Energy from uranium

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Key points

- construction costs
  - historical trend
  - cost overruns
- timescale
- uranium: how much energy?
- vulnerability
- uncertainties

Which reactor technology?

- Thermal neutron reactors only
  LWR & other (‘advanced’)
  0.7% max of natural uranium fissioned

- U-Pu breeder: unfeasible
- Th-U breeder: beyond the horizon

Energy for energy

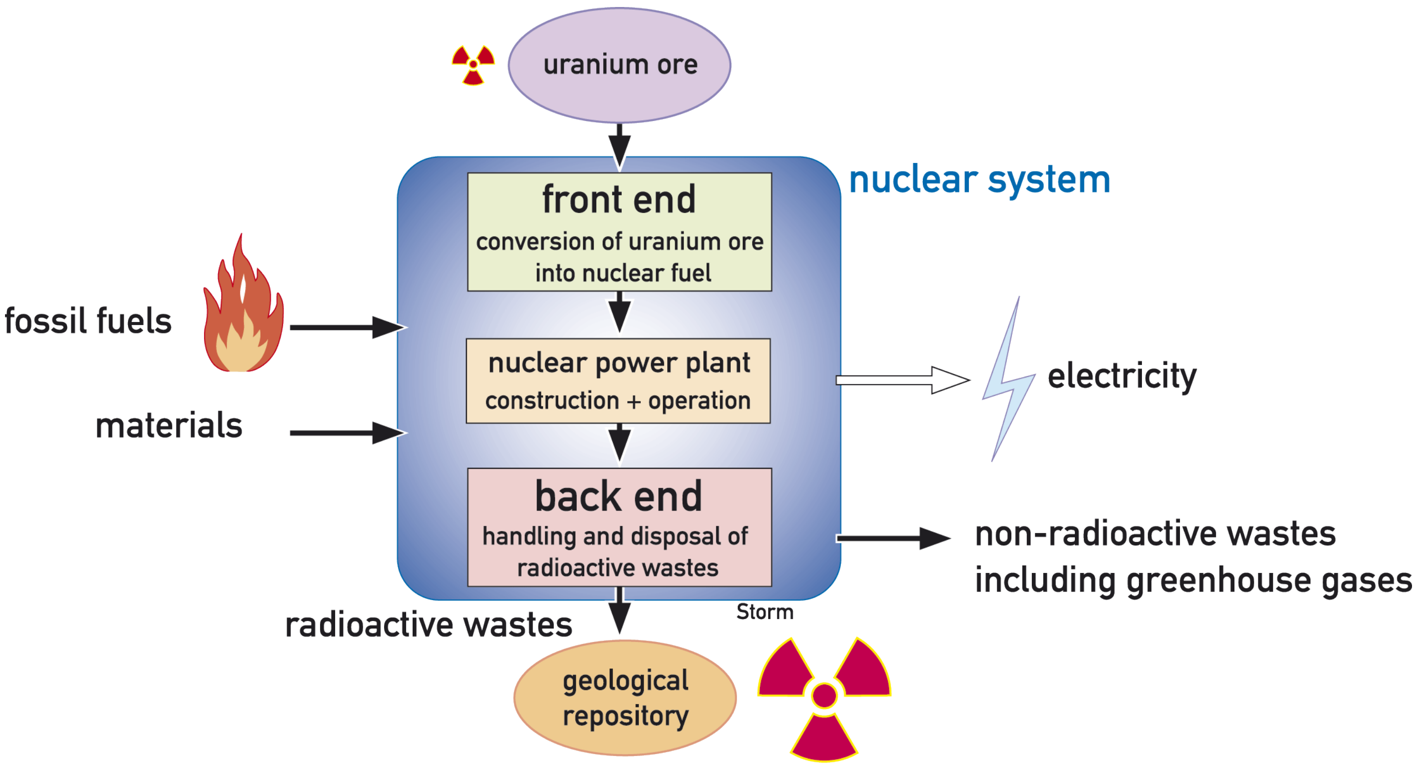
- Releasing useful energy from uranium costs energy

