Darwin in 1859: On the origin of species – Evolution. 1900: Genes explain evolution.

HIV: use 1 drug (AZT) will fail, ∵ mutation.

AZT is prone to mistakes: one mutation will be useless.

Evolution of HIV by natural selection:

- Replication errors produce **mutations**
- Mutation is **heritable** (can pass to next gen)
- Some HIV is better to **survive** and **re-produce**
- **Results: only resistance type left**

Solution:

- Increase no. of mutations to be resistance
- Lower the probability to get all mutations
- Way: use multiple drugs at once – **cocktails**

Human: CCR5 Δ32 variants: resists HIV.

Evolution: change in heritable characteristics over time

$$R0 = Survival \times Transmission\ rate$$

$$Fitness = Survival\ to\ adulthood \times Reproduction\ success$$

Fitness (and R0) is environment dependent.

Sexual selection (SS):

- Preference shown by one sex to another sex
- The other is increased strength: securing mates

Asymmetries in Sexual Reproduction:

- Eggs are more expensive than sperms
- Mothers make a larger parental investment

SS not necessarily true: “cheaters”

Mutations (All mutations are random): Germline (heritable) Somatic (non-heritable)

Mutation: alternation in sequence and creates variants.

$$(Mutation\ rate)^n \times Population\ size \times Time = Population$$

Mutation rate: Rates of base substitution in various organisms. Everyone is a mutant.

Lethal, Deleterious, Neutral (most) and Beneficial.

Genetic Drift (GD, power of randomness):

- Bottleneck effect (Randomly -> less diverse)
- Founder effect (newly founded population)

GD vs Natural selection (NS) (Most case: GD + NS):

- Population size
- Selection coefficient (1 – relative fitness)

All neutral mutations / small populations: GD > NS

Fitness landscape change dramatically: NS > GD

Kimura's Neutral Theory predicts **Molecular Clock**: deduce the time in prehistory when diverges

Neutral mutations: Substitution rate = Mutation rate

Natural selection pushes the population "uphill" in a fitness landscape. (Change of population, × migration)

NS: must uphill GD & mutation: relocate randomly

Only **1 peak** in whole population (fixed all phenotypes)

Δ Environment → Δ Fitness → Continuously uphill

High mutation rate → Around the peak, but not peak

All phenotypes are neutral: plateau, landscape is flat.

Artificial selection (AS) vs NS:

- Selection coefficient: AS > NS
- GD: AS only 1 phenotype no GD, other have
- SS: AS ignores
- Mutation: traditionally cannot Δ rate, now can, but randomness of mutation cannot change
- Neutral mutation: AS ~ NS

Fitness is large in AS

Kin selection: evolutionary strategy that favours the **reproductive success of an organism's relative**, when at a cost to the one's own survival and reproduction.

One replaces Two brothers / Eight cousins. (Germline)

Evolutionary changes can be adaptive or random.

NS produces organisms **imperfectly suited** to the environment. (Nearly impossible: Mutation + GD)

Habitat: describes the place or a set of environmental conditions in which a particular organism lives.

Ecological niche: Environmental conditions + Biological interactions.

Specialists (e.g. blue whales): Narrow niche, more vulnerable **Generalists**: Wide niche

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Principle of competitive exclusion: No two species can occupy the same ecological niche for long term.

Resource partitioning: a new niche develops, or one species disappears → exploit resources differently

Types of speciation (development of new species; leads to species diversity):

- Allopatric speciation: geographically separated
- Sympatric speciation: within one geographic area

Allopatric speciation: Key is to cut the interbreeding to stop gene flow.

Dobzhansky-Muller model of hybrid incompatibility: the more the genes, the easier the speciation.

Sympatric speciation:

- Sexual selection ignores other, so no gene flow.
- Temporal isolation: different time in breeding patterns
- Instantaneous speciation: change 1 mutation → reproductive isolation

Polyploids lead to reproductive isolation

Co-evolution is pairs of species that interact frequently. Δ traits of one → **selection pressure** on the other.

Mimicry: Bird eats B, B mimic A (toxic to bird), A look less like B, bird spots difference between A and B.

Types of species interaction:

- Mutualism (++)
- Commensalism (+0)

Intraspecific competition

- Parasitism (+-)
- Predation (+-)

Interspecific competition

- Competition

Mutualism: Coral and algae.

Diversity: the number of different species in an area

Abundance: the number of individuals of a particular species or a group in an area.

Resilience, the ability to recover from disturbance, is directly related to biodiversity and productivity.

Biomes, large-scale ecosystems, are broad categories of living systems, defined mainly by climate. They vary in biodiversity, productivity and structure. (Terrestrial, Marine, Fresh water)

Tropical rainforest: Rainfall is **abundant** (> 2000 mm), temperatures are **warm to hot year-around**. It carries high biodiversity, ~ ½ to ⅔ of all species of terrestrial plants and insects live in tropical forests.

Limiting factor: sunlight and soil. Layer to compete sunlight: Emergent > Canopy > Understory > Forest floor.

Soil in tropical rainforest are thin, acidic and nutrient poor. Most are in bodies of living organisms. Nutrients are decomposed and recycle the dead organisms.

Normally high resilient, but human deforests → soil cannot support continued cropping and resist erosion.

Tropical seasonal forest: Distinct **wet and dry seasons**, temperatures remain **hot year-around**. Tropical dry forests are more attractive than wet forests for human habitation. So, 1% of dry tropical forests remain.

Tropical savannas and grasslands are dry most of the year. Too little rainfall, so few trees.

Savanna trees and grasses have large underground root systems that survive fire and dry season. Coarse savanna grasses have vertical leaves to conserve water.

Adaption: Giraffe to savanna trees (if lots of giraffes, fitness drops, density dependent) or Great **migration**

Deserts are **dry**, temperatures can be **hot or cold**. Sparse vegetation but diverse and highly adapted.

Microbiome: our own ecosystem. Most are mutualism. Change in stress, health conditions, supplements, life style, environment, host genetics, age, diet, medications lead to change in biome.

