Introduction to Nuclear Power

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For EGY 105

at Wilkes University

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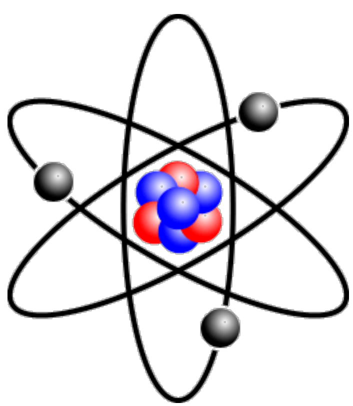
What is nuclear power?

- Ability to harness energy from atomic nuclei for consumptive uses
  - Mostly electrical generation
- Two kinds of nuclear energy
  - Fission
  - Fusion



Nuclear fission

- Heavy atoms split, producing smaller particles, electromagnetic radiation, and energy.
- Most common form of nuclear fission involves splitting of certain forms of Uranium.

Uranium

- Actinide metal with atomic # of 92.
  - Thus 92 protons in nucleus
- Slightly radioactive in nature
- Relatively abundant in Earth's crust
  - Found in rocks, soil, rivers, ocean
  - 500X more abundant than gold
  - Abundance similar to tin

Uranium resources by country in 2021

Country	tonnes U	% of world
Australia	1,684,100	28%
Kazakhstan	815,200	13%
Canada	588,500	10%
Russia	480,900	8%
Namibia	470,100	8%
South Africa	320,900	5%
Niger	311,100	5%
Brazil	276,800	5%
China	223,900	4%

Isotopes of uranium (vary accd. to # of neutrons)

- U-233: 141 neutrons
- U-234: 142 neutrons
- U-235: 143 neutrons — Used in nuclear power
- U-236: 144 neutrons
- U-237: 145 neutrons
- U-238: 146 neutrons — Most common in nature

Fission (splitting) of U-235

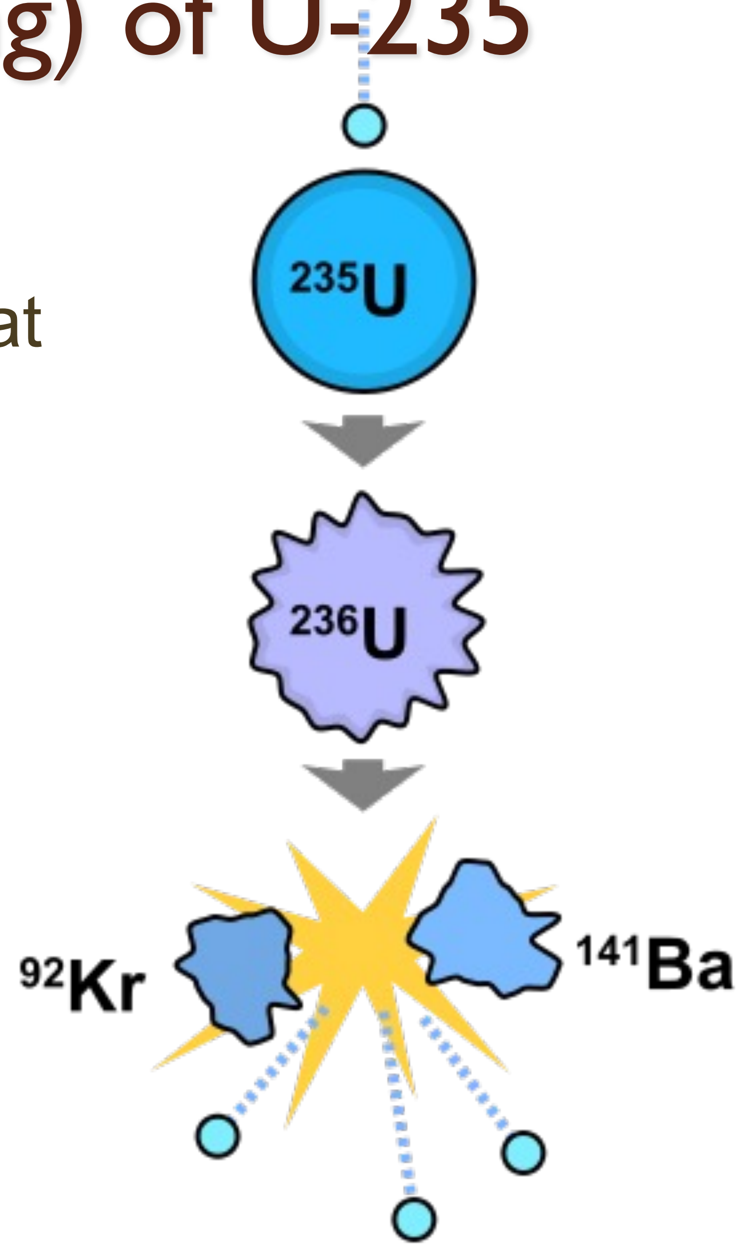
Reaction produces heat

↓

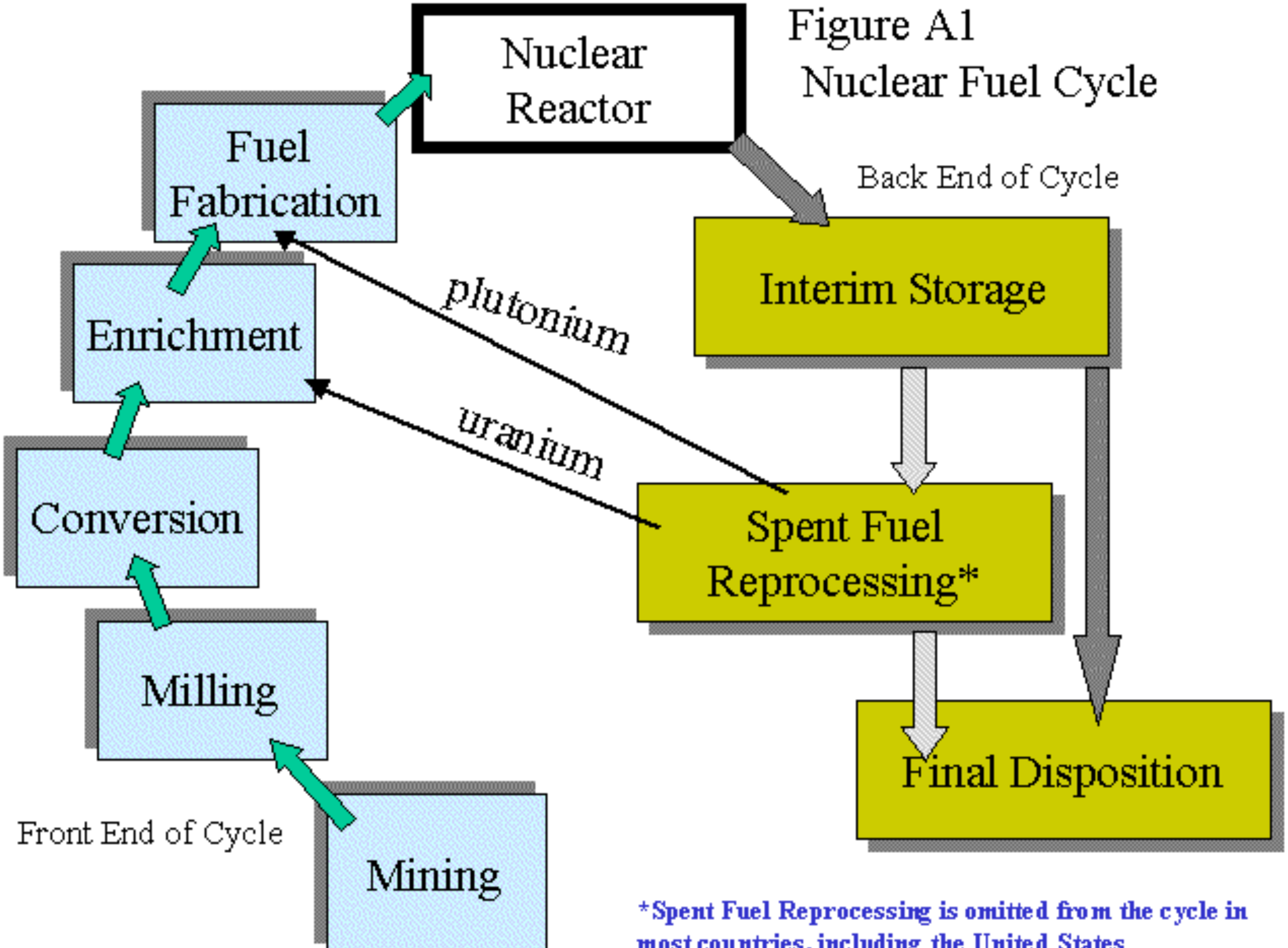
Produces steam.

↓

Steam drives turbines, creating electricity



Nuclear cycle



Check out this website for great overview

Uranium mining

- Uranium is mined using surface and underground techniques.

https://spheresofinfluence.ca/uranium-mining-unveiling-the-impacts-on-indigenous-communities/

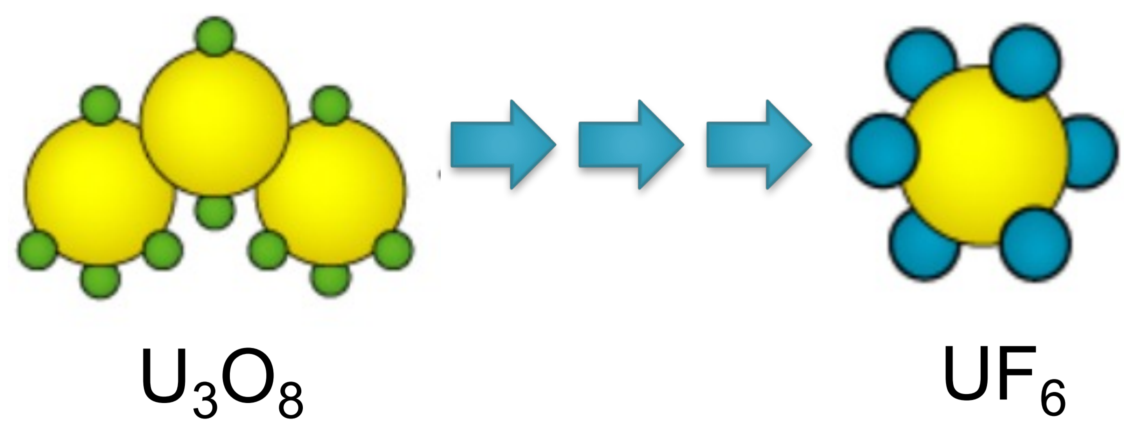
Uranium milling

- Uranium ore (1% uranium) taken to a mill
  - Usually close to a mine
  - Rock crushed and mixed with acid
    - Separates uranium from waste rock
  - Concentrated as U_3O_8
  - Placed in metal drums as "yellow cake"
    - >80% uranium
- U_3O_8 then sold
- Waste = tailings

https://www.npr.org/2022/07/06/1109518597/native-tribe-utah-u-s-uranium-mill-affects-health

