# 6.5 RENEWABLE ENERGY

College Board Topics 6.8, 6.10, 6.11, 6.12

Related Reading:  Chapter 21

# Objectives and Essential Knowledge

**SUGGESTED SKILL**

*Data Analysis*

**5.C**

Explain patterns and trends in data to draw conclusions.

**SUGGESTED SKILL**

*Concept Explanation*

**1.B**

Explain environmental concepts and processes.

**SUGGESTED SKILL**

*Environmental Solutions*

**7.B**

Describe potential responses or approaches to environmental problems.

## ENDURING UNDERSTANDING

**ENG-3**

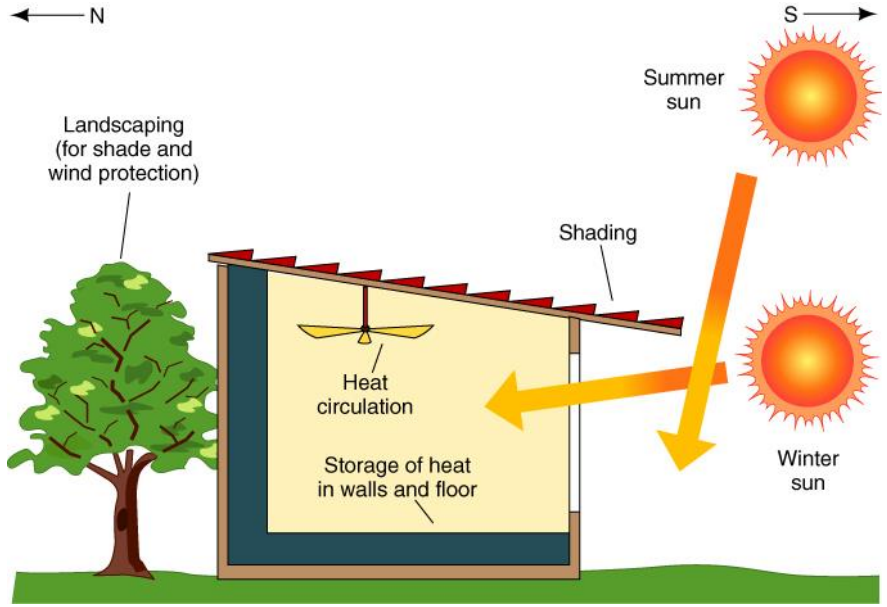
Humans use energy from a variety of sources, resulting in positive and negative consequences.

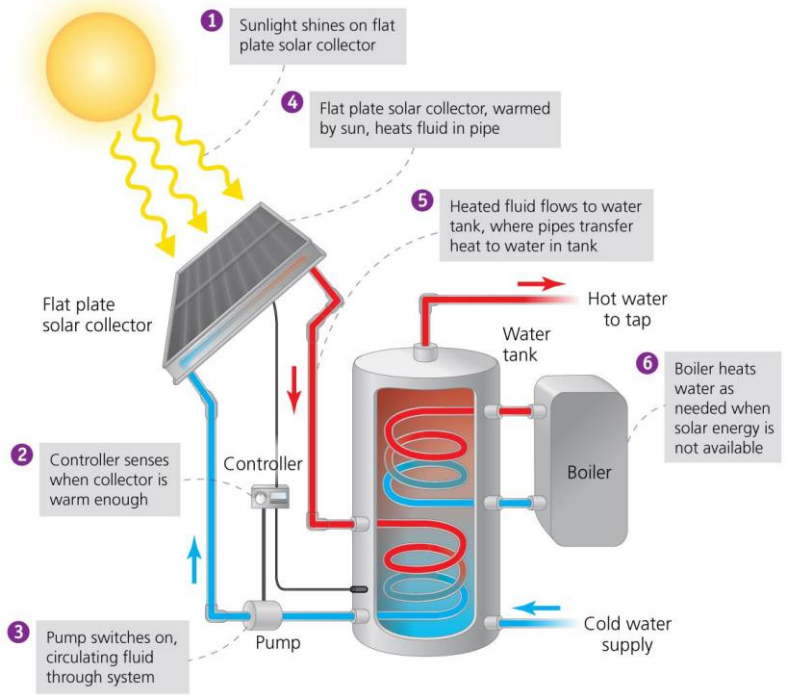
| LEARNING OBJECTIVE | ESSENTIAL KNOWLEDGE |
|---|---|
| **ENG-3.J** Describe the use of solar energy in power generation. | **ENG-3.J.1** Photovoltaic solar cells capture light energy from the sun and transform it directly into electrical energy. Their use is limited by the availability of sunlight. |
| | **ENG-3.J.2** Active solar energy systems use solar energy to heat a liquid through mechanical and electric equipment to collect and store the energy captured from the sun. |
| | **ENG-3.J.3** Passive solar energy systems absorb heat directly from the sun without the use of mechanical and electric equipment, and energy cannot be collected or stored. |
| **ENG-3.R** Describe the use of wind energy in power generation. | **ENG-3.R.1** Wind turbines use the kinetic energy of moving air to spin a turbine, which in turn converts the mechanical energy of the turbine into electricity. |
| **ENG-3.S** Describe the effects of the use of wind energy in power generation on the environment. | **ENG-3.S.1** Wind energy is a renewable, clean source of energy. However, birds and bats may be killed if they fly into the spinning turbine blades. |
| **ENG-3.N** Describe the use of geothermal energy in power generation. | **ENG-3.N.1** Geothermal energy is obtained by using the heat stored in the Earth's interior to heat up water, which is brought back to the surface as steam. The steam is used to drive an electric generator. |
| **ENG-3.O** Describe the effects of the use of geothermal energy in power generation on the environment. | **ENG-3.O.1** The cost of accessing geothermal energy can be prohibitively expensive, as is not easily accessible in many parts of the world. In addition, it can cause the release of hydrogen sulfide. |
| **ENG-3.P** Describe the use of hydrogen fuel cells in power generation. | **ENG-3.P.1** Hydrogen fuel cells are an alternate to non-renewable fuel sources. They use hydrogen as fuel, combining the hydrogen and oxygen in the air to form water and release energy (electricity) in the process. Water is the product (emission) of a fuel cell. |
| **ENG-3.Q** Describe the effects of the use of hydrogen fuel cells in power generation on the environment. | **ENG-3.Q.1** Hydrogen fuel cells have low environmental impact and produce no carbon dioxide when the hydrogen is produced from water. However, the technology is expensive and energy is still needed to create the hydrogen gas used in the fuel cell. |

# Active Solar vs. Passive Solar

- ***Passive solar***
  - absorbing or blocking heat from the sun, w/out use of mechanical/electrical equipment to transform the energy into electricity or transport the heat produced.
  - Orienting building design to block sunlight in warmer months & allow sunlight in during colder months.
  - Double paned windows, southern facing windows w/roof overhang, deciduous shade trees, skylight to decrease electricity use, dark colored sunlight floor and materials with high thermal mass.

