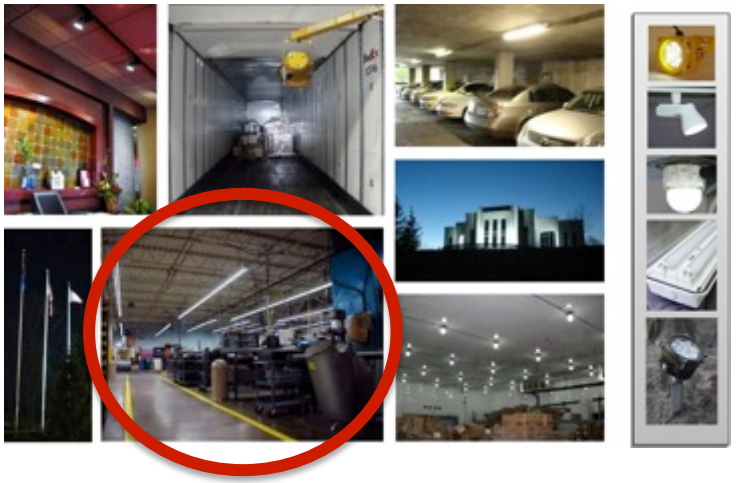
3rd Annual Market Transformation Conference:
Emerging Technologies/ Strategies for ESPC Projects

TLED Retrofits for ESPC Projects: Now or Later?

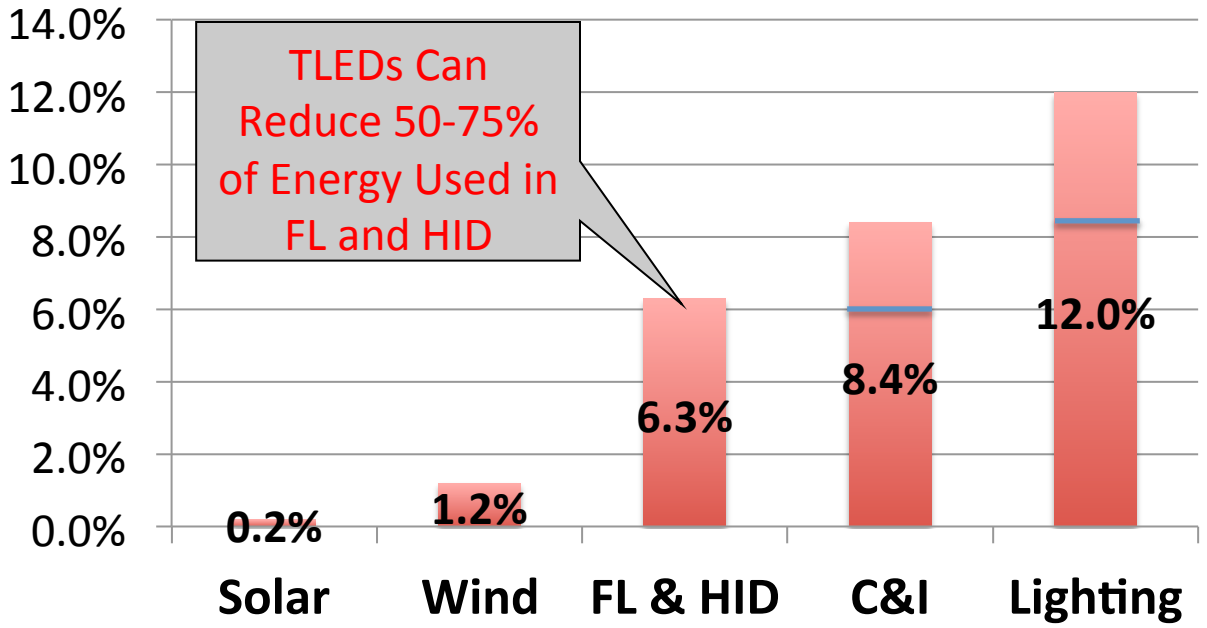
John Davenport
chief scientist and director
Energy Focus, Inc.

LED retrofits for Fluorescent (TLEDs) have potential to reduce total energy use more than 3% TODAY

Lots of opportunities for LED Retrofits but TLEDs offer greatest impact



Photos Source: Energy Focus, Inc.