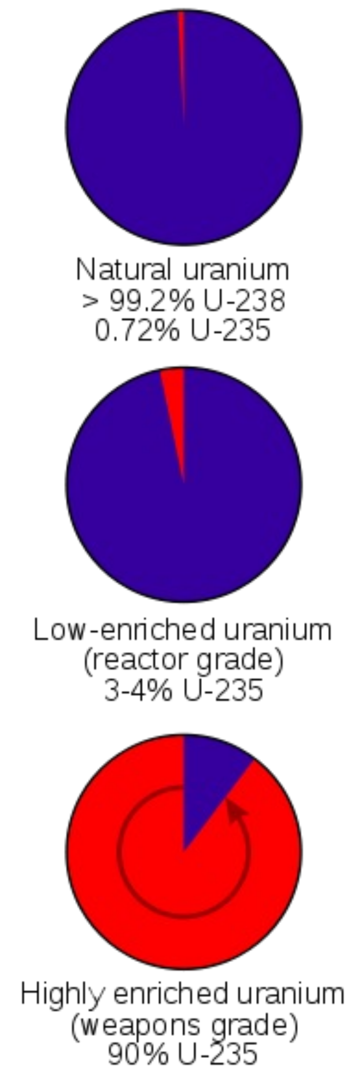
Conversion

- U_3O_8 is converted into UF_6
  - Gas at relatively low temperatures
  - Loaded into large cylinders where it solidifies.
- Most uranium is U^{238} with a little U^{235}
  - Shipped to Enrichment facility



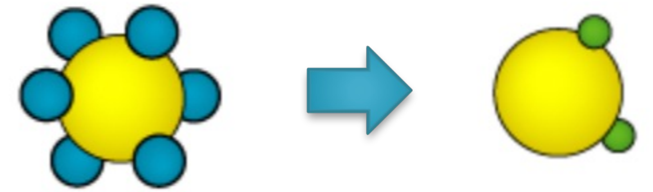
At Enrichment facility

- Most uranium in form of U-238
- U-235 concentration increased
- Enrichment typically involves removal of other isotopes
- Commonly done by spinning in a centrifuge.

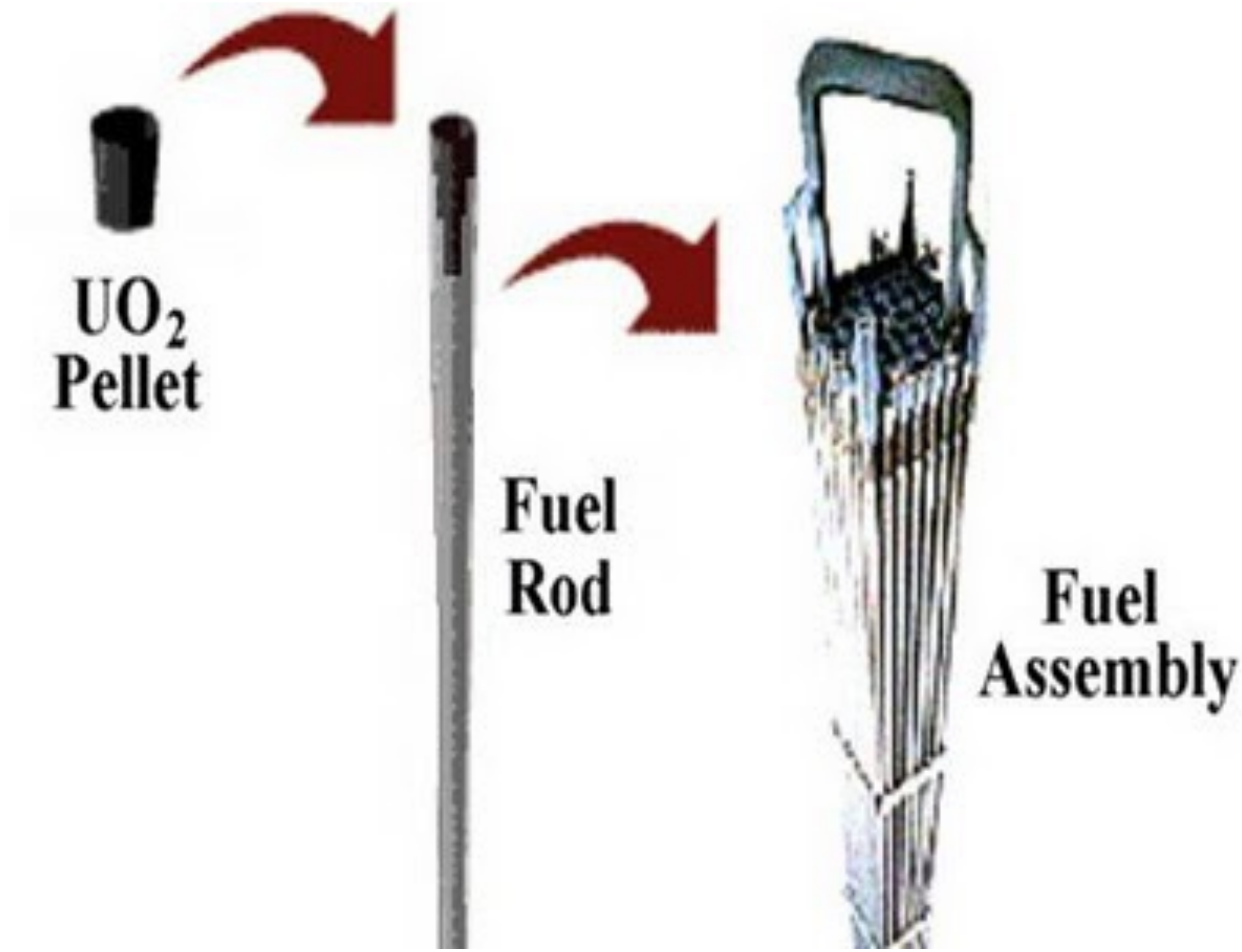


After centrifugation

- Fuel now UF_6 with more U^{238} than before.
- Converted to UO_2.
  - Ready to be made into fuel pellets
- Pellets made by heating at 1400°C

