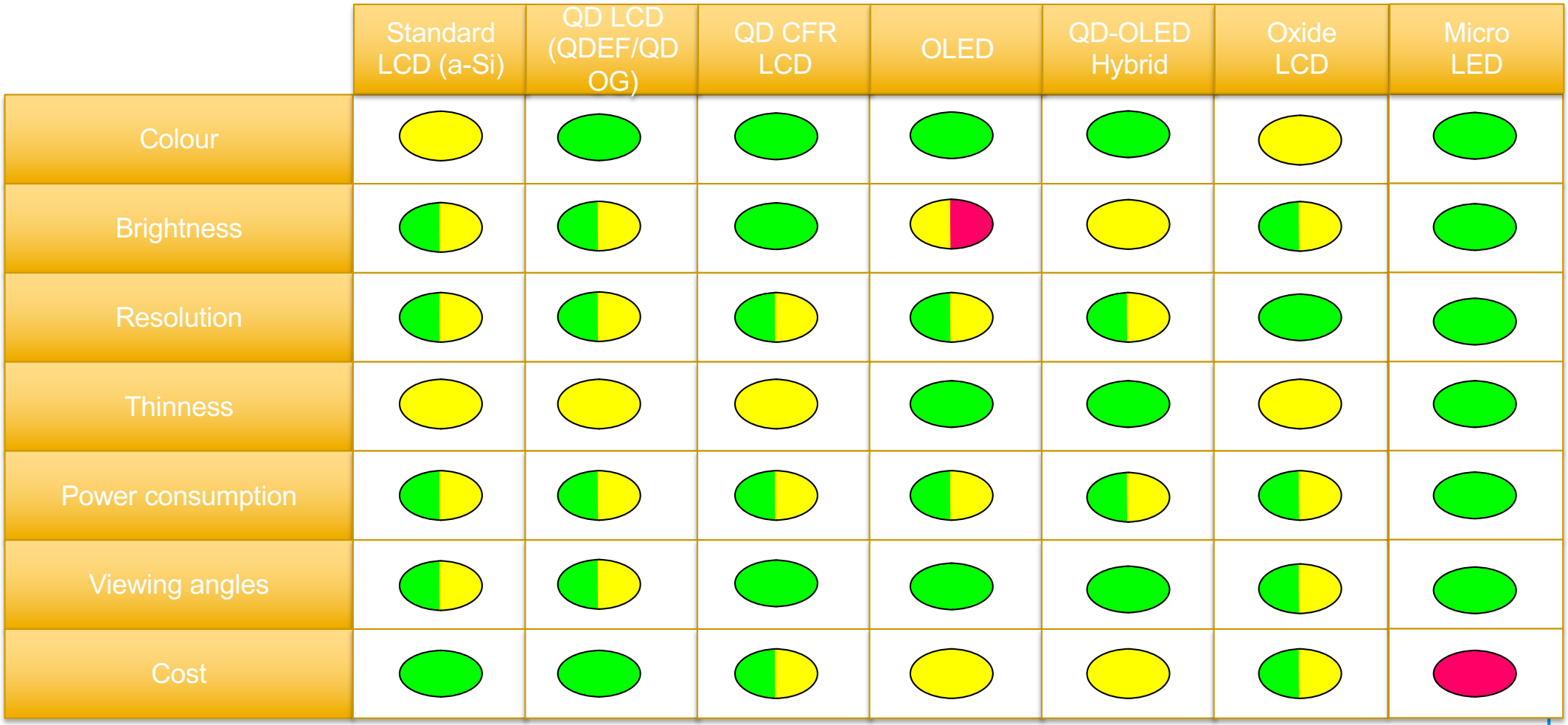
So that now there are a very wide range of options in wide colour gamut in displays:



	Standard LCD (a-Si)	QD LCD (QDEF/QD OG)	QD CFR LCD	OLED	QD-OLED Hybrid	Oxide LCD	Micro LED
Colour							
Brightness							
Resolution							
Thinness							
Power consumption							
Viewing angles							
Cost							

