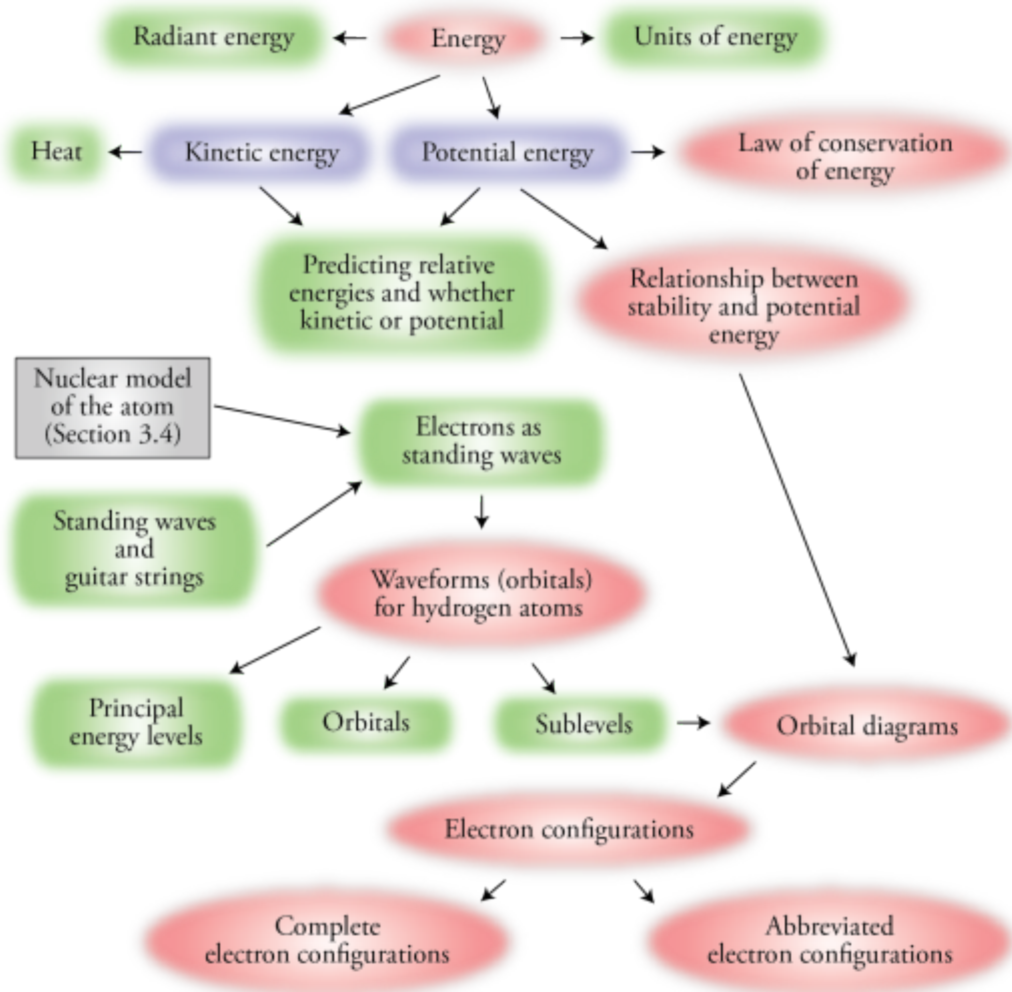
Chapter 4
Modern Atomic Theory

An Introduction to Chemistry

by Mark Bishop

Chapter Map



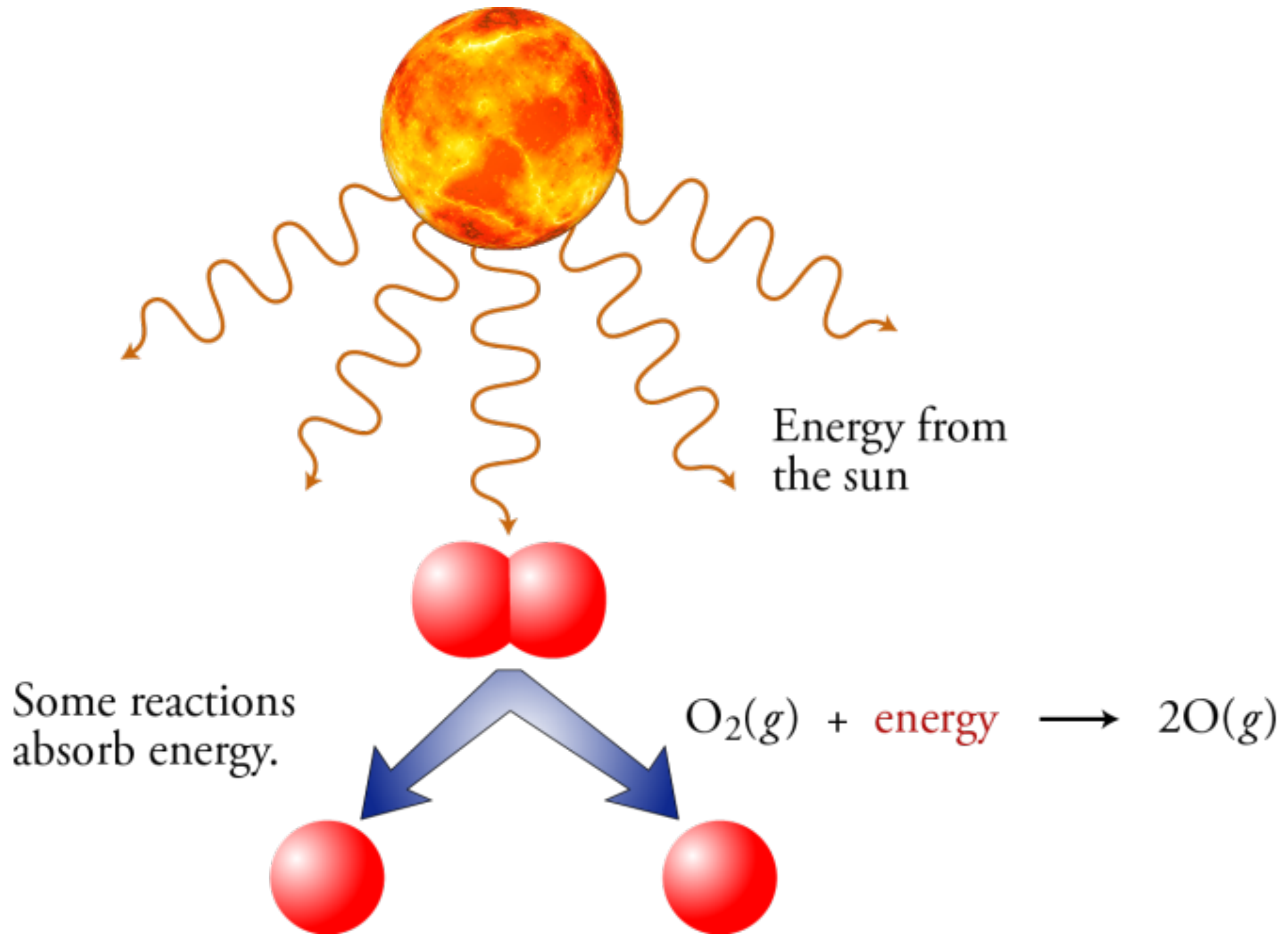
Radiant energy
Energy
Units of energy
Heat
Kinetic energy
Potential energy
Law of conservation of energy
Predicting relative energies and whether kinetic or potential
Relationship between stability and potential energy
Nuclear model of the atom (Section 3.4)
Electrons as standing waves
Standing waves and guitar strings
Waveforms (orbitals) for hydrogen atoms
Principal energy levels
Orbitals
Sublevels
Orbital diagrams
Electron configurations
Complete electron configurations
Abbreviated electron configurations

Some Chemical Changes Release Energy

Combustion of Methane

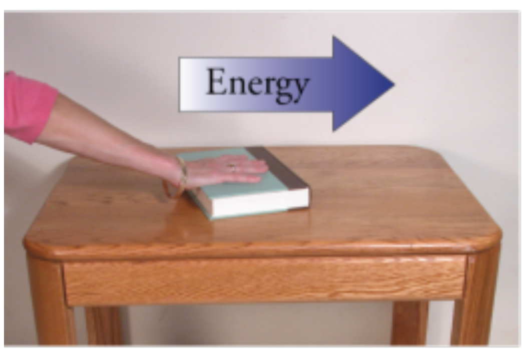
$$CH_4(g) + 2O_2(g)$$
$$\rightarrow CO_2(g) + 2H_2O(l) + \text{Energy}$$

Some Chemical Changes Absorb Energy

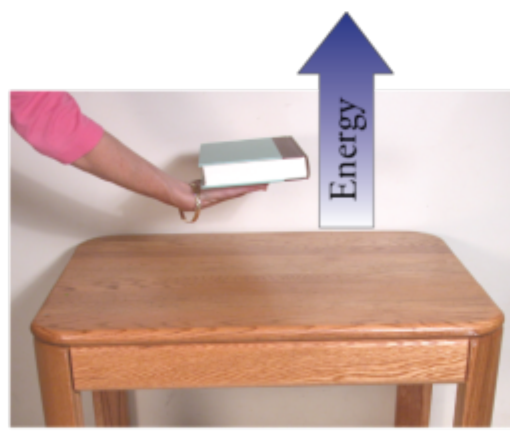


Energy Terms

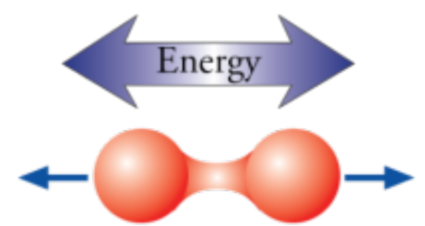
- **Energy** = the capacity to do work
- **Work**, in this context, may be defined as what is done to move an object against some sort of resistance.



Energy is required to push a book across a table and overcome the resistance to movement due to friction.



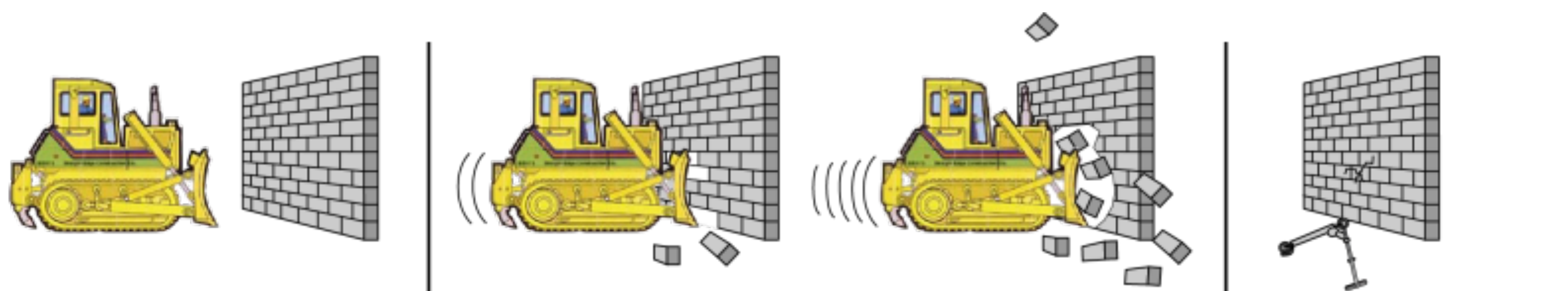
Energy is required to lift a book and overcome the resistance to movement due to gravity.



Energy is required to separate two atoms in a molecule and overcome the resistance to movement due to the chemical bond between them.

Two Types of Energy

- **Kinetic Energy** = the energy of motion = $1/2\ m\mu^2$



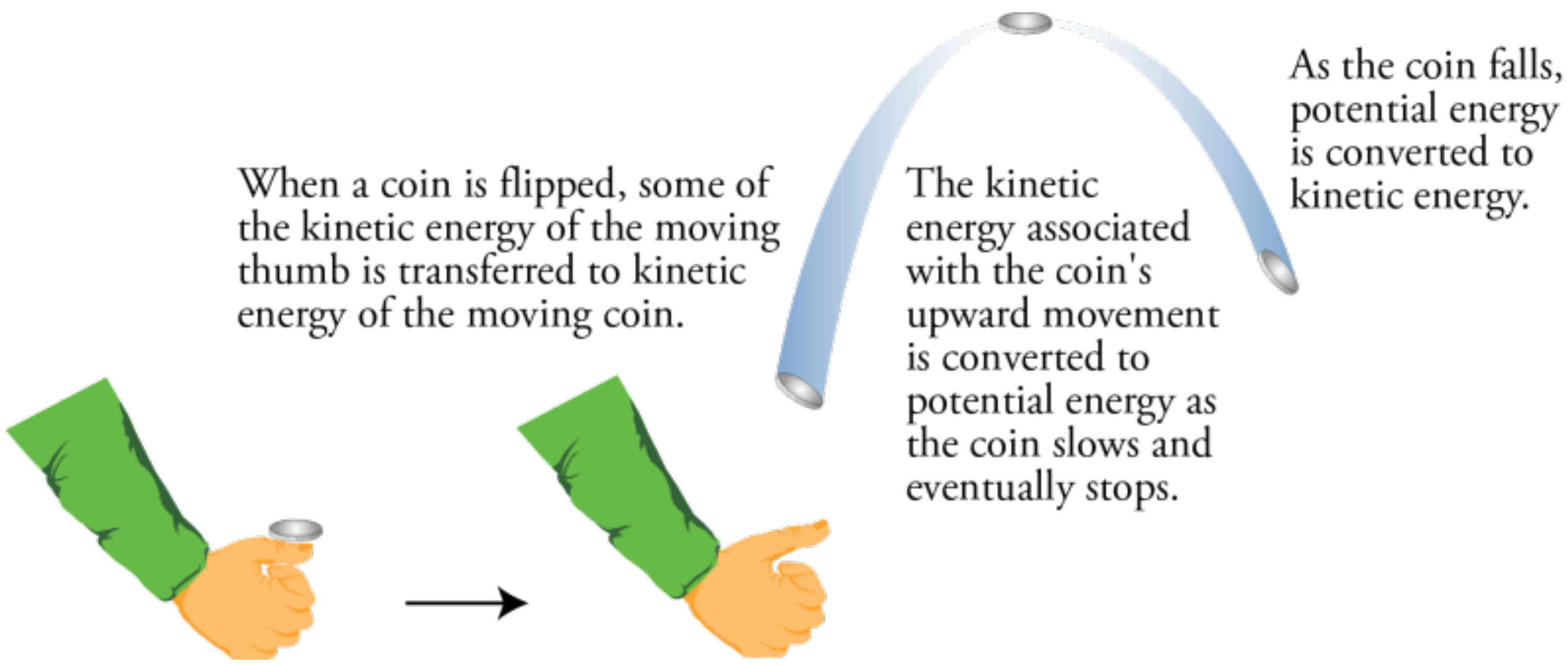
A stationary buldozer does not have the capacity to do the work of moving a wall.

The faster moving bulldozer does more of the work of moving the wall. The faster an object moves, the more work it can do, and the more kinetic energy it has.

A scooter moving at the same velocity as a bulldozer will do less work and therefore has less energy.

- **Potential Energy** = energy by virtue of position or state

Law of Conservation of Energy



Endergonic Change

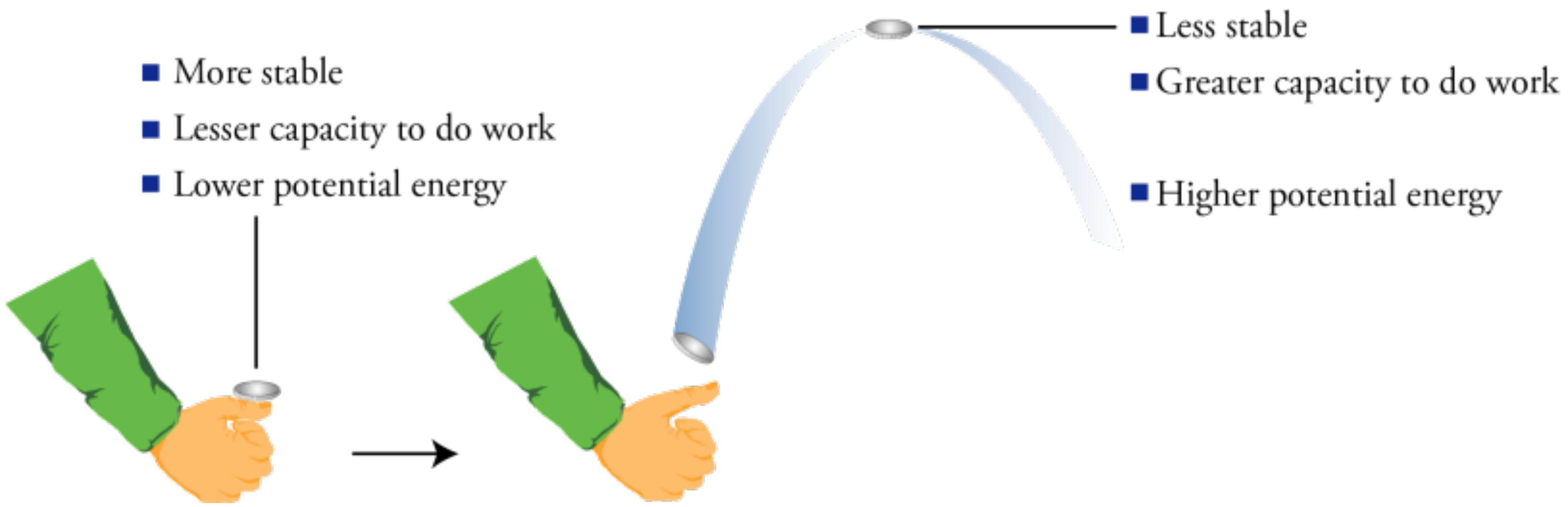
more stable + energy $\rightarrow$ less stable system

lesser capacity to do work + energy $\rightarrow$ greater capacity to do work

lower PE + energy $\rightarrow$ higher PE

coin in hand + energy $\rightarrow$ coin in air above hand

Coin and Potential Energy



Bond Breaking and Potential Energy

atoms in bond + Energy $\longrightarrow$ separate atoms

more stable + Energy $\longrightarrow$ less stable

lower PE + Energy $\longrightarrow$ higher PE

$O_2(g)$ + energy $\longrightarrow$ $2O(g)$

Exergonic Change

less stable system $\rightarrow$ more stable + energy

greater capacity to do work $\rightarrow$ lesser capacity to do work + energy

higher PE $\rightarrow$ lower PE + energy

coin in air above hand $\rightarrow$ coin on ground + energy

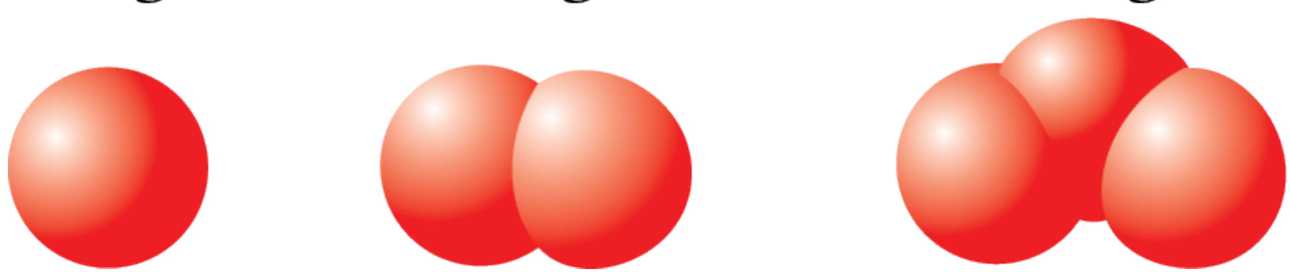
Bond Making and Potential Energy

separate atoms → atoms in bond + Energy

less stable → more stable + Energy

higher PE → lower PE + Energy

$$O(g) + O_2(g) \longrightarrow O_3(g) + \text{energy}$$



Which higher energy? Is it kinetic or potential?

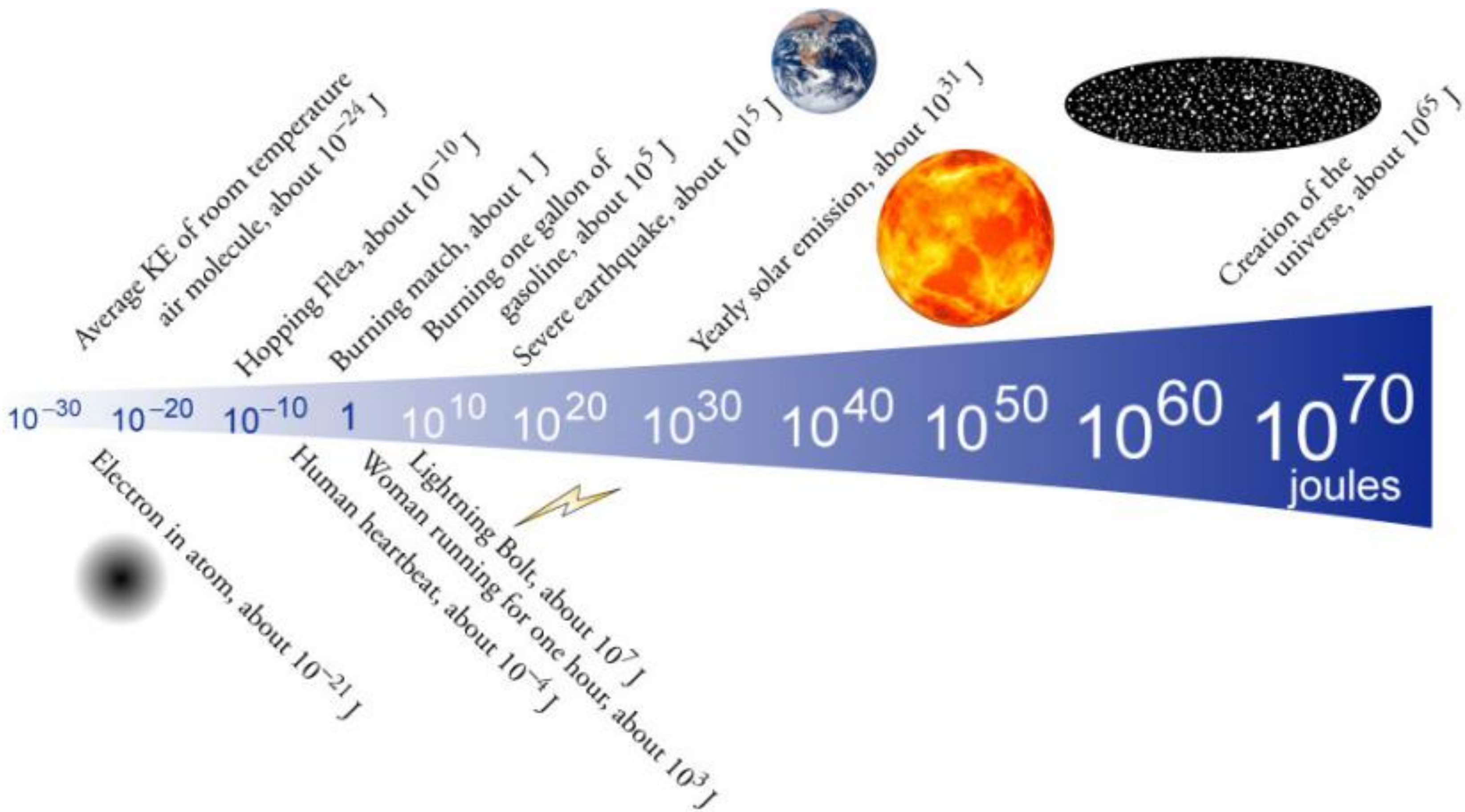
- 428 m/s Ar atoms or 456 m/s Ar atoms?
- 428 m/s Ar atoms or 428 m/s Kr atoms?
- Na^+ close to Cl^- or Na^+ and Cl^- far apart?
- ROOR or 2 RO
- $H(g)$ and $O_2(g)$ or $HO_2(g)$
- Solid CO_2 or gaseous CO_2

Units of Energy

- Joule (J) = $\frac{\text{kg m}^2}{\text{s}^2}$

- 4.184 J = 1 cal
- 4.184 kJ = 1 kcal
- 4184 J = 1 Cal (dietary calorie)
- 4.184 kJ = 1 Cal
- 42 GJ ≅ 1 toe (tons of oil equivalent)

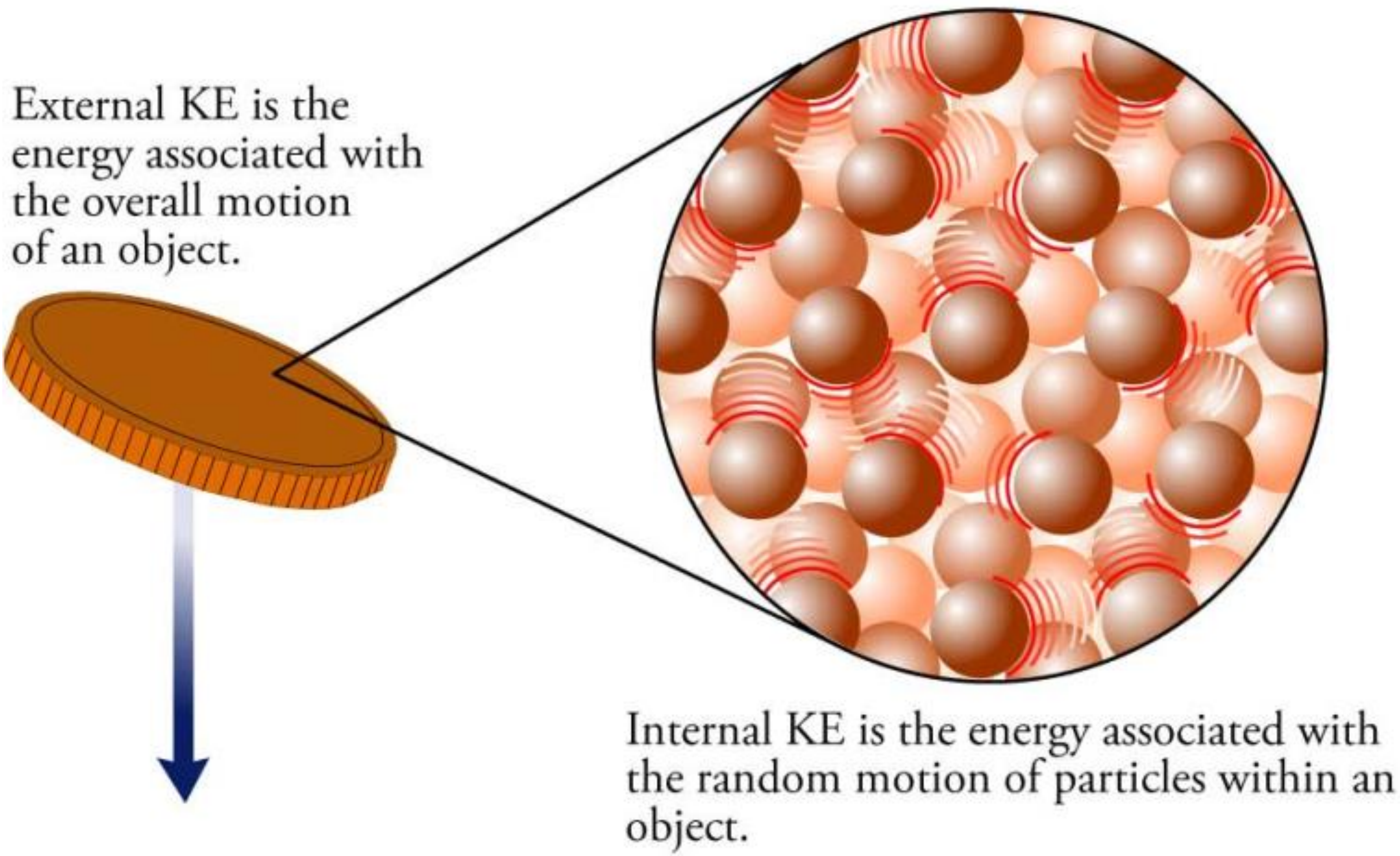
Approximate Energy of Various Events



More Terms

- **External Kinetic Energy** = Kinetic energy associated with the overall movement of a body
- **Internal Kinetic Energy** = Kinetic energy associated with the random motion of the particles within a body

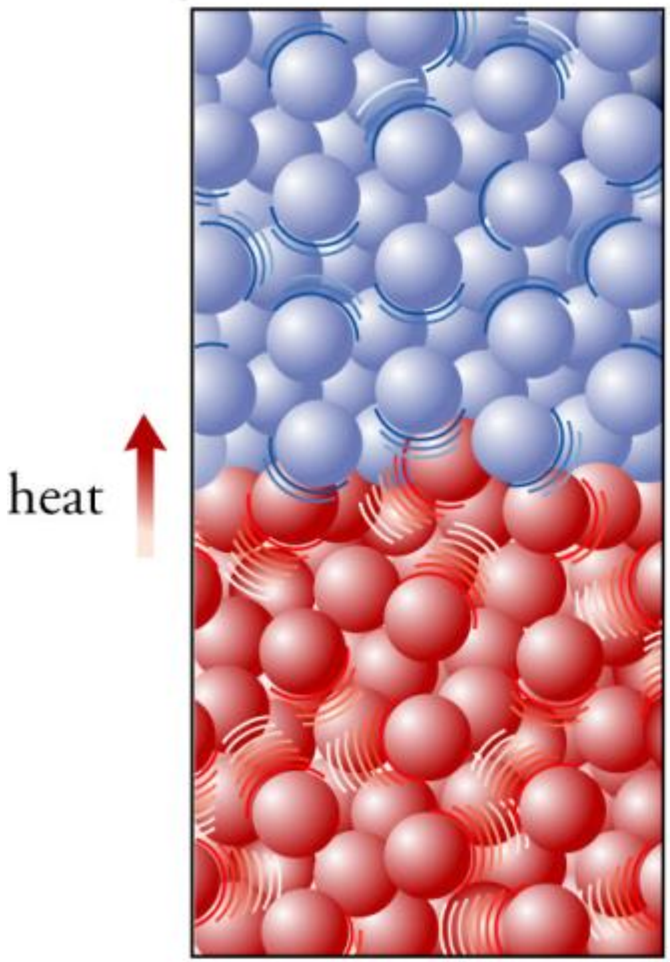
External and Internal Kinetic Energy



Heat

- **Heat** = Internal kinetic energy transfer from a region of higher temperature to a region of lower temperature due to collisions of particles.

