Natural resources

Topic 7 · SL and HL

Capacity is not generated energy

IEA report published 2024

China commissioned as much **solar** PV capacity in 2023 as the world did in 2022.

New capacity is not annual electricity generated.

Resource choices change

Technology, cost, geography, policy and values shape use.

Sunlight supported human activities long before modern panels.

Classify resources carefully

Stocks and recurring flows

Natural capital supplies goods and services as **natural income**.

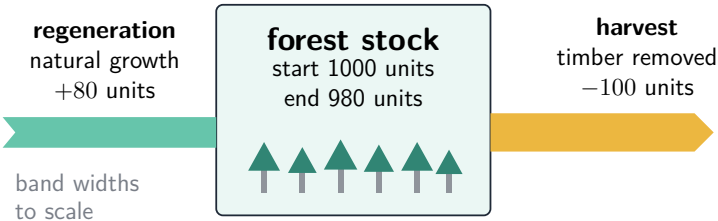
Renewable growth/recharge can be exceeded; sunlight/wind are finite-power flows.

Timescales and losses

Soil formation and fossil groundwater can be effectively non-renewable.

Metals can be recycled, but collection, energy, contamination and losses matter.

An invented stock budget



$$1000 + 80 - 100 = 980 \text{ units}$$

harvest exceeds regeneration by 20

if these flows continue, the stock falls by 20 each period

the yield is sustainable only if harvest $\leq$ regeneration

$1000 + 80 - 100 = 980$ units; use exceeds regeneration by 20 units.

Goods, services and values

Examples

Timber and fish are goods; flood regulation and nutrient removal are services.

Forests, rivers and wetlands support several functions at once.

Different values

Aesthetic, cultural, economic, environmental, health, social, spiritual and technological.

Intrinsic worth is independent of human usefulness; a market price does not capture every value.

Resource value and local choice

Dynamic examples

Lithium demand changed with batteries; whale oil lost its lighting role to alternatives.

Lithium is not a rare earth; different materials serve different functions.

Evaluate perspectives

Culture, history, cost, technology, policy and environmental concern.

Neutral voluntary surveys: willingness to pay also reflects income and access.

Resource security: two water contexts

Singapore

Four National Taps: catchments, imports, NEWater and desalination.

Diversity improves resilience but needs energy, finance and quality management.

Jordan, 2023 strategy

About 61 m^3 **renewable** freshwater/person/year in the dated account.

Scarcity, demand, groundwater and unequal access; planned supply is not delivered capacity.

Manage demand and ecological functions

Strategies

Efficiency, durability, **substitution**, repair, reuse and suitable **recycling**.

Diverse supply and trade can improve security.

Limits

Harvest at estimated growth does not alone conserve habitat or soil.

Pollutant loading must avoid harmful accumulation; security is not identical to sustainability.

Renewable, replenishable, non-renewable

renewable	**replenishable**	**non-renewable**
forests, fish, solar	groundwater, soil	coal, oil, metal ores

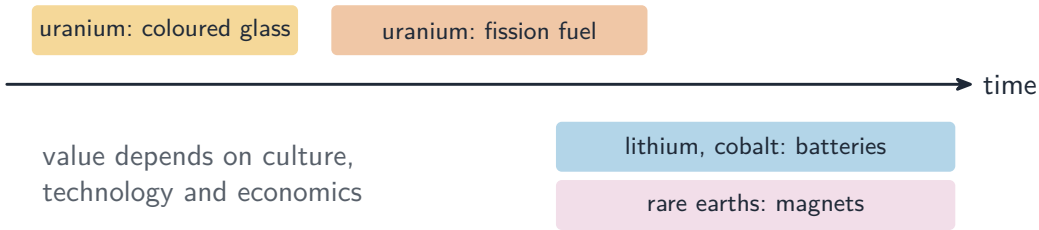


replaced fast — replaced over geological time

any resource is sustainable only while use stays within its replacement

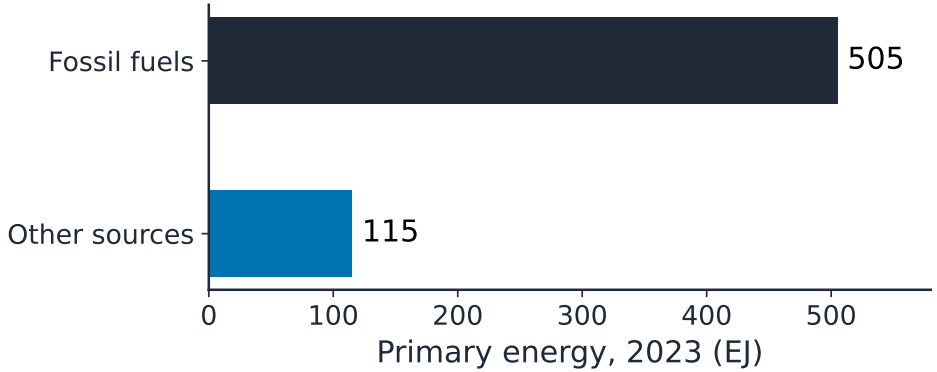
> The difference is how fast each is replaced

