
Strategies in Light
FEBRUARY 27 - MARCH 1, 2019 I MANDALAY BAY CONVENTION CENTER I LAS VEGAS, NV
ADVANCING THE
FUTURE
OF LIGHT
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PennWell
LEDs MAGAZINE
Strategies Unlimited

SESSION 1 PANEL:
Can 3D Printing Revolutionize the Lighting Industry?

N. Narendran, PhD

Lighting Research Center, RPI

Panel Moderator

Our panel today

Dustin Kloempken
Application Engineer
Hewlett-Packard
United States

Aaron Smith
VP of Technology and R&D
Finelite, Inc.
United States

Sridhar Nimma
Engineering Leader / Specialist
R&D and Innovation (printed electronics, sensors, and additive manufacturing)
Eaton
United States

Hugo da Silva
VP of Additive Manufacturing
DSM
Netherlands

Willem Sillevis Smitt
Senior Director Strategic Marketing
Lumileds
United States

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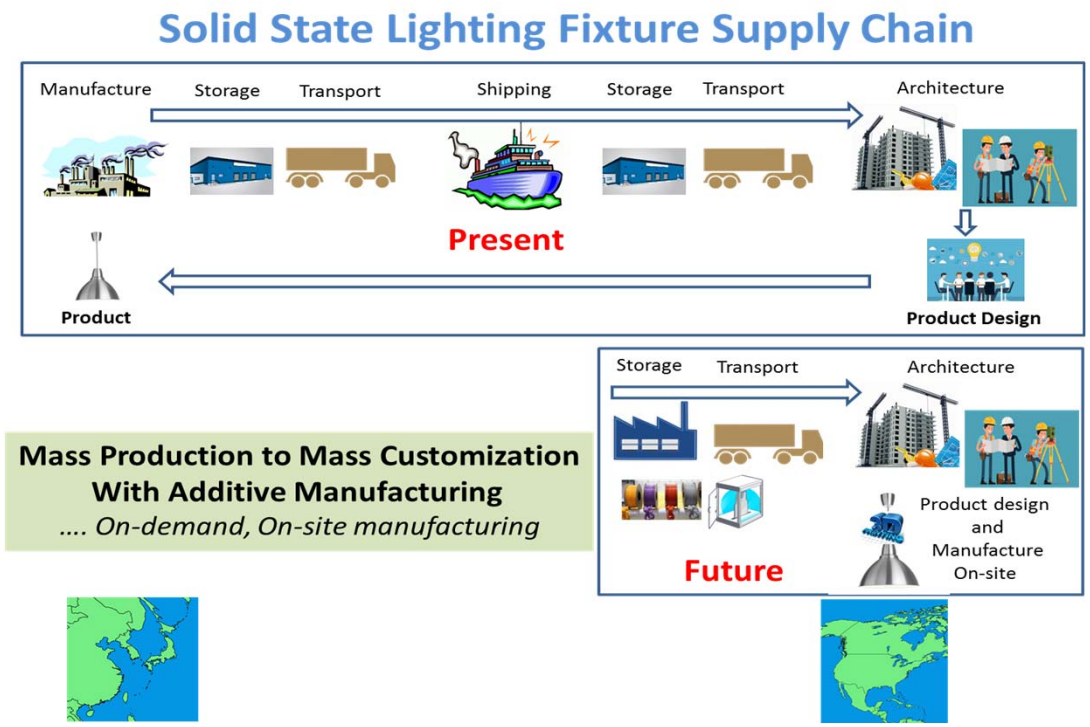
Why consider 3D printing for lighting?

- Industry trend
  - LED lighting fixtures or subassemblies are manufactured overseas and shipped to U.S.
    - Commodity market (low cost)
    - Increased carbon footprint
- Lighting trends for the next five years
  - Lighting fixtures with more functionality
    - Sensors, radios, processors, etc. (IoT ready)
- 3D printing could further add value
  - Affordable custom lighting fixtures, made on-site, on-demand



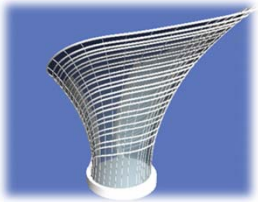
What is our vision for SSL and 3D printing?

- Ultimately, the goals are to
  - Change architectural lighting practice
    - Integrate lighting design into building design
    - Manufacture on-site, on-demand
- Impact
  - Blended light fixtures
    - Building design and improved visual appeal
  - Faster fixture design revisions and manufacture
    - Bring back jobs to construction locations
  - Reduction of cost
    - Energy-efficient manufacturing, shorter transportation distances, reduced storage time
  - Reduced environmental pollution
    - Manufacturing, transportation, and storage
  - Economy
    - Bring back manufacturing jobs

Change Architectural Lighting Practice

https://commons.wikimedia.org/wiki/File:Edificio_dise%C3%B1ado_para_el_mar.jpg

Fixture design



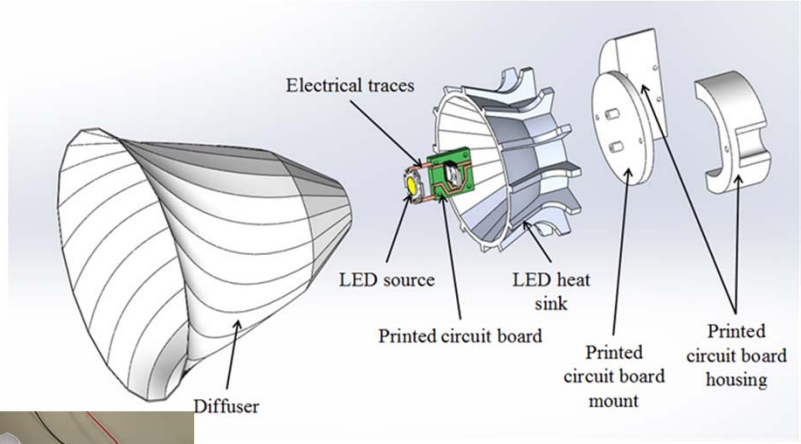
Custom fixtures

On-demand, On-site manufacturing

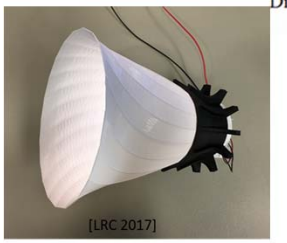
Credit: Lighting Research Center

What needs to happen?

- Need to ensure that functional thermo-mechanical, electrical, and optical components can be fabricated using current and future 3-D printing technologies and materials to produce complete SSL lighting fixtures
  - Developments needed
    - Materials
      - Mechanical
      - Thermal
      - Electrical
      - Optical
    - Printers and processes
    - Electronics integration
      - Drivers, sensors, connectors, etc.



Credit: Lighting Research Center



Credit: Lighting Research Center

Areas to be addressed by the panel today

Dustin Kloempken
Application Engineer
Hewlett-Packard
United States

Srinivas Garimella
Sr. Manager, Global Leader
Additive Manufacturing
Center of Excellence
Eaton Corporation
United States

Aaron Smith
VP of Technology and R&D
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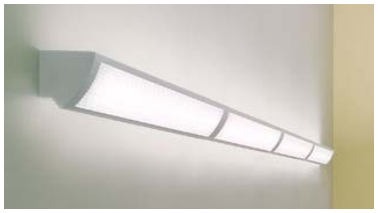

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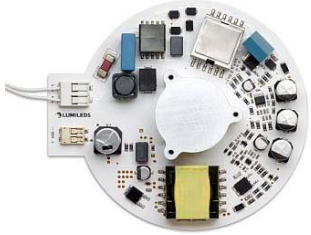

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The (near) Future of Product & Lighting Design

Dustin Kloempken

Application Engineer – 3D Printing

HP

United States

Strategies in Light

What is the purpose of a door handle?

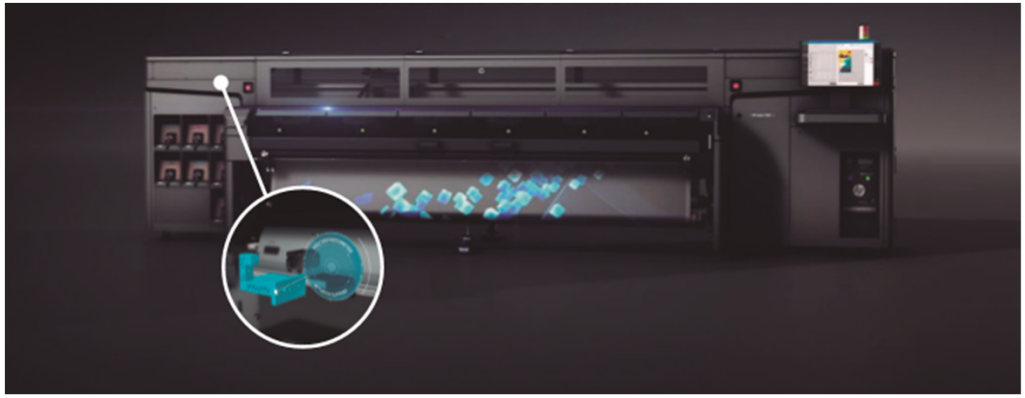
Why is a door handle typically solid?

