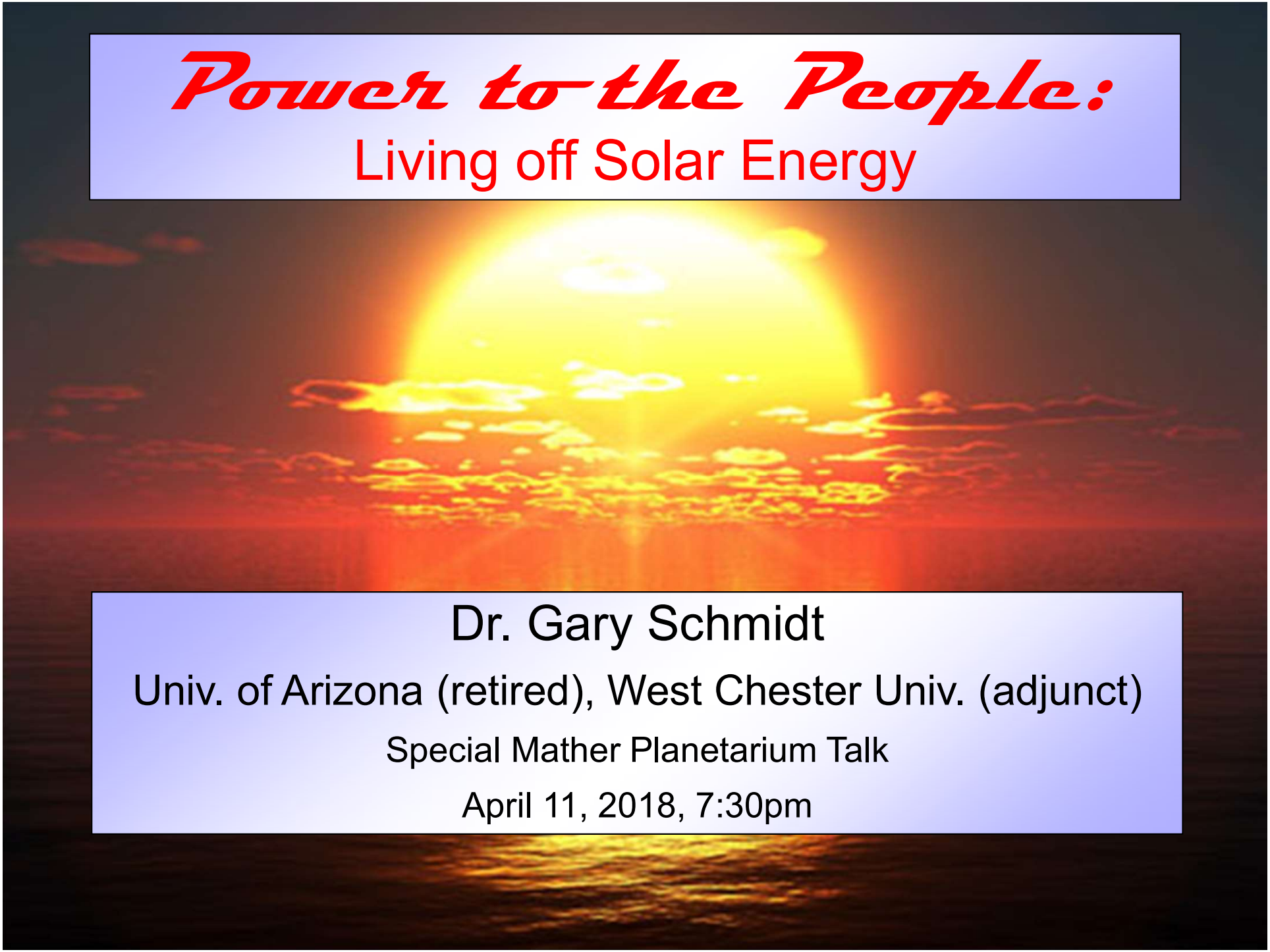
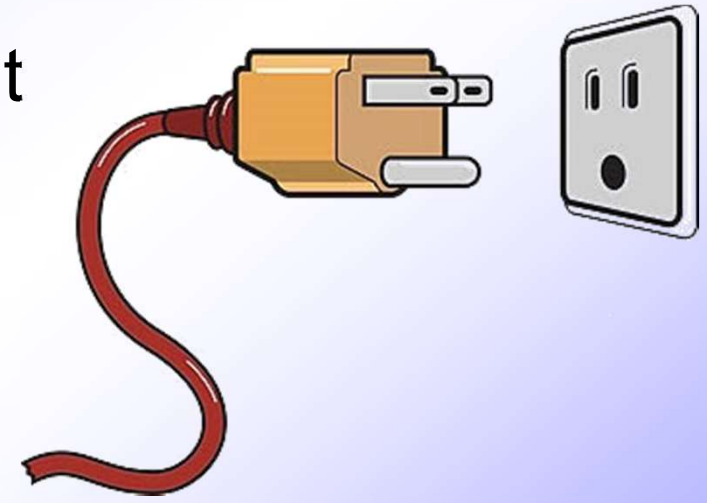

Power to the People:
Living off Solar Energy
Dr. Gary Schmidt
Univ. of Arizona (retired), West Chester Univ. (adjunct)
Special Mather Planetarium Talk
April 11, 2018, 7:30pm

What is the primary means of generating electricity in the West Chester area?

1. Coal-burning power plant
2. Oil-burning power plant
3. Gas-burning power plant
4. Nuclear power plant
5. Solar arrays
6. Wind turbines
7. Hydroelectric power
8. Geothermal energy



Solar energy is everywhere!

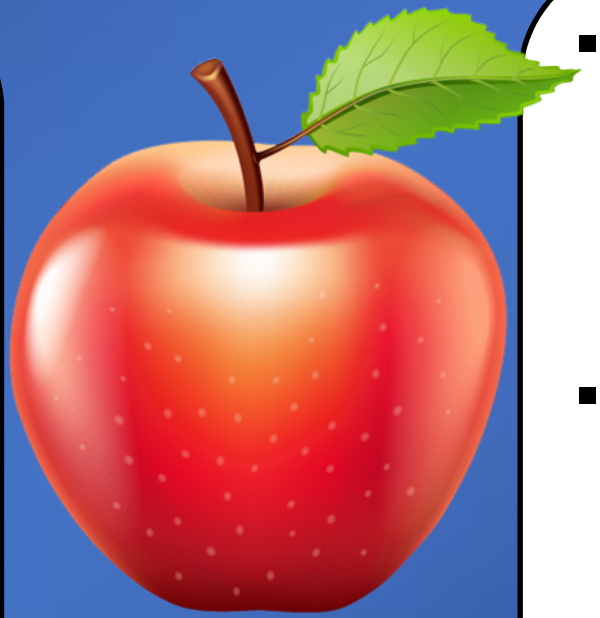
Every day, the Earth receives 10,000x more energy in the form of sunlight than is consumed by all 7.6 billion human inhabitants of the planet!

