Sun to Fiber: a thin film optical funnel for energy conversion and storage

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Outline

- Discuss energy needs that inspire the Sun to Fiber (S2F) coupler
- Propose our solution to meet these energy needs
- Possible approaches for this coupler
- Our specific design chosen for the coupler
- Collaborations and large-scale implementation plans

Reasons to Transport Sunlight

High daytime electricity usage

Himawari, La Foret Engineering, Ltd.

Solar concentrators for solar thermal

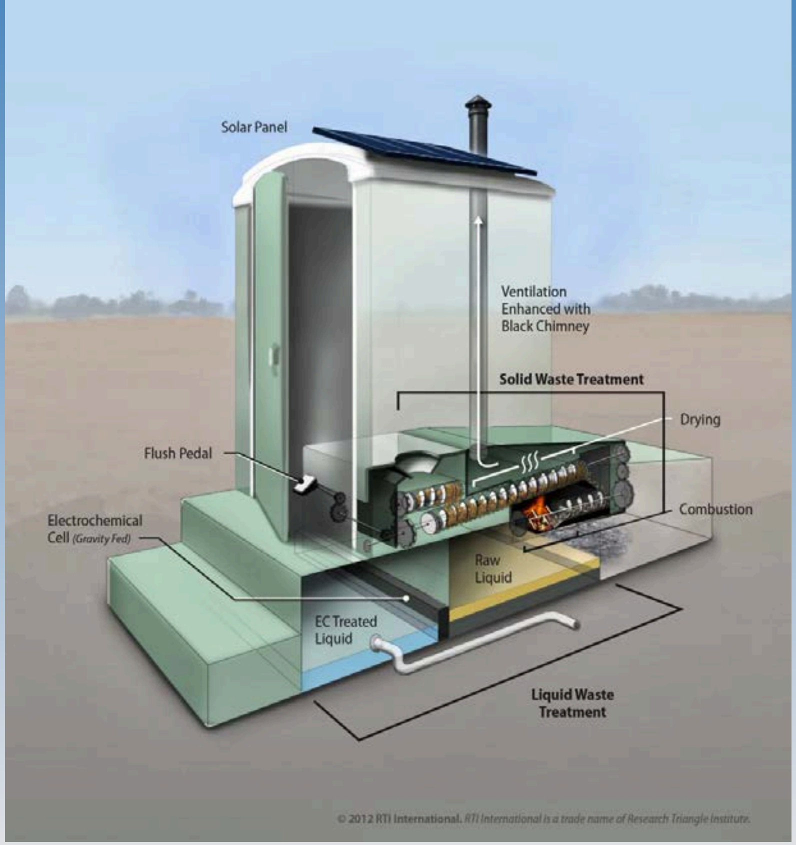
Cerro Dominador Solar Thermal Plant

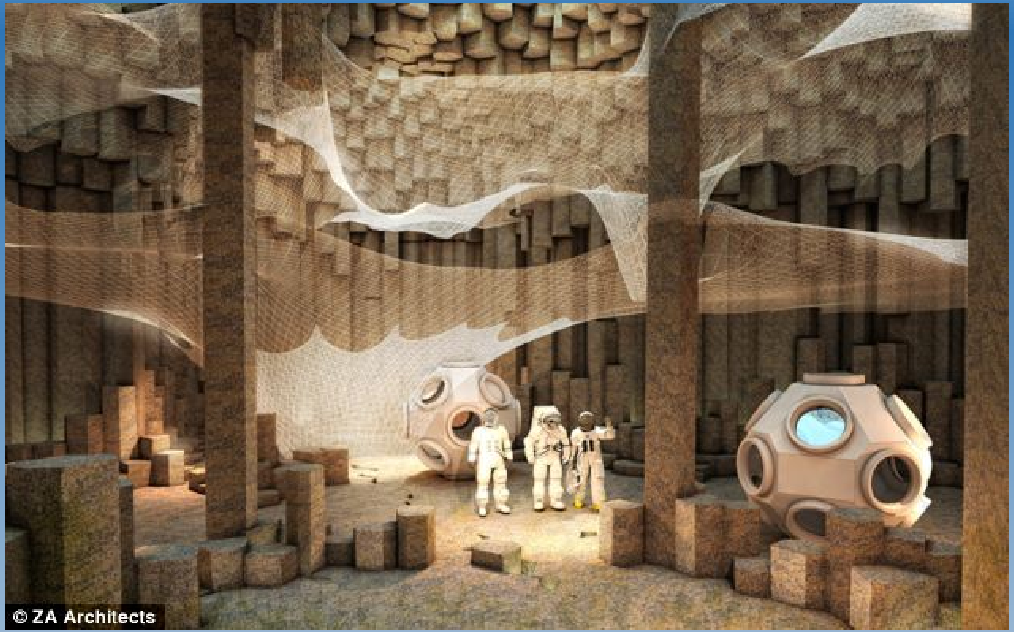
Only works when the sun is shining locally

