# NONRENEWABLE RESOURCES

Image by Albert Hyseni, Unsplash.

# Nonrenewable Resources Lecture

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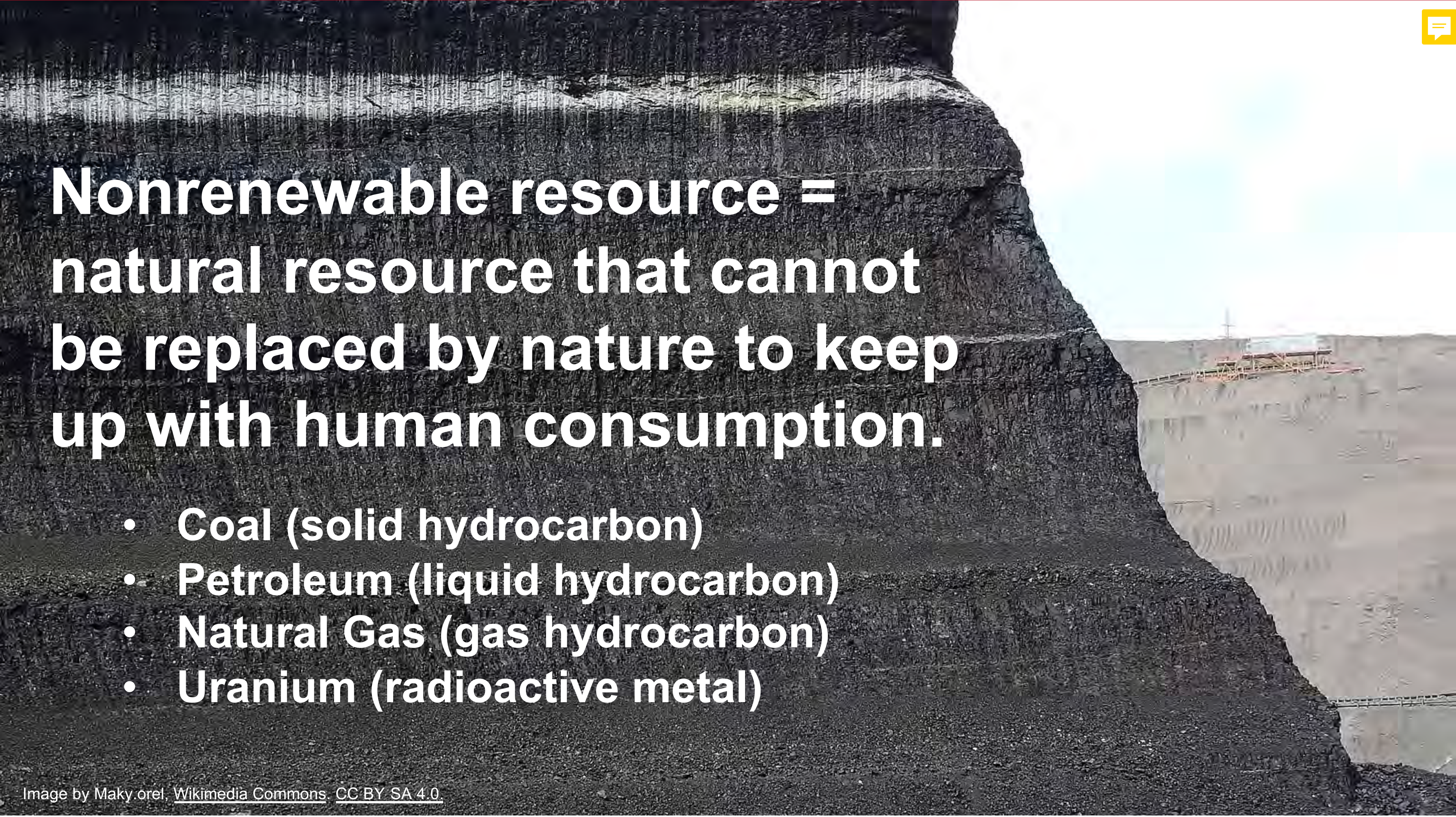
# Nonrenewable Resources Objectives

1. Define and identify nonrenewable resources and describe their uses.
2. Outline the extraction and production of nonrenewable resources into products for human use.
3. Describe the impacts of using nonrenewable resources on Earth's atmosphere, water, and ecosystems.
4. Describe how burning fossil fuels for energy causes global warming and the importance of limiting warming to $1.5^{o}C$.

**Objective 1: Define and identify nonrenewable resources and describe their uses.**



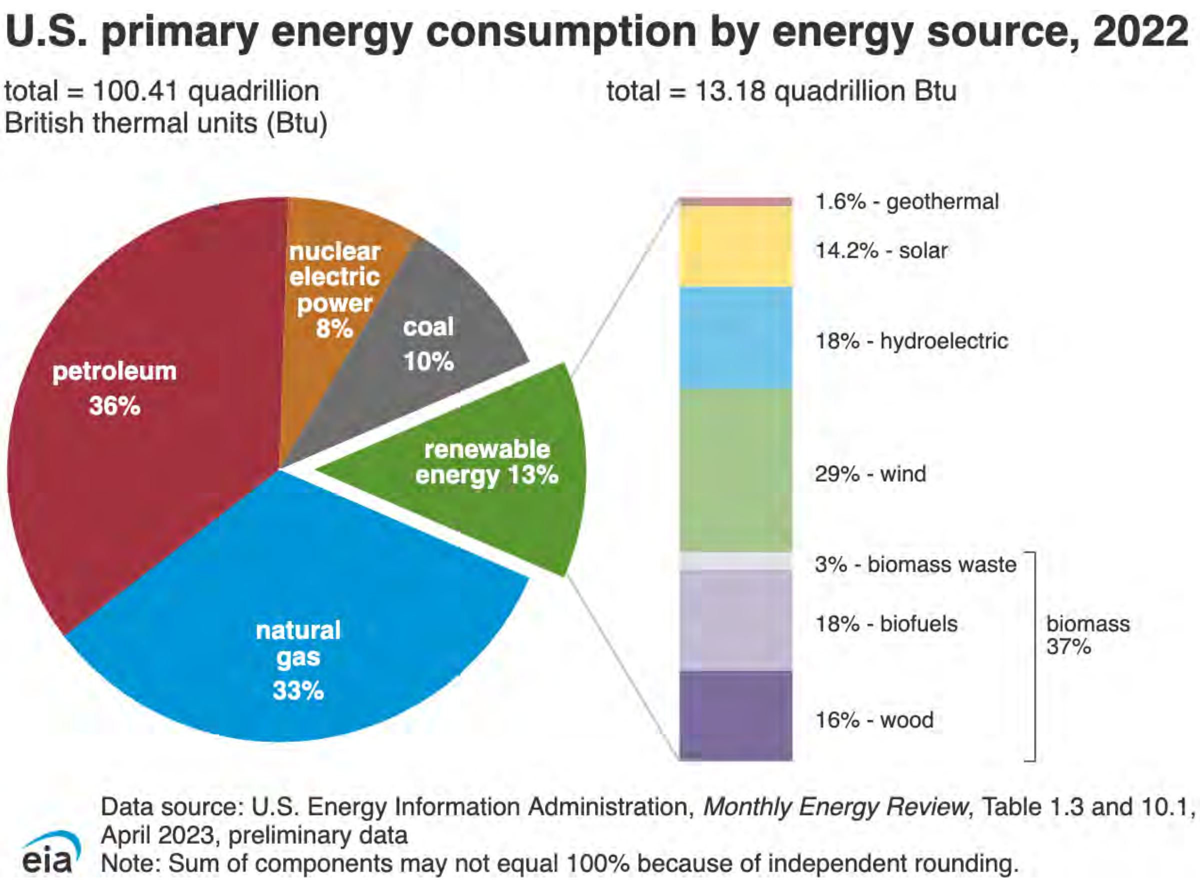
# Nonrenewable resource = natural resource that cannot be replaced by nature to keep up with human consumption.

- Coal (solid hydrocarbon)
- Petroleum (liquid hydrocarbon)
- Natural Gas (gas hydrocarbon)
- Uranium (radioactive metal)

# Energy Consumption in the USA

Humans use a lot of energy in our daily lives.  Our modern societies can't exist without energy (e.g., electricity, transportation, manufacturing, agriculture, healthcare, education).

In the United States, most (87%) of our energy comes from nonrenewable resources. While 13% of our energy comes from renewable resources.

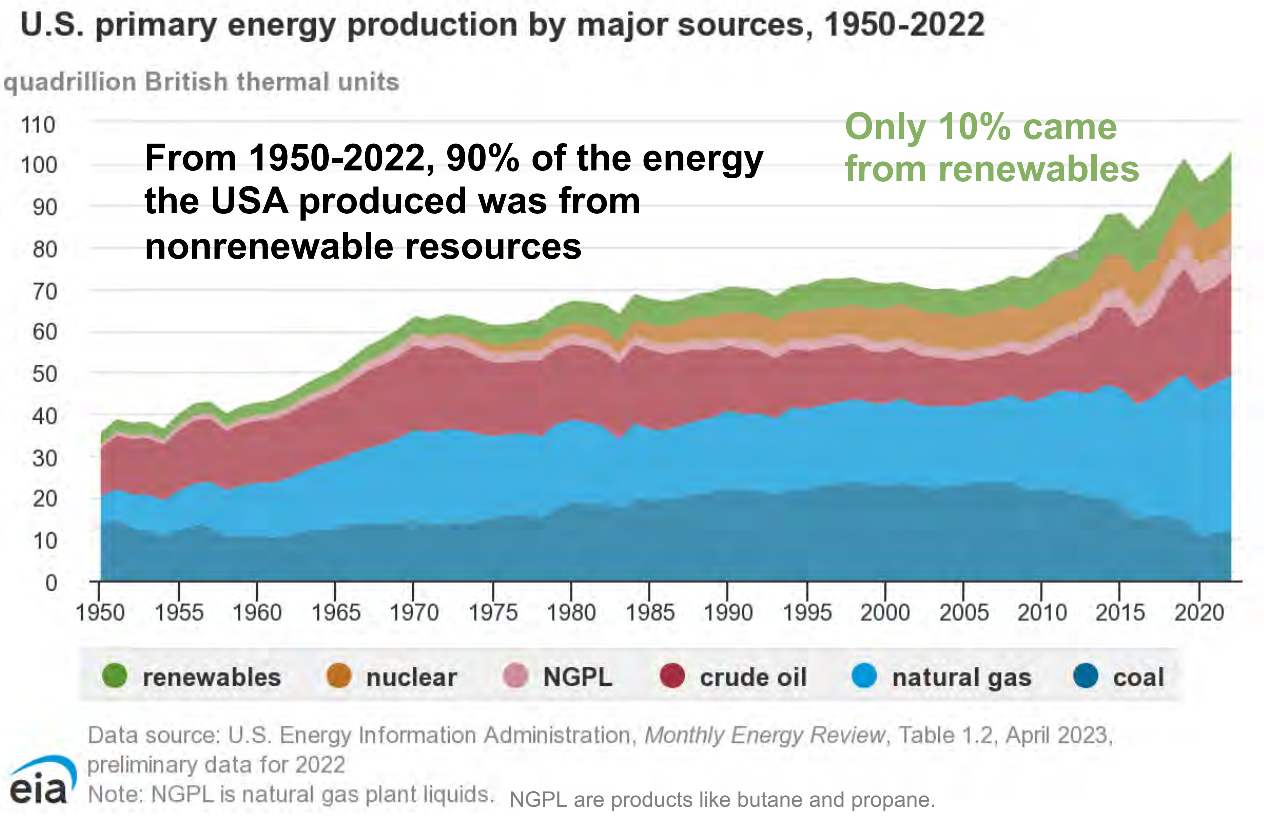



Data source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 1.3 and 10.1, April 2023, preliminary data
Note: Sum of components may not equal 100% because of independent rounding.

# Energy Production in the USA

The United States is rich in energy resources. We have always been able to produce the energy we need domestically.

Nonrenewable energy has always dominated energy production in the USA. The same is true for all countries.  We all depend on non-renewable energy for our way of life.



**Fossil Fuels = Solid, liquid, or gas hydrocarbons that formed naturally in Earth's crust from decaying organic material (plants and animals).**

A **hydrocarbon** is an organic compound consisting of carbon and hydrogen.  Hydrocarbons can be solid (coal), liquid (petroleum), or gas (natural gas).

Fossil fuels form naturally underground, over millions to hundreds of millions of years. Its form depends on type of materials that are present, the length of time compressed, and the pressure and temperature.

Humans burn fossil fuels to produce energy (e.g., electricity, transportation).  When humans burn fossil fuels, the solid carbon (coal) or liquid carbon (petroleum) is converted to carbon gases like carbon dioxide ($CO_2$).

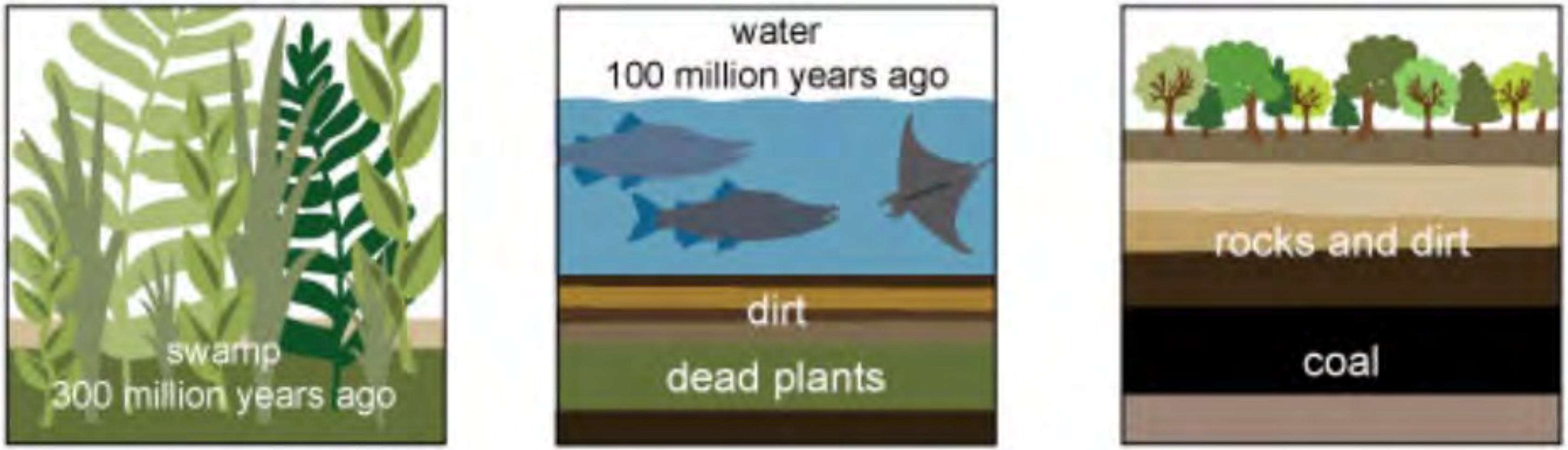


# How coal formed

Before the dinosaurs roamed Earth, many giant plants died in swamps (300-million years ago).

Over hundreds of millions of years, the plants were buried under water and dirt in oxygen poor sediment

Heat and pressure turned the dead plants into coal, which is a black or brownish sedimentary rock, which we dig from mines.



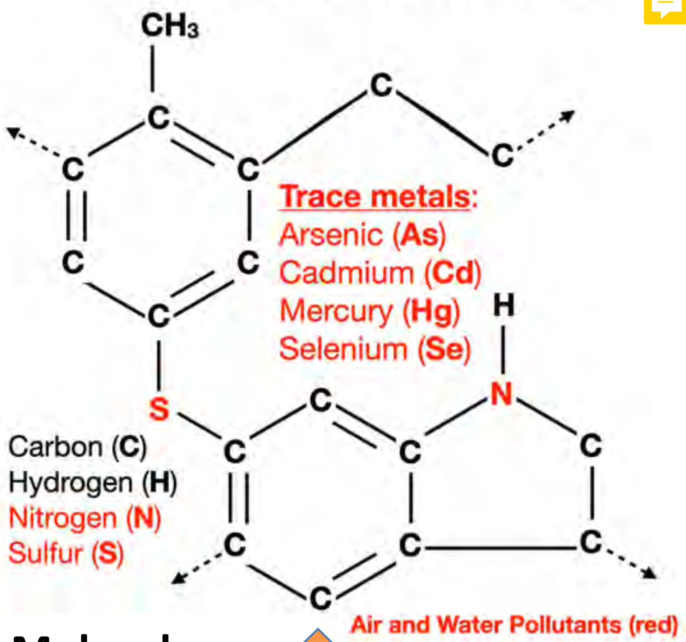

Source: Adapted from National Energy Education Development Project (public domain)

Source: EIA

# Coal = black or brownish sedimentary rock that contains high amount of carbon and is combustible

- Coal formed before dinosaurs roamed Earth.
- Coal contains the energy of plants that lived and died in forested swamps.
- Coal takes hundreds of millions of years to form, therefore it is nonrenewable.
- Coal is a hydrocarbon that releases energy (heat) and greenhouse gases ($CO_2$) when burned.
- We use coal's energy to produce electricity.
- Coal is a solid that is mined from underground sources.
- Coal contains pollutants that are released when mined or burned.

Source: EIA




**Molecular Structure**

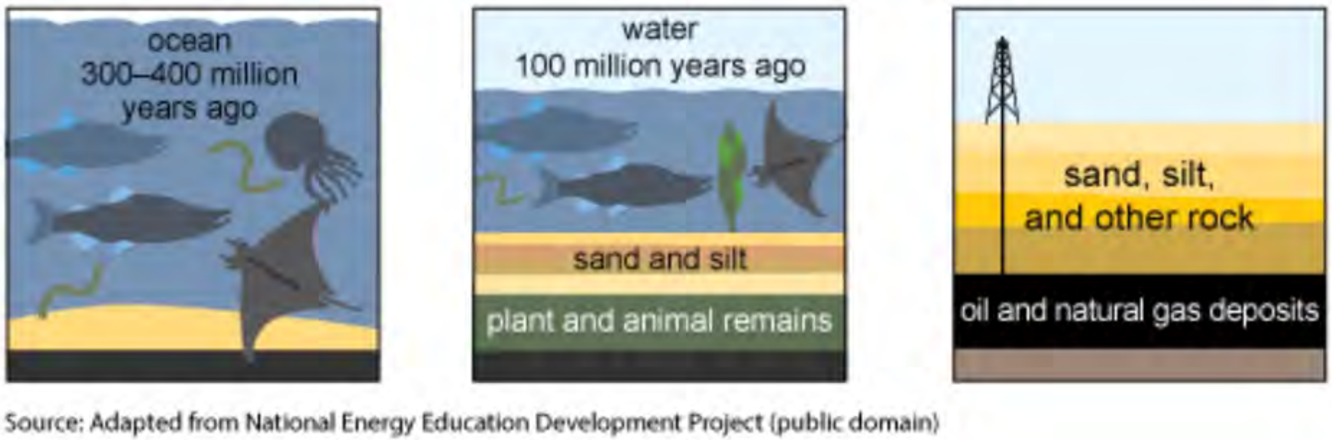
**Coal**

# How oil and natural gas formed

Tiny marine plants and animals died and were buried on the ocean floor and became covered with layers of silt and sand.

Over millions of years, the remains were buried deeper and deeper. The enormous heat and pressure turned the remains into oil and natural gas.

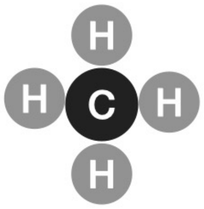
Today, we drill down through layers of sand, silt, and rock to reach the rock formations that contain oil and natural gas deposits.




Source: U.S. Energy Information Administration (public domain)

Source: EIA

**Natural Gas =** fossil fuel energy source containing a mixture of hydrocarbons, consisting of mostly **methane** (**$CH_4$**). Methane burns and thus can be used for **heating**, **cooking**, and generating **electricity**.

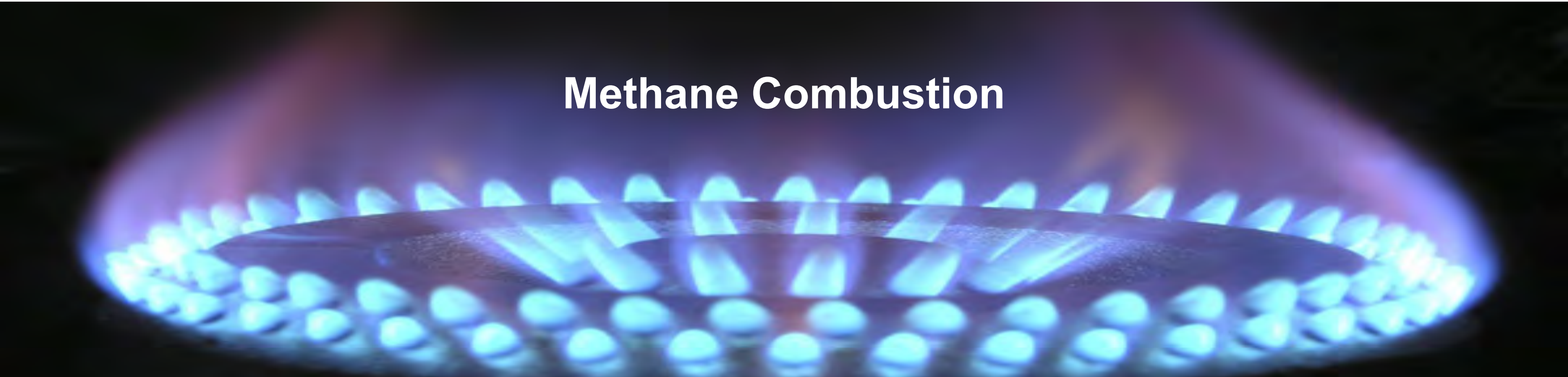



**Methane** (**$CH_4$**) is a gas hydrocarbon that is mined from underground deposits and burned for energy (combustion).