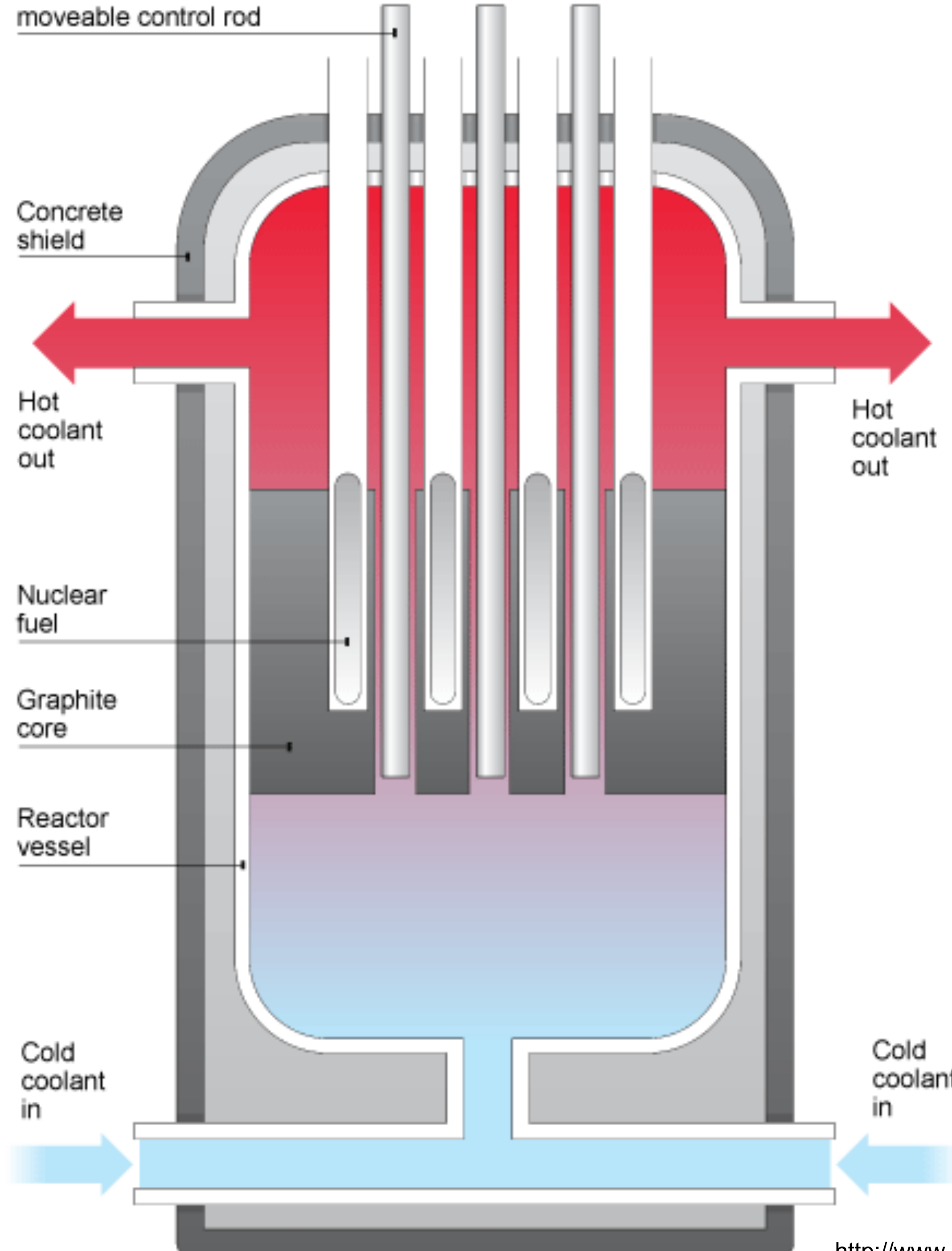


Nuclear fuel in form of rods



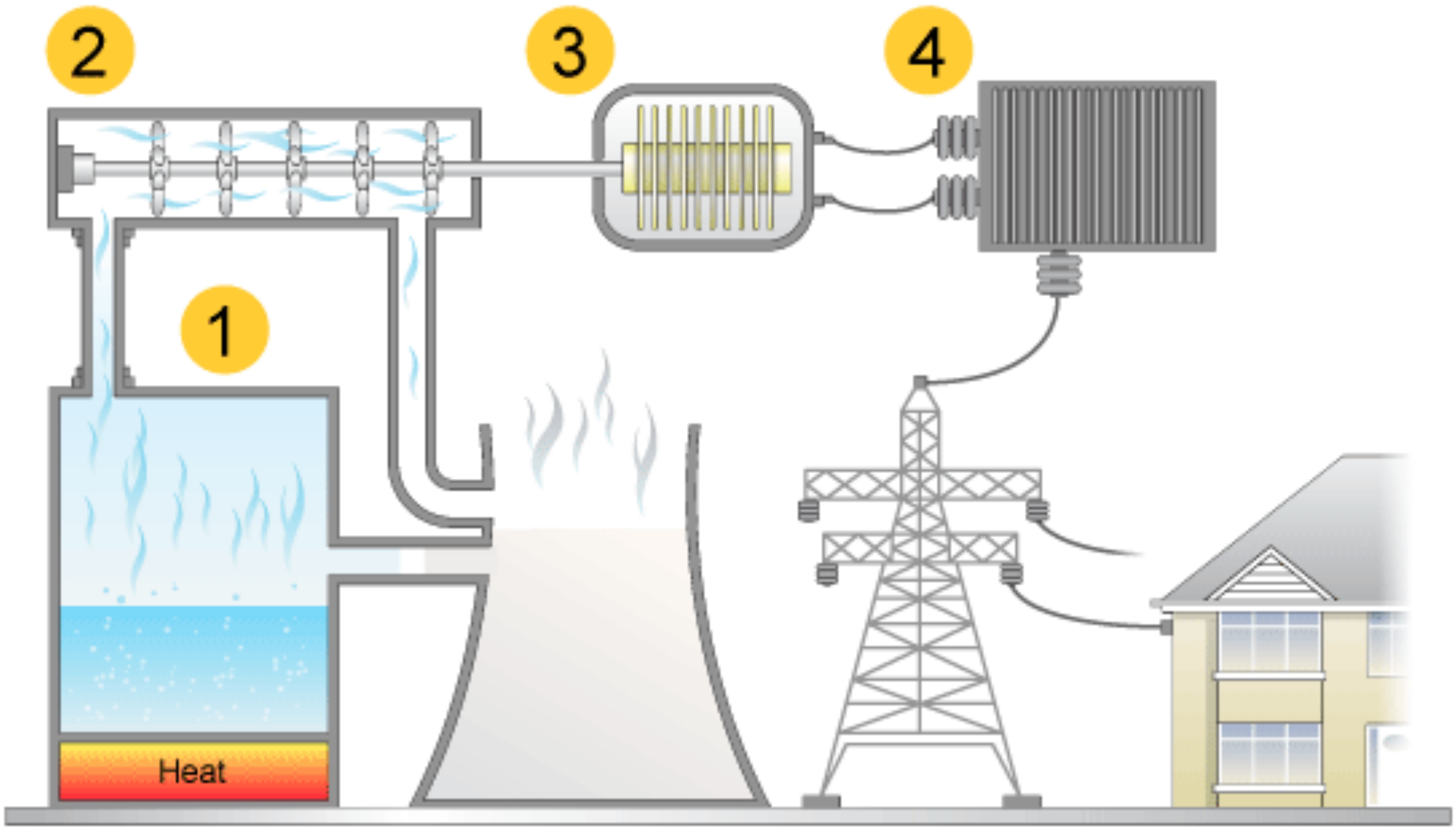
http://coto2.wordpress.com

Nuclear reactor



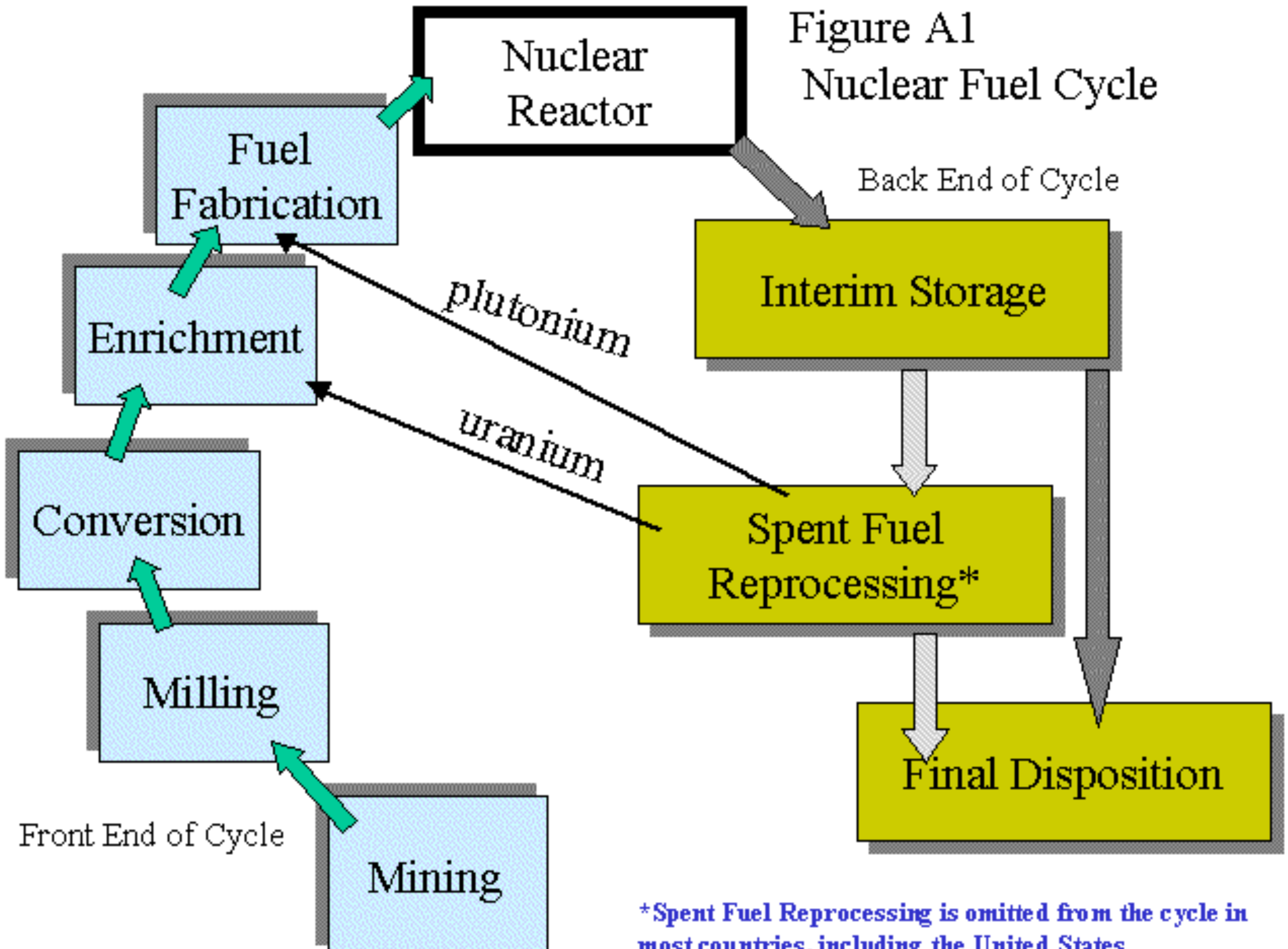
http://www.bbc.co.uk/

Nuclear reactor overview



http://www.bbc.co.uk/

Nuclear cycle



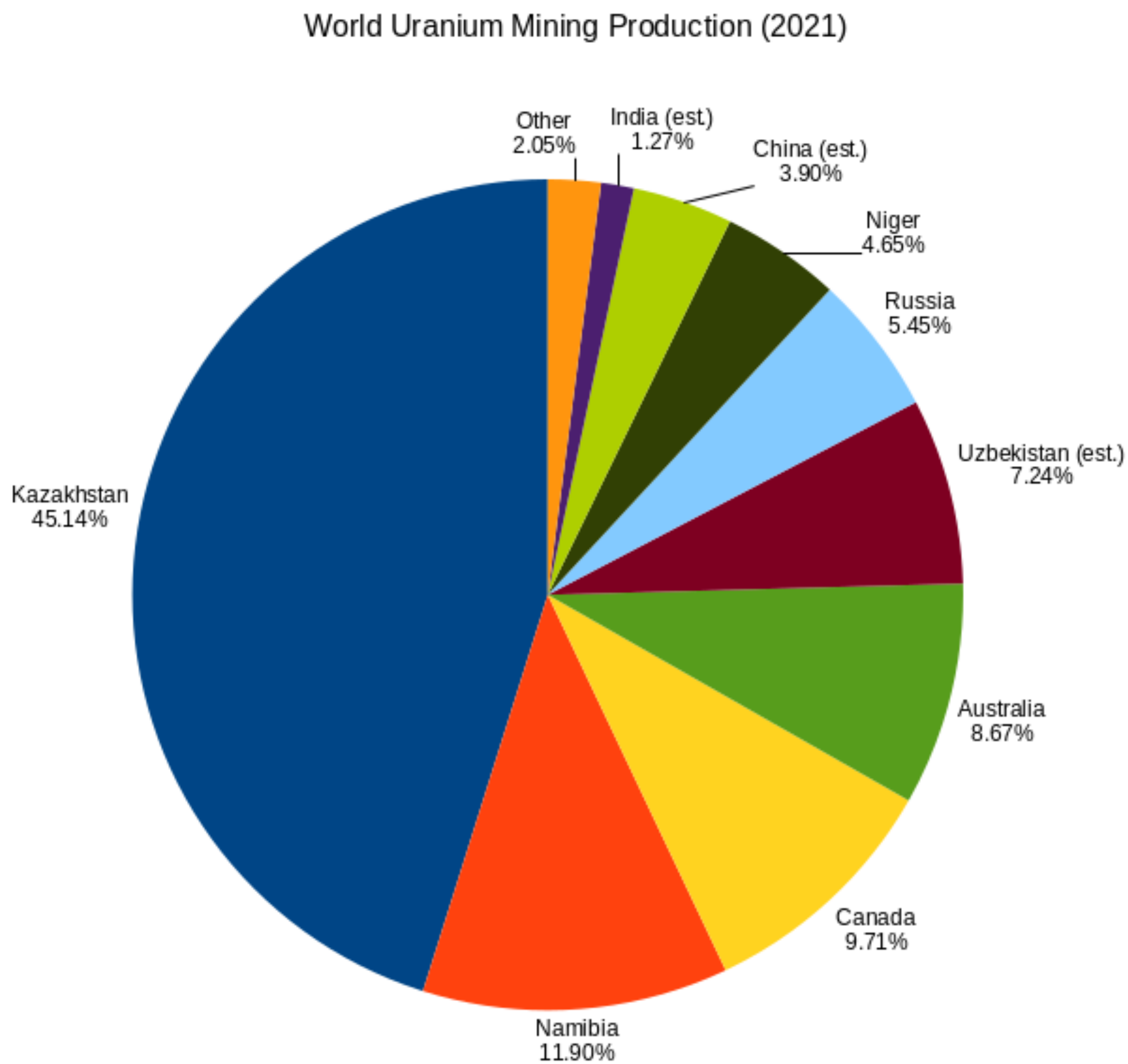
History

- Basis in 1930s
  - Atomic nuclei contain vast energy
- 1940s
  - Research on nuclear energy wrapped into Manhattan Project – atomic bomb
- Early 1950s
  - US, Canada, USSR began work on generating electricity via nuclear energy
