Objectives, EKs, and Skill
Unit 6: Energy

LEARNING OBJECTIVE

ENG-3.A

Identify differences between nonrenewable and renewable energy sources.

SUGGESTED SKILL

Concept Explanation

1.C

Explain environmental concepts, processes, or models in applied contexts.

ESSENTIAL KNOWLEDGE

ENG-3.A.1

Nonrenewable energy sources are those that exist in a fixed amount and involve energy transformation that cannot be easily replaced.

ENG-3.A.2

Renewable energy sources are those that can be replenished naturally, at or near the rate of consumption, and reused.

6.1 Renewable vs. Nonrenewable Energy Sources

Renewable vs. Nonrenewable

Renewable Energy Sources

Can be replenished naturally, at or near rate of consumption & reused.

- Depletable renewables can run out if overused
  - *Ex: Biomas (wood, charcoal, ethanol)*
- Nondepletable renewables do not run out if overused
  - *Ex: Solar, wind, hydroelectric, geothermal*

Nonrenewable Energy Sources

Exist in fixed amounts on earth & can't easily be replaced or regenerated

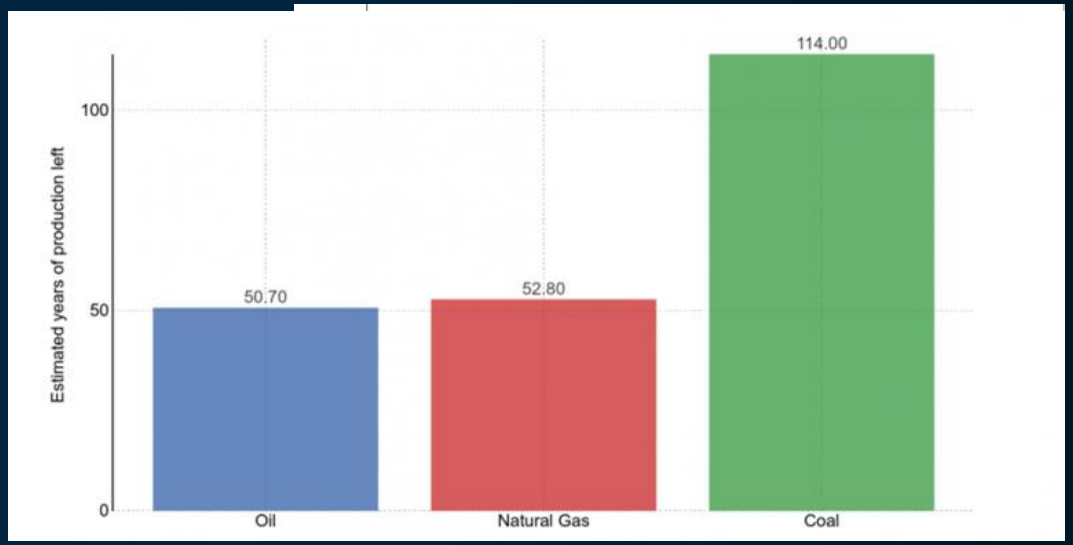
- Fossil Fuels Fossilized remains of ancient biomass that take **millions** of years to form
  - *Coal, Oil, Nat. Gas*
- Nuclear: energy generated from uranium or other radioactive fuels

Key to Renewable Energy

Rate of Consumption

- Rate of use must be **at or below rate of regeneration** for renewables

- Fossil fuels will run out because they take far **longer to regenerate than the rate we use them**



SUGGESTED SKILL

Concept Explanation

1.C

Explain environmental concepts, processes, or models in applied contexts.

Practice FRQ 6.1

Explain whether or not biomass is a renewable energy source.
Justify your answer

6.2 Global Energy Consumption

Objectives, EKs, and Skill

LEARNING OBJECTIVE

ENG-3.B

Describe trends in energy consumption.

SUGGESTED SKILL

Mathematical Routines

6.C

Calculate an accurate numeric answer with appropriate units.

ESSENTIAL KNOWLEDGE

ENG-3.B.1

The use of energy resources is not evenly distributed between developed and developing countries.

ENG-3.B.2

The most widely used sources of energy globally are fossil fuels.

ENG-3.B.3

As developing countries become more developed, their reliance on fossil fuels for energy increases.

ENG-3.B.4

As the world becomes more industrialized, the demand for energy increases.

ENG-3.B.5

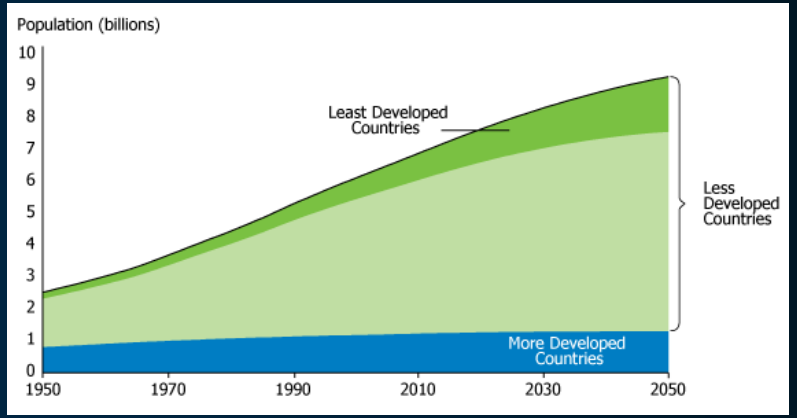
Availability, price, and governmental regulations influence which energy sources people use and how they use them.

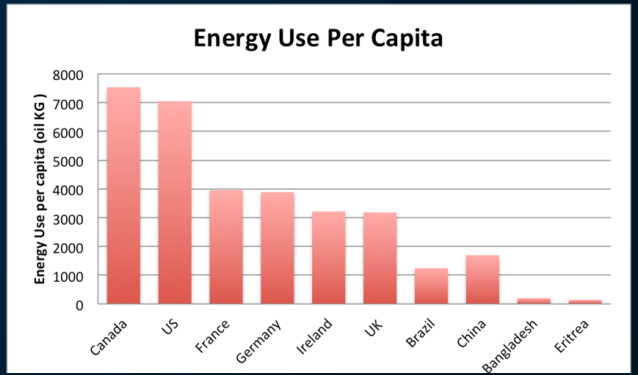
Developed vs. Developing Countries

Developed nations use more energy on a per capita basis, but developed nations use more energy in total (higher pop.)

- The avg. US resident uses 5x as much energy as the world avg.

- Developing nations are still industrializing & pop. is still growing rapidly
  - It will also increase on a per/person basis as their economies industrialize & residents achieve higher standards of living



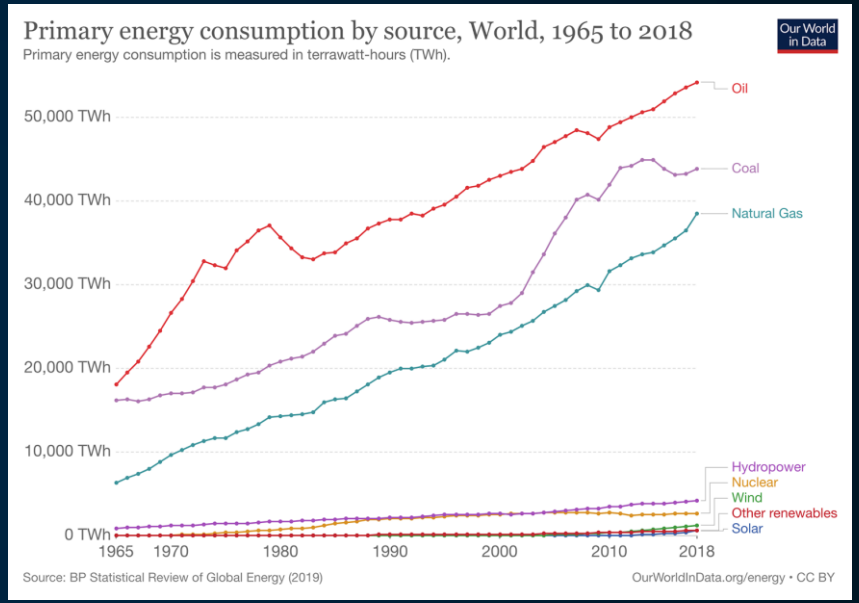


Fossil Fuels: Most Used Energy Source

Fossil fuels are by far the most common fuel source globally

- Oil ⇒ gasoline = main fuel for vehicles
- Coal = main fuel for electricity gen.
- Nat. gas = secondary fuel for electricity gen. & main fuel for heating

- Hydroelectric energy (dams used to create electricity) are second largest source
  - Water spins a turbine which generates electricity
- Nuclear is the third largest source
  - Uranium fission releases heat to turn water into steam to turn a turbine to gen. electricity

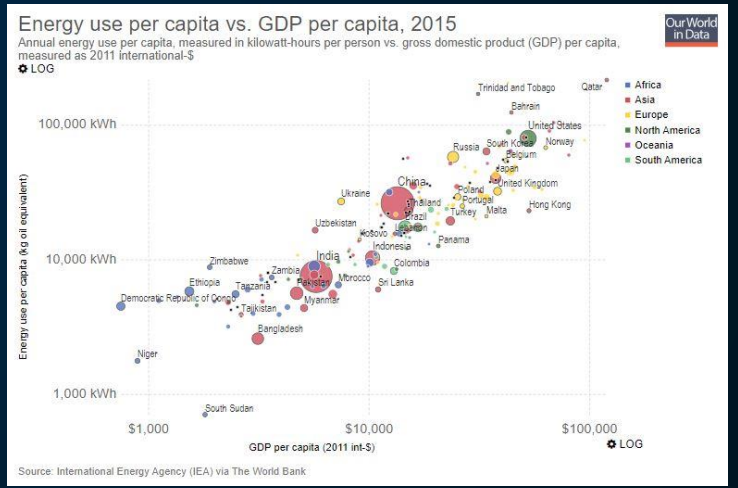


Development Increases Fossil Fuel Consumption

- Many residents of less developed nations depend on **subsistence fuels** - biomass that they can easily gather/purchase
  - *Ex: wood, charcoal, dried animal manure*
  - *Can drive deforestation*

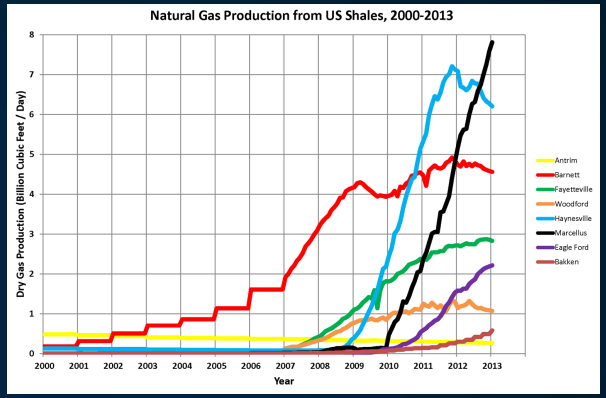
- Econ. development → affluence (wealth) → higher per capita GDP → energy use

As developing nations develop, fossil fuel consumption will increase
  - Oil → Gasoline for vehicles
  - Coal & Nat. gas → electricity
    - Electricity demand for homes & manufacturing

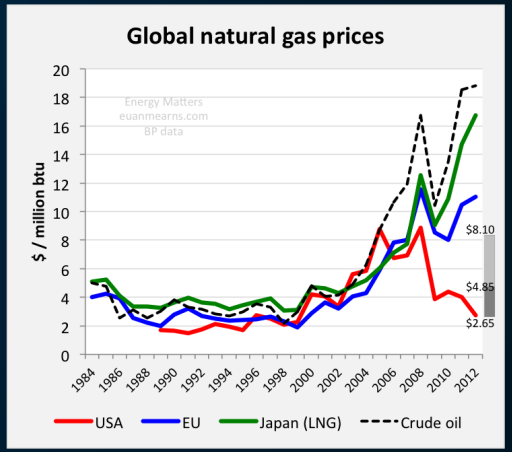


Factors That Affect Energy Source Use

- **Availability**: Fossil fuel use depends on discovered reserves & accessibility of these reserves
  - *Use of FFs varies heavily with availability*

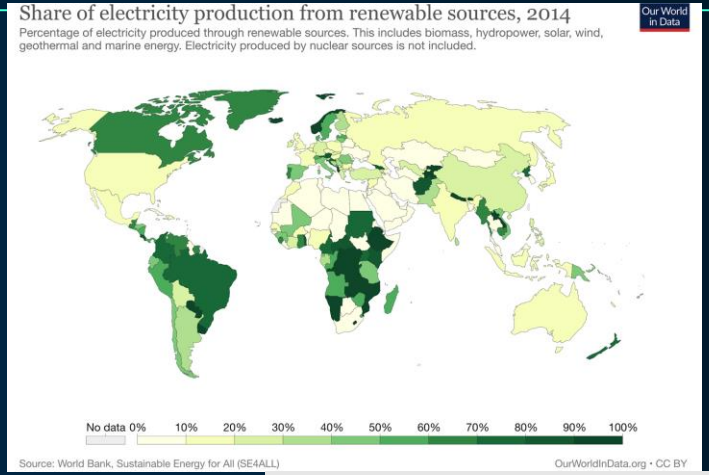


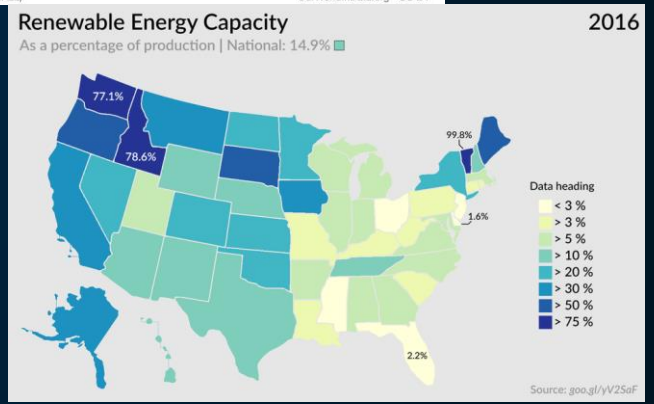
- **Price**: FF Prices fluctuate dramatically with discovery of new reserves or depletion of existing ones
  - Fracking opens new NG reserves, increasing availability, decreasing price, increasing use



Factors That Affect Energy Source Use

- **Gov. Regulation**: gov. can mandate certain energy source mixes (25% renewable by 2025)
- Gov. **CANNOT** directly raise or lower prices of energy sources (ex: raise gas to $10/gallon)
- Gov. **CAN** use:
  - Taxes increases to **discourage** companies from building FF power plants
  - Rebates, or tax credits to **encourage** companies building renewable energy power plants





Practice FRQ 6.2

SUGGESTED SKILL

Mathematical Routines

6.C

Calculate an accurate numeric answer with appropriate units.

From 2005 to 2018, the annual investment in renewable energy sources in the United States increased from $11.4 billion to $46.5 billion. **Calculate** the percent change in renewable energy investment in the US from 2005 to 2018.

Experts estimate that for the US to reach 100% renewable energy in 2050, it will require $7.8 trillion. **Calculate** the percent change this would represent from the 2018 investment level of $46.5 billion.

6.3 Fuel Types and Uses

Objectives/EKs/Skills

LEARNING OBJECTIVE

ENG-3.C

Identify types of fuels and their uses.

SUGGESTED SKILL

Concept Explanation

1.A

Describe environmental concepts and processes.

ESSENTIAL KNOWLEDGE

ENG-3.C.1

Wood is commonly used as fuel in the forms of firewood and charcoal. It is often used in developing countries because it is easily accessible.

ENG-3.C.2

Peat is partially decomposed organic material that can be burned for fuel.

ENG-3.C.3

Three types of coal used for fuel are lignite, bituminous, and anthracite. Heat, pressure, and depth of burial contribute to the development of various coal types and their qualities.

ENG-3.C.4

Natural gas, the cleanest of the fossil fuels, is mostly methane.

ENG-3.C.5

Crude oil can be recovered from tar sands, which are a combination of clay, sand, water, and bitumen.

ENG-3.C.6

Fossil fuels can be made into specific fuel types for specialized uses (e.g., in motor vehicles).

ENG-3.C.7

Cogeneration occurs when a fuel source is used to generate both useful heat and electricity.

