Direct Solar Energy

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Difference between Direct and Indirect Solar Energy

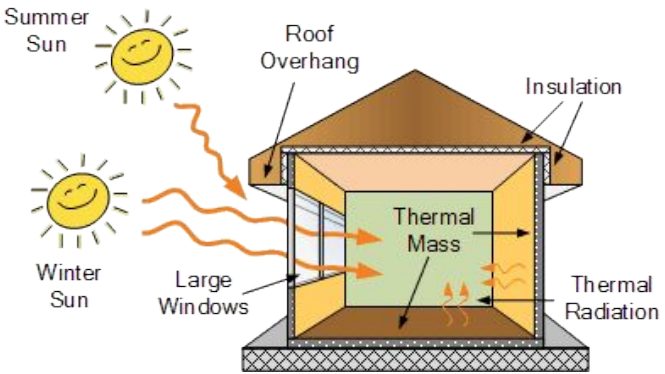
Direct Solar Energy	<- Both ->	Indirect Solar Energy
• Taking energy from the sun itself • Sunlight into electricity	• Sun is the ultimate source of energy	• In forms of biomass, wood, hydropower, etc. • Harnessing energy stored in materials that absorb sunlight during growth

Different Types of Solar Energy

- Passive Solar Energy
- Active Solar Energy
- **Photovoltaic Solar Power**
- **Solar Thermal Energy**
  - Concentrated Solar Power

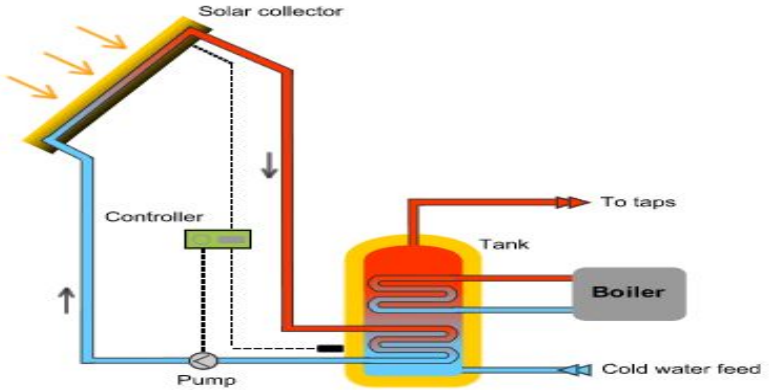
Passive Solar Energy

- Method in which solar energy is harnessed in its direct form without using any mechanical devices
- Can be used wherever there is sunlight
- Ex: Daylighting, Passive solar heating, Passive solar cooling
    - Like drying clothes in daylight