## Methane Combustion

$$CH_4 + O_2 \rightarrow CO_2 + H_2O + \text{heat}$$

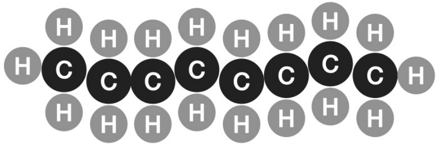
greenhouse gases ($CH_4$, $CO_2$)



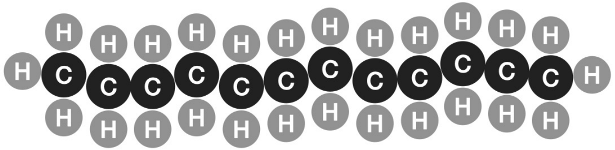
**Petroleum = black or yellowish-black liquid that contains mixture of different hydrocarbons that are combustible.**

- Petroleum is also called crude oil or oil.
- Crude oil is a complex mixture of hydrocarbons that are refined into products such as gasoline, diesel fuel, jet fuel, kerosene, asphalt, solvents, fertilizer, polyester, nylon, textiles, plastics, paint, pesticides, lubricants, pharmaceuticals.
- Combustion of gasoline, diesel fuel, or jet fuel is the technology used to power cars, trucks, buses, rockets, trains, airplanes.
- When fuel is burned it releases carbon dioxide ($CO_2$), carbon monoxide (CO), nitrogen oxides (NOx), and other air pollutants.

gasoline




diesel




Refined into products

# Products Made from a Barrel of Crude Oil

| PRODUCTS | GALLONS | PERCENT (%) |
|---|---|---|
| Gasoline | 18.0 | 43% |
| Diesel Fuel | 9.2 | 22% |
| Plastics, Synthetic Fibers, Synthetic Rubber, Paints, Solvents, Waxes, Lubricants, Pharmaceuticals | 6.7 | 16% |
| Jet Fuel, Kerosene | 3.8 | 9% |
| Heavy Fuel for Ships | 1.7 | 4% |
| Asphalt | 1.7 | 4% |
| Butane, Propane | 0.9 | 2% |
| Total | 42.0 | 100% |

Source: U.S. Energy Information Administration; 1 barrel of crude = 42 gallons.

# Plastic

- Plastic is synthetic material made from a wide range of carbon-hydrogen polymer chains derived from petroleum or natural gas.
- Inexpensive, durable, lightweight, flexible, sterile, and can be molded into different shapes.
- There are many different types like polyester, nylon, Spandex, silicones, polyvinyl chloride (PVC), polypropylene (PP), etc.
- We started using plastic products in the 1950s and since then we have produced about 10-billion tons of plastic products.
- Its estimate that only 10% of all plastic has ever been recycled. And plastic can't be recycled indefinitely, it can only be recycled 2-3 times before its quality is too poor to be reused.


Virtually every product we use today is made of plastic or has plastic components. All these products came from crude oil or natural gas.

## World's Top 10 Oil Producers (2022)

| Country | Million Barrels Per Day | Share of World Total (%) |
|---|---|---|
| USA | 20.30 | 21% |
| Saudi Arabia | 12.44 | 13% |
| Russia | 10.13 | 10% |
| Canada | 5.83 | 6% |
| Iraq | 4.61 | 5% |
| China | 4.45 | 5% |
| UAE | 4.23 | 4% |
| Iran | 3.67 | 4% |
| Brazil | 3.17 | 3% |
| Kuwait | 3.01 | 3% |
| Top 10 Total | 71.83 | 74% |
| World Total | 97.70 | 100% |

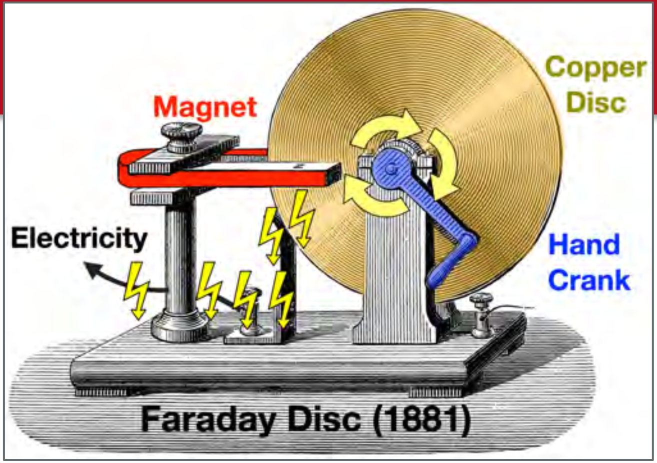
## World's Top 10 Oil Consumers (2021)

| Country | Million Barrels Per Day | Share of World Total (%) |
|---|---|---|
| USA | 19.89 | 20% |
| China | 15.27 | 16% |
| India | 4.68 | 5% |
| Russia | 3.67 | 4% |
| Japan | 3.41 | 4% |
| Saudi Arabia | 3.35 | 3% |
| Brazil | 2.89 | 3% |
| South Korea | 2.56 | 3% |
| Canada | 2.26 | 2% |
| Germany | 2.23 | 2% |
| Top 10 Total | 60.20 | 62% |
| World Total | 97.26 | 100% |

Data source: U.S. Energy Information Administration, International Energy Statistics as of September 2023 (https://www.eia.gov/tools/faqs/faq.php?id=709&t=6). 1 barrel = 42 gallons.

# How do we make electricity?

Most electricity today (around 95%) is generated using a technology that was invented 200 years ago by Michael Faraday. An **Electromagnetic Generator** creates an electric current by rotating a copper disc between a horseshoe magnet.



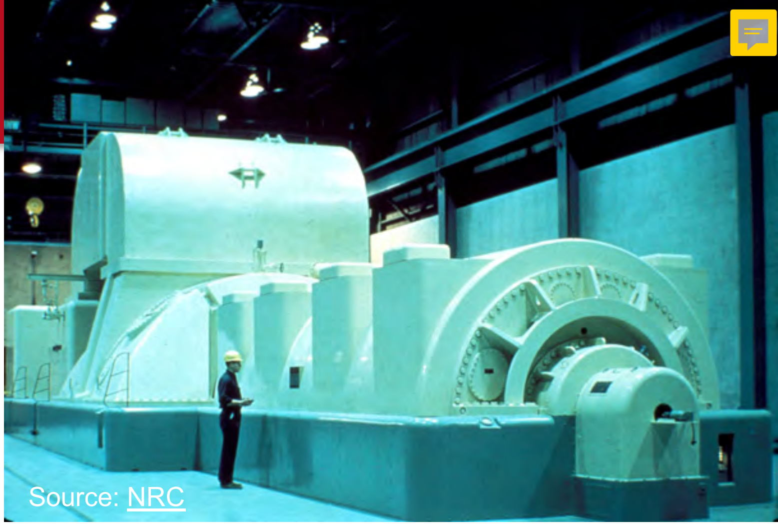

Today's generators consist of a large rotatable magnet shaft surrounded by numerous coils of copper wire. An electric current (electricity) flows through the copper wire when the shaft spins. To make the shaft spin, it is connected to a **turbine** which spins when fluid (steam, liquid water, hot gas, air) pushes on its blades causing the blades to rotate.

Coal power plants, natural gas power plants, wind turbines, nuclear power plants, geothermal power plants, and hydroelectric dams all use **turbine driven electromagnetic generators** to create electricity.

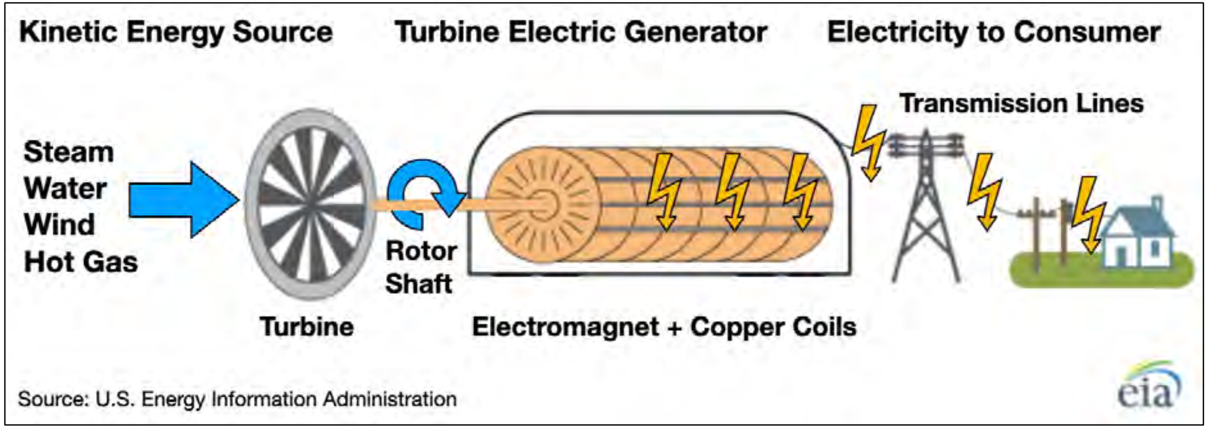
# Turbine Driven Electromagnetic Generators


Looking inside a Turbine

Steam, flowing water, hot gas, or wind turns the blades of turbine, which turns rotor shaft of electric generator creating electricity.




Electric Generator

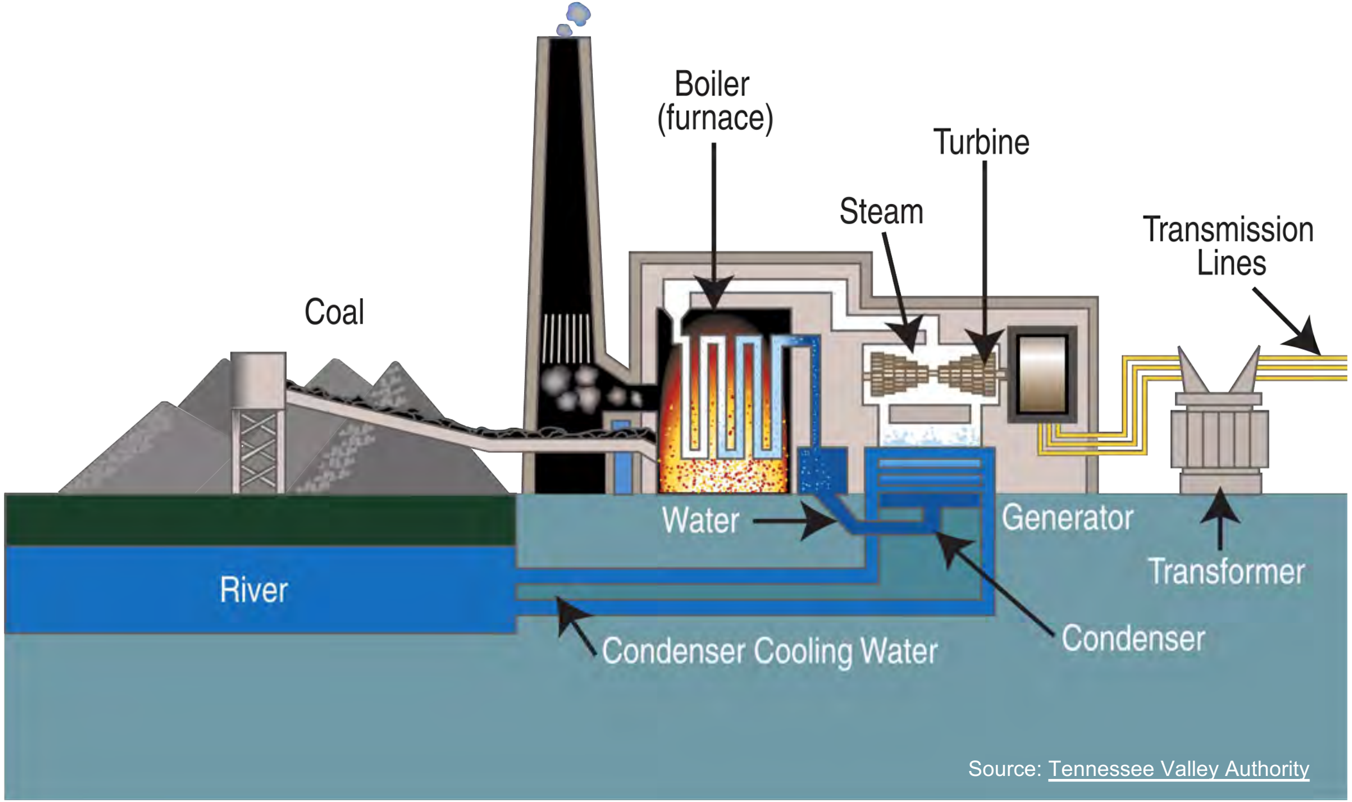


# Coal-Fired Power Plants

Coal is burned to boil water and produce steam. The steam turns a turbine, which turns a generator thereby producing electricity.

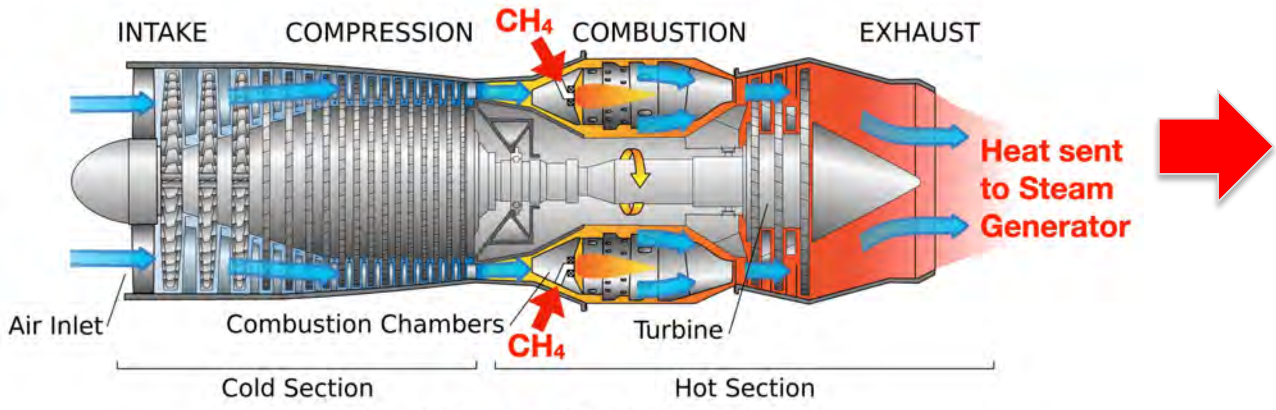
Coal-fired power plants emit greenhouse gases and air pollutants.

Over 1/3 of global electricity comes from coal-fired power plants.



# Natural Gas Power Plants

Natural gas power plants often consist of two generators (Gas turbine generator and Steam turbine generator) operating in tandem to produce electricity. This is called a **Combined Cycle Power Plant.** In the first cycle, natural gas ($CH_4$) is burned, the hot gas turns a turbine, which then turns a generator to create electricity. The heat exhaust is captured and used in the second cycle to boil water, creating steam, which turns a turbine that turns a generator and create electricity. Natural gas power plants emit greenhouse gases and air pollutants. However, they emit less than coal-fired power plants.




Source: Jeff Dahl

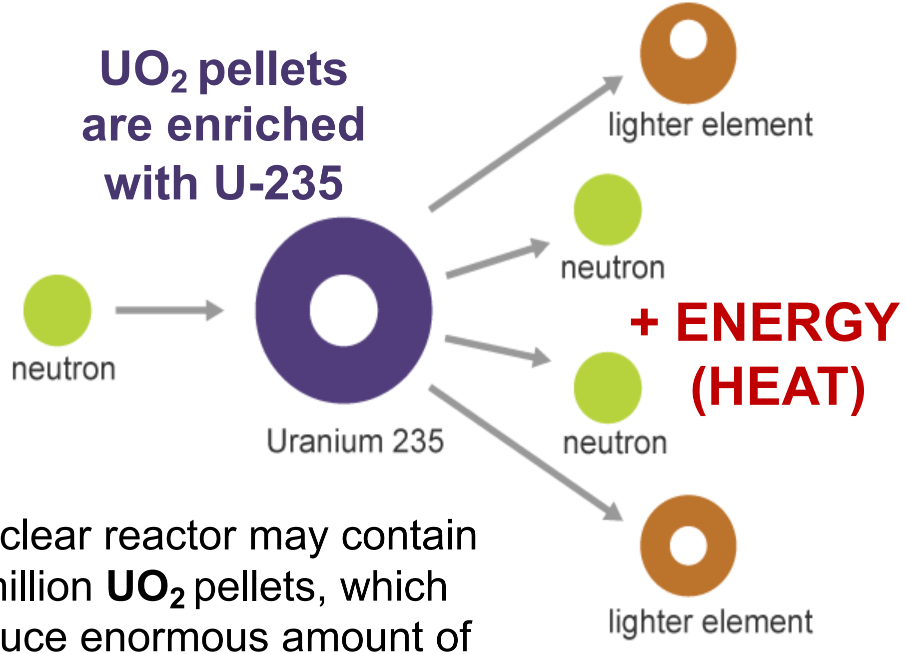

Steam Turbine Generator

# How does nuclear power work?

Nuclear power plants work by utilizing nuclear fission – a process where uranium-235 atoms split and release enormous amounts of energy (heat) used to boil water, producing steam, which turns a turbine generator that produces electricity.

**Uranium oxide** (**$UO_2$**) pellets are stacked in fuel rods contained in nuclear reactor core


## How fission splits the uranium atom

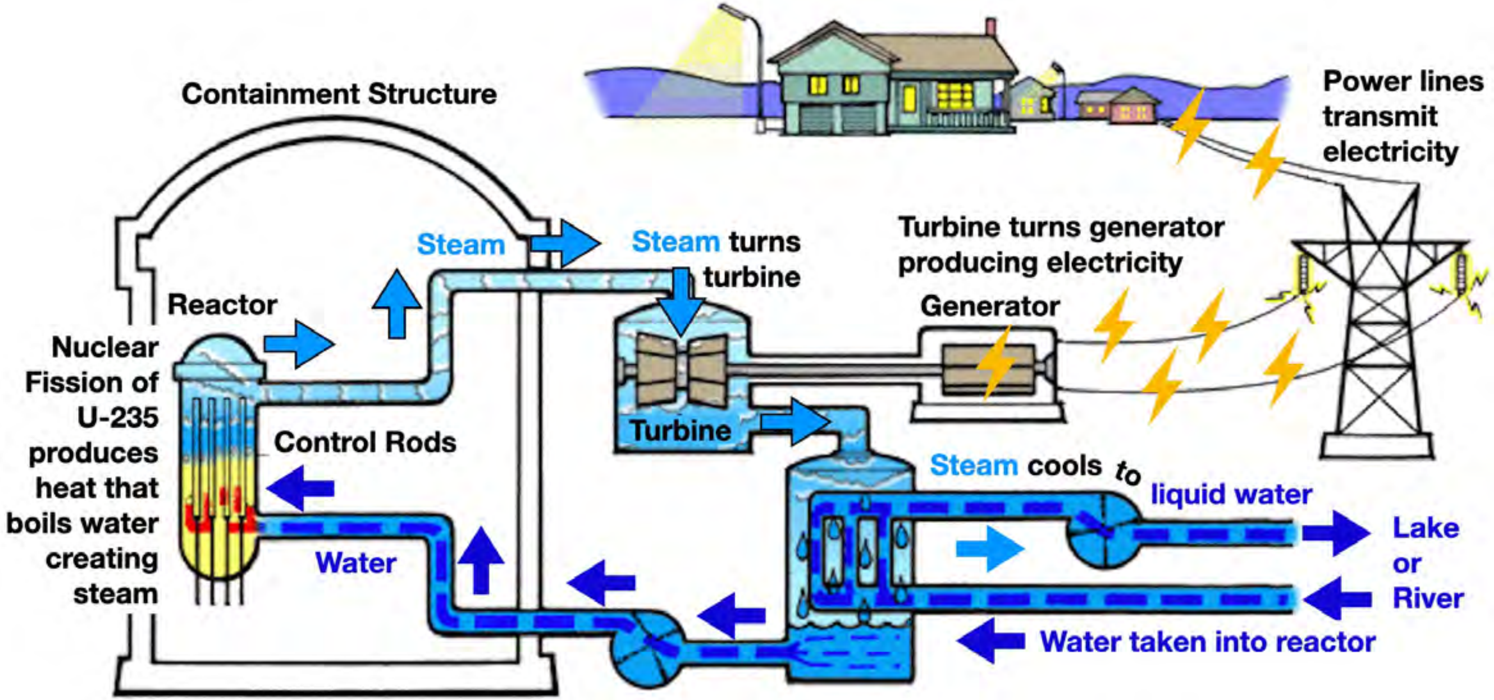



A nuclear reactor may contain 10 million **$UO_2$** pellets, which produce enormous amount of heat by nuclear fission.

Source: Adapted from National Energy Education Development Project

# Nuclear Power Plants

Nuclear power plants use the heat generated from U-235 nuclear fission to boil water and create steam. The steam turns a turbine, which turns a generator to produces electricity. As of 2023, the United States has 54 operating nuclear power plants.




Nuclear power is considered clean energy because it emits no greenhouse gases, and no air pollutants.

