Summary

The 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…."

Limit to growth (population)**:** MIT sims business as usual (BAU)
→ tipping point ≈2030 → fast decline of civilization

$$Consumption\ rate\ of\ resource: \frac{dA_{res}(t)}{dt} = -\lambda(N_{pop}) \cdot A_{res}(t);\ \lambda > 0$$

$$If\ rate\ constant\ \lambda(N_{pop}) \propto N_{pop}(t)\ increases\ in\ t \rightarrow \boxed{A_{res}(t) = A_{res}(0) - \alpha\left[e^{+\nu\cdot t} - 1\right]}$$

Premise/assumptions: no change in population dynamics, no technological advances (gene mod in agriculture, new prospecting methods), no feed-back of publication

NAP Socio-Economic Network: Previous accounts did not consider globalization, renting of finite resources by high-income regions → inequity

Human ecological footprint: Increases in time, pollution by chemical emissions, specifically CO_2. Urbanization accelerates, emerging world increases consumption → Present rate corresponds to >1.5x Earth (??)

Agenda for this week

The grand picture (Sustainability in the Anthropocene)

- Human habitat and resources
- Sustainability of Human Activity & Life on Earth, definition

  Limit to growth, Club of Rome

  Socio-economic/ecological network, Anthropocene
- Finite resources: arable land and water for food production

  Human ecological footprint, choices and dilemmas
- Energy utilization and environment

  Energy consumption and human development

  External costs (pollution, climate change) of energy use

  Planetary climate, greenhouse effect

- Stated (aspirational) public policies, mitigation vs. adaptation

Optional reading: Tools & fuels in human history

Major Economic Determinant: Energy Utilization

Main uses in industrialized economies:

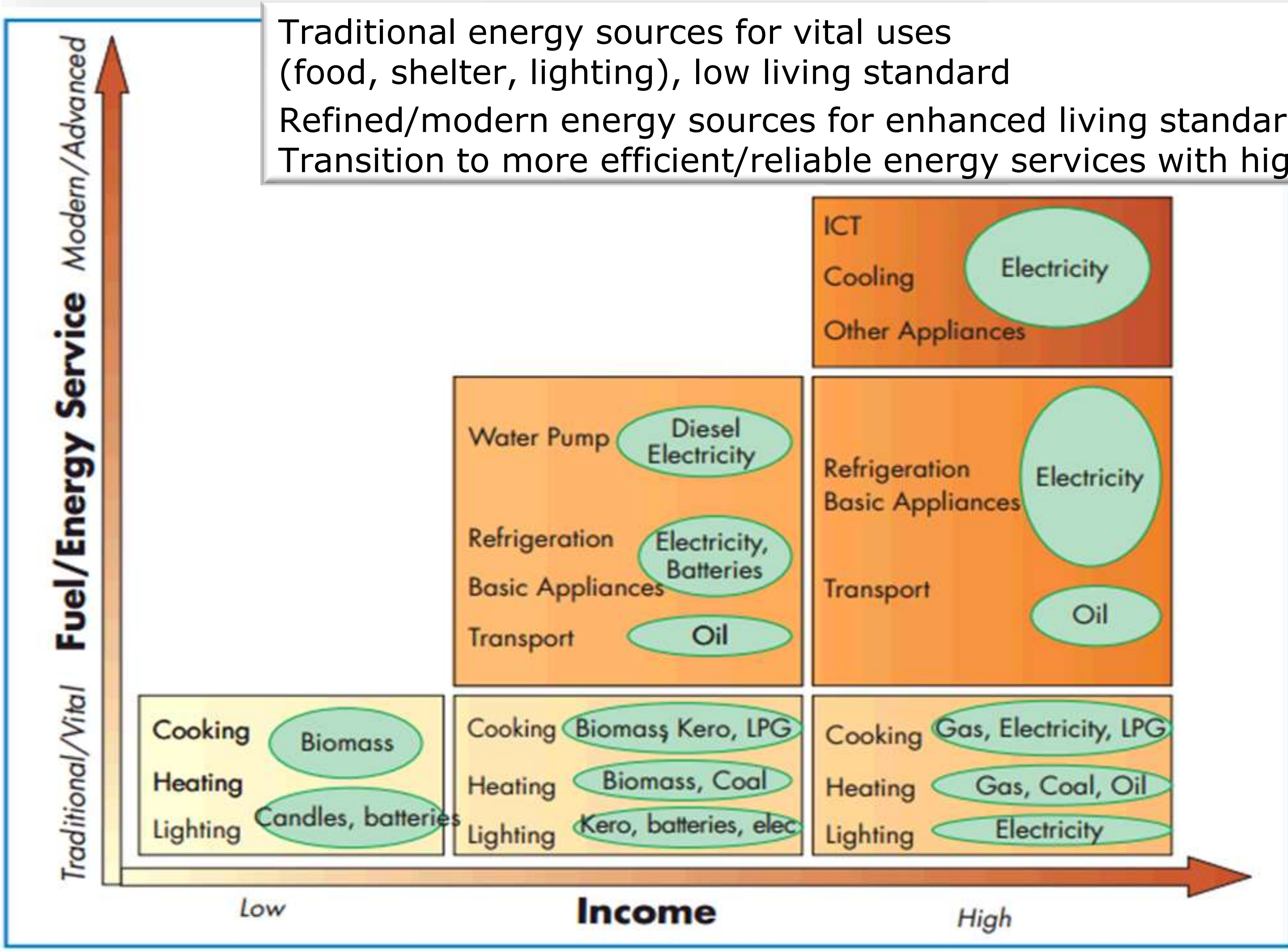
- Production of food (farming, fishing, agriculture,…)
- Processing food (cooking, preserving,…)
- Housing (shelter, heating, lighting,..)
- Sanitation and healthcare
- Construction/building
- Transportation of goods and personnel
- Fabrication of materials and goods (melting, forging, tooling,…)
- Communication,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

Sustainability of current modes of human operation ??
Basically OK or imminent disaster ("Energy Problem(s)") ?

Energy Utilization vs. Income/GDP

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

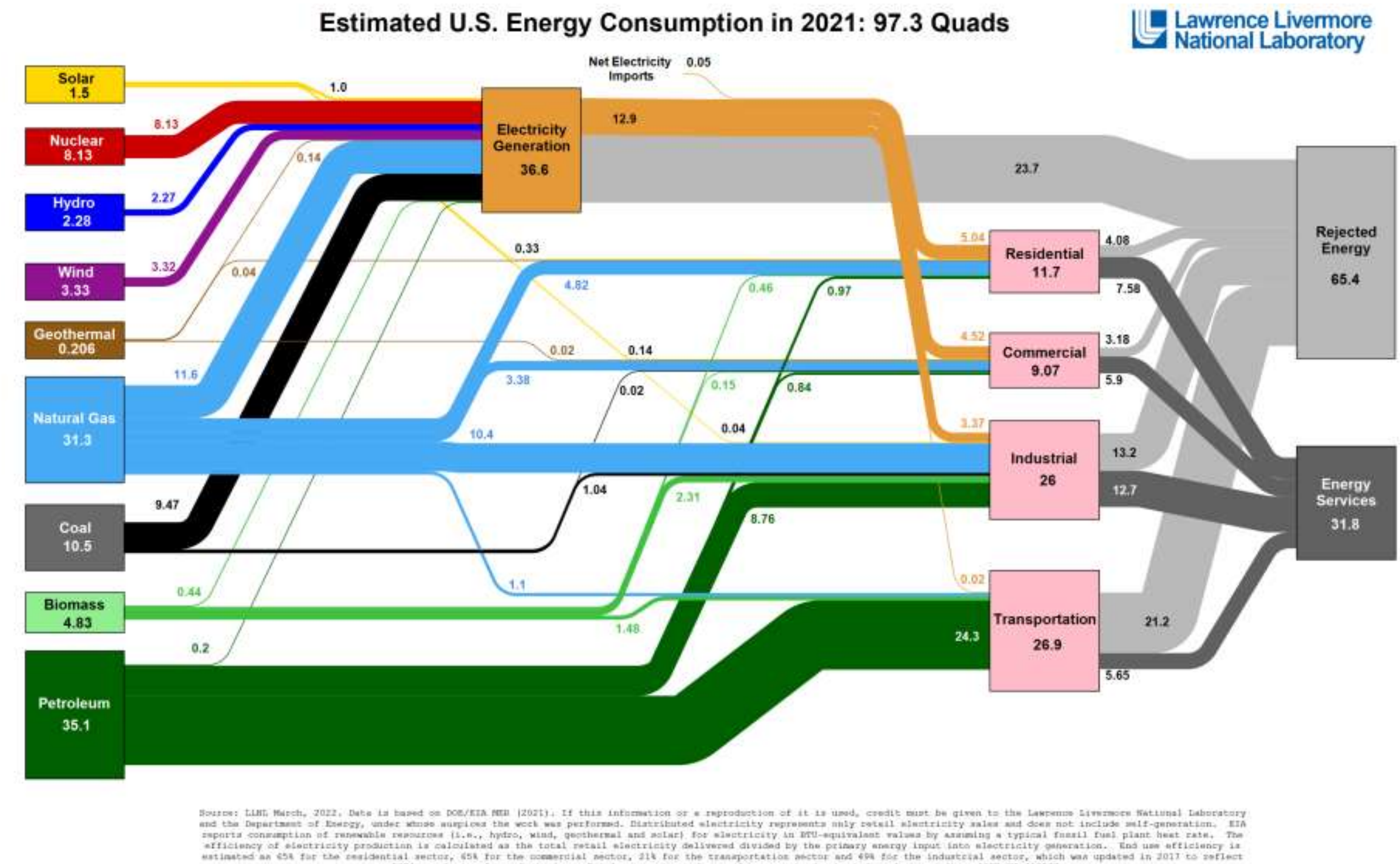
Refined/modern energy sources for enhanced living standard.
Transition to more efficient/reliable energy services with higher income.



