New Combined Solar Light And Power Systems: Hybrid Lighting

September 21st
(2:15 p.m. – 3:15 p.m.)

Duncan Earl
Oak Ridge National Laboratory

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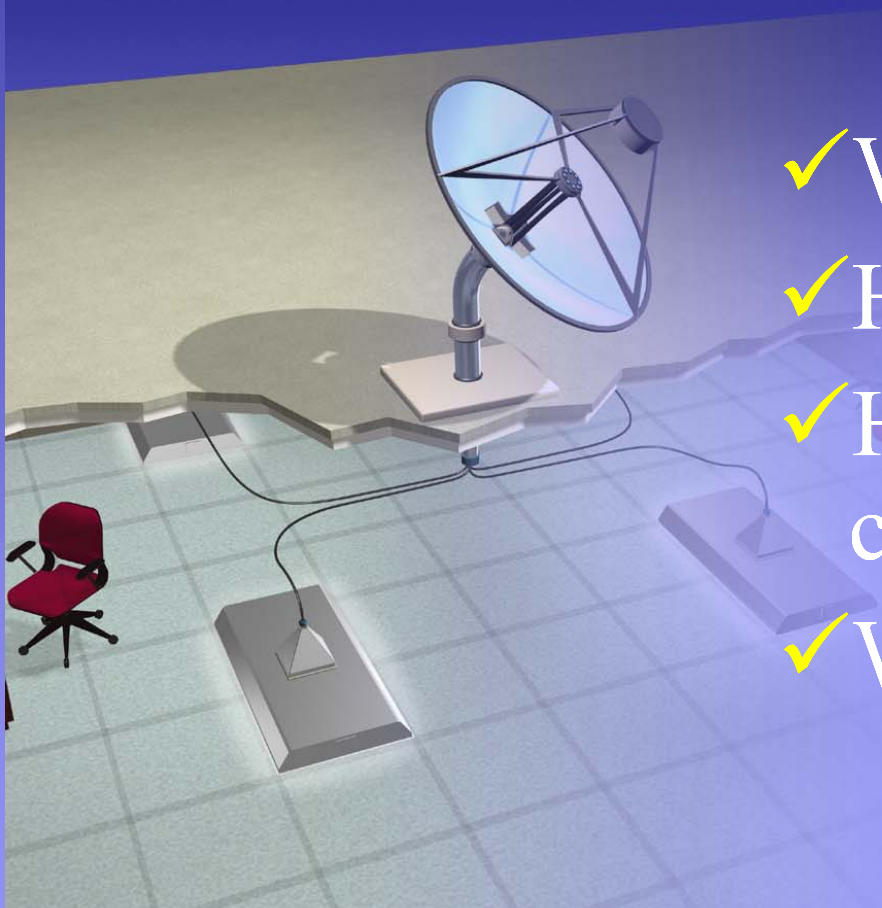
The Hybrid Lighting Partnership
Illuminating the 21st century

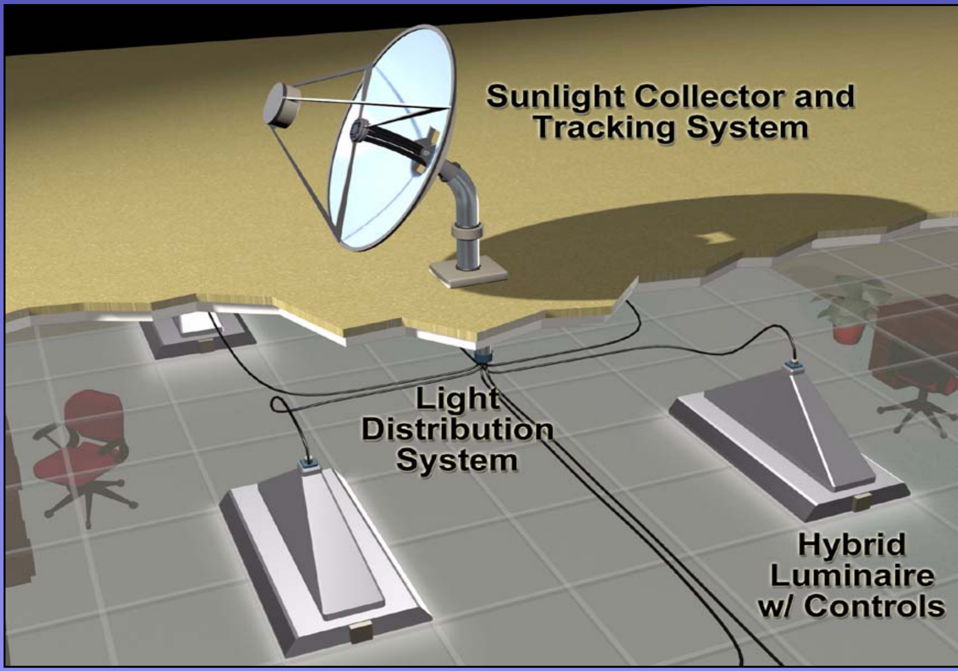
Workshop Topics



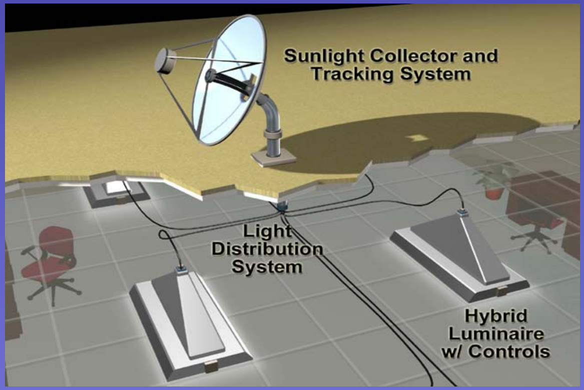
- ✓What is Hybrid Lighting?
- ✓How does it work?
- ✓How much does it cost/save?
- ✓Where can I get it?

What is Hybrid Lighting?

The **Hybrid Lighting System** reduces energy usage, associated with internal lighting, through the direct collection and redistribution of sunlight.



The Hybrid Lighting Concept



Hybrid lighting combines natural and electric light sources into integrated, energy-efficient "hybrid" lighting systems.

Competitive Advantages

- ✓ Provides spatial and temporal illumination control
- ✓ Eliminates glare and over illumination
- ✓ Functions as a true system
- ✓ Reduces architectural intrusion
- ✓ Reduces energy consumption during peak demand
- ✓ Uses visible sunlight directly
- ✓ Improves efficiency and affordability of solar energy

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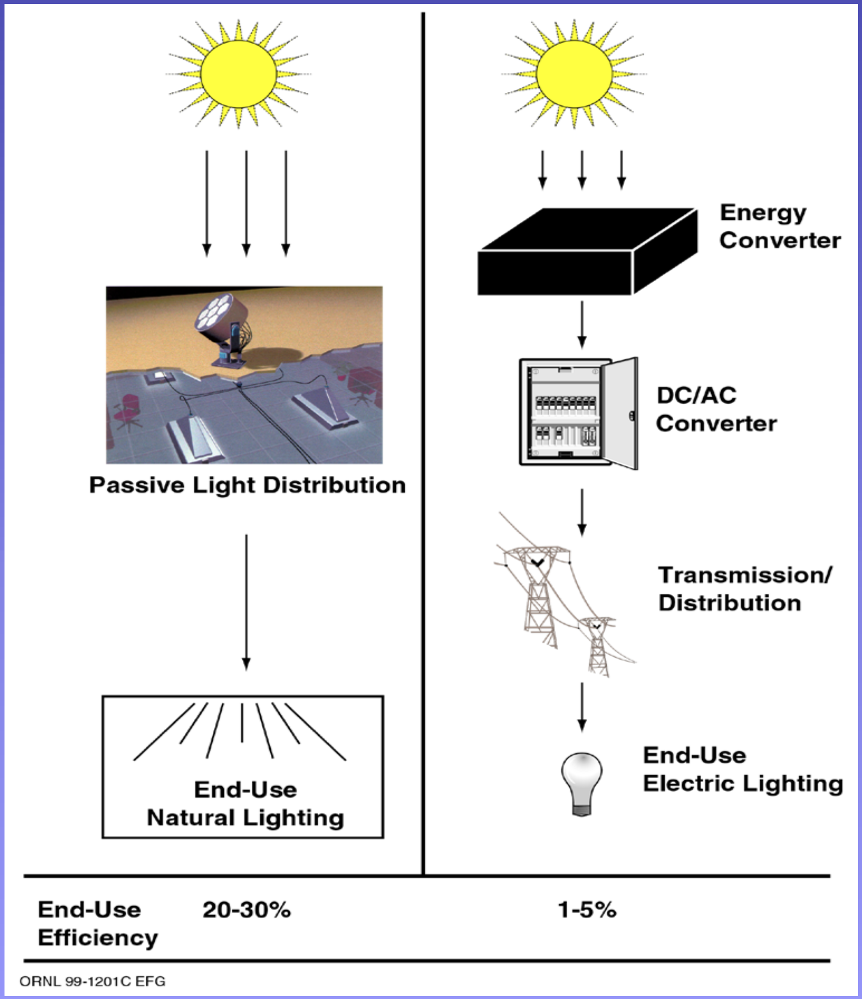
Sunlight Redistribution vs. Conversion



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Full Spectrum Solar Energy Systems

- ✓Concentrate solar energy
- ✓Generate clean electrical power using PV's in the IR spectrum
- ✓Displace conventional electrical power via passive solar lighting systems
- ✓Focus on the commercial buildings market
- ✓Improve the overall cost and performance of solar energy
- ✓Provide value-added health/performance benefits

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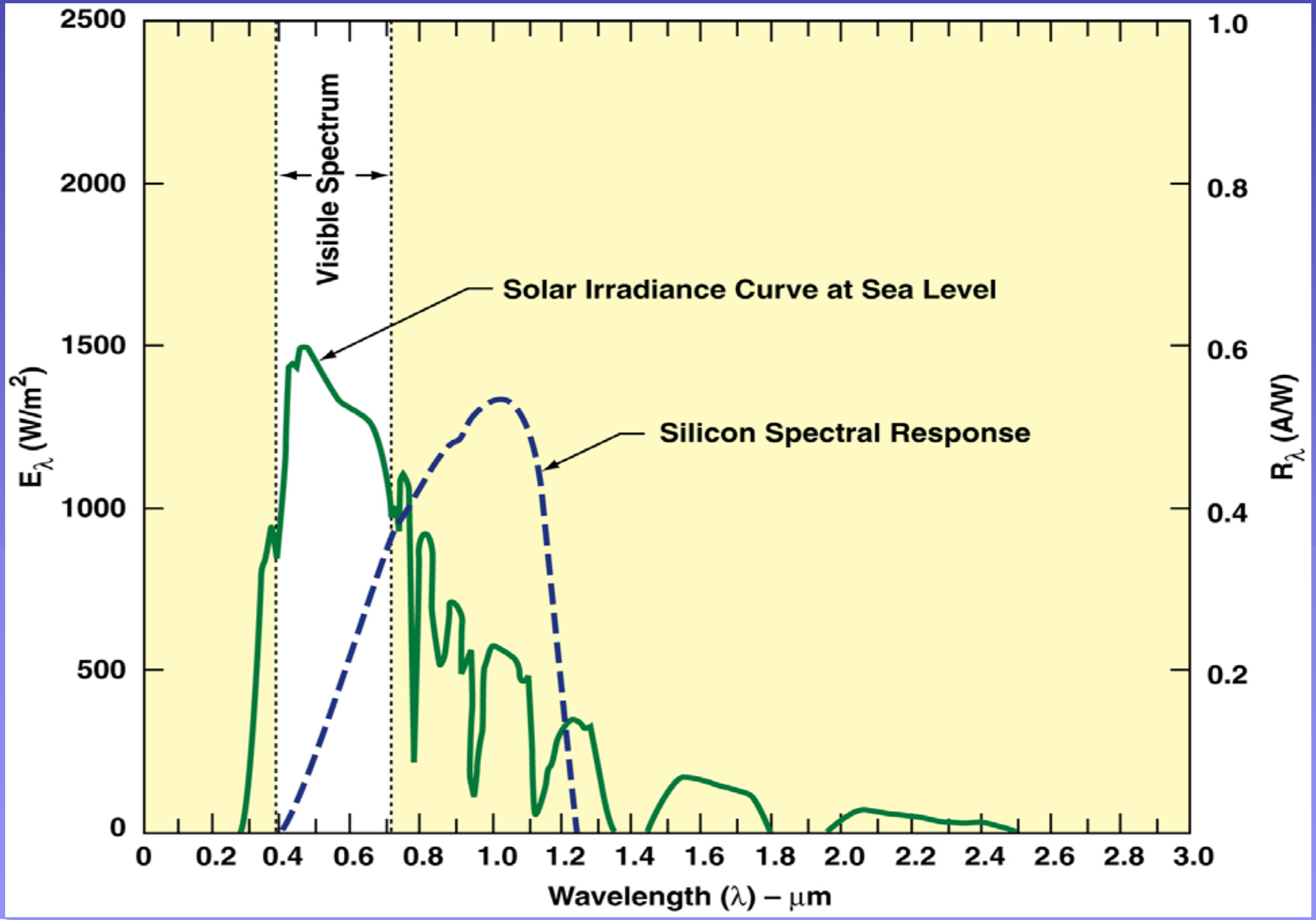
Approximate Spectral Radiance E_λ of the Sun at Mean Earth-Sun Separation and Silicon Spectral Response (R_λ)



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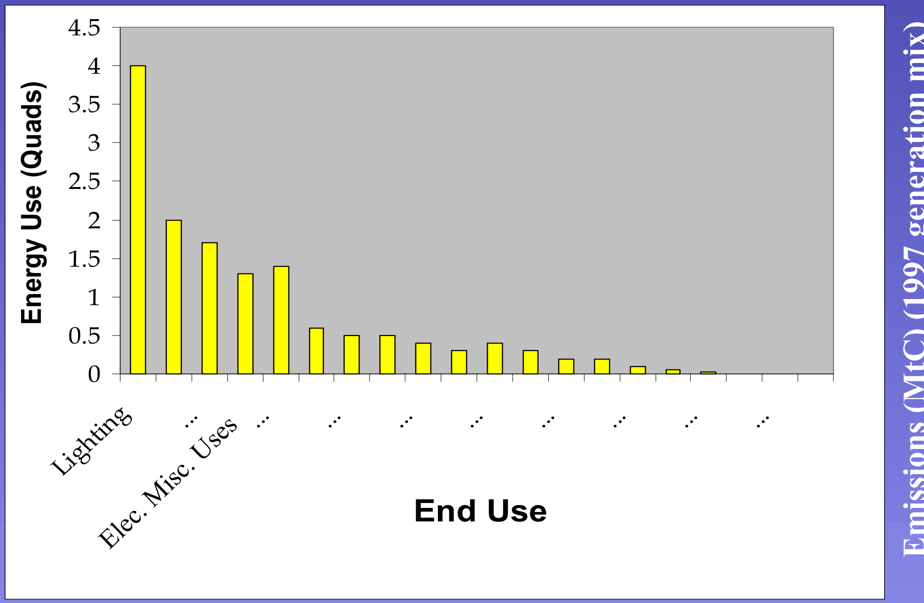
Why Build a Lighting-Specific Solution?

