能源及環境學院
SCHOOL OF ENERGY AND ENVIRONMENT

SEE 1003
Introduction to Sustainable Energy and Environmental Engineering

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01 – Global Energy Balance, Natural Resources

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SEE 1003 class overview

Week	Topics	Assignment issued	Key dates
Week 1	Course introduction; Climate Change and the Engineering approach		**Quiz 1**
Week 2	**MODULE I** Introduction to Sustainability Energy, Natural Resources and pollution, Electromagnetic energy; Electrical energy – Lighting, Light pollution, Policy	**Semester-long Project**	
Week 3		**Project deliverable 1.1**	
Week 4	**MODULE II** Motor, Generator – Transportation Air Pollution and Energy Consumption; Policy		
Week 5		**Project deliverable 1.2**	**Project deliverable 1.1**
Week 6	**MODULE III** Noise Pollution in Urban Environment	**Project deliverable 1.3**	**Quiz2**
Week 7	**MODULE IV** Urban Sustainability; Water and Energy Nexus		**Project deliverable 1.2**
Week 8	**MODULE V** Tools: Systems Analysis for Sustainability Cost-Benefit Analysis, Material Flow Analysis, Life Cycle Assessment		
Week 9			
Week 10	**MODULE VI** Advances in Environmental and Energy Engineering	**Project deliverable 1.4**	**Project deliverable 1.3; Quiz3**
Week 11	**MODULE VII** Waste management and Waste-to-Energy		
Week 12	**MODULE VIII** Economics and Policy of Energy and Environment	**Project deliverable 1.5**	**Quiz4** **Project deliverable 1.4**
Week 13	**Individual Presentations (5-mins)**		**Final Project Report**

Sustainable Development

"Humanity has the ability to make development sustainable - to ensure that it meets the needs of the present without compromising the ability of future generations to meet their needs."

Brundtland Report of the World Commission on Environment and Development (1987)

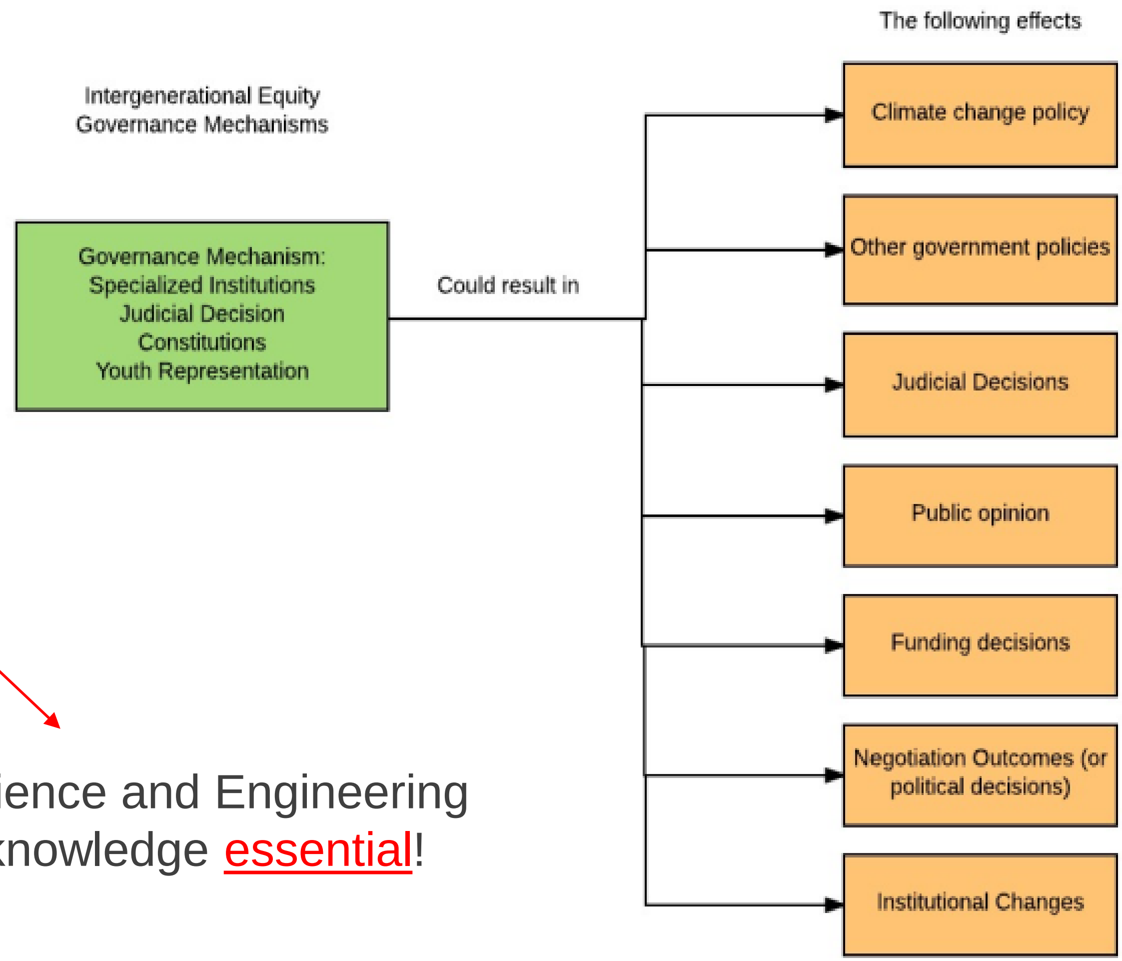
Inter-generational Equity

- Inter-generational Equity
  - Minimize any adverse impacts on resources and environment for future generation

E.g. Excessive mining of certain critical resources that results in depletion or exorbitant costs of extracting it in the future

Inter-generational Equity: Theory vs. Practice

- Implementation requires
  - **altruism, foresight, and sacrifice** that the current global social, political and economic systems don't facilitate
- **Metrics and Indicators needed** for analysis to understanding issues such as a **governance and justice**



Science and Engineering knowledge essential!

Intra-generational Equity

The future is already here — it's just not very evenly distributed

- William Gibson

- Technological development of rich countries should support economic growth of poor countries and lead to sustainability

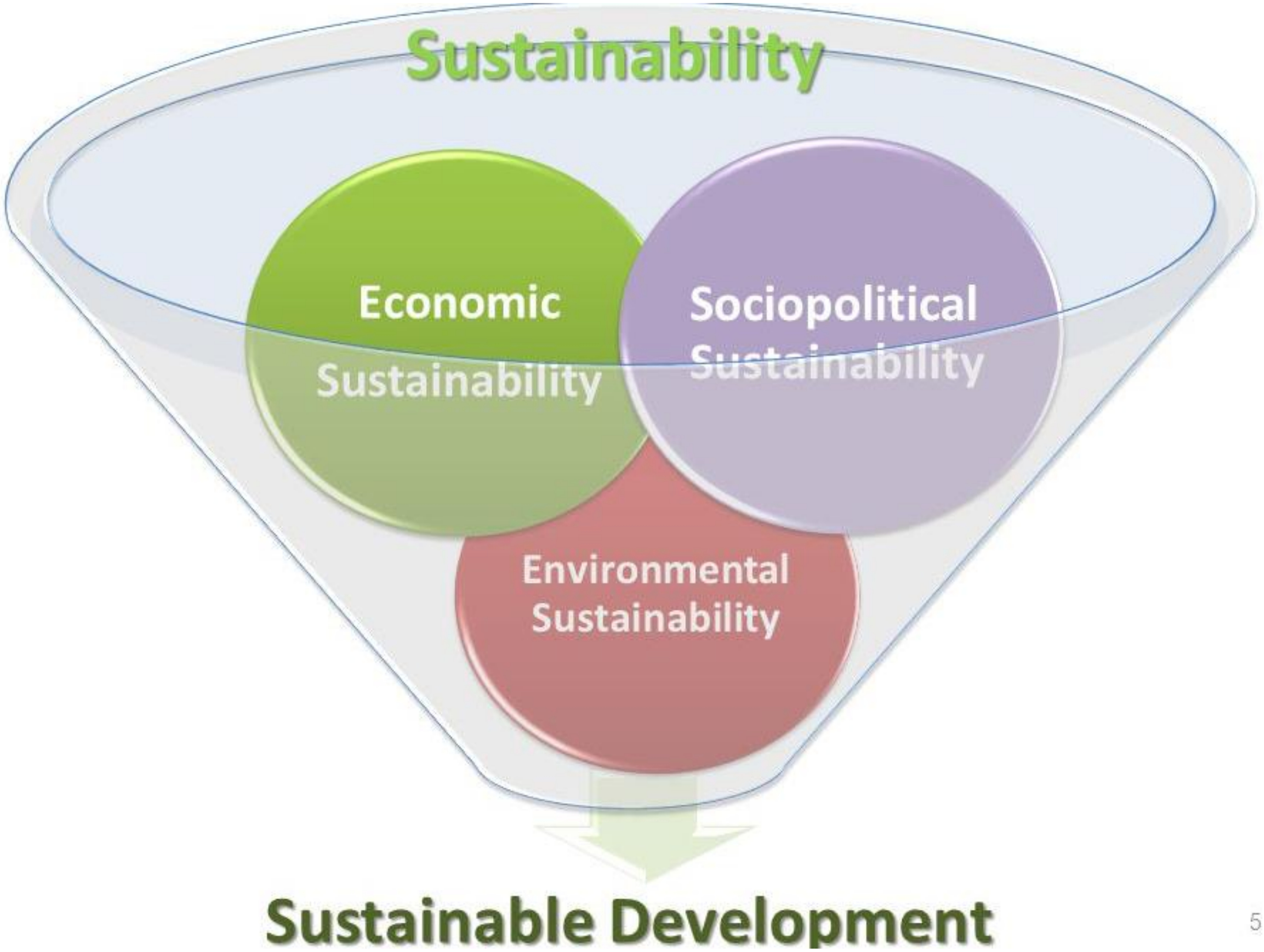
How about the conflict between **indigenous fishing communities and mechanized trawlers**? Is **technological development** a positive benefit in this case?

Sustainability vs. Sustainable Development

- Sustainable Development
  - "implies that environmental protection does not preclude economic development and that economic development must be ecologically viable now and in the long run"

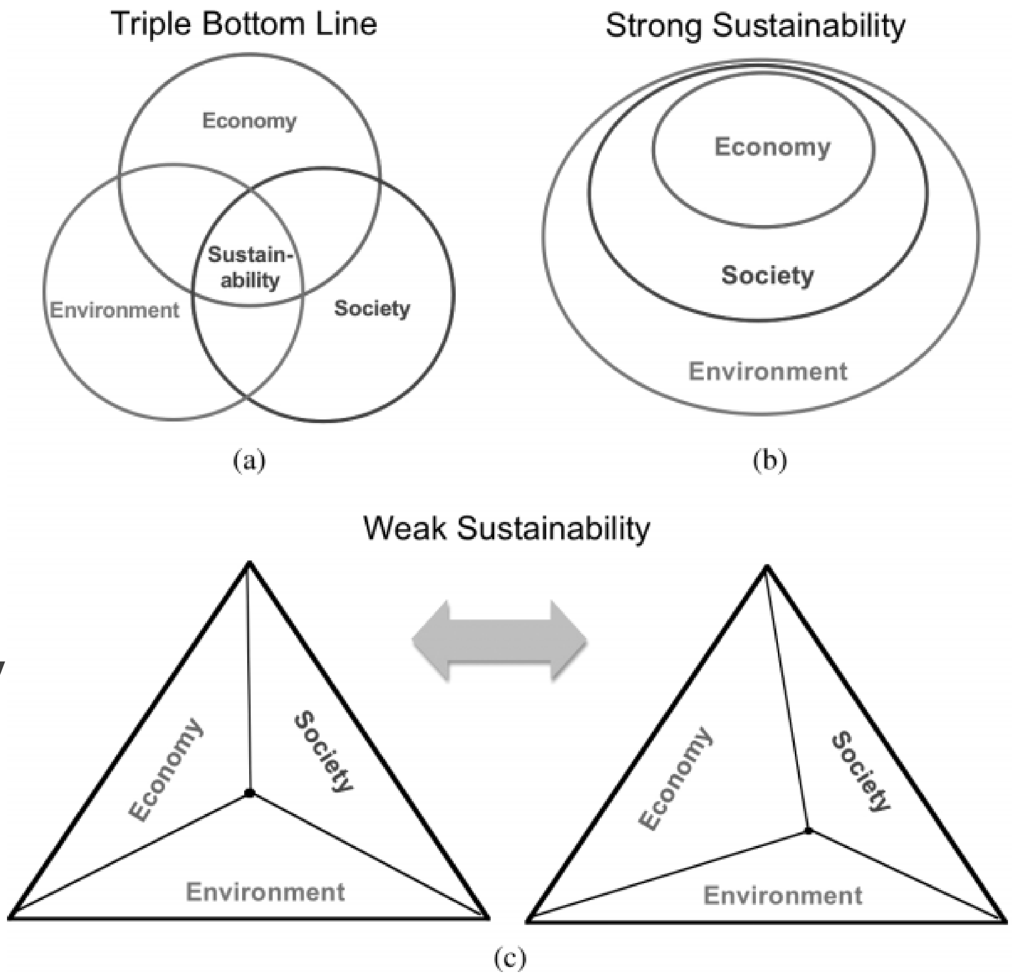
Sustainability

"encompasses <u>ideas, aspirations and values</u> that inspire <u>public and private organizations</u> to become better <u>stewards of the environment</u> and that <u>promote positive economic growth and social objectives</u>


Sustainability
Economic Sustainability
Sociopolitical Sustainability
Environmental Sustainability
Sustainable Development
5

Human and the Environment

The **triple bottom line** concept **implies that the three pillars are all necessary and equally important to sustainability**



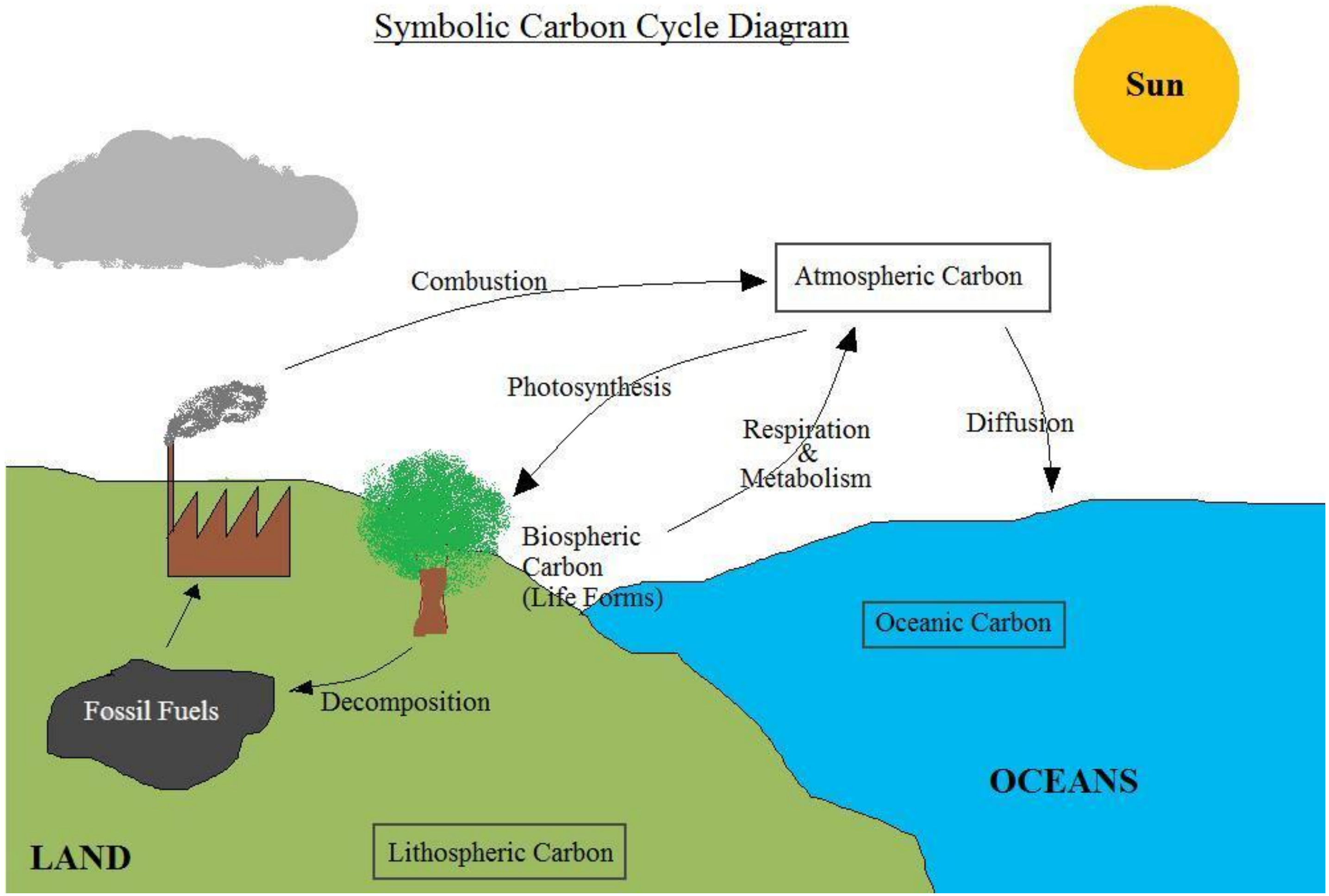
Strong sustainability implying that **the environment provides natural resources and ecosystem services necessary for economic and social development** — thus mutual substitutability between natural and human-made capital is not sensible.

