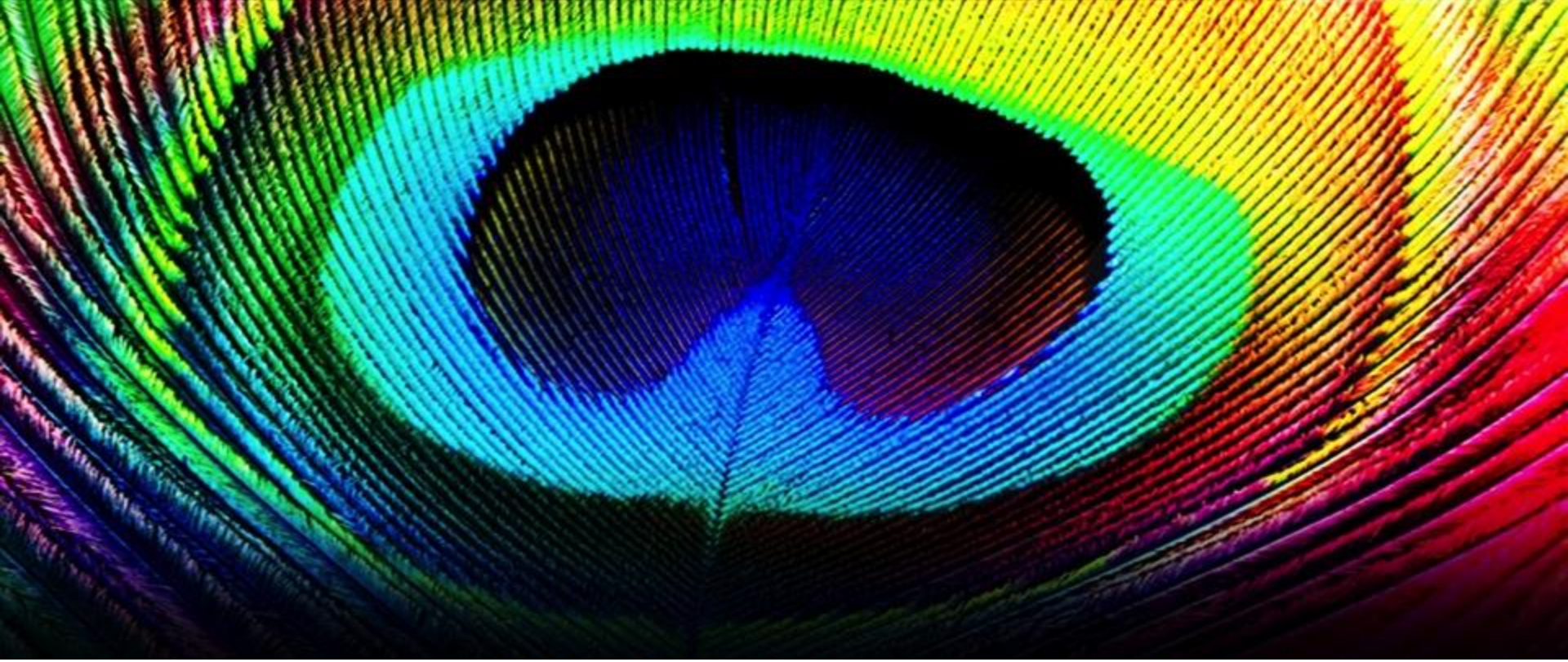

Performance Benchmarking of Wide Color Gamut Displays

8 January 2016

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Methodology

- Objective: To benchmark energy and color performance of various QD-based displays in market today

- Displays Tested: 6 - 55” Wide Color Gamut (WCG) Televisions:
  - Samsung s-UHD (UN55JS9000F) – Samsung InP film
  - Philips (55PUF6850/T3) – Color IQ CdSe optic
  - Thomson (55UA9806) – Color IQ CdSe optic
  - Hisense (LED55K7100UC) – Color IQ CdSe optic
  - Hisense (LED55XT910X3DUC) – 3M QDEF CdSe film
  - Samsung s-UHD (UN55JS7000FXZA) – Samsung White LED with notch filter

