ENERGY PRODUCTION

IB PHYSICS | COMPLETED NOTES

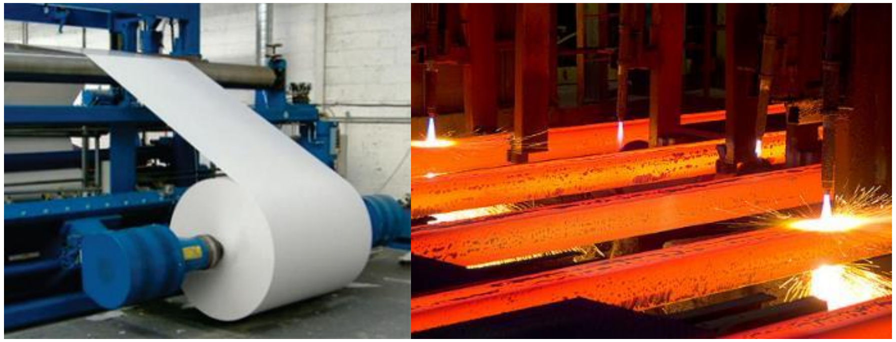
Energy Sources Overview

IB PHYSICS | ENERGY PRODUCTION

What is Energy Used For?

Residential/Commercial

Industrial



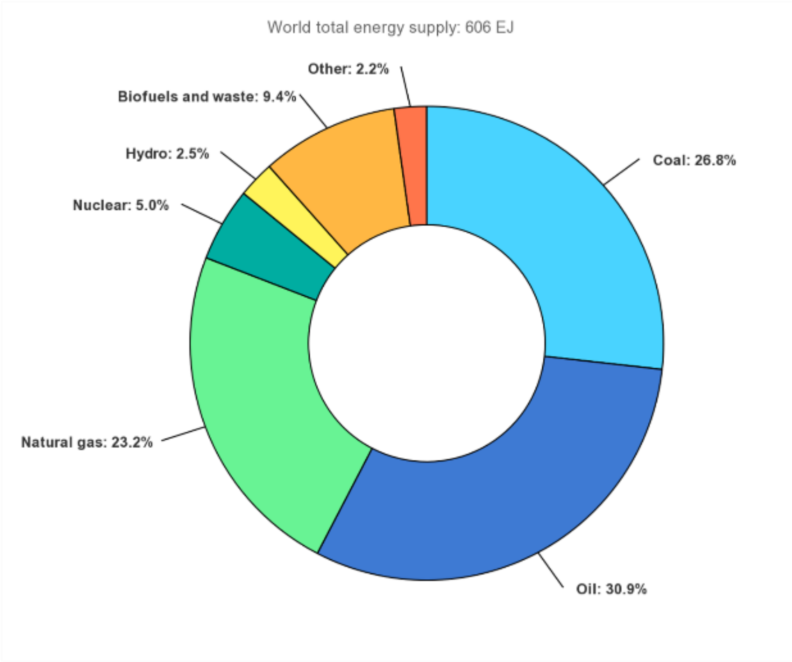
Electric Power

Transportation

Where does our Energy Come From?

World Sources

2019 Global Energy Supply

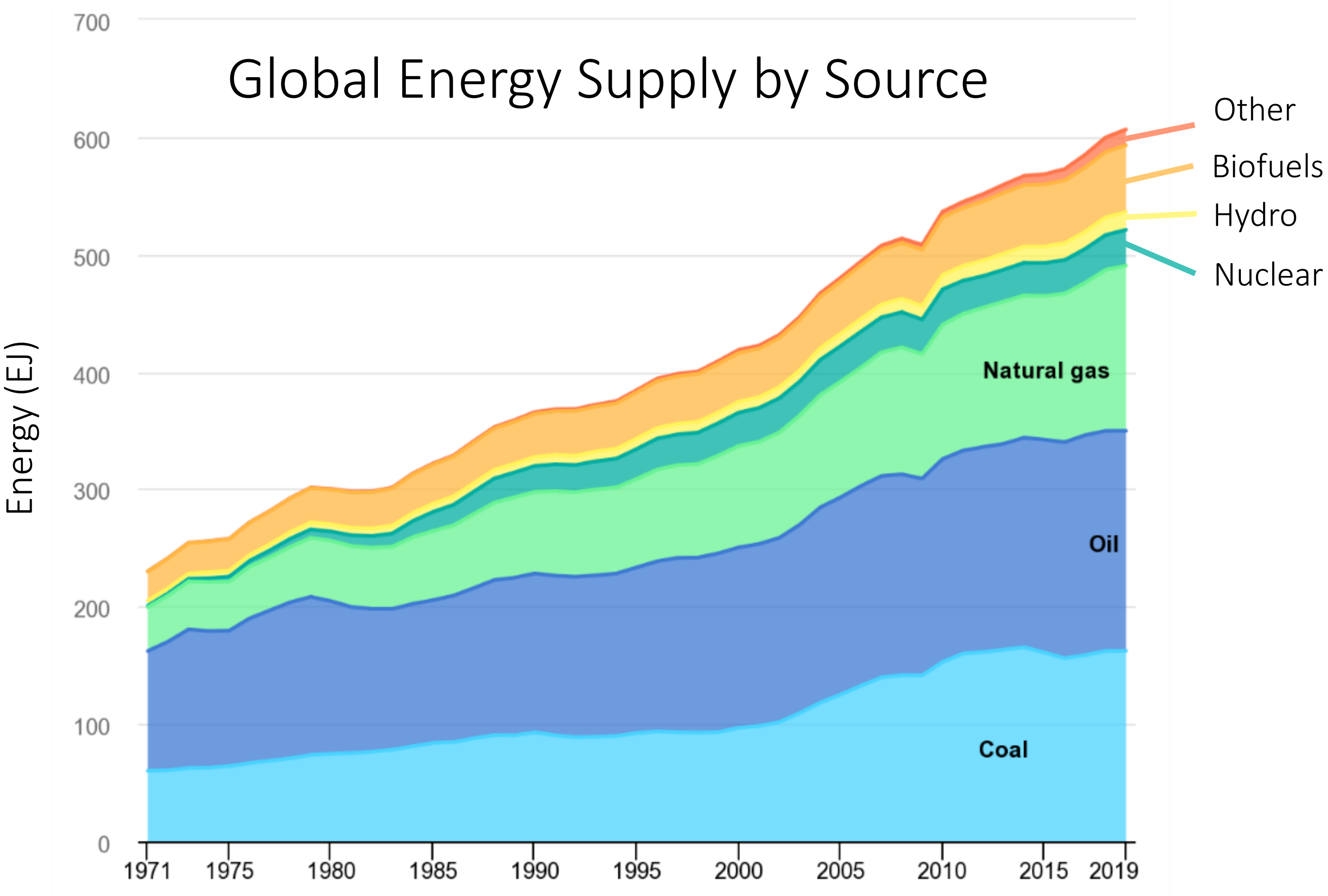


List Sources in Order:

Oil	~31%
Coal	~27%
Natural Gas	~23%
Biofuels	~9%
Nuclear	~5%
Hydropower	~2.5%

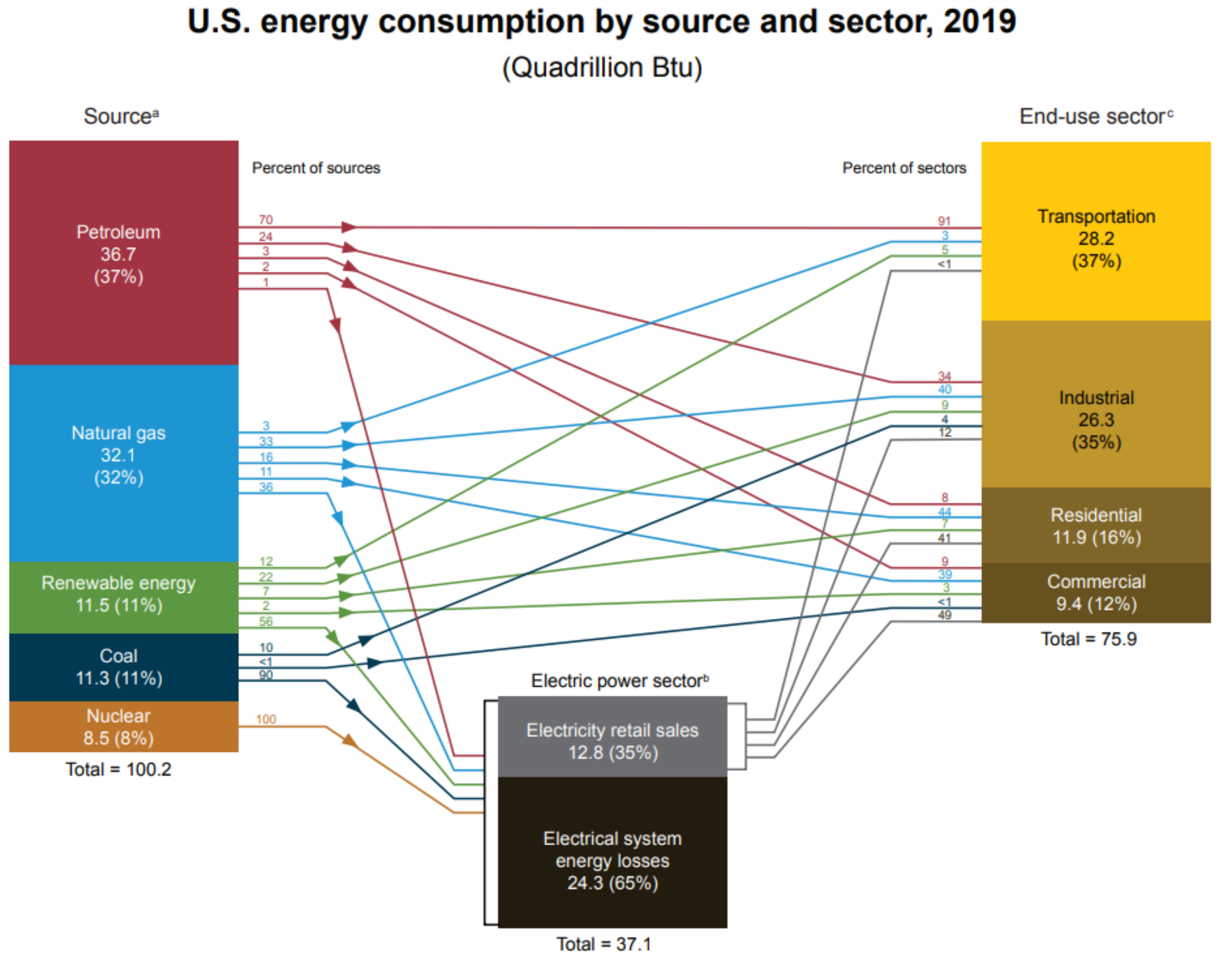
IEA, Global share of total energy supply by source, 2019, IEA, Paris
https://www.iea.org/data-and-statistics/charts/global-share-of-total-energy-supply-by-source-2019

This changes over time



IEA, World total energy supply by source, 1971-2019, IEA, Paris
https://www.iea.org/data-and-statistics/charts/world-total-energy-supply-by-source-1971-2019

Used in Many Ways…



U.S. energy consumption by source and sector, 2019

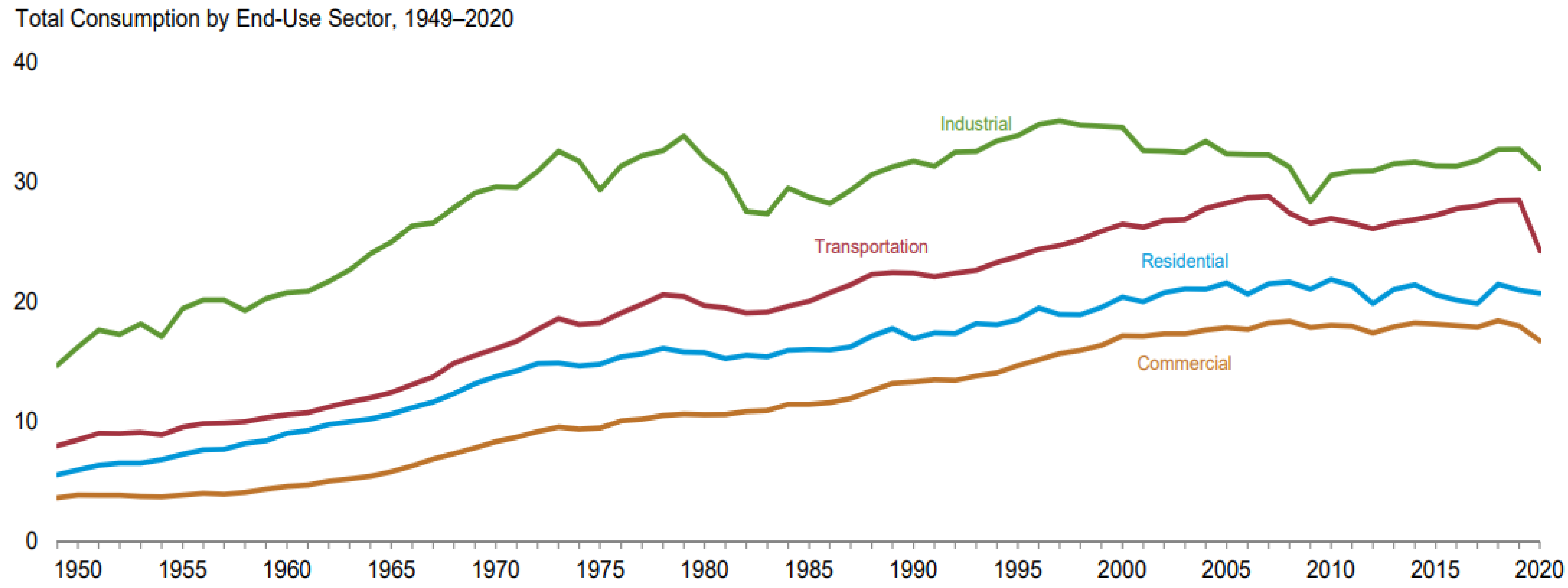
(Quadrillion Btu)

https://www.eia.gov/totalenergy/data/monthly/pdf/flow/css_2019_energy.pdf

Used in Many Ways…

Figure 2.1 Energy Consumption by Sector

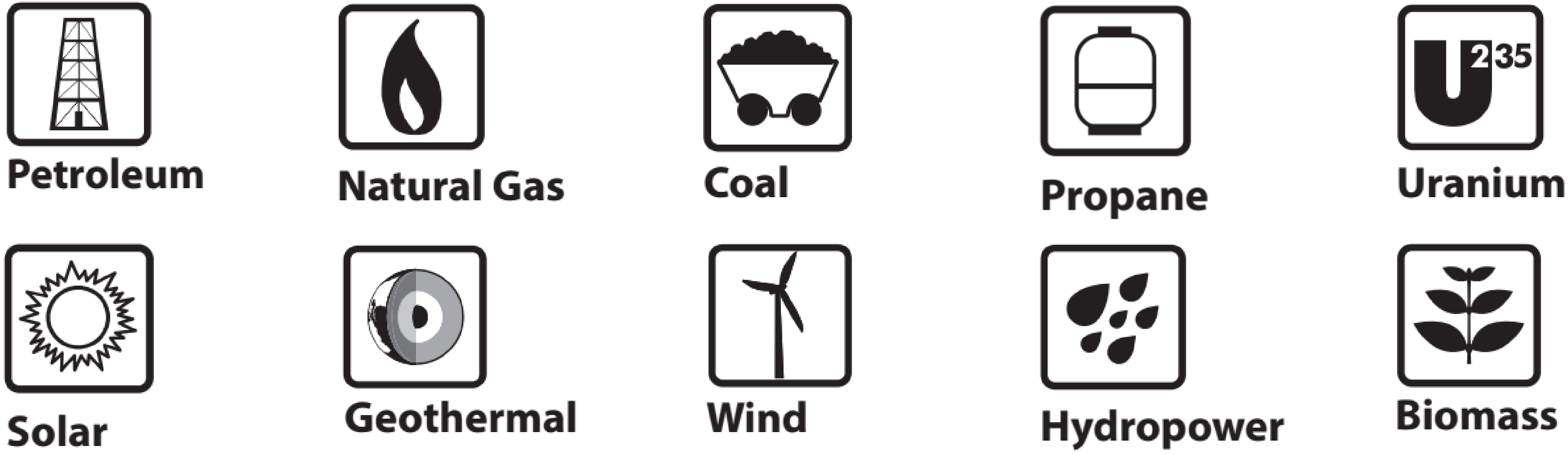
(Quadrillion Btu)



https://www.eia.gov/totalenergy/data/monthly/pdf/mer.pdf

Primary vs. Secondary Sources

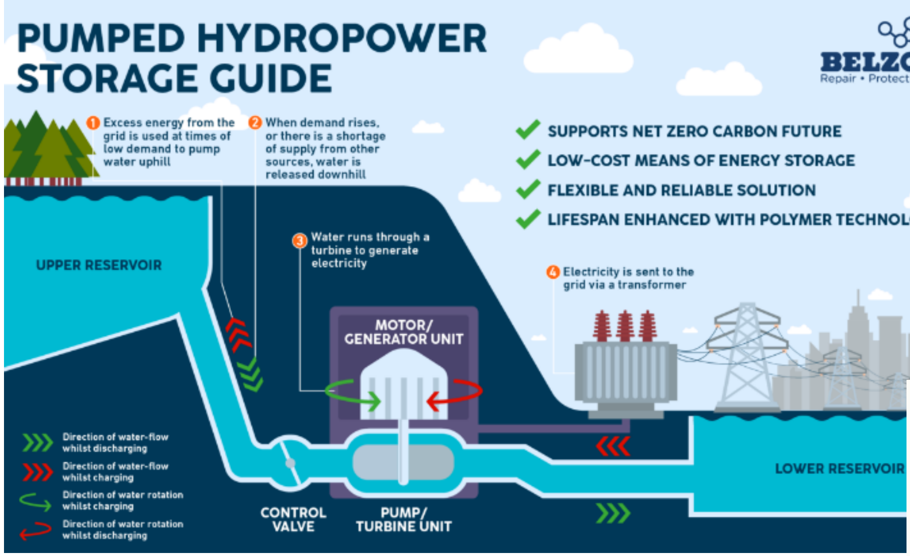
Primary energy sources are sources found in the natural environment



Secondary energy sources are useful transformations of the primary sources. (typically used to **store** energy)

Electricity – Batteries, Stored Hydropower

Other Secondary Sources…



PUMPED HYDROPOWER STORAGE GUIDE

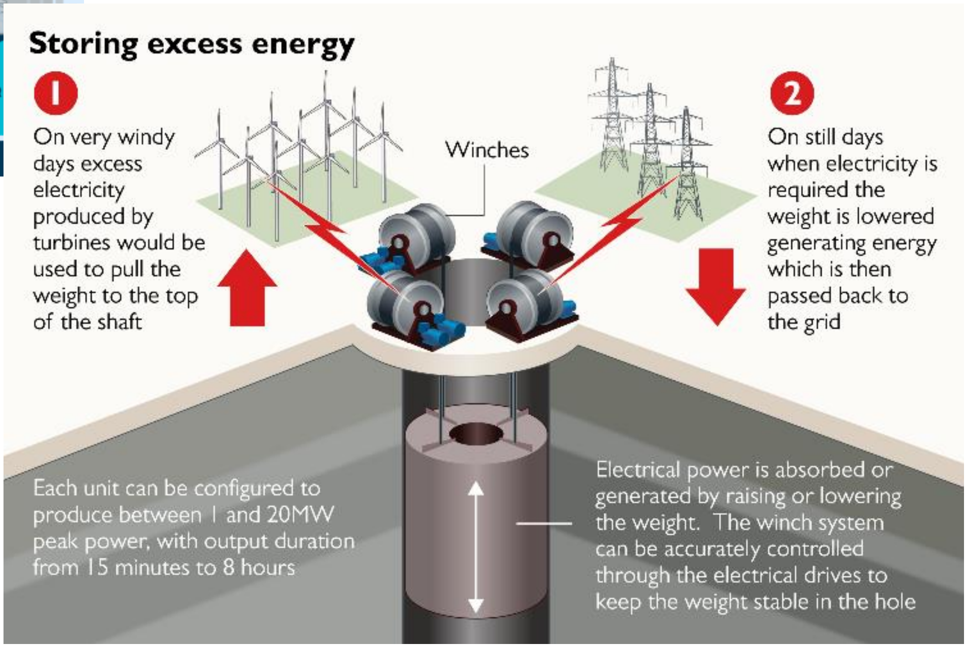
① Excess energy from the grid is used at times of low demand to pump water uphill

② When demand rises, or there is a shortage of supply from other sources, water is released downhill

③ Water runs through a turbine to generate electricity

④ Electricity is sent to the grid via a transformer

- ✓ SUPPORTS NET ZERO CARBON FUTURE
- ✓ LOW-COST MEANS OF ENERGY STORAGE
- ✓ FLEXIBLE AND RELIABLE SOLUTION
- ✓ LIFESPAN ENHANCED WITH POLYMER TECHNOLOGY



Storing excess energy

① On very windy days excess electricity produced by turbines would be used to pull the weight to the top of the shaft

② On still days when electricity is required the weight is lowered generating energy which is then passed back to the grid

Each unit can be configured to produce between 1 and 20MW peak power, with output duration from 15 minutes to 8 hours

Electrical power is absorbed or generated by raising or lowering the weight. The winch system can be accurately controlled through the electrical drives to keep the weight stable in the hole

What is the Ultimate Primary Source?

The Sun

Which one is the best?

That’s a hard question and depends on many factors

Some of the big ones are:
- Energy Density
- Cost
- Availability and Location
- Politics
- Safety
- Environmental

U.S. Electricity Generation

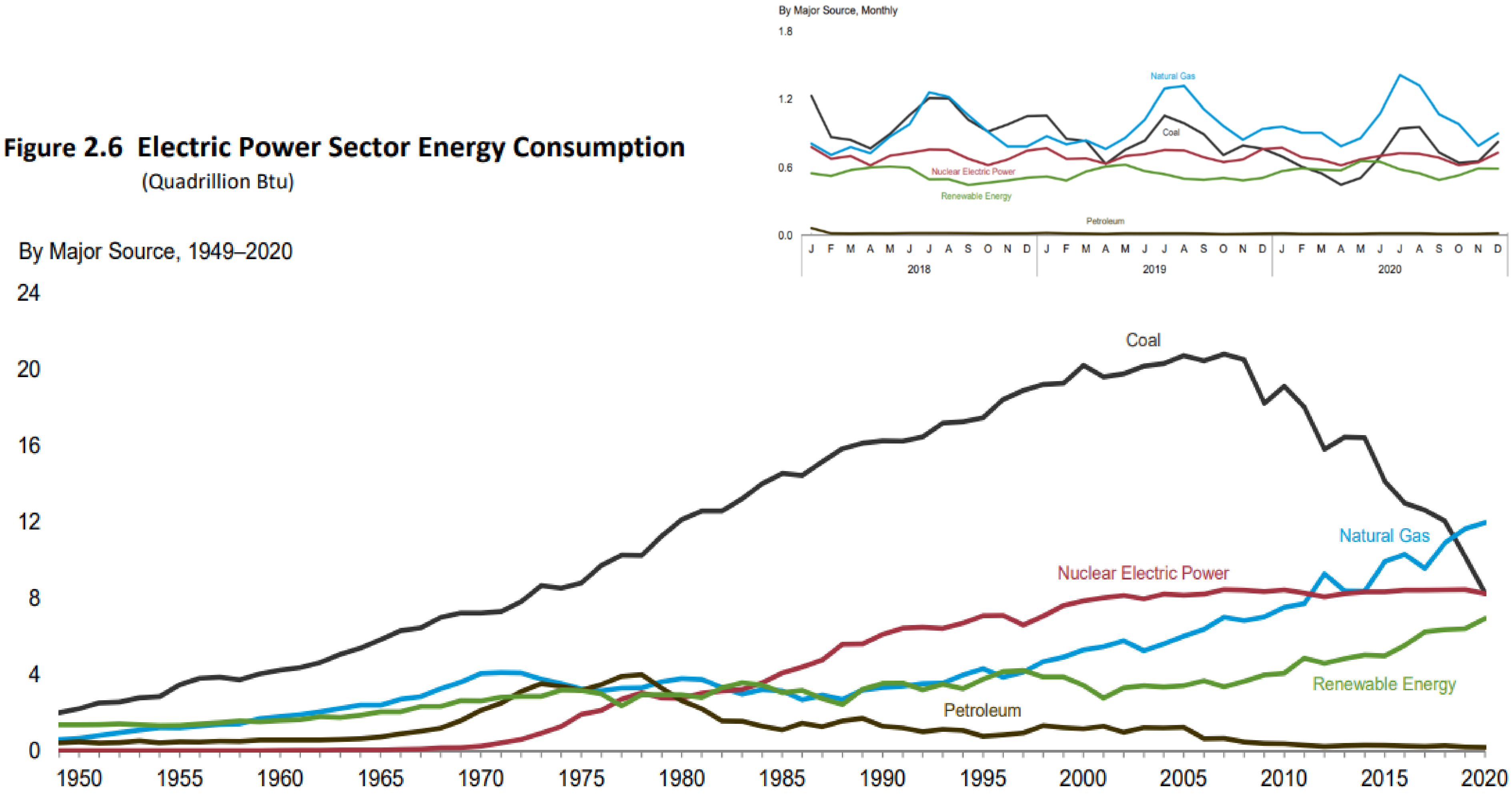
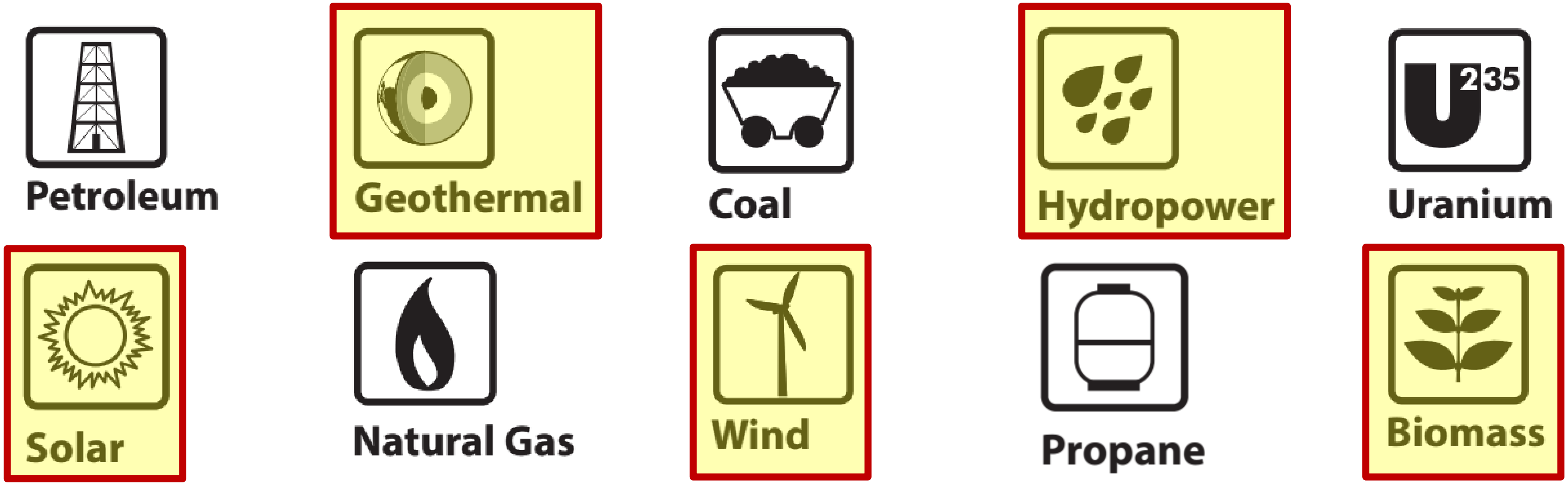


Figure 2.6 Electric Power Sector Energy Consumption
(Quadrillion Btu)

https://www.eia.gov/totalenergy/data/monthly/pdf/mer.pdf

Renewable vs. Non Renewable

Highlight the primary energy sources that are considered renewable



Petroleum

Geothermal

Coal

Hydropower

Uranium

Solar

Natural Gas

Wind

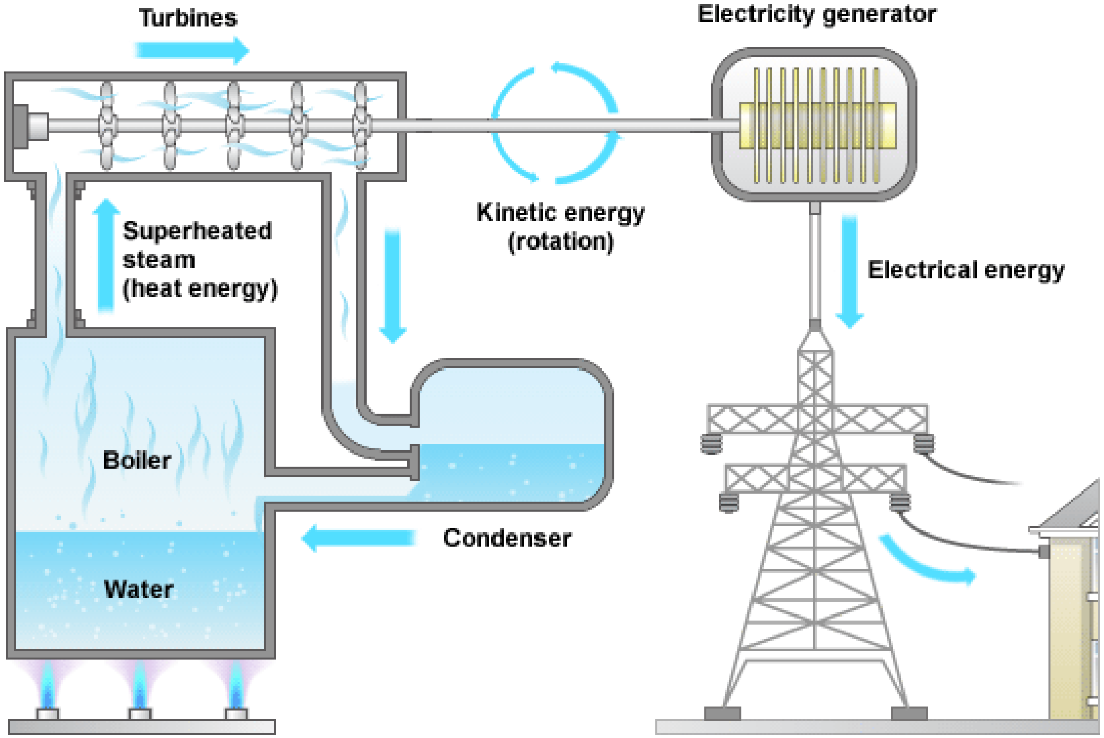
Propane

Biomass

*Note: this doesn't mean that it cannot **ever** be replaced, just that it won't happen in any sort of useful time frame…

Efficiency

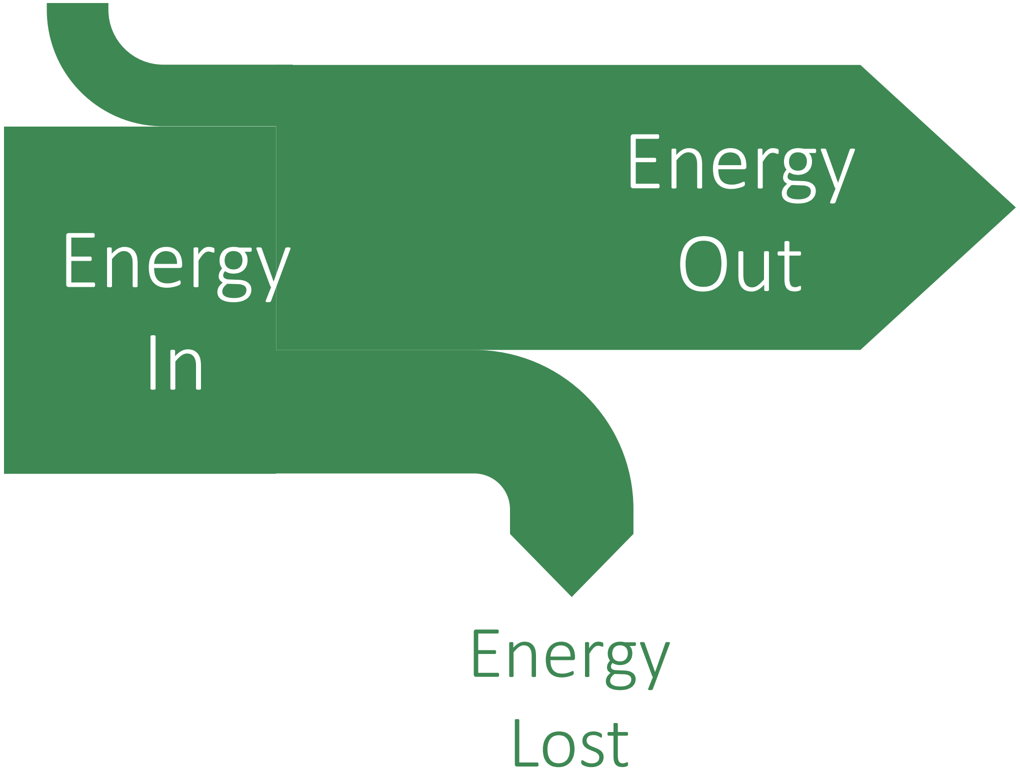
Almost every energy source has the same general path



Sankey Diagram

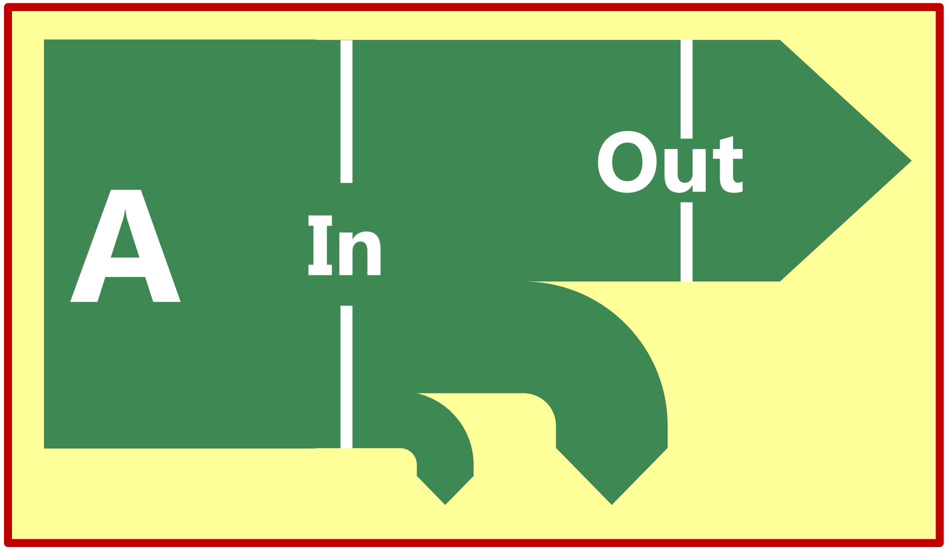
Sometimes it's easiest to represent energy flow in a picture.

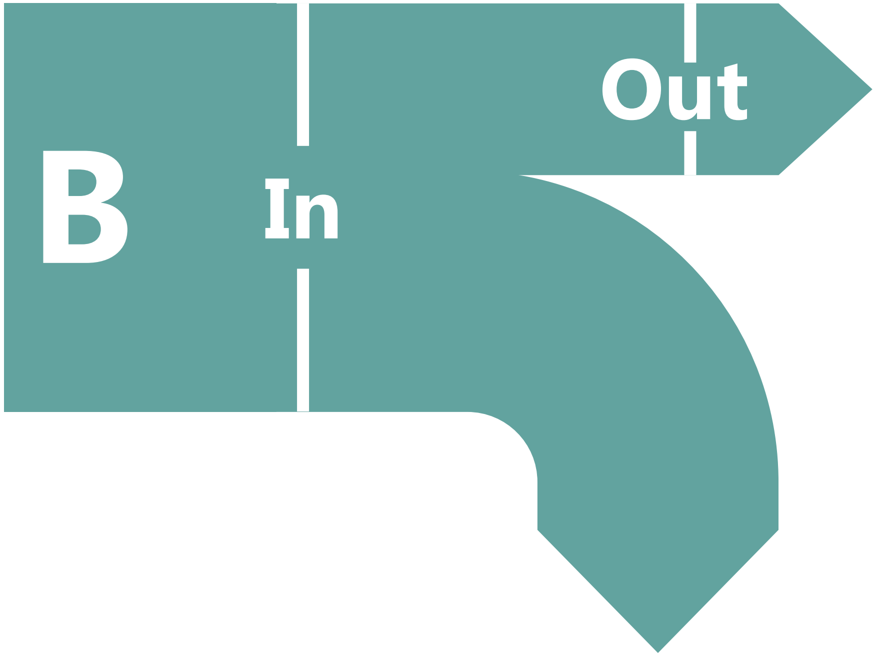
In these diagrams the width of the arrow represents the amount of energy



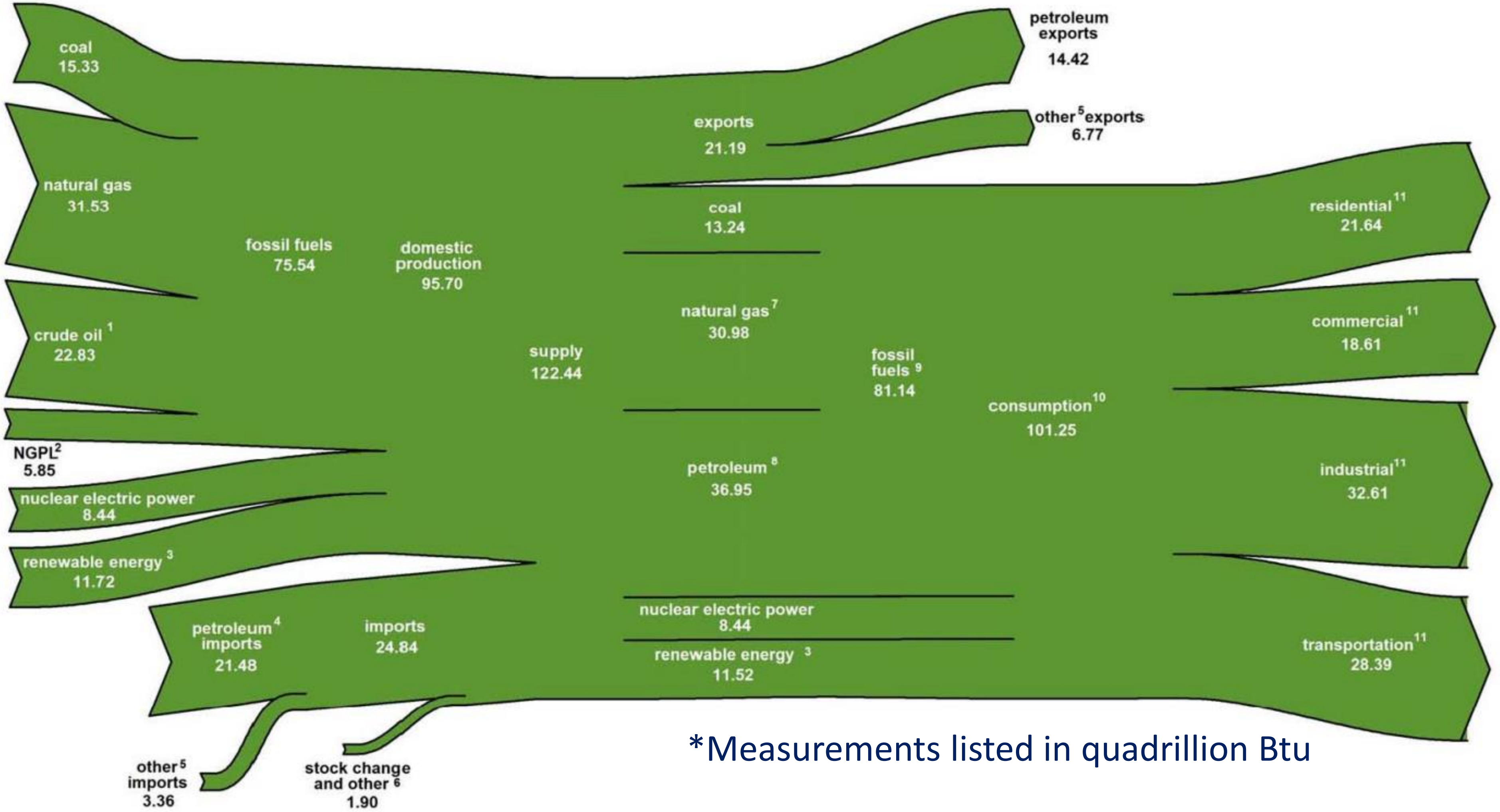
Sankey Diagrams

Which process is more efficient?