Marine biome: limiting factor is nutrients, especially in open oceans. Near shore communities have very high productivity and biodiversity but vulnerable to human disturbances. (Mangroves > Sea grass > Coral reef)

Blue carbon: Carbon captured by world's ocean and coastal ecosystems. Sea grass, mangroves, salt marsh: carbon sink. These sequester this carbon at a much faster rate. Mangrove forest store 10 times the land forest.

Mangroves are **woody plants** that grow at the interface between **land and sea** in tropical and sub-tropical. Conditions: high salinity, extreme tides, strong winds, muddy, anaerobic soils. (True mangroves only live there)

Adaption: **breathing roots**: extreme tides, strong winds, muddy, anaerobic soils; salt on leaf: high salinity

Seeds grow well in water, so can perform founder effect.

Mangroves support **rich biodiversity** and high levels of productivity; have **thick roots** to prevent **erosion** and **creating natural buffers against storm surges** (dense roots help bind and build soils); **effective carbon sinks**.

Mangroves are specialists. Their niche: the only plant lives in between land and sea water (high salinity).

Mangroves are **sensitive to disturbances** like by human activities, sewage disposal, industrial effluents, heavy metal contamination, habitat destruction, land reclamation. Close to their **tolerance limits**.

To do: Mangrove planting and Mangrove research (sediment, biodiversity)

Coral reefs, the rainforests of the sea, are the most diverse of all marine ecosystems. (Tropical + sub-tropical)

Coral reefs are built by corals, made by many identical **polyps**. Each polyp excretes hard exoskeleton ($CaCO_3$).

Algae, insides corals, gives corals colours. Corals are transparent. Algae leaves, white $CaCO_3$ shown. Bleaching.

Coral reefs like clean water. Hong Kong east part is coral hotspot. To do: Coral planting.

Deep sea has no sunlight. Population is dense. Through **chemosynthesis** with **methane** and H_2S.

Deep sea mussel and their bacteria are mutualism.

Deep sea hydrothermal vent. (400 – 500 °C) Minerals come out.

Fresh lakes have distinct vertical zones. Layers are determined by gradients of light, oxygen and temperature.

Wetland is a distinct ecosystem that is flooded or saturated by water. It supports rich biodiversity, provides irreplaceable ecological services, including water filtration, water storage, flood reduction and habitat.

Domains: Archaea, Bacteria and Eukarya. Eukarya Kingdoms: Protista, Plantae, Fungi, Animalia (Metazoa)

Extinction: the opposite of speciation. In geologic history, extinctions are common. > 99% are extincted.

Anthropocene: Mass extinctions caused by global climate change. (Change the fitness landscape)

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*H*abitat destruction: Habitat loss. Deforestation; Bottom/Midwater trawling: pulling fishing net. Banning trawling increases abundance of marine organisms. Environmental Impact Assessment (EIA) identify environmental, social and economic impacts prior to decision making, find ways to reduce adverse impacts.

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*I*nvasive alien species causes decline/extinctions of native species and negatively affecting ecosystems. They reproduce rapidly, out-compete native species for food, water and space. Causing global biodiversity loss. Intentional and Unintentional introduction of invasive species.

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*O*verharvesting depletes or eliminates species. Take more than reproduce. Habitat production: Protect enough habitat for populations, manage large scale, plan over centuries, controlled use and occupancy.

Exponential (J-curve) growth leads to overshoot and dieback cycles, as it overs the carrying capacity. Overshoots will make resources limited and death rates rises. If the habitat is damaged, lowered populations.

Logistic (S-curve) growth slows as it approaches carrying capacity (K). It comes to equilibrium.

r-selected species: high reproductive rate to overcome high mortality.

K-selected species: low reproductive rate, longer generation time, late sexual maturity.

We human are approaching earth's carrying capacity, K-selected species. Growth = Birth – Death.

Less-developed countries are growing populations. (Pyramid shape)

Food security: All people have physical, social and economic access to sufficient, safe and nutritious food that meets their food preferences and dietary needs for an active and healthy life.

Assessment: Anthropometry, Biochemical/Biophysical, Clinical, Dietary.

Surveys: Prevalence of Undernourishment (PoU), Food Insecurity Experience Scale (FIES) (household)

Hunger: Distress associated with a lack of sufficient calories.

Undernourishment: habitual consumption of too few calories to provide the minimum dietary energy an individual requires to live a healthy and productive life.

Food security is unevenly distributed, 95% are in developing countries, in sub-Saharan Africa.

GHI = (PoU / 240 + Child stunting rate / 420 + Child wasting rate / 180 + Child mortality rate / 105) × 100

Low: ≤ 9.9 Moderate: 10.0 – 19.9 Serious: 20.0 – 34.9 Alarming: 35.0 – 49.9 Extremely alarming ≥ 50.0

Zero Hunger 2030. End hunger and ensure access by all people. End all forms of malnutrition. Food diversity.

Famines are large-scale food shortages, with widespread starvation and social disruption. Trigged by drought, floods or climate change. Root cause: political instability. Economic disparities. Trigger mass migrations.

Zero hunger have positive impact to our economies, health, education, education, equality and social development. We want all of us eat safe and nutritious food.

A healthy diet includes the right nutrients. Not enough nutrients would cause health problems. Undernutrition factors: household food insecurity, inadequate maternal health or childcare practices.

Malnourishment: Undernutrition: deficiencies; Overnutrition: unbalanced diet, overeating.

Developed countries have fewer underweight. Obesity epidemic is a symptom of poverty and food insecurity.

Essential nutrients: vitamins, minerals, proteins, fats (20–35% daily calories), water, carbohydrates (45–65%)

Harvard food pyramid rests on the foundation of exercise. Emphasises fruits, vegetables and whole grains.

Eat: Grasses, 3 root crops, 20 fruits/vegetables, 6 mammals, 2 domestic fowl, a few fish species

Meat is a good indicator of wealth, expensive to produce. (Protein intake is related to meat intake)

Better use, food resources distributions are crucial. Global food waste > 30%. More than enough food now.