- ✓ Lighting is the single largest specific energy end-use in commercial buildings. Buildings represent the largest energy end-use sector in the United States.

Commercial Sector Primary Energy Use and Carbon Emissions in 1997 by End-Use for the Business-As-Usual Scenario



	Primary Energy-Use in Quads	Carbon Emissions (MTC)
Buildings	33.7	511
Industry	32.6	482
Transportation	25.5	486

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Why Build a Lighting-Specific Solution?

Widespread use of solar energy is still limited by cost and performance when compared to nonrenewable options.

- ✓Energy conversion processes are comparatively inefficient and costly
- ✓Singular solar technologies are typically ineffective in portions of the solar spectrum
- ✓Solar energy is often viewed from a power generation perspective rather than a power displacement perspective

Why Build a Lighting-Specific Solution?

Widespread use of conventional daylighting in most commercial buildings is still limited by lifecycle cost and performance when compared to electric lighting options.

- ✓Lacks spatial/temporal control
- ✓Wastes most visible and all nonvisible energy in sunlight
- ✓Requires more complex architectural modifications
- ✓Not easily reconfigurable during space renovations
- ✓Adds to HVAC load during peak demand periods
- ✓Limited penetration depth
- ✓Significantly less convenient than electric lights

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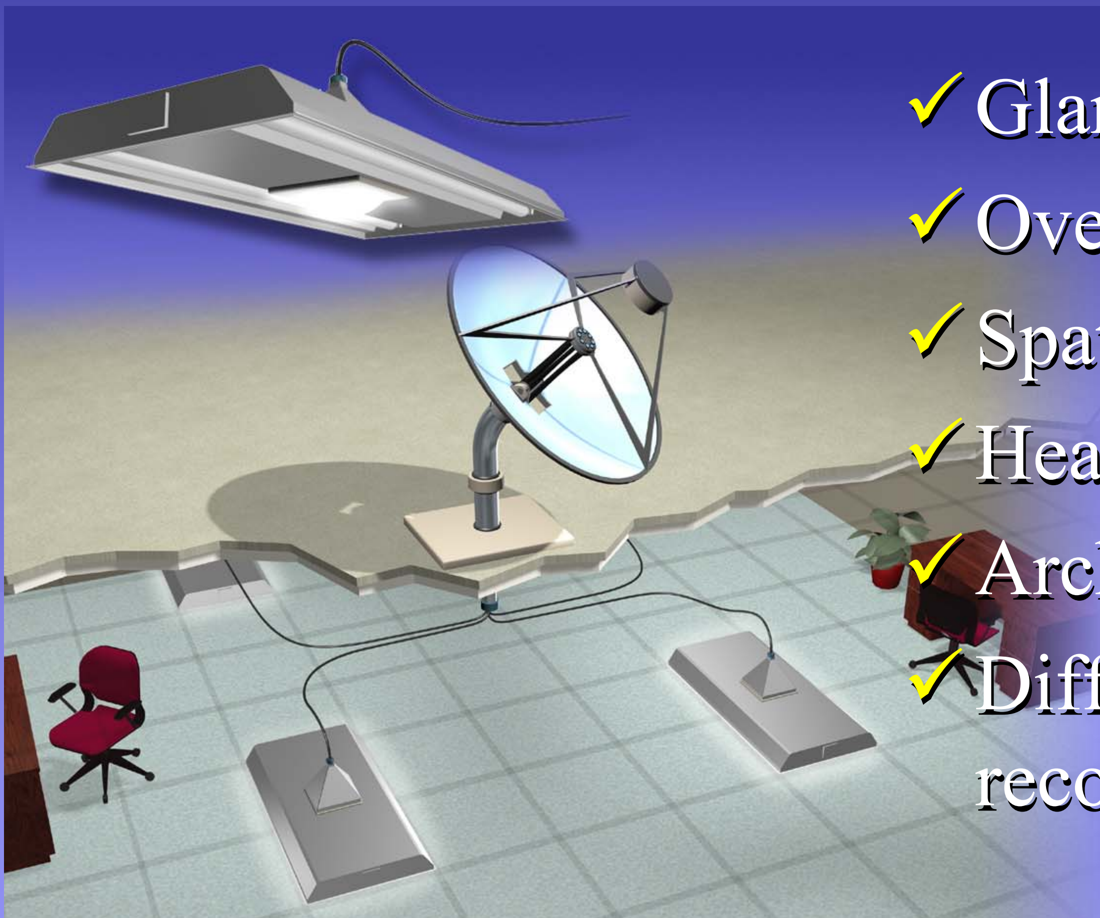
H. L. Negates Many Market Inhibitors of Topside Daylighting



- ✓ Glare
- ✓ Over- and under-illumination
- ✓ Spatial/temporal control
- ✓ Heat gain
- ✓ Architectural complexity
- ✓ Difficulty of space reconfiguration

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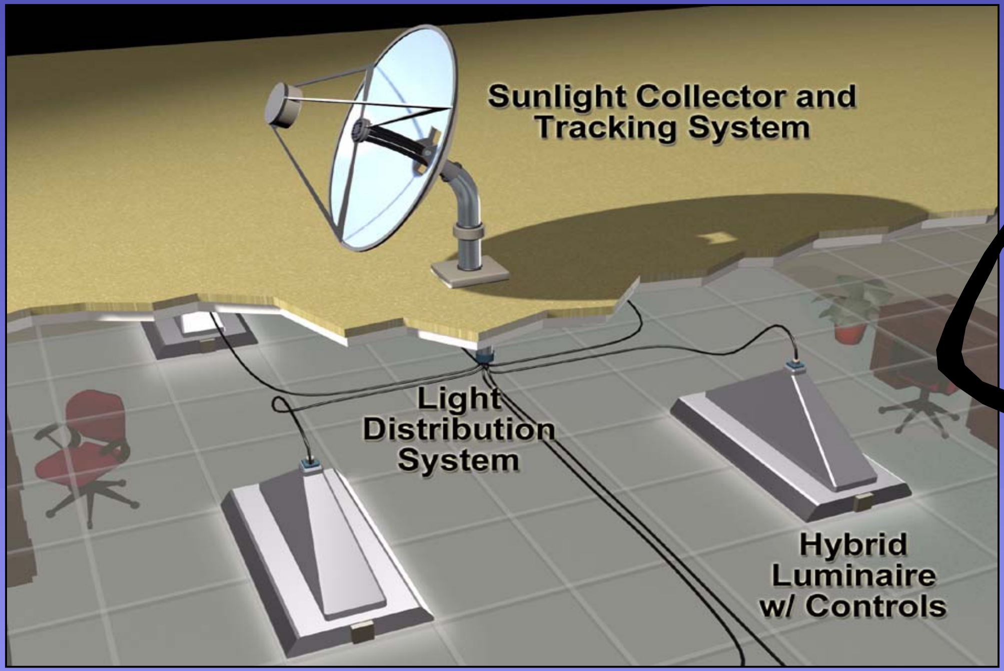
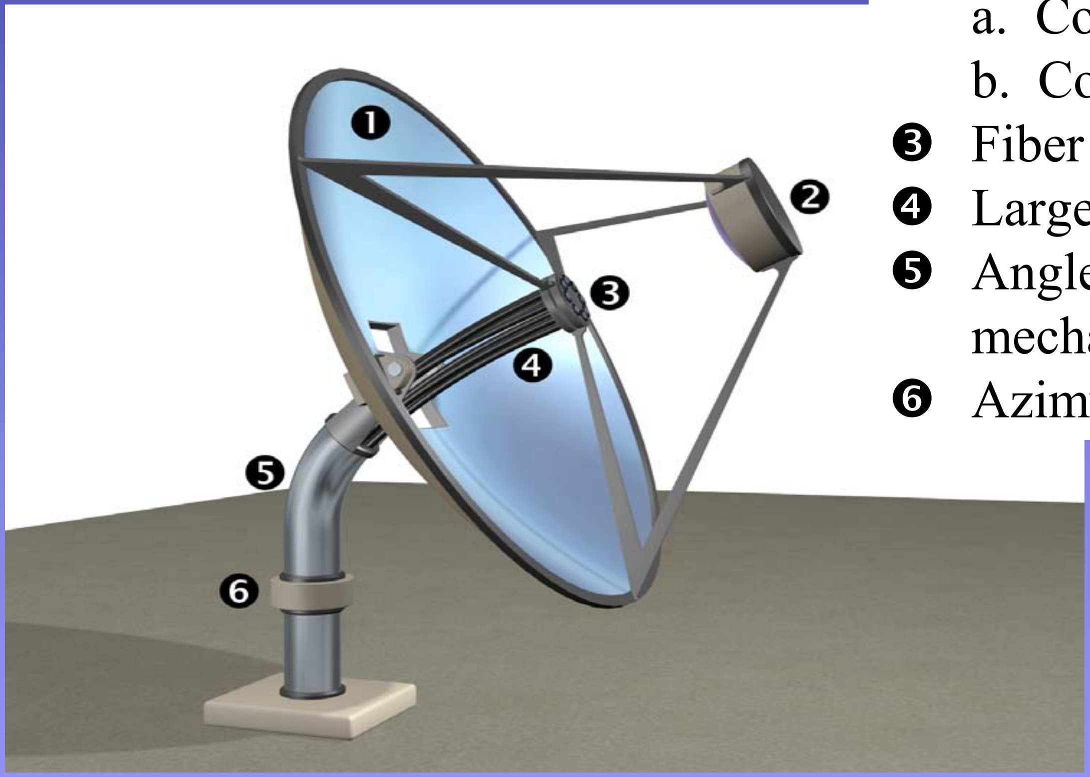
How Does it Work?



Solar Collector Design



❶ 1.5 meter diameter primary mirror

❷ Secondary optical element
   a. Cold mirror
   b. Concentrating PV cell

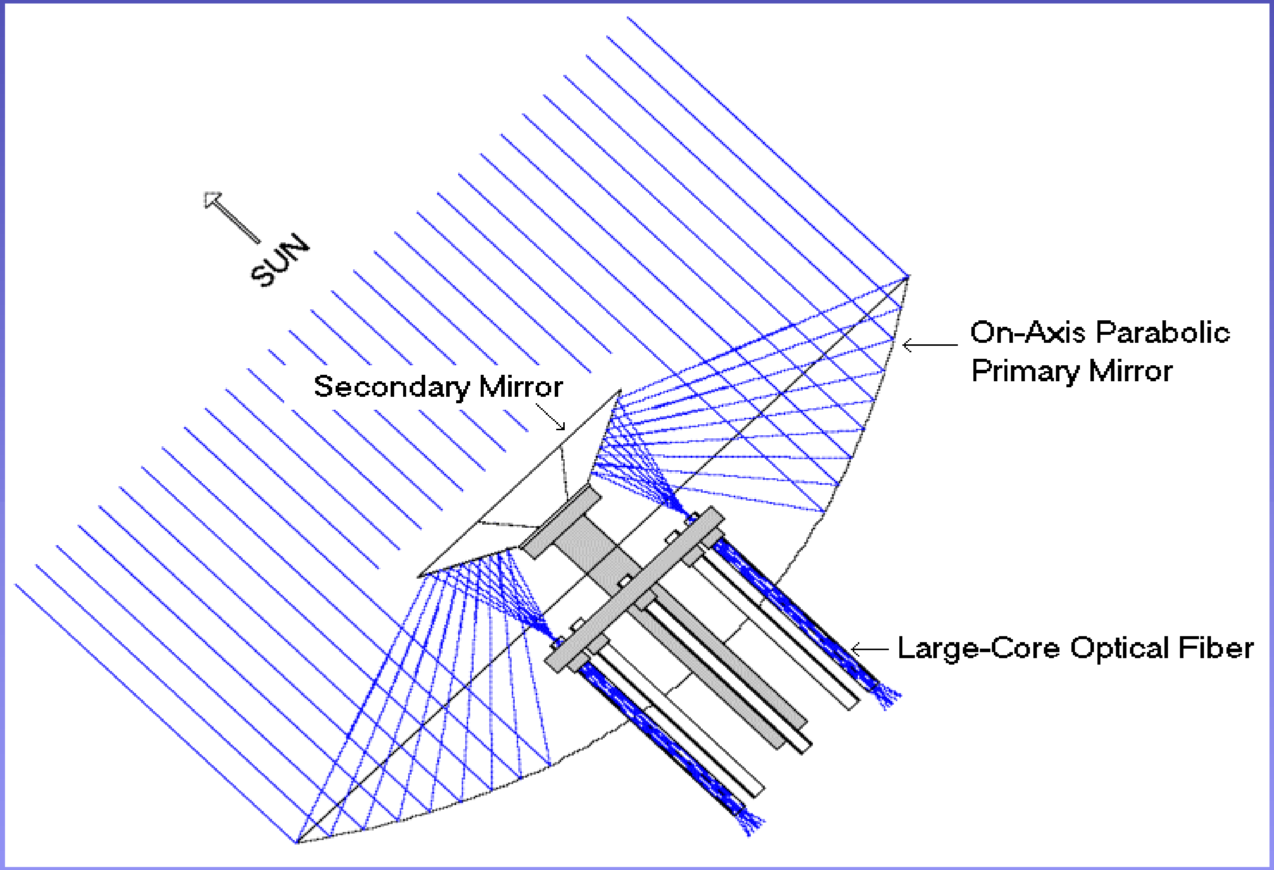
❸ Fiber mount

❹ Large-core optical fibers

❺ Angled stand with altitude tracking mechanism

❻ Azimuth tracking mechanism

Solar Collector Design (cont.)