  - USSR builds nuclear reactor to feed into power grid.

History II

- Late 1950s
  - Nuclear plants constructed in Pennsylvania and Virginia, Idaho, and USSR
- 1960-1980
  - Nuclear capacity increased greatly in US, Europe, USSR.
- 1980s and after
  - Nuclear construction slowed due to rising anti-nuclear sentiment, costs involved in meeting more stringent standards

Uranium mining production

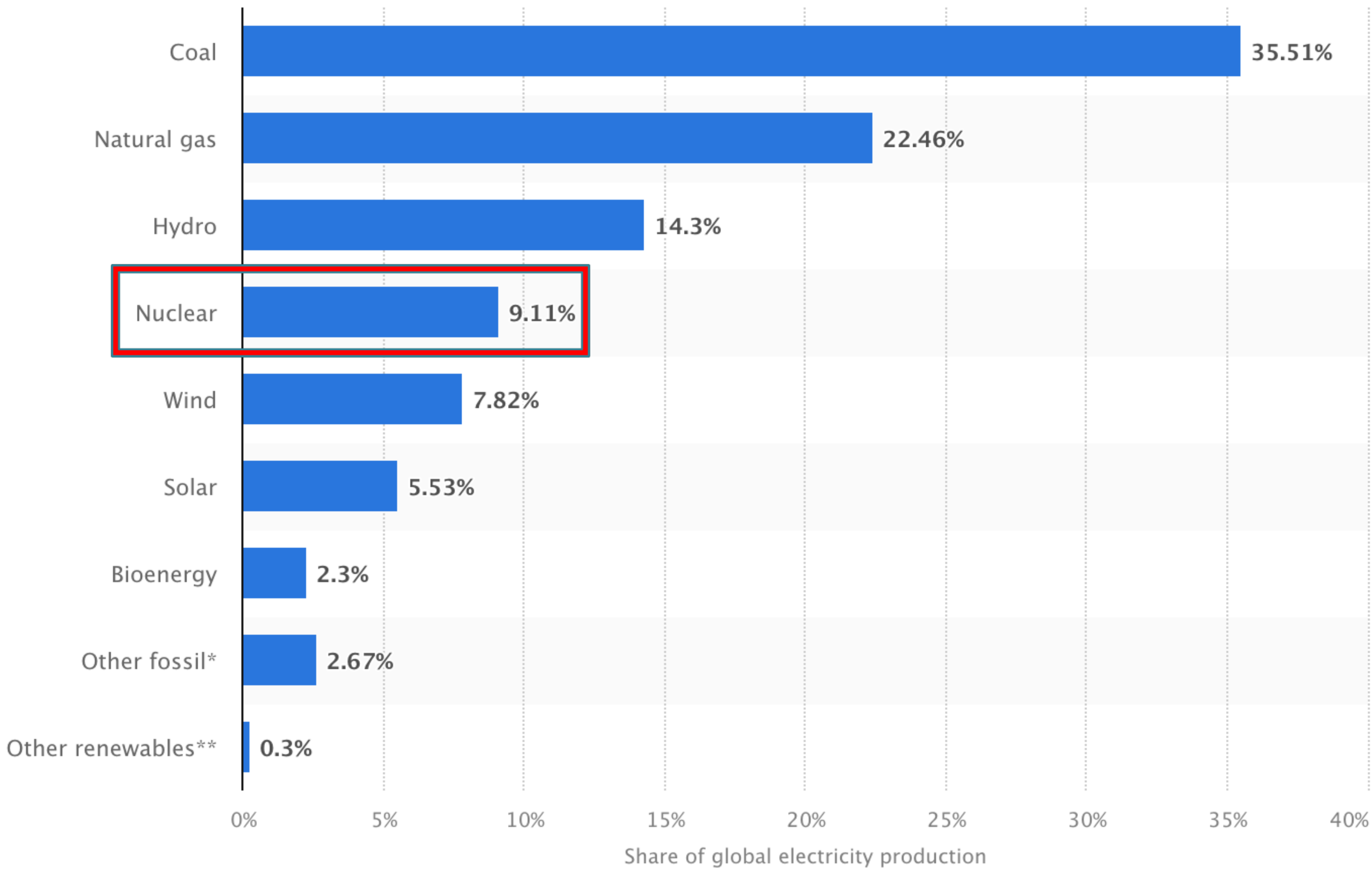


https://upload.wikimedia.org/wikipedia/commons/d/d4/World_Uranium_Mining_Production_2021.png

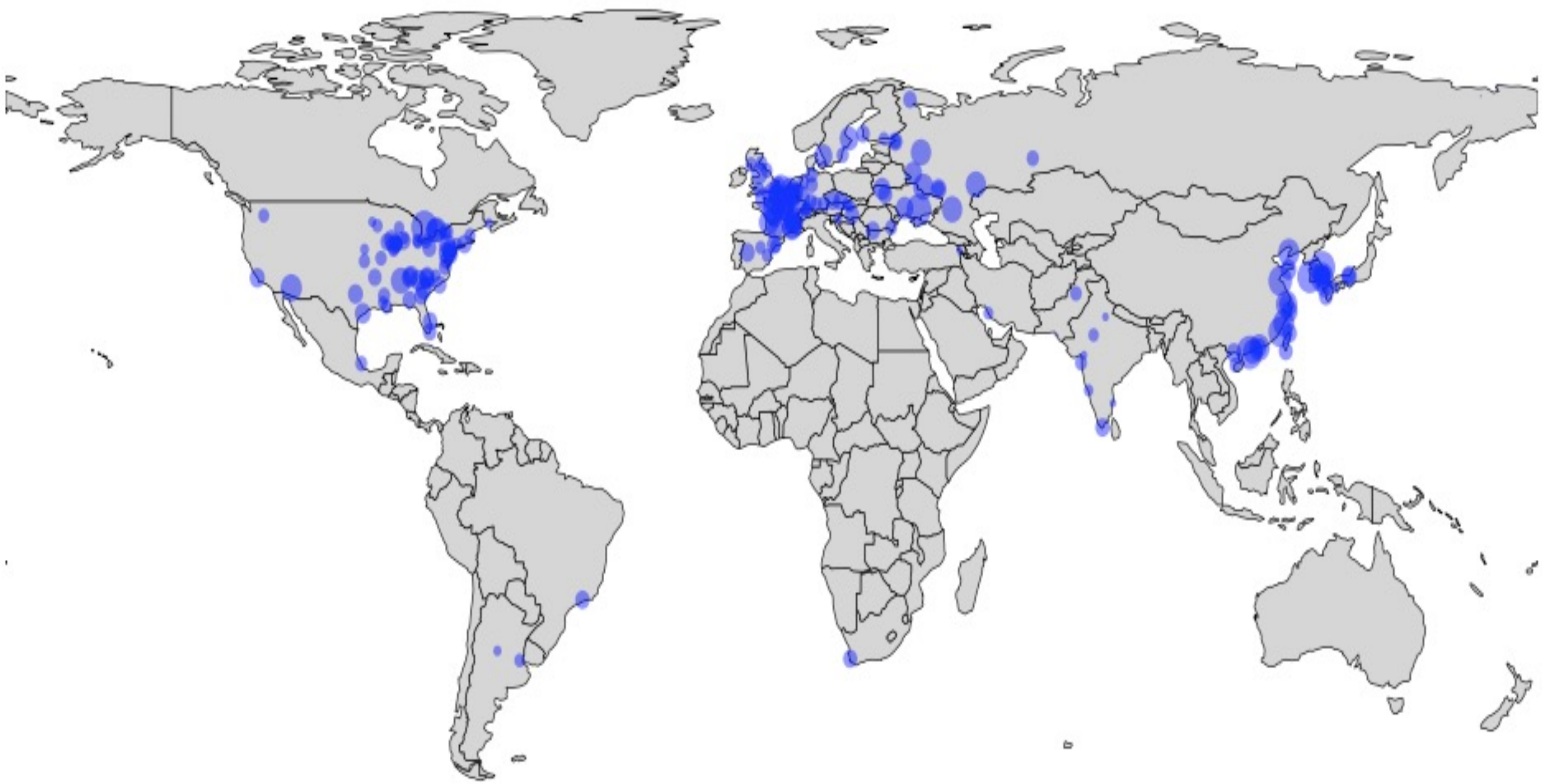
Where is Kazakhstan?

Where is Namibia?

