Challenges for Power Electronics in Solid-State Lighting

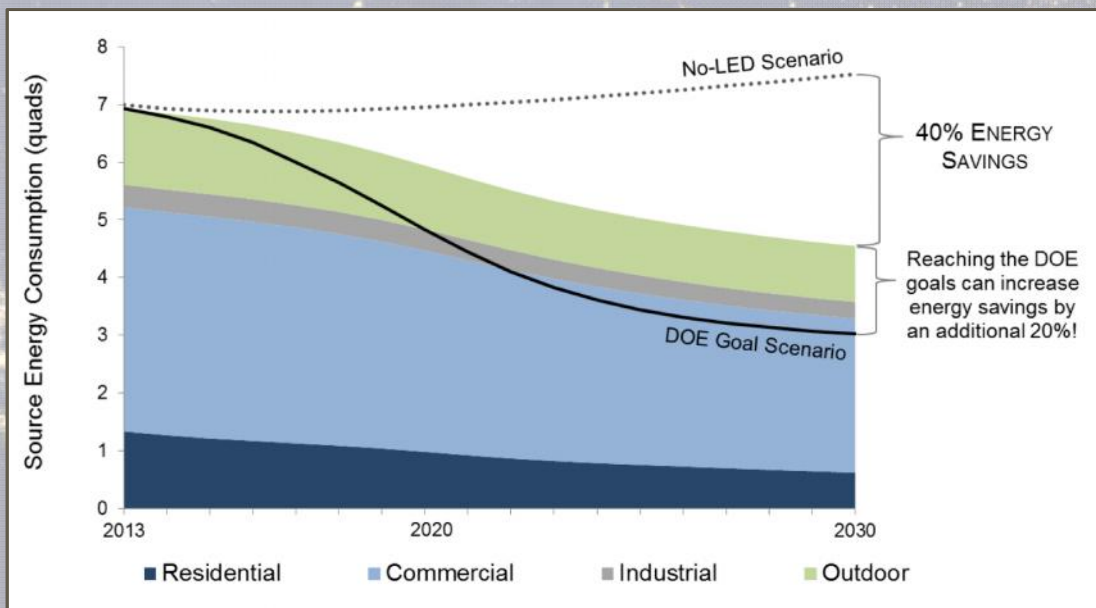
Dr. Mike Krames

Arkesso LLC

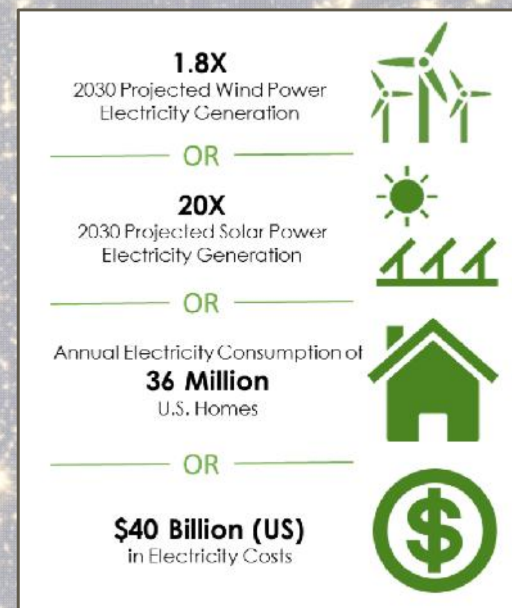
Energy Savings from Solid State Lighting

