ADVANCED MATERIALS FOR LED LIGHTING

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Cree Lighting
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What Will the Products of the Future Look Like?

- New Form Factors
- Smaller Volumetrically / Lighter Weight
  - With Illumination Performance Improvements; Brightness Control, etc.
- Less LED Material at Higher Power???
- More LED Material at Lower Power???
  - Cheaper and Better LEDs
  - Less Heat…
- More Housing Material Options
  - Plastics… Low Environmental Impact Options
- As Close to One Highly Reliable Circuit Board as Possible
  - Fully Populated for all Possible Functionality (Less SKUs)
    - Programed at Factory or During Installation (Commissioning)
  - Populated as Needed (More SKUs, More Inventory Challenges)

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Component and Process Consolidation for Greater Overall Value

- Fewer Electronic Components and Circuit Boards
- Fewer Manufacturing Process Steps and Associated Risk (Higher Reliability)
- Full Function Solutions With Flexibility to Configure/Reconfigure as Needed (programmable?)
- Higher Energy Performance Possibilities
- Less Electrical Compatibility Conflicts
- Lowest Average Product Cost
- Greater Possibilities for Highly Reliable Solutions

Do they need to be "serviceable”???

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Overcoming Resistance to the “Non-Serviceable” Solution

- High Reliability
- Long Warranty Periods
- Acceptance of Non-traditional Form-factors
- Acceptance of Non-traditional Materials and Manufacturing Processes
- Etc…

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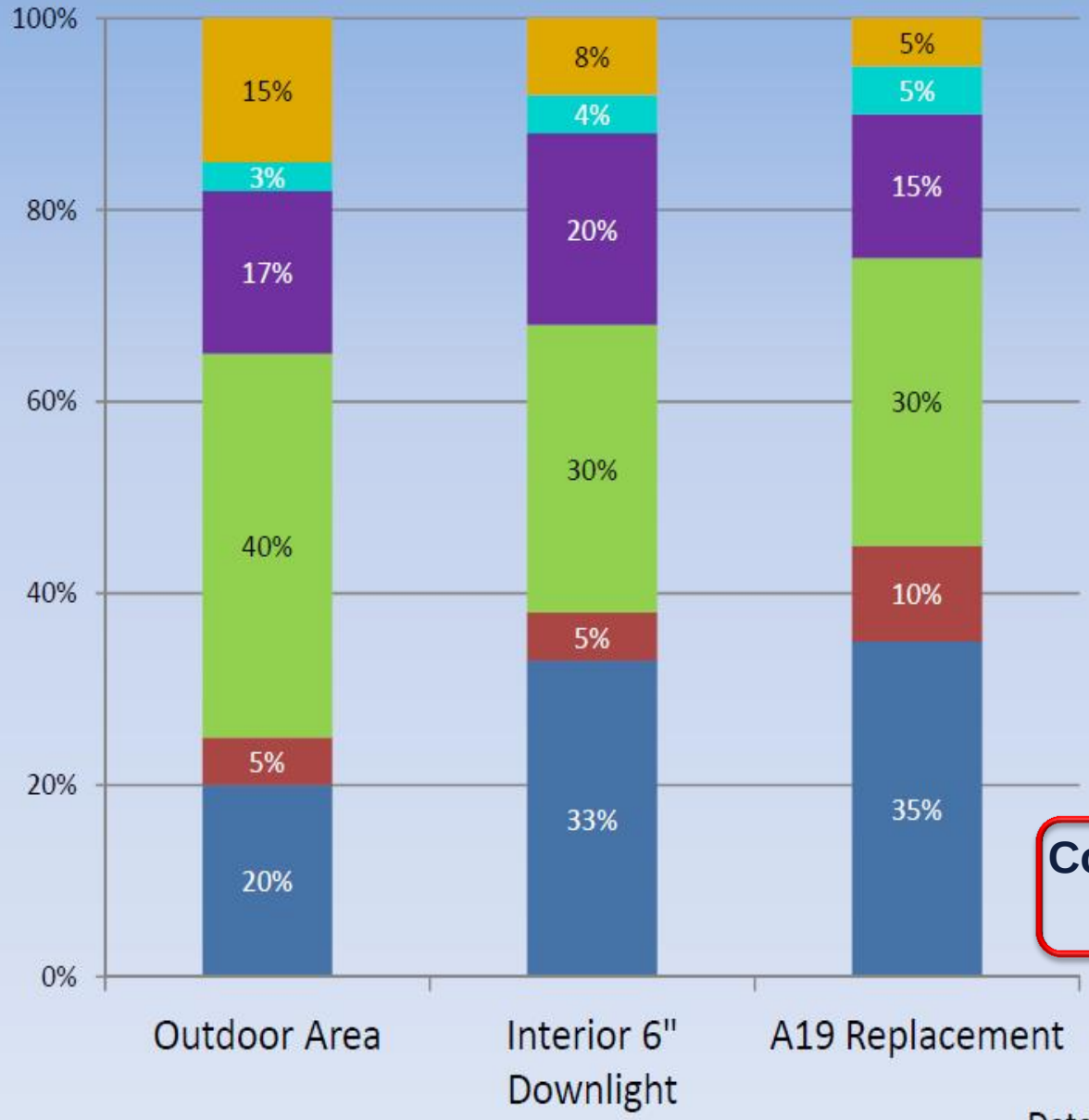
Cost Breakdown for Various LED Solutions



We Need to Shrink All Remaining Costs

- Overhead
- Assembly
- Driver
- Mech/Thermal
- Optics
- LED Package

Cost Per Delivered Performance Continues to Shrink

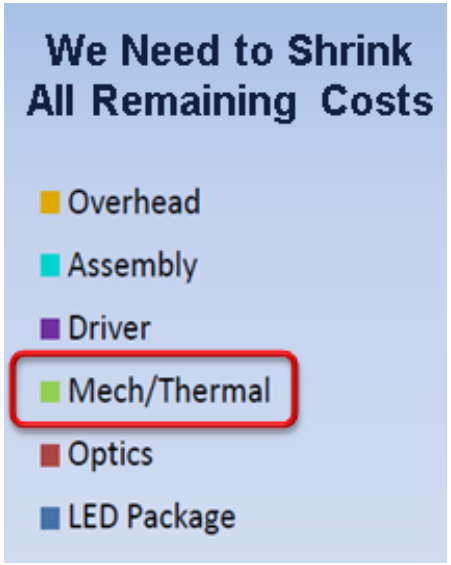
Data source: DOE R&D Manufacturing Roadmap, September 2013

Luminaire Housing Materials Challenges and Opportunities

What would the ultimate material look like?

