29th Annual INCOSE international symposium

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Alternatives for Managing Atmospheric Warming

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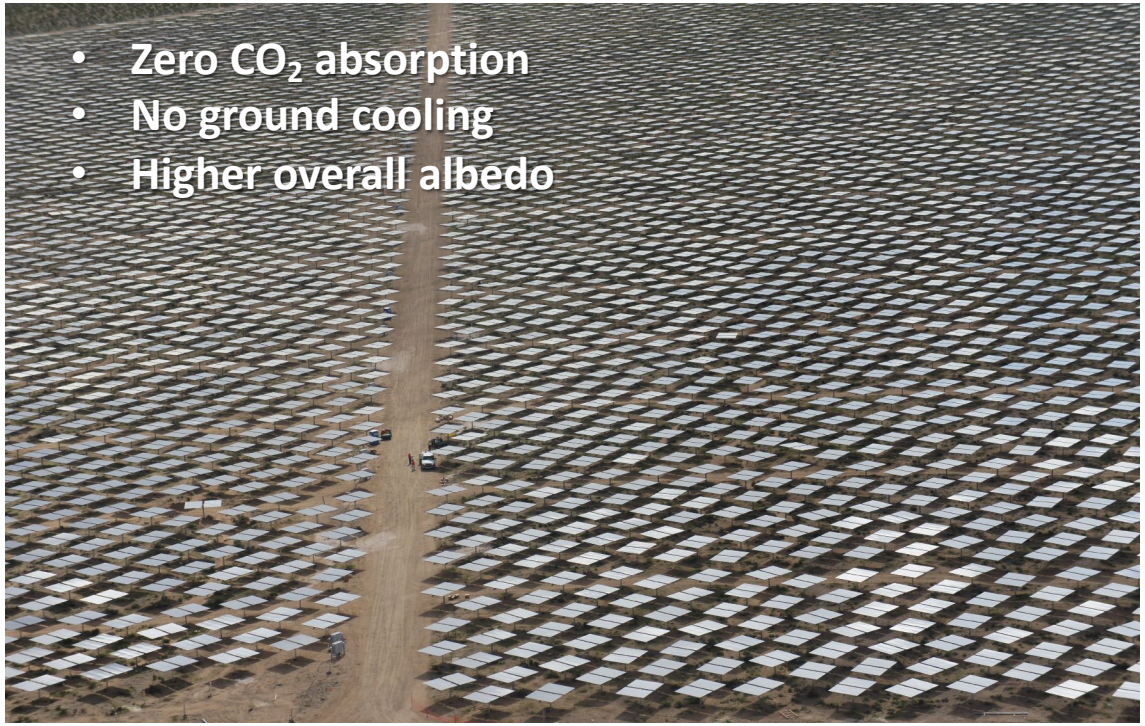
Engaging the culture, changing the world

Seattle Pacific UNIVERSITY

Trees or Mirrors: Which is better (°C/m^2) for controlling atmospheric temperature?

(Image: Stansberry 2008)



(Image: Fehrenbacher 2013)

CC BY-SA (annotations added) https://en.m.wikipedia.org/wiki/File:Oak-forest-norris-tn1.jpg

https://gigaom.com/wp-content/uploads/sites/1/2012/08/dsc02196-804x535.jpg (annotations added)

Outline

- A statement of the problem and MOEs
- Atmospheric heat sources
- Electricity-generating system options
- Summary and conclusions

