



# DOE Manufacturing R&D Workshop

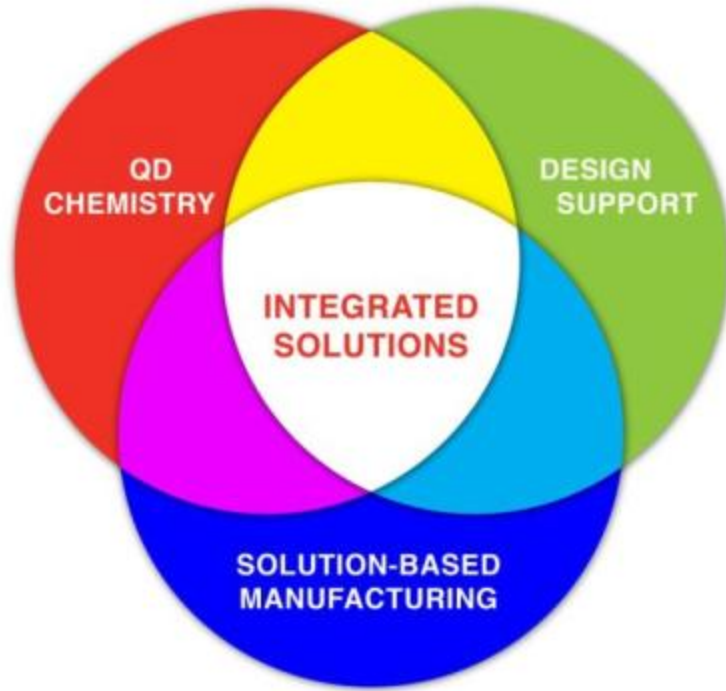
5/8/14

# Agenda

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- Quantum Dots and QD Vision
- Product Form Factors
- Green Manufacturing

# About QD Vision



- Founded in May 2005 - MIT roots
- First QD Products to market in Display and LED Lighting
- World's largest QD Mfg. facilities
- Color IQ™ optics shipping in high volume starting Q1-2013
- Multiple MP lines qualified
- High yield production processes for both QDs and final optic assembly
- ISO9000/14001, Green Partner status



# QDV Global Offices Provide Local Customer Support



QD VISION, INC.  
(Headquarters)  
Lexington, MA  
U.S.A.



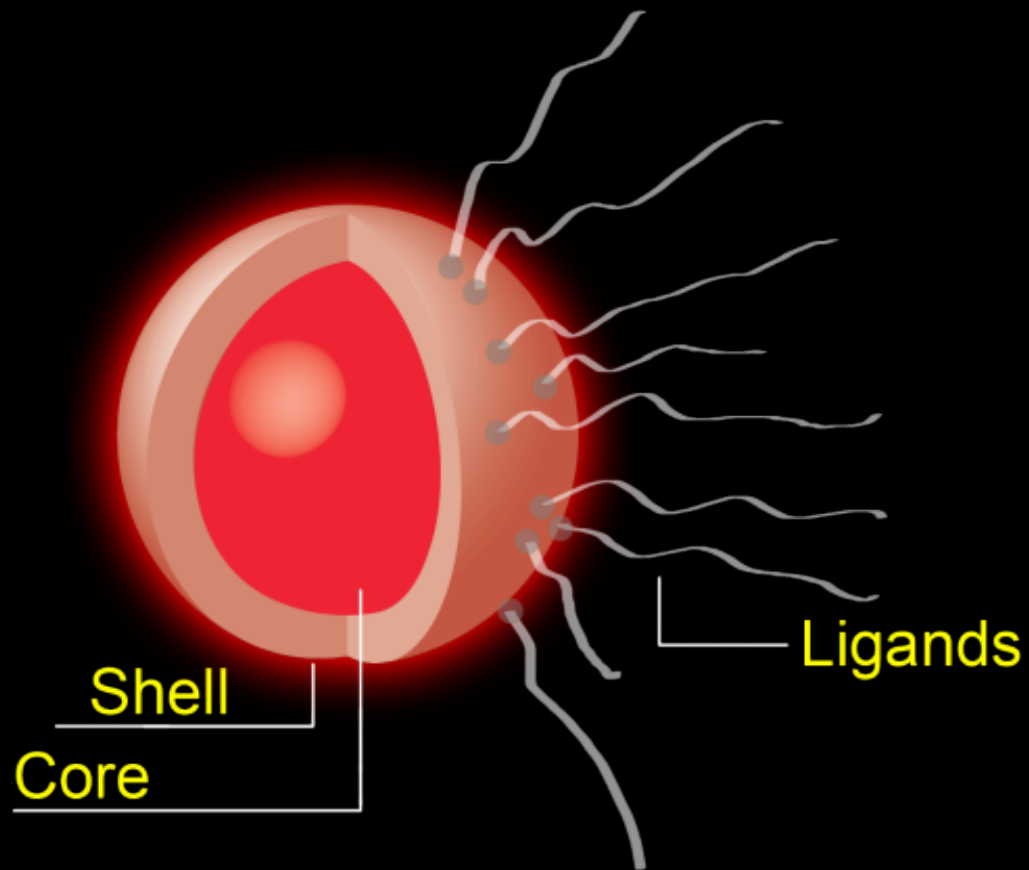
QD VISION, INC.  
Taiwan Branch  
Taipei City



