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The new frontier  
OLED vs QLED  
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Colour is the new frontier:  
The QLED and OLED battle will define the next 10 years in  
displays



4K

540 nits + and high dynamic range

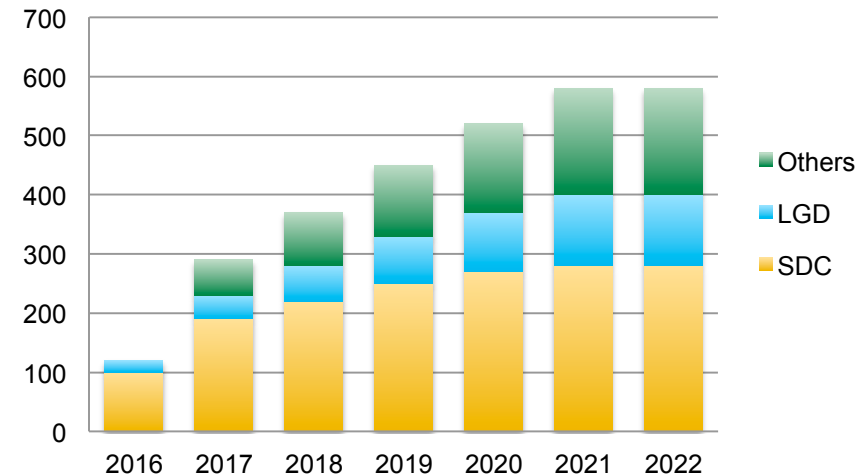
> 90% DCI P3

10-bit colour depth

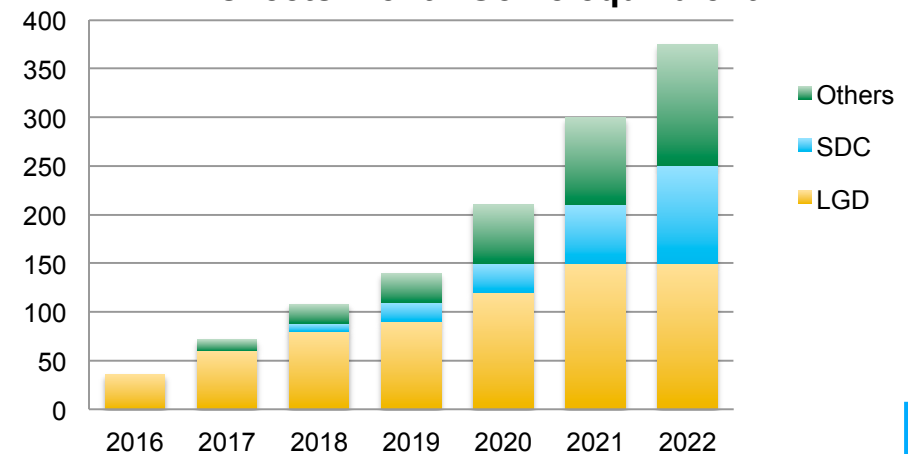
## OLED is currently in growth mode:

