Solid State Lighting Standards Update

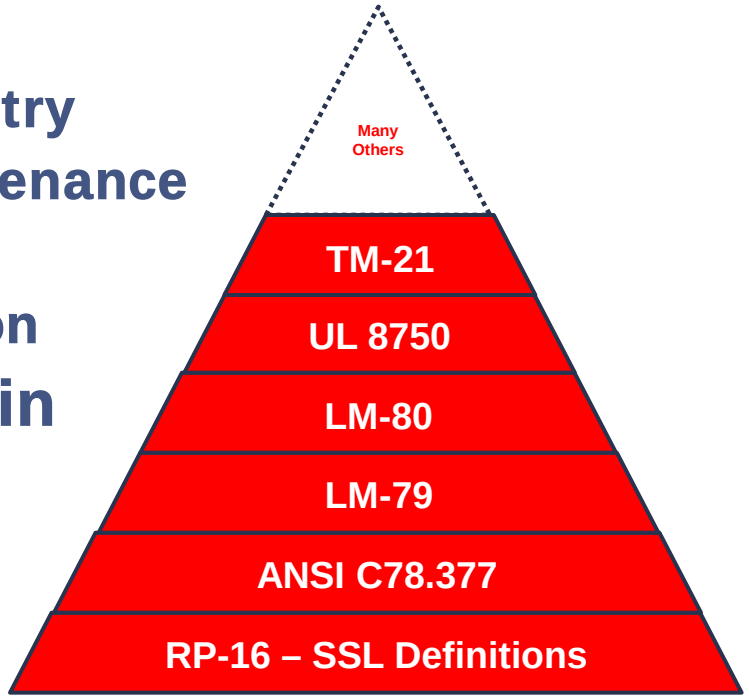
CREE

Levels of LED Standards

Level	Description	Example
Basic definition	LED chip, LED lamp, Module, Light Engine...	IES RP-16
LED Component	Color, Lumen Maintenance, Binning...	ANSI C78.377A, IES LM-80, IES TM-21, NEMA SSL-3
Fixture	Photometry, safety	IES LM-79, UL 8750
Application	Outdoor, parking	IES RP-8, IES RP-20
Program	Energy, utility	US EPA Energy Star, Design Lights Consortia, Korean Energy Program

LED Standards (U.S.)

- 4 years ago: Major and reasonable objection to LED
- Today:
  - RP-16 – SSL Definitions
  - ANSI C78.377 – chromaticity
  - IES LM-79-2008 – SSL photometry
  - IES LM-80-2008 – Lumen Maintenance
  - UL 8750 – Safety
  - TM-21 – Lumen Maint. Projection
- Most of the major pieces are in place, more on the way…
- Being practiced and referenced worldwide by industry and government programs



LED Standards Update

Status of NEMA, ANSI, IES, IEC, and CIE Solid State Lighting Standards (Partial List)

Standard	Draft	Comment	Comment Resolution	Publication Status
IES RP-16 *Definitions*	X	X	X	Complete
ANSI BSR C78.377A, *Chromaticity*	X	X	X	Complete
IES LM 79, *Luminous Flux*	X	X	X	Complete
IES LM 80, *Lumen Depreciation*	X	X	X	Complete
NEMA LSD-44, 45, 49 (White Papers) *Best Practices for SSL Interconnect, Sub-Assemblies, Dimming*	X	X	X	Complete
ANSI C82.77, *Harmonic Emission Limits – Related Power Quality Requirements for SSL*	X	X	X	Complete
NEMA SSL-1, *SSL Drivers*	X	X	X	Complete
NEMA SSL-3, *LED Lamp Binning*	X	X	X	Complete
NEMA SSL-6, *Dimming Practices for SSL Integrated Lamps*	X	X	X	Complete
NEMA-ALA Joint White Paper *Definition of Functional & Decorative Lighting*	X	X	X	Complete
UL 8750 *LED Safety*	X	X	X	Complete
IEC 62471-2, IES RP-27 *Photobiological Safety*	X	X	X	Complete
CIE TC1-69, *Color Quality System*	X			
IES TM-21 *LED Lifetime*	X	X	X	Complete*
47 CFR Part 15 (FCC) *Radio Frequency Emissions for SSL Components, Drivers*	X	X	X	Complete
IEC 62471-2, IES RP-27 *Photobiological Safety*	X	X	X	Complete

ENERGY STAR

*** Expect publication May/June 2011**

50,000 hours is:

137	Years at 1 hour/day
68.5	Years at 2 hours/day
34.2	Years at 4 hours/day
22.8	Years at 6 hours/day
17.1	Years at 8 hours/day
11.4	Years at 12 hours/day
5.7	Years at 24 hours/day

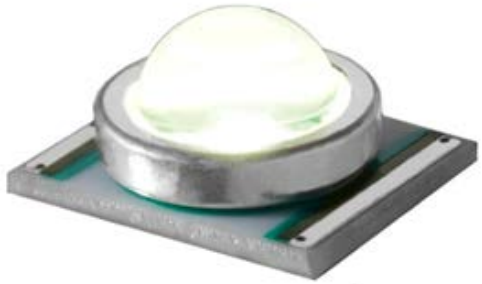
...A WAG when it comes to LED lifetime...

Semiconductor Reliability Testing

- **Reliability test methods and acceptance criteria for semiconductor components have been standardized (JEDEC, EIAJ, others…) and practiced for decades**
  - **Think: processors, regulators, microcontrollers, etc..**

