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Manufacturing Cost Analysis by Display Technology

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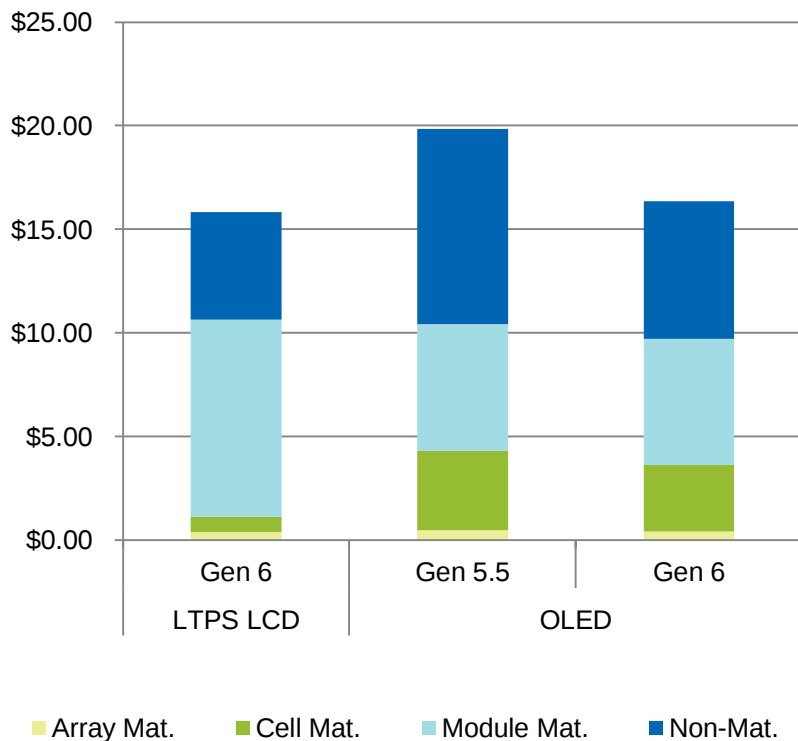
LCD, OLED and Flexible

Mobile Display

OLED trying to catch up LCD for high-resolution

Cost gap getting narrower and higher pressure over LCD component supply chain

LCD vs. OLED 5.5" QHD smartphone display



Source: IHS

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Cost table of 5.5" QHD smartphone display

Items	LTPS LCD Gen 6	OLED	
		Gen 5.5	Gen 6
Array	\$0.4	\$0.5	\$0.4
Material Cell	\$0.7	\$3.8	\$3.2
Module	\$9.5	\$6.1	\$6.1
Non-Material	\$5.2	\$9.4	\$6.6
Total Manufacturing	\$15.8	\$19.8	\$16.4
Gap to LCD	-	X1.25 (\$4.0)	X1.03 (\$0.5)

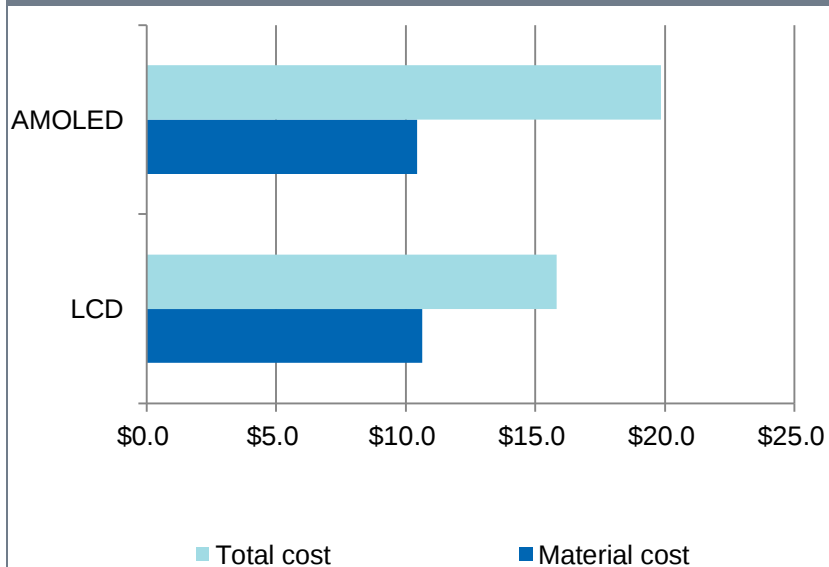
Notes: Q3'16, non-material incl. labor, depreciation, etc. Touch module is not included.

Source: IHS

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How OLED cost can be lowered?

Material and total cost for OLED vs. LCD (5.5" QHD)



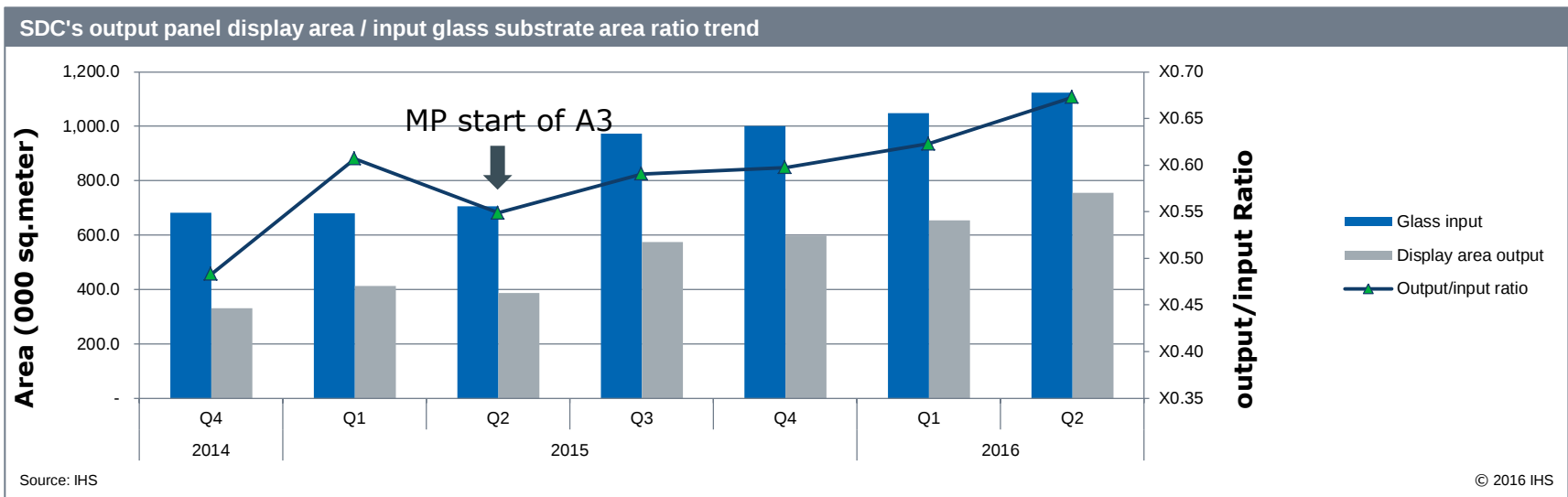
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- Material cost of OLED is estimated to almost catch up that of LCDs for 5.5" QHD smartphone display.
 - > OLED material price has been lowered consistently.
 - > No backlight for OLED
- Non-material factors become more critical.
 - > Manufacturing yield
 - > Utilization rate
 - > Substrate size (Fab Gen., quarter/half cut)
 - > Depreciation