- 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**

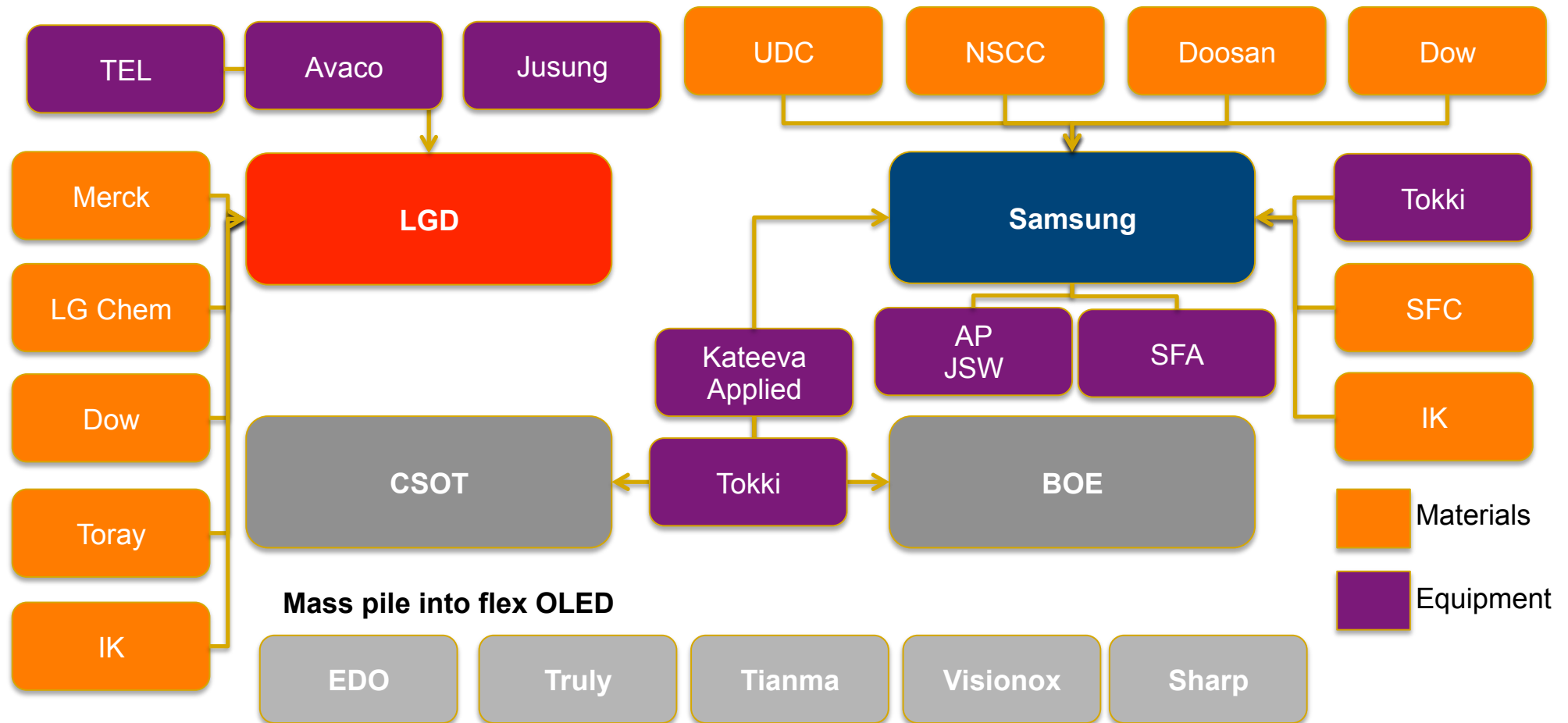


**Large panel OLED capacity expansion (estimate)  
k sheets/month Gen 8 equivalent**



Source: HCL estimates

OLED is a booming market with many now established relationships (Selected relationships): Flex OLED providing some new opportunities too



...and QLED now is on the scene potentially as a direct competitor: true QLED within 5 years