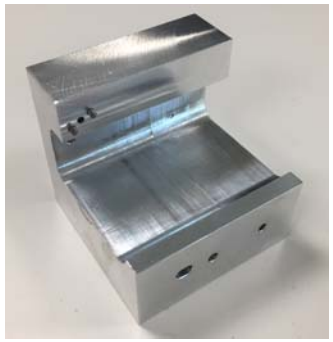
What does your part need to do?

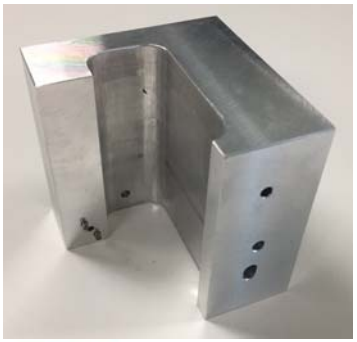
Goal:
- Optimize product design process
- Reduce supply chain costs
- Produce low volume, high value equipment via more cost efficient processes

Solution:
- A part called a "SOL actuator support" bracket was identified as a good part candidate
  - Positions a sensor that calibrates the color quality of print in the inkjet printer

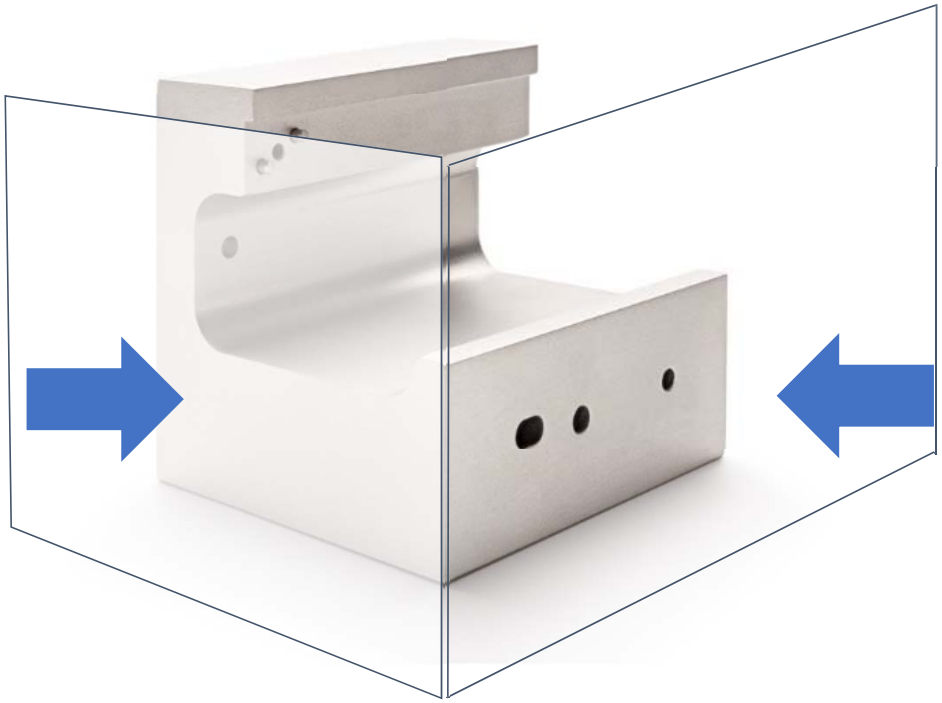
Results:
- Designed for performance
- Lighter and cheaper part with the same reliability
- Physical inventory → Digital inventory
- Part now qualified for "just-in-time" manufacturing processes







CNC machining cost relates to number of steps required to remove material

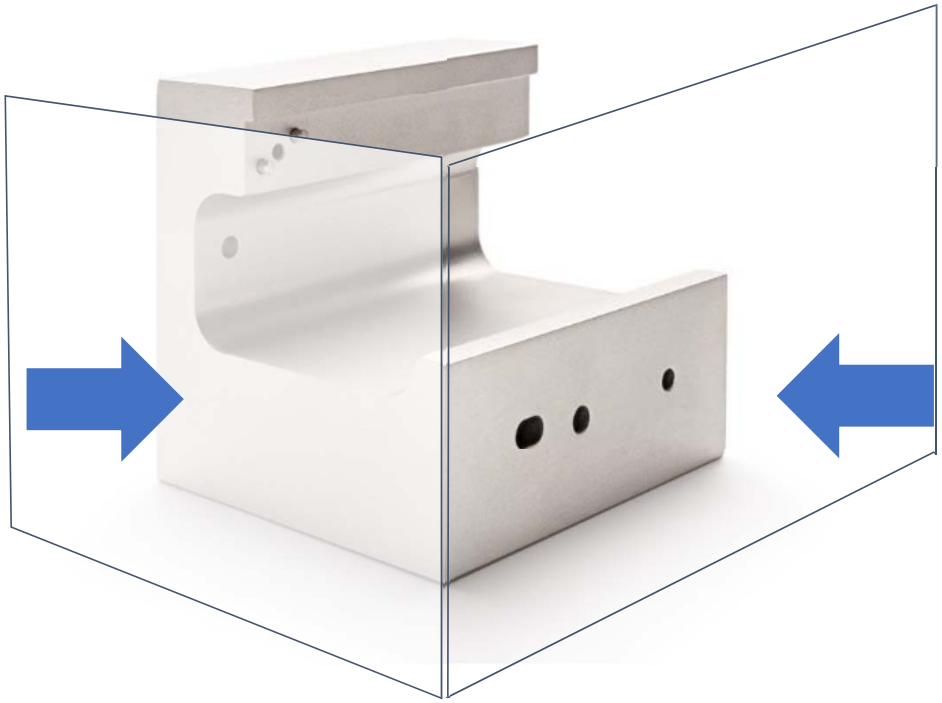


- Programming of cutter paths $
- Building jigs to hold parts being machined $$
- Fabricating custom cutters $$
  - For when standard sizes cannot create desired geometry
- Wasted material $
  - Machined chips
- Set up for machining $
  - Multiple Machines needed to cover all operations
- Break down of machining set-ups $
- Storage of jigs $

These costs are magnified as a percentage of costs for short runs common for low volume production

CNC machining cost relates to number of steps required to remove material

Subtractive Process



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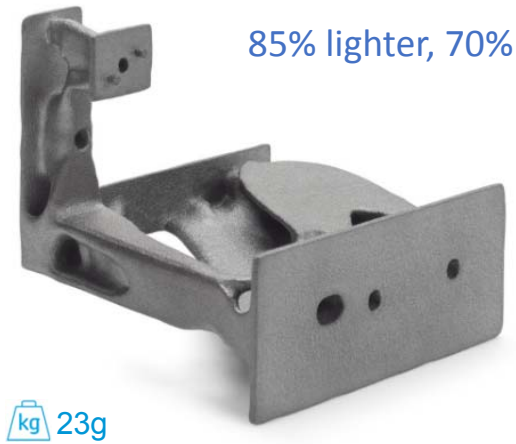
Printing costs related to amount of material consumed



85% lighter, 70% cheaper

	CNC	MJF				
	Aluminum	Solid	Topology Optimized	Topology + Lattice	Lattice Structure	Final
Volume (cm3)	129.44					43.91
Weight (g)	355					55
Cost	$22					$5.90

	Cost/part	Weight (grams)
Machined Aluminum	$22.00	355
MJF	$5.89	55
MJF Savings	***73%***	***85%***

Printing costs related to amount of material consumed

Additive Process

85% lighter, 70% cheaper

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	Cost/part	Weight (grams)
Machined Aluminum	$22.00	355
MJF	$5.90	55
MJF Savings	***73%***	***85%***

Subtractive vs Additive Manufacturing

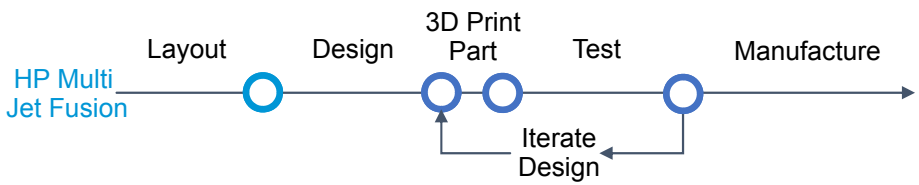
355g

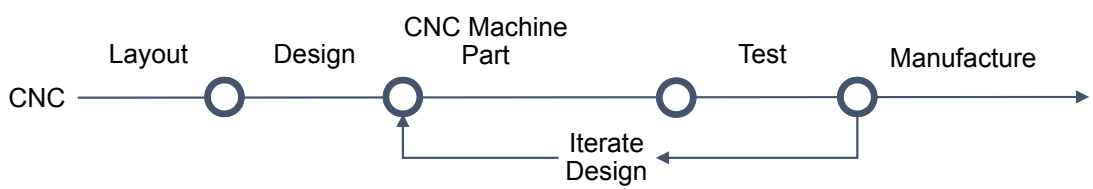
- Machined prototypes take days to weeks to make depending on design complexity
  - Programming of cutter paths
  - Building of fixtures to hold parts during machining
  - Number of CNC machines (or set-ups if constrained to one machine) for all operations
- CNC process machines one part at a time
- Each design iteration requires:
  - cutter path programming
  - Building of fixtures potentially--depending on extent of change
- More Aluminum used in part than necessary for function to minimize machining cost
  - Material wasted: Close to 40% of block removed (wasted)
- Even this simple part needs multiple operations in different orientations that require multiple stations or multiple set ups