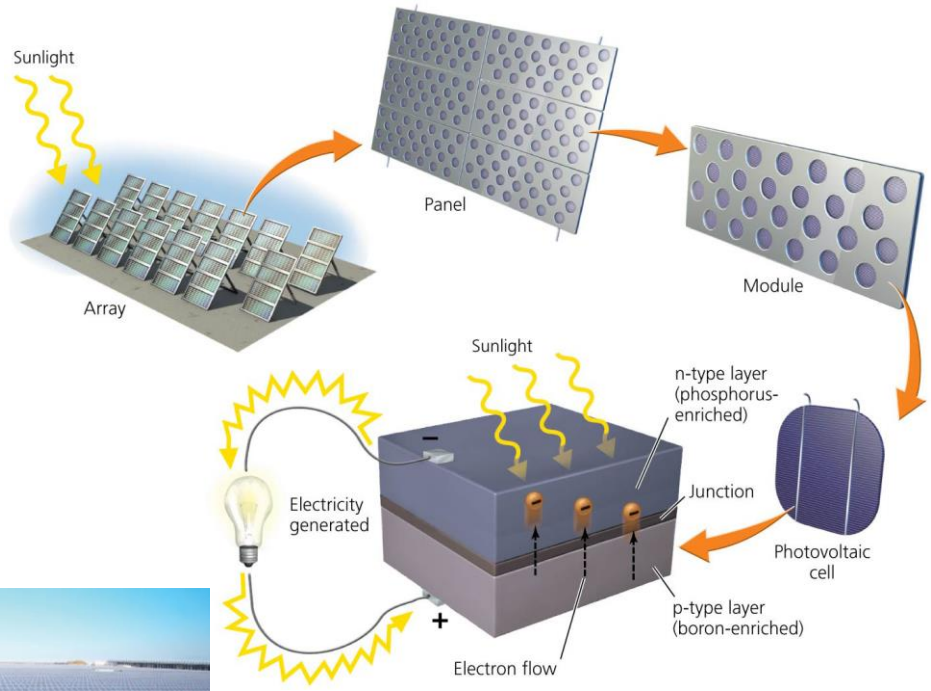
- ***Active solar***
  - use of mechanical/electrical equipment to capture sun's heat
  - Solar water heating; circulates water to reduce energy demand of water heating
  - Photovoltaic cells; convert solar energy to electricity on rooftops.
  - Concentrated Solar Power; produces large amounts of electricity through a variety of mechanical means at large centralized locations.



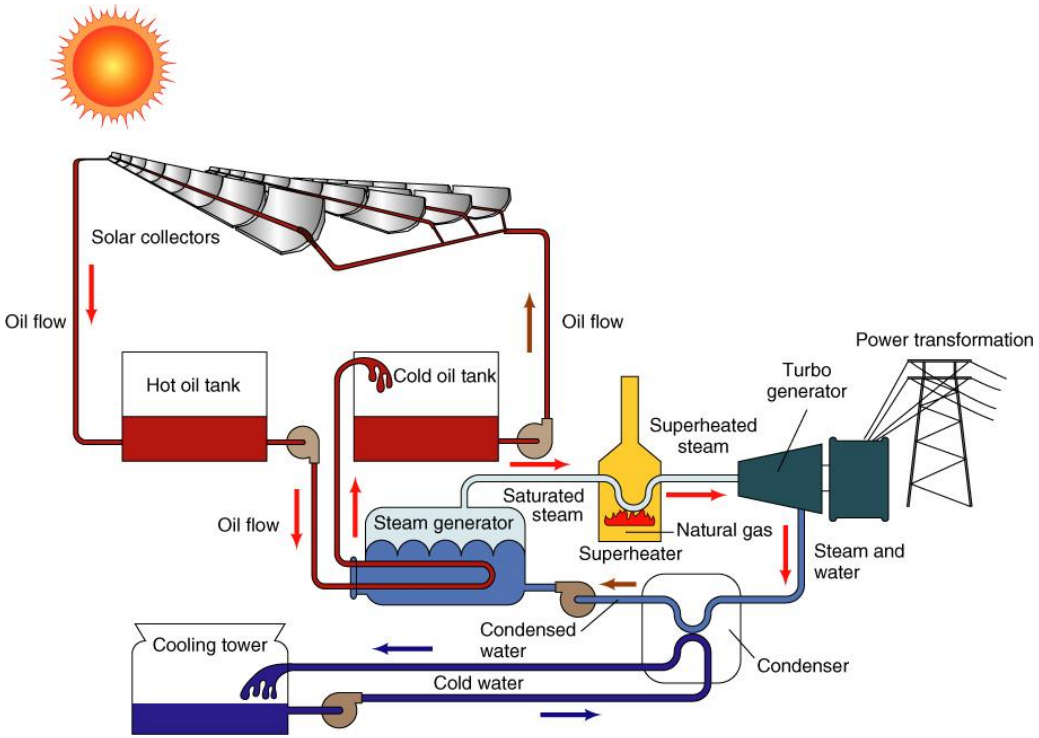
# *Photovoltaic cells*

- a.k.a. "solar panels" contain semiconductor (usually silicon) that emits low voltage electrical current when exposed to sun.
  - Photons (particles carrying energy from sun) excite electrons and cause separation of charges between two semiconductor layers (n & p)
  - electrons separate from protons & flow through circuit to load, delivering energy (as electricity).
- PV cells on a roof can provide electricity directly to the building, or send excess electricity back to the grid for other users (earning you a credit from your utility company)
  - A drawback is ***intermittency*** (solar energy can only be generated during the day) unless connected to batteries that can store the energy.
  - Solar systems with battery backups are currently not cost effective and batteries have limited life spans.
    - Batteries also require heavy metals which much be mined and disposed of as hazardous waste.
- PV cells may be arranged in large solar arrays to form ***solar farms*** capable of producing and transmitting large amounts of electricity




# Concentrated Solar Power (CSP)

- Utility companies concentrate the solar power to generate electricity at centralized facilities using a variety of approaches.
  - Frying ants with a magnifying glass.
- Heliostats (mirrors) reflect sun's rays onto a central fluid filled tower
  - Water is converted to steam and used to turn turbines, which then power generators.
  - Or the heated fluid (molten salt) can be used to convert water to steam which then generates electricity.
- Curved reflectors direct sunlight to heat an oil filled tube running through the center of the trough.
  - The heated oil transfers heat to water, which is converted to steam to produce electricity.
- CSP facilities and solar farms take up large amounts of land leading to habitat loss / fragmentation
  - Heliostats can burn curious birds / insects