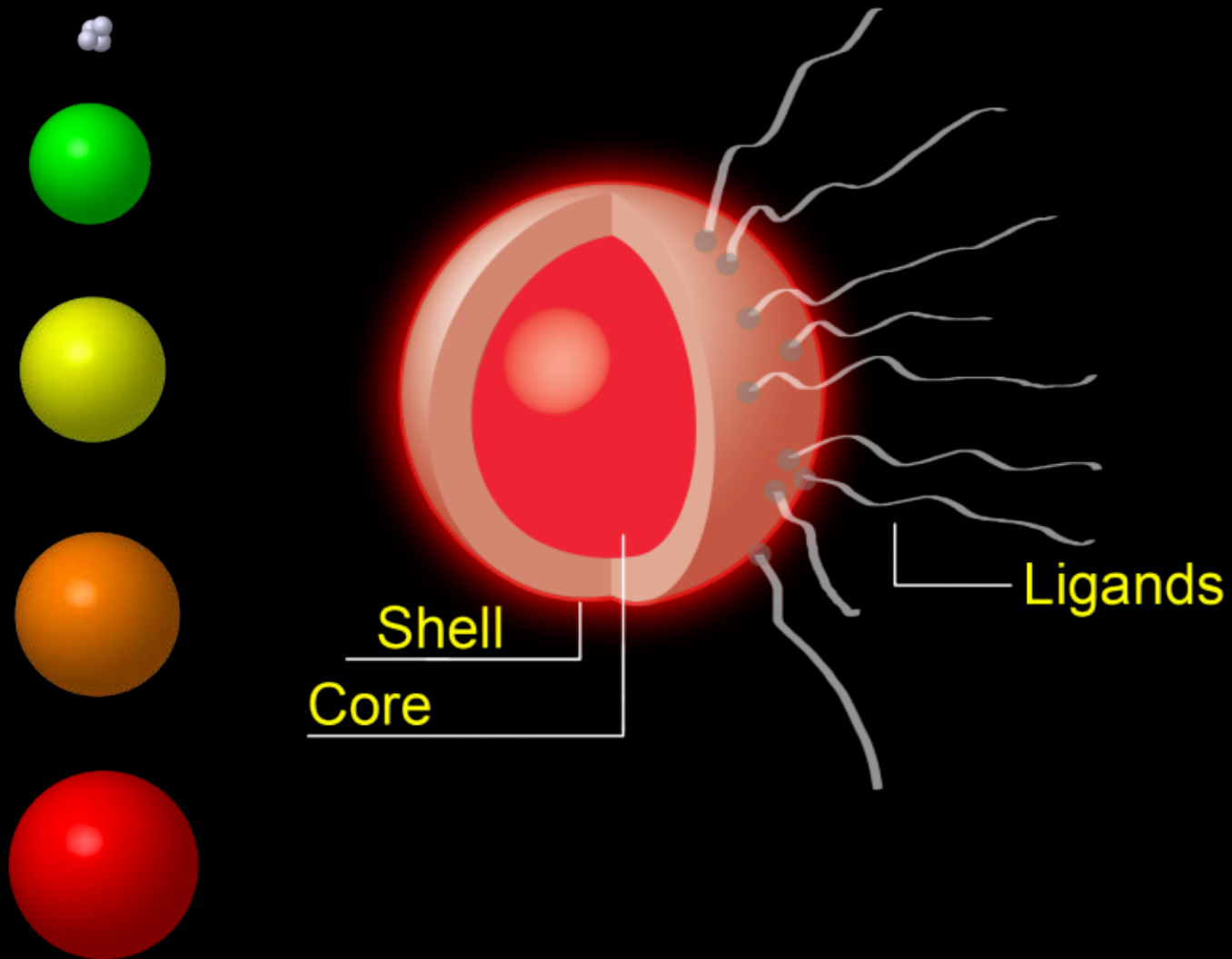
QD VISION  
Japan, G.K.  
Shibuya-ku,  
Tokyo, Japan



