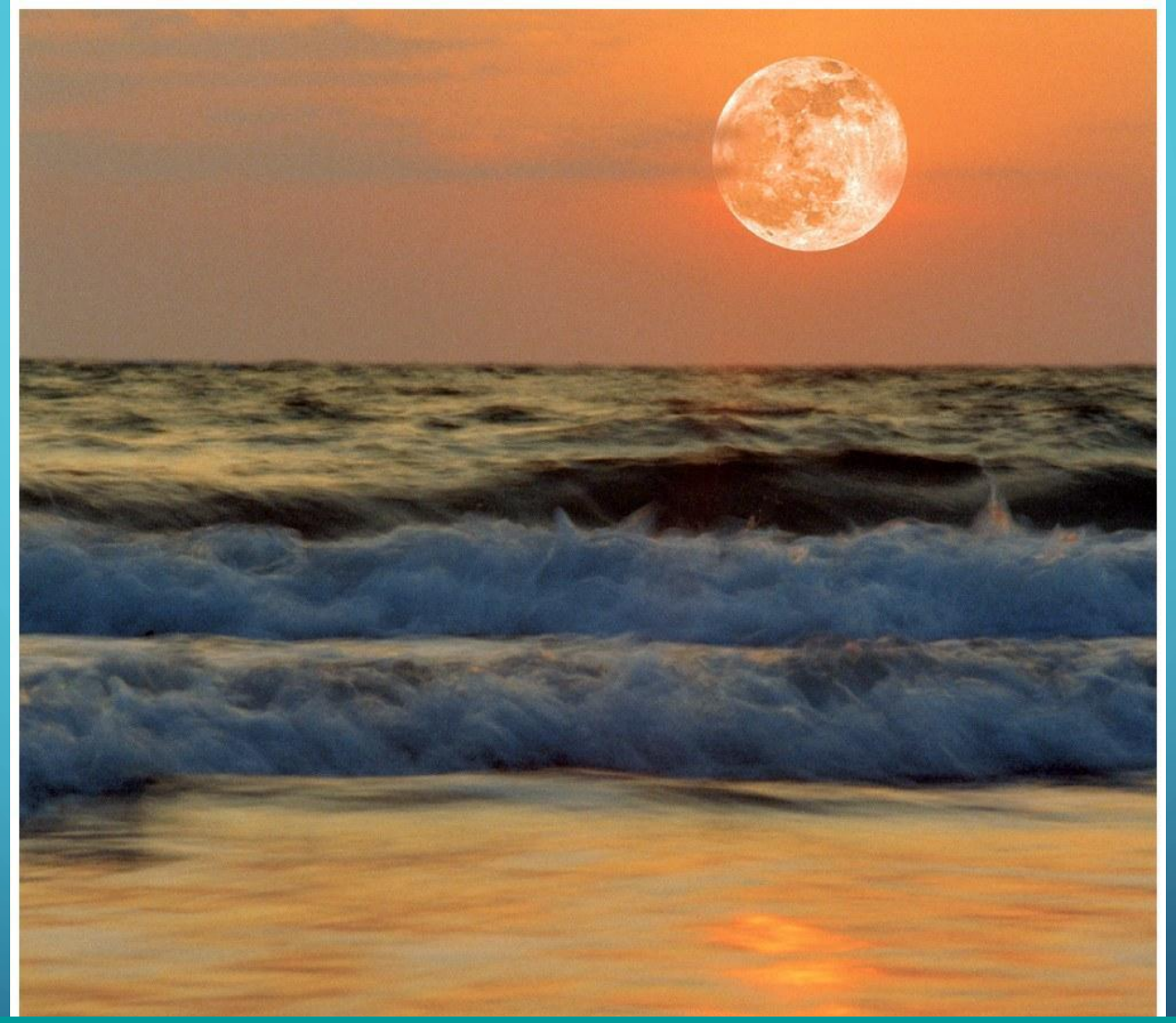
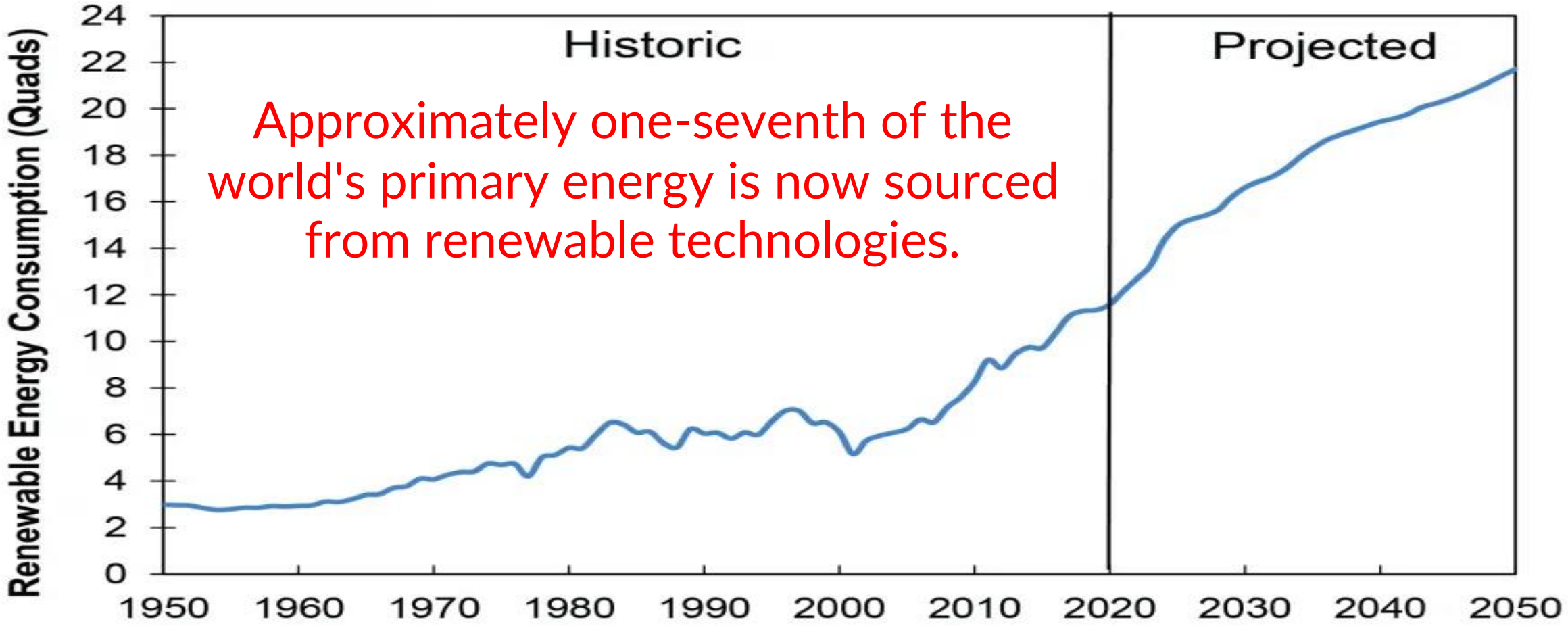


Chapter 13

Achieving Energy Sustainability

U.S. RENEWABLE ENERGY CONSUMPTION: HISTORIC AND PROJECTED

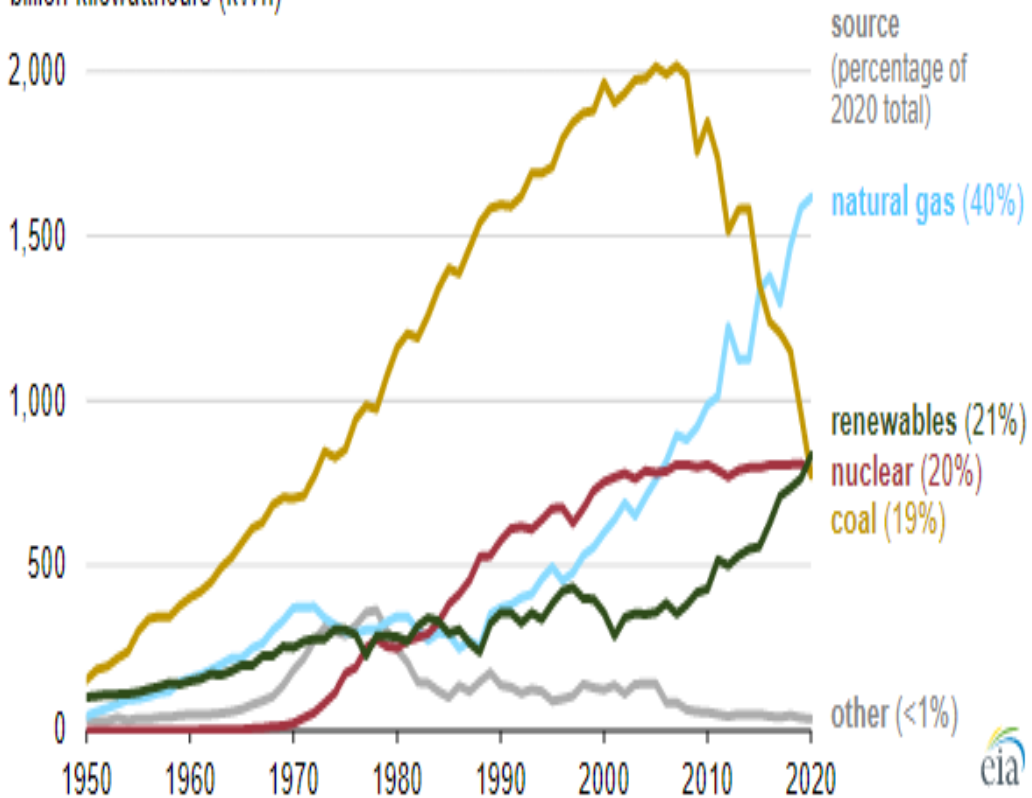
- Renewable energy is the fastest-growing energy source in the United States, increasing 42% from 2010 to 2020 (up 90% from 2000 to 2020).
- Solar generation (including distributed), is the fastest-growing electricity source



JULY 28, 2021

Renewables became the second-most prevalent U.S. electricity source in 2020

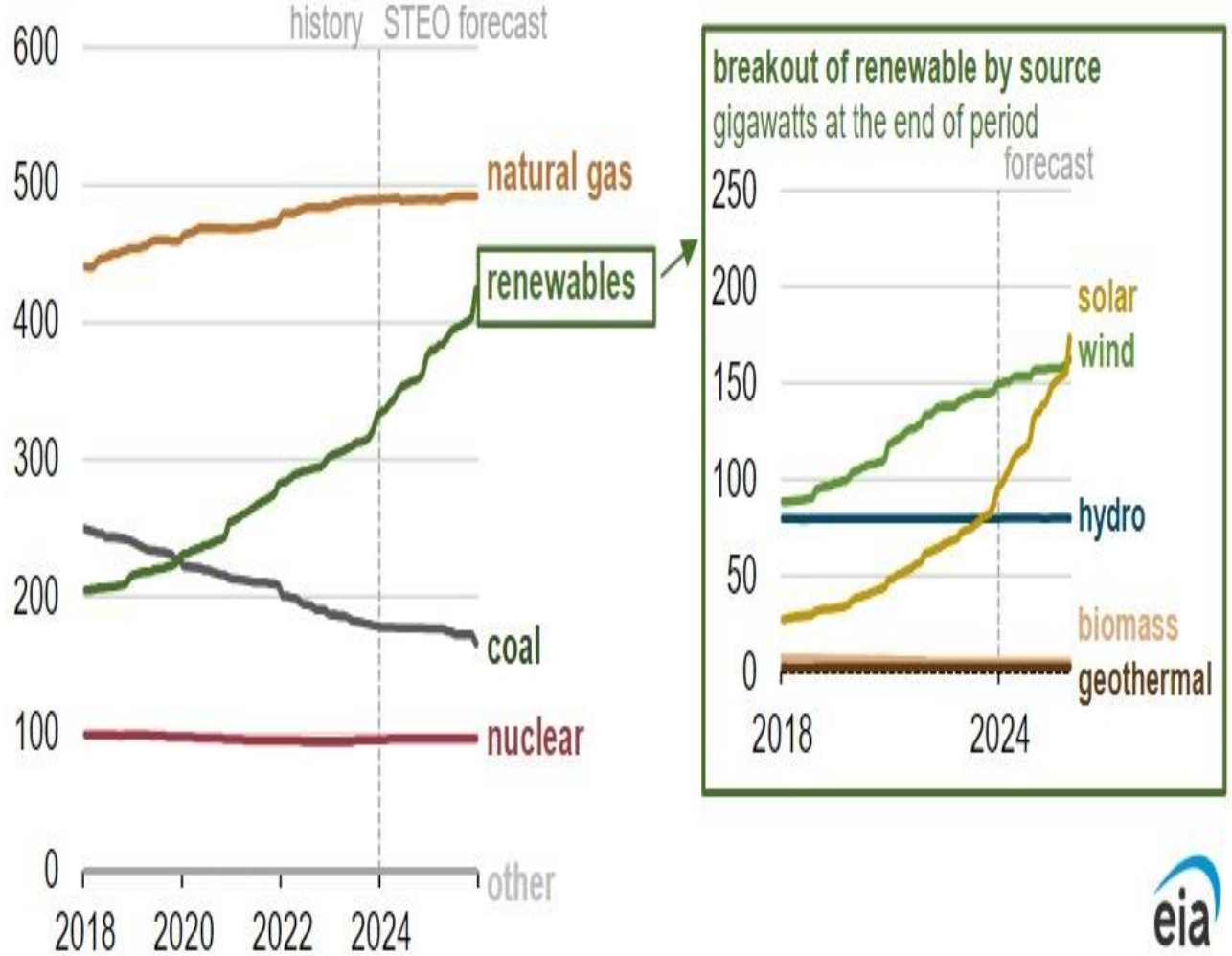
Annual U.S. electricity generation from all sectors (1950–2020)
billion kilowatthours (kWh)



Source: U.S. Energy Information Administration (EIA), *Monthly Energy Review*
Note: This graph shows electricity net generation in all sectors (electric power, industrial, commercial, and residential) and includes both utility-scale and small-scale (customer-sited, less than 1 megawatt) solar.

2023 to 797 billion kWh in 2025.