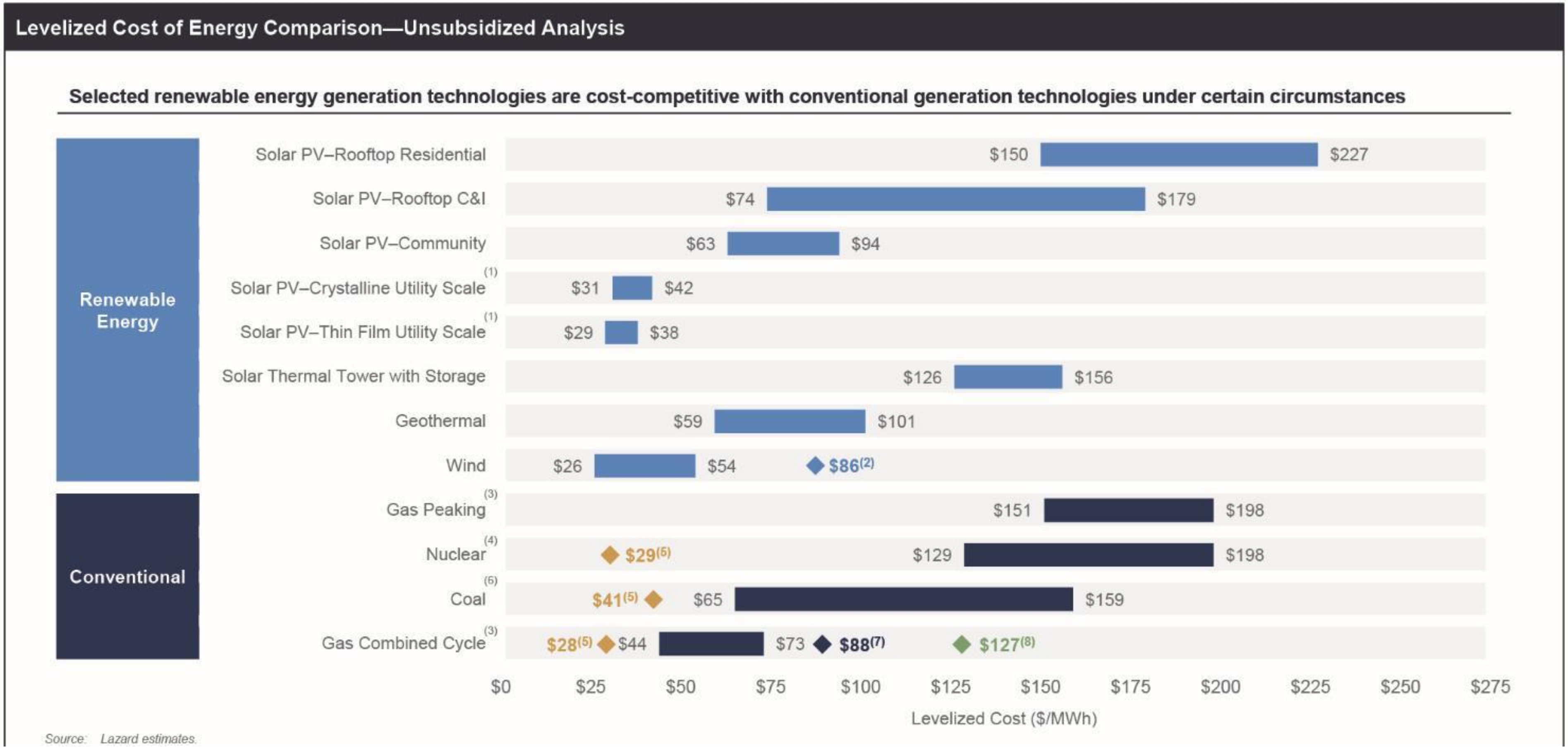
U.S. Energy Flow 2018



*Measurements listed in quadrillion Btu

https://www.eia.gov/totalenergy/data/monthly/pdf/flow/total_energy.pdf

Cost

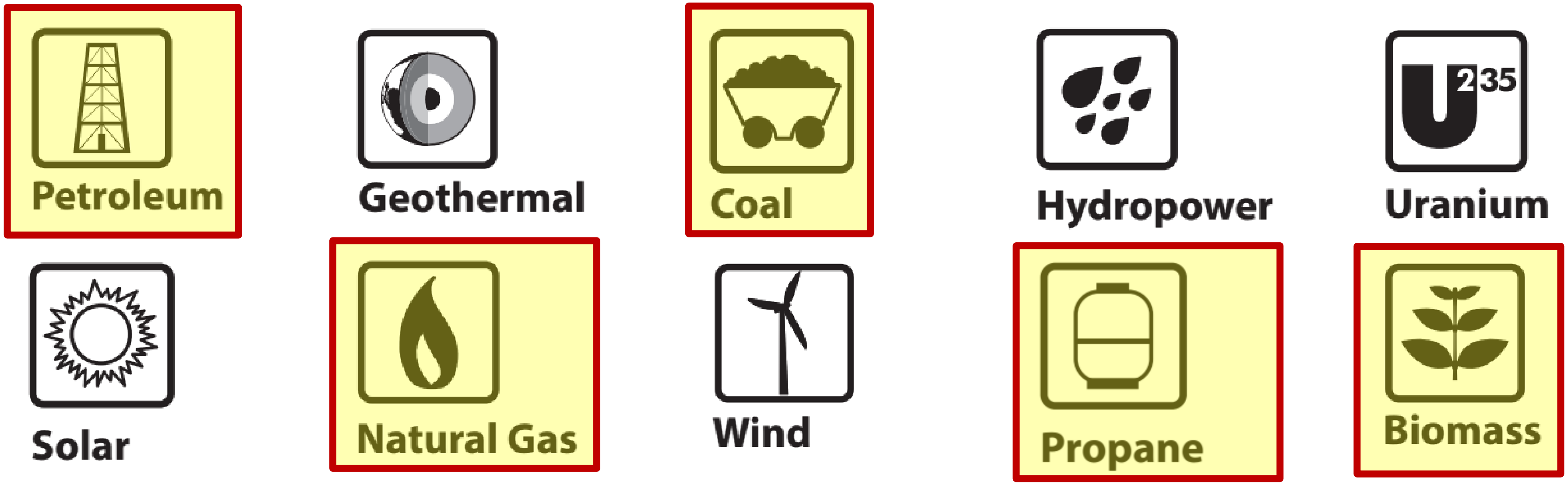


Source: *Lazard estimates.*

https://www.lazard.com/perspective/lcoe2020

CO_2 Emissions

Highlight the primary energy sources that are produce Carbon Dioxide

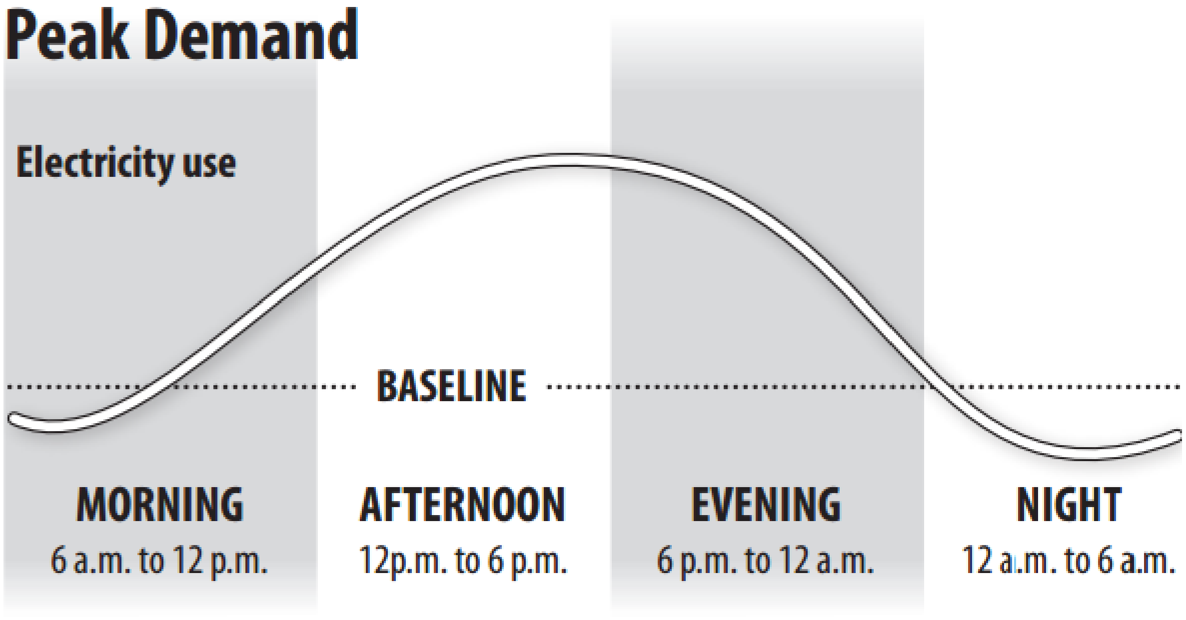


*Note: this is just one of several greenhouse gases. We’ll discuss this.

Location Dependency and Politics

Energy Load Requirements

Energy needs to be available when electricity is most needed but should also be available other times as well.



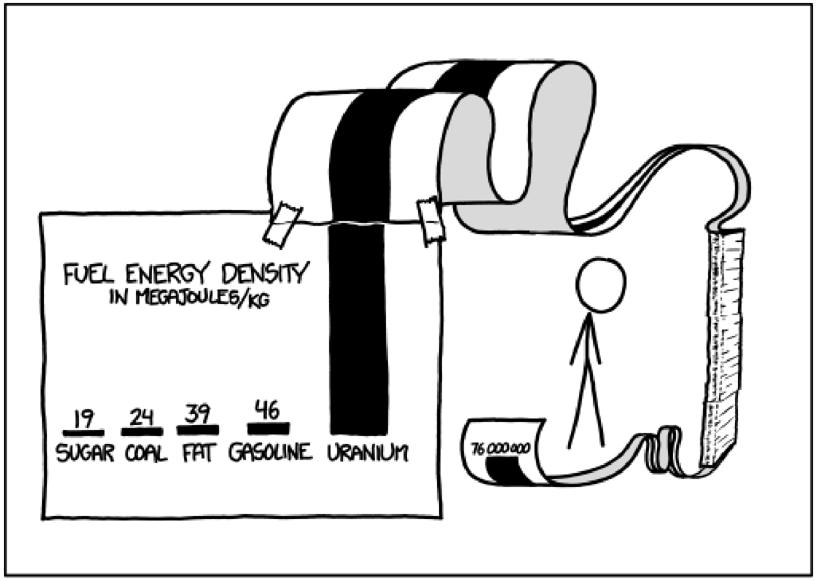
Energy Density

Specific Energy = Energy per Unit Mass [J kg^{-1}]

Energy Density = Energy per Unit Volume [J m^{-3}]

$$E_S = \frac{E}{m}$$

$$E_D = \frac{E}{V}$$



SCIENCE TIP: LOG SCALES ARE FOR QUITTERS WHO CAN'T FIND ENOUGH PAPER TO MAKE THEIR POINT *PROPERLY*.

Energy Density

Material	Specific Energy / MJ kg^{-1}	Energy Density / MJ m^{-3}
Uranium – (Nuclear Fission)	83,000,000	15,000,000,000,000
Natural Gas (Methane)	54	37
Gasoline/Petrol	46	34,000
Crude Oil	42	36,500
Coal	32	23,000
Ethanol	30	21,000
Wood	17	Varies
Average Food	17	Varies

Why are **Specific Energy** and **Energy Density** important?

Higher energy density lowers transportation and storage costs

Power and Energy

Energy	**Power**
Joules [J]	Watts [W]

How are these quantities related?

$$1\ \mathrm{W} = 1\ \frac{\mathrm{J}}{\mathrm{s}}$$

Energy Density

How much coal must be supplied per day to run a 500 MW power plant at 30% efficiency? (Specific Energy of coal is 32 MJ kg^{-1})

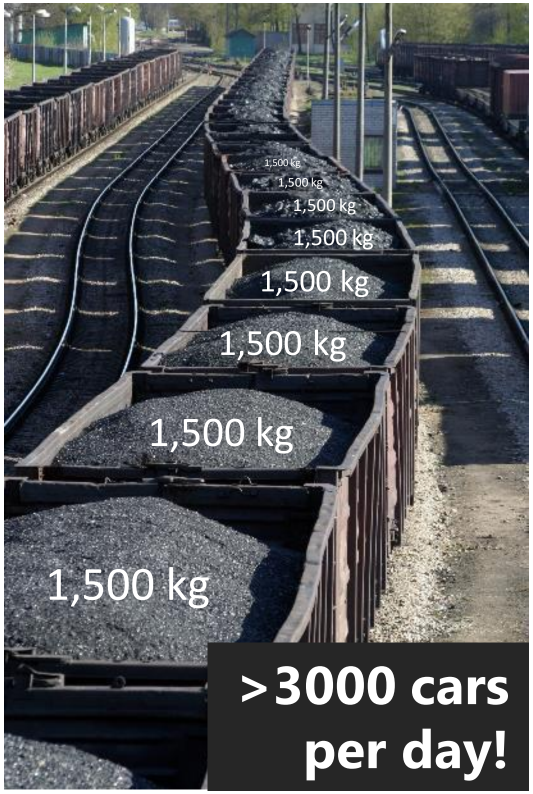
30% efficient

$$E_{in} \times 0.3 = 500\ \frac{\text{MJ}}{\text{s}}$$

$$E_{in} = 1{,}700\ \frac{\text{MJ}}{\text{s}}$$

$$\frac{1{,}700\ \text{MJ}}{1\ \text{s}} \times \frac{1\ \text{kg}}{32\ \text{MJ}} = 53.1\ \frac{\text{kg}}{\text{s}}$$

$$\boxed{\sim 4{,}600{,}000\ \frac{\text{kg}}{\text{day}}}$$



>3000 cars per day!

How many train cars per day?

Energy Density

If a nuclear power plant powered by uranium-235 (83,000,000 MJ kg^{-1}) has the same output (500 MW) and the same efficiency (30%) as the coal-fired plant of the previous example, how many kg of nuclear fuel will it burn per day? Per year?

30% efficient

$$E_{in} \times 0.3 = 500\,\frac{\text{MJ}}{\text{s}}$$

$$E_{in} = 1{,}700\,\frac{\text{MJ}}{\text{s}}$$

$$\frac{1{,}700\ \text{MJ}}{1\ \text{s}} \times \frac{1\ \text{kg}}{83{,}000{,}000\ \text{MJ}} = 0.00002\,\frac{\text{kg}}{\text{s}}$$

$$\boxed{\sim 646\,\frac{\textbf{kg}}{\textbf{year}}} \Leftarrow \boxed{\sim 1.77\,\frac{\textbf{kg}}{\textbf{day}}}$$

Nuclear Power

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Remember Binding Energy per Nucleon?

Nuclide	# of p	# of n	Nucleus Mass
Iodine-**127**	**53**	**74**	**126.87544u**

m_e	0.000549u
m_p	1.007276u
m_n	1.008665u
1u	931.5 MeV c^{-2}

53 × 1.007276 u

74 × 1.008665 u

$$128.026838\text{u} - 126.87544\text{u} = 1.15140\text{u}$$

Mass Defect

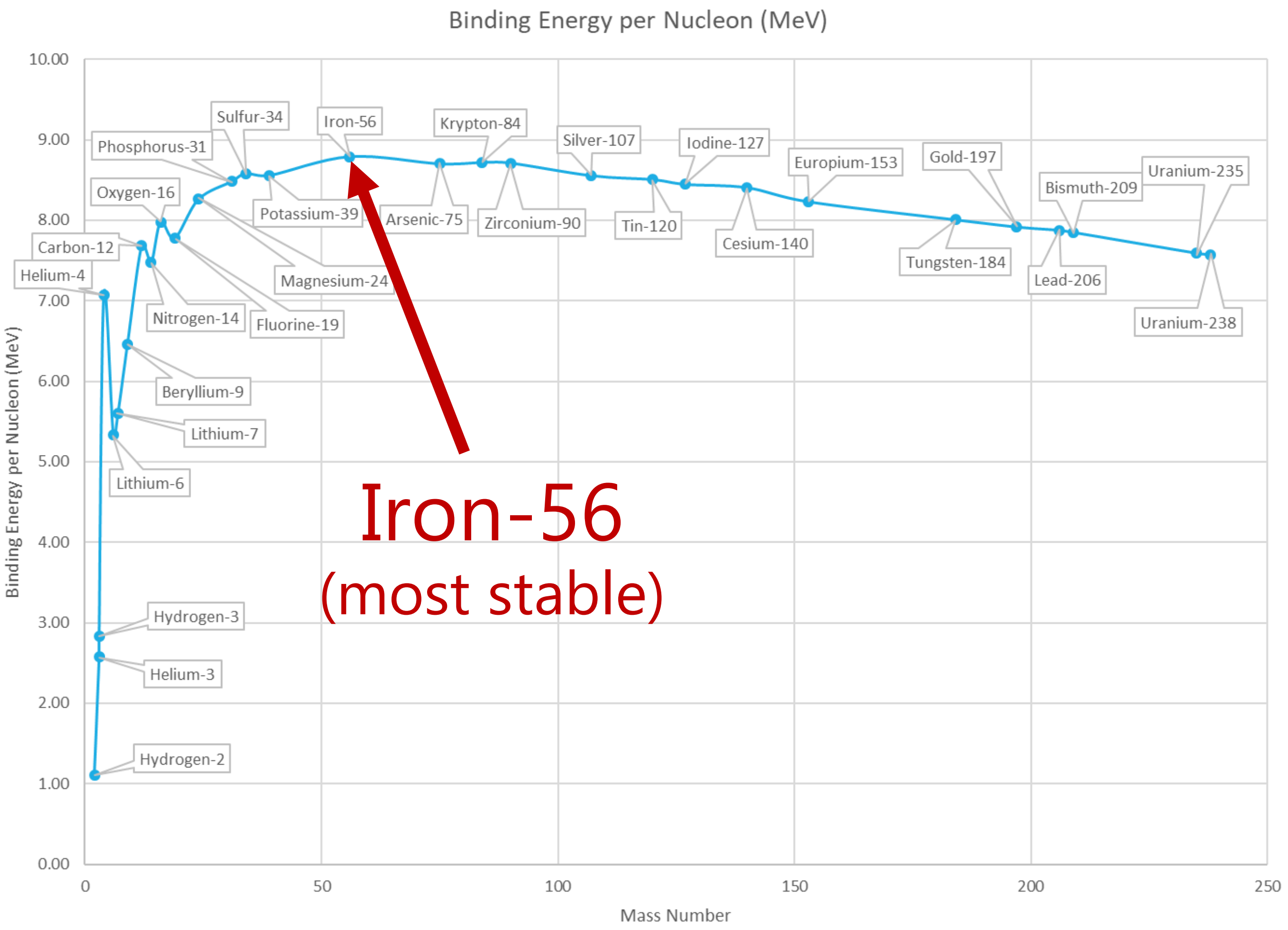
$$1.15140\ u \times \frac{931.5\ MeV\ c^{-2}}{1\ u} = 1072.53\ MeV\ c^{-2}$$

Convert mass to MeV c^{-2}

$$E = mc^2 = (1072.53\ MeV\ \cancel{c^{-2}})\cancel{c^2} = 1072.53\ MeV$$

$$1072.53\ MeV / 127 = \boxed{\mathbf{8.45\ MeV\ per\ Nucleon}}$$

Binding Energy per Nucleon

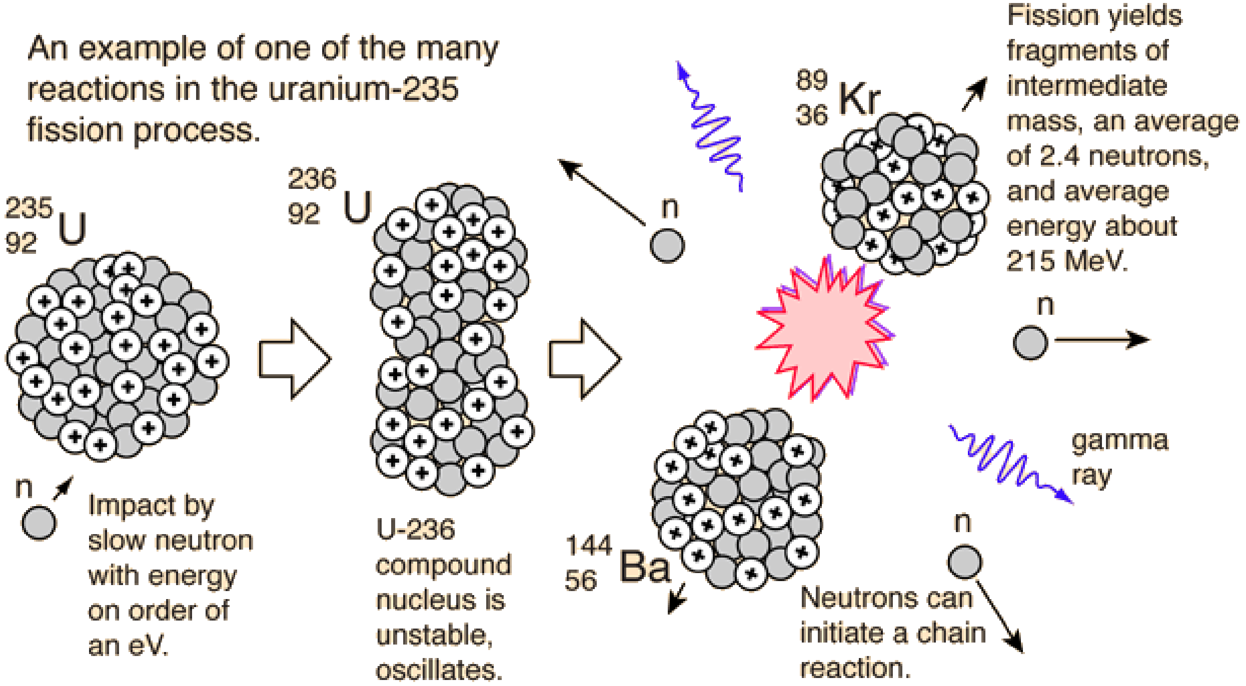


Iron-56

(most stable)

Fission

$${}^{1}_{0}\mathrm{n} + {}^{235}_{92}\mathrm{U} \rightarrow {}^{236}_{92}\mathrm{U} \rightarrow {}^{144}_{56}\mathrm{Ba} + {}^{89}_{36}\mathrm{Kr} + \underline{\;3\;}\,{}^{1}_{0}\mathrm{n}$$



An example of one of the many reactions in the uranium-235 fission process.

Impact by slow neutron with energy on order of an eV.

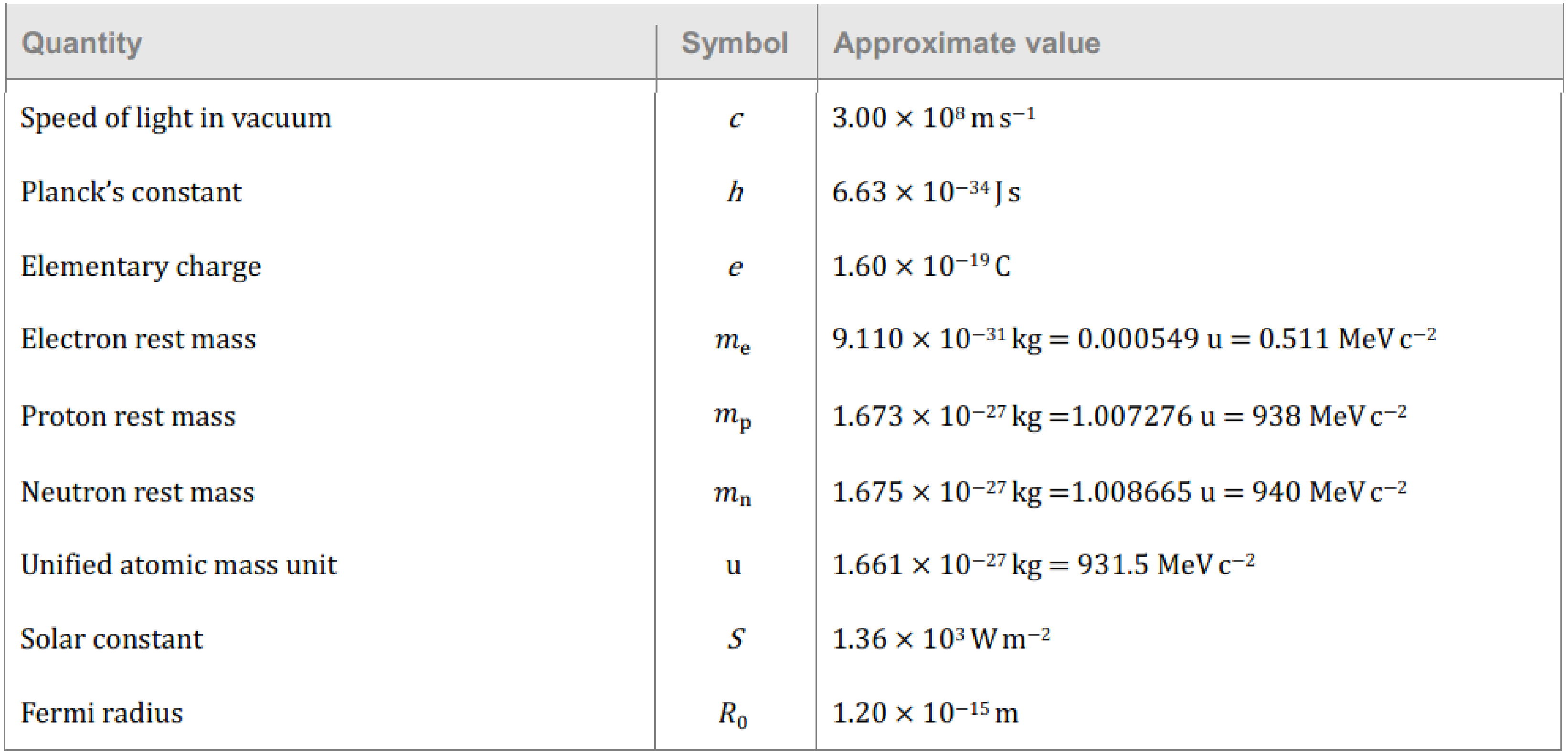
U-236 compound nucleus is unstable, oscillates.

Fission yields fragments of intermediate mass, an average of 2.4 neutrons, and average energy about 215 MeV.

Neutrons can initiate a chain reaction.

IB Physics Data Booklet

Fundamental constants



Quantity	Symbol	Approximate value
Speed of light in vacuum	c	$3.00 \times 10^{8}\,\mathrm{m\,s^{-1}}$
Planck's constant	h	$6.63 \times 10^{-34}\,\mathrm{J\,s}$
Elementary charge	e	$1.60 \times 10^{-19}\,\mathrm{C}$
Electron rest mass	m_{e}	$9.110 \times 10^{-31}\,\mathrm{kg} = 0.000549\,\mathrm{u} = 0.511\,\mathrm{MeV\,c^{-2}}$
Proton rest mass	m_{p}	$1.673 \times 10^{-27}\,\mathrm{kg} = 1.007276\,\mathrm{u} = 938\,\mathrm{MeV\,c^{-2}}$
Neutron rest mass	m_{n}	$1.675 \times 10^{-27}\,\mathrm{kg} = 1.008665\,\mathrm{u} = 940\,\mathrm{MeV\,c^{-2}}$
Unified atomic mass unit	u	$1.661 \times 10^{-27}\,\mathrm{kg} = 931.5\,\mathrm{MeV\,c^{-2}}$
Solar constant	S	$1.36 \times 10^{3}\,\mathrm{W\,m^{-2}}$
Fermi radius	R_0	$1.20 \times 10^{-15}\,\mathrm{m}$

Fission

$$ {}^{1}_{0}\mathrm{n} + {}^{235}_{92}\mathrm{U} \rightarrow {}^{93}_{37}\mathrm{Rb} + {}^{141}_{55}\mathrm{Cs} + 2\,{}^{1}_{0}\mathrm{n} + {}^{0}_{0}\gamma $$

1.675 × 10^{-27} kg	390.173 × 10^{-27} kg	154.248 × 10^{-27} kg	233.927 × 10^{-27} kg	2 × 1.675 × 10^{-27} kg

391.848 × 10^{-27} kg $>$ 391.525 × 10^{-27} kg

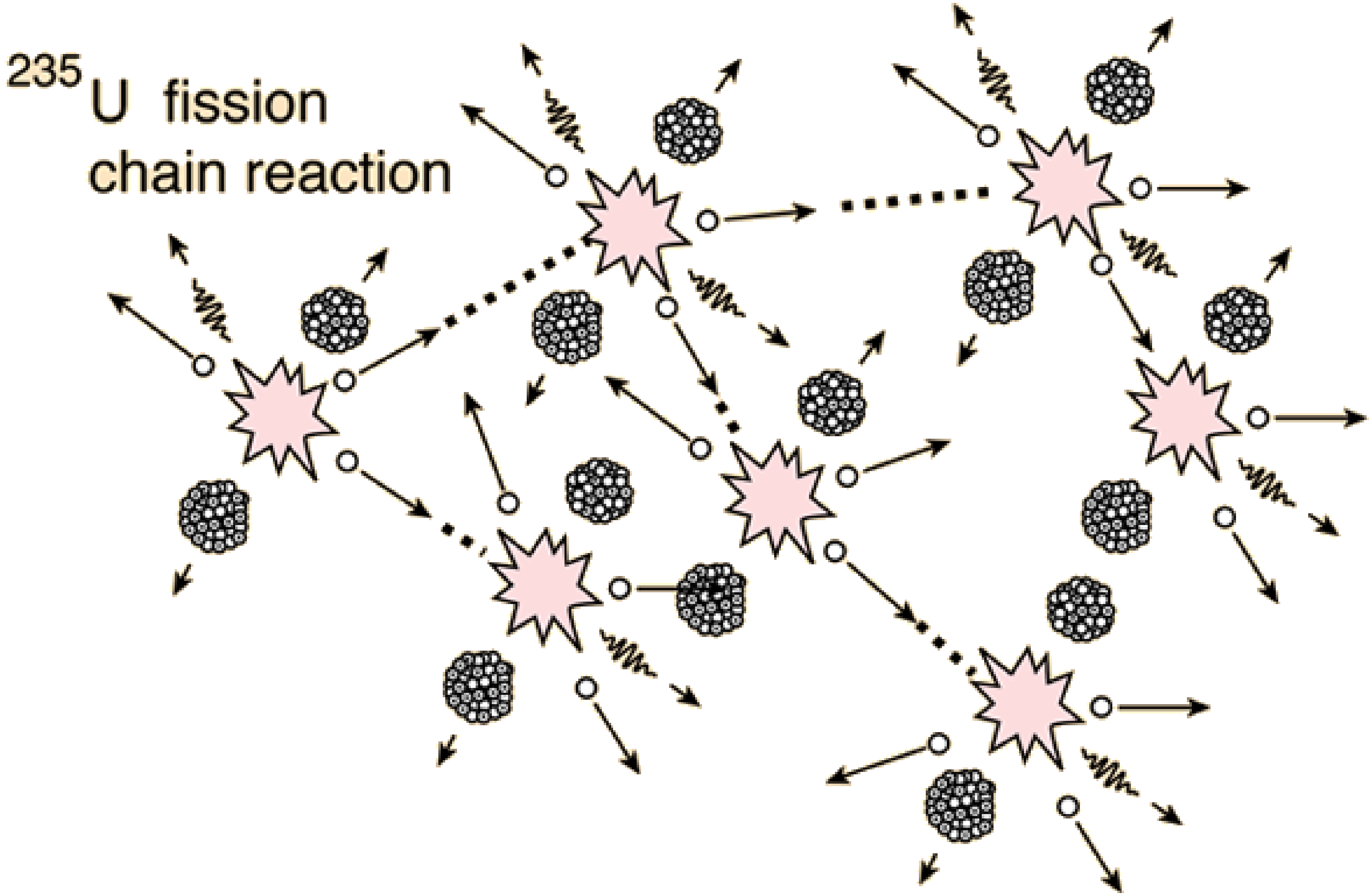
391.848 × 10^{-27} kg - 391.525 × 10^{-27} kg = 0.323 × 10^{-27} kg

$$0.323 \times 10^{-27}\,kg \times \frac{1\,u}{1.661 \times 10^{-27}\,kg} = \mathbf{0.19446\,u}$$

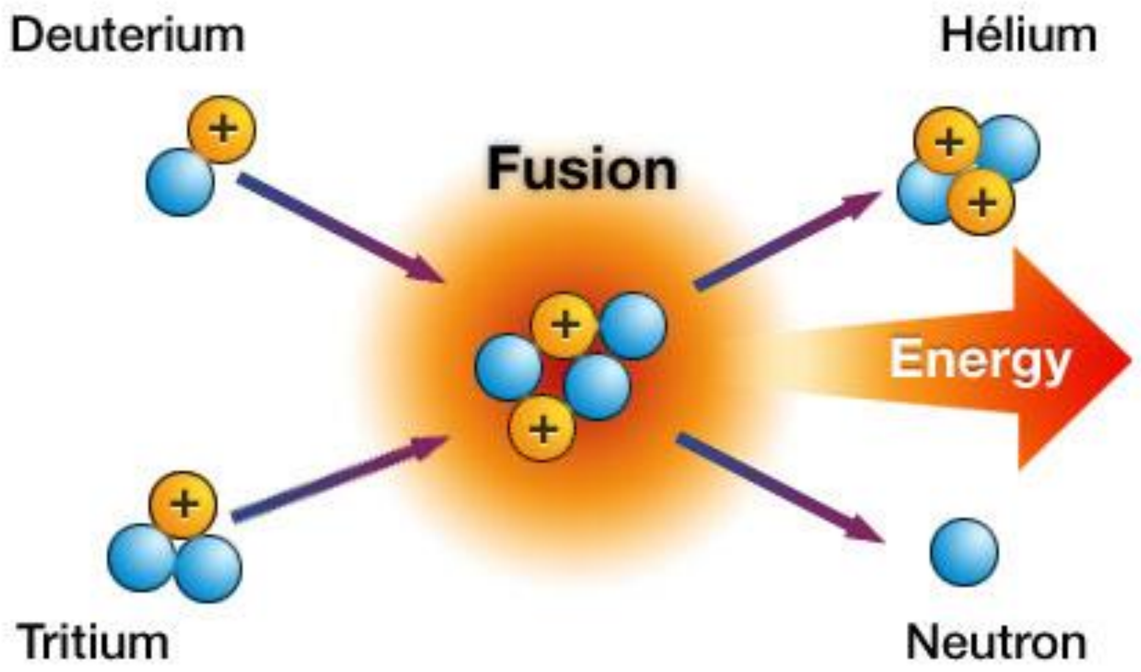
$$0.19446\,u \times 931.5 = \mathbf{181.14\,MeV}$$

Mass Defect	0.19446 u	Energy Released	181.14 MeV

Chain Reaction



Fusion



Fusion

Hydrogen-2	2.0141 u
Helium-3	3.0161 u
Neutron	1.0087 u

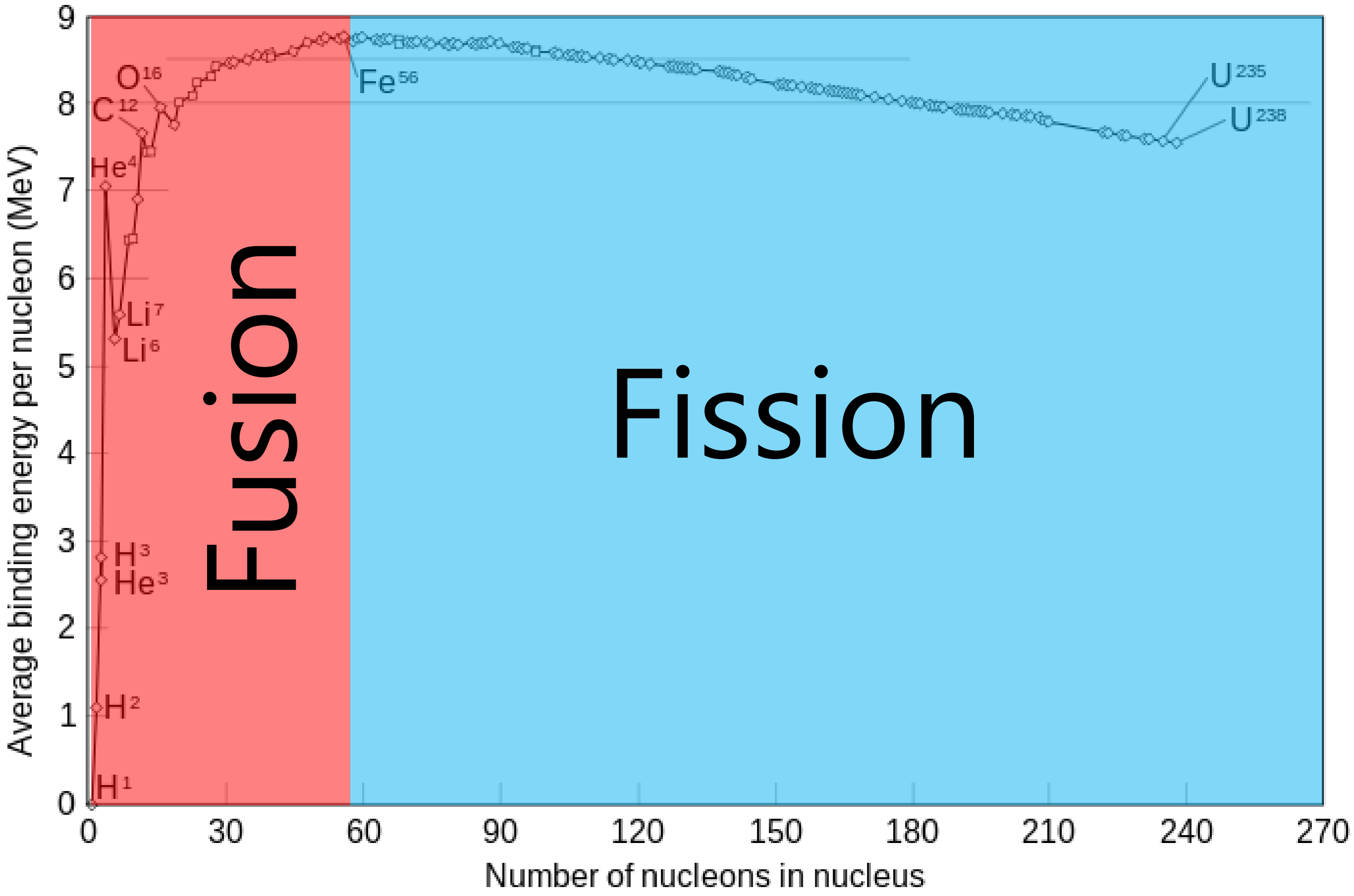
$$ {}^{2}_{1}\mathrm{H} + {}^{2}_{1}\mathrm{H} \rightarrow {}^{3}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n} $$

$$\underbrace{(2.0141\ \mathrm{u} + 2.0141\ \mathrm{u})}_{4.0282\ \mathrm{u}} - \underbrace{(3.0161\ \mathrm{u} + 1.0087\ \mathrm{u})}_{4.0248\ \mathrm{u}} = 0.0034\ \mathrm{u}$$

$$0.0034\ \mathrm{u} \times 931.5 = 3.1671\ \mathrm{MeV}$$

Mass Defect	0.0034 u	Energy Released	3.1671 MeV

Fusion vs. Fission



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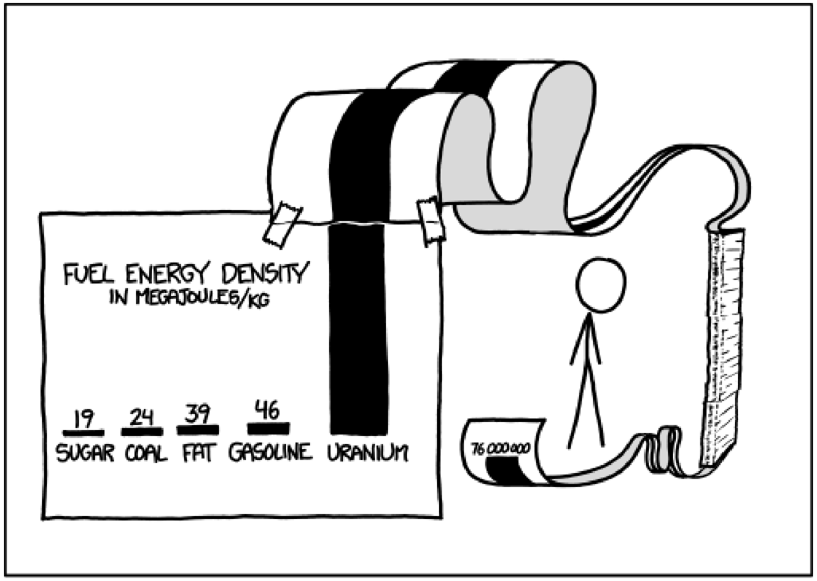

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Uranium

Uranium found in the earth's crust is primarily comprised of two different isotopes of Uranium

$^{238}_{92}\mathrm{U}$

Uranium-238

99.3%

$^{235}_{92}\mathrm{U}$

Uranium-235

0.7%

Where does the uranium used by the US come from?