Weak sustainability focuses on the attainment of **a non-declining level of the overall capital** while allowing for mutual substitution between the three pillars of sustainability

Strong and Weak Sustainability

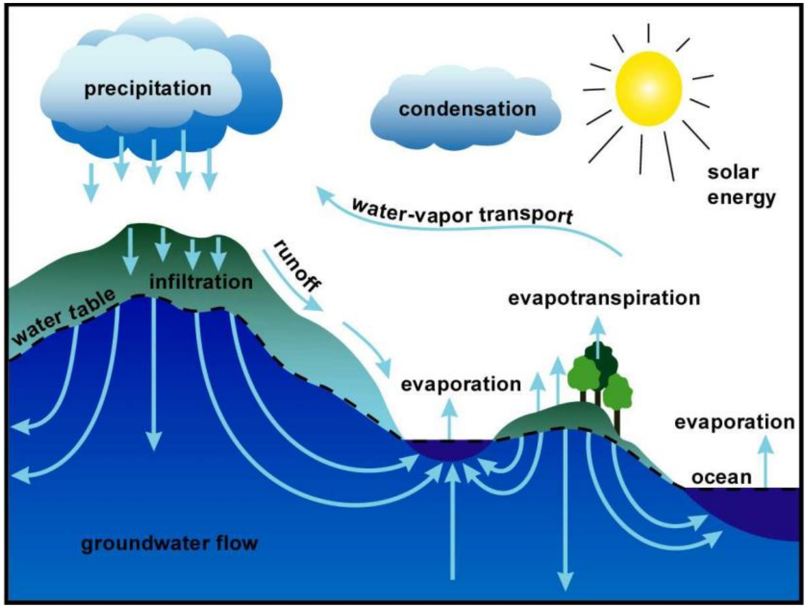
Energy for Sustainable Development

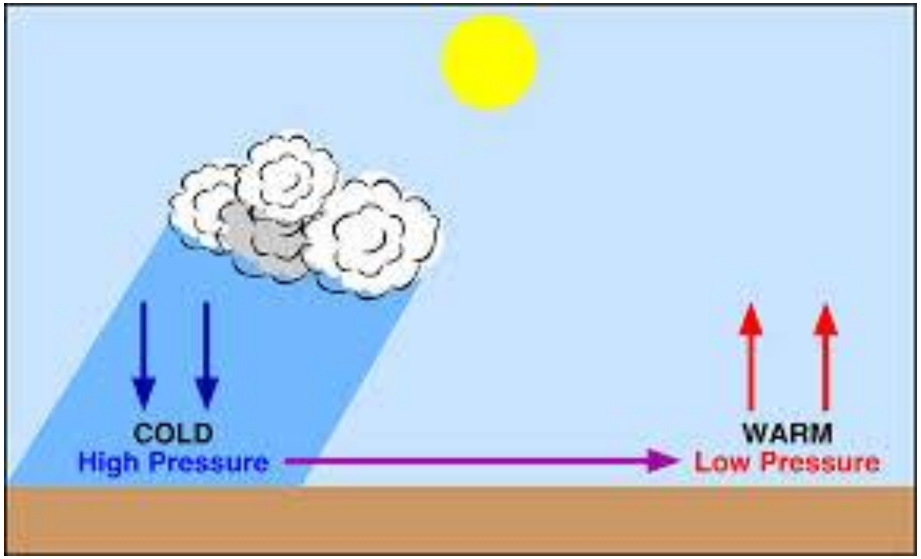
- Where do Earth's natural resources come from?
  - Fossil fuels
  - Uranium
  - Solar energy
  - Wind Energy
  - Tidal energy
  - etc.
- Most are driven ultimately by solar radiation
- On Earth there is a complex interaction between sub-systems involving oceans, cloud, land, volcanoes, plants, animals, etc.
  - So called 'natural cycles'
  - Although man has intervened somewhat to disrupt these
- Scientists define specific cycles to model flows between sub-systems, for example
  - Carbon cycle
  - Hydrological (water cycle)



Symbolic Carbon Cycle Diagram
Sun
Combustion
Atmospheric Carbon
Photosynthesis
Respiration
&
Metabolism
Diffusion
Biospheric
Carbon
(Life Forms)
Oceanic Carbon
Fossil Fuels
Decomposition
OCEANS
LAND
Lithospheric Carbon

Hydrological Cycle



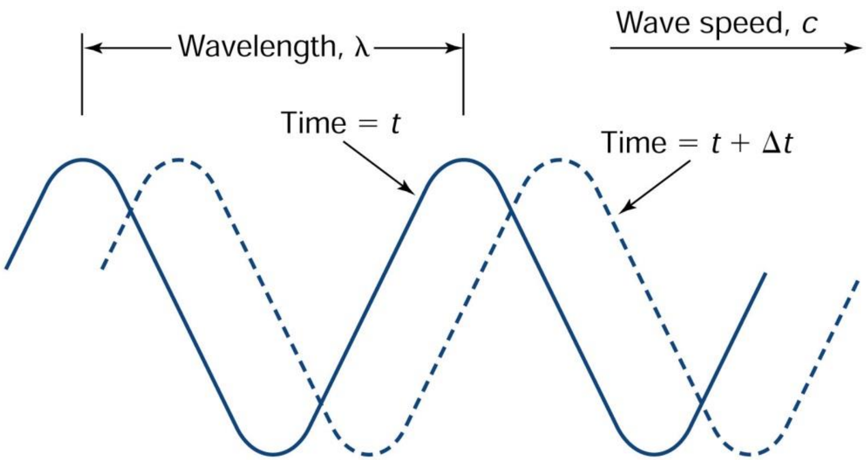


Earths Energy Budget

- The sun is responsible for most of the Earth's energy resources
- The surface of the Sun has a temperature of about 5,800K
- At that temperature, most of the energy the Sun radiates is visible and near-infrared light
- The Earth is in 'energy balance'
  - That's why it maintains a roughly constant temperature of about 288K
  - The sun's (short-wave) radiation impacting on Earth is balanced by the thermal (longwave) radiation emitted by Earth

Some basic physics

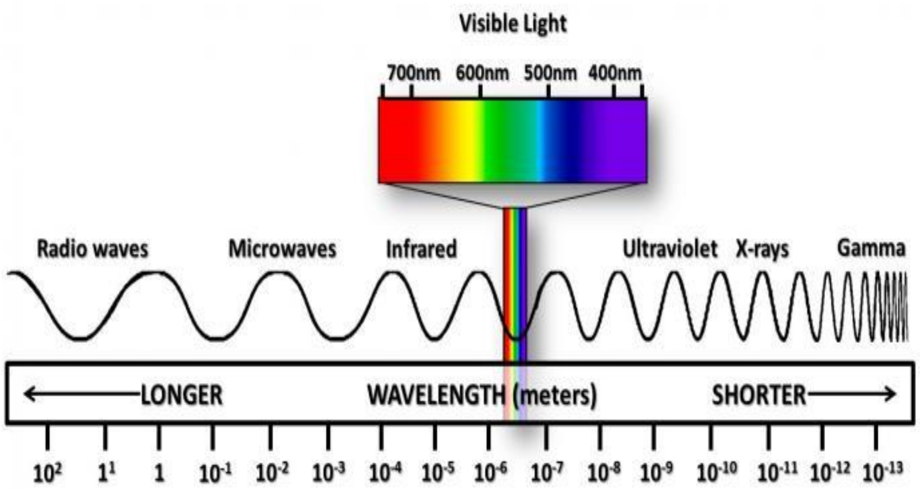
- Hot bodies (or any body with a temperature above zero degrees Kelvin) emits electro-magnetic radiation
  - This is propagated as a transverse wave
  - Waves are defined by their speed (c), wavelength λ, and frequency ν
  - Frequency and wavelength are inversely related



$$c = \lambda\nu$$
$$c = 3.8 \text{ x } 10^8 \text{ m/s}$$

Some basic physics

- The 'electro-magnetic' spectrum gives different names to these EM waves according to their wavelength (or frequency/energy)
  - For example visible light has a wavelength between 0.4 and 0.7μm
  - X rays and gamma rays have much shorter wavelength and hence higher frequency/energy explaining why they are more dangerous



$E = h\nu$

h is Planck's constant ($6.62606957 \times 10^{-34}$ m^2 kg / s)

Power and Energy

- A word on units:
  - Energy is expressed as Joules (J) – measures heat, electricity and mechanical work
    - The Joule is the SI unit of energy
      - 1 kg m^2 s^{-2}
    - 1 Joule is a *tiny* unit of energy which is why it's almost always prefixed with M(10^6), G(10^9) ……
  - There are some other more exotic units for energy which are often used in the energy business
    - For example the British thermal unit (Btu) is the energy to raise 1 lb of water by 1ºF
      - 1 Btu ≈ 1kJ

Power and Energy

- The BTU (British Thermal Unit) is often used and in particular the quadrillion (10^{15}) BTU which is about 1 exajoule (10^{18})
  - Total world energy consumption is around 500 exajoules (2010) which is roughly 500 quadrillion BTU!
- We can easily convert between different units
  - joule = 9.48×10^{-4} BTU
  - 1 boe (barrel of oil equivalent) = 5.45×10^6 BTU
  - 1 toe (ton of oil equivalent) = 39.7×10^6 BTU
  - 1 cubic feet of natural gas = 983 BTU
  - 1 metric ton of coal = $22.72 * 10^6$ BTU
  - 1 exajoule = 174 million boes

	kJ	kWh	kcal	BTU
kJ	1	2.7778×10^{-4}	0.23884	0.947817
kWh	3600	1	859.845	3412.14
kcal	4.1868	1.1630×10^{-3}	1	3.9683
BTU	1.05505	2.9307×10^{-4}	0.25200	1

kJ :Kilojoule

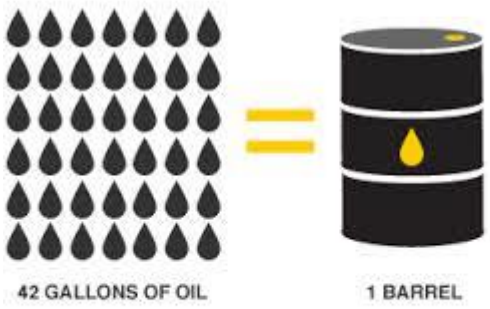
kWh:Kilowatt Hour

kcal :Kilocalory

BTU:British Thermal Unit

Power and Energy

- We can get a reasonable idea about our annual energy use per capita by using the boe (barrel of oil equivalent unit)
  - Hong Kong ranks about 69^{th} in the world with an average annual per capita energy consumption of around 78 million BTU's
    - Approximately 14 barrels of oil equivalent!
    - By contrast, average consumption is about 6 barrels in the developing world



Power and Energy

- Power is the *flow* of energy
- A good analogy is to compare it with fluid flow
- A useful unit of energy is the kilowatt-hour
  - That's the energy delivered by a power source of 1kW in 1 hour
  - It's equal to 1000 x 3600 J = 3.6MJ
  - Quite often people refer to average energy consumption (for example kWh per day) which is a power

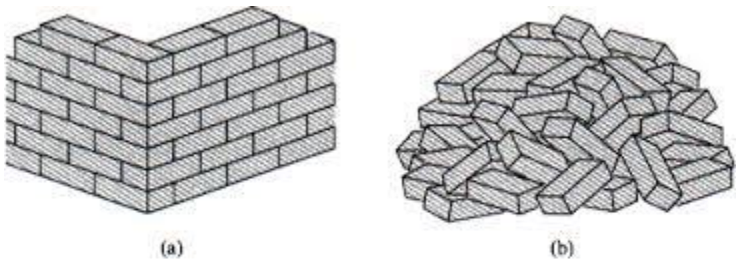
energy = power x time

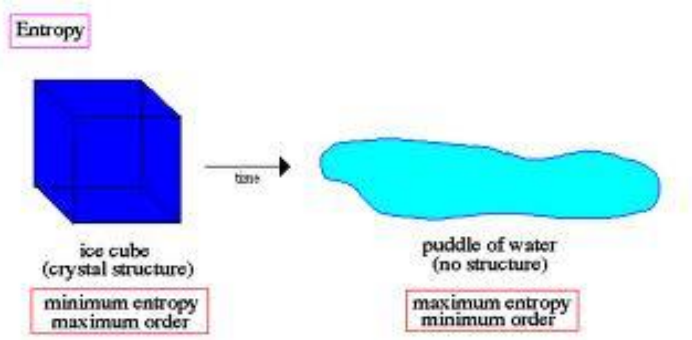
volume = flow x time

Energy (kWh)	**Power (kW)**
Volume (litres)	Flow (litres/second)

Energy and Entropy

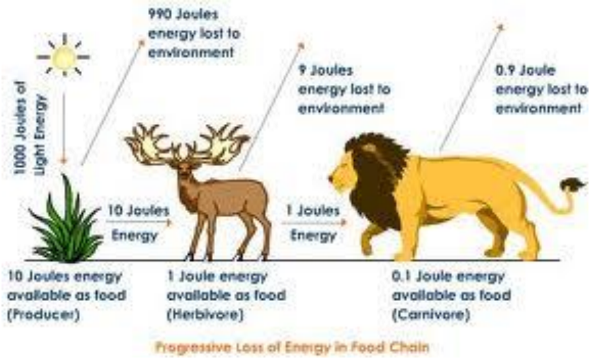
- Is all energy the same?
  - Yes and no!
    - Yes
      - In the sense of energy conservation
    - No
      - In the sense of *useful* (low entropy) and *less useful* (high entropy) energy
- Entropy is the amount of disorder (randomness) in a system
  - Highly disordered = High entropy
  - Entropy always increases meaning systems get more disordered
    - A wall of bricks will collapse
    - An ice cube melts
    - A dye will diffuse in a liquid

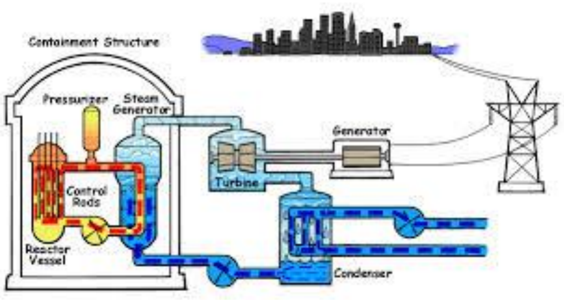




Energy and Entropy

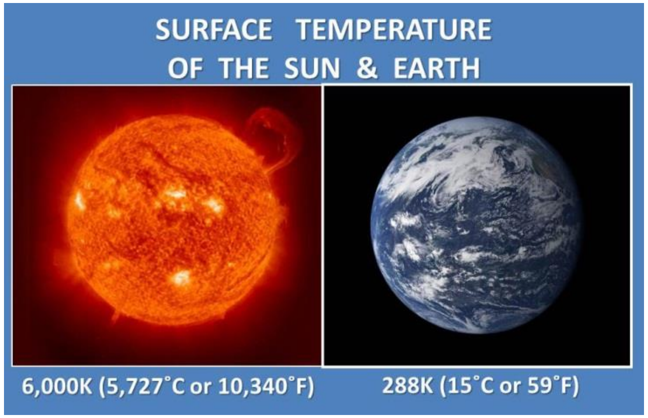
- So we can distinguish different grades of energy
- **Electrical, chemical, mechanical and nuclear** energy are all useful forms
- **Thermal energy** (especially in tepid things) is less useful
  - You can use electrical energy to run your TV or convert it to heat to boil a kettle
  - You can't do either with a tepid bath full of water
- Often the energy 'grade' is reflected in the units kWh(e) – electrical and kWh(th) – thermal
- Conversion between energy grades incurs losses usually as thermal
  - Burning chemical energy (oil) to produce electrical energy is about 40% efficient
  - The food chain is essentially a chain of increasing entropy!
  - A steam turbine needs a low temperature (condenser) to 'dump' entropy

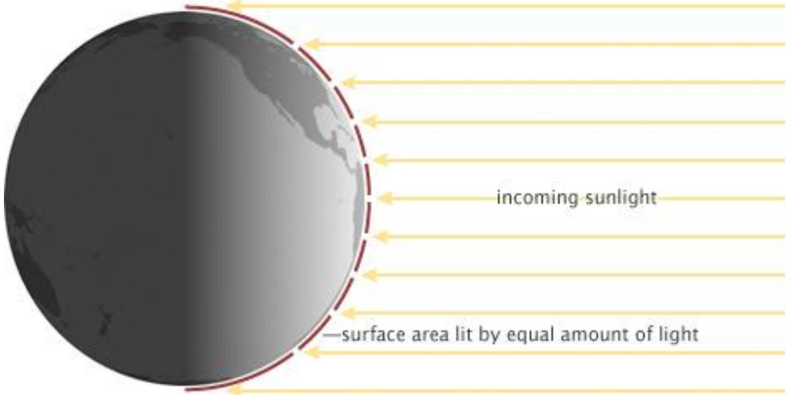




Incoming Energy to Earth

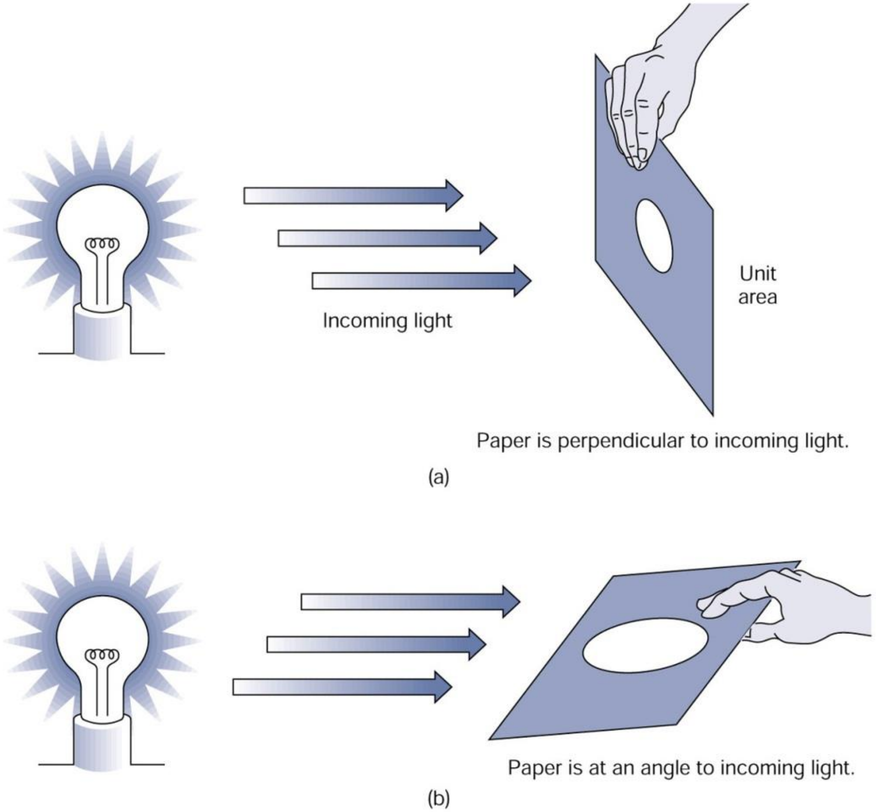
- The amount of heat energy reaching the Earth's surface (measured in watts per square metre) depends on 3 things
  - The energy flux
  - The sun's temperature
  - The distance to the sun
- Obviously, there are other factors such as the amount of reflection in the upper atmosphere