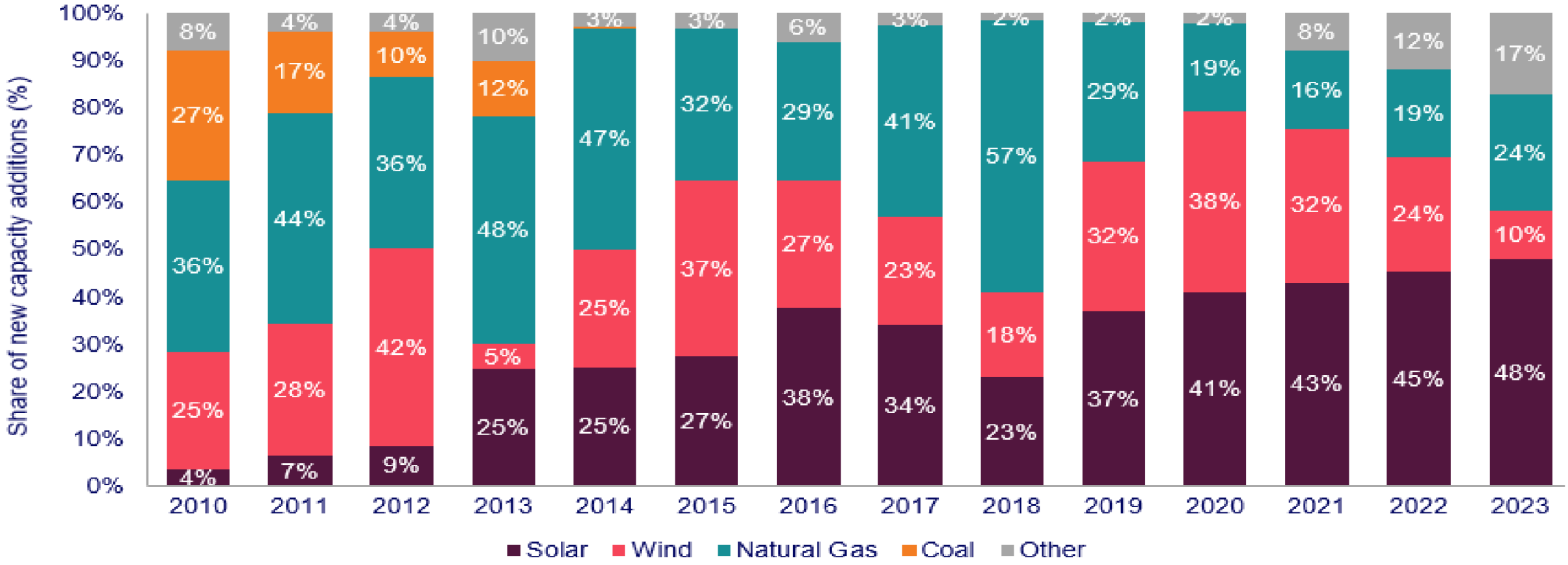
U.S. annual electric generating capacity (2018–2025)
gigawatts at end of December



Data source: U.S. Energy Information Administration, *Short-Term Energy Outlook* (STEO), January 2024

Expected that increased U.S. power generation from new renewables capacity—**mostly wind and solar** (will account for **16% of total generation in 2023**, *up from 14% last year and 8% in 2018*) will reduce generation from both coal-fired and natural gas-fired power plants in 2023 and 2024.

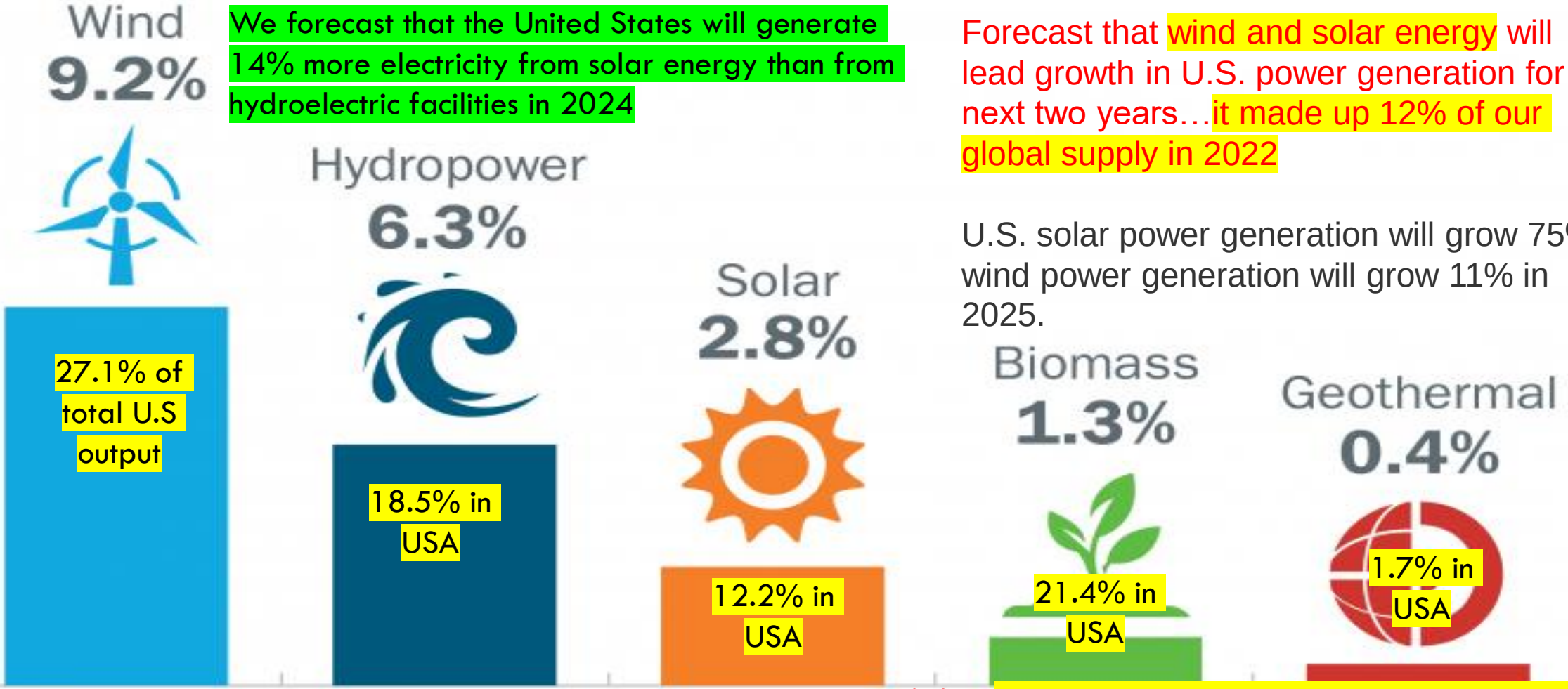
New U.S. electricity-generation capacity additions, 2010 – Q1-Q3 2023



SEIA Solar Energy Industries Association®

Wood Mackenzie

Source: SEIA/Wood Mackenzie Solar Market Insight Report Q4 2023
U.S. Energy Information Administration (for all other technologies)



We forecast that the United States will generate 14% more electricity from solar energy than from hydroelectric facilities in 2024

Forecast that wind and solar energy will lead growth in U.S. power generation for the next two years…it made up 12% of our global supply in 2022

U.S. solar power generation will grow 75%, wind power generation will grow 11% in 2025.

As of 2021 Renewable energy generates about 21% of all U.S. electricity, and that percentage continues to grow.

As of 2022, about 60% of this electricity generation was from fossil fuels—coal, natural gas, petroleum, and other gases. About 18% was from nuclear energy, and about 21% was from renewable energy sources.

In 2022, solar and wind **are expected to add** more than 60% of the utility-scale generating capacity to the U.S. power grid (46% from solar, 17% from wind).

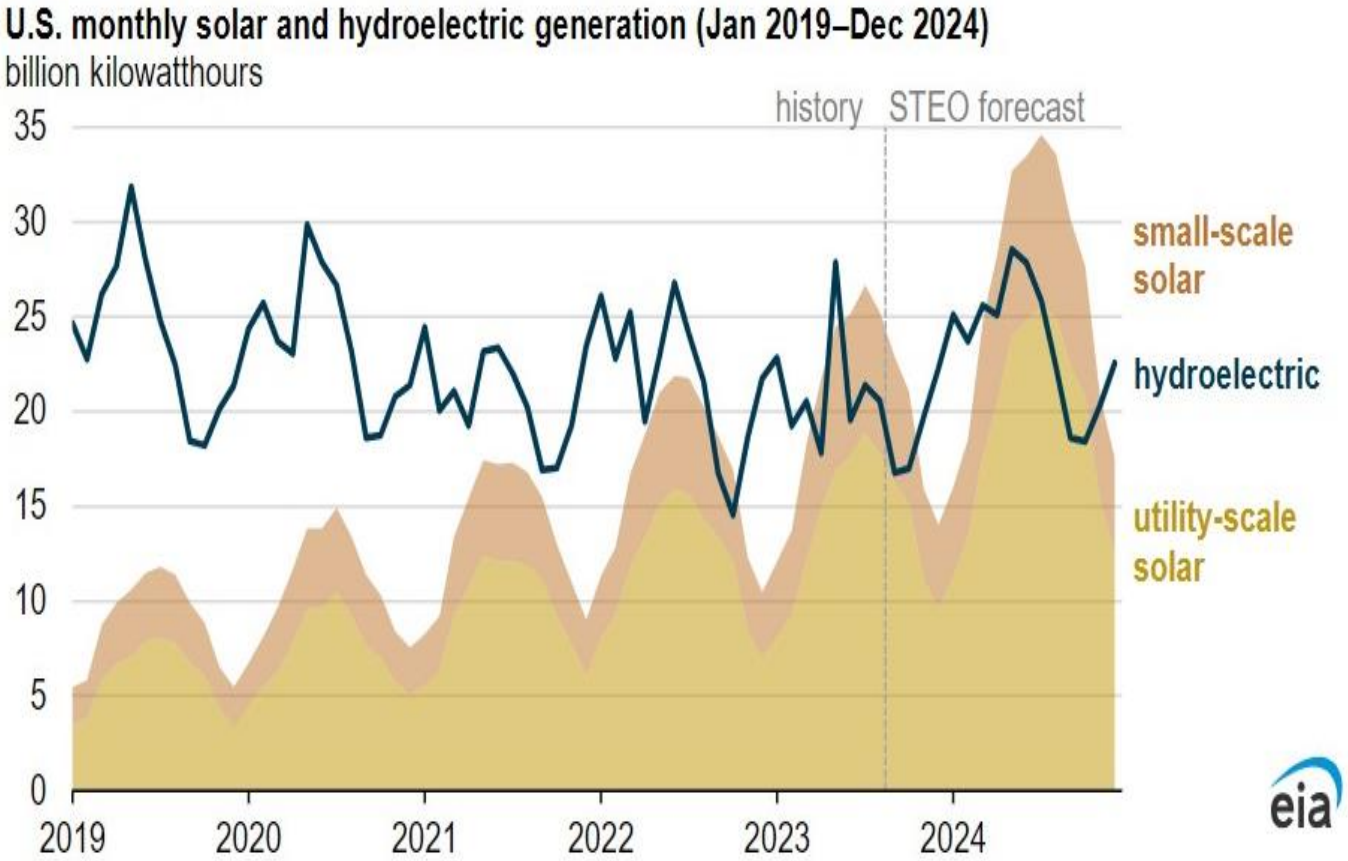
Renewable sources—wind, solar, hydro, biomass, and geothermal—accounted for 22% of generation in 2023

Globally we see that hydropower is by far the largest modern renewable source.

But we also see wind and solar power are both growing rapidly.

NOVEMBER 7, 2023

EIA expects U.S. annual solar electricity generation to surpass hydropower in 2024



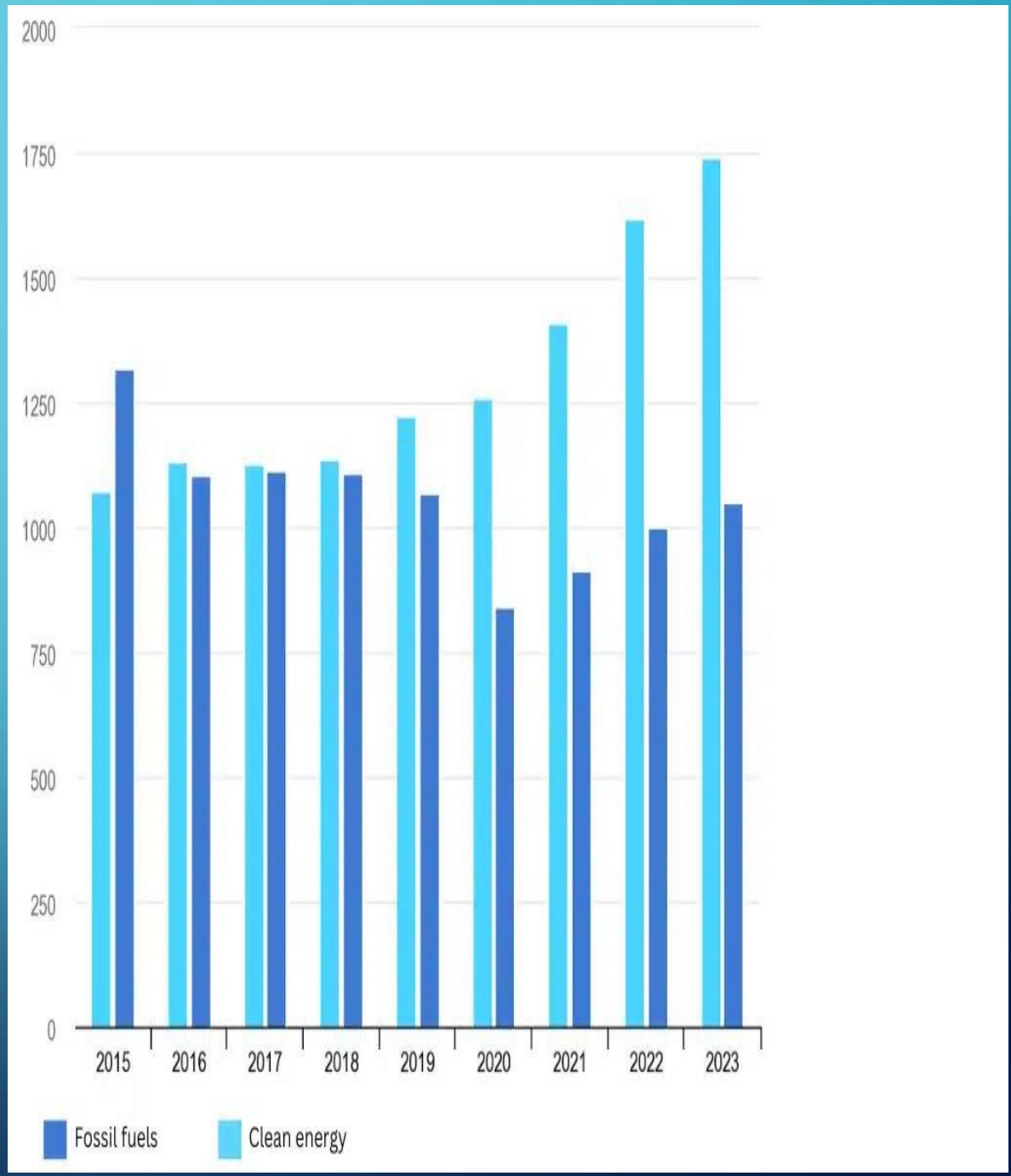
For the first time in September 2022, the United States had more solar-generated electricity than hydroelectric generation on a monthly basis

