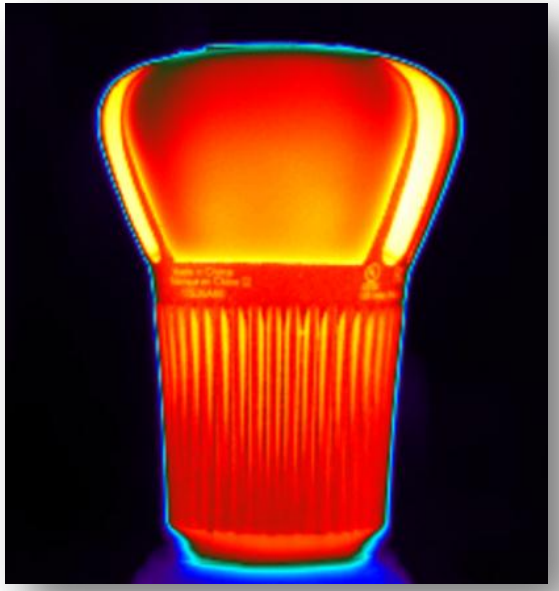
PHILIPS

sense and simplicity

LED Lighting
A **Hot** Topic With a Bright Future

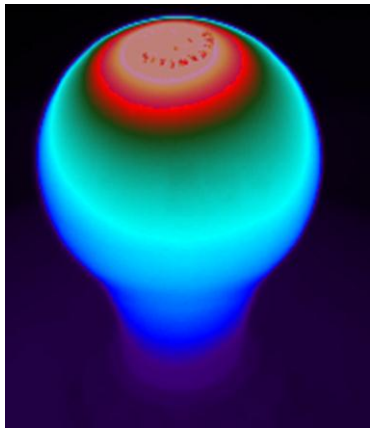


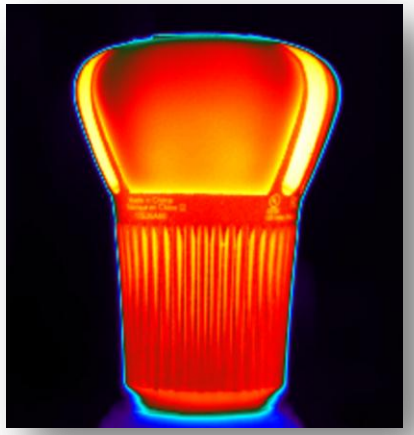
Pat Bournes
Packaging Innovation, Philips Lumileds
March 18, 2013

PHILIPS

Agenda

1. Overview of LED Market - LED Trends
2. DOE Roadmap
3. LEDs vs. Incandescent Bulbs
4. Thermal Management in LED Systems
5. Examples of an LED system level solutions
6. Industry Trends
7. Conclusions





Acknowledgements

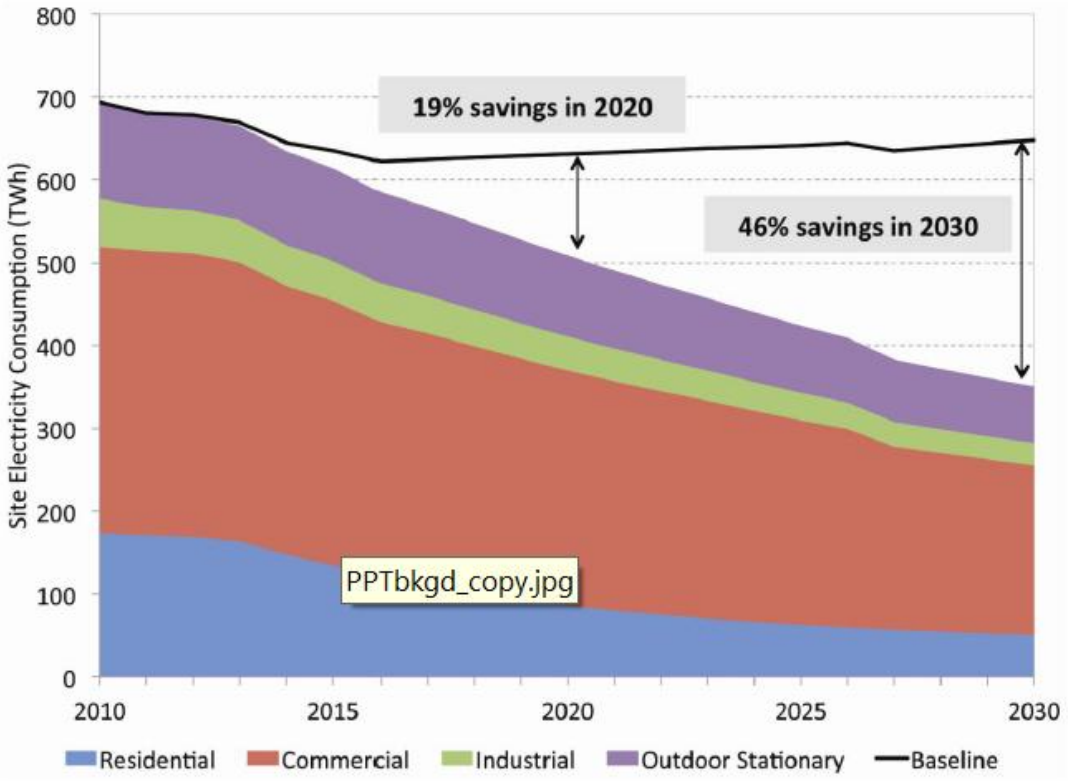
- Semi Therm organizers, in particular:
  - George Meyer IV, Celsia Technologies
  - Martin Goetz, Northrup Grumman Corporation
  - Tom Tartar, Package Science Services

- Philips Lumileds Applications Group
  - Ken Ratica

PHILIPS

SSL Savings Potential Is Significant

- Potential to reduce U.S. lighting electricity use by **nearly one half**
- Equivalent to **$30 billion** in savings in 2030



Source: Fig. ES.1, Energy Savings Potential of SSL in General Illumination Applications, January 2012: www.ssl.energy.gov/tech_reports.html

