Energy 101: Renewables

Or how we glean energy from the solar system

Jimmy Jia
jimmy@jimmyjia.com
Last Edit: April 14, 2019

History of Renewables

1st use of Solar power:

Agriculture (ancient!)

1st human technology:

Wheel - around 4000 BCE Mesopotamia

1st use of Wind power:

Sail - in ancient Egypt around 3200 BCE

1st harness of wind:

windmill around 1AD in Greece

1st harness of solar electricity:

photovoltaic in 1839 in England

Why do people keep talking about reliability?

- The wind blows (mostly)…
- The sun shines (mostly)…
- What is this reliability issue people keep talking about?

Reliability

- SAIDI – System Average Interruption Duration Index - average outage duration for each customer served.
- USA: 1.5h per year

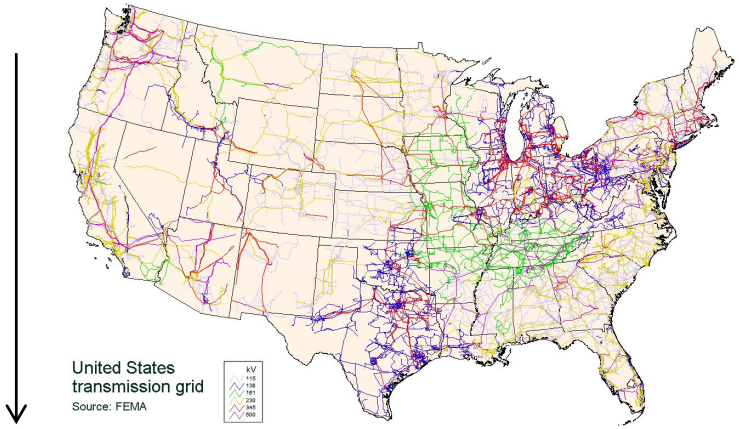
- SAIFI - System Average Interruption Frequency Index - average number of interruptions that a customer would experience.
- USA: 1.1 times per year

Reliability

Our electrical grid works 99.98%
of the time for everyone in the USA

2,800 miles

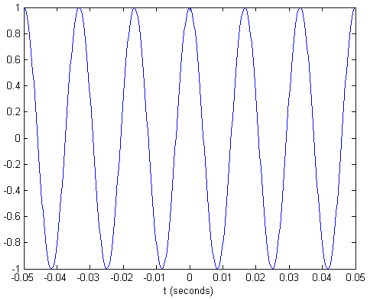
1,200 miles



As compared to:
Clothes Manufacturing: 98.5%
Most reliable car: Prius at 97.8%
Xbox/iPhone Reliability: 95-97%

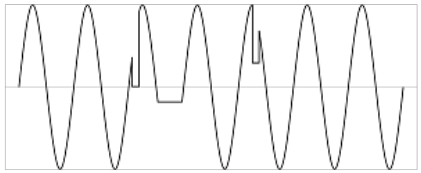
Power Quality – What is it?

Want:
60 Hz
110V

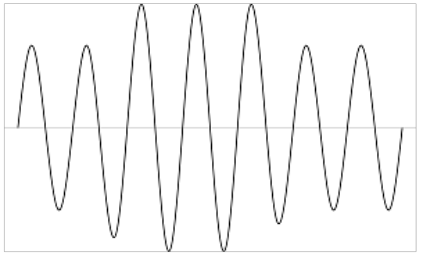


Avoid:

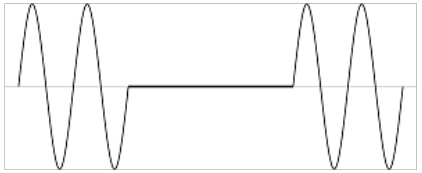
Notch



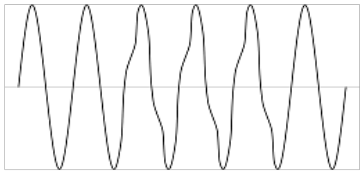
Surge



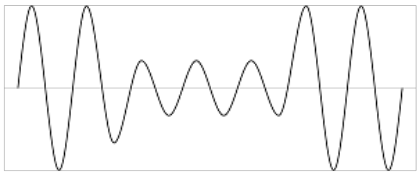
Blackout



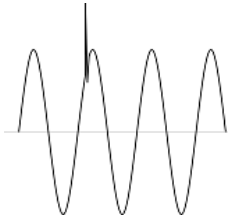
Harmonics



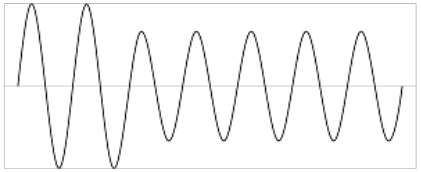
Sag or Dip



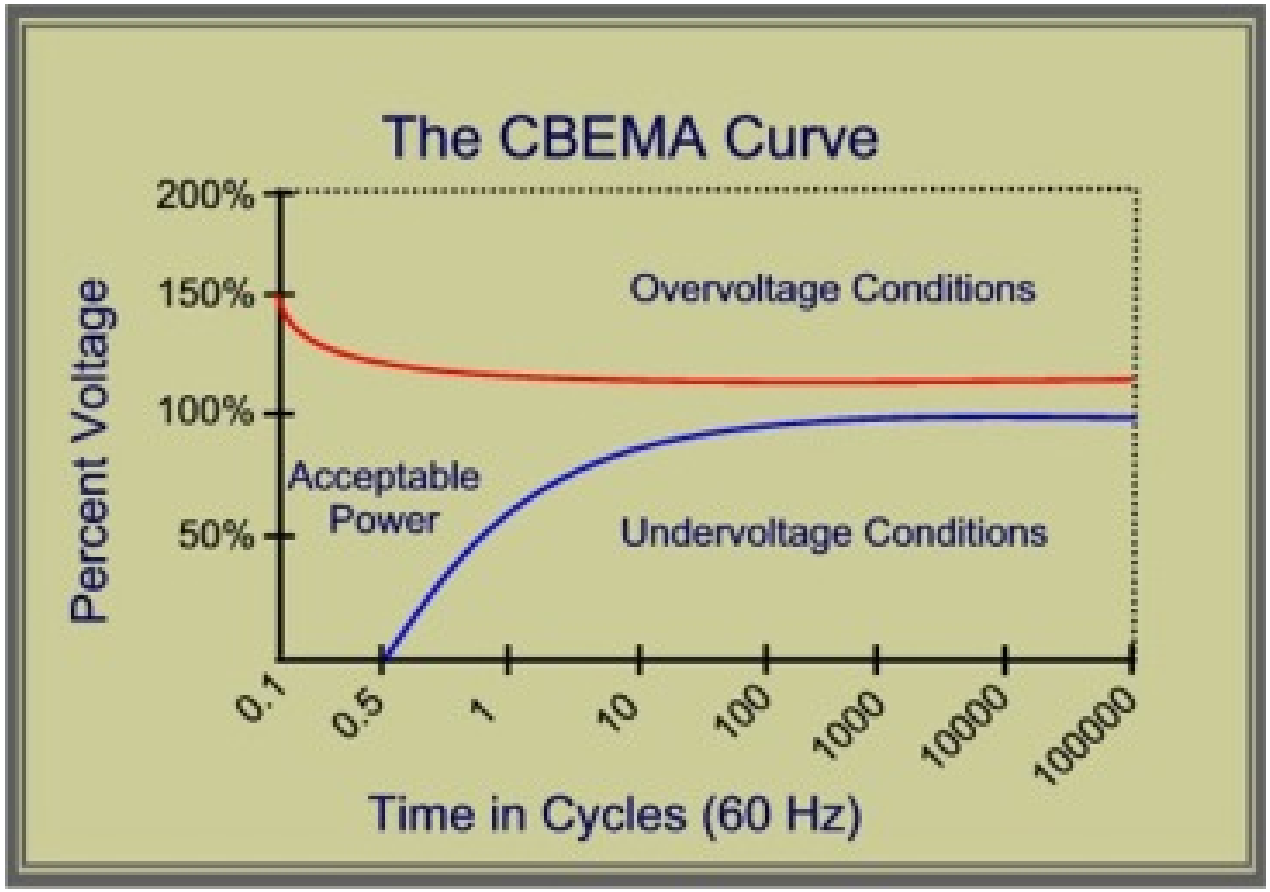
Spike



Brownout

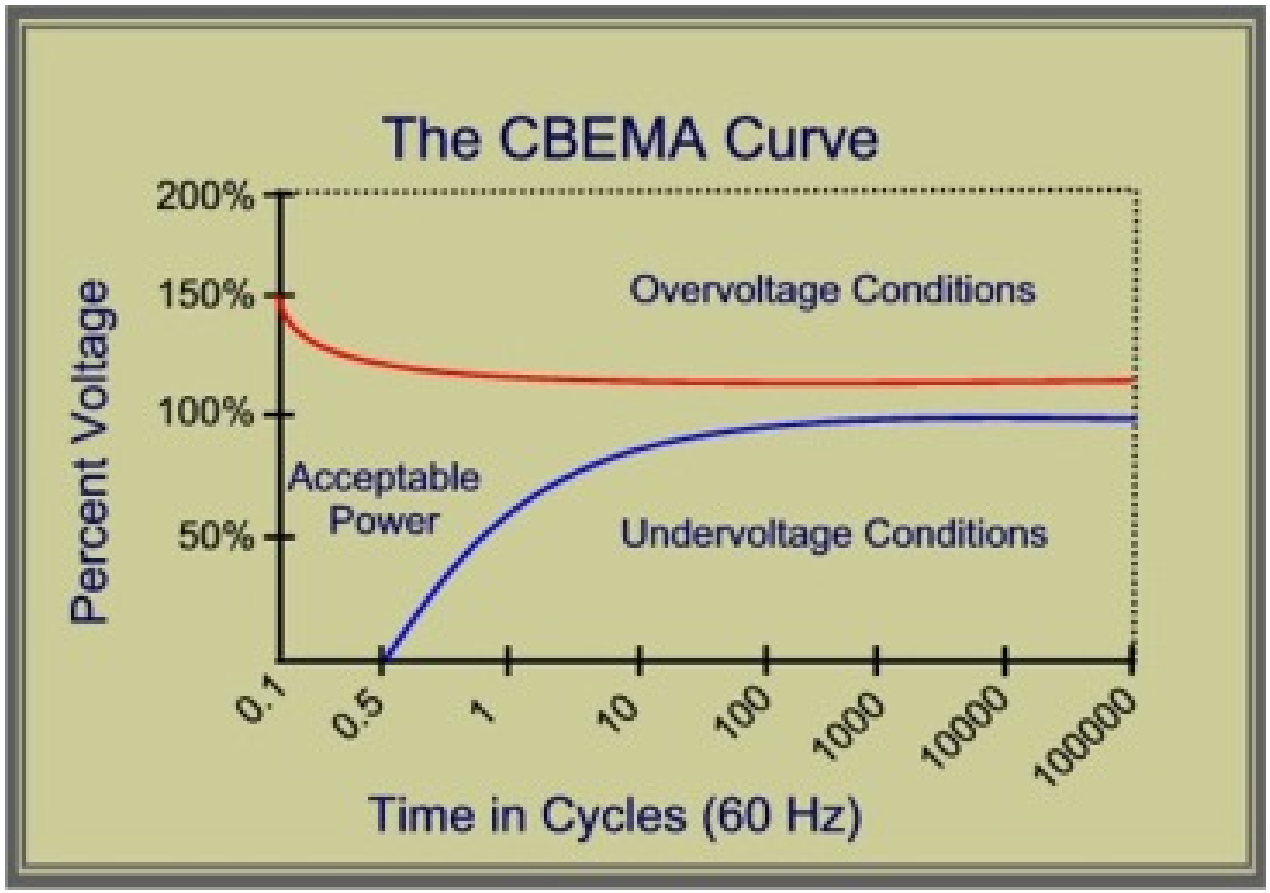


Power Quality – How long can it last for?



Power Quality – How long can it last for?

Data centers need 99.999% uptime or **5 minutes** per year downtime



CBEMA - Computer and Business Equipment Manufacturers Association

Technology: Polycrystalline Silicon Solar Cells

The energy transformation is from solar energy **to** electric energy.

What is the conversation technology? The conversion uses silicon as a medium. When sunlight hits the polycrystalline silicon inside a solar panel, it dislodges silicon electrons. The freed electrons are channeled out of the panel. Electricity is generated by this energy flow**.**

What is the typical efficiency? 13-16%. R&D cells: 20.4%.

What raw material supplies the energy? Sunlight supplies the energy. Silicon as a semiconductor in panels allows the sun's energy to be used. In polysilicon, other elements are combined with silicon in a complex multistage process to liquefy the silicon and create wafers from it. Inputs include silicon from quartzite, hydrogen and chloride.

What is the cost to build the technology? $2 billion for a new polycrystalline silicon factory. About $0.70 per Watt for polysilicon solar panels. It is cheaper than purer mono-crystalline silicon.

What location benefits? Higher light intensity produces higher output. Closer to the equator generally is better. But most of the US, Europe, and north Asia can use effectively.

