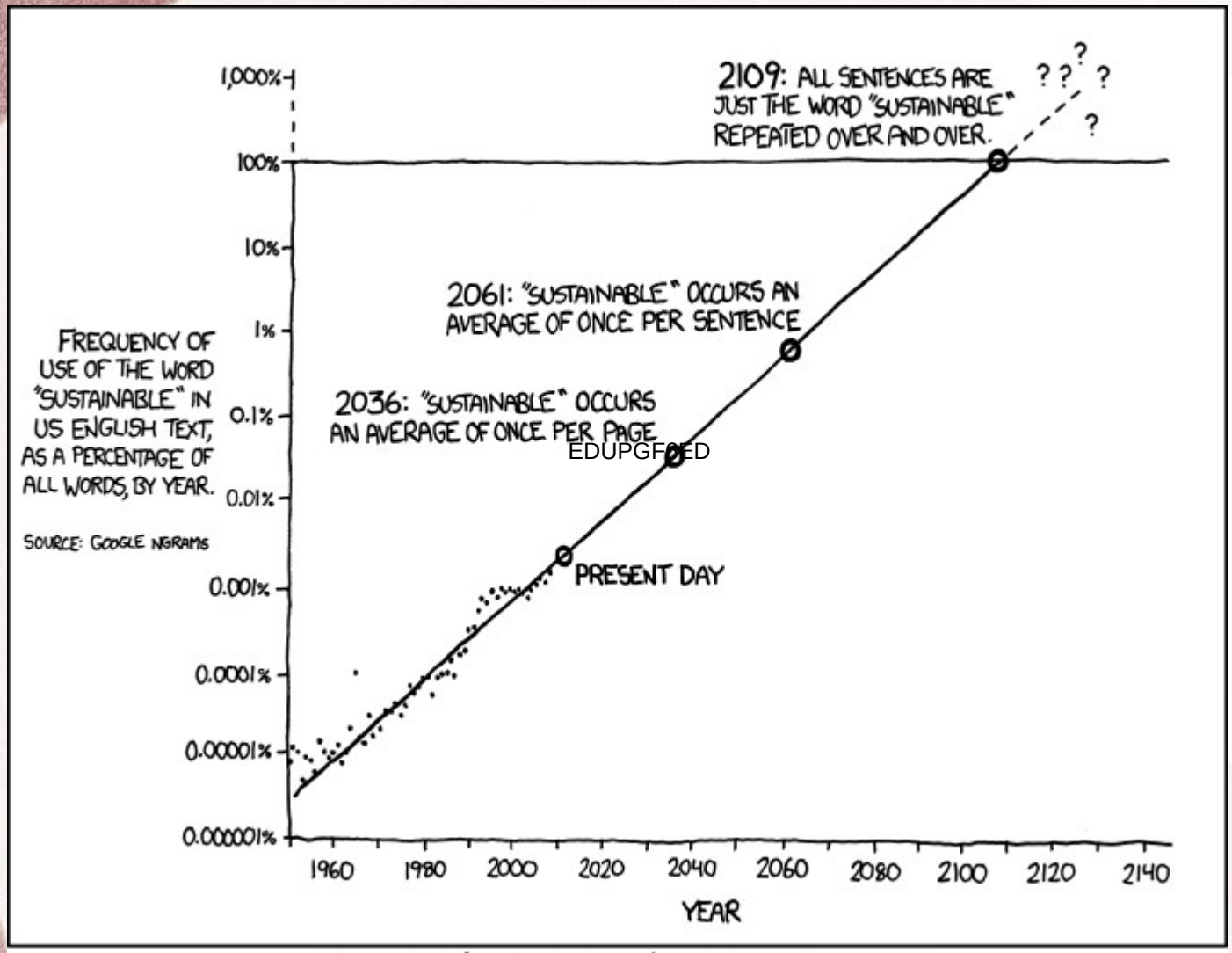
Sustainability in Civil Engineering CE G9800 / CE 59903
Sustainable Infrastructure SUS 7800B

I. Introduction and Overview

Course expectations

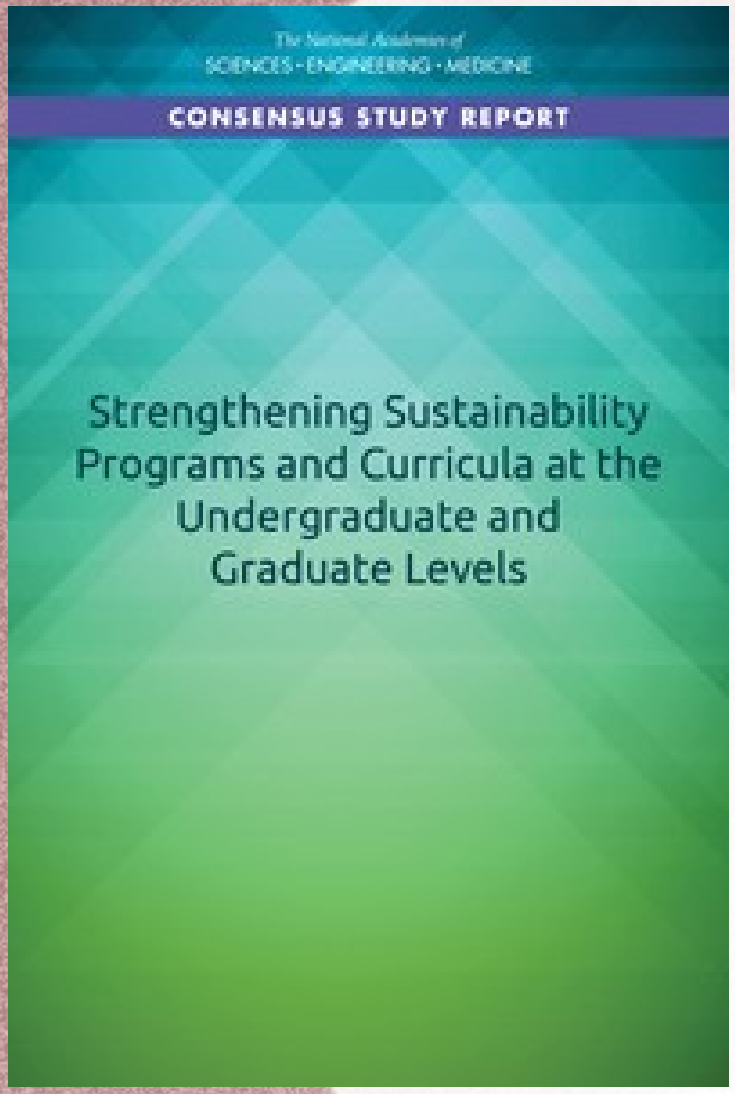
- Active participation in class – be critical, be creative
- Weekly essay assignments (submit on Blackboard discussion forum)
- Present and lead short discussions (~15') based on essay questions
- Term project (Presented in writing and to class): Develop and analyze an engineering design from sustainability standpoint(s)
- Take-home final

What is sustainability?



Munroe: "Though 100 years is longer than a lot of our resources"

It really is a problem



- A Sustainability Curriculum Consortium virtual roundtable on this National Academies report presented many criticisms of it, among others that it never precisely defined what sustainability is

What do you think?

According to civil engineers...

- “The American Society of Civil Engineers (ASCE) defines sustainability as a set of economic, environmental and social conditions in which all of society has the capacity and opportunity to maintain and improve its quality of life indefinitely, without degrading the quantity, quality or the availability of natural resources and ecosystems.”
- “Moreover, sustainable development is the process of converting natural resources into products and services that are more profitable, productive, and useful, while maintaining or enhancing the quantity, quality, availability and productivity of the remaining natural resource base and the ecological systems on which they depend.” (Policy Statement 418: The Role of the Civil Engineer in Sustainable Development)

Some ASCE sustainability activities

- Resource list (mostly conference articles):permeable pavement, storm swales, walkable cities, green roofs...
- Participates with cities in an International Coalition for Sustainable Infrastructure
- Online course on Making the Case for Sustainable Infrastructure and Sustainable Infrastructure Certificate Program
- Annual Innovation in Sustainability Civil Engineering Award (most recently for an Atlanta park)
- International Conference on Sustainable Infrastructure (2017, NYC; 2021, virtual)
- Sustainability Committee, as well as many section and branch committees

Sustainable infrastructure

- ASCE cofounded an Institute for Sustainable Infrastructure to "to develop and maintain a sustainability rating system [Envision] for civil infrastructure"
- Credits are given under the categories of Quality of Life, Leadership, Resource Allocation, Natural World, and Climate & Risk; levels for each category are “Improved”, “Enhanced”, “Superior”, “Conserving, “Restorative”

1962 ASCE Outstanding Civil Engineering Achievement award

Sustain ability as seen in award-winning projects

Sustainability?

Sustainability?

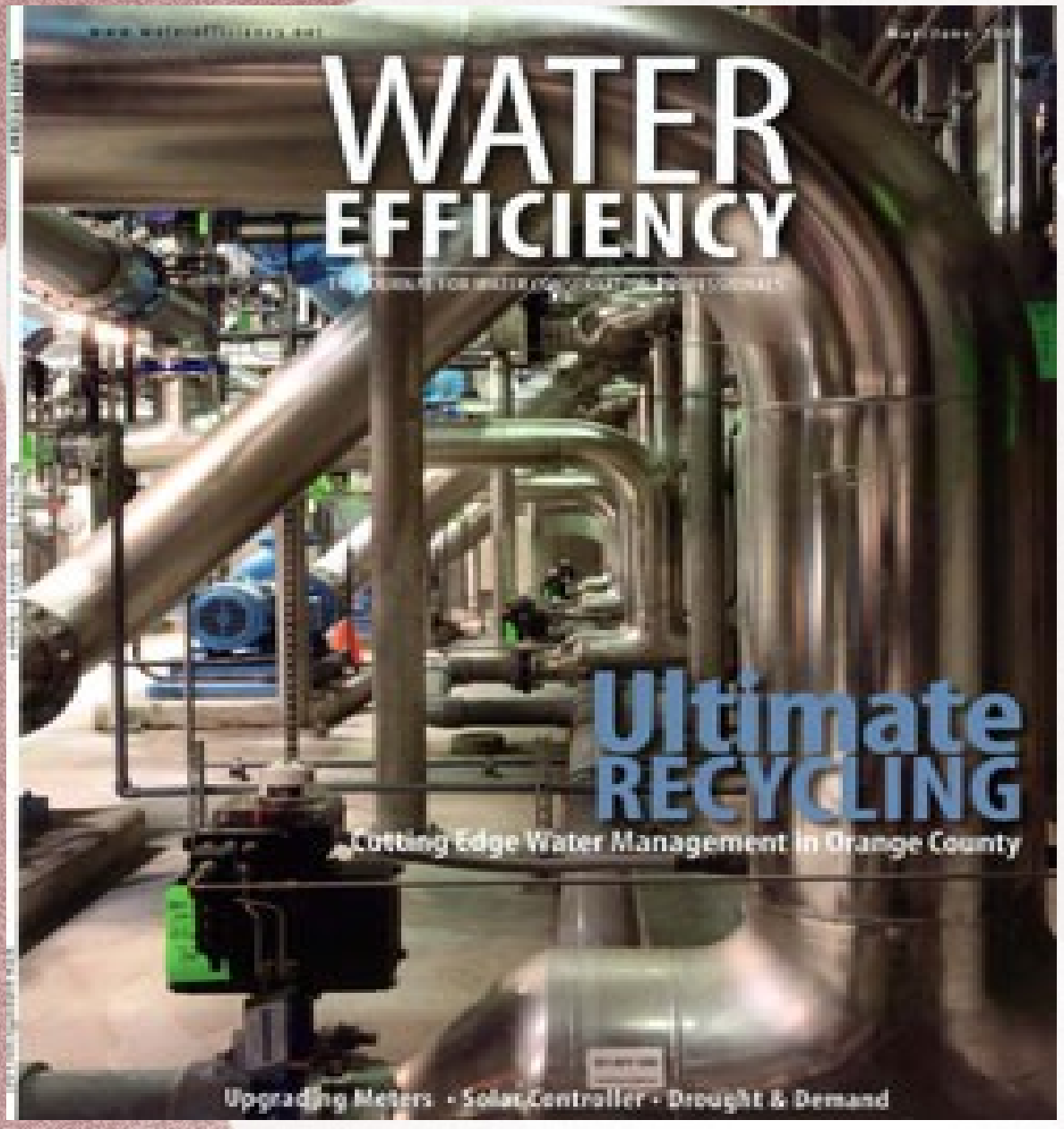
What is sustainability?