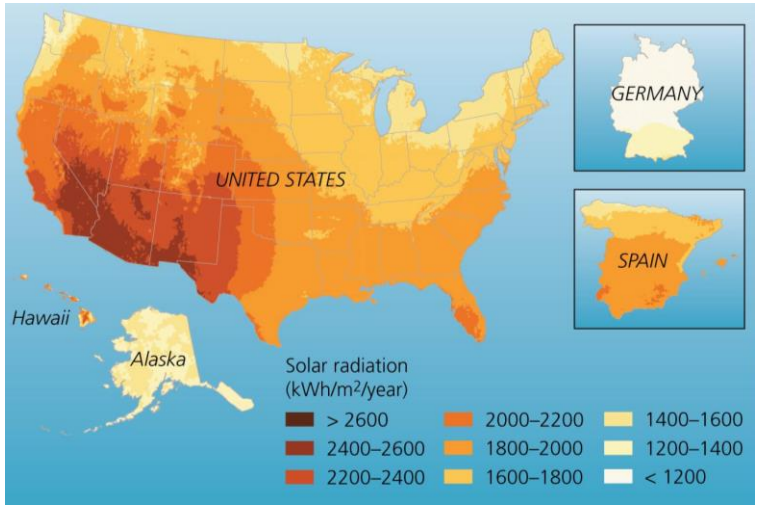


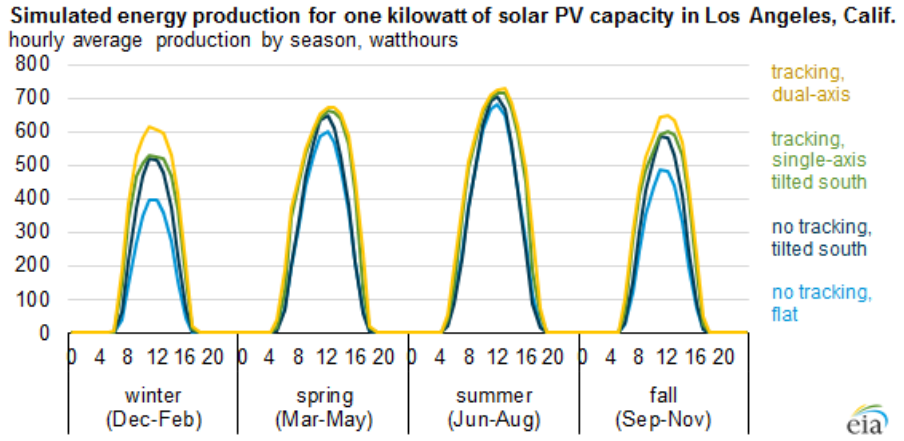
# Solar energy pros

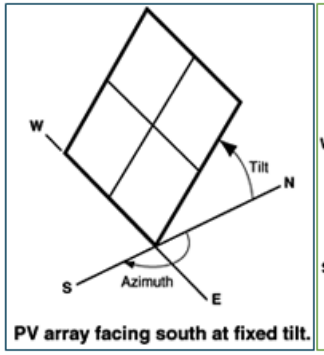
- No air pollutants ($CO_2$, PM, $SO_x$, $NO_x$) released to generate electricity
- Contain no moving parts and require little maintenance.
- Renewable, unlike FFs which will run out.
- No mining of fossil fuels for electricity production.
- Allow local, decentralized control of power and energy.
  - PV solar is Ideal in remote locations far from existing grid connected electricity sources.
  - Small, stand-alone systems can be affordable in remote locations.
  - Solar cookers can reduce indoor air pollution associated with cooking fires and reduce impacts of deforestation for fuelwood collection.

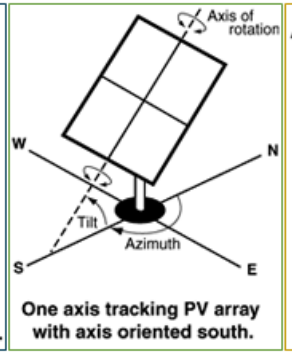

# Solar energy cons

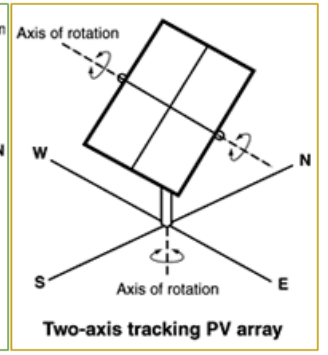
- High upfront cost to purchase, which will take a long time to break even with electricity cost savings
- Semiconductor metals (silicon) still need to be mined to produce PV cells (solar panels).
  - This can disrupt habitats & pollute water with mine tailings
  - Silicon is a limited resource.
  - Solar panels last approximately 25 years before needing to be replaced.
- Solar panel farms and CSP can lead to habitat loss / fragmentation.
- Not all locations are sunny enough to efficiently produce power (CSP and solar farms are only feasible in desert regions of the world) (PV efficiency is ≈20%)
- Solar power is an intermittent source, and even good sites can be limited by daily and seasonal fluctuations in solar energy.
  - Why does solar efficiency also affected by angle and aspect of the panel, as shown in the graphic to the right?



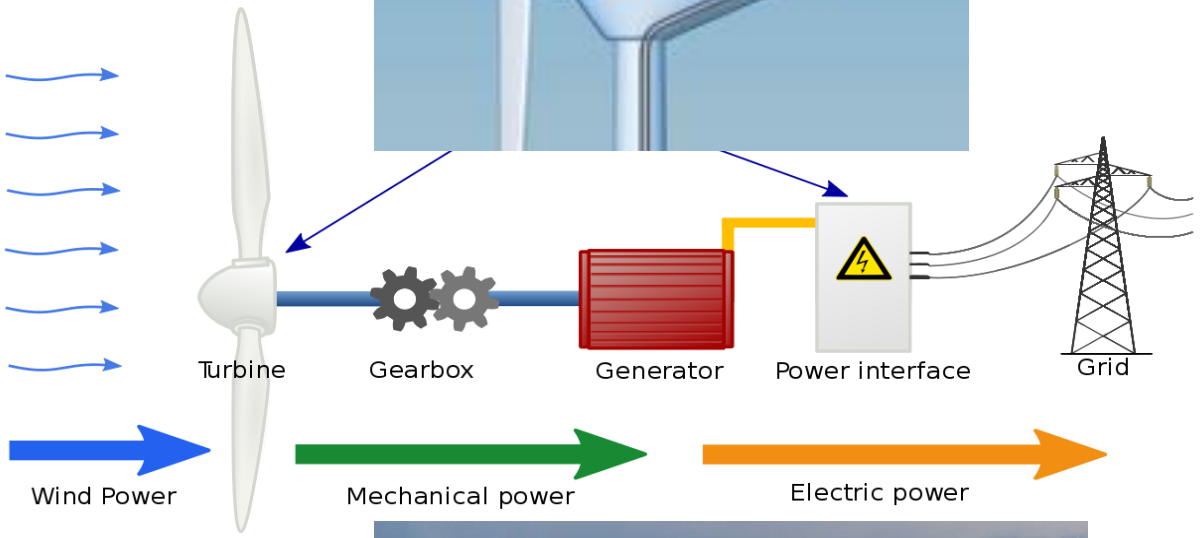



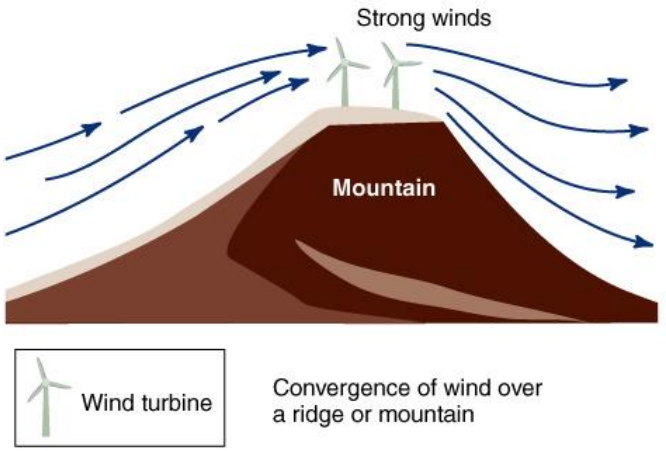
# Wind Turbine Basics

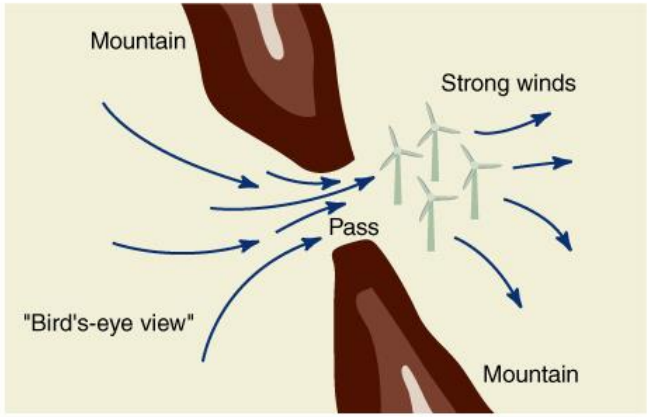
- Wind is created by the uneven heating of Earth's surface (an indirect form of solar energy).
- Kinetic energy of moving air (wind) spins a turbine to power a generate which generates electricity.
  - Towers average 80 m (260 ft) tall. The higher the tower, the more it minimizes turbulence and maximizes wind speed.
  - Blades of turbine are connected to gearbox by a shaft that rotates; rotating gears create mechanical energy that the generator transforms into electricity
  - Motorized drive within shaft can turn the turbine to face wind
- ***Wind farms*** are turbines erected in groups of up to several hundred turbines in one area
  - Average turbine can power 460 homes
  - Only produces electricity in 8-55 mph winds




# Wind Farm Locations

- Locating them together makes service, repair, and building transmission lines to them easier.
- Wind farms allow for additional forms of land use to coexist on the same land.
  - Crop agriculture, grazing, open space.
- Wind farms are often located when winds converge (vertical and/or horizontal).
- Wind farms are often located in flat open areas that allow for uninterrupted wind flow.
- ***Offshore wind farms*** show promise.
  - Wind speeds average 20% higher over large bodies of water than over land.
  - Erecting and maintaining turbines is more challenging and transmitting electricity back to shore can be a challenge.
  - Additional production capacities make overcoming these hurdles worthwhile.
  - 1800 turbines off shore of 10 European nations.
  - 130 wind turbines off the coast of Cape Cod, Massachusetts.




