Grow and Glow

A roadmap for high performance TV in the next 5 years
4k2k (QHD) and 8k4k (UHD) outlook

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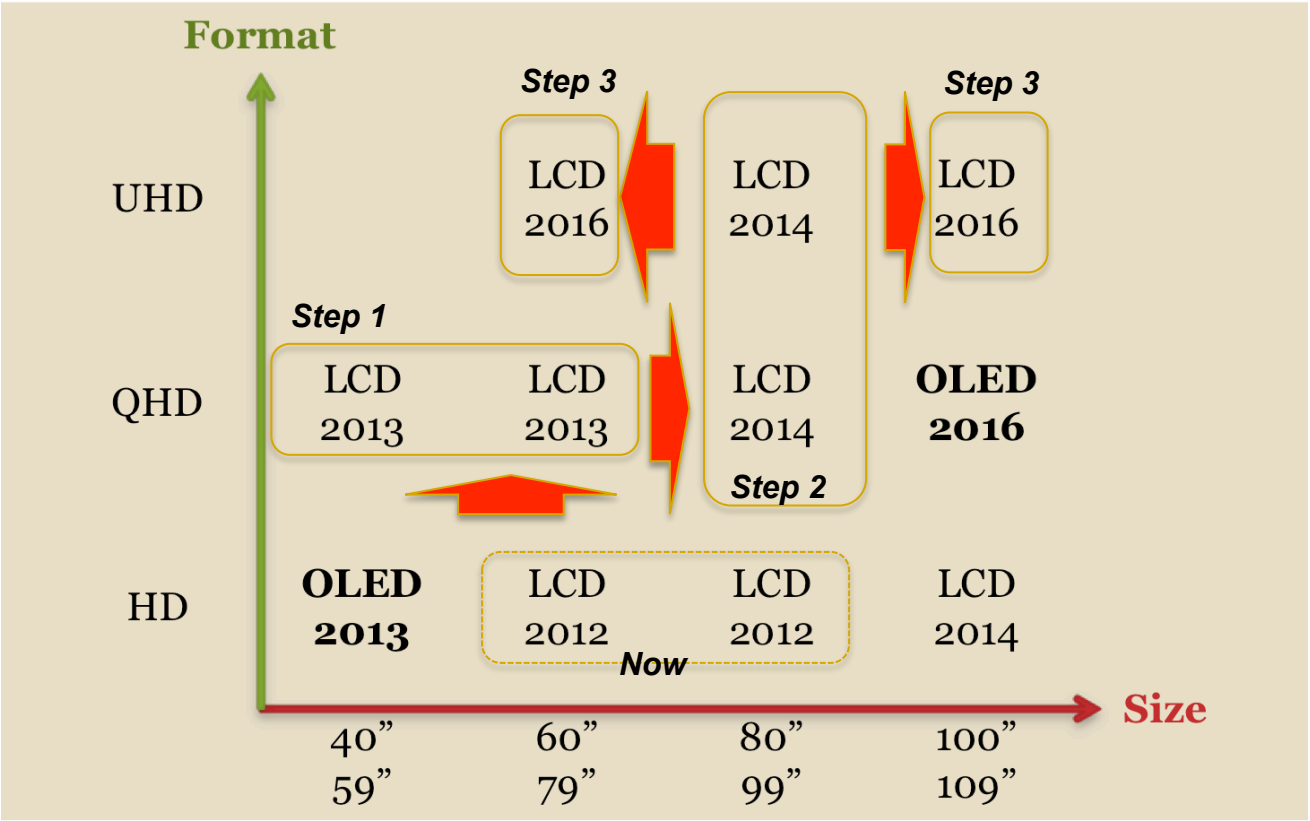
We have developed a provocative view on development of TV in the coming 5 years:

Date of appearance of fundamentally new value propositions



- Step 1: 4k2k starts in LCD in 2013 as non-OLED players introduce offerings based on a-Si and Korean leaders follow. A video speed race begins and metal oxide becomes more important than a-Si
- Step 2 moves 4k2k to larger panels (given falling prices) and initiates 8k4k
- Step 3: 60" IGZO 8k4k and larger offerings emerge

Source: HCL/BizWitz

4k2k and 8k4k are new TV formats and will represent the new thing for the LCD industry to try to sell:

- 4k2k delivers more realistic images with more depth. Many commentators have suggested that with 4k2k that 3D is not needed
- If needed, 4k2k enables glasses-free 3D TV sets
- An 8k4k standard has been released by ITU (Rec 2020)
- Up-scaling engines are beginning to be delivered for content (e.g. Xilinx)

- Display players hoping to cash in on the price premium for 4k2k of 2X the full HD price