- Manufacturability
- Durability
- Safety / Compliance
- Cost
- Etc…

- All of the Good Properties and None of the Bad
  - Aluminum
  - Engineered Plastic Composites
  - Steel
  - ABS
  - Etc…



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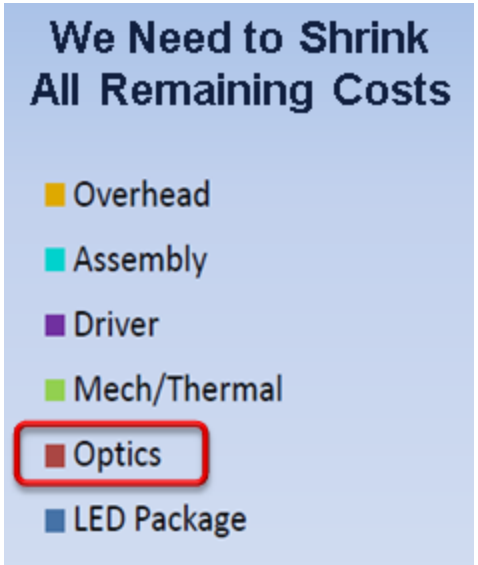
Optical Materials
Challenges and Opportunities

What would the ultimate material look like?

- Manufacturability
- Durability
- Optical Properties
- Safety Compliance
- Cost
- Etc…

- All of the Good Properties and None of the Bad
  - Acrylic
  - Polycarbonate
  - Glass
  - Silicone
  - ABS
  - Etc…
    - “Printable” optics?



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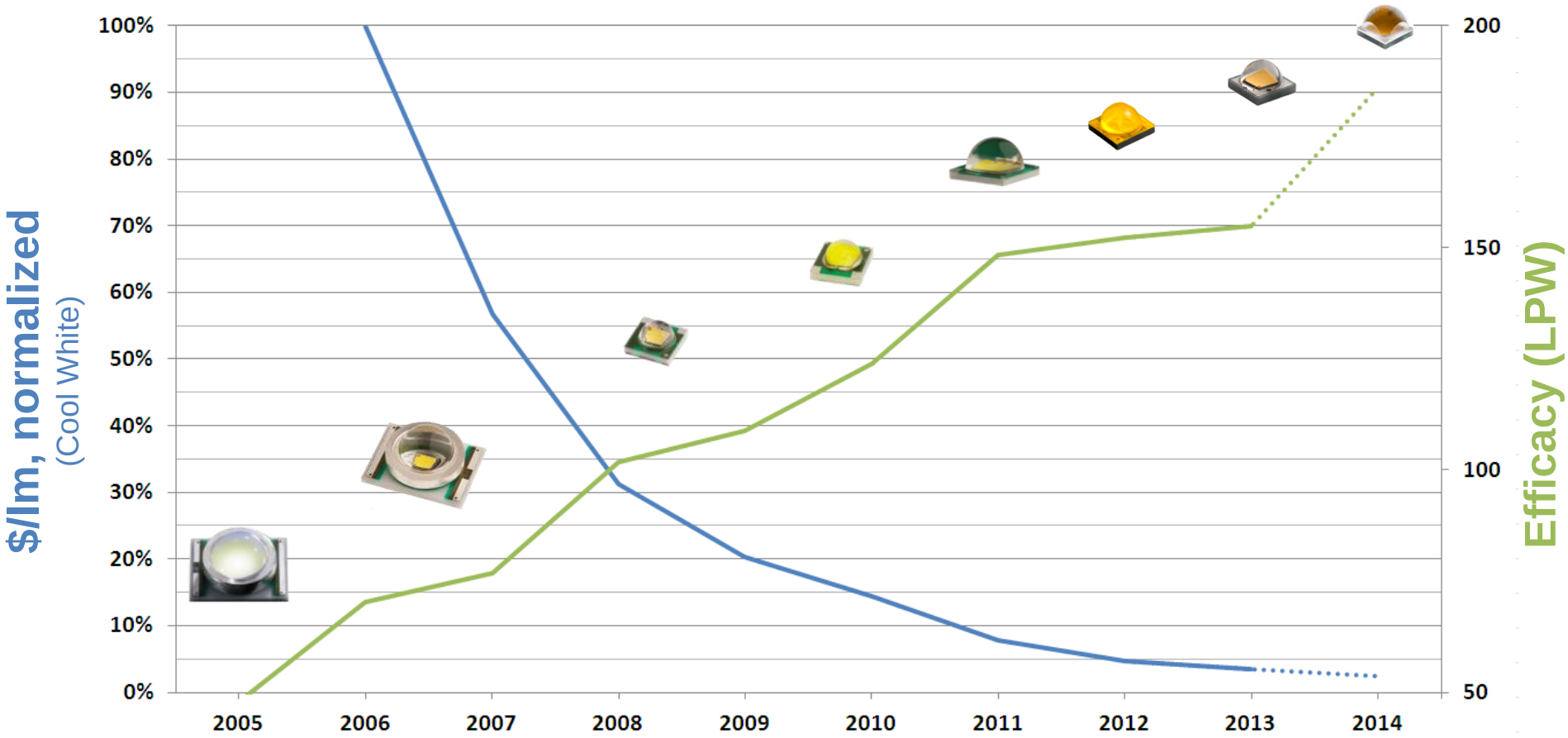
Packaged LED Value Evolution