“Ongoing environmental concerns include weed encroachment, light pollution, asbestos pollution, water and streamlife problems, and a host of other concerns; most notable among these are the ongoing decline of pueo, and other native birds, including several probable extinctions. For example, the O‘ahu ‘Alauahio (*Paroreomyza maculata*) was probably made extinct by H-3, as the species, whose last known home was Halawa, has had no sightings since H-3 construction.

“Conversely, this road is considered an engineering wonder by its admirers. It is often compared to various cinematic landscapes in Star Wars and other movies, and it does sometimes reduce travel time for cross-island commuters, which has allowed for increased real estate development and prices in Windward O‘ahu, although frequent traffic clogs and accidents have become a well-known feature of the road as well.” (Wikipedia)

Sustainability?

2009

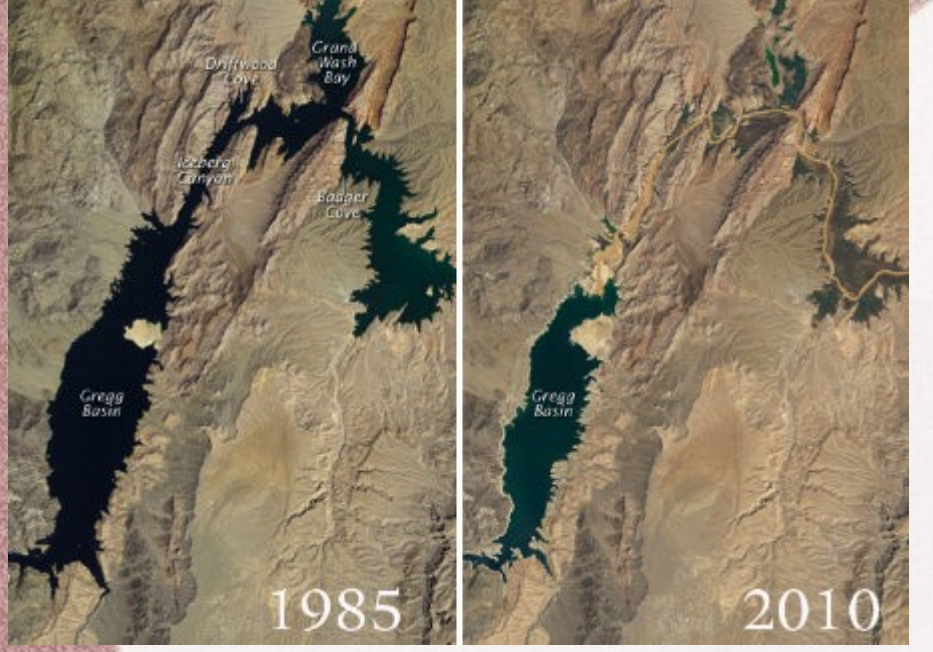


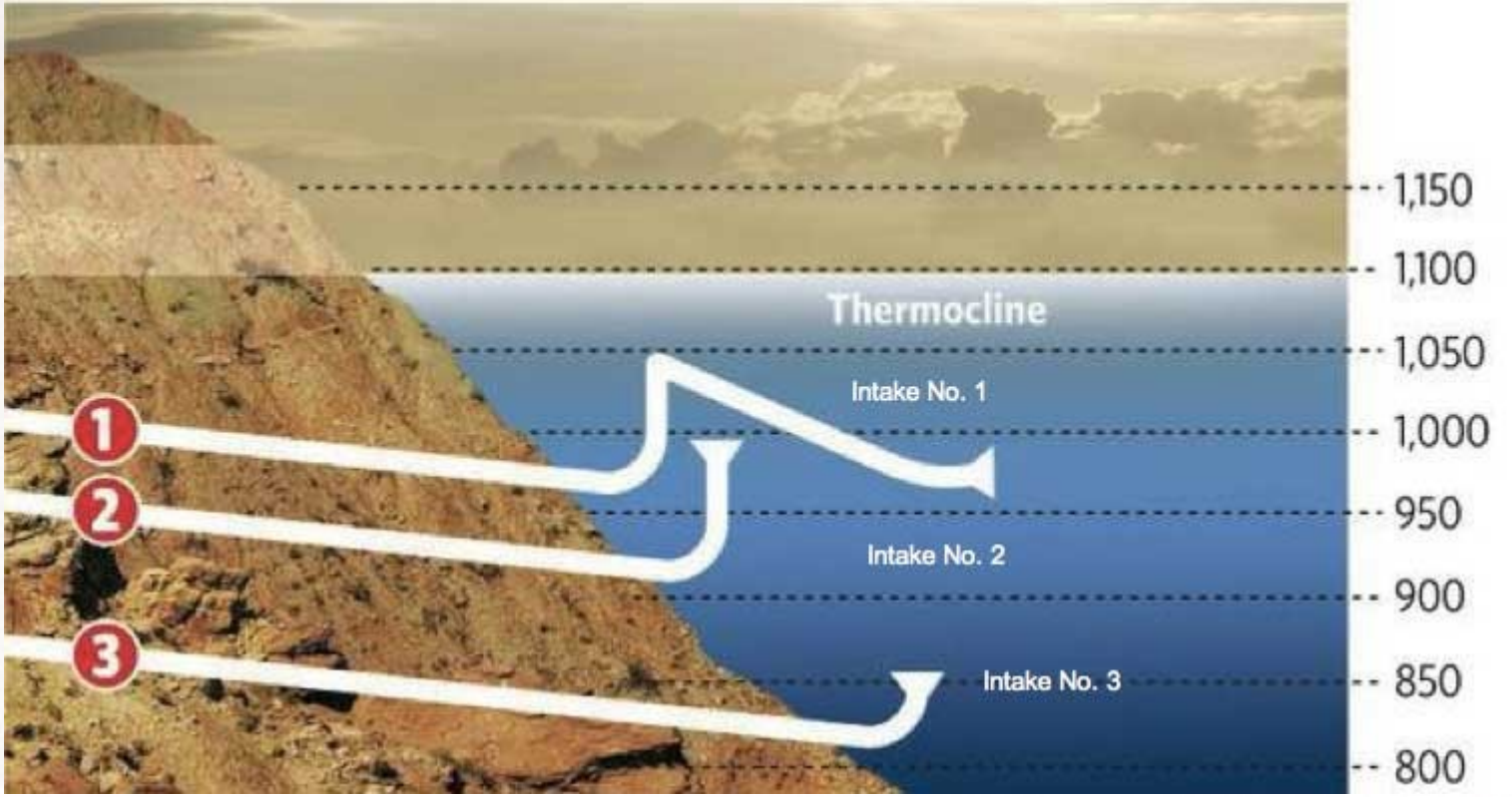
Sustainability?

- “reducing the vulnerability of the dam to a terrorist attack and safeguarding an important supply of water and the most sustainable supply source of electricity for the entire Southwest... highway underpasses were built for endangered desert bighorn sheep”

2012

Lake Mead

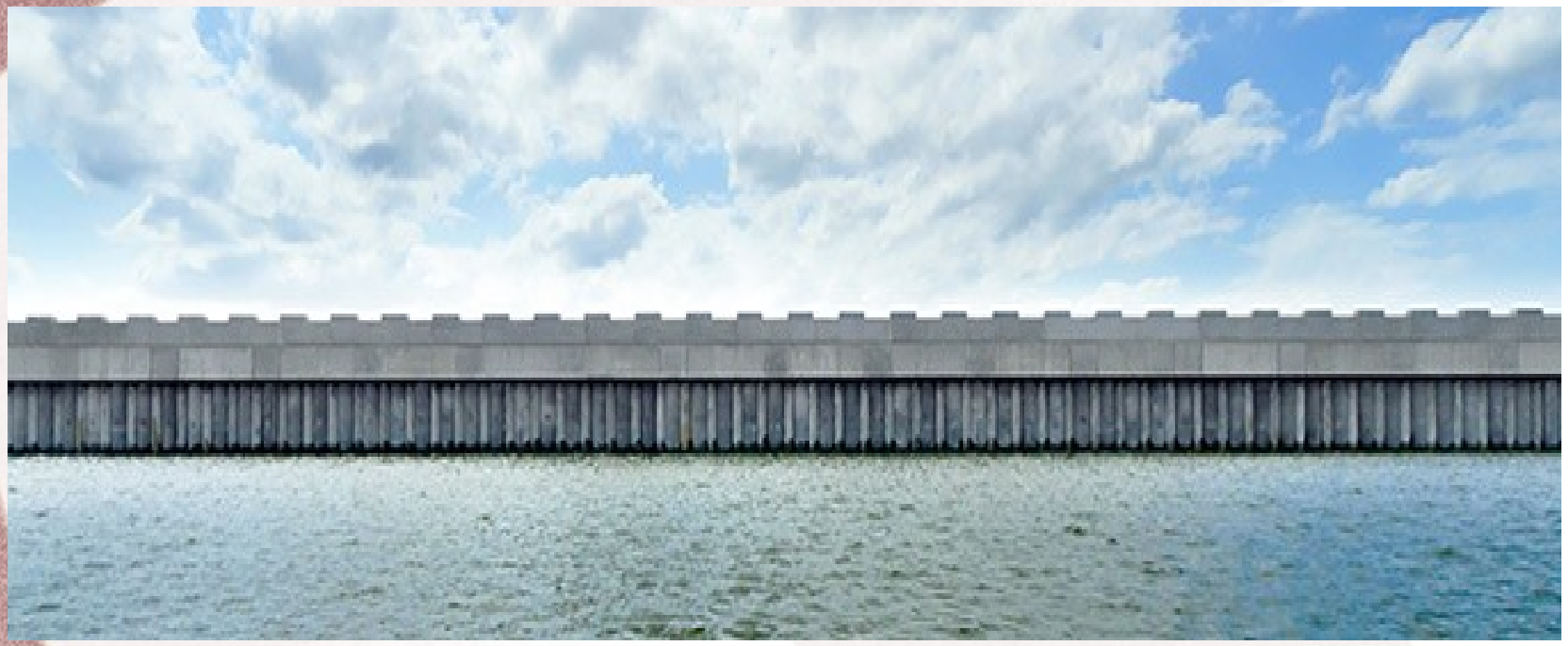




Intake No. 3 begun 2005;
now "nearly complete"

Sustainability?