23g

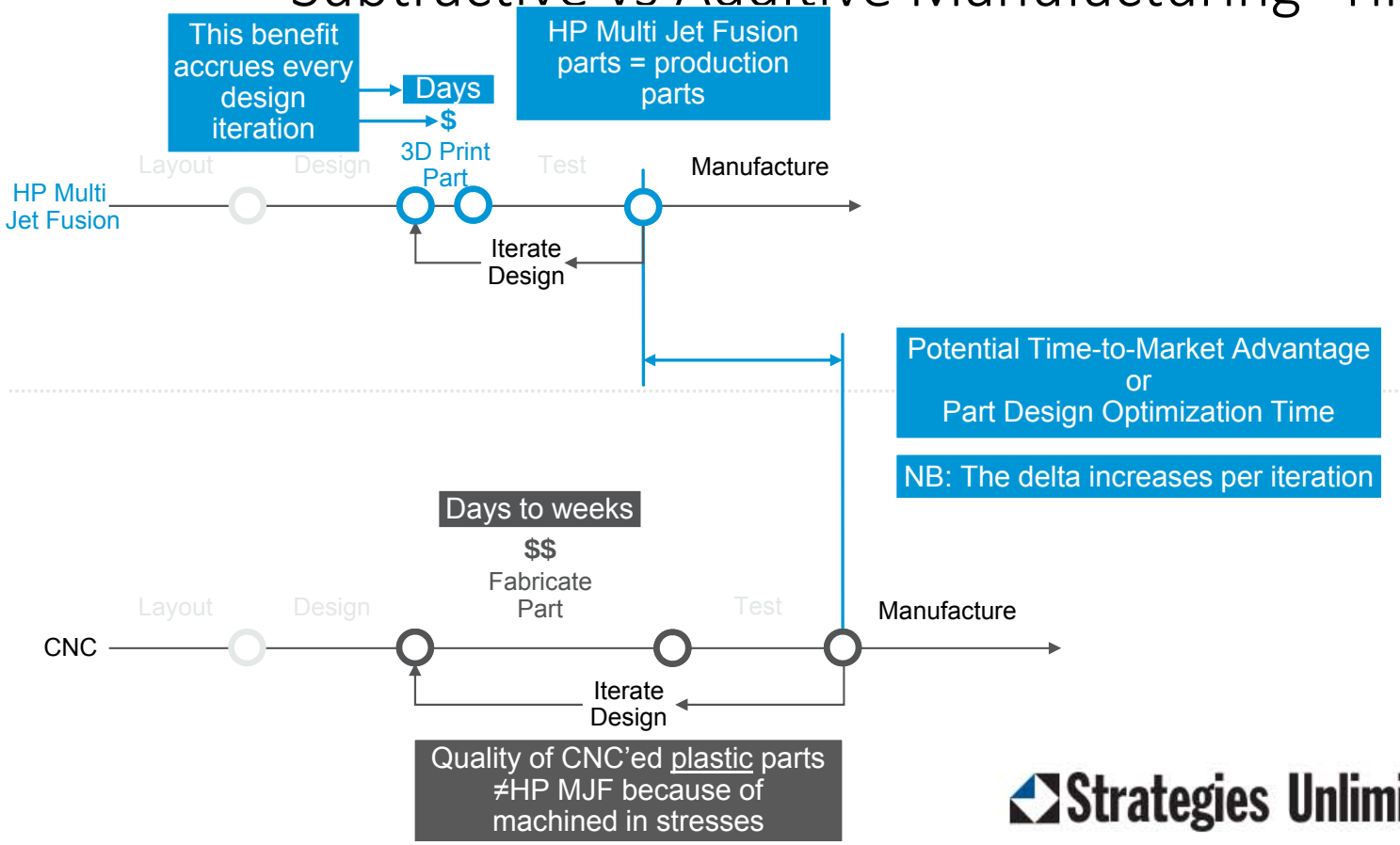
- HP Multi Jet Fusion parts can be available as fast as 24 hours
  - Complexity of design does not impact lead time
  - No fixtures needed to be built
- Multiple parts printed simultaneously
  - As many as can fit in build volume
  - Simultaneous availability of alternative designs accelerates optimization of design
- 85% lighter than CNC (due to material and lattice structure)
- Virtually all unused material captured for reuse

Subtractive vs Additive Manufacturing- Timing





Subtractive vs Additive Manufacturing- Timing



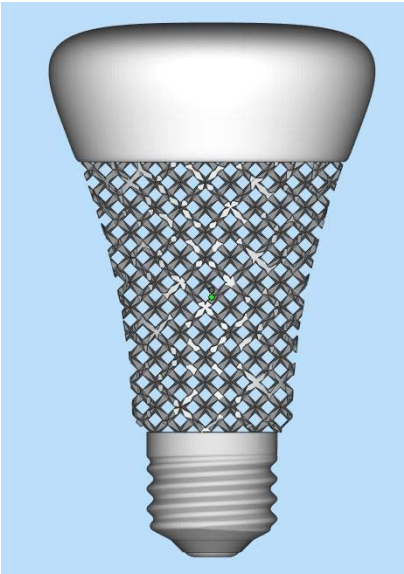
Re-imagining the lightbulb

What does a lightbulb really <u>need</u> to do?

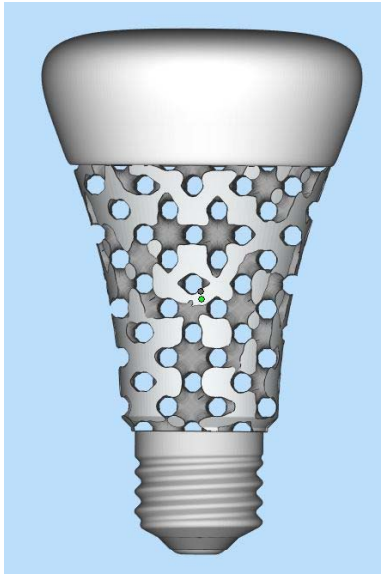
- Provide light
- Ideally: Not burn out quickly/last a long time
  - Accomplished via proper thermal management
  - Use durable materials

Heat Sinks Reimagined

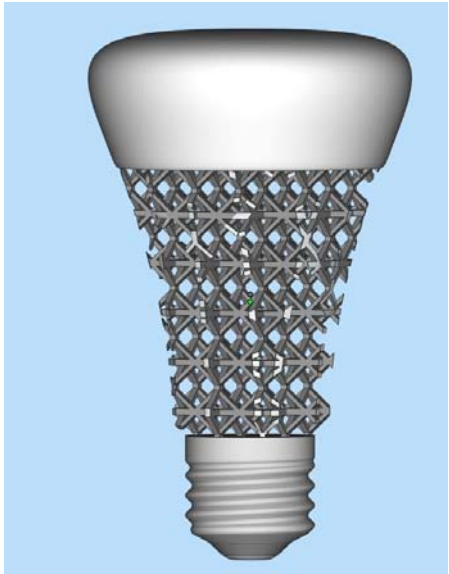
Can AM dissipate heat correctly?
Are the materials durable enough?