Subsistence Fuels

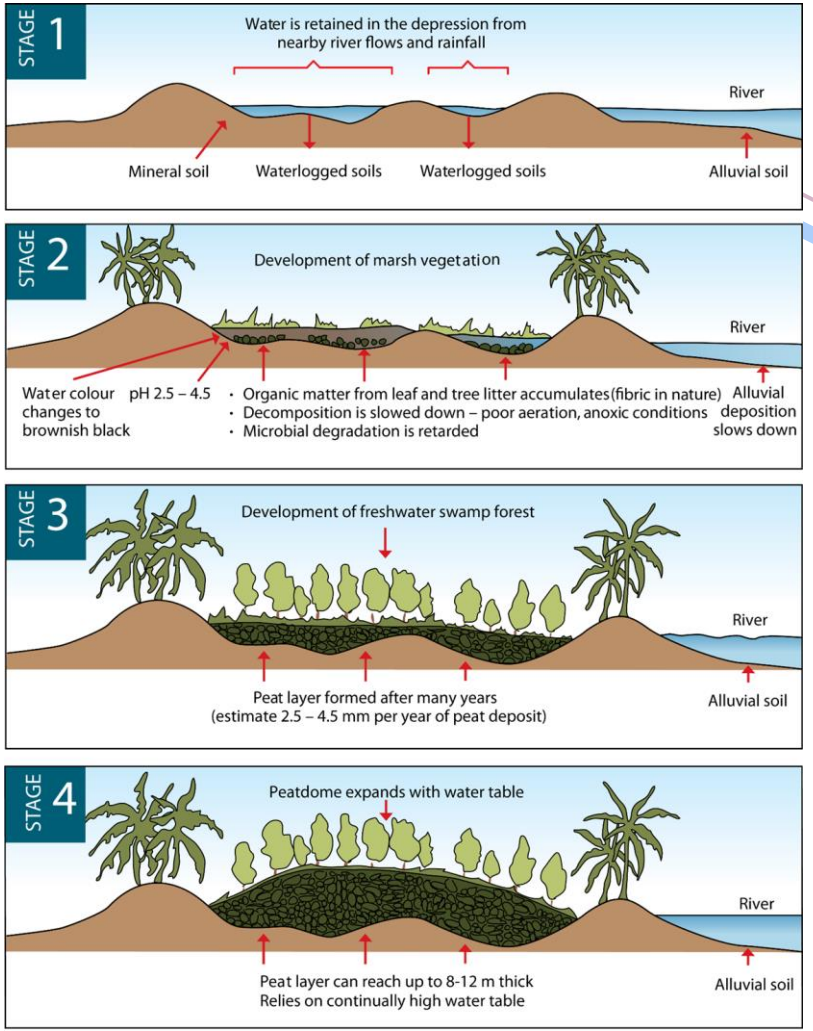
- Biomass fuel sources that are easily accessible (can be found and gathered by hand); often used in developing countries as a home heating or cooking fuel

Wood (and charcoal) are two of the most common fuel sources in developing nations

- Wood is free/cheap to cut down and utilize as fuel; can cause deforestation & habitat loss
- Charcoal is made by heating wood under low oxygen conditions for a long time

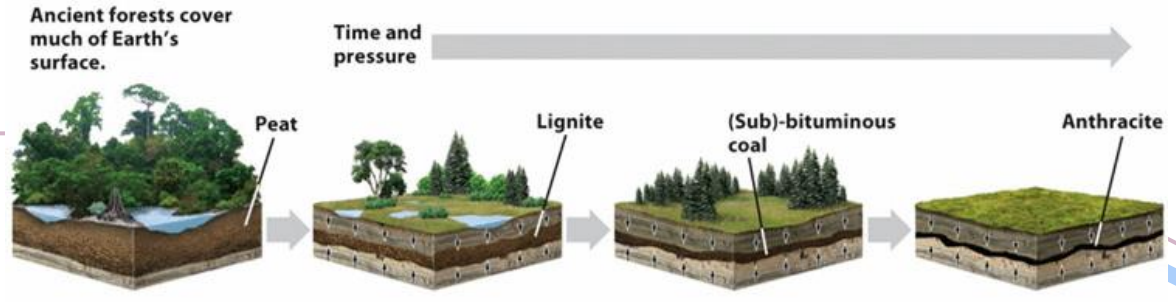
Peat is partially decomposed organic matter (often ferns or other plants) found in wet, acidic ecosystems like bogs and moors

- Can be dried and used as a biomass fuel source



Coal Formation

- Pressure from overlying rock & sediment layers compacts peat into coal over time



⛰ **In order of energy density & quality: lignite → bituminous → anthracite**

- The deeper a coal reserve is buried, the more pressure from overlying rock layers & the more energy dense

⛰ **Because higher energy density means more energy released when a fuel source is burned, anthracite is the most valuable form of coal (highest quality)**

- Coal is burned to heat water into steam, to turn a turbine that generates electricity
  - More dense coal = hotter/longer fire = more steam = more electricity

Natural Gas

- Decaying remains of plants & animals (mostly marine life) are buried under layers of rock & converted by pressure into oil (petroleum) and natural gas over time

Natural gas is mostly methane (CH_4) and is found on top of trapped oil (petroleum) deposits

Fossil Fuel Emission Levels
- Pounds per Billion Btu of Energy Input

Pollutant	Natural Gas	Oil	Coal
Carbon Dioxide	117,000	164,000	208,000
Carbon Monoxide	40	33	208
Nitrogen Oxides	92	448	457
Sulfur Dioxide	1	1,122	2,591
Particulates	7	84	2,744
Mercury	0.000	0.007	0.016

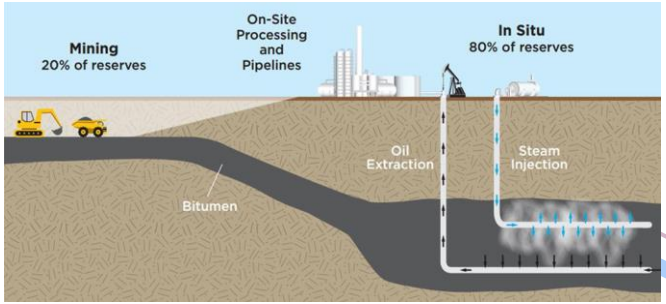
- Forms when oil is trapped in a porous, sedimentary rock, underneath a harder, impermeable rock layer that doesn't let the gas escape

Considered the "cleanest" fossil fuel (produces the fewest air pollutants & least CO_2 when burned)

- Produces about ½ as much CO_2 as coal when burned to generate electricity
- Produces virtually no PM (ash/soot)
    - Produces far less SO_x, NO_x than coal or oil, and NO MERCURY

Crude Oil (petroleum)

- Decaying organic matter trapped under rock layers is compressed into oil over time



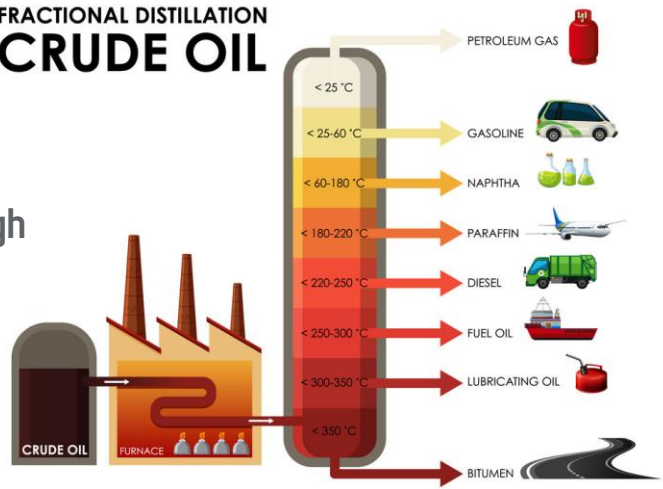
⛰ **Extracted by drilling a well through the overlying rock layers to reach the underground deposit and then pumping liquid oil out under pressure**

⛰ **Can also be recovered from <u>tar sands</u> (combination of clay, sand, water, and bitumen)**

- Bitumen is a thick, sticky, semi-solid form of petroleum (not liquid)
- Extracting & using oil from tar sands is extremely energy and water intensive
  - Lots of water needs to be heated (requiring energy) to create steam that's piped down into the tar sand to melt the bitumen into a liquid that can flow up a pipe
  - Lots more water is used to separate the oil from all of the impurities (sand, clay) at the refinery

Fossil Fuel Products

Crude oil (petroleum) is converted into lots of different products through the process of <u>fractional distillation</u>



- Crude oil is burned in a furnace and vapor passes into a column where different hydrocarbons are separated based on their boiling points
- Hydrocarbons w/lower boiling points gather at the top of the column, higher boiling points gather at bottom
- Different hydrocarbons within petroleum are used for different products
  - Petroleum gas
  - Gasoline (fuel for cars)
  - Naphtha (used to make plastic)
  - Jet fuel
  - Diesel fuel
  - Motor oil
  - Bitumen (asphalt for roads)

Practice FRQ 6.3

SUGGESTED SKILL

Concept Explanation

1.A

Describe environmental concepts and processes.

Natural gas is considered to be a better fossil fuel for the environment than coal is. **Explain** TWO environmental benefits of using natural gas as a fuel compared to using coal.

6.4 Distribution of Natural Energy Resources

Objective/EKs/Skill

LEARNING OBJECTIVE

ENG-3.D

Identify where natural energy resources occur.

ESSENTIAL KNOWLEDGE

ENG-3.D.1

The global distribution of natural energy resources, such as ores, coal, crude oil, and gas, is not uniform and depends on regions' geologic history.

SUGGESTED SKILL

Visual Representations

2.B

Explain relationships between different characteristics of environmental concepts, processes, or models represented visually:

- In theoretical contexts
- In applied contexts

FF Energy Reserves

Coal

~100-150 Years

1. US
2. Russia
3. China
4. Australia

Natural Gas

~50-60 Years

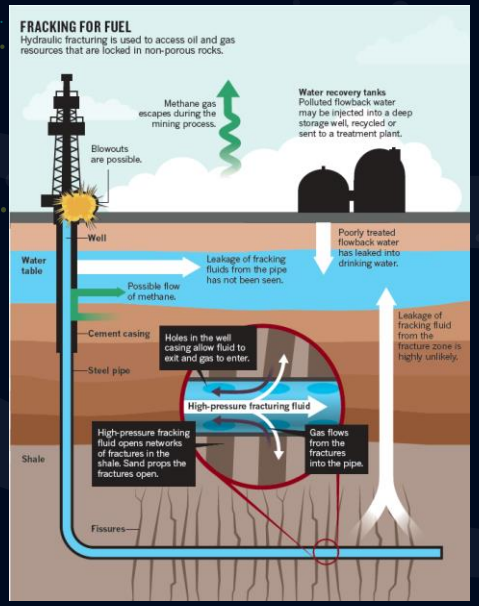
1. Russia
2. Iran
3. Qatar
4. US
5. Saudi Arabia

Oil

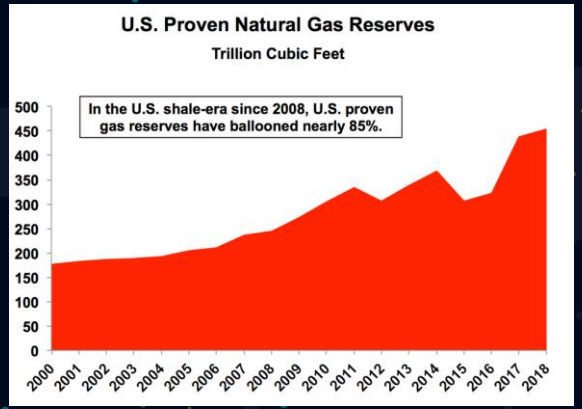
~50 Years

1. Venezuela
2. Saudi Arabia
3. Iran
4. Canada
5. Iraq

Fracking & Shale Gas



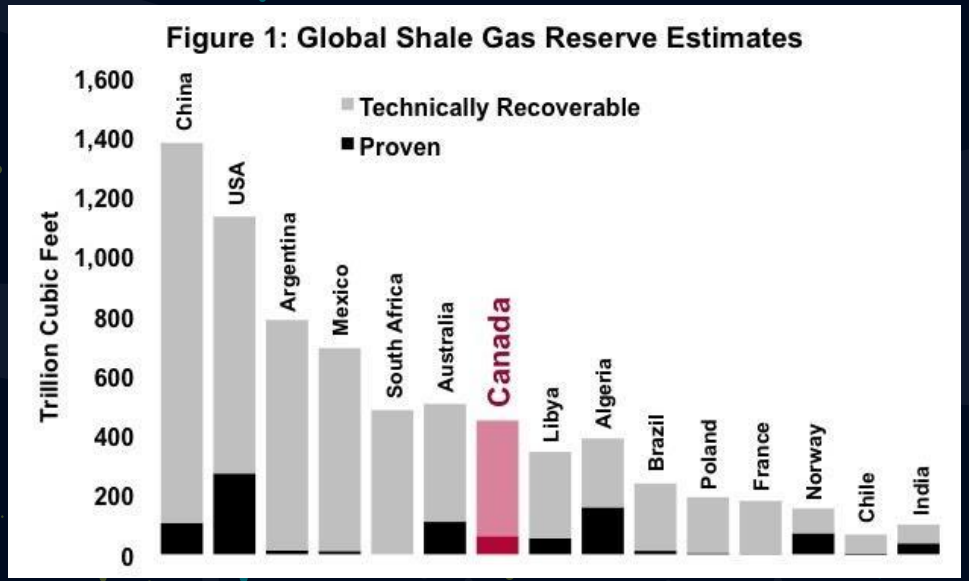
- Hydraulic fracturing (aka fracking) is a method of natural gas extraction that has extended access to natural gas
    - Gas trapped in semi-permeable, sedimentary rock layers, such as shale, is released by cracking the rock with pressurized water



Fracking natural gas from shale rock increases & extends supply of natural gas

Shale Gas Reserves

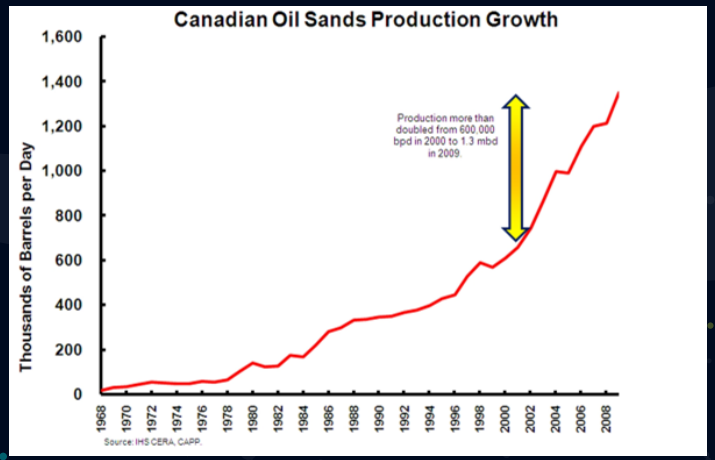
- FFs are non-renewable, and will eventually be depleted, but short-term economic profit still drives extraction & use
  - Discovered, but unharvested reserves represent economic benefit to countries



Tar/Oil Sands

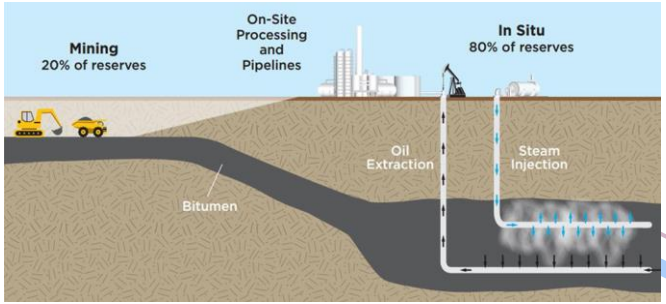
- Tar or oil sands are bitumen deposits where crude oil can be recovered, but with higher water & energy inputs

- **Canada (Alberta region) = world's largest oil sands reserve**
  - Just like fracking, tar/oil sands extraction extends the world's supply of crude oil



Crude Oil (petroleum)

- Decaying organic matter trapped under rock layers is compressed into oil over time



⛰ **Extracted by drilling a well through the overlying rock layers to reach the underground deposit and then pumping liquid oil out under pressure**

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Fossil Fuel Products

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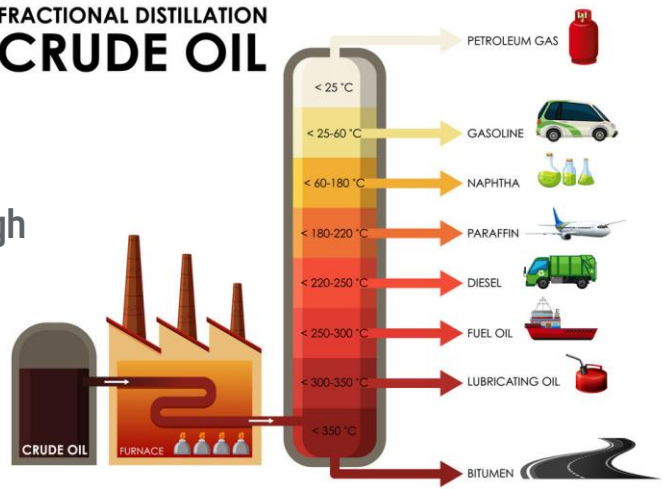

- Crude oil is burned in a furnace and vapor passes into a column where different hydrocarbons are separated based on their boiling points
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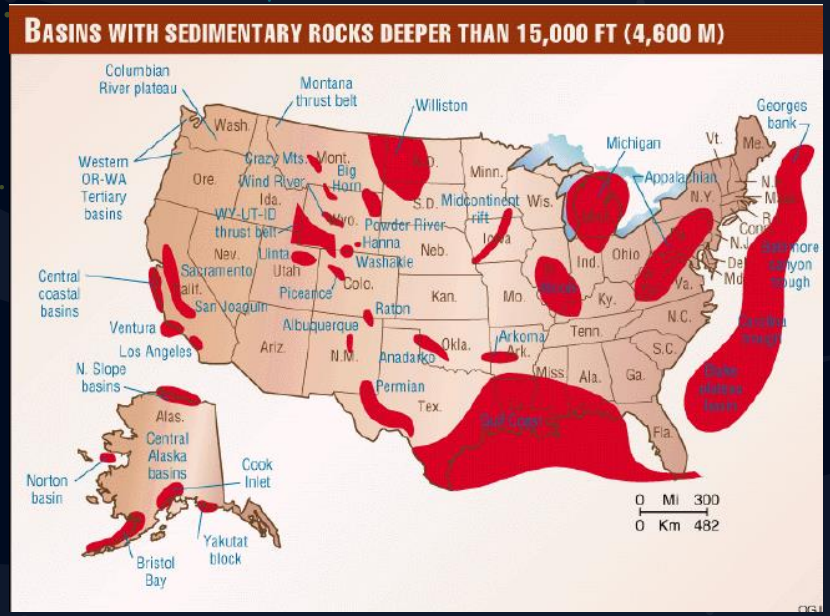
Practice FRQ 6.4



Identify a region of the United States that is likely to be a large producer of natural gas.

