Uranium availability and the energy cliff

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Nuclear power - the energy balance

by

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Key results of the study

- Nuclear is far from carbon-free.
- Discovery of the '*energy cliff*', limiting the global energy potential of nuclear power.

Potential mitigation of GHG emissions by nuclear

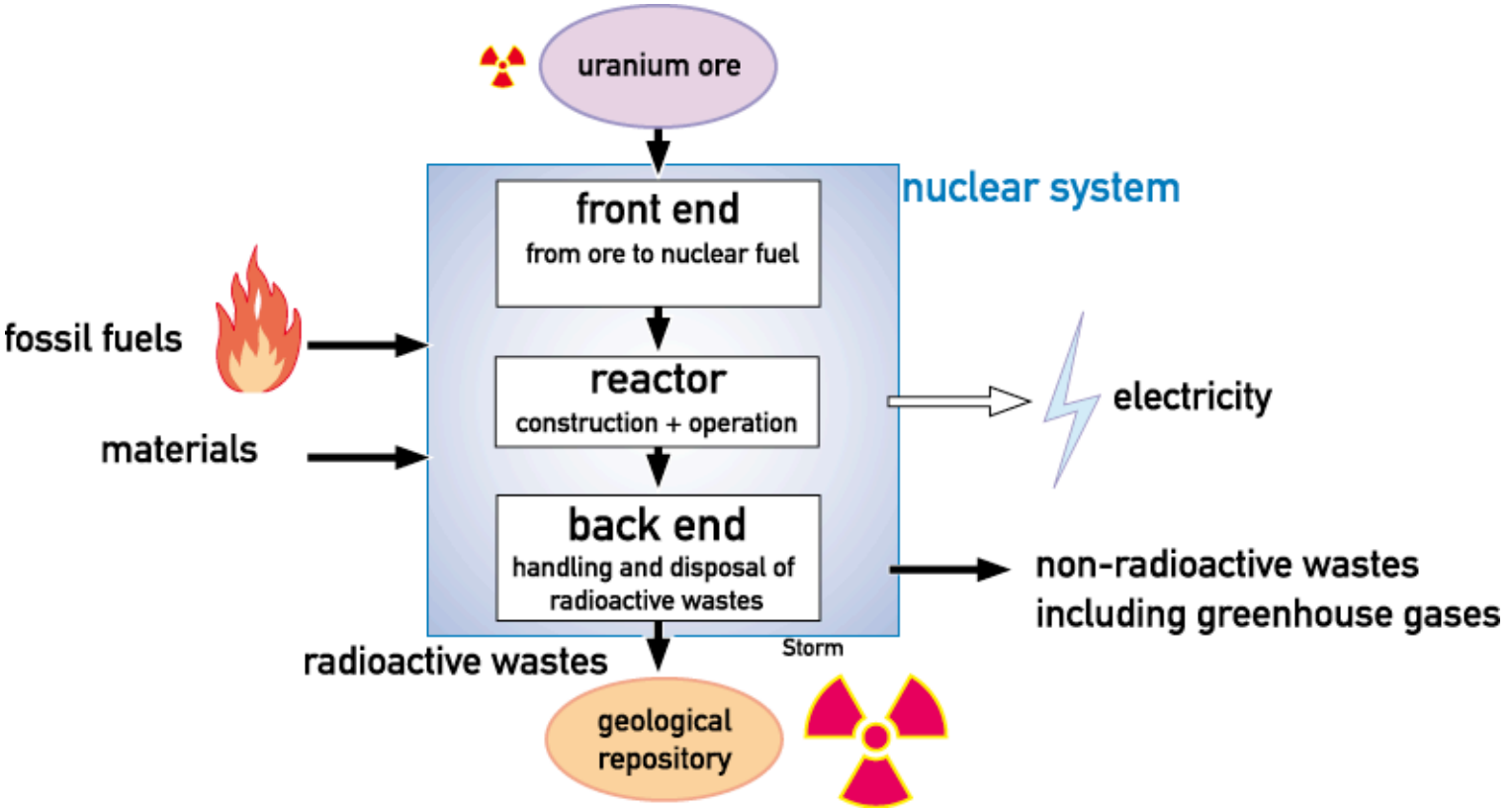
Key parameters:

1 Specific emission, per kWh

2 Nuclear share of world energy supply

3 Potential energy from uranium resources

Basic nuclear process chain



1 Specific emissions of (GHGs) by nuclear

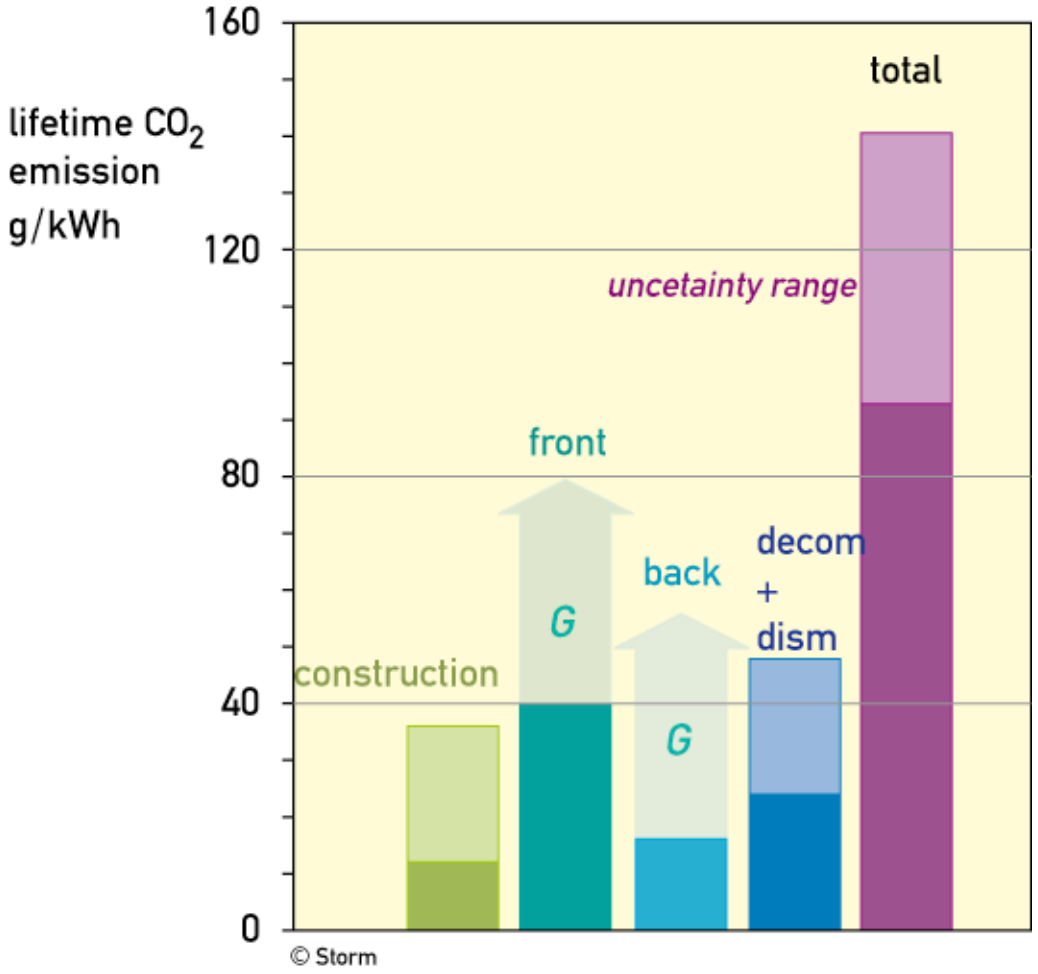
- carbon dioxide CO_2

  CO_2 emitted by all industrial processes in the nuclear process chain, except the nuclear reactor itself.