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

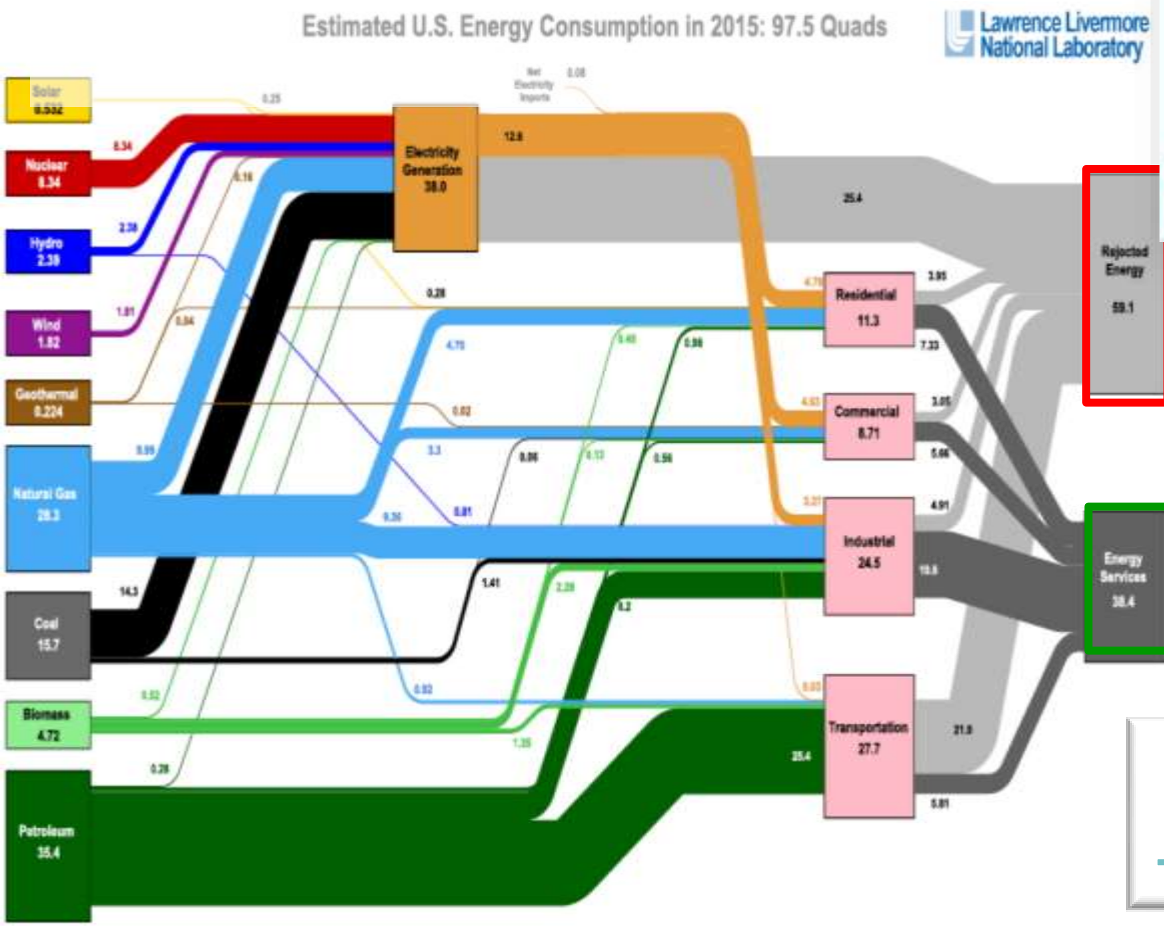
US Energy Consumption in 2021

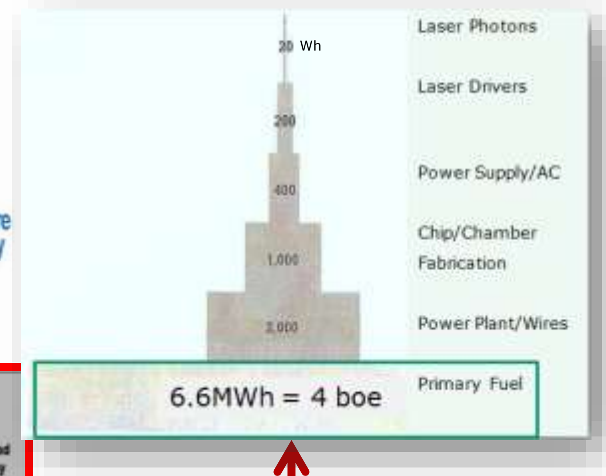
2015-2018 → Increase by 3.7 Quads *(≈EJ)* → 2021 Decrease by 2.8 Quads



Nature of "Energy Problem"

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





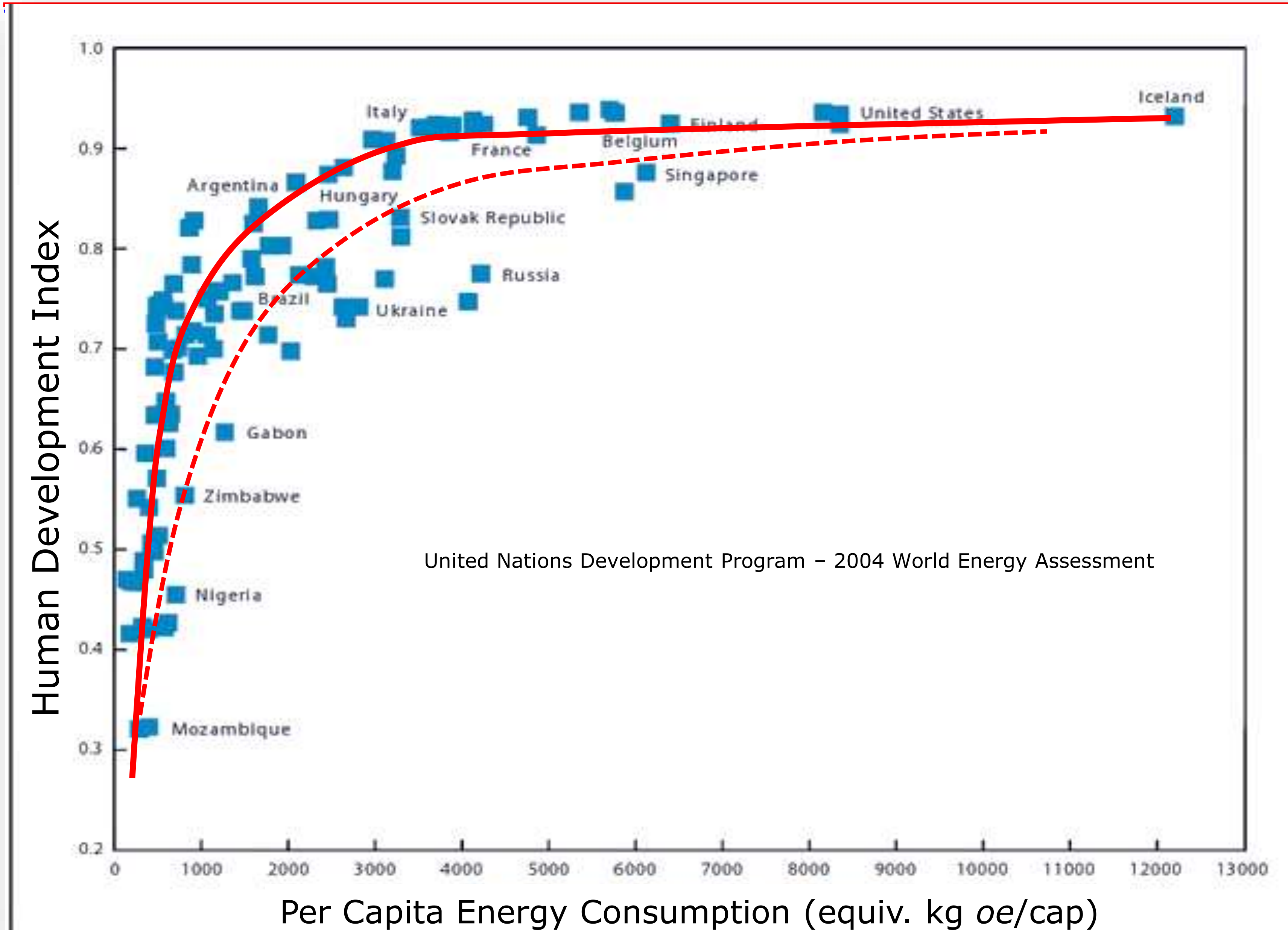
"waste"

"useful"

Reduce "waste"
→?→ "green" energy.