eia

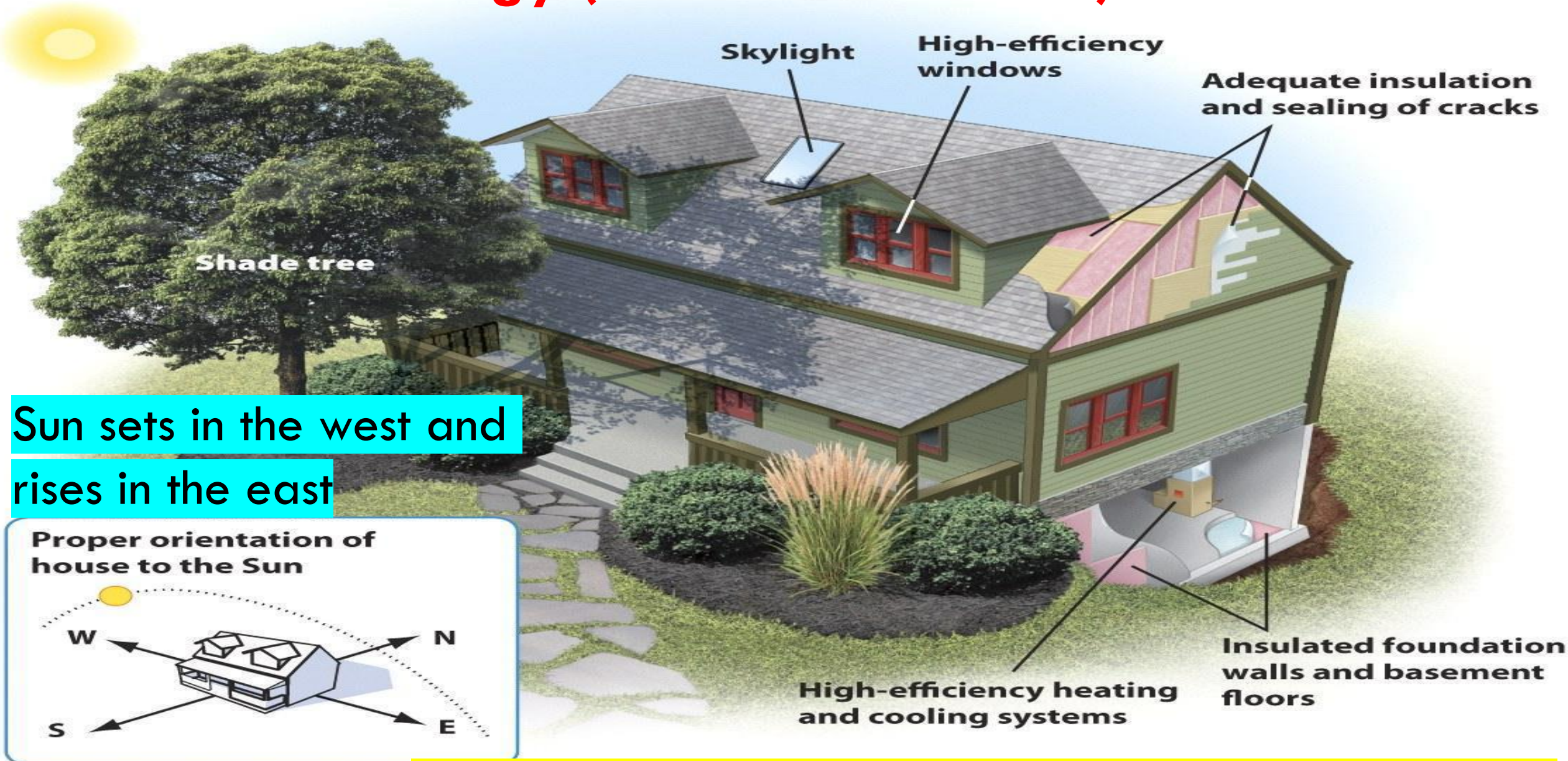
We forecast that the United States will generate 14% more electricity from solar energy than from hydroelectric facilities in 2024, according to our *Short-Term Energy Outlook* (STEO). Our forecast is driven by continued growth in new utility-scale and small-scale solar facilities.

ALTERNATIVE ENERGY

HOW A TINY SCOTTISH ISLAND RELIES ON WIND, WATER, AND SOLAR ENERGY - ~BBC NEWS



1. Solar energy (Passive vs. Active)

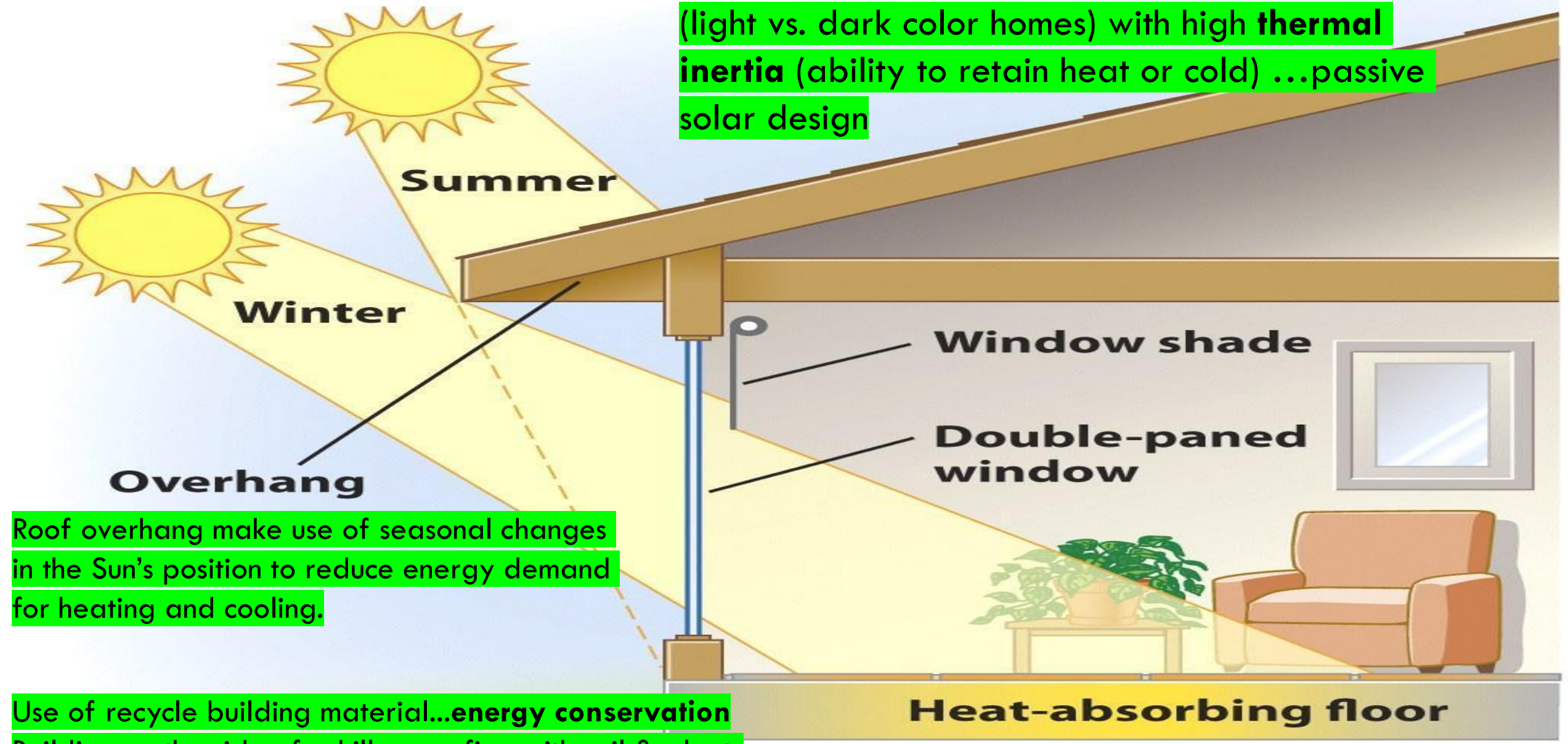


Sun sets in the west and rises in the east

Figure 13.5
Environmental Science

A sustainable building design incorporates proper solar orientation and landscaping, as well as well insulated windows (double, triple paneled), walls, and floors

High efficient windows & building materials (light vs. dark color homes) with high **thermal inertia** (ability to retain heat or cold) …passive solar design



Roof overhang make use of seasonal changes in the Sun's position to reduce energy demand for heating and cooling.

Use of recycle building material…**energy conservation**

Building on the side of a hill or roofing with soil & plants **provide insulation** (reduce heating & cooling)

This Maine home can stay 70 degrees without a furnace, even when it's freezing outside (31*F)....

~No furnace, Just this small little heat pump. Relying a lot on the sun to heat, only pay $13 a month for our connection fee (electric bill).

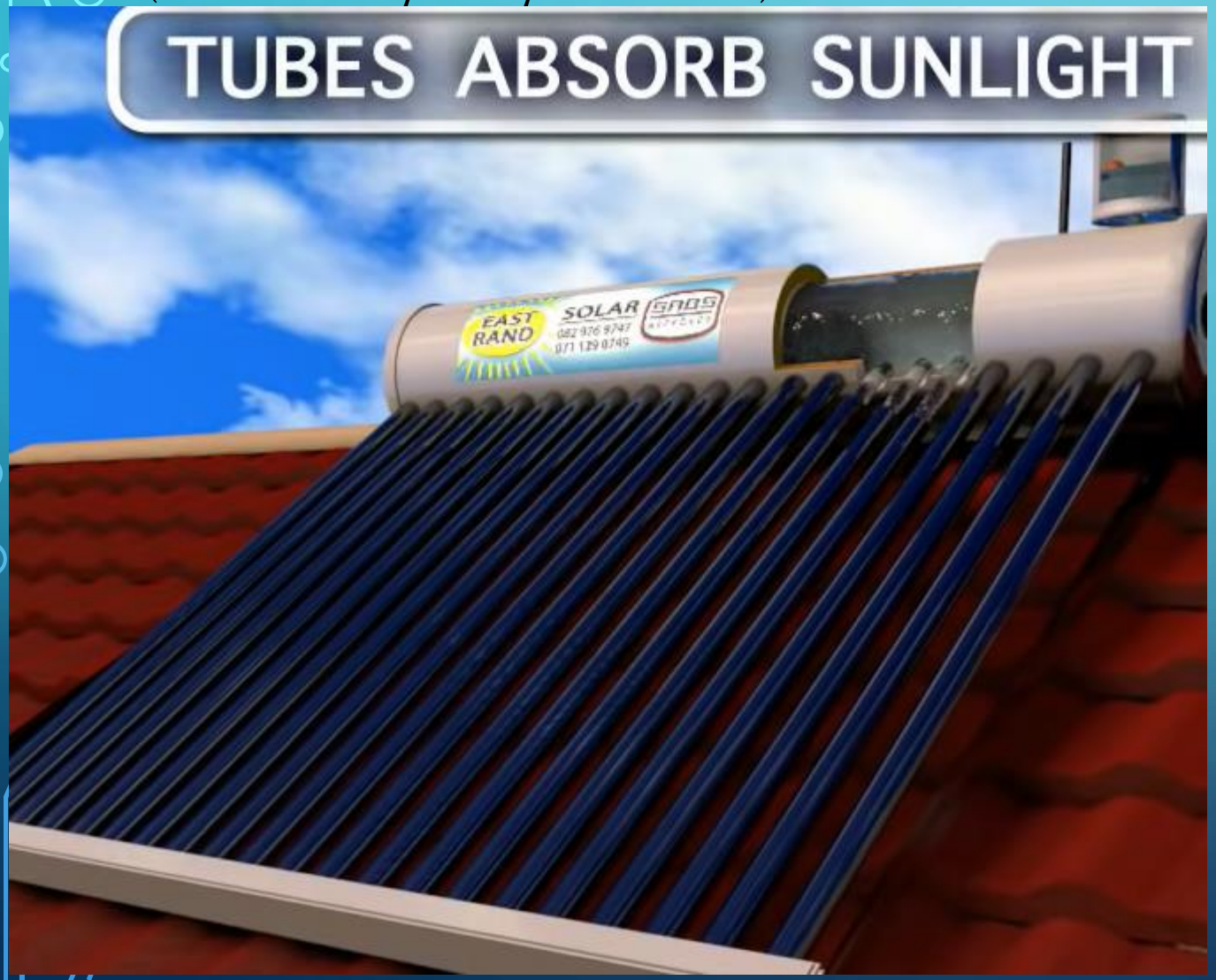
~cost about 10% more to build than conventional structures...more material

~15-inch-thick walls (average is 4-6in), with multiple layers of insulation and sheathing, high-performance triple-glazed windows and doors, and a ventilation system, which is critical in an **airtight building** to allow it and its inhabitants to breathe.