- CFCs and other greenhouse gases

  Emission never investigated and/or published, but almost certain and probably at significant rates.

Current CO_2 emissions by nuclear

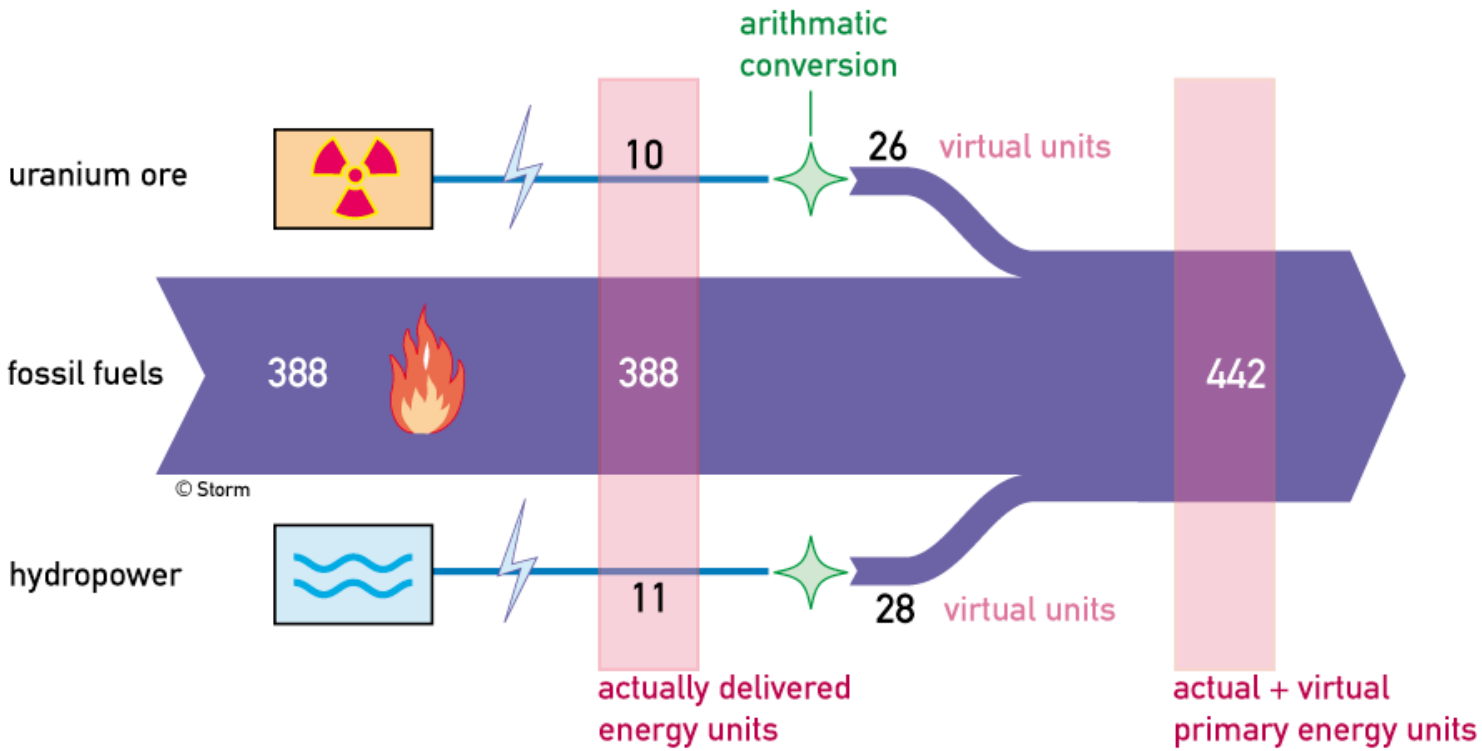


2 Nuclear share of the world energy supply

Different ways to present world energy production and consumption.

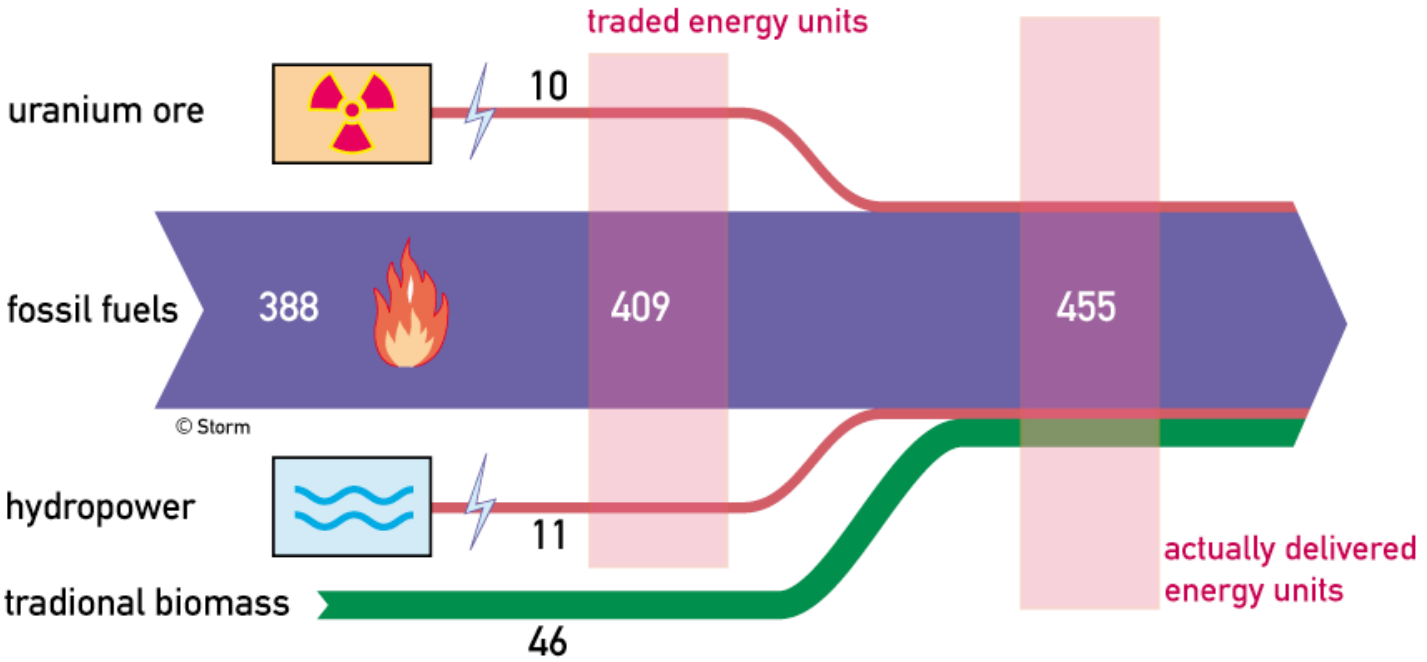
- traded energy ≠ total energy
- virtual energy units in economic statistics
- confusion with physical energy flows

