Grand picture: Sustainability of Civilization

UN-Brundtland Com. "… meets the needs of the present without compromising the ability of future generations to meet their own needs…."

CoR Limit to Growth: MIT sims business as usual (BAU)
Premise/assumptions: no change in population dynamics, no technological advances (gene mod in agriculture, new prospecting methods), no feed-back of publication

$$A_{res}(t) = A_{res}(0) \cdot \exp\left\{-(\lambda/\nu) \cdot \left[e^{\nu \cdot t} - 1\right]\right\}$$

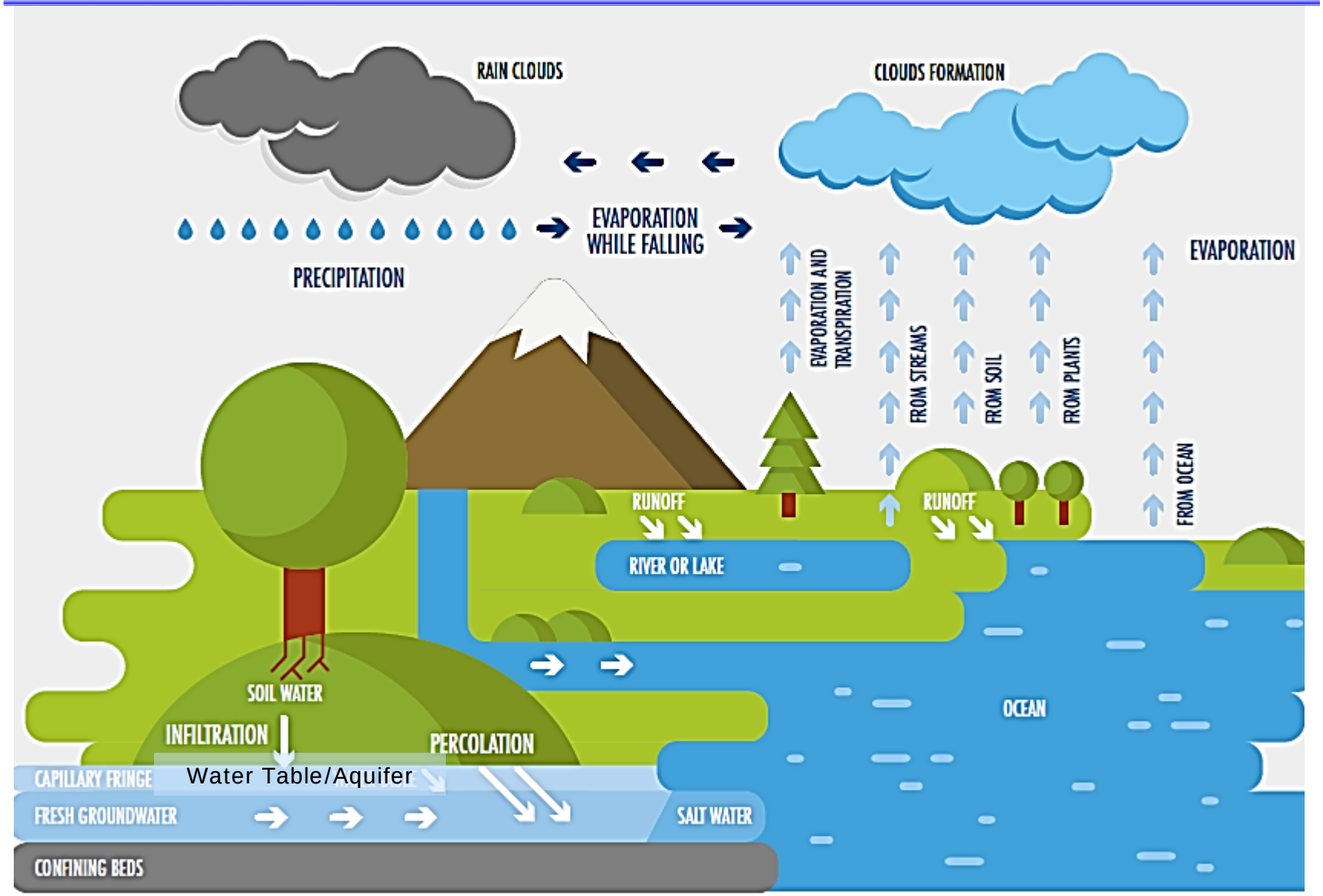
→ tipping point ≈2030 → fast decline of civilization

Did not consider globalization,… **But validity in general prospects…**

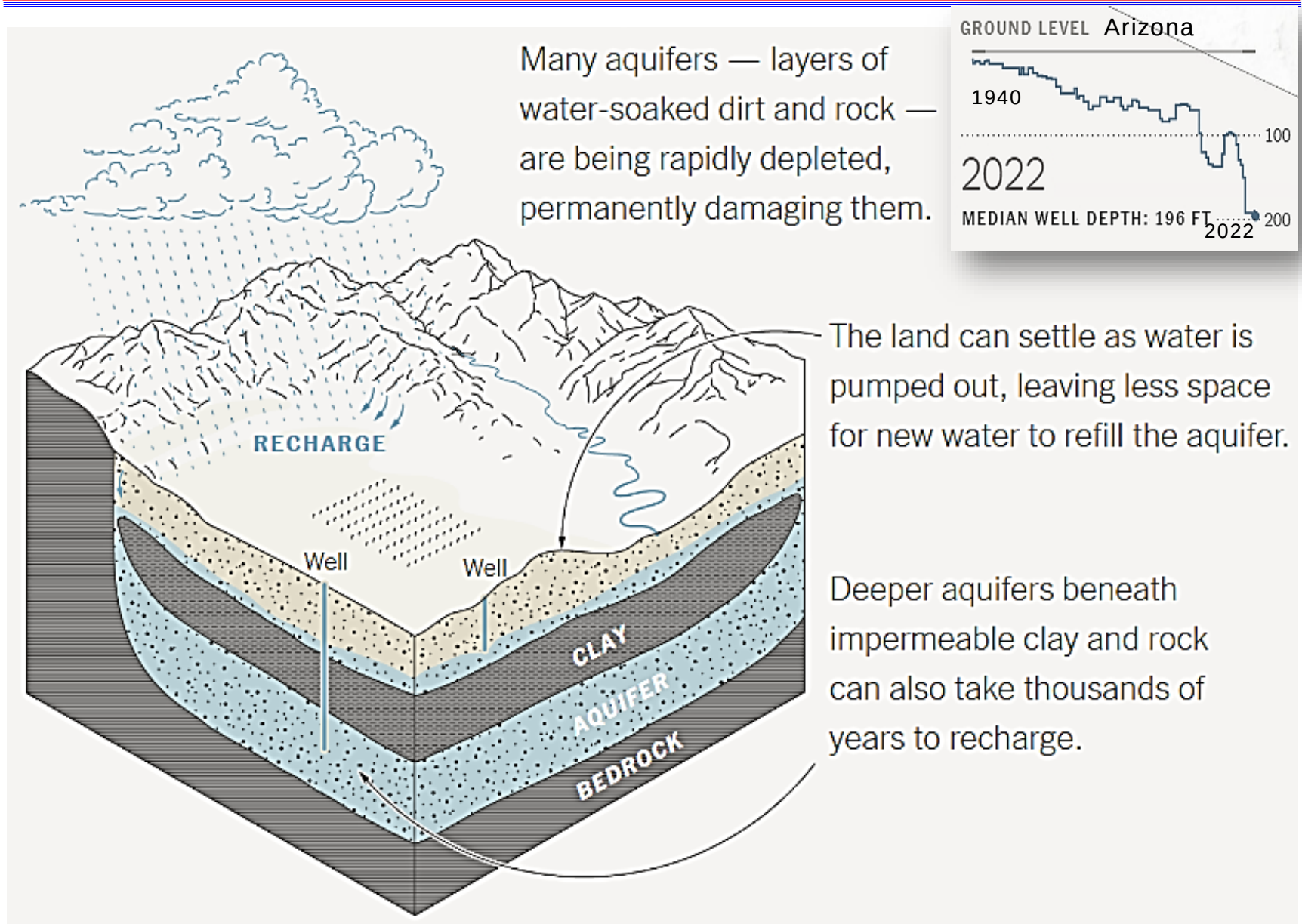
Human ecological footprint: Increases in time, pollution by chemical emissions, specifically CO_2, CH_4,.. Urbanization accelerates, emerging world increases consumption → Present rate corresponds to 1.7x Earth

Socio-Economic Network tasked with preserving resources while sustaining present population: Dilemmas
Air, water, land, essential material resources, fuels,
Inequity: renting of finite resources by high-income regions, arable land