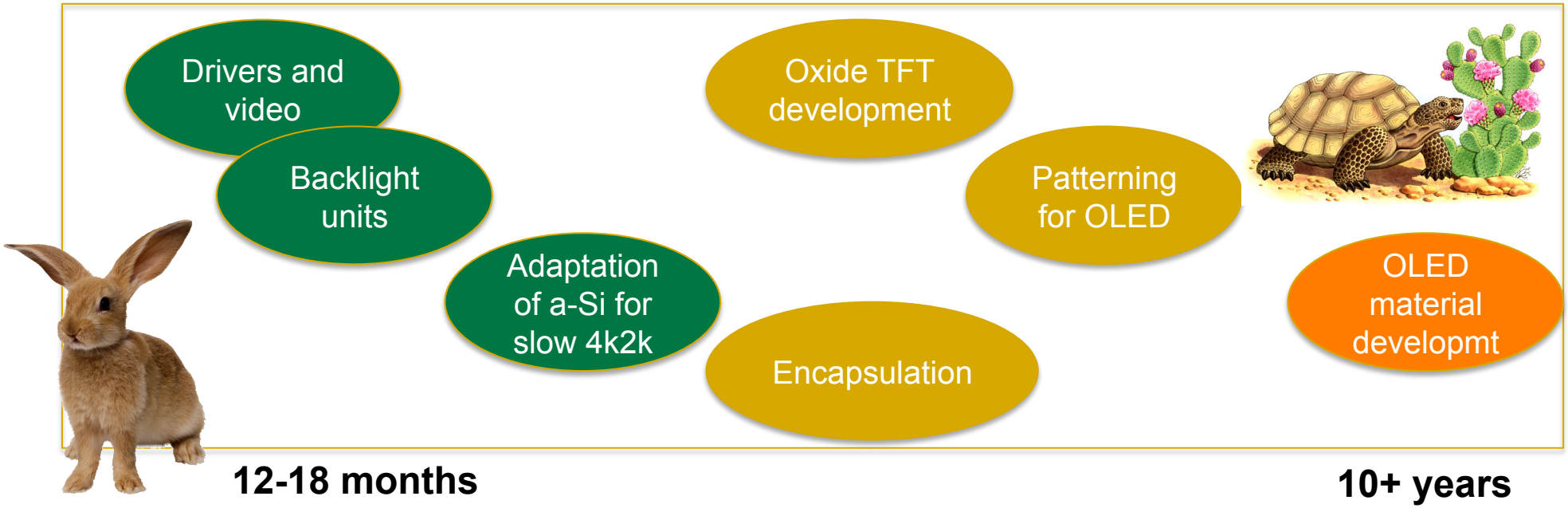
Source: ASCII.JP

We make the following assumptions:

- **Price**: Price trends will continue for LCD at 20%+ price reduction per year. Falling prices will shift the shape of the global demand curve by panel size for large panel LCD. Large panel LCD is more able to innovate in panel sizes than would be the case in small panels. 4k2k offerings could start at 2X+ premia but will then track in to 30-40% difference
- **Device technology:** Current leading players without large panel AMOLED plays can enter the 4k2k market with a-Si now and will do so. Impact will be higher material cost due to smaller apertures
  - AMOLED players will have to follow anyway
  - IGZO LCD will enable higher frame rate 4k2k and will be the natural extension from a-Si versions. We assume that 5 or more years will be needed for IGZO to mature for the leaders
- **OLED**: We assume that large panel OLED fabs will be built but the schedules may slide further. By the time then that OLED offerings are available, the space for new places to play for OLED will be constrained. OLED factory conversions substantially more complex and difficult than a-Si to IGZO LCD conversions and even these are challenging
- **OLED patterning**: We assume that OLED patterning options will continue to develop but that (1) FMM and related mask-based technologies or (2) laser based approaches will be the only ones in mass production for the middle of this decade. Other options such as nozzle print may open up later
- **Blue materials** will continue to be the Achilles's heal of OLED, leading to some potential use of PenTile approaches in the OLED space. OLED stacks will vary and will begin to see winners by end of decade
- 4k2k TV will create largely upsides for the supply chain, except perhaps for Corning and other areal output based players. Biggest winners are BLU, D-IC/ASIC companies