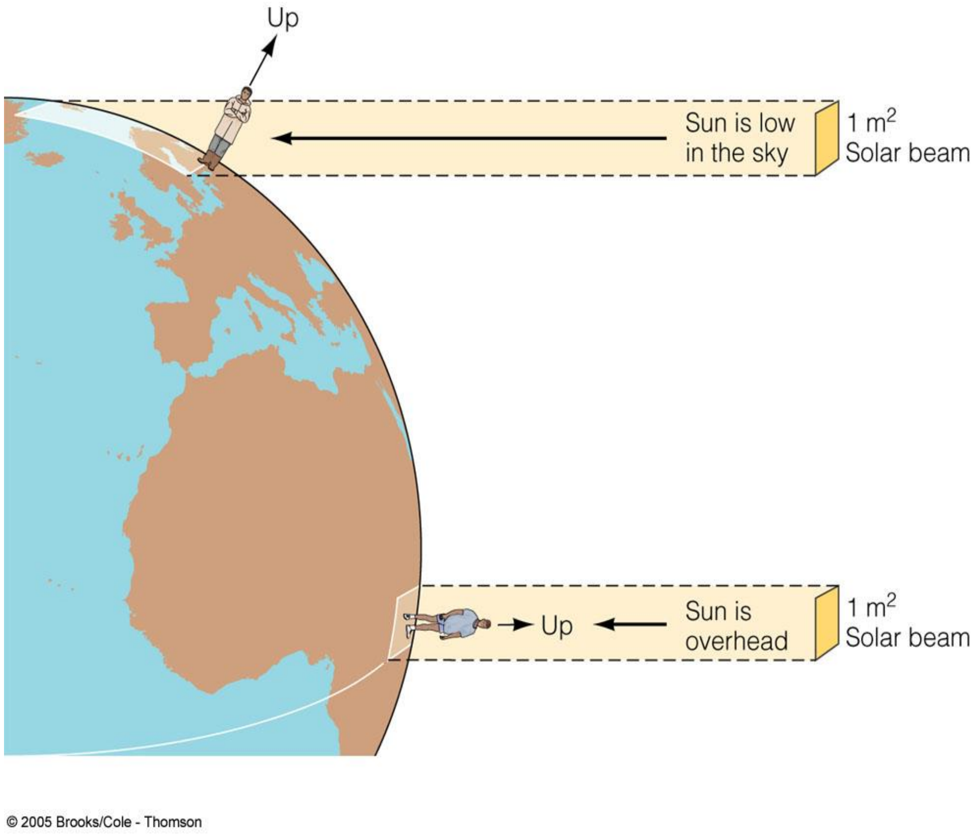
Energy Flus: basic physics

- Energy flux is how much energy (or any material) passes through a unit surface area per unit time
  - Units: W/m^2
  - $J/m^2/s$



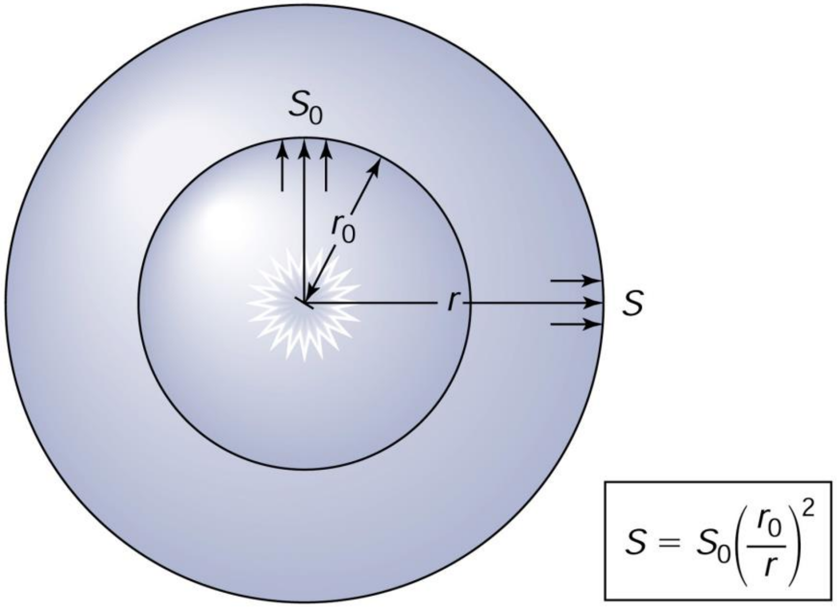
Some basic physics

- The angle of the impacted earth's surface to the sun affects the flux
- Clearly the flux depends on the latitude
- Nearer the equator – higher flux
  - More watts per square metre
- Polar regions cooler due to lower energy flux



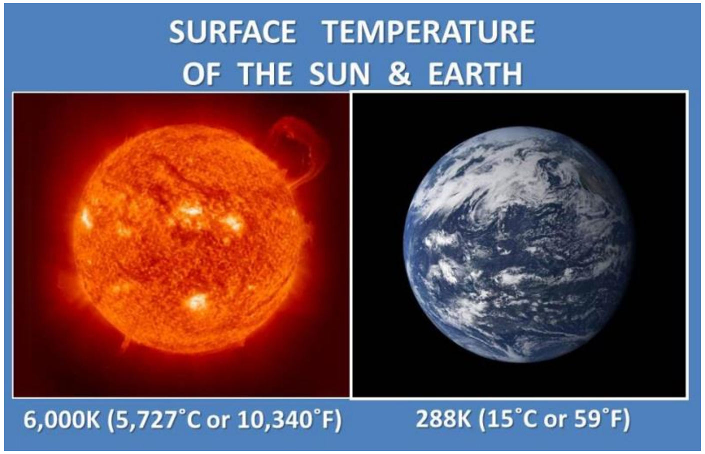
Some basic physics

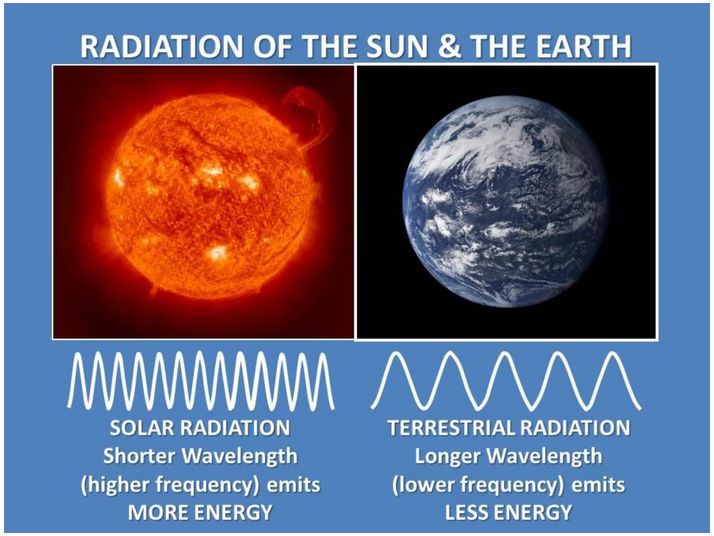
- Flux also depends on distance of an object or observer from the object emitting the radiant energy
  - Flux of solar energy decreases with distance from the sun
  - Relationship is an inverse-square law



Solar Radiation

- All matter in the universe that has a temperature above absolute zero radiates energy across a range of wavelengths in the electromagnetic spectrum
- The hotter something is, the shorter its peak wavelength of radiated energy is
  - The hottest objects in the universe radiate mostly gamma rays and x-rays
  - Cooler objects emit mostly longer-wavelength radiation, including visible light, thermal infrared, radio, and microwaves



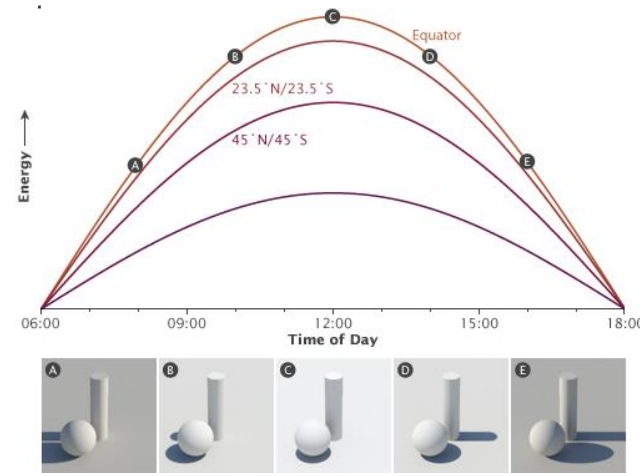


Solar Radiation

- What all this amounts to is that at Earth's average distance from the Sun (about 150 million kilometres), the intensity of solar energy reaching the top of the atmosphere directly facing the Sun is about 1,360 watts per square meter
  - This is often known as the total solar irradiance or sometimes the insolation

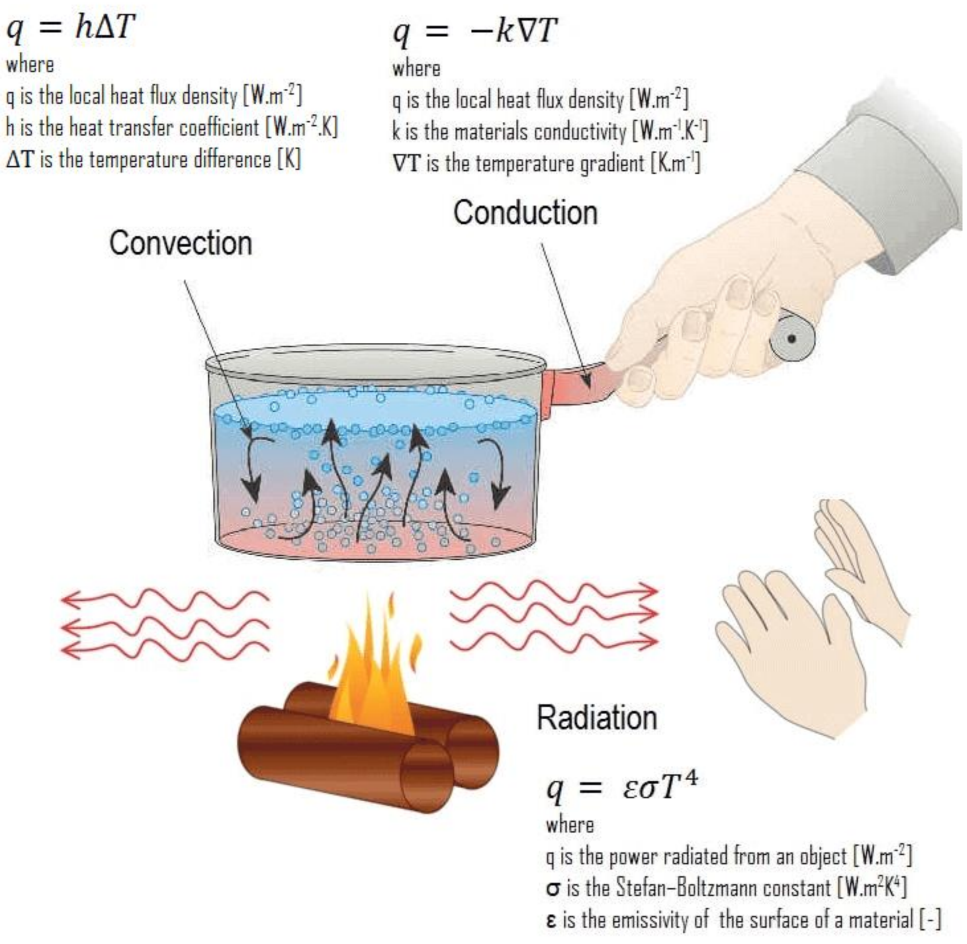
- You could run a refrigerator all day with the total solar irradiance falling on 1 square metre in 1 hour

- It's important to understand that this is a *maximum*
  - For example this assumes that the radiation hits the surface perpendicularly (maximum flux)
  - Also the value varies significantly with time of day and latitude
  - Averaged over the entire planet, the amount of sunlight arriving at the top of Earth's atmosphere is only 1/4 of the total solar irradiance, or approximately 340 watts per square

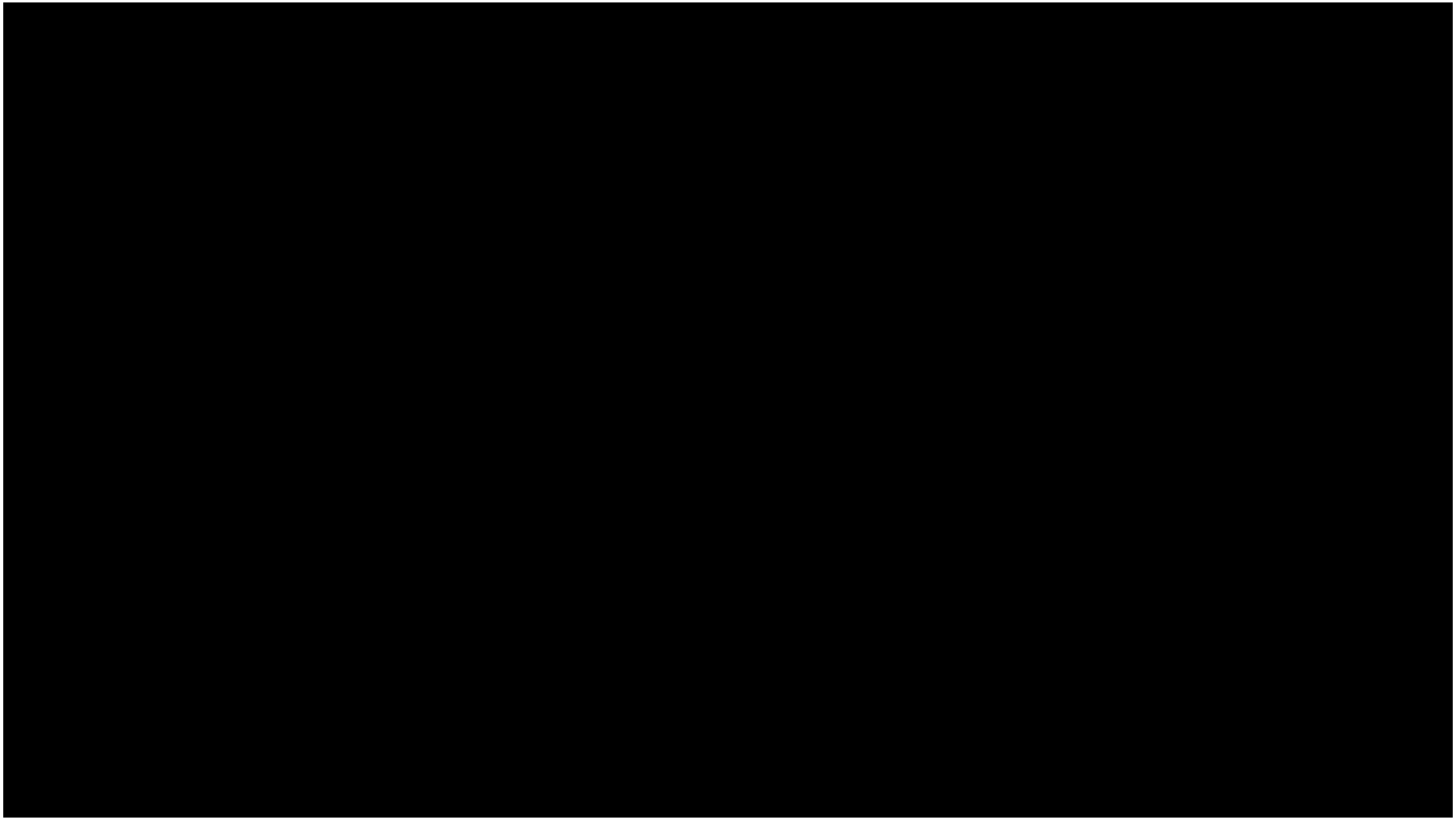


Earth's Energy Balance

- If Earth's temperature is constant, the planet has to be in radiative balance
- Many complex processes are at work to maintain a constant temperature and these are responsible (amongst other things) for our climate
  - However, the physical principles at work are basically simple mechanisms of heat transfer
    - Radiation
    - Conduction
    - Convection
    - Latent heat

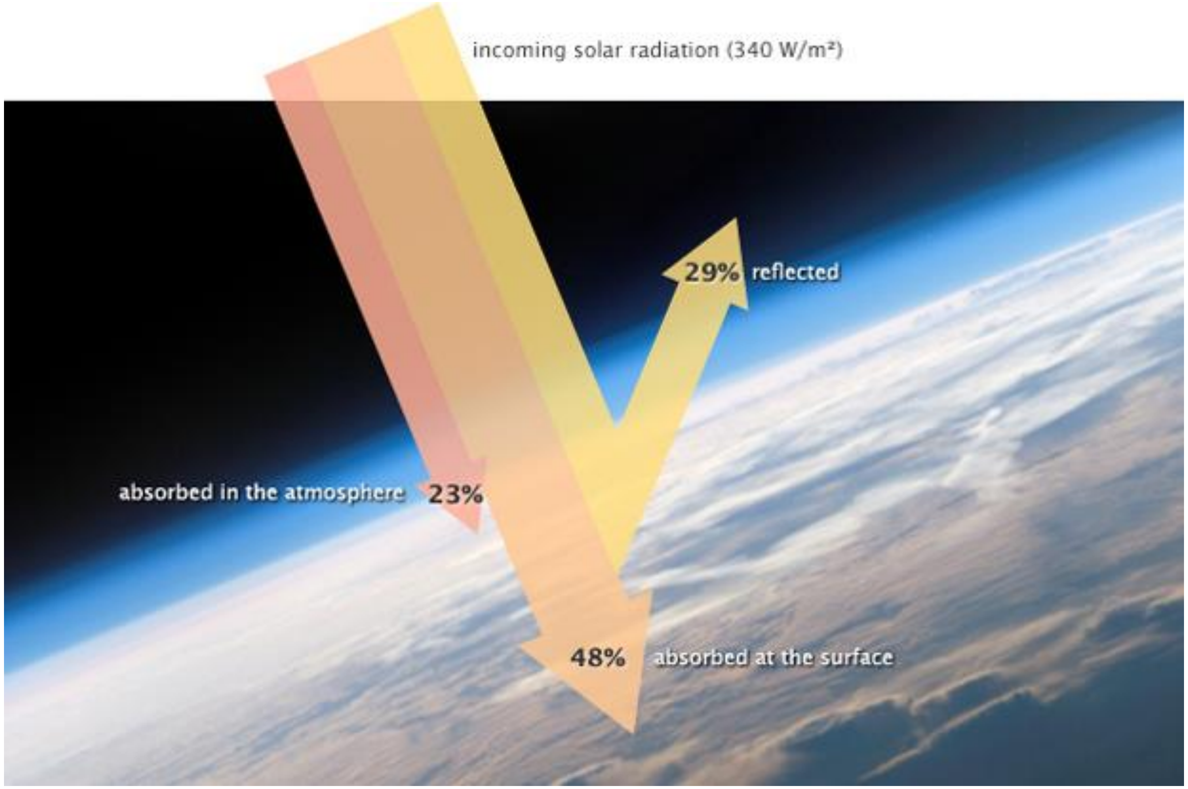


Energy Balance of the Earth



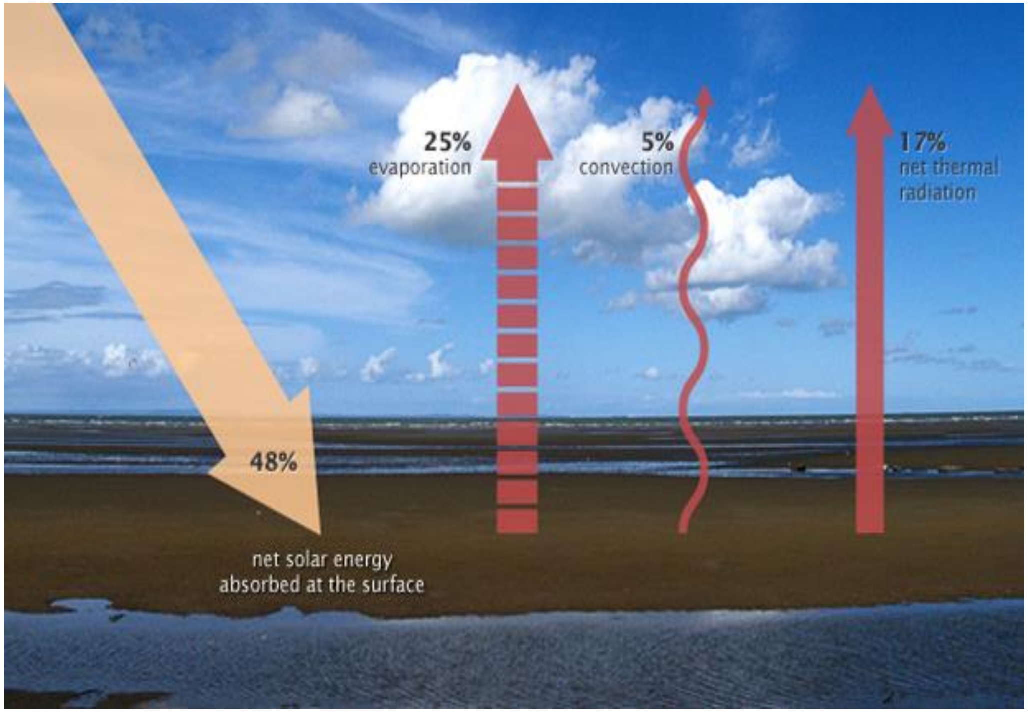
Earth's Energy Balance

- Only around 50% of incoming solar radiation gets through the atmosphere to the Earth's surface
  - Around 70% of the radiation is absorbed by Earth and ultimately returned to space as IR
  - Energy input = energy output