Source: HCL pre-existing and market views

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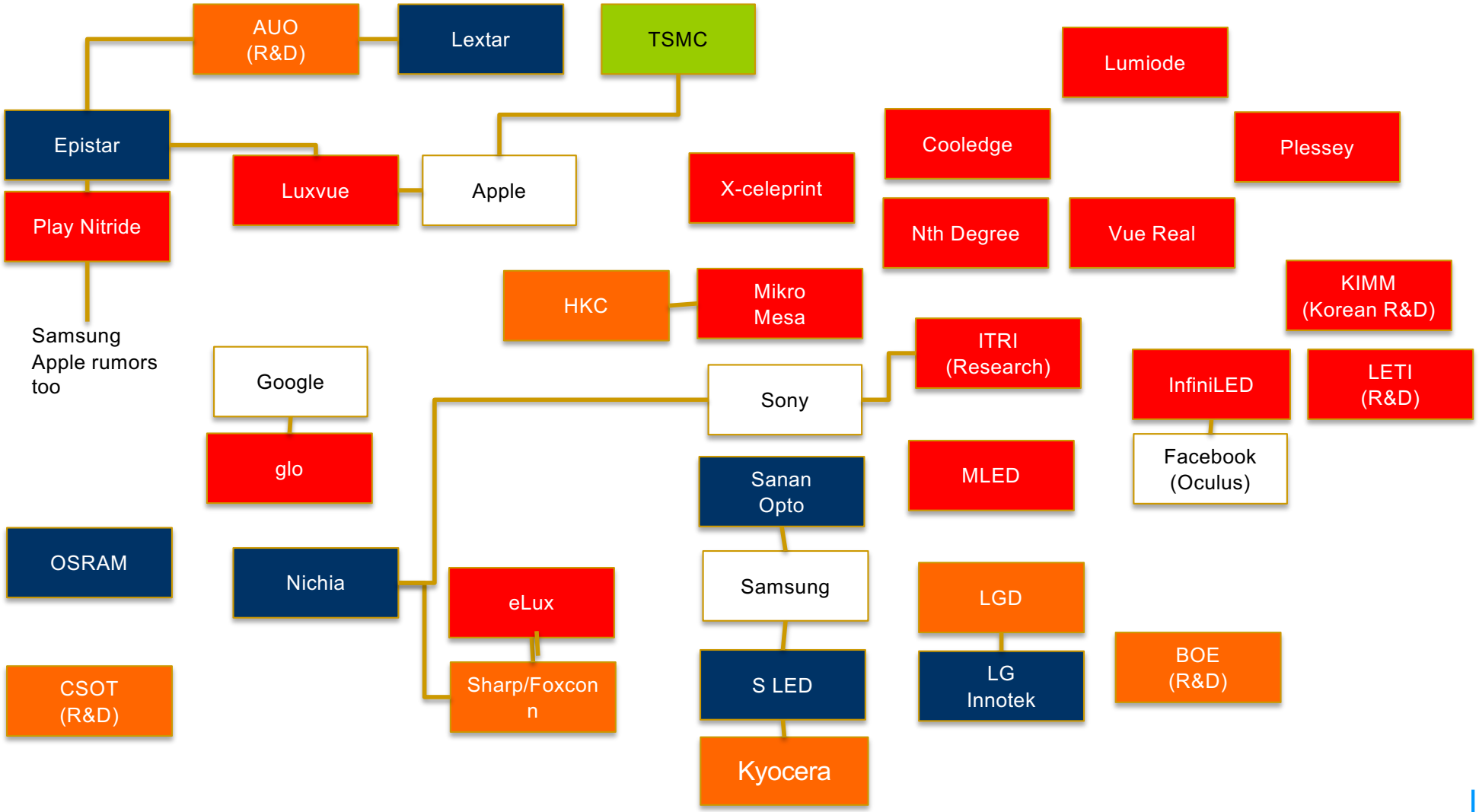
…the MicroLED environment is developing as players begin to set up collaborations



