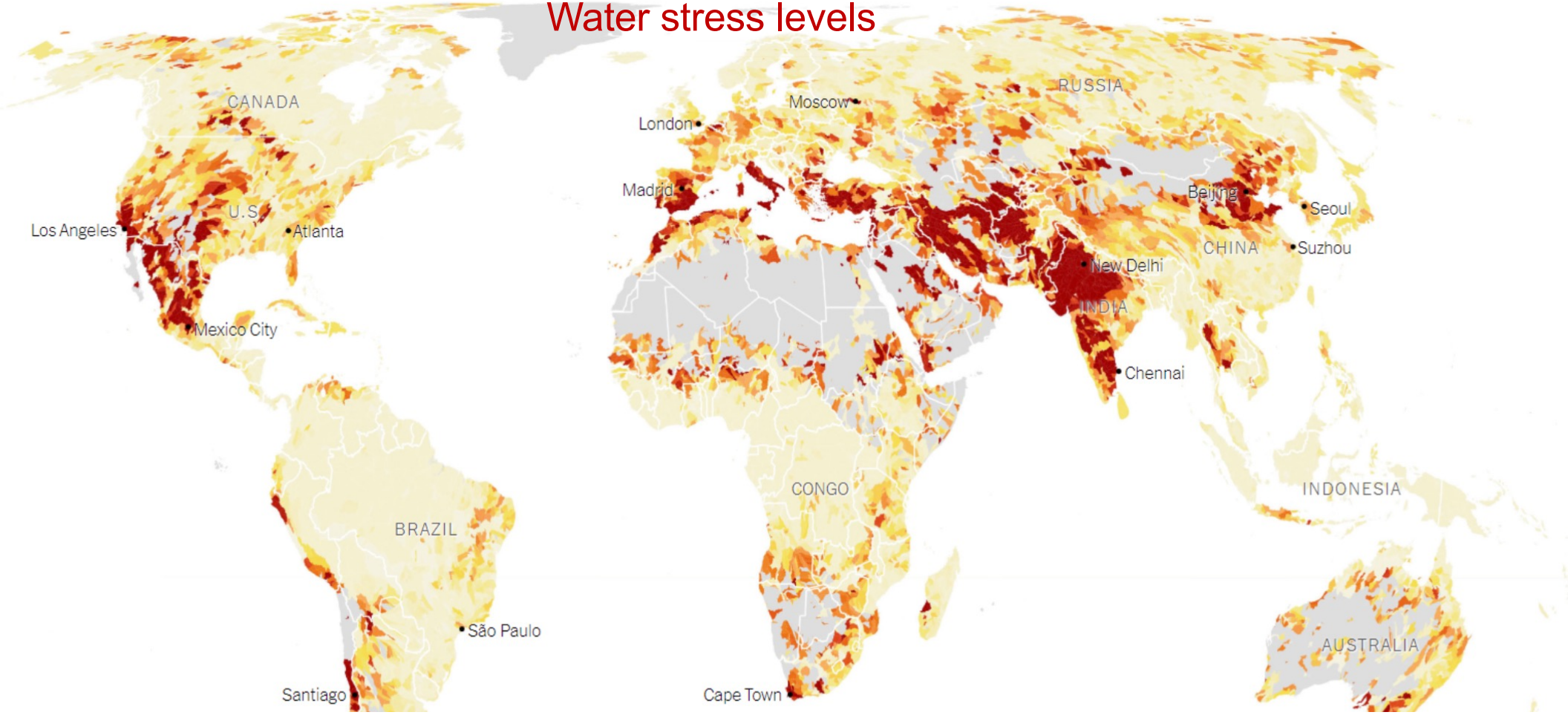
Climate Change and innovative paths to a more sustainable future

University of Wisconsin, Madison

24 February, 2019

Rising seas, increase in heat waves, floods, forest fires, droughts, and water shortages.

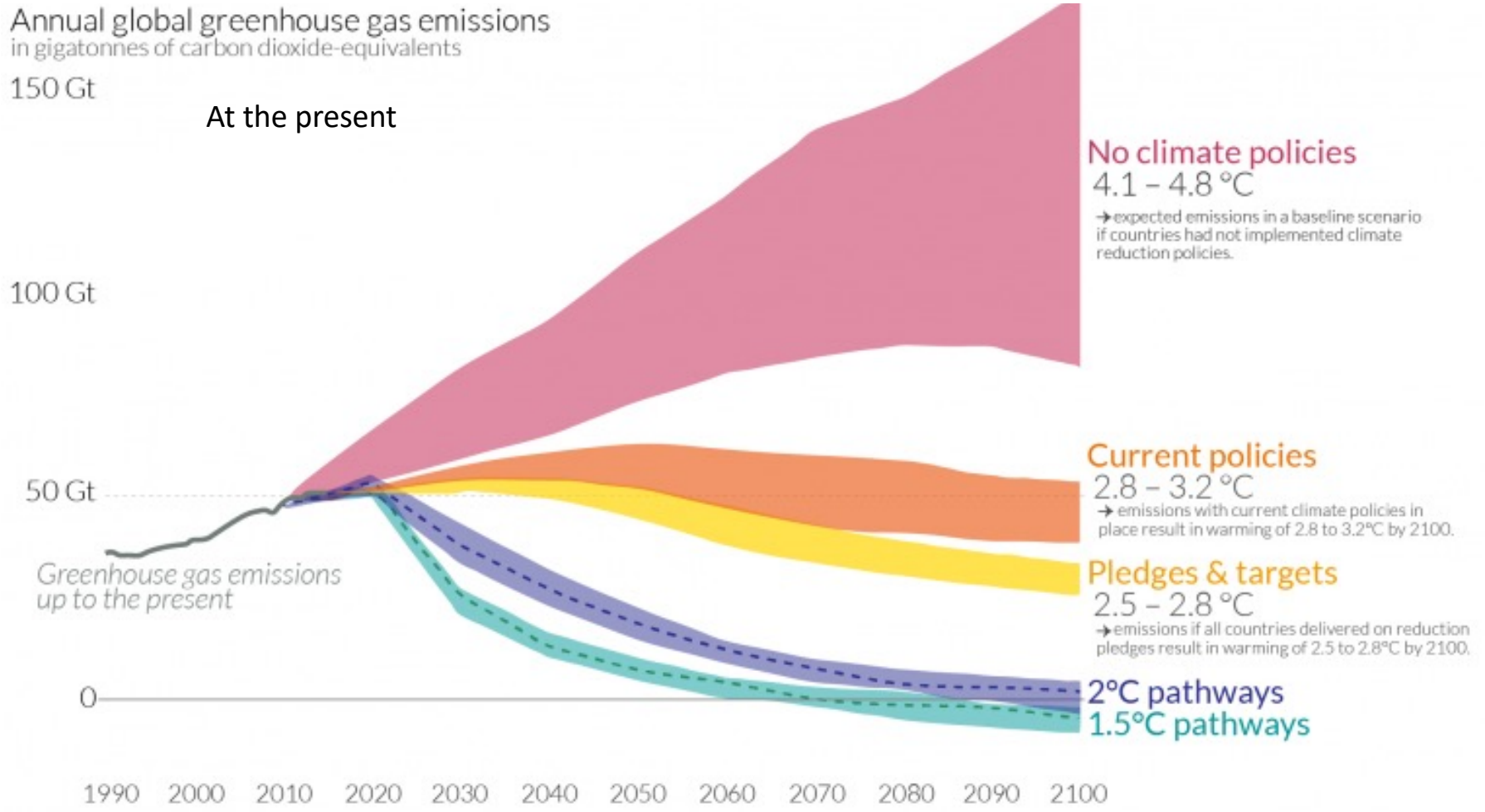
The World Bank estimates that there may be 200 million climate refugees by 2050



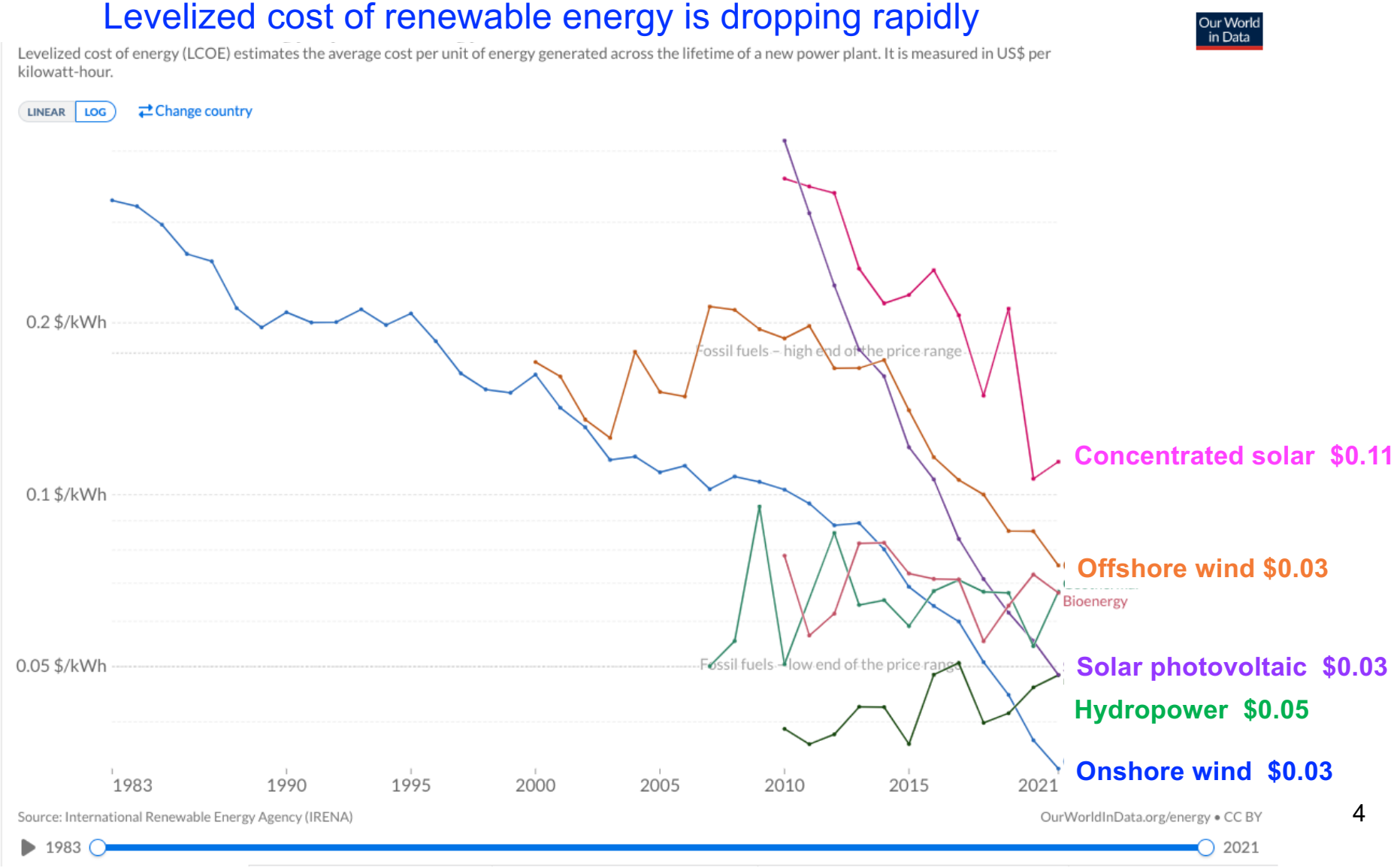
We may reach 600 ppm of $CO_{2\text{-equiv}}$ and~ 3 ℃ increase. During the last Interglacial (129,000 to 116,000 year ago), the Earth was ~ 2.5 ℃ warmer, and sea level was 6 – 9 m higher.

Our World in Data

Like cigarette smoking, the full consequences of the GHG increase today not be seen for decades.



Levelized cost of renewable energy is dropping rapidly

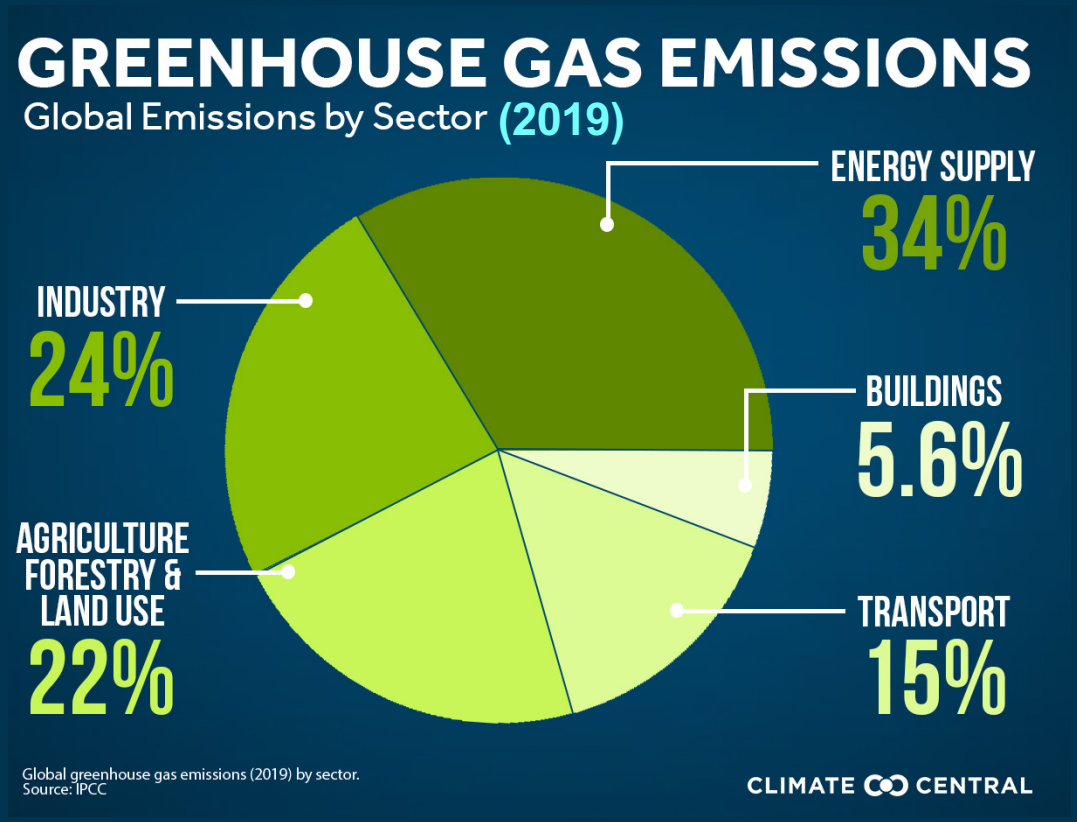


The full cost of renewable energy includes backup generation capacity, energy storage, and an enhanced transmission and distribution system.

Electricity transmission and distribution

We will need an electrical grid that can manage intermittent generation, less inherently stable sources and increased dependency in transportation, industrial processes, and building heating.

The move towards increased will reduce the resiliency the comes from multiple sources of energy



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- **The goal is "re-use," not "recycle."**
- A fundamental change in economic metrics is needed. Maximizing GDP based making, using and throwing away more "stuff" including "tear-down-and-rebuild" buildings has to change.

The Chrysler Building (1930)
Empire State Building (1931)

We should build buildings to last 100 – 150 years but where the HVAC, building controls, communications can be modernized as needed.

Chicago Merchandise Mart (1930)

Gjuteriet
The Oatly Headquarters

Varvsstaden, Malmö, Sweden

Varvsstaden AB
Kjellander Sjöberg Architects
Oatly

Gjuteriet (built in 1910) was part of the Malmö Sweden ship yard.

Before the project started.

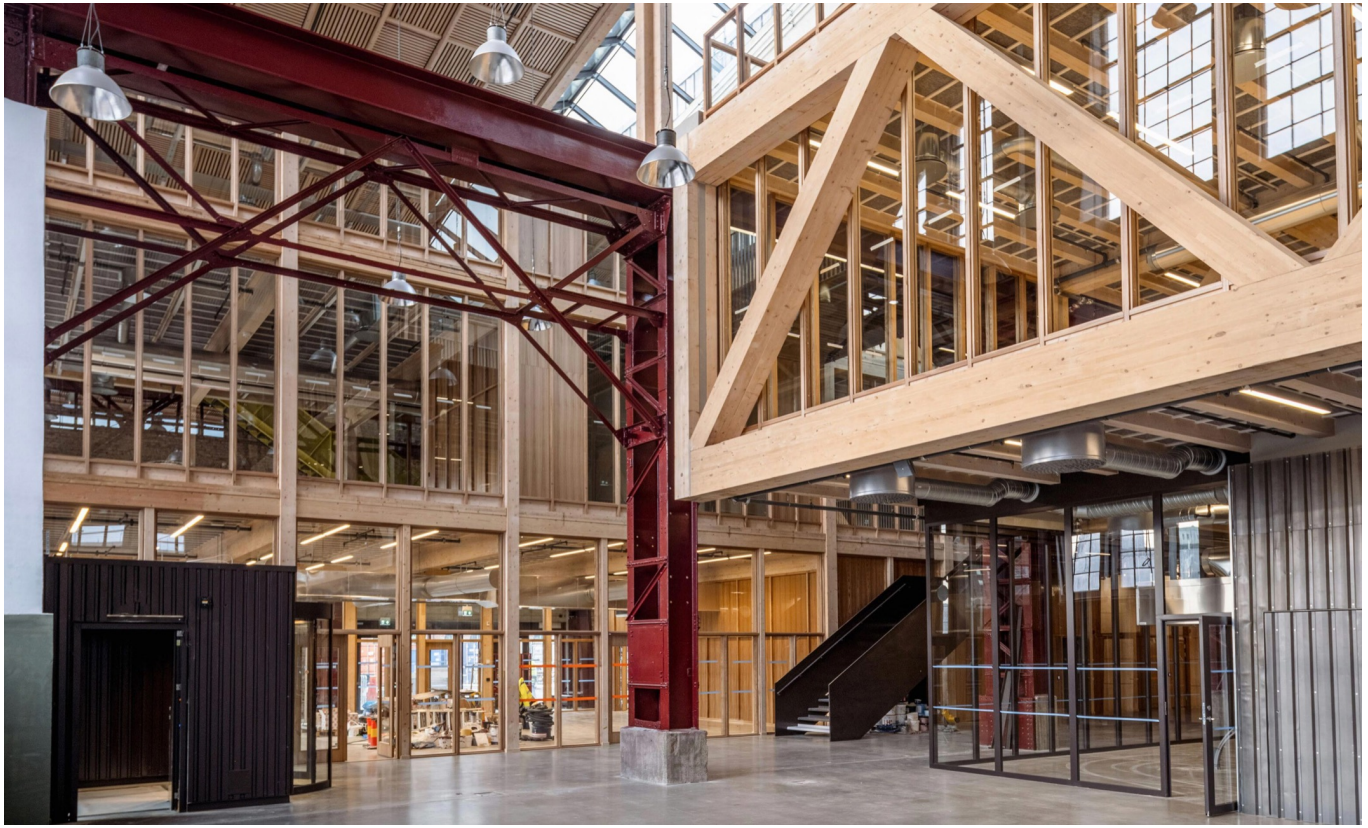
Dismantling instead of tearing down

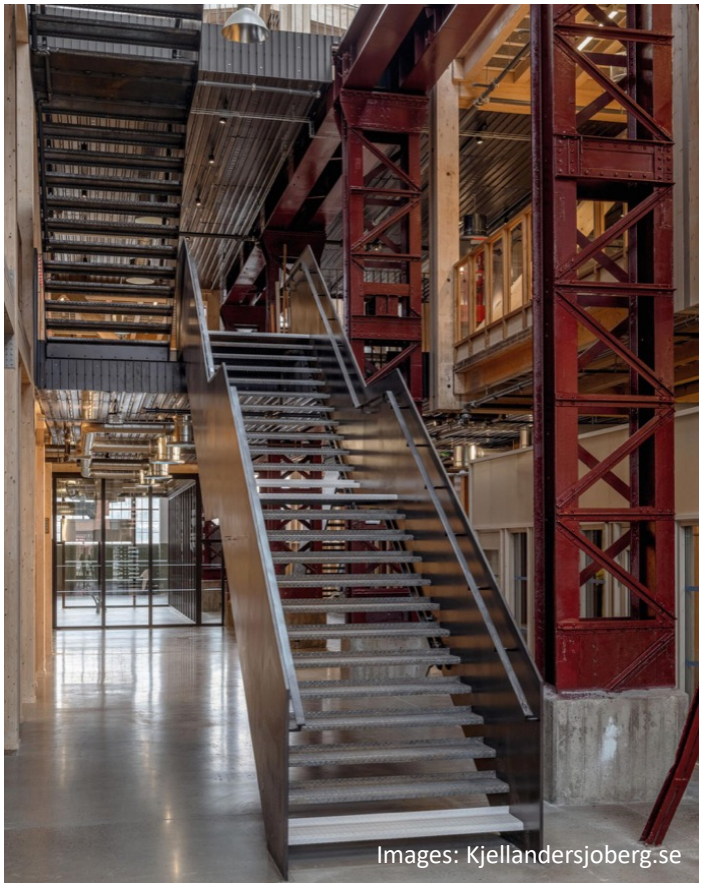



https://app.powerbi.com/view?r=eyJrIjoiODBmYzQ1YjYtNDZkYy00YjhiLWEyZjgtNDMzMmY1ZGU4MmI0IiwidCI6ImRmMDA4MmM2LWJlYmQtNDIxYS1hYjExLWIwMDU2MzJkMGI5ZiIsImMiOjI9&pageName=ReportSection5315d7db482c1f92075f

