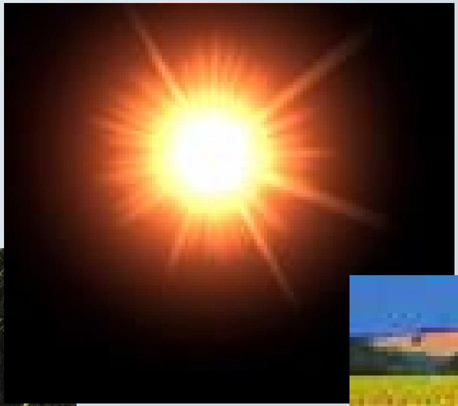
Energy

IPOL 8512

"Energy will do anything that can be done in the world."

- Goethe

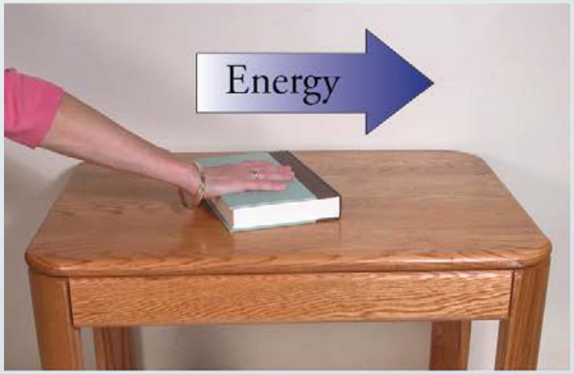


Goal and Process

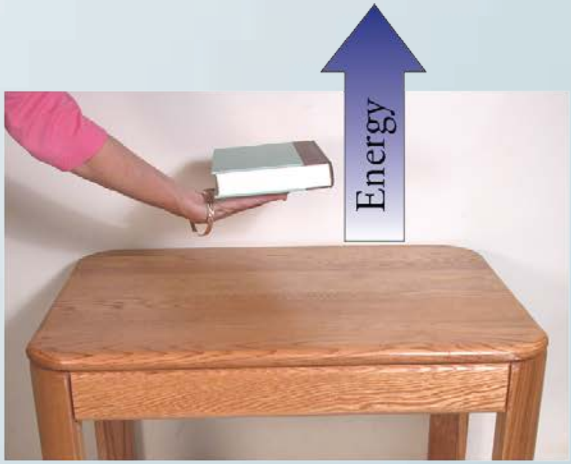
- One goal of this presentation is to understand the issues relating to improving the efficiency of power plants.
- Want to understand…
  - How do power plants generate electricity?
  - What's a heat engine?
  - What determines the efficiency of heat engines?
  - What is energy and what are the different forms of energy?
  - Where does our energy come from?
  - How is our energy used?
  - Why can some energy be harnessed to do useful work and some cannot?

Energy Terms

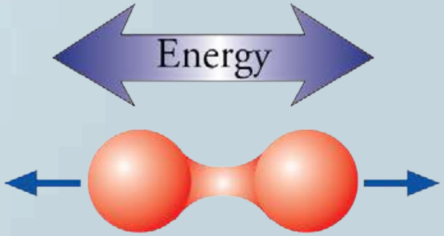
- **Energy** = the capacity to do work
- **Work**, in this context, may be defined as what is done to move an object against some sort of resistance.



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.

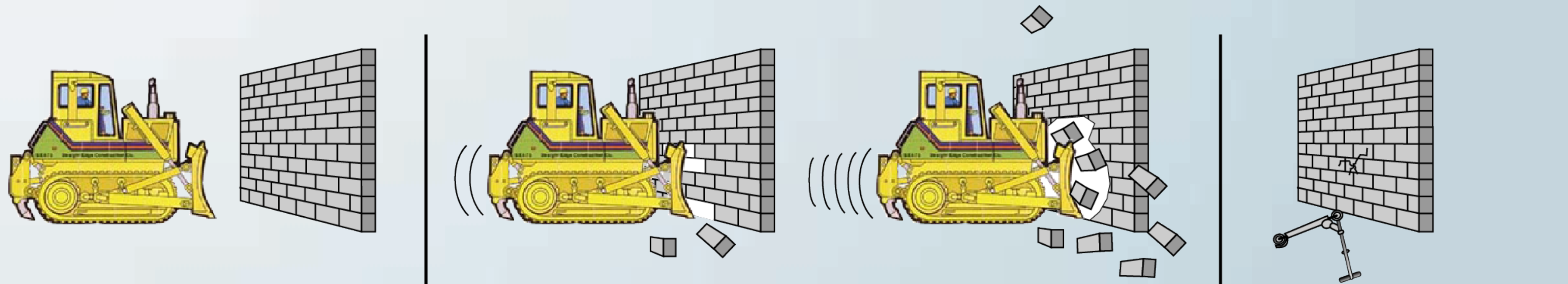


Energy is required to separate two atoms in a molecule and overcome the resistance to movement due to the chemical bond between them.

Two Types of Energy

- **Kinetic Energy** = the energy of motion

  $= 1/2\ m\mu^2$



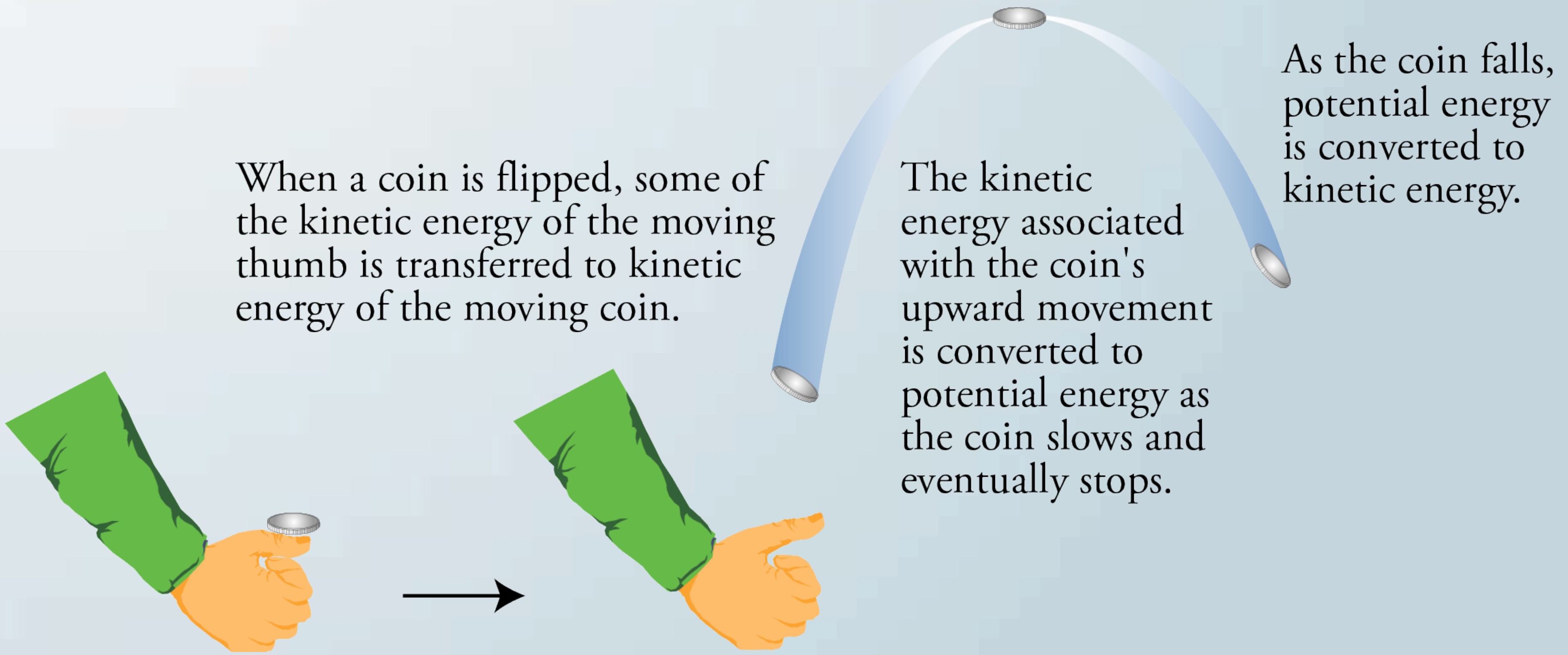
A stationary buldozer does not have the capacity to do the work of moving a wall.

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 (First Law of Thermodynamics)



Endergonic Change

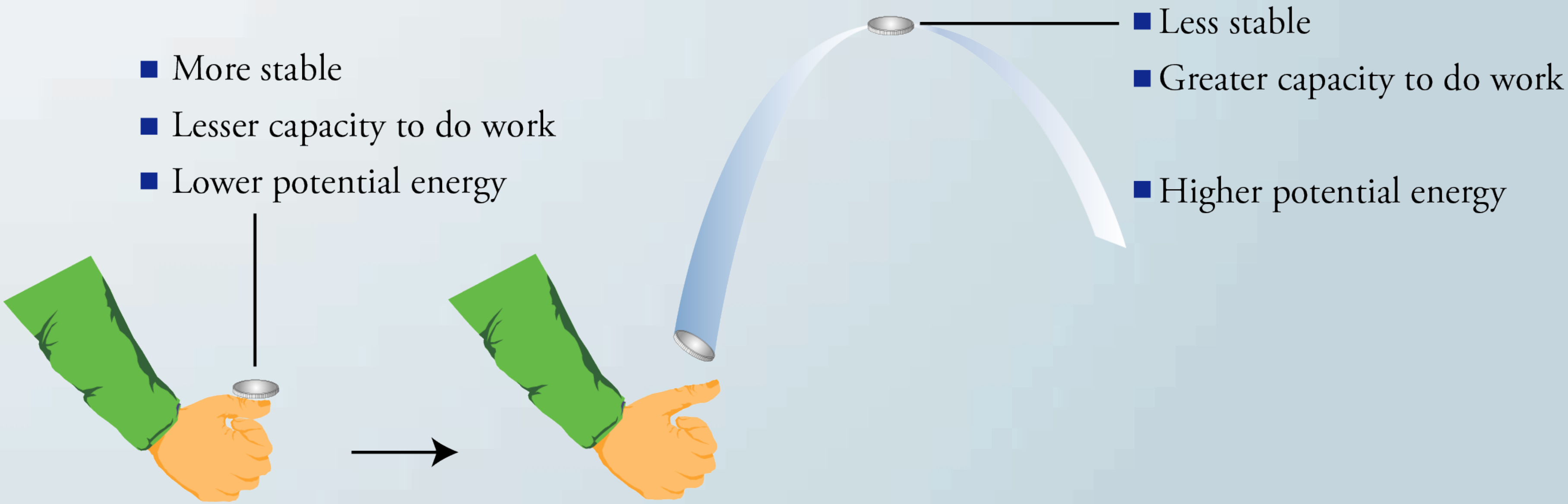
more stable + energy $\rightarrow$ less stable system

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



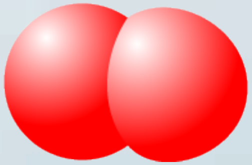
Bond Breaking and Potential Energy

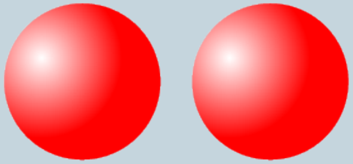
atoms in bond + Energy → separate atoms

more stable + Energy → less stable

lower PE + Energy → higher PE

$O_2(g) + \text{energy} \longrightarrow 2O(g)$





Exergonic Change

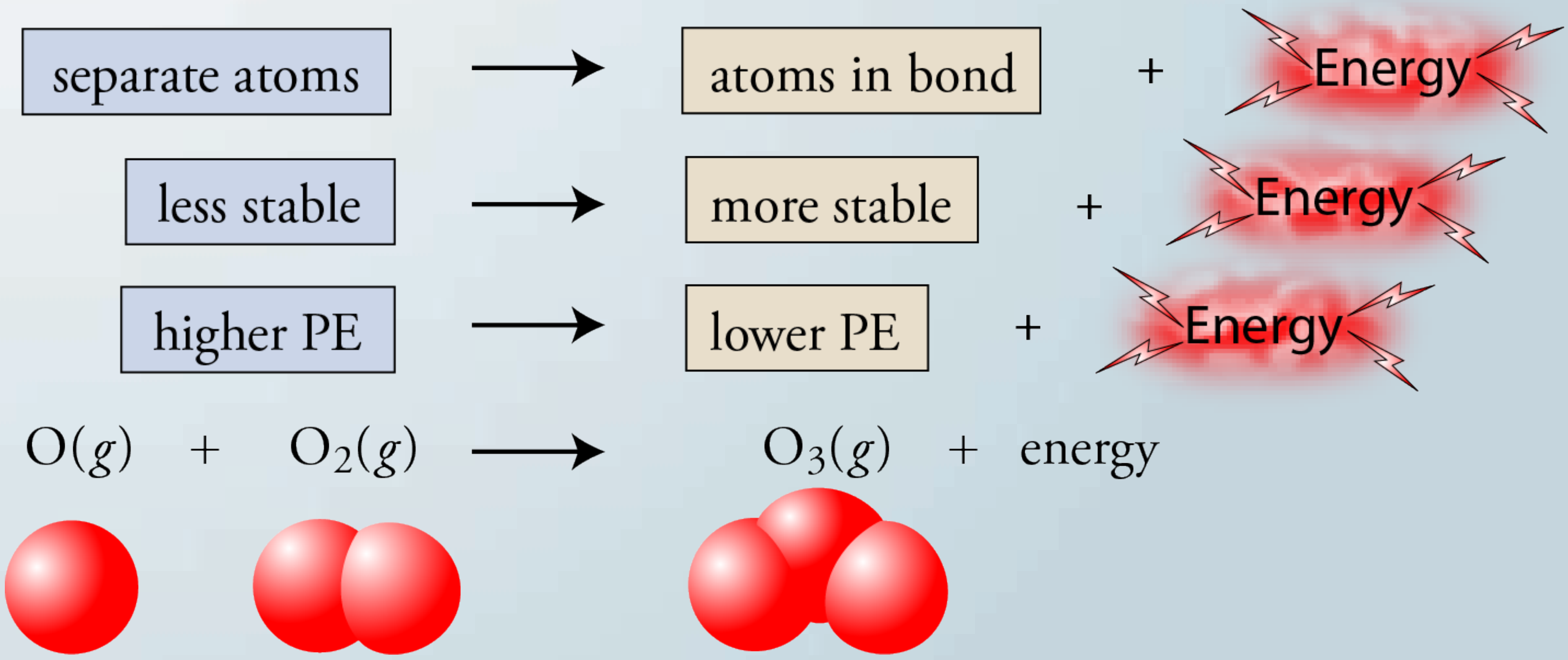
less stable system $\rightarrow$ more stable + energy

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

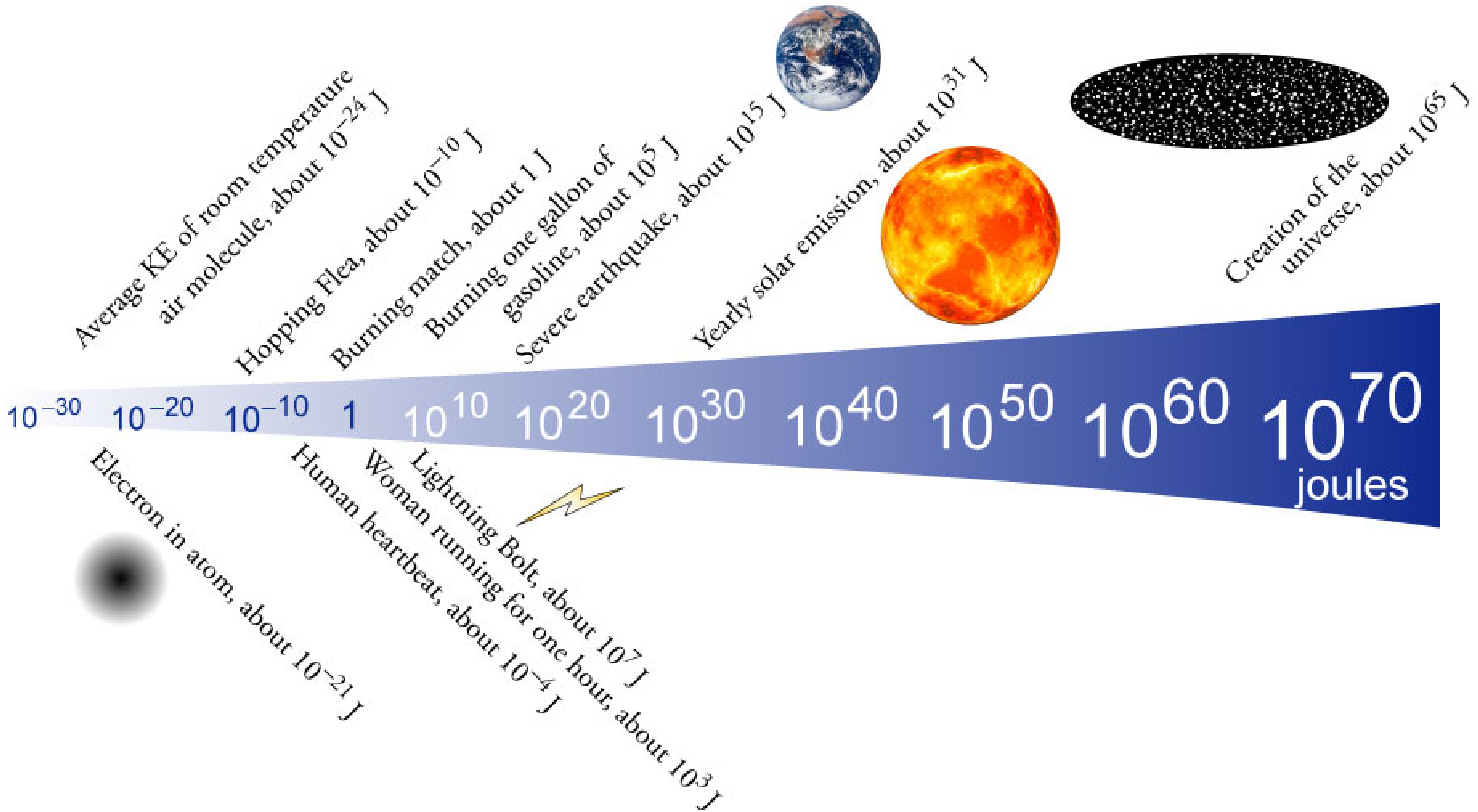
Bond Making and Potential Energy



Units of Energy

- Joule (J) = $\dfrac{kg\,m^2}{s^2}$
- Some traditional units (with conversions to J) are:
  - kinetic energy: foot-pounds (1 ft-lb = 1.36 J)
  - energy of chemical reactions: kilocalories/mole (1 kcal/mol = 4.18 kJ/mole)
  - commercial chemical energy: tonnes of oil equivalent (1 toe = 42 GJ)
  - thermal energy: British thermal units (1 Btu = 1055 J)
  - electrical energy: kilowatt-hours (1 kWh = 3.6 MJ)
  - photon energy: electron volts (1 eV = 1.6×10^{-19} J)
  - energy of nuclear reactions: million electron volts (1 MeV = 1.6×10^{-13} J)
  - energy of explosions: tonnes of TNT (1 t_{TNT} = 10^9 cal = 4.18 GJ)

Approximate Energy of Various Events

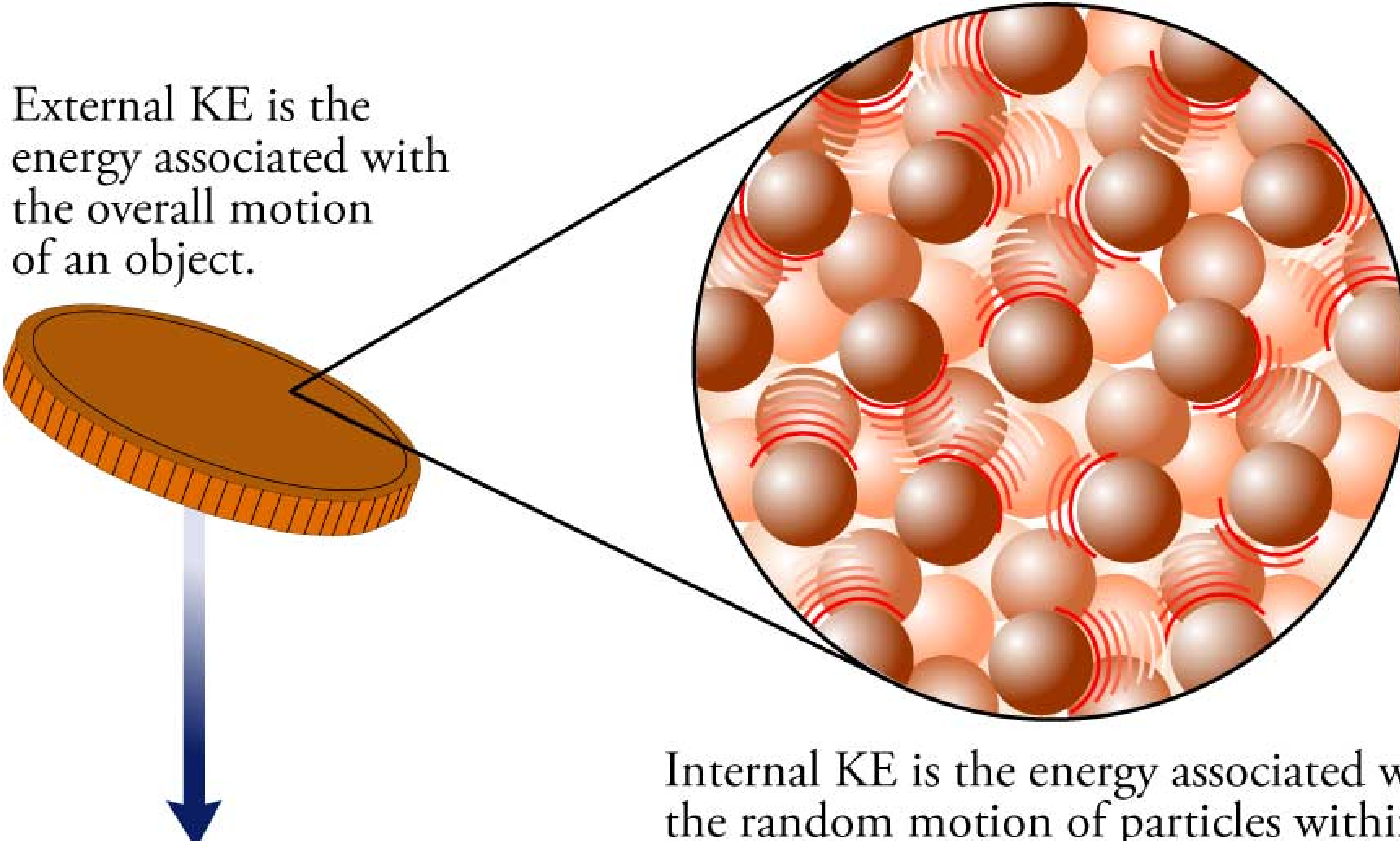


More Terms

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

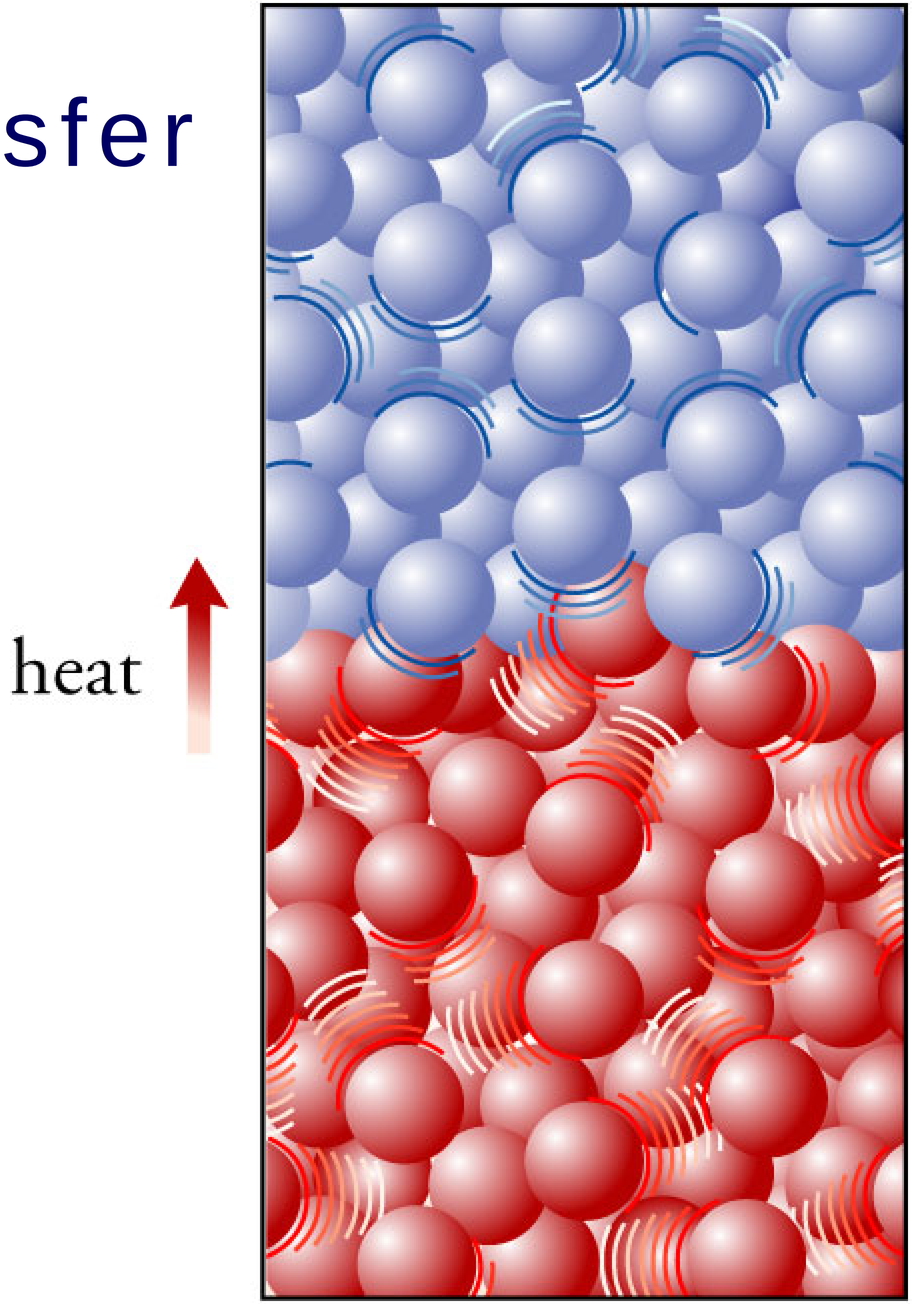
External and Internal Kinetic Energy

External KE is the energy associated with the overall motion of an object.



Internal KE is the energy associated with the random motion of particles within an object.

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

Heat Capacity and Specific Heat (Capacity)

- **Heat capacity**, C = the heat energy in kJ (or kcal or Btu) necessary to raise the temperature of an object by 1 ºC (or 1 K or 1 ºF).
- **Specific heat (capacity)**, c = the heat energy in J (or kJ or kcal or Btu) necessary to raise the temperature of 1 g (or kg or lb) of a substance (such as water) by 1 ºC (or 1 K or 1 ºF).

$$\text{Specific heat (capacity)} = \frac{\text{Energy}}{\text{mass}\bullet\text{temperature}}$$

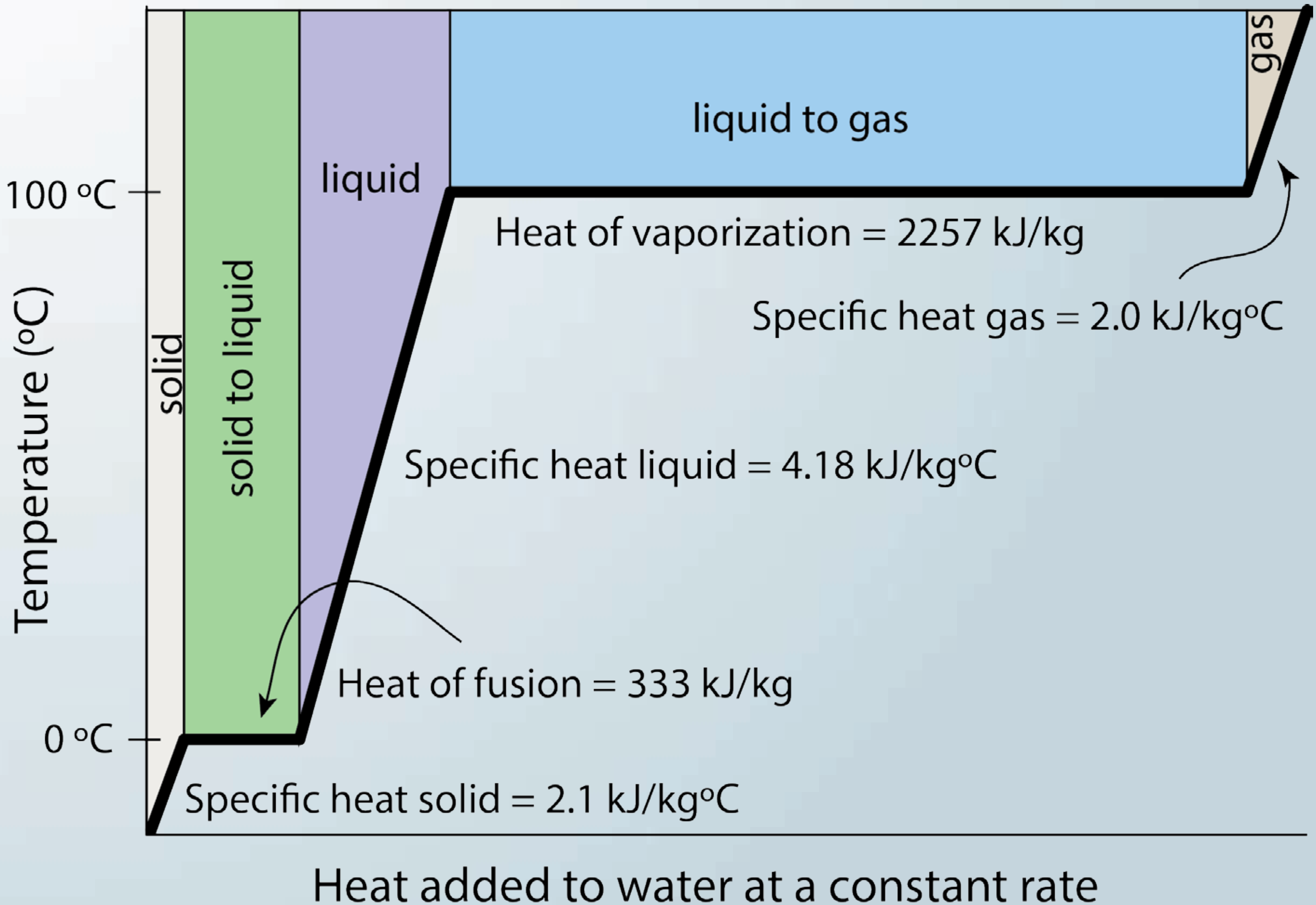
$$\text{Common units} \quad \frac{\text{kJ}}{\text{kg}\bullet{}^{\circ}\text{C}} \quad \frac{\text{kJ}}{\text{kg}\bullet\text{K}} \quad \frac{\text{kcal}}{\text{kg}\bullet{}^{\circ}\text{C}} \quad \frac{\text{Btu}}{\text{kg}\bullet{}^{\circ}\text{F}}$$

$$\frac{1\ \text{kcal}}{\text{kg}\bullet{}^{\circ}\text{C}} = \frac{1\ \text{Btu}}{\text{kg}\bullet{}^{\circ}\text{F}} = \frac{4.184\ \text{kJ}}{\text{kg}\bullet\text{K}} = \frac{4.184\ \text{kJ}}{\text{kg}\bullet{}^{\circ}\text{C}}$$

Heat and Phase Changes

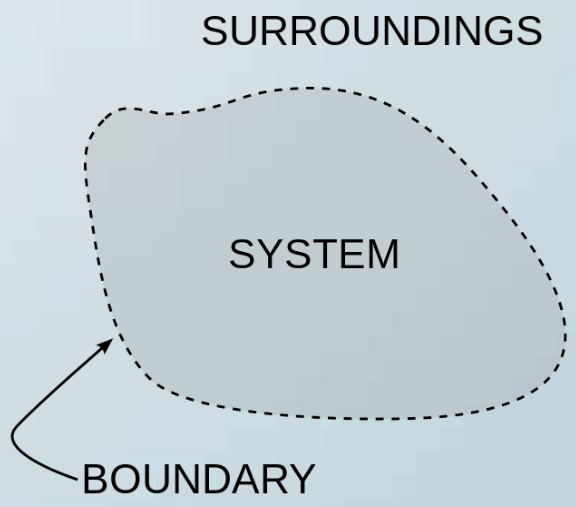
- When substances change from solid to liquid or liquid to gas, the heat added does not increase the temperature of the substance. The energy added disrupts the attractions between particles and increases the potential energy of the system, not the internal kinetic energy of the particles.
- **(Latent) heat of fusion (or enthalpy of fusion)** = the amount of heat energy necessary to convert an amount of solid to liquid, often expressed in kJ/mol or kJ/kg.
  - Often called latent heat because the temperature remains constant during the process.
  - For water, 333 kJ/kg.
- **(Latent) heat of vaporization (or enthalpy of fusion)** = the amount of heat energy necessary to convert an amount of liquid to gas, usually expressed in kJ/mol.
  - For water, 2257 kJ/kg.

Water Phase Change Diagram



System and Surroundings

- **System** = the portion of the universe upon which attention is focused. (For example, it could be the ocean, a lake, or the reaction vessel in a coal-fired power plant.)
- **Surrounding** = the portion of the universe that can exchange matter and/or energy with the system.
- **Boundary** = the border between the system and its surroundings.



Types of Systems

- **Open system** = a system that can exchange energy and matter with its surroundings.
- **Closed system** = a system that can exchange energy but not matter with its surroundings.
- **Isolated system** = a system that cannot exchange energy or matter with its surroundings.

Energy Flow

- Open system

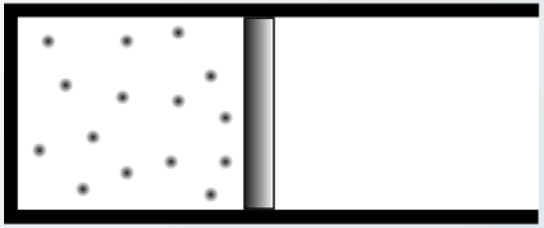
$$\begin{pmatrix}\text{Total energy}\\ \text{crossing boundary}\\ \text{as heat and work}\end{pmatrix} + \begin{pmatrix}\text{Total energy}\\ \text{of mass}\\ \text{entering system}\end{pmatrix} - \begin{pmatrix}\text{Total energy}\\ \text{of mass}\\ \text{leaving system}\end{pmatrix} = \begin{pmatrix}\text{Net change}\\ \text{of energy in}\\ \text{the system}\end{pmatrix}$$

- Closed system

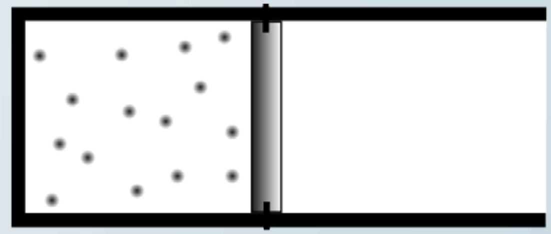
$$\begin{pmatrix}\text{Total energy}\\ \text{crossing boundary}\\ \text{as heat and work}\end{pmatrix} = \begin{pmatrix}\text{Net change}\\ \text{of energy in}\\ \text{the system}\end{pmatrix}$$

Work and Gases

When heat is added to a gas that is allowed to expand, it takes more heat to change the temperature by a given amount.



Constant volume →



↓ Constant pressure

With constant volume, the heat absorbed goes to increasing temperature.

$$q_V = mc_v\Delta T$$

Add heat → increased T → increased P_{int} → $P_{int} > P_{ext}$ → piston moves right ↓

System does work on surroundings. ← Increased volume ← gas expands

↓

System loses energy → Decreased P_{int} until $P_{int} = P_{ext}$

↓

Some of the energy that would have increased the temperature of the system is used to do work, so when heat is added to a gas that is allowed to expand, the increase in temperature will be less than for a gas that is not allowed to expand. For the same increase in temperature, more heat must be added at constant pressure.

$$q_p = q_v + q_{work}$$

Work and Liquids and Solids

- Liquids and solids have very little expansion when heated, so they do not do any significant amount of work when heated, so we can assume that

  $$q_P = q_V = mc\Delta T$$

- Specific heat of water at 15 °C = 4.18 kJ/kg°C
  - It varies a bit with changes in temperature.
  - 15 °C is the approximate current average surface temperature on the Earth's surface.

Entropy

- The *quantity* of energy is constant (First Law of Thermodynamics), but the *quality* of energy decreases over time (Second Law of Thermodynamics).
  - Only relatively concentrated forms of energy can be harnessed to do work. As useable energy does work, energy tends to become more dispersed and less able to be harnessed to do work.
- **Entropy (S)** can be defined in several ways.
  - A measure of unusable energy. (As usable energy decreases and unusable energy increases, entropy increases.)
  - Entropy is also a measure of the number of equivalent ways that particles and energy can be arranged.

    $S = k \ln W$

    k = a constant

    W = the number of equivalent ways that particles and energy can be arranged
  - Because there are more ways to arrange particles and energy in a more dispersed system, entropy can be seen as a measure of the dispersal of matter and energy.

Second Law of Thermodynamics

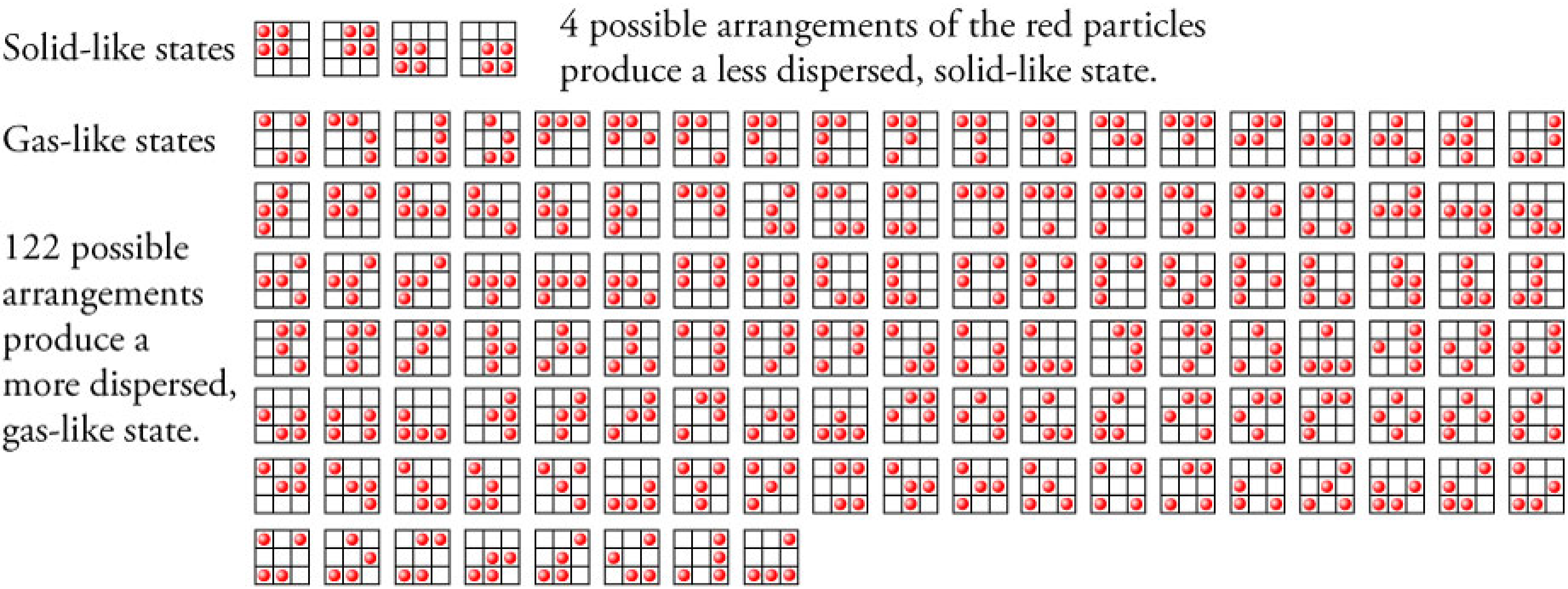
- The entropy of the universe increases.
  - Particles and energy become more dispersed.
  - Energy changes from useable to unusable. (Increased entropy means an increase in dispersal of matter and energy, and more dispersed energy is less likely to be harnessed to do work.)
- The entropy of a system tends to increase.
  - $S_{universe} = S_{system} + S_{surroundings}$
  - The entropy of a system can only decrease if the entropy of the surroundings increases more.

Why Particles Become More Dispersed

- Consider a system that can switch freely between two states, A and B.
- Probability helps us to predict that the system will shift to state B if state B has its particles and energy more dispersed, leading to more ways to arrange the particles and energy in the system.

State A $\rightleftharpoons$	**State B**
Less probable	More probable
Fewer ways to arrange particles and energy	More ways to arrange particles and energy
Less dispersed (spread out)	More dispersed (spread out)

9-Point Universe



Probability of Gas

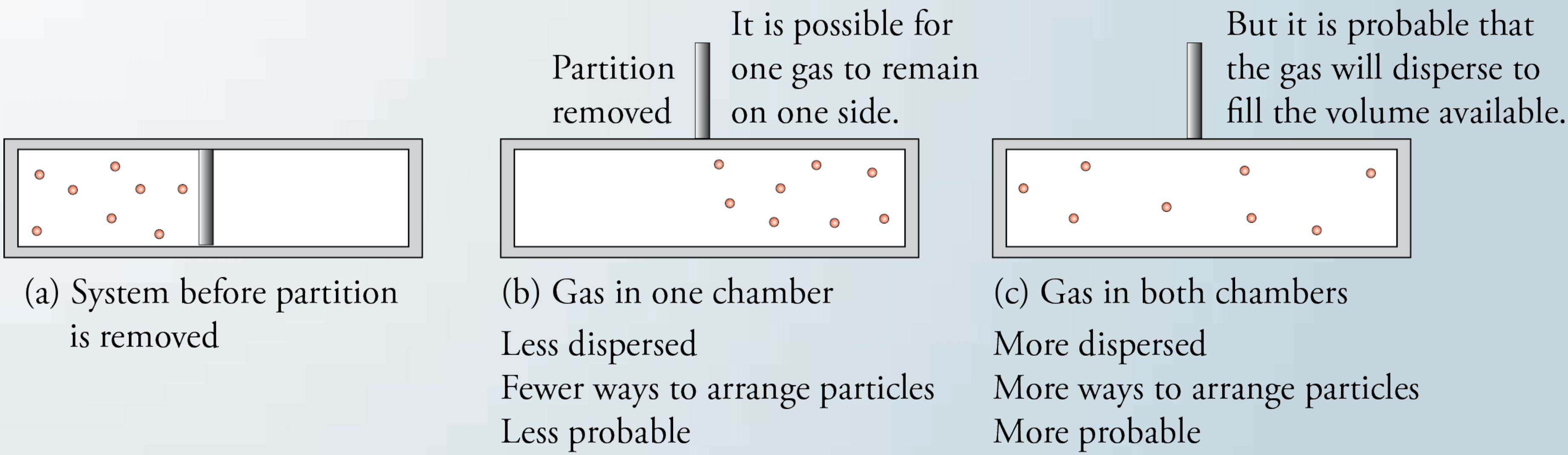
- In 9-point universe, 96% of the arrangements of 4 particles are gas-like.
- In 16-point universe, 99.5% of the arrangements of 4 particles are gas-like.
- Therefore, an increase in the number of possible positions leads to an increase in the probability that the system will be in the more dispersed, gas-like state.
- In real systems, there are huge numbers of particles in huge numbers of positions, so there is an extremely high probability that the systems will be in the more dispersed, gas-like state.

Solids shift spontaneously to gases.

- Why does dry ice, $CO_2(s)$, sublime? Why does the change favor the gas?
  - Internal kinetic energy is associated with the random movement of particles in a system.
  - Internal kinetic energy makes it possible for CO_2 molecules to move back and forth between solid and gas.
  - If the particles can move freely back and forth between solid and gas, they are more likely to be found in the more dispersed gas state, which has more equivalent ways to arrange the particles.

$CO_2(s)$	$CO_2(g)$
Less dispersed	More dispersed
Fewer ways to arrange particles	More ways to arrange particles
Less probable	More probable

Gases Expand



When the barrier between the two chambers in the container shown in (a) is raised, it is possible that the gas will end up in one chamber, like in (b), but it is much more likely that it will expand to fill the total volume available to it, like in (c).

