Solar Thermoelectric Energy Conversion

Gang Chen,[1] Daniel Kraemer,[1] Bed Poudel,[2] Hsien-Ping Feng,[1]
J. Christopher Caylor,[2] Giri Joshi,[3] Bo Yu, [3] Xiao Yan, [3] Yi Ma, [3]
Xiaowei Wang, [3] Dezhi Wang,[3] Andrew Muto,[1] Kenneth McEnaney,[1]
Matteo Chiesa,[1,4] and Zhifeng Ren[3]

[1]Mechanical Engineering Department,
Massachusetts Institute of Technology, Cambridge, MA 02139

[2]GMZ Energy, 11 Wall St., Waltham, MA 02458, USA

[3]Department of Physics, Boston College,
Chestnut Hill, MA 02467, USA

[4]Masdar Institute of Science and Technology, Abu Dhabi

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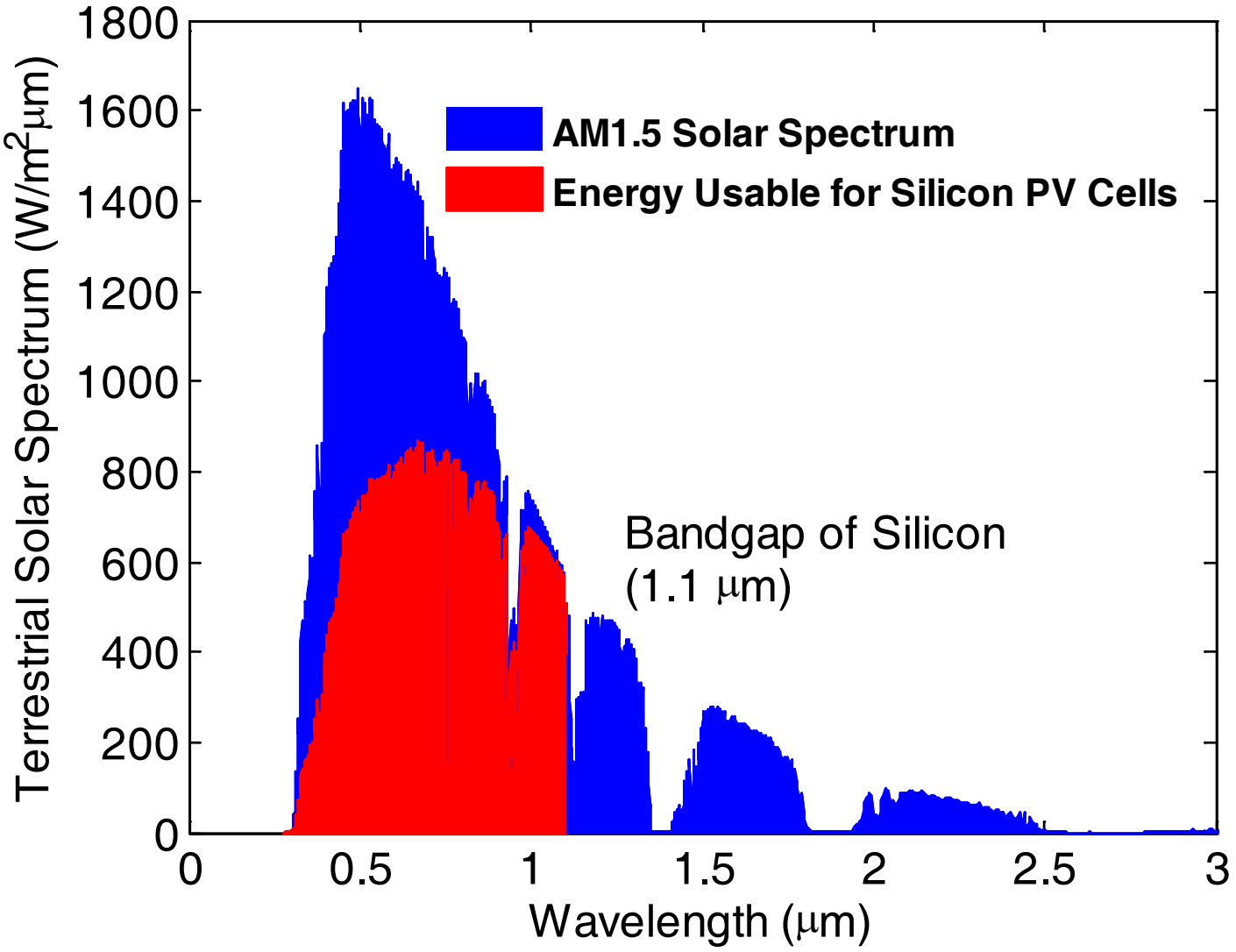
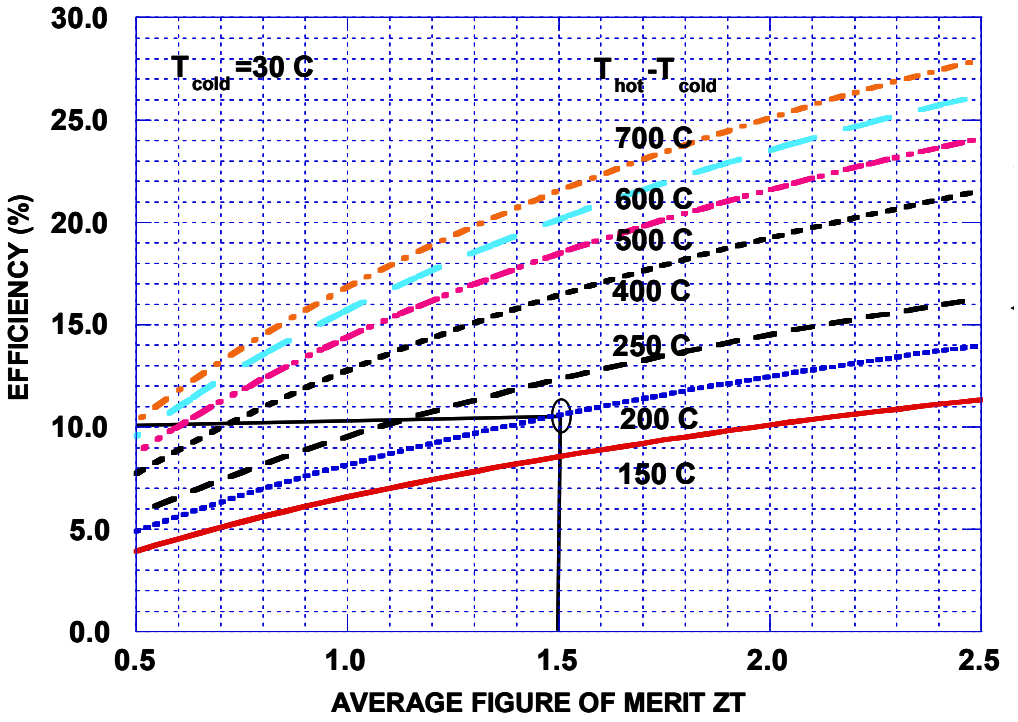
PV Usage of Solar Spectrum