What are the criticisms of the technology?

- Polycrystalline silicon production is hugely energy intense, estimated at 85% of the total energy used to make the panel.
- Lower efficiencies than monocrystalline silico (15-20%).
- Inefficiency leads to more panels so not as space efficient.
- Not as good performance in high temperatures
- Aesthetics – not from single crystal so visibly not uniform in shape or color
- Polycrystalline silicon needs more and better light to perform well.

Technology: Organic Solar Cells

The energy transformation is from visible light (primarily from the sun) converted to DC electricity.

What is the conversion technology? Materials used in the cell exhibit a property known as the photoelectric effect that causes them to absorb photons of light and release electrons. When these free electrons are captured, an electric current results that can be used as electricity.

What is the typical efficiency? ~5-10%

What raw material supplies the energy? Abundant and low-cost organic polymers, replacing silicon which is relatively expensive.

What is the cost to build the technology? There is a large range since the technology is still young. The estimated manufacturing cost for purely organic solar cells seem to range between $50 and $140/m2.

- *Assuming 5% efficiency, this leads to a module cost of between $1.00 and $2.83/Wp. Under the assumption of a 5-year lifetime, this leads to a levelized cost of electricity (LEC) of between 49¢ and 85¢/kWh. In order to achieve a more competitive COE of about 7¢/kWh, an efficiency increase to ~15% and lifetime to between 15–20 years would be needed.*

What location benefits? Sunnier is better but if costs are low enough while efficiency and durability increase, this solution may be practical in a majority of places.

