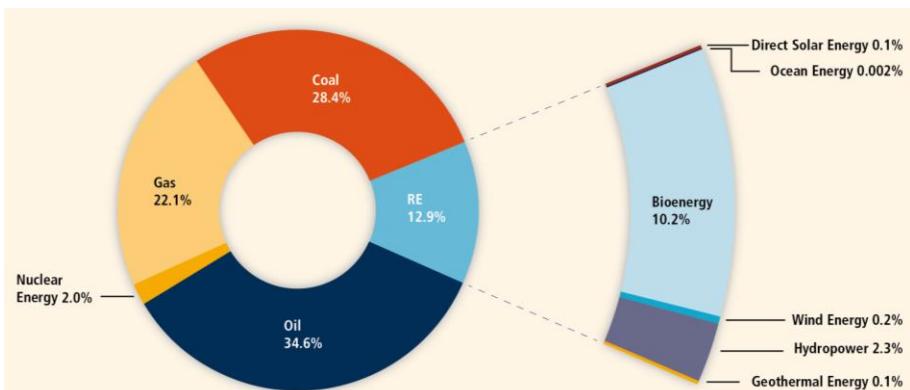


Alternate Energy Sources: Solar and Wind

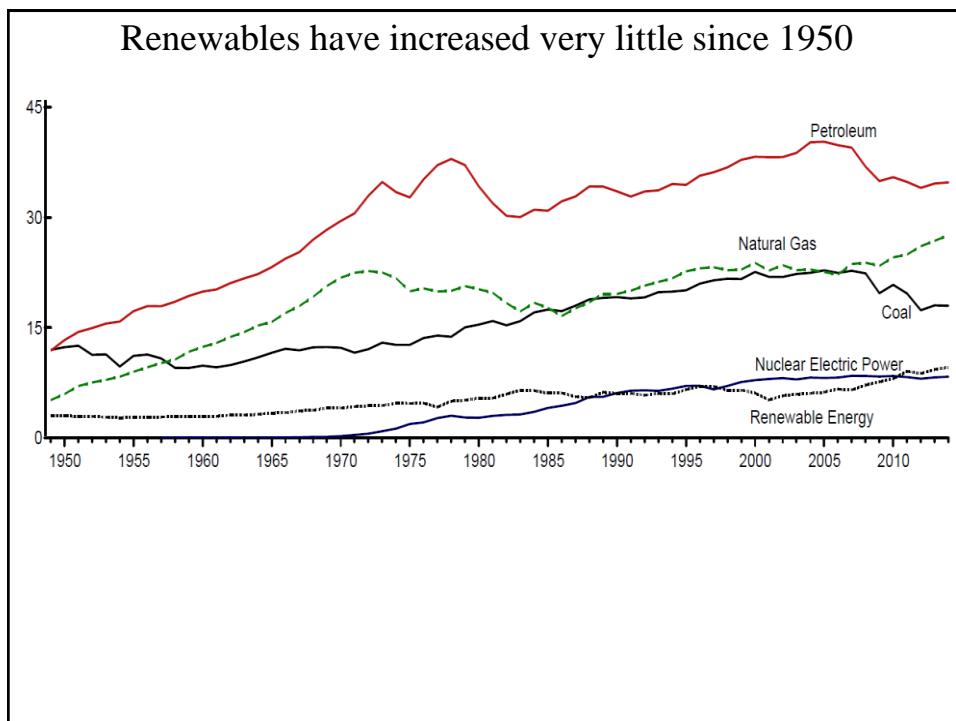
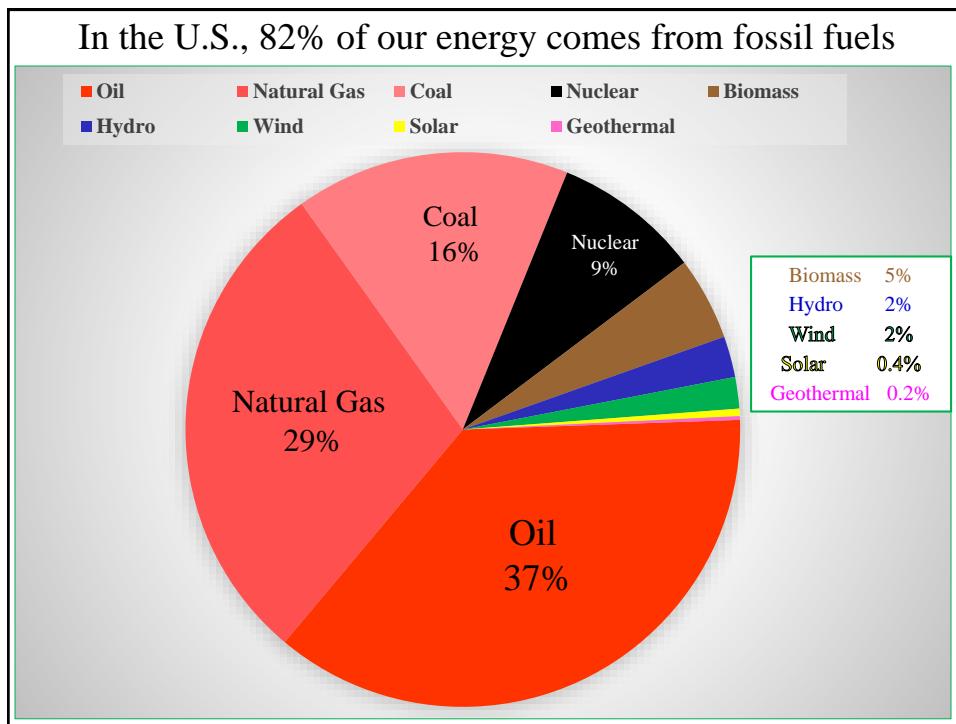


To limit warming to 2° C, we need to get 80% of our energy from carbon-free sources by 2040

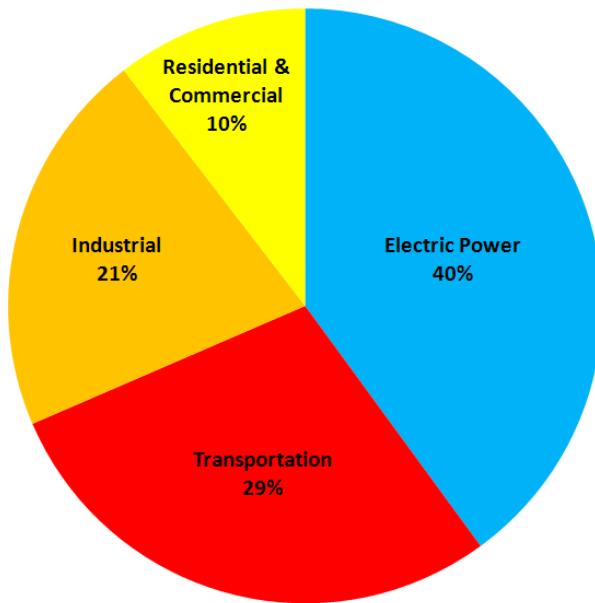
Globally, 85% of our energy is from fossil fuels