Heat Transfer



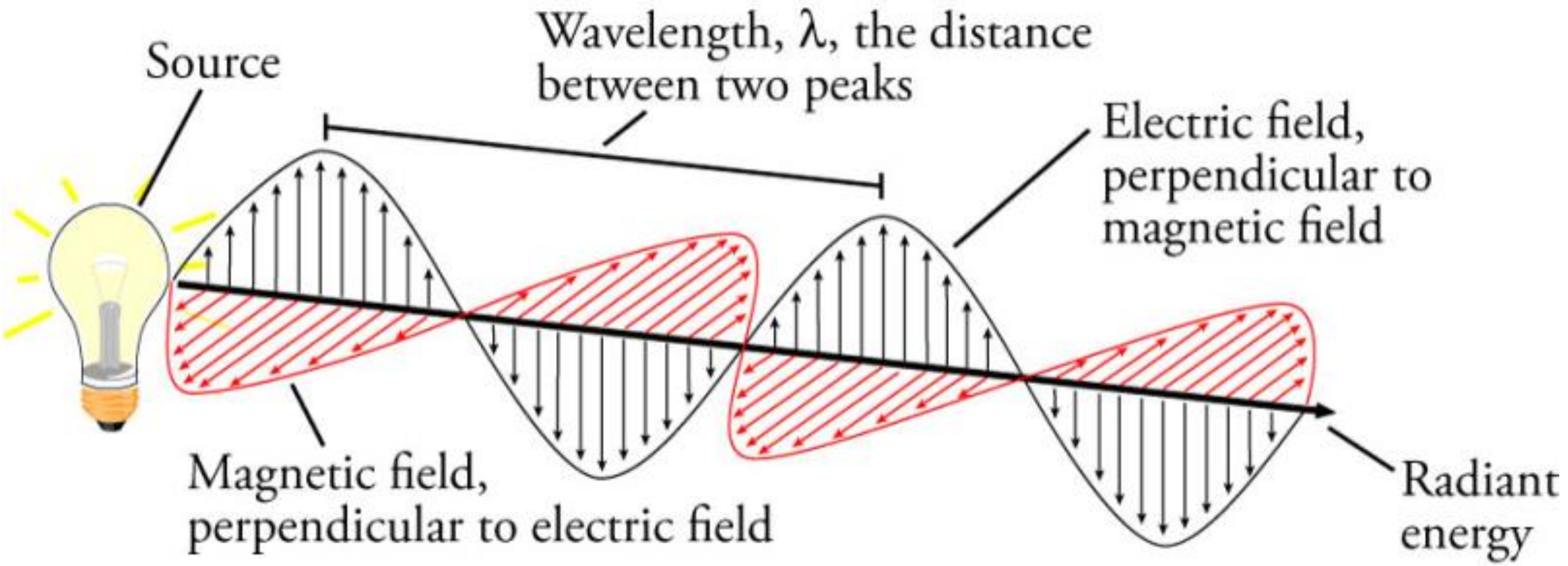
Lower-temperature object
↓
Lower average force of collisions
↓
Particles speed up when they collide with particles of the higher-temperature object.
↓
Increased energy

Higher-temperature object
↓
Higher average force of collisions
↓
Particles slow down when they collide with particles of the lower-temperature object.
↓
Decreased energy

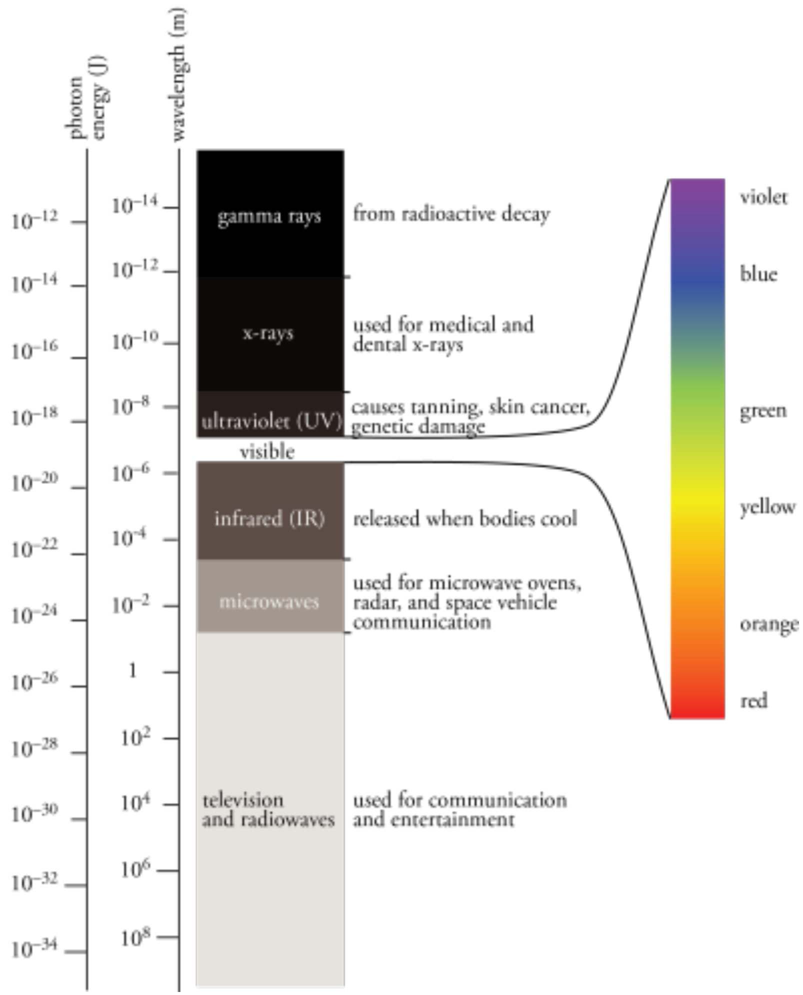
Radiant Energy

- **Radiant Energy** is electromagnetic energy that behaves like a stream of particles.
- It has a dual Nature
  - Particle
    - photons = tiny packets of radiant energy
    - 10^{17} photons/second from a flashlight bulb
  - Wave
    - oscillating electric and magnetic fields
    - describes effect on space, not true nature of radiant energy

A Light Wave's Electric and Magnetic Fields



Radiant Energy Spectrum



International Energy Agency

- *“The IEA is an autonomous organisation which works to ensure reliable, affordable and clean energy for its 28 member countries and beyond. The IEA's four main areas of focus are: energy security, economic development, environmental awareness, and engagement worldwide.”*

https://www.iea.org/

https://www.iea.org/stats/index.asp

https://www.iea.org/country/maps.asp

Renewable vs. Non-Renewable Energy

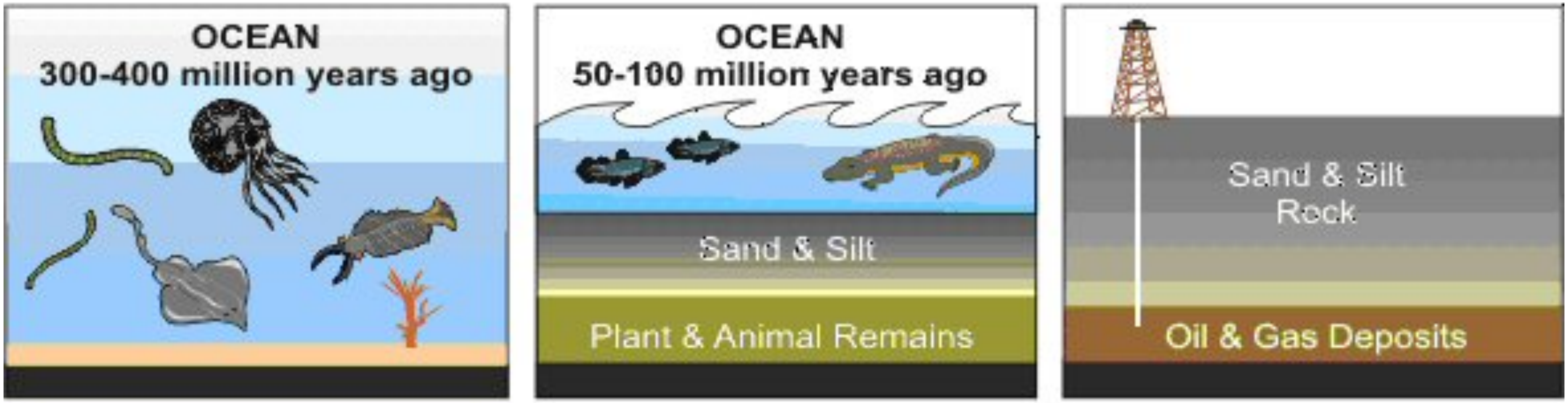
- **Renewable** energy sources are continually replenished.

- **Non-renewable** energy sources have a low or zero replenishment rate.

Petroleum

- **Petroleum** or **crude oil** is a naturally occurring flammable liquid consisting of a complex mixture of hydrocarbons and other liquid organic compounds, that are found in geologic formations beneath the Earth's surface.
- As one type of **fossil fuel**, it is formed when large quantities of dead organisms, usually zooplankton and algae, are buried underneath sedimentary rock and undergo intense heat and pressure.

PETROLEUM & NATURAL GAS FORMATION



Tiny sea plants and animals died and were buried on the ocean floor. Over time, they were covered by layers of silt and sand.

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

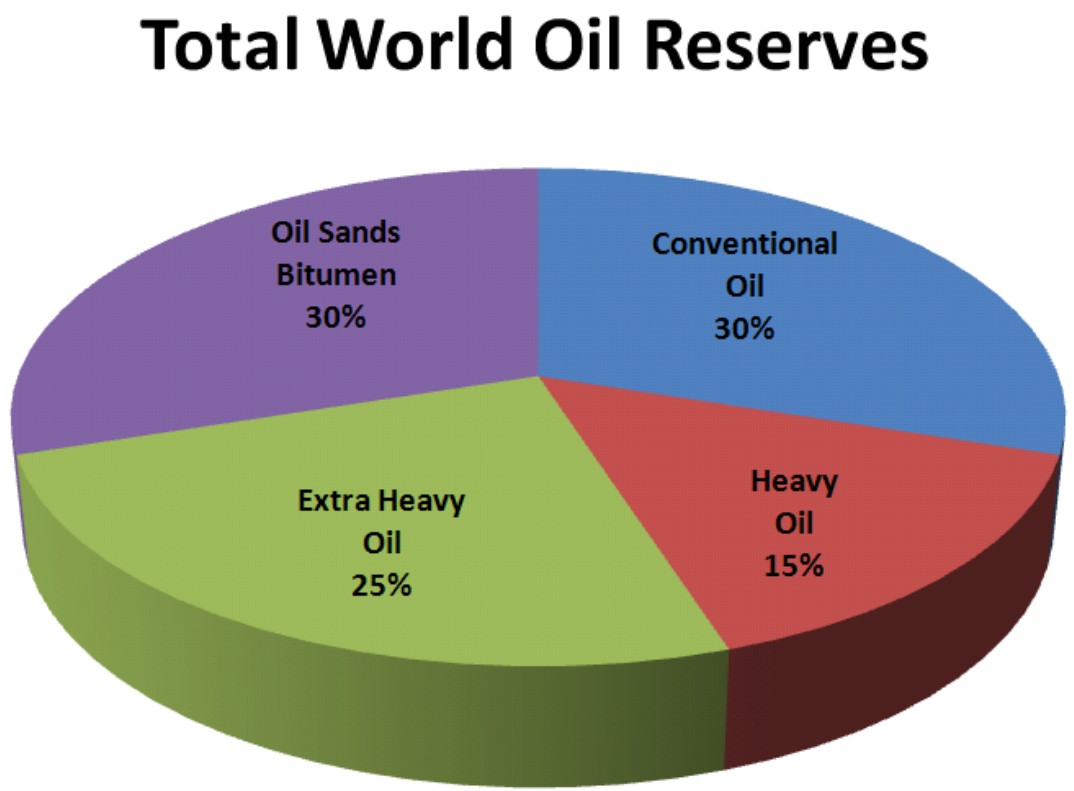
Today, we drill down through layers of sand, silt, and rock to reach the rock formations that contain oil and gas deposits.

Fraction	**Boiling Range ^{o}C**
Liquefied petroleum gas (LPG)	−40
Butane	−12 to −1
Gasoline	−1 to 180
Jet fuel	150 to 205
Kerosene	205 to 260
Fuel oil	205 to 290
Diesel fuel	260 to 315

Classification of Oil

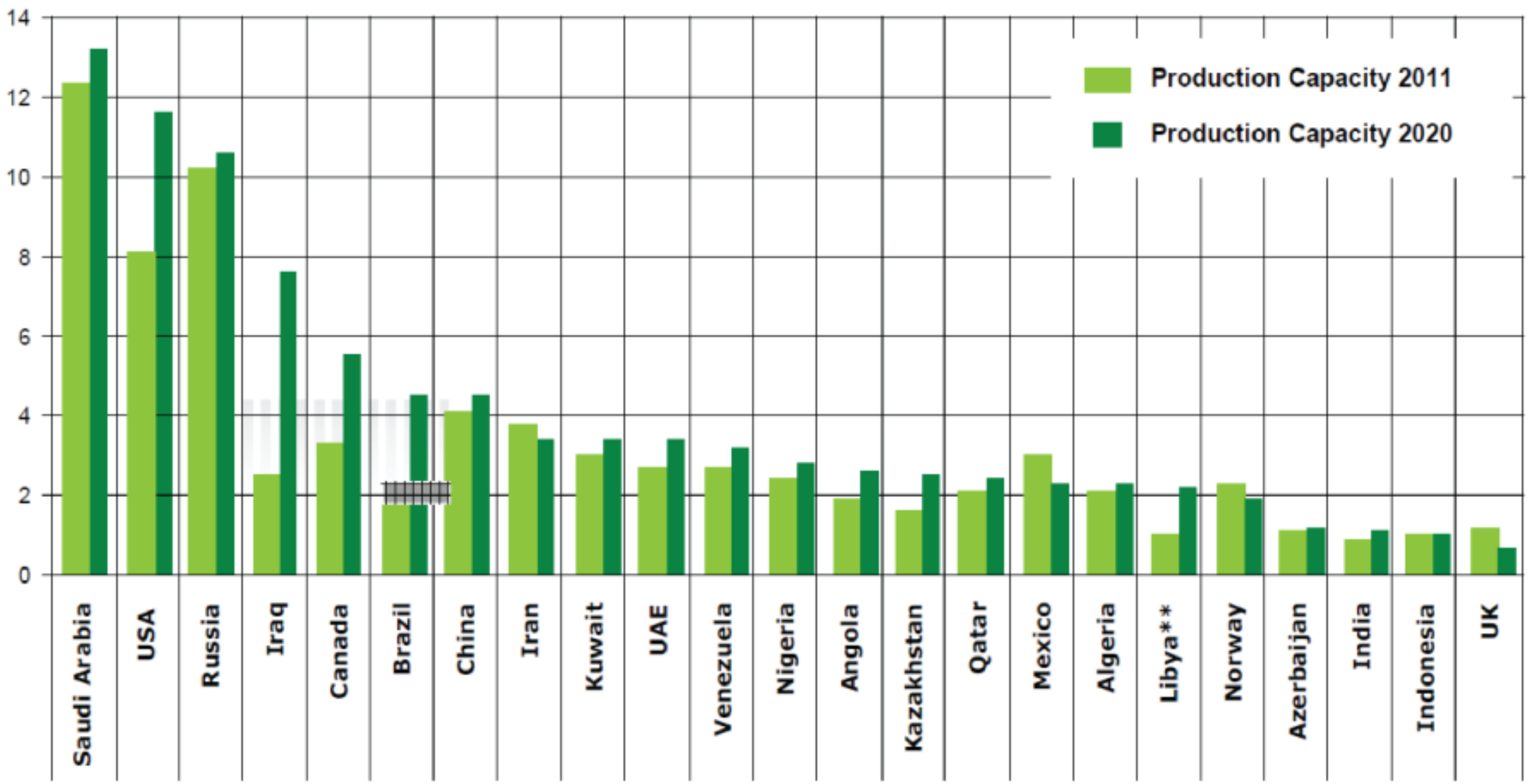
- **Light crude oil** is liquid petroleum that has a low density and flows freely at room temperature due to the presence of a high proportion of low molecular mass hydrocarbons.
- **Unconventional Oil**
  - **Heavy crude oil** or **extra heavy crude oil** is any type of crude oil which does not flow easily. It is referred to as "heavy" because its density is higher than that of light crude oil.
  - **Oil sands, tar sands (bituminous sands)** are a type of unconventional petroleum deposit. The oil sands are loose sand or partially consolidated sandstone containing naturally occurring mixtures of sand, clay, and water, saturated with a dense and extremely viscous form of petroleum technically referred to as **bitumen**.

Classifications of Oil



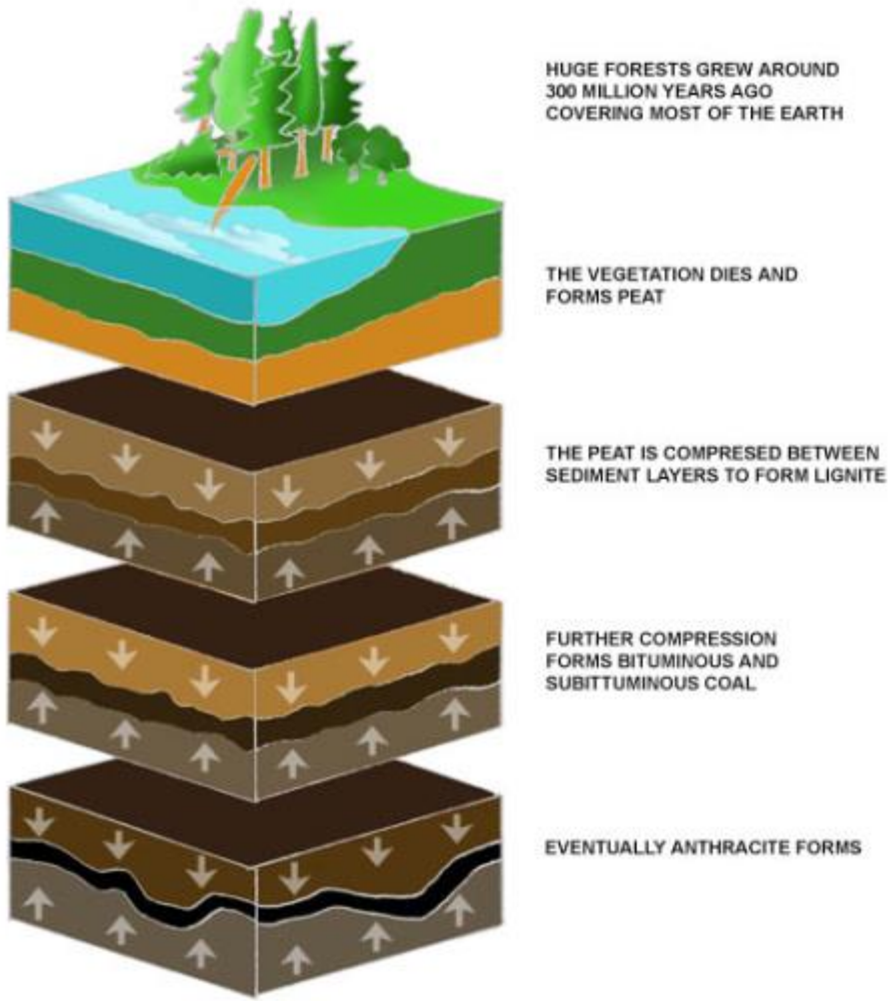
Most of the world's oil is unconventional oil.

Country-by-country evolution of oil production capacity to 2020 (in million barrels per day, mbd)



http://belfercenter.ksg.harvard.edu/files/Oil-%20The%20Next%20Revolution.pdf

COAL FORMATION PROCESS



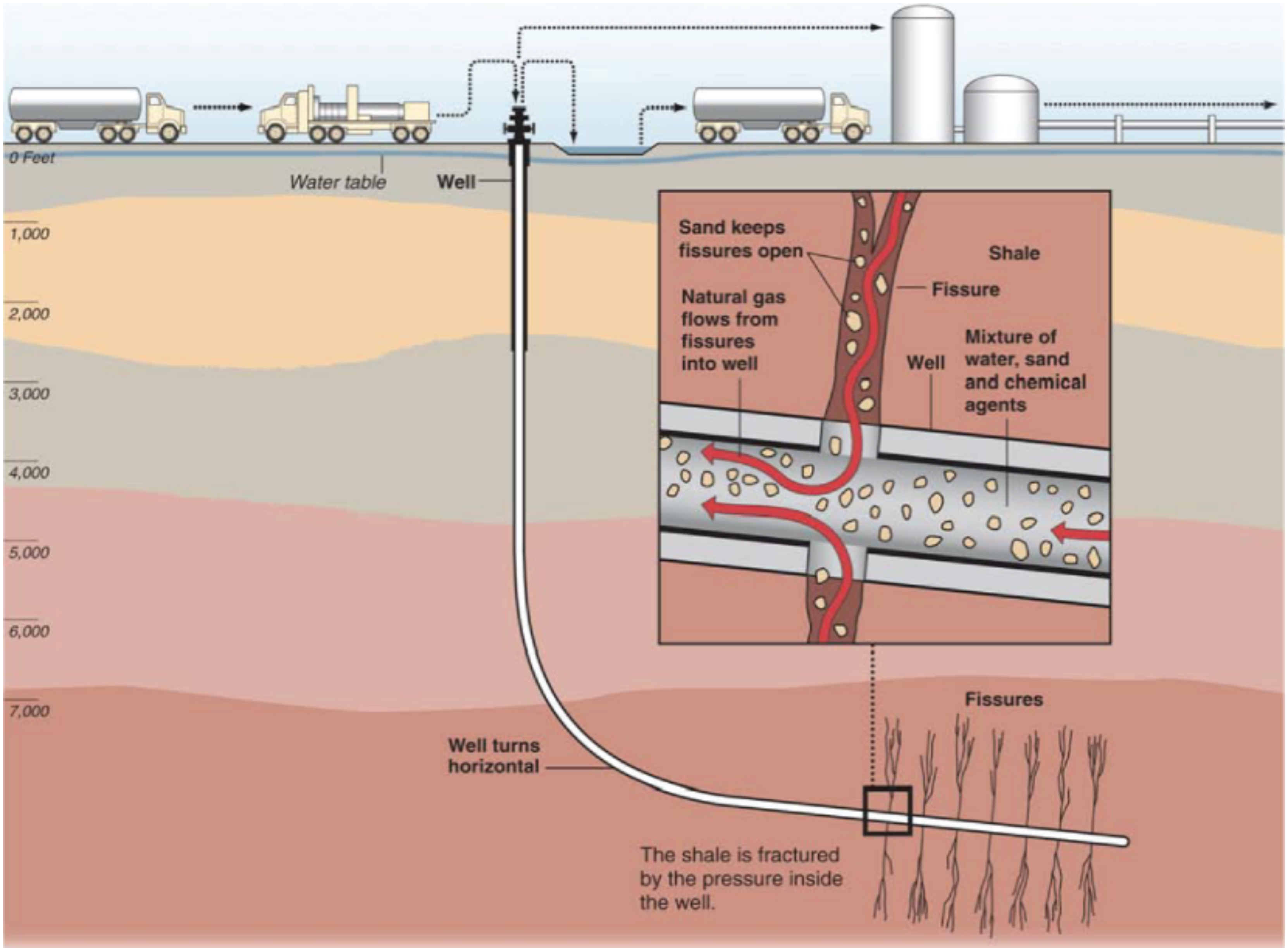
Terms Related to Coal

- **Peat** = partially decayed vegetation…a precursor of coal
- **Lignite (brown coal)** = the lowest rank of coal and used almost exclusively as fuel for electric power generation.
- **Bituminous coal** = a dense sedimentary rock, usually black but sometimes dark brown often with well-defined bands of bright and dull material, used primarily as fuel in steam-electric power generation, with substantial quantities used for heat and power applications in manufacturing.
- **Anthracite** = the highest rank of coal…harder, glossy black coal used primarily for residential and commercial space heating.

Natural Gas Liquids (NGL)

- Natural gas is primarily methane, CH_4.
- There are other hydrocarbons found in natural gas deposits, such as ethane, C_2H_6, propane, C_3H_8, butane, $CH_3CH_2CH_2CH_3$, 2-methylpropane, $CH_3CH(CH_3)CH_3$, pentanes, and even higher molecular mass hydrocarbons. When processed and purified into finished by-products, all of these are collectively referred to as **NGL (Natural Gas Liquids)**.

Hydraulic Fracturing (Fracking)



Natural Gas vs. Other Fossil Fuels

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

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

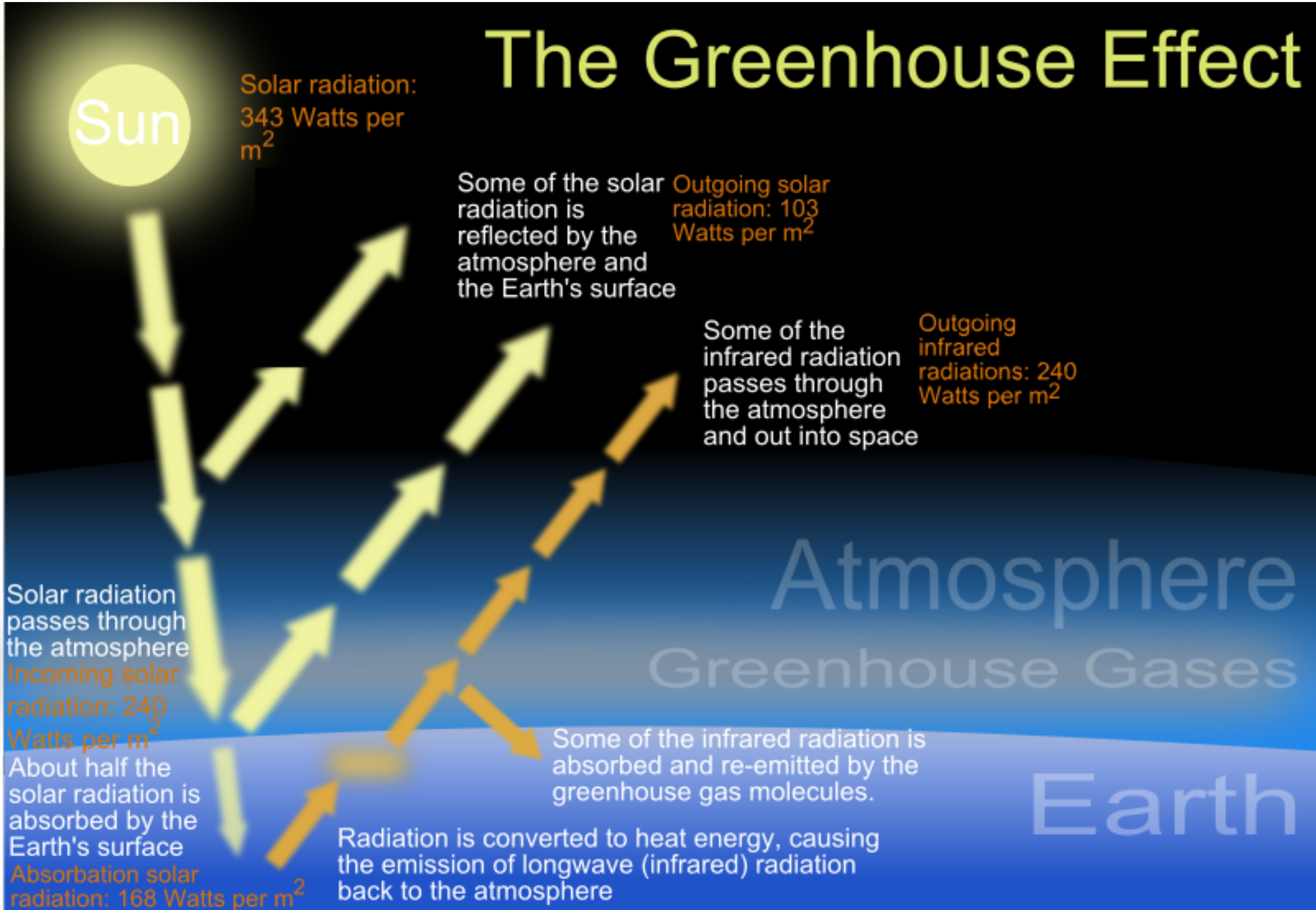
Source: EIA - Natural Gas Issues and Trends 1998

Natural Gas vs. Other Fossil Fuels

- 1-3% of methane escapes into the atmosphere in drilling and transportation.
- Methane is a potent greenhouse gas.
- Over the next 25 years, it has about 70 times the global warming potential of carbon dioxide.
- Because of the lifetime of CH_4 in the atmosphere, methane has about 25 times the global warming potential as carbon dioxide over the next 100 years.

What determines Earth's temperature?

- Earth's temperature depends on the balance between energy entering and leaving.
  - When incoming energy from the sun is absorbed by the Earth system, Earth warms.
  - When the sun's energy is reflected back into space, Earth avoids warming.
  - When energy is released back into space, Earth cools.


The Greenhouse Effect
Sun
Solar radiation: 343 Watts per m2
Some of the solar radiation is reflected by the atmosphere and the Earth's surface
Outgoing solar radiation: 103 Watts per m2
Some of the infrared radiation passes through the atmosphere and out into space
Outgoing infrared radiations: 240 Watts per m2
Atmosphere
Greenhouse Gases
Solar radiation passes through the atmosphere
Incoming solar radiation: 240 Watts per m2
About half the solar radiation is absorbed by the Earth's surface
Absorbation solar radiation: 168 Watts per m2
Some of the infrared radiation is absorbed and re-emitted by the greenhouse gas molecules.
Radiation is converted to heat energy, causing the emission of longwave (infrared) radiation back to the atmosphere
Earth

Greenhouse Gases

- **Greenhouse gas =** Any gas that absorbs infrared radiation in the atmosphere. Each gas absorbs radiation at specific wavelengths as function of its structure.
- Without them, Earth's surface would be on average about 33 ºC (59 ºF) colder than at present.