World energy, statistical view
(traded energy only), ref: BP



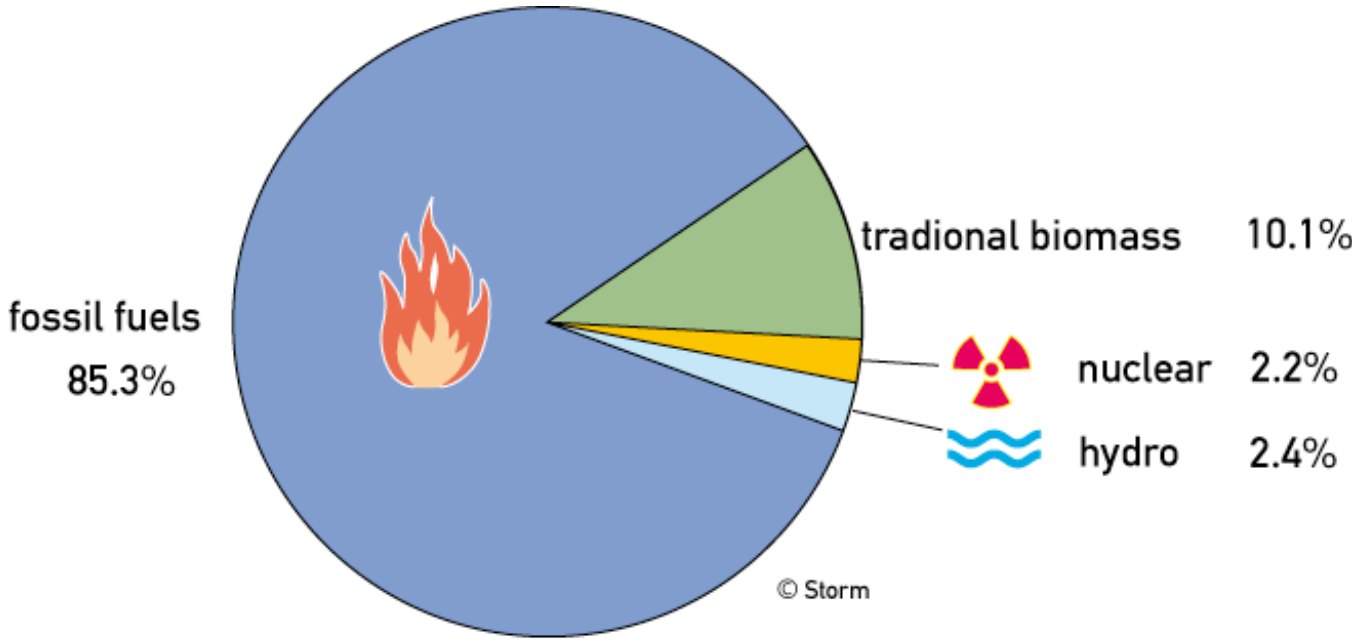
World energy 2005, statistical view

World energy, physical flows
actually produced energy units



World energy 2005, physical flows

Physical world energy flows



world energy flows in 2005: ~455 EJ

traded: 409 EJ

3 Energy from uranium

- The energy requirements to extract uranium from the earth's crust are governed by basic thermodynamic laws.

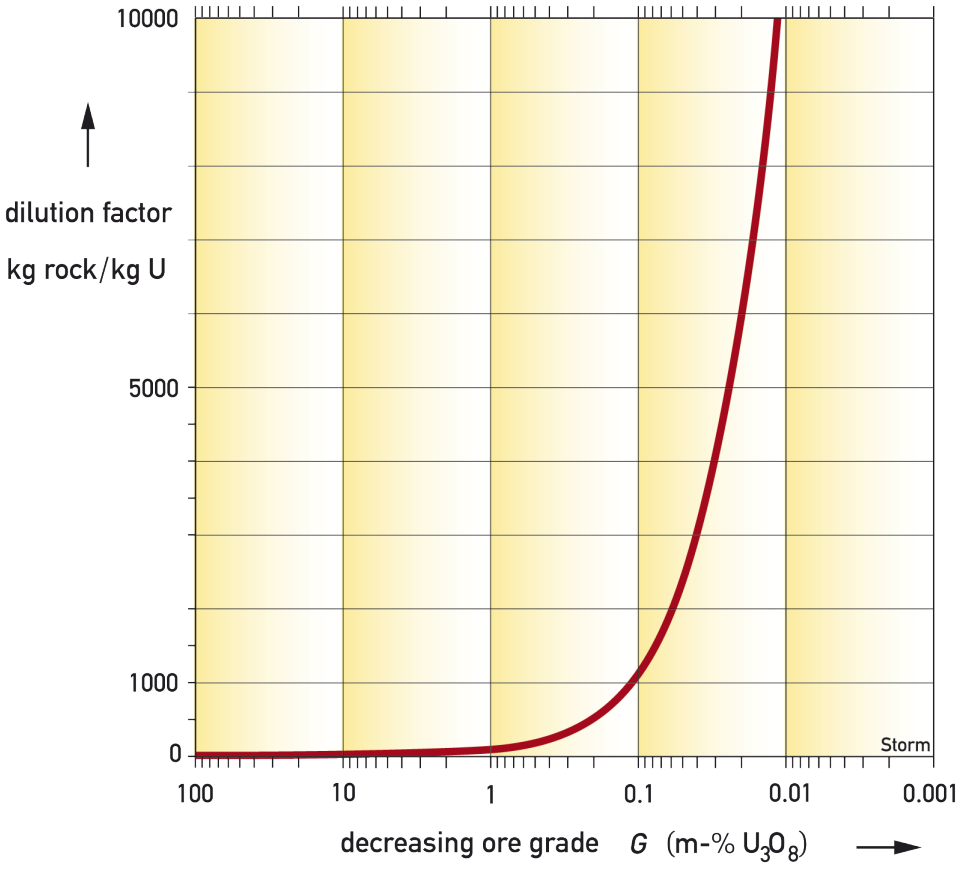
- Not the *quantity* of uranium in the earth's crust, but the *quality* of its resources determines the world nuclear power potential.