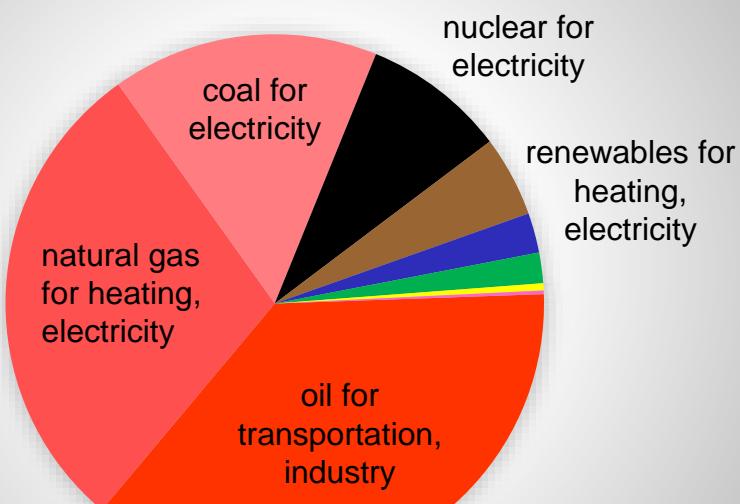
0.2% from wind
0.1% from solar



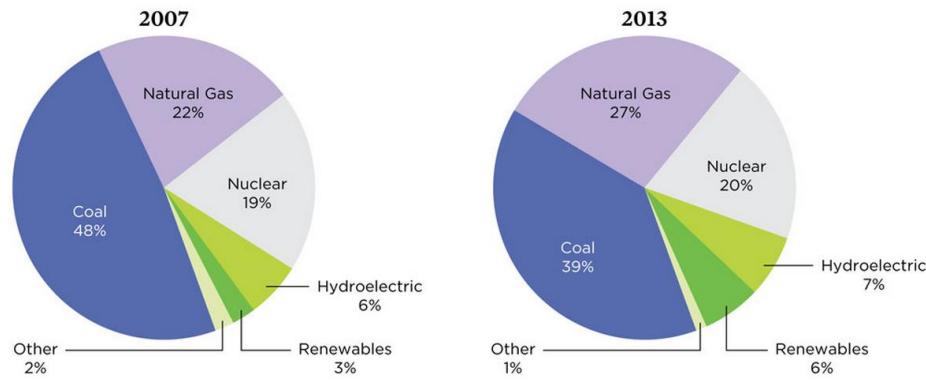
How do we use energy in the U.S.?



How do we use energy sources in the U.S.?



How do we generate *electricity* in the U.S.?



Solar and wind generate carbon-free electricity



Solar is the most plentiful energy source



More energy reaches Earth from the sun in 1 hour than humans on the entire planet use in 1 year!

Two main ways to capture solar energy

- A. Concentrating solar power (CSP)
- generates heat, then steam, then electricity



- B. Photovoltaic panels (PV)
- generates electricity without heat



Two main methods for Concentrating Solar Power

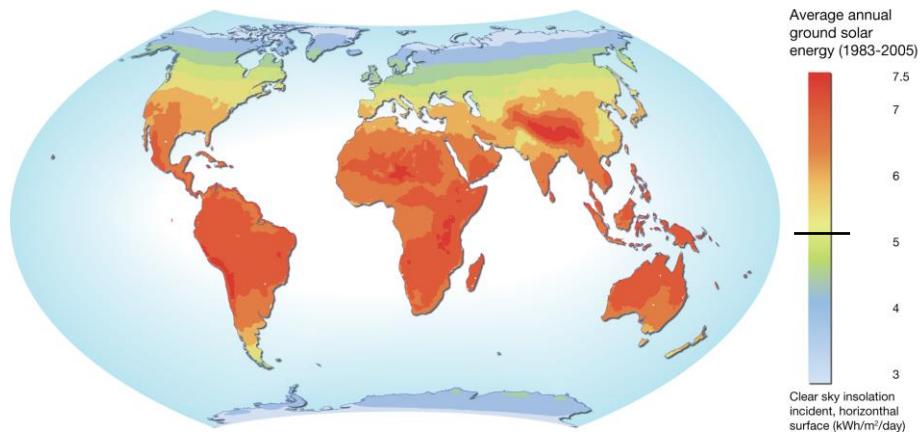
1. Solar tower: mirrors concentrate the sun's energy on a heat exchanger located on a central tower
 - heat is used to boil water in a conventional steam generator to produce electricity



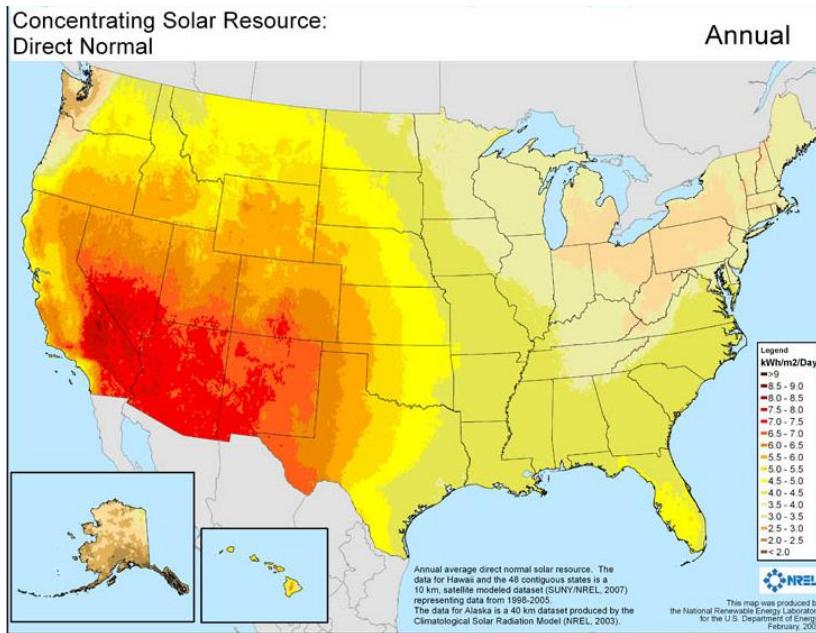
2. Parabolic trough: long, curved mirrors concentrate the sun's energy to heat oil in a pipe that runs down the center of the trough
 - heat is used to boil water in a conventional steam generator to produce electricity



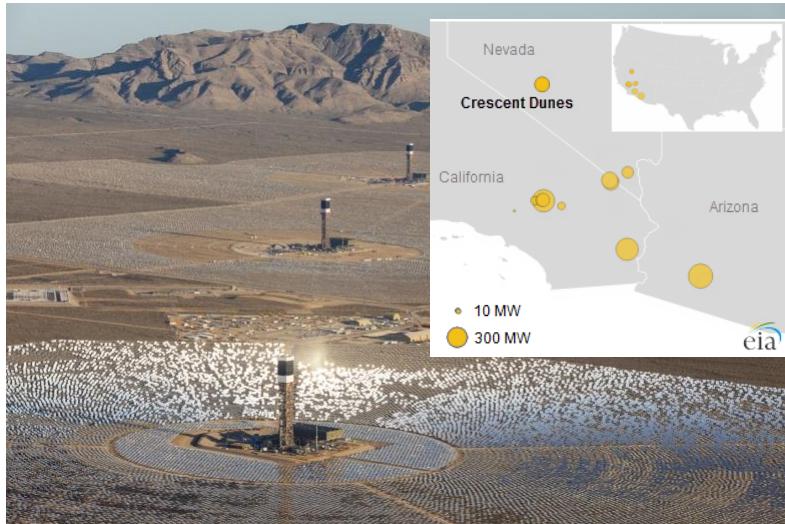
How much of the world is appropriate for CSP?



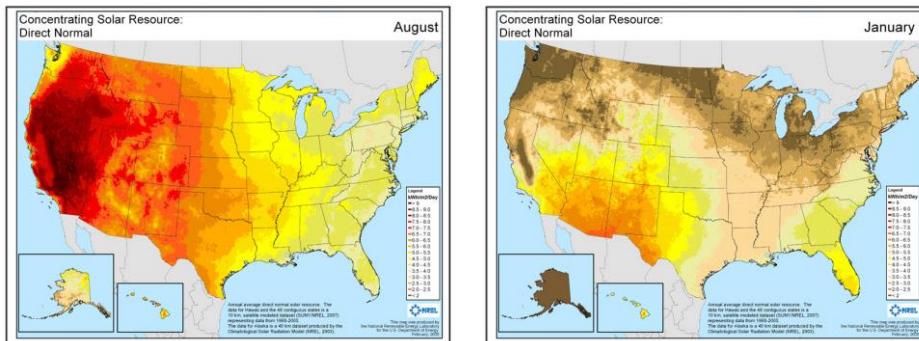
We have very good CSP sites in the U.S.