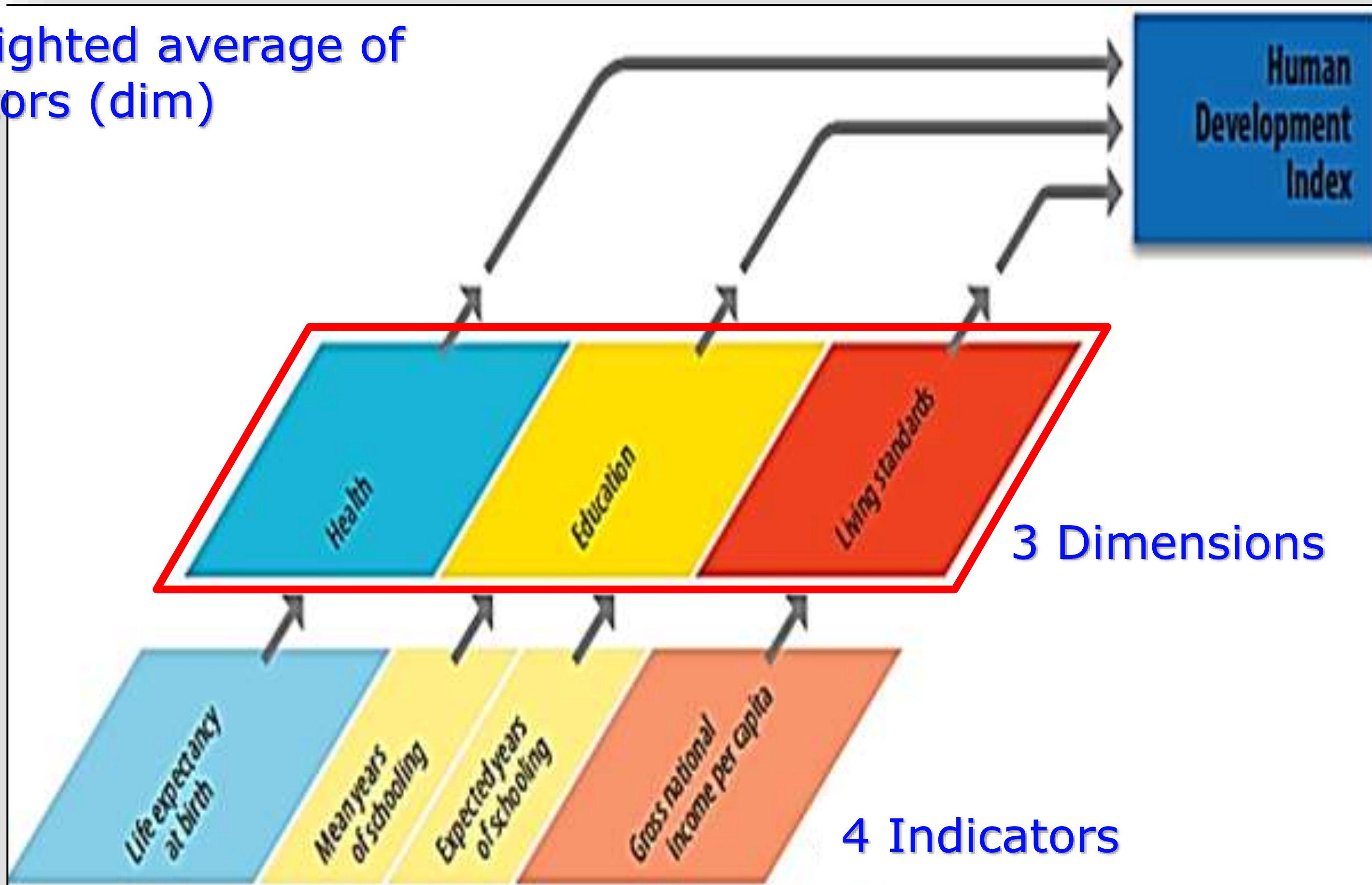
Solve ENTROPY (S) problem (3rd Law TD) ! Think BIG !

Energy and Human Development



Human Development Index (HDI)

= Weighted average of
3 factors (dim)

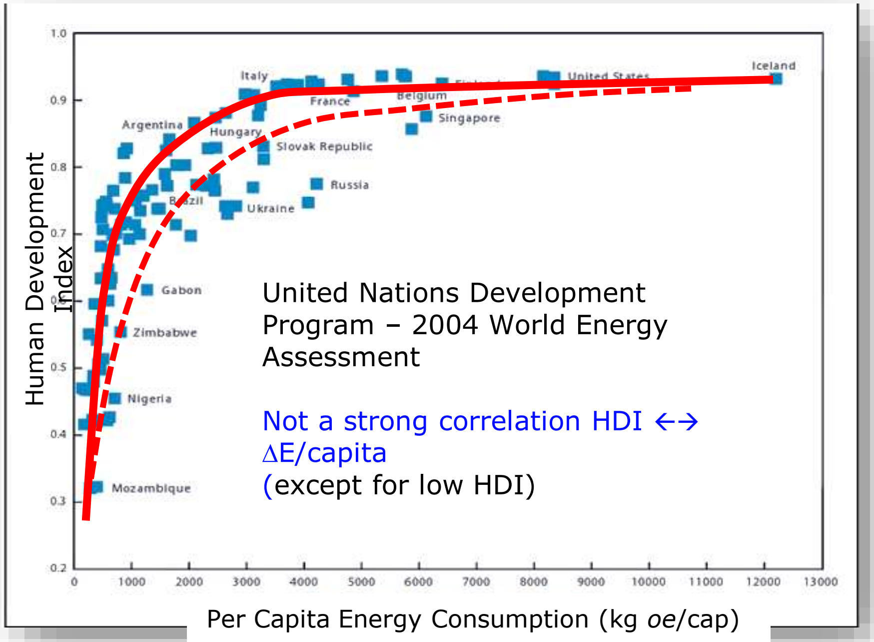


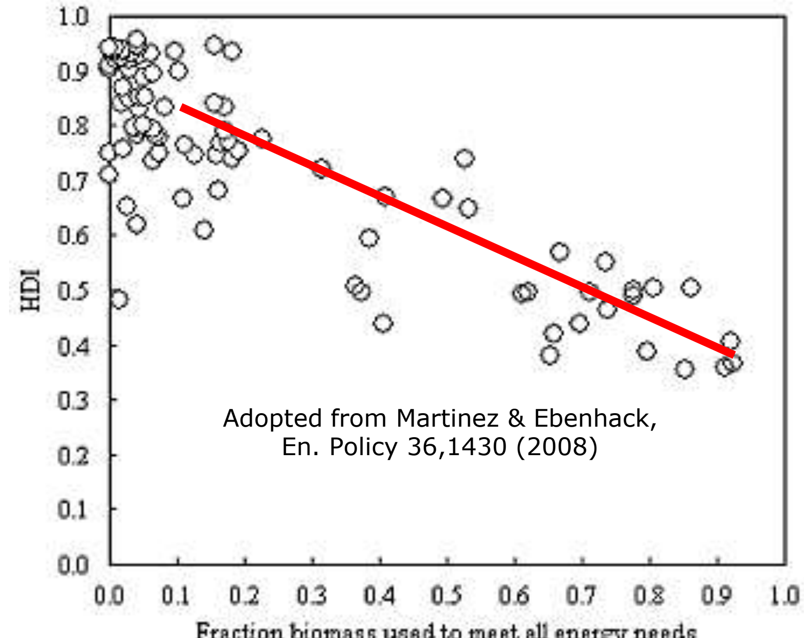
a) Health (life expectancy).

b) Education (adult literacy, enrollment).