Varvsstaden.se

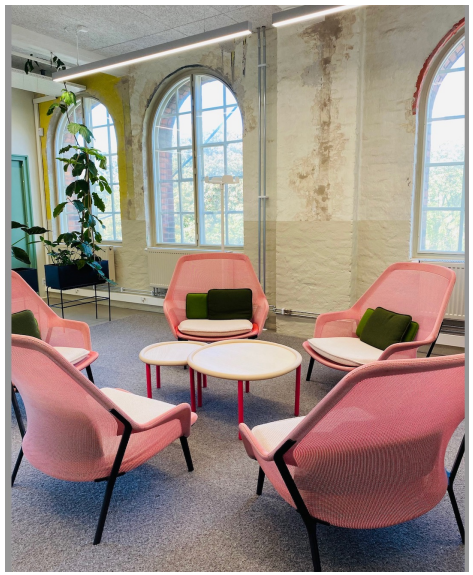
Gjuteriet. The vision.





Images: Kjellandersjoberg.se


Reuse of all our furniture from the existing office




Not milk bar.
THE ORIGINAL
OATLY!
THE ORIGINAL
OATLY!


WOW NO COW!


Image: Varvsstaden.se

Energy Storage

To achieve 80% renewable energy in the U.S. we would need 3 days of energy storage.

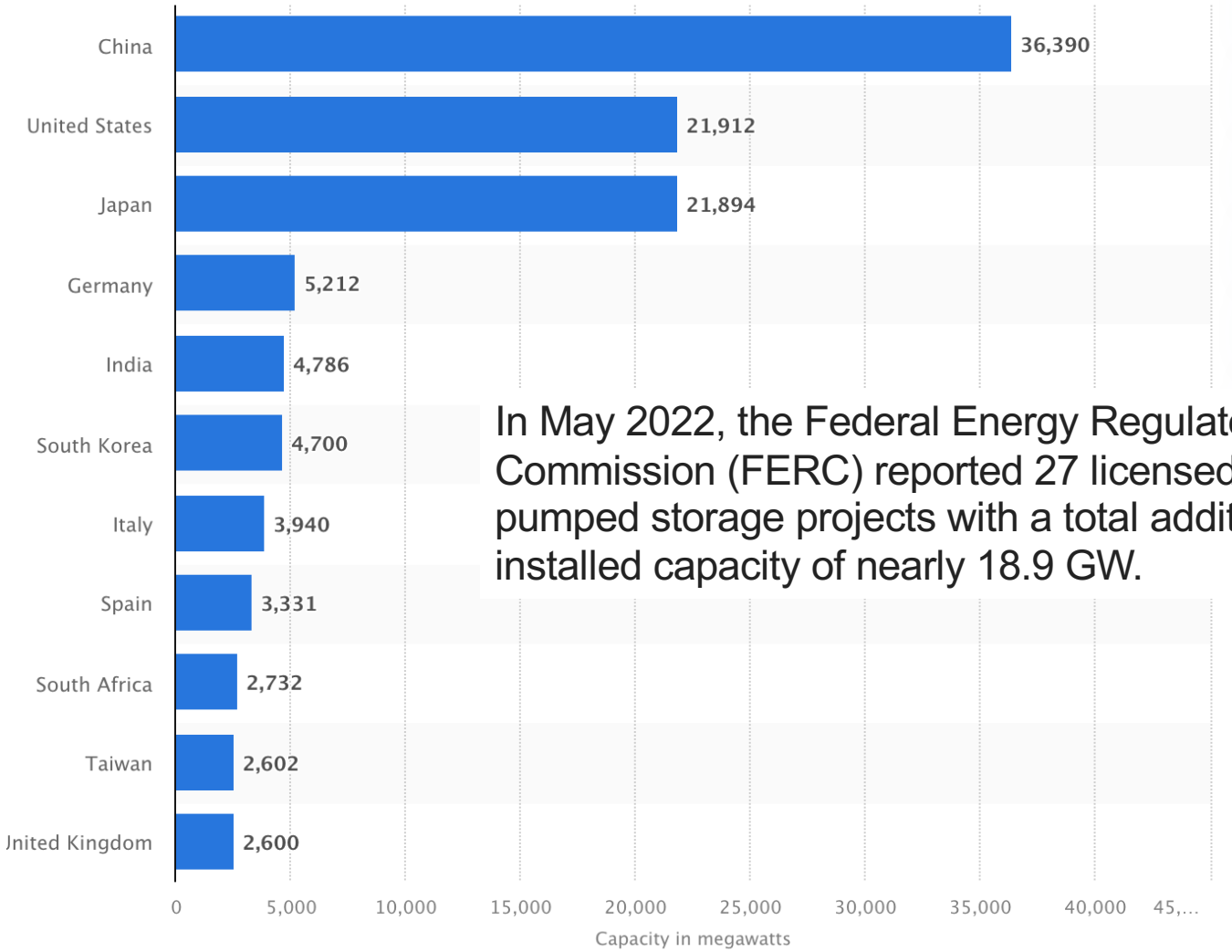
"Long-Duration Electricity Storage Applications, Economics, and Technologies,"
Paul Albertus, Joseph Manser, Scott Litzelman, Joule **4**, 21 - 32 (2020)

Greater than ~ 2000x more battery storage that we have today.
In order to compete with natural gas, the cost is \$10 - \$20 / kWh ($1/10^{th}$ – $1/20^{th}$ the current cost.)

Progress in Batteries and other forms of energy storage

Pump water when the wind blows or the sun shines

Pumped storage hydropower capacity in 2021 (in megawatts)



In May 2022, the Federal Energy Regulatory Commission (FERC) reported 27 licensed pumped storage projects with a total additional installed capacity of nearly 18.9 GW.

Gray hydrogen ~ $1.50 /kg

Blue hydrogen (CO_2 sequestration is an issue) ~ $2 - $3/kg

Green hydrogen (renewable energy) ~ $6/kg.

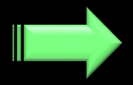
- The reduction in Capital Expense and the elimination of precious metals of is the crucial. Electrolyzers need to operate at ~ 3 amps per cm^2
- Hydrogen has been determined to keep methane in the atmosphere longer, is very leaky, and detection requires a mass spectrometer Pipeline distribution cannot use existing gas lines.
- Green hydrogen could potentially be used to de-carbonize steel, plastics chemical and fertilizer.
- A price on carbon is essential to make **Green hydrogen** competitive.

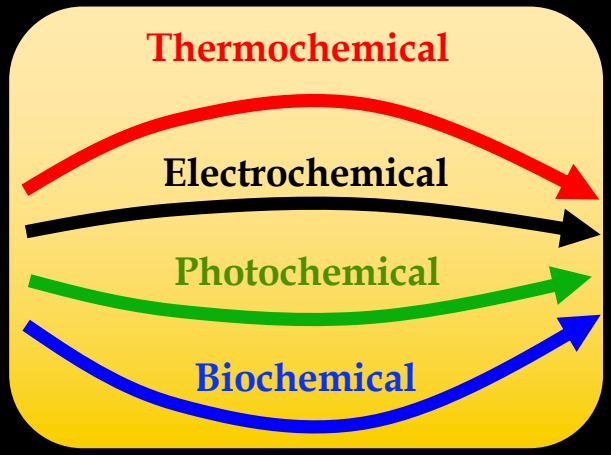
A challenge for the 21st Century

100% renewable energy based on the **recycling combustion products**

CO_2

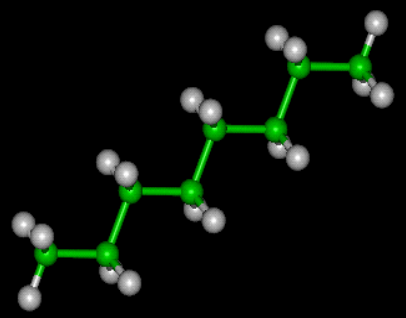
H_2O





H_2, CO

Sustainable aviation fuels that don't compete with land

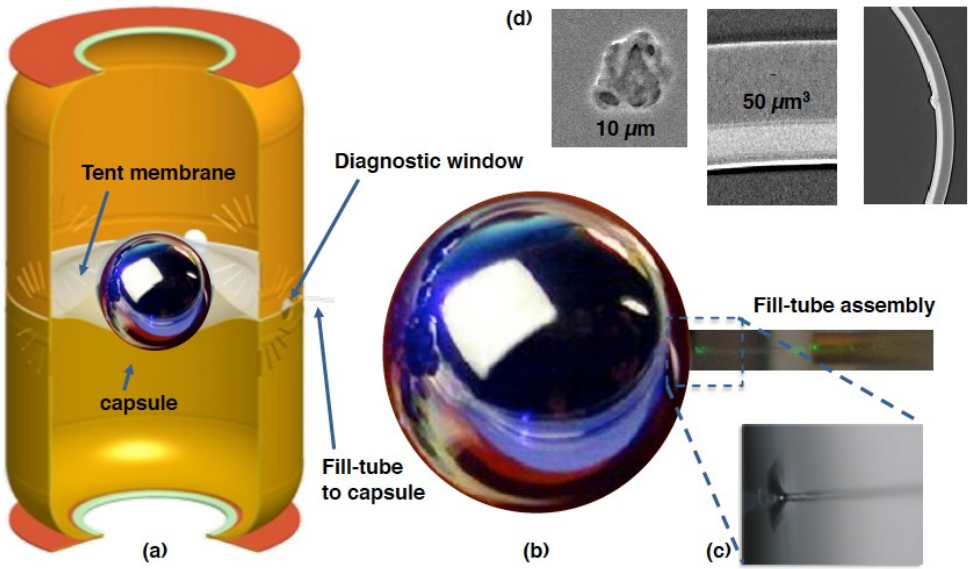


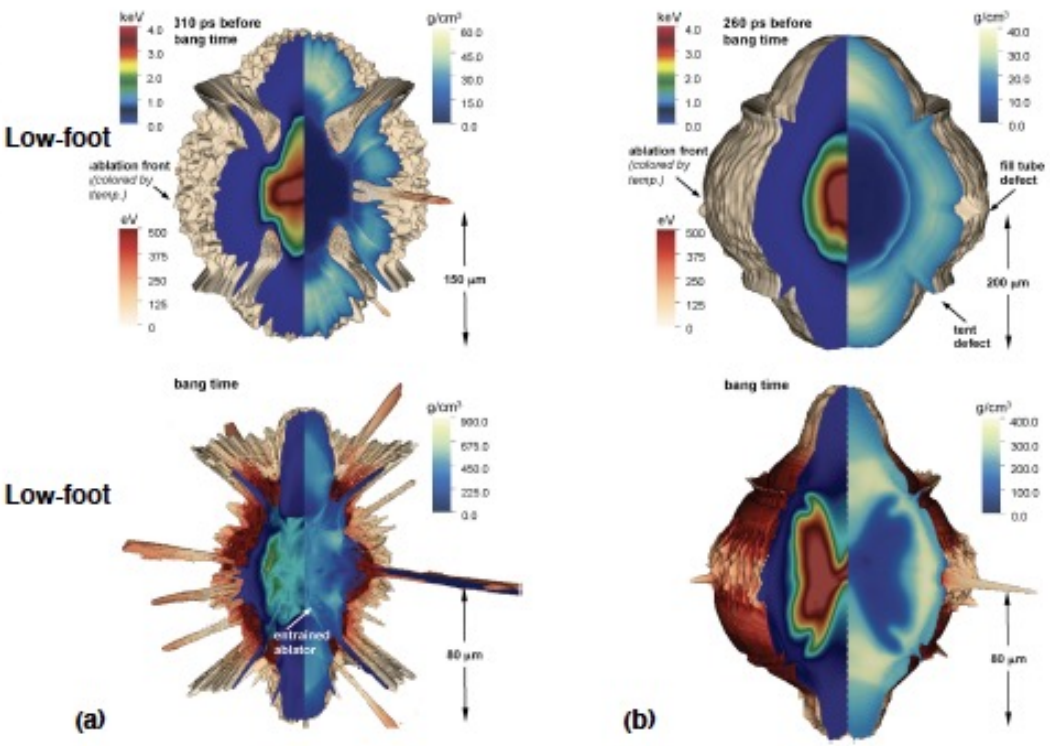
For compact energy-on-demand energy sources, our current choices are natural gas, chemical or nuclear energy.

The time before fusion can be commercially deployed is somewhere in the range of >25 years to never.

See: Optimism is not a strategy: A white paper on how to give IFE a fighting chance to be real, O. Hurricane, D. Callahan, A. Kritcher, A. Zylstra, LLNL-TR-831205

Physics Principles of Inertial Confinement Fusion and U.S. Program, O.A. Hurricane, et al. Rev. Mod. Physics, in press, (2023)


Tent membrane
Diagnostic window
capsule
Fill-tube
to capsule
(a)
(b)
(c)
(d)
10 μm
50 μm³
Fill-tube assembly

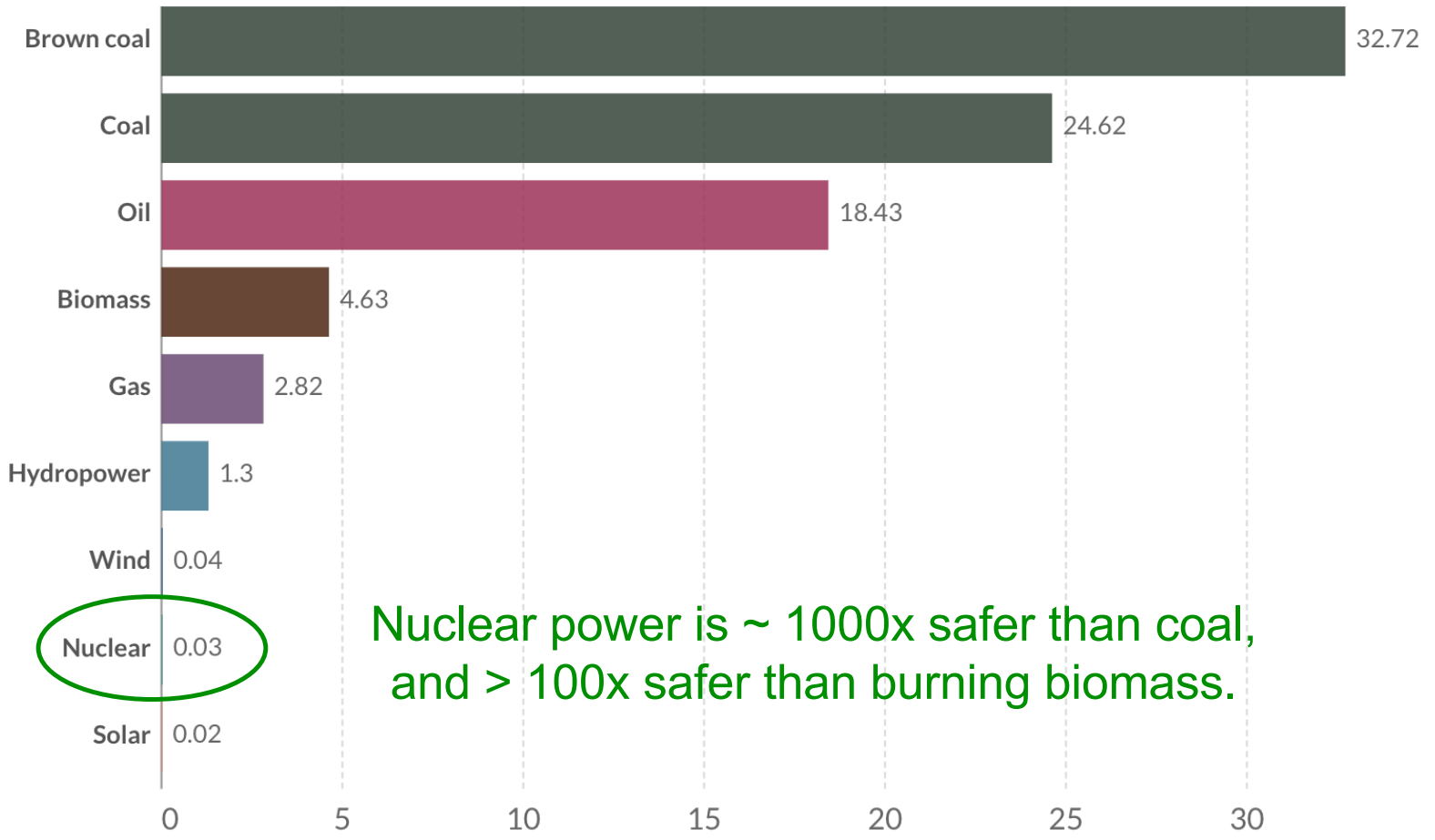

Low-foot
310 ps before bang time
ablation front (colored by temp.)
150 μm
Low-foot
bang time
entrained ablator
80 μm
(a)
260 ps before bang time
ablation front (colored by temp.)
fill tube defect
200 μm
tent defect
bang time
80 μm
(b)


Diabolo Canyon Nuclear reactors

Death rates per unit of electricity production

Death rates are measured based on deaths from accidents and air pollution per terawatt-hour (TWh) of electricity.