- Warms the surface of the Earth
- Enables photosynthesis, which grows crops and sustains animal life
- Leads to the production of coal, natural gas, oil, and other biofuels
- Evaporates water, permitting hydroelectric power
- Produces weather and (some) windpower

We measure the rate of energy use in "Watts"

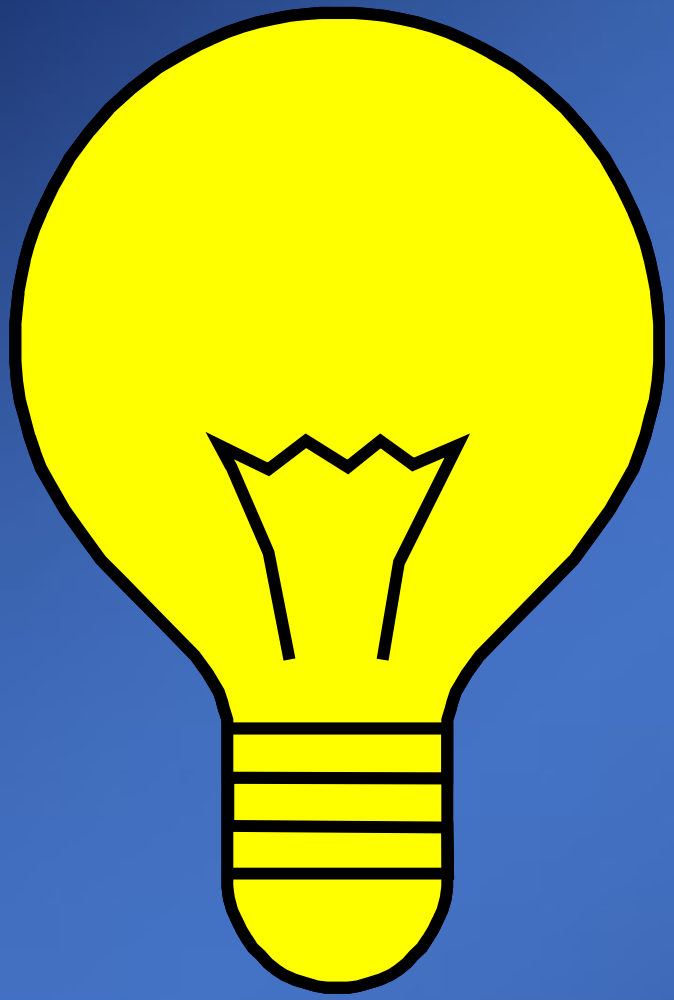
*What is a **Watt**?*

- The Watt is an unusual unit because it is a rate. Like having a new unit for "miles per hour"
- 1 *kilowatt* (kW) is simply 1000 watts



- Because the Watt is a rate, you must multiply by a length of time to obtain an amount of energy.
- So, 1 kilowatt-hour (kWh) of energy is the use of 1000 watts for 1 hour.
- PECO charges ~12¢ for every kWh used.

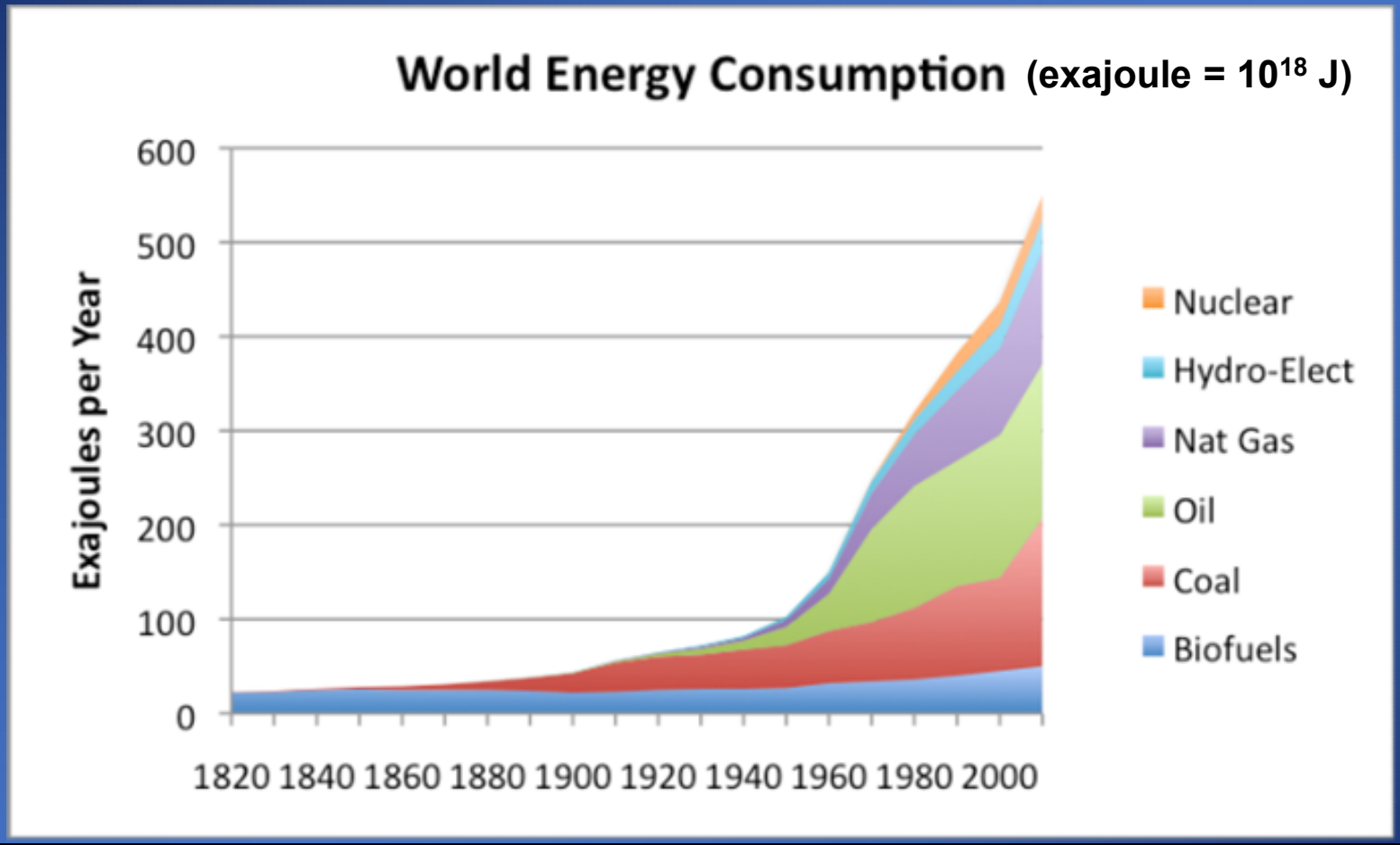
Wake Up! To Energy Use



A single 100 watt light bulb, left on 24 hrs/day for one year:

- Consumes 900 kWh of electrical energy
- Costs ~$100 in electricity
- Consumes fuel equal to ~25 gallons of oil.
- Causes ~800 lb of CO_2 to be emitted into the atmosphere