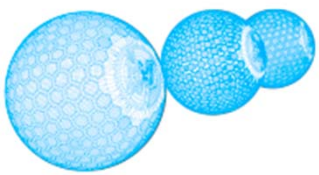
Heat Sinks Reimagined

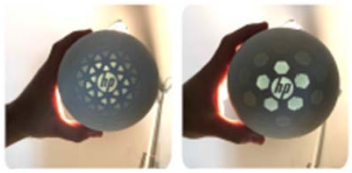


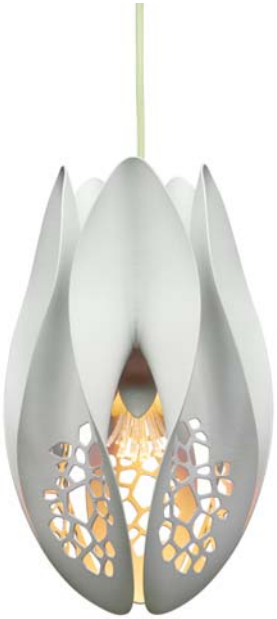
Heat Sinks Reimagined



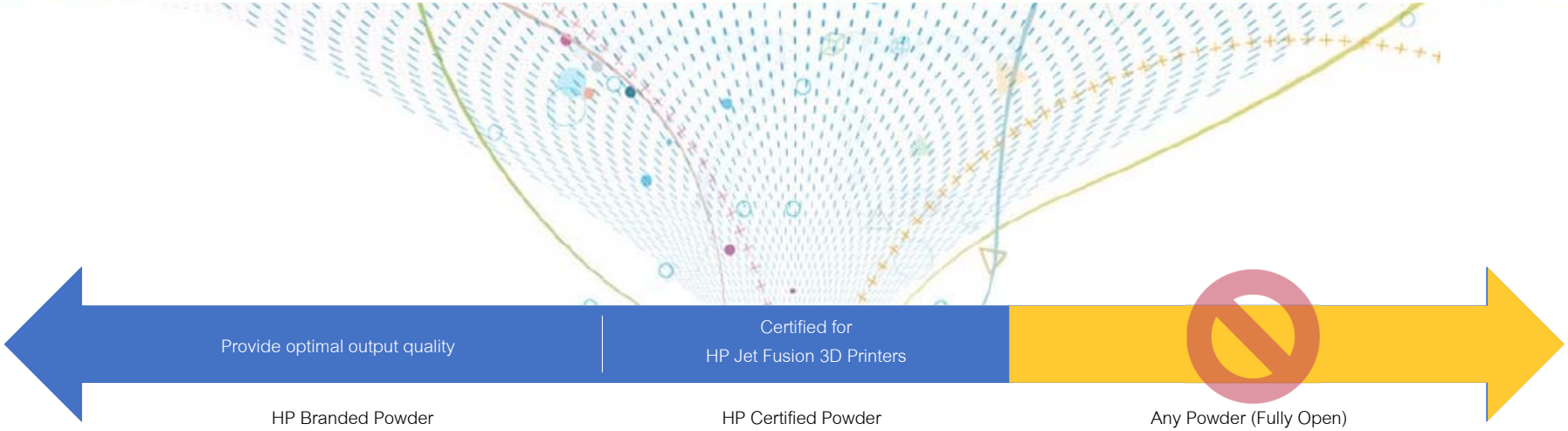
What does your design <u>need</u> to do?







Data courtesy of RP2 B.V.

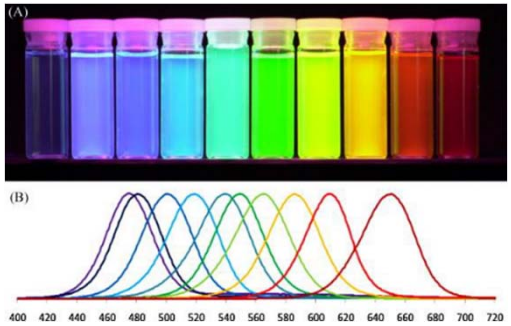


OPEN PLATFORM

ARKEMA
BASF We create chemistry
dressler group
EVONIK INDUSTRIES
Henkel
Lehmann&Voss&Co. LUV
Lubrizol
SIGMADESIGN
SINOPEC
Strategies Unlimited®
LEDs MAGAZINE
PennWell®

Color provides visible and hidden information

Embedded information



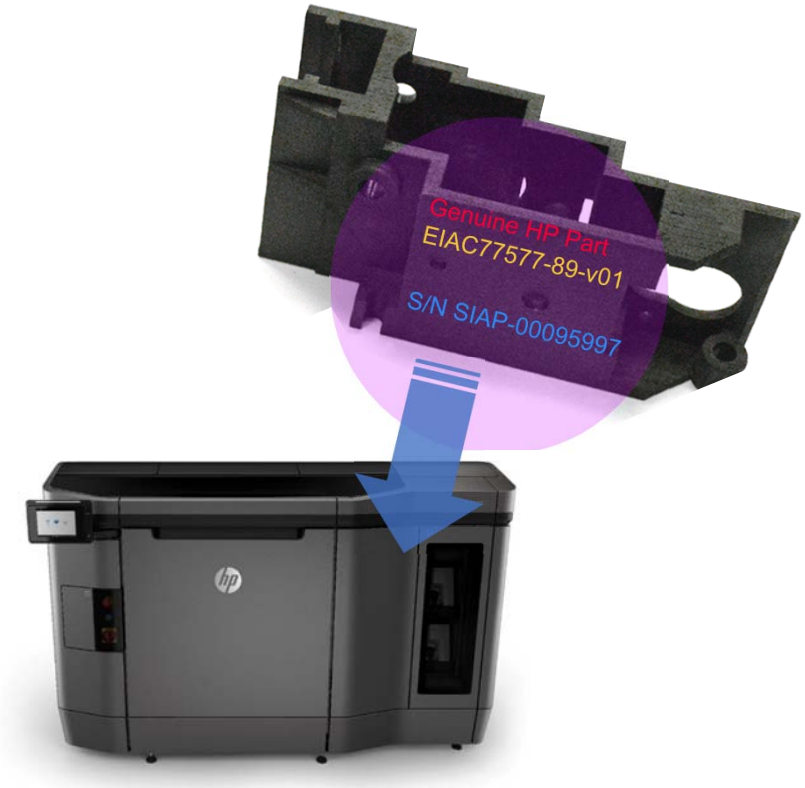
Visible color

Photoluminescent materials
visible under UV light

Marking and anti-counterfeiting

Embedded information

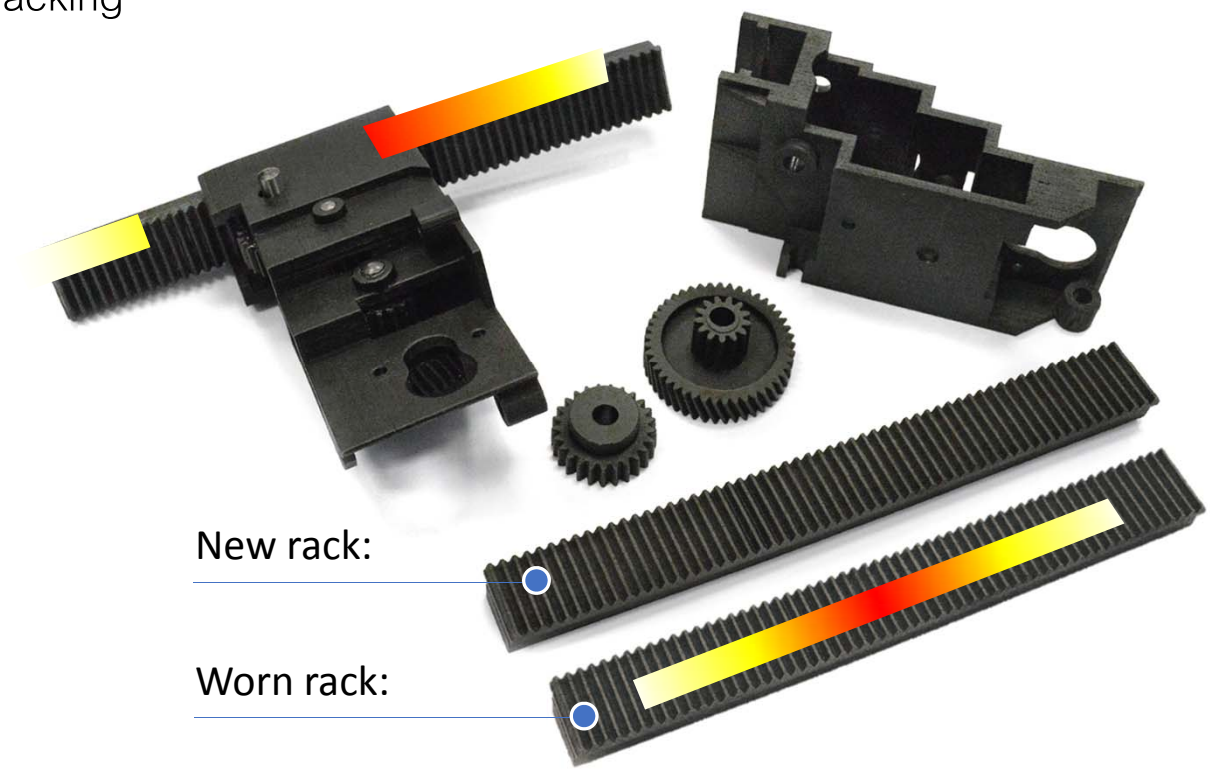
Parts can be identified, oriented, and tracked during assembly into systems



Enhanced functionality for obsolescence tracking

3D layers of color indicate changes in the surface

Embedded 3D color used
as a passive wear indicator



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LAS VEGAS, NV

How are you going to reimagine the lightbulb?