Annual Improvement in $/lm @ 100 LPW	43%	45%	35%	29%	45%	40%	27%	

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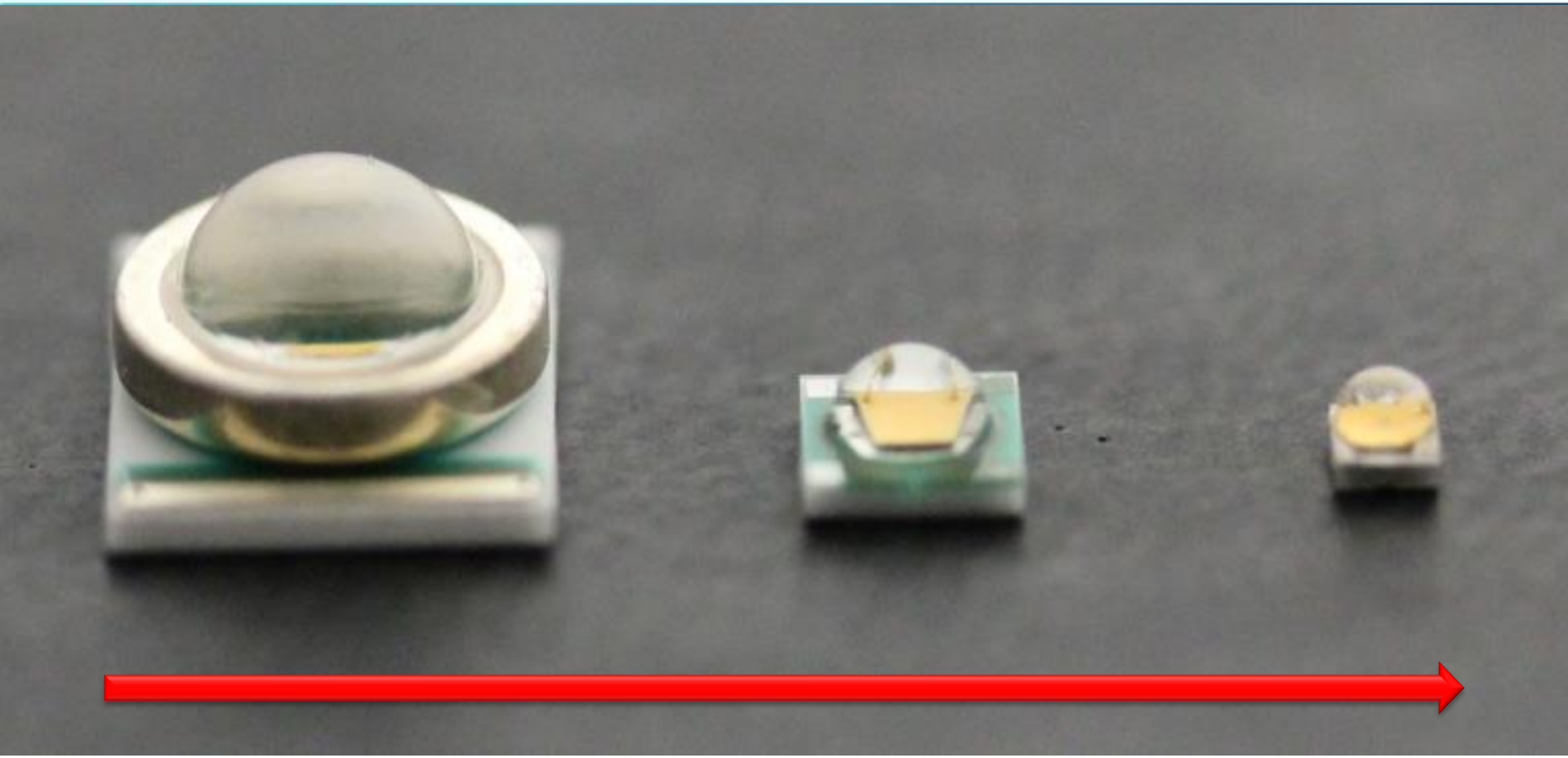
Different Die and Package, Same Performance



96% Reduction in Size (volume)

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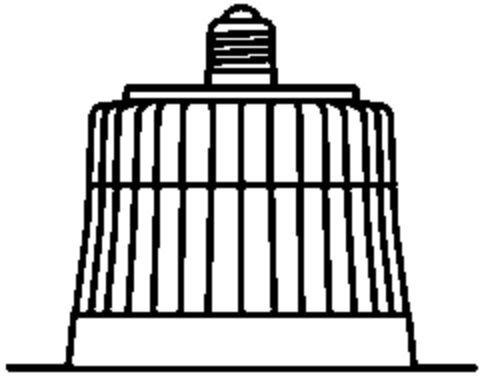
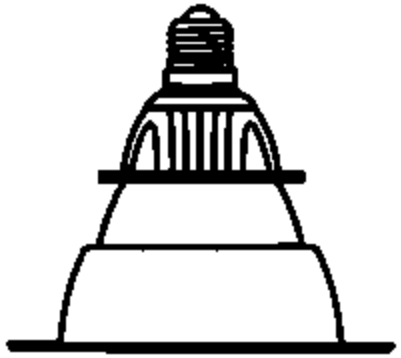
Example of the Cost Impact of Increasing LED Performance

2007

- 42 LEDs
- 650 lm
- 12W





>$100 Commercial Wholesale

$19.97

~~$39.97~~

~~$49.97~~ Retail

~~5~~ ~~3~~ 3 ~~5~~ 2011

- ~~8~~ LEDs
- 650 lm
- ~~10.5W~~ ~~10W~~ 9.5W

The same thing is happening in other segments of LED lighting

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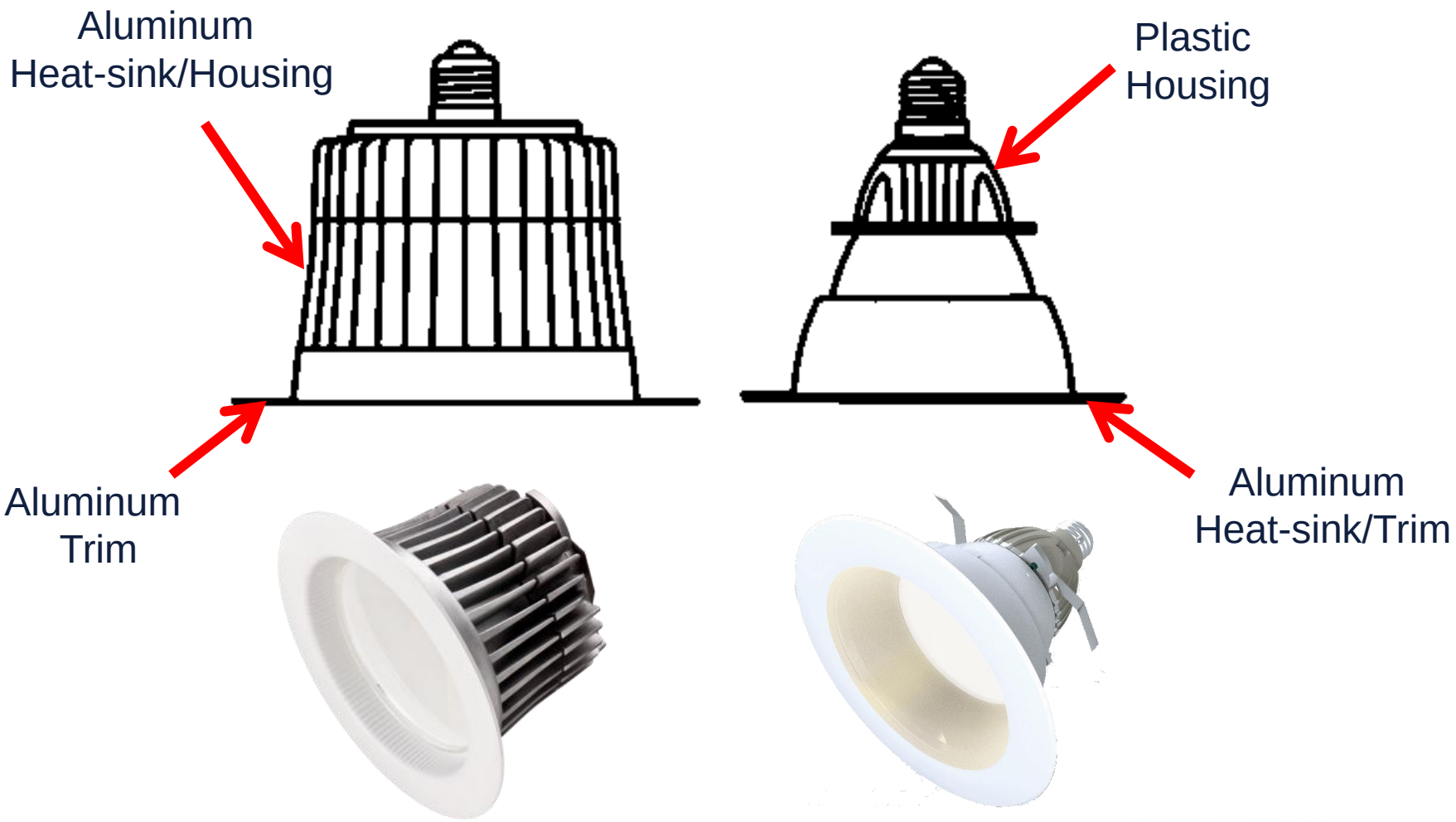
Material Use Optimization