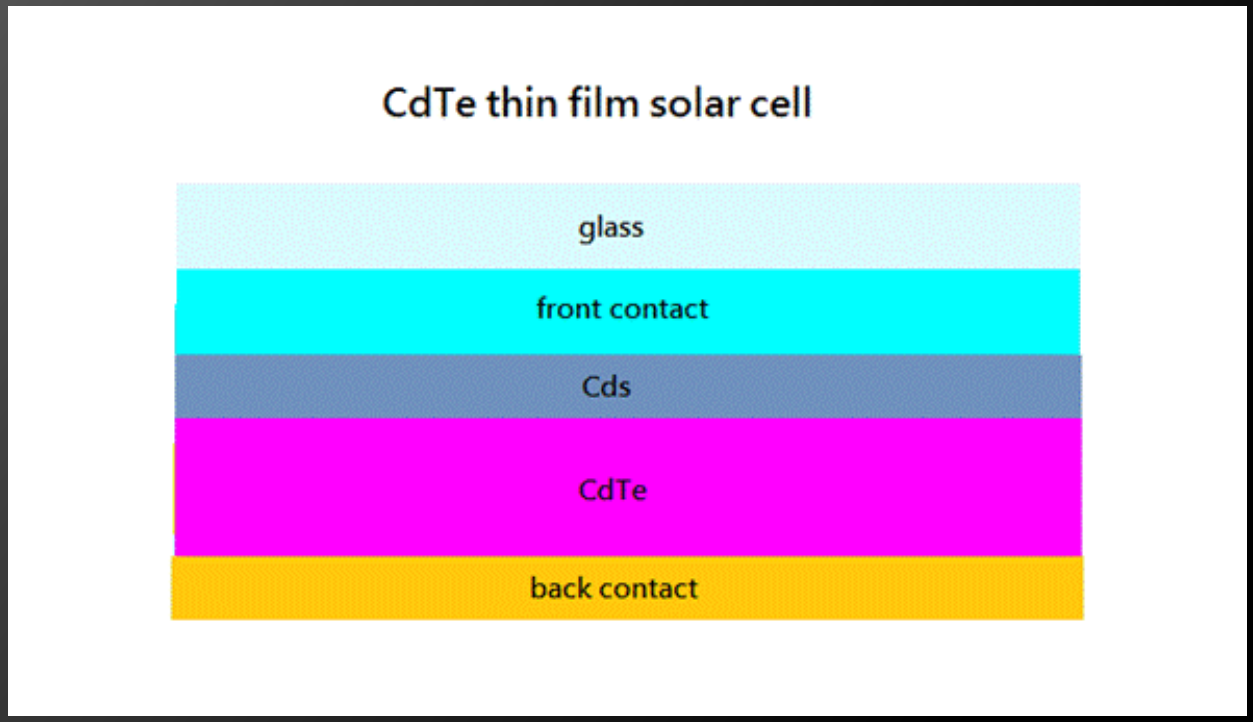
What are the criticisms of the technology? Low efficiency. Low stability which leads to degradation and decreased performance over time. Low strength compared to inorganic photovoltaic cells.

Of the fuel? Only produces electricity when there is sunlight available.

CADMIUM TELLURIDE SOLAR CELLS (THIN-FILM SOLAR CELLS)

(CdTE)

CADMIUM TELLURIDE SOLAR CELLS (THIN-FILM SOLAR CELLS)



(CdTE)

Technology:
Cadmium Telluride (CdTE)

The energy transformation is:

Solar energy to electric energy

What is the conversation technology?

Photovoltaic panels allow photons to knock electrons free for atoms to create electricity. Metal plates collect the electrons and transfer them to wires for travel

(CdTE)

Technology:
Cadmium Telluride (CdTE)

What is the typical efficiency?

Best cell efficiency published as 16.5%

What raw material supplies the energy?

Cadmium (Cd) Zinc Byproduct

Telluride (Te) Similar to Sulfide

What is the cost to build the technology?

Manufacturing Cost:$1/W

Installed Systems: $1.5/W

Electricity Cost: $.06-.08/kWh

(CdTE)

Pro

Ease of manufacturing

- easier than silicon to produce

Ideal for absorbing the sun's energy

- absorbs sunlight at close to the ideal wavelength, capturing energy at shorter wavelengths than is possible with silicon panels

Abundant and Cheap

- Cadmium is abundant, a by-product of zinc, more price stable than silicon

(CdTE)

Con

Poor Effeciency

- Record Efficiency for CdTE 16% vs. Silicon 25%

Supply of Telluride

- by-product of copper, with smaller byproduct amounts from lead and gold (rare!)

Toxicity

- Cadmium is one of top 6 deadliest minerals
  (tempered when combined with Telluride)

(CdTE)

Technology: Solar Thermal Hot Water (SHW)

The energy transformation is from solar (infrared) energy to thermal (heat) energy.

What is the conversion technology? The sun excites the electrons of a liquid -- creating heat. The heat transfer liquid, which is typically contained in a closed loop, flows through a panel of tubing (the collector) where it is heated and then flows to a coil (the heat exchanger) where the heat is transferred to the water.

What is the typical efficiency? 20-30% [had trouble finding this]

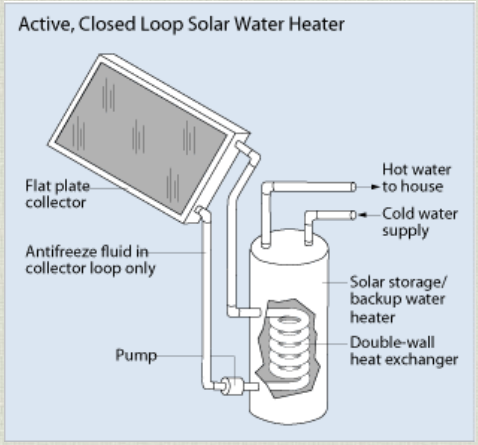
What raw material supplies the energy? Sunlight

What is the cost to build the technology? A reasonable assumption is $4,000-$7,000 installed for a commercial SHW system tied into a residential water line. DIY or off-grid systems are cheaper.

What location benefits? Sunlight is available everywhere. Some regions have very high solar energy factors others not as much.

What are the criticisms of the technology? Requires backup, freeze protection, maintenance, relatively short system life.

Of the fuel? Availability. In WA ~ 45% of demand met with SHW.



Technology: Concentrated Solar Power

The energy transformation is from _Solar Thermal Heat___ **to** _Transfer Fluid___ **to**_ Steam___ **to**_ Electricity

What is the conversation technology? Solar energy heats transfer fluid or molten salt which boils water, steam turns turbine.

