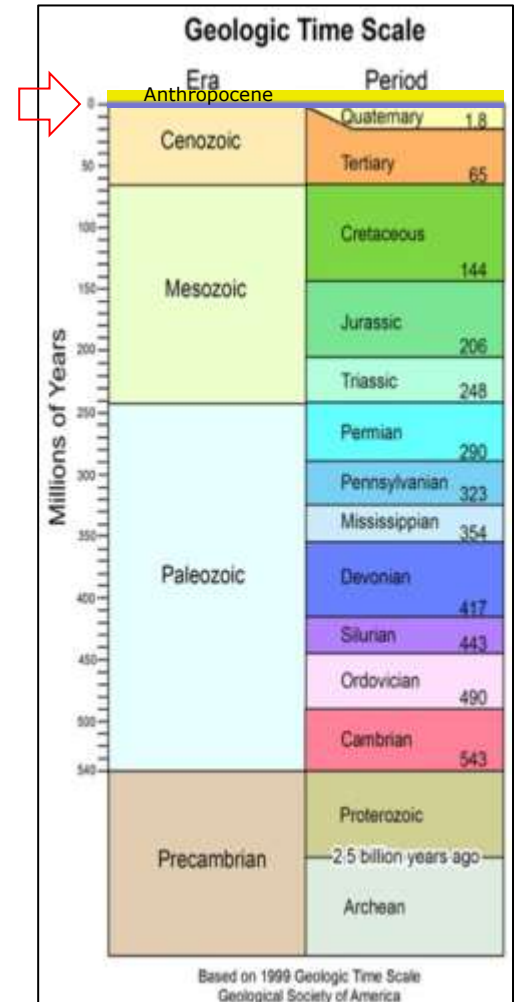


Agenda for Section (Sustainability @ "Anthropocene")

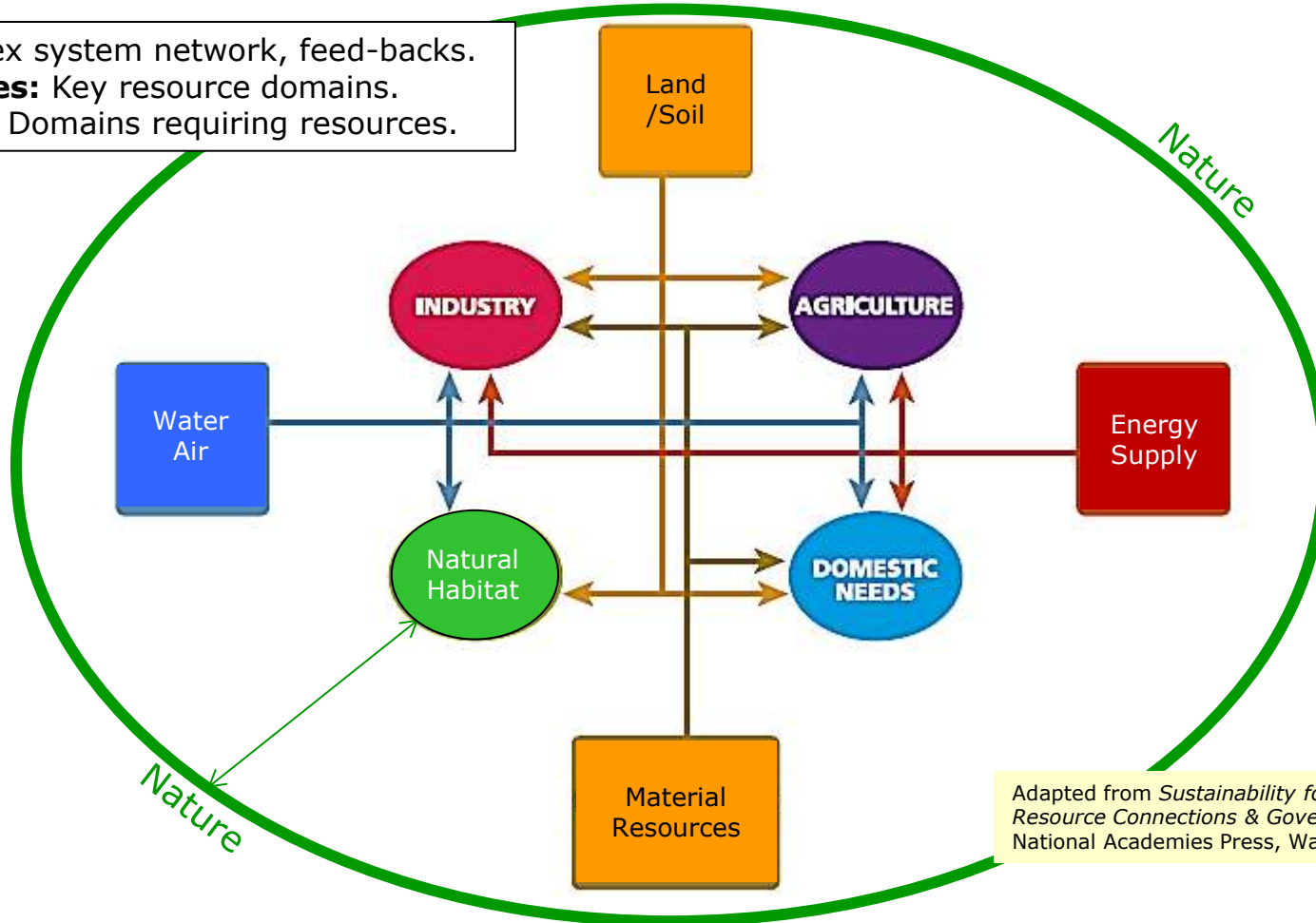
Grand picture Habitat and resource utilization

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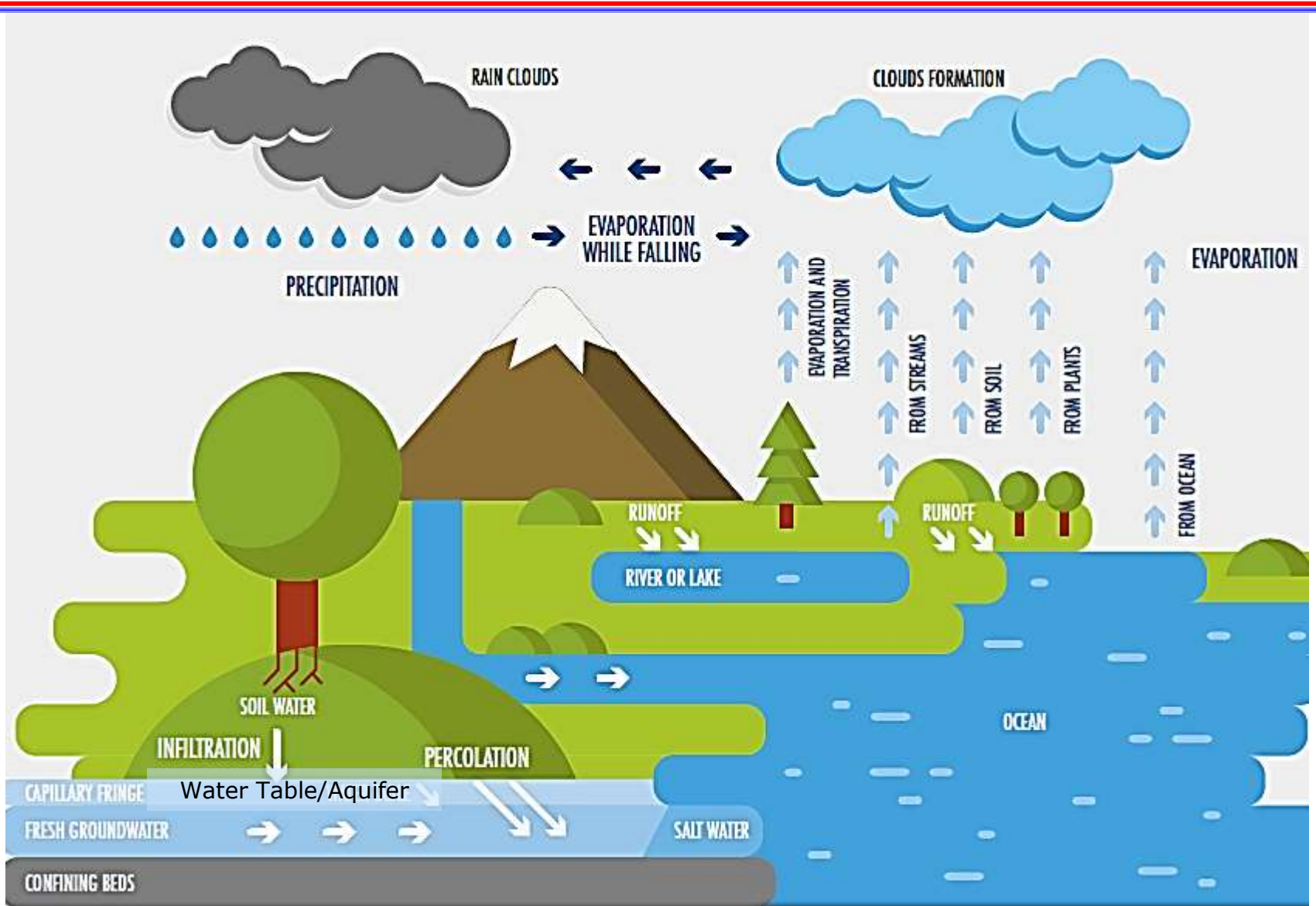
Socio-Economical Network: Major Components

Complex system network, feed-backs.
Squares: Key resource domains.
Ovals: Domains requiring resources.