- Nuclear reactor part of complex system

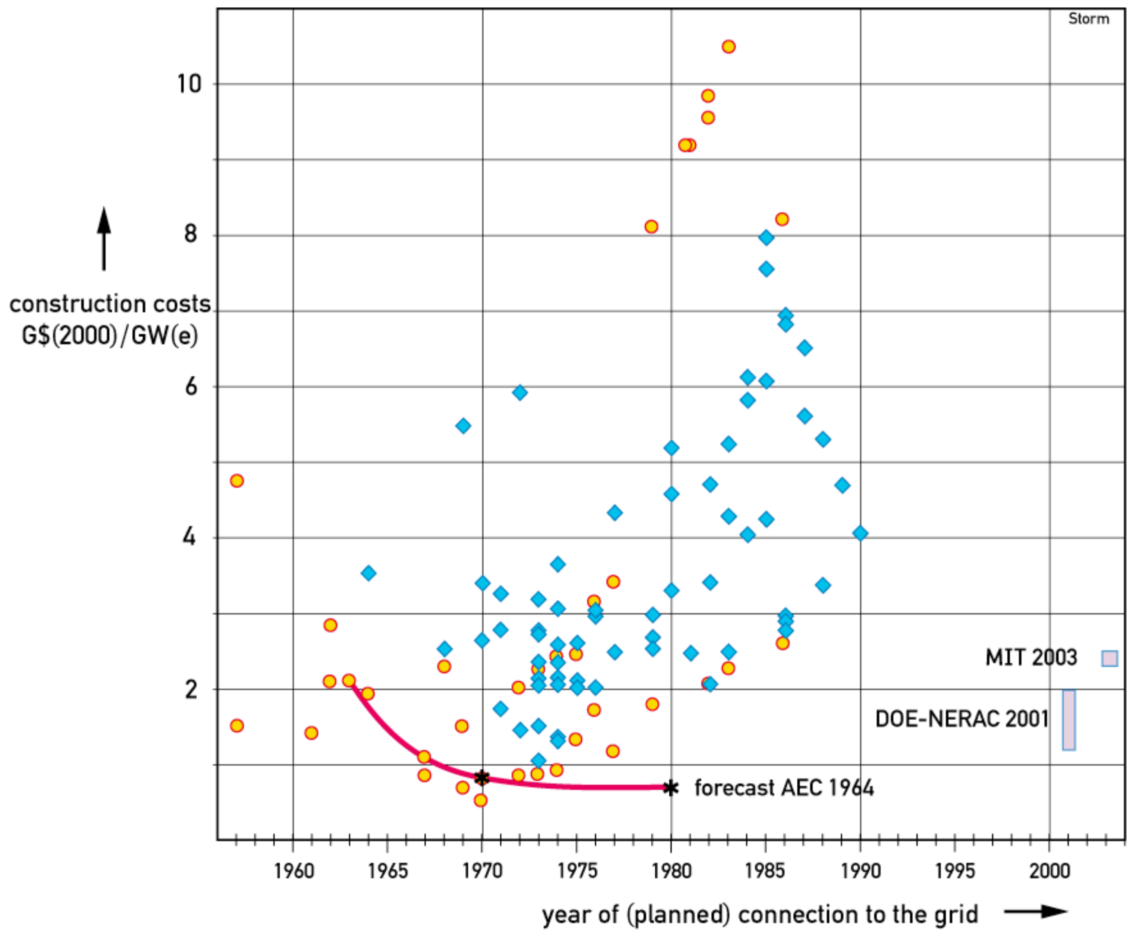
- Nuclear process chain: conventional industrial and nuclear operations

- *Nuclear power is not carbon-free nor GHG-free*

Basic nuclear process chain



Construction costs



Construction costs in the future

How solid is the basis
of the low construction cost estimates by
DOE-NERAC and MIT?

Conditions for large cost overruns
as analyzed by RAND Corporation are still
valid.