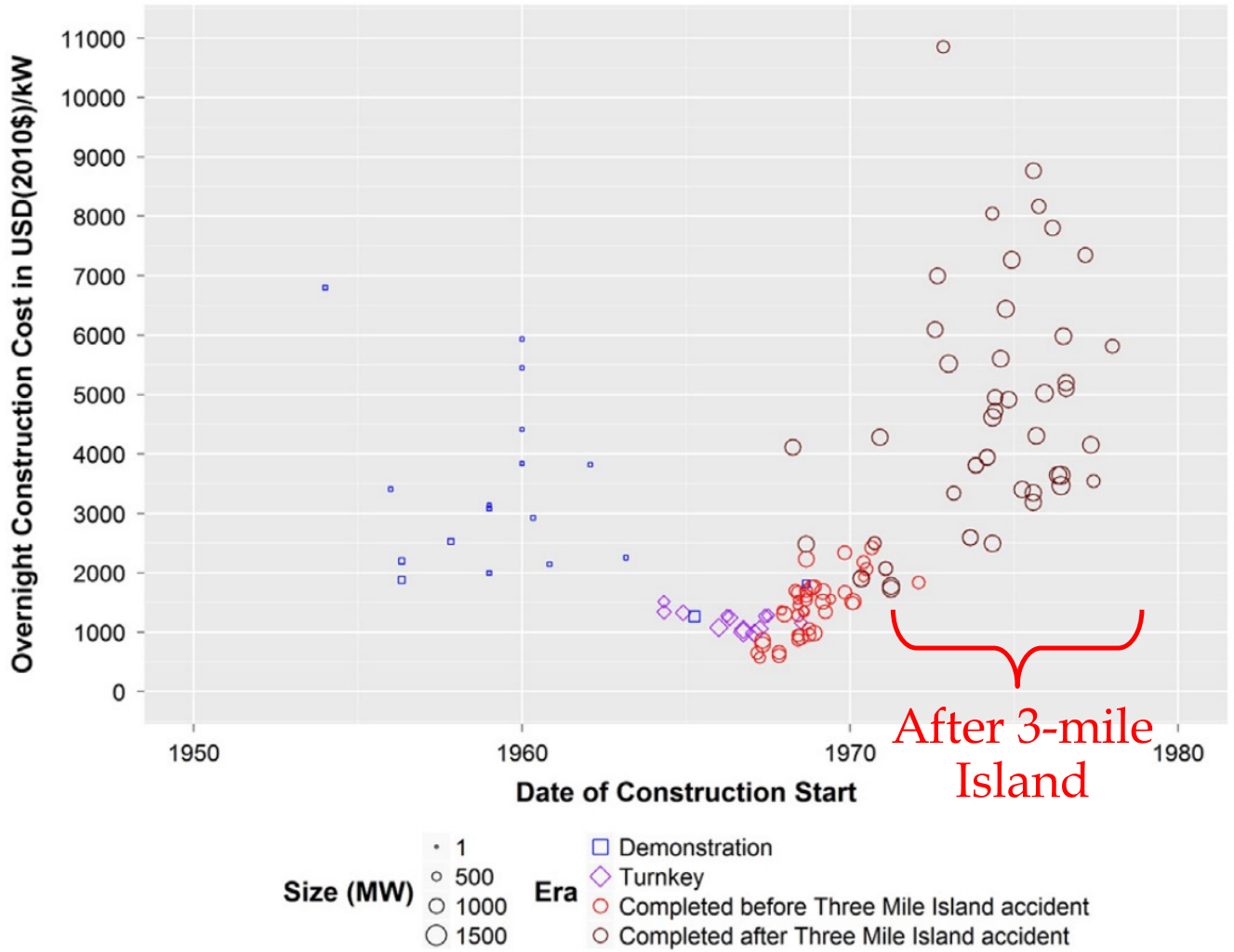
Our World in Data



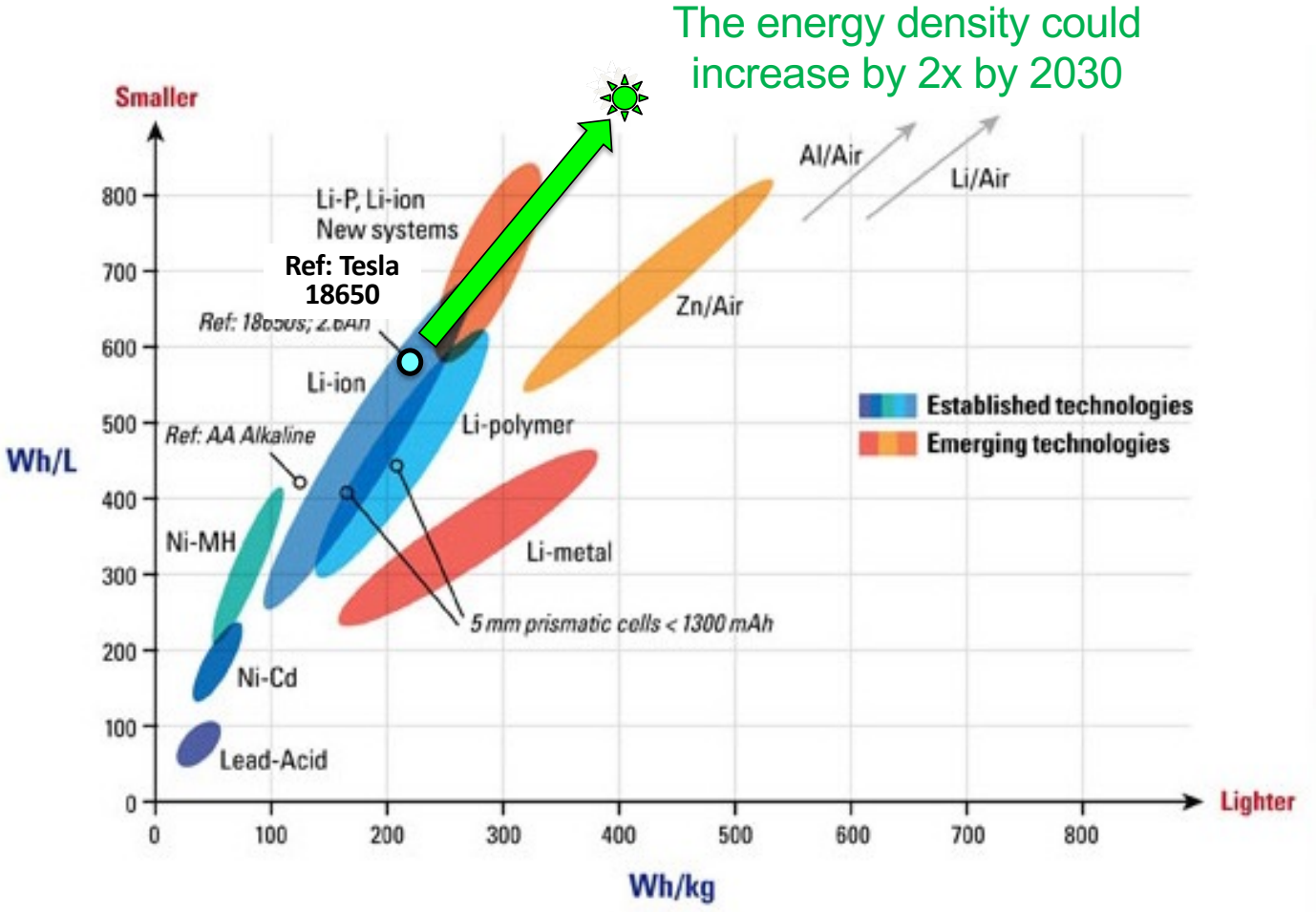
Nuclear power is ~ 1000x safer than coal, and > 100x safer than burning biomass.

Source: Markandya & Wilkinson (2007); Sovacool et al. (2016); UNSCEAR (2008; & 2018)

United States "overnight" construction costs by construction start date

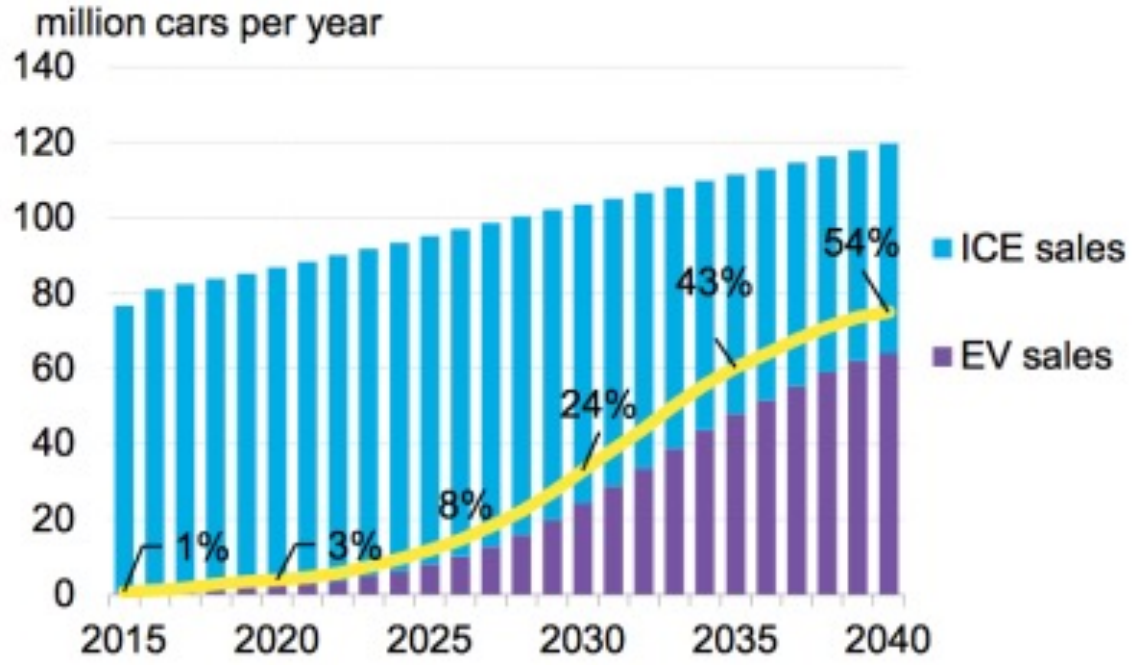


Chemical batteries have make remarkable progress:
The cost of EV batteries declined 10-fold in 2010 ➞ 2020



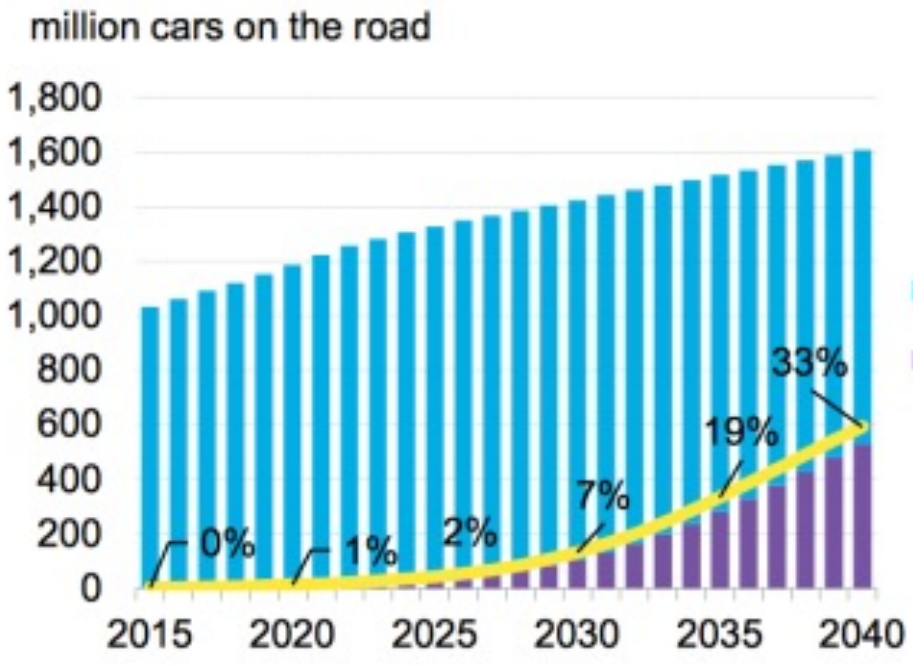
Electrification of personal and light duty vehicles is growing rapidly. (2017 forecast)
Will

Figure 1: Annual global light duty vehicle sales



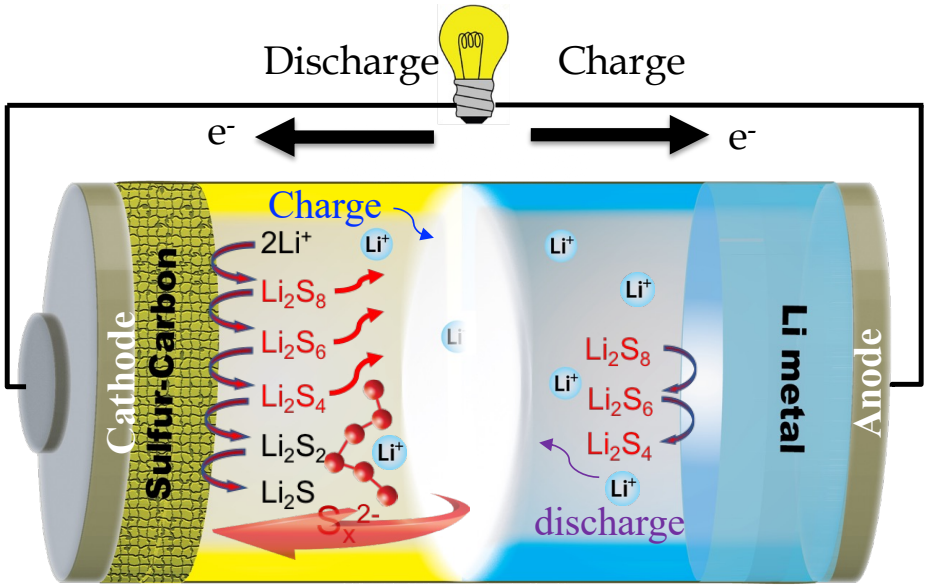
Source: Bloomberg New Energy Finance

Figure 2: Global light duty vehicle fleet



Source: Bloomberg New Energy Finance

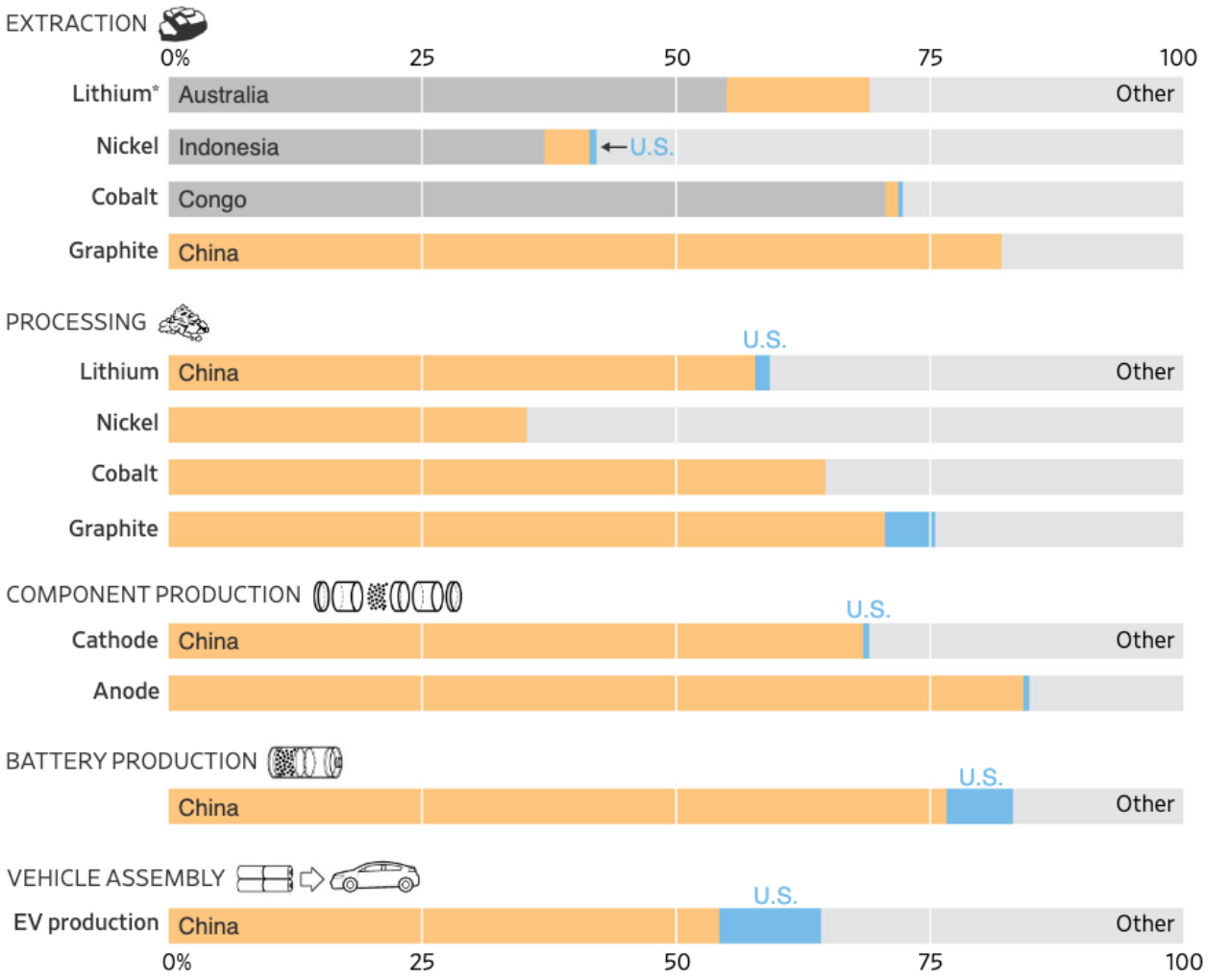
An important target: Lithium metal – sulfur battery or lithium metal –iron phosphate battery



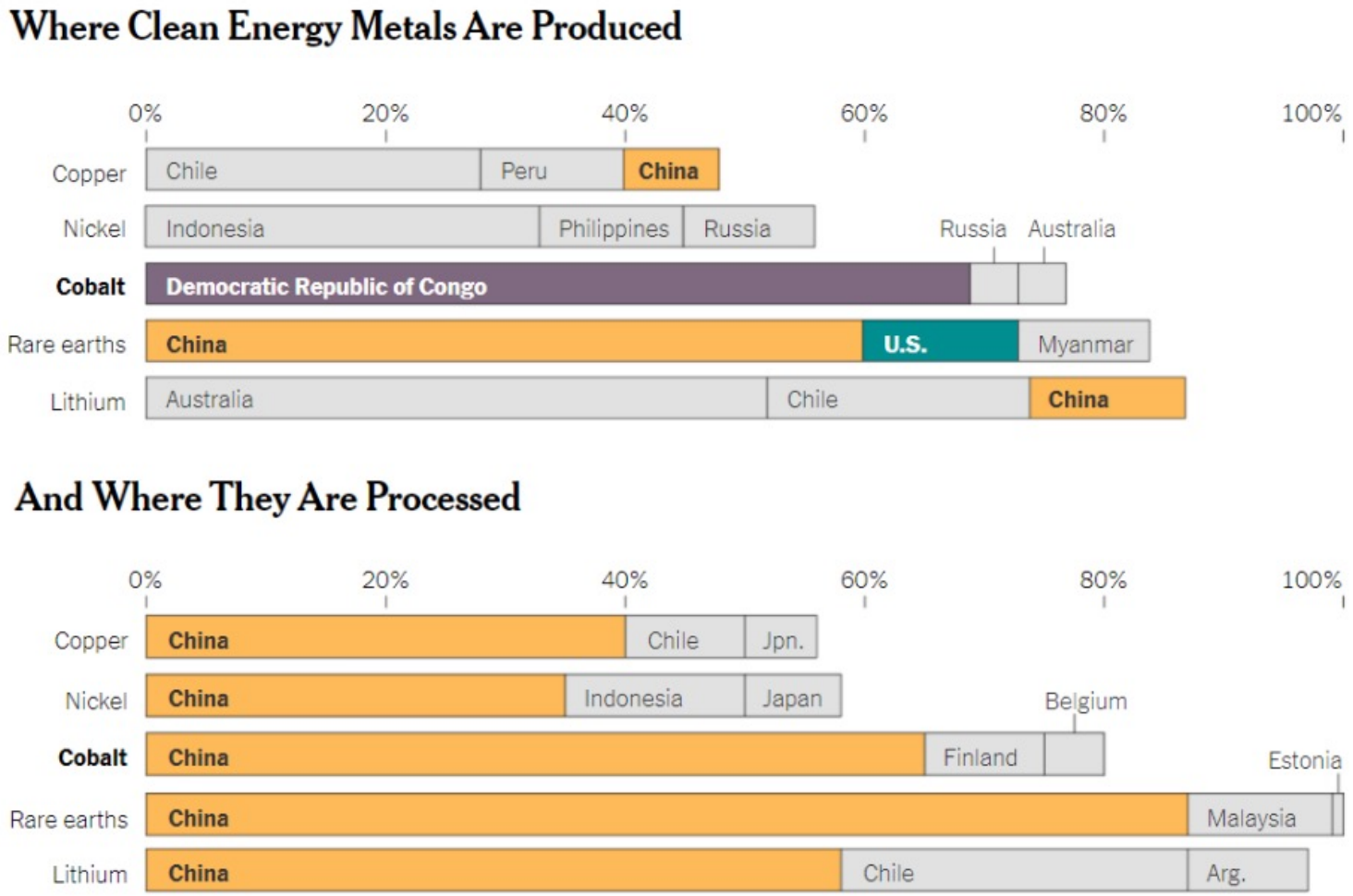
All well-known separators allow sulfur to reach the anode

With Dr. Yan-Kai Tzeng, Prof. Yi Cui and others, we are trying to develop a new separator that may allow **lithium metal**-sulfur and **lithium-metal-iron phosphate** battery that may double the energy density.