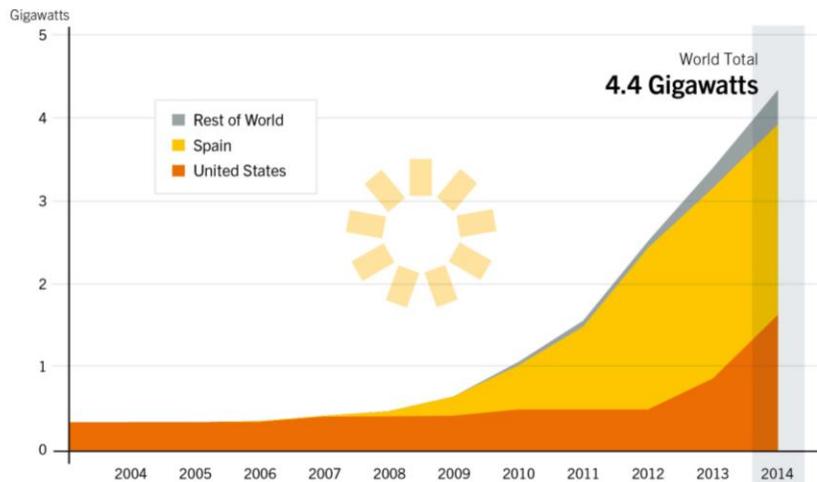
But only 10 operational CSP plants



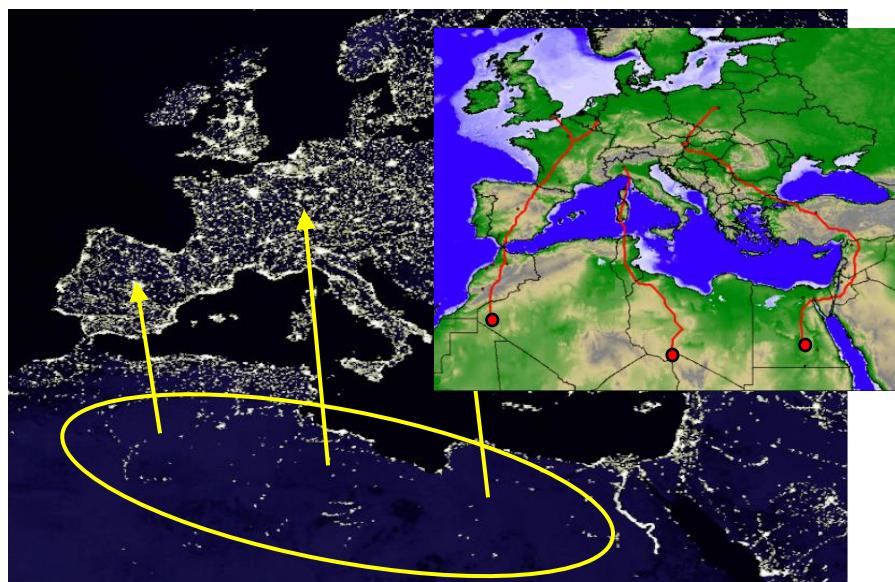
But August is much better than January



Which countries are using the most CSP?

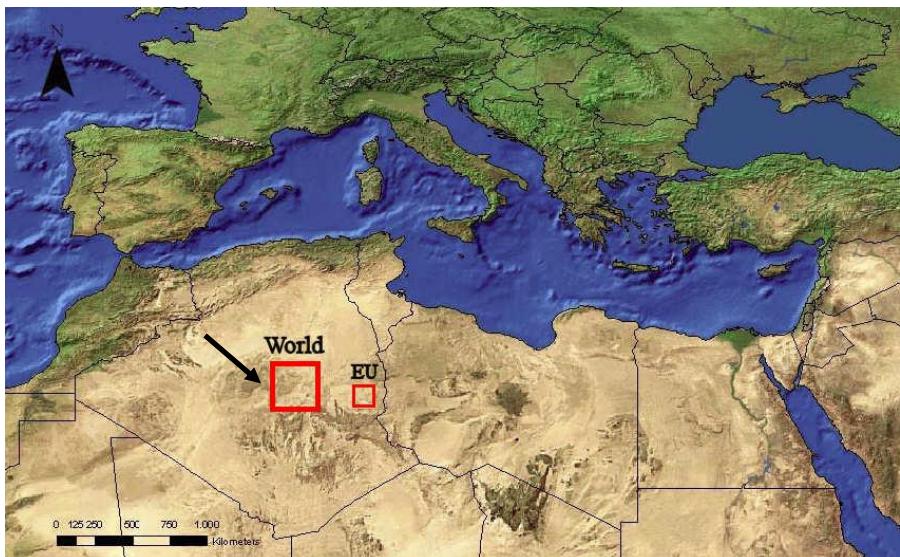


Could solar energy be used to power Europe?

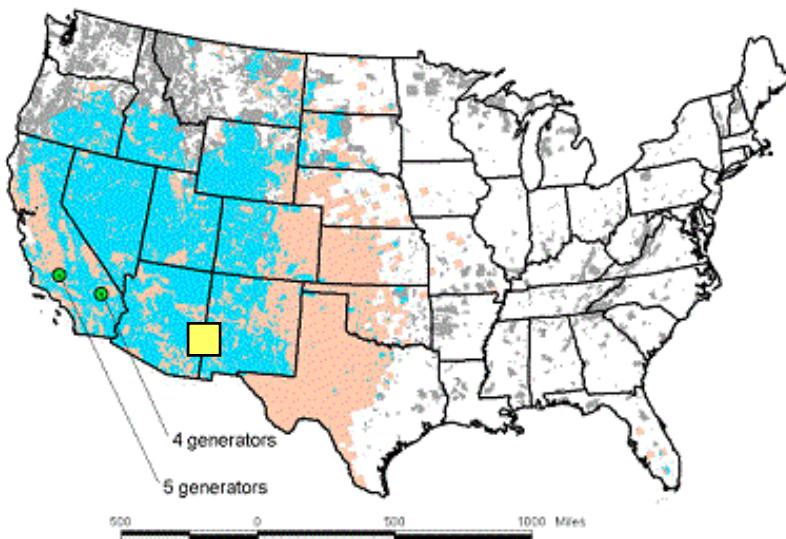


- only 3% loss over 1,000 km

A small portion of the Sahara desert could supply all of the world's electricity



A solar array 100 x 100 miles in the southwest could provide all of U.S. electricity needs today



Global potential is 3-100 times total current human energy use
(not just electricity)

REGIONS	Range of Estimates	
	Minimum, EJ	Maximum, EJ
North America	181	7,410
Latin America and Caribbean	113	3,385
Western Europe	25	914
Central and Eastern Europe	4	154
Former Soviet Union	199	8,655
Middle East and North Africa	412	11,060
Sub-Saharan Africa	372	9,528
Pacific Asia	41	994
South Asia	39	1,339
Centrally planned Asia	116	4,135
Pacific OECD	73	2,263
TOTAL	1,575	49,837
<i>Ratio of technical potential to primary energy supply in 2008 (492 EJ)</i>	3.2	101

solar potential >> all other sources combined

The “intermittency problem” can be solved easily



solar thermal

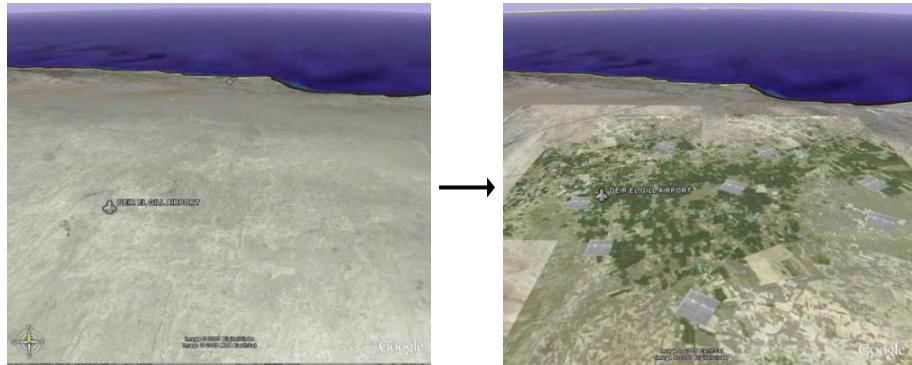


parabolic trough

- store excess heat during day, generate electricity at night
- can help “stabilize the grid”