Time scale

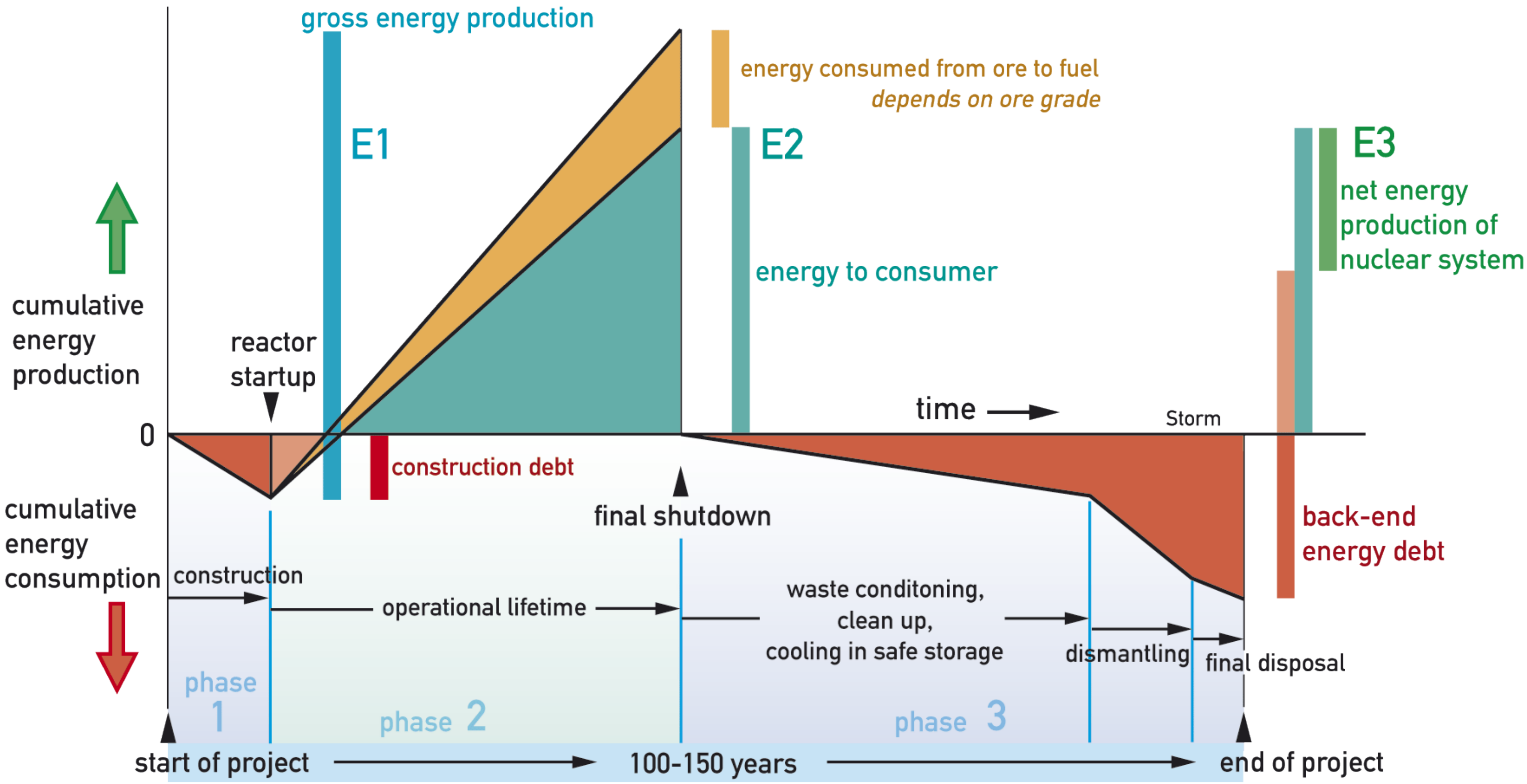
- Construction of NPP 10 years
  + development time
- Operational life 40 years?
- Aftermath, back end 30-100 years?
  no empirical data
- Total time scale 80 - 150 years

- *Large uncertainties*

Sustainability

Philosophy of
‘*Après nous le déluge*’
is not consistent
with any sustainability principle