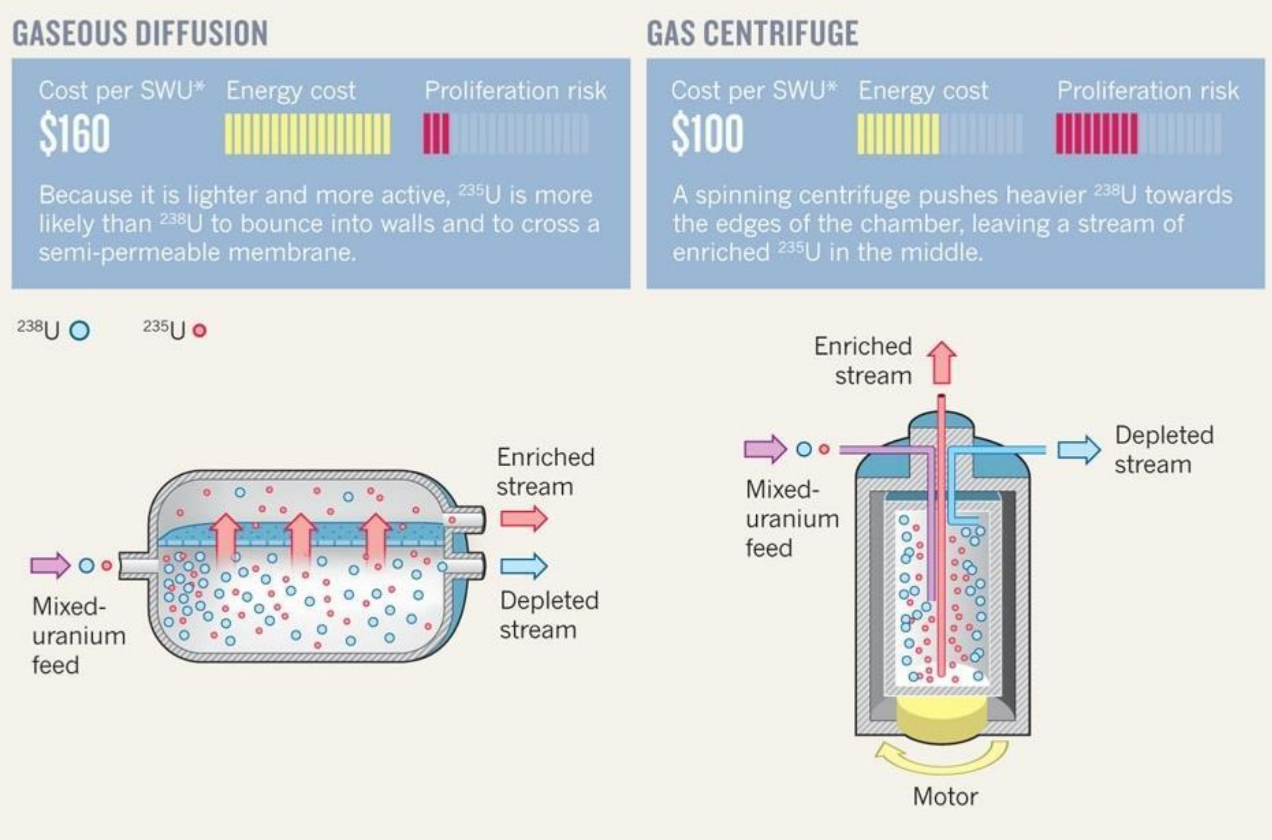
37%	Kazakhstan, Russia, and Uzbekistan
30%	Canada
17%	Australia
10%	Malawi, Namibia, Niger, and South Africa
6%	United States

Yellowcake Uranium

Uranium ore is milled into a U_3O_8 powder known as **yellowcake**

Uranium Enrichment

The yellowcake is converted into Uranium Hexafluoride gas and enriched to create a mixture with a higher percentage of U-235 nuclides



GASEOUS DIFFUSION

Cost per SWU* $160

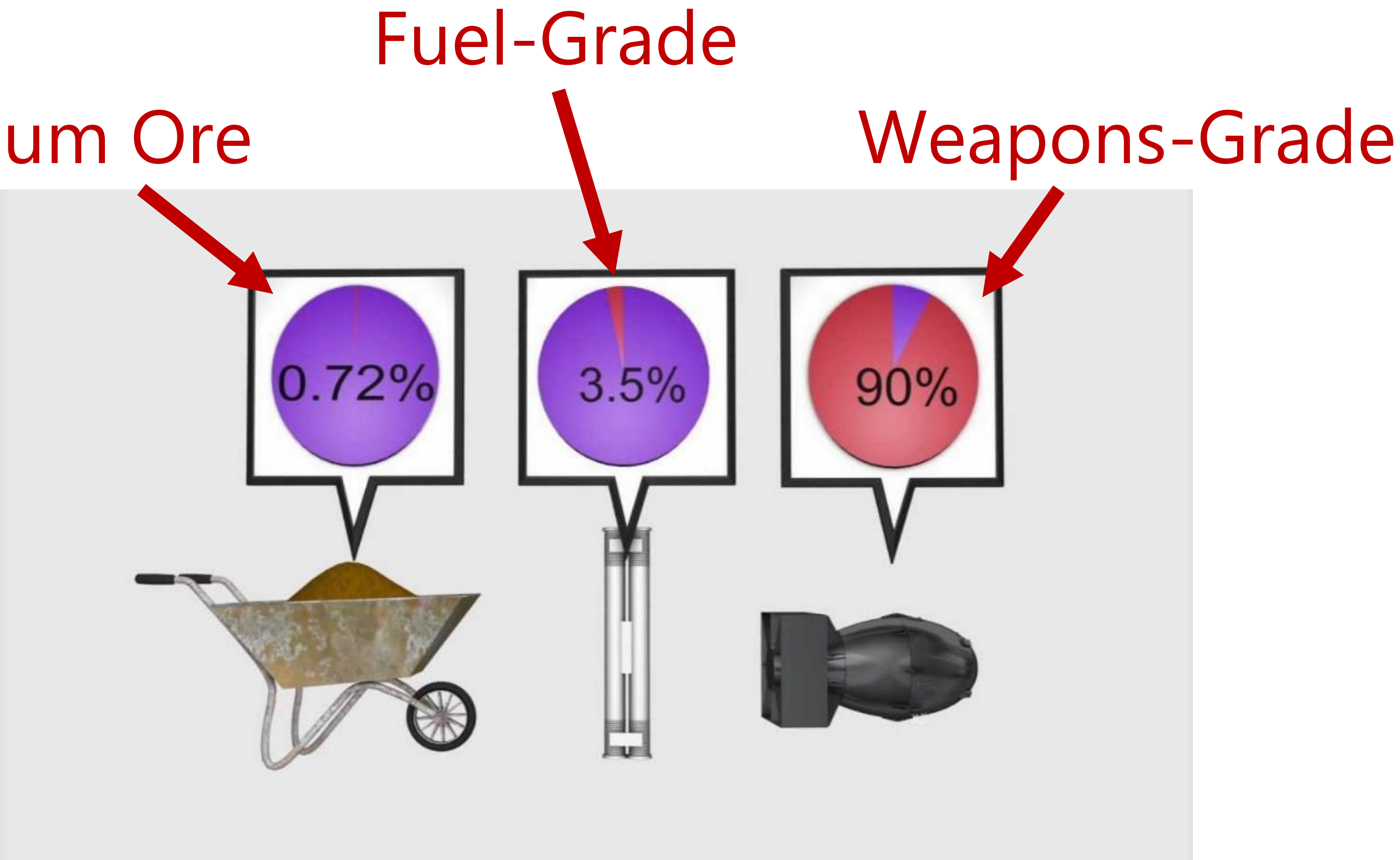
Because it is lighter and more active, ^{235}U is more likely than ^{238}U to bounce into walls and to cross a semi-permeable membrane.

GAS CENTRIFUGE

Cost per SWU* $100

A spinning centrifuge pushes heavier ^{238}U towards the edges of the chamber, leaving a stream of enriched ^{235}U in the middle.

Uranium Enrichment

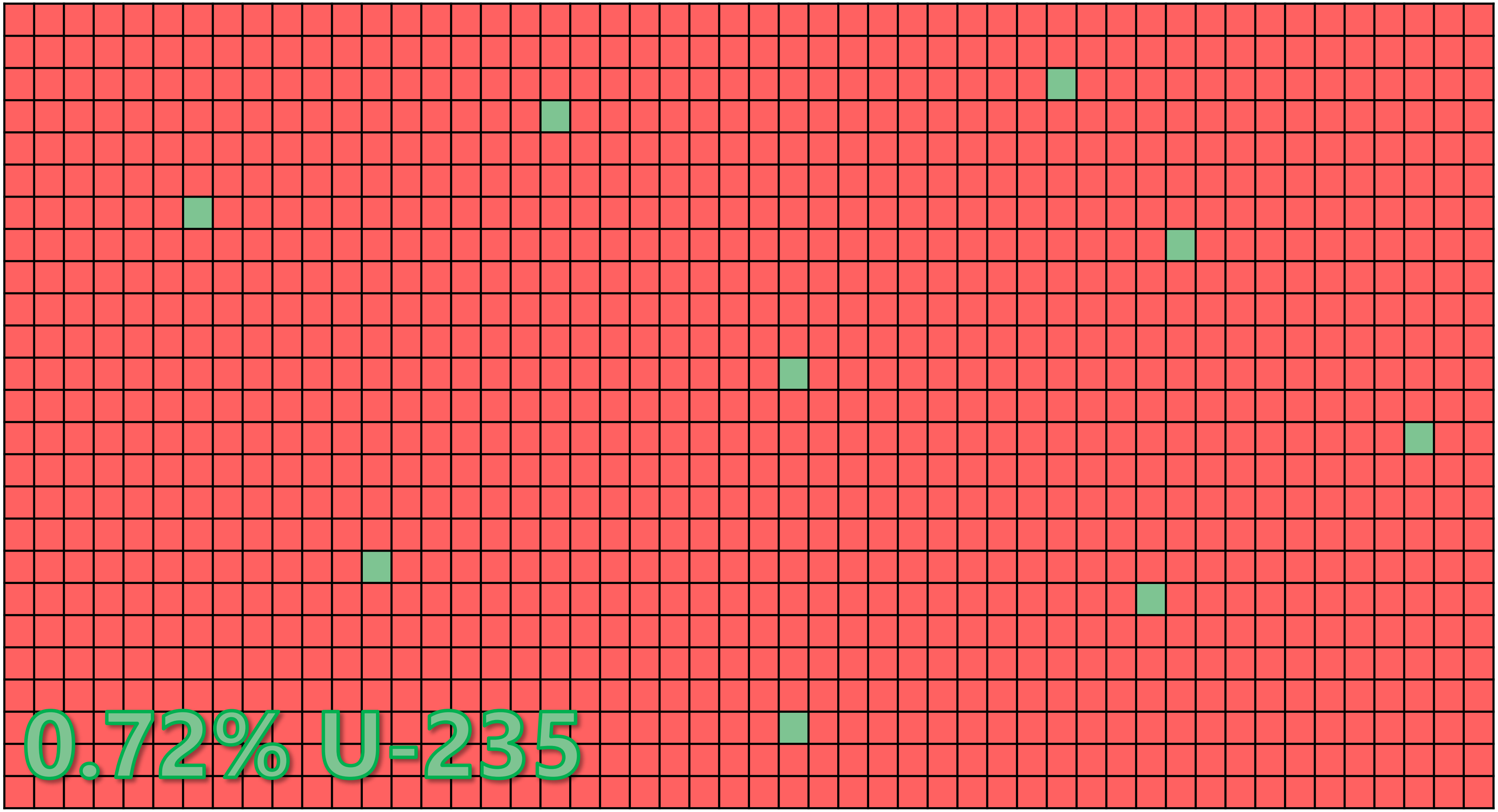


Fuel-Grade

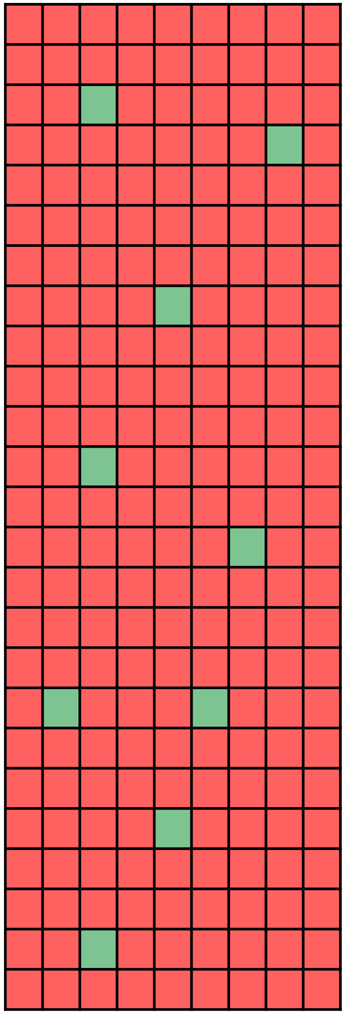
Uranium Ore

Weapons-Grade

Uranium Enrichment



Uranium Enrichment



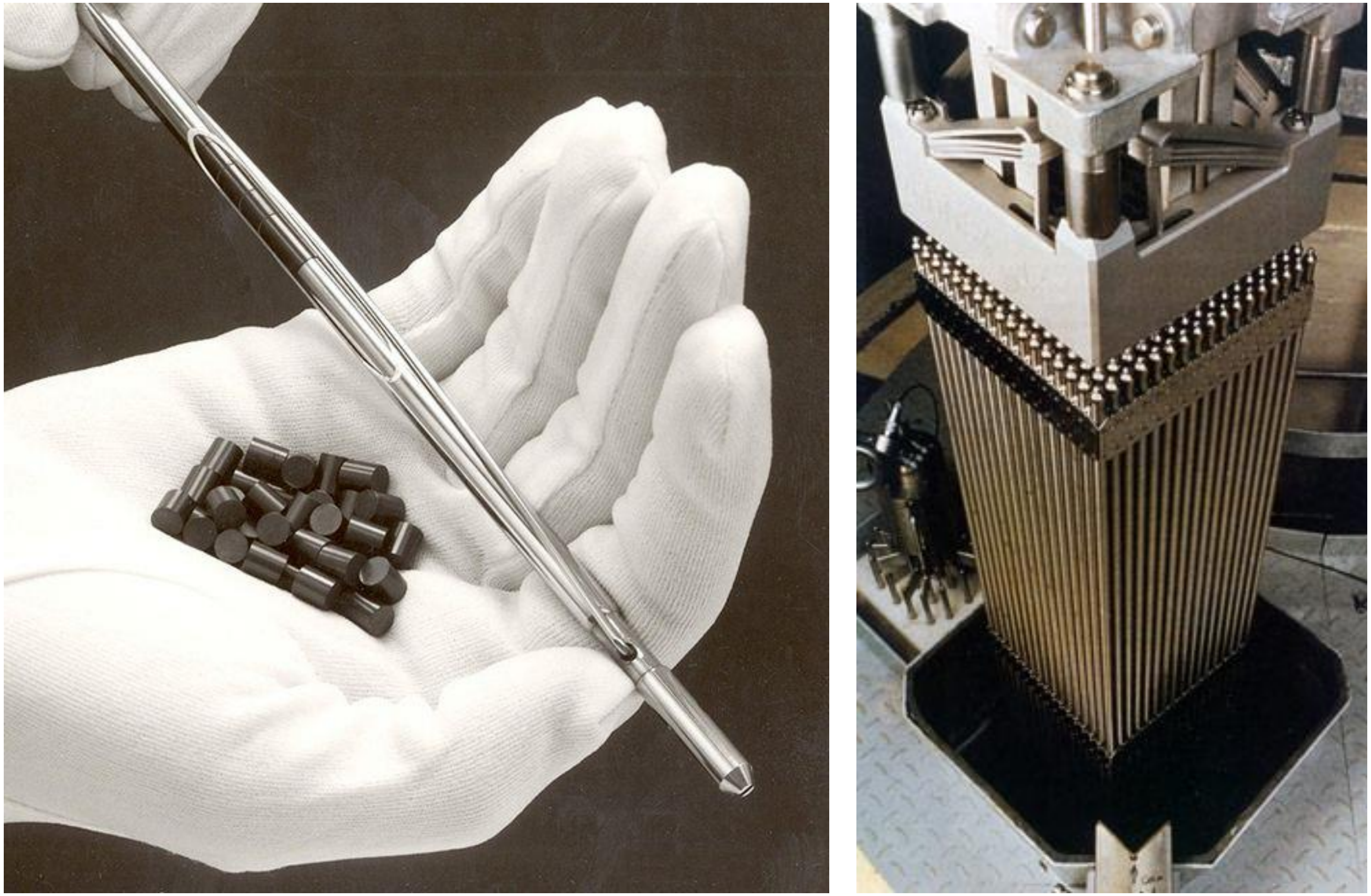
4% U-235

Uranium Enrichment

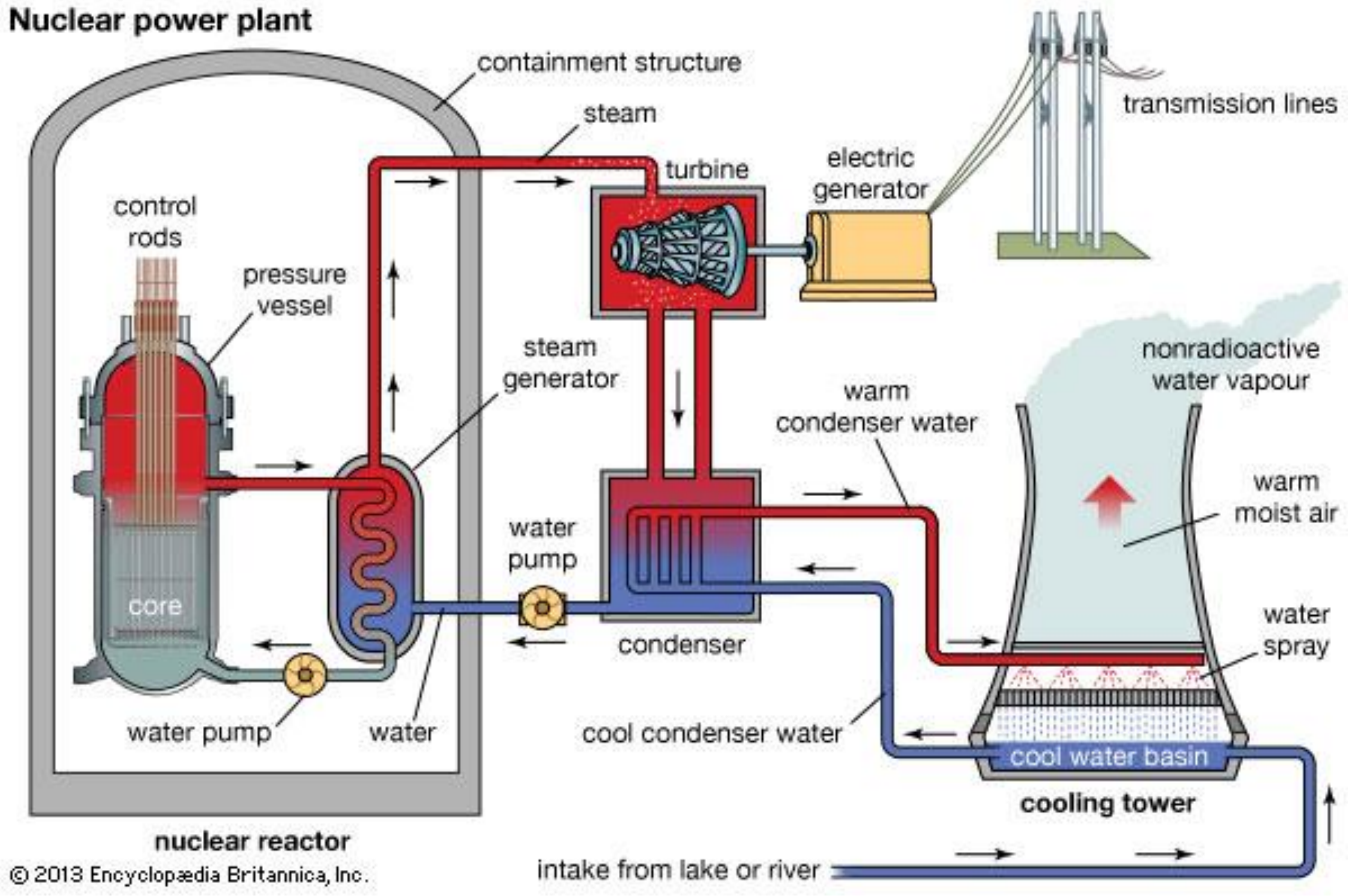
90% U-235

🟩	🟩	🟩	🟩	🟩
🟩	🟥	🟩	🟩	🟩

Uranium Fuel Rods



Nuclear Power Plant



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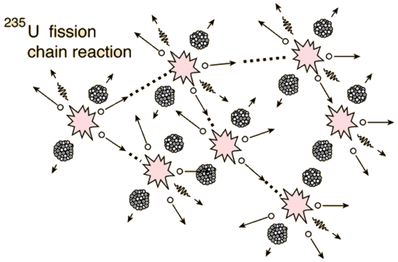
Chain Reaction

For a controlled chain reaction, each reaction should trigger one other reaction

Important Factors

- Only about 4% of the fuel is actually comprised of fissionable U-235 atoms
- Neutrons have to traveling relatively slowly to be captured by a U-235 atom



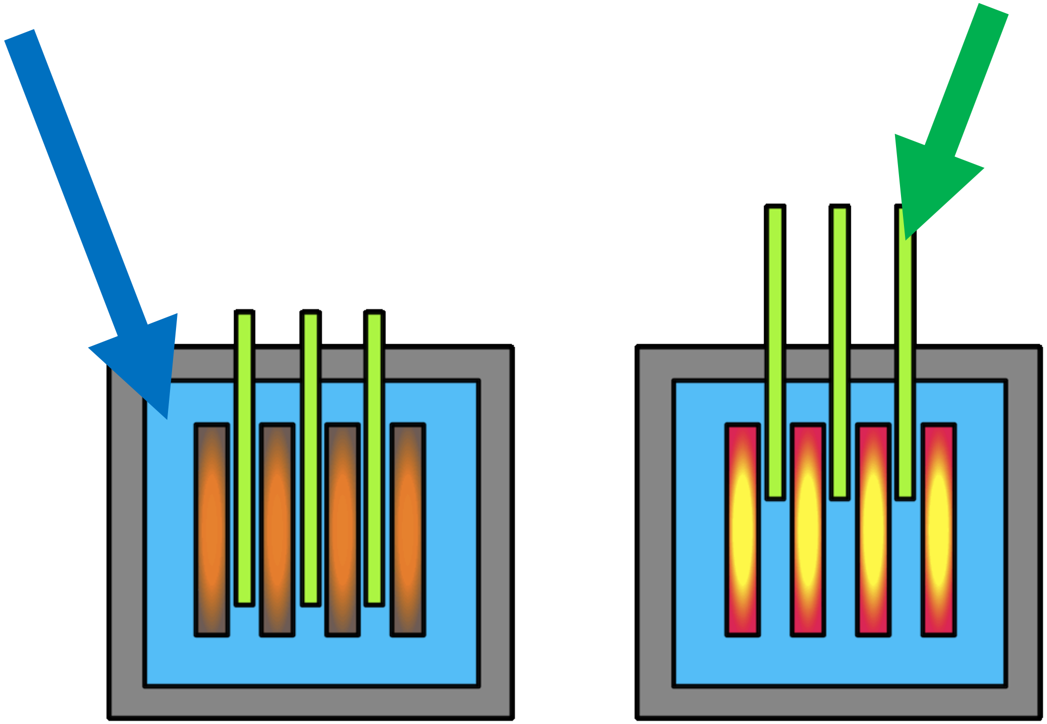
Chain Reaction

Moderator - water or graphite

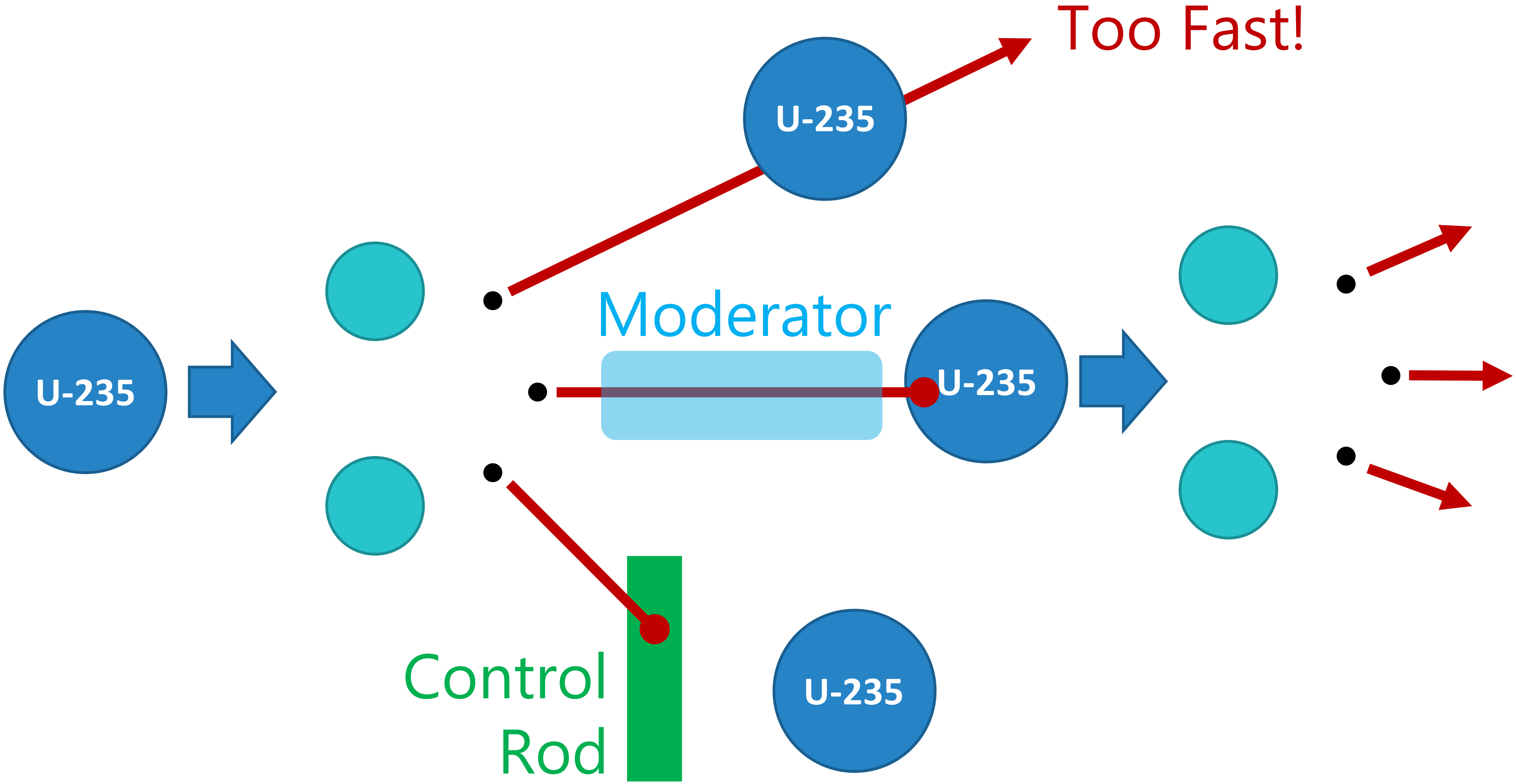
Slows down neutrons

Control Rods - boron

Absorbs neutrons



Chain Reaction



Nuclear Waste

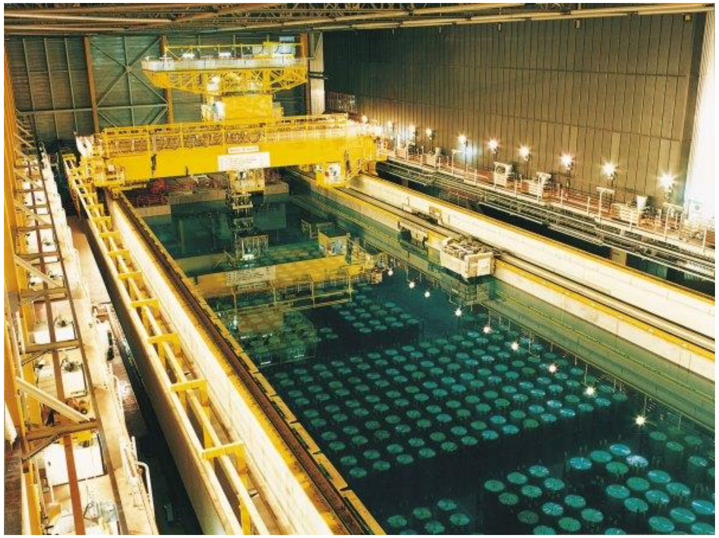
After the fuel can no longer be used to efficiently create electricity, the spent nuclear waste needs to be disposed of.

Isotope	Half Life
Strontium-90	28 years
Caesium-137	30 years
Plutonium-239	24,000 years
Caesium-135	2.3 million years
Iodine-129	15.7 million years

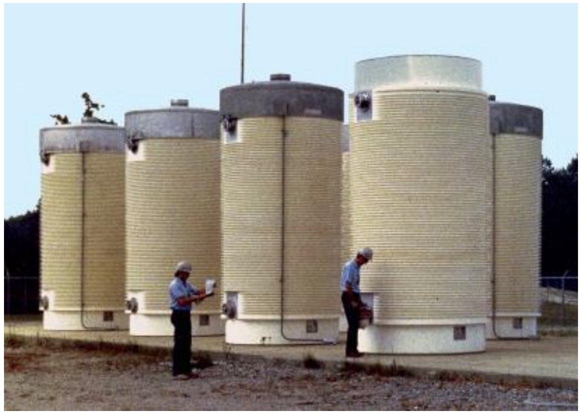
How long until it's safe?

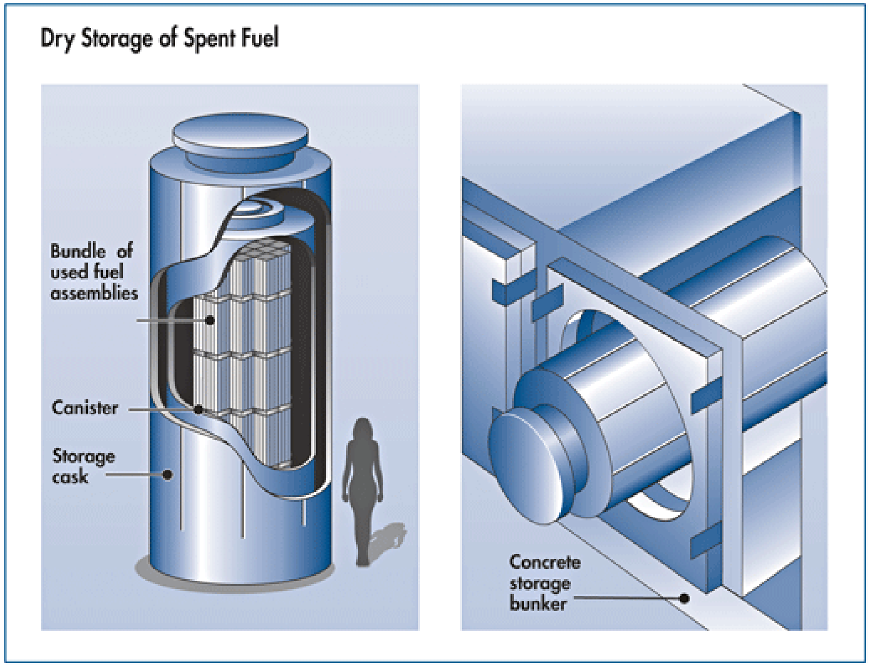
Radioactive Isotopes found in spent nuclear fuel

Nuclear Waste - Disposal



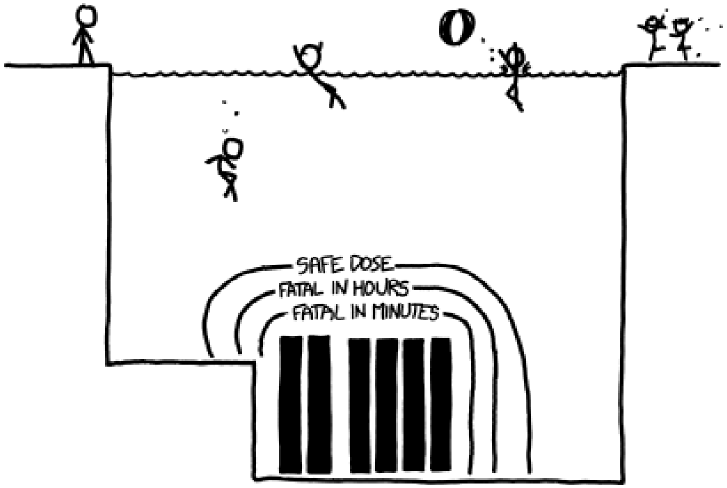
Most of the waste is stored onsite

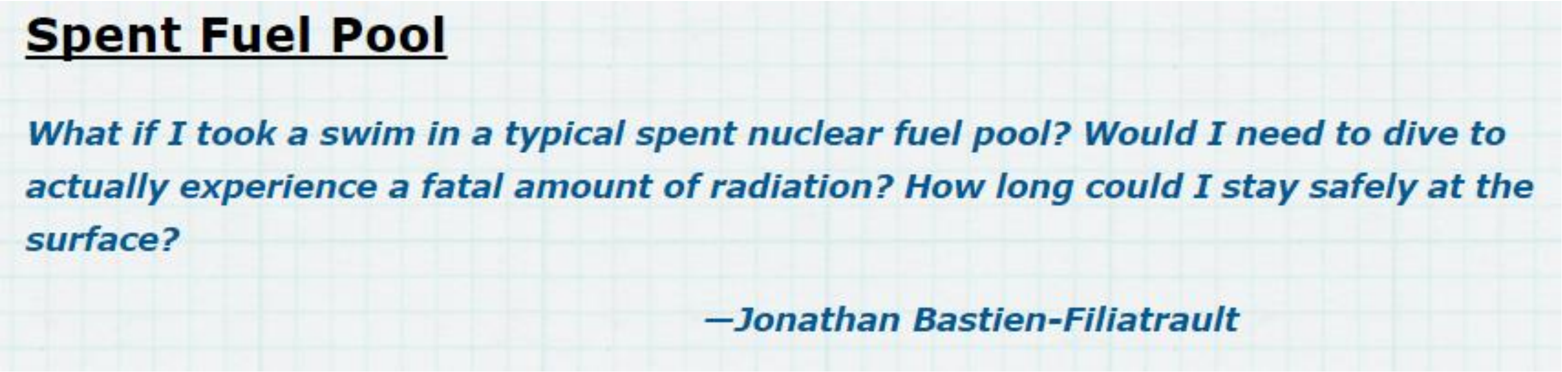




Nuclear Waste - Disposal

what if?