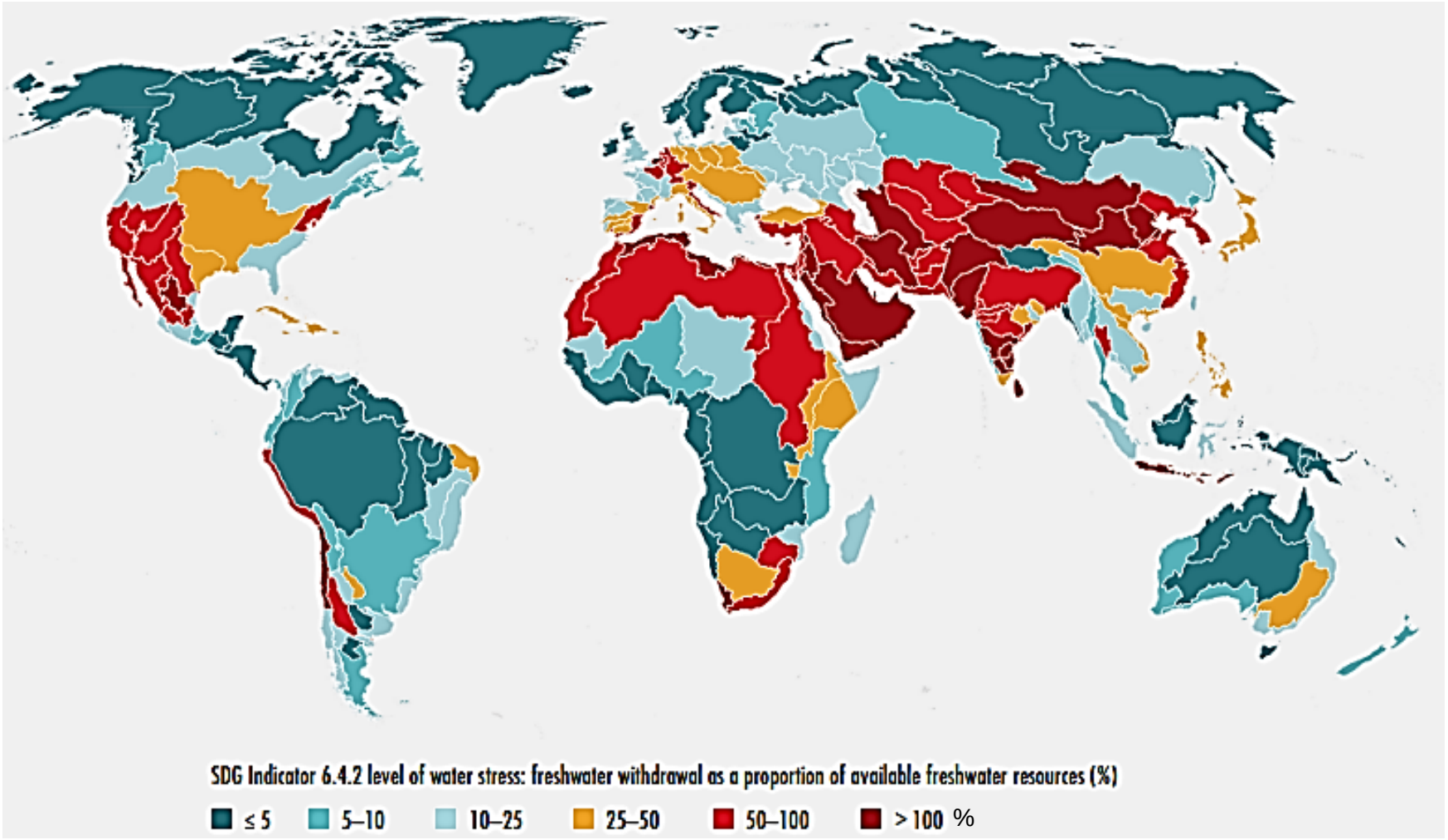
Hydrological Cycle



Tapping and Recharging of Aquifers

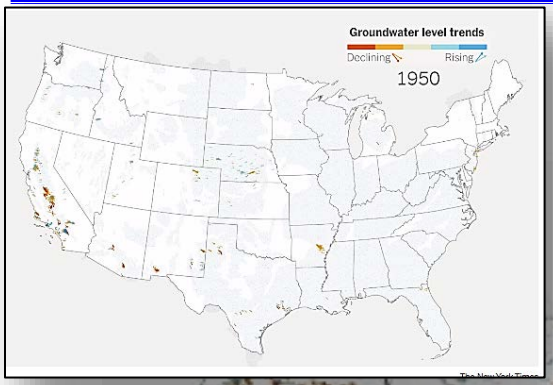


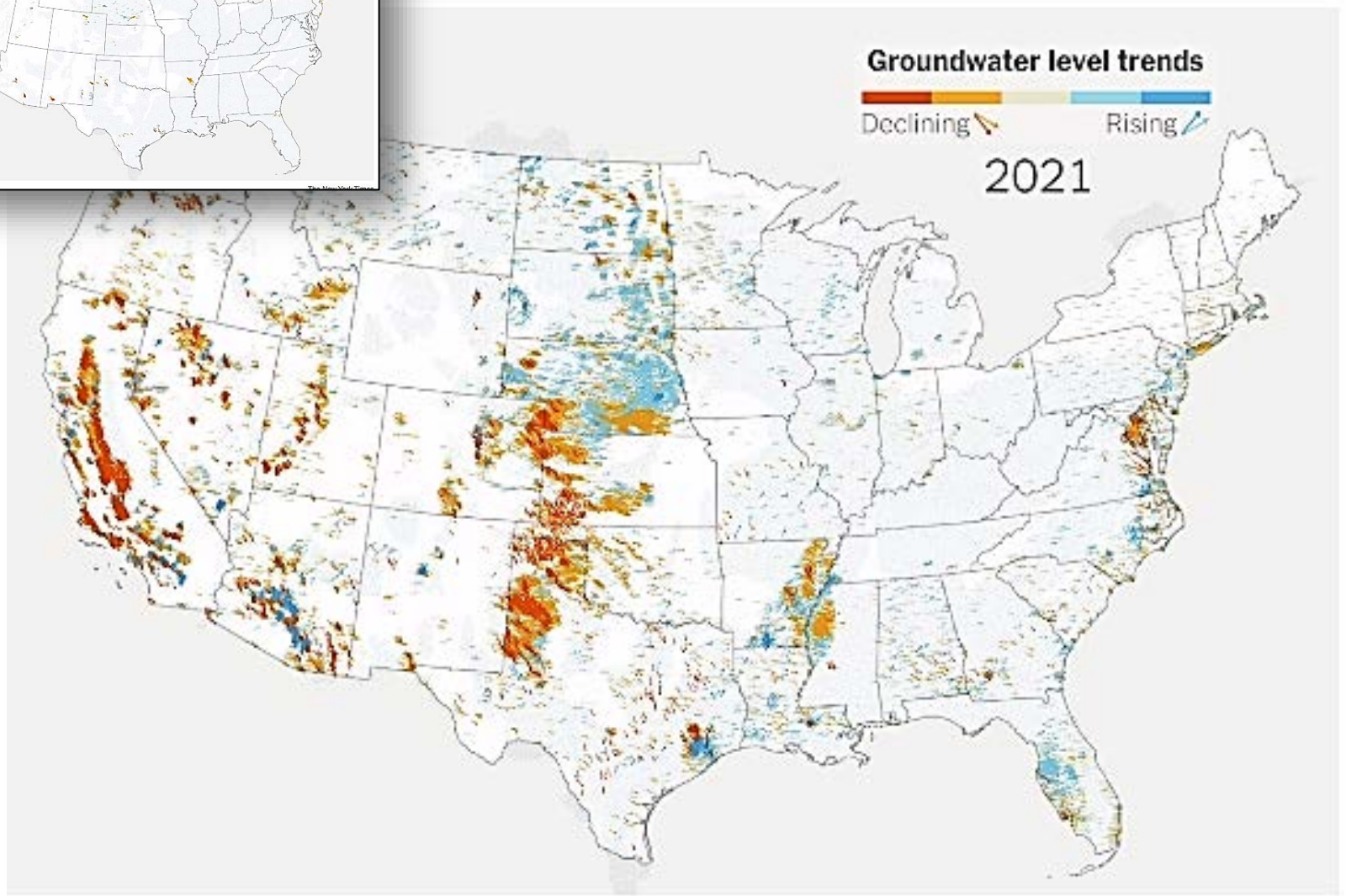
Depleting Natural Resources: Stressed Aquifers



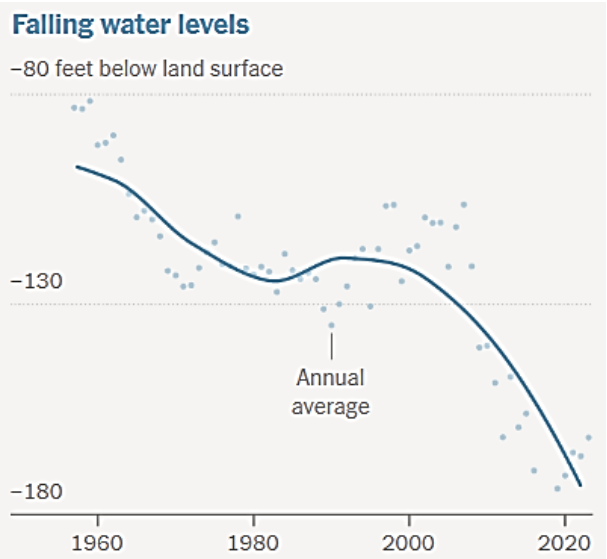
Ratio (%) between total freshwater withdrawn by all major sectors (agricultural, industrial and municipal) and total renewable freshwater resources, after considering environmental flow requirements.