## Pros of Wind Power

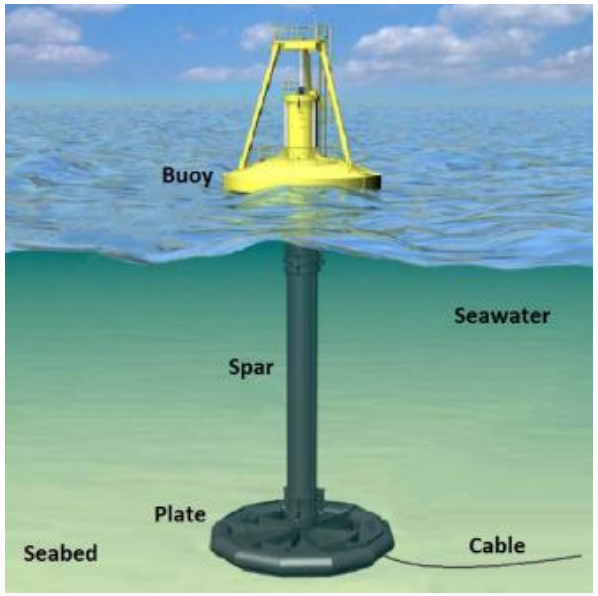
- A non-depletable source of renewable energy
- Produces no GHGs or other emissions during use.
- Allows for other land uses to coexist.
- Has a high energy return on investment (≈20:1).
- Turbines require little to no water for electricity generation.

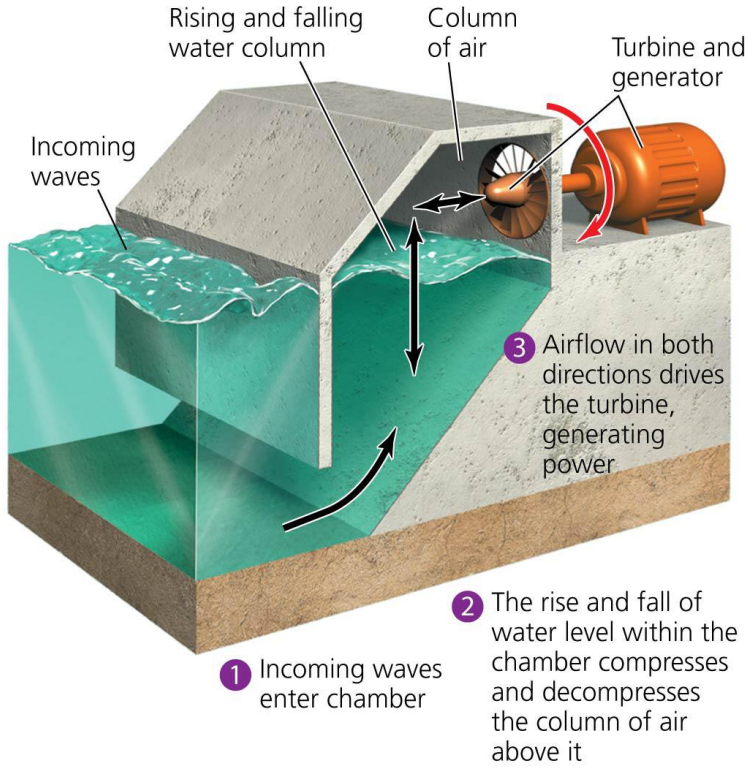
## Cons of Wind Power

- Not all sites are well suited to efficient electricity production from wind power.
- Wind is an intermittent source of power even at the best locations.
- Many of the best locations are far from population centers, requiring extensive transmission networks.
- Wind farms are typically in exposed locations and some may object for aesthetic reasons (NIMBY).
- Wind turbines pose a risk to bats and birds (especially large and migratory).
- Turbine blades last about 25 years and no recycling scheme has been devised so they are piling up in landfills.

# We can harness energy from waves

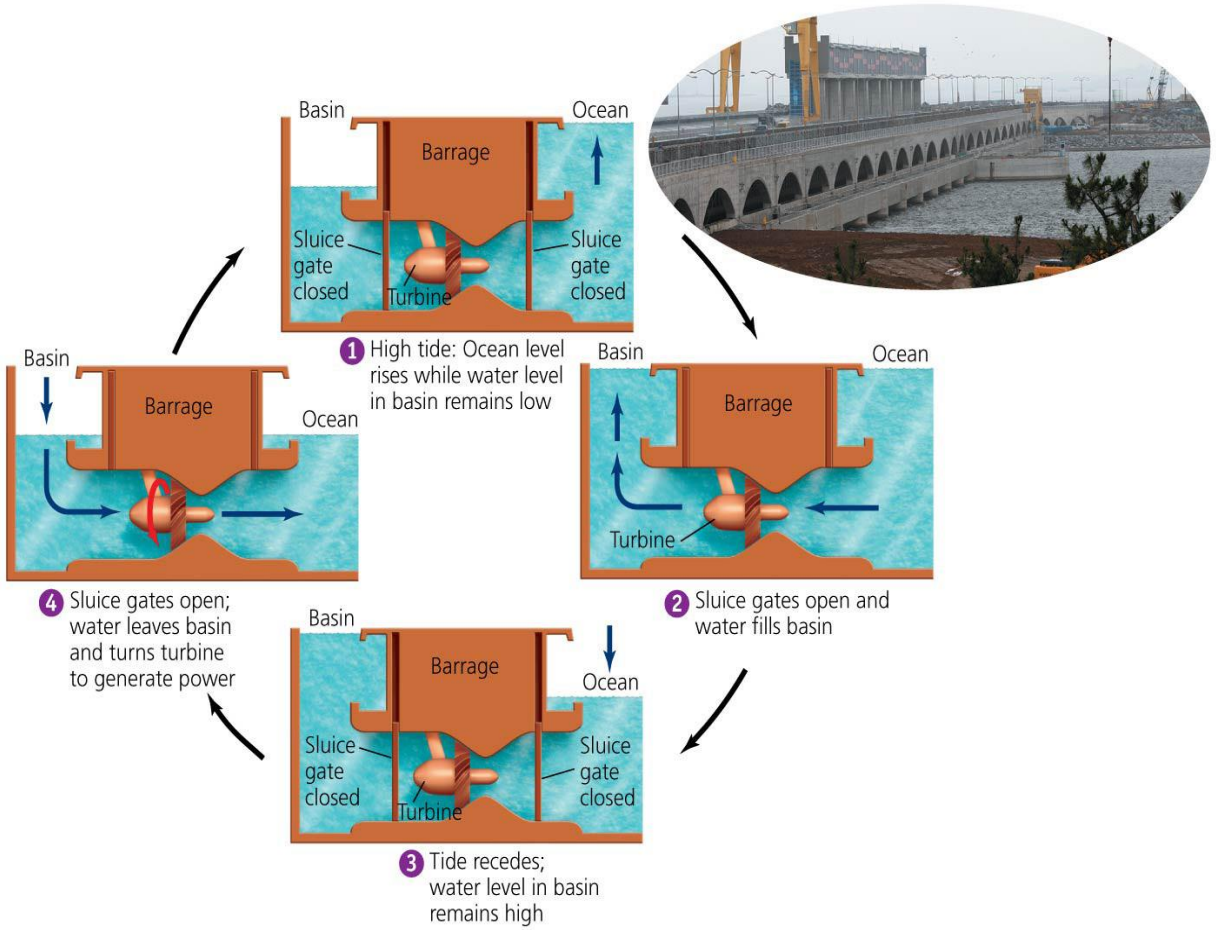
- Kinetic energy from the natural motion of ocean water can generate electrical power.
- ***Wave energy***
  - the motion of waves is harnessed and converted from mechanical energy into electricity.
  - Some designs are for offshore.
    - Involve floating devices that move up and down as the waves roll past.
    - but transmitting electricity to shore is very expensive, relative to the energy produced.
  - Some designs work along coastlines.
    - One funnels waves into elevated reservoirs.
    - Another uses waves to push air into and out of chambers, turning turbines.



