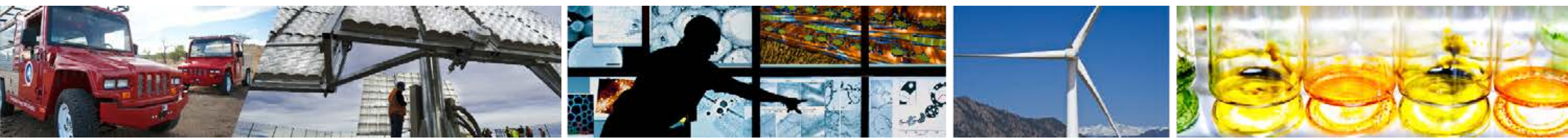
High-Temperature Solar Thermoelectric Generators (STEG)



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CHANGING WHAT'S POSSIBLE

Funded: 2/1/2013

Solar thermoelectric generator expertise

JPL
HT TE Converter fabrication
Testing and performance
Solar thermal systems

NREL
Selective absorber and optics
Fixture development and integration
Testing and performance

Technology option analysis
Quantitative cost analysis

CSM /CIT
Materials modeling
Testing and performance

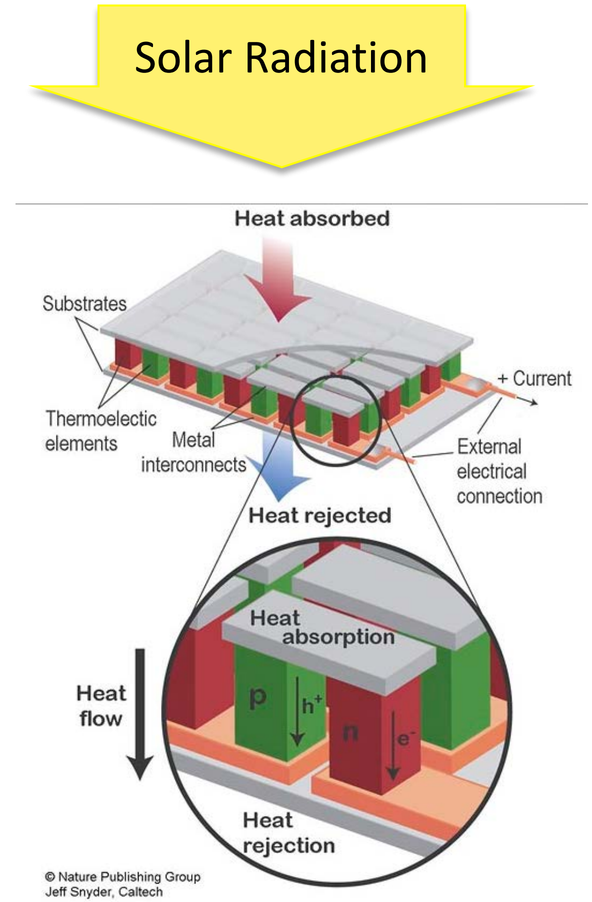
High Temp High Efficiency Solar-Thermoelectric Generators

Technology Summary

- New high-temperature, high-efficiency thermoelectric materials developed by JPL
- Low cost materials, simple processing and scalability
- High temperature (1000C) allows topping integration with existing CSP technologies
- Economic analysis will provide an underpinning for the feasibility of STEG as a CSP technology

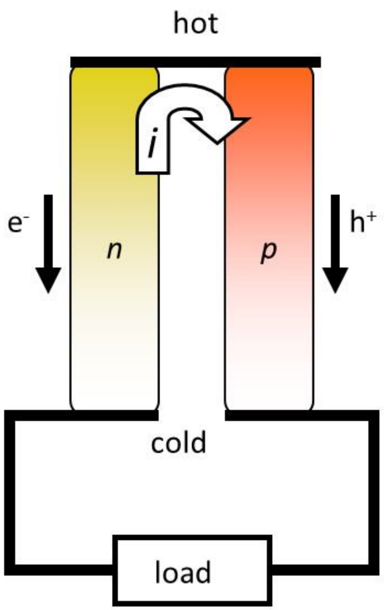
Project Plan

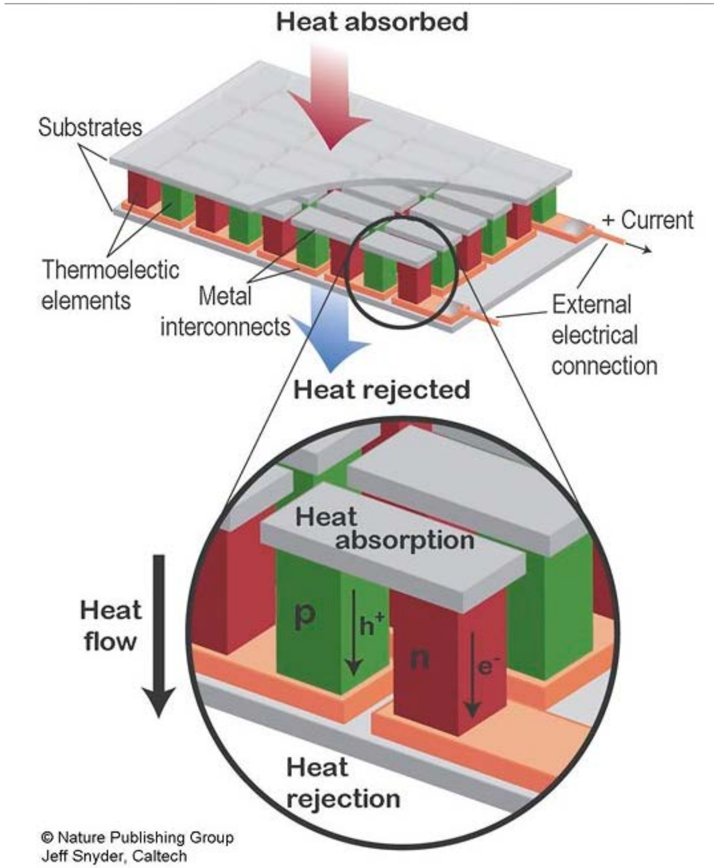
- Demonstrate 15% conversion efficiency
    - JPL-module under ~100x concentrated sunlight
- Parallel economic analysis of materials and performance cost requirements