The investment for substituting incandescent or fluorescent lighting with LED is **a fifth of the investment for installing solar power** based on CO_2 reduced*

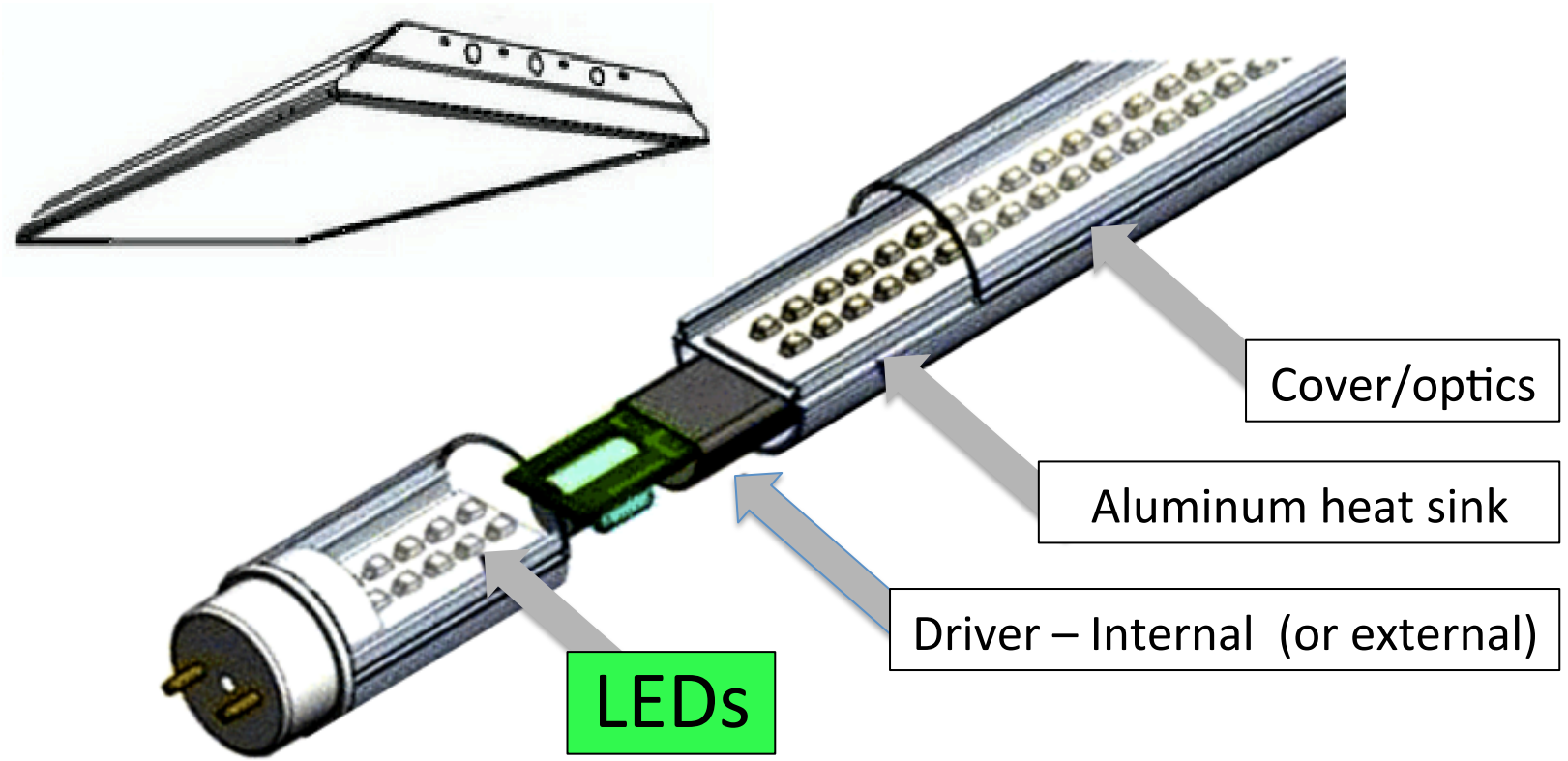
Source: Smil, V. 2014. The long slow rise of solar and wind. *Scientific American* 282 (1): 52-57*; EIA 2013 Energy Book; "Lighting The Way 2013", McKinsey Inc.*

TLEDs – why the time is now

- LEDs – Technology Overview
- TLEDs – Creating Value
- TLEDs – Market Transformation Underway
- TLEDs – Assuring Performance

The technology is ready, it's affordable and … the market transformation has begun

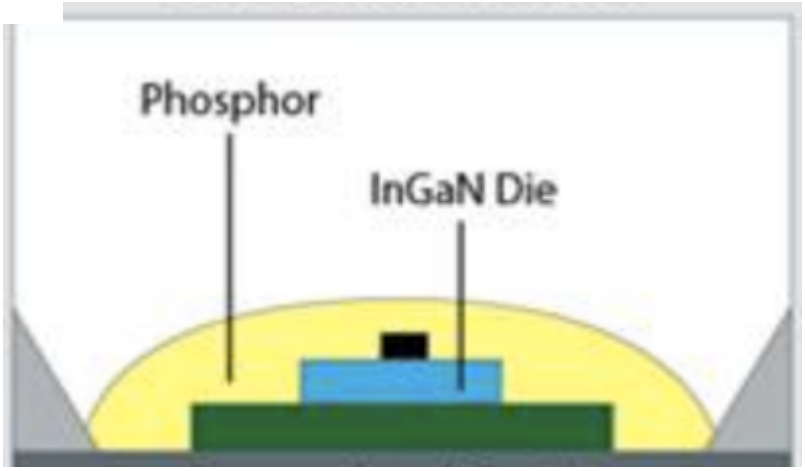
But first, just what are TLEDS?

