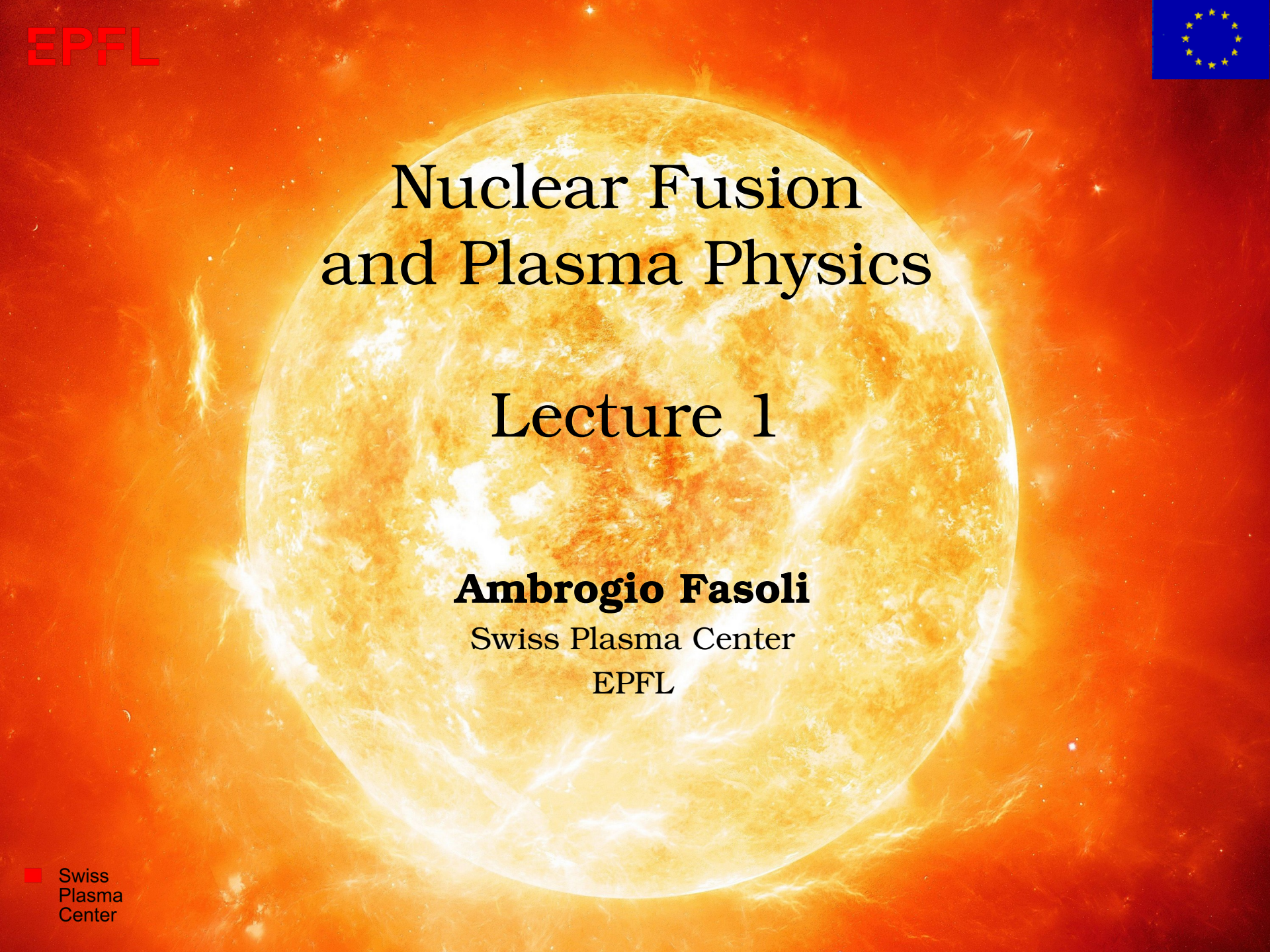


Nuclear Fusion and Plasma Physics

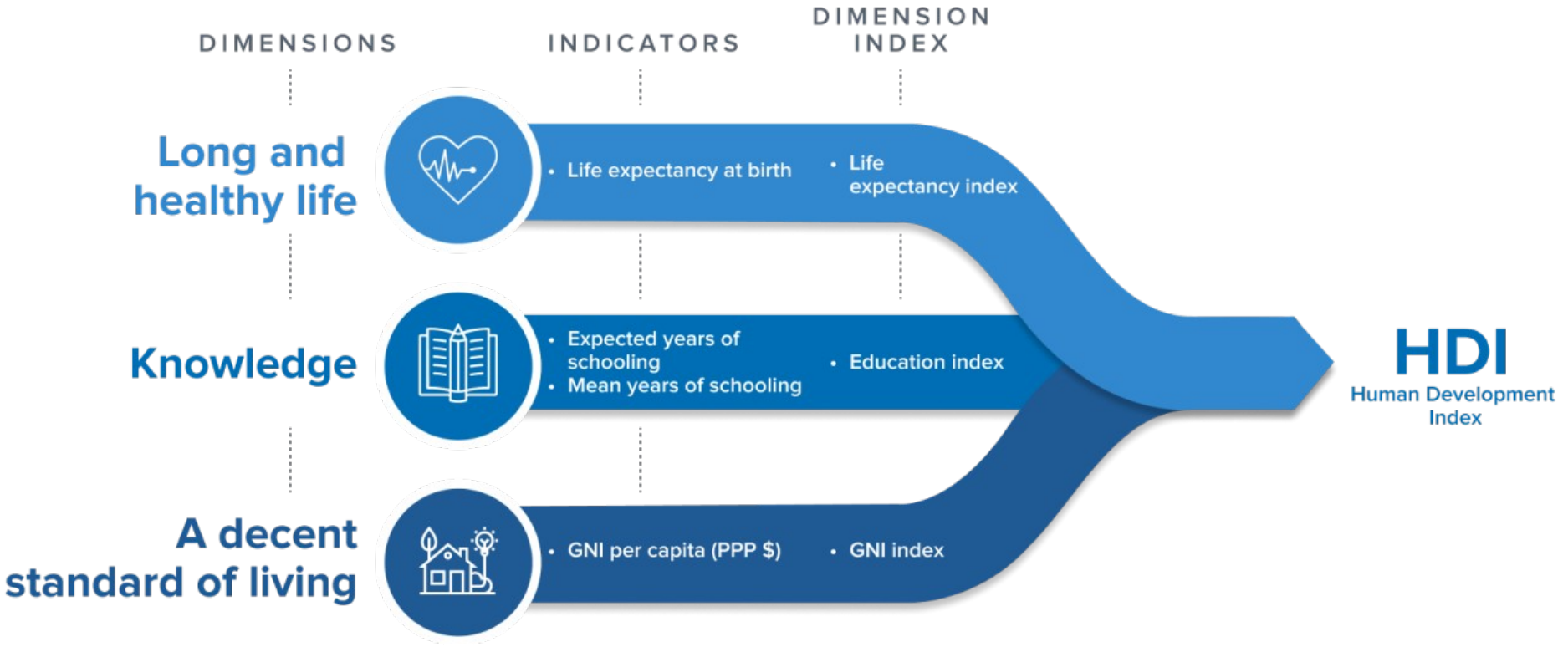
Lecture 1

Ambrogio Fasoli
Swiss Plasma Center
EPFL

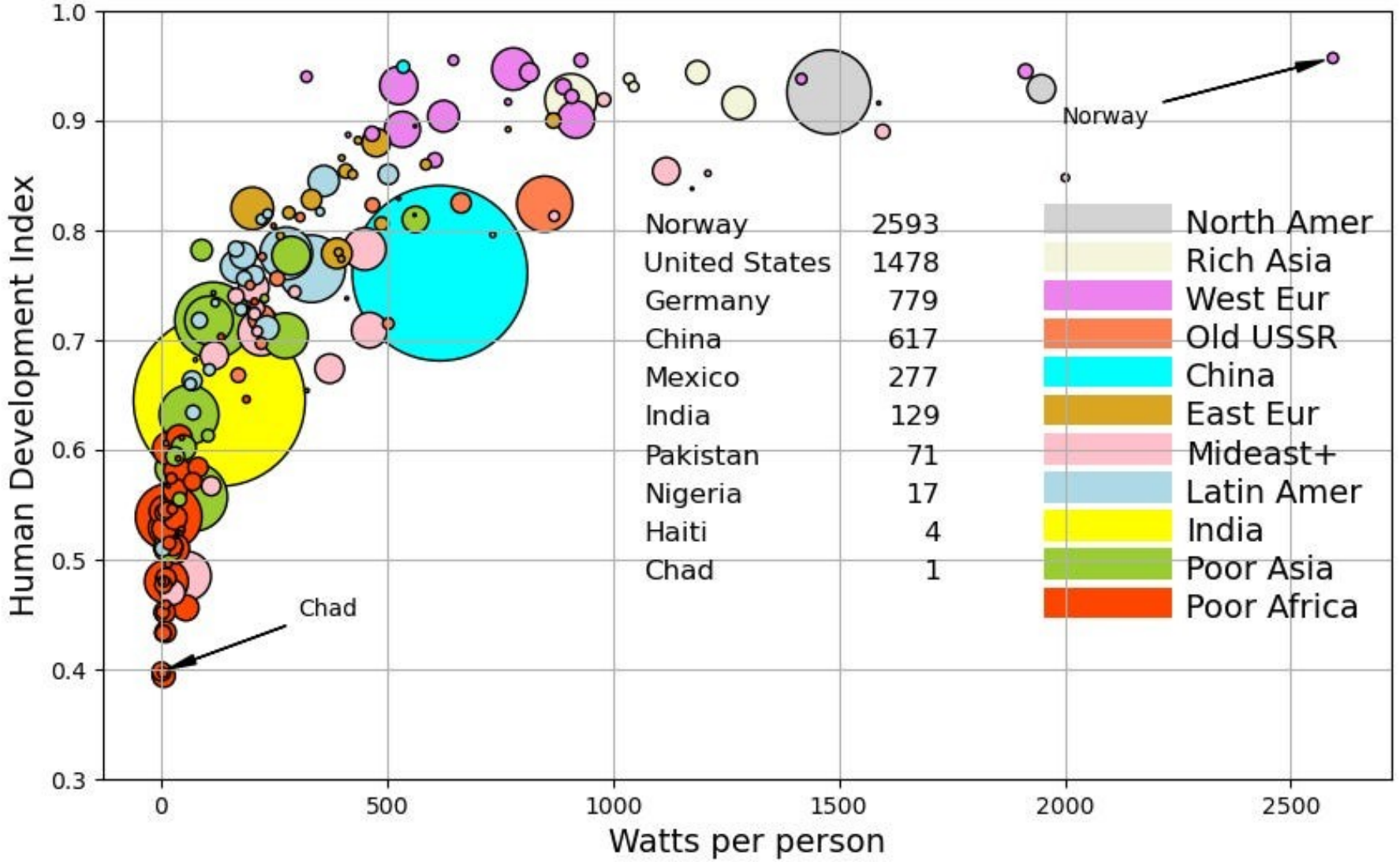
Swiss Plasma Center

Energy and human development

How to quantify human development?