Many energy needs could be met by moving sunlight to where it’s needed

Smaller Scale Uses For Sun to Fiber

Solar heat to create biochar fuel in developing countries



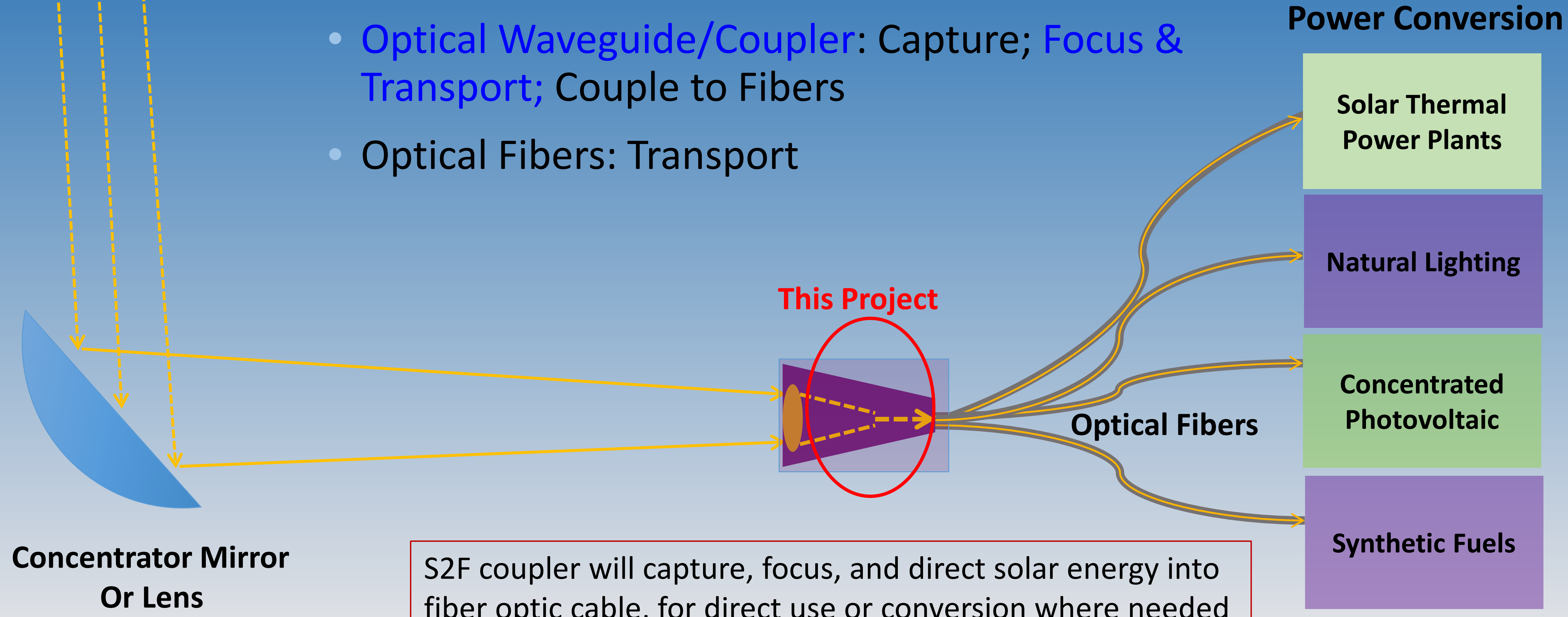


Lighting for underground Mars base

The ability to concentrate and transport sunlight will improve third-world fuel & sanitation, and reduce energy needs during space exploration.

Proposed Solution

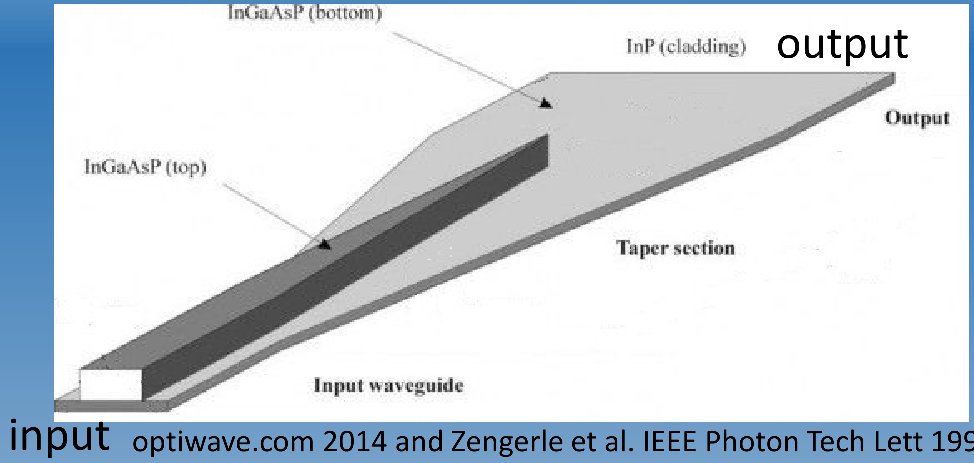
- **Optical Waveguides for transporting Solar Energy (‘S2F’ Project)**
  - Concentrate with Parabolic Mirrors or with Lenses
  - Optical Waveguide/Coupler: Capture; Focus & Transport; Couple to Fibers
  - Optical Fibers: Transport



S2F coupler will capture, focus, and direct solar energy into fiber optic cable, for direct use or conversion where needed

Our Design:
Planar Tapered Waveguide

Similar previous work

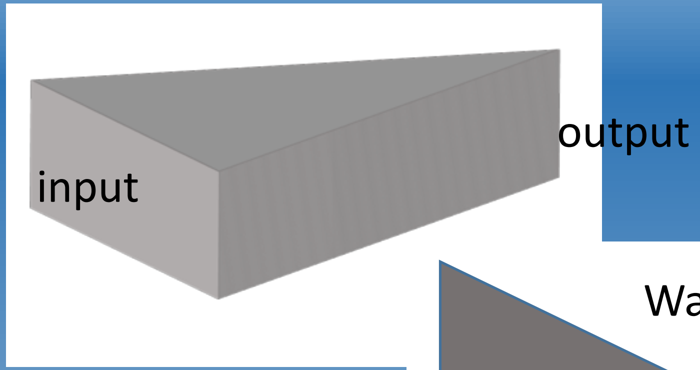


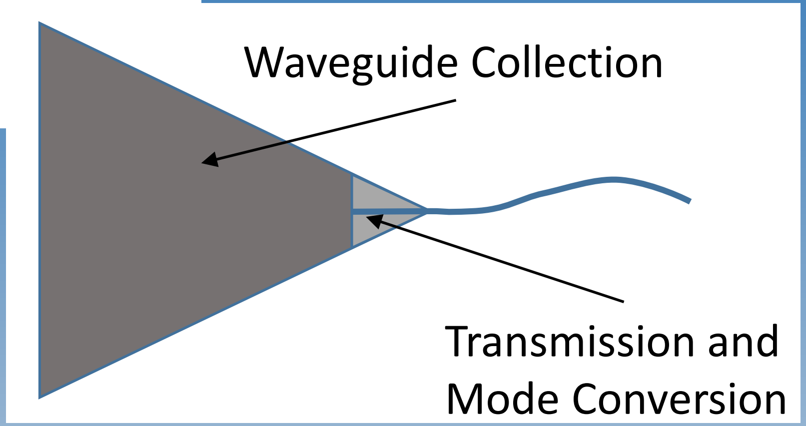
optiwave.com 2014 and Zengerle et al. IEEE Photon Tech Lett 1995

Waveguides for datacom/telecom

- Single-wavelength
- Fiber input, chip output
- ~500 um length
- Semiconductors for transparency at certain lasing wavelengths outside the visible spectrum