A resource's value changes



> Technology decides what counts as a resource

Dated world primary-energy quantities



EI 2024 edition: rounded 2023 total 620 EJ, with 505 EJ fossil and 115 EJ other sources.

Calculate a fossil-energy share

1. **Dated rounded values.** Fossil 505 EJ; total 620 EJ.
2. **Share.** $505/620 \times 100 = 81.45\%$, approximately 81.5%.
3. **Boundary.** Primary energy, under this report's accounting; not electricity shares.

Decision

Do not splice datasets with different primary-energy methods or compare MW directly with MWh.

Primary energy and industrial services

Needs and change

Population and per-person demand influence totals.

Transport, heat, steel, cement and fertiliser need specific services.

Carriers

Electricity and hydrogen are energy carriers.

Hydrogen production needs energy/feedstock; fuel cells are not a free primary source.

Evaluate non-renewable sources

Fossil fuels

Coal, oil and gas: useful energy and feedstocks, with emissions and extraction impacts.

Gas may lower direct CO_2 compared with coal, but upstream methane matters.

Nuclear

Generally low lifecycle carbon; high availability and small fuel mass.

Mining, cooling, accidents, waste, financing and decommissioning need a full boundary.

Renewables differ in constraints

Solar and wind

PV needs sunlight; **wind** varies with weather.

Land, materials, construction, ecology and end-of-life management matter.

Water, heat and biomass

Reservoir/run-of-river hydro differ; drought and ecology constrain both.

Geothermal is not only volcanic; tides are predictable, waves weather-dependent; **biomass** is not automatically carbon-neutral.

Compare Norway and Japan

Norway

Hydro-rich electricity, reservoirs and interconnections.

Geography, rainfall and existing infrastructure; ecological flows, drought and costs.

Japan: IEA 2021 context

Import dependence and post-Fukushima supply disruption.

Diversification, efficiency, resilience, renewables and **nuclear** safety; dated context, not unchanged current shares.

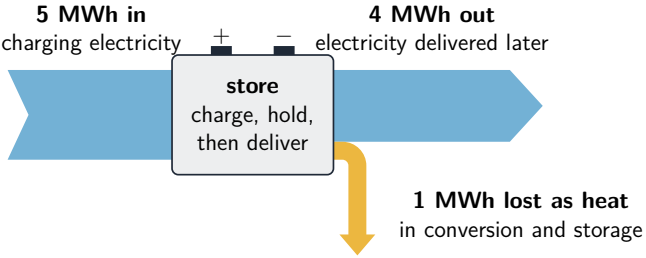
Capacity factor is not efficiency

1. **Invented installation.** Rated power 50 MW; capacity factor 0.30; interval 8760 hours.
2. **Generated energy.** $50 \times 0.30 \times 8760 = 131400$ MWh$=131.4$ GWh.
3. **Interpret.** Ratio to continuous rated output, not thermodynamic conversion efficiency.

Decision

Choose a power unit for rate and an energy unit for accumulated output.

Storage shifts energy with losses



$$\text{round-trip efficiency} = \frac{4}{5} \times 100 = 80\%$$

band widths drawn to scale

Invented round trip: 5 MWh input yields 4 MWh output and 1 MWh losses.

Match storage power and duration

1. **Invented delivered energy.** 4 MWh at 1 MW can cover 4 hours.
2. **Round-trip efficiency.** $4/5 \times 100 = 80\%$.
3. **System choice.** Batteries, pumped hydro, thermal storage, grids and flexible demand serve different needs.

Decision

Finite energy and power cannot guarantee unlimited backup through a long shortfall.

Conservation, efficiency and rebound

Two mechanisms

Behaviour can reduce service use; efficiency reduces input for comparable service.

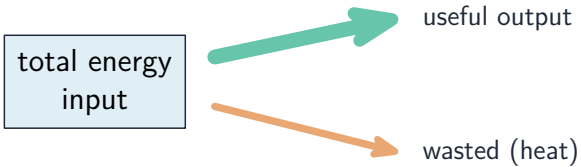
Insulation and efficient lighting need measured comfort/illumination comparisons.