Interlinked socio-ecological system needs long-term, systems sensitive, adaptive, collaborative management. Example: Sustainably managing water resources

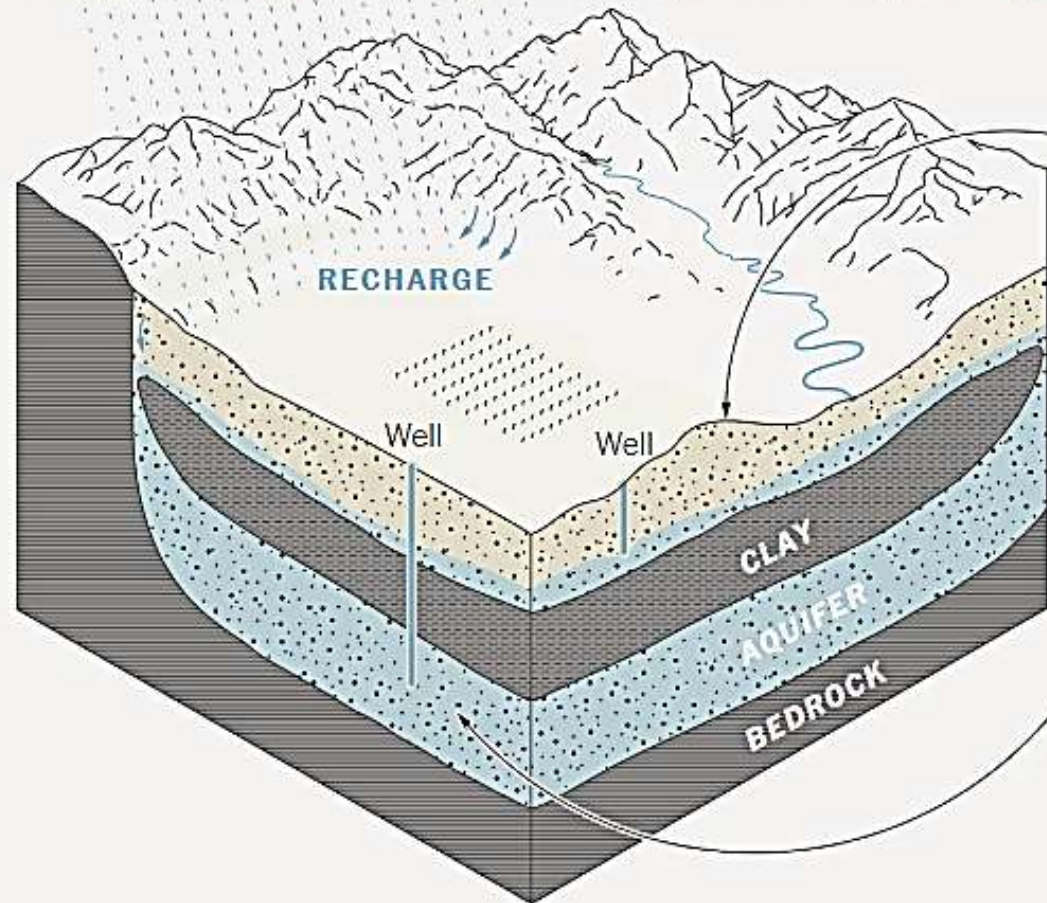
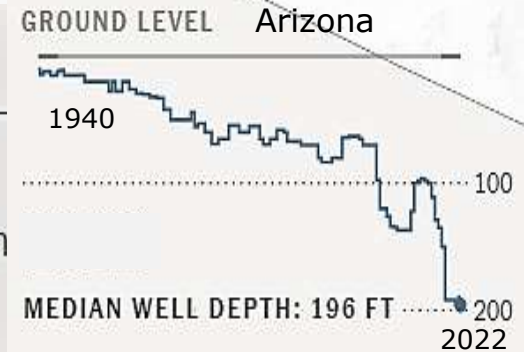
Hydrological Cycle



Tapping and Recharging of Aquifers



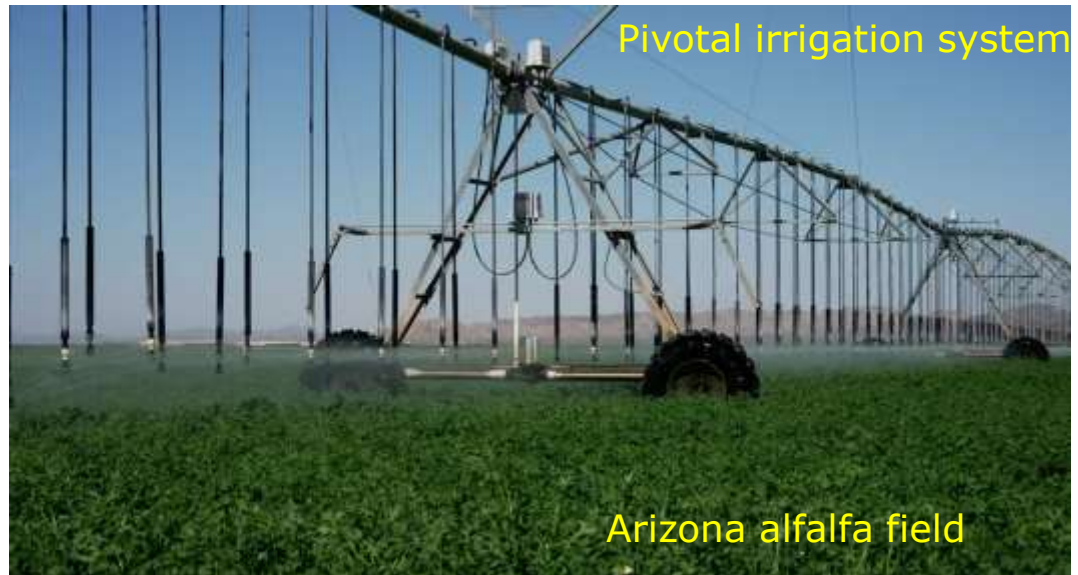
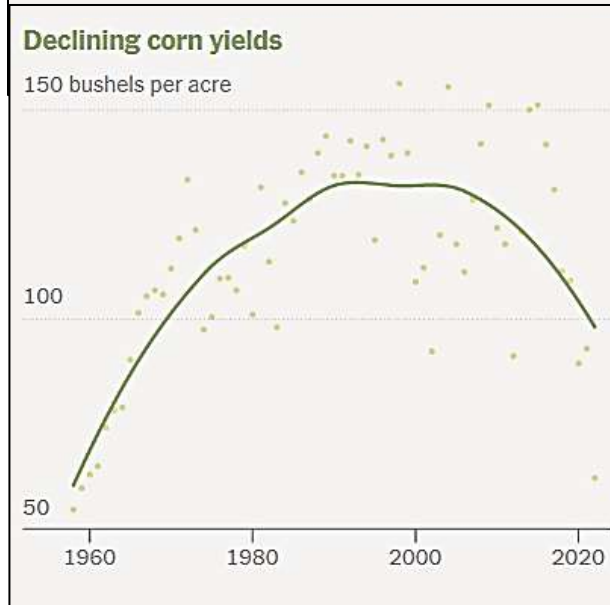
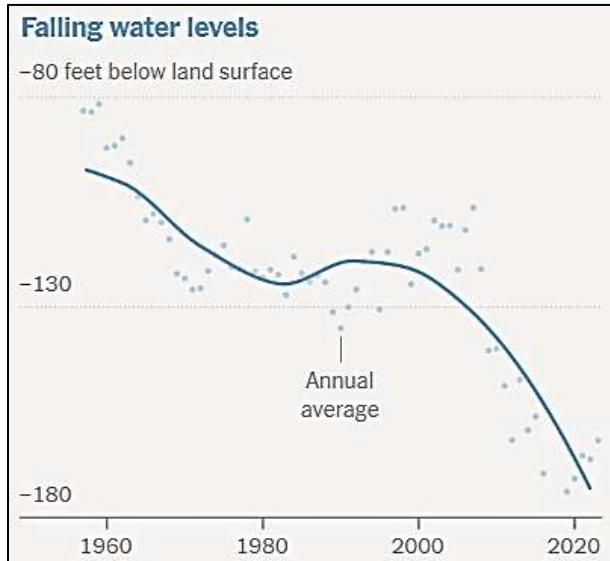
Many aquifers — layers of water-soaked dirt and rock — are being rapidly depleted, permanently damaging them



The land can settle as water is pumped out, leaving less space for new water to refill the aquifer.

Deeper aquifers beneath impermeable clay and rock can also take thousands of years to recharge.