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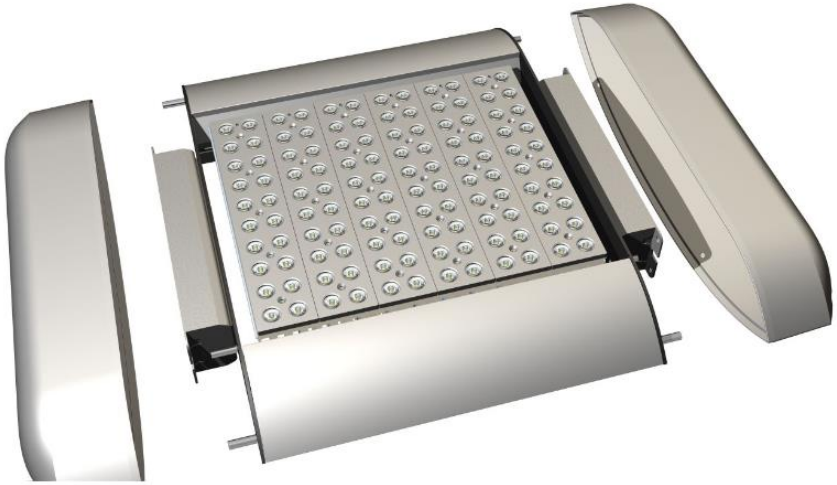
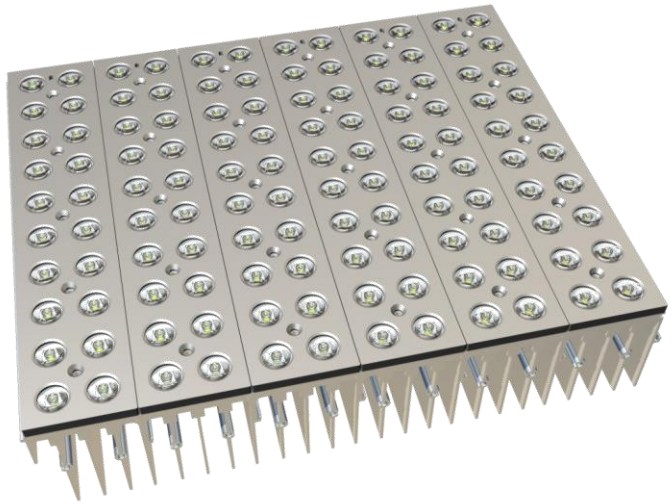
Thermal Management Value Opportunities Have Changed





Extruded Aluminum

Thermal Conductivity = ~250 W/m-K

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Thermal Management

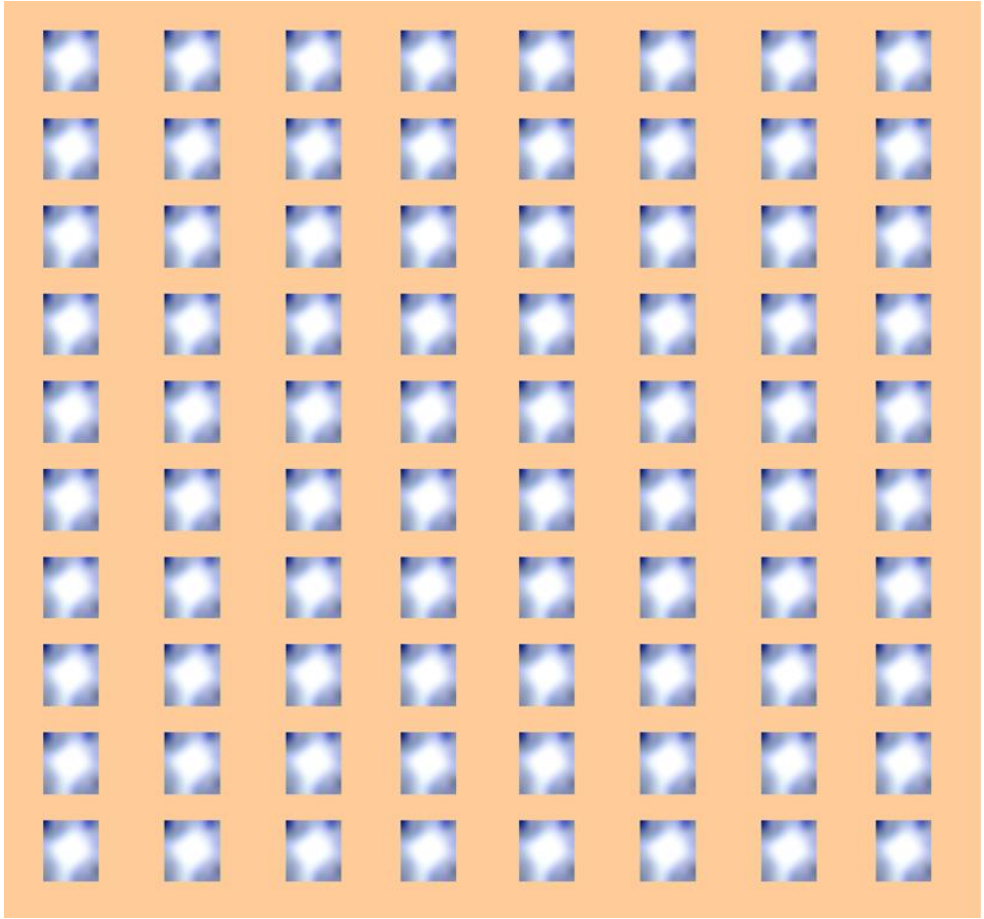
More LEDs With Same Total Power…

More Light…

Less Heat…

Less Energy…

More Cost???