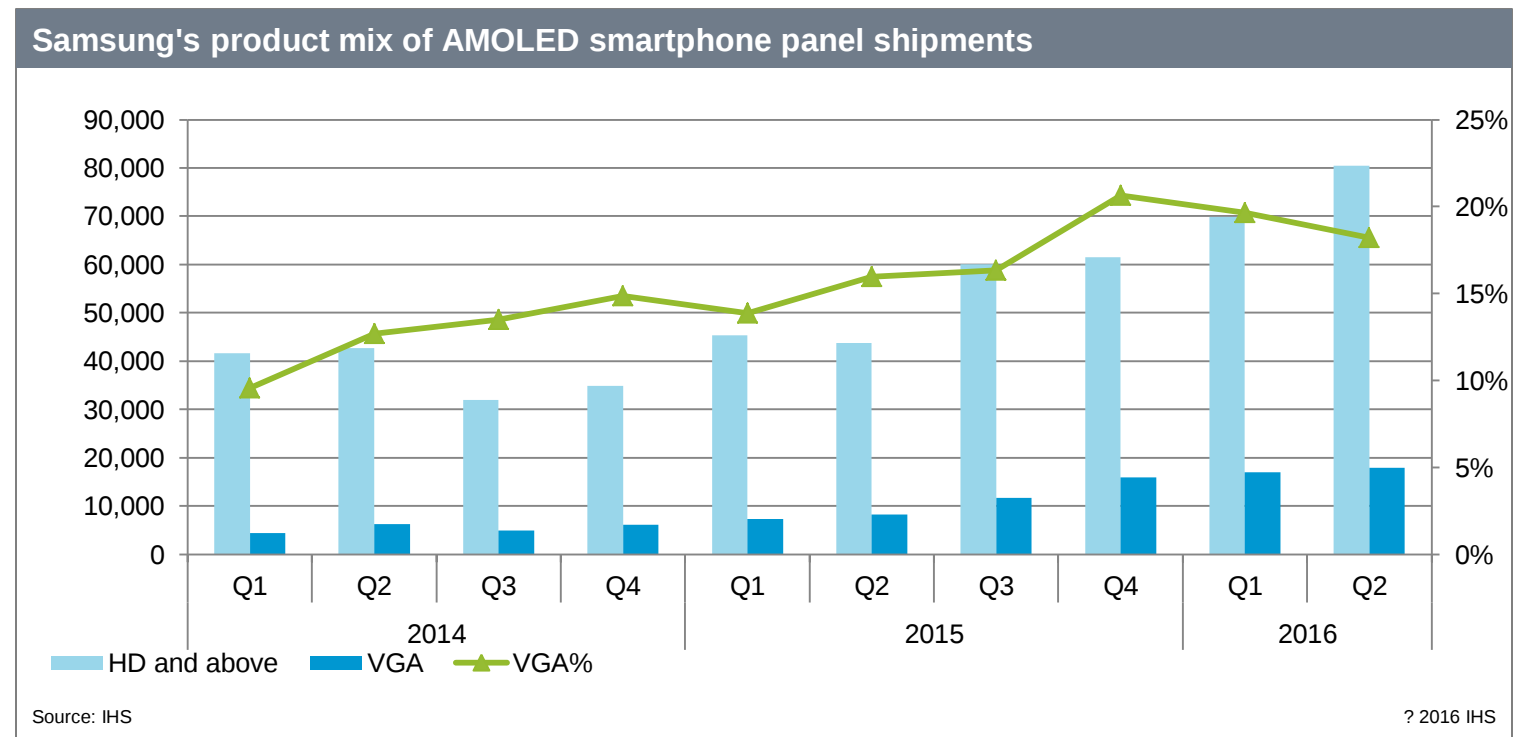
OLED manufacturing yield improvement

- Ratio of output panel display area to input glass substrate area must be highly related with manufacturing yield.
- SDC's ratio was found to increase a lot in Q1'15. Then, continued to grow again right after a sudden drop in Q2'15.
 - > Q2'15's declining must be due to MP start of A3.



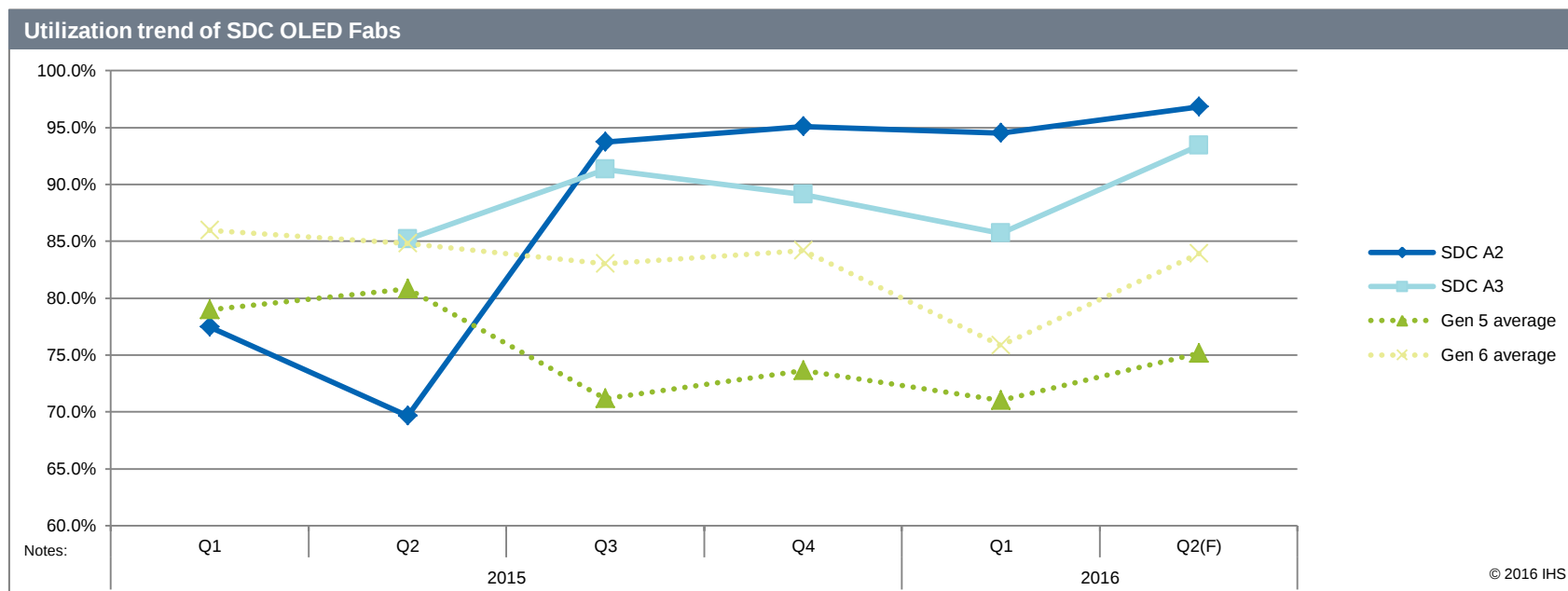
OLED shipment growth in entry segment

- Samsung raised VGA-graded panel shipments a lot in 2015, mainly helped by aggressive promotion toward China.
- Recent saturation of VGA-graded panel shipments looks maybe due to more capacity allocation for Samsung's Galaxy series.