Matter gets dispersed (spread out).

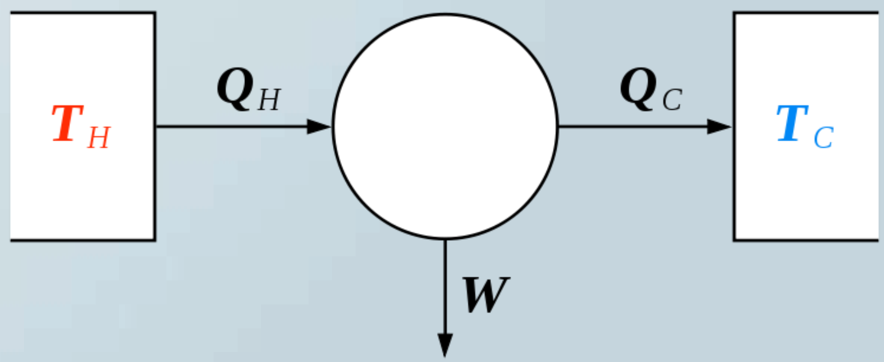
Gas in one chamber $\rightarrow$	Gas in both chambers
Fewer ways to arrange particles	More ways to arrange particles
Less probable	More probable
Less dispersed	More dispersed

Energy Dispersal

- If we view energy as quantized (or particle-like), we can use similar reasoning for the dispersal of energy.
- Because there are more ways to arrange energy quanta when they are more dispersed, if energy is allowed to disperse, probability predicts that it will become more dispersed.

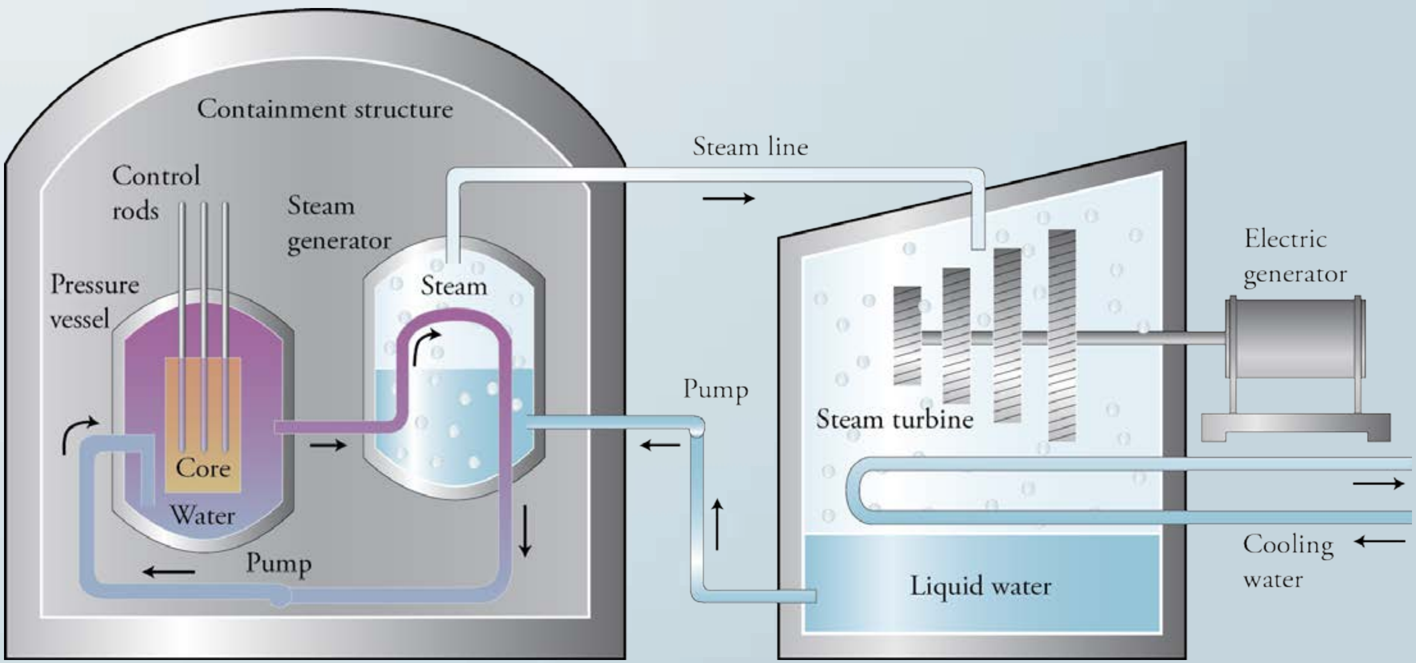
Heat Engines

- A **heat engine** is a system that converts heat to mechanical work.
- It does this by bringing a working substance (e.g. water) from a high temperature state to a lower temperature state. A heat "source“ (e.g. nuclear fission) transfers heat that brings the working substance to the high temperature. The working substance does work while transferring heat to the colder "sink" until it reaches a low temperature state. During this process some of the energy is converted into work by exploiting the properties of the working substance, e.g. turning a turbine as water vapor expands.



Nuclear Thermal Power Plant

- **Thermal power plant** = a power plant in which water is heated and turned into steam, which expands and spins a steam turbine that drives an electrical generator. After it passes through the turbine, the steam is cooled, condensed back to a liquid, and recycled to where it was heated.
- Some of the energy in the system is lost as heat to the surroundings where it disperses enough to be unusable.



Heat Engine Efficiency

- The theoretical maximum efficiency of a heat engine is dependent on the temperatures it operates between.

$$\eta_{max} = 1 - \frac{T_C}{T_H}$$

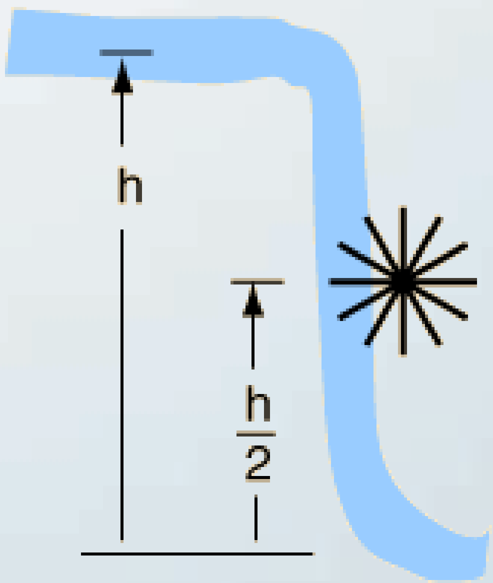
η_{max} = maximum efficiency

T_C = temperature cold in kelvins

T_H = temperature hot in kelvins

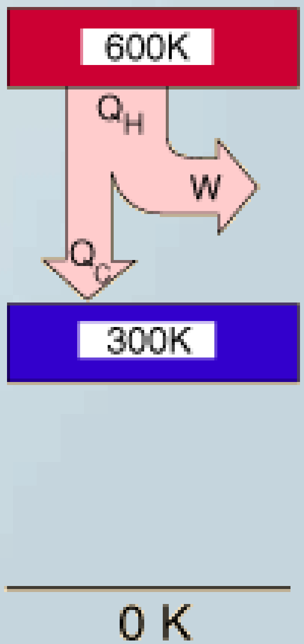
- Because the cold temperature cannot be zero, 100% efficiency is impossible.
  - New fossil fuel plants are about 40% efficient.
  - Nuclear plants are about 33% efficient.

Heat Engine Efficiencies



If you are constrained to put your waterwheel half-way up the waterfall, then you can extract at most half of the available energy.

If a 600K heat engine must exhaust heat at 300K, then it can be at most 50% efficient.



http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/seclaw.html

Power

- The rate at which energy is transferred, used, or transformed.
- Energy divided by time.
  - The SI unit of power is the watt (W), which is one joule per second.

$$\text{Power} = \frac{\text{Energy}}{\text{Time}} = \frac{1\ \text{J}}{\text{s}} = \frac{3.412\ \text{Btu}}{\text{hr}} = 1\ \text{W}$$

    - Btu = the amount of energy needed to heat 1 pound (0.454 kg) of water from 39 °F to 40 °F (3.8 °C to 4.4 °C). The unit is most often used in the power, steam generation, heating, and air conditioning industries.
  - Other units of power include ergs per second (erg/s), horsepower (hp), and foot-pounds per minute.
- Power describes the rate at which work can be performed.

Exploring the Units of Power

Since P = E / time, then E = P $\times$ time:

- A flow of 1 watt for 1 second transfers or transforms energy of 1 W-s ≡ 1 J
- A flow of 1 kilowatt for 1 hour transfers or transforms energy of 1 kW-hr = 1 kWh
- A flow of 1 terawatt for 1 year transfers or transforms energy of 1 TW-yr = 1 TWy.

Conversely, reverting to P = E / time,

- a kilowatt-hour per hour is a kilowatt
- a terawatt-year per year is a terawatt, and so on.

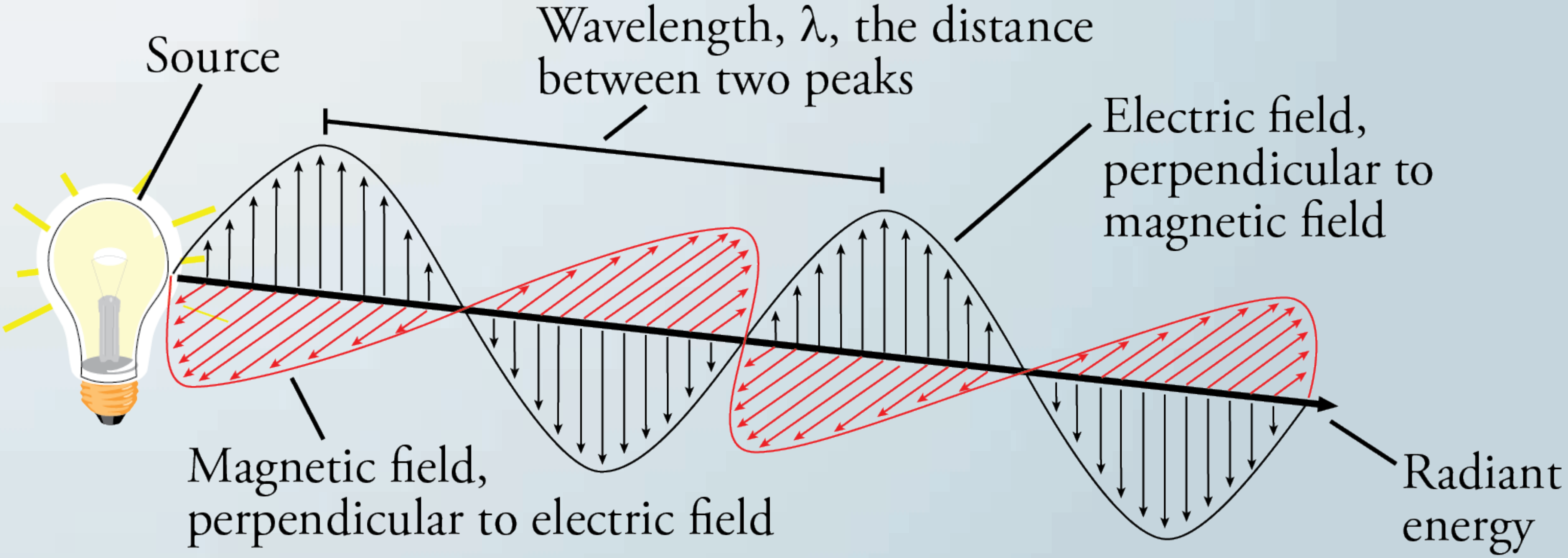
Because the units of energy are force times distance
(i.e., 1 J = 1 newton-meter),

- P = E / time is equivalent to P = F $\times$ distance/time = F $\times$ v
- This means, for example, that the power needed to propel a car at velocity v is given by the amount of force needed to overcome air drag and tire friction at that speed, multiplied by the speed itself.

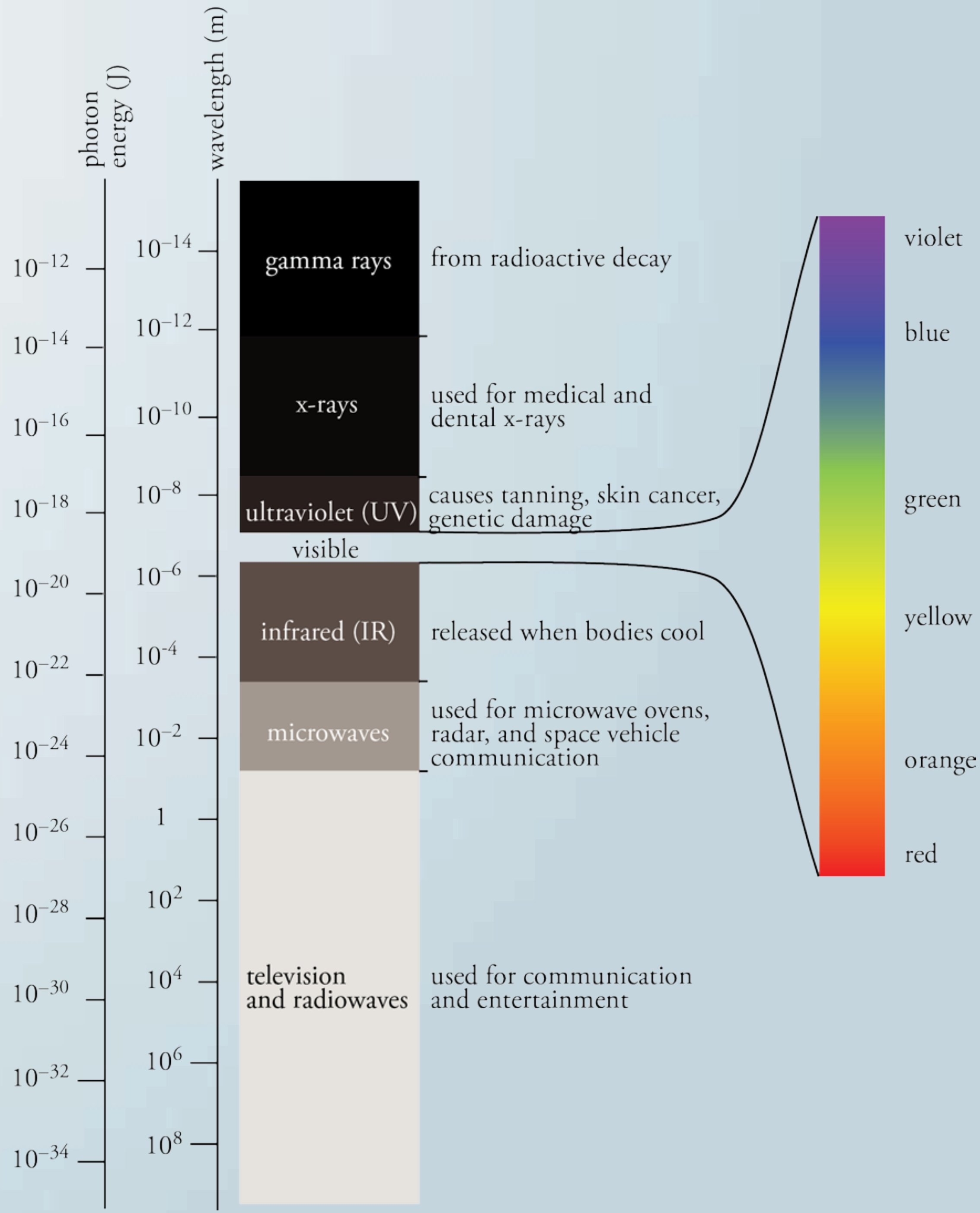
Radiant Energy

- **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

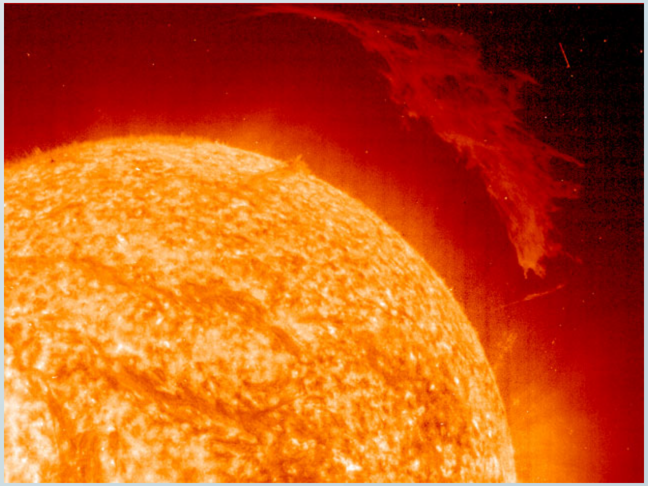


Radiant Energy Spectrum



Our Energy is (mostly) solar energy.

- The Sun is the ultimate source of nearly all of Earth's energy, including hydropower, wind, waves, biomass, and fossil fuels.
- The only energy sources not derived from the sun are tidal, nuclear, and geothermal energy.
- The Sun emits ~4×10^{26} W to space. Less than one-billionth of this, 1.74×10^{17} W or 1.74×10^{5} TW (terawatt = 10^{12} W) reaches Earth's atmosphere.

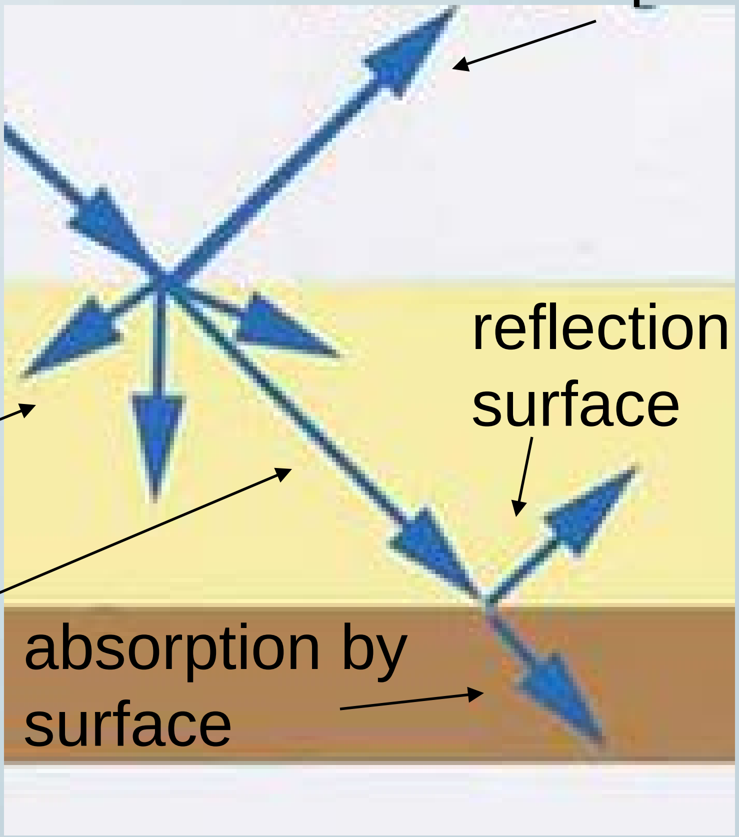


Energy from the Sun

- The total solar energy absorbed by Earth's atmosphere, oceans and land masses is approximately 3,850,000 exajoules (EJ) per year. (exa = 10^{18})
- Photosynthesis captures approximately about 3,000 EJ per year in biomass.
- The amount of solar energy reaching the surface of the planet is so vast that in one year, it is about twice as much as will ever be obtained from all of the Earth's non-renewable resources of coal, oil, natural gas, and mined uranium combined.

3 Fates of Light Incident on an Object (including the atmosphere)

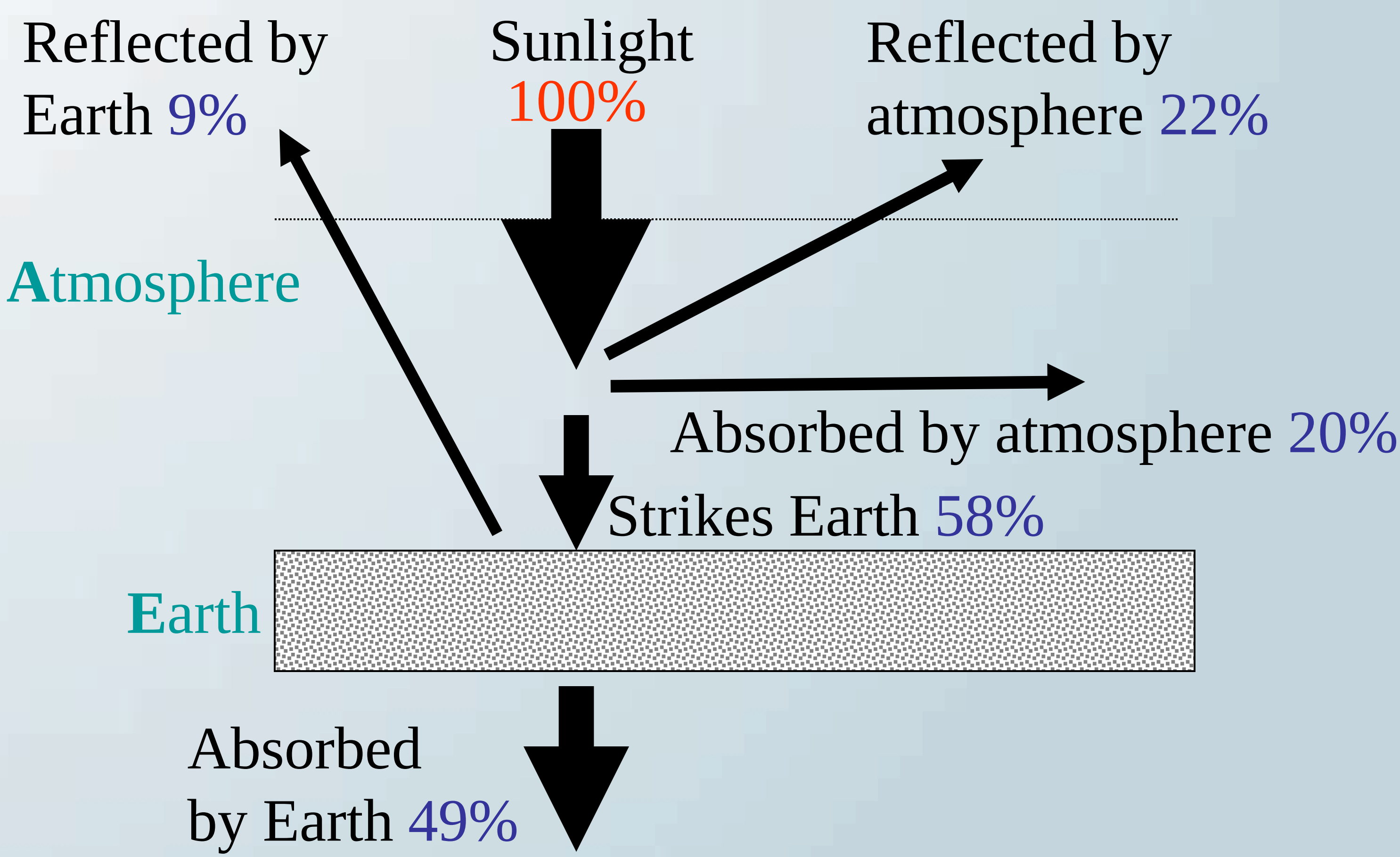
1. **reflection** - strikes a molecule bounces back
2. **absorption** - strikes a molecule and is absorbed
3. **transmission** - passes through without being reflected or absorbed



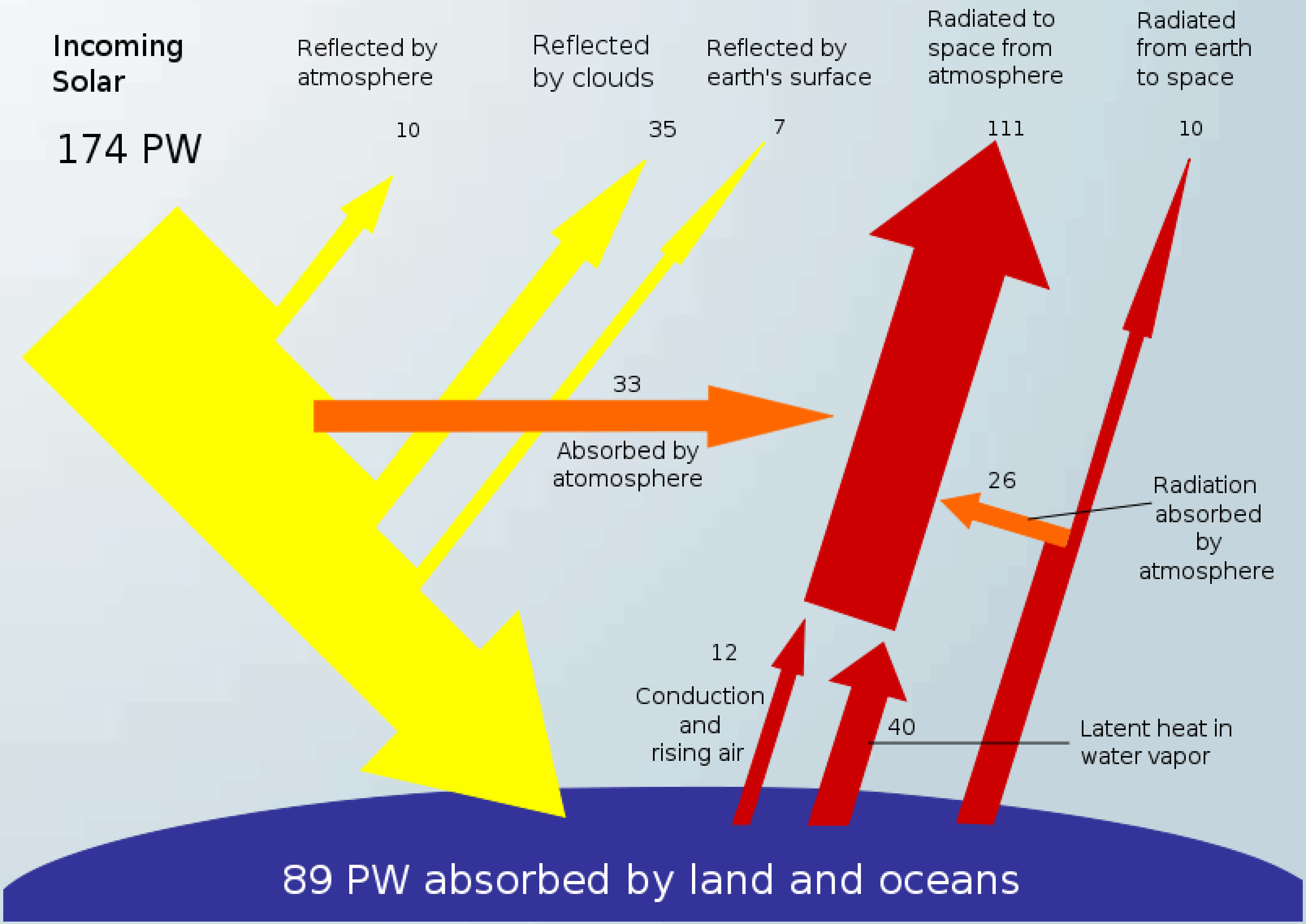
What determines Earth's temperature?

- 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.

Fate of Incoming Solar (short-wave) Radiation Striking Top of Atmosphere



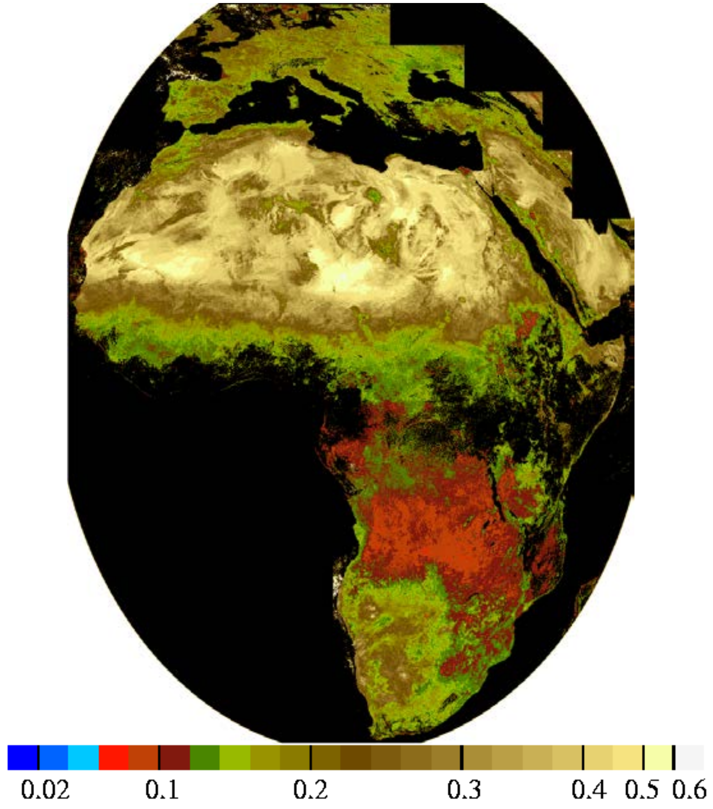
Fate of Incoming Solar Energy.



Albedo

Albedo = the ratio of reflected radiation from the surface to incident radiation upon it. It is measured on a scale from zero for no reflecting power of a perfectly black surface, to 1 for perfect reflection of a white surface. It may also be expressed as a percentage.

Clouds	= 0.25
Surface & atm	= 0.06
Total earth	= 0.31



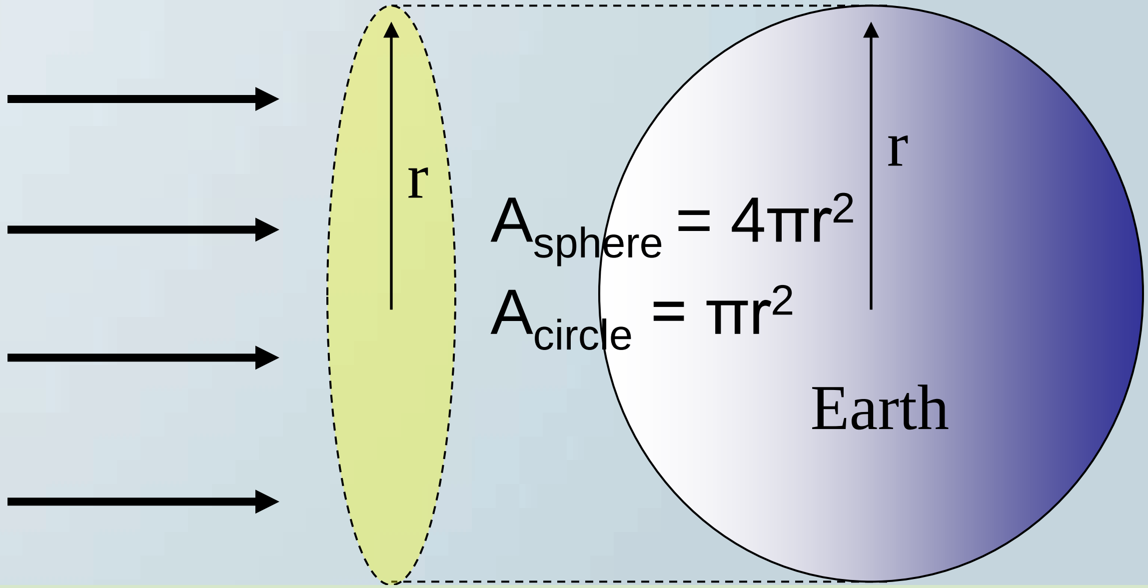
Surface albedo over African continent, June 1996.

Credits: This map was derived from data gathered by the Visible and InfraRed Imager (MVIRI) sensor on the geostationary Meteosat platform. More information on this platform, as well as on the forthcoming Meteosat Second Generation (MSG), to be launched in 2002, can be obtained from the EUMETSAT web site. The image above was processed by EUMETSAT

Rate of Solar Energy Striking Earth

- Earth's cross-sectional area: $\pi r^2 = 1.275 \times 10^{14}$ m^2 (mean radius = 6,371 km)
- Rate at which solar energy reaches Earth's disc: 174,000 TW
- Flux: 1.74×10^{17} W /1.275×10^{14} m^2 = ~1365 W/m^2 (actually 1368 W/m^2)

Solar energy flux (S_0 or Ω, called the solar "constant") is 1368 W/m^2 at *top* of atmosphere in plane perpendicular to incoming beam

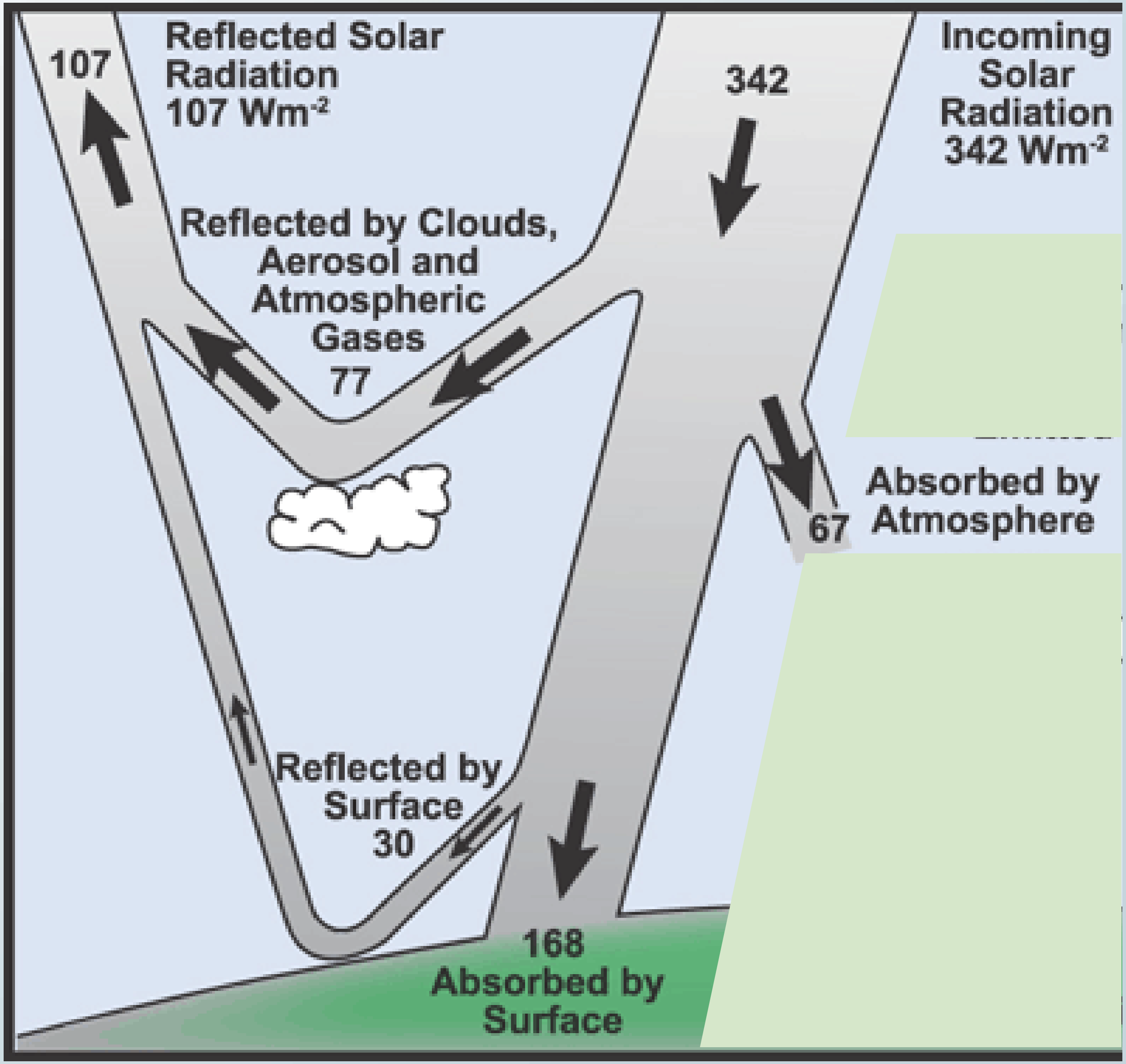


- Surface area of earth: $4\pi r^2 = 500 \times 10^{12}$ m^2
- Solar energy flux striking top of atmosphere, averaged over whole surface area of earth (light and dark sides):

$$1.74 \times 10^{17} \text{ W} / 500 \times 10^{12} \text{ m}^2 = \sim 350 \text{ W/m}^2 \text{ (actually } 342 \text{ W/m}^2)$$

Fate of Incoming Solar Radiation

In W/m²



Solar Energy Flux at Earth's Surface

- Penetrates to surface: ~ 58% (the rest is reflected or absorbed in atmosphere)

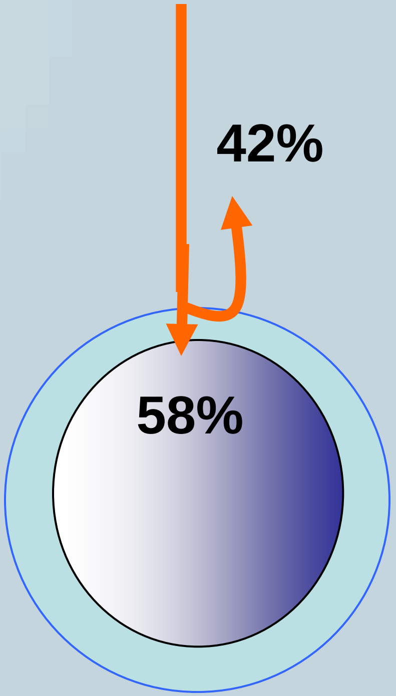
  174,000 TW $\times$ 0.58 ≈ 100,000 TW

- Average solar flux per m² at surface:

  100,000 TW / 500 $\times 10^{12}$ m² ≈ 200 W/m²

  (also, 342 W/m² $\times$ 0.58 ≈ 200 W/m²)

- Calculate the average solar energy per m² surface per year:



Calculate the average solar energy per m^2 per year.

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

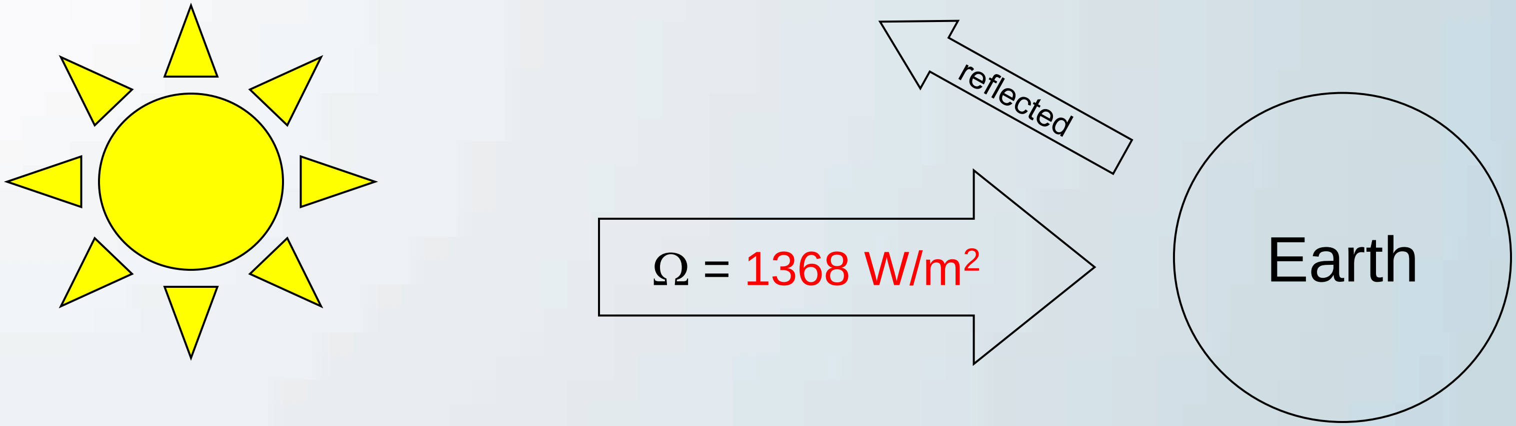
$$1\mathrm{W}\bullet\mathrm{s} = 1\ \mathrm{J}$$

$$\frac{?\ \mathrm{J}}{\mathrm{yr}\bullet\mathrm{m}^2} = \frac{200\ \cancel{\mathrm{W}}}{\mathrm{m}^2}\left(\frac{1\ \mathrm{J}}{1\ \cancel{\mathrm{W}}\bullet\cancel{\mathrm{s}}}\right)\left(\frac{60\ \cancel{\mathrm{s}}}{1\ \cancel{\mathrm{min}}}\right)\left(\frac{60\ \cancel{\mathrm{min}}}{1\ \cancel{\mathrm{hr}}}\right)\left(\frac{24\ \cancel{\mathrm{hr}}}{1\ \cancel{\mathrm{day}}}\right)\left(\frac{365\ \cancel{\mathrm{day}}}{1\ \mathrm{yr}}\right)$$

$$= 6307200000\ \mathrm{J}/(\mathrm{yr}\bullet\mathrm{m}^2) \approx 6 \times 10^9\ \ \mathrm{J}/(\mathrm{yr}\bullet\mathrm{m}^2)$$

$$1\ \text{barrel of crude oil} \approx 6 \times 10^9\ \ \mathrm{J}$$

Solar Summary



Solar energy intercepted by earth = 174,000 TW

Solar energy intercepted per m^2 Earth = 342 W/m^2

Earth's albedo α (reflectivity) = 0.31 (portion of sunlight reflected back to space)

Solar energy absorbed in atmosphere + surface

$$= (1 - 0.31) \times 342 \text{ W/m}^2 = 235 \text{ W/m}^2$$

Solar energy striking surface ≈ *200 W/m^2*

averaged over all latitudes and all seasons

Goal

- The goal is to develop a model that explains the average temperature of the Earth, 288 K or 15 °C.
- Three attempts
  - Earth as a blackbody with no greenhouse gases
  - Earth with two layers of greenhouse gases where the atmosphere is totally transparent to incoming sunlight and with the only mechanism for energy loss being infrared radiation loss with no IR radiation escaping the atmosphere unabsorbed. (A layer is the portion of atmosphere within which each IR photon would be absorbed and emitted once.)
  - Earth with two layers of greenhouse gases with corrections for incoming sunlight absorbed, some IR through the atmosphere unabsorbed, some heat transferred to the atmosphere as latent heat, and some energy transferred to the atmosphere via convection.

Assuming that the Earth is a blackbody with no greenhouse gases gives a temperature that is too low (255 K = -18 °C)

.

The Earth's Energy Balance

Solar Flux $\Omega \approx 1360\ W/m^2$

avg. over surface $\rightarrow \Omega/4 \approx 340\ W/m^2$

Albedo (reflectivity) $a \approx 0.3$ (avg.)

