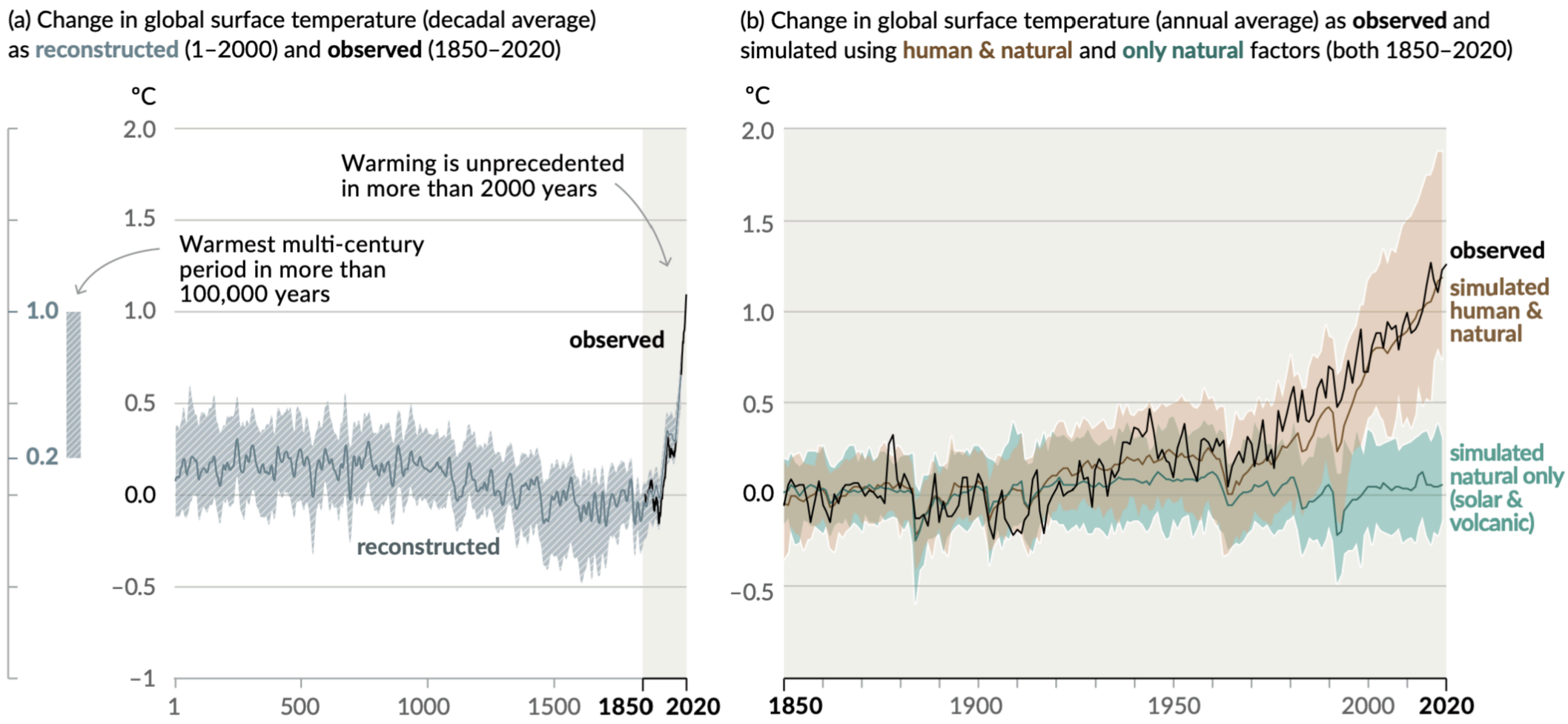
Fusion and Climate Change

Prof Ralf Kaiser

The Abdus Salam
International Centre
for Theoretical Physics

CLIMATE CHANGE IS REAL



Source: IPCC WG1 Physical Science Basis, 2021

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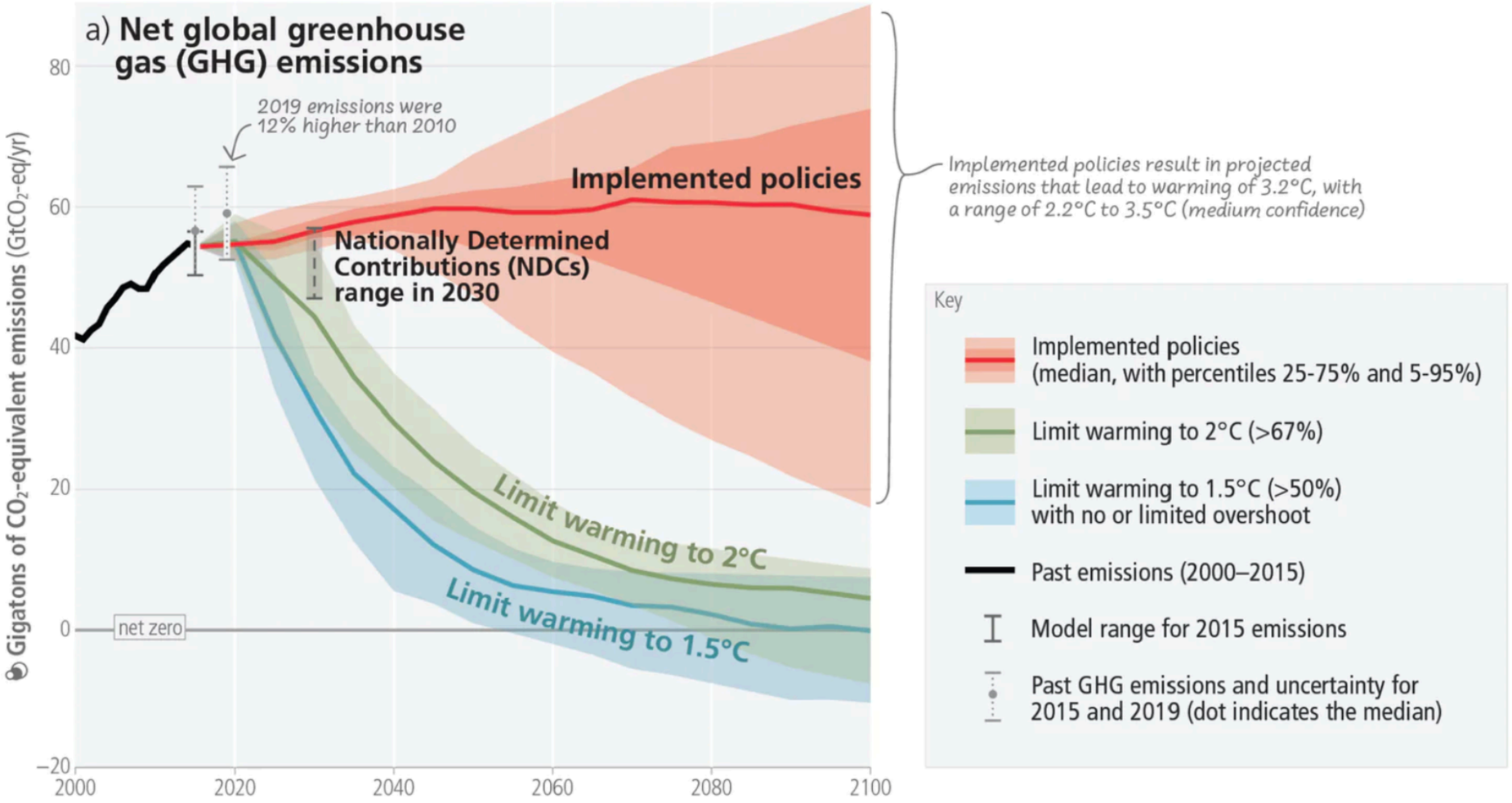
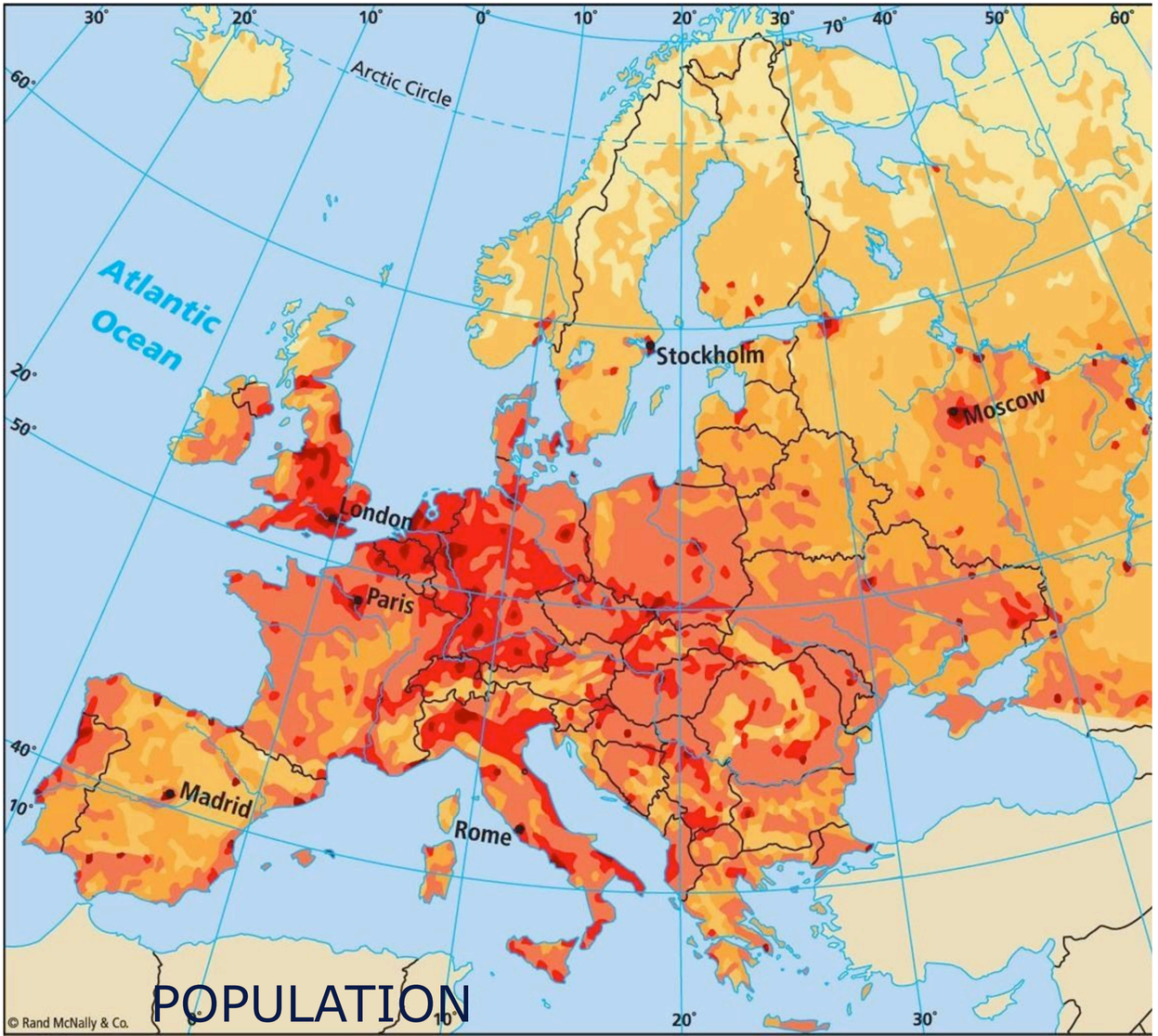


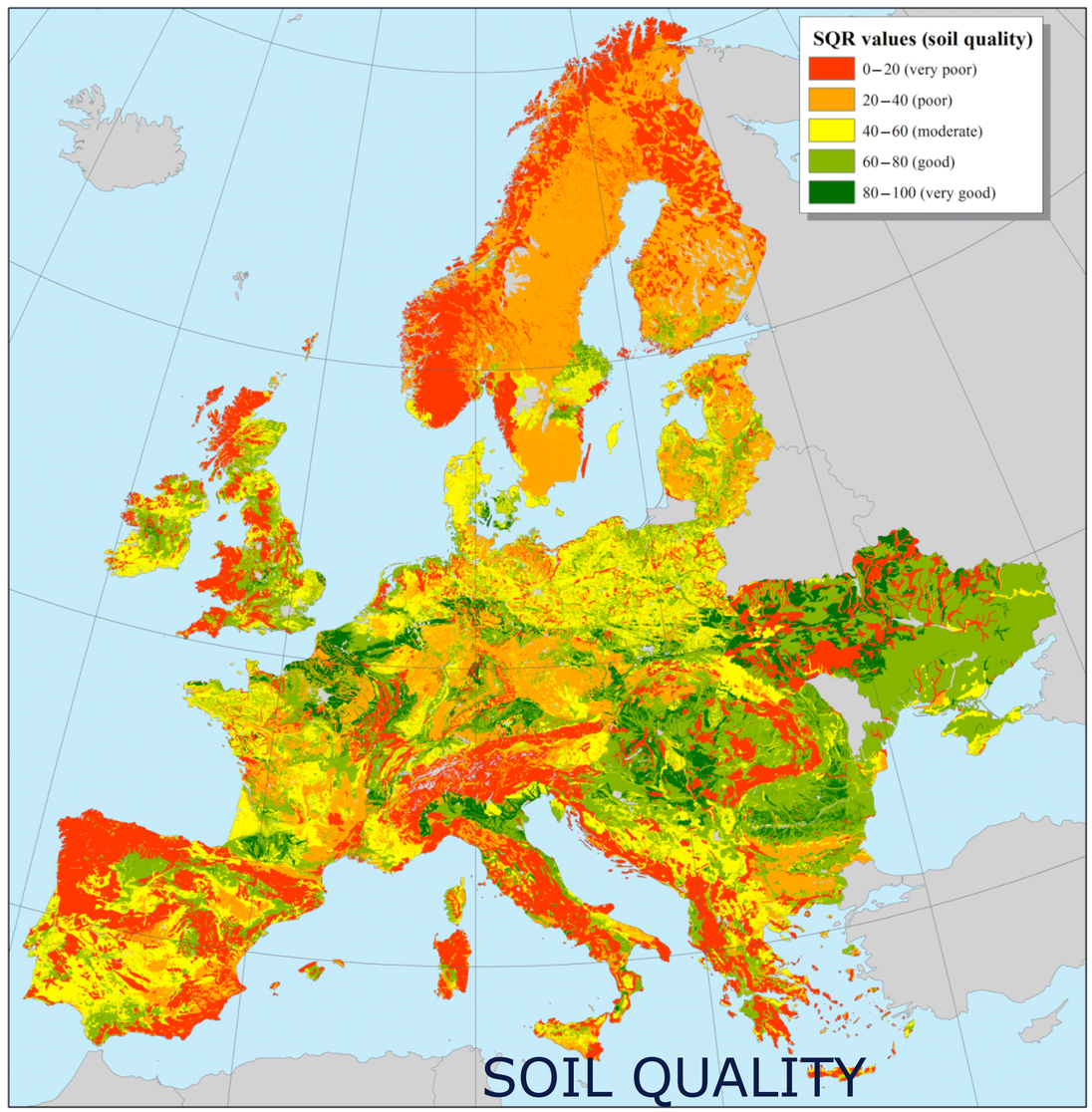
Source: IPCC AR6 SYR, Summary for Policy Makers, 2021