Lighting accounts for ~ 20% of nationwide electricity use

Total U.S. Lighting Energy Consumption Forecast
2013 to 2030

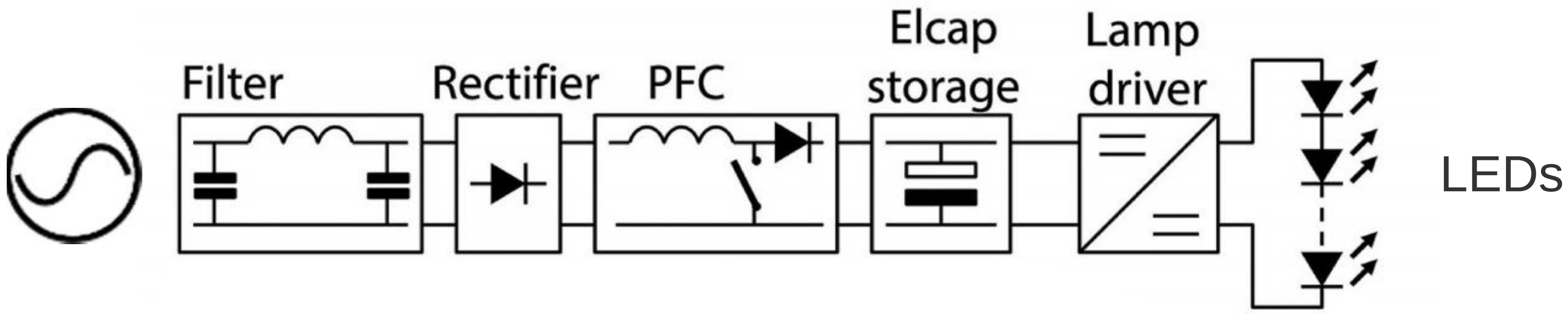


Solid State Lighting R&D Plan
U.S. Department of Energy
May 2015



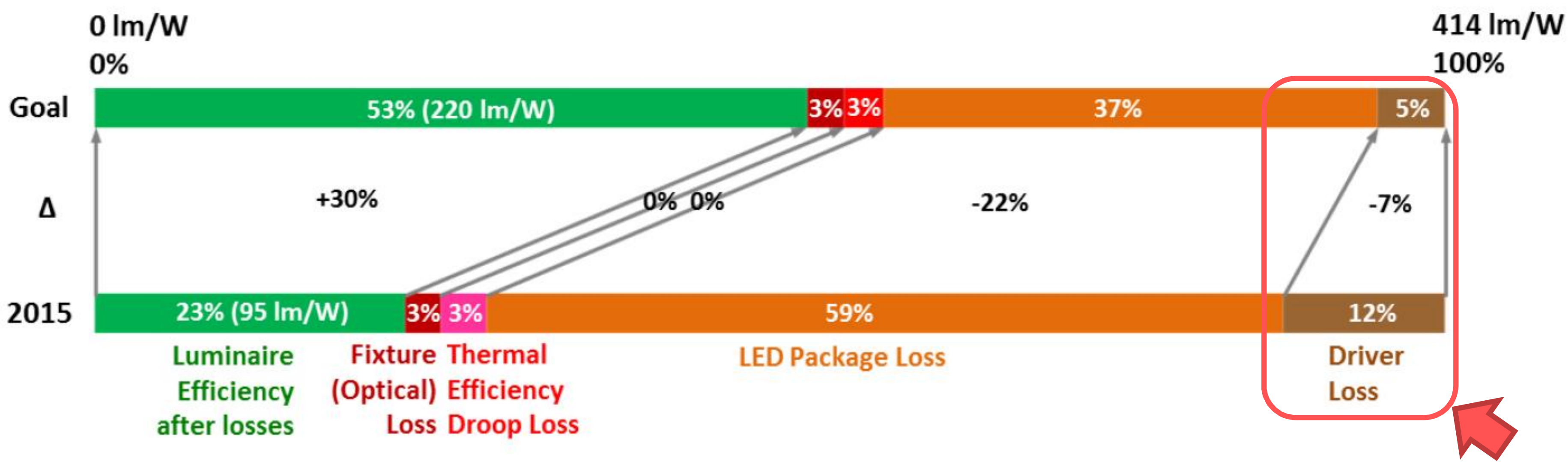
- Target savings of 395,000 gigaWatt-hours per year by 2030
- ~ 50 large coal-fired power stations
- ~ 300 million tons of reduced CO_2 emissions (or 57 M automobiles)

Driver Circuits for Solid State Lighting (SSL)



- Losses in 1) bridge diodes, 2) L/R/C components, 3) switching FETs, [and 4) LED current ripple]
- Efficiencies commonly 85-90%
- Dimming is often a requirement
- Controls (“on demand”) and sensors (data, IoT) are anticipated

SSL Driver Efficiency Roadmap



Solid-State Lighting R&D Plan, US DOE, June 2016

- US DOE Goal: reduce AC/DC driver losses from typical 12% to 5% by 2025

Wide Bandgap Opportunity

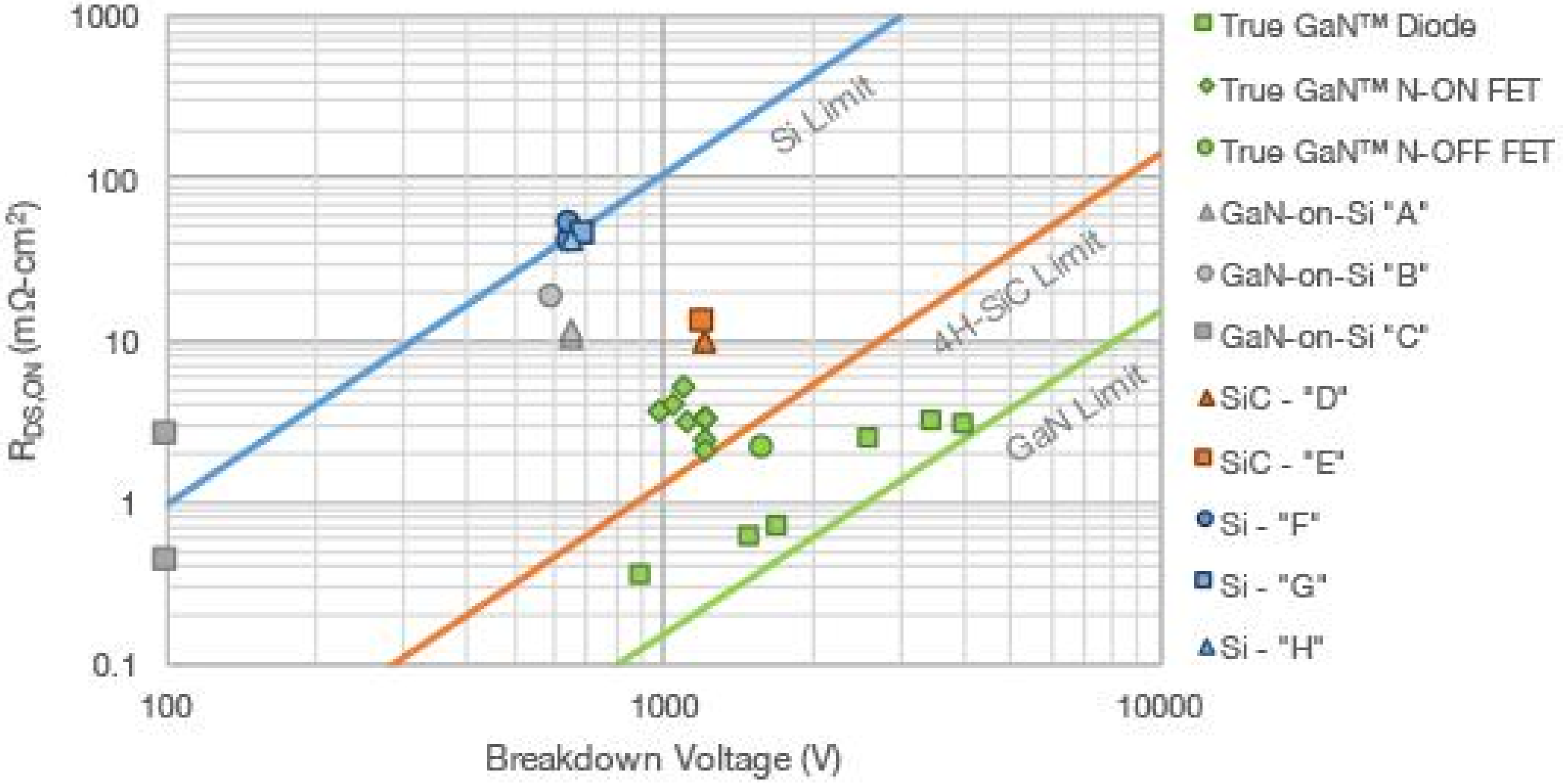


Image courtesy of Avogy, Inc.