What is the typical efficiency? Tower=17%, Sterling=24% Trough=20%

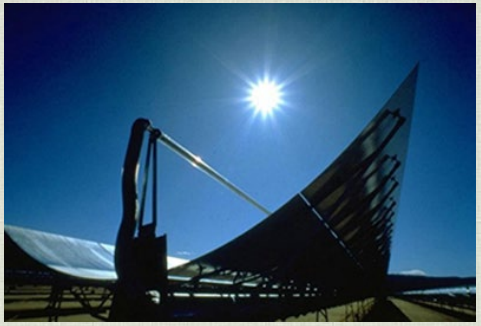
What raw material supplies the energy? Solar Thermal Energy, Therminol or Molten Salt, and Water

What is the cost to build the technology? Parabolic Trough – $2B for 280 mega-watts, Sterling – $.07-$.10/kWh

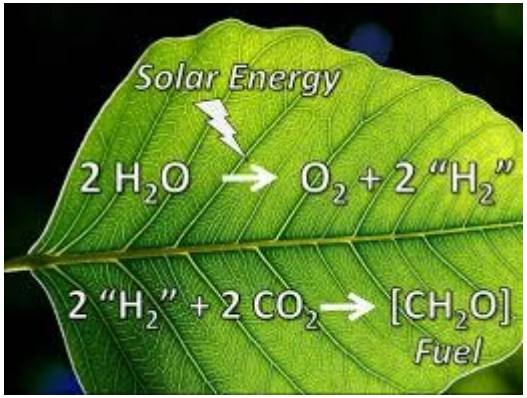
What location benefits? For the U.S., the southwest has plenty of suitable sites for CSP development. Flexible ecological footprint.

What are the criticisms of the technology? Tower and trough methods use a lot of water, typically in dessert regions

Of the fuel? Only good during daylight. However molten salt extends useful generation for six hours which eases peak evening usage. Molten salt must



Artificial Photosynthesis

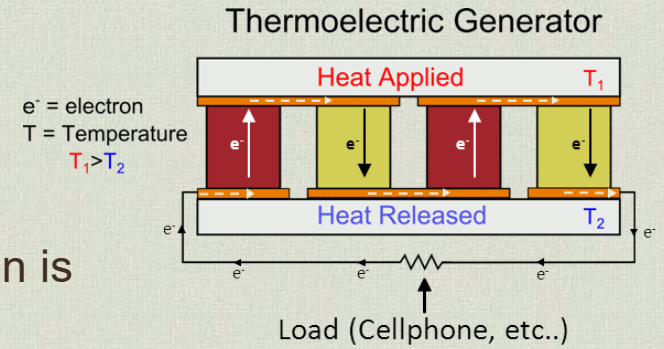


- The energy transformation is adopted from mimicking a plants use of solar energy to create chemical energy
- What is the conversion technology? Sunlight, C02,& H20

Harvesting light efficiently enough for water splitting, therefore creating hydrogen and releasing oxygen

- What is the typical efficiency? As of August 2015, 22% for H20 splitting
- What raw material supplies the energy? H20 & C02
- What are costs to build? $75 million for research
- What location benefits? Both the electrical market and gas market. Existing storage tanks and pipelines can be utilized
- What are the criticisms? Cost effectiveness of methods and materials, Scale of production, and overall much more needed R&D
- Of the fuel? Clean energy! Recycles Carbon Dioxide and only heat is the byproduct

Technology: Thermoelectric



The energy transformation is from Heat **to** electric energy

What is the conversation technology? The conversion is through the Seebeck Effect. Electricity is generated when a temperature gradient is formed between two conductive materials in a solid state generator.

What is the typical efficiency? 5-8%

What raw material supplies the energy? Various heat sources.

What is the cost to build the technology? Varies by material used for semiconductors. Theoretically $1-6/W

What location benefits? Remote locations with readily available heat sources and low wattage needs. Anywhere with waste heat.

What are the criticisms of the technology? It is highly inefficient. Only low wattage applications are currently feasible.

Of the fuel? Some applications use radioisotopes which can be dangerous.

Technology: Vertical Wind Axis Turbine (VWAT)

1. **The energy transformation is from:** kinetic energy to mechanical and electric energy.
2. **What is the conversation technology?** Wind turns the rotor blade that dives a shaft to the generator turbine to generate electricity.
3. **What is the typical efficiency?** Anywhere between 15-40% depending on
4. **What raw material supplies the energy?** None, with the exception of oil to run generators or gear boxes.
5. **What is the cost to build the technology?** The DOE capacity-weighted average costs for installation of Vertical Wind Axis Turbines was between $2,540/kW for larger turbines to $ $6960/kW for smaller turbines.
6. **What location benefits?** Locations where wind direction is highly variable. Also better suited for small scale generation or areas where high turbines are prohibited, but generally not for connecting to the electrical utility grid.
7. **What are the criticisms of the technology?** The overall efficiency and the turbines can't self-start.
8. **Of the fuel?** The wind is variable and can't be stored.

Darrieus VWAT

Savonius VWAT

Technology: Horizontal Axis Wind

The energy transformation is from Wind Energy **->** electricity. New technology is producing larger and more efficient turbines.

What is the conversion technology? Horizontal axis wind turbines turn electrical generators to produce power that is transmitted by overland wires to users – who may or may not be local to the generating field.

What is the typical efficiency? ~30-40% of wind energy converted to electricity, (**i**rrelevant since the fuel is free). However, yield may be only 15-20% of rated due to intermittency. (4MW turbine produces 4*24=96*20% = 19.2 Mwh/Day)

What raw material supplies the energy? Steel -> towers and other structural components, fiberglass -> blades, copper-> conductors.

What is the cost to build the technology? About $1.3M - $2.2M/MW. Currently 2 MW in size -> $3-$4M installed.