Causes: Water-Intense Industrial Agriculture



Industrial agriculture on High Plains → global supplier of corn, alfalfa, soy,....(livestock, bio-fuels, human food)

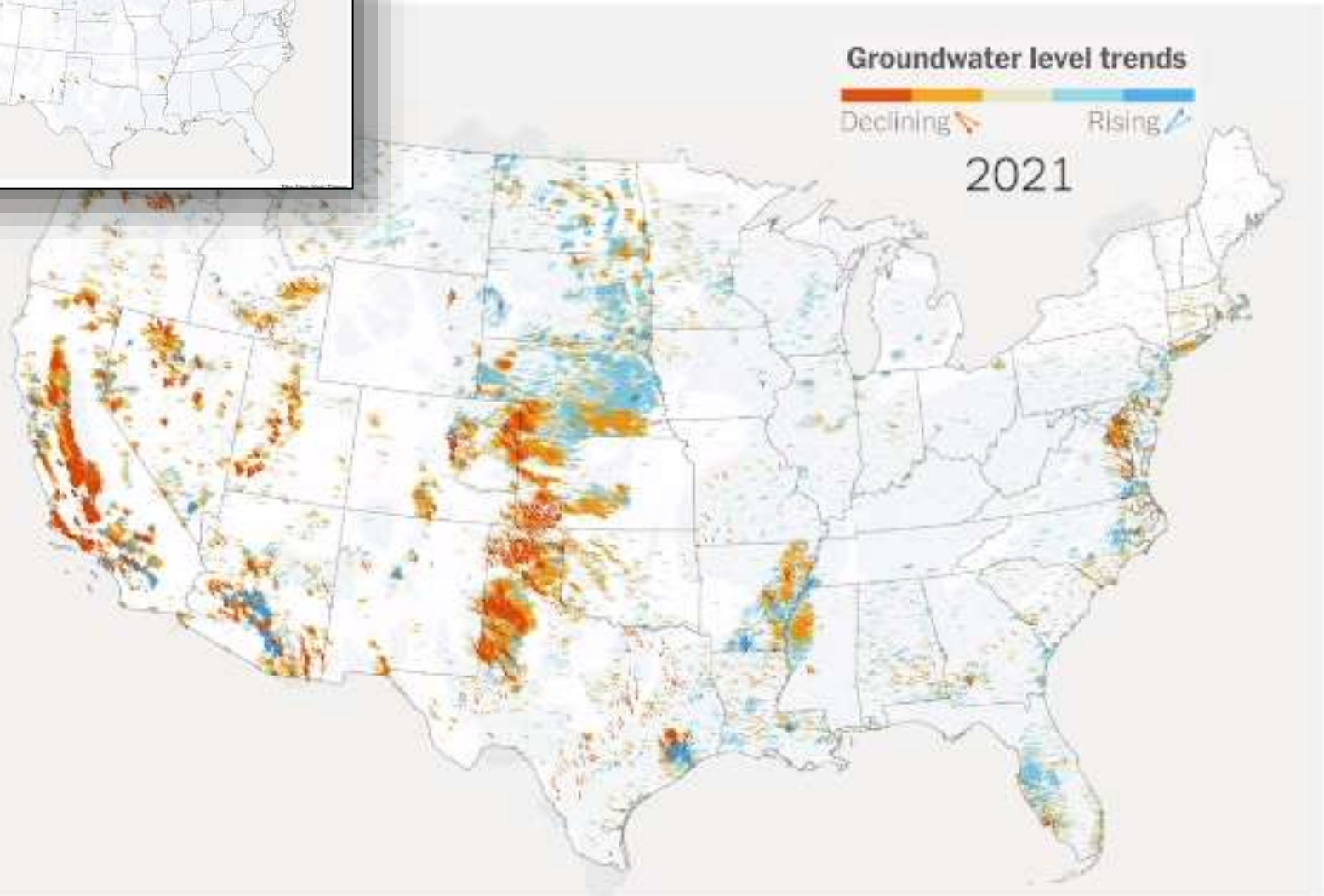
Pivotal or linear irrigation systems hooked up to aquifers. Previously depleted groundwater requires deeper wells → declining crop yields.

2000s: Increased withdrawal due to urban development in arid areas.

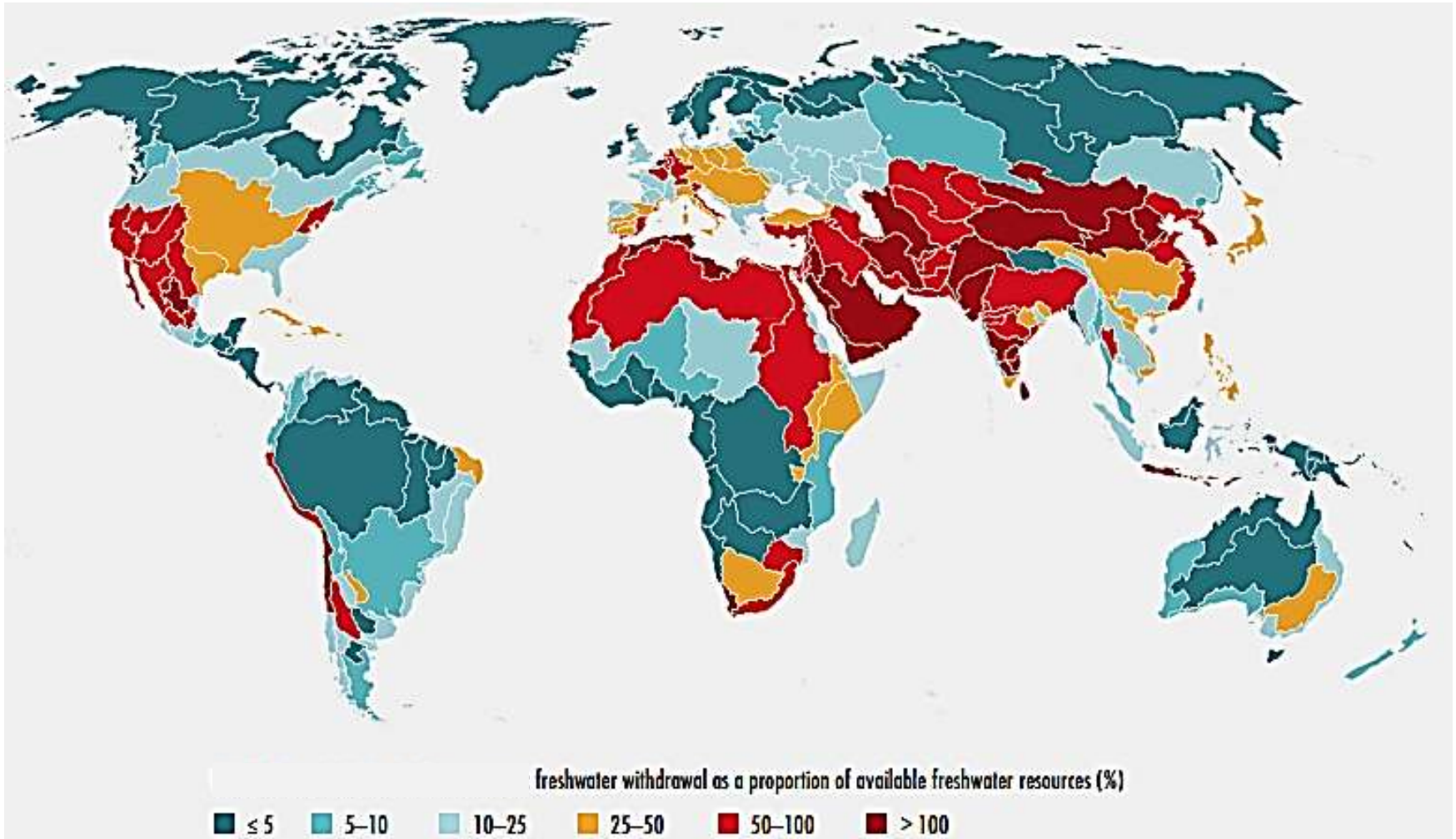
Drained U.S. Groundwater Aquifers



1950: No significant water stress

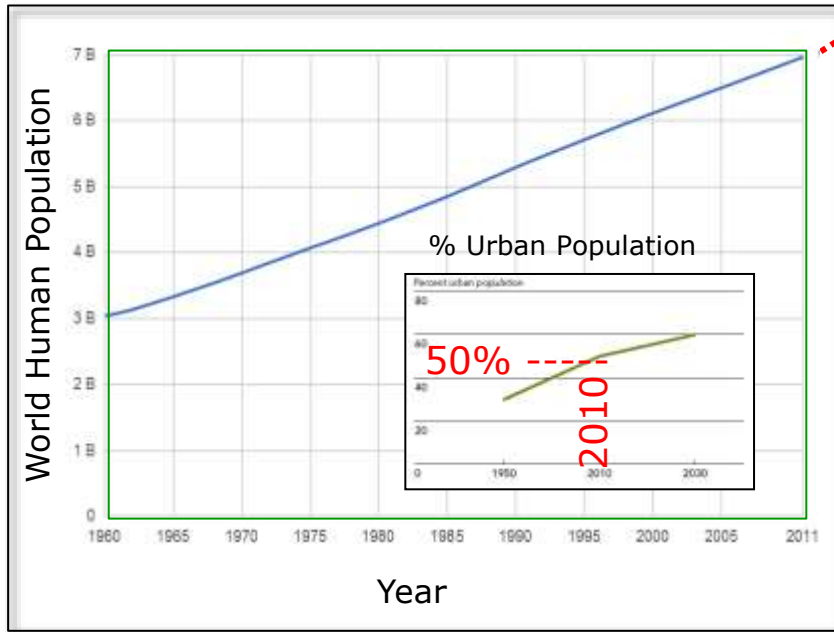


Water Stress



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

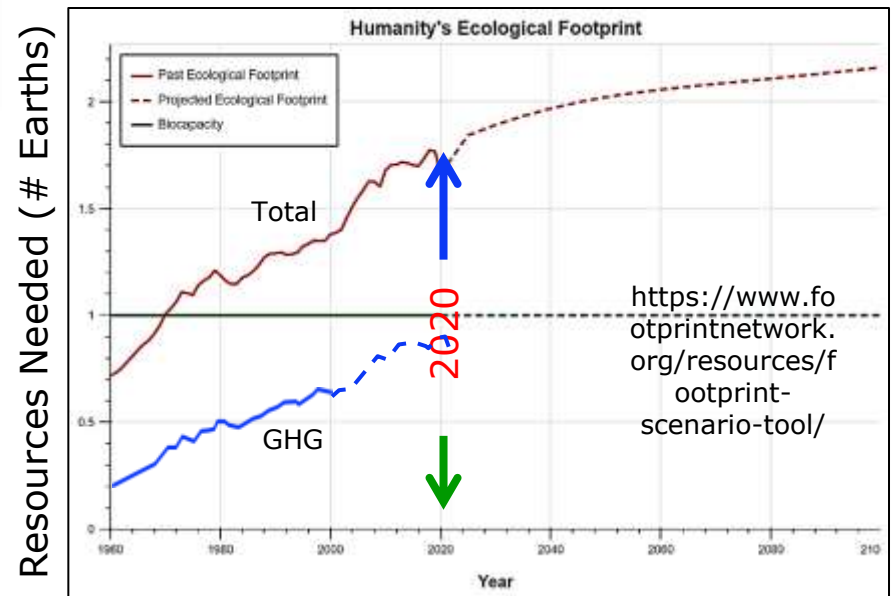
Testing the Limits: Human "Ecological Footprint"



Present population: $> 8.0 B$
 (1 Billion = $1 \cdot 10^9$) with $\sim 0.8 B$ food insecure, fresh water impoverished.
Estimated for 2050 $\rightarrow 9 B$
 (+urbanization \rightarrow more energy dem.)
 Present (2022) eco-footprint of humanity ~ 1.7 Earths \rightarrow global ecologic overshoot,
 \rightarrow 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 \rightarrow 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
 \rightarrow 3.2 Gt CO_2/a **waste not absorbed** but released to atmosphere (= measured).