World electricity production by energy type - 2023

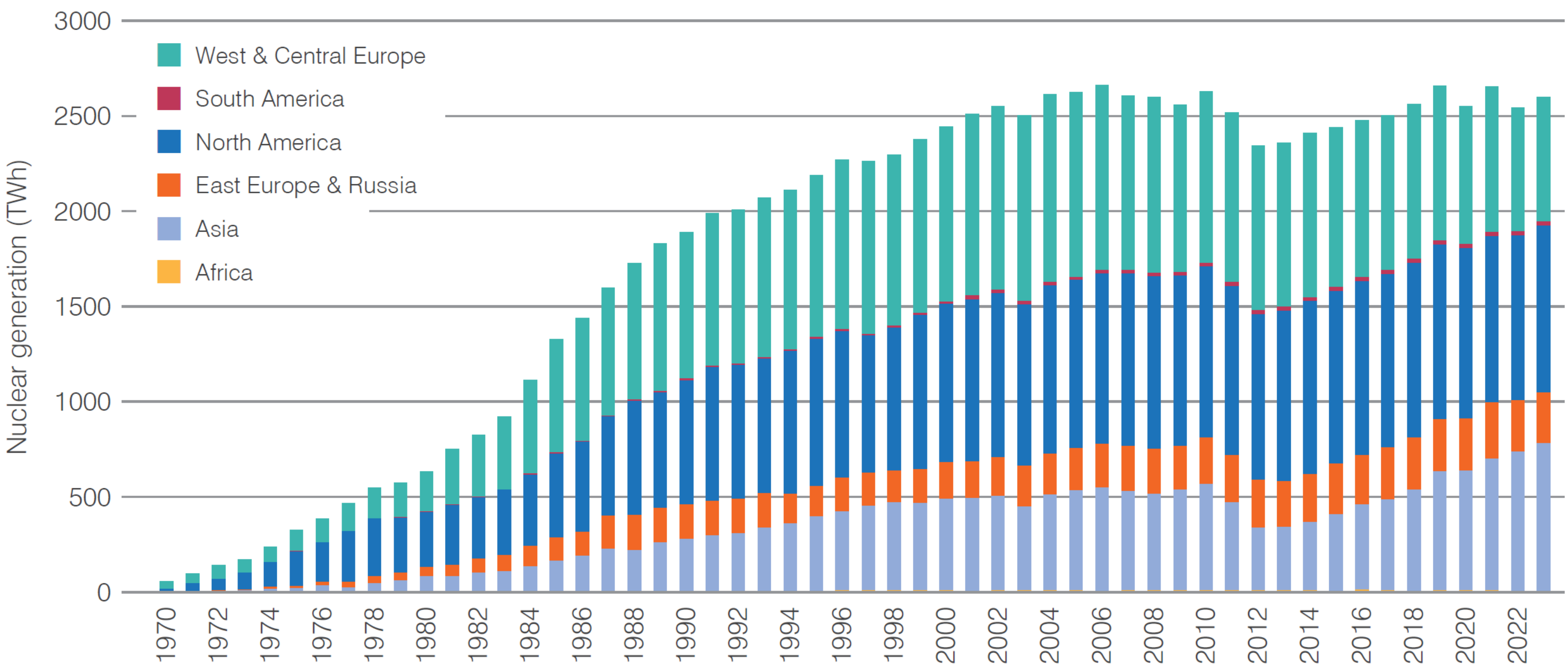


Worldwide nuclear fission plants



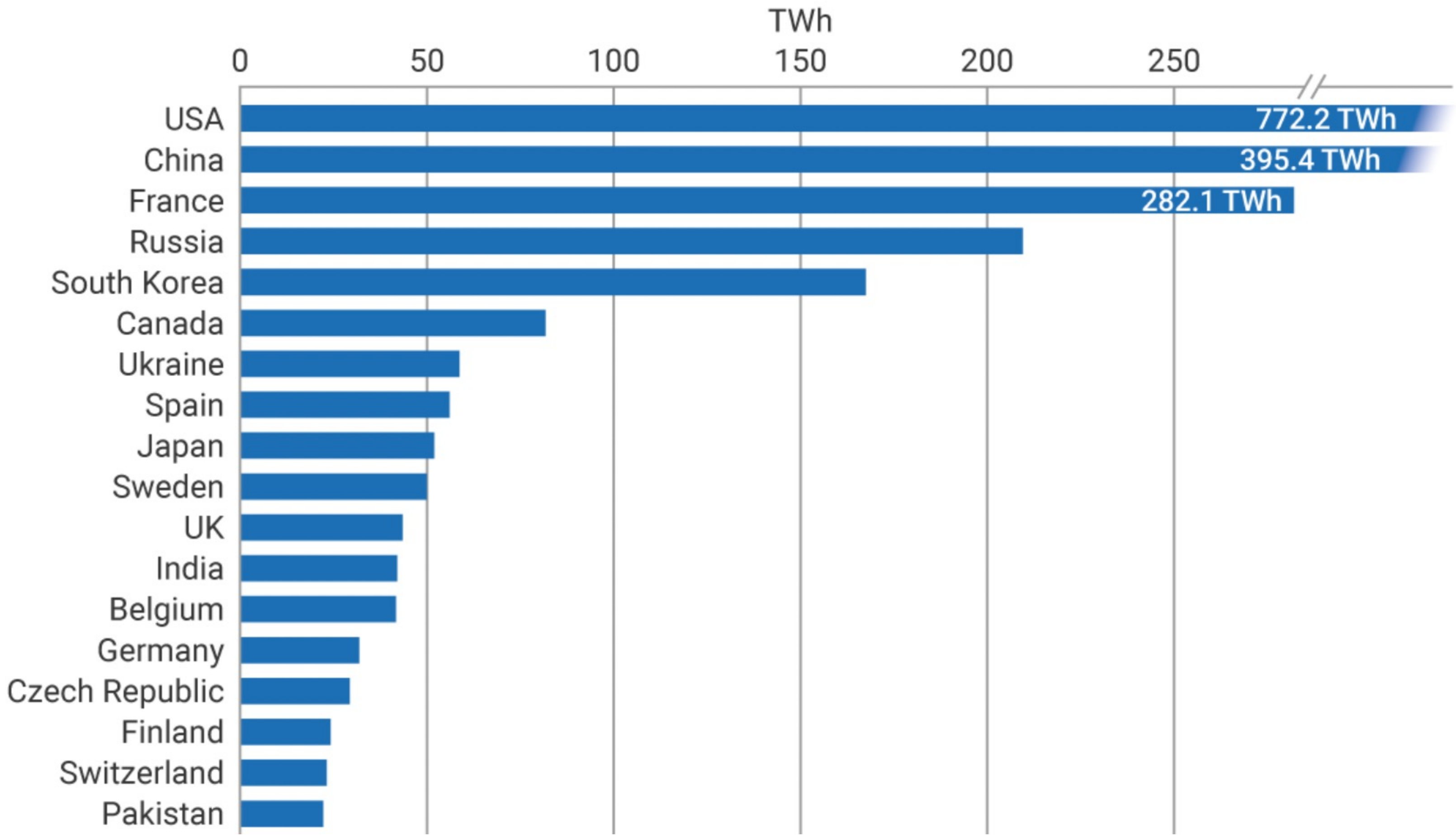
https://scipython.com/blog/where-are-the-worlds-nuclear-power-plants/

Nuclear fission electrical production by region (1970-2023).



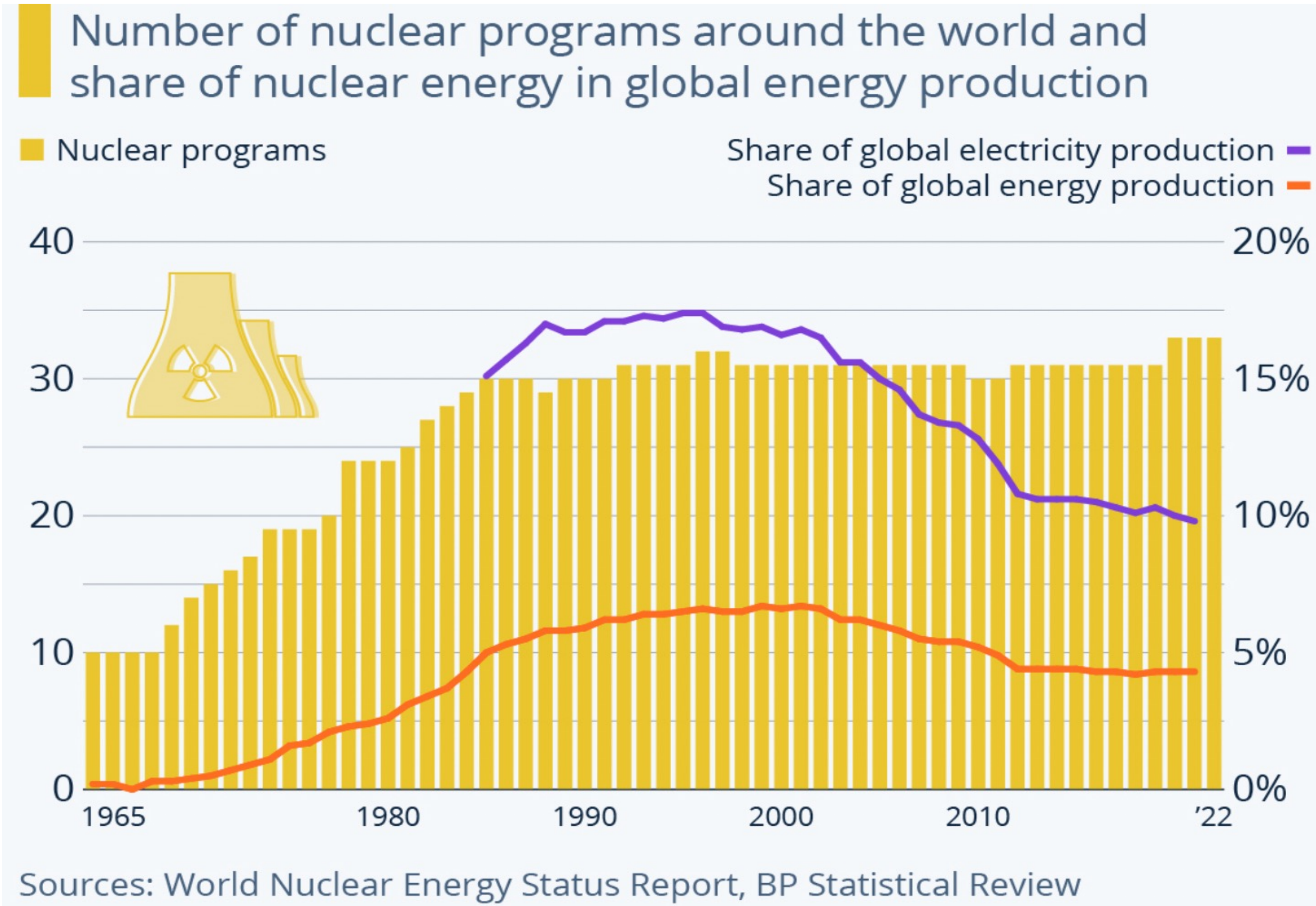
Source: World Nuclear Association and IAEA Power Reactor Information Service (PRIS)

