A PLACE IN THE SUN

Hybrid Solar Lighting and Full Spectrum Solar Energy Systems

Jeff Muhs
Oak Ridge National Laboratory

U.S. Department of Energy Solar
Buildings Program

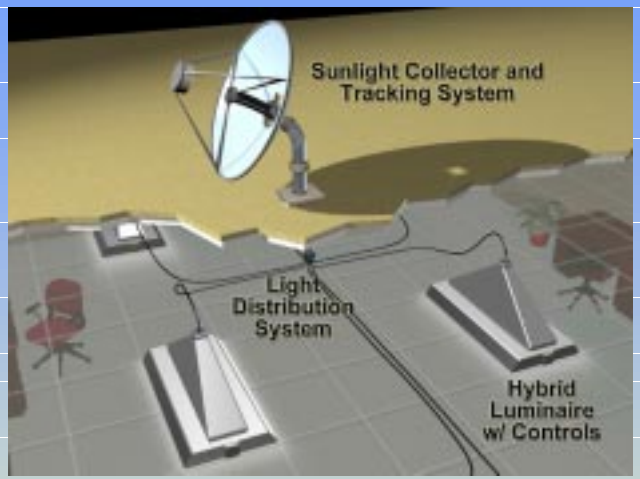
The Hybrid Lighting Partnership
Illuminating the 21st century

Situation Analysis

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

The Hybrid Lighting Concept



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

Competitive Advantages

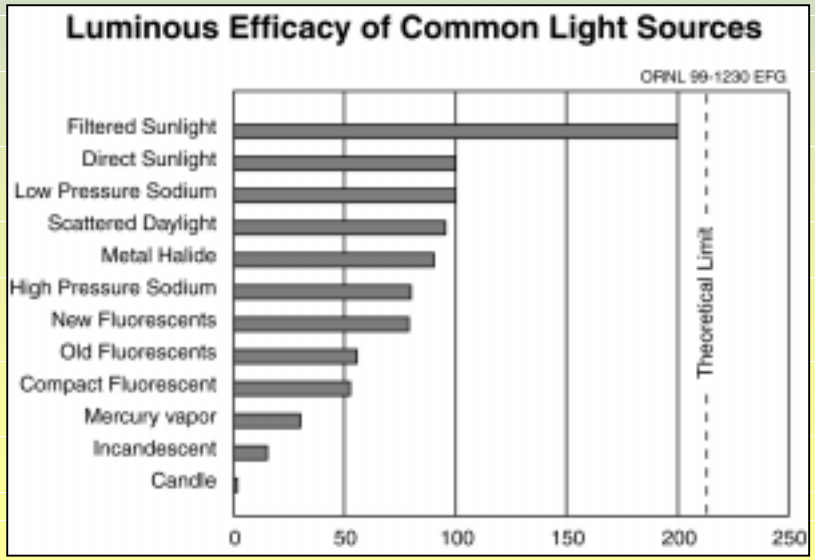
- Provides spatial and temporal illumination control
- Eliminates glare and over illumination
- Functions as a true system
- Reduces architectural intrusion
- Reduces energy consumption during peak demand
- Uses visible sunlight directly
- Improves efficiency and affordability of solar energy

Available Sources of Light

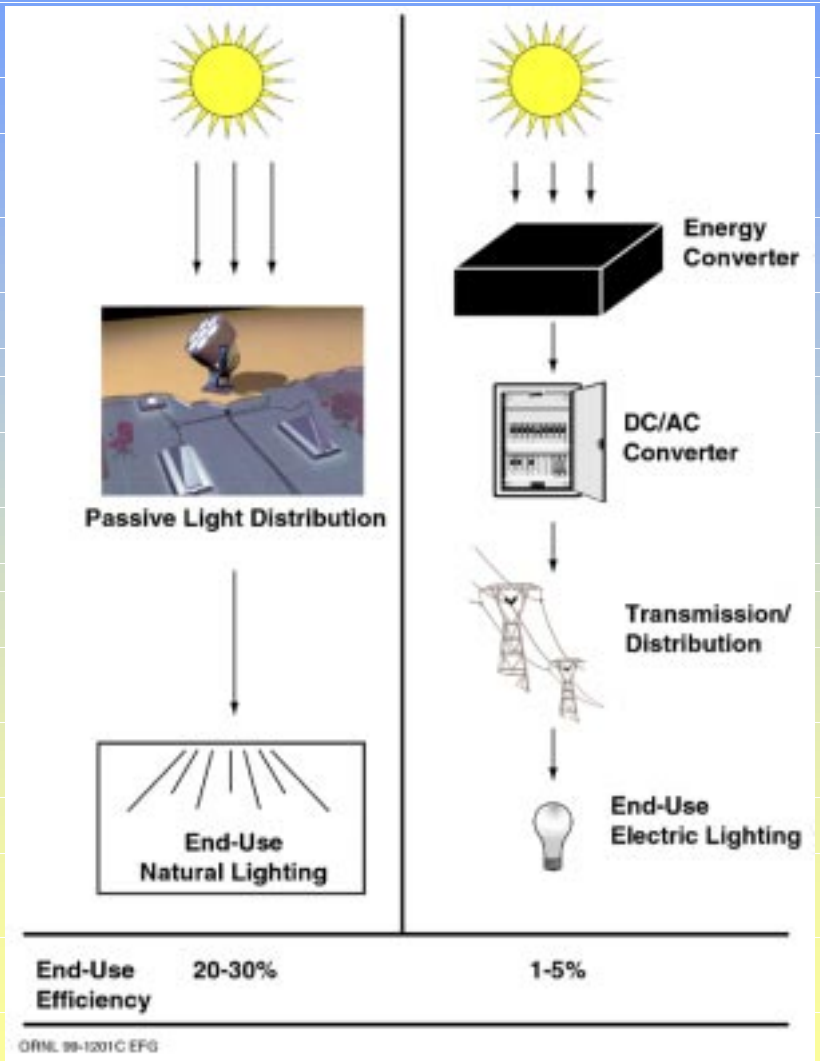
Natural Sources

- Direct sunlight (80%)
- Scattered daylight (20%)