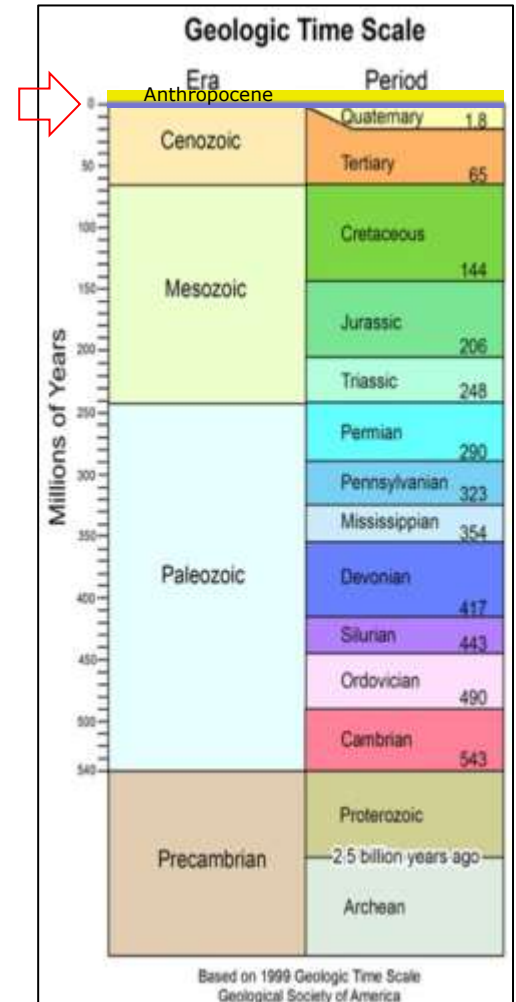


Energy Fuels

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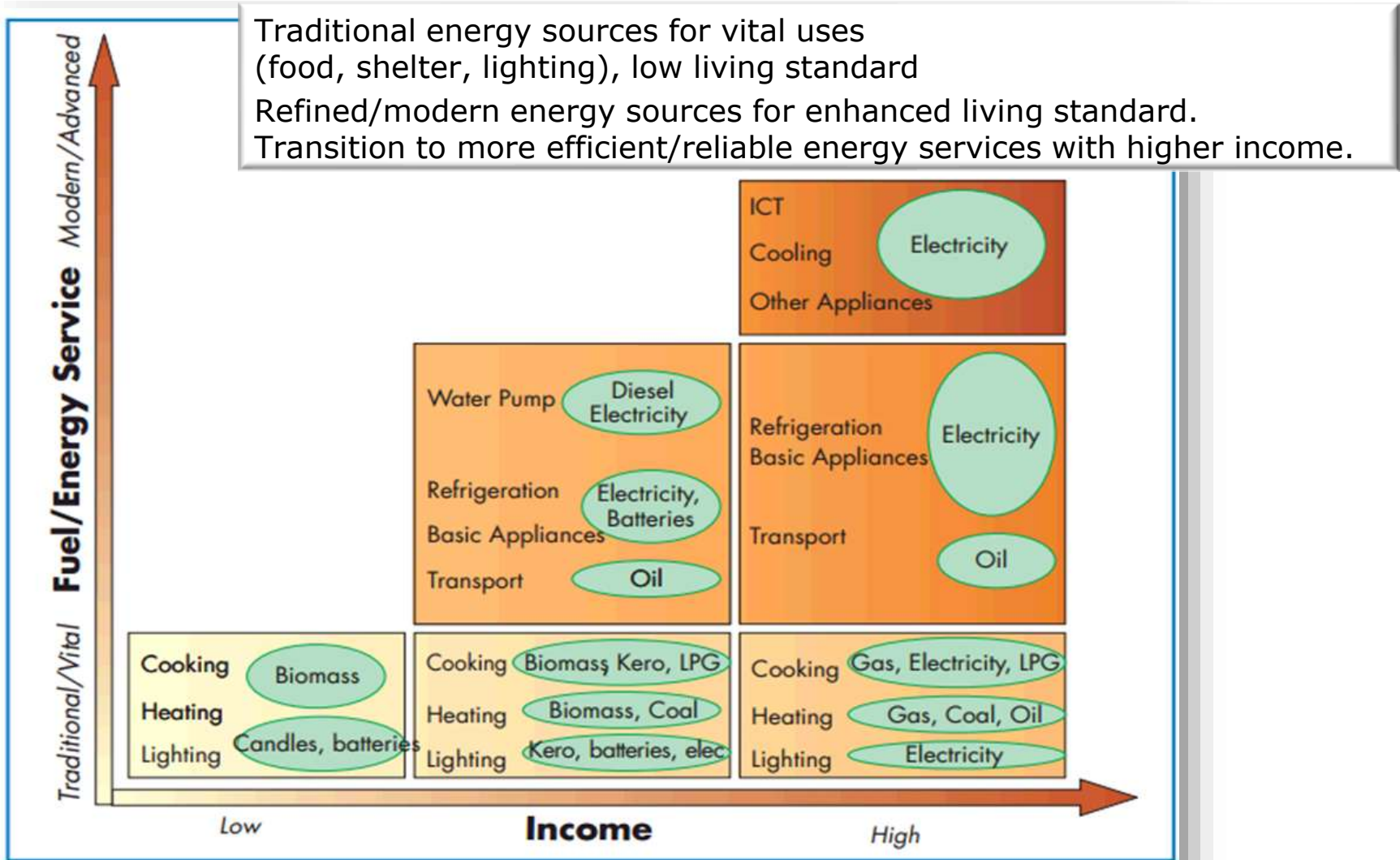


Major Economic Determinant: Energy Utilization

- 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

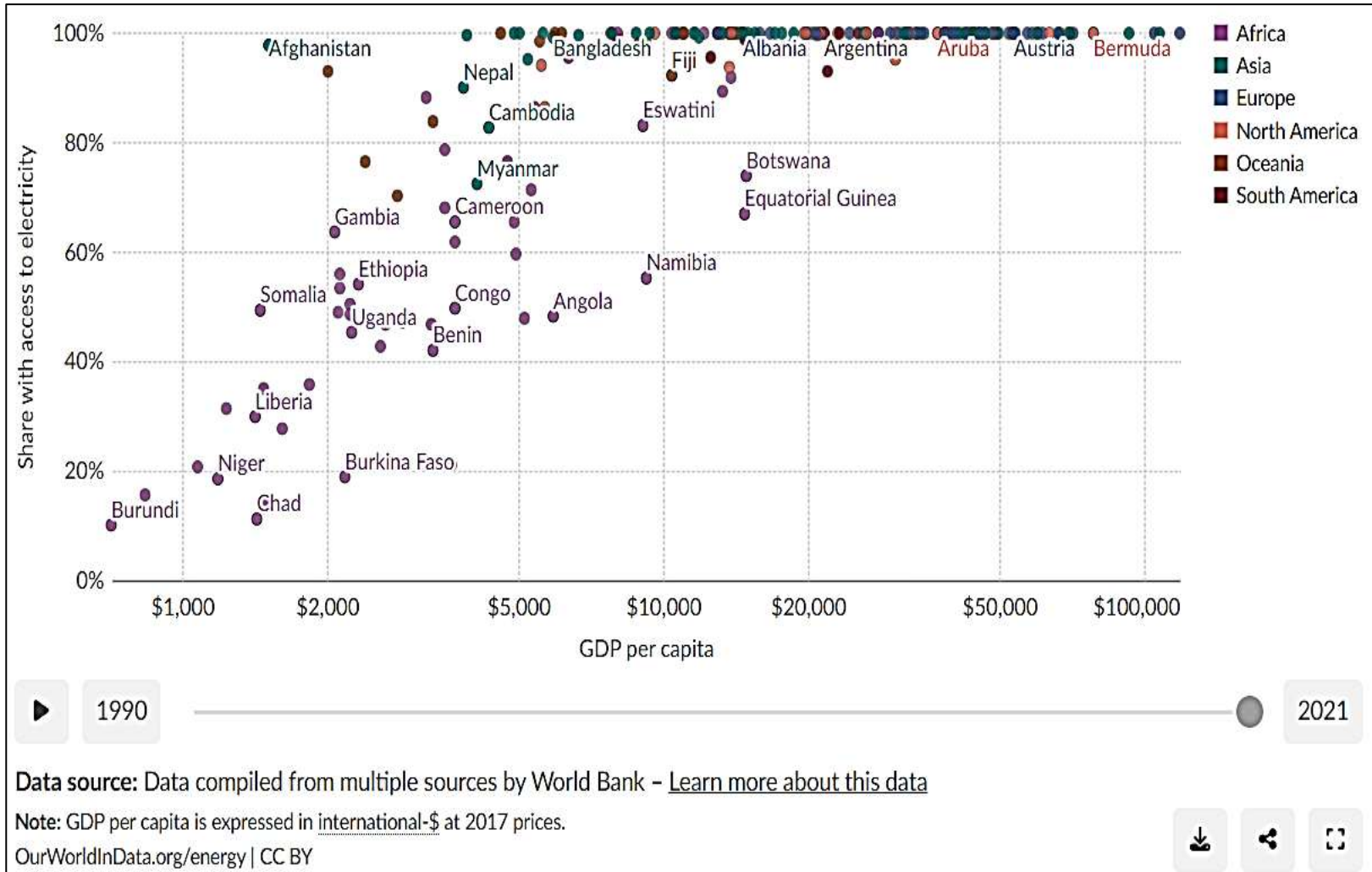
Are current human modes of operation sustainable ?
Are disasters imminent (“energy/climate Problem(s)”) ?