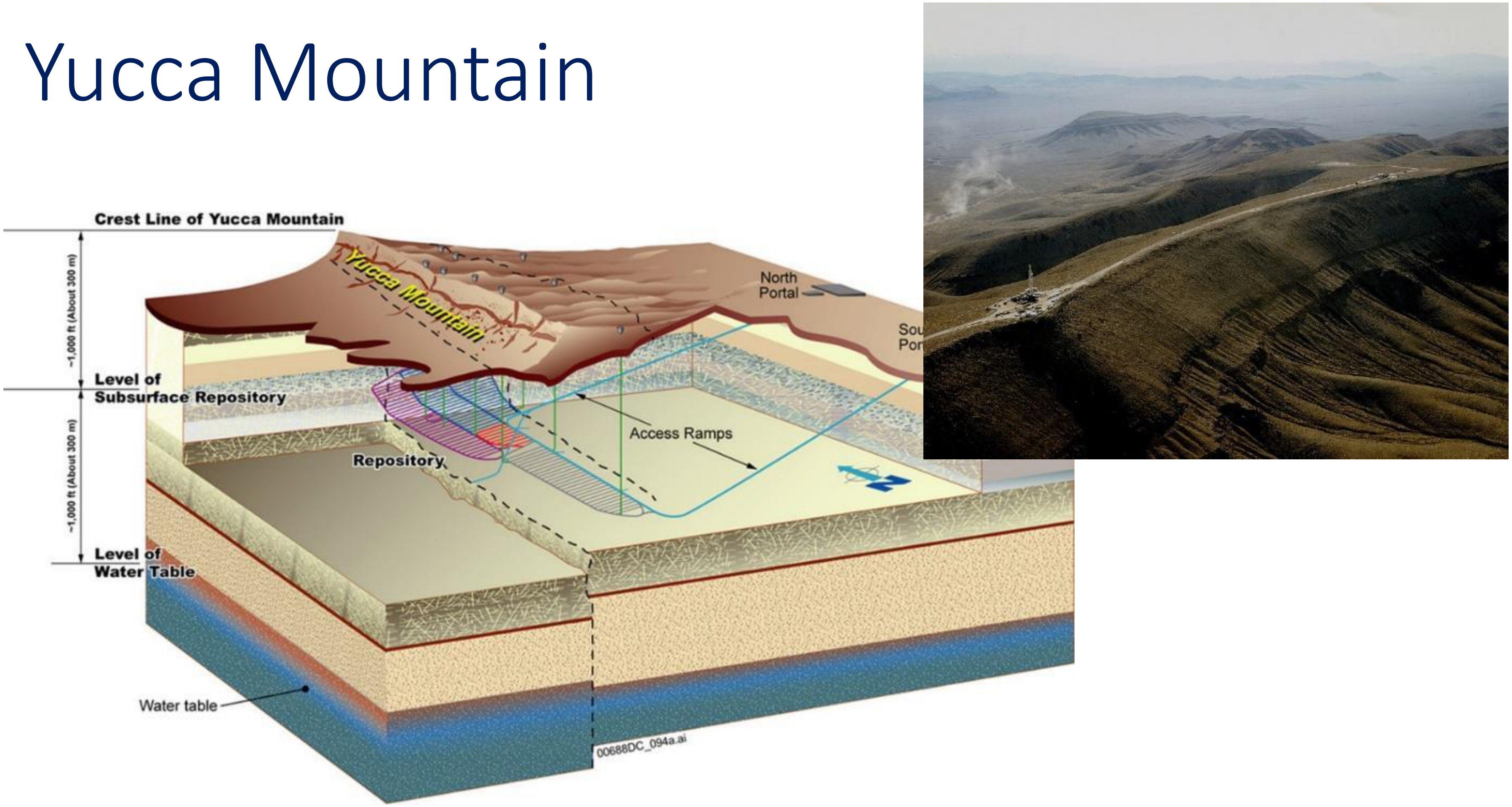
Spent Fuel Pool

What if I took a swim in a typical spent nuclear fuel pool? Would I need to dive to actually experience a fatal amount of radiation? How long could I stay safely at the surface?

—Jonathan Bastien-Filiatrault

Nuclear Waste - Disposal

Yucca Mountain



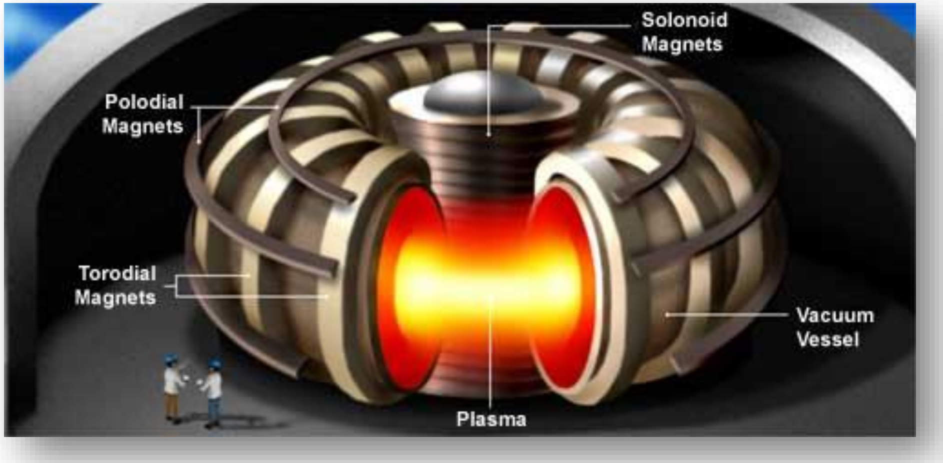
Nuclear Waste - Disposal

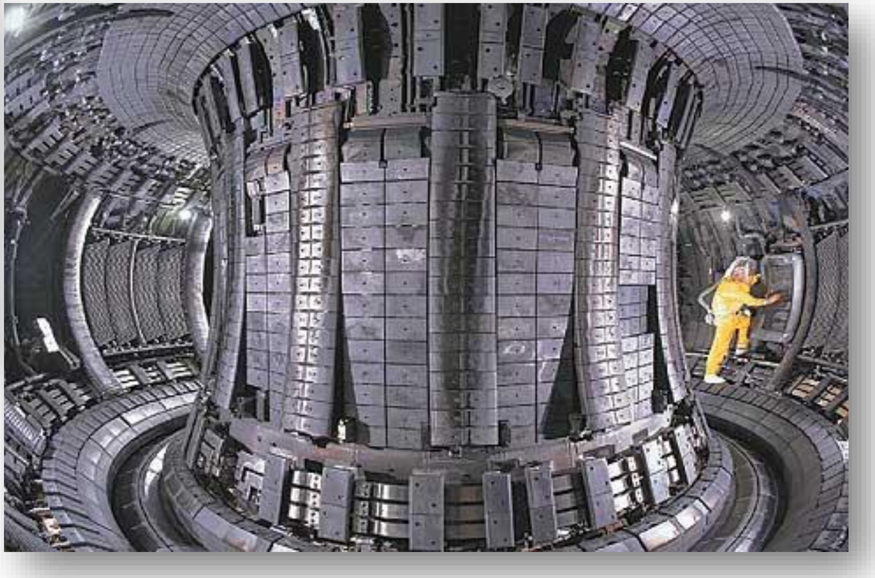
Any better options out there???

Ideas	**Examples**
Long-term above ground storage	•Investigated in France, Netherlands, Switzerland, UK, and USA. •Not currently planned to be implemented anywhere.
Disposal in outer space (proposed for wastes that are highly concentrated)	•Investigated by USA. •Investigations now abandoned due to cost and potential risks of launch failure.
Rock-melting (proposed for wastes that are heat-generating)	•Investigated by Russia, UK, and USA. •Not implemented anywhere. •Laboratory studies performed in the UK.
Disposal at subduction zones	•Investigated by USA. •Not implemented anywhere. •Not permitted by international agreements.
Sea disposal	•Implemented by Belgium, France, Germany, Italy, Japan, Netherlands, Russia, South Korea, Switzerland, UK, and USA. •Not permitted by international agreements.
Sub seabed disposal	•Investigated by Sweden and UK (and organisations such as the OECD Nuclear Energy Agency). •Not implemented anywhere. •Not permitted by international agreements.
Disposal in ice sheets (proposed for wastes that are heat-generating)	•Investigated by USA. •Rejected by countries that have signed the Antarctic Treaty or committed to providing solutions within national boundaries.
Deep well injection (for liquid wastes)	•Implemented in Russia for many years for LLW and ILW. •Investigations abandoned in the USA in favour of deep geological disposal of wastes in solid form.

Fusion as a Power Source

Fusion reactions have been successfully controlled using strong magnetic fields but the energy used to run the magnets exceeds the energy released in the reaction…

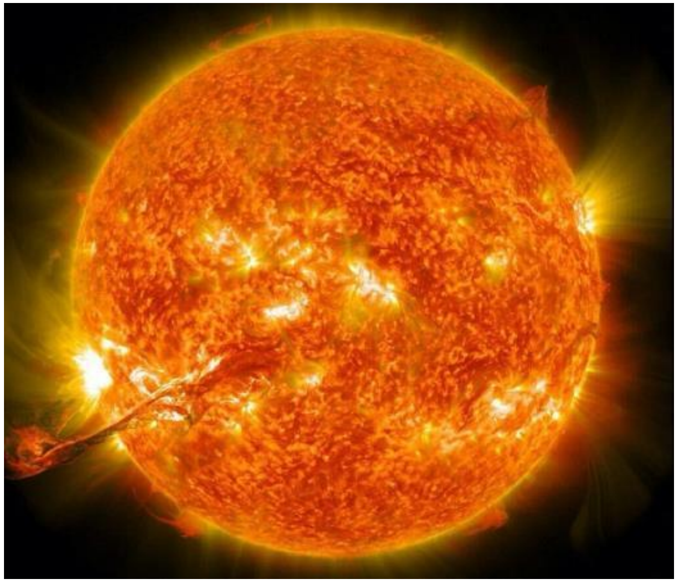




Conditions for Fusion

It’s significantly more difficult to create fusion reactions here on earth

- High Pressure
- High Temperature

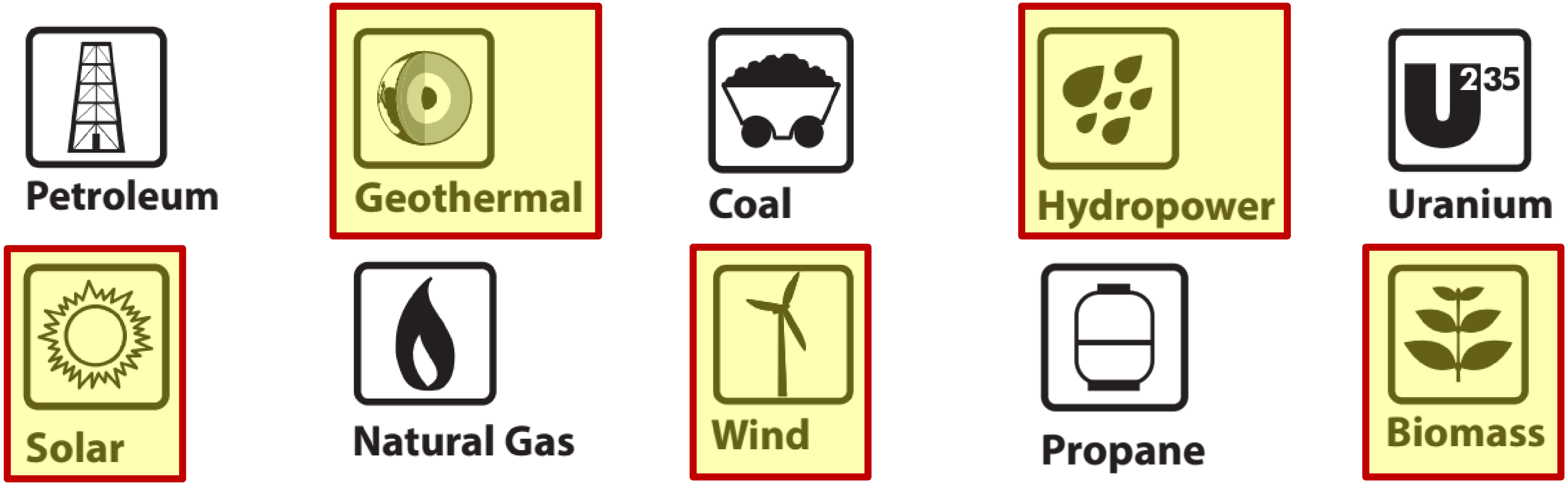


The Renewables

IB PHYSICS | ENERGY PRODUCTION

Renewable vs. Non Renewable

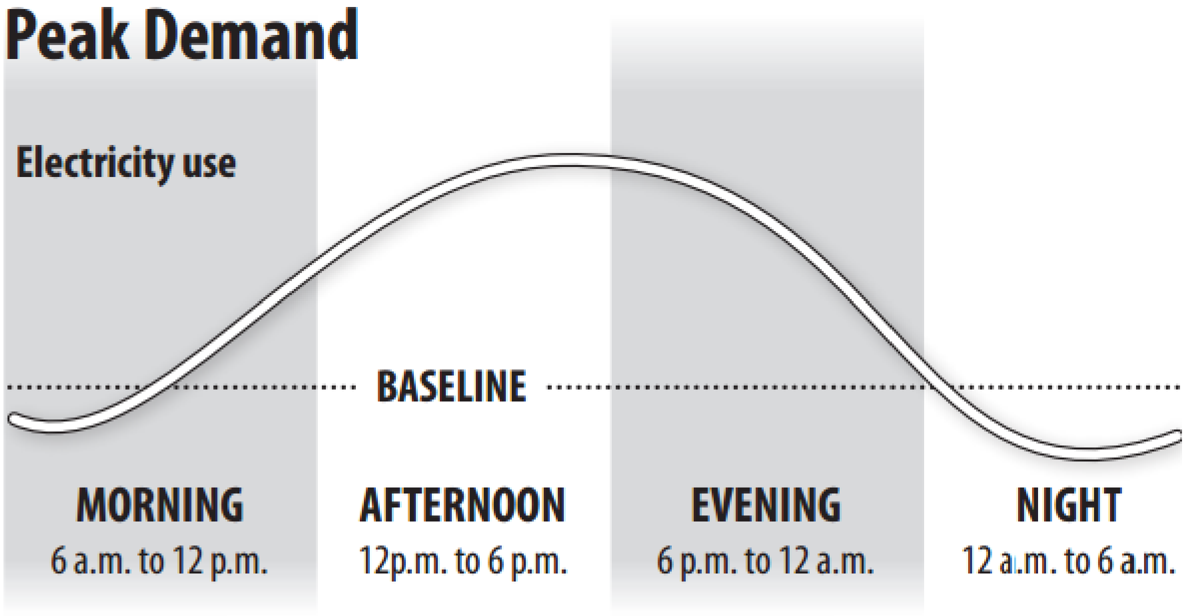
Highlight the primary energy sources that are considered renewable



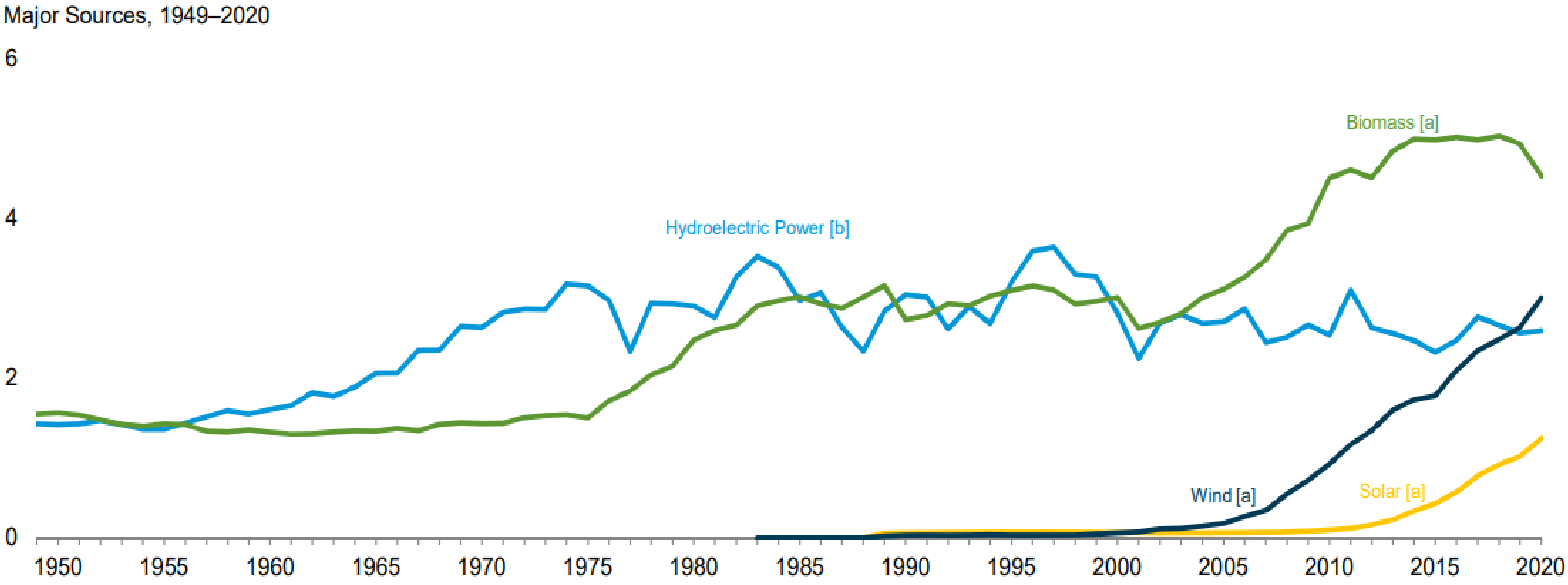
*Note: this doesn’t mean that it cannot ever be replaced, just that it won’t happen in any sort of useful time frame…

Energy Load Requirements

Energy needs to be available when electricity is most needed but should also be available other times as well.

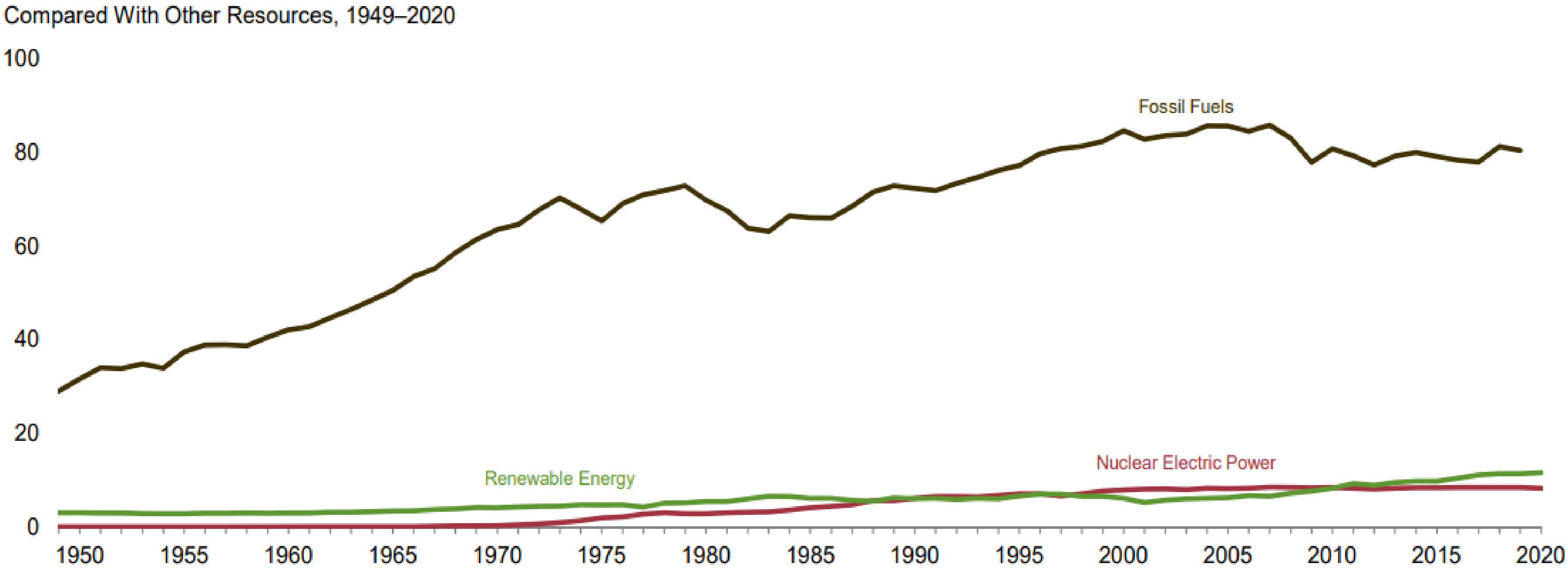


Renewable Energy in the US



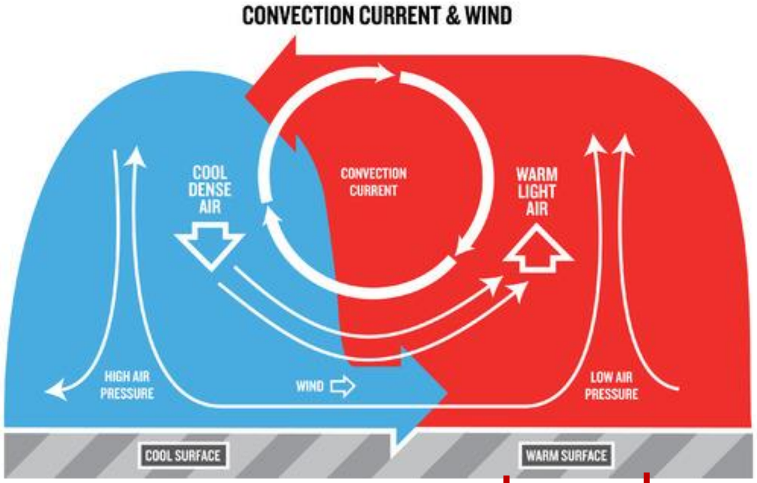
https://www.eia.gov/totalenergy/data/monthly/pdf/mer.pdf

Renewable Energy in the US

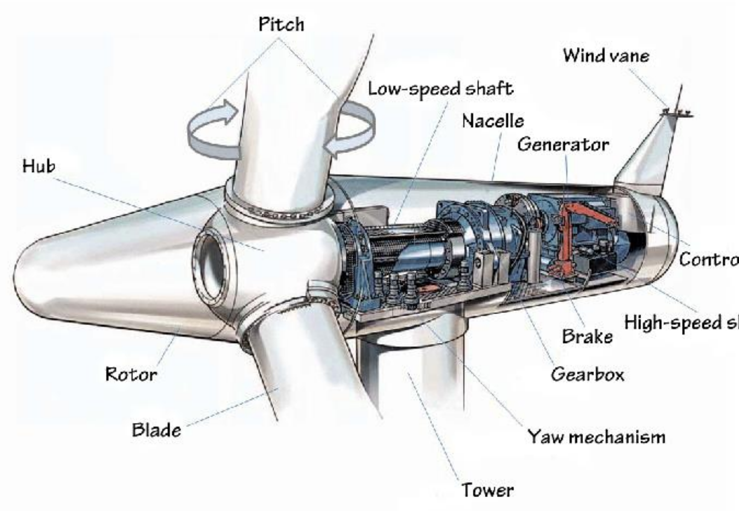


https://www.eia.gov/totalenergy/data/monthly/pdf/mer.pdf

Wind Power

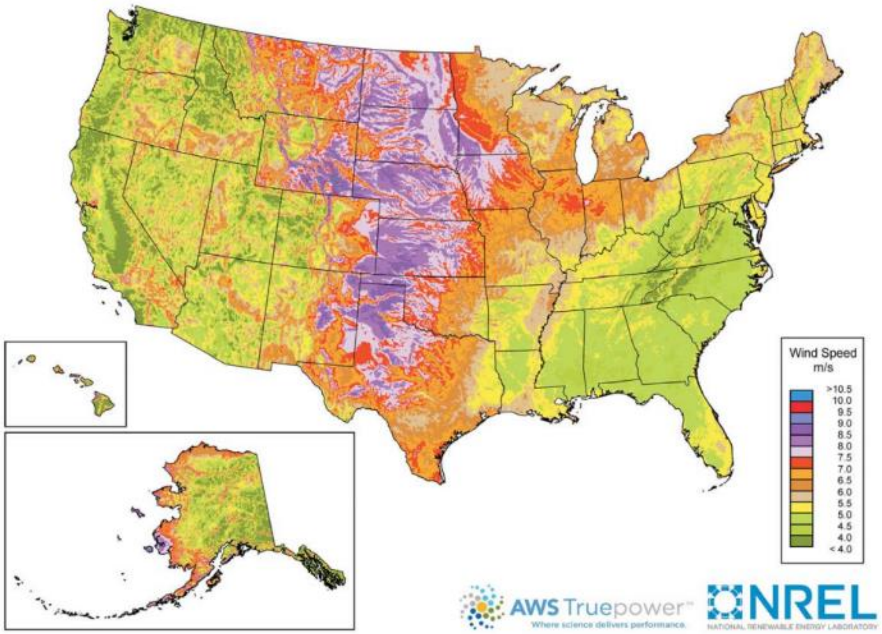


Land



Solar Energy → **KE of Wind** → **KE of Turbine** → **Electricity**

Wind Speeds


Wind Speed
m/s
>10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
< 4.0
AWS Truepower™
Where science delivers performance.
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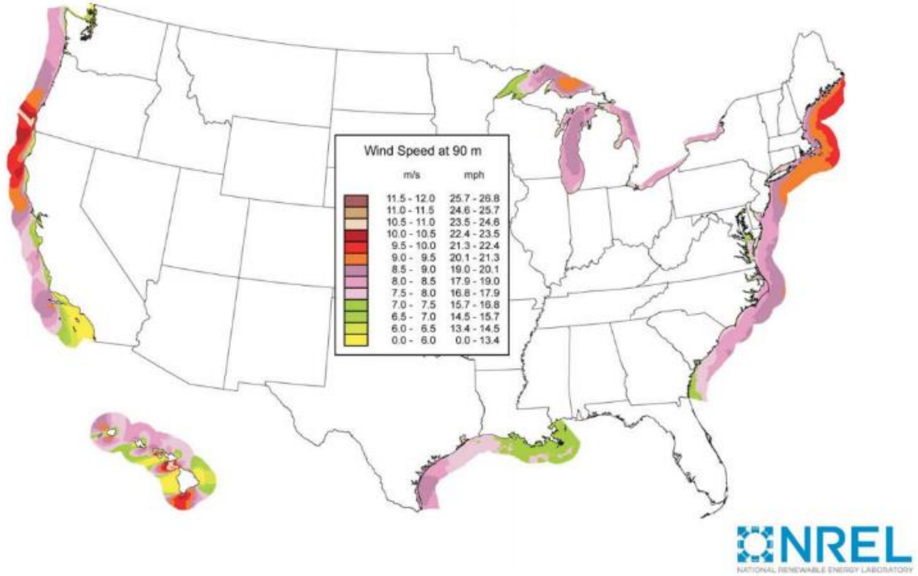
Wind Speed at 90 m
m/s
mph
11.5 - 12.0
25.7 - 26.8
11.0 - 11.5
24.6 - 25.7
10.5 - 11.0
23.5 - 24.6
10.0 - 10.5
22.4 - 23.5
9.5 - 10.0
21.3 - 22.4
9.0 - 9.5
20.1 - 21.3
8.5 - 9.0
19.0 - 20.1
8.0 - 8.5
17.9 - 19.0
7.5 - 8.0
16.8 - 17.9
7.0 - 7.5
15.7 - 16.8
6.5 - 7.0
14.5 - 15.7
6.0 - 6.5
13.4 - 14.5
0.0 - 6.0
0.0 - 13.4
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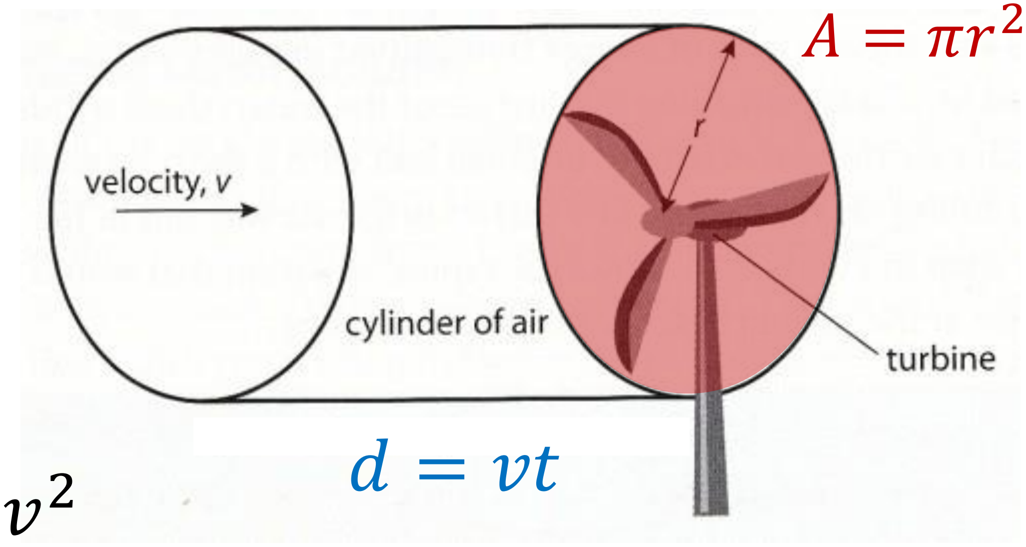
NIMBY


ARGUMENTS AGAINST–
NUCLEAR
OIL
COAL
MINE
BP
IT'S IN MY BACKYARD!
JOE HELLER ©2011 GREEN BAY PRESS GAZETTE


WIND POWER
NOT IN MY BACK YARD
WPL
WIS POWER FLIGHT

Calculating the Wind’s Energy

$$E_K = \frac{1}{2}mv^2$$



$A = \pi r^2$

$d = vt$

$$Power = \frac{E_K}{t} = \frac{\frac{1}{2}[Av\cancel{t}\rho]v^2}{\cancel{t}}$$

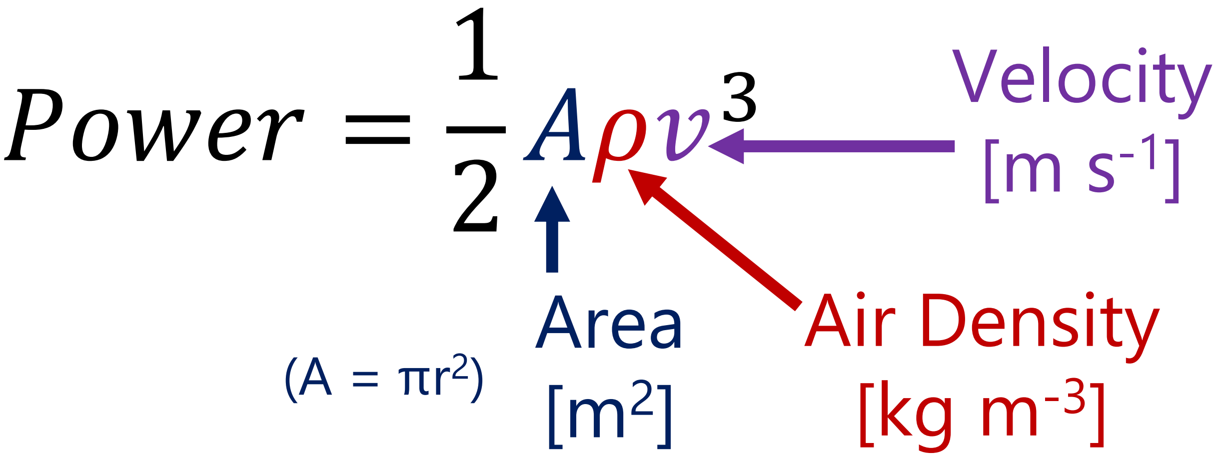
$\rho \rightarrow \text{air density}$

$$\boxed{Power = \frac{1}{2}A\rho v^3}$$

$$V = A \times vt$$

$$m = (A \times vt) \times \rho$$

IB Physics Data Booklet



$$Power = \frac{1}{2}A\rho v^3$$

Velocity

[m s^{-1}]

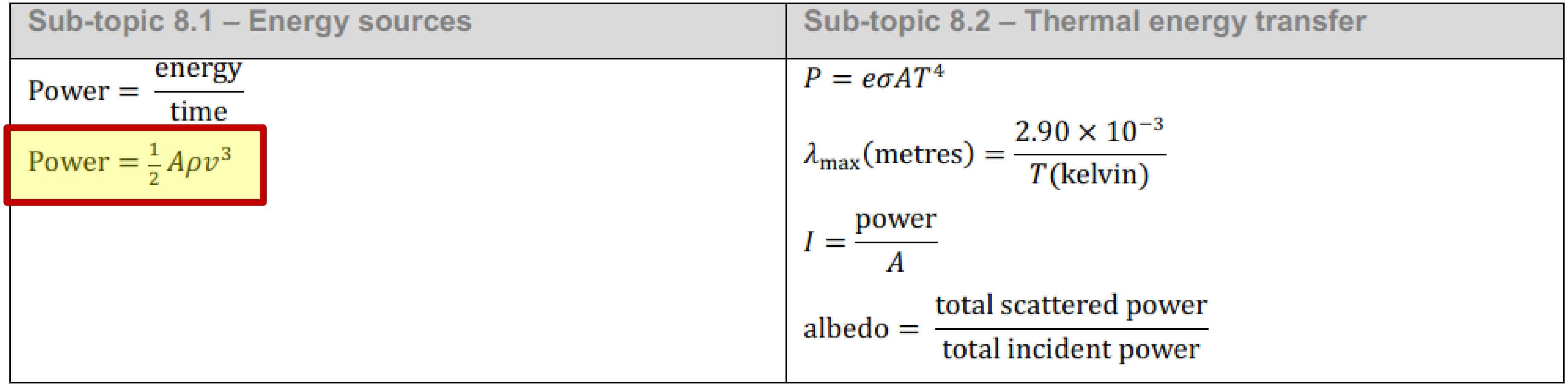
(A = πr^2)

Area

[m^2]

Air Density

[kg m^{-3}]



Sub-topic 8.1 – Energy sources	Sub-topic 8.2 – Thermal energy transfer
$\text{Power} = \frac{\text{energy}}{\text{time}}$ $\text{Power} = \frac{1}{2}A\rho v^3$	$P = e\sigma AT^4$ $\lambda_{\max}(\text{metres}) = \frac{2.90 \times 10^{-3}}{T(\text{kelvin})}$ $I = \frac{\text{power}}{A}$ $\text{albedo} = \frac{\text{total scattered power}}{\text{total incident power}}$

Conceptual Meaning of Equation

$$Power = \frac{1}{2} A \rho v^3$$

If the wind speed is doubled, then the power is multiplied by a factor of **8** 2^3

If the wind speed is tripled, then the power is multiplied by a factor of **27** 3^3

Try This...

$$Power = \frac{1}{2}A\rho v^3$$

Given a turbine having a blade length of 12 m, and a wind speed of 15 ms^{-1} find the power output if the density of air is ρ= 1.2 kg m^{-3}.

$$P = \frac{1}{2}(\pi\times 12^2)(1.2)(15)^3 = 916{,}000\ \mathrm{W}$$

$$\boxed{= 0.916\ \mathrm{MW}}$$

What is the actual power output if the efficiency is 45%?

$$0.916\ \mathrm{MW} \times 0.45 = \boxed{0.412\ \mathrm{MW}}$$

Try This…

$$Power = \frac{1}{2}A\rho v^3$$

Air of constant density 1.2 kg m^{-3} is incident at a speed of 9.0 m s^{-1} on the blades of a wind turbine. The turbine blades are each of length 7.5 m. The air passes through the turbine without any change of direction. Immediately after passing through the blades, the speed of the air is 5.0 m s^{-1}. The density of air immediately after passing through the blades is 2.2 kg m^{-3}.

$$P = \frac{1}{2}(\pi\times 7.5^2)(1.2)(9)^3 = 77{,}300\text{ W}$$

$$P = \frac{1}{2}(\pi\times 7.5^2)(2.2)(5)^3 = 24{,}300\text{ W}$$

$$53{,}000\text{ W}$$

Solar Power

Photovoltaic Cells

Solar Energy → **Electricity**

Solar Concentrator

Solar Energy → **Thermal Energy** → **Electricity**

Solar Heating Panel

Solar Energy → **Thermal Energy**

Efficiency of PV Cells

Photovoltaic Cells

10%-20% Efficient

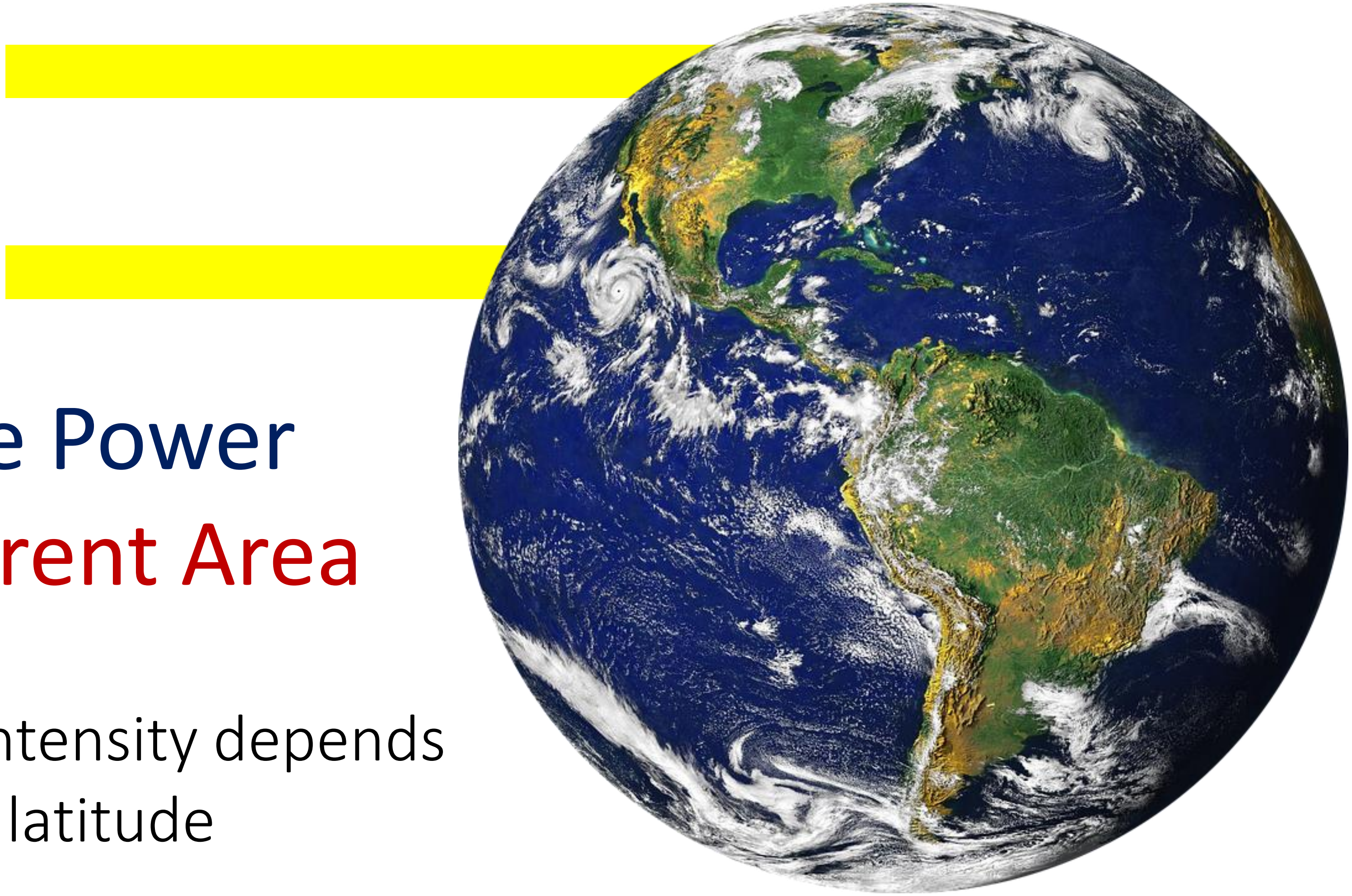
Solar Power

What Would It Take To Power The United States With Solar Energy?