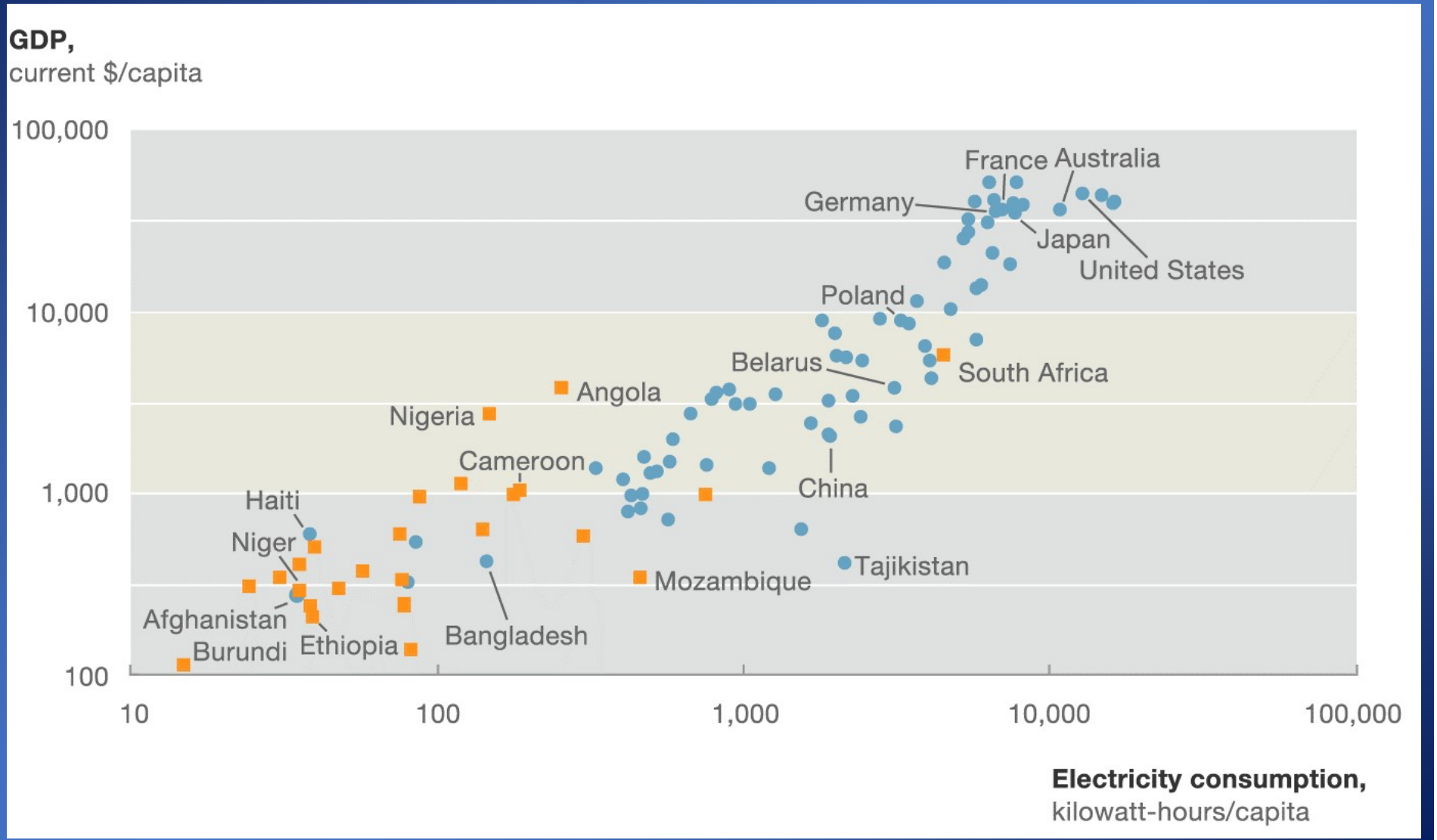
Worldwide energy use



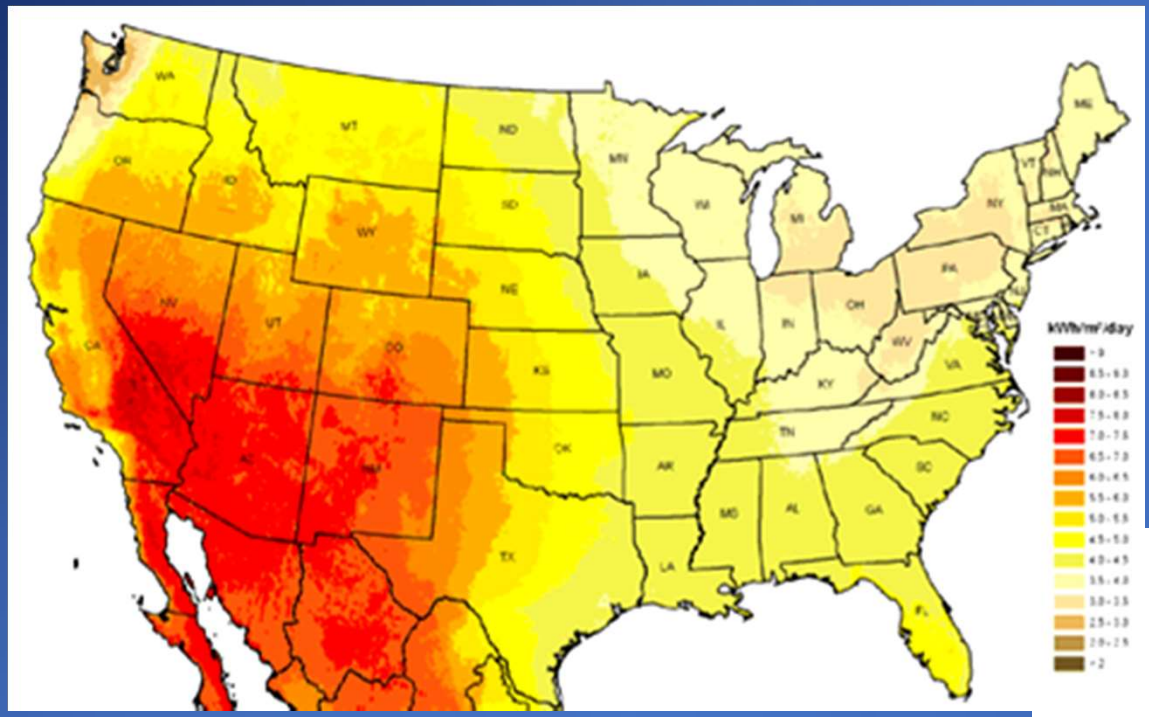
Our post-Industrial Revolution energy appetite, coupled with a skyrocketing population (double since 1960!), has resulted in an enormous surge in total energy use, more than 25x in less than 200 years!

GDP scales with consumption

"Energy is the lifeblood of our society"

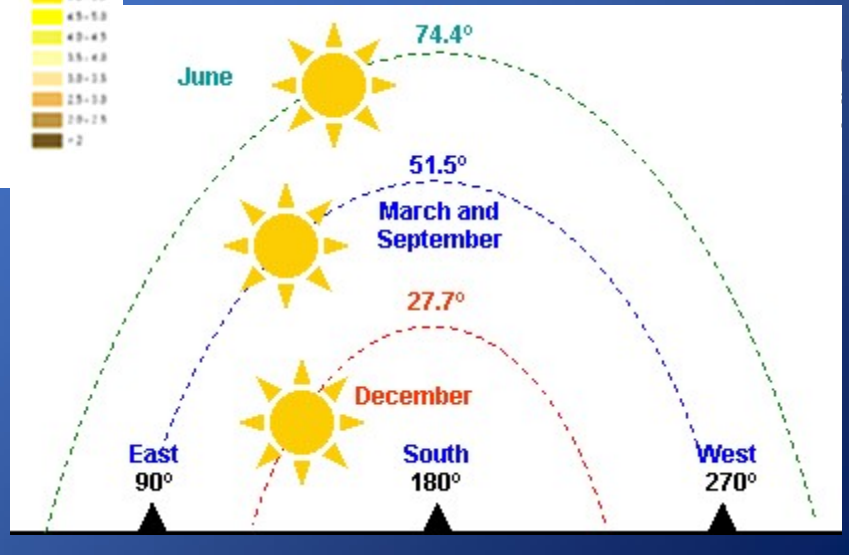


On a clear day with the Sun overhead, each square meter of the ground is receiving 1000 watts of solar energy (1 kW/m²)