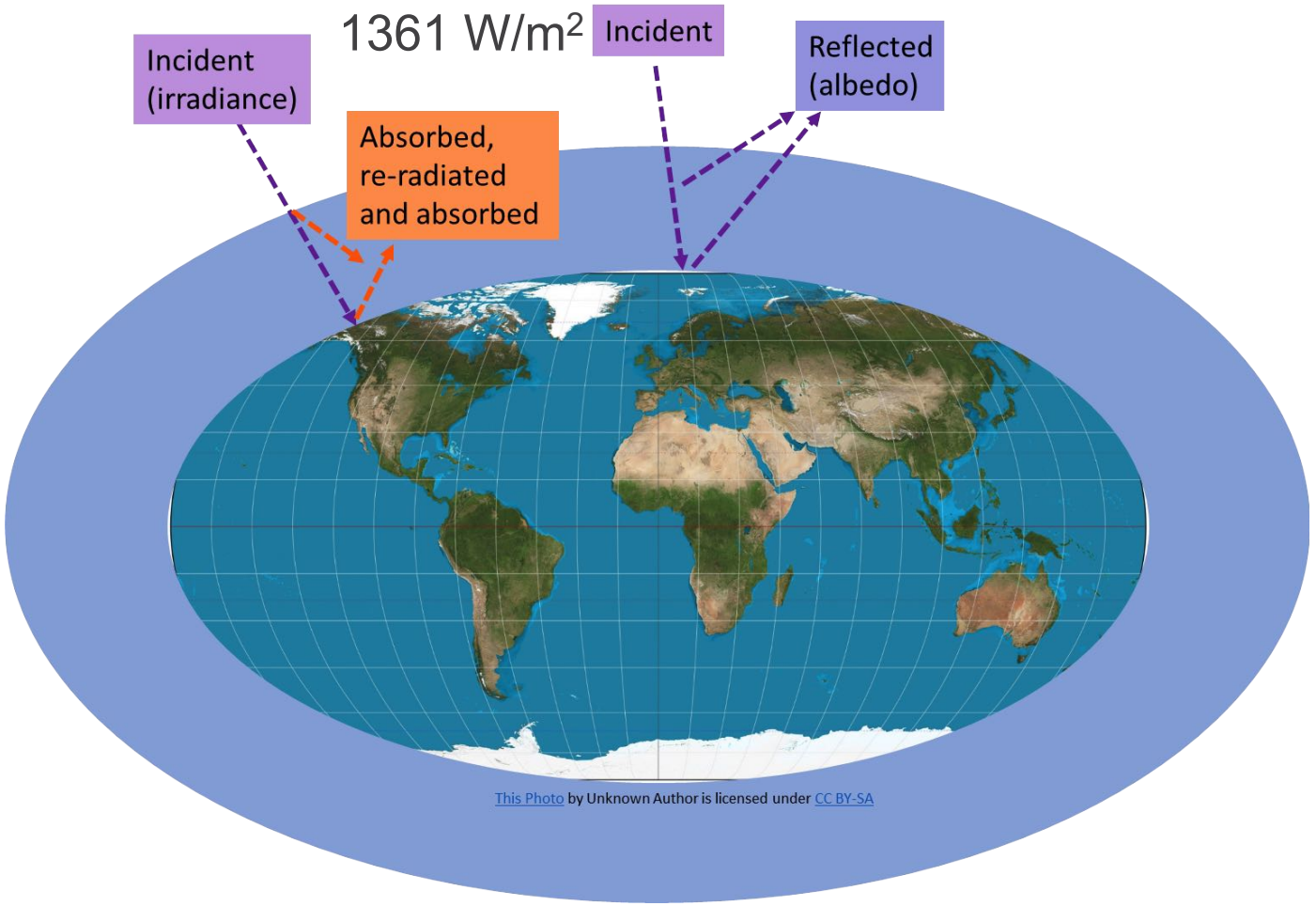
A problem? The earth is heating

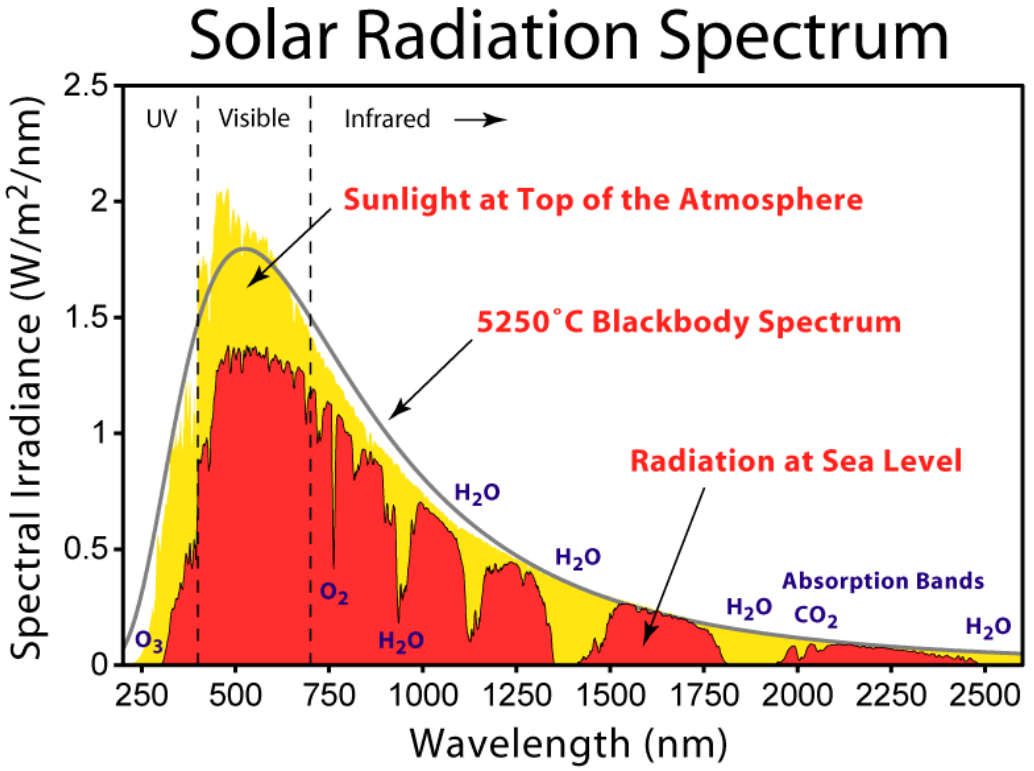
- Public assertions
  1. Atmospheric temperature increase is an unprecedented threat
  2. This temperature increase is driven by anthropogenic CO_2 emissions (1.7°C/TtC)
  3. Only control of CO_2 can reduce or limit unacceptable temperature rise
- We address #3