Energy from uranium

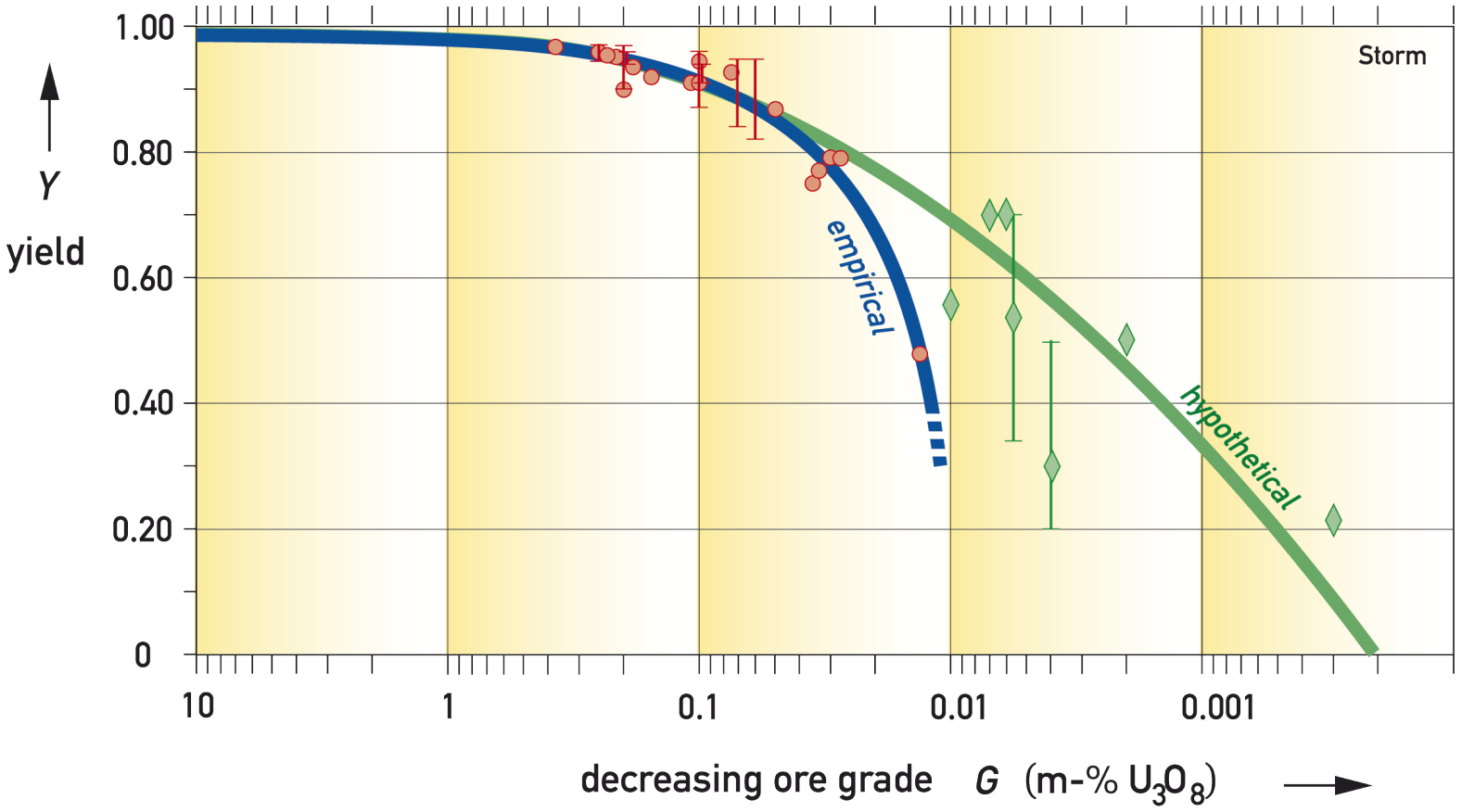
Main parameters of the thermodynamic *quality* of an uranium resource:

- ore grade
- type of rock
- geochemical characteristics of U
- size of deposit
- depth of deposit
- accessibility

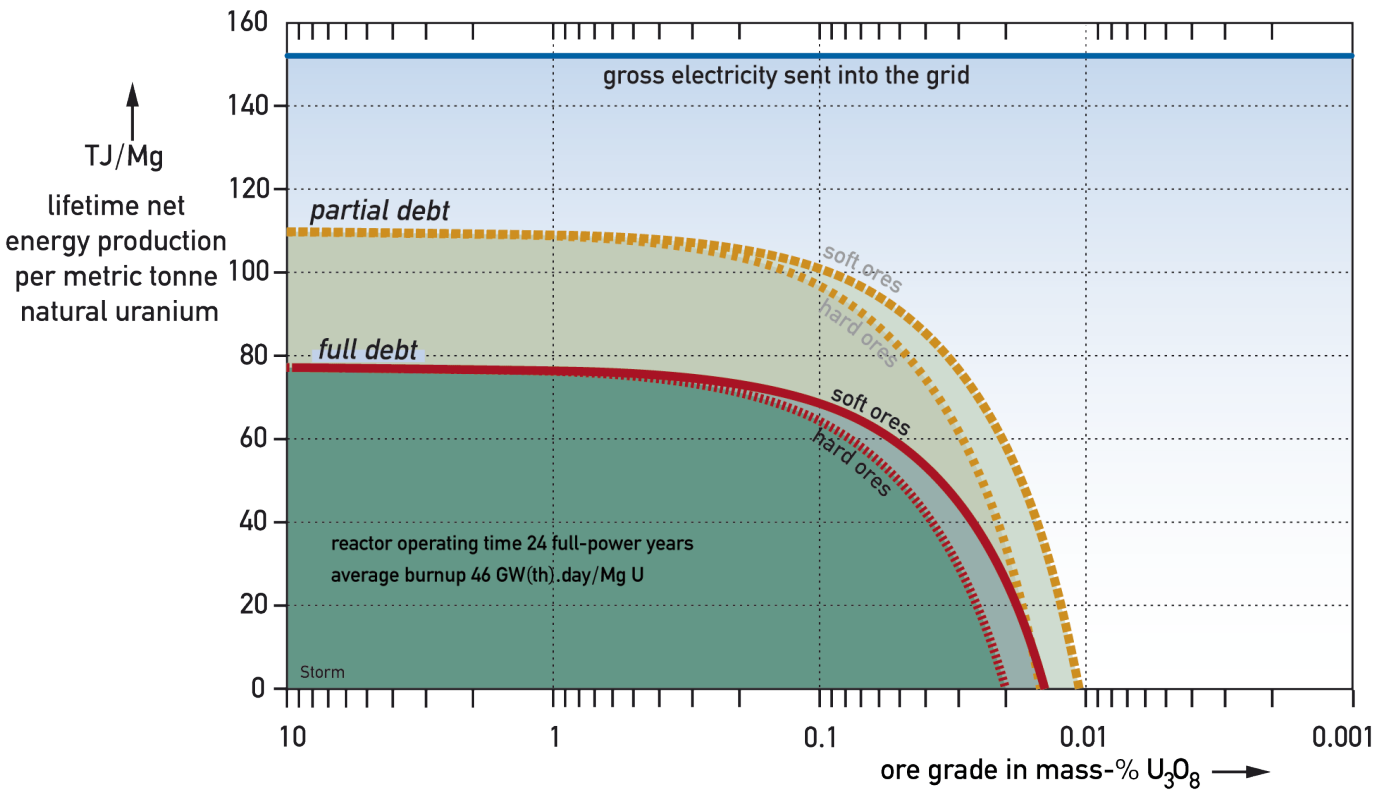
Dilution factor = kg(rock)/kg(U)