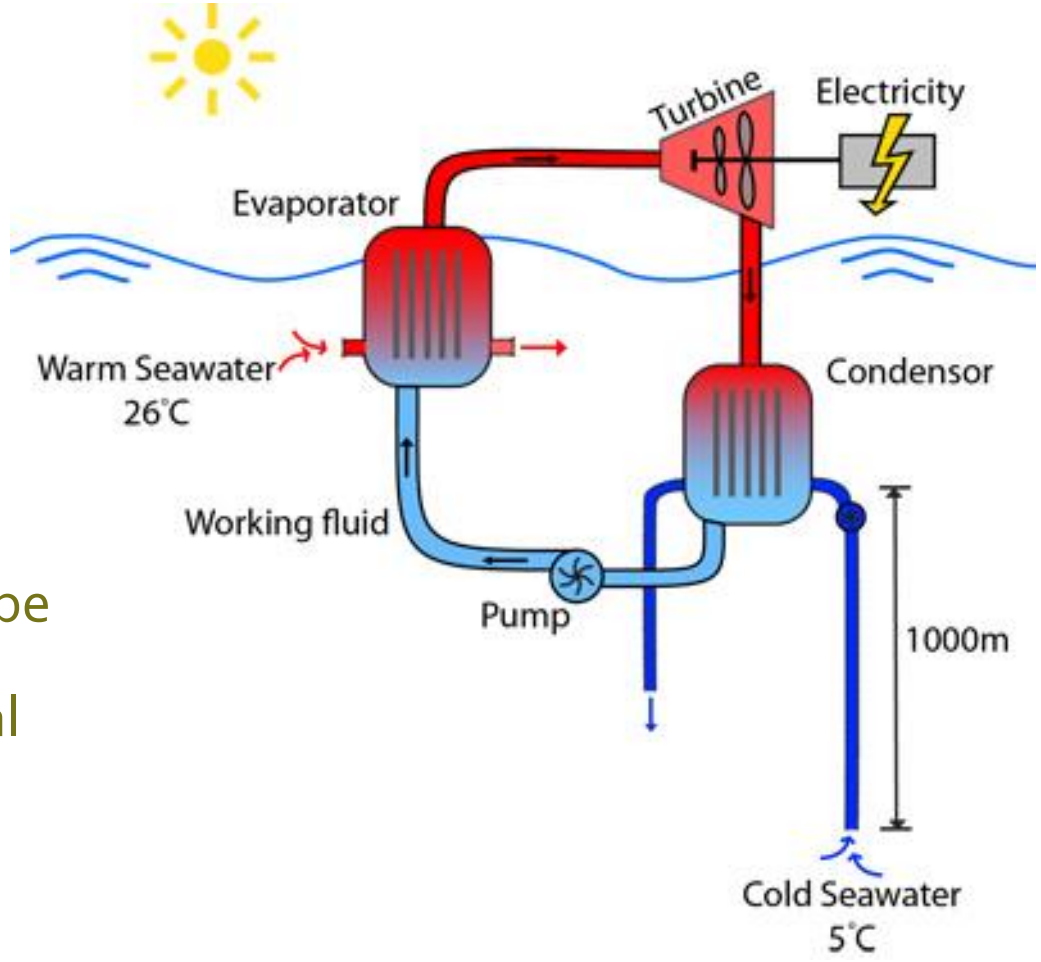
# Energy from ocean tides and currents

- The rising and falling of ocean tides each day move large amounts of water.
- ***Tidal energy***
  - energy harnessed from dams that cross the outlets of tidal basins.
  - Incoming tidal water is trapped behind gates and outgoing tides turn turbines to generate electricity.
  - Limited to areas with a large tidal range, such as those in long narrow bays (Bay of Fundy, Canada has the largest tidal power plant).
  - Tidal stations can affect the ecology of estuaries and tidal basins, much like hydroelectric dams on rivers.
- Ocean currents, such as the gulf stream, can also be used to generate electricity



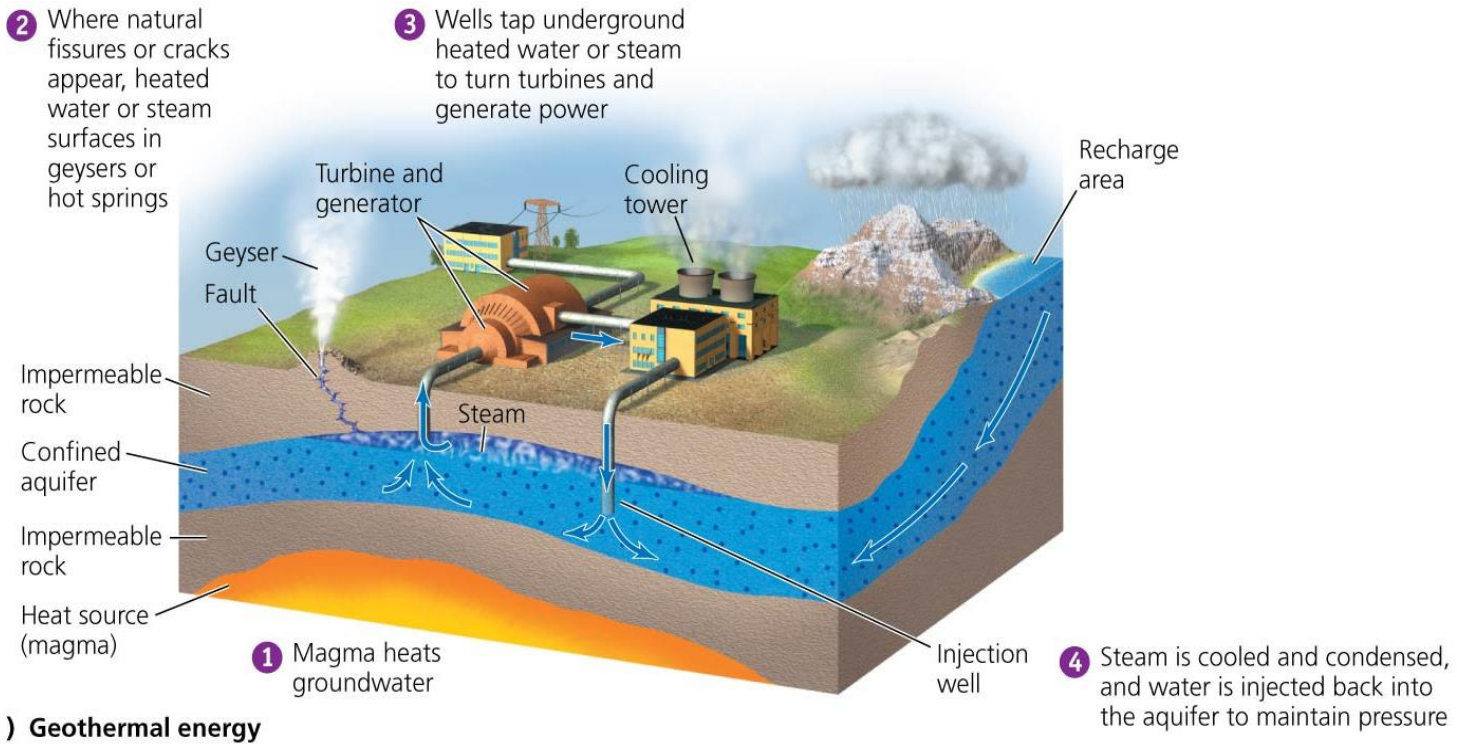
# Energy from thermal differences within the ocean