Wall Street Journal (Feb. 7, 2023)
"U.S. Car Makers' EV Plans Hinge on Made-in-America Batteries"



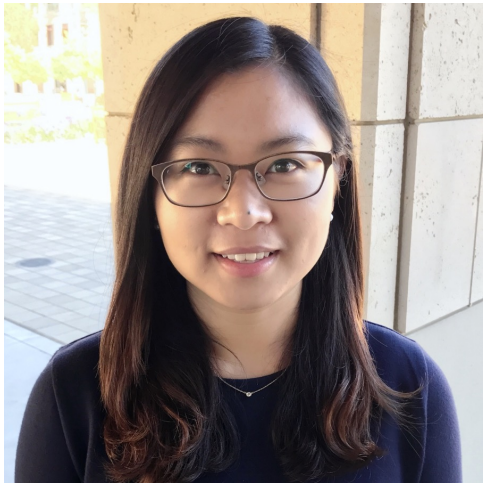
New York Times: "What's Going On in This Graph? | Clean Energy Metals"

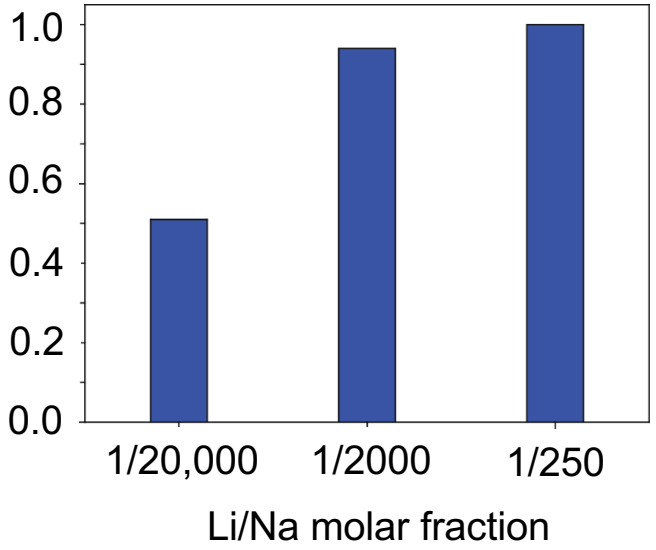


Li Extraction from salt water could increase lithium resources ~ 10,000x

(Chong Liu, … ,Yi Cui, Steven Chu, *Joule* 4, 1 – 11, July 15, 2020)

Location	Conc.	Li/Na molar
Brine (salt lakes)	0.017-0.15%	1/2000 - 1/200
“Produced water” from oil	~ 4.7×10^{-5}	1/2000 – 1/500
Sea Water	~1.7×10^{-5}	1/20,000



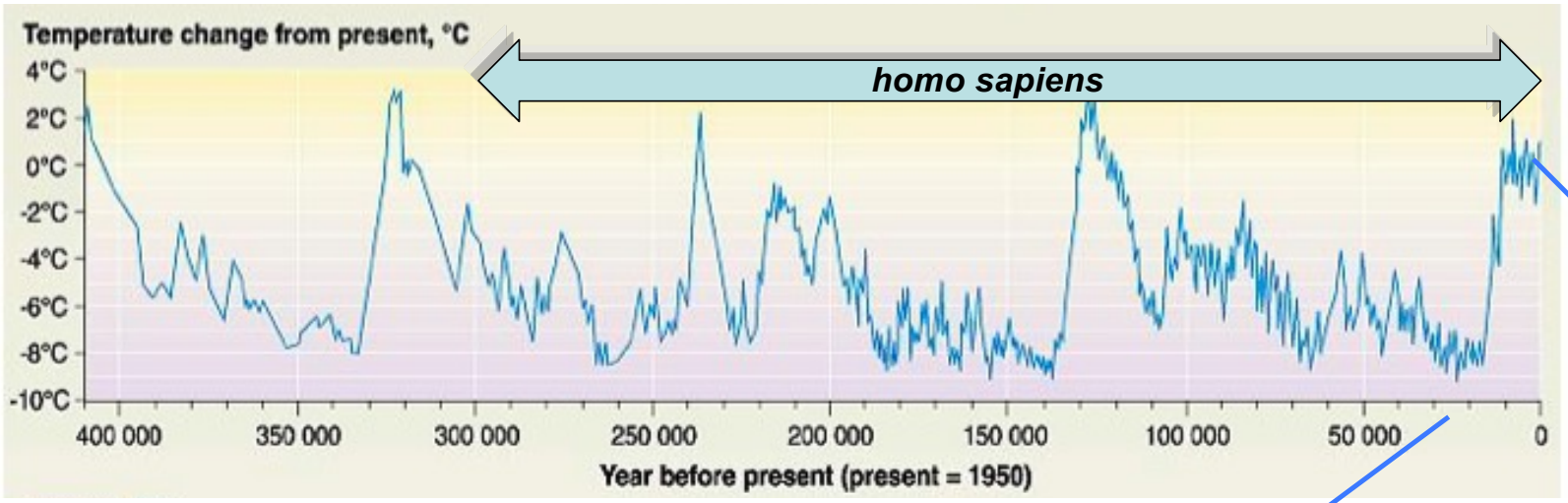


There were unintended consequences to the multiple industrial and agricultural revolutions.

Greenhouse gas emissions (CO_2, CH_4, N_20 and fluorinated gases) from agriculture are changing our climate.

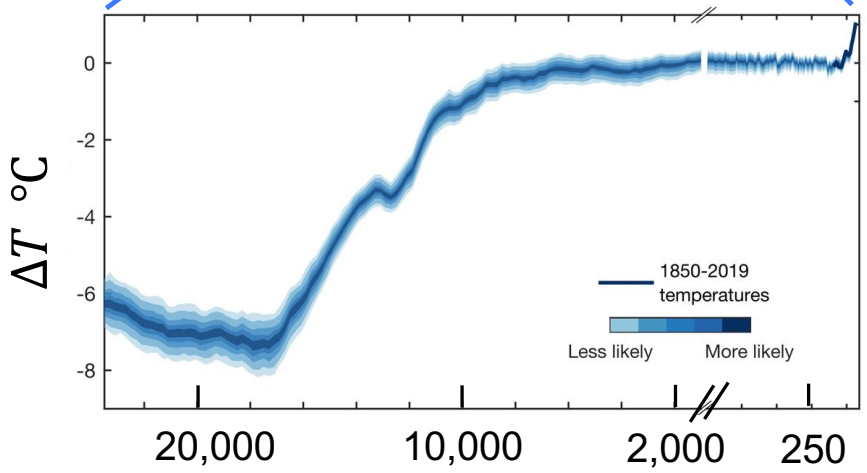
We will need a 4^{th} agricultural revolution

Homo sapiens roamed the Earth for ~300,000 years.

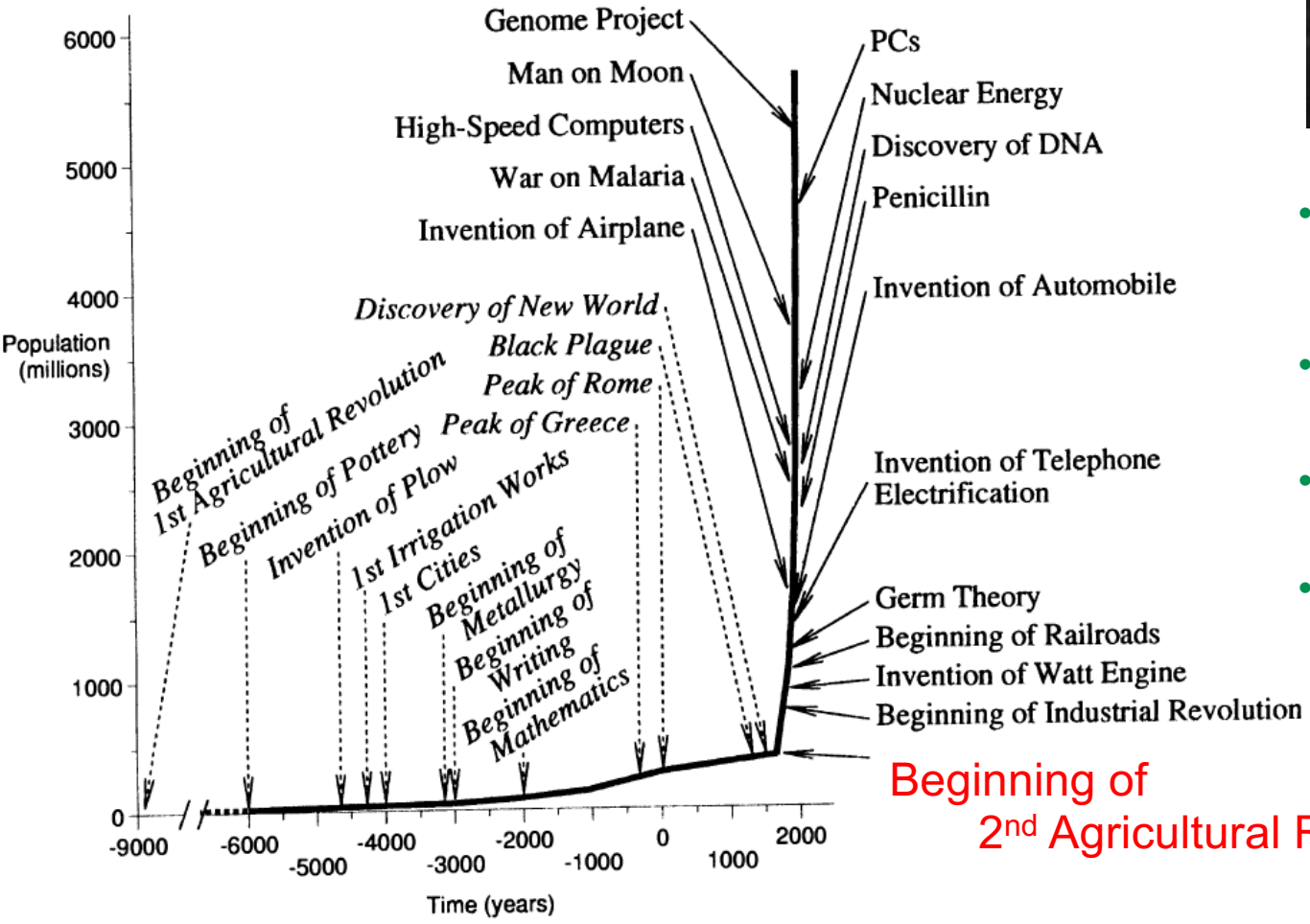


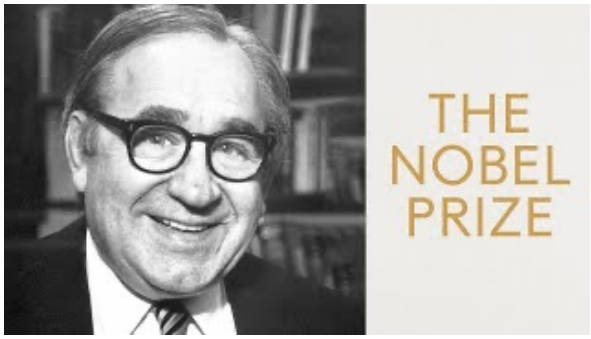
Agriculture began only 12,000 years ago in Middle East "fertile crescent", North and South China, New Guinea and Ethiopia, and in the Americas. **Why did it take so long?**

For the first time in homo sapiens history, the climate became stable enough to allow agriculture to take root.



From "Catching up with the Economy," Robert W. Fogel. The American Economic Review 89, 1-21 (1999)





- Domestication of wheat, rice cattle and chickens (7000 BC)
- Yeast for bread (4000 BC)
- First irrigation (3500 BC)
- **Fermentation of grain and fruit juice (3000 BC)**

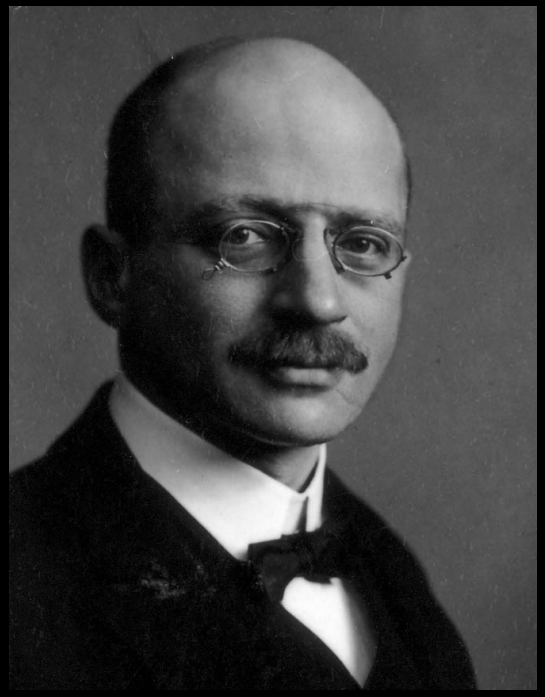
Beginning of 2nd Agricultural Revolution

Unlike the 1st agricultural revolution, the 2nd agricultural revolution (~ 1650 -1770 A.D.) were largely policy changes

- ***Enclosure: the removal of common rights access and allowed exclusive ownership of land***
- Development of a national markets free of tariffs
- Transportation infrastructure, roads, canals, railways

The 3rd agricultural revolution began with the ability to synthesize nitrogen-based fertilizers

The invention of the Haber-Bosch process enabled us to feed a world that more than doubled in population.



Fritz Haber: 1918

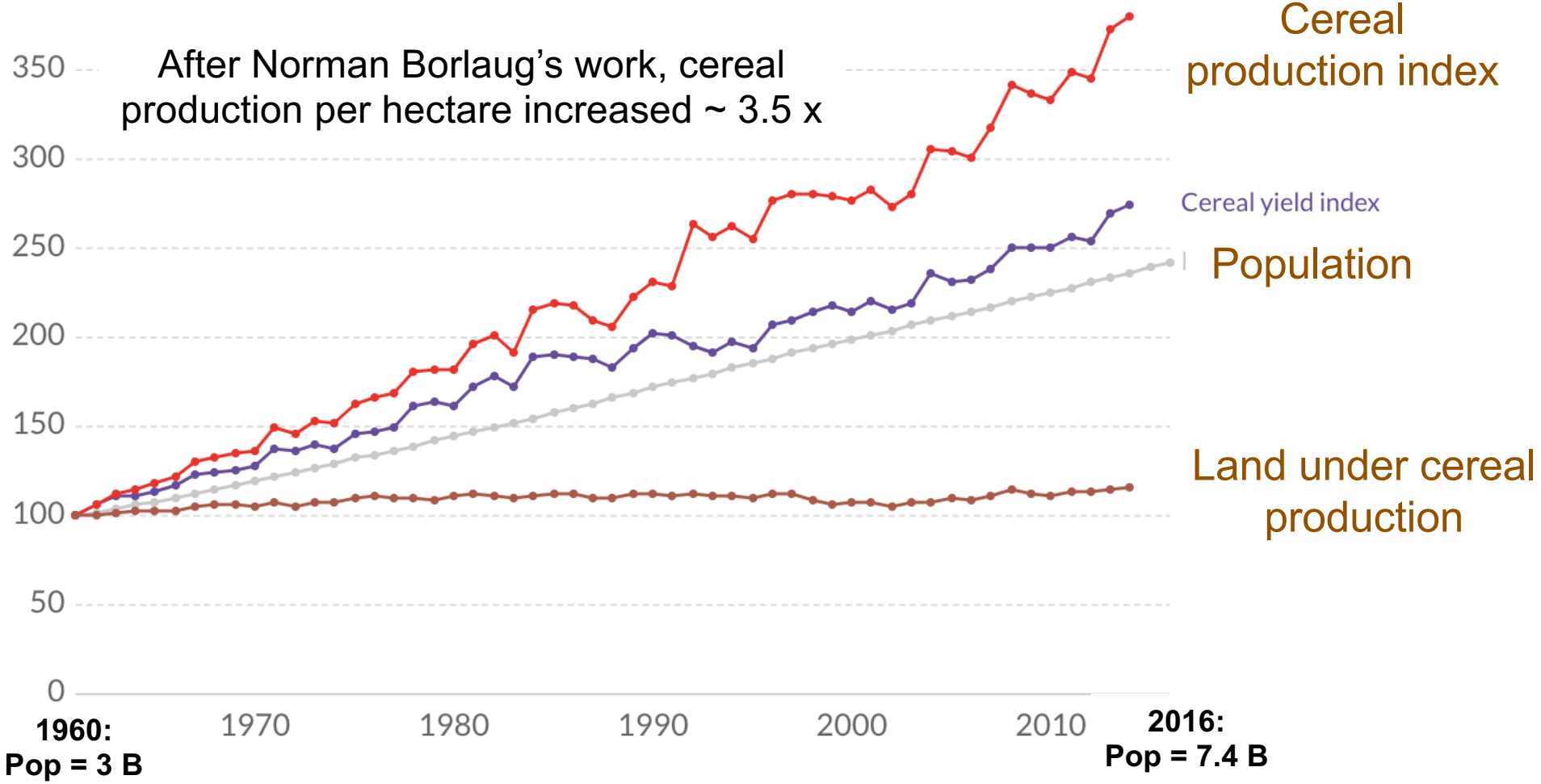
Carl Bosch: 1931

Norman Borlaug 1970 Nobel Peace Prize

Borlaug bred disease-resistant and dwarf strains of wheat (Borlaug's Mexican strain lines were susceptible to stem rust fungus) with thick stems that could support heavier kernels.