Nuclear electrical production by country (2023)



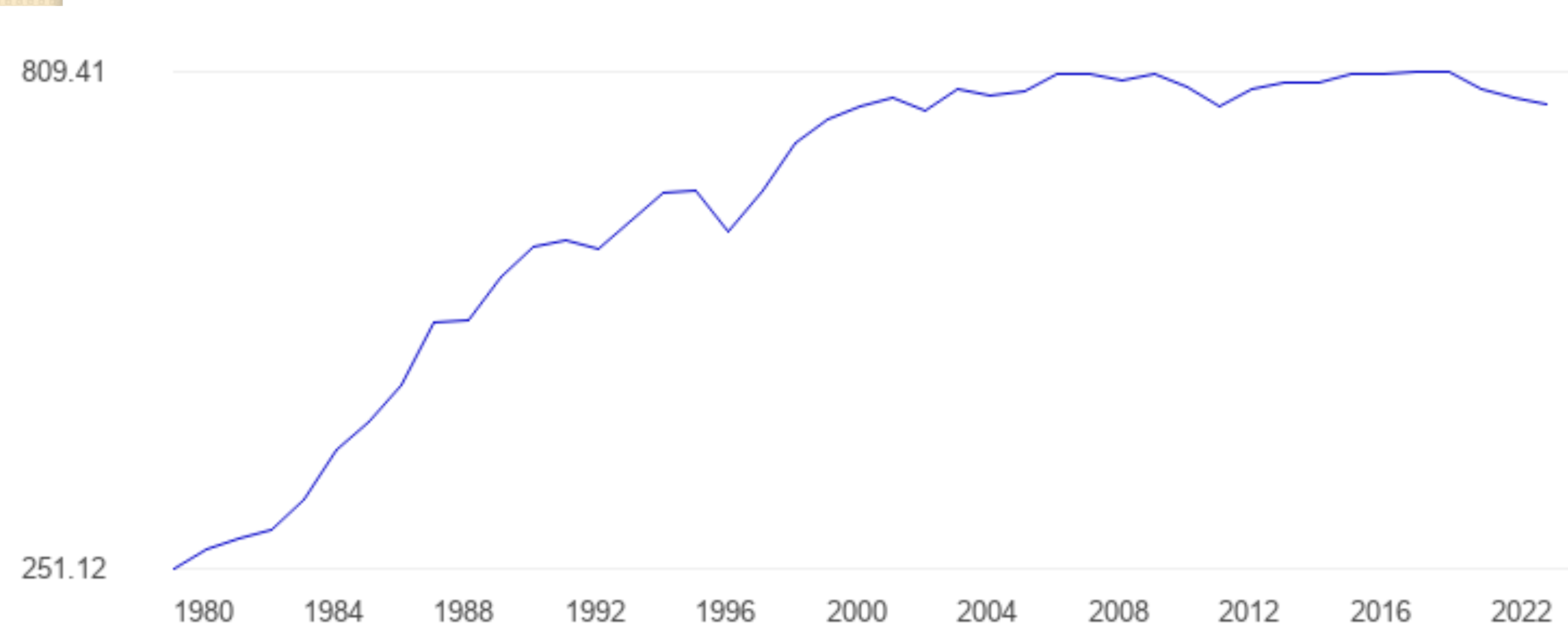
https://world-nuclear.org/information-library/current-and-future-generation/nuclear-power-in-the-world-today

Contribution of nuclear fission to our global needs.



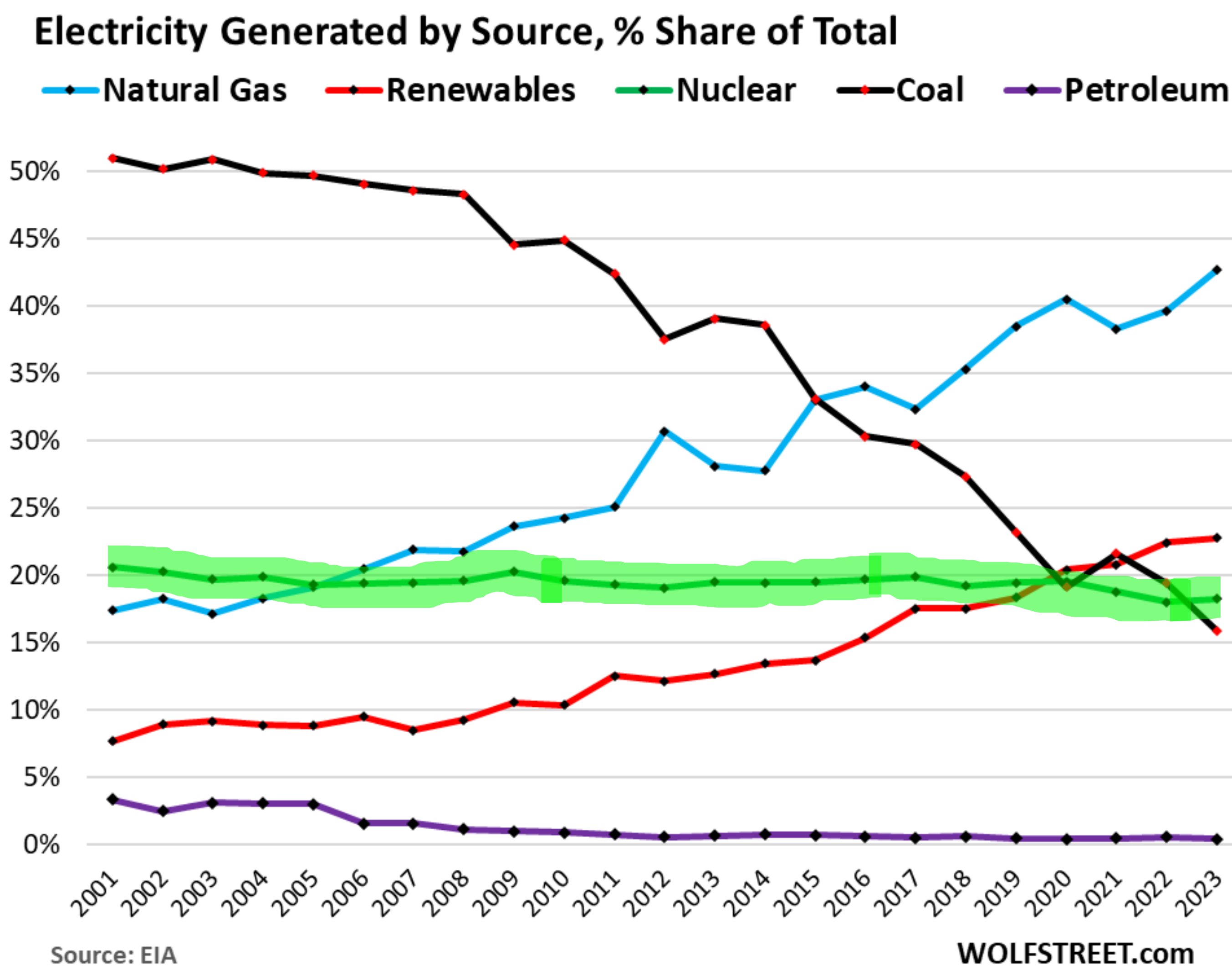
Nuclear production – United States

US Electricity production from nuclear fission.



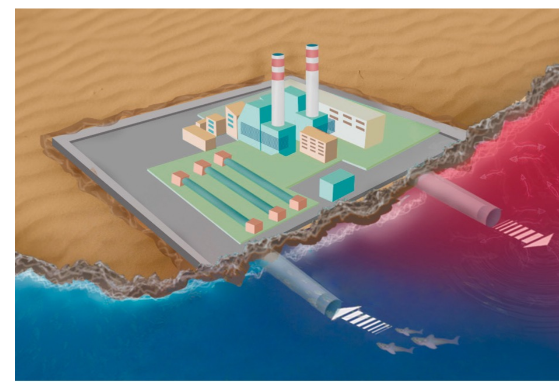
https://www.theglobaleconomy.com/USA/nuclear_power_generation/

US electricity production from nuclear fission 2001-2023



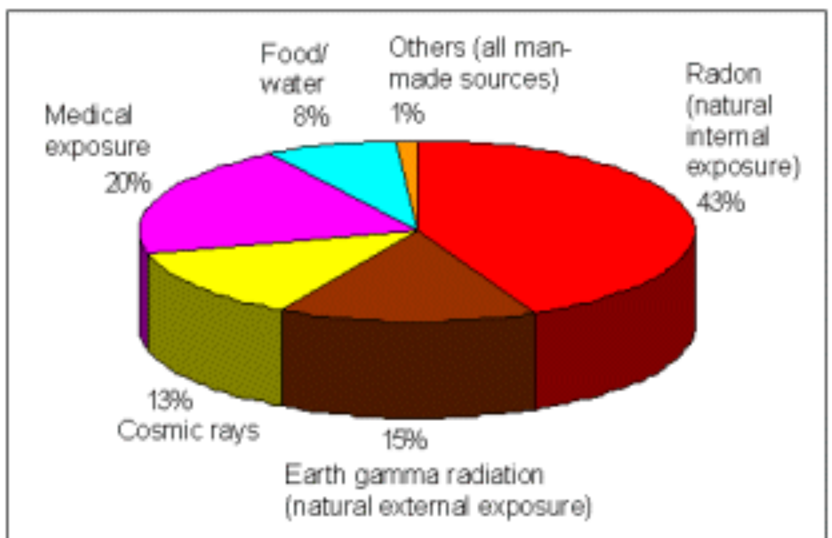
Risks associated with nuclear power

- Mainly due to radiation releases – human health
  - Small releases during routine operation
  - Accidents
  - Sabotage / warfare
  - Waste disposal
- Thermal pollution