Solar energy received at any location depends on:

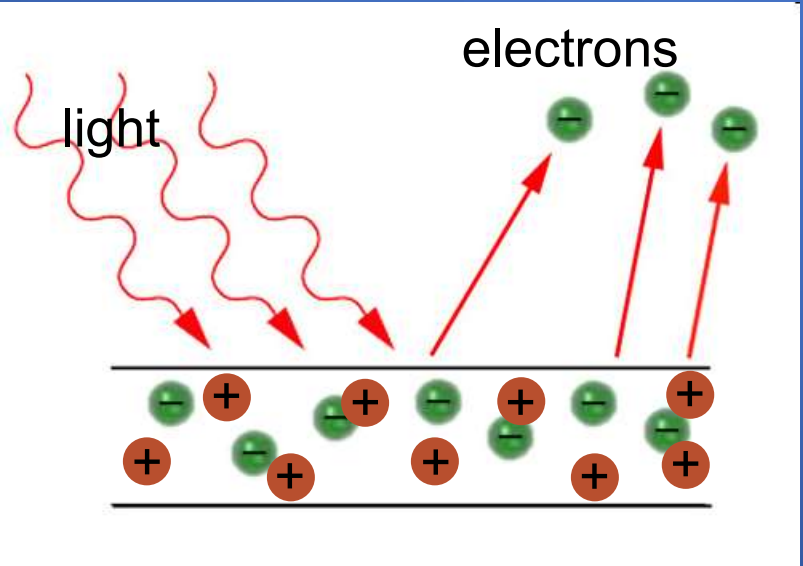
1) Angle of Sun above horizon. This varies with latitude and season.
2) Length of day. This also varies with latitude and season and is related to 1)
3) Weather (cloud cover)

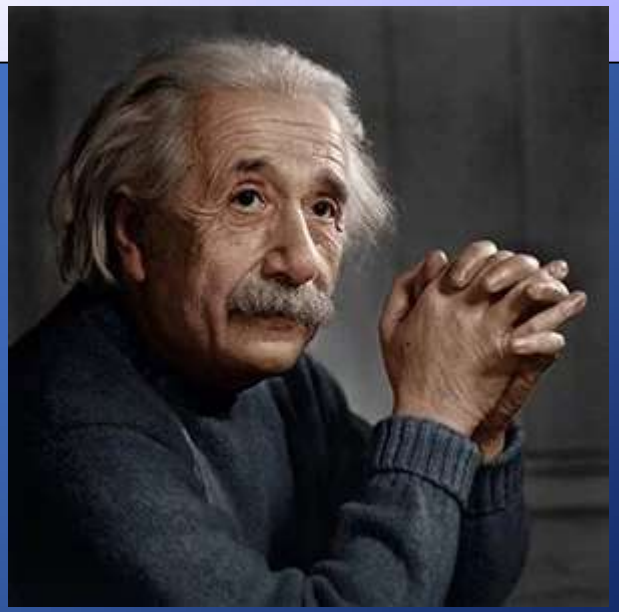


The desert southwest receives an AVERAGE of 7-8 hrs of direct sunlight/day throughout the year (day/night, rain/shine), whereas PA only averages ~2.5-3 hrs.

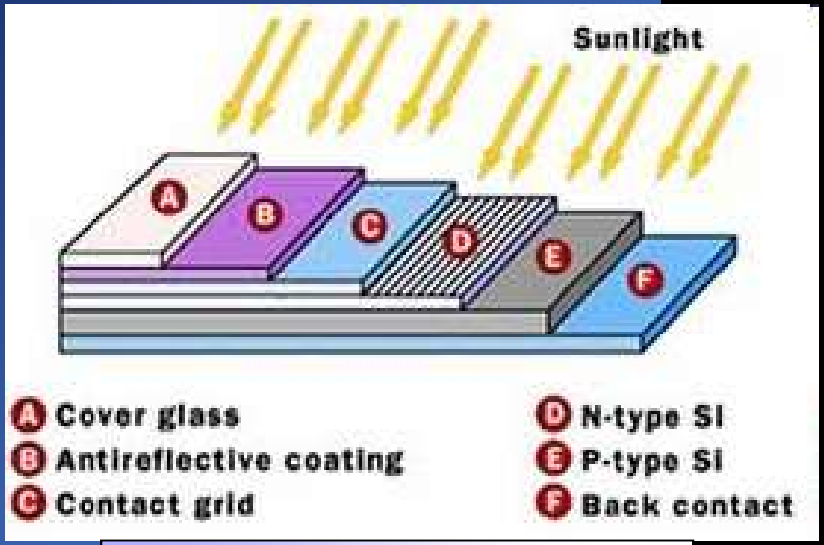
Photovoltaic effect

The fact that some materials produce an electrical voltage when light shines on them was discovered by Edmond Becquerel in 1839 (at age 19!) but an explanation awaited Einstein's development of the *photoelectric effect* in 1905.





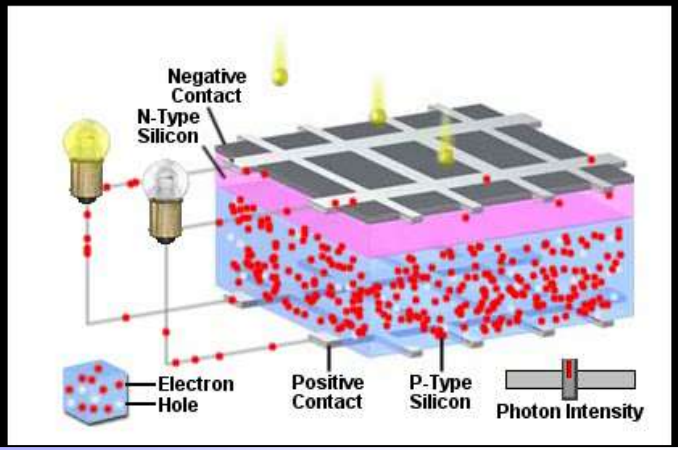
Photovoltaic effect in solar cells



Construction of a standard photovoltaic solar cell.

The “business” layers are silicon (Si).