Blackbody Radiation: $P(W/m^2) = \sigma T^4$

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

$(1-a)\Omega/4 = \sigma T^4$ (energy conservation)

$$T^4 = \frac{(1-a)\,\Omega}{4\sigma} = \frac{0.7 \times 340\ W/m^2}{5.67 \times 10^{-8}\ W/m^2 \cdot K^4}$$

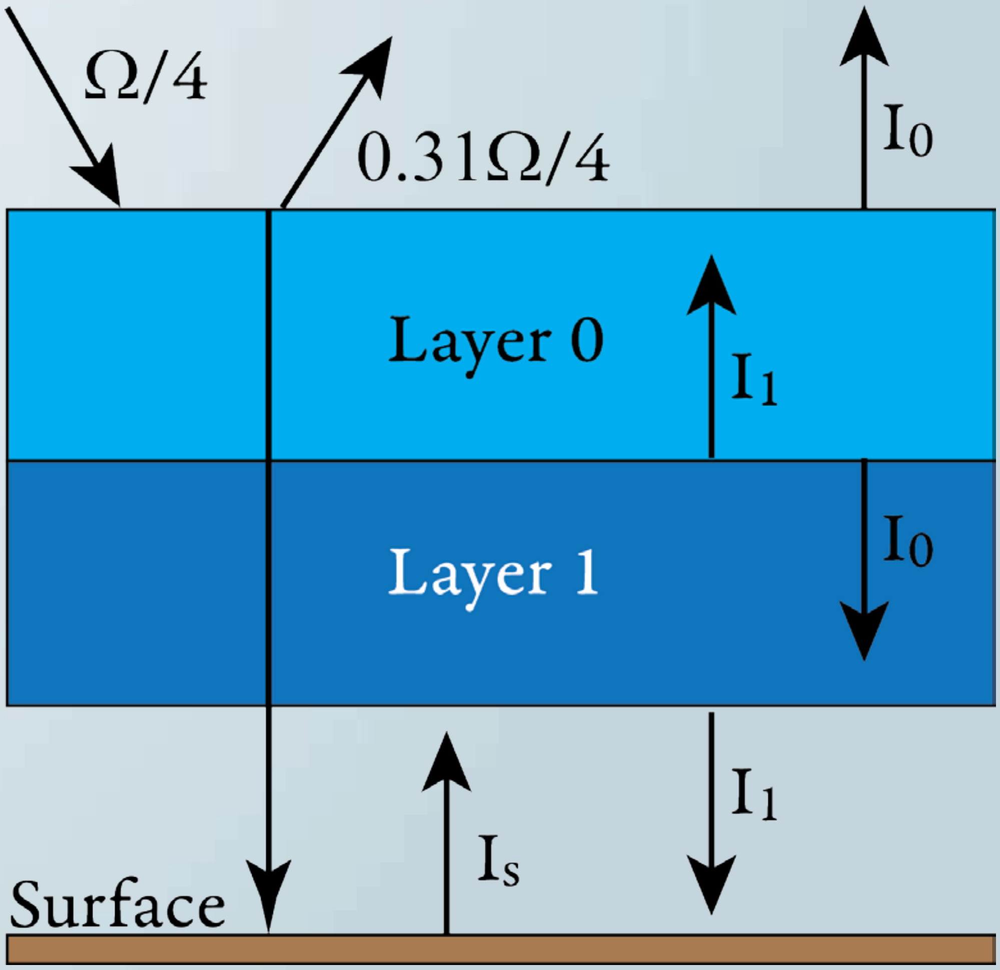
$\rightarrow T = 255\ K$

Two Layers of Greenhouse Gases

- Each layer is thick enough so that each IR photon that enters the layer is absorbed and emitted once.
- Surface and each layer act as black bodies (perfect absorbers and emitters)

$$I = \sigma T^4$$

- No incoming shortwave radiation is absorbed
- No outgoing IR escaping unabsorbed



Two Layers of Greenhouse Gases

Assumes only energy out and only energy exchange between layers was infrared (I)

Flux in total = Flux out total

$$0.69\Omega/4 = I_0 = \sigma T_0^4$$

$$I_1 = 2I_0 = 2\sigma T_0^4$$

$$I_S = \sigma T_s^4 = 0.69\Omega/4 + I_1$$

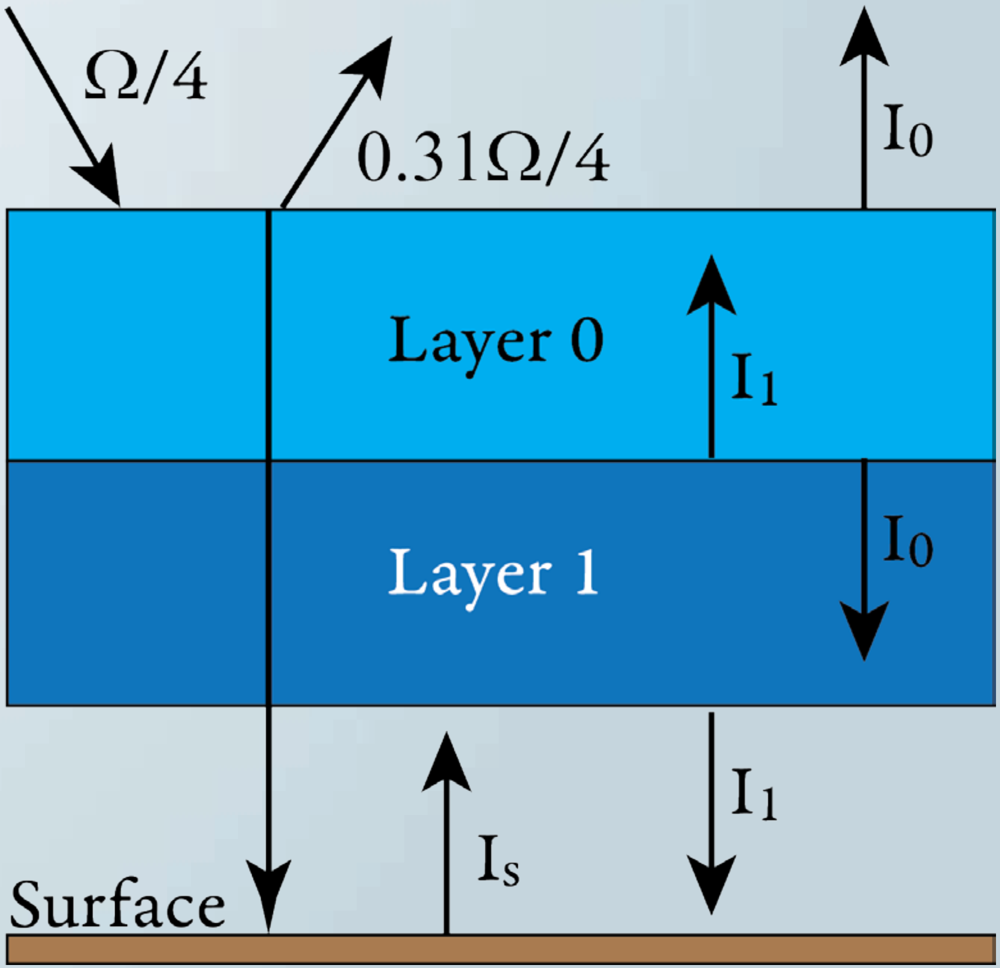
$$\sigma T_s^4 = \sigma T_0^4 + 2\sigma T_0^4$$

$$T_s^4 = T_0^4 + 2T_0^4$$

$$T_s^4 = (1+2)T_0^4$$

$$T_s = 3^{1/4} T_0 = 3^{1/4}(255\text{ K})$$

$$= 336\text{ K} = 63\ ^\circ\text{C (too high)}$$



Adjustments

- Some incoming sunlight absorbed (Energy flux = F_{abs})
- Some IR radiation escapes unabsorbed (Energy flux = F_{esc})
- Some energy escapes from the surface by
  - Energy flux due to convection (F_C)
  - Energy flux due to latent heat (F_L)

$I_s = (I_{incoming} + I_1) – (1.7F_{abs} + 2F_{esc} + F_C + 1.5F_L)$

$$\sigma T_s^4 = [(0.69\Omega/4 + 2(0.69\Omega/4)] – [1.7(86\ W/m^2) + 2(20\ W/m^2) + (17\ W/m^2) + 1.5(80\ W/m^2)]$$

$T_s = 289\ K\ (16\ °C)$

Energy Flows on Earth

- Of the 100,000 TW of solar radiation reaching the surface,
  - ~ 40,000 TW runs the hydrologic cycle
  - ~ 2,000 TW generates wind
  - ~ 300 TW runs the biosphere (Gross Primary Productivity, GPP)
    - ~ 150 TW used for plant metabolism (respiration)
    - ~ 150 TW to create new biomass (Net Primary Productivity, NPP)
- *Average* efficiency of primary producers (organisms in an ecosystem that produce bio-mass from inorganic compounds) in converting solar energy to biomass = 150 TW ÷ 100,000 TW **≈ 0.15%**

  Maximum efficiency (corn, sugarcane) **≈ 1-3%**
- Geothermal energy ≈ 44 TW (heat flow from Earth's core)
- Human energy use ≈ 16 TW (~85% fossil fuels)
  = 0.016% of solar radiation

GPP and NPP

- **Gross primary production (GPP)** = the rate at which an ecosystem's producers capture and store a given amount of chemical energy as biomass in a given length of time. Some fraction of this fixed energy is used by primary producers for cellular respiration and maintenance of existing tissues. The remaining fixed energy is referred to as *net primary production* (NPP)
- **Net primary production (NPP)** = the rate at which all the plants in an ecosystem produce net useful chemical energy; it is equal to the difference between the rate at which the plants in an ecosystem produce useful chemical energy (GPP) and the rate at which they use some of that energy during respiration. Some net primary production goes toward growth and reproduction of primary producers, while some is consumed by herbivores.

NPP = GPP - respiration [by plants]

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/

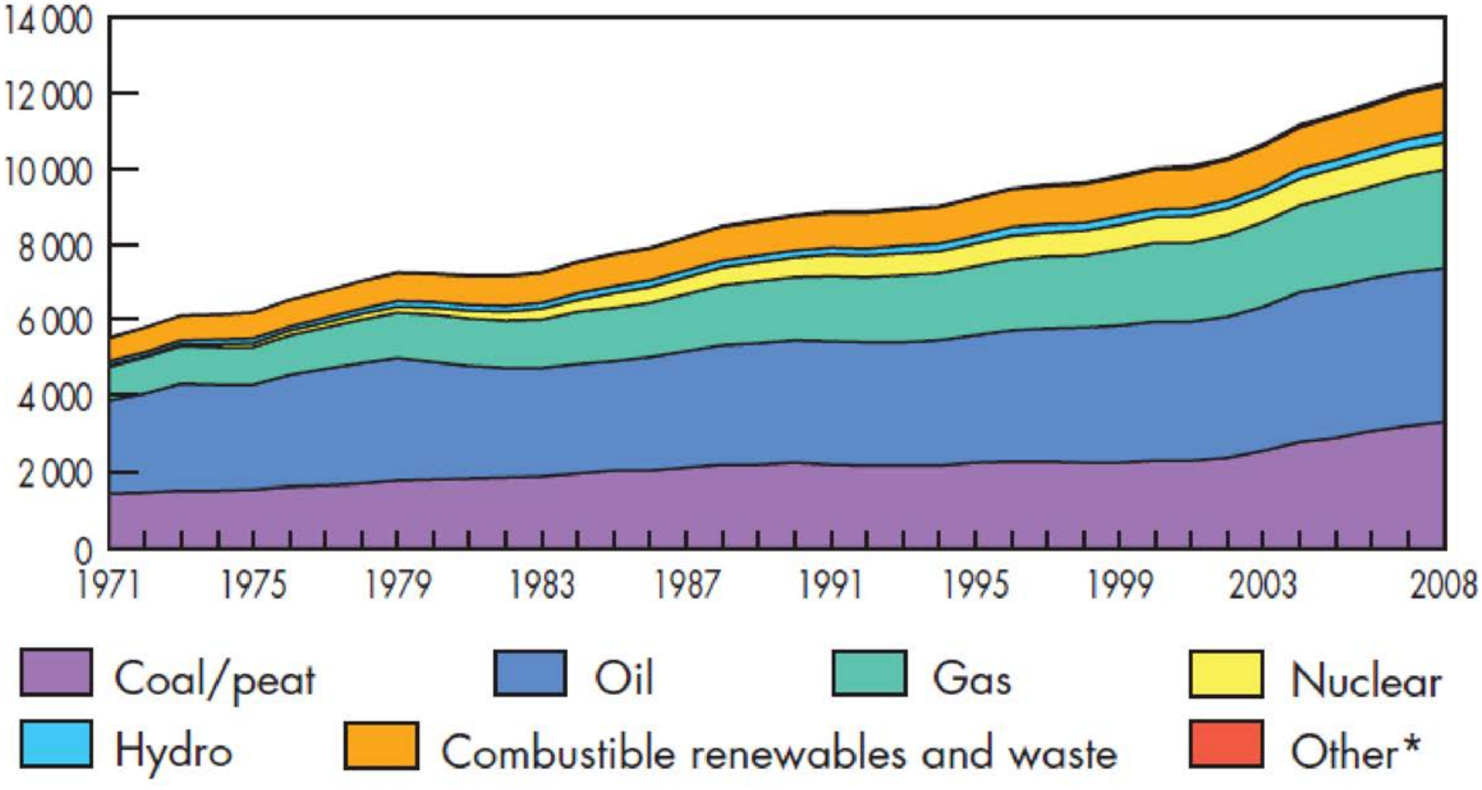
https://www.iea.org/stats/index.asp

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

TOTAL PRIMARY ENERGY SUPPLY

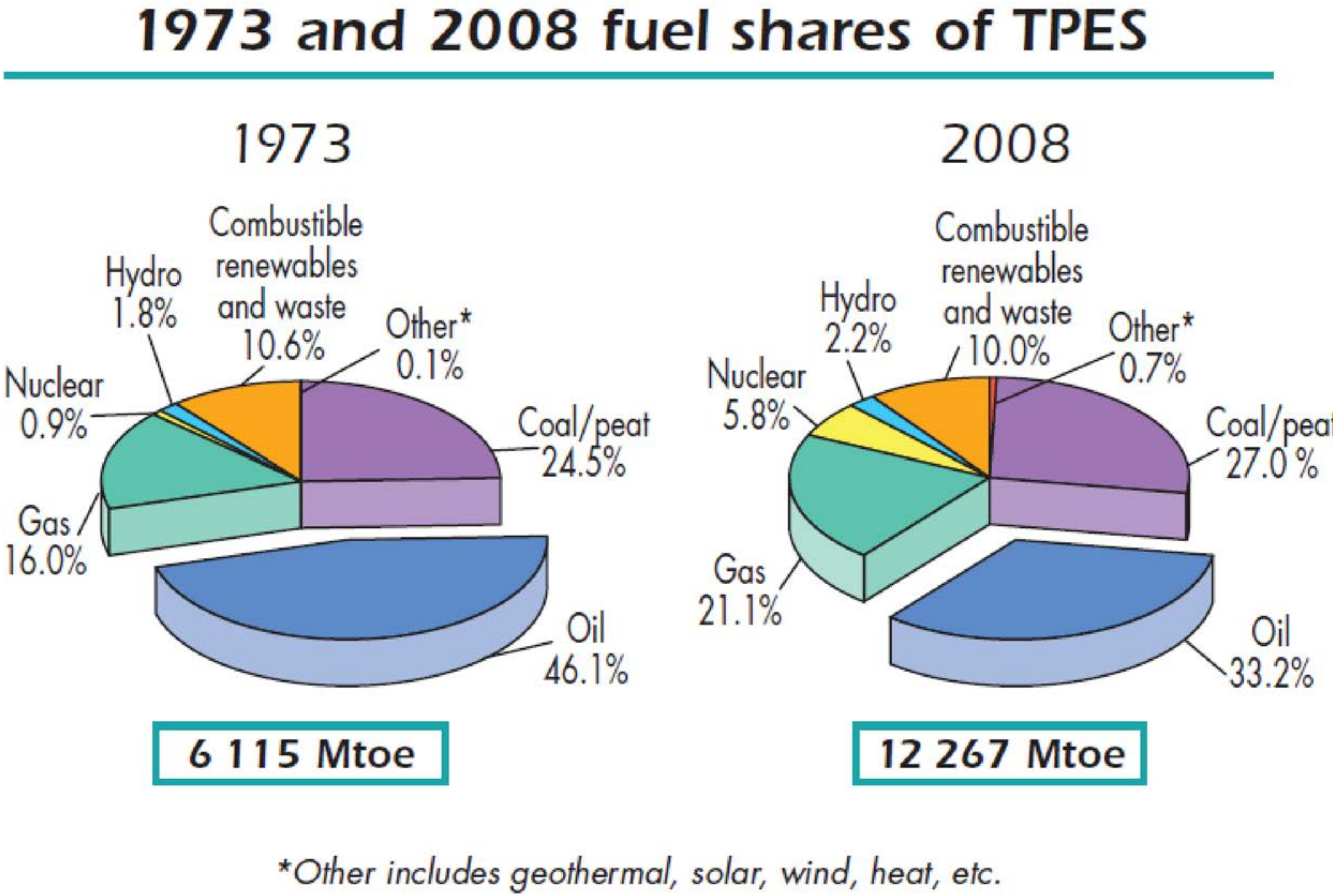
World

Evolution from 1971 to 2008 of world total primary energy supply by fuel (Mtoe)



http://www.iea.org/textbase/nppdf/free/2010/key_stats_2010.pdf

Shares of Total Primary Energy Supply (TPES)

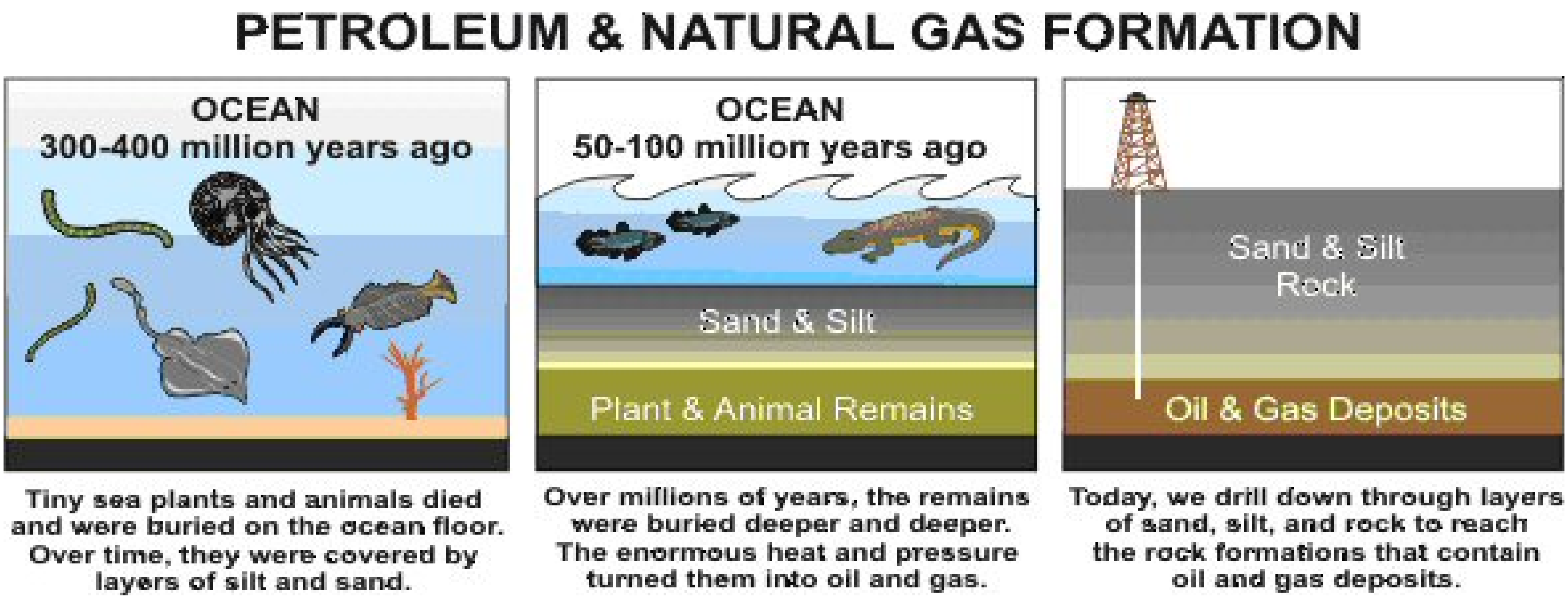


http://www.iea.org/textbase/nppdf/free/2010/key_stats_2010.pdf

World's Primary Energy Production

Source: IEA, Key World Energy Statistics 2008, p.37				
	%	EJ	quads	Mtoe
Total supply	100.0%	492	466	11,740
Oil	34.3%	169	160	4,029
Coal	26.0%	128	121	3,054
Natural Gas	20.5%	101	96	2,408
Biomass	10.1%	50	47	1,185
Nuclear	6.2%	30	29	728
Hydro	2.2%	11	10	261
Other	0.6%	3	3	75

- A **quad** is a unit of energy equal to 10^{15} BTU, or 1.055×10^{18} joules (1.055 exajoules or EJ) in SI units.
- The unit is used by the U.S. Department of Energy in discussing world and national energy budgets.



Crude oil average composition by mass

Element	Percent range
Carbon	83 to 87%
Hydrogen	10 to 14%
Nitrogen	0.1 to 2%
Oxygen	0.05 to 1.5%
Sulfur	0.05 to 6.0%
Metals	< 0.1%

Fraction	**Boiling Range ºC**
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

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.
- A 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.

Hydrocarbons in Petroleum

- **Alkanes (Paraffins)** = hydrocarbons with the general formula C_nH_{2n+2}. They are straight-chain or branched-chain hydrocarbons with all of the carbon-carbon bonds single bonds.
- **Cycloalkanes** (**naphthenes**) = alkanes that have one or more rings of carbon atoms.
- **Arenes (Aromatics)** = Hydrocarbons that contain a benzene ring.

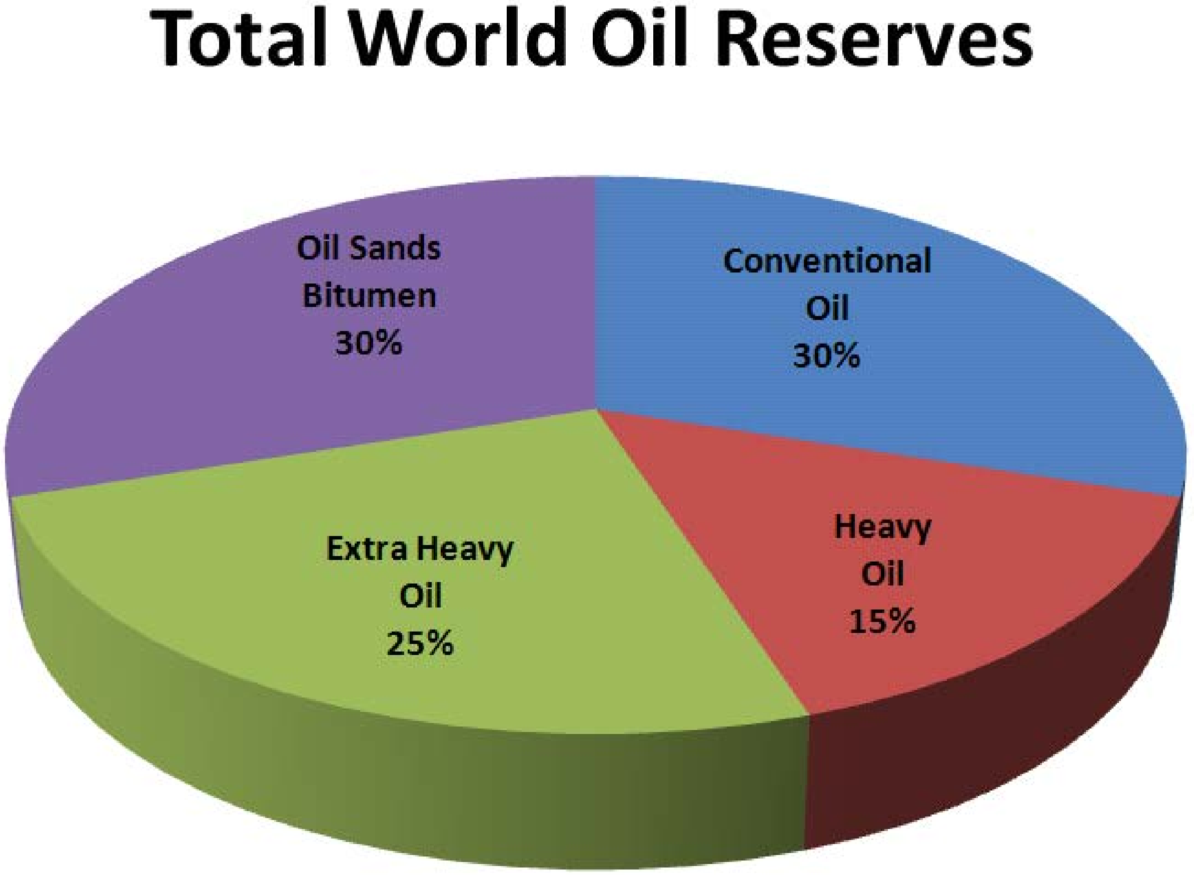
Composition by mass		
Hydrocarbon	**Average**	**Range**
Alkanes (Paraffins)	30%	15 to 60%
Cycloalkanes (Naphthenes)	49%	30 to 60%
Arenes (Aromatics)	15%	3 to 30%
Asphalt	6%	remainder

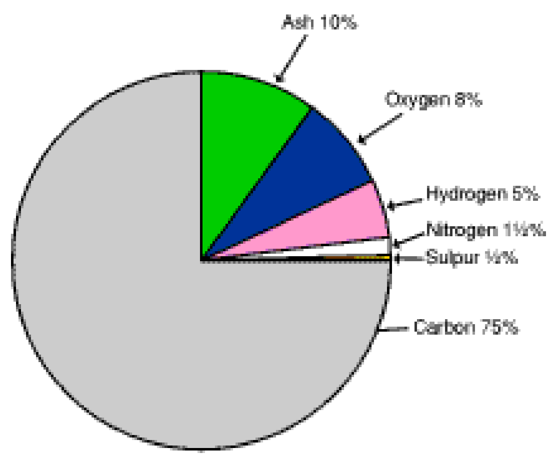
Classification of Oil

- **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.





Coal is composed of the following:-

N ITROGEN
O XYGEN
C ARBON
A SH
S ULPHUR
H YDROGEN

COAL RANK	CARBON CONTENT (%)	VOLATILE MATTER (%)	CALORIFIC VALUE (kJ/kG)	MOISTURE CONTENT%
PEAT	**60**	**>53**	**16800**	**>75**
BROWN COAL	**60 – 71**	**53 – 49**	**23000**	**35**
SUBBITUMINOUS COAL	**71 – 77**	**49 – 42**	**29300**	**25 - 10**
BITUMINOUS COAL	**77 – 87**	**42 – 29**	**36250**	**8**
ANTHRACITE	**77 – 87**	**29 -8**	**>36250**	**<8**
-	**On dry ash free basis**	**On dry ash free basis**	**Ash free basis**	**In-situ**

More complete listing of trace elements of fossil fuels in Spherical Cow, p.241

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.

Coal to Electricity

- The energy density of coal is roughly 24 megajoules per kilogram, and one kilowatt-hour is 3.6 MJ. Calculate the energy density of coal in KWh per kilogram.
- If a coal-fired power plant is 30% efficient in converting the energy released from burning coal into electrical energy, how many pounds of coal does it take to power a 100 W light bulb for one year?

Coal to Electricity

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$$\frac{?\ \text{kWh}}{\text{kg coal}} = \left(\frac{24\ \cancel{\text{MJ}}}{1\ \text{kg coal}}\right)\left(\frac{1\ \text{kWh}}{3.6\ \cancel{\text{MJ}}}\right) \approx \mathbf{6.7\ kWh/kg\ coal}$$

$$\frac{?\ \text{kg coal}}{1\ \text{yr}} = 100\ \cancel{\text{W}}\left(\frac{1\ \cancel{\text{kW}}}{10^3\ \cancel{\text{W}}}\right)\left(\frac{1\ \text{kg coal}}{6.7\ \cancel{\text{kWh total}}}\right)\left(\frac{100\ \cancel{\text{kWh total}}}{30\ \cancel{\text{kW}}\text{h elec.}}\right)\left(\frac{24\ \cancel{\text{h}}}{1\ \cancel{\text{day}}}\right)\left(\frac{365\ \cancel{\text{day}}}{1\ \text{yr}}\right)$$

$$\approx \mathbf{4.4 \times 10^2\ kg\ coal/yr}$$

Renewable vs. Non-Renewable Energy

- **Renewable** energy sources are continually replenished. It makes sense to think of them as **flows.**

- **Non-renewable** energy sources have a low or zero replenishment rate. It makes sense to think of them as **stocks.**

How long will non-renewable energy stocks last?

Estimate of total recoverable fossil energy stocks:

- Recoverable conventional oil and gas ≈ 1000 TWy
- Recoverable coal ≈ 5000 TWy
- Possibly recoverable oil shale, clathrates ≈ 50,000 TWy

1 TWy = 31.5 EJ (exajoule)

To calculate years remaining at present rate of use:

$$T = \frac{\text{quantity of resource}}{\text{rate of consumption}} = \frac{\text{Stock}}{\text{Flow}}$$

How long will non-renewable energy stocks last?

Years remaining at present rate of use:

- Oil + gas: current use rate ≈ 10 TW → T ≈ 100 years

$$T = \frac{\text{Stock}}{\text{Flow}} = \frac{1000\ \text{TWy}}{10\ \text{TW}} \approx \mathbf{100\ years}$$

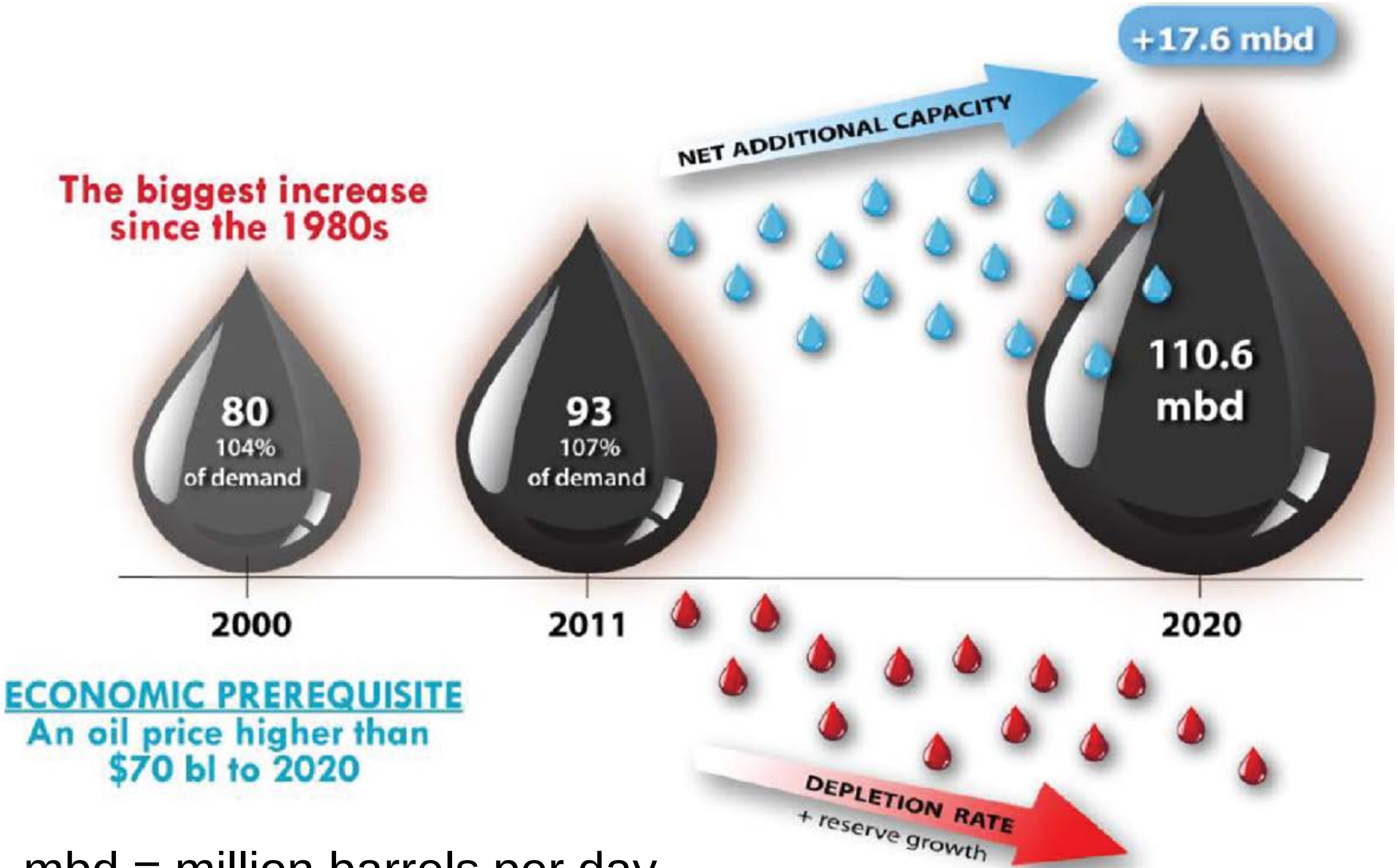
- Coal: current use rate ≈ 5 TW → T ≈ 1000 years

$$T = \frac{\text{Stock}}{\text{Flow}} = \frac{5000\ \text{TWy}}{5\ \text{TW}} \approx \mathbf{1000\ years}$$

Why estimating depletion time is an exercise in uncertainty.

- **Usage rates change**
  - population
  - economic conditions
  - consumption habits/patterns
  - efficiency of resource use (e.g. power generation technology) changes
- **Reserve estimates change**
  - new reserves discovered
  - increases in resource price makes low-quality reserves profitable
  - extraction technology improves
  - existing reserves become inaccessible

World oil production capacity to 2020 (Crude oil and NGLs, excluding biofuels)



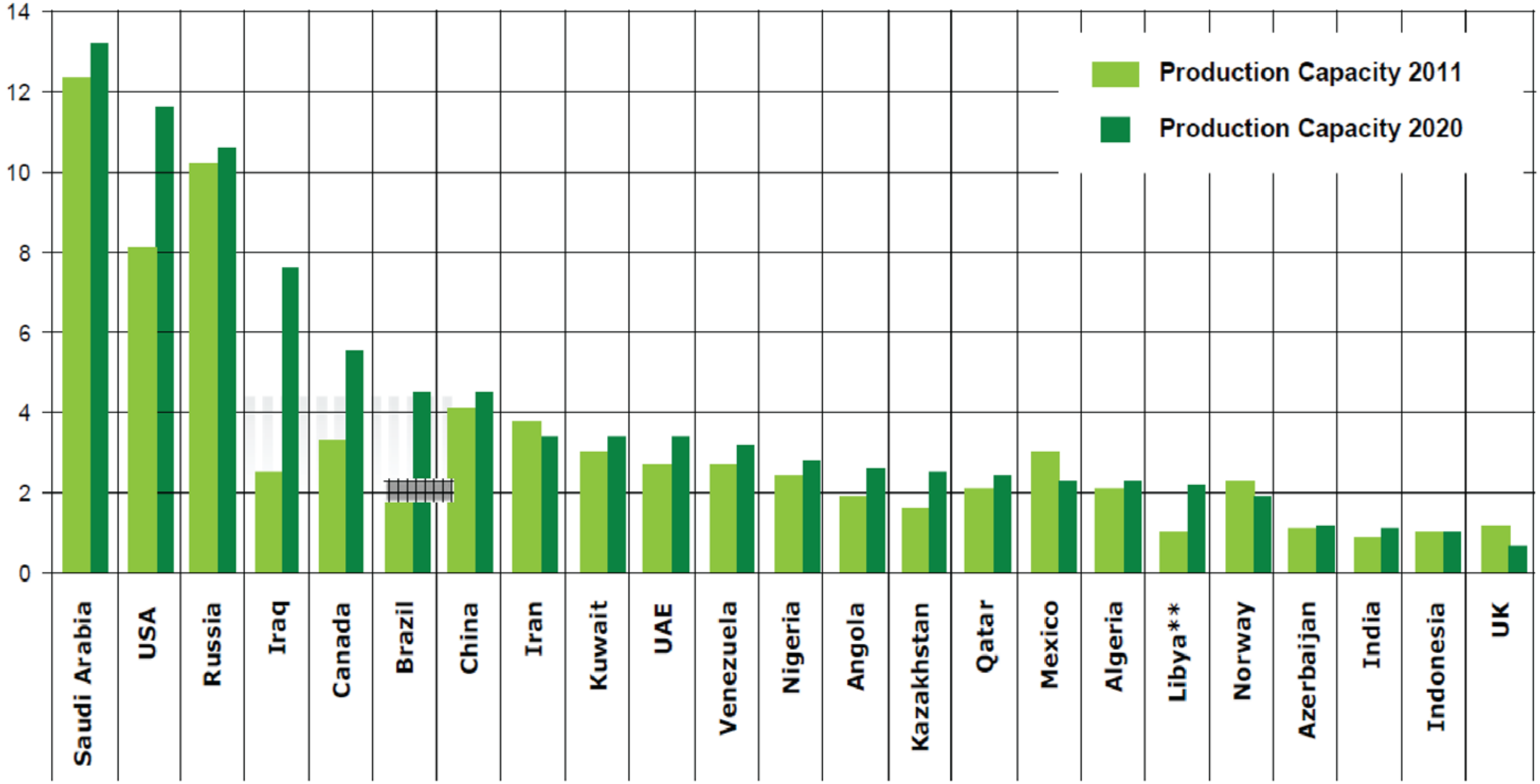
mbd = million barrels per day

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

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)**.

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

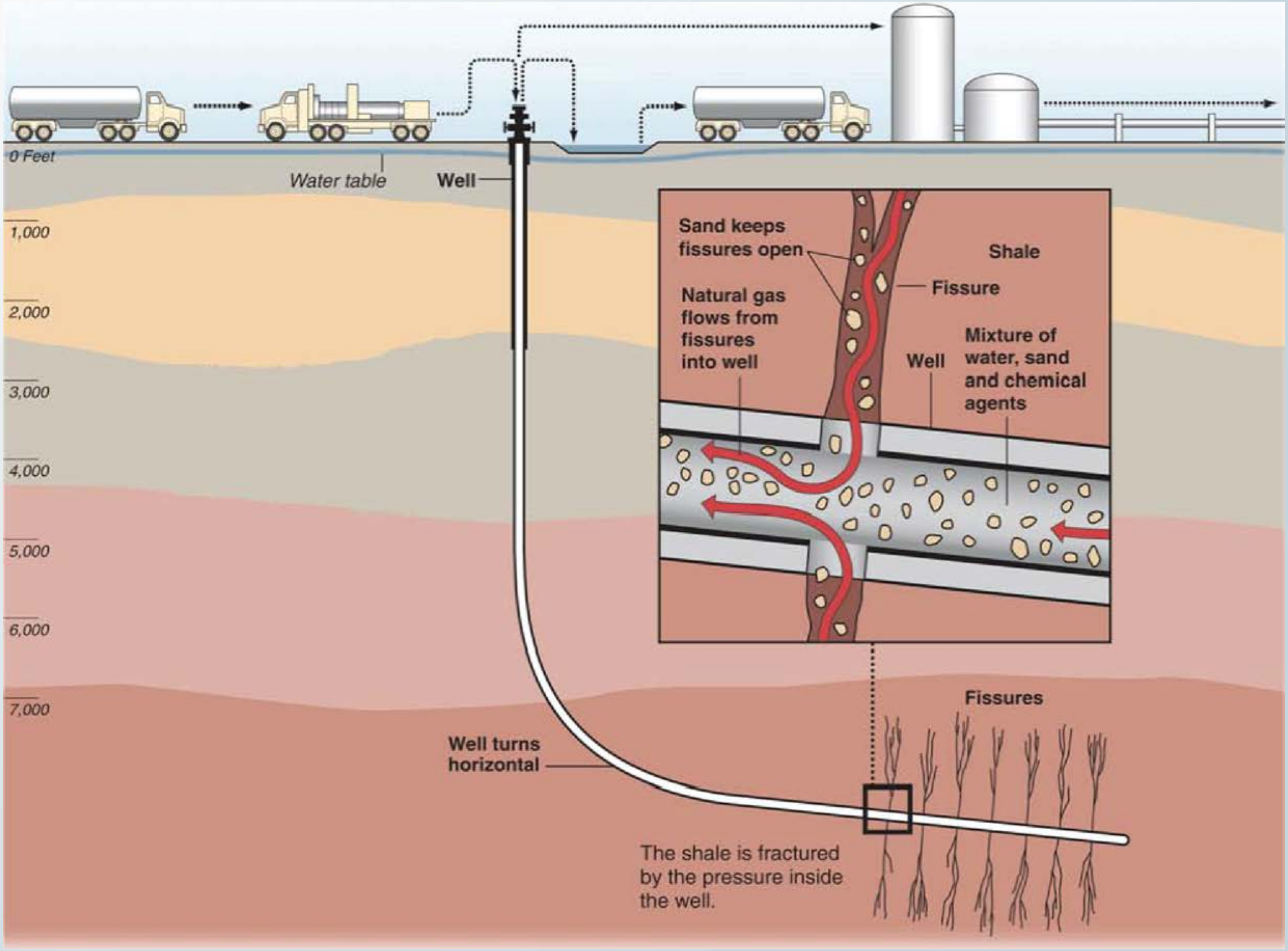
World oil production capacity to 2020

Column 1 – Country
Column 2 - Production Capacity 2011-end (mbd)
Column 3 - Production Capacity 2020   (mbd)

Saudi Arabia	12.3	13.2
United States	8.1	11.6
Russia	10.2	10.6
Iraq	2.5	7.6
Canada	3.3	5.5
Brazil	2	4.5
China	4.1	4.5
Iran	3.8	3.4
Kuwait	3	3.4
UAE	2.7	3.4
Venezuela	2.7	3.2
Nigeria	2.4	2.8
Angola	1.9	2.6
Kazakhstan	1.6	2.5
Qatar	2.1	2.4
Mexico	3	2.3
Algeria	2.1	2.3

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

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 50 years, and less than 10 times the potential 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.

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)

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 water
  - Changes in extent and condition of snow and ice
- Changes in heat added at the surface by human activities and geothermal sources

Climate Change

- Earth's average temperature has risen by about 0.8 °C (1.4 °F) over the past century, with about 2/3 of this since 1980.
- Projected to rise another 1 to 6 °C (2 to 11.5 °F) over the next hundred years.
- 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.

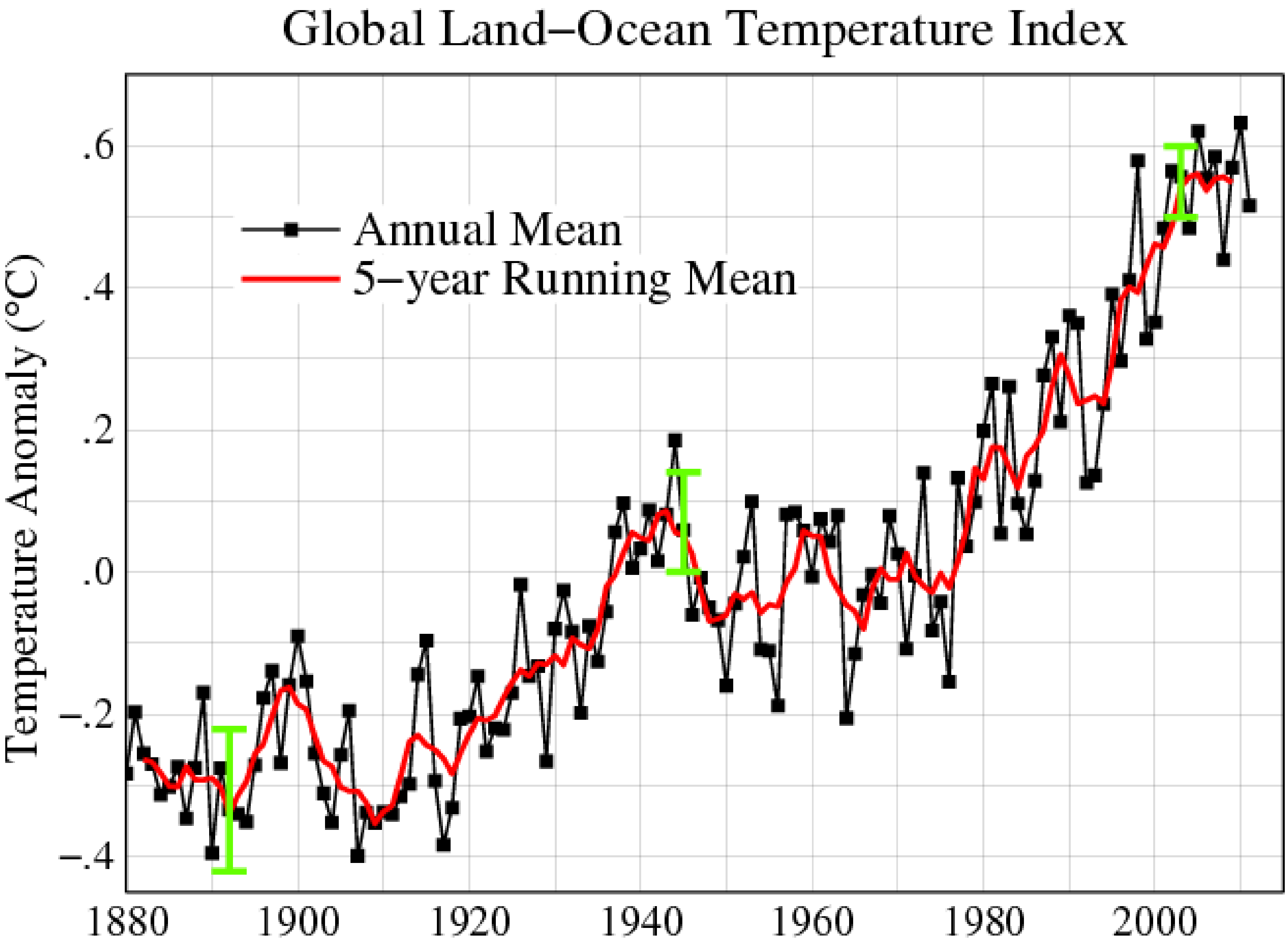
http://www.epa.gov/climatechange/basics/
http://www.explainingclimatechange.ca/

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** = 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.