Source: HCL

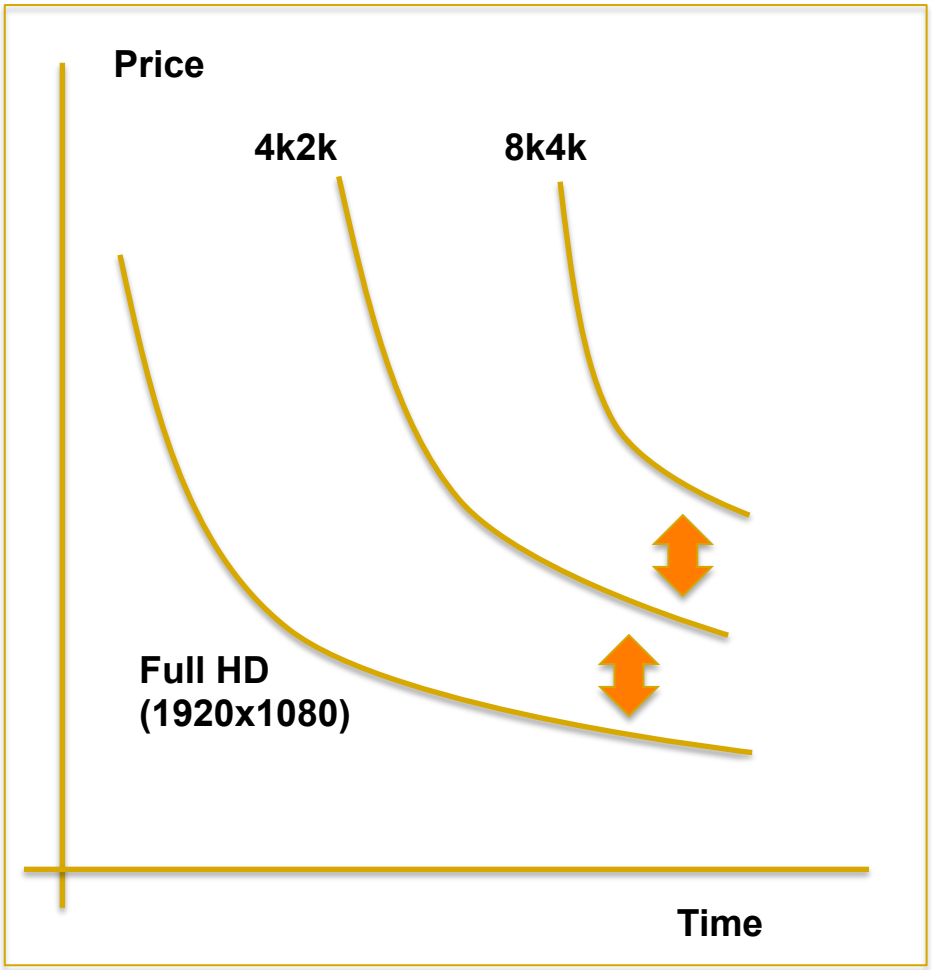
We assume that the pace of change for different elements of the offering will vary: OLED will lag IGZO LCD



- Different elements of the 4k2k puzzle will fall into place more quickly than others
- Drivers and video offerings are all possible in 12-18 months
- Supply chains for backlights already know how to deal with smaller apertures (e.g. iPad 2 to iPad 3 increased LED count by a factor of 2)
- Oxide TFT will take the leaders up to 5 years to mature based on current speed of progress
- Blue emissive materials remain the Achilles's heel but this is a multi-decade level problem

Source: HCL

4k2k offerings offer consumers more pixels. They will be priced at a premium. The premium might decay slowly.



- 4k2k offerings are already being priced at 2X the equivalent Full HD panel ($800 for a 50” display versus $400 for 50” full HD)
- Key question: What is the long term premium of 4k2k?
  - Our estimate is of the order of 30-40% long term since some long term material cost difference needs to be covered (Drivers, tabs, LEDs, optical films and yield hit from increase in number of pixels)
  - Often takes less than 3 years for prices to fall towards long term position
- 8k4k will truly start as a Pro-AV and signage offering in the first instance at commercial price points but then we would expect the same 25% per year or more price erosion

Source: DisplaySearch, HCL

Non-OLED display leaders will offer 4k2k based on a-Si forcing the hand of the two Koreans also:

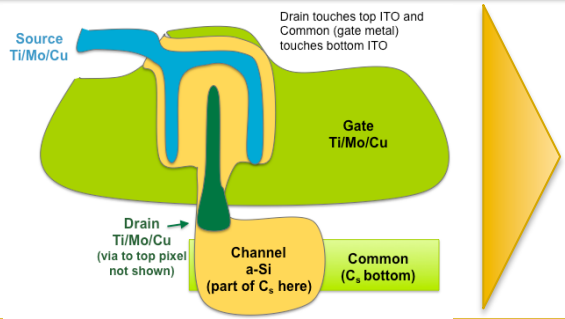
Announcements show market experimentation

OLED vs. 4Kx2K TV Announcements

	OLED			4Kx2K		
Origin	Brand	Size	Panel Maker	Brand	Size	Panel Maker
Korea	Samsung	55"	Samsung Display	Samsung	70"	Samsung Display
	LGE	55"	LG Display	LGE	84"	LG Display
Japan				Sony	84"	LG Display
				Sharp	60"	Sharp
				Toshiba	55"	AUO
					84"	LG Display
China				Hisense	50"	CMI
					65"	CMI
				Haier	65"	CMI
				ChangHong	55"	AUO
				THTF	50"	CMI