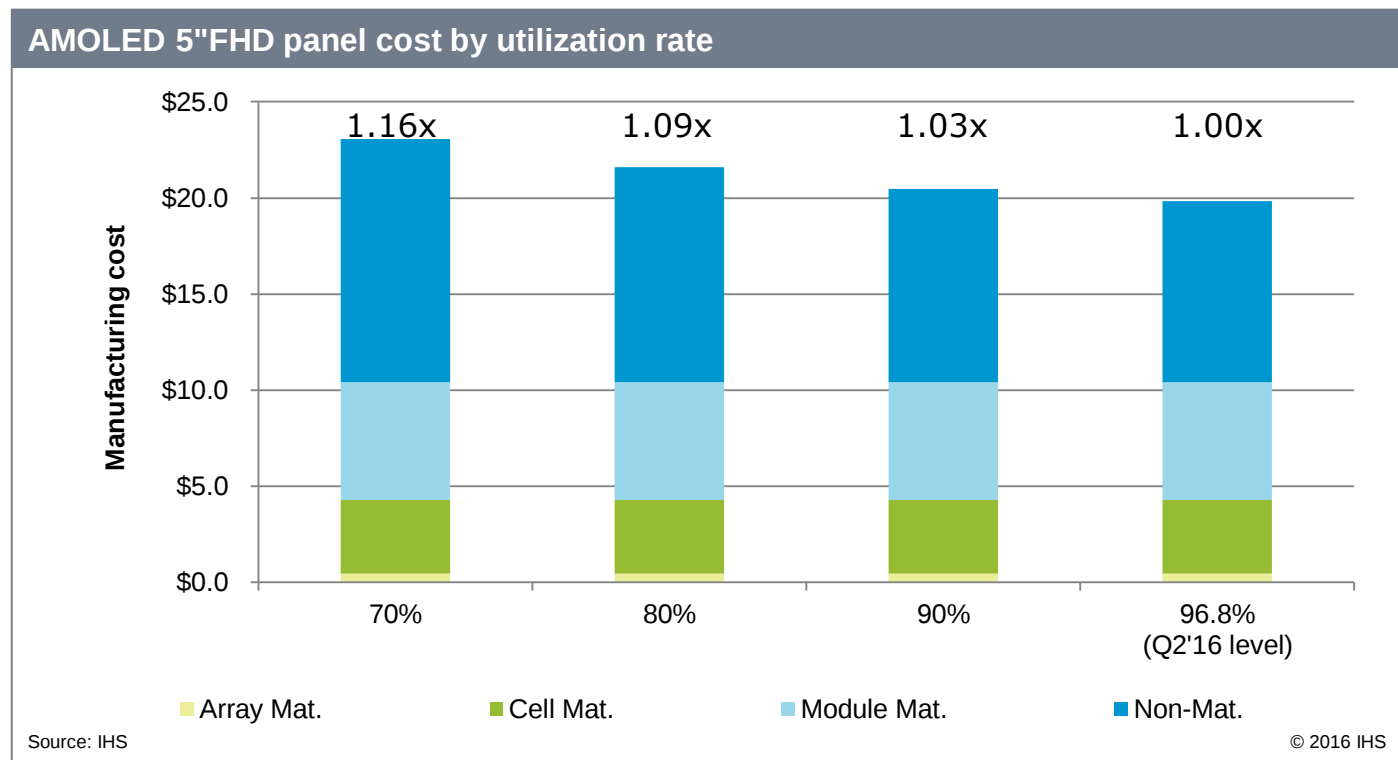
Utilization improvement with entry-segment growth

- As a result of promotion for Chinese customers, utilization rate of SDC's AMOLED Fabs has been improved a lot since 2H'15.
 - > Various customers and wide product mix would help SDC to maintain high utilization.



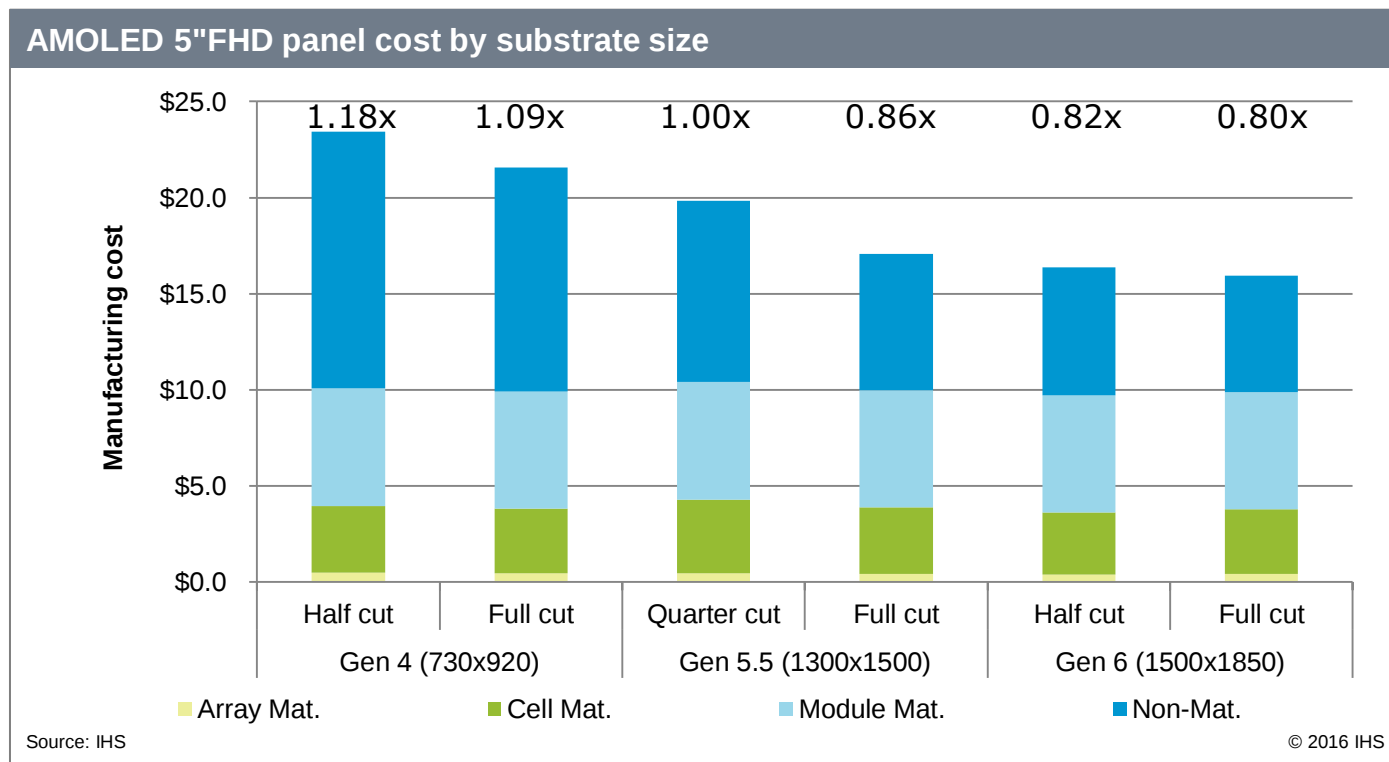
Effect of high utilization on OLED cost

- Cost may rise by ~10% when utilization is lowered to 80%
- Most of increase may be attributed to non-material part which includes most fixed items.



