GEOS 24705 / ENST 24705 / ENSC 21100

2018

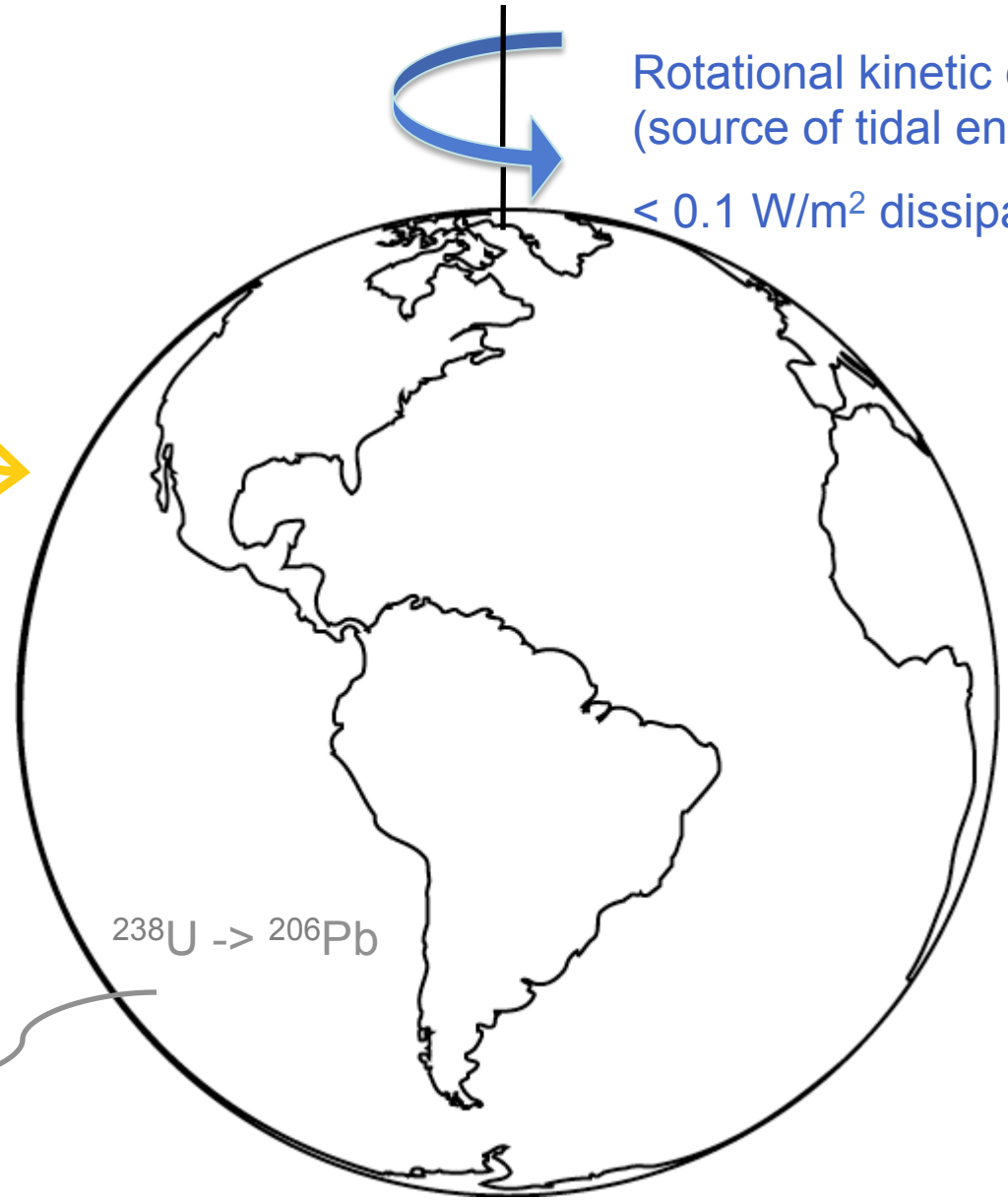
Lecture 4

Are the Earth's energy flows enough?

Comparing Earth's primary energy flows

Solar radiation
(nuclear fusion in sun)

200 W/m^2 at ground



Rotational kinetic energy
(source of tidal energy)

< 0.1 W/m^2 dissipation

Geothermal heat:
nuclear fission of
radiogenic elements
+ residual heat
< 0.1 W/m^2

Comparing Earth's primary energy flows

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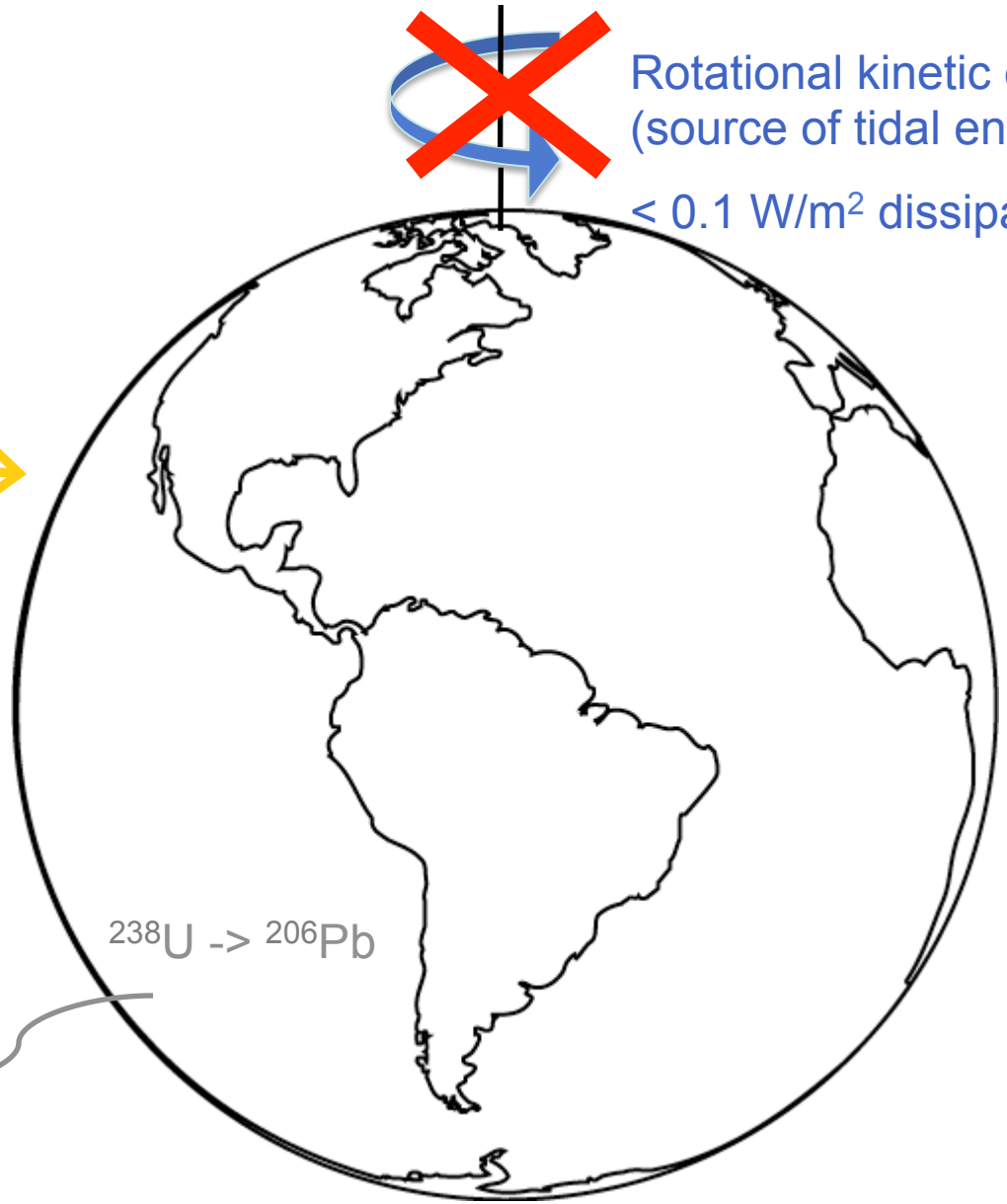