Extraction yield $Y = mU_{ex}/mU_{rock}$



Energy cliff



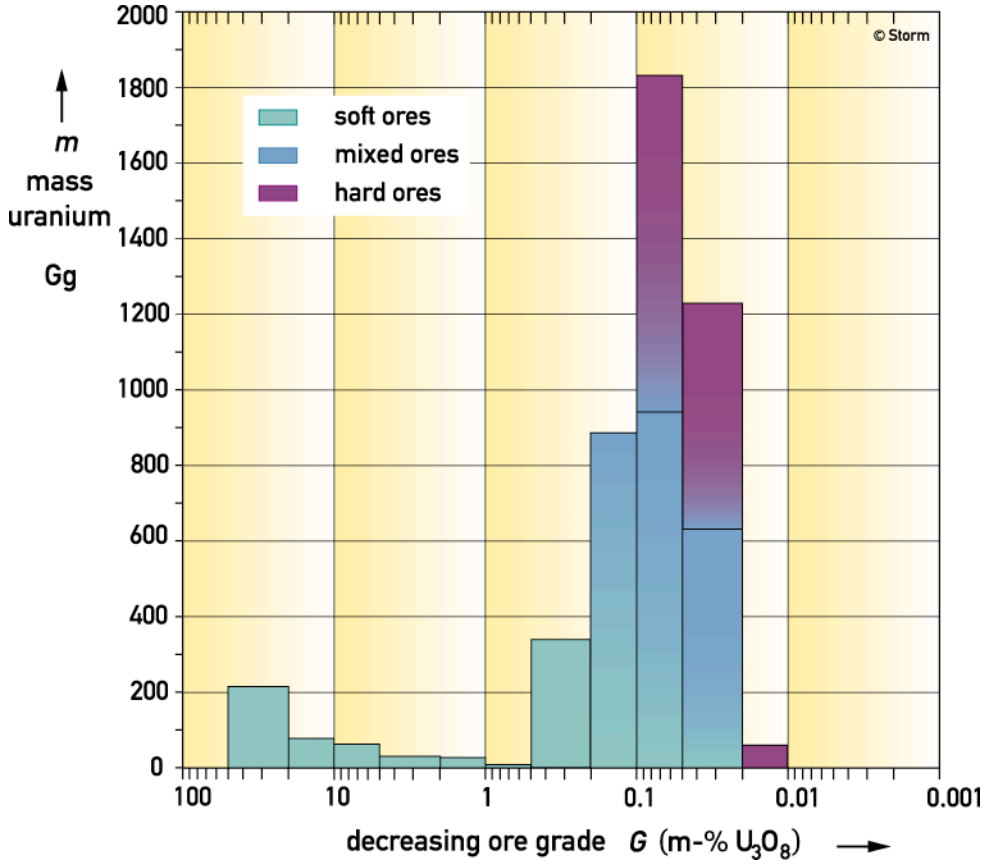
Energy from uranium

Uranium resources

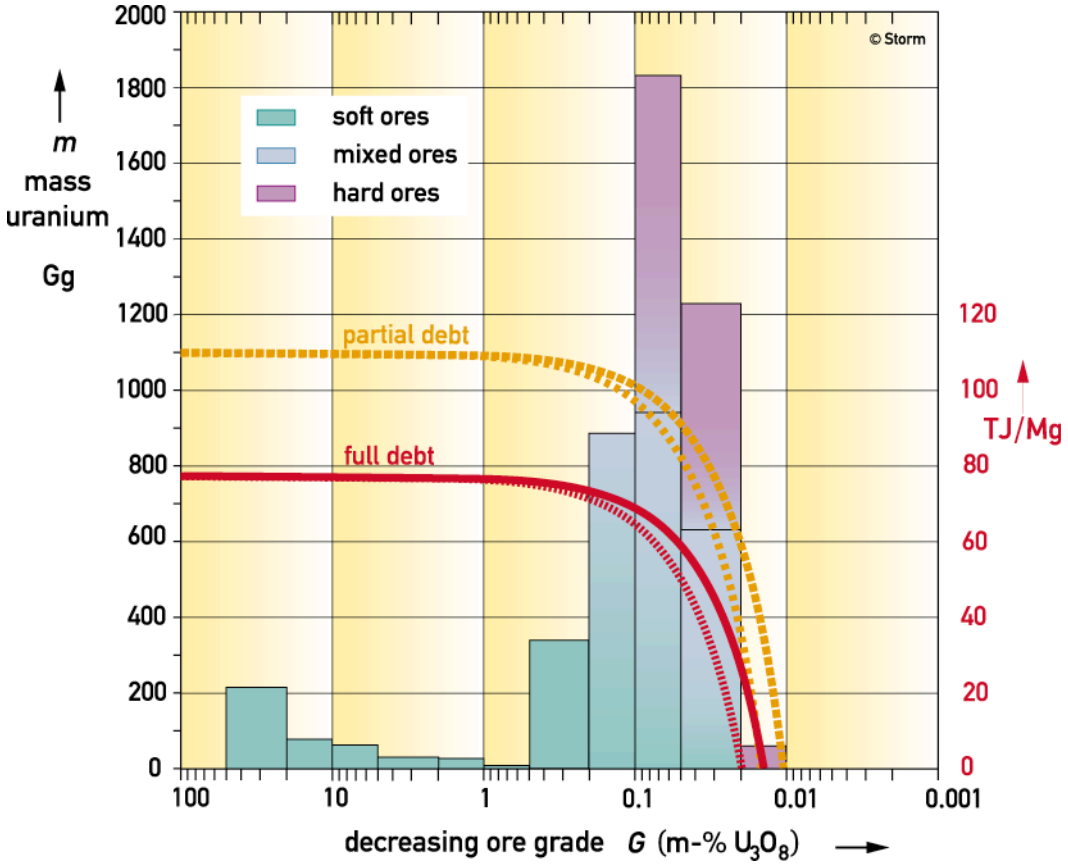
are ***not*** equal to

energy resources

Uranium resources and ore grade
(Red Book 2006, WNA)



U resources and the energy cliff



Nuclear energy in the future

Scenario 1

World nuclear capacity remains constant at current level, 370 GW(e).

Share declines to < 1% of world energy supply by 2050, due to rising world energy demand.