CLIMATE CHANGE

PEOPLE LIVE WHERE FOOD AND WATER ARE



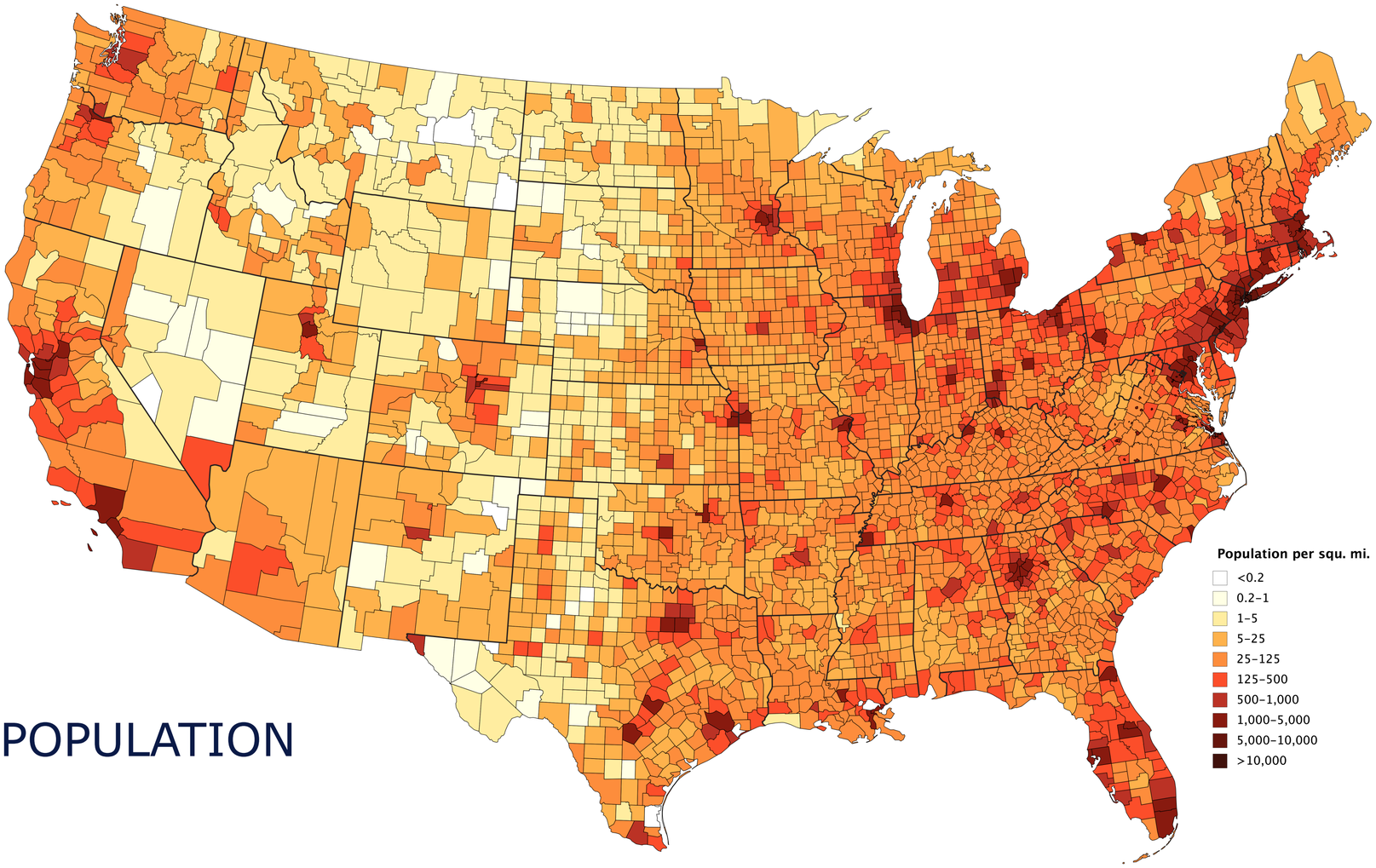
POPULATION



SOIL QUALITY

CLIMATE CHANGE

PEOPLE LIVE WHERE FOOD AND WATER ARE



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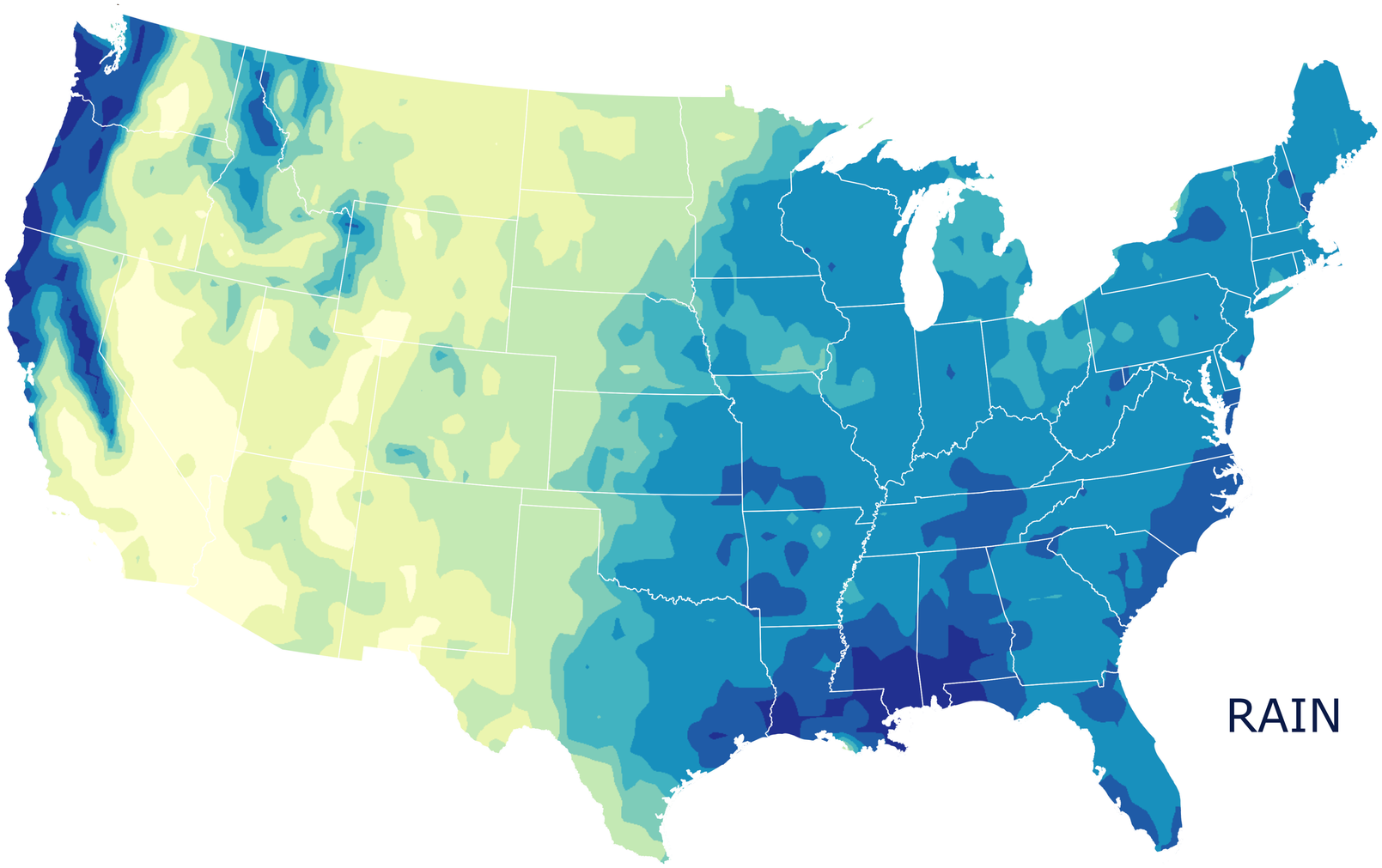
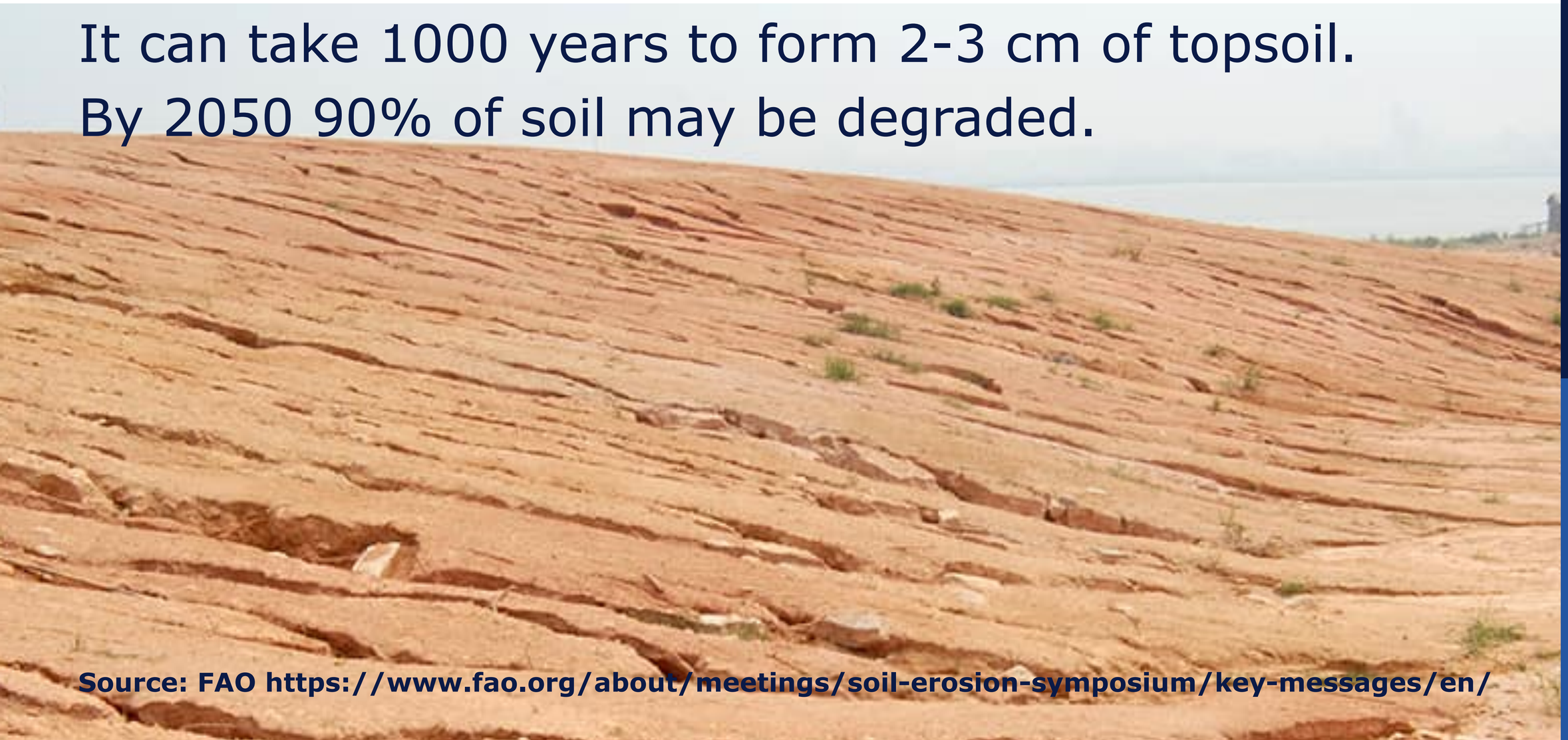


IT GETS WORSE FASTER THEN IT GETS BETTER

It can take 1000 years to form 2-3 cm of topsoil.
By 2050 90% of soil may be degraded.



Source: FAO https://www.fao.org/about/meetings/soil-erosion-symposium/key-messages/en/

WHY CLIMATE CHANGE IS BAD

Food becomes scarce: Famine.

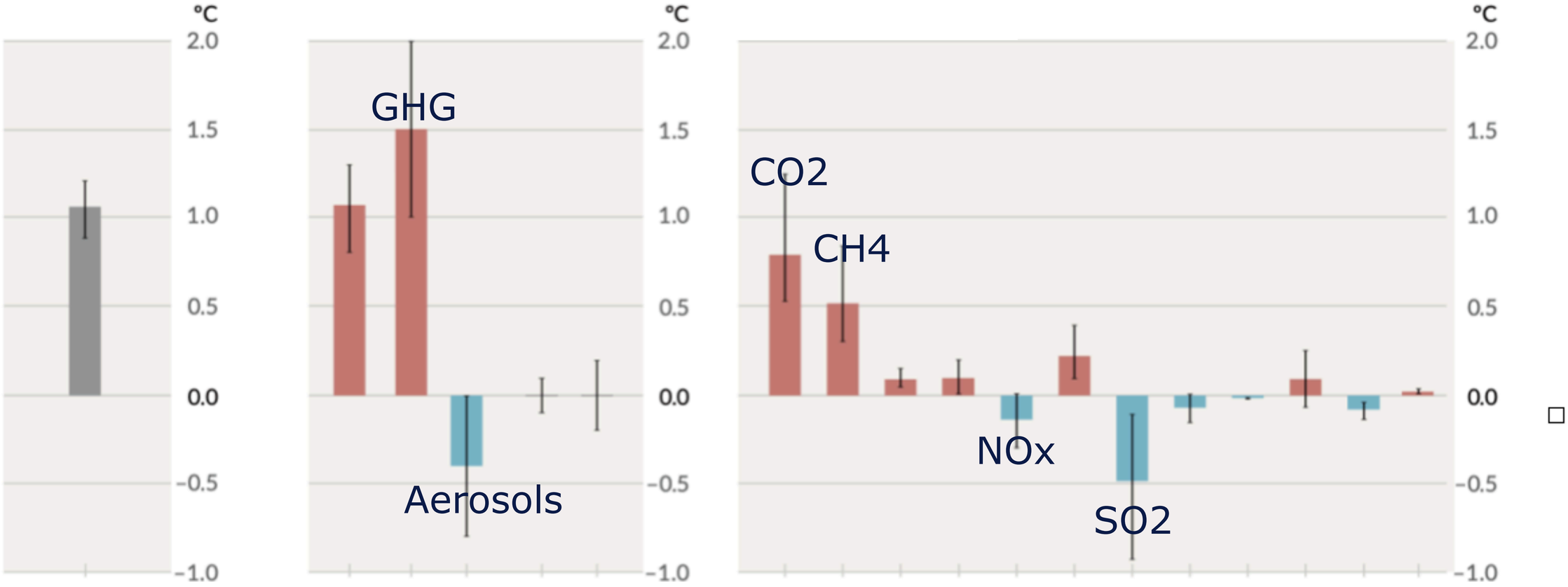
People move. Viruses move with them: Pandemics.

The people that are already there, don’t like other people to move in and fight them: War.

All in all: Death.

Four Horsemen
A.Dürer
1498

1.1 ºC INCREASE - CONTRIBUTIONS



Source: IPCC WG1 Physical Science Basis

Options to Reduce Global Warming

Reduce $C0_2$ and methane emissions

→ Keeps it from getting worse, first step

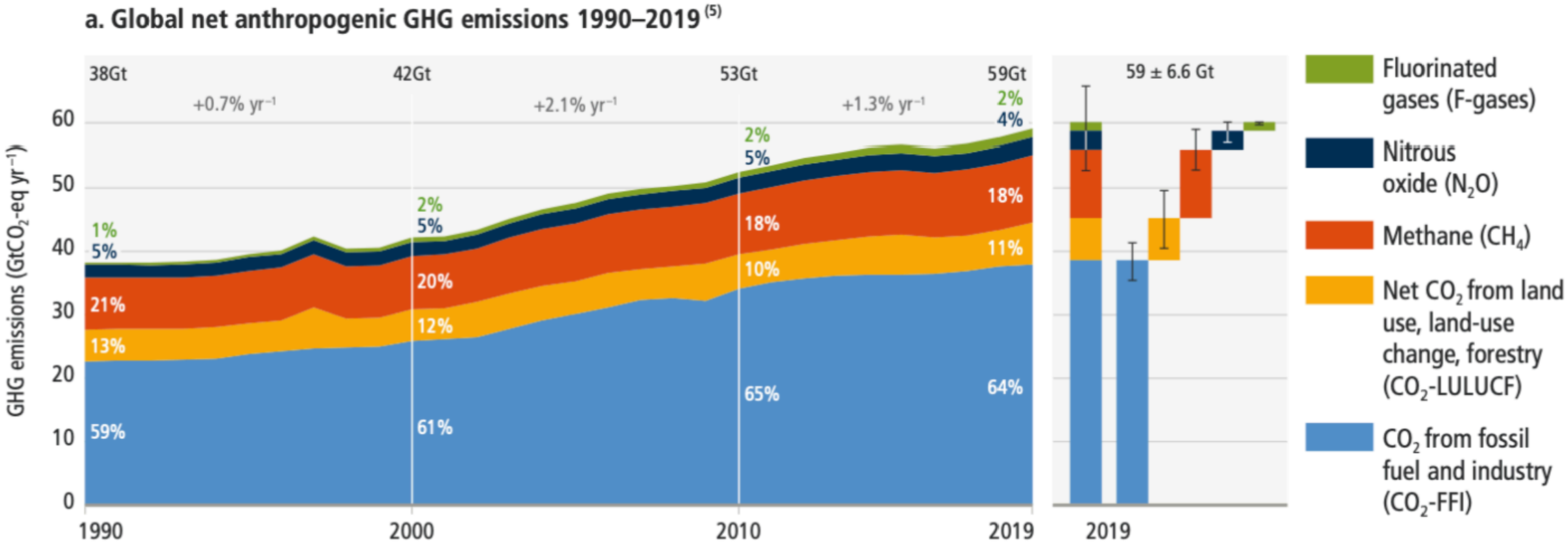
Remove $C0_2$ and methane from atmosphere

→ Actually improves the situation
Carbon Capture and Storage (CCS)

Increase $S0_2$ and $N0_X$ in the atmosphere

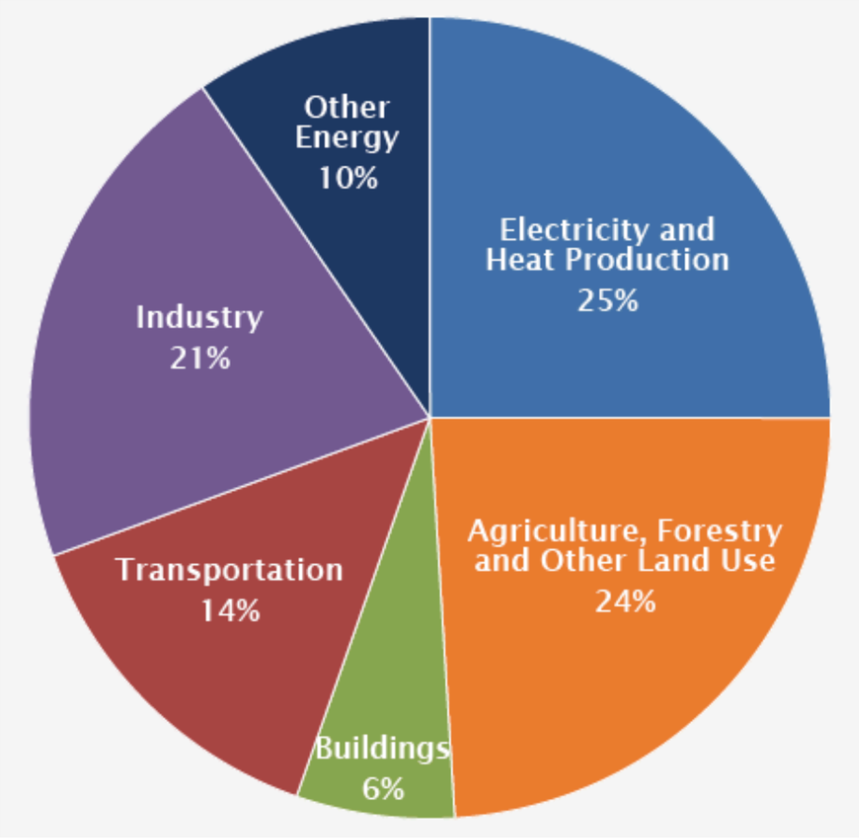
→ Actually improves the situation
Curiously, reducing our emissions would make it worse
Solar geoengineering

GREENHOUSE GAS EMISSIONS

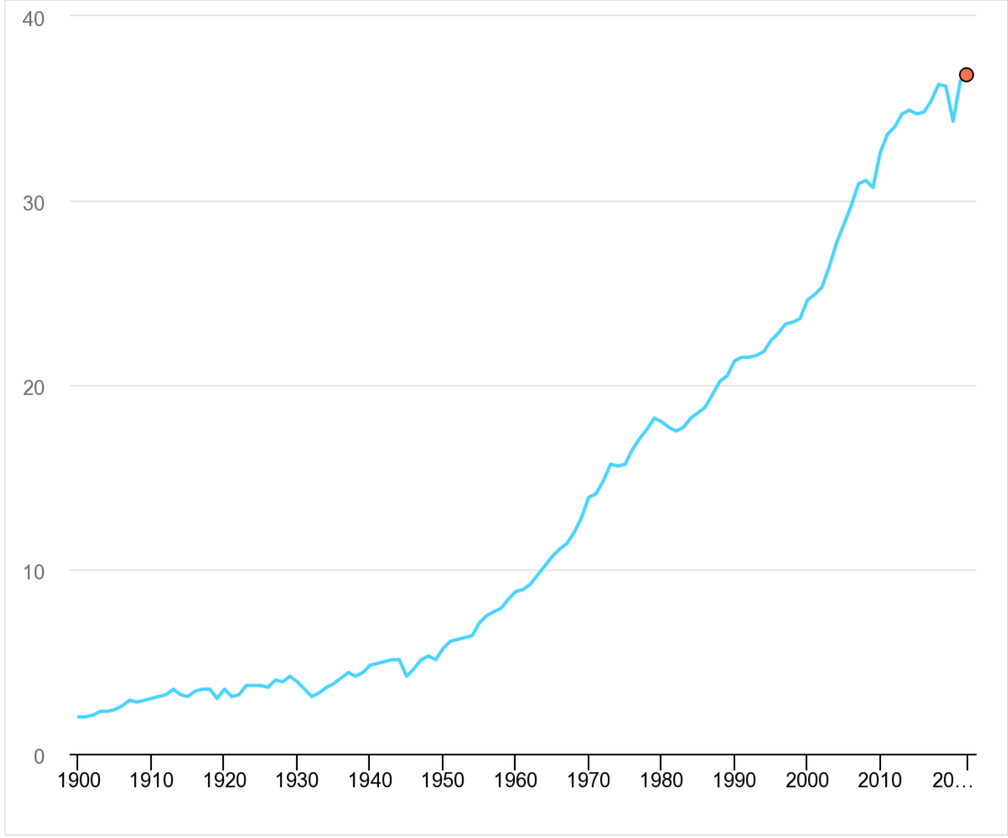


Source: IPCC AR6 WG3 Mitigation of Climate Change

GREENHOUSE GAS EMISSIONS FROM ENERGY



IPCC AR5 WG3



IEA https://www.iea.org/data-and-statistics/charts/global-co2-emissions-from-energy-combustion-and-industrial-processes-1900-2022