Electric Lamps



Comparative Analysis of Lighting End-Use Efficiency Using Solar Energy



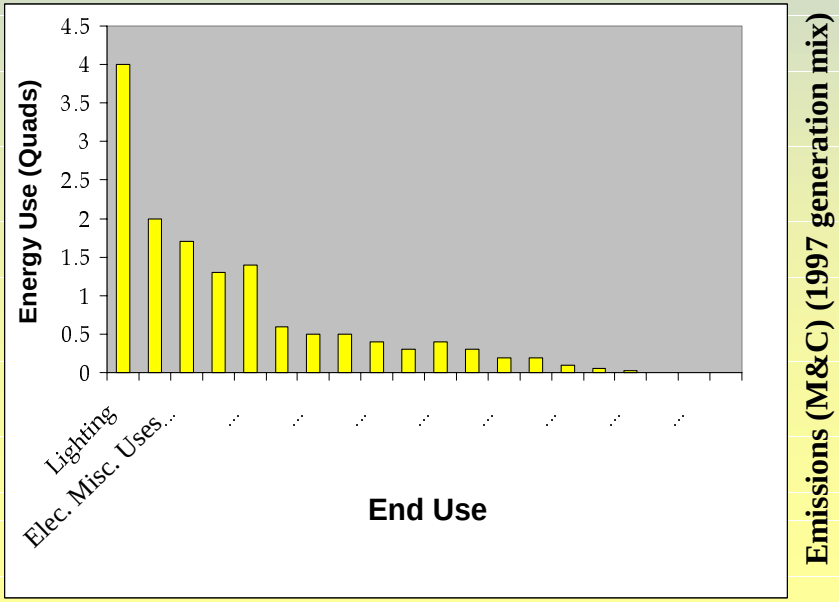
U.S. Department of Energy Solar Buildings Program

Importance of Lighting to the U.S.

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

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

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



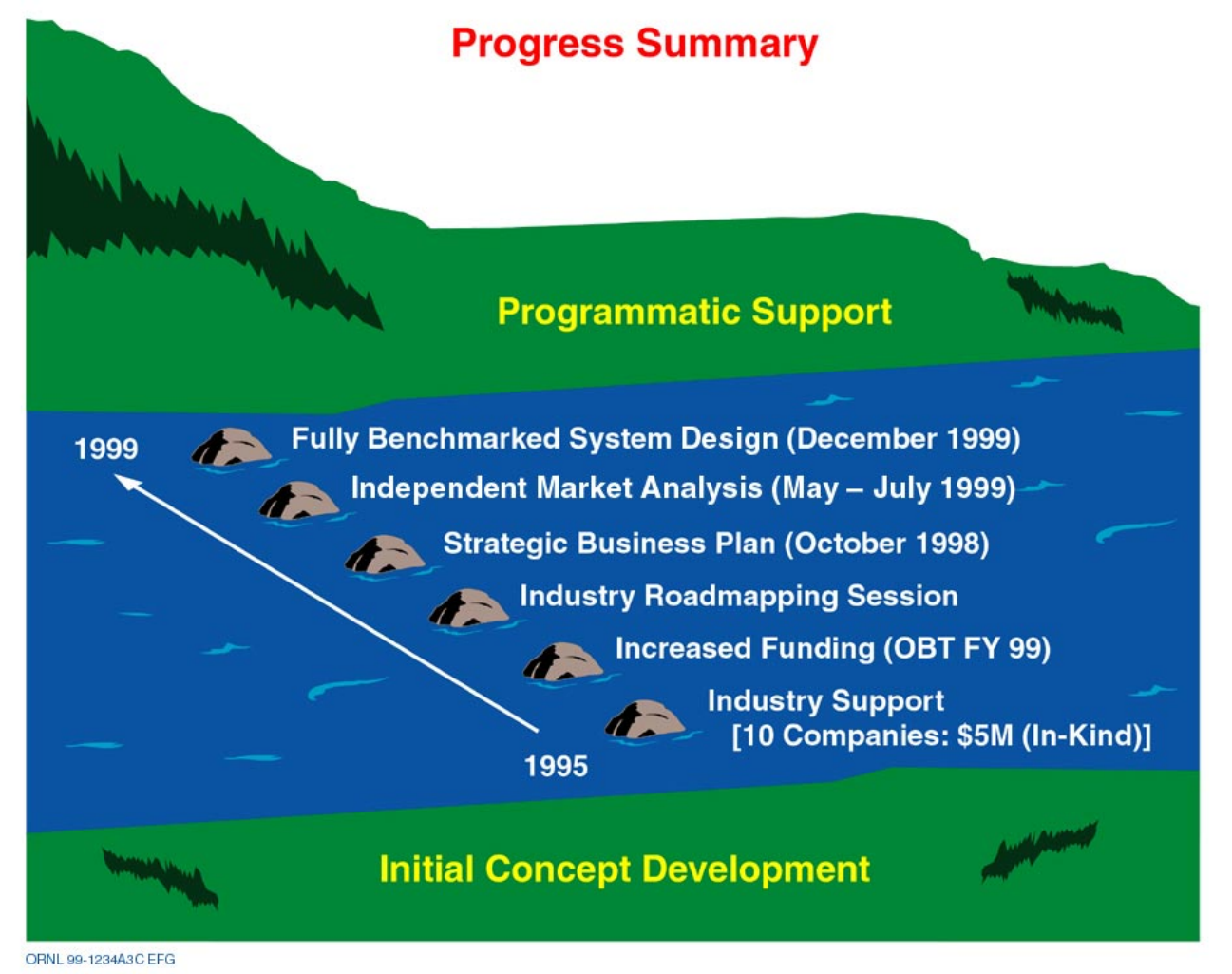
Technical Objective

Demonstrate at least a two-fold improvement in solar energy end-use efficiency and simple payback in commercial buildings by:

- ✓ Separating and using different regions of the solar spectrum for different end-use purposes
- ✓ Spectrally and temporally varying solar energy streams originating from a common solar concentrator based on building end-use needs
- ✓ Developing and demonstrating prototype systems in commercial buildings

FY 2001 Solar Buildings Program Goal:
Develop and demonstrate feasibility of a prototype solar collector for hybrid lighting applications.