Our work



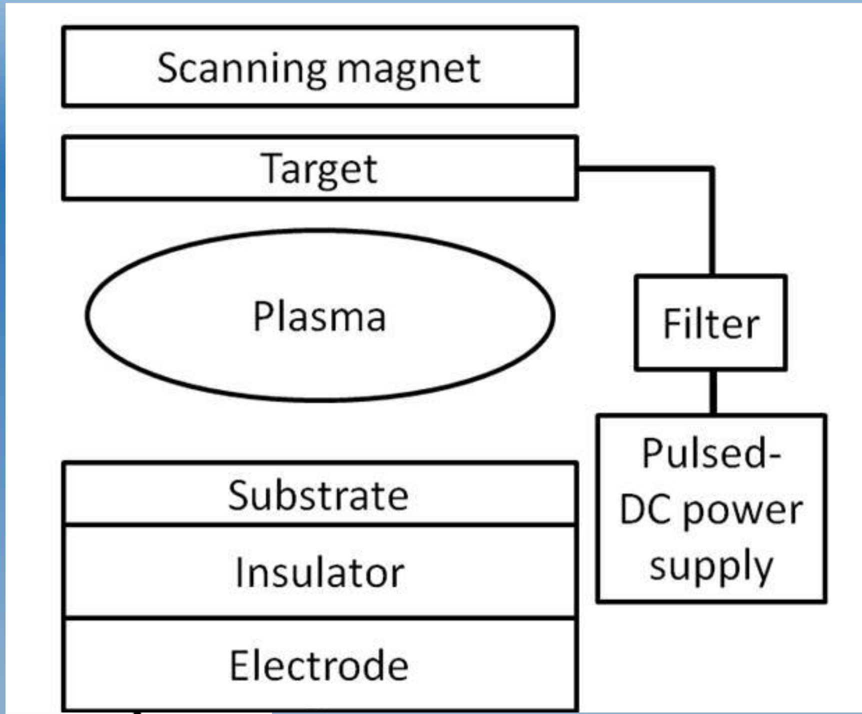


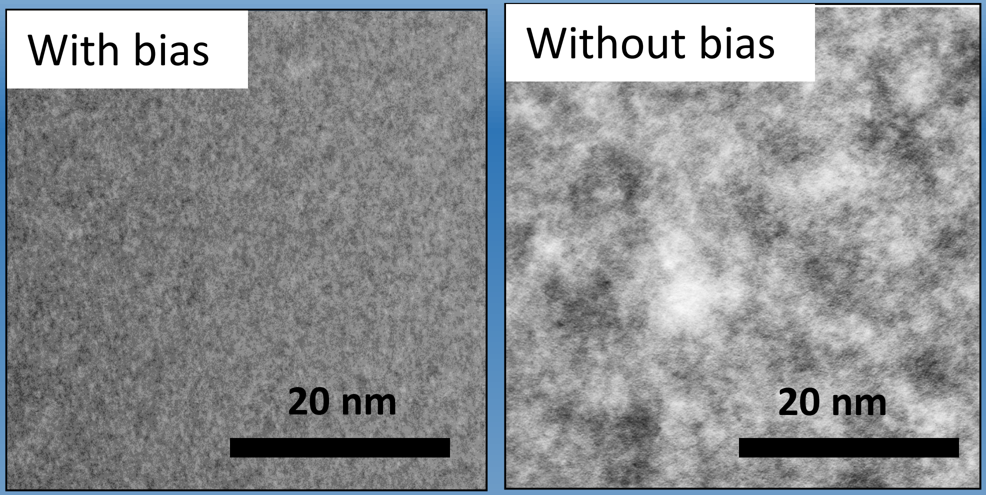
Waveguides for clean energy

- Broadband
- Thin film input, fiber output
- ~1-100 cm length
- Metal Oxides for visible spectrum transparency

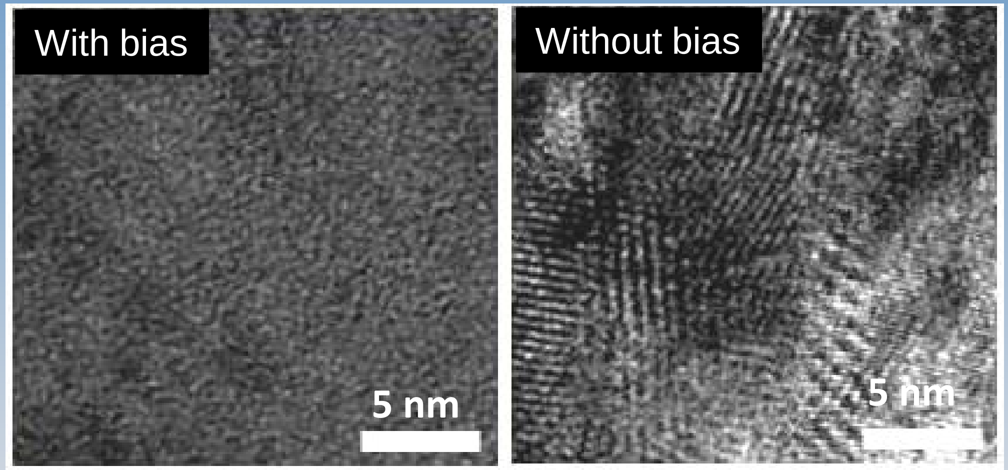
Waveguide tapers are not new, but guiding broadband, visible spectrum light requires new innovation