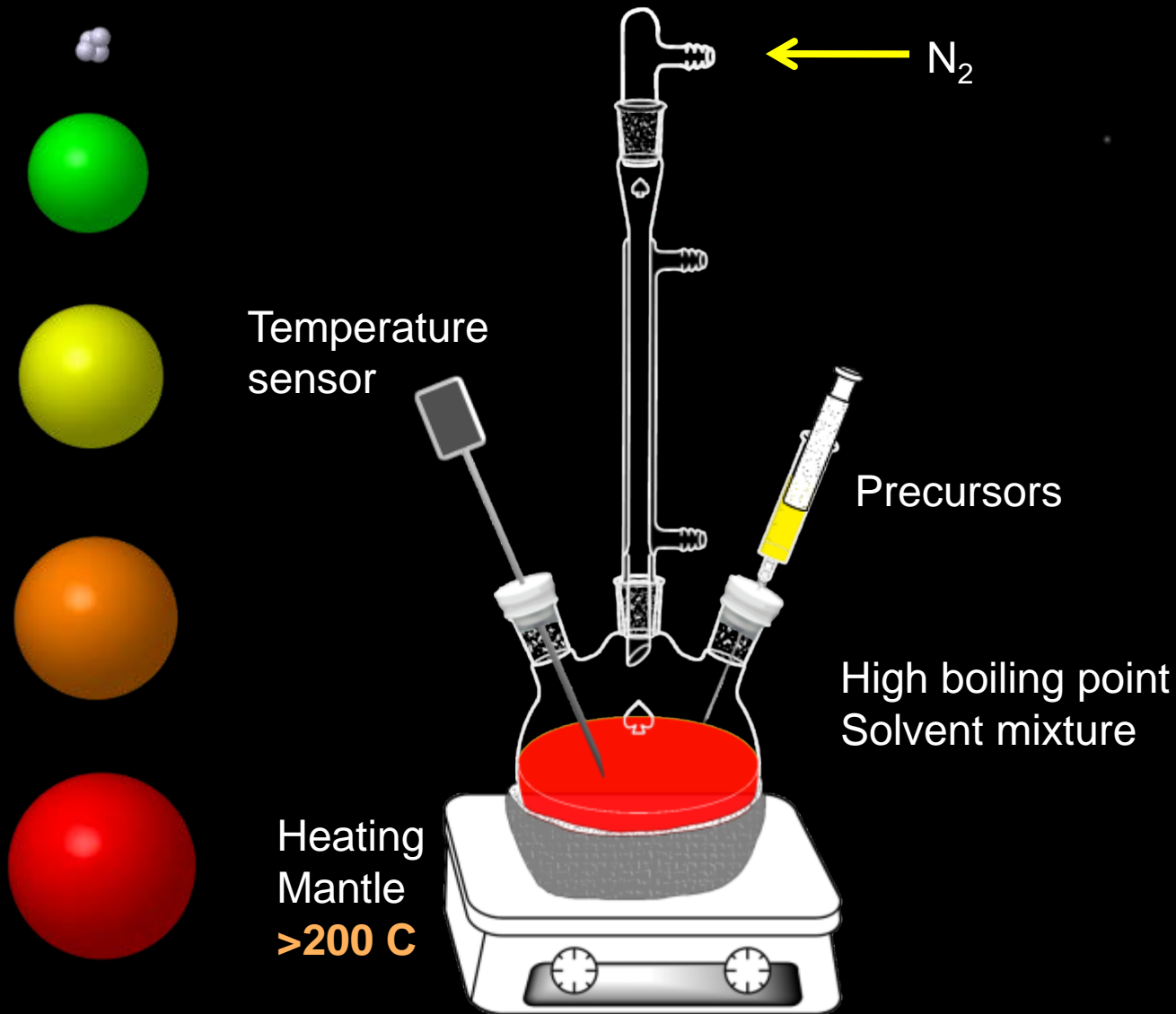
# Introduction to QDs



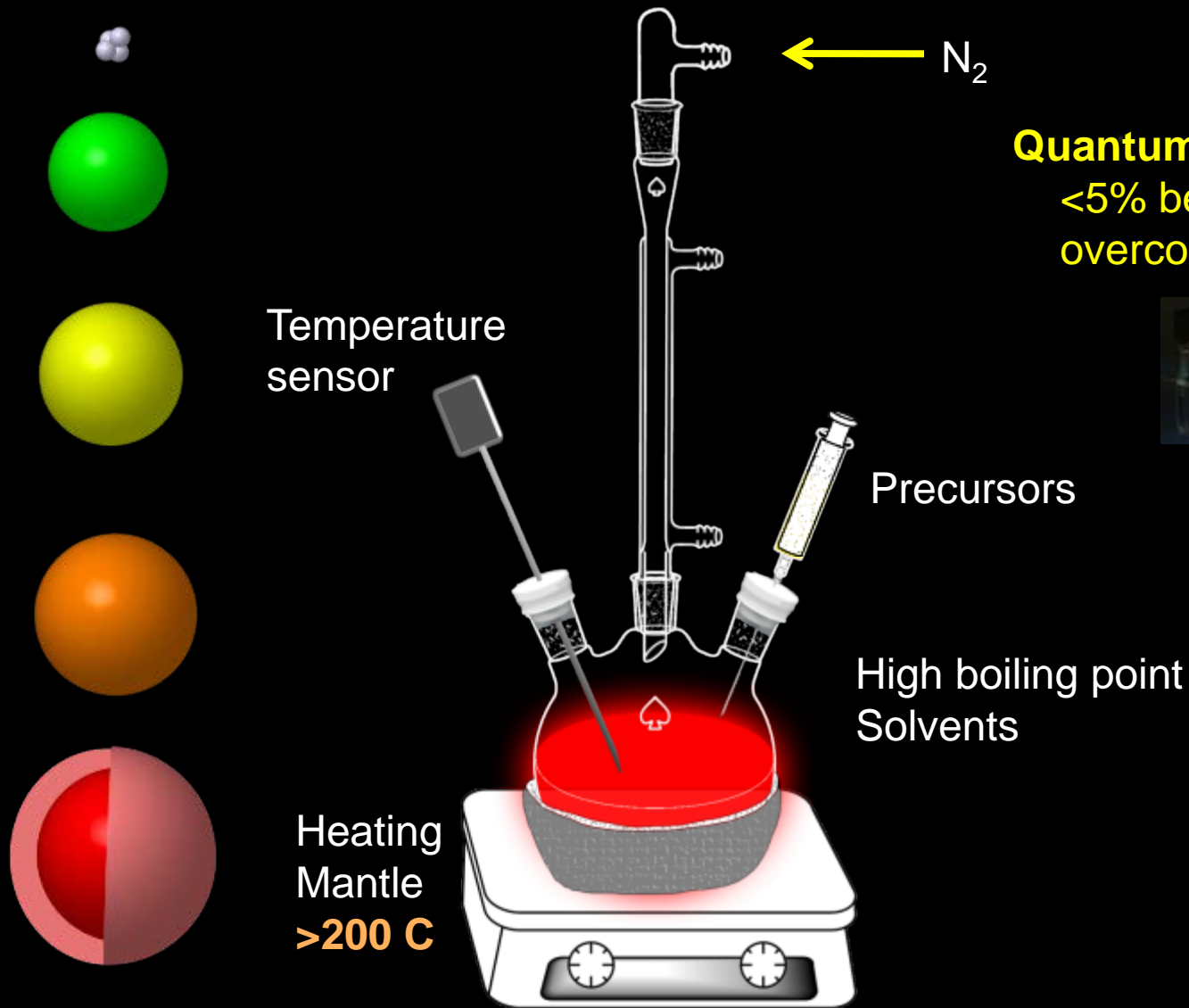
# Introduction to QDs



# Introduction: QD Core Synthesis



# Introduction: QD Shell Synthesis



**Quantum Yield:**

$<5\%$  before to  $>90\%$  after overcoating





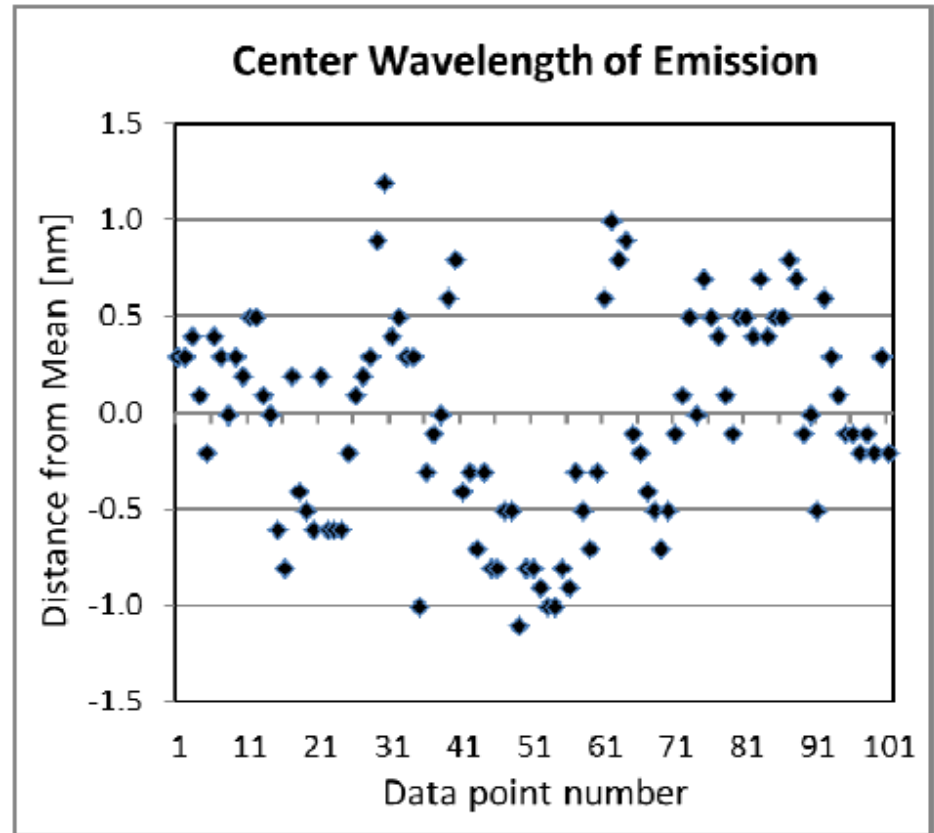
# QD Manufacturing - Color

## Rapid-Injection Method:

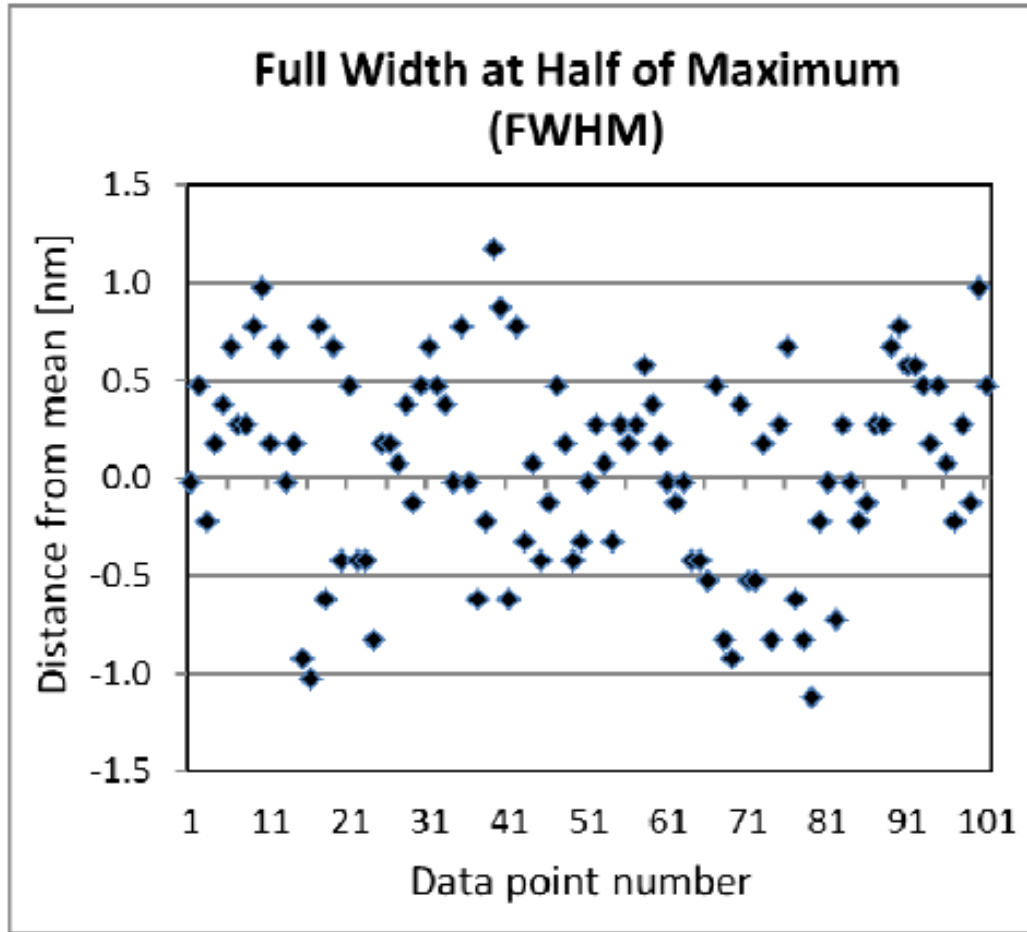
- Batch-by-batch approach
- Fast: can run >1 reaction per shift
- Reproducible
- Scalable model

## Color Control:

- $\pm 1$ nm of center wavelength
- Corresponds to less than  $1\text{\AA}$  (Angstrom =  $1/10^{\text{th}}$  of 1nm) of diameter
- Corresponds to less than  $1/5^{\text{th}}$  of one bond length

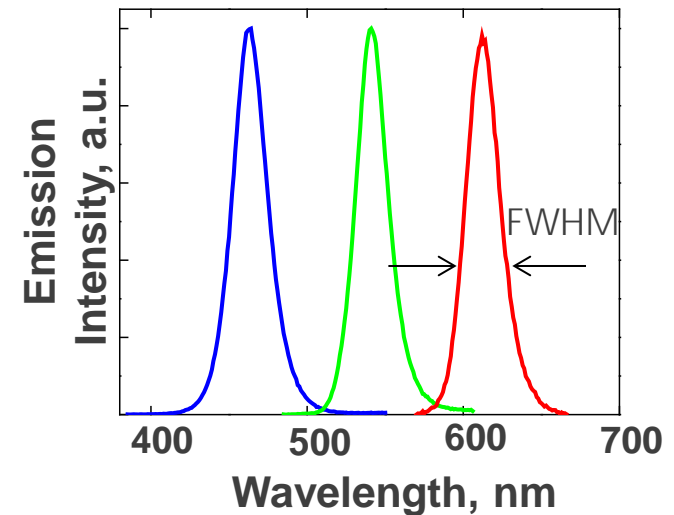


# QD Manufacturing – Color Saturation



## Color Saturation Control:

- Size distribution → saturation