2014



Inner Harbor Navigation Canal (IHNC) Surge Barrier Project
(replacing one that was destroyed in Hurricane Katrina)
26' high, designed for 100-year event

Sustainability?

2015

“Halley VI is packed with inventions, innovations, and technologies transferred from other industries, including a prefabricated integrated building envelope composed of 9-inch-thick closed-cell polyisocyanurate foam insulation to help to keep the extreme cold out; translucent glazing using nanogel technologies developed in the aerospace industry; and an aerodynamic design to improve snow management. The building is highly energy efficient and has a low environmental impact. All waste is treated for disposal or recycling on site, so that no physical waste whatsoever is left on the pristine Antarctic snowscape."

Sustainability?

Da Nang bridge, Vietnam

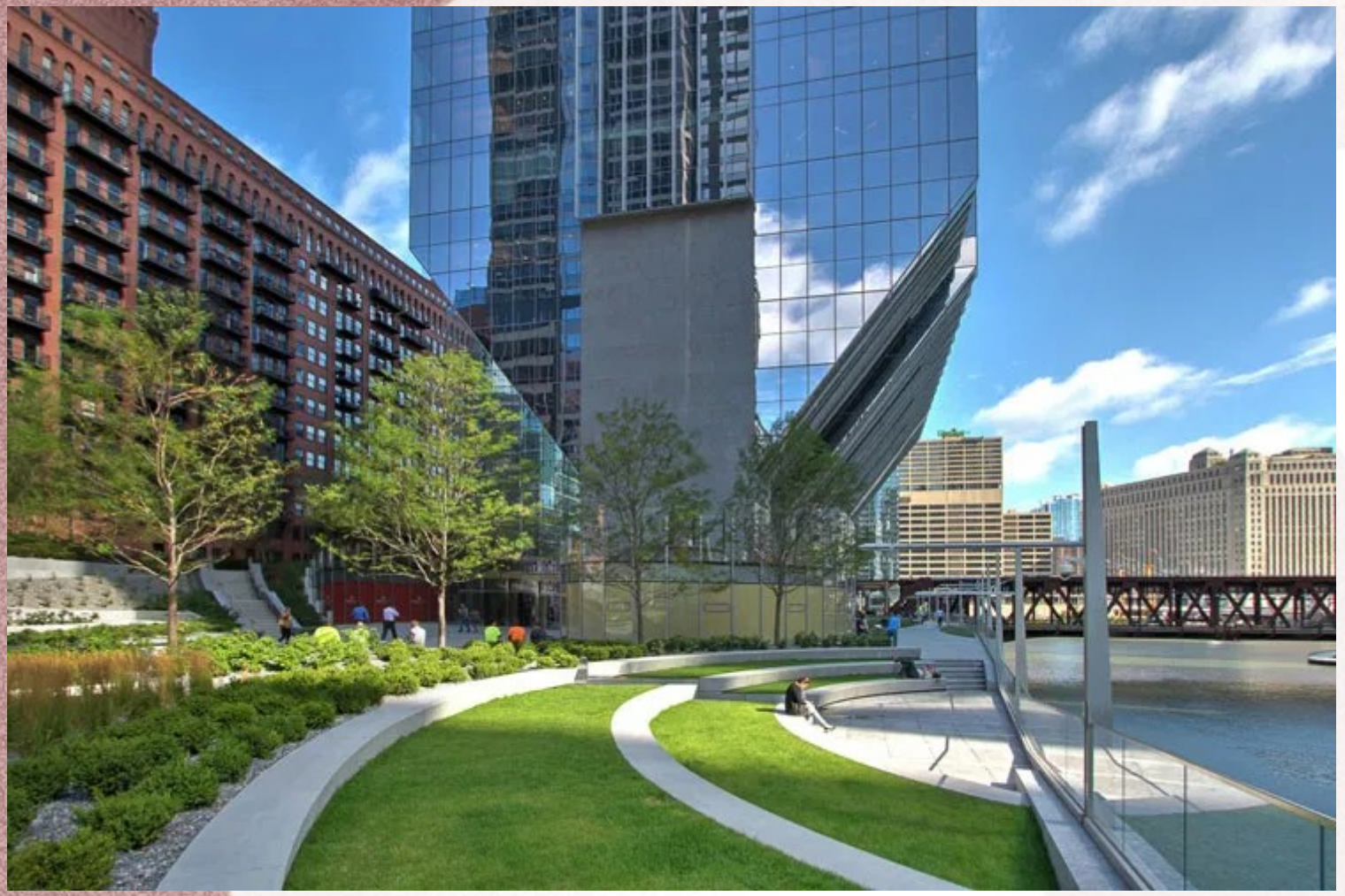
Sustainability?

2017

Emergency & Carryover Storage Project

“More than 80 percent of the water used by San Diego County residents and businesses travels hundreds of miles from Northern California and the Colorado River. Prolonged drought or earthquake damage could disrupt the delivery of imported water into the San Diego region."

Sustainability?



2019

a [narrow] 747-foot, LEED Gold Certified, 54-story office building on the Chicago Riverwalk

Sustainability?

2020

increased clearance allows larger post-Panamax vessels to travel beneath the bridge

Sustainability?

2022

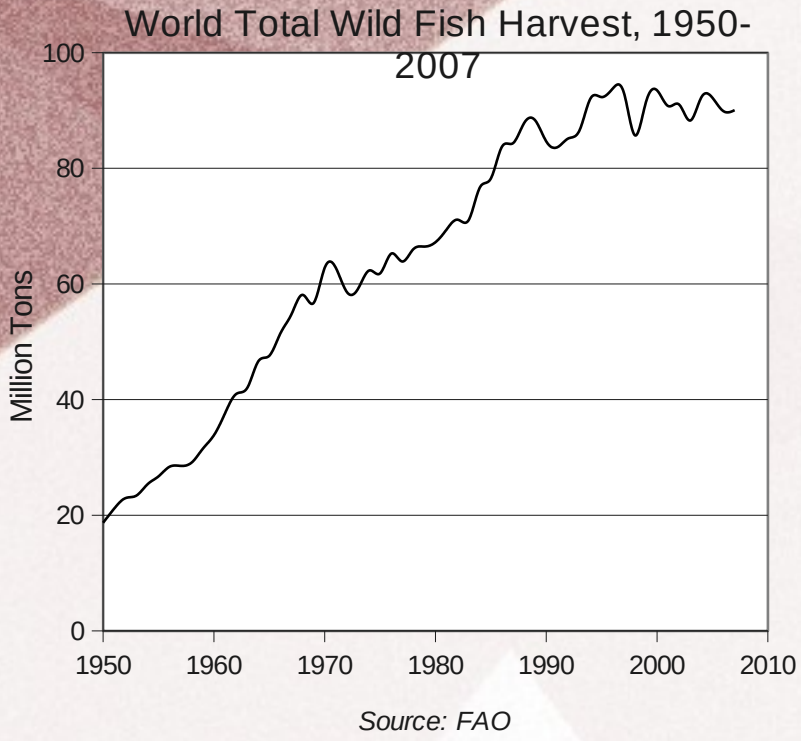
Office space, shopping, luxury apartments, underground parking

Prefab, modular composite steel-concrete shear wall reduced construction cost

Gold LEED

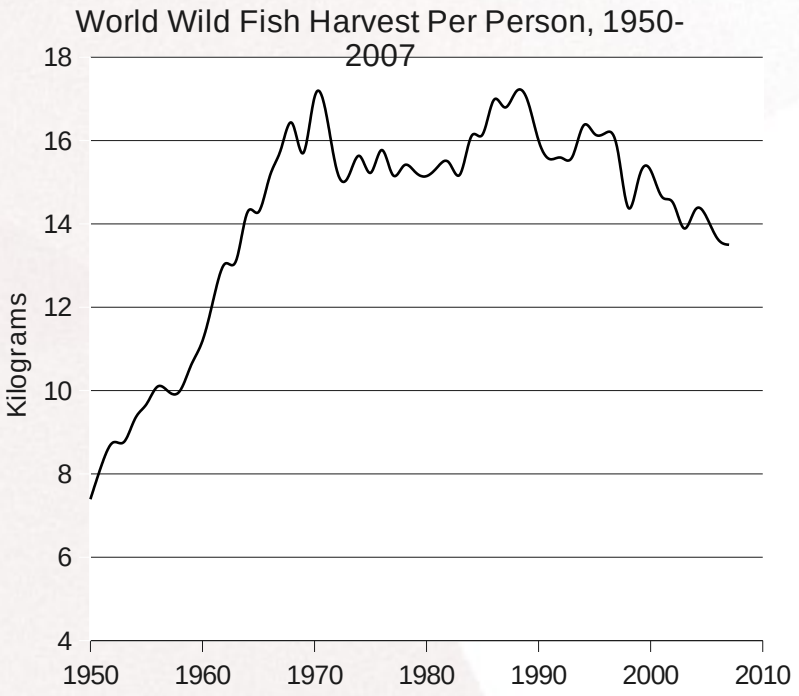
What are some manifestations of un*sustainability?*