"The German model (U.S started in 2006) has always been for larger buildings. For multi-families, for commercial projects: hospitals, prisons, dormitories. "There's not extra expense at that level, It's just a matter of knowing how to do it.

Passive House Article

Solar water heating applications can provide energy to heat up a pool (most common) or any liquid within the household (water heater), collector tank heating coils, heats water= no pump, pressurized tank...passive.
(*** *with a pump = active*)!



The Sun's energy can be captured directly

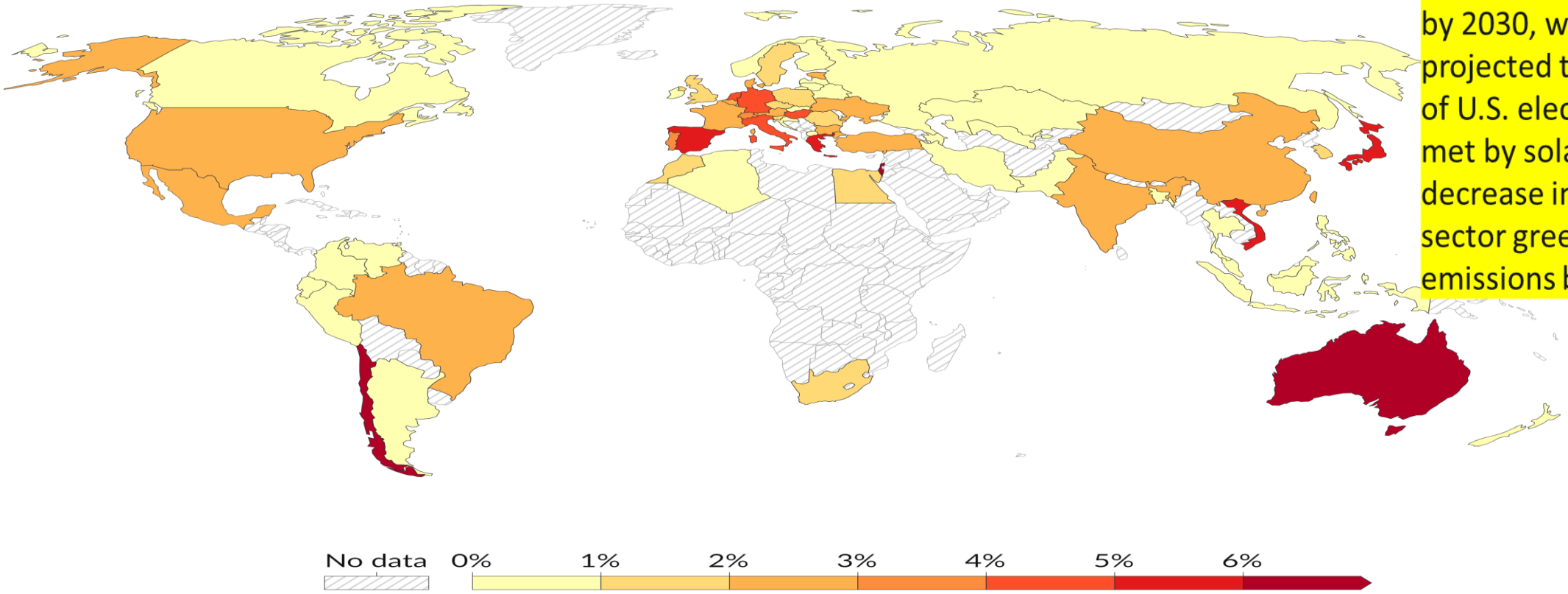
- **Active solar energy-** capturing the energy of sunlight with the use of a pump or photovoltaic solar cell and generating electricity.
  - Solar water heating applications can provide energy to heat up a pool (most common) or any liquid within the household (water heater).

- **Photovoltaic solar cells** *-(contrast to solar water heating system)* captures energy from the Sun as light, not heat, and convert it directly into electricity.
- **Solar panels** (usually on roof) connect directly to appliances or lights or used to charge batteries for later use
  - *-photovoltaic systems are tied to the electrical grid...any extra electricity generated is sent to the electric company to buy or give customer credit for later use.*

Share of primary energy consumption from solar, 2022

Measured as a percentage of primary energy[1], using the substitution method[2].

The U.S. Department of Energy aims to reduce the price of solar energy 50% by 2030, which is projected to lead to 33% of U.S. electricity demand met by solar and a 18% decrease in electricity sector greenhouse gas emissions by 2050



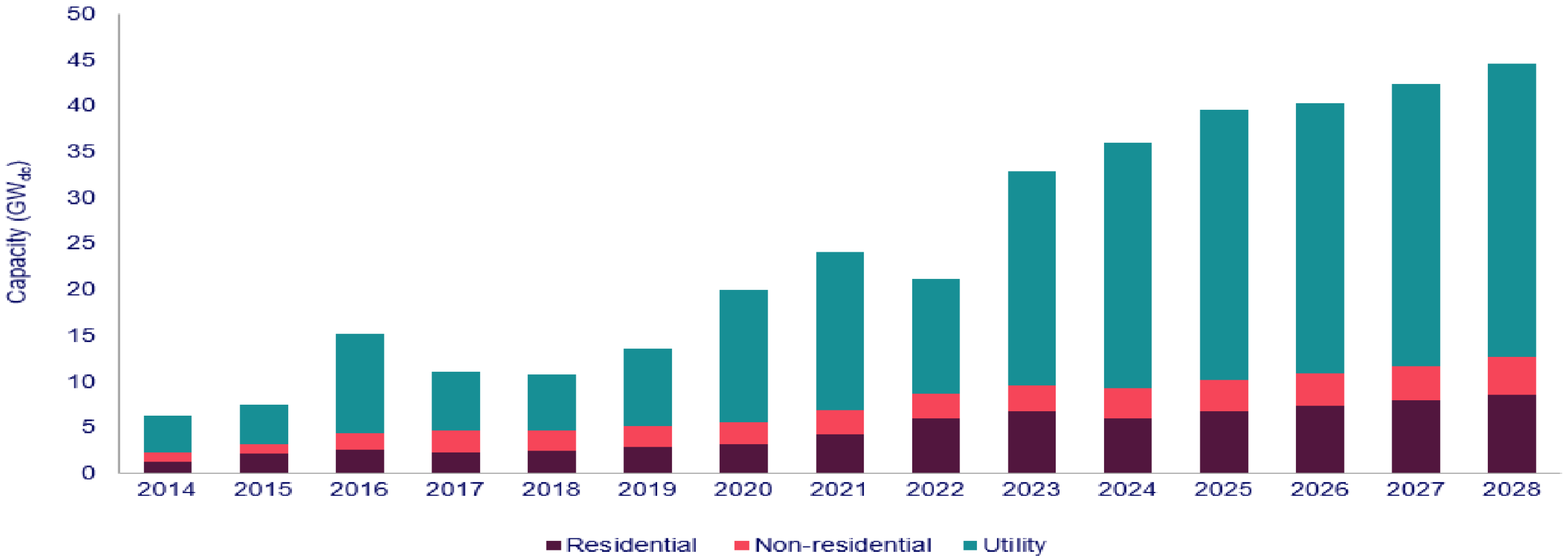
Data source: Energy Institute - Statistical Review of World Energy (2023)

OurWorldInData.org/energy | CC BY

1. **Primary energy**: Primary energy is the energy available as resources – such as the fuels burnt in power plants – before it has been transformed. This relates to the coal before it has been burned, the uranium, or the barrels of oil. Primary energy includes energy that the end user needs, in the form of electricity, transport and heating, plus inefficiencies and energy that is lost when raw resources are transformed into a usable form. You can read more on the different ways of measuring energy in our article.

2. **Substitution method**: The 'substitution method' is used by researchers to correct primary energy consumption for efficiency losses experienced by fossil fuels. It tries to adjust non-fossil energy sources to the inputs that would be needed if it was generated from fossil fuels. It assumes that wind and solar electricity is as inefficient as coal or gas. To do this, energy generation from non-fossil sources are divided by a standard 'thermal efficiency factor' – typically around 0.4 Nuclear power is also adjusted despite it also experiencing thermal losses in a power plant. Since it's reported in terms of electricity output, we need to do this adjustment to calculate its equivalent input value. You can read more about this adjustment in our article.

US PV installation historical data and forecast, 2014 - 2028



SEIA Solar Energy Industries Association®

Wood Mackenzie

Source: SEIA/Wood Mackenzie Solar Market Insight Report Q4 2023

Energy crisis has stimulated the installation and usage of solar photovoltaic cells and wind energy in 2022, which will continue to grow in the coming few years. These renewables are crucial to cutting down on pollution, generating clean energy, and addressing energy security issues. Moreover, the energy created will be cheaper and more affordable. Tapping the huge potential of solar, wind, and hydropower can accelerate the energy economy.

SOLAR – BENEFITS VS. DRAWBACKS

Benefits:

~Generate electricity w/o air pollution, water pollution or greenhouse gases emission.

~Economically feasible (credit for extra electricity generated during peak seasons)

~Tax breaks, rebates, and funding packages by various states *(Cali leading with 1.3 million solar users)*

~Price of solar panels dropped by nearly 50% compared to 2022.

Drawbacks:

~Initial install and manufacture and storage is expensive

~Low solar radiation….geography (space to house the panels…land)

~Ideal temp (electric parts work best) is ~77*F anything higher starts to lose efficiency

~Manufacturing of cells require great deal of energy & water and a variety of toxic metals and industrial chemicals to be released into the environment *(working on better technologies and metals/chemicals used in the process)*

~*Waste…Germany has now* taken 100% silicon from discarded solar panels and recycled it for use in new ones as of 2/22. (By 2050, around 1.5 million tons of solar panels will be in landfills…last btwn 15-25yrs)

3. Wind energy is the most rapidly growing source of electricity (form of solar due to heating of atmosphere by the sun and rotation of Earth)

- **Wind energy-**(largest source of renewable electricity generation in the United States, providing 10.2% (surpassed hydro as of 2019) of the country's electricity and growing.) using a wind turbine to convert kinetic energy of moving air into electrical energy
  - *Sun is the source of all winds…solar radiation & ground surface heating drives air circulation.*

- Offshore wind parks (in or near coastline water, wind blowing across the sea) generated more electricity. Typically **installed in rural locations (land-based farms)**, away from buildings & population centers

- U.S generates the most electricity from wind energy in the world (21% Texas & California)
  - *Largest use in the world is China(70%),* followed by U.S(10%), Brazil (7%)