- Each batch contains  $10^{19}$  particles (10 billion billion)
- $\pm 1$  nm of FWHM variation (full width at half of maximum)
- All particles within batch,  $< 1$  atomic length of each other



# Agenda

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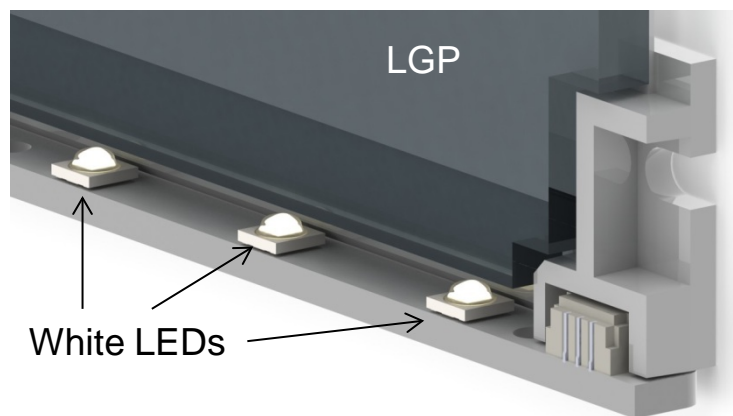
- Quantum Dots and QD Vision
- Product Form Factors
- Green Manufacturing

# Color IQ™ Optical Component

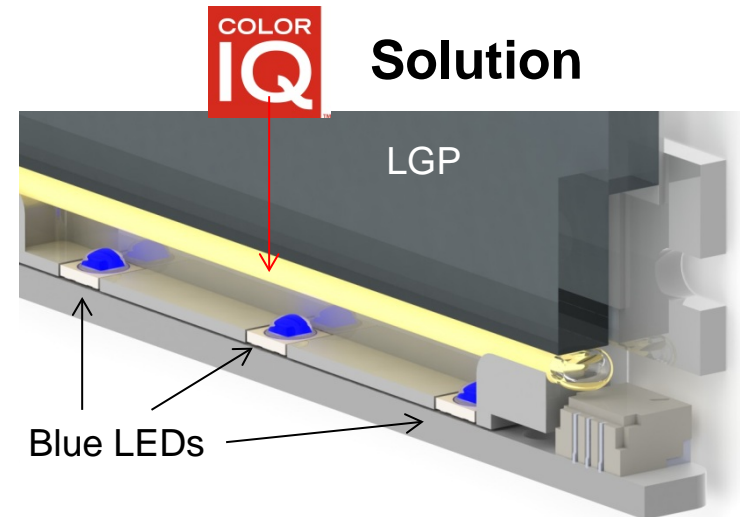
**Color IQ™ Optics deliver OLED color at LCD cost**

- Color IQ optical components containing light-emitting semiconductor nanocrystal Quantum Dots (QDs).
- Improves typical LCD TV Color performance by 50%
- Best available Color-Efficiency combination
- QDs are tuned for optimized spectra, narrowband light emission
- Highly efficient, scalable manufacturing process