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Energy from plants: food (not biofuel)

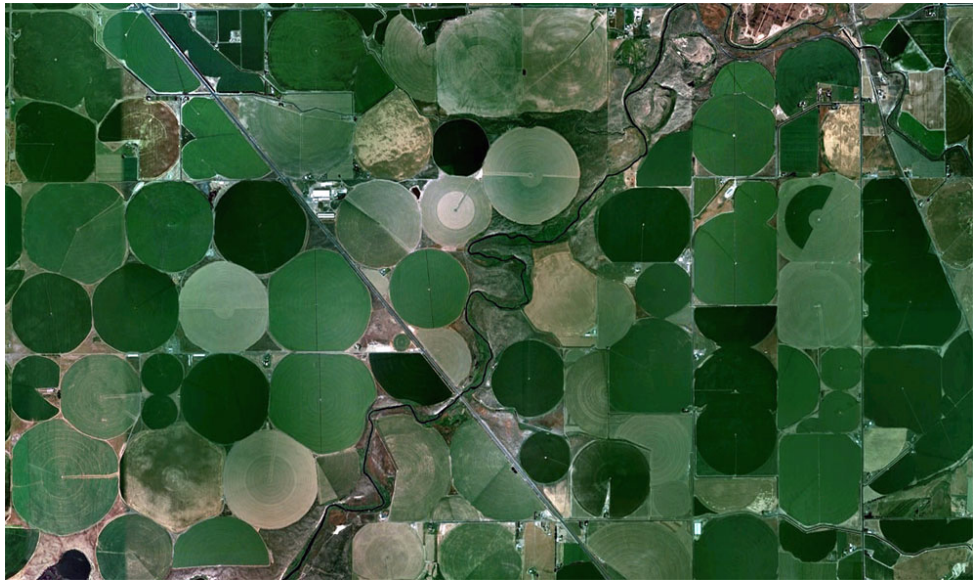
Humans dominate the Earth's surface

Fractional use of:

Earth's land surface area used for food *(farm + pasture)*	~ 38%
Land NPP appropriated	~ 30%

Farmland, Longsheng, China *(Flickr)*

Farmland, Oklahoma *(OK Farm Report)*



Farmland, Washington *(Google)*

DRC has vast stretches of unfarmed land

43,000 m^2/person
potentially arable

2,500 m^2/person
actually farmed

Rwanda is intensely farmed

1,200 m^2/person arable

top: valley near Lake Kivu
bottom: hills near Lake Kivu

Rwanda is intensely farmed

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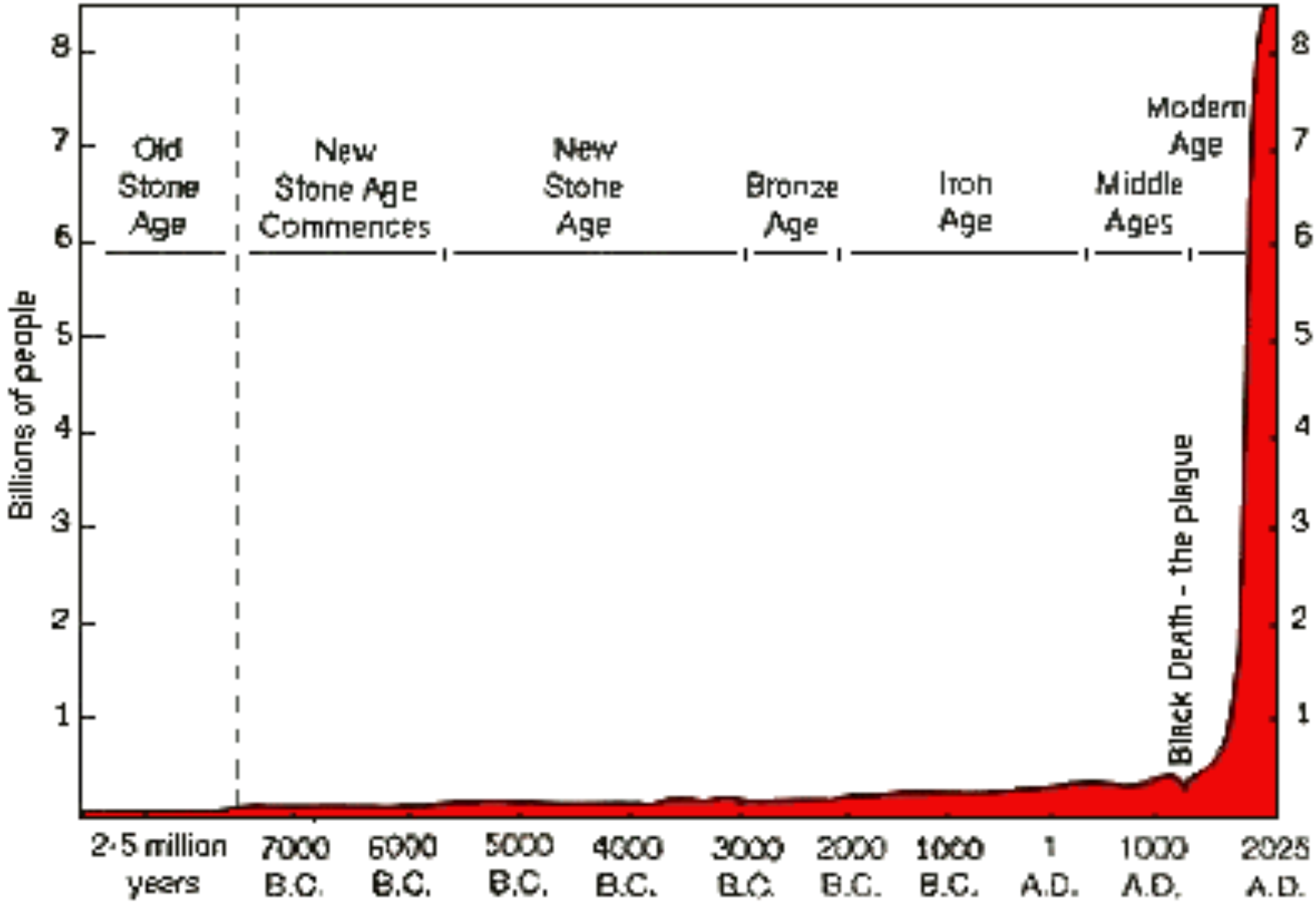
top: valley near Lake Kivu

Why does land appear limiting *exactly* now?

Are we suddenly nearing a fatal threshold?