Energy Utilization vs. Income/GDP

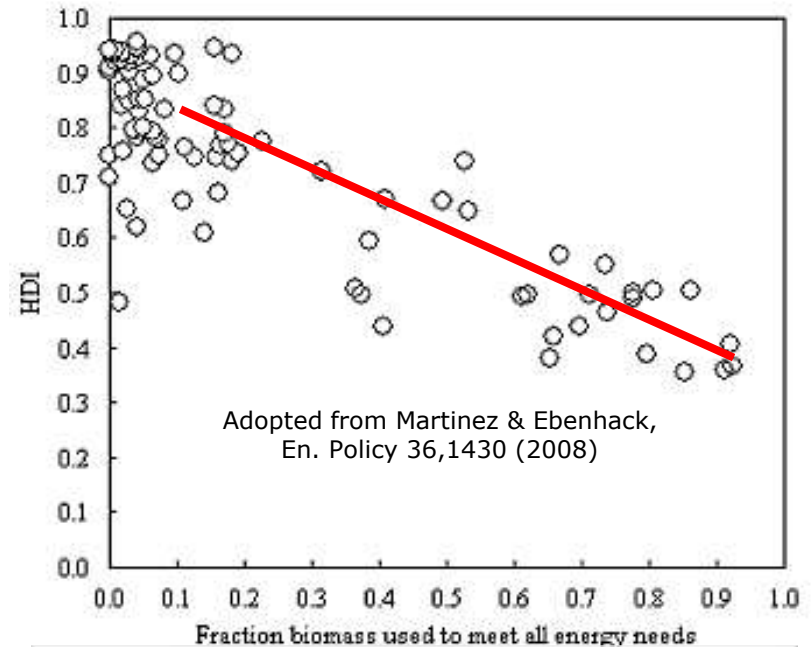
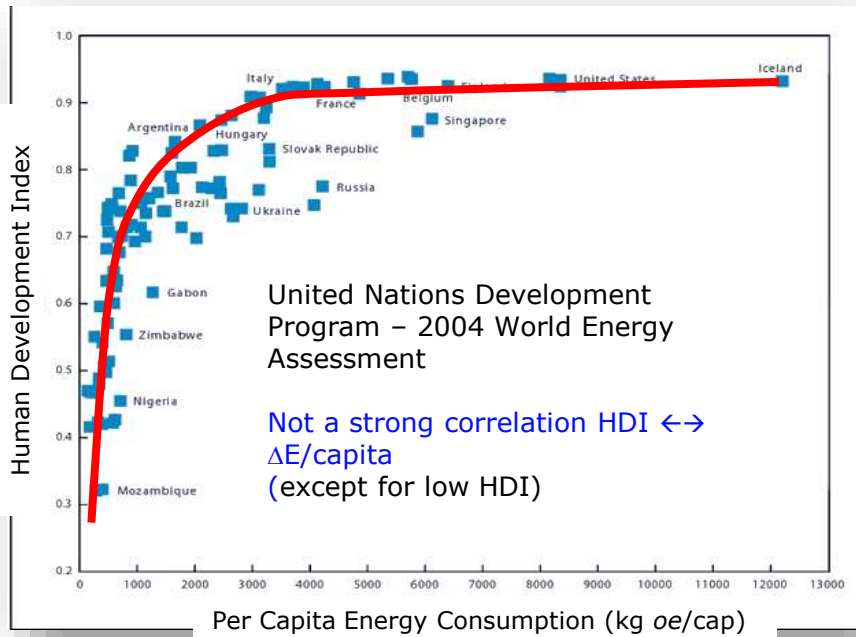


Note: ICT is information and communication technology. LPG is liquified petroleum gas (propane,..)
 Source: IEA analysis.

Access to Electricity vs. GDP (by Country)



Energy and Human Development (HDI Index)



Human Development Index HDI

= Weighted average of

- Health (life expectancy).
- Education (adult literacy, enrollment).
- Living standard (ln GDP(PPP)/c).
PPP=purchasing power parity per capita

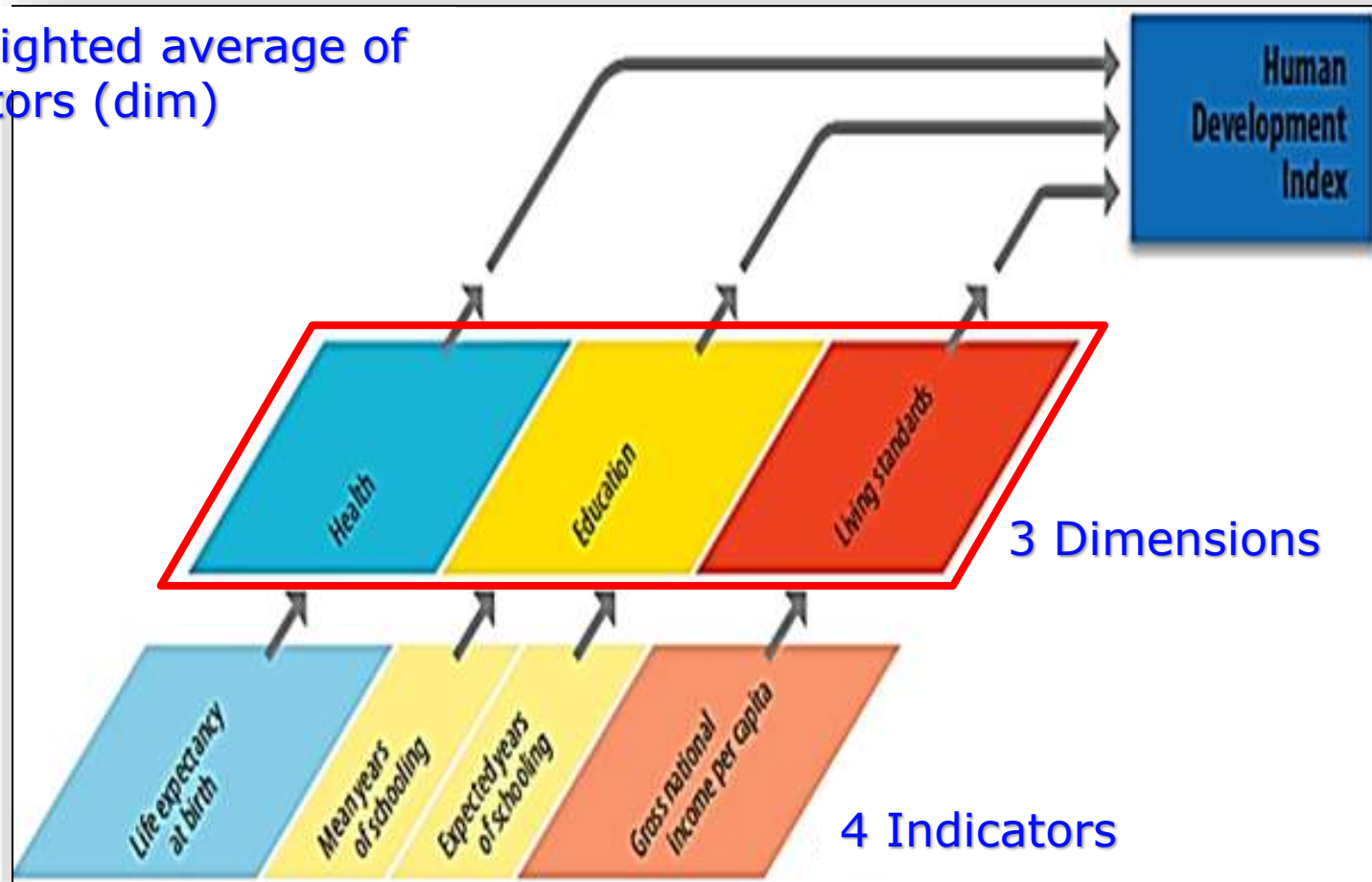
Jevon's Paradox: Technological progress in resource efficiency increases consumption, (rather than decreases consumption).