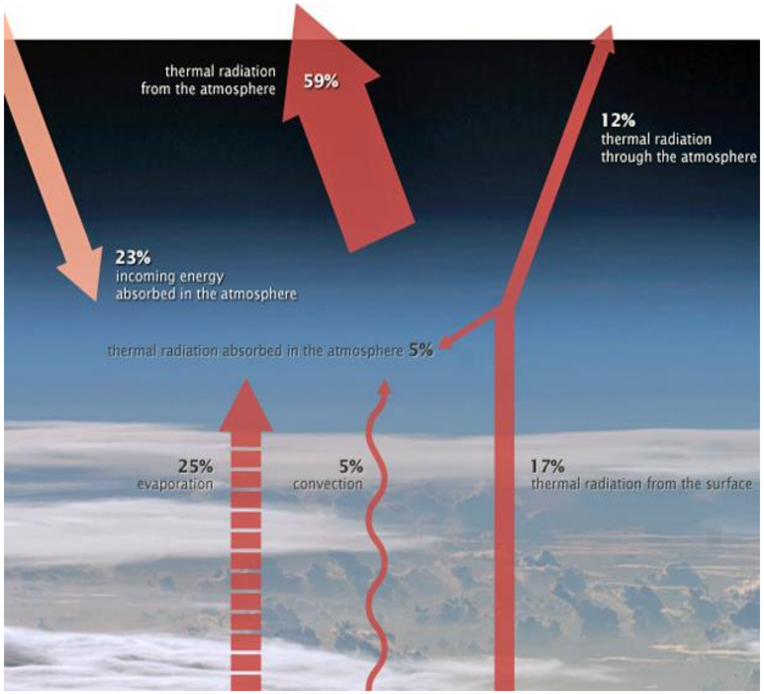
Earth’s Energy Balance

- There must be an energy balance for the 48% of radiation reaching Earth’s surface
- This is emitted through evaporation (25%)
  - Latent heat
- Convection (5%)
  - Heated warm air rising causing air currents
- Radiation (17%)
  - Thermal infrared energy (heat) radiated by atoms and molecules on the surface



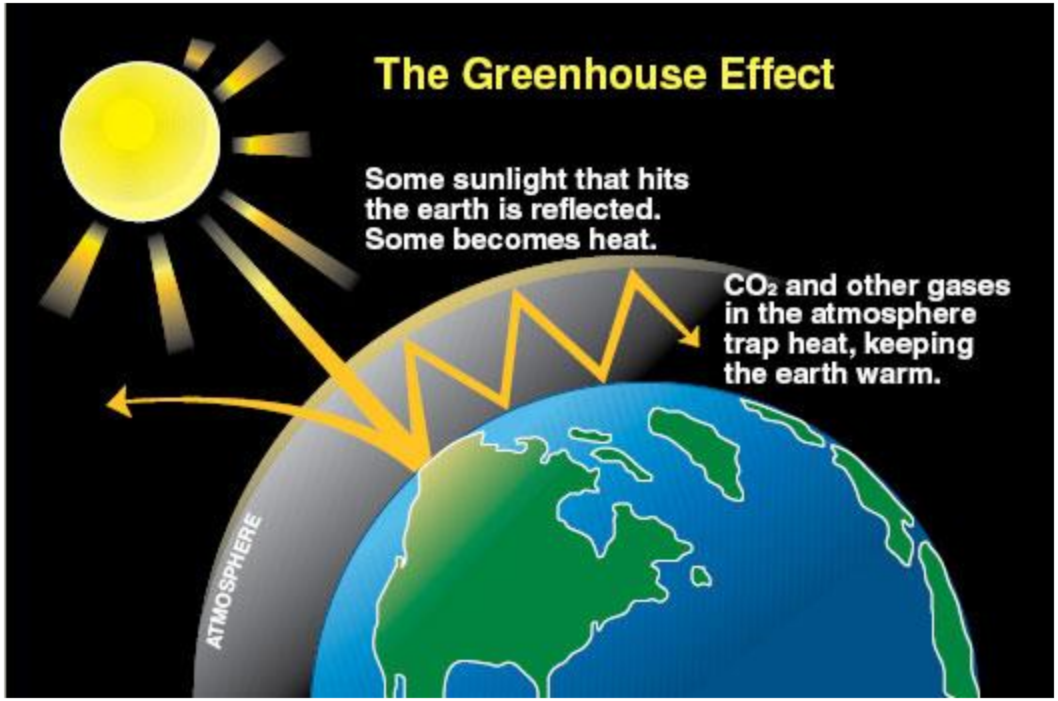
Earth’s Energy Balance

- We can work out an energy balance also for Earth’s atmosphere which demonstrates the natural greenhouse effect
  - Satellite measurements indicate that the atmosphere radiates thermal infrared energy equivalent to 59% of the incoming solar energy
  - Clouds, aerosols, water vapour, and ozone directly absorb 23% of incoming solar energy
  - Evaporation and convection transfer 25% and 5% of incoming solar energy from the surface to the atmosphere totalling the equivalent of 53% of the incoming solar energy to the atmosphere
  - The remaining 5-6% comes from the Earth’s surface
    - Absorbed by greenhouse gases, these greenhouse gas molecules radiate heat in all directions, some of it spreads downward and ultimately comes back into contact with the Earth’s surface, where it is absorbed – ‘natural greenhouse’ effect



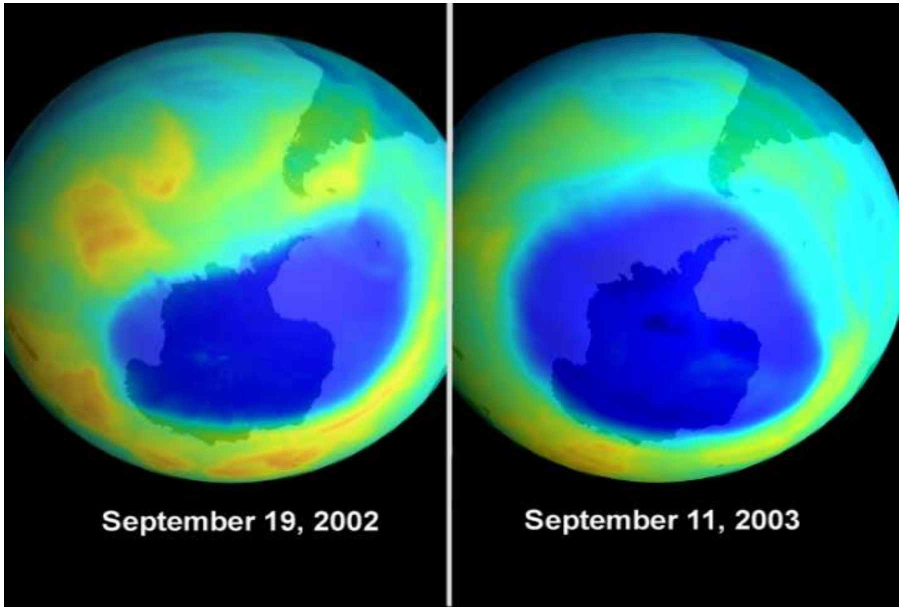
Earth's Energy Balance

- The 'natural' greenhouse effect is essential to support life
  - Major role in warming atmosphere
  - Traps heat
  - Without greenhouse gases, planet would be much colder (~ -20^{o}C)
- Note that 'greenhouse' is an unfortunate term
  - Real greenhouses suppress convection through the glass whereas the 'greenhouse effect' is all about radiated heat



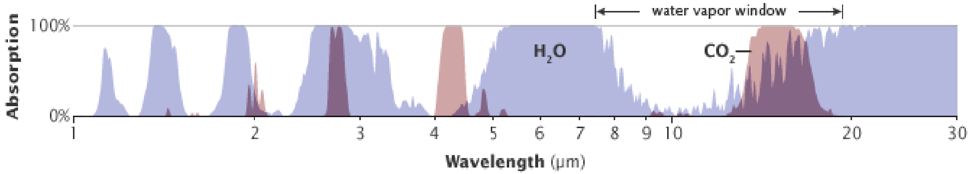
Earth's Energy Balance

- Incidentally, this explains the importance of the O_3 layer
  - Absorption takes place in the O_3 layer
  - A depleted O_3 layer is very harmful to humans
  - The size of the Antarctic ozone hole reached 11.1 million square miles on September 24, 2003, slightly larger than the North American continent
  - Check out Nasa's ozone watch web site for up to date animations
    - http://ozonewatch.gsfc.nasa.gov/



Earth’s Energy Balance

- It’s worth mentioning the man-made greenhouse effect
- About 17% of incoming solar radiation is radiated by Earth’s surface
  - Of this, 12% escapes into space and 5-6% is captured by greenhouse gases and re-radiated in all directions
  - This is a fine energy balance which keeps a stable temperature on Earth
- There are many man made phenomena which effect this energy balance and hence Earth’s surface temperature
  - Pollution (aerosols), which absorb and reflect incoming sunlight
  - Deforestation, which changes how the surface reflects and absorbs sunlight
  - The rising concentration of atmospheric carbon dioxide and other greenhouse gases, which decrease heat radiated to space



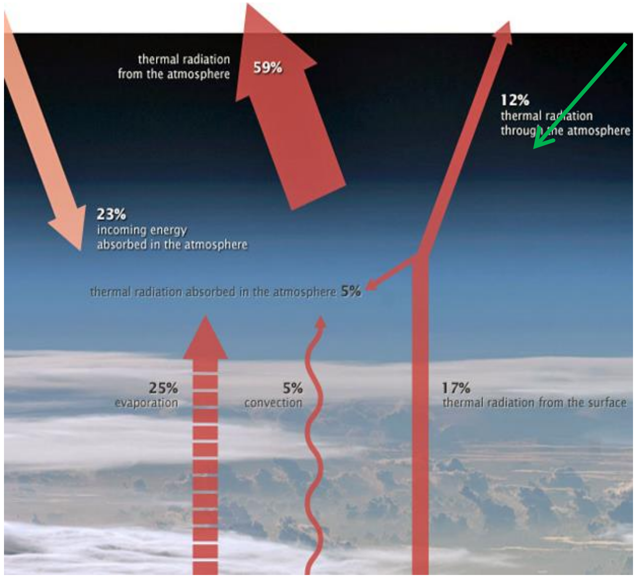
Earth's Energy Balance

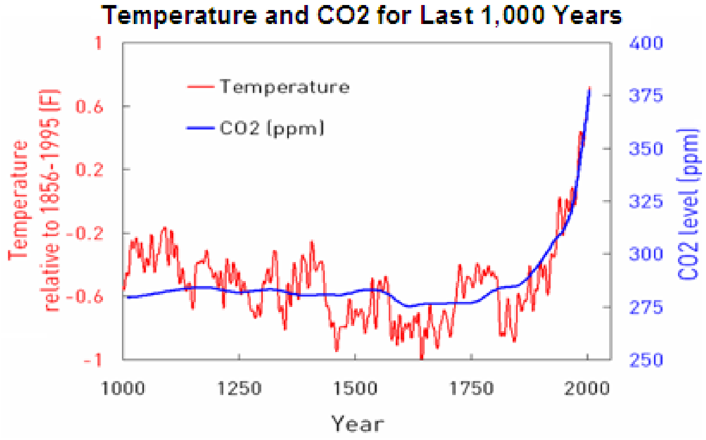
Man made reduction
12% -> ~11%

- Effectively the energy imbalance changes the temperature
  - However, remember the Stefan-Boltzmann law

$$E = \sigma T^4$$

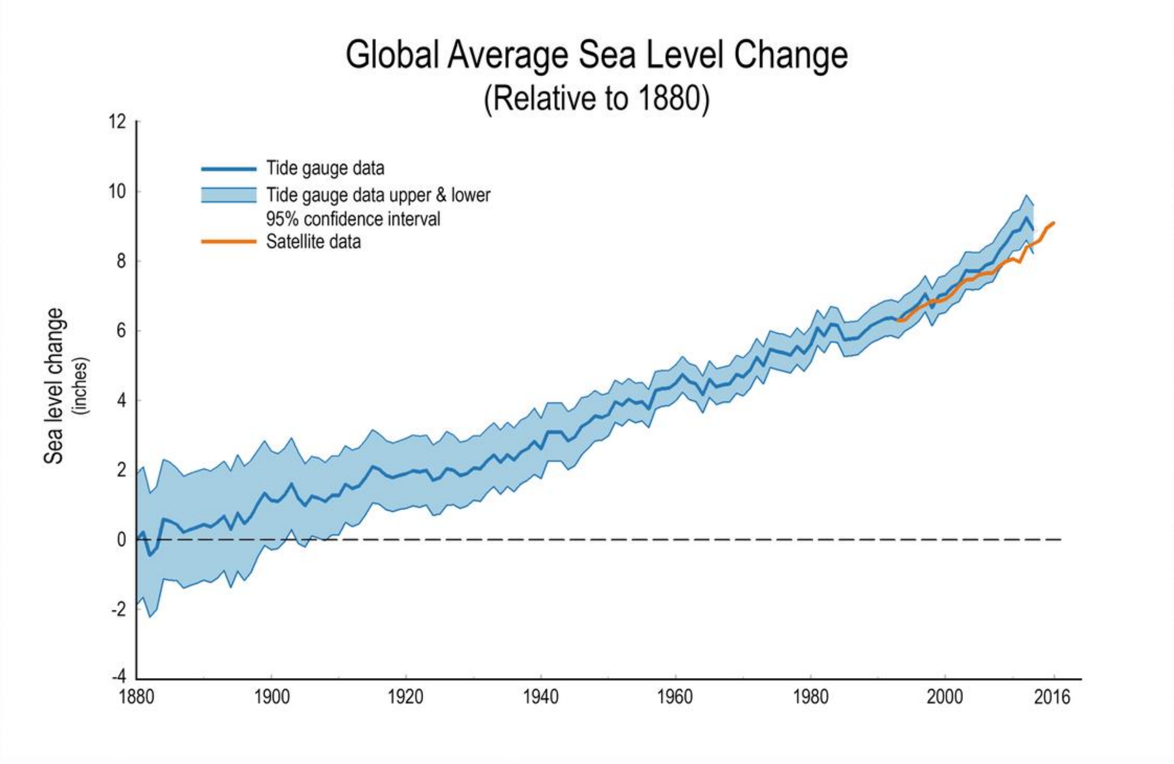
  - Changes in temperature are negligible because of the 4th power
  - Global average surface temperature has risen between 0.6 and 0.9K in the past century
  - The concern is continued and increasing concentrations of greenhouse gases