Source: *Weekly TV Supply Chain Executive Briefing* report

Some device level redesign at the pixel needed



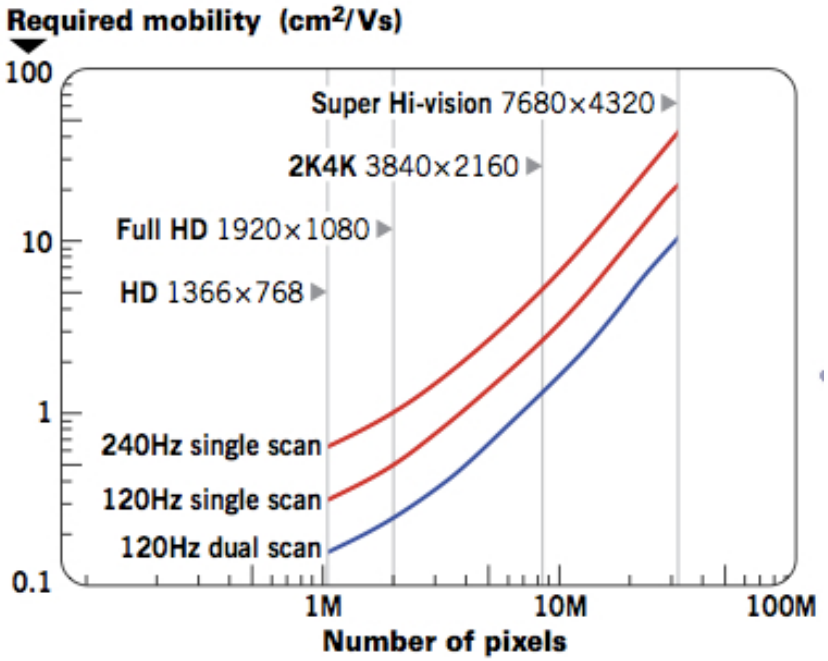
- Extension to give double "U-shaped" source drain path
- Potential need for "dual sided" addressing

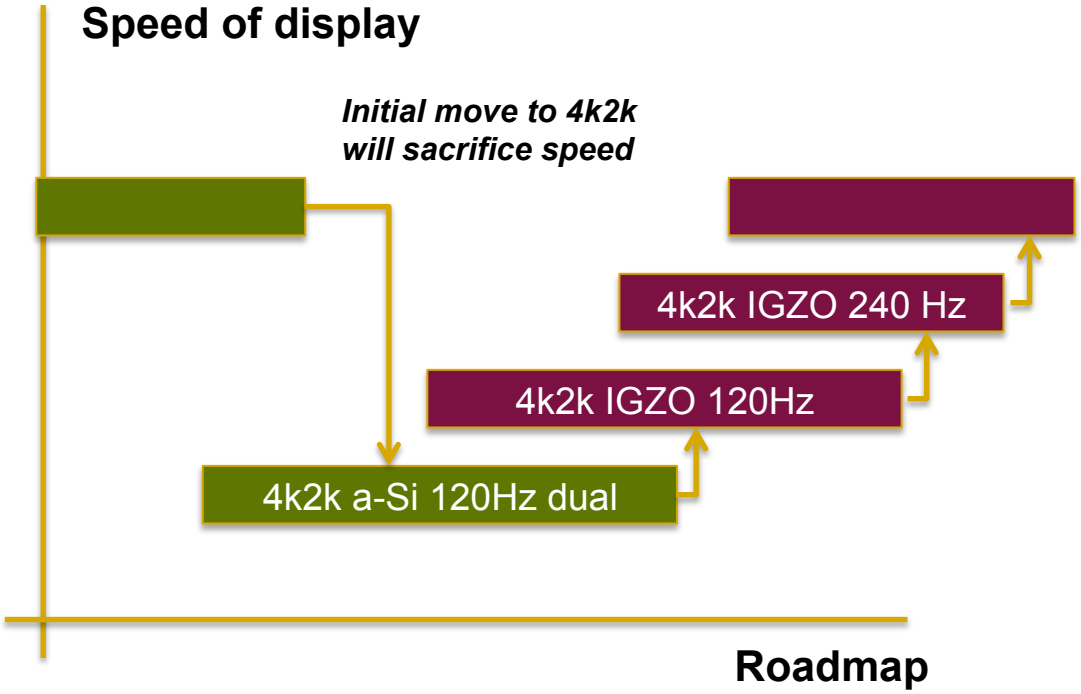
- Offerings from IPS-Alpha, Sharp, CMI and AUO have forced the hand of LGD and Samsung
- Current market announcements on launch show experimentation with the value proposition: what will the Pro-AV and early adopters accept as new 4k2k offerings?

- Changed needed to implement 4k2k a-Si TV
  - Different pixel structure may be needed with additional S-D channels
  - Beefed-up backlight unit
  - Many more drivers based on a faster speed communication set of protocols. Potential need for dual sided addressing
  - And moreover, the a-Si offerings will be limited in terms of their response speed by the mobility of a-Si

Source: DisplaySearch, HCL

However, a-Si will limit the speed of the display. Oxide is needed for the next step and oxide progress will be slow





- 4k2k panels based on a-Si (8m pixels) will be limited below 120Hz dual scan levels
- To play the speed races that we have seen in a-Si will require oxide (TAOS, IGZO) TFTs
- Oxide progress is being held back by separate development programmes at LGD, SDC and Sharp. Sharp first shipment date for IGZO TFTs fell back over 9 months on rumours of technical problems