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Materials for Additive Manufacturing

Hugo da Silva

Vice President Additive Manufacturing/3D Printing

DSM

The Netherlands

Strategies in Light

Introducing
DSM Additive Manufacturing

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DSM Additive Manufacturing Vision

APPLICATION AT THE CENTER

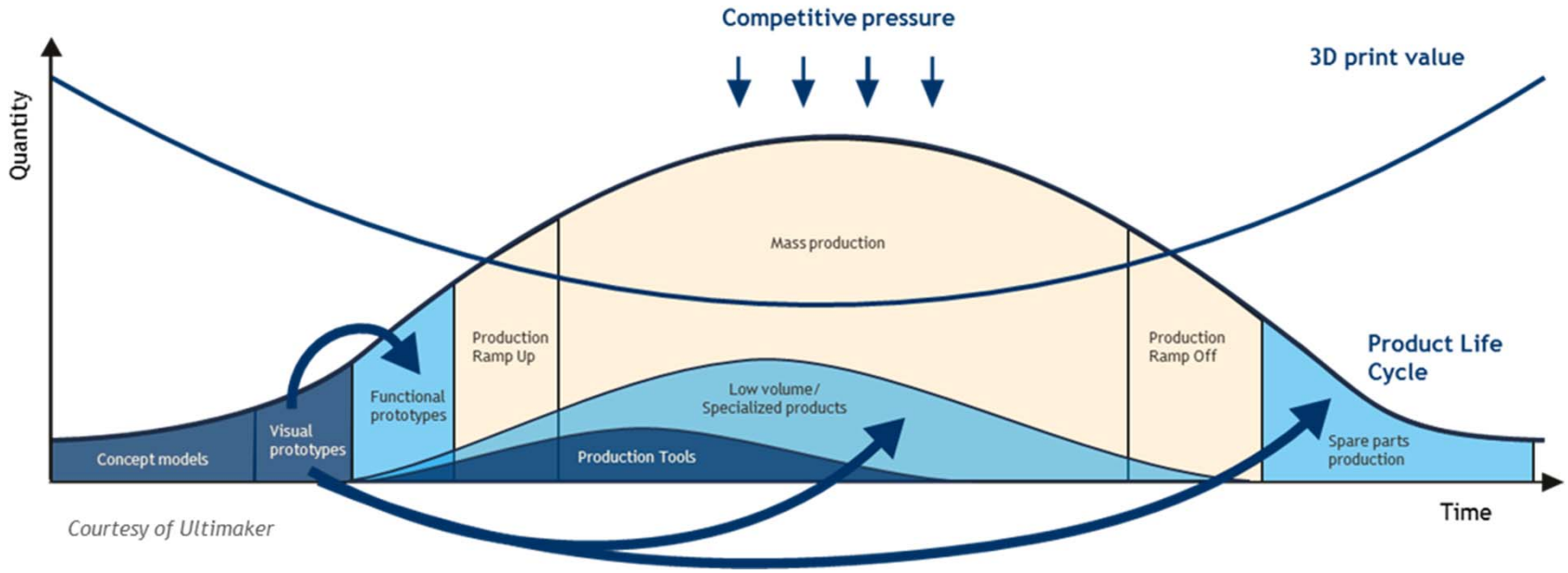
PARTNERSHIPS & ECOSYSTEM

EMBRACING NEW BUSINESS MODELS

SUSTAINABLE

Additive Manufacturing Adoption

Additive Manufacturing Adoption



Courtesy of Ultimaker

Different Technologies for 3D Printing Polymers

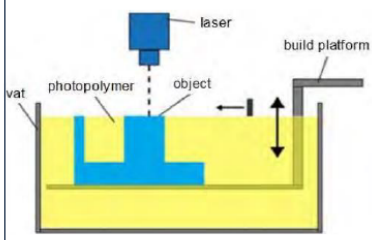
Key is to find the combination of design, materials and printing technology for the application.

Liquids (Thermoset)

Solids (Thermoplastic)

SLA / DLP

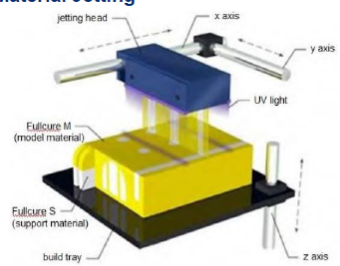
Vat Photopolymerization



Liquid photopolymer in a vat selectively cured by light-activated polymerization

Ink Jet

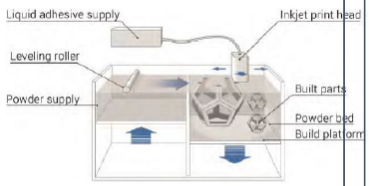
Material Jetting



Droplets of material selectively deposited

Binder Jet

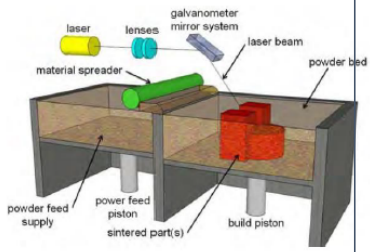
Binder Jetting



Liquid bonding agent selectively deposited to join powder materials

SLS

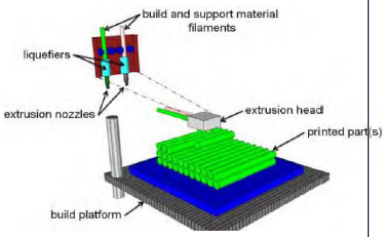
Powder Bed Fusion



Thermal energy selectively fuses regions of a powder bed

FDM/FFF

Material Extrusion



Material dispensed through nozzle

Materials for Lighting

What Can You Expect Today?

Aesthetical prototype
(1993 - 2025)

Design validation

Today

Functional prototype, Small series
(2019 - 2025)

Functional validation
Small series (functional) parts

Tomorrow

OEM's production series
(2021 - 2025)

Direct manufacturing

Future

Innovation towards digital manufacturing

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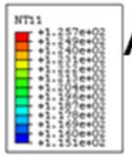
Which Parts of a Luminaire Are Interesting for AM?

LED Heat Sink

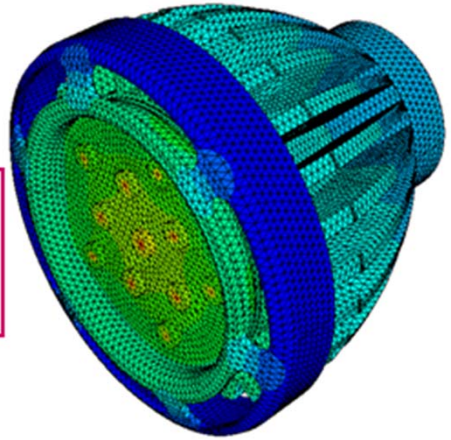
- Engineering plastic material enables the production of unique lightweight design heatsinks for lamps.
- Compared to traditional plastics, it delivers excellent cooling of the lamp while securing electrical safety.

Benefits

- Reduces the weight of heat sinks with 50% compared to aluminum
- Allows for high level of design freedom compared to metal
- Reliable solutions due to its thermo-conductivity
- 85% lower CO2 footprint than with an equivalent die cast aluminum heat sinks

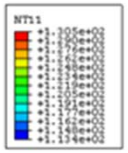


Aluminum; 150 W/mK

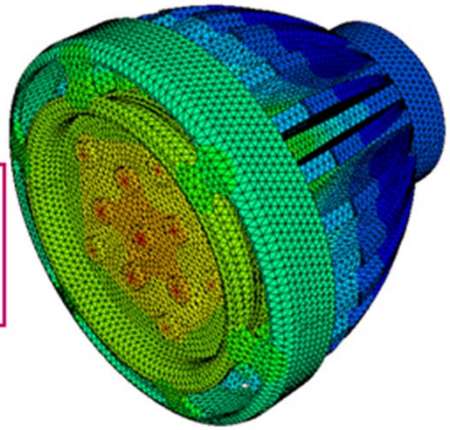


T_{LED} = 125.7°C

T_{min} = 115.1°C



TC plastic; 5 W/mK



T_{LED} = 130.5°C

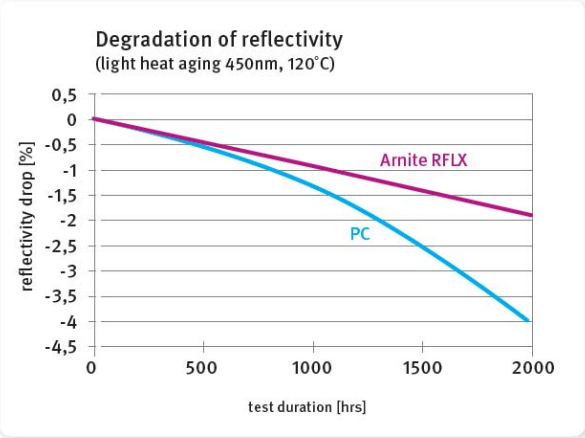
T_{min} = 113.4°C

White Diffuser

- Traditionally, white diffuse reflectors are made from polycarbonate.
- This material typically has a high level of discoloration.
- Solution: highly reflective materials specifically developed for such applications
- The materials have a bright white color in order to reflect light or to match the appearance of the application.

Benefits

- Arnite® RFLX significantly outperforms one of the best-available polycarbonates in light/heat degradation tests.
- Thickness of the reflector can be minimized to save on material costs.



Accelerated light/heat aging test results for Arnite RFLX

Thank you!