Lifetime costs: energy debt



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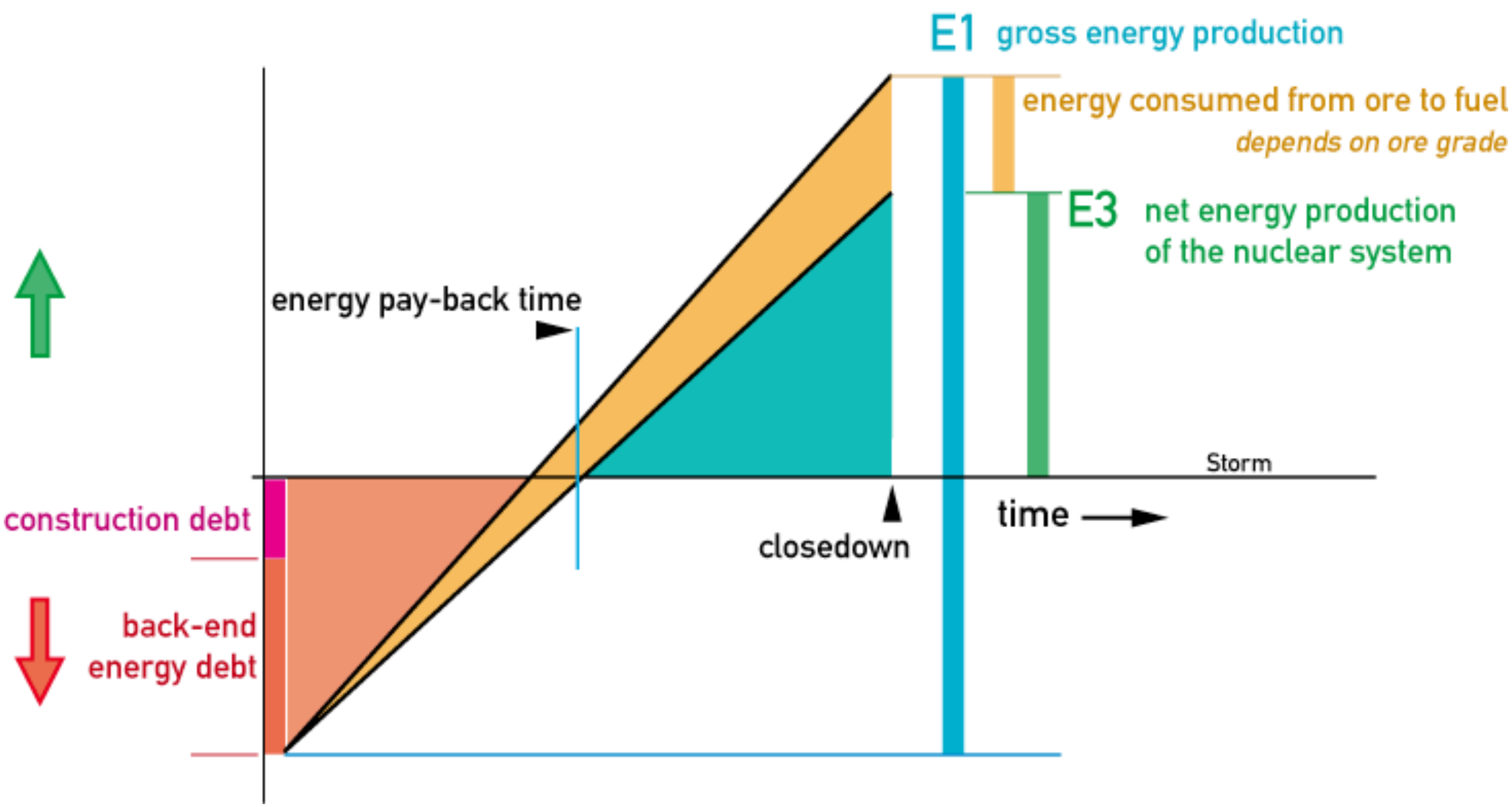
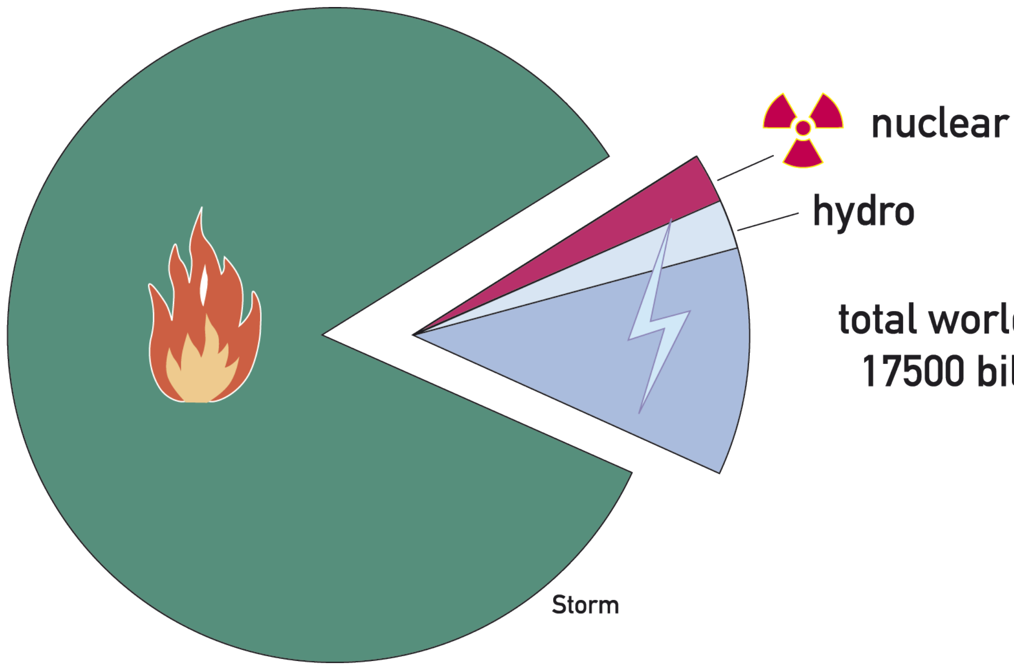
Energy debt ‘capitalized’



Energy pay-back times

System	operational life years	energy pay-back years
nuclear (LWR)	30-40	6-14 ore grade dep.
PV UK PV S.Europe	30-40 30-40	4 2
wind	20	< 1
fossil	30-40	< 1