- Approach:
  - IEC-compliant testing carried out at two distinct locations and dates using different measurement devices
    - QD Vision in-house testing lab:
      - Location: QD Vision, Lexington, MA; October, 2015
      - Equipment: Konica Minolta CS-200 color and luminance meter
    - Independent third-party testing lab:
      - Location: Gamma Scientific, San Diego, CA; December, 2015
      - Equipment: Gamma Scientific GS-1290-NVIS-2 Spectroradiometer
  - Direct film-swapping in two 55” QD-based televisions (QD Vision lab only)
    - Samsung s-UHD (UN55JS9000F) – Samsung InP film
    - Hisense (LED55XT910X3DUC) – 3M QDEF CdSe film

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Conclusions

- Performance benchmarking conducted by an independent, third-party laboratory confirms:
  - Televisions using CdSe QD solutions consistently deliver the widest color gamut of all technologies tested
  - TVs using CdSe QD solutions consistently deliver higher energy efficiency or “efficacy” (Nits/W) than other technologies tested
  - Televisions using QD solutions deliver higher energy efficiency or “efficacy” (Nits/W) than traditional WLED+notch filter technology

- Keeping all other variables the same, QD film-swapping tests confirm:
  - Replacing InP-based QD film with CdSe-based QD film results in wider color gamut and higher luminance performance
  - Replacing CdSe-based QD film with InP-based QD film results in smaller color gamut and lower luminance performance
  - Therefore, today’s QD solutions based on CdSe are superior to those based on InP in both energy efficiency and wide color gamut performance

- Superior energy efficiency and color gamut performance of televisions based on CdSe QD solutions vs. InP QD solutions can be directly attributed to material performance differences:
  - CdSe QD materials have higher quantum efficiency (EQE) directly translating to higher TV efficiency
  - CdSe QD materials have narrower emission spectra (FWHM) directly translating to wider color gamut capability

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Summary of QDV and Gamma Scientific Measurements

QDV IEC Testing

Display	FWS Luminance (Nits)	Efficacy (Nits/Watt)	Color Gamut Coverage	Gamut
Samsung sUHD JS9000	552.7	2.54	91.8%	NTSC 1931
Philips TV (Color IQ)	394.2	3.35	102.8%	NTSC 1931
Thomson (Color IQ)	462.8	2.21	108.3%	NTSC 1931
Hisense (Color IQ)	380.0	2.83	100.0%	NTSC 1931
Hisense (3M QDEF)	477.2	2.51	98.0%	NTSC 1931
Samsung sUHD JS7000*	417.2	1.84	92.7%	NTSC 1931

Gamma Scientific IEC Testing

Display	FWS Luminance (Nits)	Efficacy (Nits/Watt)	Color Gamut Coverage	Gamut
Samsung sUHD JS9000	514.3	2.45	89.2%	NTSC 1931
Philips TV (Color IQ)	362.8	3.08	100.1%	NTSC 1931
Thomson (Color IQ)	434.5	2.09	106.4%	NTSC 1931
Hisense (Color IQ)	374.4	2.81	98.2%	NTSC 1931
Hisense (3M QDEF)	498.1	2.61	95.6%	NTSC 1931
Samsung sUHD JS7000*	396.1	1.66	90.9%	NTSC 1931

** - White LED system with notch filter*

Differences Between QDV and Gamma Scientific

Display	FWS Luminance (Nits)	Efficacy (Nits/Watt)	Color Gamut Coverage
Samsung sUHD JS9000	-6.9%	-3.5%	-2.6%
Philips (Color IQ)	-8.0%	-8.1%	-2.7%
Thomson (Color IQ)	-6.1%	-5.5%	-1.9%
Hisense (Color IQ)	-1.5%	-0.9%	-1.8%
Hisense (3M QDEF)	4.4%	4.2%	-2.4%
Samsung sUHD JS7000	-5.1%	-10.0%	-1.8%

Strong agreement between measurements performed at QDV and Gamma Scientific

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On-mode Power Consumption
(Using Gamma-Scientific Data)

Gamma Scientific IEC Testing

Display	On-mode Power Consumption (W)	Annual On-mode Power Consumption (kWh)
Samsung sUHD JS9000	180.3	263.2
Philips TV (Color IQ)	84.4	123.3
Thomson (Color IQ)	209.6	306.0
Hisense (Color IQ)	127.2	185.7
Hisense (QDEF)	182.8	266.9
Samsung sUHD JS7000	165.4	241.5