Hugo da Silva
Vice President DSM Additive Manufacturing/3D Printing

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3D-Printed Electronics

Srinivas Garimella

Sr. Manager, Global Leader, Additive Manufacturing Center of Excellence

Eaton Corporation

United States

Acknowledgment: The information, data, or work presented herein was funded in part by the U.S. Department of Energy, under Award Number DE-EE0006260.

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LAS VEGAS, NV

EATON
Powering Business Worldwide

Strategies Unlimited®

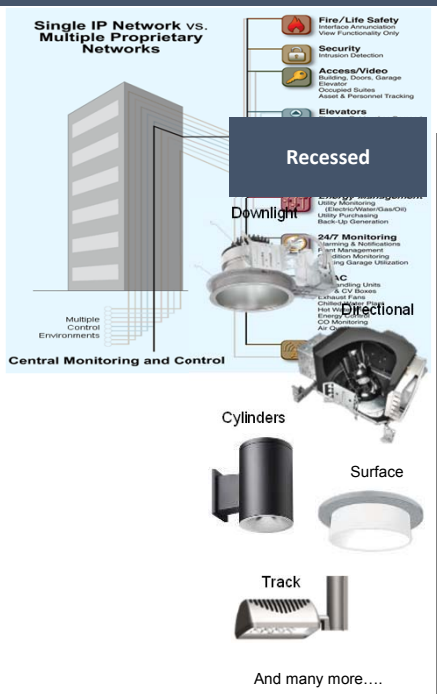
LEDs MAGAZINE

PennWell®

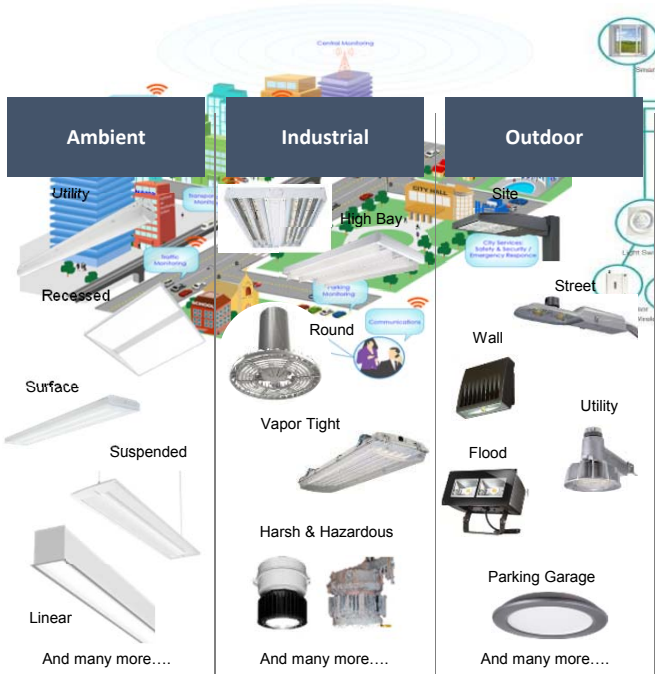
Lighting Division Business Overview

- Sales ~$2.0B
- > 20% of sales outside the US
- Top 2 player in North America; Top 3 globally
- > 5000 employees
- Broad product portfolio, diverse end markets
- Leadership technology and customer access

Connected Buildings



Connected Communities



Connected Homes

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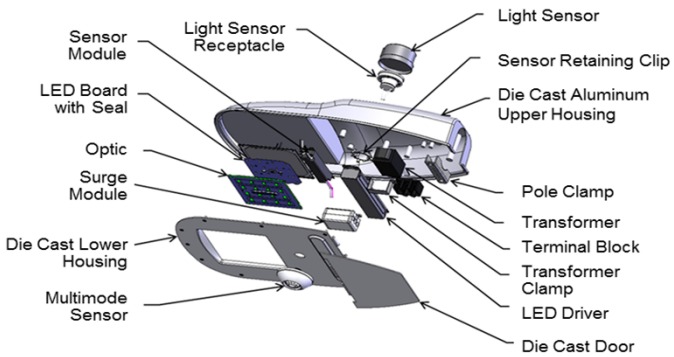
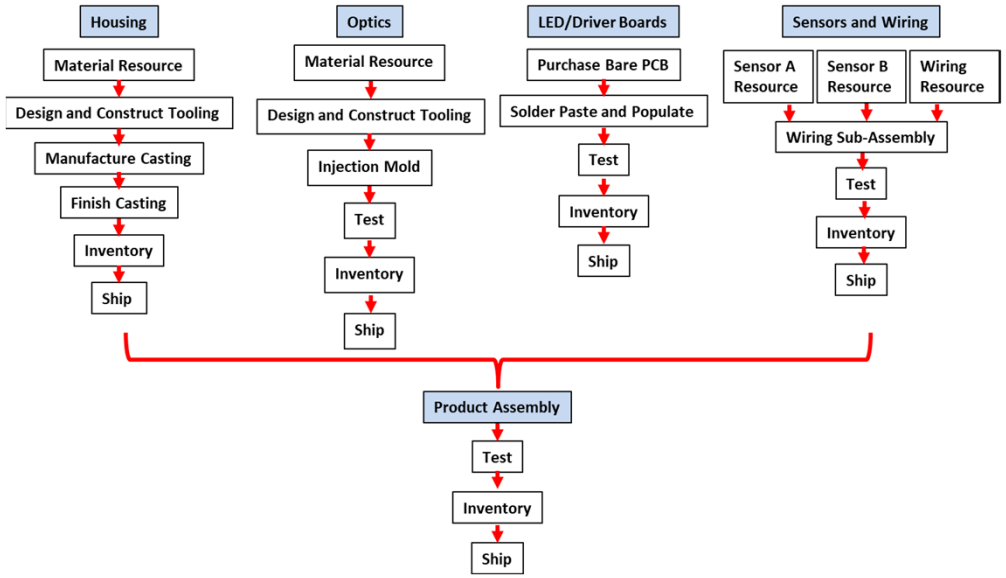
Luminaire Assemblies: Where are we today?

Typical Roadway Assembly



Typical Luminaire Manufacturing Flow



Traditional Manufacturing Approach

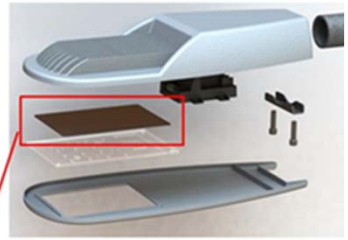
- Assembly line model
- Complex assemblies
- Many designs / components
  - **Electronic content:** discrete LED board, driver, sensors, communication, wire harnesses, connectors, etc.

- Significant labor content
- Complex supply chain
- Large inventory
- Long cycle times
- Long time to market

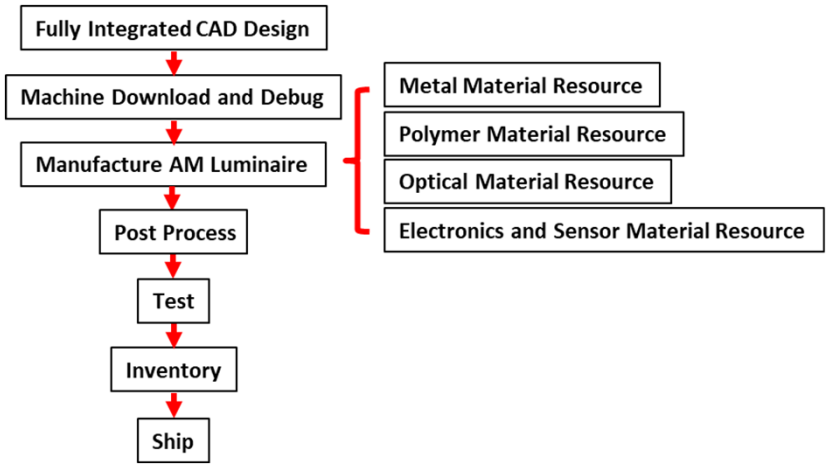
Luminaire Assemblies: Where do we want to be?