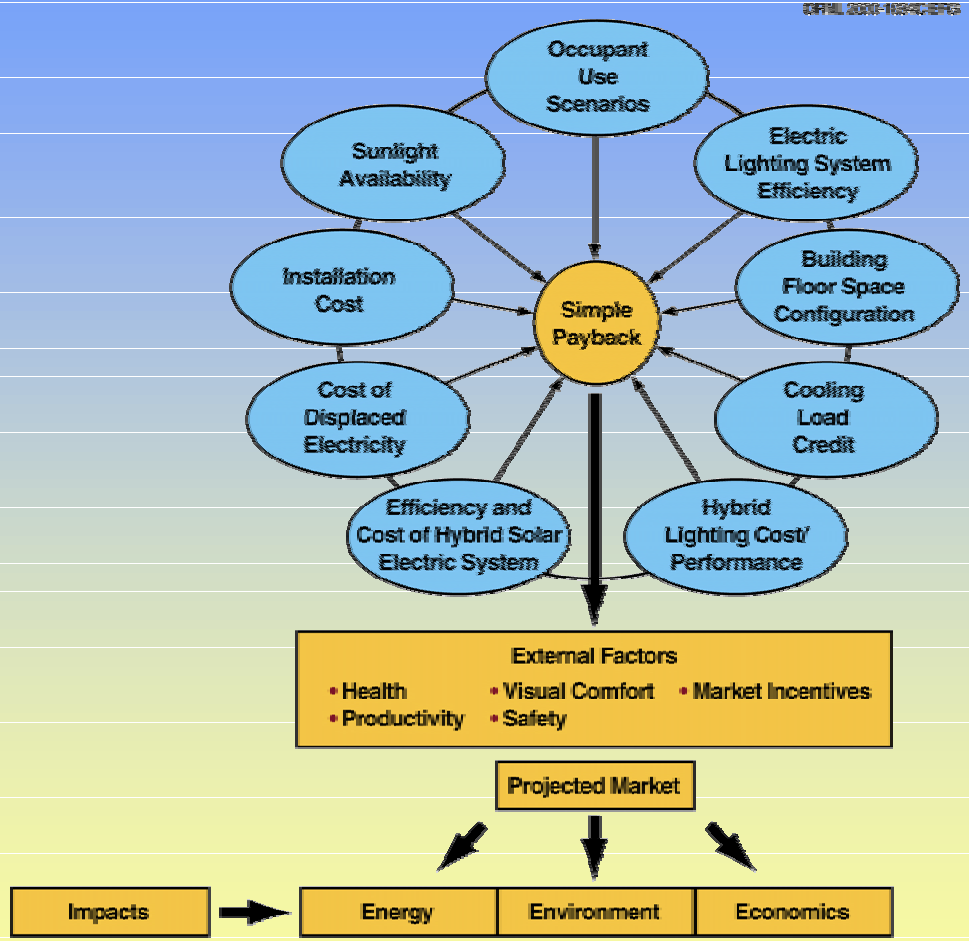
Progress Summary



Independent Hybrid Lighting Metrics

- ✓ Baselined against state-of-the-art electric lighting systems as well as energy-efficient daylighting approaches
- ✓ Based on today's cost/performance values
- ✓ Targets commercial market
- ✓ Payback dependent on several variables

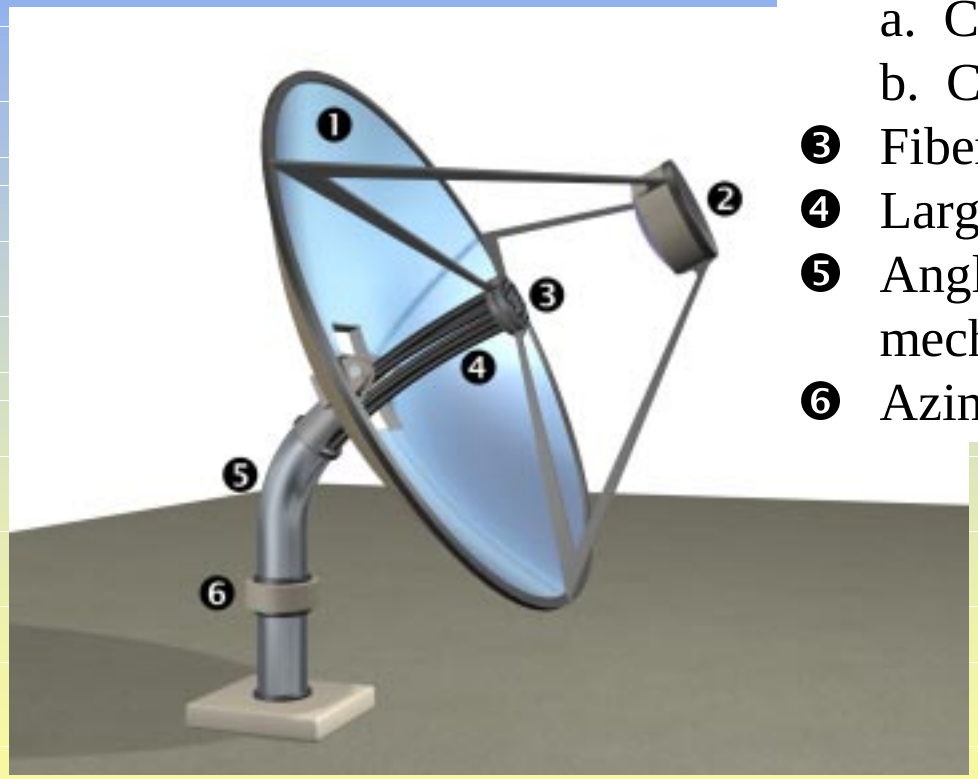
Issues Affecting the Market Potential of Hybrid Lighting



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.