What location benefits? The electrical market that can interconnect with the power plant. The property owner if the land is leased to the wind company. Effective at home, community, utility scale.

What are the criticisms of the technology? Criticisms are complex – meaning they have real and imaginary parts. R: intermittency, storm vulnerabilty. I: View damage, bird kill, noise

Of the fuel? There is none. It's like pulling electricity out of thin air. How cool is that?! Only cost is the conversion machinery.

Technology: Offshore Wind

The energy transformation is from _Wind energy___ **to** _electric energy___

What is the conversation technology? Electromagnetic induction. Shaft of wind turbine turns a motor.

What is the typical efficiency? 75% - 80%

What raw material supplies the energy? Wind

What is the cost to build the technology?

$1 to 2 million per MW

What location benefits? Natural wind channels. Lakes, oceans, seas. Typically in shallow water

What are the criticisms of the technology?

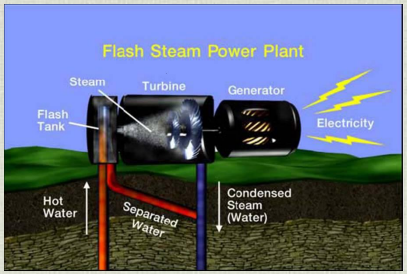
Threat to wild life, wind variability, upfront cost

Of the fuel? No waste from fuel

Technology: Geothermal Electricity

The energy transformation is from steam produced by hot, underground water resevoirs **to** electric energy

What is the conversation technology? The conversion is using a thermal steam cycle. Electricity is generated when steam, piped directly from natural underground reservoirs, turns a turbine. (http://goo.gl/jWi850)



What is the typical efficiency? 12% (http://goo.gl/rEc2xc)

What raw material supplies the energy? The Earth's Core - Magma!

What is the cost to build the technology? Reykyavek Geothermal plans to invest $50 million in building a 10 megawatt plant in the Grenadines (http://goo.gl/V1VgPO)

What location benefits? The electrical market that can interconnect with the power plant.

What are the criticisms of the technology? High Upfront cost, geographically limited

Of the fuel? Wells are often immeasurable until after extensive drilling costs (http://goo.gl/V1VgPO)

Technology: Ground Sourced Heat Pumps

The energy transformation is from _exchange temp of earth's crust_**to** _circulate ambient air in building

What is the conversion technology? Using underground loop system, pump cool air into home in the summer and warm air in the winter

What is the typical efficiency? Geothermal heat pumps typically have 250-400% efficiency (GHPs use 25% to 50% less electricity than conventional HVACs)

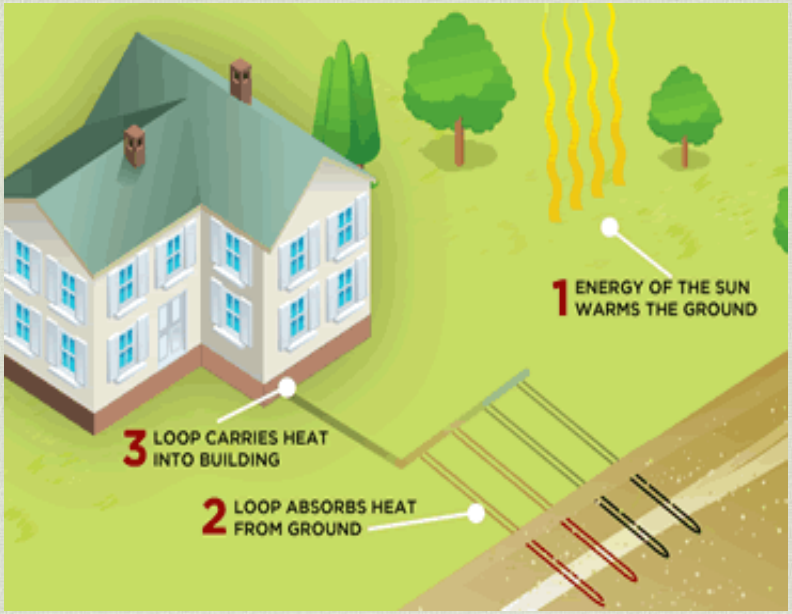
What raw material supplies the energy? Exchange of constant ground temp 50-55^{o} F (no fuel used)

What is the cost to build the technology? Typical 2,500 s.f. home (w/heating/cooling load of 60K BTU) will cost between $20-25,000 to install

What location benefits? Self-contained, quiet, long-lasting, low-maintenance

What are the criticisms of the technology? Not considered renewable because it uses electricity; needs a lot of land; HVAC systems put refrigerant into ground (ALL MYTHS)

https://www.youtube.com/watch?v=e1r7fXO0QII



Technology: Hydroelectric Dams

The energy transformation is from the flow of water through turbines and creates electric energy.

What is the conversion technology? The conversion is from capturing the energy of falling water to generate electricity. When water from the dam passes through, the turbines spin and this creates electricity.

What is typical efficiency? Hydropower is the most energy efficient power generator. Currently, hydropower is capable of converting 90% of the available energy into electricity.

What materials are required as inputs? Water

What is the cost to build the technology? $1 billion

What are the locations that benefit? The technology is reliable and provides consistent supply for customers. It requires low maintenance costs for power plants.

What are the criticisms of the technology? Hydropower destroys human and animal habitats, diverts natural water flow, uses up natural and limited water resources, displaces communities, unreliable if water is not available, limited locations to build dams.