Source: U.S. NRC

# Objective 2: Outline the extraction and production of nonrenewable resources into products for human use.

# Coal Production and Reserves

Coal production by region in million short tons and regional share of total U.S. production, 2019


**What is the amount of world coal reserves?**

As of December 31, 2021, estimates of total world proved recoverable reserves of coal were about 1,161 billion short tons (or about 1.16 trillion short tons), and five countries had about 75% of the world's proved coal reserves.

**The top five countries and their percentage share of world proved coal reserves as of 12/31/2021 were:**

| 22% | 15% | 14% | 14% | 11% |
|---|---|---|---|---|
| United States | Russia | Australia | China | India |

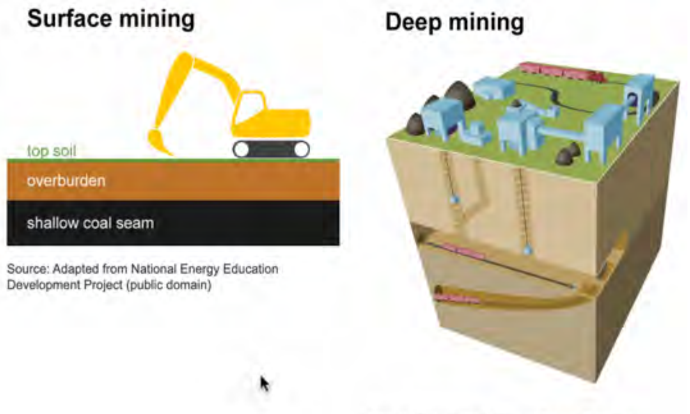
Based on 2021 coal consumption, the U.S. has enough coal to last 300-400 years.

Note: Excludes refuse recovery coal. Sum of shares may not equal 100% because of independent rounding.
Source: U.S. Energy Information Administration, *Annual Coal Report*, October 2020

# Coal is mined from underground deposits using large machinery.

1. **Surface Mining** – coal seam is less than 200 feet from surface. Land on top of coal is removed using explosives and large equipment. Draglines and excavators are used to dig coal and load it onto trucks. It is safer for workers compared to deep mining. It is more damaging to surface habitats.
2. **Deep Mining** – coal seam is greater than 200-feet from surface. Tunnels are dug underground using explosives and large equipment. Workers go into the tunnels to dig the coal and sent it to the surface using rail cars. This work is dangerous for workers due to cave-ins, explosions, fires, hearing loss, breathing issues. Less damaging to surface habitats.

Image by Martinroell, Wikimedia Commons. CC BY SA 2.5.




Source: Adapted from National Energy Education Development Project (public domain)

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**Natural Habitat of Appalachian Mountains, West Virginia, USA**

Aparkswv, 2014

**Surface Coal Mining: Mountain Top Removal, West Virginia, USA**

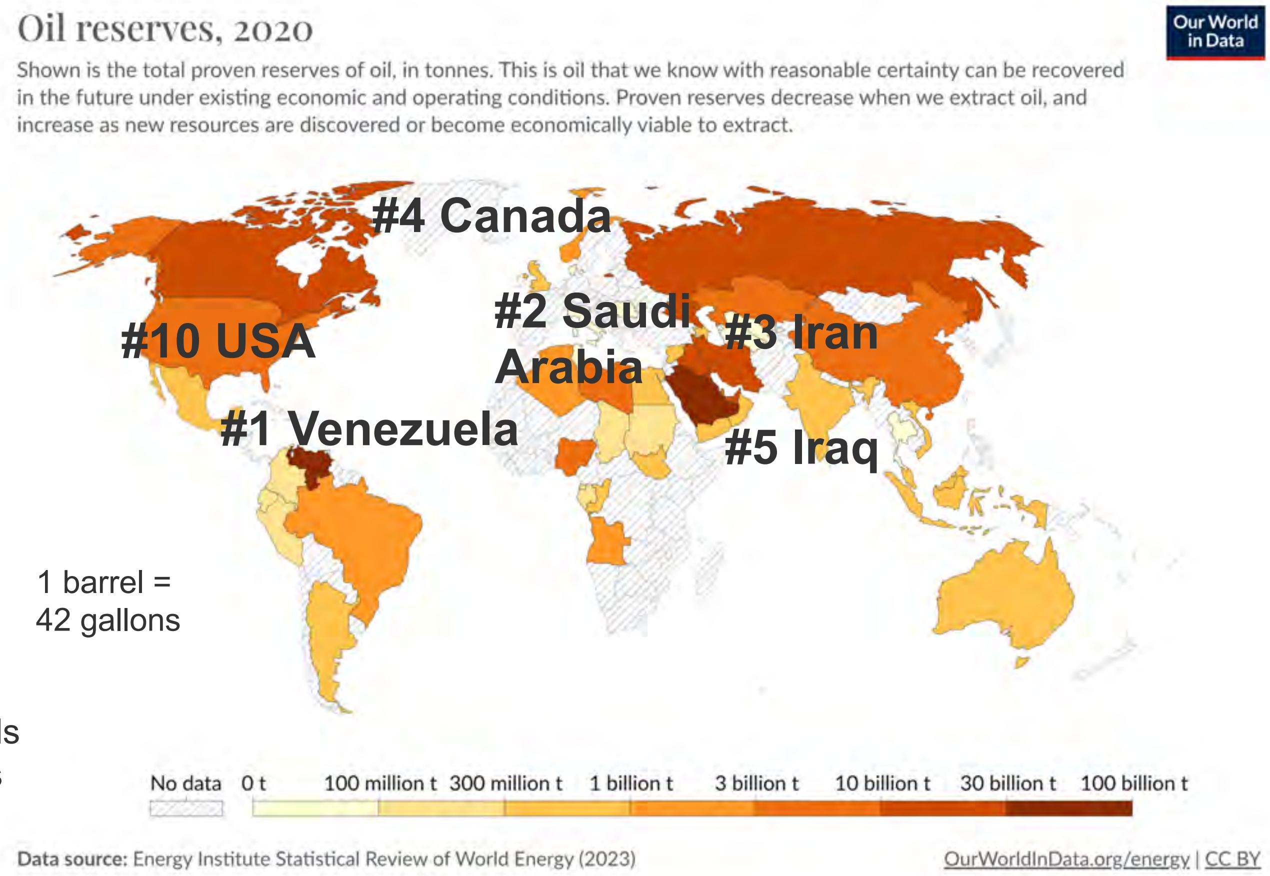
Dennis Dimick, 2013

# World's Petroleum Reserves

In 2020, global proved crude oil reserves amounted to 1.65 trillion barrels of oil. World oil consumption is 100 million barrels of oil per day. Therefore, we have about 50 years of oil remaining with current oil consumption and oil reserves.

**Top 5 U.S. Oil Reserves (2021)**

1. Texas - 18.6 billion barrels
2. New Mexico – 4.9 billion barrels
3. Gulf of Mexico – 4.6 billion barrels
4. North Dakota – 4.4 billion barrels
5. Alaska – 3.2 billion barrels



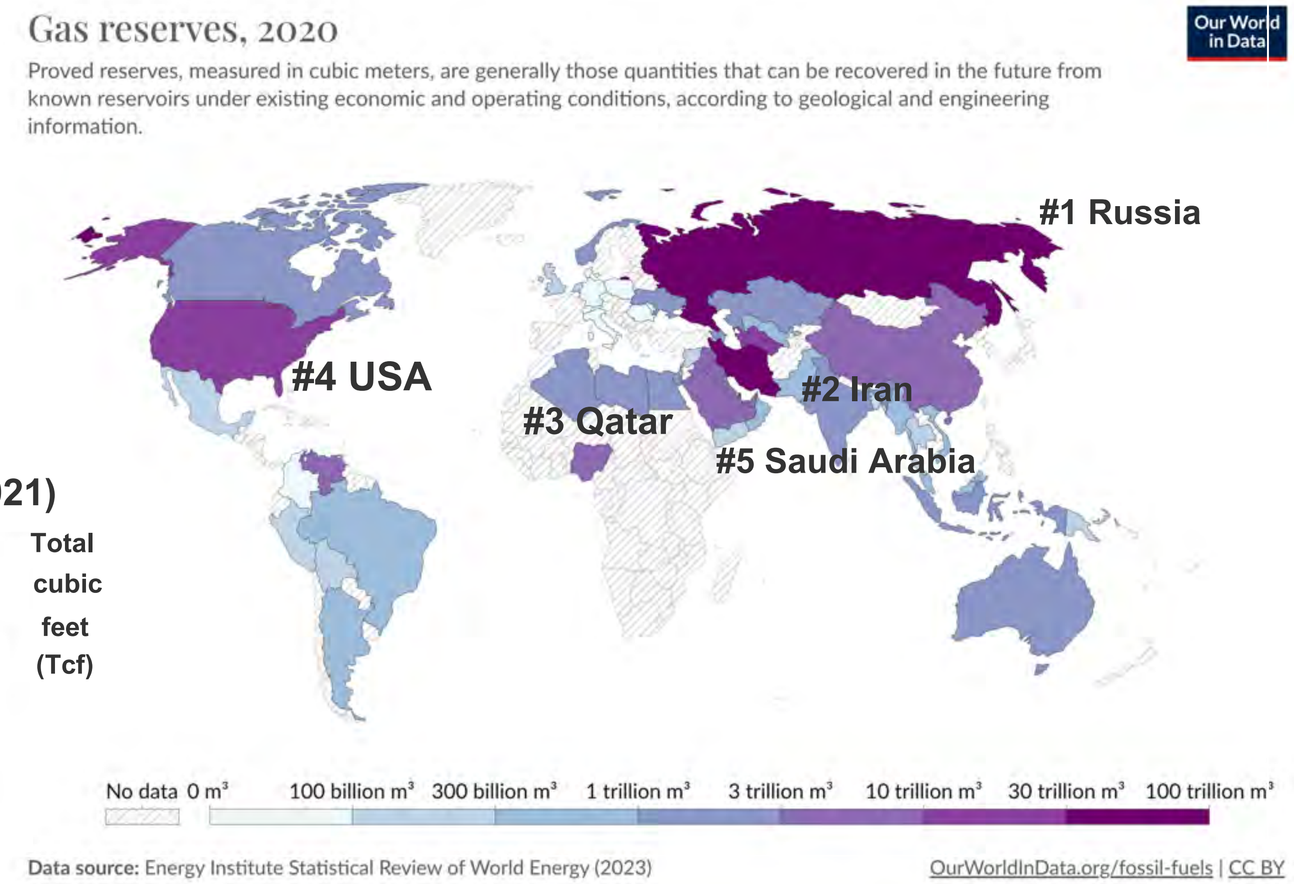
# World's Natural Gas Reserves

According to the U.S. Energy Information Administration (eia.gov), if we continue with the same rate of natural gas production as in 2021, the United States has enough natural gas to last about 80 years.

**Top 5 Producing U.S. States (2021)**

**Total cubic feet (Tcf)**

1. Texas—9.25 Tcf—25.4%
2. Pennsylvania—7.41 Tcf—20.4%
3. Louisiana—4.04 Tcf—11.1%
4. West Virginia—2.69 Tcf—7.4%
5. Oklahoma—2.51 Tcf—6.9%



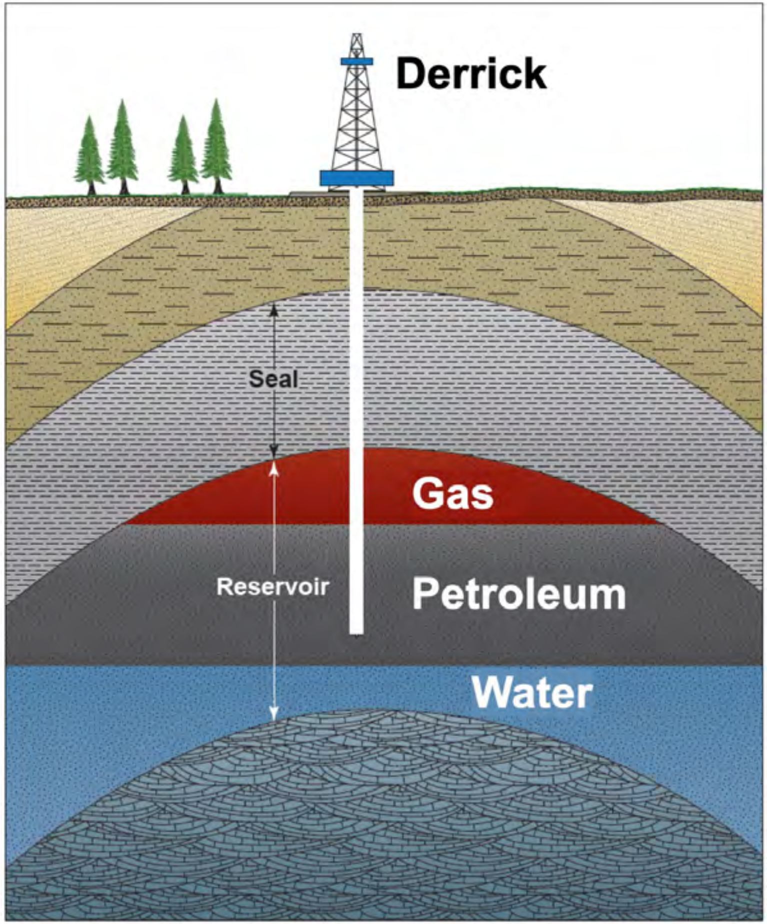
# Conventional Natural Gas and Petroleum Extraction

Geologists use seismic surveys on land and the ocean to find natural gas and petroleum.

A well is drilled into land or offshore into the ocean floor to bring the natural gas and/or petroleum to the surface where it is collected.

Natural gas is sent to a processing plant where methane is separated from natural gas liquids (NGLs = ethane, propane, butanes, and pentanes).

Petroleum is sent to an oil refinery where it is refined into gasoline, diesel fuel, jet fuel, plastics, heavy fuel, and asphalt.



# Offshore Oil Drilling Platform

# Unconventional Oil Production
# Athabasca Tar Sands, Alberta, Canada



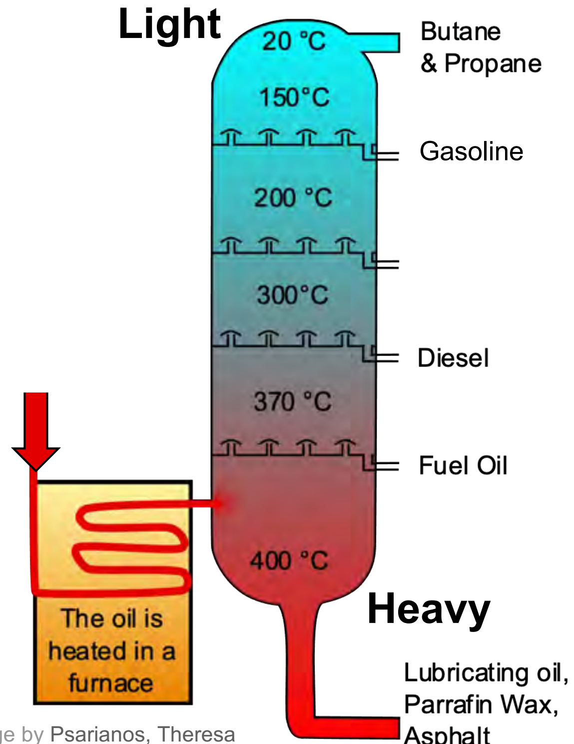
Image by NWFBlogs, Flickr. CC BY NC ND 2.0. Image by Norman Einstein , Public Domain. Image by James St. Johns CC BY NC ND 2.0

# Oil Refineries

An oil refinery is a sprawling industrial processing plant that converts (refines) crude oil into products like gasoline, diesel fuel, jet fuel, kerosene, heating oil, and asphalt.

The various products are separated from each other by distillation. The crude oil is heated in a furnace causing each hydrocarbon to vaporize according to its boiling point and separate from the mixture.

The products collected at the top of the distillation unit have lower boiling points that the products collected at the bottom.






Exxon Mobile’s Baton Rouge Oil Refinery, Louisiana

# Unconventional Natural Gas Production
# Shale Natural Gas Hydraulic Fracturing

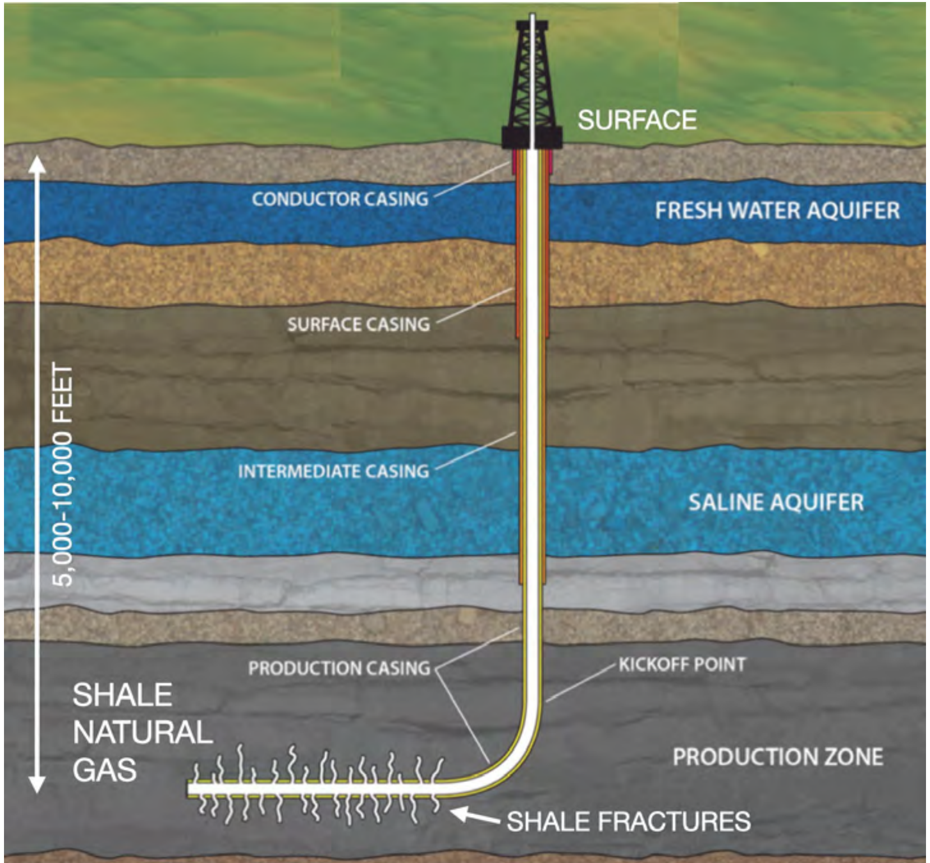



Image by R. Ressetar, Utah Geological Survey,

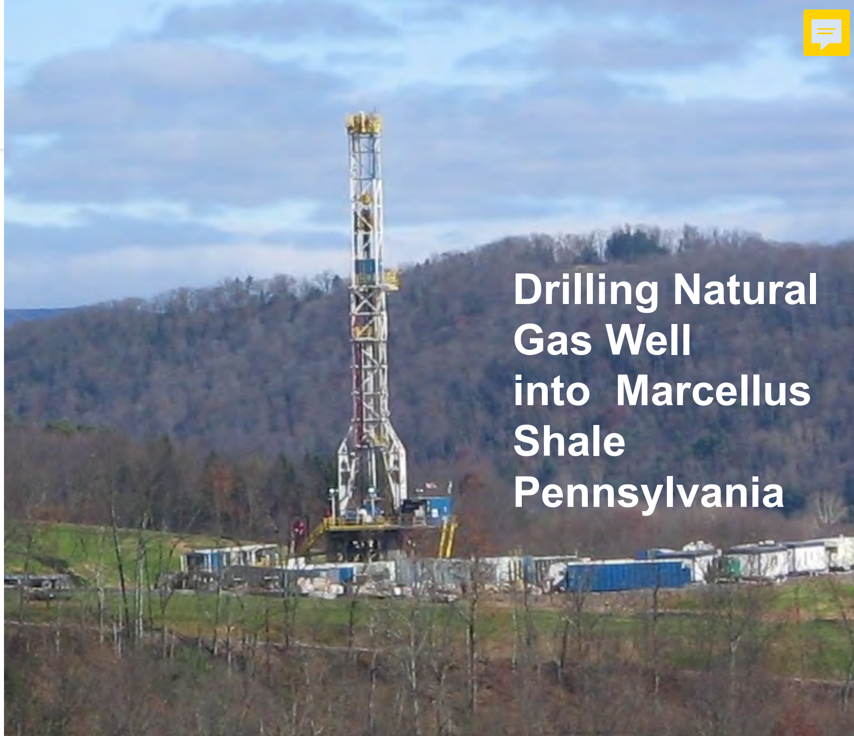
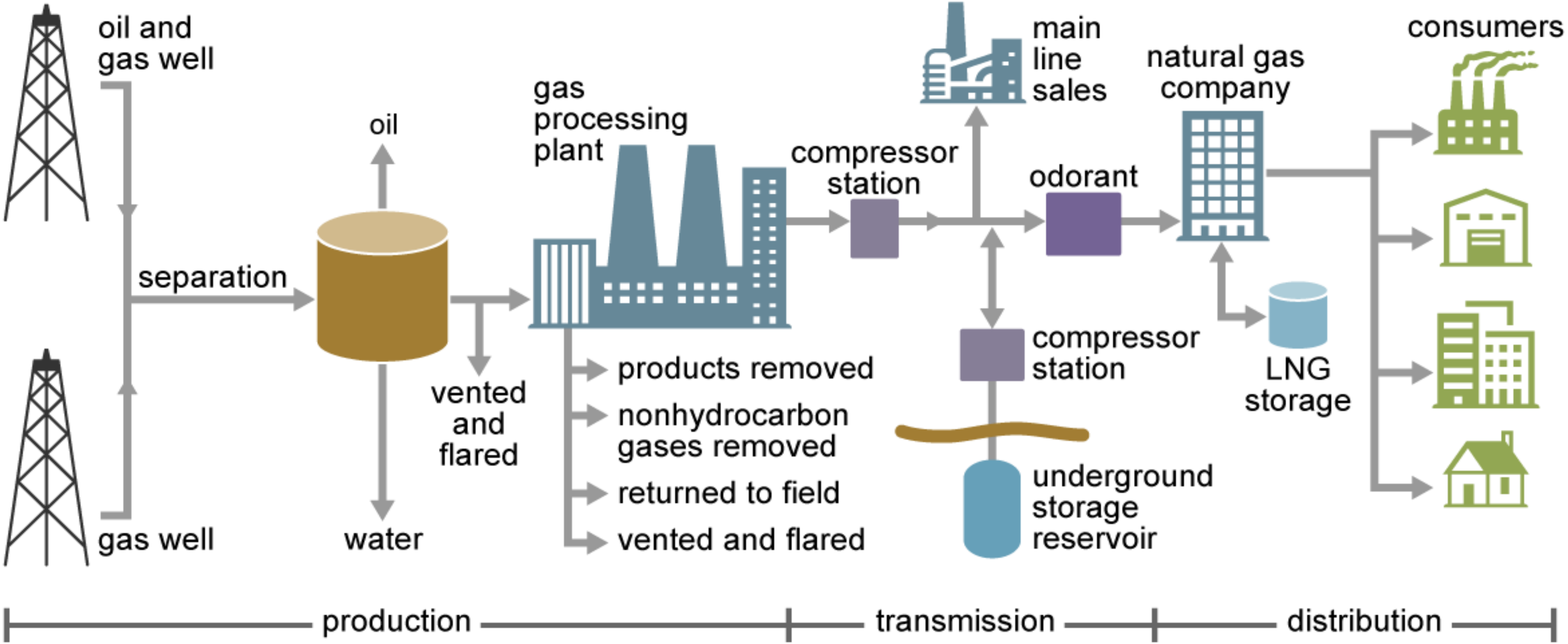