On-mode Power Consumption measured in compliance with IEC 62087 standard as average power consumption over ten minute period of dynamic broadcast signal

Annual On-mode Power Consumption calculated in accordance with EU Regulation 1062/2010

**** - White LED system with notch filter***

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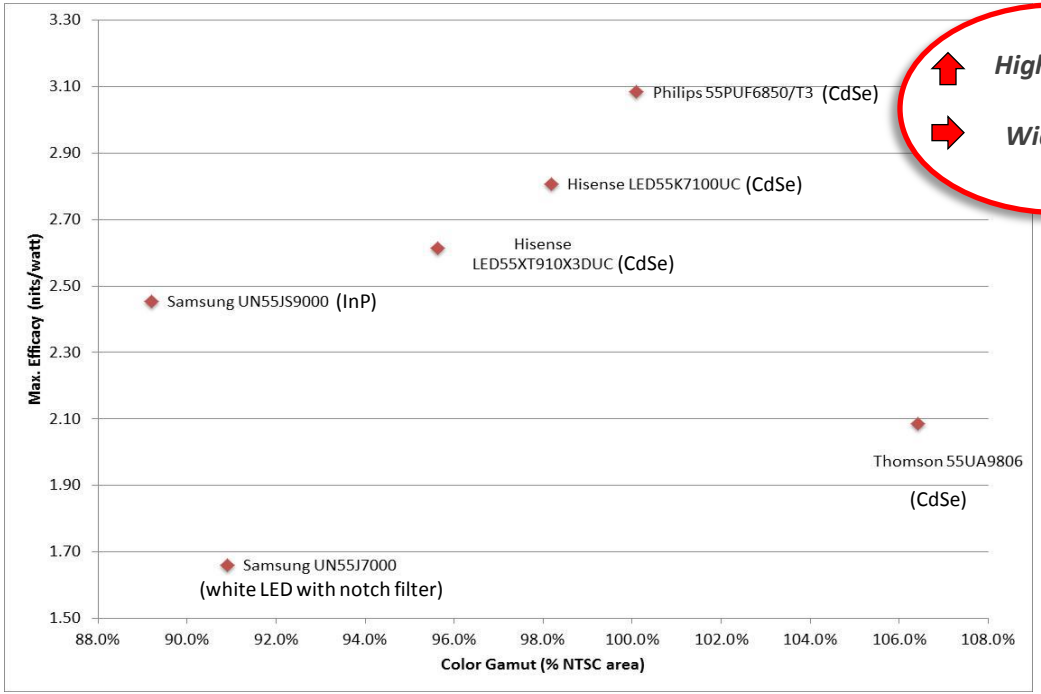
Efficacy (Nits/W) vs. Color Gamut (% NTSC)