Issues

- Infrastructure to transport electricity
- Storage for non-sun times
- High up front cost

Solar Power Intensity

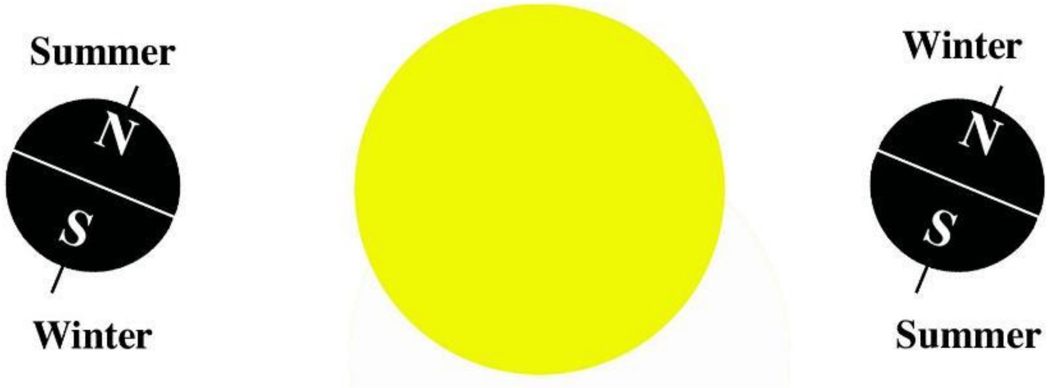


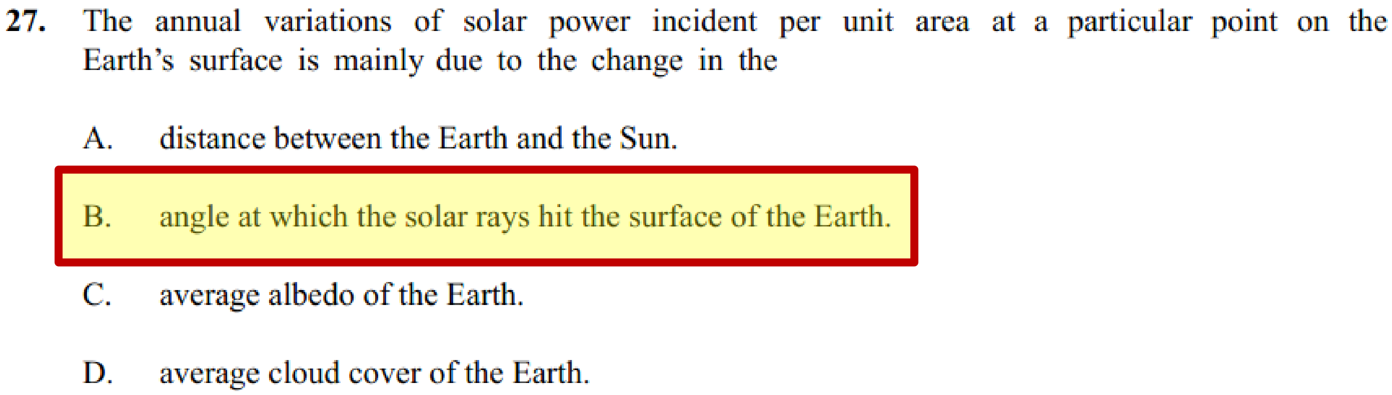
Same Power

Different Area

Solar intensity depends on the latitude

This also affects the seasons





27. The annual variations of solar power incident per unit area at a particular point on the Earth's surface is mainly due to the change in the

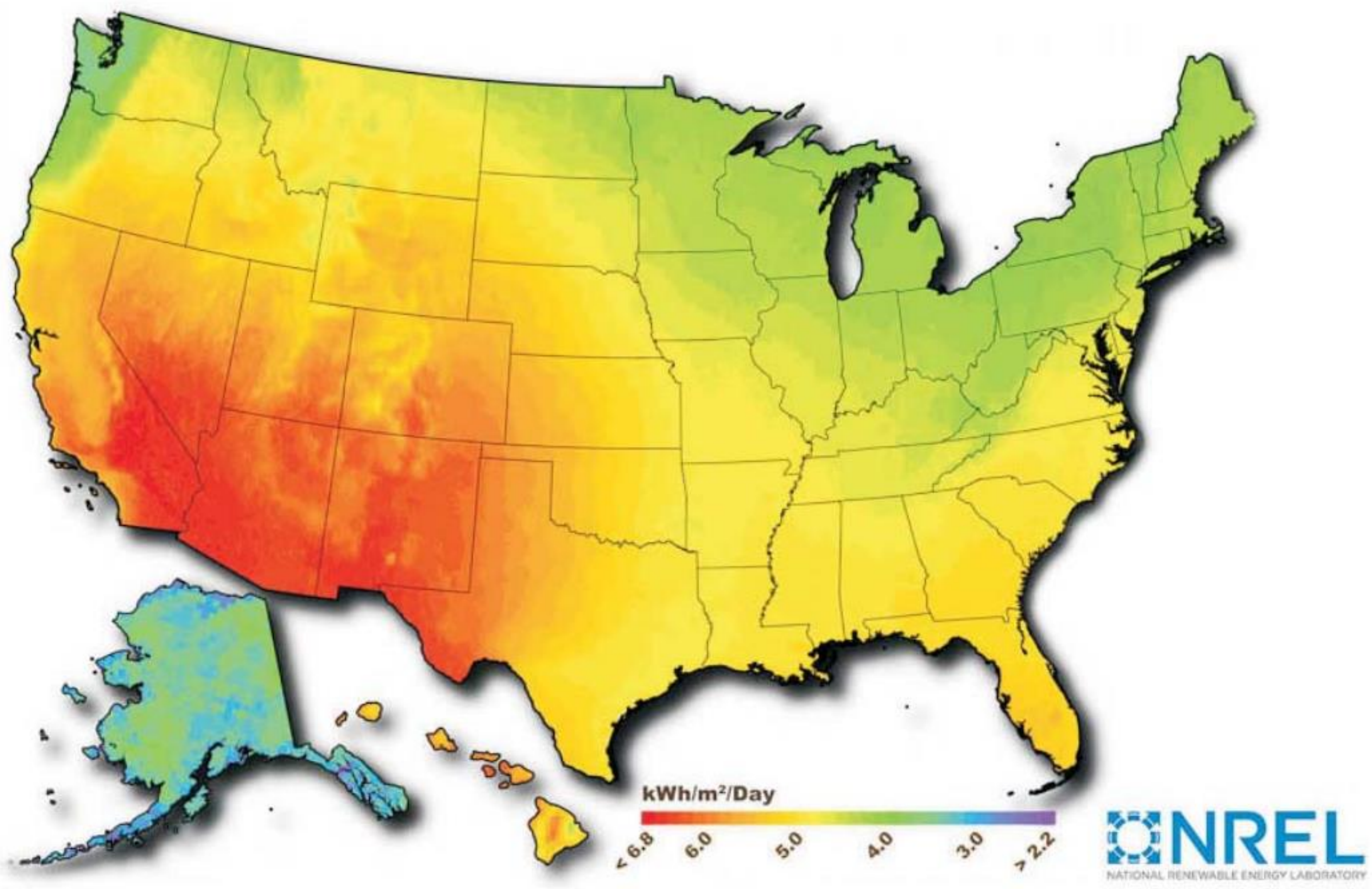
A. distance between the Earth and the Sun.

B. angle at which the solar rays hit the surface of the Earth.

C. average albedo of the Earth.

D. average cloud cover of the Earth.

Solar Map


kWh/m²/Day
< 6.8
6.0
5.0
4.0
3.0
> 2.2
NREL
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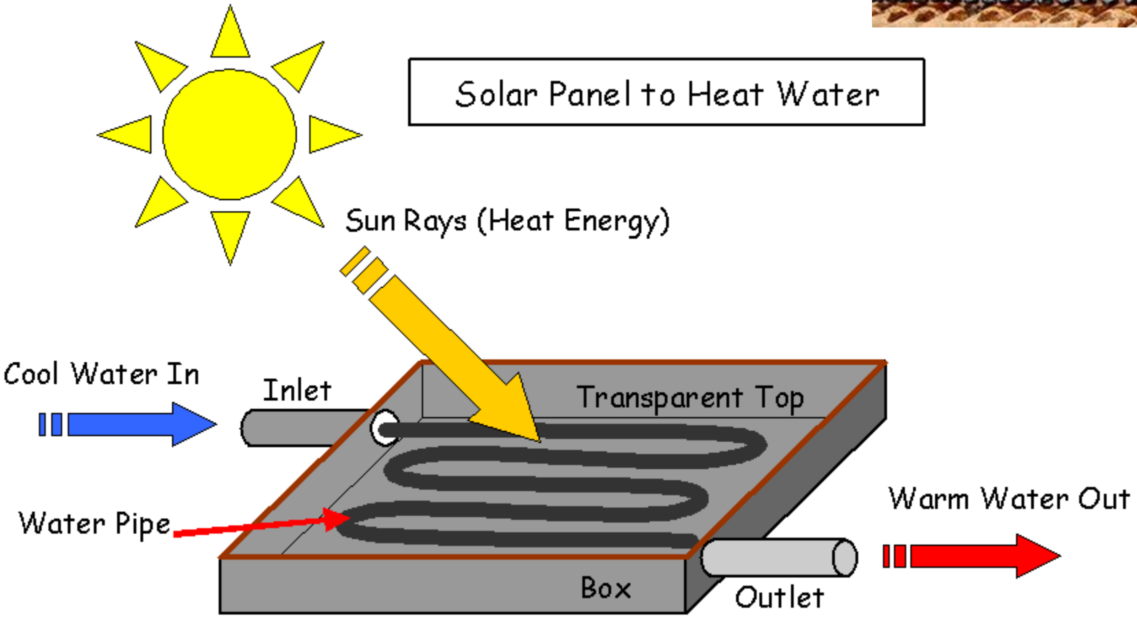
Calculating Solar Power

A photovoltaic cell has an area of $1.00\ \text{cm}^2$ and an efficiency of 10.5%. If the cell is placed in a position where the sun's intensity is $1250\ \text{W m}^{-2}$, what is the power output of the cell?

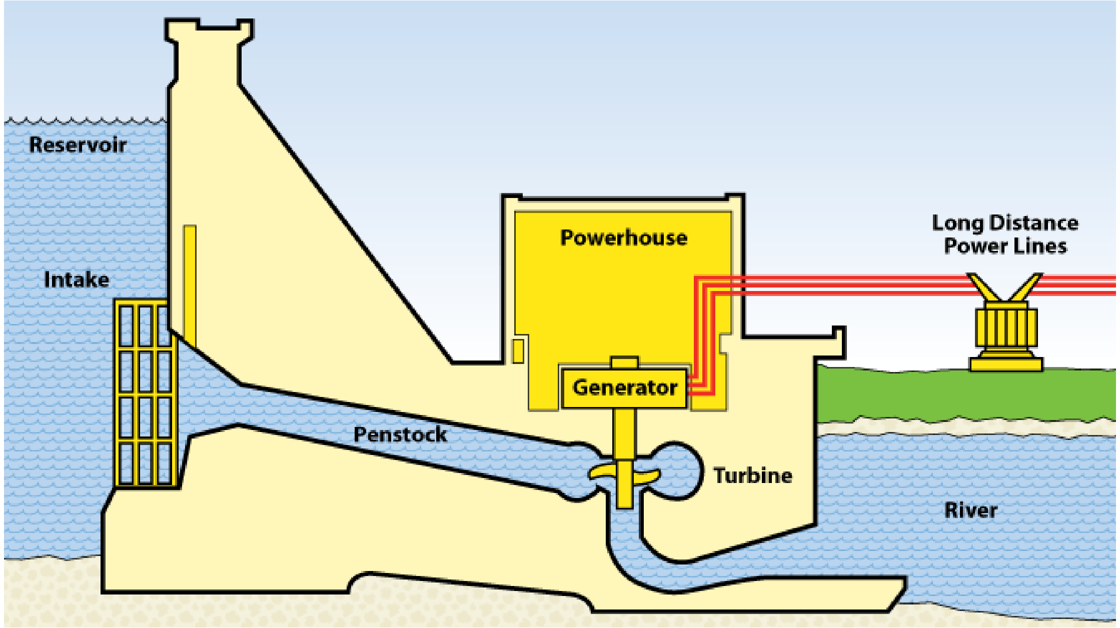
$$1\ \text{cm}^2 \times \frac{1\ \text{m}}{100\ \text{cm}} \times \frac{1\ \text{m}}{100\ \text{cm}} = 0.0001\ \text{m}^2$$

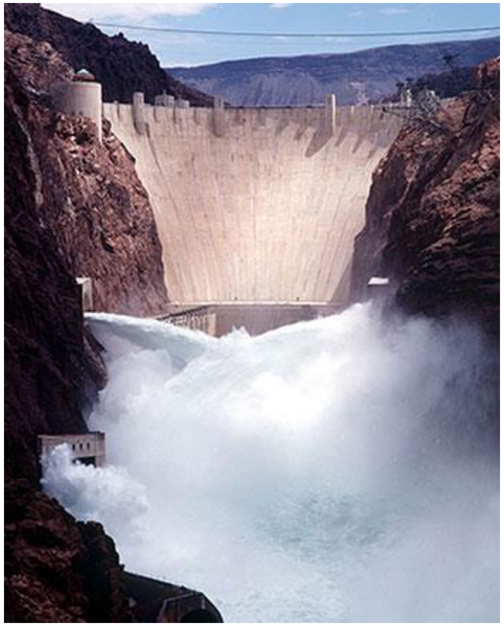
$$\frac{1250\ \text{W}}{1\ m^2} \times \underset{\substack{\uparrow \\ \text{Area}}}{0.0001\ \text{m}^2} \times \underset{\substack{\uparrow \\ \text{Efficiency}}}{0.105} = \boxed{0.0131\ \text{W}}$$

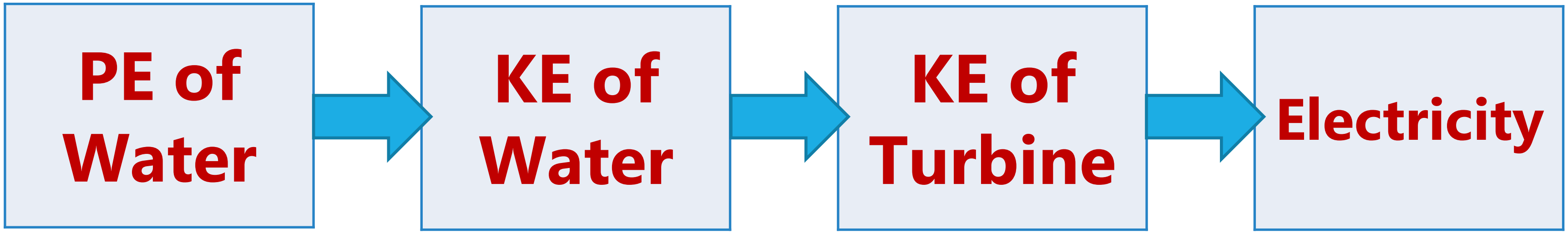
Solar Heating Panel



Hydropower



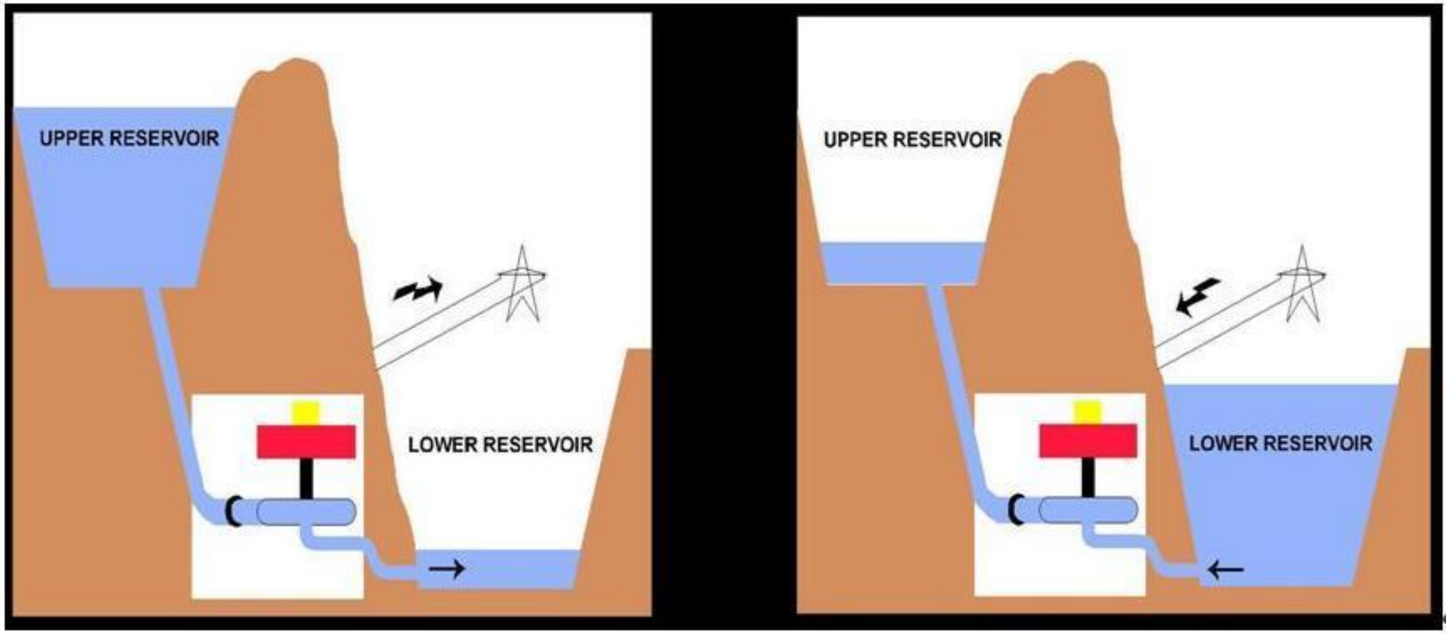




PE of Water → **KE of Water** → **KE of Turbine** → **Electricity**

Storing Energy in Hydropower

If there is excess electricity, this energy can be stored by pumping water back up to the reservoir



GENERATING MODE

PUMPING TO STORAGE MODE

pumped hydro operating principals

Issues of the Renewables

- Storage
- Upfront cost
- Control over timing

Thermal Energy Transfer & Black Body Radiation

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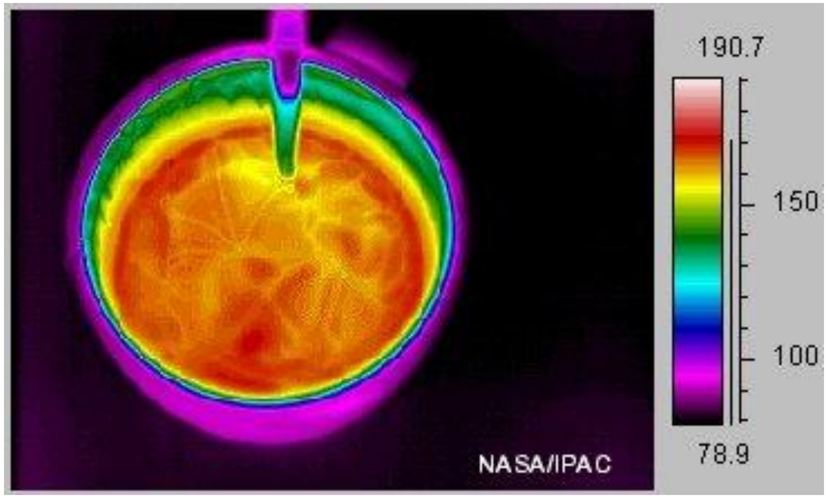
Heat Transfer

There are 3 primary ways that heat is transferred:

- Conduction
- Convection
- Radiation

Conduction

Conduction occurs between objects in direct ____contact____



Conduction

Why does this frying pan have a plastic handle?

Plastic has a high specific heat and doesn't conduct heat very quickly

Convection

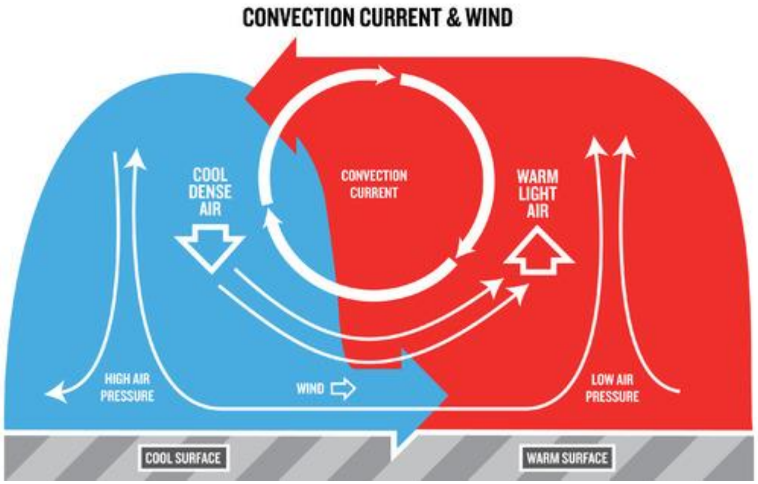
Convection occurs when fluids (liquids or gases) move around due to temperature differences

Hot Air rises

Cold Air sinks

Where should I roast my marshmallow?

Convection

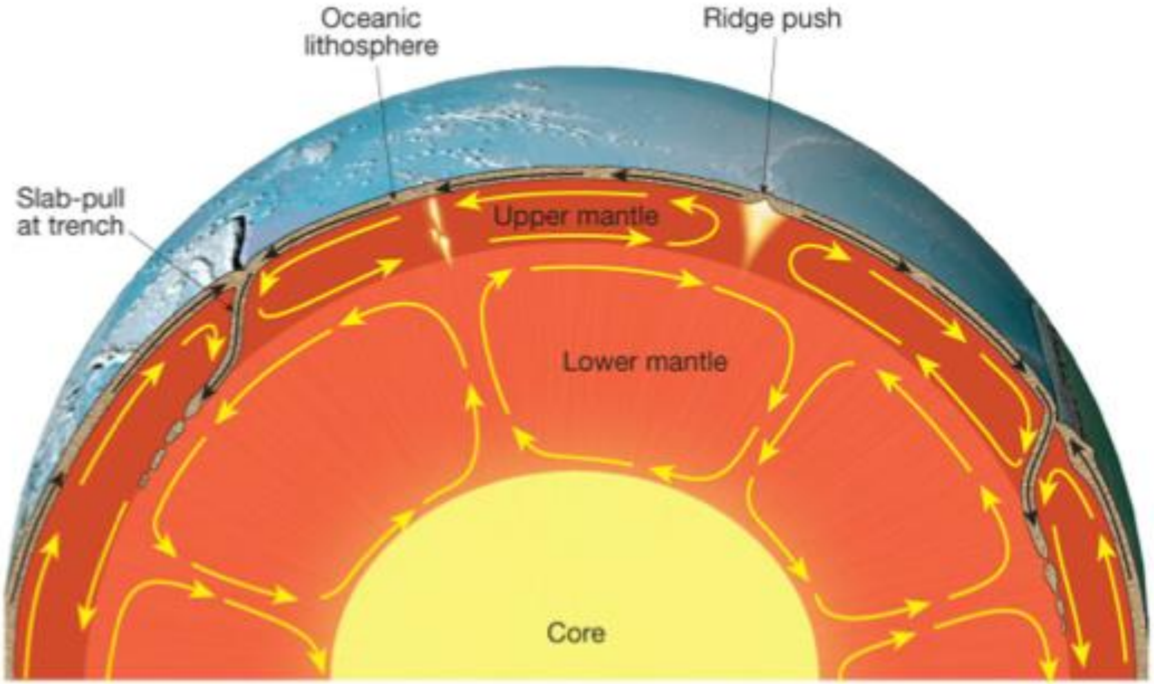


Why does hot air rise?

High Temperature
High Volume

High Volume
Same Mass
Lower Density

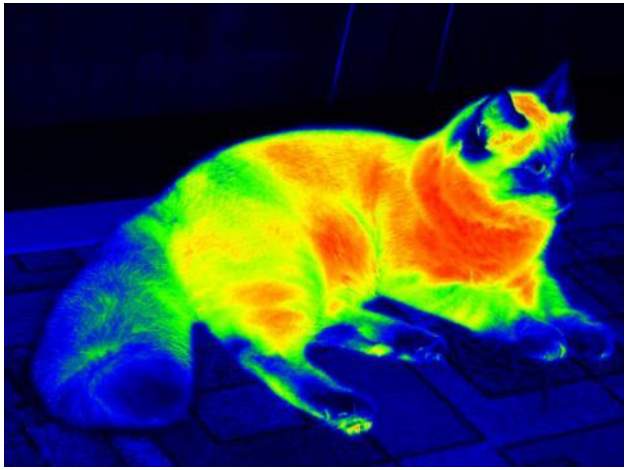
Convection

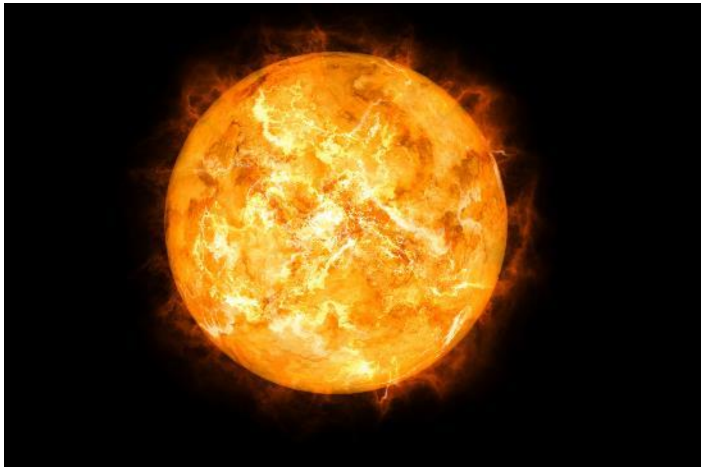

Oceanic lithosphere
Ridge push
Slab-pull at trench
Upper mantle
Lower mantle
Core


MATHMOS

Radiation

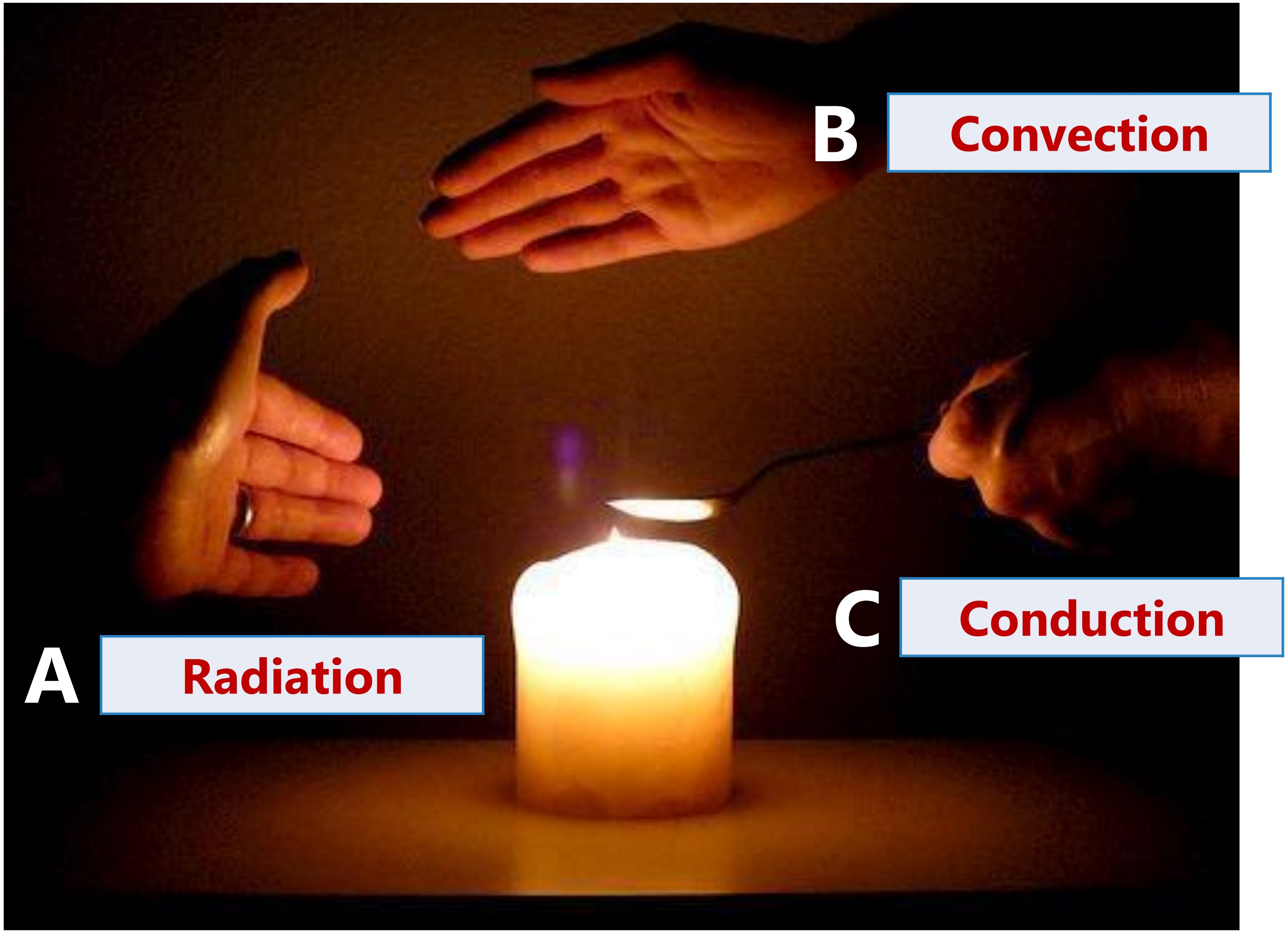
Radiation is energy that is transferred as waves such as visible light and infrared





Radiation can travel through ____a vacuum_____

Label Me



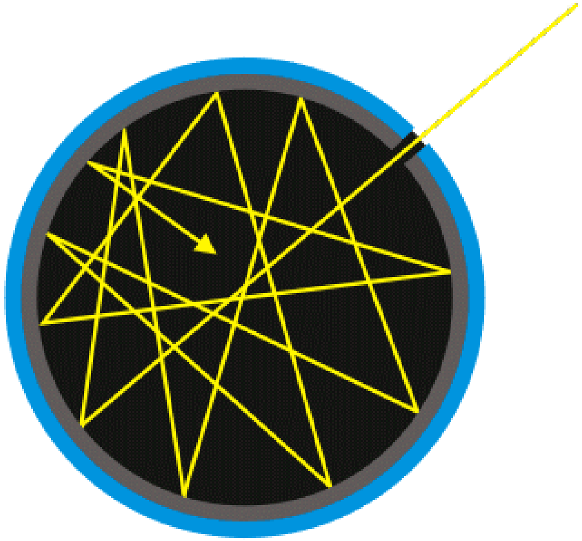
Emissivity

What color car heats up the most in the sun?

Black – Absorbs more light

Black Body Radiator

A black body radiator is an object that is perfectly opaque and absorbs all energy



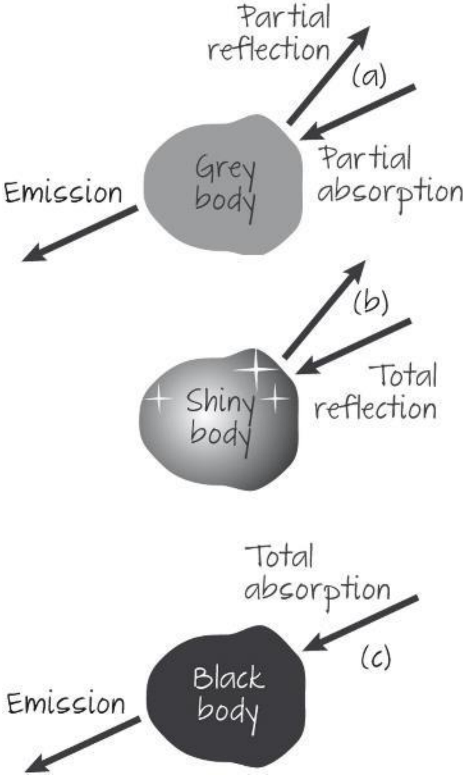
Conceptual Black Body

Emissivity

Emissivity	e	$\dfrac{power\ radiated\ by\ a\ surface}{power\ radiated\ from\ a\ black\ body\ of\ the\ same\ temperature\ and\ area}$

The emissivity is used to adjust for an object that isn't a perfect black-body radiator

This value is always between 0 and 1



$e \approx 1$

$e \approx 0.6$

Stefan-Boltzmann Law

$$P = e\sigma A T^4$$

Power [W]

e is usually = 1

5.67×10^{-8} W m^{-2} K^{-4}

Surface Area [m^2]

Absolute Temperature [K]

$A_{sphere} = 4\pi r^2$

Emissivity	e	$\frac{power\ radiated\ by\ a\ surface}{power\ radiated\ from\ a\ black\ body\ of\ the\ same\ temperature\ and\ area}$
Stefan-Boltzmann Constant	σ	5.67×10^{-8} W m^{-2} K^{-4}

Try This

A star has a radius of 8.3×10^7 m and a surface temperature of 7500°C. Calculate the power it emits.