Image by Ruhrfisch CC BY SA 4.0


Image by Pollinator CC BY SA 3.0

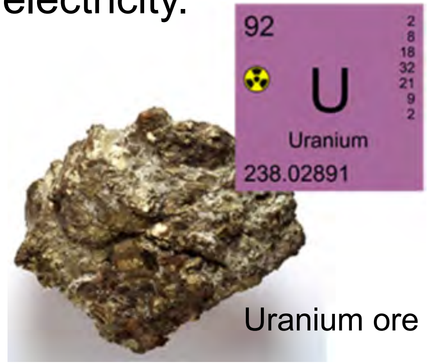
# Natural gas production and delivery




Source: U.S. Energy Information Administration

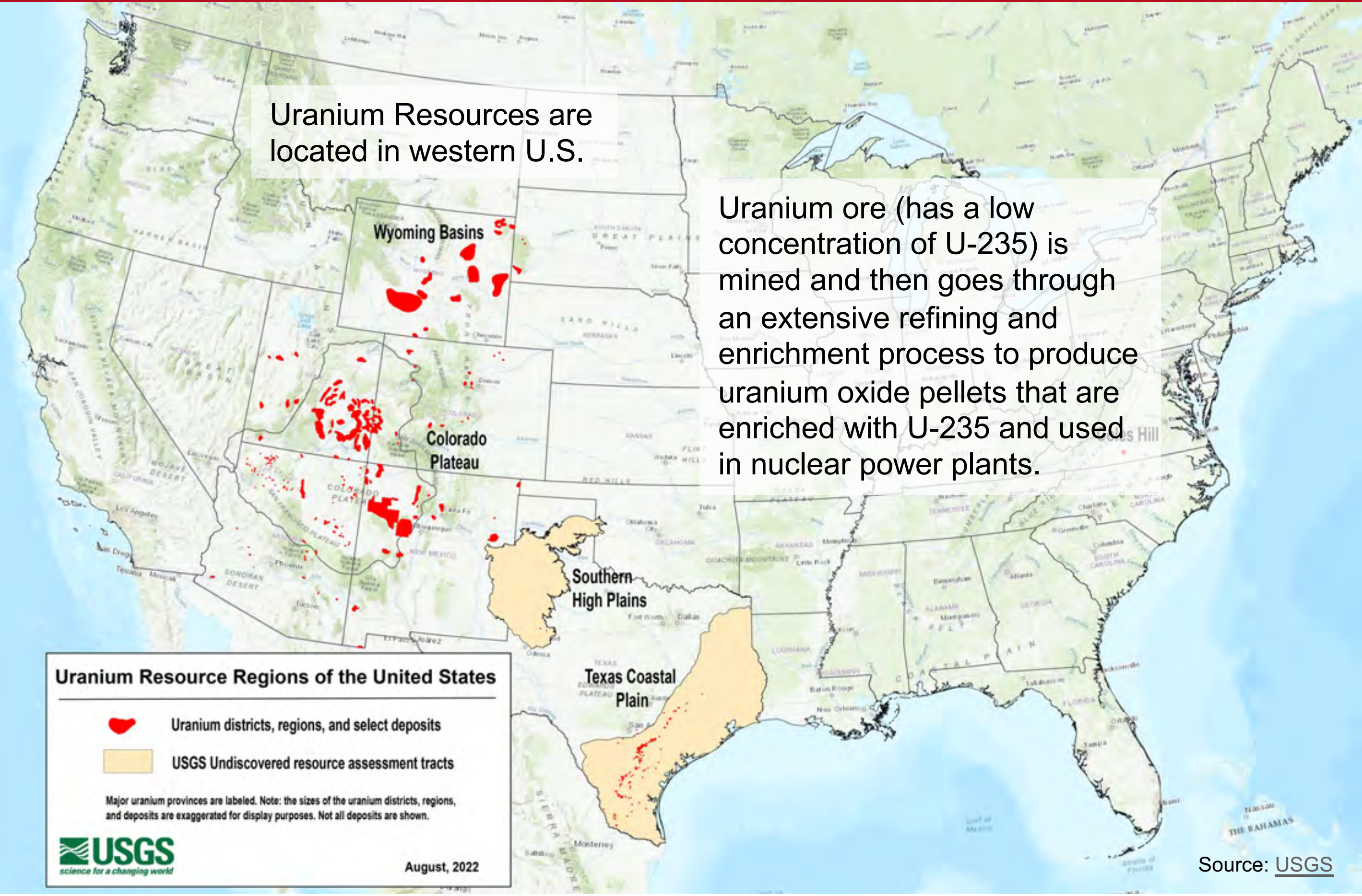
# United States Uranium Resource Regions

Uranium is a radioactive element found in natural ore deposits. Uranium-235 is one of its isotopes and **U-235** is capable of nuclear fission and used in nuclear power plants to generate electricity.




Uranium ore

Source: U.S. NRC




Uranium Resources are located in western U.S.

Uranium ore (has a low concentration of U-235) is mined and then goes through an extensive refining and enrichment process to produce uranium oxide pellets that are enriched with U-235 and used in nuclear power plants.

Source: USGS

The **United States Nuclear Regulatory Commission** (**U.S. NRC**) regulates the mining and processing of uranium ore to be fabricated into nuclear fuel for nuclear power plants. Four steps are involved in converting uranium ore into nuclear fuel.

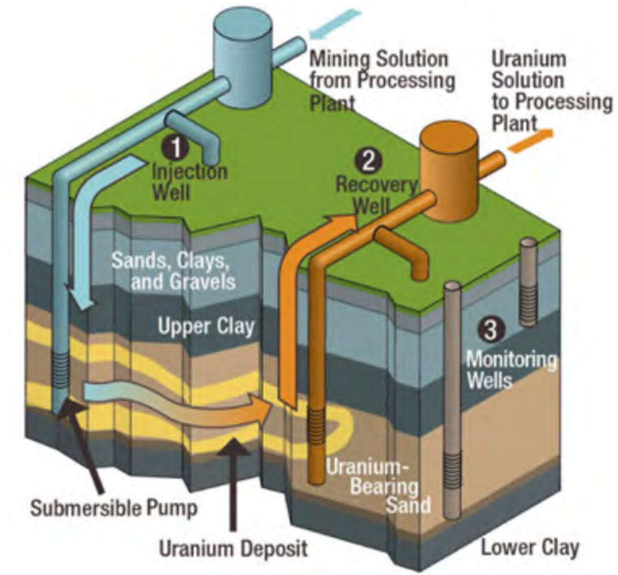
**Step 1 - Uranium Recovery.** Uranium ore is recovered from underground mines and milled (crushed) into a yellow/orange uranium oxide called yellowcake. Uranium recovery is typically accomplished in two ways:

- **Conventional Mining and Milling** - uranium ore is excavated from open pit mines or underground shafts. The ore is crushed (milled) and chemically treated to produce yellowcake (uranium oxide powder).

- **In-Situ Recovery (ISR)** - a liquid solution is injected into the uranium ore underground. The solution leaches uranium from the underground rock and is then pumped to the surface. The solution is processed to produce yellowcake (uranium oxide powder).

# Step 1 Uranium Recovery

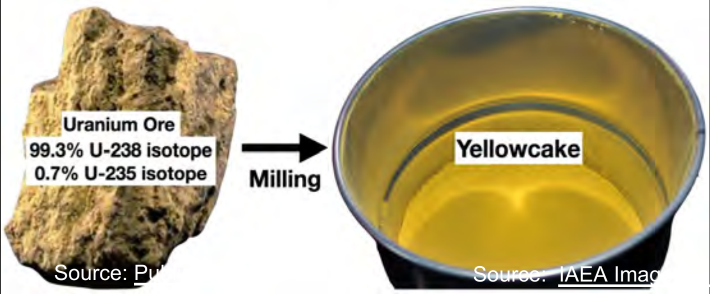

Uranium ore consists of 99.3% U-238 isotope and 0.7% U-235 isotope. U-235 is the isotope capable of fission and used in nuclear power plants.




Source: United States Nuclear Regulatory Commission (public domain)

Source: NRC

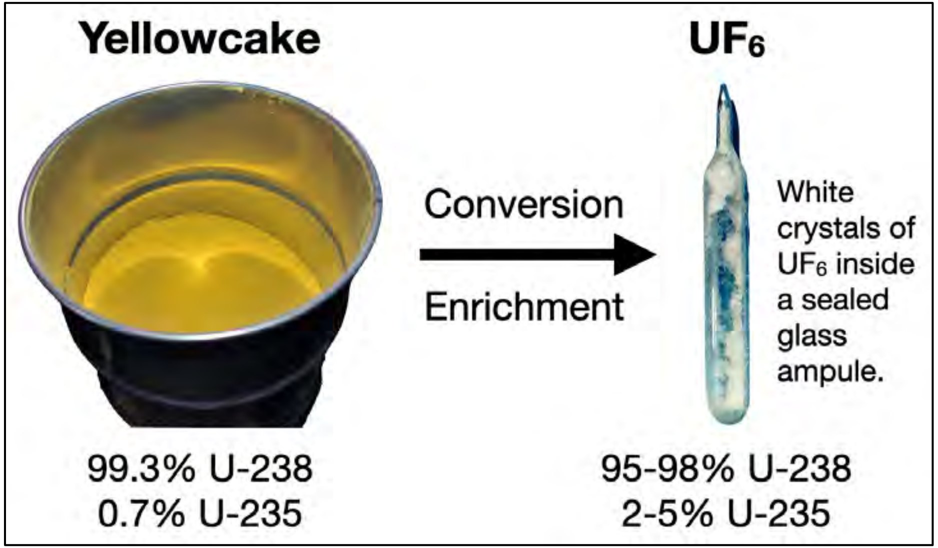
Uranium ore is recovered from Open Pit Mines or In-situ and then milled to produce yellowcake.



# Step 2 Uranium Conversion & Step 3 Enrichment of U-235

**Step 2 - Uranium Conversion.** Yellowcake is reacted with fluorine to create uranium hexafluoride ($UF_6$), a compound that is suitable for enrichment. The $UF_6$ starts out as a hot gas and over several days it cools into a liquid and finally a solid. The solid $UF_6$ can then be shipped to an enrichment plant.

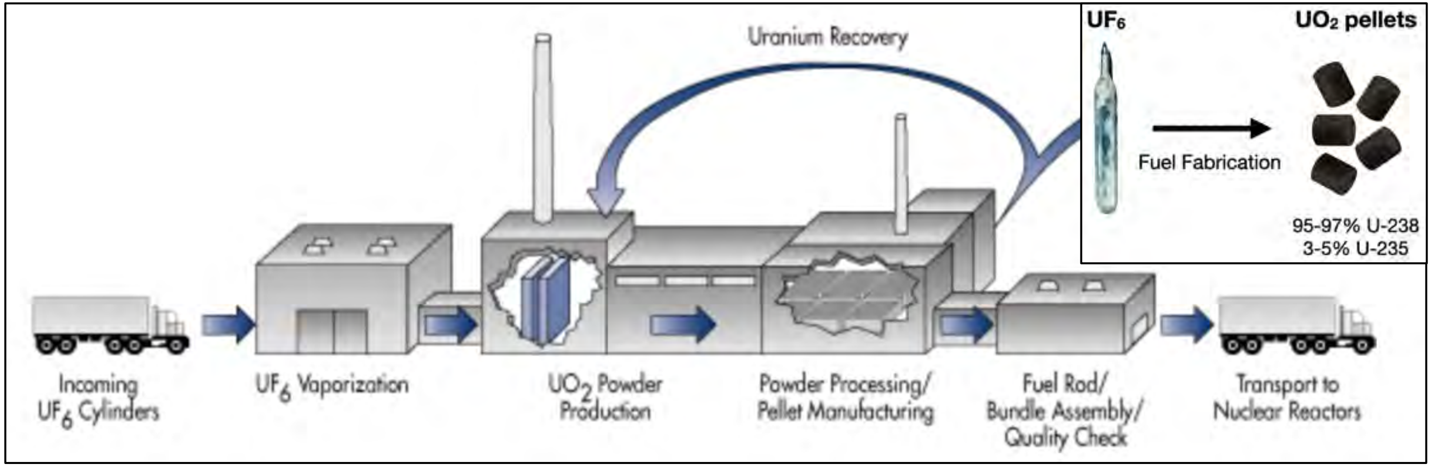
**Step 3 - Enrichment of U-235.** The nuclear fuel used in a nuclear power plant needs to have a high concentration of U-235 isotope (3% to 5%) than that which exists in natural uranium ore (0.7%). Enrichment of U-235 to concentrations of 3-5% can be accomplished by three processes: Gaseous diffusion, gas centrifuge (used in the United States), or laser separation.

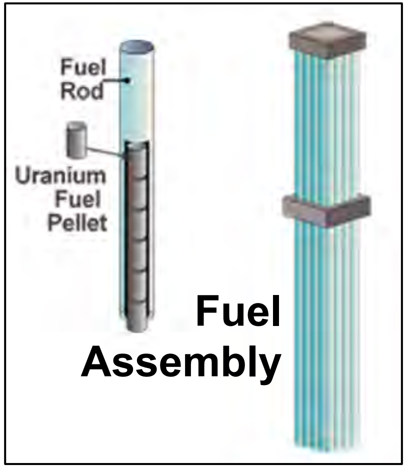



Source: IAEA Imagebank    Source: Argonne National Laboratory

# Step 4 Fuel Fabrication

**Step 4 - Fuel Fabrication** - The U-235 enriched **uranium hexafluoride** (**$UF_6$** solid form) is heated to a gaseous form, and then the $UF_6$ gas is chemically processed to form uranium dioxide ($UO_2$) powder. This powder is pressed into small **$UO_2$ pellets**, which are stacked into **fuel rods**, and grouped together into **fuel assemblies**. The fuel assemblies are transported to nuclear power plants and loaded into the nuclear reactor core where nuclear fission takes place.

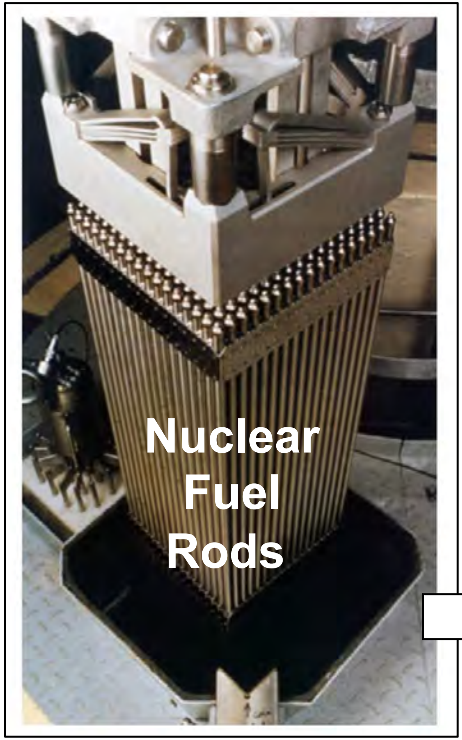



Source: NRC Source: IAEA Imagebank Source: Chemolunatic Source: NRC

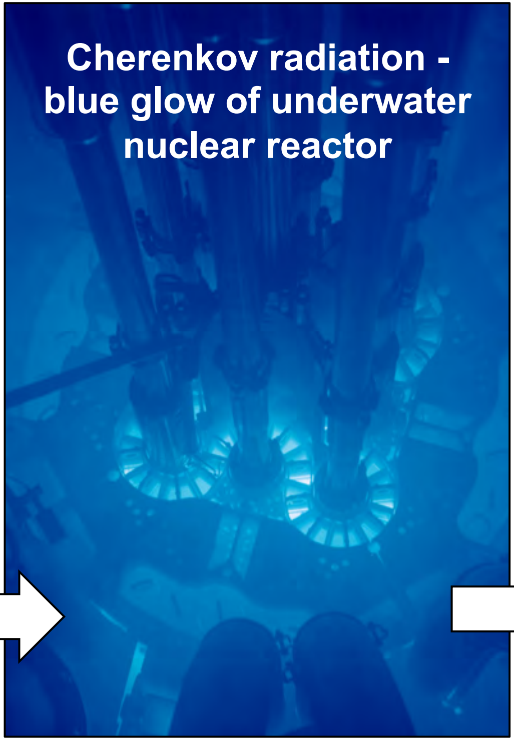
# Nuclear Power Plant

## Nuclear Fuel Assembly



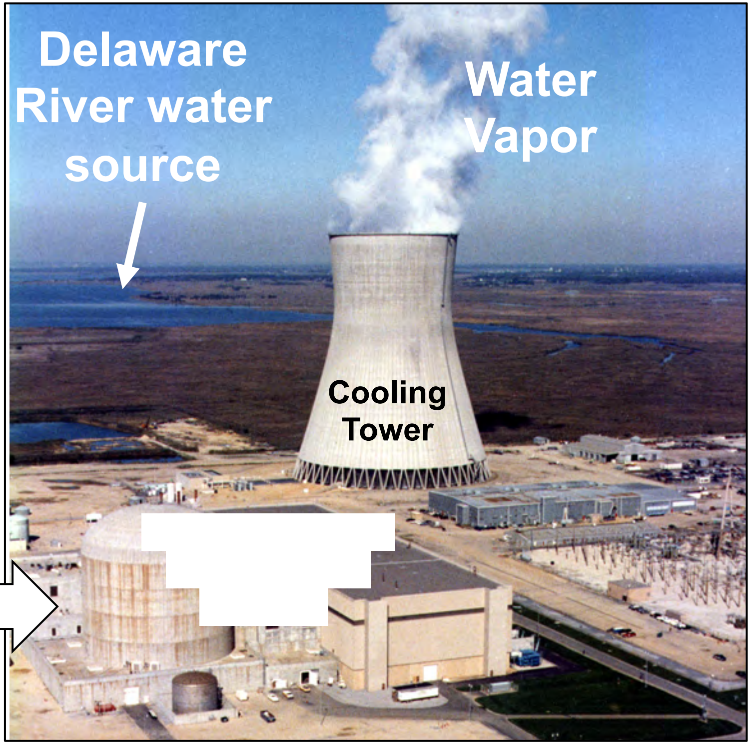

Source:CEA

## Nuclear Reactor Core




Source: Idaho National Laboratory

## Hope Creek Nuclear Power Plant, New Jersey, USA




Source: NRC

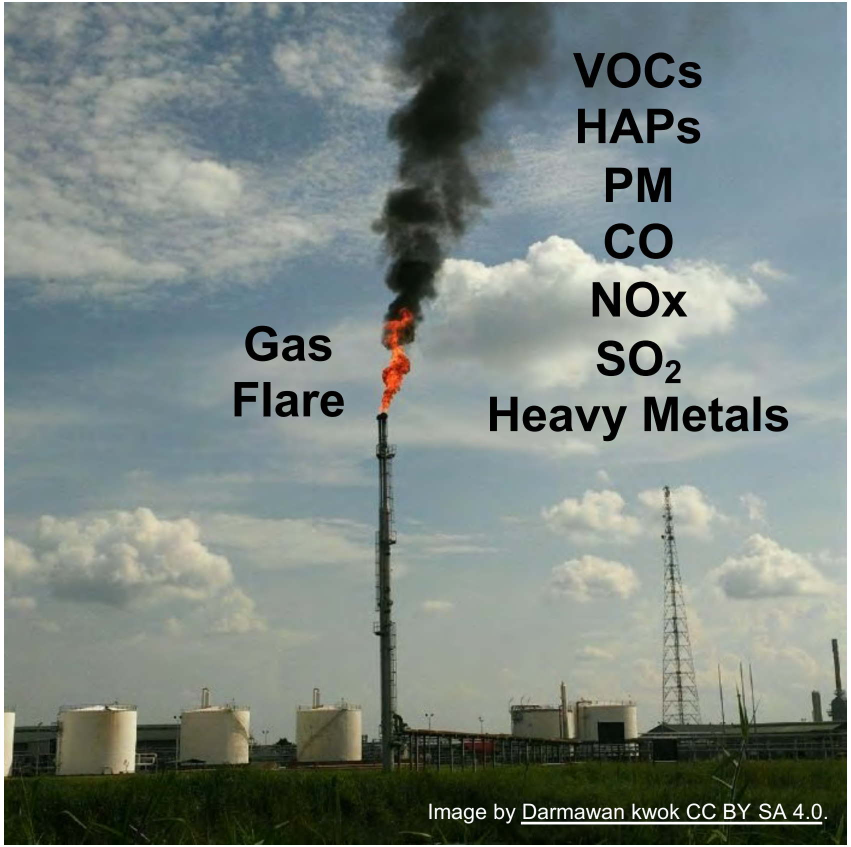
**Objective 3: Describe the impacts of using nonrenewable resources on Earth’s atmosphere, water, and ecosystems.**

# Air Pollution from Petroleum and Natural Gas Production

Air pollutants are emitted from leaks in pipelines and equipment, venting and flaring, and refining of crude oil and natural gas into numerous products.