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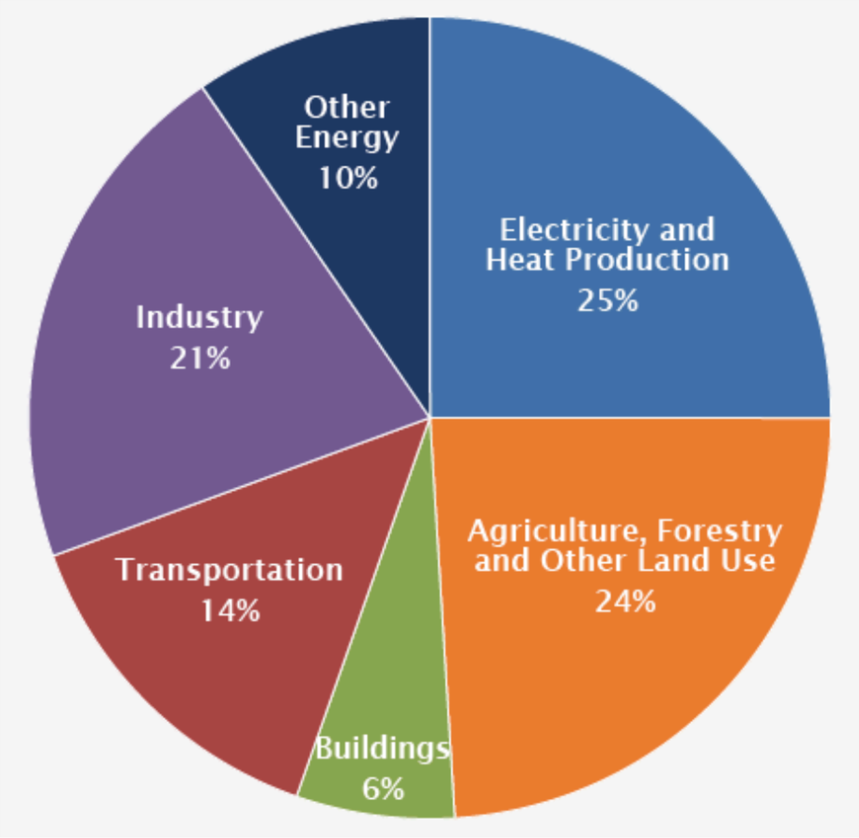

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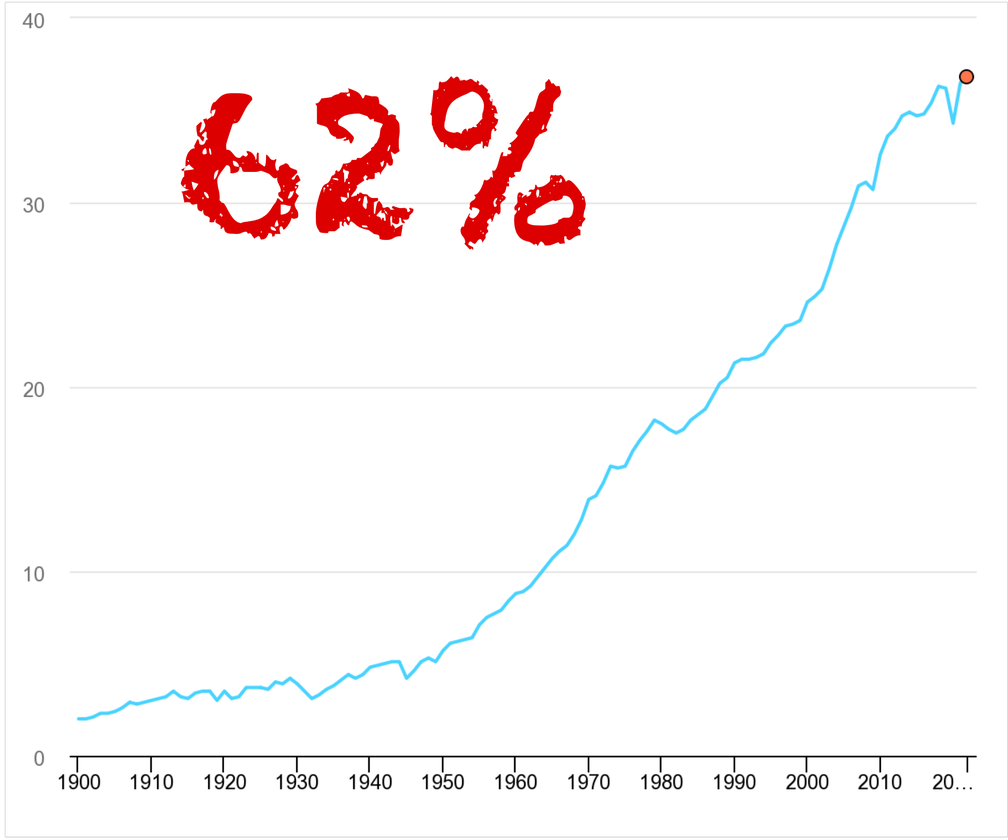


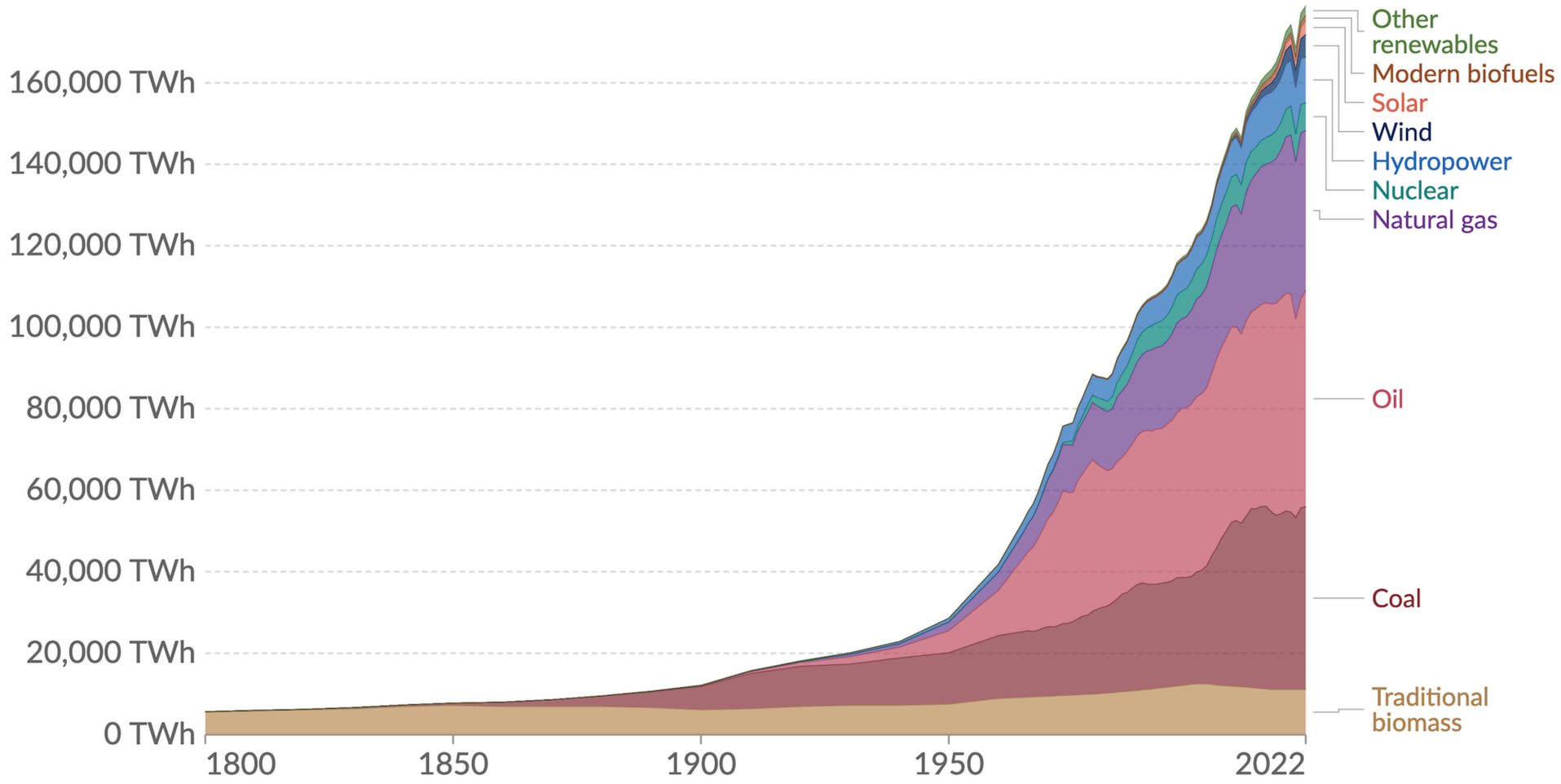
IEA https://www.iea.org/data-and-statistics/charts/global-co2-emissions-from-energy-combustion-and-industrial-processes-1900-2022

ENERGY WITHOUT GHG EMISSIONS COULD REDUCE WORLD GHG EMISSIONS BY OVER 60%.

THIS IS THE BIGGEST WHEEL WE CAN TURN.

BIGGER THAN ALL OTHER FACTORS COMBINED.

GLOBAL PRIMARY ENERGY CONSUMPTION



Data source: Energy Institute Statistical Review of World Energy (2023); Vaclav Smil (2017)
OurWorldInData.org/energy | CC BY

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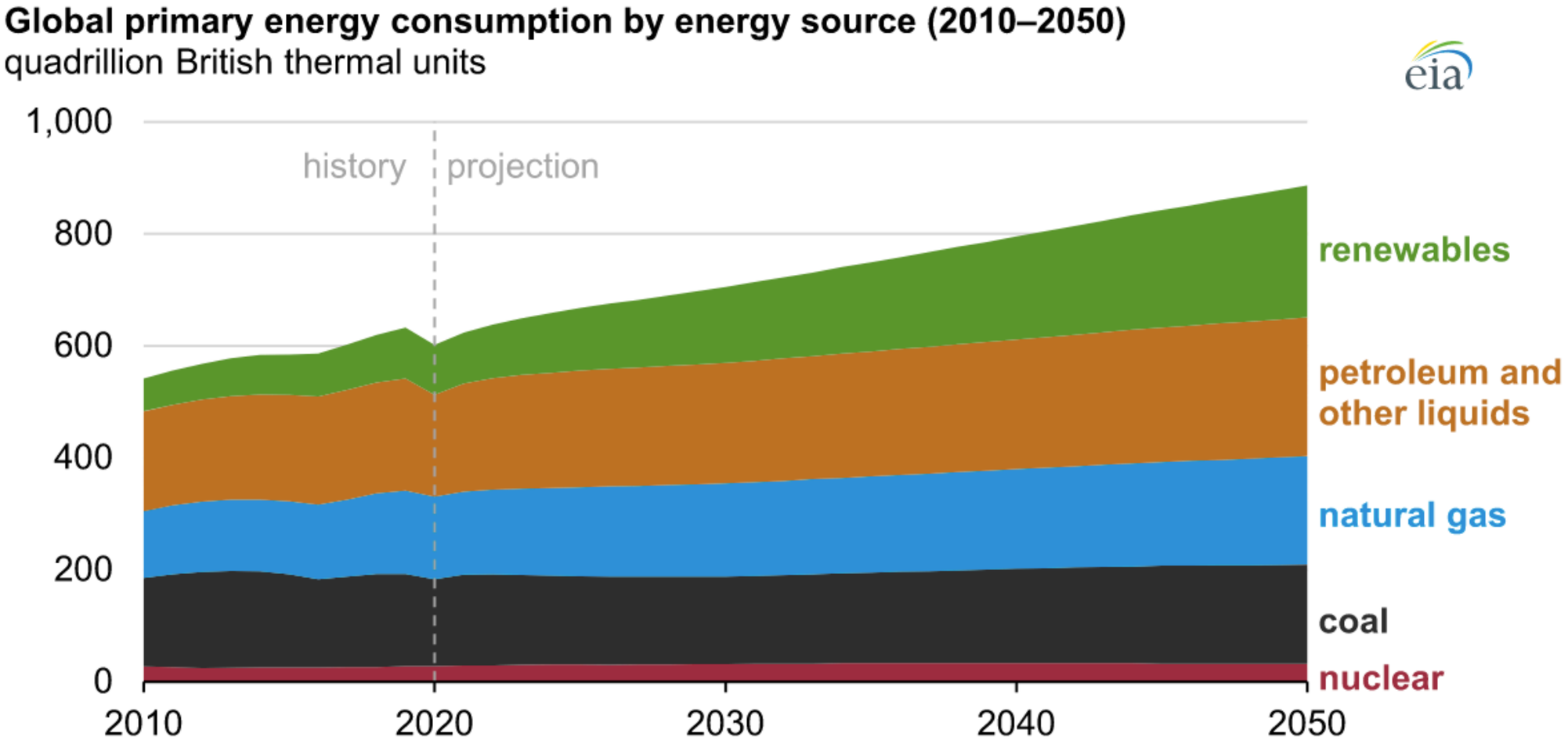
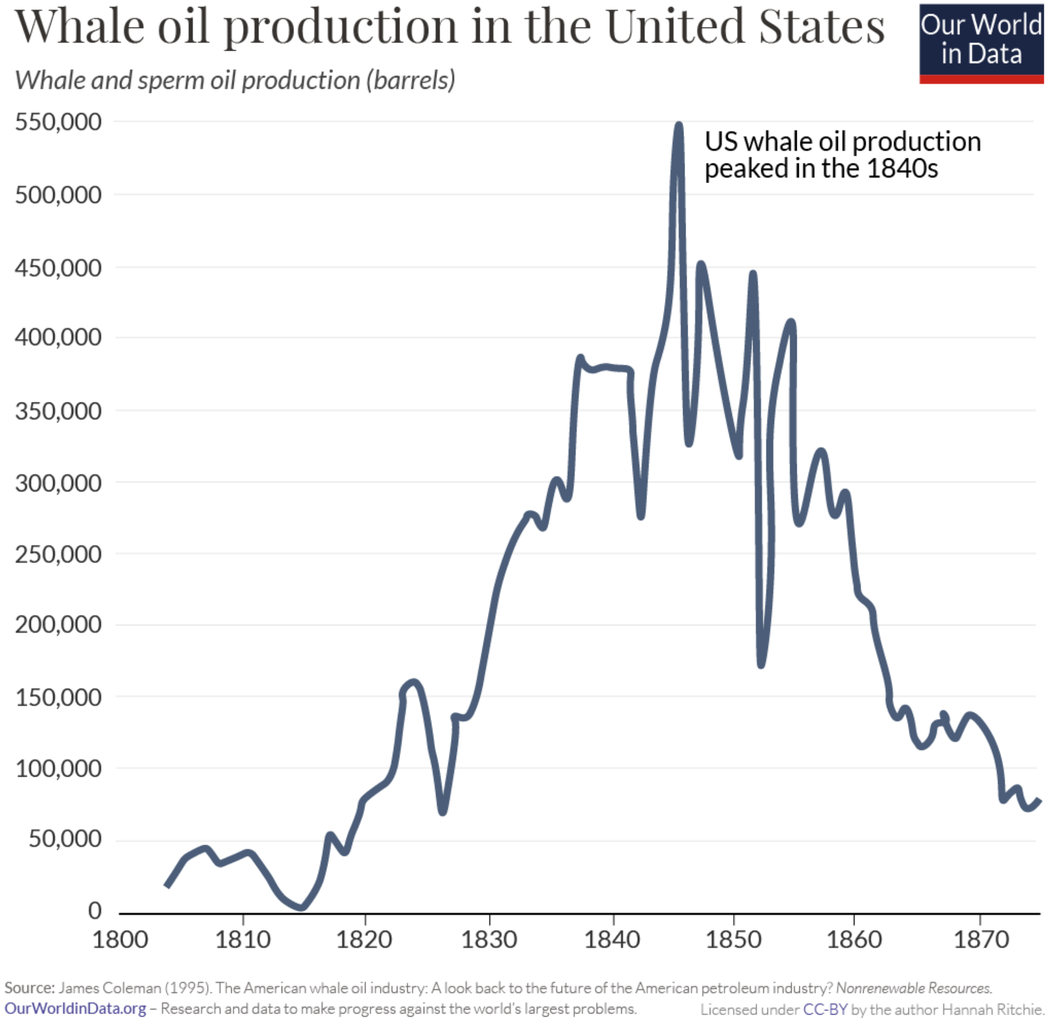
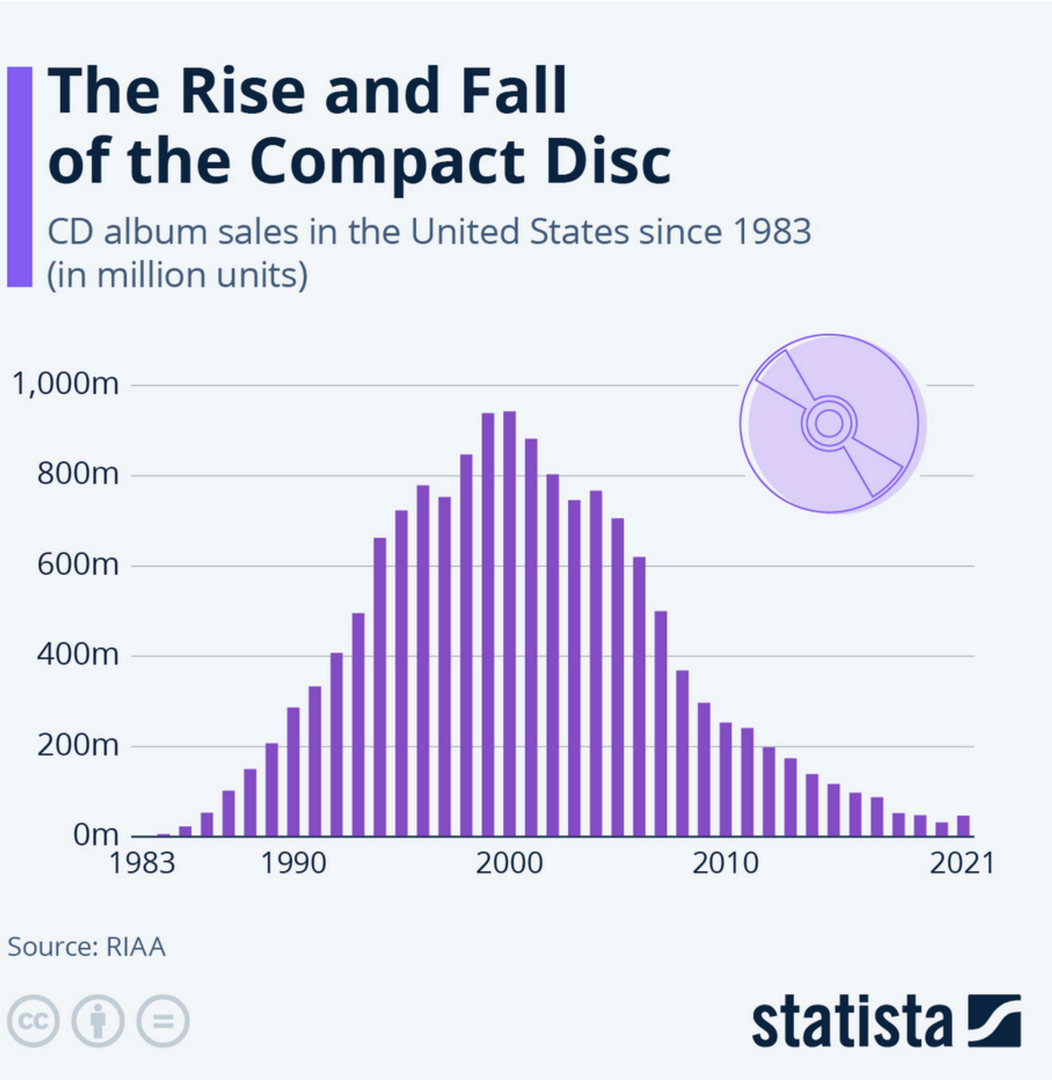