His plants didn't collapse after rapid growth spurts due to nitrogen fertilizer used in the poor soils.

World Production of Grain (1961 – 2004)



Source: Food and Agriculture Organization (FAO), United Nations

We have been genetically modifying plants and animals for over 4,000 years.

The breeding of teosinte into modern corn

Beef Cattle
(18 – 24 months)

Pigs
(22 – 26 weeks)

Average market weight of a pig: 280 lbs.

Broiler chicken
(40 days)

Turkey
(14 – 16 weeks)

Livestock have been bred to optimize early growth in a small fraction of their natural life-cycle.

Domestic turkeys (~ 3.5 months before slaughter)

Farm-bred turkeys are so breast heavy they cannot mate

Wild Turkeys

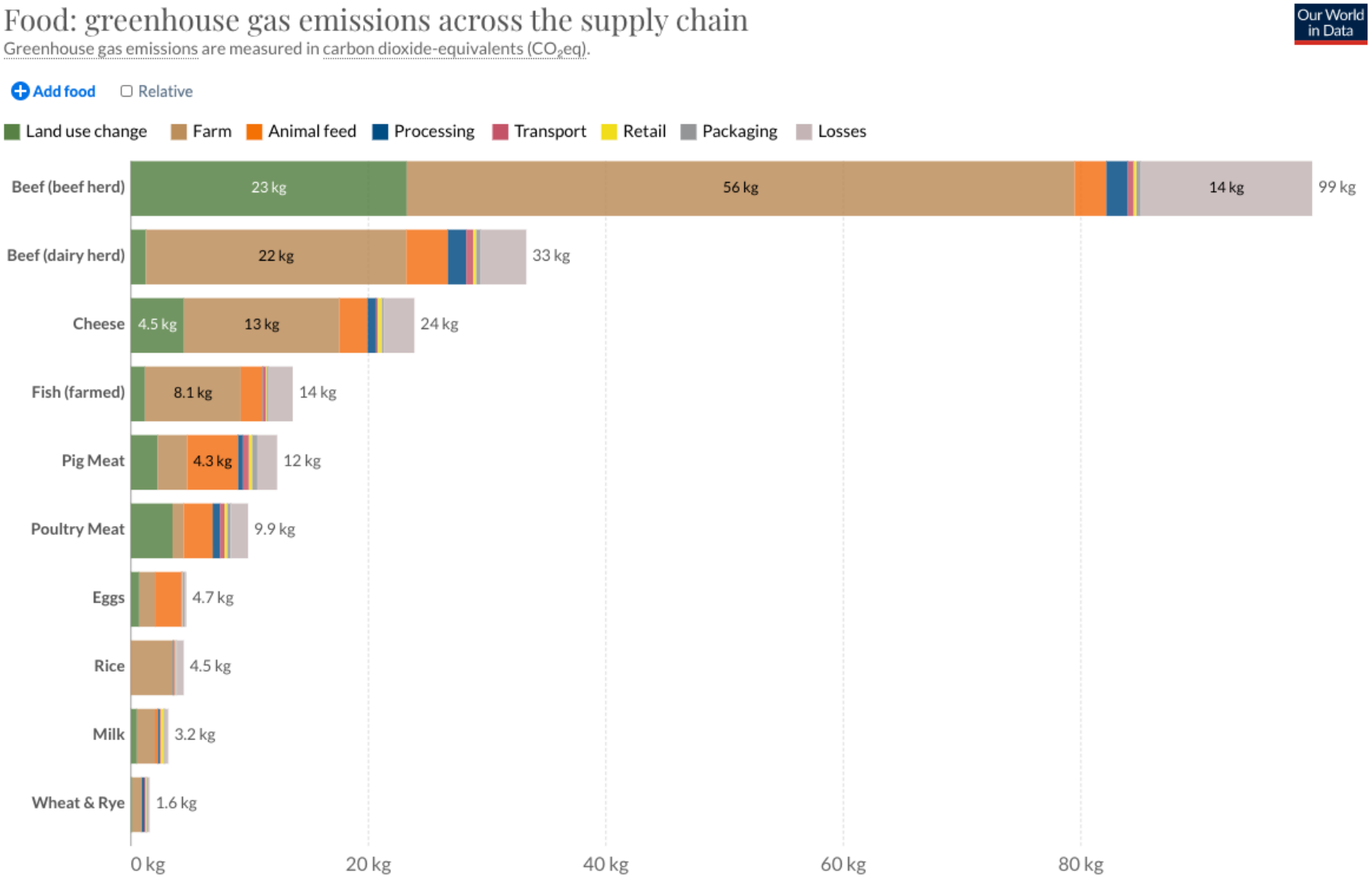
Of unknown ages

Wild Turkey (101)

Aged 8 years

Food: greenhouse gas emissions across the supply chain

Greenhouse gas emissions are measured in carbon dioxide-equivalents (CO_2eq).

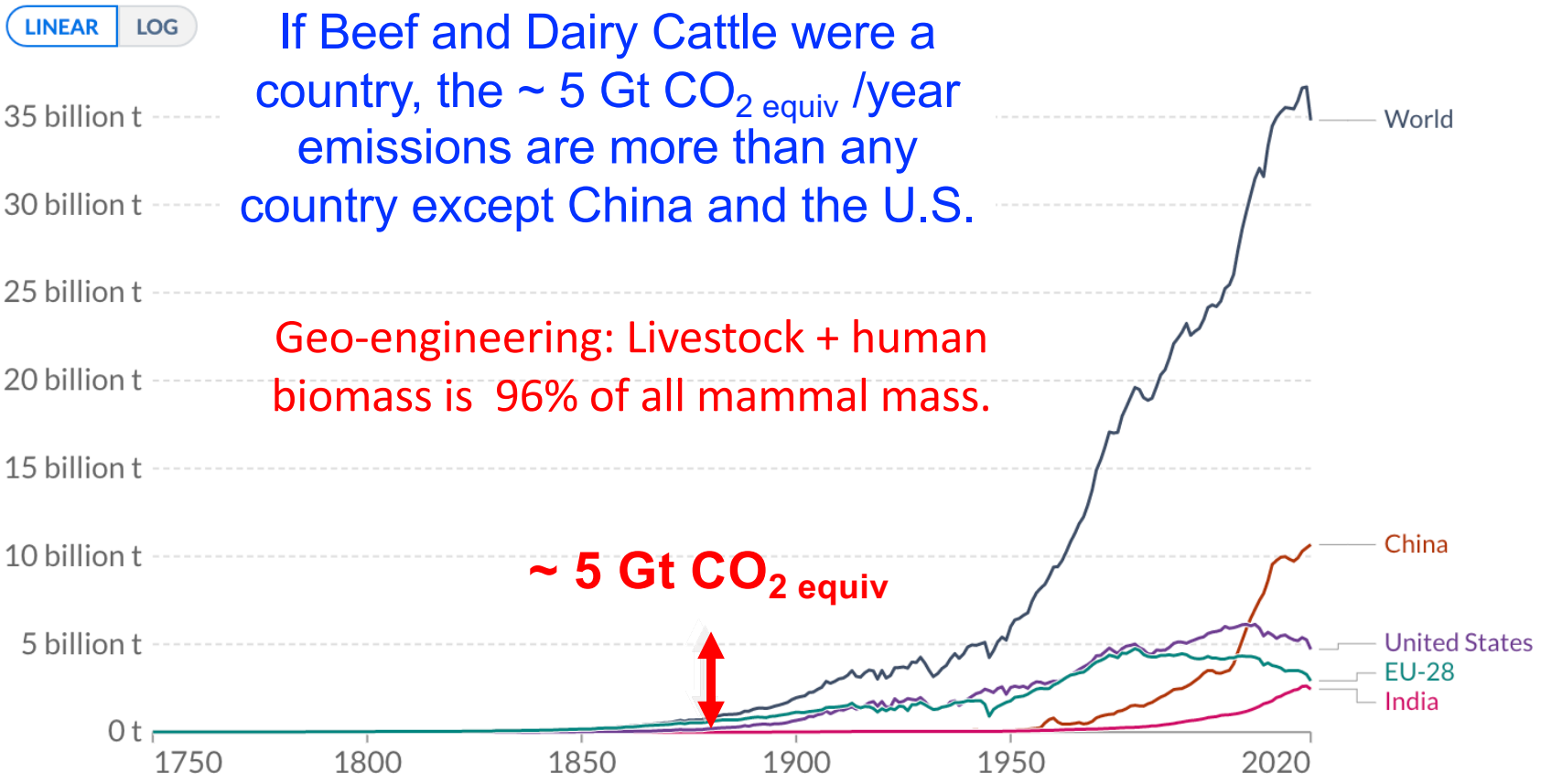


Source: Poore, J., & Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. Science.

Annual CO_2 emissions

Carbon dioxide (CO_2) emissions from the burning of fossil fuels for energy and cement production. Land use change is not included.

Our World in Data

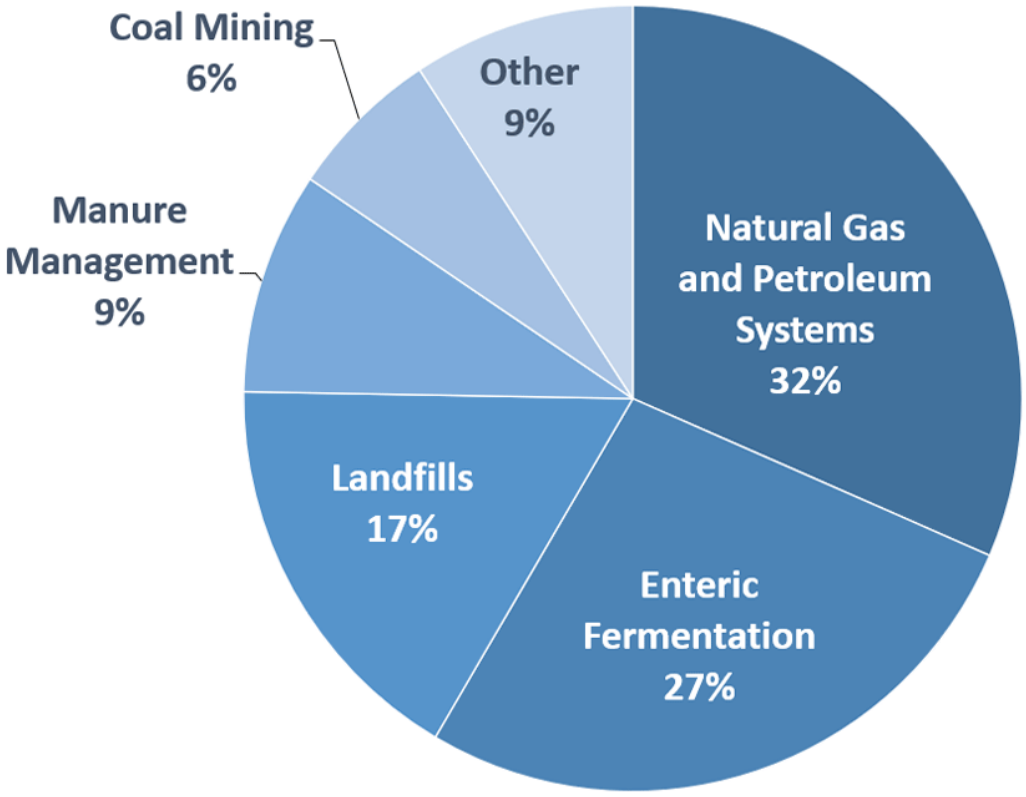


Source: Global Carbon Project

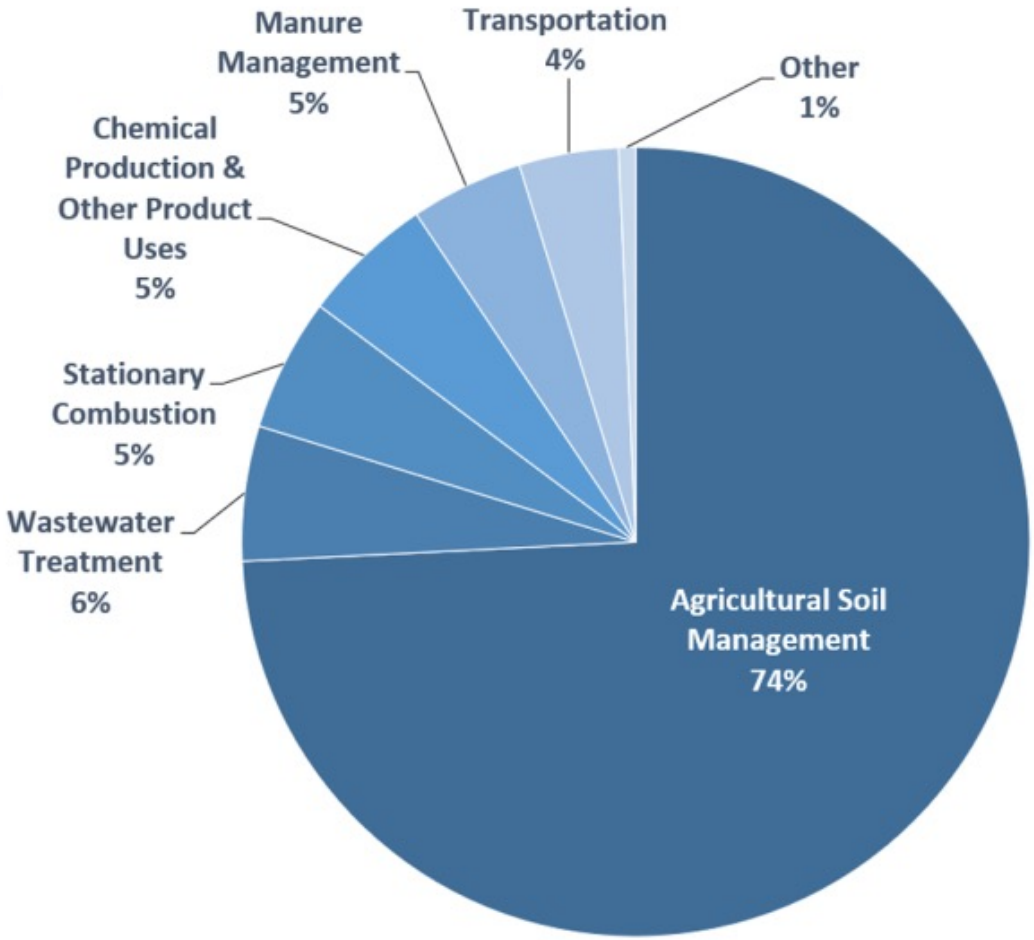
OurWorldInData.org/co2-and-other-greenhouse-gas-emissions/ • CC BY

1750 2020

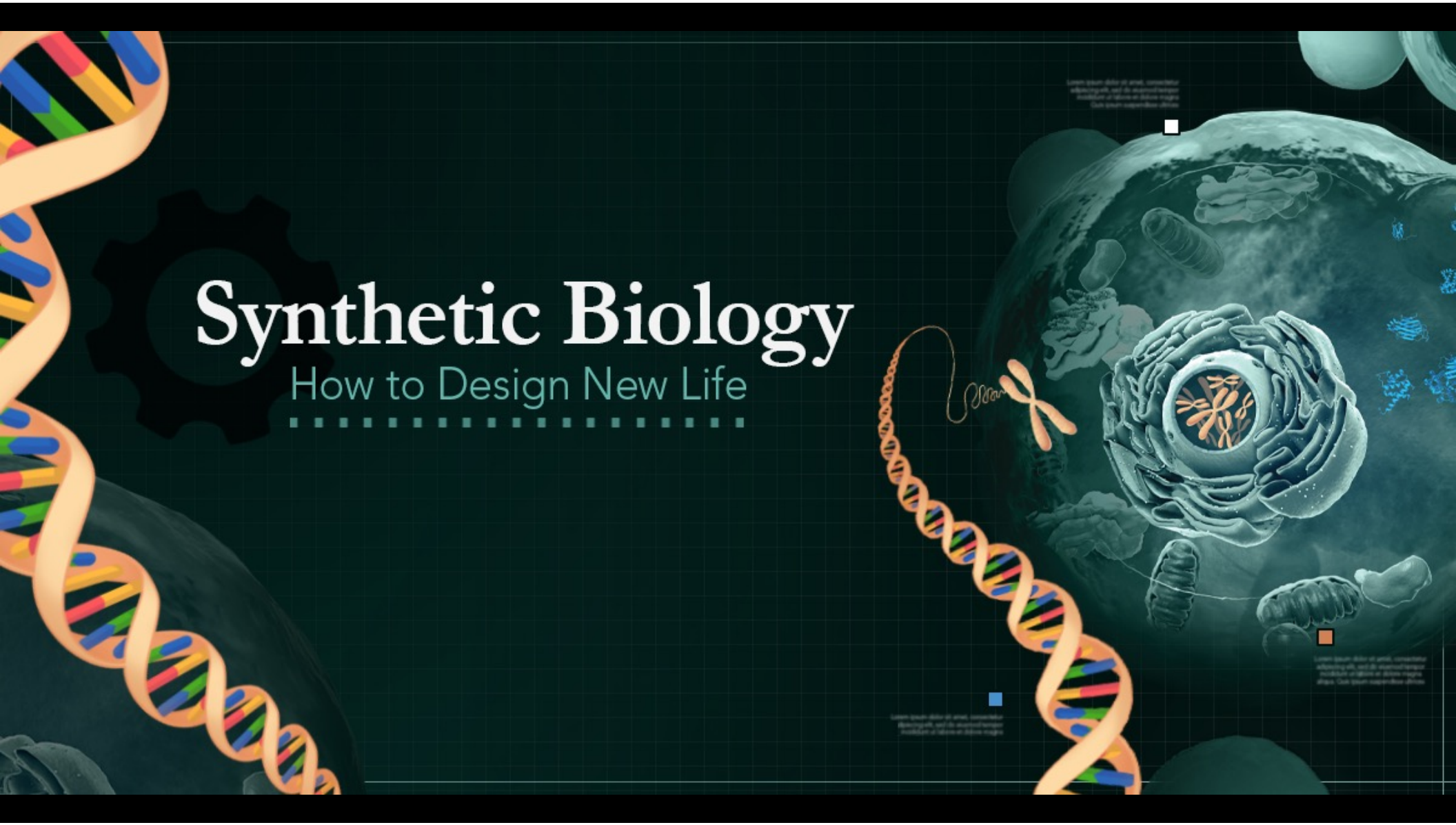
2020 U.S. methane emissions, by source



2020 U.S. nitrous oxide emissions, by source



Source: U.S. EPA

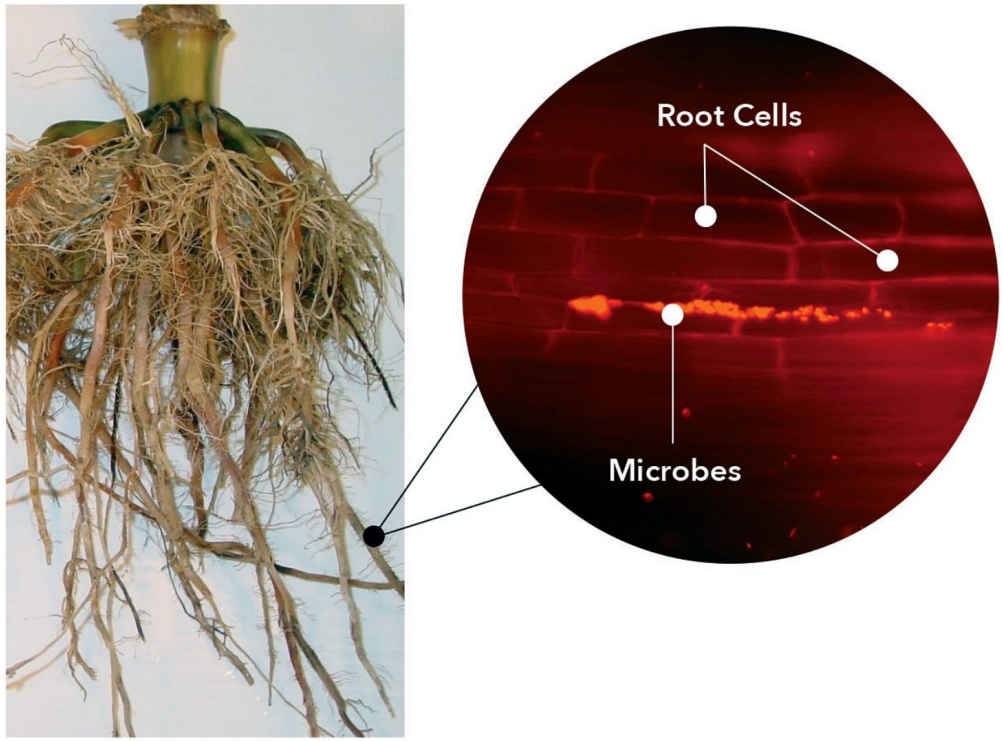

Synthetic Biology
How to Design New Life

Random mutations will not have produced BT eggplant

Eggplant is an essential food in Bangladesh (161 M people). The *eggplant fruit and shoot borer* has farmers to spray expensive and toxic insecticides more than 80 times each growing season to control the insect.