Greenhouse Gases

- *Important greenhouse gases:*
  - **Carbon dioxide (CO_2)**
  - **Methane (CH_4)**
  - **Nitrous oxide (N_2O)**
  - Chlorofluorcarbons (CFCs)
  - Halogenated fluorocarbons (HCFCs)
  - Ozone (O_3)
  - Hydrofluorocarbons (HFCs)
  - Water vapor (H_2O)

Vibration Modes of Greenhouse Gas Molecules

- As the Earth cools, it emits infrared (IR) photons.
- When a greenhouse gas molecule absorbs an IR photon, the molecule gets excited to a higher vibrational energy.
- When the molecule returns to a more stable vibrational energy, it emits an IR photon in a random direction.
- Some of the remitted photons return to Earth.

http://www2.ess.ucla.edu/~schauble/MoleculeHTML/CO2_html/CO2_page.html

http://www2.ess.ucla.edu/~schauble/MoleculeHTML/H2O_html/H2O_page.html

http://www2.ess.ucla.edu/~schauble/MoleculeHTML/N2O_html/N2O_page.html

http://www2.ess.ucla.edu/~schauble/MoleculeHTML/CH4_html/CH4_page.html

http://www2.ess.ucla.edu/~schauble/MoleculeHTML/CHClF2_html/CHClF2_page.html

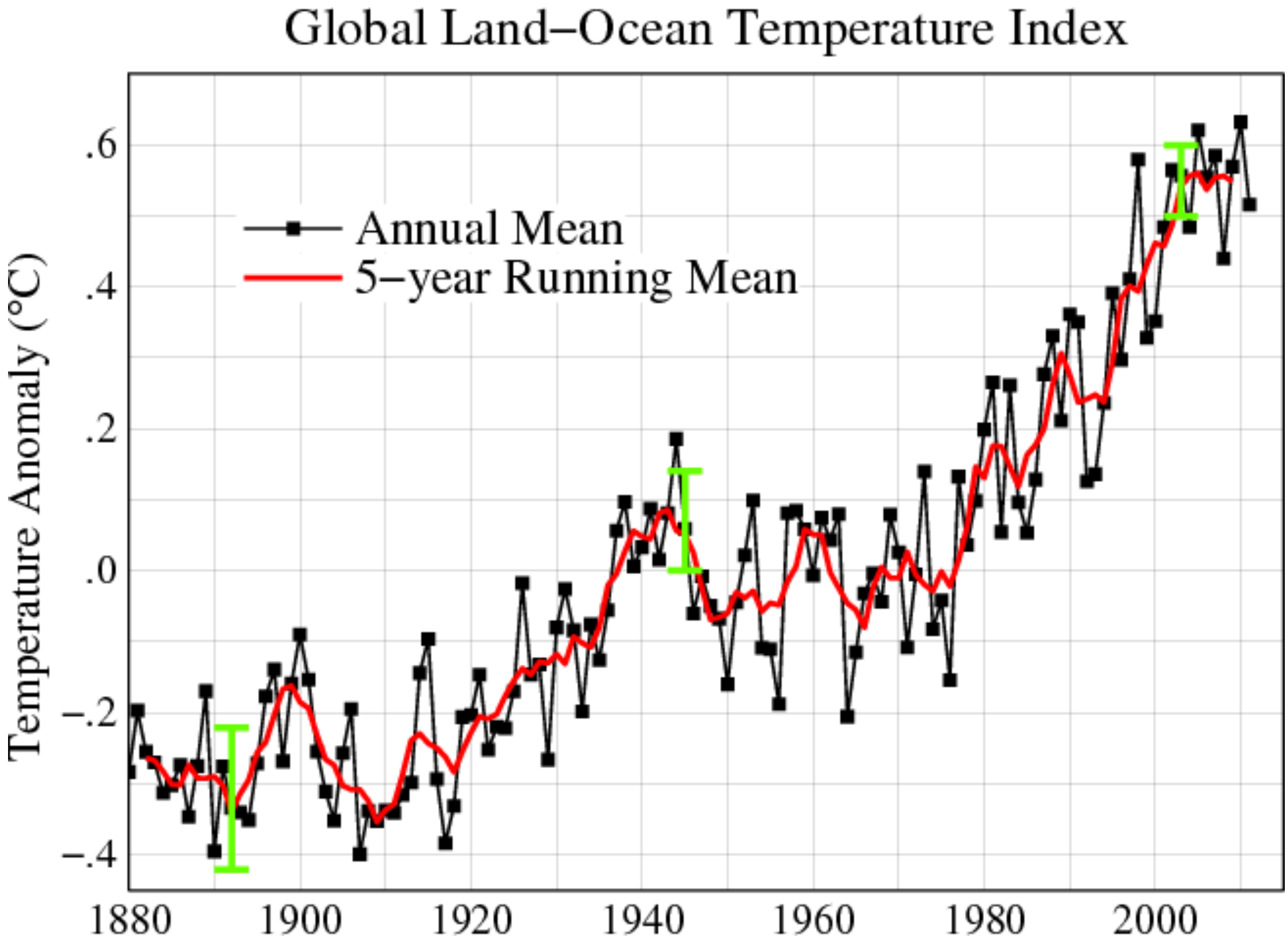
http://www.explainingclimatechange.ca/Climate%20Change/swf/irwindows/IRwindows2.swf

Climate Change

- Earth's average temperature has risen by about 1 ºC (1.4 ºF) over the past century, with about 2/3 of this since 1980.
- Projected to rise another 1 to 6 ºC (2 to 11.5 ºF) over the next hundred years.

http://www.explainingclimatechange.ca/

Temperature Variation from 1880-present



http://www.explainingclimatechange.ca/Climate%20Change/swf/videos/historical%20_temp.swf

What could change the Earth's energy balance and change the Earth's temperature?

- Changes in solar input
  - Sun's output
  - Earth's position and orientation
  - Cosmic dust
- Changes in transparency of atmosphere to incoming shortwave energy
  - Clouds
  - Dust, ash, soot
  - O_3
- Changes in transparency of atmosphere to outgoing long wave radiant energy
  - Clouds
  - Greenhouse gases (H_2O, CO_2, CH_4, N_2O, O_3)

Natural and Anthropogenic Greenhouse Effect

NATURALLY MODERATED GREENHOUSE EFFECT

ANTHROPOGENIC GREENHOUSE EFFECT - ADDING GHG' S

What could change the Earth's energy balance and change the Earth's temperature?

- Changes in reflectivity & evapotranspiration at the surface
  - Changes in extent of forests, grasslands, deserts
  - Changes in extent and condition of liquid water and ice
- Changes in heat added at the surface by human activities and geothermal sources

Climate Change

- Small changes in the average temperature lead to large and potentially dangerous shifts in climate and weather. For example,
    - Changes in rainfall, resulting in more floods, droughts, or intense rain, as well as more frequent and severe heat waves.
    - Oceans are warming and becoming more acidic, ice caps are melting, and sea levels are rising.

http://www.explainingclimatechange.ca/

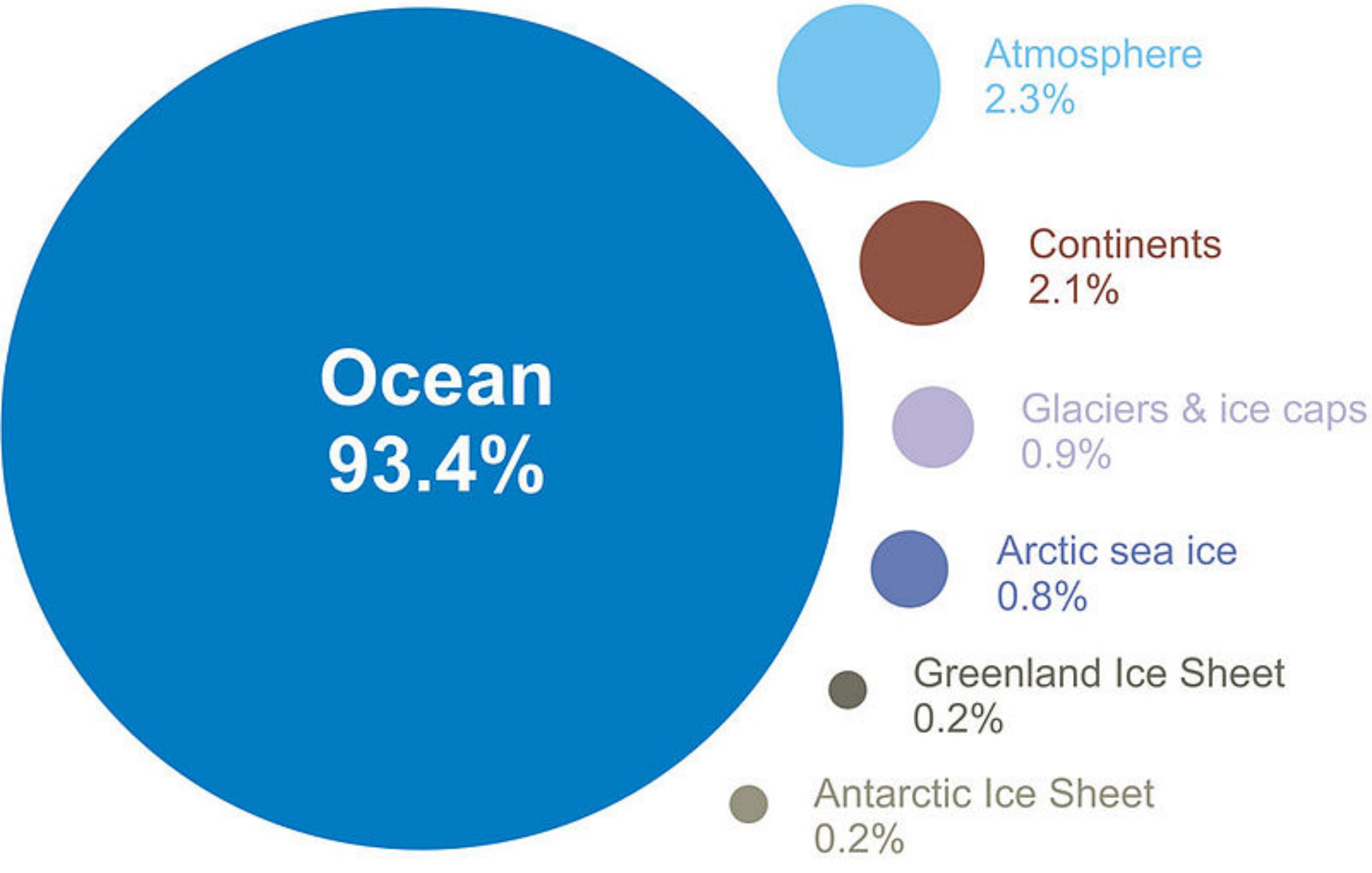
Climate vs. Weather

- **Weather** = the conditions of the atmosphere over a short period of time and typically for a local area.
  - Familiar examples of weather characteristics include the daily temperature, humidity, or the amount of precipitation produced by a storm.
  - Weather also includes severe weather conditions such as hurricanes, tornadoes, and blizzards.
  - Because of the dynamic nature of the atmosphere, it is not possible to predict weather conditions in a specific location months or years in advance.

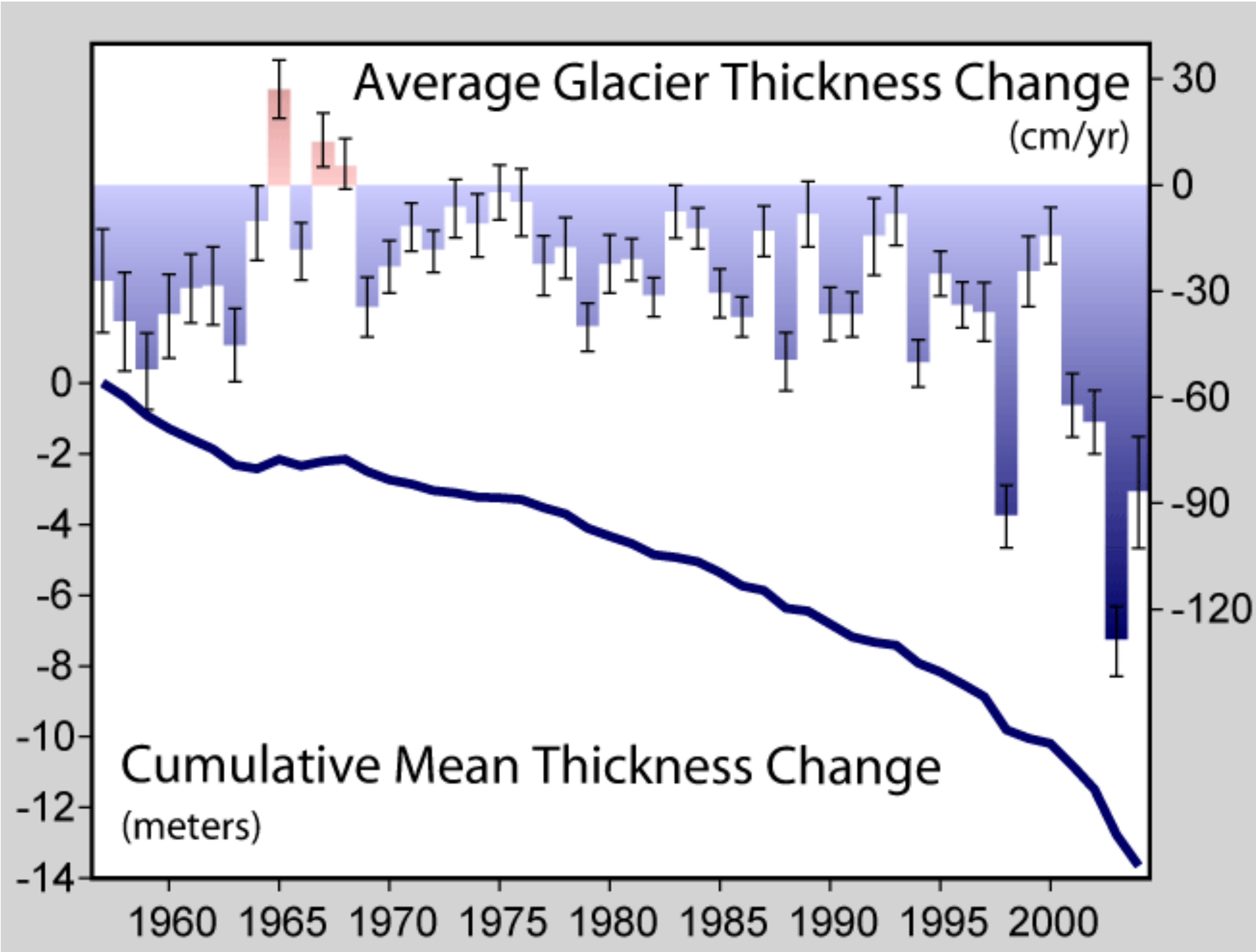
Climate vs. Weather

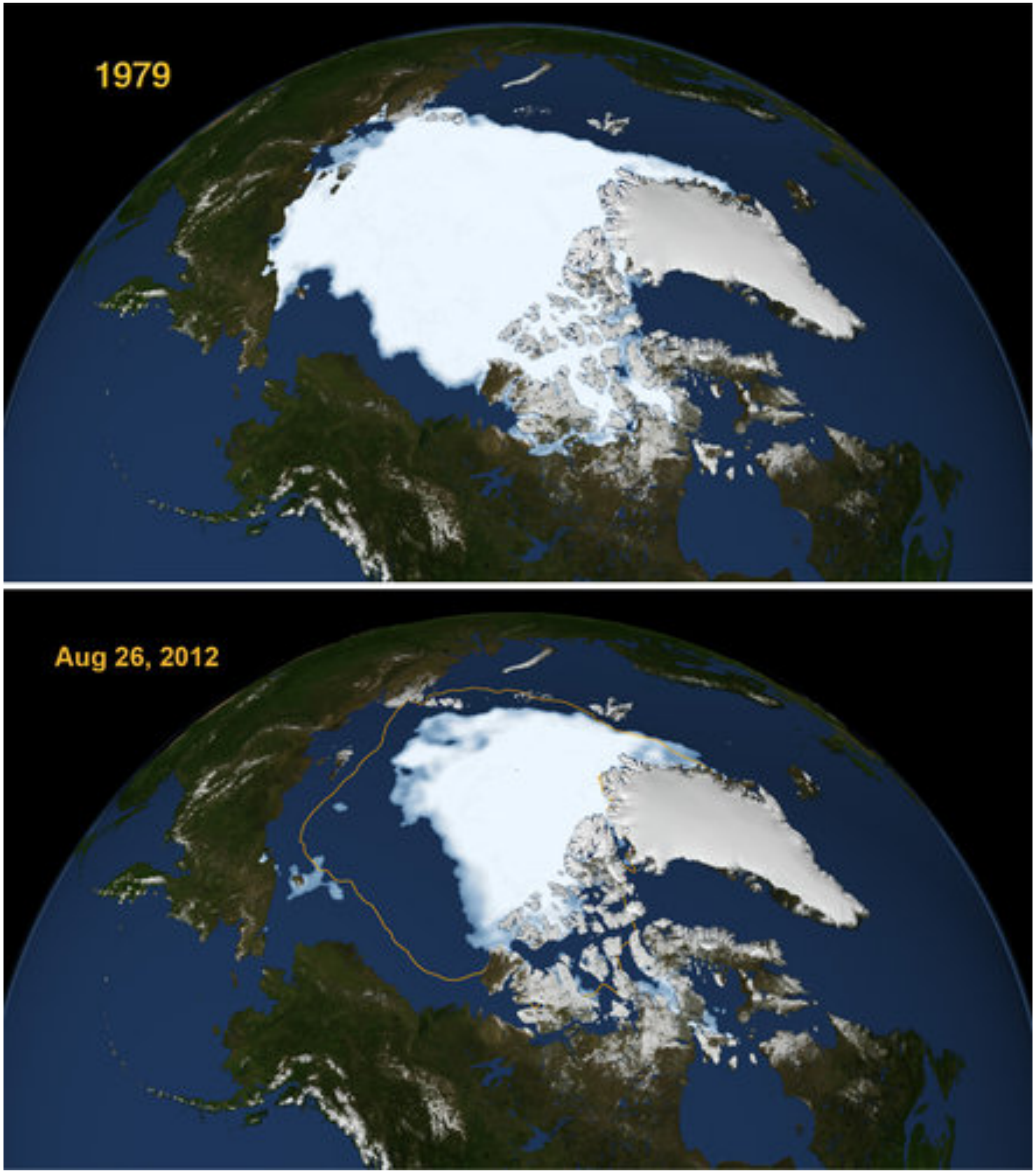
- **Climate** = the behavior of the atmosphere over a longer period of time and usually for a large area.
    - Climate is typically defined based on 30-year averages of weather.
    - Climate represents our expectations for the weather.
    - Scientists can compare recent and long-term observations of the climate to detect the influence of greenhouse gases on climate conditions.

Where is global warming going?



Effect on Glaciers



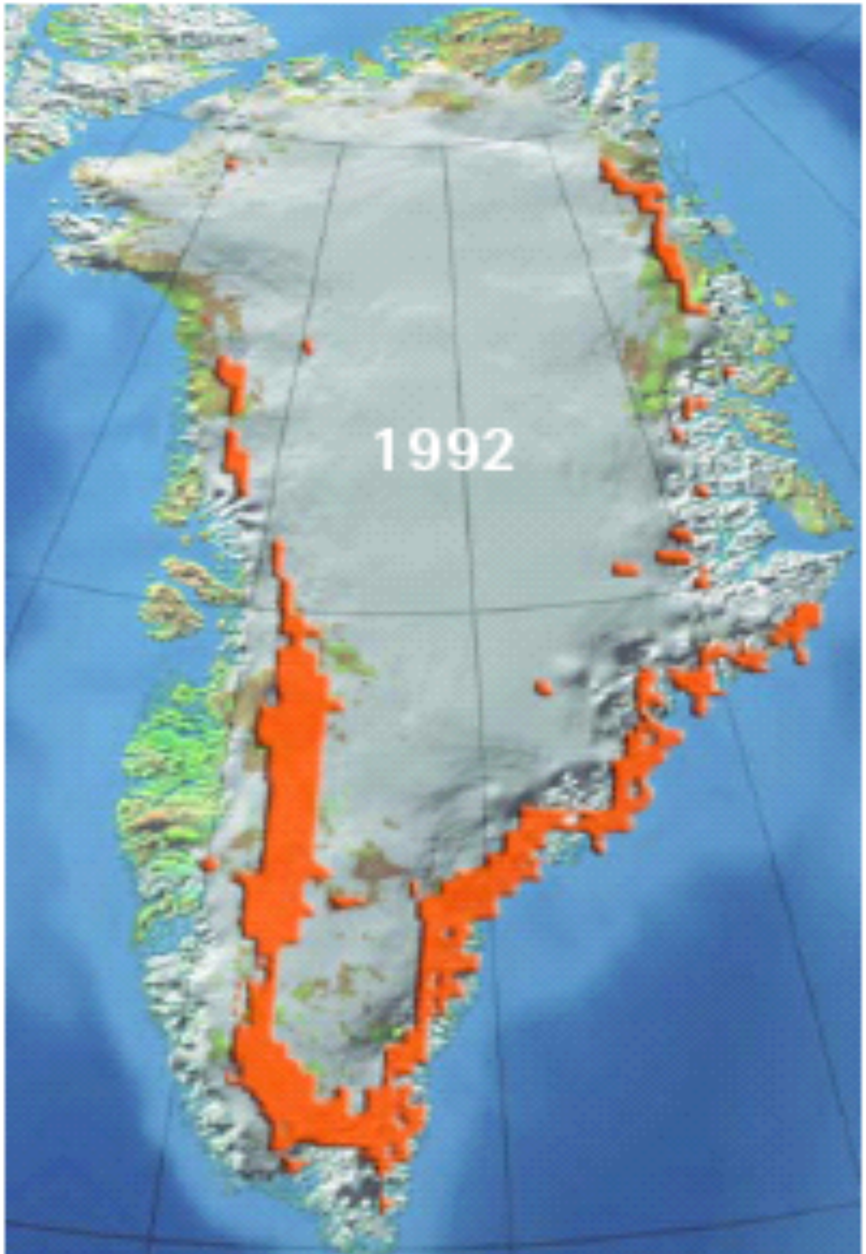


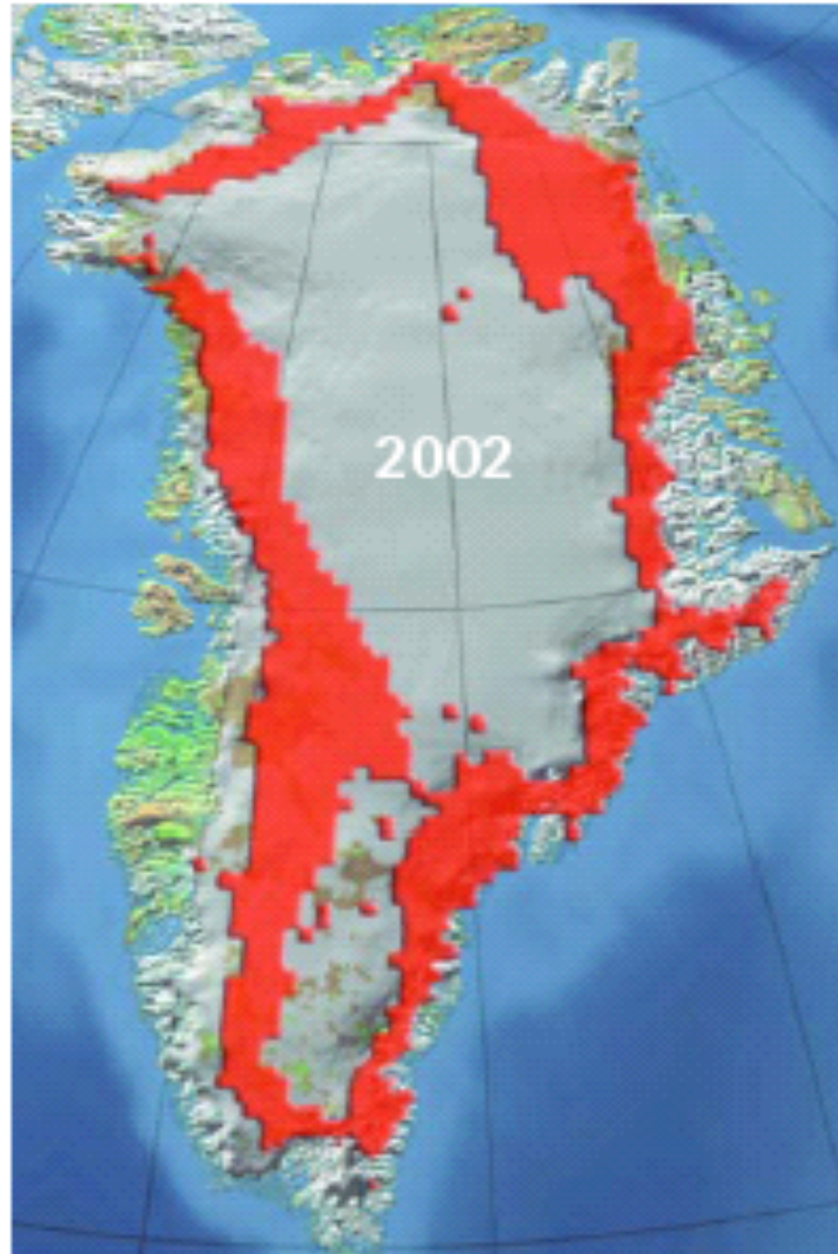
NASA photograph

Shrinking Polar Ice

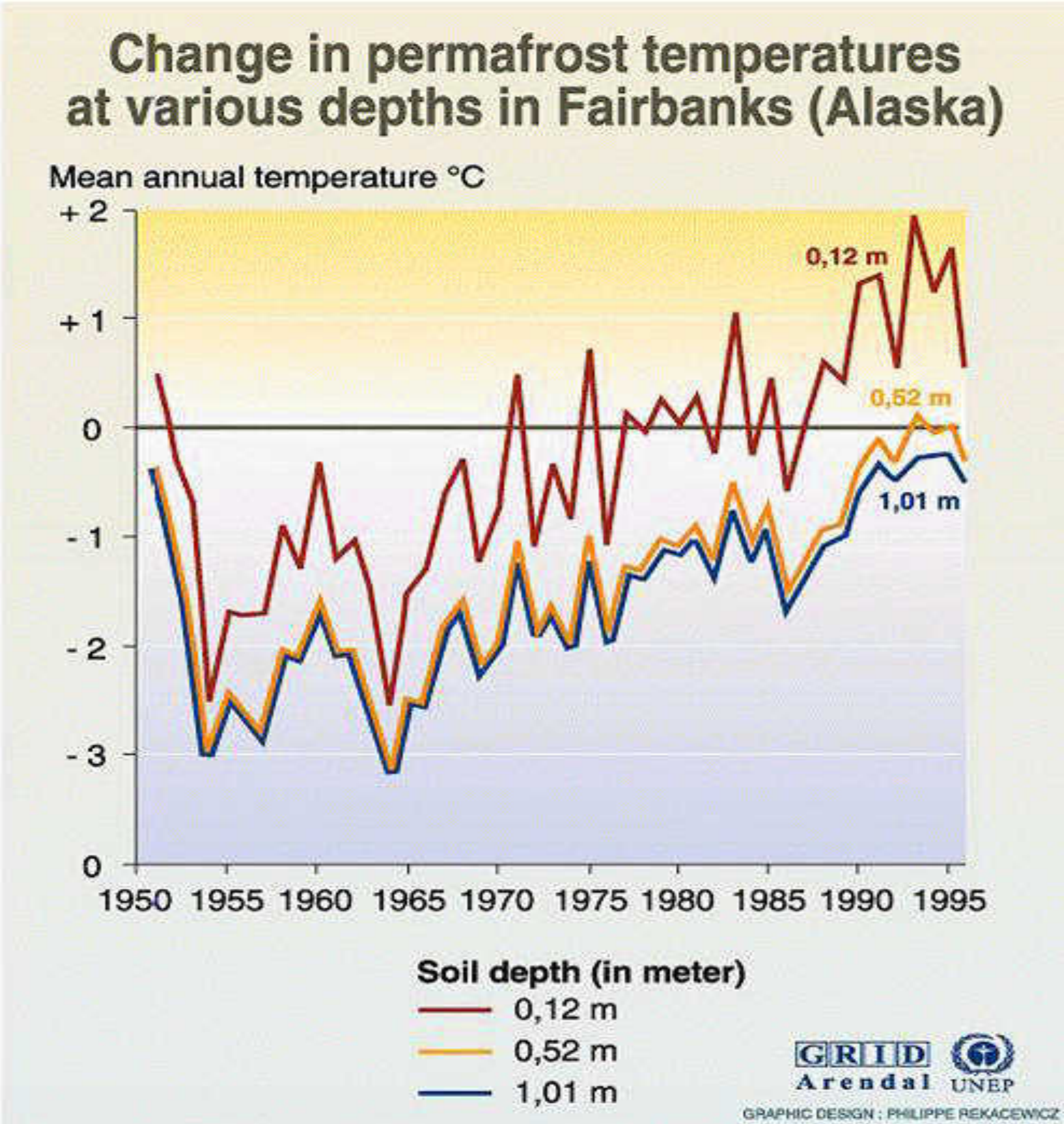
Extent of Arctic summer ice in 1979 (top satellite image) and in August 2012 (lower satellite image).

Extent of ice melt in Greenland, 1992 and 2002





Arctic Climate Impact Assessment 2004



Source: Romanovsky, in Impacts of global climate change in the Arctic regions, IASC, Tromsø, April 1999.

When permafrost temperature rises above the freezing point, and the permafrost melts, power lines, pipelines, and buildings built over the permafrost can topple, sag, and crack.

Why care about climate?

Climate governs:

- Distribution & abundance of species
- Productivity of farms, forests, & fisheries
- Geography of disease
- Livability of cities in summer
- Damages from storms, floods, wildfires
- Property losses from sea-level rise
- Expenditures on engineered environments

Hotter Summers

- https://www.nytimes.com/interactive/2017/07/28/climate/more-frequent-extreme-summer-heat.html

The Climate Change Story Line

Human Activities →

GHG Emissions and Land Use Changes →

Change in Atmospheric GHG Concentrations →

Change in Average Surface Temperature →

Direct & Indirect Feedbacks →

Direct & Indirect Biogeophysical Impacts →

Societal Impacts →

Policy Response?