Effect of substrate on OLED cost

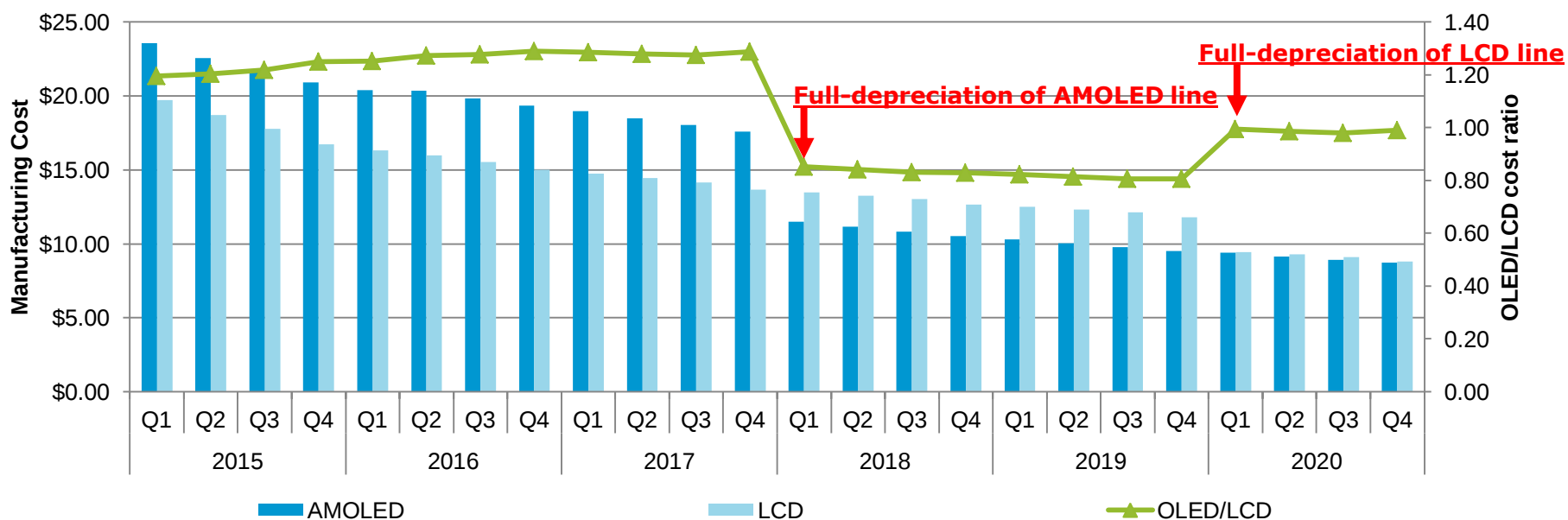
- AMOLED cost varies a lot with substrate size and quarter/half cut for OLED process.
- Further cost saving is expected as MP in Gen 6 is stabilized.



Effect of depreciation on OLED cost

- Let's imagine two line cases
 - > AMOLED: MP start on Q1'13 / LCD: MP start on Q1'15
- AMOLED has potential to show much lower cost after full-depreciation.

AMOLED vs. LCD 5.5"QHD panel manufacturing cost change by quarter



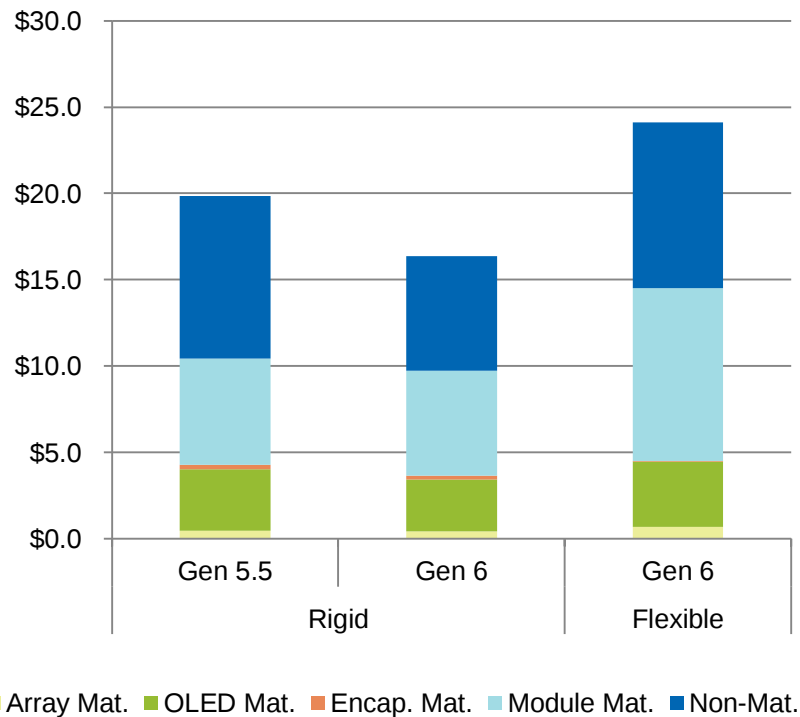
Notes: AMOLED in Gen 5.5 since Q2'11, LCD in Gen 6 since Q1'14

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Flexible OLED shows much higher manufacturing cost

Estimated to have 20% gap to current rigid panel, even can be wider to 50%.

Rigid vs. Flexible 5.5" QHD OLED smartphone display



Source: IHS

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Cost table of 5.5" QHD OLED smartphone display

Items		Rigid		Flexible
		Gen 5.5	Gen 6	Gen 6
Material	Array	\$0.5	\$0.4	\$0.7
	OLED	\$3.5	\$3.0	\$3.8
	Encap.	\$0.3	\$0.2	\$0.03
	Module	\$6.1	\$6.1	\$10.0
Non-Material		\$9.4	\$6.6	\$9.6
Total Manufacturing		\$19.8	\$16.4	\$24.1
Flexible to Rigid at different Gen		X1.21	X1.47	-

Notes: Q3'16, non-material incl. labor, depreciation, etc., Touch module is not included.

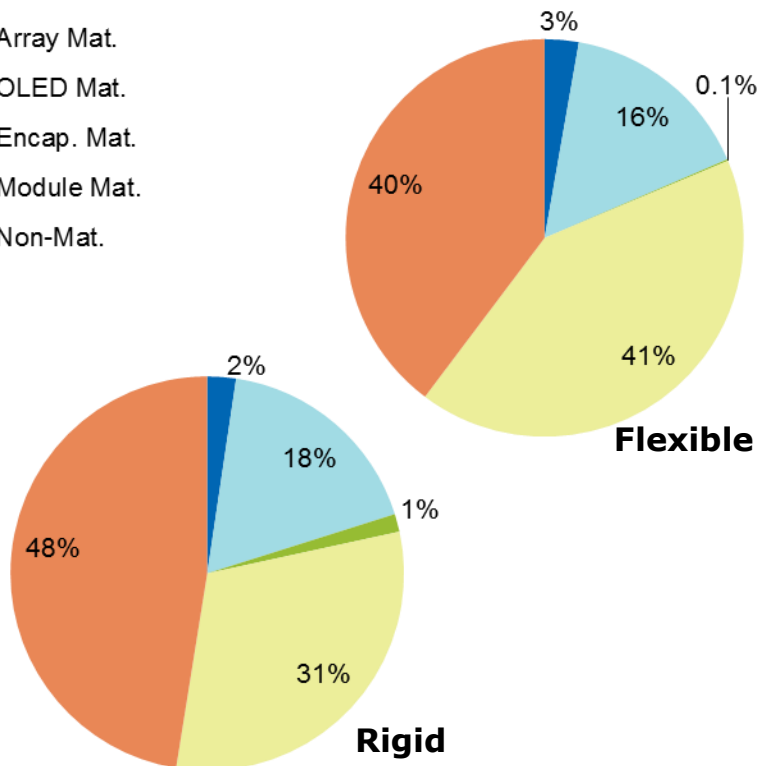
Source: IHS

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Material cost increase in Flexible OLED

Cost structure for 5.5"QHD OLED smartphone display

- Array Mat.
- OLED Mat.
- Encap. Mat.
- Module Mat.
- Non-Mat.