Overfishing

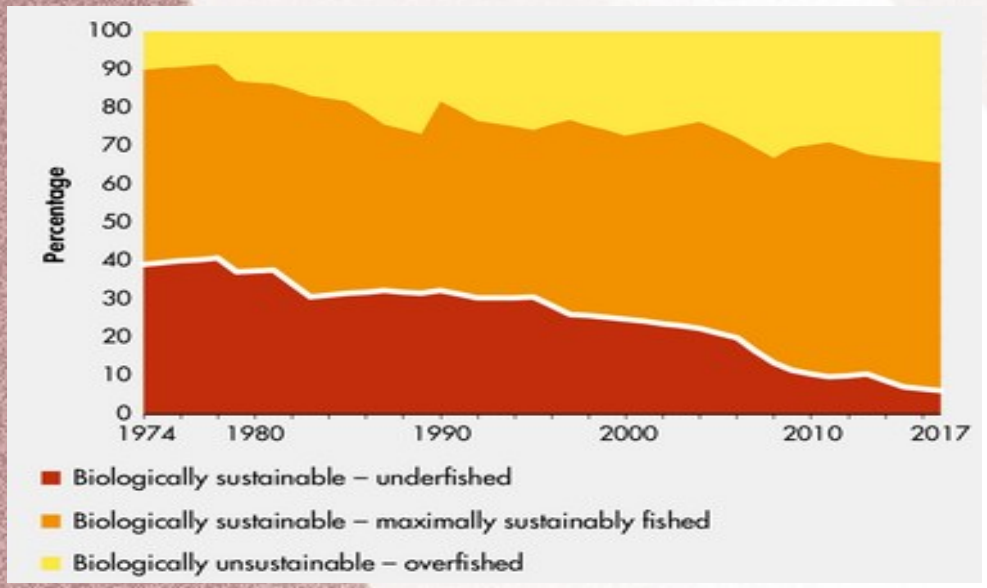


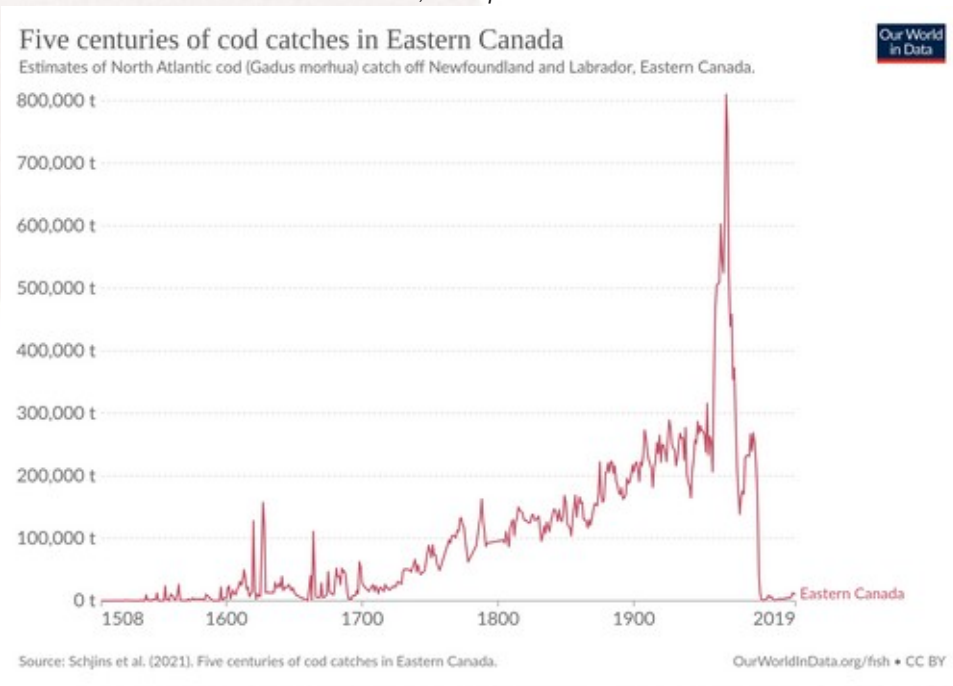
Source: FAO

peaked in 1996

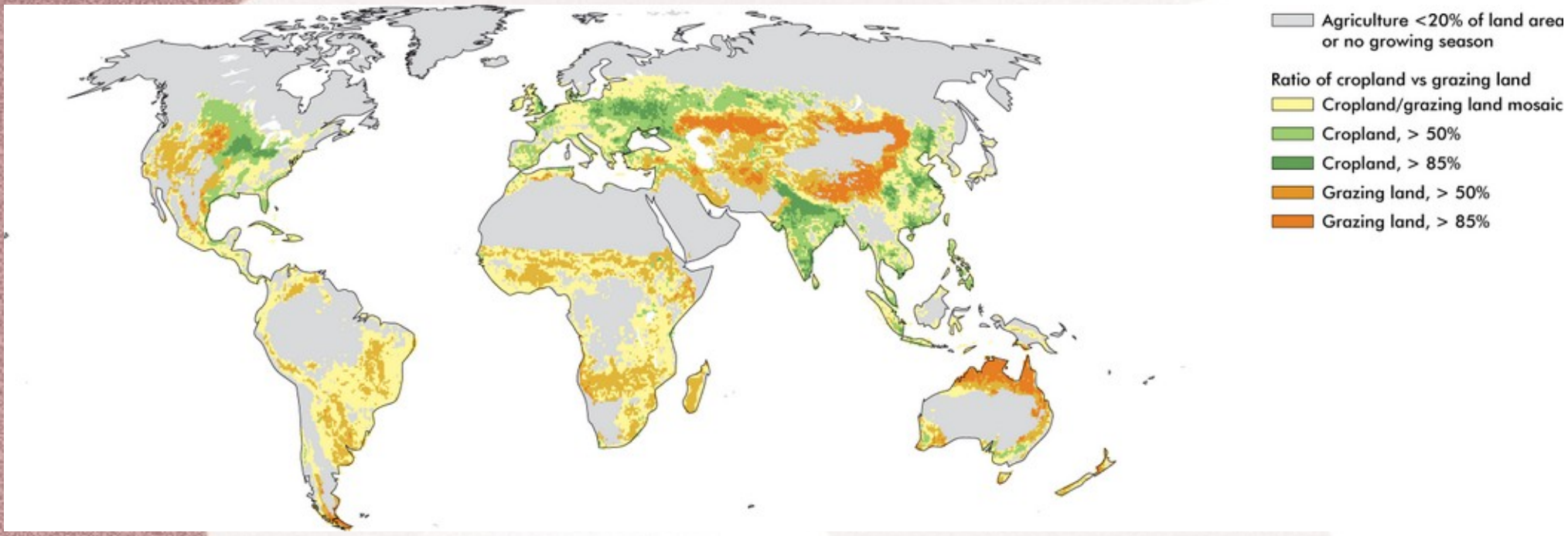


Source: FAO, UNPop

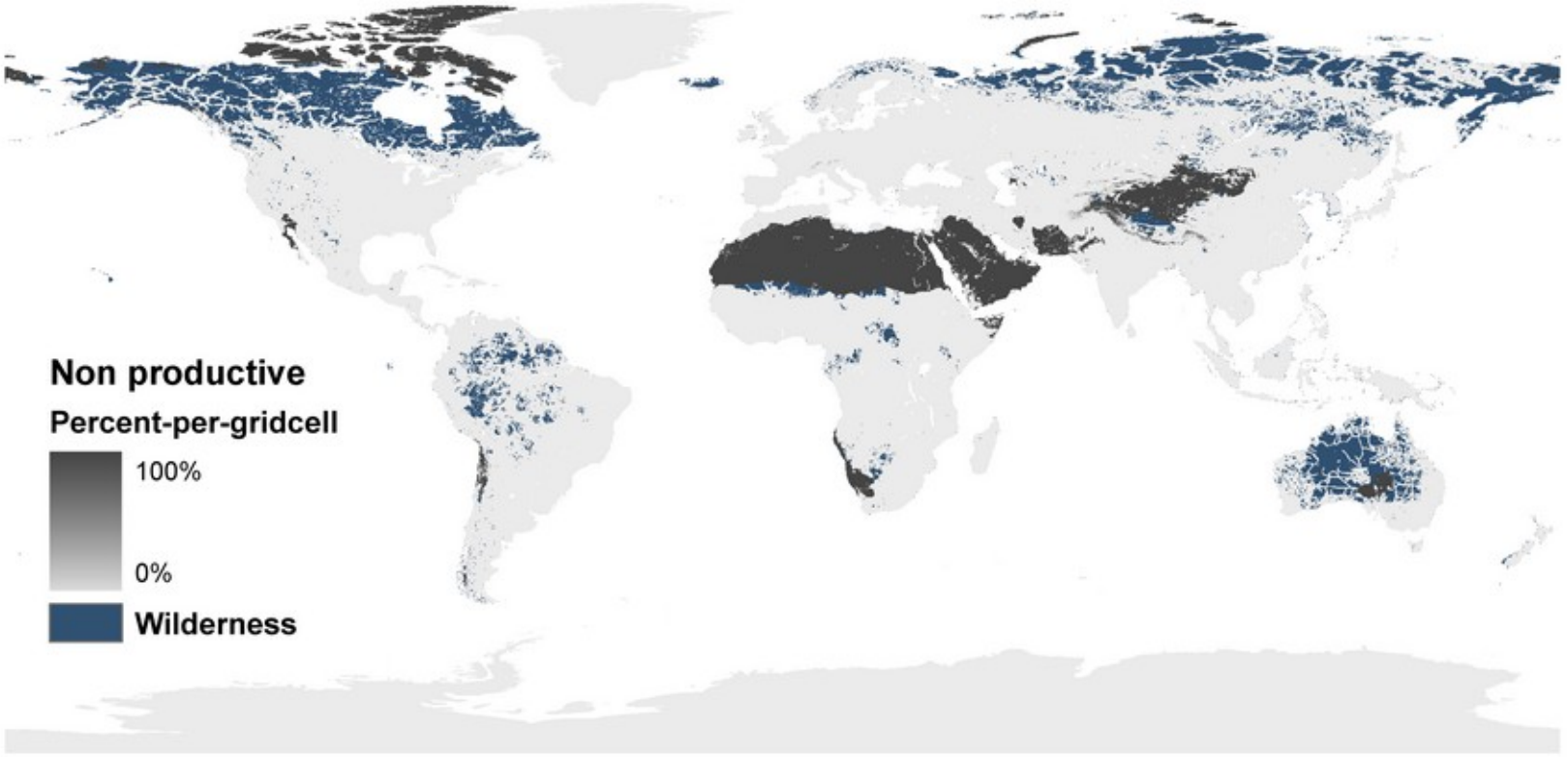




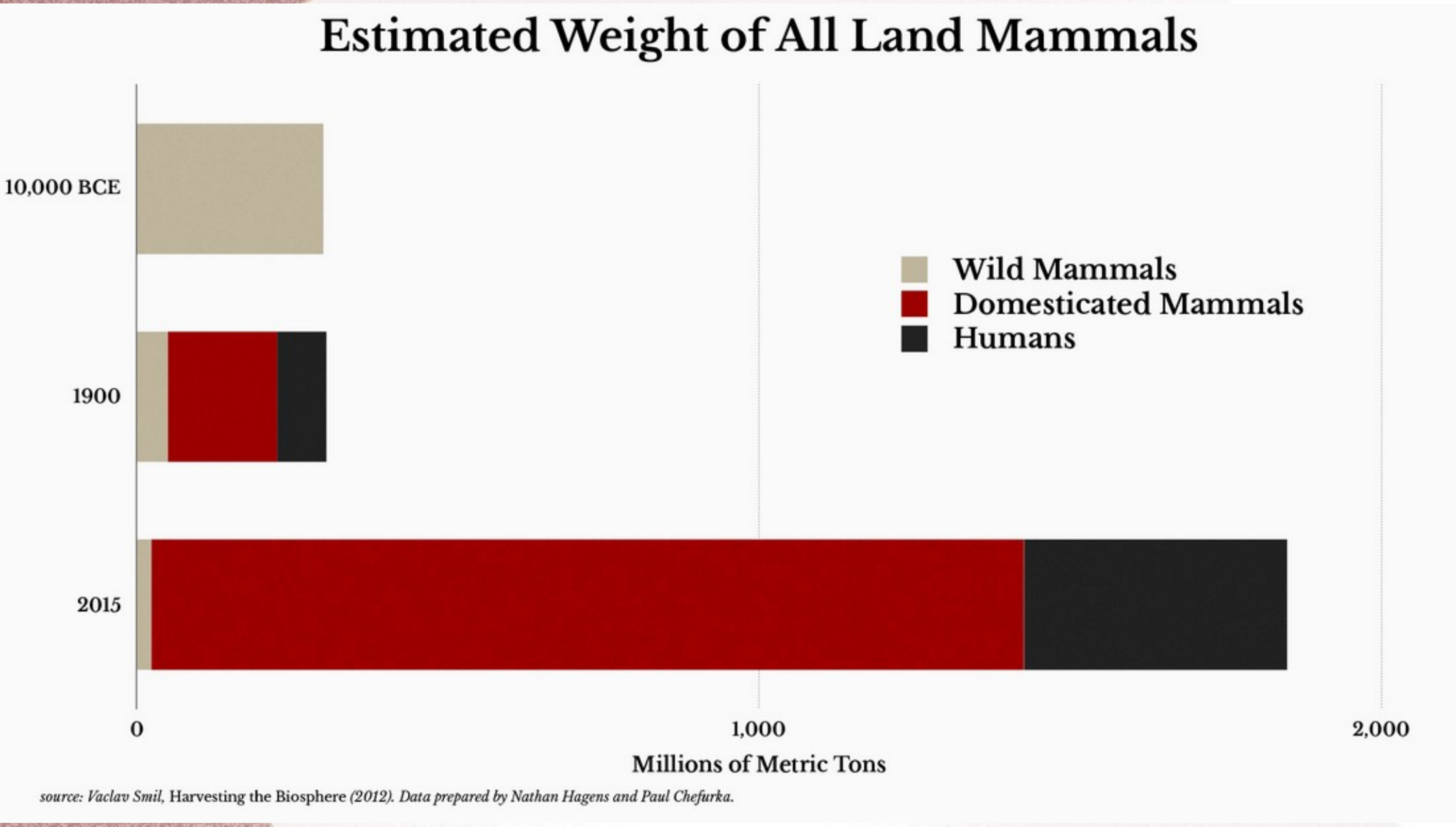
Land use change



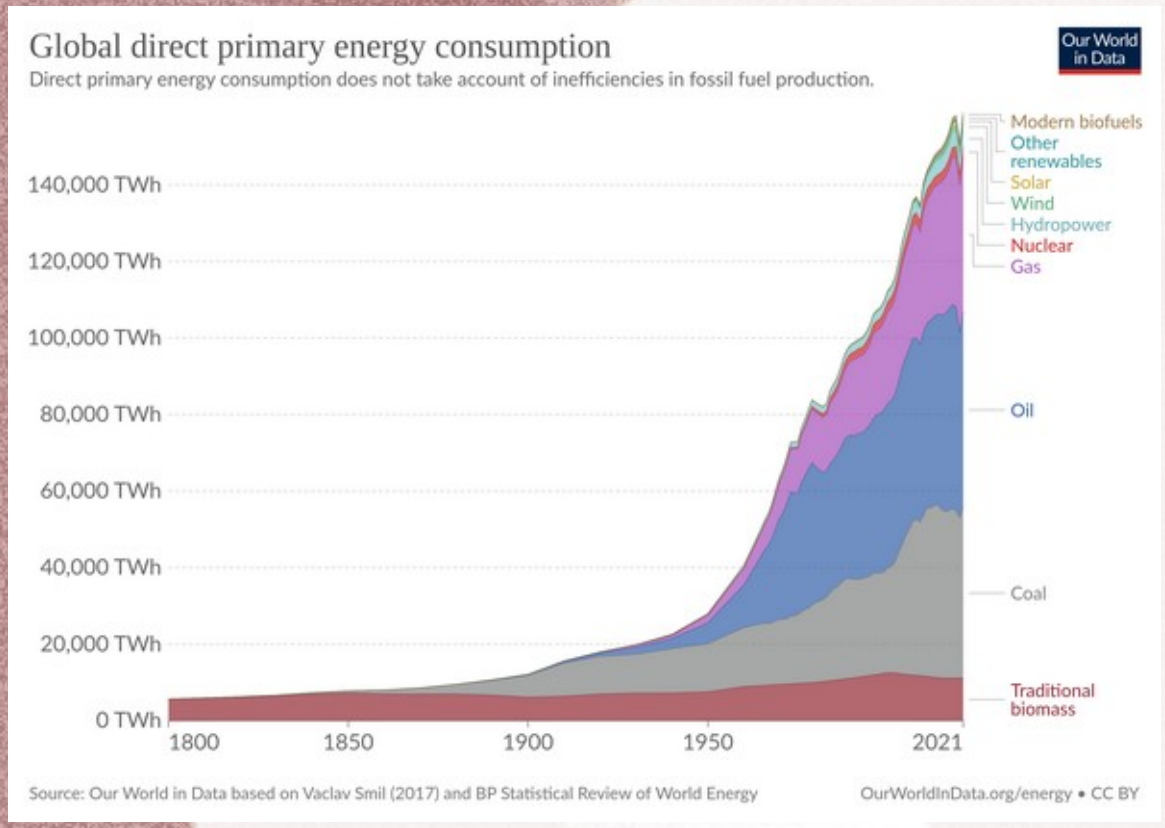
Land use change (II)