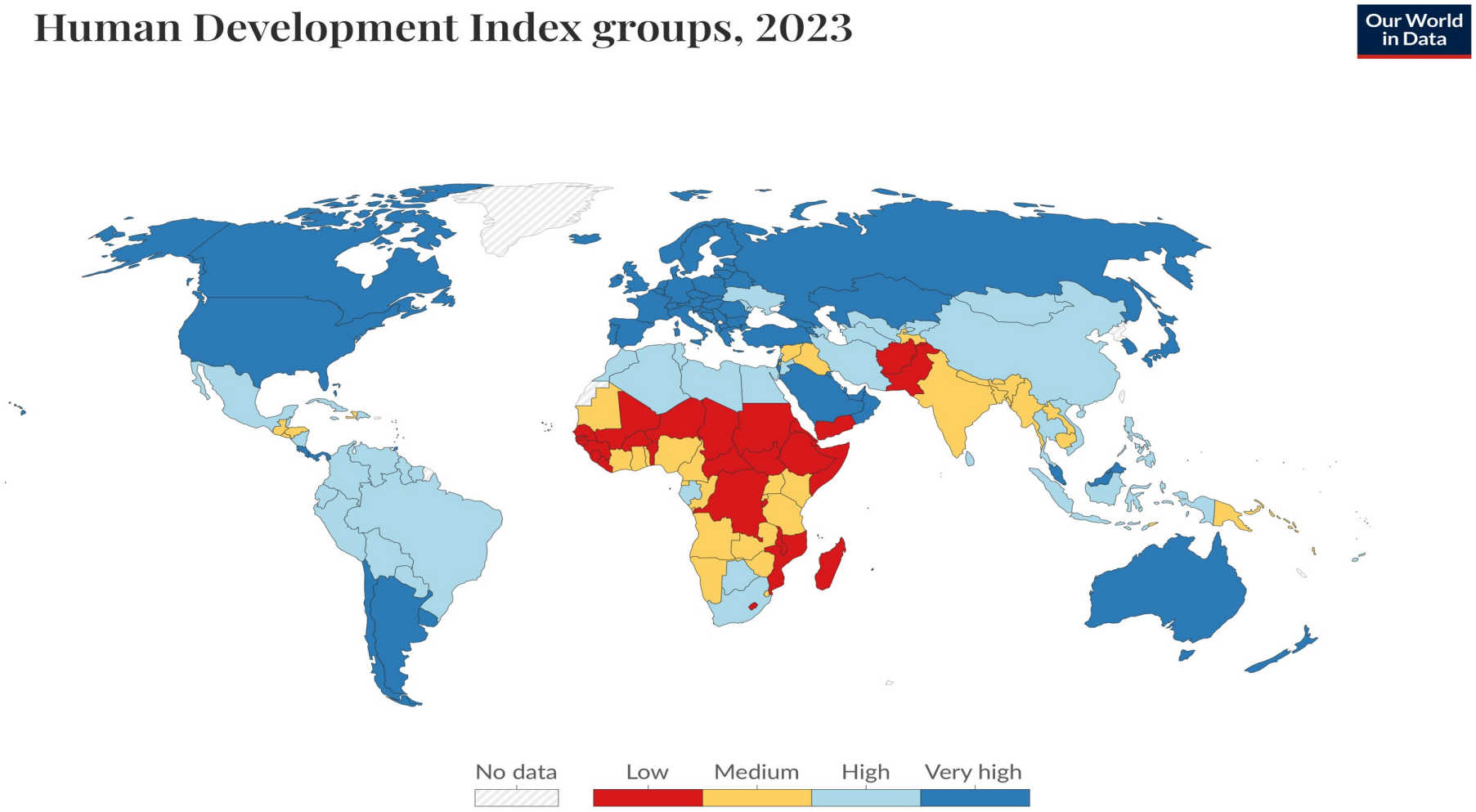


Energy and human development

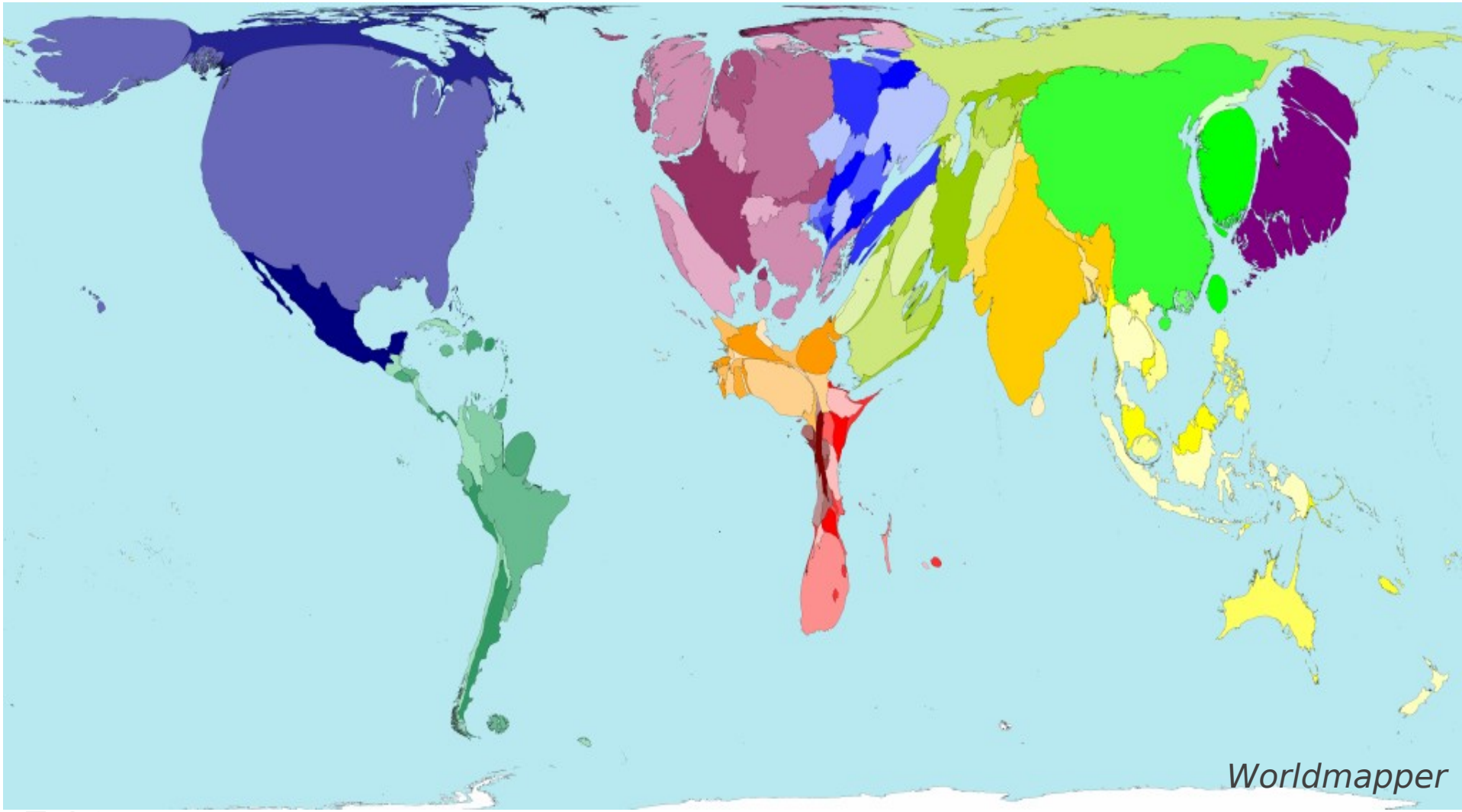


PASTERNAK, A., US Department of Energy Report UCRL-ID- 140773, LLNL , Livermore, CA (2000) 38.

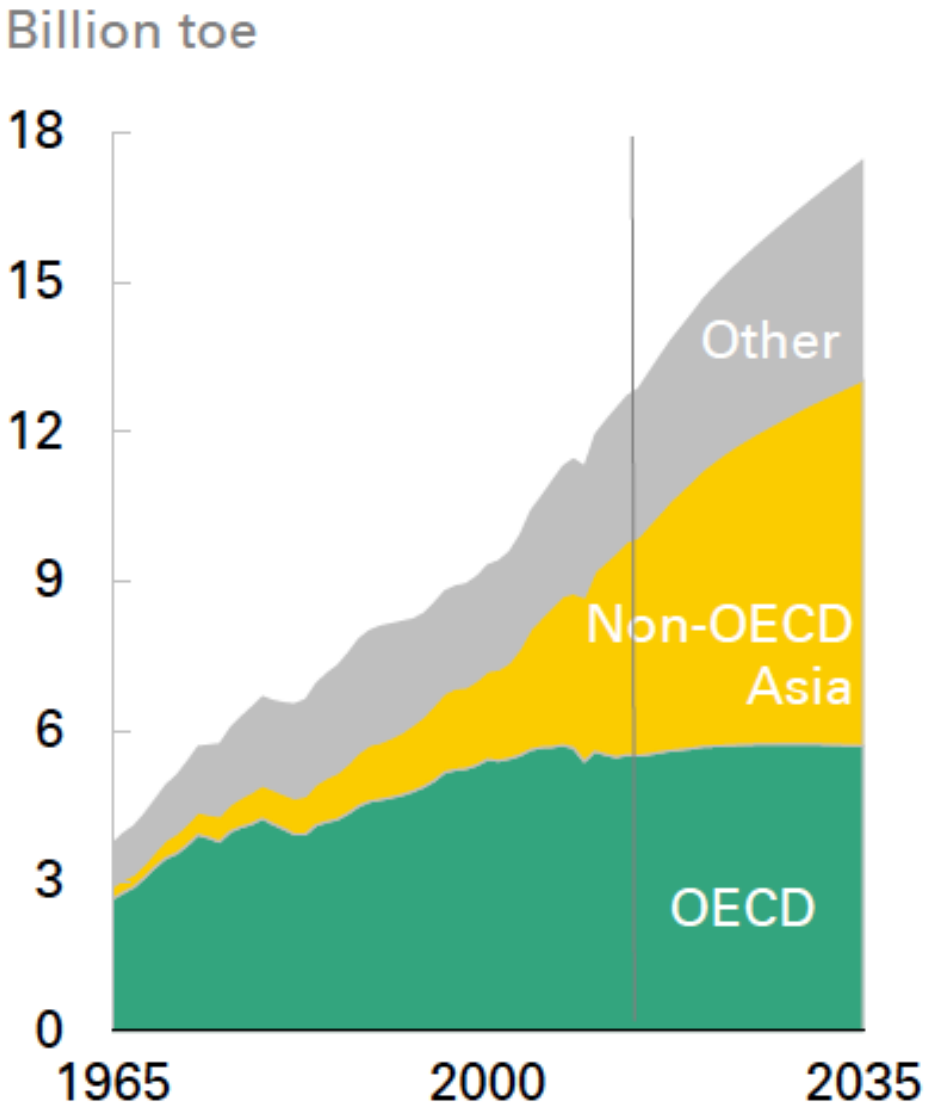
Unequal distribution of human development…