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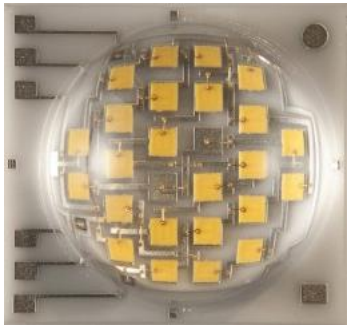
Multi-Die Packages



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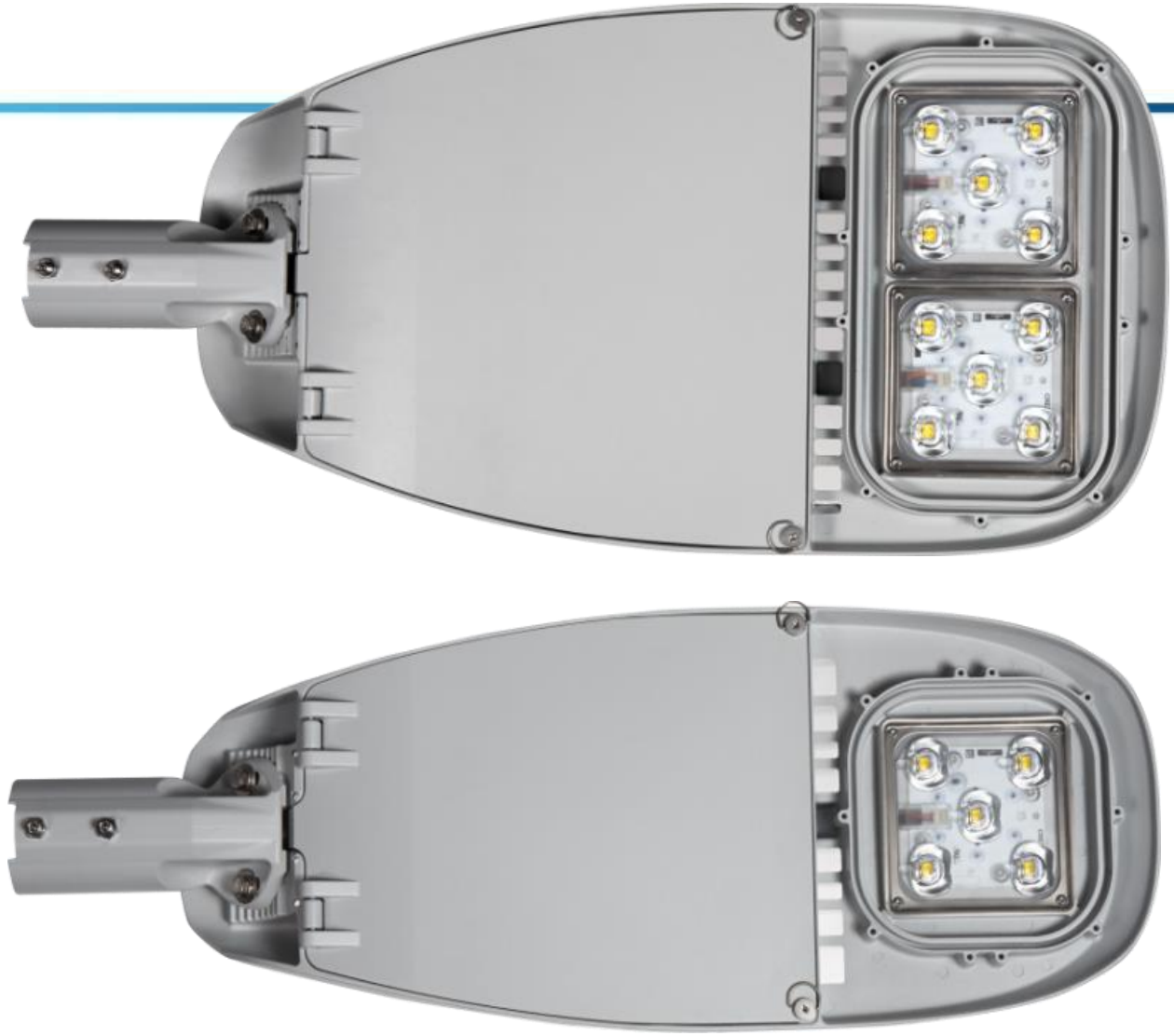

Die Cast Aluminum

Thermal Conductivity = ~125 W/m-K

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Metals to Engineered Composites

Automotive Examples

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Automotive Application Examples

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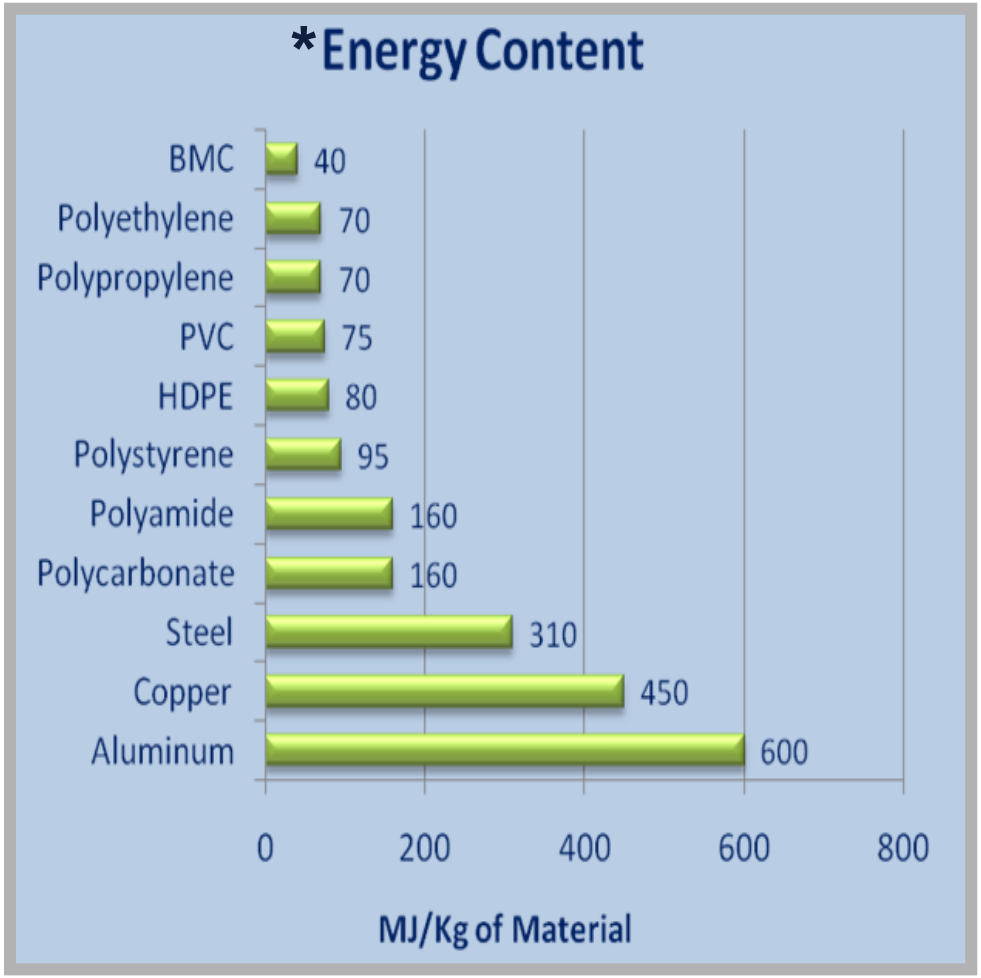
Environmental Impact