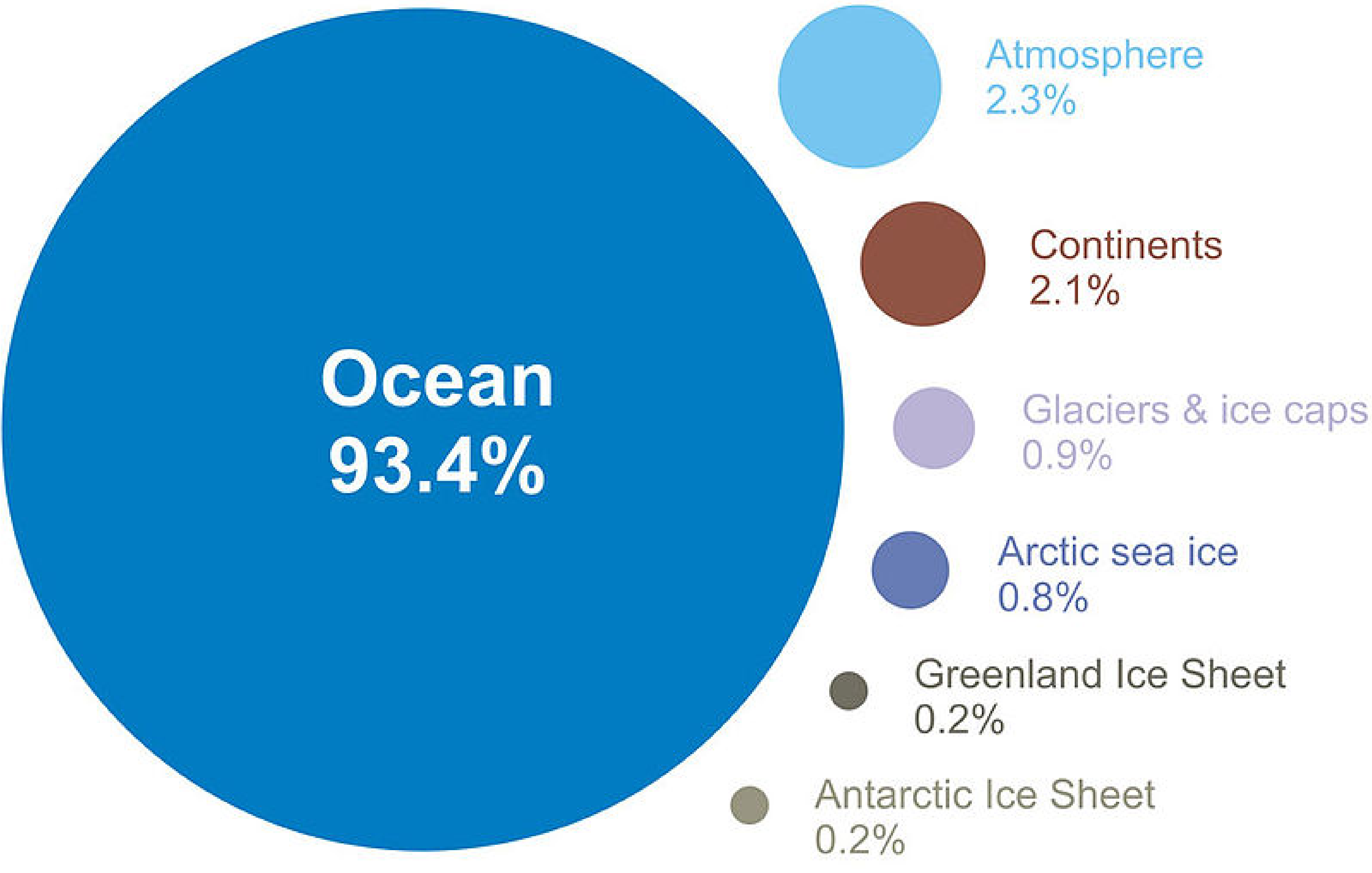
http://www.epa.gov/climatechange/science/

Temperature Variation from 1880-present

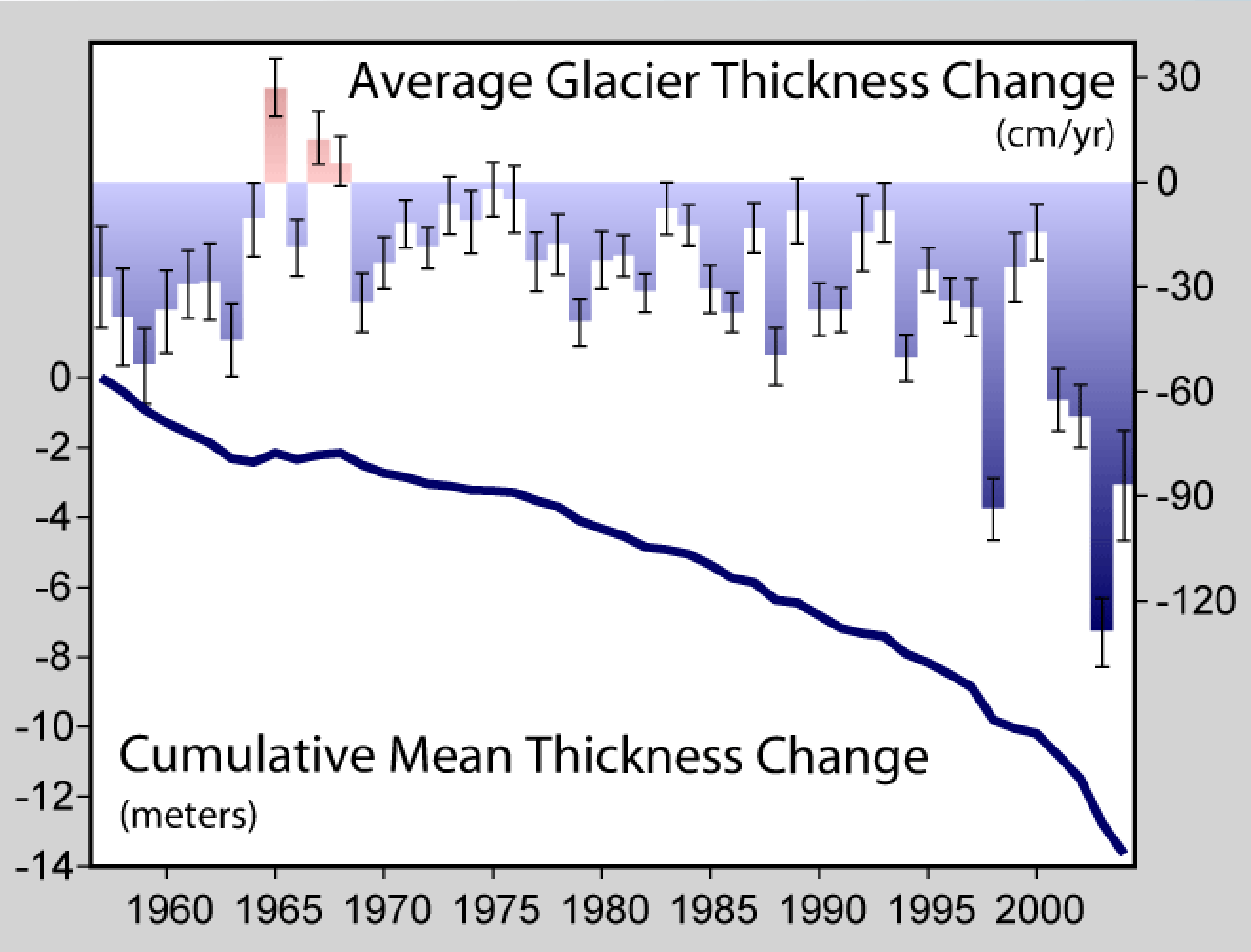


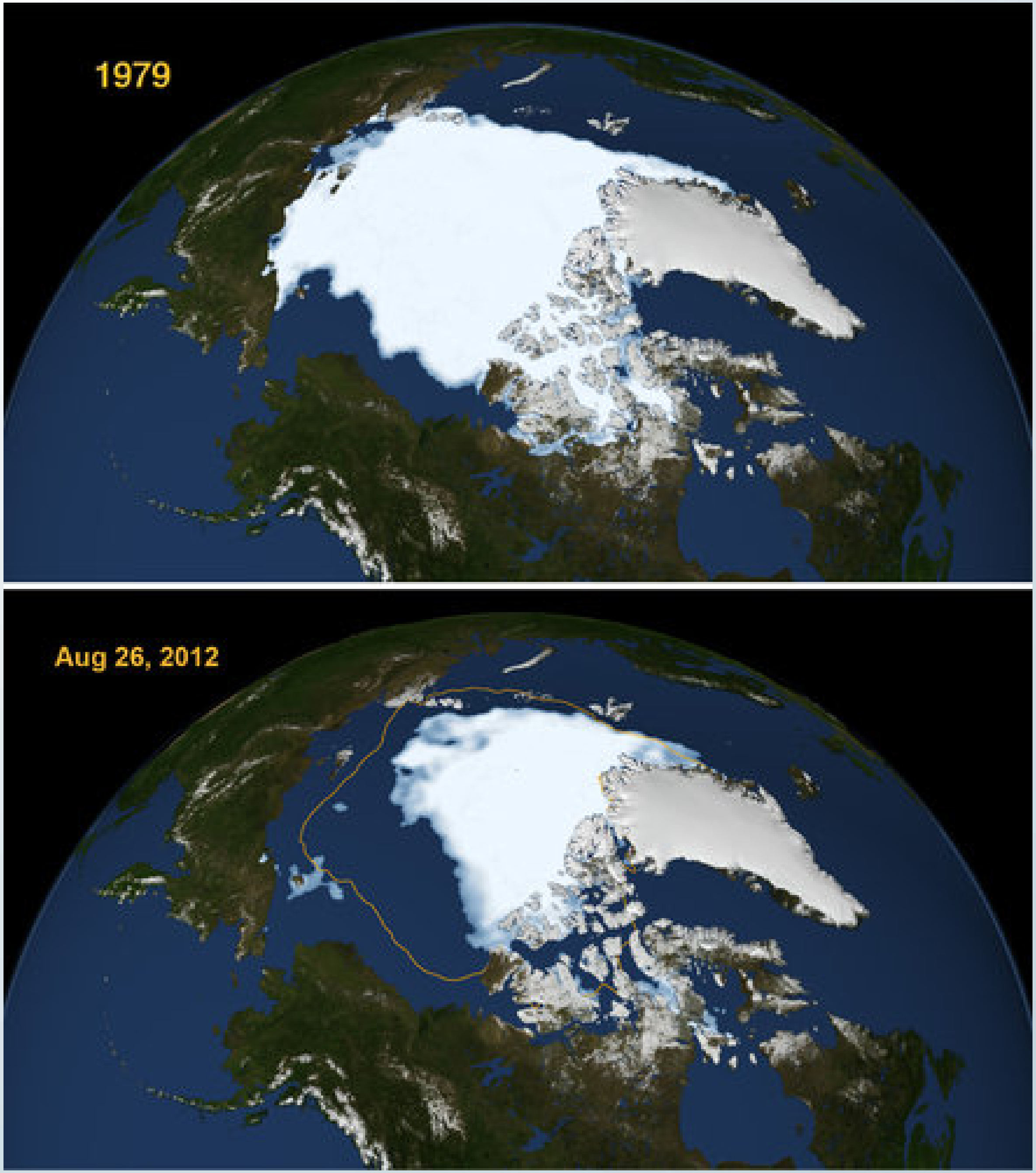
http://www.explainingclimatechange.ca/Climate%20Change/swf/videos/historical%20_temp.swf

Where is global warming going?



Effect on Glaciers



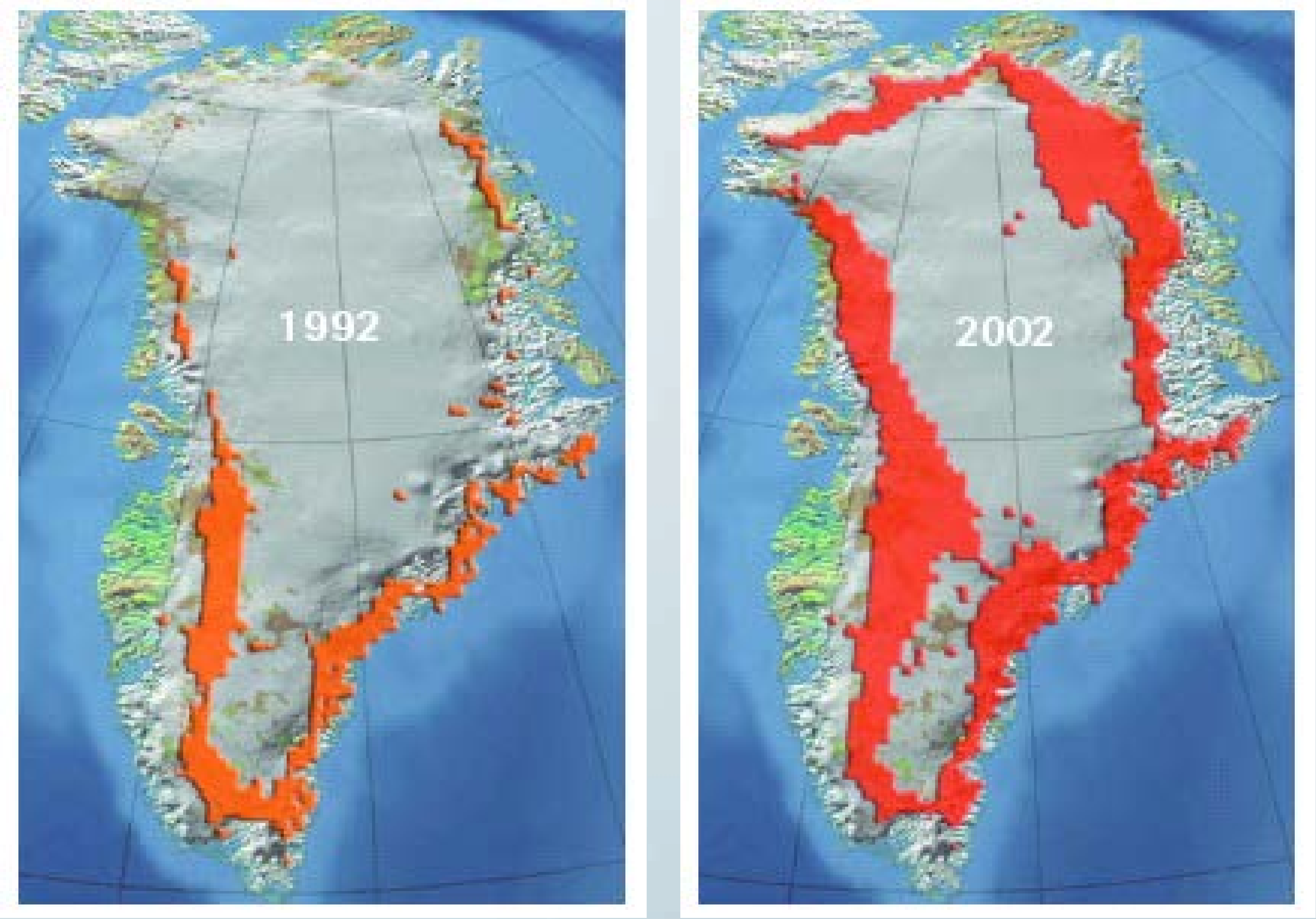


NASA photograph

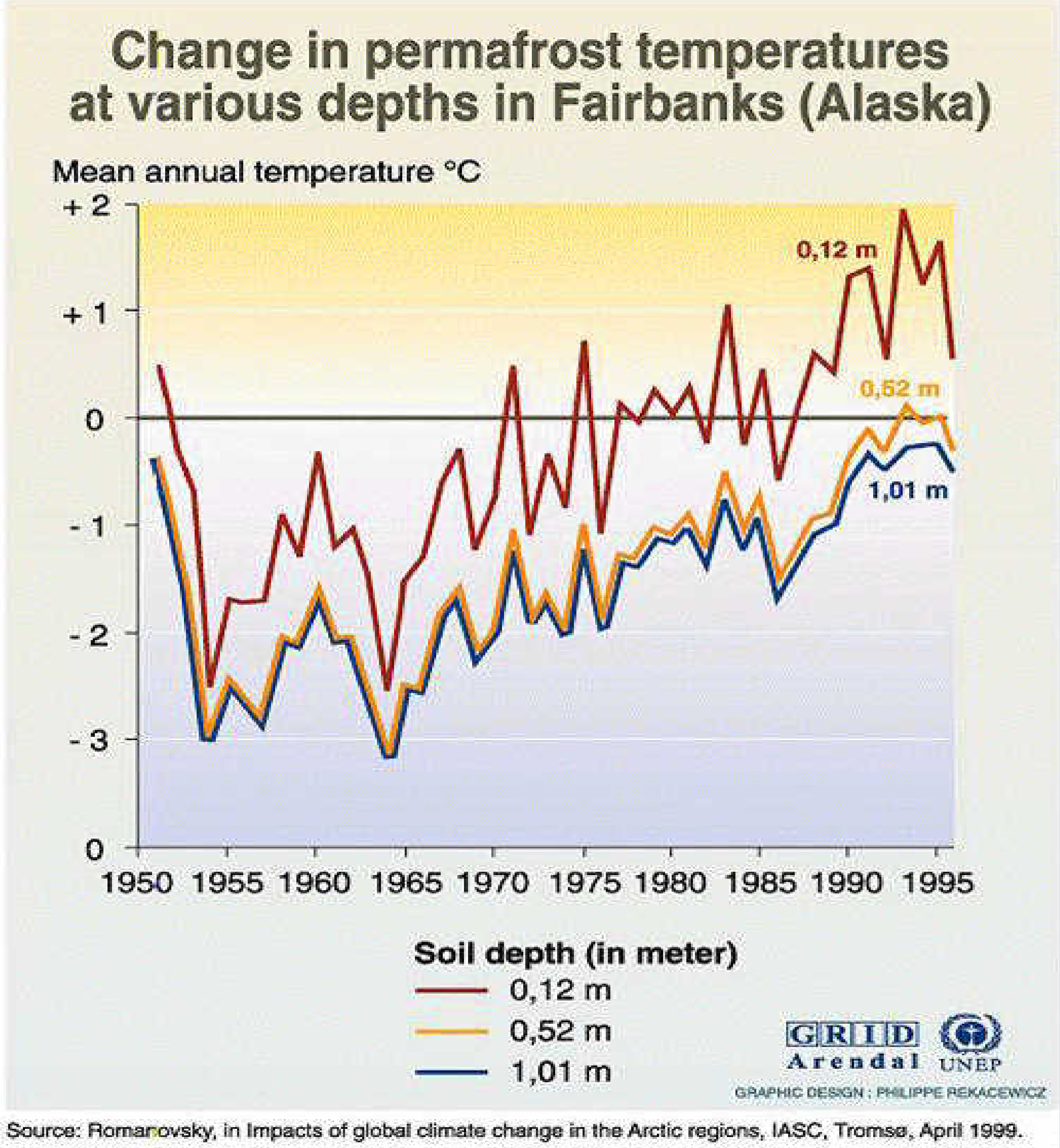
Shrinking Polar Ice

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

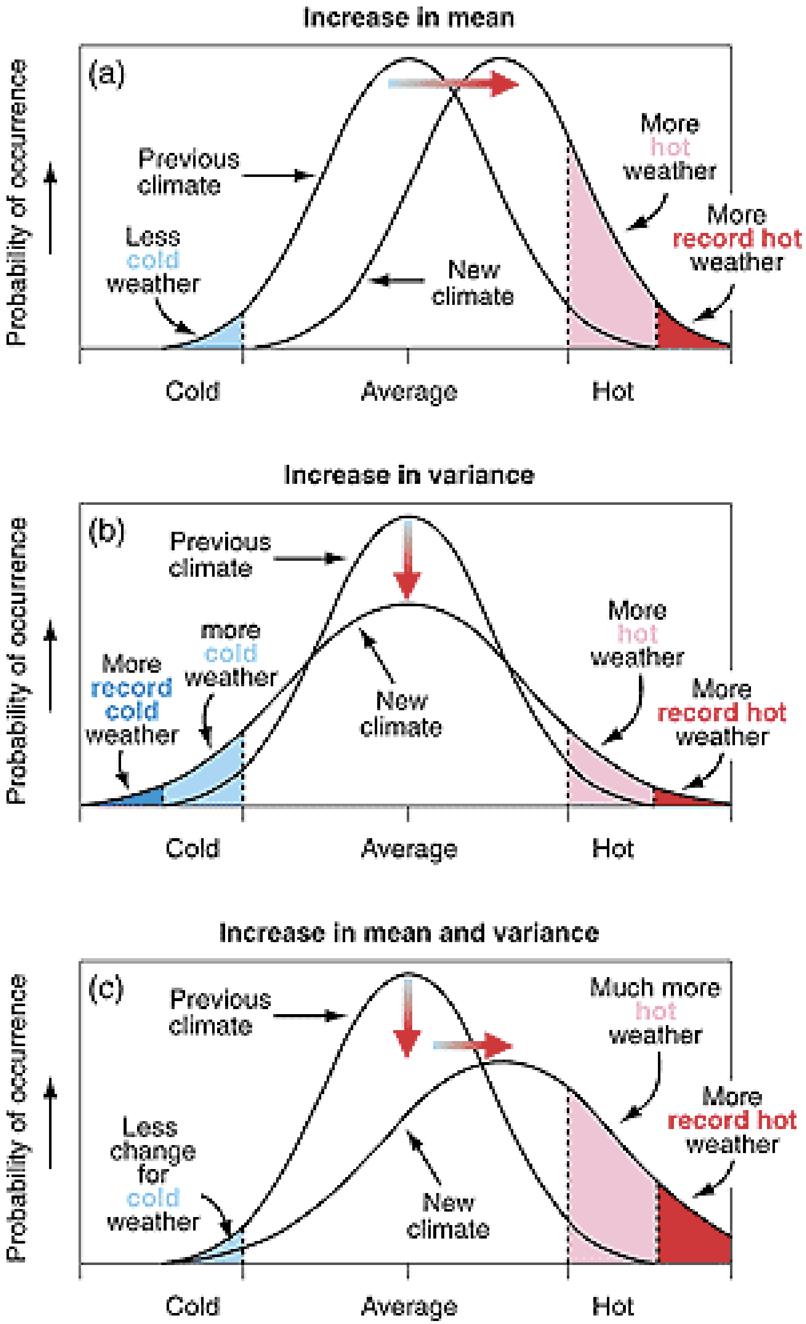


When permafrost temperature rises above the freezing point, and the permafrost melts, power lines, pipelines, and buildings built over the permafrost can topple, sag, and crack.

Why care about climate?

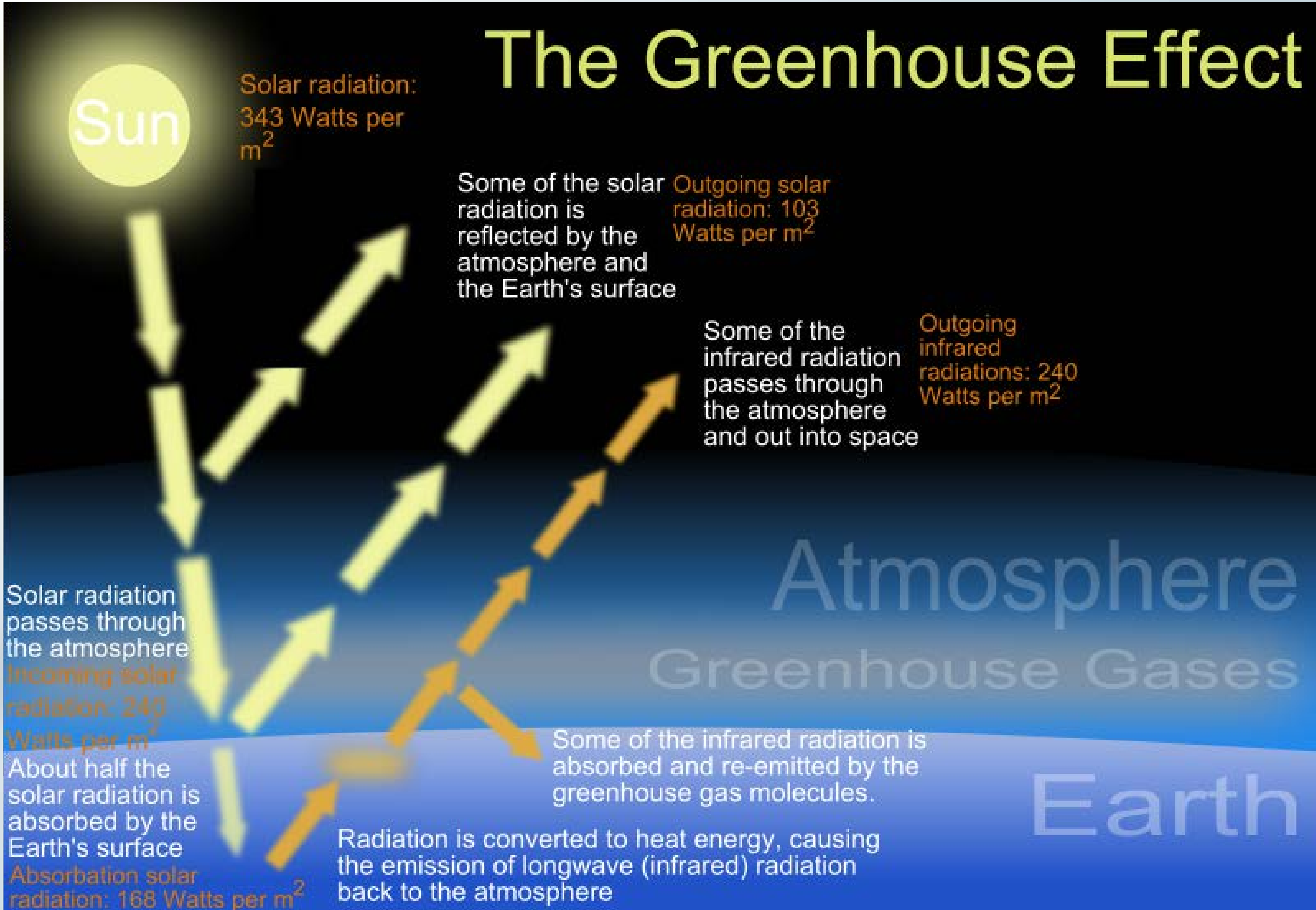
Climate governs:

- 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



"Climate change" means a change in the means and extremes (variances about the mean) that define the climate, either globally or in a particular climate zone.

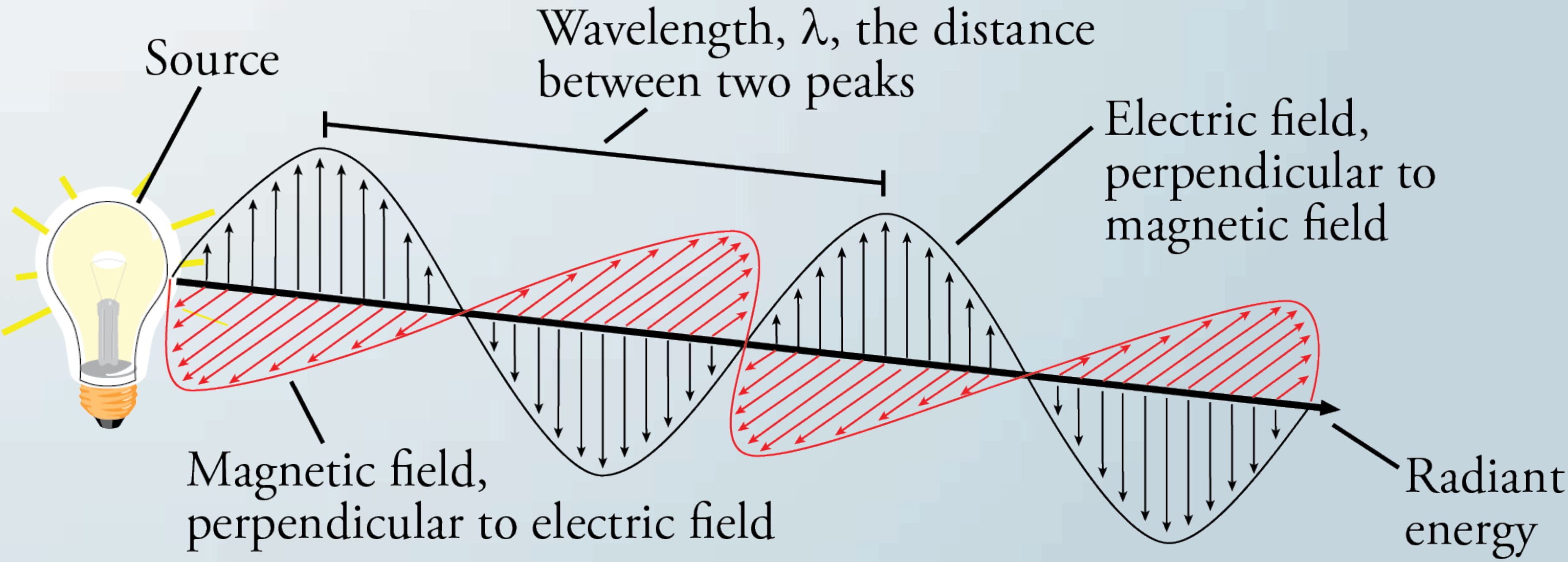
A key example is a change in average surface temperature. Another is occurrence of more extreme events - heat waves, droughts, hurricanes, etc.


The Greenhouse Effect
Sun
Solar radiation: 343 Watts per m^2
Some of the solar radiation is reflected by the atmosphere and the Earth's surface
Outgoing solar radiation: 103 Watts per m^2
Some of the infrared radiation passes through the atmosphere and out into space
Outgoing infrared radiations: 240 Watts per m^2
Atmosphere
Greenhouse Gases
Solar radiation passes through the atmosphere
Incoming solar radiation: 240 Watts per m^2
About half the solar radiation is absorbed by the Earth's surface
Absorbation solar radiation: 168 Watts per m^2
Some of the infrared radiation is absorbed and re-emitted by the greenhouse gas molecules.
Earth
Radiation is converted to heat energy, causing the emission of longwave (infrared) radiation back to the atmosphere

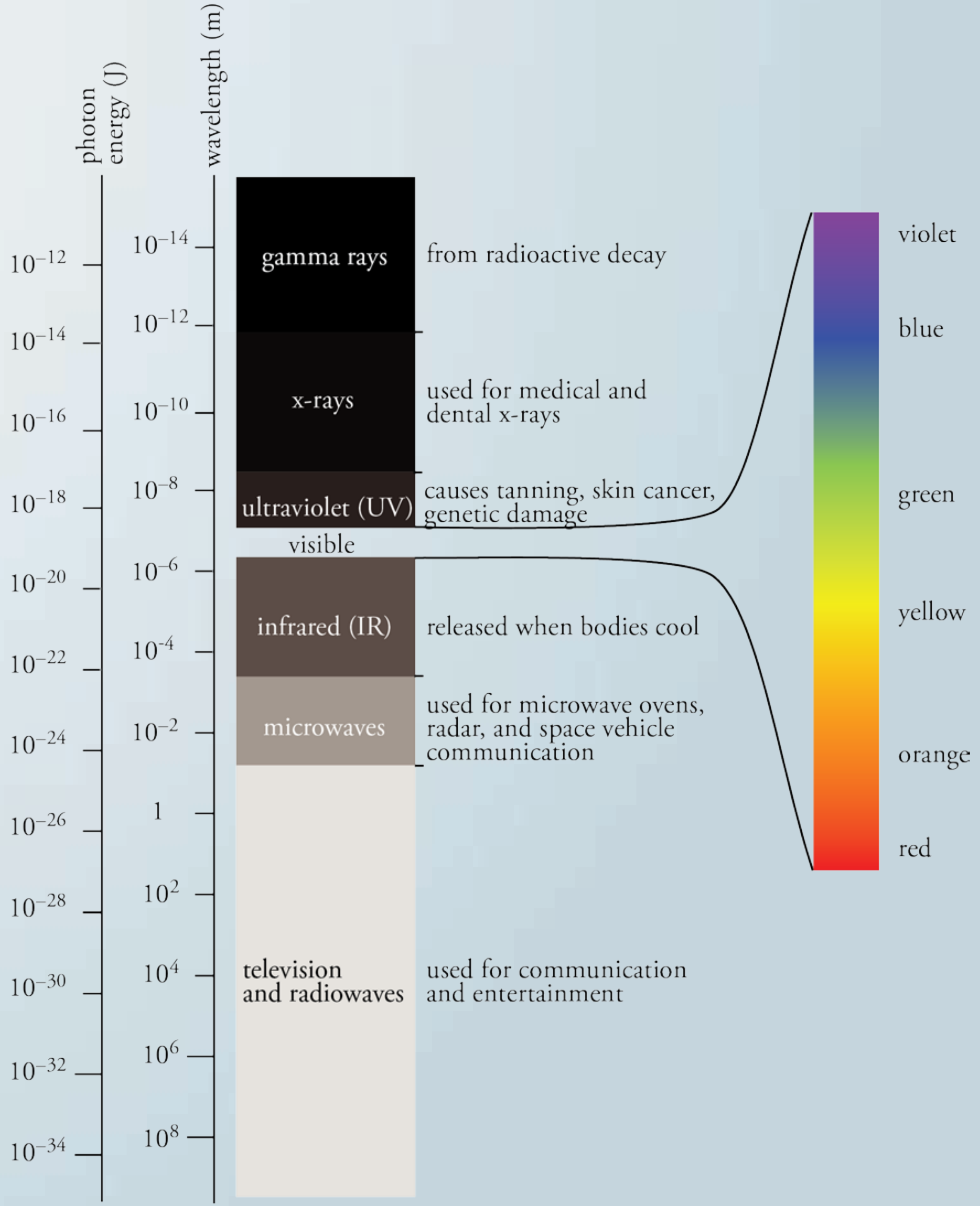
Radiant Energy

- **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



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 °C (59 °F) colder than at present.
- *Important greenhouse gases:*
  - **Water vapor (H_2O)**
  - **Carbon dioxide (CO_2)**
  - **Methane (CH_4)**
  - **Nitrous oxide (N_2O)**
  - Chlorofluorcarbons (CFCs)
  - Halogenated fluorocarbons (HCFCs)
  - Ozone (O_3)
  - Hydrofluorocarbons (HFCs).

Individual Emissions

http://www.epa.gov/climatechange/ghgemissions/individual.html

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

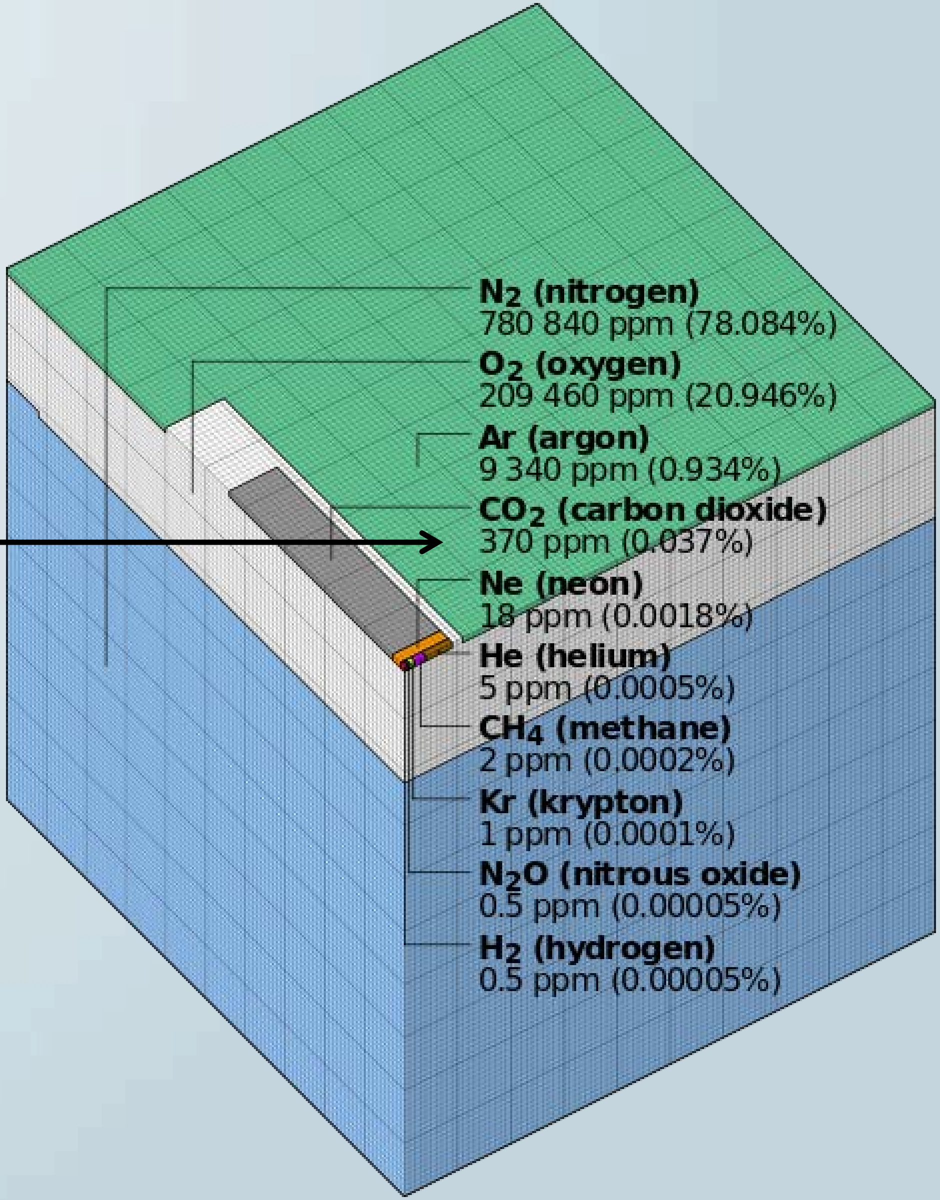
http://www2.ess.ucla.edu/~schauble/MoleculeHTML/CHClF2_html/CHClF2_page.html

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

Composition of Air

Average composition of dry atmosphere (mole fractions)

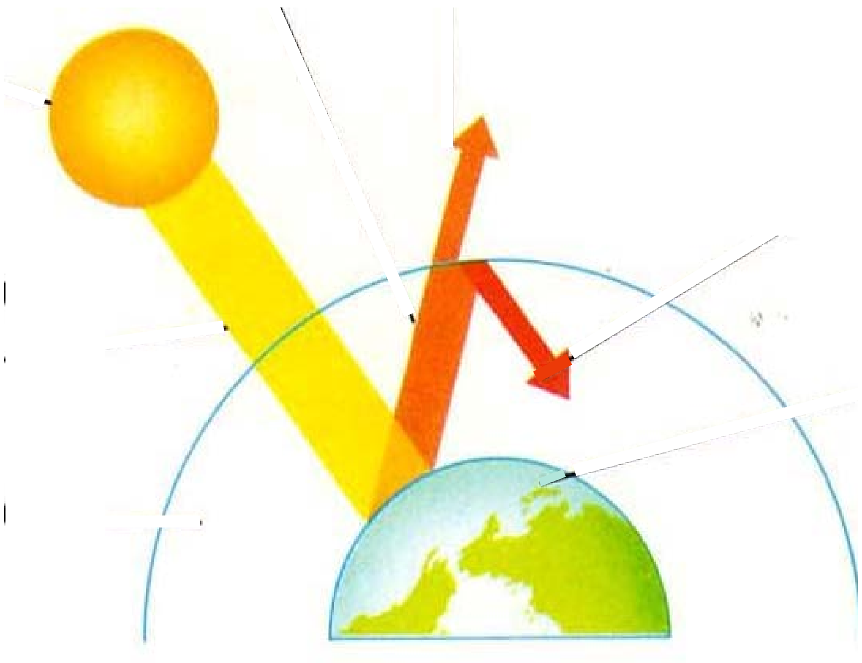
Gas	from NASA
Nitrogen, N_2	78.084%
Oxygen, O_2	20.946%
Argon, Ar	0.934%
Minor constituents (mole fractions in ppm)	
Carbon dioxide, CO_2	About 390 and rising
Neon, Ne	18.18
Helium, He	5.24
Methane, CH_4	1.7
Krypton, Kr	1.14
Hydrogen, H_2	0.55
Water vapor	Highly variable; typically makes up about 1%



Radiative Forcing

- **Radiative forcing** = anything that changes the radiation balance at earth's surface
- Measured in W/m^2
- A change in radiative forcing leads to a change in surface temperature
- Both natural and anthropogenic
  - adding greenhouse gases
  - adding aerosols
  - changing albedo (land use, black carbon)
  - change in solar radiation

Natural and Anthropogenic Greenhouse Effect



NATURALLY MODERATED GREENHOUSE EFFECT

ANTHROPOGENIC GREENHOUSE EFFECT - ADDING GHG’ S, INCREASING RADIATIVE FORCING

The Climate Change Story Line

Human Activities →

GHG Emissions and Land Use Changes →

Change in Atmospheric Concentrations →

Change in Radiative Forcing →

Change in Average Surface Temperature →

Direct & Indirect Feedbacks →

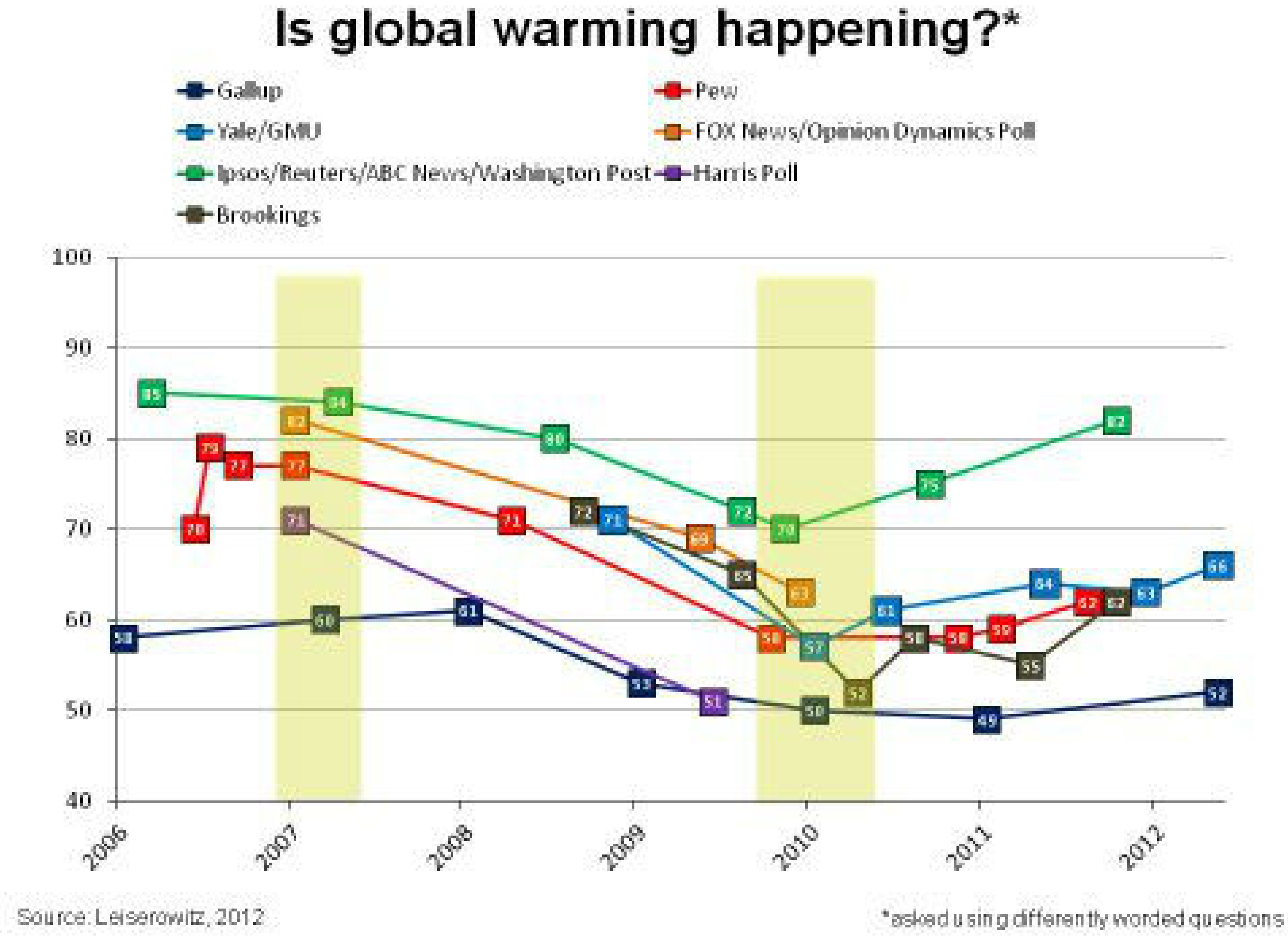
Direct & Indirect Biogeophysical Impacts →

Societal Impacts →

Policy Response?