- MOE: temperature change (ΔT, °C) and its surrogate, "radiative forcing" ($\dot{Q}$, W/m^2) according to

$$\dot{Q} = C_a \Delta \dot{T}$$

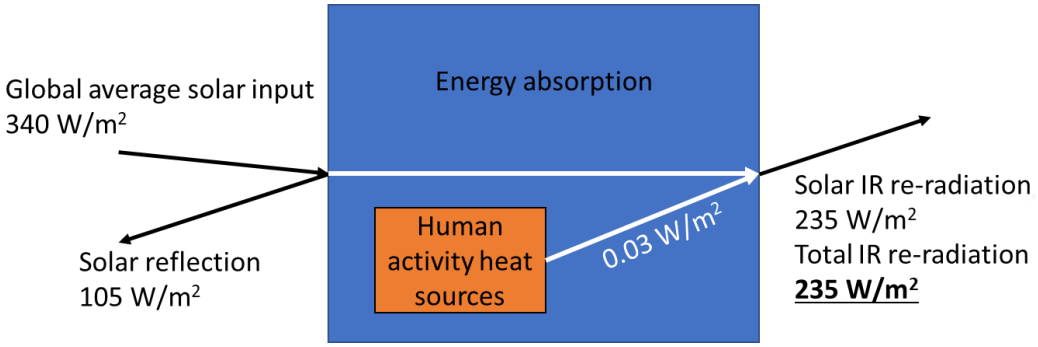
Atmospheric heat sources: It's the sun!





http://en.wikipedia.org/w/index.php?title=Image:Solar_Spectrum.png&redirect=no&oldid=137135398

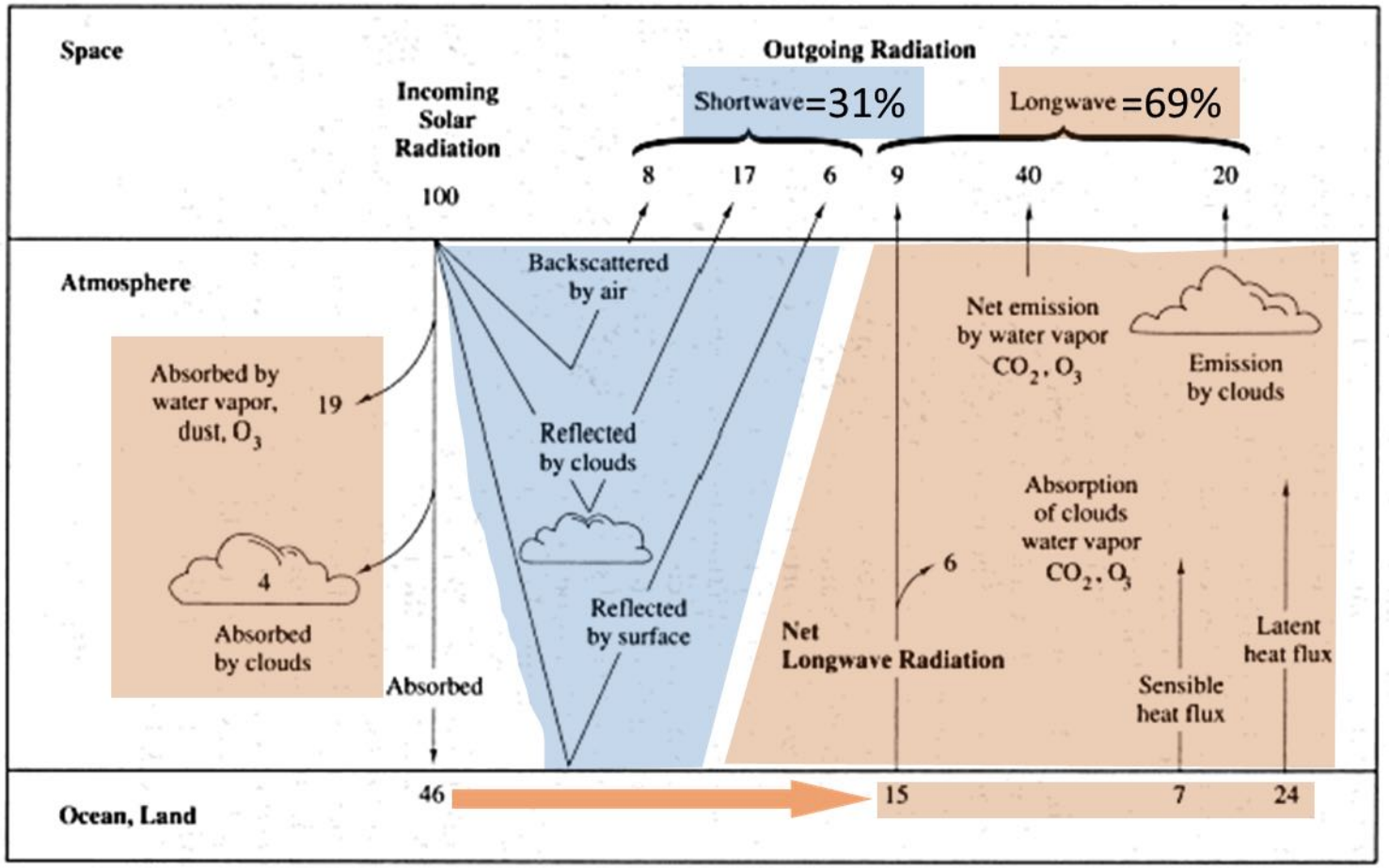
Reflection (albedo), Absorption, Re-Radiation