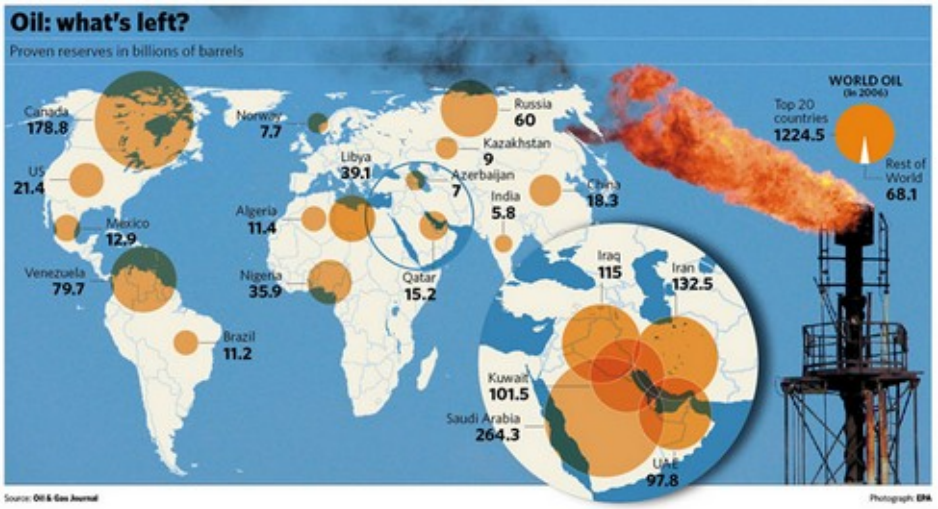


Loss of wildlife

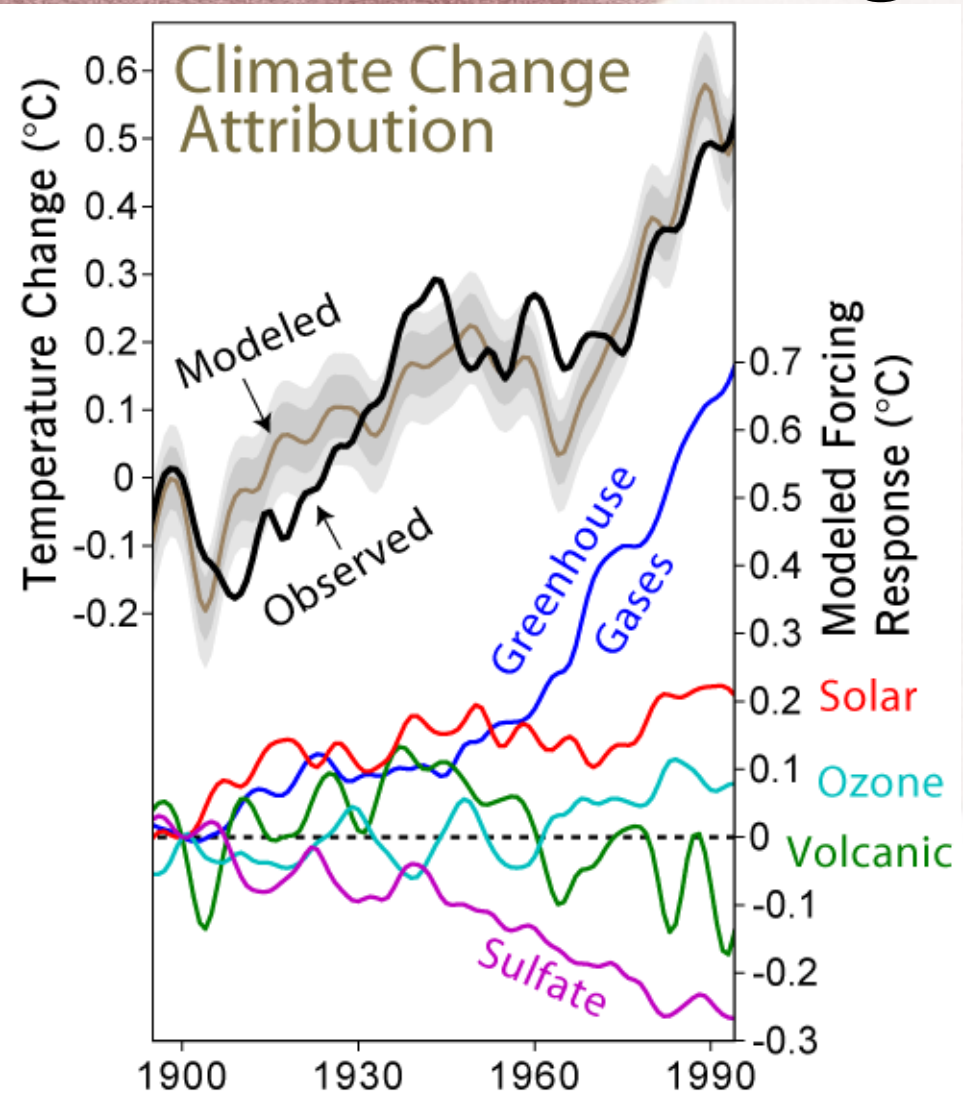


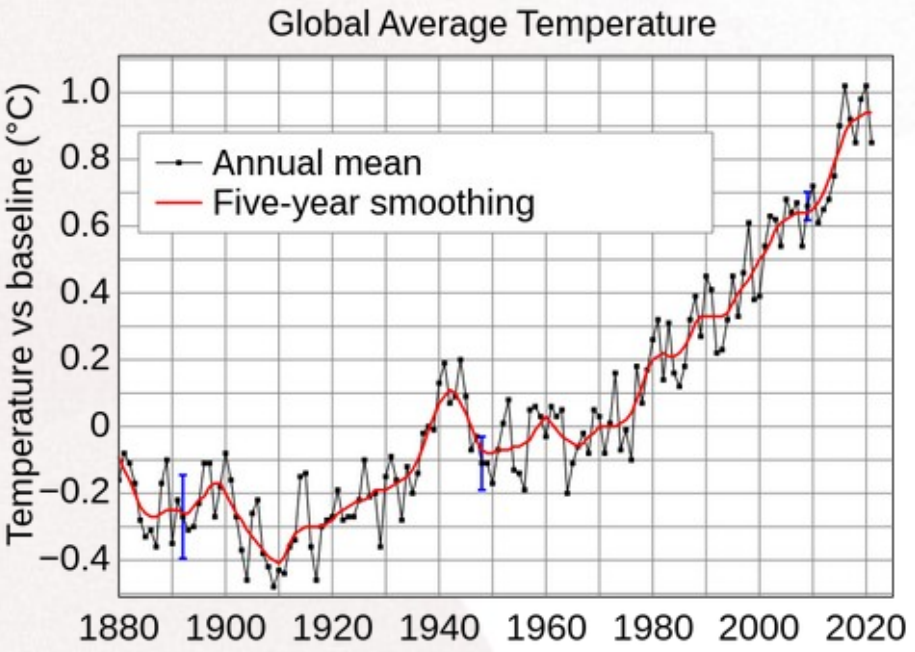
Fuel and electricity

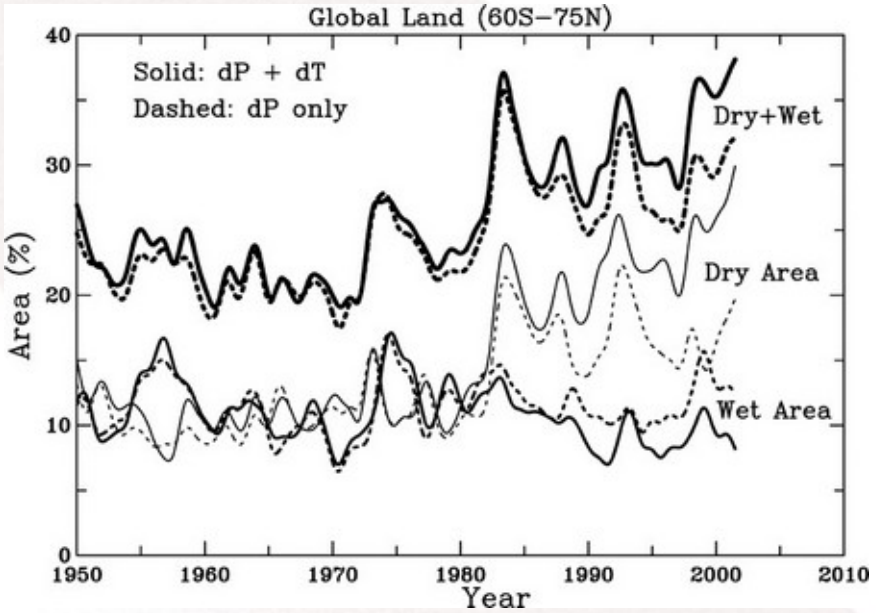




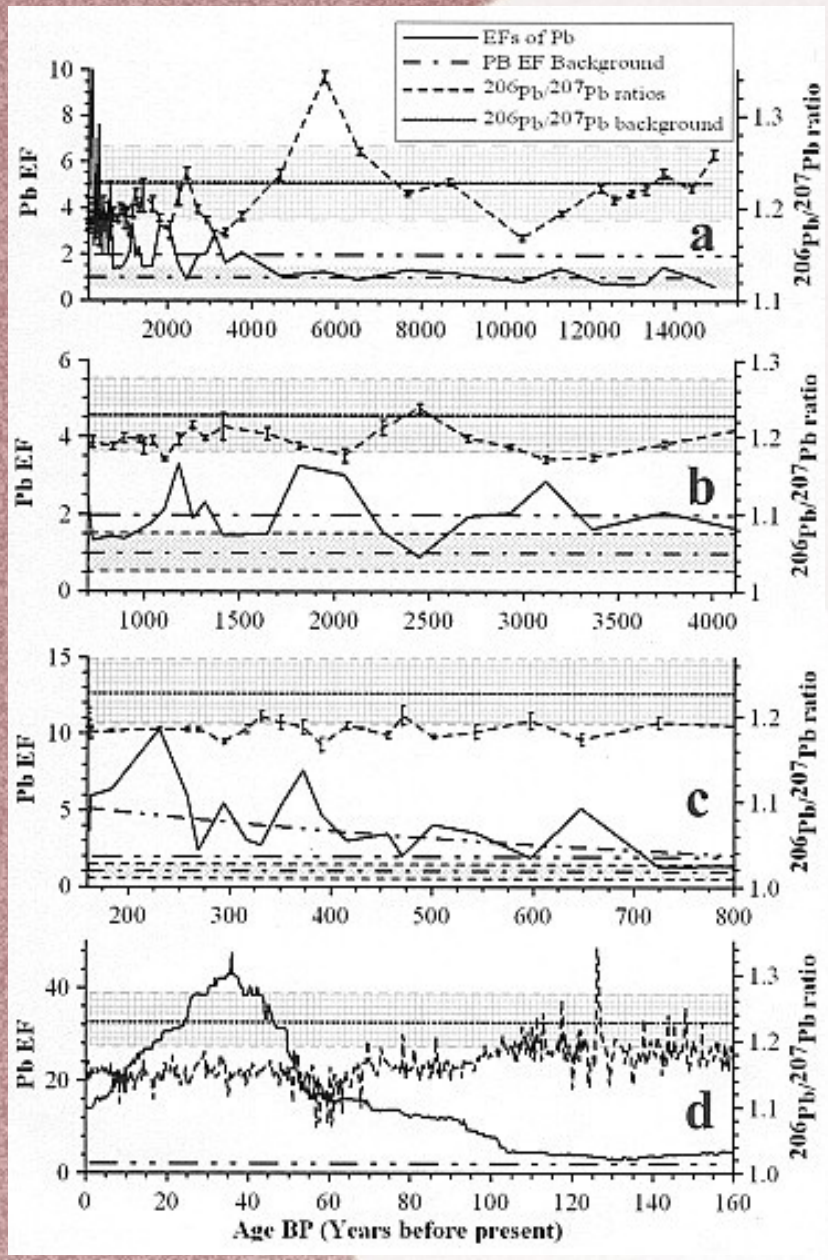
Global warming







Pollution by toxic metals and chemicals



"few areas on earth are now free of anthropogenic lead. The lead concentration in the most recent ice layers at the North Pole are 10- to 100-fold higher than the values in prehistoric times. Even at the South Pole, the rate of lead deposition is 2-5 times higher than in pre-technological times.

In this context, urban centers can be regarded as 'hot spots' for lead where levels exceed those of pre-technological times by several thousand-fold. As a result of world-wide accumulation, especially in urban centers, lead presents a more serious environmental and health hazard than does any other element. The smelting, use and toxicity of lead were already known in antiquity; but, the greatest changes in cycling occurred after the industrial revolution and especially after the introduction of leaded gasoline in 1923 because of the widespread distribution of these sources and the small dimensions of the particulates emitted.

Lead is especially toxic to children and the young of other species. A number of recent detailed studies aimed at assessing the health effects of chronic lead exposures in children have revealed significant effects on intelligence and on neuropsychological performance." (Jaworski et al. 1987)