## Current White LED Solution

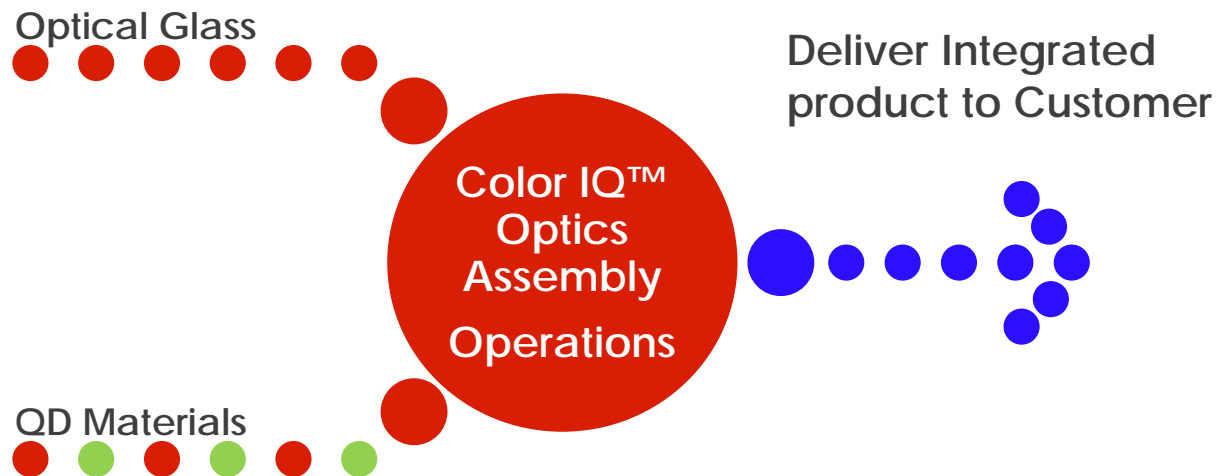


## Solution



# High Volume Color IQ Supply Chain

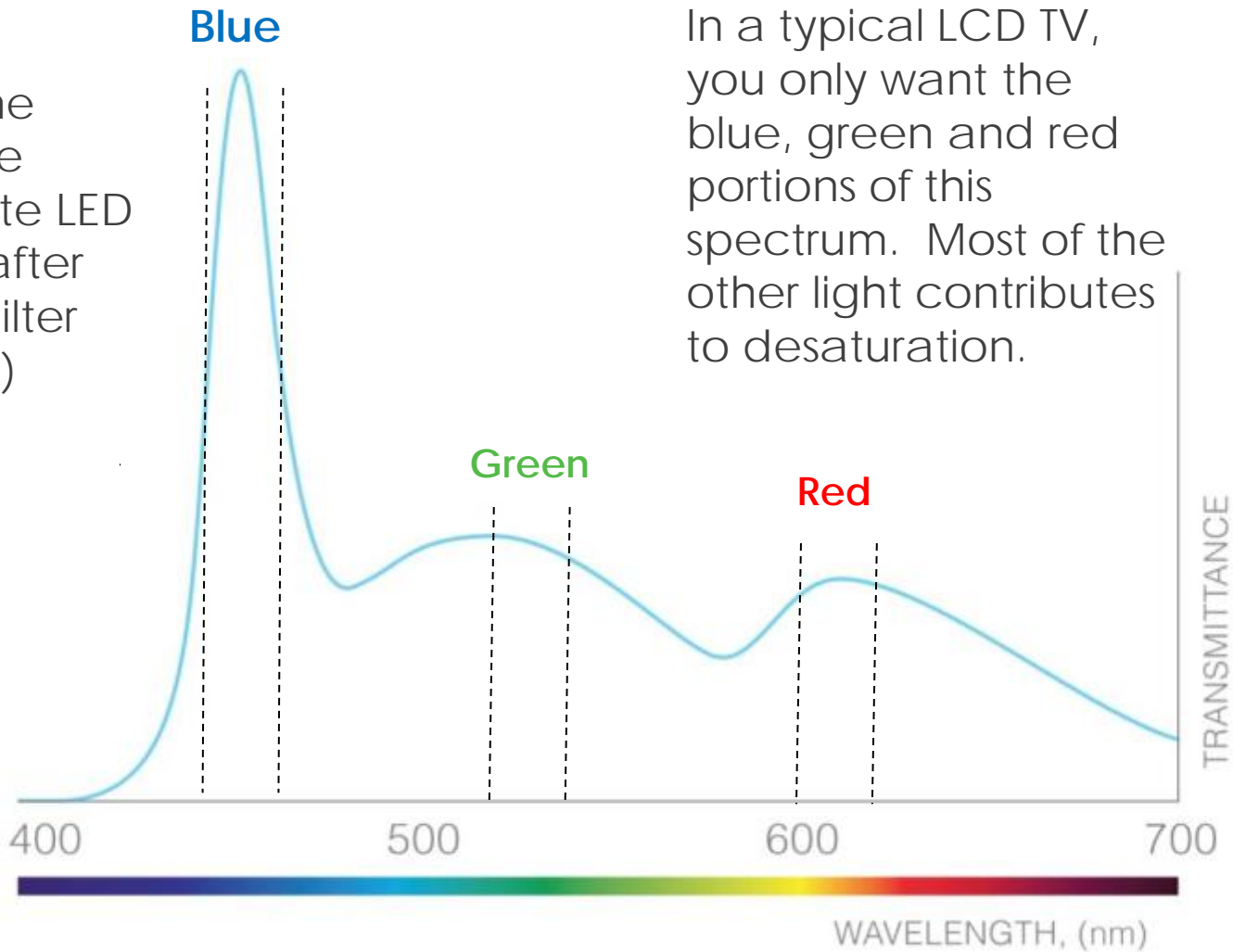
- QD Vision has established a global supply chain for the production of Color IQ™ optics:
  - U.S.A.: QD materials production at QDV Lexington
  - Global: Leading producer of optical glass
  - Taiwan: Optics Assembly Operations