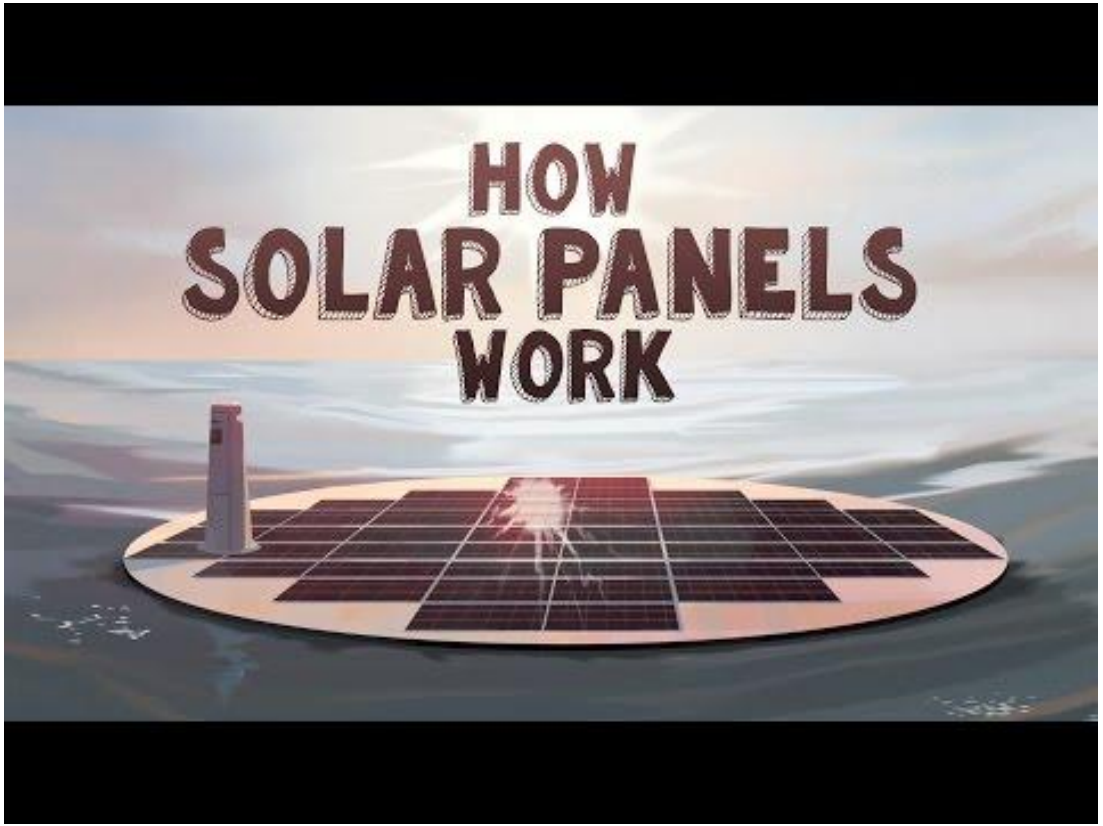


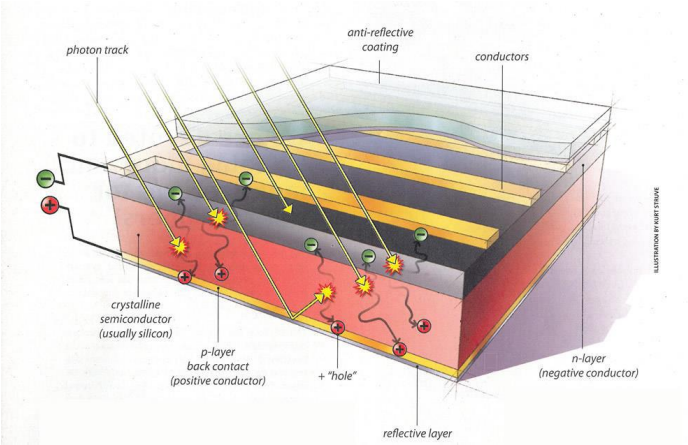
Active Solar Energy

- Employs mechanical or electrical equipment for functioning and increase system efficiency
- Ex: active solar heating, active solar pool heating, active solar space heating
    - Like water pumps used to circulate water through active solar energy water heating system



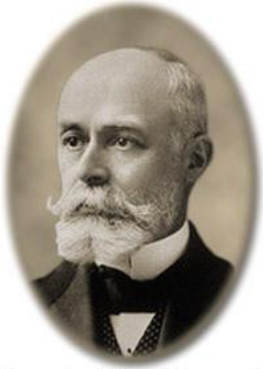
Photovoltaic Background





History of PV Cells

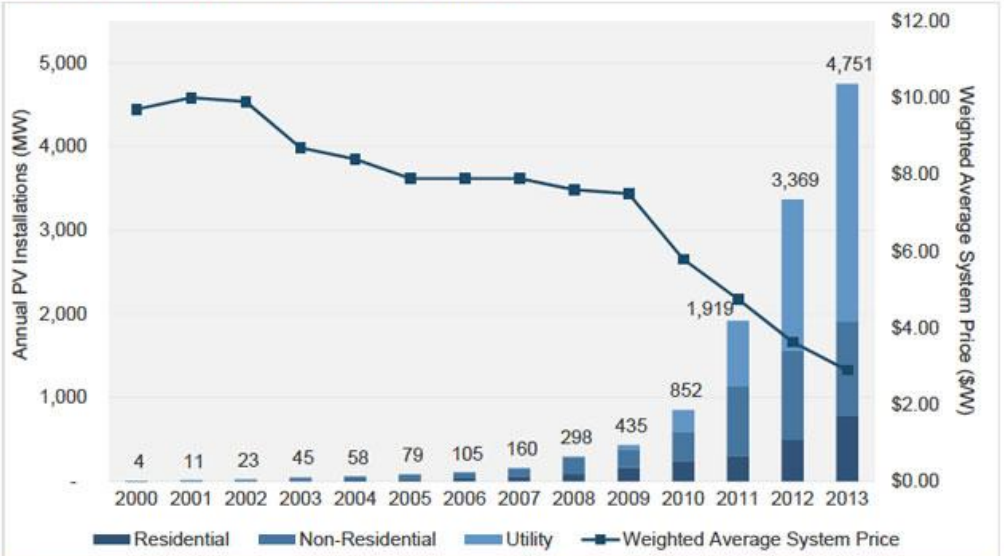
- 1839: Alexandre Edmund Becquerel observed PV effect
- 1954: Bell Labs in the US were the first to produce PV solar device that produced enough usable amounts of electricity
- 1958: solar cells were being used on small-scale scientific and commercial applications
- 1970: energy crisis sparked the major interest in using solar cells but extremely high prices prevented it from being used on larger scales



Alexandre Edmond Becquerel
(1820-1891)

Cost of PV Cells from 2000 to 2013

Figure 2.1 U.S. PV Installations and Average System Price, 2000-2013



Installations (MW)	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Residential	1	5	11	15	24	27	38	58	82	164	246	304	494	792
Non-Residential	2	3	9	27	32	51	67	93	200	213	339	831	1,072	1,112
Utility	0	3	2	3	2	1	0	9	16	58	267	784	1,803	2,847
Total Installations	4	11	23	45	58	79	105	160	298	435	852	1,919	3,369	4,751