STEG is a new low cost high efficiency solar conversion technology

$$zT = \frac{\alpha^2 T}{\rho \kappa}$$





1. THERMOELECTRIC COUPLE

Thermoelectric generators - JPL

- 50 years of NASA Investment in High Temperature TE Power Generation Technology for Deep Space Science Exploration

Images from JPL

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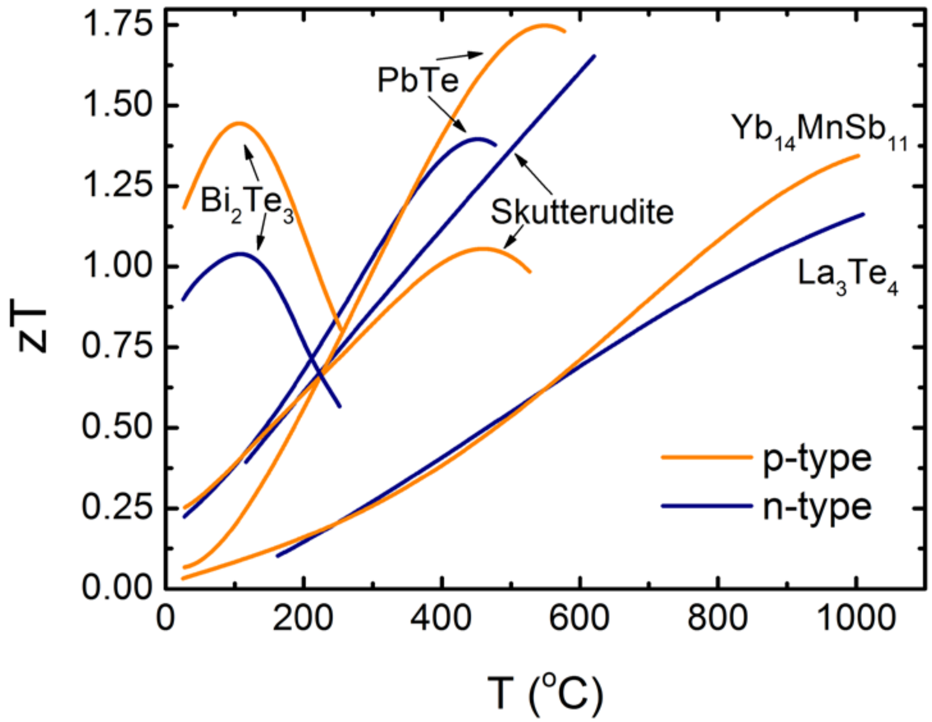
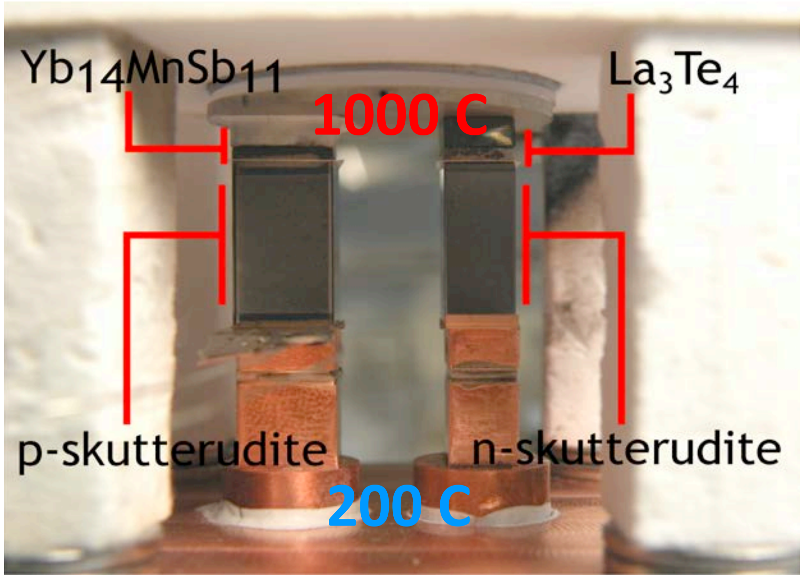
JPL Jet Propulsion Laboratory California Institute of Technology