Different soil has different products, soil's ability to hold water are different. Sand and gravel (mineral particles from bedrock). Silts and clays (extremely small mineral particles; sticky and can hold water). Dead organic material (decaying plant matter stores nutrients). Soil fauna and flora (living organisms, including soil bacteria, worms, fungi, roots of plants and insects; recycle organic compounds and nutrients). Water (moisture from rainfall or groundwater, essential for soil fauna and plants). Air (tiny pockets of air help soil bacteria and other organisms survive).

Soil horizon: a layer whose physical, chemical, biological characteristics differ from layers above and beneath.

O (Organic) horizon: Contains ≥ 20% organic carbon. Soil fauna occurs in O horizon, consume leaves.

A horizon (Topsoil): most biological activity occurs. Decomposed organic matter, roots, minerals, organisms.

E (Eluviated) horizon: loose and light-coloured. Silicates and silica. B horizon (Subsoil): Less organic stuffs.

Cropland increases, population grow; decrease, development of buildings.

Water is the leading cause of soil erosion. Soil erosion is a natural process, human accelerated the process.

Sheet erosion: removes thin layer of soil. Rill erosion: cut small channels in the soil.

Gully erosion: rills expand, bigger channels. Streambank erosion: soil washes away from streambanks.

Wind the second. Intensive farming practices rise erosion by wind. Wind and water remove 1% cropland/year.

Vegetation cover and biological control: ecological restoration, tree planting: cropland to forest and grassland.

Engineering control: flatten slop terrain, shorten surface runoff path length. Build terraces to control inter-rill and rill erosion, level steps, horizontal ditches, bamboo ditches. Construction of check dams

Conservation control: Contour planting, terracing, drought-resistant productive ditch construction, creation of horizontal furrows, grass and crop rotation, green manuring fallow land, less/no-till farming.

Water: Green water (rainwater) Blue water (surface and groundwater) Grey water (polluted)

Irrigation is the provision of water to help crops grow when rainfall is not sufficient.

Water-saving: reducing losses in water storage, improve micro-climate: plant trees for shade and windbreaks.

Nutrients: Nitrogen, Phosphorous and Potassium are primary fertilisers. Rise in crop yield as rise in fertilisers.

If fertilisers use in developing countries, crop production tripled.

Overfertilizing is a problem. The right amount of nutrients works for plants. Health impact: water is contaminated by excess fertilisers, which is fatal to infant. Ecological impact: fertilisers released to the environment may destabilise aquatic ecosystems.

Pests reduce crop yields. Weeds, animal pests, pathogens. Use chemicals to kill. Increased crop yield, control disease-causing organisms. Organophosphates: popular used synthetic pesticides. Organochlorines (toxic)

Ban of DDT as it damages the eco system. But still have DDT in soil as long time used. Spray pesticide quick, cheap but damage other fields. Pesticide treadmills due to resistance strains arise.

Use agriculture managements (cover crops/mechanical cultivation/plant mixed polycultures fields), biological controls (insect predators/pathogens), genetic breeding and biotechnology (pest-resistant crops) to reduce dependence on chemical pesticides.

Green Revolution 1960s: adoption of high-yielding varieties (HYV) seeds. Increase farming area, double-cropping, highly increased use of fertilisers and pesticides, improve irrigation facilities and farm implements and crop protection measures, modifications in farm equipment. High investment in research, infrastructure.

Pros: Yields grow dramatically, highly efficient large-scale production, pesticides grow yield, low labour costs.

Cons: Overuse pesticides, chemicals have unintended ecological consequences, new varieties are not affordable, nitrogen fertiliser is major source of greenhouse gas and consumer of fossil fuels.

Genetic engineering 1990s: Alter DNA. Increase quantity and quality of food supply. Resist extreme weathers. Pest-resistant crops, more flavour and colour, virus-resistant, faster growth rates, leaner muscle-to-fat ratio.

No evidence GM crops have risk to human health, cause-and-effect evidence to environmental problem.

Pros: Yields increase, natural insecticide, expansion of agriculture to formerly unfarmed land, increased global soy production raise protein consumption rates, reduce malnutrition.

Cons: Expensive, may affect hormones, herbicide use destroys non-targeted crops, unknown health effects.

Sustainable agriculture (modern): to meet society's food and textile needs. Gives equal weight to environmental, social and economic concerns in agriculture.

Interdisciplinary effort in research and education. Making the transition to sustainable agriculture is a process.

Plant production practices: selection of species and varieties, diversification of crops to enhance biological and economic stability, management of soil to enhance soil quality, efficient use, consider farmers' goals.

Organic production (mixed): crop rotation retains soil fertility, mixed cropping reduces pest risk, organic fertilisers and pesticides reduce cost of commercial inputs.

Pros: Low input costs, sustainable (improve water, soil quality and biodiversity), healthier diets, traditional and low costs so good for poor farmers, integrated pest management.

Cons: high labour costs, careful planning and management, creative and innovative problem solving. Expensive food as lacks large-scale. Unfamiliar to most farmers.

Consumers play critical role in creating sustainable food system. Choice sends strong message to producers.

Health is a state of complete physical, mental and social well-being and absence of disease or infirmity.

Environment: All physical, chemical and biological factors external to a person and all related behaviours.

Worldwide increase in child survival (> 95%). Mental health as a worldwide problem.

$$DALY = YLL + YLD = N_d \times L_d + I_d \times DW_d \times L_d$$

YLL: Years life lost due to premature mortality, YLD: Years lived with disability, N: Total no. of deaths, L: Life expectancy at age of death, I: Total no. of cases, DW: Disability weighting, L: average duration of disability.

Pollution: smog, outdoor toxic agents, indoor particulates, contaminants in soil and water, disease, smoking. Air pollution: half: indoor pollution. Impact on agricultural yields.