- On average 31% of incident solar energy is reflected
- Only absorbed, re-radiated solar energy is absorbed by CO_2
  - Reflected visible light is not absorbed by CO_2 (31%)
- Average 69% of incident solar power could be re-purposed to reflection

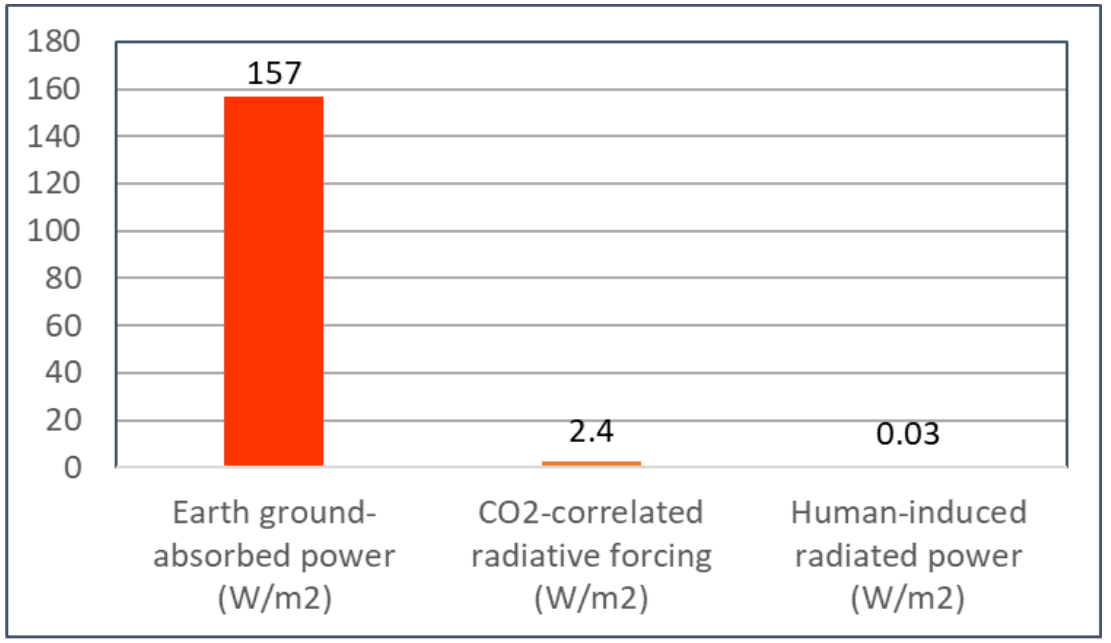
➢ If it's not absorbed it cannot heat!

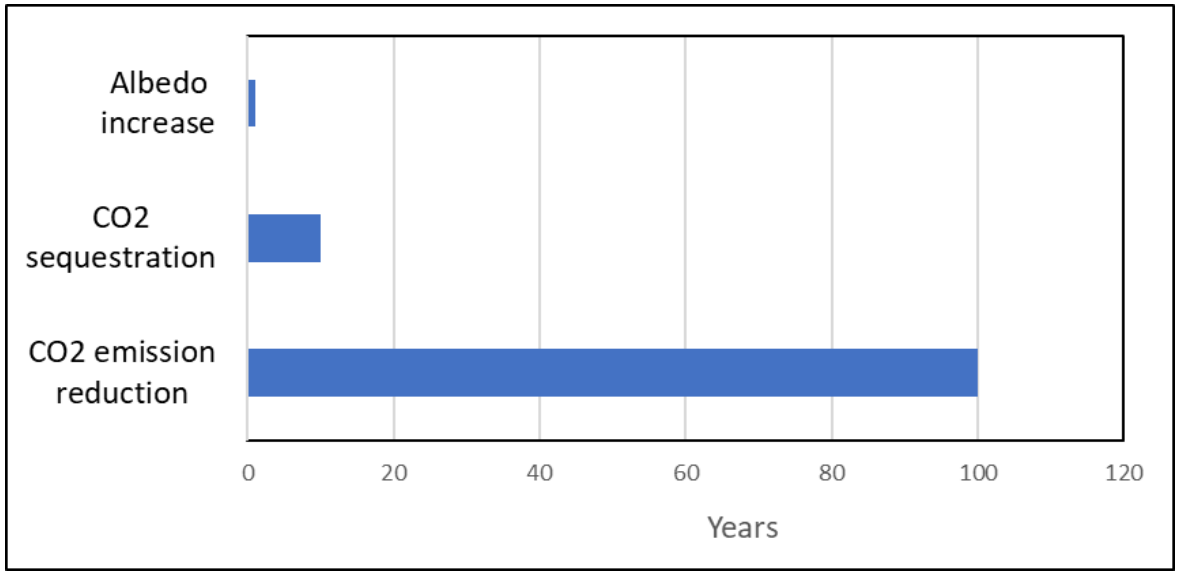
➢ Earth's temperature changes to balance radiation input and output



What to do?