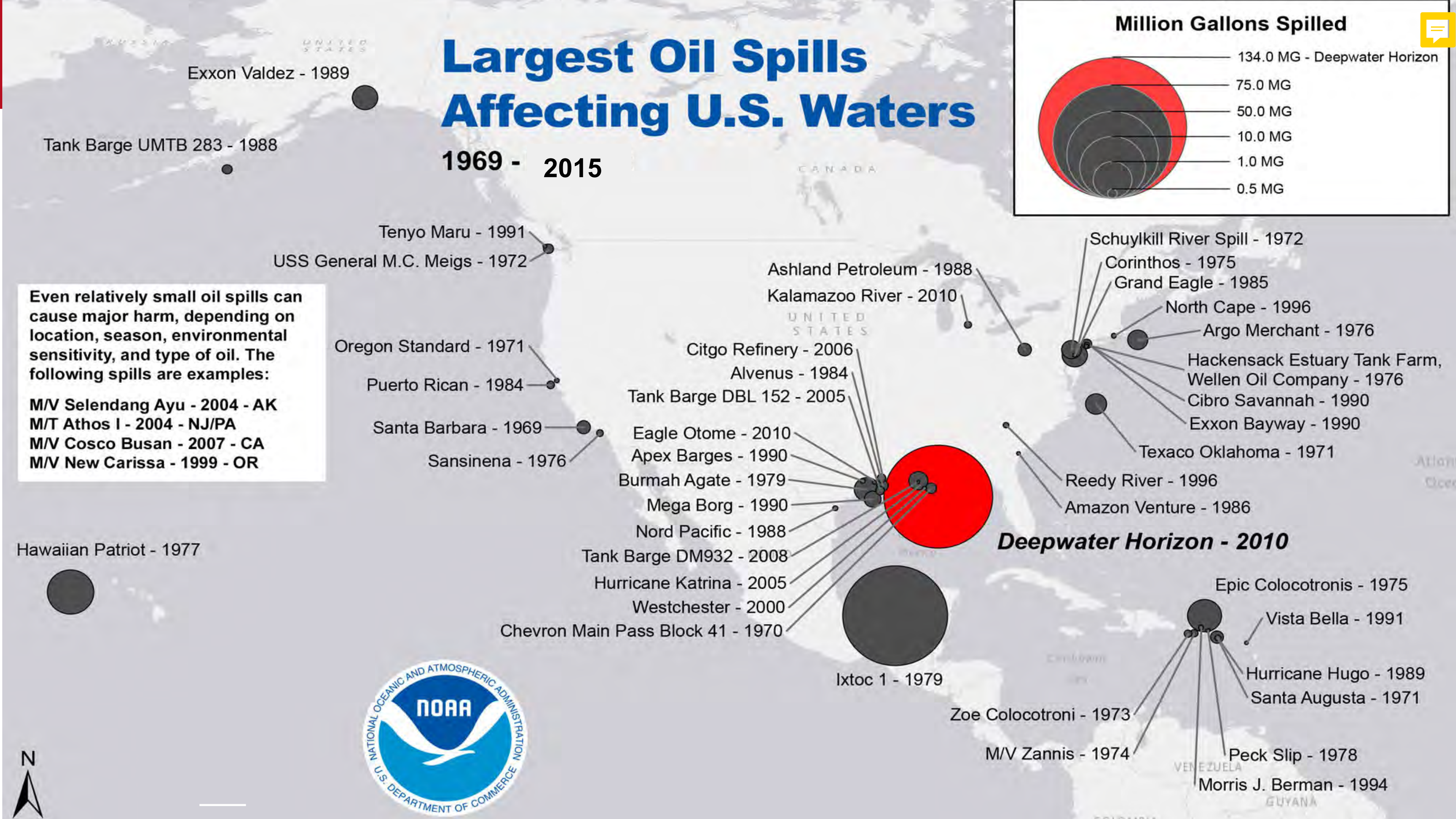
- Methane ($CH_4$), a greenhouse gas
- Volatile Organic Compounds (VOCs)
- Ground-level ozone (smog)
- Hazardous Air Pollutants (HAPs)
- Particulate Matter (PM), black soot

Pollutants linked to health effects such as asthma, emphysema, cancer, damage to immune, nervous, reproductive systems, birth defects.



# Largest Oil Spills Affecting U.S. Waters

**1969 - 2015**

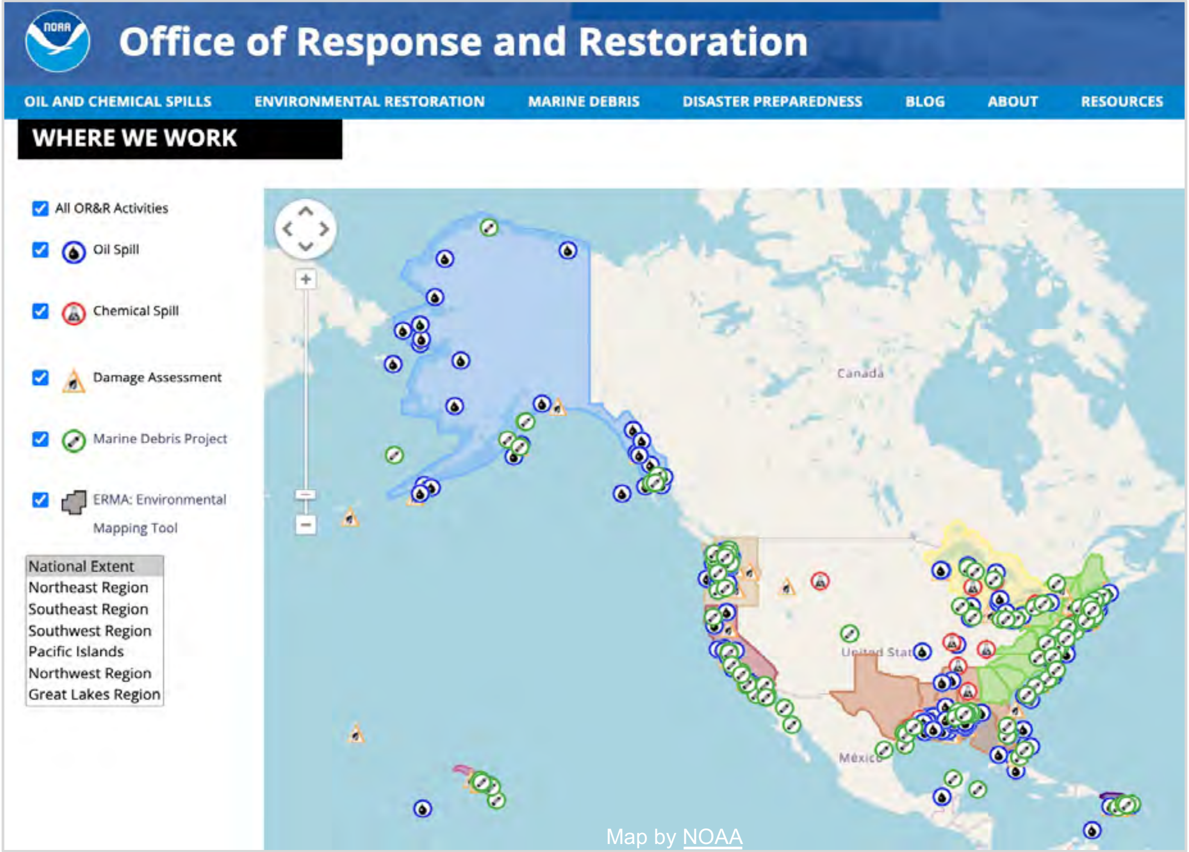



**Even relatively small oil spills can cause major harm, depending on location, season, environmental sensitivity, and type of oil. The following spills are examples:**

**M/V Selendang Ayu - 2004 - AK**
**M/T Athos I - 2004 - NJ/PA**
**M/V Cosco Busan - 2007 - CA**
**M/V New Carissa - 1999 - OR**

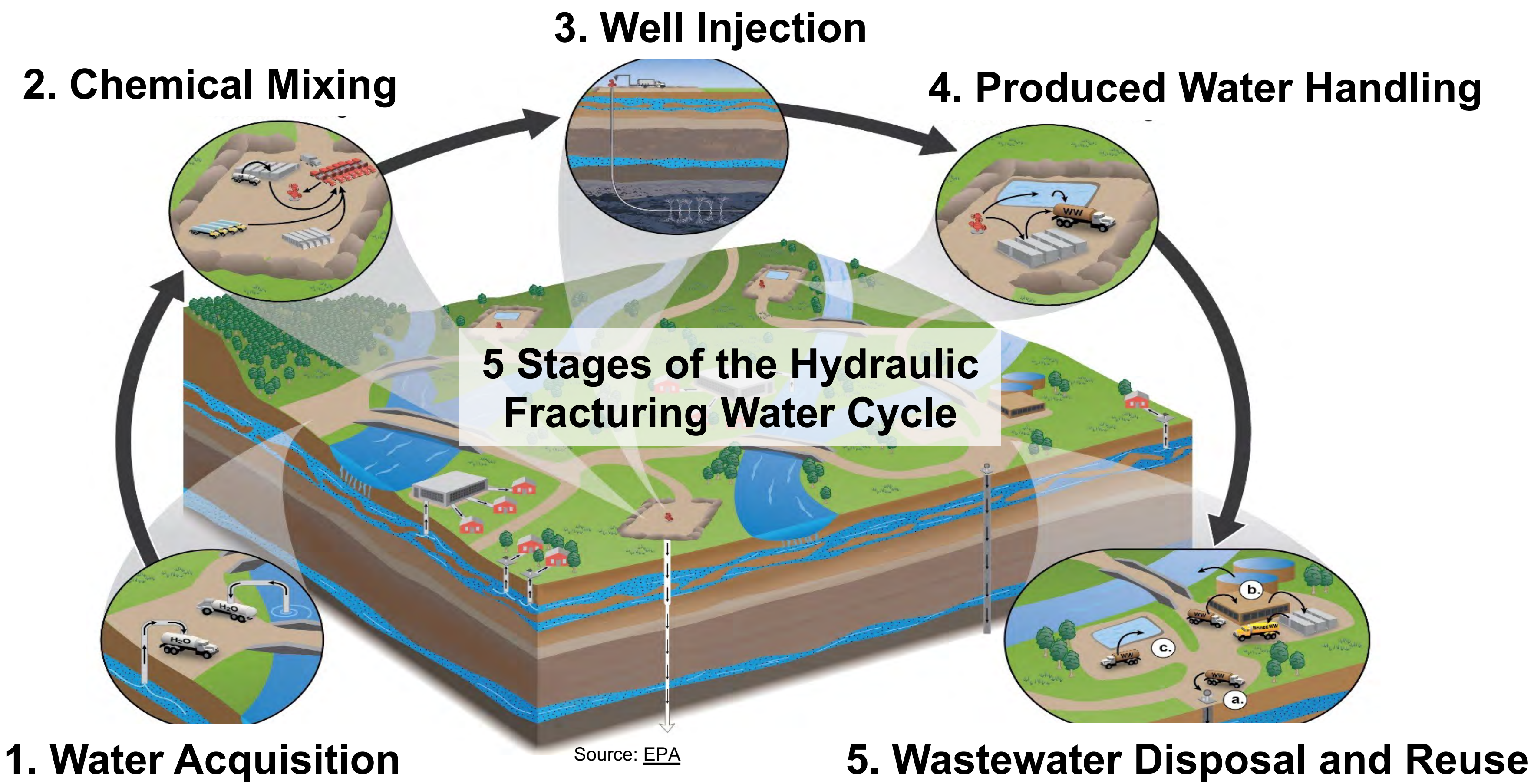
# U.S. Agencies for Oil Spills and Chemical Accidents

- **U.S. EPA** is the lead federal response agency for oil spills occurring on land or in inland waters.
- **U.S. Coast Guard** is the lead federal response agency for spills in coastal waters.
- **NOAA** provides scientific support to the federal on-scene coordinator.




Map by NOAA

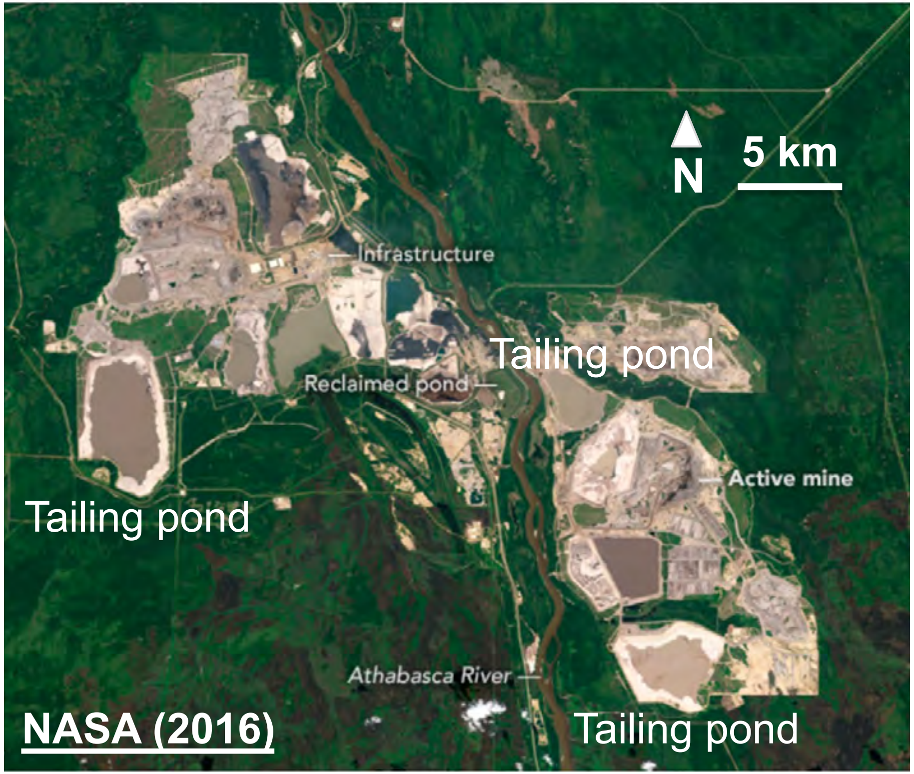
# Hydraulic Fracturing and Freshwater Resources




Source: EPA

# Alberta, Canada Tar Sands and Freshwater Resources

- Tar sands have 160 billion barrels of recoverable crude oil.
- On average, 4 barrels of freshwater is required to produce 1 barrel of crude oil from tar sand.
- By 2030, Alberta's water consumption is expected to reach 400 million gallons of per day.
- Wastewater is stored in large tailing ponds for decades until sand, clay and petroleum waste settles out.
- In 2020, Alberta had 265 billion gallons of tailings wastewater.



# Acid Mine Drainage from Coal Mines

**Acid mine drainage (AMD) is the formation and movement of acidic water, rich in heavy metals, from mining sites.**

Coal mining exposes sulfur-containing minerals that were buried underground. These minerals reach with oxygen and surface water to form sulfuric acid ($H_2SO_4$).

The sulfuric acid dissolves and transports toxic heavy metals into surface and ground water: arsenic (As), copper (Cu), cadmium (Cd), iron (Fe), lead (Pb), mercury (Hg), selenium (Se).


Image by D. Hardesty, Wikimedia Commons. Public Domain.

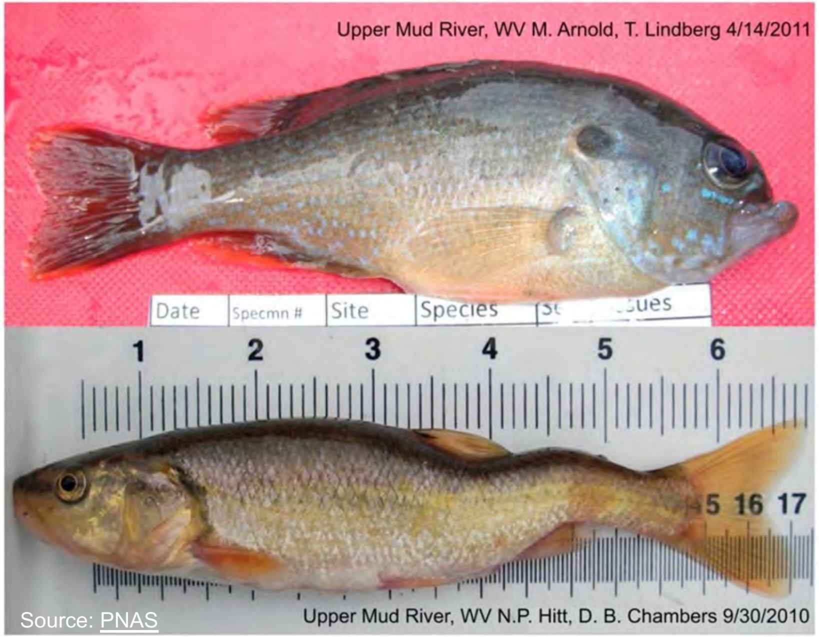
# Mountaintop Removal Coal Mining (Kentucky & West Virginia)

**Mountaintop removal (MTR) = type of surface coal mining where the mountain top is removed to expose the coal seam.  The excess rock and soil (overburden) is dumped into valleys (valley fill).**

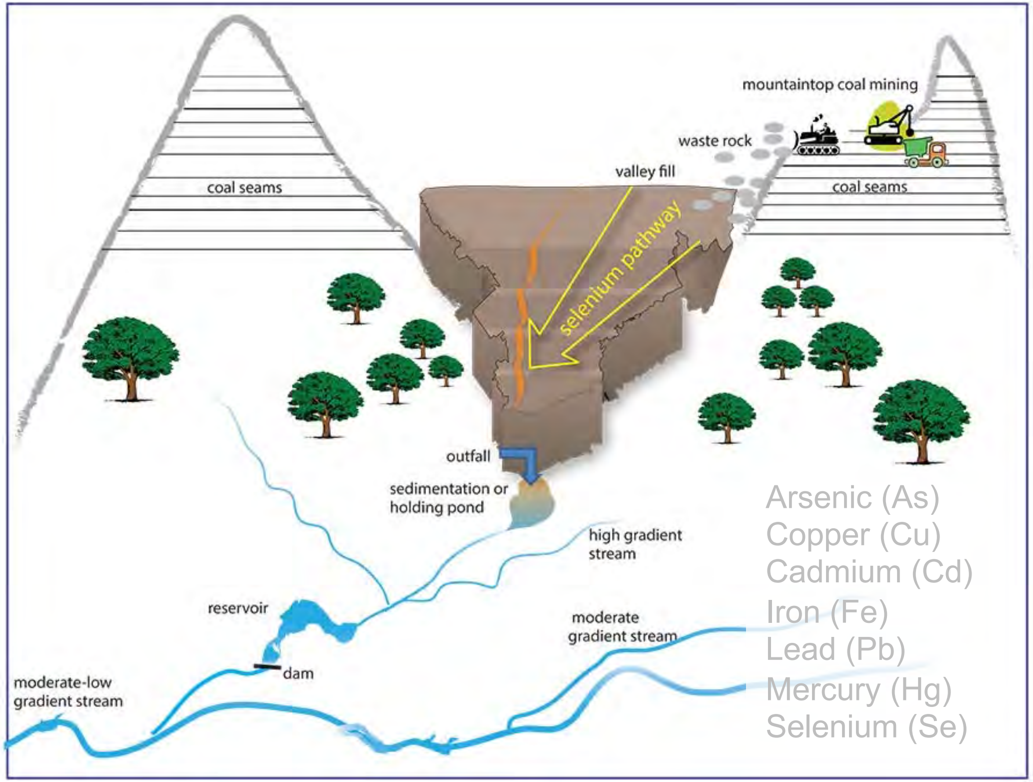
- Causes deforestation, loss of habitat and soil erosion in the mining area.
- Local streams and rivers become polluted and buried under mining waste.
- Acid mine drainage and heavy metals contaminate water ground and surface water.