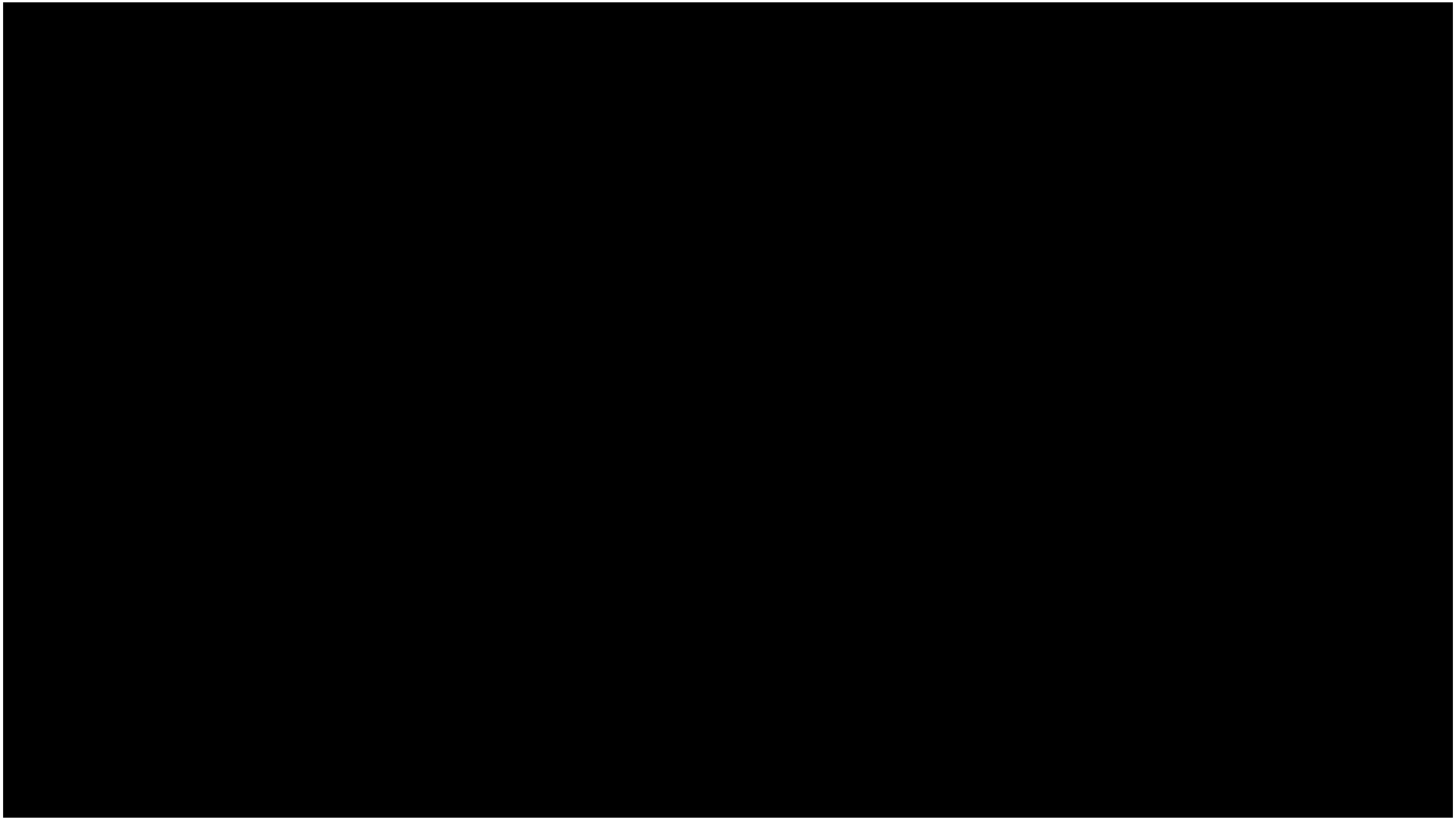




CO_2 Emissions and Climate Change

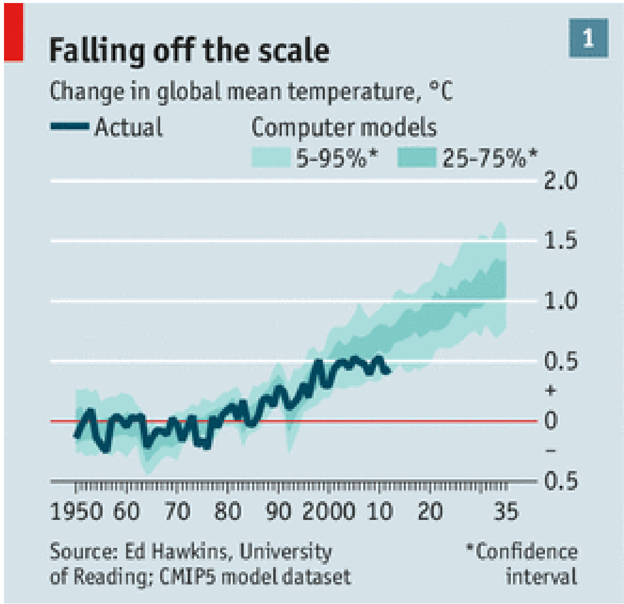
- Global warming will impact our weather patterns, affect global ecosystems, cause rising sea levels (as is happening already) in coastal low-lying areas and impact large numbers of people
- NASA satellites have shown that sea levels are rising more quickly, about 8 inches since 1880





CO_2 Emissions and Climate Change

- Global warming – fact or myth?
  - There is much debate about the extent of global warming both from serious scientists as well as vested interests
  - No one doubts that we are pumping carbon dioxide into the atmosphere at increasing rates
    - The world added roughly 100 billion tonnes of carbon to the atmosphere between 2000 and 2010 mainly through burning fossil fuels. That is about a quarter of all the CO_2 put there by humanity since 1750
  - No one doubts that CO_2 is a greenhouse gas
    - This is easily shown in the laboratory
  - However, there is a doubt as to how much the planet will be warmed
    - Predictive models are complex and must involve factors such as clouds and aerosols as well as feedback systems

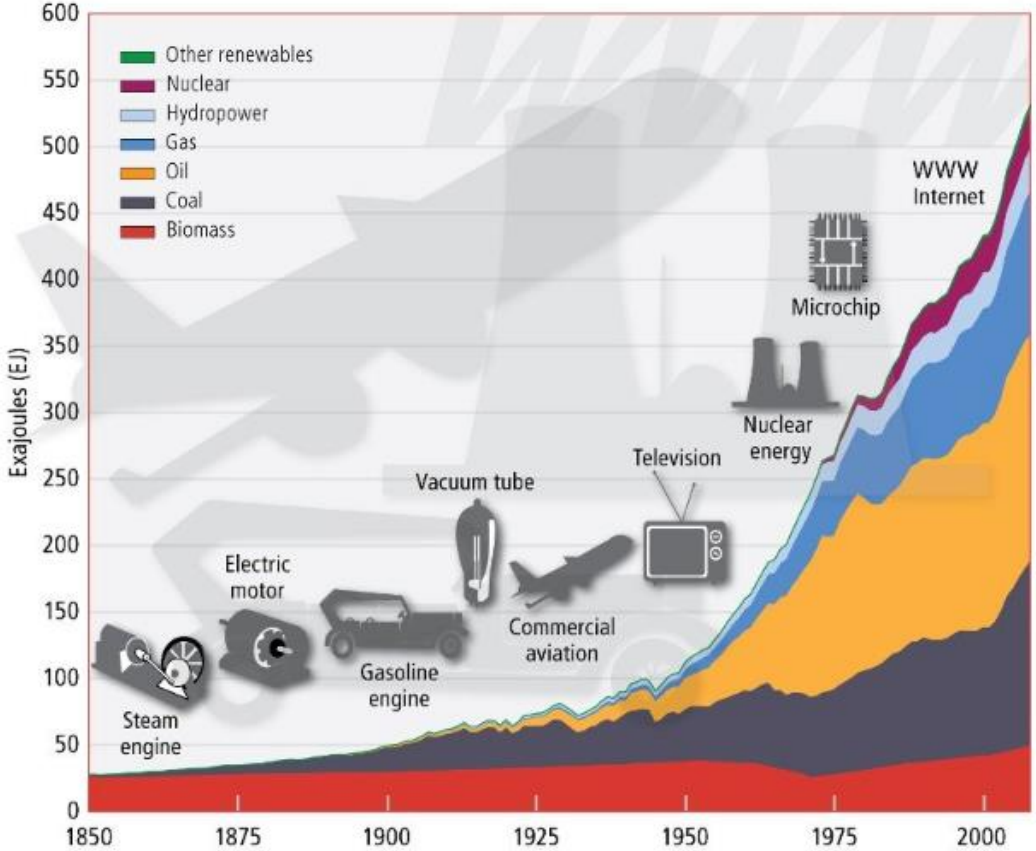


CO_2 Emissions and Climate Change

- There are ‘myth-mongerers’ and ‘myth-debunkers’ amongst both amateur scientists, commentators and serious scientists alike
- The main battleground is that the effect of ‘man’ on climate change is insignificant compared to the huge natural effects of the oceans, polar regions and the atmosphere
  - Here is an alternative view from Prager University (not a university)

Don’t believe anything that sounds professional, do your own research.

Resource that answers such myths…
https://www.skepticalscience.com/solar-activity-sunspots-global-warming.htm



GLOBAL ENERGY RESOURCES

Global Energy Resources

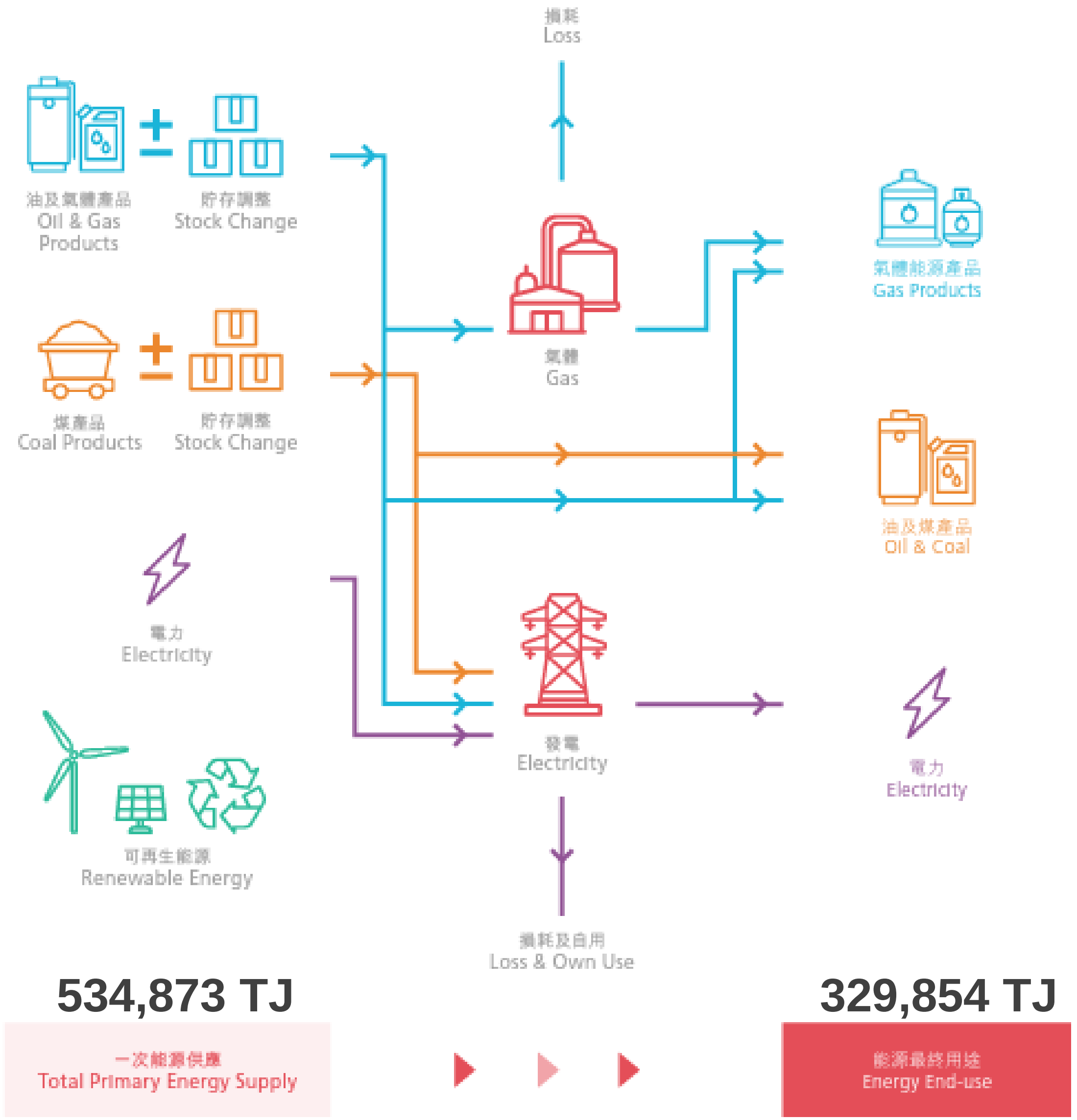
- The first distinction is into renewable and non-renewable
  - A nonrenewable resource is a natural resource that cannot be re-made or re-grown at a scale comparable to its consumption
  - Renewable resources are natural resources that can be replenished in a short period of time
  - Sustainable???

Global Energy Resources

- We are all familiar with examples of each
  - A nonrenewable resource is a natural resource that cannot be re-made or re-grown at a scale comparable to its consumption
  - Nonrenewable
    - Coal
    - Oil
    - Gas
    - Nuclear
  - Renewable
    - Solar
    - Wind
    - Water (Hydro-electric, wave)
    - Biomass
    - Geothermal

Hoover Dam

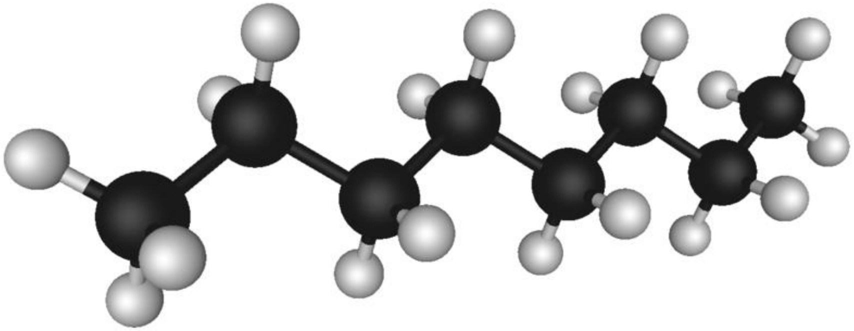
Energy Flows in Hong Kong (2020)

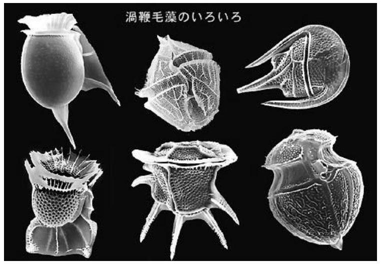


- **Gas manufacture:** approx. 3000 TJ
- **Electricity Generation:**
- approx. 188,830 TJ
- **Industry use:** approx. 13000 TJ

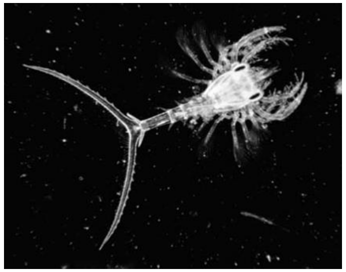
Oil and Gas

- Coal, Oil and Gas are often called "fossil fuels" because they have been formed from the fossilized remains of prehistoric plants and animals
- They are made of a mixture of different hydrocarbons
- Oil and gas have the same origin
  - Decaying microscopic marine life
  - When the plankton dies, it forms an organic mush on the sea bed
  - Under anaerobic conditions (when there is no oxygen) other animal life to feed on the plankton can't be supported and the mush accumulates





Plant plankton

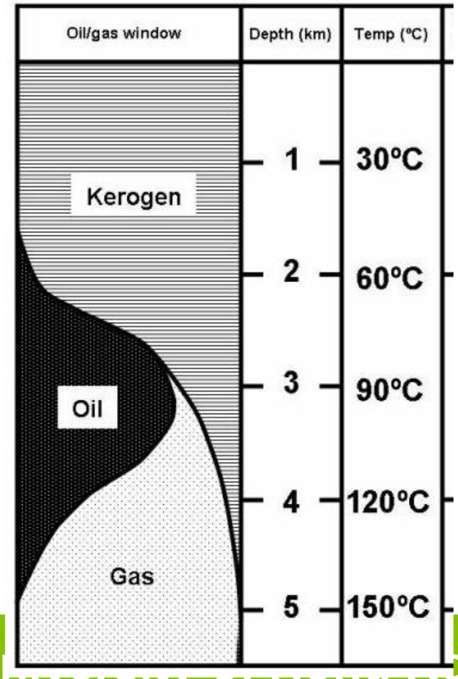


Animal plankton

Oil and Gas

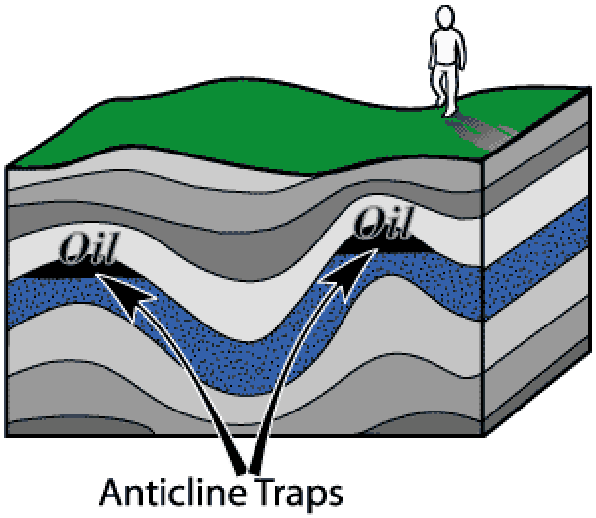
- When sediment (the sea bed) contains more than 5% organic matter, it is called black shale and it is the pre-curser to hydrocarbon reserves
- As black shale is buried, it comes under more pressure when it is heated
- The depth (and hence temperature of heating) determines if it ultimately becomes kerogen
- As kerogen is heated further, it releases oil and gas
- Shales rich in kerogens that have not been heated to a warmer temperature to release their hydrocarbons may produce oil shale deposits

Black shale deposits

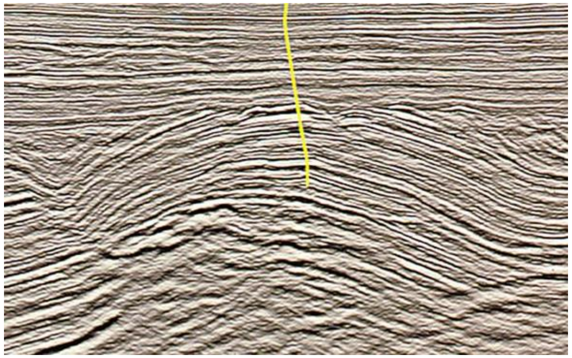


Oil and Gas

- Around 90° C, it is changed into the liquid state, which we call oil
- Around 150° C, it is changed into gas
- A rock that has produced oil and gas in this way is known as a source rock
- The last stage of the process is the hydrocarbons permeating up through the rock to form reservoirs
- Some rocks are permeable and allow oil and gas to freely but others are impermeable and block the upward passage of oil and gas
- Where oil and gas rises up into a dome (or anticline) capped by impermeable rocks it can't escape
  - Seismic surveys are used to locate likely rock structures underground in which oil and gas might be found
  - Dome like structures are a good indication of hydrocarbon reserves



Drill here!