Describe the geological features associated with natural gas reserves.

SUGGESTED SKILL

Visual Representations

2.B

Explain relationships between different characteristics of environmental concepts, processes, or models represented visually:

- In theoretical contexts
- In applied contexts

6.5
Fossil Fuels

Objectives/EKs/Skills

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
ENG-3.E Describe the use and methods of fossil fuels in power generation.	**ENG-3.E.1** The combustion of fossil fuels is a chemical reaction between the fuel and oxygen that yields carbon dioxide and water and releases energy. **ENG-3.E.2** Energy from fossil fuels is produced by burning those fuels to generate heat, which then turns water into steam. That steam turns a turbine, which generates electricity. **ENG-3.E.3** Humans use a variety of methods to extract fossil fuels from the earth for energy generation.
ENG-3.F Describe the effects of fossil fuels on the environment.	**ENG-3.F.1** Hydrologic fracturing (fracking) can cause groundwater contamination and the release of volatile organic compounds.

SUGGESTED SKILL

Environmental Solutions

7.A

Describe environmental problems.

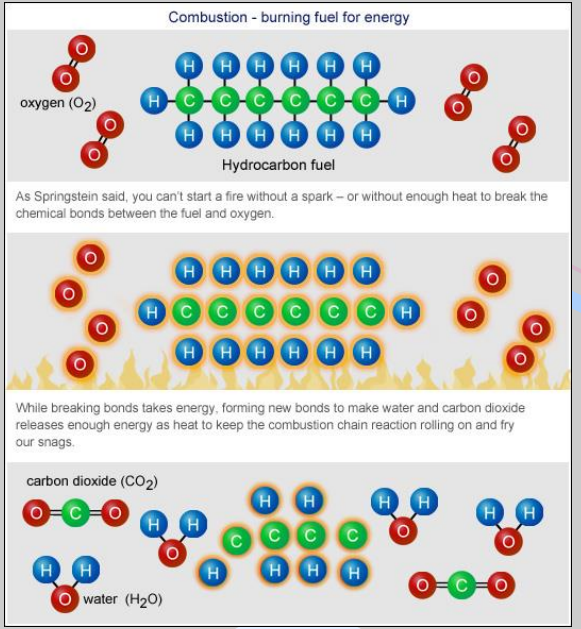
Fossil Fuel Combustion

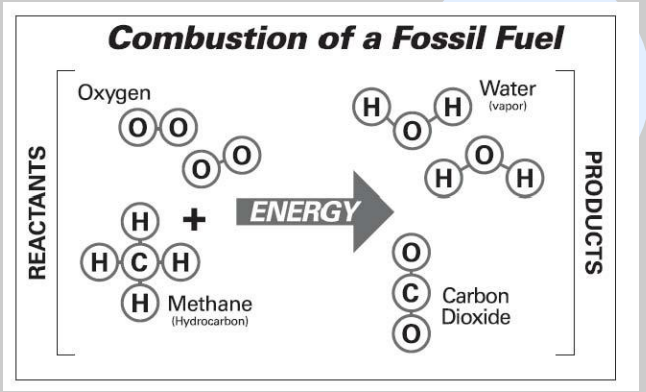
- Reaction between Oxygen (O_2) & fossil fuels (hydrocarbons) that releases energy as heat and produces CO_2 & H_2O as products

Remember: Combustion is a step in the **CARBON** cycle: hydro**CARBONS** (FFs) are burned to release energy & the **carbon** stored in them reacts with O_2 in the air to form CO_2

Methane (natural gas), gasoline, propane, butane, coal are all fossil fuels (hydrocarbons) that release energy in the same way

Wood and biomass work the same, carbon is burned & reacts with O_2 to form CO_2 & give off energy





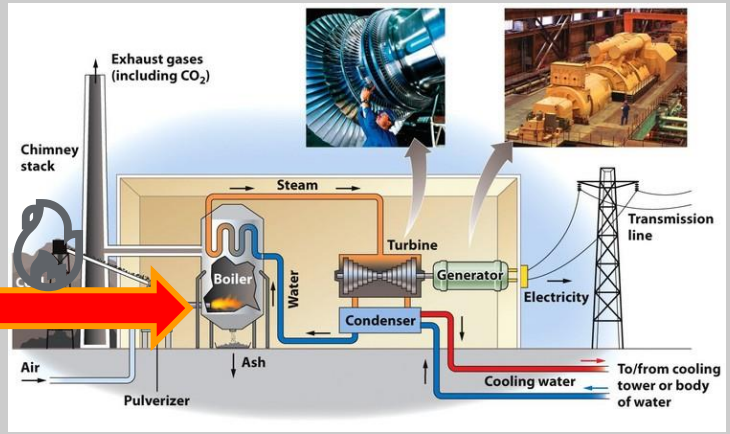
FF to Generate Electricity

- The #1 source of electricity production globally is coal, followed by natural gas

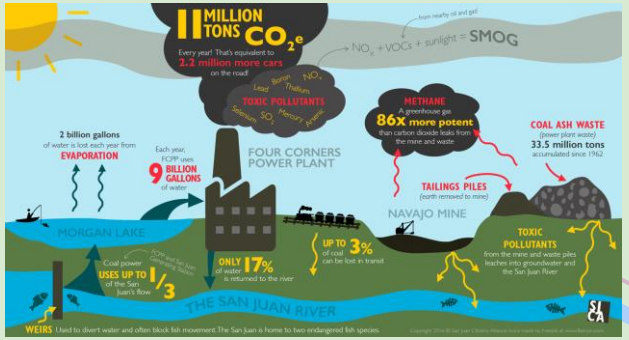
These steps of electricity gen. are the same, no matter what you're burning to produce the initial heat

Heat → Water into Steam → Steam turns a turbine → Turbine powers generator → Generator produces electricity

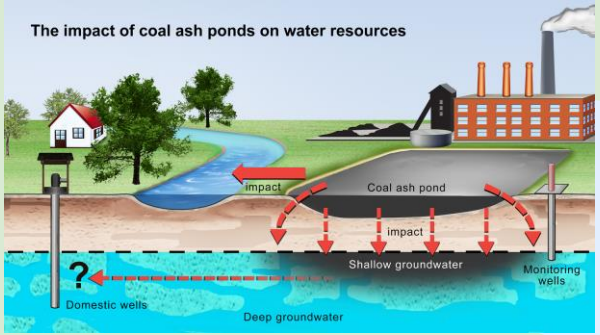
Coal, oil, natural gas, biomass, and trash can all be burned to drive this same process and create energy. Even nuclear energy work similarly, with nuclear fission producing the initial heat



Environmental Consequences: Coal



- **Habitat destruction to clear land for mining**
- **Produces pollutants & releases CO_2 (GHG → global warming)**
  - Releases more CO_2 than any other FF when burned for electricity gen.
  - Releases PM (soot, ash) which can irritate respiratory tracts of humans/animals
  - Produces toxic ash contaminated with lead, mercury, and arsenic
    - Taken to landfills or stored in ash ponds; both can leak into ground/surface waters, or into soil
  - Releases SO_x & NO_x (sulfur and nitrogen oxides) which irritate resp. systems, and contribute to smog and acid precipitation



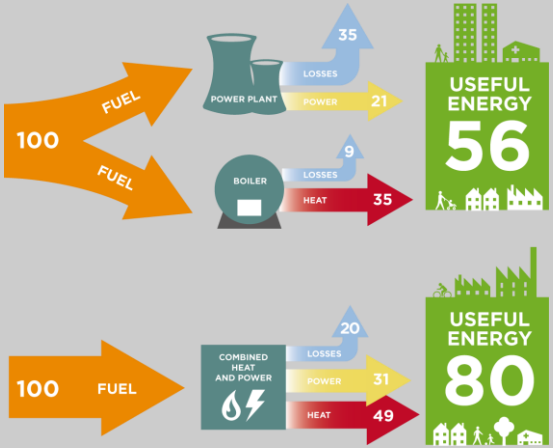
Generating Electricity

- Coal is ~30% efficient as a fuel source for generating electricity (30% of energy from the bonds in the hydrocarbons are converted to electricity)
  - Nat. Gas is ~60% efficient when it's burned to generate electricity

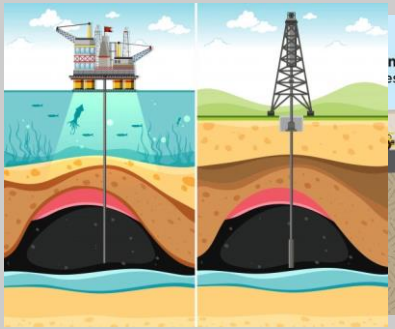
Much of the energy "lost" or not converted into electricity escapes as heat

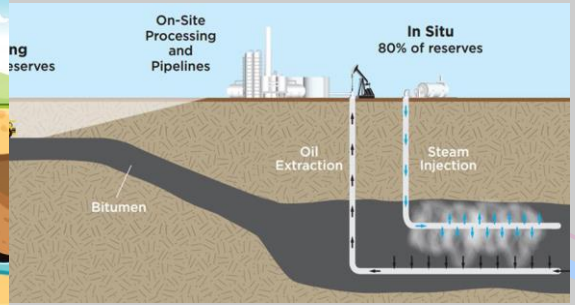
Cogeneration: when the heat produced from electricity generation is used to provide heat (air & hot water) to a building;

CHP (Combined Heat and Power) systems are close to 90% efficient (much better than coal/NG alone)



Oil/Petroleum Extraction





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Can also be recovered from <u>tar sands</u> (combination of clay, sand, water, and bitumen)

- Bitumen is a thick, sticky, semi-solid form of petroleum (not liquid)
- Extracting & using oil from tar sands is extremely energy and water intensive
  - Lots of water needs to be heated (requiring energy) to create steam that's piped down into the tar sand to melt the bitumen into a liquid that can flow up a pipe
  - Lots more water is used to separate the oil from all of the impurities (sand, clay) at the refinery

Environmental Consequences: Tar Sands

⚠ **Habitat destruction to clear land for: roads, drilling equipment, digging throu ground surface to reach deposits (biodiv. loss)**

⚠ **Ground or nearby surface water depletion (H_2O needed for steam & for wa impurities from bitumen at refinery)**

- 🚱 Water contamination: tailing ponds (holes dug for storing wastewater) can overflow & run into nearby surface waters, or leach into groundwater
  - Benzene (carcinogen) salts, acids, hydrocarbons, bitumen
  - All toxic to plant and animals
- CO_2 released by machinery during extraction, transport, refinement

Environmental Consequences: Crude Oil/Petroleum

Possibility of spill (either from tanker ships or pipelines breaking

- Spills in water = crude oil covering sun, clogging fish gills, suffocating many ocean animals, sticking to bird feathers
- Spills on land = toxic to plant roots, surface or groundwater contamination (with hydrocarbons/crude oil)

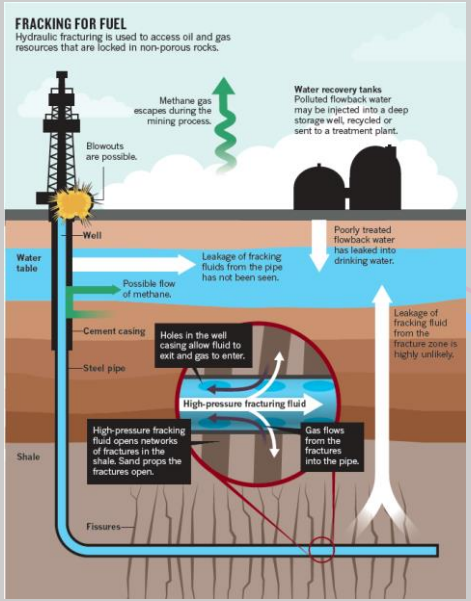
Habitat loss or fragmentation when land is cleared for roads, drilling equipment, pipelines

Fracking (Hydraulic Fracturing)

Used to extract natural gas from sedimentary rock

Vertical well is drilled down to sed. rock layer, then turns horizontally into the rock layer

- Perforating gun cracks (fractures) the rock layer around hor. well, making it more permeable
- Fracking fluid (water, salt, detergents, acids) is pumped into well @ very high pressure to crack the rock even more & allow natural gas to flow out
- Nat. gas is collected @ surface & shipped for processing/use
- **Flowback water** (used fracking fluid) flows back out well & is collected and stored in containers or ponds nearby



Environmental Consequences: Fracking

Possibility of well leaking & contaminating groundwater with fracking fluid (salt, detergents, acids) or hydrocarbons

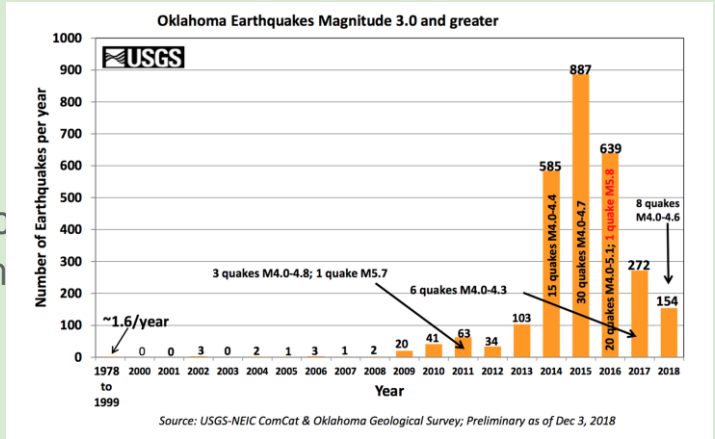
- Ponds can overflow or leach into ground & contaminate surface or ground waters with fracking fluid (salt, detergents, acids)
  - Can be toxic to plants & animals that rely on these water sources

Hab. loss/fragment

CH_4 (GHG) release

Depletion of ground or surface waters nearby (as they're drawn from for fracking fluid)

- Increased seismic activity (earthquakes) linked with wastewater injection wells (sto fracking fluid deep undergroun



Practice FRQ 6.5

Explain one environmental consequence of tar sands petroleum extraction.

Explain a different environmental consequence of hydraulic fracturing.

SUGGESTED SKILL

Environmental Solutions

7.A

Describe environmental problems.

6.6 Nuclear Energy

Objective/EKs/Skills

LEARNING OBJECTIVE

ENG-3.G

Describe the use of nuclear energy in power generation.

SUGGESTED SKILL

Visual Representations

2.B

Explain relationships between different characteristics of environmental concepts, processes, or models represented visually:

- In theoretical contexts
- In applied contexts

ESSENTIAL KNOWLEDGE

ENG-3.G.1

Nuclear power is generated through fission, where atoms of Uranium-235, which are stored in fuel rods, are split into smaller parts after being struck by a neutron. Nuclear fission releases a large amount of heat, which is used to generate steam, which powers a turbine and generates electricity.

ENG-3.G.2

Radioactivity occurs when the nucleus of a radioactive isotope loses energy by emitting radiation.

ENG-3.G.3

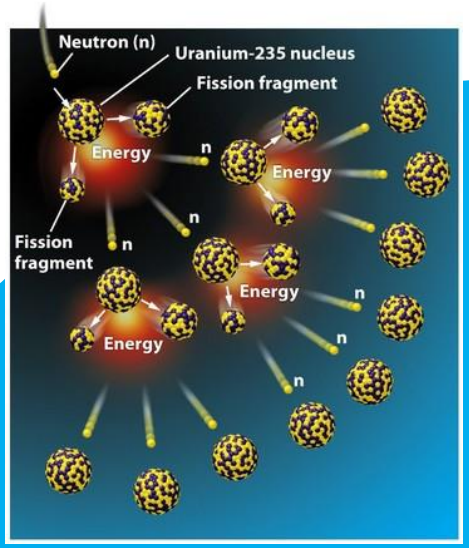
Uranium-235 remains radioactive for a long time, which leads to the problems associated with the disposal of nuclear waste.

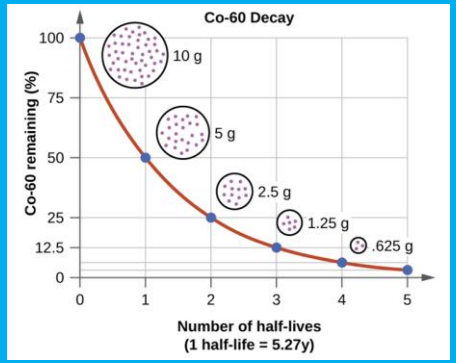
ENG-3.G.4

Nuclear power generation is a nonrenewable energy source. Nuclear power is considered a cleaner energy source because it does not produce air pollutants, but it does release thermal pollution and hazardous solid waste.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
ENG-3.H Describe the effects of the use of nuclear energy on the environment.	**ENG-3.H.1** Three Mile Island, Chernobyl, and Fukushima are three cases where accidents or natural disasters led to the release of radiation. These releases have had short- and long-term impacts on the environment. **ENG-3.H.2** A radioactive element's half-life can be used to calculate a variety of things, including the rate of decay and the radioactivity level at specific points in time.