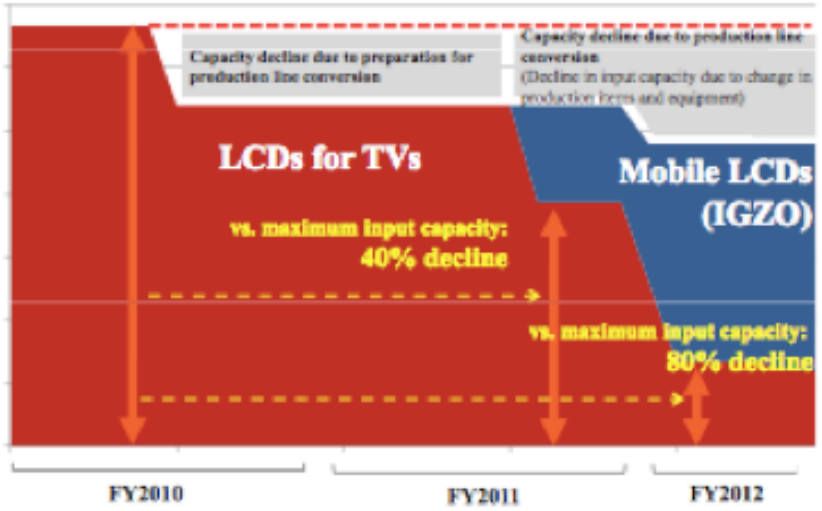
Source: Solid state technology magazine, HCL

Oxide TFT progress will be fairly slow. Factory conversions are challenging as Sharp has shown:

Fundamental challenges in oxide TFT

- Sputter uniformity
- Device stability due to interface issues (oxygen vacancies, charge traps)
- Protection of the channel material (Use of E/S processes in medium term)
- Density of states and leakage characteristics
- Ohmic contacts and desorption at ohmic interface

Decline in Production of LCDs for TVs (Smaller Than 40") at Kameyama No.2



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- The lack of collaboration between leading IGZO players and differences in approach may well tend to slow the pace of technical resolution of remaining technical challenges
- Conversion to IGZO reduces effective capacity and puts the fab out of service for months: Kameyama 2 conversion has been a great example of how not to do it. Problems in resolving panel yields and stability have given way to drop test and other execution errors

Source: HCL, Sharp Investor Relations

Factory conversions for LCD are substantially simpler than going from LCD to OLED:

a-Si to IGZO LCD

- Capacity loss of 22-40% according to LGD
- Neutral for CVD, additional equipment required for PVD
- Likely to lead to line rebalancing and then the process of debottlenecking can begin to manage down the total number of masks and migrate back towards a BCE-type process

A-Si to IGZO based OLED

- IGZO rededication is broadly similar:
  - 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 (move to 4 colour CF has limited impact)
- Replacement of the cell shop with OLED patterning (FMM, LITI or other). Expensive and new equipment risk
- Likely to lead to line rebalancing
- LGD believes that this is an 18 month process

- There is a perception, that factory conversions to OLED (or IGZO LCD for that matter) are a simple matter, but this is far from being the case as we have seen with the conversion of Sharp Kameyama 2
- Here we show a conversion to IGZO OLED. A move to LTPS based OLED is more complex again