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

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

Human Development Index (HDI)

= Weighted average of
3 factors (dim)



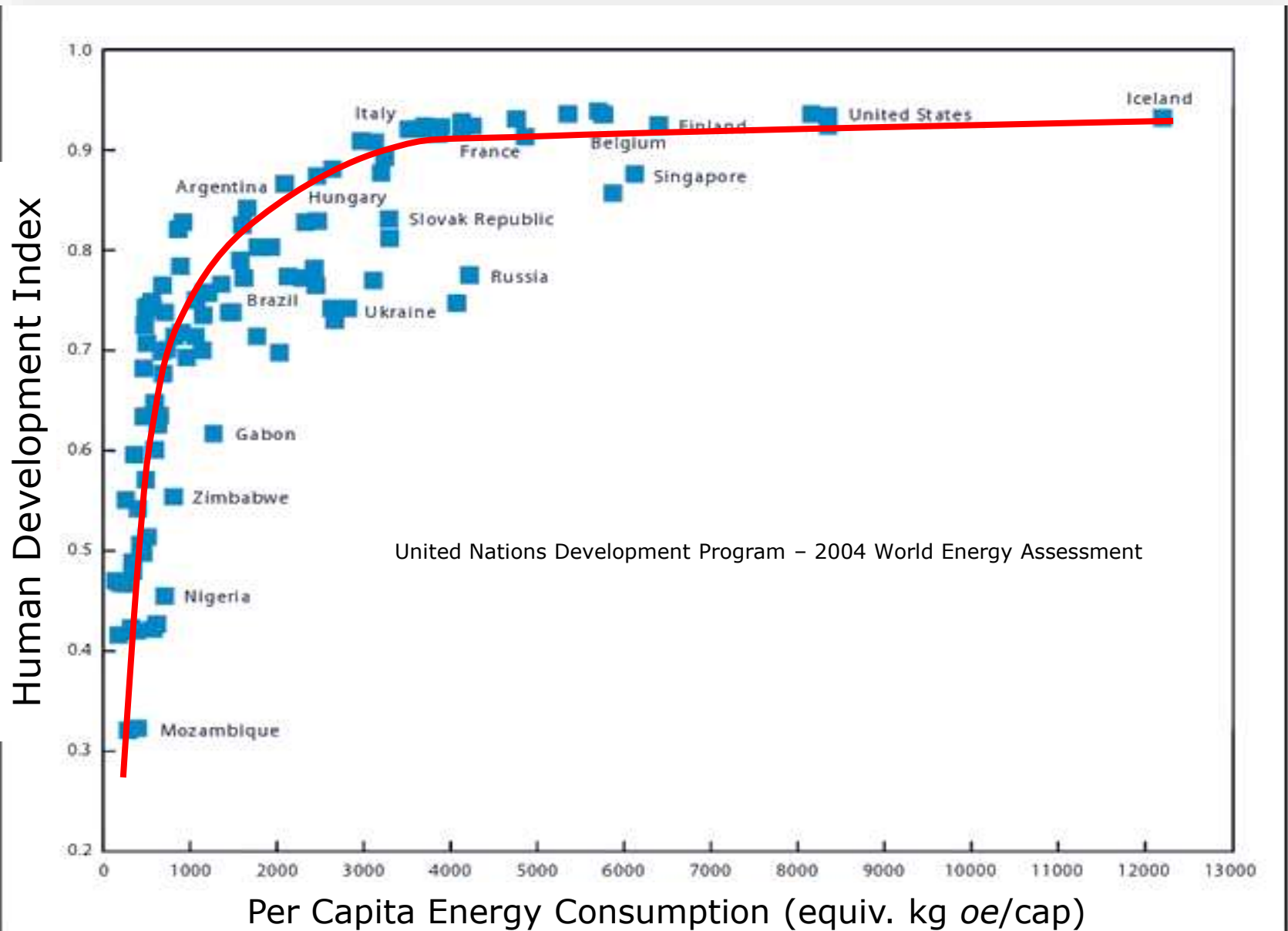
a) Health (life expectancy).

b) Education (adult literacy, enrollment).

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

(PPP=purchasing power parity per capita)

Energy and Human Development

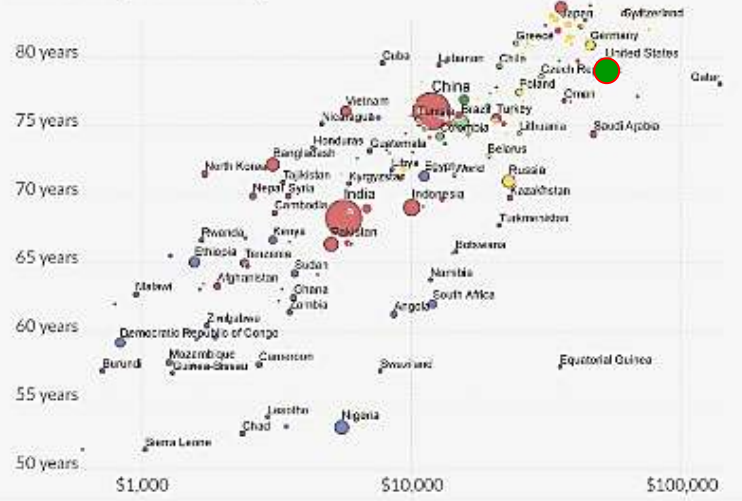


United Nations Development Program - 2004 World Energy Assessment

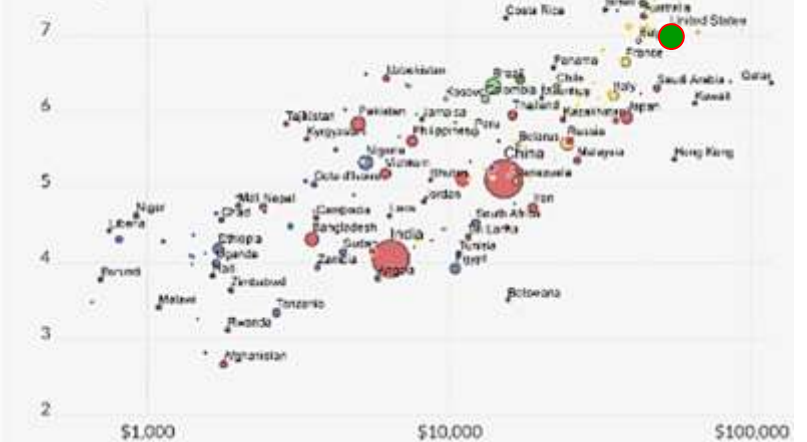
Living Standard vs. Income

16
Status Quo & Sustainability

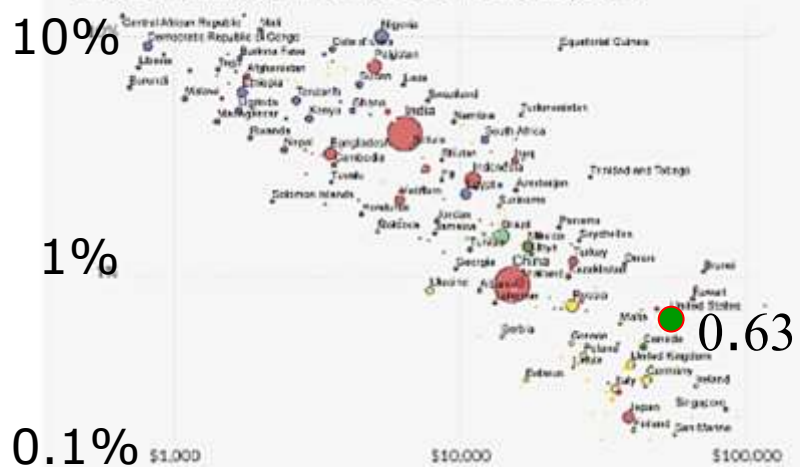
Life expectancy



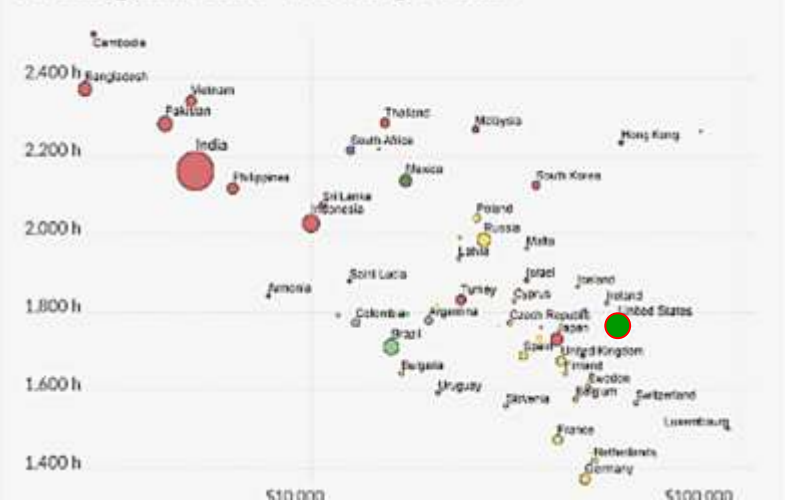
Life Satisfaction self-reported on a scale from 0 to 10