Nuclear Fission & Radioactivity





A neutron is fired into the nucleus of a radioactive (unstable) element, such as Uranium

- Nucleus breaks apart and releases lots of energy (heat) + more neutrons that break more nuclei apart, releasing more energy (chain reaction)

Radioactivity refers to the energy given off by the nucleus of a radioactive isotope (Uranium-235)

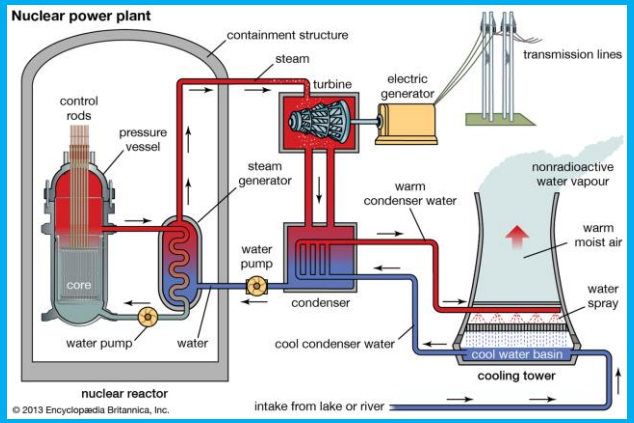
- Radioactive nuclei decay, or breakdown and give off energy (radiation) even without fission; nuclear fission just releases tons of energy all at once
- **Radioactive Half-Life** = the amount of time it takes for 50% of a radioactive substance to decay (breakdown)
  - Ex: ½ life of Cobalt-60 isotope = 5.27 yrs.
  - In 5.27 yrs, ½ of a Co-60 sample would be Gone (decayed)

Generating Electricity

Same electricity generation process as with FFs, just uranium fission to heat water into steam

- Heat →Water into Steam → Steam turns a turbine → Turbine powers generator → Generator produces electricity

U-235 stored in fuel rods, submerged in water in reaction core; heat from fission turns H_2O → steam…



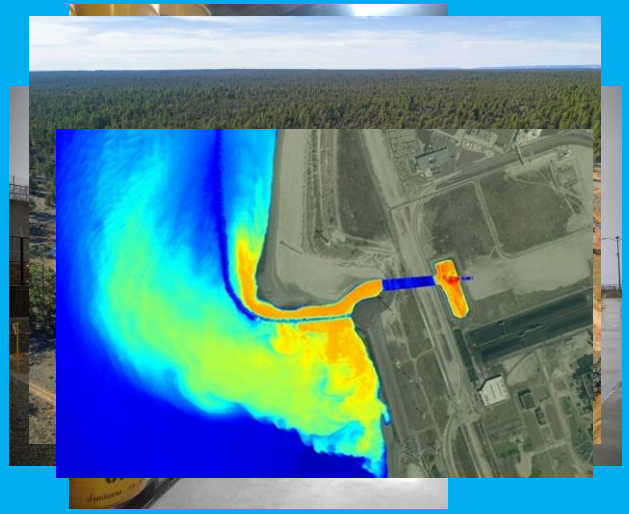
- Control rods are lowered into reactor core to absorb neutrons and slow down the reaction, preventing meltdown (explosion)
- Water pump brings in cool water to be turned into steam and also cools reactor down from overheating
- Cooling tower allows steam from turbine to condense back into liquid and cool down before being reused (this gives off H_2O vapor)

Nonrenewable, but cleaner than FFs

Nuclear energy is NONRENEWABLE because radioactive elements like Uranium are limited

- No air pollutants (PM, SO_x/NO_x) or CO_2/CH_4 released when electricity is generated; mining of uranium & plant construction still release GHGs
- Only gas released from elec. gen. is water vapor (which is technically a GHG, but stays in atm, very briefly)

Other drawbacks of nuclear energy include possibility of meltdown & radioactive contamination



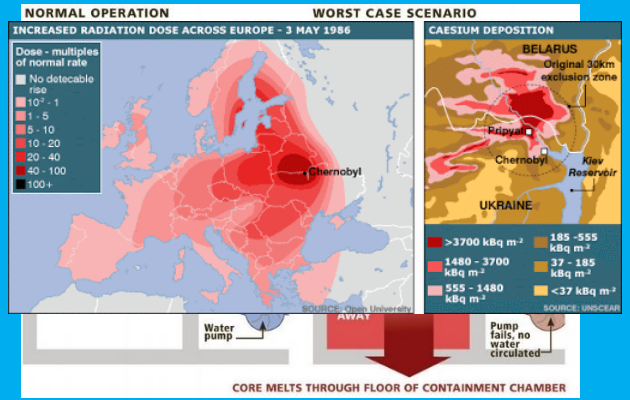
- Spent Fuel Rods: used fuel rods remain radioactive for millions of years & need to be stored in lead containers on site @ Nuclear PPs
- Mine tailings: leftover rock & soil from mining may have radioactive elements that can contaminate water or soil nearby
- Water use: nuclear PPs require lots of water and can deplete local surface or groundwater sources
- Thermal Pollution: hot water from PP released back into surface waters can cause thermal shock (decreased O_2 & suffocation)

Nuclear Meltdowns

Three Mile Island (US), Fukushima Japan, and Chernobyl Ukraine = 3 most famous nuclear meltdowns

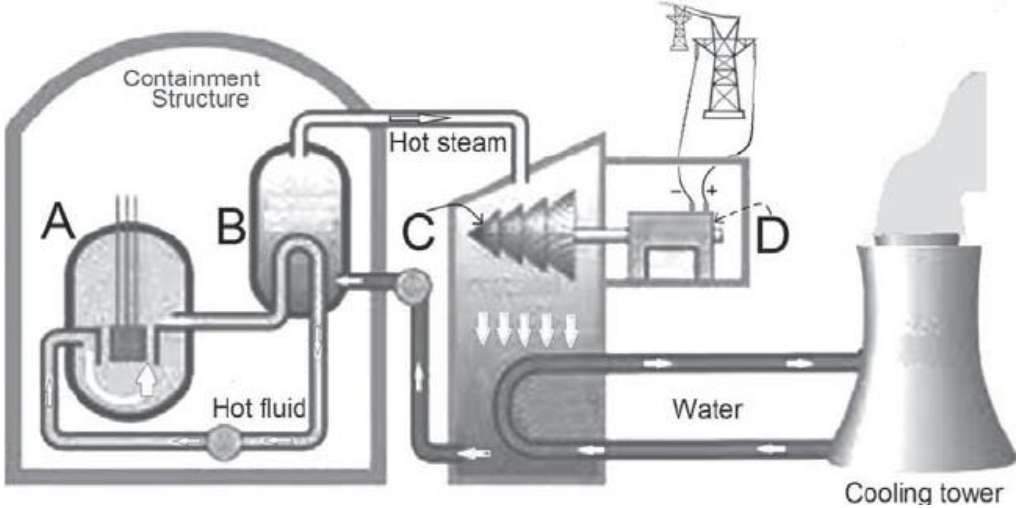
- Three Mile Island (US): partial meltdown due to testing error; radiation released but no deaths or residual cancer cases
- Fukushima (Japan): an earthquake and tsunami triggered cooling pump failure that lead to a meltdown (explosion of reactor core) & widespread radiation release
- Chernobyl (Ukraine): stuck cooling valve during test lead to complete meltdown (explosion of reactor core), several deaths, and widespread radiation release

Environmental consequences of meltdowns: genetic mutations & cancer in surrounding people, animals, and plants due to radiation released from reactor core



- Contaminated soil: radiation can remain in soil and harm plants and animals in the future (genetic mutations)
- Radiation spread: radiation can be carried by the wind over long distances, affecting ecosystems far from the meltdown site

Practice FRQ 6.6



Identify and **describe** one letter in the diagram that is common to both nuclear and fossil fuel electricity production.

Identify and **describe** one letter in the diagram that is found ONLY in nuclear power plants.

SUGGESTED SKILL

Visual Representations

2.B

Explain relationships between different characteristics of environmental concepts, processes, or models represented visually:

- In theoretical contexts
- In applied contexts

6.7 ENERGY FROM BIOMASS

SUGGESTED SKILL

Environmental Solutions

7.B

Describe potential responses or approaches to environmental problems.

OBJECTIVE/EKS/SKILL

LEARNING OBJECTIVE

ENG-3.I

Describe the effects of the use of biomass in power generation on the environment.

ESSENTIAL KNOWLEDGE

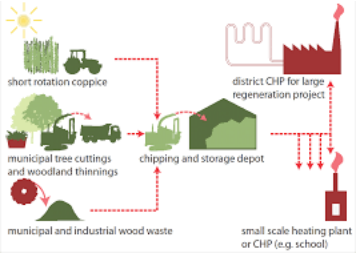
ENG-3.I.1

Burning of biomass produces heat for energy at a relatively low cost, but it also produces carbon dioxide, carbon monoxide, nitrogen oxides, particulates, and volatile organic compounds. The overharvesting of trees for fuel also causes deforestation.

ENG-3.I.2

Ethanol can be used as a substitute for gasoline. Burning ethanol does not introduce additional carbon into the atmosphere via combustion, but the energy return on energy investment for ethanol is low.

BIOMASS VS. BIOFUELS



BIOMASS organic matter (wood/charcoal, dried animal waste, dead leaves/brush) burned to release heat - primarily for heating homes/cooking

- Utilized primarily in developing world for heating homes & cooking food
  - Easy to harvest, available, cheap/free (subsistence fuel)
- Can also be burned in PPs to generate electricity (less common than FFs)

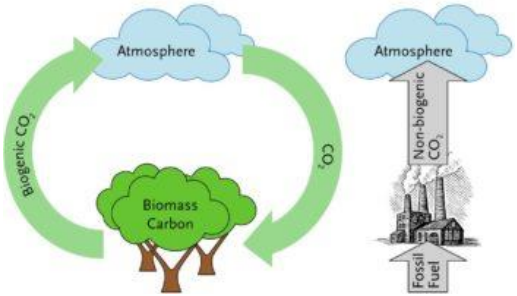
BIOFUELS liquid fuels (ethanol, biodiesel) created from biomass (corn, sugar cane, palm oil)

- Used as replacement fuel sources for gasoline, primarily in vehicles

MODERN VS. FOSSIL CARBON

⛰ Biomass burning releases CO_2, but doesn't increase atmospheric CO_2 levels like FF burning does

- Burning biomass releases <u>modern carbon</u> (CO_2 that was recently sequestered, or taken out of the atmosphere) whereas FF burning releases <u>fossil carbon</u> that had been stored for millions of years
    - Biomass burning is considered "carbon neutral"
    - Think of spending a dollar someone just gave you vs. withdrawing from your long-term savings account to spend



HUMAN HEALTH & ENV. CONSEQUENCES OF BIOMASS BURNING

Biomass burning releases CO, NO_x, PM, and VOCs - <u>all respiratory irritants</u>

- 3 billion people globally cook on open, biomass fires, mostly in developing world
- Biomass burn. <u>indoors</u> for heat/cooking worsens effects (pollutants trapped & conc.)
  - Worsened asthma, bronchitis, COPD, emphysema, eye irritation

Environmental consequences = deforestation & air pollutants

- Lack of environmental protection laws & financial resources for other fuels lead to more biomass <u>deforestation</u> in developing nations
  - Hab. loss, soil erosion, loss of CO_2 sequestration, air & H_2O filtration

- NO_x, VOCs, and PM all contribute to smog formation

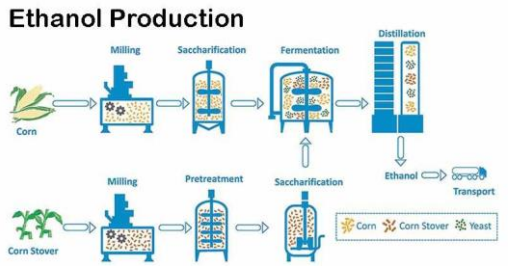
BIOFUELS: ETHANOL & ALGAE

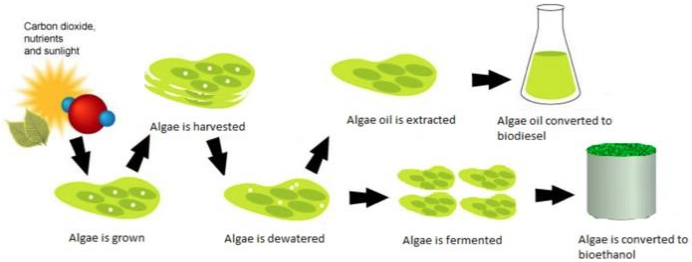
Corn & sugar cane are fermented into ethanol which is mixed w/ gasoline

- Corn grain/sugar cane broken down & yeast ferment sugars → ethanol
- E85 or flex fuel = 51-83% ethanol + gasoline mix; used in flex-fuel vehicles
  - Decreases oil consumption for transport, but is less efficient than pure gasoline
- "renewable" only to the extent that the production of corn is sustainable (sugar cane is a perennial, and is more sustainable)

Environmental consequences = all the neg. consequences of monocrop ag.

- Soil erosion, hab. loss, GHG release (ag. soils, tractors, fertilizers) H_2O use
- Lots of corn needed, relative to petroleum; can compete w/human cons. of corn
- Algae produce oils that can be used as biofuels more sustainably than corn

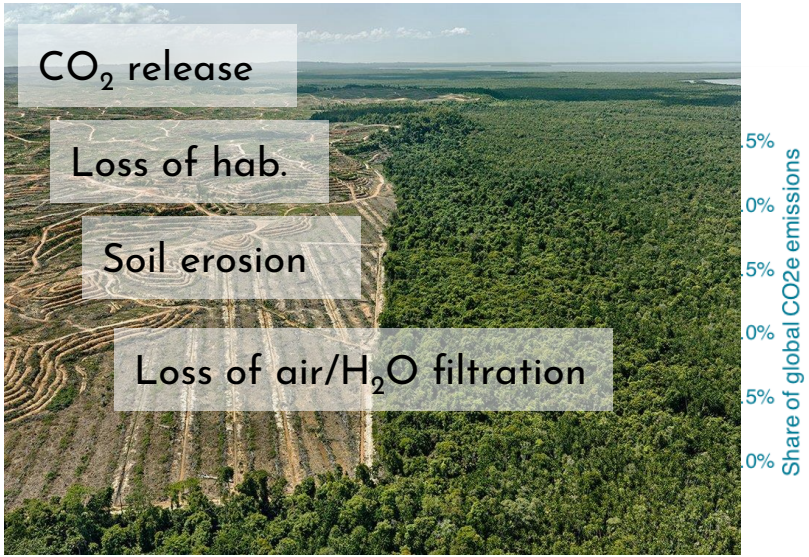




BIODIESEL

Liquid fuels produced specifically from plant oils (soy, canola, palm)

- Palm oil biodiesel has been found to produce 98% **MORE** GHGs than FFs, due to clearing of forest for palm plantations
    - Can be more sustainable if already cleared land is used, or if plantations are continually replanted (however, also causes all the env. impacts of ag.)



SUGGESTED SKILL

Environmental Solutions

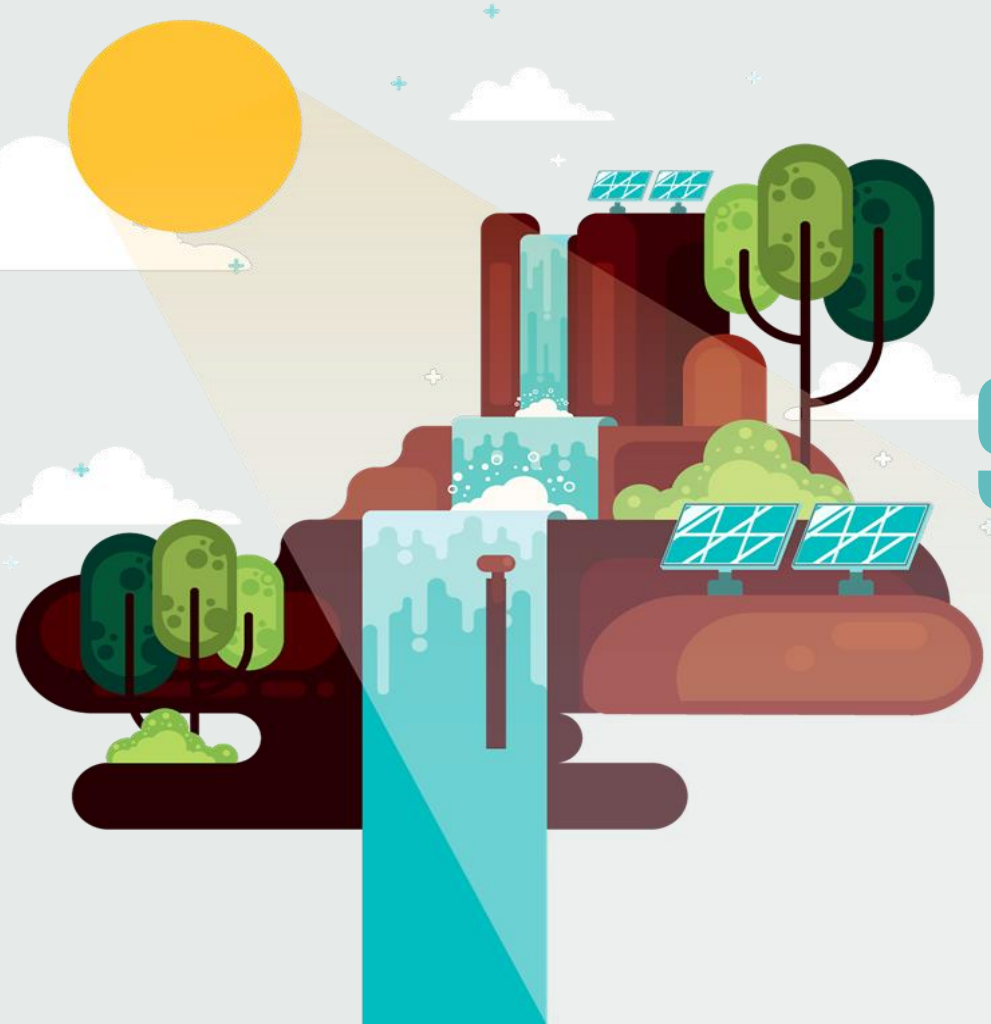
7.B

Describe potential responses or approaches to environmental problems.