Inadequate water sanitation: water-borne (direct intake), water-washed/scarce (inadequate water supply and hygiene), water-based (transmission of infections), water-related insect vector (transmission by insects)

Improve quality; Increase supply, improve hygiene; Reduce contact infected; improve management.

Wastewater reuse: high reliability, nutrient values, sustainable use of fresh water.

Pesticide use: harm underestimated, lag regulation, counterfeit pesticides, misunderstood guidelines.

Reduce exposure to radiation: Time, distance, shielding.

Continuous exposure to 70 dB will not cause hearing impairment. Regulations.

Occupational risks: back pain, hearing loss; male deaths. Use standard protocols to protect themselves.

Built environment influences our health. Climate change affects social, environmental determinants of health.

Environmental health: relation: people and their environment; promotes, fosters healthy; safe communities.

Toxin implies Hazardous, but not the reverse. Toxins such as mercury and DDT (non-point contamination)

Allergens: activate the immune system. (Food allergens, formaldehyde)

Neurotoxins: Inhibit enzymes (AChE) Organophosphorus, block channels Tetrodotoxin, block receptors.

Mutagens: agents that can damage or alter genetic materials. Birth defects/fatal growth

Carcinogens: cause cancer. Teratogens: factor cause abnormalities when embryonic growth, development

Endocrine hormone disrupters: Pseudo-estregon: do at wrong time; Antiestrogens do nothing.

Obesogens: disrupt body's normal homeostatic controls to promote adipogenesis and lipid accumulation

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Toxicology: study of adverse effects of external factors on an organism or a system.

Environmental toxicology: interactions/transformation/fate/effects of toxic in biosphere.

Aquatic: sediment/water, water/organisms, water/air; Terrestrial: soil fauna and population effect metal

Water-soluble chemicals move rapidly and widely; Oil/fat-soluble: penetrate readily into tissues and cells.

BCF = [Organism]/[Ambient environment] *BAF = [Organism]/[Food (or ingested water)]*

Factors: Molecular size/solubility/stability/reactivity, Dose/Route of entry/Timing of exposure/Senstivity

Persistence makes some materials a greater threat.

Antagonism: A + B reduce effect Additivity: No change Synergism: A + B more toxic.

Risk = Hazard × Exposure (Concentration)

Toxic Evolution: Expose a population of laboratory animals to measured dose under controlled condition. Expensive, time-consuming, painful to animals; most reliable foundations; Computer simulation.

Dose/response curve. Specify the species. Find the 50% lethal dose (among population) (LD50)

Base line level: other factors caused; Straight-line: any exposure has risks Threshold

Detectable levels are not always dangerous. Need to after the NOAEL then can see the adverse effects.

Acute: single exposure immediate health crisis; Chronic: Continuous/Single very toxic dose

Risk assessment: 1 in 1 million is acceptable; Hazard Identification > Dose-response, Exposure assessment

Weather: state of the atmosphere at a place and time (meteorological var: dryness, wind, rain, sunshine)
Climate: pattern of variation (meteorological var) in a given region over long periods of time.

Climate can vary with (be contrasted to) weather in a short period of time. Climate describes the variability of weather events (Climate: prob of rain; weather: rain effect). Climate is controlled by the processes in the atmosphere, on the land and in the ocean. (Var: precipitation, pressure, temp, wind speed, atmospheric composition; groundwater, above-ground biomass ∝ [Precipitation], albedo; sea level, currents)

Troposphere (10km): 85% of atmosphere's mass (higher pressure) & all water vapour. Most weather occurs. Heat source: from below (radiation from Earth), Temp ↓ for higher. (Enough air → aircrafts here)

Stratosphere (50km): Ozone layer (absorbs UV light from sun → heat, temp ↑ for higher) Very stable (aircrafts)

Mesosphere (85km): Meteors burn up (Friction). Heat from below ozone layer. Temp ↓ for higher. Thin air.

Thermosphere: Heat source: radiation from sun. Temp ↑ for higher. Arora in high latitudes (Polar) e^- collide.

Air density ↓ when altitude ↑. (Air parcel: body of air) Pressure: average force pushing on surface of unit area.

Temp: Avg KE, Cold contracts sinks, hot expands rise. Circulation in Troposphere. Temp below *dew point temp*, water vapour condenses → precipitation. Frontal ~: Cold air ↔ Warm air. Warm ↑ → cools → precipitation.

Atmospheric circulation: **Uneven solar heating**, (*Solar radiation*) (**Insolation**: measure of solar radiation energy received on given surface area during given time) Single cell circulation model: (Converge in lower atmosphere, diverge in upper, surface wind: poles → equator) + **Coriolis Effect** (N deflect to right (Inertia))

Tropical (Equatorial): Air heated up → temp ↓ → cools and precipitate (rainfall & **wet**); if balance → N/S.

Subtropical: Upper **Dry** air to high latitudes cold → // Equator on subtropical region → sinking air → S/N.

Subpolar: Lower air (close ground) to N → (Coriolis) // Equator at subpolar Region. Cold from pole + relative warm lower air → frontal precipitation. If density balance → N/S. **Pole**: Cold air sinks, diverging S.

Ocean circulation: Norm: Trad winds on equator push warm water to Indonesia. Cold water in deep sea upwells → dry in America, wet in Asia. Upper dry air to east (America). **El Nino**: Weak or reversed trade wind, less upwell of cold water. Warm water and precipitation spread out in Pacific Ocean. (Every El Nino is different)

Reflection: (Albedo: the ratio of reflected solar energy to incident solar energy, Albedo ∝ Reflectivity, Avg: 30%) Arctic warm faster than other due to a loop. (warm → ice melt → albedo effect ↓ → more warming).

Adsorption: Greenhouse gas effects (Global warming, F >> N_2O >> CH_4 >> CO_2) + Aerosol, clouds, ozone.

CO_2: Ocean – Main reservoir. Plants (Mangroves > Salt marsh > Sea grass) bury CO_2 in soil and sediments.