Source: IHS

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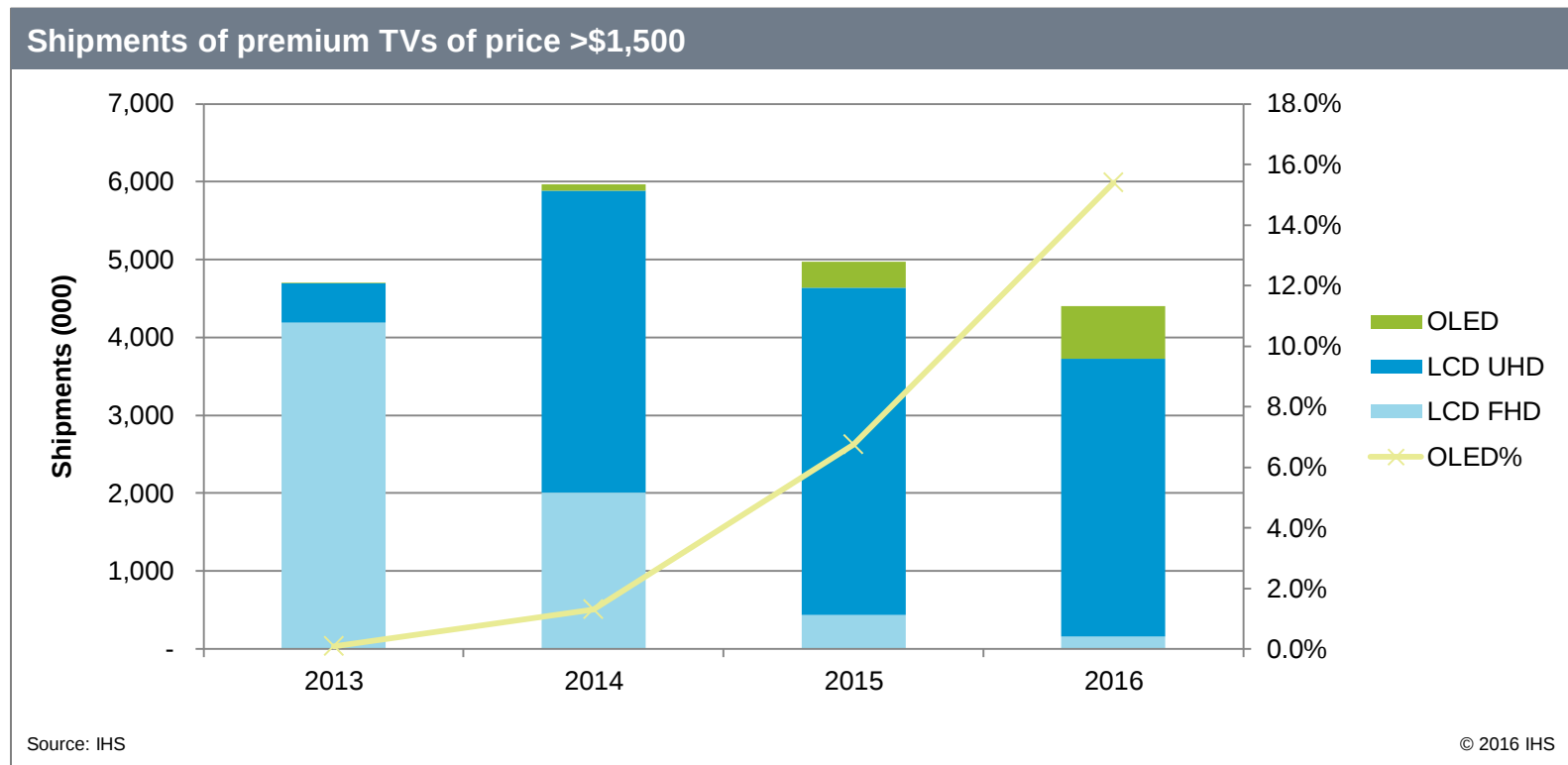
- Array material
 - > Differed by PI layer insertion. Carrier glass assumed to be non-recycled.
 - > Not a big portion gap observed, affected by price down of PI material.
- Encapsulation material
 - > Material cost of TFE can be lowered than glass frit + Encapsulation glass
- Module material
 - > Increase in *PCB&others* due to COF
 - > Lamination on curved surface may lower manufacturing yield a lot.

Emerging technology and OLED

TV Display

Struggling premium LCD TVs

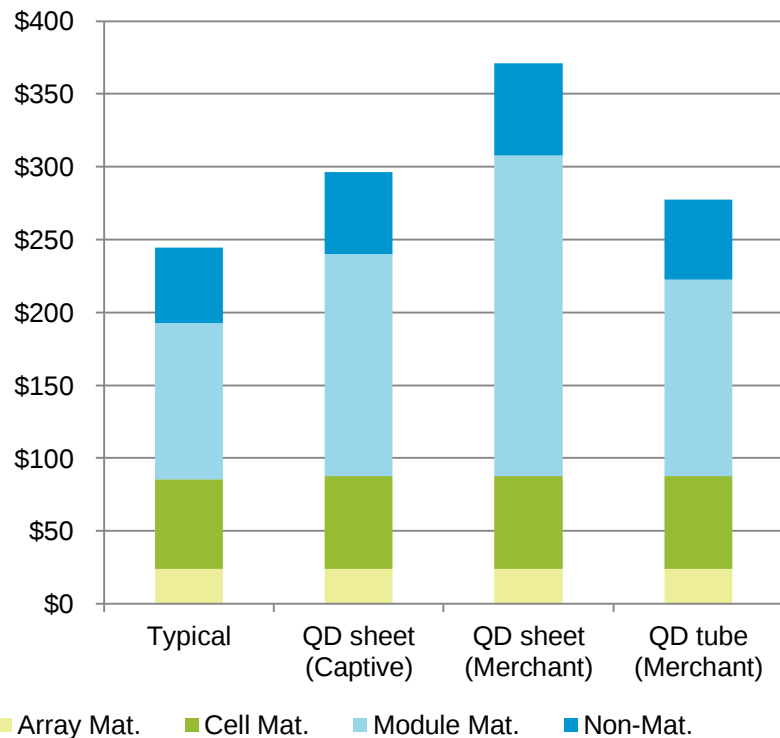
- UHD LCDs have helped to raise premium LCD shipments, but its driving force is declining.
- Meanwhile, portion of OLED TV shipments continues to increase in 2016.



QD for premium LCD market

Samsung has lowered QD sheet cost a lot with its captive supply chain.

Typical vs. QD 55" UHD ELED LCD TV



Source: IHS

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Cost table of 55" UHD ELED LCD TV

Items		Typical (72%)	QD Sheet Captive (nonCd)	QD Merchant (Cd)	
				Sheet	Tube
Material	Array	\$24	\$24	\$24	\$24
	Cell	\$62	\$64	\$64	\$64
	Module	\$107	\$152	\$220	\$135
Non-Material		\$52	\$56	\$63	\$55
Total Manufacturing		\$244	\$296	\$371	\$277
Gap to LCD		-	X1.21 (\$52)	X1.52 (\$127)	X1.13 (\$33)

Notes: Q3'16, Fully-depreciated Gen8 Fab case, non-material incl. labor, depreciation, etc.

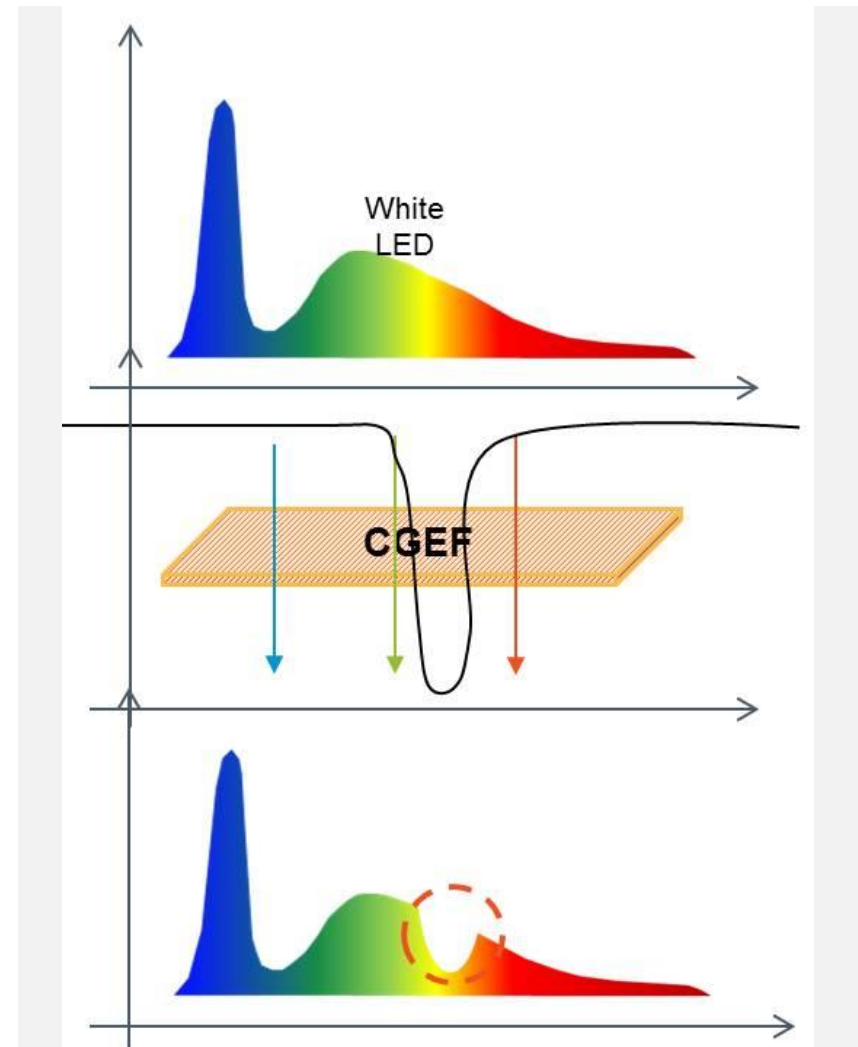
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Alternative WCG