Eggplant was engineered to express a protein from a common bacterium, *Bacillus thuringiensis* (Bt). In 2013, regulatory approval was given. In 2014, 20 farmers tried the new variety. Today more than 27,000 farmers in Bangladesh grow Bt eggplant.

PIVOT BIO



Microbes used to produce nitrogen-based fertilizer on demand in the soil

PIVOT BIO

Pivot Bio microbes deliver nitrogen fertilizer to corn (right). Currently fertilizer use is reduced by one half; wider adoption if most of fertilizer can be replaced. Microbes that can develop symbiotic relationships with all major grains is the goal.

- Investigate ***all*** the genes of the microbe
- Use Robots for repeatable results
- Use machine-learning to analyze the next step in gene reprograming

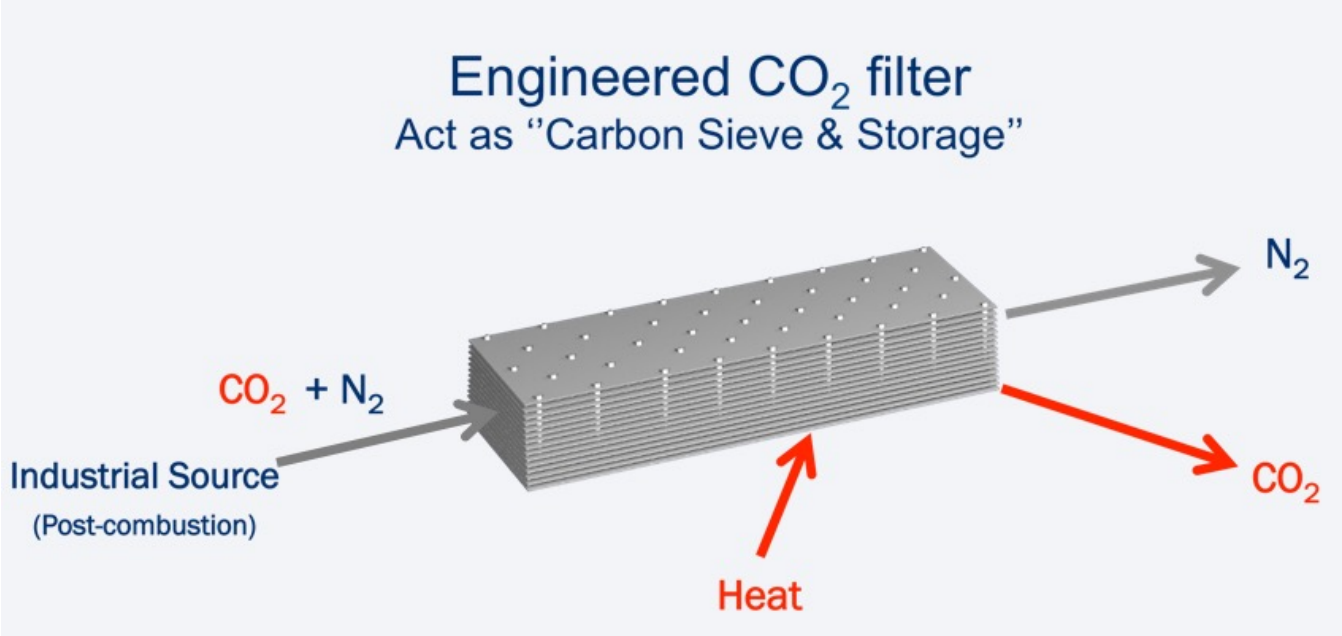
Current synthetic biology technology allow the insertion of only one gene at a time. If dozens of genes can be inserted with reasonable cell survivability, the optimization would increase exponentially.

My lab has developed methods to insert λ-phage DNA (48k base pairs) with very high cell survival. When this technology is proven for microbial and plant cells, the speed of synthetic biology could leap forward.

Greenhouse gas capture from all major sources ***and*** the atmosphere will be essential

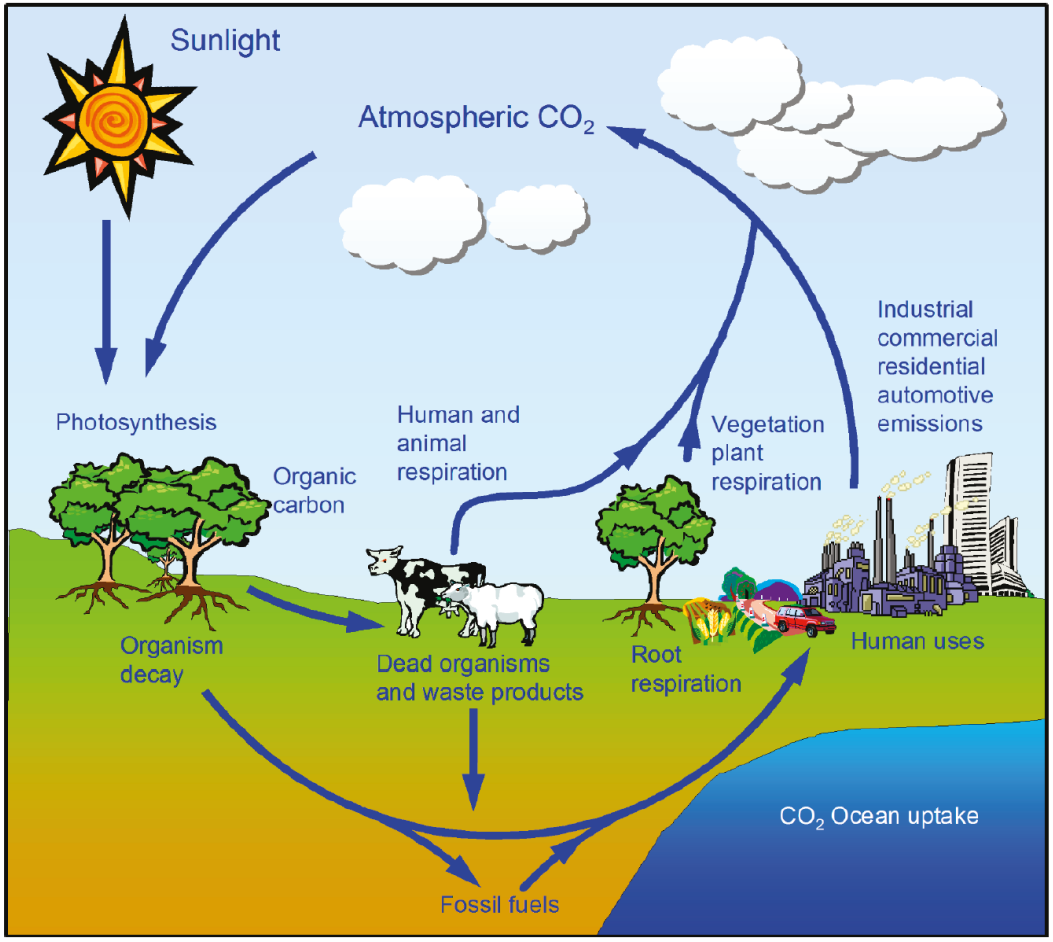
Svante

Carbon capture at half the cost of today's technology?



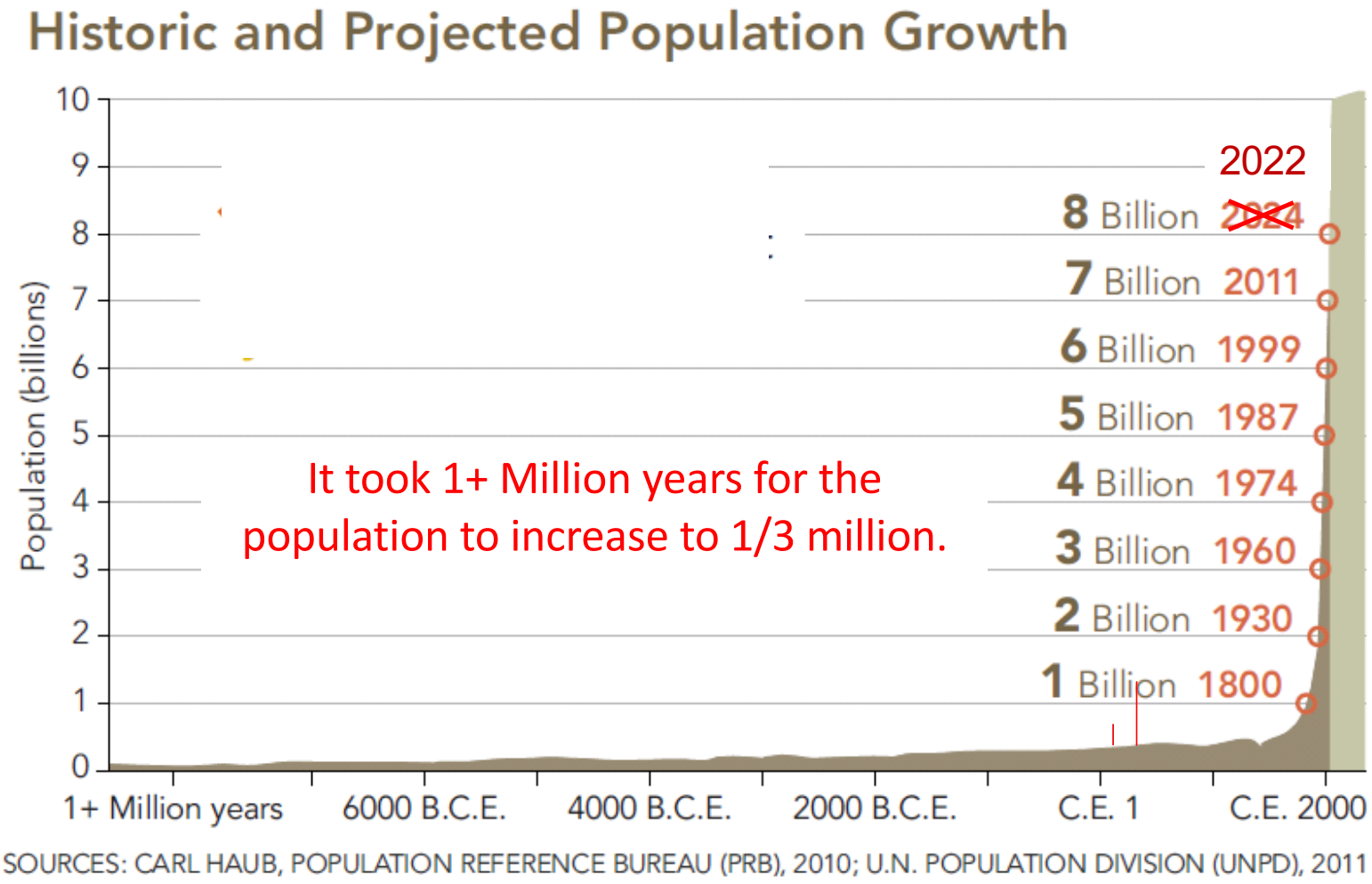
Crops capture 30 $GtCO_2$ /year. Pasture: 48 $GtCO_2$

Total Global human emissions ~ 40 $GtCO_2$



The burial of compacted biomass from residual biomass form food and plants grown capture carbon ~5x more biomass per hectare) is may provide a partial solution.

How long can we postpone an inevitable population crisis?



Source: Science **333,** 489-660 (2011)

Increased economic prosperity of virtually all countries is based on having more young workers to support a smaller aging population.

"Ponzi" scheme

A Ponzi scheme is a form of **fraud** that lures investors and pays profits to earlier investors with funds from more recent investors. The victims to believe that profits are coming from legitimate business activity and are unaware that other investors are the source of funds.

A Ponzi scheme can maintain the illusion of a sustainable business as long as more new investors contribute new funds.

People all over the world are choosing to have fewer or no children. We should let the population decline naturally instead of offering rewards (e.g. tax incentives) to have more children.

We need a different measure of “wealth”.

We need a new model of how to have a rising standard of living that does not rely on population growth and increased production and consumption of “stuff.”

What do we care about in our lives?

We want to feel our family, friends, neighborhoods are safe, and our country is safe from hostile takeover. We want maintain our health and vitality in old age, remain emotionally connected vitality, and continue to learn and broaden our horizons in old age.

Robert Kennedy (March, 1968, one month before his assassination)

“The gross national product does not allow for the health of our children, the quality of their education or the joy of their play. It does not include the beauty of our poetry or the strength of our marriages, the intelligence of our public debate or the integrity of our public officials. It measures neither our wit nor our courage, neither our wisdom nor our learning, neither our compassion nor our devotion to our country, it measures everything in short, except that which makes life worthwhile.

Extra slides

"Have you ever tried buying lots of stuff?"

Clean electricity at 1¢ – 1.5 ¢/kWh may become a reality in 10-20 years at the best sites in the world.

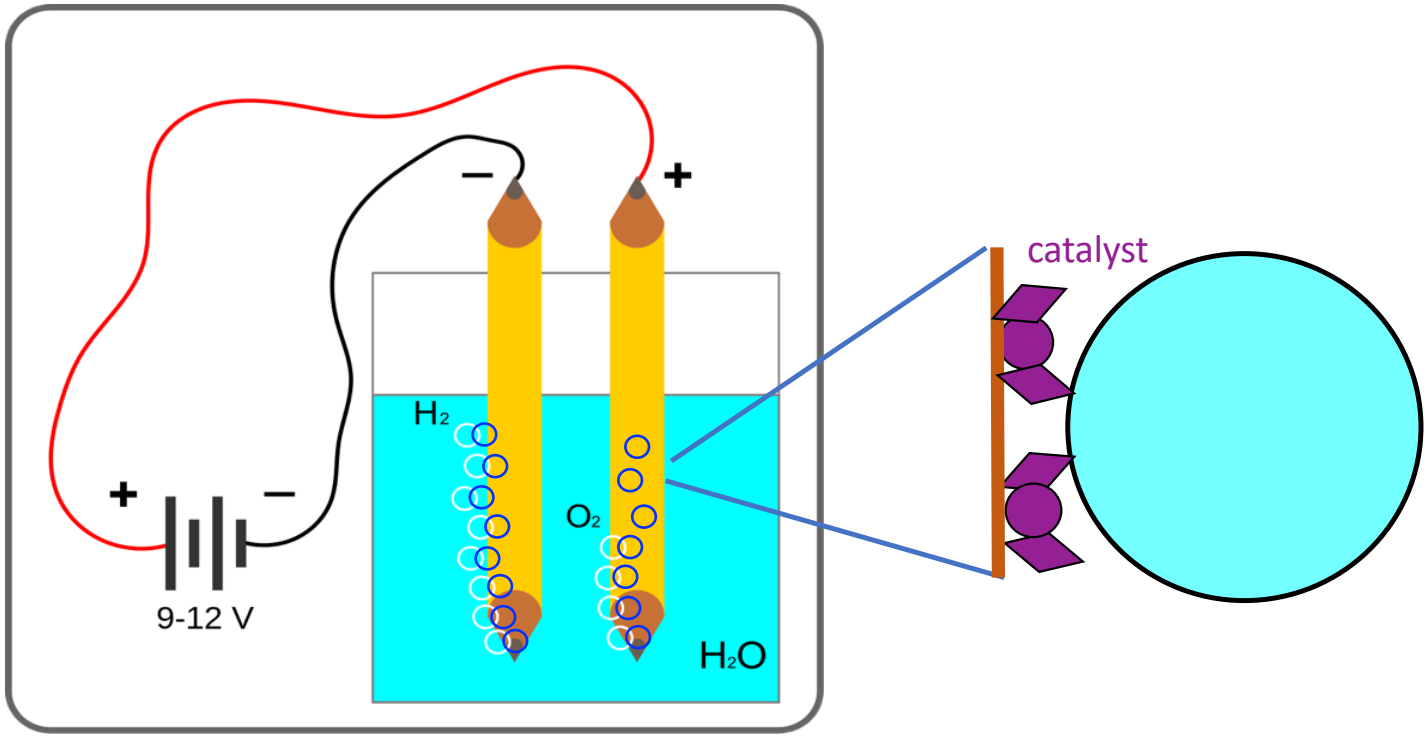
This opens up exciting opportunities in electrochemistry.