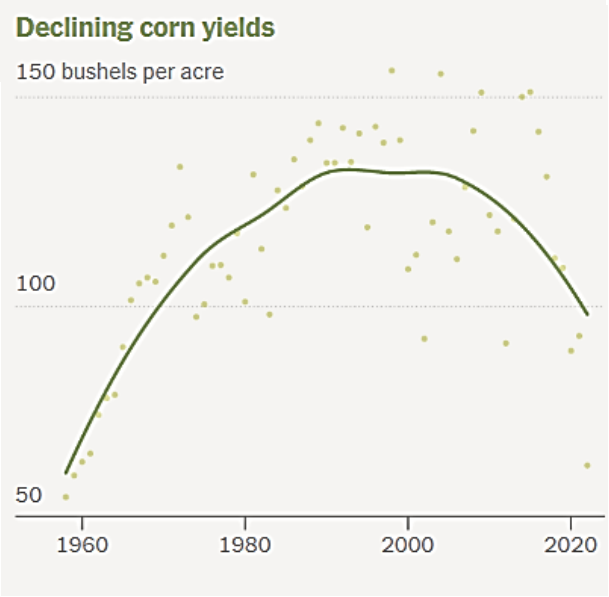
Example: Drained U.S. Groundwater





Consequences of Falling Aquifer Levels



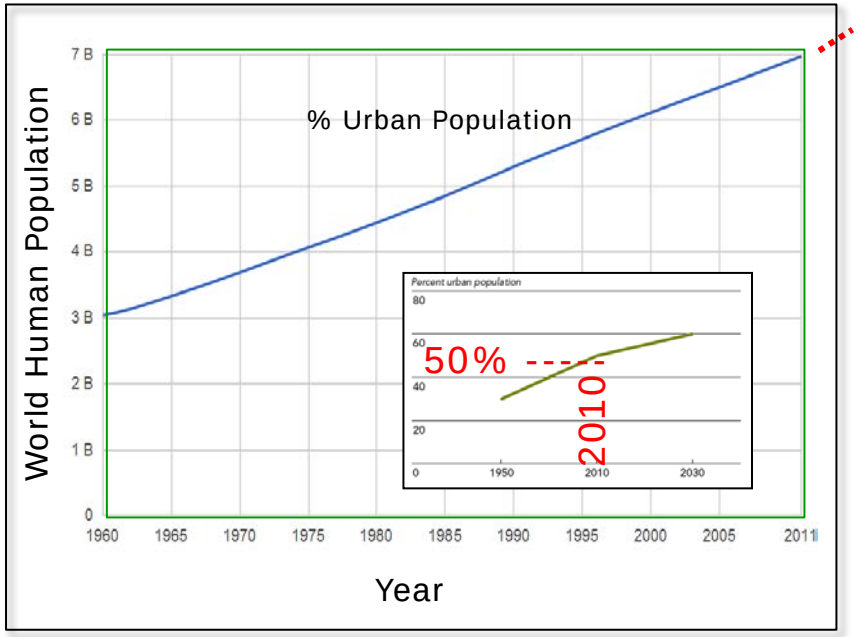


Center-pivot irrigation. Farming is a major groundwater user. Loren Elliott for The New York Times

Industrial-type agriculture on the High Plains produces large fractions of global supply in several crops (corn, alfalfa, soy,…).
Feed for stock, bio-fuels, human food

Center Pivotal Irrigation: Sprinkler systems hooked up to aquifers, R~ 400m.
Drained groundwater requires deeper wells, declining yields.

Testing the Limits: Human "Ecological Footprint"



Present population: 8.0 *B* (1 Billion = $1 \cdot 10^9$) ~0.8 *B* food insecure/starving/impoverished

Estimated for 2050 → 9 B (+urbanization → more energy dem.)

Present (2022) eco-footprint of humanity ~ 1.7 Earths → global ecologic overshoot, diffuse **unsustainability** effect.

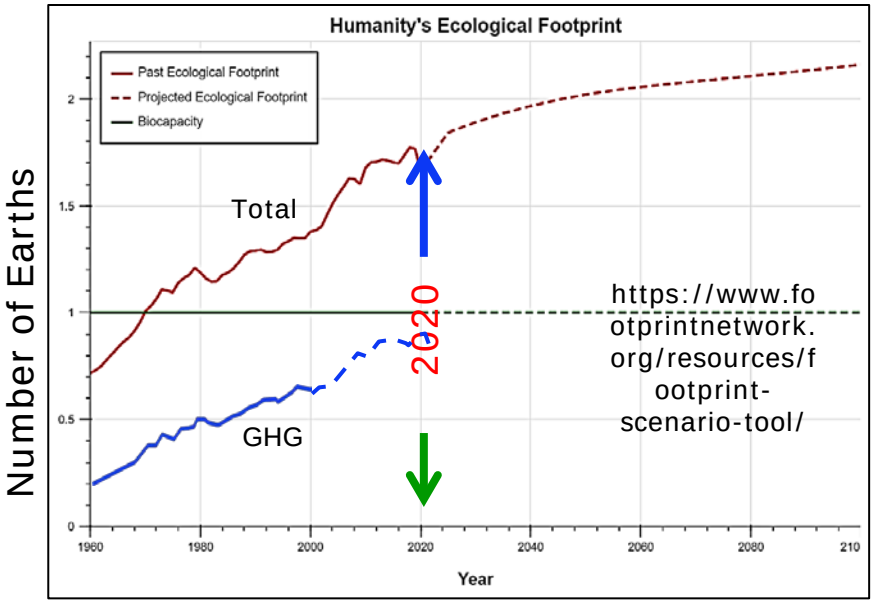
Method to estimate eco-footprint: Sum regenerative capacity (observe+model) of land w/r to maintaining resource, power production, absorbing waste.

Example (1990s): fossil fuel combustion → 6.3 Gt CO_2/a, Ocean absorbs 1.7 Gt CO_2/a

Land absorbs 1.4 Gt CO_2/a

Total absorbed 3.1 Gt CO_2/a

→ 3.2 Gt CO_2/a waste not absorbed but released to atmosphere (= measured).



Energy Fuels

Major Economic Determinant: Energy Utilization

Main uses in industrialized economies:

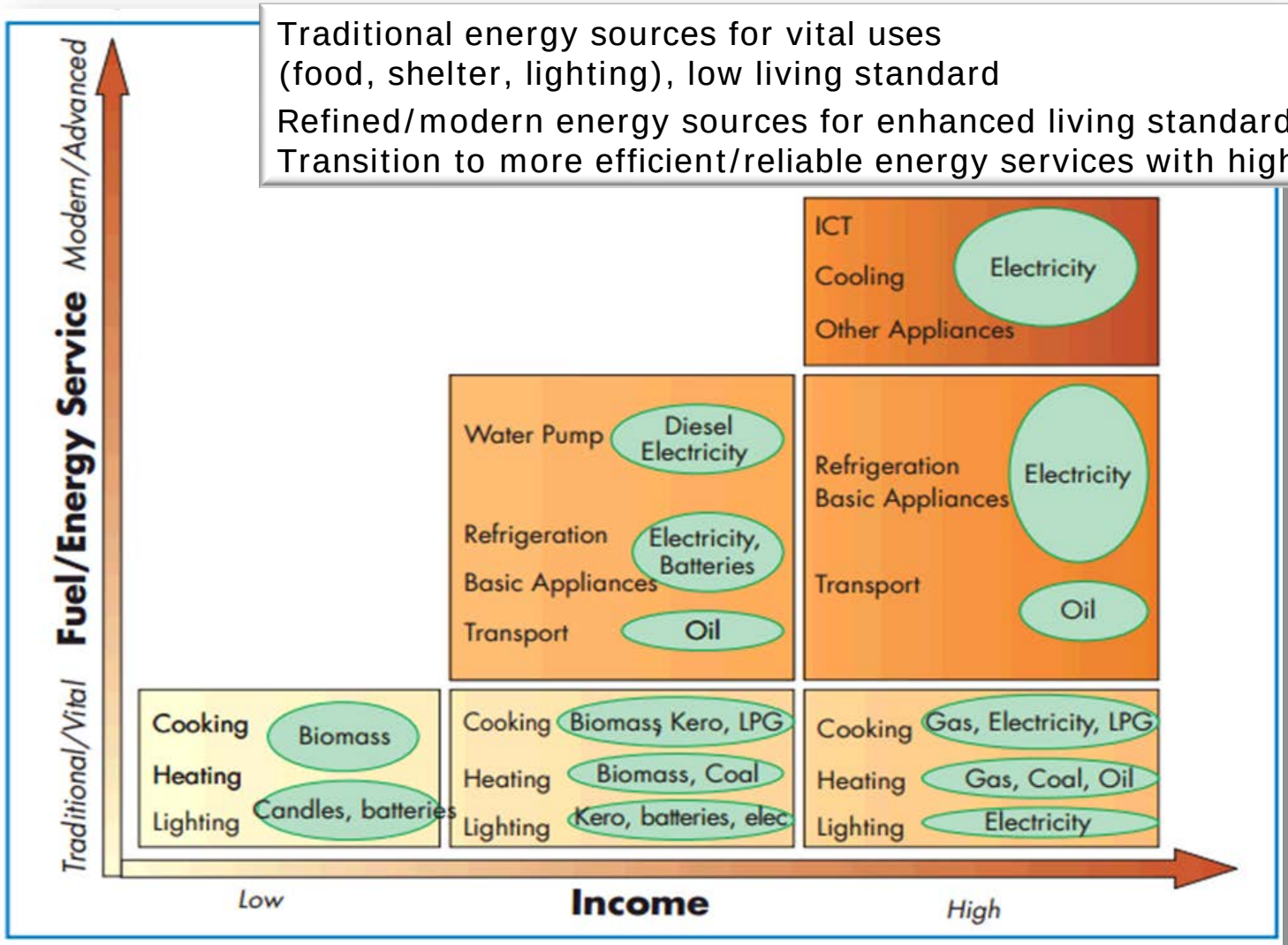
- Production of food (farming, fishing, agriculture,…)
- Processing food (cooking, preserving,…)
- Housing (shelter, heating, lighting,..)
- Construction/building
- Sanitation and healthcare
- Transportation of goods and personnel
- Fabrication of materials and goods (melting, forging, tooling,…)
- Communication, cultural & intellectual development (training)
- Resource prospecting/production (irrigation, ore mining, …)
- Warfare

Are current human modes of operation sustainable ?
Are disasters imminent (“energy/climate Problem(s)”) ?