PHILIPS

LED Statistics – The Market

- Americans purchased 4 billion light bulbs of all types in 2012 (US DOE)
- LED bulbs will be a $10 Billion/year business by 2015 (IMS Research)
- 33 million LED bulbs sold in 2012 -> 370 million expected to be sold in 2016 – ***1000% growth*** (NY Times)
- Retrofit bulbs are just part of the story

PHILIPS

LED Trends – A View in Early 2013

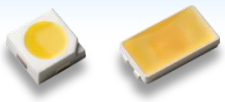
- LED market will grow at double digit rates for the next 5 years
- $/lumen has to be decrease 90% from 2010 to 2020.
  - Simultaneously Lumen/W has to be increased considerably.
- No standards have emerged for HB LED
  - Variety in package types will further increase
- Asia is the center of LED production. Within Asia, China is gaining more and more importance (70 % of new MOCVD installations in 2010)

PHILIPS

2012: LUXEON Product Portfolio in Illumination

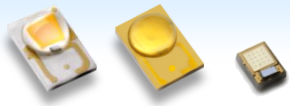
30–90 lm

LUXEON Mid-Power 3535/5630



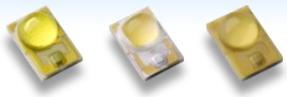
60–150 lm

LUXEON Rebel
LUXEON Z
LUXEON Rebel PLUS



90–300 lm

LUXEON Rebel ES
LUXEON A
LUXEON R

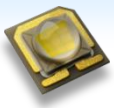


180–900 lm

LUXEON H
LUXEON M
LUXEON T

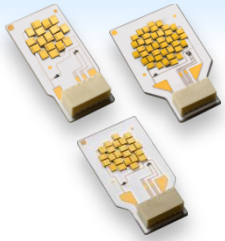
900–1,500 lm

LUXEON S
(S1000)



1,500 – 7000 lm

LUXEON S
(S2000, S3000
and S5000)



High lumen density (lm/mm2), compact, ideal for directional lighting

400–800 lm

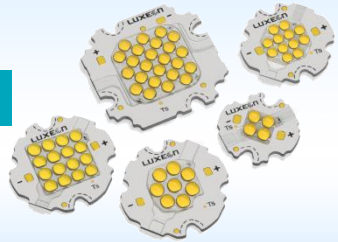
800–1,200 lm

1,200–2,000 lm

2,000–3,000 lm

3,000–4,000 lm

LUXEON K



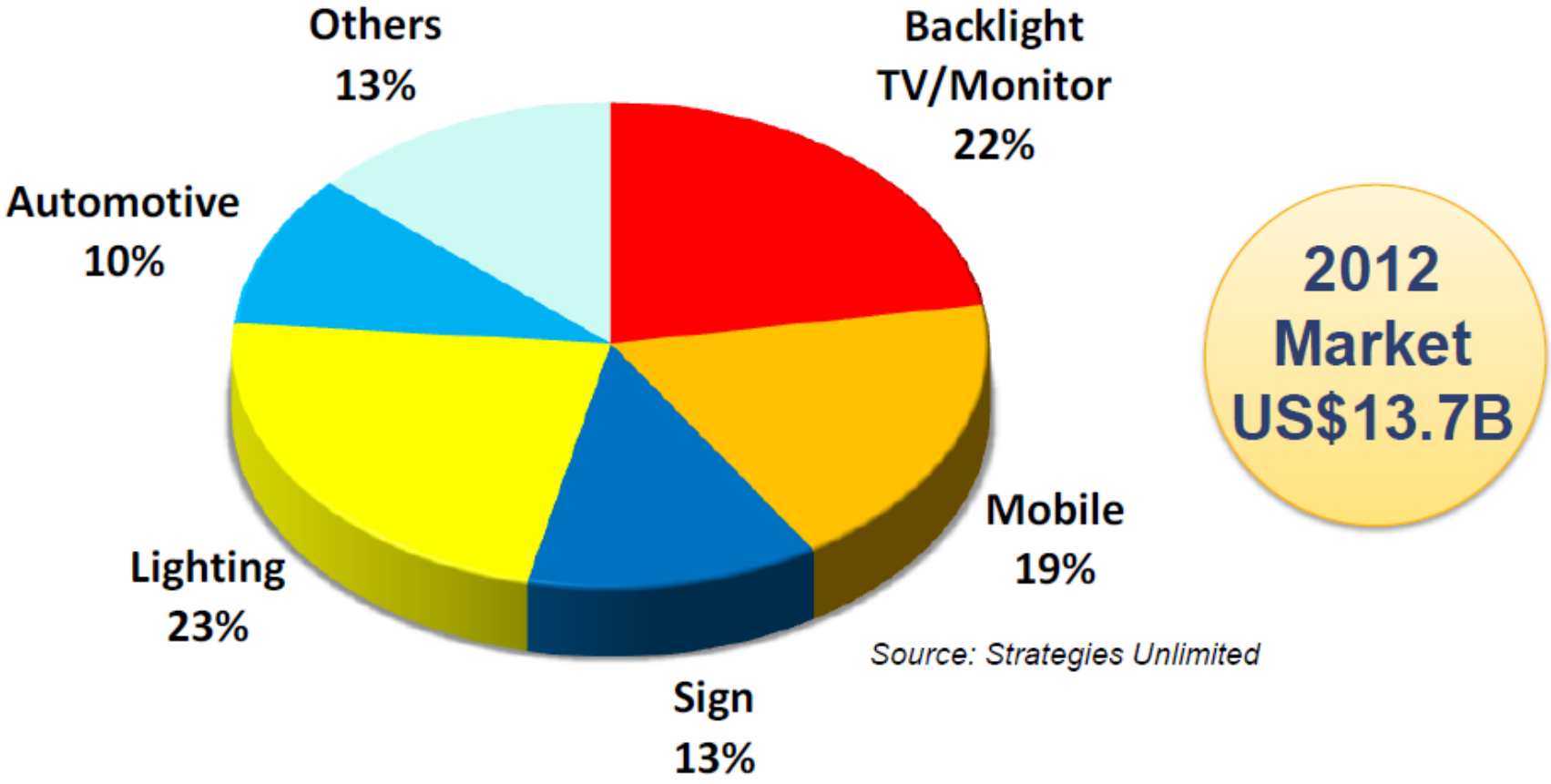
High lumen packages, easy to assemble, ideal for diffuse lighting