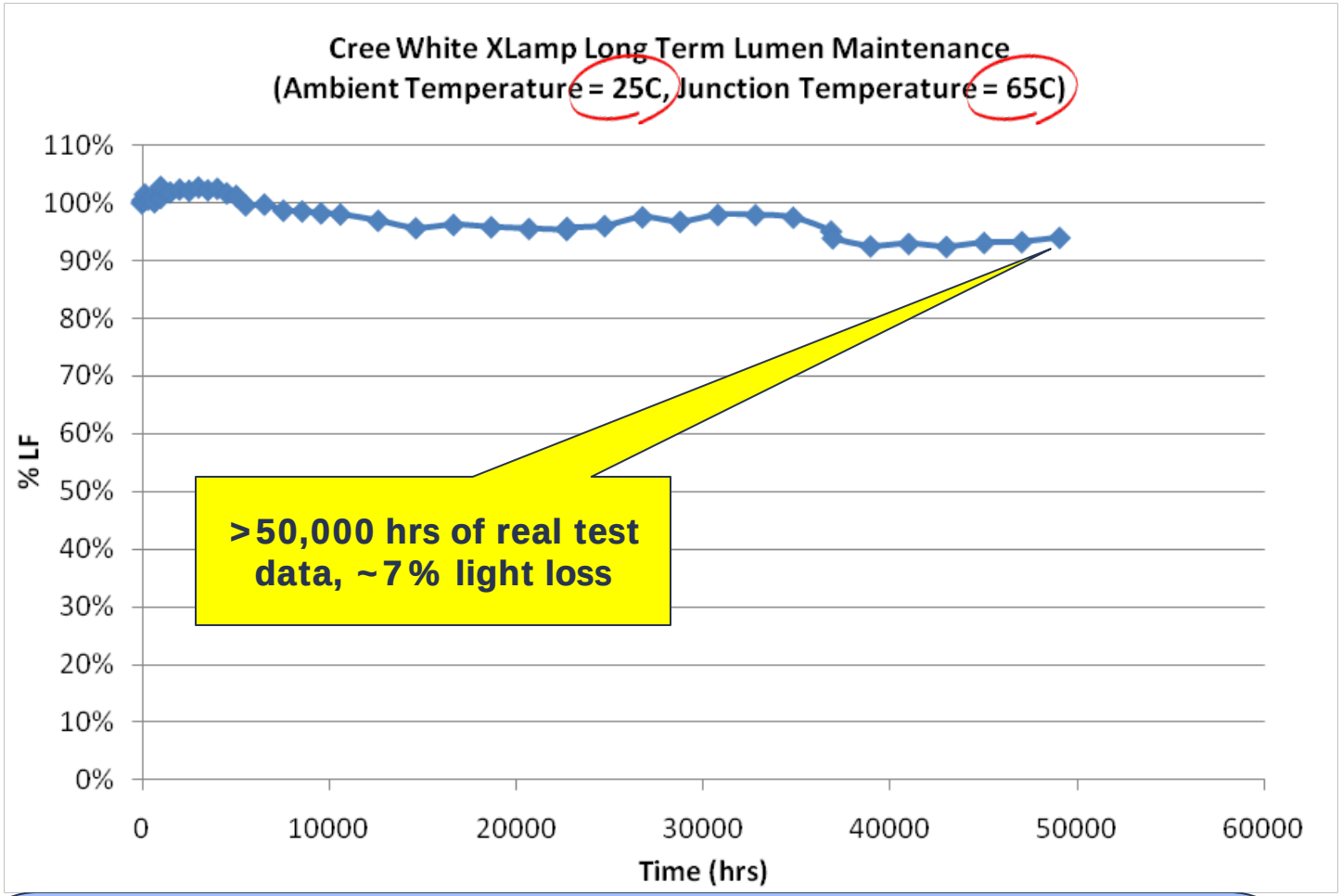
If you've ever flown in an airplane, driven in a car, or talked on a cell phone, you've depended on this body of scientific work and testing…

LED Reliability Testing



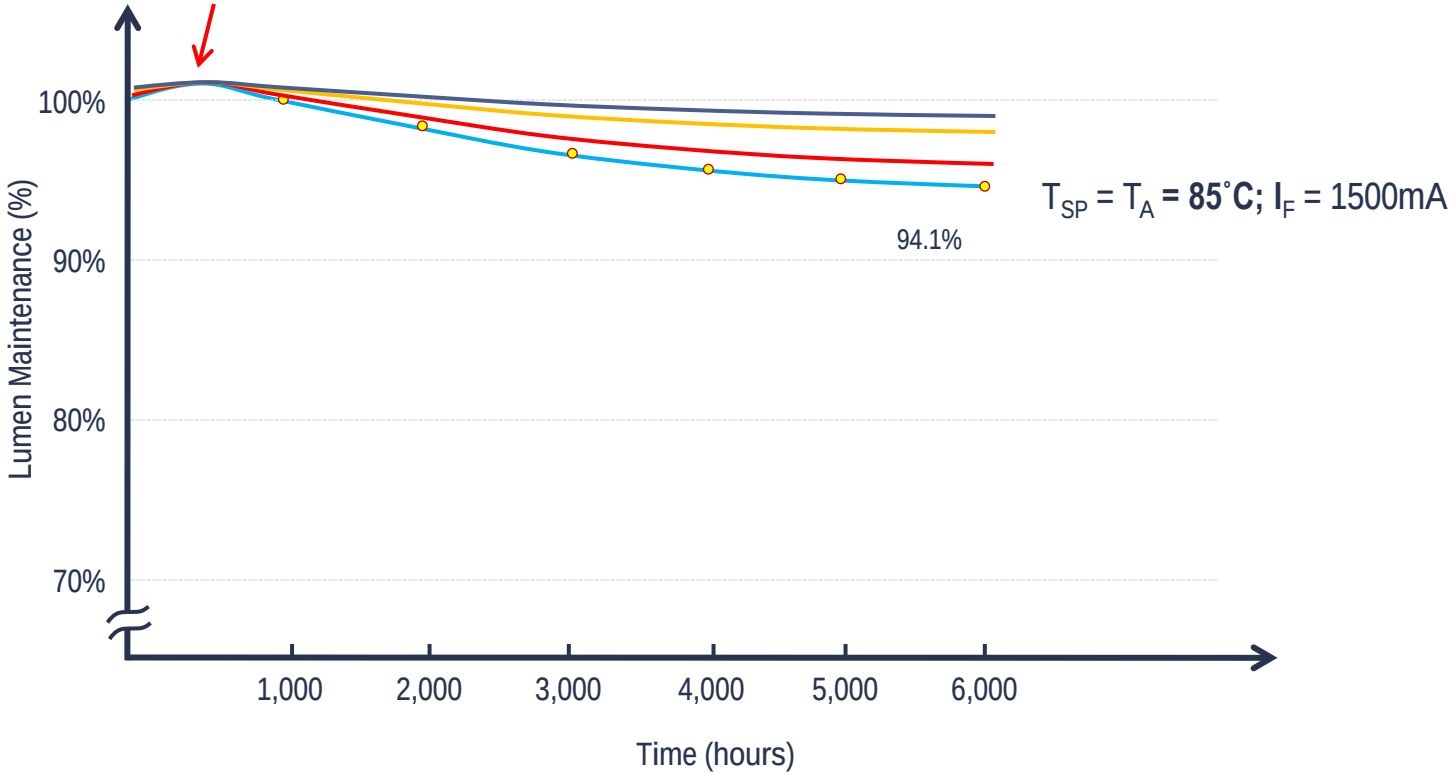
- LEDs are semiconductor components that happen to emit light…
- Most LED manufacturers conduct standardized semiconductor component reliability testing – the same tests Intel tests their microprocessors with – on their LED lamps
- The Illumination Engineering Society of North America published IES LM-80 in 2008 to characterize the Lumen Maintenance aspect of LED semiconductor components
- Note: Lumen Maintenance ≠ LED Lifetime

LEDs Last Forever!! [under ideal conditions]



Well-designed systems with Lighting-class LEDs at low T_A, T_J will run a very, very long time…