- Each day, tropical oceans absorb solar radiation equal to the heat content of 250 billion barrels of oil.
- ***Ocean thermal energy conversion (OTEC)***
  - uses temperature differences between the ocean's warm surface water and cold deep water
- Closed cycle approach
  - warm surface water evaporates volatile chemicals such as ammonia, whose vapors spin turbines to generate electricity.
  - Cold water condenses the gases back into liquids to be reused again.
  - Requires deep water immediately offshore in tropical regions, to have enough of a temperature difference in the ocean.
    - Hawaii is the only current location generating electricity from OTEC.
    - Costs are high, and the facility does not operate commercially yet.



# Geothermal Power

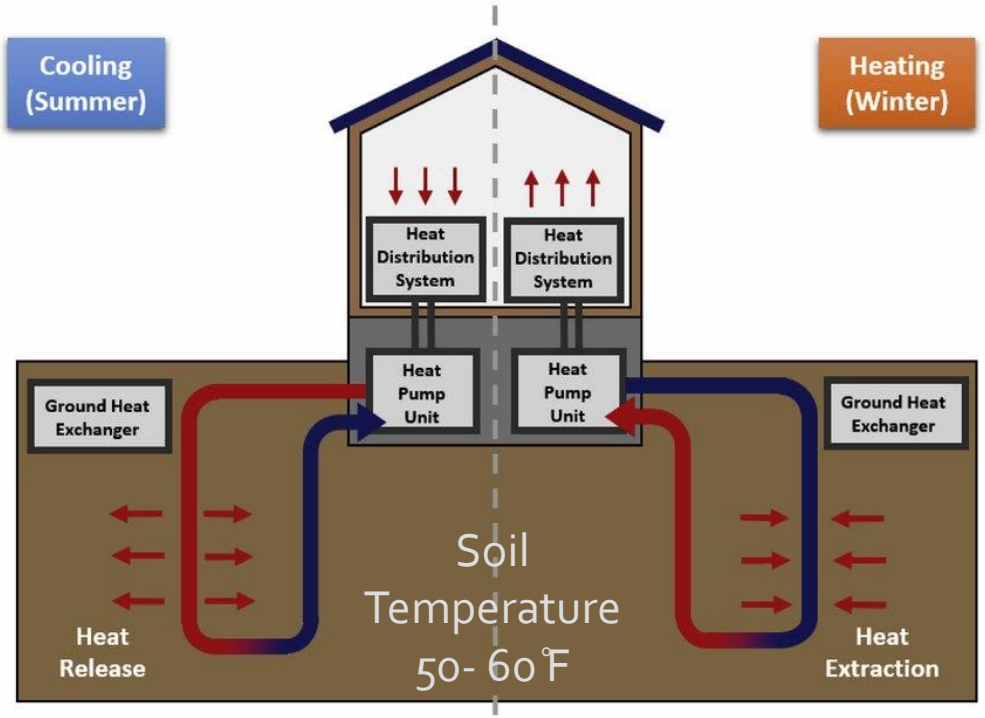
- Radioactive decay of elements deep inside the planet generates heat.
- Heat rises through magma, fissures, and cracks
- ***Traditional geothermal power***: underground aquifers heated by magma are drilled into & steam is piped up to the surface.
  - Steam can be used to heat buildings.
  - Steam can be used in centralized geothermal power plants to turn a turbine, powering a generator, and generating electricity.
  - Water is cooled in cooling tower and returned to the ground to start the process over.
- Where heat rises near Earth's surface, but water is not present, water can be pumped into the ground to generate steam (***enhanced geothermal***).



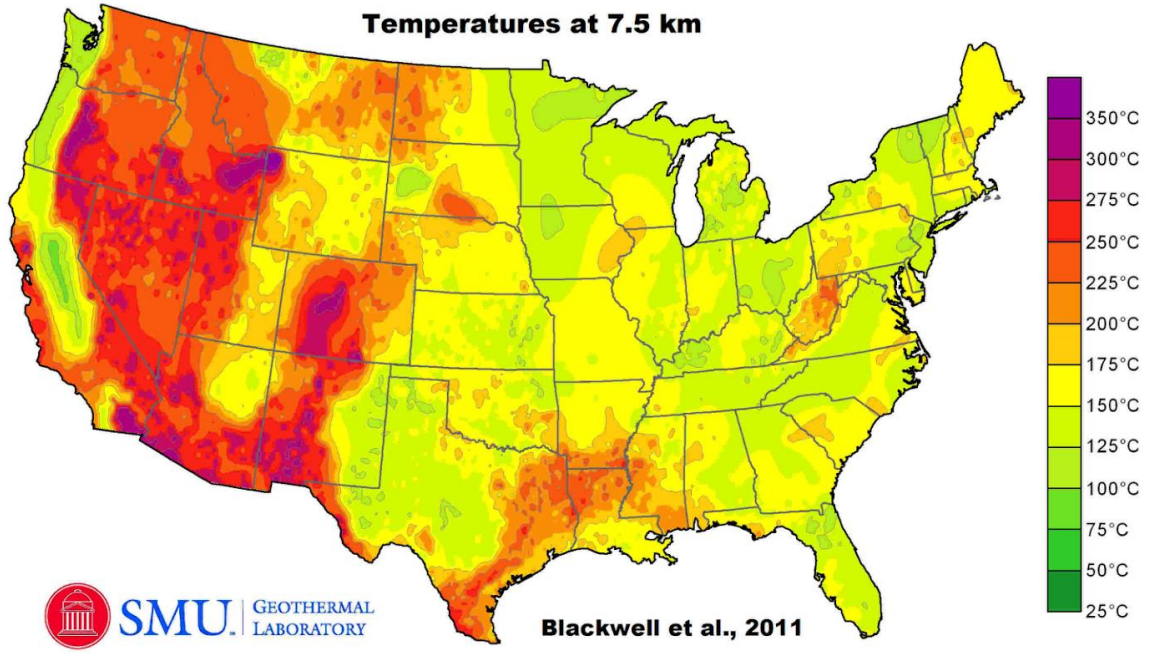

) Geothermal energy

# Ground Source Heat Pumps (GSHP's)

- Often referred to as "geothermal" but technically the heat does not come from geologic activity (comes from the ground, which stores heat from the sun)
- More accurate name is ***ground source heat pump*** (GSHP).
  - 10 feet down, the ground stays a consistent 50-60° due to holding heat from sun (**not** warmed by geothermal energy from magma - so not technically geothermal energy).
  - Heat absorbing fluid is pumped through a pipe into the ground where it either takes on heat from the ground, or gives off heat to the ground.
- In summer, heat from home transfers to liquid & liquid transfers heat to the ground, cooling house.
- In winter, liquid takes heat from ground & transfers it to the house, warming house.