… and of energy consumption



Evolution of distribution of energy consumption

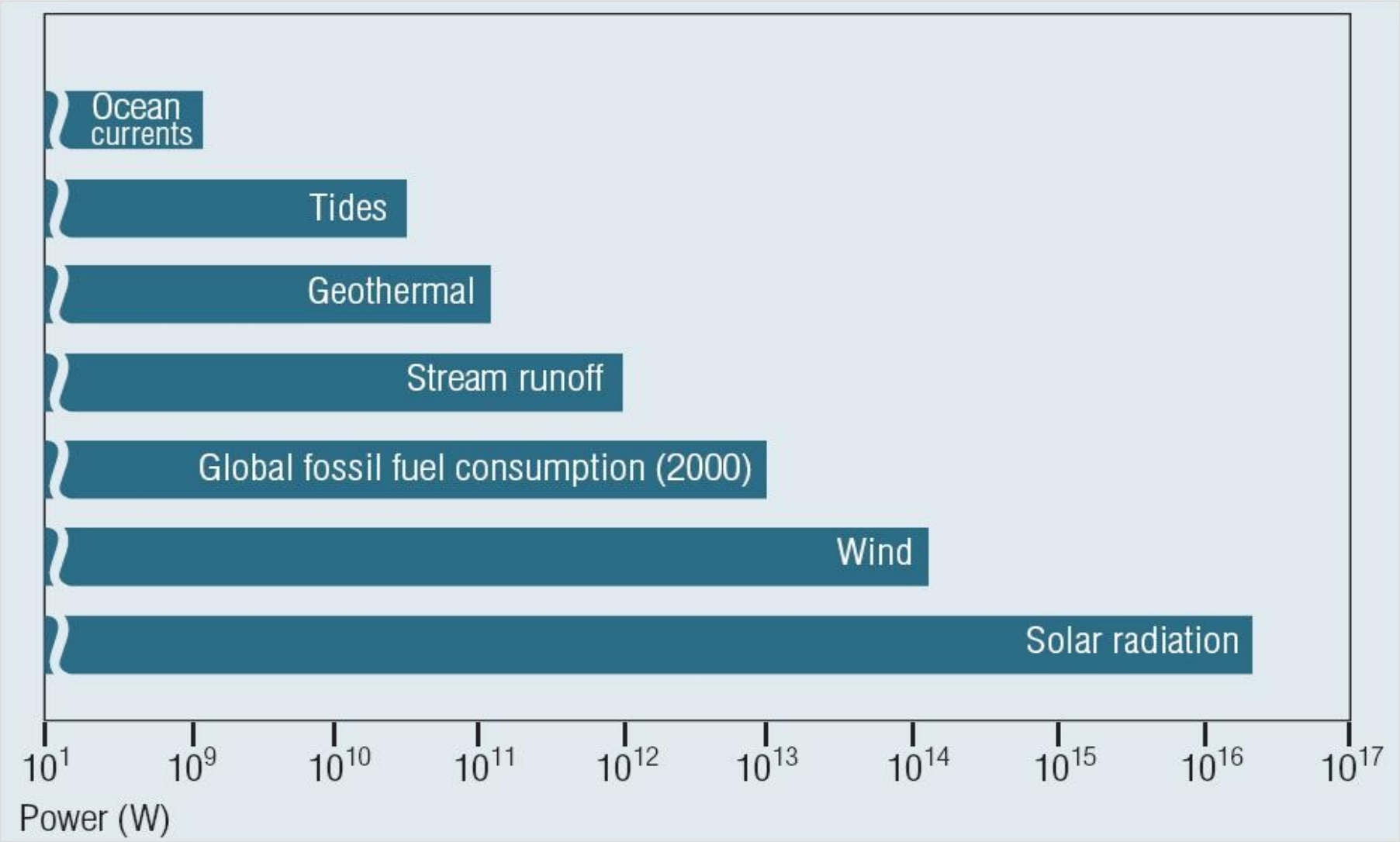


EPFL


SUSTAINABLE DEVELOPMENT GOALS

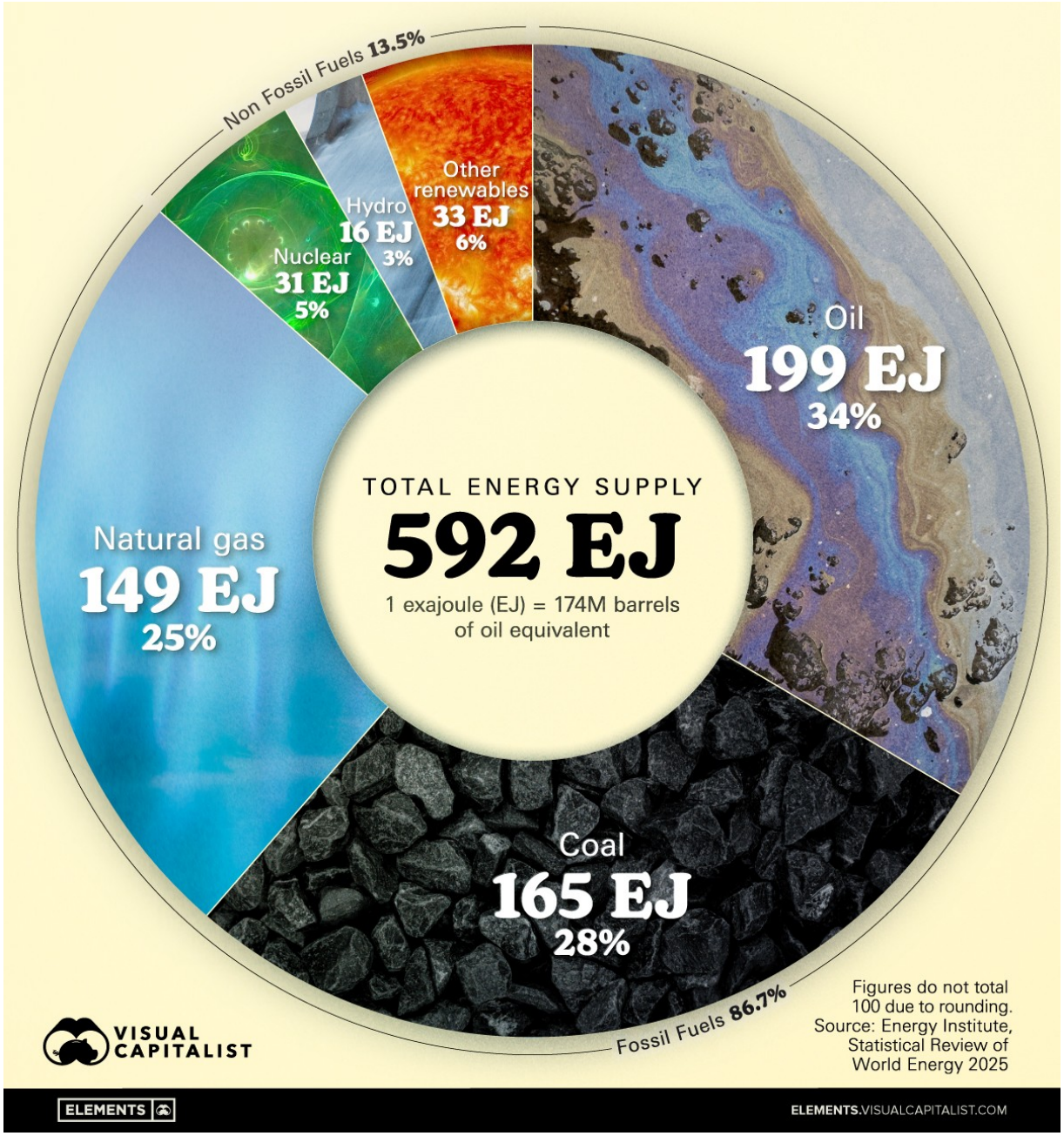

1 NO POVERTY
2 ZERO HUNGER
3 GOOD HEALTH AND WELL-BEING
4 QUALITY EDUCATION
5 GENDER EQUALITY
6 CLEAN WATER AND SANITATION
7 AFFORDABLE AND CLEAN ENERGY
8 DECENT WORK AND ECONOMIC GROWTH
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
10 REDUCED INEQUALITIES
11 SUSTAINABLE CITIES AND COMMUNITIES
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
13 CLIMATE ACTION
14 LIFE BELOW WATER
15 LIFE ON LAND
16 PEACE, JUSTICE AND STRONG INSTITUTIONS
17 PARTNERSHIPS FOR THE GOALS

Global view of energy fluxes



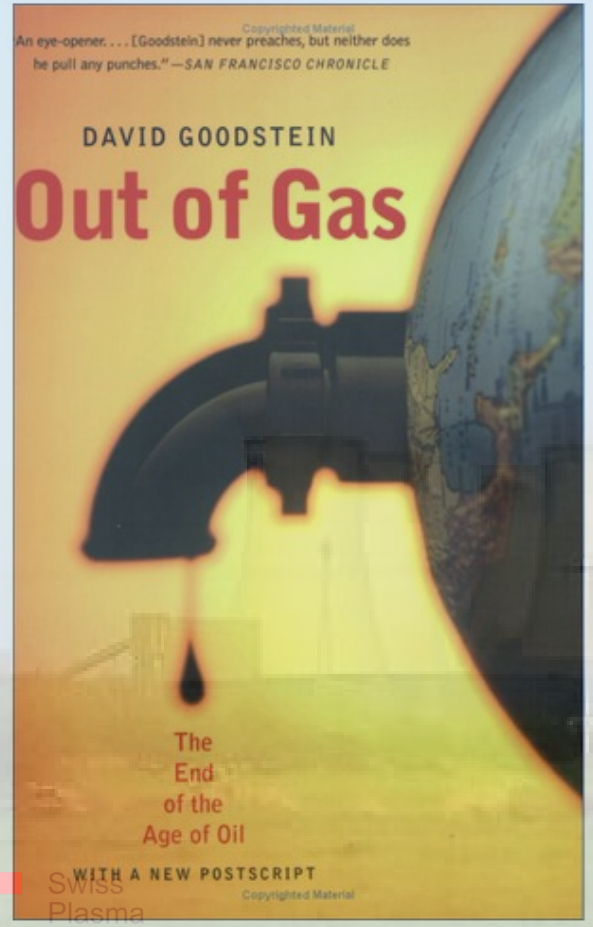
The global flux of fossil and renewable fuels. (Source: Smil, V. 2006. "21st century energy: Some sobering thoughts." OECD Observer 258/59: 22-23.)

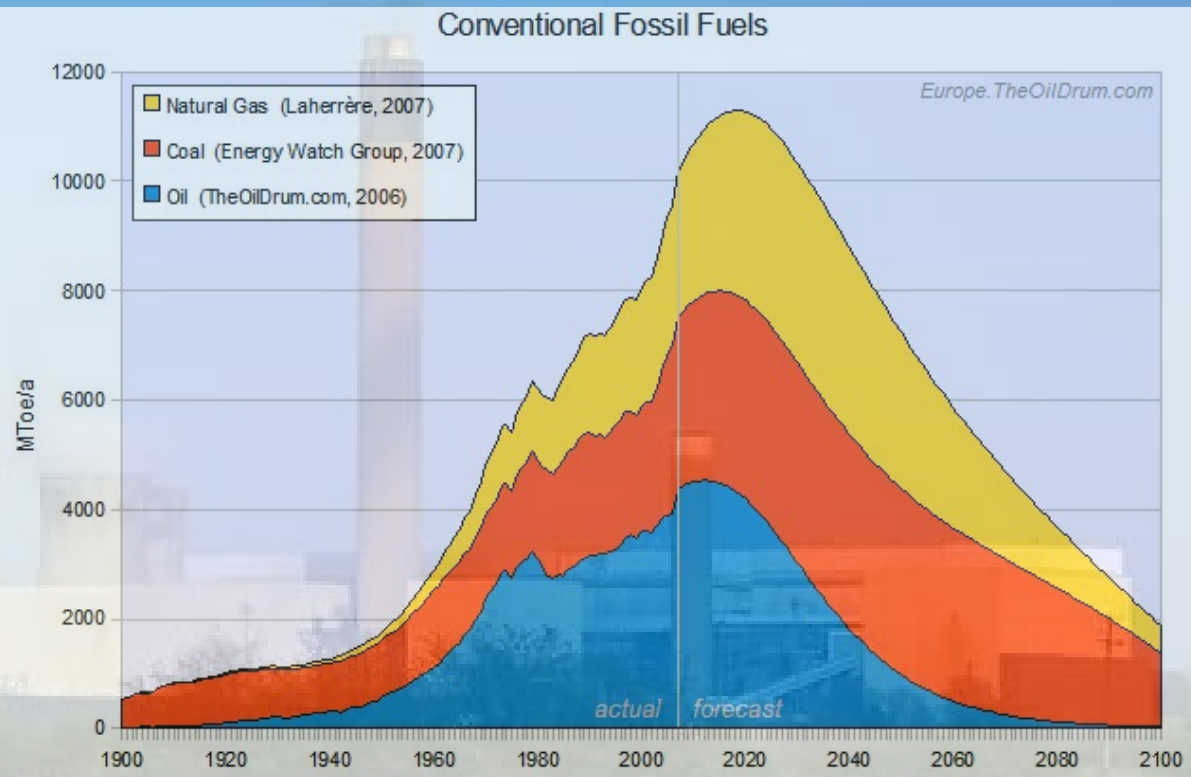
What powered the world in 2025 ?