$e = 1$

$\sigma = 5.67 \times 10^{-8}\ \mathrm{W\ m^{-2}\ K^{-4}}$

$A = 4\pi(8.3 \times 10^7)^2 = 8.66 \times 10^{16}\ \mathrm{m^2}$

$T = 7500 + 273 = 7773\ \mathrm{K}$

$$P = e\sigma AT^4$$

$$P = (1)(5.67 \times 10^{-8})(8.66 \times 10^{16})(7773)^4$$

$$\boxed{P = \mathbf{1.79 \times 10^{25}\ W}}$$

Proportionality

How much more heat energy is radiated from a 80°C cup of water than from a 20°C cup of water?

$$P = e\sigma AT^4$$

**Careful! Temperature must be converted into Kelvin*

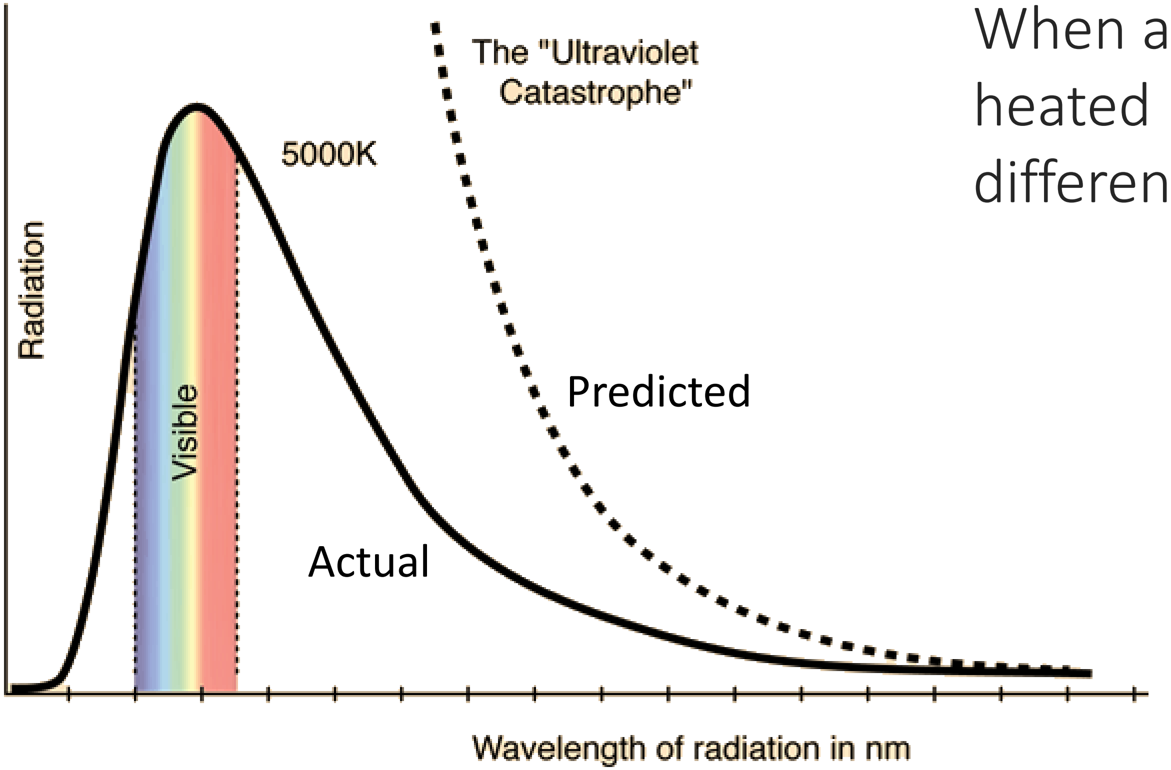
$$T_1 = 80 + 273 = 353\ \mathrm{K}$$

$$T_2 = 20 + 273 = 293\ \mathrm{K}$$

e, σ, and A are all the same before and after…

$$\frac{P_1}{P_2} = \frac{\cancel{e}\cancel{\sigma}\cancel{A}T_1{}^4}{\cancel{e}\cancel{\sigma}\cancel{A}T_2{}^4} = \frac{353^4}{293^4} = 2.1\ times\ more$$

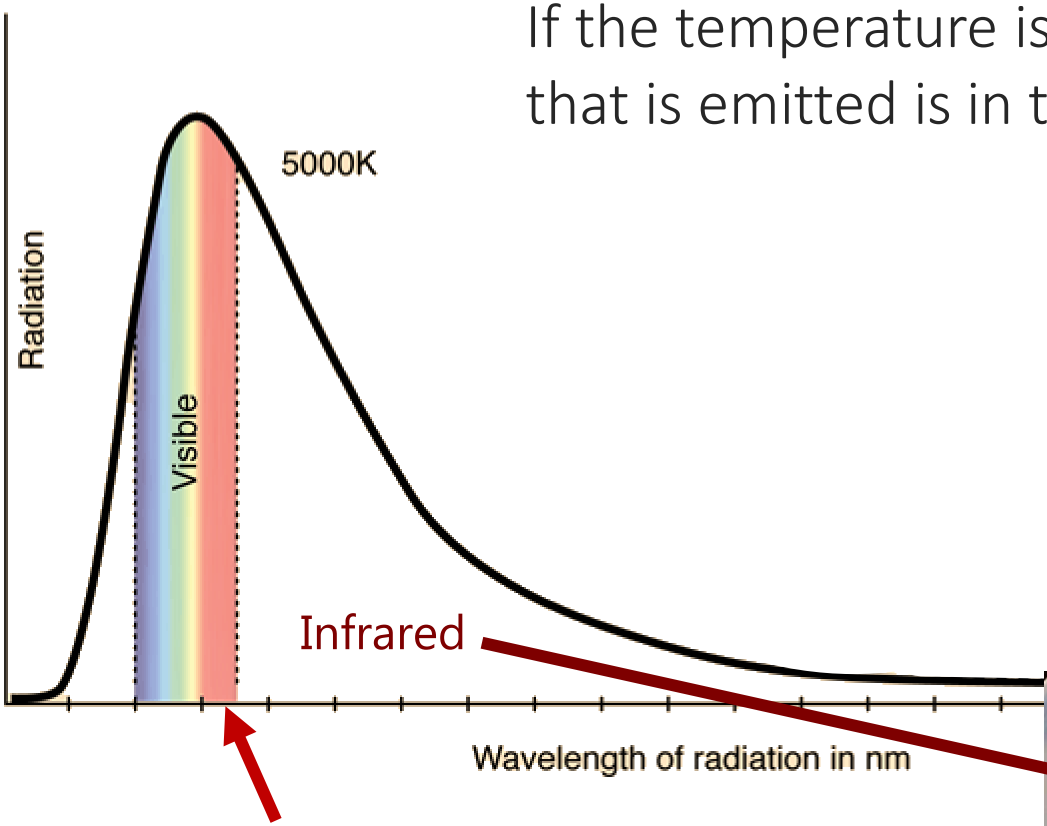
Radiated Energy

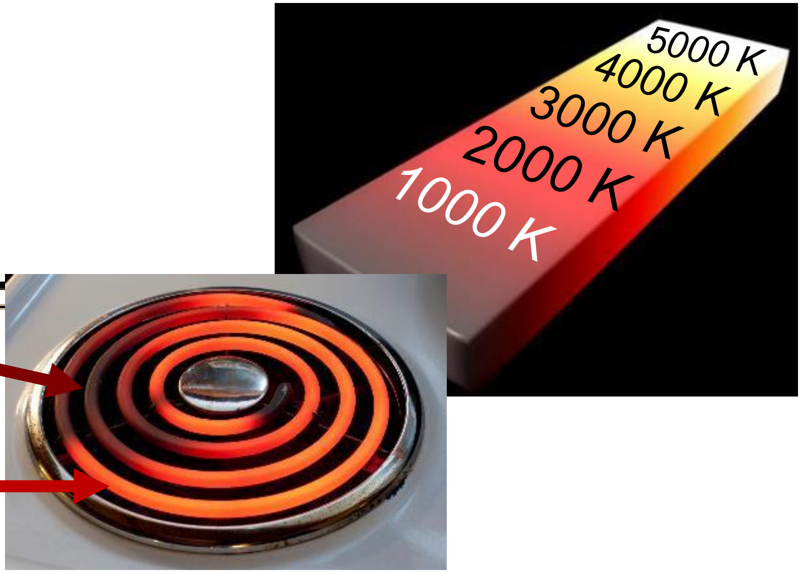


When a black body radiator is heated up, it emits a range of different wavelengths

Glowing Hot

If the temperature is high enough the radiation that is emitted is in the visible spectrum



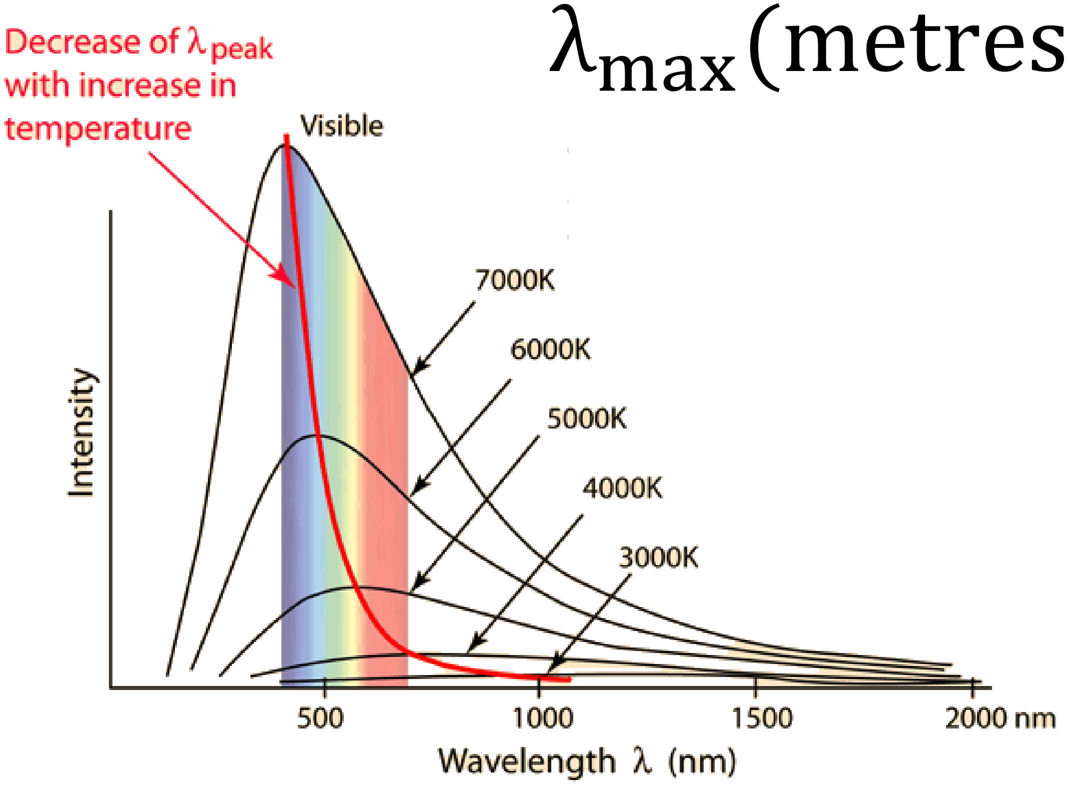


Infrared

Visible
Red Light

Wien’s Displacement Law

$$\lambda_{\text{max}}(\text{metres}) = \frac{2.90 \times 10^{-3}}{\text{T (kelvin)}}$$



*Note: This assumes perfect blackbody radiation

Try This

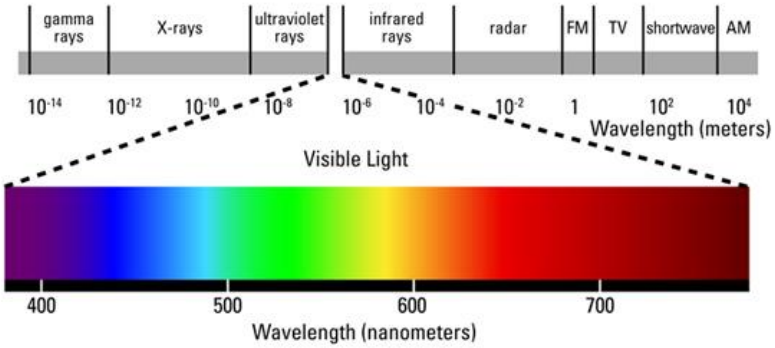
$$\lambda_{\max}(\text{metres}) = \frac{2.90 \times 10^{-3}}{\text{T (kelvin)}}$$

At what wavelength is the emitted radiation of the Sun maximized if it has a surface temperature of 5780 K?

$$\lambda = \frac{2.90 \times 10^{-3}}{5780} = 5.02 \times 10^{-7}\text{m} = \boxed{502\text{ nm}}$$

What is the most prevalent color of sunlight?

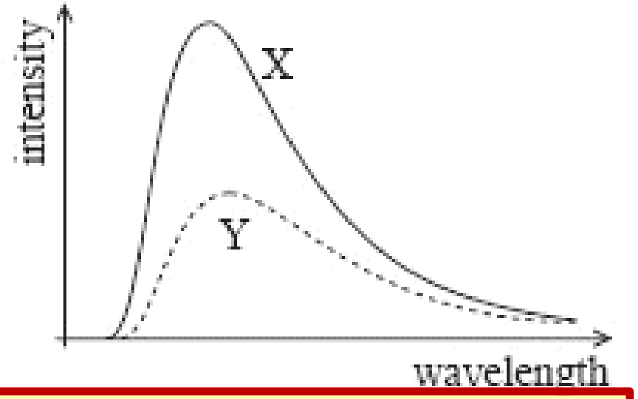
Green



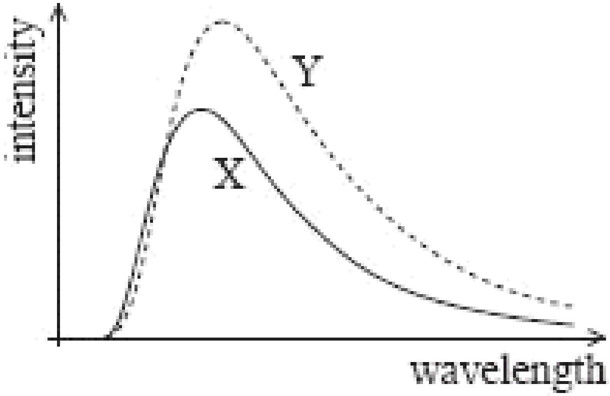
Sample IB Question

Two black bodies X and Y are at different temperatures. The temperature of body Y is higher than that of body X. Which of the following shows the black body spectra for the two bodies?

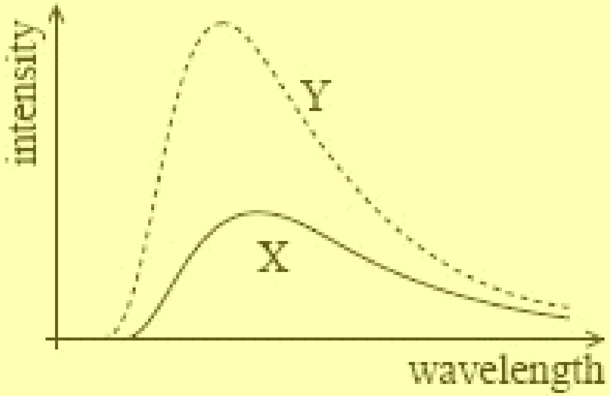
A.



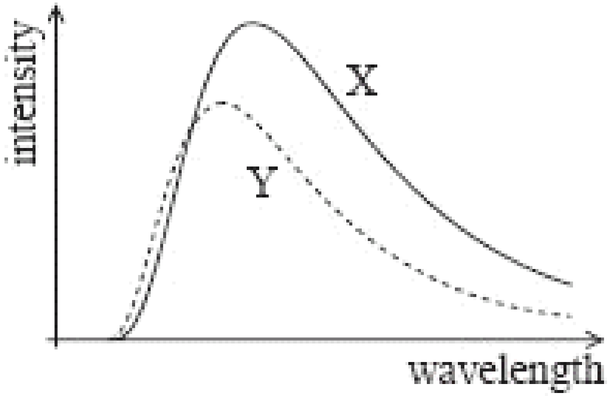
B.



C.



D.



Takeaways from Today

Know the difference between:

- Conduction
- Convection
- Radiation

Black Body Radiators

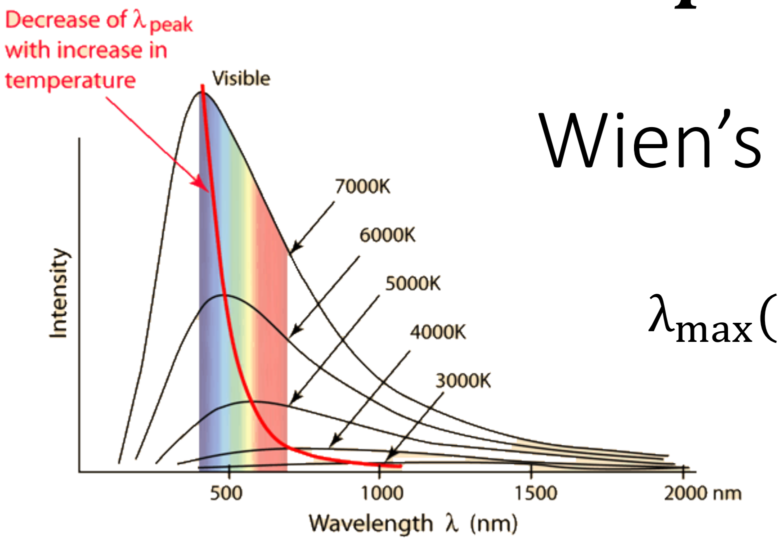
Emissivity

Stefan-Boltzmann Law

$$P = e\sigma A T^4$$

Wien's Displacement Law

$$\lambda_{\text{max}}(\text{metres}) = \frac{2.90 \times 10^{-3}}{\text{T (kelvin)}}$$



Radiation from the Sun

IB PHYSICS | ENERGY PRODUCTION

Intensity

$$Intensity = \frac{Power}{A}$$

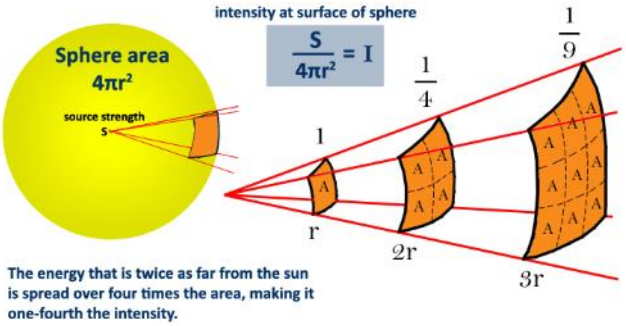
$$Units = \frac{W}{m^2} = Wm^{-2}$$

Intensity

Calculate the intensity of the Sun’s radiation arriving to Earth

Sun’s Power = 3.84×10^{26} W

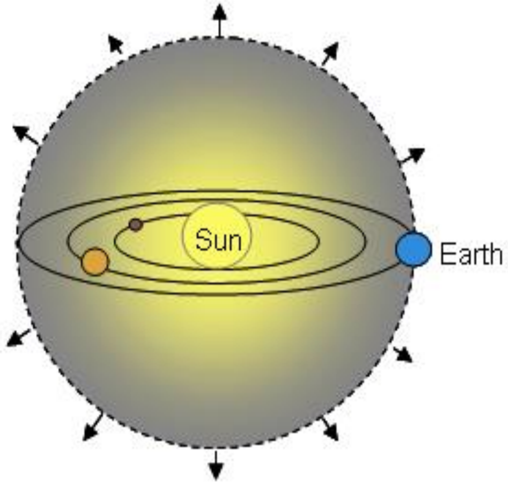
Earth’s Distance from Sun = 150×10^{6} km



The energy that is twice as far from the sun is spread over four times the area, making it one-fourth the intensity.

$$I = \frac{P}{A} = \frac{3.84 \times 10^{26}}{4\pi(150 \times 10^{9})^{2}}$$

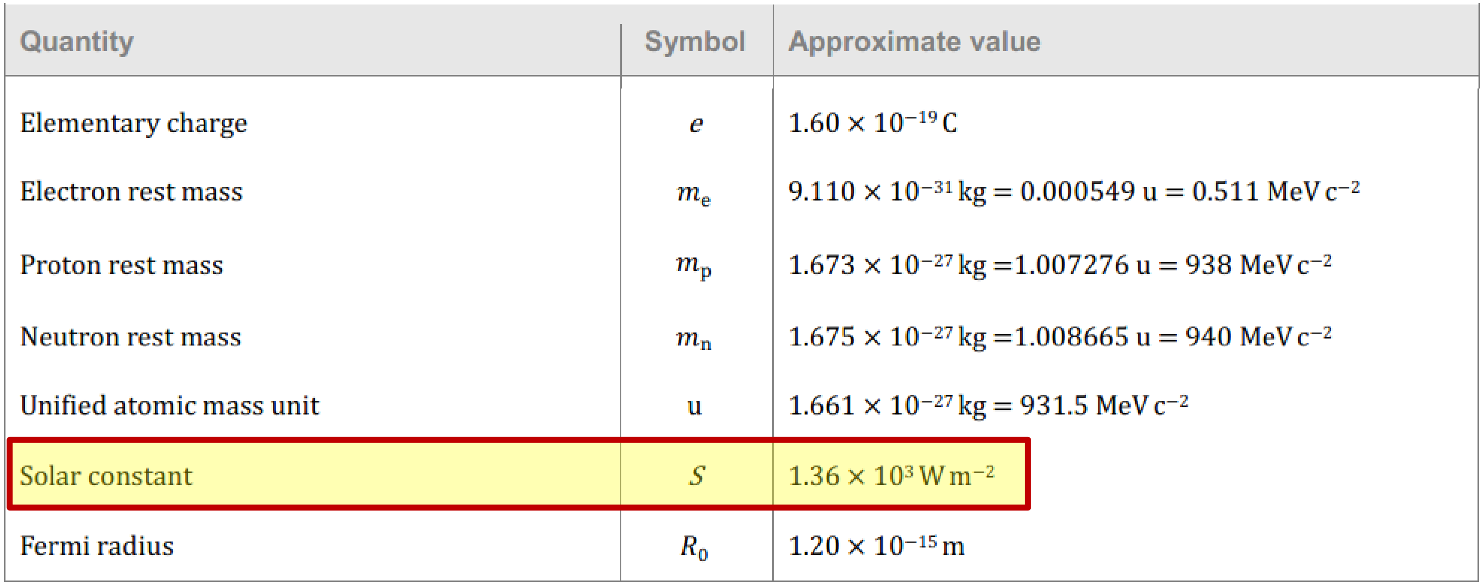
$$\boxed{I = 1358\,\mathrm{Wm^{-2}}}$$



Solar Constant

The average intensity falling on an area above the earth’s atmosphere perpendicular to the direction traveled by the radiation

$$S = 1360 \text{ W m}^{-2} = 1.36 \times 10^{3} \text{ W m}^{-2}$$



Quantity	Symbol	Approximate value
Elementary charge	e	1.60×10^{-19} C
Electron rest mass	m_e	9.110×10^{-31} kg = 0.000549 u = 0.511 MeV c^{-2}
Proton rest mass	m_p	1.673×10^{-27} kg =1.007276 u = 938 MeV c^{-2}
Neutron rest mass	m_n	1.675×10^{-27} kg =1.008665 u = 940 MeV c^{-2}
Unified atomic mass unit	u	1.661×10^{-27} kg = 931.5 MeV c^{-2}
Solar constant	S	1.36×10^{3} W m^{-2}
Fermi radius	R_0	1.20×10^{-15} m

Average Solar Intensity on Earth

Earth's Radius = 6.37×10^6 m

Area of sun power captured:

$$\pi r^2 = \pi(6.37 \times 10^6)^2 =$$

$$\boxed{1.27 \times 10^{14}\ \mathrm{m}^2}$$

Total sun power captured:

$$1.27 \times 10^{14}\ \mathrm{m}^2 \times \frac{1360\ \mathrm{W}}{1\ \mathrm{m}^2} =$$

$$\boxed{1.7 \times 10^{17}\ \mathrm{W}}$$

Average spread out across Earth's surface:

$$\frac{P}{A_{sphere}} = \frac{1.7 \times 10^{17}\ \mathrm{W}}{4\pi(6.37 \times 10^6)^2} =$$

$$\boxed{340\ \mathrm{W\ m}^2}$$

Total Power Received by the Earth

$$1.7 \times 10^{17}\ \mathrm{W}$$

Average Solar Intensity on Earth

$$340\ \mathrm{W\ m}^2$$

Albedo vs. Emissivity

Albedo

$$\frac{power\ scattered\ by\ a\ body}{incident\ power}$$

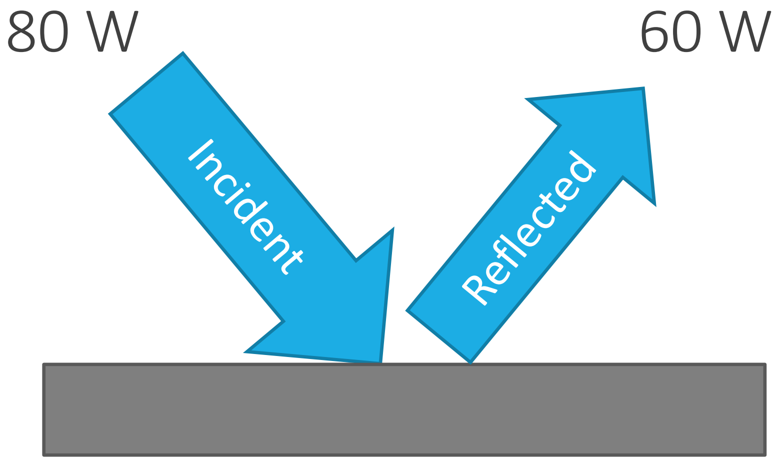
% Reflected

Emissivity	e

$$\frac{power\ radiated\ by\ a\ surface}{power\ radiated\ from\ a\ black\ body}$$

% Absorbed

Albedo vs. Emissivity



Albedo

$$\frac{60}{80} = 0.75$$

Emissivity

$$\frac{20}{80} = 0.25$$

Albedo of Earth

$$Albedo = \frac{102}{340} = 0.3$$

Albedo of Earth

Highest Albedo?

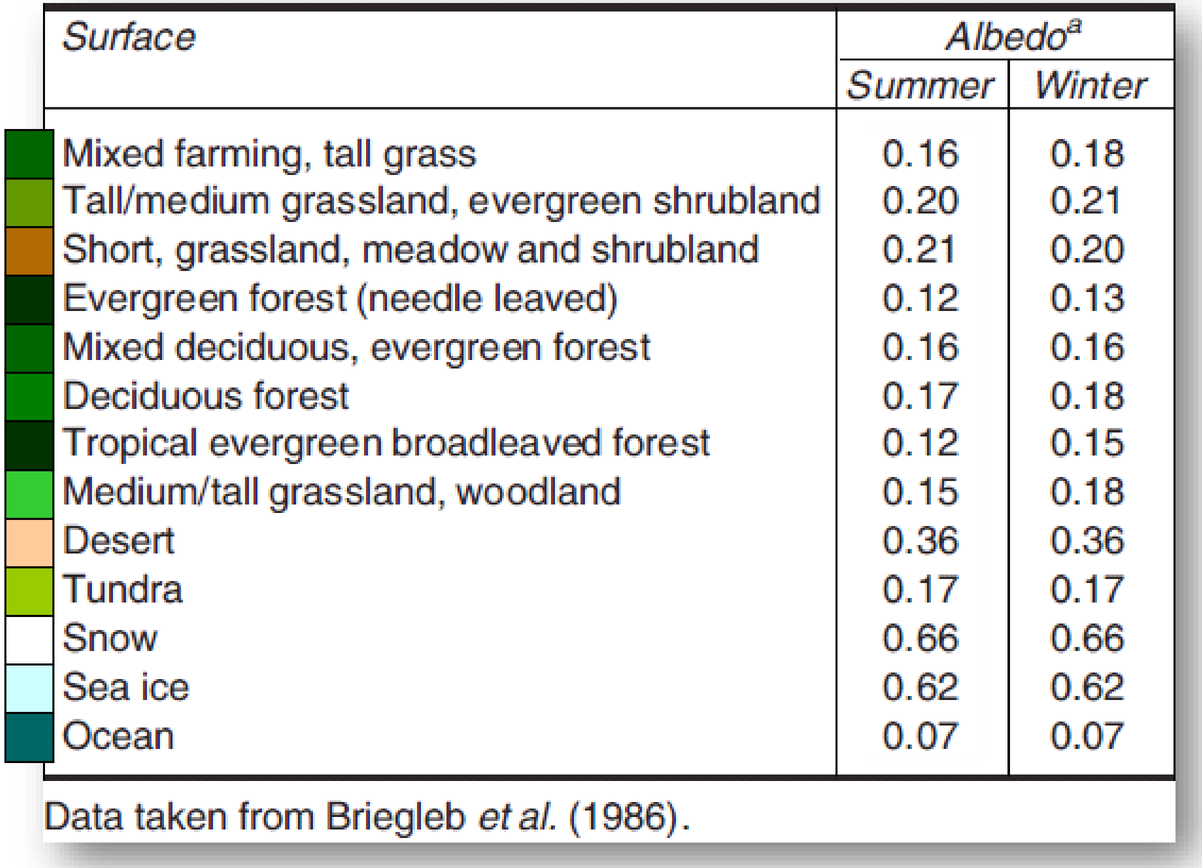
0.66

Snow

Lowest Albedo?

0.07

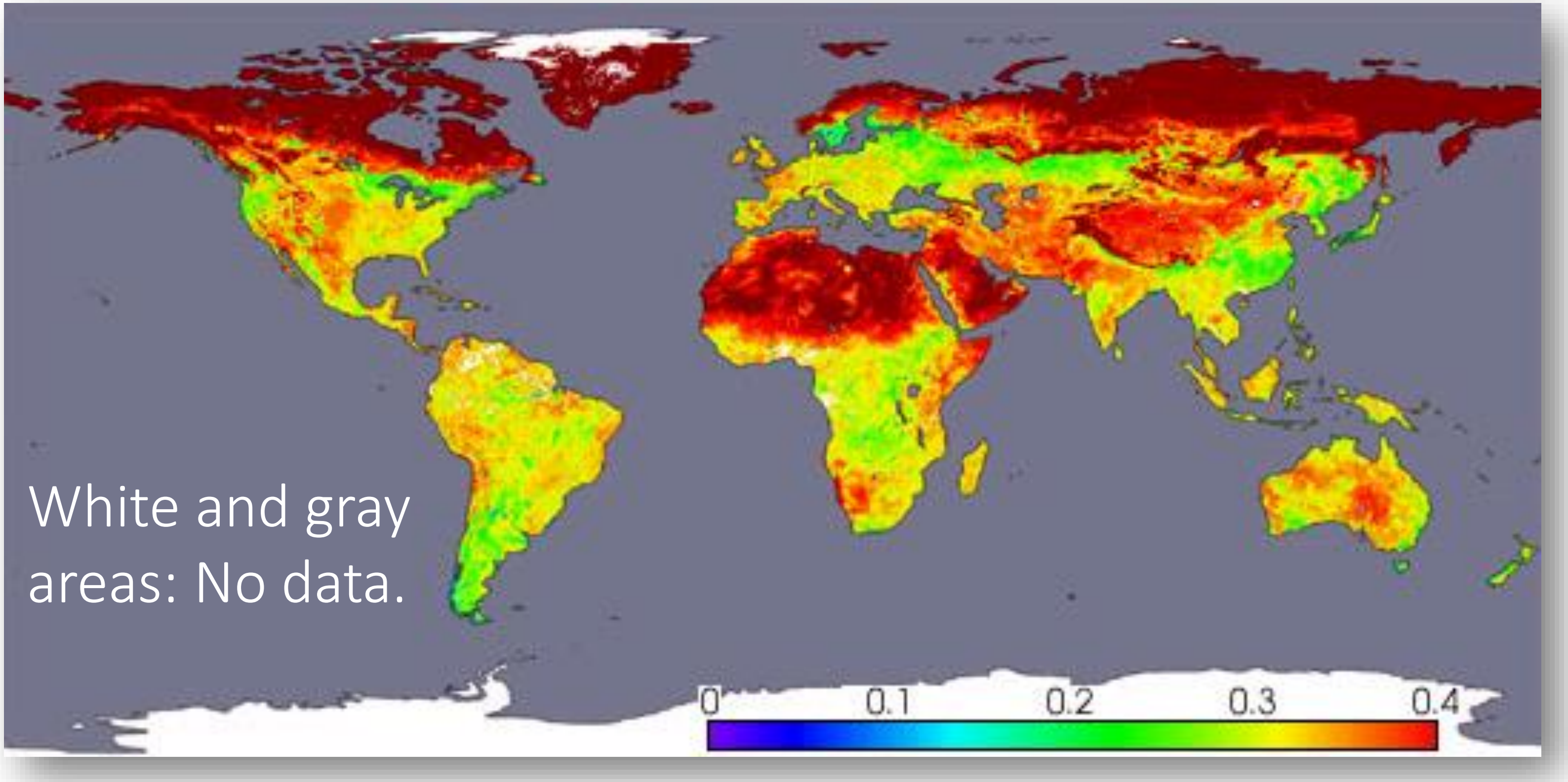
Ocean



	Surface	*Albedo*[a]	
		Summer	*Winter*
🟩	Mixed farming, tall grass	0.16	0.18
🟩	Tall/medium grassland, evergreen shrubland	0.20	0.21
🟫	Short, grassland, meadow and shrubland	0.21	0.20
🟩	Evergreen forest (needle leaved)	0.12	0.13
🟩	Mixed deciduous, evergreen forest	0.16	0.16
🟩	Deciduous forest	0.17	0.18
🟩	Tropical evergreen broadleaved forest	0.12	0.15
🟩	Medium/tall grassland, woodland	0.15	0.18
🟧	Desert	0.36	0.36
🟩	Tundra	0.17	0.17
⬜	Snow	0.66	0.66
⬜	Sea ice	0.62	0.62
🟦	Ocean	0.07	0.07

Data taken from Briegleb *et al.* (1986).

Albedo of Earth

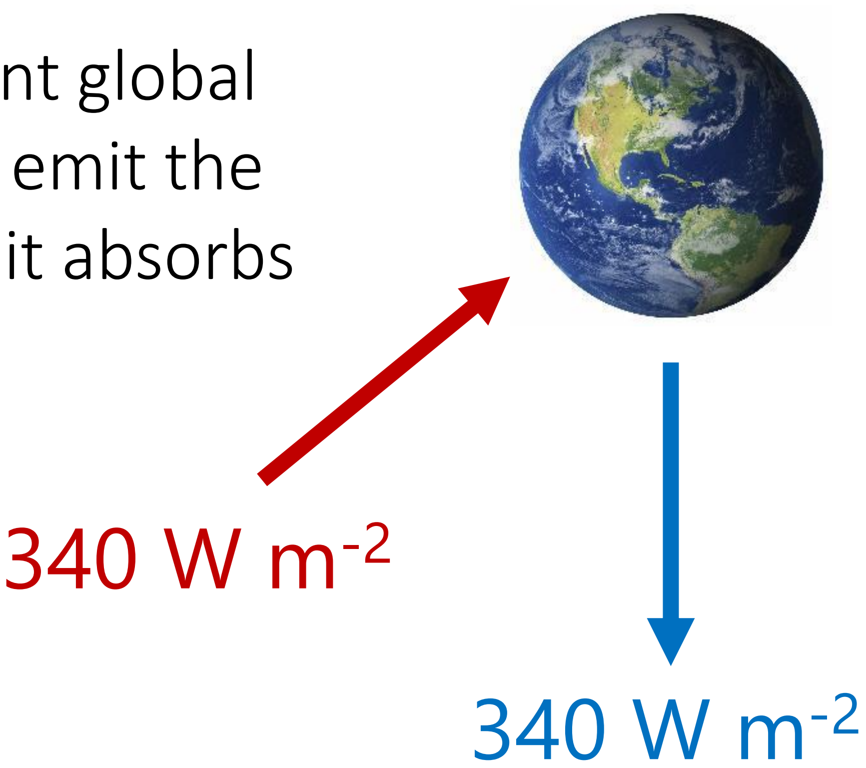


White and gray areas: No data.