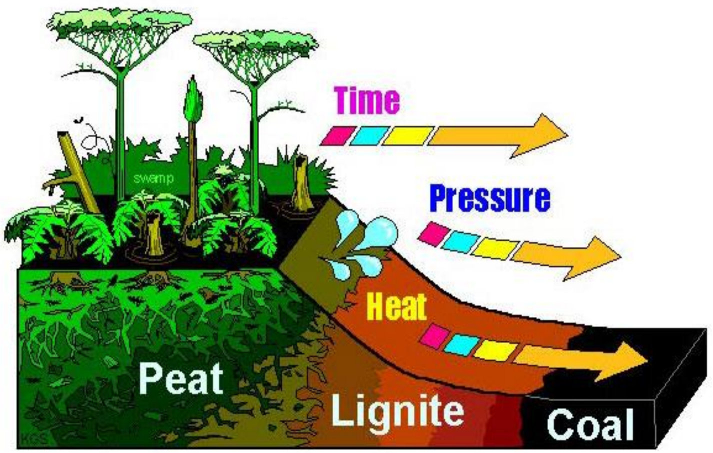


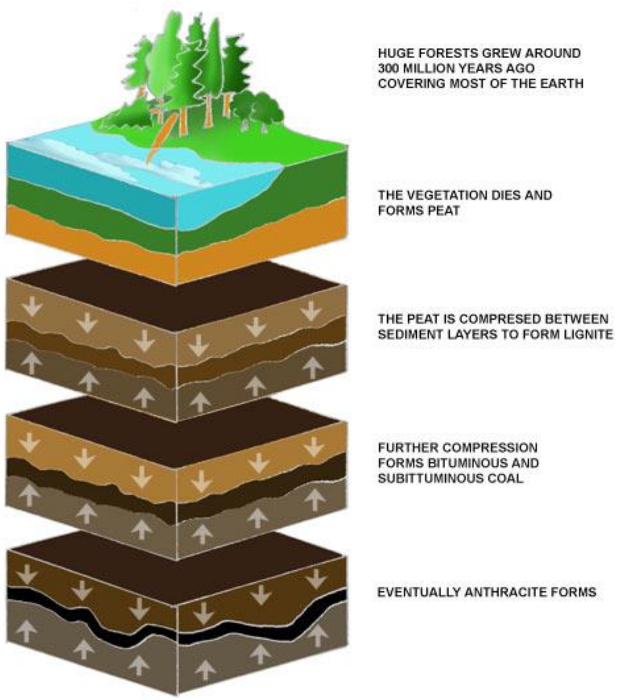
Coal

- Coal currently provides about 34% of the total Hong Kong electricity production (with gas at around 26%)
- Now that oil and gas are dwindling, many energy producers and users are looking again at the potential of coal
- Unlike oil and gas, coal is not formed from marine organisms, but from the remains of land plants
- A swampy setting, in which plant growth is lush and where there is water to cover fallen trees, dead leaves and other plant debris, is ideal for the initial stages to create coal

Coal

- The formation of coal from dead plant matter requires burial, pressure, heat and time
- The process works best under anaerobic conditions (no oxygen) since the reaction with oxygen during decay destroys the organic matter
- It is the carbon content of the coal that supplies most of its heating value
- The greater the carbon to oxygen ratio the harder the coal, the more potential energy it contains
- Over time there are different stages to coal deposit formation





Coal

- The products of coalification are divided into four major categories based on the carbon content of the material
  - Peat
  - Lignite
  - Bituminous
  - Anthracite
- Peat is an accumulation of partially decayed vegetation matter and is the first stage in the formation of coal
- Peat forms in wetlands
- It contains a large amount of water and must be dried before use
- Historically, it has been used as a source of heat and burns with a long flame and considerable smoke

Coal

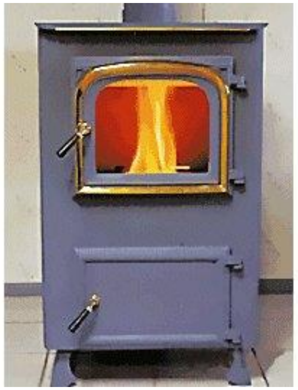
- Lignite is the second step in the formation of coal and is formed when peat is subjected to increased vertical pressure from accumulating sediments
- Lignite, often referred to as brown coal, is the lowest rank of coal and used almost exclusively as fuel for steam-electric power generation. It’s inefficient to transport and often burn in power stations close to the mines
- Bituminous coal is the third stage of coal formation
- Additional pressure over time has made it compact and virtually all traces of plant life have disappeared
- It is of higher quality than lignite coal but of poorer quality than anthracite coal
- It is greatly used in industry as a source of heat energy
- Because of its low energy density, it is inefficient to transport and it is often burned in power stations constructed very close to the mines

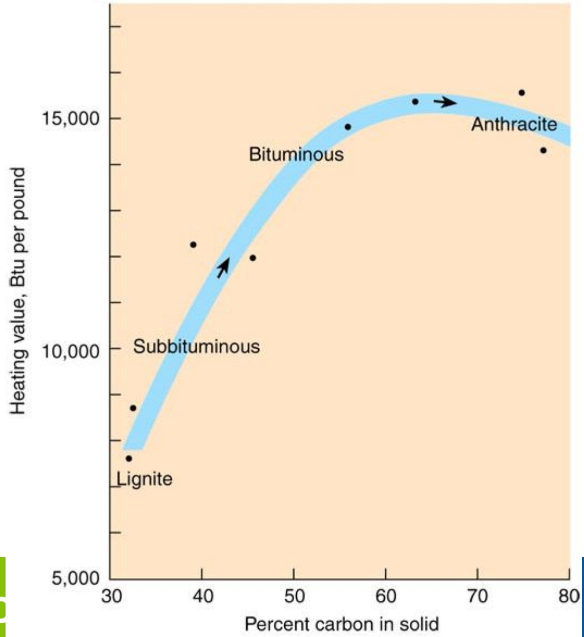
Lignite

Bituminous coal

Coal

- Anthracite is formed during the forth stage of coal formation
- It is the most valuable and highest grade of coal, and has a carbon content
- It burns far more efficiently with less smoke
- The principal use of anthracite is for a domestic fuel It delivers high energy per its weight and burns cleanly with little soot but it’s prohibitively expensive to use in power stations
- As the coals becomes harder, their carbon content increases, and so does the amount of heat released
  - Anthracite produces twice the energy (BTUs) of lignite





Pro’s and Con’s of Fossil Fuels

- Pro’s
  - Transporting coal, oil and gas to the power stations is easy
  - Fossil fuels are cheap and reliable sources of energy. They are excellent types of fuel to use for the energy base-load, as opposed to some of the more unreliable energy sources such as wind and solar energy

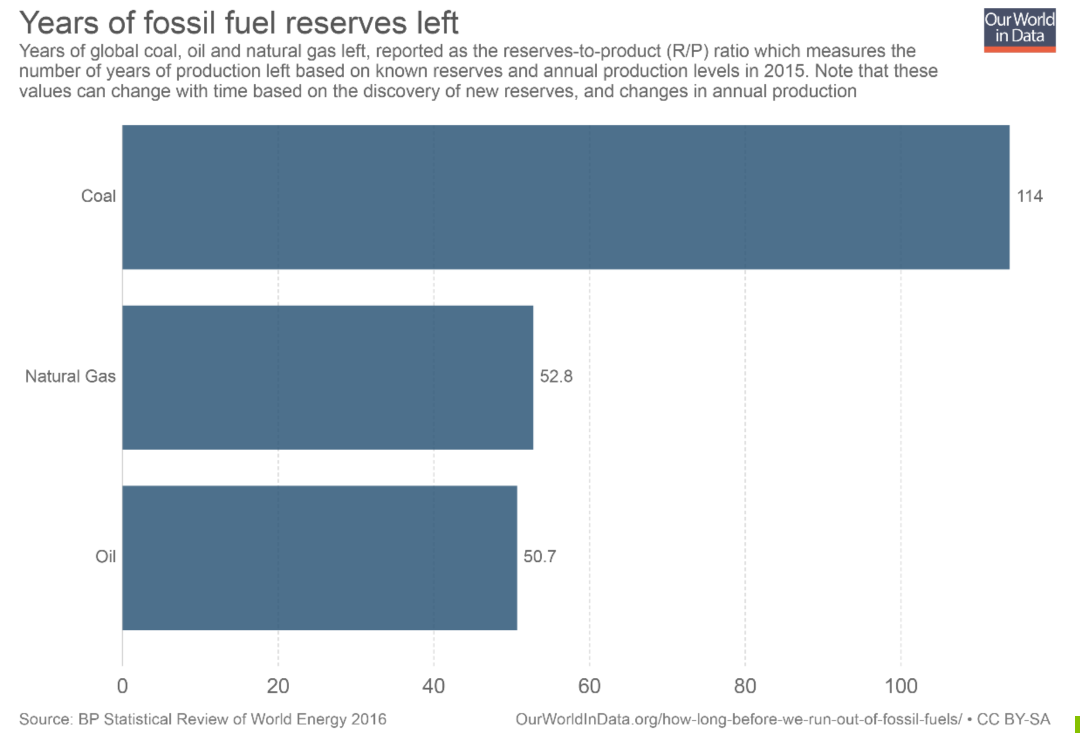
- Con’s
  - Basically, the main drawback of fossil fuels is pollution
  - Coal is by far the worst pollutant and has the highest carbon density
  - Burning any fossil fuel produces carbon dioxide, which contributes to the "greenhouse effect", warming the Earth.
  - Burning coal produces sulphur dioxide, a gas that contributes to acid rain.
  - Mining coal can be difficult and dangerous. Strip mining destroys large areas of the landscape

So how much fossil fuel is left?

- We can get an estimate of this by dividing the ‘known recoverable’ resources by the rate of usage
- The figure can change because of
  - Increased conservation
  - New discoveries
  - Better technologies leading to more efficient electricity production
  - Existing known reserves will become more profitable as the supply dwindles leading to more exploitation

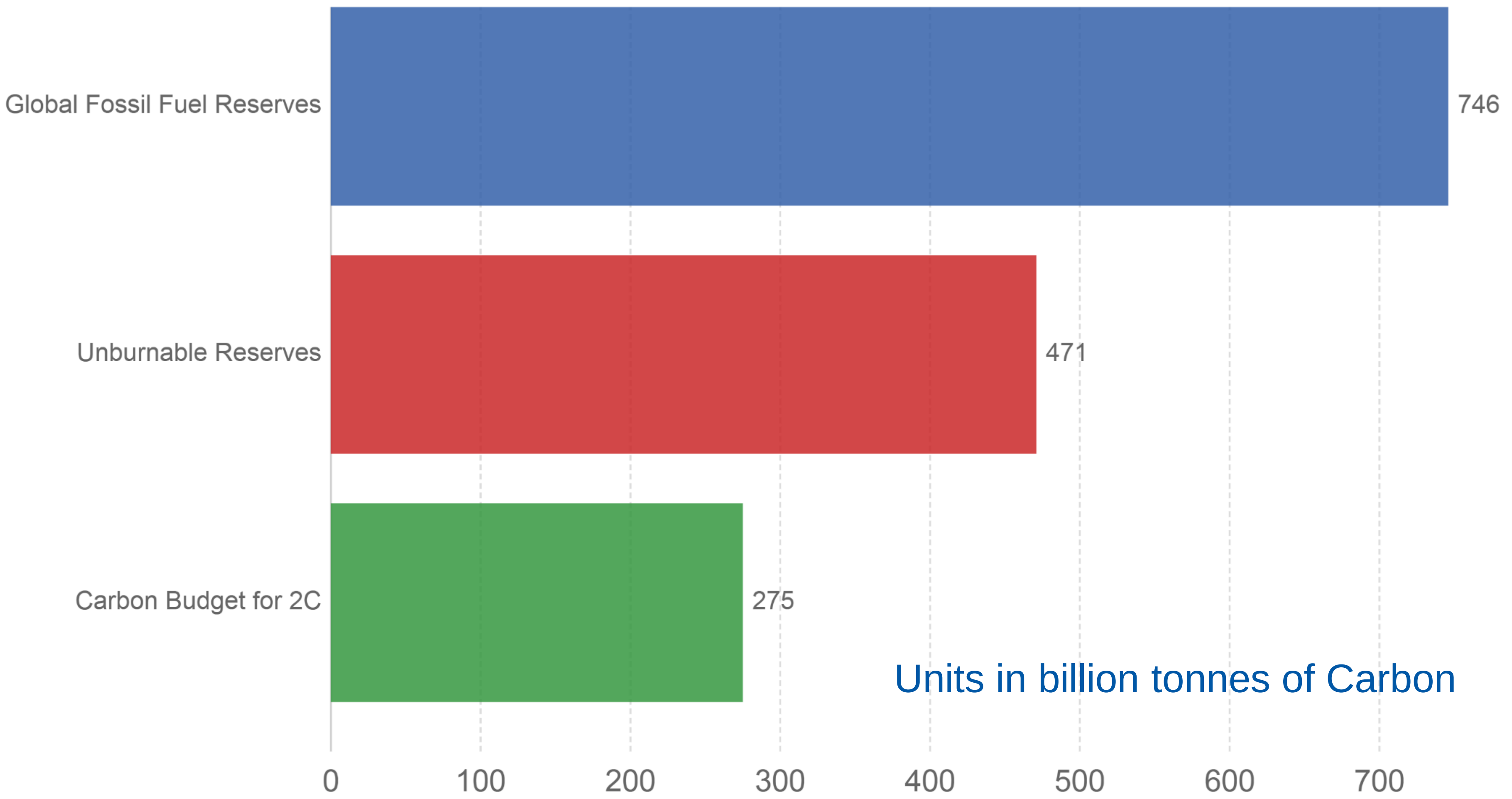
So how much fossil fuel is left?

- **Oil**
  - 1,300 billion barrels of proven reserves still in the ground, worldwide
- **Gas**
  - 6,400 trillion cubic feet of natural gas reserves around the world about the same as having 1,140 billion barrels of oil (BOE), in terms of its energy content
- **Coal**
  - Worldwide, there is roughly 3,100 billion BOE of coal



Global carbon budget for a two-degree world

The carbon budget refers to the maximum quantity of carbon which can be released to maintain a 50 percent probability of global average temperature rise remaining below two-degrees celcius (the target set within the UN Paris climate agreement). This has been measured relative to the quantity of carbon which would be released if all fossil fuel reserves were burned without the use of carbon capture and storage (CCS) technology. The difference between the two is defined as 'unburnable carbon'.



Source: Intergovernmental Panel on Climate Change (IPCC, 2013)

So how much fossil fuel is left?

- Don’t panic!
  - Existing and new resources will expand to fill the gap
    - Nuclear power?
    - Existing fossil fuel technologies such as fracking to extract shale gas will come on stream
      - Shale gas already constitutes 20% of US gas reserves
      - But controversial
    - Also carbon capture technology may lengthen the lifespan of coal
    - Massive expansion of renewable energy sources are planned
- Think of it as an opportunity ☺

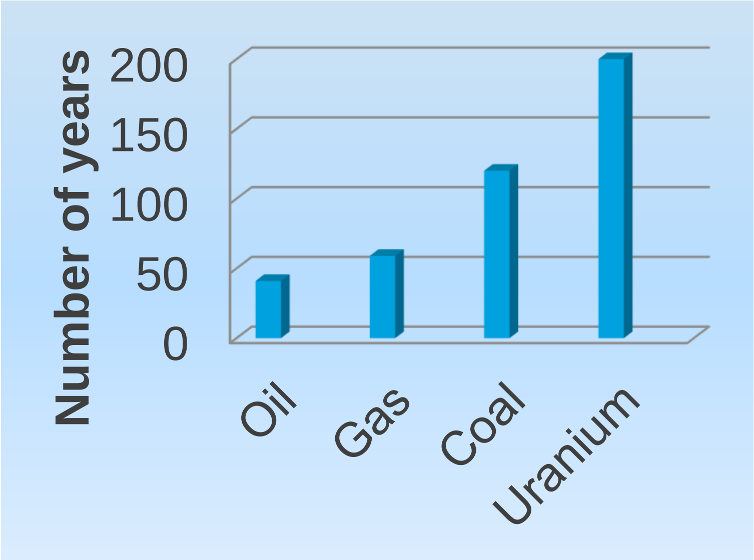
Uranium

- Uranium is the basis of nuclear power which currently produces about 17% of the world's electricity needs
- Uranium is one of the more common elements in the Earth's crust and it can be found almost everywhere in rock, soil, rivers, and oceans
- Uranium ore is processed near the mine to produce "yellow cake", a material rich in U_3O_8
  - 200 tons of this are needed per year for a 1GW nuclear power plant
- Only 0.7% of U in yellow cake is ^{235}U. Most of the rest is ^{238}U which does not work for fission power
  - There is a huge amount of processing to convert yellow cake to useable nuclear fuel
- Whilst some reactors run on unenriched uranium, in most cases it must be enriched so it contains about 5% ^{235}U

Uranium ore concentrate – "yellowcake"

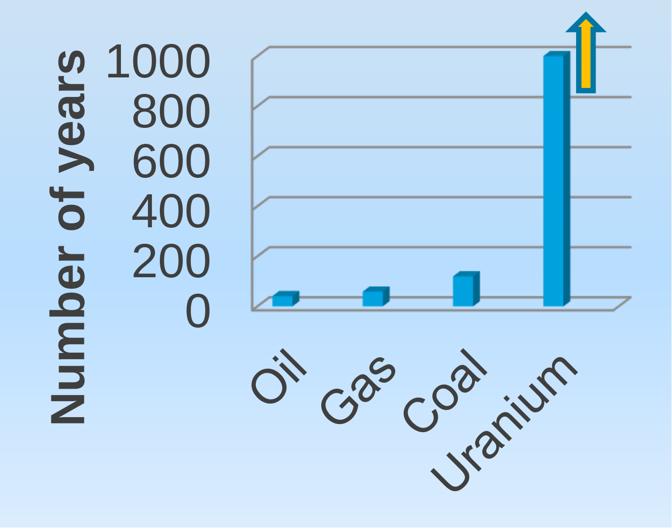
Uranium

- How long will our uranium reserves last?
- Most current nuclear reactors are light water reactors (LWRs) which use low enriched uranium (LEU)
- There are about 400 civil nuclear power plants currently operating in the world and each requires about 200 metric tons of uranium to operate per year
  - So present-day reactors require about 80,000 metric tons of natural uranium a year
- Identified uranium resources total 5.5 million metric tons, and an additional 10.5 million metric tons remain undiscovered—a roughly 200-year supply at today's consumption rate in total