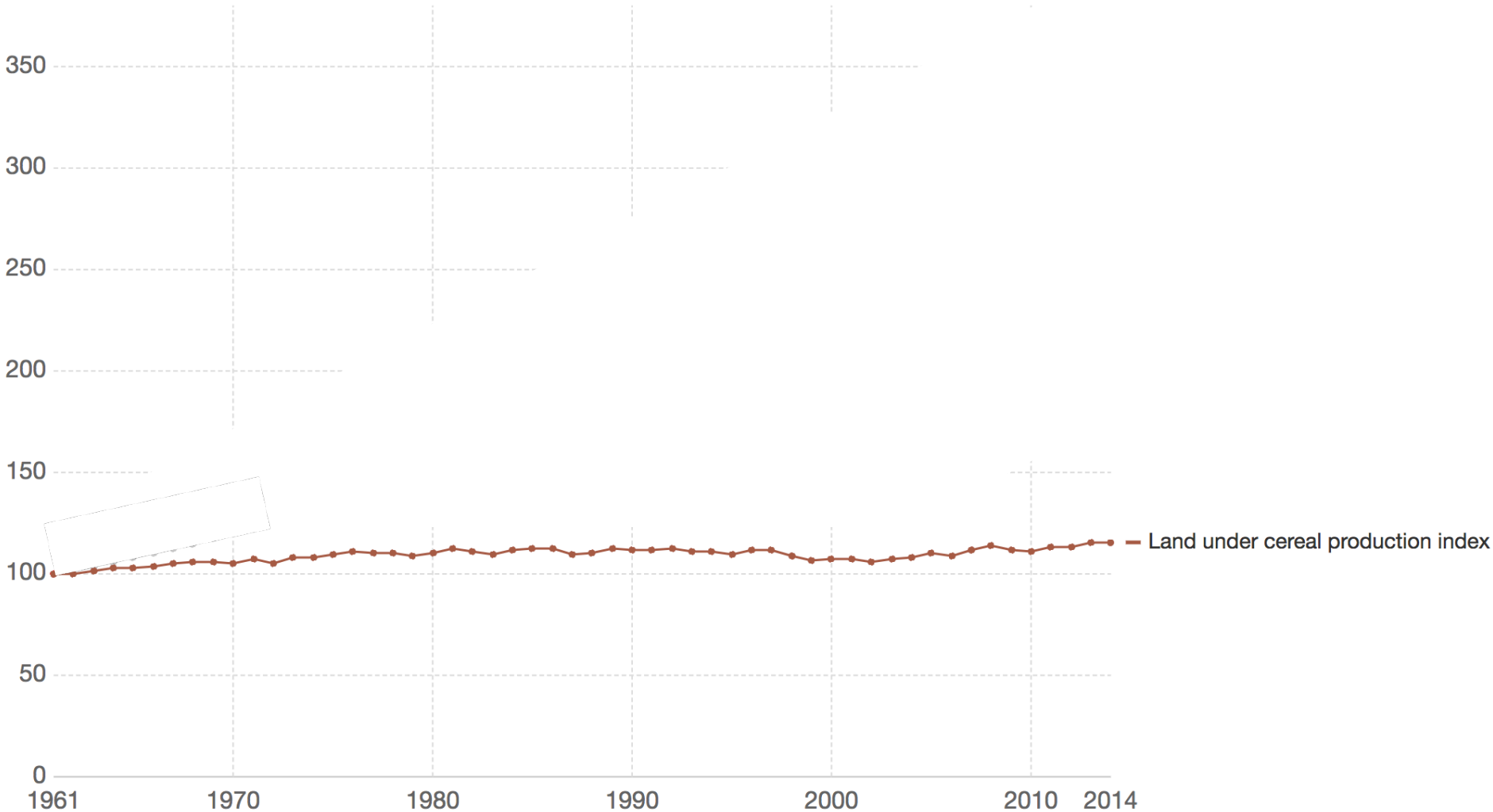
population has more than doubled since 1960



How is this possible?

Index of cereal production, yield and land use, 1961-2014, World

The index of total cereal production (measured in metric tonnes), cereal yield (kilograms per hectare), and land used for cereal production (hectares). The index is calculated as the production, yield and land use in any given year divided by that in the year 1961 (i.e. 1961 = 100). The index of total population (all ages and genders) relative to 1961 is also shown. Trends for individual countries can be viewed using the "change country" wheel.



Source: OWID based on World Bank, World Development Indicators (WDI)

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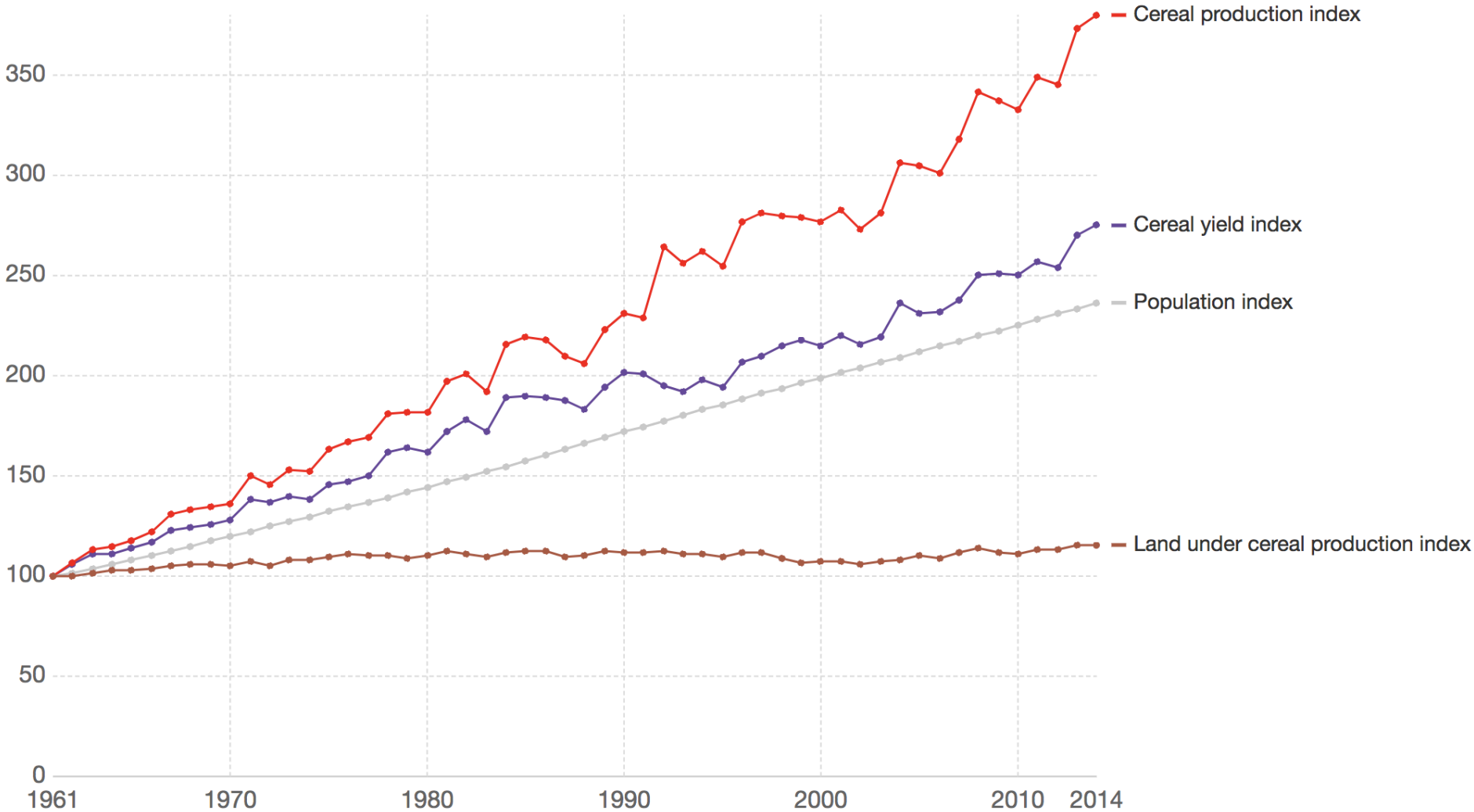