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

Public Opinion of Climate Change



GHG Atmospheric Lifetimes and Global Warming Potential

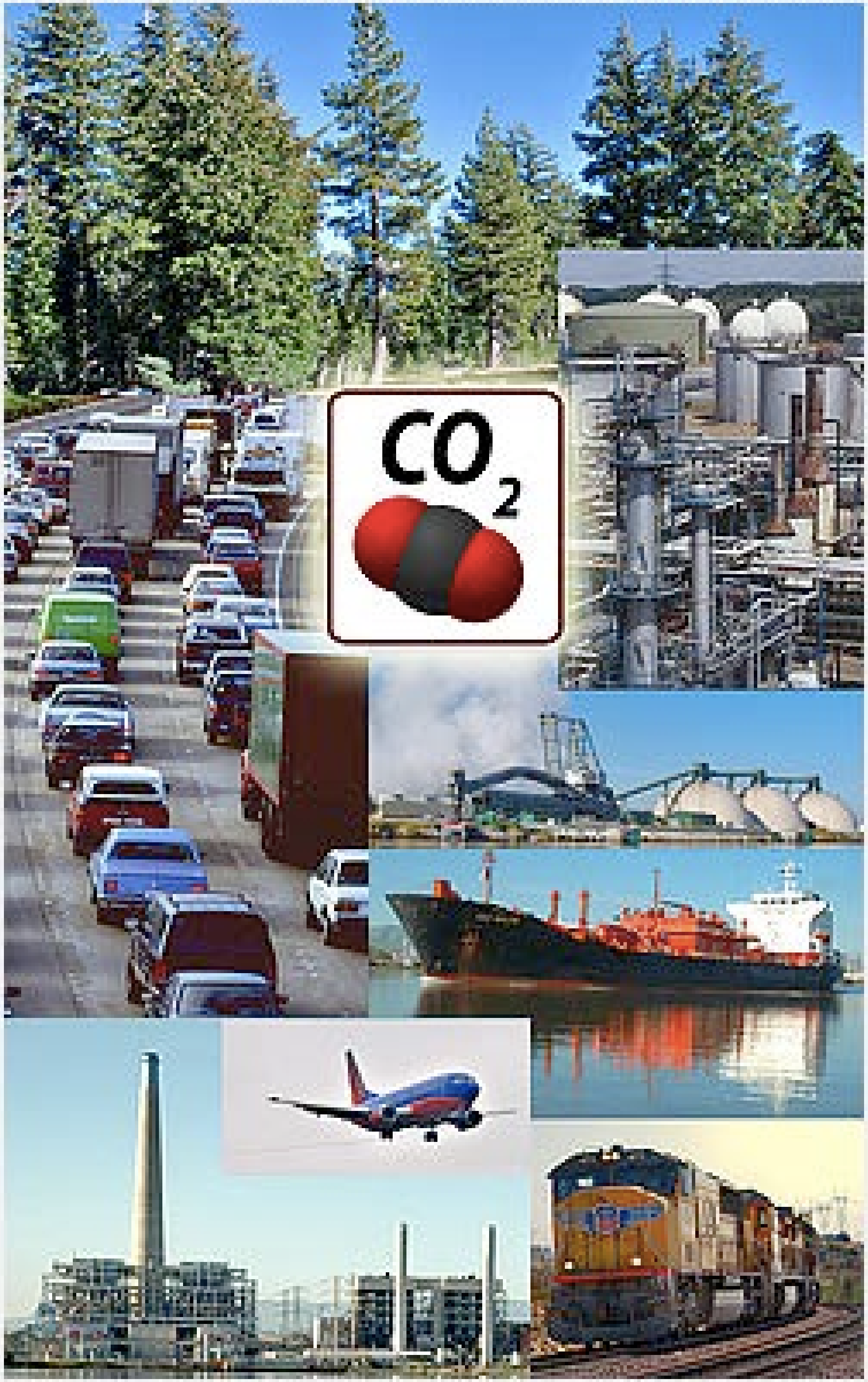
- Each GHG has its own atmospheric residence time, governed by the sinks that remove it from the atmosphere.
- The global warming potential (GWP) of each GHG is measured relative to CO_2. GWP combines the GHG's efficiency at trapping IR radiation with its residence time in the atmosphere.
- Example: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

Global Warming Potential (GWP) =

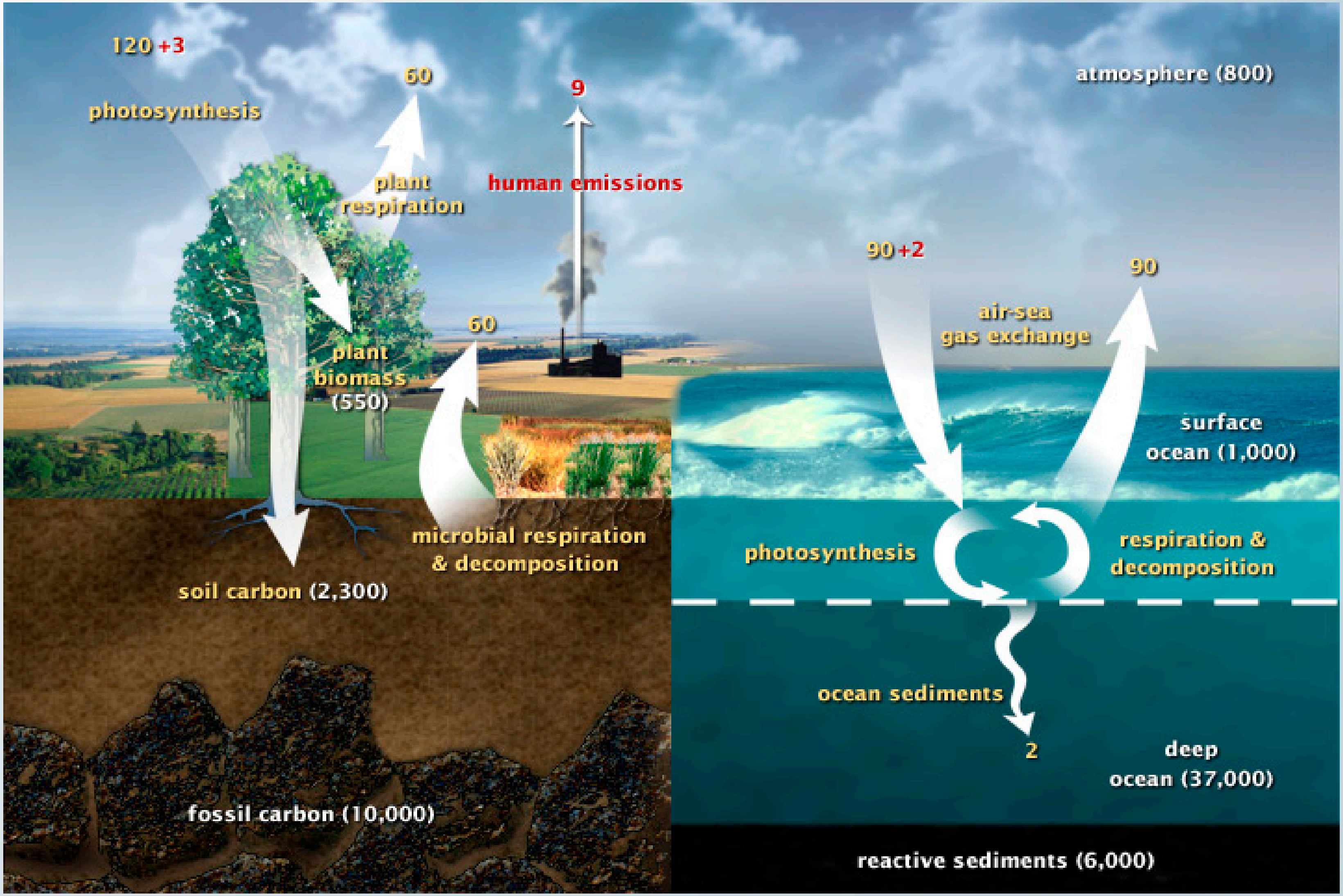
radiative impact of a GHG per molecule relative to impact of CO_2, taking into account its radiative properties and atmospheric lifetime

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

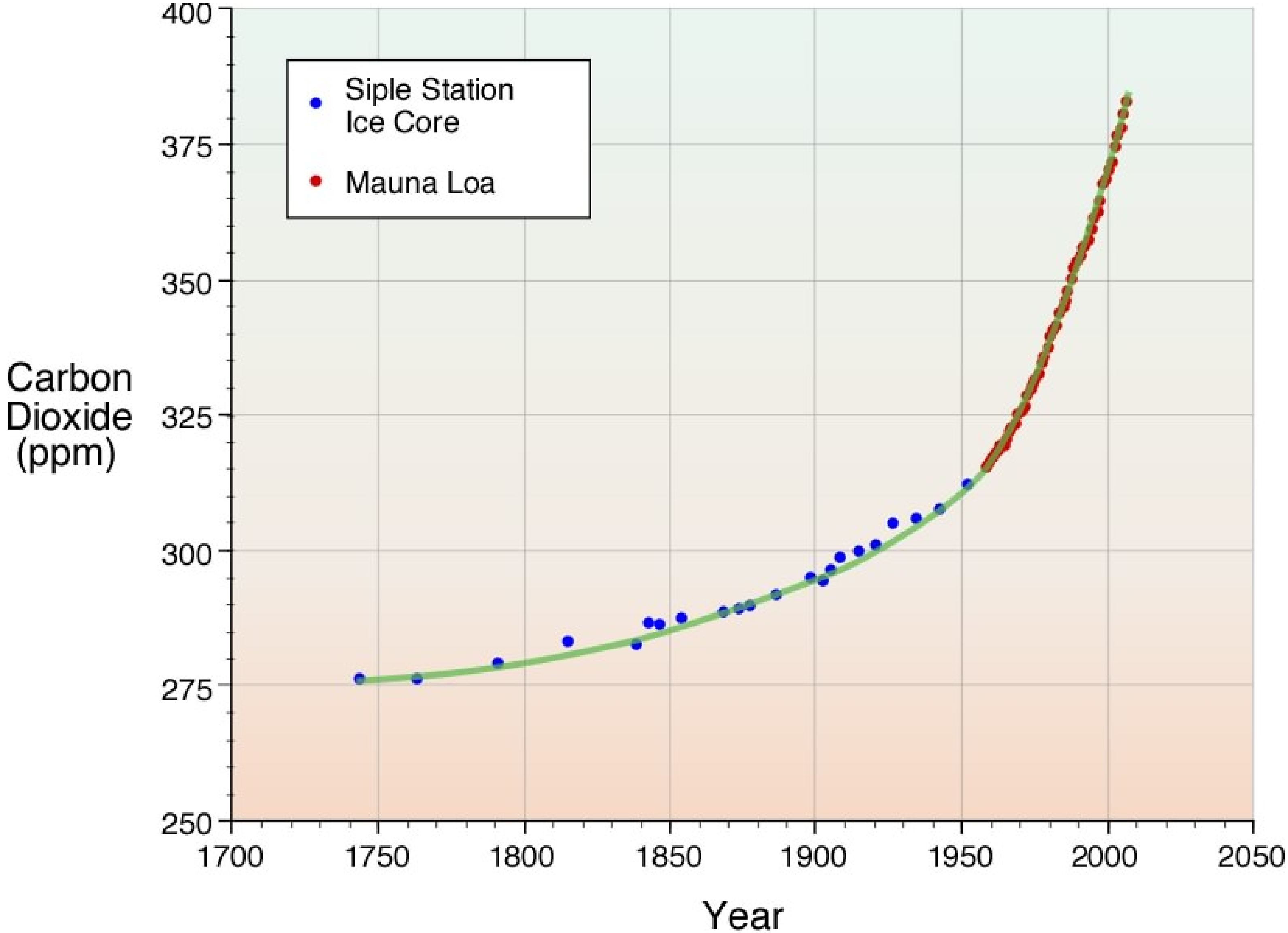

CO2

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.

CO_2 Concentrations



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

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.

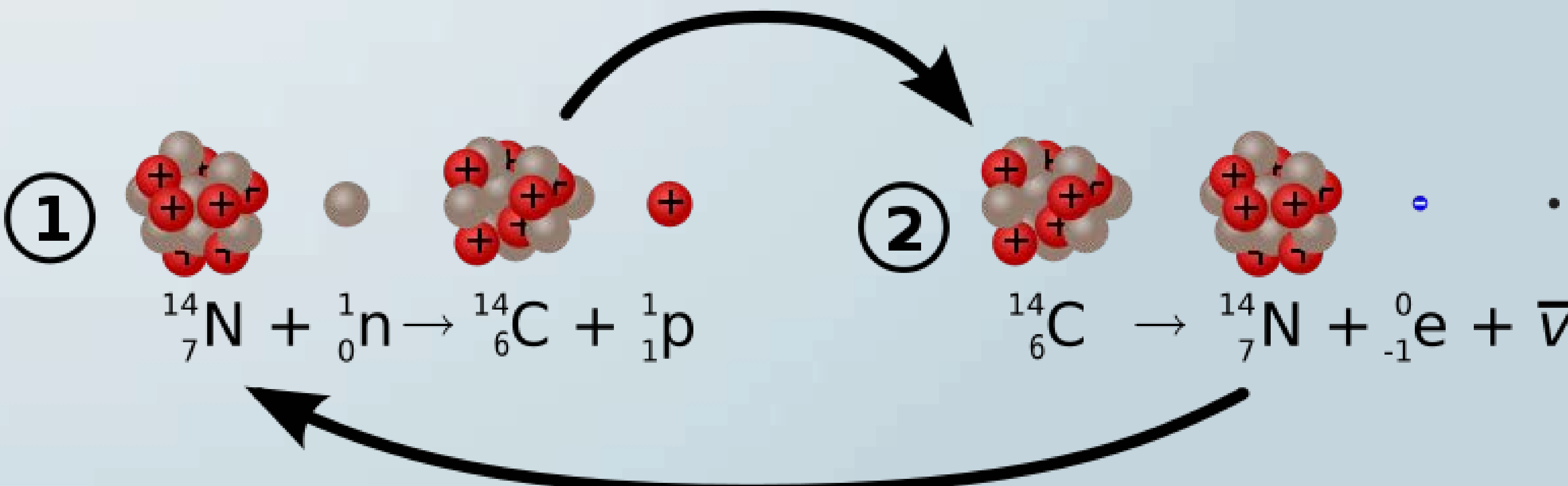
http://www.eoearth.org/article/Greenhouse_gas

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 390 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 90 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.

Carbon-14

- Carbon-14 is produced in the atmosphere when neutrons are absorbed by nitrogen atoms.
- Carbon-14 then undergoes beta decay, emitting an electron and an antineutrino and forming nitrogen-14.
- Carbon-14 has a half-life of 5730 years.



Measuring CO_2 from fossil fuels by Measuring $^{14}CO_2/^{12}CO_2$ Ratio

- About one in a trillion CO_2 molecules naturally contain ^{14}C, but the carbon locked up in fossil fuels, such as coal and oil has none.
- Because the half-life of ^{14}C is 5730 years, the carbon-14 in fossil fuels decayed to ^{14}N millions of years ago

$$^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e$$

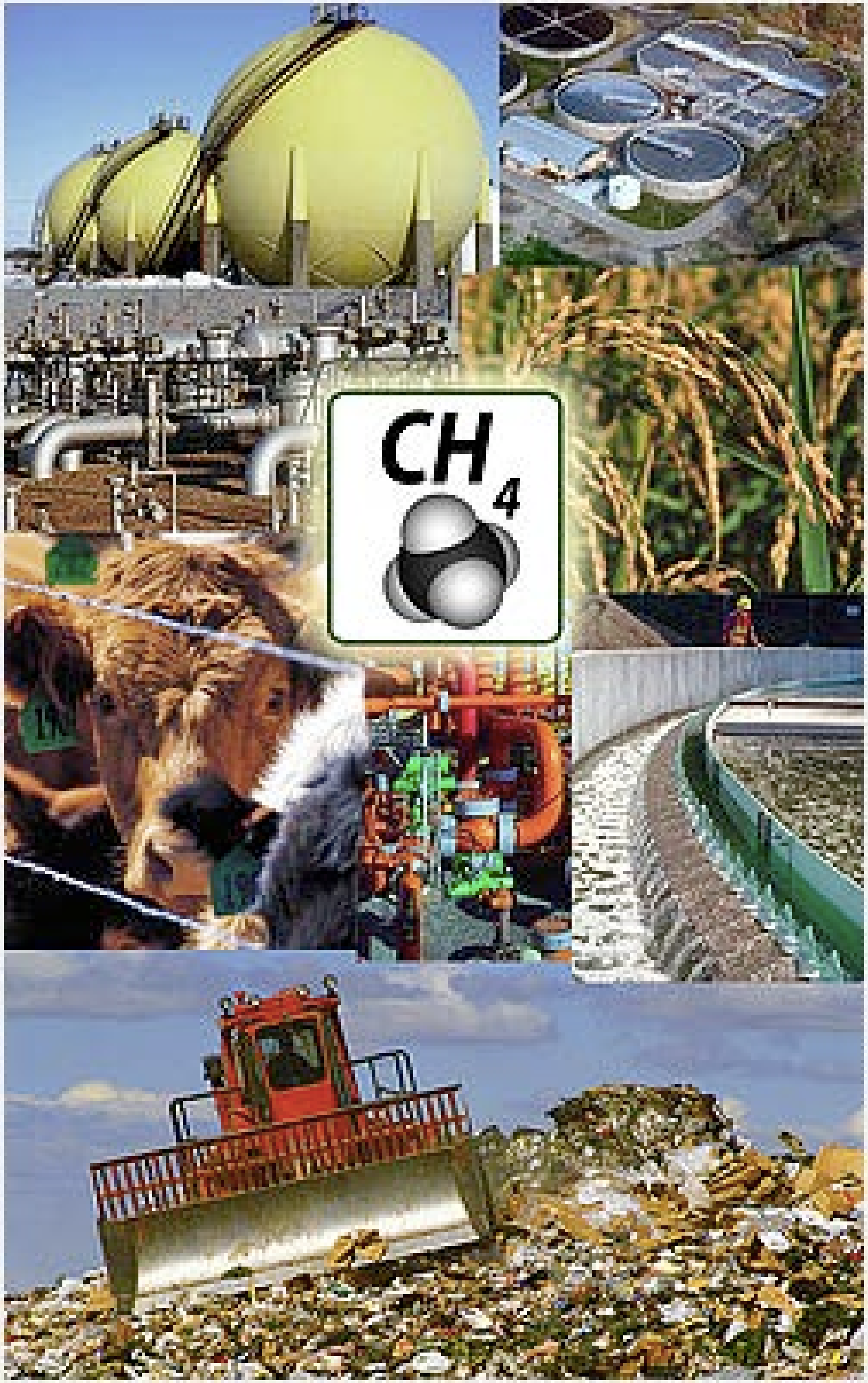
- Therefore, as the amount of CO_2 in the atmosphere from fossil fuels rises, the ratio of $^{14}CO_2/^{12}CO_2$ decreases in a measurable way.

Measuring CO_2 from fossil fuels by Measuring $^{14}CO_2/^{12}CO_2$ Ratio

- Monitoring stations in the Swiss Alps and in Antarctica found that the $^{14}CO_2/^{12}CO_2$ is now about 0.5% lower in the Northern Hemisphere than in the Southern Hemisphere.
- Reversal since preindustrial days…tree ring records show that the Southern Hemisphere had less $^{14}CO_2$ because upwelling of deep waters in the southern oceans brought radiocarbon-depleted CO_2 to the surface.

Measuring CO_2 from fossil fuels by Measuring $^{14}CO_2/^{12}CO_2$ Ratio

- Uncertainties in estimates of fossil-fuel emissions from $^{14}CO_2$ are still large, because accurate modeling depends on knowing all possible sources of both radioactive and nonradioactive CO_2.
- One confounding factor is emissions from nuclear power plants, which generate a significant amount of ^{14}C in regions where nuclear plants are concentrated, offsetting at least 20% of the reduction in $^{14}CO_2$ due to fossil fuels.


CH_4

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:

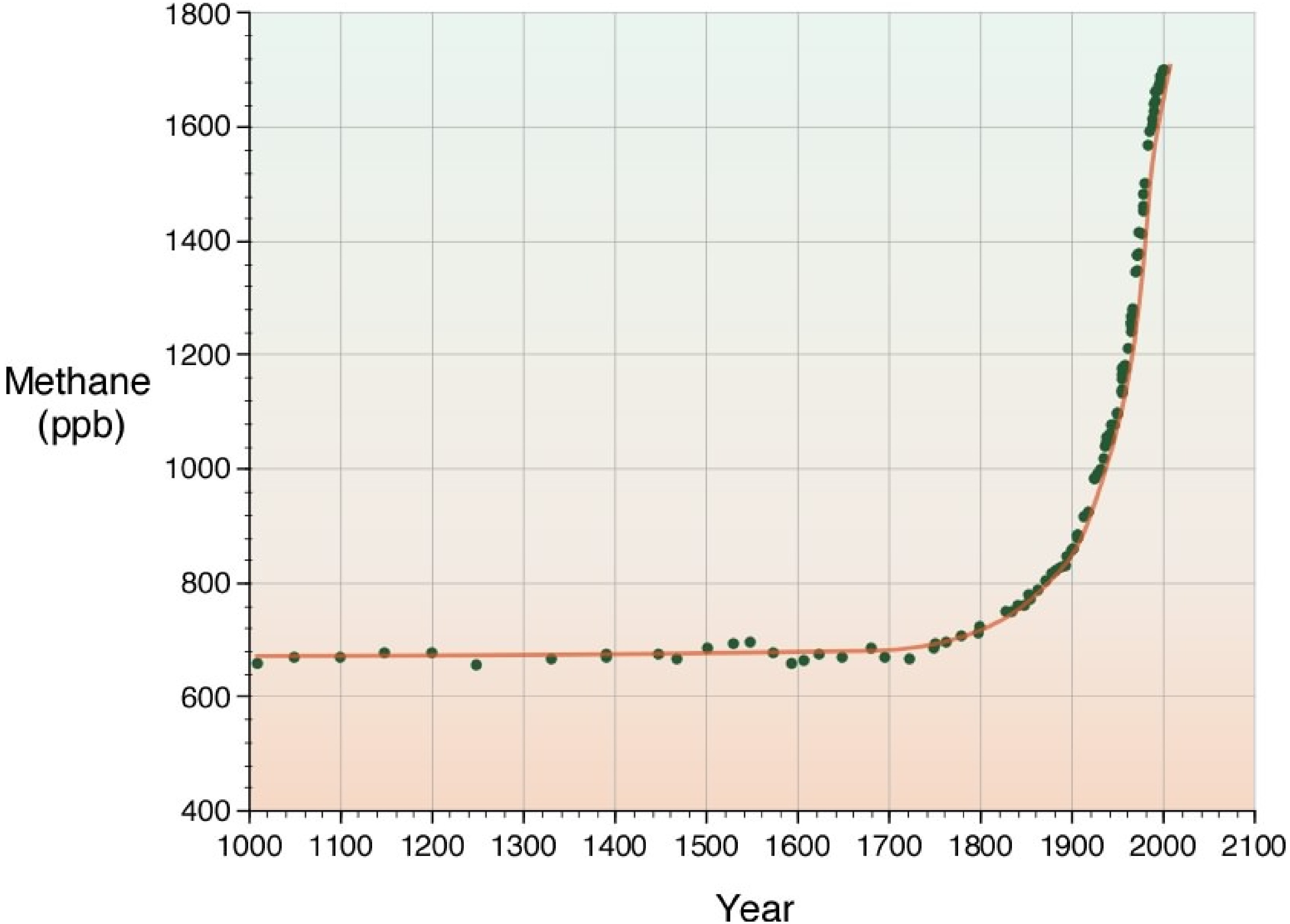
$$CO_2 + 8\ H^+ + 8\ e^- \rightarrow CH_4 + 2\ H_2O$$

- 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

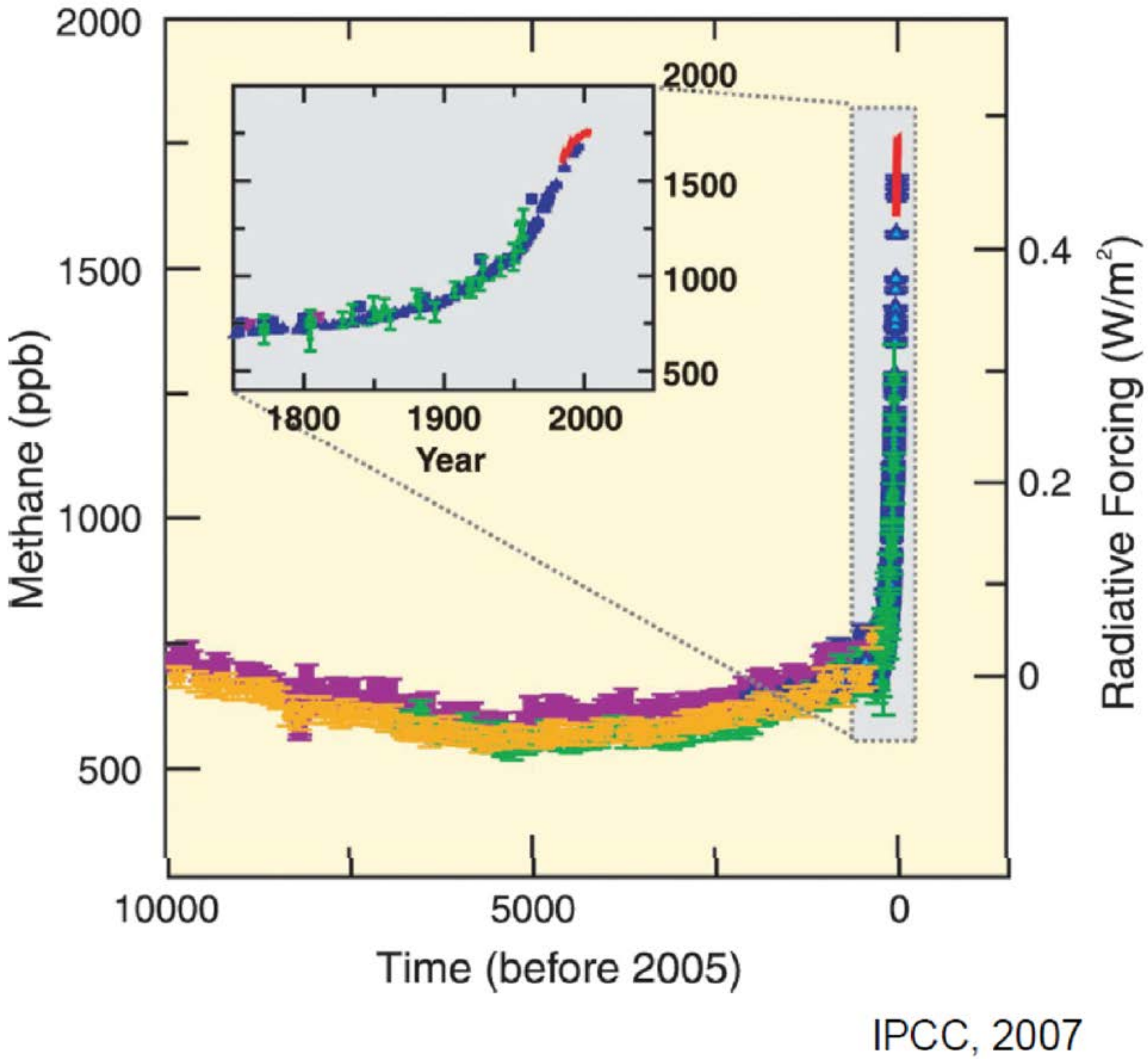
- Biogenic sources (>70% of total)
  - Wetlands
  - Rice agriculture
  - Livestock
  - Landfills
  - Biomass burning
  - Forests
  - Oceans
  - Termites
- Non-biogenic sources
  - Emissions from fossil fuel mining and burning
  - Natural gas, petroleum and coal
  - Waste treatment
  - Geological sources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

Methane Concentrations 1000-2000 AD



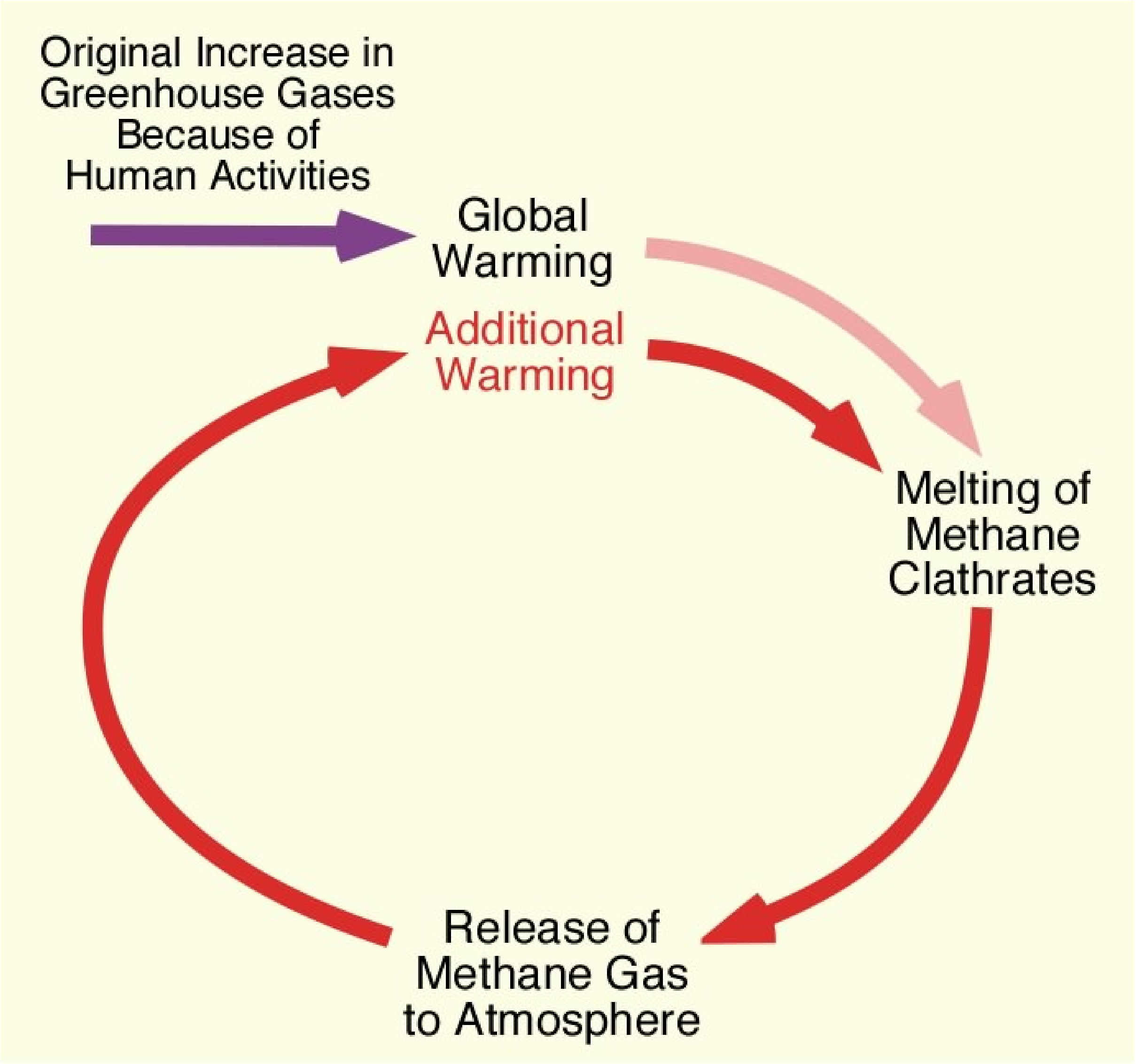
http://www.eoearth.org/article/Greenhouse_gas

Methane Concentrations and Radiative Forcing



IPCC = Intergovernmental Panel on Climate Change http://www.ipcc.ch/

Feedback Example



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

Estimated Global Methane Balance (Tg CH_4/yr)

NATURAL SOURCES	220
• Wetlands	175
• Termites	20
• Ocean	15
• Hydrates	10
HUMAN SOURCES	380
• Energy	110
• Landfills	40
• Ruminants	115
• Waste treatment	25
• Rice agriculture	50
• Biomass burning	40
TOTAL SOURCES	**600**

NATURAL SINKS	580
• Soils	30
• Tropospheric OH	510
• Stratos. destruction	40
TOTAL SINKS	**580**

ANNUAL IMBALANCE

= SOURCES - SINKS

= 600 – 580 = **+20**

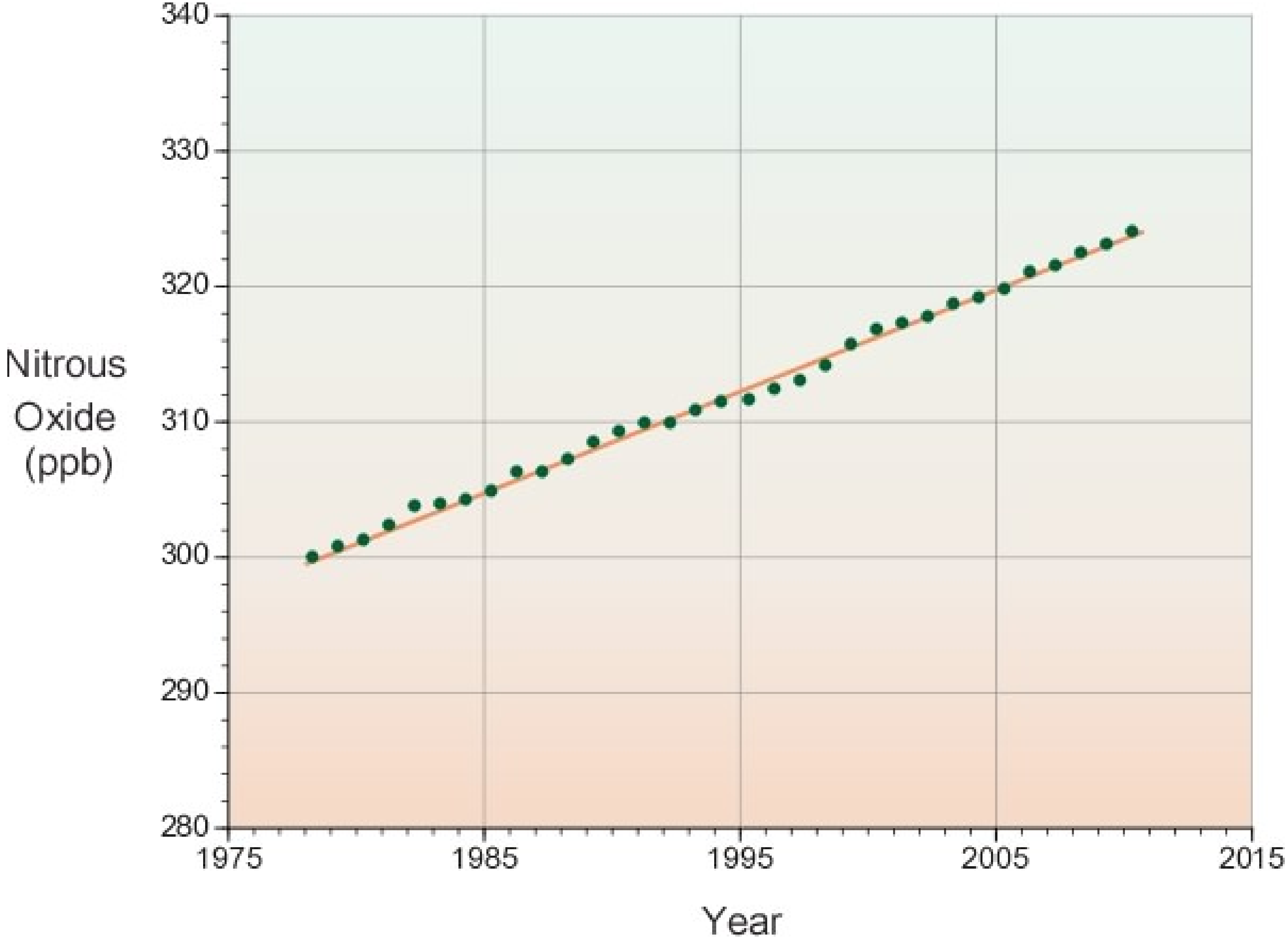
N_2O

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

N_2O Concentrations



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

Global Nitrous Oxide Balance (Tg(N)/yr)

NATURAL SOURCES 9.6

- Oceans 3.0
- Atmosphere 0.6
- Tropical soils 4.0
- Temperate soils 2.0

HUMAN SOURCES 5.4

- Agriculture 3.0
- Biomass burning 0.5
- Industry/energy 1.3
- Cattle/feedlots0.6

TOTAL SOURCES **15.0**

ONLY SINK IS…

- Destruction in stratosphere 11.0

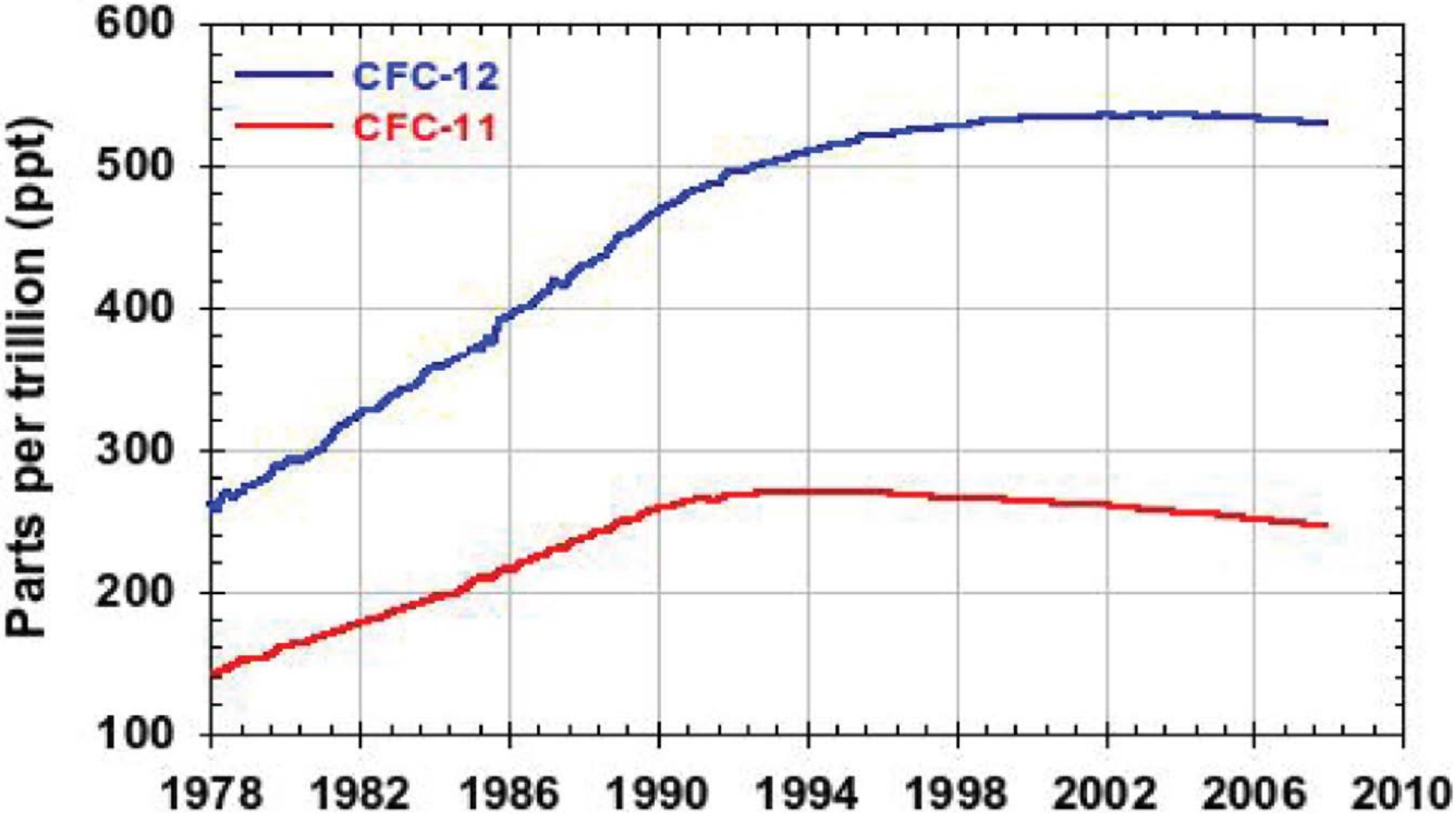
TOTAL SINK **11.0**

ANNUAL IMBALANCE

= INFLOWS – OUTFLOW

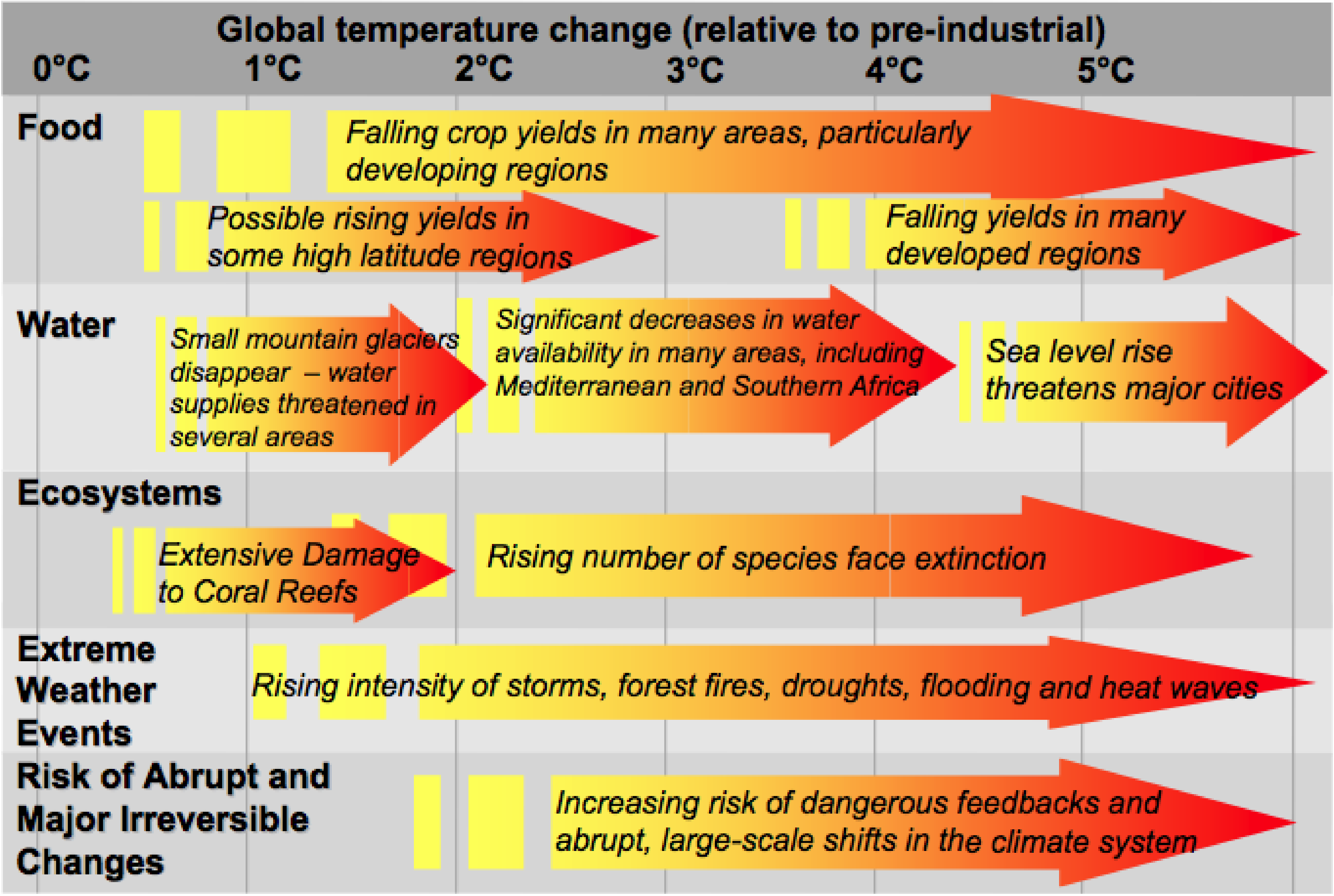
= 15.0 – 11.0 = 4.0 Tg N/y

CFC Concentrations



NOAA global flask sampling network, http://www.esrl.noaa.gov/gmd/ccgg/

Projected impacts of climate change



SOME EXAMPLES OF CLIMATE CHANGE IMPACTS

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

Energy Technology Perspectives (ETP 2012)

- **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 °C Scenario (2DS)
  - identifies the technology options and policy pathways that ensure an 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.