Energy Utilization vs. Income/GDP

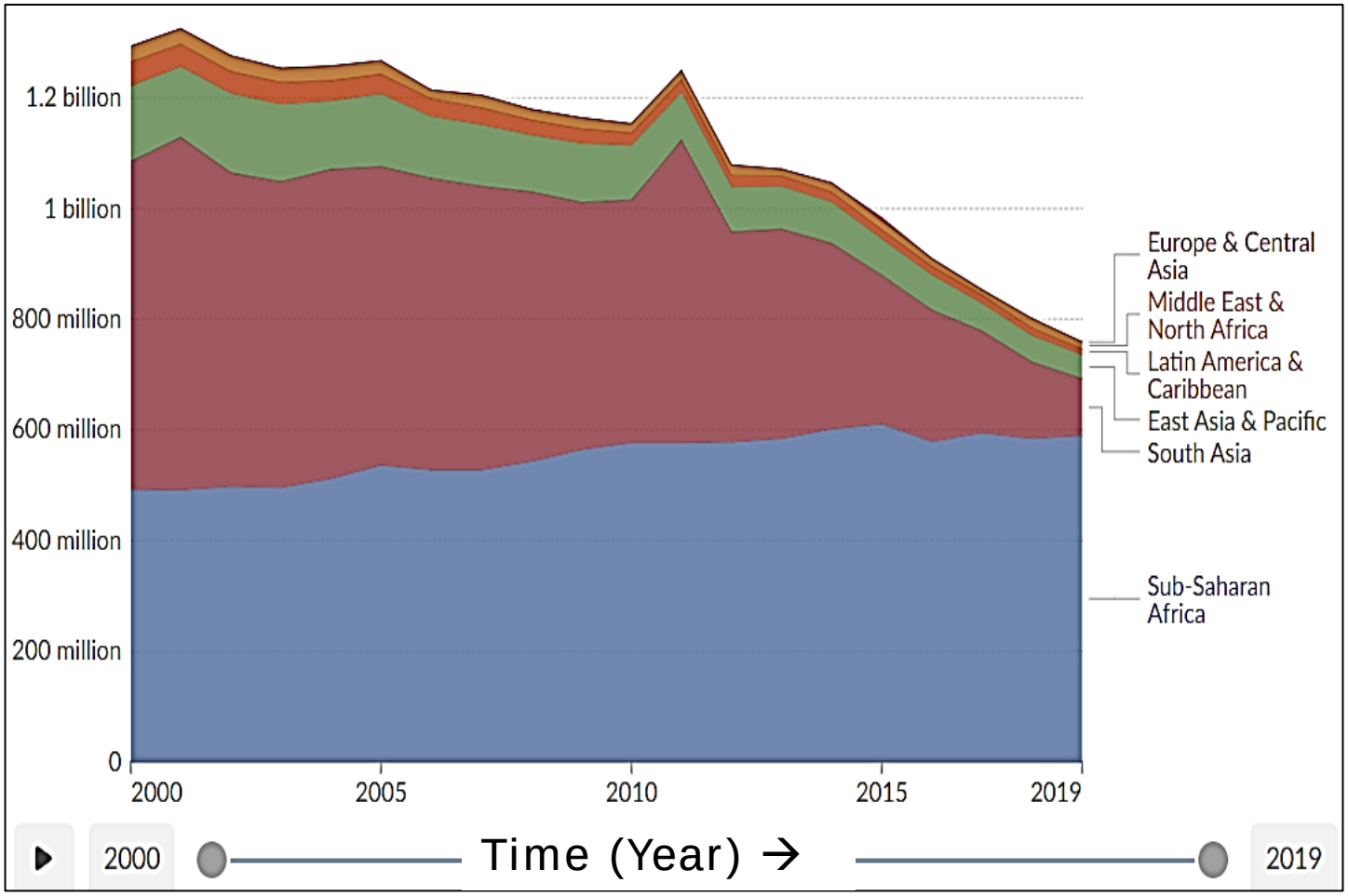
Traditional energy sources for vital uses
(food, shelter, lighting), low living standard

Refined/modern energy sources for enhanced living standard.
Transition to more efficient/reliable energy services with higher income.

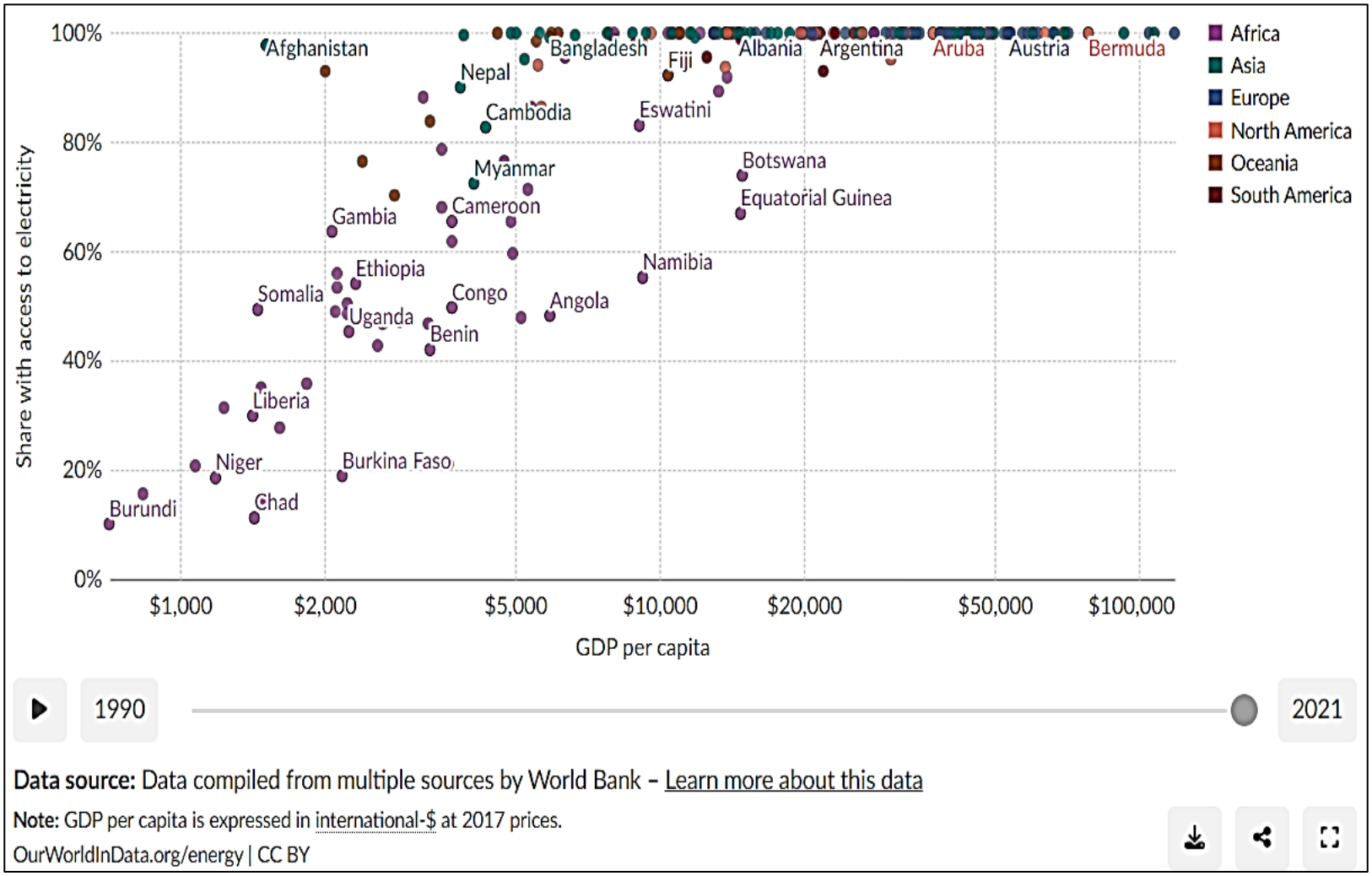


Note: ICT is information and communication technology. LPG is liquified petroleum gas (propane,..)
Source: IEA analysis.

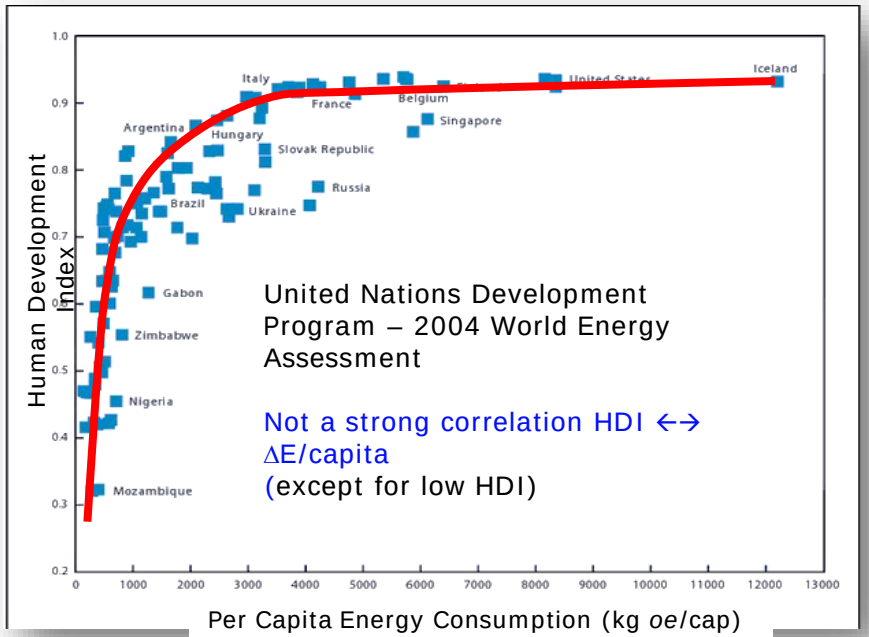
Populations without Access to Electricity



Access to Electricity vs. GDP (by Country)