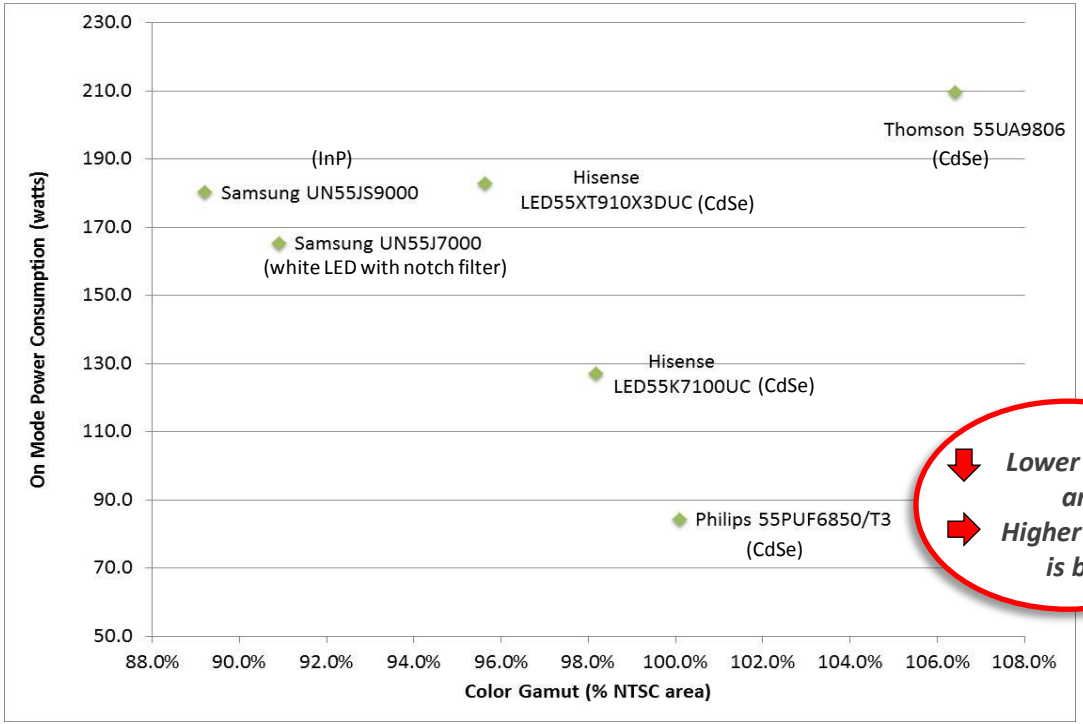


Televisions using CdSe QD solutions consistently deliver the widest color gamut of all technologies tested

Televisions using CdSe QD solutions consistently deliver higher energy efficiency or "efficacy" (Nits/W) than other technologies tested

Televisions using QD solutions deliver higher energy efficiency or "efficacy" (Nits/W) than traditional WLED+notch filter technology

On Mode Power Consumption (W) vs. Color Gamut (% NTSC)



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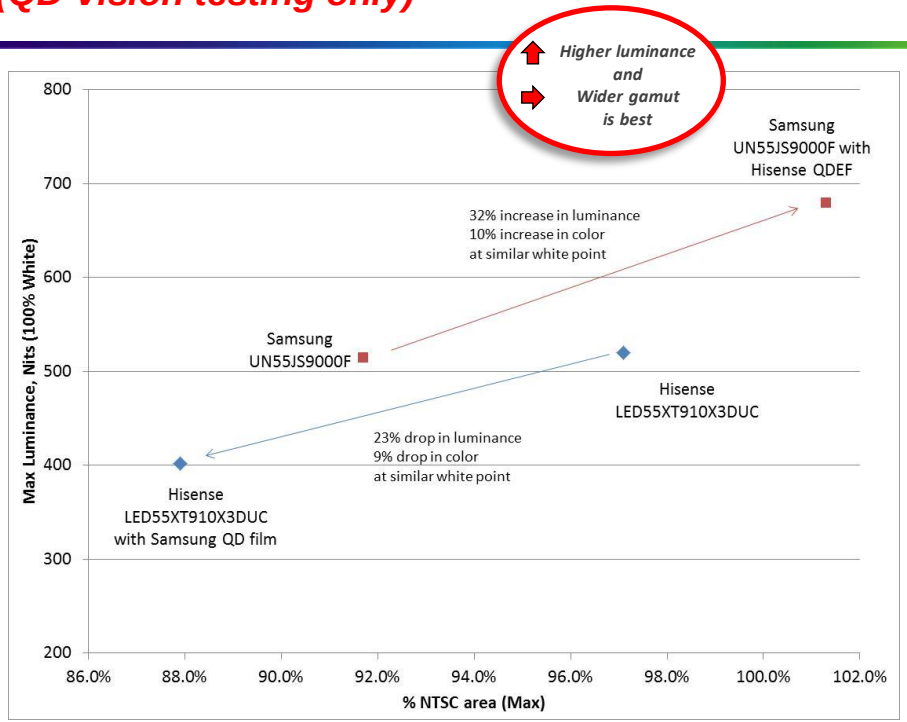
Head-To-Head Comparison Of CdSe and InP QD Films

(QD Vision testing only)



3M CdSe (QDEF) and Samsung InP QD films were swapped between Hisense and Samsung TVs, enabling a direct comparison of material performance independent of television set design factors

In both displays, color gamut and luminance (and thereby energy efficiency) were significantly higher when configured with CdSe QD-based film as compared to the InP QD-based film