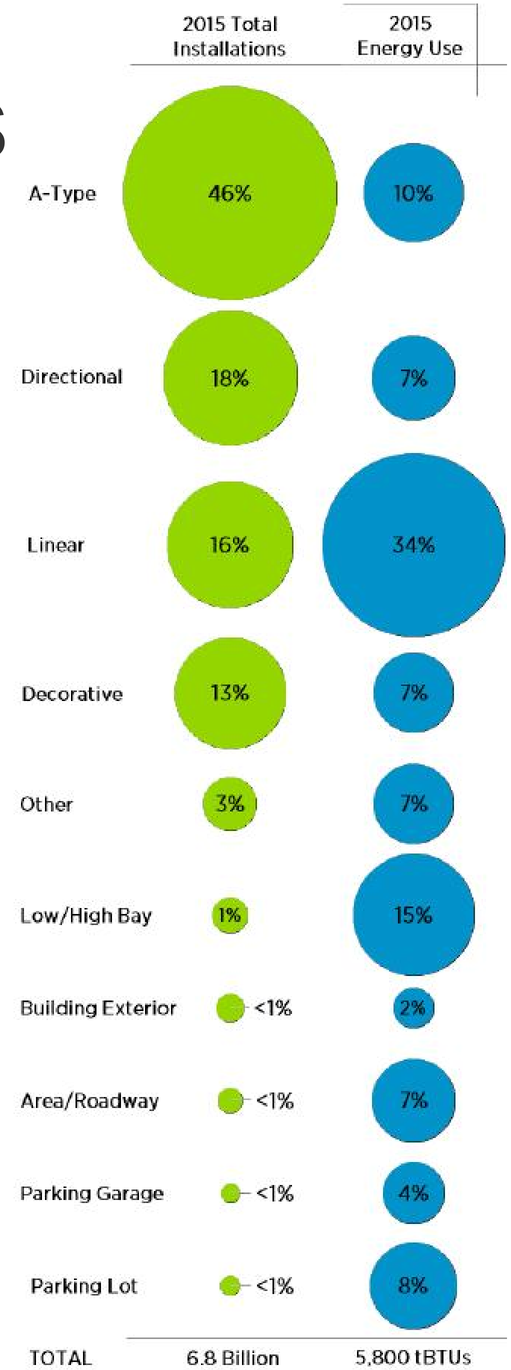
- Lower on-resistance, higher breakdown voltages
- Higher frequencies (smaller components)

Example: High Wattage Drivers

Comparing 220-W LED drivers	650V Silicon Based 2-Stage Topology	C3M 900V SiC Based Single-Stage Topology
Input voltage Range	120-277V AC	120-277V AC
Output Voltage Range	150-210V DC	150-210V DC
Max Output Current	1.45 A	1.45 A
Peak Efficiency	93.5 %	94.4 %
Input THD	< 20%	< 20%
Output Current Ripple	>0.95	>0.95
Output Current Ripple	±5 %	±10 %
Size	220×52×30 mm	140×50×30 mm
Weight	2.7 lbs / 1.3 kg	1.1 lbs / 0.5 kg
Relative cost	1	0.85

A Barkley and V Pala, *Power Electronics Tips*, 18 Nov 2015.

- Low/High Bay lighting is 2nd largest energy consumer (after office)
- Better FETs can improve efficiency and reduce size (cost)
- GaN must not only outperform Si, but also SiC, solutions



Energy Savings Forecast of Solid-State Lighting in General Illumination Applications, U.S. Department of Energy Solid-State Lighting Program, September 2016