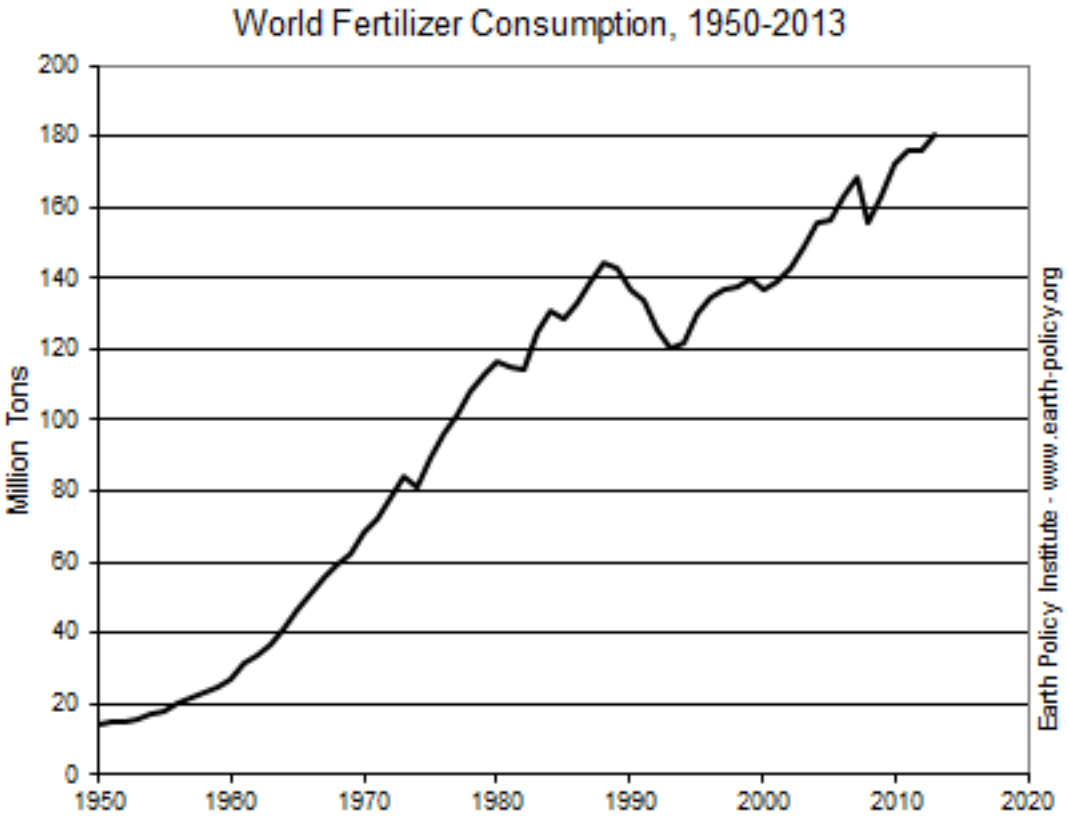
Source: OWID based on World Bank, World Development Indicators (WDI)

Green Revolution: 3x yield increase

Saved world from starving

Norman Borlaug, 1914-2009
born Iowa, college U. Minn.
Nobel Peace Prize 1970

Image: Associated Press, 1970



Yields go with fertilizer use
world fertilizer use quadruples
during Green Revolution

Image: U.N. FAO

Green Revolution: 3x yield increase

Prevented hunger, but at cost in $ and energy

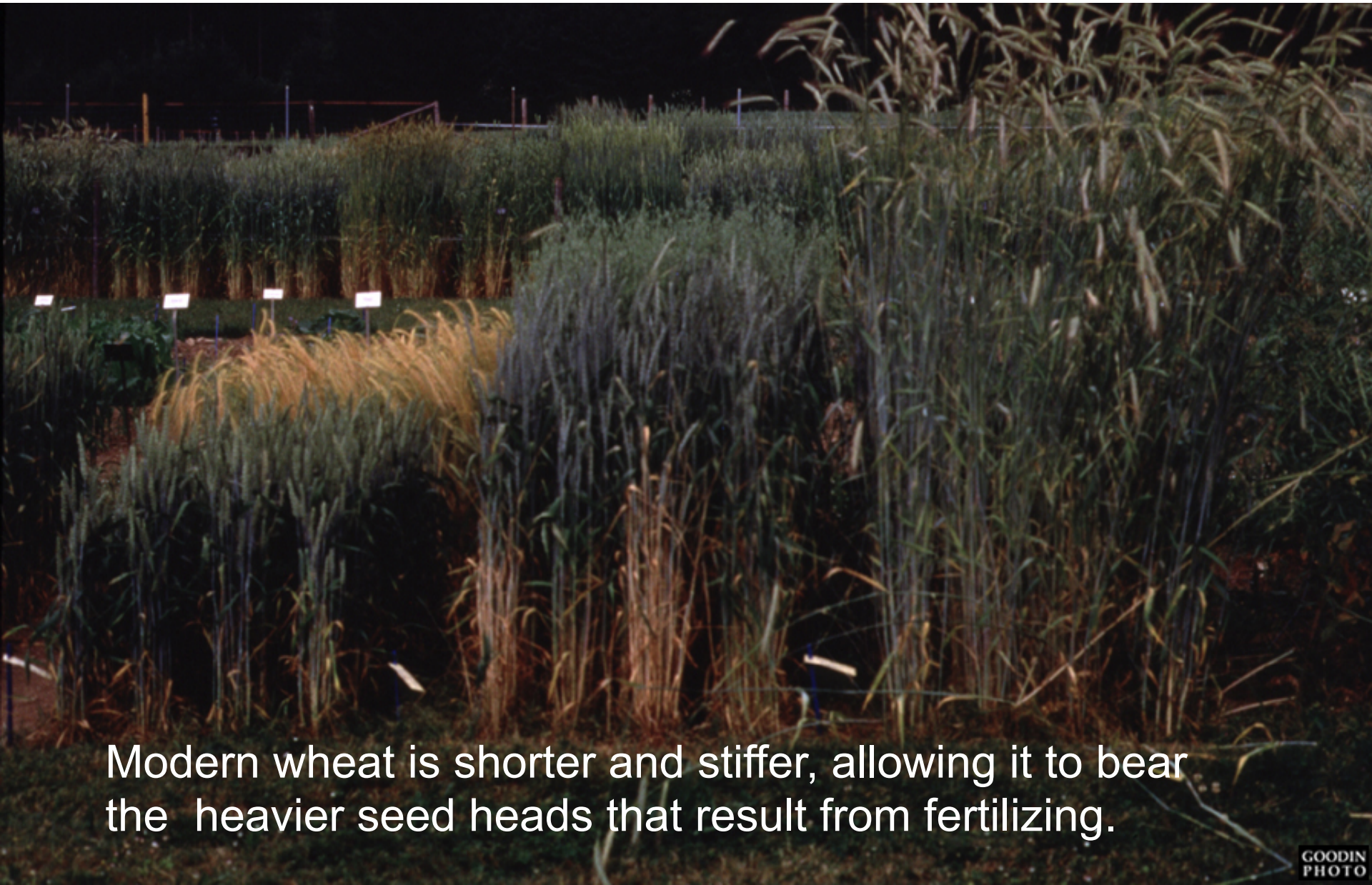
Norman Borlaug, 1914-2009
born Iowa, college U. Minn.
Nobel Peace Prize 1970

Image: Associated Press, 1970

Fertilizer plant
ammonia and urea production

Image: Hyosung Power & Industrial Systems

Modern vs. ancient wheat



Modern wheat is shorter and stiffer, allowing it to bear the heavier seed heads that result from fertilizing.

Photosynthetic efficiencies and energy flows

photosynthetic	ε_{photo}	W/m^2
Rainforest	1%	2
Good farmland, fert. corn	1%	2
Good farmland, ave.	0.5%	1
Land mean	~0.2%	0.4
World mean ε_{photo}	~0.1%	0.2

food	ε_{food}	W/m^2
U.S. fertilized corn	~0.3%	0.5
World ave., all cereal	~0.1%	0.2
Pre-modern	~0.015%	0.03 (10 times worse)

Sources: various internet, unverified. Pre-modern efficiency from Grigg, `Population Growth and Agrarian Change - an Historical Perspective', estimate of ca. 1200 AD British yield of ~700 kg/ha = 125 W/acre. Fertilized efficiency calculated from figures from the Iowa Corn Growers association, 183 bushels/acre -> 10,000 kg/ha or 1700 W/acre. Stover fraction from Iowa State Univ. Extension Fact Sheet BL-112. World average efficiency from USDA estimates from 2010. (Note that wheat is less than corn)

Yield increases still matter...