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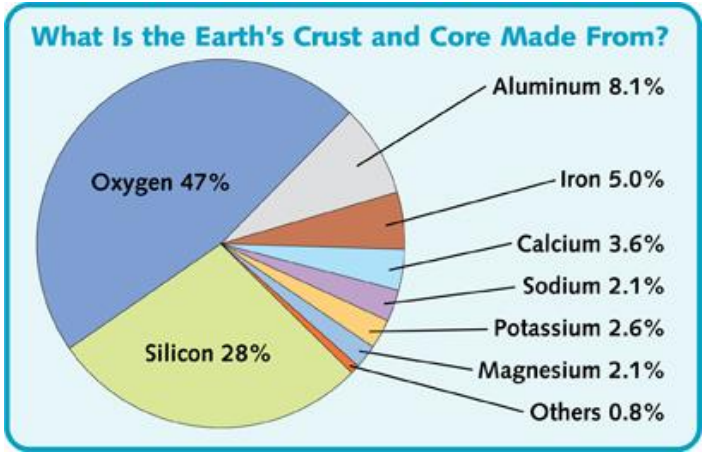
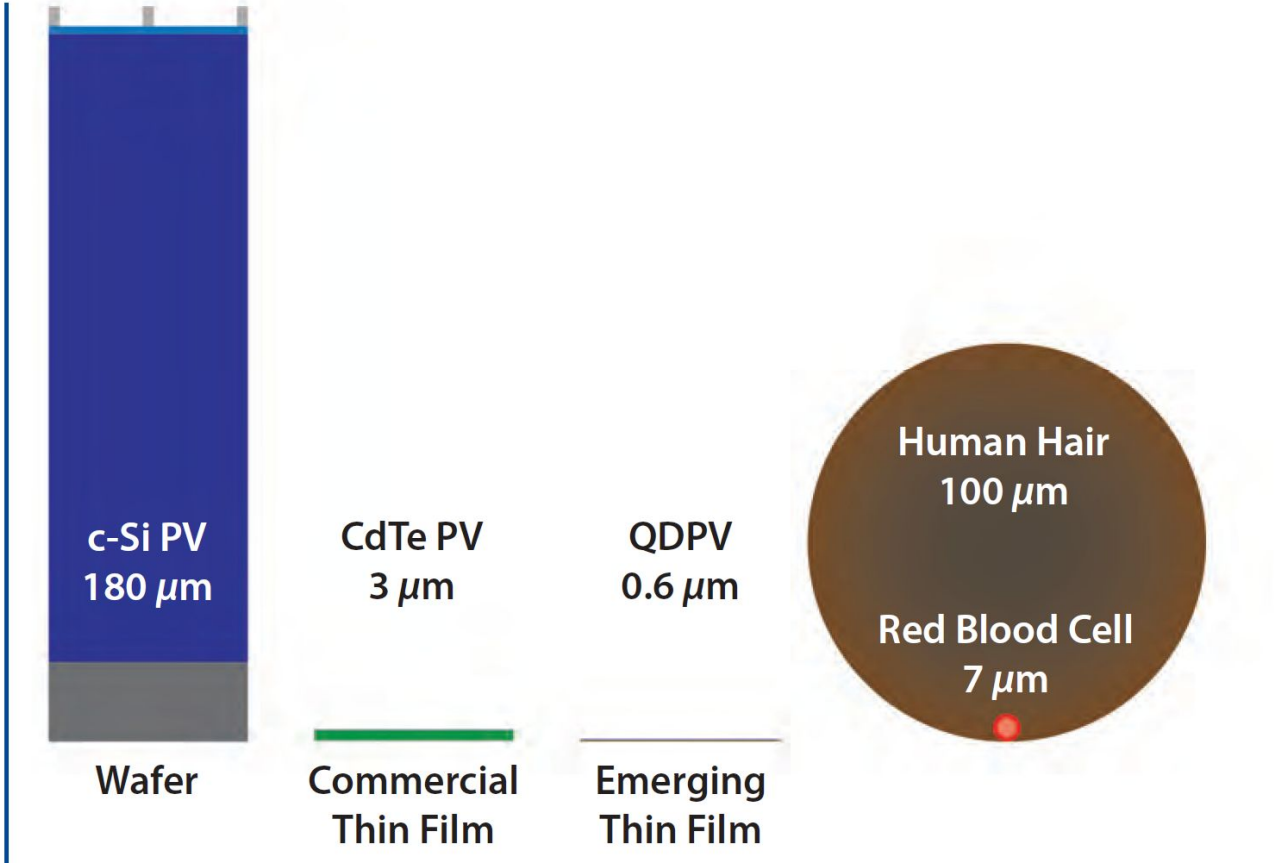


PV Cell Efficiencies

- Mono/polycrystalline Silicon Cell:
  - Produce most power/unit area. Longer lifetime and perform better in low light conditions.
  - 15-21% effective. Monocrystalline better than polycrystalline but also more expensive.
  - Expensive and not good in the cold.
- Thin Film:
  - Extremely thin and use little raw materials (10-50x less). Lightweight and flexible.
  - inexpensive
  - 12-15% efficient.
  - Good for small devices
  - Lots of new technology. CIGS -> Copper zinc tin sulfide 12.6% efficient. Hybrid cells. Organic cells.