Nuclear share of world energy



total world electricity in 2004:
17500 billion kWh (62.8 EJ)

total world final energy consumption in 2004: ~400 EJ

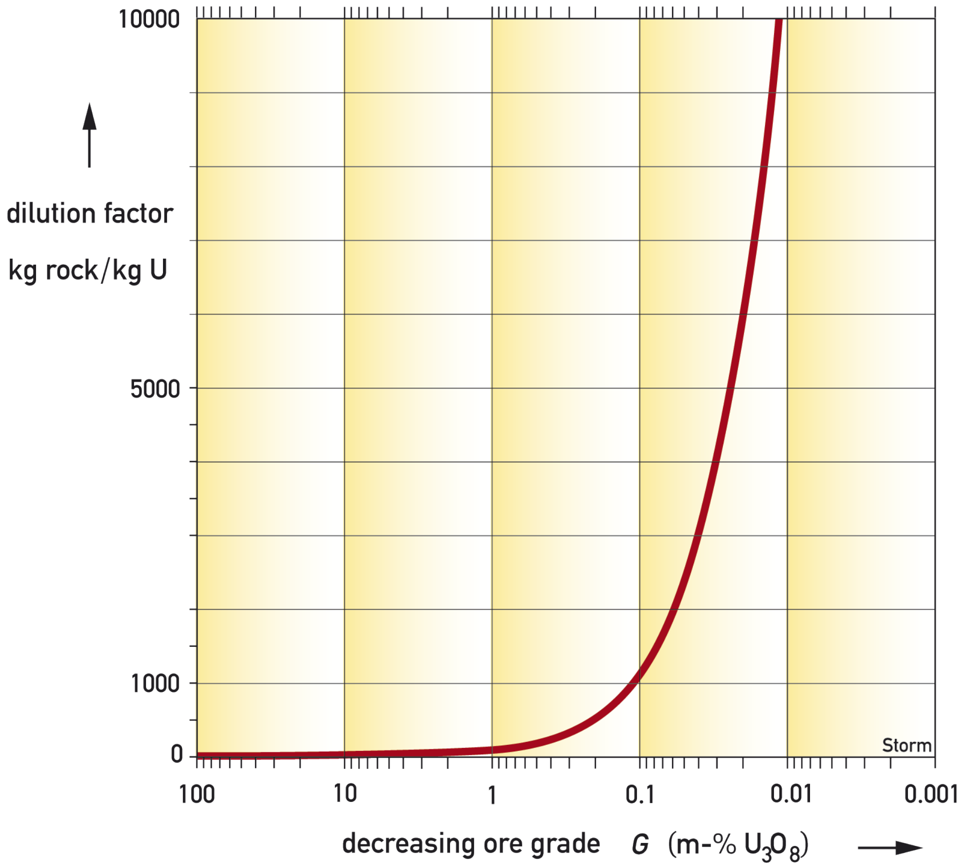
Energy from uranium

- Uranium extraction from ore:
  - dilution factor
  - extraction yield
- Energy cliff
- Uranium resources
- Uranium peak

Extraction of uranium from ore

- excavation of rock
- transport
- grinding
- leaching (chemical processing)
- extraction
- purification
- concentration