Reactive Scanning Magnetron Sputtering with AC Substrate Bias





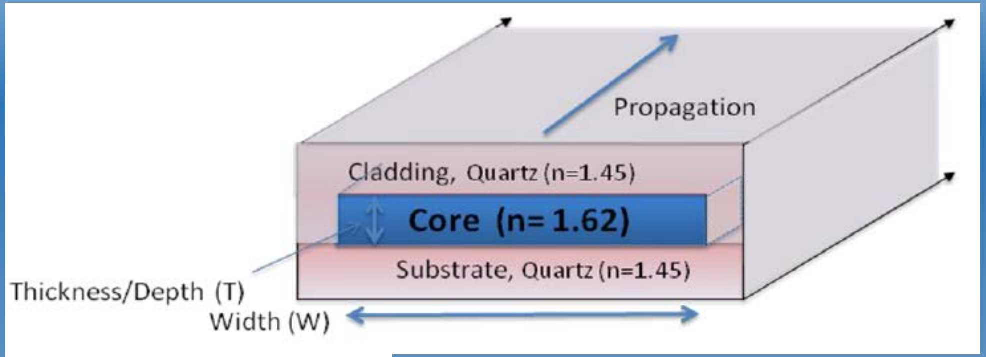
$Ti_xHf_{1-x}O_y$

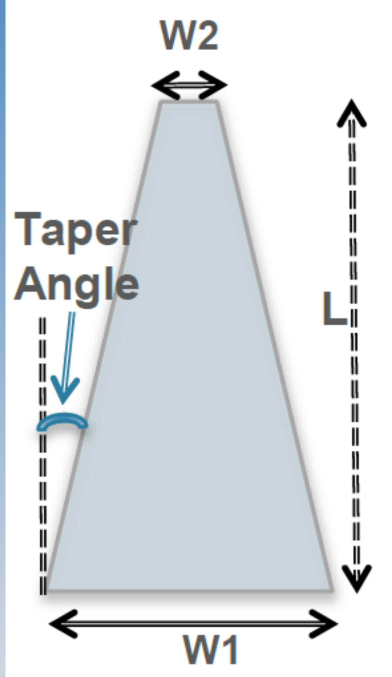


Niobium oxide

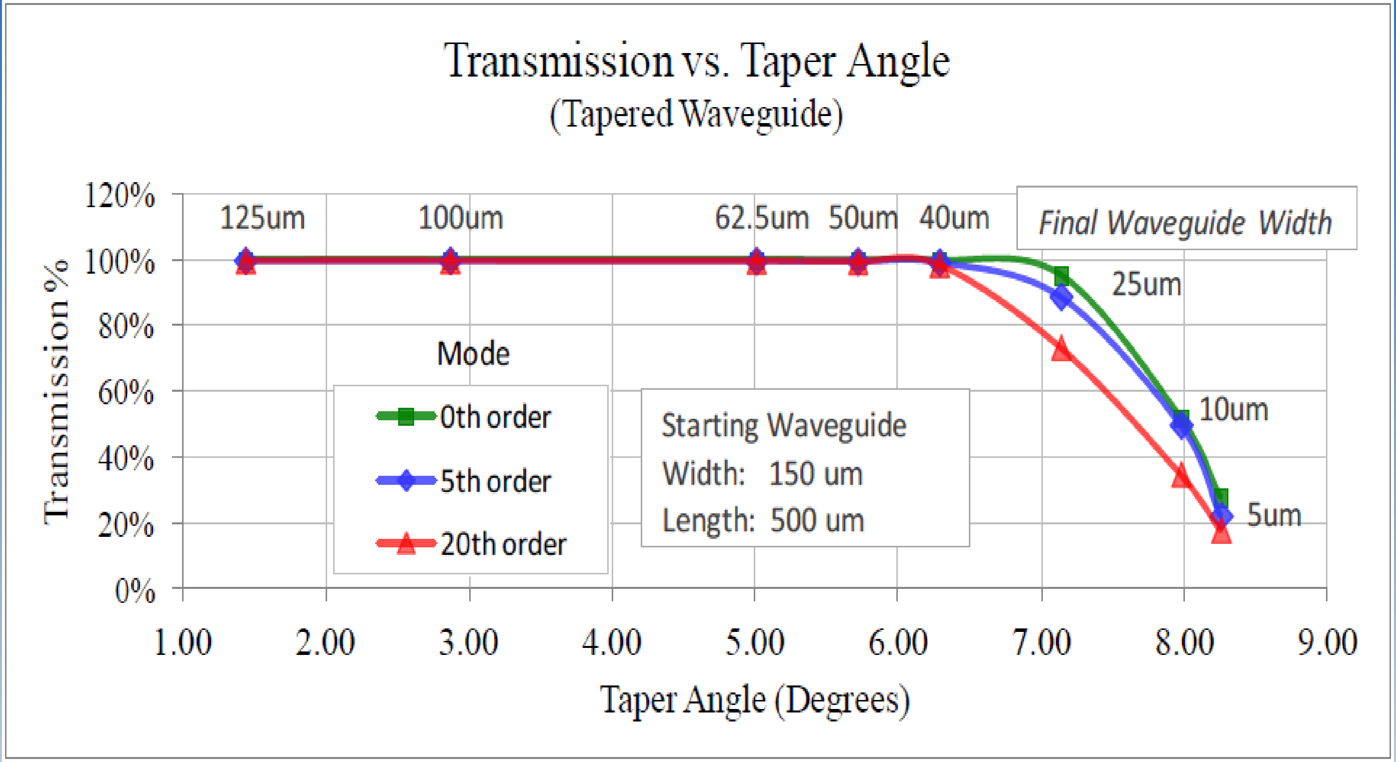
This method yields a uniform film, with precise control over stoichiometery, crystallinity/amorphousness, and index of refraction