Invented conversion

30 MJ useful from 100 MJ input gives 30% efficiency.

Rebound can offset engineering savings; a lower impact per service need not lower total use.

Energy efficiency



$$\text{efficiency} = \frac{\text{useful output}}{\text{total input}} \times 100\%$$

Waste heat cannot be avoided entirely

Classify waste by source and type

Source

Domestic, industrial and agricultural.

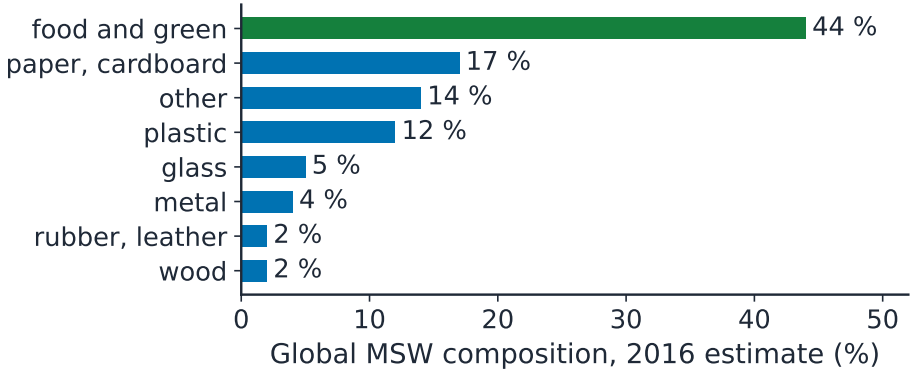
Municipal definitions and collection coverage vary.

Type and measure

Food, e-waste, biohazardous materials, paper, plastic, metals and others.

Categories overlap; mass, volume, moisture basis and per-person rates differ.

A dated global waste composition



World Bank 2018 report: approximate 2016 composition, not every city or a current measurement.

Trends are conditional and unequal

World Bank 2018 report

2016 estimate 2.01 billion tonnes MSW; conditional 2050 projection 3.40 billion.

Not a current annual count.

Society and time

Income, diet, policy, technology, packaging, season and collection matter.

Do not treat all higher- or lower-income households as identical.

Plastic persistence and exposure

Physical effects

Entanglement, ingestion, habitat effects and fragmentation.

No universal lifetime; a garbage patch is not a solid island.

Read the denominator

OECD: 9% of 2019 plastic waste ultimately recycled after losses.

Microplastic detection establishes exposure, not by itself a particular disease.

Half-life is a conditional model

1. **Invented assumptions.** 80 g substance; fixed 10-year half-life.
2. **After one and two half-lives.** 40 g after 10 years; 20 g after 20 years.
3. **Limits.** Not a universal model for weathering, every polymer or elemental metals.

Decision

Biodegradable does not guarantee rapid harmless breakdown in every environment.

Waste can transfer social costs

Exposure

Leachate, uncontrolled smoke and unsafe recovery affect workers and neighbours.

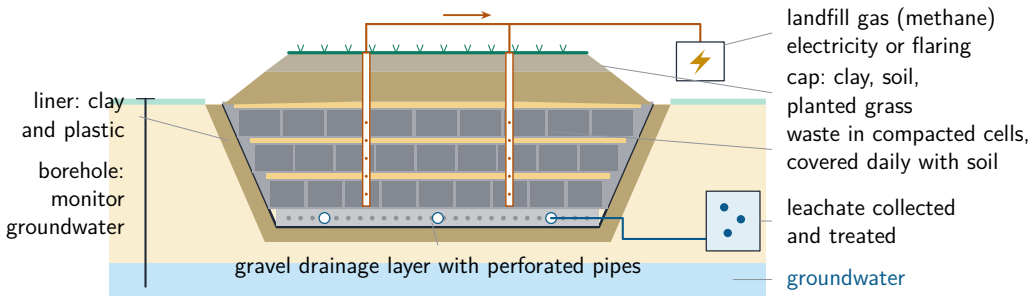
Export may provide materials/income while moving environmental risks.

Governance

Basel e-waste amendments effective January 2025 extend prior-informed-consent controls.

Not proof that illegal movement ended or a universal ban on every working used device.

Engineered landfill reduces rather than eliminates risk



Keep drainage above the liner; collect **leachate** and gas; monitor after closure.

Compare treatment pathways

Landfill and incineration

Engineered **landfill** needs containment, gas and long-term monitoring.