A photovoltaic solar cell in action

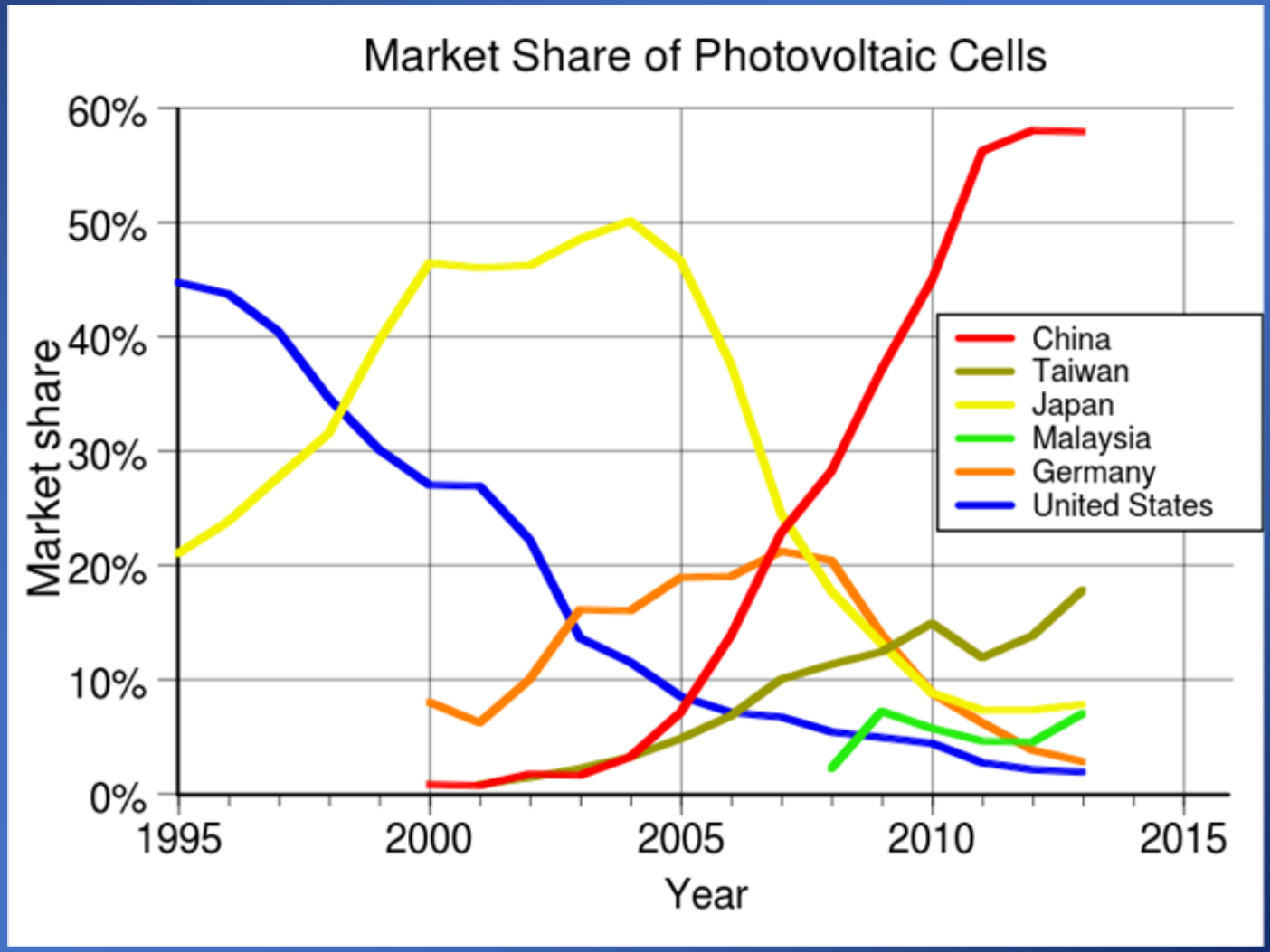


Standard solar panels cannot utilize the full 1 kW/m^2 because silicon does not detect all the colors of light emitted by the Sun.

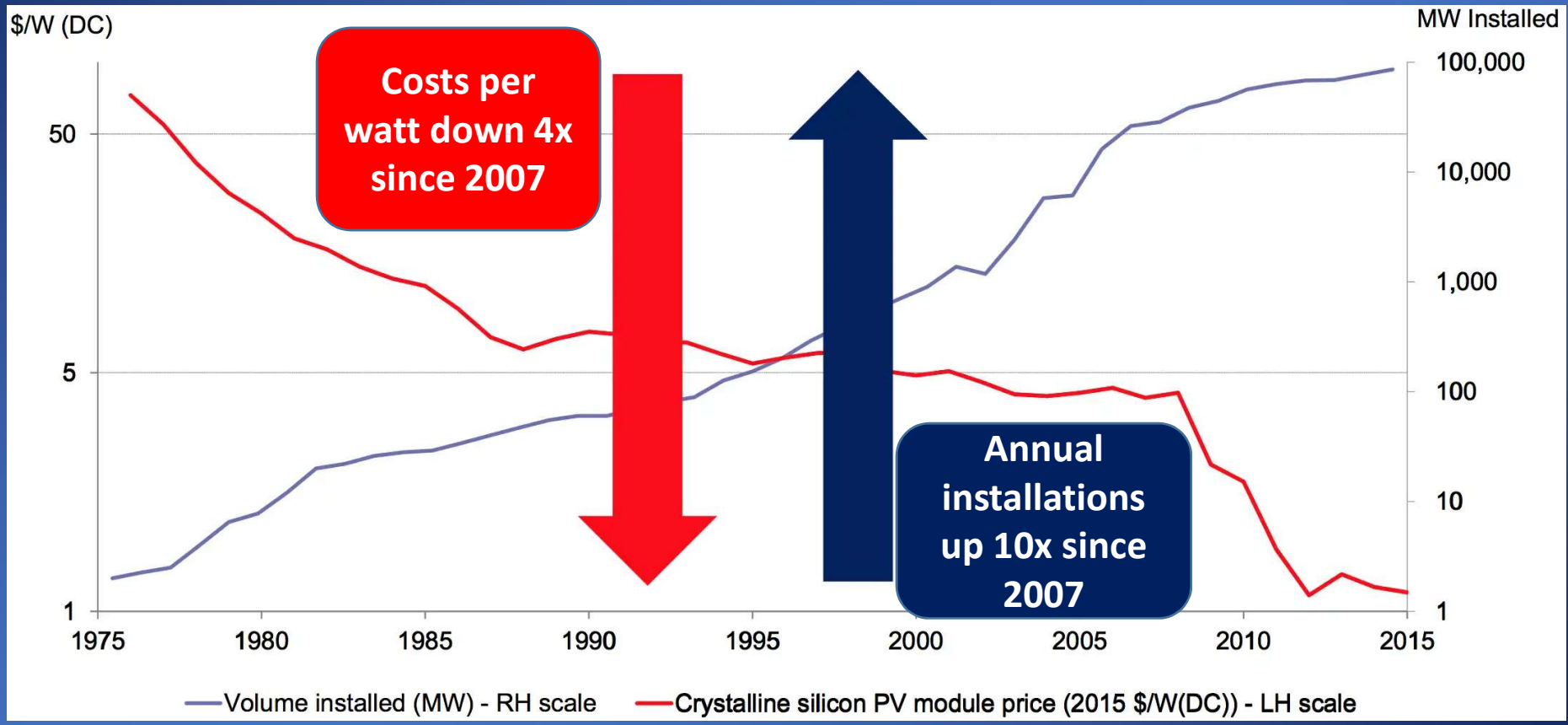
Solar power for everyday needs

Backpacker's solar power source charging an old IPOD with about 1 W of power

With recent massive investments in solar manufacturing, China now dominates the solar scene…