Preliminary Hybrid Solar Collector Design Concept

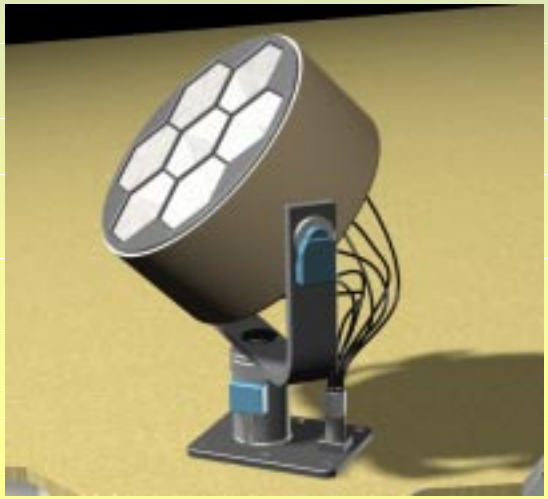


1. 1.5 meter diameter primary mirror
2. Secondary optical element
   a. Cold mirror
   b. Concentrating PV cell
3. Fiber mount
4. Large-core optical fibers
5. Angled stand with altitude tracking mechanism
6. Azimuth tracking mechanism

Design Advantages

- ✓ 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



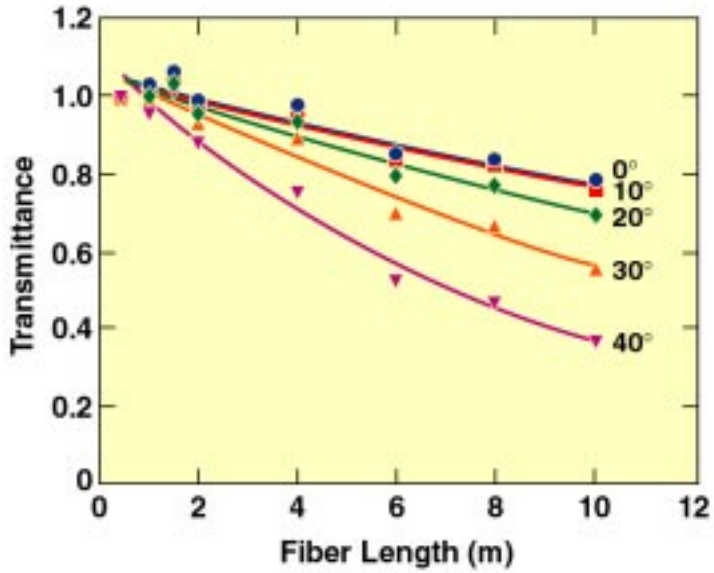
ORNL Design

Optical Performance Summary for Preferred Collector Design

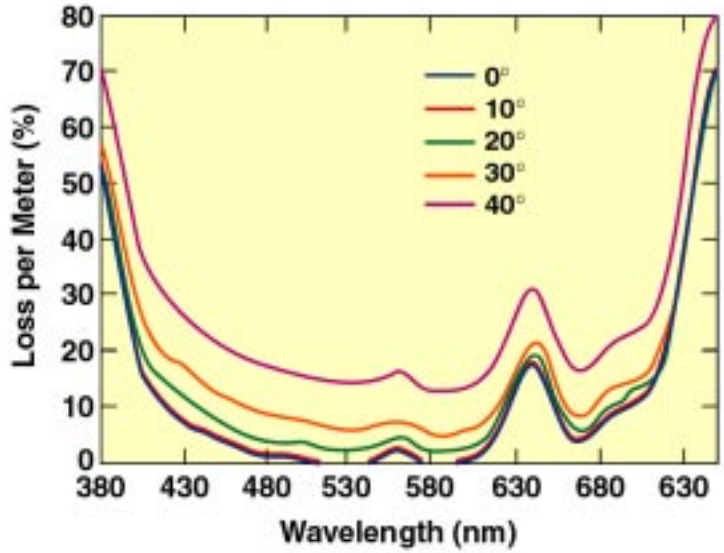
System Performance

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%

*Transmission Data for Large-Core Optical Fibers**



Transmittance as a function of fiber length for various angles of incident flux relative to that of a 0.5 meter fiber. The source spectrum is that of a 2600 K incandescent lamp (12.7 mm fiber).



Spectral transmittance loss per meter for various angles of incident flux for 12.7 mm diameter fiber.