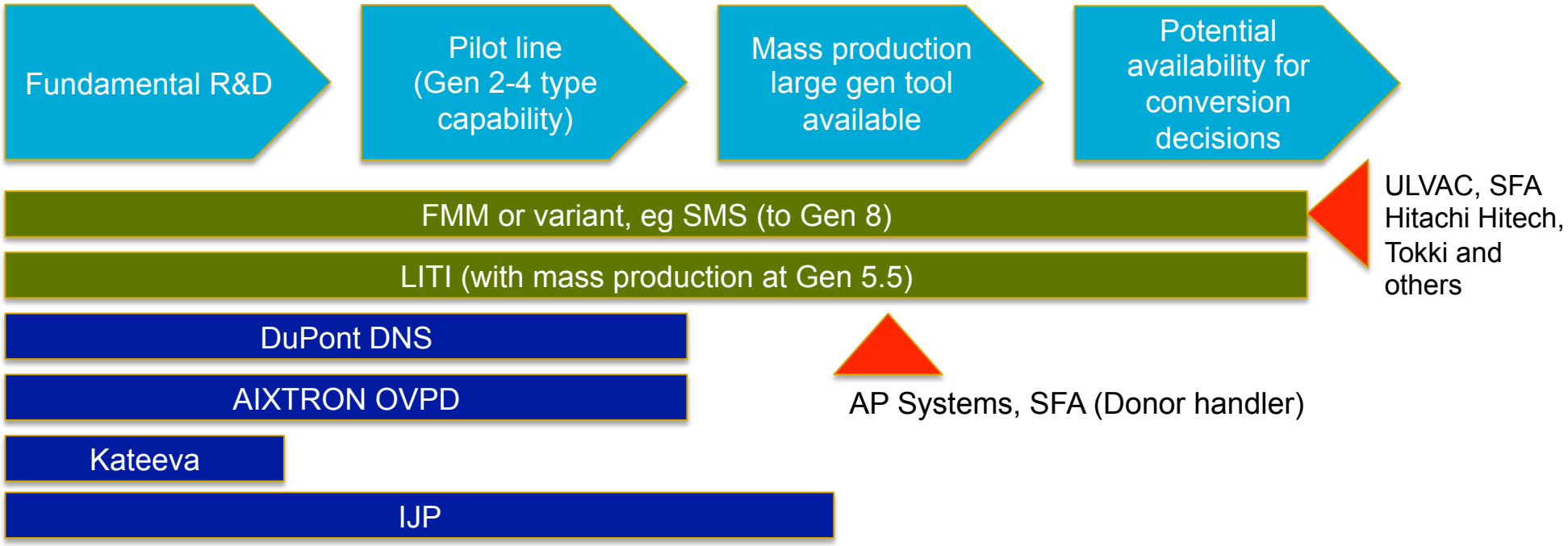
Source: HCL

Late breaking news: blue-phase LC and semi-polar LED

- During the 50th anniversary meeting of the Society for Information Display, three things were noted.
  1. LCD TV makers are managing costs by decreasing brightness. Such spec reduction was seen in PC market segments last decade and it may be accepted in commodity TV market segments this decade. If so, that extends the competitive life of a-Si technology in 4k2k applications.
  2. Blue-phase liquid crystal modes are being perfected that promise sub-millisecond switching times. That is fast enough to enable field-sequential color TV, which would increase effective aperture ratio and extend the reach of a-Si.
  3. Semi-polar LED may reduce polariser costs and light losses, thus boosting LCD TV efficacy closer to OLED specifications.
- The implication is that AMLCD momentum may carry a-Si or moderate-mobility IGZO technologies forward to close the gap with AMOLED.

Source: HCL

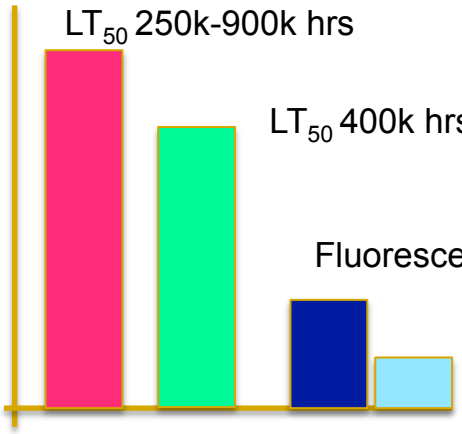
On the OLED side, we assume that FMM and LITI type processes will dominate mass production decisions this decade since they are mass-production proven already:



- Each of these phases is 2 years: only FMM and LITI have mass production experience (and LITI only really at SMD, now SDC). HPS combines FMM with LITI
- For now expect to see mask based or laser based approaches as the dominant ones
- That set of options broadens towards the end of this decade

Source: HCL research. BNP Paribas
View is over simplification

Material progress has been slow for emissive materials. Expect blue emitters to remain the Achilles heel and for PenTile to play a role in the AMOLED TV roadmap (for Samsung, at least):



- Despite a decade and a half of development blue is still the achilles heel

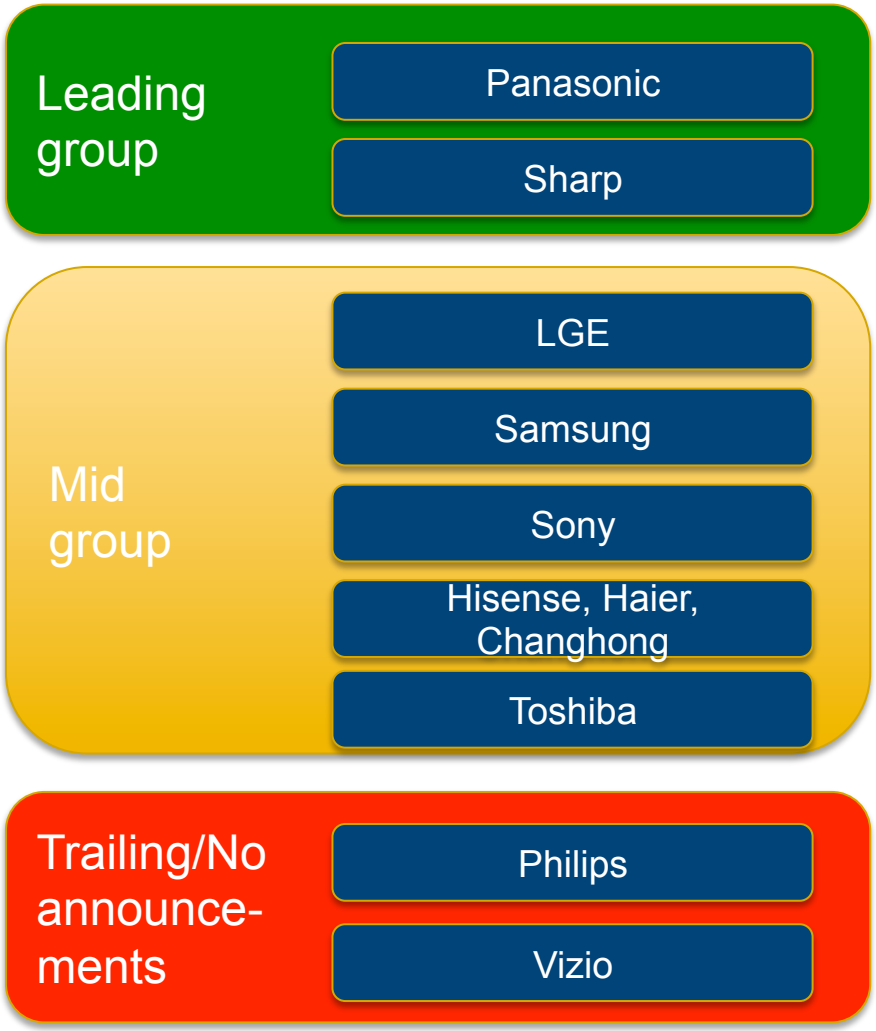
- PenTile reduces the current density required in the blue pixel
- RGBW pixel structures being used for wOLED + CF