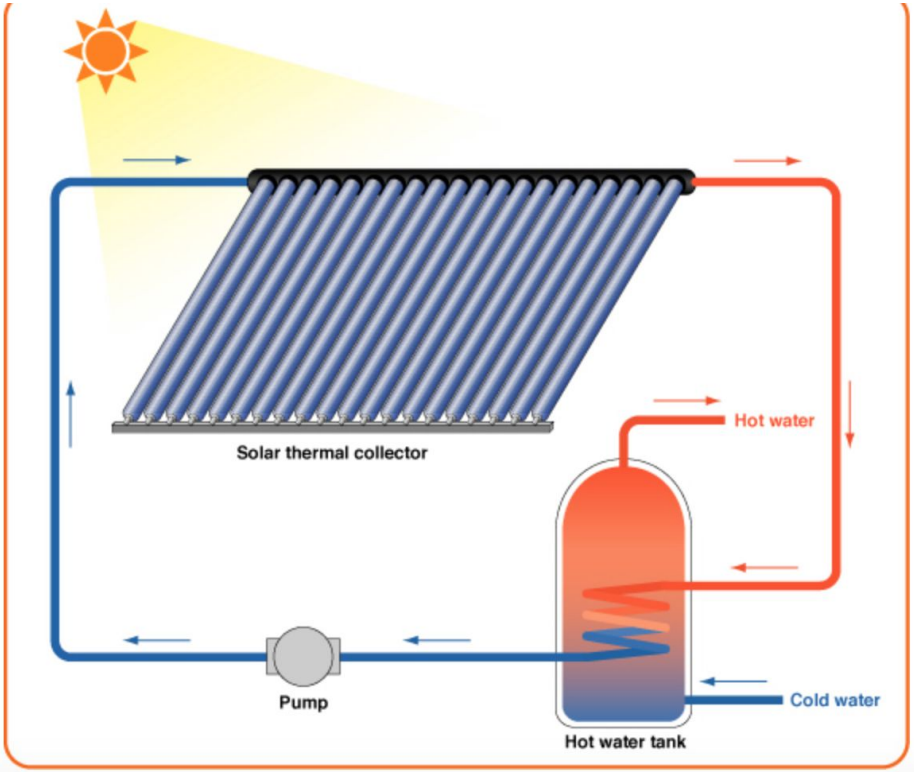
Figure 2.4 Solar Cell Thickness by Technology Classification



Solar Thermal

- differ from PV systems which generate electricity rather than heat
- uses the sun’s energy to generate low-cost, environmentally friendly energy.
- used to heat water or other fluids, and can also power solar cooling systems.
- Heat can be stored during the day and then converted into electricity at night.

Solar Water Heating System



1. Solar thermal panels on a roof absorb solar energy.
2. Solar fluid circulated through the collectors by a low-energy pump delivers heat to a water storage tank.
3. When users need hot water, the solar heated water in the storage tank feeds the primary water heating system

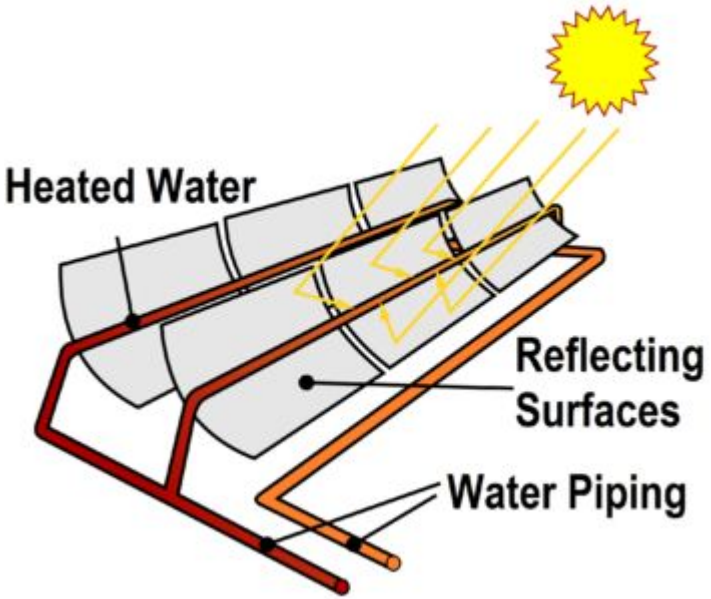
Advantages of using a Solar Water Heating System

- **Reduced Utility Bills:** Businesses that require large quantities of hot water or other fluids have to must pay for the fuel required to heat those fluids.
  - Solar thermal systems use solar energy to heat fluids, which reduce utility bills by up to 70%.