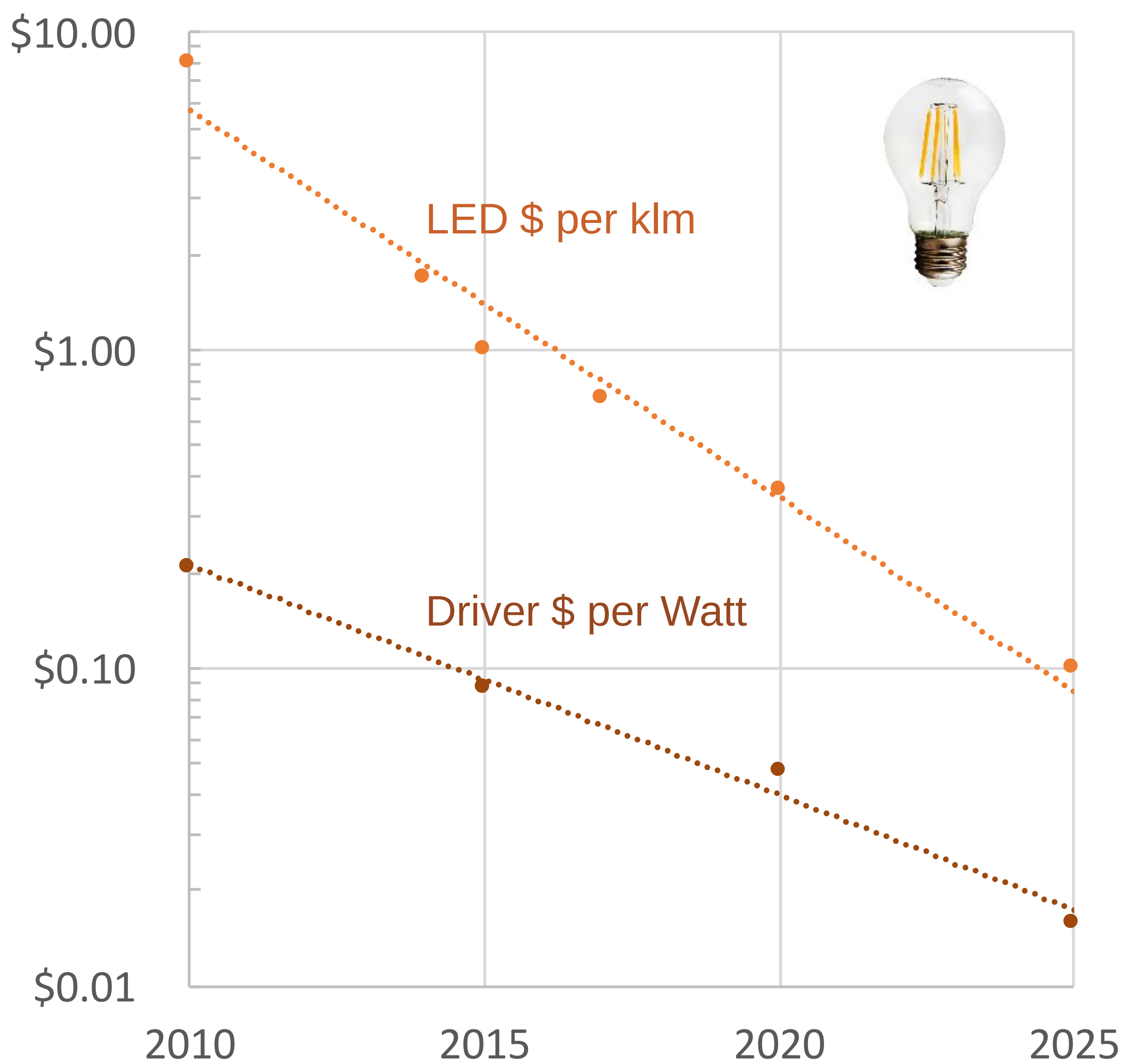
SSL Driver Cost Roadmap

Projected costs for LED driver are below 2¢ per electrical Watt* by 2025.

Can better components reduce cost of other aspects of luminaire? (e.g., size, heatsinking requirements, etc.)

[Adapted from *Solid-State Lighting R&D Plan,* US DOE, June 2016]

*based on A19 60-Watt equivalent LED bulb



Flicker

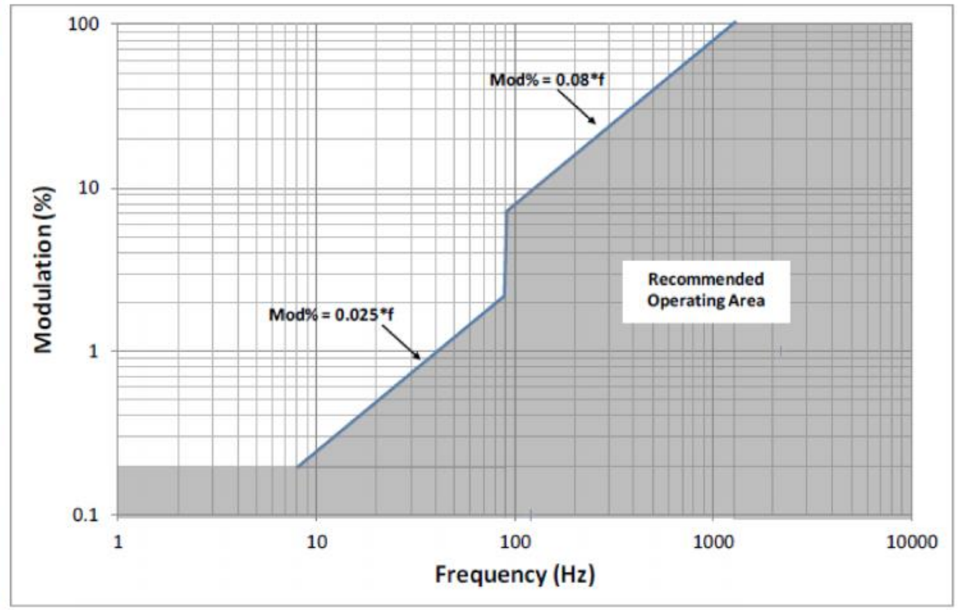
*IEEE Std 1789™-2015, "IEEE Recommended Practices for Modulating Current in High-Brightness LEDs for Mitigating Health Risks to Viewers"
**"Building Energy Efficiency Standards for Residential and Nonresidential Buildings, Title 24, Part 6, and Associated Administrative Regulations in Part 1," California Energy Commission (2016)

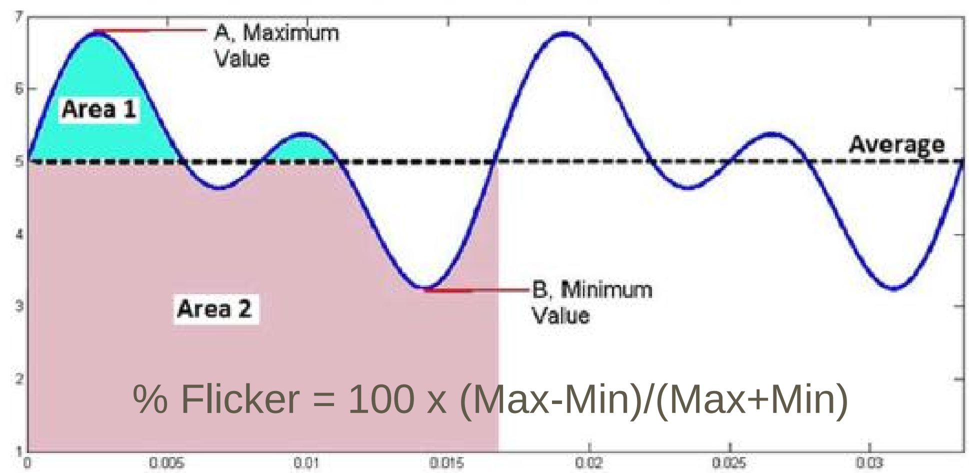
120 Hz flicker from LED "filament" bulb (photographed using iPhone)

Appendix JA8: Qualification Requirements for High Efficacy Light Sources — Partial List

Specification	Requirement
Initial Efficacy	≥ 45 lumens/Watt
Power Factor at Full Rated Power	≥ 0.90
Correlated Color Temperapture (CCT)	For inseparable SSL luminaires, LED light engines and GU24 LED lamps, ≤4000 Kelvin. For all other sources, ≤3000 Kelvin.
Color Rendering Index (CRI)	≥90
R9	≥50
Rated Life	≥ 15,000 hours
Minimum Dimming Level	≤ 10%
Flicker	<30% for frequencies of 200 Hz or below, at 100% and 20% light output.