NATIONAL CORN GROWERS ASSOCIATION

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2017 Winners Announced!

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“Fixed” nitrogen is a limited resource in nature

Nitrogen is fundamental to life:

Required in all amino acids (proteins), most ecosystems N-limited
Hard to “fix” nitrogen because N_2 triple bond so stable (N≡N)
Breaking that bond takes energy

Bacteria-mediated N fixation

$$N_2 + 6\,H^+ + 6\,e^- \rightarrow 2\,NH_3$$

happens in root nodules of certain plants, including:

- Soybeans, peanuts, peas,
- Clover, lupines

Photo: W. Eberhart, Getty Images

N also fundamental to explosives

Violent reaction as fixed nitrogen goes back to N_2

Most explosives are N based

nitroglycerin, gunpowder, dynamite, C4 (mostly nitroamines), ammonium nitrate fertilizer

The drive for "nitrogen independence"

In 1913, Chile is the world's largest producer of fixed nitrogen … from guano. Nitrogen seen as critical national priority.

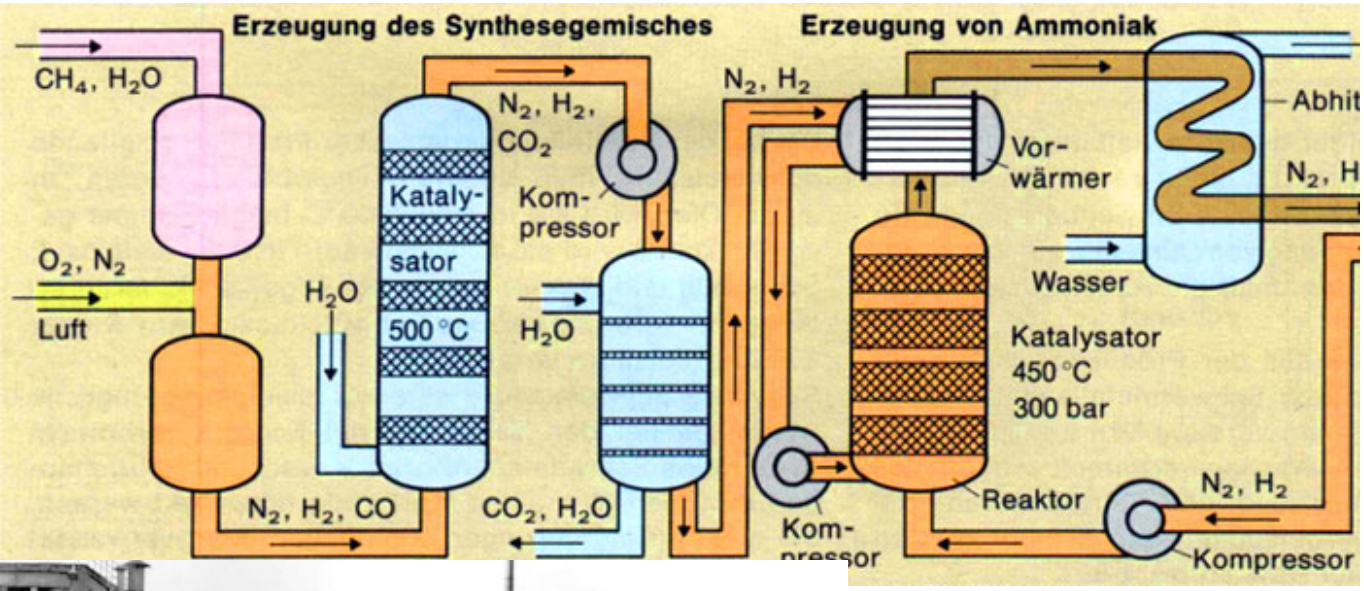
Ballestas Islands, also called Guano Islands

Who figured it out first?

Haber-Bosch process (invented 1909)

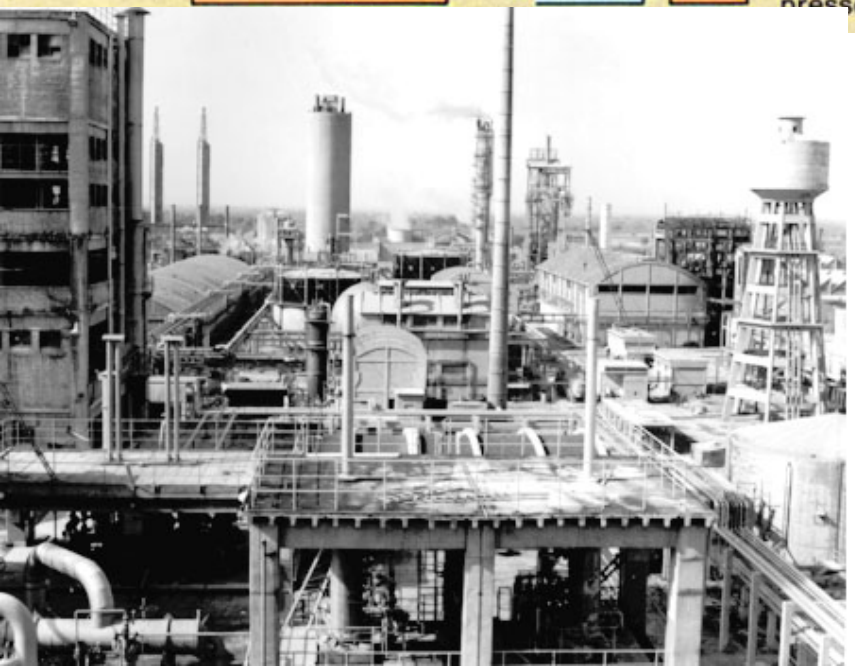
Making ammonia (NH_3) from air (N_2) and natl. gas (CH_4)