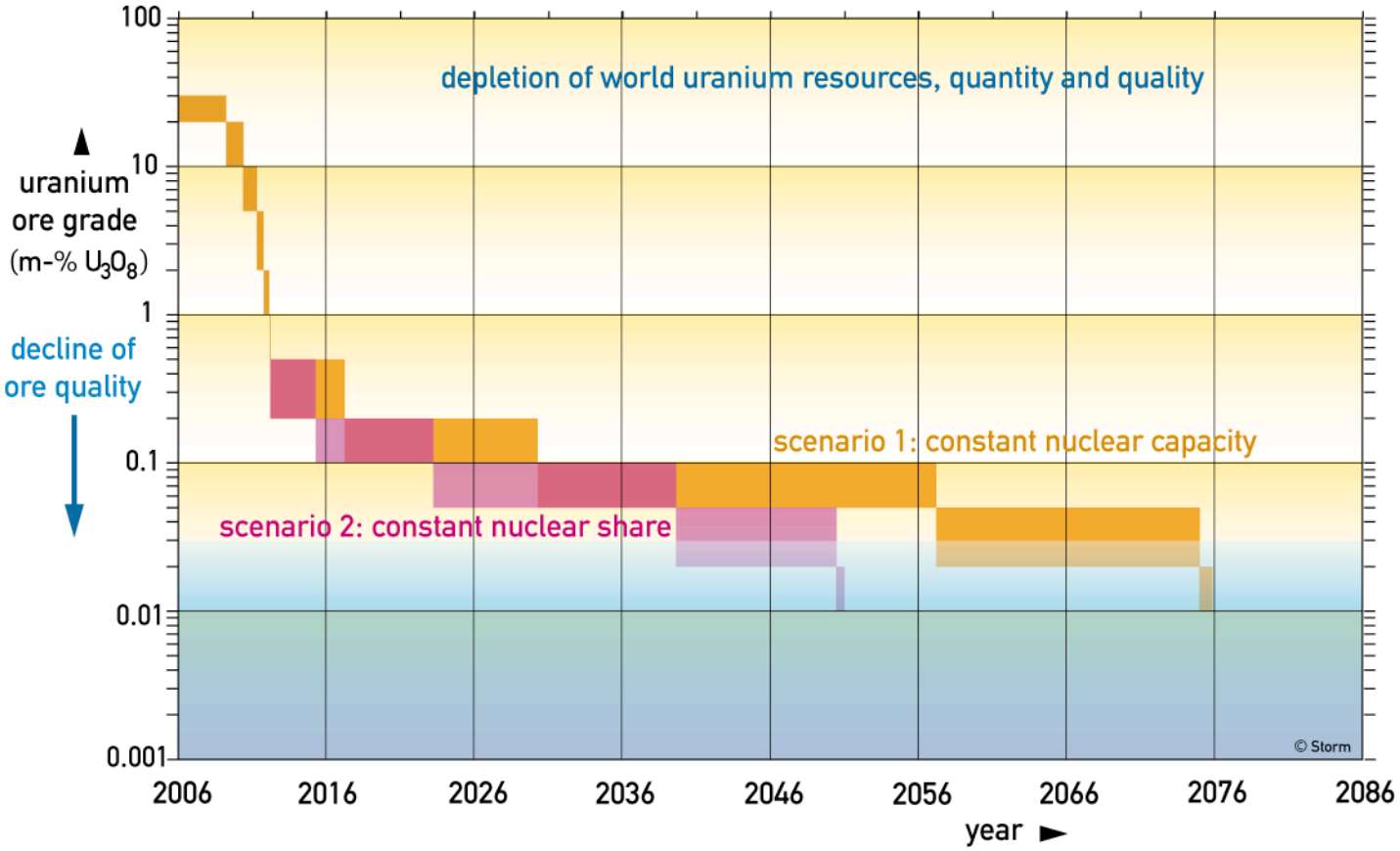
nuclear energy in the future

Scenario 2

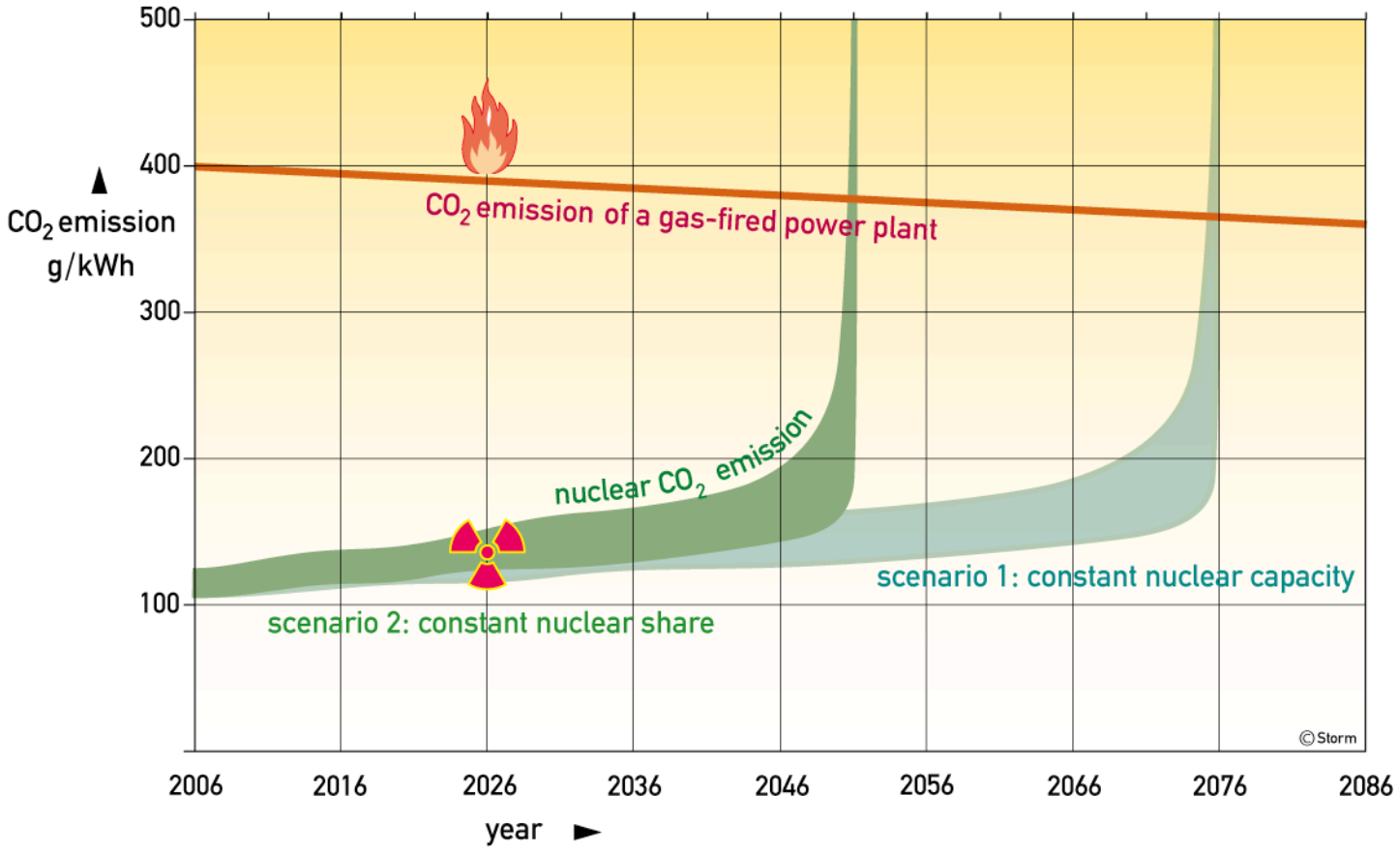
World nuclear share remains constant at current level, 2.2% of world energy supply, from 2012 on.

World nuclear capacity increases by 2-3% a year (7.5-10 GW/a), to keep pace with rising world energy demand.