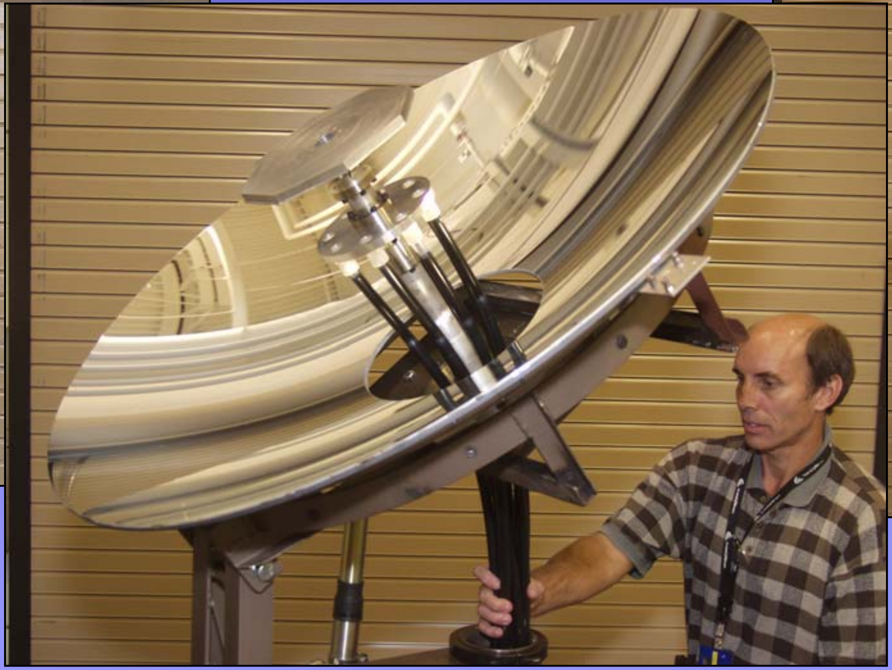


Optical Performance Summary for Solar Collector Design

System Performance

Loss Parameter	Transmission
Primary Mirror	92%
Secondary Mirror	94%
Collection losses	97%
Fresnel losses	94%
Fiber attenuation (@ 6 meters)	78%
Fresnel losses	94%
Luminaire losses	85%
Total	50%

Prototype Solar Collector System



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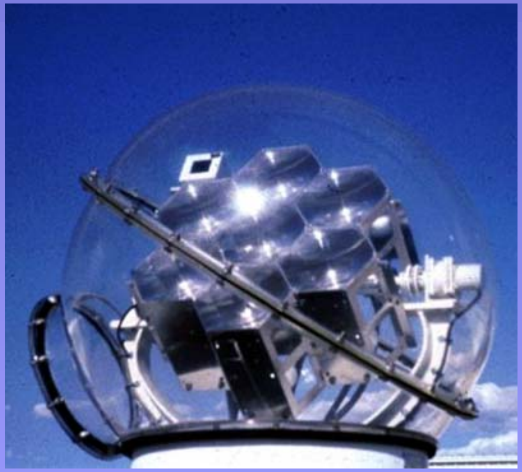
Advantages of ORNL Solar Collector Design

- ✓ Fewer, easily assembled, less costly components integrated into a smaller, more compact design
- ✓ Improved IR heat removal/management
- ✓ Centralized optical fiber placement with reduced range of motion
- ✓ Longer optical path length enabling low-angle entry of light into optical fibers reduced overall transmission losses
- ✓ Concentrated IR radiation available for other uses

Prior Art



ORNL Design

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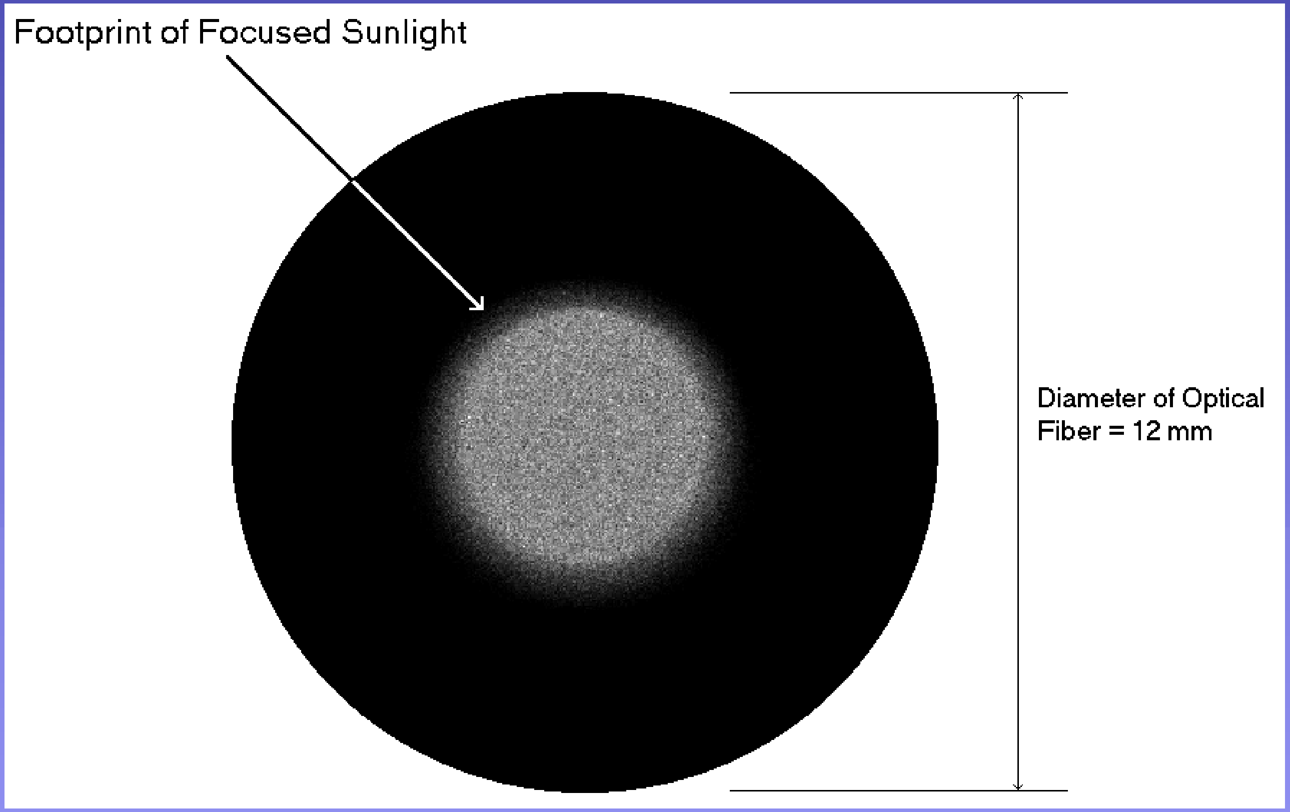
Footprint of focused sunlight on optical fiber



Large-Core Plastic Optical Fibers

Advantages

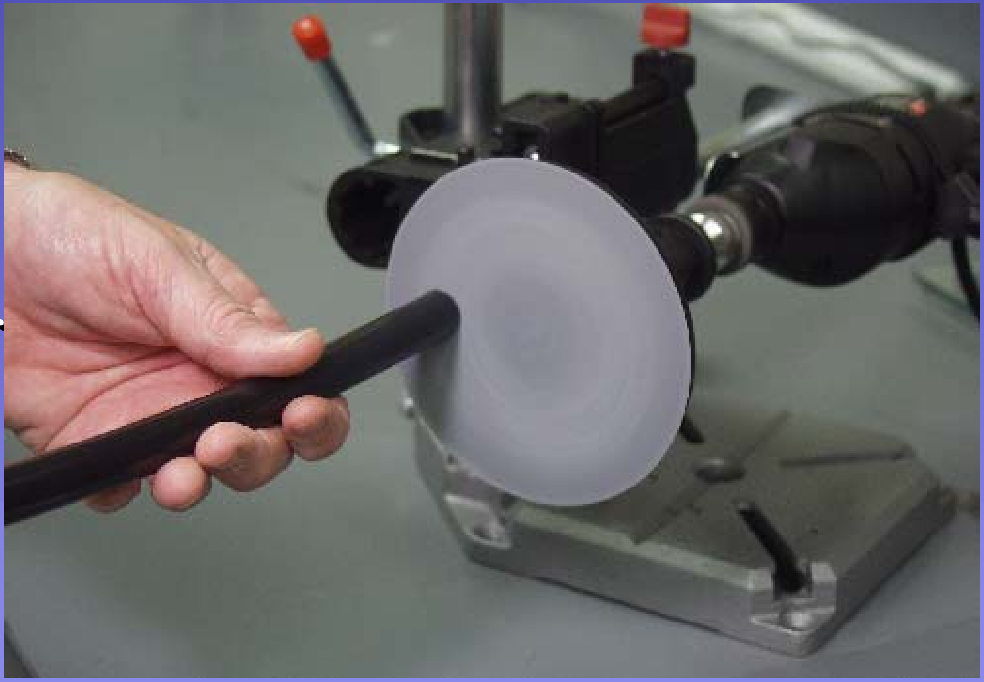
✓Commercially available large-core plastic optical fibers can deliver sunlight in an inexpensive, durable, and flexible manner.

Disadvantages

✓Optical fibers absorb some of the collected light and can shift the color slightly.

Working with Large-Corp Plastic Optical Fibers

- ✓ Fibers can be polished and connectorized using a simple polishing technique suitable for use in the field.
- ✓ Commercially available coupler designs allow accurate fiber end-to-end connections.
- ✓ Optical fiber path can be split and divided among multiple paths using splitters.



Fiber End Polishing Technique

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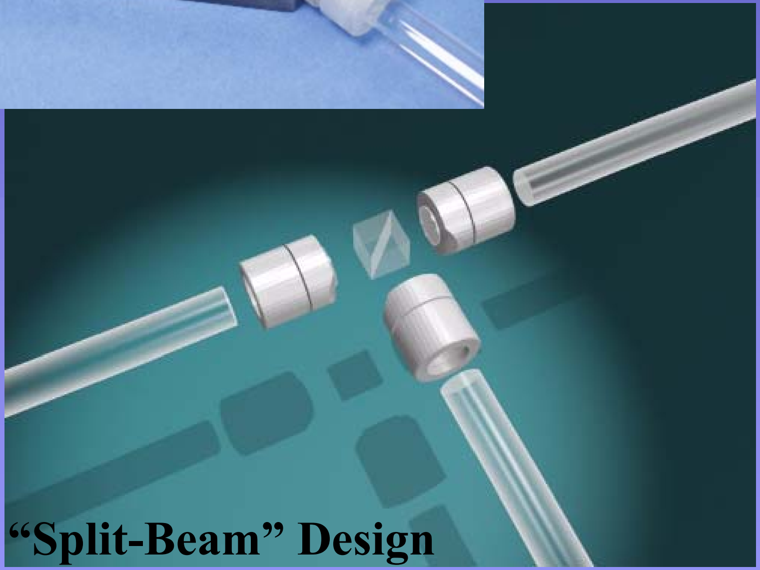
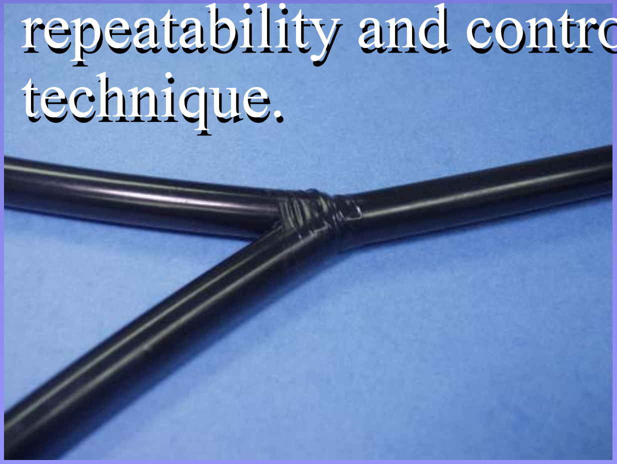
Large-Core Fiber Optic Splitters

- ✓ Have developed three prototype 1x2 splitters. Currently testing optical performance.
- ✓ Investigating pros and cons of modular constructing vs. in-field splicing.
- ✓ Analyzing construction repeatability and control for each technique.