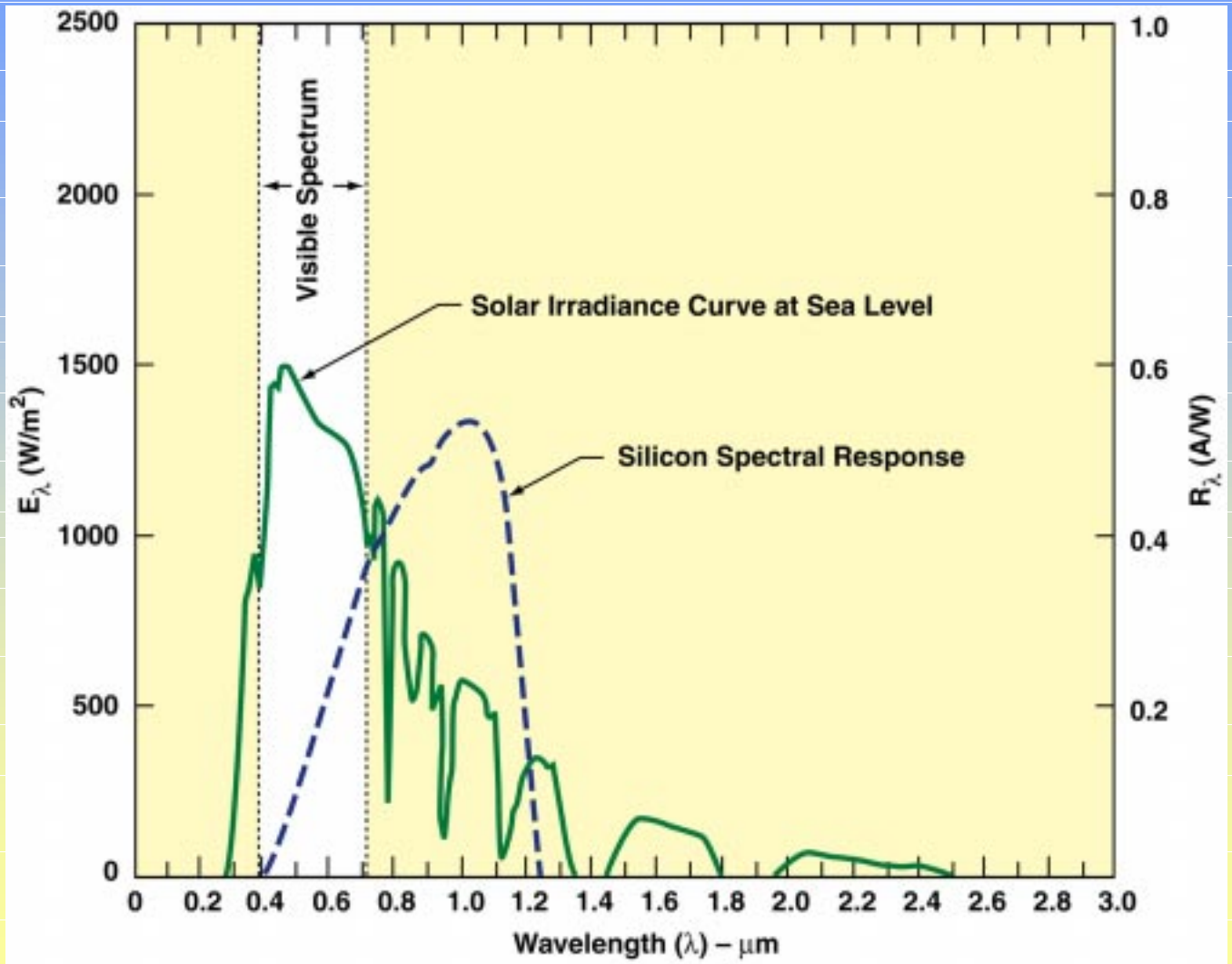
*Data provided by LRC/RPI

ORNL 2000-920C EFG

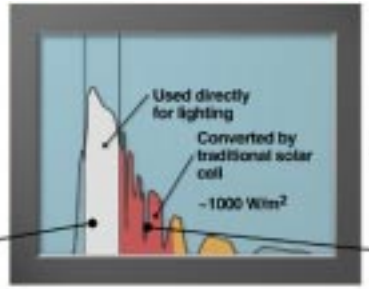
Full Spectrum Solar Energy Systems

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

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



Energy Displacement Summary



Initial Electrical Energy Displacement Efficiency = 97%

Estimated Available Solar Energy/m²			
490 W		**360 W**	
x 200 lm/W	Luminous efficiency of filtered sunlight	15%	Collection losses
98,000 lm	Available visible light	25%	IR energy conversion efficiency
x 0.5	Passive distribution losses	90%	Power conversion efficiency (dc/ac)
50,000 lm	Distributed light	~70 W	Electrical energy generated
÷ 63 lm/W	Efficiency of electric lamp/ ballast/luminaire		
+15%	Cooling load credit		
900 W	Electrical energy displaced		

Total Grid-Provided Electrical Energy Displaced = 900 + 70 = 970 W

ORNL 99-1592A3C EFG

Systems-Level Cost and Performance Summary

	Current (2000)		Projected (2004)	
Component	***Cost***	***Performance***	***Cost***	***Performance***
Collector/Tracker	**$1600**	**Total grid provided electricity displaced** ↓ **(See Table 9 and Figure 23)** ↓	**$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**		**$250**	
Hybrid Luminaire (add-on cost)	**$350**		**$150**	
Installation	**$350**		**$200**	
Total Installed System	**$3200**	**2500 Wp**	**$1500**	**2800 Wp**
Lifecycle Maintenance (18 years)	**$1000**		**$600**	
Total Lifecycle System	**$4,000**		**$2,100**	

Summary of the Projected Performance of Hybrid Lighting Systems

ORNL 99-1593 EFG

Region	Building Use Scenario	¢/kWh Displaced		Years to Payback at 12.5¢/kWh	
		Current	Projected	Current	Projected
Sunbelt (9 kWh/m^2/day)	Everyday	4.5	1.9	4.9	2.0
	300 days	5.5	2.3	6.0	2.5
	250 days	6.6	2.8	7.2	3.0
Average Location (7 kWh/m^2/day)	Everyday	5.8	2.4	6.3	2.6
	300 days	7.0	2.9	7.6	3.2
	250 days	8.5	3.5	9.2	3.8
Suboptimal Location (5.5 kWh/m^2/day)	Everyday	7.4	3.1	8.0	3.3
	300 days	9.0	3.8	9.7	4.0
	250 days	10.9	4.5	11.7	4.9