Of the fuel? The energy is clean but the process for creating hydropower is not – building dams take a long time and the destruction of plants and trees creates GHG emissions.

Technology: Hydrokinetic wave energy

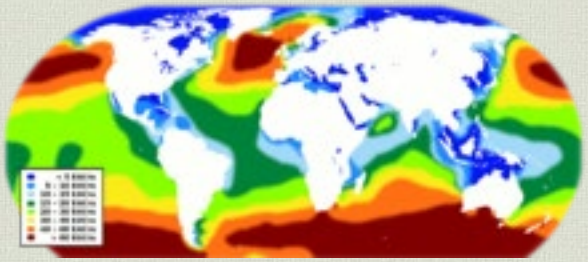
The energy transformation is from mechanical (kinetic) energy **to** electric energy

What raw material supplies the energy? The motion of water

	Conversion Technology	Efficiency
Oscillating H_20 Column	Like a piston, waves force air to pass back and forth through turbine-generator at high velocity	50-60%
Oscillating Body Converters	Bobbing motion activates a linear electric generator or a piston pump and hydraulic turbine	70-90%
Overtopping Converters	H_20 is directed into a reservoir and converted via hydraulic turbine	70-90%

What is the cost to build the technology? Largest single power plant to date ~2MW capacity. Cost of capacity is approx $5,500 - $10,000 per kW

What location benefits? see map



What are the criticisms of the technology?

- Unknown environmental impact: noise, structures, EMF
- Operation and maintenance is expensive

Of the fuel?

- The waves of highest energy density are in the most challenging to access
- Intermittent

Technology: Tidal

The energy transformation is from the tides to electric energy.

What is the conversion technology? A barrage is built, forcing water through turbines, which activate generators.

What is the typical efficiency? 85 % efficiency but 25% capacity.

What raw material supplies the energy? Ocean water.

What is the cost to build the technology? 12 euro cents per kWh for La Rance in France.

What location benefits? Few places on Earth as large tides are necessary. Very predictable. Last for a long time (century), low operating costs.

What are the criticisms of the technology? Limited possibilities of implementation. Can disrupt the ecosystems or the entire tide in an area.

Of the fuel? None.

Above : La Rance tidal plant, France.

Technology: Manure

The energy transformation is from chemical energy **to** electric energy

What is the conversation technology? Gas is collected from anaerobic digester and burned to create steam that turns a turbine to generate electricity. Some manures can also be combusted directly. Frequently combined with cogeneration to recycle waste heat.

What is the typical efficiency? 33% (gas to electricity)

What raw material supplies the energy? Livestock manure

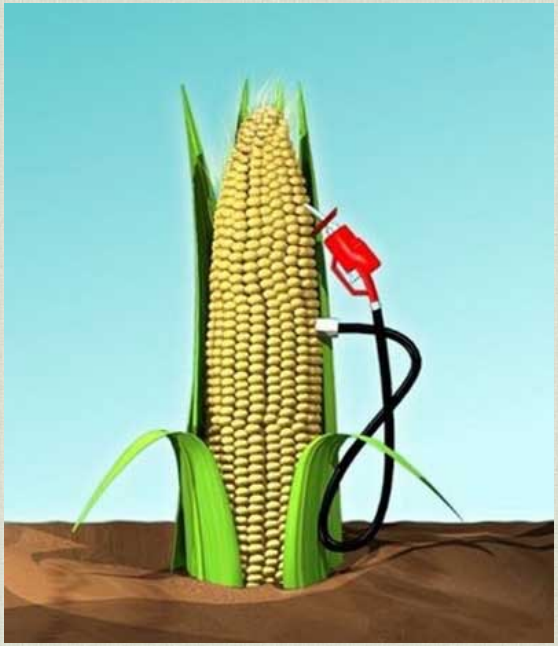
What is the cost to build the technology? $3000-$7000/kW installed, ongoing maintenance costs

What location benefits? Plants built on farm, heat and electricity used on farm and excess electricity can also be exported to grid.

What are the criticisms of the technology? High upfront cost.

Of the fuel? Limited applications. Most economical on large farms with confined animals.

Technology: Corn Ethanol



The energy transformation is from _Chemical Potential Energy_ **to** _Mechanical Energy_

What is the conversation technology? Internal combustion where force is generated and applied to components of the engine by moving it over a distance, which generates useful mechanical energy.

What is the typical efficiency? 84,600 BTU/Gallon.

What raw material supplies the energy? Ethanol

What is the cost to build the technology? The construction of a corn ethanol plant is approx. $60M to construct for approximately 30M gallons of production per year.

What location benefits? Reduce foreign oil and greenhouse gas emissions.

What are the criticisms of the technology? Depletes amount of land used for food. Required electricity from distilleries comes mainly from coal plants.

Of the fuel? Contains less energy units, or BTU's, than gasoline.

TECHNOLOGY: ALGAE FUEL

The energy transformation is from _chemical energy__ to _mechanical energy___

What is the conversion technology? The conversion is using a internal combustion engine in the case of bio gasoline.

What is the typical efficiency? Algal oil has roughly 80% of the caloric energy value of crude petroleum

What raw material supplies the energy? Lipid from algae biomass

What is the cost to build the technology? $600 million in development & $3/gallon of fuel

What location benefits? Rural areas with a lot of land

What are the criticisms of the technology? Commercial viability is too far off to focus on right now

Of the fuel? More expensive to produce than petroleum fuel

Technology: Wood Biomass

The energy transformation is from cellulose in wood to electric or steam energy

What is the conversation technology? Direct combustion, fermentation, or pyrolysis.