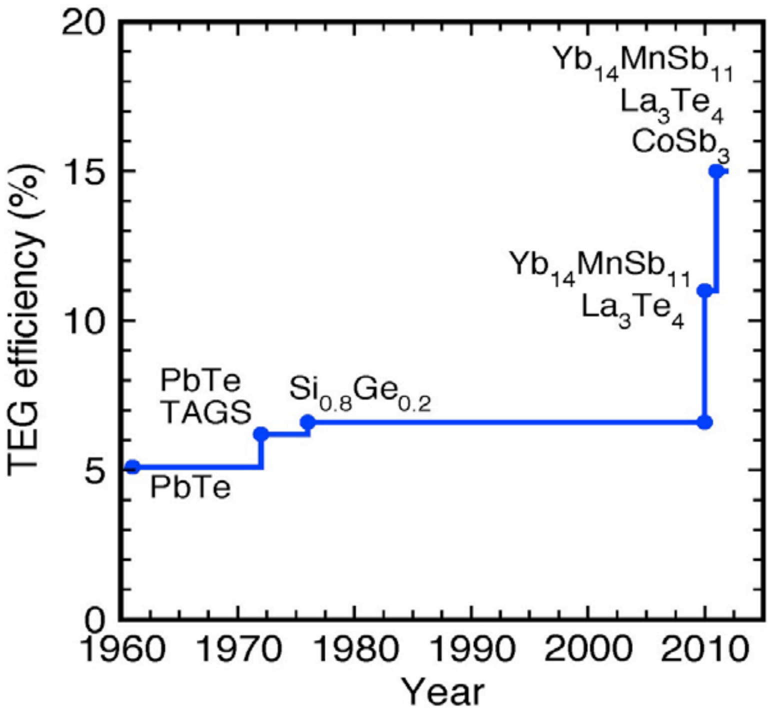
Thermoelectric generators - JPL

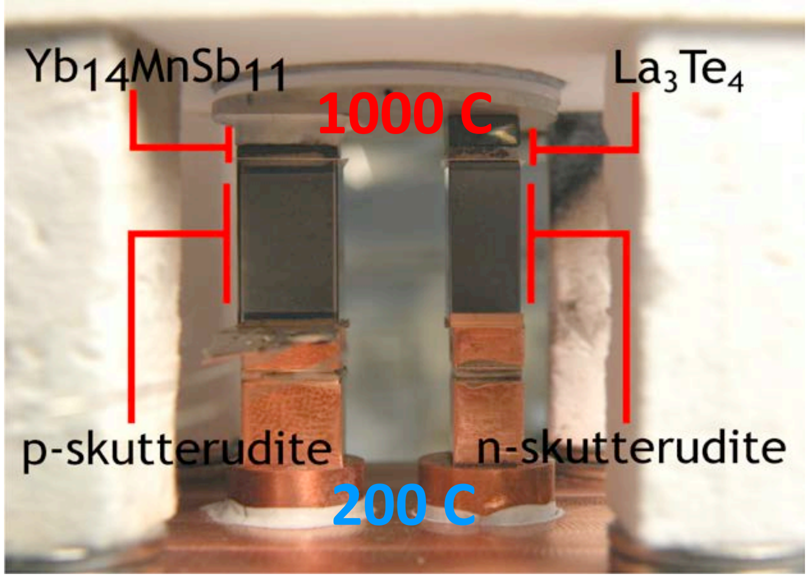




- New generation of TE materials with large performance gains over traditional Si-Ge and Bi_2Te_3 couples
  - Requires multiple materials to achieve highest efficiency over large ΔT