Source: HCL pre-existing and market views

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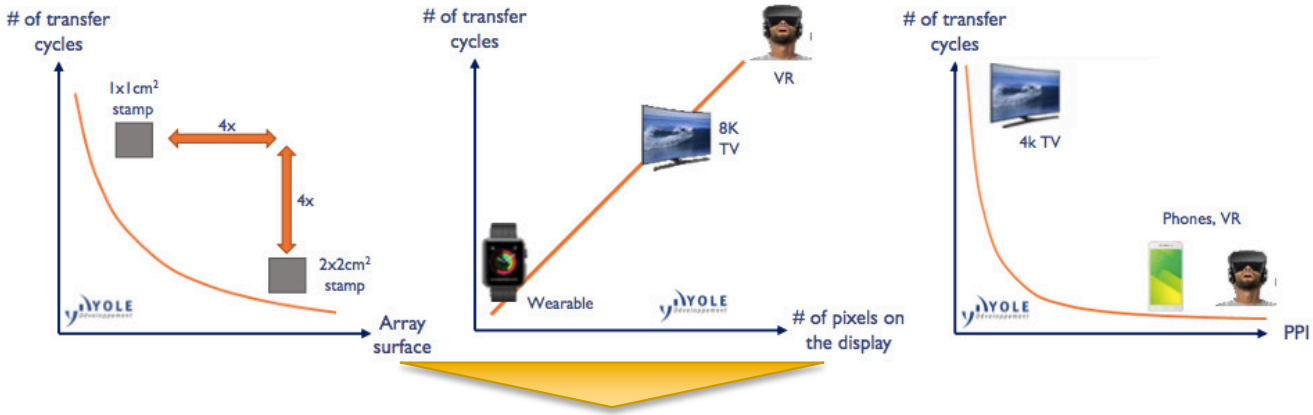
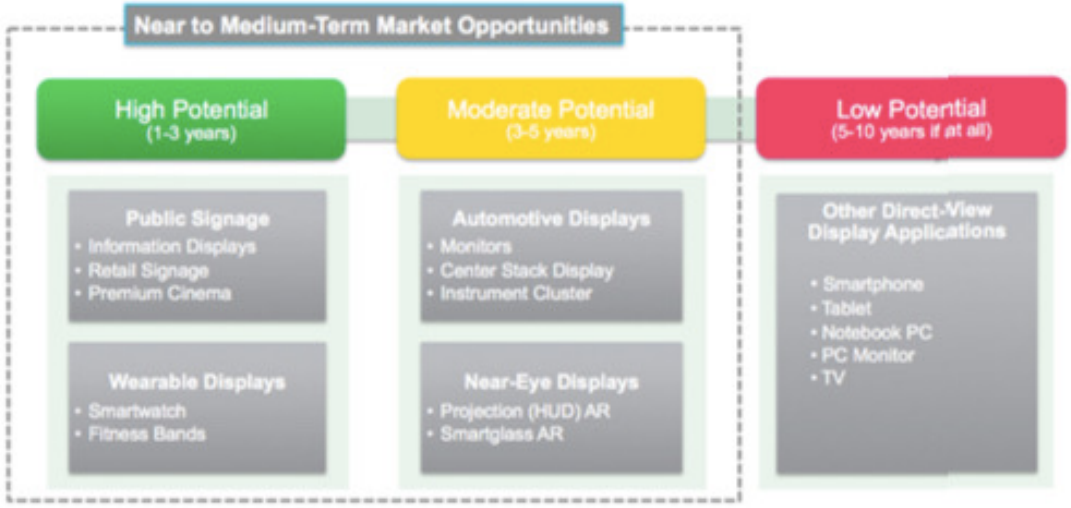
MicroLED markets are counter intuitive to display marketeers, due to unusual transfer economics and redundancy measures and other differences:





- MicroLED served markets are arrived at based on the particular strengths of the technology and the transfer economics
- Initial markets are at opposite ends of the scale of display markets
- Progress seems to be happening but costs are still too high
- Several display groupings in Asia seem interested since this is premium display without the capex

Source: Yole, HCL and IHS

5 A number of factors will influence the future industry structure for MicroLED

Requirements for the drive backplane

- While most industry observers claim that MicroLED can be driven by IGZO and LTPS, there are already players deploying CMOS or the use of distributed ICs
- The specifics of PWM for MicroLED and the way that the peak current needs to be managed for MicroLED may mean that distributed ICs may be the way to go and not a TFT backplane

Implications of mass transfer economics/repair

- The specific economics of mass transfer are very different to the usual cost factors in the display industry that often mean that display cost scales with area. For MicroLED the cost scales with the number of pixels and their geometric spacing (and on a number of optimisations of repair strategies, transfer strategies – including intermediate transfer locations)
- We think the specifics on placing and repairing the right dies in situ will create specific valuable competencies

Role of verticalisation

- Already at this early stage Apple is leading the way towards captive business models (and Google and Facebook among others seeking to do similar things)
- The LG and Samsung groups may also try differentiated vertical strategies

Role of non-display participants

- If the world does evolve into a distributed IC driving method then there is a potential role for assembly players and others to get into this business
- Display companies still might act as channel partners but their role in the business could be substantially reduced
- LED and semi assembly players could take a greater share of the value

How colour is generated?

- Not yet clear whether players will use blue dies with QD or other colour conversion layer or use discrete R, G, B dies

Source: HCL

Source: HCL pre-existing and market views

5 So we can define a set of scenarios for the future of the MicroLED industry: some may not be display centric

	Display Centric world	LED and non display players win	Vertically integrated players win	MicroLED fails to emerge
Who leads the business development	Display players dominate this	LED companies with CMOS partnerships and assembly capability	Individual vertically integrated chains	Many players try but few successes
Specific Winners or losers	Foxconn Samsung LG Group win on revenue tho' value winners not so clear	Nichia, Epistar Sanan Opto and/or TSMC	Apple, Foxconn glo ITRI?	Most fail given the complexity of the new technology
How the displays are addressed	LTPS or oxide with modifications	Discrete ICs or other CMOS backplanes	Different specific methods in each case	Different specific methods is one of the causes of failure
Summary	A strong potential outcome but value may accrue to materials and equipment	If TFT is not needed then a different structure could result	Whole technology probably delayed if vertical player model results	There is still a chance that this technology fails to achieve promise

- We have four different scenarios for now for how the world might evolve
- The simplest one is that display players end up at the centre of this technology but that still does not necessarily mean that most value will be captured by them
- However, there is a strong chance that a vertically integrated model might result with chains of proprietary technology
- Or that the LED companies work with semiconductor (assembly) houses to form the industry based on distributed ICs

Source: HCL

Source: HCL pre-existing and market views

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What is interesting is to look for those display conglomerates who may already have most of the pieces in house from LED to transfer method etc to backplane. We should watch LGD/LG Innotek and Samsung and Sharp/Foxconn. Apple will be key also:

	LED	Mass transfer	Display - Oxide	Channels	Segments interest	Summary
Sharp Foxconn Innolux	✓	R&D	✓	✓	TV Phone+ Watch?	We hear rumours of quite some work here by Innolux/Foxconn. Sharp has LED capability also
AUO	-	R&D	No	✓	Many	AUO interest seems to be at R&D level for now
Samsung	✓	R&D	Not yet but can develop	✓	Watches TV/Video displays	SDC and SEC seem to be taking competing approaches right now
LG Group	✓	R&D	✓	✓	TV Smartphone? Video displays	LG Group could be key player in this with access to many of the pieces
CSOT-TCL	-	R&D	Not yet	✓	Many but mostly large panel	Some established research on elastomer stamps and micro optics
BOE	-	R&D	Developing	✓	Many	BOE interest for now is research and development. Does have partnerships for AR/VR
Apple-Luxvue	✓	✓	No	✓	Watch	Apple reportedly in discussion with TSMC and Play Nitride for SmartWatch MicroLED partnering