- Change in GHG Emissions? (**Mitigation**)
- Adapting to Changes? (**Adaptation**)
- Suffering the Consequences? (**Suffering**)

Public Opinion on Climate Change

- http://www.gallup.com/poll/206030/global-warming-concern-three-decade-high.aspx
- https://www.nytimes.com/interactive/2017/03/21/climate/how-americans-think-about-climate-change-in-six-maps.html

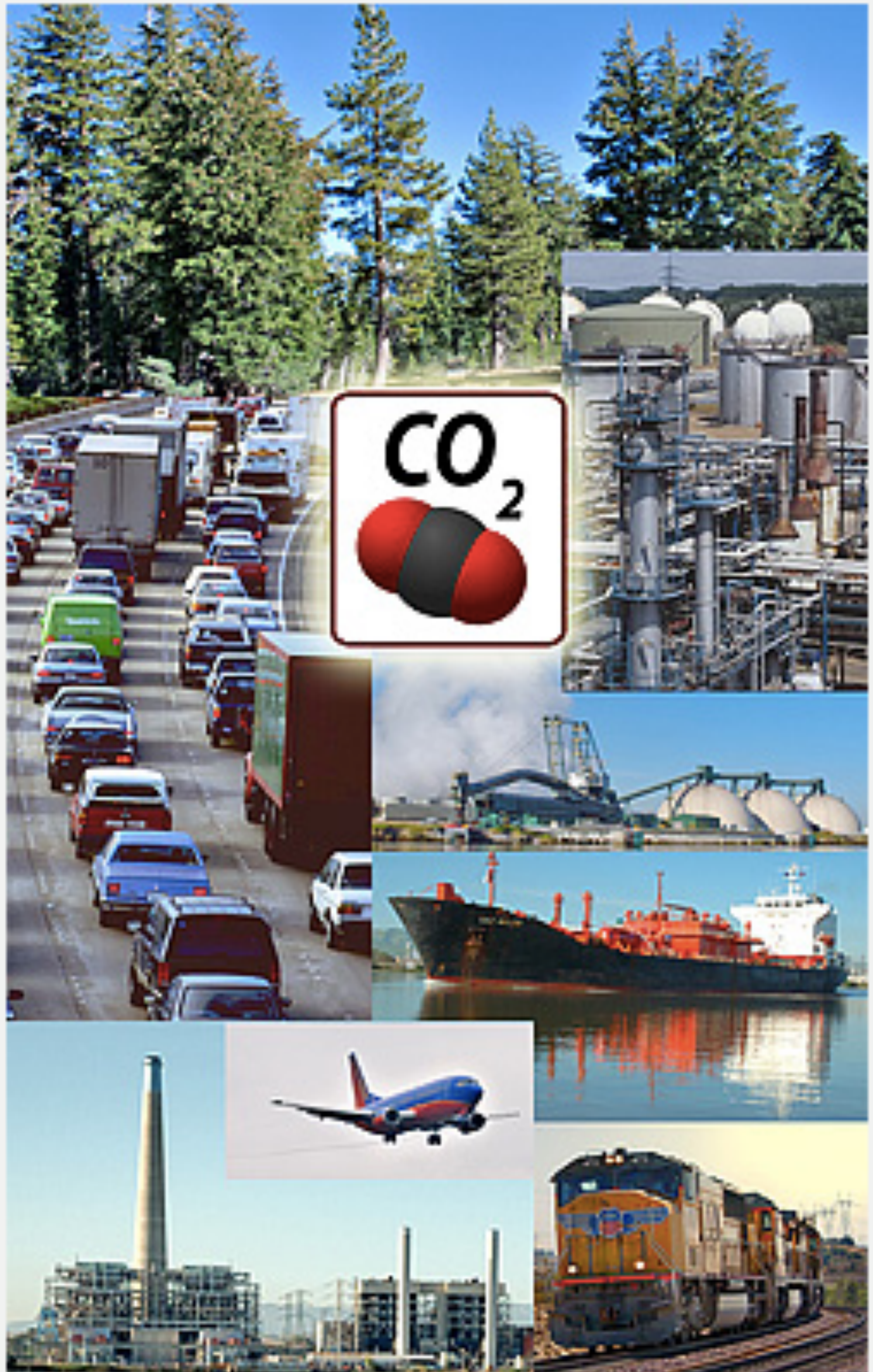
GHG Atmospheric Lifetimes and Global Warming Potential

- Each GHG has its own atmospheric residence time, governed by the sinks that remove it from the atmosphere.
- The global warming potential (GWP) of each GHG is measured relative to CO_2. GWP combines the GHG's efficiency at trapping IR radiation with its residence time in the atmosphere.
- Example: Over a 100 year period, a molecule of CH_4 contributes as much effect on climate change as 25 molecules of CO_2.

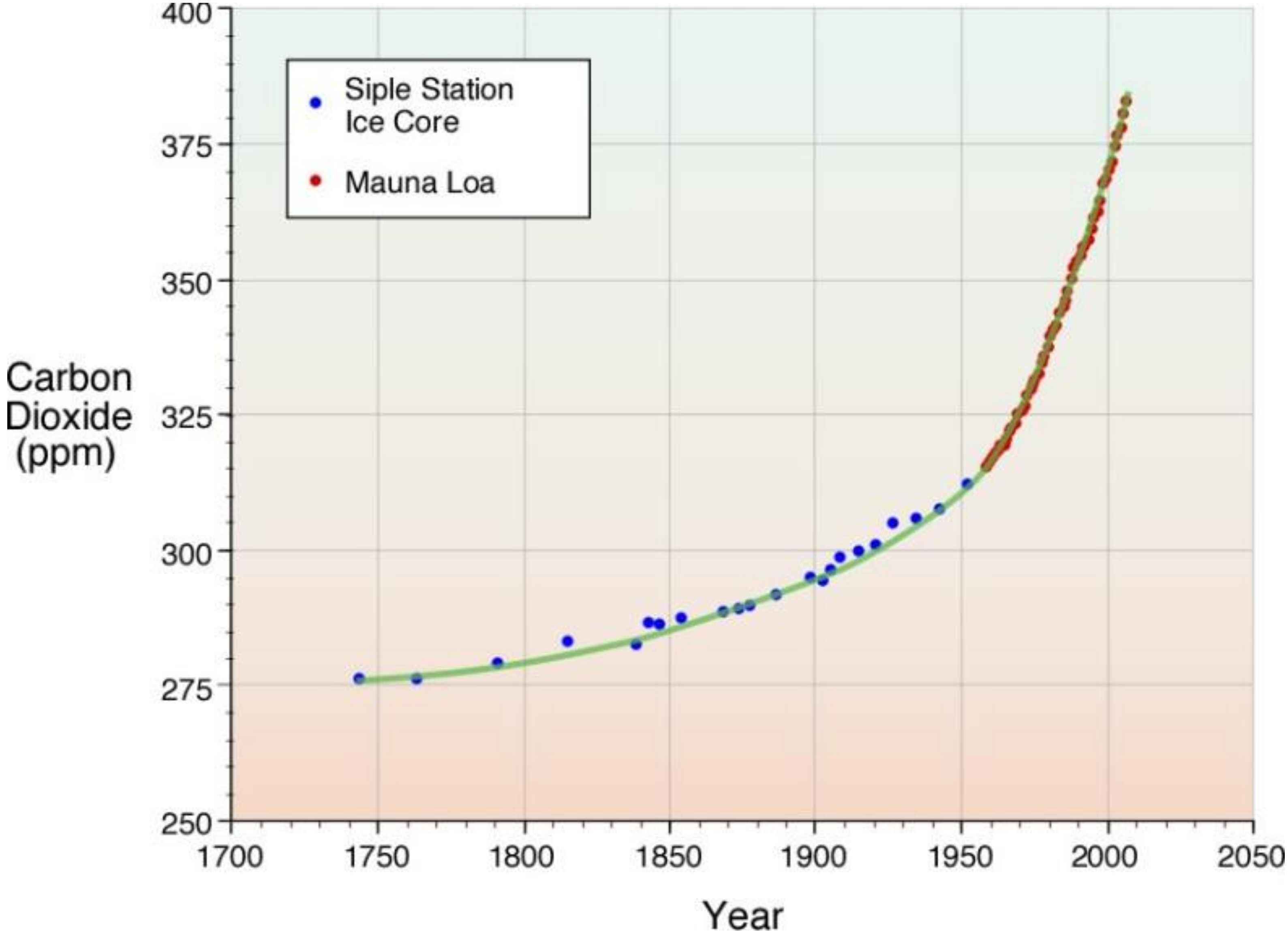
Global Warming Potential (GWP) = radiative impact of a GHG per molecule relative to impact of CO_2, taking into account its radiative properties and atmospheric lifetime

Atmospheric lifetime and GWP relative to CO_2 at different time horizon for various greenhouse gases.

Gas name	Chemical formula	Lifetime (years)	Global warming potential (GWP) for given time horizon		
			20-yr	100-yr	500-yr
Carbon dioxide	CO_2	See above	1	1	1
Methane	CH_4	12	72	25	7.6
Nitrous oxide	N_2O	114	289	298	153
CFC-12	CCl_2F_2	100	11,000	10,900	5 200
HCFC-22	$CHClF_2$	12	5160	1810	549
Tetrafluoromethane	CF_4	50,000	5210	7390	11,200
Hexafluoroethane	C_2F_6	10,000	8630	12,200	18,200
Sulphur hexafluoride	SF_6	3200	16,300	22,800	32,600
Nitrogen trifluoride	NF_3	740	12,300	17,200	20,700

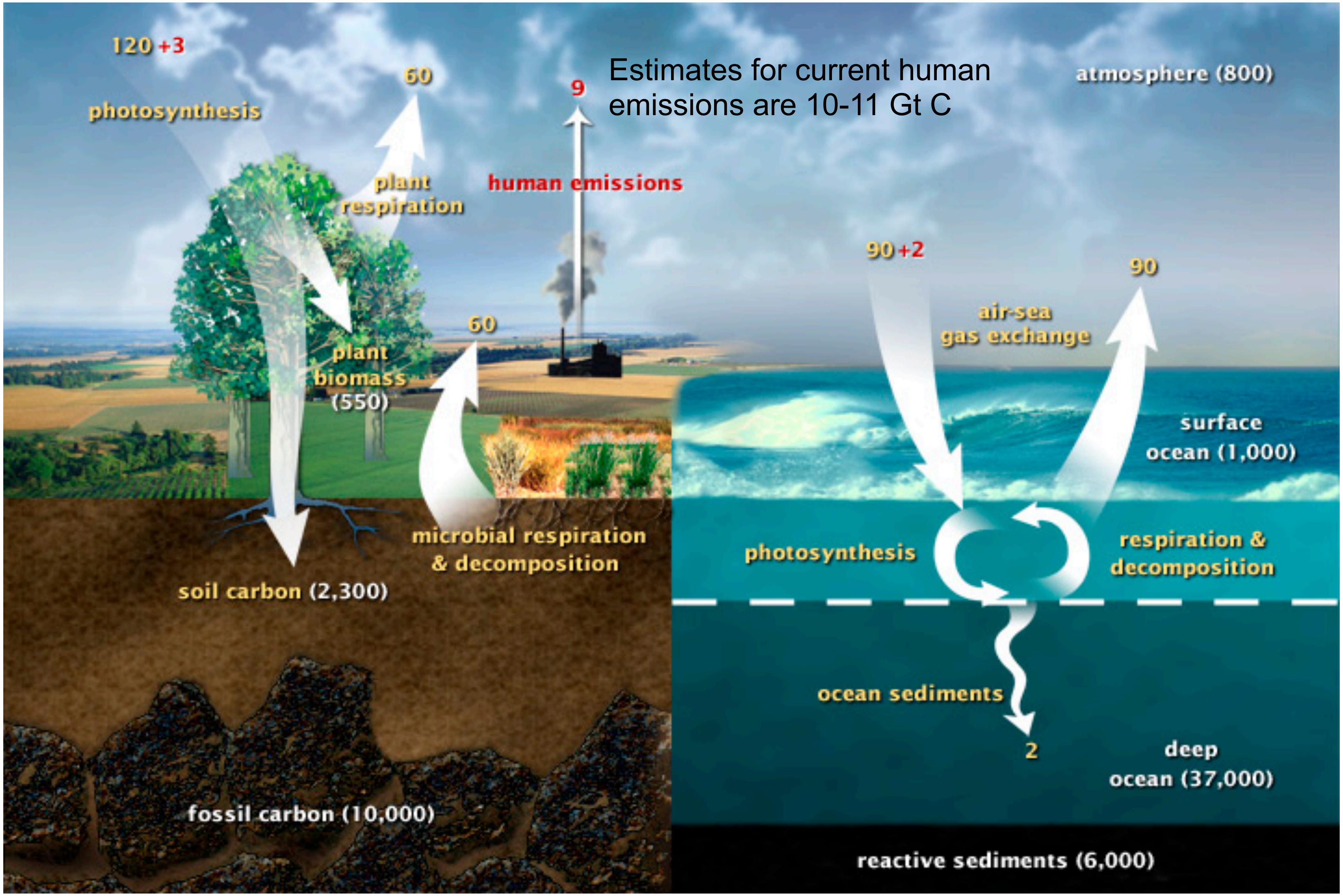

CO_2

CO_2 Concentrations



http://www.eoearth.org/article/Greenhouse_gas

Fast Carbon Cycle



The movement of carbon between land, atmosphere, and oceans in billions of tons of carbon per year. Yellow numbers are natural fluxes, red are human contributions in Gt of carbon per year. White numbers indicate stored carbon.

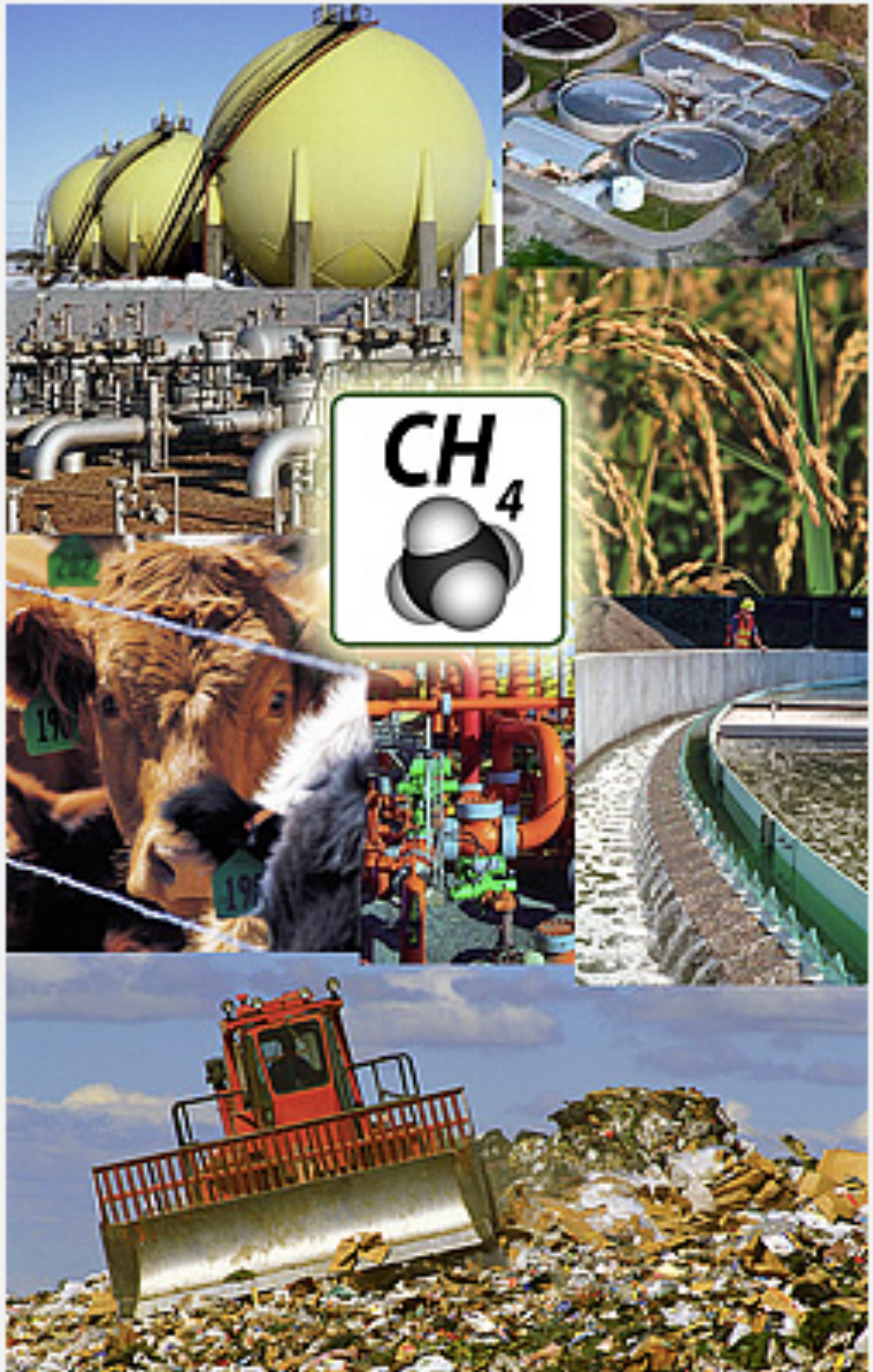
Role of Humans in the CO_2 Increases

- About 65% of anthropogenic CO_2 to atmosphere is from combustion of fossil fuels.
- Remaining 35% from deforestation and the conversion of prairie, woodland, and forested ecosystems primarily into less productive agricultural systems.
- Natural ecosystems can store 20 to 100 times more carbon dioxide per unit area than agricultural systems.

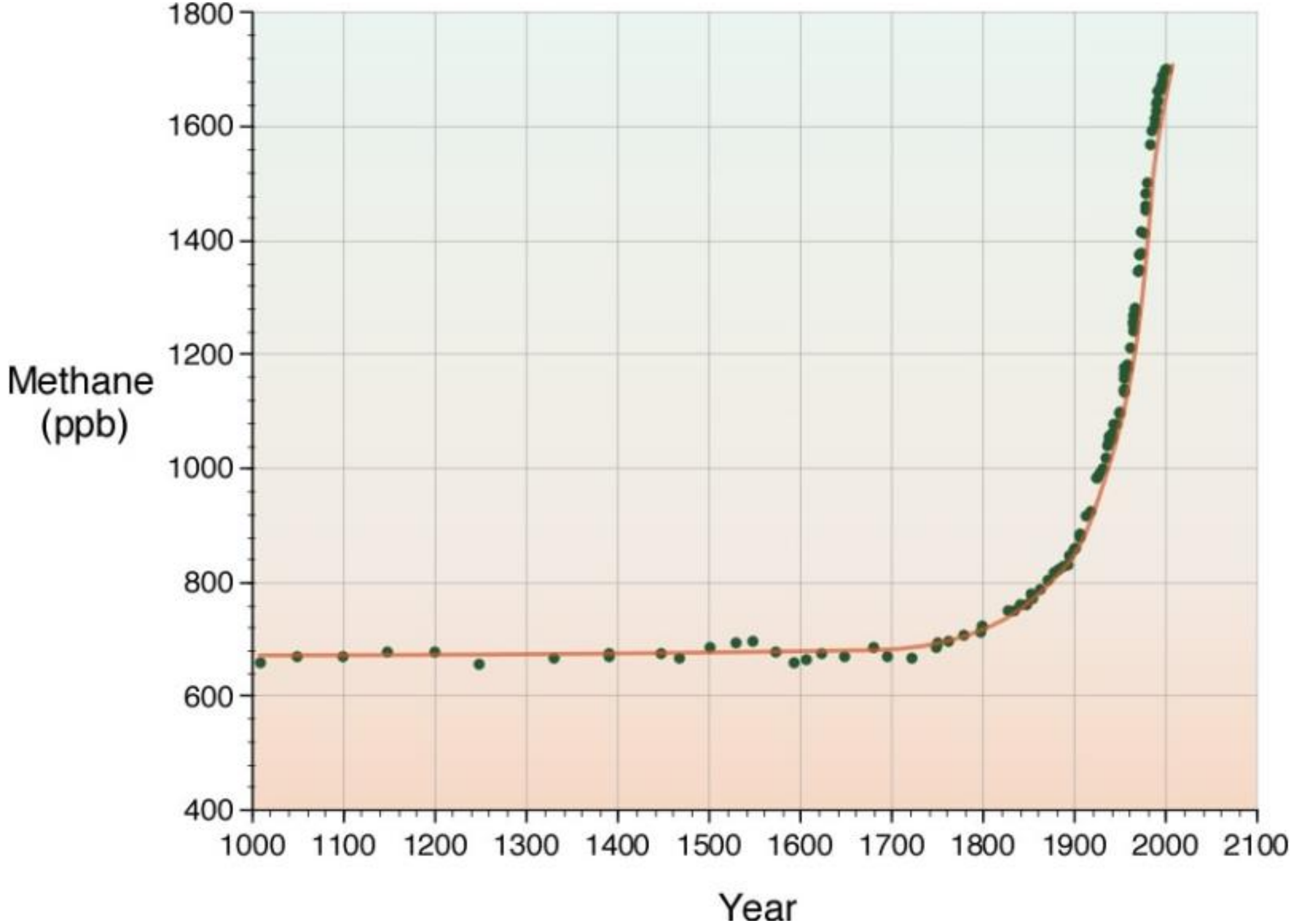
http://www.eoearth.org/article/Greenhouse_gas

Role of Humans in the CO_2 Increases

- The main human sources of CO_2 – deforestation and fossil-fuel burning – are quite well quantified. The observed CO_2 build-up in the atmosphere matches these human inputs, after subtraction of estimated rates of uptake in the oceans and northern forests.
- The ice-core data show that atmospheric CO_2 has not been above 300 ppm in the last 400,000 years (it's over 400 ppm today) and that natural fluctuations in atmospheric CO_2 over the past 10,000 years have been only $\pm$10 ppm (compared to the over 100 ppm increase since the start of the Industrial Revolution).
- Carbon-14 analysis of tree rings back to 1800 confirms the fossil-fuel contribution to the atmospheric CO_2 burden in the last 200 years.


CH4

Methane Concentrations 1000-2000 AD



http://www.eoearth.org/article/Greenhouse_gas

Naturally Occurring Methane

- Naturally occurring methane is mainly produced by the process of methanogenesis, a multistep process is used by microorganisms as an energy source. The net reaction is:

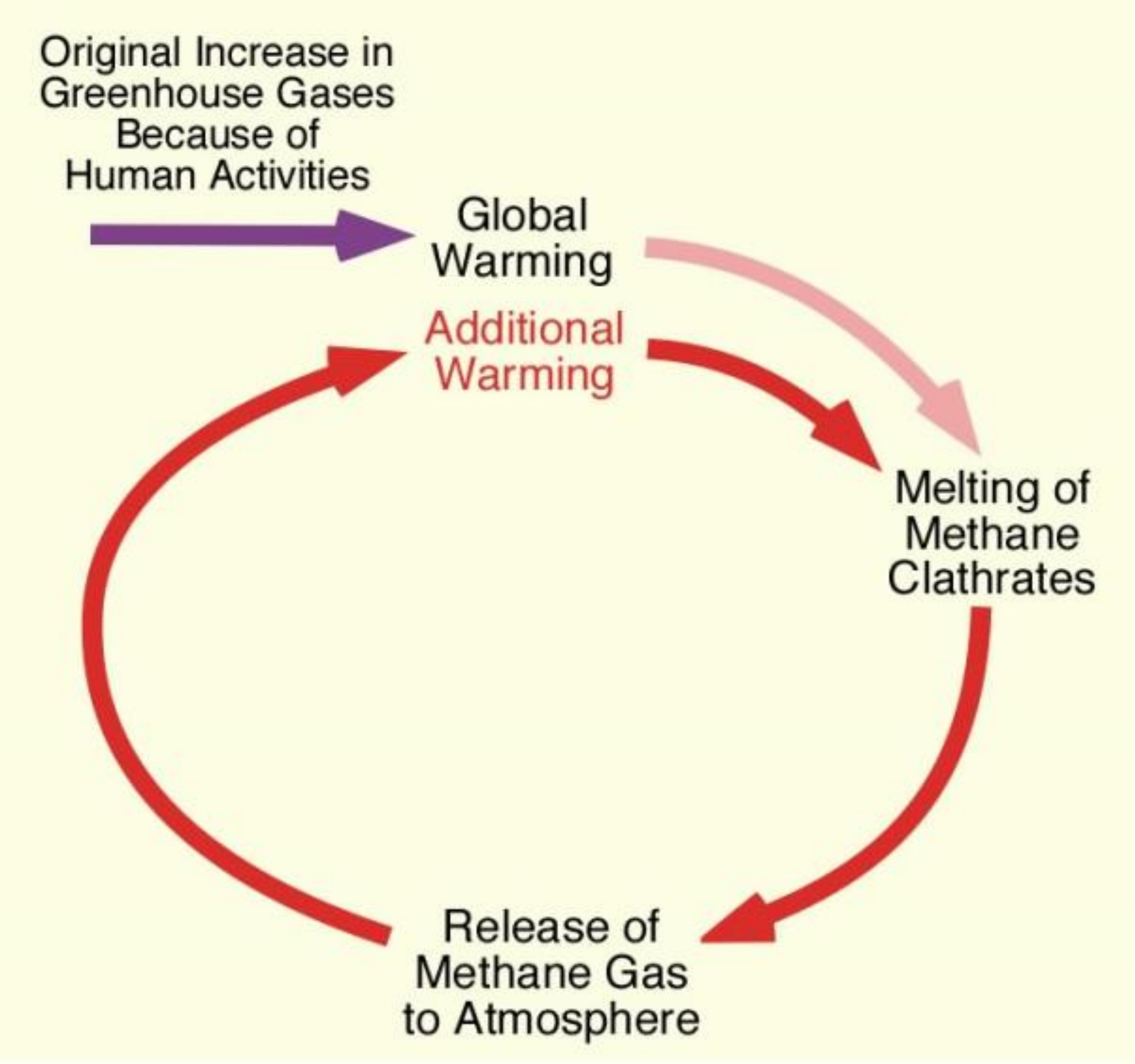
$$CO_2 + 8\ H^+ + 8\ e^- \rightarrow CH_4 + 2\ H_2O$$

- Methanogenesis is a form of anaerobic respiration used by organisms that occupy landfill, ruminants (e.g., cattle), and the guts of termites.

Atmospheric Methane Sources

- Biogenic sources (>70% of total)
  - Wetlands
  - Rice agriculture
  - Livestock
  - Landfills
  - Biomass burning
  - Forests
  - Oceans
  - Termites
- Non-biogenic sources
  - Emissions from natural gas, petroleum and coal mining and burning
  - Waste treatment
  - Geological sources (methane clathrates in ocean and permafrost)
  - Fossil CH_4 from natural gas seepage
  - Geothermal/volcanic CH_4

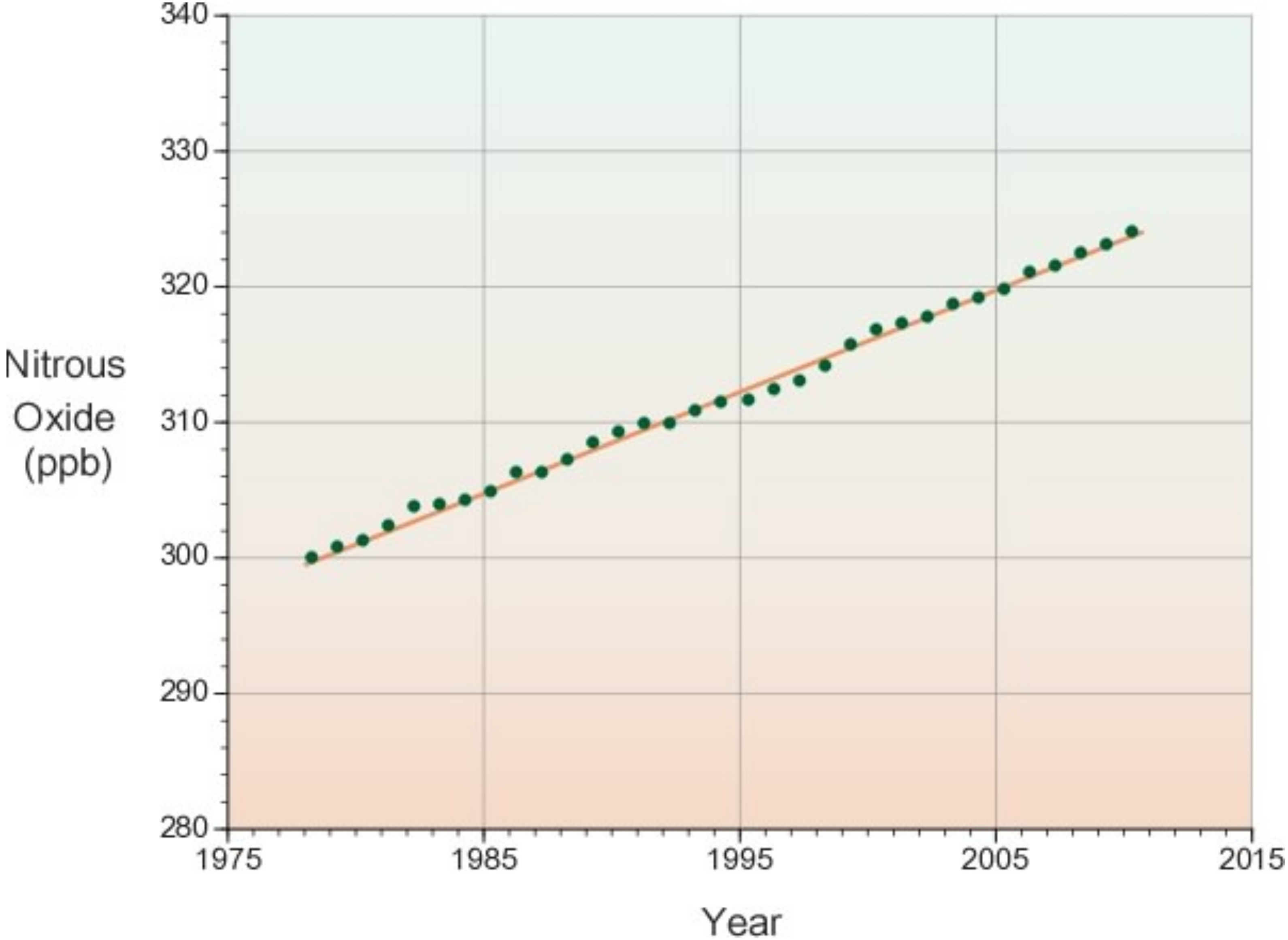
Feedback Example



http://www.eoearth.org/article/Greenhouse_gas


N_2O

N_2O Concentrations



http://www.eoearth.org/article/Greenhouse_gas

Role of Humans in the N_2O Increases

- The average concentration of nitrous oxide in the atmosphere is now increasing at a rate of 0.2 to 0.3% per year.
- Sources for the increase of nitrous oxide in the atmosphere include land-use conversion, fossil fuel combustion, biomass burning, and soil fertilization.
  - Most of the nitrous oxide added to the atmosphere each year due to human activities comes from agricultural soils, where nitrogen-rich fertilizer and manure is converted to nitrous oxide by soil bacteria. Nitrous oxide is also released into the atmosphere when fossil fuels and biomass are burned.