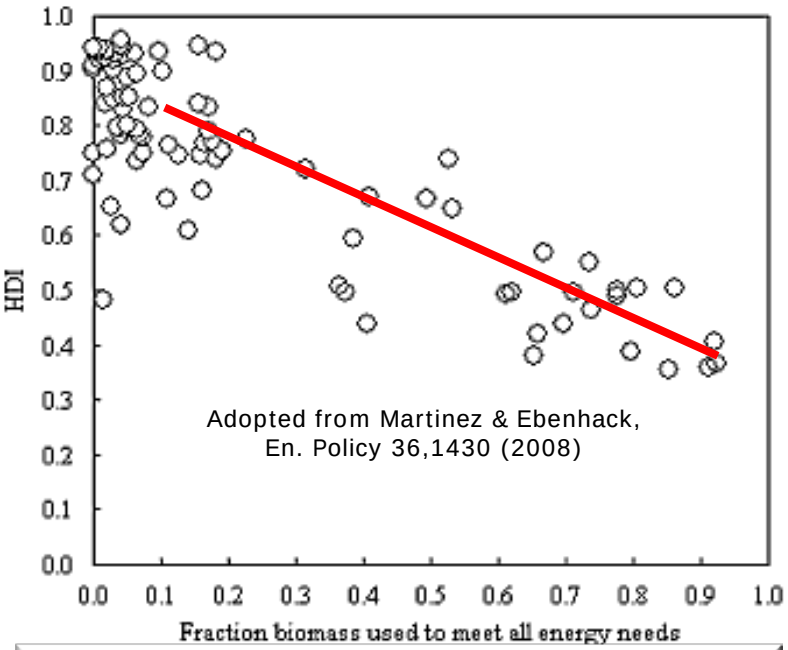


Energy and Human Development



United Nations Development Program – 2004 World Energy Assessment

Not a strong correlation HDI ←→ ΔE/capita (except for low HDI)



Adopted from Martinez & Ebenhack, En. Policy 36,1430 (2008)

Human Development Index HDI

= Weighted average of

a) Health (life expectancy).

b) Education (adult literacy, enrollment).

c) Living standard (ln GDP(PPP)/c).

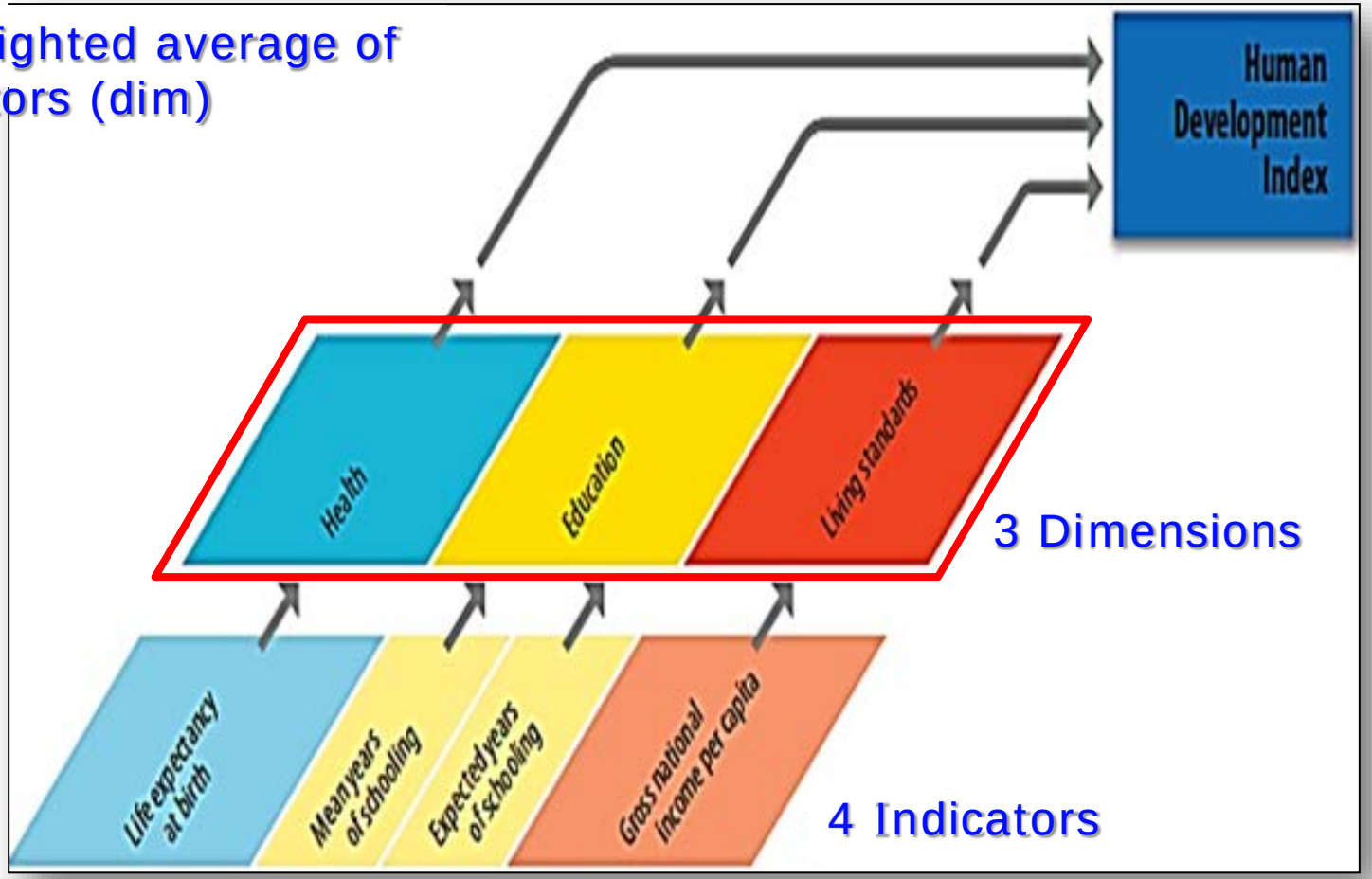
PPP = purchasing power parity per capita

Refined energy source important: Biomass as primary energy resource associates with low HDI. → Emerging and poor societies.

Jevon's Paradox: Technological progress in resource efficiency increases consumption, (rather than decreases consumption).

To raise living standard of emerging world → need refined energy (electricity)

Human Development Index (HDI)

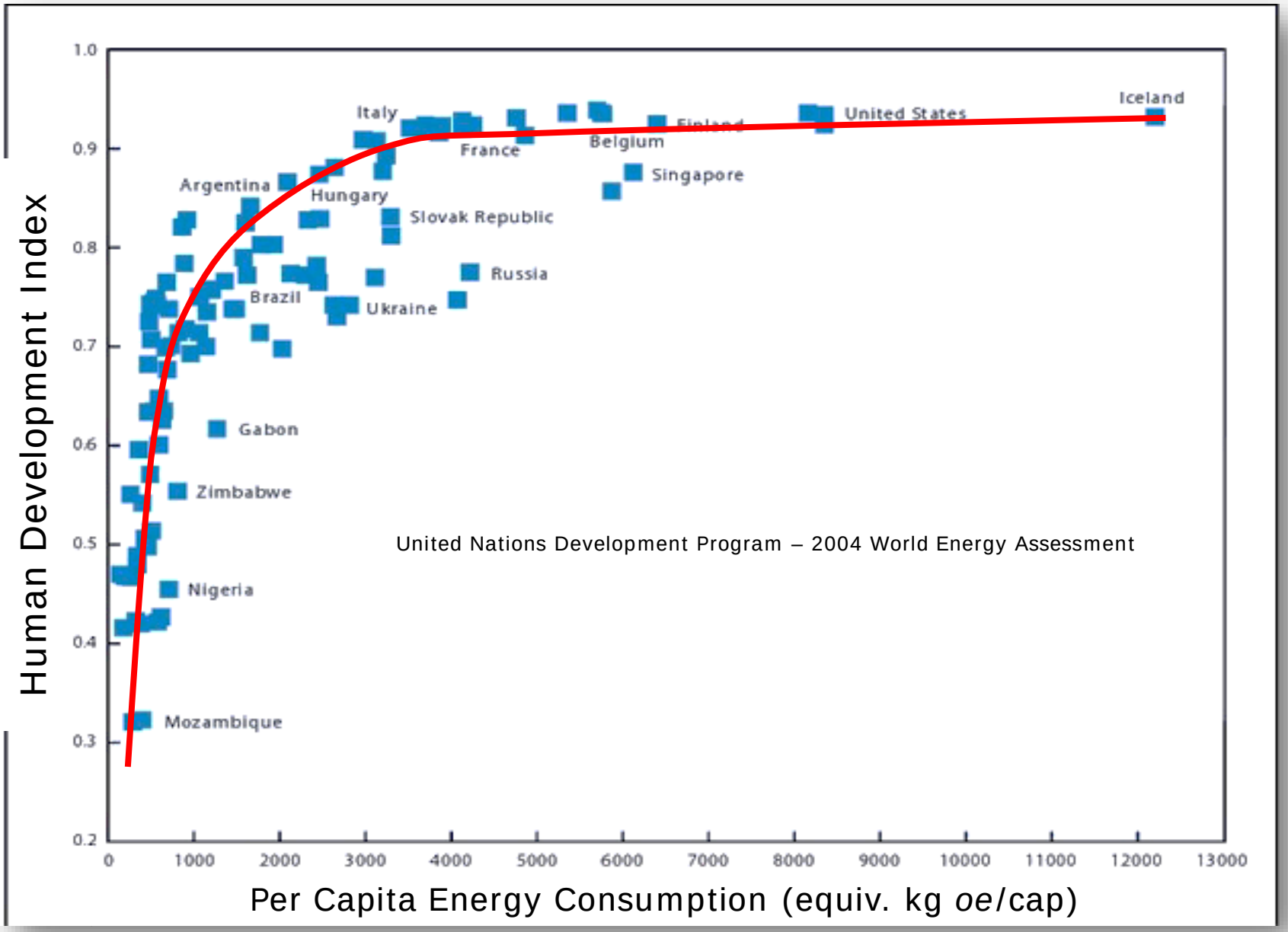


a) Health (life expectancy).