# Geothermal Pros and Cons




## Pros of Geothermal

- Potentially renewable, only if water is piped back into the ground for reuse. Otherwise groundwater will be depleted.
- Much less $CO_2$ emission than FF electricity
- No release of ($PM/SO_x/NO_x/CO$) as is case with FFs.

## Cons of Geothermal

- Not everywhere on earth has access to geothermal energy reaching close enough to surface to access it. (average well depth is 7.5 km)
- Hydrogen sulfide can be released, which is toxic and can be lethal to humans & animals.
- Salts in the steam can corrode equipment make operational costs and maintenance high.
- Enhanced geothermal requires fracturing the bedrock to allow water to be injected into the heat source rock, and has been associated with an increase in earthquakes (similar to the effects of fracking)
- Cost of drilling deep enough in the earth to reach the heat source can be very high initially.

# Energy from thermal differences within the ocean

- Each day, tropical oceans absorb solar radiation equal to the heat content of 250 billion barrels of oil.
- ***Ocean thermal energy conversion (OTEC)***
  - uses temperature differences between the ocean's warm surface water and cold deep water
- Closed cycle approach
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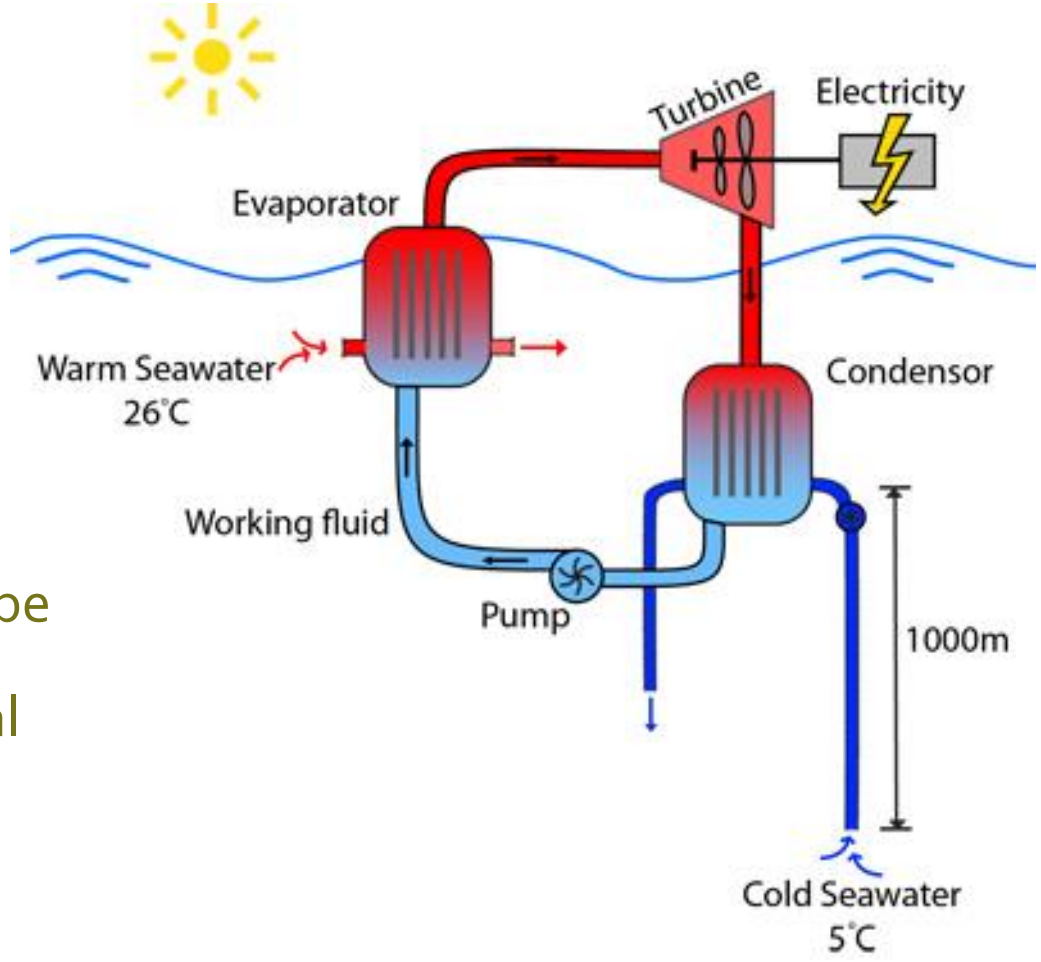
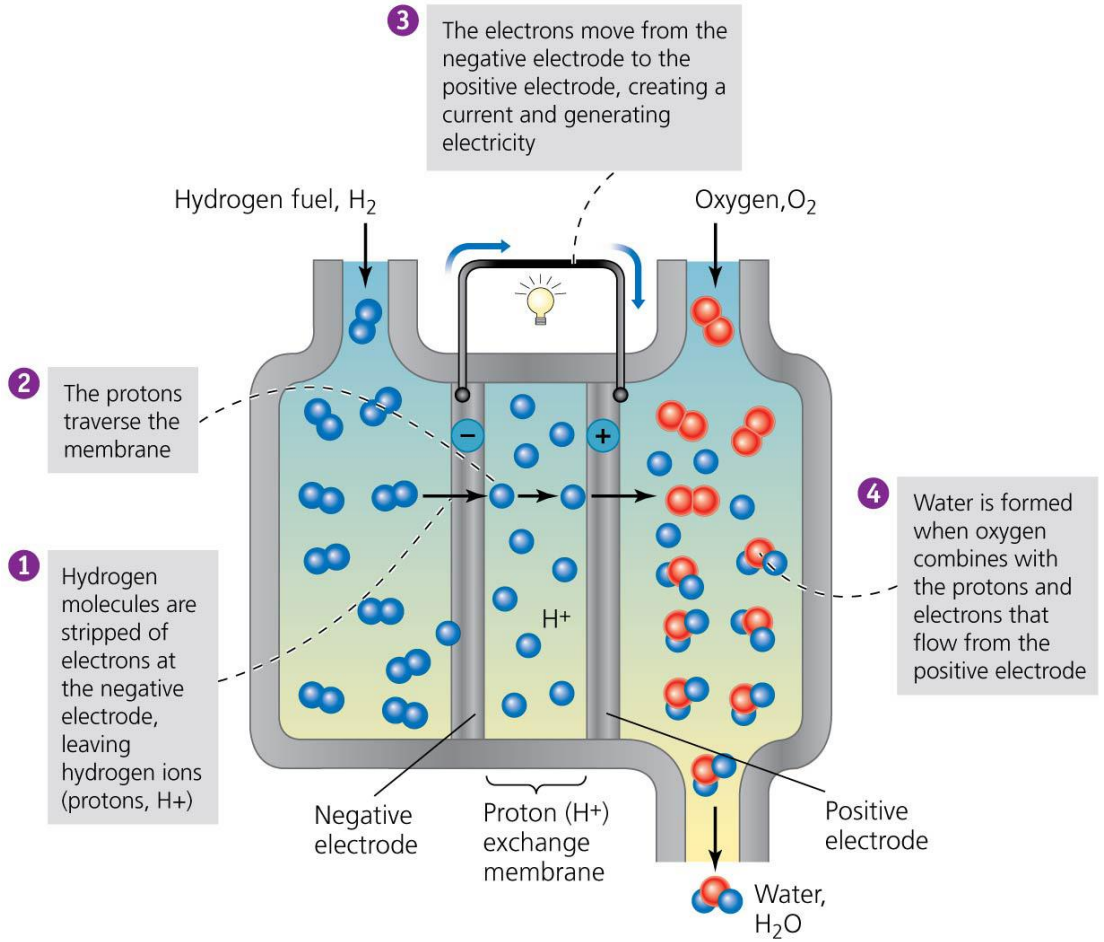