IEEE Std 1789-2015
IEEE Recommended Practices for Modulating Current in High-Brightness LEDs for Mitigating Health Risks to Viewers

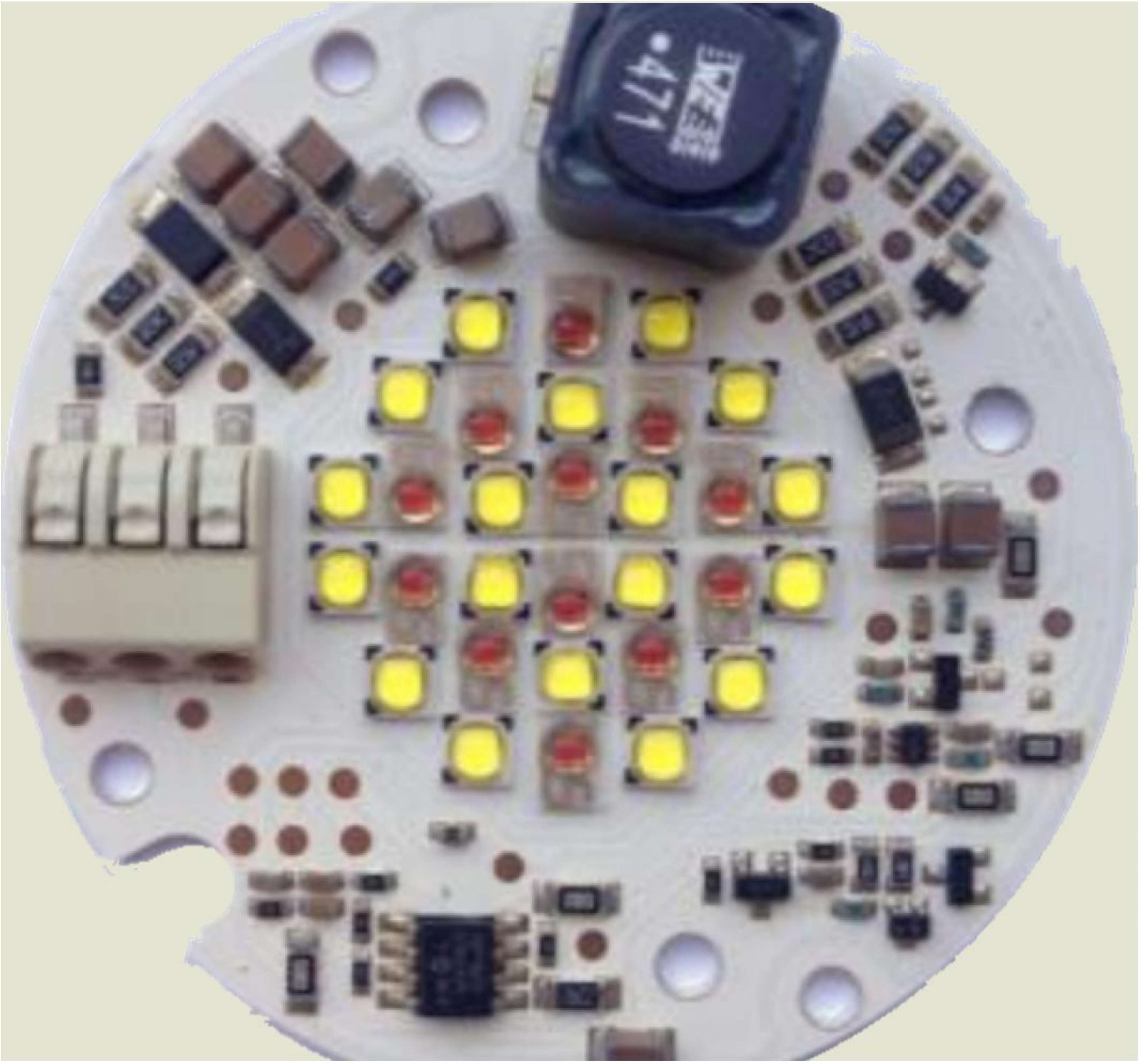




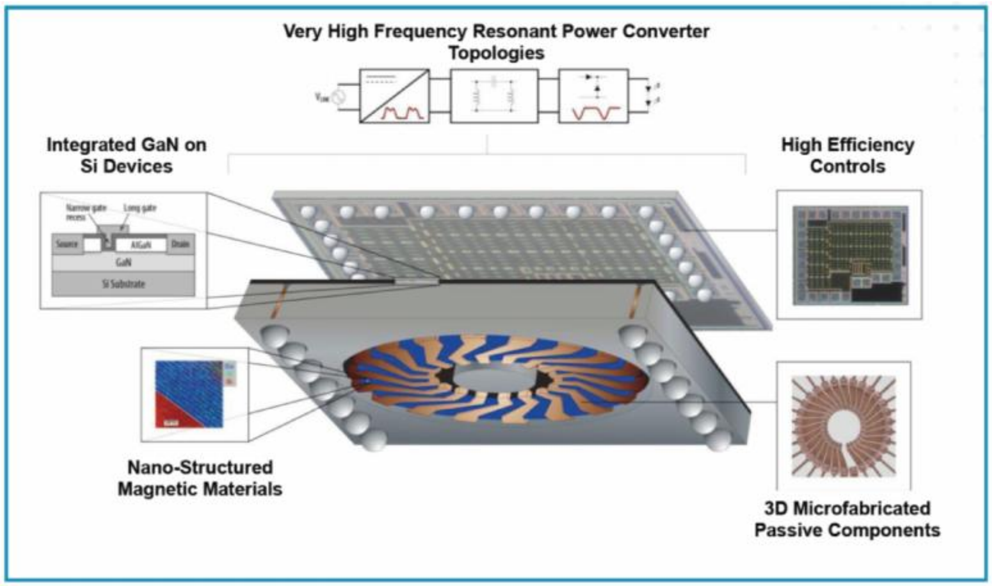
- Stroboscopic flicker is an acknowledged potential health/safety risk*
  - Mandated to < 30% (California**)
  - Recommended to < 10% (IEEE*)
- Directly impacts allowable ripple in driver output (LED) current
- Trade-off with Power Factor