Wind turns blade, connected to the generator, generates electricity

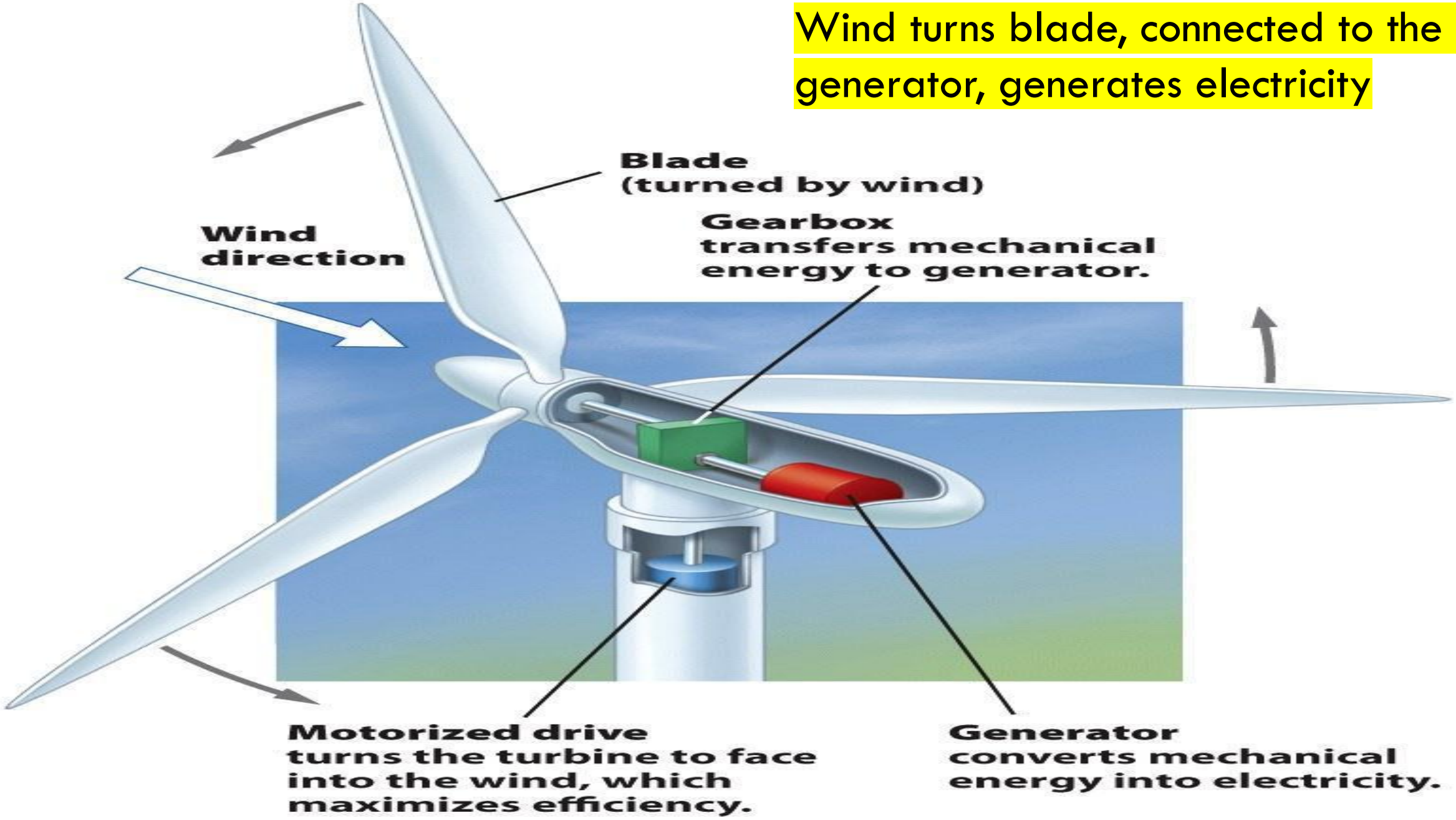
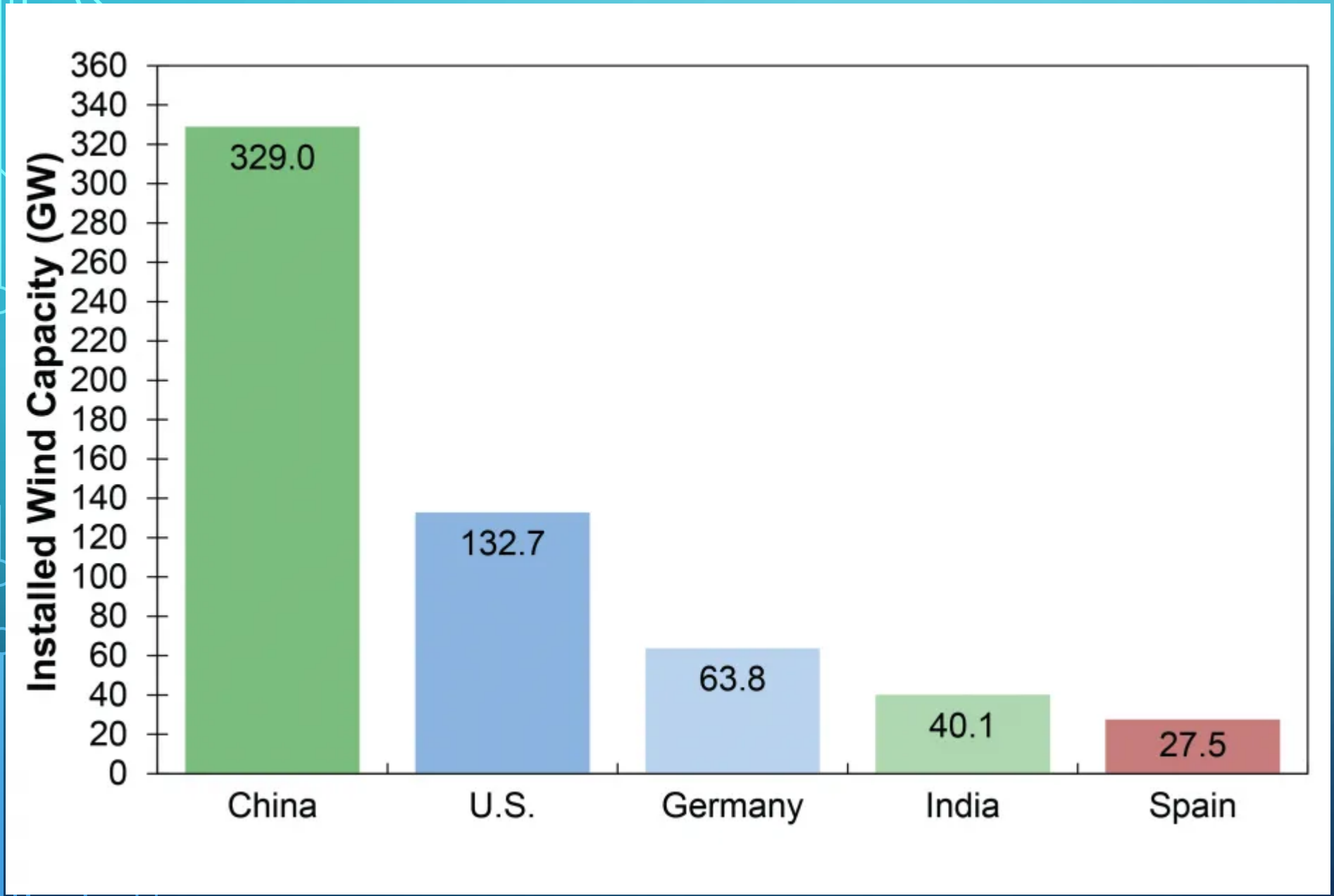


Figure 13.22
Environmental Science

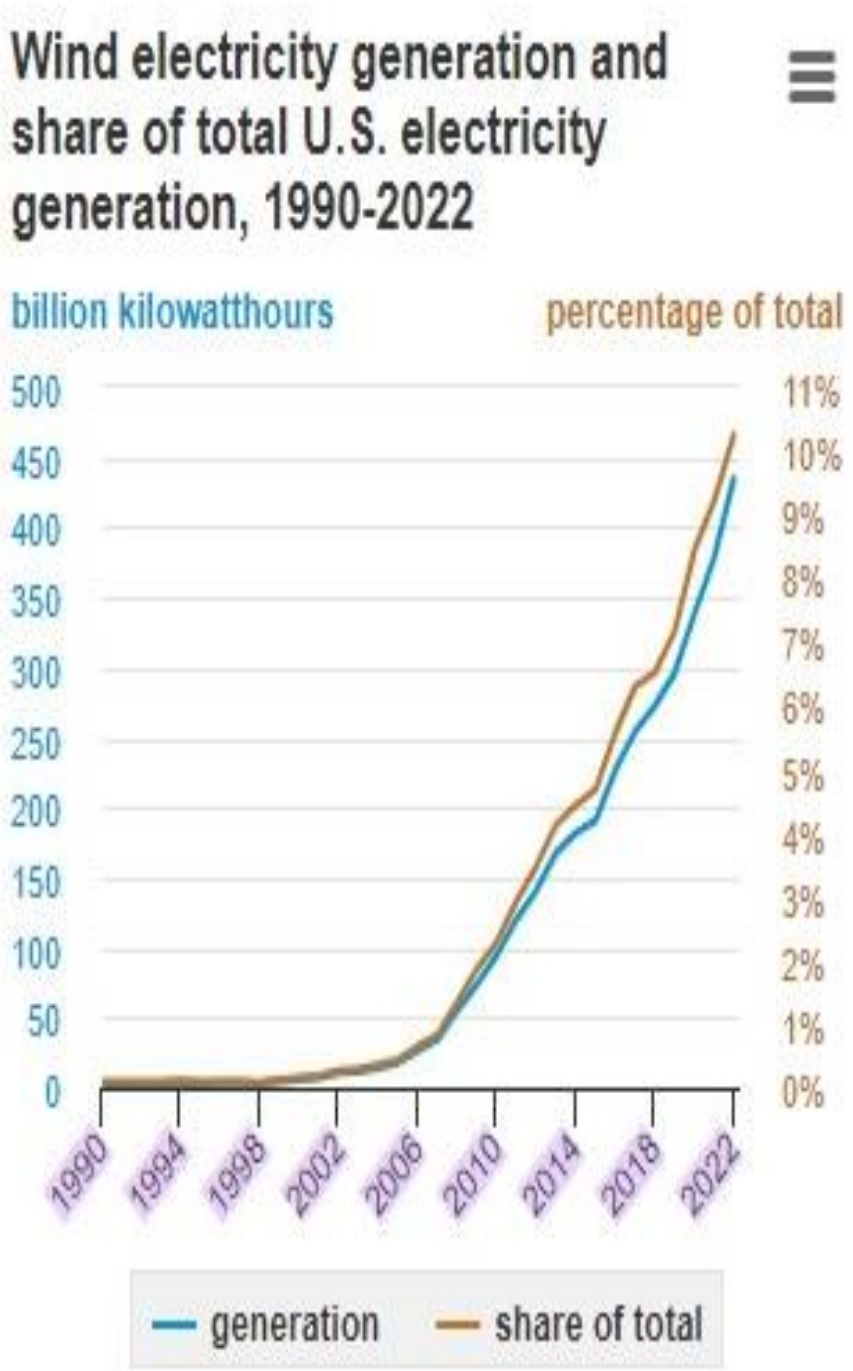


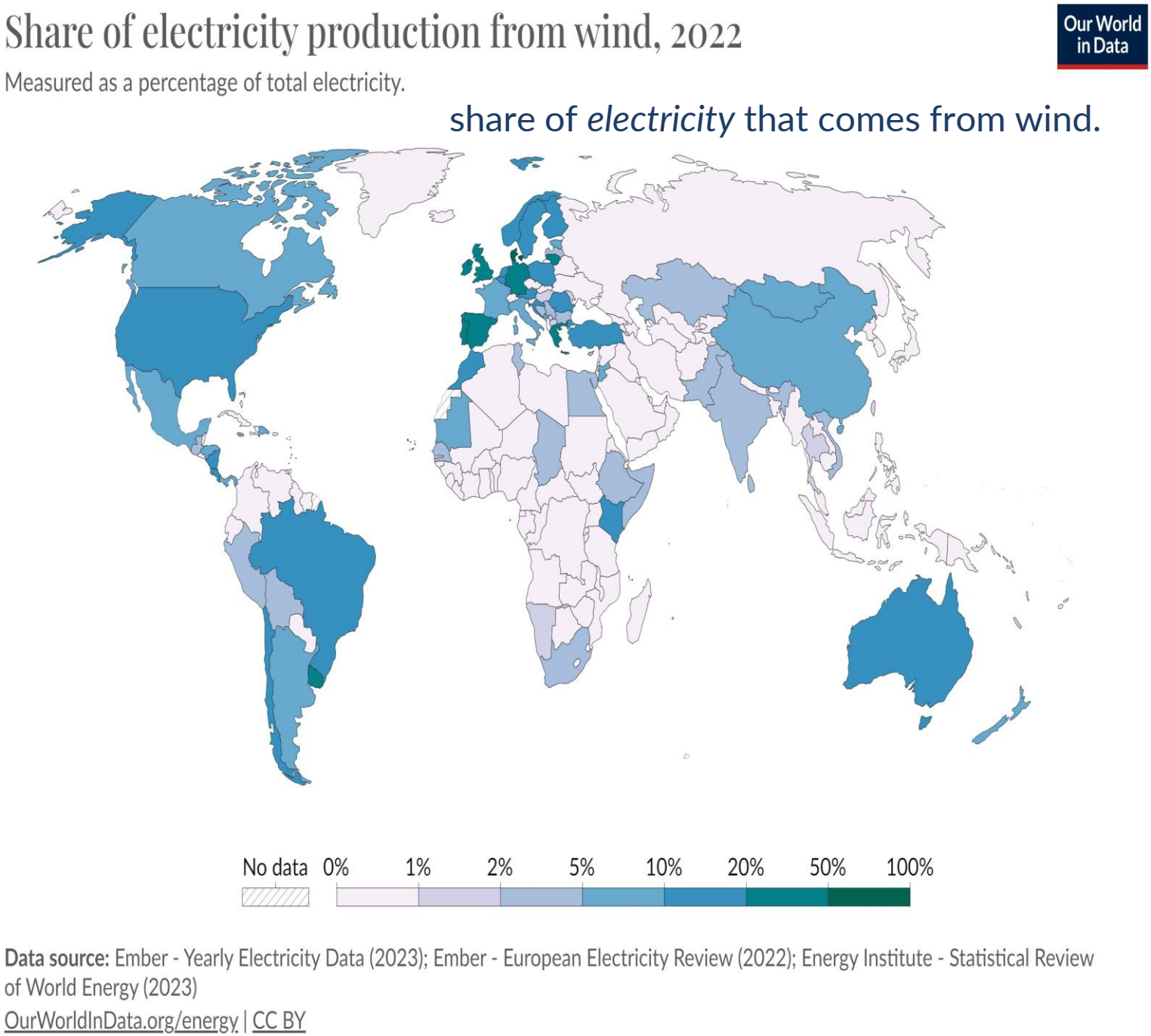
Over 16 GW of wind capacity was installed in the U.S. in 2020, 85% increase from 2019.

By 2050, 404 GW of wind capacity would meet an estimated 35% of U.S. electricity demand and result in 12.3 gigatonnes of avoided CO_2 emissions, a 14% reduction when compared to 2013.

US achieved a new record in April 2022 – for the first time, the US generated **20%** of its electricity from wind and solar power

Wind turbines generate no emissions and use no water when producing electricity, but concerns include bat and bird mortality, land use, noise, and aesthetics.


Wind electricity generation and share of total U.S. electricity generation, 1990-2022
billion kilowatthours
percentage of total
500
450
400
350
300
250
200
150
100
50
0
11%
10%
9%
8%
7%
6%
5%
4%
3%
2%
1%
0%
1990
1994
1998
2002
2006
2010
2014
2018
2022
generation
share of total


Share of electricity production from wind, 2022
Measured as a percentage of total electricity.
Our World in Data
share of *electricity* that comes from wind.
No data
0%
1%
2%
5%
10%
20%
50%
100%
Data source: Ember - Yearly Electricity Data (2023); Ember - European Electricity Review (2022); Energy Institute - Statistical Review of World Energy (2023)
OurWorldInData.org/energy | CC BY

Wind - Benefits vs. Drawbacks

Benefits:

- Like sunlight, wind is nondepletable, clean, and free energy resource (subjective on climate)
- No demand for water for cooling
- Produces no pollution or greenhouse gases *once installed and manufactured*

Drawbacks:

- Wind energy systems rely on batteries, which are expensive to produce and hard to dispose of or recycle (intermitted...climate)
- Transmission...requires infrastructure to get the energy to generation site
- Noise and visual pollution
- Killing of organisms (placement in non-migration paths)
- Land coverage...need to be place 80-500 meters (~1/3 mile) apart

The kinetic energy of water can generate electricity

- **4. Hydroelectricity**- electricity generated by the kinetic energy of moving water *(falling over vertical distance, flowing with a river or tidal)*.
  - This is the second most common form of renewable energy in the world (China #1 producer, followed by Brazil & U.S).
  - **Hydroelectric power was (as of 2019) the largest producer of renewable power in the United States but was recently surpassed by WIND.**

-The amt. of electricity generated depends on the flow rate, the water travels at (higher rate, more spinning of the turbine, more electricity)