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

Challenges

- CO_2 emissions are at an historic high
- Global economy remains in a fragile state
- Energy demand continues to rise.
- Energy industry events
  - Deepwater Horizon oil spill off the Gulf of Mexico
  - Fukushima nuclear accident in Japan
  - Arab Spring, which led to oil supply disruptions from North Africa.

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

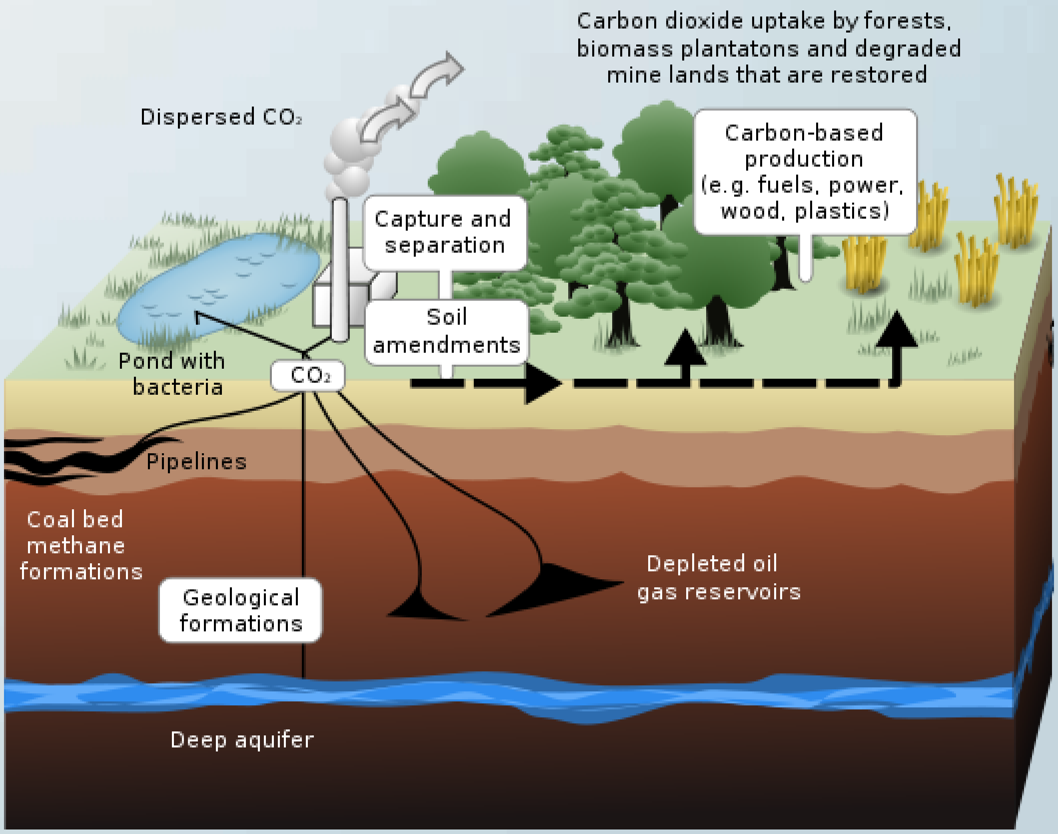
2DS Status

- 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

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.



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

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.
	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.	
23%	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

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

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)
  - Government develop 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

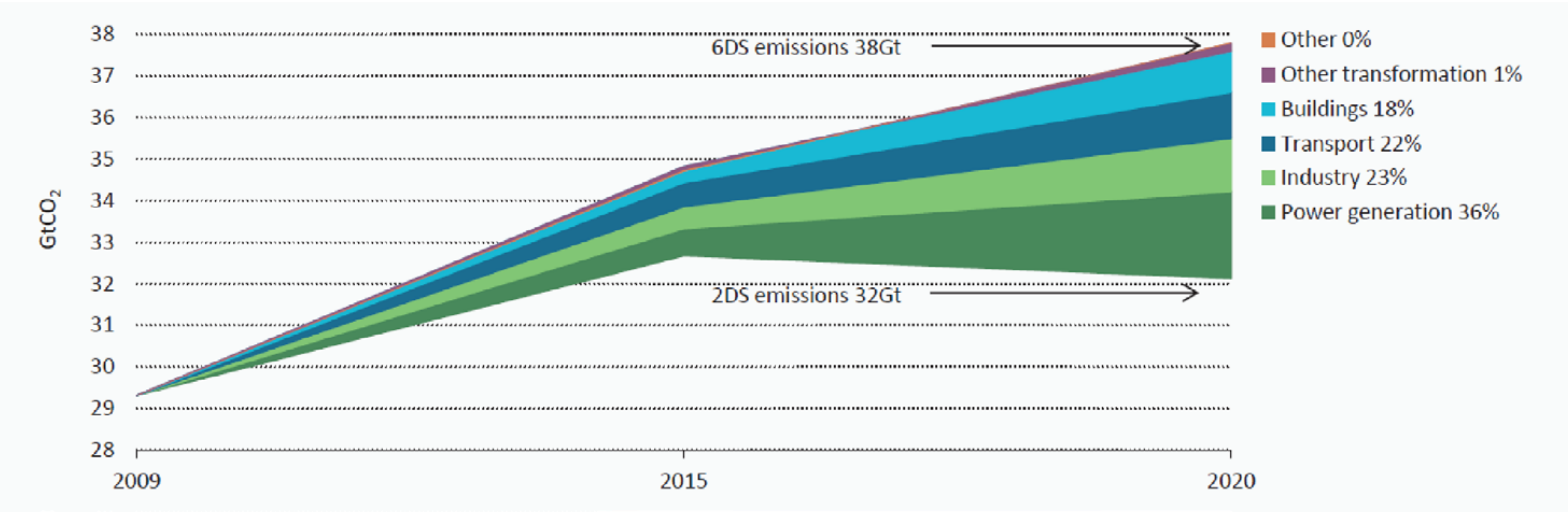
Factors Affecting Clean Energy

Table 1.1 Factors that influence clean energy technology development and deployment progress

Technology progress	Technical efficiency improvements Competitive cost of technologies
Market development	Creation of technology markets through enabling policies Knowledge and competencies of market analysts and private-sector investors Parity of energy and electricity prices Manufacturing capacity and supply chain development Skills and competencies to build and operate new technologies
Institutional, regulatory and legal frameworks	Changes to institutions and processes to support adoption of new technologies Legal and regulatory frameworks to enable technology deployment
Acceptance by social frameworks	Knowledge and education Acceptance of new technologies

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

Key sector contributions to world CO_2 emissions reductions



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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).

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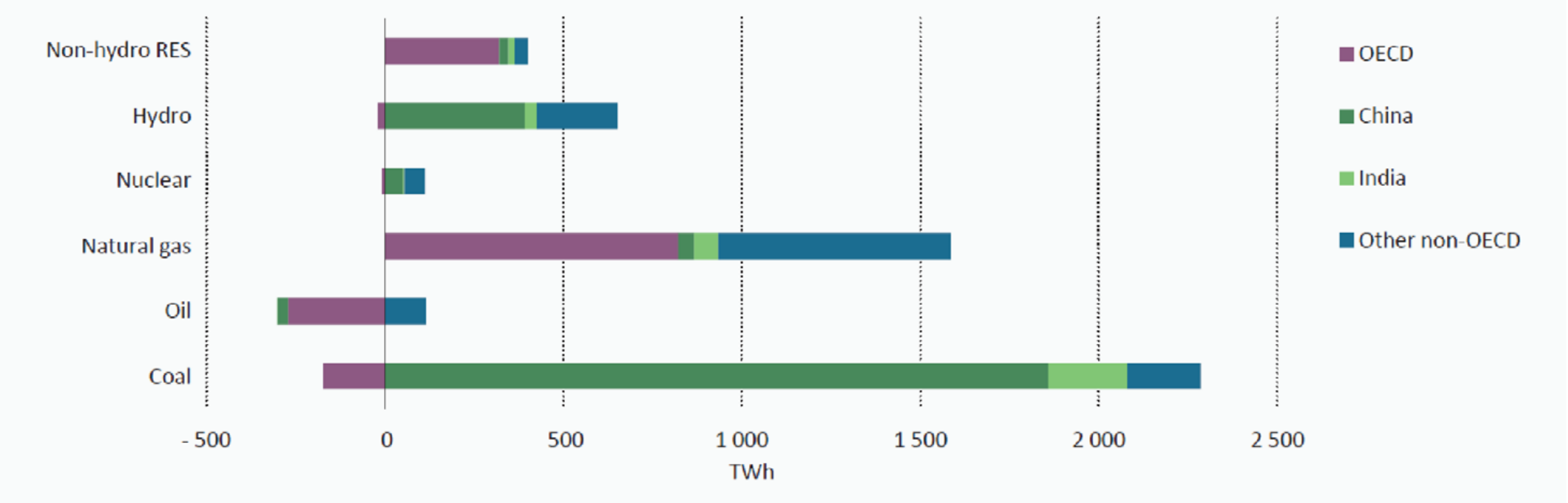
Changes in Sources of Electricity Supply, 2000-2009

- Power sector – 1/3 of potential CO_2 emissions reductions by 2020 and 40% of 2050 emission savings - Enhanced power generation efficiency, a switch to lower-carbon fossil fuels, increased use of renewables and nuclear power, and the introduction of CCS are all required.



Note: Non-hydro RES = renewable energy sources other than hydropower. TWh = terawatt hours.

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Organisation for Economic Co-operation and Development (OECD)

- *The mission of the Organisation for Economic Co-operation and Development (OECD) is to promote policies that will improve the economic and social well-being of people around the world.*
- *The OECD provides a forum in which governments can work together to share experiences and seek solutions to common problems. We work with governments to understand what drives economic, social and environmental change. We measure productivity and global flows of trade and investment. We analyze and compare data to predict future trends. We set international standards on a wide range of things, from agriculture and tax to the safety of chemicals.*
- *The 34 member countries span the globe, from North and South America to Europe and the Asia-Pacific region. They include many of the world's most advanced countries but also emerging countries like Mexico, Chile and Turkey. We also work closely with emerging giants like China, India and Brazil and developing economies in Africa, Asia, Latin America and the Caribbean.*

http://www.oecd.org

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.)

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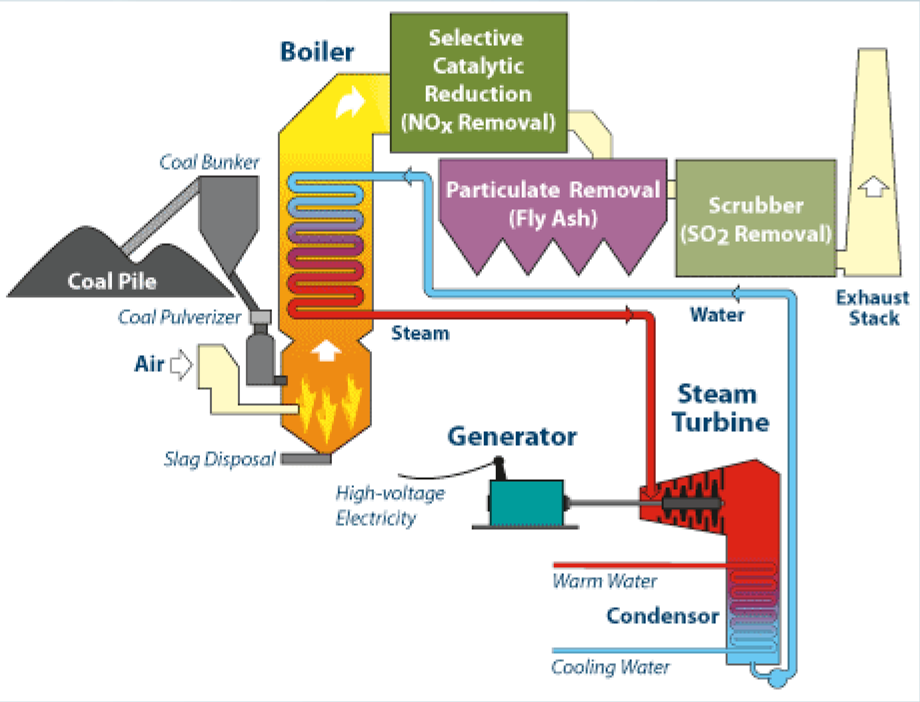
Supercritical Pulverized Coal Combustion (SCPC)

- Operate at very high temperature and pressure (580 °C and 23 MPa), resulting higher heat efficiencies (46%) than sub-critical coal-fired plants, which are about 40% efficient.
  - Reduced fuel costs due to improved plant efficiency;
  - Reduction in CO_2 emissions;
  - Plant costs comparable with sub-critical technology and less than other clean coal technologies;
  - Much reduced NO_x, SO_x and particulate emissions;
  - Can be fully integrated with appropriate CO_2 capture technology.



http://saferenvironment.wordpress.com/2008/12/29/%E2%80%98supercritical-coal-fired-power-plant%E2%80%99-necessary-to-promote-advanced-technology-in-power-generation-for-achieving-better-efficiency-cleaner-and-safer-environment/

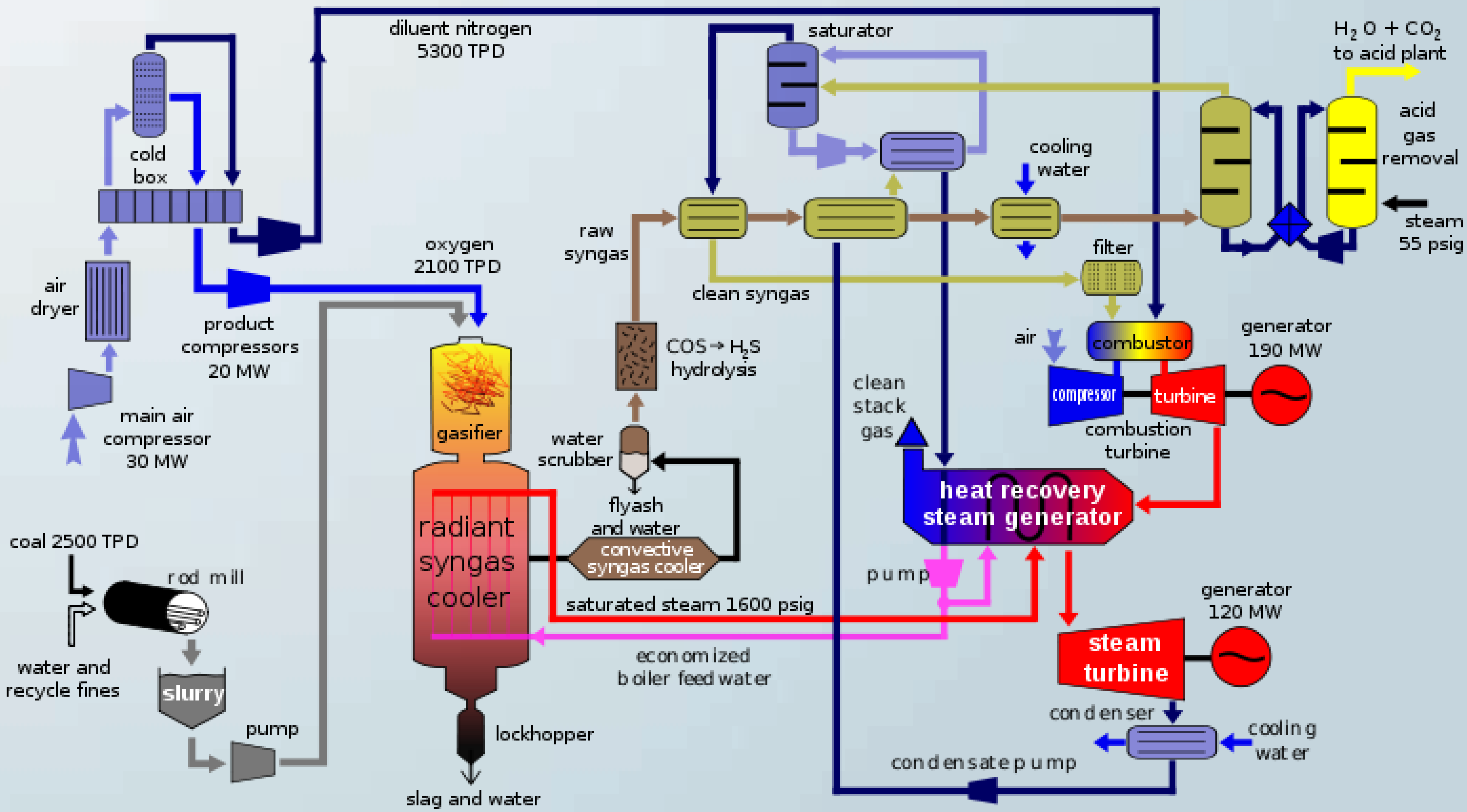
Integrated Gasification Combined Cycle (IGCC)

- Uses a gasifier to turn coal and other carbon based fuels into gas—synthesis gas (syngas), which contains carbon monoxide, CO, and hydrogen gas, H_2.
- Removes impurities from the syngas before it is combusted.
- Some of these pollutants, such as sulfur, can be turned into re-usable byproducts.
- Lower emissions of sulfur dioxide, particulates, and mercury.
- With additional process equipment, the carbon in the syngas can be shifted to hydrogen via the water-gas shift reaction, resulting in nearly carbon free fuel. The resulting carbon dioxide from the shift reaction can be compressed and permanently sequestered.
  - The **water-gas shift reaction** (WGS) is a chemical reaction in which carbon monoxide reacts with water vapor to form carbon dioxide and hydrogen:

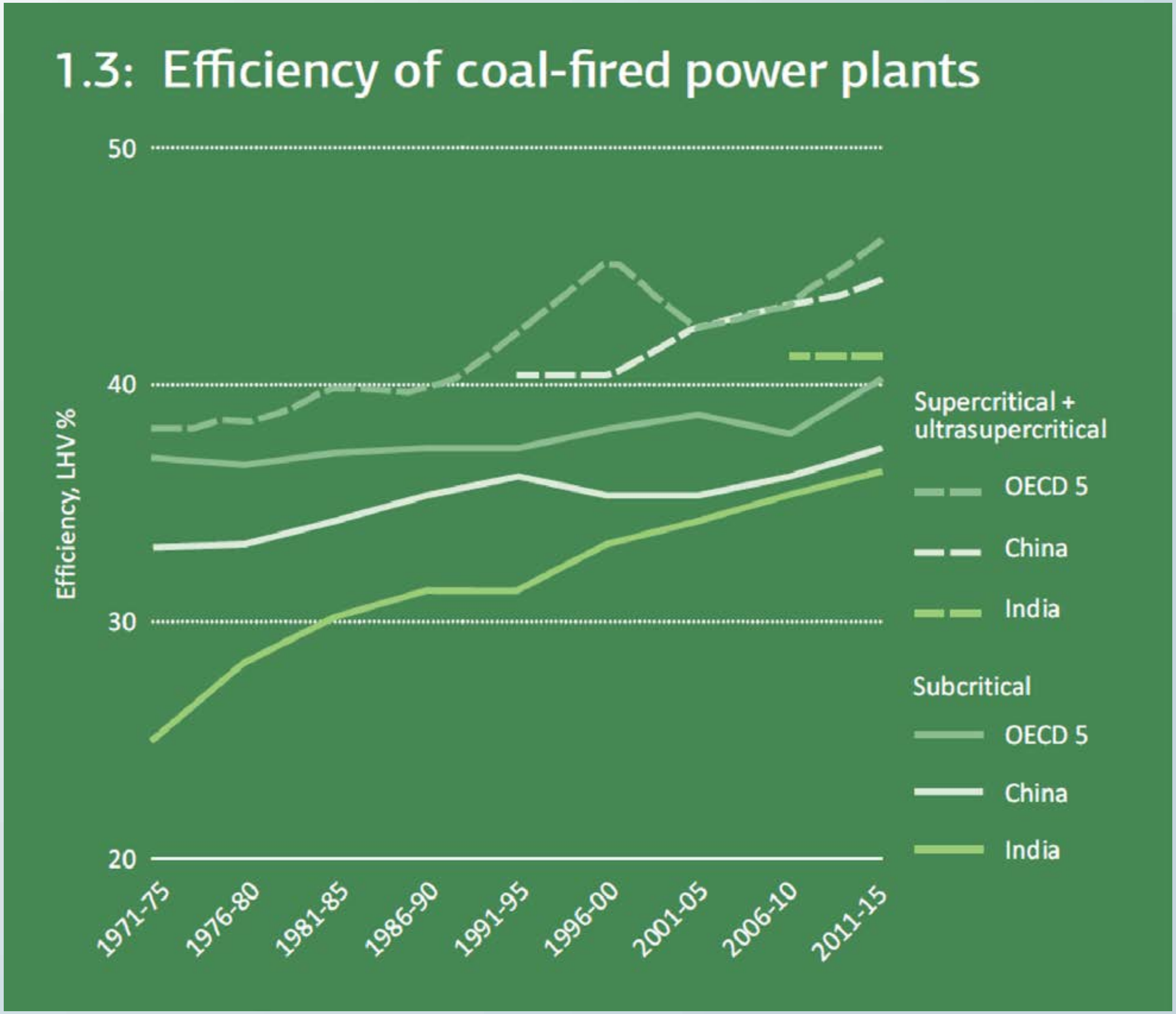
    $CO(g) + H_2O(g) \rightarrow CO_2(g) + H_2(g)$

Integrated Gasification Combined Cycle (IGCC)

- Offers greater efficiency and greater reductions of CO_2 emission than alternatives
- Few plants are under construction
- Costs remain high



Efficiency of Coal-fired Power Plant



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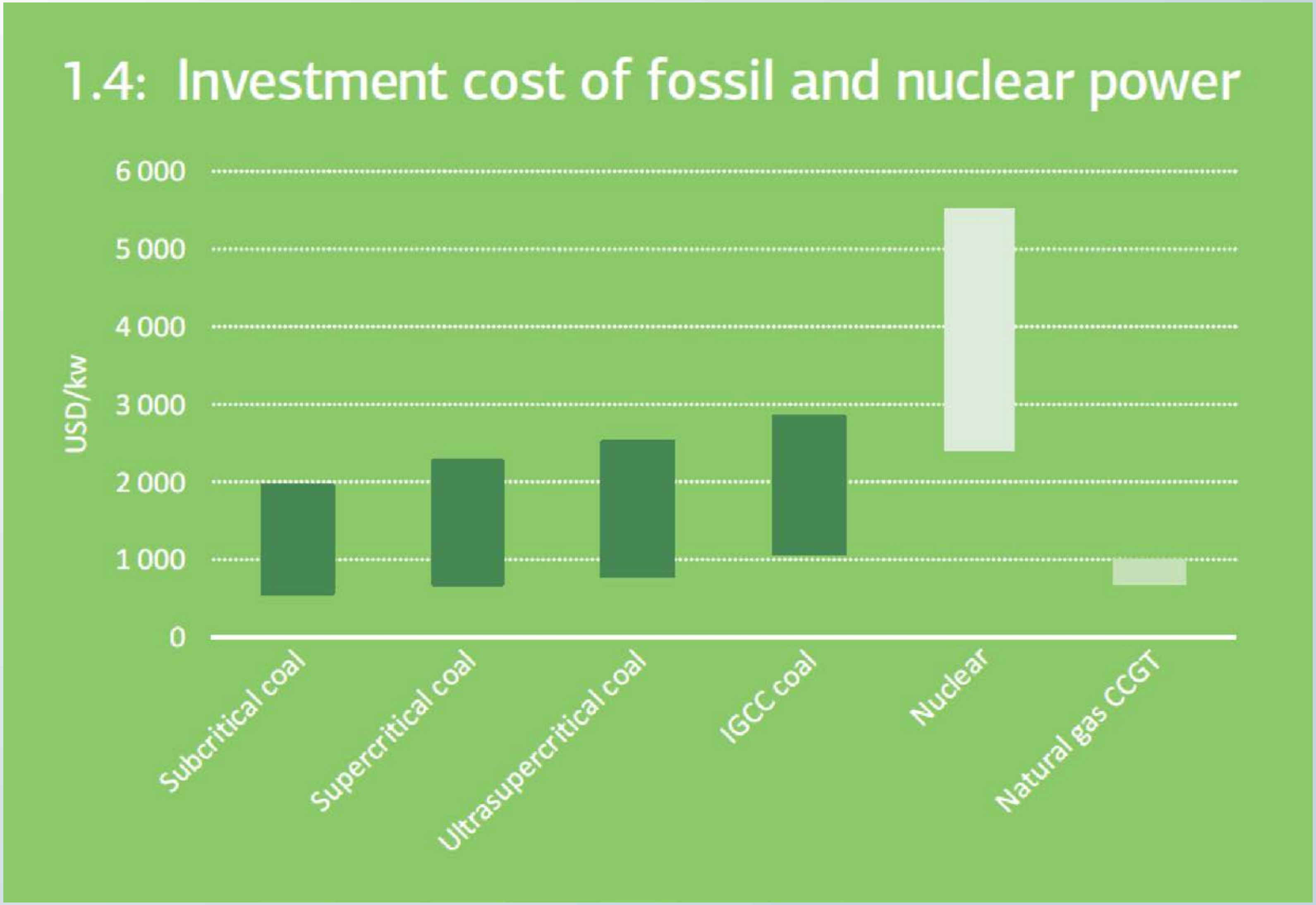
Investment Costs for Fossil and Nuclear Power



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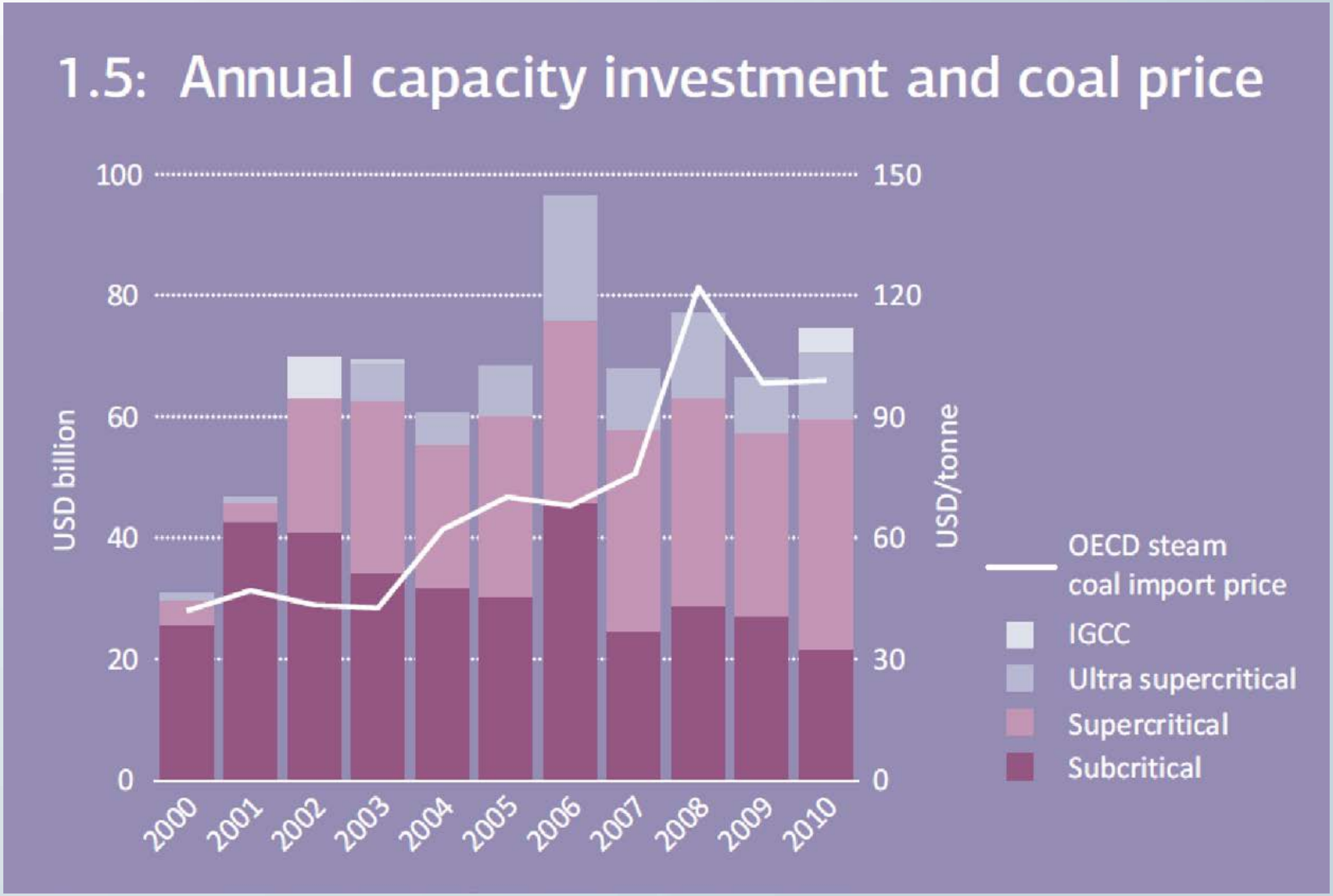
Annual Capacity Investment and Coal Price



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Coal Technology Deployment

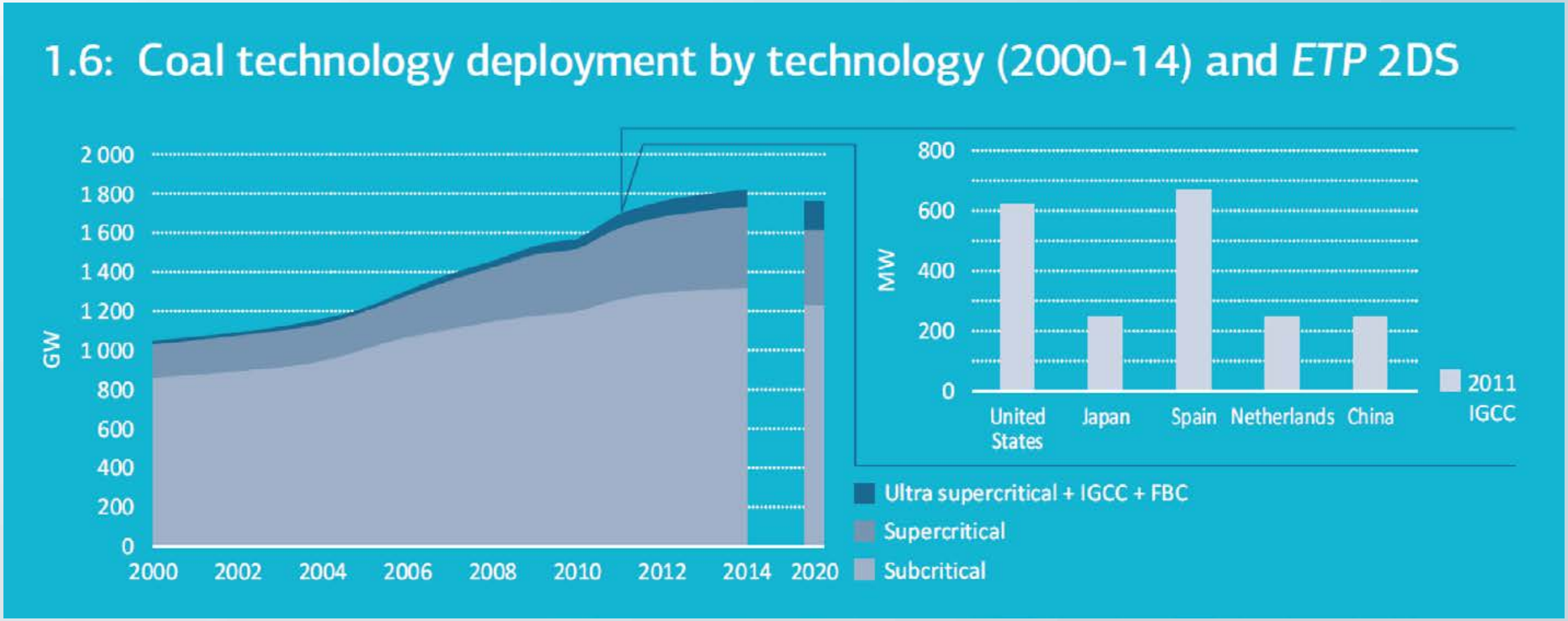

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Table 1.2 Key policies that influence coal plant efficiency in select countries

Country or region	Policy	Impacts and goals of policy
China	Its 11th Five Year Plan mandated closure of small, inefficient coal-fired power generation. In 12th Five Year Plan, coal production is capped at 3.8 billion tonnes by 2015; all plants of 600 MW or more must be SC or USC technology.	In 2010, 70 GW of small, inefficient coal-fired power generation was shut down; in 2011, 8 GW closed. 17% reduction in carbon intensity targeted by 2015; and 40% to 45% reduction by 2020.
India	The 12th Five Year Plan (2012 to 2017) states 50% to 60% of new coal-fired capacity added should be SC. In the 13th Five Year Plan (2017 to 2022), all new coal plants should be at least SC; energy audits at coal-fired power plants must monitor and improve energy efficiency.	The 12th and future Five Year Plans will feature large increases in construction of SC and USC capacity.
Indonesia	Began indexing Indonesian coal prices to international market rates (2011); put emissions monitoring system in place.	Likely to increase coal prices paid by large importers of Indonesian coal.
European Union	Power generation covered by the EU ETS. The first two phases saw over 90% of emissions credits "grandfathered" or allocated to power producers without cost, based on historical emissions. Beginning with phase 3 in 2013, 100% of credits will be auctioned.	GHG emissions reduction of 21% compared to 2005 levels under the EU ETS. Credit auctioning will provide further incentive to coal plants to cut emissions.
United States	The US EPA's GHG rule recommends use of "maximum available control technology".	New plants are all likely to have SC or USC technology, although pending EPA regulation, combined with low natural gas prices, suggest limited coal capacity additions in the future.
Australia	Generator efficiency standards defined best practice efficiency guidelines for new plants: black coal plant (42%) and brown coal (31%). Both have higher heating value net output. Emissions trading is under consideration for in 2013.	New plants will likely be SC or USC technology.

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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.

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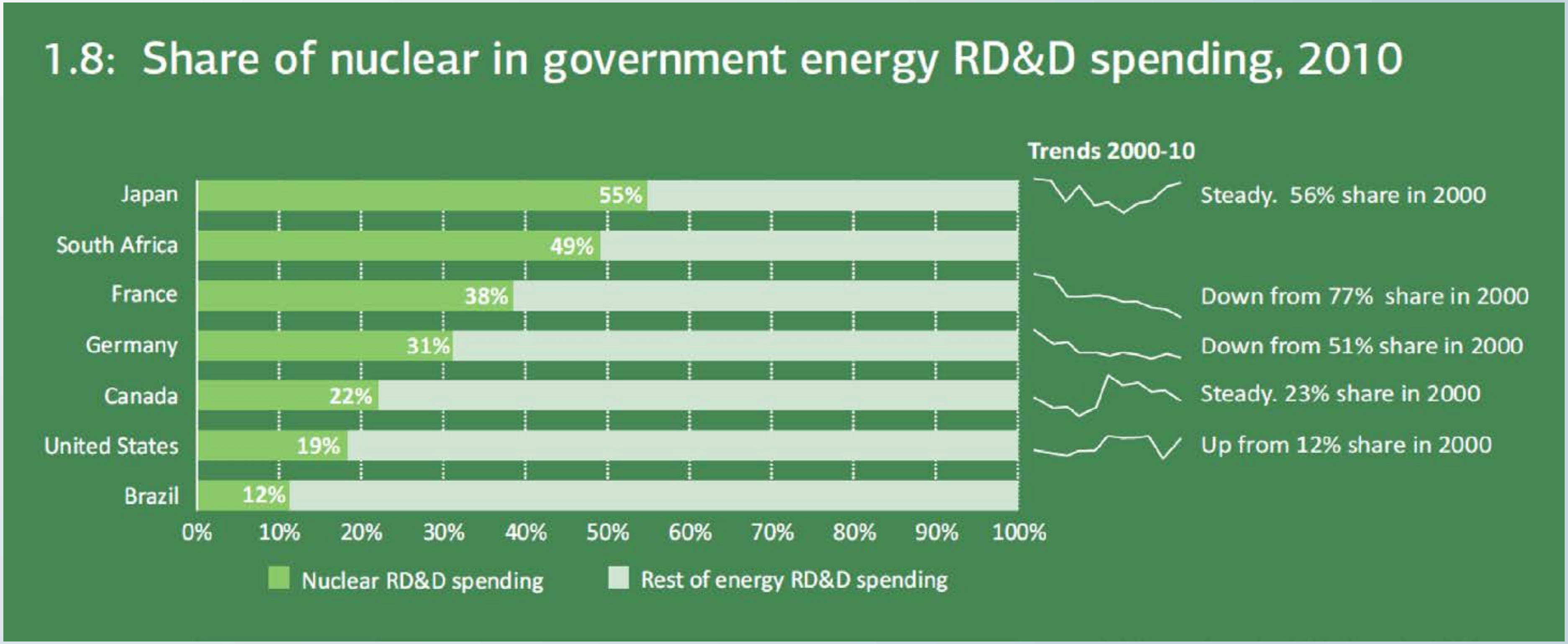
Share of Nuclear Government RD&D Spending



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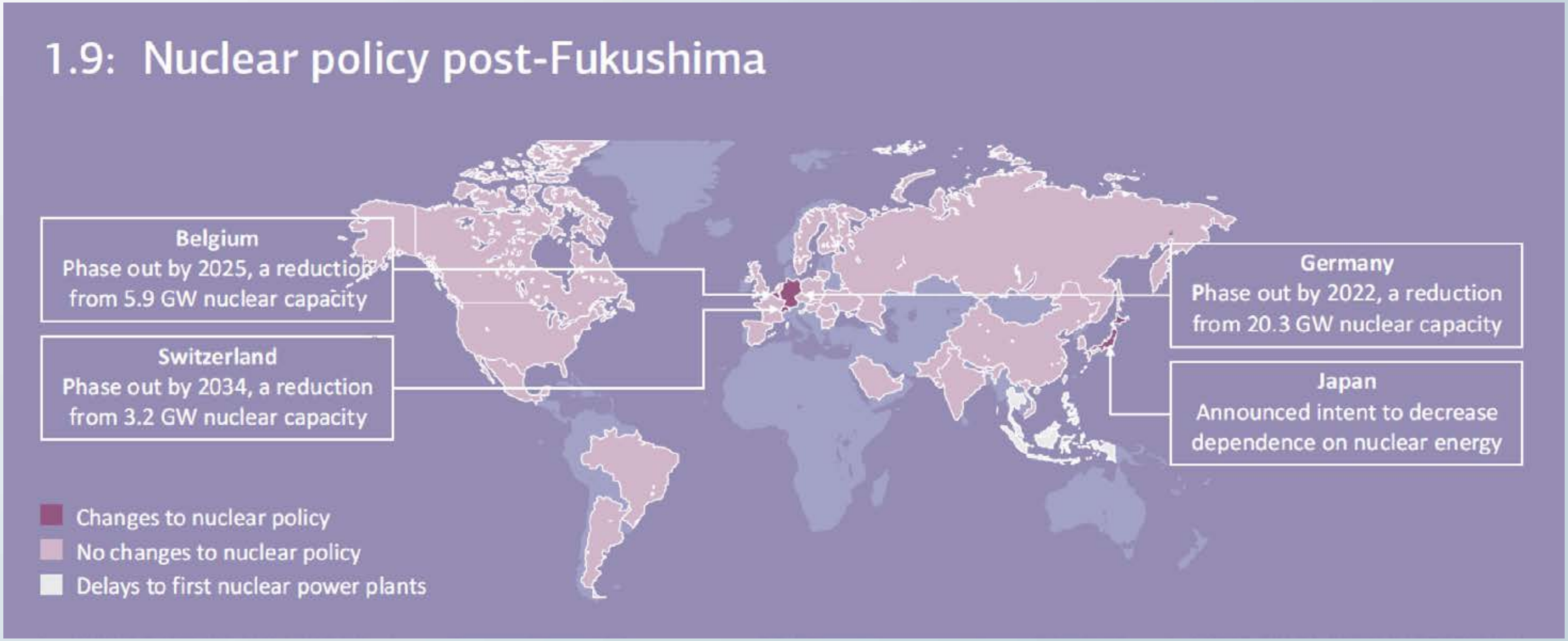
Nuclear Policy Post-Fukushima



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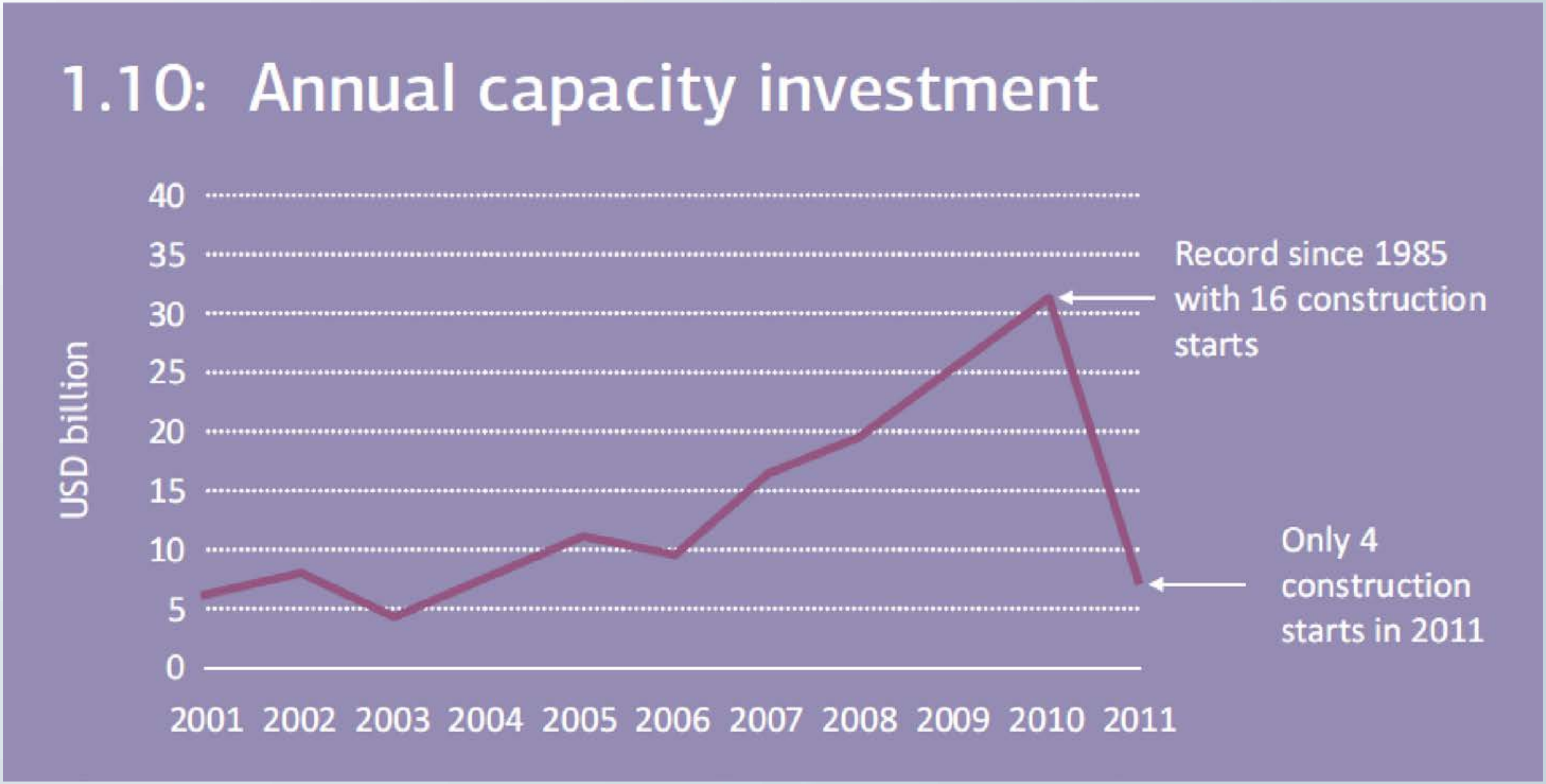
Nuclear Annual Capacity Investment