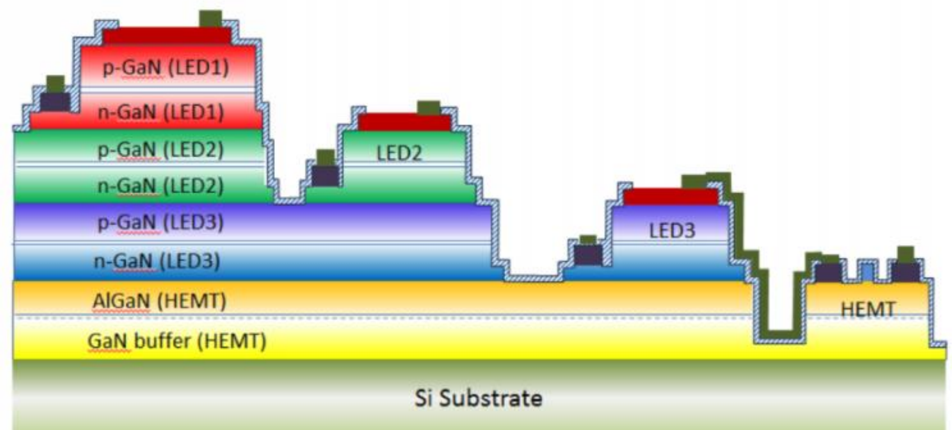
Driver Integration

Can’t we do better than this..?



Opportunity: Upstream Integration



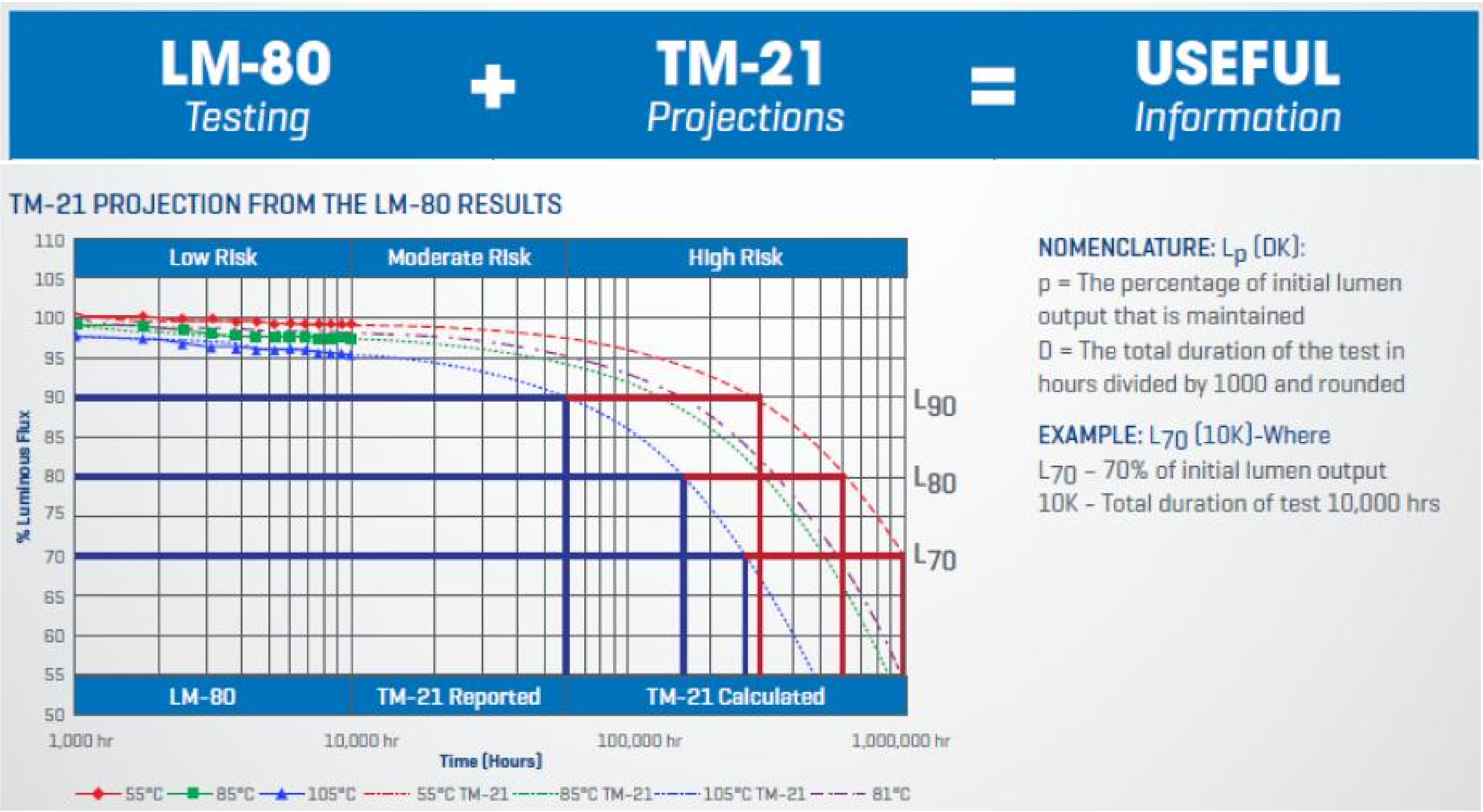


tpalacios@mit.edu

- Fully contained driver and multi-primary LED in a single epitaxial stack
- Maximum theoretical luminous efficacy (no Stoke’s heat) and control
- Combine with MEMS for integrated primary optics
- Completely disruptive to luminaire design