Performance difference between the CdSe and InP QD films can be directly linked to the External quantum efficiency (EQE) and FWHM of the film samples

- **Lower EQE of the InP film results in lower luminance**
- **Broader FWHM of the InP film results in lower color gamut**

Film Performance Metrics (as measured by QDV)	Samsung InP QD Film	3M QDEF CdSe QD Film
Green Peak Wavelength	537 nm	532 nm
Green FWHM	41 nm	33 nm
Red Peak Wavelength	635 nm	627 nm
Red FWHM	55 nm	37 nm
EQE	56.5%	73.2%

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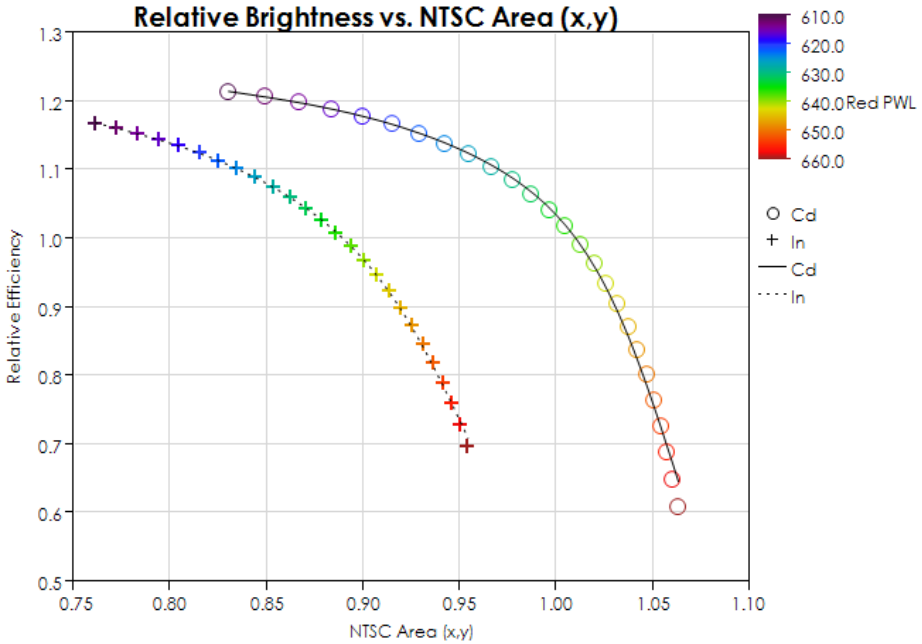
Correcting for Gamut Differences Between TVs



Simulated relative efficiency vs. NTSC area for CdSe and InP QDs with a 536nm green QD and Samsung CFA measured from JS9000 TV.

Due to the photopic response of the human eye (which is most sensitive to yellow light), there is an inherent tradeoff between color gamut and brightness

Relative efficiency of displays can be compared at the same gamut by correcting for this effect

Two different curves for the two materials are driven by the "Full Width-Half Maximum" performance (or FWHM) of the materials, where a narrower FWHM translates to a higher efficiency for a given color gamut

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Ranking the Efficiency of TVs at the Common Color Gamut (90% NTSC Area)

Display	FWS Luminance (Nits)	Efficacy (Nits/Watt)	Color Gamut (% NTSC Area)	Relative Spectral Efficiency Native Color Gamut	Relative Spectral Efficiency 90% NTSC Gamut	Efficiency Change 90% NTSC Gamut	Calculated Efficacy 90% NTSC Gamut (Nits/Watt)
Thomson (Color IQ)	434.5	2.09	106.40%	0.61	1.18	1.93	4.04
Philips TV (Color IQ)	362.8	3.08	100.10%	1.02	1.18	1.16	3.56
Hisense (Color IQ)	374.4	2.81	98.20%	1.06	1.18	1.11	3.13
Hisense (3M QDEF)	498.1	2.61	95.60%	1.12	1.18	1.05	2.75
Samsung sUHD JS9000	514.3	2.45	89.20%	0.99	0.97	0.98	2.45
Samsung sUHD JS7000*	396.1	1.66	90.90%	0.95	0.97	1.02	1.66

**** - White LED system with notch filter***

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