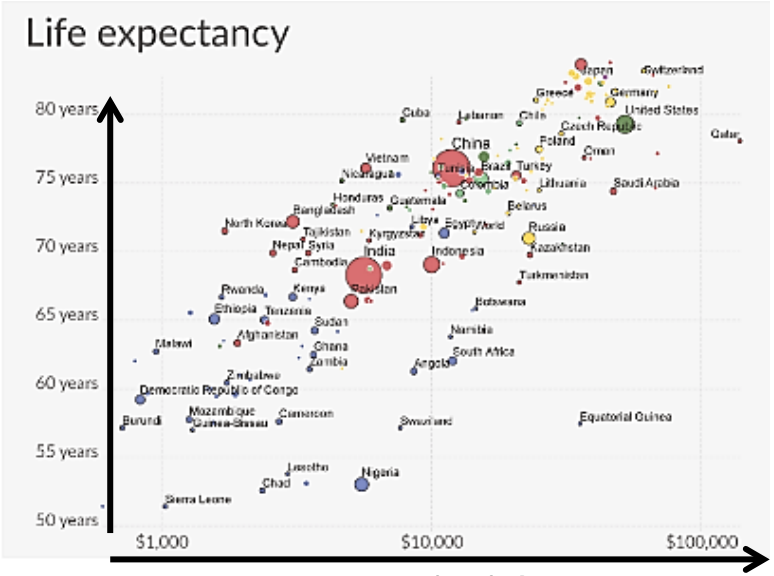
b) Education (adult literacy, enrollment).

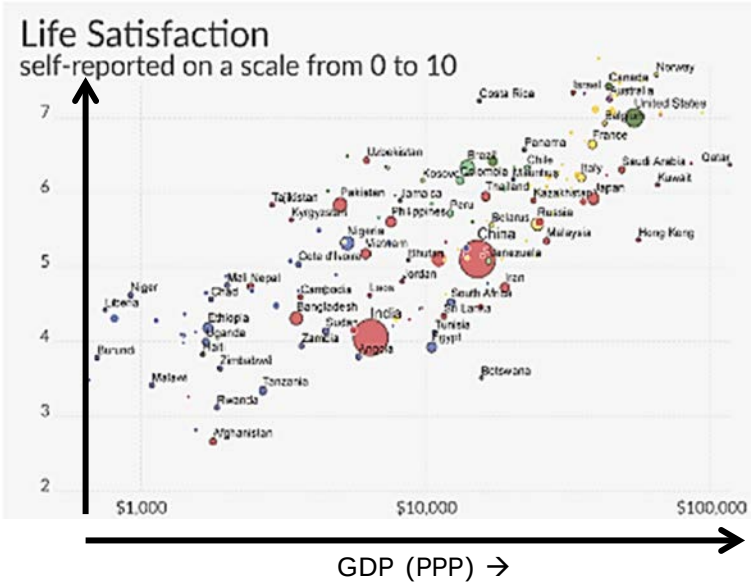
c) Living standard (ln GDP(PPP)/c). (PPP=purchasing power parity per capita)