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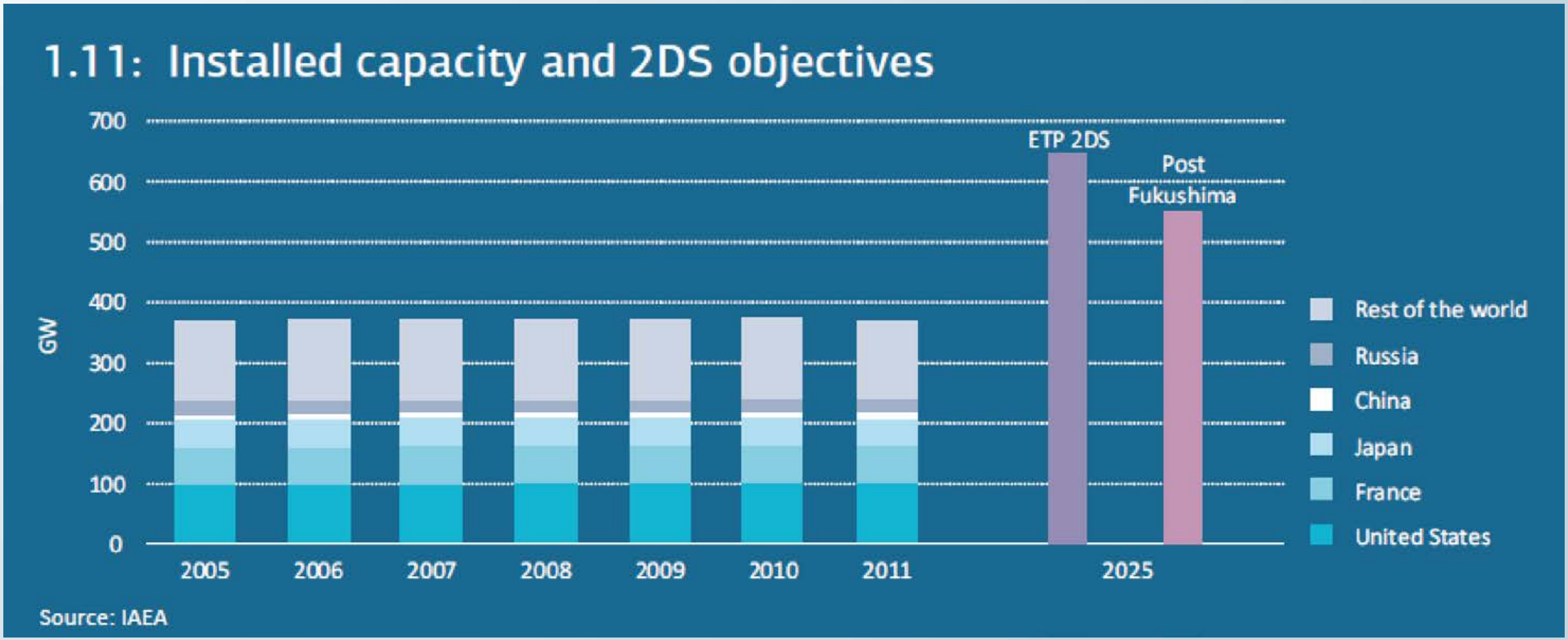
Nuclear Installed Capacity



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Reactors Under Construction

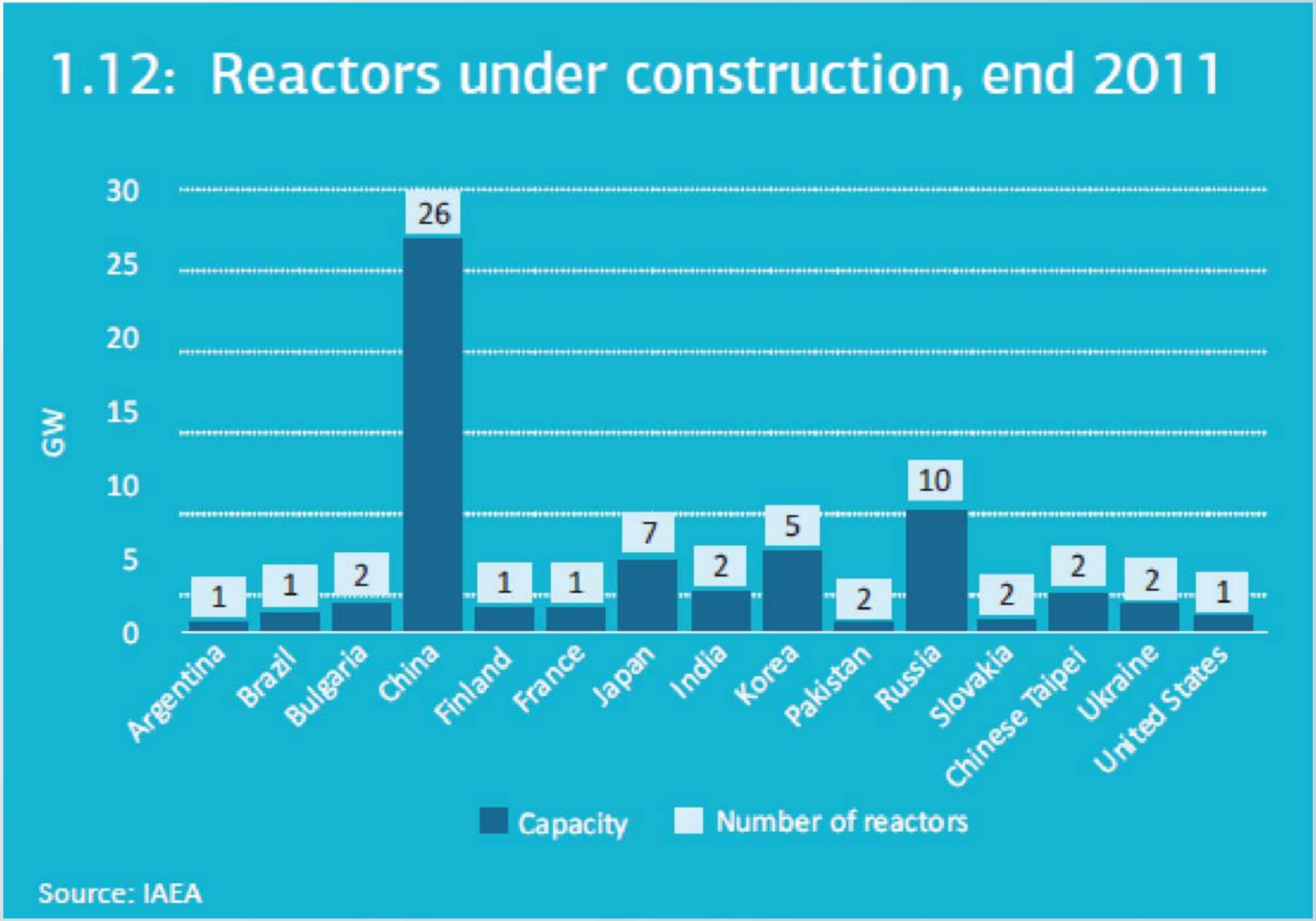

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Table 1.3 Nuclear policies, post-Fukushima

	Countries	Summary and implications
No changes to nuclear targets as a result of Fukushima accident	Argentina, Armenia, Bulgaria, Brazil, Canada, China*, Czech Republic, Finland, France, Hungary, India, Korea, Lithuania, Mexico**, Netherlands, Pakistan, Poland, Romania, Russia, Slovak Republic, Slovenia, Spain, Sweden, Taiwan, Ukraine, United Kingdom, United States.	Most countries have not changed their plans for nuclear energy as a result of the Fukushima accident. It is, however, expected that the execution and cost of projects will take longer than previously planned, given potential additional safety requirements, siting and permitting restrictions, and possible public opposition.
Changes to nuclear targets post-Fukushima	Belgium	Will phase out nuclear power by 2025, a reduction of 5.9 GW from nuclear capacity.
	Germany	Plans to phase out nuclear power use for commercial power generation by 2022, a reduction of 20.3 GW from nuclear capacity.
	Japan	Announced intent to decrease dependence on nuclear energy in the mid- and long term.
	Switzerland	Will phase out nuclear power by 2034, a reduction of 3.2 GW from nuclear capacity.
Delays or changes to first nuclear power plant introductions	Thailand, Malaysia, Philippines, Indonesia.	Further assessments to planned introductions of nuclear power, resulting in delays, or modifications to plans.

* After Fukushima, China froze the approval process for new plants, pending lessons learned from the damage, especially with respect to siting. The currently ambitious new building programme is under revision and may result in a decrease of 10 GW compared to 90 GW initially planned by 2020.
** Mexico recently declared that it was abandoning plans to build 10 reactors in the next 15 years and will instead develop gas-fired generation capacities. The decision is not the result of the Fukushima accident.

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Post-Fukushima Nuclear Plants

- *Following the Fukushima damage, all countries operating nuclear reactors have carried out stress tests to assess plant safety in the event of extreme natural events (earthquakes and flooding).*
- *The results, currently under review by regulatory bodies, are expected to increase the stringency of safety standards and thus require more investment in safety upgrades, especially for older plants.*
- *Overall, the outcome of the stress tests may speed up the rate at which older plants are shut down (making approval of reactor life extensions more difficult to obtain); slow the start of new reactor projects (with siting and licensing expected to take more time), and negatively affect public acceptance of nuclear energy.*
- *Deployment is projected to be about 100 gigawatts (GW) below the level required to achieve the 2DS objectives by 2025. This represents a drop of about 15% against capacity projections before the Fukushima accident.*
- *At this rate, it is unlikely that nuclear deployment levels under the 2DS will be achieved.*

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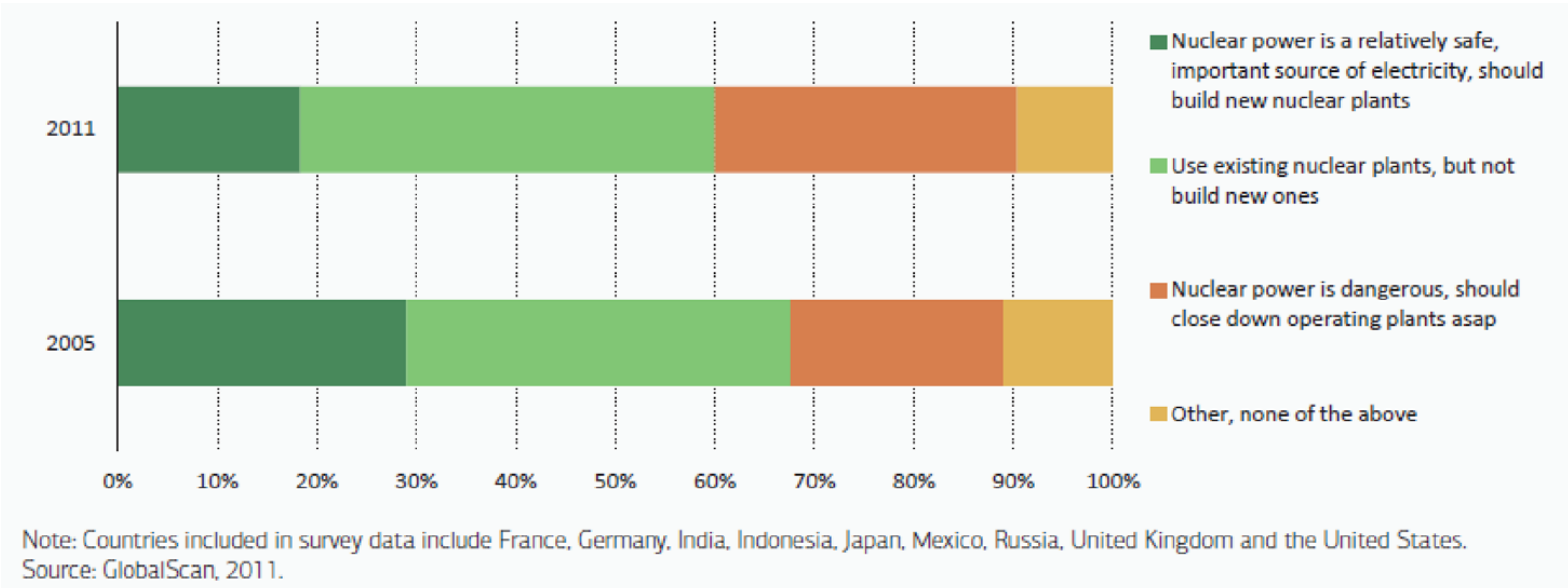
Public Opinion of Nuclear Energy



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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

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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.

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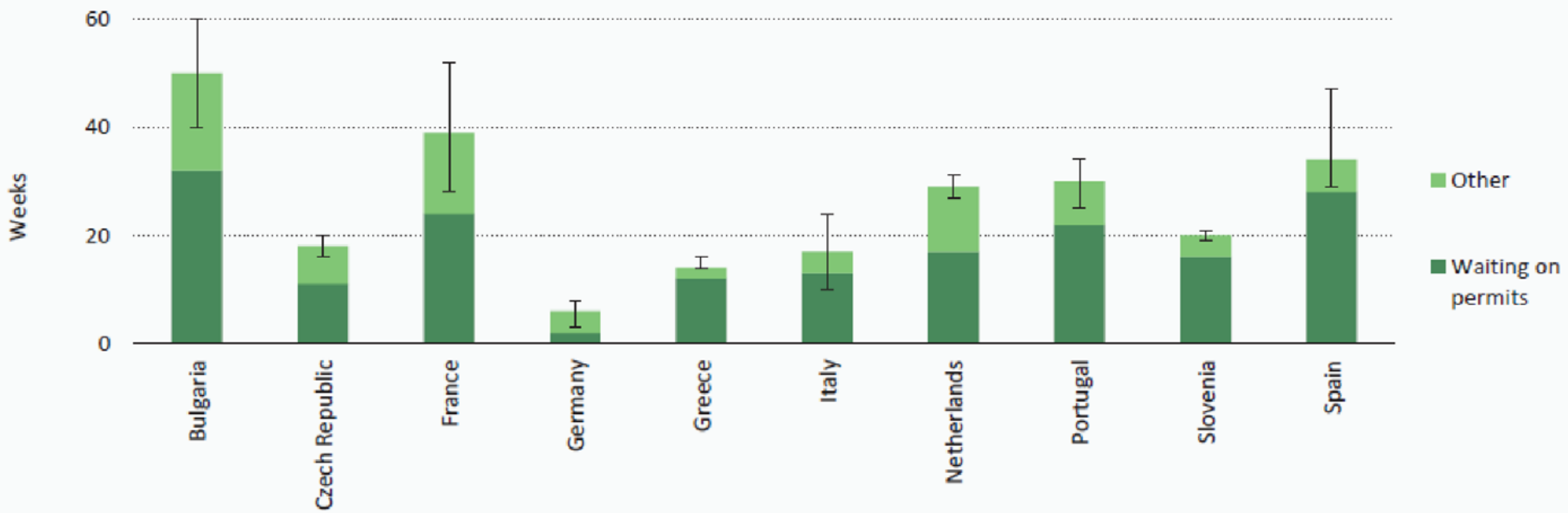
Time for Small-scale Rooftop Photovoltaic



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

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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.

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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.

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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.

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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.

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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.

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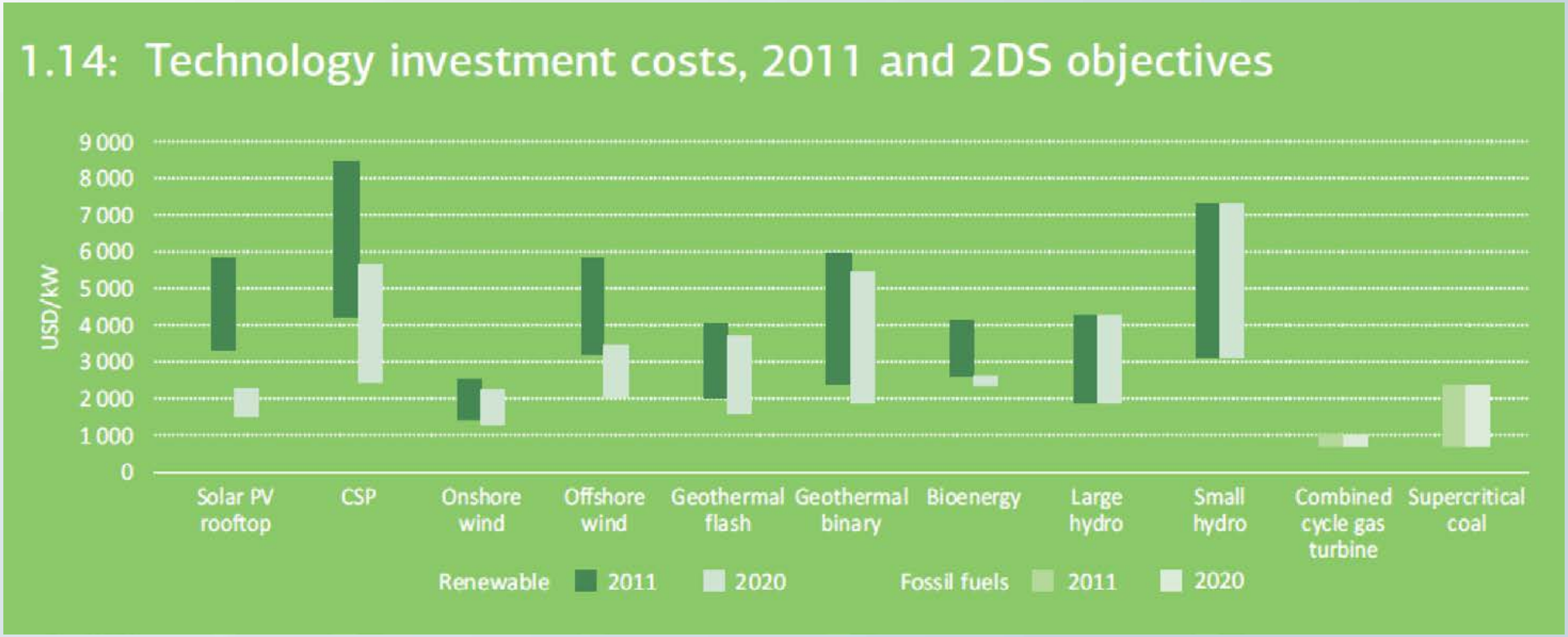
Renewable Power



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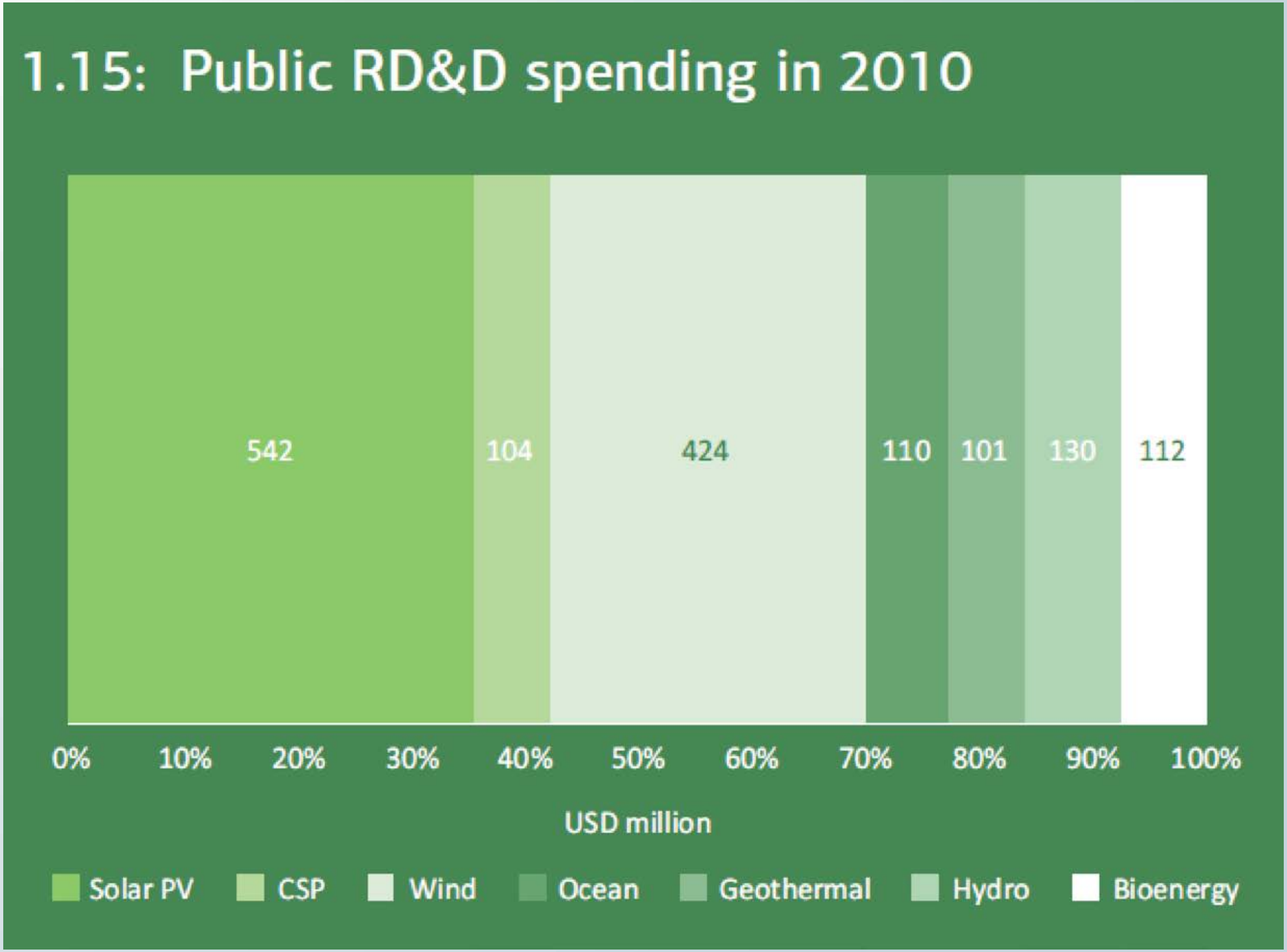
Renewable Energy: Public Spending



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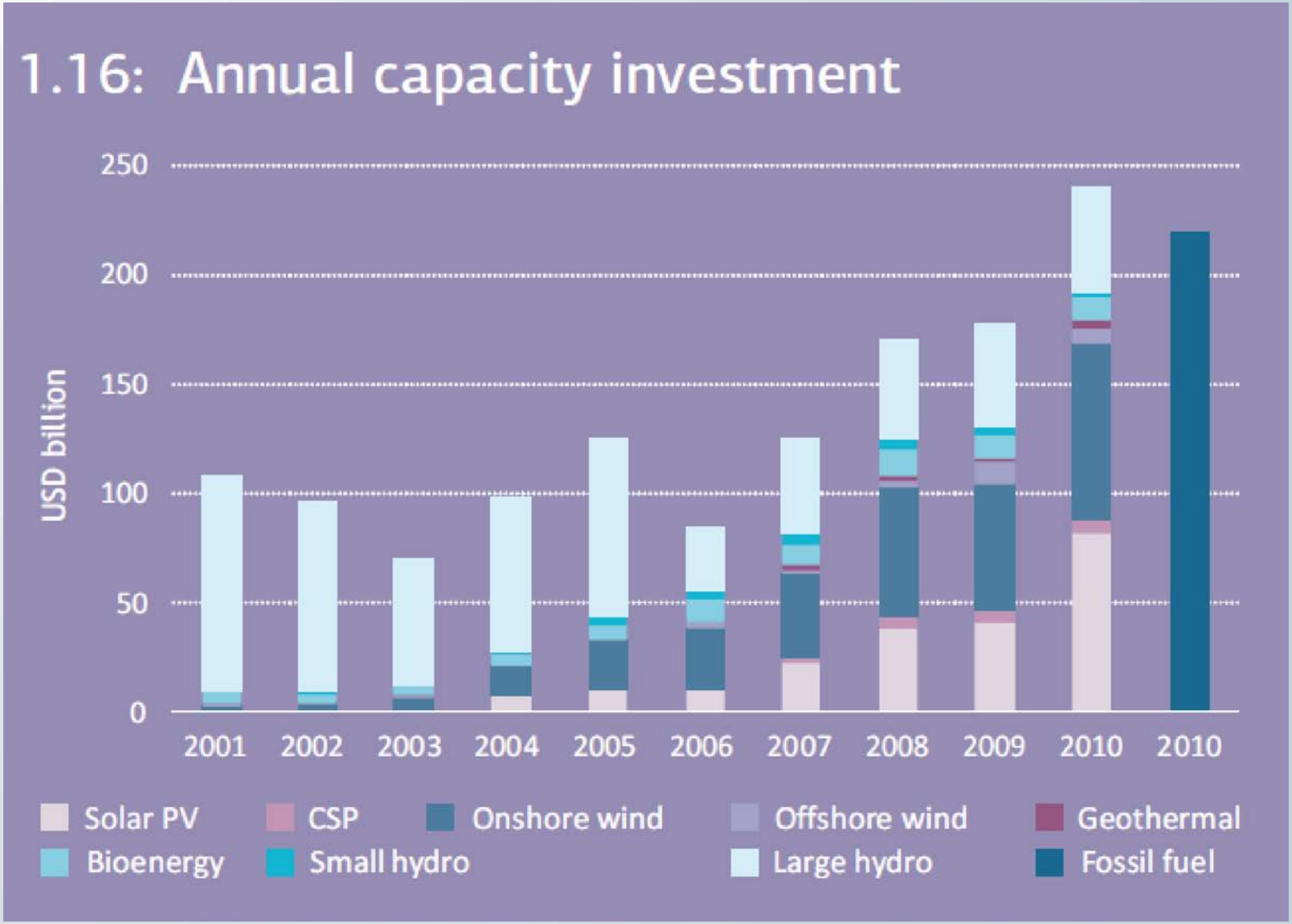
Renewal Energy Investment



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Renewable Energy: Investments

Average annual investments required to 2020

Onshore wind 60

Offshore wind 10

Solar PV 50

CSP 15

Hydro 80

Bioenergy 10

Geothermal 10

USD billion

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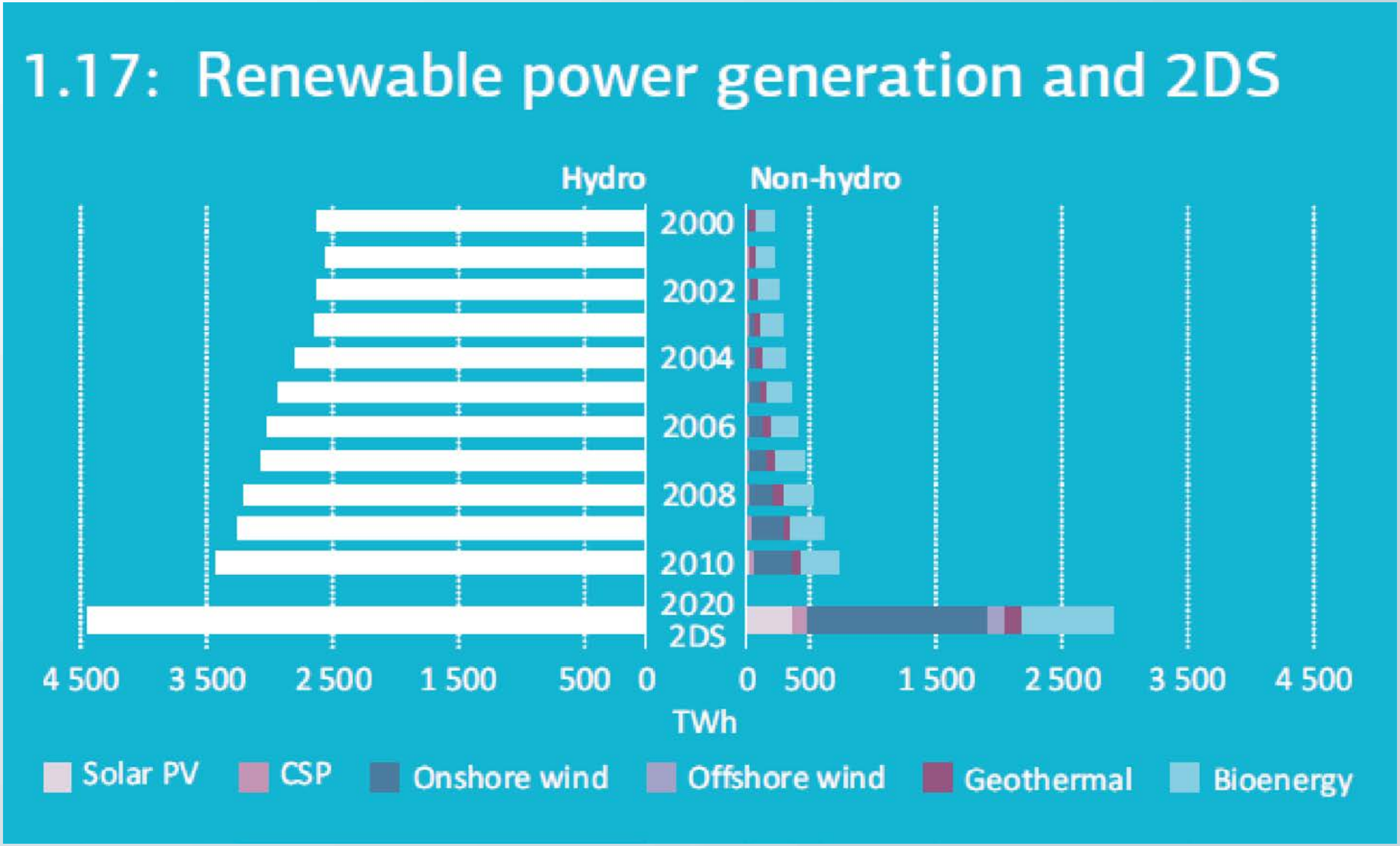
Renewable Power Generation



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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

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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.

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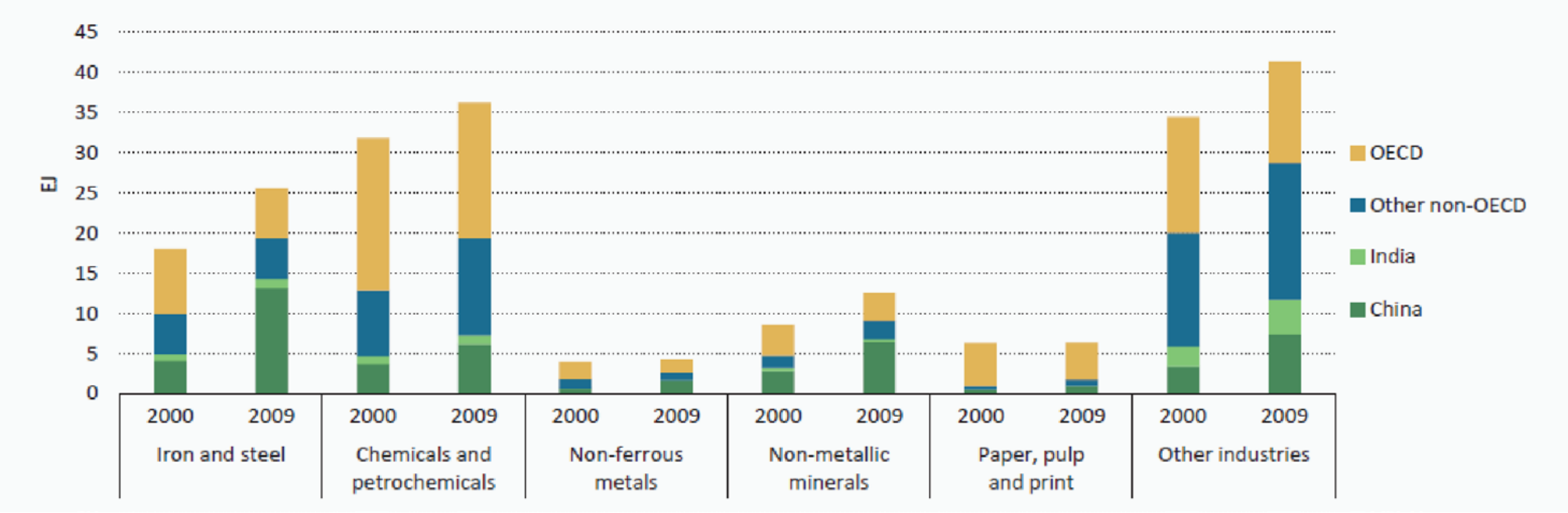
Industry Energy Use



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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.

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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.

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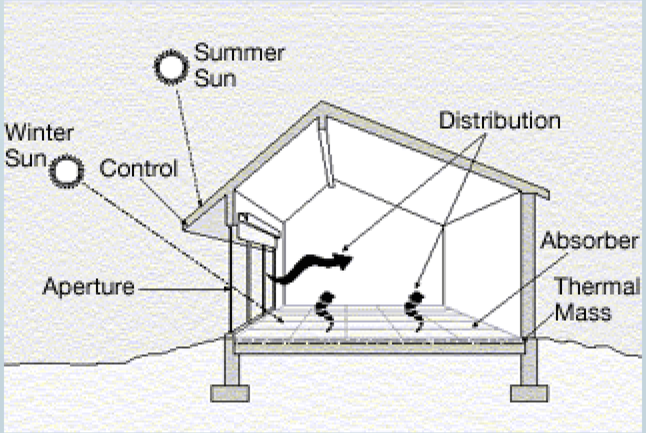
Low- or Zero-Carbon Heating and Cooling

- Active 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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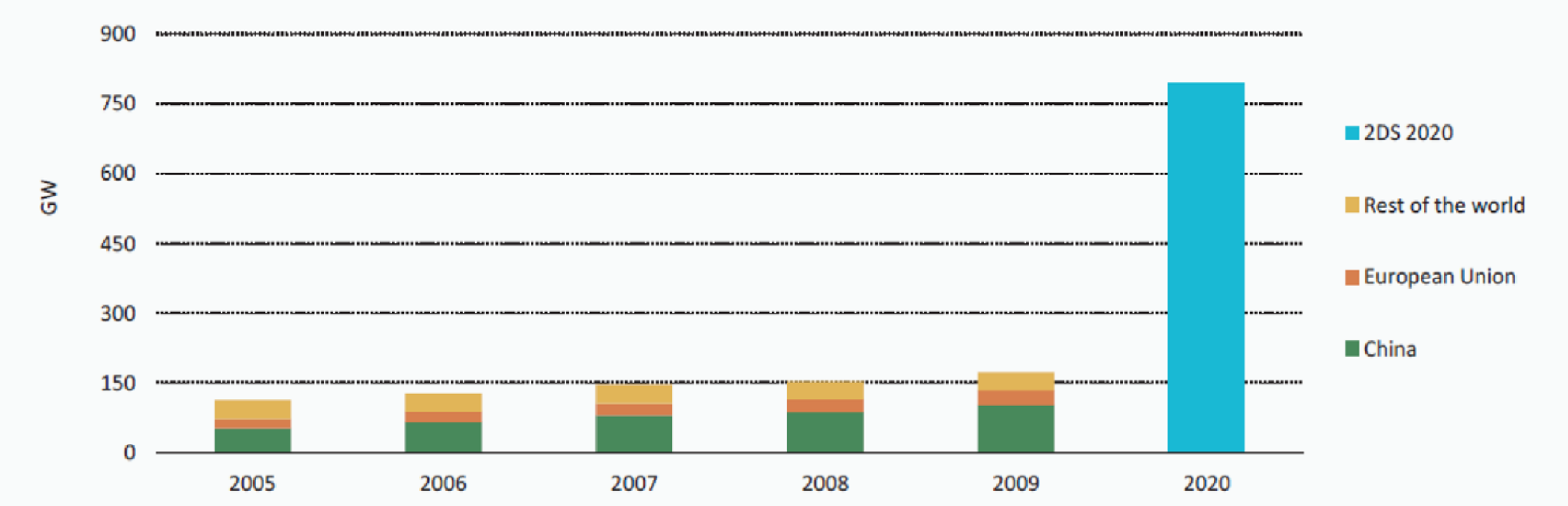
Active Solar Energy Deployments



Source: IEA analysis; IEA SHC, 2011.

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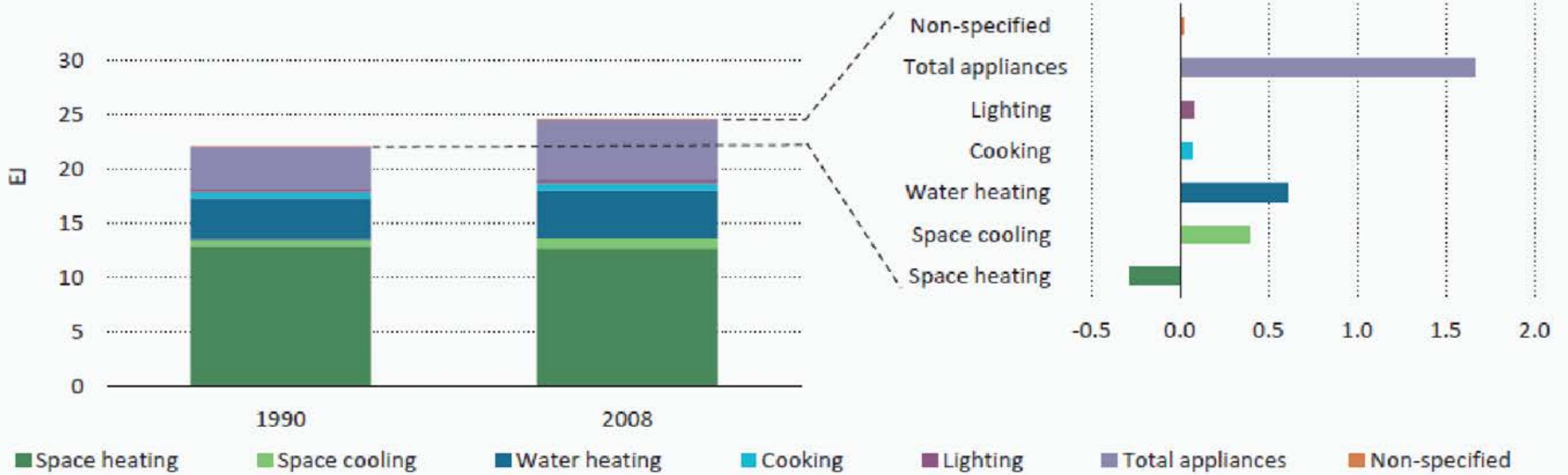
Government Steps

- 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.

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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).

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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.

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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 CO2 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.

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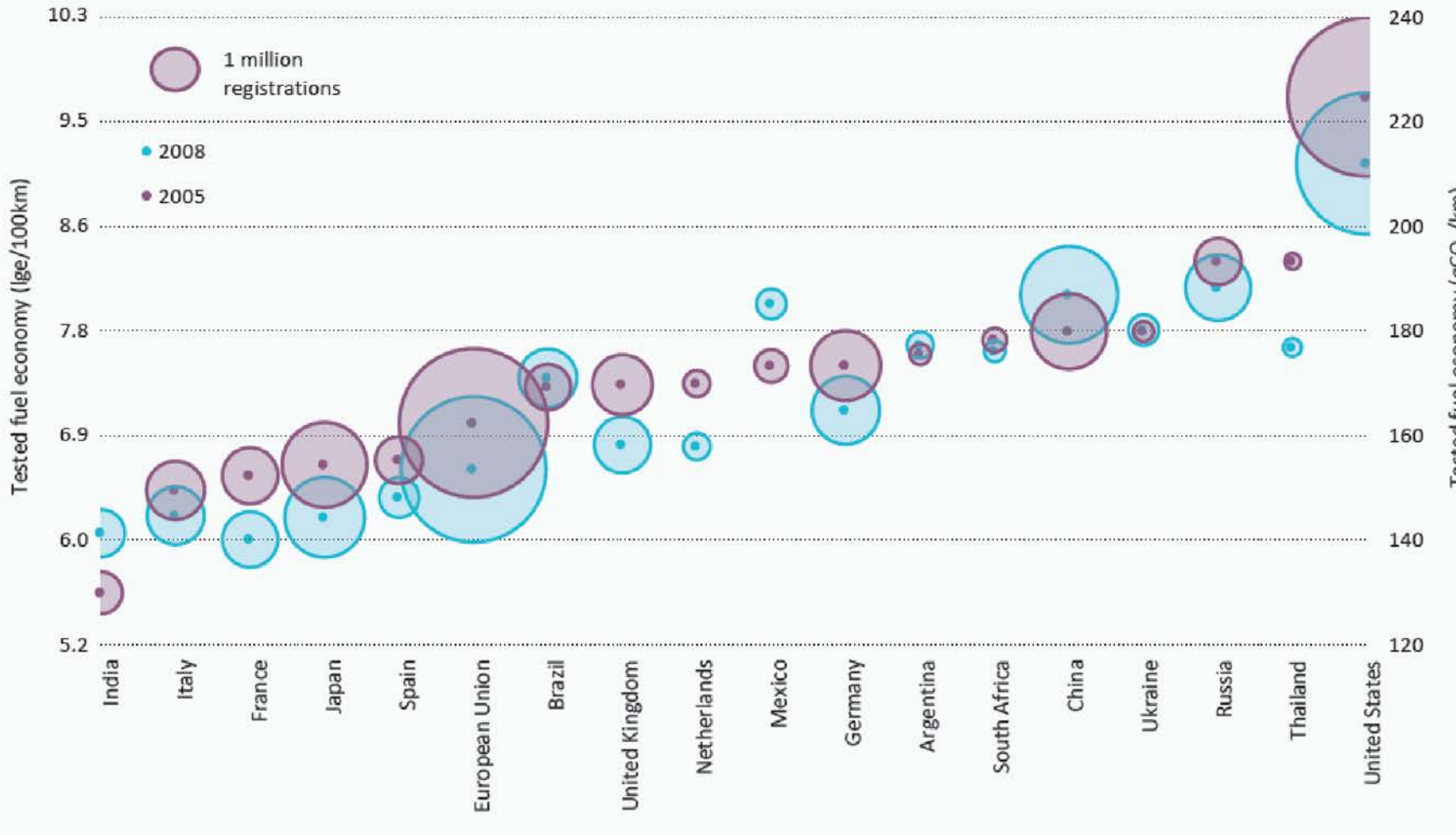
Light-duty Vehicle Fuel Economy



Note: Lge = litre of gasoline equivalent. GCO_2/km = grams of CO_2 emissions per kilometre.
Source: Polk, 2009; IEA analysis and data.

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).

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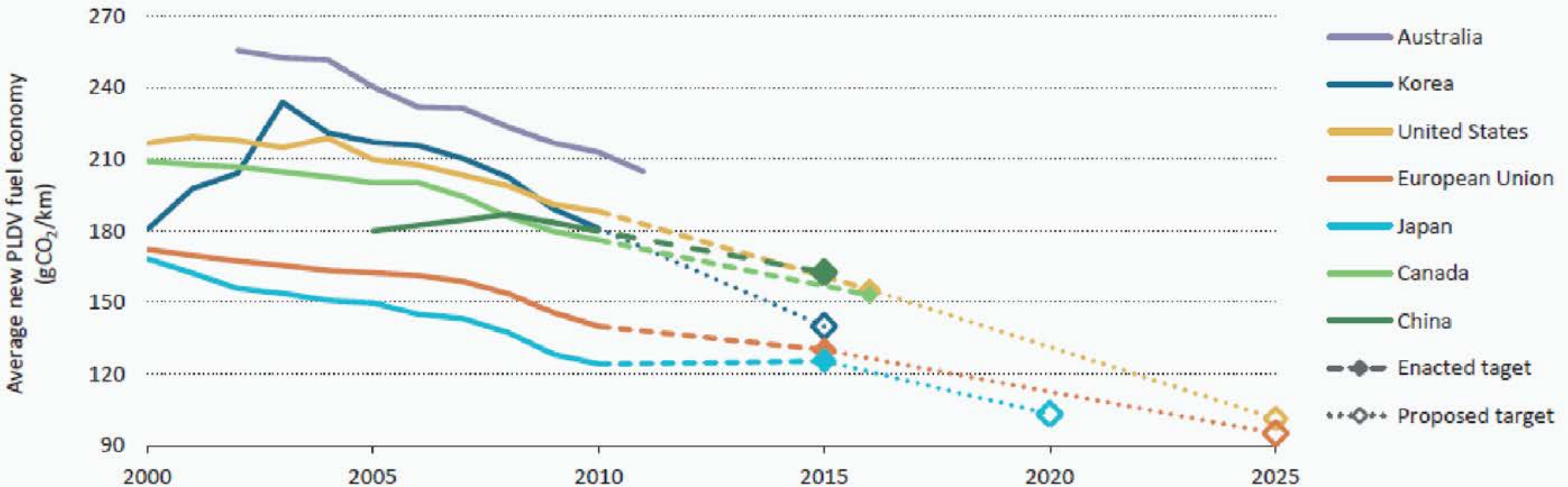
Vehicle Fuel Economy Standards



Note: United States and Canada LDVs include light-commercial vehicles, SUVs and passenger vehicles.
Source: Enacted and proposed targets: GFEI, 2011; IEA analysis and data.