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

Energy and Human Development





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

Human Development Index HDI
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PPP=purchasing power parity per capita

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)

Direct and External Costs of Energy

The real direct costs of energy production in a given power plant :

"Levelized cost of electricity (energy)" per kWh, averaged over 1 year. What consumer have to pay for 1 kWh from that provider

$$LEC = \frac{annuity_N \cdot C_{capital} + \left(Operations + Maintenance\right)_{fixed}}{8760 \cdot Capacity - Factor} + \left(Operations + Maintenance\right)_{variable} + fuel$$

annuity: break-even return on the capital after N years of operation. Estimates are based on Life Cycle Analysis ("from cradle to grave").

Long neglected, but potentially much more significant, and harder to estimate in terms of $$:

→ → "External Costs of Energy"

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.

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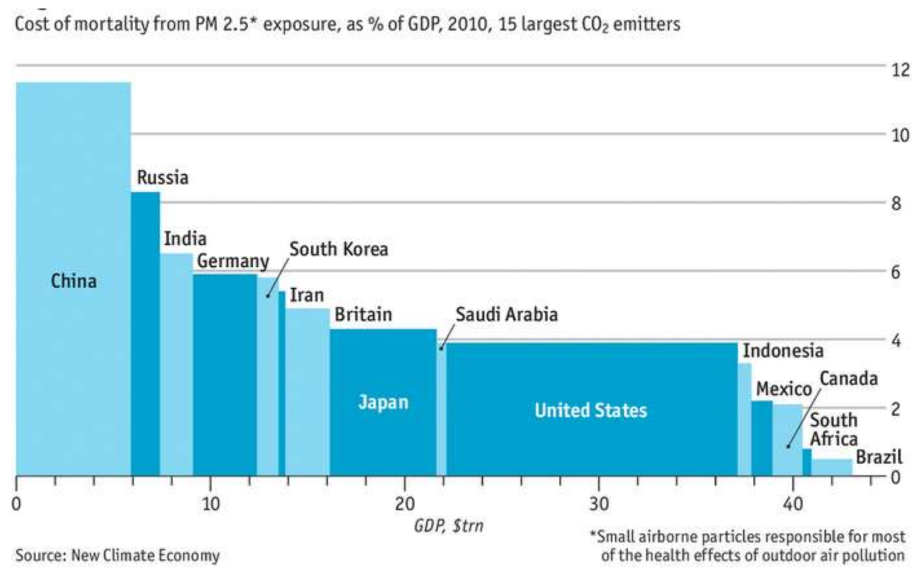
Direct External Costs of Energy Consumption

Sulfur, nitrogen oxides, particulates from China's coal-fired power plants → acid rain on Seoul/SK, Tokyo/JP, particulate pollution in Los Angeles (J. Geophys. Res.).

Loss of life & health → economic costs.



New Delhi/India 2021 (l) vs. < 2019(r)

During pandemic lockdown (left), absence of automotive traffic clears air of smog, which is normally present (right panel)

Direct External Costs of Energy Consumption

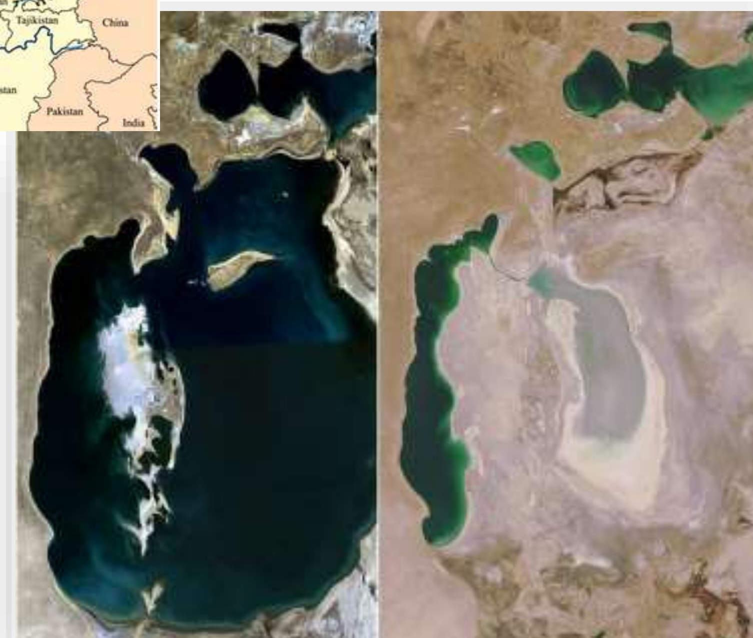
Indirect External Costs of Energy Consumption

Melting Sea Ice in Arctic Ocean
(Economist)

Indirect effects due to anthropogenic climate change, warming, desertification.

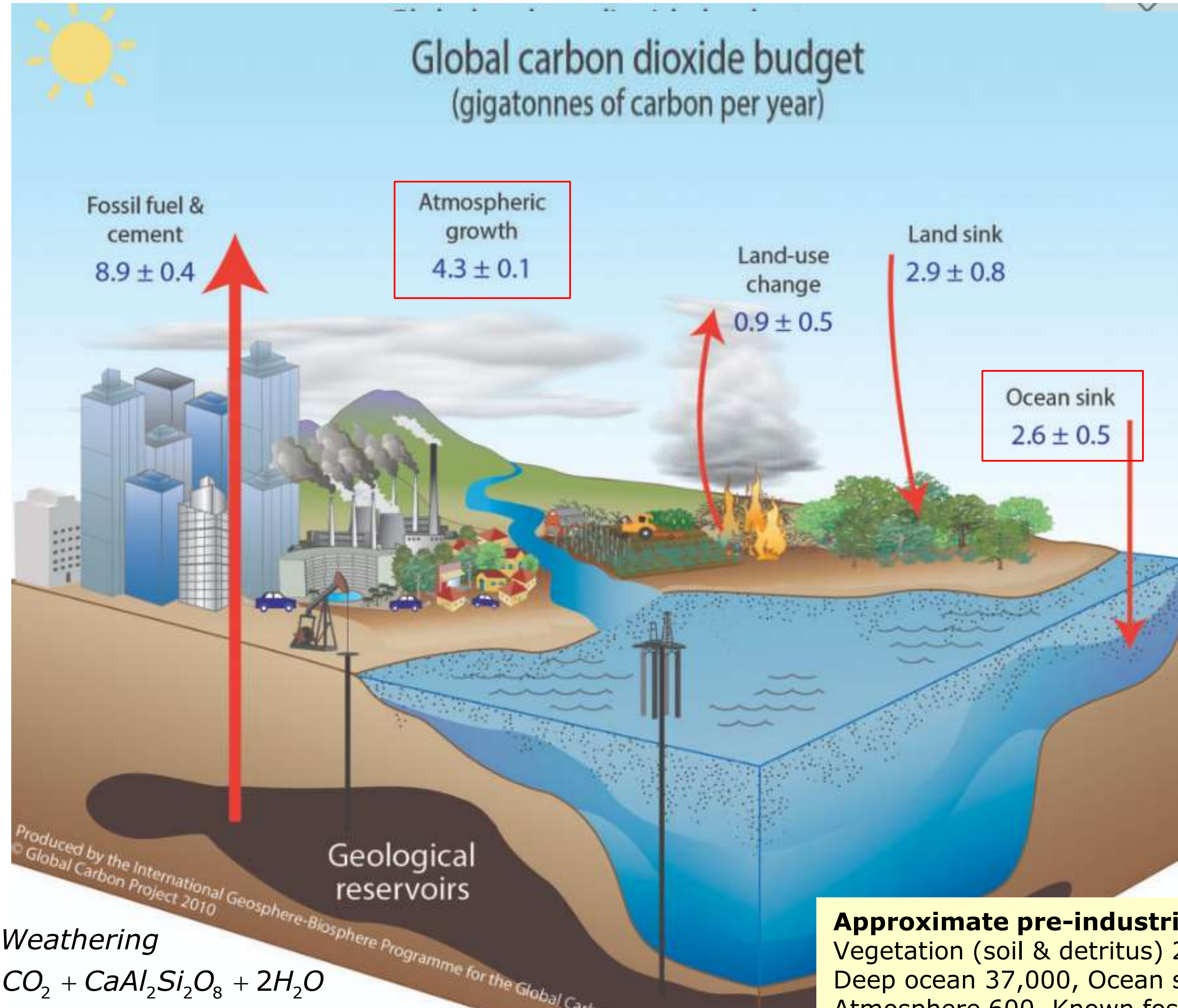
Desertification is exaggerated by over-irrigation - agriculture

Fresh water lake: Aral Sea (1960→1989): A=68,000 km^2 V=1,100 km^3 → 28,687 km^2 square.



Dwindling/unclean water resources in Africa

Changing a Natural Balance



Man-induced changes in Earth's Carbon Cycle between surface and ocean reservoirs. Anthropogenic changes (+ or -) due to burning fossil fuel, land use,…).