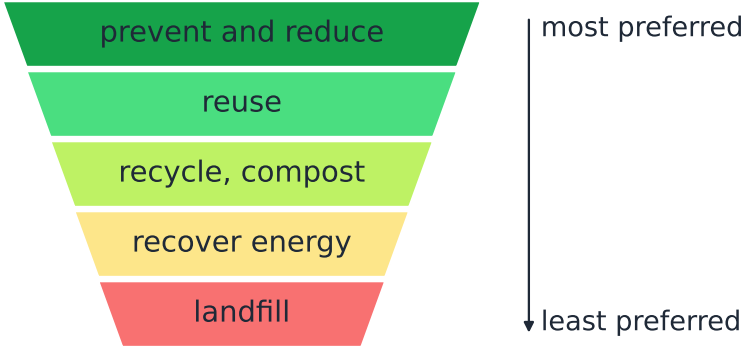
Incineration may recover energy but needs emissions control and ash management.

Biological and material routes

Compost needs sorted organics, oxygen and quality control.

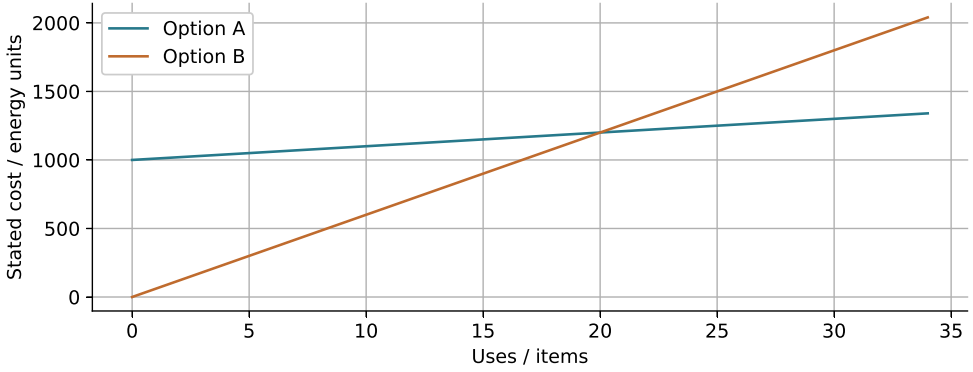
Digestion yields biogas/digestate; **recycling** needs collection, clean streams, energy and markets.

Prefer prevention with safe residual treatment



Avoid upstream demand where possible; hazardous contamination can limit safe recovery.

A matched-service lifecycle model



Invented energy boundary: reusable $1000 + 10n$, disposable $60n$; equality at 20 uses.

Use an inequality for lower energy

1. **Invented bottle.** Reusable: $1500+15n$ kJ; disposable: $90n$ kJ.
2. **Lower energy.** $1500+15n<90n \rightarrow n>20$.
3. **First whole-number use.** 21; equality at 20 is not a saving.

Decision

One wash per use is assumed; water, transport, detergent, breakage and other impacts remain outside the model.

Shanghai sorting: stages need evidence

Regulation effective July 2019

Recyclables, hazardous, wet/food and dry/residual streams.

Labels, facilities, education, monitoring and penalties can support behaviour.

Evaluate downstream

Track contamination, processing, recovered output and residues.

Before/after sorted collection alone does not prove causation or complete **recycling**.

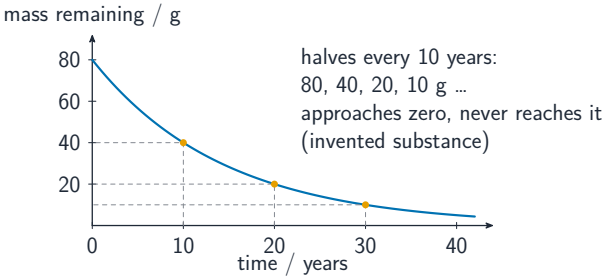
Follow a material through circular recovery

1. **Pathway.** Ore $\rightarrow$ refining $\rightarrow$ aluminium can manufacture $\rightarrow$ use $\rightarrow$ collection $\rightarrow$ sorting/remelting.
2. **Invented efficiencies.** 100 units $\times$80% collected $\times$90% recovered $=$72 units returned.
3. **Loss.** 28 units uncollected or lost; prevention/reuse can reduce primary demand earlier.

Decision

Technical recyclability differs from observed recovery; growth in demand can outweigh lower use per item.

Radioactive waste and half-life



It approaches zero but never reaches it

AHL: Incentives and SDGs

Intervention

Taxes, limits, bonds, penalties; procurement, subsidies, research and standards.

NGOs and communities can monitor and organise action.

Two linked goals

SDG 6 water and SDG 12 consumption/production.

Water reuse can support both, with energy, access and treatment safeguards.

AHL: Renewable does not prove sustainable extraction

Timber supply chain

Roads, habitat fragmentation, soil loss and transport emissions.