Reliance on fossil fuels

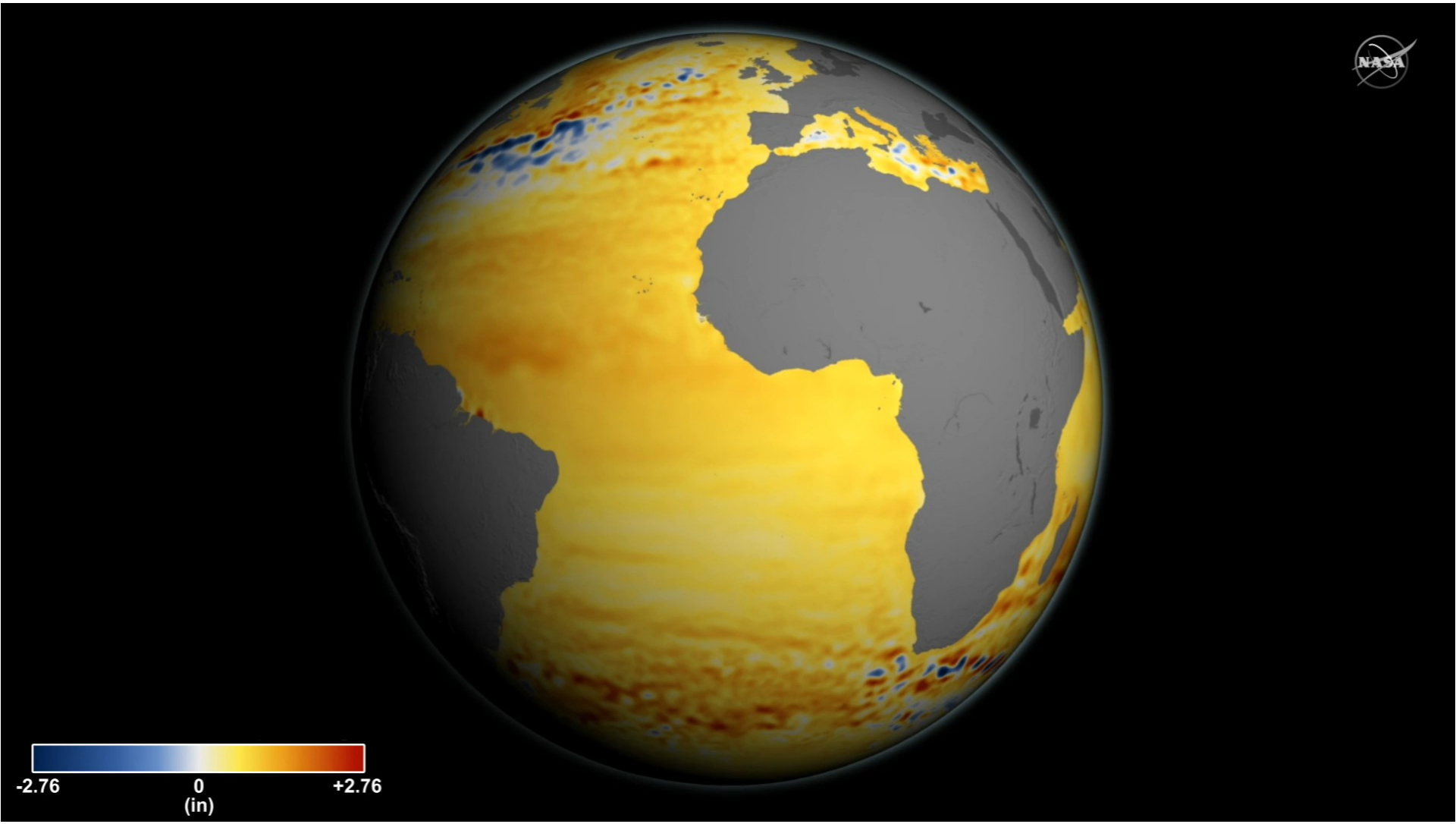
Fossil Fuels have been produced from decayed plant and animal matter over millions of years, cannot be re-formed in time





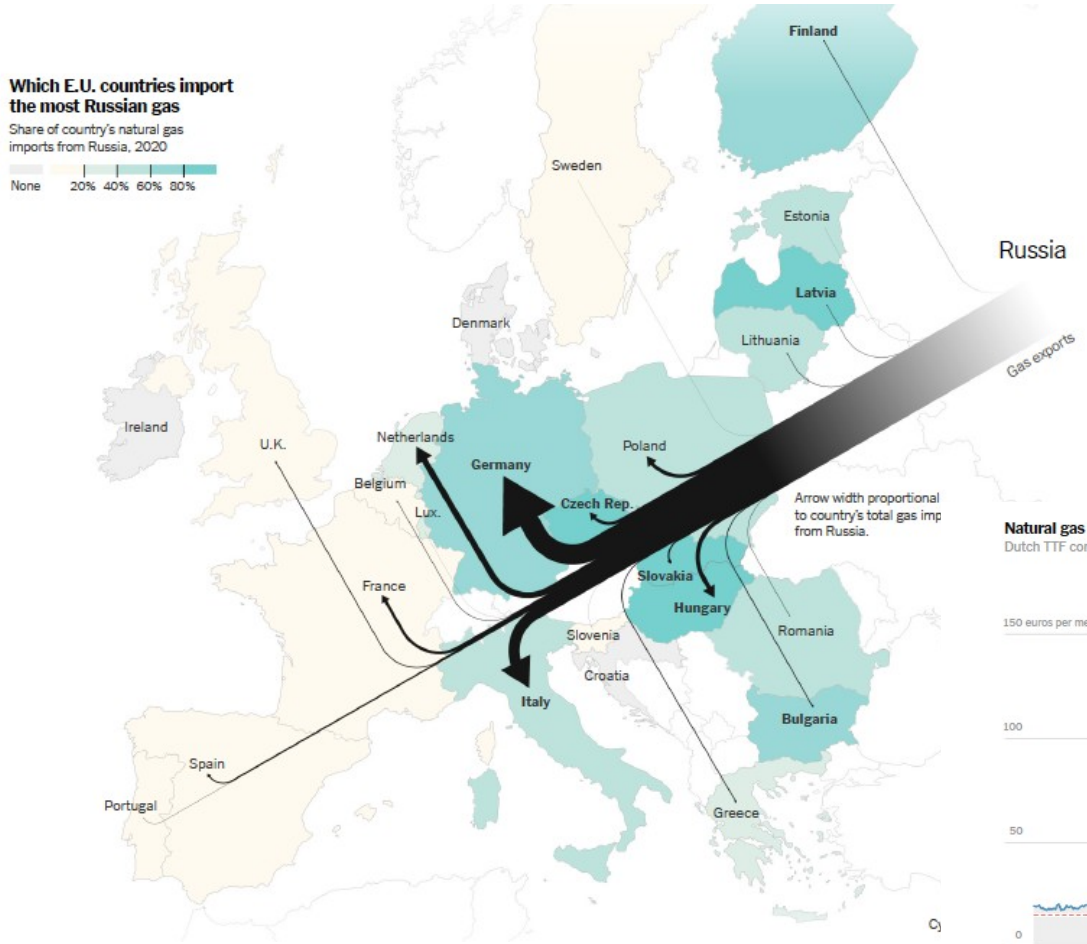
Urgency of alternates development

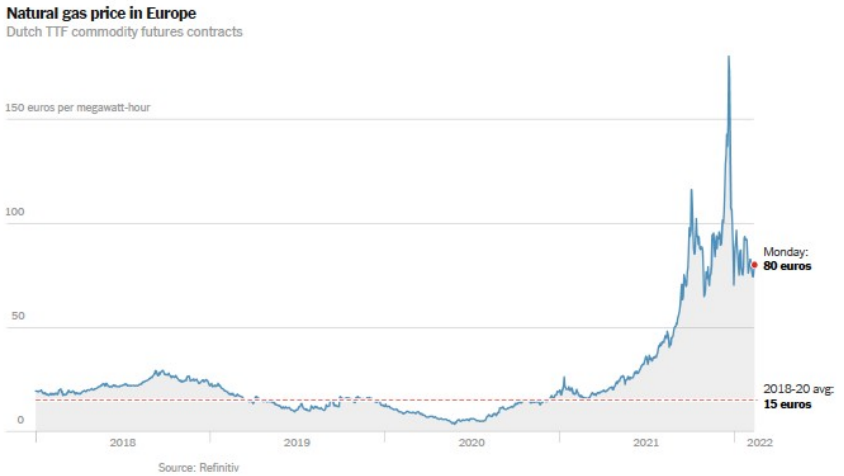
Climate change



Urgency of alternates development

Geopolitical issues





The New York Times

ENERGY & ENVIRONMENT | How a Ukraine Conflict Could Reshape Europe's Reliance on Russia

Discussion of today's energy options

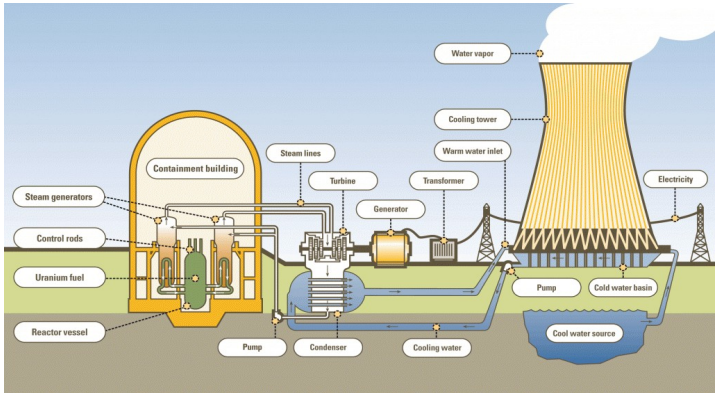


Fossil
- Coal
- Natural gas
- Oil



Renewables
- Hydro-electric
- Wind
- Solar

Nuclear fission



Growth in energy demand is dominated by electricity and by renewables

IEA (2026), Change in energy demand in selected regions, 2025, IEA, Paris https://www.iea.org/data-and-statistics/charts/change-in-energy-demand-in-selected-regions-2025, Licence: CC BY 4.0

Discussion of today's energy options

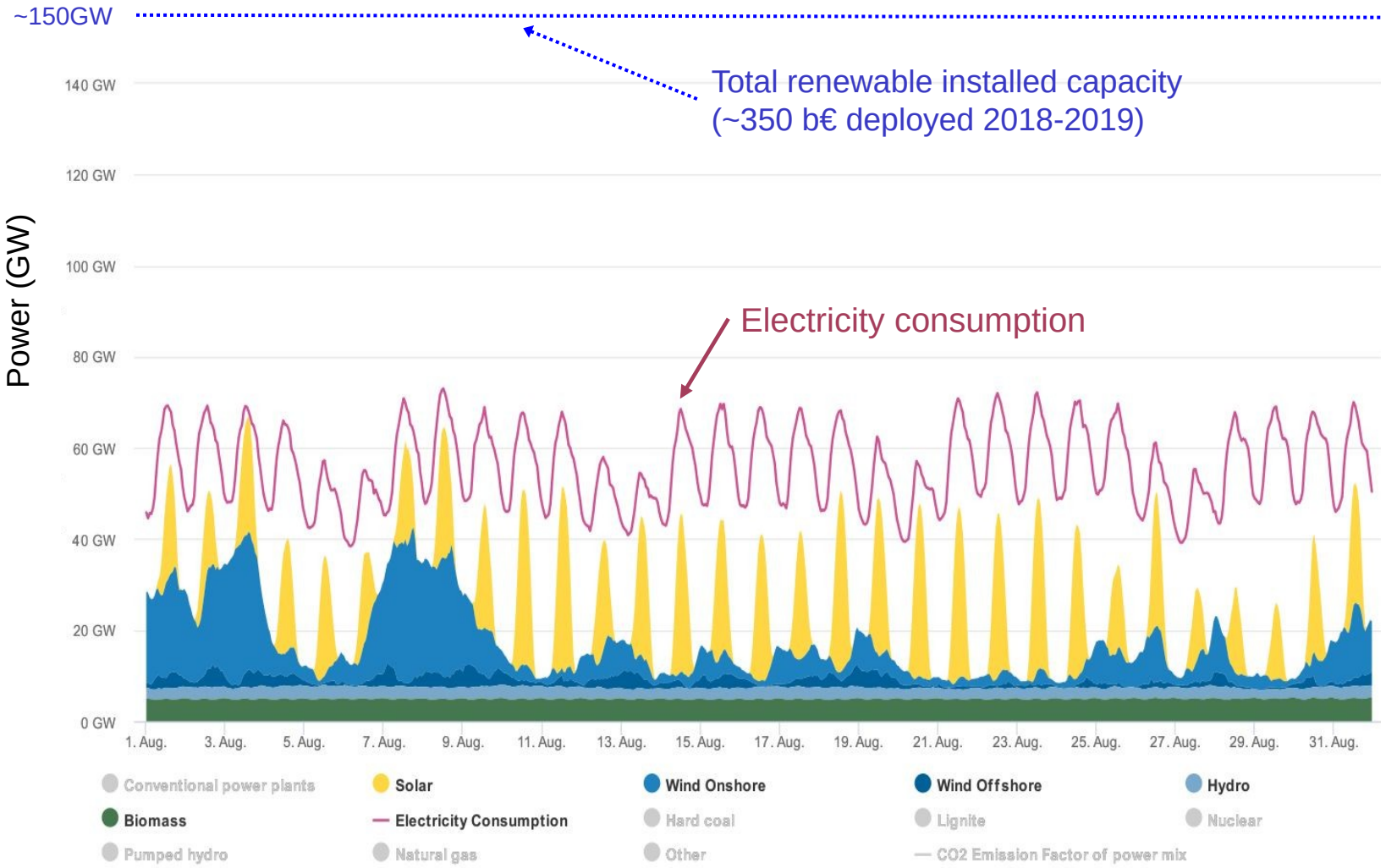
Why not only renewables ?