CSP could also help greenify the desert

- excess energy could be used to run desalination plants



Northern Egypt coast

Greenhouses could even be located under parabolic trough arrays

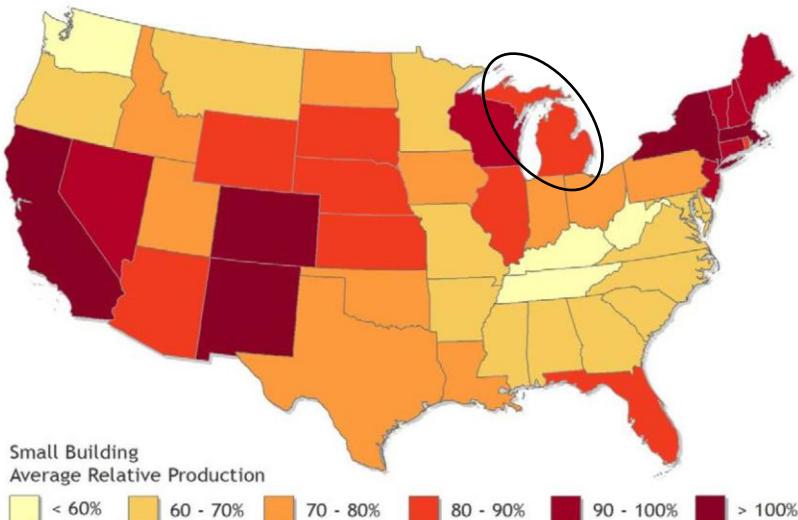


Photovoltaic panels (PV) are more widely used today than CSP

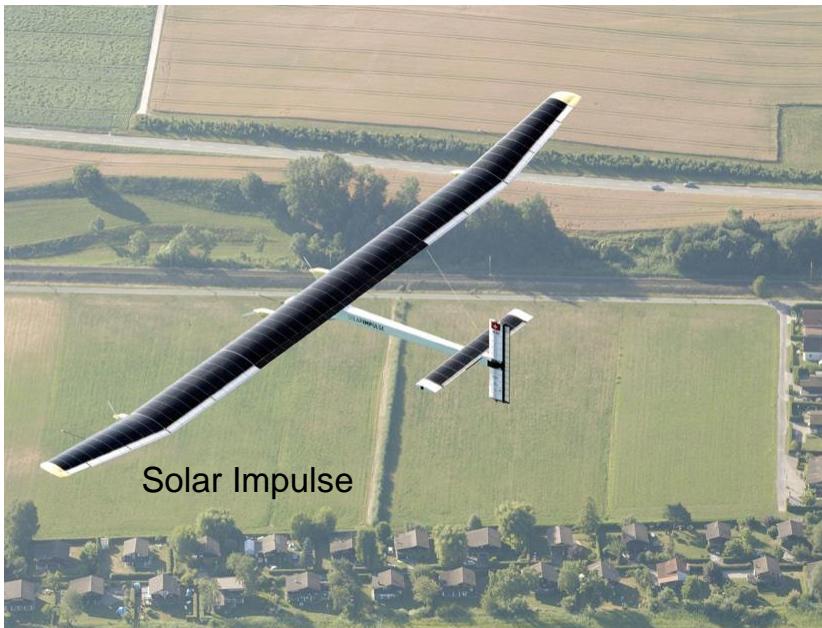


PV panels on just 0.6% of the total U.S. land area could power the entire country

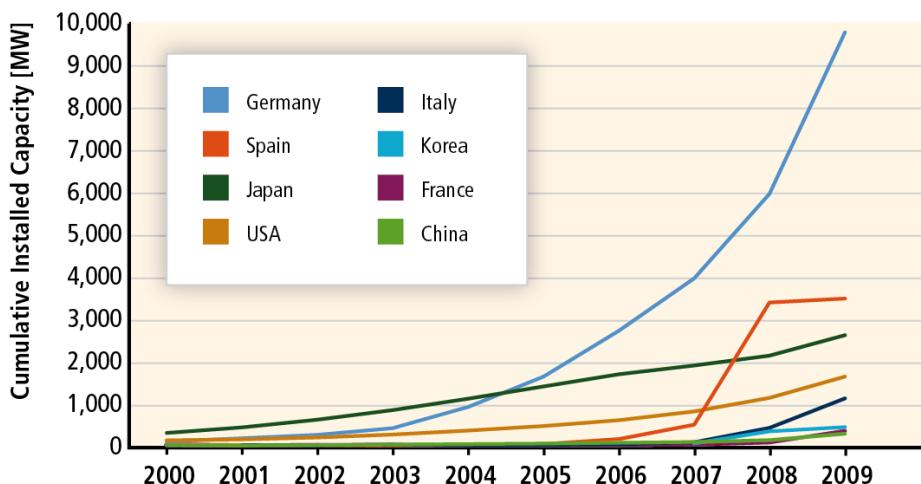
For most states, rooftop PV could provide
> 60% of household electricity



We eventually may be able to fly using solar PV



Which countries are using the most PV?



1 of every 78 new jobs created in the U.S. recently was created by the solar industry

Which countries have the top 10 PV companies?

<u>Company</u>	<u>Country</u>
Trina Solar	China
Canadian Solar	Canada
Jinko Solar	China
JA Solar	China
Hanwha Q Cells	South Korea
First Solar	USA
Yingli Green	China
Shunfeng Energy	China
ReneSola	China
Sunpower	USA

Alternate Energy Sources: Wind



Wind

Wind has enormous electricity production potential

- global potential is >40 times current worldwide use

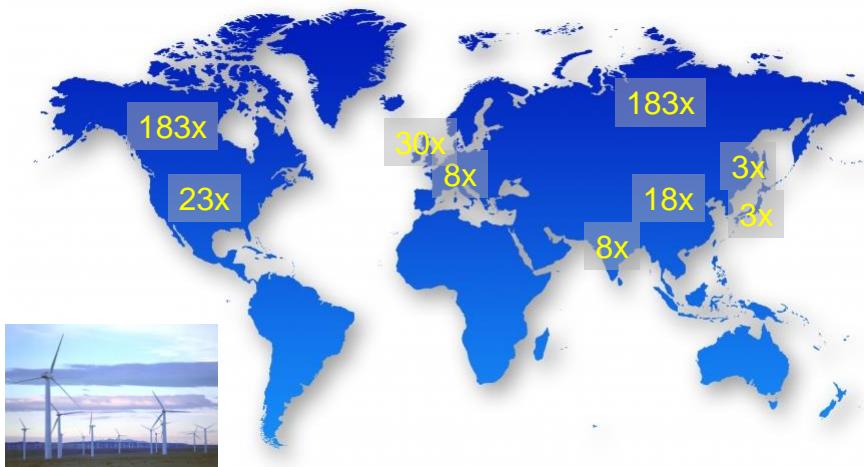


onshore



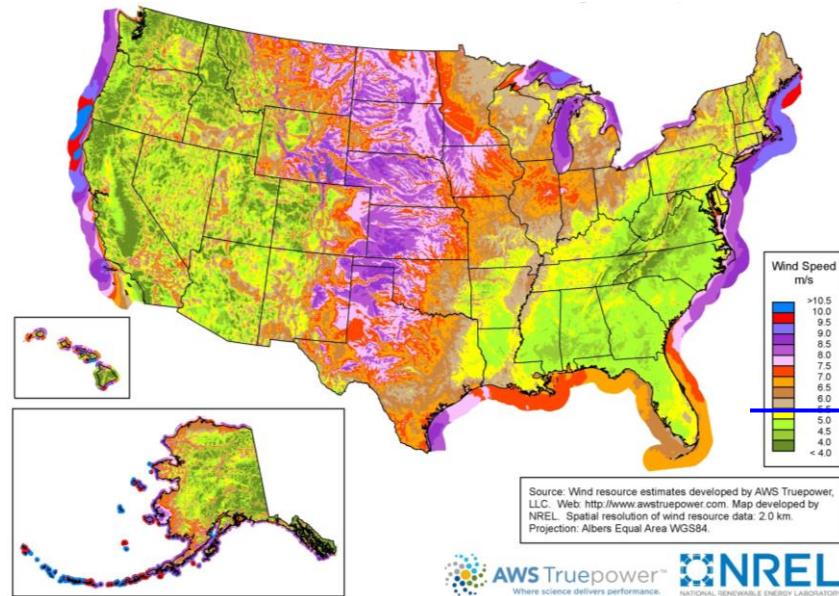
offshore

Using only wind, all 9 top CO₂-emitting countries could produce ≥ 3 times their current electricity use