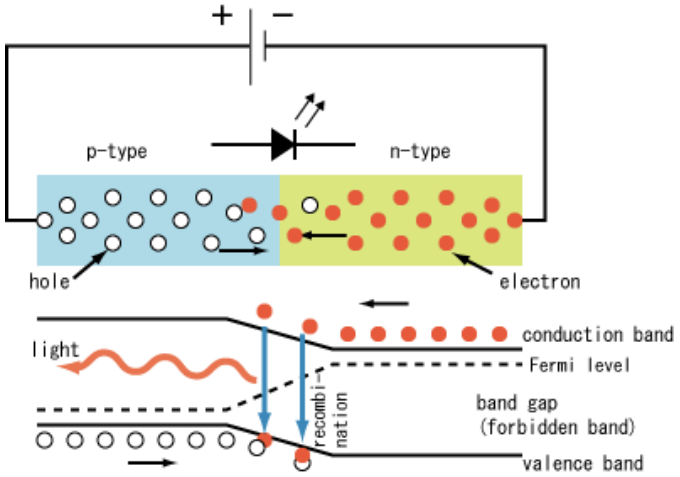


TLED are Tube LED Retrofits for Fluorescent

(TLED = "Tubular" LED, also called "LED Tube")

Let's start with "Blue LED" Technology Breakthrough





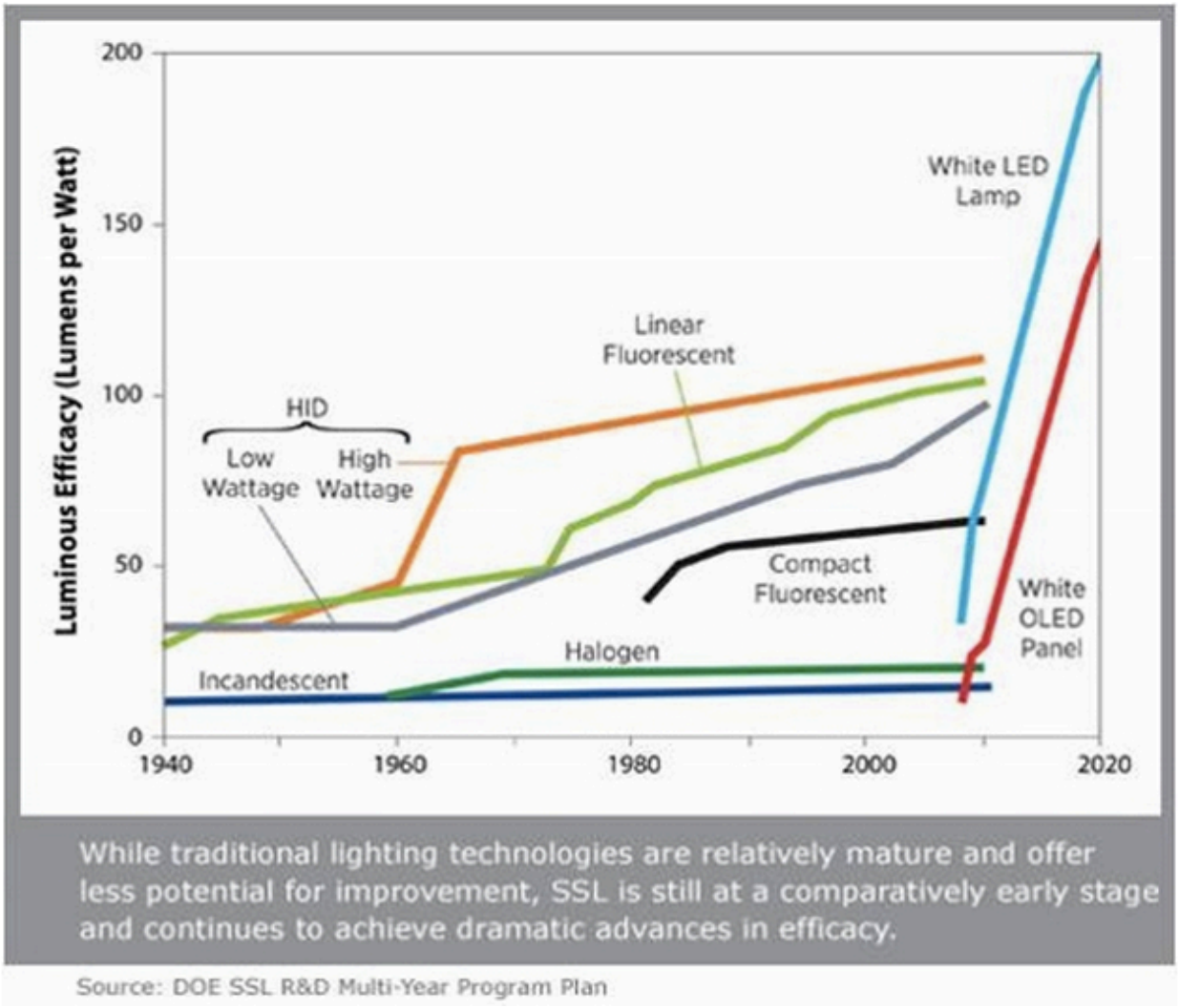
Shuji Nakamura demonstrates the first practical blue **"direct band gap" LED** in 1993