Modular 1x2 Splitter Design



"Split-Beam" Design



"In-the-Field" 1x2 Splice

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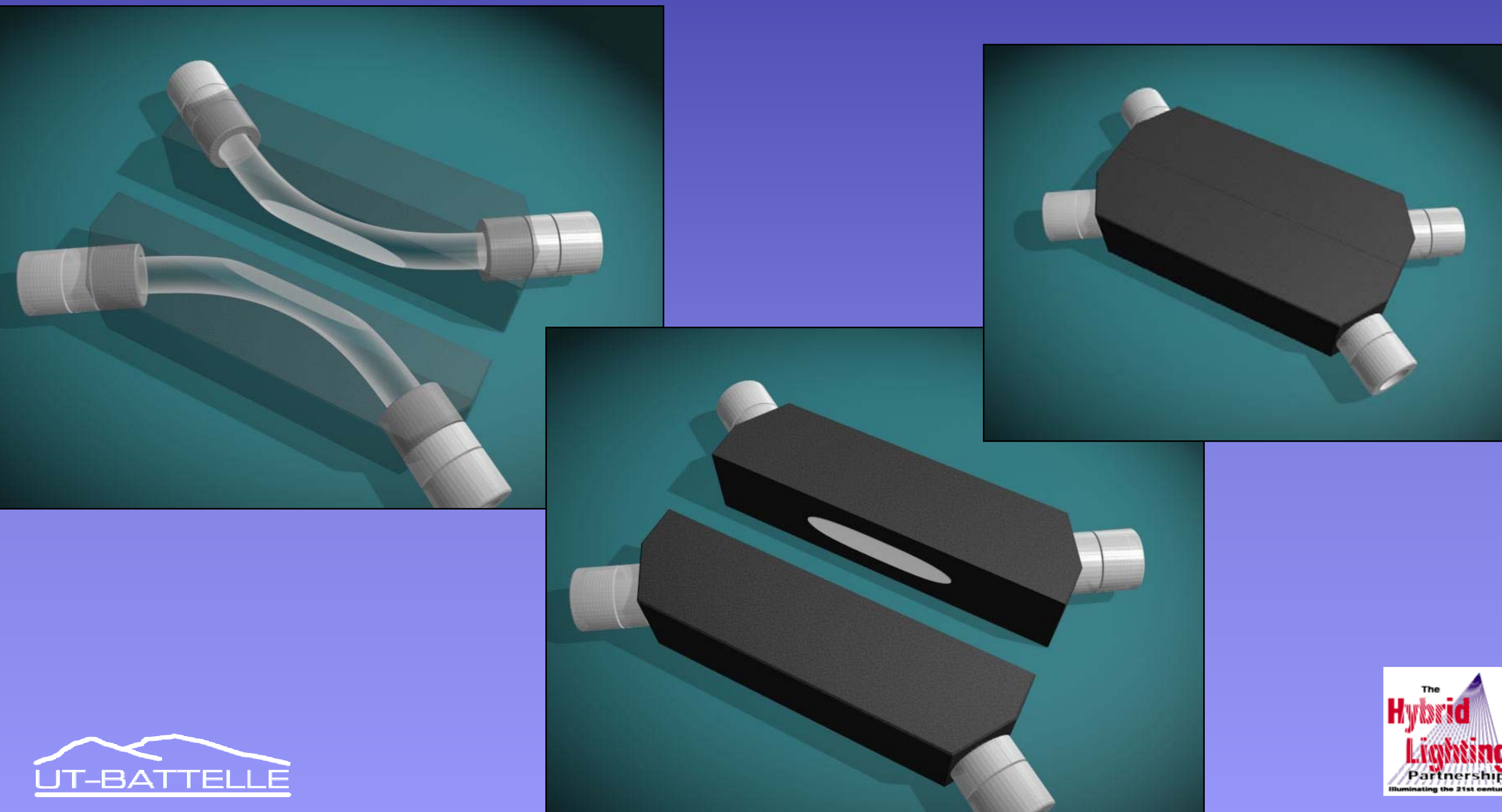
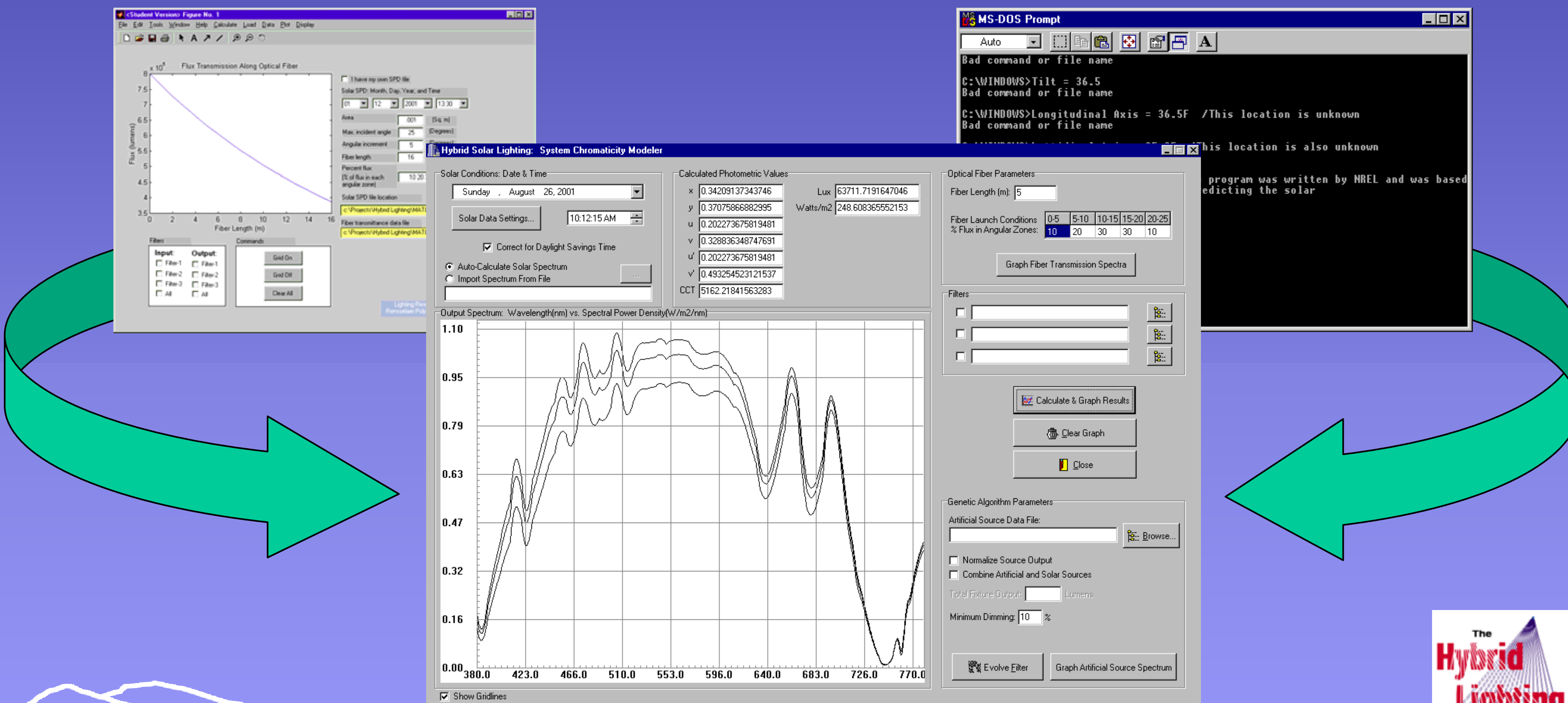
Overview of Modular Splitter Design



Controlling Color Shifting - The HSL Chromaticity Modeler

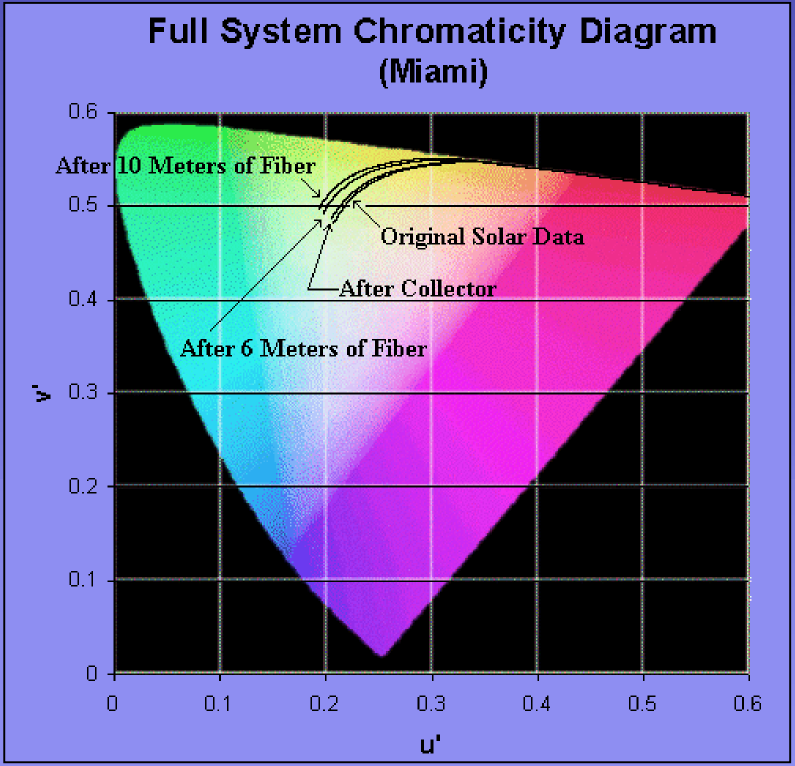
Chromaticity Calculator -**RPI**

Solar Spectral Irradiance Program - **NREL** (Bird and Riordan)



HSL Chromaticity Modeler

Features of HSL Chromaticity Modeler



Calculates chromaticity (CIE values) of light transmitted through a multi-element HSL system for a partial/full solar year.

- ✓ Uses experimentally verified optical fiber transmission data.
- ✓ Allows prescribed fiber launch conditions.
- ✓ Calculates the effects of solar collector component reflectivity (primary mirror, secondary mirror, etc.)
- ✓ Investigates chromatic effects across a full or partial solar year.
- ✓ Blends solar sources with artificial sources
- ✓ Genetic algorithm optimization
- ✓ Many More Features…

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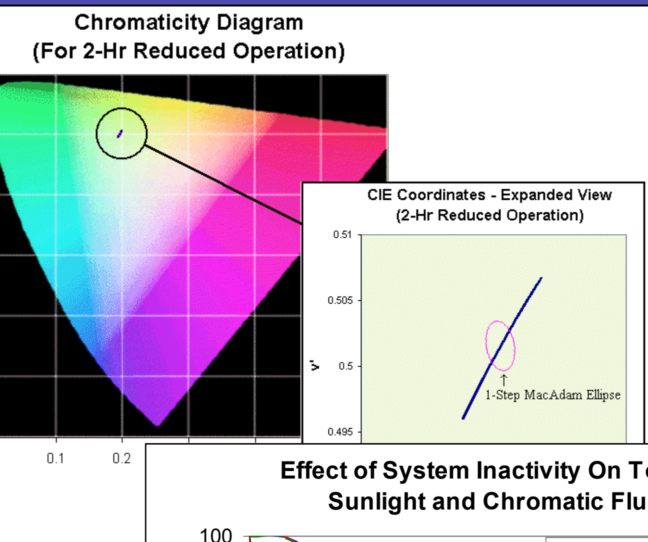
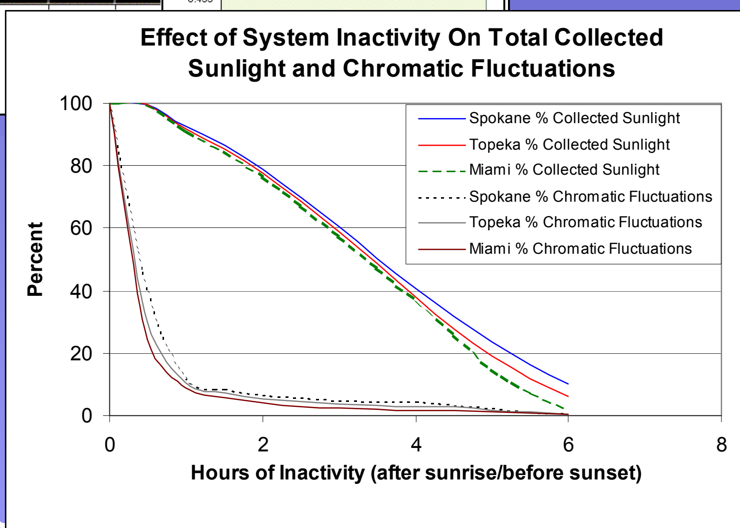
Results of 2000 Chromaticity Study





By filtering collected sunlight and reducing system operation times, color variations between natural and artificial sources can be significantly minimized.

- ✓ Multiple positions in the continental US were analyzed..
- ✓ High quality optical fibers were tested, modeled, and verified for actual launch conditions.
- ✓ 2-Hour reduced operations system produced minimum color difference with acceptable reduction in collected sunlight (20%).
- ✓ **Analysis was a worst case scenario**.