Efficiency --- TE vs. PV



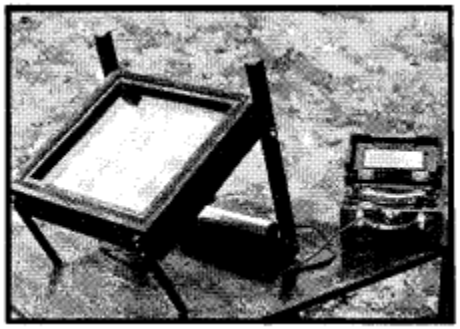
Ideal Thermoelectric Device Efficiency

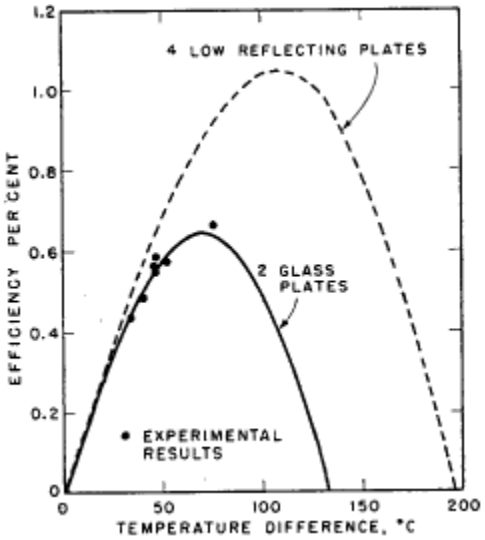
PV Efficiency

Bulk:
sc-Si: ~18%
poly-Si: ~15%

Thin-Films
a-Si: ~6-8%
CdTe: ~10%

Past Studies on Solar Thermoelectric Generators





- Weston, 1888, Cu-Constantan
  - Efficiency 0.008%
- M. Telkes, J. Appl. Phys., 1954
  - 0.63% flat panel
  - 3.35% with 50 optical concentration
  - Assumed incident solar insolation
- Goldsmid, 1980s
  - <1% efficiency
- Dent and Cobbles, 1982
  - Helliostat, unknown optical concentration
  - 6.3% Device Efficiency, 30% higher than prediction
- Amatya and Ram, 2010
  - 3% at 66 optical concentration

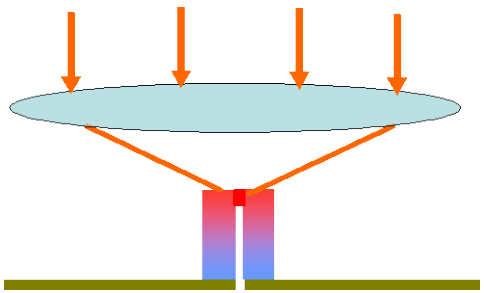
System Challenge --- Mismatch in Heat Flux

- Solar insulation: ~ 1,000 W/m^2
- Heat flux through a thermoelectric leg

$$q \sim k\frac{\Delta T}{d} \sim 1\frac{W}{m.K} \times \frac{100K}{0.001m} = 10^5 \frac{\mathrm{W}}{\mathrm{m}^2}$$

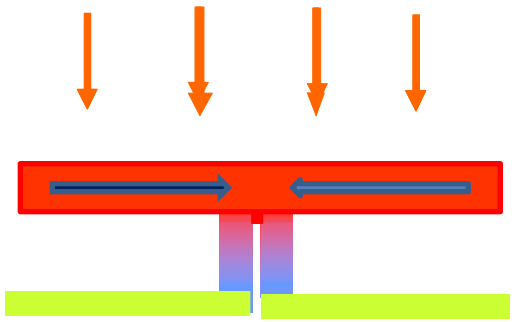
- Need to concentrate heat by ~100 times