What is the typical efficiency? 60-80%

What raw material supplies the energy? Wood

What is the cost to build the technology? $0.01-0.03/kWh. Burners cost $50-75,000 per 300kWh/hr produced.

What location benefits? Cheap production costs and Co2 emissions are 90% of those of fossil fuels. Renewable.

What are the criticisms of the technology? Upstart costs 50% more than for fossil fuel systems.

Of the fuel? Encourages mass deforestation.

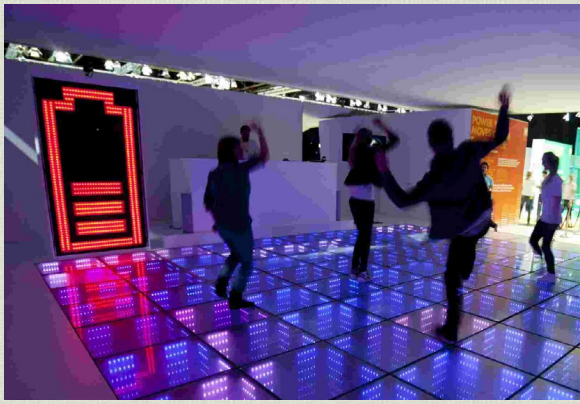
Technology: Piezoelectric Generator

The energy transformation is from mechanical energy **to** electric energy. Piezoelectricity means electricity resulting from pressure. Also works conversely.

What is the conversion technology? Electricity is generated from an applied mechanical force.

What is the typical efficiency? 5%-15%

What raw material supplies the energy? Stimuli for piezoelectric materials can be from human walking, wind, rain, tide, wave, etc.



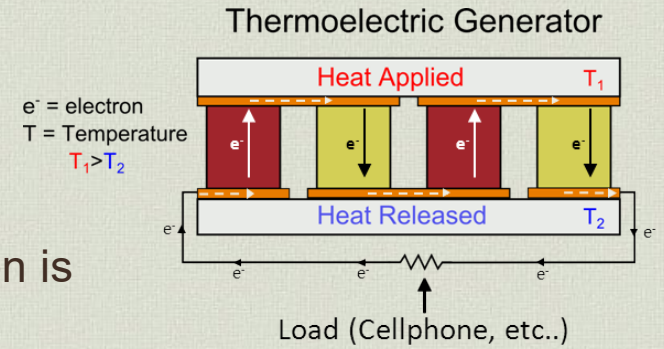
What is the cost to build the technology? Depends!

What location benefits? Anywhere there are humans that want decentralized electricity.

What are the criticisms of the technology? Costs and inefficiency.

Of the fuel? N/A, you are the fuel! Or the elements are the fuel.

Technology: Thermoelectric



The energy transformation is from Heat **to** electric energy

What is the conversation technology? The conversion is through the Seebeck Effect. Electricity is generated when a temperature gradient is formed between two conductive materials in a solid state generator.

What is the typical efficiency? 5-8%

What raw material supplies the energy? Various heat sources.

What is the cost to build the technology? Varies by material used for semiconductors. Theoretically $1-6/W

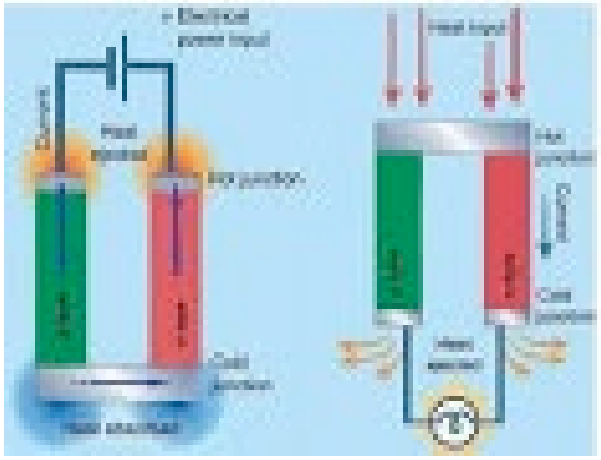
What location benefits? Remote locations with readily available heat sources and low wattage needs. Anywhere with waste heat.

What are the criticisms of the technology? It is highly inefficient. Only low wattage applications are currently feasible.

Of the fuel? Some applications use radioisotopes which can be dangerous.

Thermal-Electric Generators (TEG)

Transforming Heat to Electric Power



2/3 of all Human Energy Produced becomes Waste Heat

Imagine if we could transform 1/10 into Electricity?

Current Examples Include

- Space probes use Heat from plutonium for power
- Natural gas lines use TEG to power remote monitors
- Backpacking stoves to power phones
- Small fridges that plug into 12V car power plugs

Major Advantage No moving parts, extreme reliability

Limitations

- Requires a high temperature difference between heat source/heat sink
- Relatively low efficiencies

Interlude

http://www.youtube.com/watch?v=uLpu2UP3rGI

In Summary

- Our society isn't just built on an abundance of energy,
- It is built on an abundance of *reliable* energy
- And that makes the whole problem far more difficult….

Topic for Discussion

- Renewables face many challenges to being interconnected on the grid. Which do you feel will tip the balance:

- Good policy (such as CA RPS)

  OR

- Good business practice (such as lowering costs of adoption)

- List some challenges for your choice and how you would address them.

Presentation of Discussion