PRACTICE FRQ 6.7

Explain why biodiesel fuels have a different effect on atmospheric carbon levels than fossil fuels do.

Describe TWO environmental benefits of using algae for biofuel production, rather than corn, palm oil, or sugarcane.



6.8
Solar Energy

Objectives, EKs & Skill

LEARNING OBJECTIVE

ENG-3.J

Describe the use of solar energy in power generation.

SUGGESTED SKILL

Data Analysis

5.C

Explain patterns and trends in data to draw conclusions.

ESSENTIAL KNOWLEDGE

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.K

Describe the effects of the use of solar energy in power generation on the environment.

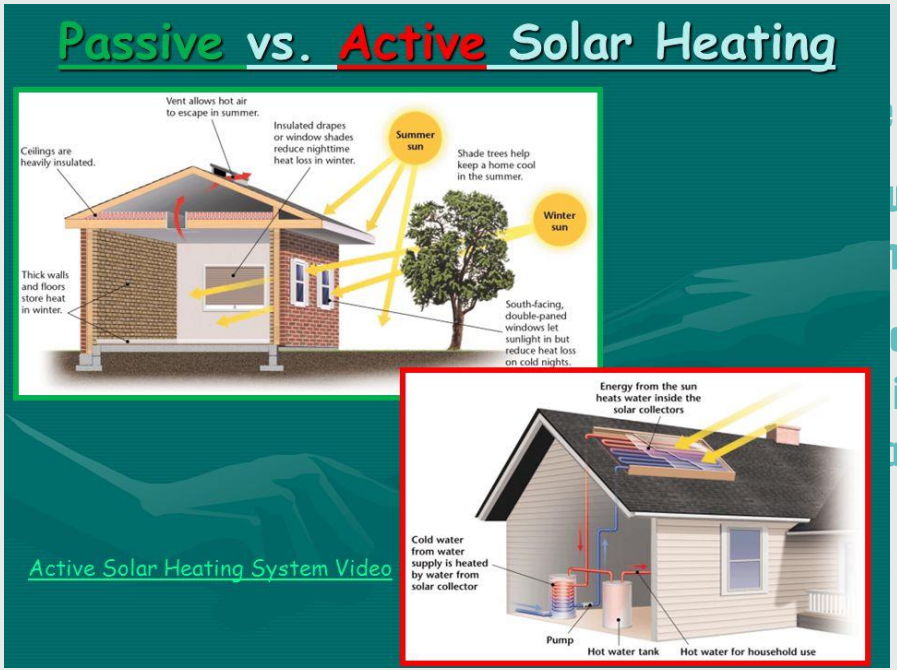
ENG-3.K.1

Solar energy systems have low environmental impact and produce clean energy, but they can be expensive. Large solar energy farms may negatively impact desert ecosystems.

Active vs. Passive Solar Energy

Passive solar: absorbing or blocking heat from the sun, w/out use of mechanical/electrical equip.

- Using sun's heat to cook food in a solar oven
- Orienting building design to block sunlight in warmer months & allow sunlight in during colder months

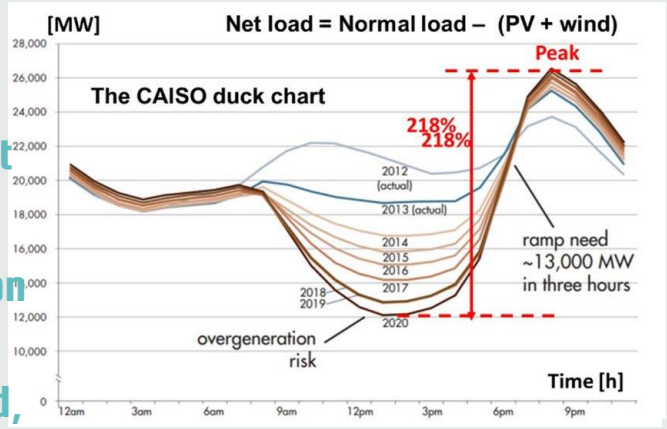


facing windows w/roof overhang, deciduous
elect. use, dark colored sunlight abs. floor

uip. to capture sun's heat (solar water heaters or
nt rays directly into electricity (PV cells)

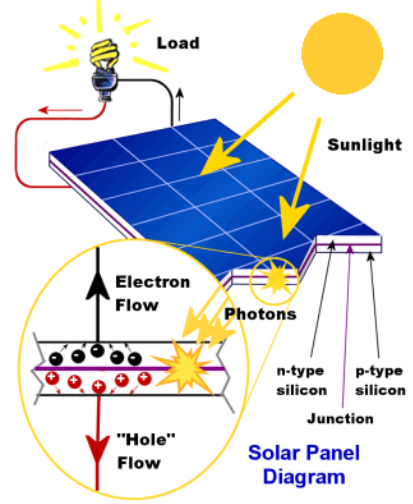
ers capture sun's heat in water
id & transfer heat to warm water
ace of electric/gas water heater

Photovoltaic Cells (PV)



⚠ Aka "solar panels"; contain semiconductor (usually silicon) that emits low voltage electrical current when exposed to sun

- Photons (particles carrying energy from sun) 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 directly power the building, or send excess electricity back to the grid for other users (earning you a credit from your utility company)

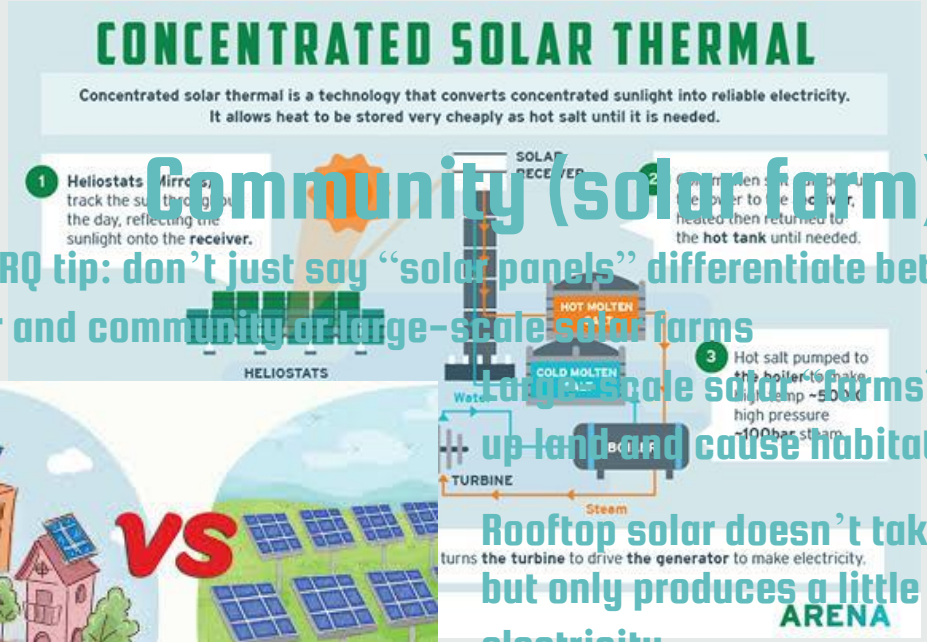
⚠ A drawback is <u>intermittency</u> (solar energy can only be generated during the day)

- Could be solved by cheaper, larger batteries that can store energy generated during the day for use at night
  - Currently these aren't cost-effective yet

Concentrated Solar Thermal (CST)

- Heliostats (mirrors) reflect sun's rays onto a central water tower in order to heat water to produce steam to turn a turbine → electricity

⚠ A drawback is habitat destruction & light beams frying birds in mid air



Community (solar farm) vs. rooftop solar

⚠ FRQ tip: don't just say "solar panels" differentiate between rooftop (individual home/business) solar and community or large-scale solar farms

"Large-scale solar farms" can generate lots of electricity, but do take up land and cause habitat loss/fragmentation

Rooftop solar doesn't take up land, but only produces a little electricity

Solar Energy Pros

⚠ No air pollutants (PM, SO_x, NO_x) released to gen. electricity

- No CO_2 released when gen. electricity
- Renewable, unlike FFs which will run out
- No mining of fossil fuels for electricity production

Solar Energy Cons

⚠ Semiconductor metals (silicon) still need to be mined to produce PV cells (solar panels)

- This can disrupt habitats & pollute water with mine tailings, air with PM
- Silicon is a limited resource
- Solar panel farms can displace habitats

Practice FRQ 6.8

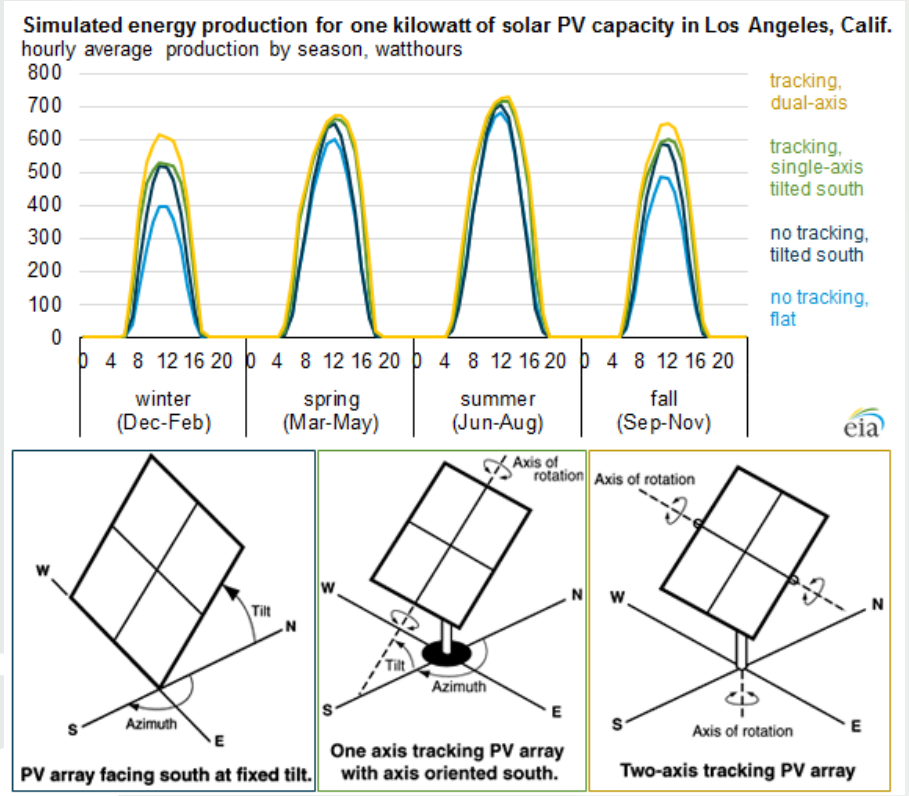
Explain the relationship between the tracking ability of a solar PV system and its energy production.

SUGGESTED SKILL

Data Analysis

5.C

Explain patterns and trends in data to draw conclusions.



6.9
HYDROELECTRICITY

OBJECTIVES/EKS/SKILL

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
ENG-3.L Describe the use of hydroelectricity in power generation.	**ENG-3.L.1** Hydroelectric power can be generated in several ways. Dams built across rivers collect water in reservoirs. The moving water can be used to spin a turbine. Turbines can also be placed in small rivers, where the flowing water spins the turbine. **ENG-3.L.2** Tidal energy uses the energy produced by tidal flows to turn a turbine.
ENG-3.M Describe the effects of the use of hydroelectricity in power generation on the environment.	**ENG-3.M.1** Hydroelectric power does not generate air pollution or waste, but construction of the power plants can be expensive, and there may be a loss of or change in habitats following the construction of dams.

SUGGESTED SKILL

Environmental Solutions

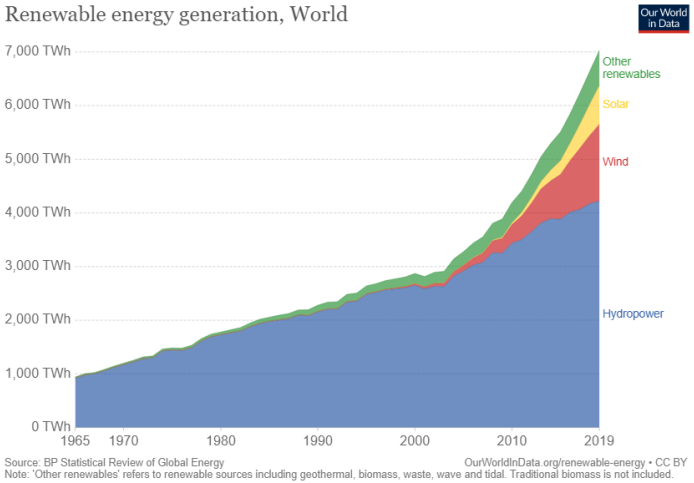
7.F

Justify a proposed solution, by explaining potential advantages.

HYDROELECTRICITY BASICS

Kinetic energy of moving water → spins a turbine (mechanical energy) → turbine powers generator

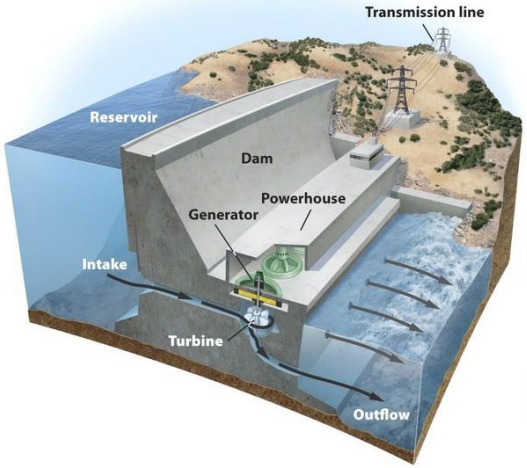
- Water moves either with natural current of river or tides, or by falling vertically through channel in a dam
- By far the largest **renewable** source of electricity globally
- China, Brazil, and US = 3 biggest hydroelectricity producers

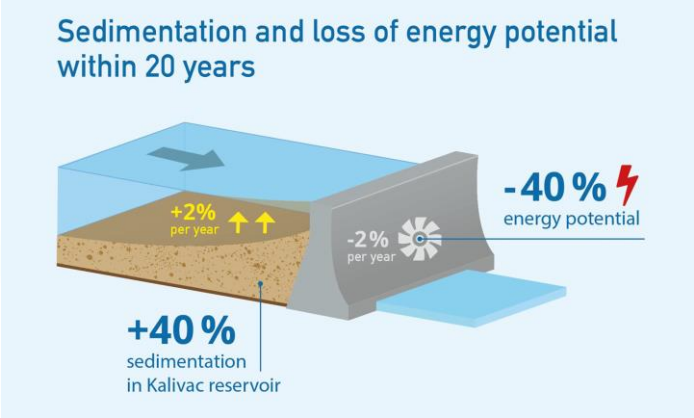


WATER IMPOUNDMENT (DAMS)

Dam built in a river creates a large artificial lake behind the dam (reservoir)

- Damming the river enables operators to allow more or less water through the channel in the dam, increasing or decreasing electricity production (water flows through channel, turns turbine, turbine powers generator →)
- Also allows for control of flow downstream, prevention of seasonal flooding due to high rainfall
- Reservoirs are also a source of recreation money (boating fees, tourism, increased property values, fishing, etc.)
- 2 big impacts = flooding of ecosystems behind dam & sedimentation (buildup of sediments behind dam)

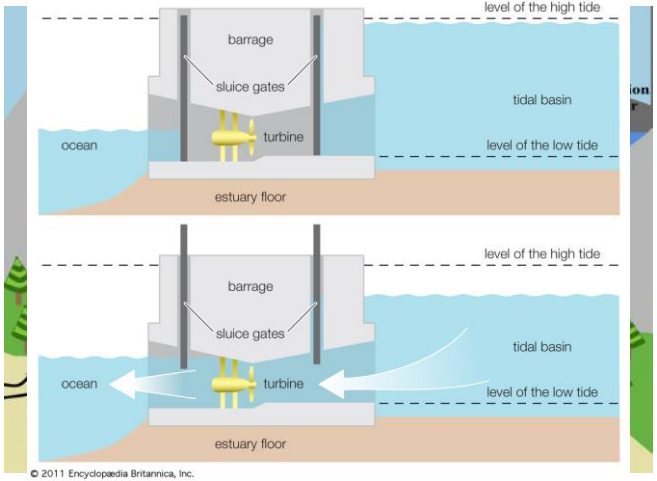




RUN OF RIVER SYSTEM & TIDAL ENERGY

A dam diverts the natural current of a river through man-made channel beside the river

- Natural current of the river turns the turbine…powers the generator…
- Less impactful to surrounding ecosystem since no reservoir is formed & ecosystems behind dam aren't flooded
- Doesn't stop natural flow of sediments downstream like water impoundment systems do
- Doesn't generate nearly as much power & may be unavailable in warmer seasons when river water levels are lower