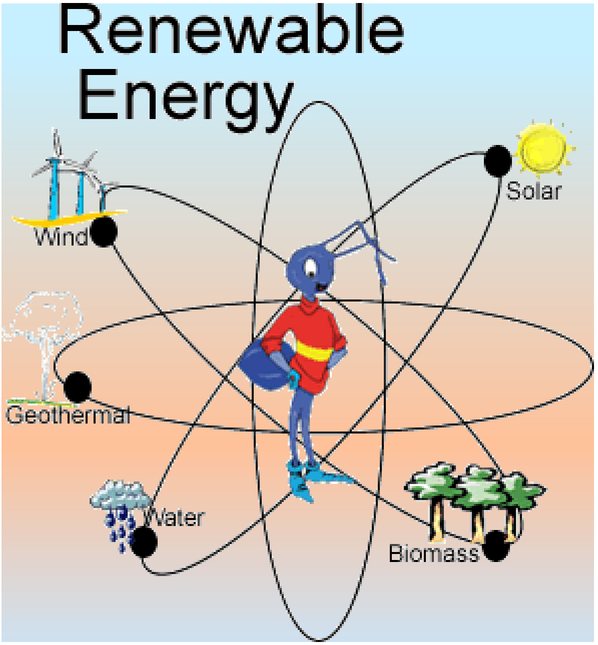
Uranium

- Likely to be an underestimate
  - Developments in technology could reduce the uranium needs of LWRs by as much as 30 percent per metric ton of LEU
  - Development of fuel-recycling fast-breeder reactors, which generate more fuel than they consume, would use less than 1 percent of the uranium needed for current LWRs. Breeder reactors could match today's nuclear output for 30,000 years
  - Extraction of uranium from seawater would make available 4.5 billion metric tons of uranium—a 60,000-year supply at present rates
  - Thorium?? Far more abundant than uranium
- Nuclear power is likely to be a significant contributor to our energy needs (29% already)



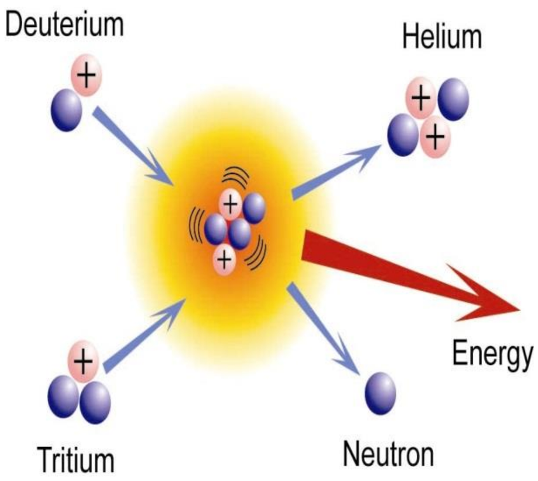
Renewable Energy Resources

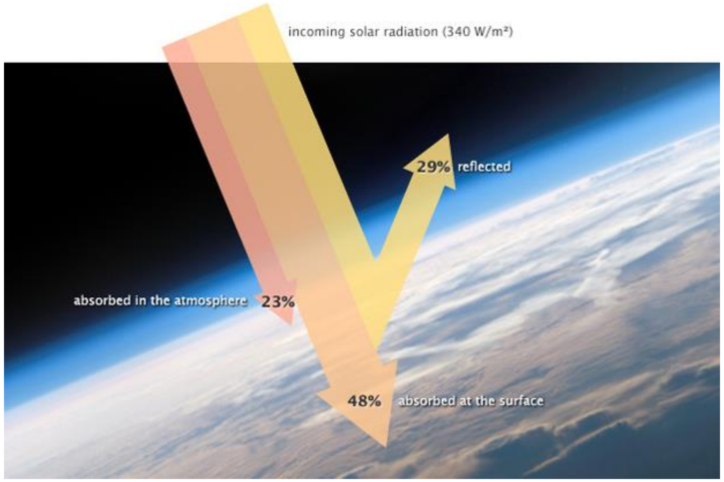
- We will briefly look at renewable energy resources although in theory these are infinite by definition
  - Limitations only come about because of lack of economic viability or technical restrictions
  - We will look in more detail about how energy is produced from these resources later
  - There's no doubt that these will play an increasing role in our energy supply over the next few decades



Solar Energy

- Solar power comes from thermonuclear reactions in the sun and is the ‘ultimate’ renewable energy source
- We have seen that around 48% of the sun’s energy is absorbed at Earth’s surface
  - Only this is useable
- The potential for exploitation of this resource is massive
  - The amount of solar energy that reaches the Earth’s surface every hour is greater than humankind’s total demand for energy in one year
- There are 2 main principles to exploit solar power
  - Direct heating
  - Photovoltaic cells

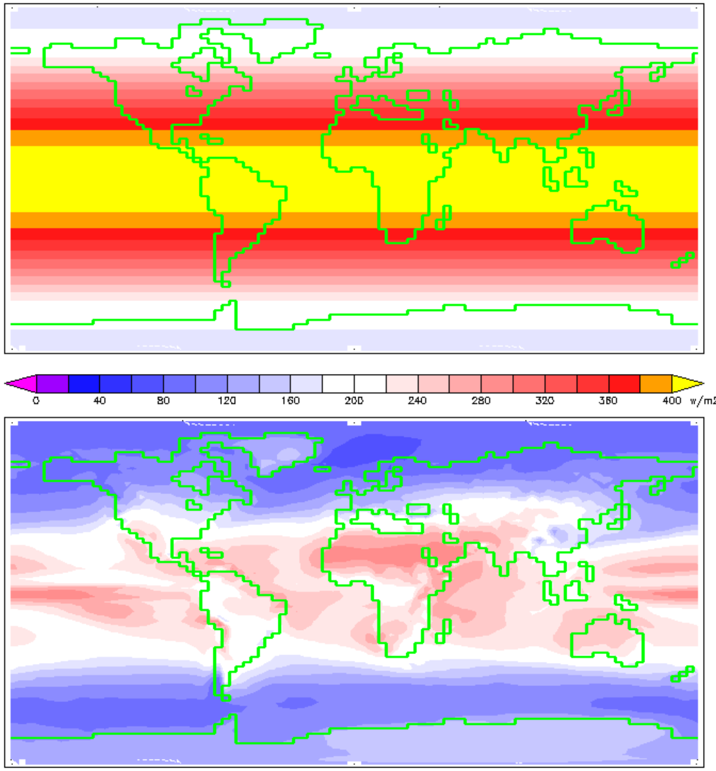




Solar Energy

- We measure the potential for a location to be suitable for solar energy generation by the amount of *insolation*
  - **Insolation** is the total amount of solar radiation energy received on a given surface area during a given time
  - It is also called **solar irradiation** and expressed as "hourly irradiation" if recorded during an hour or "daily irradiation" if recorded during a day
  - The unit is the megajoule per square metre (MJ/m^2) or joule per square millimetre (J/mm^2)
  - Practitioners in the business of solar energy may use the unit watt-hour per square metre (Wh/m^2)
  - The average solar radiation arriving at the top of Earth's atmosphere is $1366 W/m^2$ but the amount arriving at the surface is a fraction of this

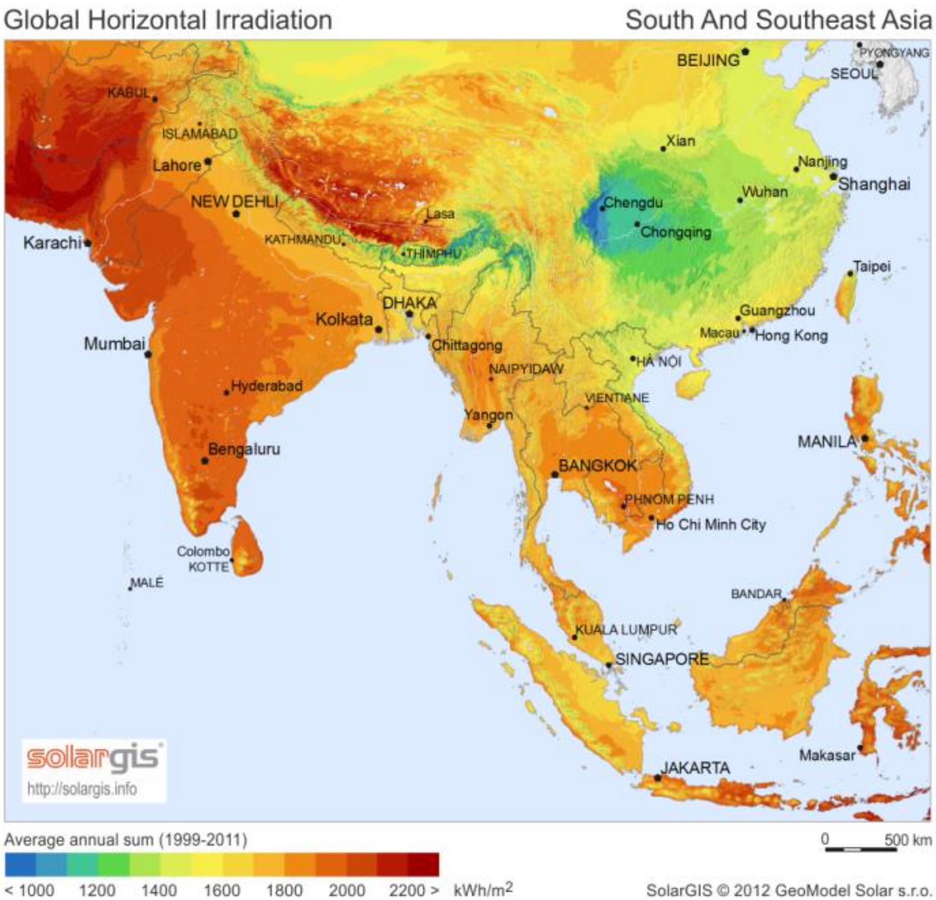
Top of atmosphere

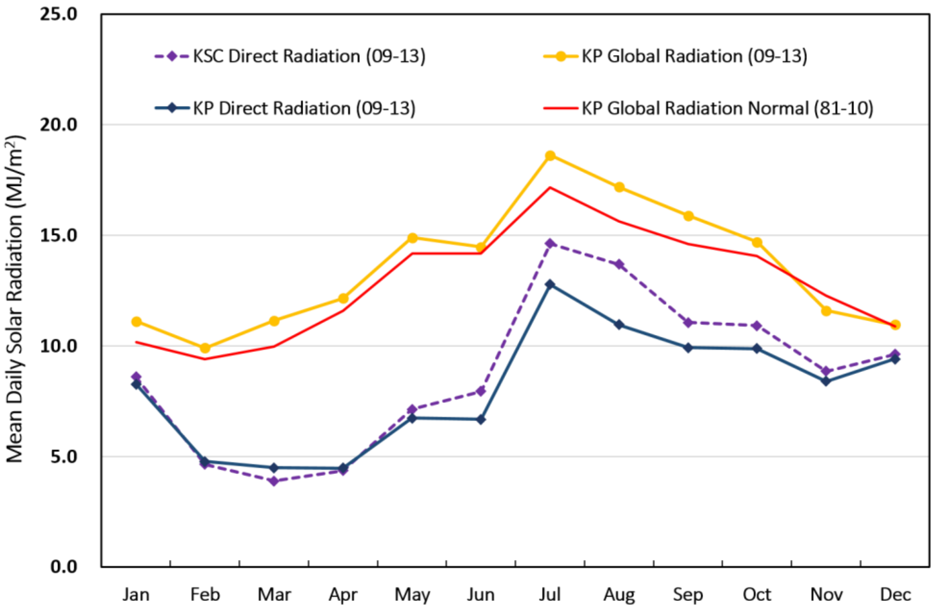


Surface

Solar Energy

- Hong Kong's insolation is around 3.6 kWh/m²/day
- Even so, 100 km² (2/3rd of the area of Lantau), where the insolation is about 1000 kWh/m²/year would provide 20,000 GWh/year, equal to 1/4th of all of our energy demands

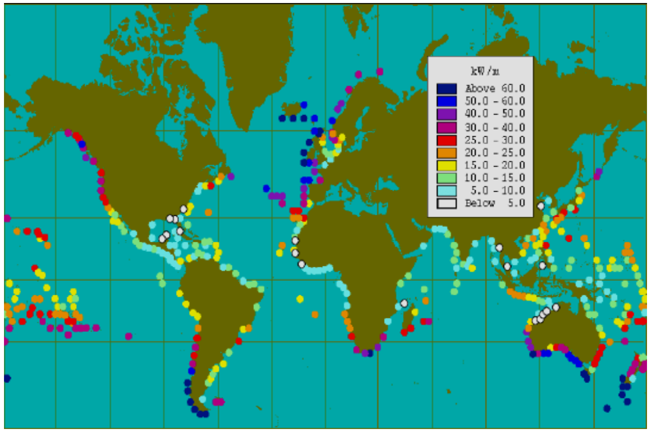




Source: https://www.hko.gov.hk/education/article_e.htm?title=ele_00443

Wave Energy

- Among other types of renewable energy, oceans contain energy in the form of waves and tidal currents
- Differential warming of the earth causes pressure differences in the atmosphere, which generate winds
- As winds move across the surface of open bodies of water, they transfer some of their energy to the water and create waves
- The amount of energy transferred and the size of the resulting wave depend on
  - the wind speed
  - the length of time for which the wind blows
  - the distance over which the wind blows
- Therefore, coasts that have exposure to the prevailing wind direction and that face long expanses of open ocean have the greatest wave energy levels

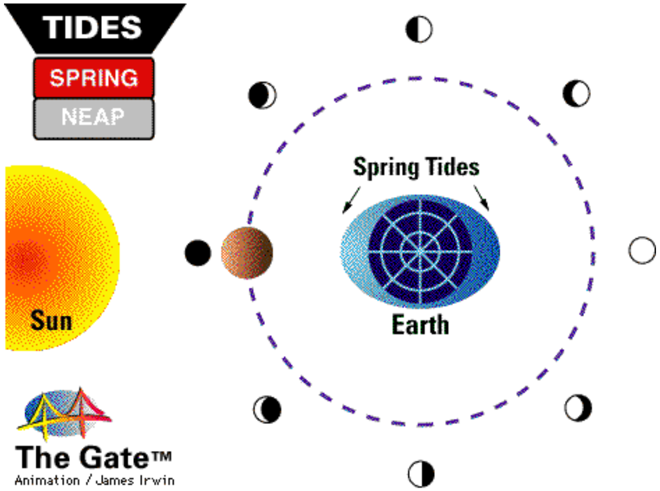


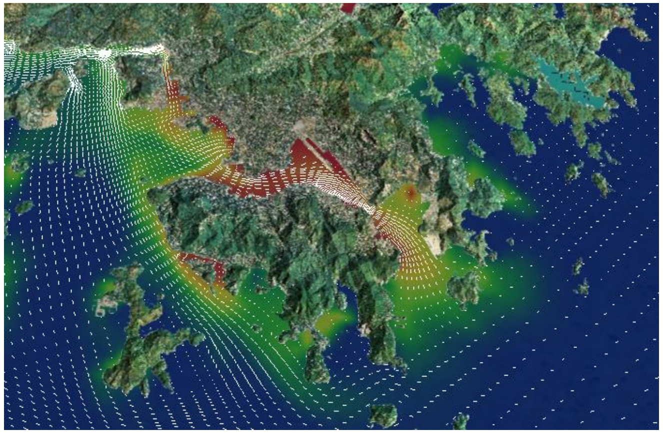
Wave Energy

- The best wave resources occur in areas where strong winds have travelled over long distances
- Nearer the coastline, wave energy decreases due to friction with the seabed, therefore waves in deeper, well exposed waters offshore will have the greatest energy
- There are 2 basic principle that designs exploit
  - A change of water level by tide or wave can move or raise a float, producing linear motion from sinusoidal motion
  - Water current can turn a turbine to yield rotational mechanical energy to drive a pump or generator

Tidal Energy

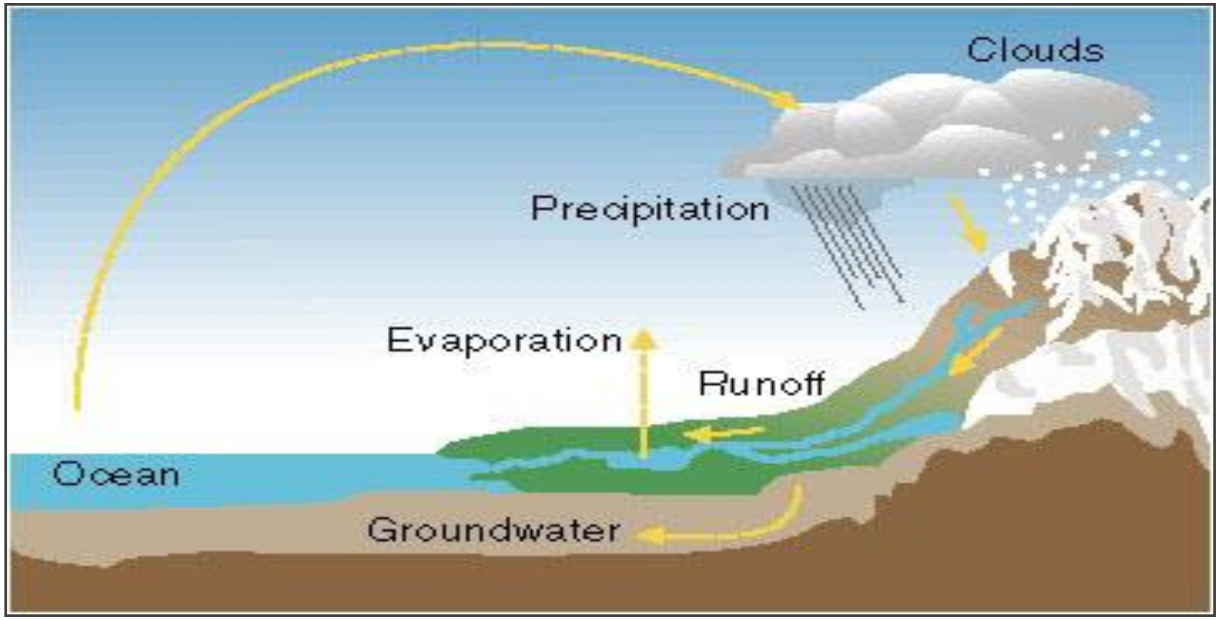
- Tidal streams are created by the constantly changing gravitational pull of the moon and sun on the world's oceans
- Tidal stream technologies capture the kinetic energy of the currents flowing in and out of the tidal areas
- Since the relative positions of the sun and moon can be predicted with complete accuracy, so can the resultant tide. It is this predictability that makes tidal energy such a valuable resource
- Tidal stream resources are generally largest in areas where a good tidal range exists, and where the speed of the currents are amplified by the funnelling effect of the local coastline and seabed, for example, in narrow straits and inlets, around headlands, and in channels between islands