Renewables

- Hydro-electric
- Wind
- Solar



The example of Germany - August '23



Agora Energiewende (2023): Agorameter. Model version 3.0, Berlin, 13.09.21

Germany - August ‘23 - March ‘24

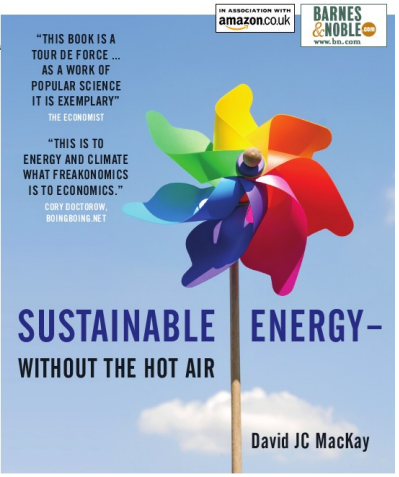


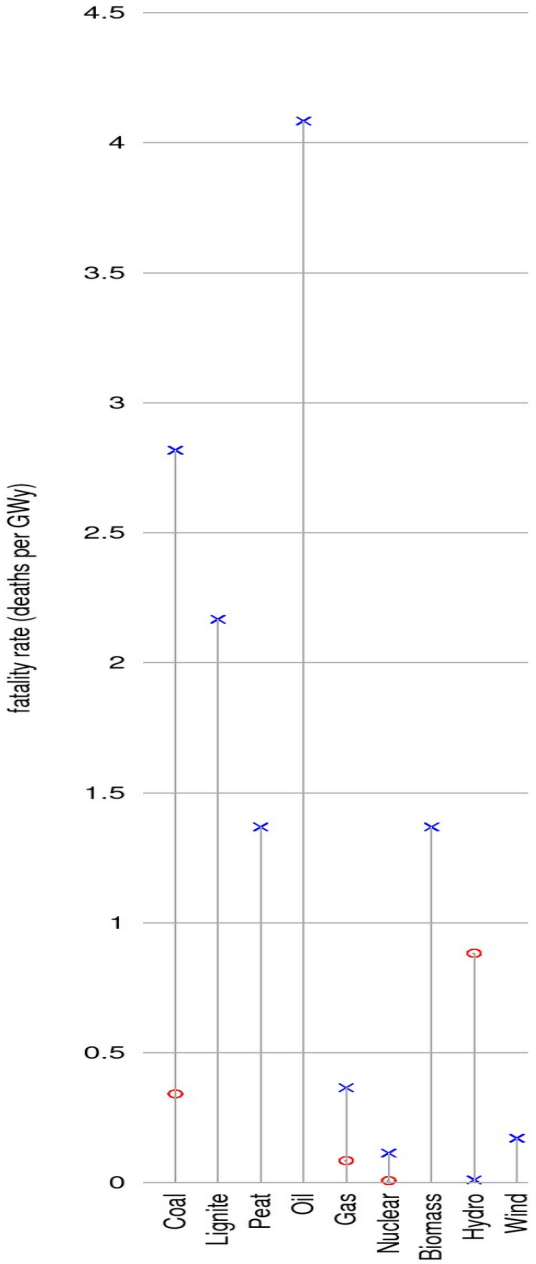
Agora Energiewende (2023): Agorameter. Model version 3.0, Berlin, 13.09.21

Discussion of today's energy options

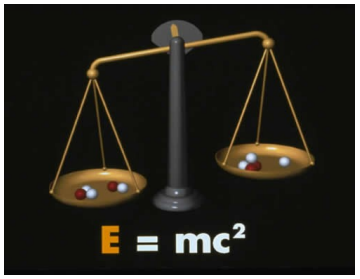
A politically incorrect view

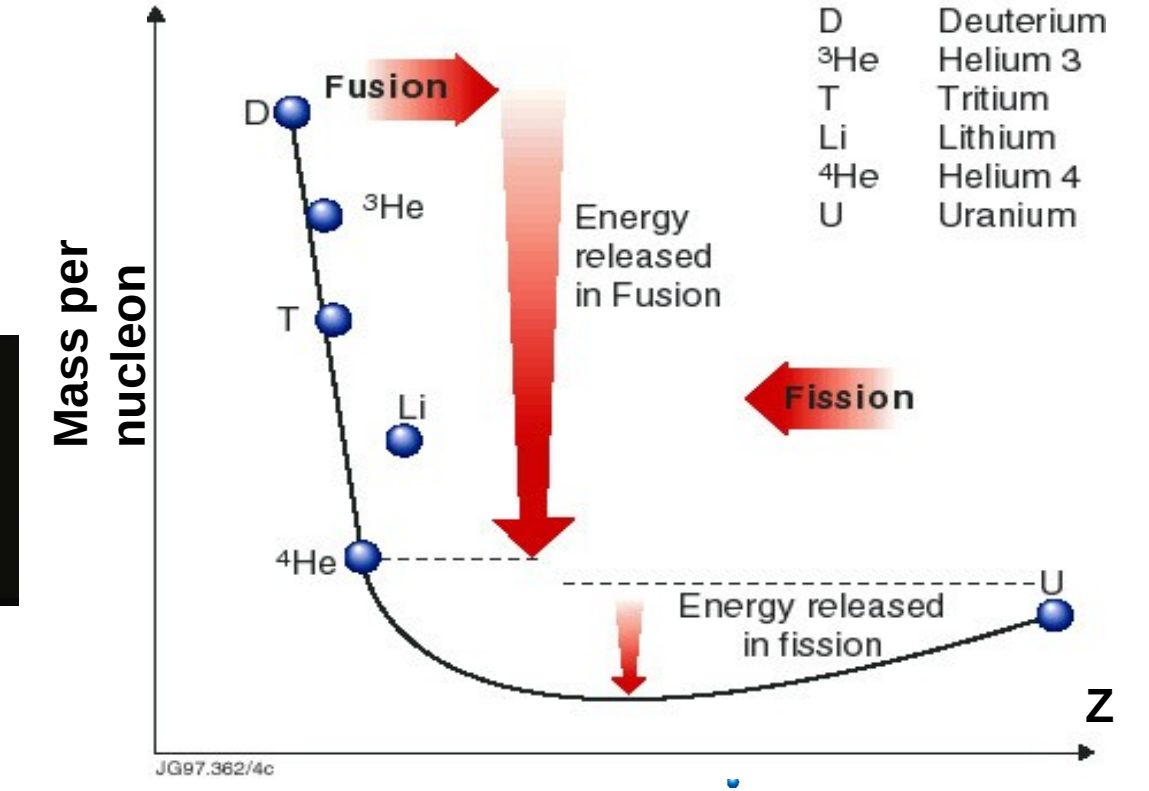
Human deaths per energy

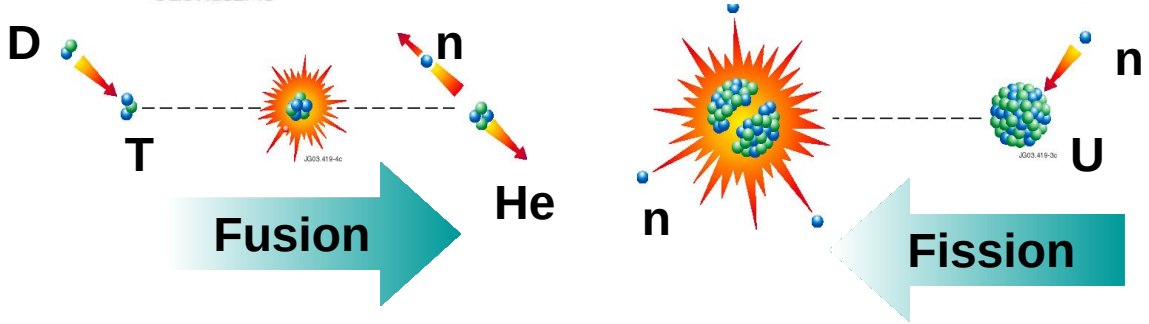




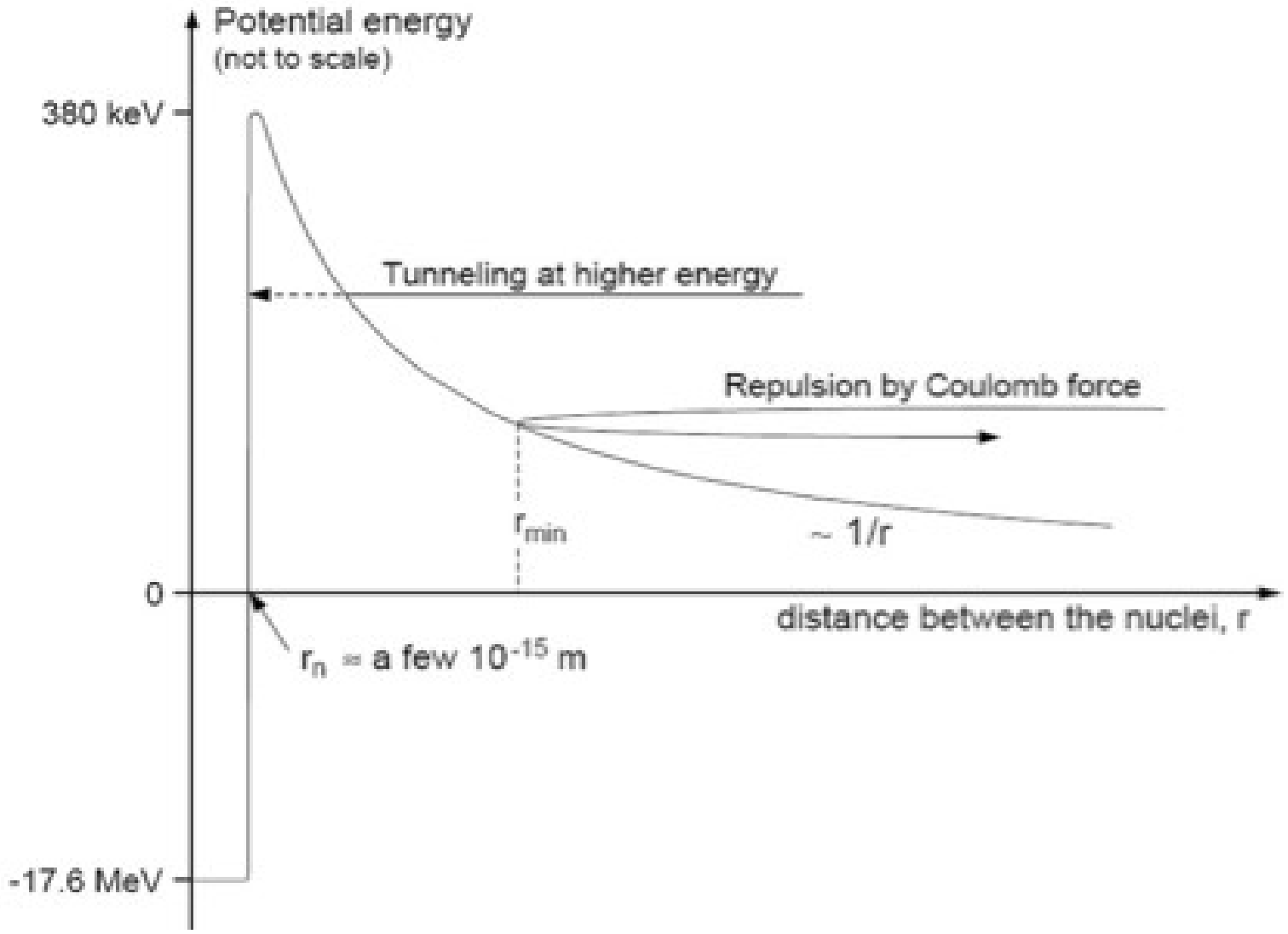
A solution in the nucleus ? Fusion vs. fission