CGEF(Color Gamut Enhanced Film)

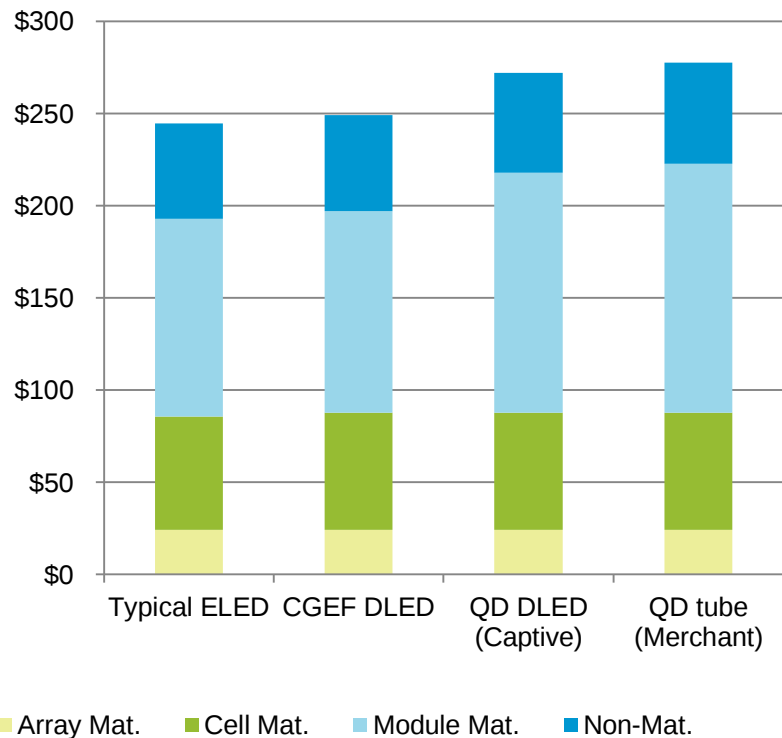
- Enhance the color by blocking yellow.
 - > Avoiding mix of RGB is important
 - > Similar effect like C/F tuning
- Easy to adopt for MP
 - > Minimum modification of BLU structure
 - > MP at Q3'15, right after only a few months' development
- Recently, LAP(Light Absorption Polarizer) of similar function is newly introduced.



CGEF's cost competitiveness

As QD price drops, its competitiveness looks weaker than last year.

QD vs CGEF 55" UHD LCD TV



Source: IHS

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Cost table of 55" UHD LCD TV

Items		Typical ELED (72%)	CGEF DLED	QD DLED Captive sheet	QD ELED Tube
Material	Array	\$24	\$24	\$24	\$24
	Cell	\$62	\$64	\$64	\$62
	Module	\$107	\$109	\$130	\$147
Non-Material		\$52	\$52	\$54	\$56
Total Manufacturing		\$244	\$249	\$272	\$277
Gap to LCD		-	X1.02 (\$5)	X1.11 (\$27)	X1.13 (\$33)

Notes: Q3'16, Fully-depreciated Gen8 Fab case, non-material incl. labor, depreciation, etc.

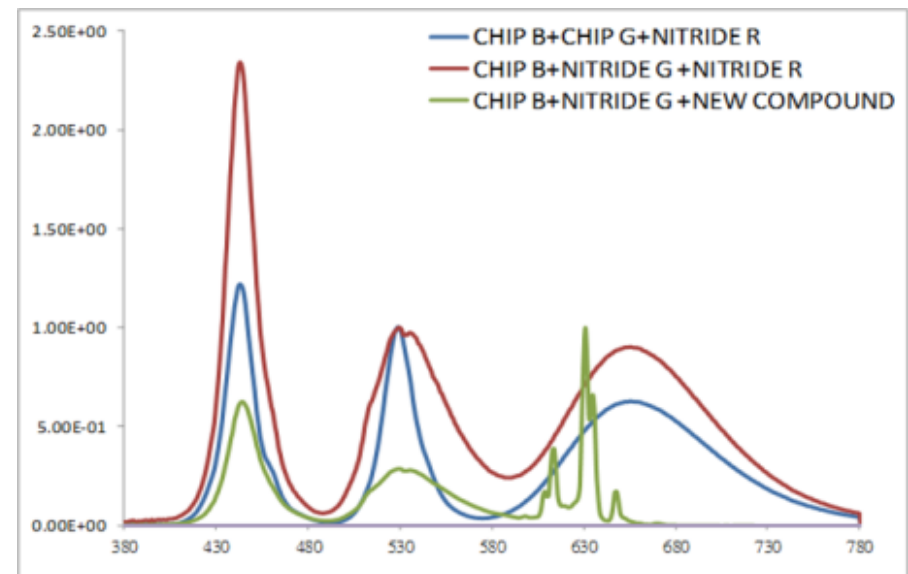
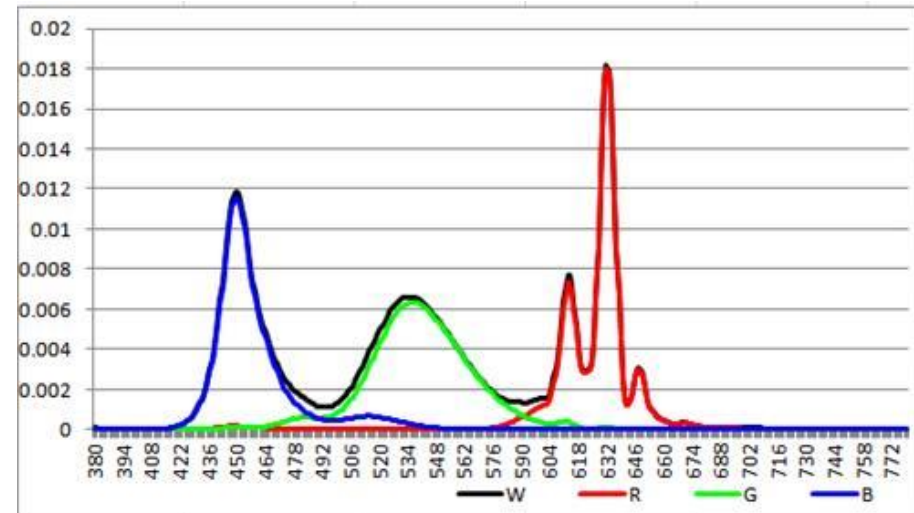
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Alternative WCG