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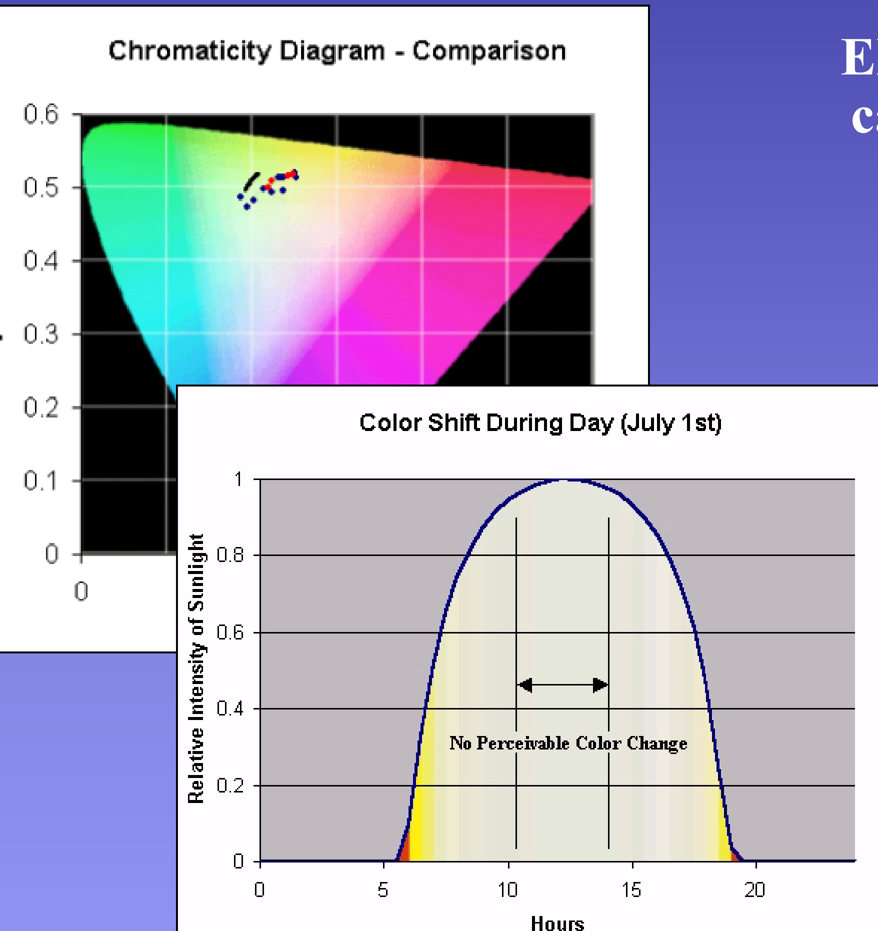
FY2000 Chromaticity Study Cont…



Elements affecting the color of collected sunligh can now be adequately modeled and controlled

- ✓ Collected sunlight can be filtered to match the chromaticity values of various fluorescen and metal-halide sources.
- ✓ Analysis considers a worse-case scenario. Color fluctuations in a spatially well-blended hybrid luminaire will actually be much more "hidden" due to source color mixing.
- ✓ Using a genetic algorithm, a system filter can be designed to provide maximum system performance (high efficiency, minimal color difference, longer operating times, etc.)

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The Hybrid Luminaire

- ✓ Must incorporate both solar and electric illuminants
- ✓ Must maintain a constant total output intensity
- ✓ Must exhibits high optical efficiency for both solar and electric illuminants
- ✓ May need to compensate for color differences between solar and electric illuminants
- ✓ Must maintains a static spatial intensity distribution
- ✓ Should be easily integrated and installed
- ✓ Must be reasonably priced

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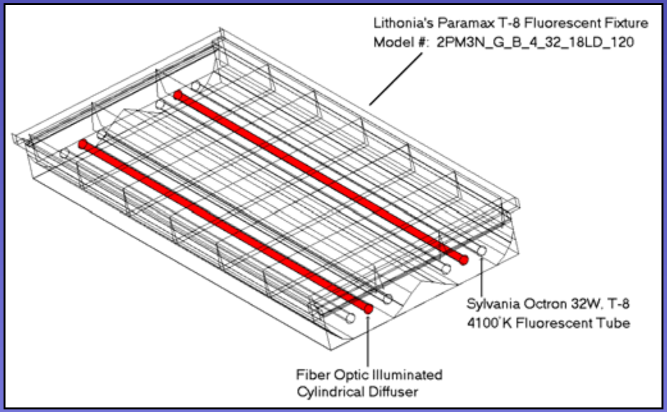
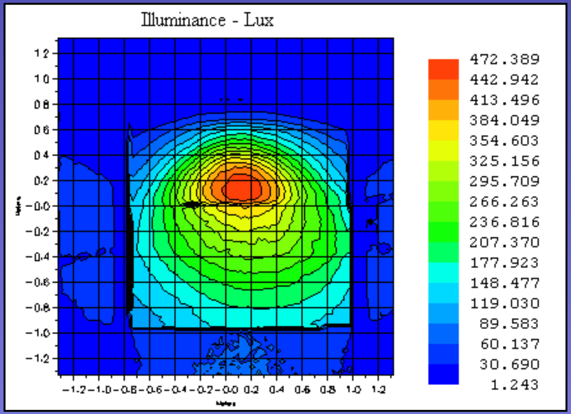
Hybrid Luminaire Development Cycle

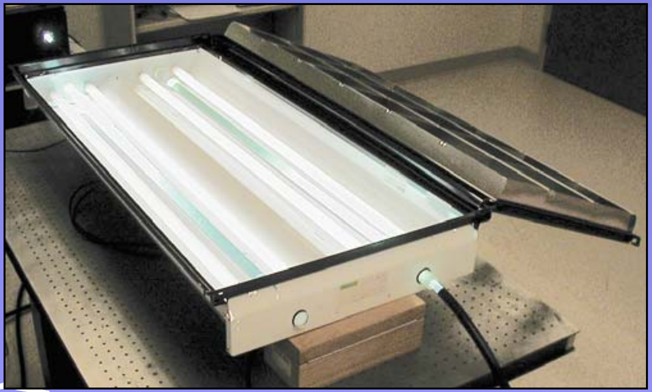


Design



Construct

Analyze



Test

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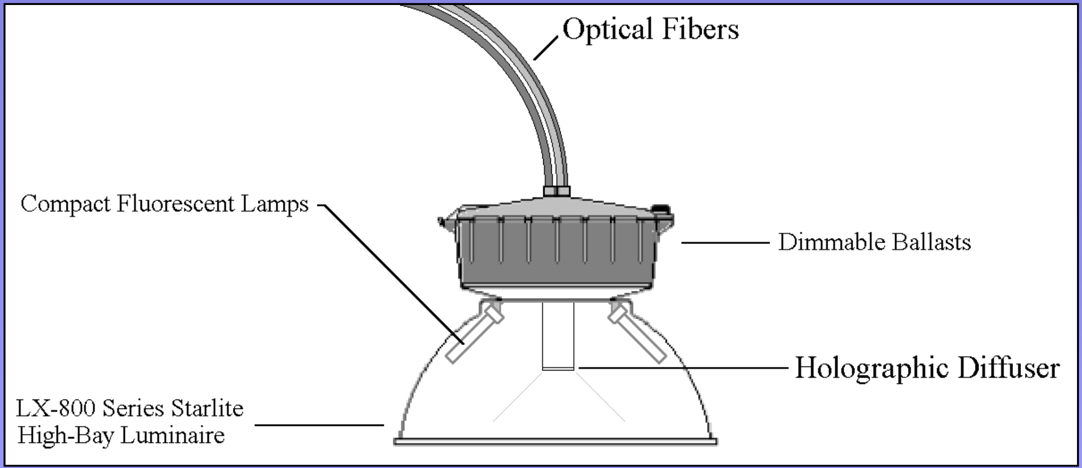
Finished Hybrid Luminaire Design #1

Finished Hybrid Luminaire Design #2

High-Bay Hybrid Luminaire Development

- ✓ Retrofit of commercially-available compact fluorescent high bay luminaire (Starliter LX-800).
- ✓ Dimmable ballasts allow artificial output to be adjusted from 25,000 to 5,000 lumens.
- ✓ Solar lighting expected to displace 15,000 lumens (60% @ max)
- ✓ Design utilizes holographic light shaping diffuser for high efficiency spatial intensity matching.
- ✓ Modeled and optimized using ZEMAX Ray Tracing software.



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Simplified Daylight Harvesting Control for HSL

Commercially Available Absolute Intensity-Based Daylight Sensors

- ✓ Development of a low-cost daylight harvesting control sensor for HSL. (Because the HSL system removes UV and IR portions of the solar spectrum and creates the same spatial intensity distribution as the artificial source, control sensors do not require a human response filter and their electronics can be greatly simplified).
- ✓ Current daylight harvesting photosensor designs can be easily converted.

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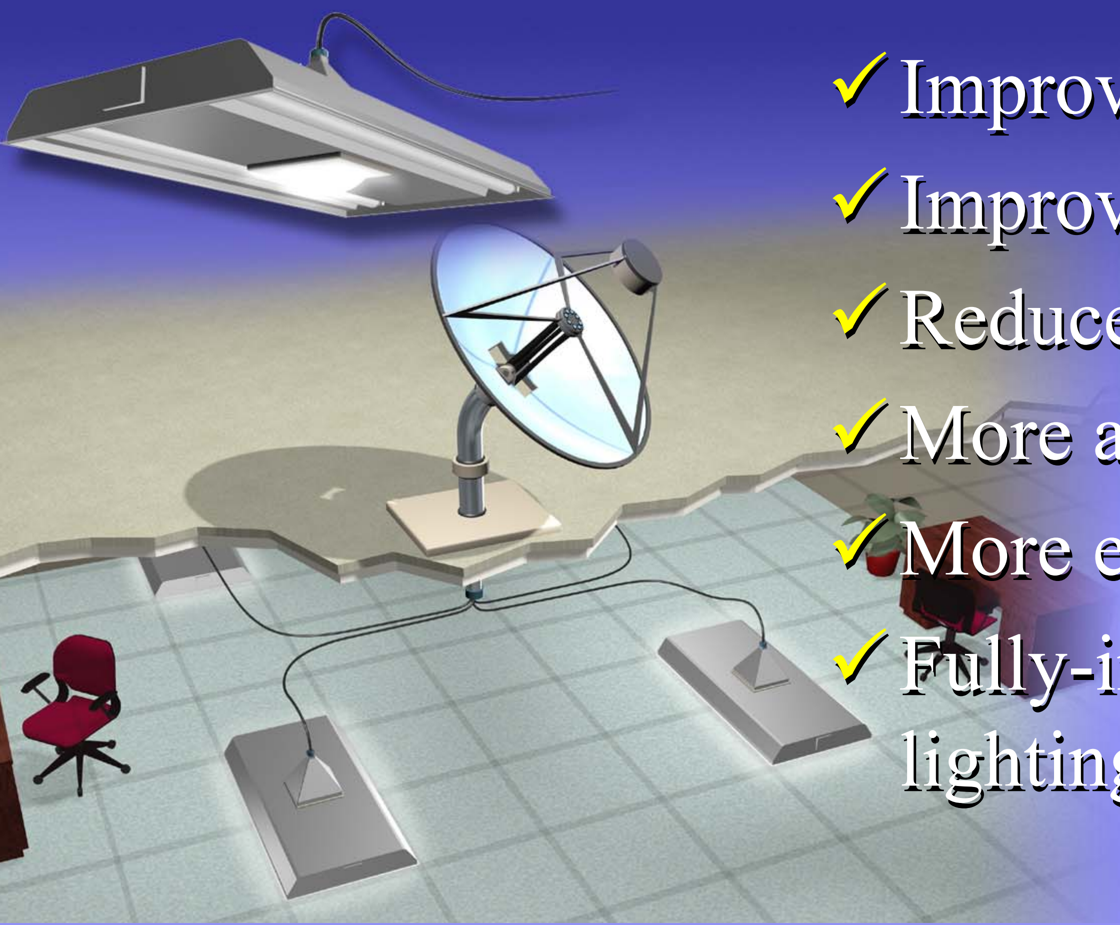
Hybrid Luminaire Design Advantages



- ✓ Improved luminaire efficiency
- ✓ Improved spatial/temporal contr
- ✓ Reduced glare and heat gain
- ✓ More architecturally compatibl
- ✓ More easily reconfigured
- ✓ Fully-integrated w/ electric lighting system