Angle Dependency of Taper



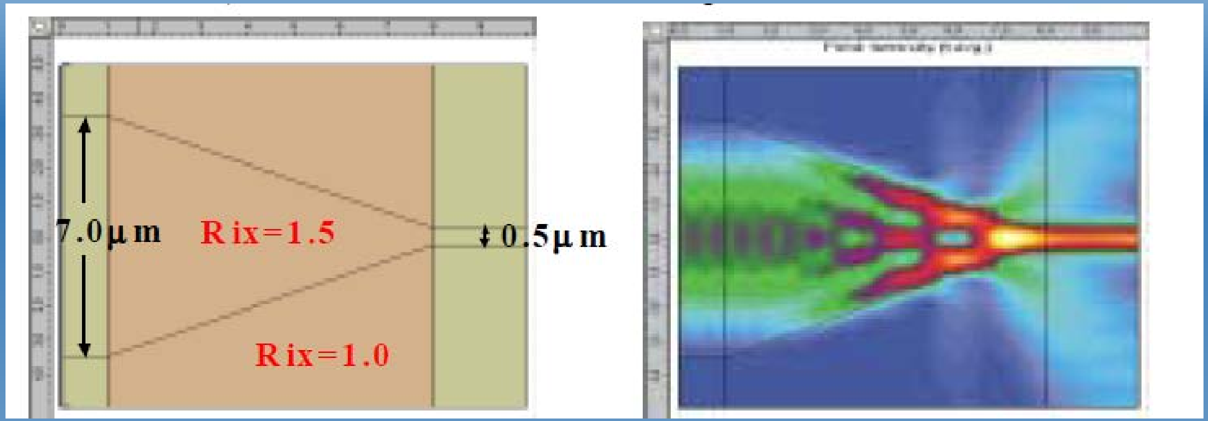


Works only if
L > 5W



Taper must be over five times as long as it is wide to achieve >90% efficiency

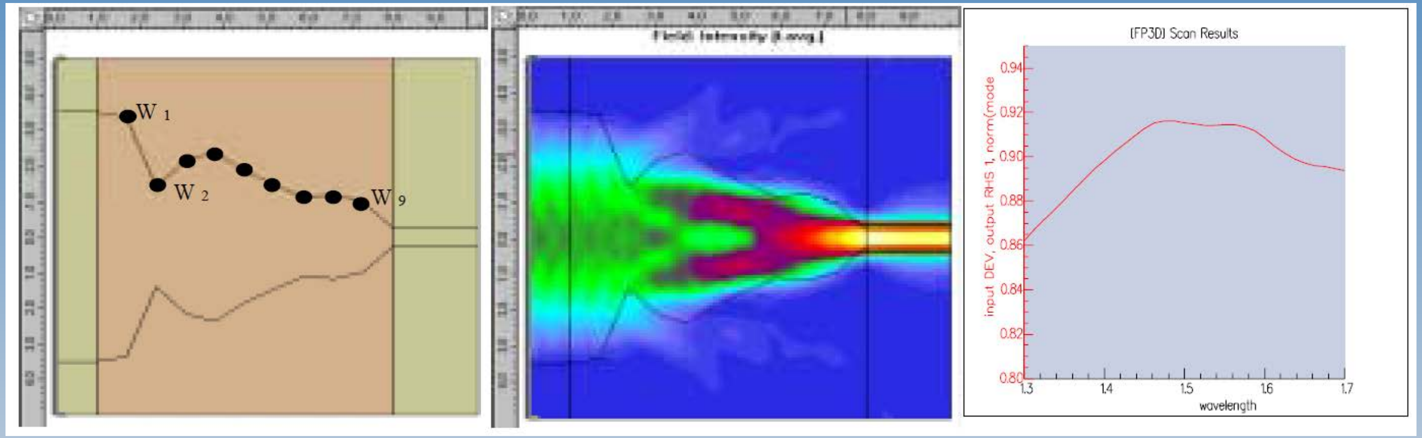
One shape-changing approach



Felici et al. LEOS 2002

Straight Taper
50% output efficiency

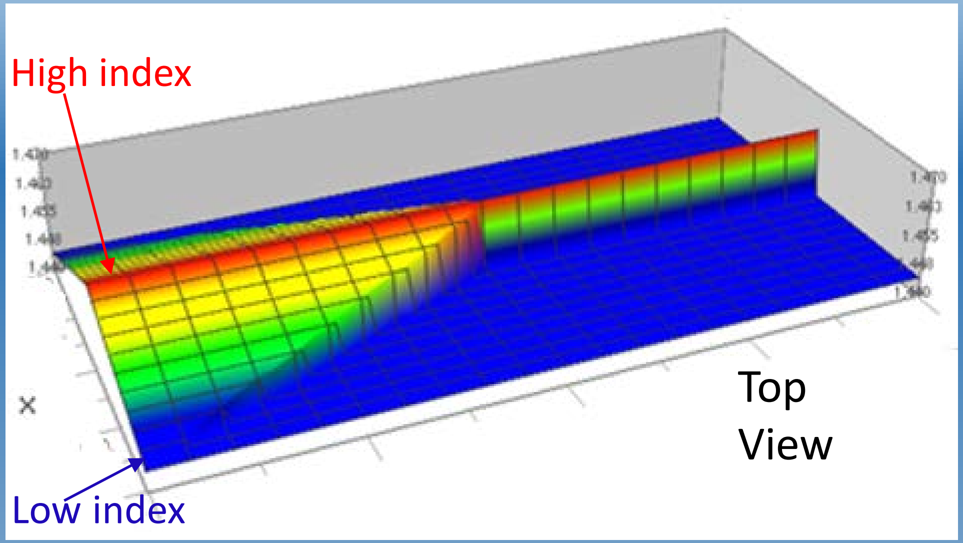
Irregular Taper
86%-92% output efficiency from λ = 1300nm-1700nm



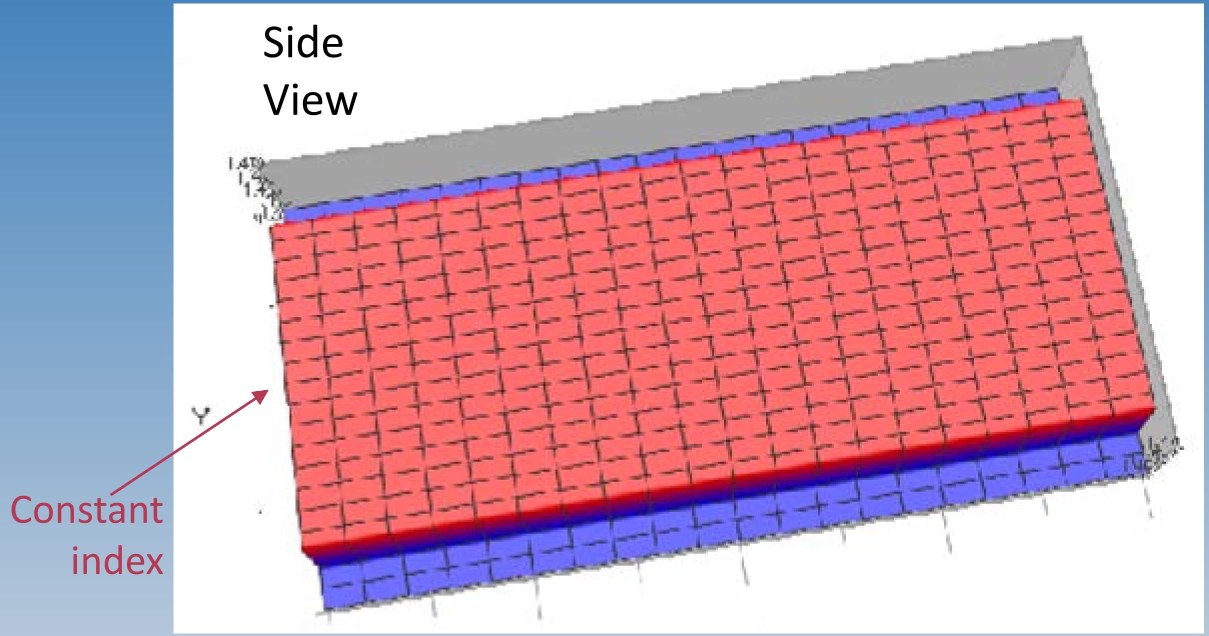
Felici et al. LEOS 2002

Non-intuitive shapes can increase the amount of input light guided into the fiber, but is still very wavelength dependent