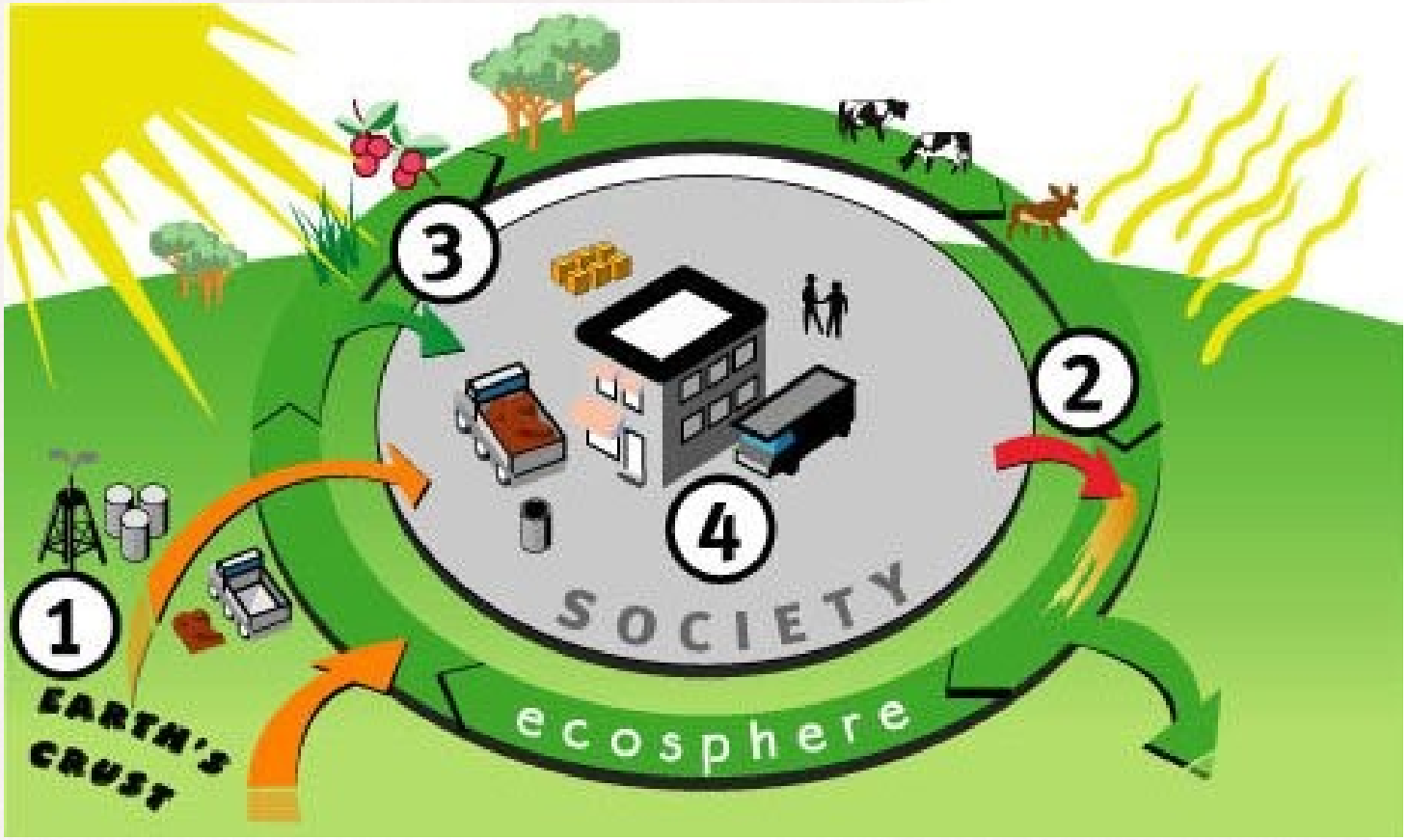
What would constitute sustainability?

What would constitute sustainability?

- A good starting point is given by the Natural Step:

  - *To become a sustainable society we must...*
  - *1. eliminate our contribution to the progressive buildup of substances extracted from the Earth's crust (for example, heavy metals and fossil fuels)*
  - *2. eliminate our contribution to the progressive buildup of chemicals and compounds produced by society (for example, dioxins, PCBs, and DDT)*
  - *3. eliminate our contribution to the progressive physical degradation and destruction of nature and natural processes (for example, over harvesting forests and paving over critical wildlife habitat); and*
  - *4. eliminate our contribution to conditions that undermine people's capacity to meet their basic human needs (for example, unsafe working conditions and not enough pay to live on).*

Natural Step's conditions



Why are these conditions not being attained now? How does engineering practice need to change?

- There are a number of useful quantitative measures of different aspects of sustainability that we'll touch on in this course (and that you might explore in more detail in your projects)
- For now, let's start by thinking about energy...