Red arrows: anthropogenic flows
Zero= pre-industrial flow.
Units: 10^9 tons of carbon per year (G*t*C/a).

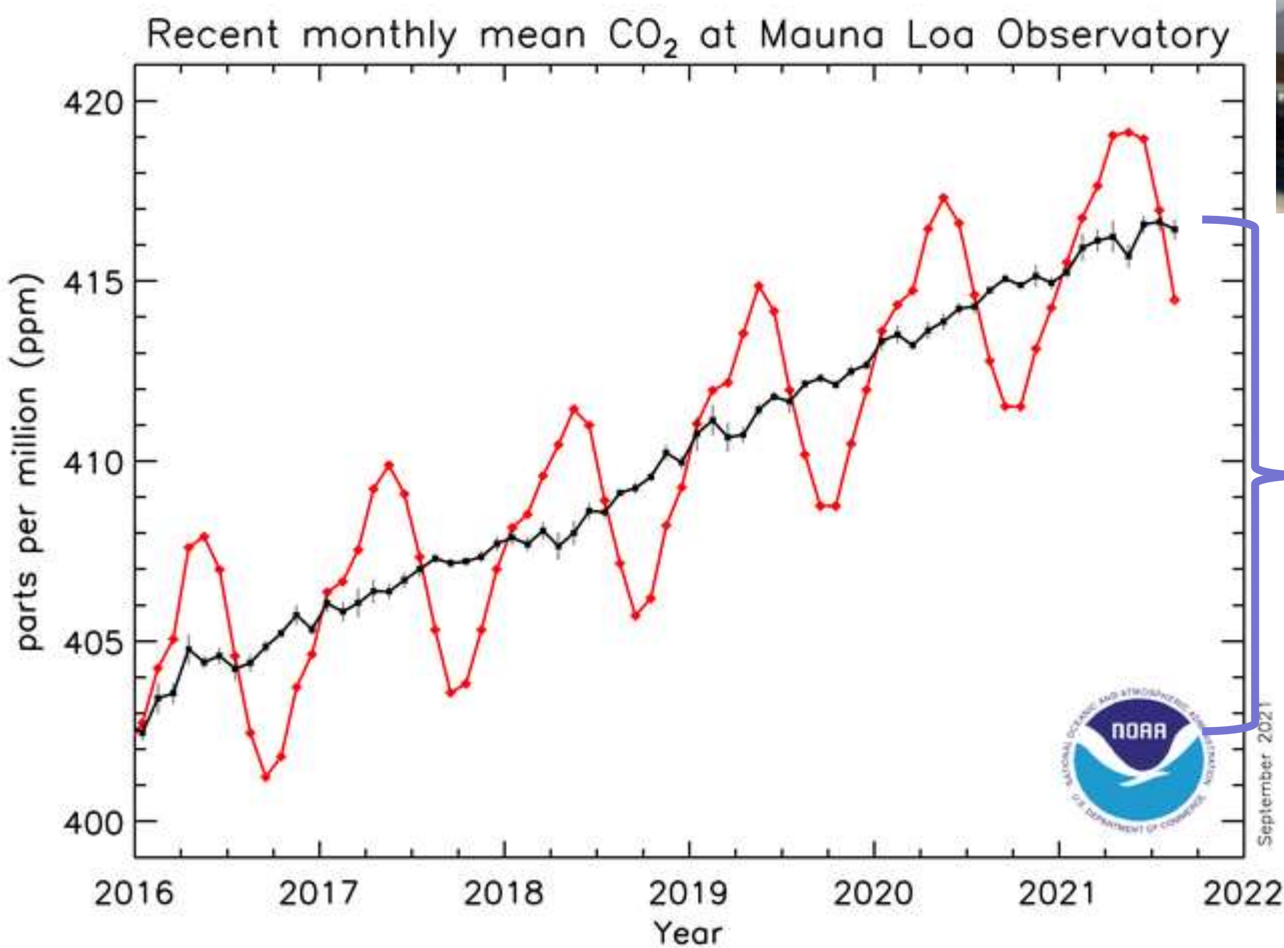
Emissions (2012):
+9.6 G*t* C/a
+35.2 G*t* CO_2 equ./a
(NOAA)

Weathering

$$CO_2 + CaAl_2Si_2O_8 + 2H_2O \rightleftharpoons CaCO_3 + Al_2Si_2O_5(OH)_4$$

Approximate pre-industrial inventory carbon (Gt)
Vegetation (soil & detritus) 2,300, Surface oceans 900, Deep ocean 37,000, Ocean sediments 150
Atmosphere 600, Known fossil fuels 3,700

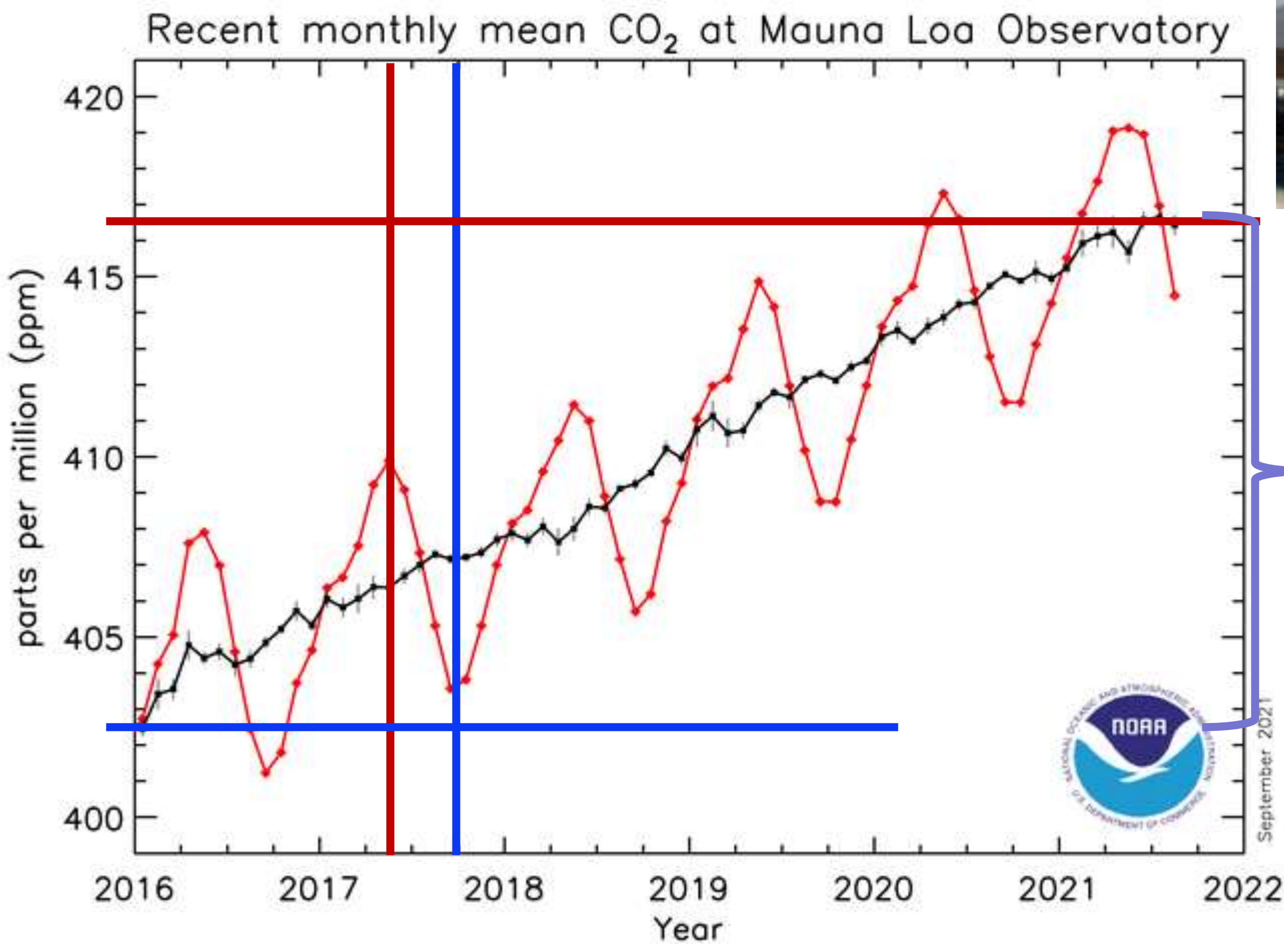
Annual Global CO_2 Emissions



Δ**C**=
14ppm
=5.5ppm/a

Annual pattern: Sept-March/Apr CO_2 emission increases
March/Apr-Aug CO_2 emission decreases