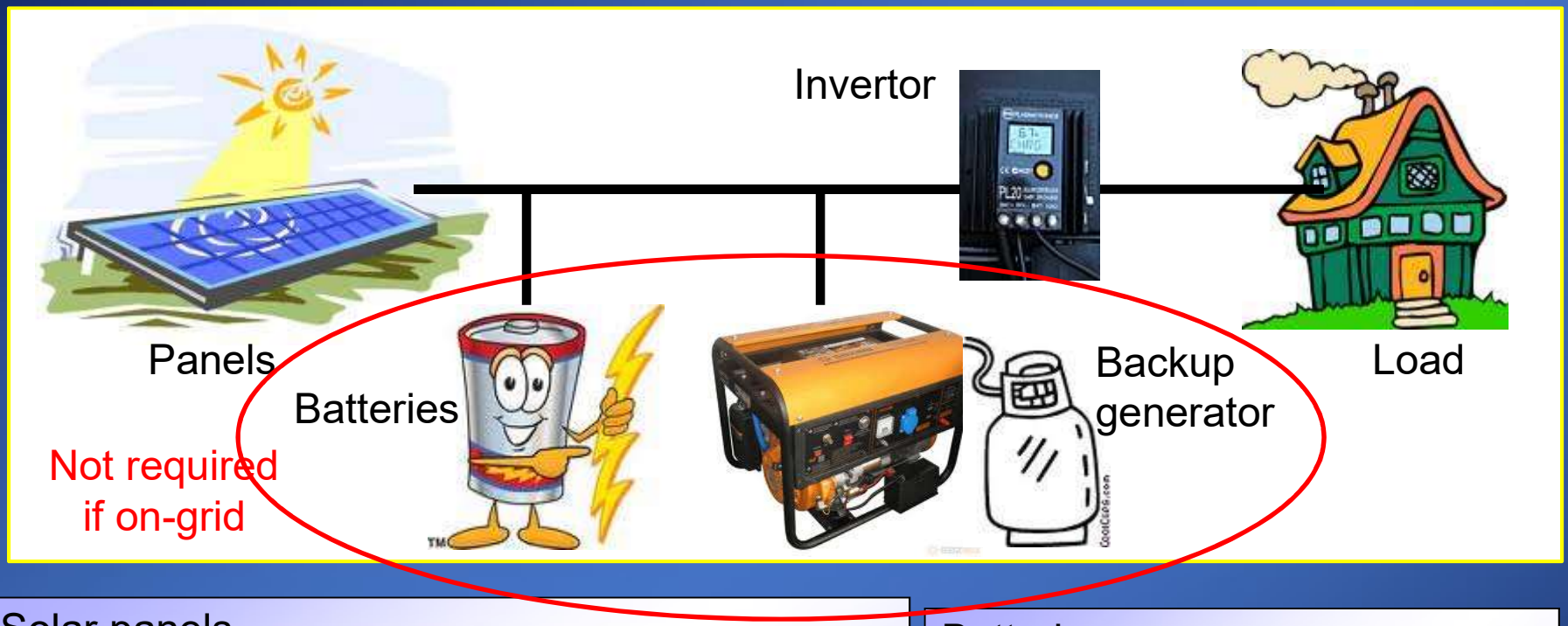
…causing plummeting prices and an explosion in installations…



…and enabling solar power on a **LARGE** scale!

8-million panel, 550 MW Desert Sunlight Solar Farm in the California Mohave desert powers 160,000 homes on most days.

Ingredients of an individual solar system



Solar panels
- Produce DC power at their rated output on a sunny day when pointed directly at the Sun

Electronics
- Invertors convert DC to 120 VAC to power standard appliances.
- Battery charger charges/monitors batteries for greatest life & efficiency

Batteries
- Provide power at night or when cloudy

Backup generator
- Provides “emergency” power and charges batteries during long cloudy spells

Questions for the homeowner when considering solar power

- Climate and location?
- Available infrastructure?
- House construction and lifestyle?
- To track or not to track?
- On-grid (grid-tie) or off-grid?
- Financial benefits?
- Budget?

Designing a photovoltaic system from the ground up for Flagstaff, AZ

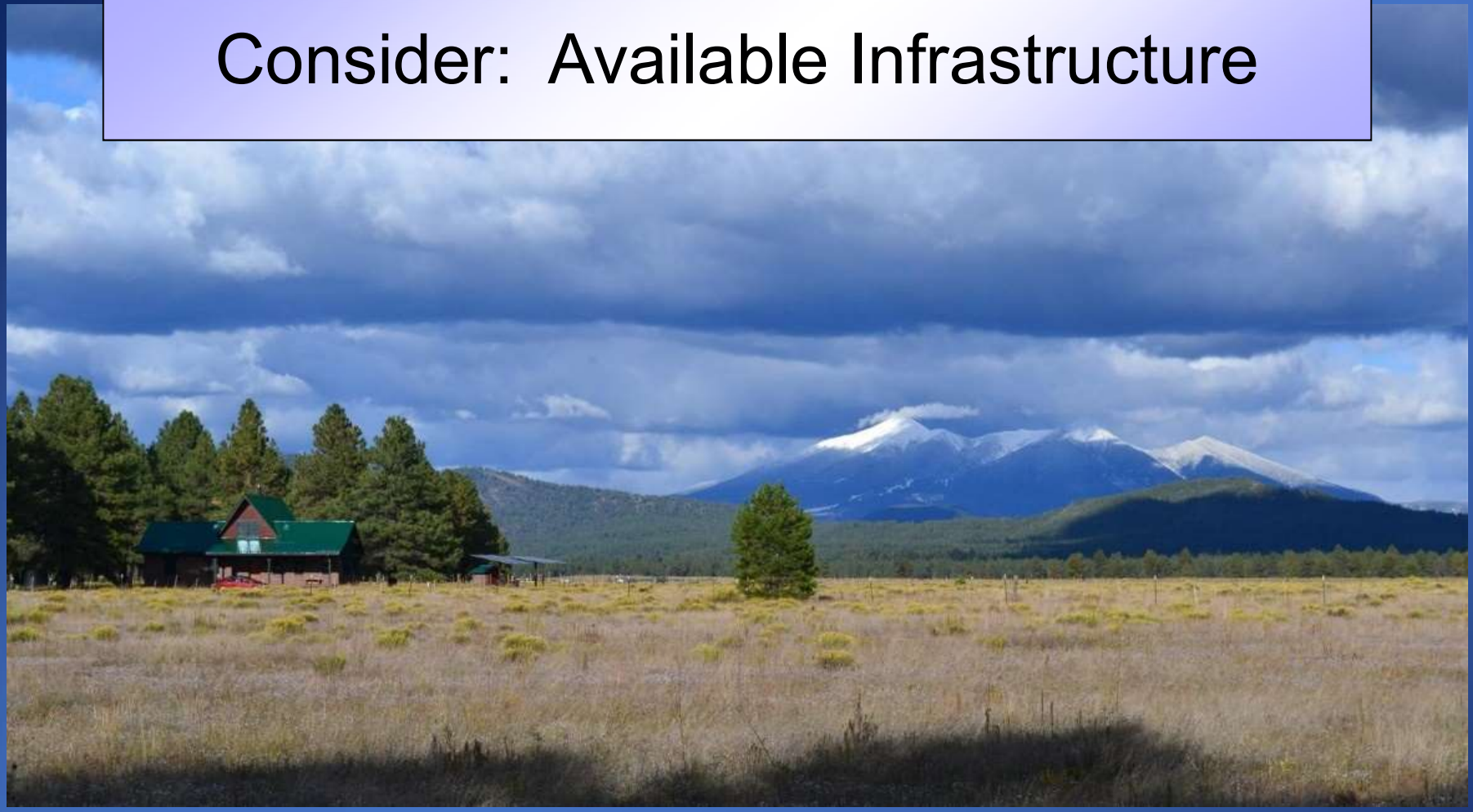
3 bd, 2 bath household with solar photovoltaic system in a remote location 25 miles outside Flagstaff, AZ.