1 Megajoule (MJ) = ~1/4 Kilowatt-hour (kWh)

Engineered Composite Bulk Molding Compound (BMC) Example

- **Inherently Low Energy Content**
  - **Requires Less Energy to Produce / Process Than Other Materials**
- **Recyclable as Filler into Virgin BMC or Other Applications**

Embedded Energy

Aluminum = 15X BMC

*The non-renewable energy required to produce a unit of finished material.

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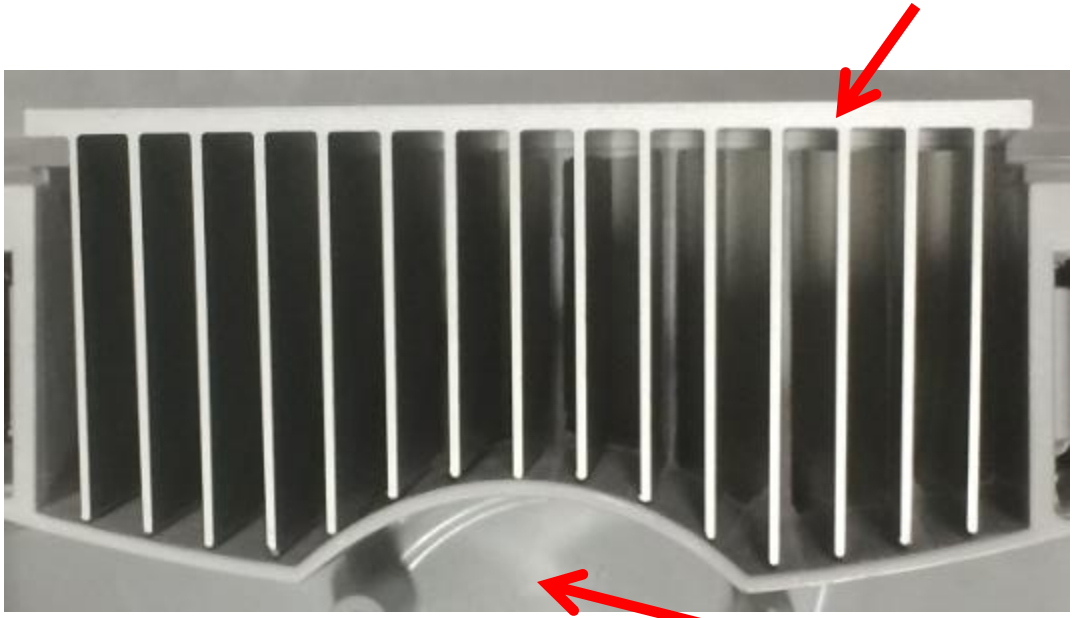
Hybrid Luminaire Housing

Heat Sink
Thermal Conductivity = ~250 W/m-K



Housing
(Engineered Composite)
Thermal Conductivity = ~25 W/m-K

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Non-Metallic Engineered Composites

- **Possible Advantages**

  Durability
  - Corrosion Resistance
  - UV Resistance
  - Mechanical Vibration and Shock

  Molded in Color (no secondary painting required)
  - Long Life Color Retention

  High Strength-to-Weight Ratio
  - Comparably Lighter Weight Products
    - Installation Benefits
    - Lower Shipping Costs
  - Generally Higher Resistance to Brittle Fractures Compared to Aluminum and Other Materials

  Non-Metallic
  - Electrical Insulating Properties (safety… ground fault protection, etc…)