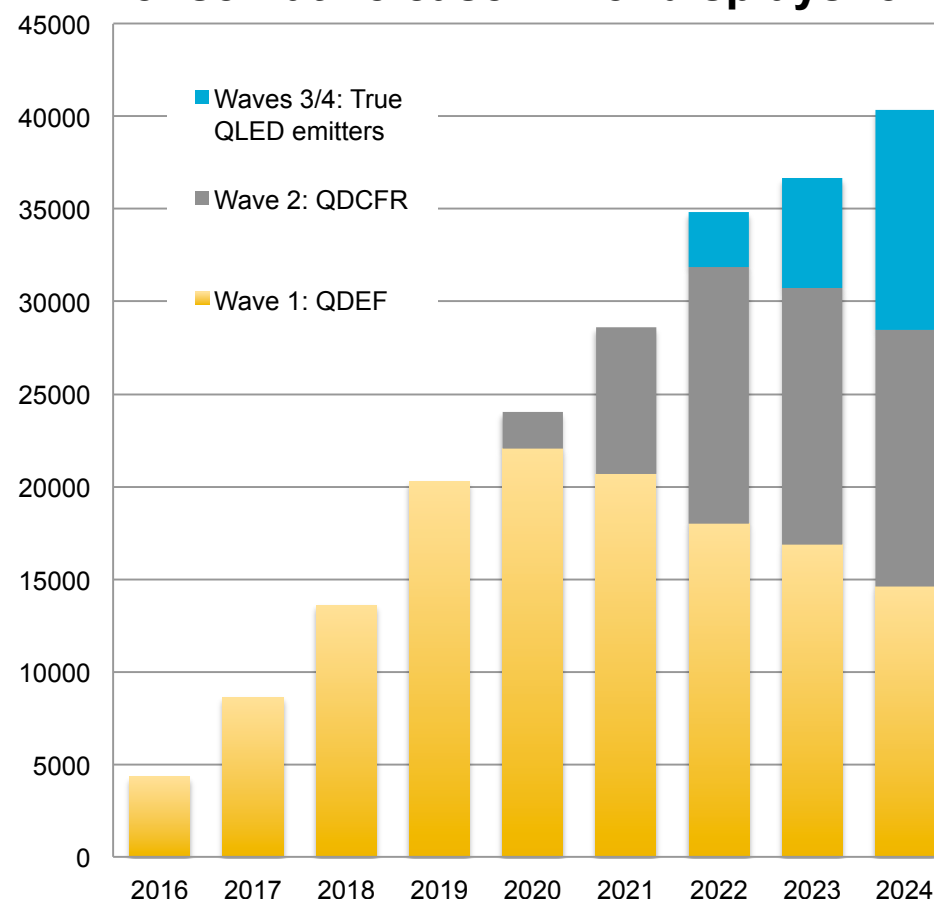
|                                       | OLED                                  | True QLED                            |
|---------------------------------------|---------------------------------------|--------------------------------------|