Annual Global CO_2 Emissions



$\Delta \mathbf{C}$=
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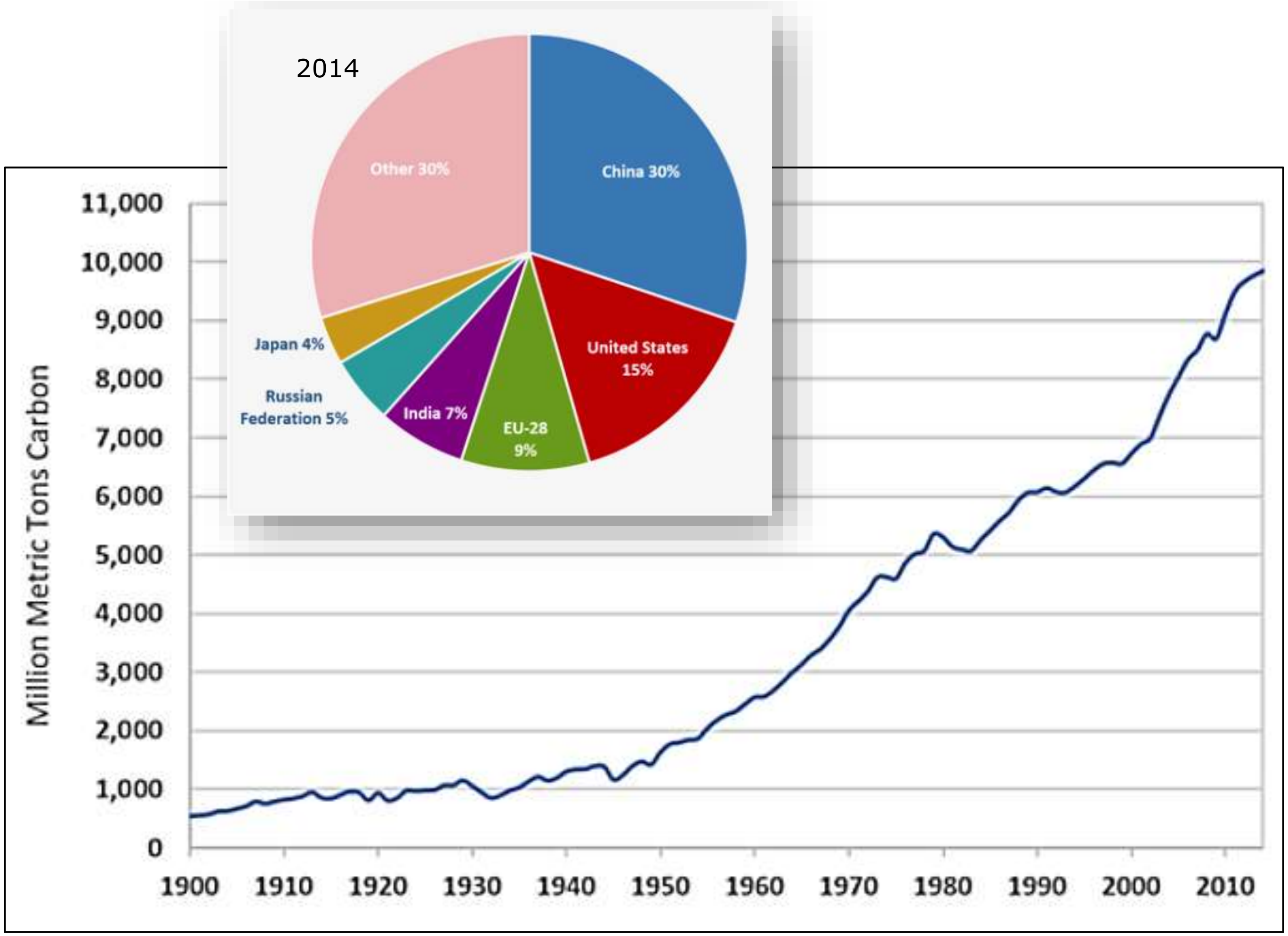
Global Carbon (CO_2) Emissions 1900-2014



Boden, T.A., Marland, G., and Andres, R.J. (2017). Global, Regional, and National Fossil-Fuel CO2Emissions. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. doi 10.3334/CDIAC/00001_V2017.

Anthropogenic Pollution (GHG++ Emissions)

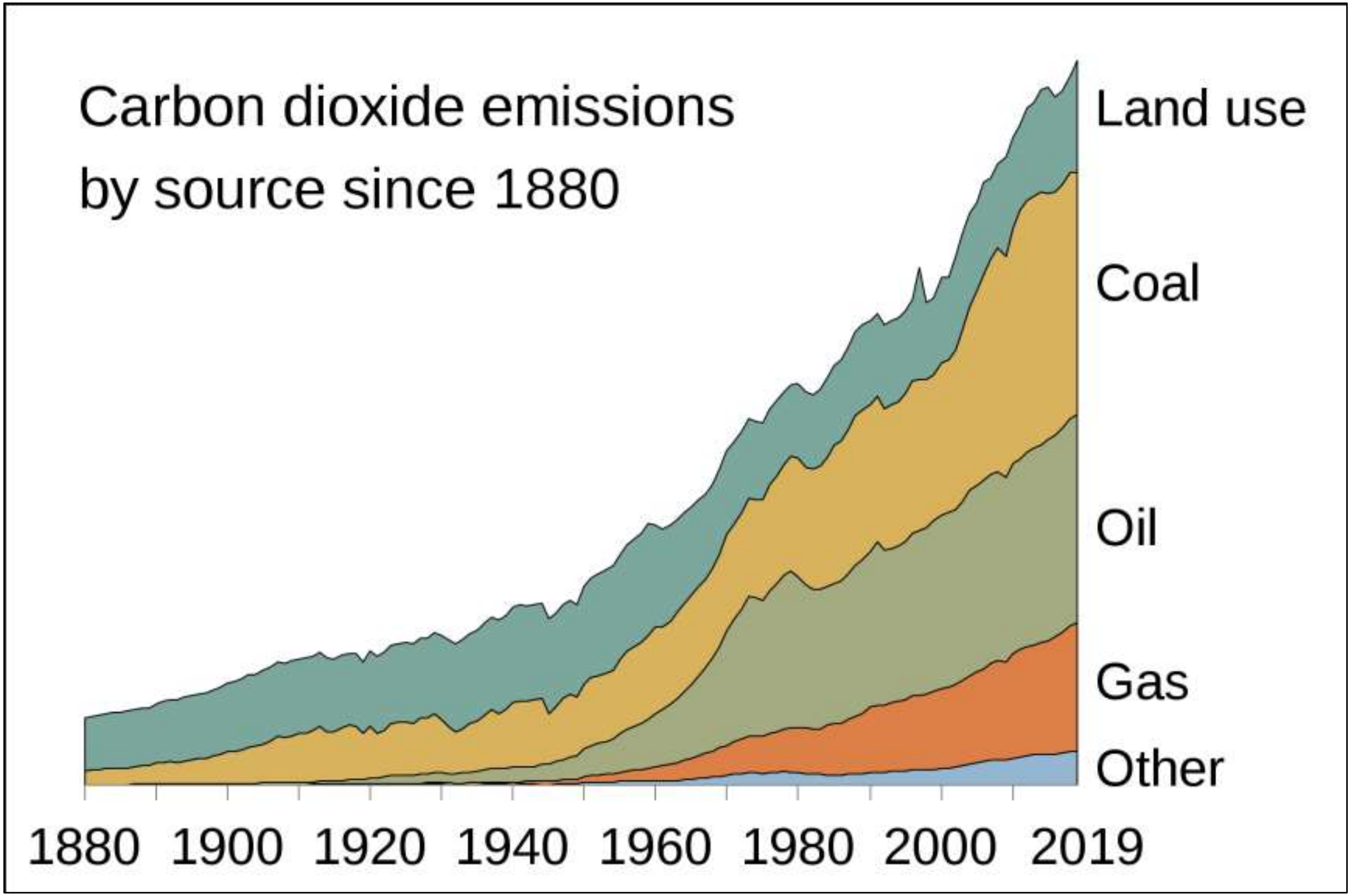
Source	Emissions sector (Mt CO_2/year)						Exhaust mixture
	Trans	Elec.	Comm.	Ind.	Res.	*Total*	
Petroleum	1952.68	102.30	54.93	416.83	100.91	2627.64	CO_2 (3–8 vol%) SO_2; NO_X; PM; CO
Natural gas	33.1	319.11	163.06	397.54	262.42	1175.24	CO_2 (3–5 vol%) NO_x; CO; PM
Coal	~0	1983.81	9.28	187.99	0.81	2181.89	CO_2 (12–15 vol%) PM; SO_2; NO_X; CO; Hg; ..U
Total	1985.79	2405.22	227.26	1002.6	364.14	5984.77	