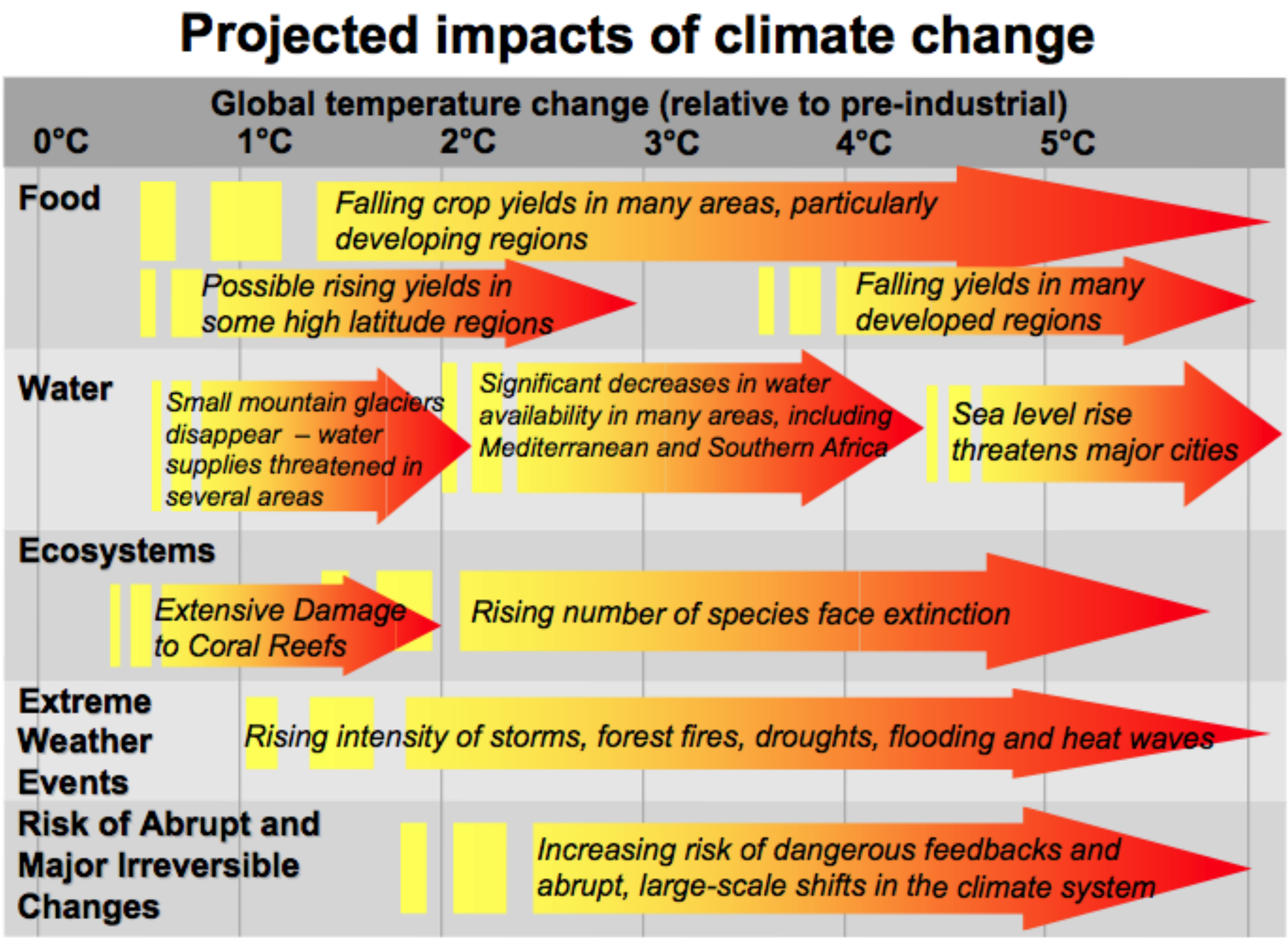
http://www.eoearth.org/article/Greenhouse_gas

Do other factors explain the temperature rise?

http://www.bloomberg.com/graphics/2015-whats-warming-the-world/

Some Examples of Climate Change Impacts

- Biodiversity
- Coral Reefs
- Disease vectors
- Extreme Weather
- Sea level rise
- Water supplies
- Wildfires



Projected impacts of climate change
Global temperature change (relative to pre-industrial)
0°C
1°C
2°C
3°C
4°C
5°C
Food
Falling crop yields in many areas, particularly developing regions
Possible rising yields in some high latitude regions
Falling yields in many developed regions
Water
Small mountain glaciers disappear – water supplies threatened in several areas
Significant decreases in water availability in many areas, including Mediterranean and Southern Africa
Sea level rise threatens major cities
Ecosystems
Extensive Damage to Coral Reefs
Rising number of species face extinction
Extreme Weather Events
Rising intensity of storms, forest fires, droughts, flooding and heat waves
Risk of Abrupt and Major Irreversible Changes
Increasing risk of dangerous feedbacks and abrupt, large-scale shifts in the climate system

2015 Paris Climate Change Agreement

http://www.nytimes.com/interactive/2015/11/23/world/carbon-pledges.html

http://www.nytimes.com/interactive/2015/12/12/world/paris-climate-change-deal-explainer.html

https://www.nytimes.com/interactive/2017/11/06/climate/world-emissions-goals-far-off-course.html

Ocean Impacts of Anthropogenic Climate Change

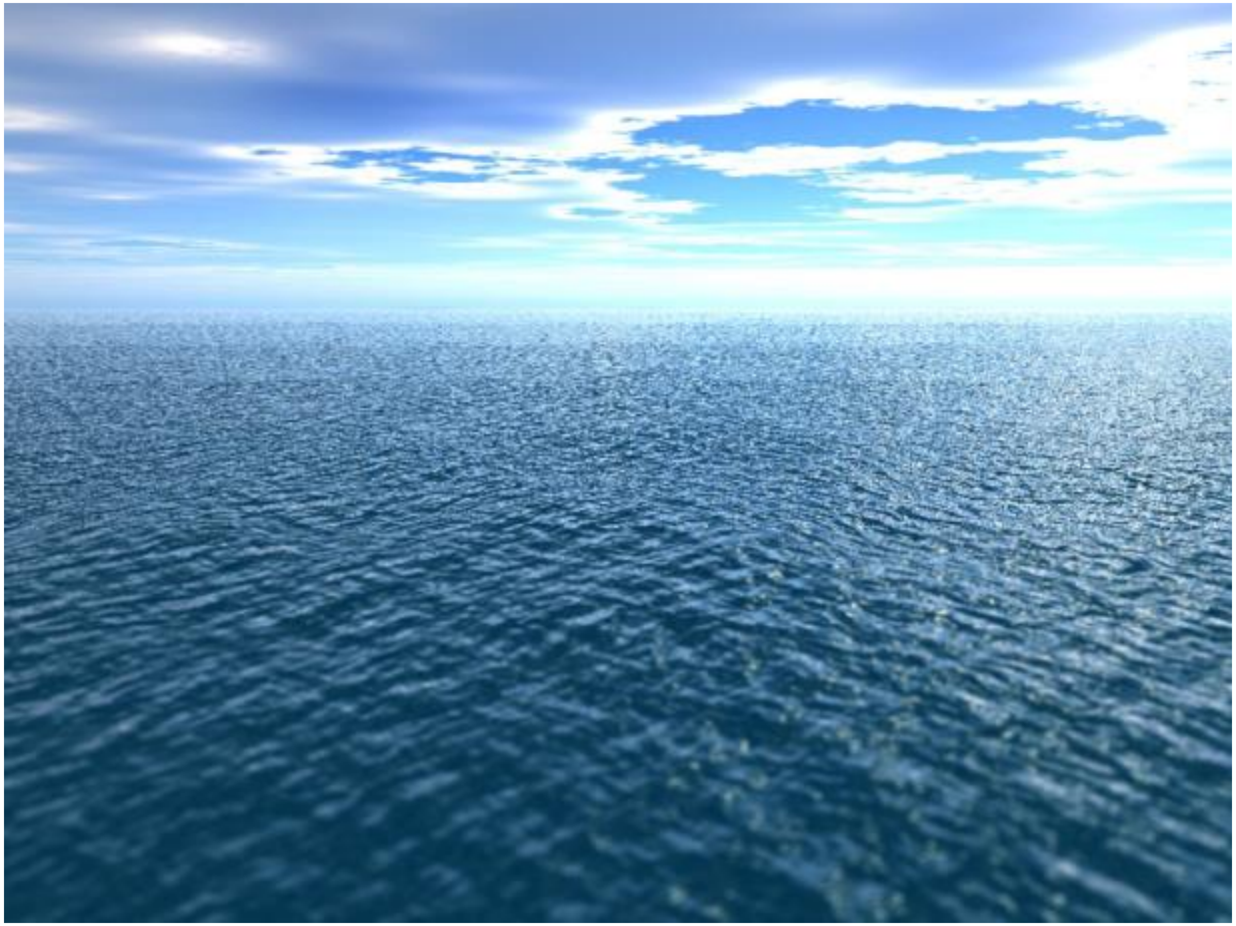
- Decreased ocean productivity,
- Altered food web dynamics,
- Reduced abundance of habitat-forming species,
- Shifting species distributions,
- A greater incidence of disease.

O Hoegh-Guldberg, J F Bruno
Science 2010;328:1523-1528

Less Understanding of Effect of Climate Change on Ocean Ecosystems

- Due to to the size and complexity of the ocean,
- And relative difficulty of taking measurements in marine environments.

O Hoegh-Guldberg, J F Bruno
Science 2010;328:1523-1528



Effect of CO_2 Absorption in Ocean

- *Oceans have absorbed approximately one-third of the carbon dioxide produced by human activities.*
- *The absorption of anthropogenic CO_2 has acidified the surface layers of the ocean, with a steady decrease of 0.02 pH units per decade over the past 30 years and an overall decrease since the pre-industrial period of 0.1 pH units.*
- *Although these increases appear small in terms of pH, they are associated with a substantial decline in the concentration of carbonate ions.*

O Hoegh-Guldberg, J F Bruno Science 2010;328:1523-1528

Other Effects of Climate Change on Oceans

- *Increased ocean volume and sea level from*
  - *Thermal expansion of the oceans*
  - *Increased meltwater and discharged ice from terrestrial glaciers and ice sheets*
- *Warmer oceans also drive more intense storm systems and other changes to the hydrological cycle.*
- *The warming of the upper layers of the ocean also drives greater stratification of the water column, reducing mixing in some parts of the ocean and consequently affecting nutrient availability and primary production. These changes have increased the size of the nutrient-poor "ocean deserts" of the Pacific and Atlantic by 6.6 million km^2, or 15%, over the period 1998 to 2006.*
- *General circulation models also predict that oxygen concentrations in the upper layers of the ocean are likely to decrease as a consequence of increasing stratification.*

O Hoegh-Guldberg, J F Bruno Science 2010;328:1523-1528

Other Effects of Climate Change on Oceans

- *Changes in the behavior of ocean currents have the potential to strongly influence the distribution and abundance of marine ecosystems.*
- *Some of the most striking impacts of global climate change have appeared in polar oceans, where temperatures and acidities of the polar oceans are changing at more than twice the global average.*
- *Arctic sea ice is steadily decreasing, its area being 16.5 million km^2 in March 1979 but reduced to 15.25 million km^2 by March 2009.*
- *Summer sea ice (measured in September each year) is projected to disappear completely by 2037.*
- *Satellite altimeter data reveal that the average global sea level is changing at a rate of 3.3 $\pm$ 0.4 mm/year (over the period 1993–2006).*

O Hoegh-Guldberg, J F Bruno Science 2010;328:1523-1528

Temperature Effect on Organisms

- *Increases in temperature increase metabolic rates, which ultimately determine life history traits, population growth, and ecosystem processes.*
- *Organisms tend to adapt to local environmental temperatures, with optimal physiological responses matching temperatures that are close to the environmental average.*
- *Organisms are able to acclimatize to a range of temperatures around these optimal values. Beyond this range, however, acclimatization fails, mortality risk increases, fitness is reduced, and populations decline or are driven to local extinction.*

O Hoegh-Guldberg, J F Bruno Science 2010;328:1523-1528

What can we do?

- Eat lower on the food chain, less meat and more fruits and vegetables.
- Waste less food and encourage businesses to sell imperfect produce.
  - Food production worldwide produces about 18% of the carbon dioxide emissions.
  - About 1/3 of the food produced worldwide goes uneaten.
- Walk or bicycle for trips under a mile or two.
  - The average car produces about 411 grams (almost a pound) of carbon dioxide per mile.

What can we do?

- If you can afford it…
  - Insulate your home
  - Solar panels for electricity
  - Drive a hybrid or any high mpg car
  - LED light bulbs
- Fly less
- ***Encourage your elected representatives to take action.***

Meat and Climate Change

- *The global livestock industry produces more greenhouse gas emissions than all cars, planes, trains and ships combined.*
- *The recent landmark report from the Intergovernmental Panel on Climate Change found that dietary change can "substantially lower" emissions.*
- *Two recent peer-reviewed studies calculated that, without severe cuts in this trend* [to more meat consumption]*, agricultural emissions will take up the entire world's carbon budget by 2050, with livestock a major contributor. This would mean every other sector, including energy, industry and transport, would have to be zero carbon, which is described as "impossible".*

http://www.theguardian.com/environment/2014/dec/03/eating-less-meat-curb-climate-change

Energy Technology Perspectives (ETP)

- **International Energy Agency (IEA),**
  - an autonomous agency
  - established in November 1974
  - Mandate – to promote energy security amongst its member countries through collective response to physical disruptions in oil supply and provide authoritative research and analysis on ways to ensure reliable, affordable and clean energy for its 28 member countries and beyond.
- Objectives:
  - Secure member countries' access to reliable and ample supplies of all forms of energy; in particular, through maintaining effective emergency response capabilities in case of oil supply disruptions.
  - Promote sustainable energy policies that spur economic growth and environmental protection in a global context – particularly in terms of reducing greenhouse-gas emissions that contribute to climate change.

http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress.pdf

Energy Technology Perspectives (ETP 2012)

- International Energy Agency (IEA) objectives (cont.)
  - Improve transparency of international markets through collection and analysis of energy data.
  - Support global collaboration on energy technology to secure future energy supplies and mitigate their environmental impact, including through improved energy efficiency and development and deployment of low-carbon technologies.
  - Find solutions to global energy challenges through engagement and dialogue with non-member countries, industry, international organisations and other stakeholders.
- ETP 2012 2 ºC Scenario (2DS)
  - identifies the technology options and policy pathways that ensure an 80% chance of limiting long-term global temperature increase to 2 ºC - provided that non-energy related CO_2 emissions, as well as other greenhouse gases, are also reduced.

http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress.pdf

2012 2DS Status

- Few clean energy technologies are currently on track to meet the 2DS objectives.
  - Cost reductions over the past decade and significant annual growth rates have been seen for onshore wind (27%) and solar photo-voltaic (PV) (42%).
- The technologies with the greatest potential for energy and CO_2 emissions savings are making the slowest progress:
  - Carbon capture and storage (CCS) is not seeing the necessary rates of investment into full-scale demonstration projects
  - Nearly one-half of new coal-fired power plants are still being built with inefficient technology;
  - Vehicle fuel-efficiency improvement is slow;
  - Significant untapped energy-efficiency potential remains in the building and industry sectors.

http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress.pdf

Investing in Clean Energy Makes Sense

- Each dollar invested can generate three dollars in future fuel savings by 2050.
- Achieving the 2DS would require $36 trillion (35% more in investments from today to 2050 than under a scenario in which controlling carbon emissions is not a priority).
- Equivalent of an extra $130 per person every year
- By 2050, $100-150 trillion in fuel savings
- In 2DS, save 450 exajoules (EJ) in cumulative fossil fuel purchases by 2020 and 9000 EJ by 2050

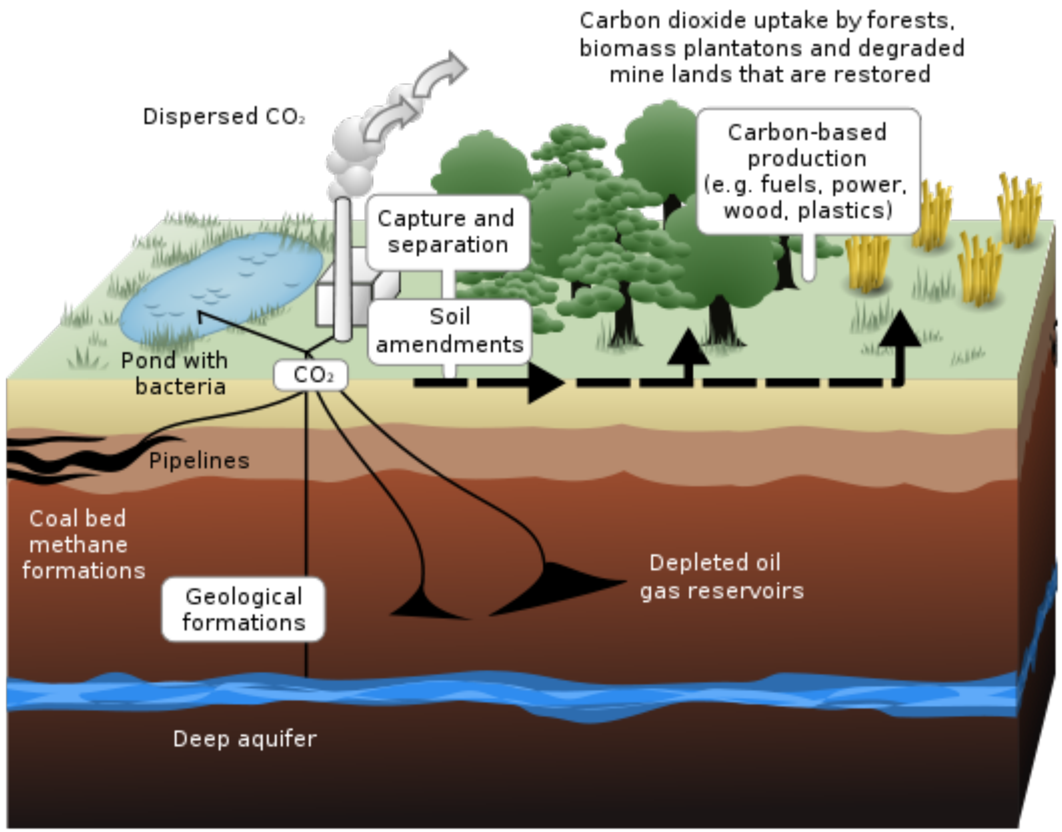
http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress.pdf

Future of Fossil fuels

- Limiting warming to 2 ºC would require that industrial emissions of greenhouse gases come to an end by roughly 2050.
- Limiting warming to 1.5 ºC would require an end by about 2030.
- This would require an end to gasoline cars, to coal- or gas-burning power plants in their current form, and to planes or ships powered by fossil fuels.

Carbon Capture and Storage (CCS)

- **Carbon capture and storage** (**CCS**), (**carbon capture and sequestration**) = technology attempting to prevent the release of large quantities of CO_2 into the atmosphere from fossil fuel use in power generation and other industries by capturing CO_2, transporting it and ultimately, pumping it into underground geologic formations to securely store it away from the atmosphere. It is a potential means of mitigating the contribution of fossil fuel emissions to global warming.



2012 - Summary of 2DS Progress

CO_2 reduction share by 2020*	On track?	Technology	Status against 2DS objectives	Key policy priorities
		HELE coal power	Efficient coal technologies is being deployed, but almost 50% of new plants in 2010 used inefficient technology.	CO_2 emissions, pollution, and coal efficiency policies required so that all new plants use best technology and coal demand slows.
		Nuclear power	Most countries have not changed their nuclear ambitions. However, 2025 capacity projections 15% below pre-Fukushima expectations.	Transparent safety protocols and plans; address increasing public opposition to nuclear power.
36%		Renewable power	More mature renewables are nearing competitiveness in a broader set of circumstances. Progress in hydropower, onshore wind, bioenergy and solar PV are broadly on track with 2DS objectives.	Continued policy support needed to bring down costs to competitive levels and deployment to more countries with high natural resource potential required.
			Less mature renewables (advanced geothermal, concentrated solar power (CSP), offshore wind) not making necessary progress.	Large-scale research development and demonstration (RD&D) efforts to advance less mature technologies with high potential.

http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress.pdf

2014 - Summary of 2DS Progress

	CCS in power	No large-scale integrated projects in place against the 38 required by 2020 to achieve the 2DS.	Announced CCS demonstration funds must be allocated. CO_2 emissions reduction policy, and long-term government frameworks that provide investment certainty will be necessary to promote investment in CCS technology.
23%	CCS in industry	Four large-scale integrated projects in place, against 82 required by 2020 to achieve the 2DS; 52 of which are needed in the chemicals, cement and iron and steel sectors.	
	Industry	Improvements achieved in industry energy efficiency, but significant potential remains untapped.	New plants must use best available technologies; energy management policies required; switch to lower carbon fuels and materials, driven by incentives linked to CO_2 emissions reduction policy.
18%	Buildings	Huge potential remains untapped. Few countries have policies to enhance the energy performance of buildings; some progress in deployment of efficient end-use technologies.	In OECD, retrofit policies to improve efficiency of existing building shell; Globally, comprehensive minimum energy performance codes and standards for new and existing buildings. Deployment of efficient appliance and building technologies required.

http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress.pdf

2012 - Summary of 2DS Progress

22%	Fuel economy	1.7% average annual fuel economy improvement in LDV efficiency, against 2.7% required to achieve 2DS objectives.	All countries to implement stringent fuel economy standards, and policies to drive consumers towards more efficient vehicles.
	Electric vehicles	Ambitious combined national targets of 20 Million EVs on the road by 2020, but significant action required to achieve this objective.	RD&D and deployment policies to: reduce battery costs; increase consumer confidence in EVs, incentivise manufacturers to expand production and model choice; develop recharging infrastructure.
	Biofuels for transport	Total biofuel production needs to double, with advanced biofuel production expanding four-fold over currently announced capacity, to achieve 2DS objectives in 2020.	Policies to support development of advanced biofuels industry; address sustainability concerns related to production and use of biofuels.

Note: *Does not add up to 100% as 'other transformation' represents 1% of CO_2 emission reduction to 2020; Red= Not on track; Orange= Improvements but more effort needed; Green= On track but sustained support and deployment required to maintain progress.

http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress.pdf

2012 - Recommendations to Reach 2DS

- Level Playing field
  - Prices reflect “true cost”, e.g. through carbon pricing
  - Remove inefficient fuel subsidies (2010 – about $409 billion for fossil fuels and about $66 billion for renewable energy)
  - Develop government policy frameworks to encourage private sector investment in low-carbon energy options
- Unlock the potential of energy efficiency
  - Implement energy efficiency policies and enhance efficiency standards
- Accelerate energy innovation and public RD&D

http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress.pdf

2012 - Clean Energy Scenarios

Box 1.1 ETP 2012 scenarios

6°C scenario (6DS). This scenario is not consistent with a stabilisation of atmospheric concentrations of greenhouse gases. Long-term temperature rise is likely to be ***at least*** 6°C. Energy use will almost double in 2050, compared with 2009, and total GHG gas emissions will rise even more. The current trend of increasing emissions is unbroken with no stabilisation of GHG concentrations in the atmosphere in sight. The 6DS emissions trajectory is consistent with the *World Energy Outlook (WEO)* Current Policy Scenario through 2035 (IEA, 2011a).

4°C scenario (4DS): Energy use and GHG emissions rise, but less rapidly than in the 6DS and, by 2050, at a declining rate. This scenario requires strong policy action. Limiting temperature rise to 4°C will also require significant efforts to reduce other greenhouse gases besides carbon dioxide. It will also require significant cuts in emissions in the period after 2050. The 4DS emissions trajectory is consistent with the *World Energy Outlook (WEO)* New Policy Scenario through 2035 (IEA, 2011a).

2°C scenario (2DS). The emission trajectory is consistent with what the latest climate science research indicates would give a 80% chance of limiting long-term global temperature increase to 2°C , *provided that non-energy related CO_2 emissions, as well as other greenhouse gases, are also reduced*. Energy-related CO_2 emissions are cut by more than half in 2050, compared with 2009, and continue to fall after that. The 2DS emissions trajectory is consistent with the *World Energy Outlook (WEO)* 450 Scenario through 2035 (IEA, 2011a).

http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress.pdf

2014 - IPCC (AR5)

- *"Despite a growing number of climate change mitigation policies, annual GHG emissions grew on average by 1.0 giga tonne carbon dioxide equivalent ($GtCO_2eq$) (2.2%) per year from 2000 to 2010 compared to 0.4 $GtCO_2eq$ (1.3%) per year from 1970 to 2000.*
- *Total anthropogenic GHG emissions were the highest in human history from 2000 to 2010 and reached 49 (±4.5) $GtCO_2eq/yr$ in 2010.*
- *The global economic crisis 2007/2008 only temporarily reduced emissions."*

https://www.ipcc.ch/report/ar5/wg1/

2014 - IPCC (AR5)

- *“CO_2 emissions from fossil fuel combustion and industrial processes contributed about 78% of the total GHG emission increase from 1970 to 2010, with a similar percentage contribution for the period 2000–2010. Fossil fuel-related CO_2 emissions reached 32 (±2.7) $GtCO_2$/yr, in 2010, and grew further by about 3% between 2010 and 2011 and by about 1-2% between 2011 and 2012.”*

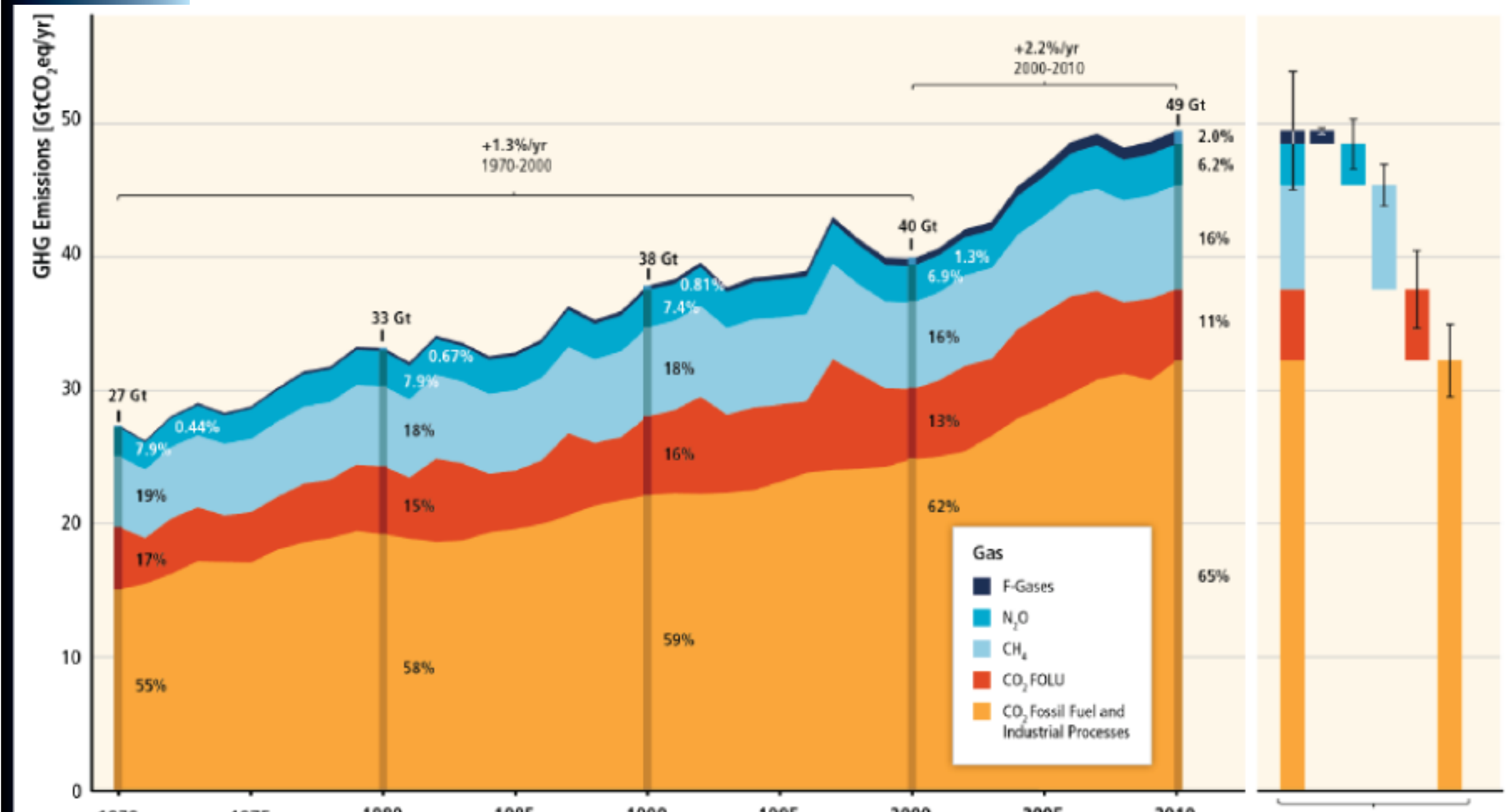
https://www.ipcc.ch/report/ar5/wg1/

2014 - IPCC (AR5)

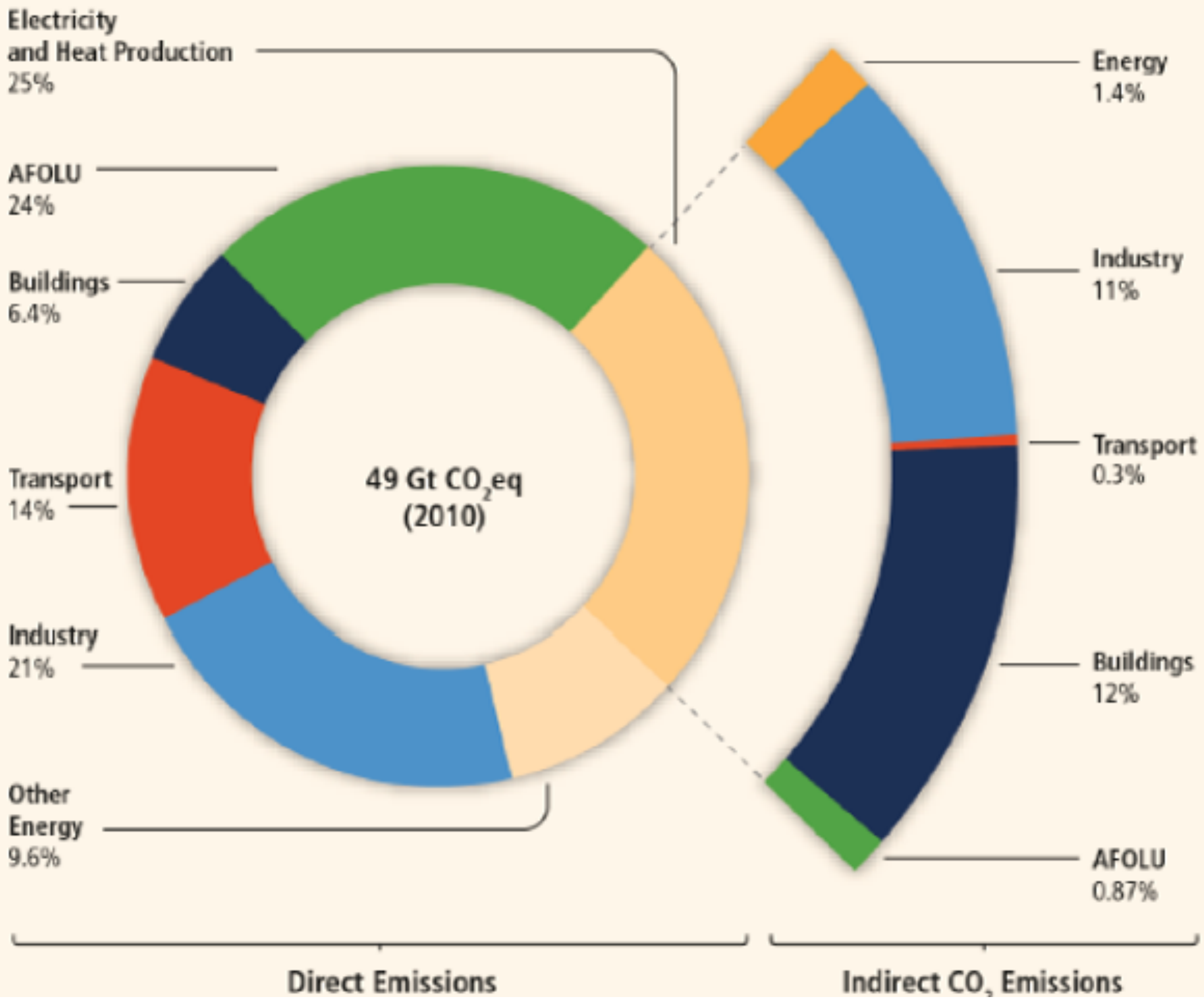
- *"Of the 49 ($\pm$4.5) $GtCO_2eq$/yr in total anthropogenic GHG emissions in 2010, CO_2 remains the major anthropogenic GHG accounting for 76% (38$\pm$3.8 $GtCO_2eq$/yr) of total anthropogenic GHG emissions in 2010. 16% (7.8$\pm$1.6 $GtCO_2eq$/yr) come from methane (CH_4), 6.2% (3.1$\pm$1.9 $GtCO_2eq$/yr) from nitrous oxide (N_2O), and 2.0% (1.0$\pm$0.2 $GtCO_2eq$/yr) from fluorinated gases.*
- *Annually, since 1970, about 25% of anthropogenic GHG emissions have been in the form of non-CO_2 gases."*

https://www.ipcc.ch/report/ar5/wg1/

IPCC (AR5)
GHG Emissions



IPCC (AR5)
GHG by Sector



IPCC (AR5)
GHG and Population

- *"Globally, **economic and population growth continue to be the most important drivers of increases in CO_2 emissions from fossil fuel combustion**. The contribution of population growth between 2000 and 2010 remained roughly identical to the previous three decades, while the contribution of economic growth has risen sharply**.***
- *Between 2000 and 2010, both drivers outpaced emission reductions from improvements in energy intensity. Increased use of coal relative to other energy sources has reversed the long-standing trend of gradual decarbonization of the world's energy supply."*