Energy in physics

- Motion or the ability to cause motion
- Defined so that the total amount stays the same (*conservation*; First Law of Thermodynamics)
- Many different forms
- Can be at least partly *converted* from form to form

Example energy forms and expressions

- Kinetic (or mechanical): $\frac{1}{2}mv^2$, $\frac{1}{2}I\omega^2$
- Gravitational potential: mgh
- Thermal: $3/2nkT$ (for an ideal gas)
- Chemical potential: $\Sigma_i \mu_i N_i$
- Electrostatic potential: $q_1 q_2/(4\pi\varepsilon_0 r)$
- Blackbody radiation: $\sigma T^4 \cdot A\Delta t$
- Nuclear potential: $c^2\Delta m$

Energy and us

- People only need around 8 MJ (2000 kcal) per day (100 W) chemical energy from eating plants and animals and breathing oxygen (somatic energy) to
  - Grow into adulthood
  - Maintain and replenish body structures
  - Maintain body temperature and chemistry
  - Carry out activities like walking and talking

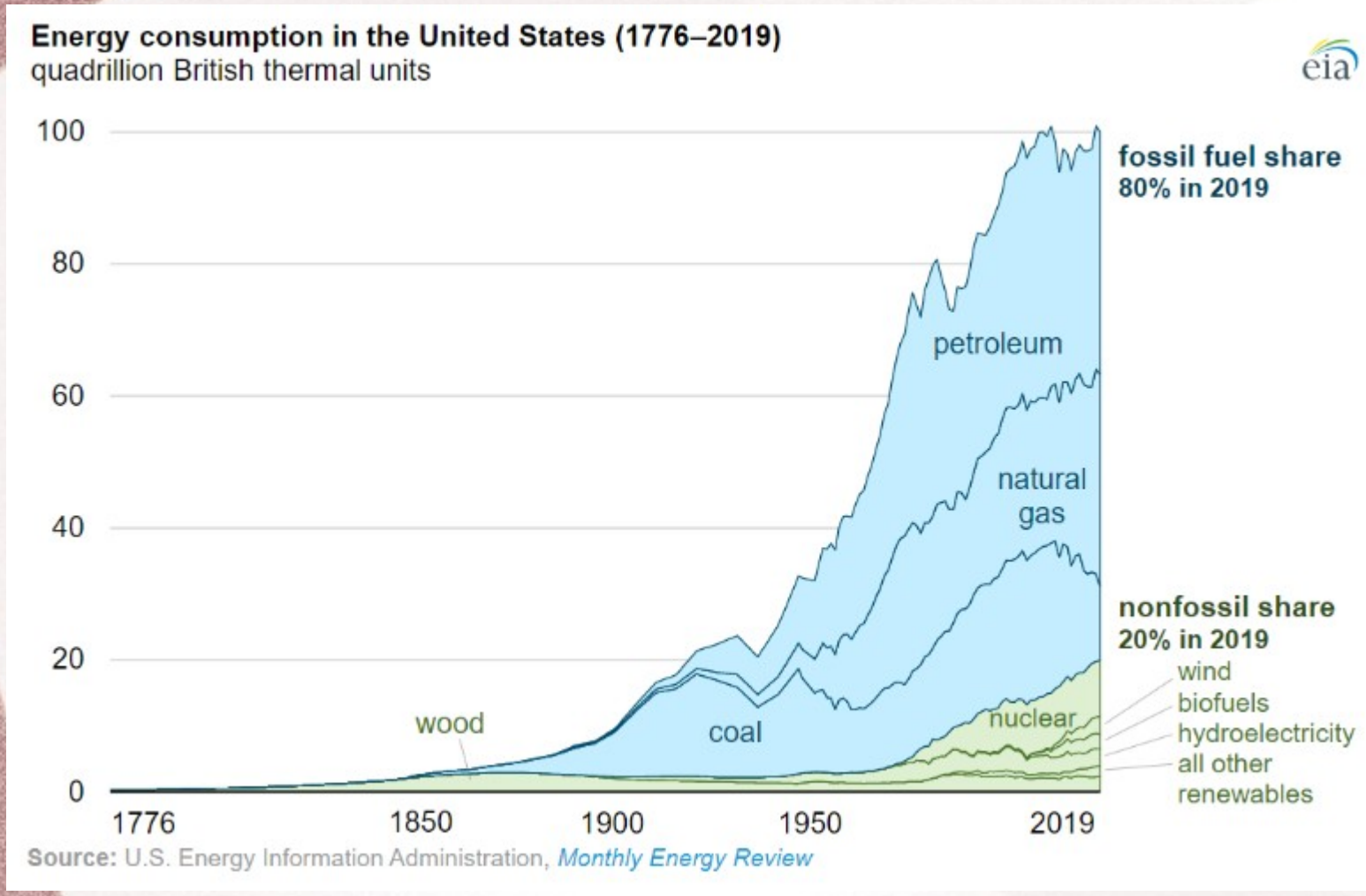
Energy and preindustrial technology

- In preindustrial societies, people also converted energy through extrasomatic channels:
  - Fire was used to hunt, clear land, keep warm, cook, smelt metal
  - The somatic energy of draft animals was used to carry loads and plow
  - Flowing water and wind were used to mill grain and operate machinary
- Overall use of high-quality energy was on the order of 500 W/person

Energy recently

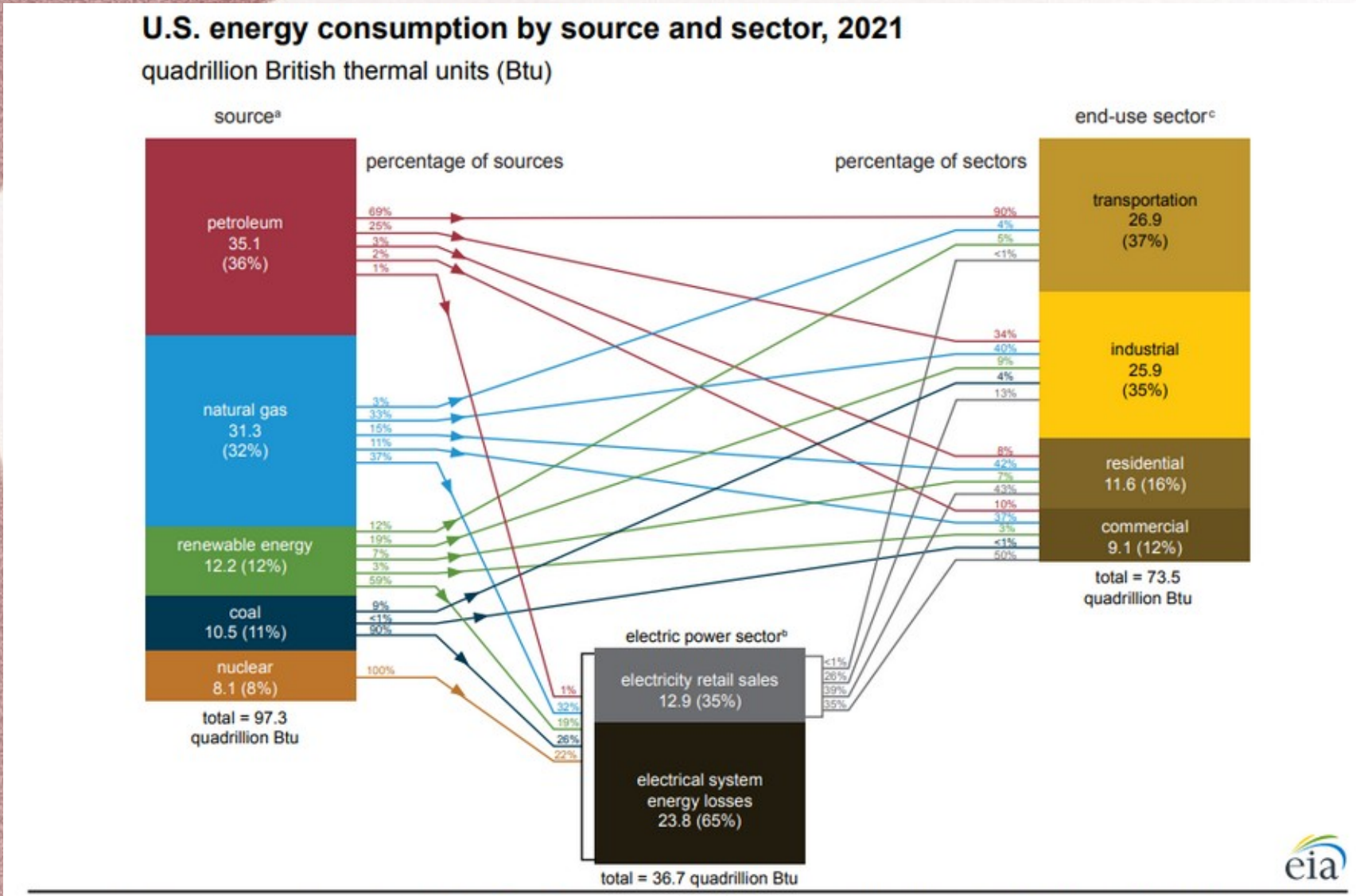
- In the last 200 years, people have been burning fossil fuels (chemical energy derived from ancient plants) at an ever-increasing pace
- Currently, world energy use is near 0.02 PW (2500 W/person), concentrated in wealthy countries
  - 11 kW/person in USA
  - Many/most people are still near preindustrial levels
  - ~90% fossil fuels
  - Population has also increased by a factor of 7

Energy sources over time (USA)



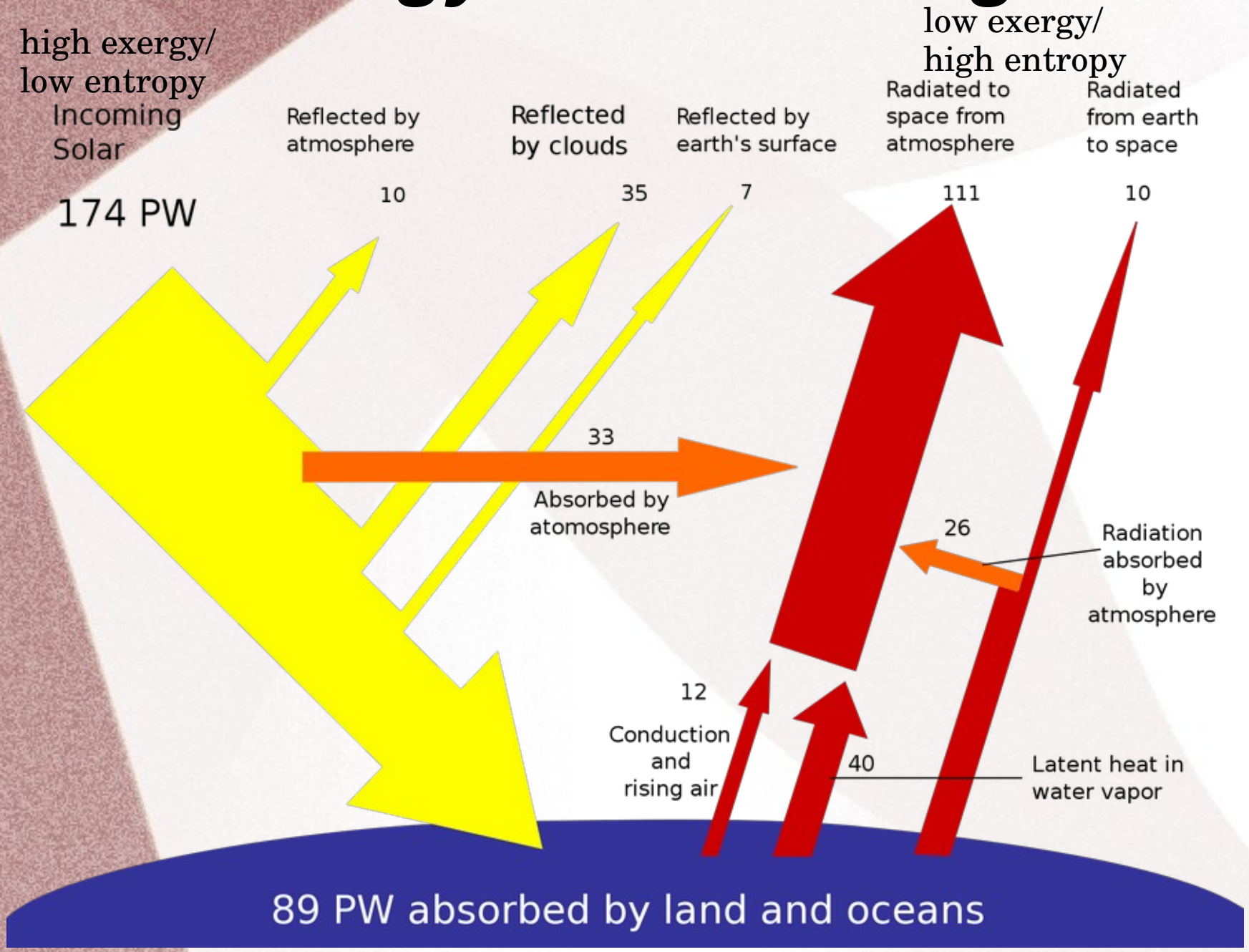
Notice the changes over the last 100 and 10 years