Electrolysis of water

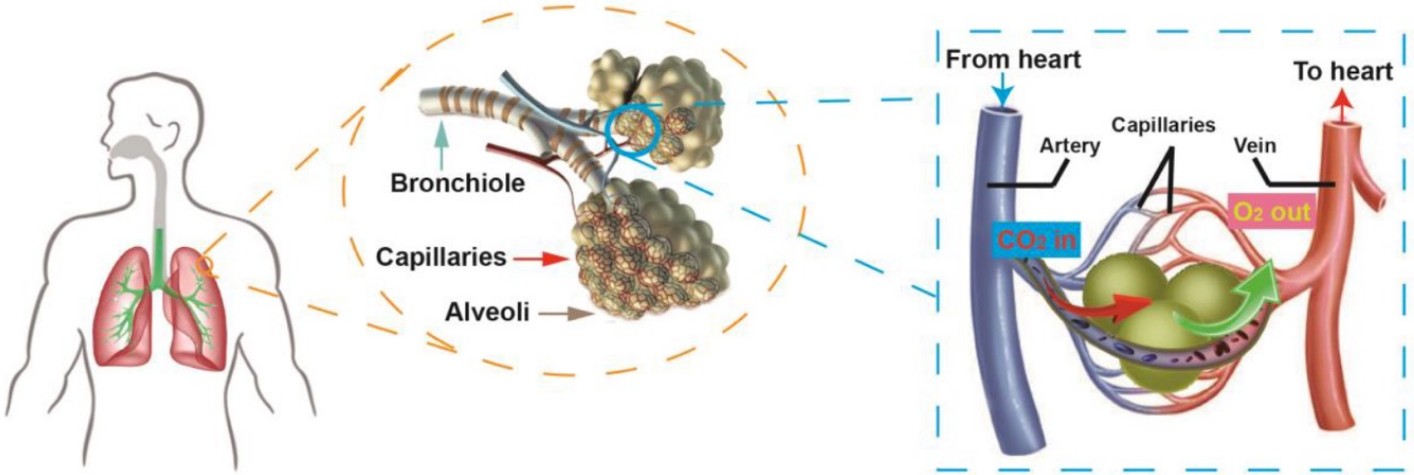
Cathode (reduction): H_2O (liq.) + $2e^-$ → H_2 (gas)+ 2 OH^-(aq)

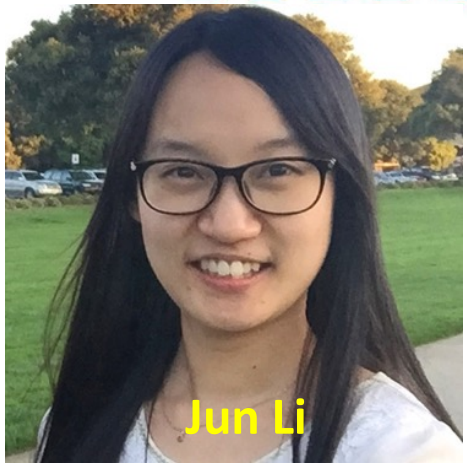
Anode (oxidation): 2 OH^-(aq) → ½ O_2 (gas) + H_2O (liq.) +$2e^-$

(Note: OH- ions have to move from the cathode to the anode



Jun Li … Steven Chu and Yi Cui





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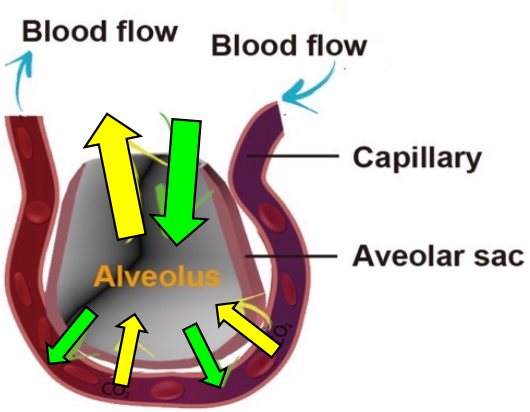
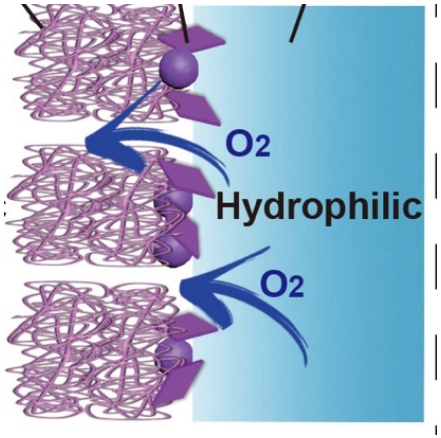
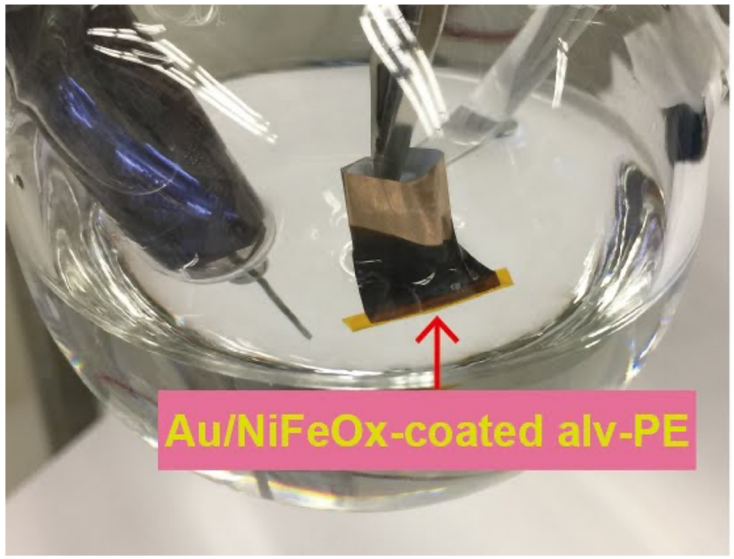
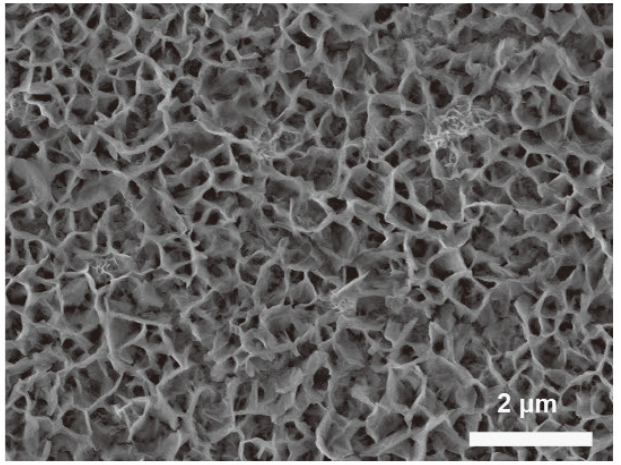


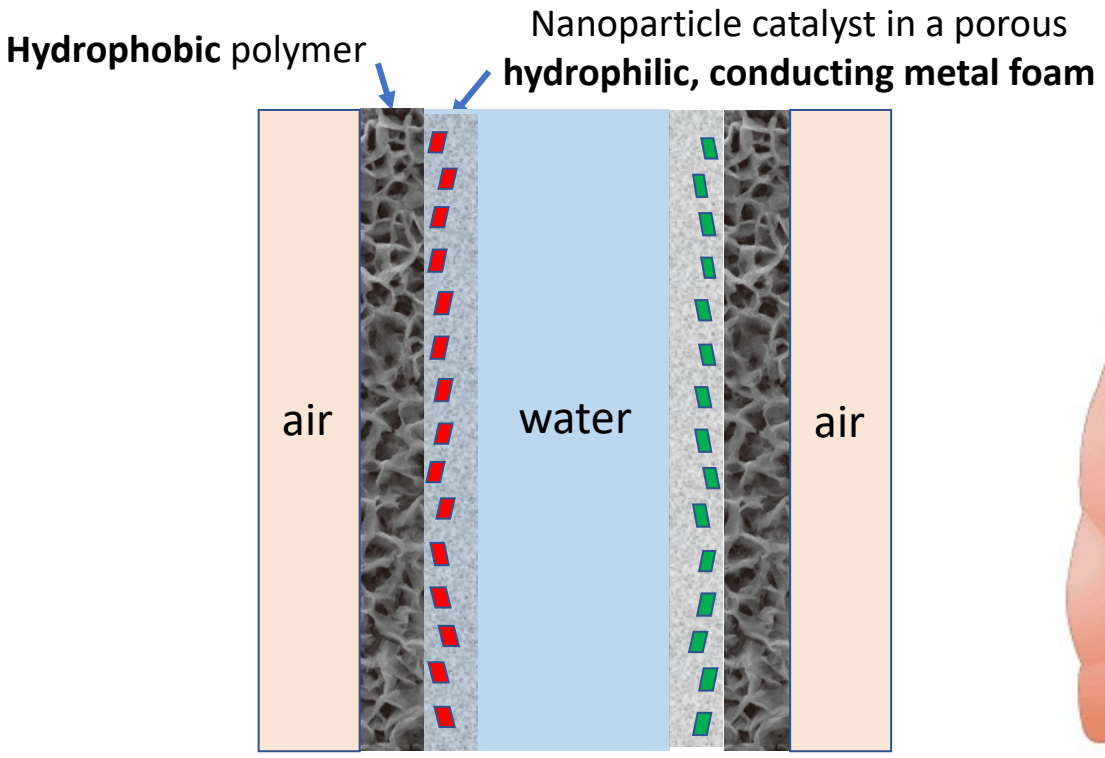


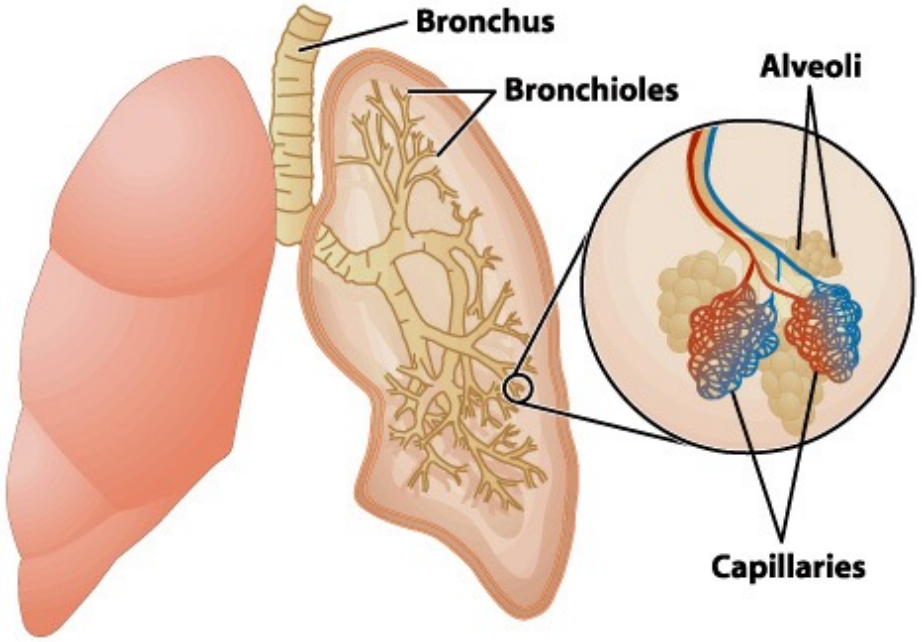


hydrophobic polyethylene



As the gap between electrodes decreases, the drift velocity of the OH^- ions increases

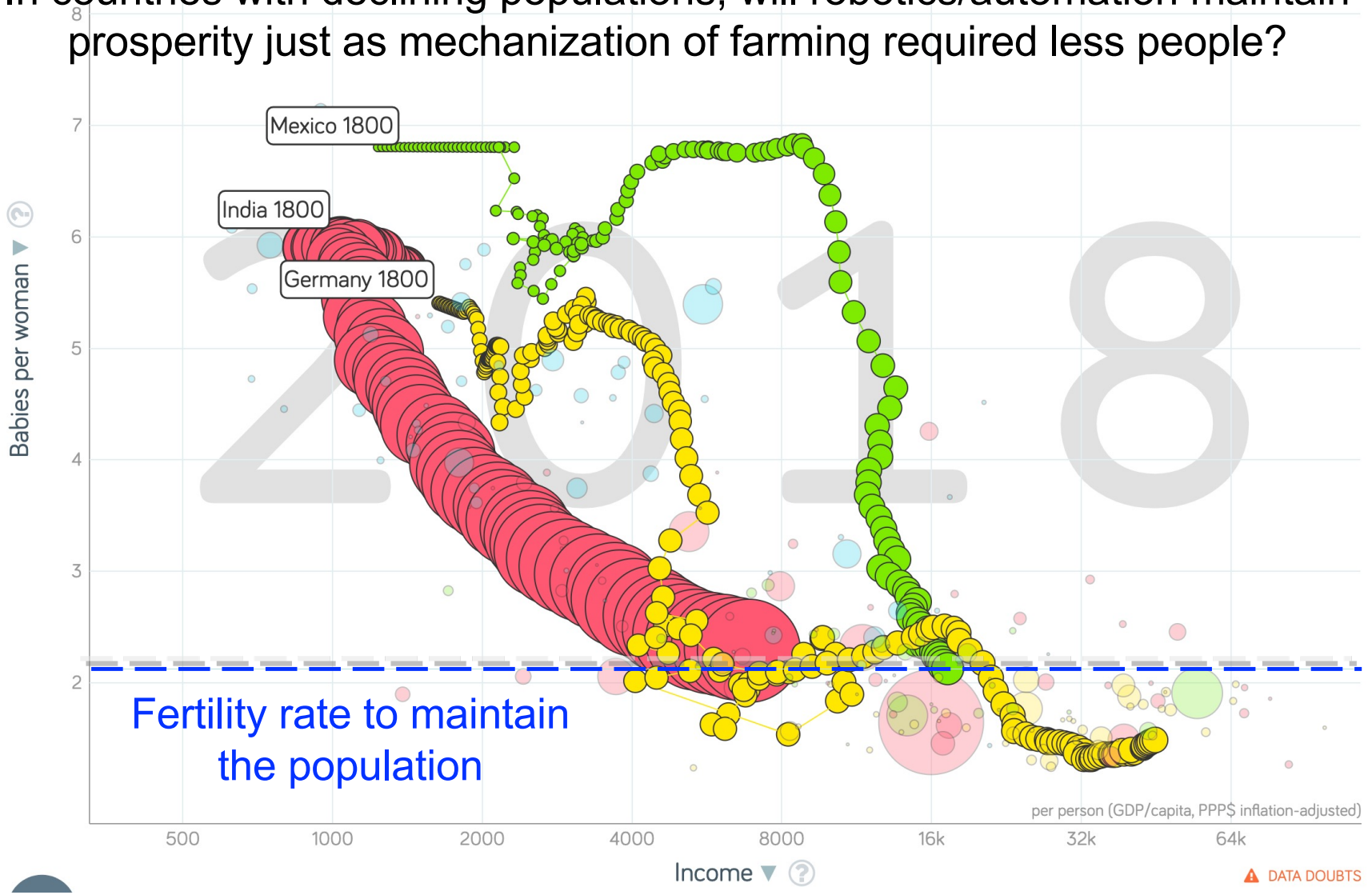




If we want a more sustainable world,

the world population cannot continue to increase.

In countries with declining populations, will robotics/automation maintain prosperity just as mechanization of farming required less people?



In addition to accepting the stabilization and decline of population, the world needs a different measure of the "wealth."

As long as we use GDP as the measure of a country's wealth, the increased production and consumption of "stuff"

The Human Development Index (the logarithm of GDP/person, longevity and level of education) is a step in the right direction.

A better definition of **"wealth"** would include quality of health in old age, low level of stress, enhanced connections to family and friends.

In the transition to mechanized farming, fewer farmers are needed.

Displaced workers migrated to cities and manufacturing jobs.

Re-defining wealth and robot-assisted jobs – including assisted living may be a solution allow us to have increasingly better lives, provide quality care to an aging population, and of how to break the global pyramid-scheme.

Impossible Food Burger

Beyond Meat Burger

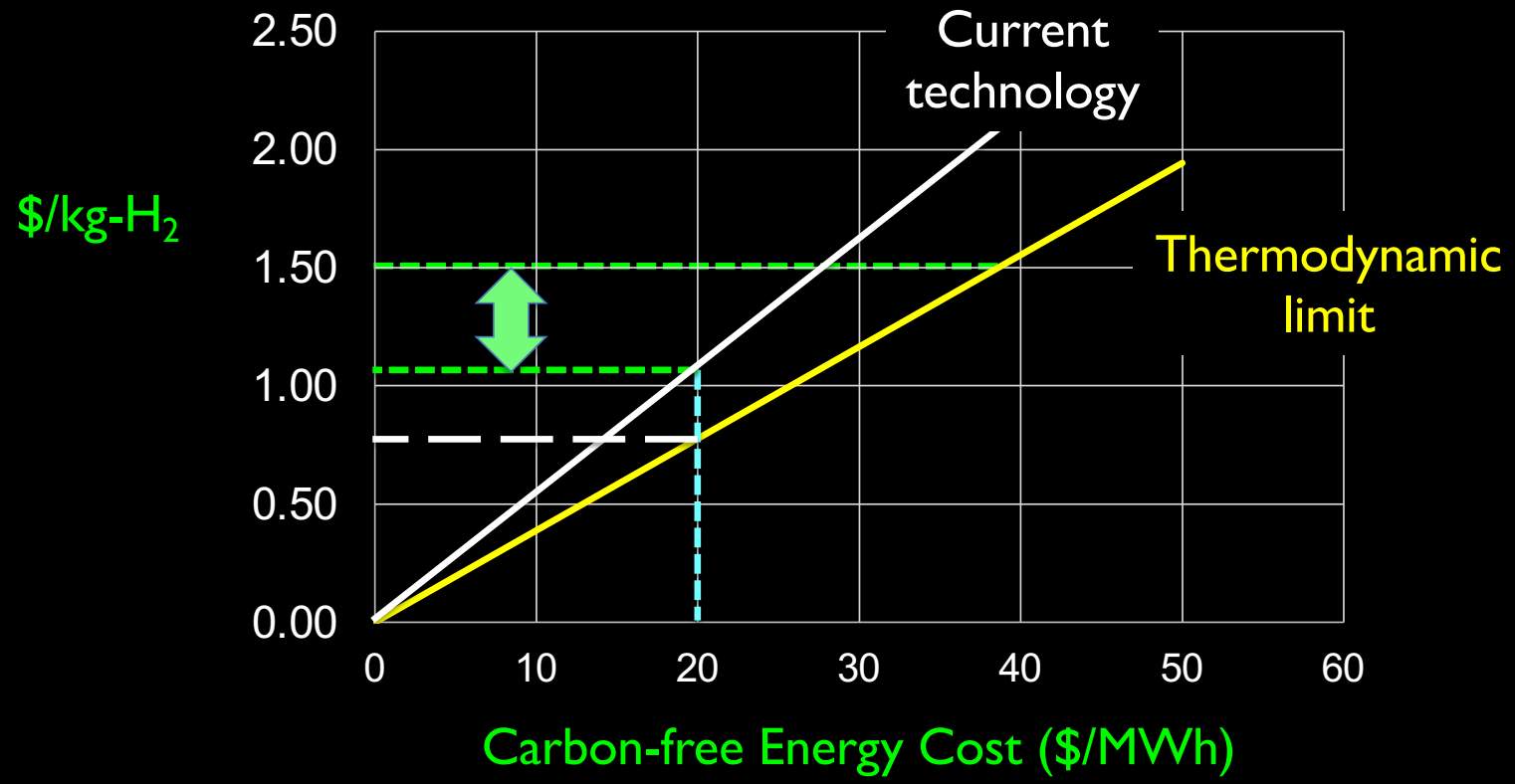
Blood taste from **hemoglobin-like molecules** derived from plants. Juices released from **myosin** molecules.