2100 Scenarios

- Scenarios reaching atmospheric concentration levels of about 450 ppm CO_2eq by 2100 (consistent with a likely chance to keep temperature change below 2 ºC relative to pre-industrial levels) include substantial cuts in anthropogenic GHG emissions by mid-century through large-scale changes in energy systems and potentially land use (high confidence).

https://www.ipcc.ch/report/ar5/wg1/

2100 Scenarios

- Scenarios reaching these concentrations by 2100 are characterized by lower global GHG emissions in 2050 than in 2010, 40% to 70% lower globally, and emissions levels near zero $GtCO_2eq$ or below in 2100.
- In scenarios reaching 500 ppm CO_2eq by 2100, 2050 emissions levels are 25% to 55% lower than in 2010 globally.
- In scenarios reaching 550 ppm CO_2eq, emissions in 2050 are from 5% above 2010 levels to 45% below 2010 levels globally.

https://www.ipcc.ch/report/ar5/wg1/

ETP 2016
Executive Summary

- *A low fossil fuel price outlook poses both unique opportunities and threats for low-carbon technology deployment.*
- *The transition requires massive changes in the energy system, and the 2 Degree Scenario (2DS) highlights targeted measures needed to deploy low-carbon technologies so as to achieve a cost-effective transition.*
- ***The investment costs of the 2DS across the power sector and the three enduse sectors (buildings, industry and transport) would not require unreasonable additional financial efforts from the global economy.***

https://www.iea.org/publications/freepublications/publication/EnergyTechnologyPerspectives2016_ExecutiveSummary_EnglishVersion.pdf

ETP 2016 *The energy landscape is shaped by cities.*

- *With more than half of global population and about 80% of the world's GDP in 2013, cities account for about two-thirds of primary energy demand and 70% of total energy-related carbon dioxide (CO_2) emissions.*
- *Cities can enable unique, cost-effective options and synergies to accelerate the decarbonisation of the buildings sector.*
- *Urban transport systems can lead the low-carbon transition in mobility.*
- *Mobilising the urban sustainable energy potential requires strong support from national governments to local policy makers.*

https://www.iea.org/publications/freepublications/publication/EnergyTechnologyPerspectives2016_ExecutiveSummary_EnglishVersion.pdf

2012 - Changes in Sources of Electricity Supply

- Higher-efficiency and lower-emissions coal
  - For 2DS, coal share of electricity generation is expected to decline from 40% in 2009 to 35% in 2020, and its use becomes increasingly efficient and less carbon-intensive.
  - Higher efficiency, lower emissions (HELE) coal technologies - including supercritical pulverized coal combustion (SC), ultra-supercritical pulverized coal combustion (USC) and integrated gasification combined cycle (IGCC) - must be deployed. (A **supercritical fluid** is any substance at a temperature and pressure above its critical point, where distinct liquid and gas phases do not exist. It can effuse through solids like a gas, and dissolve materials like a liquid.)

http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress.pdf

Nuclear Power

- About 440 nuclear reactors in world – nearly constant for a decade
- 6% increase in capacity due to larger reactors and increased rates of power production for existing reactors
- 2011 – 67 reactors under construction, 26 of which are in China
- 2011 - construction began on only four new nuclear reactors, a significant drop from 2010
- Projections suggest that nuclear deployment by 2015 will be below the level needed for 2DS.

http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress.pdf

Renewable Power

- Includes hydropower, solar, wind, biomass, geothermal and ocean
- 13% average annual growth in installed capacity in the last 10 years.
- While starting from a small base, non-hydro renewables have been growing more rapidly, with generation doubling over the past five years.
- In 2010, their share of total electricity production remained at about 3%.
- While the portfolio of renewable technologies is becoming increasingly competitive, given the right resource and market conditions, renewables are still more expensive than fossil fuel-based power technologies

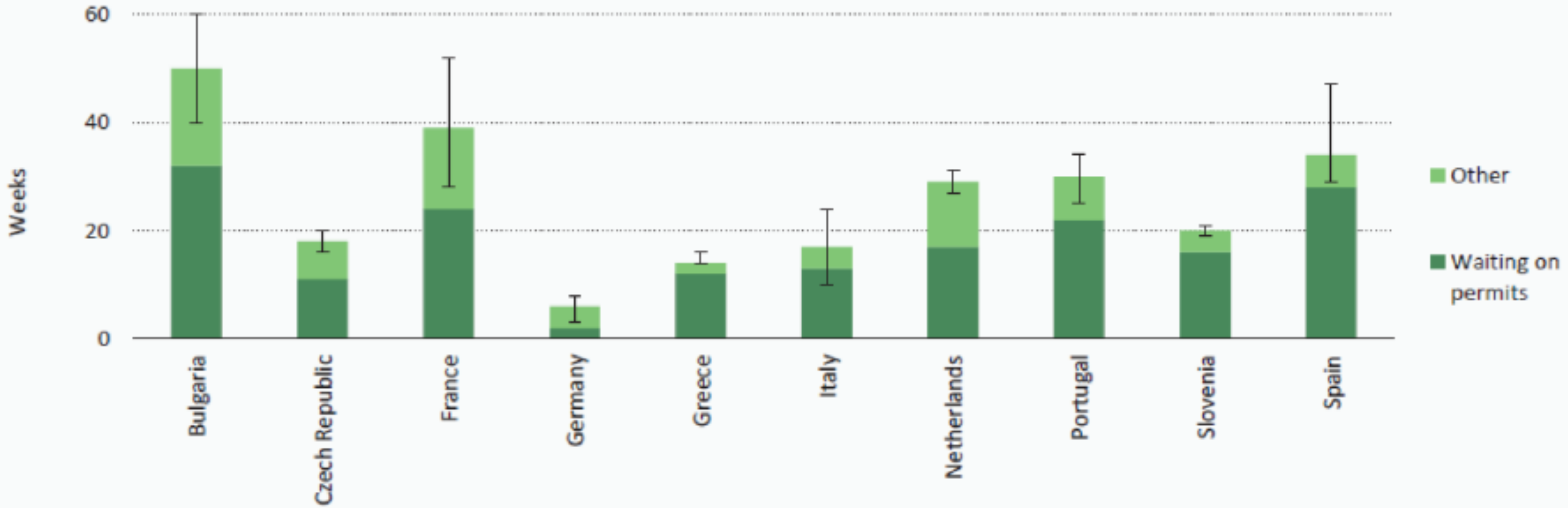
http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress.pdf

Solar Photovoltaic (Solar PV)

- Use solar panels to convert sunlight into electricity
- From 2000 to 2011, fastest-growing renewable energy technology worldwide with an average annual growth above 40% in this period.
- Growth concentrated in only a few markets (Germany, Italy, the United States and Japan)
- Regions with good solar potential (*e.g.* Africa and parts of Asia) need to add significant solar capacity to meet the technology contribution share in the 2DS scenario.

http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress.pdf

Time for Small-scale Rooftop Photovoltaic



Note: Average values shown; error bars show minimum and maximum total durations.
Source: PV legal, 2010; from IEA, 2011c.

http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress.pdf

Concentrated Solar Power (CSP)

- Use mirrors or lenses to concentrate a large area of sunlight, or solar thermal energy, onto a small area. Electrical power is produced when the concentrated light is converted to heat, which drives a steam turbine connected to an electrical power generator.
- Spain has taken over as the world leader in CSP and, together with the United States, accounted for 90% of the market in 2011.

http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress.pdf

Onshore Wind

- On pace to achieve the 2DS scenario objectives by 2020, if its current rate of growth continues (27% average annual growth over the past decade).
- It is among the most cost-competitive renewable energy sources and can now compete without special support in electricity markets endowed with steady winds and supportive regulatory frameworks.

http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress.pdf

Offshore Wind

- An emerging technology
- Requires further RD&D to enhance technology components (*e.g.* offshore wind platforms and large wind turbines) and bring down technology costs.

http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress.pdf

Geothermal Power Plants

- **Geothermal electricity** is electricity generated from geothermal energy.
- Geothermal electricity generation is currently used in 24 countries, while geothermal heating is in use in 70 countries.
- Estimates of the electricity generating potential of geothermal energy vary from 35 to 2,000 GW.

Nesjavellir Geothermal Power Station in Iceland

Geothermal Power Plants

- Largest capacity in the United States, Philippines, and Indonesia.
- Geothermal power is considered to be sustainable because the heat extraction is small compared with the Earth's heat content.
- Average annual growth in **geothermal** electricity generation reached 3% between 2000 and 2010.
- Where an accessible high-temperature geothermal resource exists, generation costs are competitive with other power generation alternatives. Despite this, geothermal electricity generation has not reached its full potential and is falling behind the deployment levels required to achieve the 2DS objectives by 2020.

http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress.pdf

Solid Biomass, Biogas, Renewable Municipal Waste and Liquid Biofuels

- **Biomass**, as a renewable energy source, is biological material from living, or recently living organisms. As an energy source, biomass can either be used directly, or converted into other energy products such as biofuel.
- **Biogas** = a gas produced by the biological breakdown of organic matter in the absence of oxygen. Organic waste such as dead plant and animal material, animal feces, and kitchen waste can be converted into a gaseous fuel called biogas. Biogas originates from biogenic material and is a type of bio fuel.
- **Biofuel** = a type of fuel whose energy is derived from biological carbon fixation. Biofuels include fuels derived from biomass conversion, as well as solid biomass, liquid fuels and various biogases. Although fossil fuels have their origin in ancient carbon fixation, they are not considered biofuels because they contain carbon that has been "out" of the carbon cycle for a very long time.
- Steadily increasing as a source of power since 2000, at an average of 8% annual growth. This progress is broadly on track with the 2DS objectives. But future progress will depend heavily on the cost and availability of biomass.

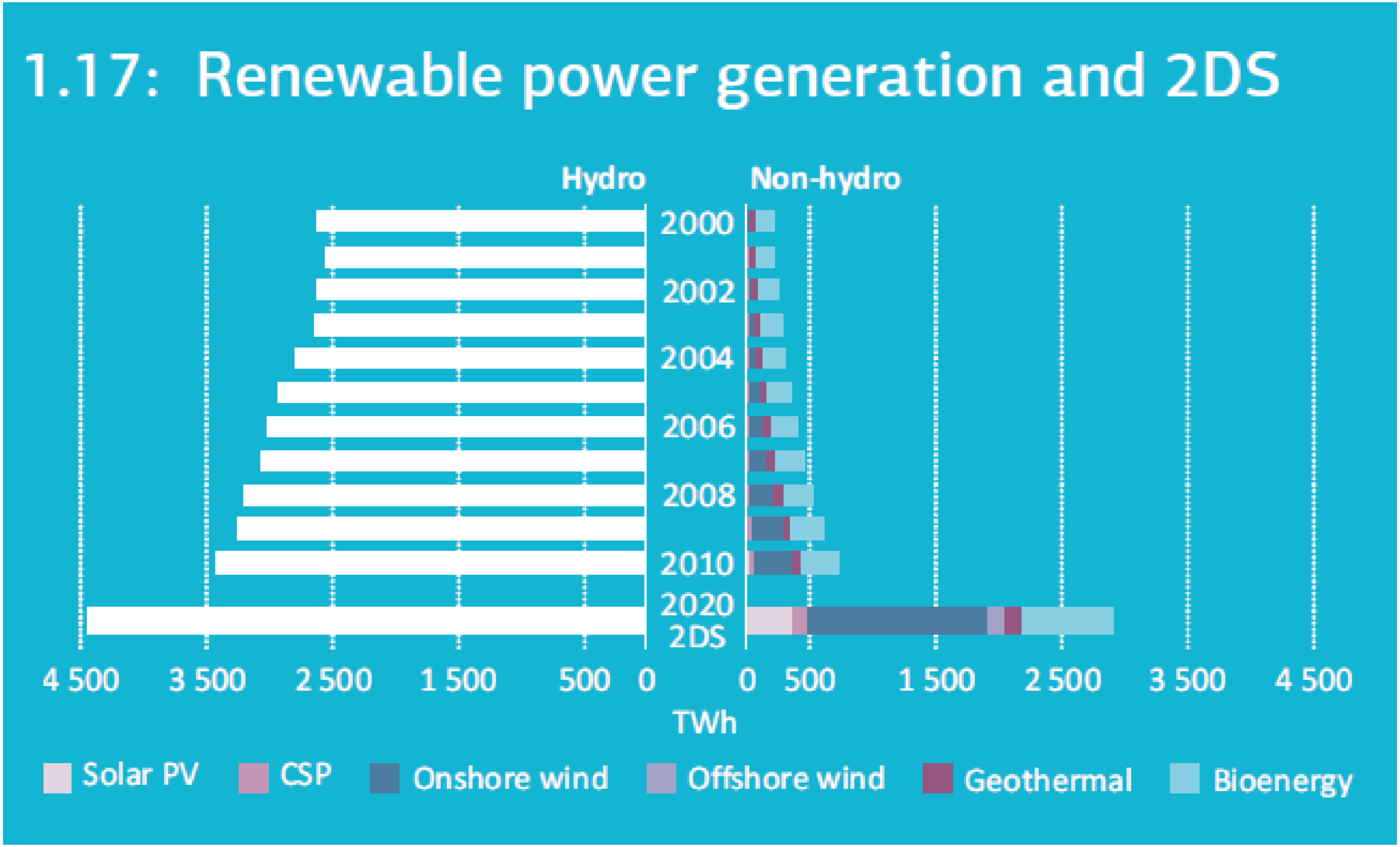
Hydropower

- The production of electrical power through the use of the gravitational force of falling or flowing water.
- About 82% of all electricity from renewable energy sources in 2010, increasing at an average rate of about 3% per year between 2000 and 2010.

The Gordon Dam in Tasmania is a large hydro facility, with an installed capacity of 430 MW.

http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress.pdf

Renewable Power Generation



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Government Action Needed for Renewable Power

- Effective and efficient policy design: (*e.g.* feed-in tariffs, tradable green certificates, tenders, tax incentives, grants etc).
- Smooth planning and permitting processes
- Broader environmental management and public acceptance
- Grid integration and priority access
- Market diversification
- Continued support for innovation and RD&D

http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress.pdf

Industry

- Accounts for about one-third of total final energy consumption and almost 40% of total energy-related CO_2 emissions
- CO_2 emissions in the industry sector is projected to increase by close to 30% by 2020, but to achieve the 2DS objectives, industry must limit its increase of direct CO_2 emissions in 2020 by about 17% compared to the current level.
- If industry takes advantage of available options – deploying existing best available technologies (BATs), developing new technologies that deliver improved energy efficiency or enable fuel and feedstock switching, and promoting recycling and introducing CCS – it can achieve its 2DS targets.

http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress.pdf

Industry Policy Action

Table 1.5 Policy action to enhance industrial energy efficiency

Recommendations	Policy options
Energy management in industry	Industrial energy management policies, including monitoring and measuring energy consumption, identifying energy-savings potential, setting benchmarks for industry energy performance, publicly reporting progress.
High-efficiency industrial equipment and systems	Mandatory minimum energy performance standards for electric motors and other categories of industrial equipment, such as distribution transformers, compressors, pumps and boilers. Measures to address barriers to energy-efficiency optimisation in design and operation of industrial processes (*e.g.* providing information on equipment energy performance, training initiatives, audits, technical advice and documentation, and system-assessment protocols).
Energy efficiency services for small and medium-sized enterprises	Support for energy audits, supported by information on proven energy efficiency practices; energy performance benchmarking.
Complementary policies to support industrial energy efficiency	Removal of energy subsidies and internalisation of external costs of energy through policies, such as carbon pricing. Increased investment in energy-efficient industrial equipment and processes through targeted financial incentives, such as tax incentives, risk-sharing or loan guarantees with private financial institutions, and promotion of the market for energy performance contracting.

Source: Adapted from IEA, 2011b.

http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress.pdf

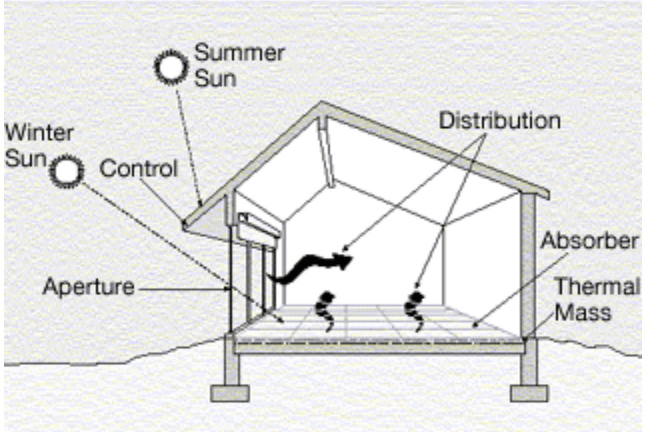
Buildings

- Residential and commercial buildings account for approximately 32% of global energy use and almost 10% of total direct energy-related CO_2 emissions.
- Including electricity generation emissions, buildings are responsible for just over 30% of total end-use energy-related CO_2 emissions.
- Energy demand from the buildings sector will more than double by 2050. Much of this growth is fuelled by the rising number of residential and commercial buildings in response to the expanding global population.

http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress.pdf

Low- or Zero-Carbon Heating and Cooling

- Solar thermal
  - **Active solar** technologies are employed to convert solar energy into another more useful form of energy. This would normally be a conversion to heat or electrical energy. Inside a building this energy would be used for heating, cooling, or off-setting other energy use or costs. Active solar uses electrical or mechanical equipment for this conversion.
  - **Passive solar building design**, windows, walls, and floors are made to collect, store, and distribute solar energy in the form of heat in the winter and reject solar heat in the summer. This is called passive solar design or climatic design because, unlike active solar heating systems, it doesn't involve the use of mechanical and electrical devices.



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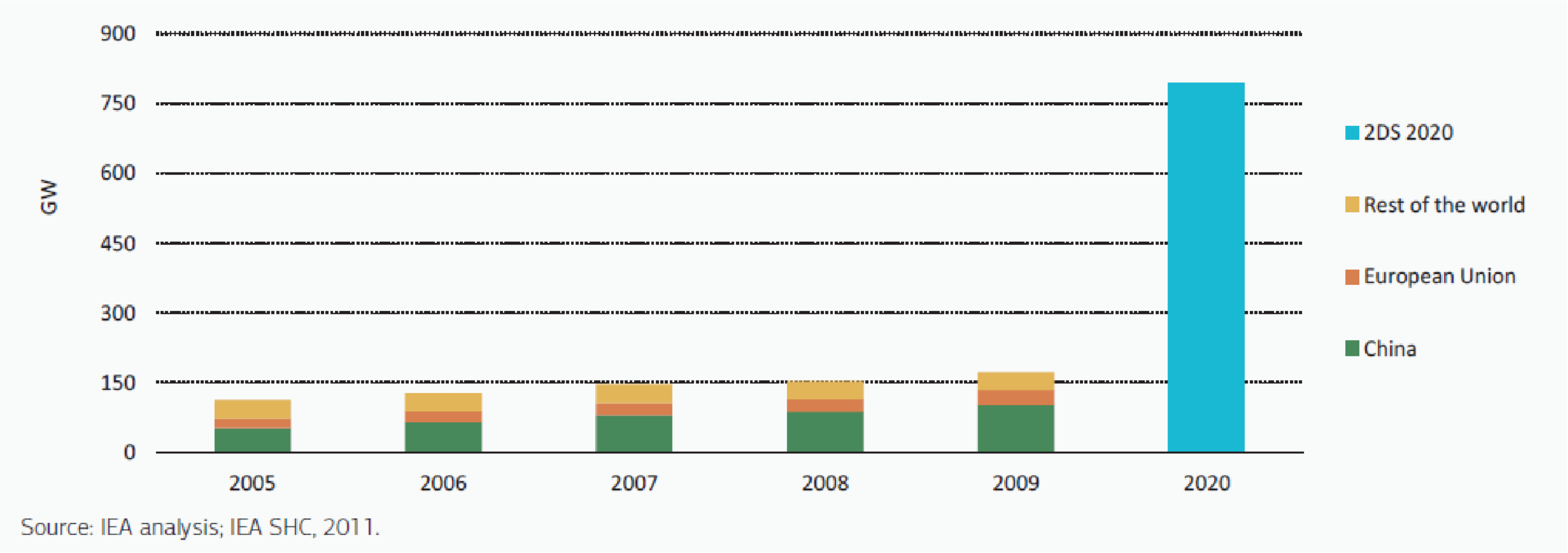
Active Solar Energy Deployments



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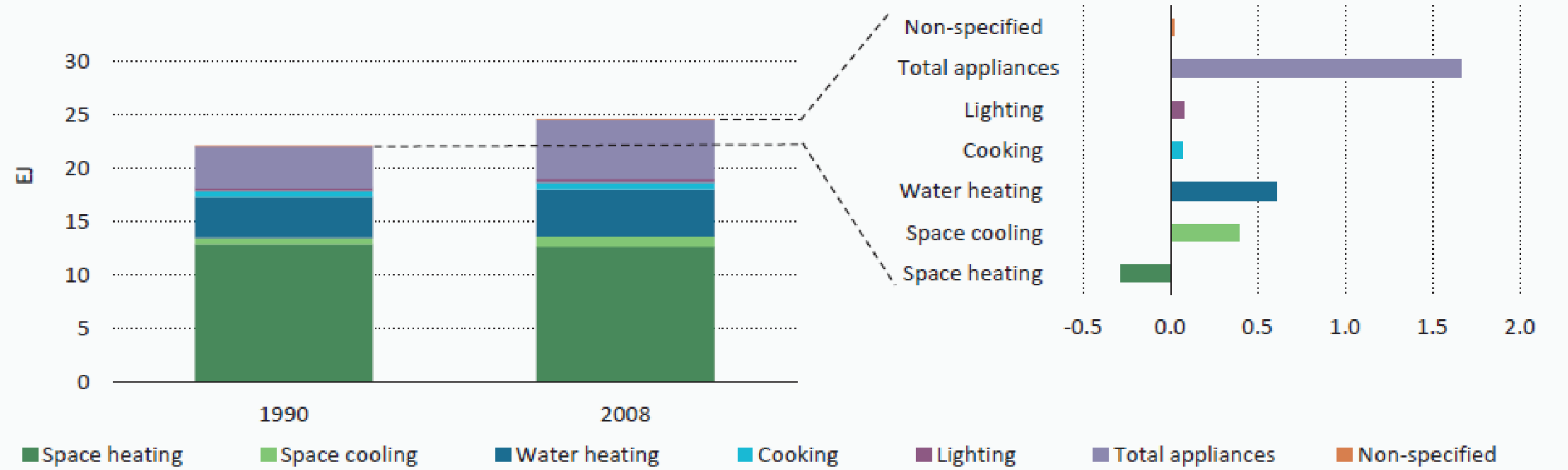
Government Steps

- Require all new buildings, as well as buildings undergoing renovation, to meet energy codes and minimum energy performance standards;
- Support and encourage construction of buildings with net-zero energy consumption;
- Implement policies to improve the energy efficiency of existing buildings with emphasis on significant improvements to building envelopes and systems during renovations;
- Require building energy performance labels or certificates that provide information to owners, buyers and renters; and
- Establish policies to improve the energy efficiency performance of critical building components in order to improve the overall energy performance of new and existing buildings.

http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress.pdf

Building Energy Consumption



Note: Countries analysed are Australia, Austria, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, the Netherlands, Norway, Slovakia, Spain, Sweden, Switzerland, the United Kingdom and the United States.

http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress.pdf

Transport

- Economic growth - more demand for personal vehicles and moving freight by road.
- Energy demand in the transport sector projected to more than double by 2050.
- Currently, the transport sector accounts for 20% of the world's primary energy use and 25% of energy-related CO_2 emissions, but under the 2DS, it also holds the potential to reduce CO_2 emissions by 30% from current levels by 2050.
- Achieving this target requires a combination of improved fuel efficiency; new types of vehicles, such as battery electric (BEVs) and plug-in hybrid electric vehicles (PHEVs); and alternative fuels capable of reaching very-low CO_2 emissions per kilometer (*e.g.* advanced biofuels).

http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress.pdf

Transport

- Road transport, including both light-duty vehicles (LDVs) and heavier-duty trucks, consumes the most energy (approximately three-quarters) in the transport sector and has experienced the most rapid growth in absolute terms (close to a 20% increase from 2000 to 2009).
- The best opportunity to make the transport sector more energy efficient lies primarily with LDVs.

http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress.pdf

Fuel Economy

- Enhancing the fuel economy of vehicles and vehicle fleets is the single most important measure to put into action over the next decade to curb fossil fuel use and reduce CO_2 emissions within the transport sector.
- Evidence to date suggests that many governments' fuel economy ambitions are not set high enough to achieve the 2DS objectives.
- Fuel economy levels vary significantly by country, from approximately 6 litres (L) per 100 km for the least fuel-intensive end of the spectrum (India) to over 9 L/100 km at the most fuel-intensive end (the United States). Average new-LDV global fuel economy improved at a rate of 1.7% between 2005 and 2008.

http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress.pdf

Fuel Economy

- While the overall picture of fuel economy is positive, the rate of improvement is too low to achieve the 2DS by 2020. The 2DS is consistent with the Global Fuel Economy Initiative (GFEI) (http://www.globalfueleconomy.org/Pages/Homepage.aspx) to improve the fuel economy of new LDVs by 50% by 2030: attaining average annual fuel economy improvement of 2.7%.
- If fuel economy standards, in line with the 2DS (5.6 L/100 km by 2020), become compulsory for all new vehicles worldwide LDV, fuel consumption in 2020 would drop by approximately 25%, rising to 50% in 2050 as the vehicle stock turns over (compared to the 2005 base level of fuel economy).

http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress.pdf

Government Fuel Economy Policies

- *To improve fuel economy at the scale and pace required to meet efficiency and emissions objectives of the 2DS, governments must implement policies that address technical fuel economy requirements and consumer choice determinants.*
- *In addition, other measures, including vehicle taxes and incentives, fuel taxes, traffic control measures and the provision of consumer information, are required to help guide decision making by consumers.*

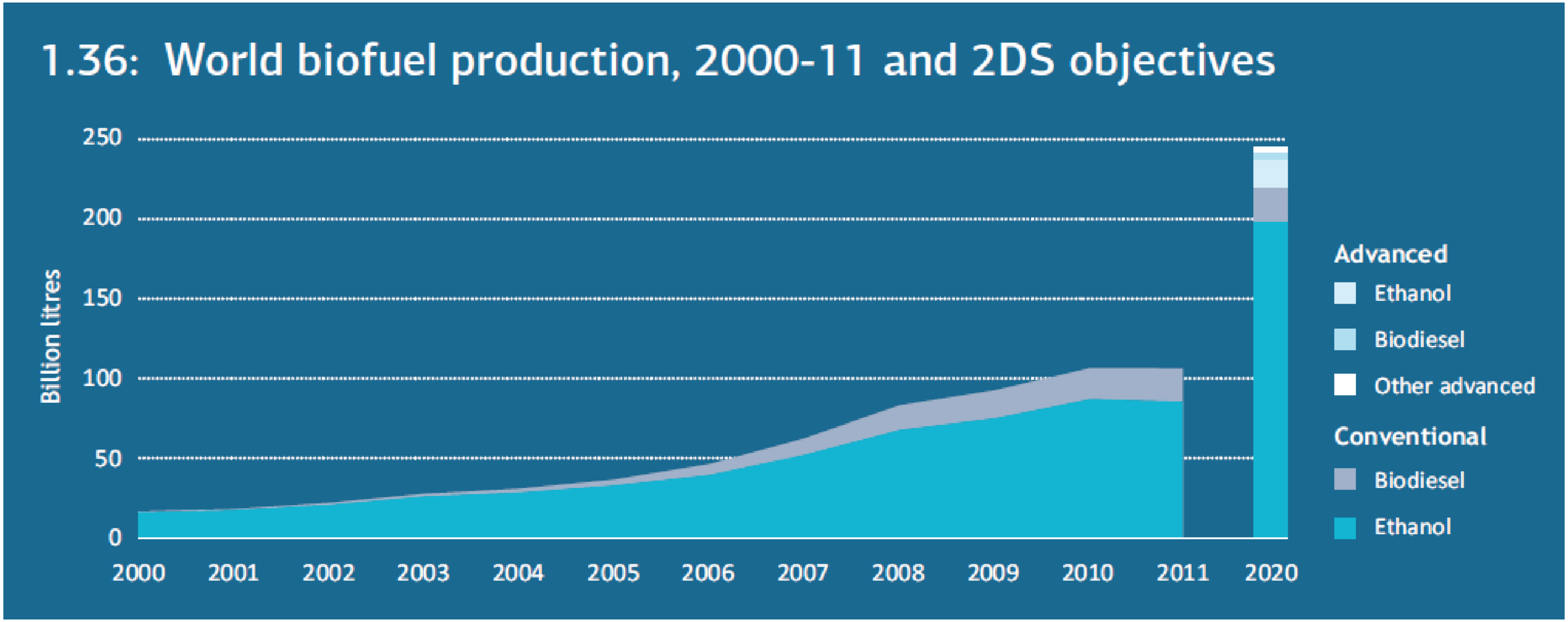
http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress.pdf

Biofuels

- Biofuels are one of the main alternative fuels that can offer very low net-GHG performance.
- Driven by policy support in more than 50 countries, production of global biofuels grew from 16 billion liters in 2000 to more than 100 billion liters in 2011.
- Globally, biofuels accounted for around 3% of road transport fuels, with a considerable share in Brazil (21%), and an increasing share in the United States (4%) and the European Union (about 3%).
- Achieving the 2DS by 2020 will still require a four-fold increase in production capacity beyond current announcements, which represents a major challenge. Achieving this will require a significant and sustained push by policy-makers.

http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress.pdf

World Biofuel Production



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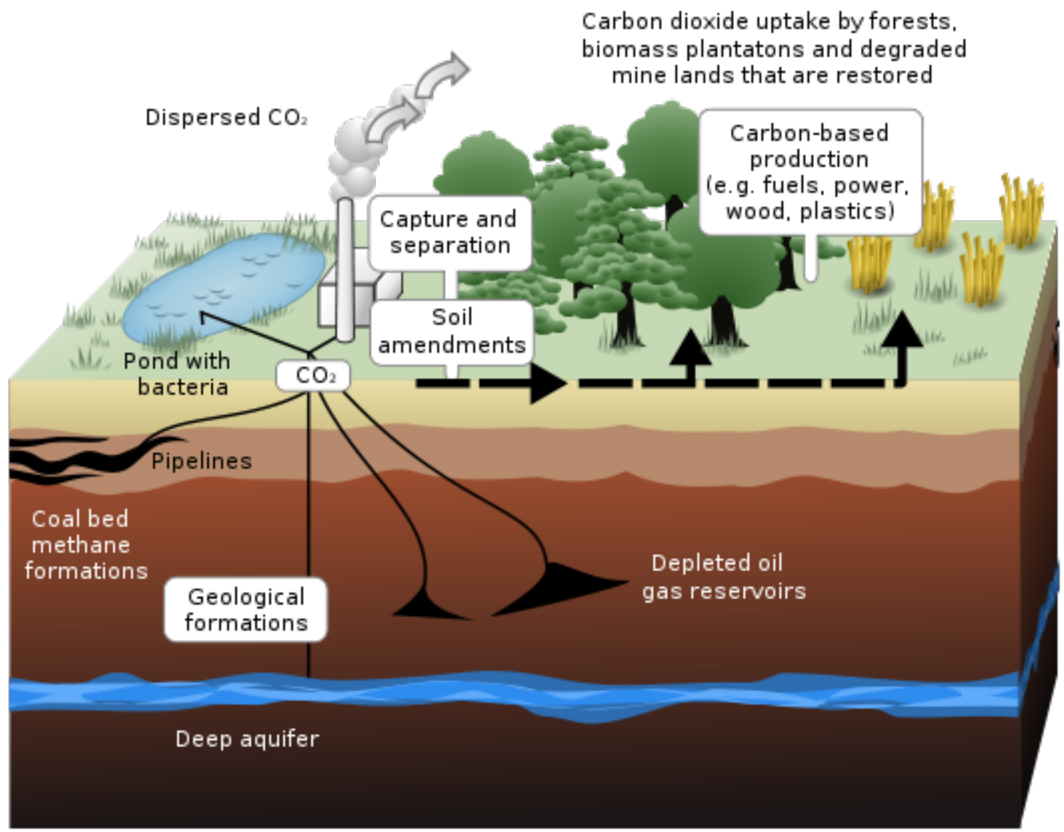
Government Policy - Biofuels

- The development of advanced biofuels needs to be accelerated, primarily through dedicated government support for RD&D.
- Financial support - direct financing, loan guarantees or guaranteed premiums for advanced biofuels - are crucial to reduce risks associated with large investment in pre-commercial technologies.
- A premium for advanced biofuels, similar to feed-in tariffs for renewable electricity, also effectively addresses the currently higher production costs compared to conventional biofuels.
- Support for advanced and other, truly low-GHG biofuels must continue until at least 2020 to ensure the scale-up and cost reductions necessary for biofuels to reach maturity and full commercialization.

http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress.pdf

Carbon Capture and Storage

- **Carbon capture and storage** (**CCS**), (**carbon capture and sequestration**) = technology attempting to prevent the release of large quantities of CO_2 into the atmosphere from fossil fuel use in power generation and other industries by capturing CO_2, transporting it and ultimately, pumping it into underground geologic formations to securely store it away from the atmosphere. It is a potential means of mitigating the contribution of fossil fuel emissions to global warming.