LUXEON Differentiators

- Lumen Maintenance
- Quality of Light
- Guaranteed Performance at Temperature
- Freedom from Binning™

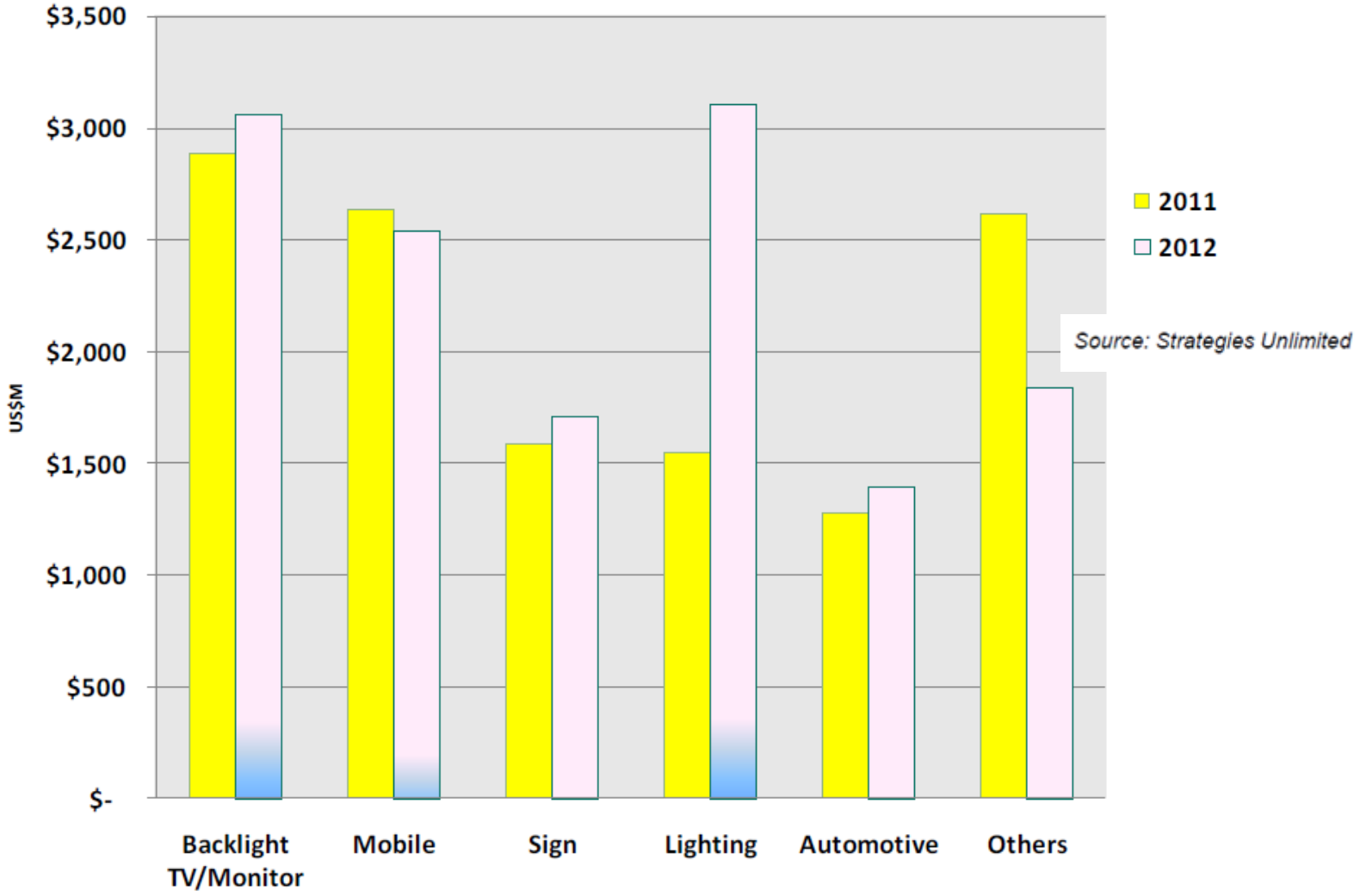
PHILIPS

2012 LED Market by Application



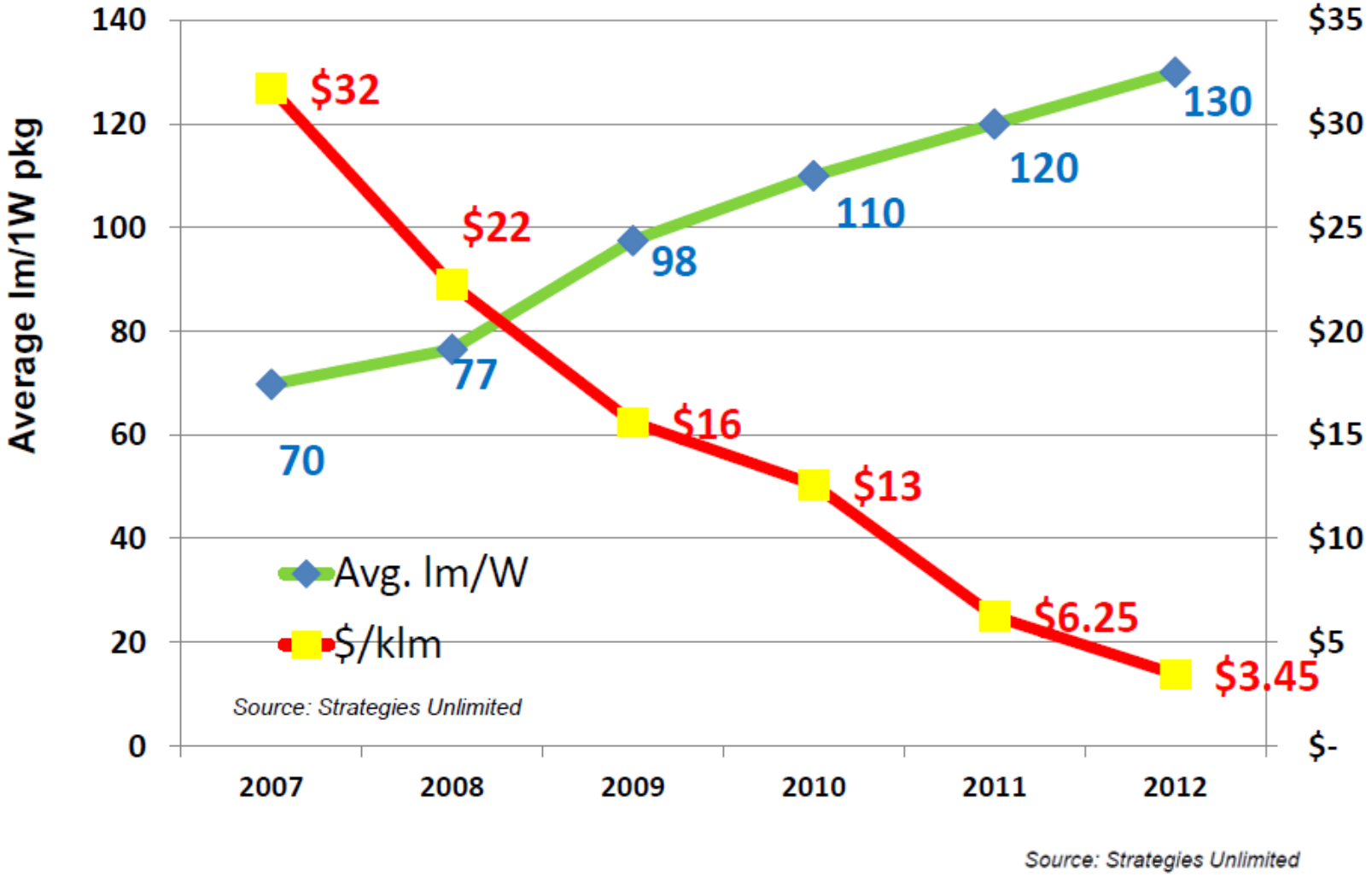
PHILIPS

LED Market Growth by Sector



PHILIPS

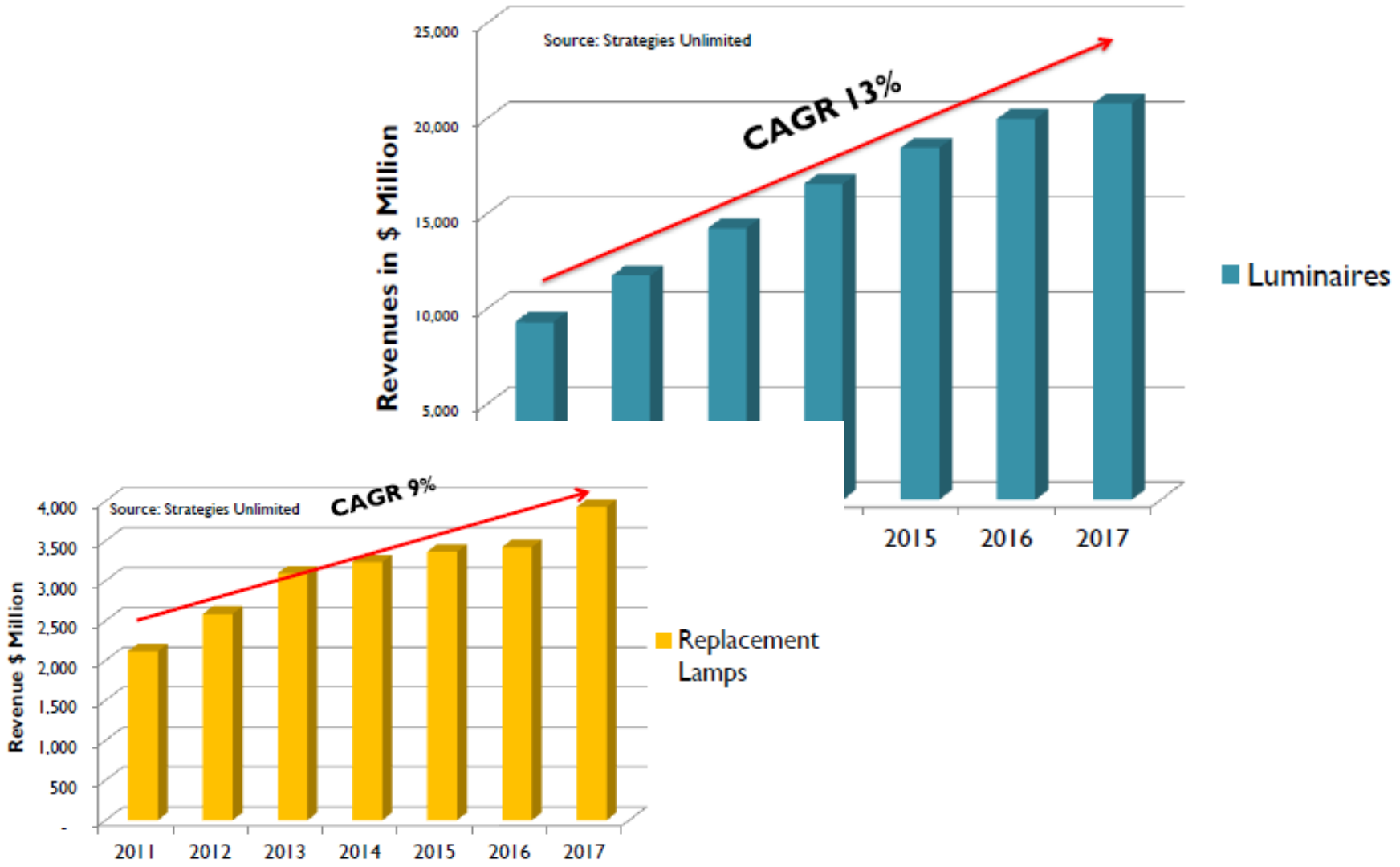
lm/W - $/klm



Source: Strategies Unlimited

PHILIPS

Luminaires vs Retrofit Bulbs



PHILIPS

DOE Roadmap

4.1. LED Milestones

Milestone	Year	Target
Milestone 1	FY10	LED Package: >140 lm/W cool white; >90 lm/W warm white; <$13/klm (cool white)
Milestone 2	FY12	Luminaire: 100 lm/W; ~1000 lm; 3500 K; 80 CRI; 50,000 hrs
Milestone 3	FY15	LED Package: ~$2/klm (cool white) ~$2.2/klm (warm white)
Milestone 4	FY17	Luminaire: >3500 lm (neutral white); <$100; >150 lm/W
Milestone 5	FY20	200 lm/W luminaire

Assumption: packaged devices measured at 35 A/cm2.