Source: HCL pre-existing and market views

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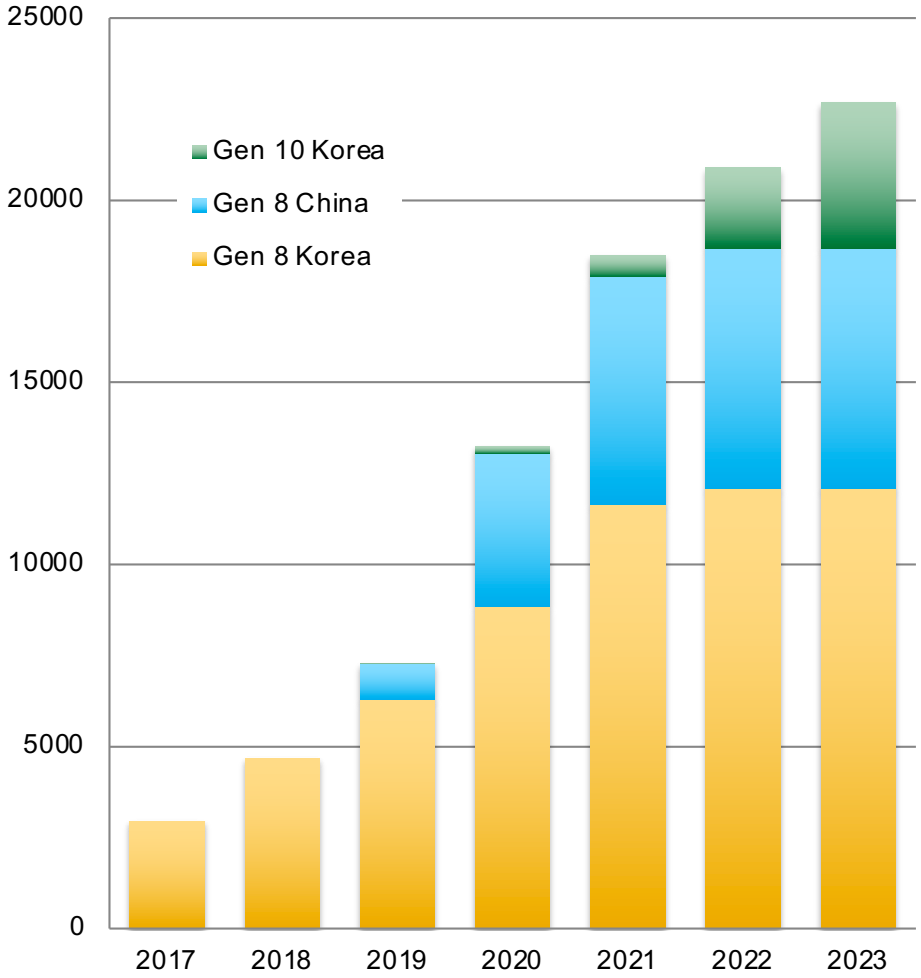
In OLED, LGD stepping on the gas, bringing forward Gen 10 plans. The OLED train is running down the track