Optical vs. Thermal Concentration

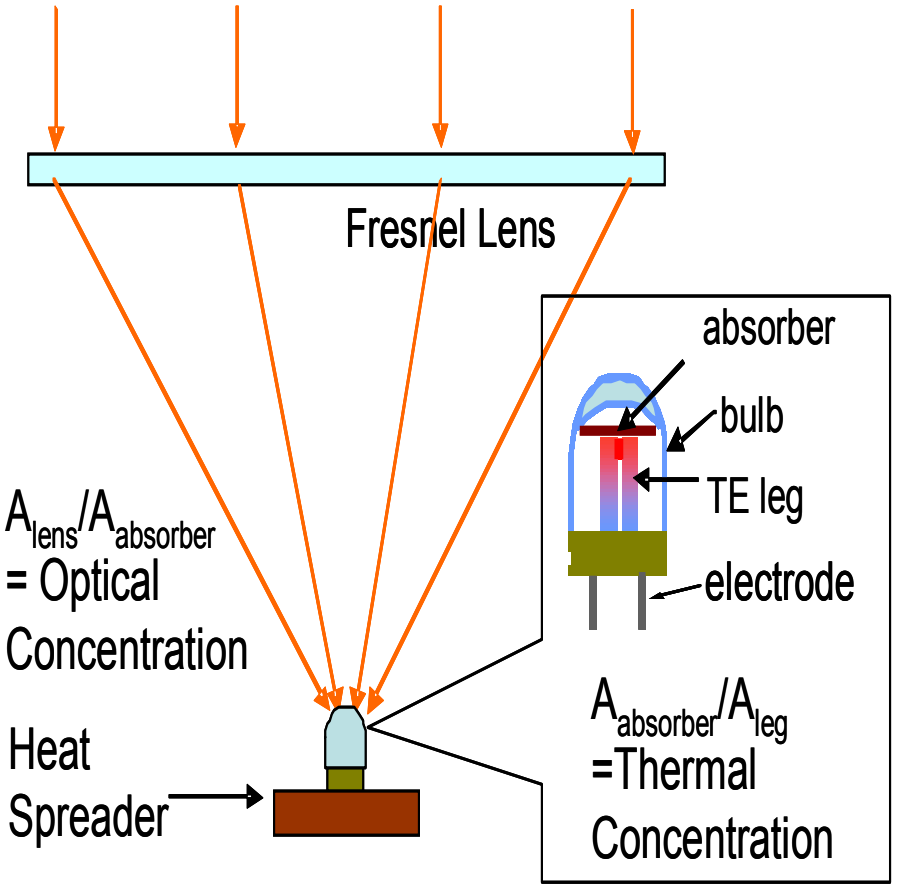


(b)