The Vision:

1) Led Chip Efficacy – 250 Lm/W
2) Luminaire Efficacy – 200 Lm/W

http://www1.eere.energy.gov/buildings/ssl/techroadmaps.html.

PHILIPS

From the DOE Manufacturing Roadmap

1. **LED lighting needs to venture away from existing form factors – the industry needs to move away from retrofit designs.**

2. **Next generation luminaires will incorporate a broader range of technologies to achieve specific form factors and enhanced performance.**

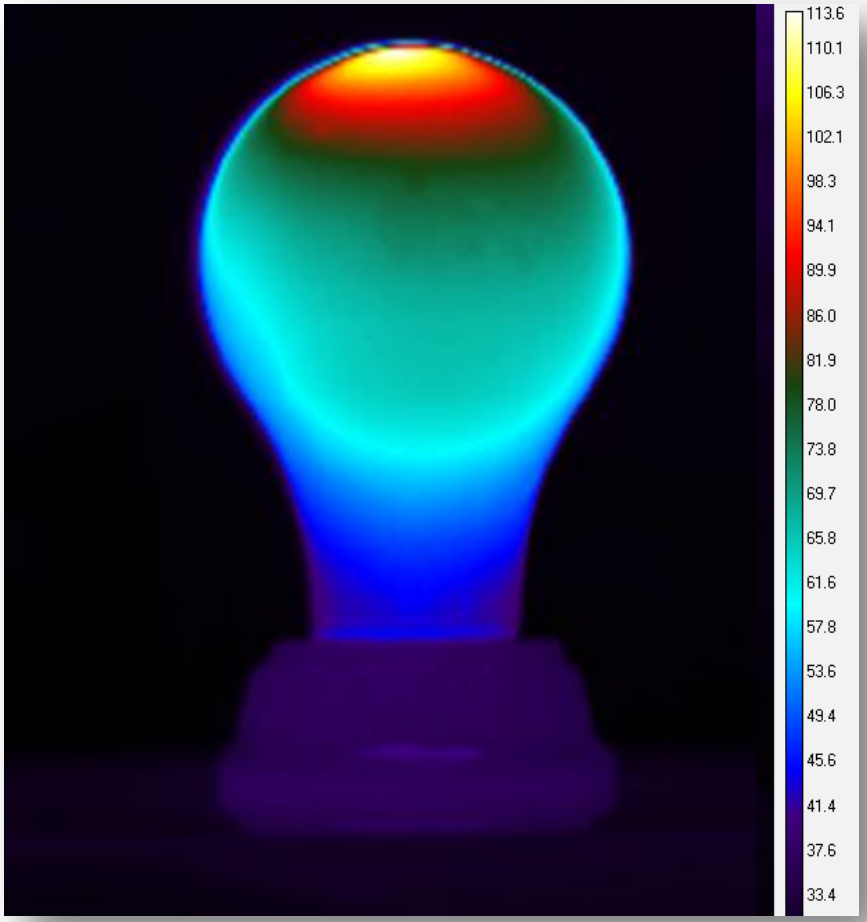
3. **Novel approaches to reducing parts counts and complexity in luminaires should be encouraged.**