  - Demonstrated ~ 15% conversion efficiency (1000C -200C) in 2010 under NASA program

Thermoelectric generators - JPL





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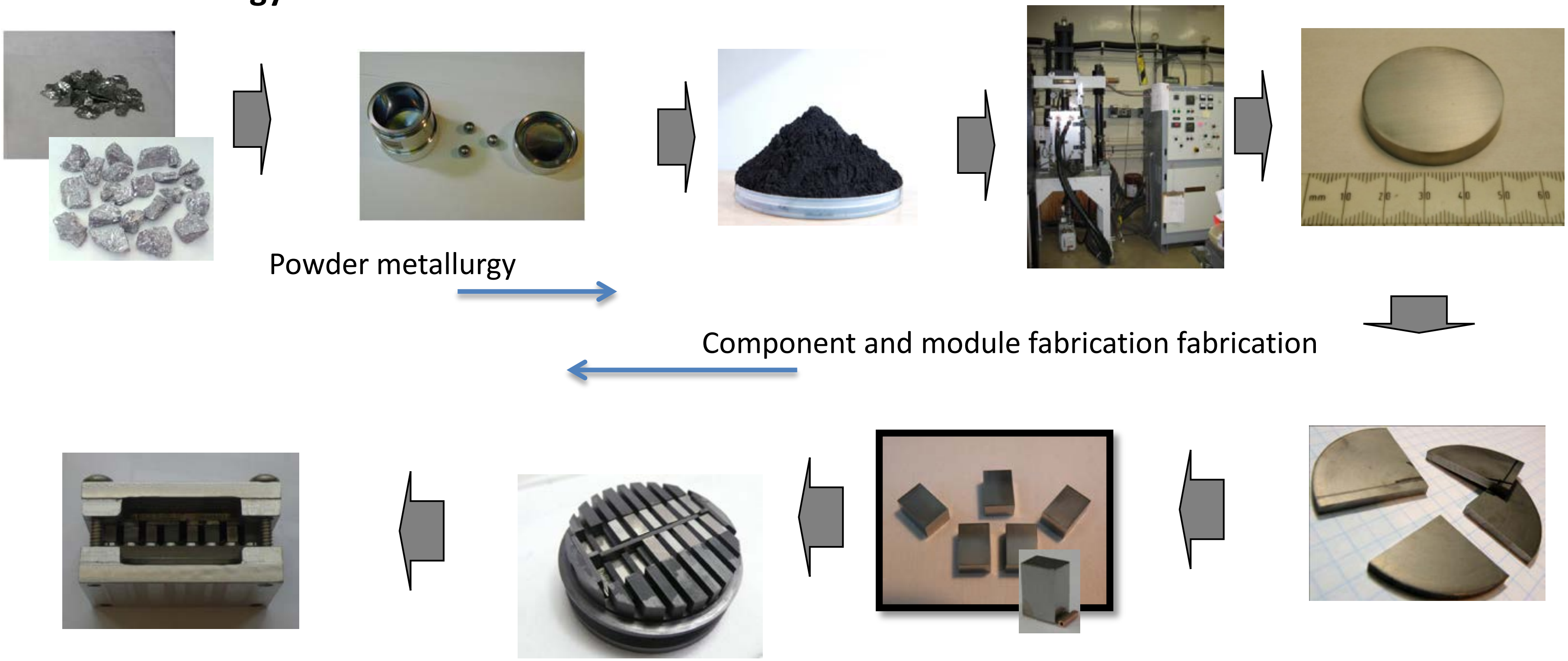
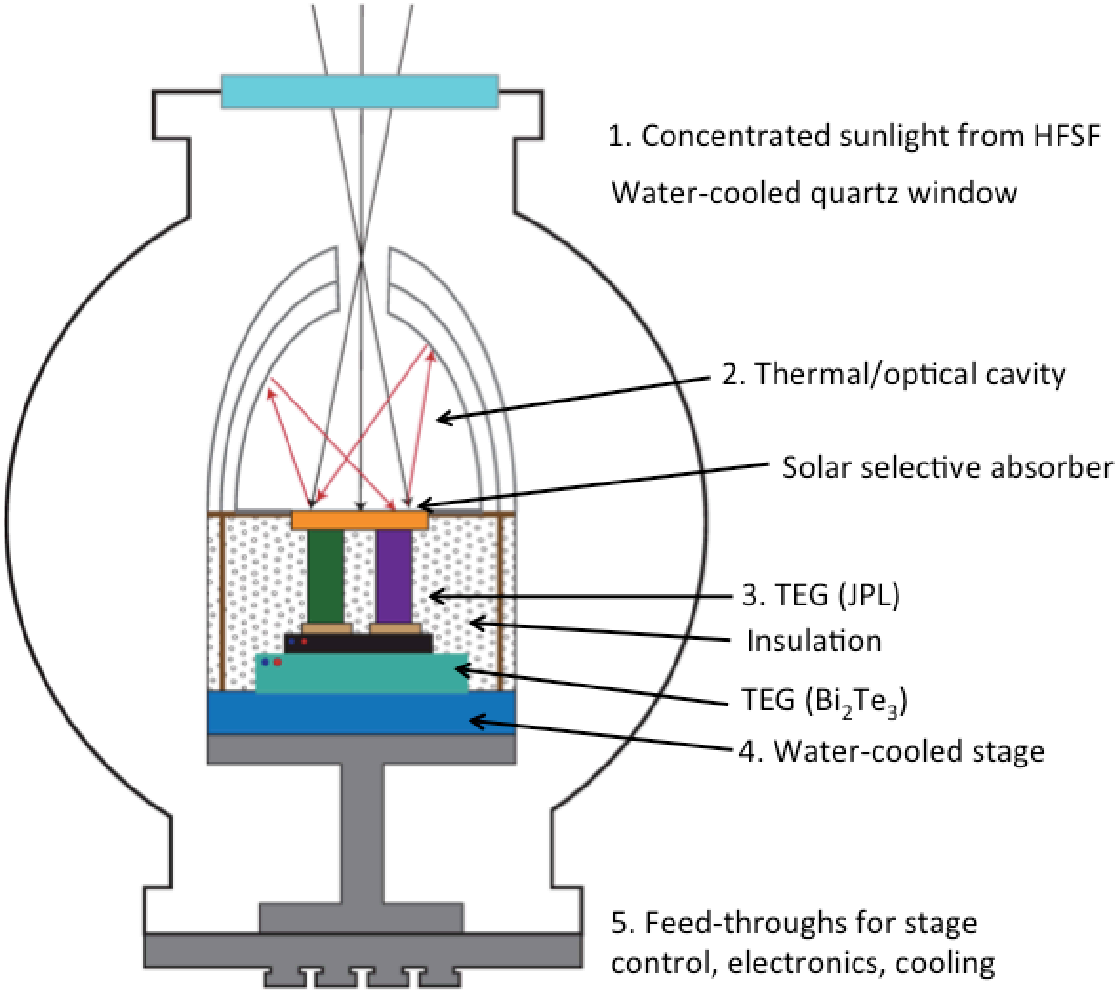
Segmented TE Module Fabrication - JPL