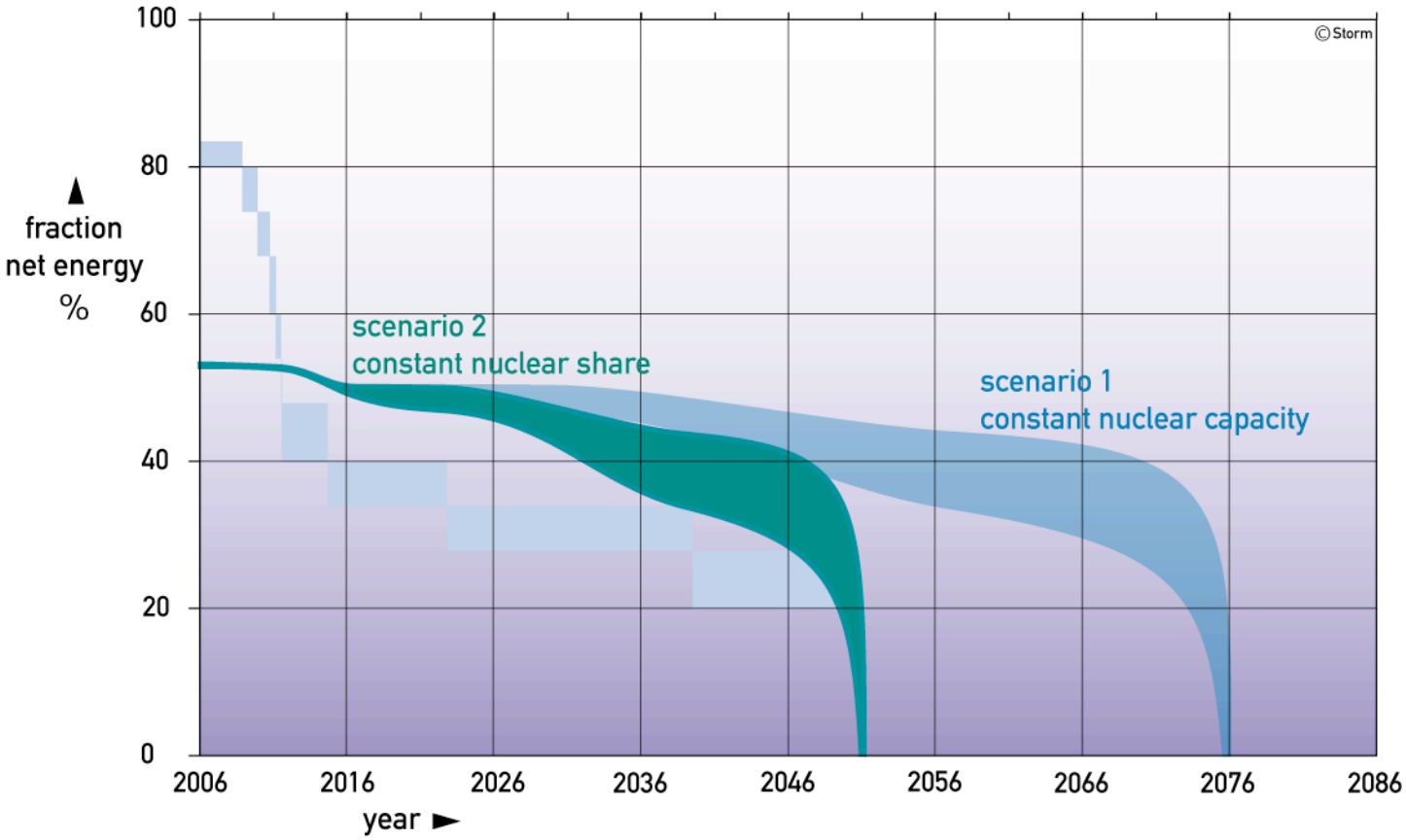
Depletion of uranium resources quantity and quality



Specific CO_2 emission by nuclear power with time



The energy cliff in time
Net energy from nuclear power.



Outlook

- Highest-quality uranium deposits already known and in production.
- Chances of finding new large high-quality deposits unknown, but might be very slim.

Outlook

- New finds: large deposits have lower quality.
- Lower quality means more energy consumed per kg extracted uranium.

Outlook

- New finds of uranium deposits will be closer to the energy cliff, due to lower quality.
- Note the difference between *high-grade* and *high-quality* ores.

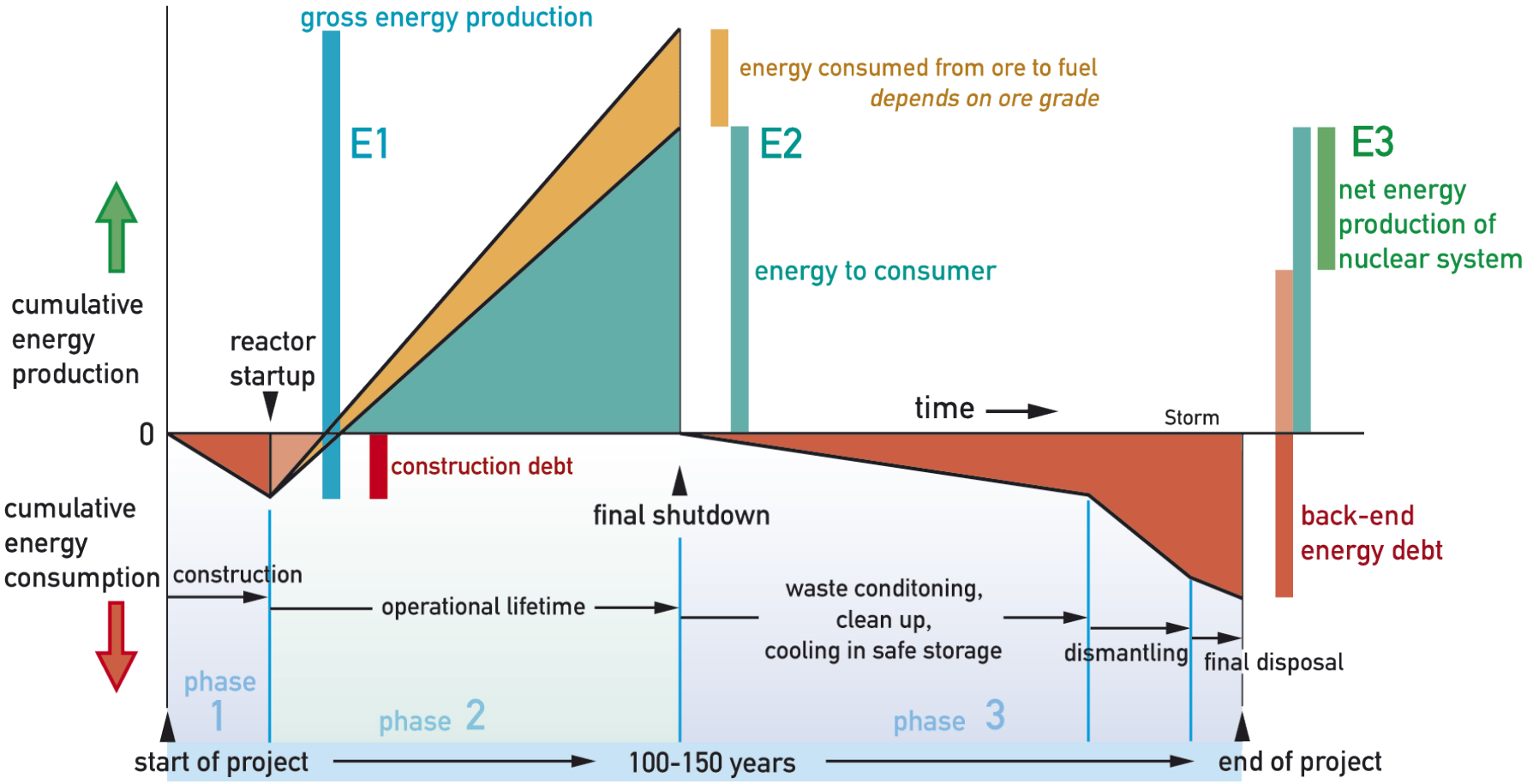
Conclusion

Potential amount of net nuclear energy from uranium ores may not change significantly in the future,