Volume replacement alone does not protect all services.

Incentives and claims

Short-term income may undermine long-term renewal.

Biological nitrogen fixation is not an established replacement for every industrial ammonia need.

AHL: Assess a proposed reservoir

EIA sequence

Define alternatives/no project; baseline; predict; avoid/mitigate; evaluate residuals.

Requirements vary by jurisdiction.

Follow-up

Seasonal flow, sediment, fish, water quality, rights and livelihoods.

Indicators, triggers, independent scrutiny, actions and accountable funding.

AHL: Participation and resource security

Public evidence

Accessible information, local knowledge, documented disagreement and rights.

A late meeting does not automatically establish informed consent.

Trade and resilience

Demand reduction, supply and technology choices in food, water and energy.

Trade can spread risk but dependence on narrow suppliers/routes can create vulnerability.

AHL: Rank association does not prove causation

1. **Invented matched observations.** A: 2,4,6,8; B: 3,5,7,9 units/person.
2. **Rank differences.** Both rank 1,2,3,4; every d=0, so Spearman r=1.
3. **Interpret.** Amounts differ; annual observations may not be independent.

Decision

Real secondary-data studies need matched units/periods, metadata, sample-size justification and uncertainty.

AHL: Reserves-to-production is conditional

1. **Invented snapshot.** Reserves 120 units; extraction 3/year $\rightarrow$ R/P=40 years.
2. **Change assumptions.** Extraction 4 $\rightarrow$30 years; reserves 150 at extraction 3 $\rightarrow$50 years.
3. **Limits.** Discovery, prices, technology, policy and demand change values.

Decision

Climate constraints can limit burning before physical exhaustion; R/P is not a guaranteed countdown.

AHL: Nuclear costs, wastes and safety

Full lifecycle

Fission heat $\rightarrow$ steam $\rightarrow$ electricity; fuel **non-renewable**, lifecycle carbon generally low.

Mining, cooling, financing, construction and decommissioning.

Different hazards

Waste heat, shielding, containment and long-term management have distinct roles.

Availability is not absolute and low operating fuel cost does not guarantee a cheap new project.

AHL: Battery chemistry and supply chains

Materials

Lithium: alkali metal. Cobalt: transition metal. Neither is a rare earth.

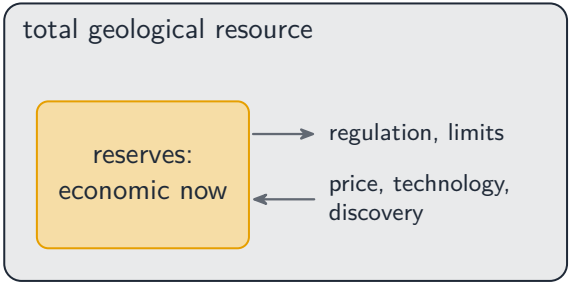
Some lithium-ion cathodes contain cobalt; LFP contains none.

Stages and outcomes

Mining/brine extraction, refining, cell manufacture, use and recovery.

Water, tailings, energy, rights and safety; mining and processing concentration differ.

Reserves and the R/P ratio



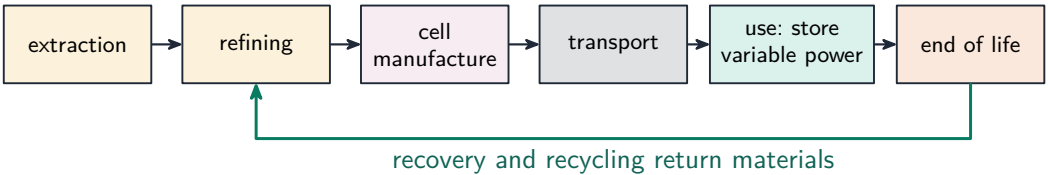
$$\text{R/P ratio} = \frac{\text{reserves}}{\text{annual production}}$$

a conditional snapshot:
both terms change,
so it is not a countdown

R/P = reserves / annual production

A battery's lifecycle

every stage has environmental and social impacts; LFP cathodes avoid cobalt



Recycling loops materials back to refining

Exam tips

State the quantity

Stock/flow; MW/MWh; primary energy/electricity; capacity factor/efficiency.

Collection versus actual recovery; mass versus volume.

Evaluate

Named context, full boundary, equity and evidence.

Renewable/recyclable labels are not outcomes; equality is not a strict saving.

Check yourself

Your turn

A reusable item matches disposable energy at 20 uses and grows more slowly thereafter. At which whole-number use does it first use less?

A. 21 uses.

B. 20 uses.

C. 19 uses.