Optical Concentration



Thermal Concentration



Optical + Thermal Concentration

Key Factors

Efficiency $\eta = \eta_{TH}\eta_{TE}$

Thermal Efficiency

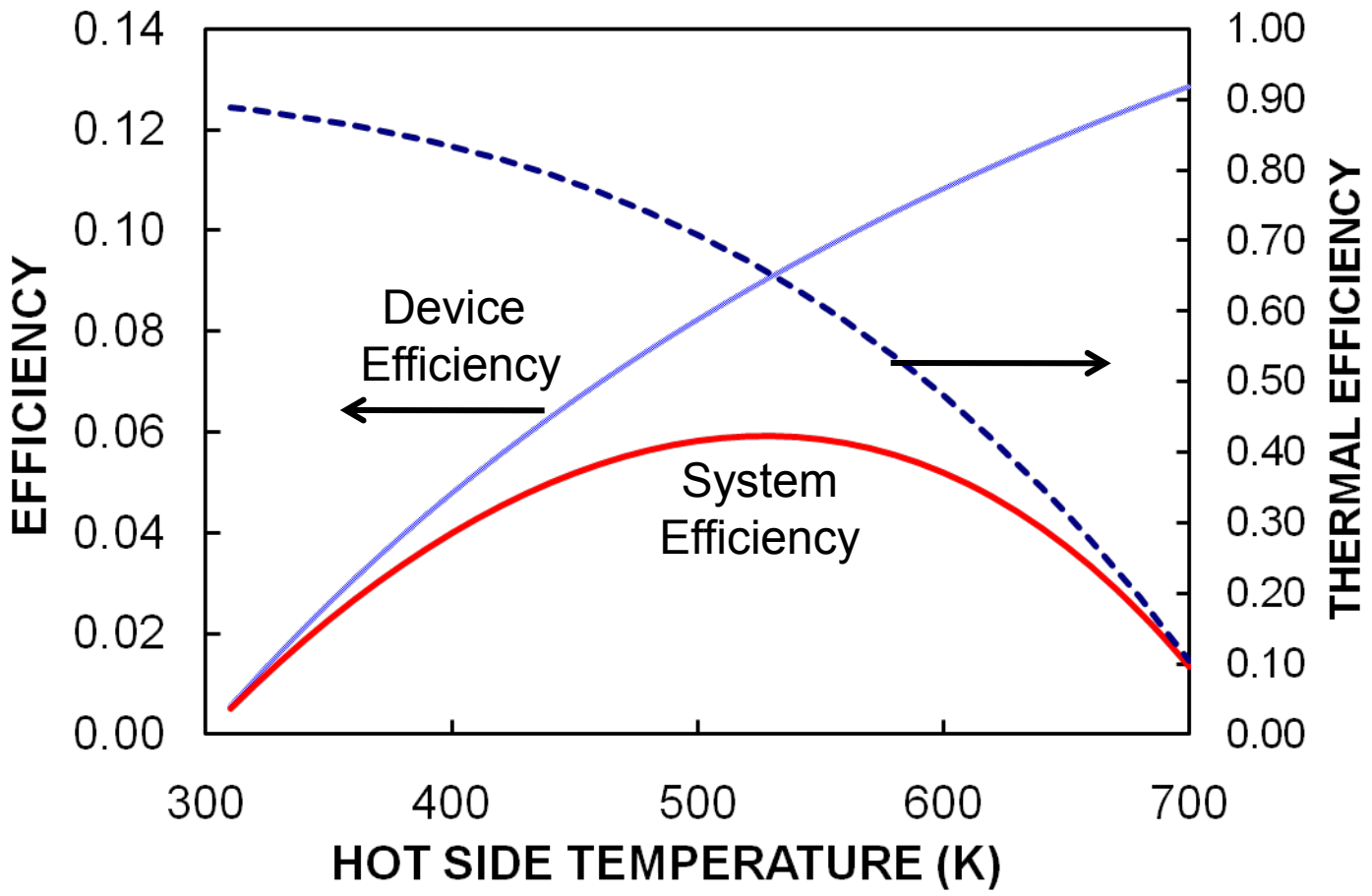
- Absorption efficiency
- Radiation loss to ambient
- Radiation loss between top and bottom surfaces
- Convection loss

Thermoelectric Efficiency

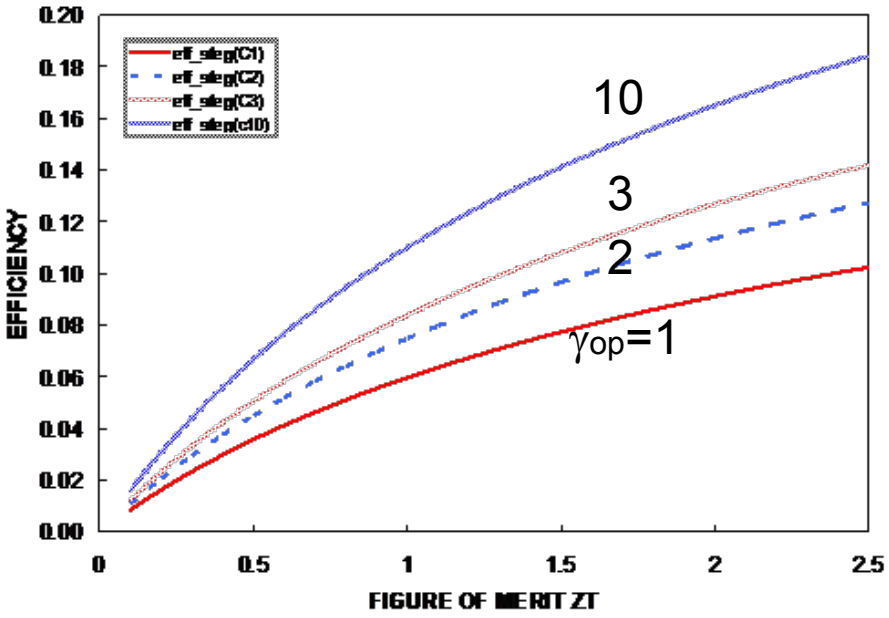
- Figure of merit
- Electrical contact
- Thermal contact