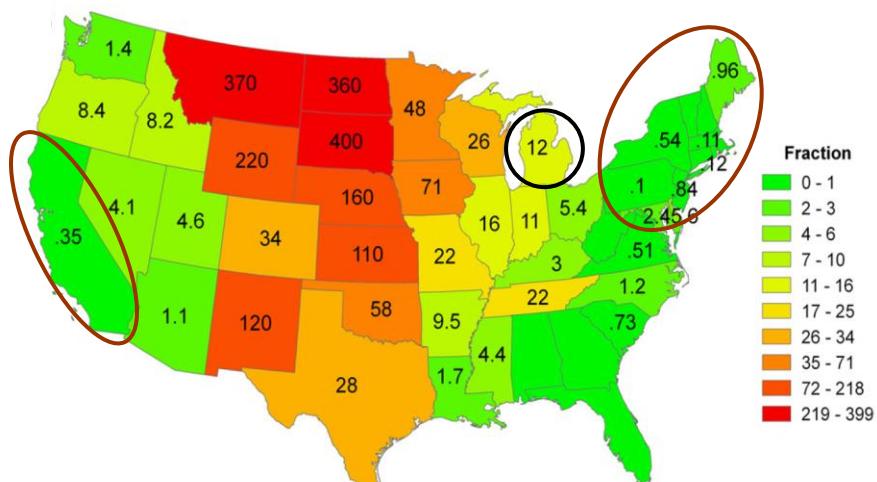


- China, U.S., India, Russia, Japan, Germany, Canada, England, South Korea

Many areas of the U.S. have 80 m wind speeds > 6 m/s



Wind power could supply 16 times current U.S. electricity demand using only onshore sites



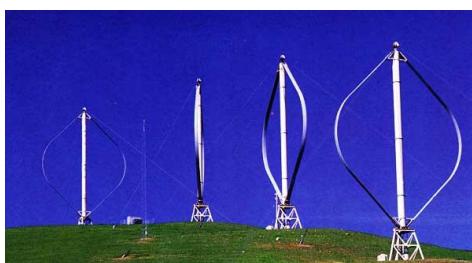
- Michigan can supply 12 times our use

Many new technologies are under development

new turbine designs

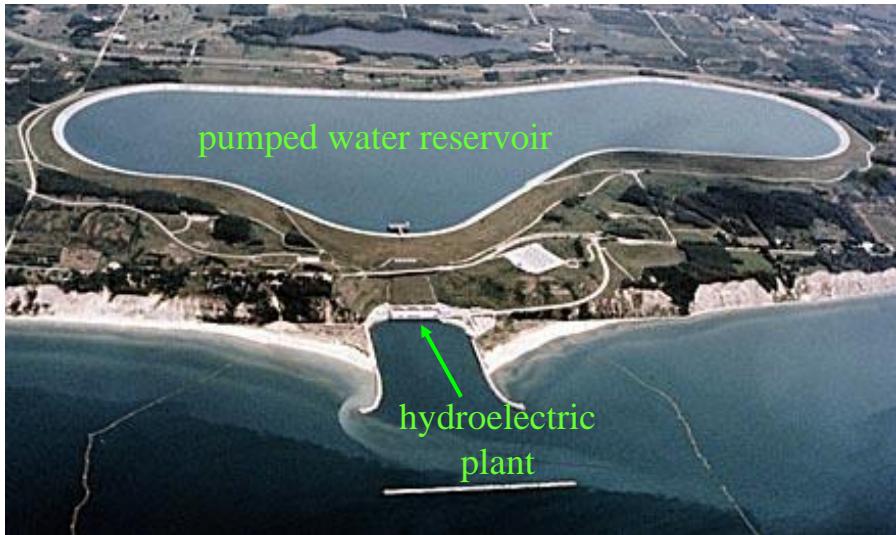


tethered turbines

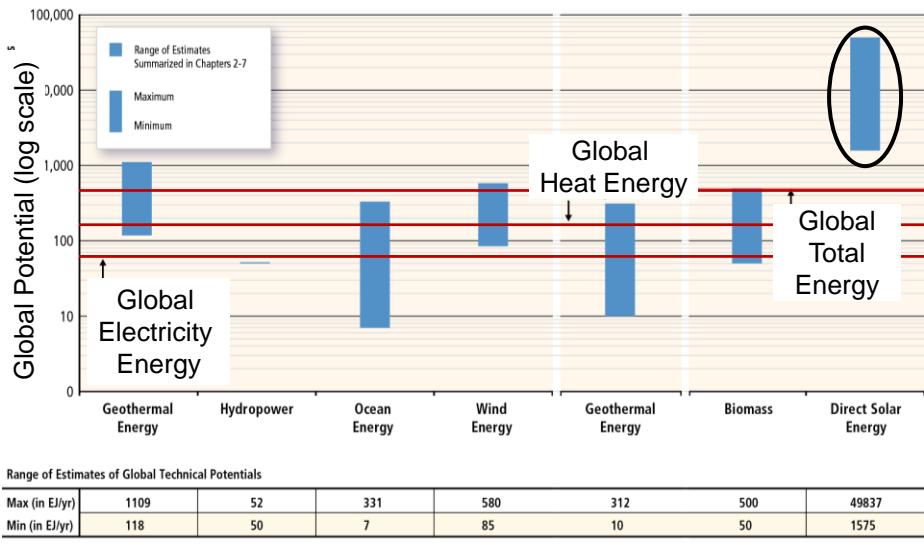


Again, the “intermittency problem” is easily solved

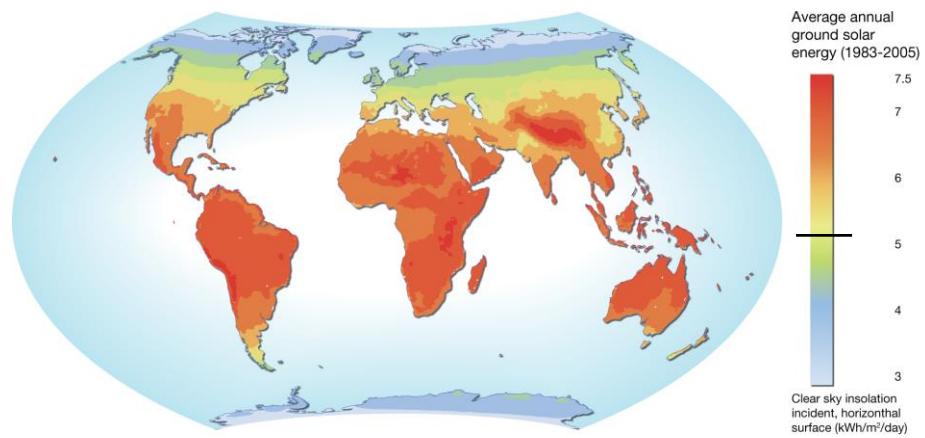
e.g. Luddington pumped storage plant



Limiting warming to 2° C will require 80% reduction in emissions by 2040

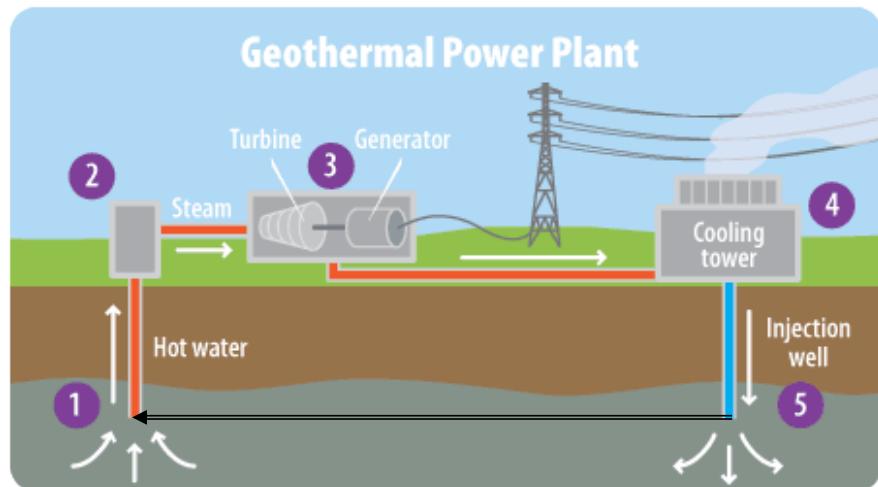


Who would benefit from conversion to solar?