Large energies are required for fusion

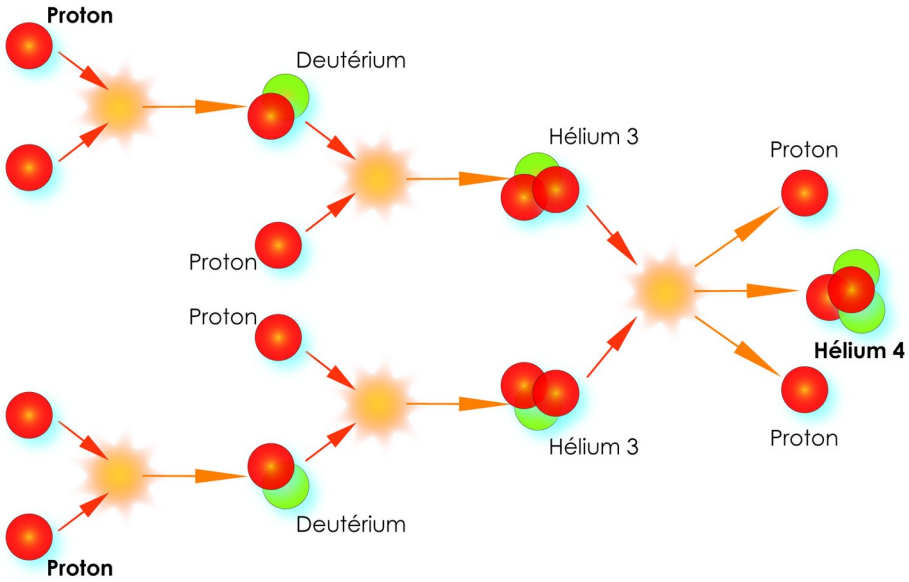


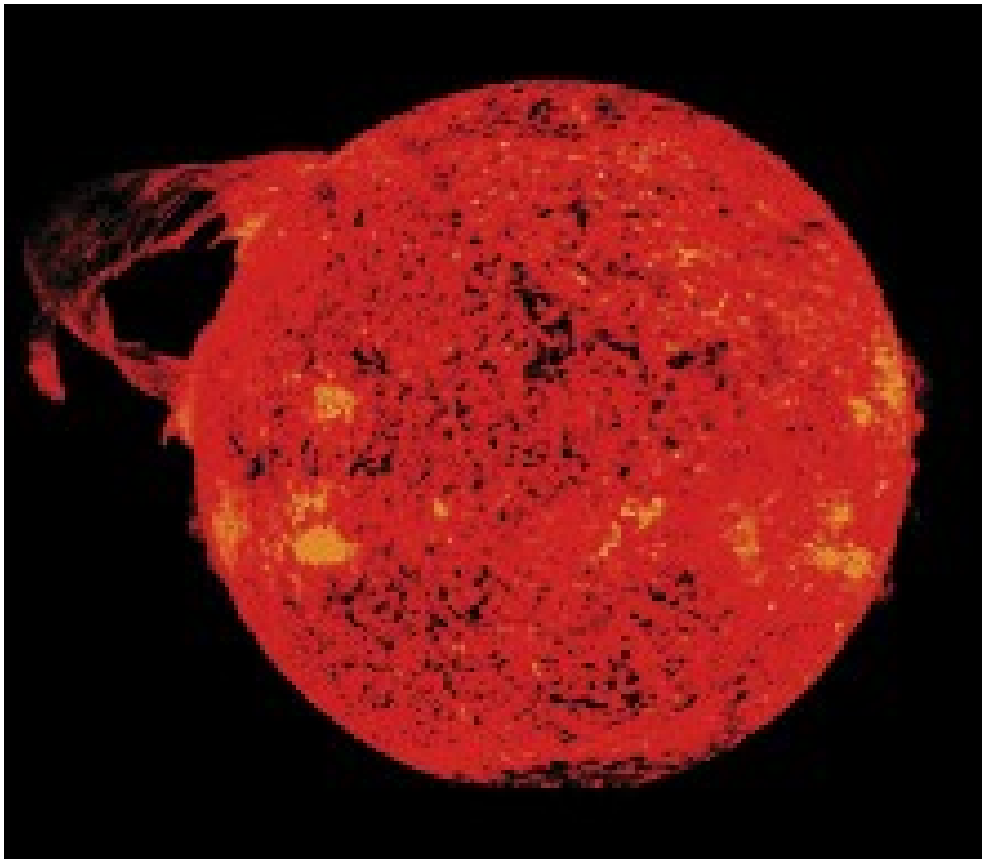
At such large energies matter is in the form of **plasma**