- Despite a range of competing suppliers, UDC's phosphorescent materials are still the ones to beat for red and green, but their (light) blue material has substantially worse performance
  - Many players using a fluorescent blue (e.g. DuPont has claimed fluorescent blues with LT_{50} of more than 30k hours)

- PenTile then becomes a way of reducing current density on the blue material and also potentially a cost saving in terms of the implications for column driver density. While full RGB stripe may well be seen as the "gold standard" for Samsung at least, then we expect to see some experimentation with RGBG as well as deployment of RGBW by LGD

Source: HCL research
UDC Feb 2012, DuPont

The different TV brands seem at different places in preparedness for 4k2k TV:



- Of all the TV brands, Panasonic and Sharp have been the most vocal about capabilities in 4k2k and above. IPS-Alpha has touted 20”, 220 ppi displays
- Sharp also has been strong to announce capabilities in line with their leading work on IGZO TFT
- LGE and Samsung are being forced to offer product so as not to lose position, despite being more strategically interested in AMOLED TV

Source: HCL research, Factiva

….and while the display makers will push ahead there are real content and compression and broadcast questions to be solved. However, this was also the case with the move to full HD:

Broadcast or transmission is not ready for 4k2k content though media companies already use 4k2k as an intermediary standard for their own editing of content:

- The delivery mechanisms for content that are not ready for the new challenge
  - While a number of companies are already looking at up-scaling engines, native delivery of 4k2k requires a minimum of 144 Mbps broadband (better 500 Mbps) and a standard movie would be up to 212 Blue-ray disks worth of content (2-3 TB)*
- For the broadcast industry, 4k2k has been a working standard for quite a while and is used for intermediary content manipulation
- NHK has shown the capability to broadcast the higher 8k4k standard over 2.6 miles
- Korea planning test transmissions based on 4k2k soon

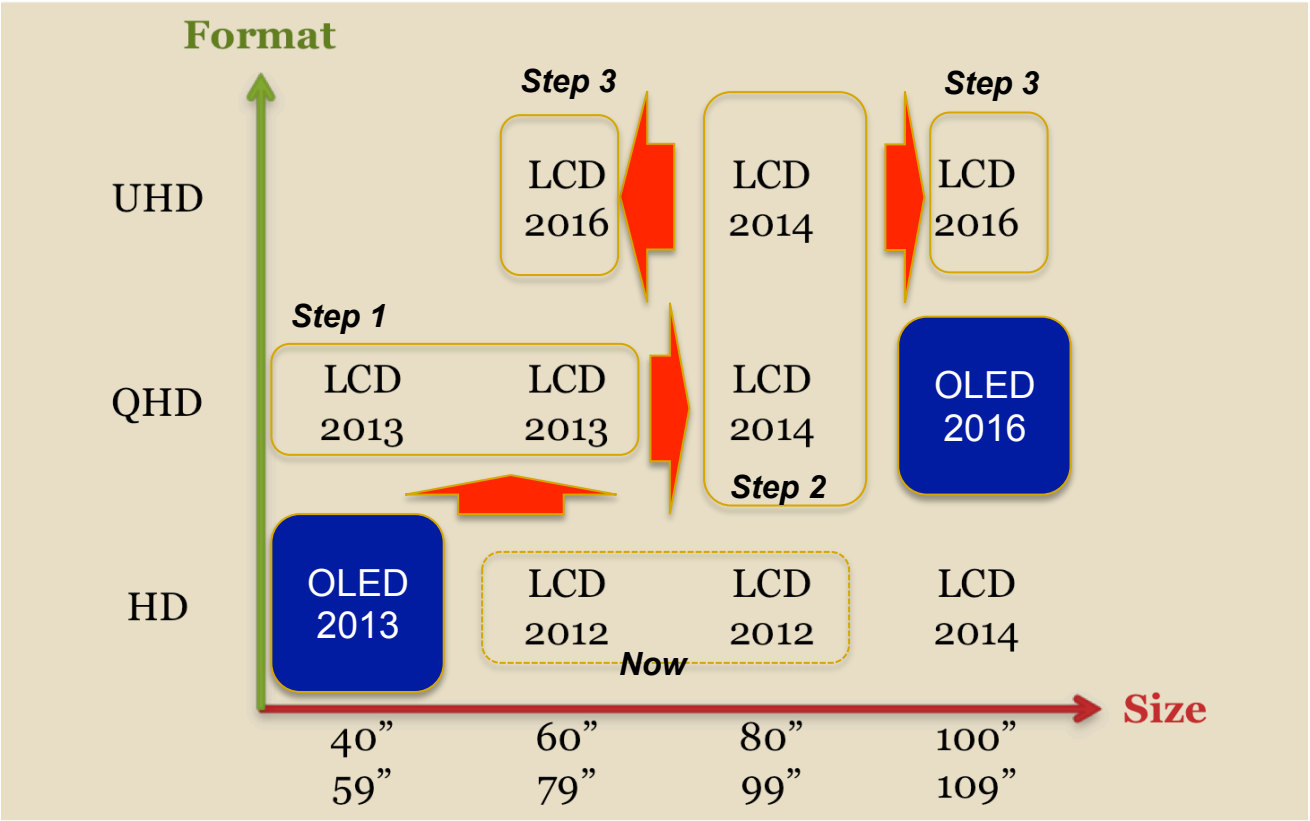
…but this was also the case in the move to full HD displays and true for Retina