LGD mass production m² input capacity 000s

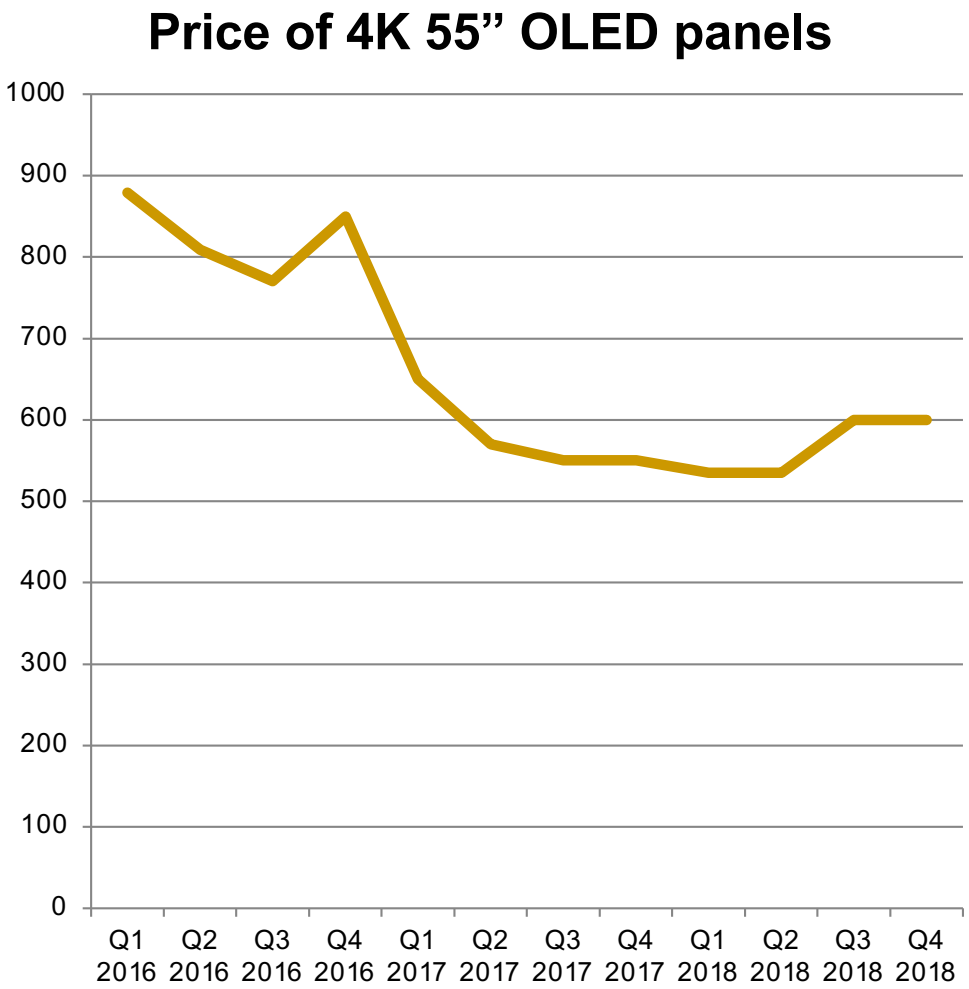


- LGD already close on ramping GP3 in China
- LGD have dropped plans for Gen 10.5 LCD to move to OLED faster
- Considering more fab conversions for Gen 8 capacity also
- LGD may well investigate IJP top emission as an alternative to WOLED+CF
- Samsung which is still going through R&D and first tool construction is going to have to move fast to catch up, so the talk has been about a fairly fast move from Gen 8 mass production to Gen 10

Source: IHS

6

And even LGD putting up the price of OLED modules at the end of the year. Such is the demand for OLED TV now:



- Recent news from DSCC has suggested LGD has increased the price on OLED panels in peak season
  - Demand is more than supply
- Price relatively stable compared to the reductions in LCD of late

Source: IHS and DSCC

7 Printing is more proven, with a new player to challenge the top 2 IJP companies

- Kateeva
- TEL
- Panasonic-JOLED SCREEN

- Options with pixelated QD need printing not evaporation
- In the last 12 months, printing seems to have moved forward
  - Printing being used for TFE and YOCTA
  - Announcement of Panasonic-JOLED and SCREEN partnership to commercialise and sell IJP equipment
  - QDCFR programme at Samsung also based on printing
  - Seems obvious move for LGD to consider printing as soon as possible
- Panasonic Production Engineering-JOLED-SCREEN construction is interesting
  - Panasonic Production does custom design of the equipment
  - SCREEN sells the equipment and process
  - JOLED licenses display technology to accompany