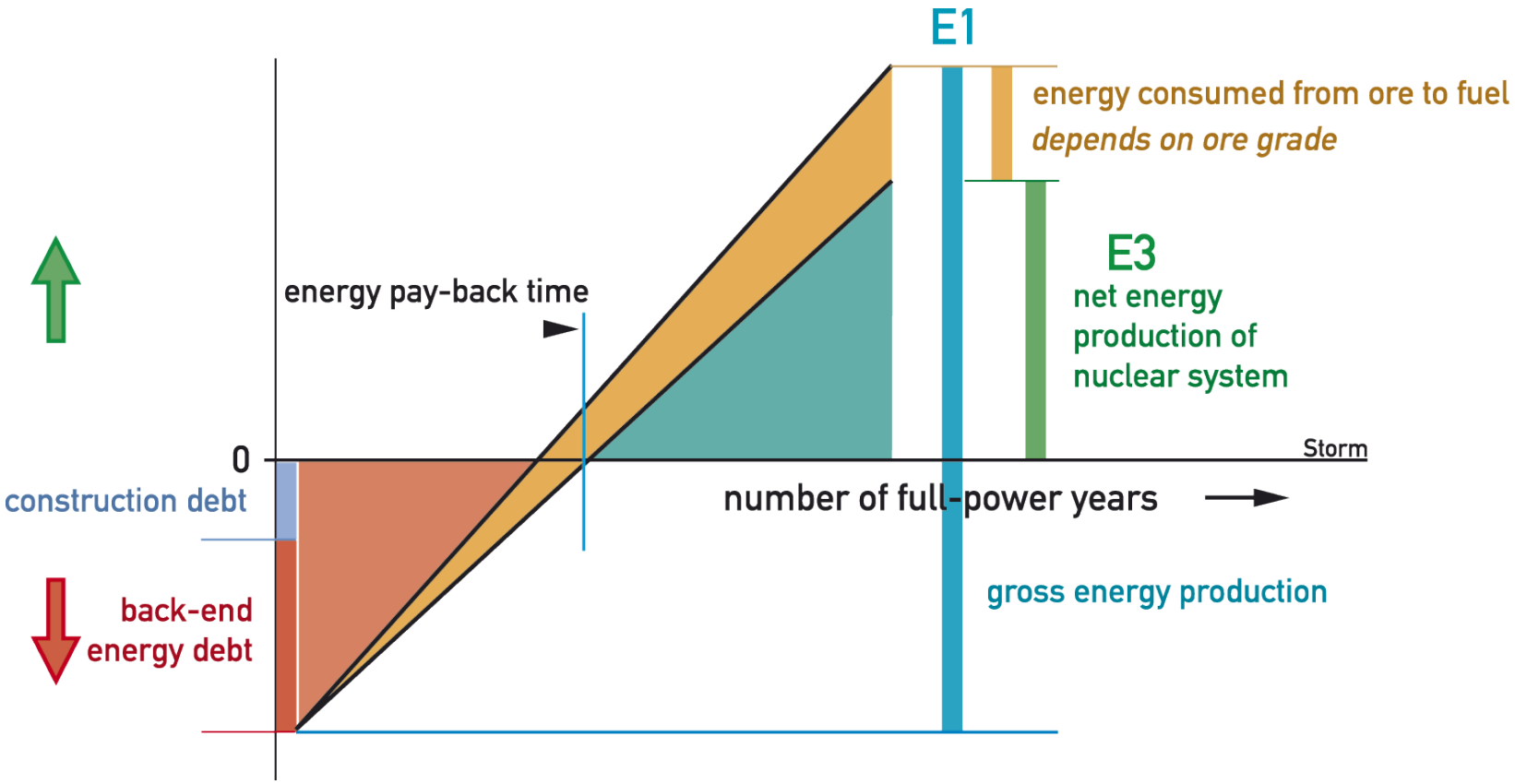
nor by new finds,

nor by advanced technology.

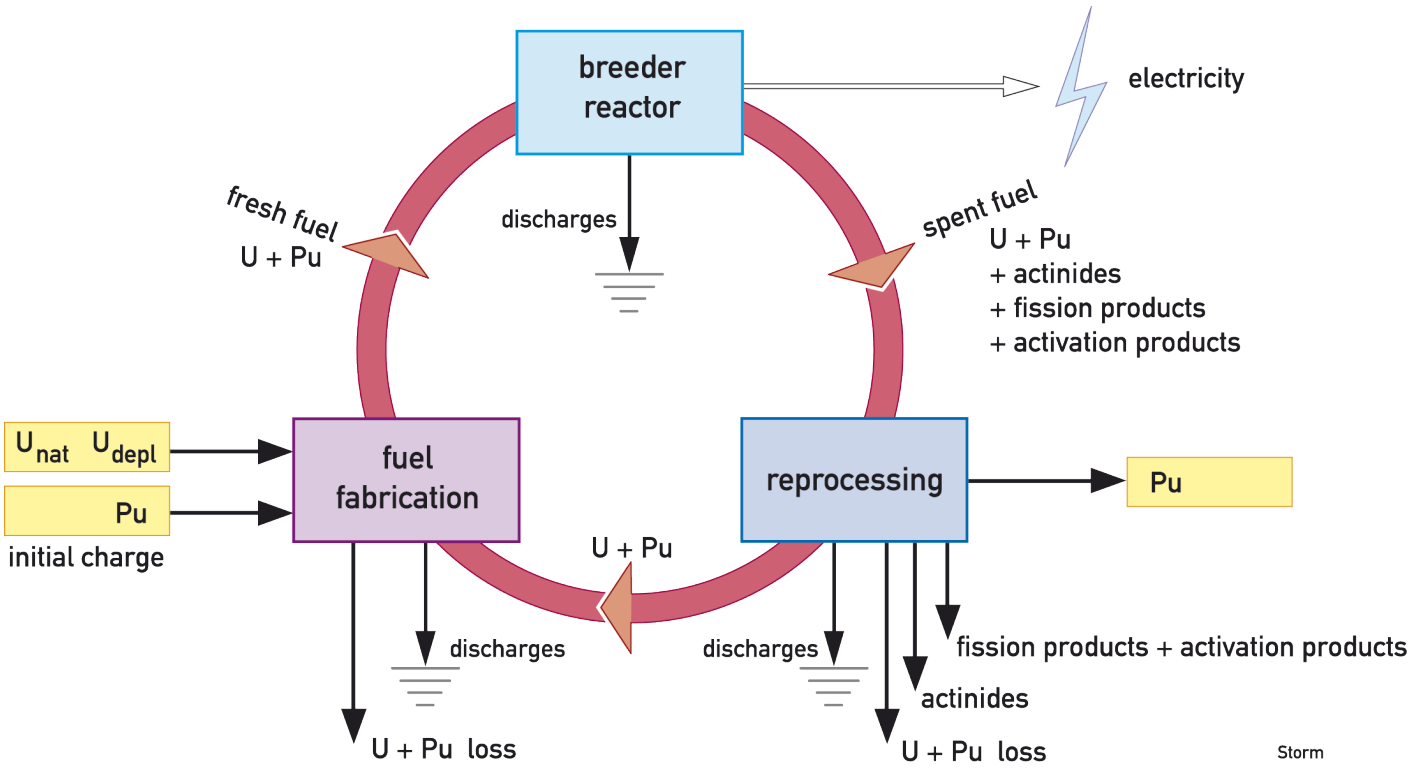
Energy debt


gross energy production
E1
energy consumed from ore to fuel
depends on ore grade
E2
energy to consumer
E3
net energy production of nuclear system
cumulative energy production
0
reactor startup
time
Storm
construction debt
final shutdown
back-end energy debt
cumulative energy consumption
construction
operational lifetime
waste conditoning, clean up, cooling in safe storage
dismantling
final disposal
phase 1
phase 2
phase 3
start of project
100-150 years
end of project

Energy debt 'capitalized'



Breeder cycle



Breeder scenarios: assumptions

- textbook operation
- in 2016 140 breeders on line
- plutonium-limited
- doubling time 40 years

Breeder scenarios