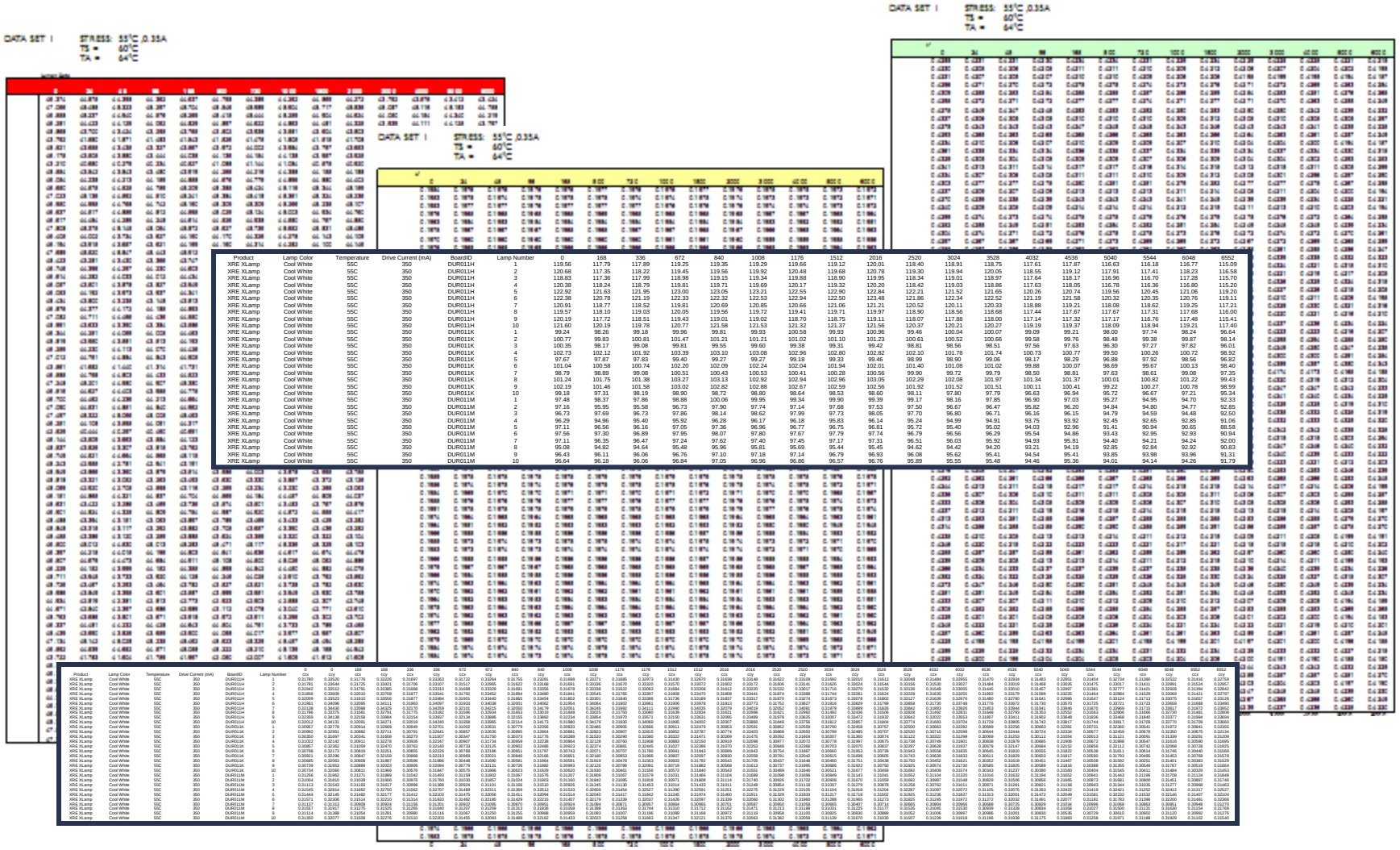
Typical LM-80 Lumen Maintenance Behavior



- **LEDs do not normally fail catastrophically; gradually lose light output over very long time periods**
- **Small "hump" is frequently observed between 0 and 500 hours**
- **Lower drive currents and lower temperatures yield higher Lumen Maintenance curves**

Everyone Asks for an “LM-80 Report”

Here is what one looks like (very detailed, no interpretation, just data…):