Examples of plasmas

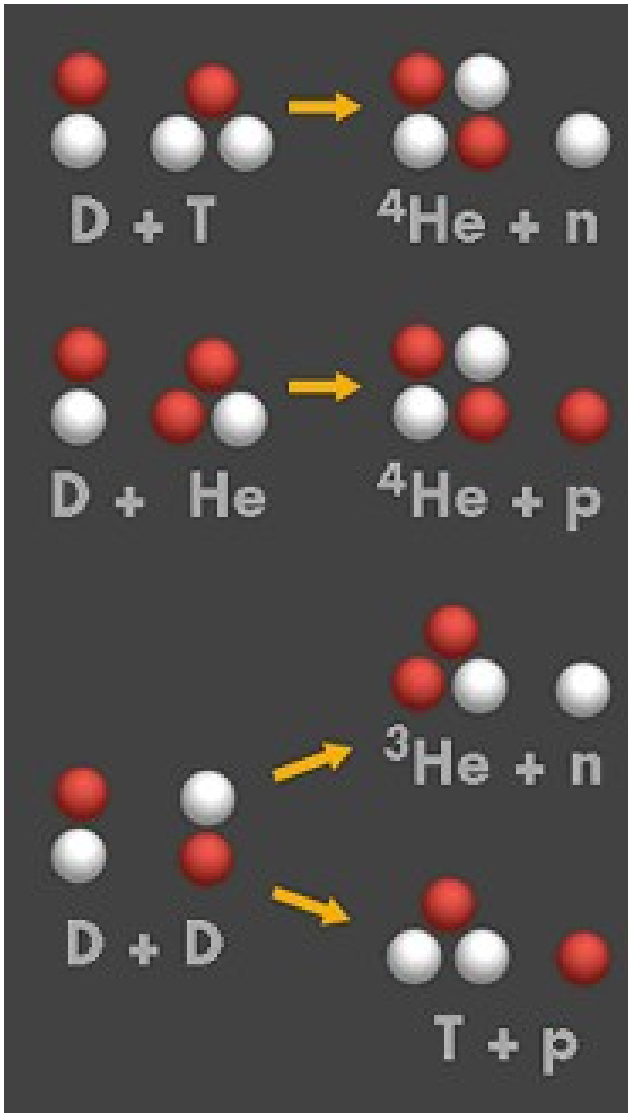


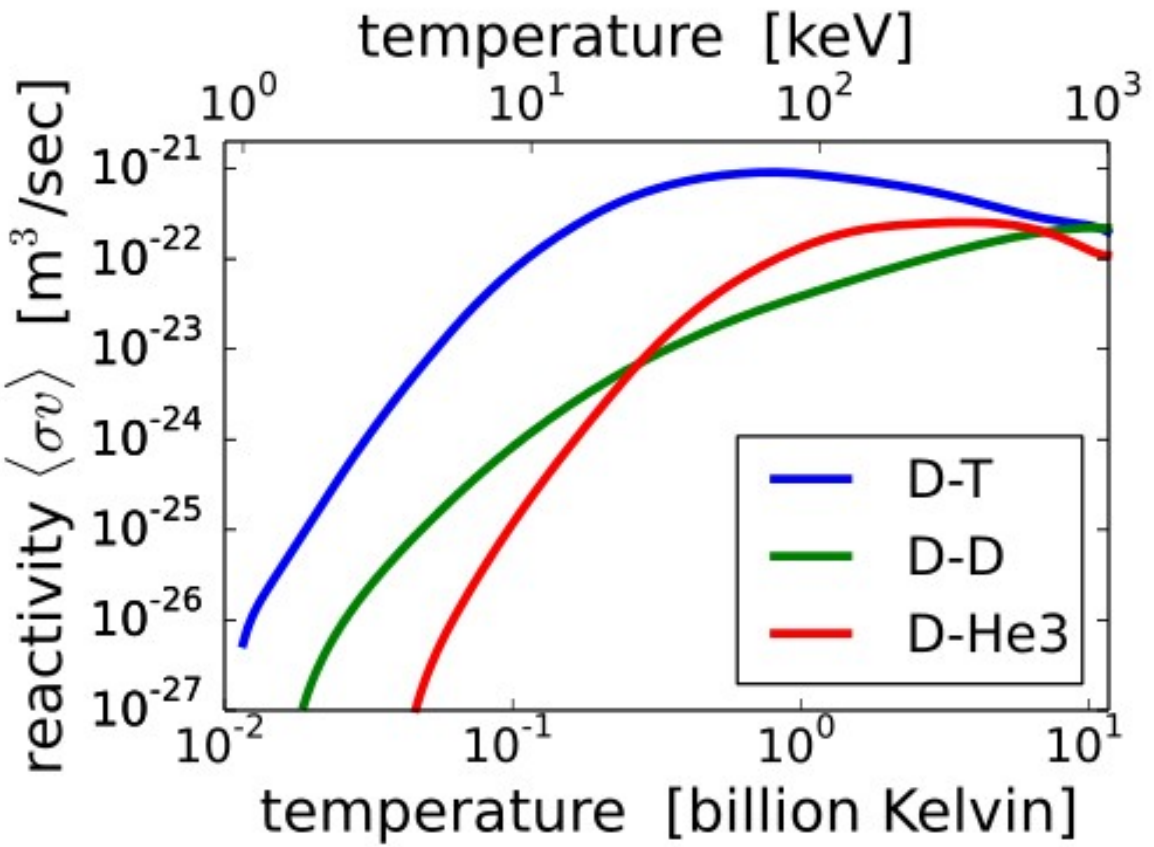
Fusion powers the sun and all the stars



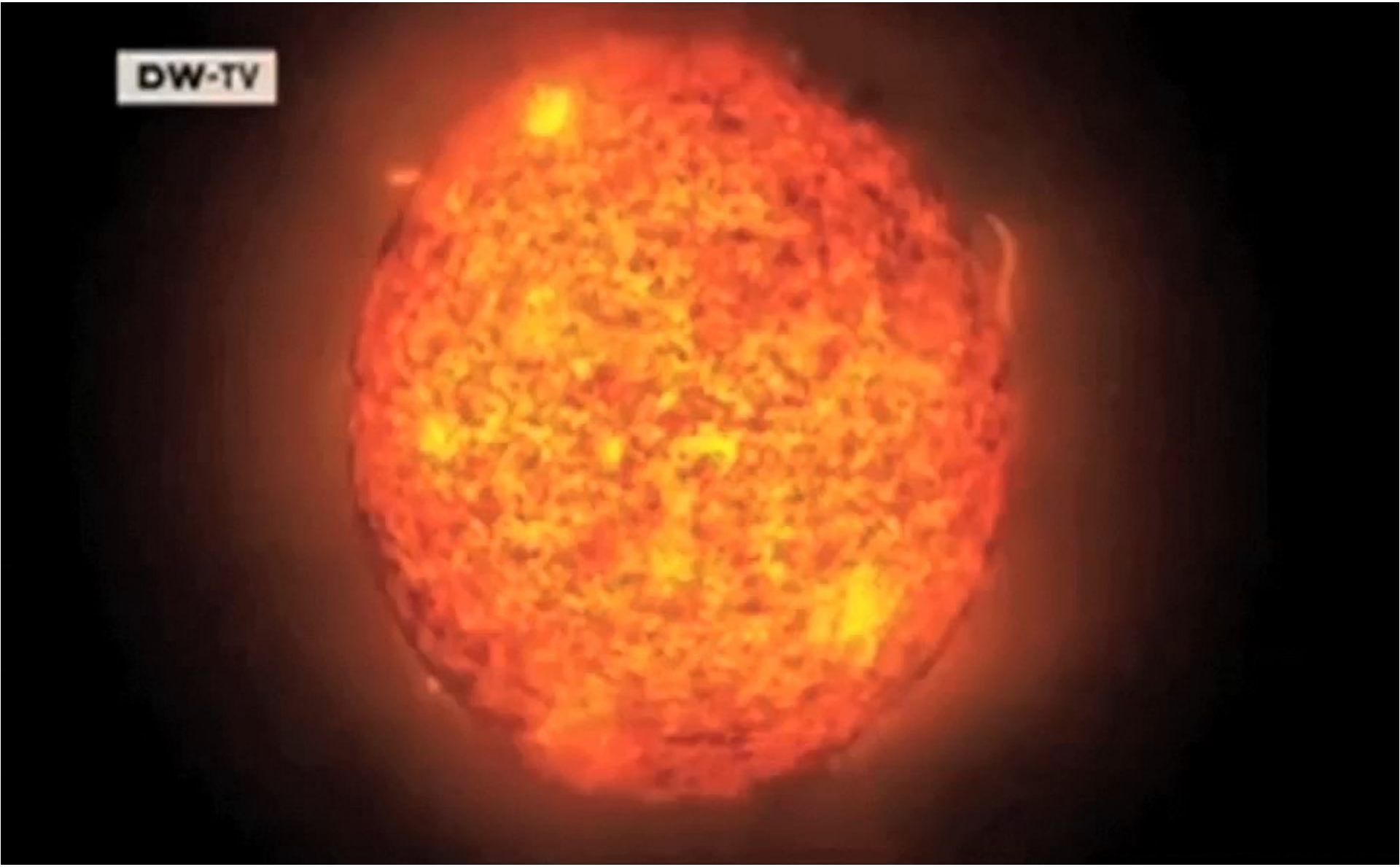


Fusion reactions and cross-sections

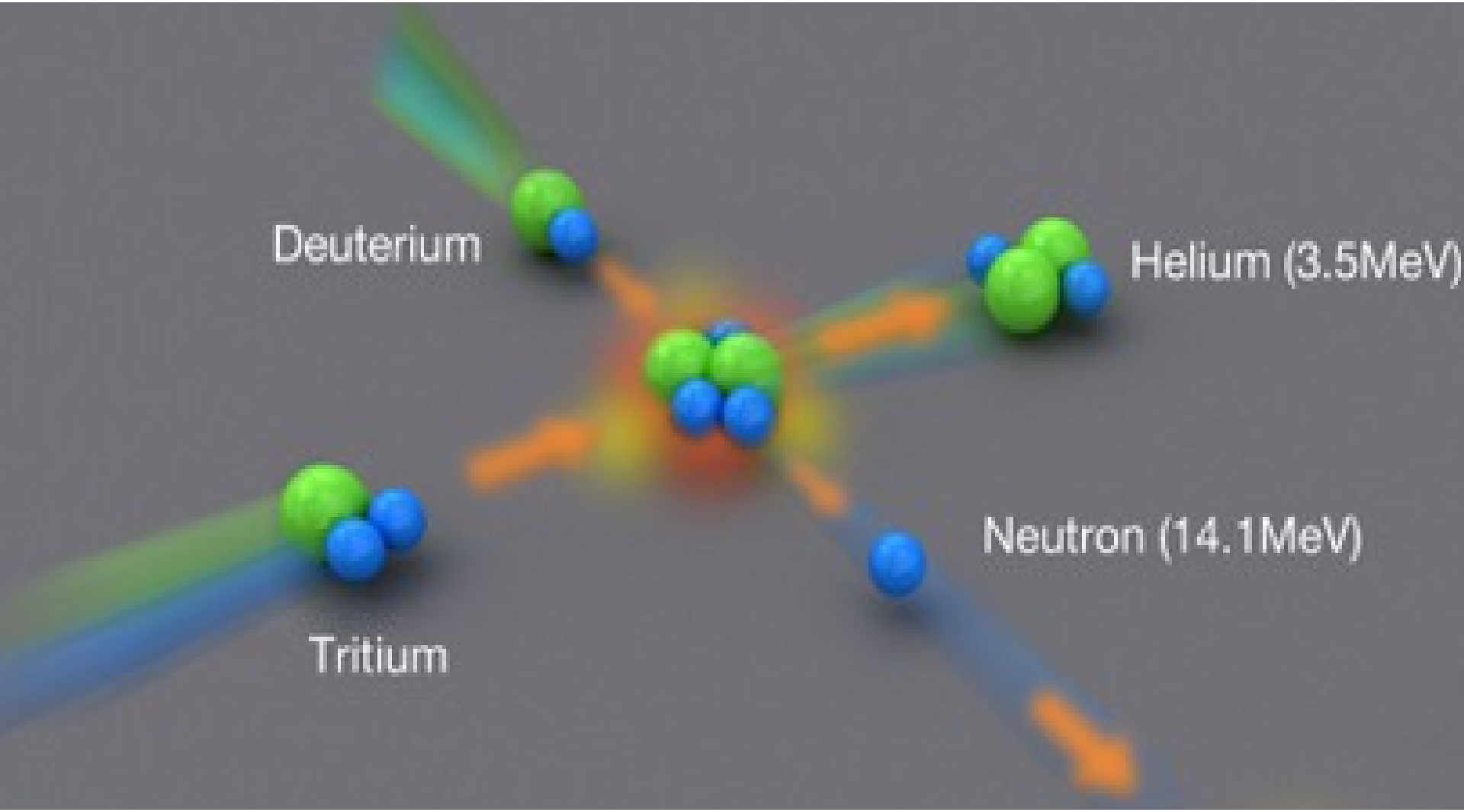




The fusion challenge



The D-T reaction



Sources of fuel for D-T reaction

D is 1/6700 of hydrogenic atoms in oceans, i.e. 1.6g/l

T does not exist in nature, as is radioactive and short-lived (12.5y)

But can be produced from Lithium

$n_0^1 + Li_3^6 \rightarrow T_1^3 + He_2^4 + 4.8MeV$

(Li_3^6 is ~7%)

$n_0^1 + Li_3^7 \rightarrow T_1^3 + He_2^4 + n_0^1 - 2.5MeV$

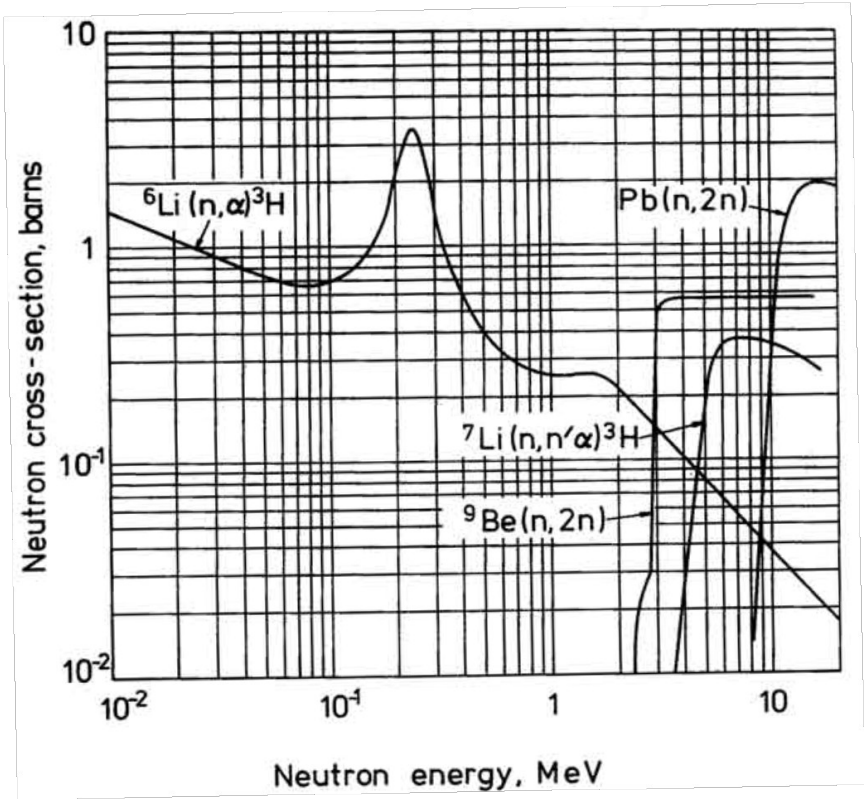
(Li_3^7 is ~93%)