Year 2008

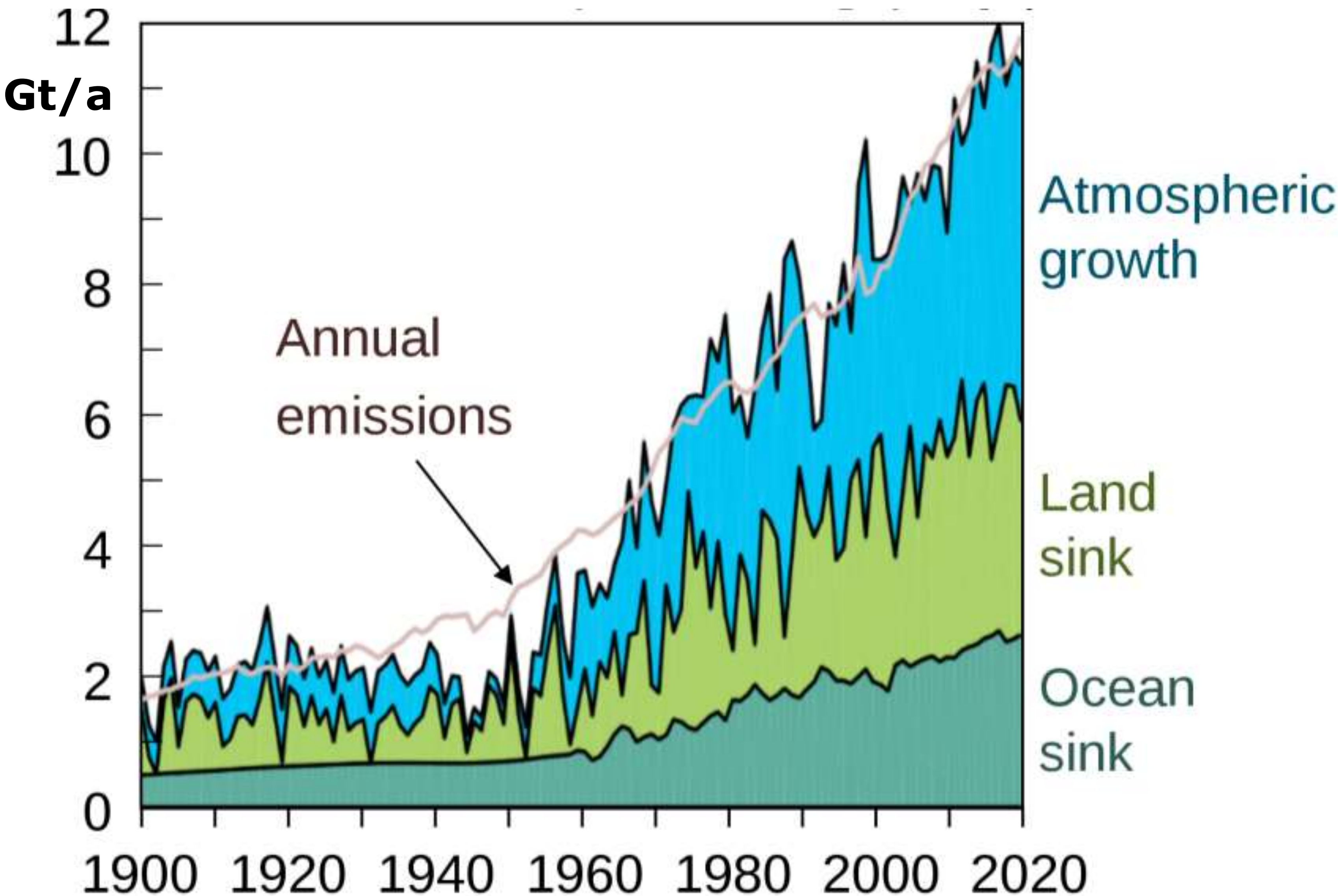
Estimated 2008 U.S. and worldwide CO_2 process emissions

Non-Fossil	Emissions (Mt CO_2/year)	CO_2 content (vol %)
Cement production	50 (world 2000)	14–33
Refineries	159 (world 850)	3–13
Iron and steel production	19 (world 1000)	15
Ethylene production	61 (world 260)	12
Ammonia processing	7 (world 150)	100
Natural gas production	30 (world 50)	5–70
Limestone consumption	19	50
Waste combustion	11 (electricity)	20
Soda ash manufacture	4	
Aluminum manufacture	4 (world 8)	