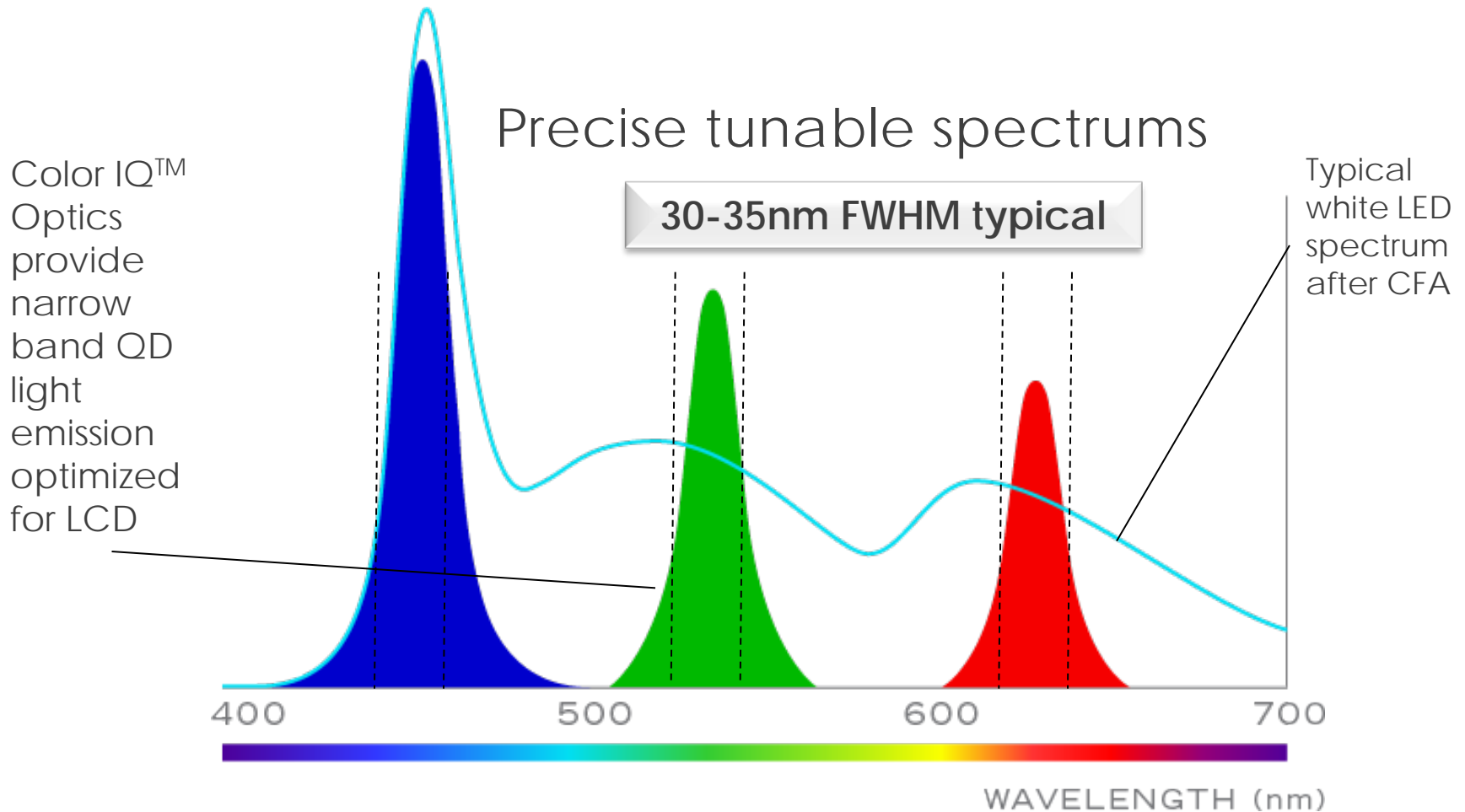
# White LED Spectrum for LCD Systems

This blue line depicts the typical white LED spectrum after the Color Filter Array (CFA)

In a typical LCD TV, you only want the blue, green and red portions of this spectrum. Most of the other light contributes to desaturation.

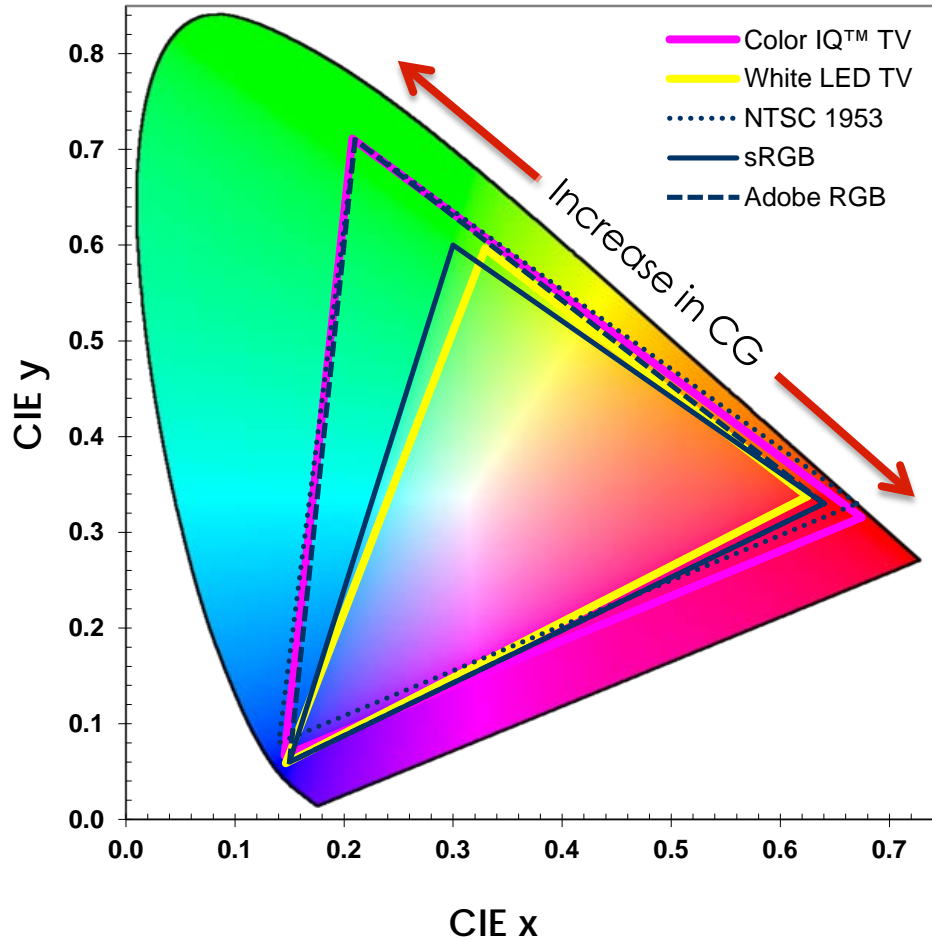


# Color IQ™ Optics-Optimal for LCD Systems



- Narrow band blue, green and red delivers highly saturated colors
- Saturated colors significantly expand color gamut

# Color IQ™ Optimizes LCD Color Gamut



Color IQ™ optics offer the best LCD wide gamut solution:

- Maximizes LCD color performance with existing color filter array
- Tunable to >100% NTSC, Adobe RGB, DCI gamut area and coverage
- Cost-effective color gamut enhancement



# Ten Sony TV Models In the Market



Four Sony TV Series	N.America	S. America	Europe	Asia	RoW
XBR-65X900A XBR-55X900A 55", 65" (4K)	65 55	65 55	65 55	65 55	65 55
KDL-55W905A KDL-46W905A KDL-40W905A 40, 46" 55" FHD	55		55 46 40	55 46 40	55 46
KDL-55W950A KDL-46W950A 46", 55" FHD		55 46		55 46	
KDL-55W850A KDL-47W850A KDL-42W850A 42", 47", 55" FHD					55 47 42