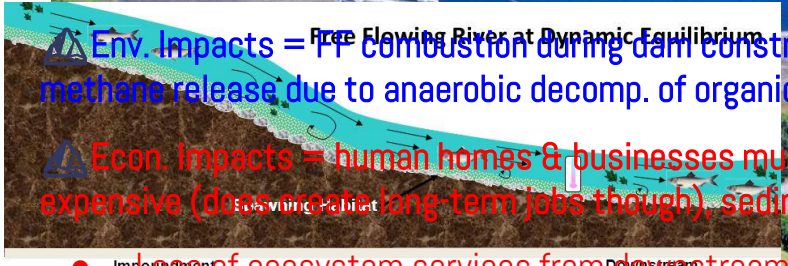


- Tidal power comes from tidal ocean flow turning turbine (coastal areas only)

DRAWBACKS OF HYDRO ⚡ DAMS (ECOL/ENV/ECON)

⚠ Reservoir floods habitats behind dam (forests/wetlands → gone; river becomes a lake)

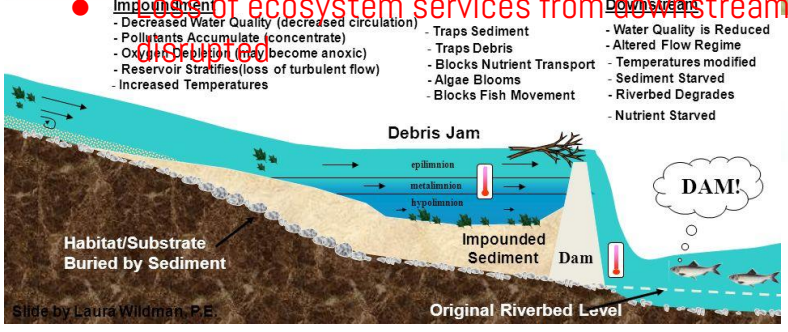
- Prevents upstream migration of fish like salmon, that need to swim up to spawning grounds to reproduce
- Sedimentation changes upstream & downstream conditions
  - Upstream becomes warmer (less O_2) and rocky streambed habitats covered in sediment
  - Downstream loses sediment (important nutrient source), decreased water level, loses streambed hab.
- Downstream wetlands especially suffer since nutrients in sediment doesn't reach them



⚠ Env. Impacts = ↑↑ combustion during dam construction, increased evap. due to larger surface area of reservoir, and methane release due to anaerobic decomp. of organic matter in reservoir

⚠ Econ. Impacts = human homes & businesses must be relocated due to reservoir flooding, Initial construction is very expensive (does create long-term jobs though), sediment buildup must be dredged (removed by crane) eventually

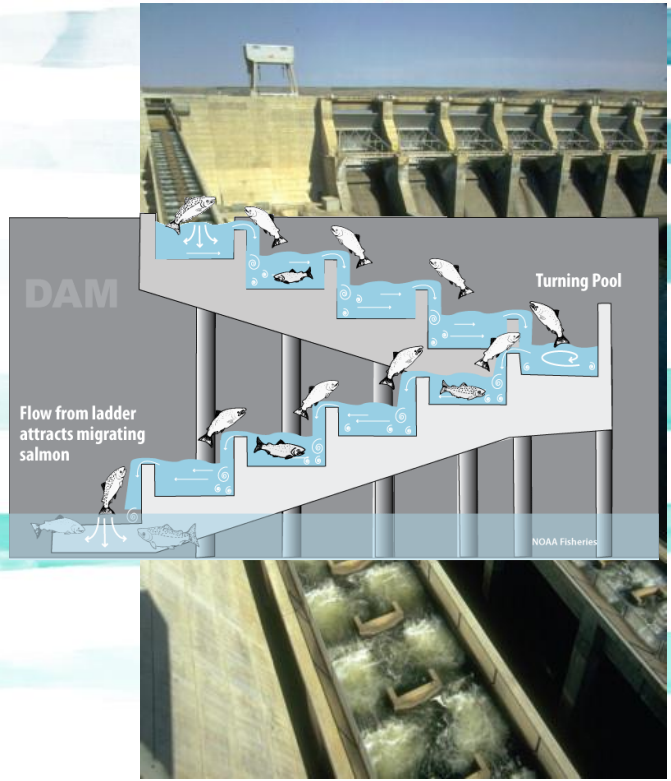
- Loss of ecosystem services from downstream wetlands, potential loss of fishing revenue if salmon breeding is disrupted



FISH LADDERS

Cement "steps" or series of pools that migratory fish like salmon can use to continue migration upstream, around or over dams

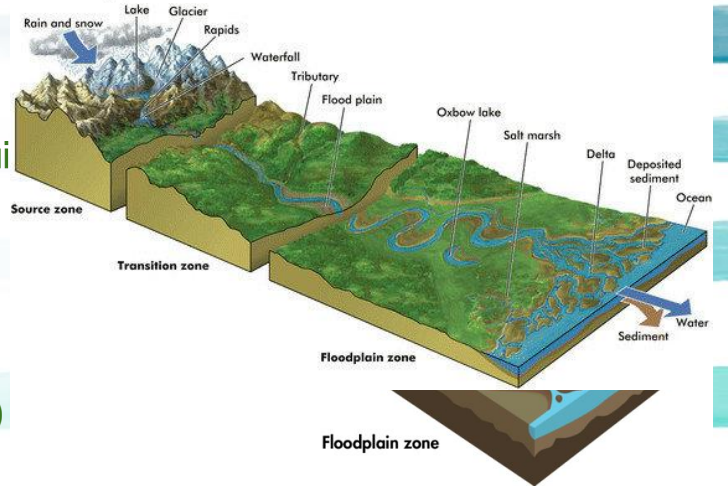
- Enables continued breeding for salmon, food source for predators like large birds, bears, and fishing revenue for humans
- "Salmon cannon" is a similar alternative that enables salmon to be captured or directed into a tube that carries them over the dam



BENEFITS OF HYDRO ⚡ DAMS

⛰ No GHG emissions when producing electricity (initial construction does requi

- Reservoir & dam can be tourist attractions
- Jobs are created to maintain the dam
- Reliable electricity source generated for surrounding area
- No air pollutants released during electricity generation (no PM/SO_x/NO_x)



⛰ Allows for control of downstream seasonal flooding

- In US, only 3% of dams are for hydro ⚡; 37% are for recreation/scenic purposes; 2nd most common purpose is flood control (allowing humans to build closer to rivers in floodplains that would normally be flooded seasonally)
    - This flood prevention is good for humans, but deprives river flood plains of nutrient-rich sediment that supports plant growth & nearby wetland habitats

OBJECTIVES/EKS/SKILL

SUGGESTED SKILL

Environmental Solutions

7.F

Justify a proposed solution, by explaining potential advantages.

Explain TWO benefits other than agriculture and recreation that people gain from constructing dams on rivers.

6.10 Geothermal Energy

Objectives/EKs/Skills

SUGGESTED SKILL

Concept Explanation

1.B

Explain environmental concepts and processes.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
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.

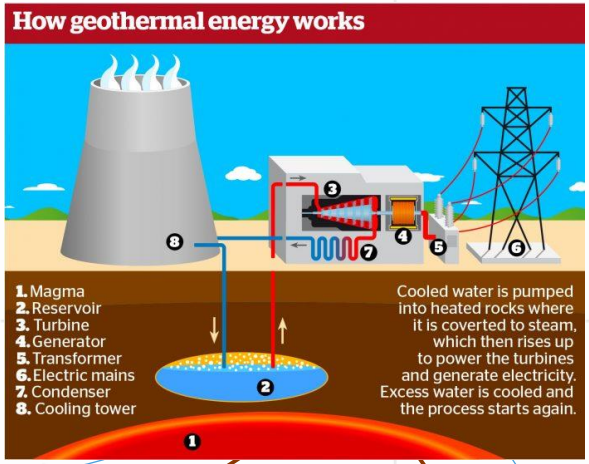
Geothermal Basics

🌋 **Natural radioactive decay of elements deep in earth's core gives off heat, driving magma convection currents which carry heat to upper portion of mantle, close to earth's surface**

- Water can be piped down into the ground and heated by this heat from the mantle
  - Hot water can be converted into steam → turbine → elect. or be used to heat homes directly

⚡ **Geothermal for electricity**: naturally heated water reservoirs underground are drilled into & piped up to the surface (or water can be piped down into naturally heated rock layers

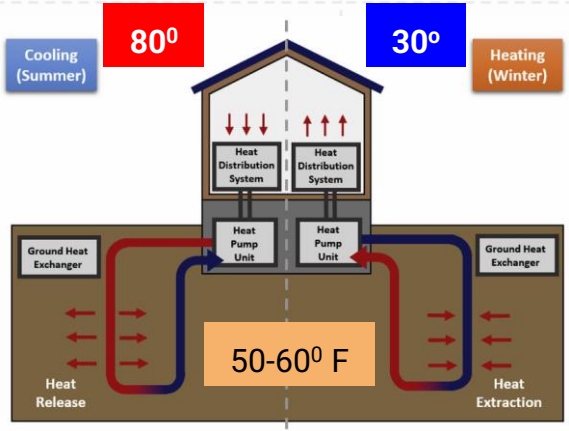
- The heat from magma turns the water into steam, which is forced through pipes to spin a turbine
- Water is cooled in cooling tower & returned to the ground to start the process over
- Renewable since heat from earth's core won't run out; but only if groundwater is returned after use



Ground Source Heat Pump

⚠ **Often referred to as “geothermal” but technically the heat does not come from geologic activity (comes from the ground storing heat from the sun)**

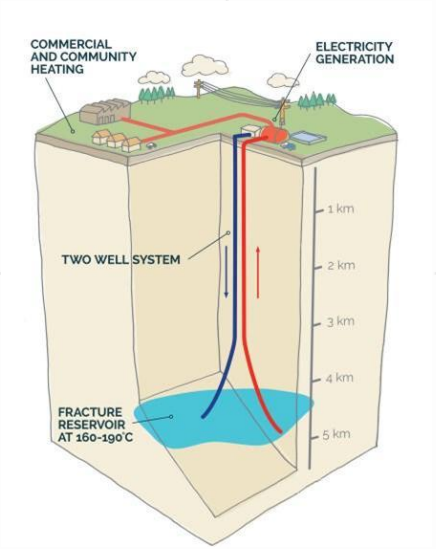
- More accurate name is “ground source heat pump”
  - 10 feet down, the ground stays a consistent 50-60º due to holding heat from sun (**not** warmed by geothermal energy from magma - so not technically geothermal energy)
  - Heat absorbing fluid is pumped through a pipe into the ground where it either 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 Heating

⛰ **True geothermal heating involves piping water deep into ground to be heated by magma & then transfering heat from water to the building**

- **Different** than ground source heat pump
- Well must go thousands of meters (kms) down into the ground to reach heated water reservoir
- Heated water is piped up to surface & sent to homes or businesses to heat them

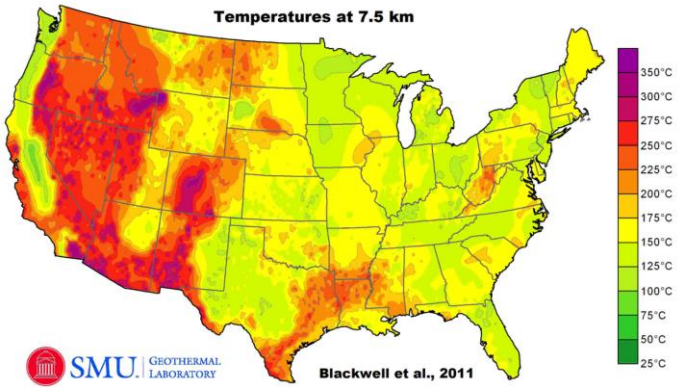


Geothermal Pros

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

Geothermal Cons

- Not everywhere on earth has access to geothermal energy reaching close enough to surface to access it
- Hydrogen sulfide can be released, which is toxic and can be lethal to humans & animals
- Cost of drilling that deep in the earth can be very high initially
  - Sometimes so high that it's not even worth it



Practice FRQ 6.10

SUGGESTED SKILL

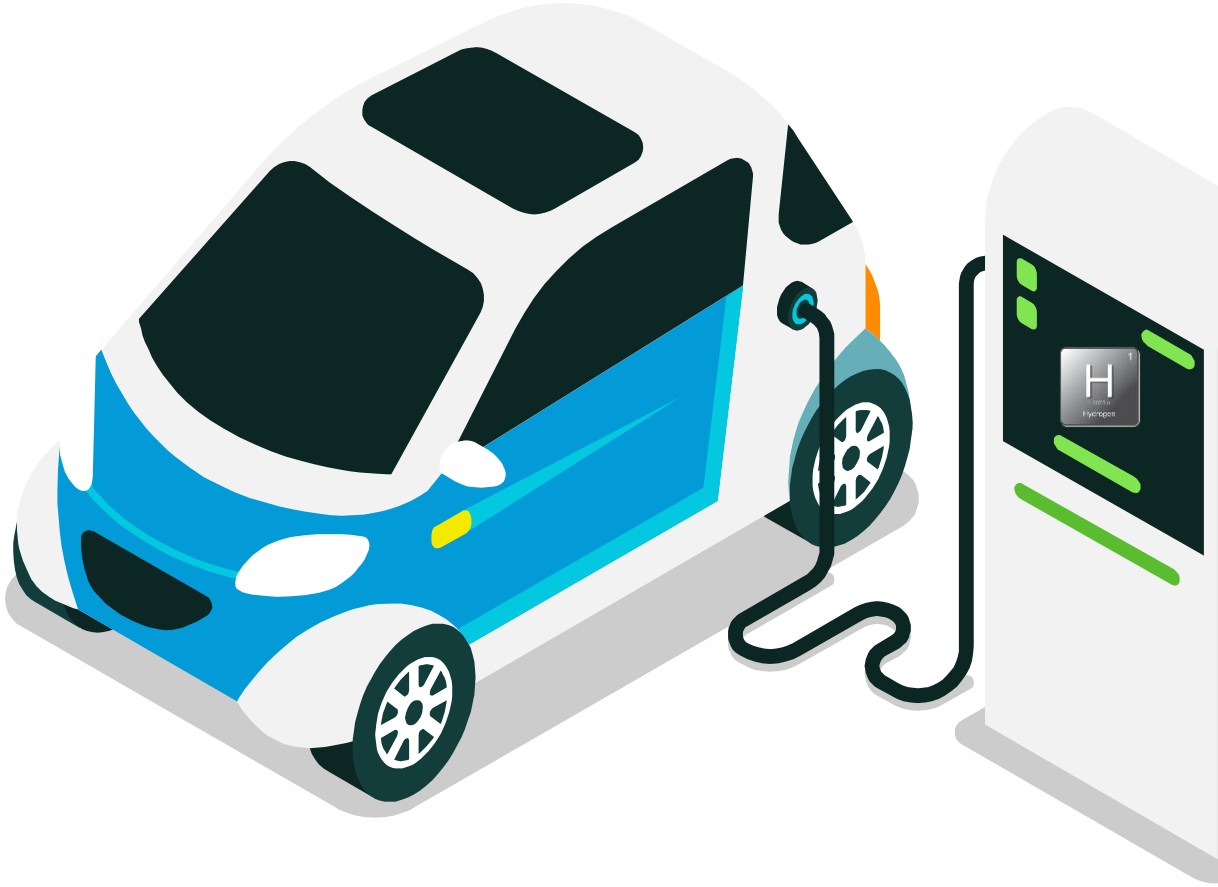
Concept Explanation

1.B

Explain environmental concepts and processes.

Identify the source of initial energy in geothermal power generation and **explain** how geothermal systems can be used to generate electricity.

6.11 Hydrogen Fuel Cell



Objective/EKs/Skill

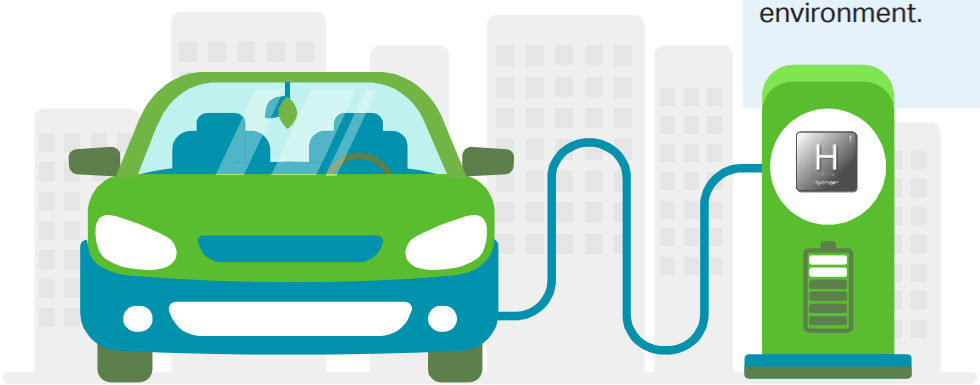
SUGGESTED SKILL

Concept Explanation

1.C

Explain environmental concepts, processes, or models in applied contexts.

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
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.