- **Reduced Carbon Footprint:** Solar thermal systems reduce the amount of site-generated, carbon-based greenhouse gases a business emits into the atmosphere.

Two Methods for Solar Thermal Collection

Line Focus Collection



VS.

Point Focus Collection

Line Focus Collection

- Less expensive, less difficult BUT less efficient than Point Focus
- Cylindrical parabolic shaped mirror with an array of collectors that reflects sun rays on a conducting pipe that is on a focus axis
- 2-3m length,1-1.5m width.
- Fluid can only reach temperatures up to 250℃

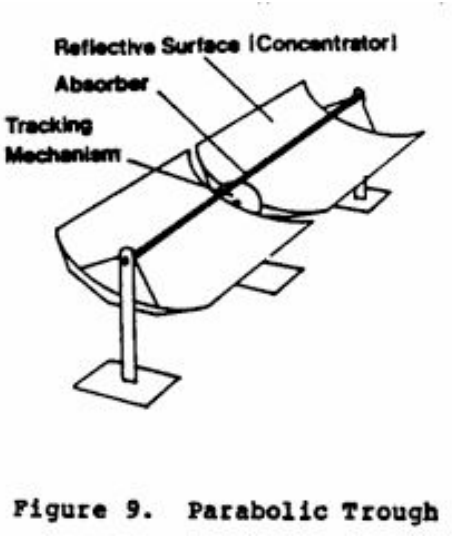


Figure 9. Parabolic Trough

Example: The Ausra Line Focus in Australia:

Point Focus Collection

- requires a series of mirrors surrounding a power tower.
- Power Tower: General idea is to collect the light from many reflectors spread over a large area at one central point to achieve high temperature.
- Sun rays are focused on a point on absorber cavity and the liquid in the cavity gets heated

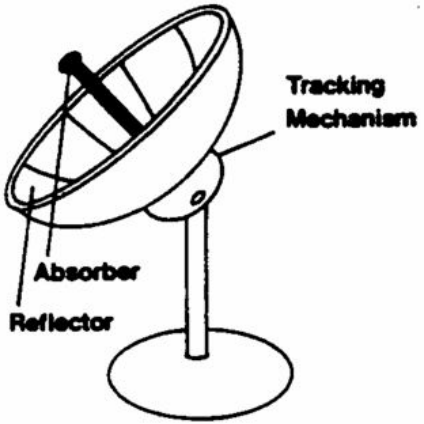


Figure 7. Parabolic Dish

Point Focus Collection

- The mirrors focus the sun's rays onto a point on the tower, which then transfers the heat into more usable energy
- Fluid inside can reach temperatures 500℃ and higher
- Higher efficiency= drives down land usage, and the effective cost per kWhr of the plant.
    - kWhr= a unit of energy equal to the work done by a power of 1000 watts in one hour

Example of Point Focus: Solar Two

-ability to produce 10 megawatts→ enough to power ~7500 homes

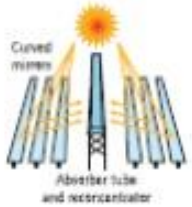
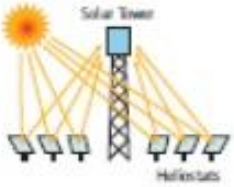
- used molten salt (60% sodium nitrate and 40% potassium nitrate) as an energy storage medium which helped in energy storage during interruptions in sunlight caused by clouds

-dismantled and decontaminated in 1999 and demolished in 2009

Solar Tres

Replacing Solar Two:

- 3x larger than Solar Two
- Built in Spain with an official launch in October 2013
- 2,493 heliostats- device that include a plane mirror which turns to keep reflecting sunlight toward a target
- Plane Mirrors have a reflective surface of 96 m^2
- A larger molten salt storage tank used in order to run 24/7 during the summer

Receiver type \ Focus type	Line focus	Point focus
	Collectors track the sun along a single axis and focus irradiance on a linear receiver. This makes tracking the sun simpler.	Collectors track the sun along two axes and focus irradiance at a single point receiver. This allows for higher temperatures.
Fixed Fixed receivers are stationary devices that remain independent of the plant' s focusing device.This eases the transport of collected heat to the power block.	**LinearFresnel Reflectors** 	**Towers (CRS)** 
Mobile Mobile receivers move together with the focusing device. In both line focus and point focus designs, mobile receivers collect more energy.	**Parabolic Troughs** 	**P arabolic Dishes** 

Challenges with both:

- Amount of space required:
  - Solar thermal power plants typically require 1/4 to 1 square mile or more of land