Fritz Haber
Nobel Prize, 1918



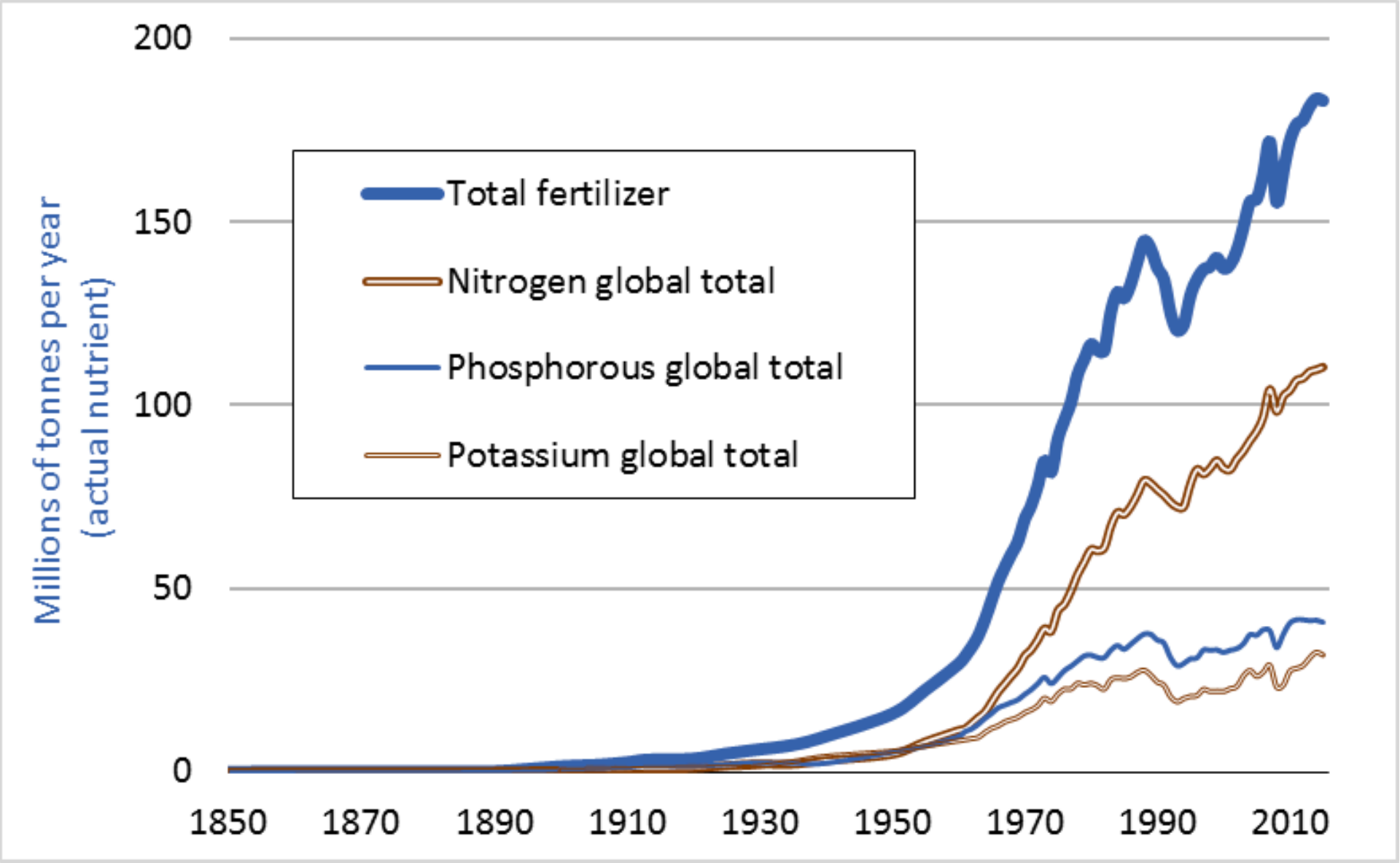
Currently 1% of world energy use.

Half the N in your body came from a factory like this.



What drove the timing of the fertilizer boom?

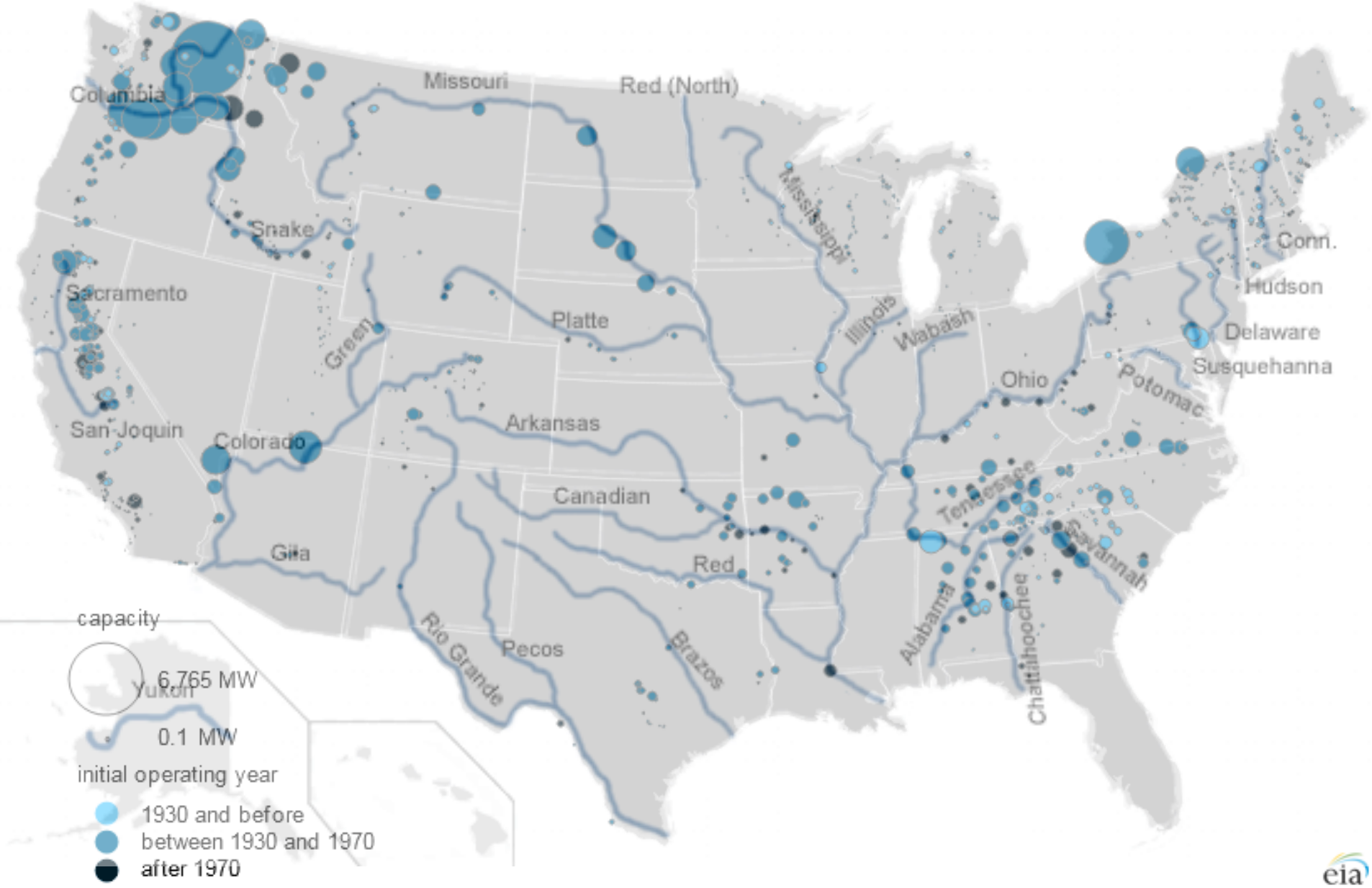
Borlaug was not the only relevant factor