N_2O: Agriculture, Oceanic (Uncertain in estimation, not exactly match actual). Excess fertiliser, marine N cycle.

CH_4: Anthropogenic: Agri-waste (⅓): ruminant animals e.g. cow, sheep, deer, goat, from burping, fossil fuels, wetlands (Methanogenesis), biomass burning > Natural. Melting of ice (Global warming) and permafrost.

Sea Level rise: Higher storm waves & tides; rate accelerating; 2100 – 1/2 m higher.

Frequent Extreme weather events: Warmer → Evaporation → dries out soils and vegetation (drier); Increased aridity of forest → to more fires. Increase precipitation on dry places. Tropical cyclones: warm, moist air fuels.

Loss of biodiversity: Loss of local species, more diseases, mass mortality of plants and animals.

Intergovernmental Panel on Climate Change (IPCC): Risks of CC by human, Env & Soc-Econ Consequences. Possible options to adapt consequences/mitigate effect. Climate consequences create inequity: Poorer countries pay price for CC. More frequent wildfires, longer drought, ↑ wind intensity & rainfall, flooding.

Major Air Pollutants: Highly corrosive: SO_2, NO_x; Reactive: NO_x, O_3, VOCs. Toxic: CO, Pb, SPM (PM2.5, PM10)

Non-point source (fugitive): Fossil fuel burning & Transportation. (Difficult to be monitored and to control)

SO_2: Form SO_3, sulphuric acid. [Acid rain] (The Great Smog of London) HK: Burn coal before 2009, NG, Nuclear.

NO_x: Heat of combustion to N_2 and O_2. (Also O_3 and VOCs). Form nitric and nitrous acid. [Acid rain]

CO: Incomplete combustion of fuel. (Combustion engines, forest fires, cooking fires)

O_3: Highly reactive, bad in troposphere. VOCs (Formaldehyde – Engineered wood): open windows.

Pb: Industrial and mining, burning of gasoline (Pb is added). HK banned. Cheep Lead based paint.

Particulate materials: Aerosols/small particle. < 2.5 μm → lung damage. HK: Navigation main, decreasing.

HK now ozone the highest. Different countries set different air quality standards.

Surface water: fresh water (NOT ocean); Runoff: Movement of fresh water from precipitate → ocean.

97.6% Ocean; Of 3% fresh water: 12% groundwater, 0.8% surface water (Earliest civilisations) ~ WT Lvl

Precipitation → infiltrate Zone of Aeration, air-filled spaces → (Water Table) Zone of Saturation (Groundwater)

In confined aquifer (cannot penetrate): Artesian Well (if lower WT, +flowing); Unconfined: Water-Table Well

Water Usage ∝ Population. **75% Agricultural**: Water withdrawal ↓ when higher incomes. Exceptions: High precipitation; Not demand water crops. **20% Industrial**: Cooling water for power plants, Biofuel production (corn to ethanol), Fracturing (fracking) of NG and Oil production. Most contaminated. 5% Domestic: developed = 10 × developing. No infrastructure for fresh water, cost to obtain is high. Provide clean water to poor population is the primary aim of international development organisations.

Renewable internal freshwater resources refer to the quantity of internal freshwater inflowing river basins and recharging groundwater aquifers. Tropical region more groundwater resources. Per capita ~: Total quantity of renewable flows & size of population. Takes time to be renewable.

Desalination: For dry coastal area. Need Technology, capital, and the need for fresh water.

Point source water pollution: Drainpipes, ditches, sewer outfalls (separate sewage & stormwater)

Biological Pollutants: Infectious agents (Pathogens) from human, animal waste in water (Water borne). Developed countries: Sewage treatment plants eliminate worst; Developing only primitive or no treatment. 80% sickness and diseases in developing is waterborne and inadequate sanitation. 1.6M child <5 yr die.

Chemicals dissolve in soil contaminated to groundwater (Fracture); Some to Deep aquifer but may leak.

Fracking fluid contains toxic additives. Produced water (flowback): highly saline, heavy metals, naturally occurring radioactive materials. Leaking & contaminate groundwater, soil. Methane leakage.

Seawater Intrusion → ocean invades groundwater. Reason: Overextraction (local depression); Sea level rises.

Organic pollutants: Runoff (11%), Air pollution (4.2%), Transportation Norm operation (24.1%). Oil spill (9.8%)

Nutrients & Eutrophication: (N, P, NH_4^+) Sewage, Manure, *Agricultural* & Landscaping runoff → Overgrowth of algae (Harmful, Red tide) → Depletion of dissolved oxygen and death of fish.

Oxygen-demanding wastes: by Aerobic bacteria, organic matter consumes O_2. From sewage, feedlots, algae. Most fish cannot survive in water less than 4 ppm (4 mg/L) O_2 at 20 °C. Under 2 ppm: Hypoxia. Unsustainable land management and agricultural prices → Nutrients levels in soil ↑ → Nutrient runoff ↑ → [Nutrients] in ocean ↑ → Overgrowth of Algae → High amount of Organic matter → consume O_2. (Oxygen Depletion Zone) Expanding east HK hypoxia. Solution: Technology to remove nutrients from wastewater; Sustainable land use to reduce soil erosion and nutrient runoff; Better agriculture practices; More research.

Municipal Treatment:

Primary treatment solids. Screens block floating debris. Comminutor can grind and shred debris to remove material by sedimentation or flotation. Grit chambers can slow down the flow so solids can settle out of water. Primary clarifiers: solid (primary sludge) sink to the bottom.

Secondary treatment: organic matters. Removal by biological process, microbes consume organic impurities in Aeration tank. Secondary clarifier to recycle activated sludge. Disinfection of water before discharge.

Nitrogen removal: Dissolved inorganic N (NH_4^+, NO_3^-, nutrients cause eutrophication) (Unstable NO_2^-). Aeration tank: ON → DIN, + O_2 to nitrate (Nitrification). Anoxic tank to denitrification.