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Optics

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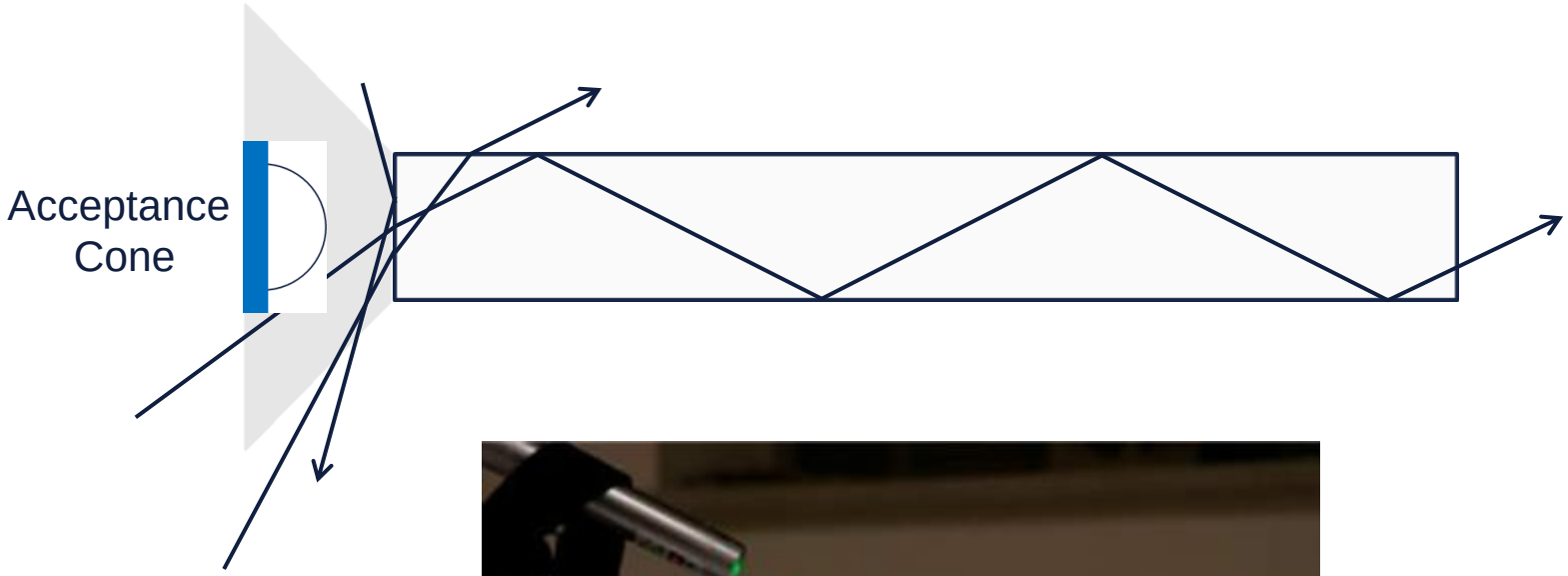
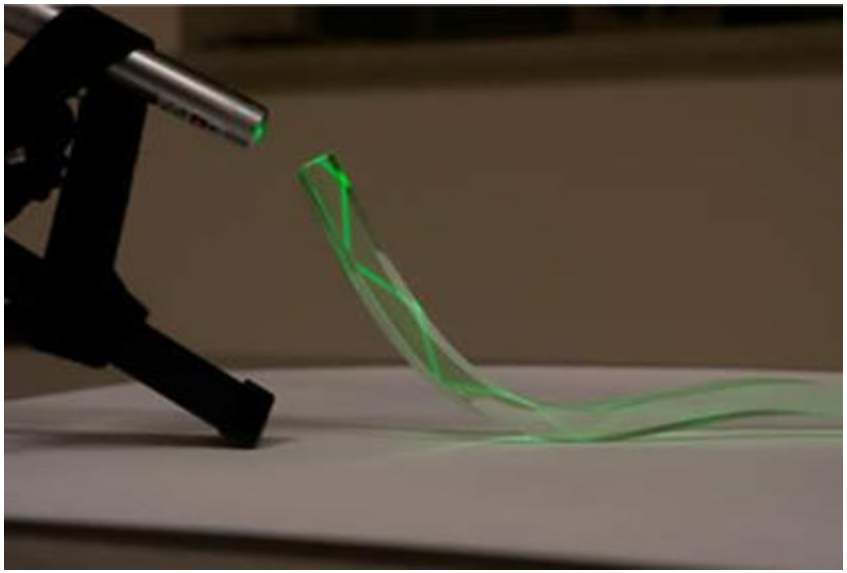
Optical Coupling and Extraction

- **Total Internal Reflection (TIR) Example**





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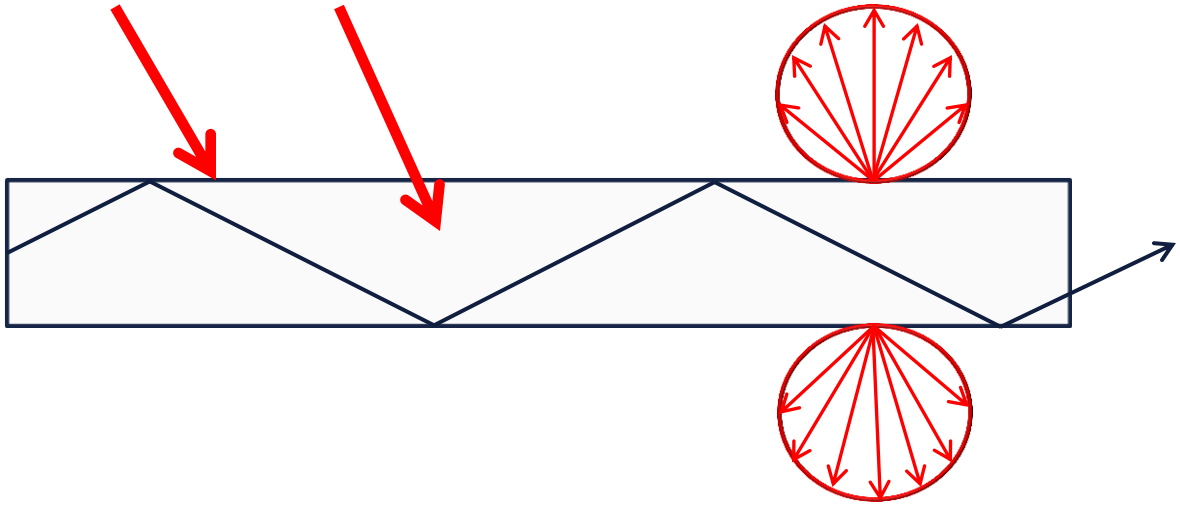
Simple Extraction

Roughen / Diffuse to Extract and Distribute Light



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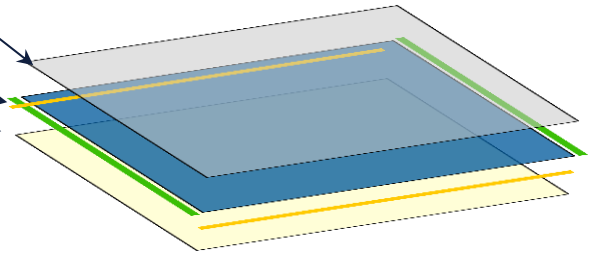
Simple Waveguides

- Core Technology from Display Backlighting
- Optical Coupling Losses
- Often Requires Addition of Reflectors, Etc…, to Recycle Light Not Efficiently Extracted
- Usually Around 80% Optical Efficiency
- Typically Limited Optical Control Possibilities

Typical "Simple" Waveguide :

1) Room-Side Diffuser
2) Side Reflectors
3) Waveguide
4) Back Reflector



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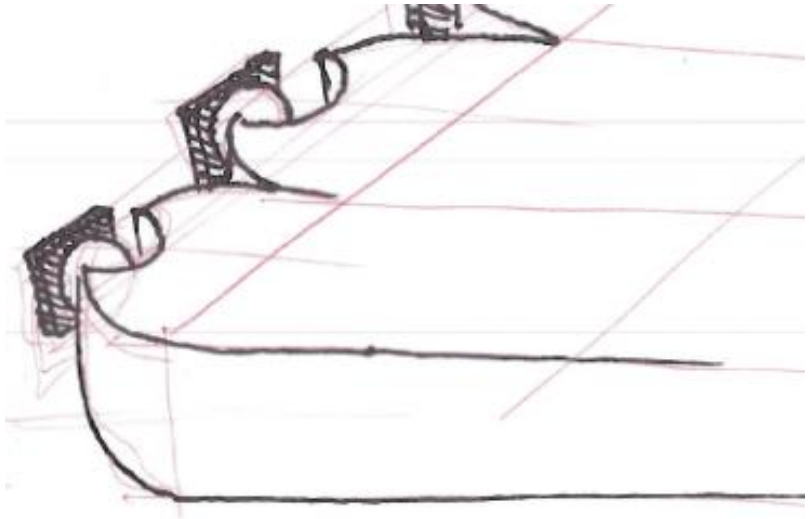
Maximizing Optical Coupling

