High-Temperature Solar Thermoelectric Generators (STEG)

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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 (1000°C) 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**
1. THERMOELECTRIC COUPLE

\[ zT = \frac{\alpha^2 T}{\rho \kappa} \]
Thermoelectric generators - JPL

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

Images from JPL
Thermoelectric generators - JPL

• New generation of TE materials with large performance gains over traditional Si-Ge and Bi$_2$Te$_3$ couples
  • Requires multiple materials to achieve highest efficiency over large $\Delta T$
  • Demonstrated ~ 15% conversion efficiency (1000C -200C) in 2010 under NASA program
Thermoelectric generators - JPL

- New generation of TE materials with large performance gains over traditional Si-Ge and Bi₂Te₃ couples
  - Requires multiple materials to achieve highest efficiency over large ΔT
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Segmented TE Module Fabrication - JPL

Powder metallurgy of Advanced TE materials & elements

Component and module fabrication fabrication

Images from JPL
Proposed Demonstration Technology Components

1. Concentrated sunlight from HFSF
   Water-cooled quartz window

2. Thermal/optical cavity

Solar selective absorber

3. TEG (JPL)
   Insulation
   TEG (Bi₂Te₃)

4. Water-cooled stage

5. Feed-throughs for stage control, electronics, cooling
2. THERMAL ABSORBER & OPTICAL CAVITY MODELING
Maximizing Absorber Efficiency

- 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.
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
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.
NREL’s High-Flux Solar Furnace (HFSF)

25 mirrors each with 0.5 m² 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 ($r_{\text{STEG}}/r_{\text{waist}}=2.9$):

<table>
<thead>
<tr>
<th></th>
<th>W/o shield</th>
<th>W/ shield</th>
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<tr>
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</tr>
<tr>
<td>SA</td>
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STEG efficiency: future

- 25% efficiency achievable with advanced materials
- $zT = 2.2$, Kanatzidis et al *Nature*, 2012

- New TE materials are still being discovered
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 ($\eta_{\text{STEG}}$) 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
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?