Carbon Capture and Storage Progress

- CCS is a critical technology to reduce CO_2 emissions and decarbonize both the industry and power sectors.
- Development and deployment of CCS is woefully off pace to reach the approximately 269 Mt CO_2 captured across power and industrial applications in 2020 in the 2DS. This is equivalent to about 120 facilities.
- Currently, 65 large-scale integrated CCS projects (LSIP) are under construction or in planning phases (GCCSI, 2012).
- Given the high capital cost, risks associated with initial projects and the fact that CCS is motivated primarily by climate policy, the technology needs strong government backing by way of CO_2 emissions-reduction policies and dedicated demonstration funding.

http://www.iea.org/publications/freepublications/publication/Tracking_Clean_Energy_Progress.pdf

Energy and Climate Policy

- Energy Policy Act of 2005

  http://en.wikipedia.org/wiki/Energy_Policy_Act_of_2005

- Energy Independence and Security Act of 2007

  http://en.wikipedia.org/wiki/Energy_Independence_and_Security_Act_of_2007

- Global Challenges 2010: Climate and energy policy in the new Congress

  http://membercentral.aaas.org/multimedia/videos/global-challenges-2010-climate-and-energy-policy-new-congress

Atomic Theory

- *To see a World in a Grain of Sand*
  And a Heaven in a Wild Flower
  Hold Infinity in the palm of your hand
  And Eternity in an hour
  William Blake   Auguries of Innocence
- *Thus, the task is not so much to see what no one has yet seen, but to think what nobody has yet thought, about that which everybody sees.*
  Erwin Schrodinger

3 Physics "Trust Me's"

- **"Trust Me's" that lie at the basis of our description of the electron**
  - All matter has both particle and wave character.
  - The less massive the particle, the more important its wave character.
  - The electron has a very low mass, low enough to have significant wave character.

A Problem

- **Problem:** We have a barrier to our understanding, and things with significant wave character are to some degree outside that barrier. This means that the behavior of electrons is non-intuitive.

How We Solve the Problem

- One way we have been able to “describe” things outside our barrier of understanding is through mathematics.
- We describe things outside our barrier of understanding with mathematical equations, we solve the equations, we drag the results back under our barrier, and we apply them to things we do understand.
- If this helps us explain things or predict things, we assume we are on the right track.

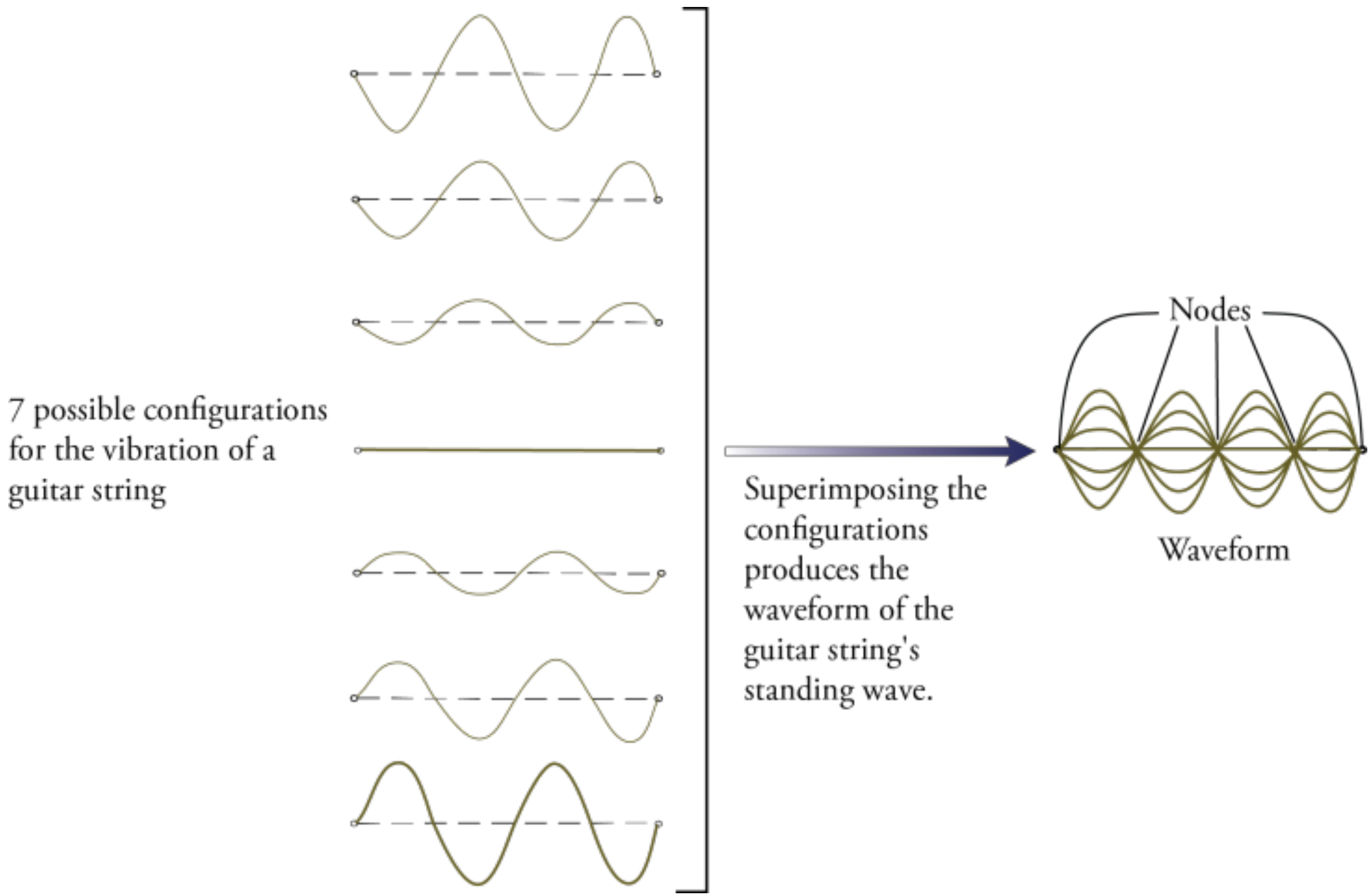
Strangeness of Tiny Particles

- Things become very strange in the realm of the very, very small.
- One element of this strangeness if that we lose the possibility of being able to predict with certainty where small particles are going to be and how they are moving.
- Thus we shift from talking about where tiny things will be to where they will probably be.

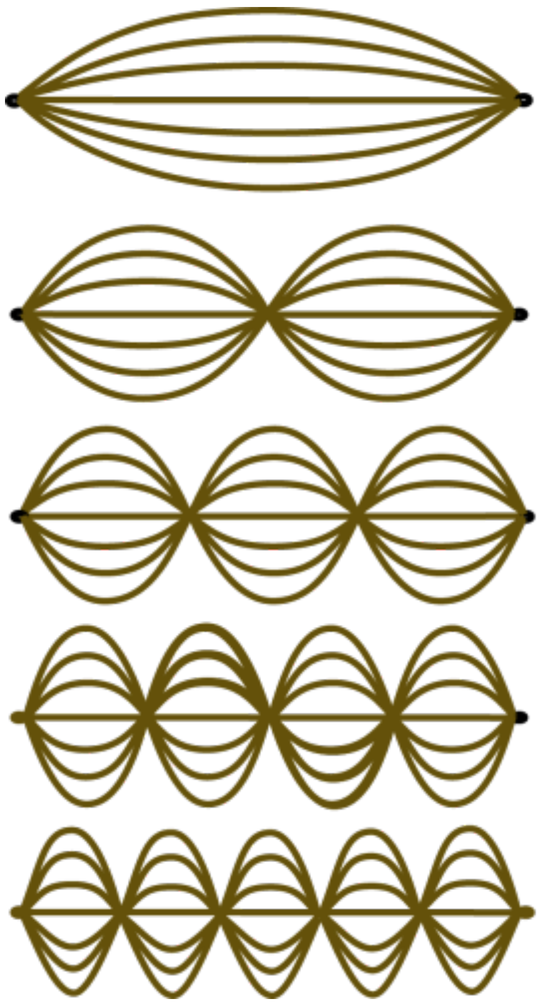
Ways to deal with Complexity and Uncertainty

- **Analogies** In order to communicate something of the nature of the electron, scientists often use analogies. For example, in some ways, electrons are *like* vibrating guitar strings.
- **Probabilities** In order to accommodate the uncertainty of the electron's position and motion, we refer to where the electron *probably is* within the atom instead of where it definitely is.

Guitar String Waveform



Allowed Vibrations for a Guitar String

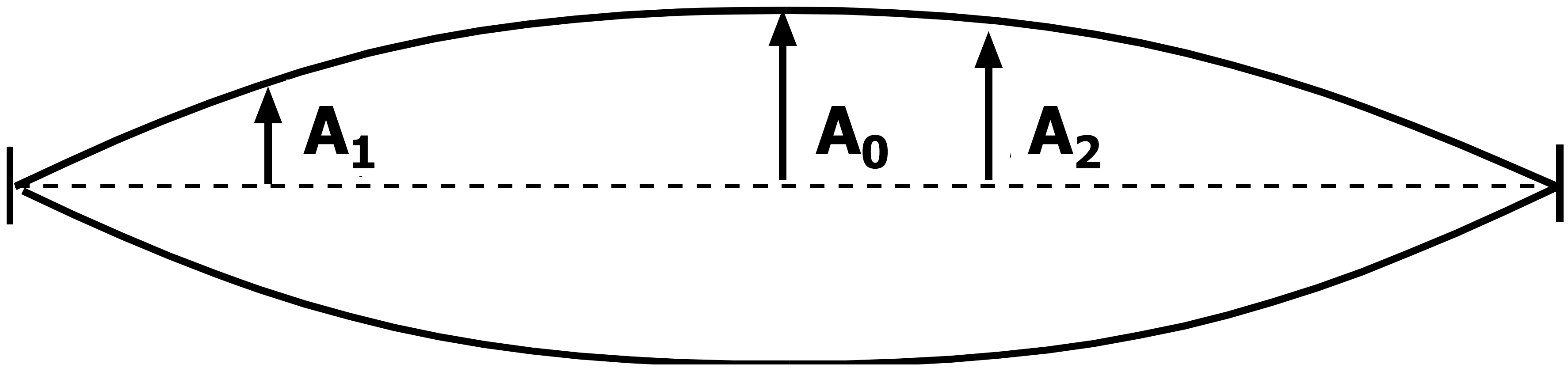


Equation for Guitar String

$$A_x = A_o \sin \frac{n\pi x}{a}$$

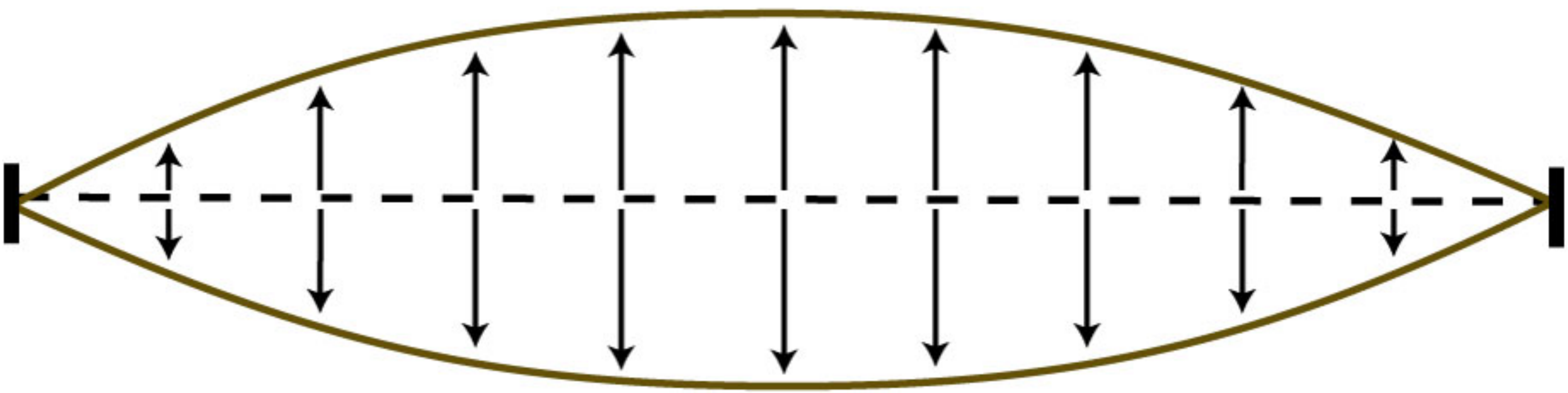
- A_x = the amplitude at position x
- A_o = the maximum amplitude at any point on the string
- n = 1, 2, 3, ...
- x = the position along the string
- a = the total length of the string

Guitar String Amplitudes



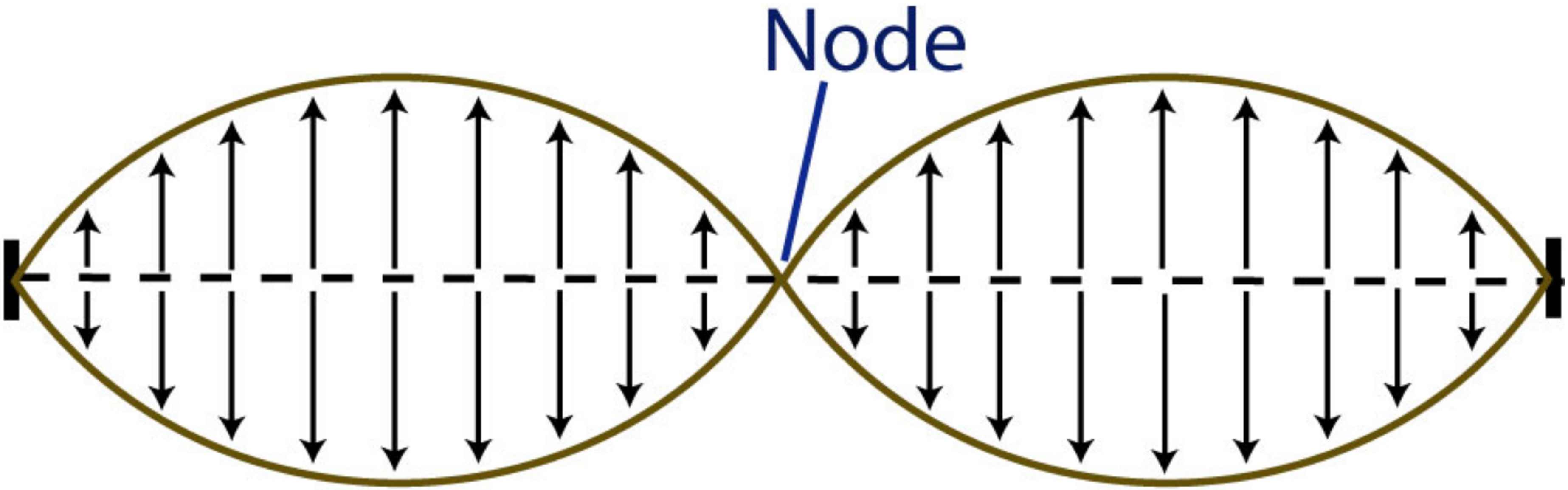
Guitar String Waveform 1

$$A_X = A_O \sin \frac{\pi x}{a}$$



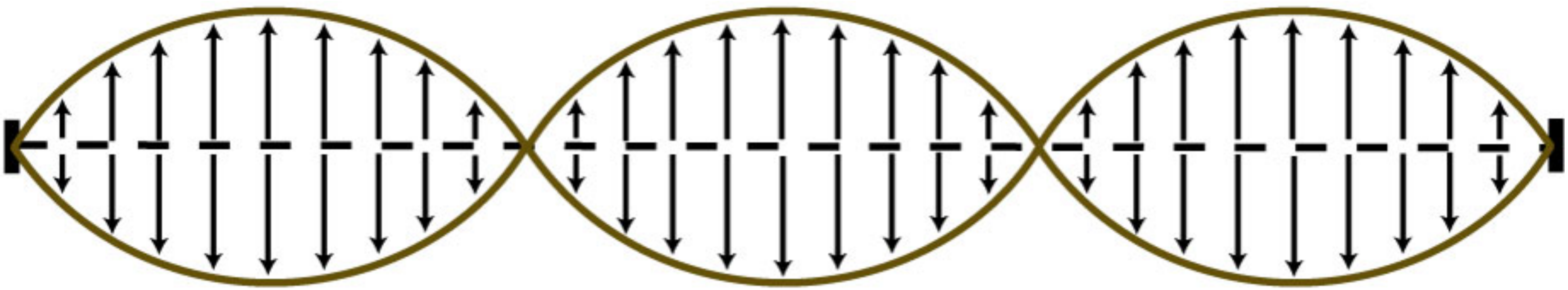
Guitar String Waveform 2

$$A_X = A_O \sin \frac{2\pi x}{a}$$



Guitar String Waveform 3

$$A_X = A_O \sin \frac{3\pi x}{a}$$



Determination of the Allowed Electron Waveforms

- Set up the general form of the wave equation that describes the electron in a hydrogen atom.

  $\Psi_{x,y,z} = f(x,y,z)$

- Determine the forms of the general equation that fit the boundary conditions. Each equation has its own set of three quantum numbers: n, l, and m_ℓ.

  $\Psi_{1s} = f_{1s}(x,y,z)$ with 1,0,0 for quantum numbers

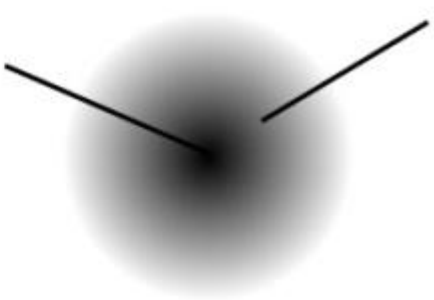
  $\Psi_{2s} = f_{2s}(x,y,z)$ with 2,0,0 for quantum numbers

  $\Psi_{2p} = f_{2p}(x,y,z)$ with 2,1,1 or 2,1,0

  or 2,1,−1 for quantum numbers

  Etc.

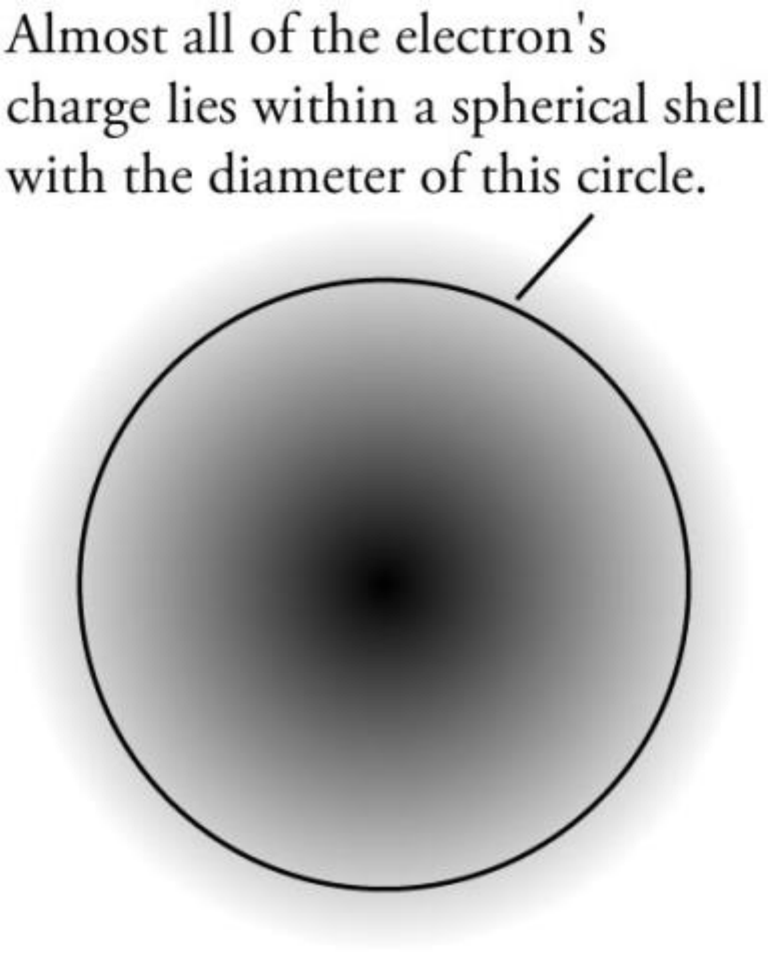
Waveform for 1*s* Electron

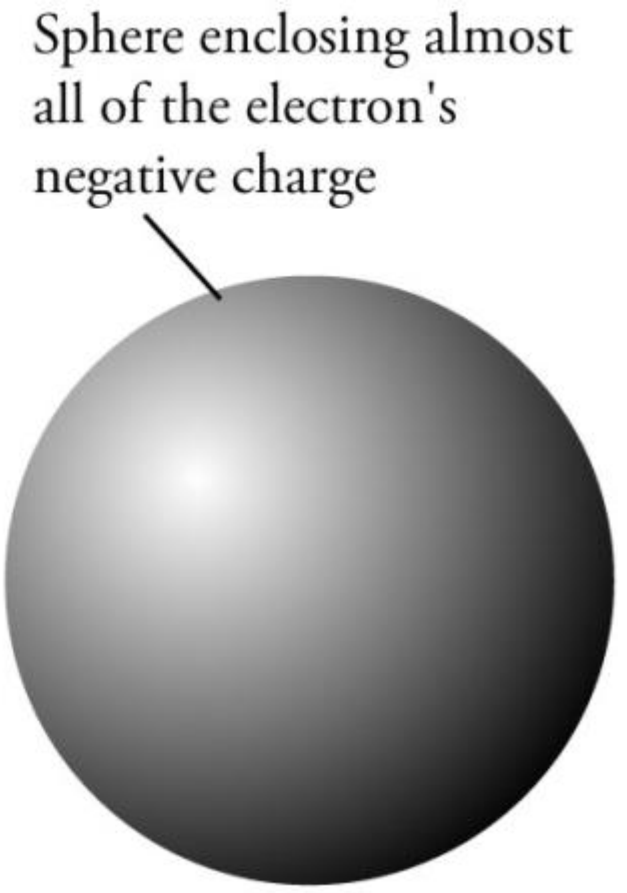


Particle Interpretation of 1*s* Orbital

A multiple exposure picture of the electron in a 1*s* orbital of a hydrogen atom might look like this.

1*s* Orbital


Almost all of the electron's charge lies within a spherical shell with the diameter of this circle.


Sphere enclosing almost all of the electron's negative charge

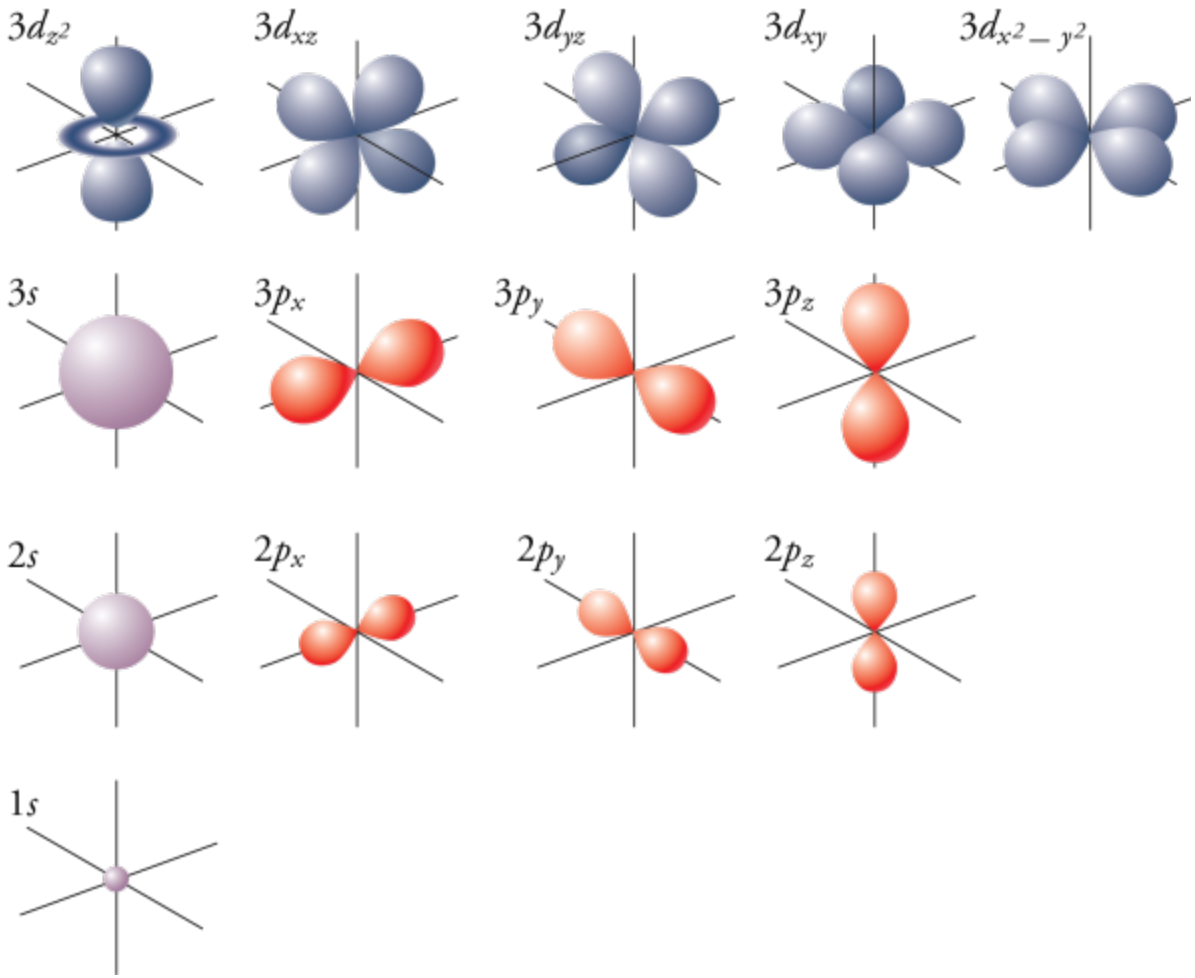
Wave Character of the Electron

- Just as the intensity of the movement of a guitar string can vary, so can the intensity of the negative charge of the electron vary at different positions outside the nucleus.
- The variation in the intensity of the electron charge can be described in terms of a three-dimensional standing wave *like* the standing wave of the guitar string.

Wave Character of the Electron

- Although both the electron and the guitar string can have an infinite number of possible waveforms, only certain waveforms are possible.
- We can focus our attention on the waveform of varying charge intensity without having to think about the actual physical nature of the electron.

Other Allowed Waveforms



2*s* Orbital

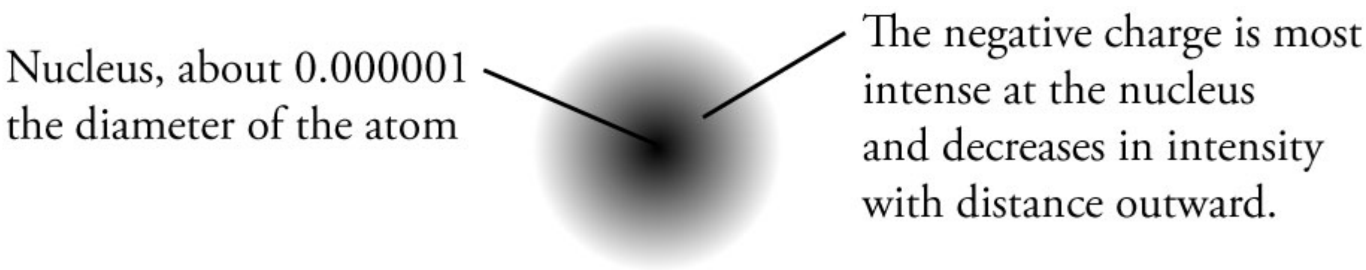
- The 2*s* orbital for a hydrogen atom is larger than the 1*s* orbital and has a node, which is a region within the orbital where the charge intensity decreases to zero.