On-chip KSF

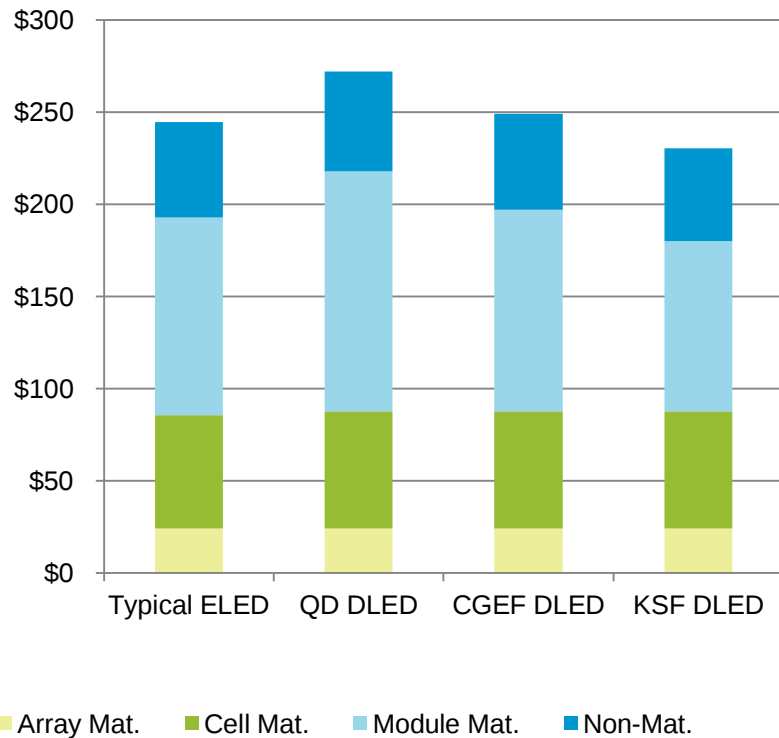
- Mn^{4+} red phosphor (so-called KSF)
 - > Sharp red peak enables >90% NTSC without any C/F tuning.
- Weak point due to long remnant light
 - > Difficulties in SG 3D, Blinking 240Hz...
 - > As 60Hz UHD becomes popular, the weak point looks not so critical now.
 - > No issue for mobile: iPhone7 adopts
- Able to be coated on chip directly.
 - > Material consumption can be saved when compared with sheet/tube type.



KSF as new WCG light source

KSF is a strong candidate for mid-segment WCG solution.

55" UHD LCD TV with various WCGs



Source: IHS

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Cost table of 55" UHD LCD TV

Items		Typical ELED (72%)	QD DLED	CGEF DLED	KSF DLED
Material	Array	\$24	\$24	\$24	\$24
	Cell	\$62	\$64	\$64	\$64
	Module	\$107	\$130	\$109	\$92
Non-Material		\$52	\$54	\$52	\$50
Total Manufacturing		\$244	\$272	\$249	\$230
Gap to LCD		-	X1.11 (\$27)	X1.02 (\$5)	X0.94 (\$14)

Notes: Q3'16, Fully-depreciated Gen8 Fab case, non-material incl. labor, depreciation, etc.

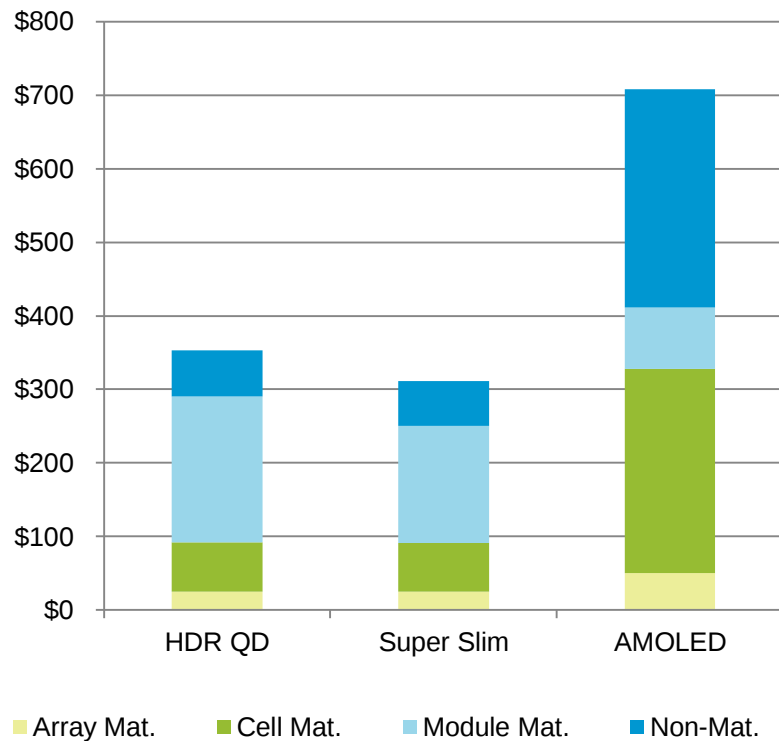
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Can OLED survive as Special One?

OLED is still expensive due to large investment and small production volume.

AMOLED vs Finest LCD 55" UHD TV



Source: IHS

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Cost table of 55" UHD TV

Items		Finest LCD		OLED
		Curved HDR QD	Super Slim	
Material	Array	\$25	\$25	\$50
	Cell	\$67	\$66	\$277
	Module	\$198	\$159	\$84
Non-Material		\$63	\$61	\$296
Total Manufacturing		\$353	\$311	\$708
OLED to LCD of different tech.		X2.00 (\$355)	X2.28 (\$397)	

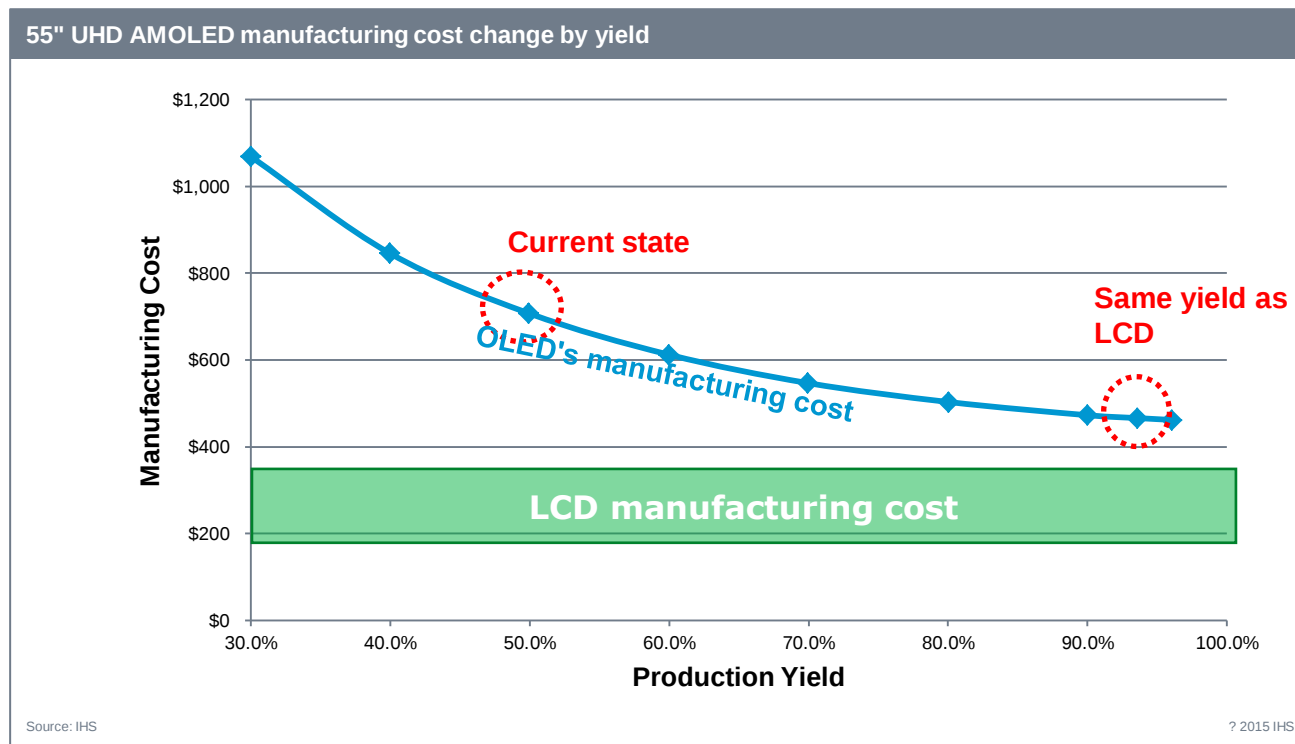
Notes: Q3'16, Fully-depreciated Gen8 Fab case for LCD, non-material incl. labor, depreciation, etc.