- Efficiency

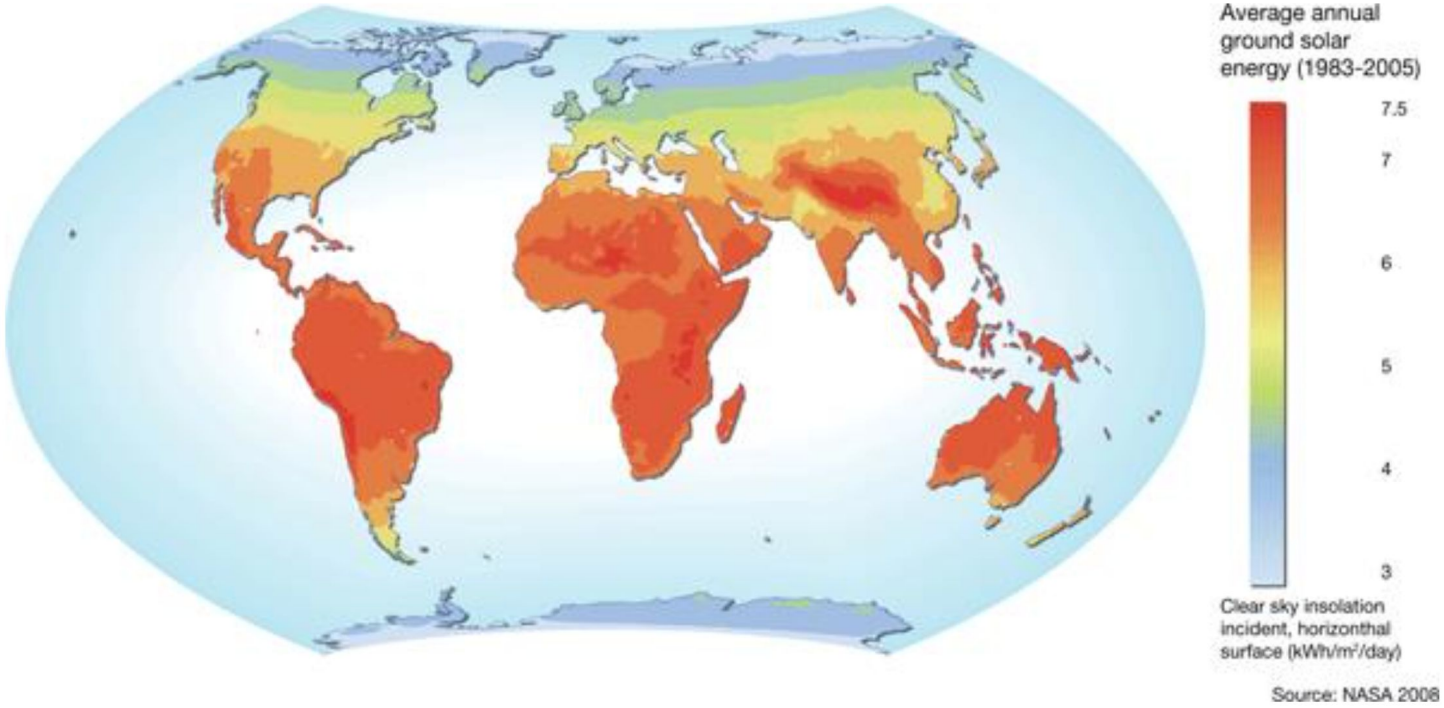
LINE FOCUS: maximum concentration is 212:1(the amount of light energy concentration achieved by a given collector.). Line focus solar thermal plants are reporting about half of maximum concentration (80-100x concentration).

- At these concentrations a steam turbine can be run at 25% efficiency.

POINT FOCUS: concentration ratio at 44,000:1 but current technology is reaching only about 1,000x concentration which allows a steam turbine to run at 35-50% efficiency.

- Lack of concentration comes from: errors in the parabolic shape, thermal expansion and shifting of parts over time