Index Grading Approach



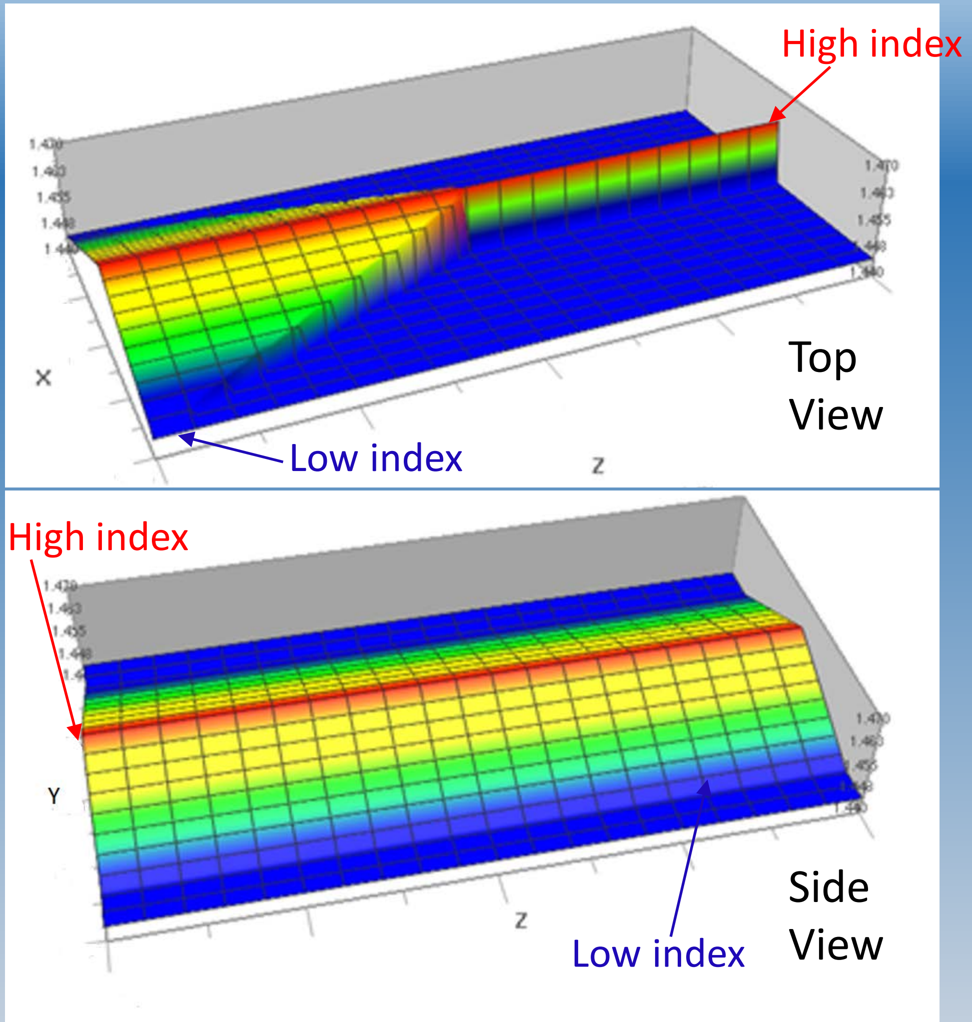
Uniform index of refraction vertically, and graded index (1.38-1.47) horizontally

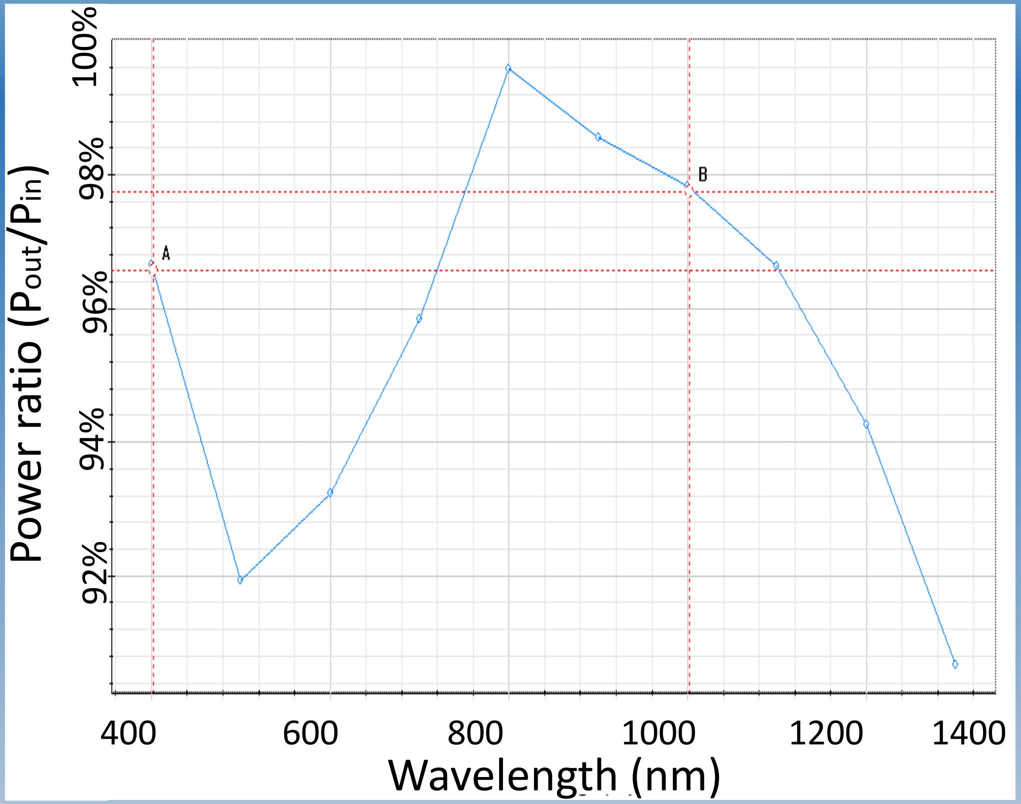


If we do not want to make L >> W, then a non-uniform core index can increase efficiency, without changing waveguide geometry

Laterally graded index with uniform index vertically, increases efficiency to 75%

Index Grading Approach





Index graded both vertically and laterally, with matching to the fiber core, yields 96% efficiency across the visible spectrum