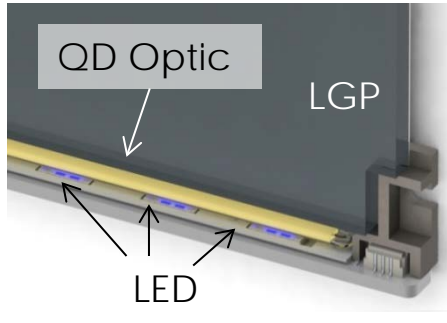
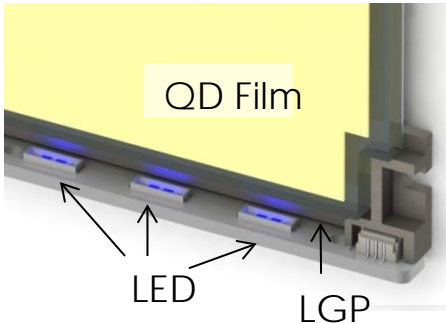
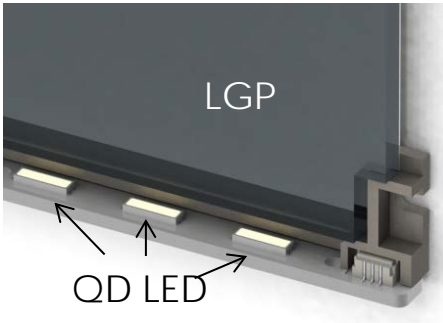
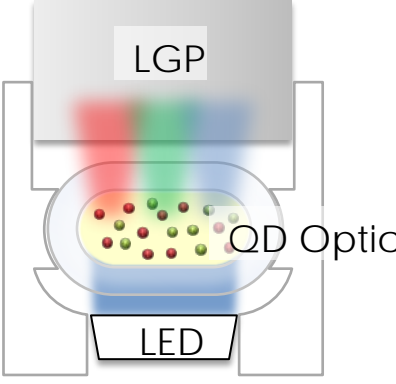
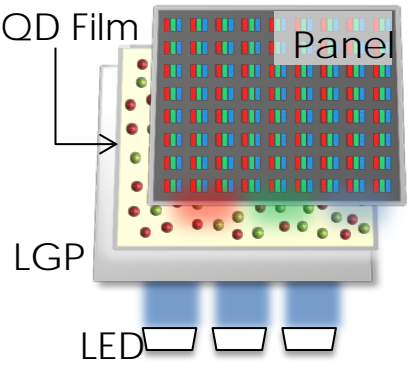
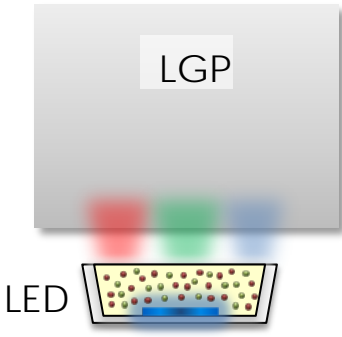





= Award winner

BELIEVE YOUR EYES



# Form Factors for all Sized *Displays*

Edge Optic	Film	On-chip
 <p>QD Optic LGP LED</p>	 <p>QD Film LED LGP</p>	 <p>LGP QD LED</p>
 <p>LGP QD Optic LED</p>	 <p>QD Film Panel LGP LED</p>	 <p>LGP LED</p>
	 <p>Source: Nanosys Online Media K</p>	 <p>Source: LumenMax Optoelectron</p>

On-chip is not yet market-ready.  
Is it required for lighting?

- Cost
- Value prop
- Etendue

# Agenda

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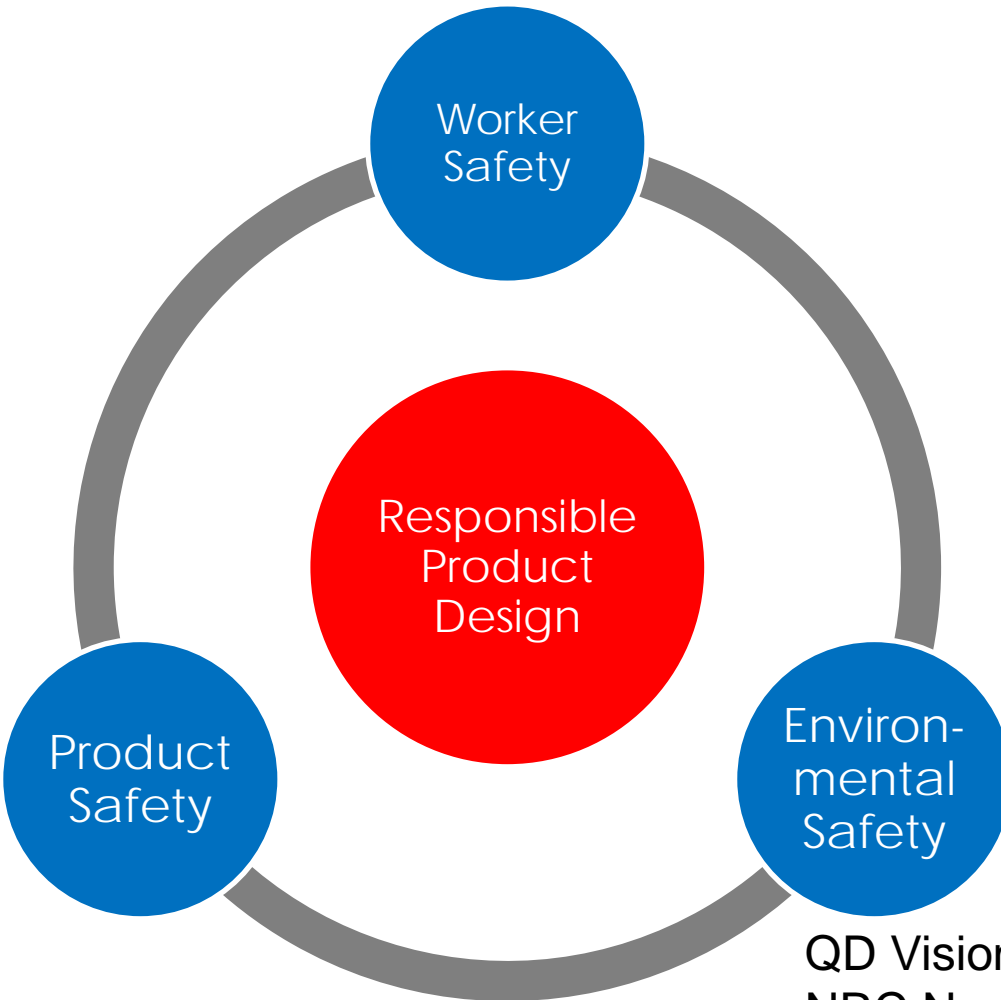
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# DOE SSL Mission is 'Green'

- Lighting → Energy → Environment
- “SSL technology has the potential to reduce U.S. lighting energy usage by nearly one half and contribute significantly to our nation's climate change solutions.”
- Phosphor requirements → Energy
- Must preserve → Environmental mission
- QDs: Cadmium and Nano
  - Are they 'green'? Are they 'on mission'?