Best Regions for Solar Energy

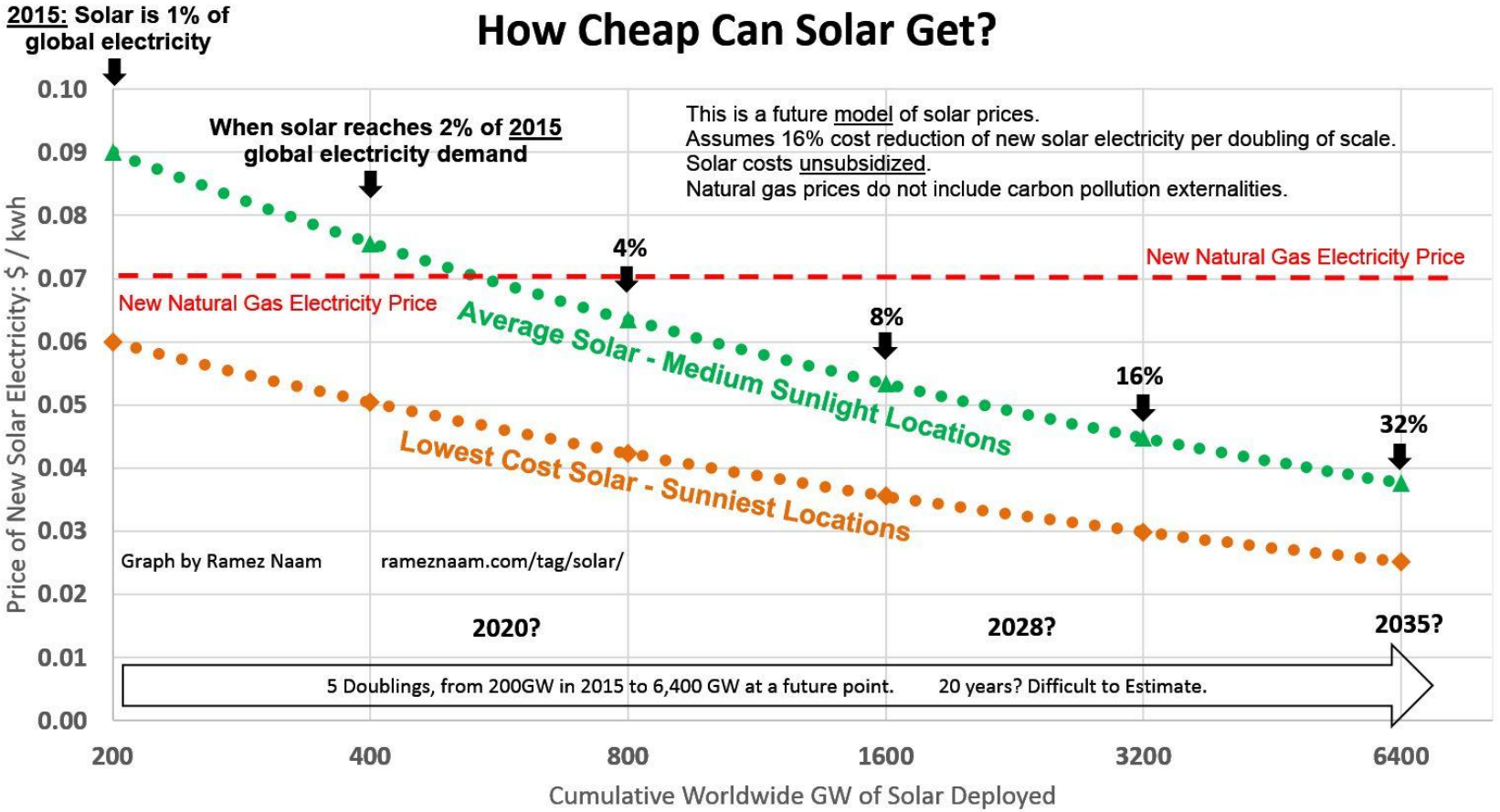


Current Storage

- Battery banks: similar to car batteries.
- Grid inter-tie: use grid as storage through net-metering.

Without cost-effective storage, solar electricity can never be a primary energy source

Storage could be attained using batteries, but nothing we have so far is inexpensive enough to make Solar Energy attractive

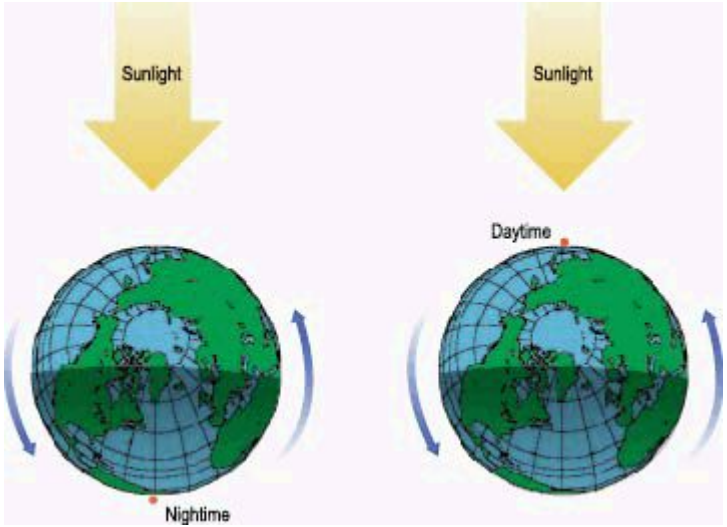

2015: Solar is 1% of global electricity
How Cheap Can Solar Get?
When solar reaches 2% of 2015 global electricity demand
This is a future model of solar prices.
Assumes 16% cost reduction of new solar electricity per doubling of scale.
Solar costs unsubsidized.
Natural gas prices do not include carbon pollution externalities.
4%
8%
16%
32%
New Natural Gas Electricity Price
New Natural Gas Electricity Price
Average Solar - Medium Sunlight Locations
Lowest Cost Solar - Sunniest Locations
Graph by Ramez Naam
rameznaam.com/tag/solar/
2020?
2028?
2035?
5 Doublings, from 200GW in 2015 to 6,400 GW at a future point.
20 years? Difficult to Estimate.
Price of New Solar Electricity: $ / kwh
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
200
400
800
1600
3200
6400
Cumulative Worldwide GW of Solar Deployed