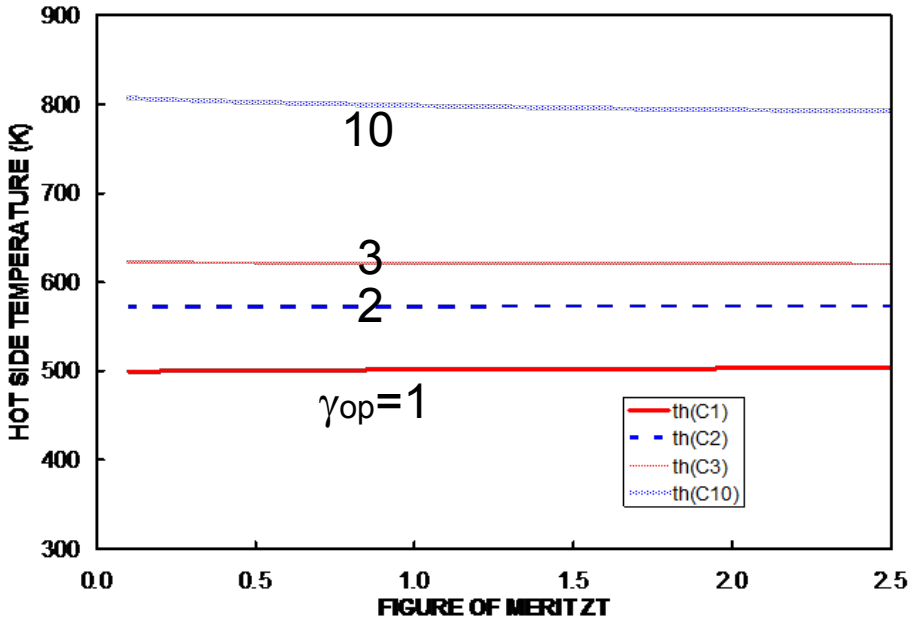
$$\eta = \eta_{th}\eta_{te} = \left[\tau_g \alpha_s \eta_{op} - \frac{\varepsilon_e \sigma\left(T_h^4 - T_c^4\right)}{\gamma_{op} q_i}\right]\left[\frac{(T_h - T_c)}{T_h}\frac{\sqrt{1+ZT_m}-1}{\sqrt{1+ZT_m}+T_c/T_h}\right]$$