DATA SET 1 STRESS: 55°C @ 0.35A TS = 60°C TA = 64°C

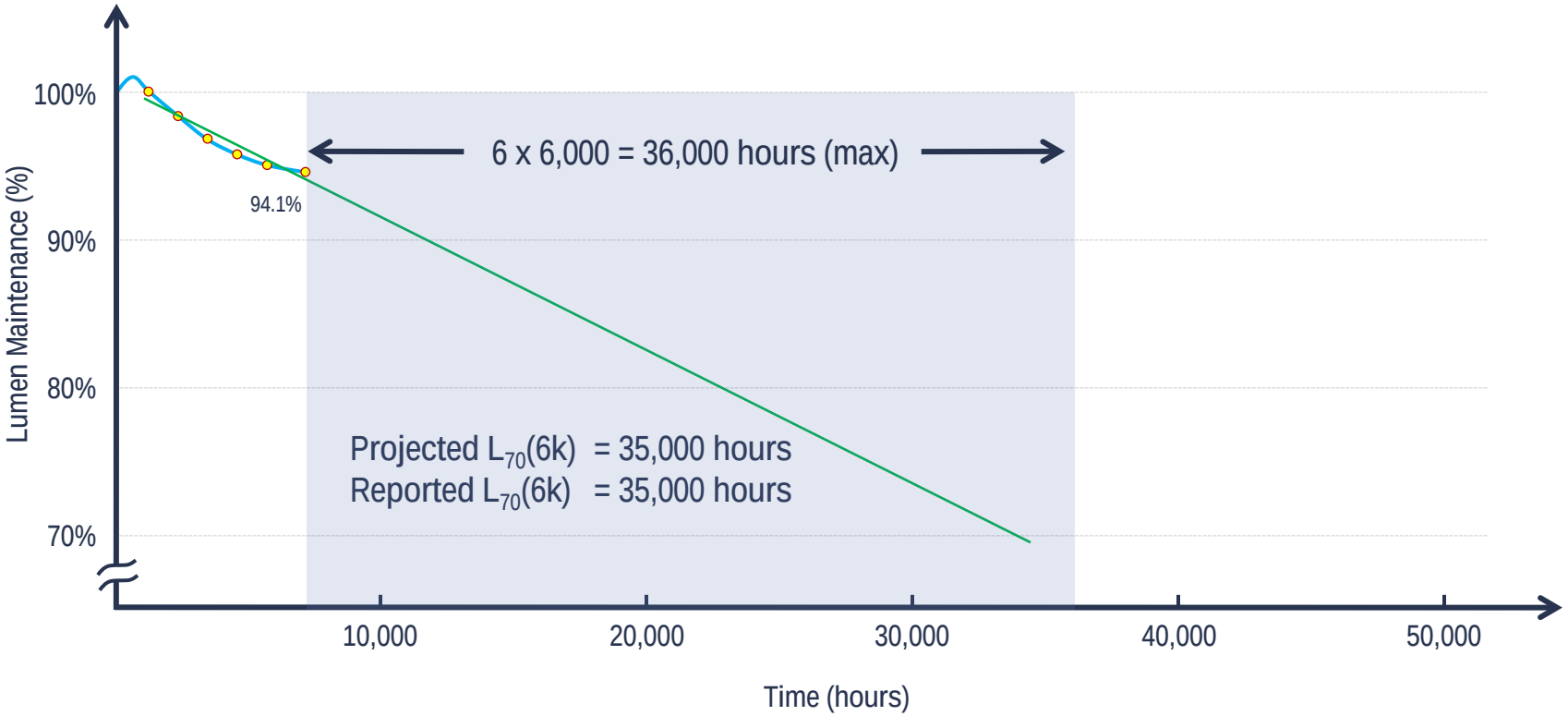
Product	Lamp Color	Temperature	Drive Current (mA)	BoardID	Lamp Number	0	168	336	672	840	1008	1176	1512	2016	2520	3024	3528	4032	4536	5040	5544	6048	6552
XRE XLamp	Cool White	55C	350	DUR011H	1	119.56	117.79	117.89	119.25	119.35	119.29	119.66	119.12	120.01	118.40	118.91	118.75	117.61	117.87	116.63	116.18	116.77	115.09
XRE XLamp	Cool White	55C	350	DUR011H	2	120.68	117.35	118.22	119.45	119.56	119.92	120.48	119.68	120.78	119.30	119.94	120.05	118.55	119.12	117.91	117.41	118.23	116.58
XRE XLamp	Cool White	55C	350	DUR011H	3	118.83	117.36	117.99	118.98	119.15	119.34	119.88	118.90	119.95	118.34	119.01	118.97	117.64	118.17	116.96	116.70	117.28	115.70
XRE XLamp	Cool White	55C	350	DUR011H	4	120.38	118.24	118.79	119.81	119.71	119.69	120.17	119.32	120.20	118.42	119.03	118.86	117.63	118.05	116.78	116.36	116.80	115.20
XRE XLamp	Cool White	55C	350	DUR011H	5	122.92	121.63	121.95	123.00	123.05	123.21	122.55	122.90	122.84	122.21	121.52	121.65	120.26	120.74	119.56	120.45	121.06	119.20
XRE XLamp	Cool White	55C	350	DUR011H	6	122.38	120.78	121.19	122.33	122.32	122.53	122.94	122.50	123.48	121.86	122.34	122.52	121.19	121.58	120.32	120.35	120.76	119.11
XRE XLamp	Cool White	55C	350	DUR011H	7	120.91	118.77	118.52	119.81	120.69	120.85	120.66	121.06	121.21	120.52	120.11	120.33	118.88	119.21	118.08	118.62	119.25	117.21
XRE XLamp	Cool White	55C	350	DUR011H	8	119.57	118.10	119.03	120.05	119.56	119.72	119.41	119.71	119.97	118.90	118.56	118.68	117.44	117.67	117.67	117.31	117.68	116.00
XRE XLamp	Cool White	55C	350	DUR011H	9	120.19	117.72	118.51	119.43	119.01	119.02	118.70	118.75	119.11	118.07	117.88	118.00	117.14	117.32	117.17	116.76	117.48	115.41
XRE XLamp	Cool White	55C	350	DUR011H	10	121.60	120.19	119.78	120.77	121.58	121.53	121.32	121.37	121.56	120.37	120.21	120.27	119.19	119.37	118.09	118.94	119.21	117.40
XRE XLamp	Cool White	55C	350	DUR011K	1	99.24	98.26	99.18	99.96	99.81	99.93	100.58	99.93	100.96	99.46	100.04	100.07	99.09	99.21	98.00	97.74	98.24	96.64
XRE XLamp	Cool White	55C	350	DUR011K	2	100.77	99.83	100.81	101.47	101.21	101.21	101.02	101.10	101.23	100.61	100.52	100.66	99.58	99.76	98.48	99.38	99.87	98.14
XRE XLamp	Cool White	55C	350	DUR011K	3	100.35	98.17	99.08	99.81	99.55	99.60	99.38	99.31	99.42	98.81	98.56	98.51	97.56	97.63	96.30	97.27	97.82	96.01
XRE XLamp	Cool White	55C	350	DUR011K	4	102.73	102.12	101.92	103.39	103.10	103.08	102.96	102.80	102.82	102.10	101.78	101.74	100.73	100.77	99.50	100.26	100.72	98.92
XRE XLamp	Cool White	55C	350	DUR011K	5	97.67	97.87	97.83	99.40	99.27	99.27	99.18	99.33	99.46	98.99	98.90	99.06	98.17	98.29	96.88	97.92	98.56	96.82
XRE XLamp	Cool White	55C	350	DUR011K	6	101.04	100.58	100.74	102.20	102.09	102.24	102.04	101.94	102.01	101.40	101.08	101.02	99.88	100.07	98.69	99.67	100.13	98.40
XRE XLamp	Cool White	55C	350	DUR011K	7	98.79	98.89	99.08	100.51	100.43	100.53	100.41	100.28	100.56	99.90	99.72	99.79	98.50	98.81	97.63	98.61	99.08	97.35
XRE XLamp	Cool White	55C	350	DUR011K	8	101.24	101.75	101.38	103.27	103.13	102.92	102.94	102.96	103.05	102.29	102.08	101.97	101.34	101.37	100.01	100.82	101.22	99.43
XRE XLamp	Cool White	55C	350	DUR011K	9	102.19	101.46	101.58	103.02	102.82	102.88	102.67	102.59	102.56	101.92	101.52	101.51	100.11	100.41	99.22	100.27	100.78	98.99
XRE XLamp	Cool White	55C	350	DUR011K	10	99.18	97.31	98.19	98.90	98.72	98.80	98.64	98.53	98.60	98.11	97.80	97.79	96.63	96.94	95.72	96.67	97.21	95.34
XRE XLamp	Cool White	55C	350	DUR011M	1	97.48	98.37	97.86	98.88	100.06	99.95	99.34	99.90	99.39	99.17	98.16	97.85	96.90	97.03	95.27	94.95	94.70	92.33
XRE XLamp	Cool White	55C	350	DUR011M	2	97.16	95.95	96.58	96.73	97.90	97.74	97.44	97.14	97.68	97.53	97.50	96.67	96.47	96.62	96.20	94.84	94.80	94.77
XRE XLamp	Cool White	55C	350	DUR011M	3	96.73	97.69	96.73	97.86	98.14	98.62	97.99	97.73	98.05	97.70	96.80	96.71	96.16	96.15	94.79	94.59	94.48	92.50
XRE XLamp	Cool White	55C	350	DUR011M	4	96.29	94.96	95.40	95.92	96.28	96.17	96.18	95.83	96.14	95.24	94.99	94.91	93.75	93.92	92.45	92.65	92.85	91.06
XRE XLamp	Cool White	55C	350	DUR011M	5	97.11	96.56	96.16	97.05	97.36	96.96	96.77	96.75	96.81	95.72	95.40	95.02	94.03	92.96	91.41	90.94	90.65	88.58
XRE XLamp	Cool White	55C	350	DUR011M	6	97.56	97.30	96.89	97.95	98.07	97.80	97.67	97.79	97.74	96.79	96.56	96.29	95.54	94.86	93.43	92.95	92.93	90.94
XRE XLamp	Cool White	55C	350	DUR011M	7	97.11	96.35	96.47	97.24	97.62	97.40	97.45	97.17	97.31	96.51	96.03	95.92	94.93	95.81	94.40	94.21	94.24	92.00
XRE XLamp	Cool White	55C	350	DUR011M	8	95.08	94.82	94.64	95.48	95.96	95.81	95.69	95.44	95.45	94.62	94.42	94.20	93.21	94.19	92.85	92.84	92.92	90.83
XRE XLamp	Cool White	55C	350	DUR011M	9	96.43	96.11	96.06	96.76	97.10	97.18	97.14	96.79	96.93	96.08	95.62	95.41	94.54	95.41	93.85	93.98	93.96	91.31
XRE XLamp	Cool White	55C	350	DUR011M	10	96.64	96.18	96.06	96.84	97.05	96.96	96.86	96.57	96.76	95.89	95.55	95.48	94.46	95.36	94.01	94.14	94.26	91.79