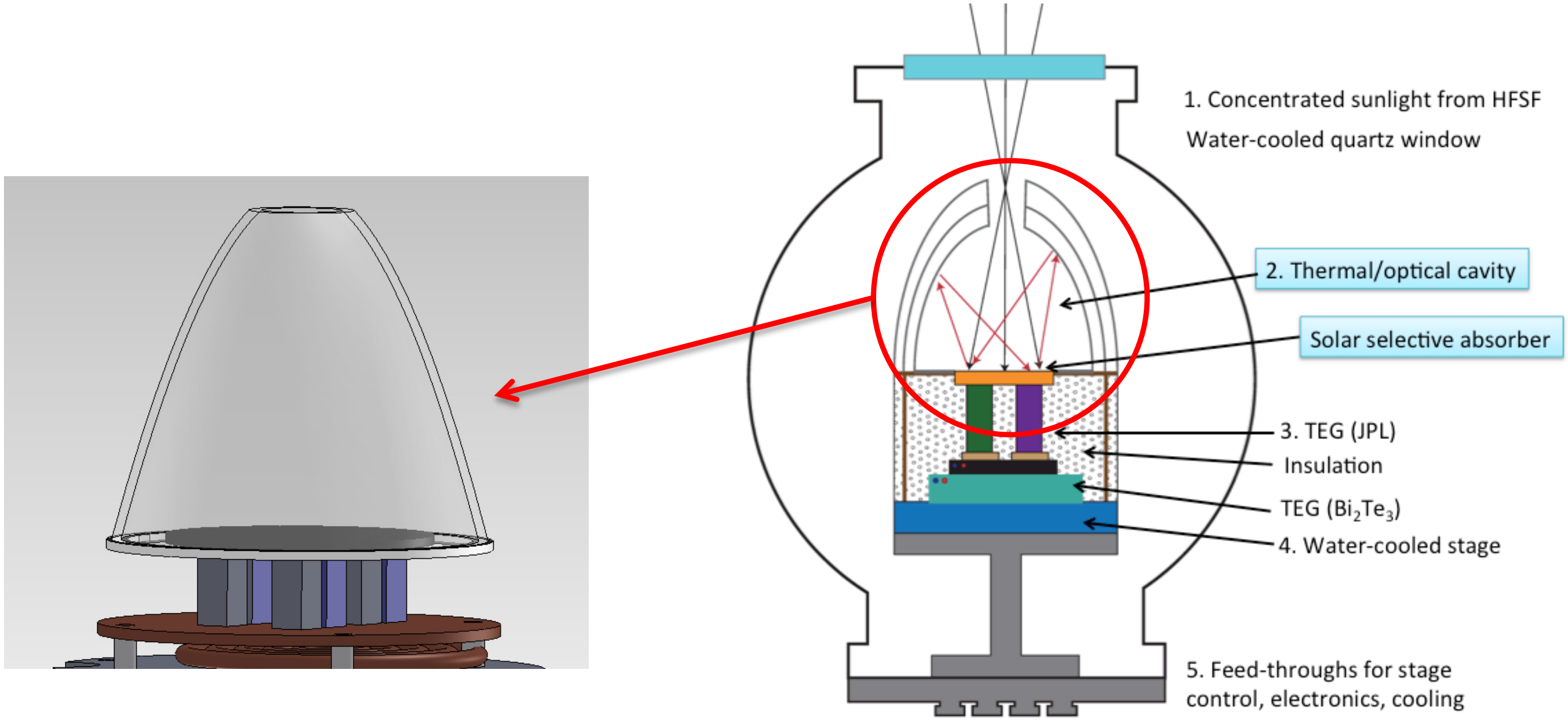
Powder metallurgy of Advanced TE materials & elements