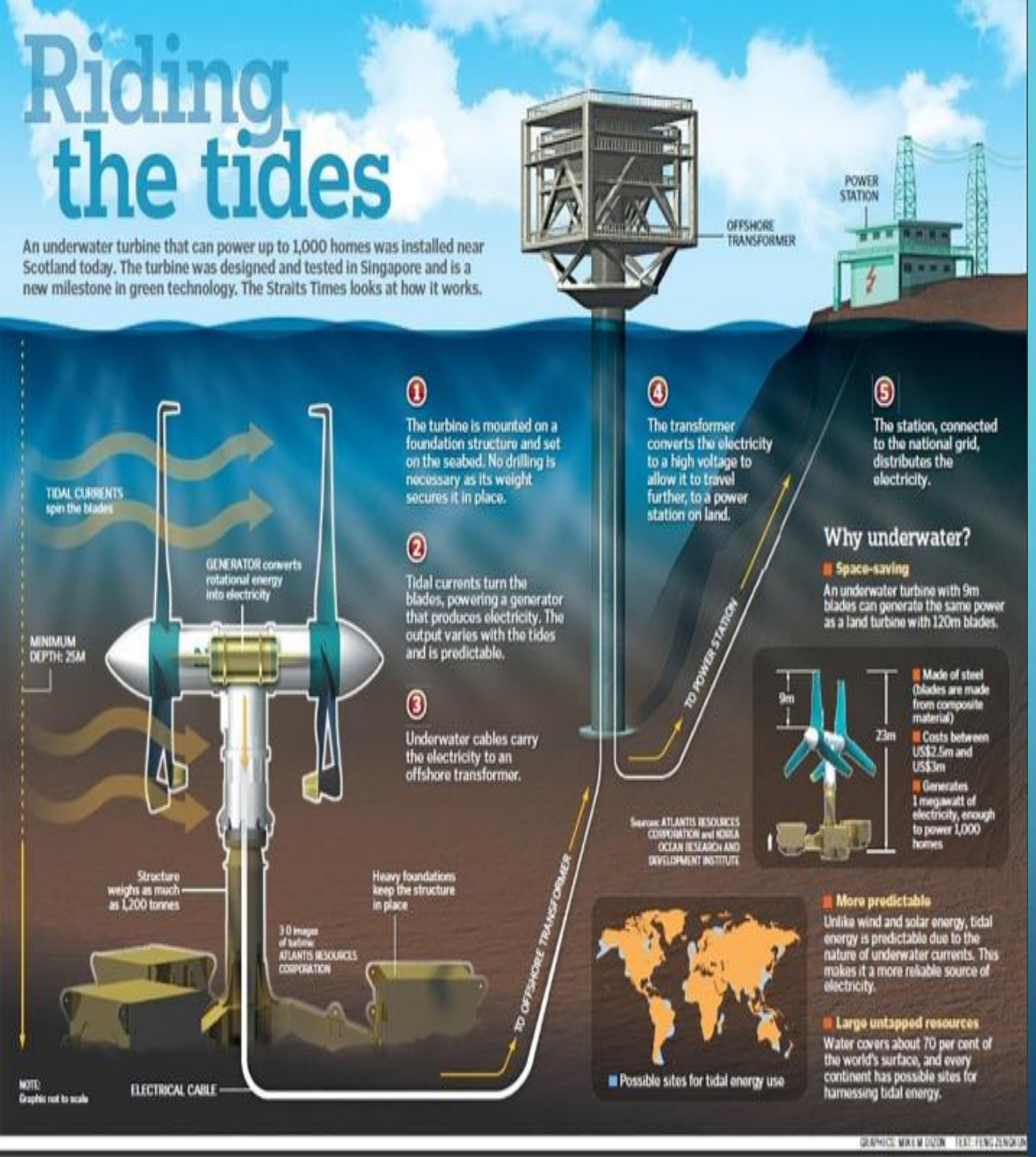
Types of hydroelectric power systems

1. **Run-of-the-river systems-** water is held behind a dam and runs through a channel before returning to the river **(not controlled).**

   ~Natural water flows (small), not a reservoir. Dry, hot period, flow of water is low….little electricity generated.

2. **Water impoundment** *(most common method, biggest environmental & economic costs)-* water is stored behind a dam and the gates of the dam are opened and closed *controlling the flow of water (isolation of species…fish ladders (structure that helps migration of fish over an obstacle up & downstream) help this problem).*

Washington State (**the Grand Coulee Dam**)has the largest one generating 6,800MW at peak capacity (in U.S, largest is in China)

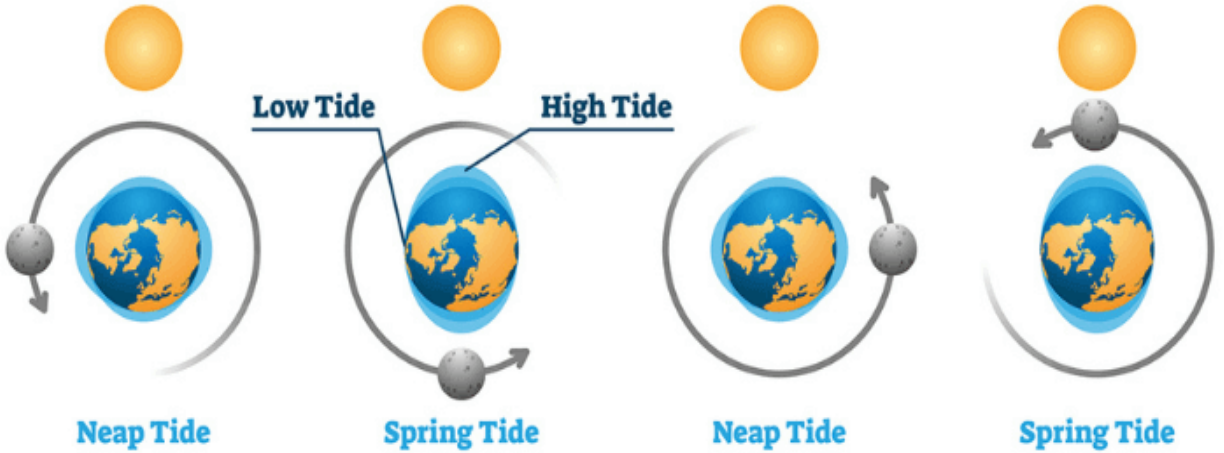


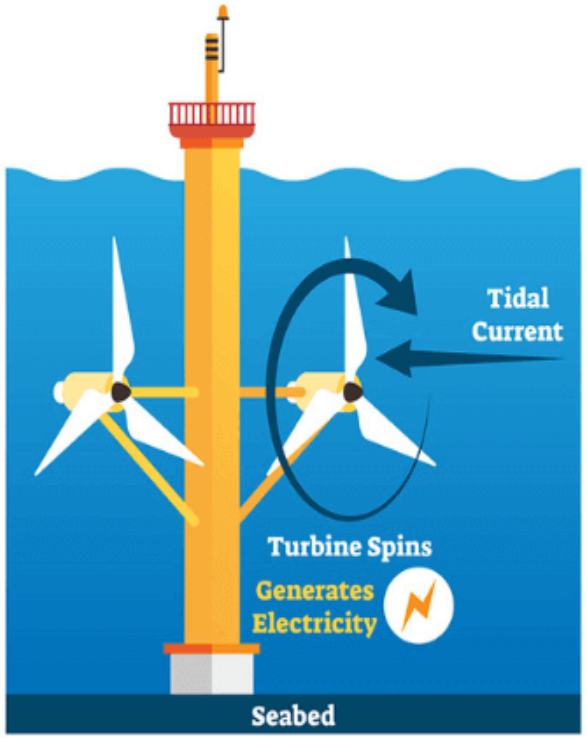
3. Tidal systems- the movement of water is driven by the gravitational pull of the Moon (not a major energy source).

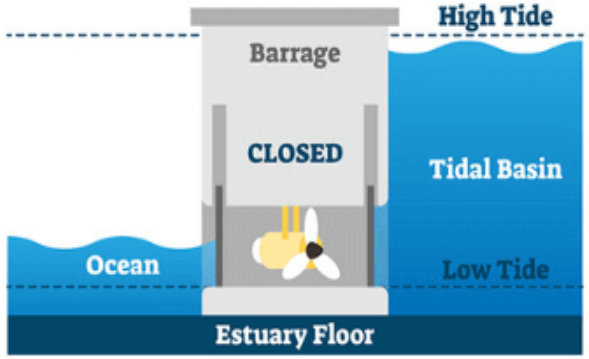
~generated in locations with a large difference between high and low tides

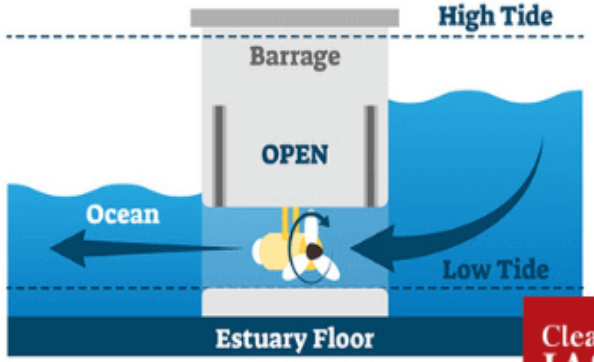
~Uses gates & turbines underwater to capture KE of water flowing through estuaries, rivers and bays & convert it into electricity.

TIDAL ENERGY

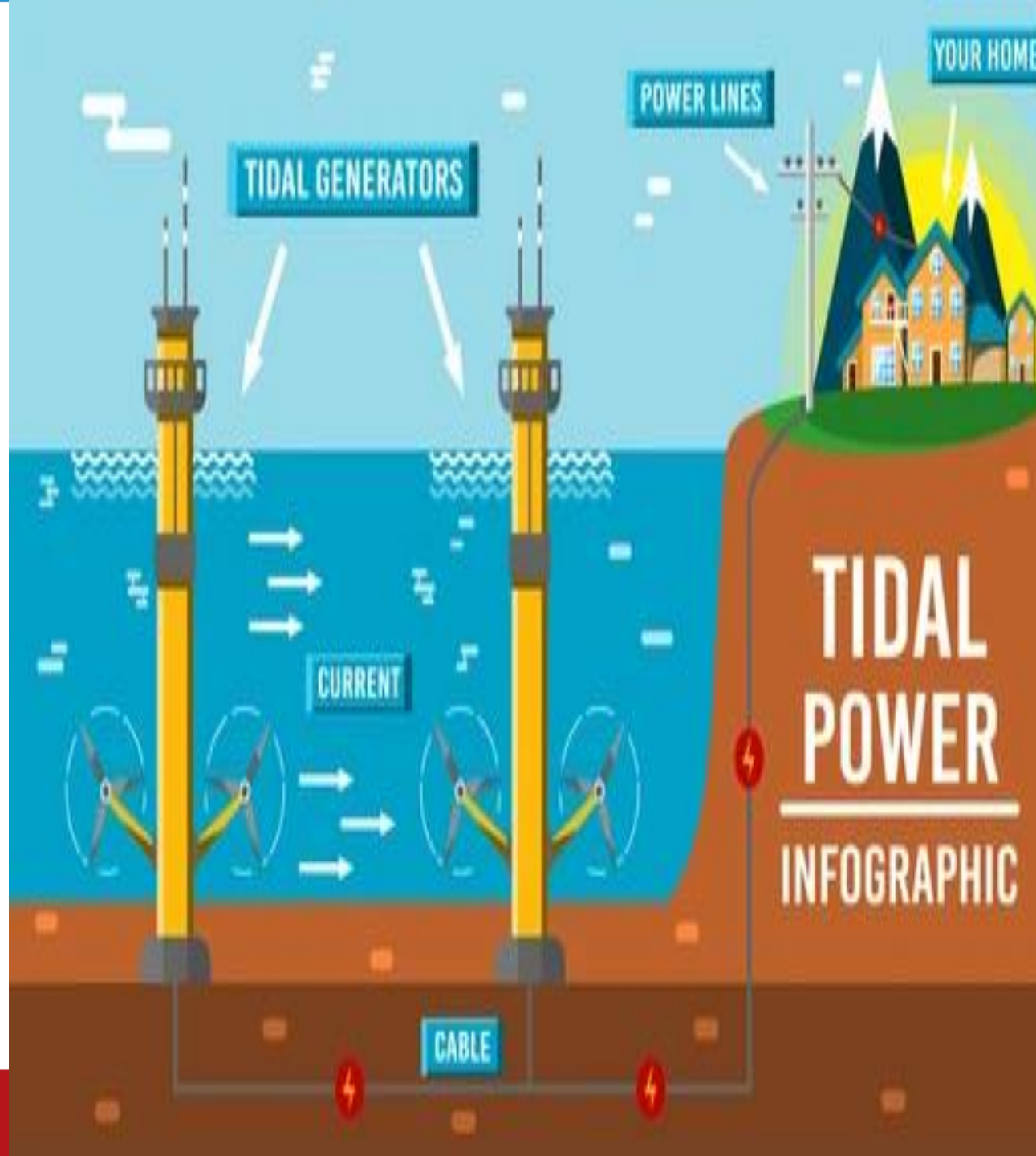








Clear IAS



HYDROELECTRICITY BENEFITS

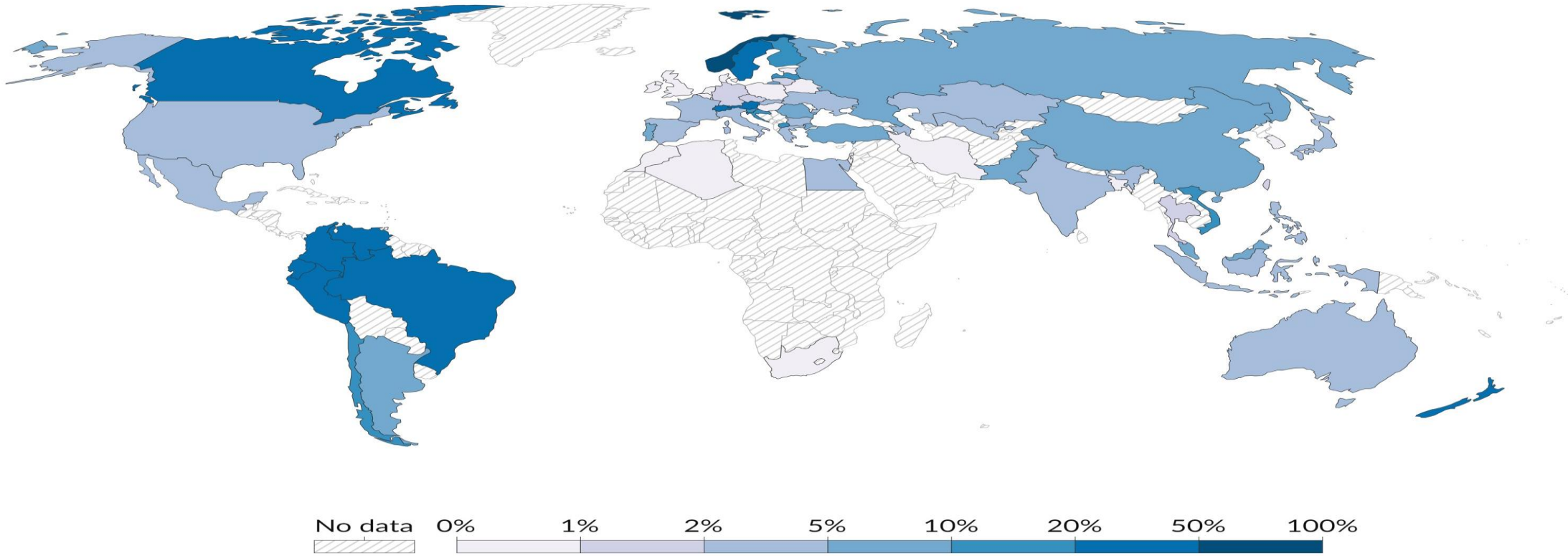
- Require minimal fossil fuels
- Generate large quantities of electricity w/o creating air pollution, waste products, or Carbon dioxide emissions
- Less expensive for the consumers *(than electricity generated using nuclear or natural gas - $.5 to $.11/kW)*
- Reservoir behind a dam can provide recreational & economic opportunities *(generate millions of dollars and visitors)* as well as downstream flood control for flood-prone areas

Share of primary energy consumption from hydroelectric power, 2022

Our World in Data

Measured as a percentage of the total primary energy[1] using the substitution method[2].

share of *electricity* that comes from hydropower.