Radiation risks - general

- Radiation can cause cancer (1% of all causes)
- Radiation all around us
  - 15,000 "hits" / second
  - Chance of any one hit causing cancer: 1/30,000,000,000,000,000



http://www.who.int/ionizing_radiation/env/en/

Increased risk by nuclear power

- Represents 0.2% of increased exposure
- Thus 0.002% increased cancer rate
  - Reduces life expectancy by one hour
  - Risks from fossil fuel sources: 3-40 days

Accidents

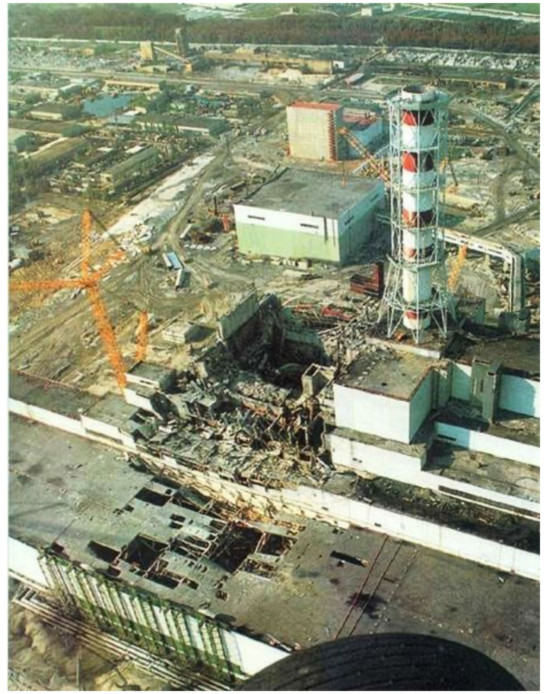
- Main concern of accident: damage to reactor leading to "meltdown"
- Nuclear plants built to reduce risk of accidents
  - Reactor shielded by steel and concrete
- Predicted loss of life by probability analysis
  - Chance of meltdown estimated to be 1/20,000 years of operation
  - Loss of life in 1/3 accidents
  - Average # deaths 400 / meltdown
- Compare to coal burning
  - 10,000 deaths / year
  - Thus would need 25 meltdowns / year to equal risk from coal

Cohen, B. http://www.physics.isu.edu/radinf/np-risk.htm

Three major accidents in past

Three Mile Island - PA

- March 1979
- >140,000 evacuated
- No deaths
- No incidence of cancer



Chernobyl – Ukraine

- April 1986
- >350,000 evacuated
- 64 died
- Toll could reach 4000

Fukushima - Japan

- March 2011
- >300,000 evacuated
- No deaths
- Toll could reach 130

Terrorism / War

- By their nature, nuclear plants now viewed as targets for terrorism and war.
- Terrorism incidents relatively rare.
- In warfare
  - Article 56 of Geneva Convention states that nuclear power plants should not be attacked, even if they are military targets, if the attack could cause civilian harm.
  - But Zaporizhzhia is a counter-example

Radioactive waste

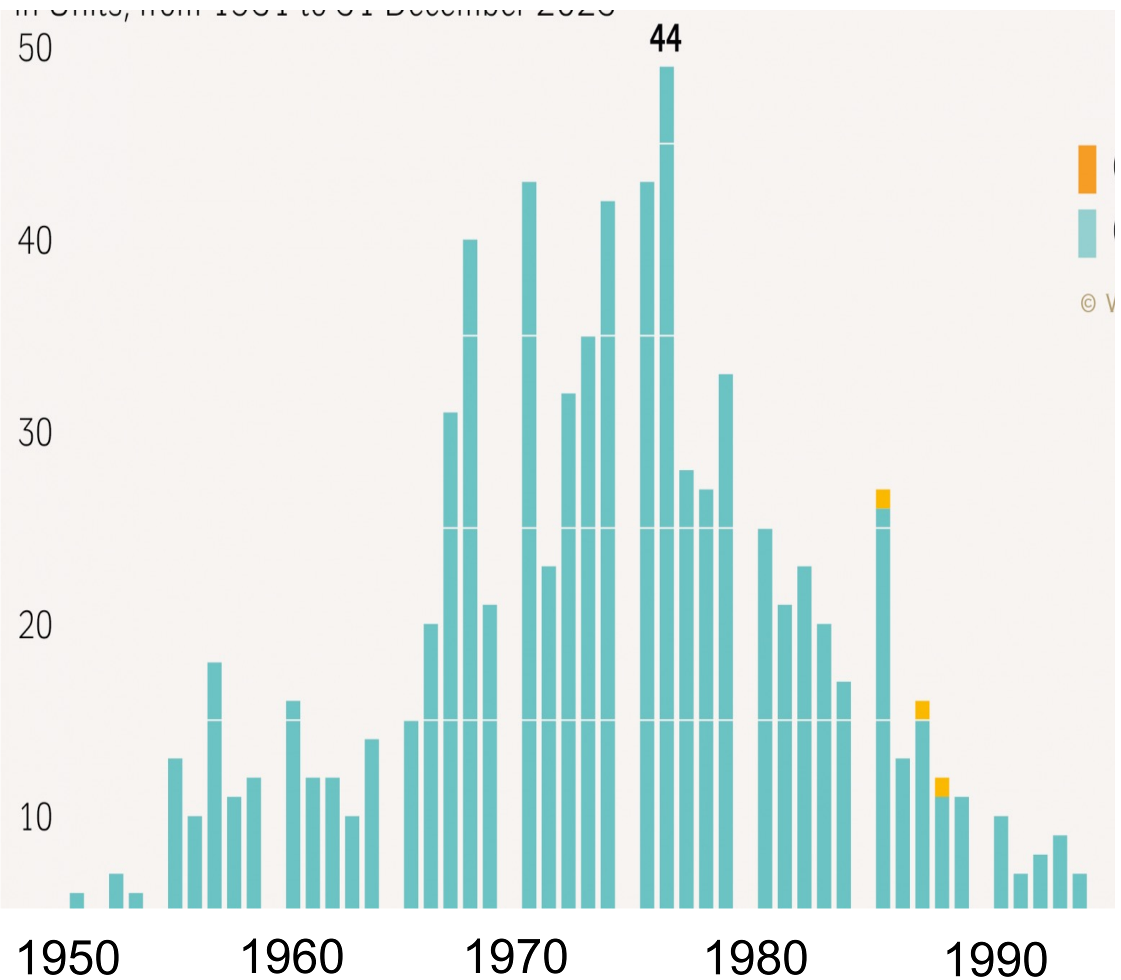
- Spent rods converted into rock-like material and buried deep underground
  - Plan to bury in Yucca Mountain, NV defeated in 2011
- Other material buried into soils
- Some U-235 can be recycled

https://sites.google.com/site/nuclearenergyinjapan/home/possible-solutions

Does nuclear power have a future?

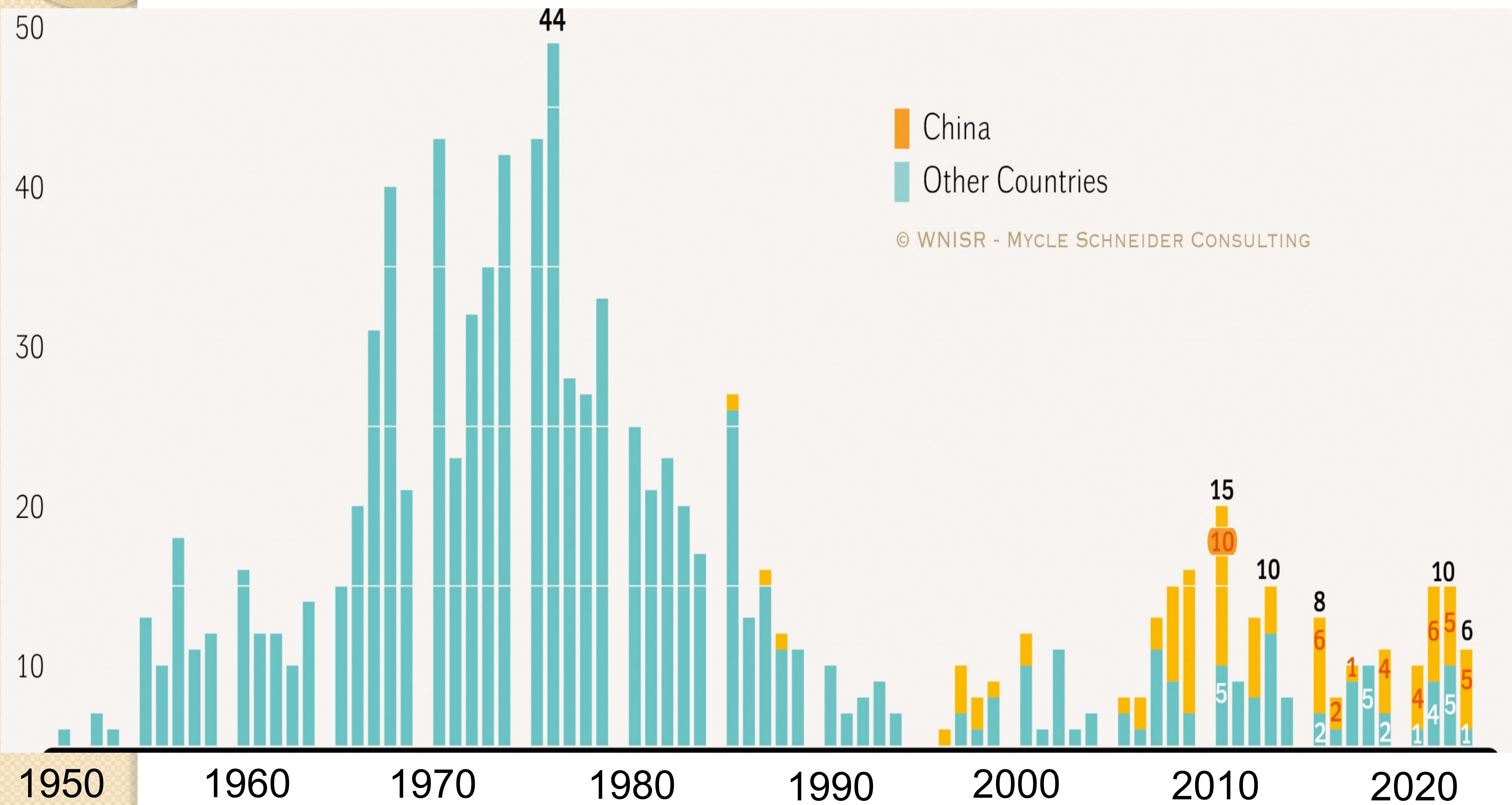
Does nuclear power have a future?