- CO_2-correlated radiative forcing is *much smaller* than total solar power absorption
- CO_2 reduction effectiveness is decades-to-millenia vs. years
- Therefore, *if near-term heating is the problem,* we should enhance reflection (albedo) in the near term to reduce absorbed power, heating and temperature increase
- Hypothesis: offset heating effects of CO_2 by increasing earth's albedo (reflection)
- Space-based mirrors:
  - US$590T to offset CO_2 doubling
  - Compares with proposed CO_2 tax of US$3200T/°C avoided



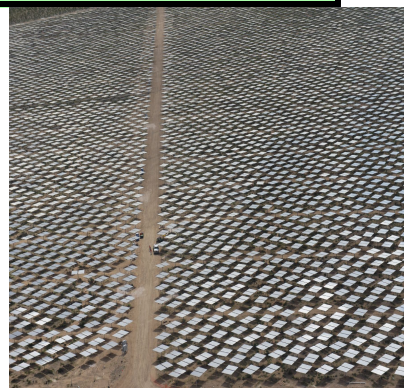


System Alternatives: 150 MW Data Center

1. System	2. Collector / Mirror Area (km2)	3. Energy Storage (GWh)	4. System Cost (M$)	5. System Cost (M$/ MW)	6. Electricity Cost ($/MWh)	7. Annual CO2 (Mtonne /yr)	8. Net annual addition-al heat (GJ/yr)	9. Net average radiative forcing (W/m2)	10. Net increment-al Temp rise (°C)	11. Net annual Temp rise (°C/yr)
1. Solar + batteries	5.0	3.60	$1,338	$8.92	$137	0.00	0.00	0.00	0.00	0.00
2. Solar + natural gas	5.4	NA	$999	$6.66	$99	0.282	5.55E+06	2.42E-05	1.96E-05	1.54E-06
3. Natural gas + mirrors	146.5	NA	$12,627	$84.18	$539	0.376	-5.14E+08	0.00E+00	0.00E+00	0.00