| Colour volume                         | Very dark blacks 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                                  |



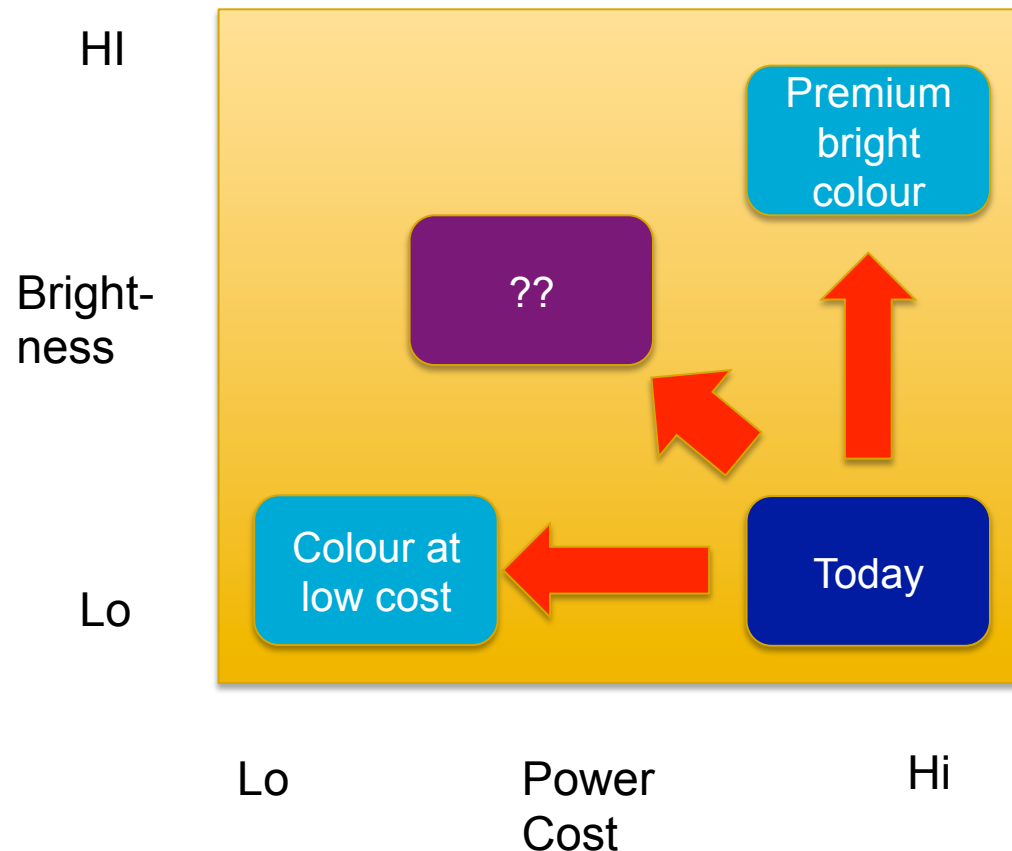
## QLED is a multi-step pathway with a number of technical issues and commercial uncertainties:

- QD now is delivered through a drop in film: QDEF
- The next embodiment is QDCFR where the CF resins of an LCD are replaced with QD material by printing or coating/lithography. A number of technical issues are raised: front fluorescence suppression and in-cell polarisation
- The “holy grail” embodiments are “Colour by Blue” (using blue light source, e.g. blue OLED to excite the QD and downshift light from there) or true QLED emitters
- Paul Gray from IHS will talk more about the specific embodiments in his keynote

**Conservative case m2 of displays for QD**

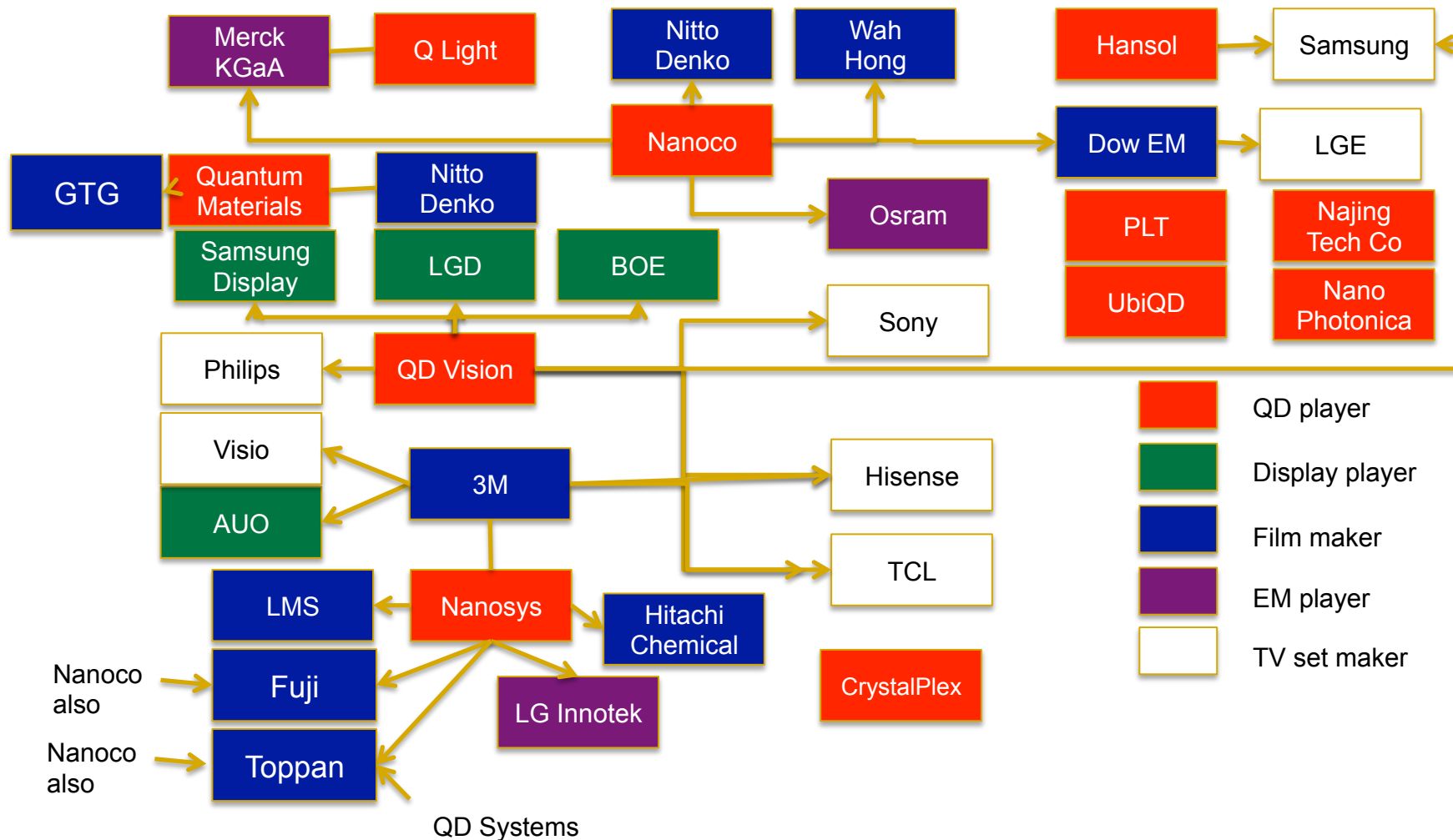


QDEF is now a growth market. The next big thing will be QDCFR but this gives many open options:



- QD CFR removes the CF
  - Massive increase in brightness in the display since the CF responsible for taking out about 2/3 of the light from the BLU. The question then is how to deploy the optionality that comes from this
- Could reduce power and cost and match the same amount of output lumens: a low cost, lower power high colour platform
  - Or could have a high brightness colour premium product: more of an OLED competitor

There are many relationships already established in the new QD world. Samsung have just purchased QD Vision:





## So what will the top two do: Samsung using QD as the killer blow to OLED



### Samsung

- Samsung will vertically integrate
- Samsung already has a strong minority position in Nanosys
- Samsung has just purchased QD Vision for \$70m
- New SUHD displays are now being sold under the “Quantum Dot” or QLED moniker
- Samsung recently made the decision to allow other brands to use the notion of Quantum dot as part of the marketing: this is an LG killer (OLED killer)