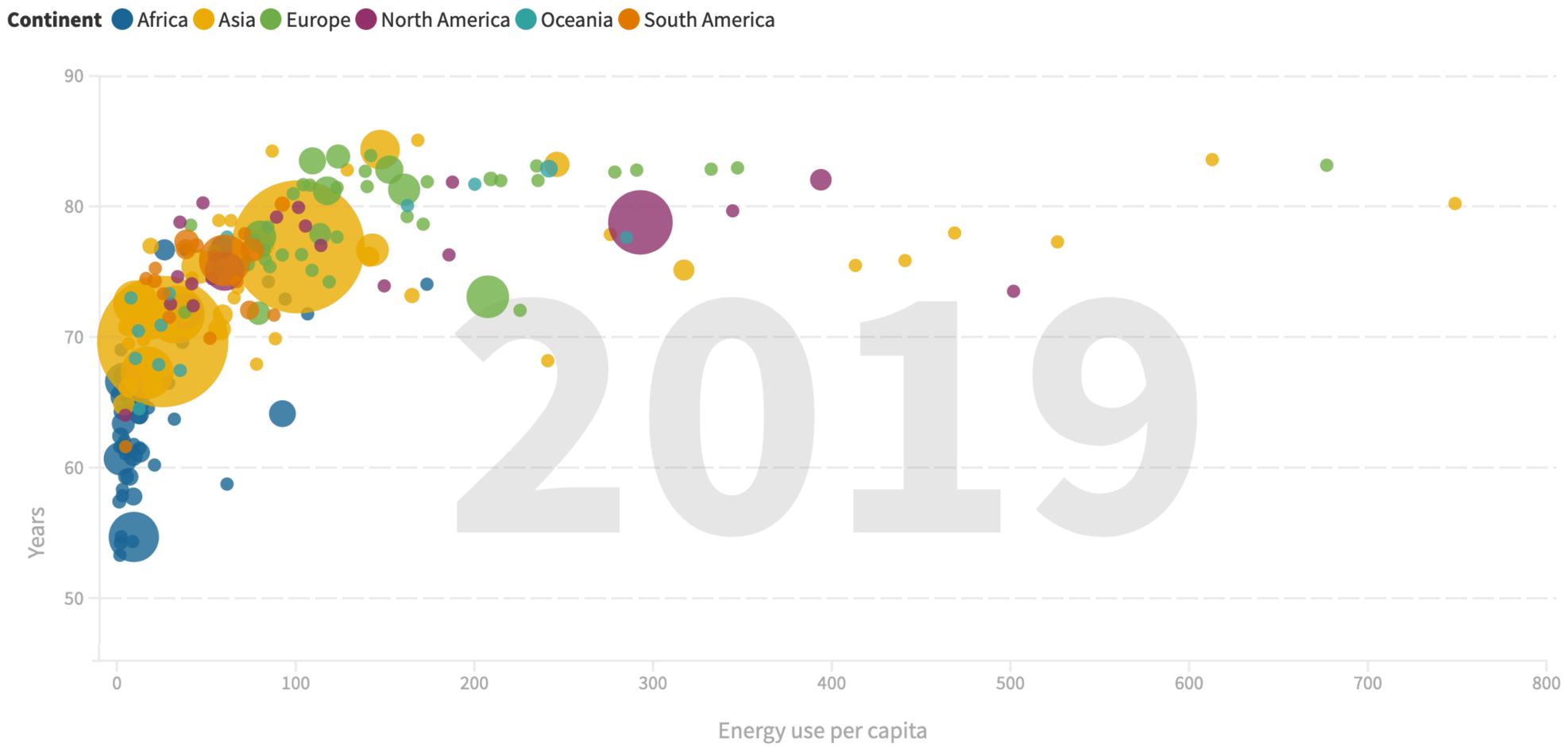
Source: U.S. Energy Information Administration, *International Energy Outlook 2021* Reference case
Note: *Petroleum and other liquids* includes biofuels.

TECHNOLOGICAL CHANGE





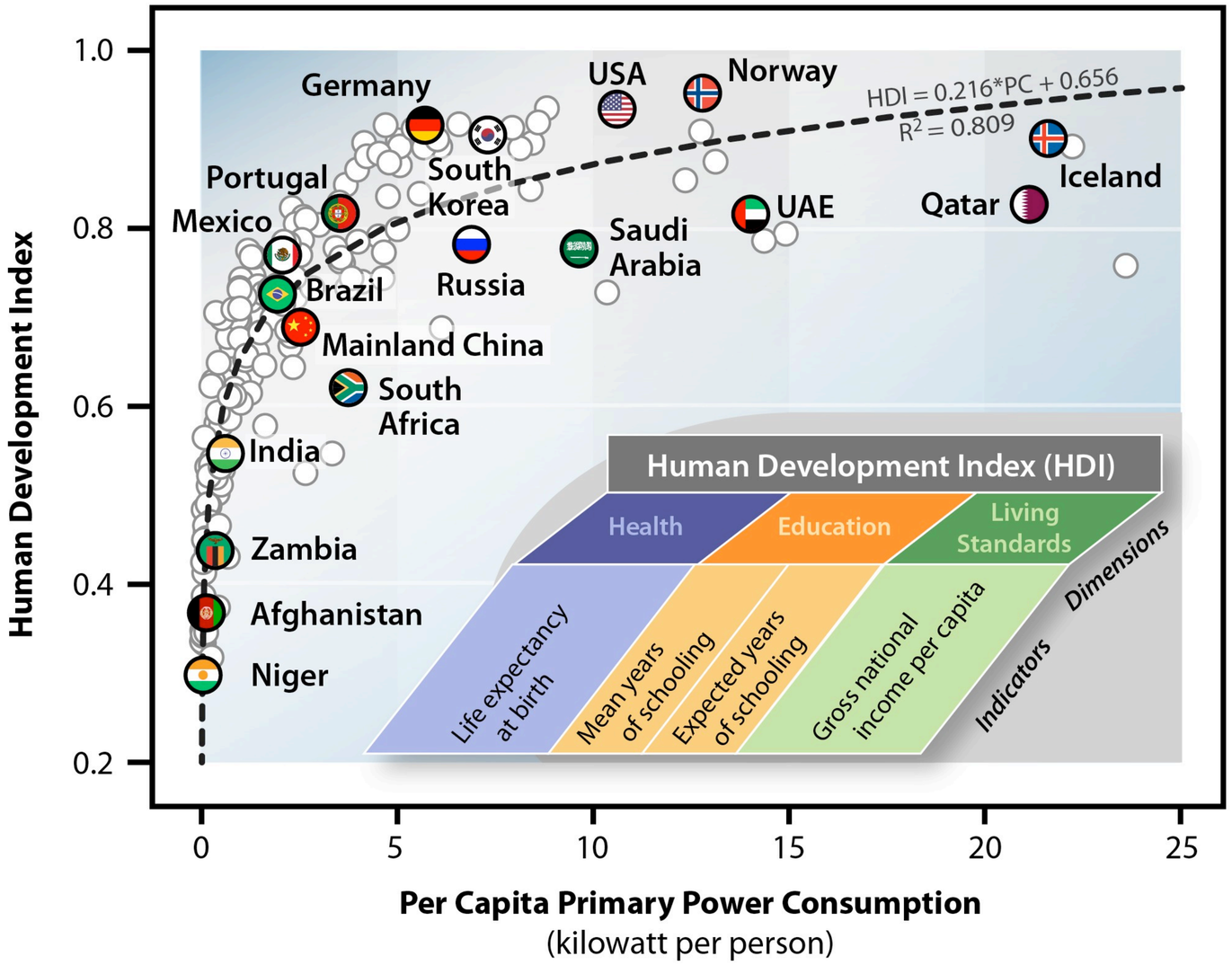
LIFE EXPECTANCY VS ENERGY CONSUMPTION



Source: Our World in Data; World Bank; United Nations Population Division

visualizingEnergy

HUMAN DEVELOPMENT INDEX



CLIMATE CHANGE ITSELF NEEDS ENERGY

- Adaptation to Climate Change requires more energy for cooling, heating, irrigation, construction, water purification
- Mitigation of Climate Change requires more energy for direct air capture of CO2, carbon capture and storage, construction
- Climate Change itself drives the need for more energy, not less.

ENERGY

WHERE DOES ENERGY COME FROM?

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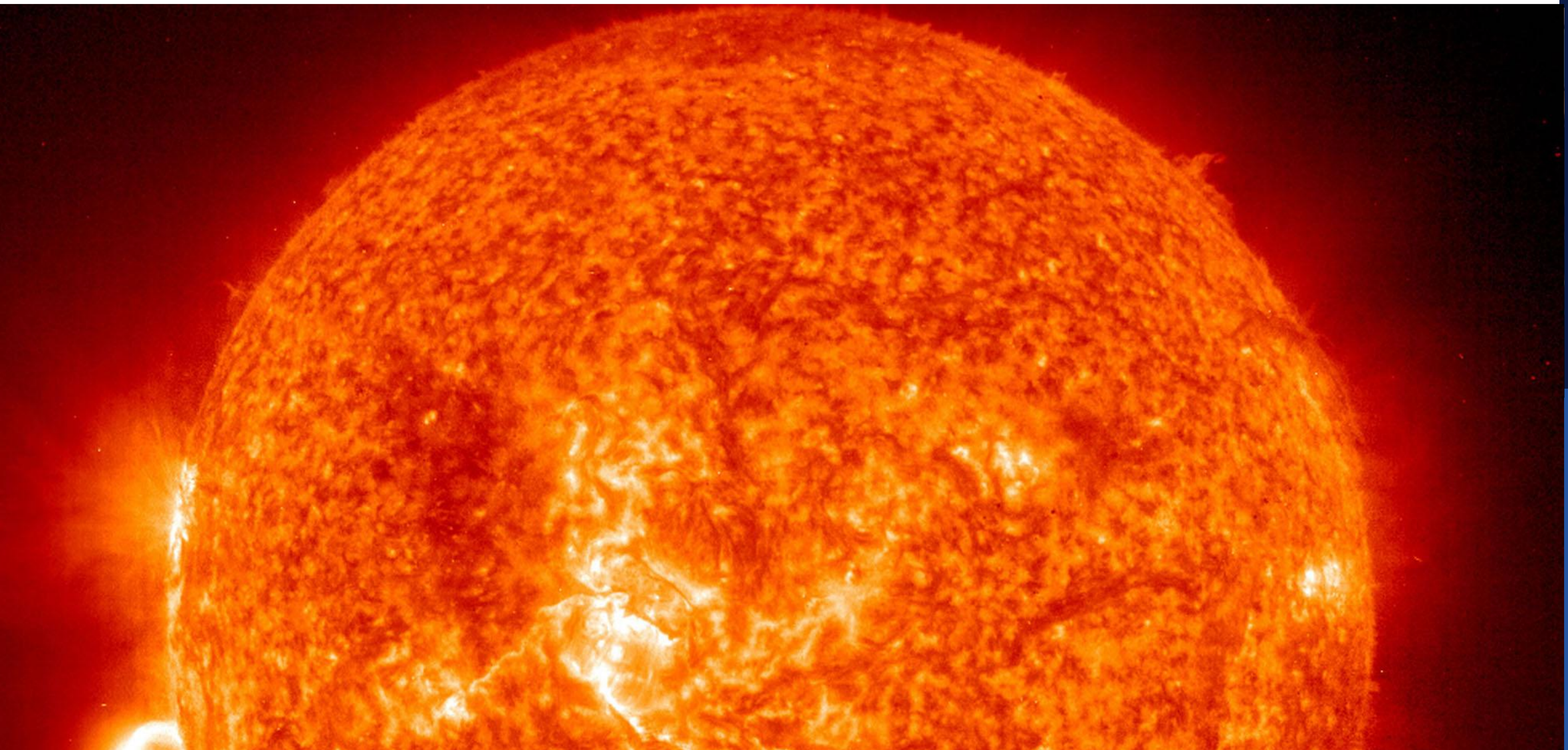
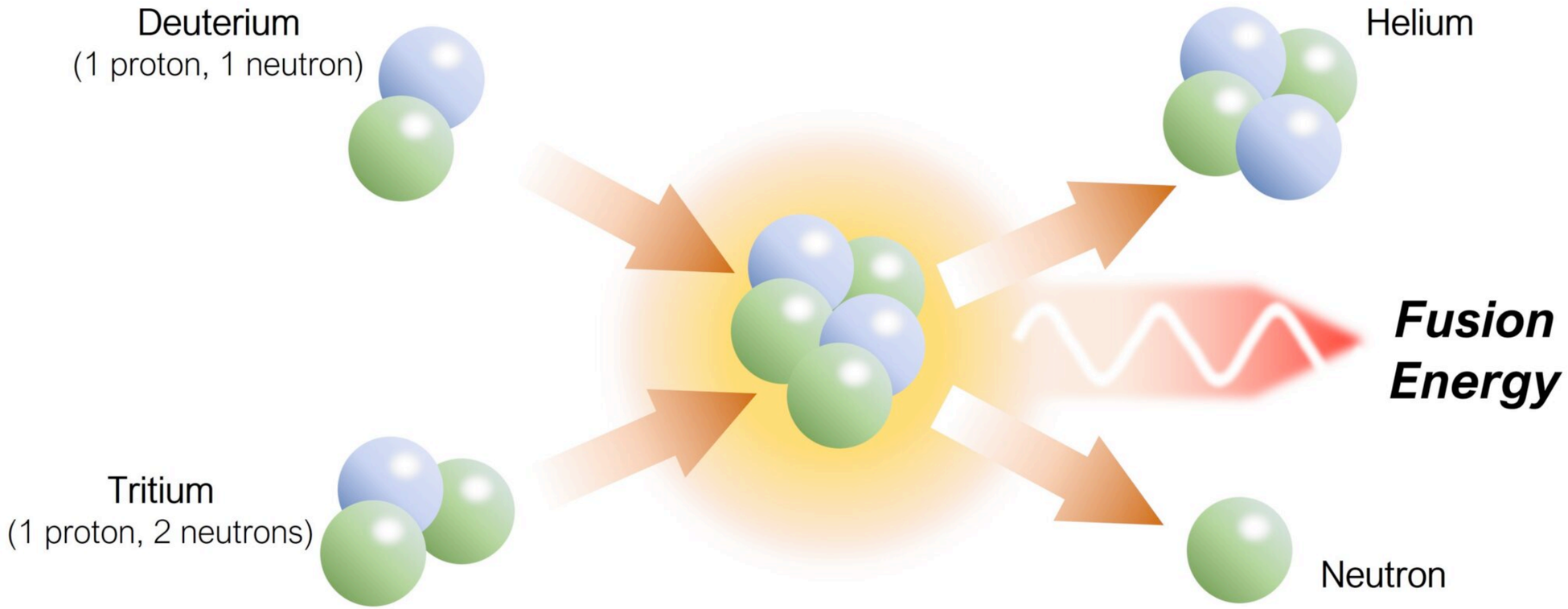


WHERE DOES THE SUN'S ENERGY COME FROM?



https://blog.ucsusa.org/dylan-spaulding/what-does-a-nuclear-fusion-breakthrough-mean-for-energy-production-and-nuclear-weapons/

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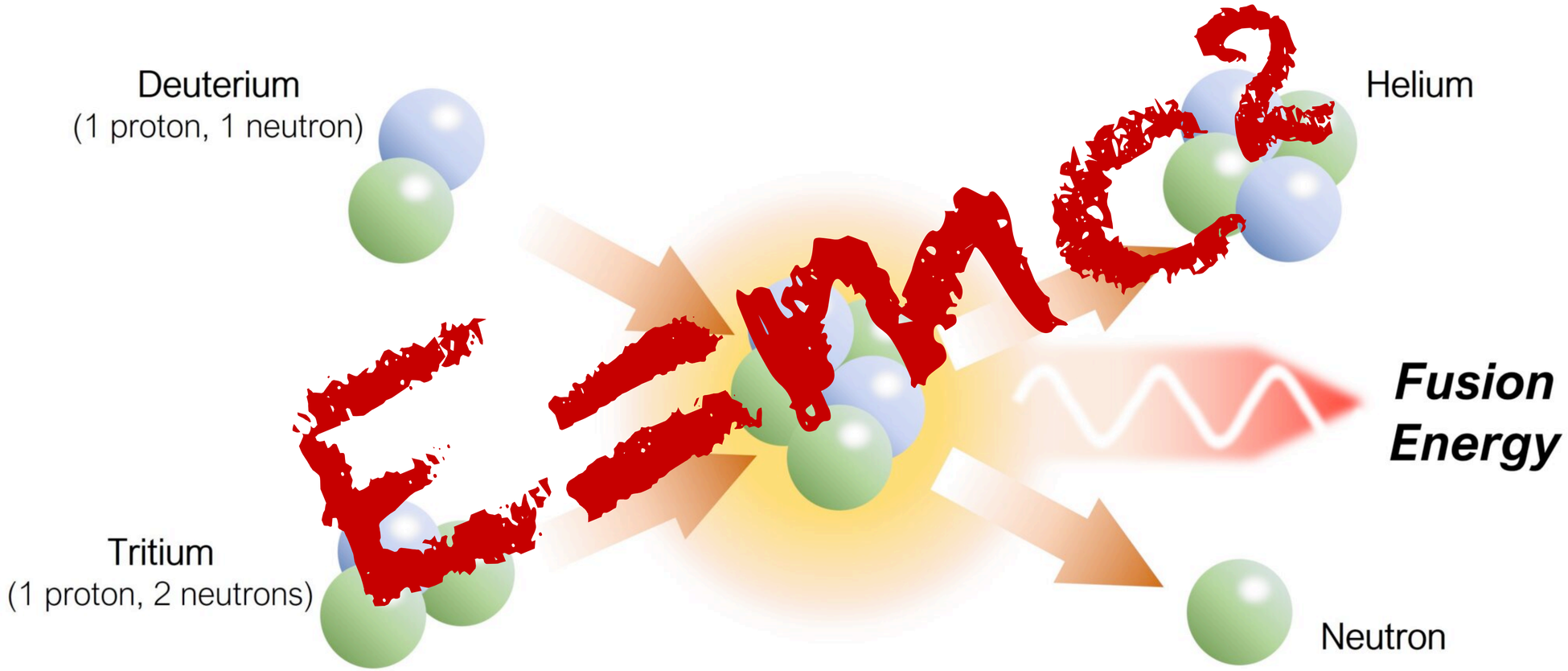

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EVERYTHING COUNTS IN LARGE AMOUNTS

- There are **8 Billion** of us.
- **Everything** that we all do will have a **large impact** on the environment.
- There is **no technology** that **will not have a large impact** on the environments when we all apply it.
- This also applies to fusion power.
- But there are **orders of magnitude of difference** between different technologies.