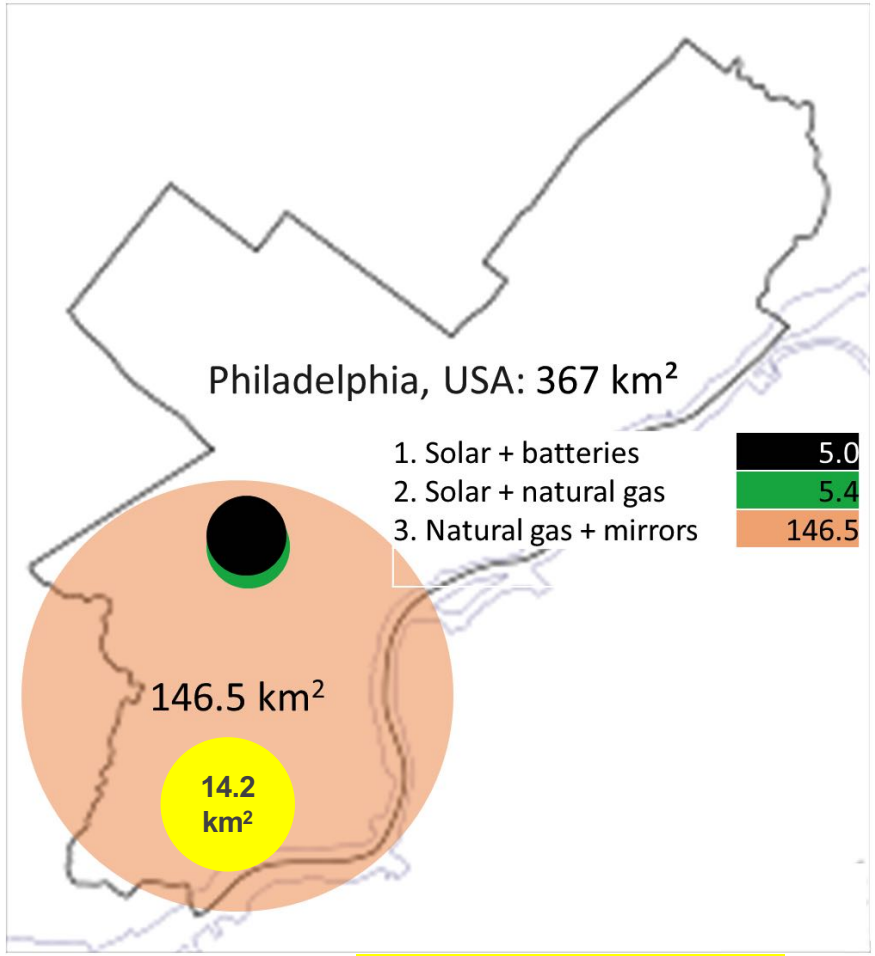
System 1 – Solar PV

System 2 – Solar CSP

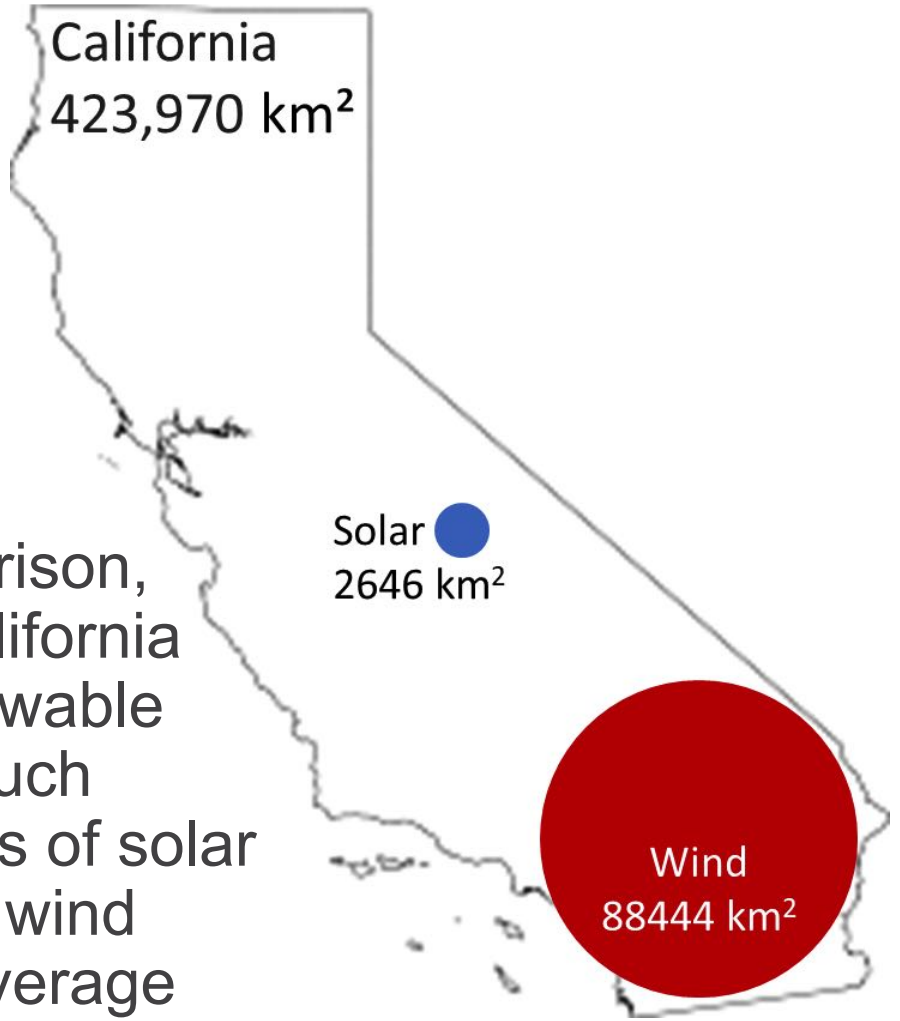


System 3 – Natural Gas + Mirrors

Footprint – Baseline Sizing



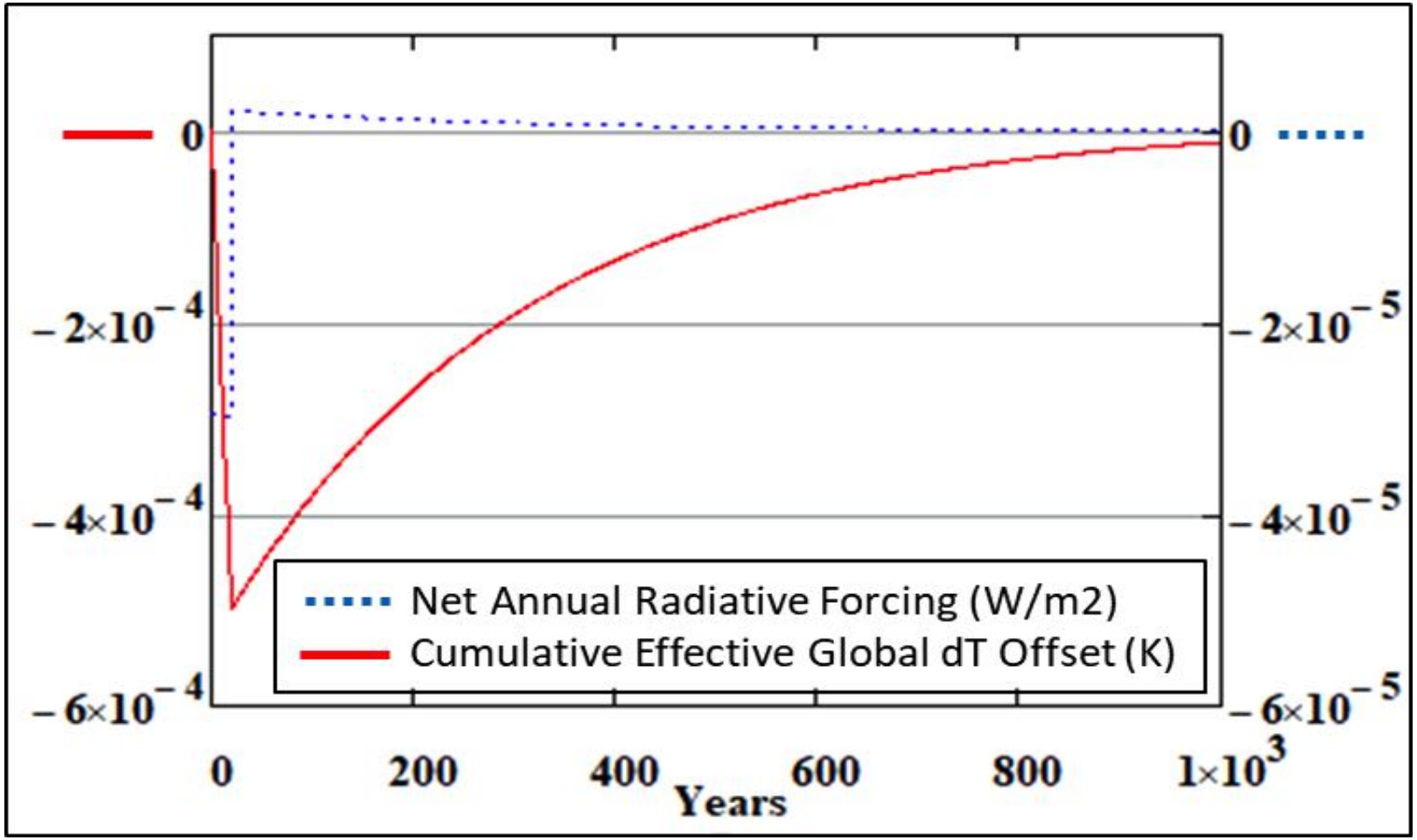