LED Reliability

Courtesy D. Hamilton, Hubbell Lighting

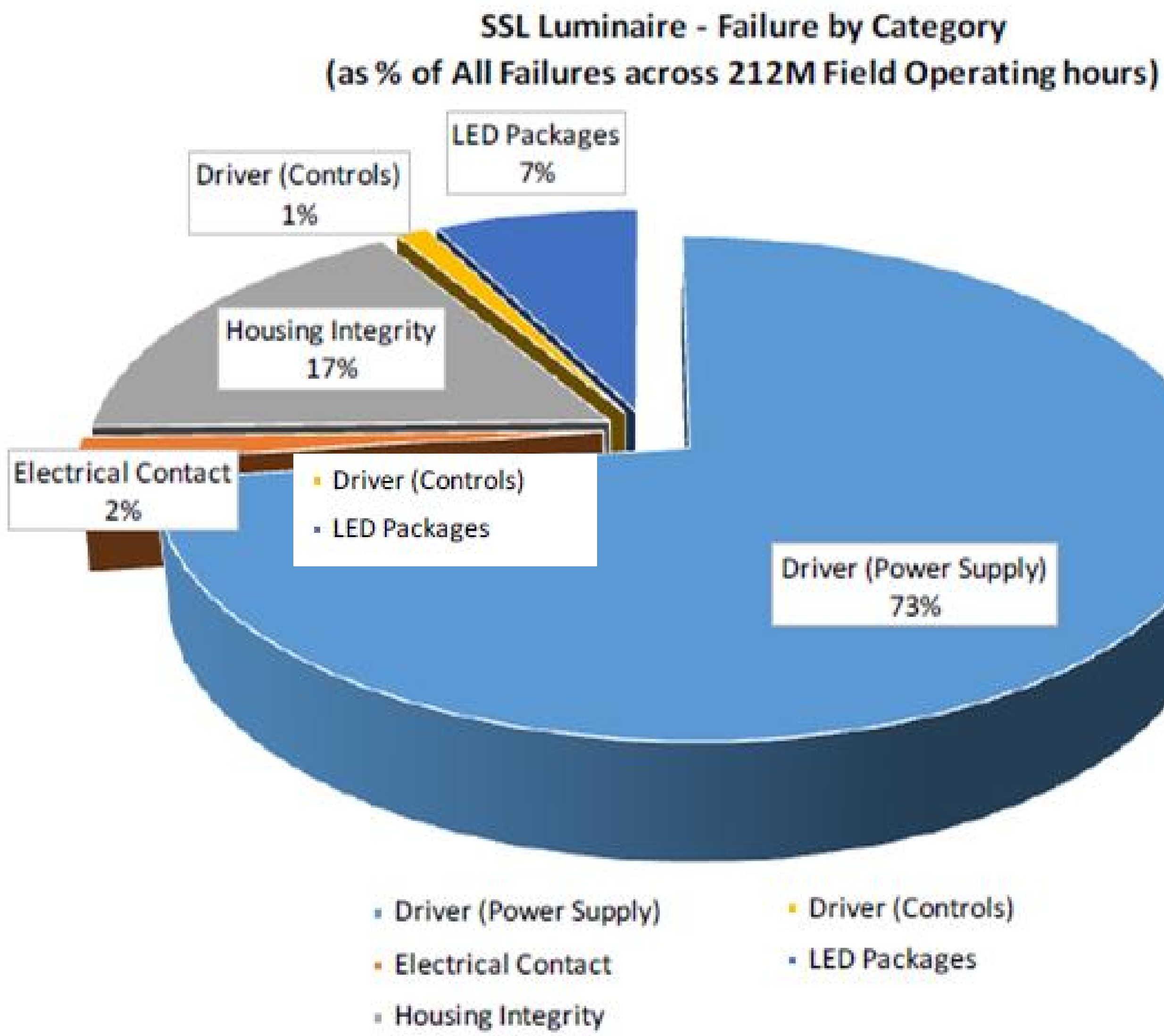


- Illuminating Engineering Society (IES) guides standards (e.g., ENERGY STAR®)
- What is missing? Something similar for *drivers*…!

Luminaire Reliability

Improvements in driver components, robustness and integration can address majority of SSL luminaire failure modes.

"LED Luminaire Lifetime: Recommendations for Testing and Reporting, Third Edition," LED Systems Reliability Consortium, Sept 2014.