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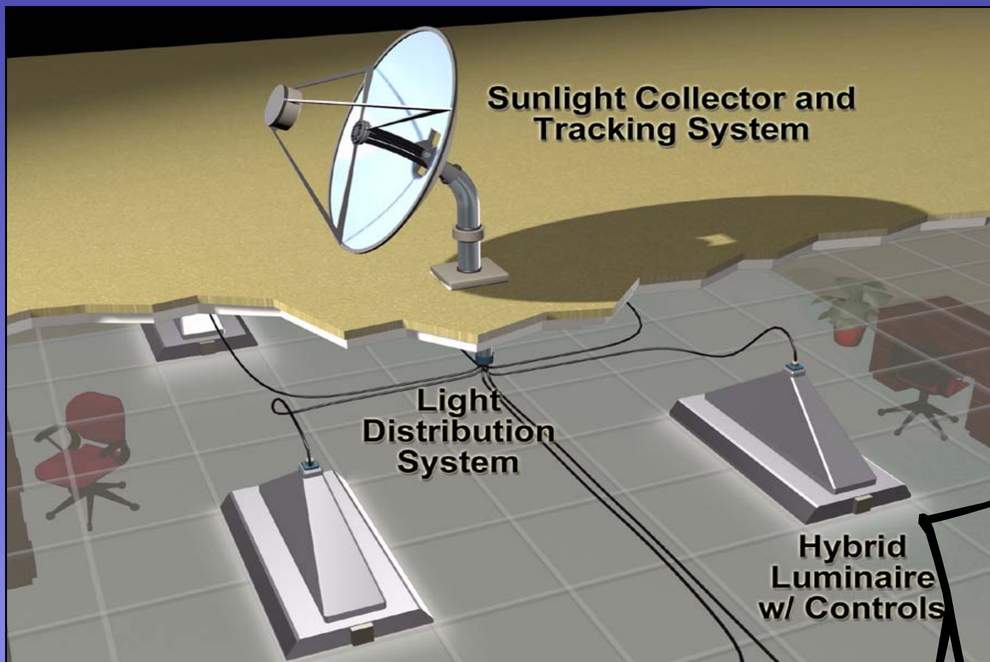
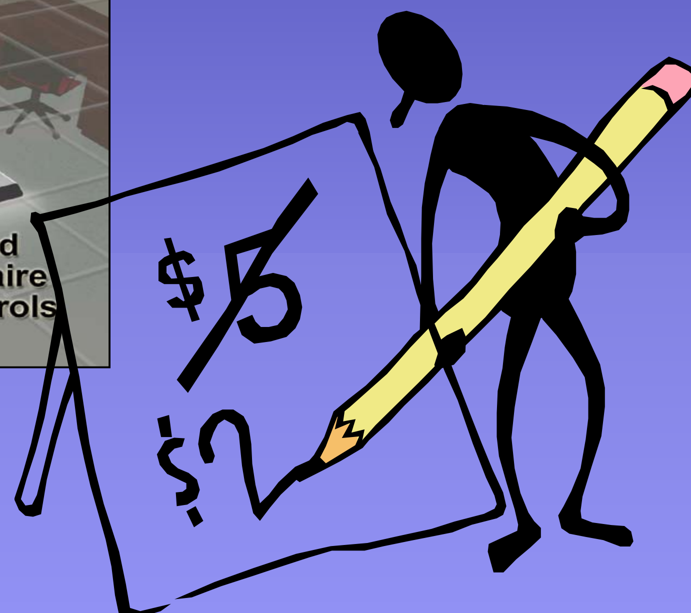
How Much Does It Cost/Save?





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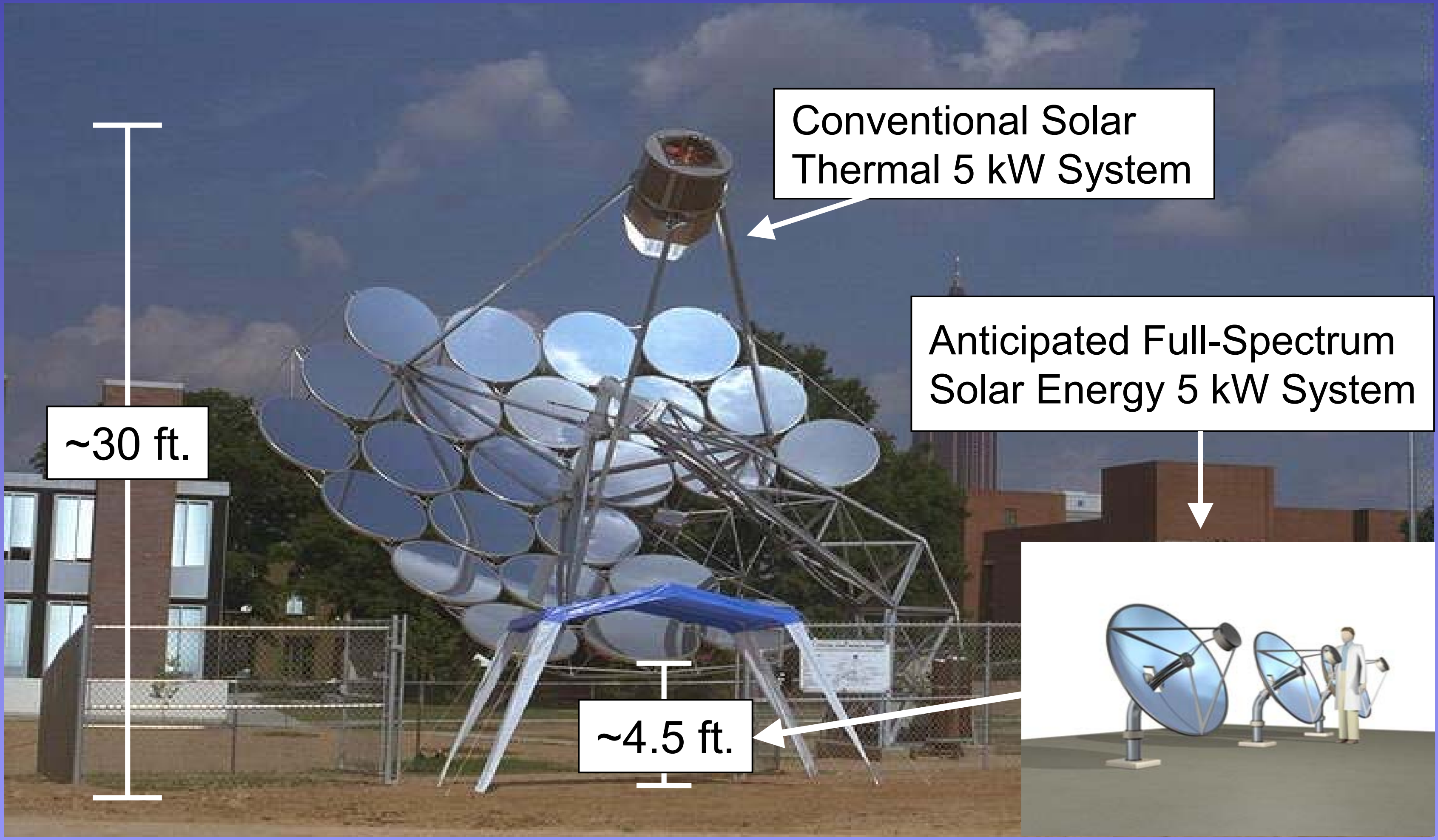
Real Estate Costs



Systems-Level Economic Cost and Performance Summary

	Current (2000)		Projected (2010)	
Component	**Cost**	**Performance**	**Cost**	**Performance**
Collector/Tracker	**$1600**	**Total grid provided electricity displaced** ↓	**$800**	**Estimated total grid provided electricity displaced** ↓
Primary Mirror	*400*		*200*	
Secondary Optical Element	*200*		*100*	
Structural Support	*300*		*200*	
Tracking System	*500*		*200*	
Assembly	*200*		*100*	
Concentrating PV Cell	**$200**		**$100**	
Optical Fiber (70m @ $10/M)	**$700**		**$350**	
Hybrid Luminaire (add-on cost)	**$350**		**$175**	
Installation	**$350**		**$170**	
Total Installed System	**$3200**	**1940 Wp**	**$1600**	**2300 Wp**
Lifecycle Maintenance (20 years)	**$800**		**$400**	
Total Lifecycle System	**$4,000**	~$2/Wp	**$2,000**	~$1/Wp

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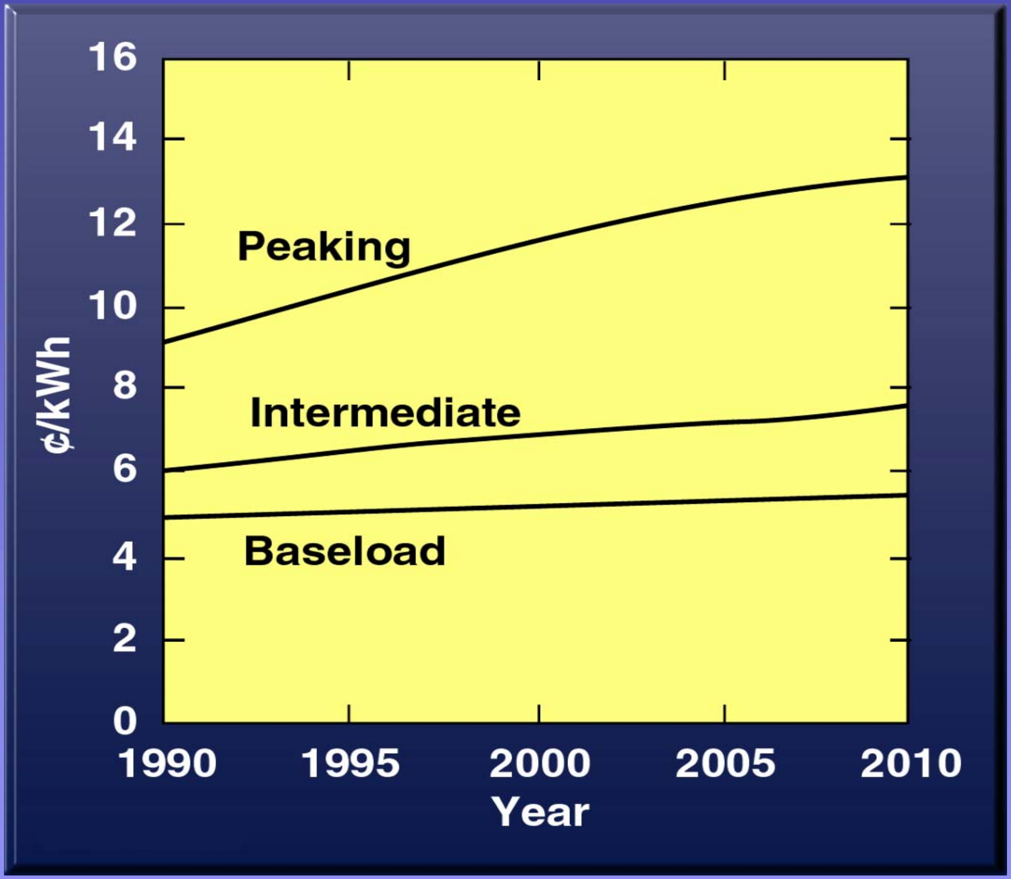
Projected Cost of Conventional Electric Power Generation (U. S. Average)



Reference:
Scenarios of U. S. Carbon Reductions
(Five lab Report)

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Summary of the Projected Performance of Hybrid Lighting Systems

Region	Building Use Scenario	Cost/kWh Displaced		Years to Payback at 12.5¢/kWh	
		Current	Projected	Current	Projected
Sunbelt (7.0 kWh/m^2/day)	Everyday 313 days 261 days	4.5 5.5 6.6	1.9 2.3 2.8	4.9 6.0 7.2	2.0 2.5 3.0
Average Location (4.5 kWh/m^2/day)	Everyday 313 days 261 days	5.8 7.0 8.5	2.4 2.9 3.5	6.3 7.6 9.2	2.6 3.2 3.8
Suboptimal Location (3.0 kWh/m^2/day)	Everyday 313 days 261 days	7.4 9.0 10.9	3.1 3.8 4.5	8.0 9.7 11.7	3.3 4.0 4.9

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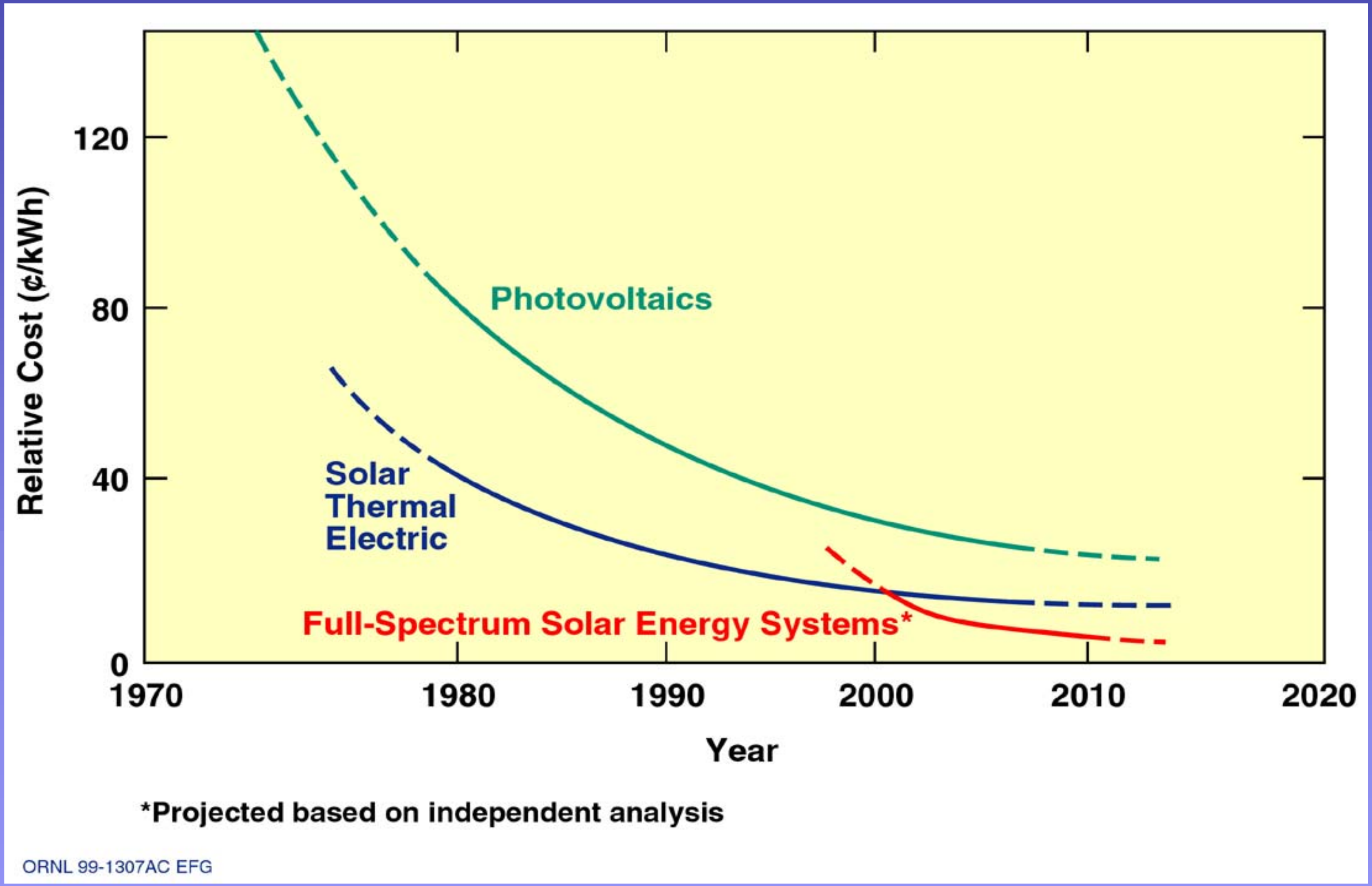
Value of National-Scale R&D Effort: Historical Case Studies