# QDV's Responsible Development

Responsible Development → Safe, but not necessarily Green



1. Worker Safety –  
2x NIOSH Studies
2. Product Safety –  
Multiple Layers of  
Packaging
3. Environmental Safety - Life  
Cycle Risk Analysis; Disposal  
Study; Net Environmental  
Benefit

QD Vision shares leadership responsibility via e.g. NRC Nano-EH&S Research Strategy Committee.

# Green Chemistry

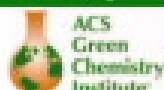
## Green Chemistry Pocket Guide

### The 12 Principles of Green Chemistry

Provides a framework for learning about green chemistry and designing or improving materials, products, processes and systems.

1. Prevent waste
2. Atom Economy
3. Less Hazardous Synthesis
4. Design Benign Chemicals
5. Benign Solvents & Auxiliaries
6. Design for Energy Efficiency
7. Use of Renewable Feedstocks
8. Reduce Derivatives
9. Catalysis (vs. Stoichiometric)
10. Design for Degradation
11. Real-Time Analysis for Pollution Prevention
12. Inherently Benign Chemistry for Accident Prevention

[www.acs.org/greenchemistry](http://www.acs.org/greenchemistry)



## The Chemistry of Nature

**Green Chemistry Definition:** *The design, development and implementation of chemical products and processes that reduce or eliminate the use and generation of hazardous substances.*

Green Chemistry is doing chemistry the way nature does chemistry – using renewable, biodegradable materials which do not persist in the environment.

Green Chemistry is using catalysis and biocatalysis to improve efficiency and conduct reactions at low or ambient temperatures.

Green Chemistry is a proven systems approach.

Green Chemistry reduces negative human health and environmental impacts.

Green Chemistry offers a strategic path way to build a sustainable future.

*To catalyze and enable the implementation of green chemistry and engineering throughout the global chemical enterprise*

Contact us: [gci@acs.org](mailto:gci@acs.org)

# RoHS Status – ‘Recommended’

- OEKO recommendation published on 4/22/14
  - Cd-QDs offer a quantified net benefit to the environment
- They recommend exempting:
  - “Cadmium in components for display lighting applications, containing downshifting cadmium based semiconductor nanocrystal quantum dots, where the cadmium per display screen area is limited to less than 0.2 ug/mm<sup>2</sup>”
  - Period of 3 years: 7/14-7/17
- Specific to QDs, and encompassing our products
- Does NOT include general illumination:
  - Arguments were persuasive
  - No product plans to support exemption at this time

# Cadmium is Reduced

As Presented to European Commission for RoHS Exemption

Net cadmium reduction - lighting	units	number	Notes/References
Typical efficiency of warm white light with QD Ink	lm/W	130	QD benefit is 30% or possibly greater
Typical efficiency of warm white light with two phosphor mixture	lm/W	100	many vendors make LEDs of this quality or better
Basis	1 W chip		
Lumen output from a single LED	lumens	100	1W * 100lm/W
Lifetime of a single LED	hours	50000	typical rating from most LED vendors
Power consumed by LED with QD optic	W	0.77	C6/C2
Power consumed by LED w/o QD optic	W	1.0	C6/C3
Savings with QD-based LED	W	0.23	C10-C9
Total energy saved over lifetime	kW-hr	11.5	C12*C7/1000
EU cadmium AIR emissions from electricity generation (2010)	tonnes	12.228	<a href="http://www.eea.europa.eu/publications/eu-emission-inventory-report-1990-2010">http://www.eea.europa.eu/publications/eu-emission-inventory-report-1990-2010</a>
Electricity generation by EU27 2010	TWh	3181	<a href="http://epp.eurostat.ec.europa.eu/statistics_explained/index.php?title=File:Electricity_Statistics,_2011_(in_GWh).png&amp;filetimestamp=20121128151011">http://epp.eurostat.ec.europa.eu/statistics_explained/index.php?title=File:Electricity_Statistics,_2011_(in_GWh).png&amp;filetimestamp=20121128151011</a>
EU Cd emissions per kWh of electricity generation	ug/kWh	3.8	C16/C17*1000
Cd saved during 1 LED lifetime	ug	44	C18*C14
			Exceeds 3ug Cd in QD LED by >10 times.



# Carbon is Reduced

- Estimation of environmental benefits in economic terms of reductions in CO<sub>2</sub> emissions within EU:
  1. Estimated reduction in CO<sub>2</sub> emissions = Projected sales \* [carbon net saving per TV(tonnes) \* conversion factor]
  2. Economic benefits associated with reductions in CO<sub>2</sub> = estimated reductions in CO<sub>2</sub> emissions \* SCC



Total environmental benefits : **euro 65,165,348**

- 43kg CO<sub>2</sub>/TV lifetime = 3kg CO<sub>2</sub>/TV/yr
- 20M TVs → 60,000 tonnes CO<sub>2</sub>/yr

See QDV RoHS Dossier for full analysis

# Alternatives are Worse for EH&S

- Conventional Phosphor solutions
  - Lower efficiency creates more environmental impact (calculations above)
  - Rare-earth materials represent their own problem
    - Availability
    - Mining practices
    - Quotas and price shocks
- Cadmium free QDs
  - Lower efficiency creates more environmental impact (same calculations as previous)
  - InP is a known carcinogen
    - Thorough analysis needed to better understand risks
    - Cd-free does not mean safety is assured

# Green Chemistry – Solvents

- Solvents are Reduced:
  - ~8x reduction in overall solvent use
    - Correlated reduction in energy to heat solvent
  - ~80% reduction in phosphorous containing chemicals overall
- Solvents are Safer:
  - Replace phosphorous containing solvents with hydrocarbons

NFPA Rating	TOPO	TOP	TBP	C18
Health	3	3	1	0
Fire	1	0	3	1
Reactivity	0	0	2	0

# Green Chemistry – Precursors

NFPA Rating	CdMe <sub>2</sub>	ZnEt <sub>2</sub>
Health	3	3
Fire	3	4
Reactivity	2	3

- Historically, QD metal precursors are pyrophoric, and hazardous (and expensive)
- QD Vision novel precursors completely eliminate the use of these alkyl metal reagents

# Green Chemistry - Summary

- At manufacturing level, green chemistry improvements increase the net benefit of QD products
- Reduce costs
- Green over entire lifecycle, not just 'in use'

	Annual Green Chemistry Savings
Phosphorous Chemicals	30,000 lbs
Pyrophoric Chemicals	200 lbs
Flammable Liquids	150,000 L
Cadmium Waste	250 lbs

# Conclusions

*Quantum Dots demonstrate the green manufacturing opportunities that may be found throughout the solid state lighting ecosystem.*

QD Vision's Color IQ:

- Safe for Workers
- Safe for Consumers
- Beneficial to the environment
- Green production methods
- The best efficiency-performance option

Thank you for your  
attention

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