Images from JPL

Proposed Demonstration Technology Components

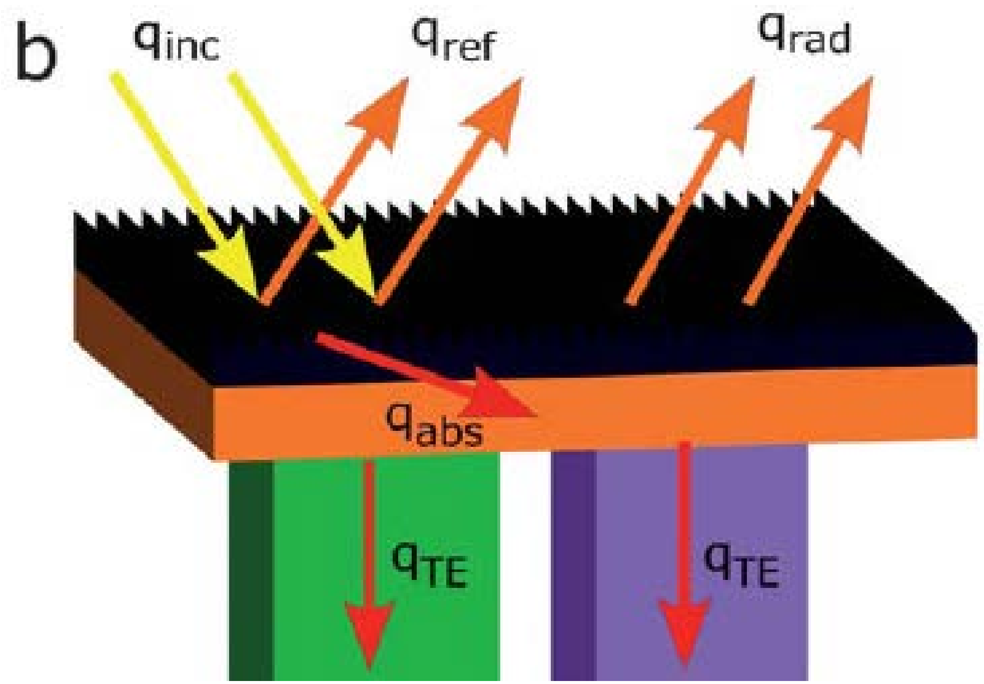




2. THERMAL ABSORBER & OPTICAL CAVITY MODELING

Maximizing Absorber Efficiency

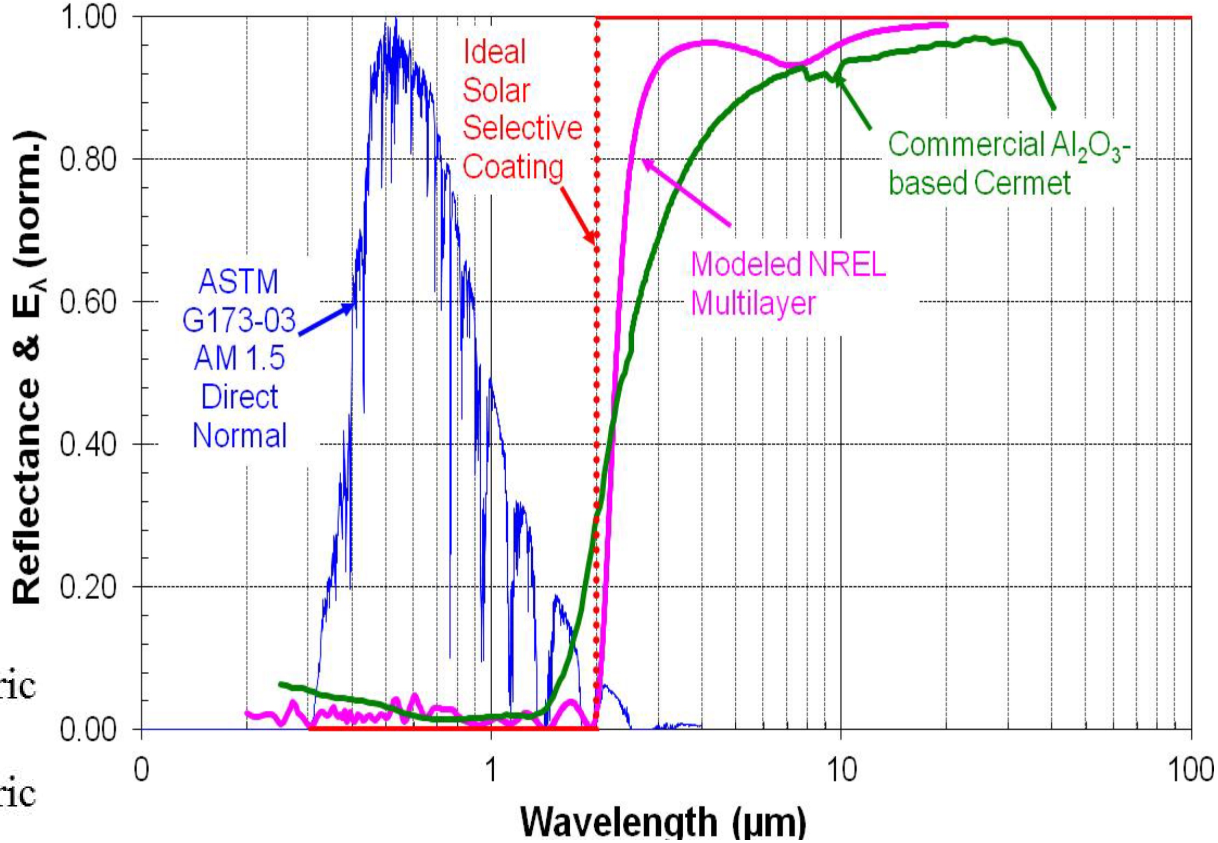
$$\eta_{abs} = \frac{q_{TE}}{q_{inc}}$$

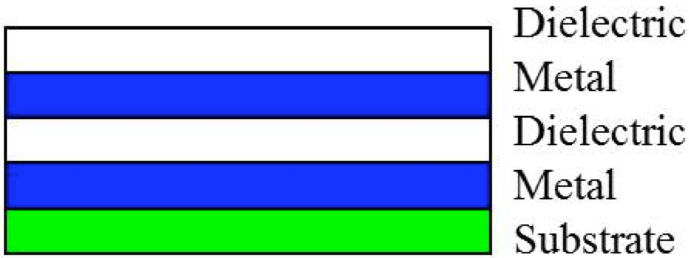


- Energy losses due to black body radiation can be minimized by a selective absorber
- A thermal cavity can achieve the same effect by thermal radiation shielding

High Temperature Selective absorbers

- Multilayer stacks designed to maximize absorbed solar energy and minimize radiation losses
- Refractory metal/ silicon alloys provide performance and temperature stability



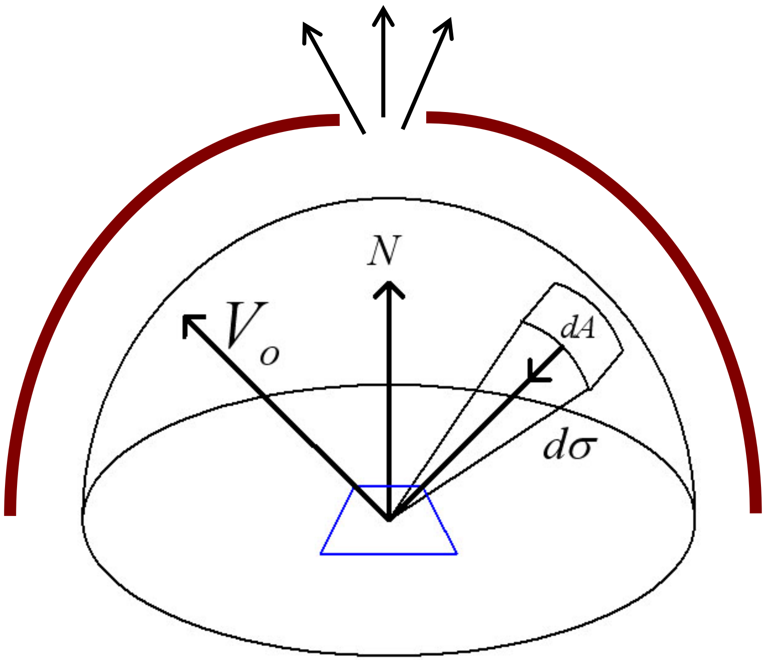


Multilayer absorbers

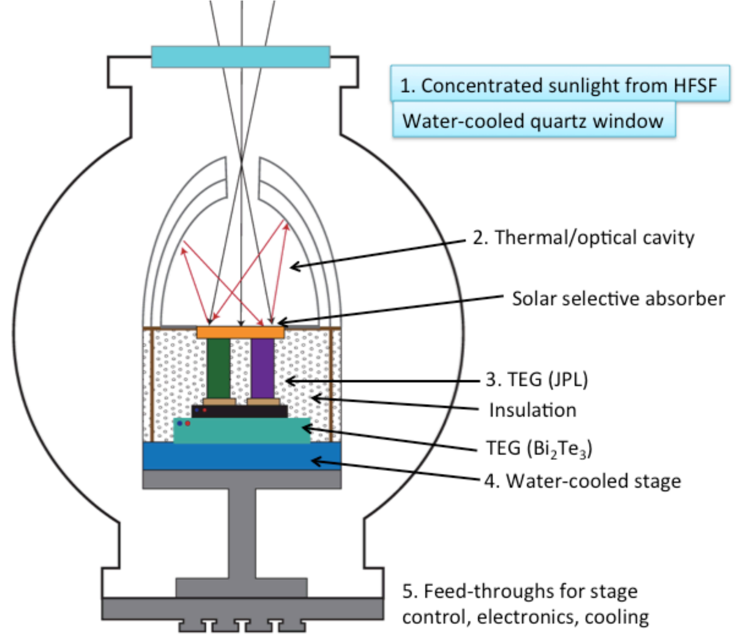
NREL Patent pending

Thermal Cavity Design

- Limit solid angle over which radiation can be lost
- Desired characteristics:
  - Low emissivity
  - Diffuse reflectance
- Thermal circuit and ray-tracing modeling