Li^6 cross section is larger for low energies

moderate neutrons first

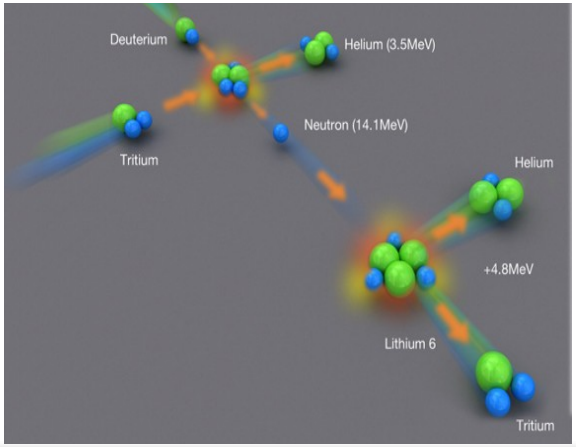
Neutron multiplication is needed, and

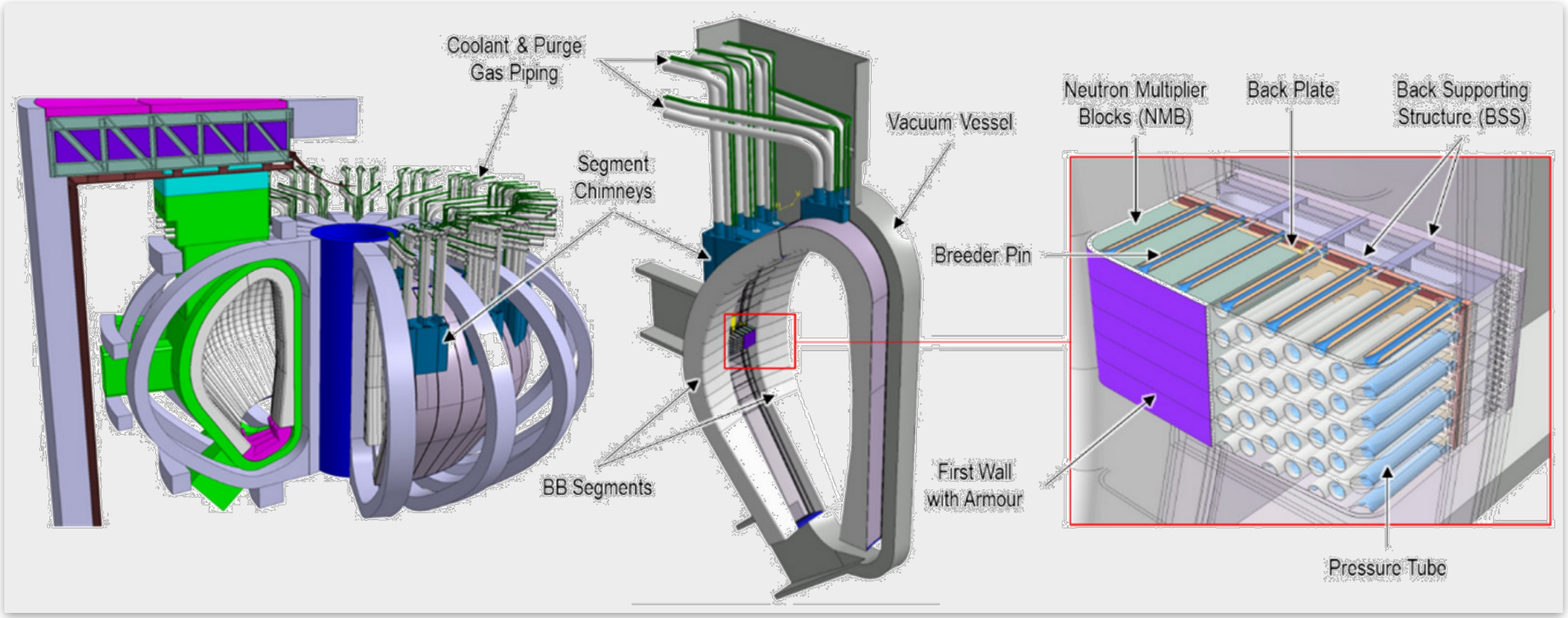
is possible above ~3MeV with Pb or Be



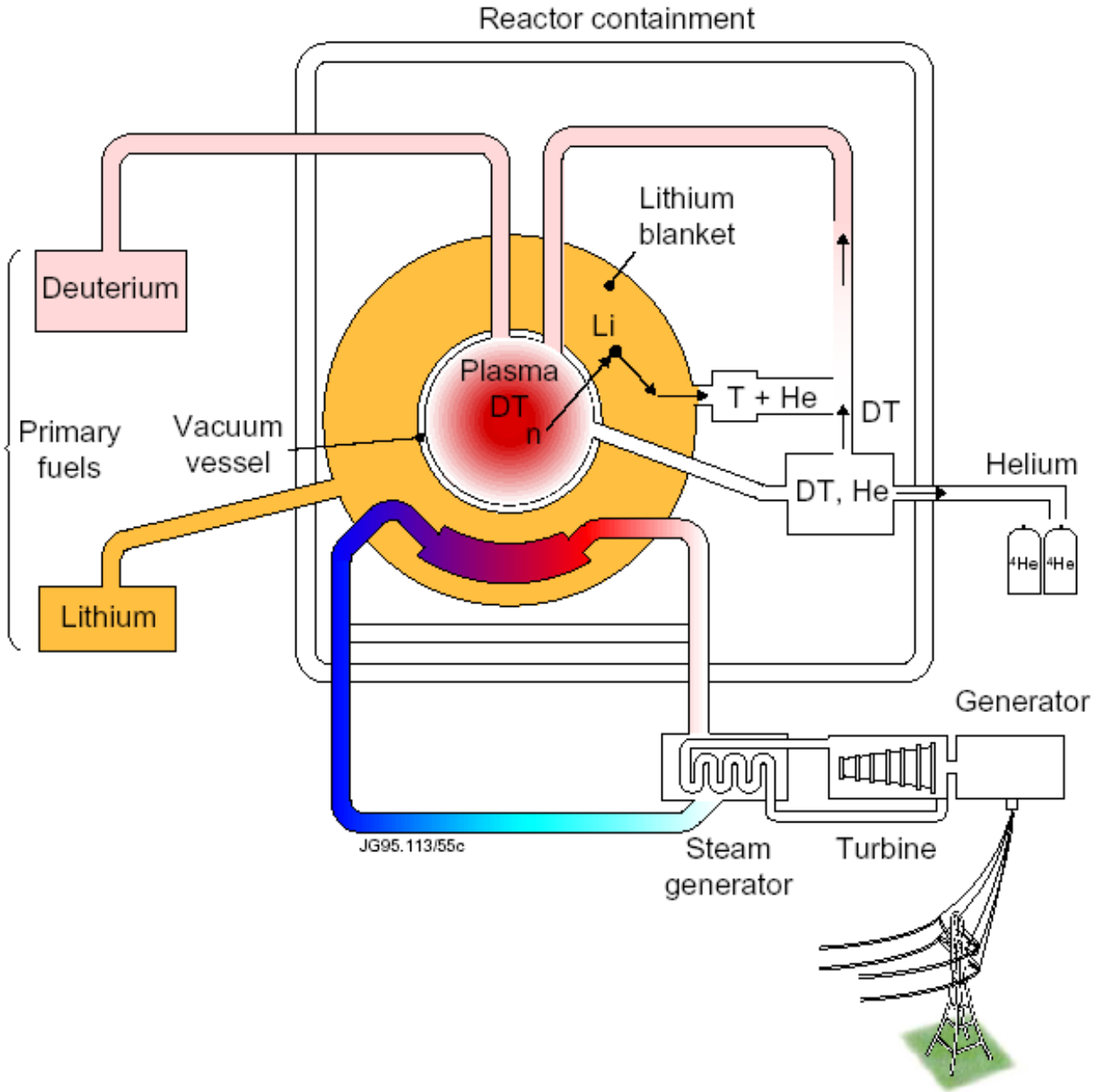
Lithium is in earth crust and in ocean water (0.15g/m^3)

Tritium breeding





Schematic of a fusion power plant



Advantages of fusion energy

High energy density fuel

Fuel	Specific Energy (MJ/kg)
Water, 100m-high dam	0.001
Coal, oil, food	30-50
Fission (U-235)	85’000’000
Fusion (D-T)	**350’000’000**



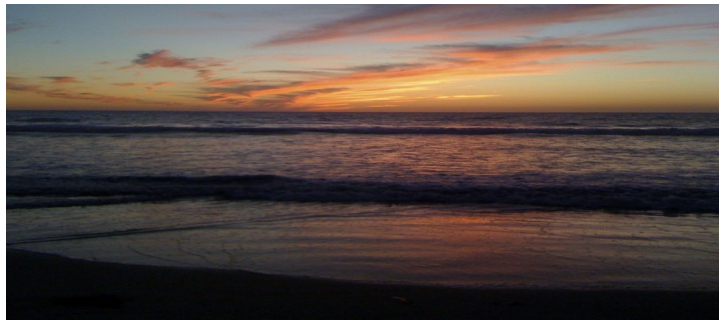
Advantages of fusion energy

High energy density fuel

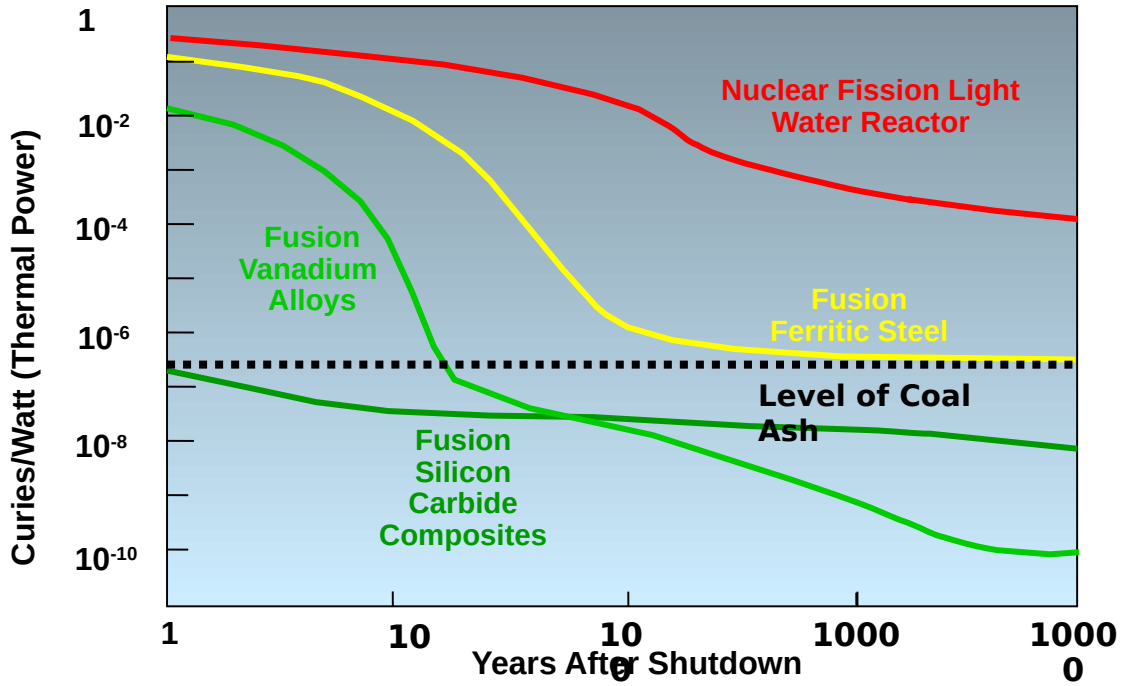
Practically inhestaustible fuel

Environmental

- No CO_2 emission
- No high-level radioactive wastes







Advantages of fusion energy

High energy density fuel

Practically inhestaustible fuel

Environmental

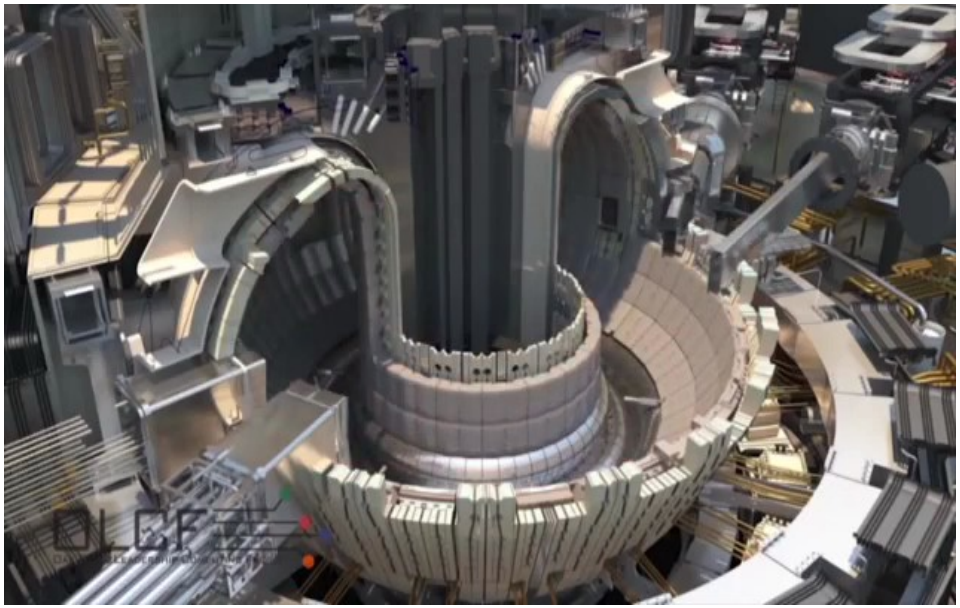
- No CO_2 emission
- No high-level radioactive wastes

No risk of nuclear accidents

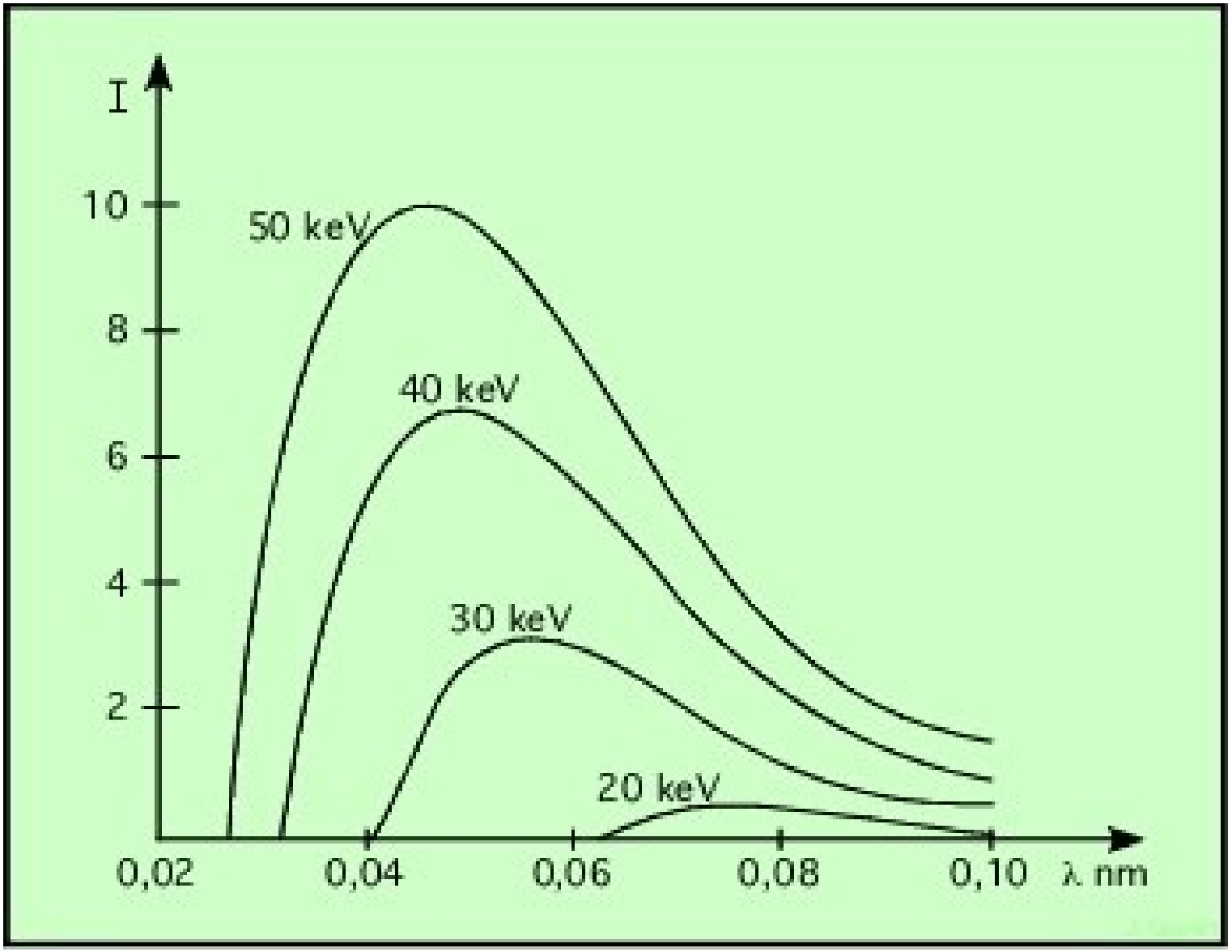
- Only ~1g of fuel in reactor
- No chain reactions

No link with weapons proliferation

Geographically concentrated, not subject to wheather variations



Bremsstrahlung radiation spectrum



Fusion <σv> vs. plasma temperature