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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.*

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Vehicle Fuel Economy Policies

Table 1.9 Technical and consumer policies in place, 2011

	Policy aspects	Governments
Policies targeting technical efficiency		
Fuel economy standards	Limit to litres/100 km across fleets or based or vehicle weight or class. Stringency of standards, test procedures and number of vehicles classes vary by country	Australia*, Canada, China, Korea*, Japan, United States
GHG emissions standard	Limit on emissions/km	European Union, California (United States)
Policies targeting consumer choice		
Fiscal incentives	Registration taxes increase with vehicle and engine size, and CO_2 emissions; sales incentives for more fuel efficient ad lower CO_2 emitting vehicles	Brazil, China, France, Germany, India, Italy, Japan, Korea, Russia, South Africa, Spain, Turkey, United Kingdom, United States
Consumer information	Labels showing vehicle fuel economy and GHG emissions	Australia, Brazil, Chile, European Union, China, India, Korea and others
Driving prioritisation and penalty	Driving lane prioritisation for high-efficiency vehicles; banning of SUVs and charges for low-efficiency vehicles	Several US states; London, Paris

* Policy under development.
Source: IEA analysis; UNCSD, 2011.

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Electric and Hybrid Vehicles

- *While fuel economy plays the central role in reducing transport-sector CO_2 emissions by 2020, the 2DS scenario also shows strong penetration of hybrid vehicles, plug-in hybrid electric vehicles (plug-in HEVs) and battery electric vehicles (BEVs), which reach substantial yearly sales (over 7 million) and stocks (over 20 million) in this time frame. While this represents rapid development of a nascent market, if achieved, BEVs and plug-in HEVs will still only account for 2% of the world vehicle fleet in 2020.*
- *Many governments have adopted strong targets for electric vehicle deployment in the 2015 to 2020 timeframe in line with the 2DS objectives, but to achieve this goal, sales must nearly double each year between 2012 and 2020, cost must continue to decline, infrastructure needs to develop, and consumer choice and confidence requires a boost.*

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Electric and Hybrid Vehicles

- *Batteries had, roughly, a cost-based price at medium-high volume production of around USD 750/kWh in early 2011. Reported costs through the year declined, and at the beginning of 2012 stand at around USD 500/kWh. If this improvement continues, EVs can reach USD 325/kWh or less by 2020, which is sufficient to bring them close to cost-competitiveness with vehicles with internal combustion engine, which is years ahead of past projections.*

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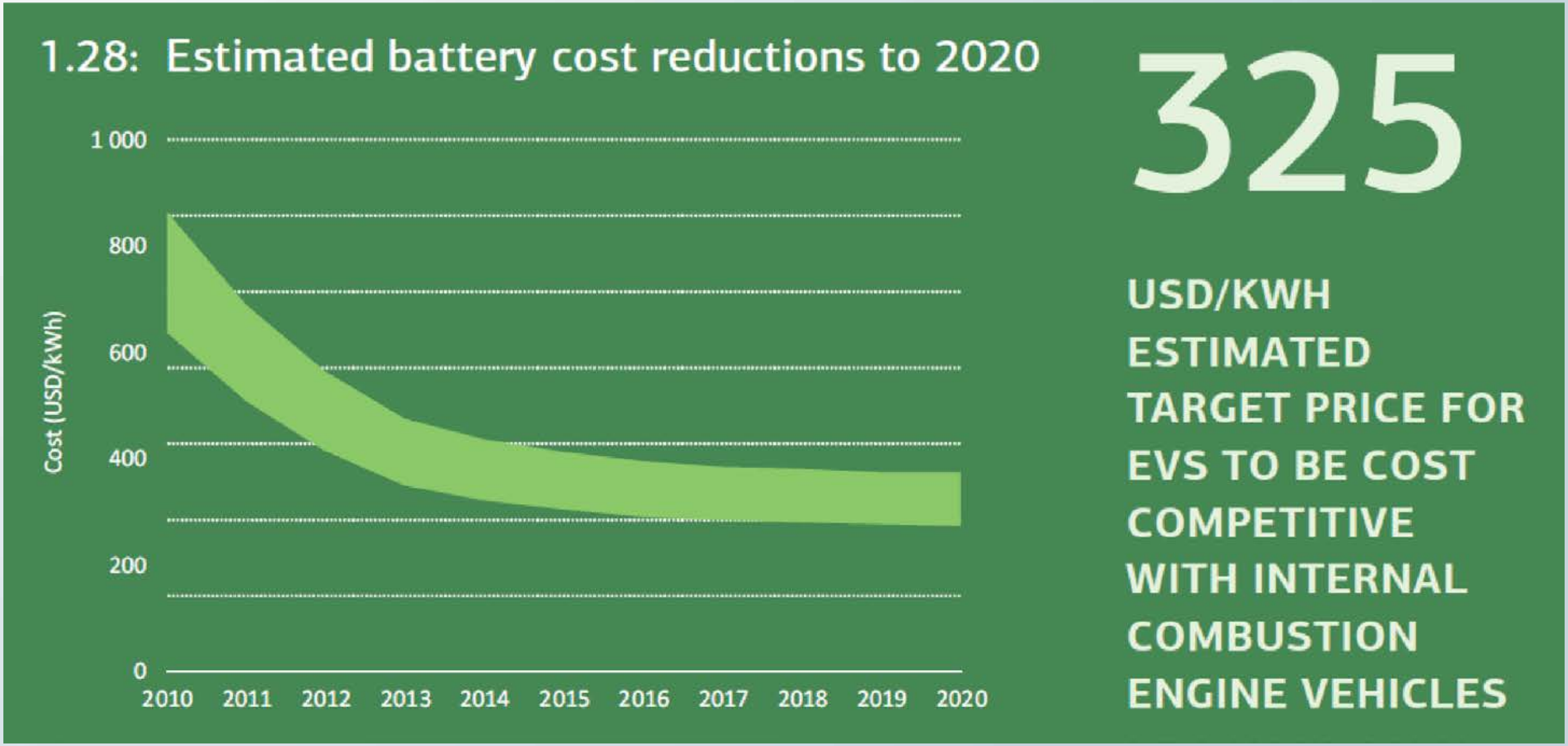
Battery Cost Reductions



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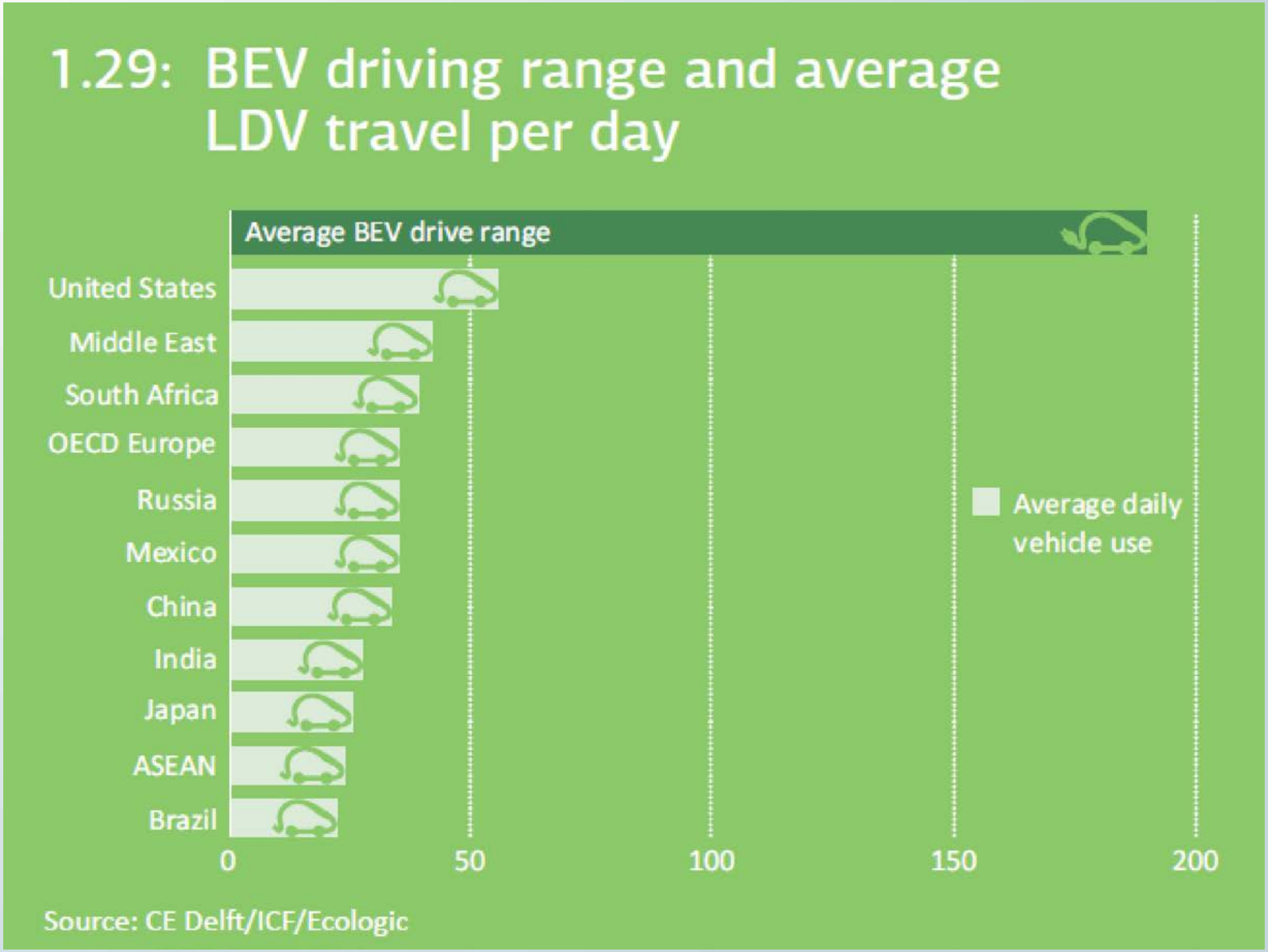
Electric Car Driving range



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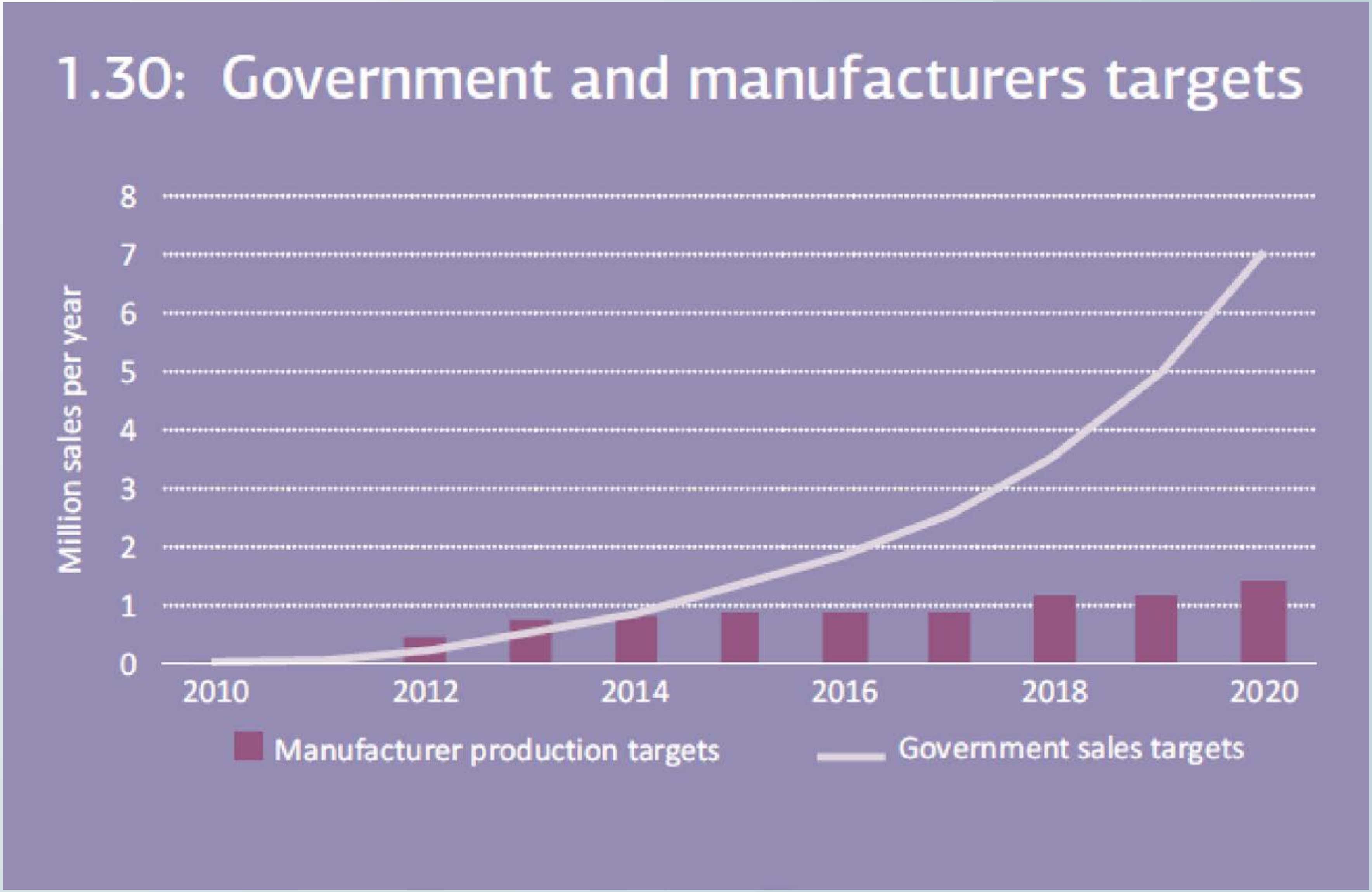
Electric Car Targets



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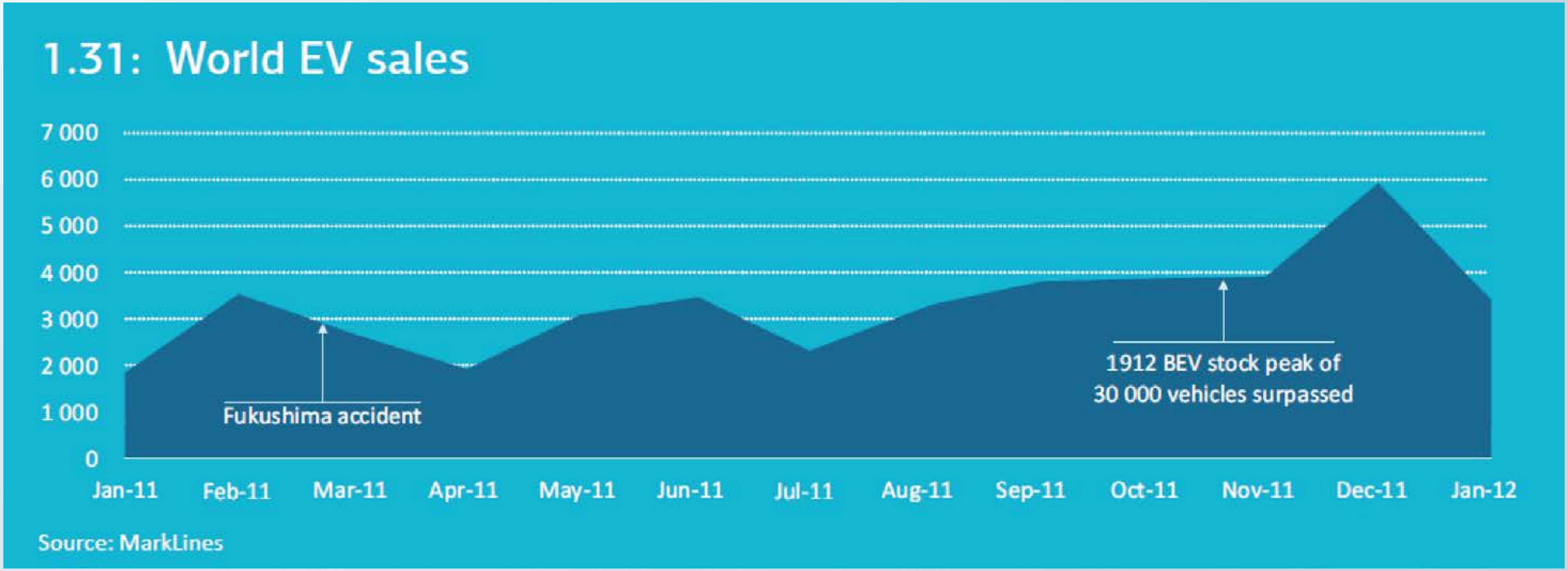
Electric Vehicle Sales



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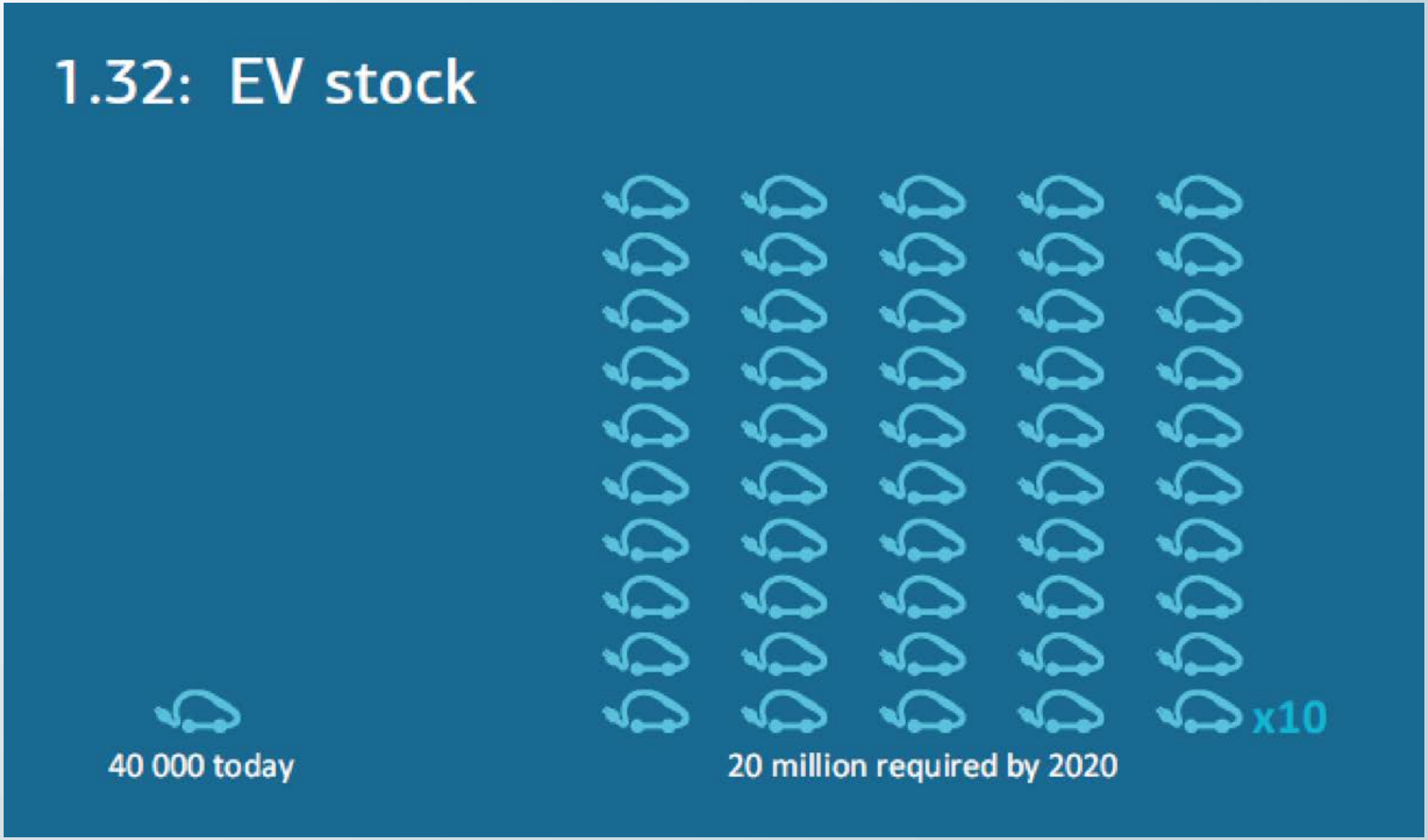
Electric Vehicle Stock



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Government Policy for Electric and Hybrid Vehicles

- Leveling the cost of ownership of EVs via incentive programs.
- Reducing concerns about battery life and vehicle resale value, possibly through battery leasing programs.
- Providing adequate recharging infrastructure to enable full local access and mobility, and assuage range anxiety. Consumer education will also be an important factor in this regard, as evidence shows that current EV driving range (190 km) is well above average daily vehicle use in many countries.
- Implementing some temporary advantages, such as priority access to urban parking spaces, access to low-emission zones, or access to priority access lanes on highways.

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.

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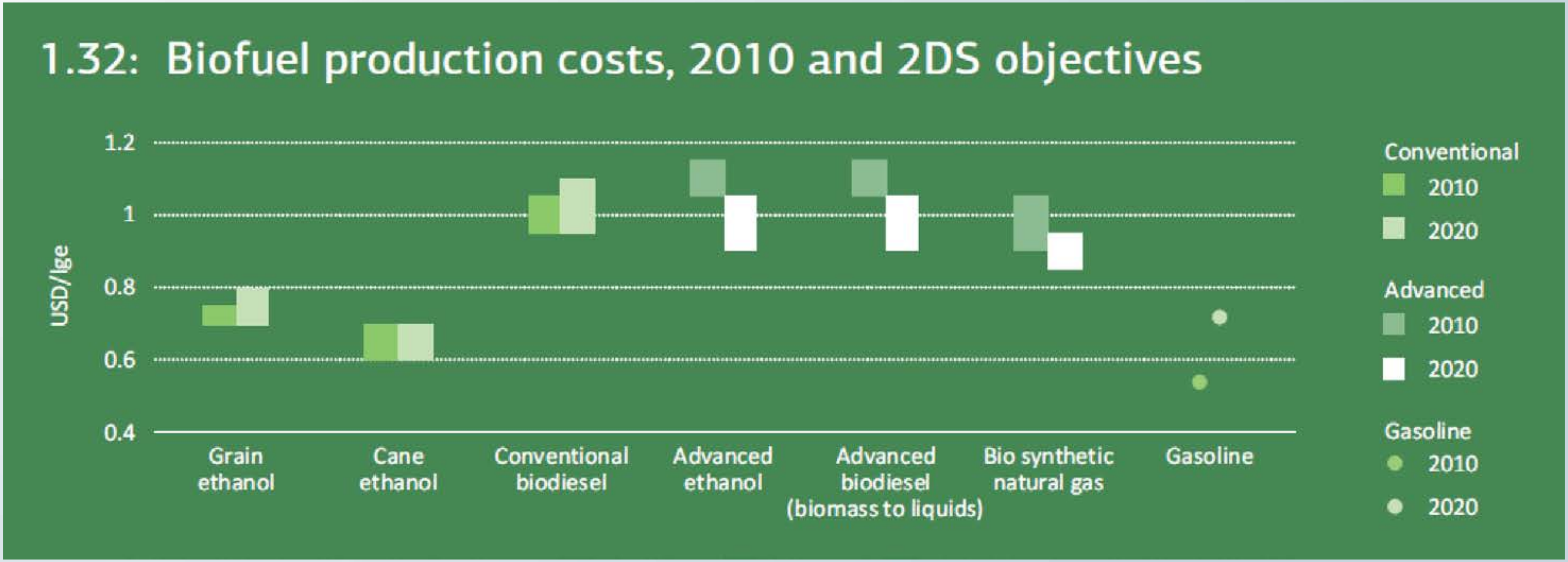
Biofuel Production



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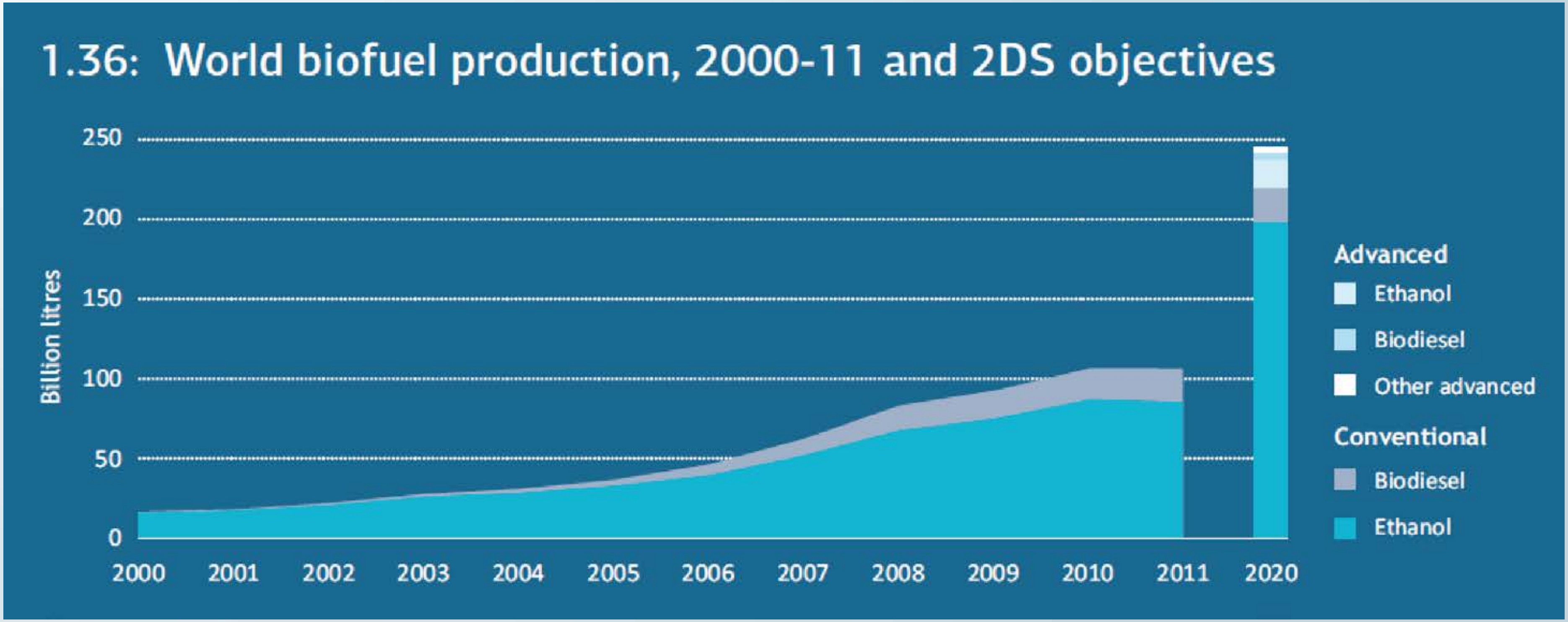
World Biofuel Production



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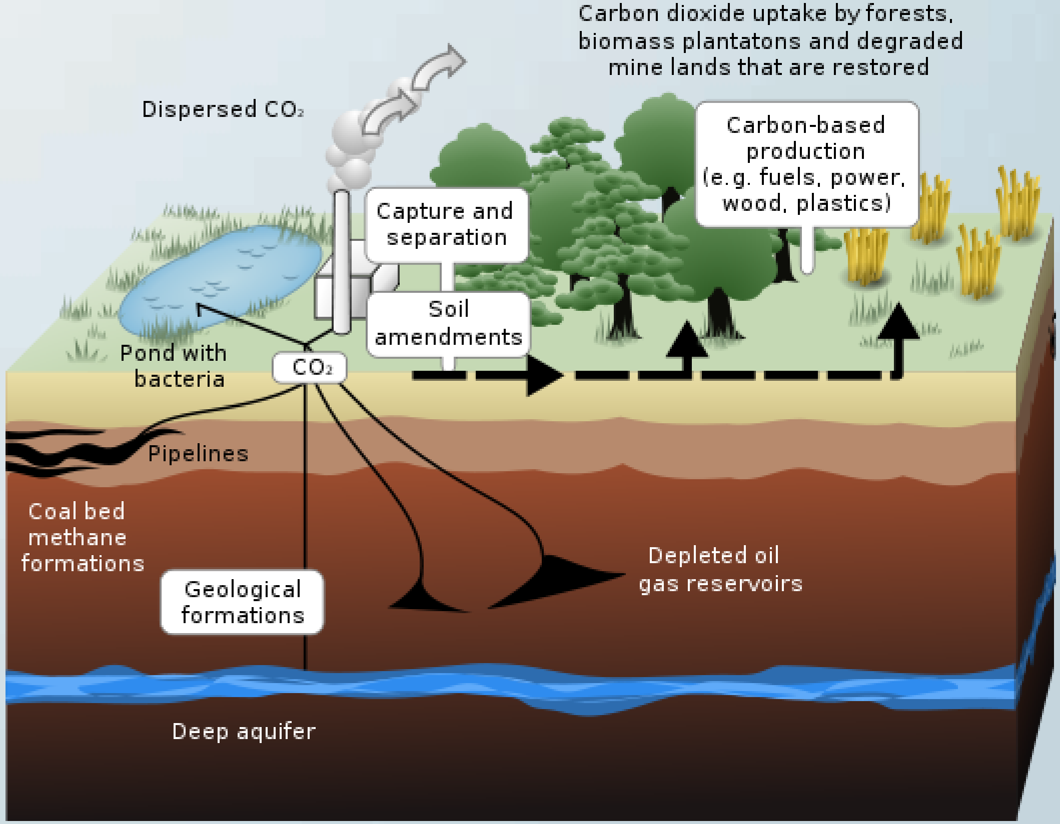
Government Policy - Biofuels

- 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.

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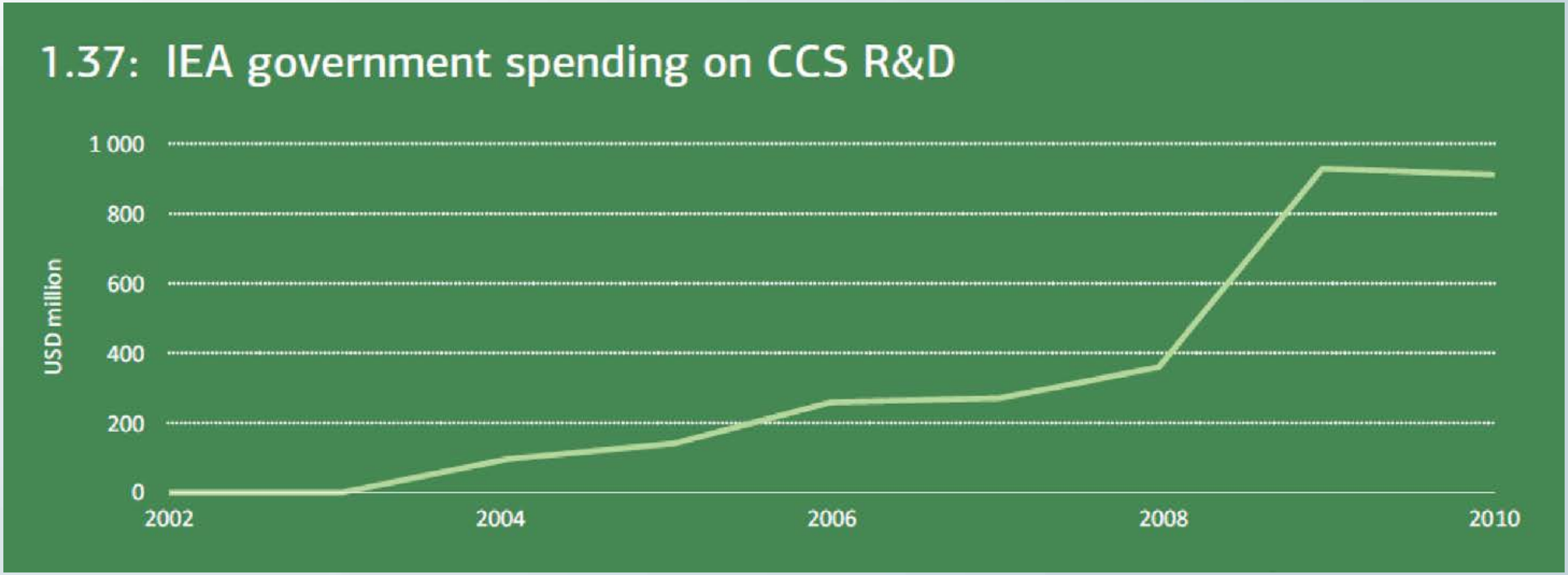
Carbon Capture and Storage Spending



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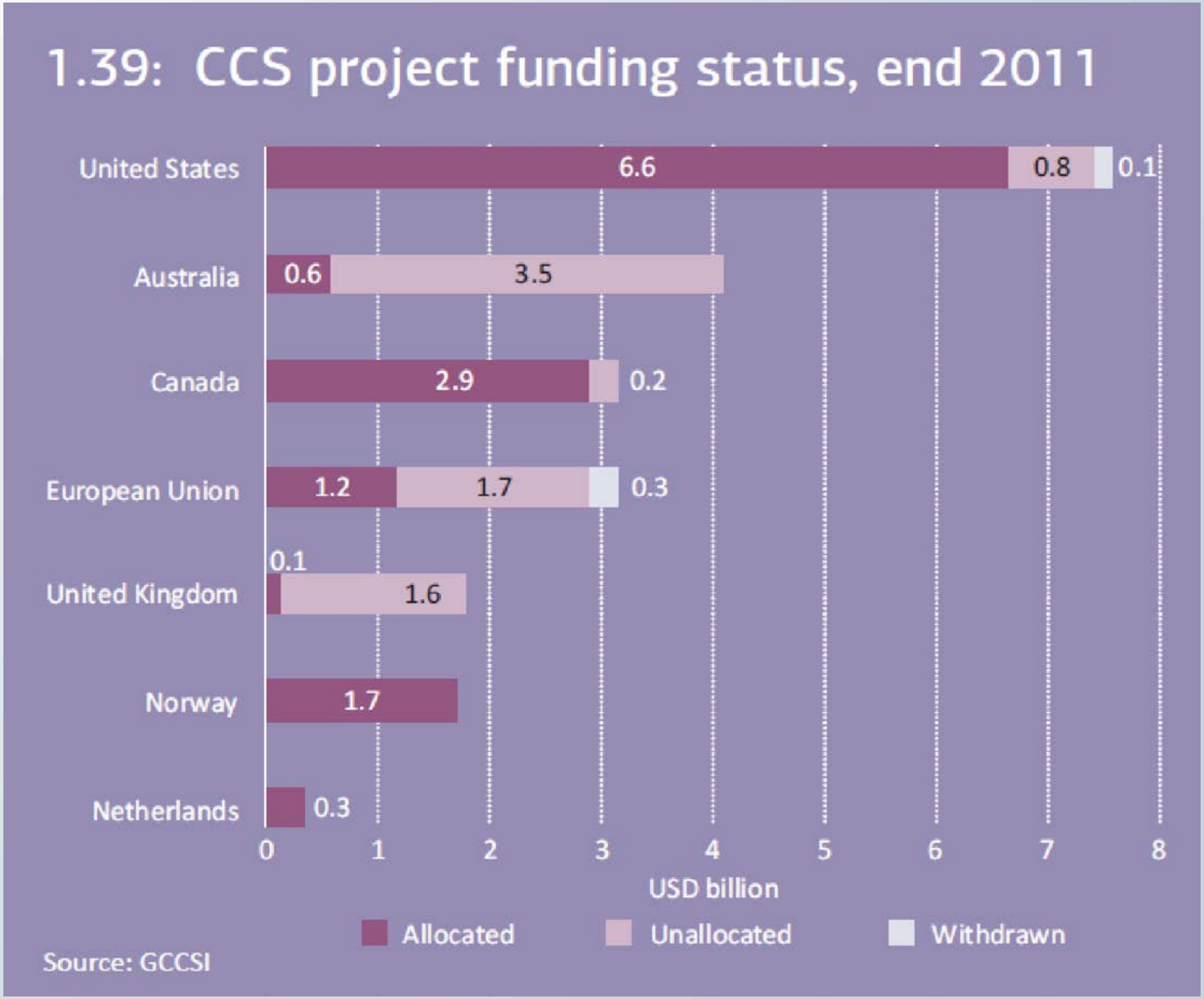
Carbon Capture and Storage



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Low-carbon Energy Investments

- Over the next decade, an estimated $24 trillion will need to be invested in power, transport, buildings and industry sectors in the 2DS. Investments in the transport sector represent the largest share, accounting for 34% of total investments, and globally will exceed USD 8 trillion over the next decade.
- Investments in the power sector are estimated at $6.4 trillion under the 2DS, of which China will account for nearly 30% of investments – equal to the combined investments of the United States and Europe.
- Compared to the investment requirements over the next decade under the 6DS of $19 trillion, total additional investment needs to achieve the 2DS is projected to be $5 trillion or 25% above investments needed in the 6DS.

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

Low-carbon Energy Investments

- The additional investment needed to transition to a low-carbon sector will have significant benefits, not only in terms of reduced environmental damage, but also improved global energy security, as dependence on fossil fuels is reduced. Improvements in energy efficiency will reduce the growth rate of energy consumption. The amount spent to purchase fuel will decline sharply with the switch from fossil fuels to renewables.
- The move away from traditional fossil-based energy technologies will result in significant fuel savings with reductions in the purchase of oil, gas and coal. An estimated $4 trillion will be saved in the 2DS from lower fossil fuel use and an additional $0.2 trillion will be spent on additional biomass for a net fuel savings of $3.8 trillion between 2010 and 2020.

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

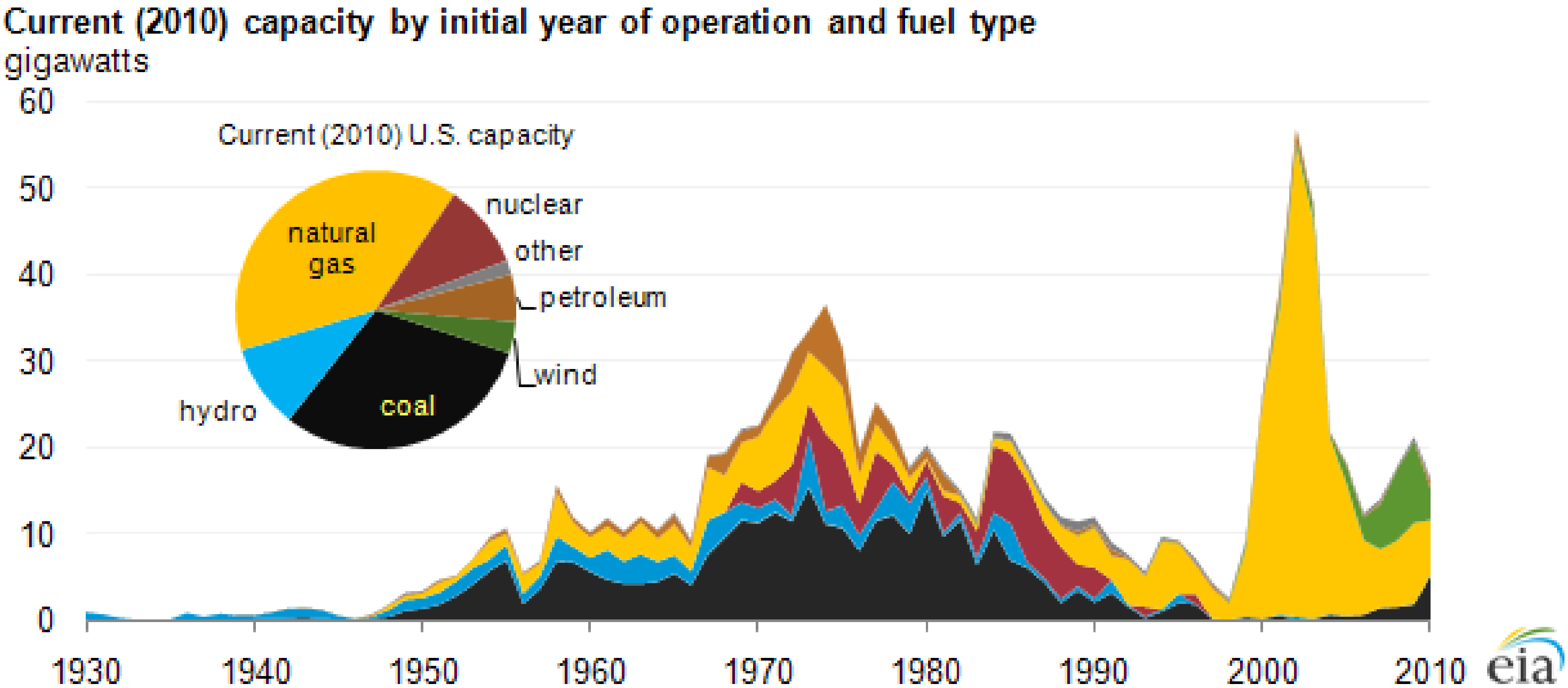
  http://membercentral.aaas.org/multimedia/videos/global-challenges-2010-climate-and-energy-policy-new-congress

Age of U.S. Power Plants

- According to the U.S. Energy Information Administration (EIA), *about 530 gigawatts, or 51% of all generating capacity, were at least 30 years old at the end of 2010.*
- The Nation's oldest power plants tend to be hydropower generators.
- *Most coal-fired plants were built before 1980.*
- *There was a wave of nuclear plant construction from the late 1960s to about 1990.*
- *The most recent waves of generating capacity additions include natural gas-fired units in the 2000s and renewable units, primarily wind, coming online in the late 2000s.*

http://www.eia.gov/energy_in_brief/age_of_elec_gen.cfm

Age of U.S. Power Plants



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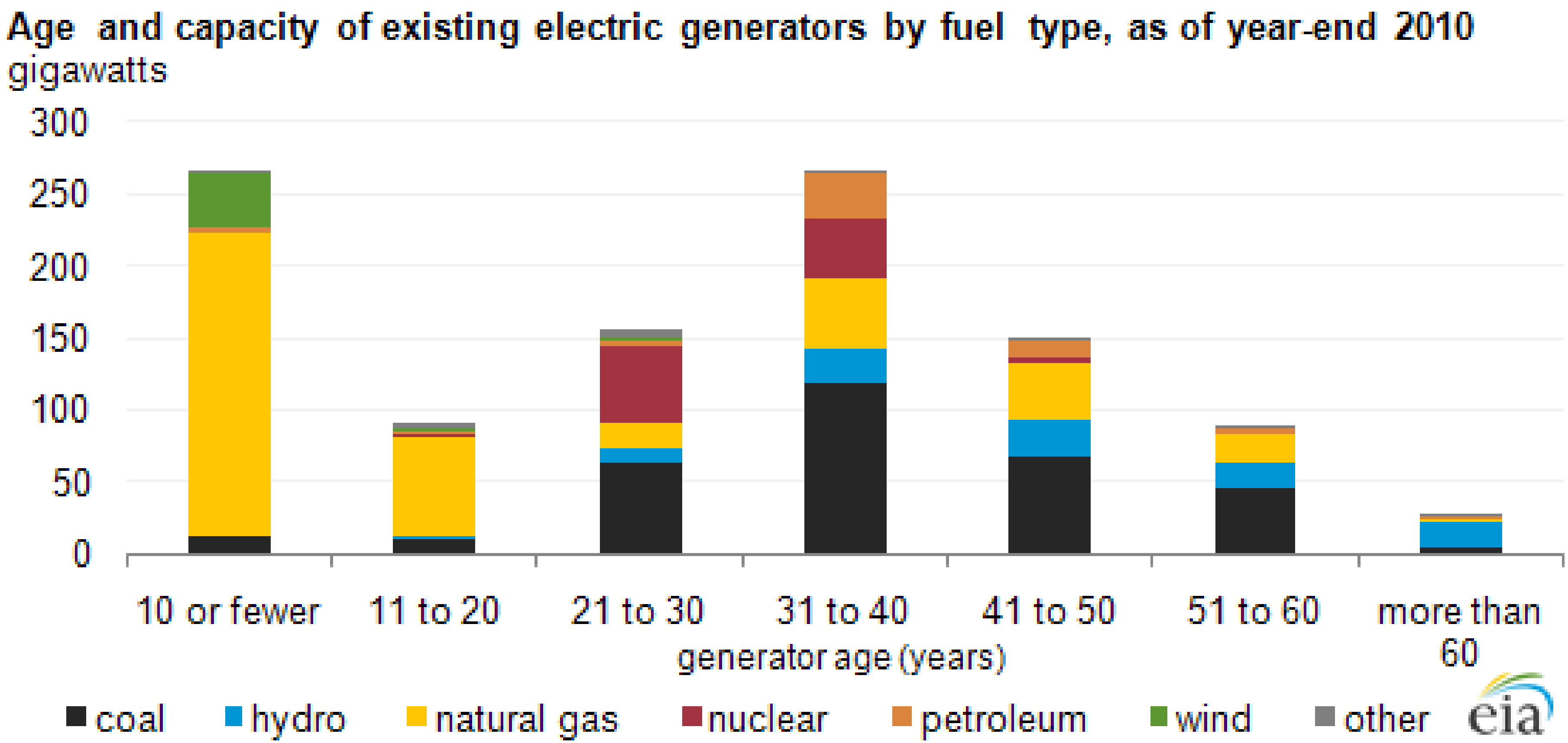
Age of U.S. Power Plants



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