3. OPTICAL CONCENTRATION



Approaches

- **Heliostat**
- **Trough**
- **Hybrid**

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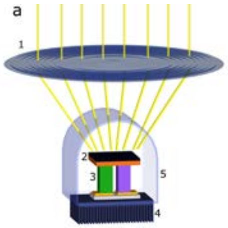
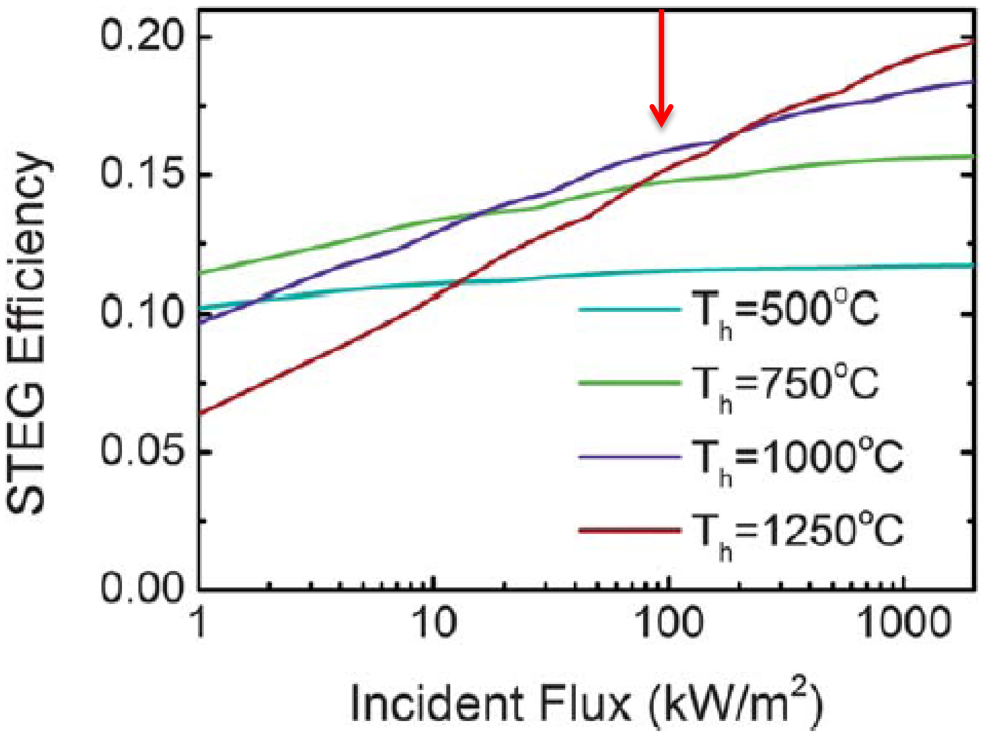


Optical concentration

Preliminary modeling suggested 1000°C hot side temperature and >100 kW/m² to achieve ~15% conversion efficiency using JPL module



Concentrated STEG demonstration will use NREL's high-flux solar furnace (HFSF) to achieve required levels of optical concentration.

Baranowski et al, Energy & Environ. Sci 2012

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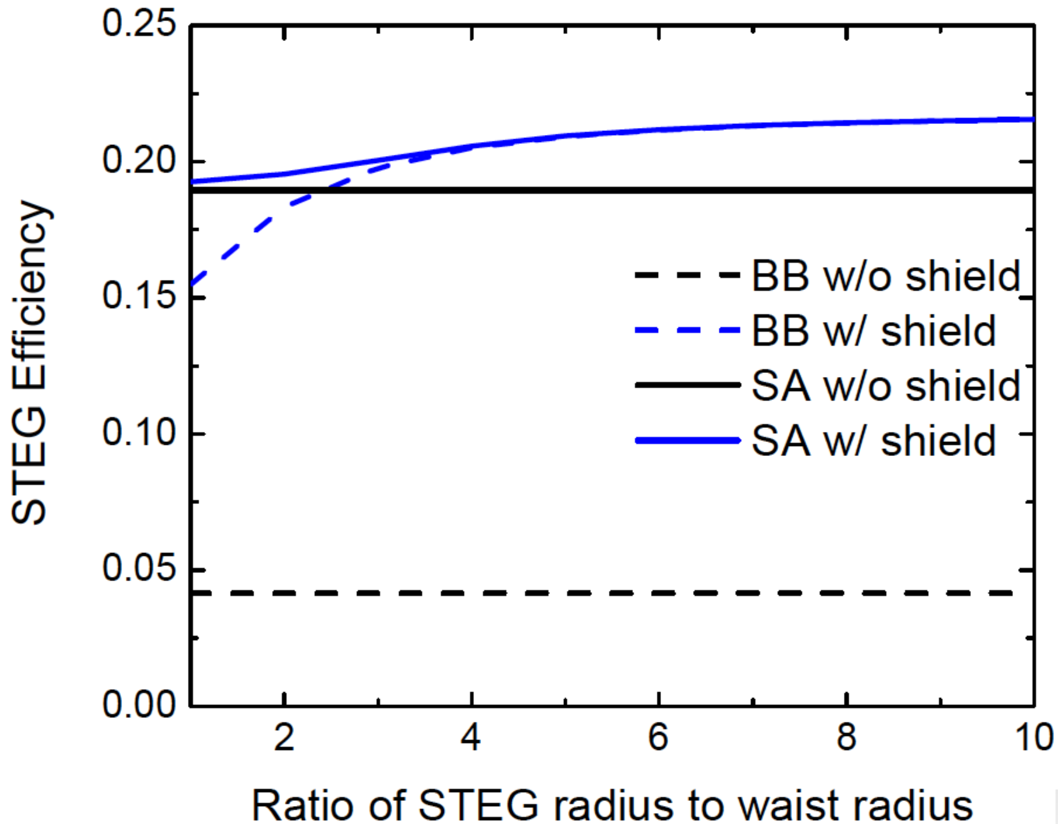
NREL's High-Flux Solar Furnace (HFSF)

25 mirrors each with 0.5 m^2 area can deliver 2500 Suns at focus
Can fully analyze optical performance with SolTrace software