LM-80 & TM-21

- **LM-80 is just an LED testing standard**
- **IES TM-21-2011 provides the mathematical framework for taking LM-80 data and making useful LED lifetime projections**
- **Key points of TM-21:**
  - **Developed by major LED suppliers with support of NIST, PNNL.**
  - **Projection limited to 6x the available LM-80 data set**
  - **Projection algorithm: least squares fit to the data set**
  - **L_{70}, L_{80}, L_{90}, L_{xx} projections easily possible**
  - **Nomenclature: $L_p(Yk)$**
    where p is the Lumen Maintenance percentage and Y is the length of the LM-80 data set in thousands of hours

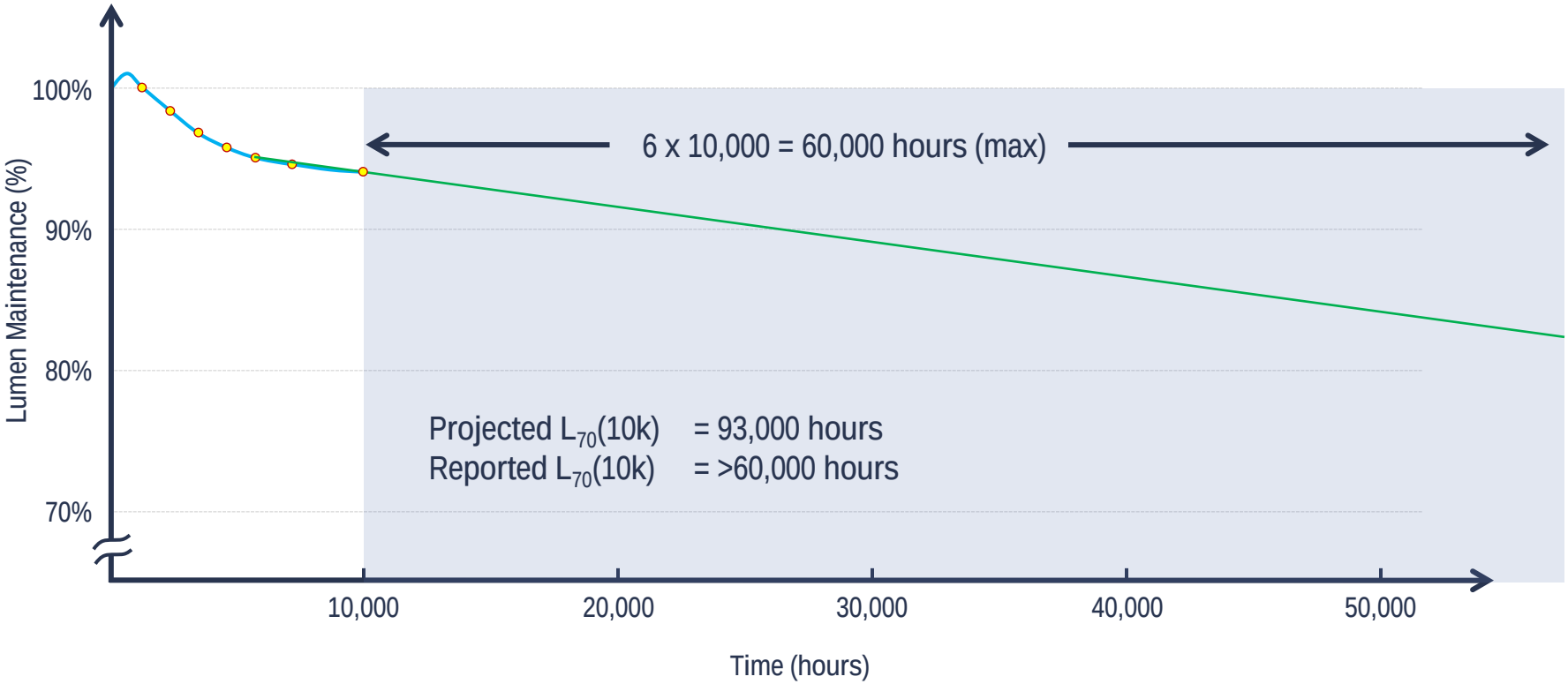
Example: $L_{85}(10k)$

Typical LM-80 Test Behavior and TM-21 Lumen Maintenance Projection (6k)



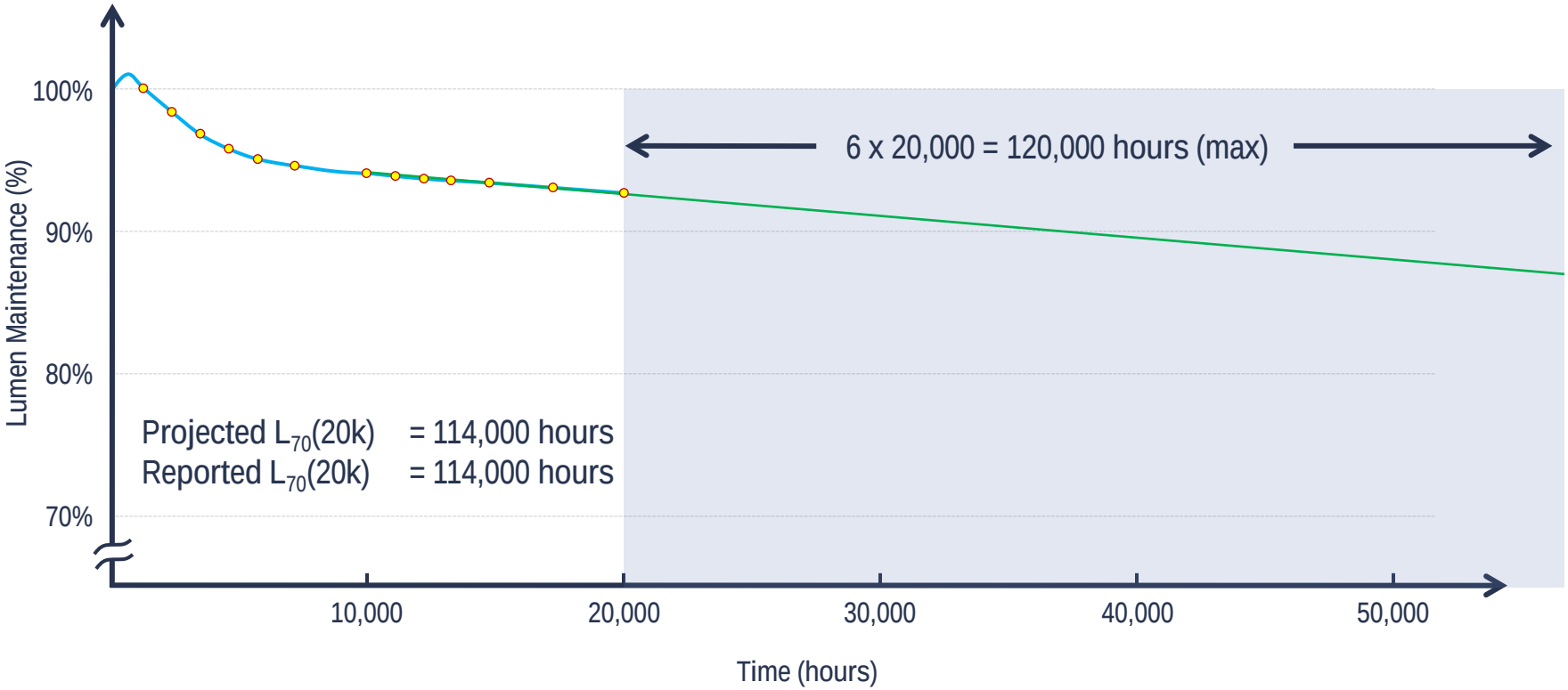
- First 1k hours is ignored for TM-21 projection purposes
- Upper reporting bound set by 6x available data (6 x 6k = 36k hrs)
- Exponential extrapolation to least squares mathematical fit between 1k and 6k hours
- Reported and projected L_{70} may or may not be the same number