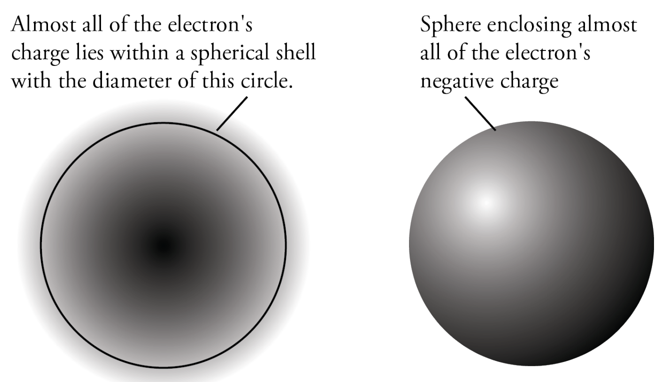
Here's what we know

- Everything has both particle and wave character, the less massive the particle the more important the wave character is, and electrons are small enough to have significant wave character.
- We don't intuitively understand waves, and therefore, we don't understand electrons, but we can describe the one electron of a hydrogen atom with 3-D wave mathematics.
- There's a general form of the wave equation and specific forms of the general wave equation, and each has a unique set of allowed quantum numbers (1,0,0 or 2,0,0 etc.).
- When we ask the computer to create an image that summarizes the results of repetitive calculations with one specific form of the general wave equation, the computer provides a 3-D image.

Here’s what we know

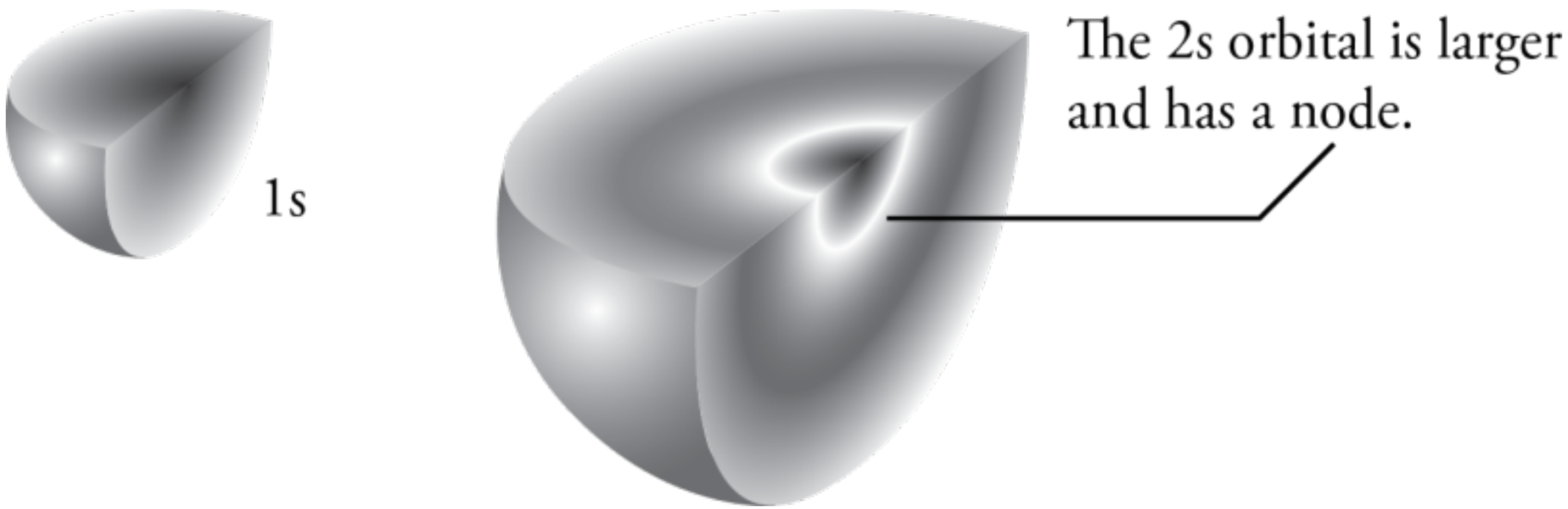
- We call these orbitals, and we choose to think that they describe the distribution of negative charge around the nucleus.





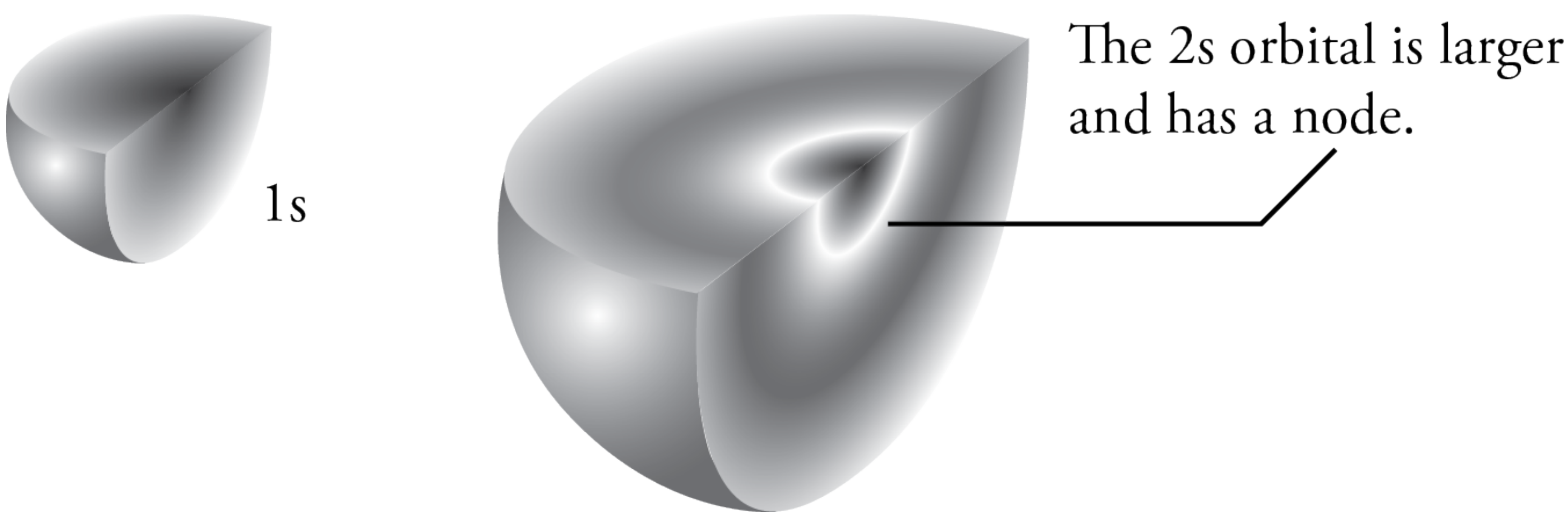
- Each specific form of the general wave equation provides a different image with different sizes and shapes.

Cutaway of 1*s* and 2*s* Orbitals



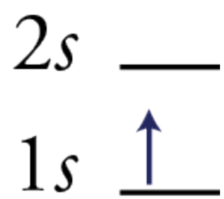
An electron in 2s is less stable and higher PE than an electron in 1s

- Electron in 2s is a greater average distance from the positive nucleus than an electron in the 1s.
- 2s electron less attracted.
- 2s electron is less stable (more likely to change).
- 2s electron is higher potential energy.
- The one electron of hydrogen is more likely to be in the smaller, more stable, and lower PE 1s orbital where it is most strongly attracted to the nucleus.

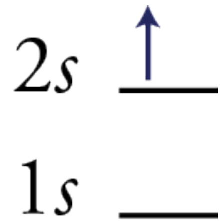


Ground State and Excited State

- Hydrogen atoms with their electron in the 1*s* orbital are said to be in their ***ground state***.



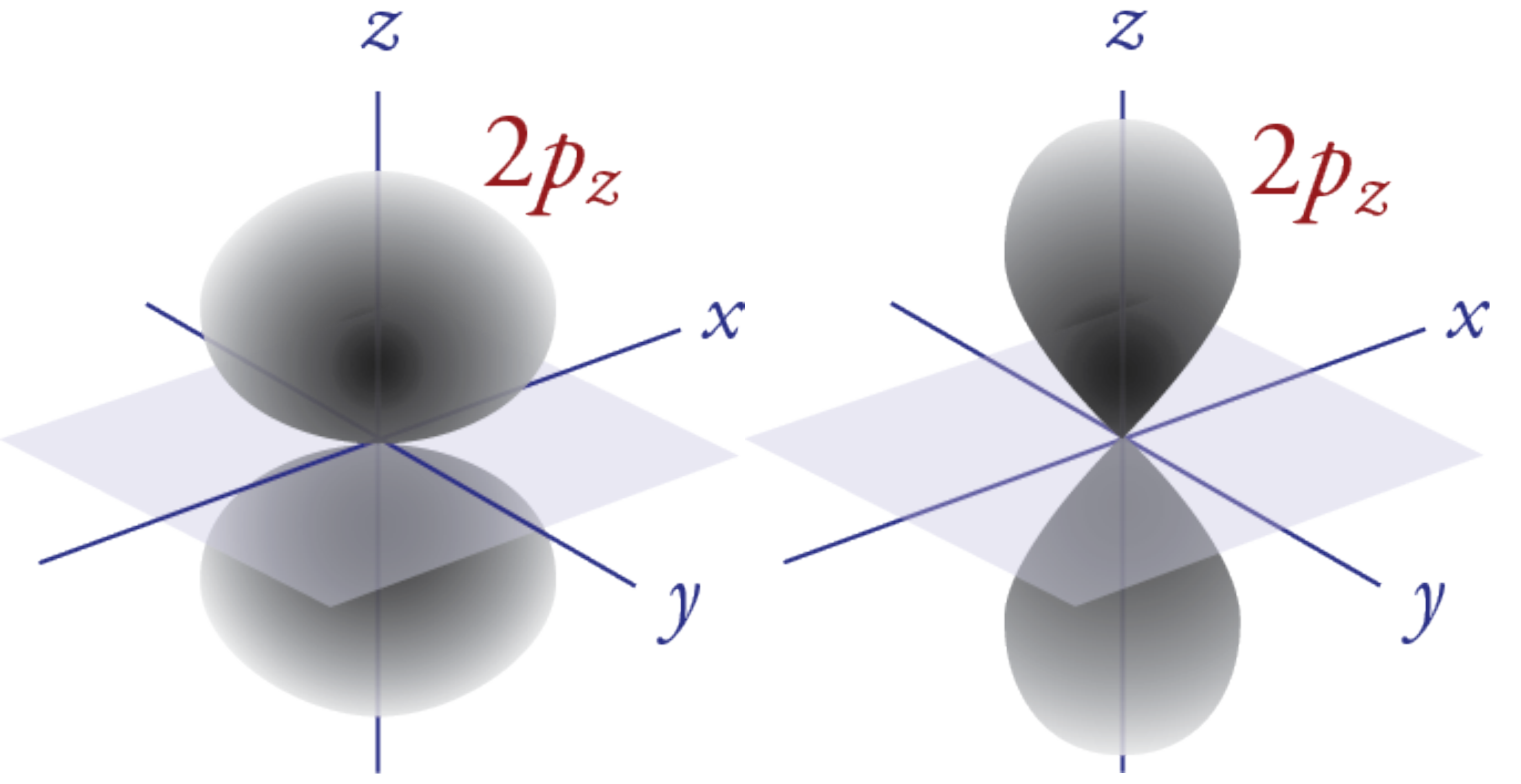
- A hydrogen atom with its electron in the 2*s* orbital is in an ***excited state***.



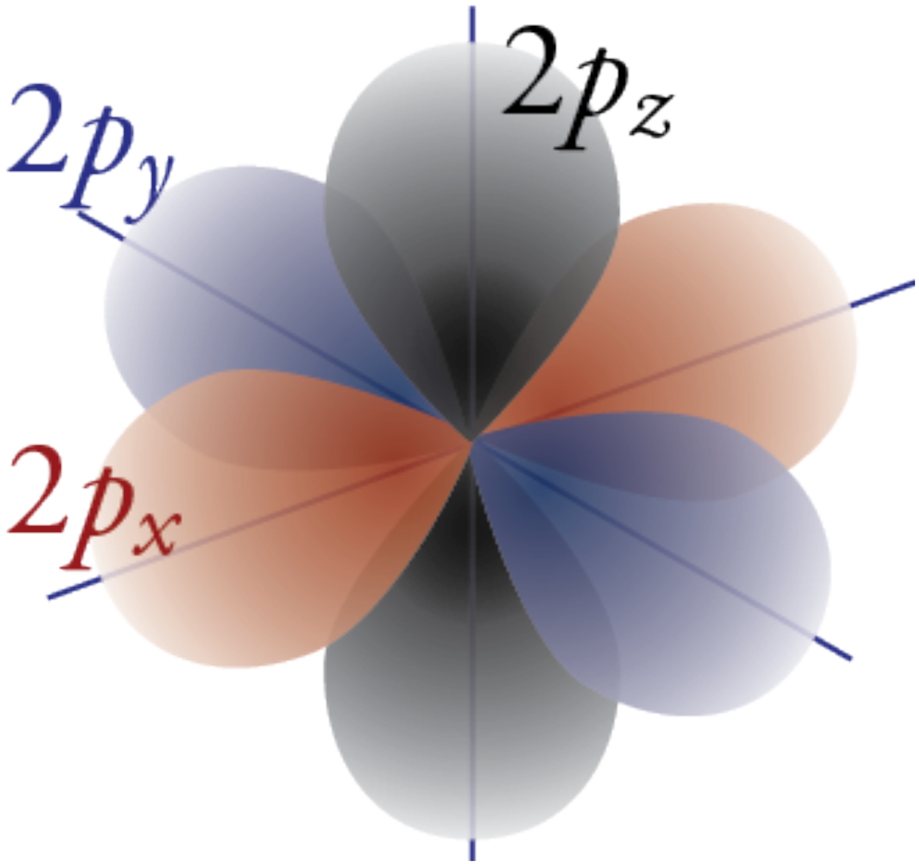
Ground State and Excited State

- Hydrogen atoms with their electron in the 1*s* orbital are said to be in their ***ground state***.
- A hydrogen atom with its electron in the 2*s* orbital is in an ***excited state***.

Realistic and Stylized $2p_y$ Orbital

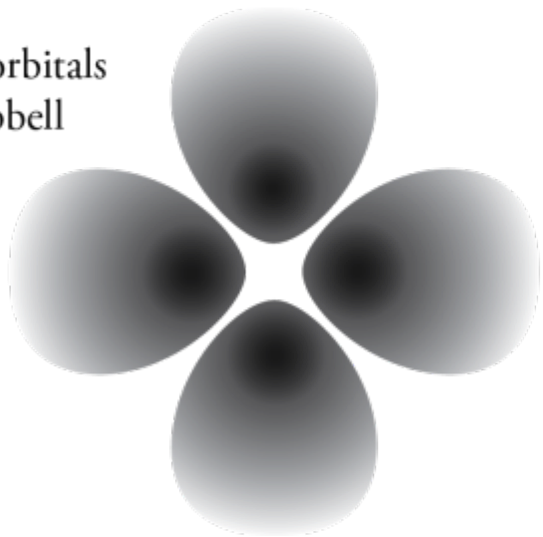


$2p_x$, $2p_y$, and $2p_z$ Orbitals

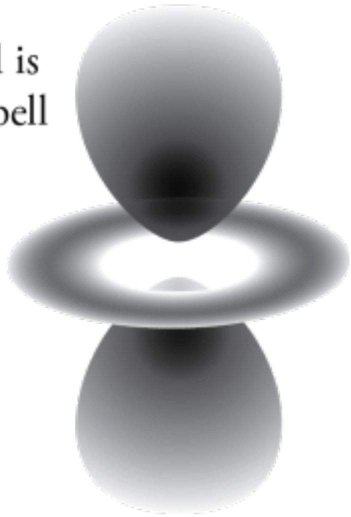


3*d* Orbitals

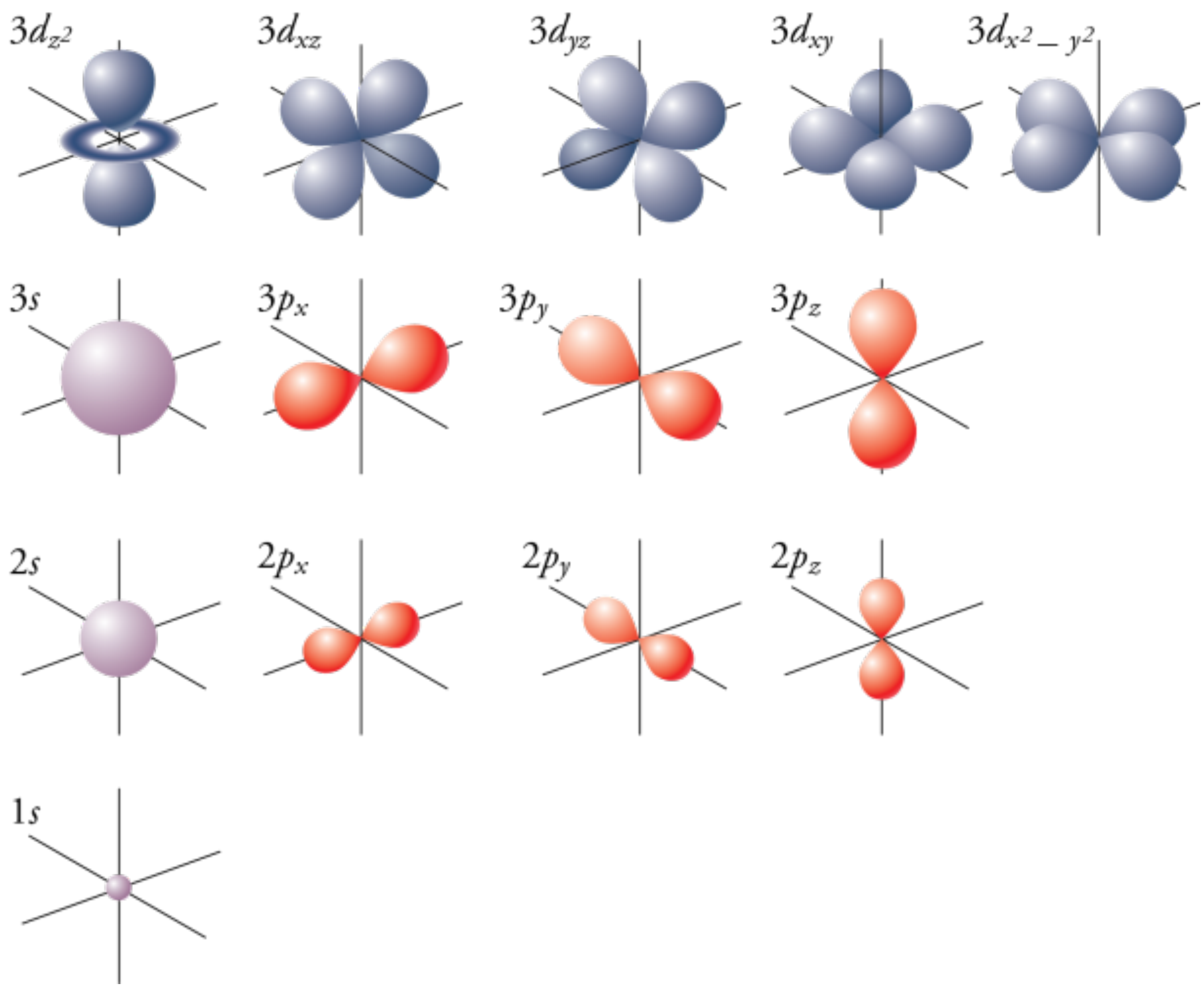
Four of the five 3*d* orbitals have a double dumbbell shape like this one.



The fifth 3*d* orbital is shaped like a dumbell and a donut.



Other Allowed Waveforms



Sublevels

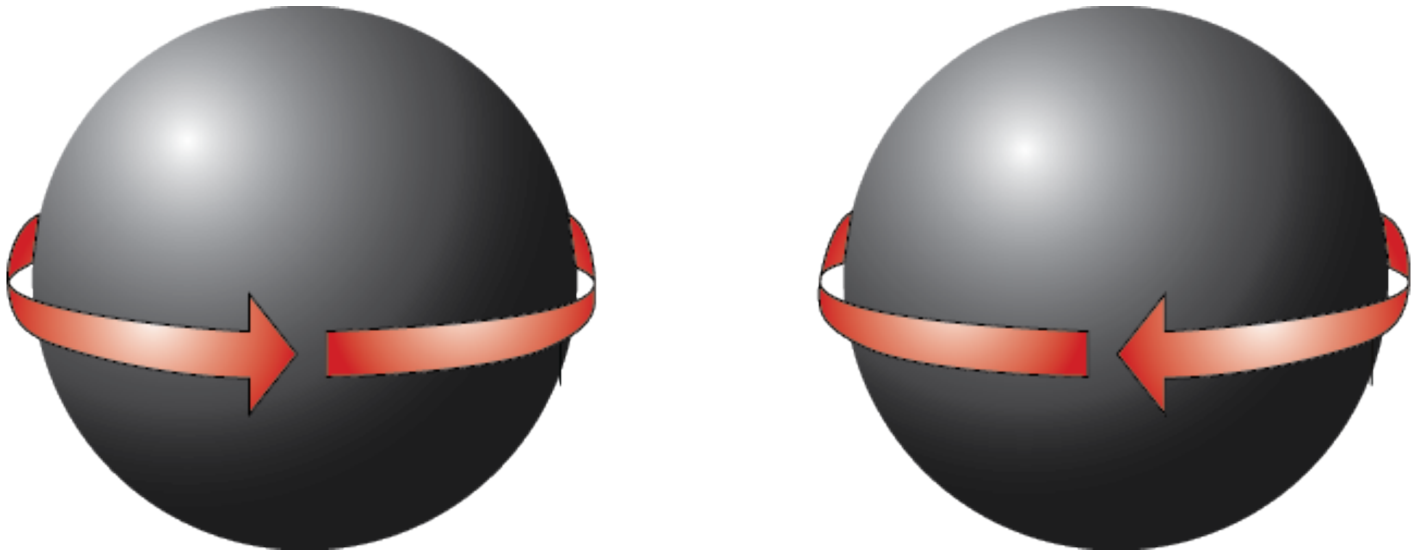
- Orbitals that have the same potential energy, the same size, and the same shape are in the same ***sublevel***.
- The sublevels are sometimes called ***subshells***.

Orbitals for Ground States of Known Elements

7*s* ___	7*p* ___ ___ ___		
6*s* ___	6*p* ___ ___ ___	6*d* ___ ___ ___ ___ ___	
5*s* ___	5*p* ___ ___ ___	5*d* ___ ___ ___ ___ ___	5*f* ___ ___ ___ ___ ___ ___ ___
4*s* ___	4*p* ___ ___ ___	4*d* ___ ___ ___ ___ ___	4*f* ___ ___ ___ ___ ___ ___ ___
3*s* ___	3*p* ___ ___ ___	3*d* ___ ___ ___ ___ ___	
2*s* ___	2*p* ___ ___ ___		
1*s* ___			

No other orbitals are necessary for describing the electrons of the known elements in their ground states.

Electron Spin

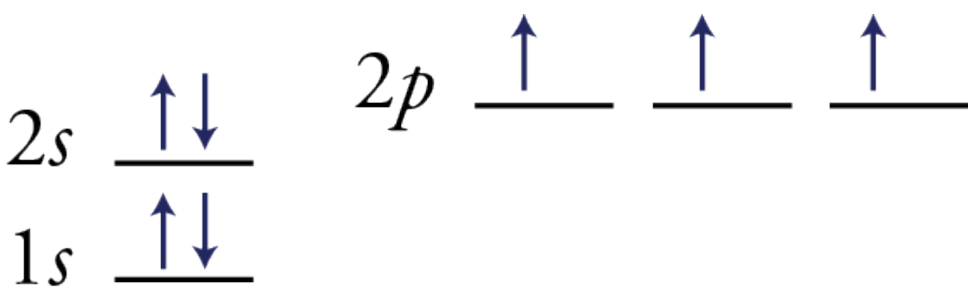


Pauli Exclusion Principle

- No two electrons in an atom can be the same in all ways.
- There are four ways that electrons can be the same:
    - Electrons can be in the same principal energy level.
    - They can be in the same sublevel.
    - They can be in the same orbital.
    - They can have the same spin.

Ways to Describe Electrons in Atoms

- Arrows are added to an ***orbital diagram*** to show the distribution of electrons in the possible orbitals and the relative spin of each electron. The following is an orbital diagram for a nitrogen atom.



- The information in orbital diagrams is often described in a shorthand notation called an ***electron configuration***.

$$1s^2\ 2s^2\ 2p^3$$

Electron Configurations

- The sublevels are filled in such a way as to yield the lowest overall potential energy for the atom.
- No two electrons in an atom can be the same in all ways. This is one statement of the ***Pauli Exclusion Principle***.
- When electrons are filling orbitals of the same energy, they prefer to enter empty orbitals first, and all electrons in half-filled orbitals have the same spin. This is called ***Hund's Rule***.

Electron Configurations (cont.)

Represents the principal energy level

Shows the number of electrons in the orbital

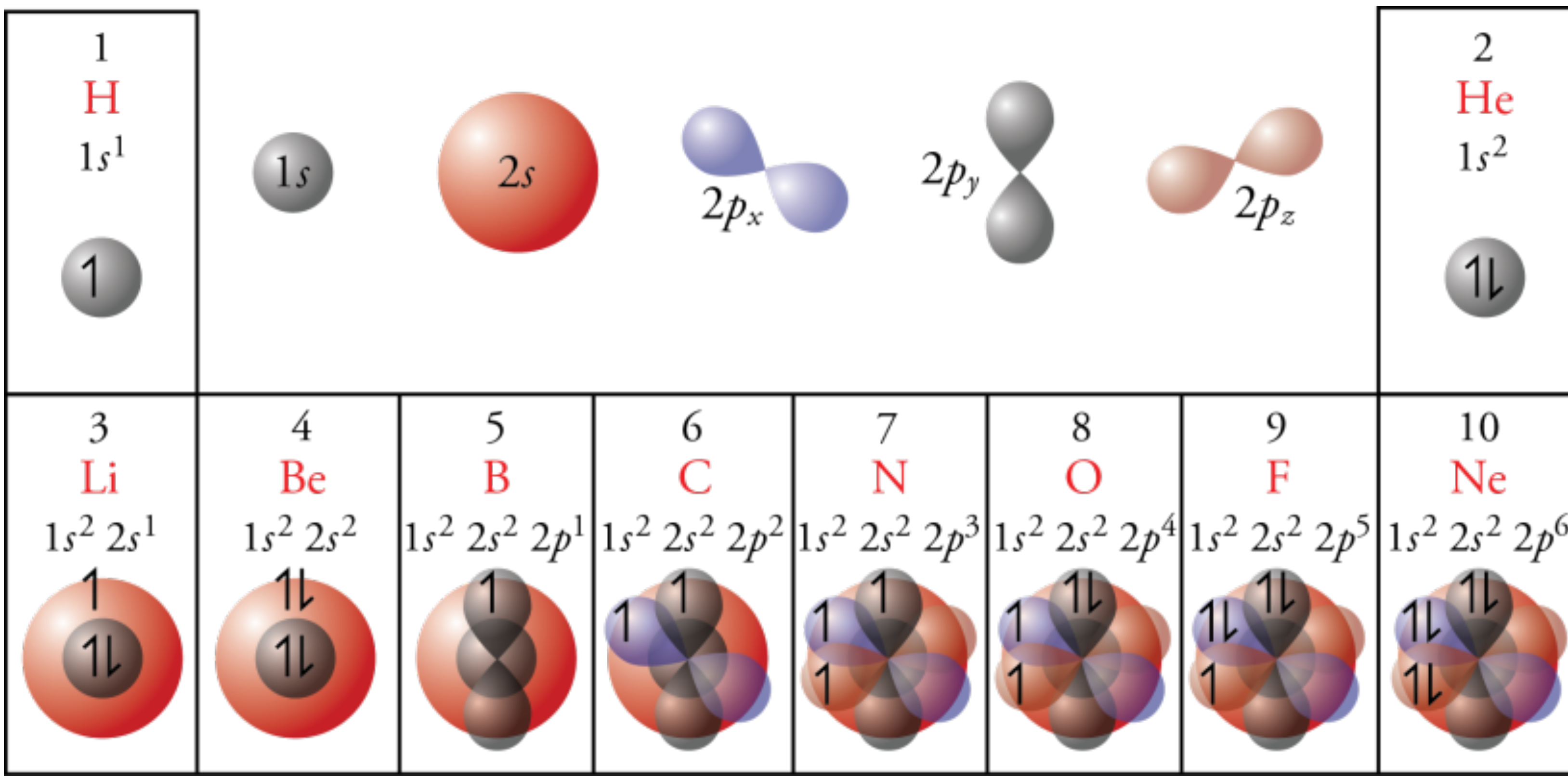
$1s^2$

Indicates the shape of the orbital

Chemistry 10
Electron Configurations

- You will be expected to write electron configurations for the first 18 elements, H through Ar.
- For these elements, you need to know the following order of filling
  $1s\ 2s\ 2p\ 3s\ 3p$
- Number of electrons per uncharged atom = atomic number
- You add 2 electrons to each s-orbital and 6 electrons to each p-orbital until you have added all of the electrons.
- For example, because the atomic number of chlorine is 17, chlorine atoms have 17 electrons, so chlorine's electronic configuration is
  $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^5$

Second Period Electron Configurations



Drawing Orbital Diagrams for H to Ar

- Draw a line for each orbital of each sublevel mentioned in the complete electron configuration. Draw one line for each *s* sublevel, and three lines for each *p* sublevel.
- Label each sublevel.
- For orbitals containing two electrons, draw one arrow up and one arrow down to indicate the electrons' opposite spin.
- For unfilled sublevels, follow Hund's Rule.

Abbreviated Electron Configurations

- The highest energy electron are most important for chemical bonding.
- The noble gas configurations of electrons are especially stable and, therefore, not important for chemical bonding.
- We often describe electron configurations to reflect this representing the noble gas electrons with a noble gas symbol in brackets.
- For example, for sodium

$1s^2\ 2s^2\ 2p^6\ 3s^1$ goes to [Ne] $3s^1$

Writing Electron Configurations

- Determine the number of electrons in the atom from its atomic number.
- Add electrons to the sublevels in the correct order of filling.
- Add two electrons to each *s* sublevel, 6 to each *p* sublevel, 10 to each *d* sublevel, and 14 to each *f* sublevel.
- To check your complete electron configuration, look to see whether the location of the last electron added corresponds to the element's position on the periodic table.