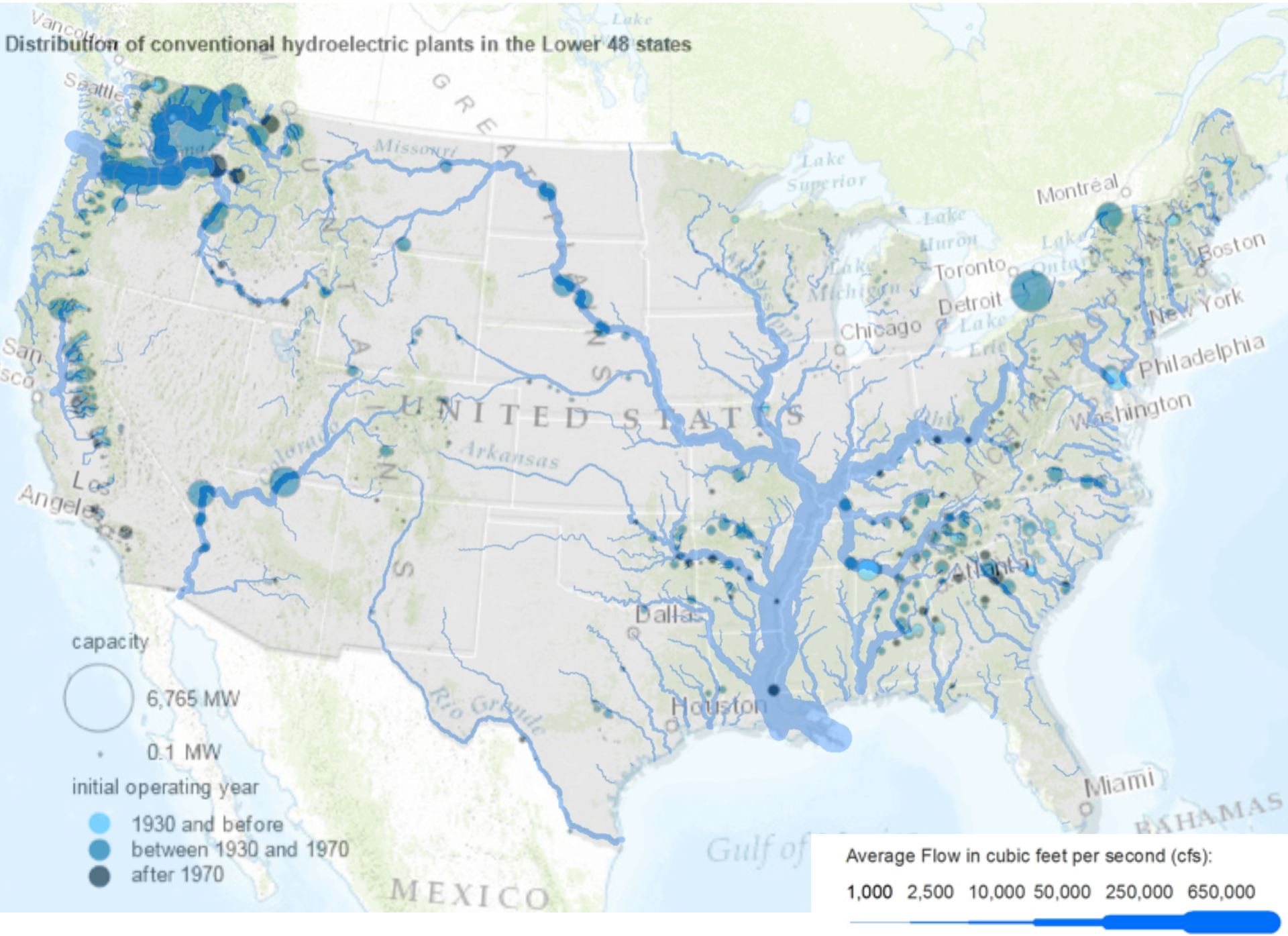


Energy from the water cycle: hydropower

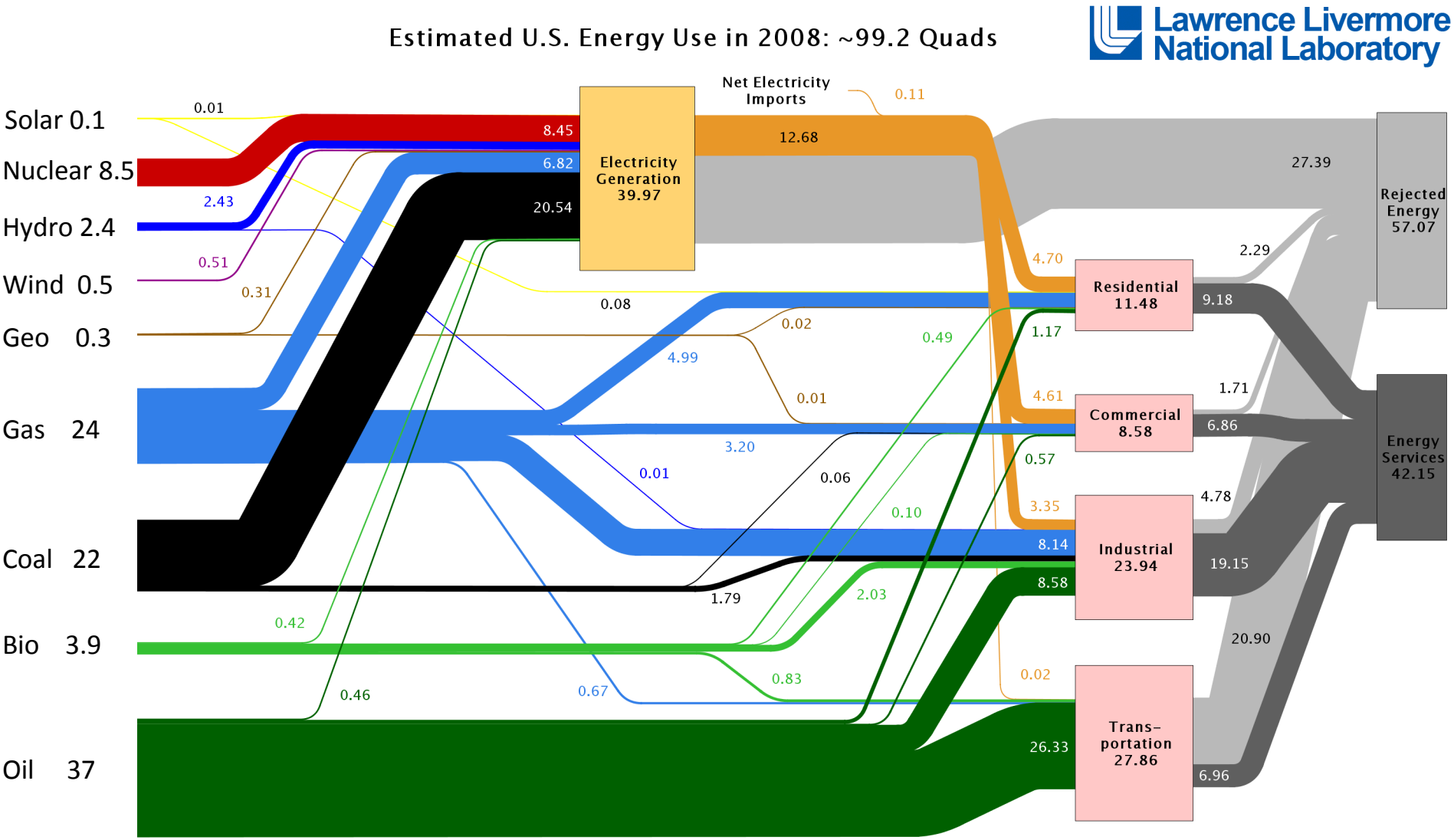

Columbia
Missouri
Red (North)
Mississippi
Snake
Sacramento
Green
Platte
Illinois
Wabash
Ohio
Potomac
Conn.
Hudson
Delaware
Susquehanna
San Joquin
Colorado
Arkansas
Canadian
Tennessee
Savannah
Gila
Red
Alabama
Chattahoochee
Rio Grande
Pecos
Brazos
Yukon
after 1970
eia