# Heavy Metal Pollution from Coal Mining Runoff Pollution

**Selenium toxicity - cranial-facial deformities**



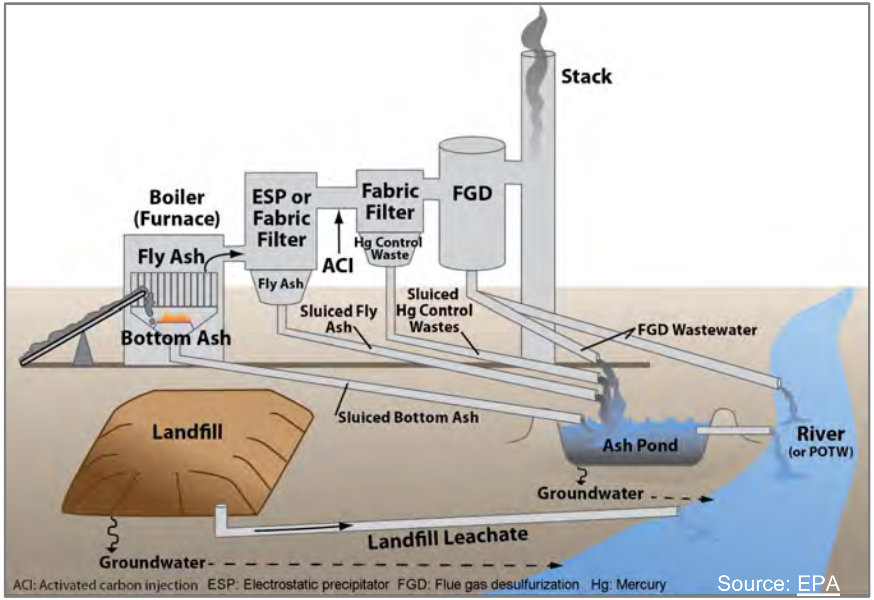

**Selenium toxicity - spine deformities**




Arsenic (As)
Copper (Cu)
Cadmium (Cd)
Iron (Fe)
Lead (Pb)
Mercury (Hg)
Selenium (Se)

# Coal Ash Waste Ponds

Coal ash is a waste product from burning coal to generate electricity. Power plants may recycle the coal ash, dispose of it by releasing it into nearby waterways or store it in landfills or ponds.




Source: EPA


Image by Antony 22, Wikimedia Commons. CC BY SA 4.0.

# Coal Ash Waste Pond Accidents

- The U.S. has about 250 coal power plants.
- The U.S. has over 700 coal ash waste sites.
- Environmental disasters have occurred in the U.S. when coal ash waste ponds ruptured.

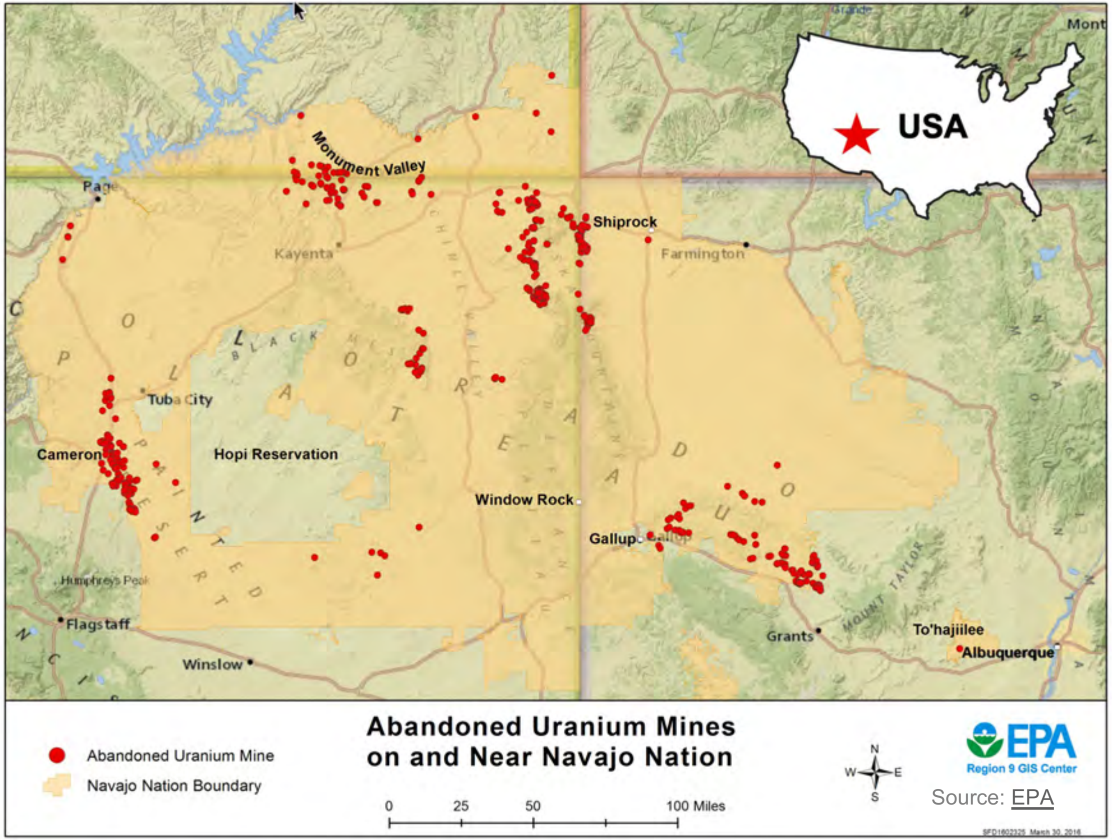
Source: Public Domain

Aerial Image Of Kingston Ash Slide 12/23/08

Source: Public Domain

# Legacy Pollution from Uranium Mining and Processing

- Major uranium deposits are in western United States.
- From 1944 to 1986, about 30 million tons of uranium ore extracted from Navajo land.
- There are 500 abandoned uranium mines, and homes and water sources with high levels of radiation.
- The EPA has a 10-year plan (2020-29) will spend $1.7 billion to reduce risks of radiation exposure to the Navajo people.




Source: EPA

# Radioactive Waste from Nuclear Power Plants

**Four Types of Regulated Radioactive Waste**

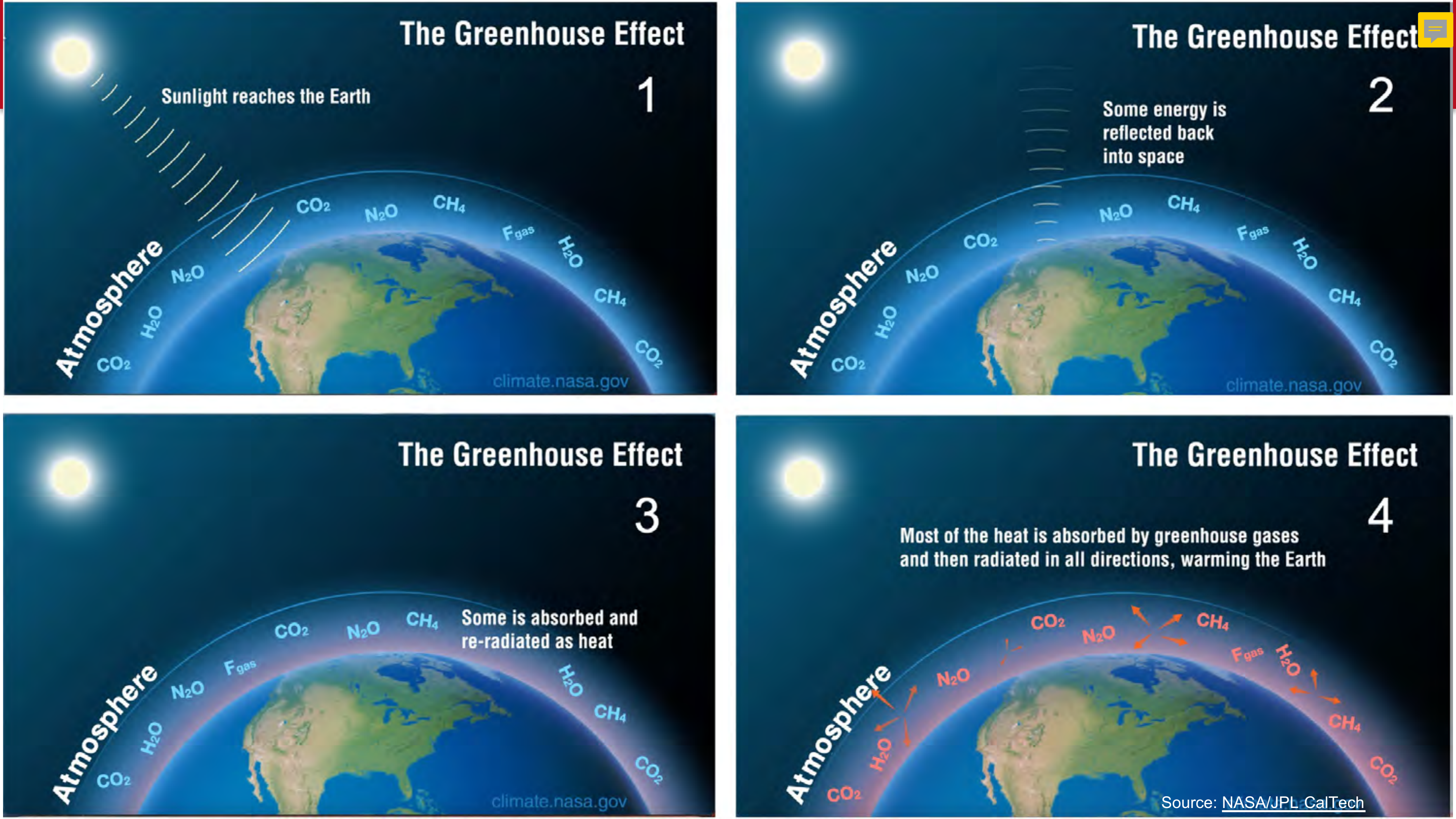
1. Low-level Waste - protective clothing, tools, equipment.
2. Waste Incidental from reprocessing spent nuclear fuel - recovery of used nuclear fuel.
3. High-level waste - used nuclear fuel (spent fuel rods).
4. Uranium mill tailings - from processing natural uranium ore.



# Nuclear Waste Storage Sites in the United States


Source: L. Larson CRSReports

**Objective 4: Describe how burning fossil fuels for energy causes global warming and the importance of limiting warming to 1.5°C.**



Source: NASA/JPL CalTech

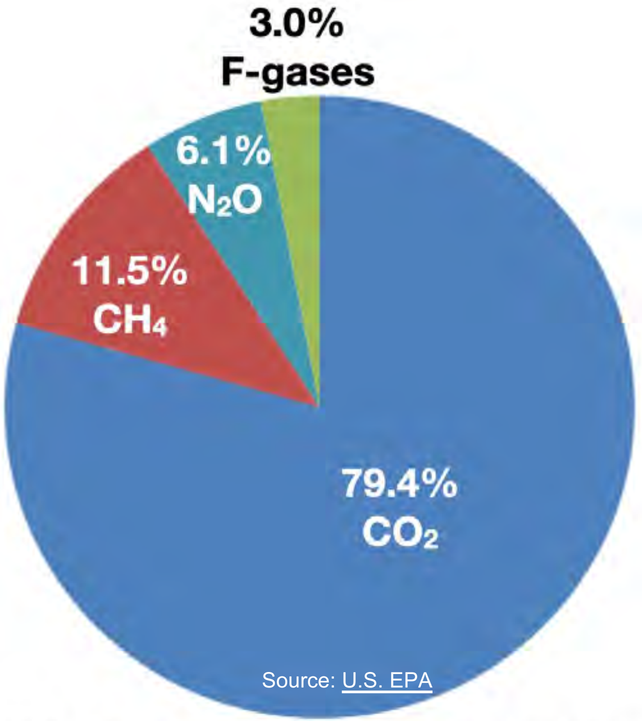
# Greenhouse Gases

**Carbon dioxide ($CO_2$) –** emitted from burning coal, oil, and natural gas, cement manufacturing, solid waste decomposition.

**Methane ($CH_4$) –** emitted from natural gas processing and transportation, cattle, agriculture waste, landfills.

**Nitrous Oxide ($N_2O$) –** emitted from agriculture, burning fossil fuels, wastewater treatment.

**F-gases –** synthetic gases used as refrigerants, aerosol propellants, foam blowing agents, solvents, and fire retardants.

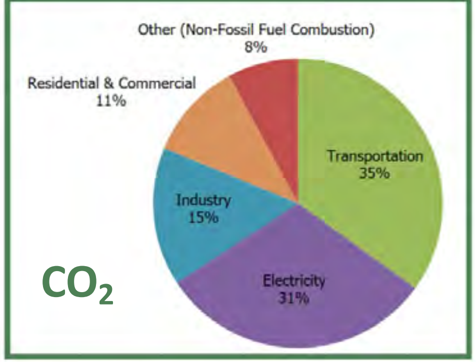



**Total Greenhouse Gas Emissions United States in 2021**

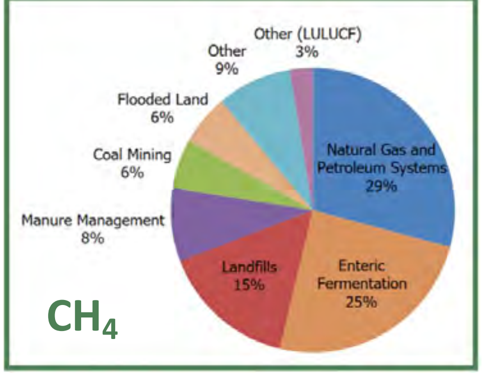
Total = 6,340 million metric tons of $CO_2$ equivalent

# U.S. Greenhouse Gas Emissions

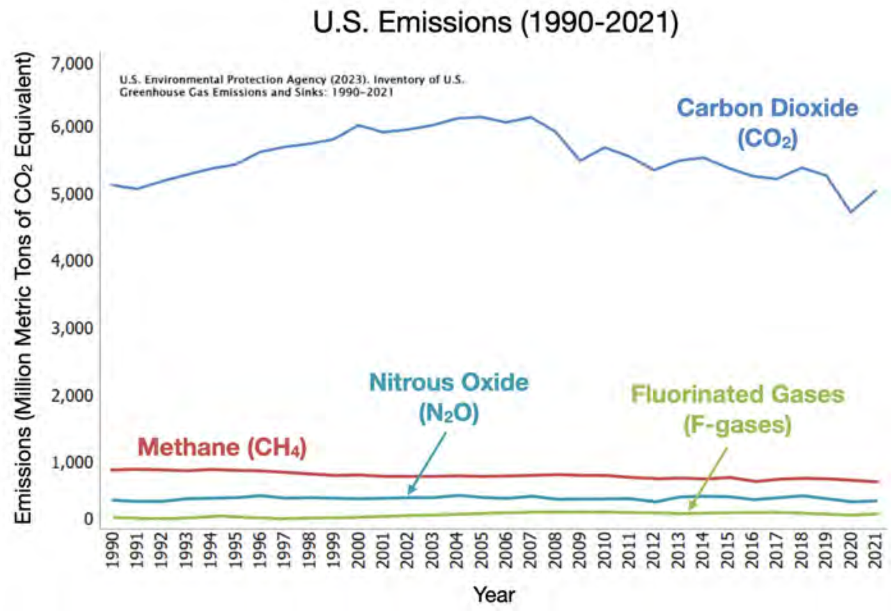
## U.S. Carbon Dioxide Emissions, by Economic Sector




## U.S. Methane Emissions, By Source



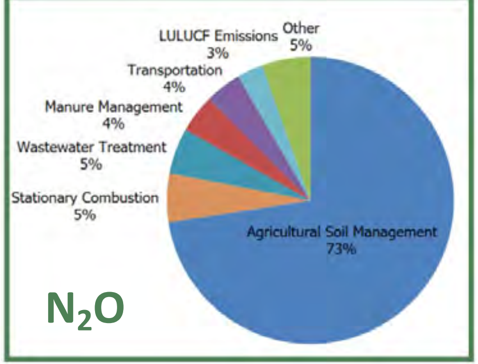

$CO_2$ = transportation > electricity >> industry
$CH_4$ = gas, oil > cattle >> landfills



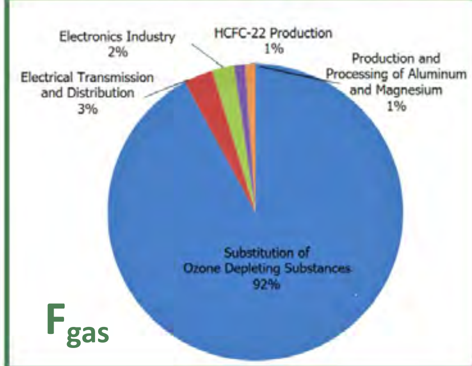

Source: U.S. EPA

$N_2O$ = agriculture soil and manure
$F_{gas}$ = substitutions for ozone depleting gas

## U.S. Nitrous Oxide Emissions, By Source




## U.S. Fluorinated Gas Emissions, By Source



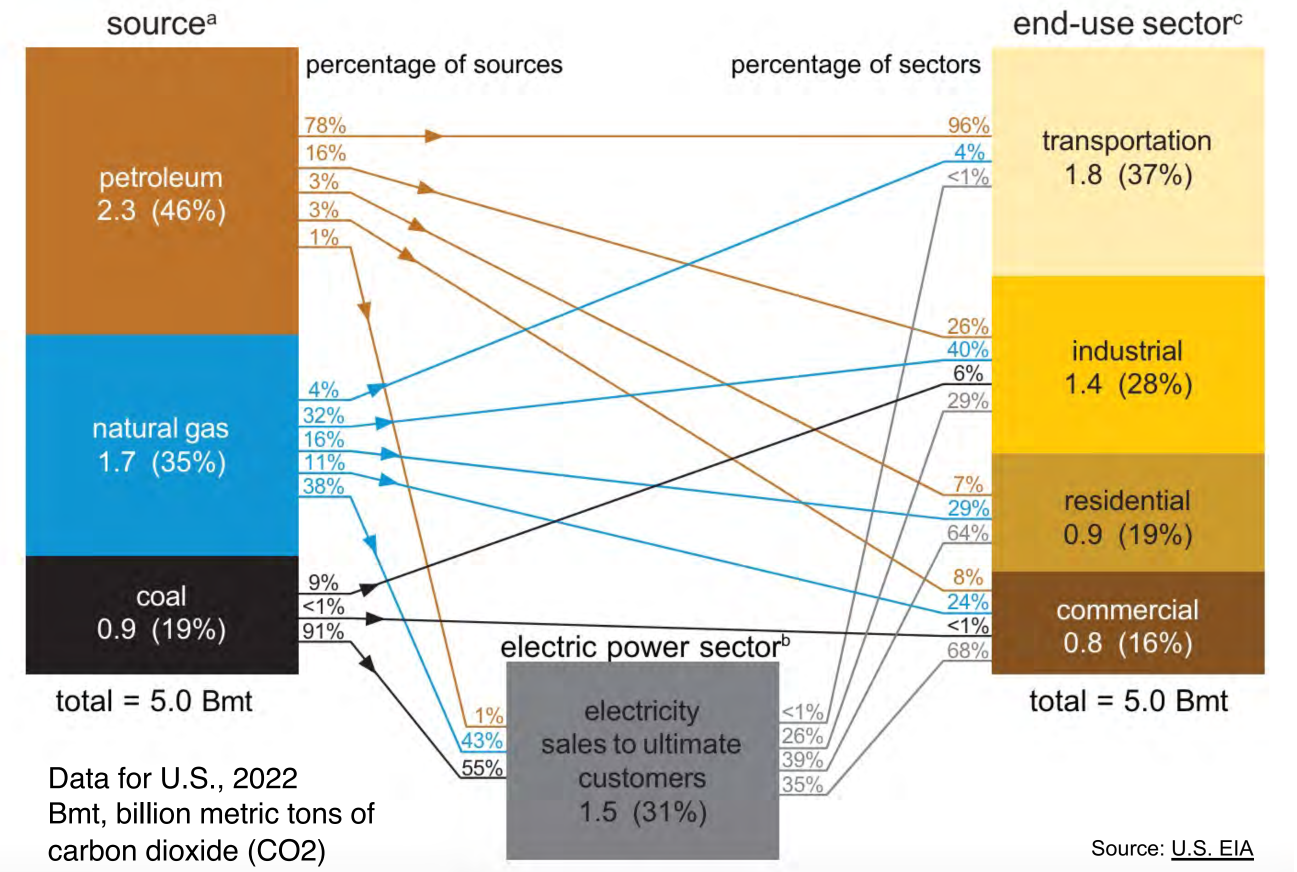
# U.S. 2022 $CO_2$ Emissions from Energy Consumption by Source and Use

**An example of how to read chart:**

Petroleum accounted for 46% of all $CO_2$ emissions in the United States in 2022 = 2.3 Bmt of $CO_2$.

78% of this petroleum was used for transportation, which fueled 96% of all transportation in the U.S.

Transportation accounted for 37% of all CO2 emissions in the United States in 2022 = 1.8 Bmt.