The minimum voltage for electrolysis of water ($H_20 = H_2 = ½ O_2$) = 1.23 volts

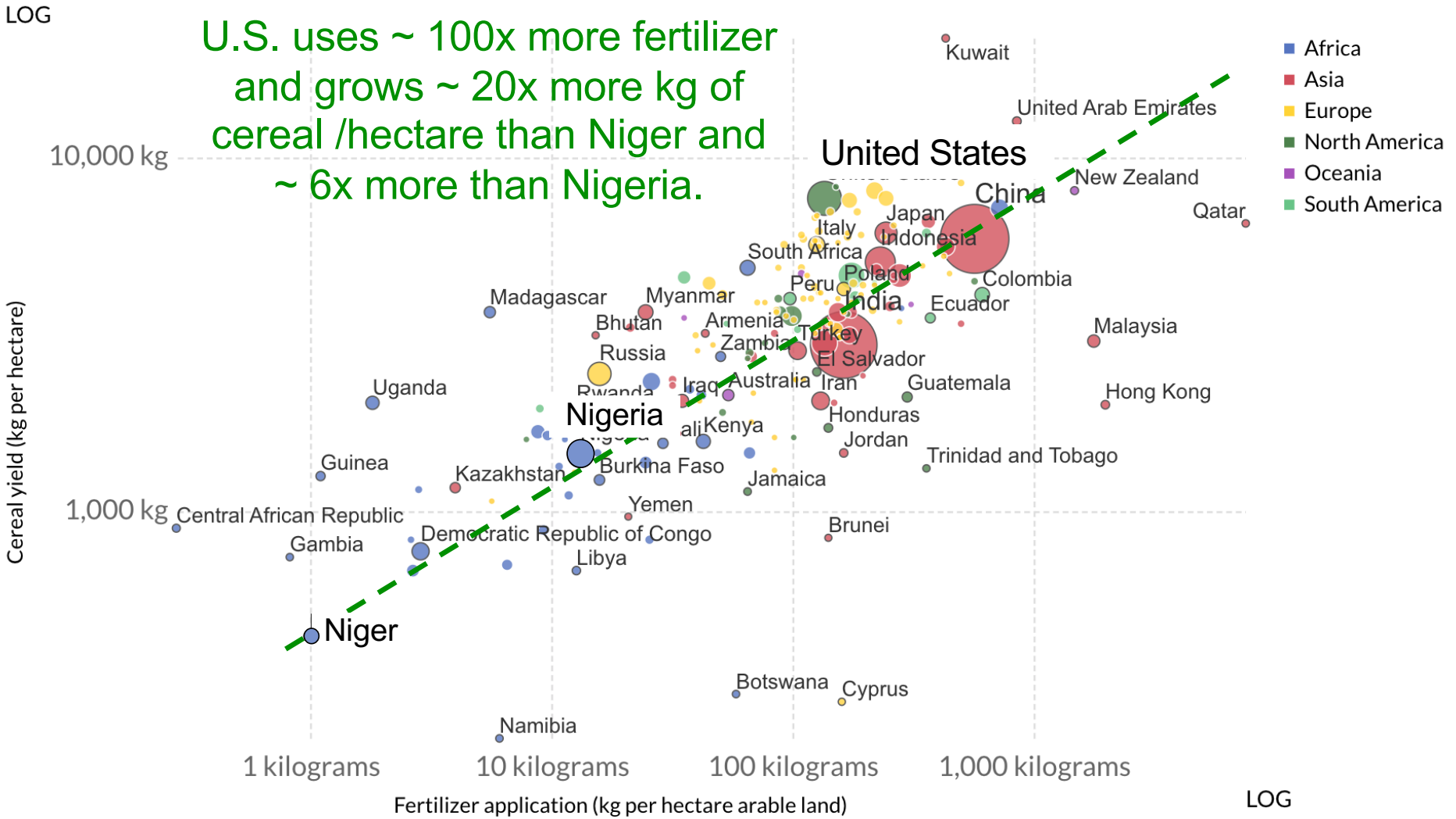
At least 32.9 kWh of energy is needed to produce 1 kg of hydrogen

Current electrolyzers are ~ 60% efficient.

At 1.5 ¢ / kWh, the energy is only half the cost of producing H_2.

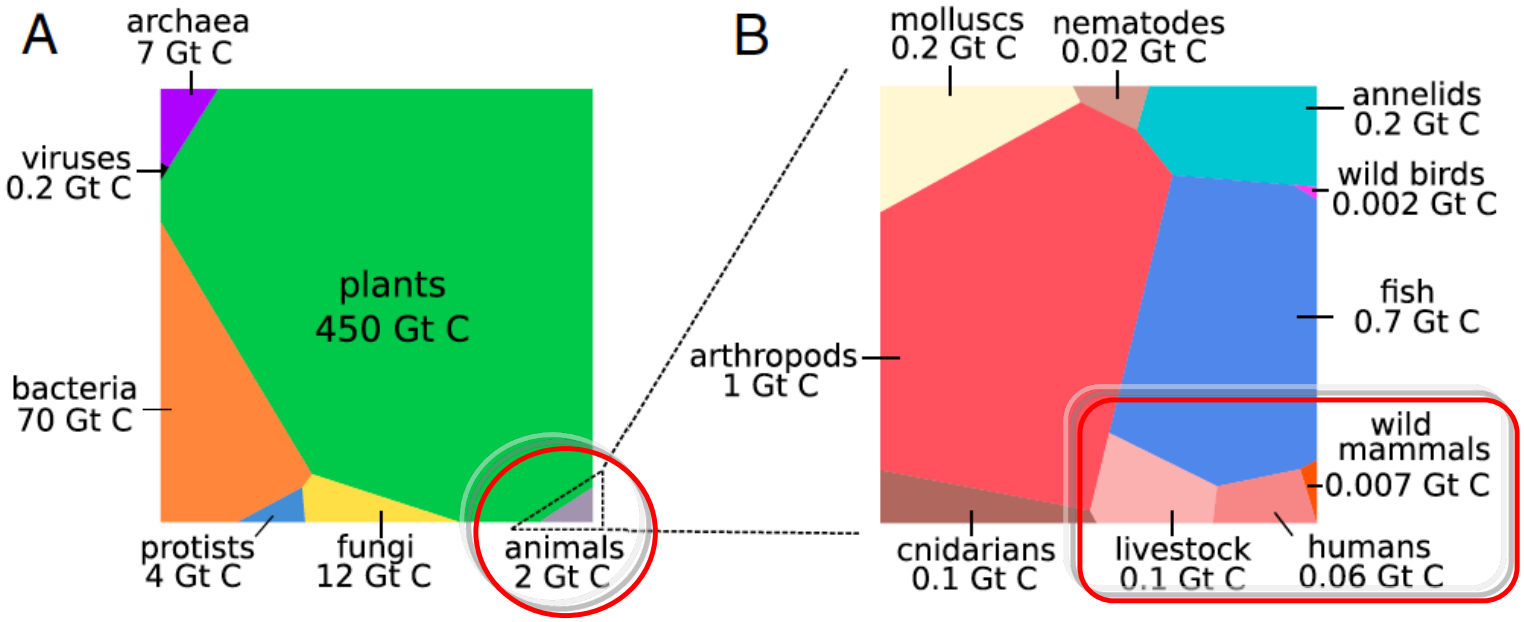


Cereal crop yield vs. fertilizer application (2014)



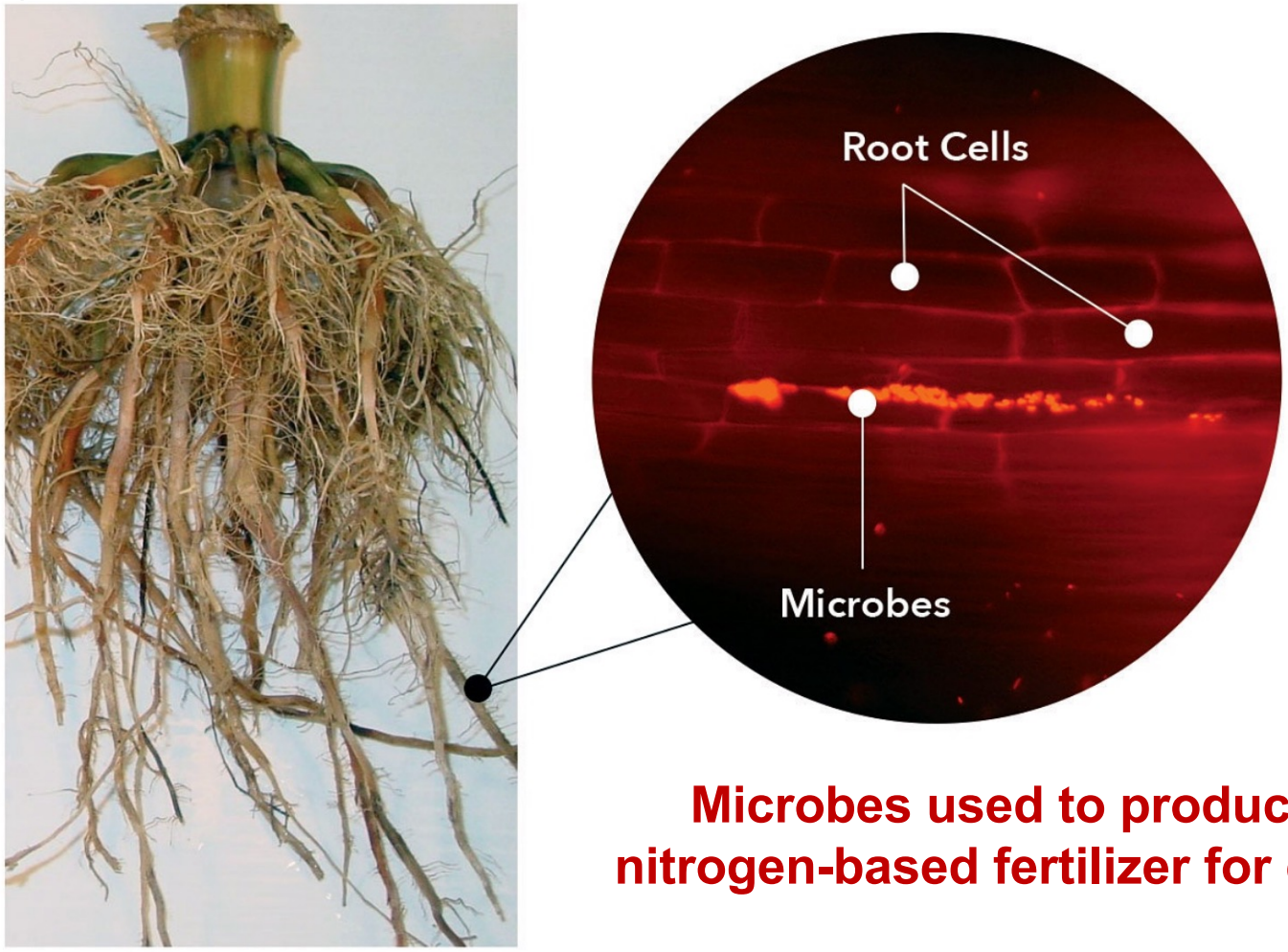
The Biomass Distribution on Earth

- **Arthropods:** Spiders, insects, millipedes, crustaceans, …
- **Livestock + human biomass is 96% of all mammal mass.**



Source: "The biomass distribution on Earth," Yinon Bar-Ona, Rob Phillips, Ron Milo, PNAS (2018), www.pnas.org/cgi/doi/10.1073/pnas.1711842115

PIVOT BIO

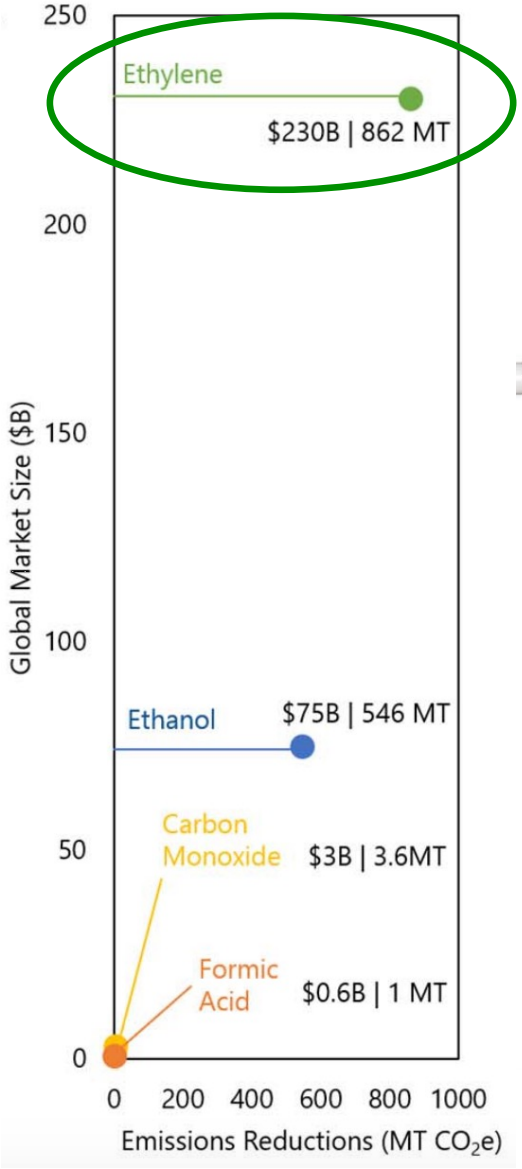


Microbes used to produce nitrogen-based fertilizer for corn

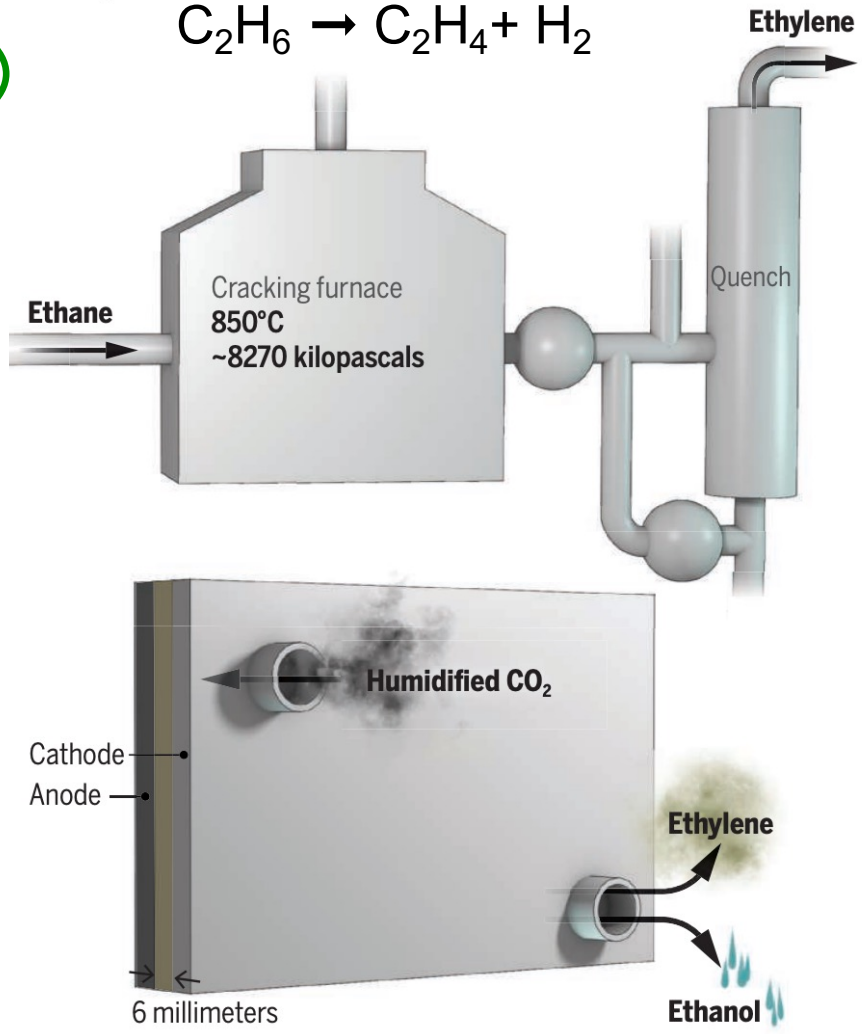
"What would it take for renewably powered electrosynthesis to displace petrochemical processes?"

Science **364**, eeav3506 (2019)

Thomas Jaramillo, Edward Sargent

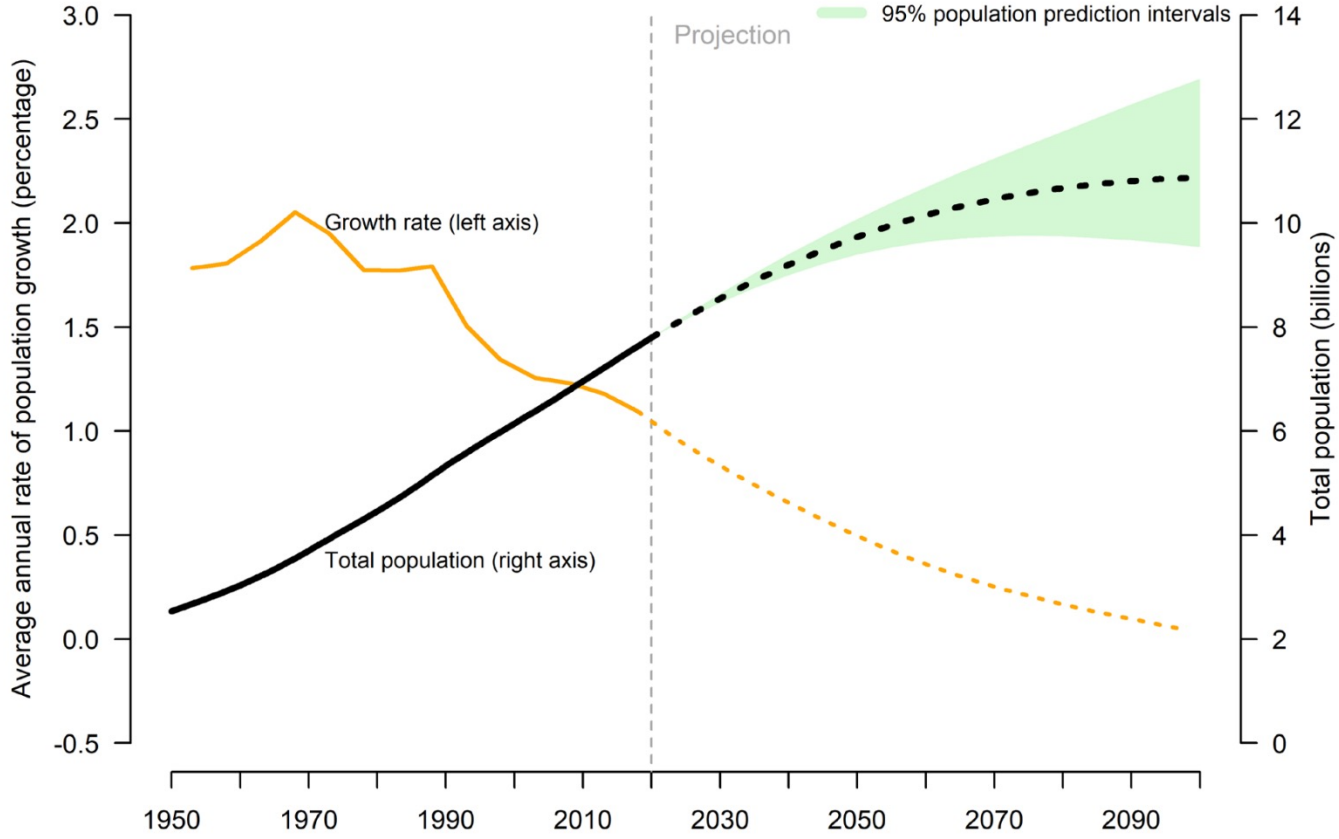


$C_2H_6 \rightarrow C_2H_4 + H_2$



$H_2O + CO_2 \rightarrow C_2H_4 + C_2H_5OH$

The world population (currently 7.7 B) may peak at 11 B at 2100



Source: U.N. Dept. of Economic and Social Affairs Population Division, World Population

IPCC 2019 Report: The Ocean and Cryosphere in a Changing Climate