PHILIPS

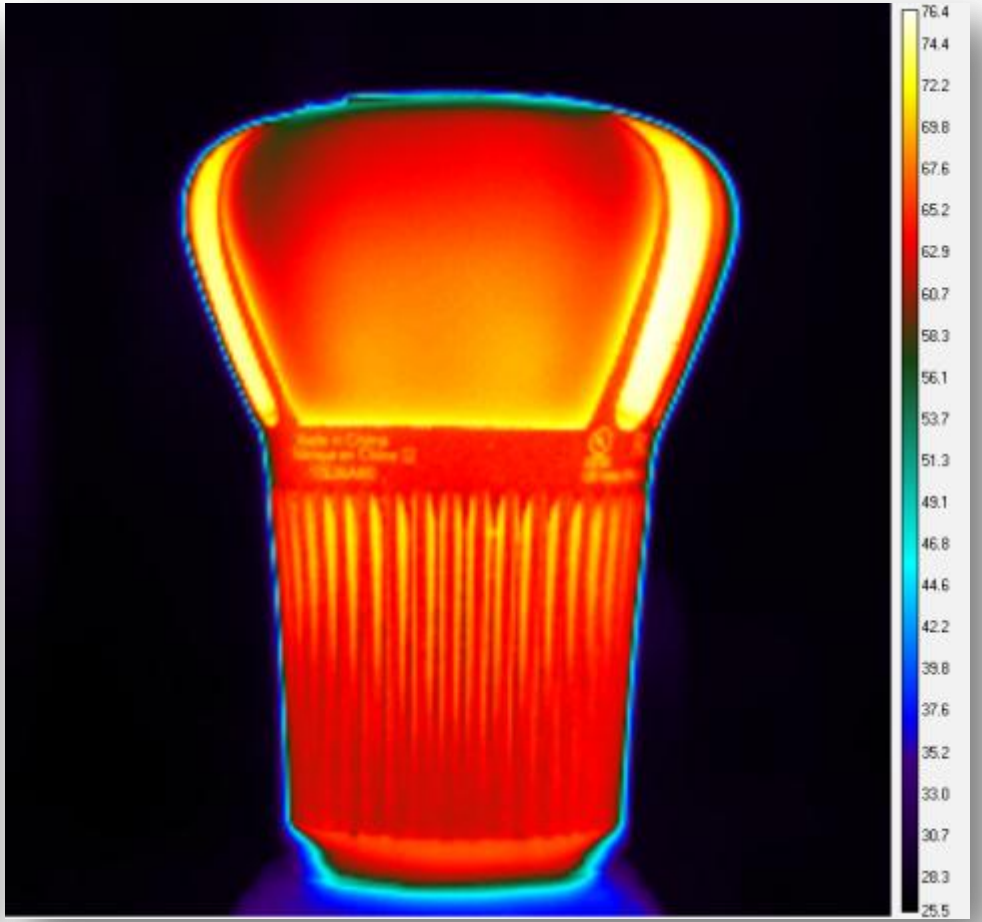
Mimicking the Vacuum Bulb

- Revolutionary technologies “shoehorned” into existing designs
- Thermal, Optical, Mechanical and Electrical (TOME) constraints imposed on LEDs
- Designs do not take advantage of all the attributes of LEDs

Incandescent vs LED Bulbs



40 Watt Incandescent



Philips LED "Prince 1"

LEDs and Bulbs

How do LED's differ from typical Bulbs?

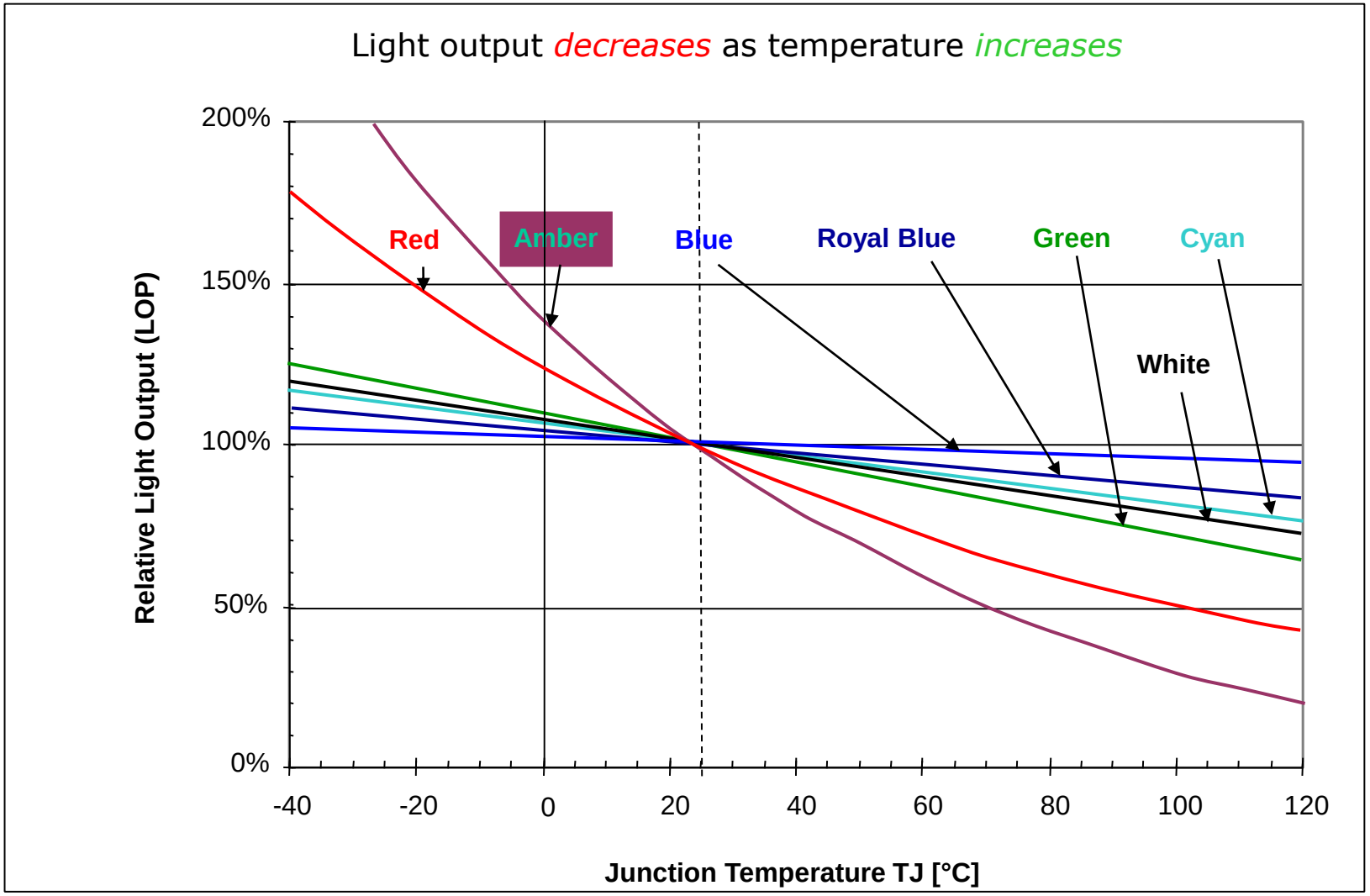
1. **Thermally** - LEDs work more efficiently the cooler they are.
   - Incandescent bulbs radiate heat out , only 10% of the heat conducted to the socket.
   - LEDs rely on conduction then convection

2. **Electrically** - LEDs are current driven, Bulbs are voltage driven.
   - LEDs are a DC product in an AC world

3. **Optically** - LEDs are a directional light source, Bulbs have a 360 degree radiation pattern.
   - Optics need to be different. This can be an advantage of LEDs.