April, 2002, *Terra* satellite, NASA

Thermal Equilibrium

In order to maintain a constant global temperature, the Earth must emit the same amount of energy that it absorbs

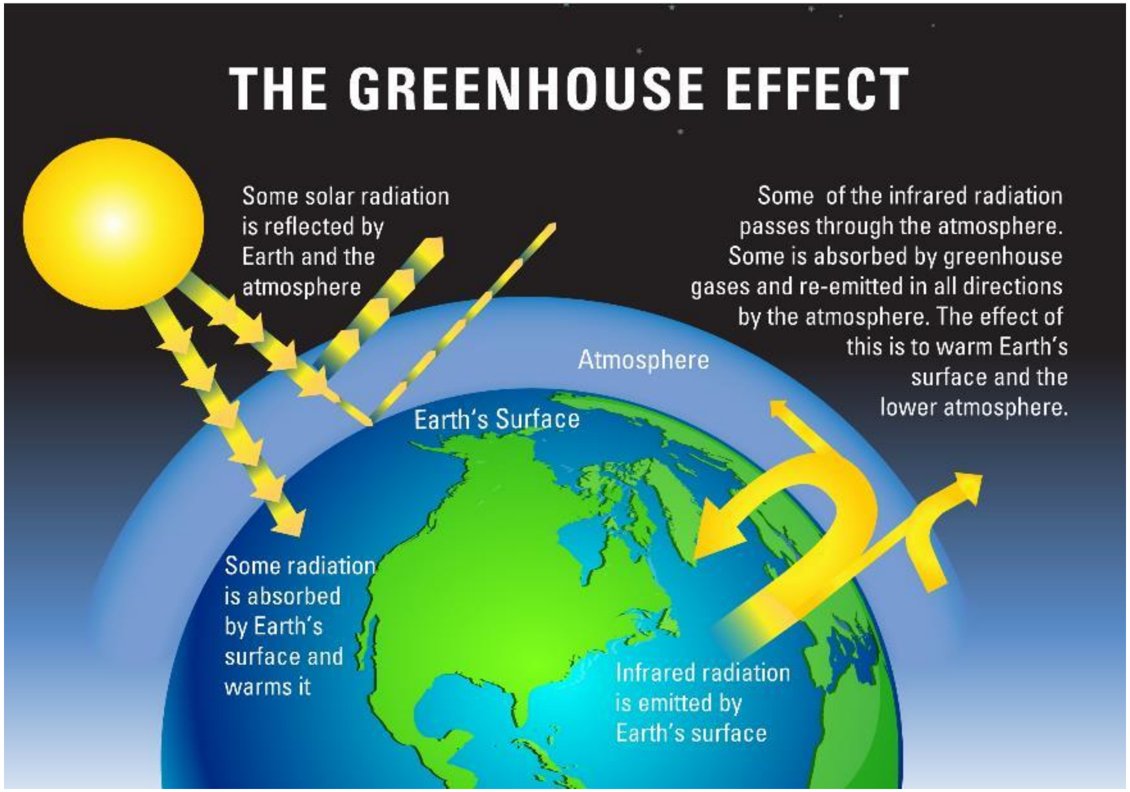


$340\ \mathrm{W\ m^{-2}}$

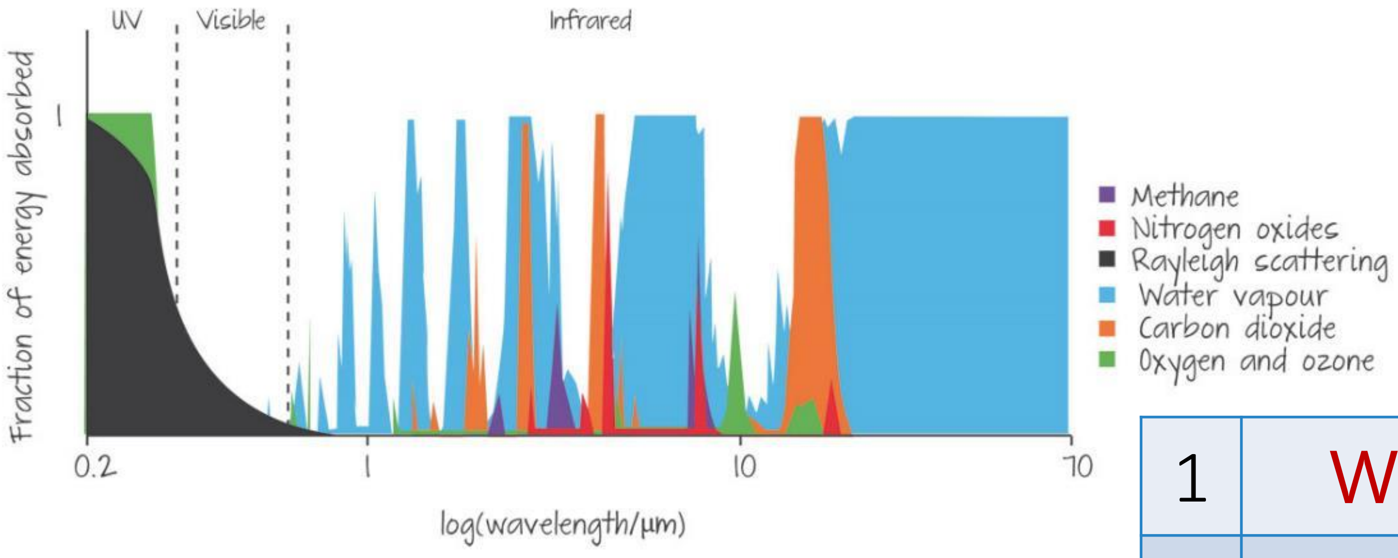
$340\ \mathrm{W\ m^{-2}}$

Greenhouse Effect

If there was no atmosphere, the earth would experience a net loss of energy and reach equilibrium at an average temperature about 30°C colder than it is currently.



Role of the Atmosphere



Rank the following Greenhouse Gases based on the amount of infrared energy they absorb →

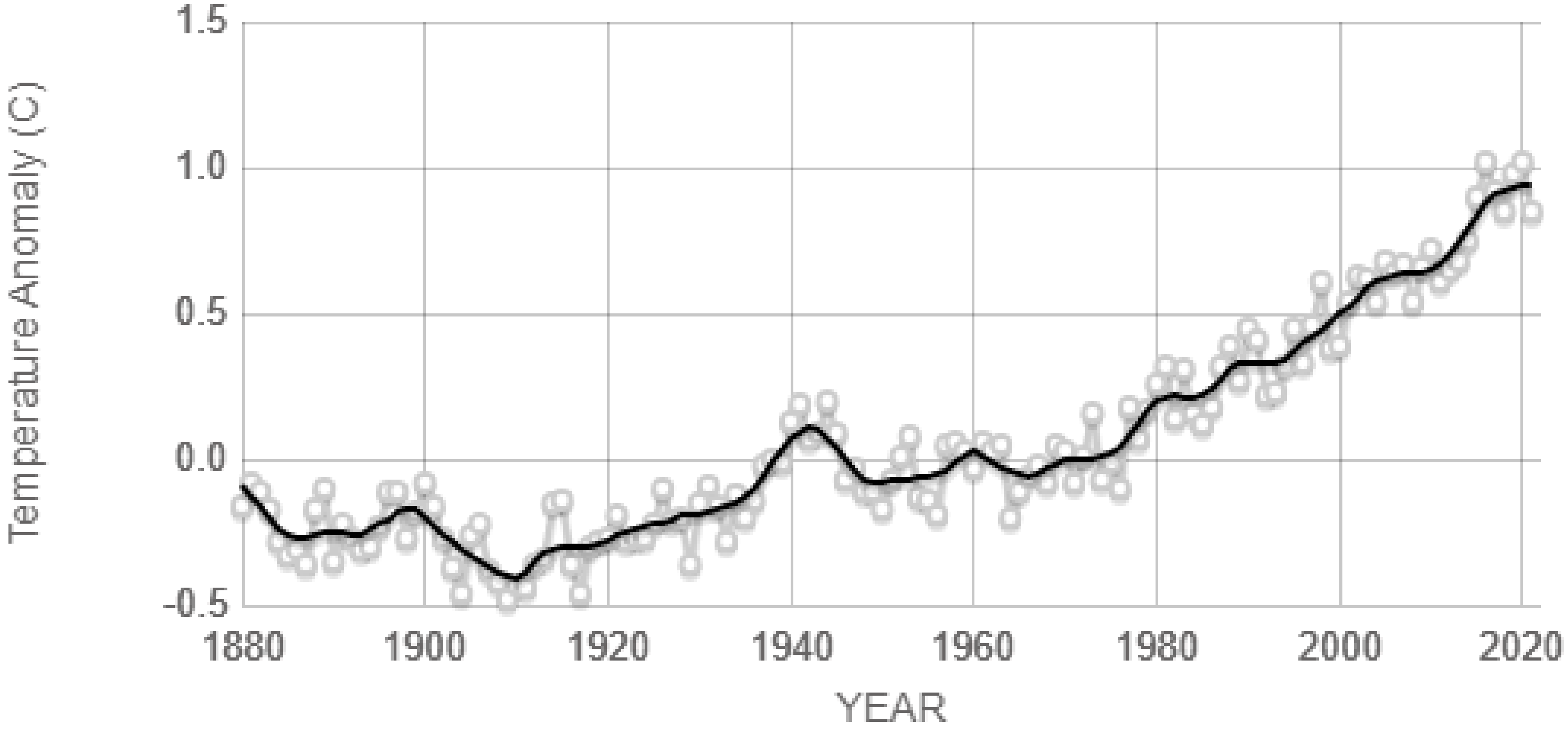
1	Water Vapor
2	Carbon Dioxide
3	Methane
4	Nitrogen Oxides
5	Oxygen/Ozone

More on this later…

Climate Change

IB PHYSICS | ENERGY PRODUCTION

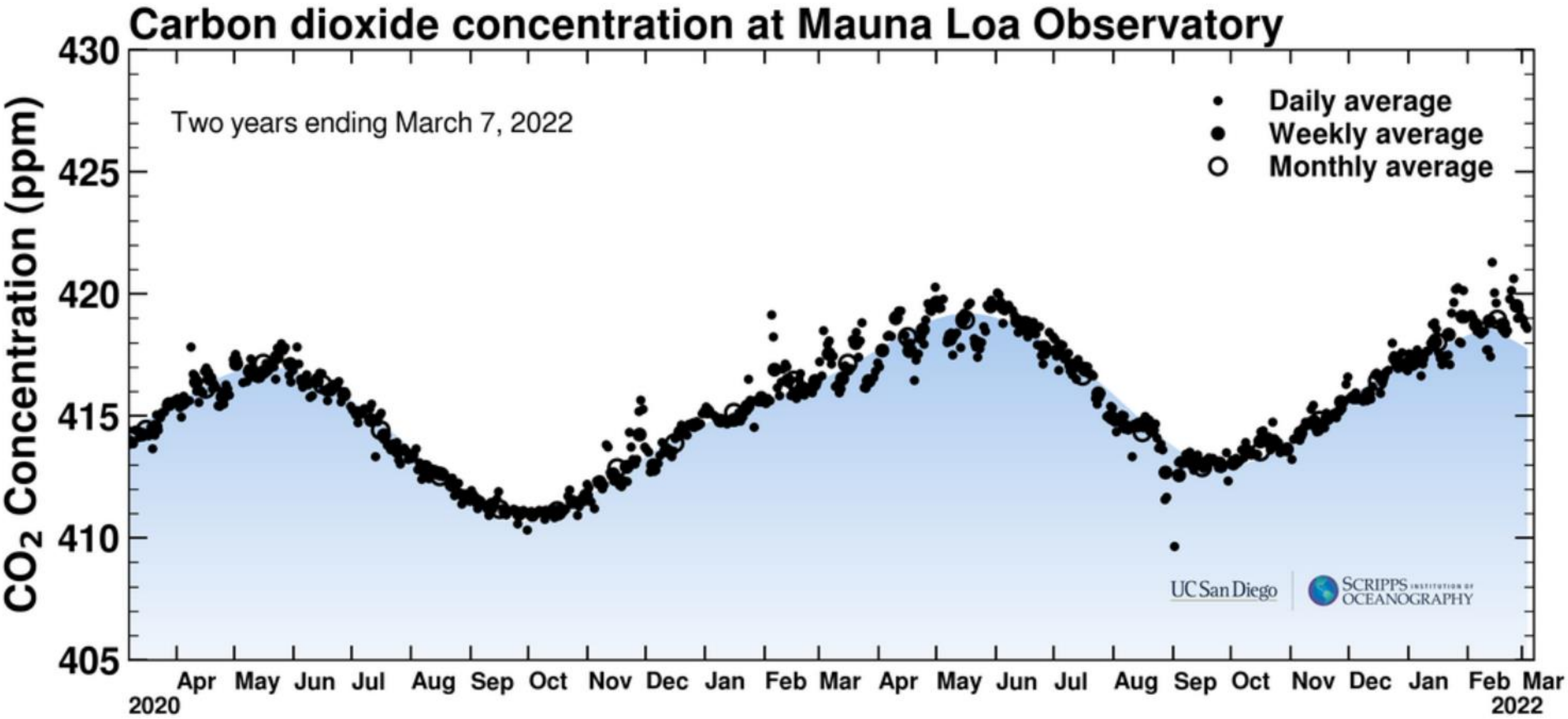
Temperature has been Rising



Source: climate.nasa.gov

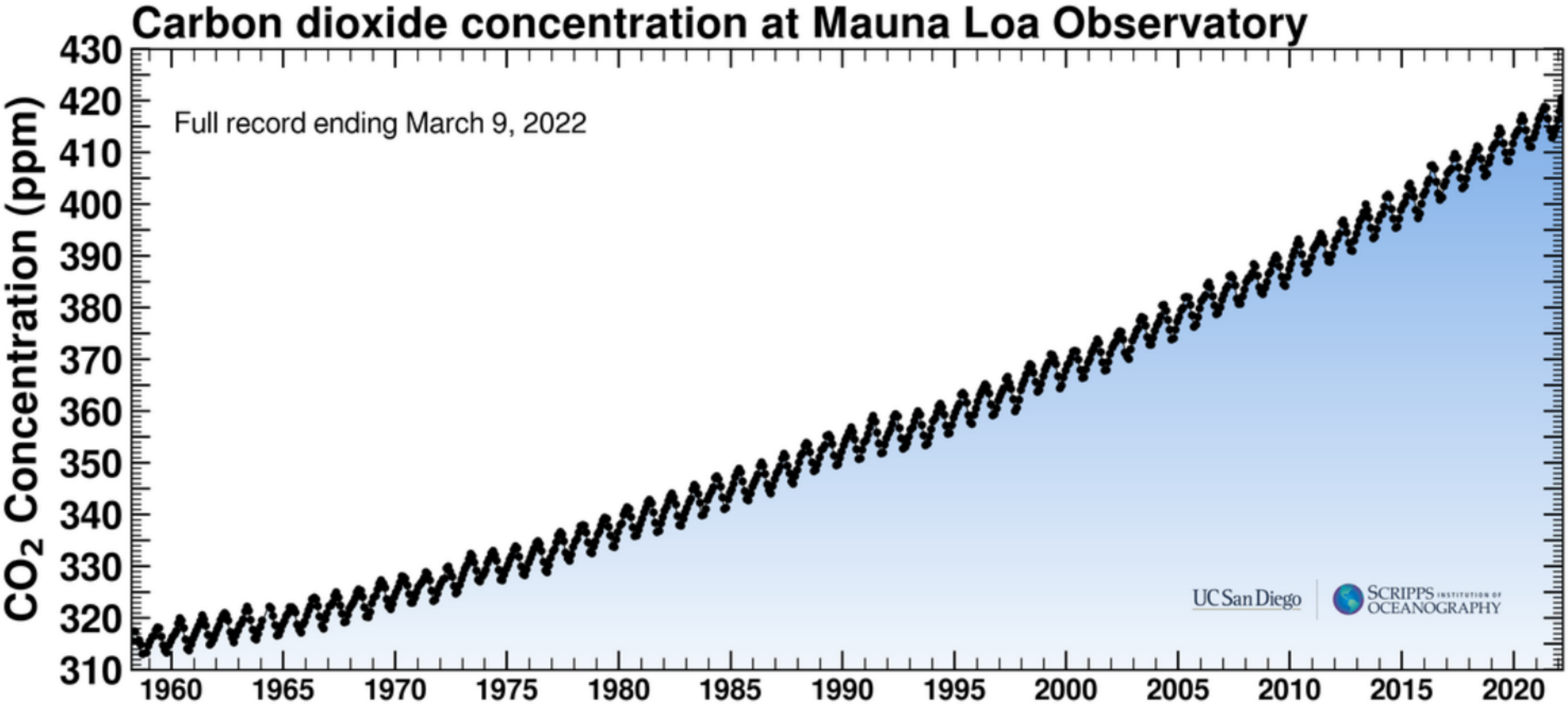
CO_2 Concentration | 2 years

Latest CO_2 Reading: **417.88 ppm**



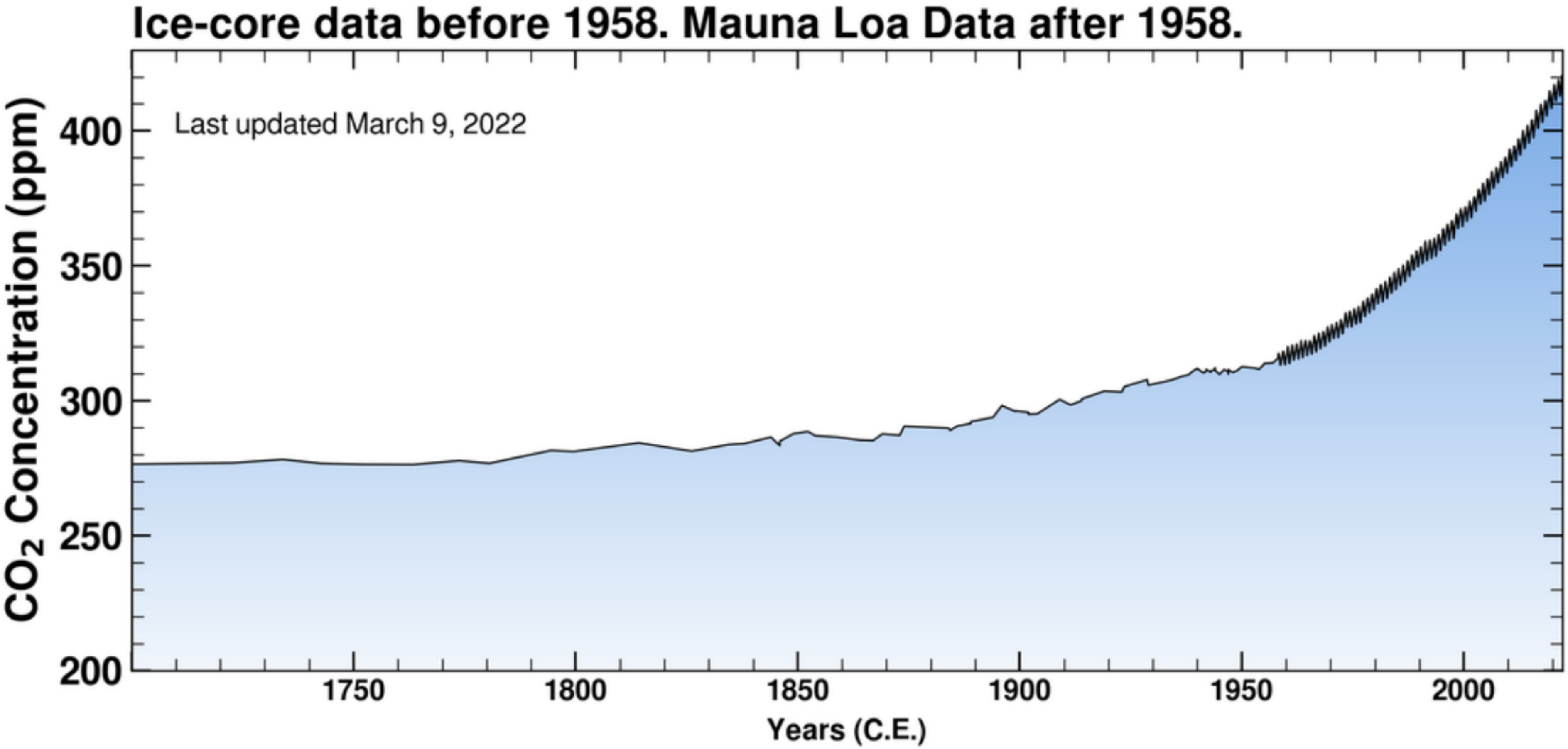
https://scripps.ucsd.edu/programs/keelingcurve/

CO_2 Concentration | 63 years



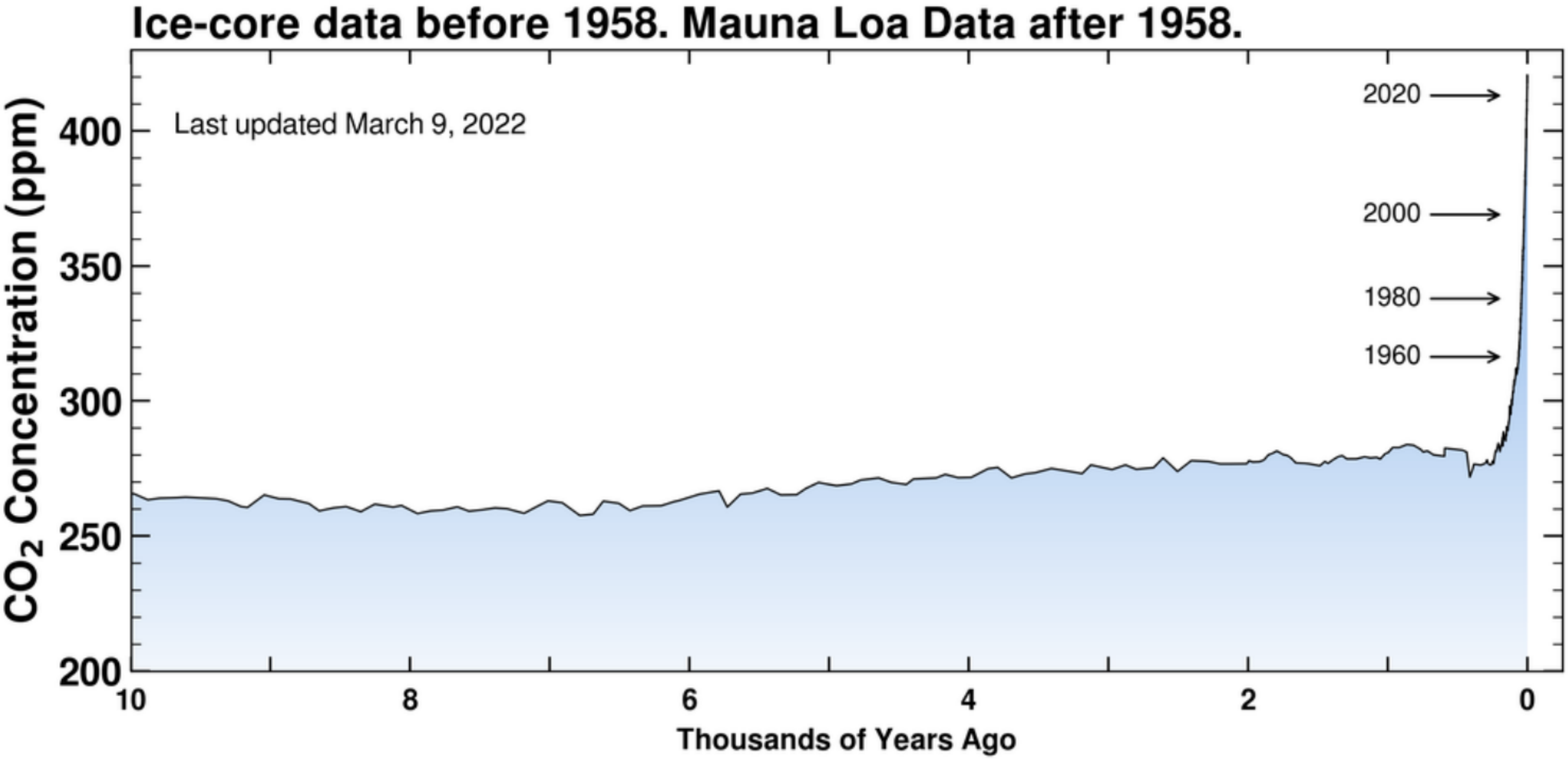
https://scripps.ucsd.edu/programs/keelingcurve/

CO_2 Concentration | 300 years



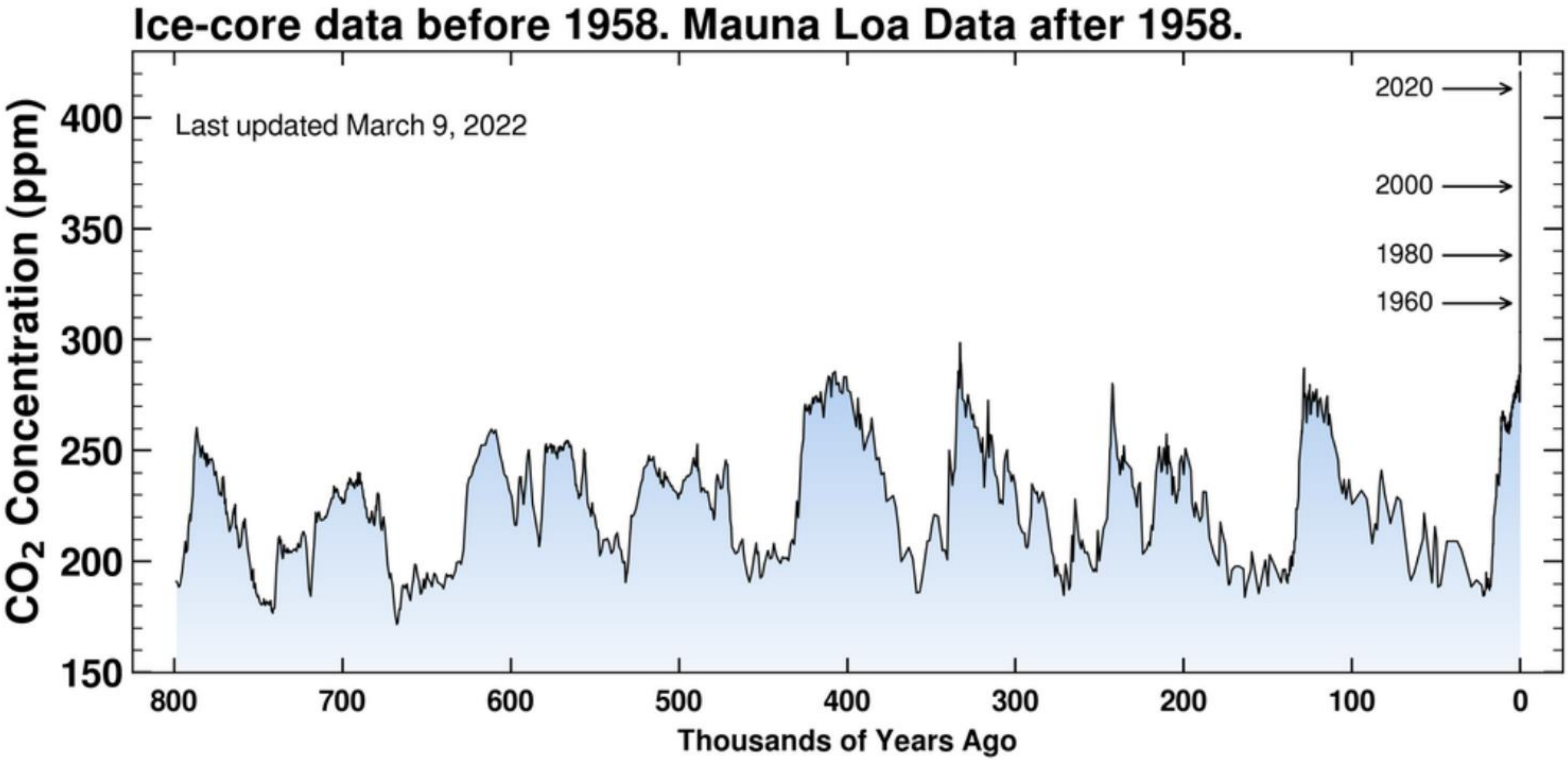
https://scripps.ucsd.edu/programs/keelingcurve/

CO_2 Concentration | 10,000 years



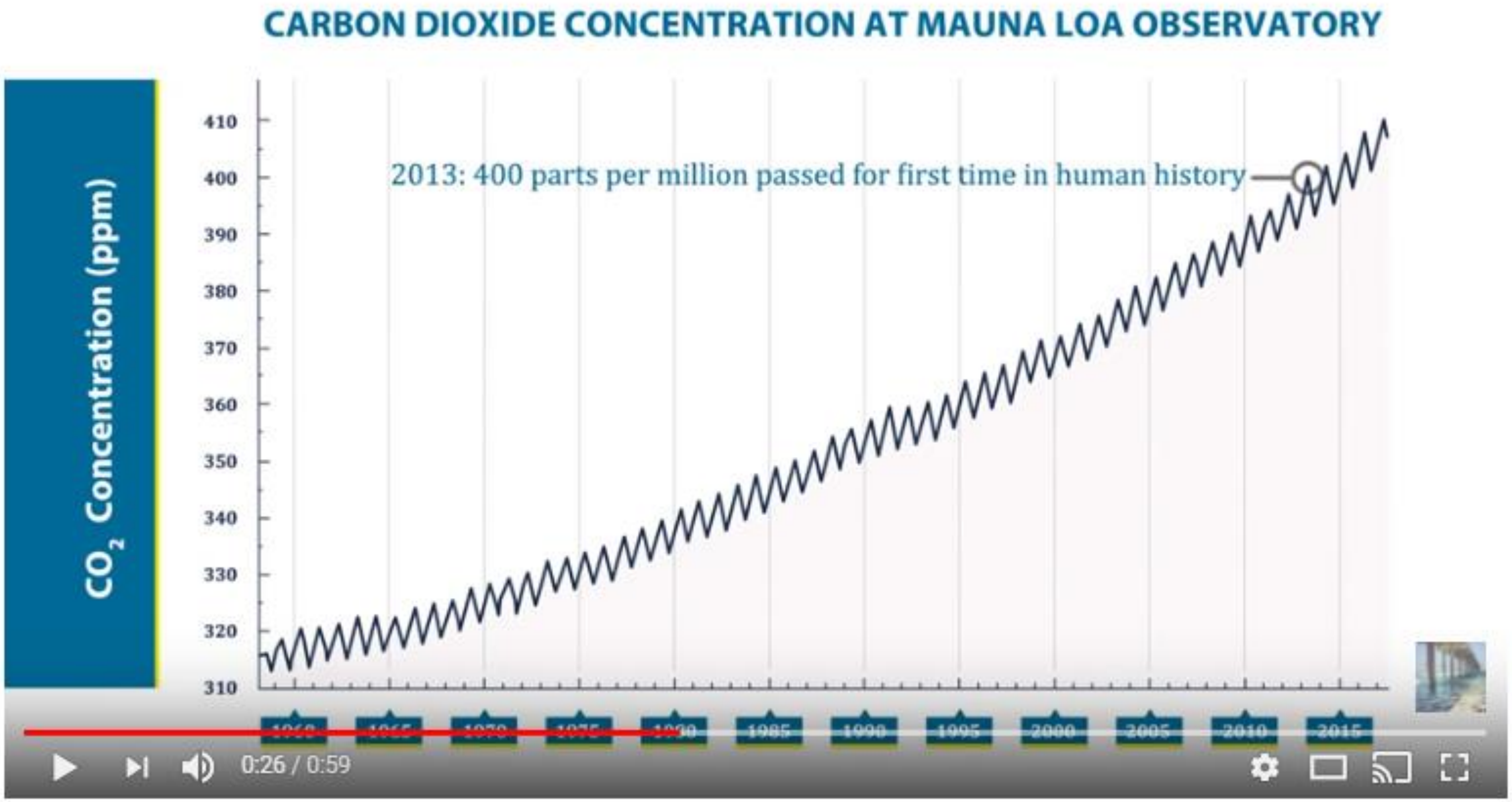
https://scripps.ucsd.edu/programs/keelingcurve/

CO_2 Concentration | 800,000 years



https://scripps.ucsd.edu/programs/keelingcurve/

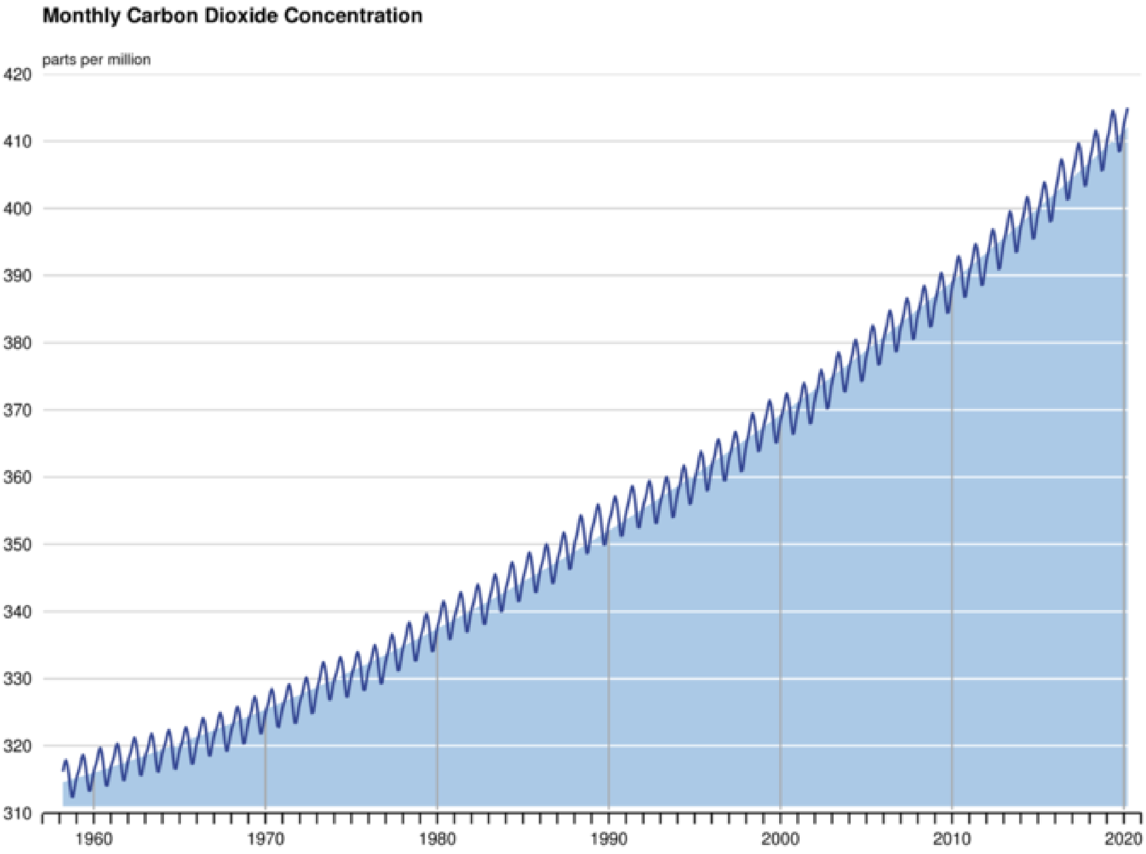
CO$_2$ Concentration



The Keeling Curve animation

https://scripps.ucsd.edu/programs/keelingcurve/

Why does the level fluctuate yearly?



Seasons

**There are more land (plants) in the Northern Hemisphere that remove CO_2 from the atmosphere during the summer months*

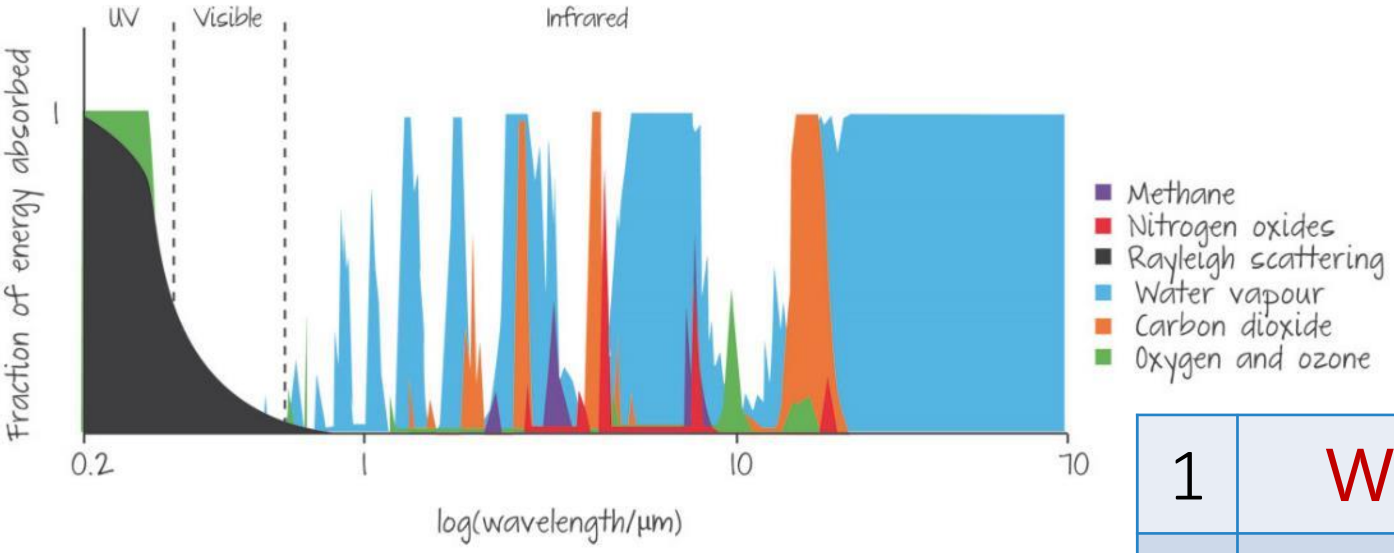
The Greenhouse Effect

How Do Greenhouse Gases Actually Work?