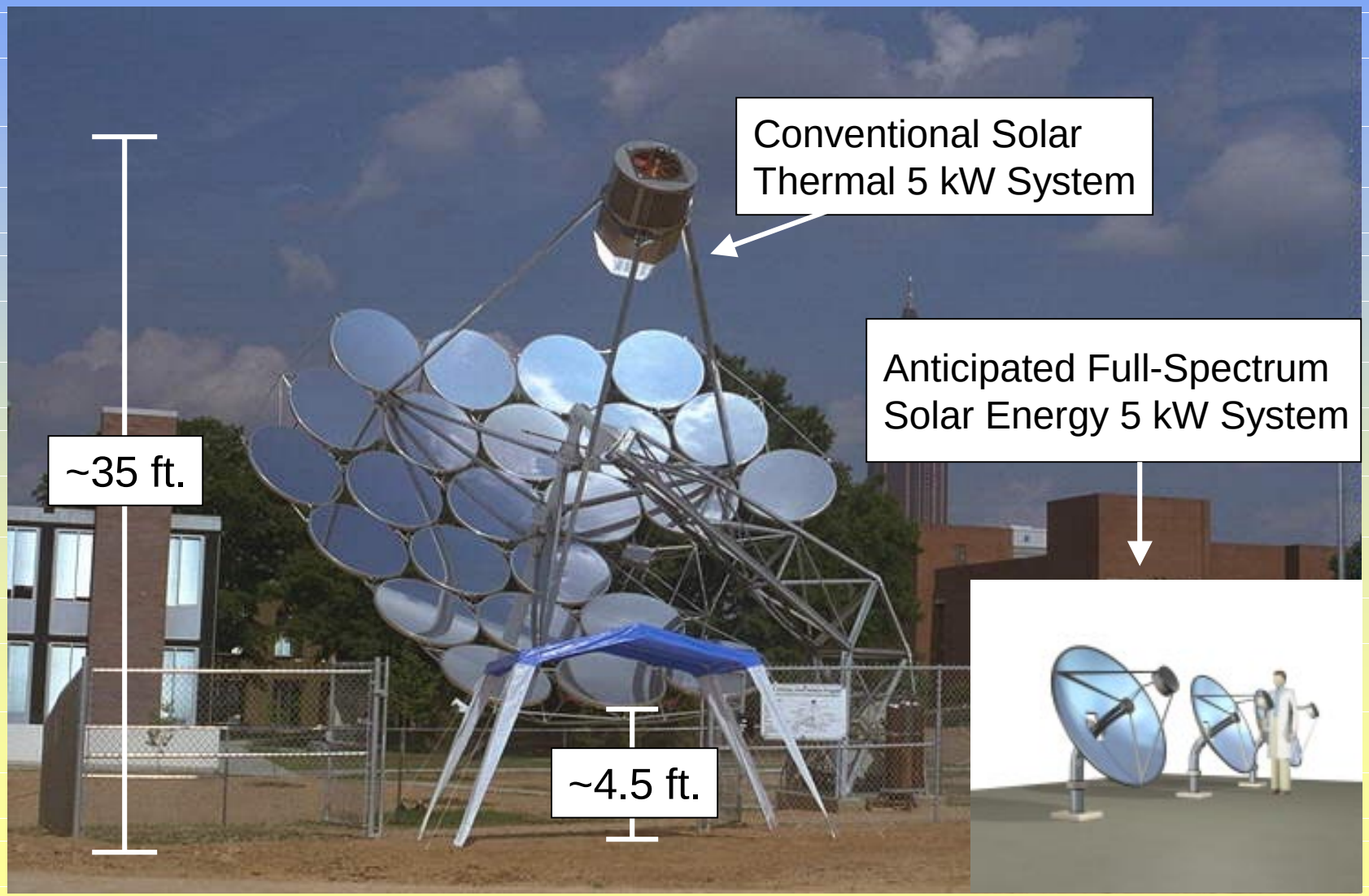
Displaced Energy Comparison

	Proposed Full-Spectrum Solar Energy Systems	Conventional Solar Technologies
Electrical Energy Displacement Efficiency	97%	10–25%

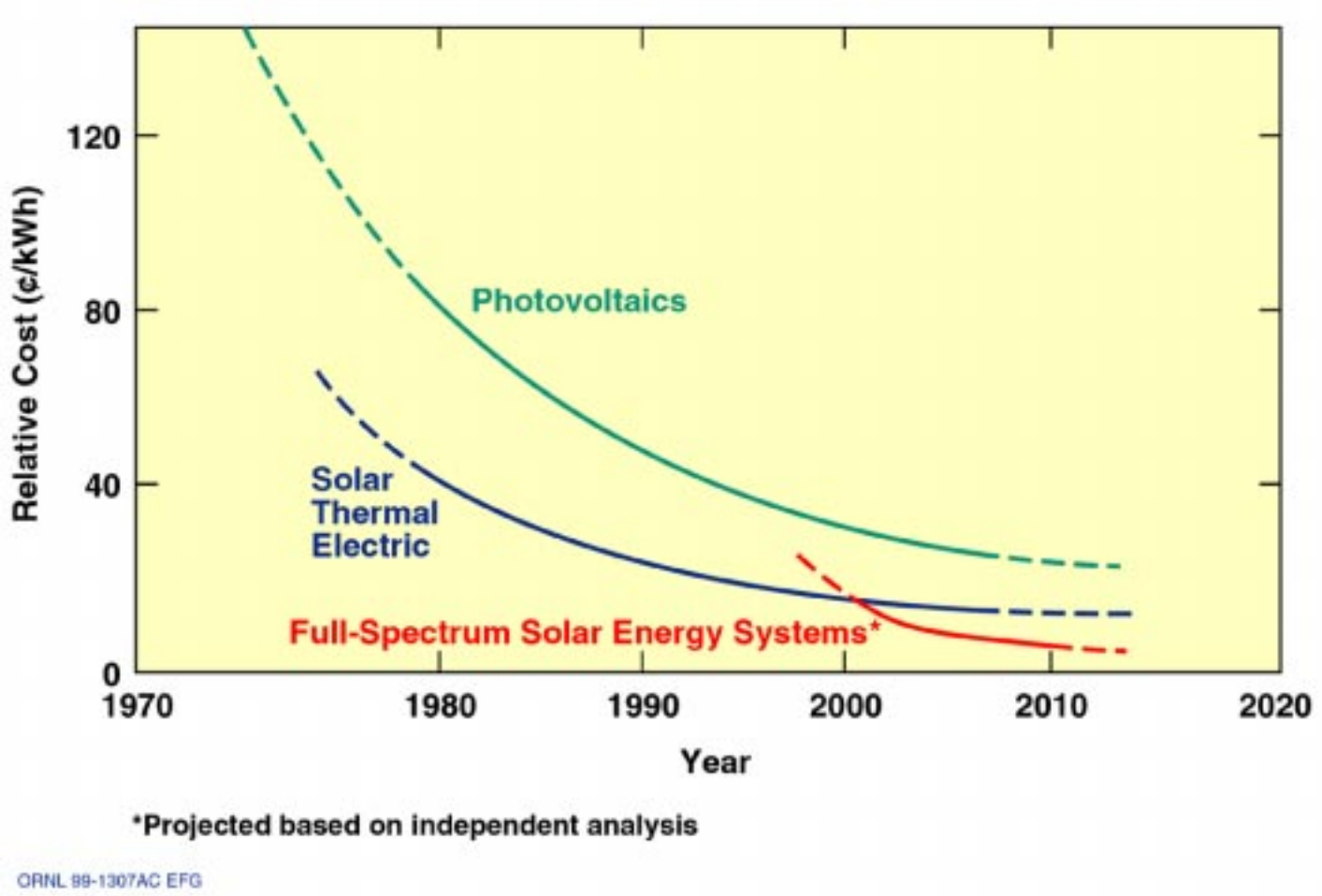
Anticipated Improvement ⟶ ~4x – 10x

ORNL 99-1306A3C EFG

The 5 kW Comparison



Cost Comparison of Solar Technologies



The Bottom Line

Hybrid lighting is poised to compete favorably with both conventional daylighting and conventional solar technologies as the preferred use of solar energy in commercial buildings.