Virginia solar farm



For comparison, making California 100% renewable requires much larger areas of solar (~0.6%) or wind (~21%) coverage

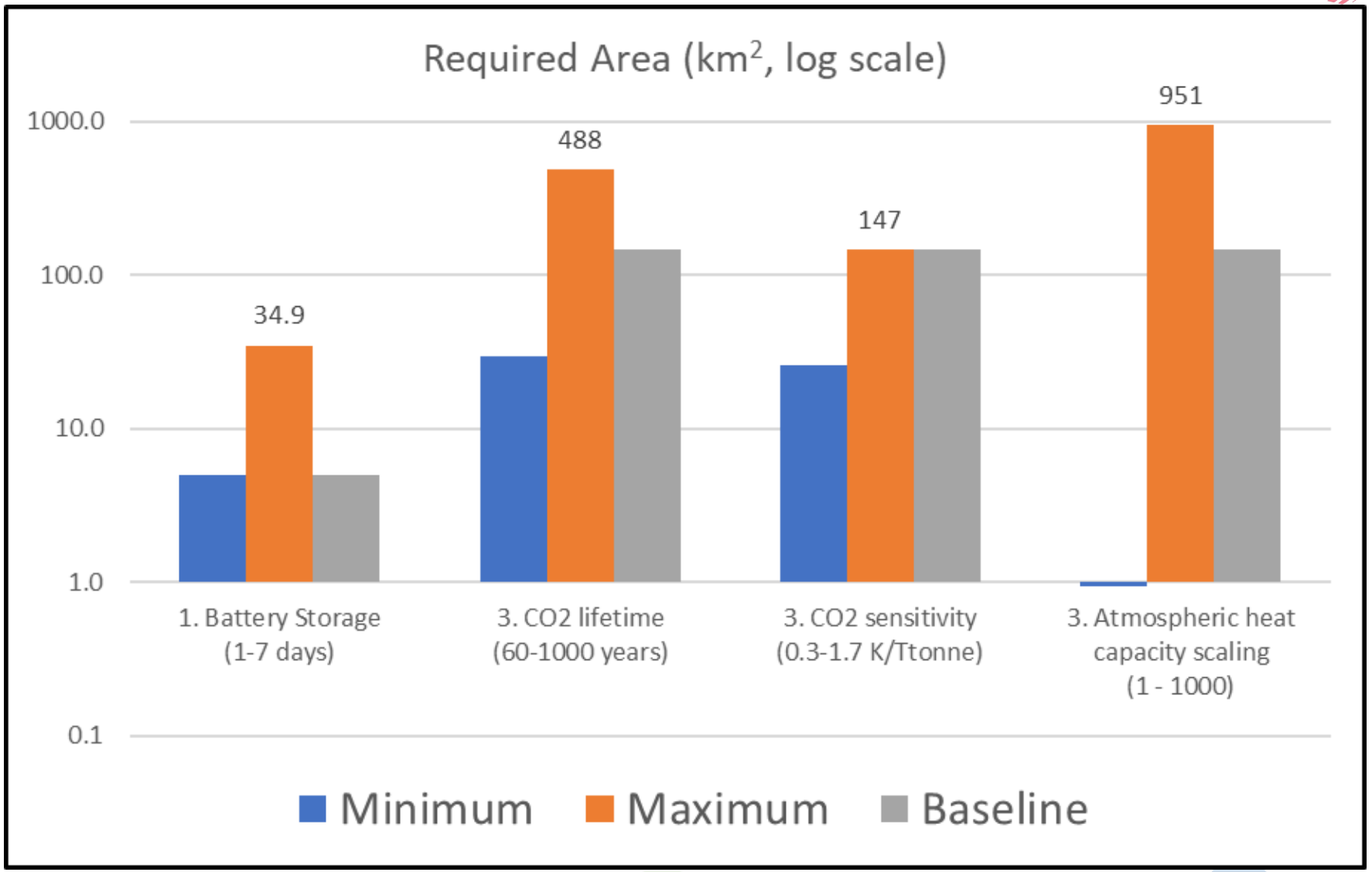
Effectiveness: Atmospheric Temperature Changes