Gas molecules absorb and reemit infrared radiation

**This happens because the shape of these molecules means that they have natural vibration frequency that matches the frequency of infrared waves*

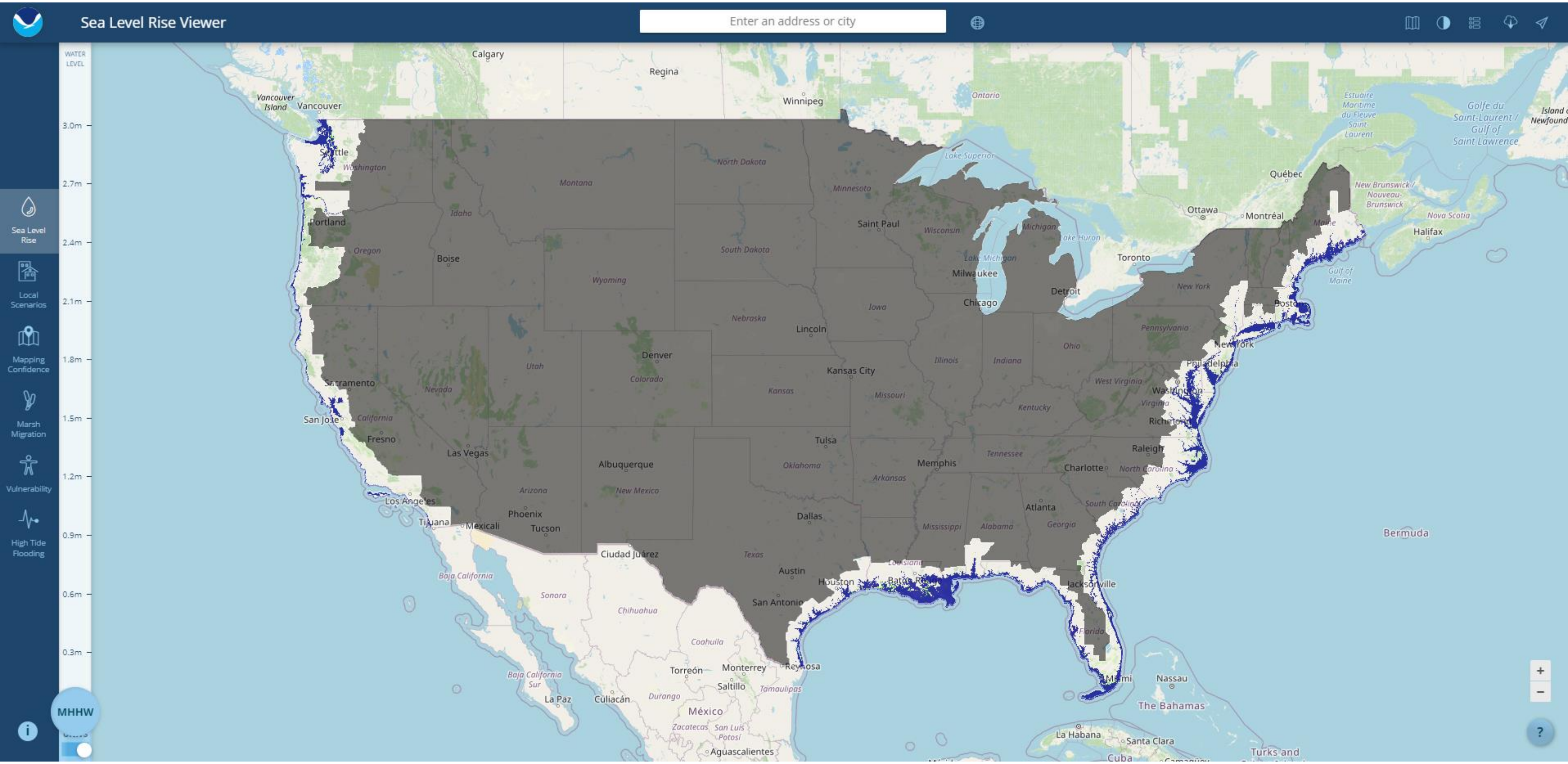
The Top Greenhouse Gases



Rank the following Greenhouse Gases based on the amount of infrared energy they absorb

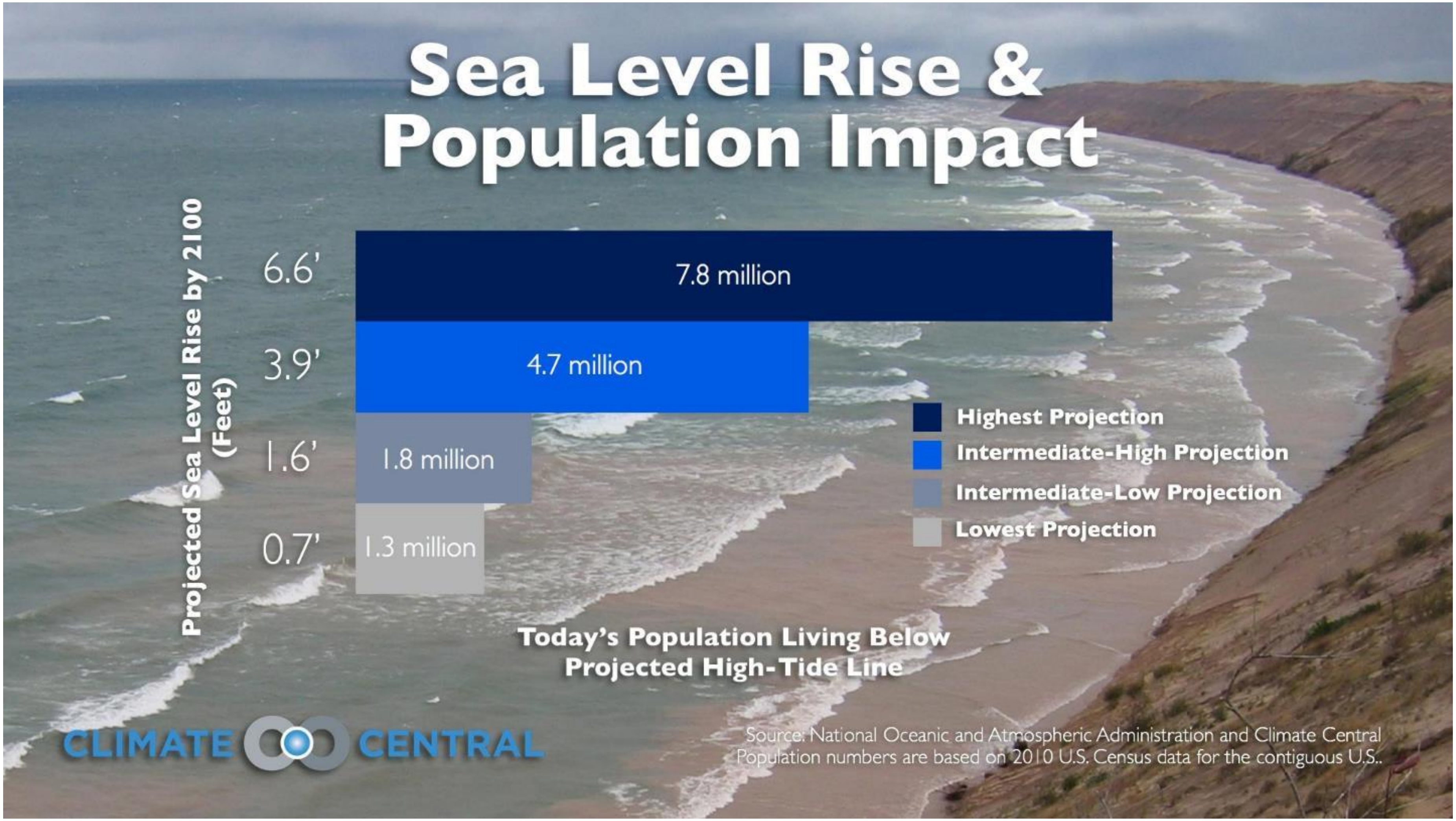
1	Water Vapor
2	Carbon Dioxide
3	Methane
4	Nitrogen Oxides
5	Oxygen/Ozone

Impacts of Climate Change



https://coast.noaa.gov/slr/#

Impacts of Climate Change



Source: National Oceanic and Atmospheric Administration and Climate Central
Population numbers are based on 2010 U.S. Census data for the contiguous U.S..

https://www.climatecentral.org/gallery/graphics/sea-level-rise-and-population-impact

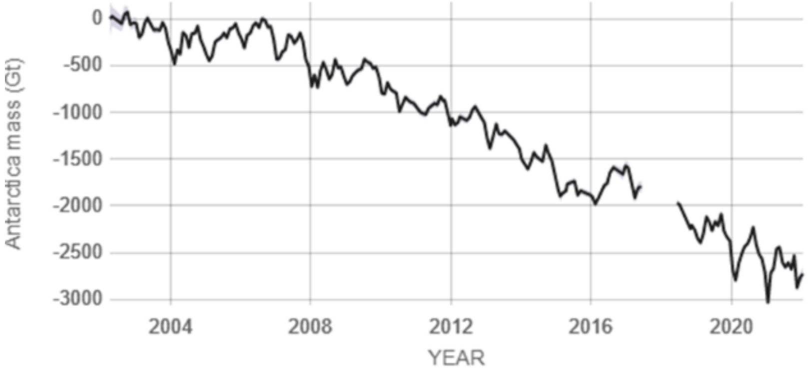
Sea Levels Rising | Melting Ice

A melting iceberg does not cause a direct change in sea level

A melting glacier adds water to the ocean and causes a direct change in sea level

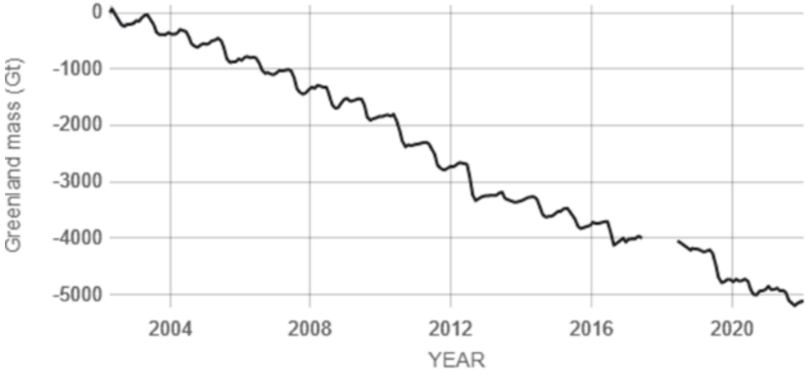
Why?

Sea Levels Rising | Melting Ice



Source: climate.nasa.gov

Antarctica ice mass is decreasing at a rate of 1521 billion tons per year

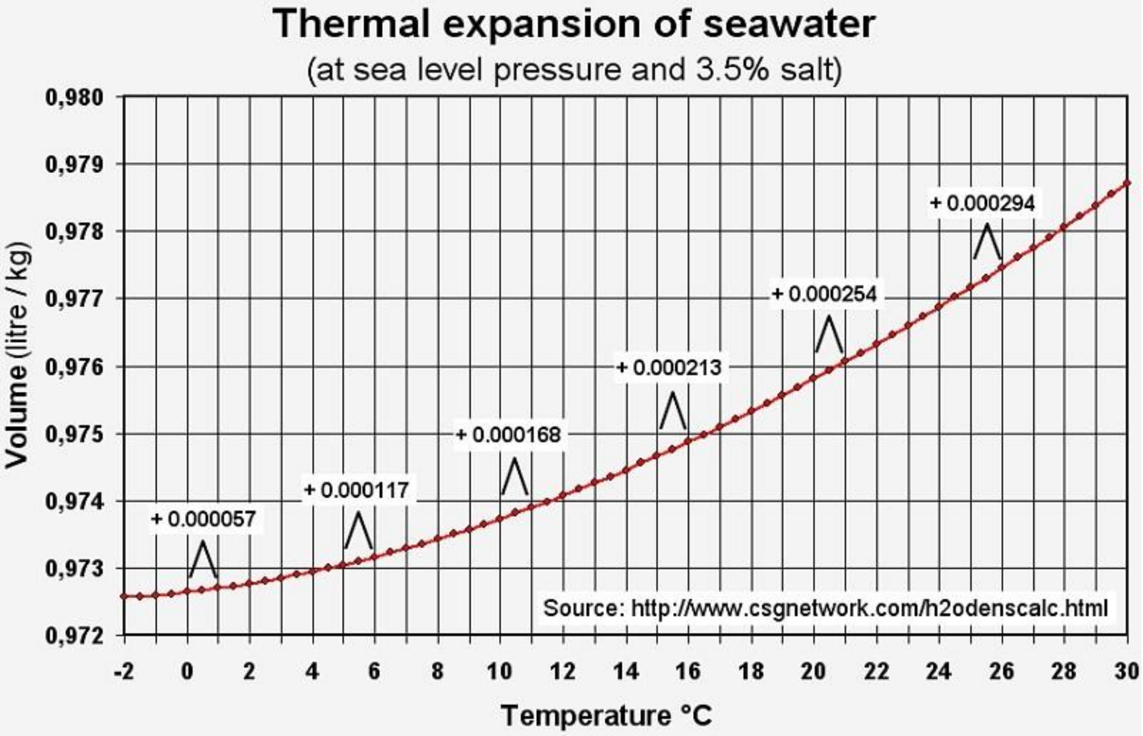


Source: climate.nasa.gov

Greenland ice mass is decreasing at a rate of 275 billion tons per year

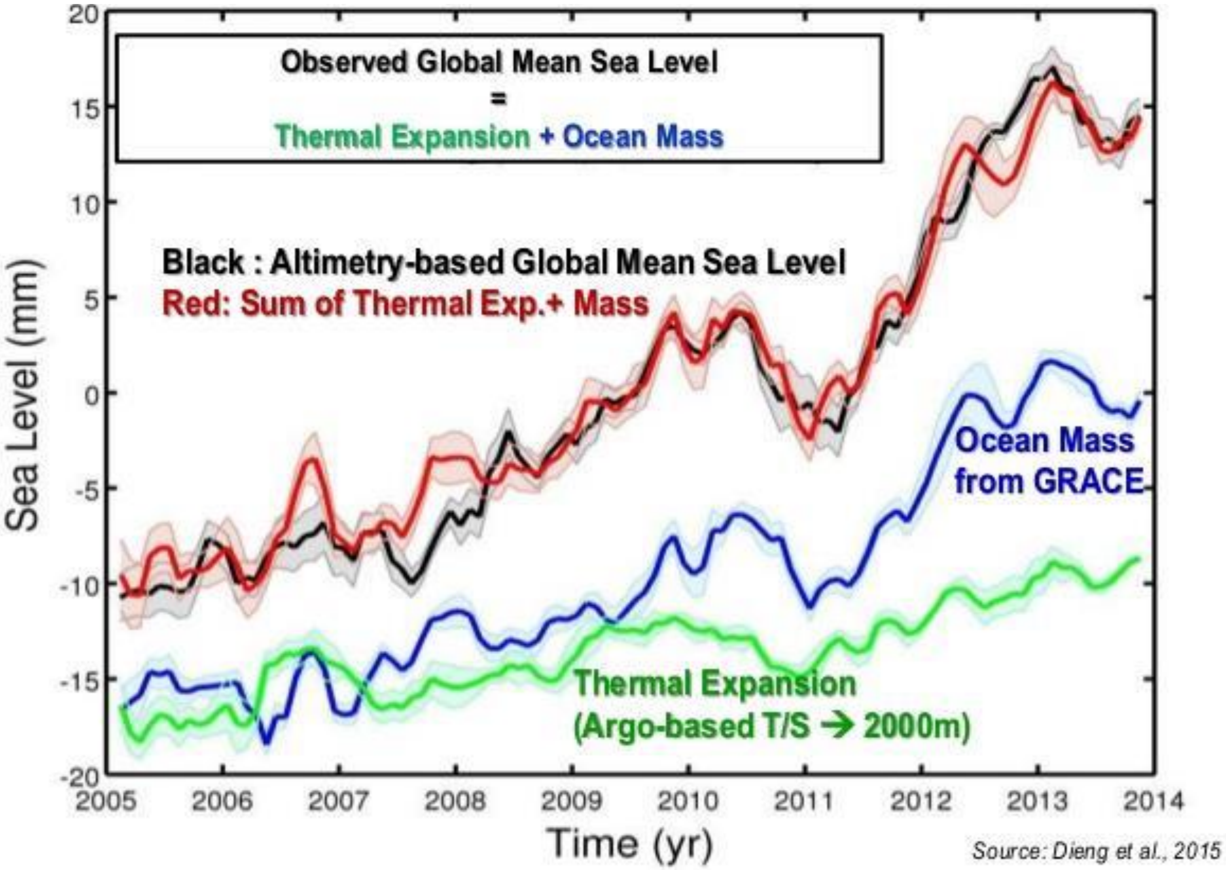
Sea Levels Rising | Expansion

When most objects are heated they expand. Water is no different.



Source: http://www.csgnetwork.com/h2odenscalc.html

Sea Levels Rising



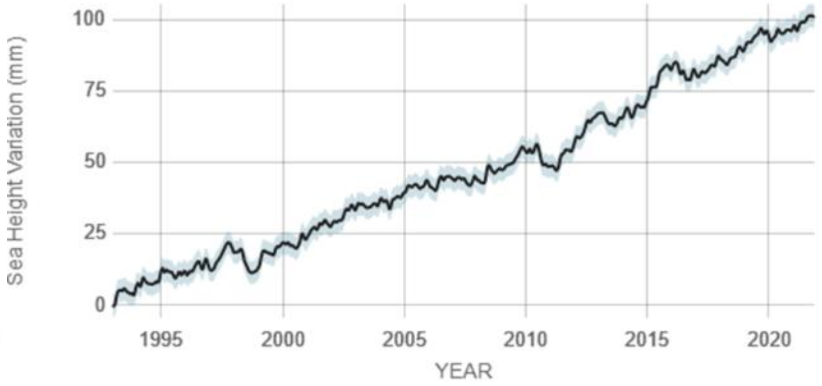
Source: Dieng et al., 2015

Ground Based Sea Level | 1900-Present

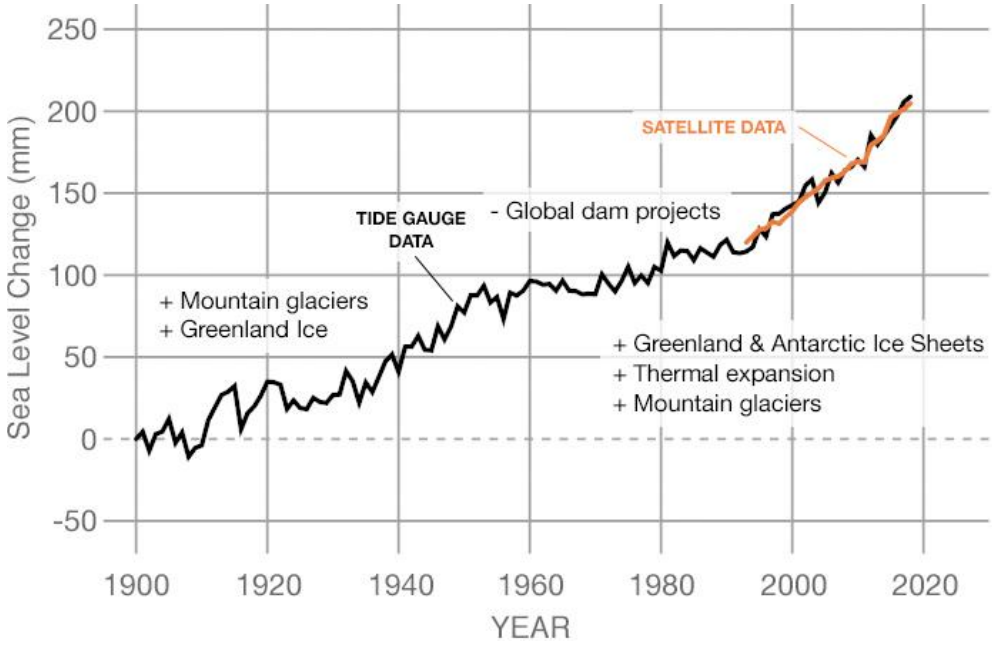
RATE OF CHANGE

↑ 3.3

millimeters per year

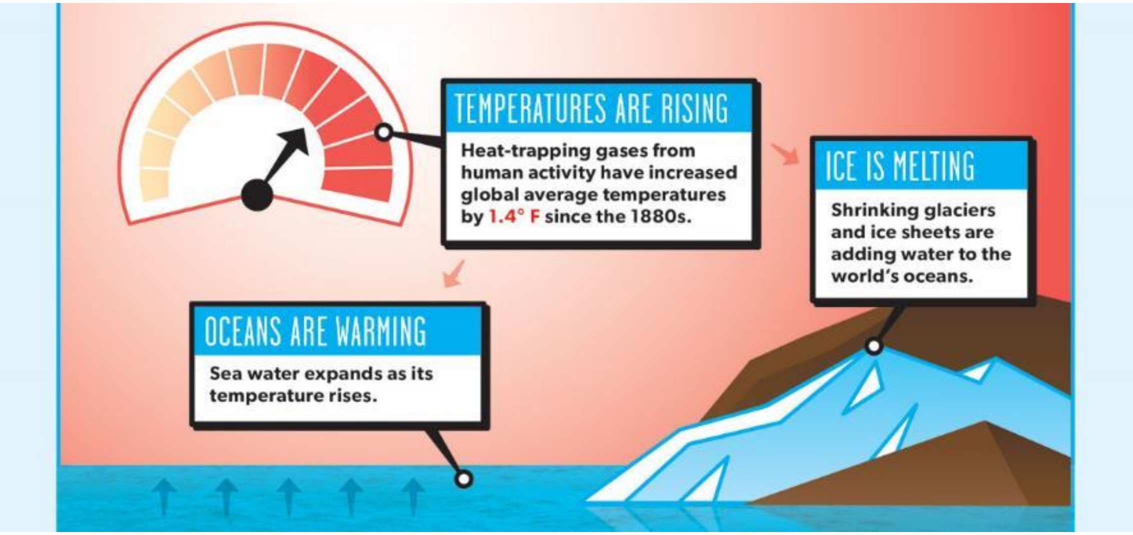


Source: climate.nasa.gov



https://climate.nasa.gov/vital-signs/sea-level/

Sea Levels Rising



TEMPERATURES ARE RISING

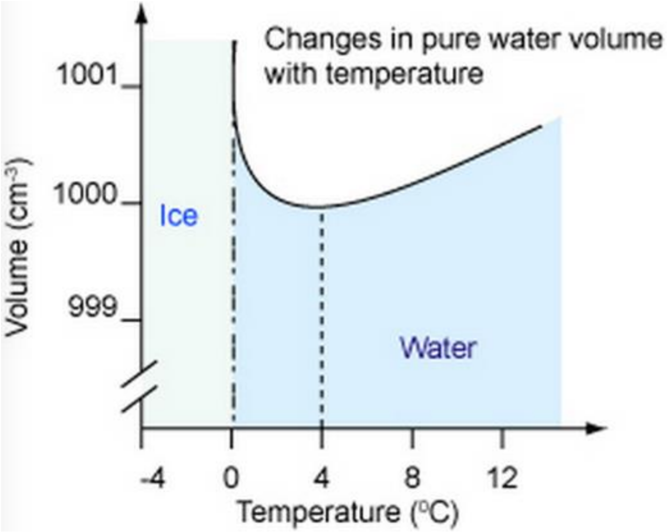
Heat-trapping gases from human activity have increased global average temperatures by 1.4° F since the 1880s.

ICE IS MELTING

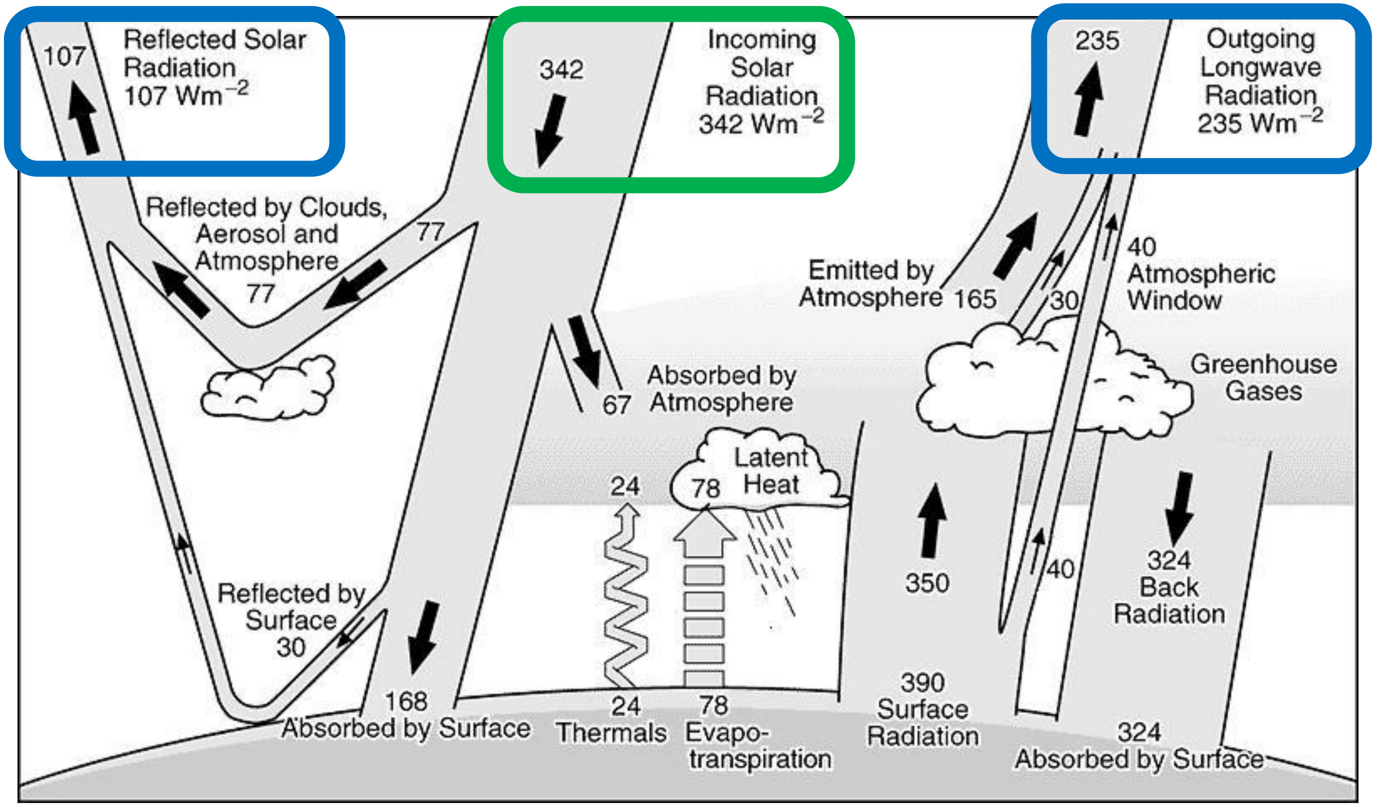
Shrinking glaciers and ice sheets are adding water to the world's oceans.

OCEANS ARE WARMING

Sea water expands as its temperature rises.

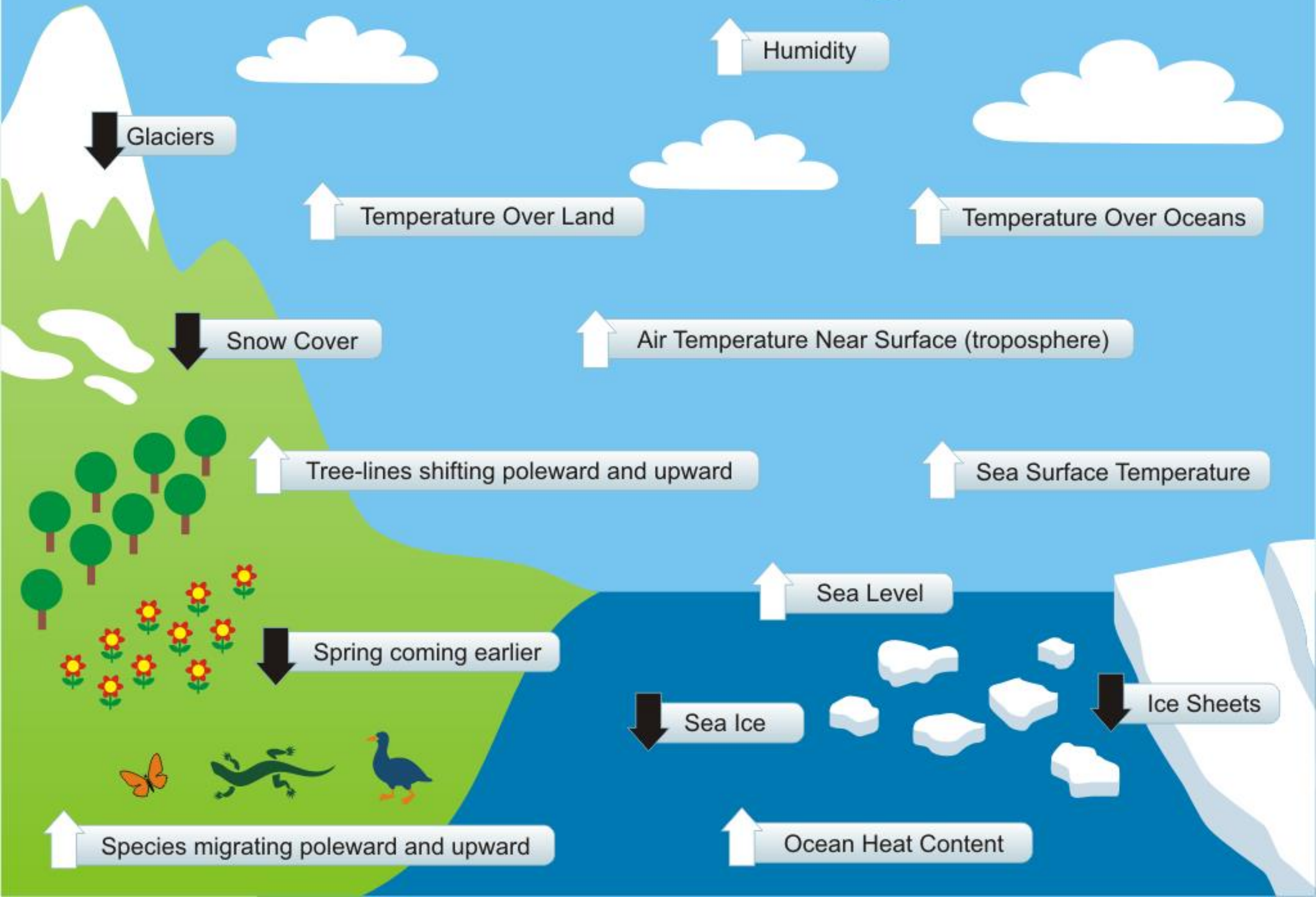


Thermal Equilibrium



(in) **342 W m^{-2} = 342 W m^{-2}** (out)

Indicators of a Warming World



↑ Humidity

↓ Glaciers

↑ Temperature Over Land

↑ Temperature Over Oceans

↓ Snow Cover

↑ Air Temperature Near Surface (troposphere)

↑ Tree-lines shifting poleward and upward

↑ Sea Surface Temperature

↑ Sea Level

↓ Spring coming earlier

↓ Sea Ice

↓ Ice Sheets

↑ Species migrating poleward and upward

↑ Ocean Heat Content

Feedback Loops

Positive Feedback Loop

Warming of Earth leads to events that further warm the Earth

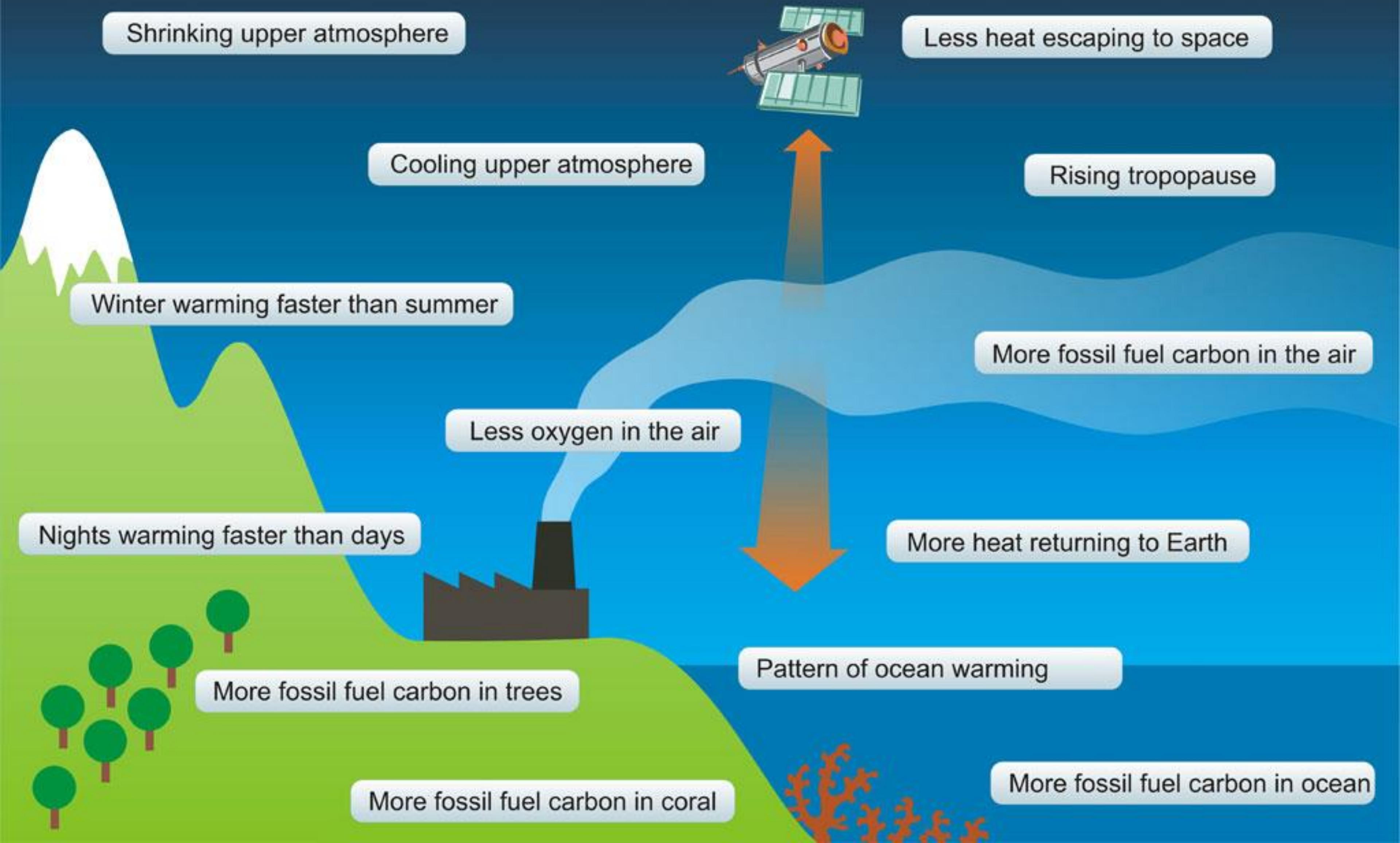
- Melting ice
  - Higher temps decrease ice cover on the planet
  - Decreases albedo
- Melting permafrost
  - Releases methane
- Methane on ocean floor
  - Higher ocean temperatures release frozen methane deposits

Negative Feedback Loop

Warming of Earth leads to events that start to cool the Earth

- More Clouds
  - Higher temps evaporate more water
  - Increase Albedo
- Increased Photosynthesis
  - More CO_2 leads to more plant life that absorbs CO_2
- Renewable Investment
  - Higher temperatures lead to a greater urgency for change

How we know we're causing global warming



Shrinking upper atmosphere

Less heat escaping to space

Cooling upper atmosphere

Rising tropopause

Winter warming faster than summer

More fossil fuel carbon in the air

Less oxygen in the air

Nights warming faster than days

More heat returning to Earth

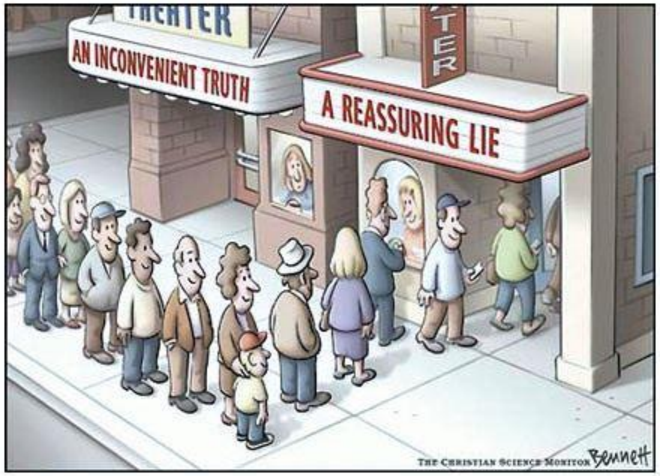
Pattern of ocean warming

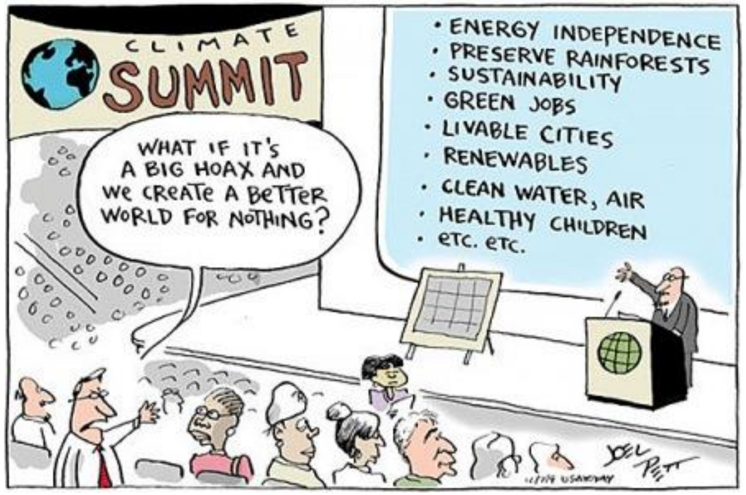
More fossil fuel carbon in trees

More fossil fuel carbon in ocean

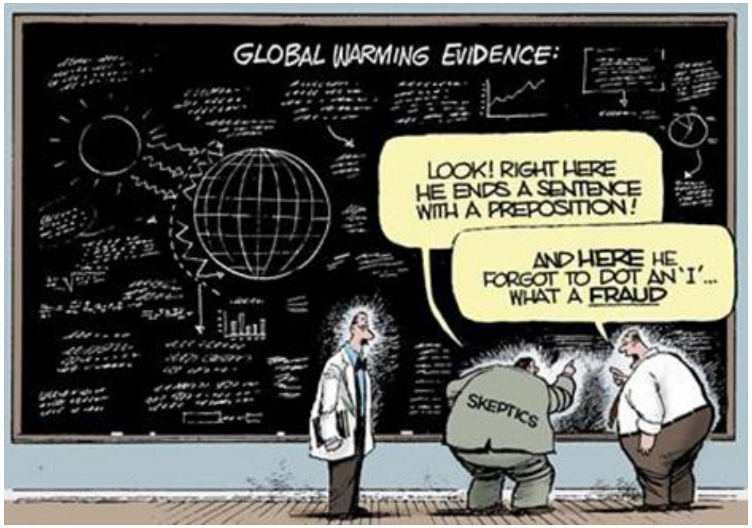
More fossil fuel carbon in coral

Why Deny?


THEATER
AN INCONVENIENT TRUTH
A REASSURING LIE
THE CHRISTIAN SCIENCE MONITOR Bennett


CLIMATE SUMMIT
WHAT IF IT'S A BIG HOAX AND WE CREATE A BETTER WORLD FOR NOTHING?
• ENERGY INDEPENDENCE
• PRESERVE RAINFORESTS
• SUSTAINABILITY
• GREEN JOBS
• LIVABLE CITIES
• RENEWABLES
• CLEAN WATER, AIR
• HEALTHY CHILDREN
• ETC. ETC.
JOEL PETT
USA TODAY


AN AGE-OLD ARGUMENT
2nd Edition
15th CENTURY
IF the EARTH IS ROUND, then EXPLAIN THIS!
17th CENTURY
IF GRAVITY IS REAL, EXPLAIN THAT!
19th CENTURY
IF EVOLUTION IS REAL, then EXPLAIN THIS!
21st CENTURY
IF GLOBAL WARMING IS REAL, EXPLAIN THAT!
ADAM ZYGLIS BUFFALO NEWS


GLOBAL WARMING EVIDENCE:
LOOK! RIGHT HERE HE ENDS A SENTENCE WITH A PREPOSITION!
AND HERE HE FORGOT TO DOT AN 'I'... WHAT A FRAUD
SKEPTICS