Consider: Climate and Location

- Climate: Desert mountain (6800 ft)
- Annual precip.: 20” (W.C. gets 47”)
- Sunny days/yr: 162 (W.C. gets 93)
- Typical cloudy period 1-2 days (W.C. is ~3-5).

- Annual temperature range approx. -20F to +90F
- Daily temperature swings up to 45F
- Typical humidity 10-30%
- Winds to 80 mph

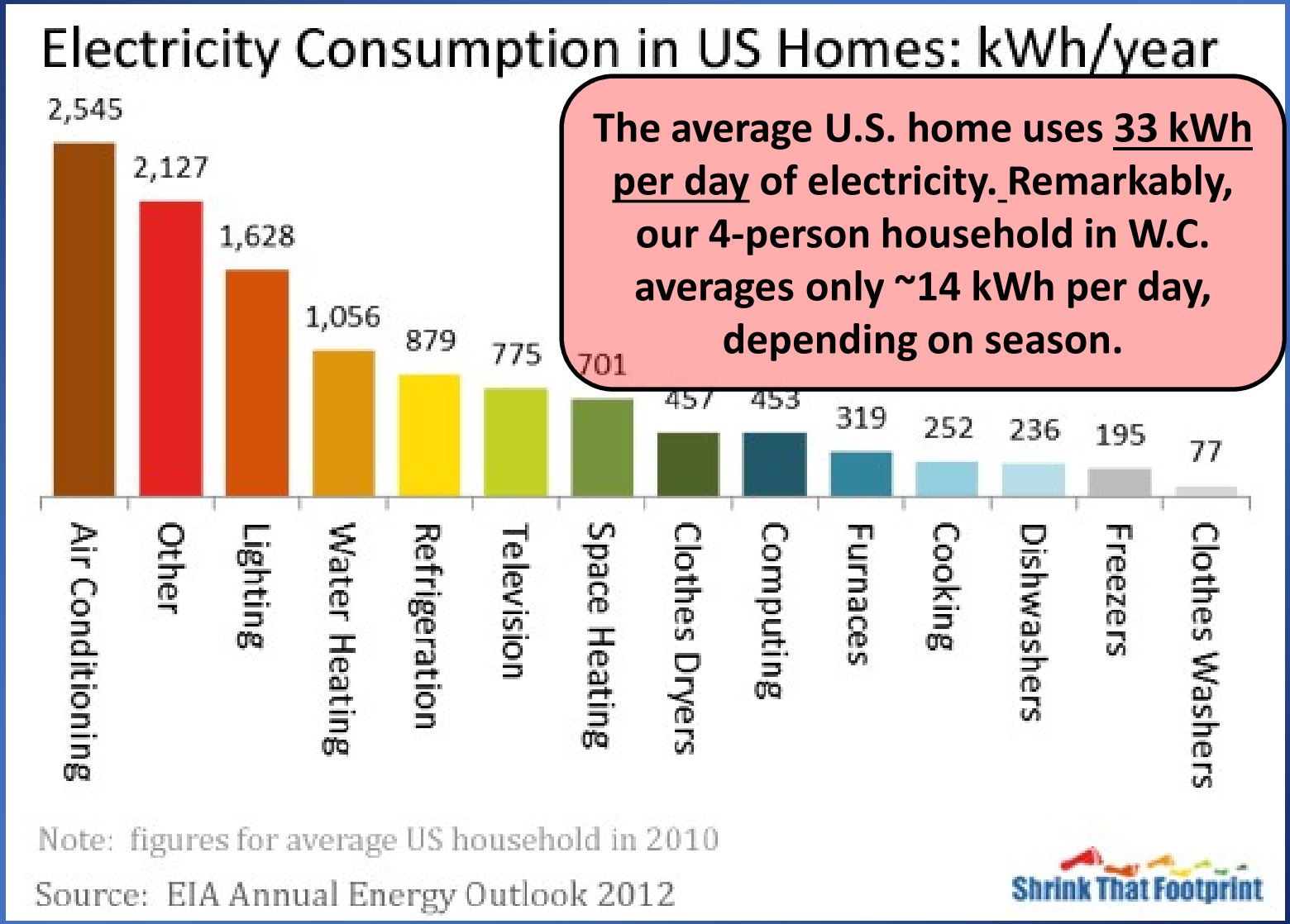
Consider: Available Infrastructure



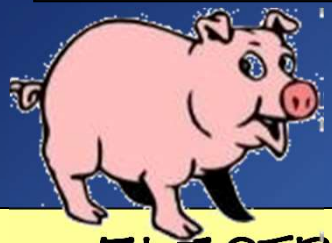
- Nearest utility: power line, ½ mile
- Community water: No
- Sewer: No
- Natural gas main: No

- Nearest neighbor: ½ mile
- Nearest town: 25 miles
- Cable TV/internet: No
- Cell phone: Yes

Consider: Construction and Lifestyle



Electricity Hogs and Sippers



ELECTRICITY HOGS

Heat pump: 3-10 kW when running

A/C: 2-5 kW when running

Electric oven: 2.5 kW

Water heater: 5 kW when heating

Hair-dryer: 1.5 kW

ELECTRICITY SIPPERS

100 W equiv. LED bulb: 10 W

45" TV: 50 W

Laptop computer: 10-90 W

Refrigerator: 50 W average

Ceiling fan: 20-75 W

The Lighting Revolution

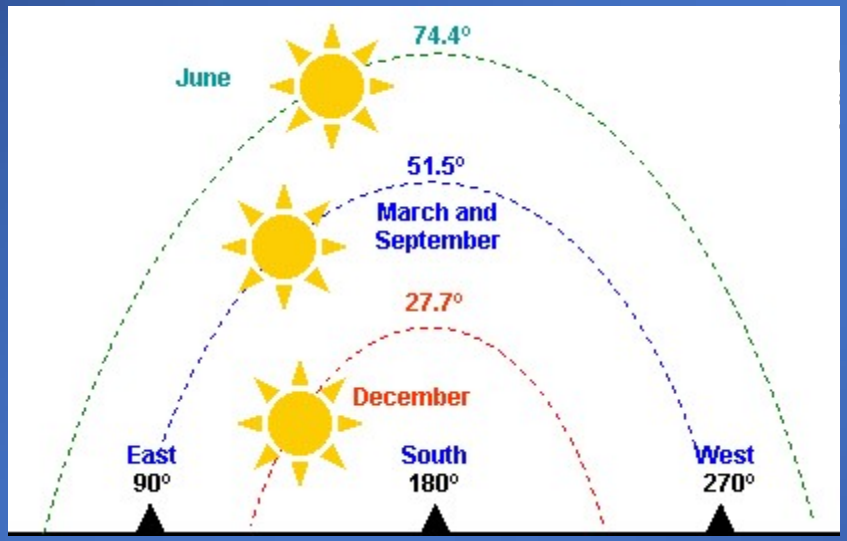
Incandescent

Compact Fluorescent

LED

Type	Visible Energy
Incandescent	1-2%
Compact fluorescent (CFL)	10-12%
Light Emitting Diode (LED)	>15%

Track the Sun for Highest Power



- Tracking, so that the panel always directly faces the sun, can provide up to 25% more power over a day, compared to fixed-position panels.
- But tracking requires motors and gears, which can be maintenance issues in rain/snow/ice/wind and must be very sturdy to support large panel arrays.
- Compromise: orient them directly south and adjust the altitude manually.