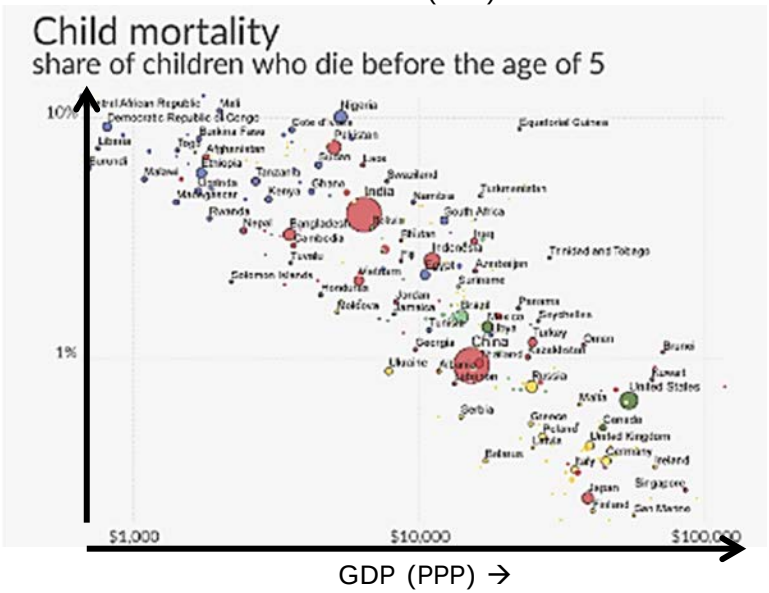
Energy and Human Development

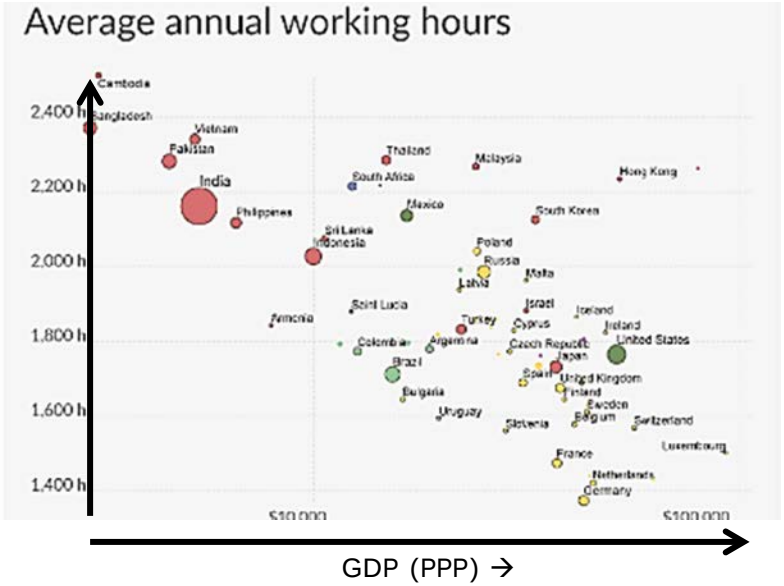


Average Benefits of GDP Value

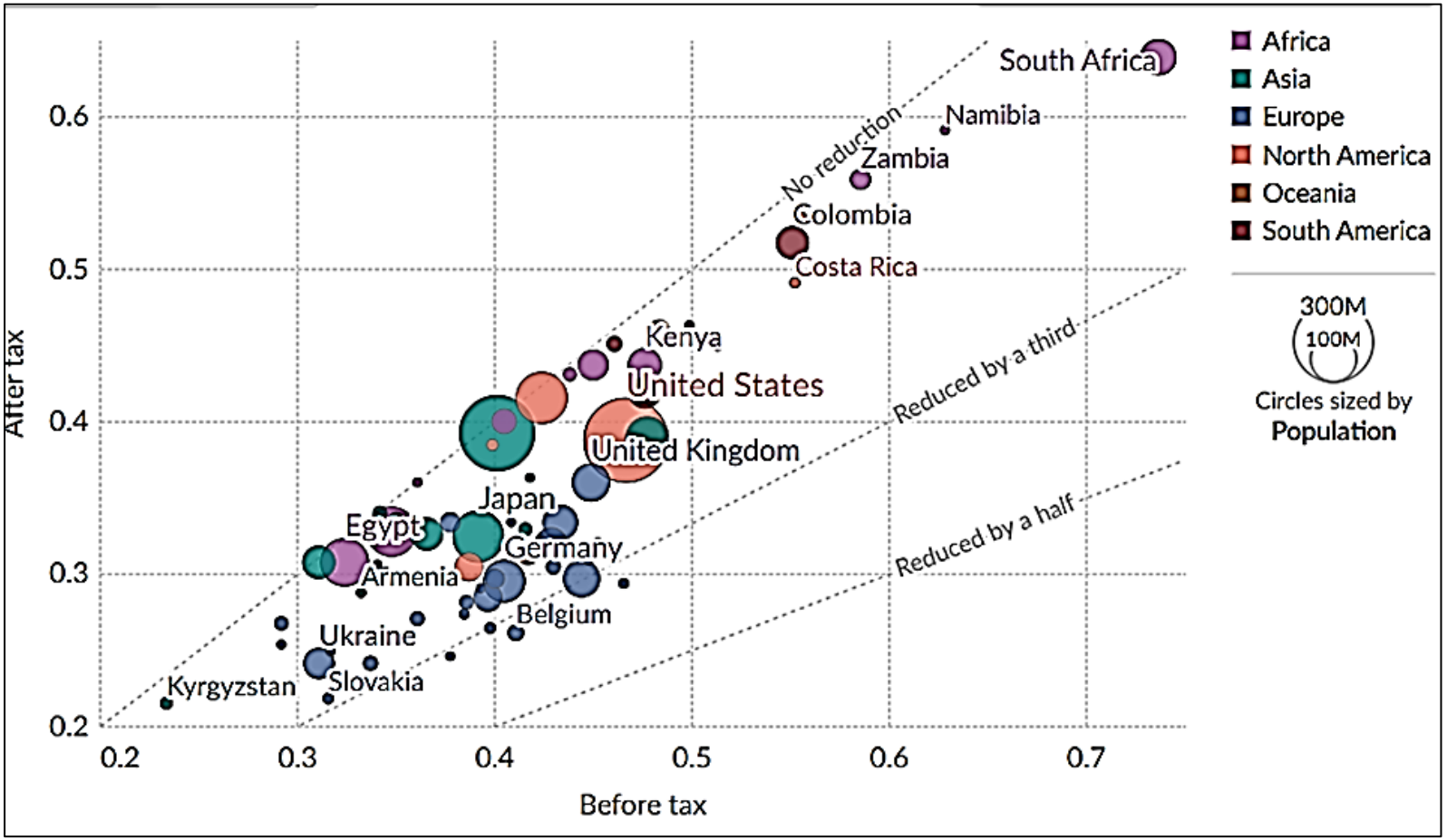








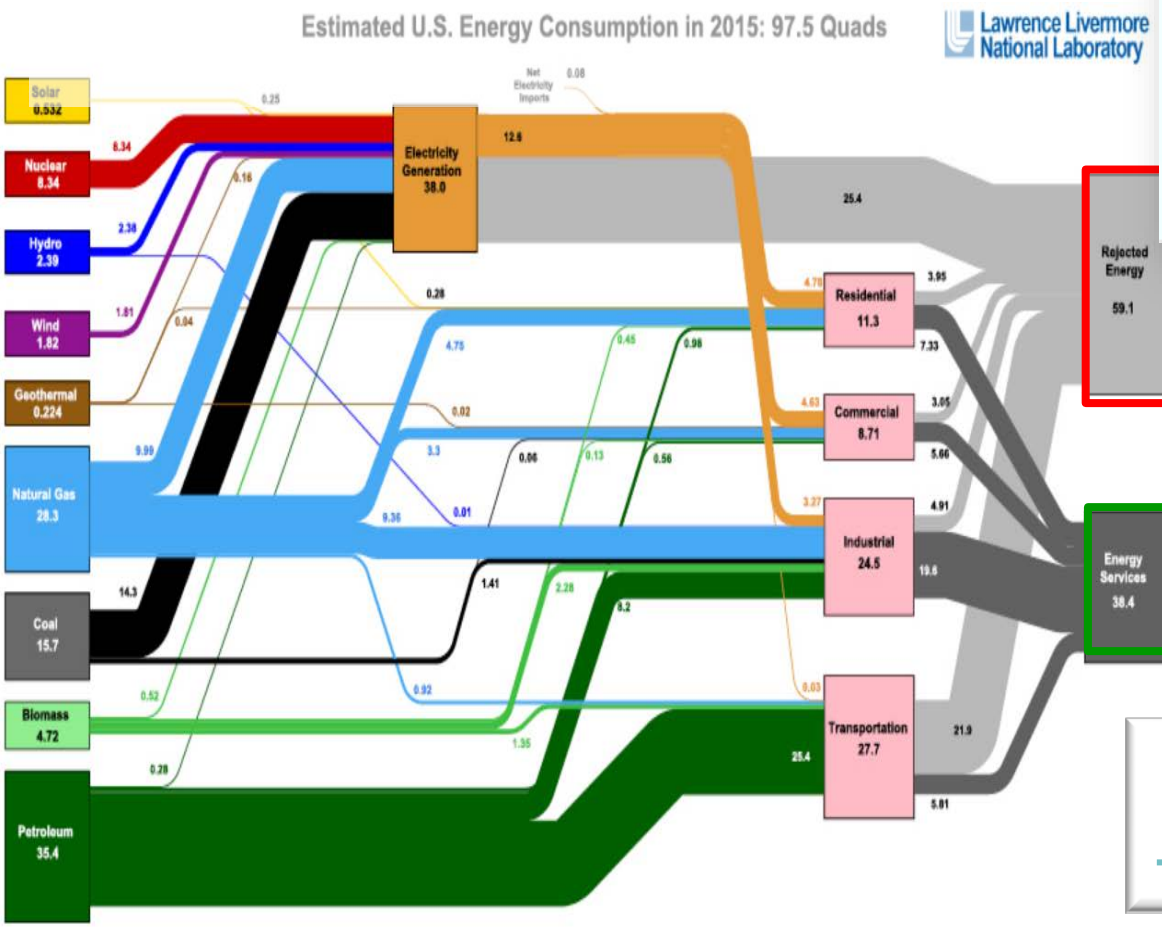
Redistribution of Income Inequality: GINI 2020

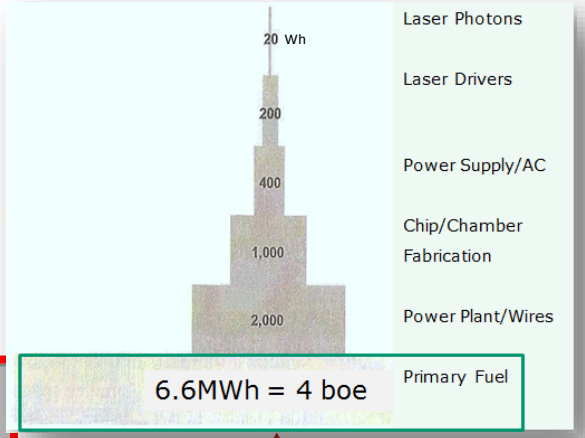


GINI coefficient [0 → 1] indicates inequality in income/cap. G=1 means 1 person receives all income, others none. G=0 all equal.

Nature of “Energy Problem”

1st Law TD:
Energy is plentiful and conserved
Need it in useful (refined) form





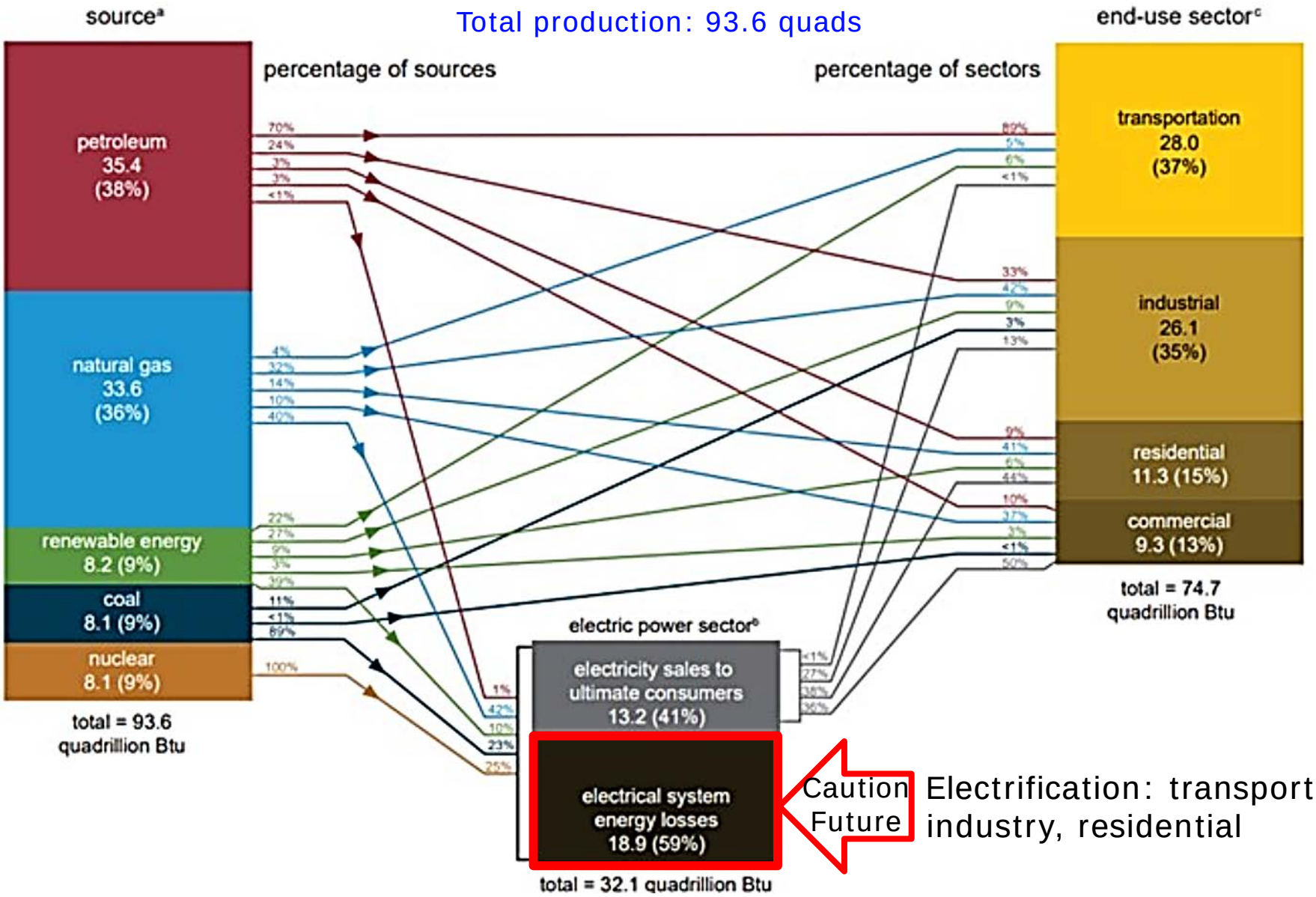
“waste”

“useful”