ENERGY SOURCES AND SHOWSTOPPERS

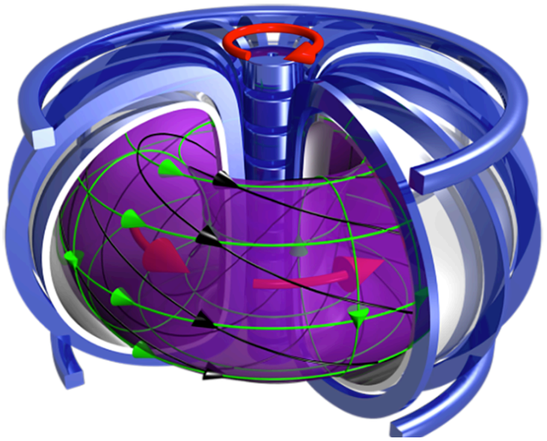
- **Fossil fuel** is **finite**. Even if more is discovered, it will still be finite. That is its very nature.
- **Renewables** use a **lot of land**. Eventually they will compete with food production.
- **Nuclear** comes with a **proliferation risk** and always will. We are not really trusting ourselves with that.

FUSION ENERGY IS INEVITABLE

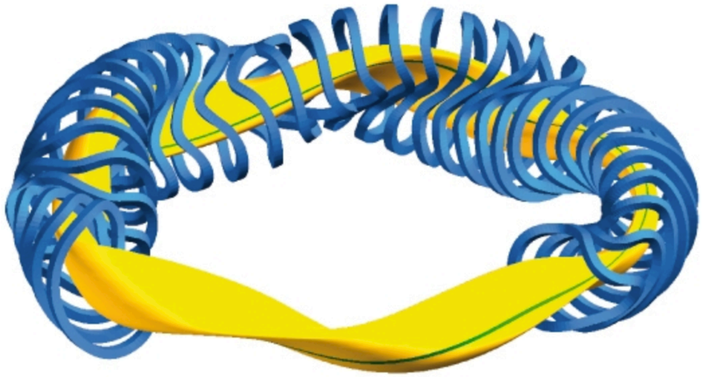
- **Fusion Energy is neither finite, nor does it need a lot of space and it has no proliferation risk. There is no showstopper.**
- We will eventually use fusion, the only question is how much damage we will do the environment and to our civilisation beforehand. Sooner would be better.
- **Fusion Energy is inevitable**.

TYPES OF (MAGNETIC) FUSION REACTORS

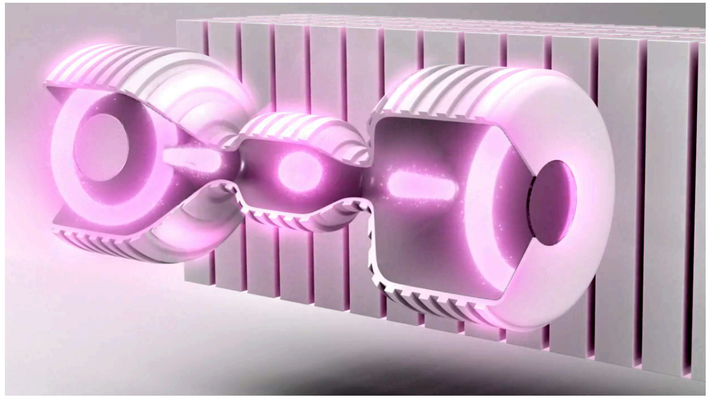
Tokamak

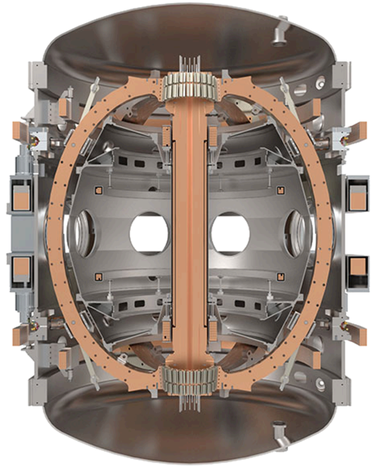


Stellarator

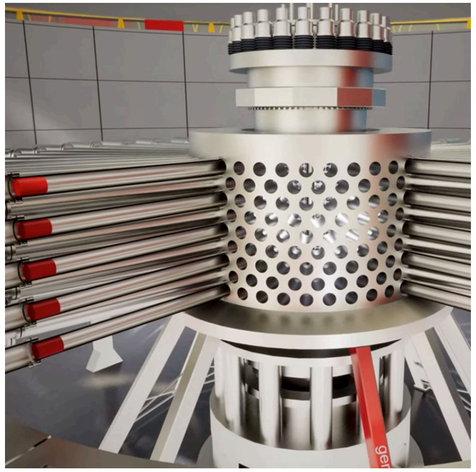


Reverse Field Conf.





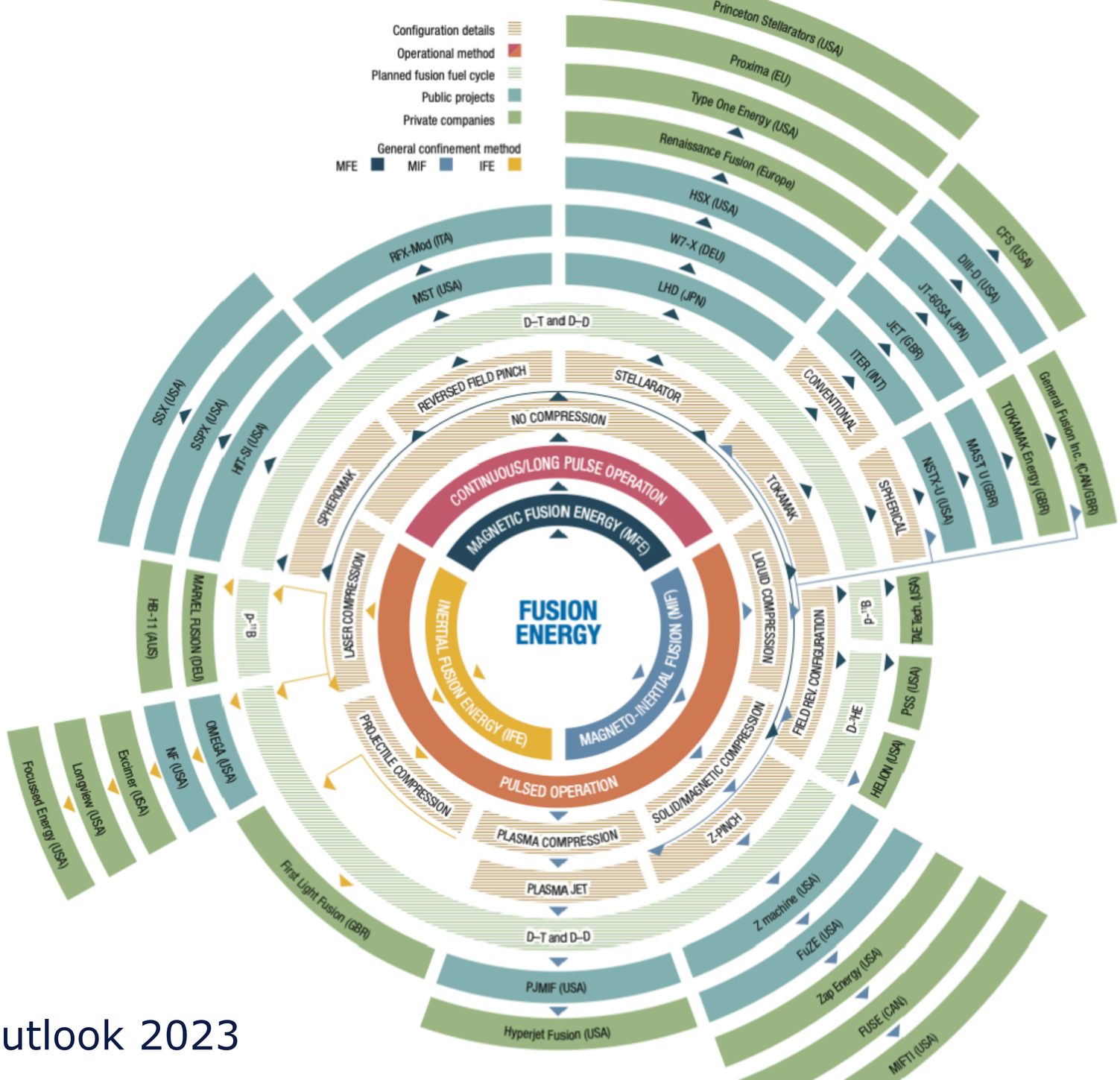
Spherical Tokamak



Magneto-Inertial

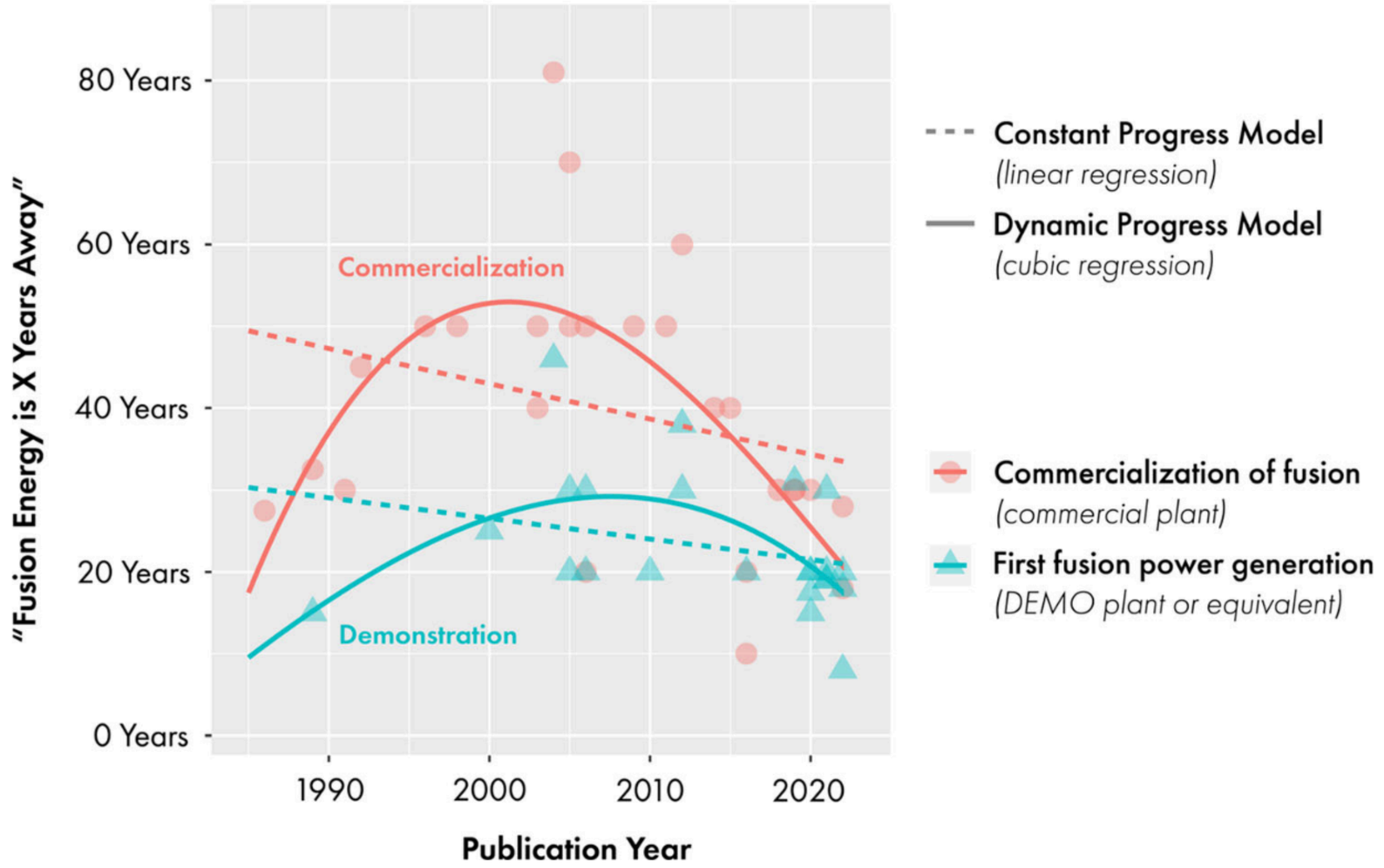
Z-Pinch

FUSION TAXONOMY



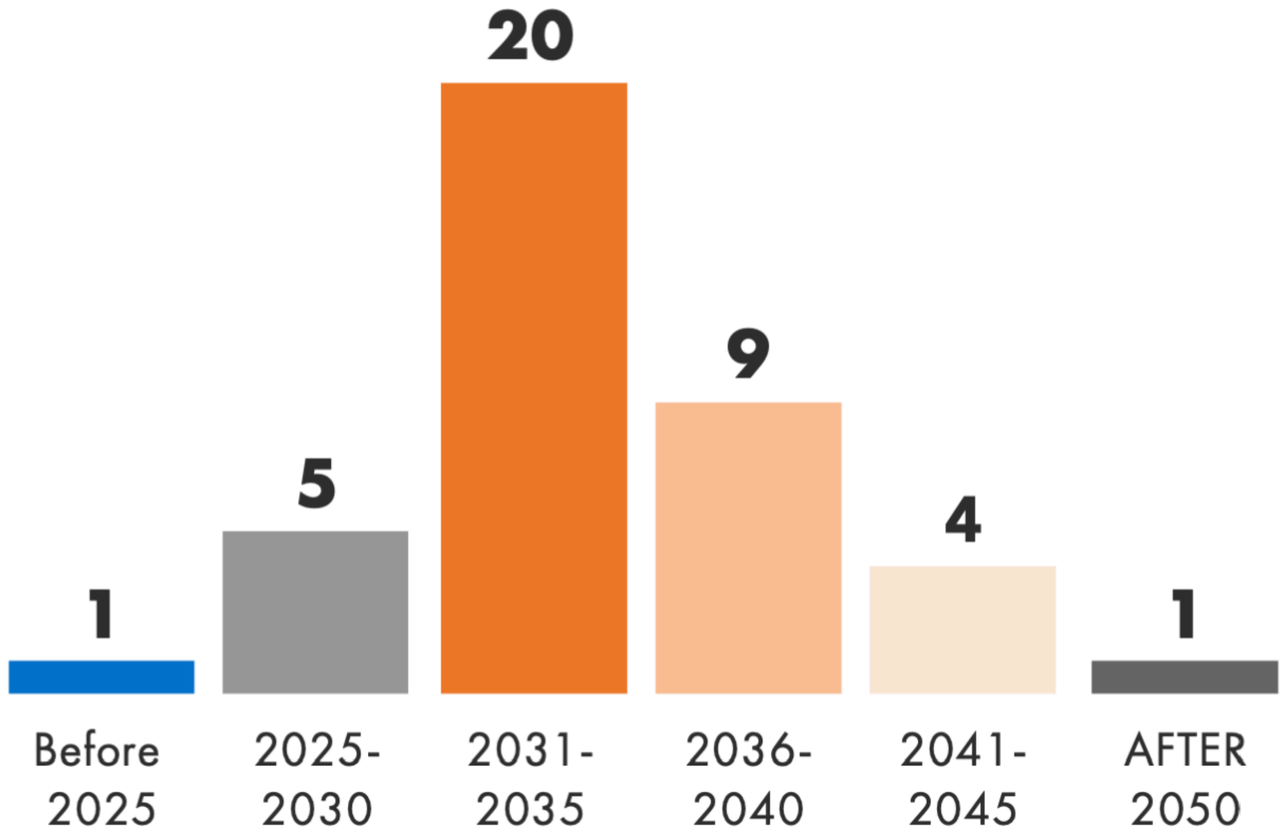
Source: IAEA Fusion Outlook 2023

‘FUSION IS ALWAYS 40 YEARS AWAY’



https://link.springer.com/article/10.1007/s10894-023-00361-z

WHEN WILL THE FIRST FUSION PLANT DELIVER POWER TO THE GRID ?