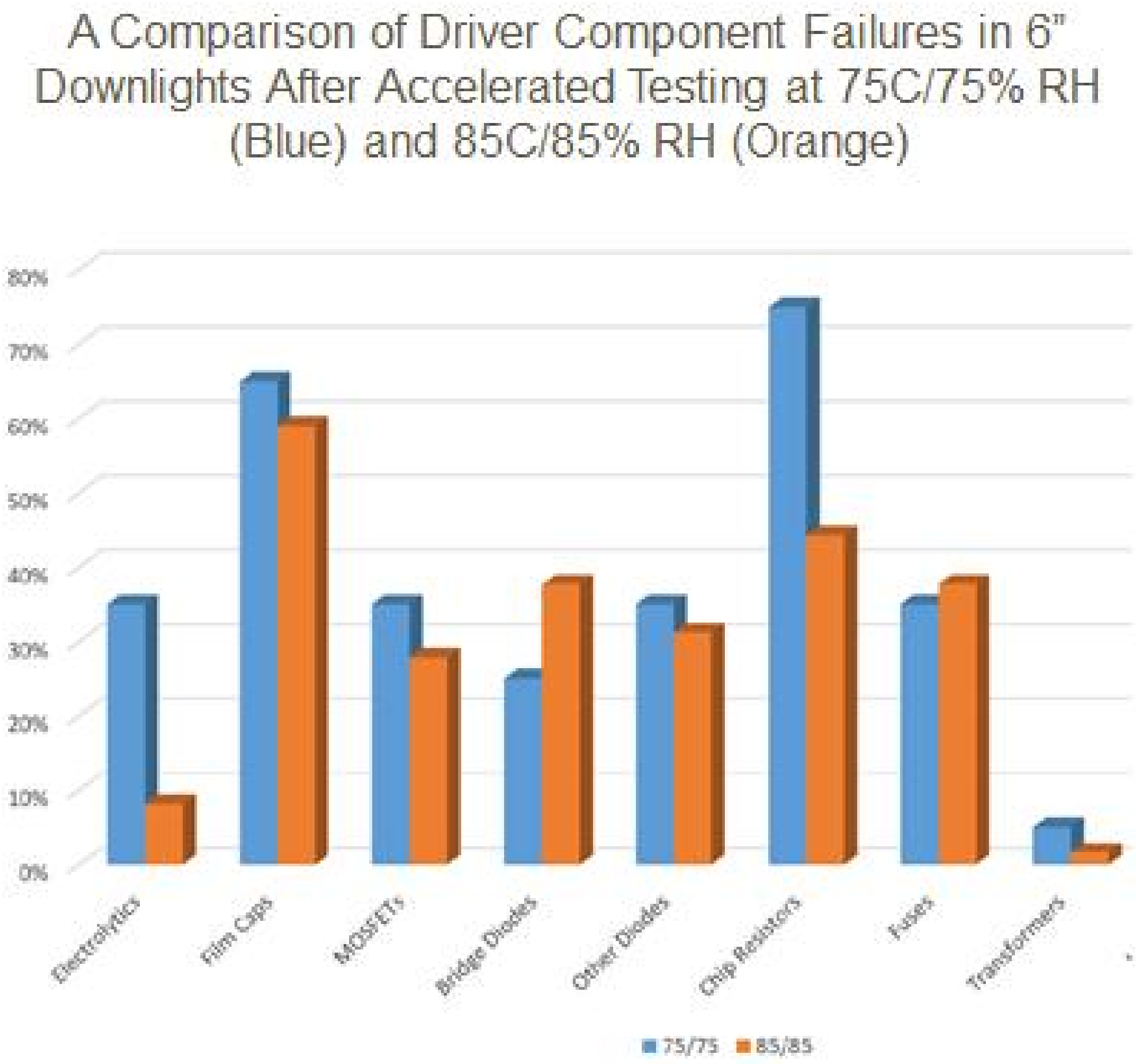


Driver Reliability

Electrolytic capacitors are *not* the dominant failure mechanism for drivers.

We need better predictor of lifetime than component MTBF.

L. Davis, "Accelerated Life Testing Results for SSL Luminaire Electronics," *US DOE SSL R&D Workshop*, San Francisco, CA, Jan 2015.



Is the Future a DC World?

No bridge?

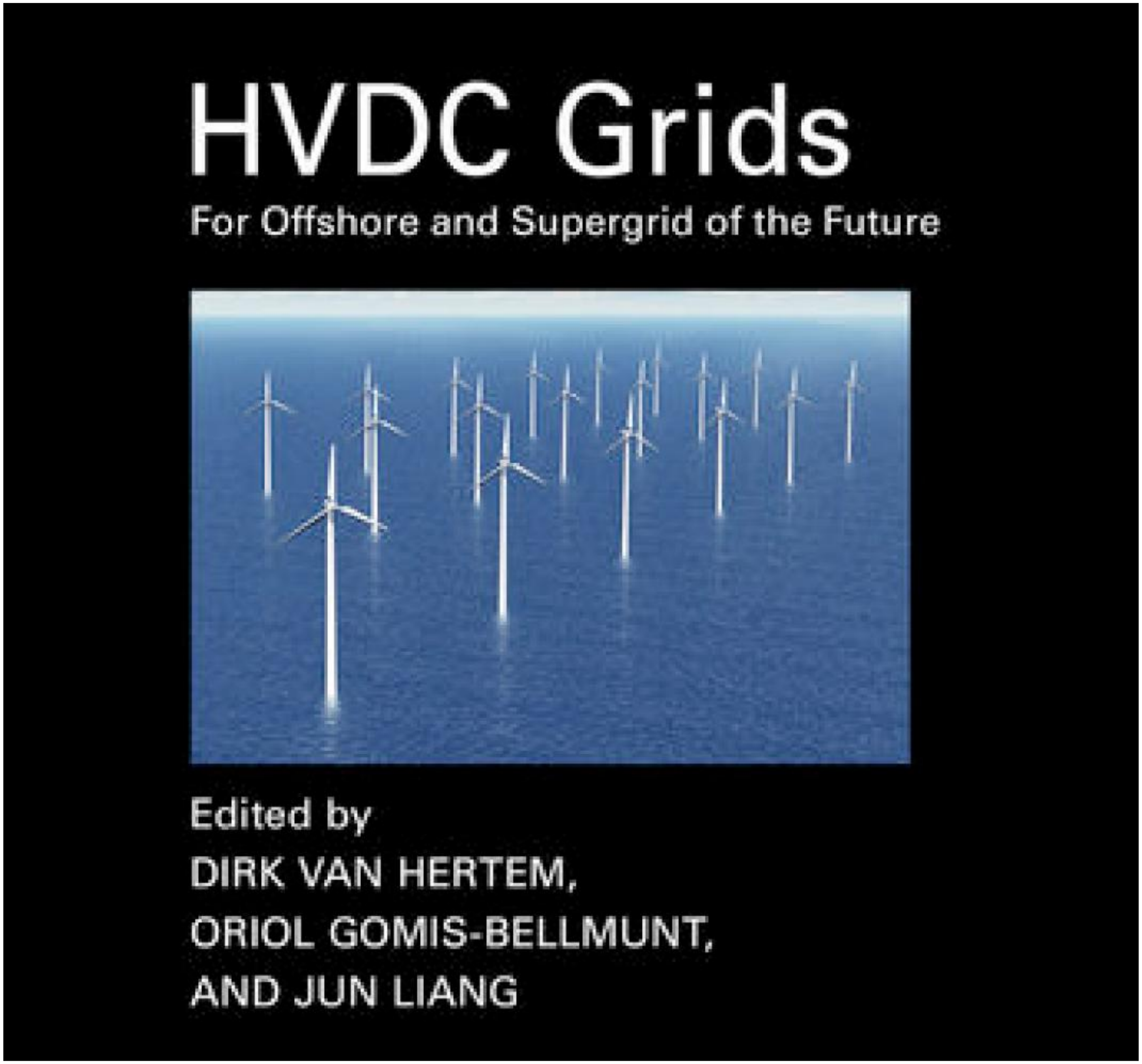
No flicker?

No elcaps?

No PFC?

…

How would this impact circuit design and power components performance requirements?



Goals for SSL Driver Circuits

Application	Metric	State of the Art	Must	Want
SSL Driver Circuits	AC to DC power conversion efficiency	88%	≥ 95%	≥ 98%
	Reliability (hrs w/o failures 85C/85% RH)	var.	≥ 1000	
	Volume (Watts per cm^3)	1.0	≥ 5	≥ 10
	Weight (Watts per g)	0.4	≥ 1	≥ 5
	Output Ripple @ 120 Hz (100% to 1% dim)	var.	< 30%	< 10%
	Power Factor	var.	≥ 0.7	≥ 0.9
	Standby Power (% Full-On Wattage)	var.	< 5%	< 1%
	Cost ($ per electrical Watt)	$0.10	≤ $ 0.04	≤ $ 0.02

THANK YOU

Arkesso LLC

Palo Alto, CA — Austin, TX

www.arkesso.com
info@arkesso.com