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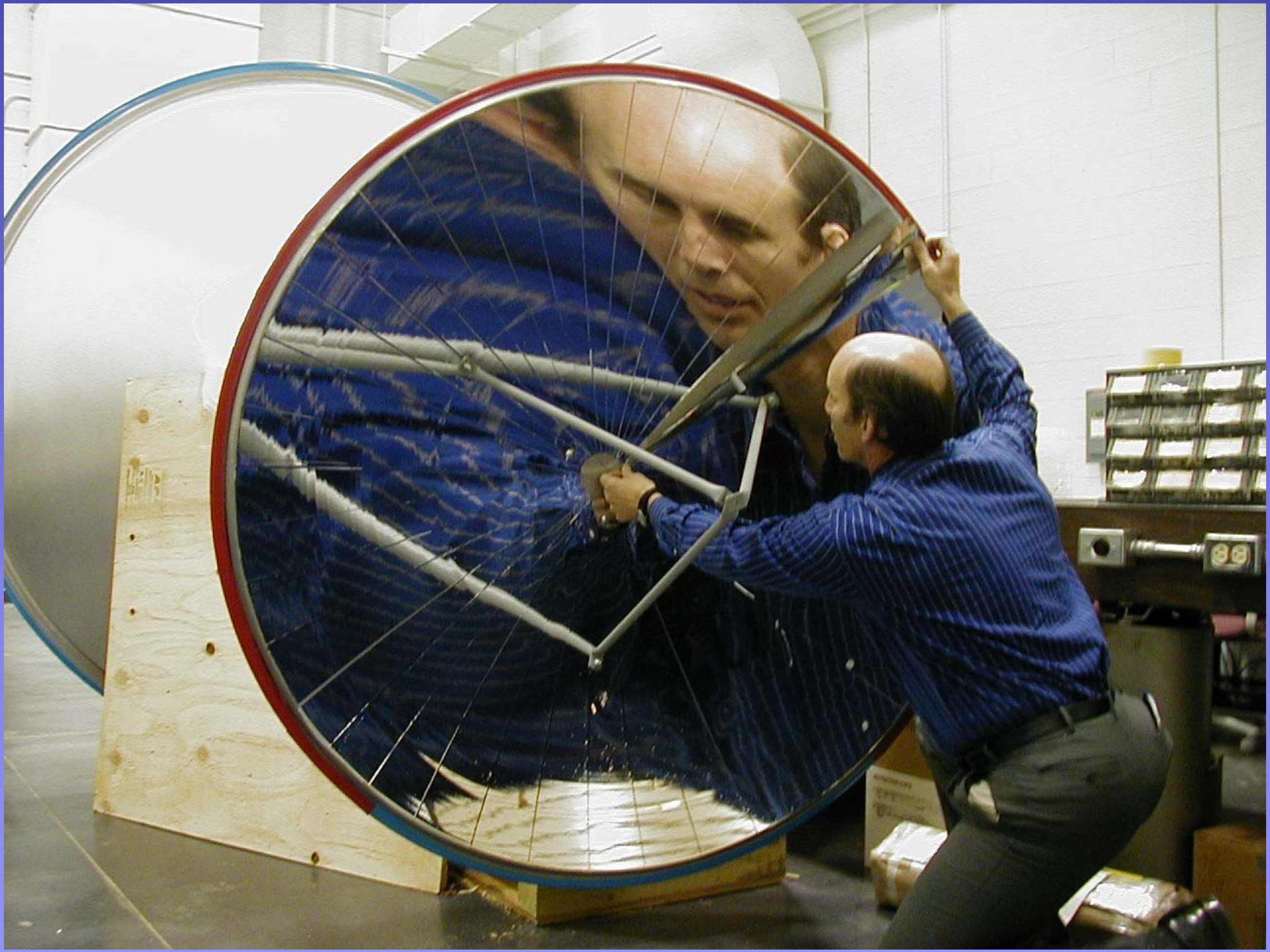
Significant Cost-Reductions Anticipated in Near Future through R&D



<u>Prototype Low-Cost Solar Collector</u>

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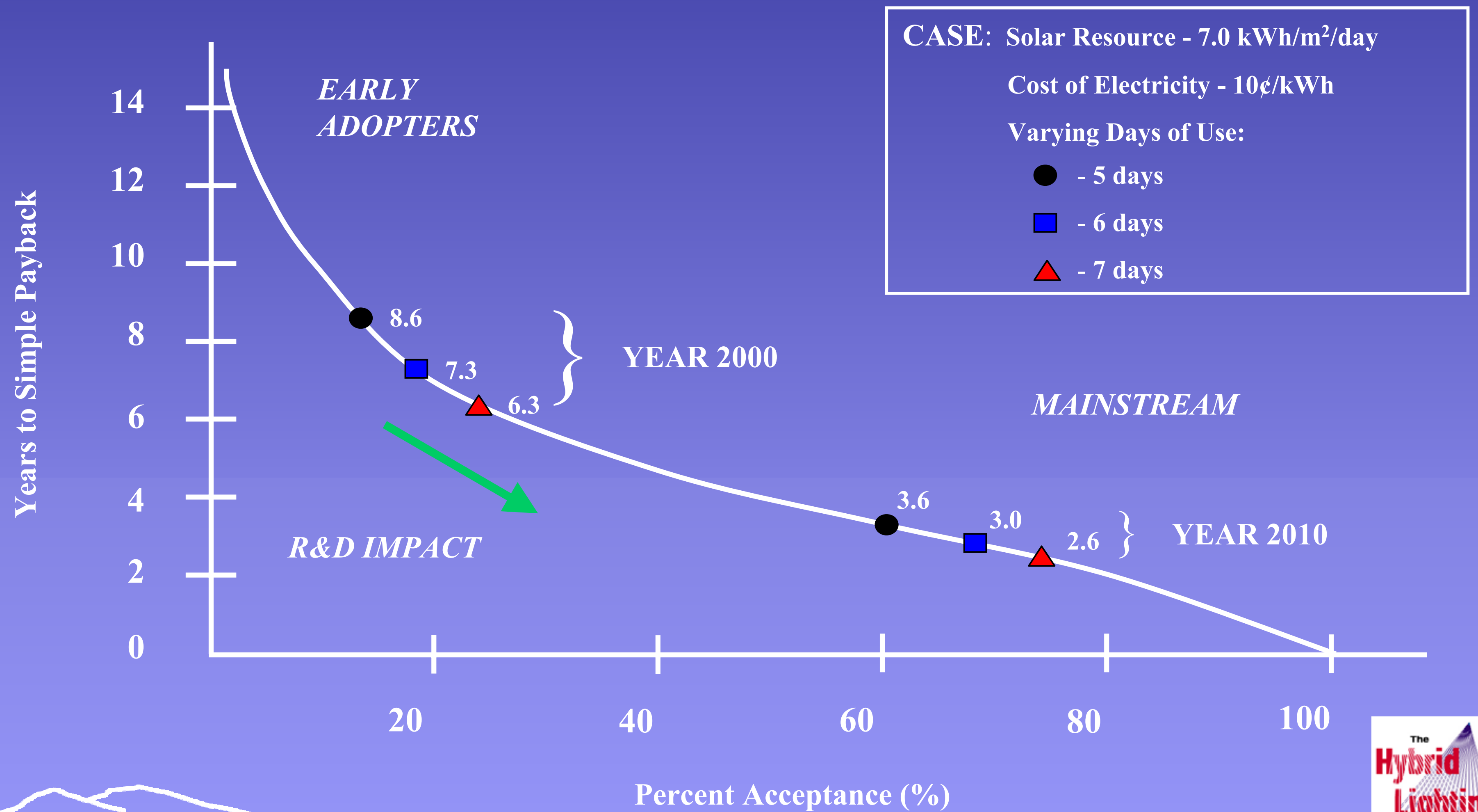
Market Potential of Hybrid Lighting Systems



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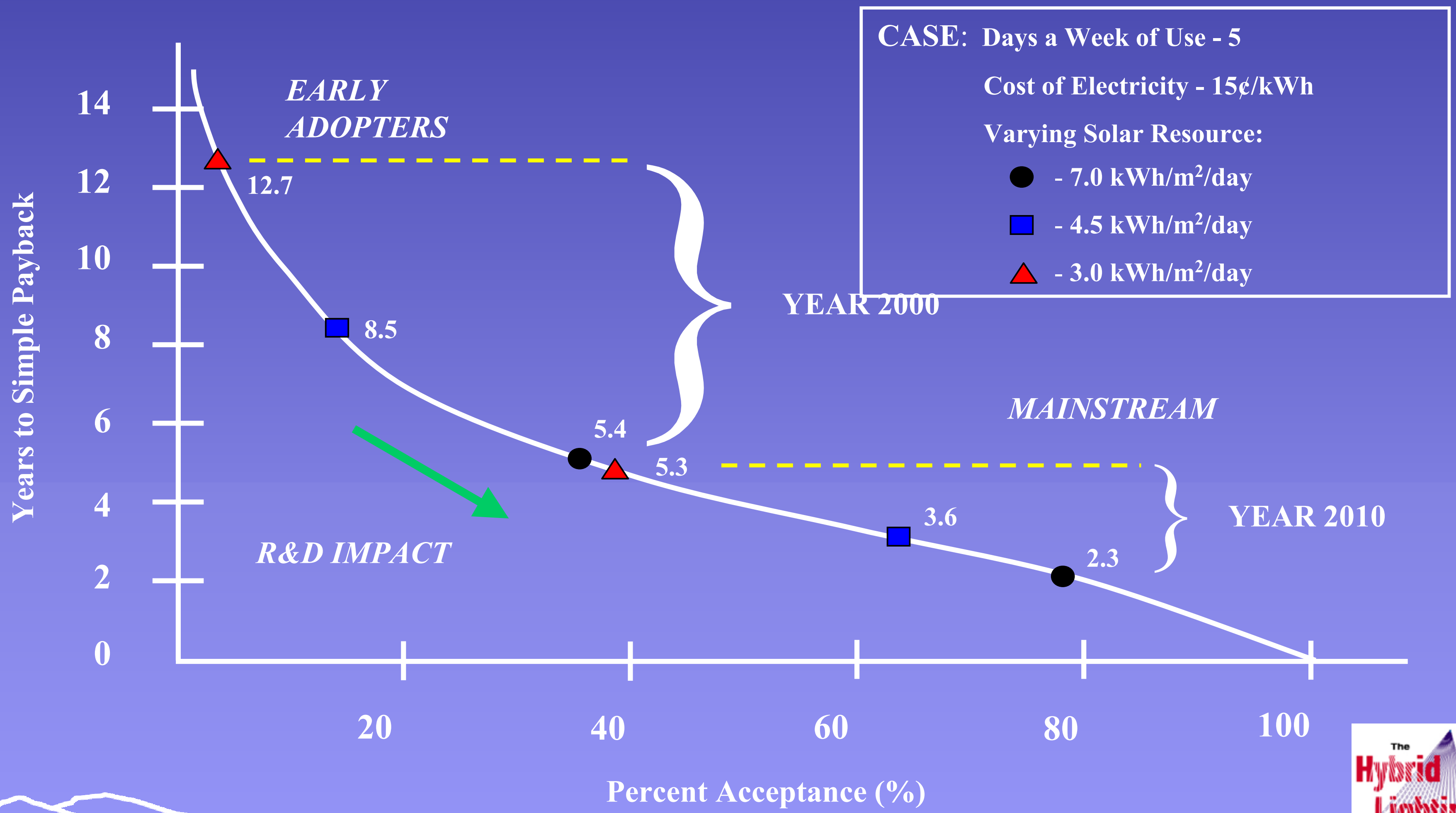
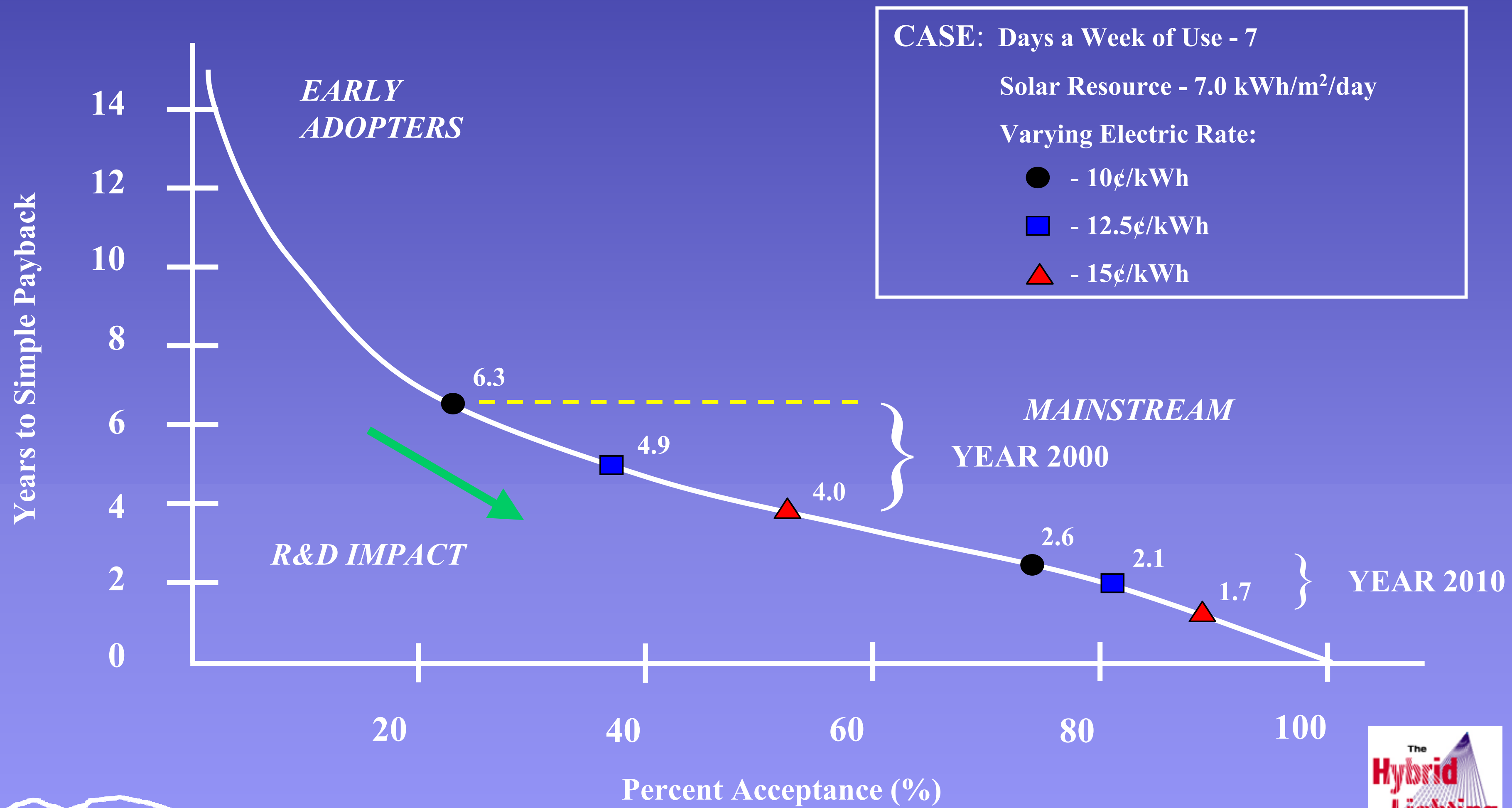
Market Potential of Hybrid Lighting Systems