Source: The global fusion industry in 2023

FUSION INDUSTRY ASSOCIATION

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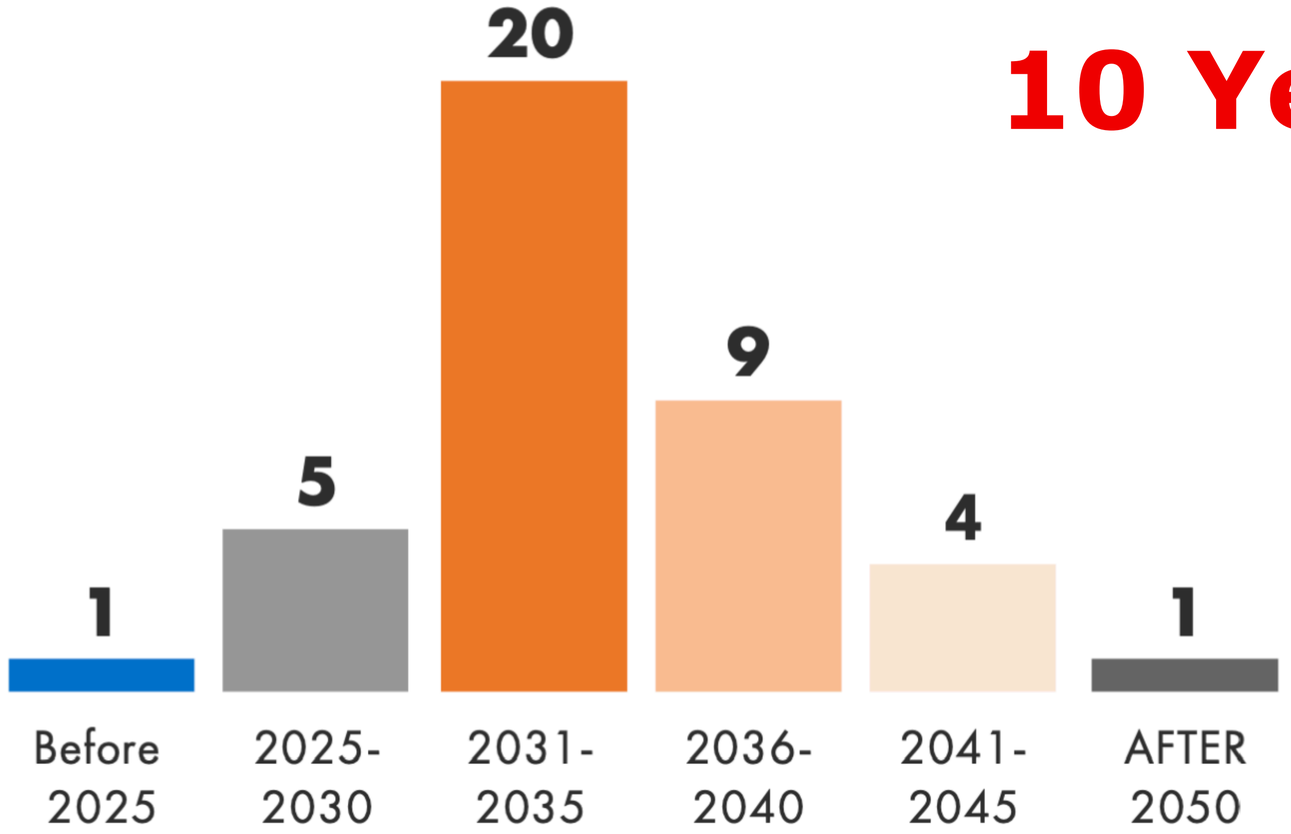
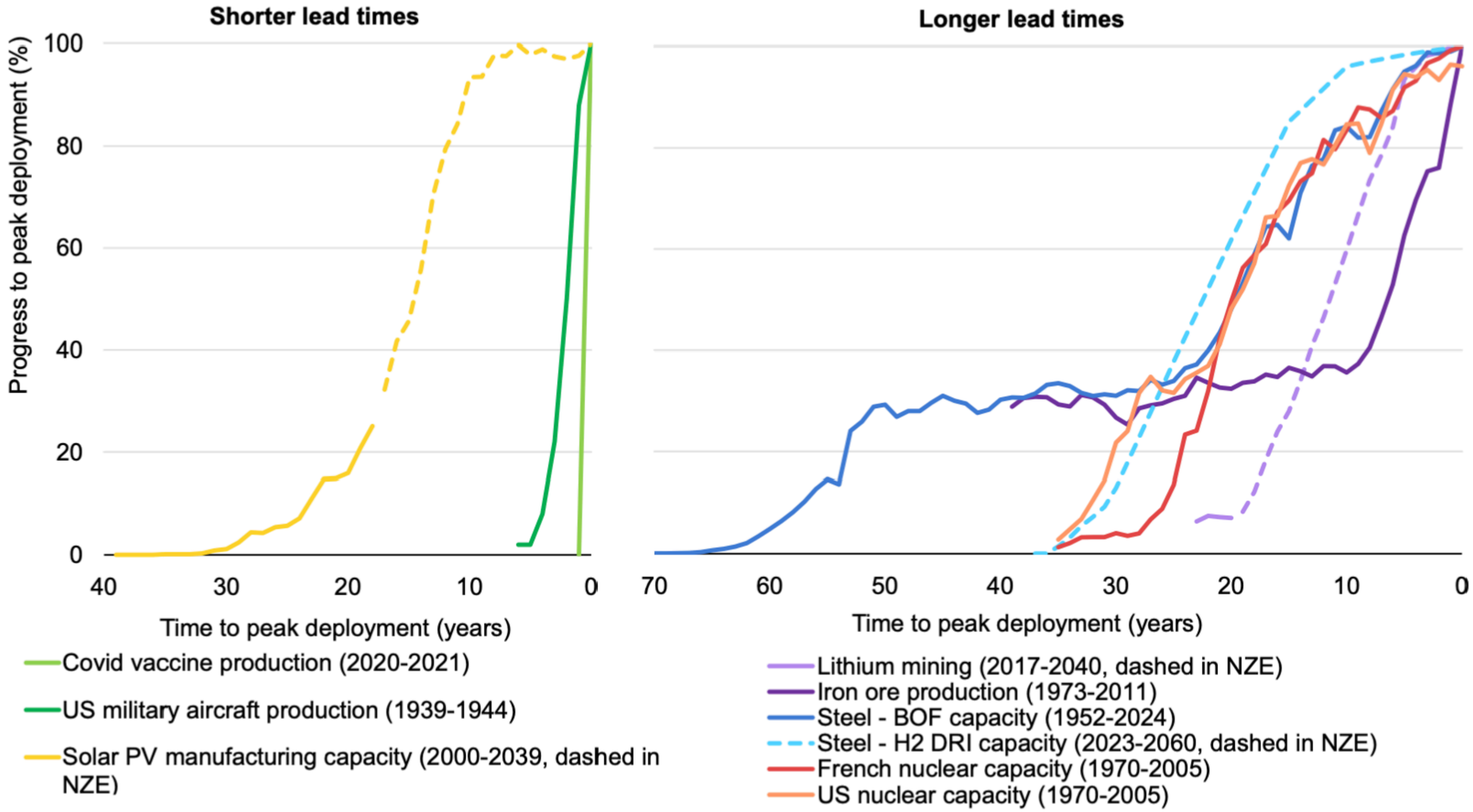


10 Years

FUSION INDUSTRY ASSOCIATION

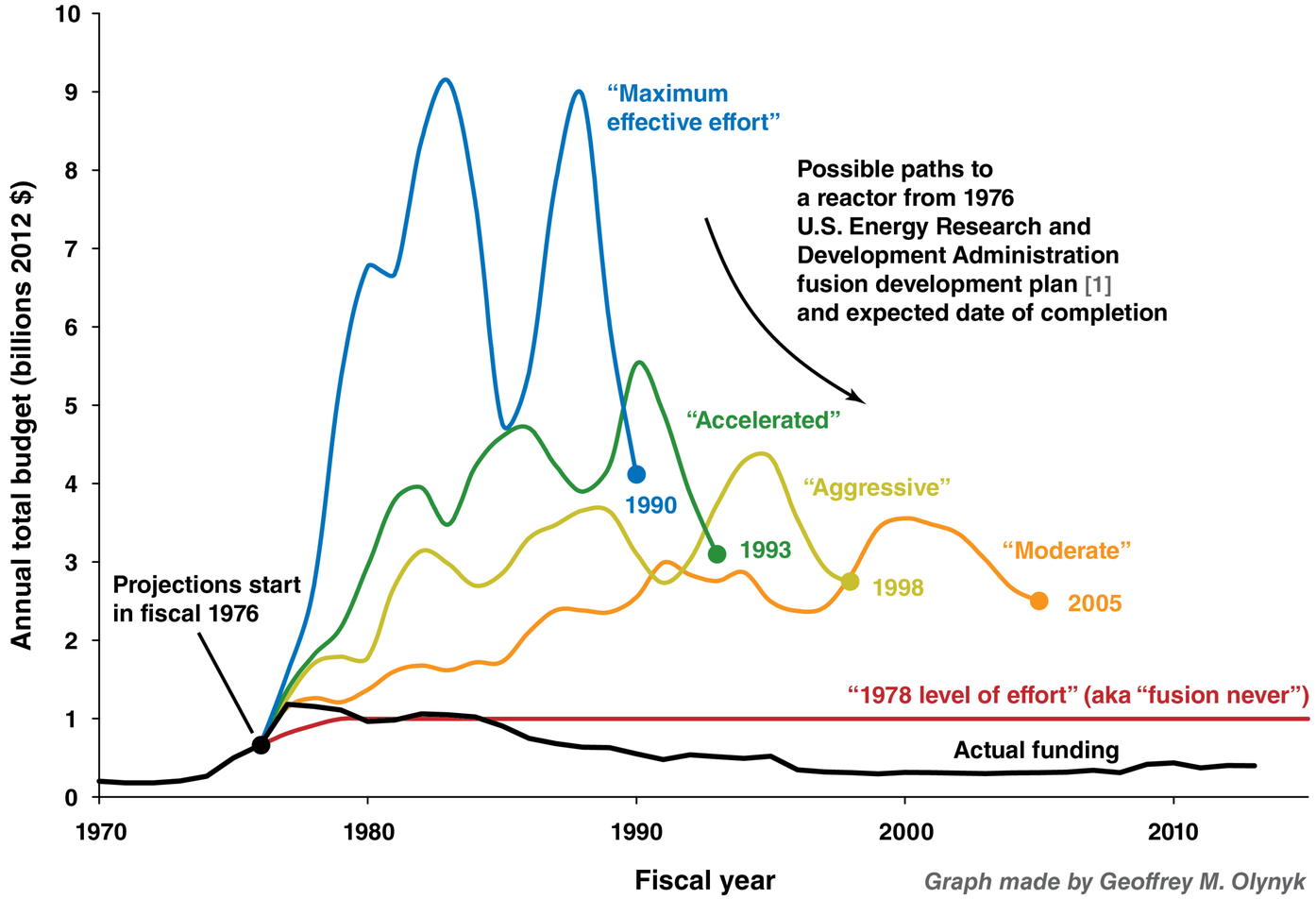
Source: The global fusion industry in 2023

RAMPING UP TECHNOLOGIES



Source: IEA Energy Technology Perspectives 2023

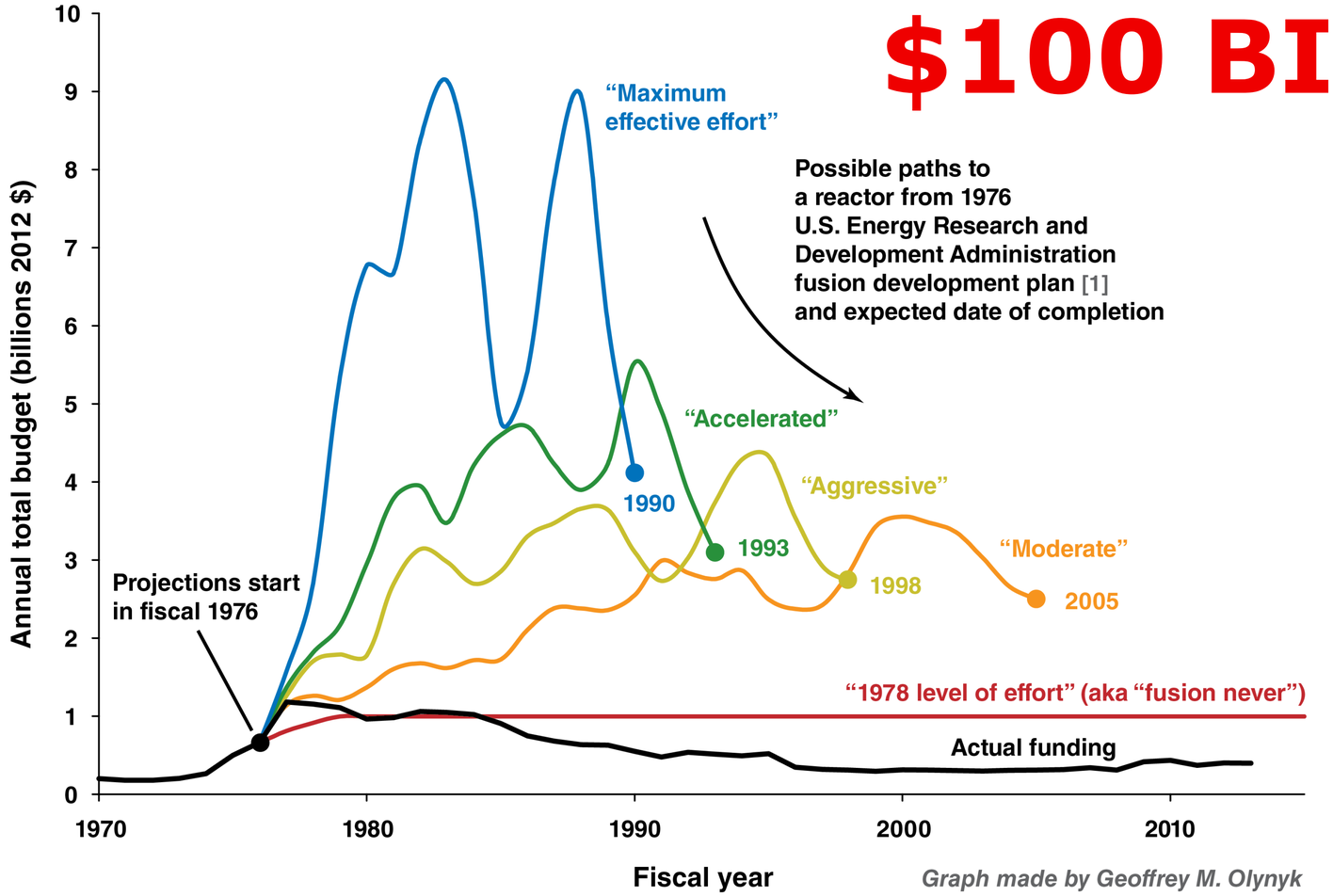
FUSION: HOW MUCH DOES IT COST



[1] U.S. Energy Research and Development Administration, 1976. "Fusion power by magnetic confinement: Program plan" ERDA report ERDA-76/110. Also published as S.O. Dean (1998), *J. Fus. Energy* **17**(4), 263–287, doi:10.1023/A:1021815909065

FUSION: HOW MUCH DOES IT COST

$100 BILLION



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THE FASTEST WAY FORWARD - 3 IDEAS

Global Fusion Investment Fund: Invest $100 Billion

Fusion Technology Area(s): Speed up Development

International Regulator: Speed up Deployment

THE BIGGEST FUSION STARTUPS

Commonwealth Fusion Systems

Tokamak, >$2Billion

Bill Gates

ZAP ENERGY

Z-Pinch, >$200 Million

Bill Gates

tae

proton Boron, >$1Billion

Google, Chevron, Paul Allen

generalfusion®

Magnetized Target,

$0.5 Billion, Jeff Bezos

HELION

Field Reversed Config.

>$2Billion,

Sam Altmann, Peter Thiel

Tokamak Energy

Tokamak, >$250 Million

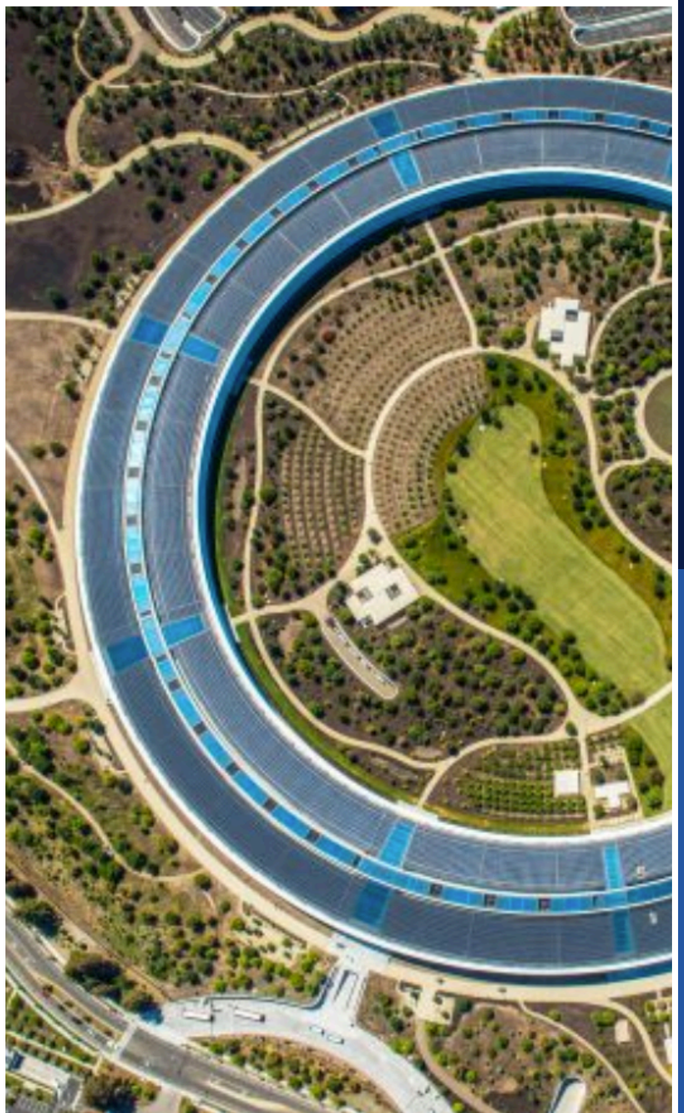
Hans-Peter Wild

GLOBAL FUSION INVESTMENT FUND

- Fusion will eventually be a $40 Trillion business (based on 1% of global energy production, Bloomberg 2021)
- The first trillionaire will be made in fusion.
- Current fusion investors:
  Billionaires, Fossil Fuel Companies, Countries
- Set up a global holding company traded at the stock market that only invests in fusion companies and direct fusion suppliers
- Once one or several fusion companies make it big, so does the Global Fusion Investment Fund
- Democratise the opportunity to invest in fusion:
  10 million investors with $10k each make $100 billion.
- Save the world and get rich in the process.

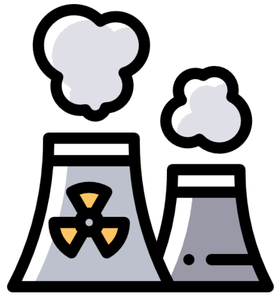
FUSION TECHNOLOGY AREA(S)

- Create a favourable environment and especially remove all obstacles to the creation of a fusion power plant.
- Set up an area with basic infrastructure near an international airport, a port and and area with a high quality of life for the people that will work there.
- Extraterritorial area without red tape, with no or few regulations.
- Make this area tax-free as well. The investment will come, quickly.
- The US has large national laboratories, like Idaho National Lab, that can fulfil this function. Other parts of the world, like Europe, would benefit from having this as well.