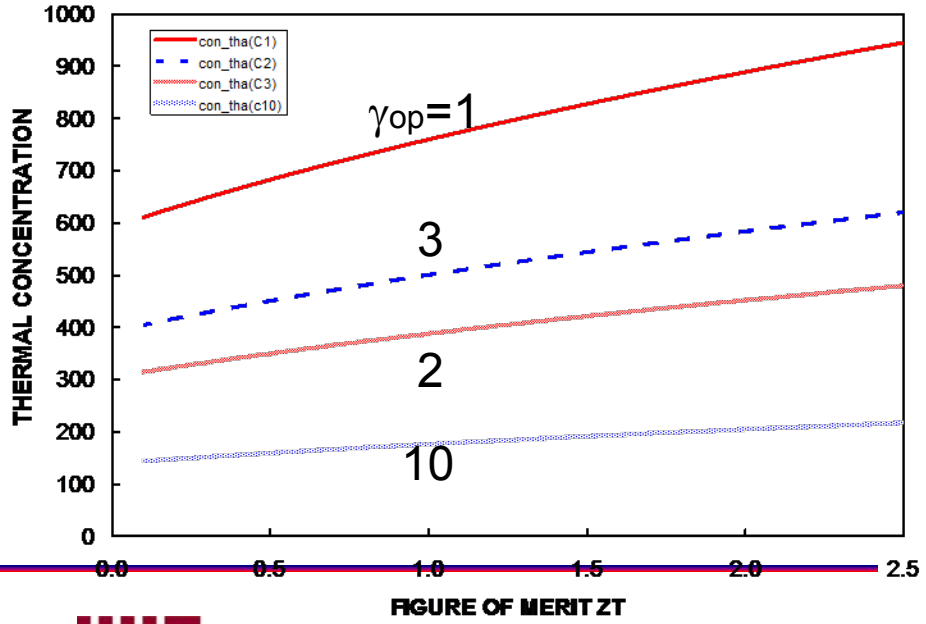
System Efficiency



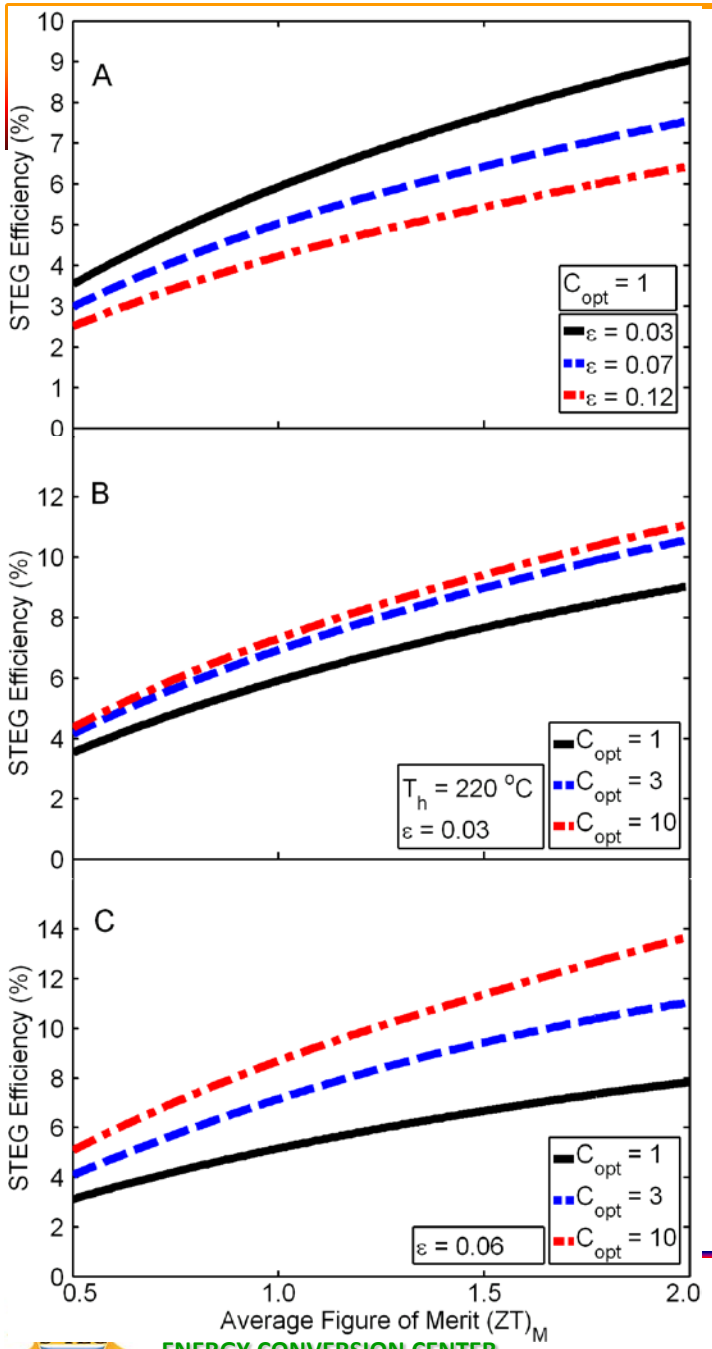
Predicted System Performance

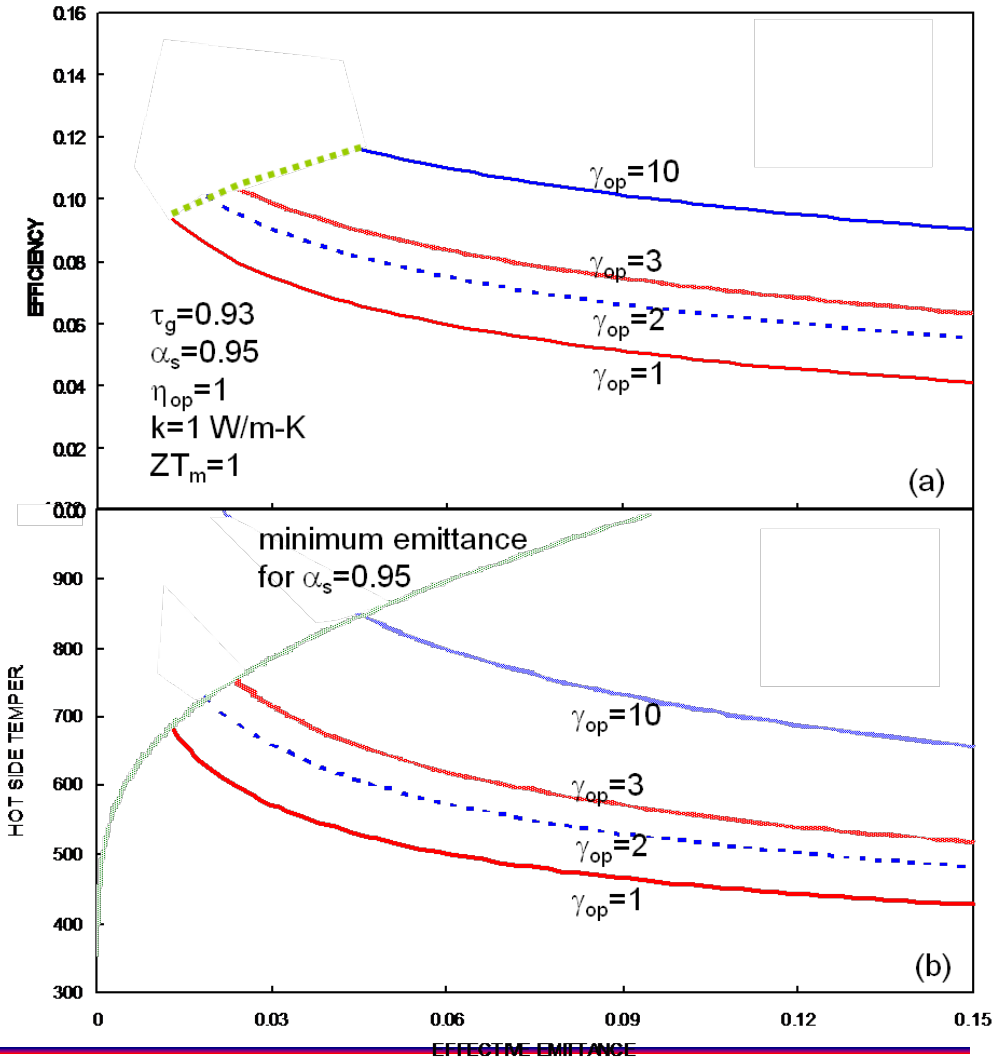






Potential Improvements





Summary

- Record high solar thermoelectric energy conversion efficiency.
- High efficiency due to (1) vacuum operation, (2) selective surfaceshigh performance materials.
- Solar thermoelectric energy conversion provides an alternative between solar PV and solar thermal-mechanical energy conversion.
- Key factors are materials ZT and spectrally selective surfaces.

Acknowledgments: DOE EFRC and MITEI