Integrated with what we call "full-spectrum solar energy systems," it offers even further advantages.

- ✓ Significantly improve simple payback of PV's
- ✓ Increase market penetration of solar technologies

Committed Partners

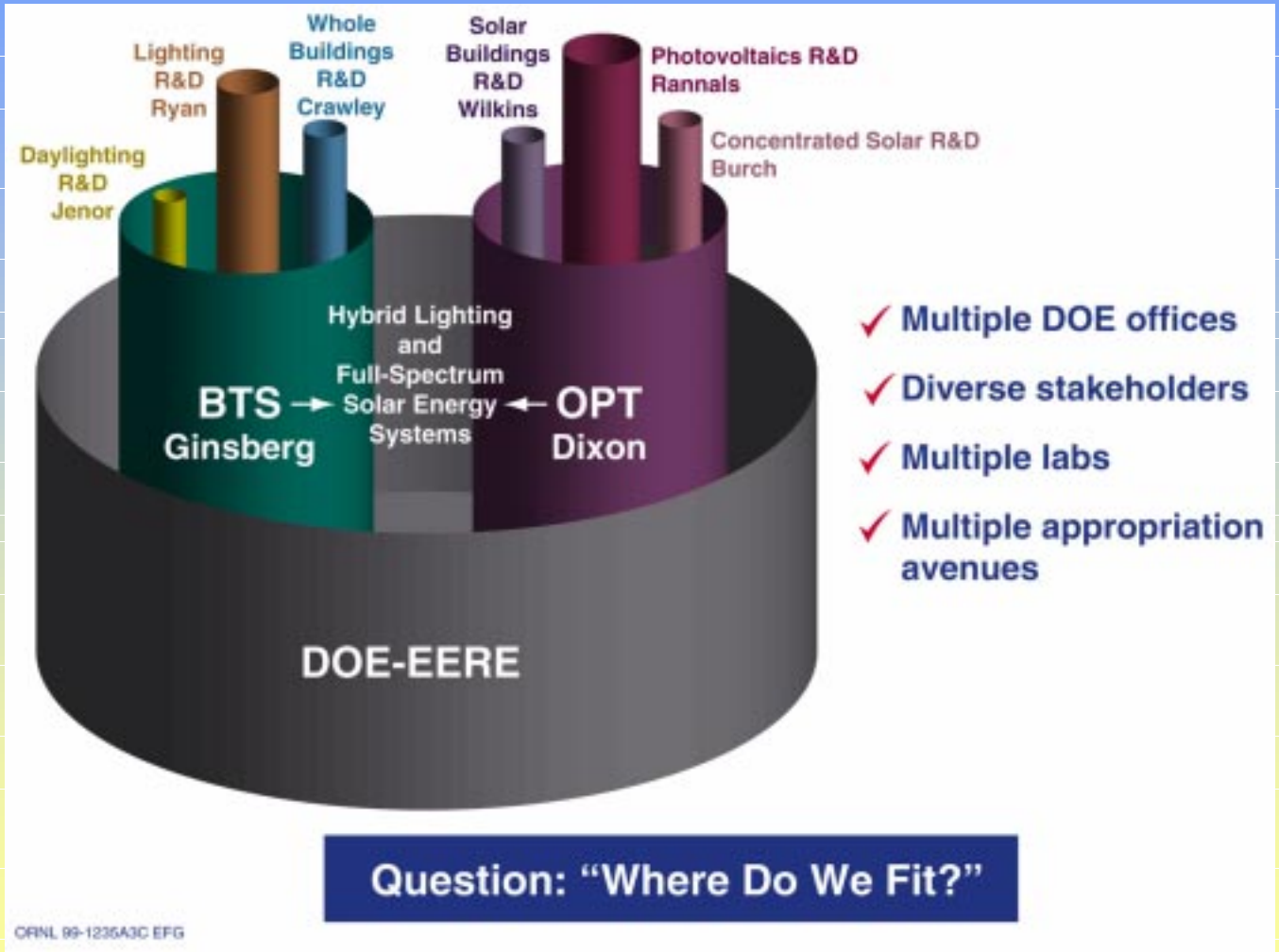
ORNL	DOE-OPT
SAIC	DOE-BTS
Duke Solar	3M
Translight LLC	Honeywell
Innovative Design	DSI
Fiber Optic Technologies Inc.	JX Crystals
The Daylite Company	ELI
ITN	

"If we build it, they will come."