Typical LM-80 Test Behavior and TM-21 Lumen Maintenance Projection (10k)



- $T_{max/2}$ is used for TM-21 projection (10K/2 = last 5K hours)
- Upper reporting bound set by 6x data (6 x 10k = 60k hrs)
- Exponential Extrapolation to least squares mathematical fit between 5k and 10k hours
- Reported and projected L_{70} may or may not be the same number

Typical LM-80 Test Behavior and TM-21 Lumen Maintenance Projection (20k)



- $T_{max/2}$ is used for TM-21 projection (20K/2 = last 10K hours)
- Upper reporting bound set by 6x data (6 x 20k = 120k hours)
- Exponential Extrapolation to Least squares mathematical fit between 10k and 20k hours
- Reported and projected L_{70} may or may not be the same number

LED Lifetime Is Irrelevant

System Lifetime is What Creates Value

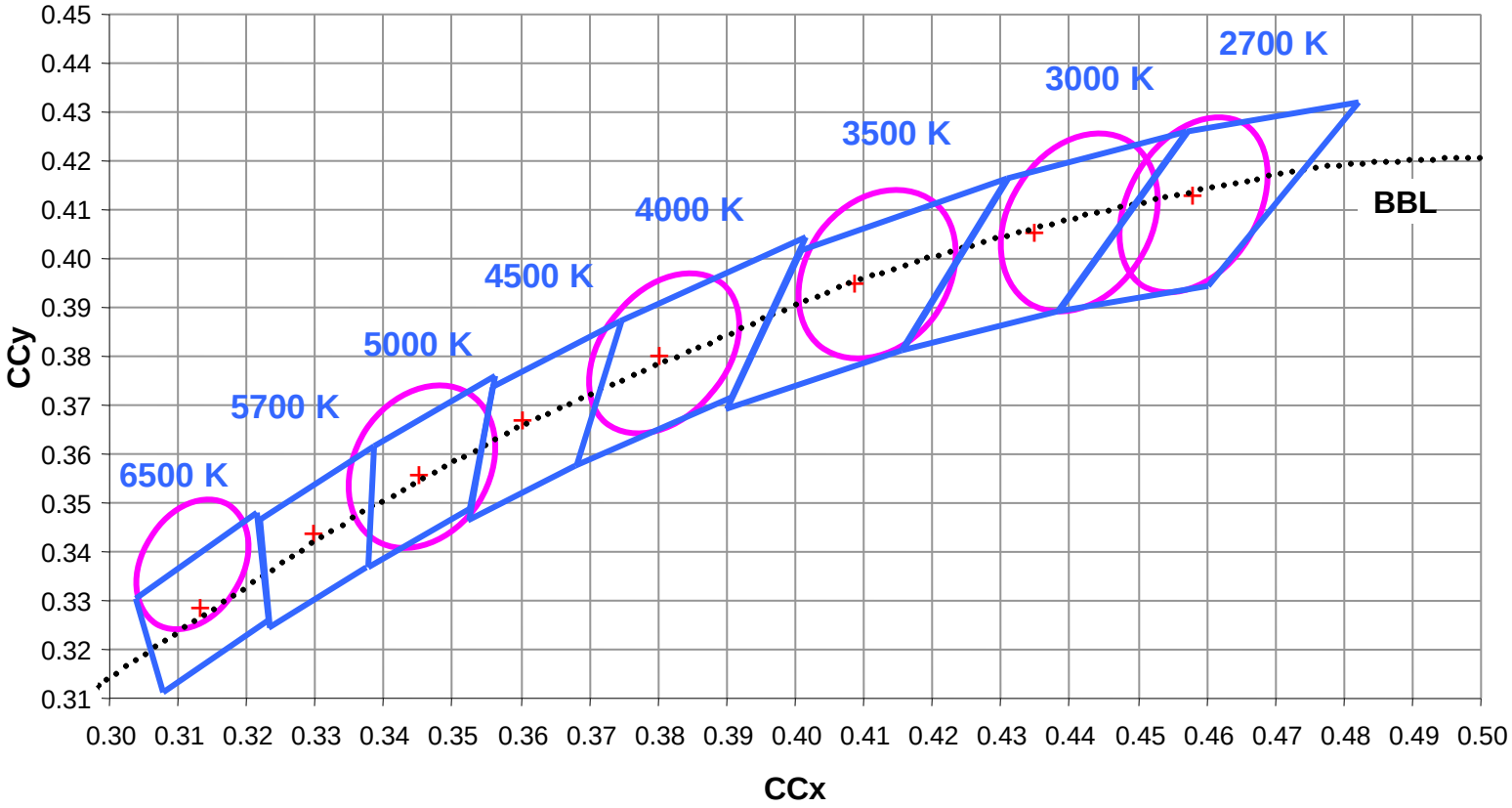
Heat Sink: Linchpin of the entire system. If this is poorly designed, all the other components can be compromised

Driver: Currently the weakest point of the system, but the big companies are working on this

LED Lamps: Practically never fail; depreciate very slowly in a well-designed system

Optical Components: Can (rarely) yellow over time and lose light; system design choice