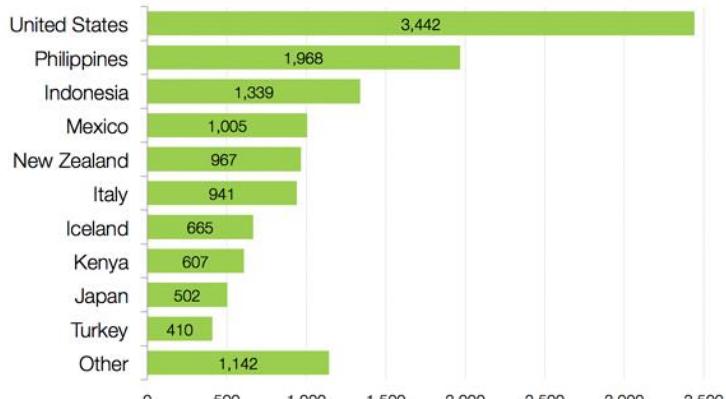


The rest of these slides were not presented due to lack of time,
but are included here in case you're interested

Geothermal energy makes use of Earth's heat



Which countries are producing the most geothermal electricity?

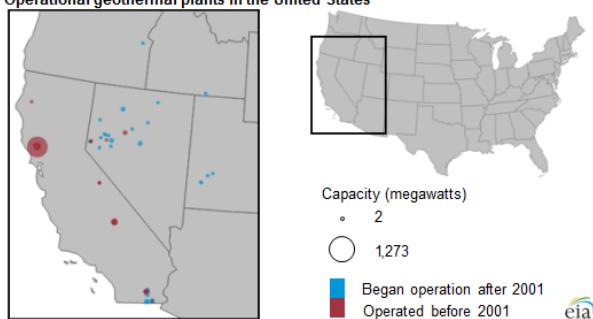


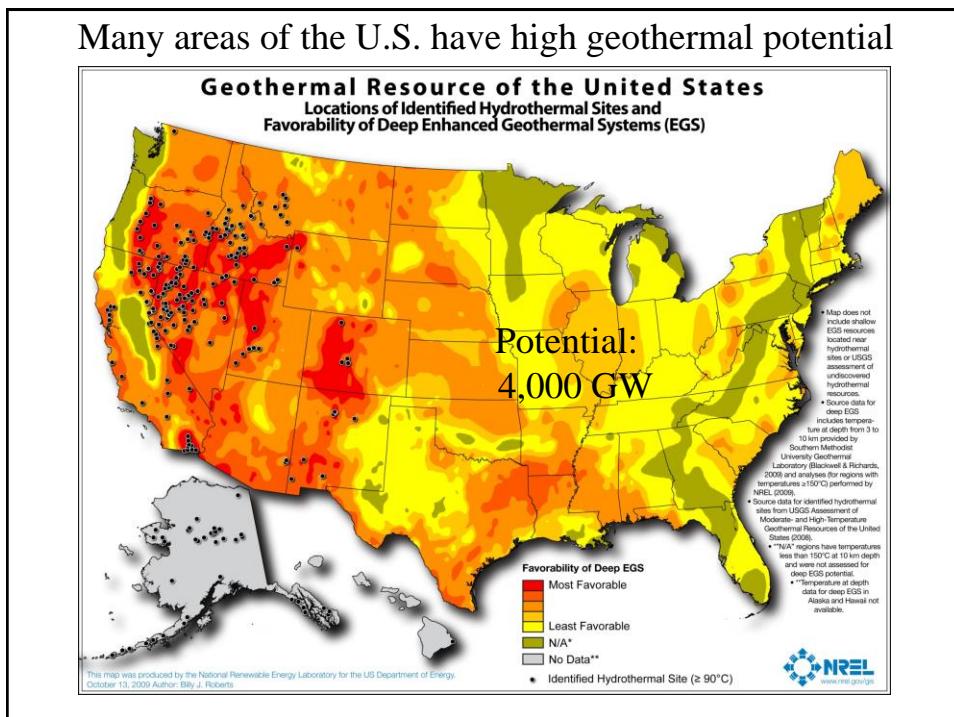
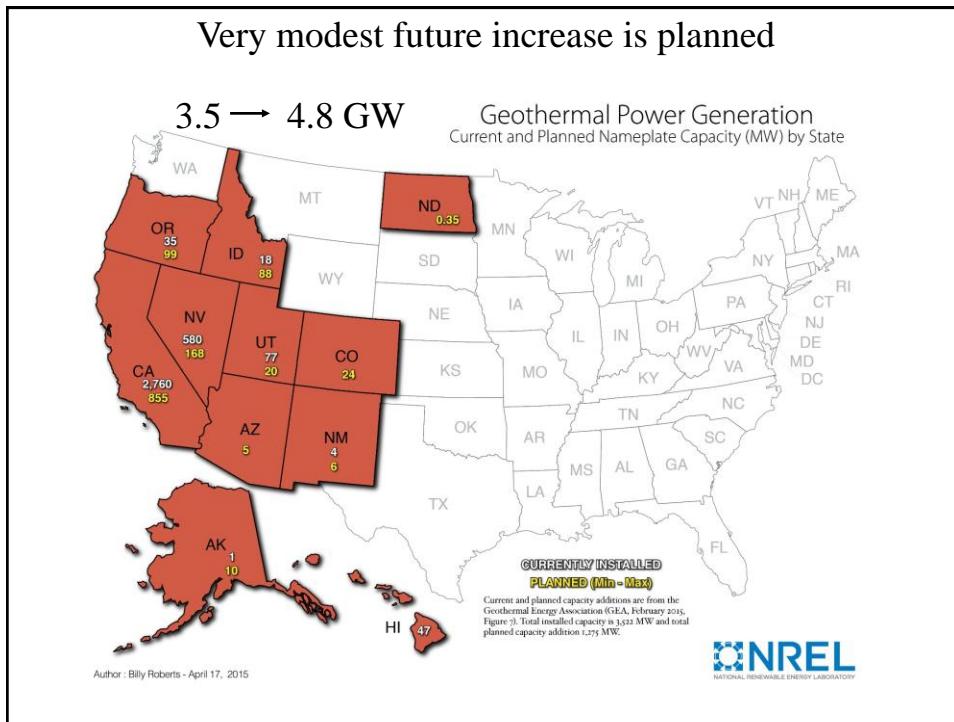
* In installed power generation capacity (MW) - Source: ThinkGeoEnergy Research, GEA, IGA (2015)