Direct band gap LED

- Can (in principle) produce blue light (photons) without loss
- An efficient path from blue to white existed using phosphors

The possibility for making very efficient LED light sources "suddenly" existed

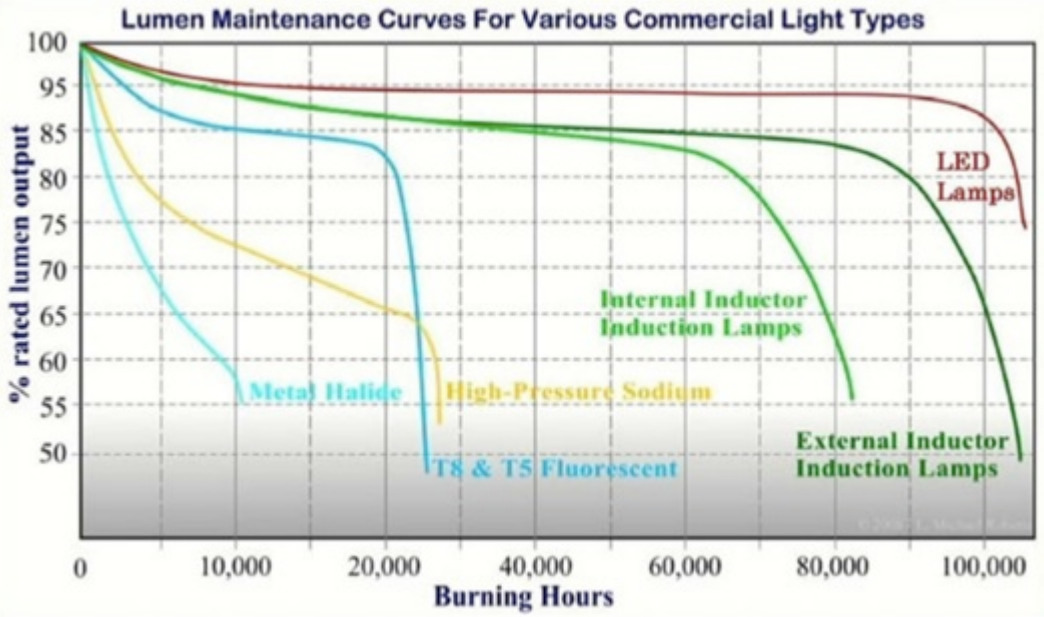
LED LPW growth - nothing short of amazing!



LPW (lumens per watt) is a lot like MPG – the more you have the better off you are .. a lighting fixture at 2 times the LPW can produce the same light for half the watts

TLED LPW will double over the next 10 years!

In addition to LED efficacy gains …



* Source: Relume White Paper "Comparing Light Technologies"

many other important improvements in LED construction, phosphors coatings, materials and packaging have occurred …

… giving LED products the potential to have the highest efficacy, best quality of light and longest life of any (artificial) light source

Commercial TLEDs ahead of other LEDs

Thermals are easier:

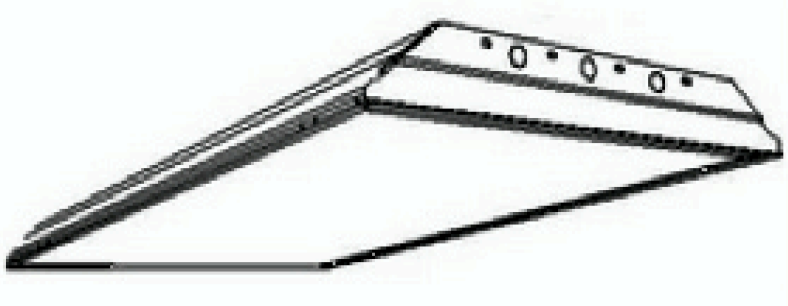
- LEDs
- Electronics

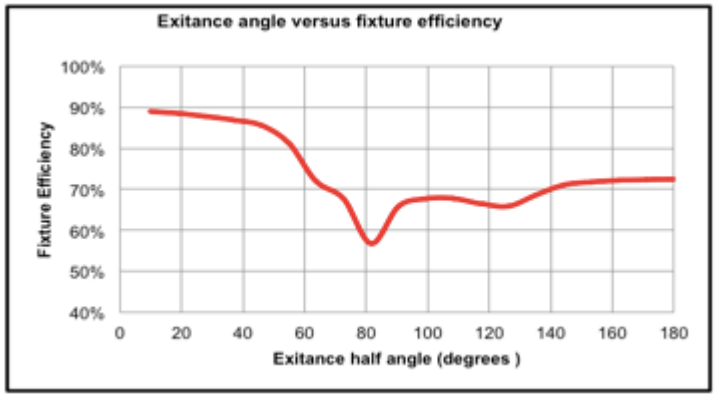
Affordable high performance LEDs

available first in smaller lumen packages

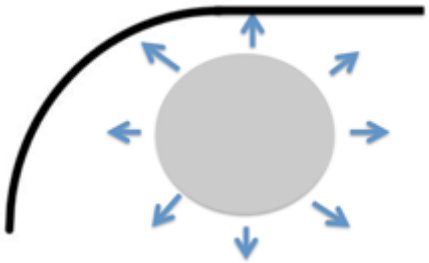
Affordable, high quality, TLED tubes now available with LPWs typically between 110 and 130 LPW

TLEDs are also more efficient in fixtures*





* Source: Energy Focus, Inc.



Fluorescent 360° pattern results in significant light "lost" in the fixture

LED typical 60° (half angle) pattern results in much less light loss in fixture

Optical gains plus lamp LPW gains typically result in power reductions of half or more

TLEDs have reached the Payback Tipping Point*

LED tubes can save customers $35/year with about a 70% reduction in power which can qualify a project for even more savings with rebates

	Existing Fixture 4 Fl Tubes	3 TLED 110 lpw 15W Tubes	2 TLED 130 lpw 18W Tubes
Upgrade Approach	N/A	Retrofit – 3 LED Tubes	Retrofit – 2 LED Tubes
Fixture Watts	118	45	36
Product Cost	NA	$60	$55
Annual Energy Cost[1]	$50	$19	$15
Annual Savings	NA	$31	$35
Simple Payback[2]	NA	**1.9 years**	**1.6 years**

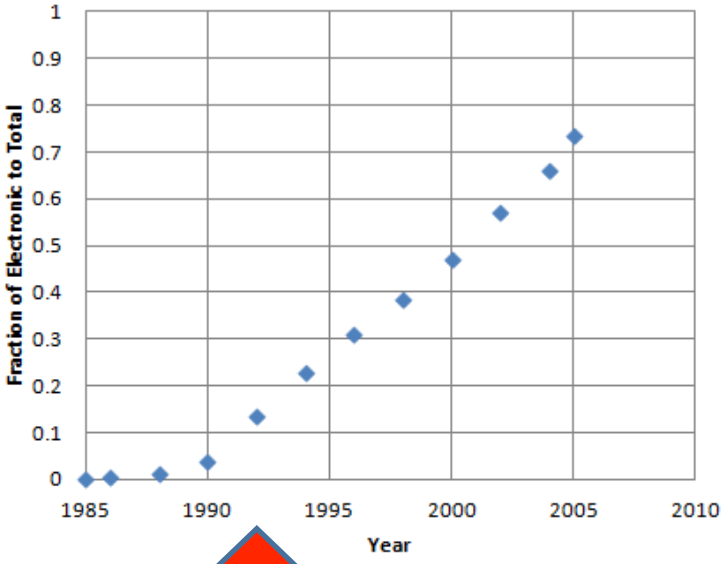
- *All energy savings calculated using $0.10per kilowatt-hour and 4200 lighted hours; does not include installation costs*

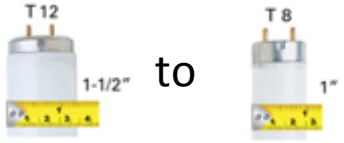
Source: Energy Focus, Inc.