Child mortality share of children who die before the age of 5



Average annual working hours

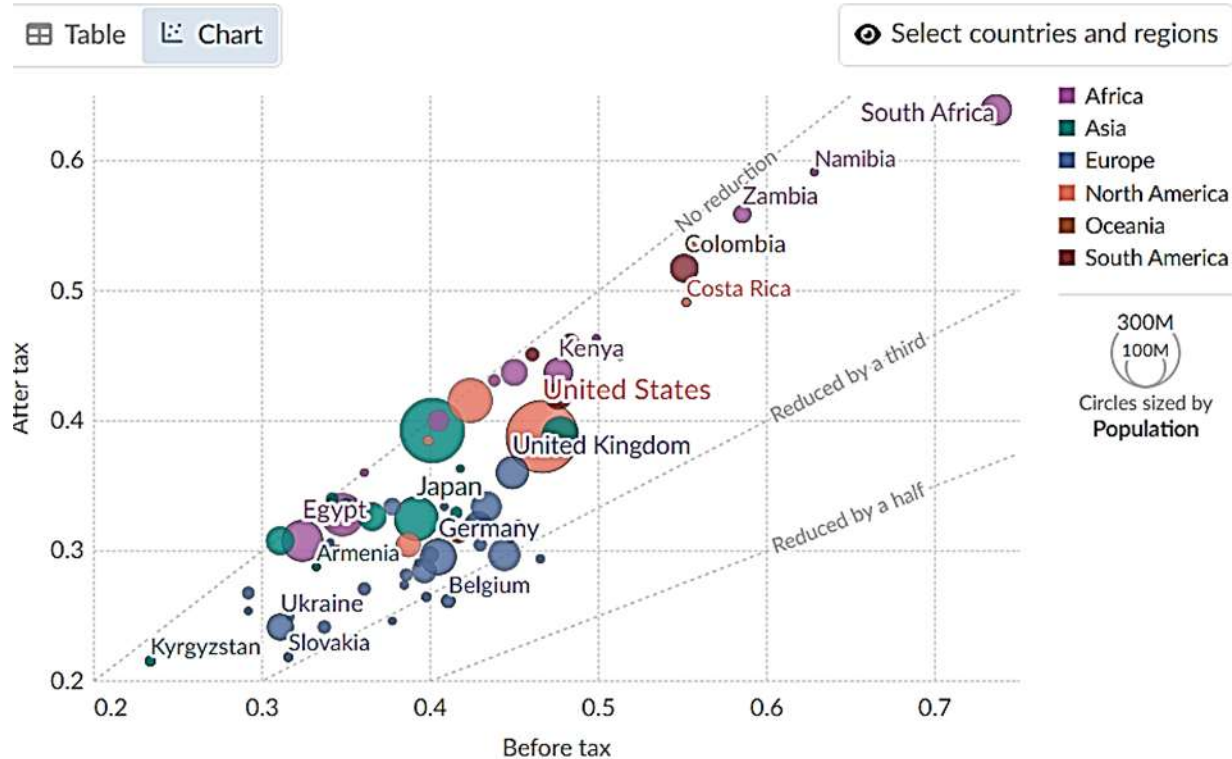


Redistribution of Income Inequality

Income inequality: Gini coefficient before and after tax, 2020

Our World in Data

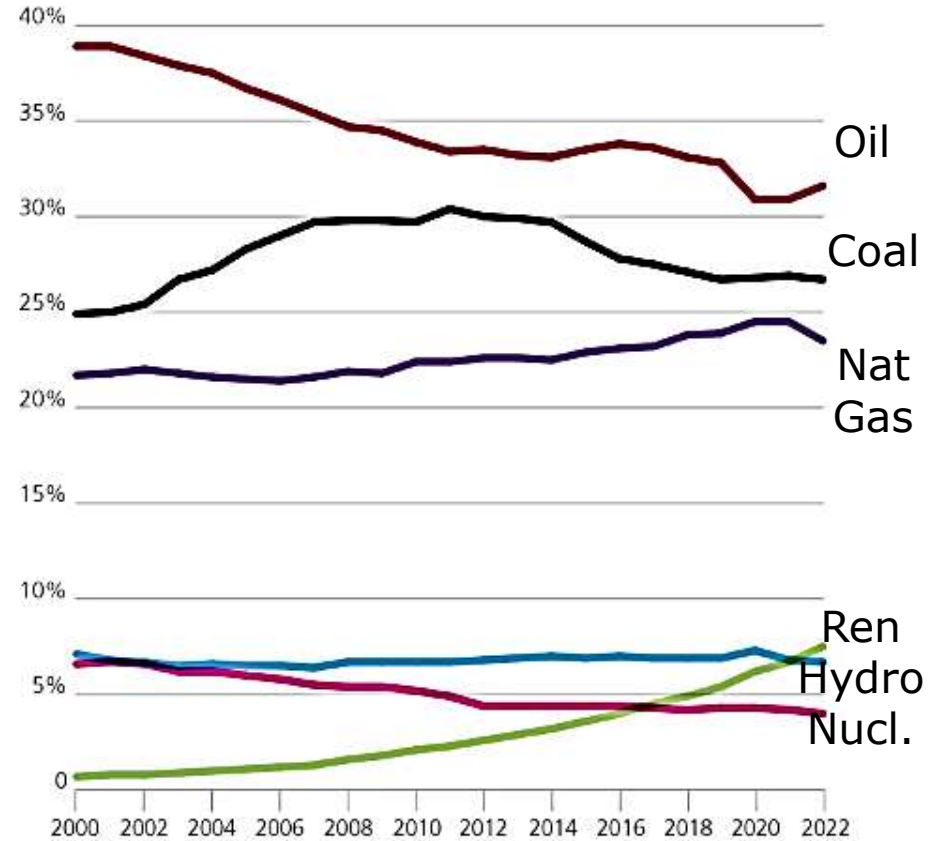
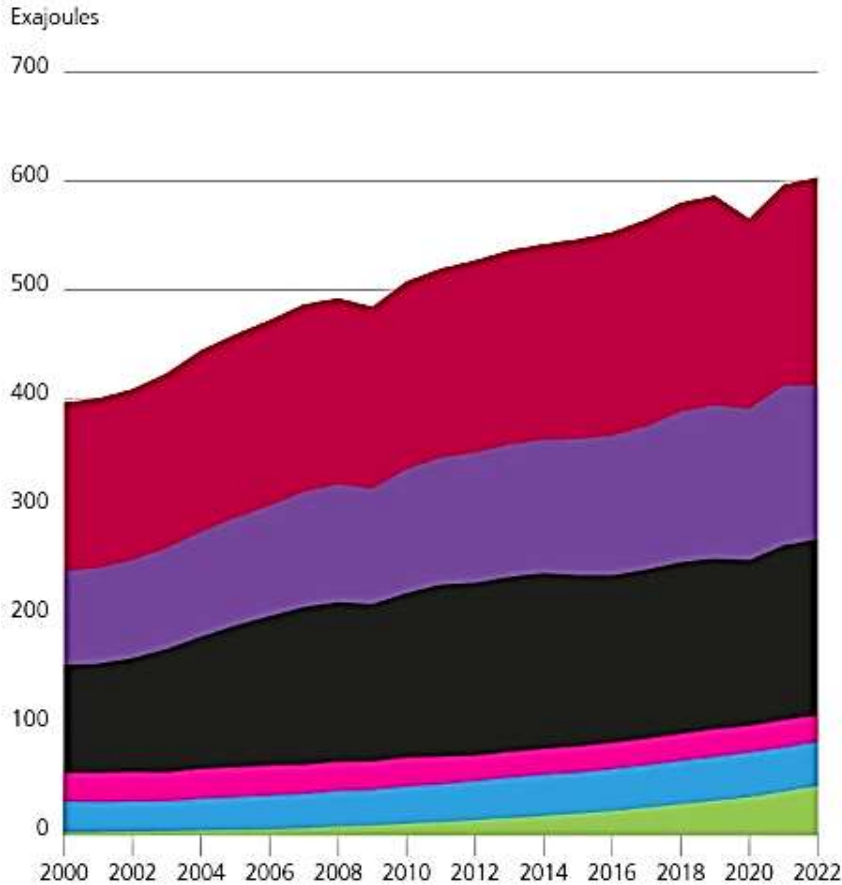
Income inequality is measured in terms of the Gini coefficient of income before taxes on the horizontal axis and after taxes on the vertical axis.