Pros of Solar Energy

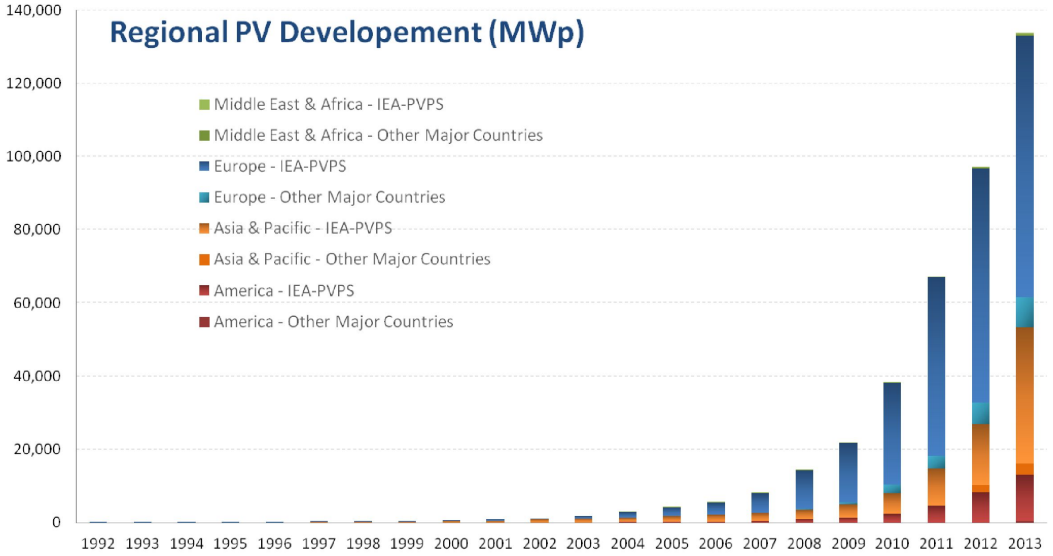
- **Unlimited**: surface of the Earth receives 120,000 terawatts of sunlight which is 20,000 times more power than needed to supply entire world
- **Reduce energy cost**: can sell excess electricity produced
- **Easy to integrate**: multipurpose.
  Incorporated in windows, roofs, roads etc; Easy to access
- **Silent**: no moving parts when generating solar power so no noise is produced
- **Low Maintenance**: systems only require cleaning a couple times a year
- **Clean**: does not create pollution and is sustainable.
- **Still improving**: large advances have been made over very few years
- **Safety**: have less safety risks than fossil fuel plants or nuclear power plants

Cons of Solar Energy

- **Expensive**: PV cells cost $0.11/hour. Coal: $0.09. Natural gas: $0.06.
  - However, costs are dropping drastically. In 2010, was $0.21. Germany, Italy and Spain have made solar power the same as buying from the grid.
- **Intermittent**: weather and time dependent
  - Diurnal Cycle
- **Efficiency**: at best converting at ~20%



World Leaders in Solar Energy



	Installations -GW		Total Installed Capacity -GW	
1	CHINA	11.3	GERMANY	35.5
2	JAPAN**	6.9	CHINA	18.3
3	USA	4.8	ITALY	17.6
4	GERMANY	3.3	JAPAN**	13.6
5	ITALY	1.5	USA	12.0
6	INDIA*	1.1	SPAIN**	5.6
7	ROMANIA*	1.1	FRANCE	4.6
8	GREECE*	1.0	AUSTRALIA	3.3
9	UK	1.0	BELGIUM	3.0
10	AUSTRALIA	0.9	UK	2.9

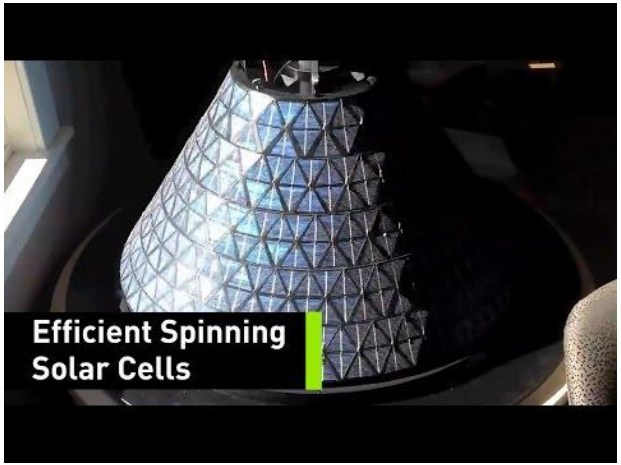
9 "GW COUNTRIES"

17 "GW COUNTRIES"

* Non-PVPS Countries / ** Spain & Japan data delivered in AC, these numbers are a DC recalculation.

Solar contribution minimal.
Less than 1% for U.S.
Italy has highest percentage but only at 8%.

New Solar Energy Technologies



New Technologies Continued

- Artificial Photosynthesis Method
- Thin-film PV Cells
- Hydrogen and Methanol: Professor at UNC studying way to use solar energy to convert water into hydrogen and carbon dioxide into methanol. Both burned at night/when no light available.
- Molten Salt: energy stored as heat in thermal tanks through molten salt which is non-toxic and inert. Problem with birds.

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