# Global Warming Potential (GWP) of Greenhouse Gases

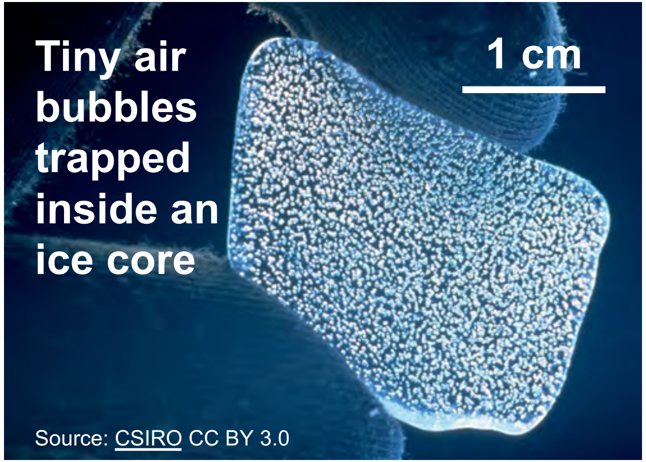
Global Warming Potential (GWP) is an index to measure how much heat (infrared radiation) a greenhouse gas will absorb in the atmosphere over a period.

| Gas | Formula | Lifetime | GWP (100 years) |
|---|---|---|---|
| Carbon dioxide | $CO_2$ | variable | 1 |
| Methane | $CH_4$ | 12 years | 28 |
| Nitrous Oxide | $N_2O$ | 114 years | 265 |
| Fluorinated Gas | HFCs, PFCs, $SF_6$, $NF_3$, others | 5-50,000 years | 800-24,000 |

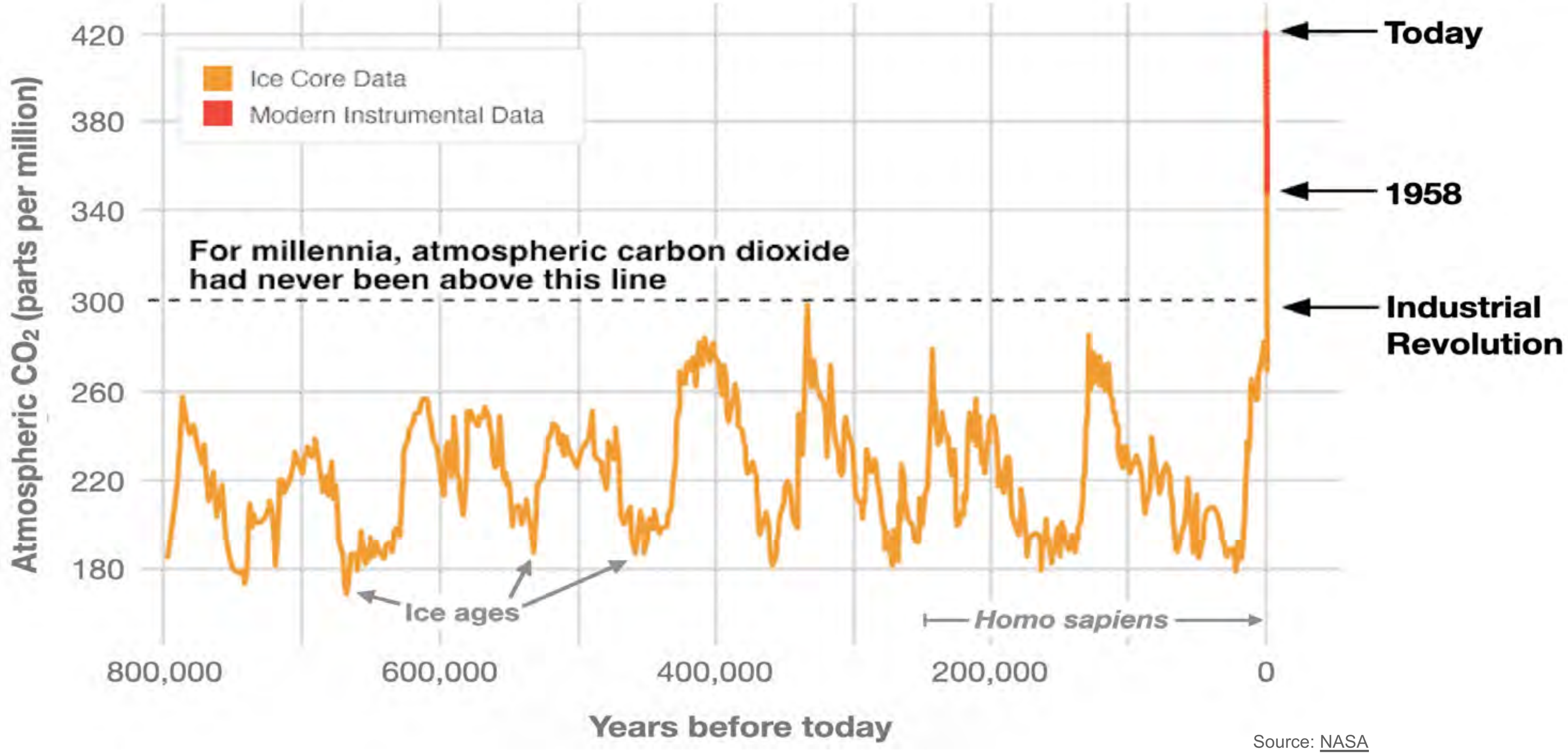
Source: U.S. EPA

# Using Ice Cores to Reconstruct Past Climates

- Ice cores are time capsules of past climates
- Ice cores trap bubbles of air (e.g., carbon dioxide and methane) from past atmosphere.



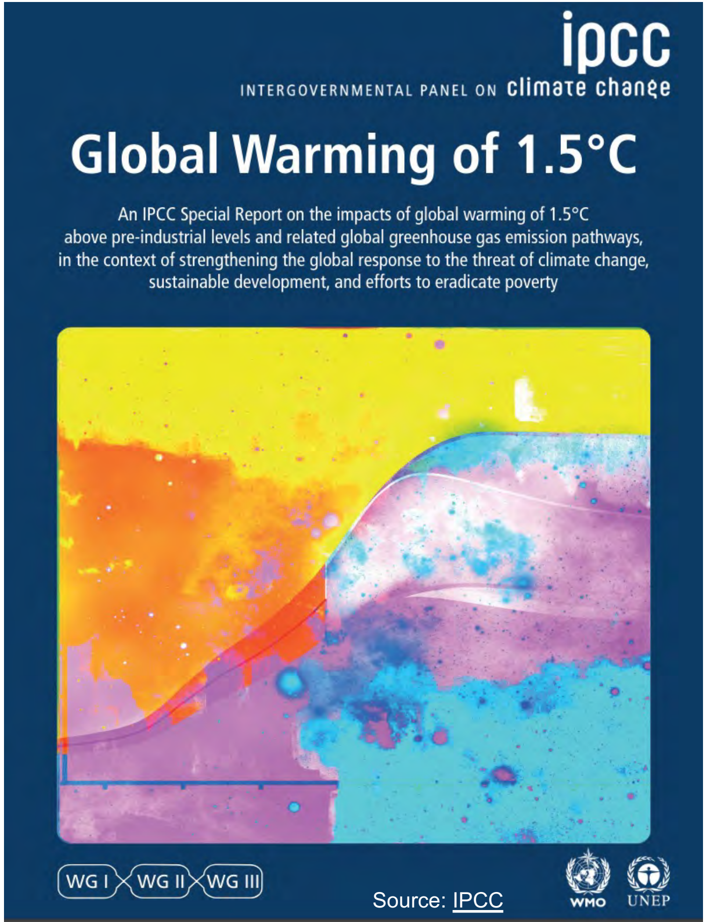

# Atmospheric Carbon Dioxide over past 800,000 Years




Source: NASA

# Intergovernmental Panel on Climate Change (IPCC)

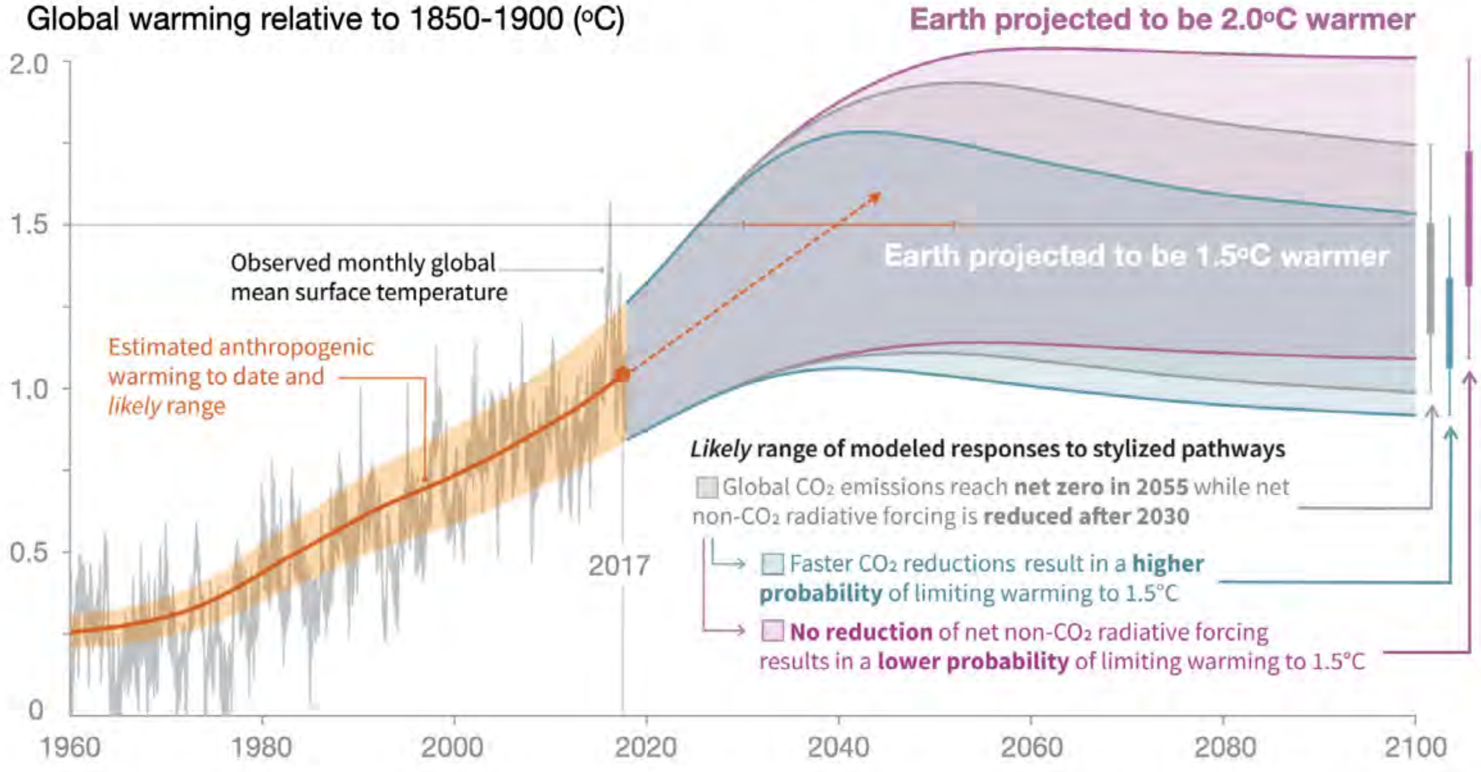
- In 2018 the IPCC published a Special Report titled ***Global Warming of 1.5°C***.
- Limiting global warming to 1.5ºC above pre-industrial levels (1850-1900) would require rapid, far reaching, and unprecedented changes in all aspects of society.
- 1.5°C increase in global temperatures will have a significant impact on climate, but a 2°C increase will be far worse.
- Global warming reached 1°C above pre-industrial levels in 2017. If this pace of warming continues, we will reach 1.5°C sometime between 2030-2040.




Source: IPCC

# Cumulative emissions of $CO_2$ and future non-$CO_2$ radiative forcing determine the probability of limiting warming to 1.5°C

## a) Observed global temperature change and modeled responses to stylized anthropogenic emission and forcing pathways



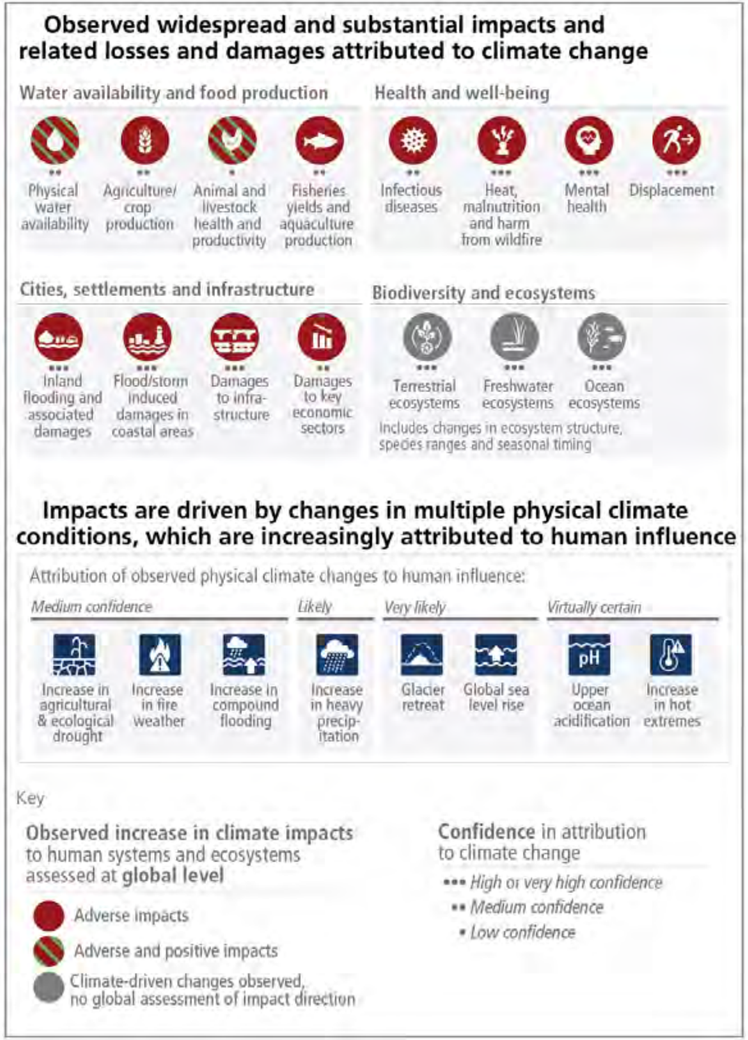

Three modeled pathways are shown in graph using gray, blue, purple plumes to predict hypothetical warming from 2020 to 2100.

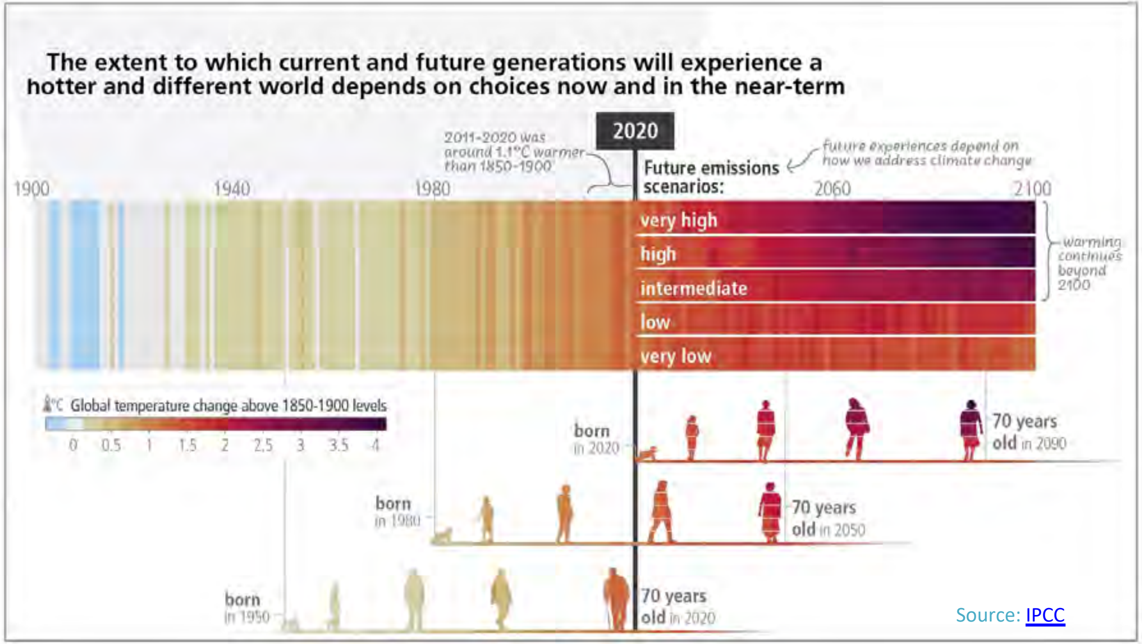
The models take into account the rate of warming (solid orange line and dashed arrow) and the anthropogenic emission of $CO_2$ and non-$CO_2$ radiative forcing due to $CH_4$, $N_2O$, fluorinated gases, aerosols, land use, land cover, and other anthropogenic agents.

Source: IPCC

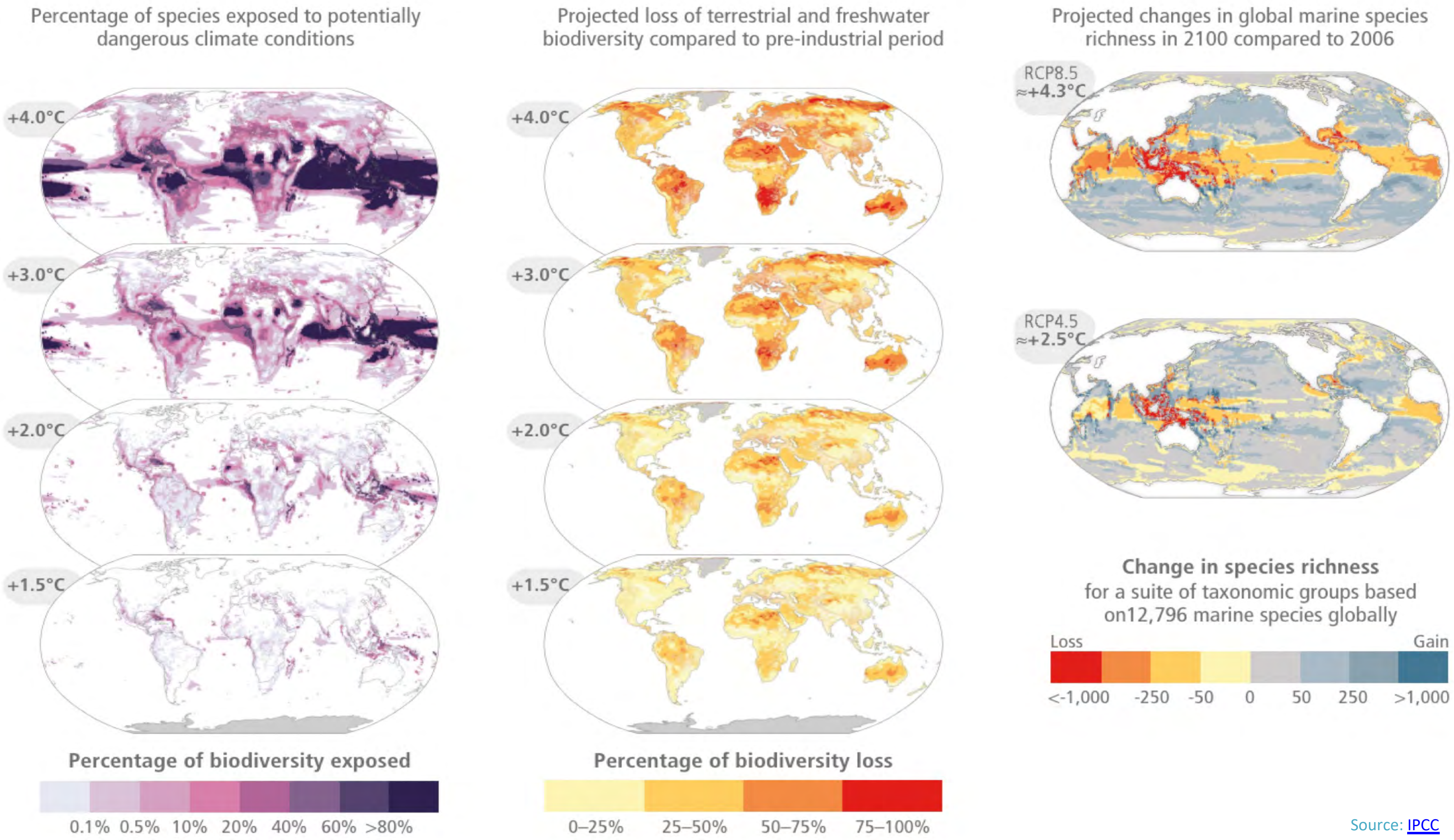
# IPCC Sixth Assessment Report, *Climate Change 2022: Impacts, Adaptation and Vulnerability*

This report assesses the impacts of climate change on ecosystems, biodiversity, and human communities at global and regional levels.