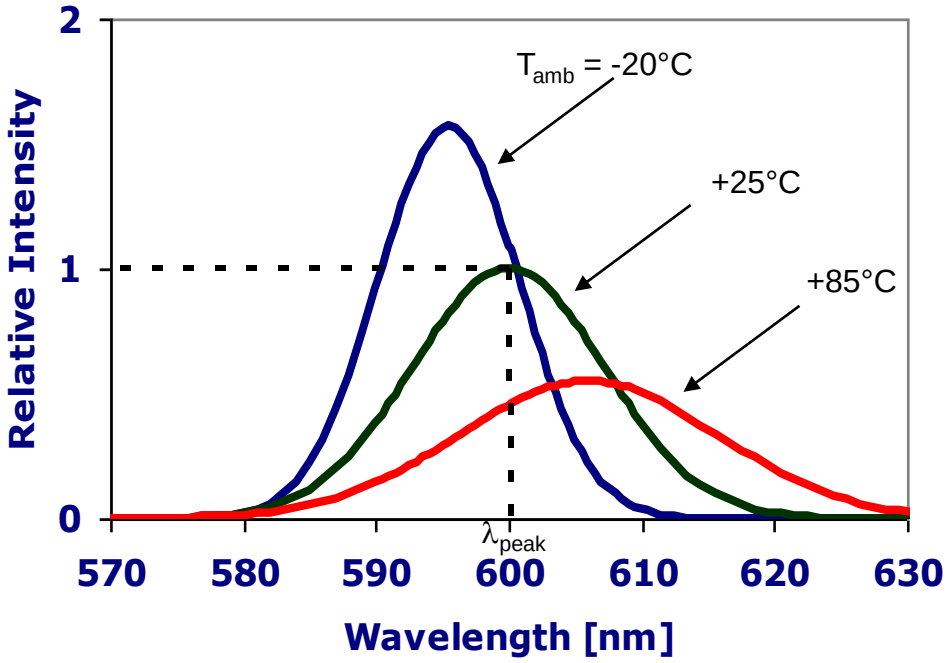
PHILIPS

Effects of Excessive Heat on the LED (1 of 3)



Effects of Heat on the LED (2 of 3)

Dominant wavelength *shifts* with temperature

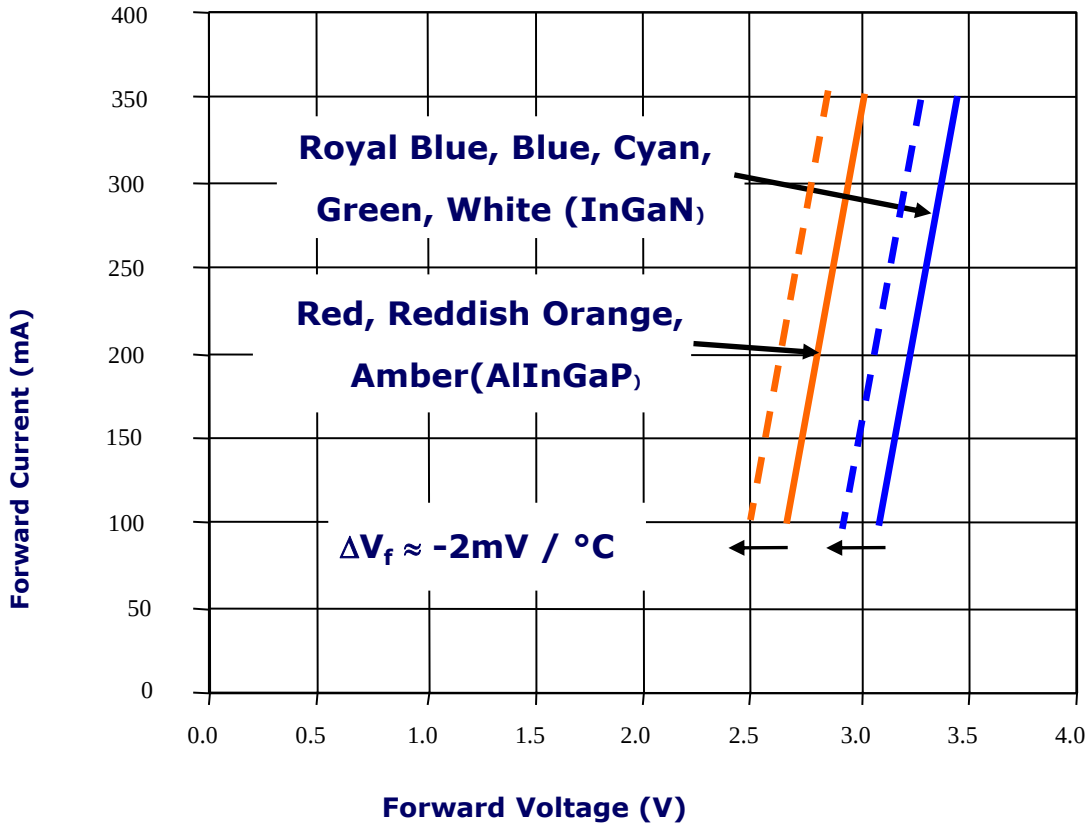


Color	Shift (nm/°C)
Amber	.09
Red	.03
Blue	.04
Green	.04
Cyan	.04

PHILIPS

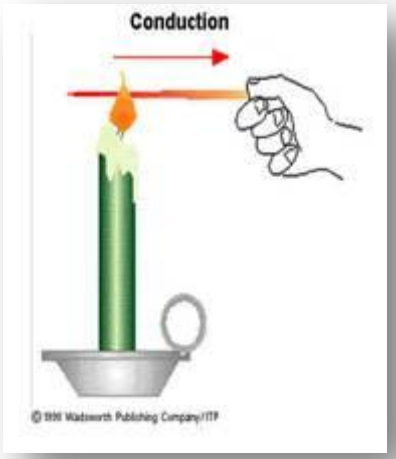
Effects of Heat on the LED (3 of 3)

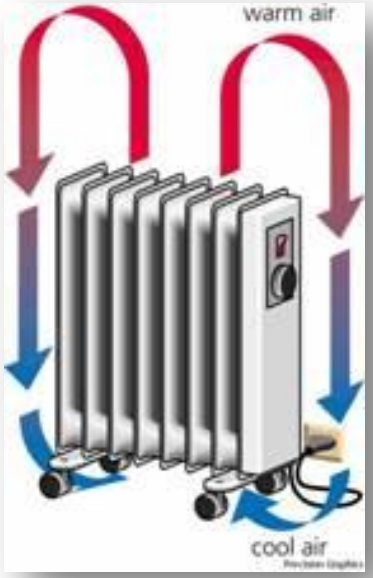
Forward voltage *decreases* with temperature



Cooling considerations

- Conduction:
  - The transfer of heat energy through a substance or from one substance to another due to temperature difference
- Convection:
  - 2 kinds of convection: **natural** and **forced**
- ***In an LED application both principles are used: conduction followed by convection to the air***





PHILIPS

Where does the Power Go?