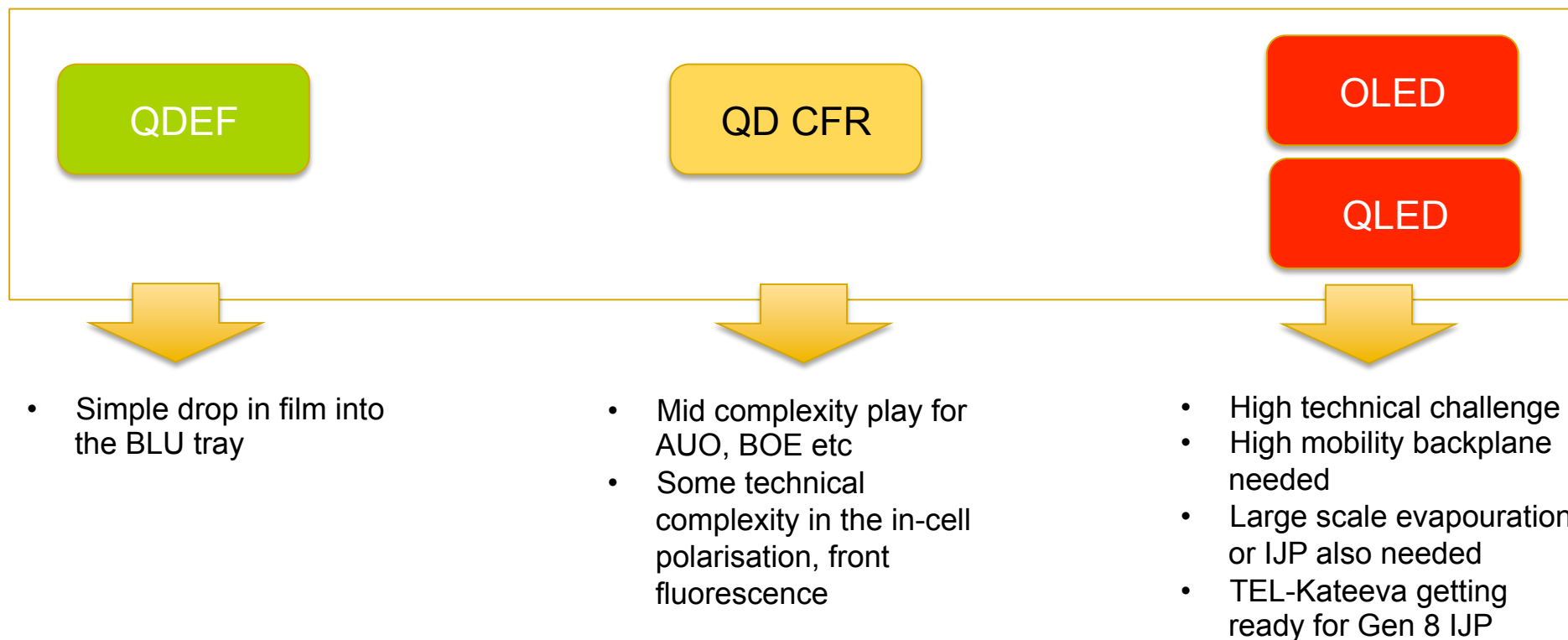
### LGD

- Head-aches for them as they consider how to respond to QLED
- LGD is trying to forge its premium position based on OLED
- Will probably need to respond at least internally on QLED
- Expect LGD to quietly make some moves to evaluate and have a back-up plan in place
- LGD is trying to push (but not heavily) their own nanocrystal technology

For the other players, QDCFR gives a mid-complexity play for the high colour space. QLED will be more challenging:

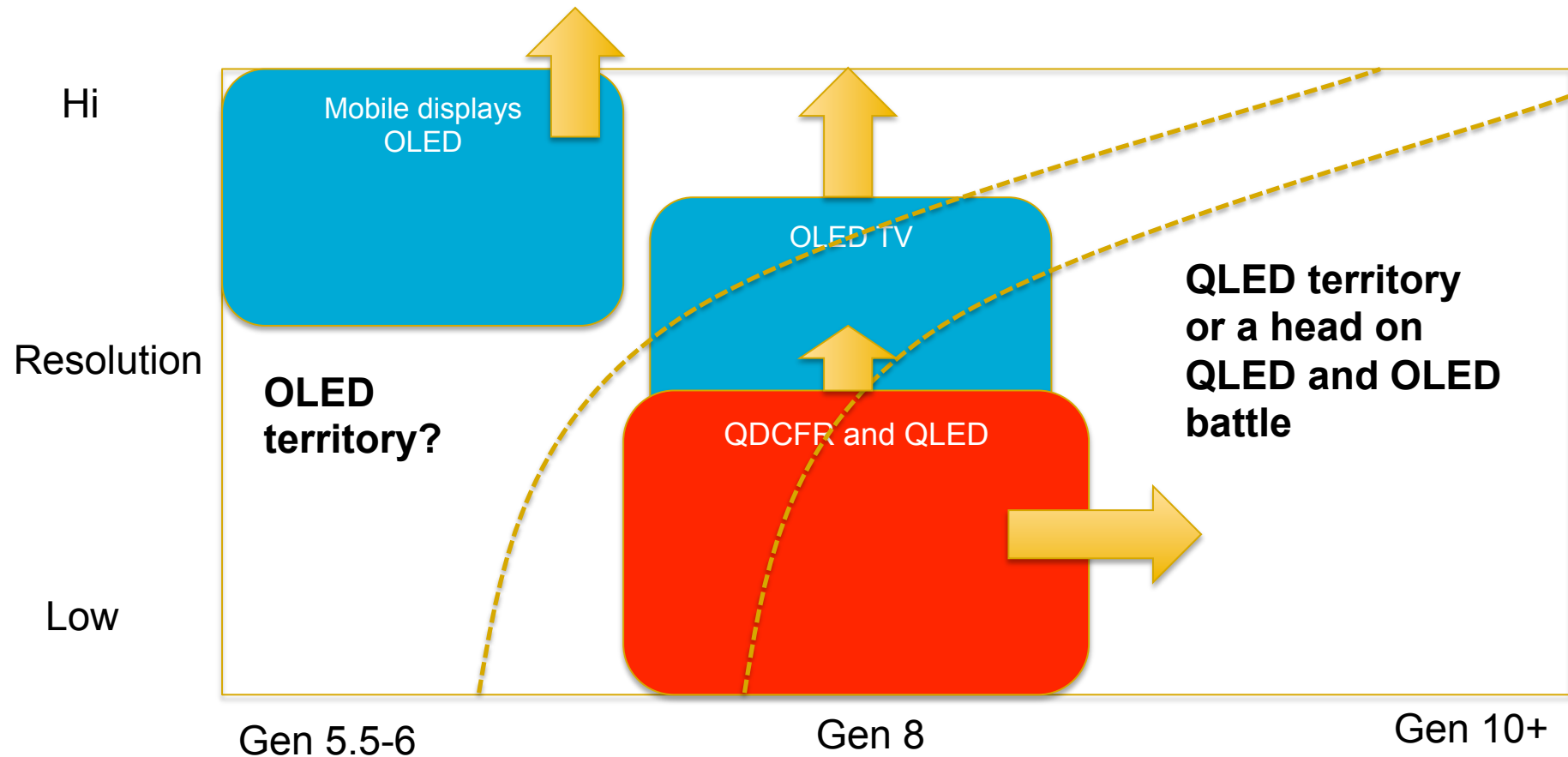
Low technical complexity

High technical complexity



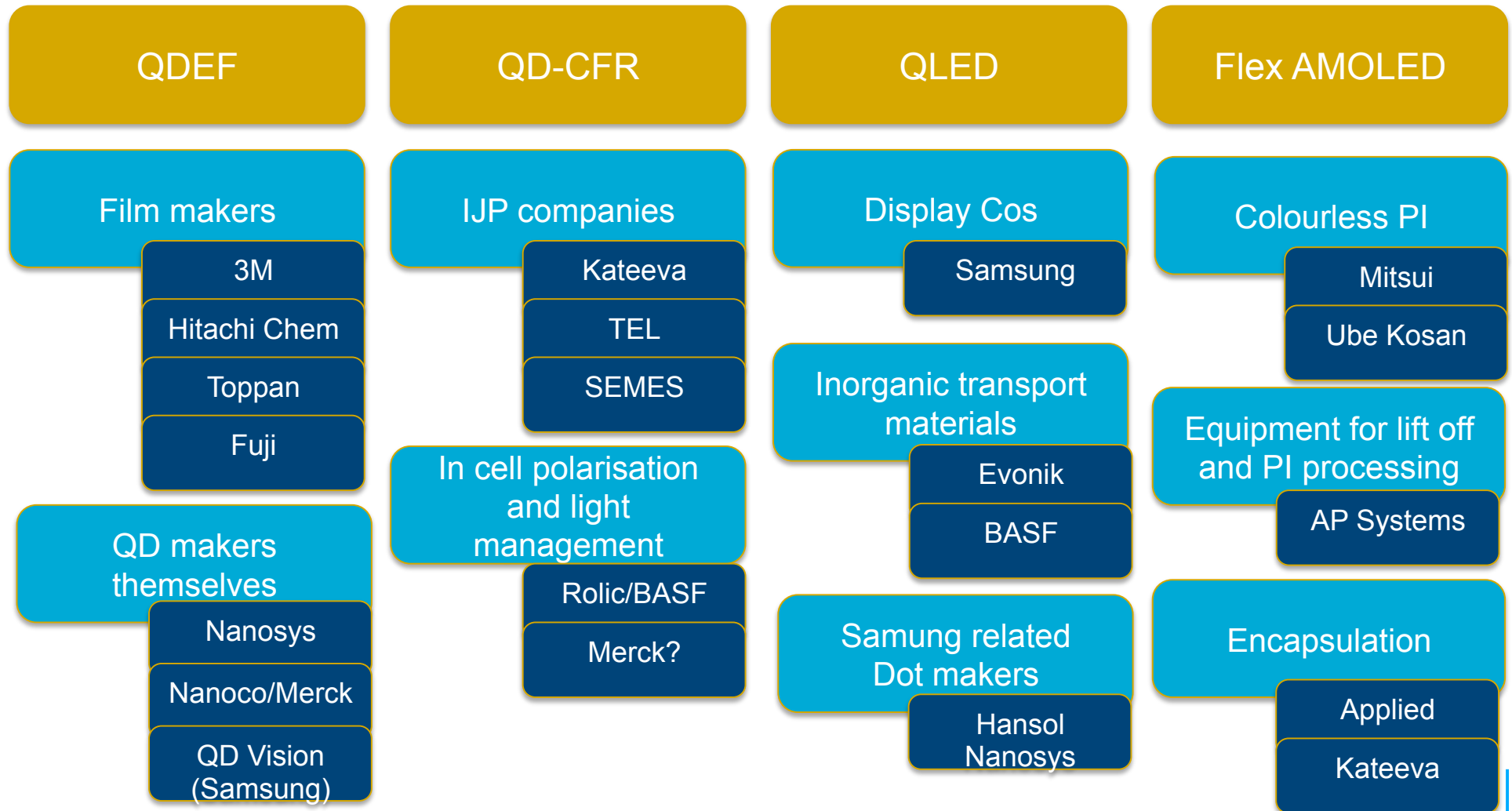
- QDCFR opens up strategic options at a mid complexity play that may be very attractive to the Taiwanese and the Chinese. QLED (like OLED) may remain the domain of the most capable

There are some limitations of QLED which will define how it can play as compared with OLED



- 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

But new markets will mean new opportunities for new players  
(and some old players):



## And what will it mean for us here in Europe?

- Today most of the development of QD materials is happening in the USA? Why?
  - Opportunities for research in Europe
- Opportunities for transport materials for QLED: Evonik and BASF could have options
- Options for in-cell polarisation approaches (controlling the optics of the interaction of the QDs and polarisation)
  - Perhaps one of the motivations for the BASF acquisition of Rolic
- Trickle down for more high colour displays across other applications later
- Nanoco (UK) making some progress but still less commercial momentum than the big two US players
- There may be options for us to seize value in these new growth opportunities

## Summary

- OLED going through boom times due to moves from Apple
- The new big thing is QLEDs: Which will move towards us in four tiers of product from QDEF to QDCFR to “colour by blue” and true QLEDs
- OLED vs QLED will be the new Pepsi vs Coke battle for the two major leaders: but true QLED is a sophisticated technical challenge
  - QDCFR may be an interesting mid-sophistication play for the mid-tier display players but requires addressing in-cell polarisation and front fluorescence
  - The wild card is QD on chip which could radically change the outlook
- QLED requires IJP: cannot be evaporated so this will be good business for the new IJP printing companies
- In general new technology shifts mean new market opportunities
- Relationships are now being formed and there may be options for Europe to play

## 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> |