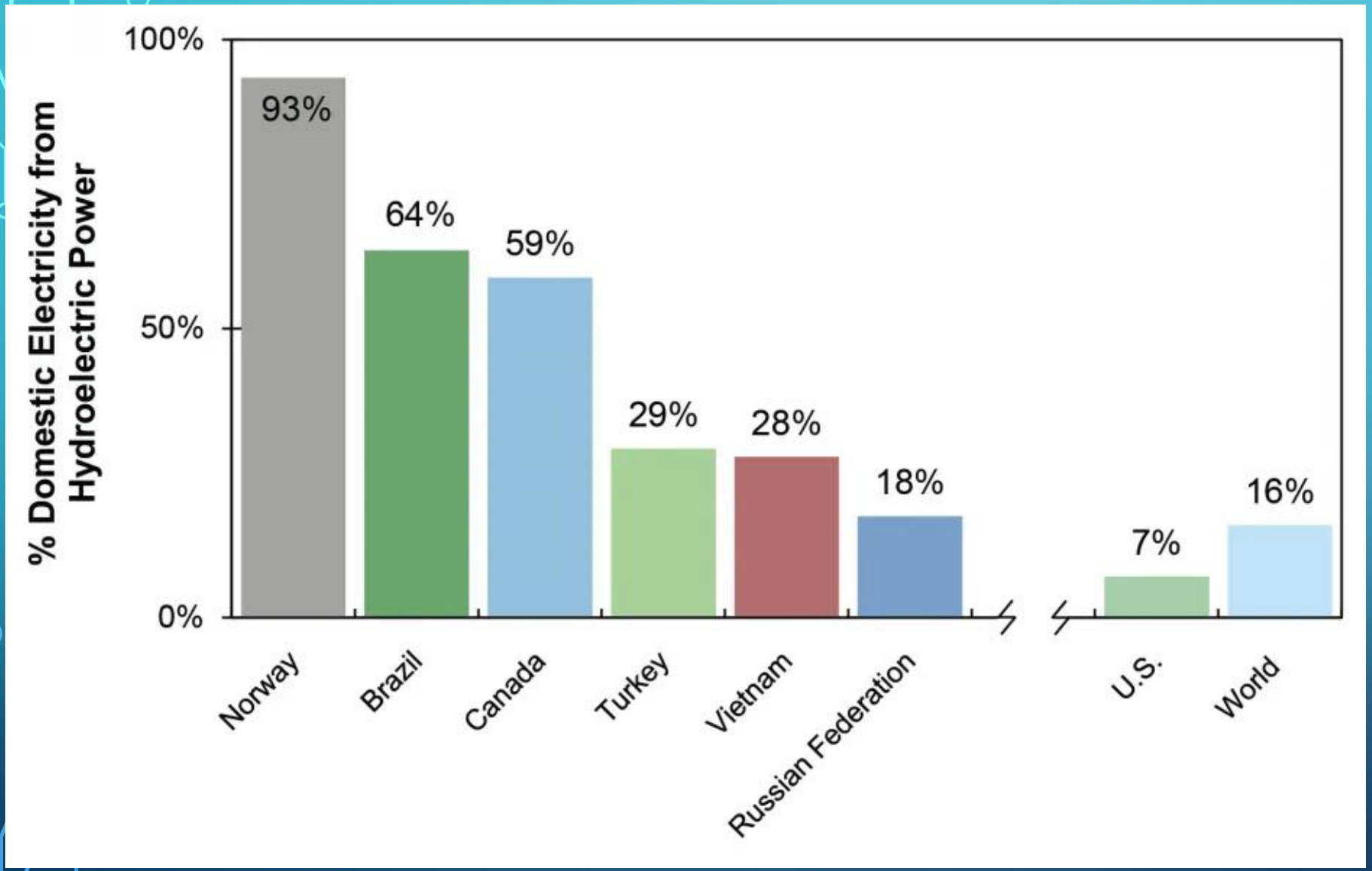


Data source: Energy Institute - Statistical Review of World Energy (2023)

OurWorldInData.org/energy | CC BY

1. Primary energy: Primary energy is the energy available as resources – such as the fuels burnt in power plants – before it has been transformed. This relates to the coal before it has been burned, the uranium, or the barrels of oil. Primary energy includes energy that the end user needs, in the form of electricity, transport and heating, plus inefficiencies and energy that is lost when raw resources are transformed into a usable form. You can read more on the different ways of measuring energy in our article.

2. Substitution method: The 'substitution method' is used by researchers to correct primary energy consumption for efficiency losses experienced by fossil fuels. It tries to adjust non-fossil energy sources to the inputs that would be needed if it was generated from fossil fuels. It assumes that wind and solar electricity is as inefficient as coal or gas. To do this, energy generation from non-fossil sources are divided by a standard 'thermal efficiency factor' – typically around 0.4 Nuclear power is also adjusted despite it also experiencing thermal losses in a power plant. Since it's reported in terms of electricity output, we need to do this adjustment to calculate its equivalent input value. You can read more about this adjustment in our article.



WHILE ELECTRICITY GENERATED FROM **HYDROPOWER IS VIRTUALLY EMISSION FREE**, SIGNIFICANT LEVELS OF METHANE AND CO_2 MAY BE EMITTED THROUGH THE DECOMPOSITION OF VEGETATION IN THE RESERVOIR.

NEGATIVE DRAWBACKS (CONSEQUENCES)

- Hydroelectric dams are expensive to build
- Flooding prime valley agricultural land or canyons
- Large reservoirs of standing water hold more heat, contain less oxygen & release greenhouse gases (*to build & fill reservoirs*) than free-flowing rivers
- Regulating water flow, & flooding, dams can alter dynamics of ecosystem
- Environmental concerns include fish injury and mortality, habitat degradation, and water quality impairment.
- Accumulation of sediments **(siltation)**, over time (hundreds of years, or decades depending on geology of area), reservoir fills with sediment, water is impounded, generating electricity is reduced…major reason to *dismantle dams*

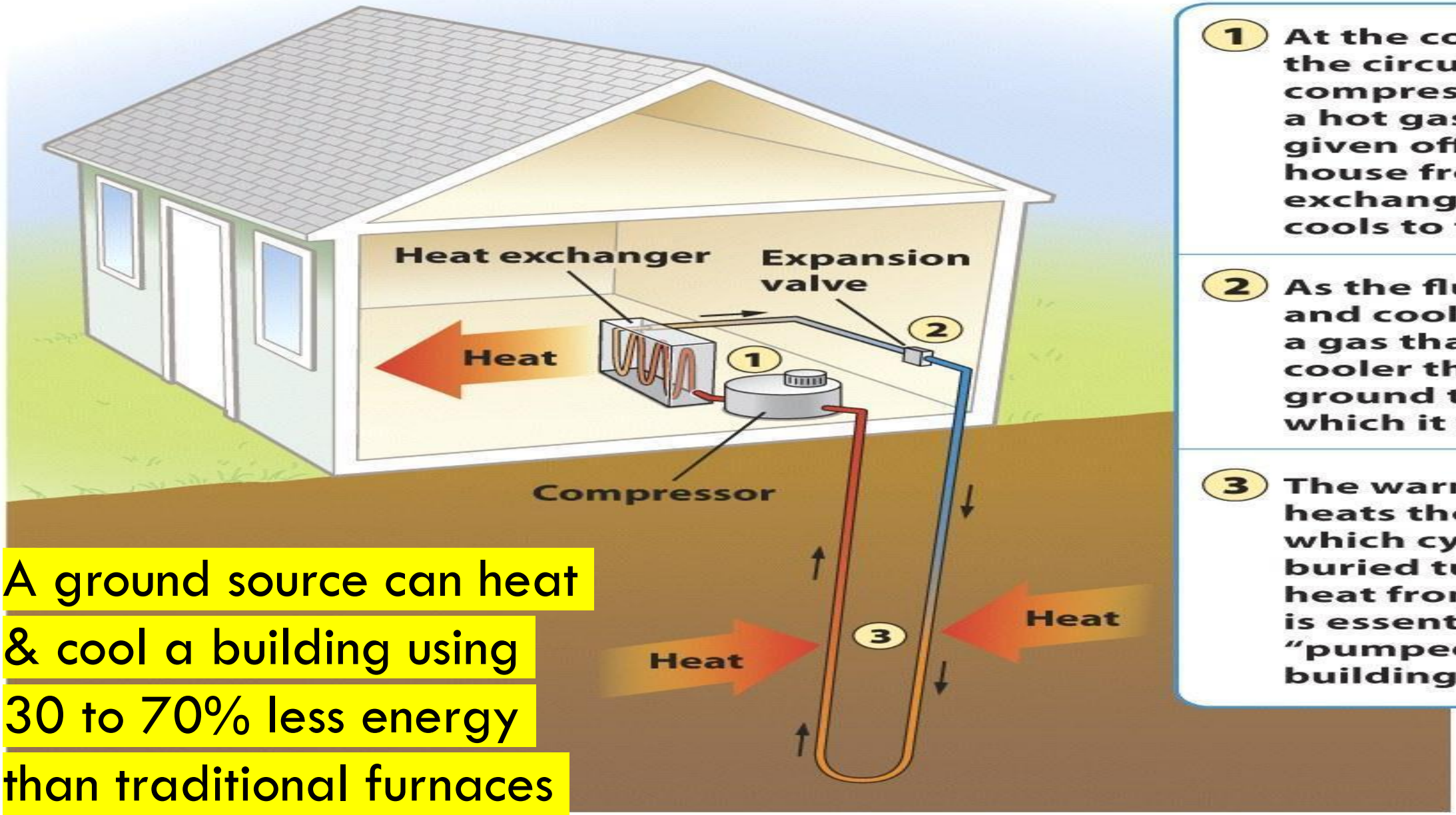
Earth's internal heat produces geothermal energy

- **5. Geothermal energy-** is **heat** that comes from the natural radioactive decay of elements deep within Earth ***(Sun has no point in this process).***

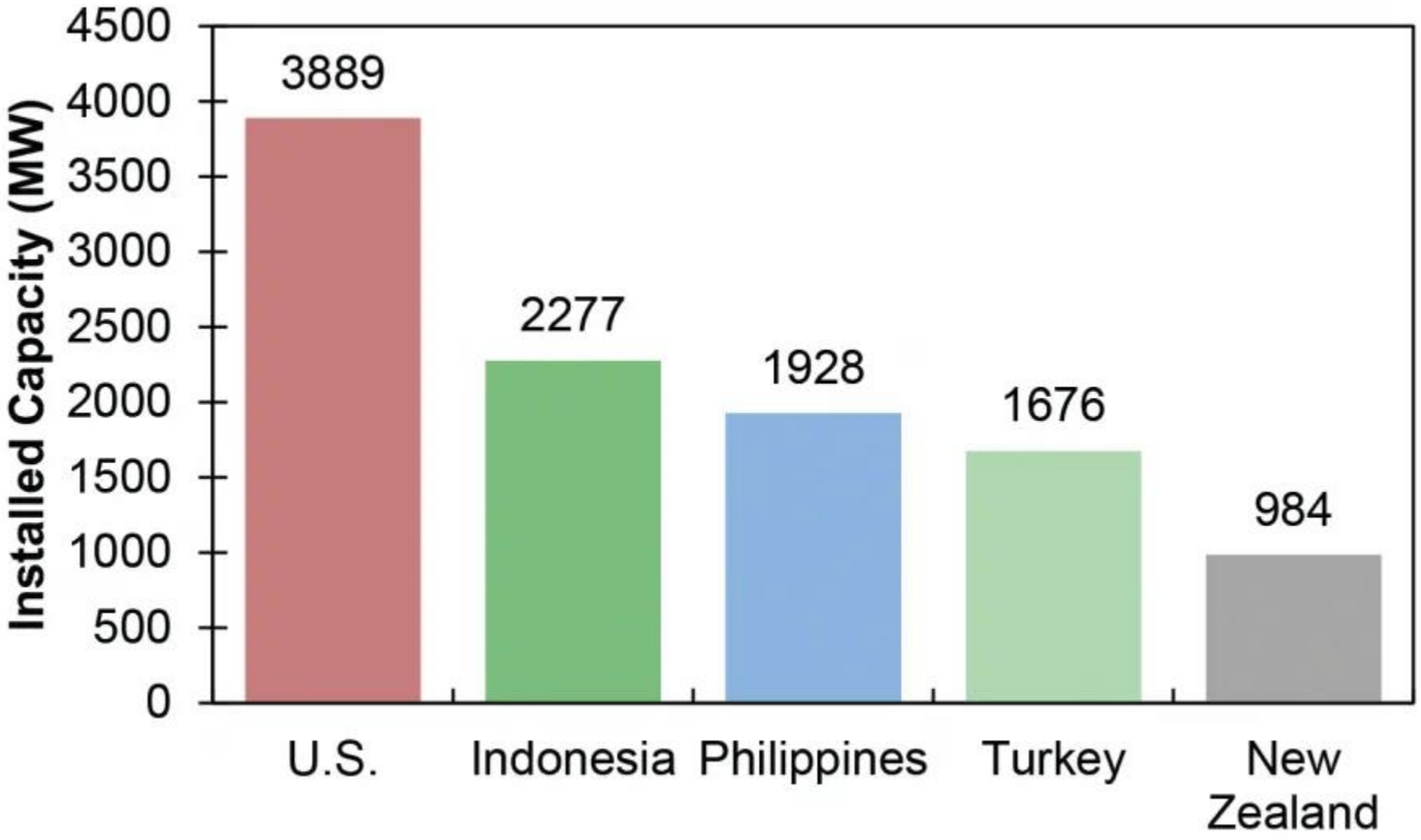
- Electricity-generating process is like thermal power plant, steam run the turbines come from water evaporated by Earth's internal heat instead of burning fossil fuels

- Unfortunately, long periods of harvesting groundwater from a site may deplete it to a point of no return …returning the water to the ground to be **reheated is needed for sustainably.**

Whenever magma comes close enough to groundwater (heats up), pressure builds up from the hot liquid...drives to the surface **causing a geyser or hot spring** to occur. *(not easily accessible everywhere, need suitable site - active sites are usually found along major tectonic plate boundaries "Ring of Fire")*



A ground source can heat & cool a building using 30 to 70% less energy than traditional furnaces & air conditions



Hydrothermal resources, i.e., steam and hot water, are **available primarily in the western U.S., Alaska, and Hawaii.**

Some geothermal facilities **produce solid waste such as salts and minerals that must be disposed** of in approved sites, but some by-products can be recovered and recycled.