Today about 1/3 the cost of the TLEDS of 2010

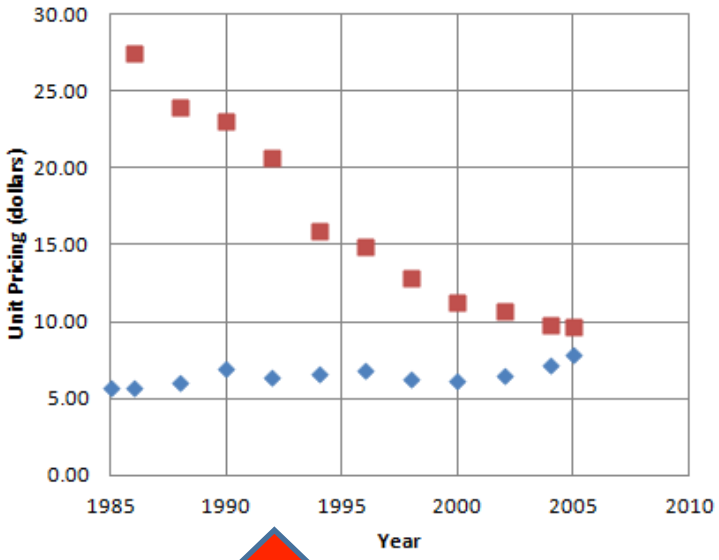
are providing the ESPC value to drive adoption

Conversion from old Technology Fluorescent to Electronic Fluorescent: Fraction of Fluorescent Electronic to Total (Fluor + Elec) Ballast Units Sold





Magnetic and Electronic Fluorescent Unit Pricing

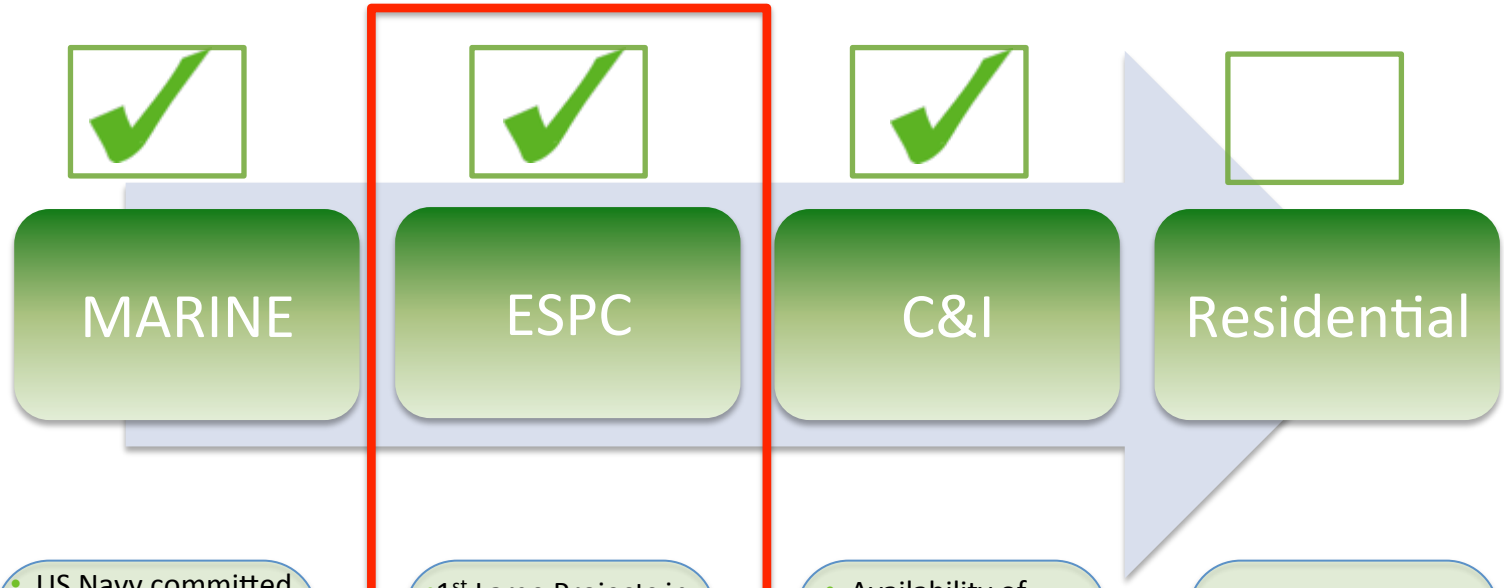


** Data Source: Buildings Energy Data Book*

Just like the market transformation to T8 from T12 occurred as value (cost and energy savings) tipped in favor of T8

exactly the the situation for TLED today as for T8 in the 90s

TLED Market Transformation is occurring now



Source: Energy Focus Inc.