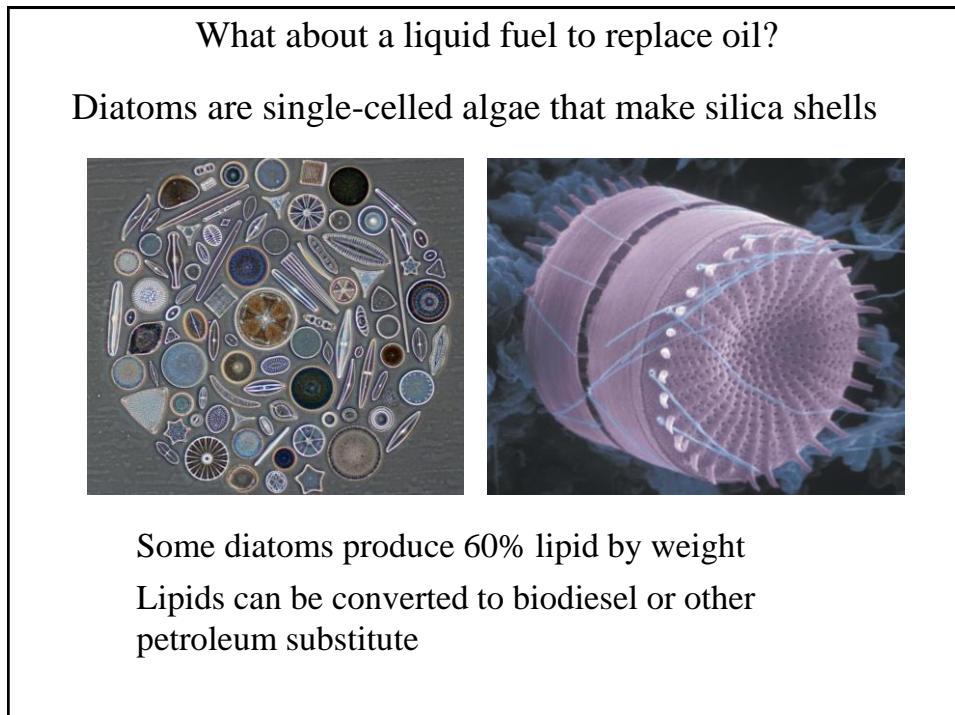
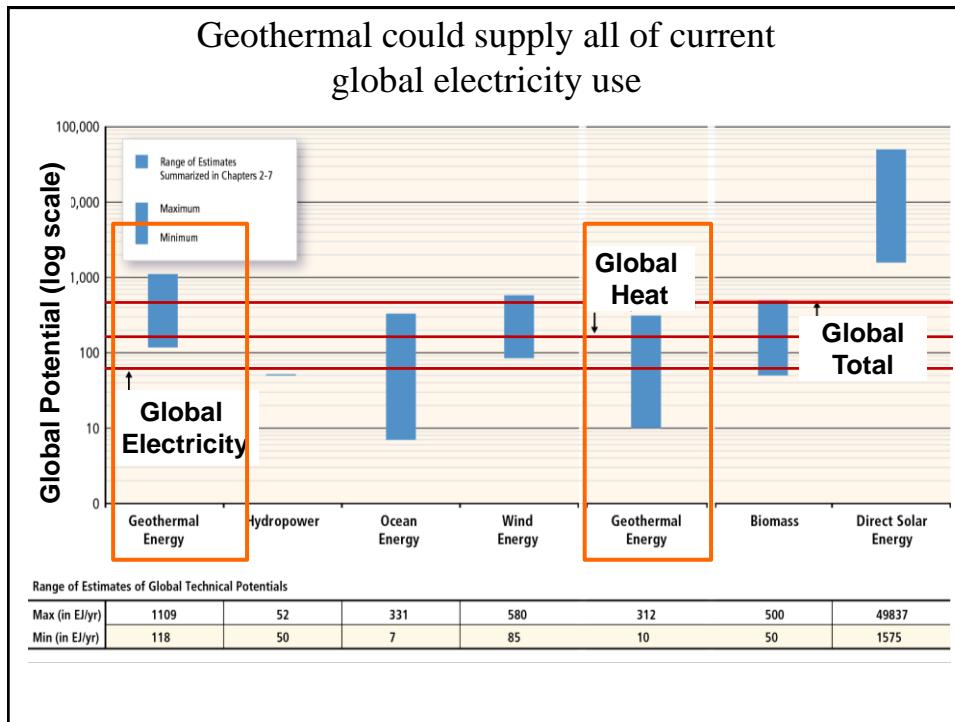
U.S. currently has 64 operational geothermal plants
- together, they produce 0.4% of U.S. electricity



Operational geothermal plants in the United States

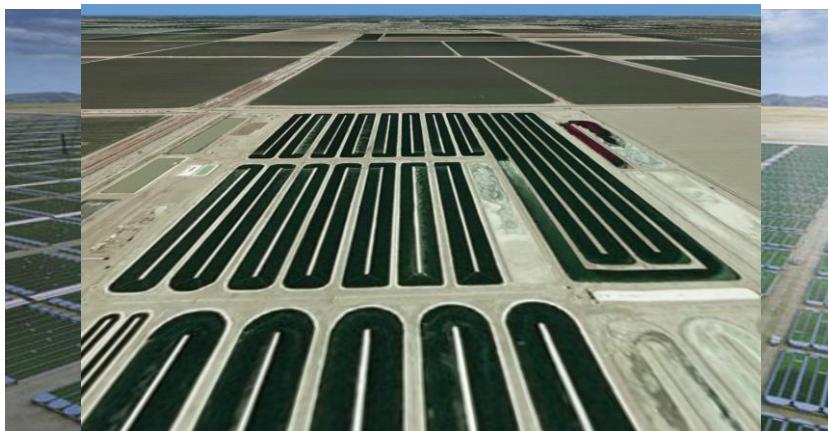








Estimated oil production:
5,000-20,000 gallons/acre/year



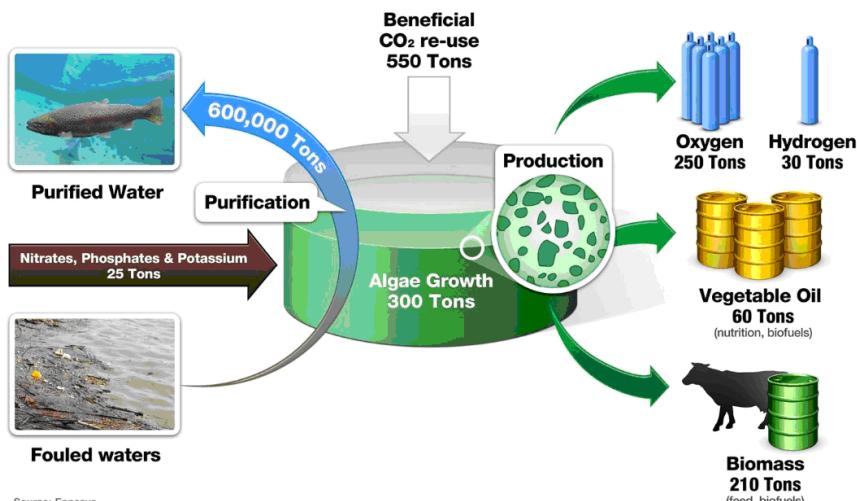
At least 10 times yield of next best biofuel crop (palm oil)
>200 times higher yield than corn ethanol

DOE: in open raceway ponds, enough biodiesel to replace all U.S. petroleum transportation fuel could be grown in ~10 million acres (~12.5% of the Sonora desert)



- cost estimated by U.S. National Renewable Energy Laboratory to be \$1.65 to \$2.75/gallon

Can be used to produce several useful products



If we don't do enough mitigation, can we geoengineer our way out of catastrophe?

Solar Radiation Management (SRM): reduce the amount of sunlight absorbed by the Earth by making more reflective surfaces

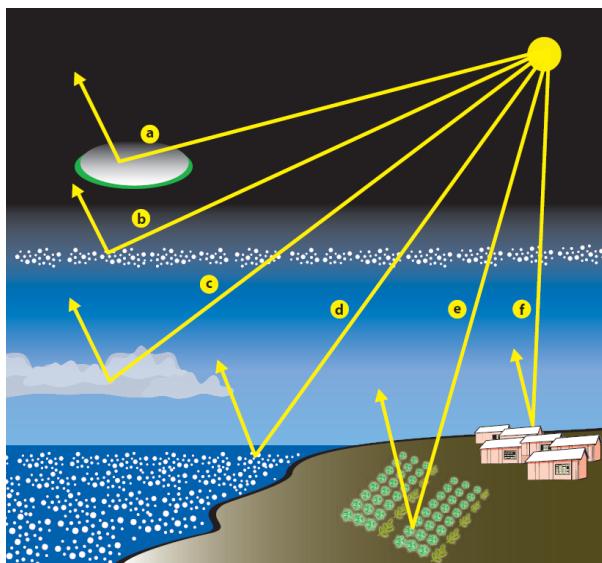
- would have to reflect 3.5% of incoming sunlight to offset warming under RCP 8.5