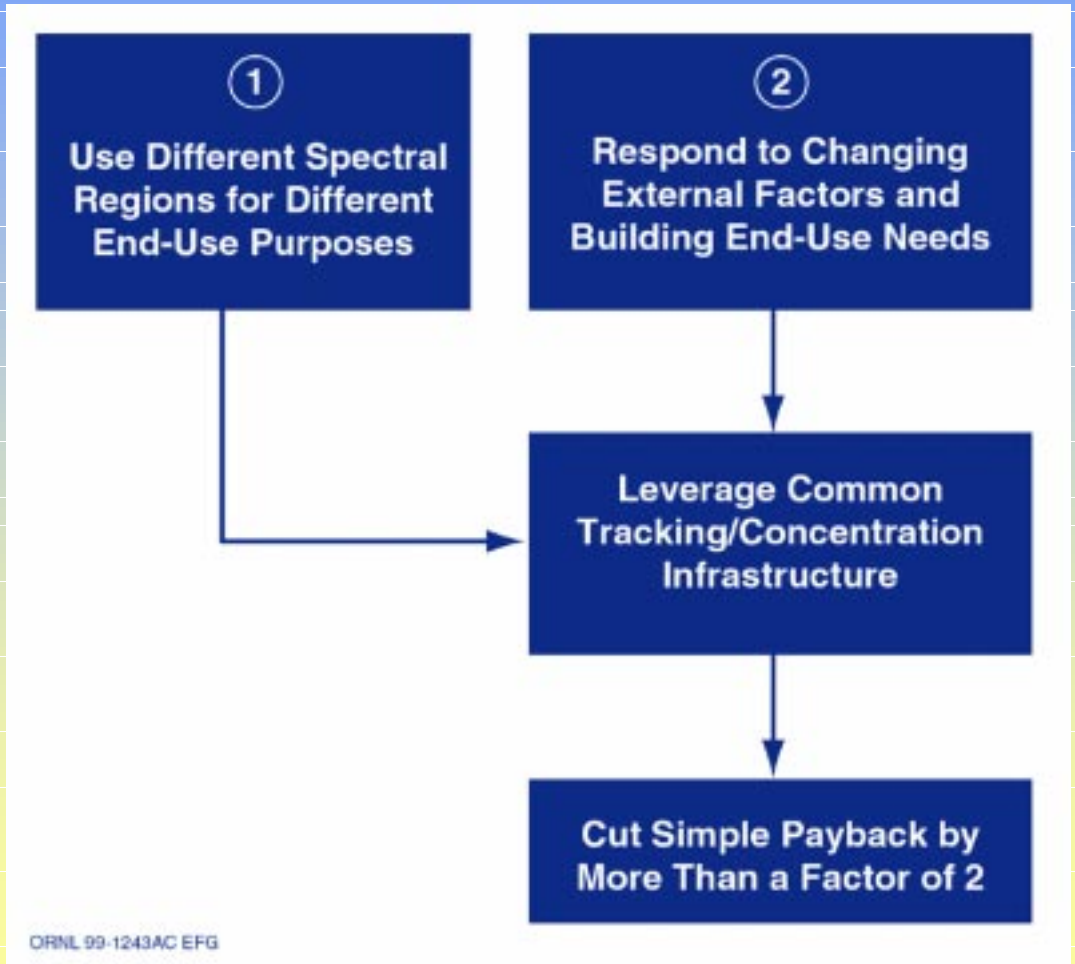
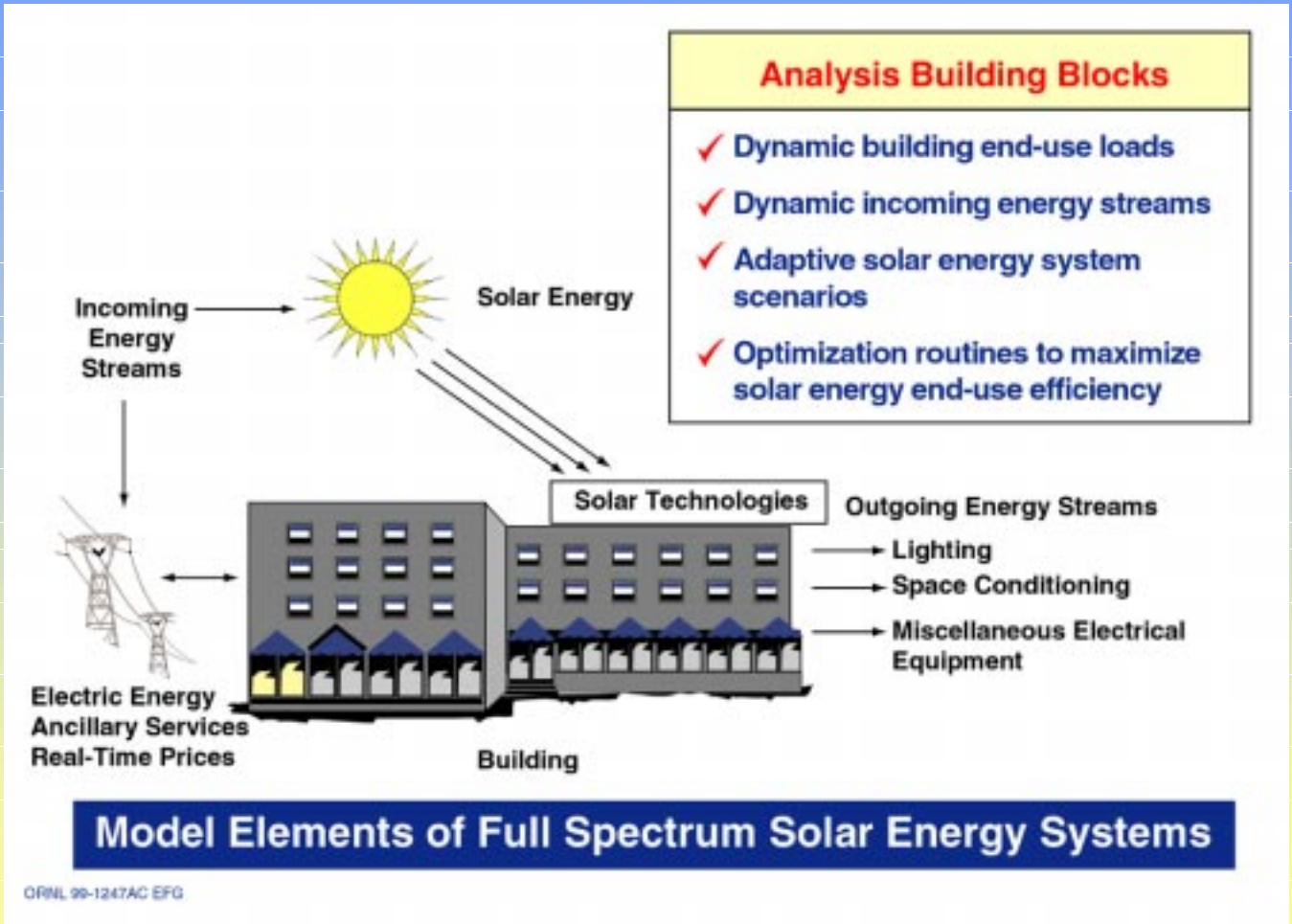
Why this Program?

- ✓ Accelerates the pace of solar energy technology development
- ✓ Innovation driven from a systems perspective
- ✓ Dramatically improves the affordability of solar energy
- ✓ Incorporates a national perspective
- ✓ Broadens and diversifies DOE's clean energy portfolio using interdisciplinary capabilities
- ✓ Establishes Solar Building Program leadership in promising clean energy technology pathway
- ✓ Crosscuts several programs in two EERE Offices
- ✓ Forms the technical basis for answering DOE's challenge

Not All "Full-Spectrum" Issues Are Technical



Full Spectrum Solar Energy System Strategies



Systems Analysis Architecture