World Energy Consumption per Year

World consumption Trend: $\Delta E/a \sim +1\%$


Share of global primary energy

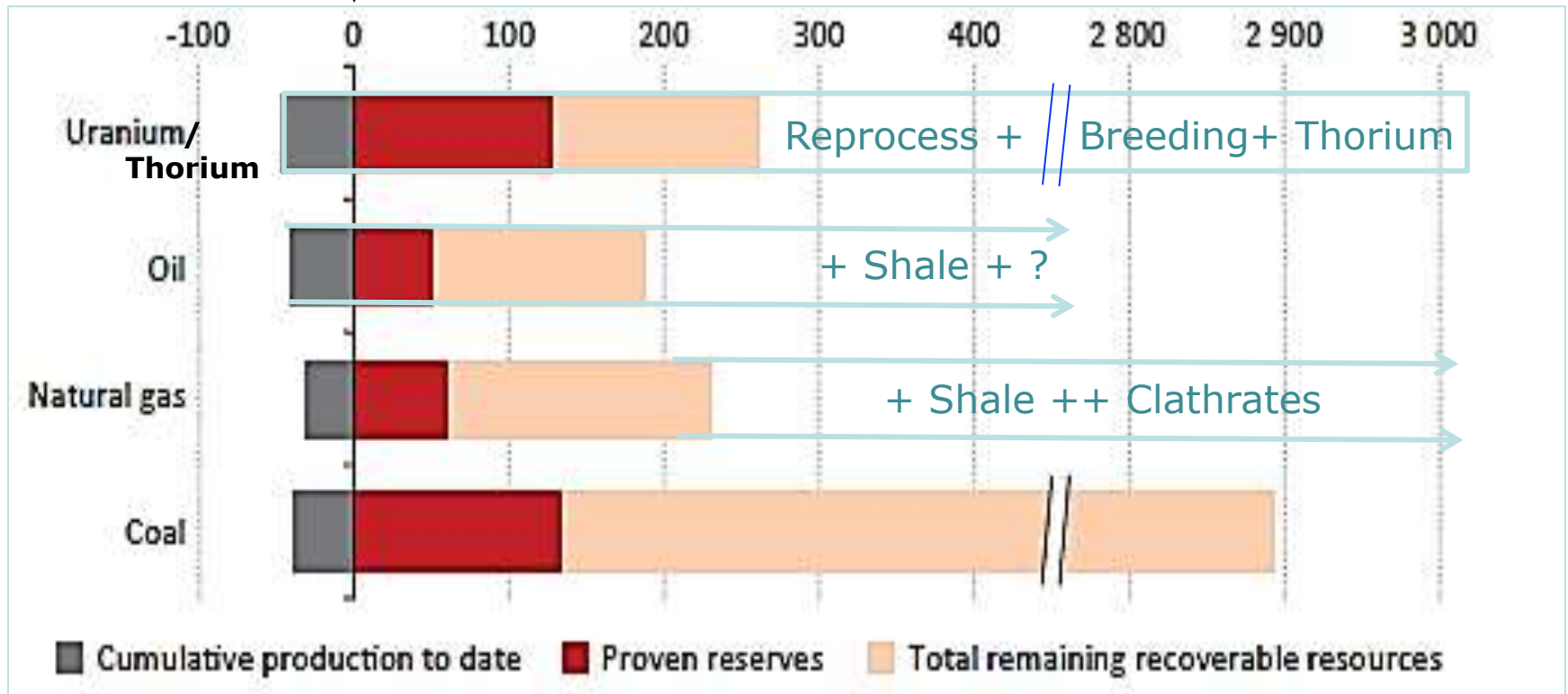


Oil Coal Natural gas Nuclear energy
Hydroelectricity Renewables

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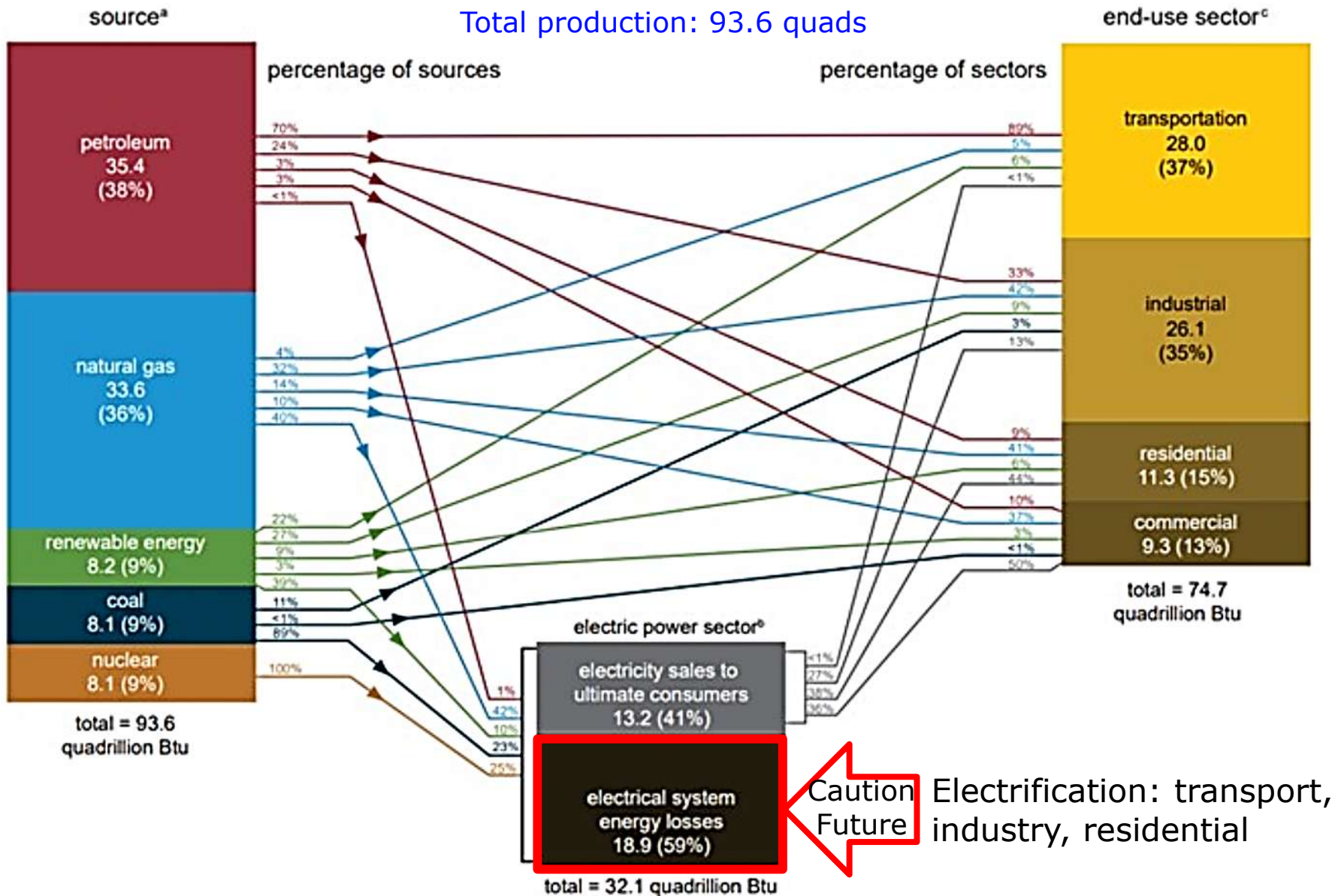
World Primary Energy Resources/Constant Use

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.

U.S. Primary Energy Consumption 2023

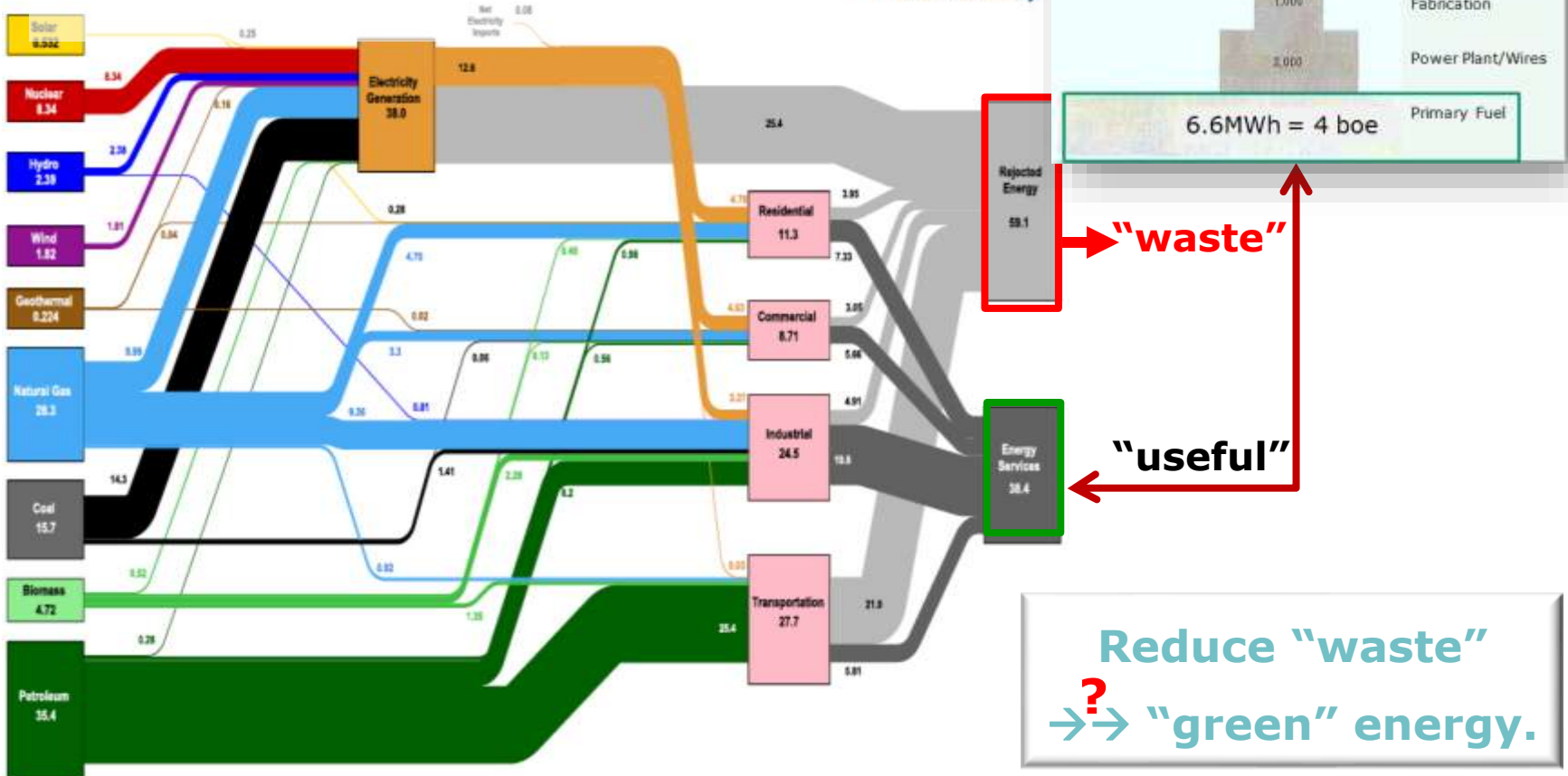


Nature of "Energy Problem"

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

Estimated U.S. Energy Consumption in 2015: 97.5 Quads

Lawrence Livermore
National Laboratory



Reduce "waste"
 →?→ "green" energy.

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