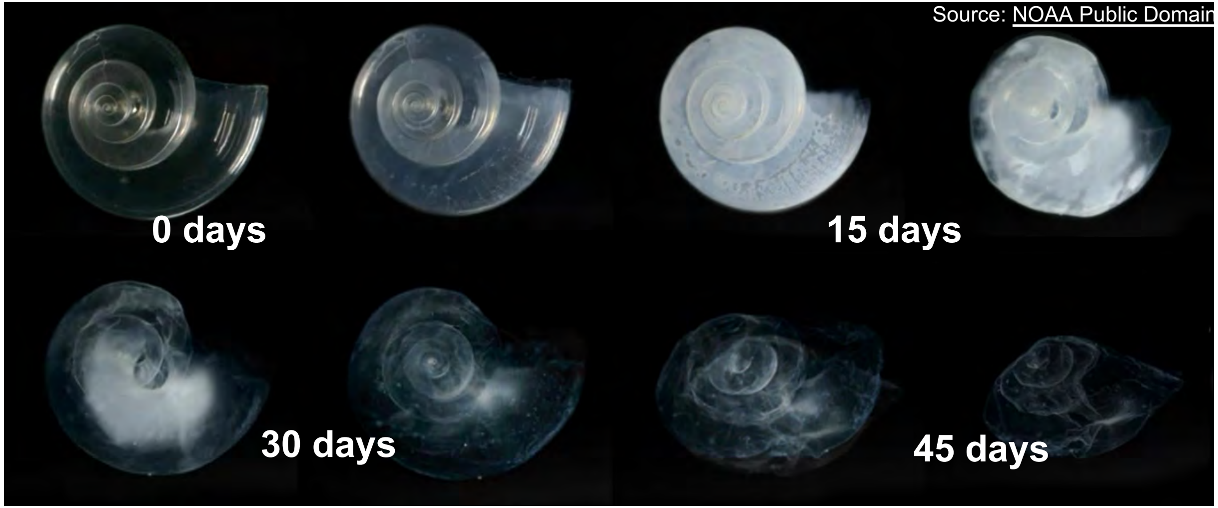

Source: IPCC


Percentage of species exposed to potentially dangerous climate conditions
+4.0°C
+3.0°C
+2.0°C
+1.5°C
Percentage of biodiversity exposed
0.1% 0.5% 10% 20% 40% 60% >80%
Projected loss of terrestrial and freshwater biodiversity compared to pre-industrial period
+4.0°C
+3.0°C
+2.0°C
+1.5°C
Percentage of biodiversity loss
0–25% 25–50% 50–75% 75–100%
Projected changes in global marine species richness in 2100 compared to 2006
RCP8.5 ≈+4.3°C
RCP4.5 ≈+2.5°C
Change in species richness
for a suite of taxonomic groups based on12,796 marine species globally
Loss
Gain
<-1,000 -250 -50 0 50 250 >1,000

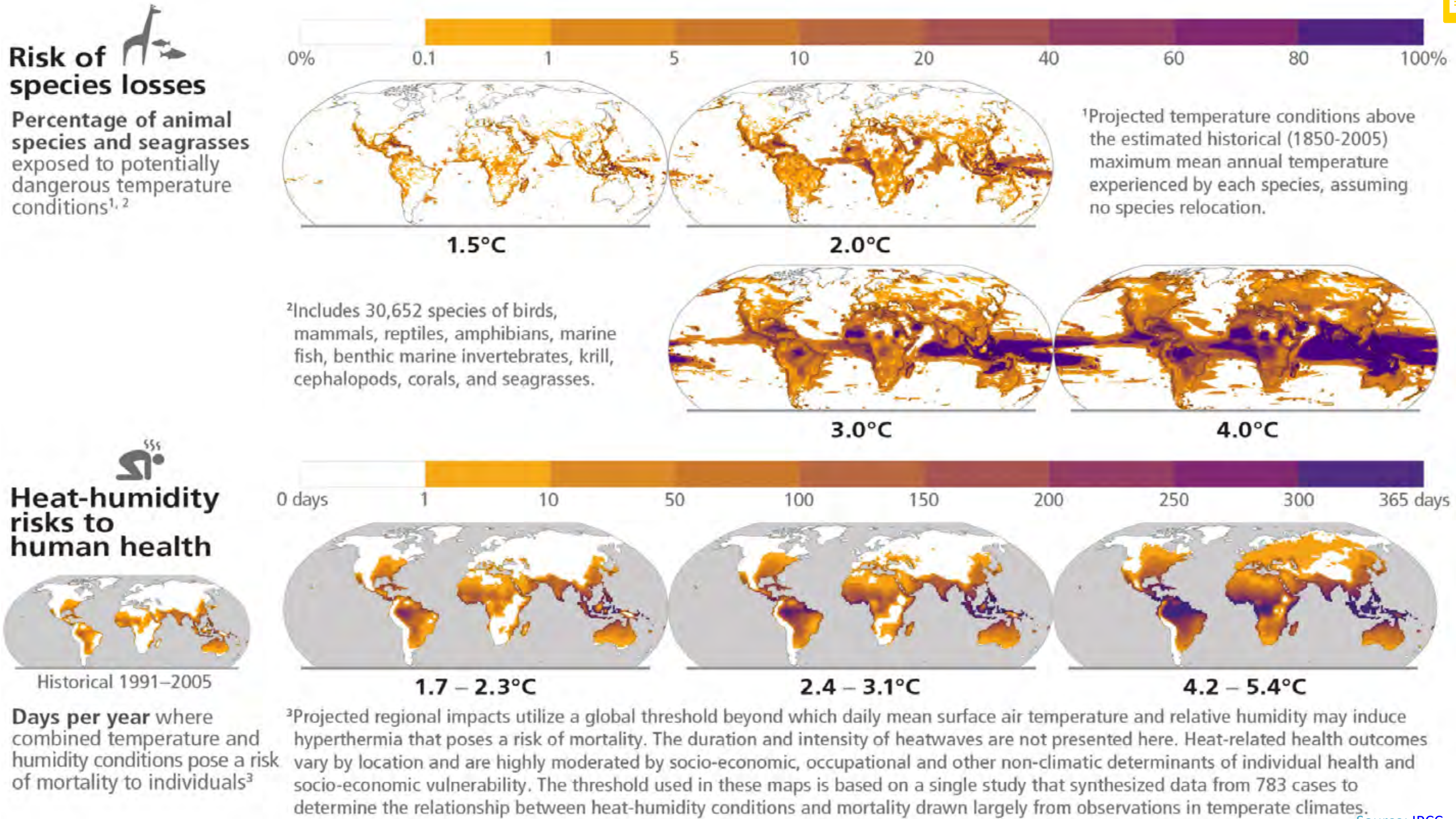
Source: IPCC

# Carbon Dioxide and Ocean Acidification

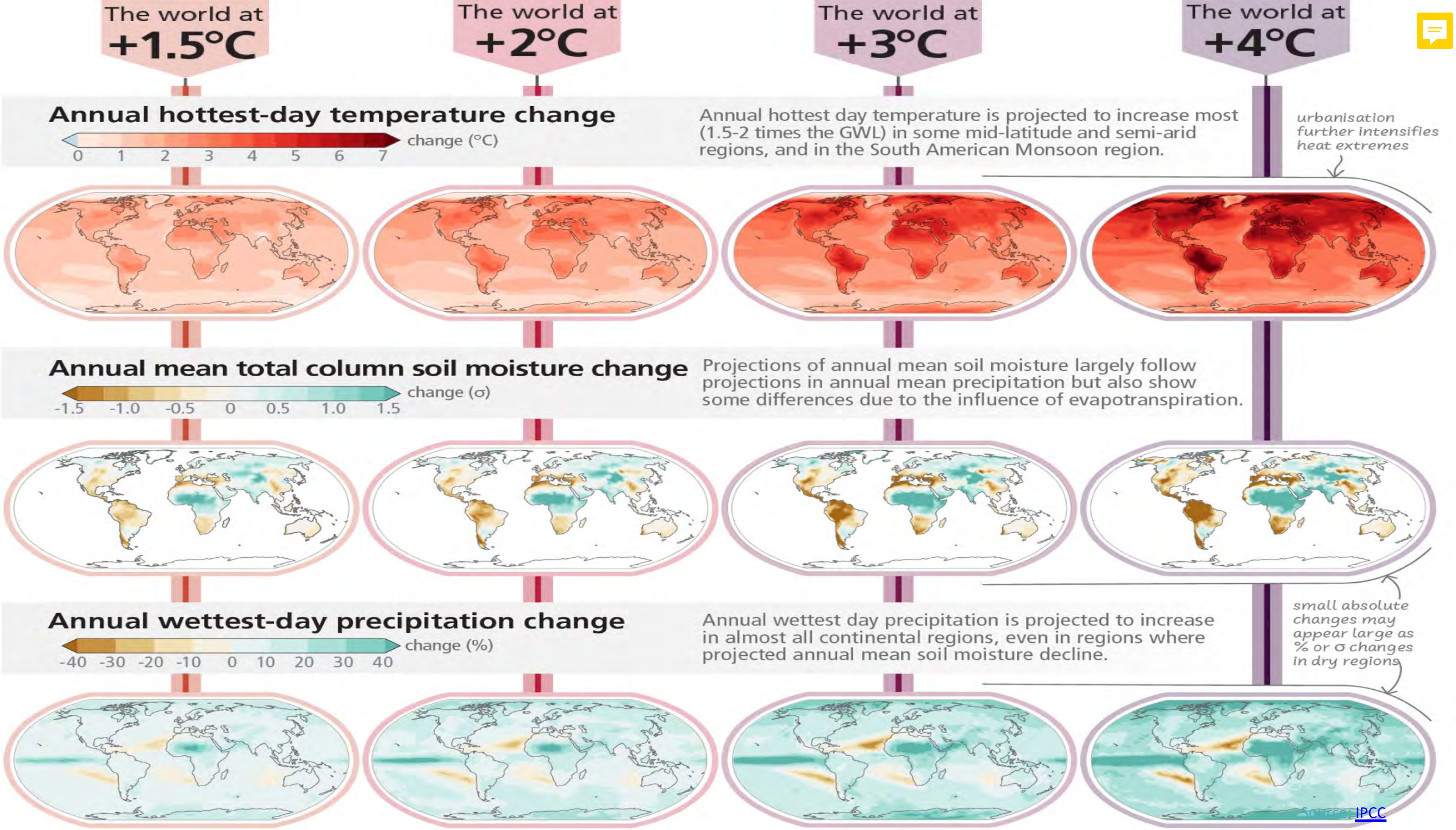
- Oceans absorb carbon dioxide ($CO_2$) which reacts with water ($H_2O$) to form carbonic acid ($H_2CO_3$). Acid lowers the pH of water.
- Acid dissolves shells and skeletons of marine species and slows shell formation. This impacts corals, oysters, clams, mussels, snails, phytoplankton and zooplankton.
- Oceans are 30% more acidic today than at the start of Industrial Revolution.




Sea butterfly shell dissolves in pH 7.8 seawater. This is the pH projected for the ocean in the year 2100. These species sit at the base of marine food chains.


Risk of species losses
Percentage of animal species and seagrasses exposed to potentially dangerous temperature conditions[1, 2]
0%
0.1
1
5
10
20
40
60
80
100%
1.5°C
2.0°C
3.0°C
4.0°C
[1]Projected temperature conditions above the estimated historical (1850-2005) maximum mean annual temperature experienced by each species, assuming no species relocation.
[2]Includes 30,652 species of birds, mammals, reptiles, amphibians, marine fish, benthic marine invertebrates, krill, cephalopods, corals, and seagrasses.
Heat-humidity risks to human health
0 days
1
10
50
100
150
200
250
300
365 days
Historical 1991–2005
1.7 – 2.3°C
2.4 – 3.1°C
4.2 – 5.4°C
Days per year where combined temperature and humidity conditions pose a risk of mortality to individuals[3]
[3]Projected regional impacts utilize a global threshold beyond which daily mean surface air temperature and relative humidity may induce hyperthermia that poses a risk of mortality. The duration and intensity of heatwaves are not presented here. Heat-related health outcomes vary by location and are highly moderated by socio-economic, occupational and other non-climatic determinants of individual health and socio-economic vulnerability. The threshold used in these maps is based on a single study that synthesized data from 783 cases to determine the relationship between heat-humidity conditions and mortality drawn largely from observations in temperate climates.

Source: IPCC

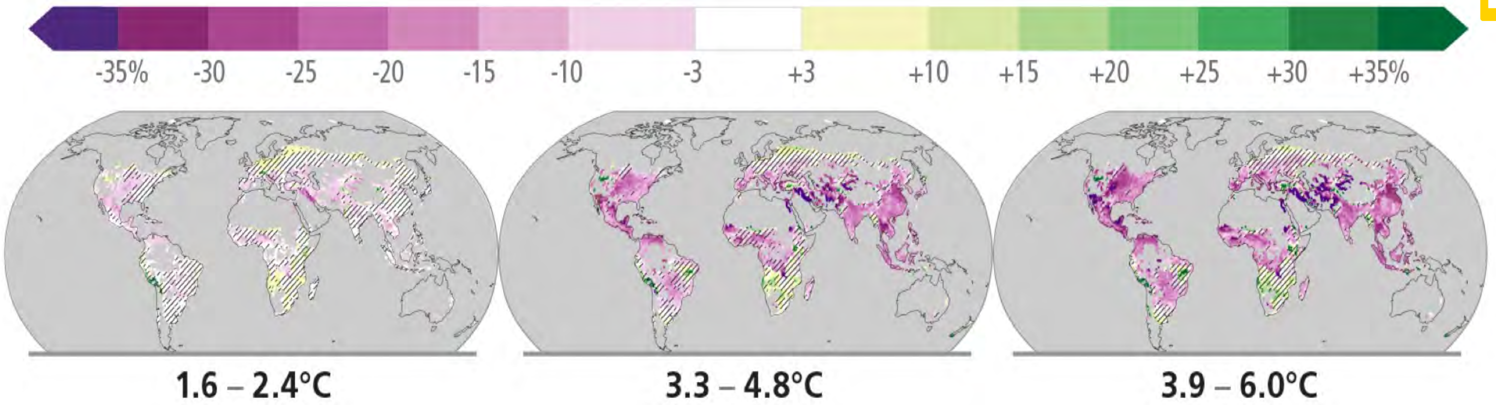

The world at +1.5°C
The world at +2°C
The world at +3°C
The world at +4°C
Annual hottest-day temperature change
change (°C)
0 1 2 3 4 5 6 7
Annual hottest day temperature is projected to increase most (1.5-2 times the GWL) in some mid-latitude and semi-arid regions, and in the South American Monsoon region.
urbanisation further intensifies heat extremes
Annual mean total column soil moisture change
change (σ)
-1.5 -1.0 -0.5 0 0.5 1.0 1.5
Projections of annual mean soil moisture largely follow projections in annual mean precipitation but also show some differences due to the influence of evapotranspiration.
Annual wettest-day precipitation change
change (%)
-40 -30 -20 -10 0 10 20 30 40
Annual wettest day precipitation is projected to increase in almost all continental regions, even in regions where projected annual mean soil moisture decline.
small absolute changes may appear large as % or σ changes in dry regions

Source: IPCC

# Food production impacts

## Maize yield[4]

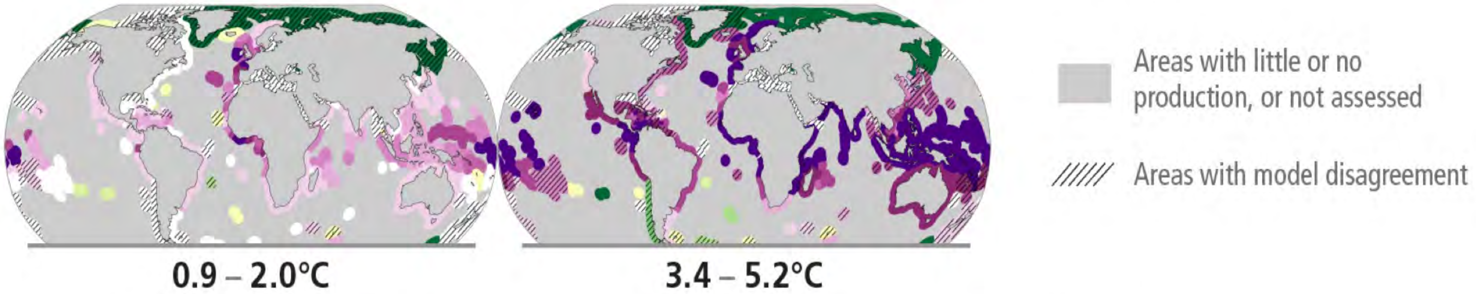
Changes (%) in yield




[4]Projected regional impacts reflect biophysical responses to changing temperature, precipitation, solar radiation, humidity, wind, and $CO_2$ enhancement of growth and water retention in currently cultivated areas. Models assume that irrigated areas are not water-limited. Models do not represent pests, diseases, future agro-technological changes and some extreme climate responses.

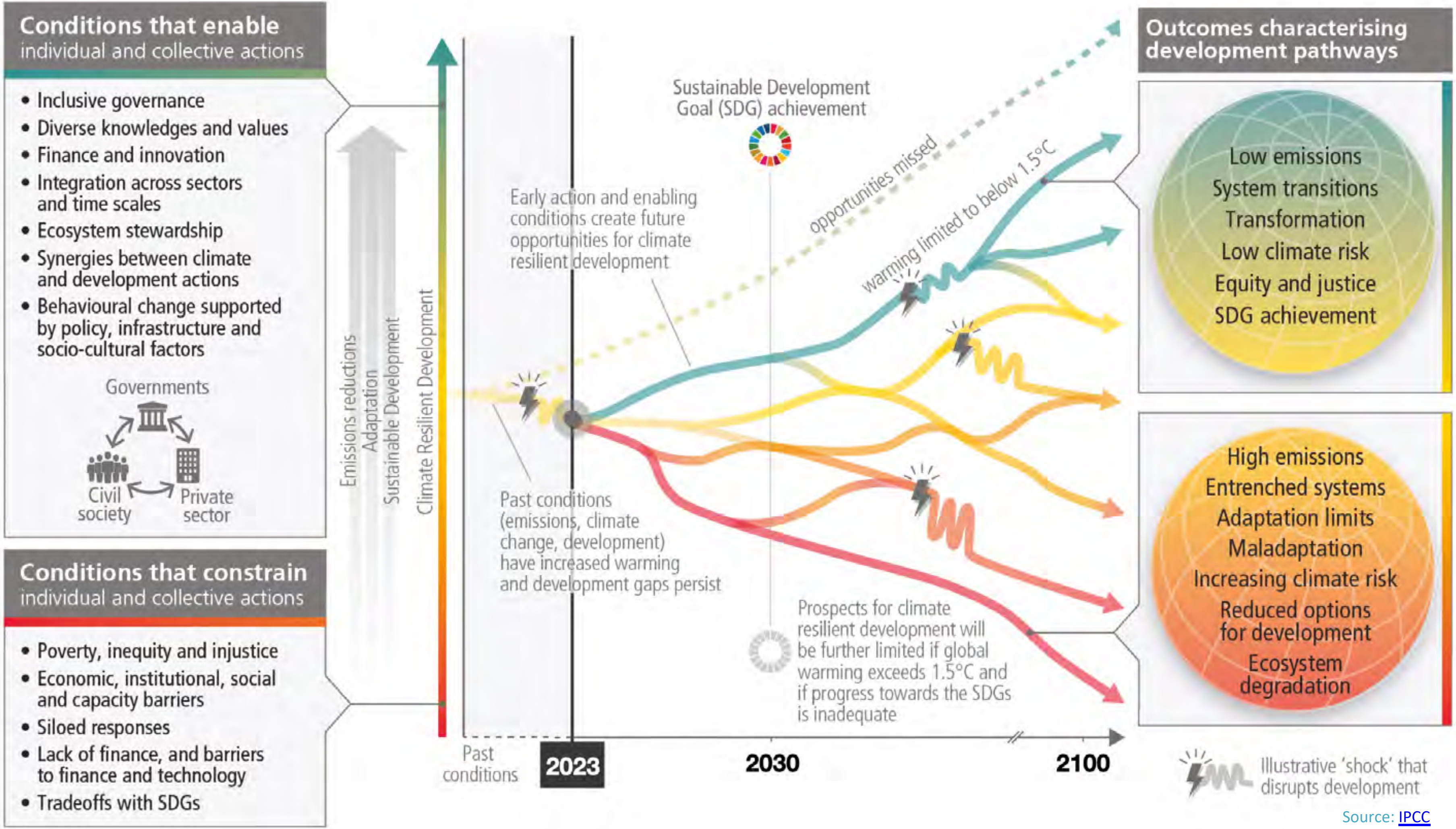
## Fisheries yield[5]

Changes (%) in maximum catch potential




[5]Projected regional impacts reflect fisheries and marine ecosystem responses to ocean physical and biogeochemical conditions such as temperature, oxygen level and net primary production. Models do not represent changes in fishing activities and some extreme climatic conditions. Projected changes in thea Arctic regions have low confidence due to uncertainties associated with modelling multiple interacting drivers and ecosystem responses.

Source: [IPCC]



Conditions that enable
individual and collective actions
Inclusive governance
Diverse knowledges and values
Finance and innovation
Integration across sectors and time scales
Ecosystem stewardship
Synergies between climate and development actions
Behavioural change supported by policy, infrastructure and socio-cultural factors
Governments
Civil society
Private sector
Conditions that constrain
individual and collective actions
Poverty, inequity and injustice
Economic, institutional, social and capacity barriers
Siloed responses
Lack of finance, and barriers to finance and technology
Tradeoffs with SDGs
Emissions reductions
Adaptation
Sustainable Development
Climate Resilient Development
Sustainable Development Goal (SDG) achievement
Early action and enabling conditions create future opportunities for climate resilient development
opportunities missed
warming limited to below 1.5°C
Past conditions (emissions, climate change, development) have increased warming and development gaps persist
Prospects for climate resilient development will be further limited if global warming exceeds 1.5°C and if progress towards the SDGs is inadequate
Past conditions
2023
2030
2100
Outcomes characterising development pathways
Low emissions
System transitions
Transformation
Low climate risk
Equity and justice
SDG achievement
High emissions
Entrenched systems
Adaptation limits
Maladaptation
Increasing climate risk
Reduced options for development
Ecosystem degradation
Illustrative 'shock' that disrupts development


Source: IPCC