- Natural gas + mirrors system front-loads cooling
- Lifetime net effect on T is *zero*
- *Albedo reduction can completely offset incremental CO_2-induced heating*



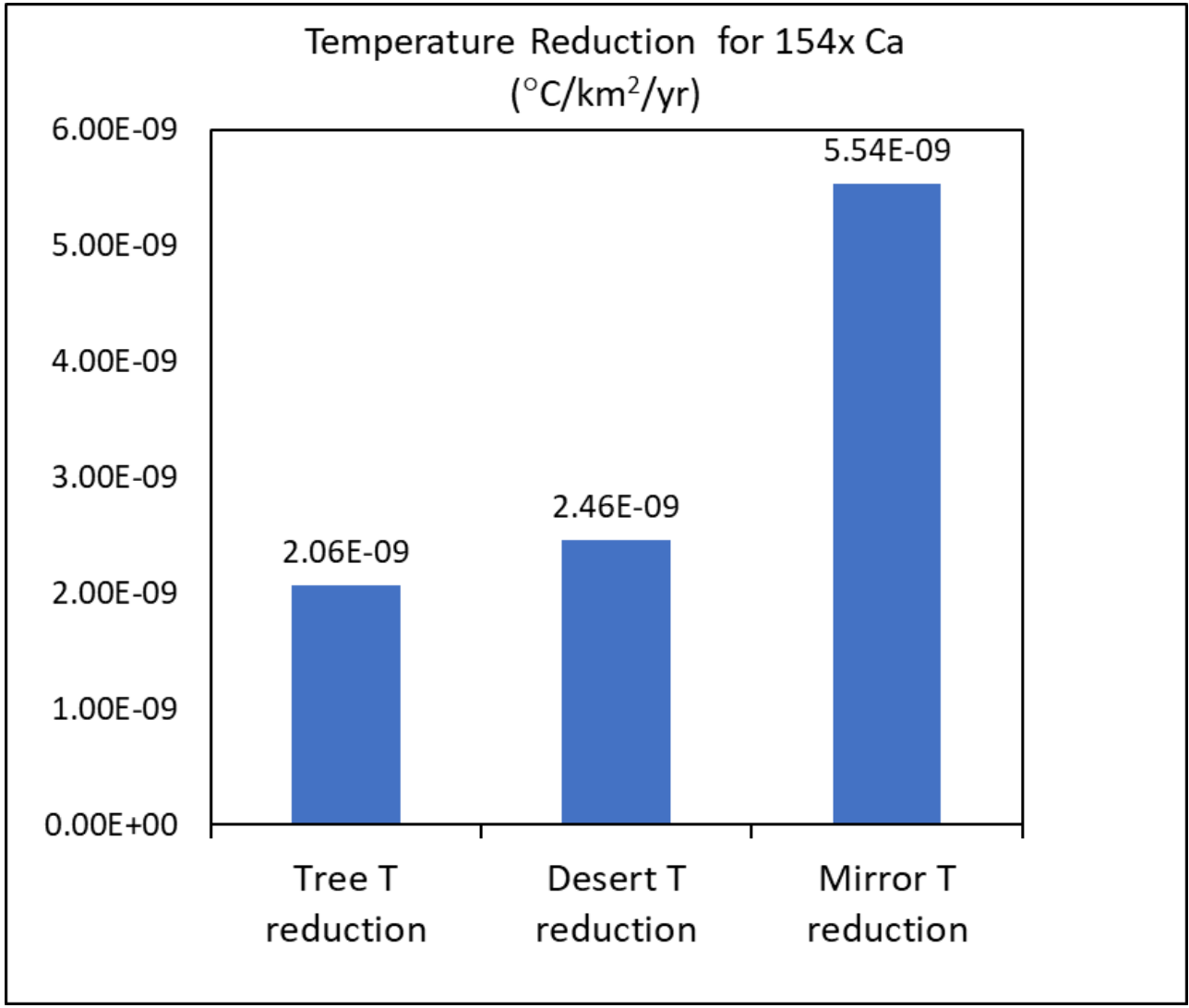
Uncertainties and Sensitivities

- Results are sensitive to assumptions regarding
  - Battery storage (system S1)
  - CO_2 lifetime (S3)
  - CO_2 sensitivity (S3)
  - Atmospheric heat capacity (S3)



Trees, Desert, or Mirrors?

- Trees are *worst* for reducing temperature because of enhanced power absorption, even accounting for enhanced CO_2 power absorption.
- Mirrors (albedo = 90%) are *best* for reducing atmospheric temperatures
- If we're concerned about *temperature,* ground-based mirrors are immediately effective, can be quickly deployed, and are easily reversed if necessary



Summary and Conclusions

- Domain-specific
  - Atmospheric warming is driven by solar heating (incident global average 340 W/m^2)
  - Earth's albedo is more important than CO_2 in controlling solar power absorption (157 W/m^2 vs. 2.4 W/m^2)
  - Heating by CO_2 can be offset by increasing earth's albedo (above global average 0.3)
  - If limiting or reducing temperature is *critical*, increasing earth's albedo, even at the ground, is a more effective (time, degrees) but possibly more costly alternative to controlling CO_2
- Selecting the wrong system MOE can lead to selecting a non-optimum solution

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