Integrated Roadway Concept

Eaton Concept Prototype (2017)*
- Fully printed, integrated circuitry with LED, driver, sensors and antennas
- Minimal part count
- Simplified assembly



Integrated Manufacturing Flow



Integrated Manufacturing Approach

- "Print on demand" model
- Few components and assemblies
- Integrated mechanical/electronics
  - **Electronic content:** Fully printed, integrated electronic functionality

- Reduced operations and mfg. footprint
- Consolidated supply chain
- "Near" zero inventory
- Faster time to market

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Source: **Print-based Manufacturing of Integrated, Low Cost, High Performance SSL Luminaires, Final Report,** DoE/SSL Funded Project, **Contract Number: DE-EE0006260, 2016**

Printed Electronics for Lighting: 2019

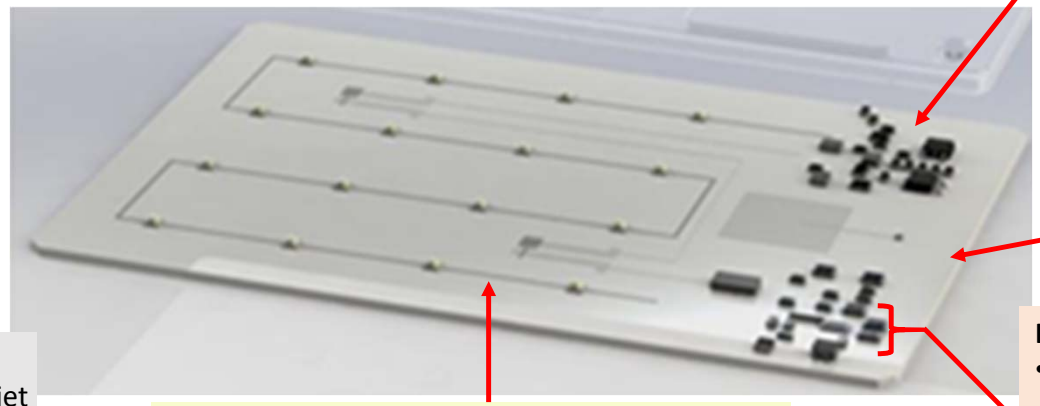
Design Tools
- Predominantly 2D with "in house" design rules
- 3D emerging, integrated with AM tool
  - Constrained to specific materials and processes

Components (active, passive, sensors)
- Mostly discrete
- Printed: Resistors, small value capacitors and magnetics, some sensors (T, RH, antennas)

Materials (inks, pastes)

Available
- Dielectric
- Conductor
- Resistive

Emerging
- Ferromagnetic
- Piezo
- Semiconductor



Substrates
- Aluminum, Steel, ceramic, FR4, polymer/flex, specialized polymer

Processing
- 2D: screen, gravure, slot-die, ink/aero jet
- 3D: Ink/aero jet, in-mold
- Thermal cure/sinter

Circuit Traces/Wiring
- Available: Silver, Copper, Carbon
- Emerging: Carbon Nanotube filled, discrete round gage wire

Interconnect
- Discrete + solder or conductive epoxy
- "Edge" connect
- Printed over component termination

3D Printed Electronics for Lighting: What's Missing?

Integrated Design Mindset
- Combine functionality (electrical, mechanical, optical)
- Eliminate redundancy
- Leverage the AM capability where it makes sense

Tools
- Seamless CAD for mechanical and electrical
- Open Platform Printers with ability to use various electronic inks and processes

Materials
- Higher conductivity (for circuit traces, wiring)
- Improved dielectric properties (for metal substrates)
- Functional inks (sensor)

Processing
- 3D capability with good parameter control
- Non-thermal / localized curing (UV, laser, induction)

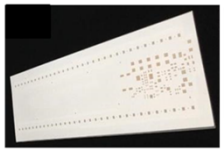
Component Attachment
- 3D placement
- Joining materials (to meet reliability requirements)

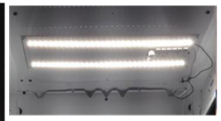
Eaton Printed Electronics Pilot Line

Printed Electronics for Lighting (Prototypes)

Roadway

Indoor





Ambient

Closing Thoughts …

- 2D Printed Electronics for Lighting is ready today
- 3D Printed Electronics is being driven by rapidly developing adjacent markets
  - Wearables
  - Consumer electronics
  - Medical / Biosensing
- Leading applications may not have the requirements demanded by Lighting right now…
  - High Power
  - High Reliability
  - Low Cost

… but the technology is advancing quickly

DOE Announces Selections for SSL R&D Funding Opportunity (Round 13)

Recipient: Eaton Corporation (Menomonee Falls, WI)
Title: Additively Manufactured Solid-State Luminaire
Summary: This project seeks development of an additive manufacturing process for LED luminaires that includes mechanical and thermal management structures, electrical and electronic structures and optical and light reflector structures.

LED Light Engines for 3D Printing

Willem Sillevis Smitt

Senior Director Strategic Marketing

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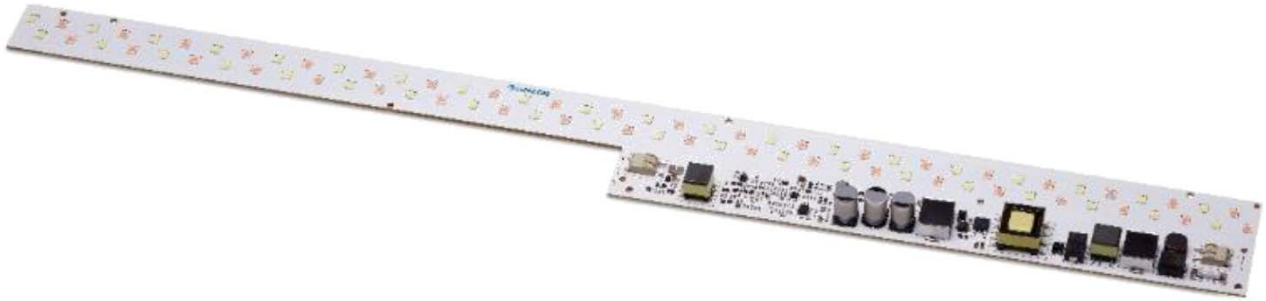
Strategies in Light

Light Engine Requirements

- Integrated monitoring and protection
- Small
- Optically integrated
- Color selectable
- Safe
- Scalable
- Easy to fault free integrate



Challenges and solutions

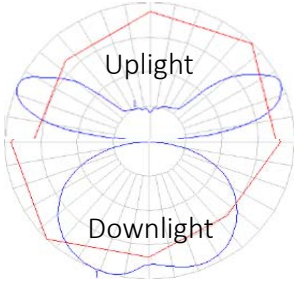
Challenge	Prevent overheating ✓	Prevent electrical overstress ✓	Has to be scalable ✓	Has the right color point ✓
Solution	Thermal monitoring and current throttling	Constant voltage power supply and on-board current regulation - Example 48VDC power distribution	Variable length light engine	Color selectable light engine
Exists today?				

Challenges and solutions

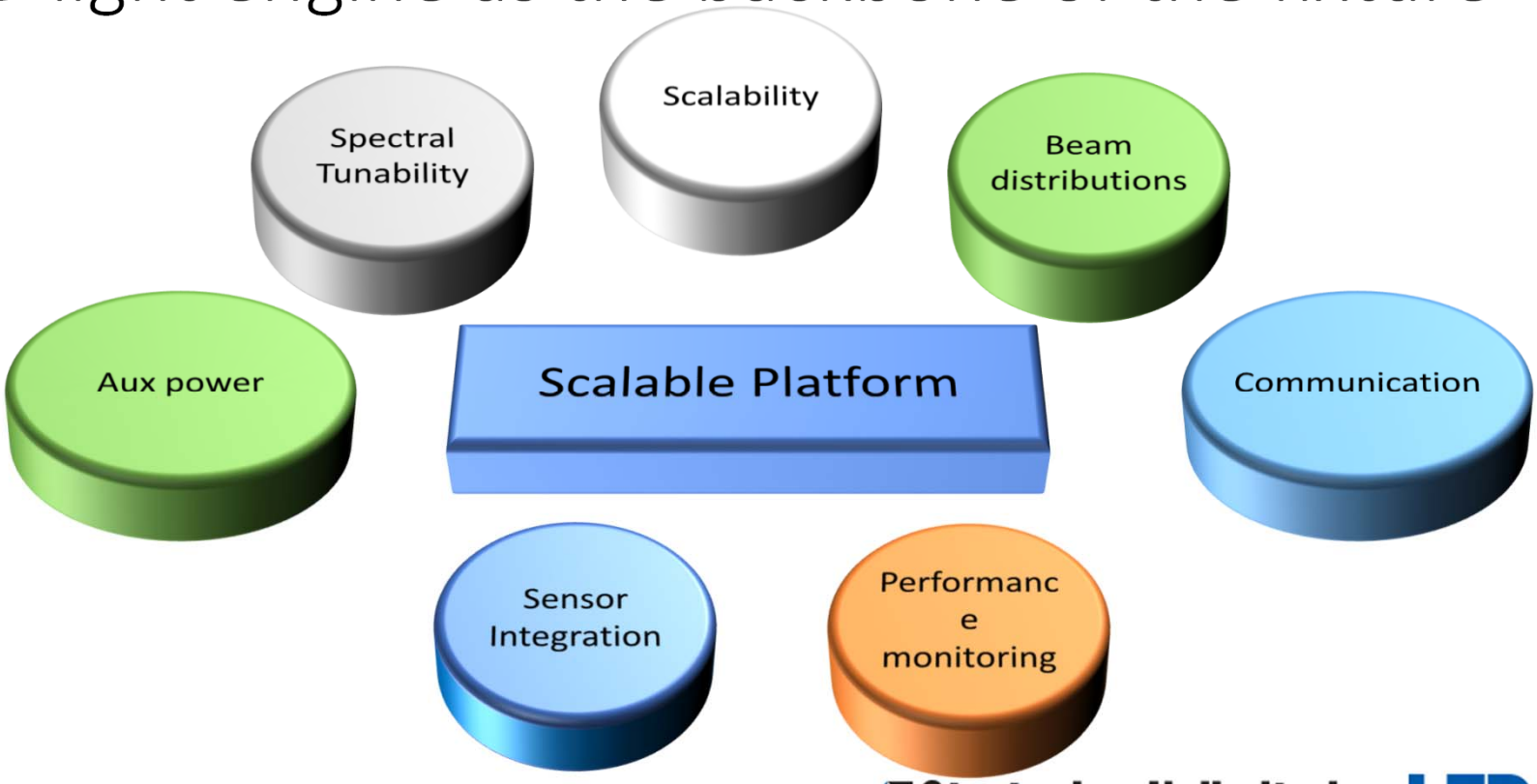
Challenge	Fault free easy fixture assembly	Safety	Controls integration
Solution	Clean environment Testing Skilled and trained workforce …	Can be inherent with low voltage	Requires protocol specific interface card
Exists today?			