FUSION ENERGY REGULATION

Nuclear Fission Power



Fissionable Material

Moderator

Control Rods

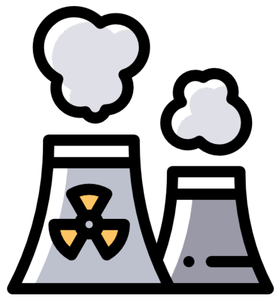
Cooling

High Radiation

High Radioactivity

FUSION ENERGY REGULATION

Nuclear Fission Power



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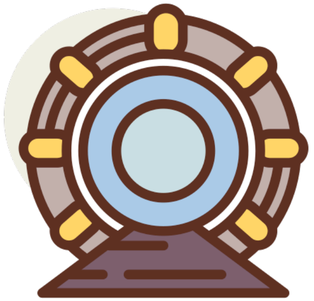
Particle Accelerator



Strong Magnets

RF EM Waves

Cryogenics

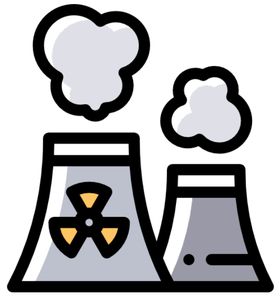
Vacuum

High Radiation

Low Radioactivity

FUSION ENERGY REGULATION

Nuclear Fission Power



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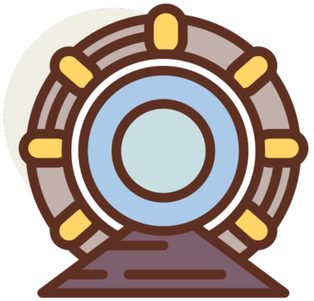

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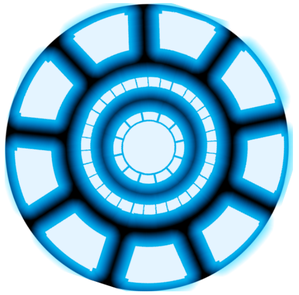
Fusion Energy



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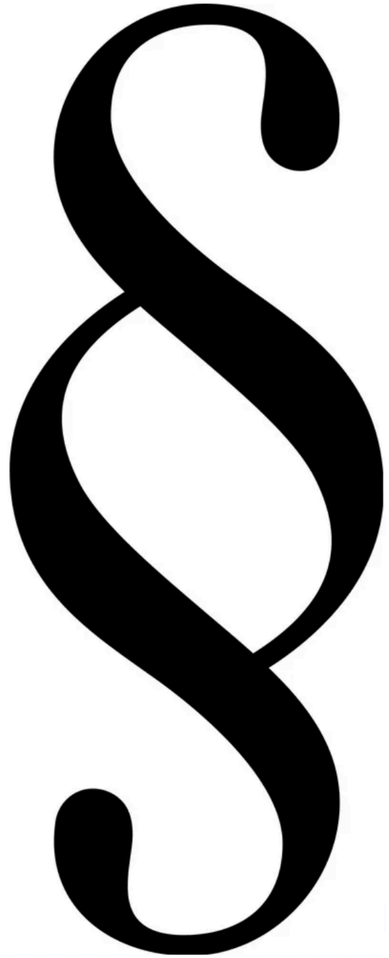
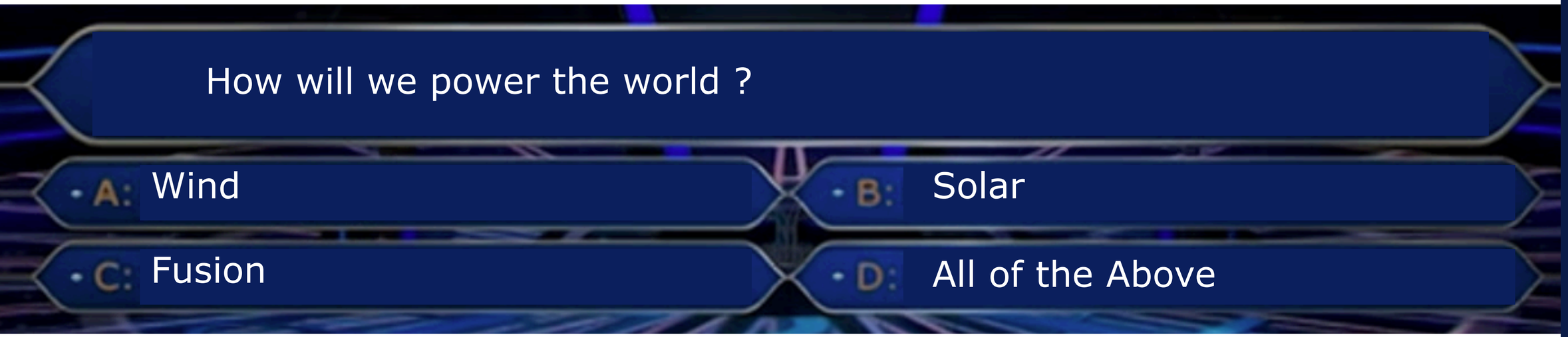
INTERNATIONAL LICENSING & REGULATOR

- International licensing agreement that multilaterally or unilaterally accepts licensing from other countries
- International Regulator that oversees fusion power plants.
- IAEA or ITER could become this International Regulator and the organisation that manages the international licensing agreement.
- License and regulate like accelerators, or even better, like planes.
- Massively speeds up deployment.
- Advantage for developing countries: Not necessary to set up licensing and regulator, just membership in organisation and subscription.



OPTION D - ALL OF THE ABOVE



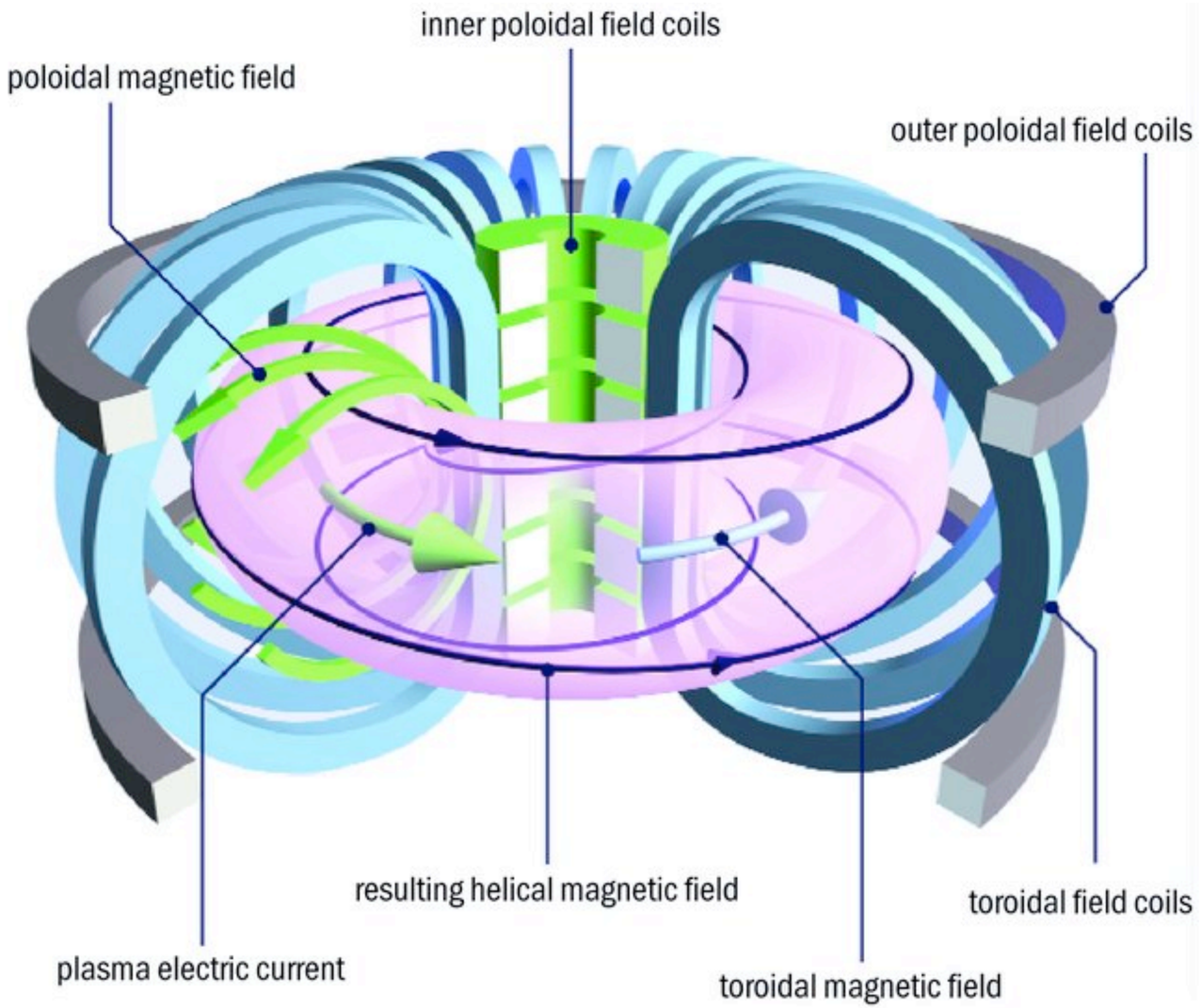
- Fusion is not a replacement for the other renewables, but an addition.
- In fact, we need so much clean energy that we need to use everything that we can, it’s a case of ‘Option D - All of the above’.
- Fusion can be turned on and off and it is the perfect partner for solar and wind - instead of the fossil fuel power plants that are needed now.

AN OPTIMISTIC SCENARIO

- **10 years** to the first fusion power plant.
- **$100 Billion** to realise clean energy for all time.
- **10 years** to set up licensing and regulation for fast rollout, in parallel.
- **30 years** to build **10,000 fusion power plants**. That’s about one per day and about the speed at which Boeing builds airplanes.
- **Replace all fossil fuel in 40 years**.
- ‘**Option D - All of the Above**’ Scenario:
  Fusion works together with wind, solar and nuclear.

Thank you!

HOW FUSION ENERGY WORKS



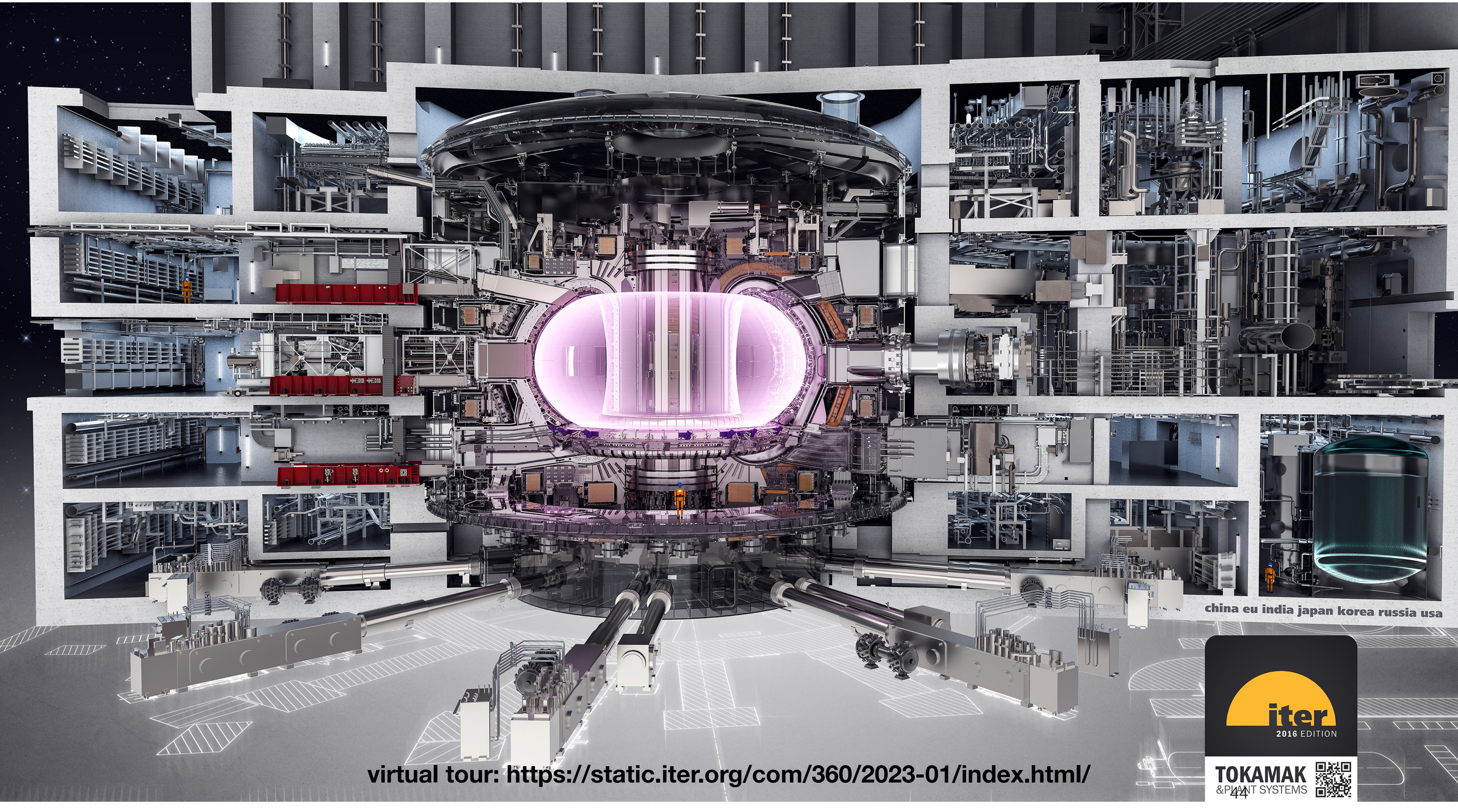
Schematic Tokamak

Source: www.eurofusion.org

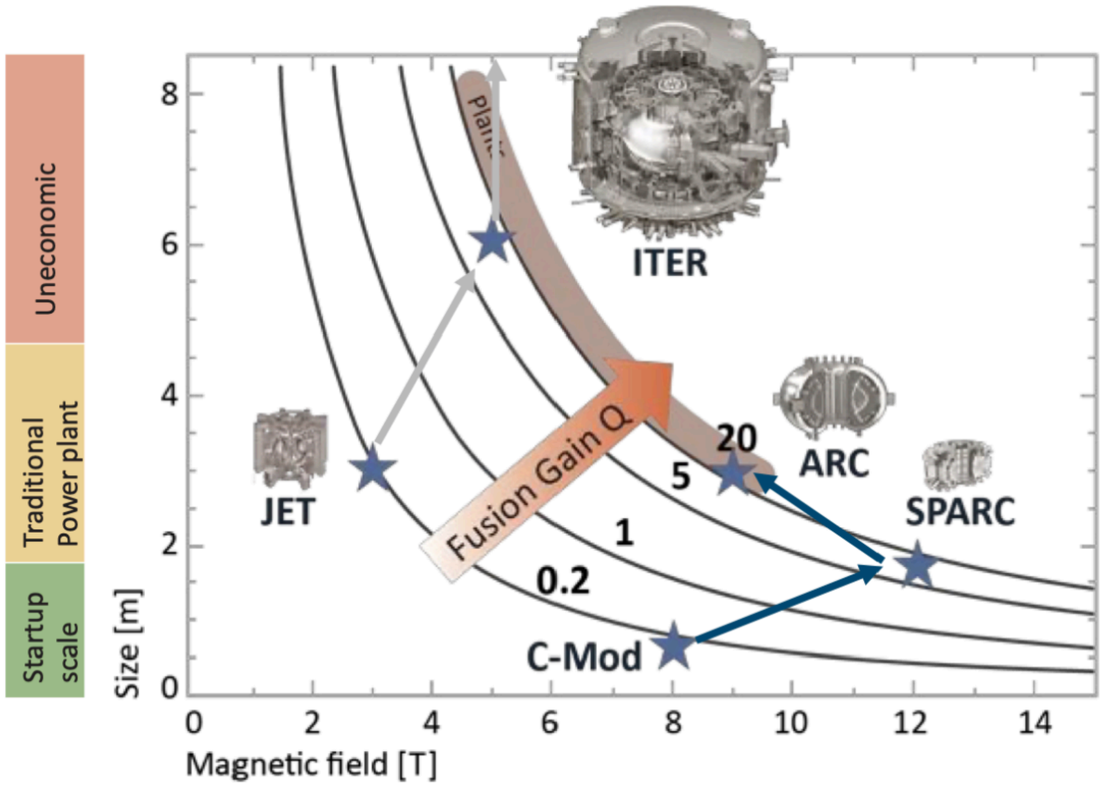

ITER

ITER

- ITER - Latin: The Way
  (International Thermonuclear Experimental Reactor)
- 1985 Reagan - Gorbachev Summit (Evgeny Velikhov suggestion)
- 2006 ITER Agreement signed under auspices of IAEA
- 50% of the world’s population and 85% of the world’s GDP
- 13 out of the 20 largest economies in the world
- EU is member, not the EU members states
- IUA - ITER Unit of Accounting

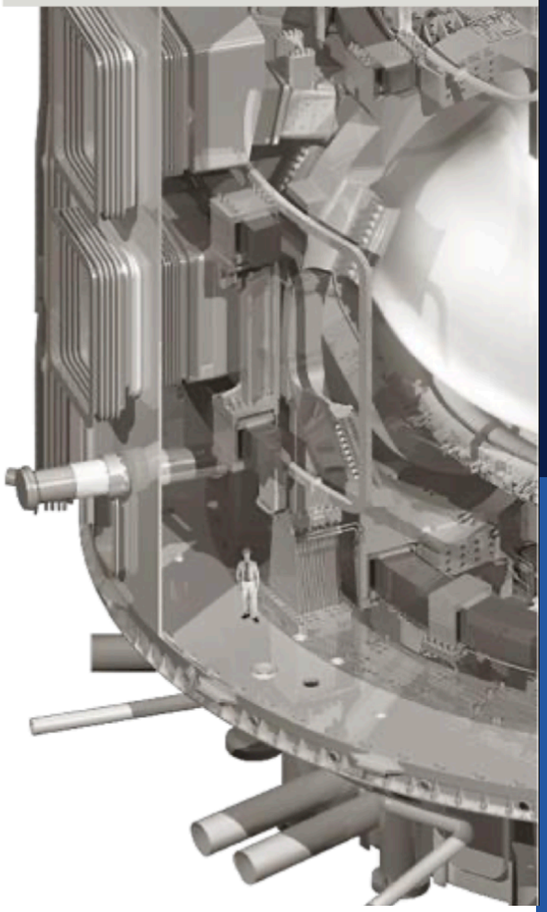

china eu india japan korea russia usa
virtual tour: https://static.iter.org/com/360/2023-01/index.html/

SPARC: COMPACT HTS TOKAMAK



SPARC

ITER – to scale



Commonwealth Fusion Systems

Affordable
Robust
Compact

Headline Bold

Headline Bold

Testimonial

NAME SURNAME IN CAPS

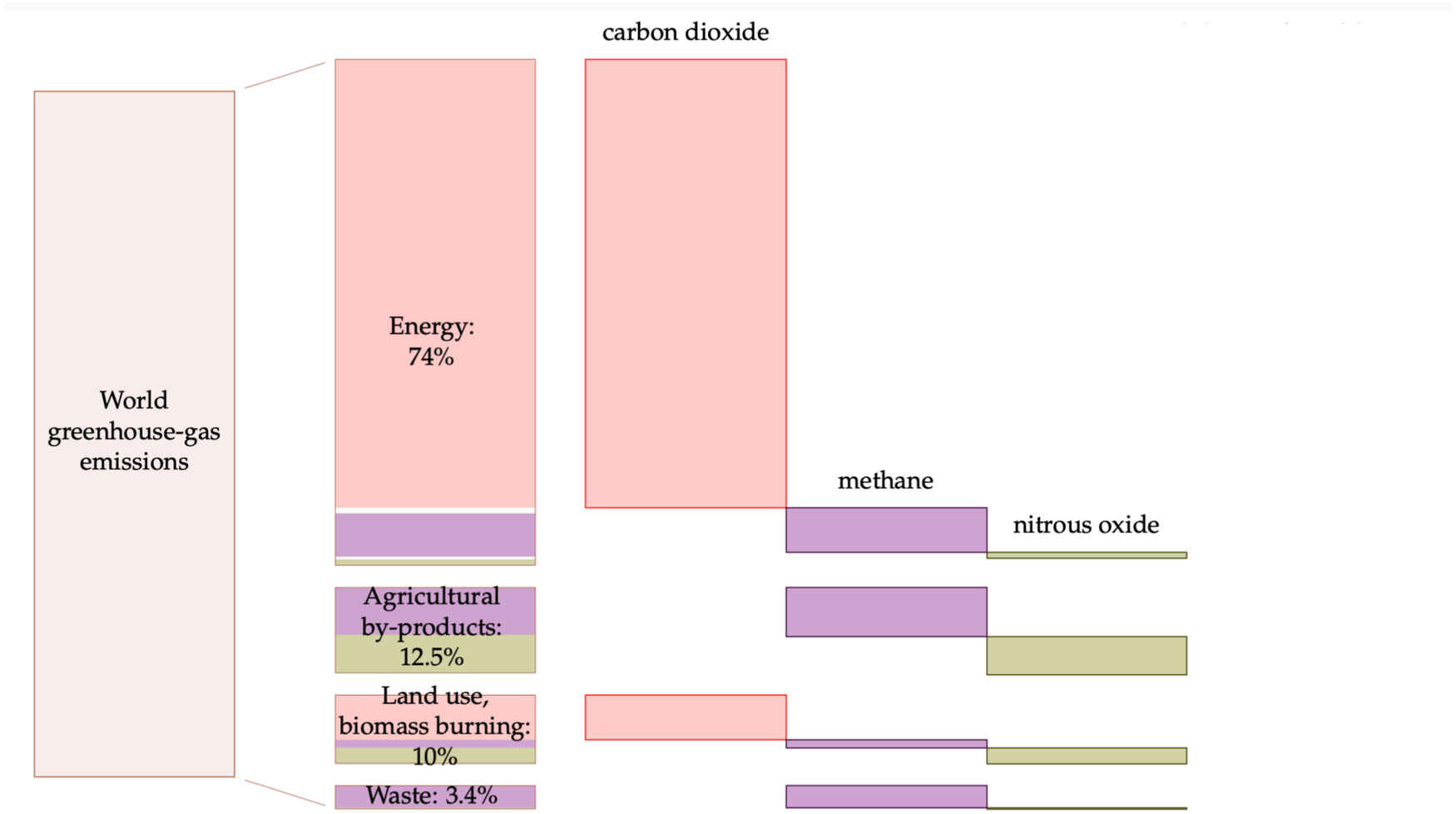
FUSION AND CLIMATE CHANGE

- 10 years to the first fusion power plant.
- 10 years to set up licensing and regulation for fast rollout, in parallel.
- 30 years to build 30,000 fusion power plants.
- In an