Distribution of conventional hydroelectric plants in the Lower 48 states



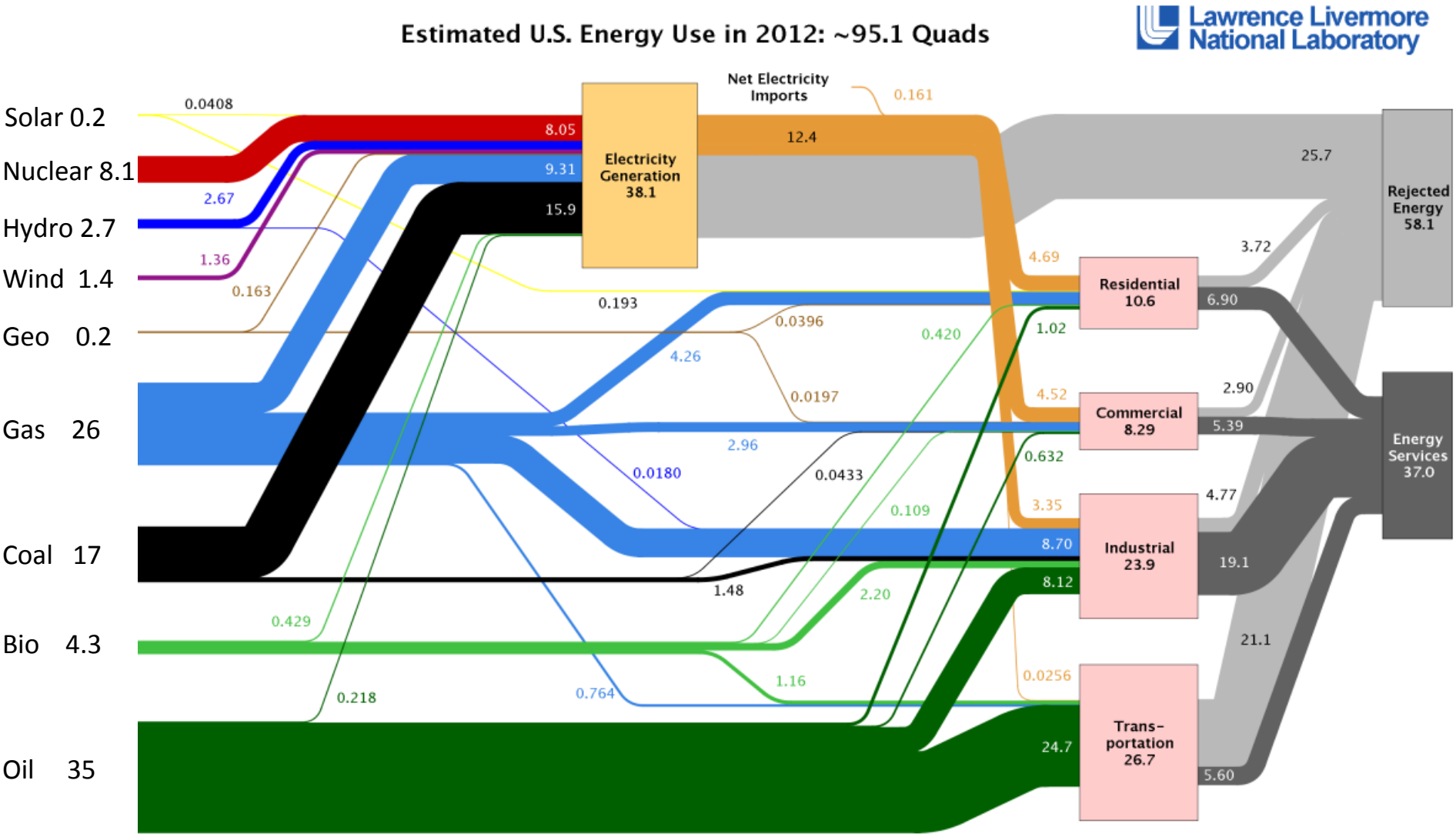

Distribution of conventional hydroelectric plants in the Lower 48 states
capacity
6,765 MW
0.1 MW
initial operating year
1930 and before
between 1930 and 1970
after 1970
Average Flow in cubic feet per second (cfs):
1,000
2,500
10,000
50,000
250,000
650,000
UNITED STATES
MEXICO
BAHAMAS
Missouri
Arkansas
Rio Grande
Lake Superior
Lake Huron
Lake Michigan
Lake Erie
Montréal
Toronto
Detroit
Chicago
Boston
New York
Philadelphia
Washington
Atlanta
Dallas
Houston
Miami
Seattle
San Francisco
Los Angeles

2008: Most of our power comes from fossil fuels



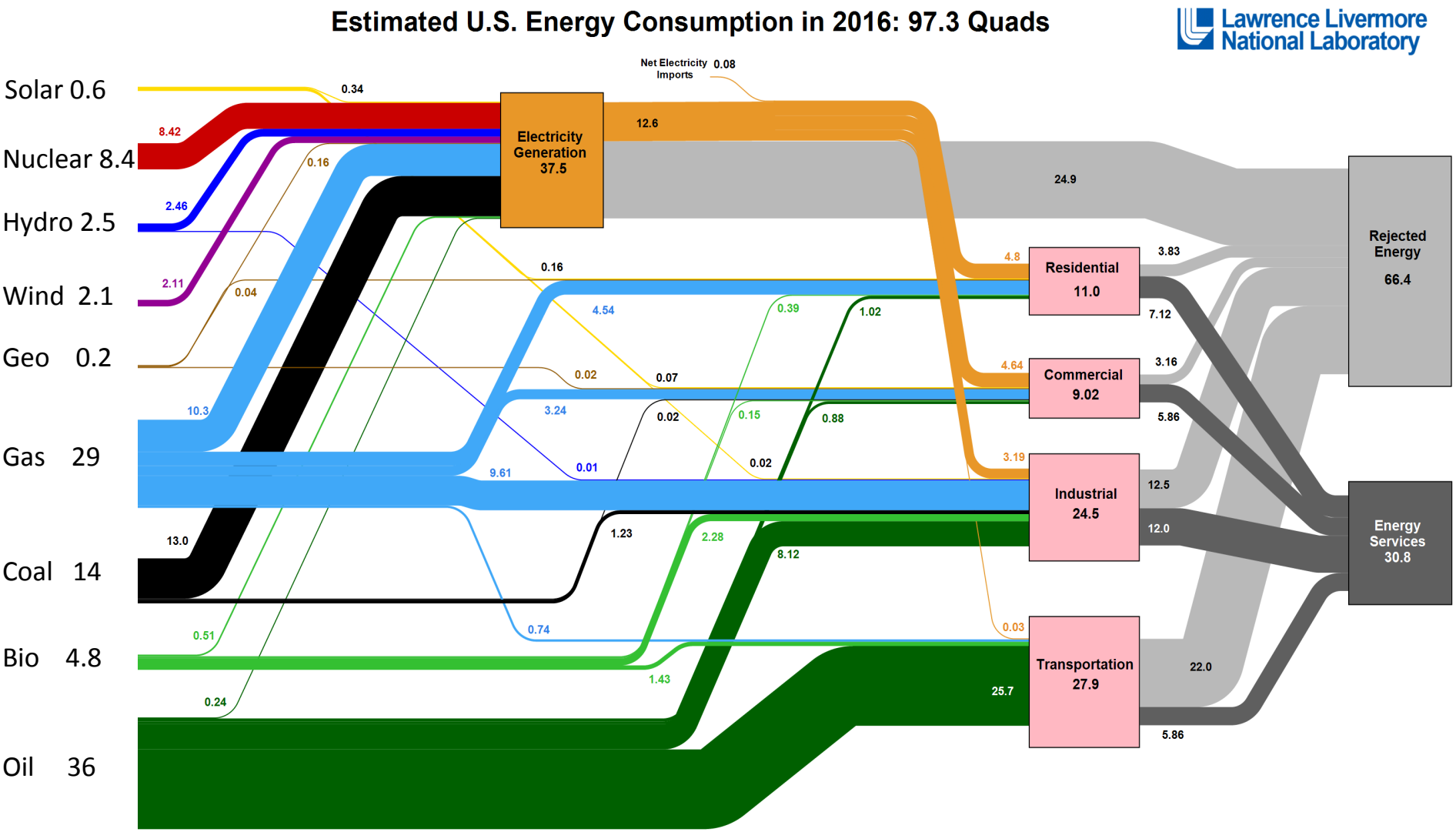
Source: LLNL 2009. Data is based on DOE/EIA-0384(2008), June 2009. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for non-thermal resources (i.e., hydro, wind and solar) in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 80% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

2012: Most of our power comes from fossil fuels



Source: LLNL 2013. Data is based on DOE/EIA-0035(2013-05), May, 2013. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential and commercial sectors 80% for the industrial sector, and 21% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

2016: Most of our power comes from fossil fuels



Source: LLNL March, 2017. Data is based on DOE/EIA MER (2016). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. This chart was revised in 2017 to reflect changes made in mid-2016 to the Energy Information Administration's analysis methodology and reporting. The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential sector, 65% for the commercial sector, 21% for the transportation sector, and 49% for the industrial sector which was updated in 2017 to reflect DOE's analysis of manufacturing. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527