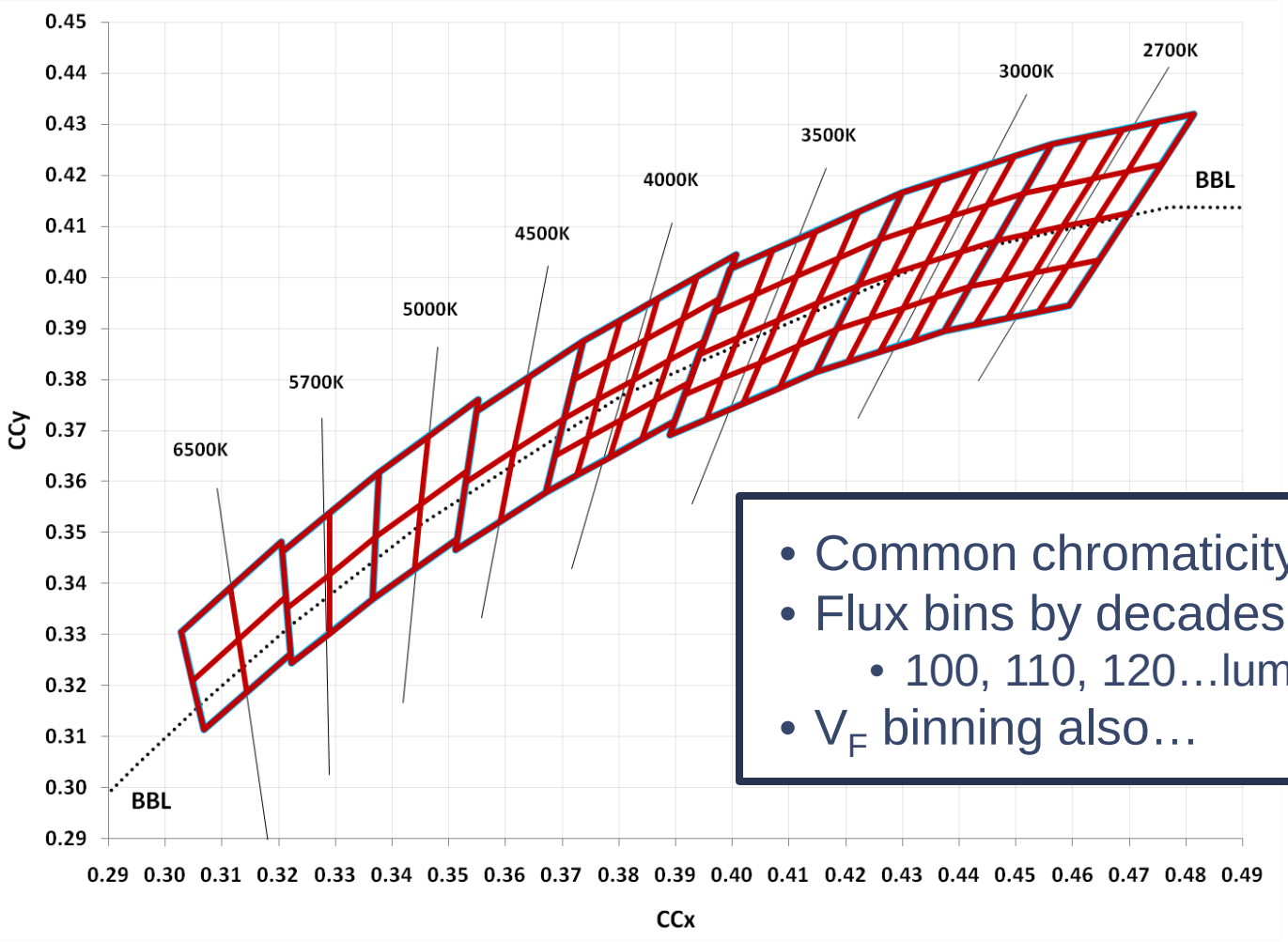
ANSI Chromaticity Standard



ANSI Fluorescent Lamp Standard

ANSI C78.377A LED Standard

NEMA SSL-3 Binning Standard



- Common chromaticity bins
- Flux bins by decades:
  - 100, 110, 120…lumens
- V_F binning also…

New NEMA "SSL-3" Binning Standard

ANSI C78.377A SSL Chromaticity Standard

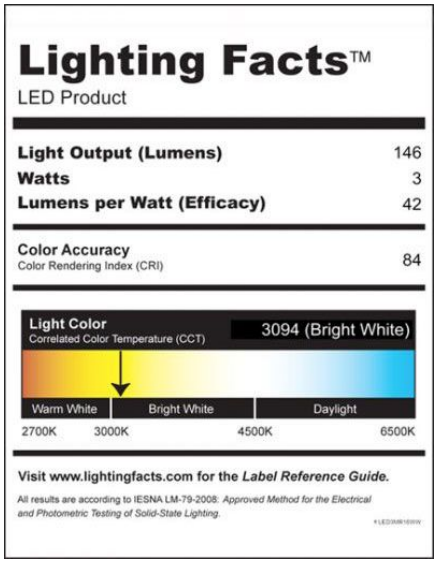
U.S. Department of Energy Programs

Retailer Energy Alliance

LIGHTING for tomorrow

CALiPER

NEXT GENERATION LUMINAIRES



Technical Information Network

GATEWAY Demonstrations

STANDARDS

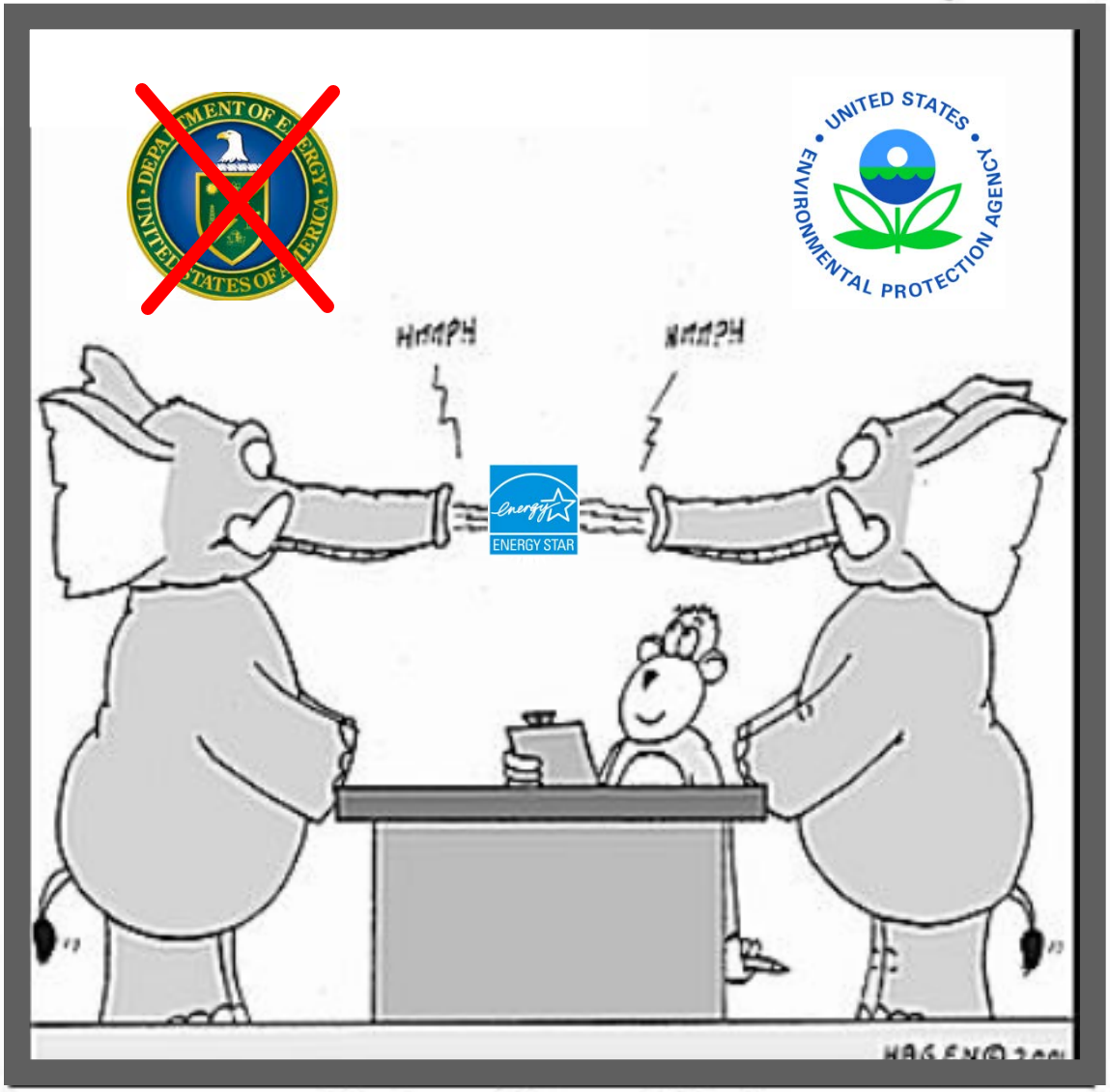
SSL Quality Advocates

CREE

Original U.S. EPA Energy Star Program

- **Consumer-oriented, focused on energy**
  - **Household appliances**
  - **Computer systems, servers**