The coupling surface is designed to maximize the amount of light entering the wave guide from the source



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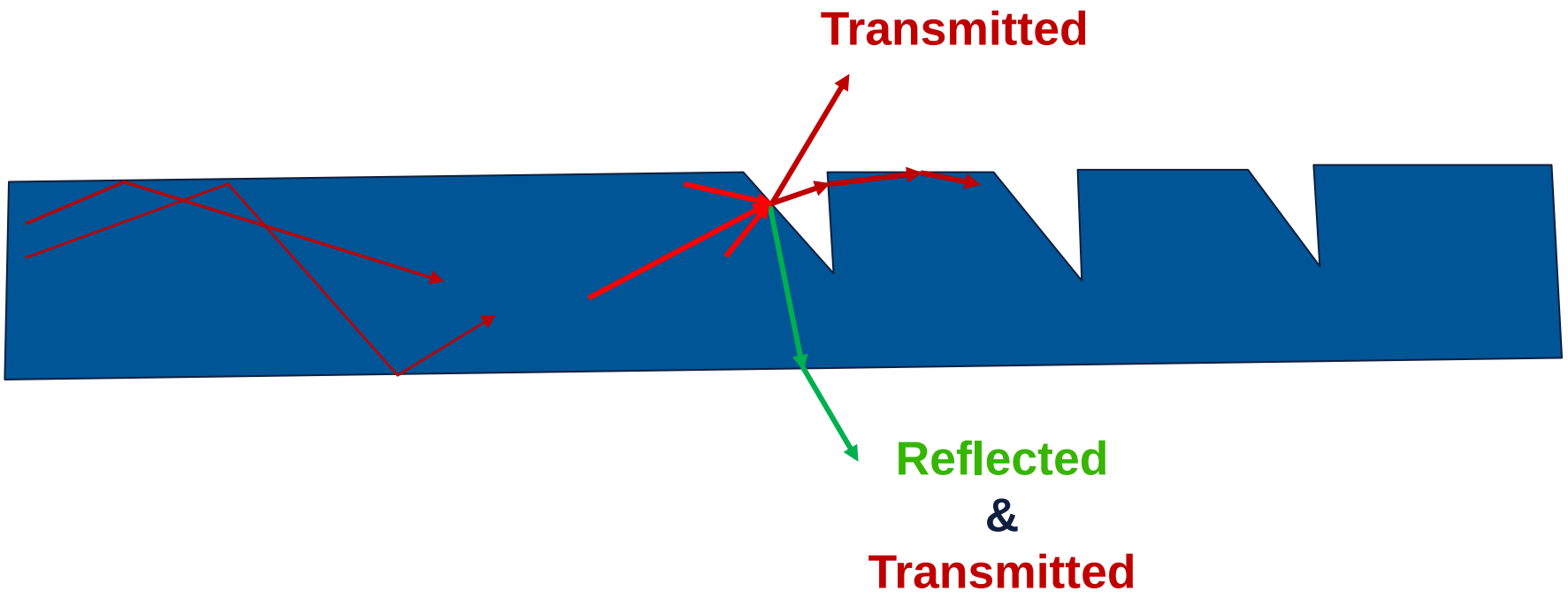
Precise Light Extraction Features



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Features Can Be Very Small

Minimum feature size required is approximately 80 microns

80µ = ~0.003 in

Maximum allowable surface "roughness"

0.0000015 in

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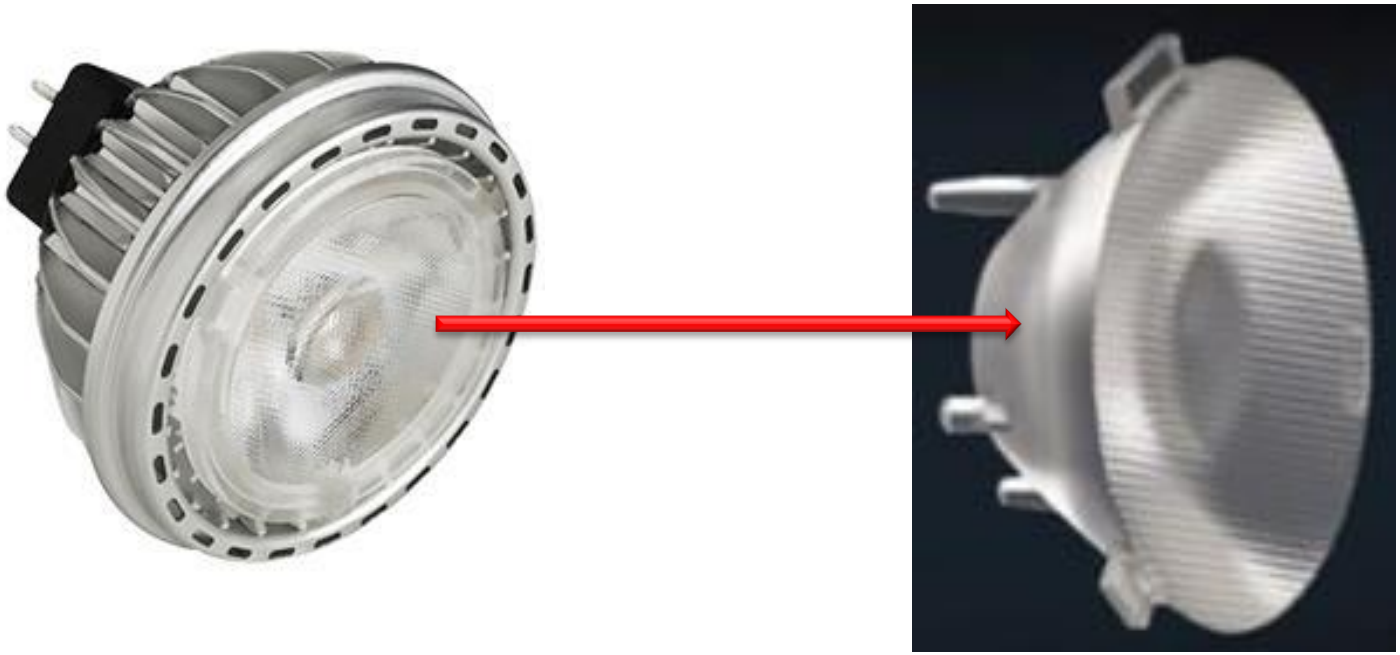
Molding Challenges

Precision, Repeatability, Processing Cost



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Eric Haugaard
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January 28, 2015

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