On-Grid?

Advantages of On-Grid

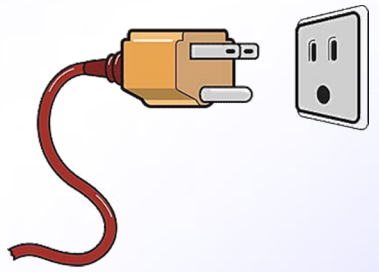
- **Provides *some* portion of power at all locations**
- Can sell back unused power to grid at about the retail rate (~8-12¢ per kWh)
- Requires no battery, battery charger, nor backup generator

Disadvantages of On-Grid

- **Fee required to connect to grid, which may be very large in remote locations**
- “Grid maintenance tax” may be assessed (e.g., Arizona)
- If no battery or backup generator, home is susceptible to power outages when grid goes down
- Homeowner is impacted by political and economic pressures on utility and utility commission

or Off-Grid?

Advantages of Off-grid



- No grid-connect fee
- No taxes for grid availability
- No overhead wires
- **Homeowner has control of his/her own energy picture**

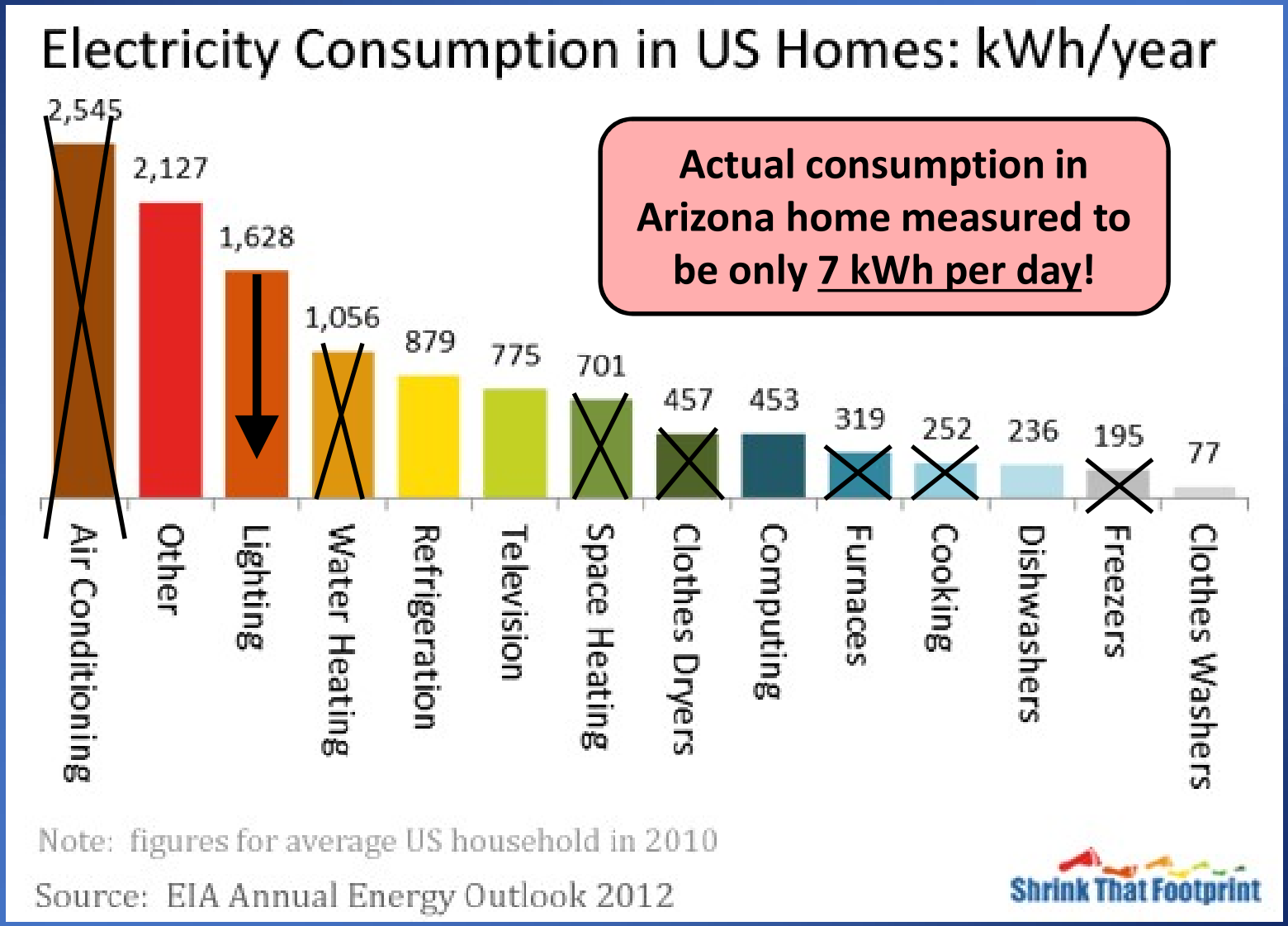
Disadvantages of Off-grid

- **Must have batteries and backup generator for cloudy spells = larger up-front cost**
- **Usually can't heat or A/C home using electricity**
- Additional kWh come at sizeable expense (e.g. propane)
- "Some assembly required" (performance, batteries, maintenance)

Decisions for the Flagstaff, AZ home…

- Off-grid! (grid connect fee was exorbitant)
- No A/C (nighttime cooling and ceiling fans)
- All lighting CFL or LED
- Clothes dryer and hot water to be propane
- Heat with propane using 95% efficient boiler and radiant heat, plus wood-burning stove
- Super-insulate house (15” thick walls)
- Cook using propane range/oven and microwave
- Adjust lifestyle slightly to accommodate limited electricity (dishwasher, clothes washer/dryer, vacuum, heavy power tools in daytime)

…and their impact



- Panels do not track Sun. They are tipped to different elevation angles 4x each year to accommodate changing elevation of Sun.
- Snow in winter melts off within 1 day of the skies clearing.
- Steel posts have outlasted winds 75 mph.
- Panel lifetime: >25 yrs.
- Since off-grid, propane generator needed for emergency power/charging.

Batteries: The Weak Link

Need: Better Batteries!

Two fork-lift batteries

- Capacity 20 kWh, can supply needs for 2+ consecutive cloudy days.
- Weight: 1700 lb apiece! Lifetime: 10-20 yr

Testimonial after 10+ yrs

- With careful planning and some change in habits, electrical use can be reduced to less than ½ of average U.S. home.
- Photovoltaic systems can fully serve individual electrical needs, at least in sunny locations.
- Systems can be costly to install but costs have dropped considerably.
- Systems are efficient, automated, and reliable.
  - Backup generator turns on ~3x per year because of cloudy weather
  - NO electrical outages of any type!
  - Electricity sufficient even for power tools, fresh water well, septic pumps
- Maintenance required:
  - Tip panels 4x/yr
  - Top off water in batteries every 2 months or so
  - Keep generator serviced for reliable backup.

Home on the Range…