Phosphorus removal: DIP (PO_4^{3-}, HPO_4^{2-}, HPO_4^-, nutrients) Aeration tank (OP → DIP) PolyP accumulating bacteria: Phosphate → PolyP (in bacterial cells) → sinks, bacterial sludges.

Natural: plants provide O_2, assimilate nutrients (N, P); bacterial: decompose ON, OP, transform N.

Household septic system through trees; Biofiltration (Constructed wetland).

Biological Pump (POC); Carbonate Pump (PIC); Microbial Carbon Pump (RDOC)

Energy: Industrial, Transportation; Residential; Commercial.

Primary energy (Natural energy): Fossil fuels, nuclear, hydroelectricity, solar energy, **shale gas**, wind, tides.

Secondary energy (Energy from processing primary): Electricity, Gasoline, diesel, Steam.

Most primary energy: Oil (33%) > Coal (27%) > Natural Gas (24%) >> Hydro (6.8%) > Nuclear (4.4%) > Ren (4%)

Main source: America, Europe, Africa: Oil; Soviet Union, Middle East: NG; Asia: Coal

Asia is a big energy consumer for all fuel types (Fossil & renewable). Nuclear: EU, NA; Ren: AS, EU, NA

In 2018, 81% of global population lived in countries where average energy demand per capita was less than 100 GJ/head, 2% more than 20 years ago, but share consuming less than 75 GJ/head declined from 76% to 57%. Average energy demand per capita in China increased from 17 GJ/head in 1978 to 97 GJ/head in 2018.

Energy per capita: NA >>> CIS > ME > EU >> World average > … > Africa.

China (34%), US (20%), India (15%) contributed to primary energy growth in 2018. (Coal drop much in US)

Rejected energy (66.7%). It is important to minimise rejected energy (Most from coal fuel).

Fossil fuels: Coal mining: mountaintop removal. Can use 1000 yrs but environmental issues. Renewable energy growth (Cheaper); Less efficient fuel; Environmental regulations; Expensive to retrofit aging plants.

US exports unconventional oil (shale gas). 12 countries control 88% resources. Risks of extreme oil: Oil spilling. Tar sands cause water pollution, forest destruction and energy to liquefy tar. Natural gas: growing importance.

Nuclear fission: splitting of heavy nucleus into lighter nuclei. Not much energy. Nuclear fusion: fusing of light nuclei to heavier nucleus. Requires much energy. Energy: Fusion >> Fission >> Chemical reaction.

Pressurised water nuclear reactor: Water is superheated and pressurised when to reactor core. Heat is transferred to non-pressurised water in steam generator, which drives the turbine to produce electricity.

USA > France > China in production. In prop, France. Accidents: Chernobyl, 3 Mile Island, Fukushima.

Fukushima: 9.0 earthquake, ¾ nuclear reactor destroyed, tsunami knocked out emergency cooling systems.

Radioactive waste: running out of pool storage. Lack safe storage.

Shale gas: natural gas that is trapped within shale formations. Shales have low permeability (reservoirs). Combination of horizontal drilling and hydraulic fracturing has allowed access to large volumes of shale gas.

(Fracking technology extracts methane gas and fracturing fluid). (Shale gas ~69% in 2018 in US gas production)

Hydroelectricity: abundant electricity but large dams have impacts. (China >> US > Brazil).

Wind and Solar energy: less expensive and quicker to install. Potential energy available. Wind creates 5 × jobs to create same amount of energy than coal. Concentrating solar power. Photovoltaic cells generate electricity directly. Highly versatile. (Base-load power facility; flexible, thin-film solar tiles; roof-top solar array)

HK: Oil (63%) > Coal (29%) > Imports; Commercial (43%) > Transport (31%) > Residential >> Industrial.

Most use Natural gas to produce energy (Asia for coal; S/CA: Hydro; EU: avg) Renewable increasing (EU).

Wind and Solar: Actual installation >> Predictions. So renewable energy is more important now. (HK a little)

Coal Mining & Processing → Transportation → Generate Electricity → Consumption. (Real clean energy hard)

Solid waste: unwanted or discarded solid material: MSW and ISW; Hazardous waste: threatens human health and the environment; toxic, chemically active, corrosive or flammable.

Food and green >> Paper and cardboard > Plastic. Averages 0.74 kg per day per capita, but 0.11 – 4.54 kg. East Asia and Pacific high waste generation, then South Asia. (ME lowest)

Primary recycling: Turned into new products of same type (cans, newspapers) (closed loop) Secondary recycling: converted into different products.

Great Pacific Garbage Patch: region floating plastic debris. (Pacific gyre islands and reefs in circulating) more than 100 M tons of plastic. "Reduce, Reuse, Recycle"

Waste stream: steady flow of all forms of trash; MSW challenge: mixed 50% Agri-waste. Industrial waste: hazardous and toxic waste. (~400 M per year) Small but challenging.

Disposal methods: Landfilled, Recycled, Incinerated, Composted. Sanitary landfills dominate US but costly. Ocean dumping is mostly uncontrolled. (Release hazardous substances into air and water)

Sanitary landfills manage CH_4. Export waste to countries ill-equipped to handle it.

Incineration produces energy from trash, but toxic substances released. (Recycling better)

Reducing waste is the most important; Recycling and reuse save materials and energy. (Hard to implement)

It saves money, energy, raw materials, land space, reduces pollution. (Easiest when materials are separated)

~50% of aluminium cans are recycled in US. Recycling easier? (Low prices for new materials) Plastic is cheaper than collecting and transporting used one, when disposal and others not considered.

2M trees every day to produce paper. Most efficient? How much we produce, landfill, incinerate, recycle.

Composting recycles organic waste. Decrease landfill space. Biological degradation of organic matter. Making nutrient-rich soil amendment that aids water retention, slow soil erosion, improves crop yields.

Reuse is better than Recycling. Cleaning and reusing materials in their present form saving cost and energy.

Using materials that are compostable or degradable. Photodegradable, Biodegradable.

Less packaging; Use own; reuseable/easier-to-recycle glass/metal; separate recycle; compost.