Source: HCL pre-existing and market views

8 But if we look at the herds of elephants, no one is following Samsung Display, yet

LG AUO BOE 华星光电 CSOT SAMSUNG

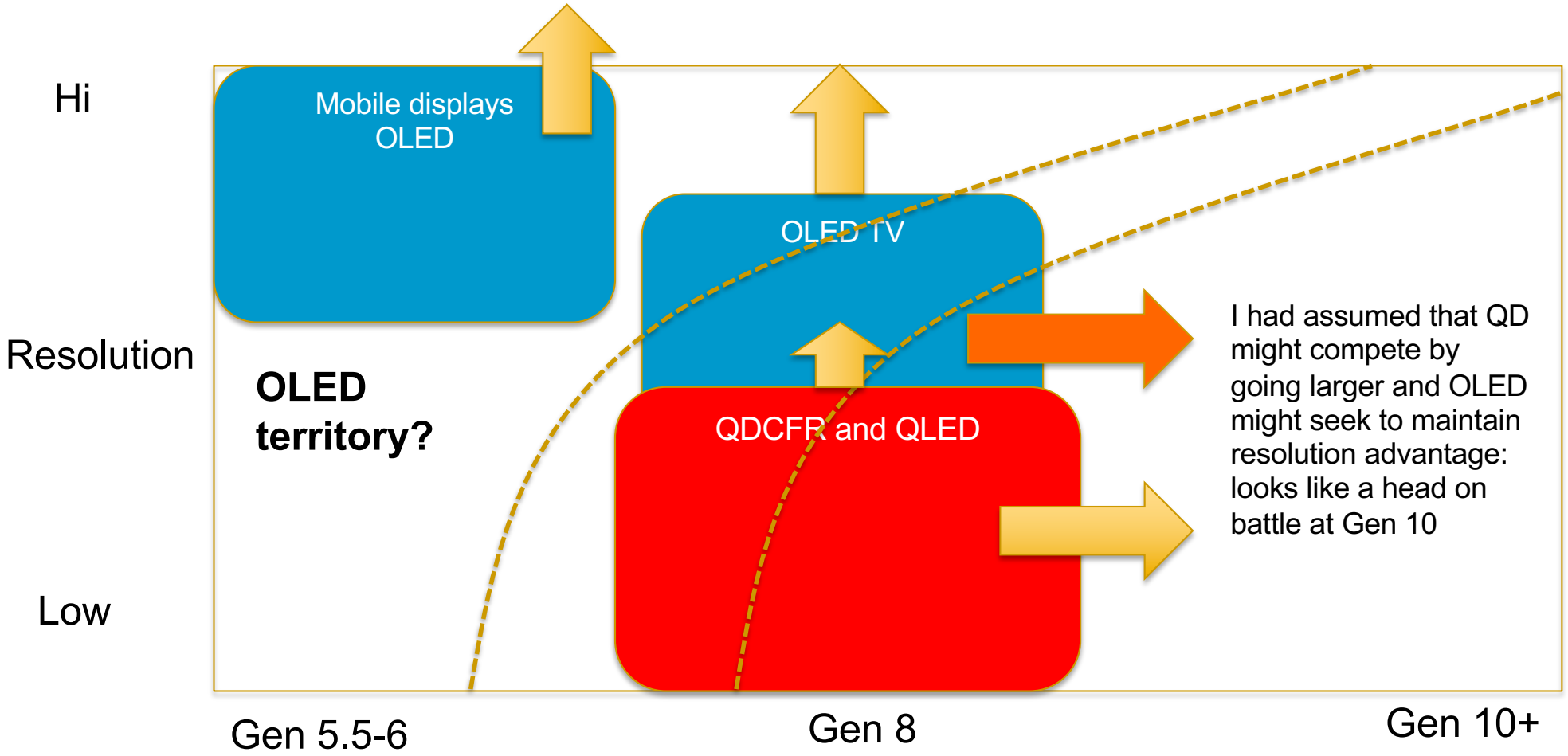
SONY Panasonic PHILIPS Hisense life reimagined TCL