Examples of current light engine capabilities

- Optical integration
  - Light guide based
  - Collimating optic based
- Driver and controls integration
  - AC–DC or DC–DC, multi or single channel
- Status monitoring and closed loop feedback
  - Including reporting and data logging
- Control system integration
  - Integration on board through protocol translation
- Self programming
  - Embedded LED test data
- Color selecting



LED light engine as the backbone of the fixture



Conclusions

- Current state of light engine technology provides a solid foundation for on-site 3D printed fixtures
- 3D printing approaches fit well with a vision of light engines as platforms that can be the backbone of light fixtures
- Current assembly practices have to be re-thought when brought on construction site

3D Printing Manufacturing Challenges Today

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Strategies in Light

FEBRUARY 27 - MARCH 1, 2019

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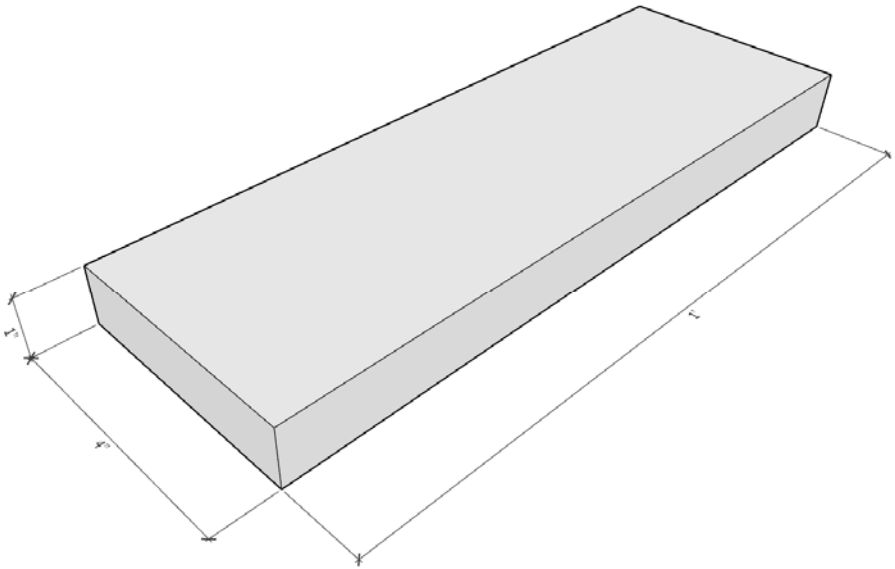
Project Concept:

- Decorative component
- Combine parts
- Complex shapes
- Tailoring
- Reduce cost
- 10 units to 1000 units
- Just in time

Dimensions = 12” x 4” x 1”

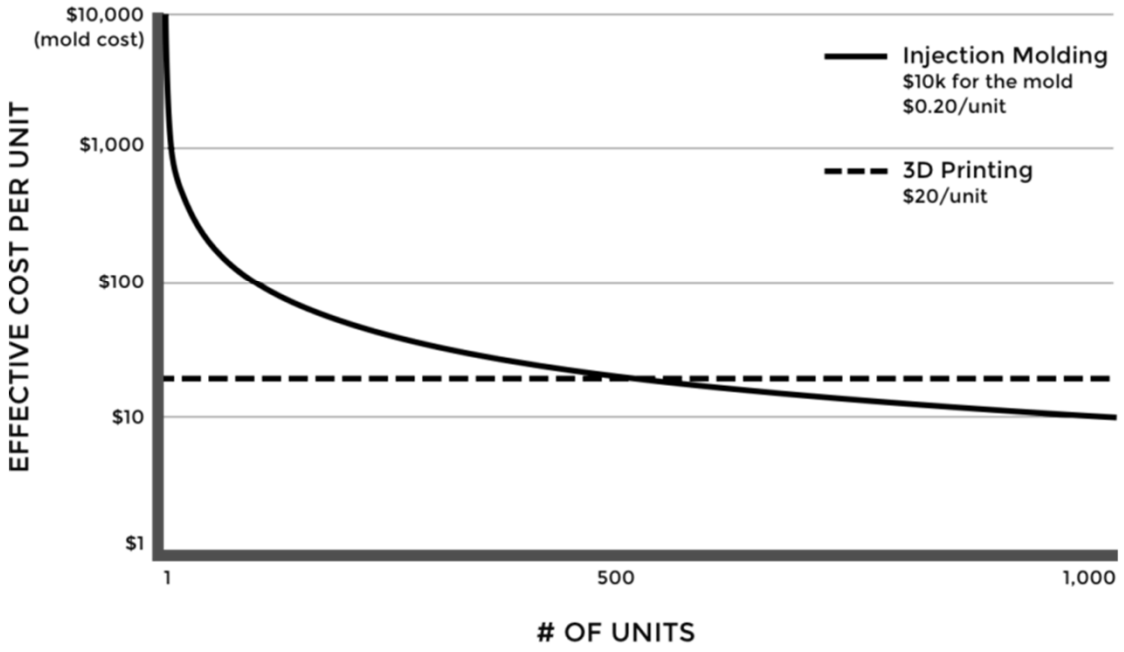


Challenges

Limited production partners

- Build size
- Finish
- Material selection
- Cost
- Delivery at volume

Injection Molding vs. 3D Printing Unit Costs

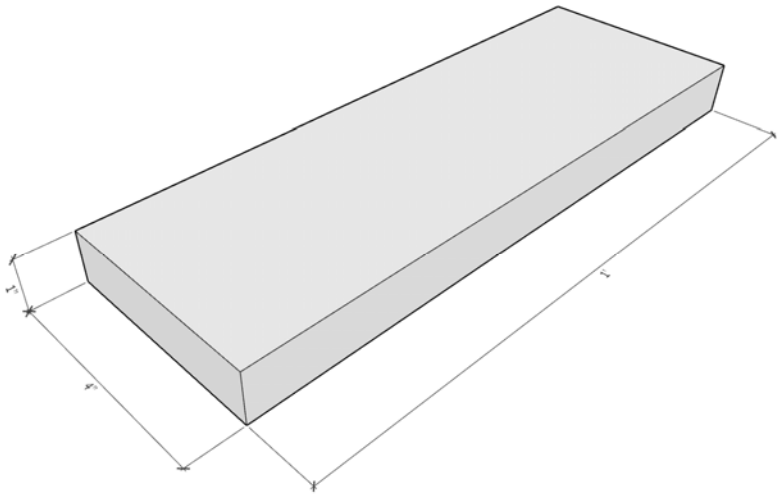


Reference:
https://www.shapeways.com/blog/archives/35860-high-volume-3d-printing-vs-injection-molding.html

Part Cost / Lead-time

Dimensions = 12” x 4” x 1”

Selective Laser Sintering			
PA 12 White (Nylon)			
Qty.	Total Cost	Cost per unit	Lead-time (days)
1	$382	$382	3
10	$2,972	$297	8
50	$14,487	$290	15
100	$28,881	$289	19
200	$57,669	$288	48



Current outlook:

- Traditional processes still have an advantage for our business model and scale
- Big low cost parts not yet viable
- Continue to look for production opportunities


Summary
Strategies in Light

Summary

- Vision for 3D printing for lighting
  - Affordable custom lighting fixtures designed by architects and lighting designers that can be manufactured on-site when needed
- 3D printer technologies and materials must be capable of producing complete SSL lighting fixtures (mechanical, thermal, electrical, and optical elements)
  - Need newer materials and single printing technology capable of making all types of components
- 3D printing materials
  - Optical and thermal materials need the most development
- 3D printing fits well with the vision of future of light engines as platforms that form the backbone of light fixtures
  - However, current assembly practices have to be re-thought
- 3D printer technologies are gearing up to compete with traditional manufacturing technologies in cost and speed
  - Need education to rethink optimized design process for 3D printing (different than traditional designs)
- For many lighting fixture manufacturers the current 3D printing technology cannot compete with traditional processes on cost
  - Further development needed for broader adoption

Thank you!

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