Electricity generated from geothermal power plants is projected to increase from 15.9 billion kWh in 2021 to 47.4 billion kWh in 2050.

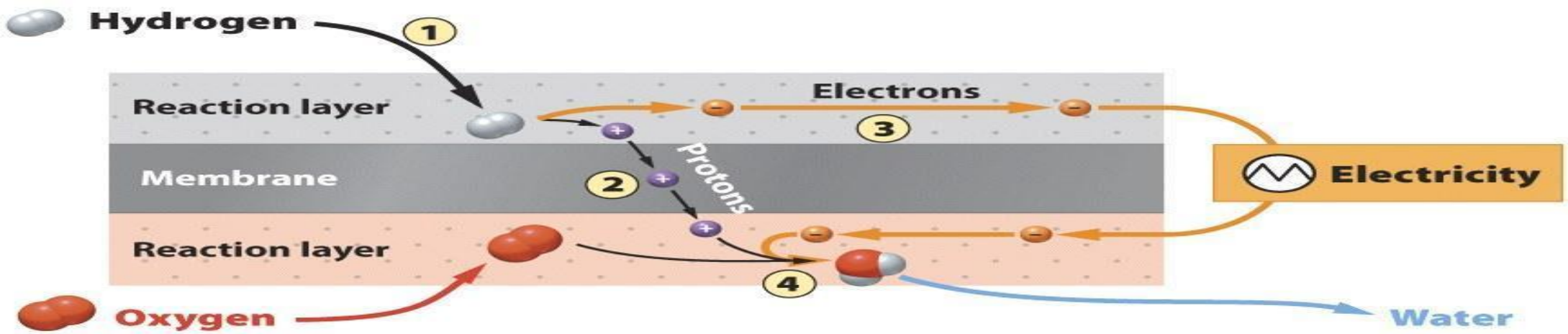
Hydrogen fuel cells have many potential applications

- **Fuel cell-** a device that operates like a common battery (nickel & cadmium) where electricity is generated by a **reaction between two chemicals** but will not deplete as long as supplied with fuel (hydrogen & oxygen).

- **Electrolysis-** electric current is applied to water to "split" it into hydrogen & oxygen gas. **(using a chemical reaction to generate power rather than combustion)**

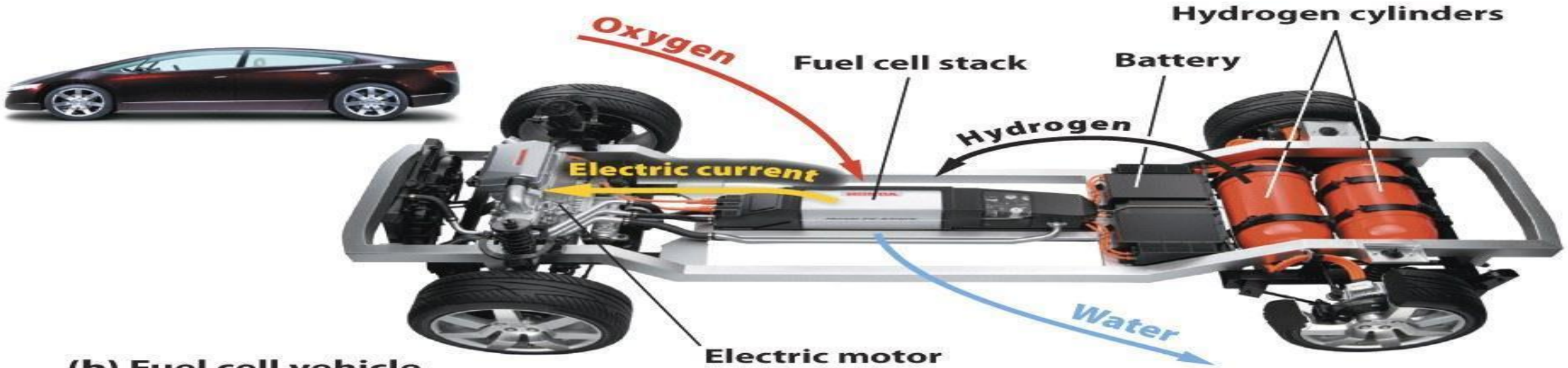
- Electricity is generated by the reaction of

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



1 Hydrogen molecules (H_2) are split into protons (H^+) and electrons in the upper reaction layer.	2 Protons move across membrane	3 Electrons take alternate route (electric current)	4 Oxygen molecules (O_2) are split and combine with protons and electrons to form water in the lower reaction layer.

(a) One common fuel cell design



(b) Fuel cell vehicle

Figure 13.25
Environmental Science

Is hydrogen the future?

Clean hydrogen is advertised as **the future fuel of the European Union (EU)**, promising to deliver an abundance of carbon-neutral energy by 2030. It will power long haul freight vehicles, airplanes, steel production and domestic heating

Hydrogen Fuel – Benefits vs. Drawbacks

Benefits:

~**Hydrogen fuel cells** are 80% efficient in converting potential energy of hydrogen and oxygen into electricity

~Byproduct is water (no carbon monoxide…no emissions)

~Electric motors *(60% is converted into motion…lithium batteries)* are more efficient than internal **combustion engines** *(20% is converted into motion)*

~**Flex-Fuel Vehicle** - the ability to run on both gasoline and E-85

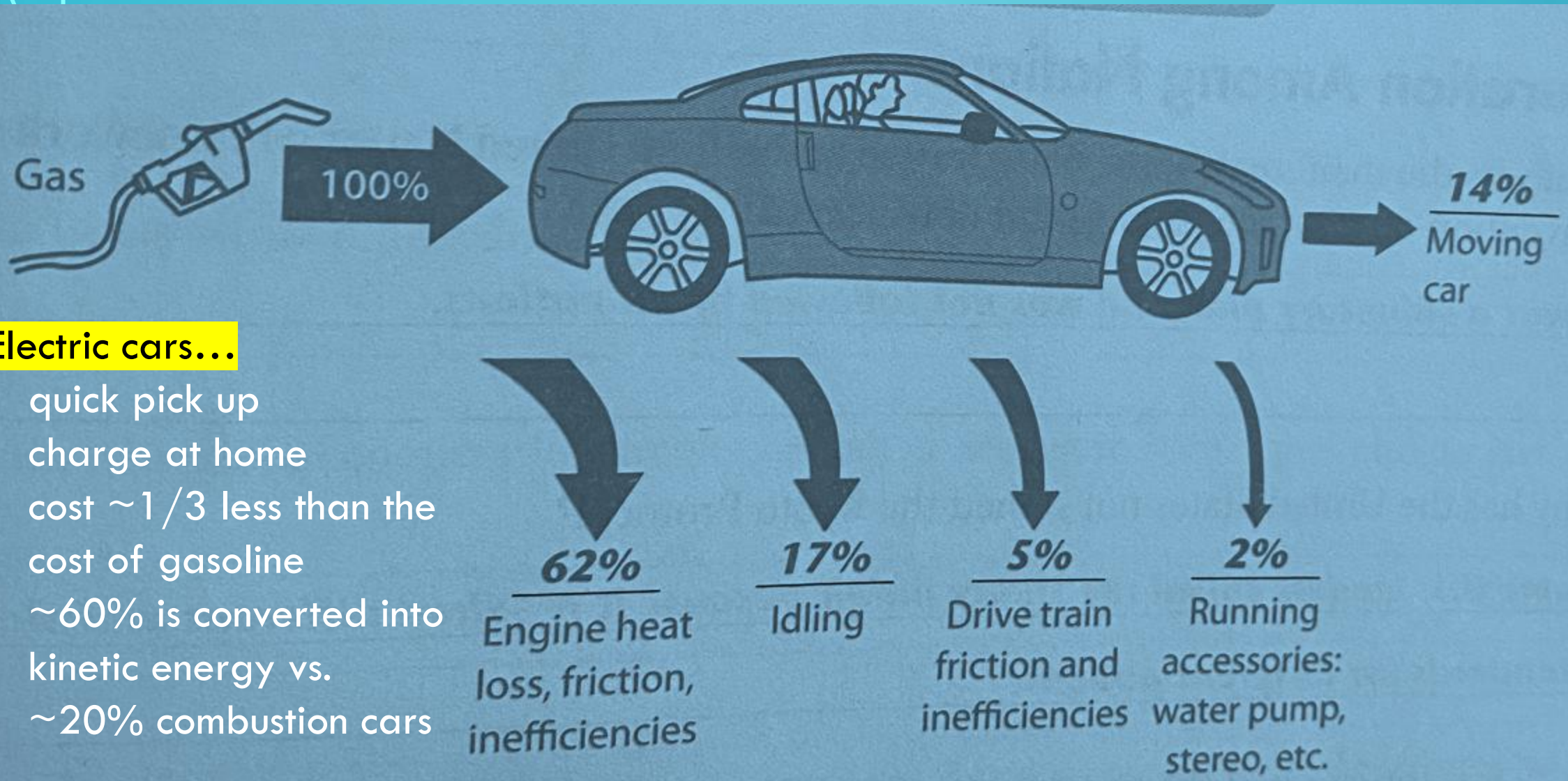
Drawbacks:

~Be able to obtain Hydrogen w/o expending more fossil fuel energy (not easily available)

~Cost of production is high, unlike other gases (electrolysis of water for production…costly process and time consuming…energy invested!!)

~Safety – driving and suppling hydrogen gas to consumers (unstable – very flammable)

~Redesigning of vehicles with fuel tanks much larger



Electric cars…

- quick pick up
- charge at home
- cost ~1/3 less than the cost of gasoline
- ~60% is converted into kinetic energy vs. ~20% combustion cars

FUSION -*ATOMS OF HYDROGEN TO FUSE TOGETHER (MIMICKING THE SUN)*

- U.S. Department of Energy's **Lawrence Livermore National Laboratory** (after 6 decades of trial and error of uncontrolled fusion – California) the world's largest lasers *forced atoms of hydrogen to fuse together (Helium)* in the same kind of *energy producing reaction that fires the sun*.
- National Ignition Facility, or NIF, was built for $3.5 billion to ignite self-sustaining fusion
- **If fusion can be deployed on a large scale (still decades away from this…)**, it would offer an energy source devoid of the pollution and greenhouse gases caused by the burning of fossil fuels and the dangerous long-lived radioactive waste created by current nuclear power plants, which use the splitting of uranium to produce energy.
- **Inside the nuclear fusion breakthrough that could be a step to unlimited clean energy in the distant future**

Sustainable Design

Improving the efficiency of the buildings we live and work in.

Potential Consequences:

- **Biomass** can lead to overharvesting of wood leading to deforestation and degradation of the land. *(potential renewable), land to grow biomass.*
- **Wind turbines** can unintentionally kill birds and bats and spacing.
- **Hydroelectric turbines** kills million of fish/marine life.
- **Photovoltaic solar panels** require heavy metals and great deal of water and land.

- All energy choices have environmental consequences…**best choice is to conserve and be efficient with our uses and choices in lifestyles.**

Sustainable Design (San Francisco) maximizes the use of natural light & ventilation. This building generates much of its own electricity with Solar panels on the roof and captures water in its **rooftop garden** (*improves insulation (cooling and warming), air quality and water capturing for buildings*).

CELL (MECHANICAL) TECHNOLOGY

WALKING ENERGY PAVEMENT

Ford and DTE Energy massive steps in the fight of climate change…

- As of Aug. 2022, DTE adding 650 megawatts of new solar energy in Michigan for Ford, increasing the total amount of installed solar in Michigan by nearly 70%
- By 2025, DTE will be adding 650 MWs of solar energy for Ford (creating jobs).
- By 2025, all Ford vehicles assembled in MI, will be assembled with 100% carbon-free electricity…(ex. *Rouge Electric Vehicle Center)*
- Once, the solar panels are installed, they will boost the amt. of solar energy in MI close to 70%.
- Live-streamed Ford
- Ford is planning to go carbon neutral ***(Carbon neutrality refers to achieving zero carbon emissions by balancing such emissions with carbon removal.*** *To achieve its goal, Ford will focus initially on three areas that account for approximately 95 percent of its CO_2 emissions – vehicle use, its supply base and the company's facilities)* by 2050 (Paris Climate Agreement). Ford plans to invest over $50 billion by 2026 to scale EV production and transform its business.