Hazardous wastes: Legislation enforces cleanup and safe handling (expensive). Dangerous in small doses. Can be used, recycled, decontaminated, or stored permanently. They are liquid/material/solid: fatal to humans or animals in small doses; toxic, carcinogenic, mutagenic, teratogenic to life-forms; ignitable with a flash point <60 °C; corrosive; explosive or highly reactive. Most is recycled, converted to non-hazardous forms.

Persistent Organic Pollutants (POPs): remain intact for long periods; widely distributed; accumulate in the fatty tissue; toxic to both humans and wildlife. (Bioaccumulation and redistribution/biotransformation).

Pesticides, industrial chemicals, unintentional production cause POPs. Stockholm Convention: eliminate production and use of intentionally and unintentionally produced POPs; manage disposal of POPs waste. HK quite low. Dioxins (PCDDs) and Furans (PCDFs) under Stockholm convention. (toxicity equivalent values)

POPs distributed worldwide via atmosphere/ocean. In arctic from river discharge, ocean currents, air, ice.

Polycyclic Aromatic Hydrocarbons (PAHs): Lipophilic. Poor solubility in water but easy to penetrate body cells.

Anthropogenic sources: coal combustion, open flame grilled meats, cigarette smoke and oil spills. Natural sources: forest fires, volcano eruptions and biogenic formation. (Monitor absolute [PAHs] to management but hard to measure)

Oil spill accident: offshore oil platform; pipeline; oil tanker; storage tanks. Type: crude oil, diesel, gasoline…

Use Gas spectrometry. Diesel oil has high relative content of aromatic and heterocyclic compounds with UCM. Gasoline: light hydrocarbon ($<C_{12}$) Fuel oil: PAHs and heavy components. Pollution control vessel, oil spill response team clean up spilled oil. Invisible pollution: UOG and wastewater retention.

Hazardous waste: Produce less waste (recycling and reusing), Convert to less hazardous substances (Physiochemical treatment, Incineration, Chemical processing), Store permanently (permanent retrievable storage and secure landfills: thick plastic liner, compacted clay and gravel bed)

Bioremediation: releasing toxins. Bacteria, fungi absorb, accumulate, detoxify toxic compounds. Risks: plants with toxics – insects – food chain. Absorbed contaminants are volatilised. Cost-effective, but need efficient.

Degradation of organic contaminants (MTBE, TCE, PCB) and transform heavy metals.

Subsurface contaminants: surface and groundwater threatened, inadequate tech, risk public, special cleanup.

Monitoring of pollutants through modelling. (Atmosphere, Lithosphere, Hydrosphere and sediment + AI)

Primary microplastics: < 5 mm, manufactured industrial product. Secondary MP: debris of large plastics

MP: 1 μm to 5 mm. Nano-plastics is < 1 μm. An emerging environmental issue. (PET, PVC, PE, PP, PS)

Exponential growth of plastic production. In 2050, marine MP >> fish (Most abundance populations)

MP are ubiquitous in Oceans. Transported by hydrodynamic process, winds and ocean currents. Broken down into smaller pieces, found everywhere. Transport within food chain and threat to ecosystems. Absorb some POPs and become a carrier for their transport.

Source: Atmospheric deposition, riverine input, coastal tourism, direct emissions from land sources, marine farming and fishing, ship transportation. Floating on sea surface: 0.5%.

Microplastics affect element biogeochemical cycles. Plastisphere-microbe interface. (Plastisphere)

Plastisphere might be a hotspot for elemental biogeochemical cycles.

The plastic you discard is making its way back into your body. Plastic rain, Plastic people.

China faces great pressure of environmental diplomacy. (Solid waste, Population density, economic status)

Mass of mismanaged plastic waste (8.82 MMT/yr in China, 0.28 MMT/yr in US, sim in inadequate managed)

Distribution of MPs: Near-shore, Aquiculture area, Deep Ocean, Open Ocean, Antarctica. (UNITS)

Marine MPs issues: Ecological civilisation construction; Environmental diplomacy.

Changjiang Estuary is a main contributor to plastic pollution in the ocean. Minjiang river (Downstream highest, middle lowest). Modelled > Measured. (Dutch Canal, Netherland; US and Canada are the largest)

Riverine input of microplastics: Concentration of microplastics × River discharge (well-constrained)

Measured: River: Plastic fragments to sea, Pearl River and Yangtze River (large diff in data + model)

Mass Flow Analysis: flows and stocks of materials. Mismanagement Plastic Waste: Geographic region and income level; Human Development Index: Interactions between human development and plastics pollution.

With modern society development, pressure of population increases and MPs management become difficult.

Estuary-offshore MP transport: Tidal process – 24 h change; River plume: MP floating pathway, plastic accumulation area, transport. Affect temporal and spatial distribution of plastics. MP transport depends on floating plume. Biogeochemical process: adsorption (MP runoff to marine); Microbiofouling (biofilms $\propto$ exposure time but decrease with water depth. Typical morphologies and compositions of biofilms); Deposition (Bacterial communities attached to MPs).

Trawling with **Manta net** to collect particles from surface seawater. Higher MP may relate coverage of sea ice.

China: Largest plastic consumption and waste generating country, Largest plastic producer, Largest importer of plastic waste, cannot survive mismanagement on plastic pollution.

Pearl River Estuary one of the most polluted region:

Upstream: Sheet fragmental, fibrous PE, PP, PE-PP copolymers; Increase MP abundance in sedimentary core.

Along cities: PP-PE dominant, wastewater treatment plant in GZ can reduce MP pollution in MSW. Fibre found.

Urban section: Films, polyamide, and cellophane. Wastewater effluents may be main source.

Tourist beach: PP (60%), PE (32%). Small-plastic debris (64%) + Large plastic. Zhuhai > Macao > HK

HK beach: Wet >> Dry (Seasonal variation). West >> East. MPs controlled by fluvial inputs. Beach: reservoirs

Mudflat & Sandy beach: PE, PP, PET. Mangrove wetland: PE/PP Coral Reef: PE.