"All LED" Army Base Installation*

3-4 week installation;
50,000 Lamps
Complete base retrofit

Project Facts
Lighting Retofit
Performance Contract

Energy Cost Savings	$919,000
Power Savings	3,700 kW
Energy Savings	3,832,300 kWh
Num. of Locations	1

Applied Technologies:
LED, Lighting Controls

* Source: Energy Focus, Inc. (also announced retrofit of Wayne state University – 35,000 tubes) with 60% power reduction

TLEDs are Meeting Payback and Cash NPV hurdles

TLED Performance, Reliability & Safety

Performance Measures

- Lumens
- LPW
- Flicker
- Power Factor
- Conducted EMI
- Radiated EMI
- Susceptibility
- Thermals
- UL 1598C compliant
- Flame Retardation
- Warranty
- Shock and Vibration
- No Hg/ Safe Disposal
- LM79/LM80/LM70
- TM21
- Long MTBF

TLEDs - How do you know what you're getting?

Standards and Test Development can help

Two primary sources:

- Industry development
  - IES
  - ANSLG (ANSI)
  - NEMA
  - UL
  - IEC/CIE/IEEE
- Regulatory/Program development
  - Federal Commercial Equipment Standards
  - Energy Star

Source: DOE presentation as LightFair 2014

Many LED Standards in Place & Under Development

IN PLACE

- ANSI C78.377 – Chromaticity for white light LED (harmonized with fluorescent)
- EIED RP-16 – Lighting Definitions (now includes LED terms)
- UL 8759 LED Safety General safety requirements for LED components
- UL 1598C – Light-Emitting Diode (LED) Retrofit Luminaire Conversion Kits
- LM-80 LED Device Reliability Tests
- TM-21 defines LED life and maintenance calculations using LM-80 data
- MIL HDBK 217 F – accepted DOD electronics reliability standard; can be used to estimate TLED reliability

UNDER DEVELOPMENT

- ANSLG/ANSI C82.15 and 16 LED Drivers Test
  - Provide standards for driver reliability as well as test methods
- LM-85, LED Reliability Tests (LED packages)
- LM-86– measurement of remote phosphor products
- S408-11 Optical Waveform Measurements (Flicker)
- S412-13 Color Point Stability
- CIE TC1-69, Color Quality Scale (Replace CRI metric)
- IEEE- P1789 Biological Effects and Health Hazards From Flicker

… which, however, can be confusing to say the least

The DOE is playing a helpful educational role

http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/richman_standards_lightfair2014.pdf

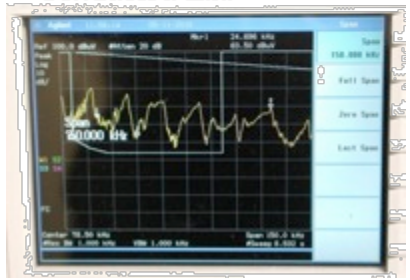
… and so are conferences like the 3rd Annual Market Transformation Conference

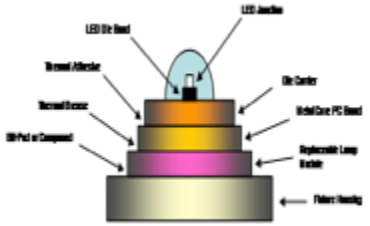
but, it's also important to work with suppliers