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



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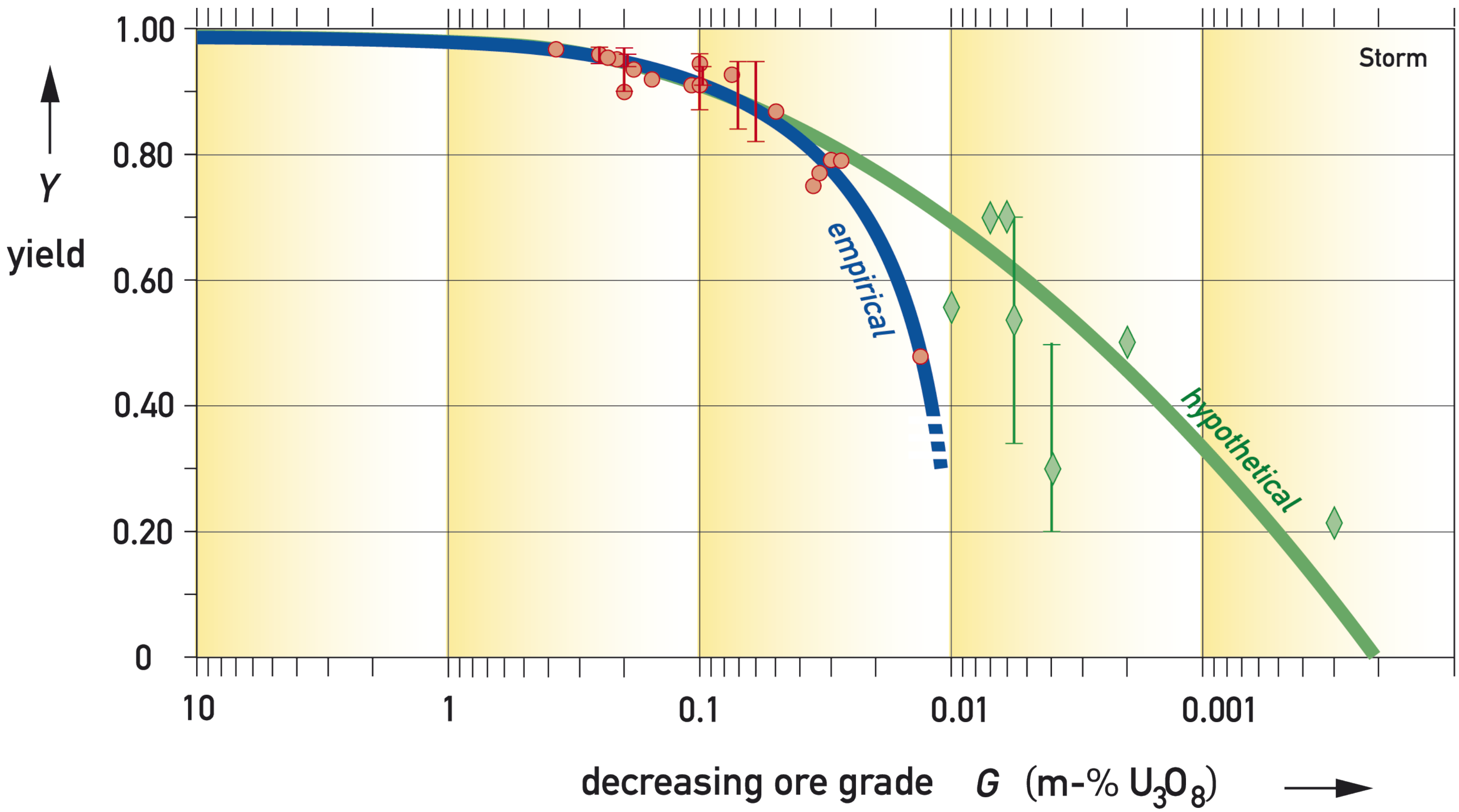
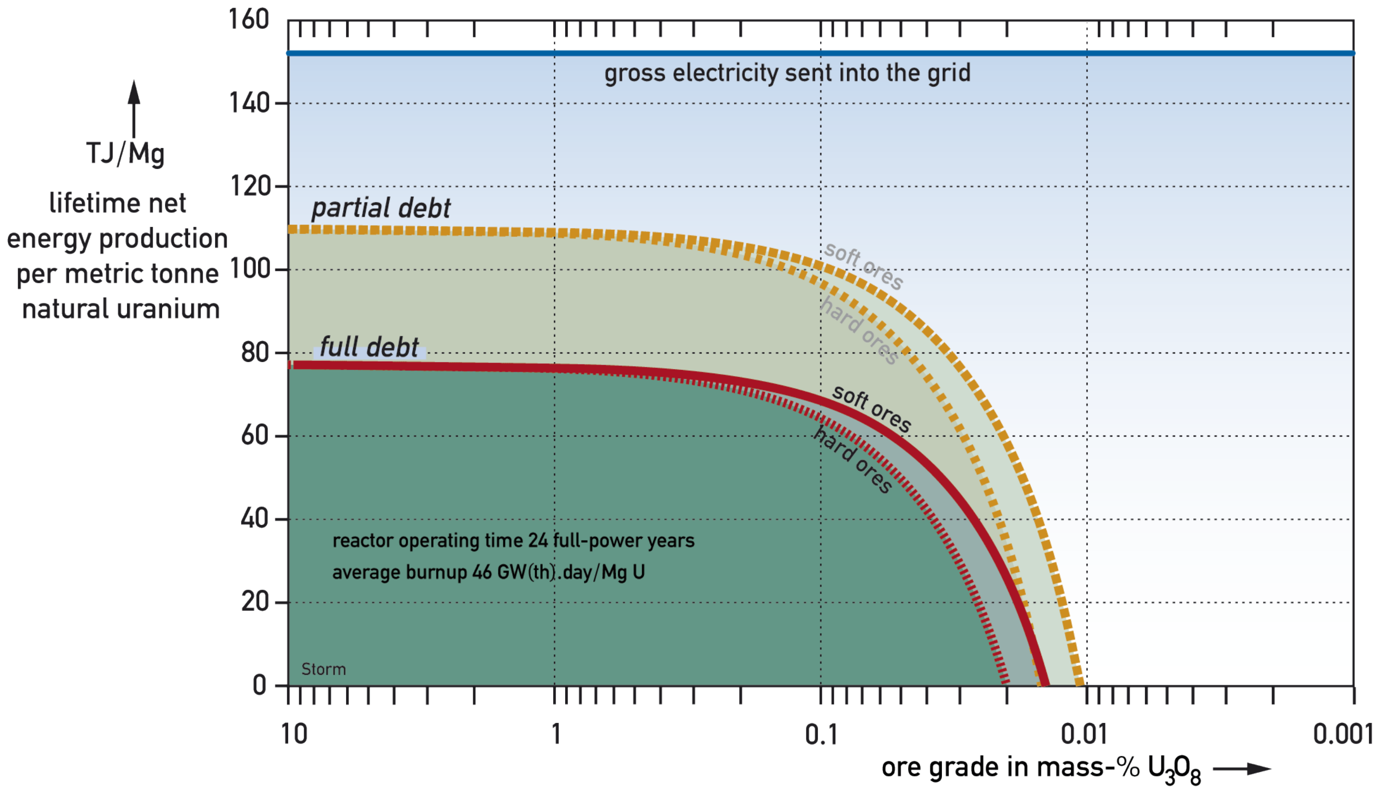
Extraction yield $Y = mU_{ex}/mU_{rock}$