Freshwater fish: Fibre, transparent, PET, PE, PP. Oyster: Wild < Farmed. Fibre

Mussel: Medium. Fibre. Fish: Fibre in gills, stomach, and intestine.

Commercial fish: in gills and intestines, some liver, no muscle. Crabs: in gills and intestine.

Mullet: Wild: 60%, Captive: 16.7%. Fibres, green small size PP.

Hong Kong MP: Film/sheet, Fragment, Line/fibre, Foam, Pellet.

$$\text{Carbon contribution of MP} = \frac{\text{mass of MP} \times \text{Carbon content of MP}}{\text{Bulk density} \times \text{Sediment carbon content} \times \text{Sediment core length}}$$

Mangroves efficient in MP trapping than tidal flats. More concentrate at upper than lower.

MP may not be a major sediment C component in coastal wetland but hidden contributor.

Plastic additives, PVC, PS may be toxic after burning. To Cu^{2+} or Hg. PE, PP MPs Significant changes in 180-day.

River Norm: < 5ppm, Now 180 day 900 ppm. Organic compound to solvent.

MPs are ubiquitous in the GBA, including environmental metrics and organisms. Dominant MPs: fibres, small size, PP and PE. MPs frequently detected in gills and intestines of organisms.

(Over 79 years, a person will eat 20 kg of MPs) Drinking water (Tap < Bottle) << Table salt <<<< Inhalation.

Air: dry < wet. Urban vs Rural. Indoor MPs > Outdoor MPs. Dust important source.

Adult men highest annual consumption through inhalation.

Area of Ocean: 70.8% of Earth. Average depth: 3688m. Deepest: 10916 m. Only explore 5% of ocean bottom.

Total econ: 24.2 Trillion USD. Approx ¼ GDP in marine.

Royal Navy Research ship (1768-1771) → Coastal Zone Color Scanner, MODIS, for monitoring ocean var.

High pressure in Marine trench. Communication and materials for deep sea.

Bozo: hollow metal ball to 165m in 1894. Pinault: ellipsoidal 2ppl 130m. Trieste submersible: 150 ton, 8.20, 10916m; Alvin: 3 ppl, 4500m, underwater camera, manipulators, power. Nautilus: multimetallic nodule area. Russia's Mir I and II. 6 km 17-20h. Deepsea 6500 JP, 6527m, 6h. Jiaolong: 7000m 3ppl. Largest submersible in same depth. Record: 10909m

BGC-Argo: robotic floats for temp, salinity, pressure, biogeochemical measurements.

Climate change: global warming, river material input, sea level rise, storm surge, extreme weather events, ocean acidification and hypoxia. Anthropogenic factors: overfishing, eutrophication of culture area, habitat destruction, oil spill disaster, reclamation project, microplastics pollutions.

Global offshore environment and resources: food demand, marine engineering construction, illegal behaviours, fishery collapses, ecosystem degradation, climate change.

Increasing ocean temperatures. Deep water also. Typhoon (tropical cyclone) in coastal region. Huge disaster and economic loss. Have to better prepare. Heavy rain, lower salinity, atmospheric pressure, less fish.

Sea level rise in China >> global. Overexploitation and utilisation of groundwater resources. Construction of high-rise buildings in coastal areas.

Land reclamation and habitat destruction: Nutrients, heavy metals, and toxics to ocean. Dust events in NW.

Global Ocean Acidification: consumption of carbonate ions impedes calcification.

Oil spill: Alaska 50000 tons of crude oil → 1300 km^2 along coast contaminated.

Global MP pollution: 5.25 trillion plastic particles floating on surface. 2.7×10^5 tons. (Accumulated in body)

Many MP but also Macroplastics. Wind, human, biological transport, plastic break in river tributaries merge into ocean and along sea currents. UV light bath to break down.

Ideal marine environment: clean seawater, abundant safe seafood, stable coast, normal current, normal thermohaline, sea floor full of life, normal red tide.

Observation method: China Argo Real-time Data Center, Novel Observation Platform, Satellite Information Processing System, National Marine Early Warning Platform, Regional Ocean Observation Network.

Surface Spatial distribution of global primary productivity: ~70% of the earth surface for 50% of total production: low unit production at oceans.

Factors limiting: surface: enough light, limited nutrients, mixed layer, low chlorophyll-a; subsurface: light, low nutrients, bottom of ML, max chl-a; Deep sea: no light, sufficient nutrients, beath ML, low chl-a

Primary producers ∝ chlorophyll concentration (N, P, Si, Fe) Indicator: water quality + [chlorophyll]

Tidal zone breeding and interbreeding: ecological farming. Green healthy aquaculture environment.Blue carbon and sustainable development of aquaculture ecosystem. (carbon cycle cost ~ food cost).

Capture production since 1980s remains stable, aquaculture production increases steadily.

Green macroalgae eco-dynamic model (remote sensing data, current, wind, light, temperature) to inform local government and agricultural where have harmful algae.

Scallop bottom culture ecosystem model → length and weight of scallop bottom.

Carbon dioxide removal and Solar radiation management (manage climate)

Ocean-based CDR: biotic CDR (add nutrients, ecosystem recovery, seaweed farming, ocean tubes) abiotic (Ocean alkalinity, electro-chemistry) Persistence!!! Carbon sequestration: Land-ocean integrated eco-engineering, enhancement of seawater alkalinity, seaweeds culture, artificial upwelling, coastal blue carbon, ocean fertilisation, biomass dumping, CO_2 injection, CO_2 seafloor burial.

BCP, MCP, CO_2 injection, macro algae cultivation, alkalinity addition to increase carbon store.

Seaweed farming offset ocean acidification. Wastewater alkalinity addition (ocean -ve carbon emission)

BCP-CCP-MCP-SCP (BCMS) approach to overcome climate change.

Observation to Model to (Current ocean, ongoing changes, management impacts, forecast, sustainable resources, ecosystem health) to Marine ecological health.