# Hydrogen Fuel Cell Basics

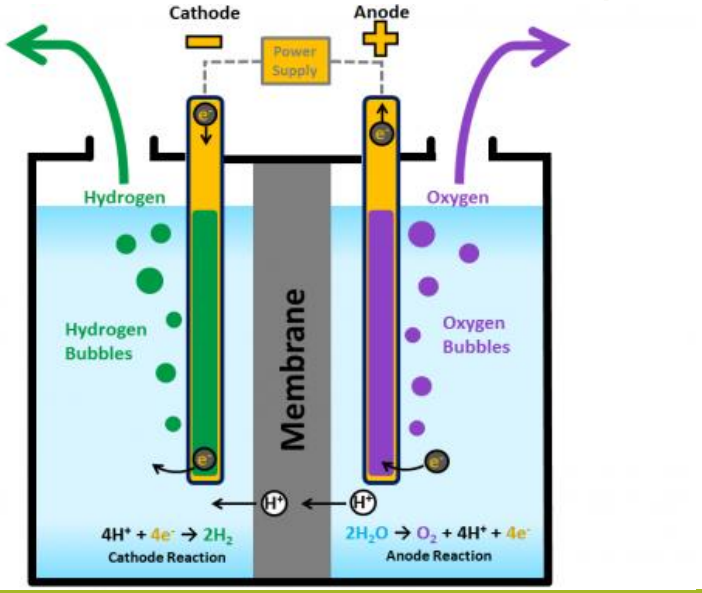
- **Use hydrogen as a renewable, alternative fuel sourc to fossil fuels.**
  - Hydrogen fuel cells store energy from other sources in hydrogen gas ($H_2$)
  - $H_2$ gas and $O_2$ are the inputs used to generate electricity; $H_2O$ is given off as a waste product.
  - Most common application of fuel cells is in vehicles where they replace gasoline (non-renewable, GHG releasing & air polluting) with $H_2$ fuel.




- **$H_2$ gas enters fuel cell from a tank of compressed hydrogen gas.**
  - A catalyst (usually platinum) strips away electrons from $H_2$, transferring the electrons to the anode of the fuel cell and forming $H^+$ in the process.
  - The remaining protons ($H^+$) move across a selective membrane to the cathode, where the positive charge pulls electrons back into the fuel cell through an external circuit.
  - The external electrical circuit of electrons can power electric motors and other electronics, before returning to the fuel cell.
  - Hydrogen atoms then combine with oxygen, pulled into the fuel cell from the surrounding air, to form water ($H_2O$) which is the waste product of fuel cell use.

# Creating Hydrogen Gas

- Key challenge to hydrogen fuel cells is obtaining pure $H_2$ gas.
  - $H_2$ does not exist in earths atmosphere naturally.
  - $H_2$ gas is obtained by splitting other molecules that contain hydrogen, most commonly water (H2O) or methane ($CH_4$).
  - Sustainability of Hydrogen fuel cells is dependent on the energy used to split and Hydrogen and the source of the hydrogen itself.




- ***Steam Reforming*** burns natural gas ($CH_4$) and uses steam to separate H2 from the methane ($CH_4$)

$$CH_4 + 2H_2O \rightarrow 4H_2 + CO_2$$

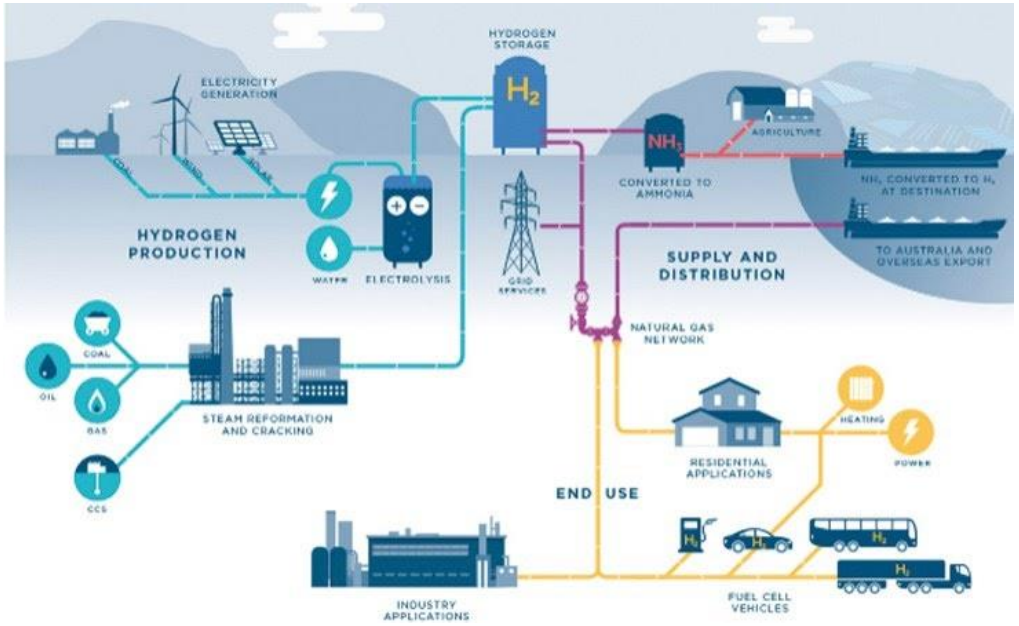
  - Requires large inputs of energy
  - Produces CO2 (a greenhouse gas)
  - Requires drilling wells to obtain methane ($CH_4$) unless sourced as a waste from feedlots, dairy operations, or landfills.
  - 95% of H2 is currently produced by steam reforming

- ***Electrolysis*** splits water to produce $H_2$

$$2H_2O \rightarrow 2H_2 + O_2$$

  - Requires energy which can be clean and sustainable if sourced from other renewable energy sources (solar, wind, hydroelectric)
  - No atmospheric pollution or solid waste production.

- Because $H_2$ gas can be stored in pressurized tanks, it can be stored for creating electricity later and/or transported to new locations.
  - Unlike solar, hydro, and wind where the electricity must be used as it is generated & relatively close to the location of generation.
  - Allows storage of energy from renewable sources when production exceeds demand (on especially sunny or windy days, power could be used for electrolysis and energy stored in $H_2$ gas)




# Benefits of Hydrogen

- Can replace gasoline for fueling vehicles
- As a gasoline replacement, it emits no air pollutants ($NO_x$/PM/CO) and only $H_2O$ (tech. a GHG) no $CO_2$
  - Hydrogen fuel cell vehicles use electric motors which are much quieter than gas or diesel engines, thereby reducing noise pollution
  - H fuel cells are ≈80% efficient in converting chemical energy in $H_2$ & $O_2$ into electricity (Coal PP ≈35% efficient)
  - Pressurized (liquefied $H_2$) is no more dangerous than gasoline (fire and explosion risk in a car accident)
- Hydrogen gas is used in manufacture of many different industrial chemicals requiring $H_2$ gas

# Video Resources

- Renewable Energy
  - https://www.youtube.com/watch?v=B8WuEyL-YNY&feature=emb_logo