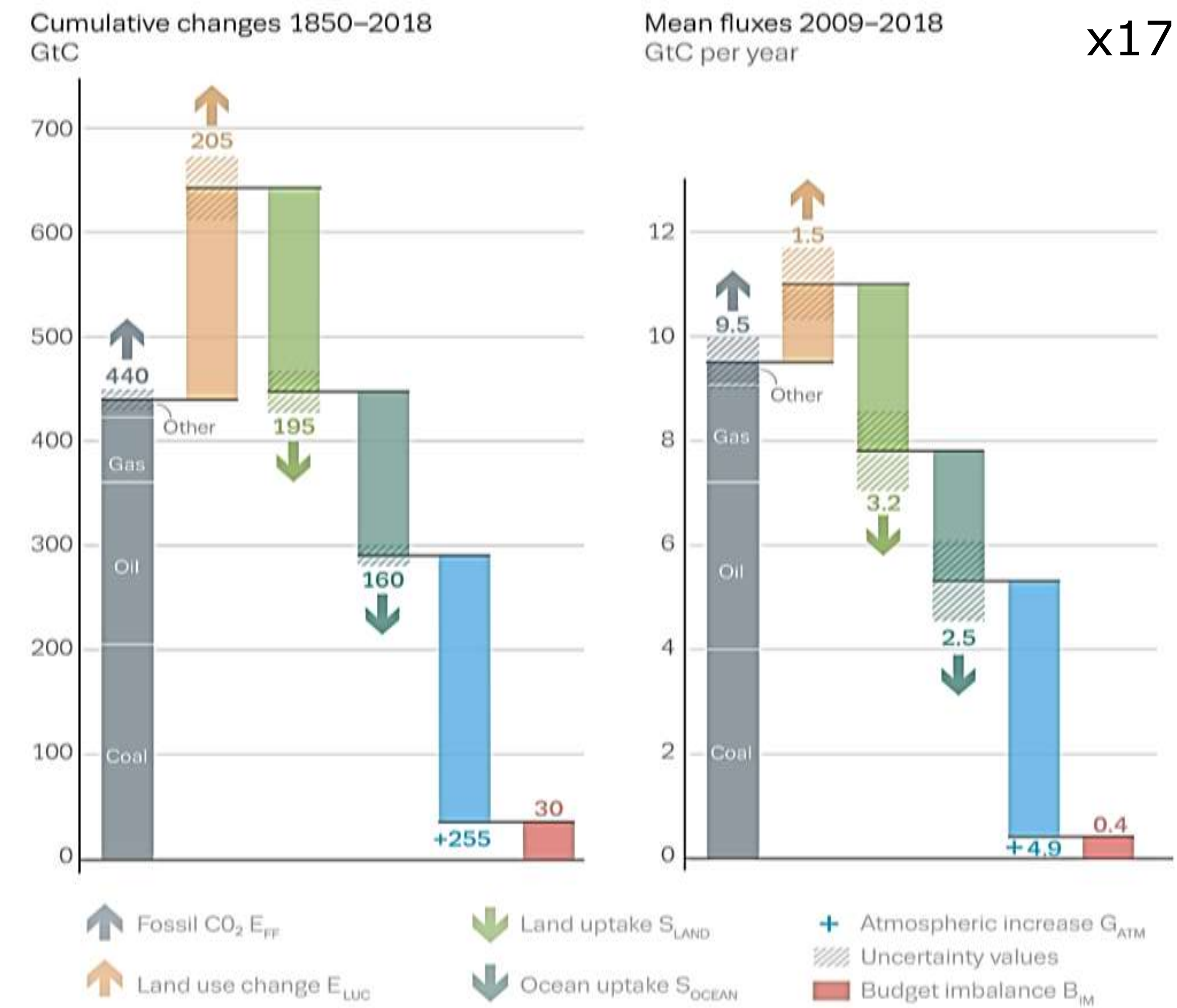
Anthropogenic Pollution Sources



Sources and Sinks of Gas Pollutions



Anthropogenic Carbon Flow: Historic & Now



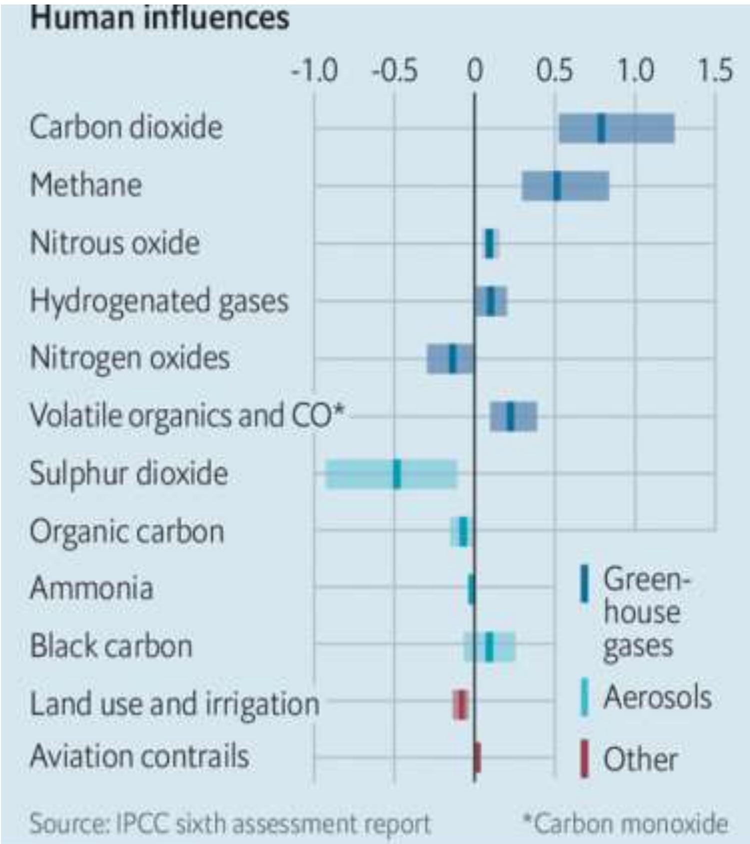
x17

x50

Other Anthropogenic Influences on Health & CC

Mean (2010-2019) global temperature deviation relative to 1850-1900

The Economist, 14 Aug 2021

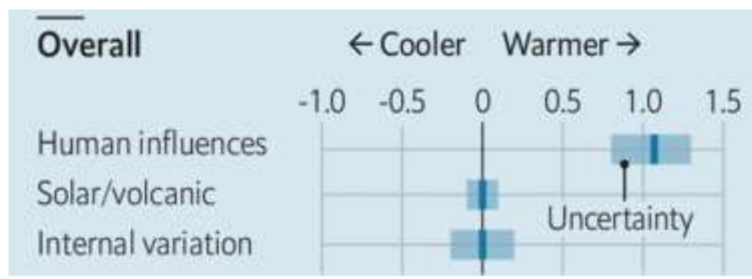


The Economist, 14 Aug 2021

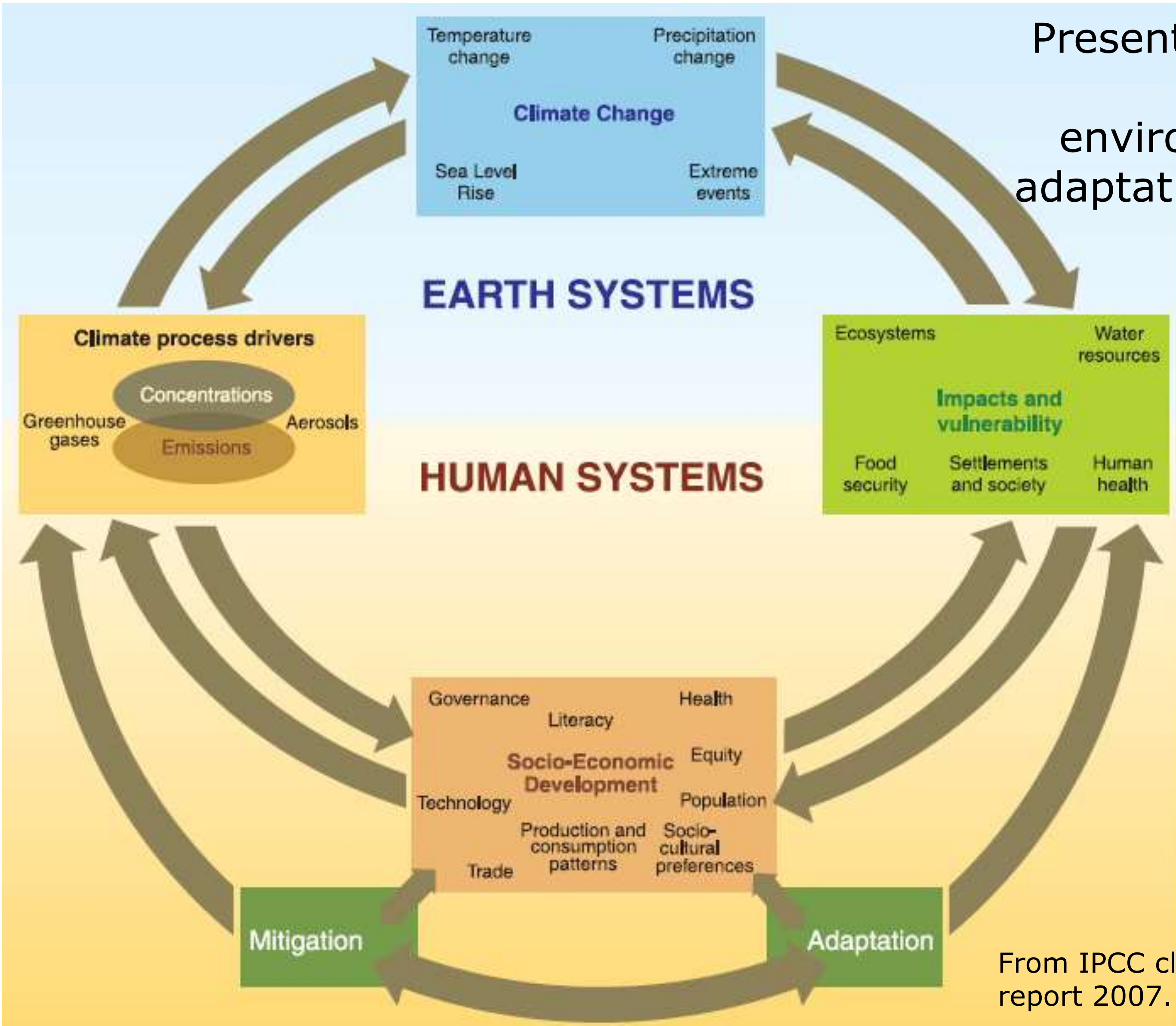
Other greenhouse gases and particles, aerosols.

Toxic gases

Land use, mitigating CC



Climate Change Drivers, Impacts and Responses



Present levels of GHG (>450 ppm) in environment require adaptation, in addition to mitigation.

Feed back effects

From IPCC climate synthesis report 2007.

Ethical and Policy Dilemmas

1. Conservation of resources for future generations *vs.* sustaining larger population & developing capacity to solve future problems.
2. Protection of environment *vs.* economic efficiency.
3. Relative emphasis of current welfare *vs.* that of future generations.
4. Utilization of powerful new technologies *vs.* extensive risk/benefit study.
5. Imposition of technology risks/cost without public consent *vs.* paralysis of decision making. Role of experts *vs.* public.
6. Public interest *vs.* individual liberties and preferences (eminent domain).
7. Social and political merits of simple *vs.* complex technologies (coal/nuclear).
8. Responsibility of developed nations towards poor/emerging societies. Equitable resource/wealth sharing.
9. Technological possibilities *vs.* basic human needs (biofuels vs. bio-food).
10. Mitigation *vs.* adaptation to climate change.

Loosely adapted from: I. Barbour, H. Brooks, S. Lakoff, J. Opie, "Energy and American Values," Praeger Publishers, Nat. Hum. Center, Research Triangle Park, NC, 1982.

Literature and Credits

I. Barbour, H. Brooks, S. Lakoff, J Opie, *Energy and American Values*, National Humanities Center, Triangle U., Praeger Scientific, 1982

D. Yergin, *The Quest, Energy, Security, and the Remaking of the Modern World*, Penguin Press, New York, 2011

D. M. Martinez & B. W. Ebenhack, En. Policy 36,1430 (2008)

N. Klein, *This Changes Everything, Capitalism vs. Climate*, Simon&Schuster, New York, 2014.

The Clean Air Act (CAA), 42 U.S.C. §7401 et seq. (1970). http://en.wikipedia.org/wiki/Clean_Air_Act_(United_States)

Monographs (MS, PhD) on administration energy policies, e.g.,

Kevin L. Murray, U.S. energy policy under the Reagan Administration, MS Thesis, San Jose State University, 1990.

Bodenatlas 2015, Bund f. Umwelt- u. Naturschutz Deutschland, Le Monde diplomatique, heinrich Boell Stiftung, Inst. Sust. Studies.

Following (on the next page) are sources and footnotes for the emission estimates from *The Economist*, Sept. 20th, 2014 issue reproduced on 2 charts above.

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