Source: IHS

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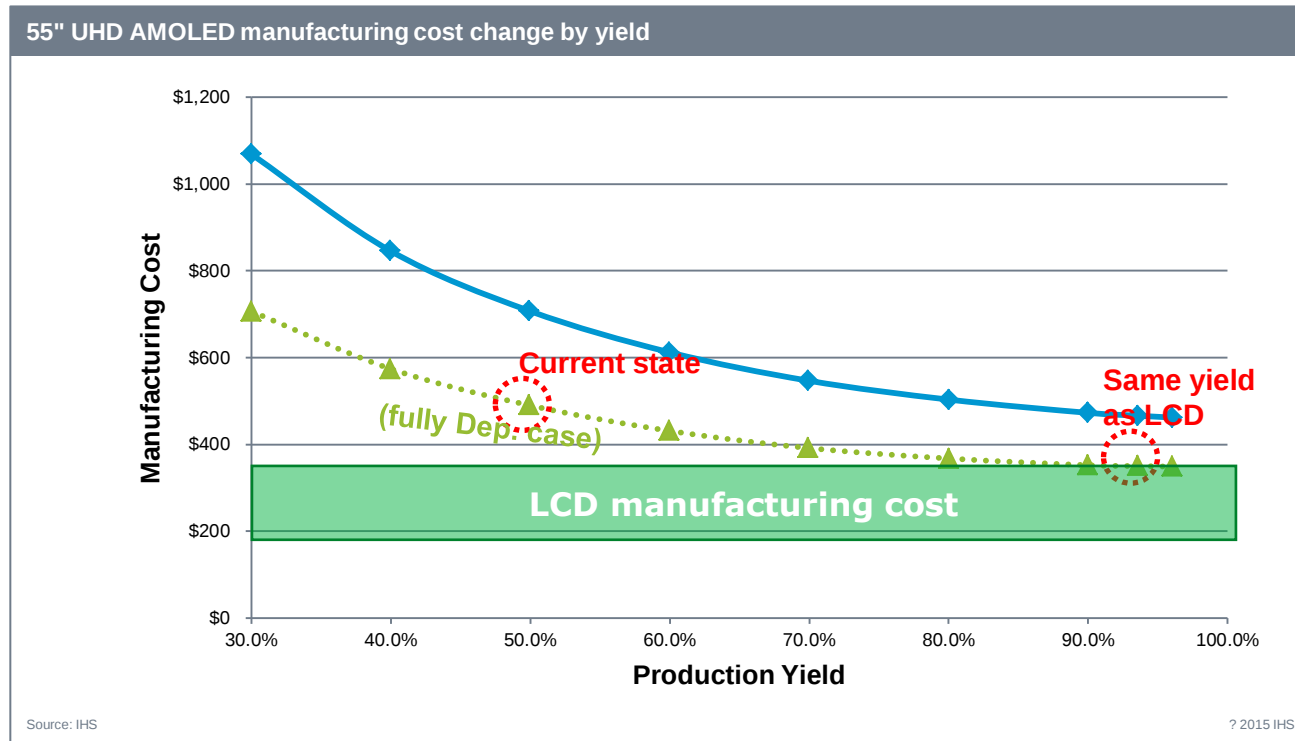
OLED cost by yield

- As yield of AMOLED improves, the cost gap will shrink rapidly.
- However even under same yield condition, cost gap of 1.3X still remains due to large depreciation of OLED Fab.



OLED cost by yield after full-depreciation

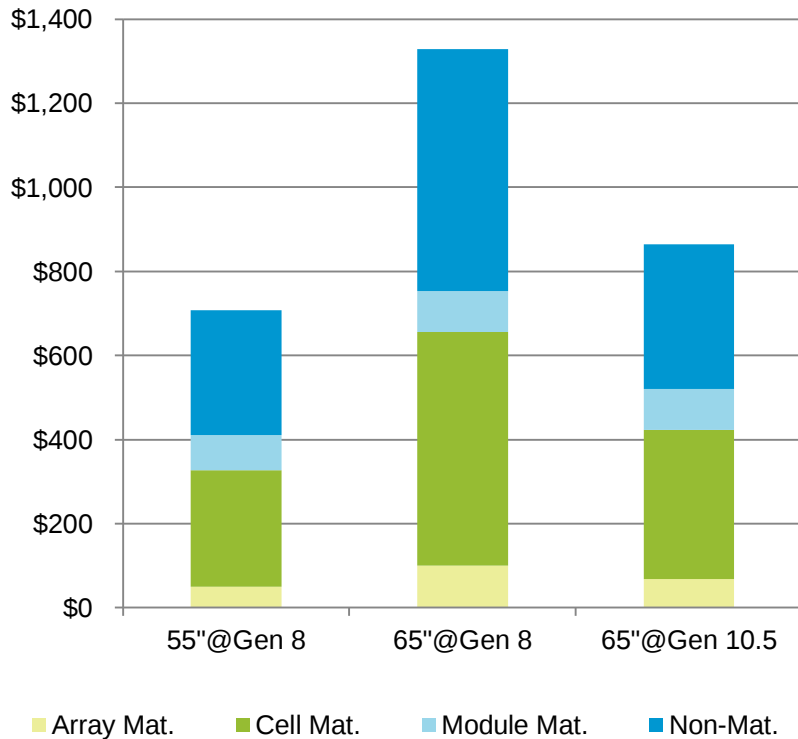
- Under same yield and full depreciation, cost gap with premium LCDs can be almost negligible.



Need for larger OLED Fab

Cost for 65" OLED panel jumps a lot due to low glass efficiency at Gen8 Fab.

Gen 8 vs Gen 10.5 for 65" OLED TV



Source: IHS

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Cost table of 55" UHD ELED LCD TV

Items		55" @Gen8	65"	
			@Gen8	@Gen10.5
Material	Array	\$50	\$100	\$68
	Cell	\$277	\$555	\$354
	Module	\$84	\$98	\$98
Non-Material		\$296	\$575	\$344
Total Manufacturing		\$708	\$1,328	\$864
			X1.88 (\$620)	X1.22 (\$156)

Notes: Q3'16, non-material incl. labor, depreciation, etc.

Source: IHS

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Wrap-Up

- Mobile display
 - > Cost of AMOLED has lowered a lot recently mainly helped by yield improvement and utilization increase with promotion to Chinese customers.
 - > Further improvement is expected with MP ramp-up in Gen 6 Fab and lowering depreciation cost.
- TV display
 - > Many of emerging technologies are competing against AMOLEDs
 - Design: Curved, Super-slim / Picture quality: QD, WCG(KSF, CGEF), HDR
 - > UHD OLED technology improved a lot. However, top emission and substrate size will be the next hurdle for further improvement.

Thank You