SSL Energy Star Wars



Elephant "Tug-a-War"

Now That the Elephants Are Done…

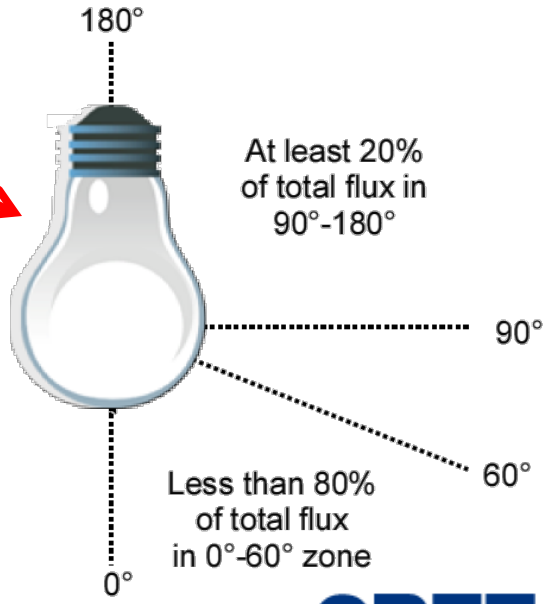
- DOE initiated three Energy Star Programs for SSL:
  - Energy Star for LED Integral lamps (published, effective August 2010)
  - SSL 1.1 for luminaires (published, in effect since 2009)
  - Energy Star for Outdoor luminaires (out for comment, in limbo)

- DOE has completed all of their obligations on all three Energy Star programs
- EPA now managing the program

ES for Integral Lamps: *Quality*

- **Minimum efficacy: 50/55 LPW (<10W/≥10W)**
- **Minimum lumens: Varies by thermally stabilized "wattage equivalent"**
- **Minimum CRI: 80**
- **Lumen Maintenance (L_{70}): 25,000 hours**
- **CCT: 2700 K, 3000 K, 3500 K, or 4000 K**
- **Duv tolerances: per ANSI C78.377-2008**
- **Power Factor: >0.7 for lamps ≥5W**
- **Intensity distribution:**
  - **Less than 80% of total flux in the 0° to 60° zone and at least 20% of total flux above 90°**
- **Dimming NOT required (very desired)**
- **Must provide:**
  - **IES LM-79-2008 goniophotometer report**
  - **IES LM-80-2008 report on LEDs used**
- **Restrictions on "product equivalency" marketing claims, must use "Lighting Facts" label**
- **Warranty: 3-years**

Wattage Equivalent	Lumens
25	200
35	325
40	450
60	800
75	1,100
100	1,600



Energy Star Program Requirements – Next Steps

- **EPA will complete the re-work the DOE Integral Lamps program and merge it into the existing EPA CFL bulb program in 2011**

DOE Energy Star SSL 1.1

- **Residential**

– Kitchen under-cabinet	CRI>75; 2700K, 3000K 3500K	24 (29*) lm/W
– Portable desk lights		29 lm/W
– Recessed , pendant downlights		35 (42*) lm/W
– Ceiling-mounted luminaires		30 (45*) lm/W
– Cove lighting		45 lm/W
– Surface-mounted directional lights		35 lm/W
– Outdoor porch lights		24 lm/W
– Outdoor step lights		20 lm/W
– Outdoor pathway lights		25 lm/W
– Outdoor decorative lights		35 lm/W
– All others		(70*) lm/W

- **Non-residential**

– Recessed downlights	35 (42*) lm/W
– Under-cabinet	29 lm/W
– Portable desk lights	29 lm/W
– Wall-wash luminaires	40 lm/W
– Bollards	35 lm/W

http://www.energystar.gov/ia/partners/product_specs/program_reqs/SSL_prog_req_V1.1.pdf

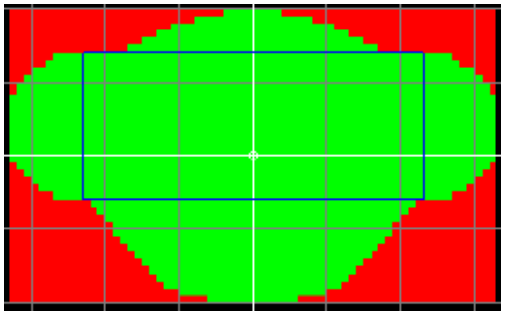
* Proposed update as of Oct 2010

EPA's Plan for SSL 1.1

- **SSL 1.1 will be merged into the EPA Energy Star program for luminaires, effective Sept 1, 2011**
- **Many, Many new requirements:**
  - **Labeling and merchandising requirements**
  - **Lighting Facts**
  - **Laboratory accreditation**

Energy Star for Outdoor Luminaires

- Least mature of the three original DOE programs
- Disagreements – from everyone – over the Fitted Target Efficacy metric, was going into re-work anyway before the EPA take-over
- EPA has no existing template or “playbook” for this class of product (commercial vs. consumer)
- Expect EPA to get around to this eventually, but focus is on 1) integral lamps, 2) luminaires



DOE proposal on Fitted-Target Efficacy (FTE); currently being reworked…

Europe & Asia SSL Standards

- **Europe**
  - Working very hard to catch up, get their standards program running through IEC
  - Multiple layers of regulation, confusion, bureaucracy
  - Country-by-Country Standards
- **Asia & ROW**
  - Following many of the LED Component, and LED Fixture standards from the U.S., e.g., LM-80, ANSI, etc.
  - Country-by-Country Application and Program standards, e.g., Taiwan & China: street lighting; Korea: SSL luminaire (similar to Energy Star)

Standards Summary

- **The essential standards are all in place; lack of standards is no longer an impediment to SSL adoption**
- **EPA has prevailed in the inter-agency struggle for control of the Energy Star program for SSL**
  - **Three programs (bulbs, luminaires, outdoor)**
  - **Technology- neutral (CFL, SSL, HID…)**
  - **Lots of details**
- **U.S. leads the world in SSL standards – big jump-start thanks to the leadership of the U.S. Department of Energy investments in this area**
  - **Rest of the world is largely following the U.S. in Basic & Component standards (e.g., LM-80, ANSI)**

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LED lighting: Energy efficient & planet friendly.

Cree. Leading the LED lighting revolution.

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