Carbon Dioxide Removal (CDR): remove carbon emitted into the atmosphere

- would have to remove 8,000 gigatons of CO₂ to offset warming under RCP 8.5

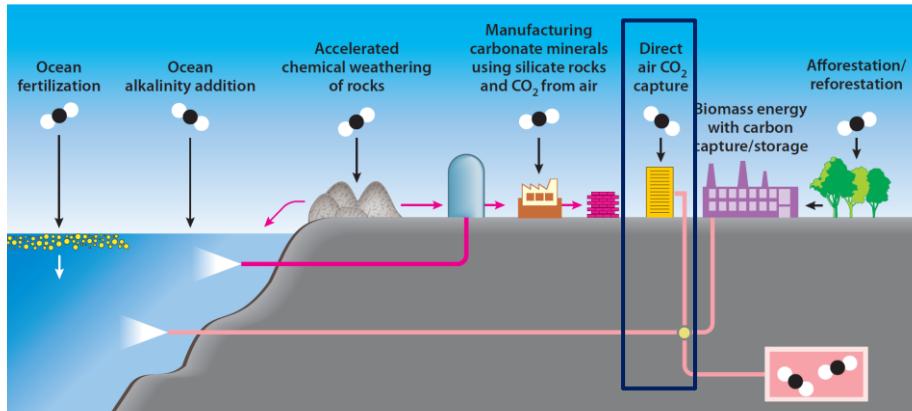
Solar Radiation Management (SRM)

- a. mirrors in space
 - b. stratospheric aerosols
 - c. cloud brightening
 - d. more reflective oceans
 - e. more reflective plants
 - f. rooftop whitening
- only (a) and (b) could fully offset 4° warming



Which of these prevents ocean acidification? None.

Carbon Dioxide Removal (CDR)



- only direct air CO₂ capture and storage could potentially offset 4° warming
- but no feasible technologies exist

Carbon Dioxide Removal (CDR)



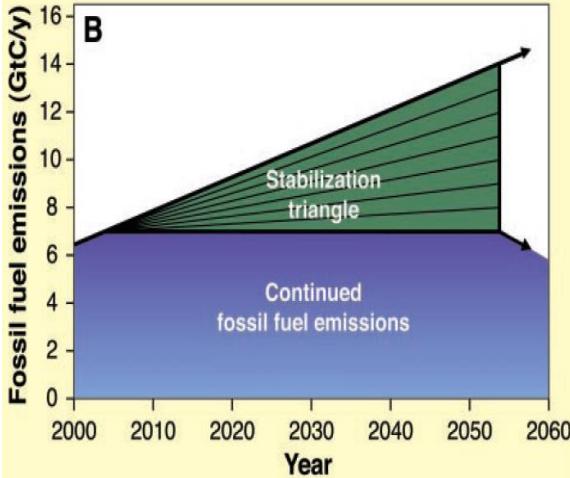
Worthy of further research?

What can I do to minimize climate change?



“Humanity already possesses the fundamental scientific, technical, and industrial know-how to solve the carbon and climate problem for the next half-century.”

(Pacala and Socolow, *Science* 2004)



7 emission reduction
“wedges” needed to
maintain emissions at
2004 levels through
2054

- would keep CO₂
level <500 ppm
by 2054

Household behaviors could provide one “wedge”

Household energy use accounts for ~38% of overall U.S. CO₂ emissions

- ~ 8% of global emissions
- more than any country's emissions (except China's)
- reducing by 20% would provide one “wedge”

What can I do over the next 10 years to minimize adverse impacts of climate change?

Most important behavioral changes:

1. Buy a more fuel efficient (+10 mpg) vehicle



- eliminates 5% of household emissions (and saves \$585/yr)

2. Weatherize your house: weather-strip, adequately insulate attic, and replace single-pane windows with triple-pane windows



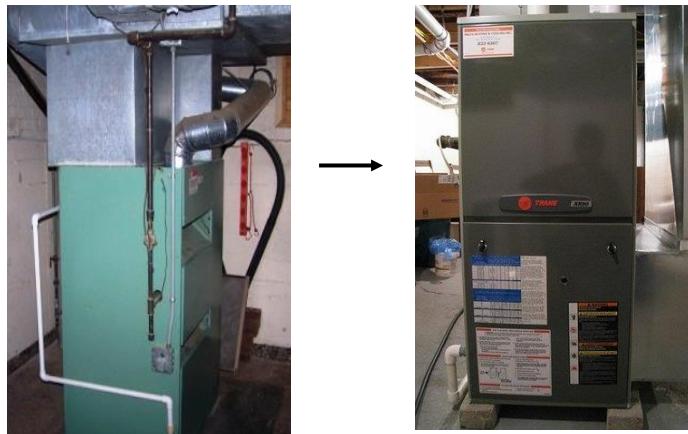
- eliminates 3.4% of household emissions

3. Next time, buy energy star appliances



- eliminates 1.9% of household emissions

4. HVAC equipment: when necessary, replace older furnace and central AC unit with Energy Star model



- eliminates 1.7% of household emissions

5. Drive more efficiently



- eliminates 1.7% of household emissions

6. Change to compact fluorescent light bulbs



- one per household = taking 6 million cars off the road

7. Turn the thermostat down (winter) or up (summer)



- most people don't notice a change of 1 degree per week
- can save 7 tons of CO₂ per household

8. Buy green electricity



- one GreenBlock = driving 3,300 fewer miles per year
(\$1.50/month)

Unfortunately, energy conservation is not a solution

- really just delays the inevitable



Money Isn't All You're Saving



50 mpg

To avoid worst scenarios, we need to rapidly and substantially reduce greenhouse gas emissions

Target: 80% reduction by 2040

Urgent need for alternate energy sources

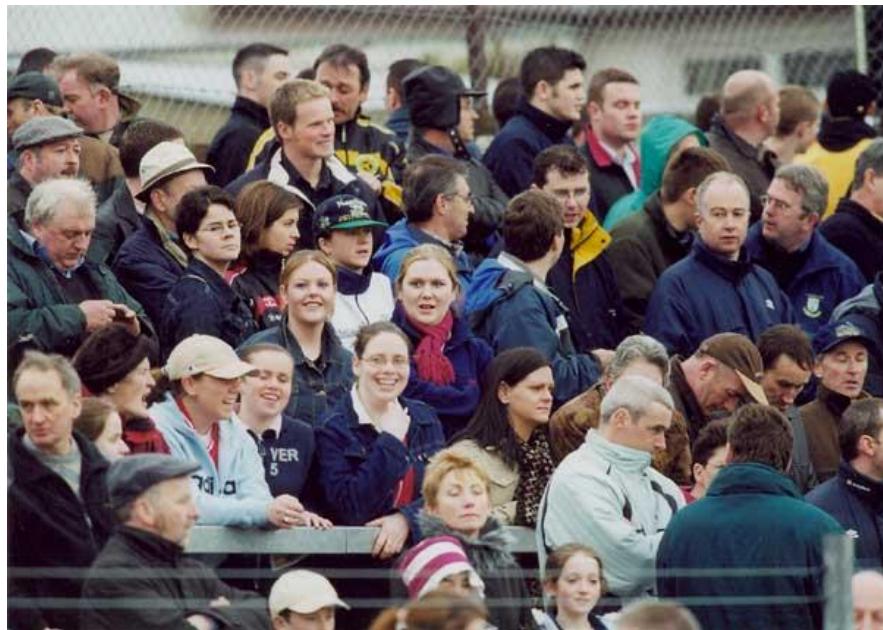


Solar

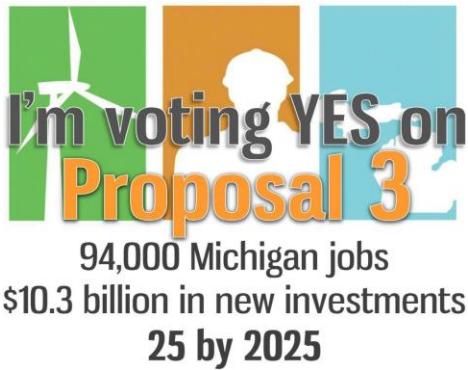


Wind

9. Educate others



10. Vote



No real progress will be made until climate change is an important voting issue!