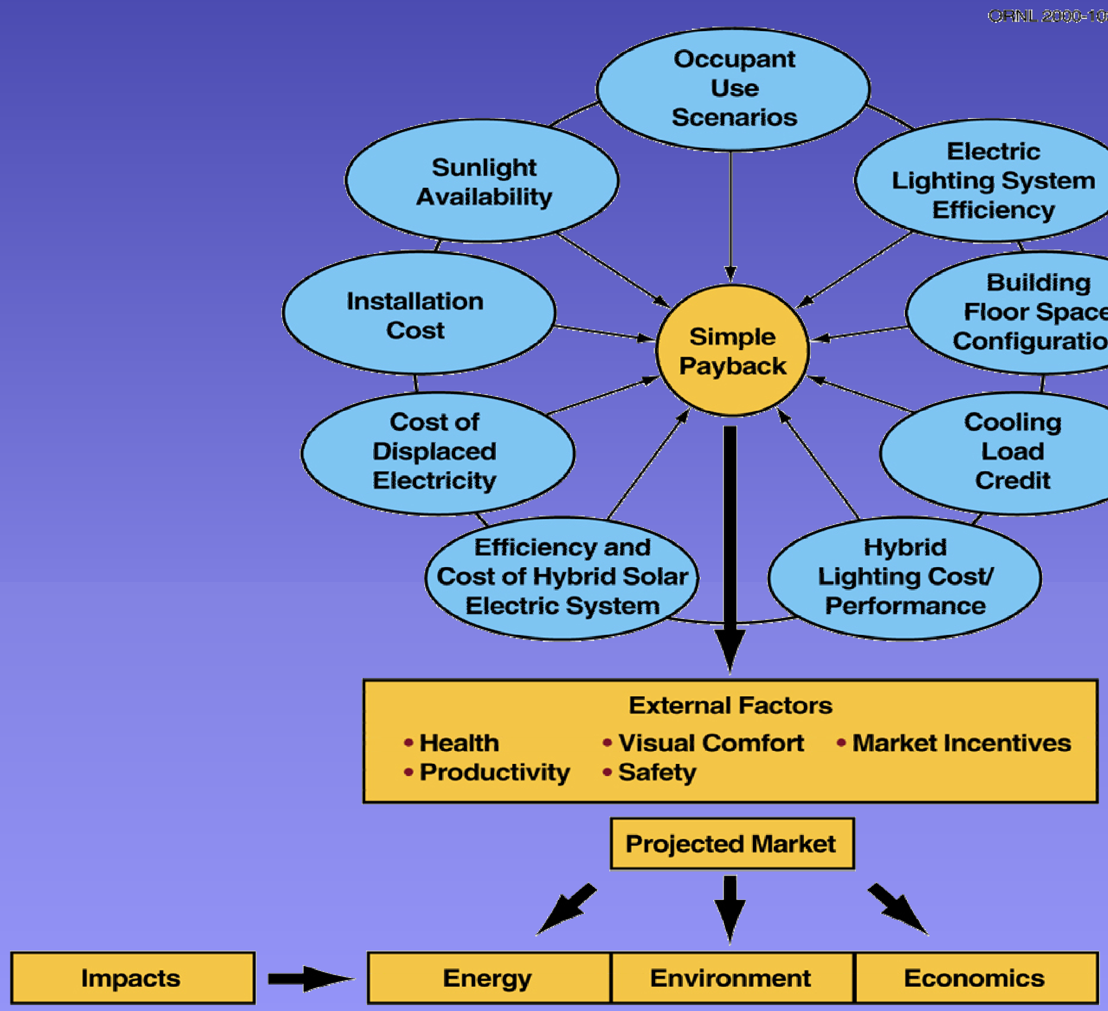
Market Potential of Hybrid Lighting Systems



Preliminary Independent Market Analysis

- ✓Conducted By: Antares Group, Inc.
- ✓Initiated in May 1999 - completed in Aug. 1999
- ✓Baselined against state-of-the-art electric lighting systems and energy-efficient daylighting approaches
- ✓Based on today's cost/performance values
- ✓Targeted commercial market

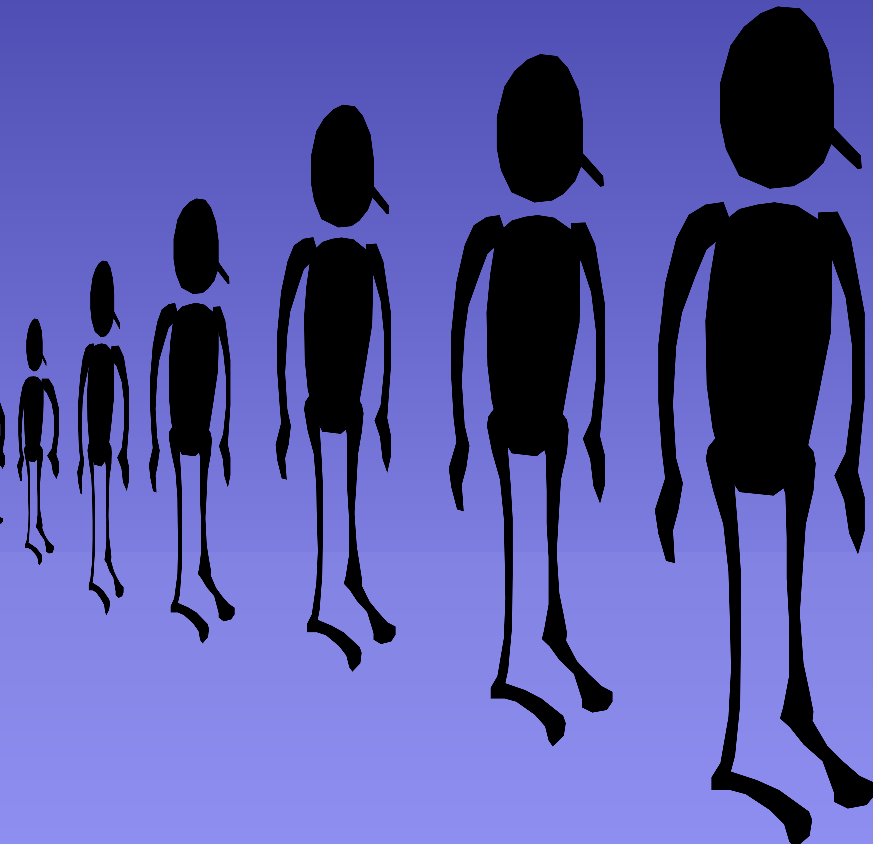
Issues Affecting the Market Potential of Hybrid Lighting

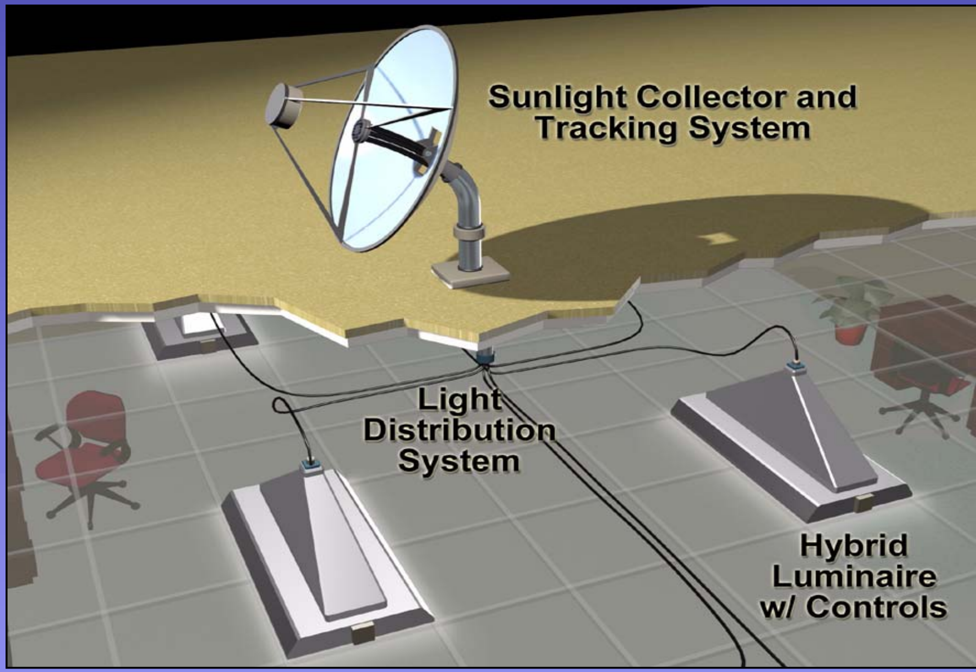


Antares' Key Findings

- ✓ Hybrid lighting will likely be more economical than conventional daylighting and solar technologies of today.
- ✓ Hybrid lighting may achieve simple paybacks in the 3-5 year range in the sunbelt in deregulated utility markets.
- ✓ Projected energy savings estimates are 10–30 BkWh/year by 2020 assuming an integrated R&D program is initiated.

Where Can I Get It?





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ORNL
TVA
SAIC
Translight LLC
Fiber Optic Technologies Inc.
The Daylite Company
ITN

DOE-OPT
DOE-BTS
3M
Honeywell
DSI
JX Crystals
ELI

Committed University/Lab Participants

- ✓University of Nevada – Reno
- ✓University of Wisconsin – Madison
- ✓University of Arizona – Tuscon
- ✓Ohio University
- ✓Rensselaer Polytechnic Institute
- ✓Sandia National Laboratories
- ✓National Renewable Energy Laboratory

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Commercial Development

- ✓ Still 18 – 24 months away from commercialization.
- ✓ Demonstration system can be seen in Sacramento, CA in 2002.
- ✓ Check ORNL's Hybrid Lighting web page for technical updates and commercial availability.

www.ornl.gov/hybridlighting/

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Summary

- ✓Hybrid lighting reduces energy usage, associated with internal lighting, through the direct collection and redistribution of sunlight with the potential to dramatically **improve** the overall efficiency (> 90%) and affordability (< $1.00/Wp) of solar energy in the near future.