CHANGHONG Skyworth VIZIO

Source: HCL pre-existing and market views
Hisense also has a WOLED offering under another brand

8

Last year I sought to say there may be different strategies: Actually it looks like a head on battle



- True QLED is going to require IJP so will be resolution limited despite improvements to IJP accuracy
- Evaporation for now is the proven approach for high resolution mobile devices

Source: HCL pre-existing and market views

Things have indeed changed a fair bit

Momentum moved towards OLED at this point in time

OLED QLED

+ MicroLED just beginning to register

1. Environment worse and 8K coming
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Source: HCL pre-existing and market views

It's not about Pepsi vs Coke any more: Things are more complicated

	OLED	QLED	Micro LED
LG Group	✓	-	✓
Samsung Group	-	✓	✓
Foxconn Sharp Innolux	-	-	✓
AUO	✓	-	✓
China Star	✓	✓	-
BOE	✓	✓	-

- There will clearly be portfolio decisions being made in these firms
  - Also worth saying that the "Samsung Group" is actually several different businesses with almost competing objectives; LG group almost similar
- BOE for now taking a technology agnostic approach within its BOE 8425 strategy, but we think OLED may win
- China Star getting ready for Gen 11 OLED

Source: HCL pre-existing and market views

So then what are our thoughts on winners and losers:

Momentum moved towards OLED at this point in time

OLED QLED

+ MicroLED just beginning to register

Winners

- LG and Samsung groups
  - For now LGE and LGD winning with OLED and have backup play in MicroLED
- Foxconn and Innolux have all the pieces to make MicroLED successful
- OLED material companies both evaporation and solution based
- Driver companies

Losers

- The LTPS LCD players are likely to suffer
- Smaller fab owners
- Many of the display owners without high technology
- Those heavily exposed to the LCD price declines from Gen 10
- Materials firms exposed to heavy downward price pressure

Source: HCL

…and overall implications:

- 12 months on, and our position has moved from “Don’t bet against Samsung” last year to “OLED is winning, Samsung under pressure” this year
  - LGD is driving forward based on a known ecosystem and production processes
  - Moving to printing now instead of open mask evapouration is a single technical risk not a basket of risks which is what Samsung has to deal with

- The market place is under more price pressure than it was 12 months ago: discretionary projects may come under more pressure and this may force panel makers to make hard choices (“this project OR that project”)

- QDCFR LCD seems to be slower with real challenges around the in-cell polariser: MicroLED has caught the imagination of many, at least at an R&D level
- For now the industry faces more uncertainty and wealth of choices than in previous times: expect the Korean’s to make some big bold moves and then the pack to follow their lead
- Overall wide colour gamut and 4K represent good business we believe: differentiated solutions and LGD is finally talking about being profitable on OLED TV in H2 2018

Our services:

Growth strategy	Performance improvement	Equipment and Capex	Sourcing strategy (Purchasing)
• Market entry strategy • Business unit strategy • Growth strategies for new technologies	• Product portfolio management • Pricing strategy • Cost reduction	• LCD/OLED factory capex decisions • Strategies for equipment makers	• Sourcing strategies, especially LCD and medical detectors • Make/buy decisions

Technology strategy and technology assessment	Partnering and alliances	Professional advisory and business planning	Strategies for materials providers
• Market and commercial strategies for new technology businesses • Market tracking services for corporates monitoring technology	• M&A candidates and assessments • Alliance formation support • Post merger integration planning	• Specialist insights for bankers, equity investors and other consultancies • Reviews of business plans and models (Strategic audits)	• Strategy support for materials providers in the FPD, SSL, and PV markets • IP and pricing plans