- The first Full HD displays also appeared before there was any direct new content that could serve them at pixel to pixel resolution. ESPN led the way
- Xilinx and Realtek have already started work on different approaches for upscaling
- In the move to retina displays in the Apple case also, for example iPad 3, in the first instance the user saw up-scaled iPad 2 content before new apps were designed

Source: HCL research, Factiva, Tech Radar*

As a result 4k2k LCD will stream everywhere. So what are the options open for OLED TV?

Date of appearance of fundamentally new value propositions



- We expect to see first 55" product from LGD and SDC in 2013 though based on very different approaches (full RGB stripe vs wOLED + CF)
- While we expect these players then to try to pick up additional volumes by migrating towards larger volume markets (sub 50 inch) we think that LCD will already be moving in here and at lower price points. The next new market for OLED may have to go back onto the large size frontier, at 80-100 or more inches

Source: HCL view

Implications throughout the supply chain

Glass

- Potential for areal dip as factories convert and capacity is lost

BLU

- Higher performance BLU solutions required with more premium elements

LED

- Near term likely 2x increase in numbers of LEDs and move from edge lit to double edge lit

Drivers

- Increase in demand based on resolution plus IGZO may not support GoA mux

Video-TCON et cetera

- Upside for new video compression and transmission schemes plus conversion of content

Polariser and films

- Potential area demand loss
- Potentially richer product mix may offset some of the area loss

LC and emissive materials

- LC: A richer mix or new modes
- Emissive OLED: later and smaller opportunity

Equipment players

- Upside for IGZO sputter; CVD neutral; more AOI and test
- OLED equipment may be smaller

Technology and IP layers

- Key technology holders for IGZO will see upside (JIST, SEL)
- Blue-phase LC IP holders, makers

TV Brands

- A new option to establish a premium value proposition

Source: HCL view

Winners and losers:

	Winners	Losers
Display	The big 4 depending on their capability at fab conversion	LTPS players and fabs Tier 3 players
Materials	Drivers, backlights and video processing or communications	Near term dip perhaps for glass and polarisers, LC
Equipment	PVD, factory automation perhaps, AOI-repair	OLED players may have a smaller opportunity
Brands	Panasonic, LG, Samsung, Sharp (maybe)	Sony, Philips, Visio
IP/Technology providers	Japan Inst Sci/Tech, SEL, Nouvoyance/Samsung	None

Source: HCL view

Summary: 4k2k is the next big thing in *premium TV* but with confusion and chaos in the short-term. AMOLED TV will lag and have its opens reduced by ubiquitous LCD

- 4k2k will be the next big thing in large panel displays; offerings are coming and will be coming soon. We expect more consumer confusion. Already in North America, UHD and QHD are used interchangeably to describe 4k2k while in Japan it is very clear that UHD is 8k4k
- 4k2k is important because it is a way for the leading display companies to try to offer a new premium value proposition but without having to resort to OLED. Allows the 4-5 display leading players to break away from the lower ranks, and in particular the new Chinese entrants
- The biggest winners from this move are the driver and video-processing companies and backlight firms, where more pixels will need to be driven and higher brightness backlights used to overcome smaller apertures over the near term
- Other winners may include suppliers or LC materials or quantum dot materials
- Broadly this outlook is more challenging for the OLED supply chain. By the time OLED brings products to market, OLED will need to compete with a range of lower priced LCD premium offerings

Source: HCL view