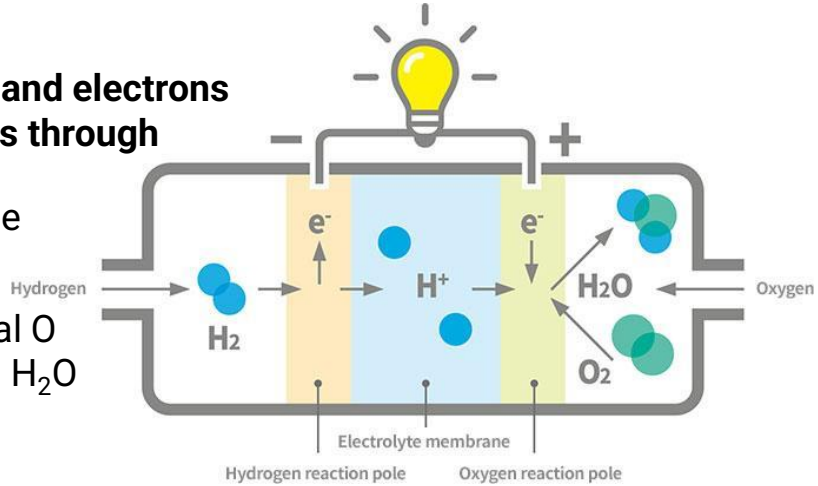
Hydrogen Fuel Cell Basics

⚠ Use hydrogen as a renewable, alternative fuel source to fossil fuels

- H_2 gas and O_2 are the inputs used to generate electricity; H_2O is given off as a waste product

⚠ H_2 gas enters fuel cell where it's split into protons (H^+) and electrons (e^-) by an electrolyte membrane that only lets protons pass through

- Electrons take an alternative route (circuit) around the membrane, which generates an electrical current
- O_2 molecules enter fuel cell break apart into individual O atoms and combine with two hydrogens (H^+) to form H_2O as a by product (only emissions from F fuel cells)



⚠ Most common application is in vehicles

- Replaces gasoline (non-renewable, GHG releasing & air polluting) with H fuel (no air pollutants released & only H_2O vapor)

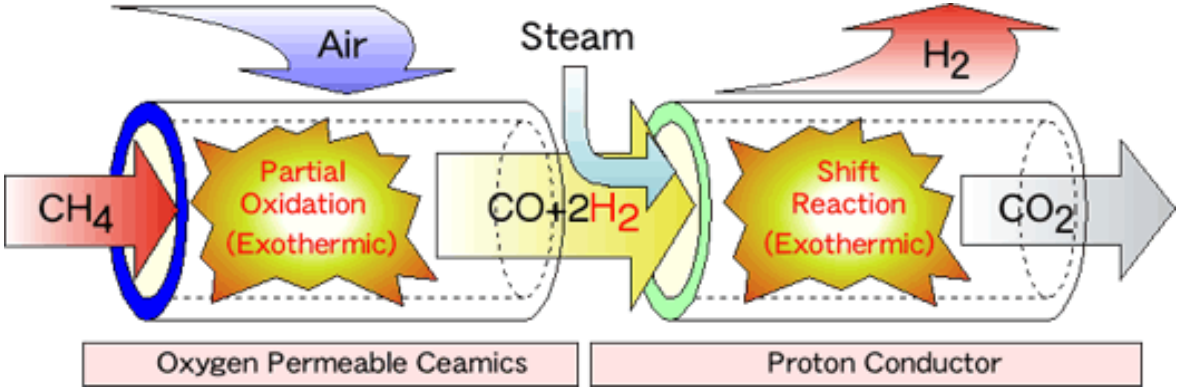
Creating H_2 Gas

Key challenge to H fuel cells is obtaining pure H gas (b/c it doesn't exist by itself as a gas naturally)

- Separating H_2 gas from other molecules like H_2O or CH_4 is very energy intensive
    - Two main processes are steam reforming (95% of all H production) and electrolysis (less common, but more sustainable)

<u>Steam Reforming</u>: burning natural gas (CH_4) & using steam to separate the H gas from the methane (CH_4)

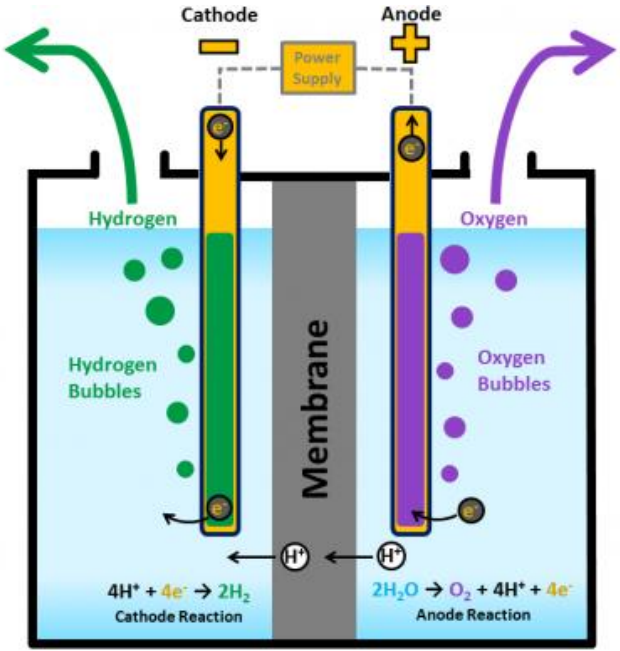
- Emits CO_2 & requires NG (FF) input



Creating H_2 Gas

Electrolysis: electrical current is applied to water, breaking it into O_2 and H_2

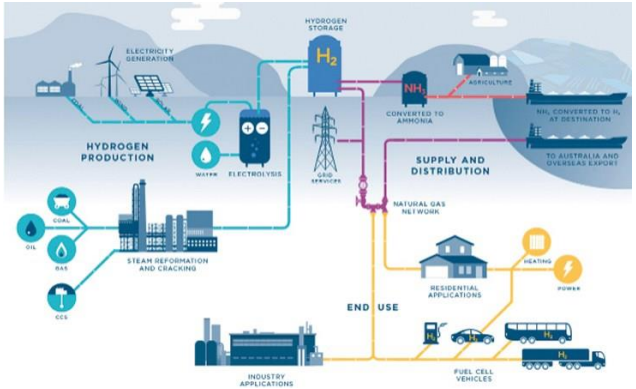
- No CO_2 emission, but does require electricity



Hydrogen As an Energy Carrier (Pros)

⚠**Because H_2 gas can be stored in pressurized tanks, it can be transported for use creating electricity later, in a different location**

- Unlike solar, hydro, and wind where the electricity must be used as soon as it's generated & relatively closely to the location of generation



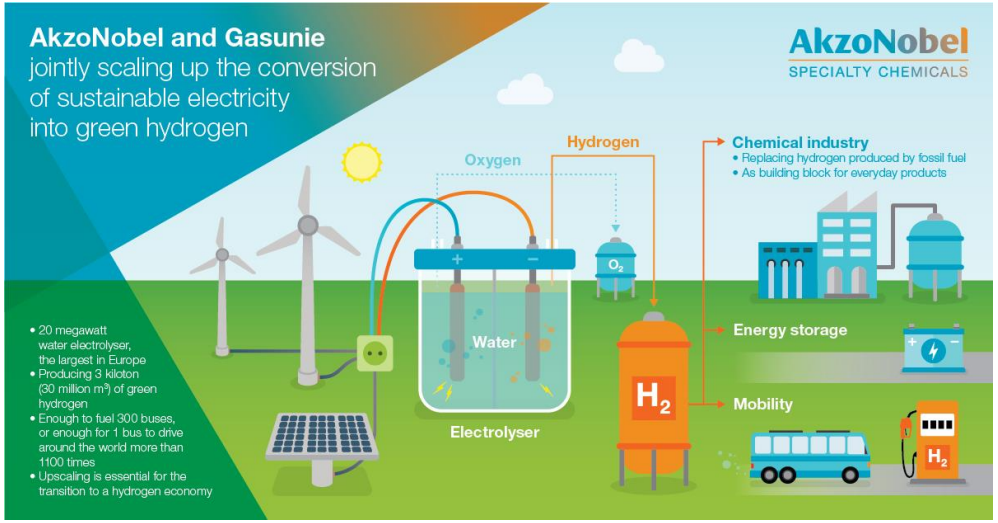
⚠**Can also be used as a fuel for vehicles (replacing gasoline) or to create ammonia for fertilizer, or in the chemical industry**

- As a gasoline replacement, it emits no air pollutants (NO_x/PM/CO) and only H_2O (tech. a GHG) no CO_2
- Manufacture of many different industrial chemicals requires H_2 gas
- Can be stored as liquid or gas, making it easy to transport
- H fuel cells are ~80% efficient in converting chemical energy in H_2 & O_2 into electricity (Coal PP = 35% efficient)

Drawbacks of H Fuel Cells

⚠ **Since 95% of H_2 production requires methane (CH_4), H fuel cells are based on a non-renewable & CO_2 releasing energy source**

- If electrolysis is used to produce H_2, it's only as sustainable as the electricity source
- Widespread H fuel cell use would require building widespread H distribution network (similar to current system for gasoline)
- H fuel stored in gas form in vehicles would require much larger tanks than current gasoline tanks



SUGGESTED SKILL

Concept Explanation

1.C

Explain environmental concepts, processes, or models in applied contexts.

Practice FRQ 6.11

Explain how hydrogen gas can be used to generate electricity.

6.12 Wind Energy

SUGGESTED SKILL

Environmental Solutions

7.B

Describe potential responses or approaches to environmental problems.

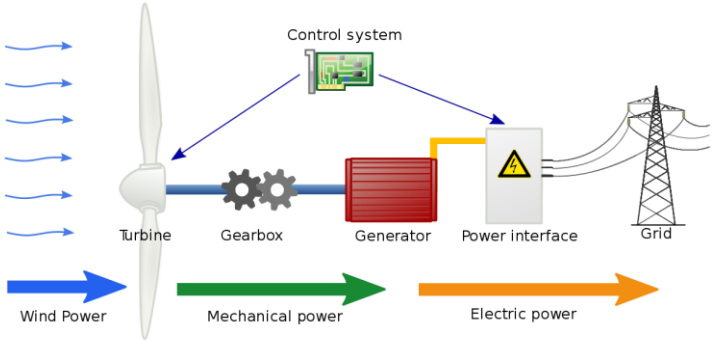
Objective/EKs/Skill

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
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.

Wind Turbine Electricity Generation

Kinetic energy of moving air (wind) spins a turbine; generator converts mechanical energy of turbine into electricity

- Blades of turbine are connected to gearbox by a shaft that rotates; rotating gears create mechanical energy that the generator transforms into electricity
  - Avg. turbine can power 460 homes
  - Avg. wind turbine has 15-30% capacity factor (% of total possible energy it could generate)
    - Only produces electricity in 8-55 mph winds
  - Motorized drive within shaft can turn the turbine to face wind



Wind Turbine Location

⛰Clustered in groups (wind projects or farms) in flat, open areas (usually rural)

- Locating them together makes service, repair, and building transmission lines to them easier
    - Can share land with agricultural use

⛰Offshore wind = wind farms in oceans or lakes

- Capitalizes on faster wind speeds
- Does require transmission lines built across long distances to reach land though

Wind Energy Benefits and Drawbacks

Benefits	Drawbacks
Non-depletable (isn't decreased by its use) - even better than renewable!	Intermittency (isn't always available) can't replace base-load power (sources that are always available like FFs, nuclear or Geothermal)
No GHG emissions or air pollutants released when generating electricity	Can't replace base-load power (sources that are always available like FFs, nuclear or Geothermal)
No CO_2 (climate change) or NO_x/SO_x/PM as with burning FFs	Can kill birds and bats (especially larger, migratory birds)
Can share land uses (don't destroy habitat or cause soil/water contamination as FFs do)	Can be considered an eyesore or source of noise pollution by some

SUGGESTED SKILL

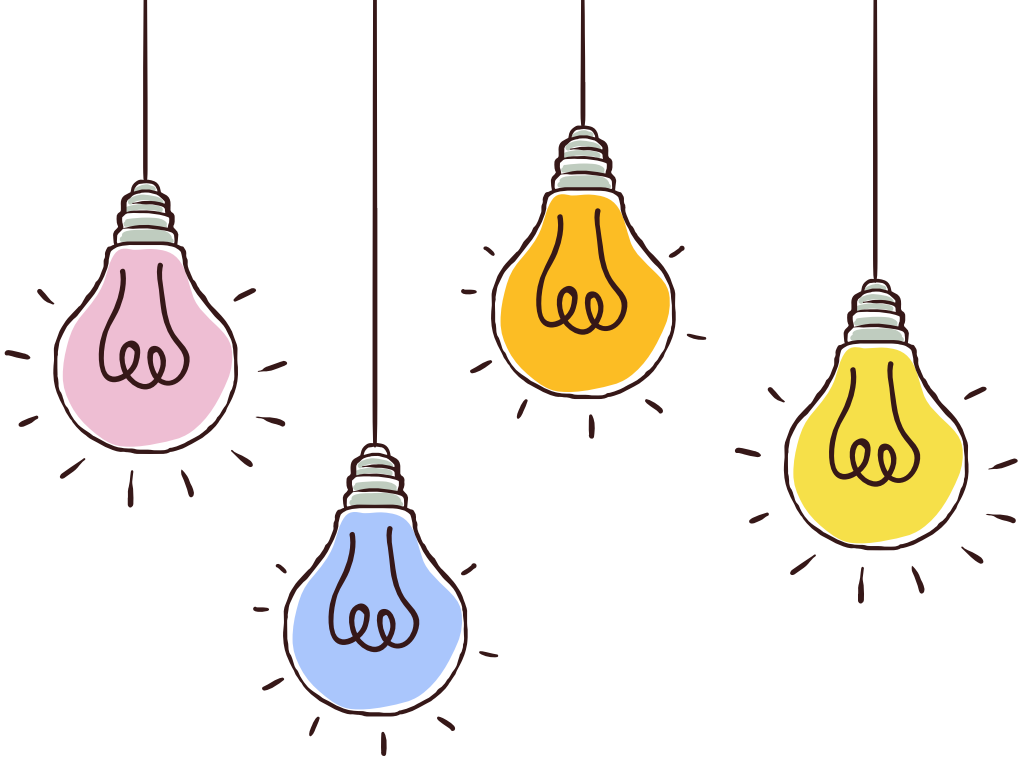
Environmental Solutions

7.B

Describe potential responses or approaches to environmental problems.

Practice FRQ 6.12

Explain an environmental benefit a town might experience if it switches from a coal fired power plant to a wind farm as its primary source of energy.



6.13 Energy Conservation

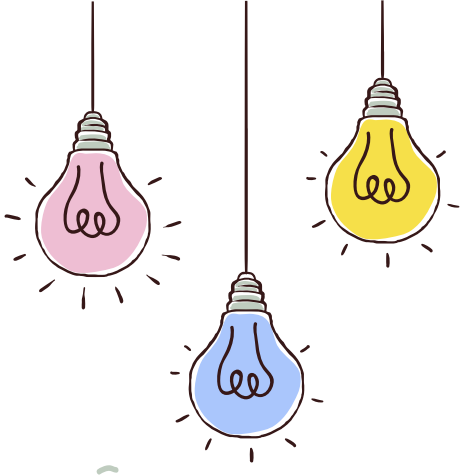
SUGGESTED SKILL

Mathematical Routines

6.C

Calculate an accurate numeric answer with appropriate units.

Objective/EKs/Skills



LEARNING OBJECTIVE

ENG-3.T

Describe methods for conserving energy.

ESSENTIAL KNOWLEDGE

ENG-3.T.1

Some of the methods for conserving energy around a home include adjusting the thermostat to reduce the use of heat and air conditioning, conserving water, use of energy-efficient appliances, and conservation landscaping.

ENG-3.T.2

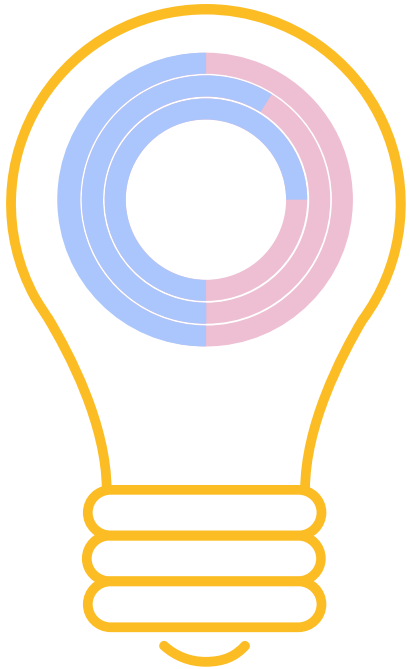
Methods for conserving energy on a large scale include improving fuel economy for vehicles, using BEVs (battery electric vehicles) and hybrid vehicles, using public transportation, and implementing green building design features.