•98% of an incandescent bulbs' energy is converted to heat.

- 10% of this heat is removed from the back of the lamp via conduction.

• On average, 65% of the energy through an LED is converted to heat. All of this heat must removed by conduction then convection.

• Thermal design is critical to an LEDs lifetime and performance.

Source	Lm/W	Visible Light	Radiated Heat (IR)	Conducted Heat
Bulb	5-25	0.7-2 %	88%	10%
LEDs	80-140	34%	0.2 - 1%	65%

What are the thermal challenges facing LED lighting?

- Being buried in a ceiling or bulb - little airflow to remove heat. Lots of weight (cost), active cooling (cost), bracing (cost), codes (cost). Can we develop luminaires that are on the floor or attached to the wall?

- PCB boards (L2s) – MCPCB, FR-4,Ceramic –
  - L2 s equal money and soldered interfaces = lower reliability , higher thermal resistances, higher cost.
  - How do we eliminate PCBs?

- Can the thermal solution be part of the mechanical/optical system?

Megatrends

1. Lighting will cease to pierce the plane of the ceiling

2. Direct Current may become standard in residences (?)

3. Smart building design will enable a new building system approach: Lighting, HVAC, Desk-top, Security, Sound, etc. Software controlled.

4. Specialty applications: color, behavioral control, learning acceleration, horticulture, agriculture, etc.

5. The US lighting market will bifurcate: New Market v. Installed Market

Courtesy of EGRET CONSULTING GROUP

PHILIPS

How Companies Will Succeed

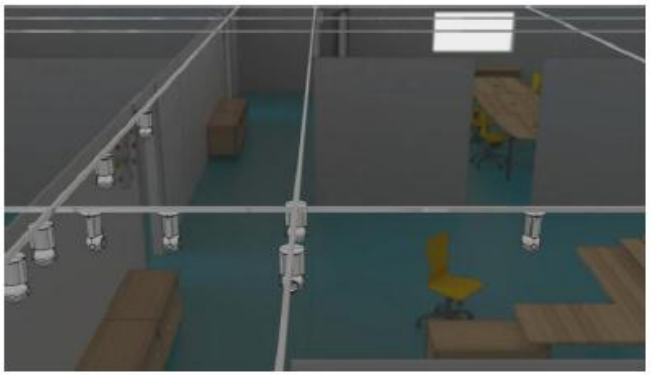
- Clear strategy
- Multiple channel agility and relationships – DOE, County Govt, industry
- Design innovation – Thermal/ Optical/ Mechanical/ Electrical (TOME) integration.
- Broad grasp of building product changes:
  - HVAC, controls, security, communications
  - Installation, labor issues, technology R&D
- Capital
- TALENT

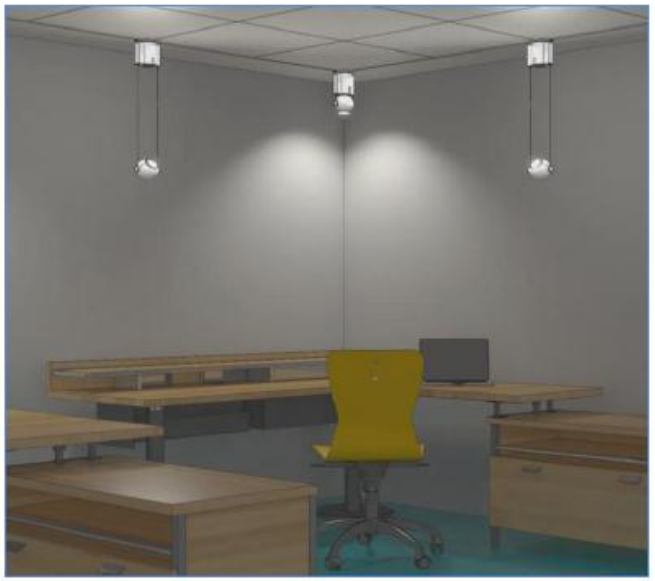
Courtesy of EGRET CONSULTING GROUP

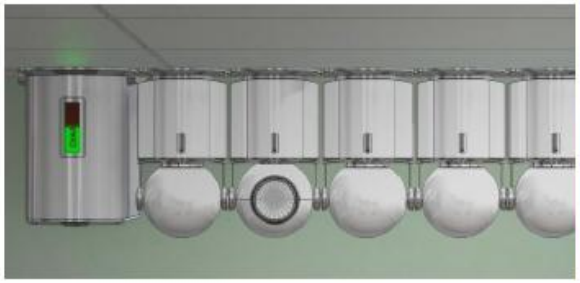
PHILIPS

LEDs in Lighting Systems

- Mobli™ concept: Track-mounted luminaires for flexible lighting in office spaces
  - Wirelessly controlled, battery-powered mobile light heads
  - Users define lighting schemes using workstations or smartphones
  - Powered by rechargeable batteries, charged at night when power is cheapest







Mobli concepts courtesy of Pacific Northwest National Laboratory.

The LED Revolution – M.O.T.E

Luxeon S 5000

Courtesy Celsia Technologies

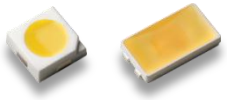
PHILIPS

Conclusions

- **The LED industry is experiencing a rapid decrease in price per lumen** – commoditization has come to the industry early

- **Simple, elegant and cost –effective thermal solutions are key** to an LED lighting system

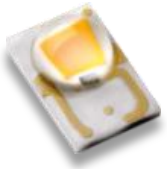
- Technologies that **eliminate layers of product** can reduce cost, improve thermal resistance and increase overall system performance- these will be winners



Thank you for your time !

Questions ?

Patrick Bournes
Packaging Innovation, Philips Lumileds
patrick.bournes@philips.com




PHILIPS

Spectral Comparison of Warm White LED, Fluorescent Tube and Incandescent Bulb