Combined Thermal & Optical Models

- Thermal model can be applied for geometry specified by optical modeling of HFSF – predicts goal is achievable



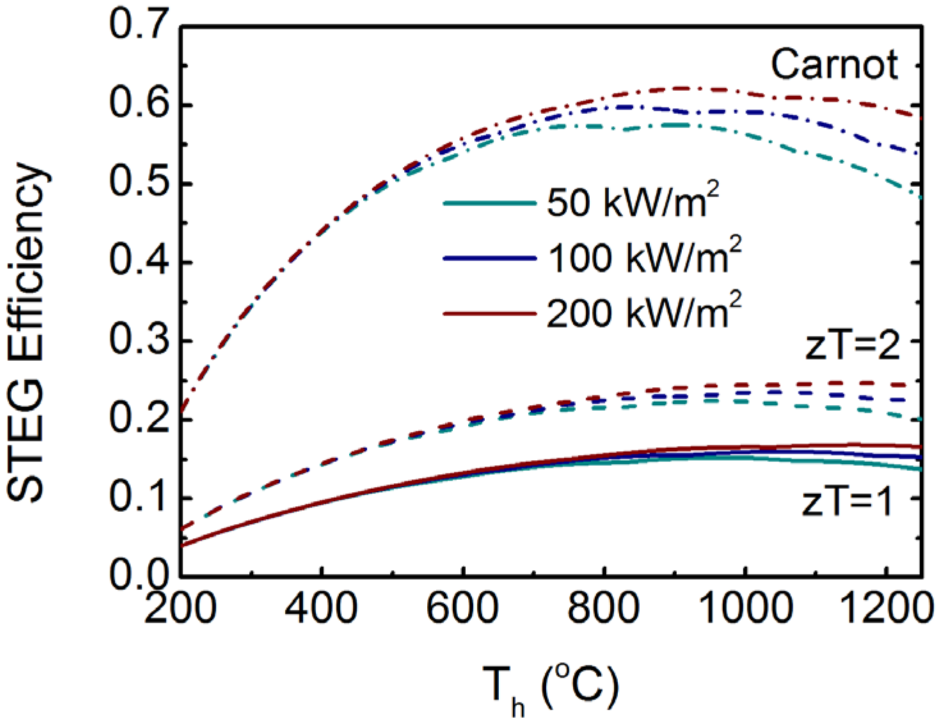
For HFSF experimental conditions (r_{STEG}/r_{waist}=2.9):

	W/o shield	W/ shield
BB	4.1%	19.8%
SA	19.0%	**20.1%**

Publication In prep

STEG efficiency: future

- 25% efficiency achievable with advanced materials
- zT = 2.2, Kanatzidis et al N*ature,* 2012
- New TE materials are still being discovered



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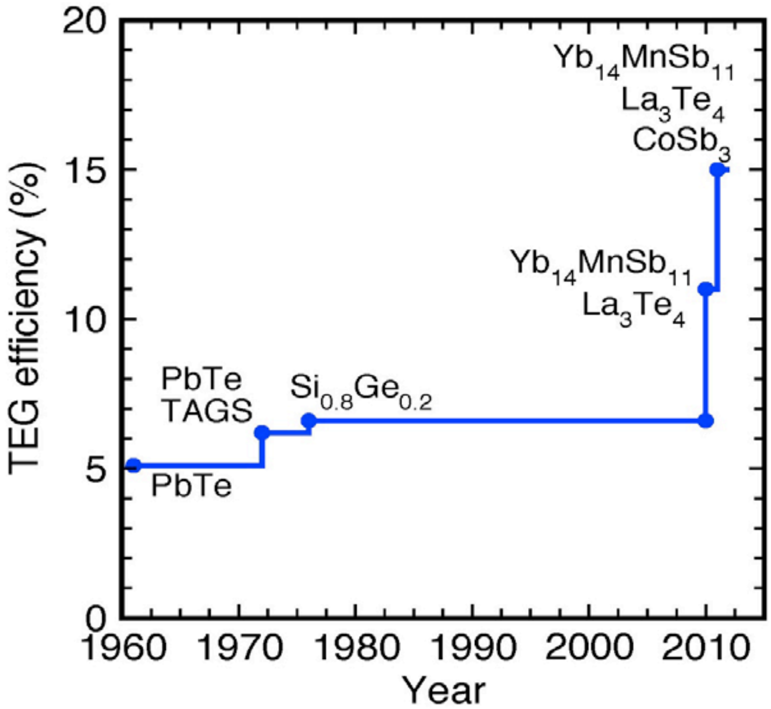

Economic analysis of STEG Approach

1. Establish baseline device description

- Device geometry, legs (materials), and receiver
- SolarPILOT and SolTrace: model expected energy production

2. Leverage CSP costs (SAM) to establish STEG technology goals

- STEG device and receiver: costs and performance (η_{STEG}) budgets
- Benchmark alternative pathways:
  - Standalone vs. CSP topping cycle
  - System configurations (e.g. dish, heliostat, etc.)

3. Conduct detailed cost analysis for most promising pathways

- Work with industry to assess installed system costs
- Develop detailed manufacturing cost model and road map

4. Complete U.S. market analysis for STEG technology

- Utilize industry-validated cost analysis and NREL GIS capabilities

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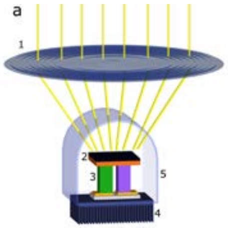

Summary

- STEG appears to be a candidate for both hybrid (topping cycle) or direct solar conversion
- Enabled by a set of new materials with zT coefficients > 1 and now approaching 2.
  - zT of 2-2.5 would produce a 25% conversion technology
- Heat management is key and overall integration of the TEG/absorber/cavity is under development
- Economic analysis will provide an underpinning for the feasibility of STEG as a CSP technology

Questions?