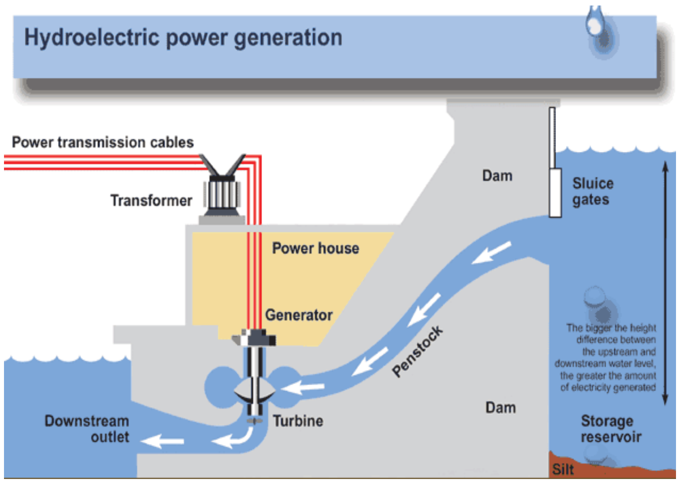
Hydro-Electric Energy

- Hydropower energy is ultimately derived from the sun, which drives the **water cycle**
  - Rivers are recharged in a continuous cycle. Because of the force of gravity, water flows from high points to low points
  - There is **kinetic energy** embodied in the flow of water



Hydro-Electric Energy

- Man-made dams create a large difference in height and hence in potential energy between the reservoir and the run-of area
  - The flow of water through sluice gates can be controlled by valves
  - This controls the power output
- Since hydroelectric dams do not burn fossil fuels, they do not directly produce carbon dioxide
  - While some carbon dioxide is produced during manufacture and construction of the project, this is a tiny fraction of the operating emissions of equivalent fossil-fuel electricity generation
  - Reservoirs created by hydroelectric schemes often provide facilities for water sports, and farming fish in the reservoirs is common



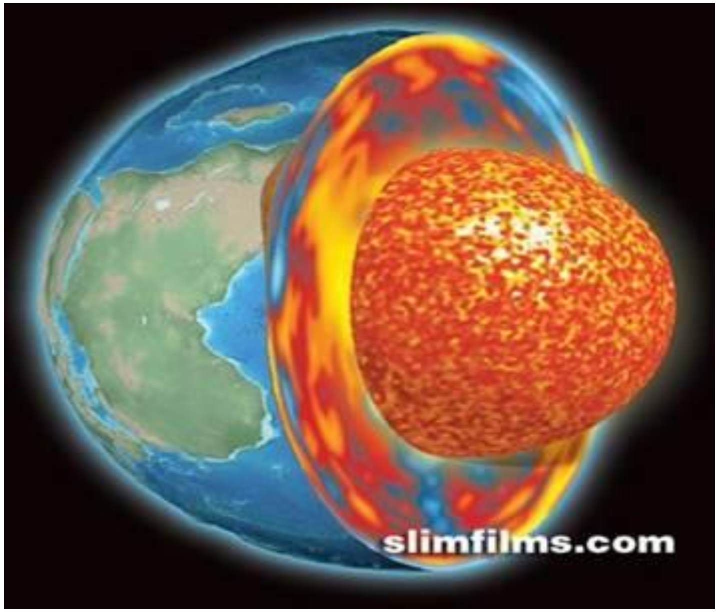
Hydro-Electric Energy

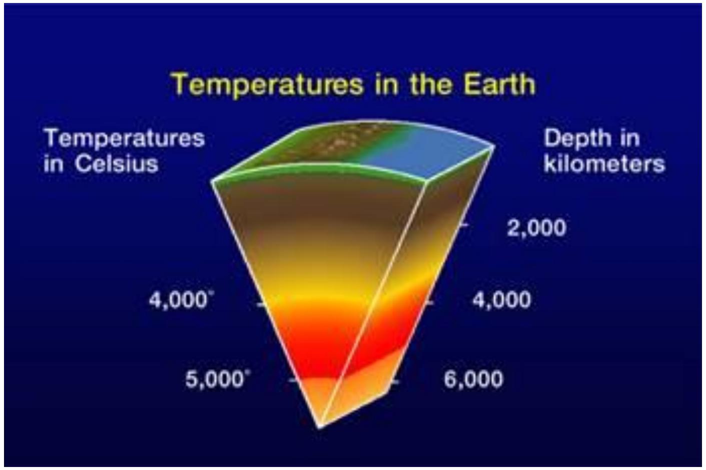
- Hydropower has had some renewed interest because of renewable energy targets set by HKSAR govt.
- Typical sites for hydropower projects tend to be in remote areas including areas of outstanding beauty so possibilities for development are limited
  - So called ‘run of the river’ schemes use the flow of the river to drive turbines and require little storage
  - Less impact to the environment as no dams are required

The **Three Gorges Dam, China** can generate 22,500 megawatts (MW) compared to 14,000 MW for the **Itaipu Dam, Brazil and Paraguay.**

Geothermal Energy

- Geothermal energy is a renewable source
- It is energy ‘stored’ in Earth usually at great depth
- 70% comes from the decay of radioactive nuclei with long half lives that are embedded within the Earth
- Some energy is from residual heat left over from Earths formation
- The rest of the energy comes from meteorite impacts



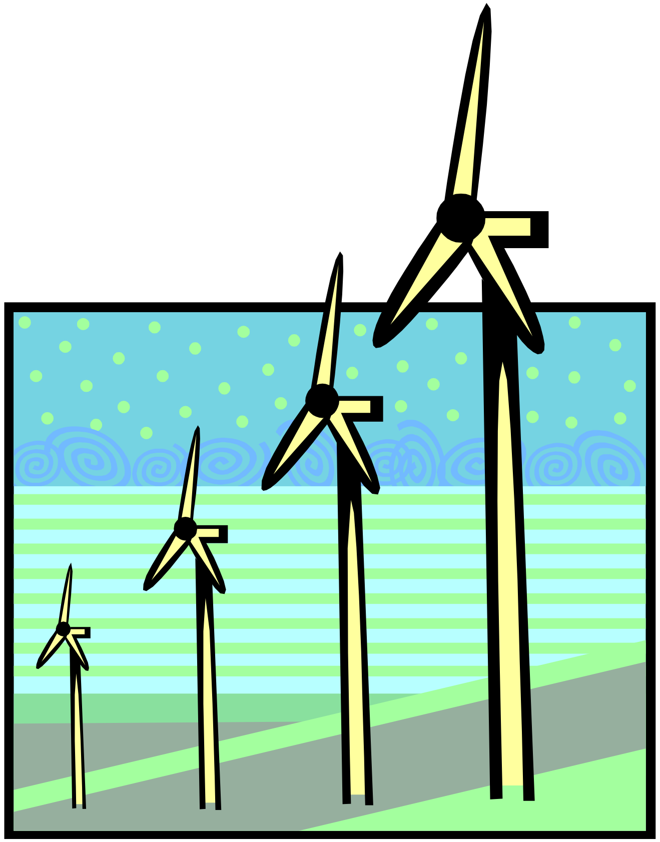


Geothermal Energy

- On average, the Earth emits 1/16 W/m^2. However, this number can be much higher in areas such as regions near volcanoes, hot springs and fumaroles
- As a rough rule, 1 km^3 of hot rock cooled by 100^0C will yield 30 MW of electricity over thirty years
- It is estimated that the world could produce 600,000 EJ over 5 million years
- There is believed to be enough heat radiating from the center of the Earth to fulfill human energy demands for the remainder of the biosphere's lifetime
- Geothermal production of energy is 3rd highest among renewable energies. It is behind hydro and biomass, but before solar and wind
  - For example, Iceland is one of the more countries successful in using geothermal energy where 86% of their space heating and 16% of their electricity generation uses geothermal energy

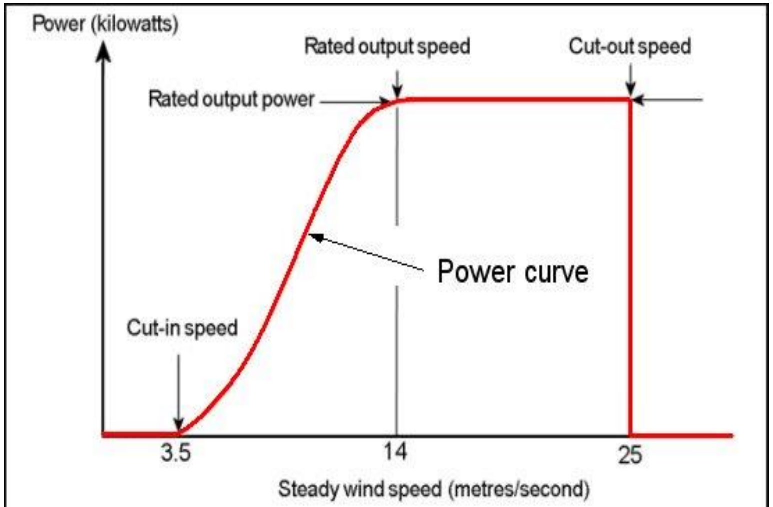
Wind Energy

- Wind energy is essentially a limitless and inexhaustible resource
- Differential heating of the earth's surface and atmosphere induces vertical and horizontal air currents that are effected by Earth's rotation and contours of the land -> WIND
- There is enough power in the wind blowing at any one time on Earth to provide all of our energy needs
  - The practical problems are of building enough wind turbines and finding the area to put them to harness it



Wind Energy

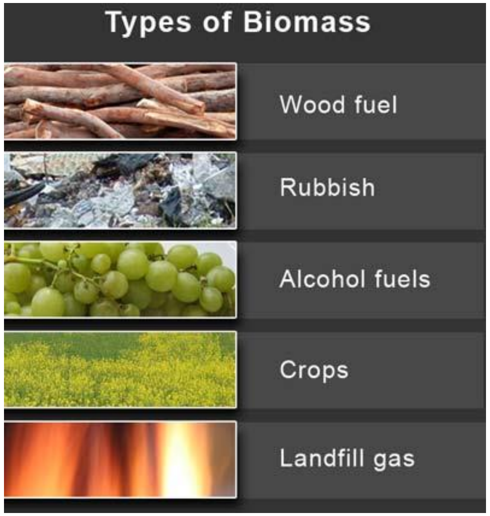
- Measuring wind speeds is crucial for planning the development of wind farms
- Average wind speeds over a 10-15 minute deadline taken over several years are typically used
- Heights of 10, 25 and 45m are used
  - Typical heights of wind turbines
- Typically wind speeds of around 10m/s are optimum
  - As we shall see, the energy generated varies with the cube of the wind speed
- Wind speeds greater that 25m/s cause a shut off of the turbine



Typical wind turbine power output with steady wind speed.

Biomass

- Biomass is a renewable energy source that is derived from living or recently living organisms
- Biomass includes biological material, not organic material like coal.
- Energy derived from biomass is mostly used to generate electricity or to produce heat
- Biomass can be sourced locally, from within Hong Kong, on an indefinite basis, contributing to security of supply and has a much lower carbon footprint than fossil fuels
- The waste matter will rot anyway if we don't use it producing methane which is a potent greenhouse gas



A Comparison of Renewables

- There are a number of ways to compare renewables such as cost/kWh, human disruption and so on
- Renewables are *diverse* energy sources
  - They take up space, unlike a fossil or nuclear fueled power station which can produce 1GW in less than $1km^2$
  - We can compare the power per unit area of various renewables

POWER PER UNIT LAND OR WATER AREA

Wind	$2 W/m^2$
Offshore wind	$3 W/m^2$
Tidal pools	$3 W/m^2$
Tidal stream	$6 W/m^2$
Solar PV panels	$5–20 W/m^2$
Plants	$0.5 W/m^2$
Rain-water (highlands)	$0.24 W/m^2$
Hydroelectric facility	$11 W/m^2$
Solar chimney	$0.1 W/m^2$
Concentrating solar	$15 W/m^2$

Cost of fossil and renewable energy sources

Levelized cost of electricity (LCOE) and levelized cost of storage (LCOS), is a measure of the average net present cost of electricity generation for a plant over its lifetime.

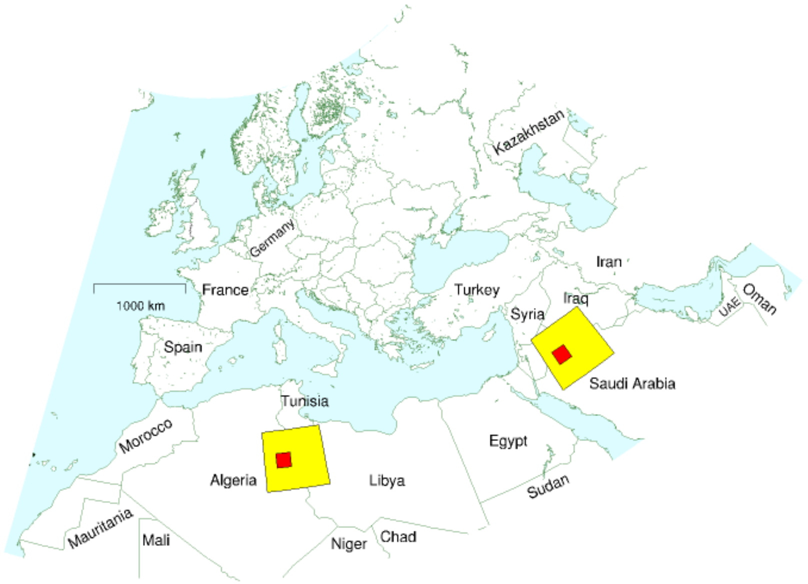
Table 1b. Estimated unweighted levelized cost of electricity (LCOE) and levelized cost of storage (LCOS) for new resources entering service in 2026 (2020 dollars per megawatthour)

Plant type	Capacity factor (percent)	Levelized capital cost	Levelized fixed O&M[1]	Levelized variable cost	Levelized transmission cost	Total system LCOE or LCOS	Levelized tax credit[2]	Total LCOE or LCOS including tax credit
Dispatchable technologies								
Ultra-supercritical coal	85%	$43.80	$5.48	$22.48	$1.03	$72.78	*NA*	$72.78
Combined cycle	87%	$7.78	$1.61	$26.68	$1.04	$37.11	*NA*	$37.11
Combustion turbine	10%	$45.41	$8.03	$44.13	$9.05	$106.62	*NA*	$106.62
Advanced nuclear	90%	$50.51	$15.51	$9.87	$0.99	$76.88	-$6.29	$70.59
Geothermal	90%	$19.03	$14.92	$1.17	$1.28	$36.40	-$1.90	$34.49
Biomass	83%	$34.96	$17.38	$35.78	$1.09	$89.21	*NA*	$89.21
Battery storage	10%	$57.98	$28.48	$23.85	$9.53	$119.84	*NA*	$119.84
Non-dispatchable technologies								
Wind, onshore	41%	$27.01	$7.47	$0.00	$2.44	$36.93	*NA*	$36.93
Wind, offshore	44%	$89.20	$28.96	$0.00	$2.35	$120.52	*NA*	$120.52
Solar, standalone[3]	29%	$23.52	$6.07	$0.00	$3.19	$32.78	-$2.35	$30.43
Solar, hybrid[3, 4]	28%	$31.13	$13.25	$0.00	$3.29	$47.67	-$3.11	$44.56
Hydroelectric[4]	55%	$38.62	$11.23	$3.58	$1.84	$55.26	*NA*	$55.26

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2021*

A Comparison of Renewables

- However, *concentrated solar power* is a realistic possibility of supplying Hong Kong's (and the World's) energy needs
- In deserts, solar power can deliver typically 15W/m^2 of power
- So, choose your local desert
- All the worlds *power* consumption (15000GW) could be delivered by an 1000km x 1000km of the Sahara desert
  - Or taking the Sahara as the local desert for Europe, 600km x 600km (yellow square)
  - Or for the UK, it would be 145km x 145km (red square)
- Easily transported using HVDC cables
- Check out the DESERTEC video
  - https://www.youtube.com/watch?feature=player_embedded&v=QXx02iMsDqI



Semester-long Project

- Compare and contrast the finding for questions 1-5 with all four types of car technologies:

1) Biofuel-based cars, 2) Electric Cars, 3) Hybrid Cars and 4) Hydrogen Cars.

- Present your findings with respect to the questions below for each type of cars.

1) Research the underlying technology of all four types of car.
    - What is the underlying technology?
    - What is the performance of this technology?
2) Identify the major components and energy source of the technology.
    - What raw materials are needed to manufacture this technology?
    - Is there enough material available to meet the demand?
    - Will the car produced using this technology be cost-effective?
3) Is the infrastructure available to scale up this technology?
    - Can one easily store the energy source of this technology?
    - Is the infrastructure cost of the distribution network high?
4) What are the potential environmental impacts during the operation of this technology?
5) Are there any foreseeable challenges with the disposal of this technology?

- Compare and contrast the four types of car technologies in terms of environmental impacts based on your findings.

(Tip: you can find the best and worst technology for each of the questions; is there a technology that is clearly better?)

Semester-long Project: Example Table

	Q1. Underlying Technology		Q2. Raw materials and energy source			Q3. Infrastructure		Q4. Environmental Challenges	Q5. Disposal Challenges
	Principle	Performance	Raw Materials	RM availability	Cost effective	Energy Storage	Energy Distribution		

Semester-long Project

Sub-assignment	Topics	Released	Due
Project Deliverable 1.1	Module 1: Sustainable Energy	Jan 24th	Feb 14th
Project Deliverable 1.2	Module 2: Environmental Impacts	Feb 14th	Feb 28th
Project Deliverable 1.3	Module 3: Noise Pollution	Feb 21st	Mar 21st
Project Deliverable 1.4	Module 4-6: Systems Analysis	Mar 21st	Apr 4th
Project Deliverable 1.5 + Presentation + Final Report	Module 7-8: Policy and Economics	Apr 4th	Apr 11th

- Individual Project: **Report** and **Presentation**
  - No group work allowed.
  - Plagiarism check mandatory: Turnitin or ithenticate

- Final Report is to be submitted in a PDF or WORD format to Canvas.

- Answer to each question to be no less than 500 words and no more than 1000 words, exclusive of the table and bibliography (double spaced, 1-inch margins, 11 or 12 point Times Roman or Arial fonts).

- References used are to be gathered in the bibliography at the end of the paper and cited at the appropriate place in the text of the paper as "(author, date)".

Summary

- Defined Sustainability and Sustainable Development
  - Difference between Weak and Strong Sustainability
- We looked at the sun's incident radiation and Earth's energy budget
- Also, we have looked at both non-renewable and renewable energy sources briefly
- In the next lecture, we will look in more detail at energy generation and its applications
  - Dive into Electrical Energy and Lighting