Look at construction of new nuclear power plants worldwide 1950-1994



Does nuclear power have a future?

Look at more recent data (1050-2023).



Nuclear plants now more costly to build.

- Siting the plant
- Design
- Permitting
- Construction
- Operation

Cost of nuclear fission power varies by country

Average construction cost (inflation adjusted million GBP) per MW for all plants with reliable cost data built since 2000.

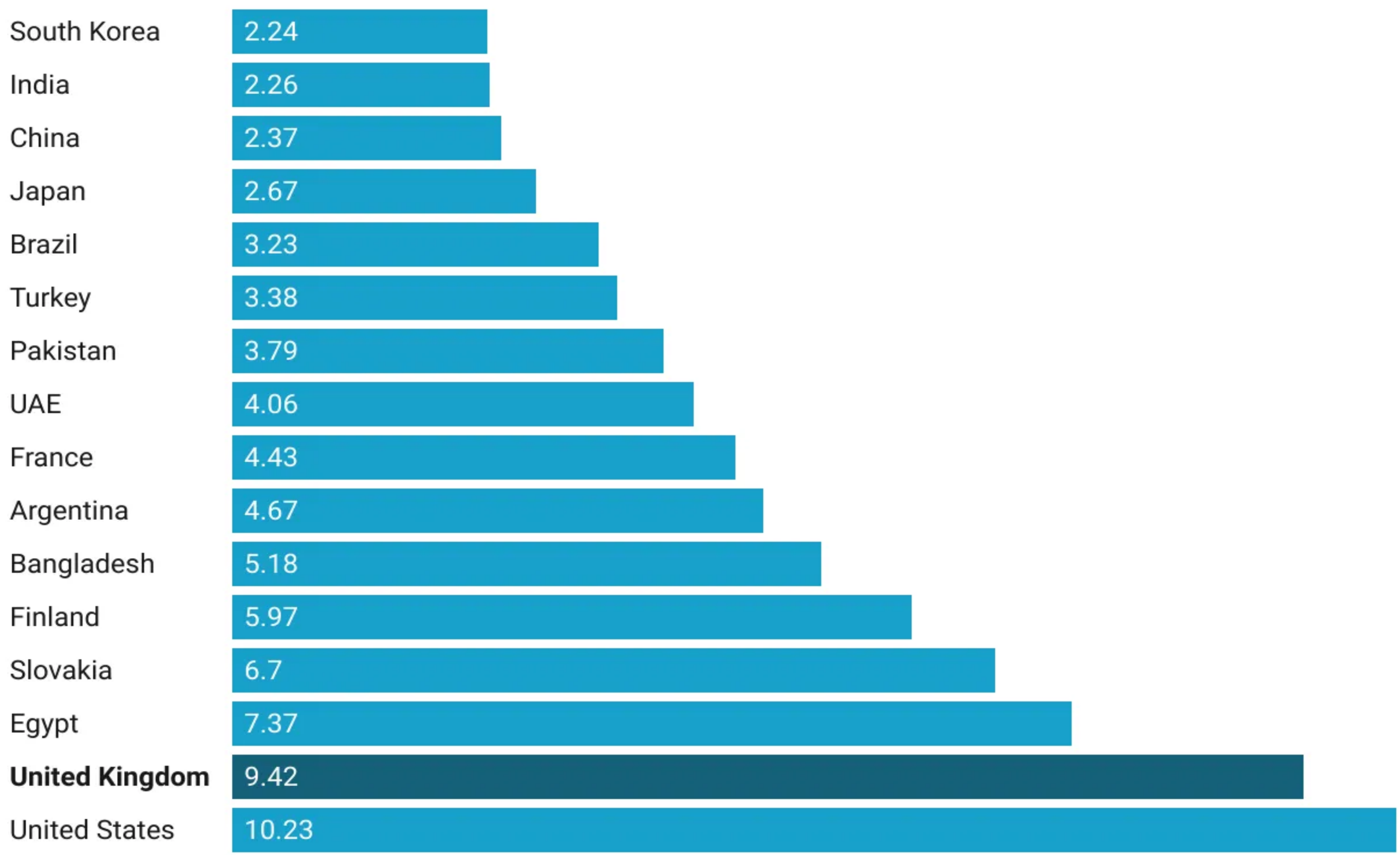


Chart: Britain Remade • Created with Datawrapper

Recent trends in nuclear fission

- Many older plants are closing
- Interest in creating more, smaller plants
- Since 2020 all construction starts have been in China or implemented by Russian industry.
- Since start of 2023, five new plants have started up – one in the U.S.
- In December 2023, 22 countries agreed to triple nuclear power by 2050.
  - Deemed impossible to achieve.

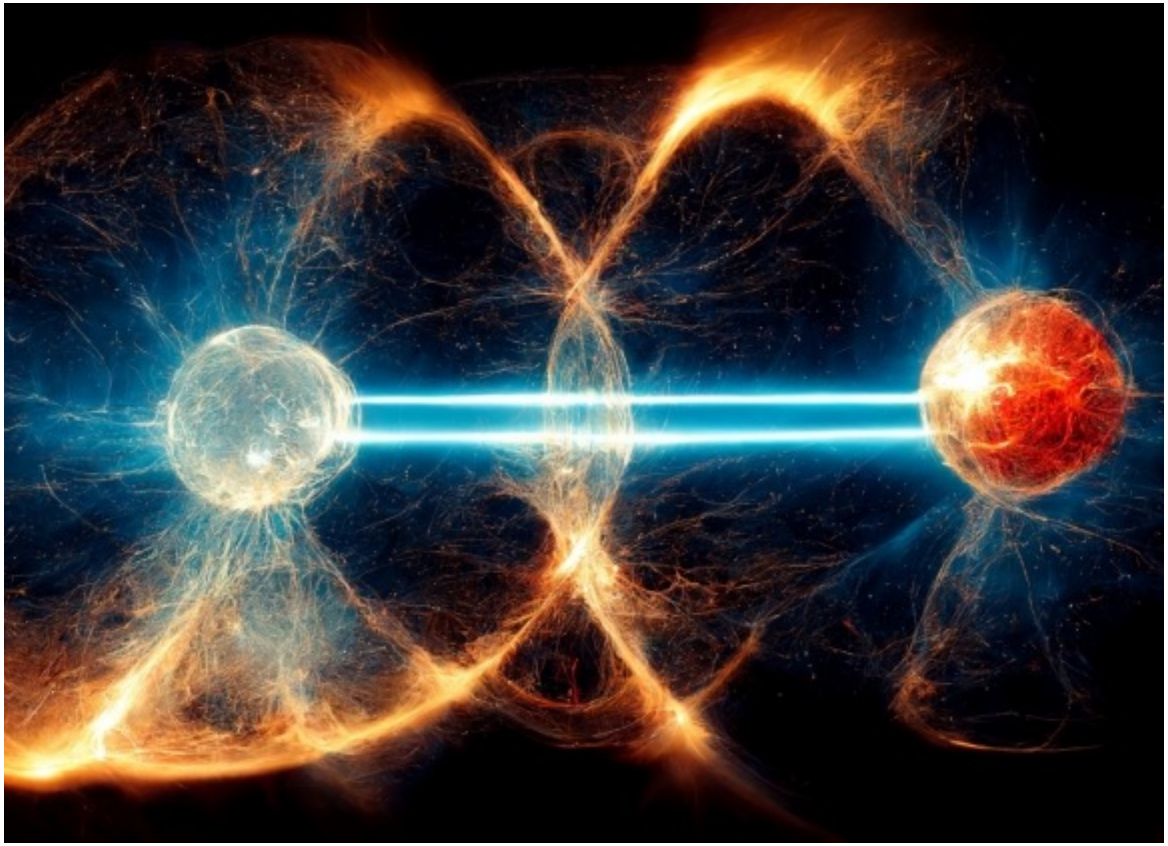
Nuclear fission - advantages

- Very high energy density
- Not a fossil fuel – no greenhouse gas emissions
- Reliable

Thorium (Th) as a possible future nuclear source

- Thorium – A.n. = 90, A.w = 232
- Absorbs neutrons to produce U-233
  - Thus have a Thorium-Uranium cycle
- Benefits
  - Less toxic on 10,000 year cycle
  - 3.3x more abundant than uranium
- Drawbacks
  - We lack experience with Th
  - Th harder to prepare as a fuel
  - Initially more radioactive

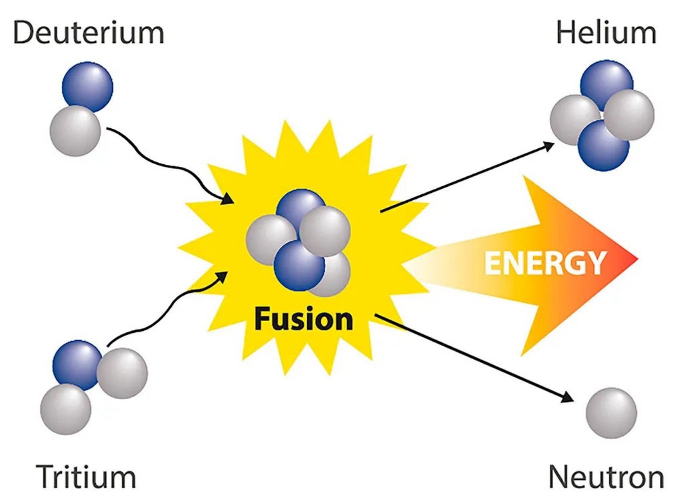
What about nuclear fusion?



https://www.maucherjenkins.com/commentary/what-is-nuclear-fusion

Essentials of nuclear fusion:

- Two smaller atomic nuclei combine to form larger nucleus
  - Energy released in process
- Common reaction is deuterium + tritium gives helium + neutron + energy



Fusion powers the sun and other stars.

- Conditions on the sun:
  - Pressure 100×10^9 times that on earth's surface
  - Temperature 15,000,000 °C
- Difficult to maintain on earth – poses engineering challenge.

Recent advances in fusion

- In December 2022, Lawrence Livermore National Laboratory (50 mi E of San Francisco) had net release of energy from fusion reaction.
  - Used lasers to briefly achieve high, localized temperatures
- Project in Europe uses plasma contained in magnetic field to maintain high temperatures.
- Breakthrough could revolutionize energy picture worldwide.