Where is the energy going?



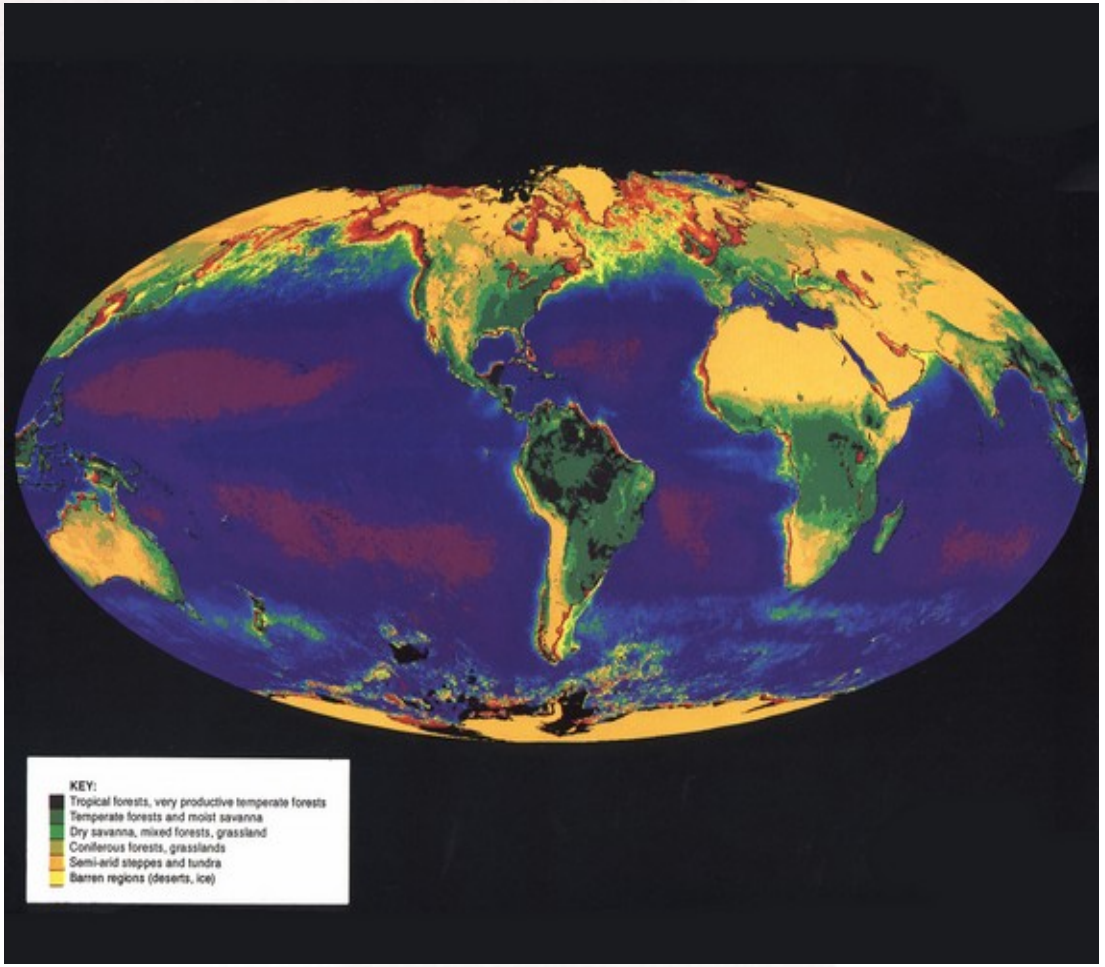
Energy sources are not freely interchangeable

Energy flows through Earth



Converting sunlight to other useful forms

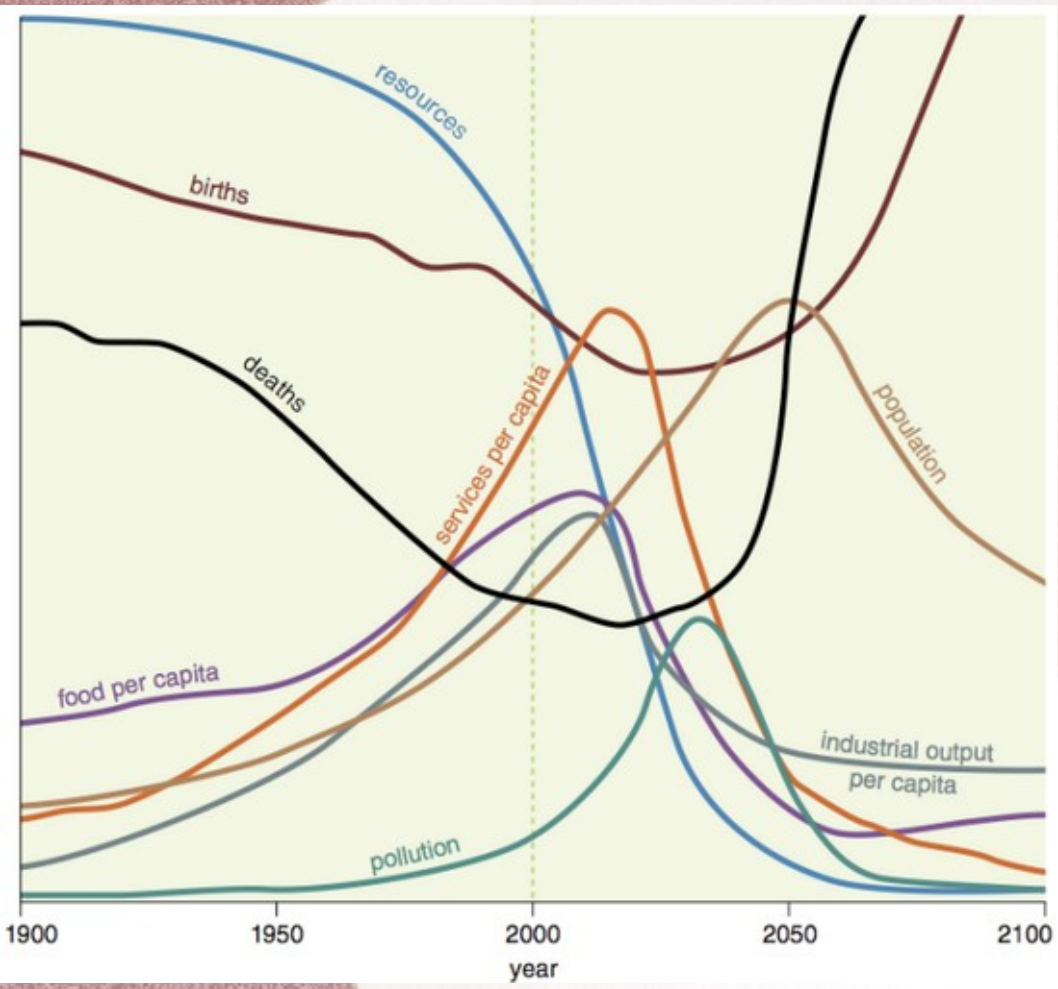
- Plants do this! Photosynthesis generates ~0.1 PW chemical energy (~0.1% of incoming sunlight)
- Fossil fuels are from past photosynthesis
- We can convert sunlight with higher efficiency (e.g. ~10% with photovoltaics), but with expensive apparatus



Energy-related problems

- The amount of fossil fuels is limited; many deposits have been exhausted and remaining ones are the more difficult to extract
- Greenhouse gas emissions from fossil fuel burning and other industrial processes are heating the earth with not fully known but dangerous consequences
- Dumping of fossil energy and industrial waste is ruining many natural stocks (soil, clean freshwater, oceans), especially those that depend on delicate interactions between many species (interactions with *ecology* – more later)

If these problems are not solved, the ecological / industrial human system may break down



"The World3 model was a computer simulation of interactions between population, industrial growth, food production and limits in the ecosystems of the Earth. It was originally produced and used by a Club of Rome study that produced the model and the book *The Limits to Growth*. The principal creators of the model were Donella Meadows, Dennis Meadows, and Jørgen Randers.

The "reference run" is the one that the authors state "represent the most likely behavior mode of the system if the process of industrialization in the future proceeds in a way very similar to its progress in the past, and if technologies and value changes that have already been institutionalized continue to evolve." In this scenario, in 2000, the world population reaches 6 billion, and then goes on to peak at 7 billion in 2030. After that population declines because of an increased death rate. In 2015, both industrial output per capita and food per capita peak ... The persistent pollution peaks in the year 2035 at 11 times 1970s levels."

Cf. Jared Diamond, *Collapse*

Optimism/pessimism

- People are better off than ever before (trends)
- Previous worries often haven't materialized
- Faith in markets
- Adaptability
- Dematerialization
- Computers

- Overshoot in natural systems
- Previous societies have collapsed
- Extinctions and loss of biocapacity
- Fragility
- Inequality and disconnects

Related to pro- vs. anti- economic growth

In this course, we won't focus on the debate, so much as on what engineering can do

What sort of design approaches could help?

- Require *less* high-quality energy, by
  - Dropping energy uses of marginal benefit to people (conservation/thrift)
  - Greater exergy efficiency (e.g. heat pumps vs. combustion heating)
- Replace fossil fuels with *renewable* sources of high-quality energy (drawing on incoming sunlight)
- Respect life forms by
  - Reconfiguring manufacturing, building, agriculture... to eliminate toxic elements and chemicals
  - Minimizing disruption of existing rich ecosystems