Specific Applications

Indoor Solar Daylighting

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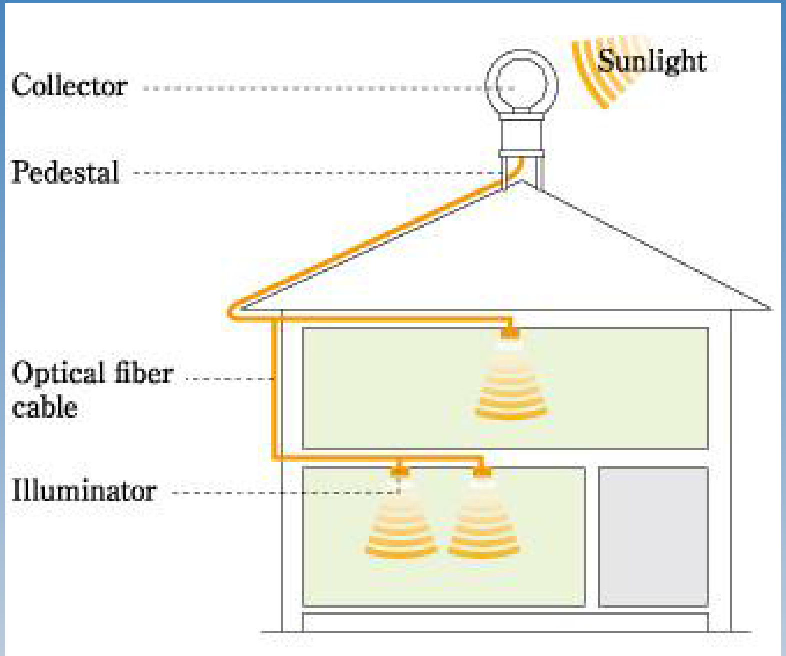

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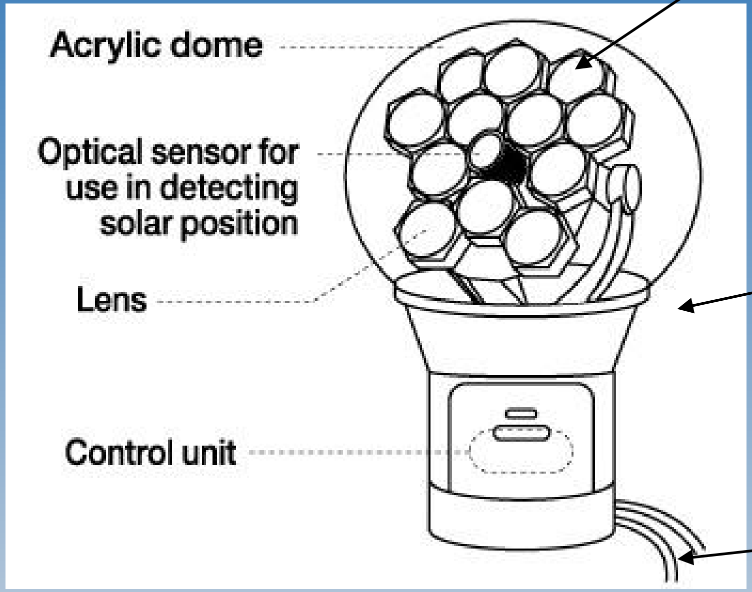
Effective rooftop sunlight capturing systems have already been developed by the Himawari Corporation

S2F coupler for the Himawari system

S2F couplers to replace lens array



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Illuminates ~100 sq ft per unit

S2F couplers will reduce the need for 12 fiber optic cables into only two fiber optic cables

- S2F coupler will reduce the need for 12 Fresnel to only one larger lens.
- Highly directed light from the S2F coupler permits use of low numerical aperture fiber, and also reduces the number of fiber optics needed.

Himawari-UCSC collaboration with NASA Ames Sustainability Base will improve upon this promising technology

Problems with Concentrated Solar Power

A common set of problems across technologies

High working fluid transmission losses

High emission losses

Solana - Abengoa

Stirling Energy Systems

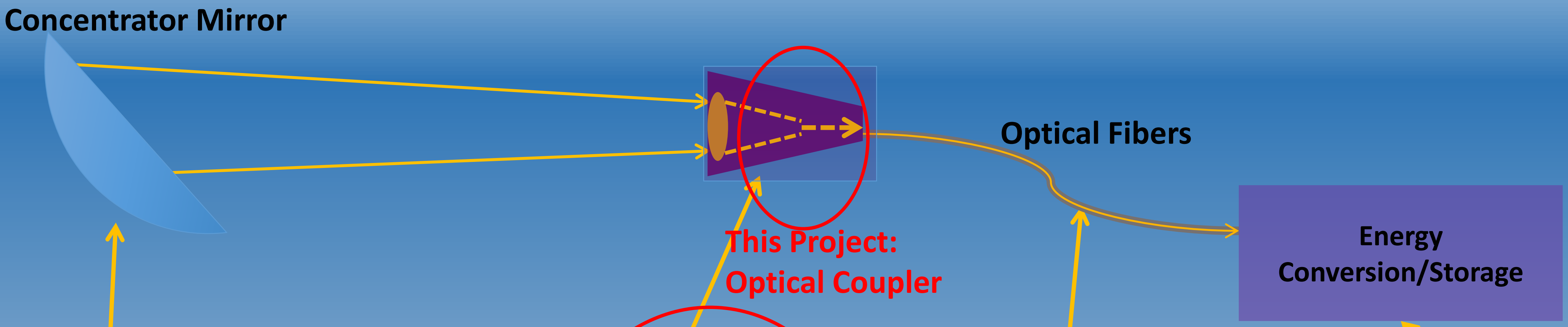
High thermal conversion losses because of Low $T_{working}$

PS10 - Abengoa

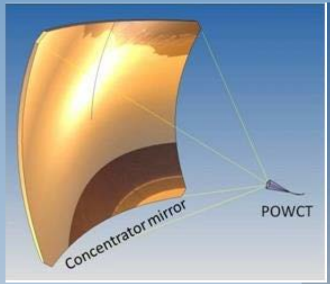
S2F Coupler can improve all types of concentrated solar power systems