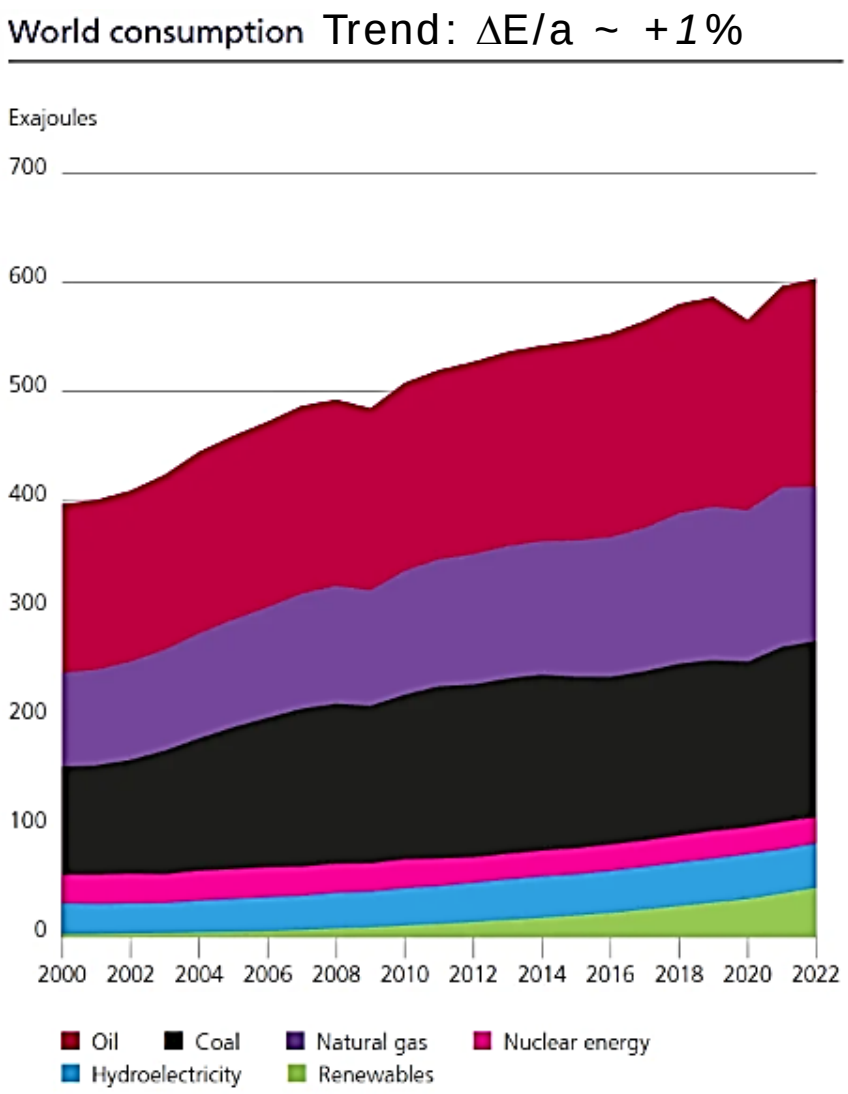
Reduce “waste”
→? → “green” energy.

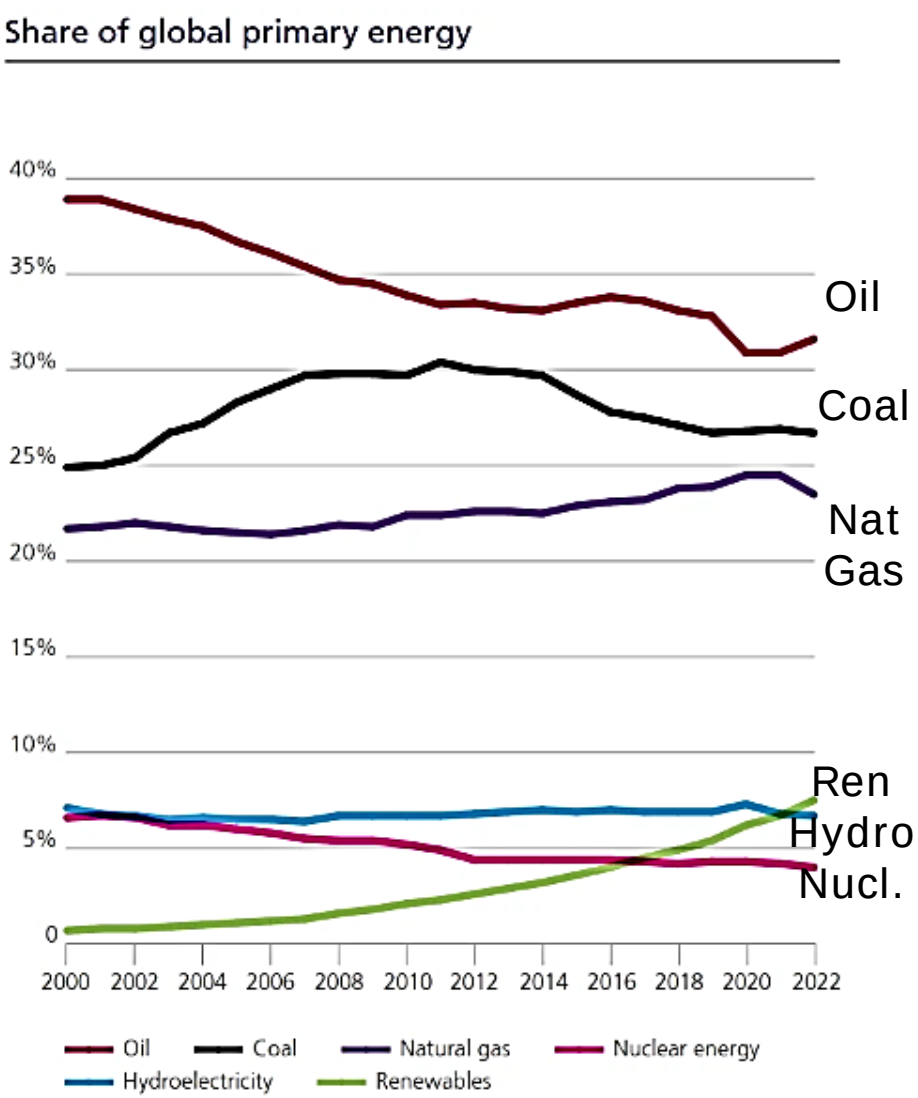
Solve ENTROPY (S) problem (3rd Law TD) ! Think BIG !

U.S. Primary Energy Consumption 2023



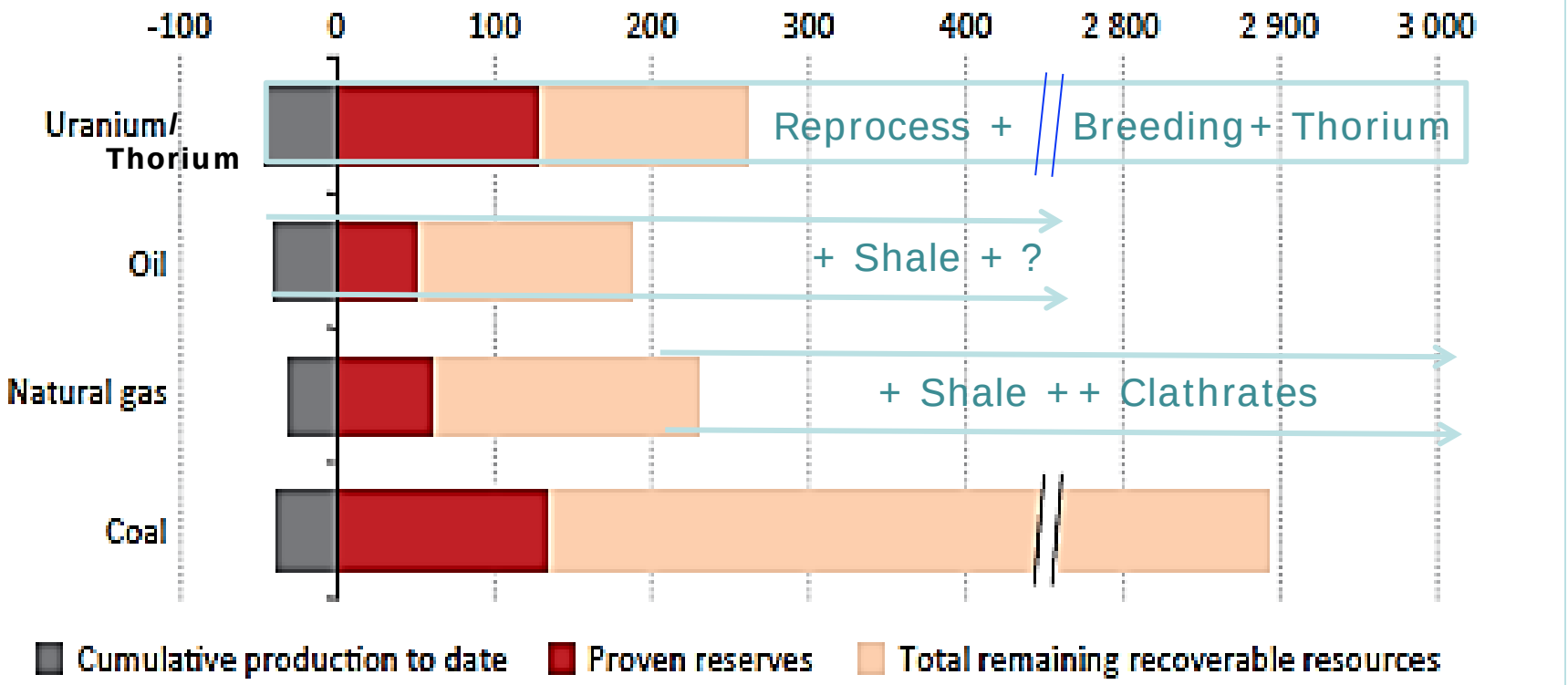
World Energy Consumption per Year





World Primary Energy Resources/Constant Use

Use up to 2000 with current (inequitable) resource allocation



Modified after IEA World Outlook 2014, in light lettering: use reprocessing + U-238 breeding, Th 232 fertile fuel,

unconventional gas (fracking) + clathrates in frozen environments.

Neglect losses in reprocessing and breeding. Assumed present rate of consumption in future.

External Costs of Energy Production/Consumption

Direct and indirect costs and effects that are typically not included in price of primary energy carriers

- Addition of heat-trapping gases (GHG) to atmosphere → large changes climate/environment, large economic costs
- Pollution: reduced air and water quality → public health, economic cost
- Reduction of water quantity → agriculture, public health (food)
- Destruction of arable and wet land, forests→ lasting economic cost
- Ocean acidification, changes marine bio environment, food chain
- Destruction of animal/fish habitat
- Ecological effects from accidental spills and waste release
- Physiological & aesthetic (audio, visual) effects → quality of life

- Limits to energy security: Susceptibility to external political pressure from energy producers
- Military defense of access to foreign primary energy resources.