Small Scale vs. Large Scale Energy Conservation

Lowering thermostat to use less heat or use AC less often

Conserving water with native plants instead of grass, low flow shower heads, efficient toilets, dishwashers, dryers

Energy efficient appliances, better insulation to keep more heat in home



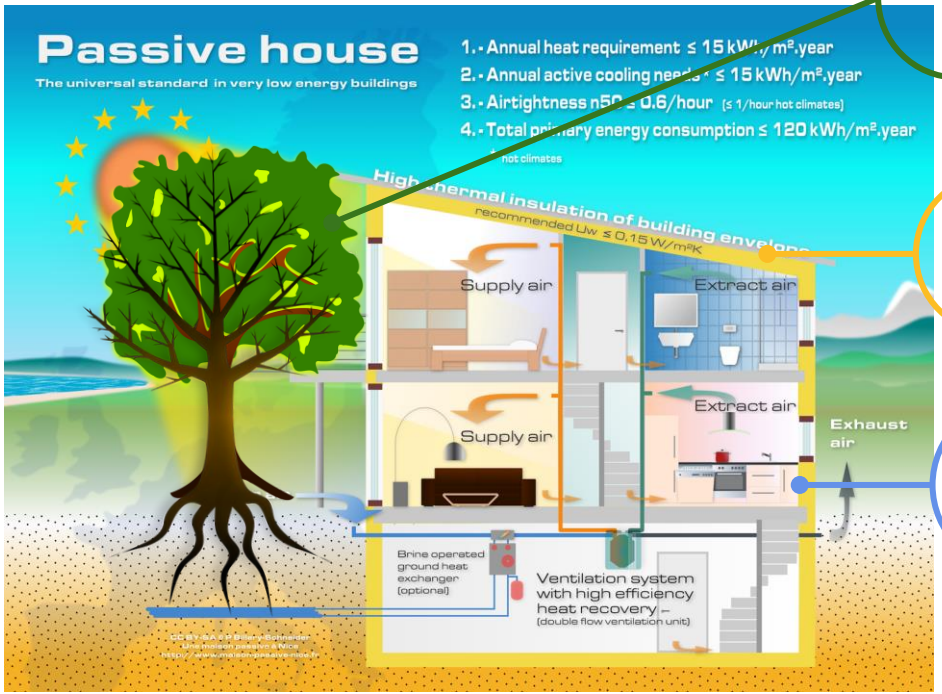
Improving fuel efficiency (fuel economy) standards
Ex: 20 mpg → 30 mpg

Subsidizing (tax credits for) electric vehicles, charging stations, and hybrids

Increased public transport (buses & light rails), green building design

Sustainable Home Design

⛰ Ways to either block out or take advantages of sun's natural heat, or keep in heating/cooling to decrease energy required



- Deciduous shade trees for landscaping (leaves block sun in summer, but allow it in during winter)
- Using passive solar design concepts to trap sun's heat & decrease energy from heating system (heat absorbing walls, triple or double paned windows)
- Well-insulated walls/attic to trap heat in winter & cool air from AC system in summer
- This decreases electricity used by AC unit & energy used by heating system

Water Conservation

Native plants require less watering than traditional lawns (also increase biodiversity of pollinators & require less fertilizer)

Low-flow showers, toilets, and dishwashers do the same job with less total water (less energy to purify & pump to homes)

Rain barrels allow rain water to be used for watering plants or washing cars

Energy Conservation - Transportation

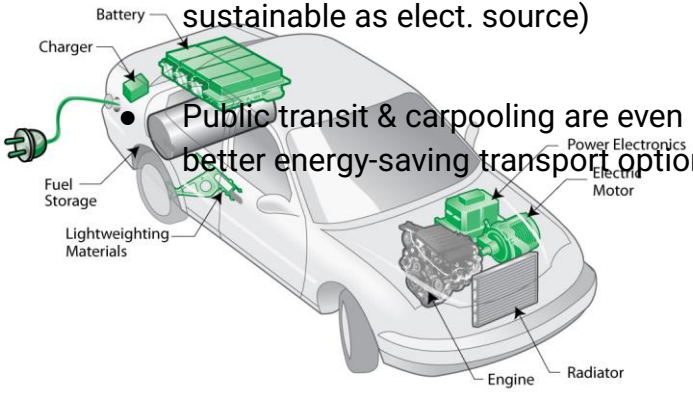
~28% of total US energy use comes from transport of goods & people (2019)

- Improving fuel economy of US fleet of vehicles conserves energy as less gasoline/diesel is needed to travel same distance
  - CAFE (Corporate Average Fuel Economy) standards are regulations set in US to require auto manufacturers to make cars that meet certain MPG standards, or pay penalties

- Hybrids (Prius) have both a gasoline & electric engine, enabling them to have higher MPG ratings
  - Breaking system charges the electric battery, which powers electric motor

- Electric vehicles (EVs or BEVs) like the Tesla or LEAF use no gasoline, but still require electricity (only as sustainable as elect. source)

- Public transit & carpooling are even better energy-saving transport options



Sustainable Building Design

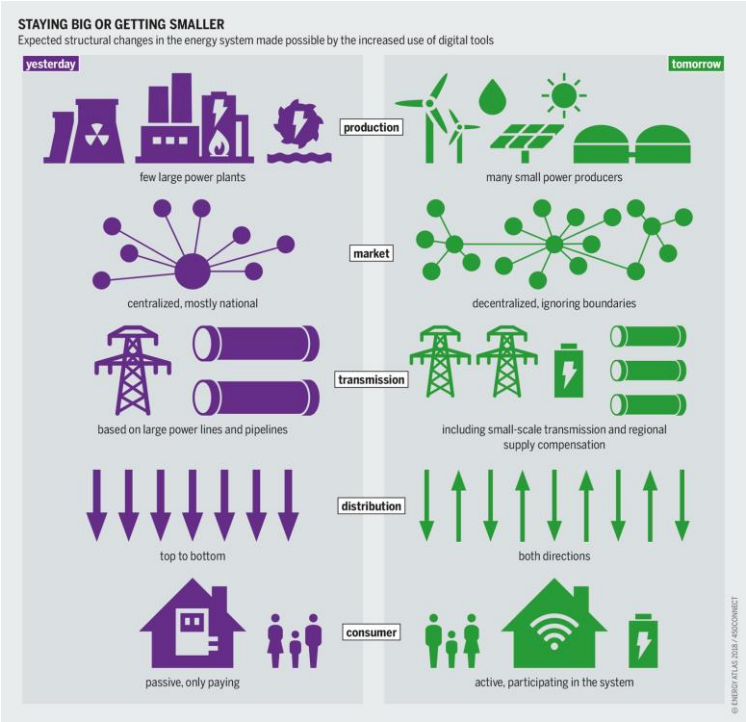
⛰ Decreasing the amount of energy required to build larger buildings & heat/cool them

- Green roof or walls can decrease runoff, and absorb sun's heat, decreasing energy needed for cooling building & surrounding area (lessens heat island effect)
- Sun lights on roof, or windows on sides can decrease electricity used for lighting
- Recycled materials can reduce energy required to produce new ones (glass, wood, even fly ash from coal can be used in foundation)

Managing Peak Demand & Smart Grid Tech.

⚠ Peak demand is the time of day or year (often early night time hours or very hot weather events) that electricity demand is highest

- If demand exceeds supply, rolling blackouts occur



lities use a **variable price model** for electricity

g peak demand hours or events, to discourage use

when using a lower amount of energy (incentivizes

⚠ "Smart Grid" is just the idea of managing demand & energy sources in a more varied way

Ex: using smart meters for variable price models, allowing rooftop solar to direct electricity back to grid, integrating more total energy sources (especially renewable)

Practice FRQ 6.13

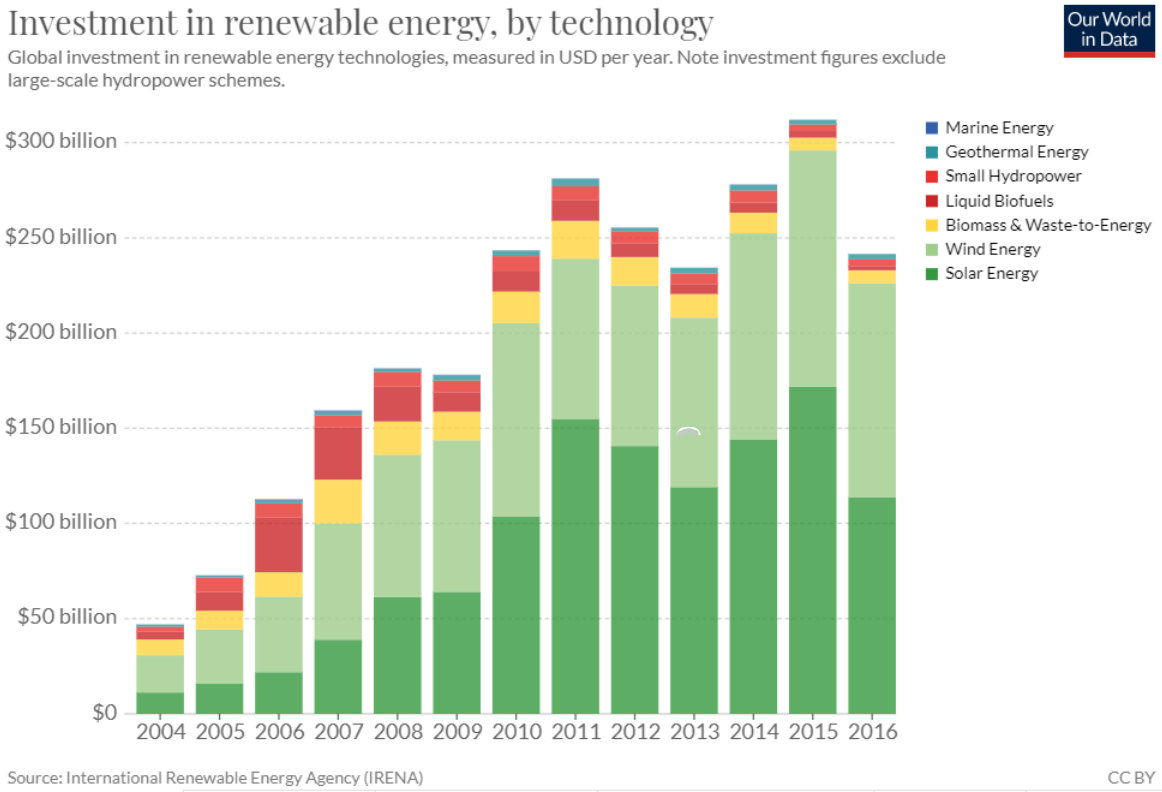
SUGGESTED SKILL

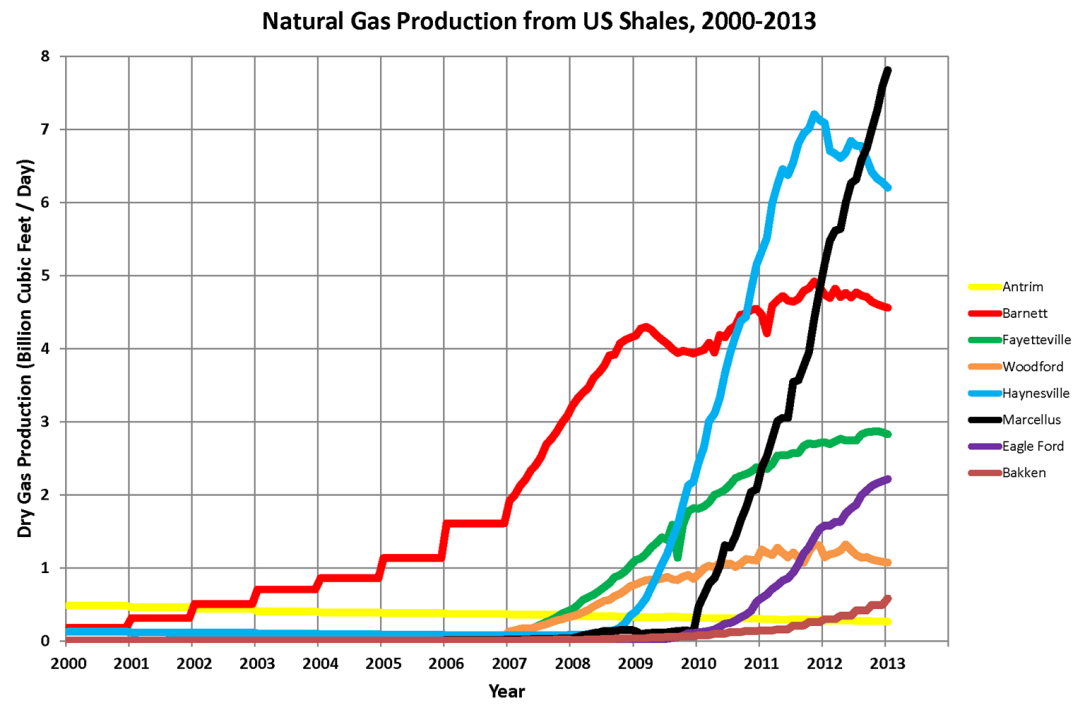
Mathematical Routines

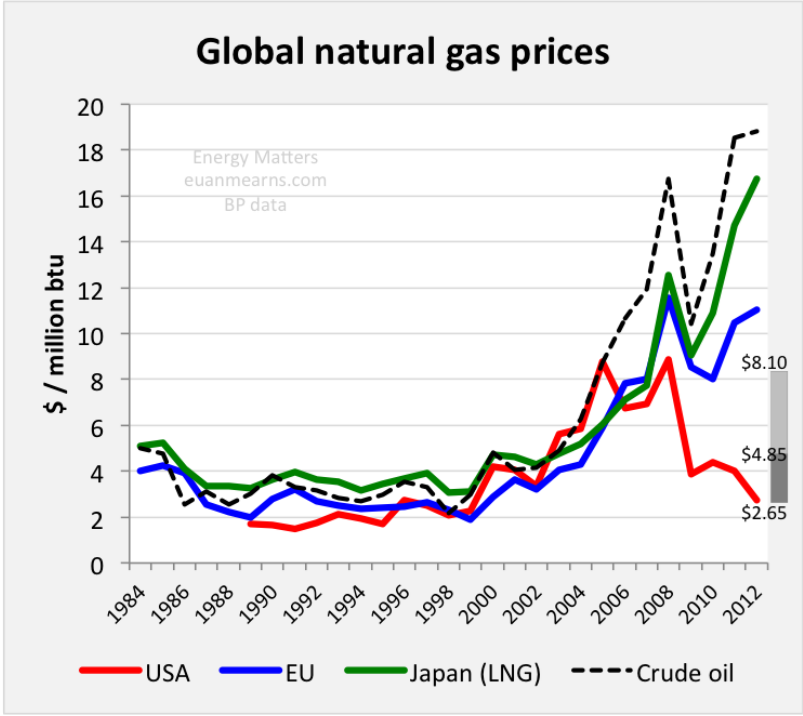
6.C

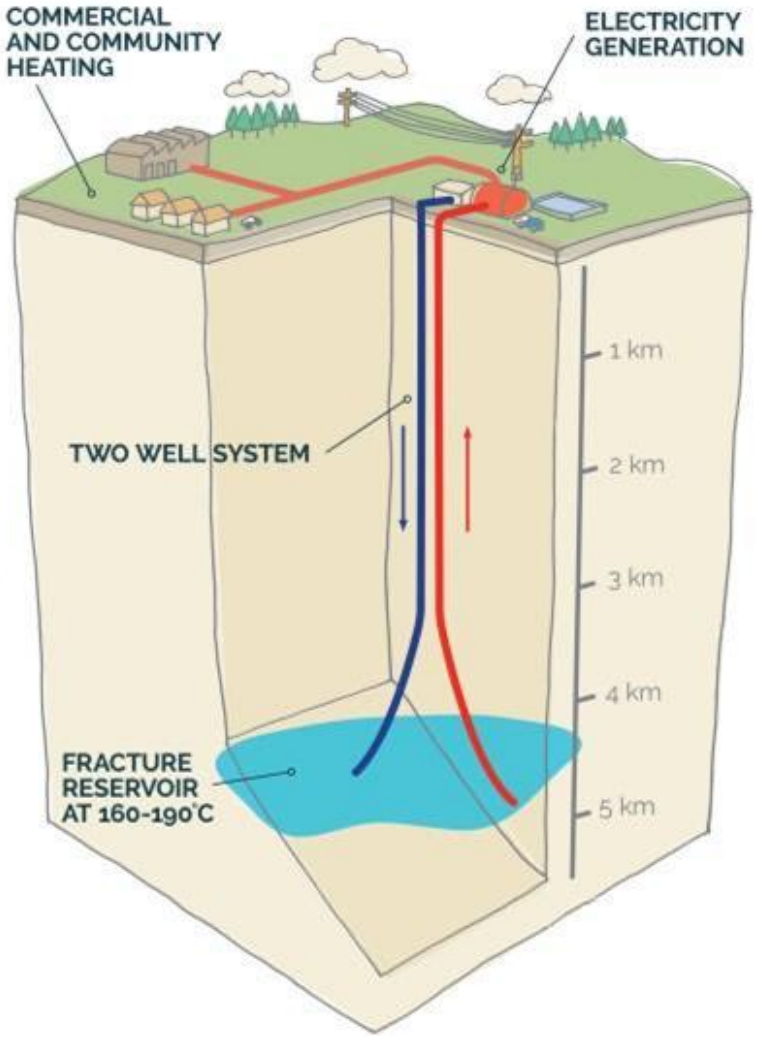
Calculate an accurate numeric answer with appropriate units.

Calculate the % change in global investment in renewable energy from 2004 to 2014.




Natural Gas Production from US Shales, 2000-2013
Dry Gas Production (Billion Cubic Feet / Day)
Year
Antrim
Barnett
Fayetteville
Woodford
Haynesville
Marcellus
Eagle Ford
Bakken


Global natural gas prices
$ / million btu
Energy Matters
euanmearns.com
BP data
$8.10
$4.85
$2.65
USA
EU
Japan (LNG)
Crude oil


COMMERCIAL AND COMMUNITY HEATING
ELECTRICITY GENERATION
1 km
2 km
3 km
4 km
5 km
TWO WELL SYSTEM
FRACTURE RESERVOIR AT 160-190˚C