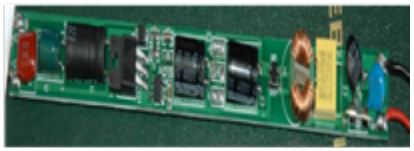
Markings & Certifications

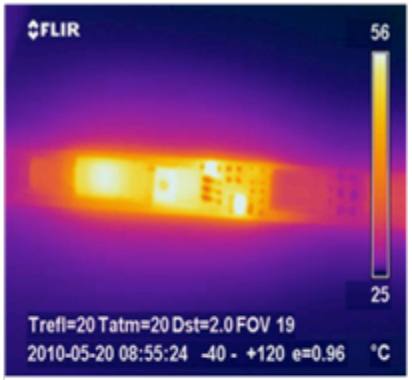
Line Current Waveform

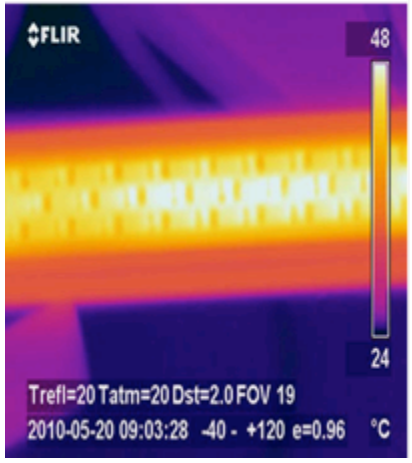
Conducted EMI

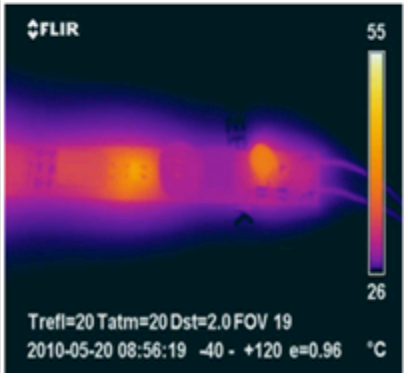








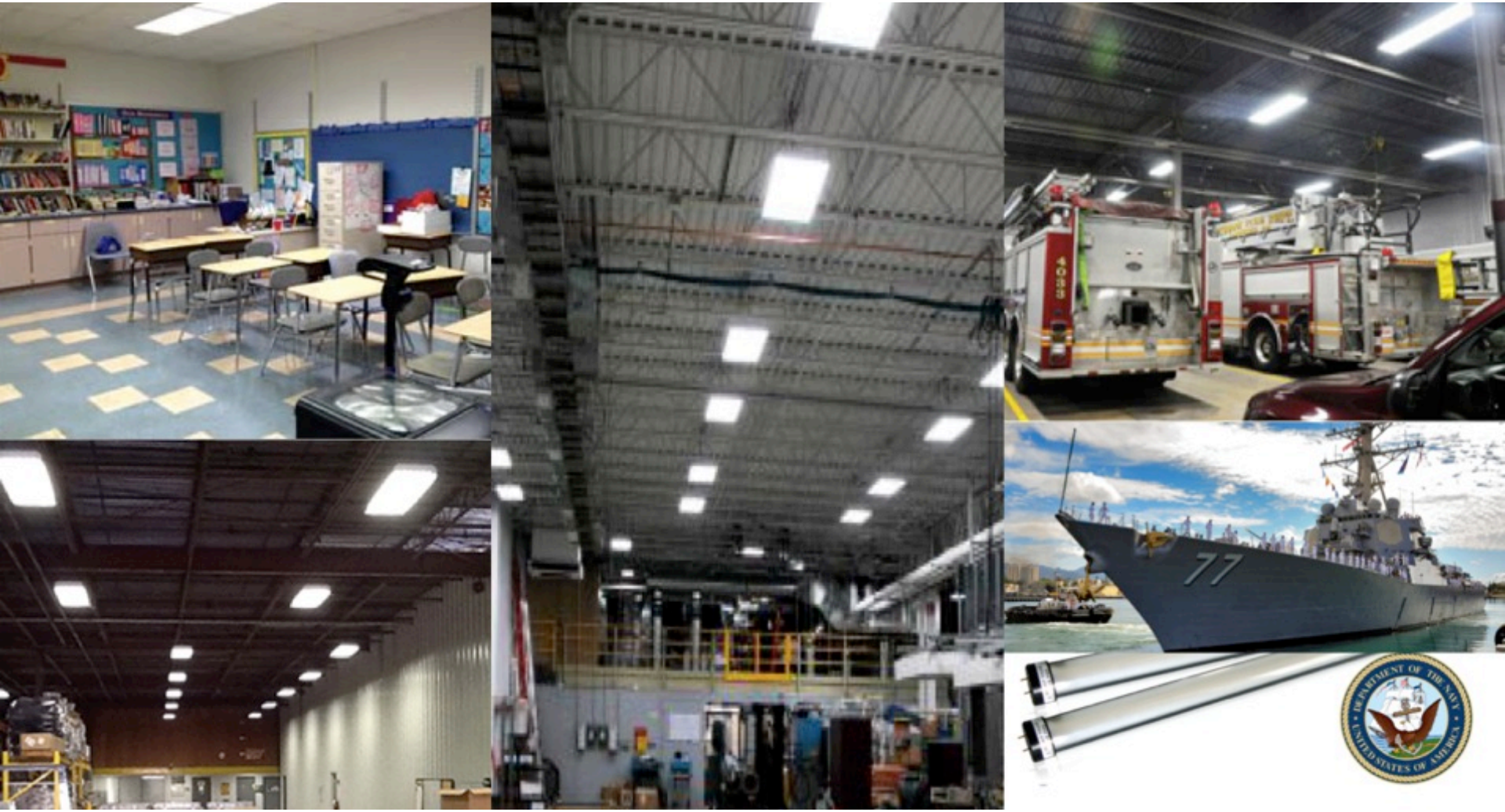




- Lumens Per Watt
- Thermal Mgmt
- Voltage Ranges
- Parts Tolerances
- Flicker
- Power Factor
- THD
- Conducted EMI
- Radiated EMI
- Flame Retardation
- Structural
- Shock
- Vibration
- Certifications

… who have extensive product testing capability

… as well as proven TLED experience



TLEDs - the time is now