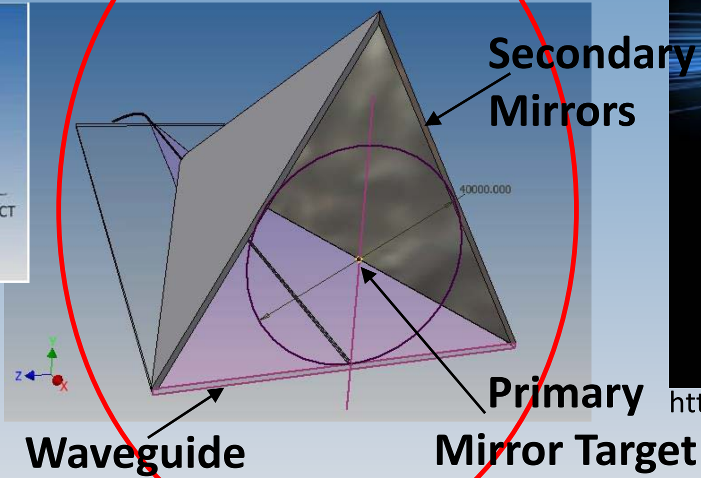
Tango Systems, Inc. Baskin Engineering UC SANTA CRUZ ASL The Advanced Studies Laboratories

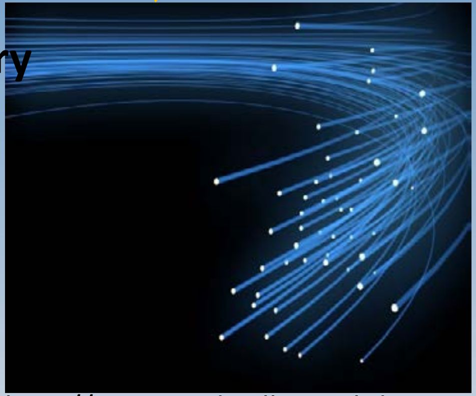
S2F for Large-Scale Energy Generation



http://www.aboutmyplanet.com





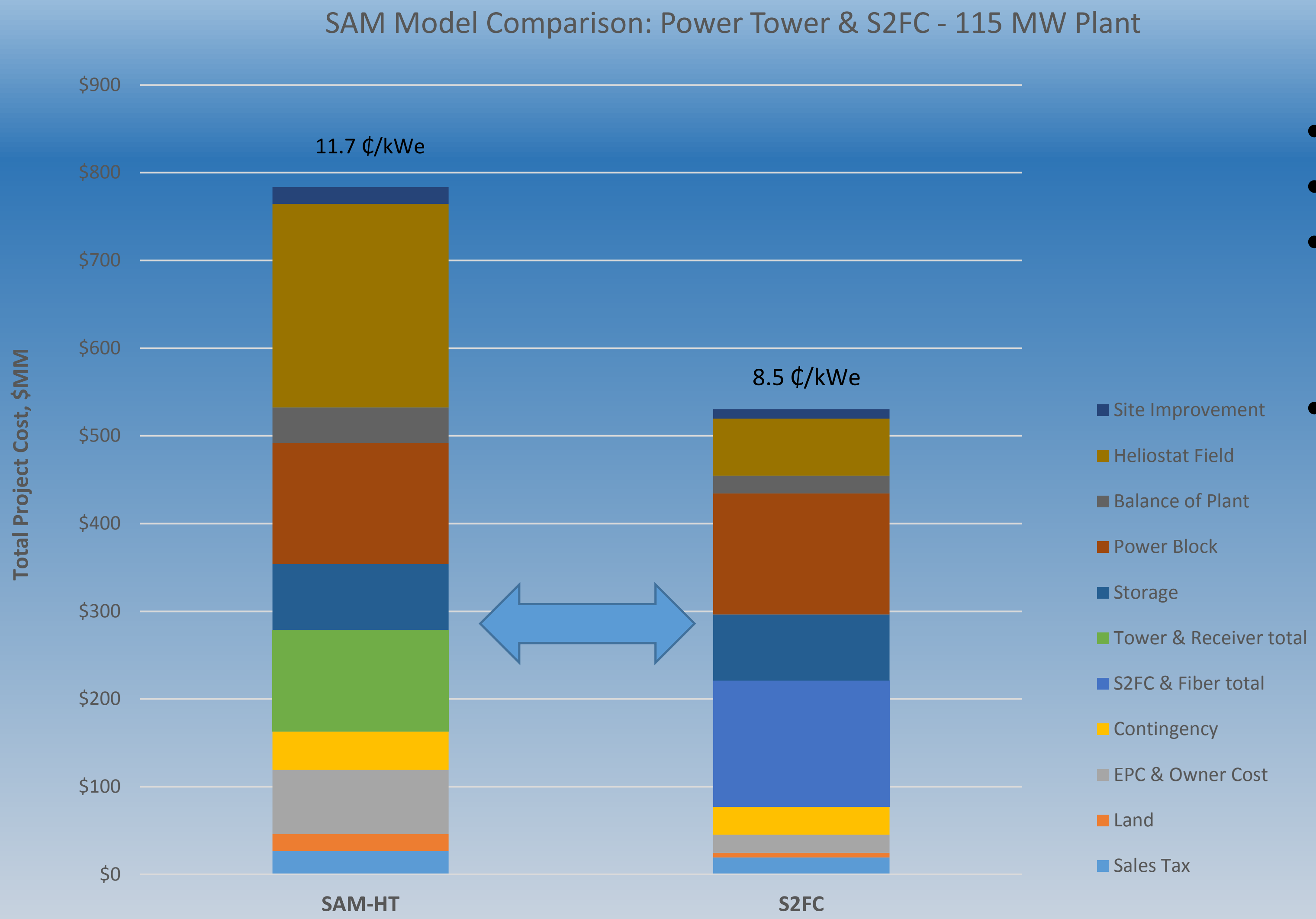


http://www.ipadwallpaperhd.com

www.eia.gov

The S2F coupler can be used for high-power energy conversion

Cost analysis of an S2F solar plant compared to a power tower



- 70% smaller heliostat field
- Lower total system cost
- Enables substantially lower economic system size with goal of 20 – 50 kW
- Potential for easy diversion of power to storage

Electricity generated with S2F technology is predicted to cost <75% of current state of the art solar thermal technology

Conclusions

- We have designed and modeled a planar optical waveguide coupler transformer
- The effective coupler utilizes thin metal oxide films, with high visible spectrum transparency
- These films rely on a graded index of refraction and a tapered shape
- The coupler allows broadband light to be directed, with near-zero loss, into fiber optic cable, and transmitted away from the point of collection
- Captured light can be harnessed for daylighting, electricity generation, or for storage thermally or as synthetic fuels