CARBON CAPTURE AND STORAGE

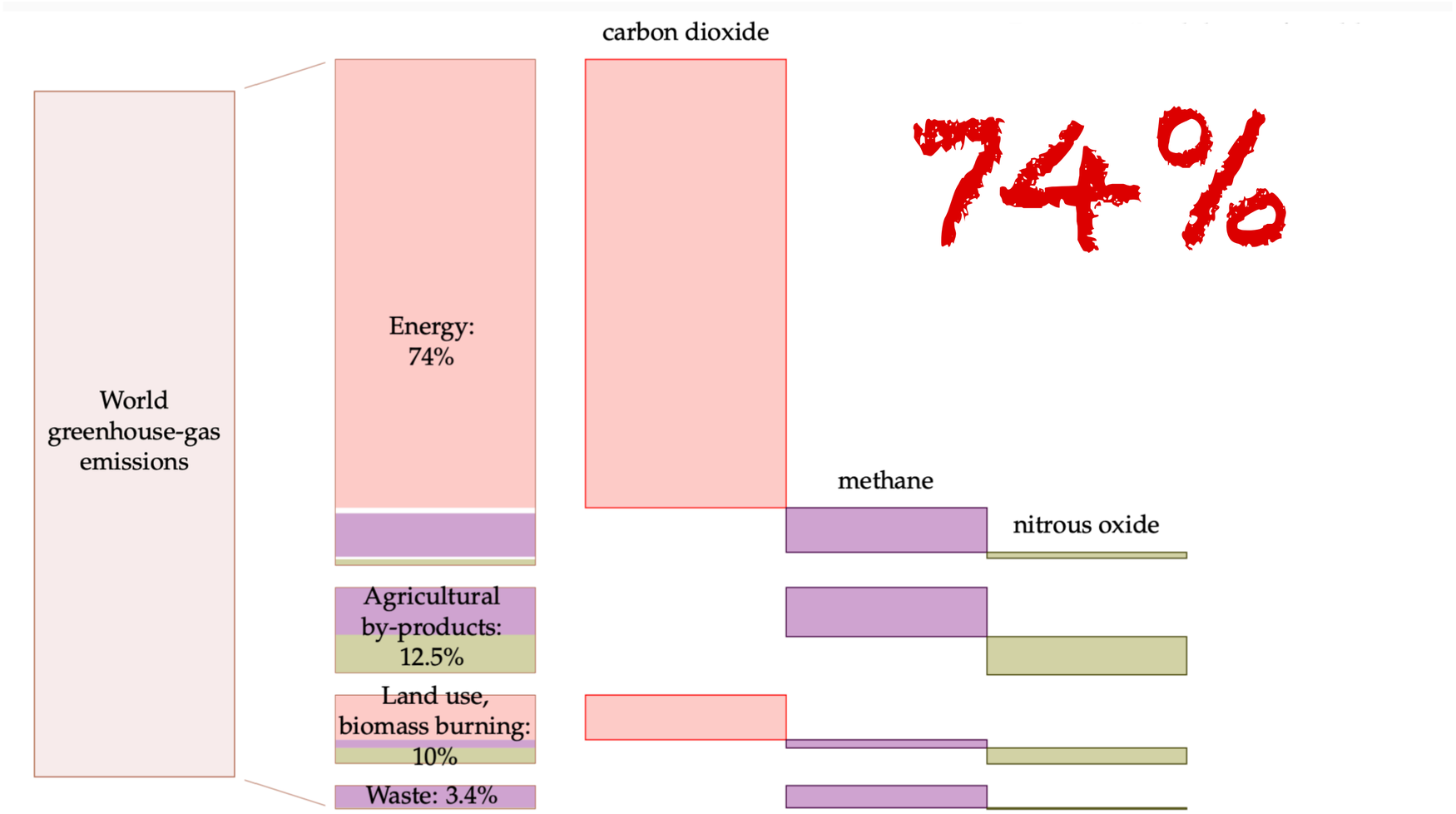
CARBON CAPTURE AND STORAGE

GHG EMISSIONS DUE TO ENERGY



Source: David MacKay, Sustainable Energy without the Hot Air, www.withouthotair.com

GHG EMISSIONS DUE TO ENERGY



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Solar Geoengineering

Aerosol injection in the upper atmosphere would work, see Mt.Pinatubo

about 0.5 degrees for 2 years

Cost: $18 billion per degree per year

https://www.giss.nasa.gov/research/briefs/archive/1997_hansen_02/

https://iopscience.iop.org/article/10.1088/1748-9326/aba7e7/pdf

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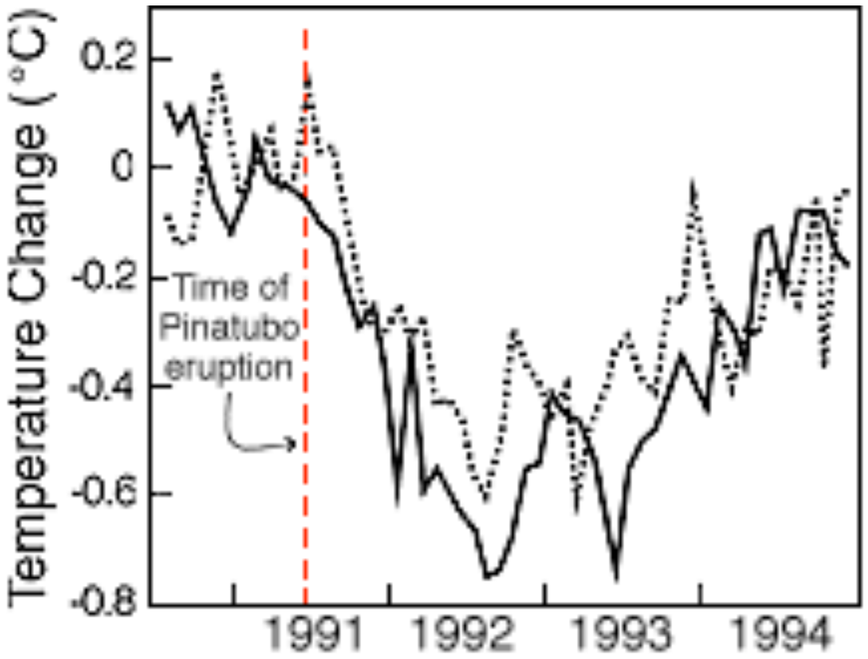

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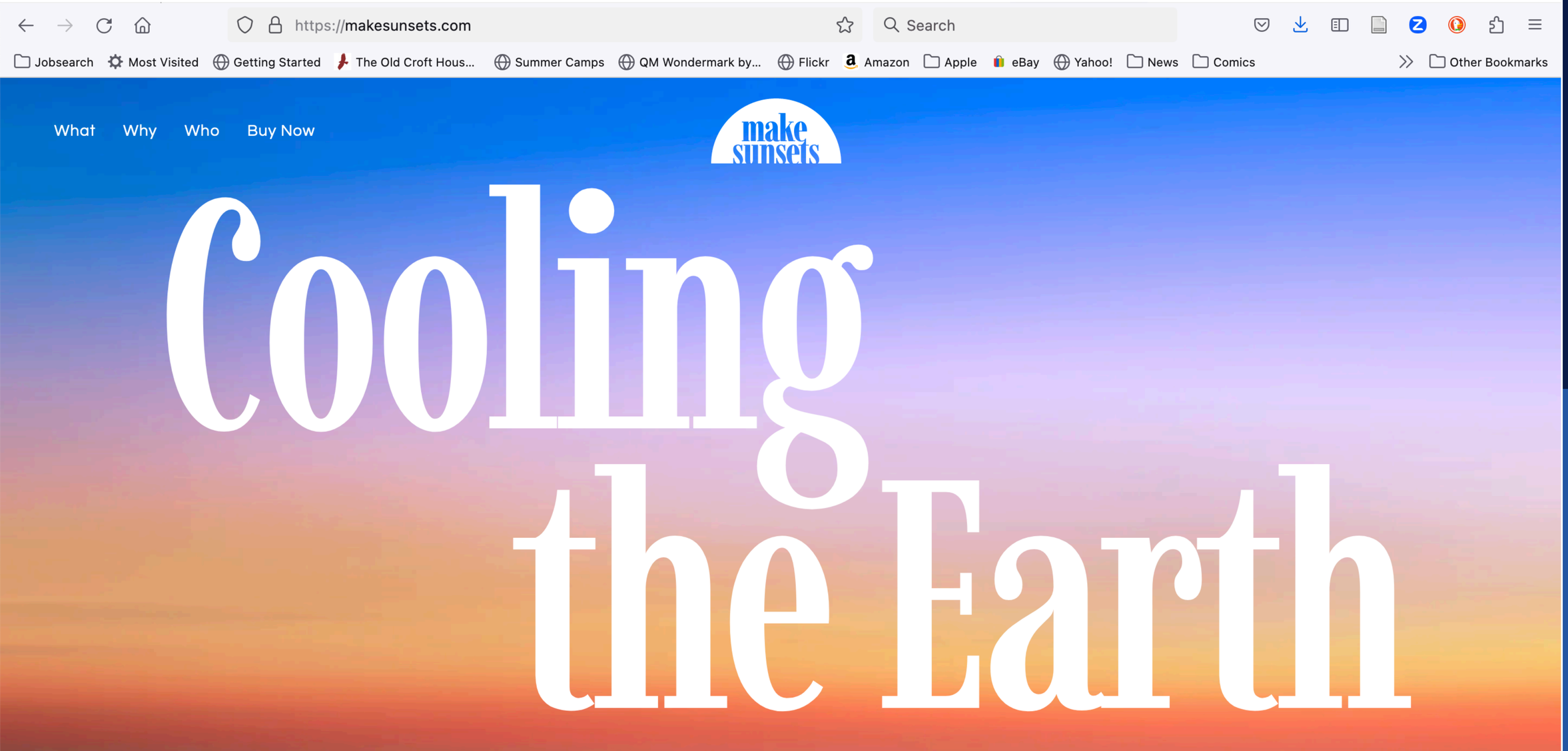
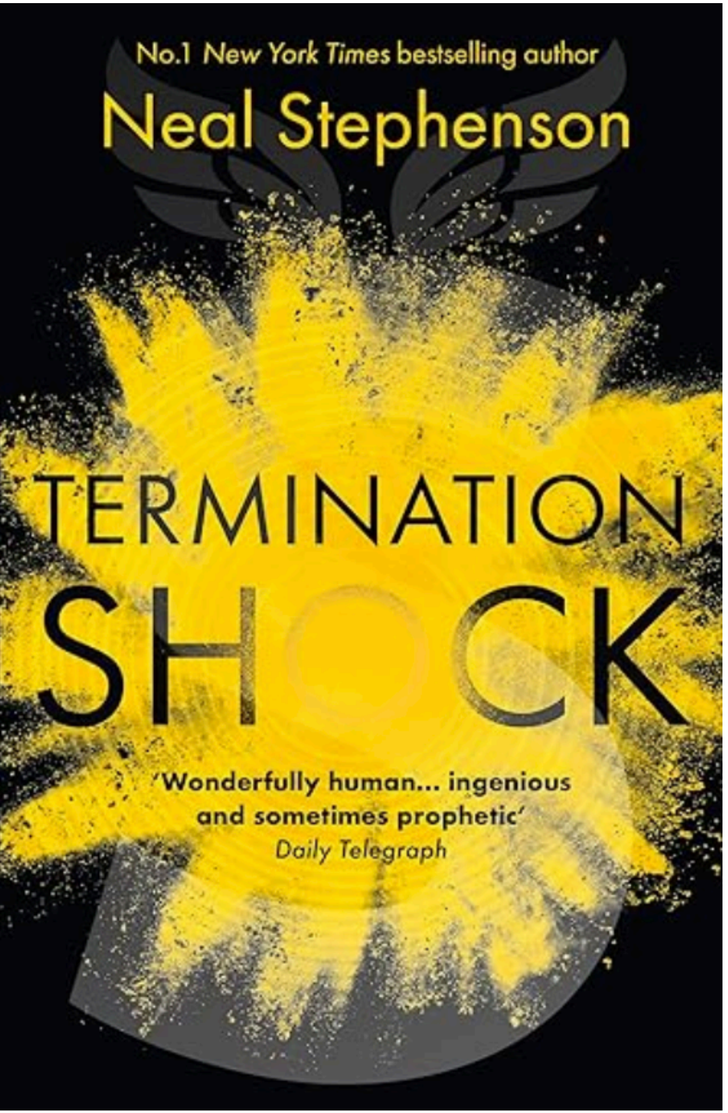
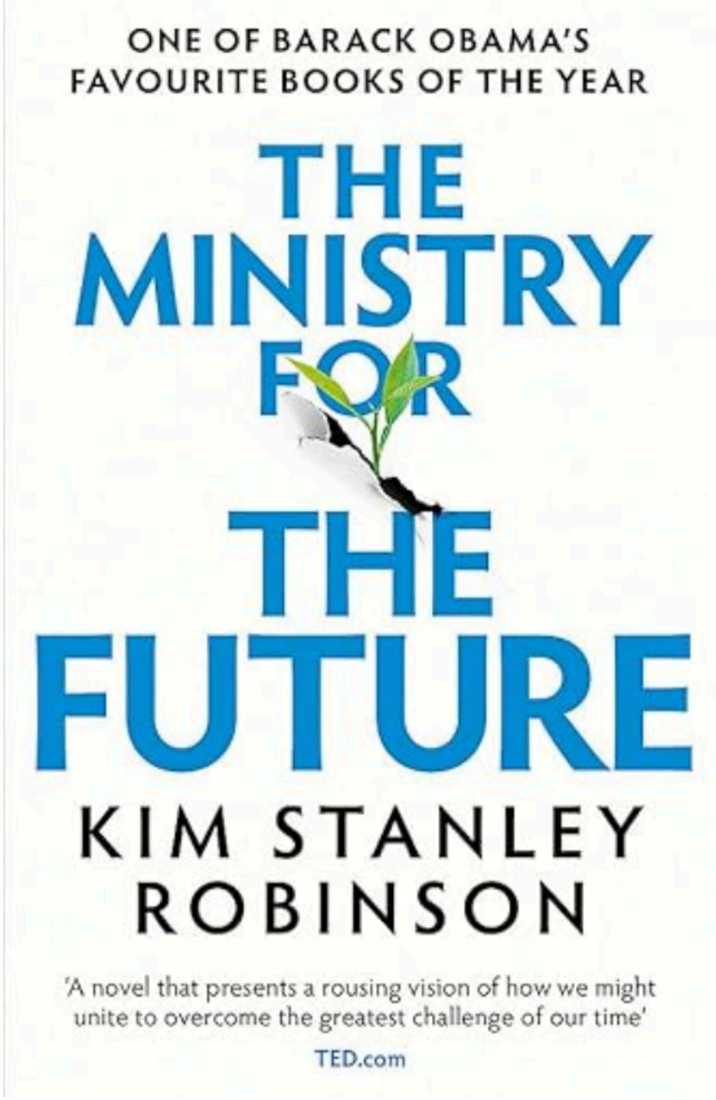
CLIMATE CHANGE

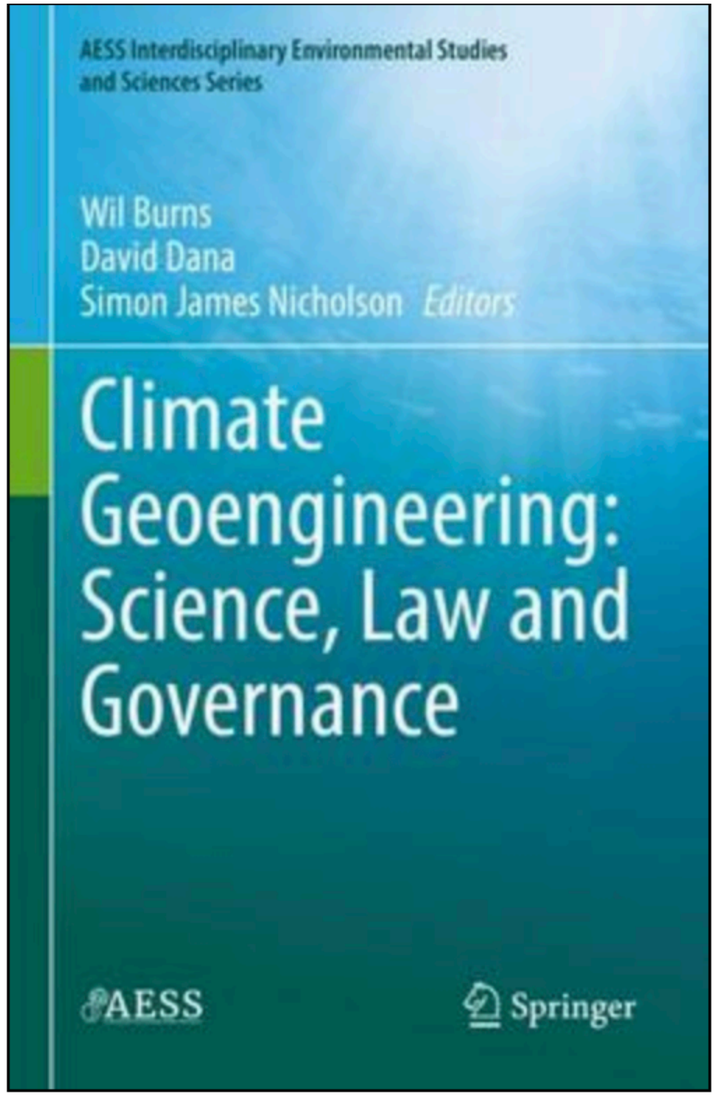
Solar Geoengineering



Solar Geoengineering - Fact and Fiction

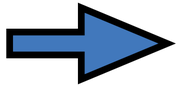






Solar Geoengineering - Risks

- Moral Hazard - We'll keep burning fossil fuels
- Termination Shock - We can't stop, ever
- Unintended Effects - e.g. on regional weather patterns
- Potential Damage to the Ozone Layer
- Geopolitical Problems



- R&D, Climate Modelling
- International Agreements
- International Watchdog Organisation

GLOBAL PRIMARY ENERGY CONSUMPTION

FUSION ENERGY REGULATION LIKE PLANES

40,000 planes in the world

60,000 power plants in the world

TITLE