Energy cliff



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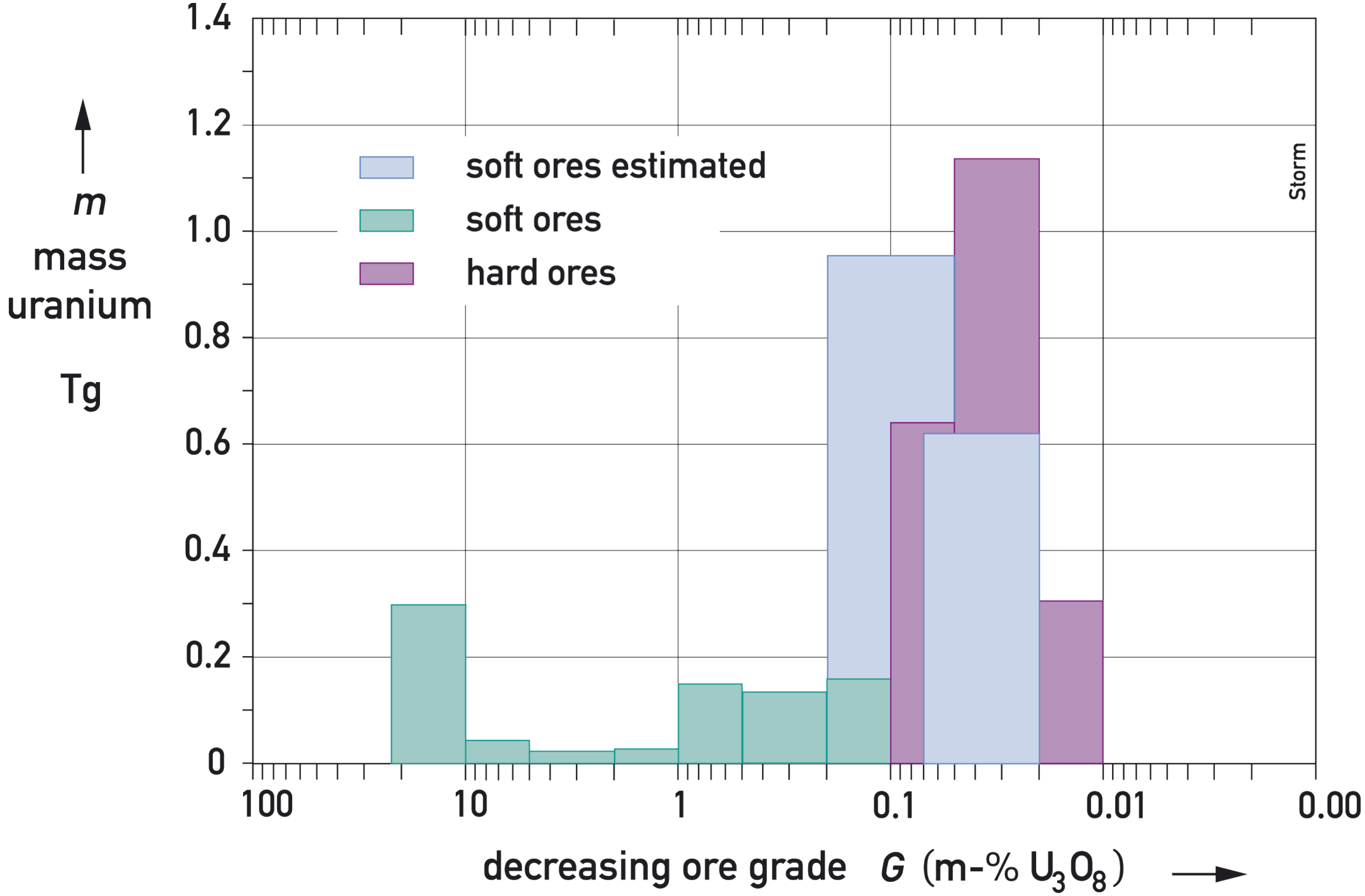
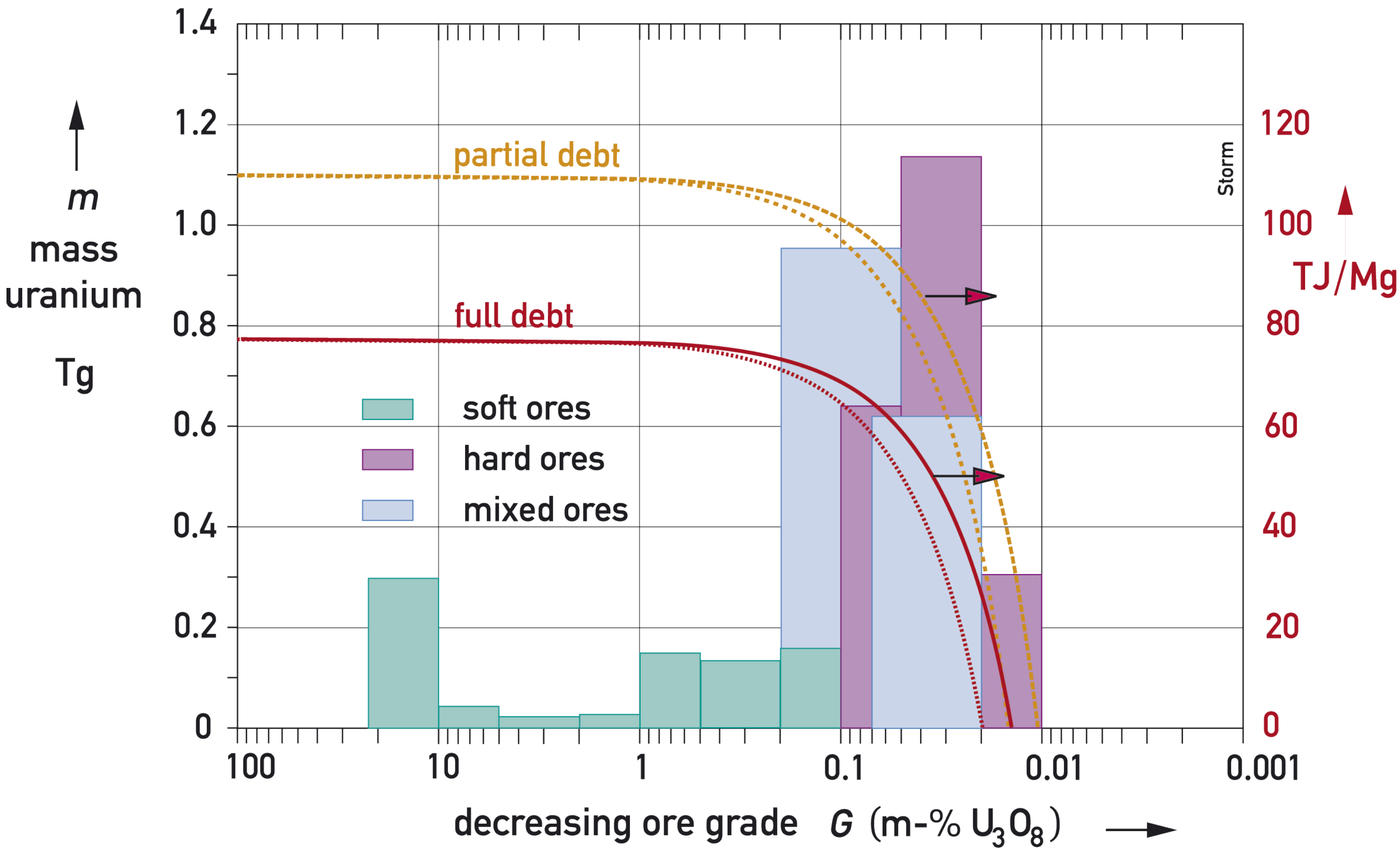
Currently known recoverable uranium resources



Nuclear energy resources



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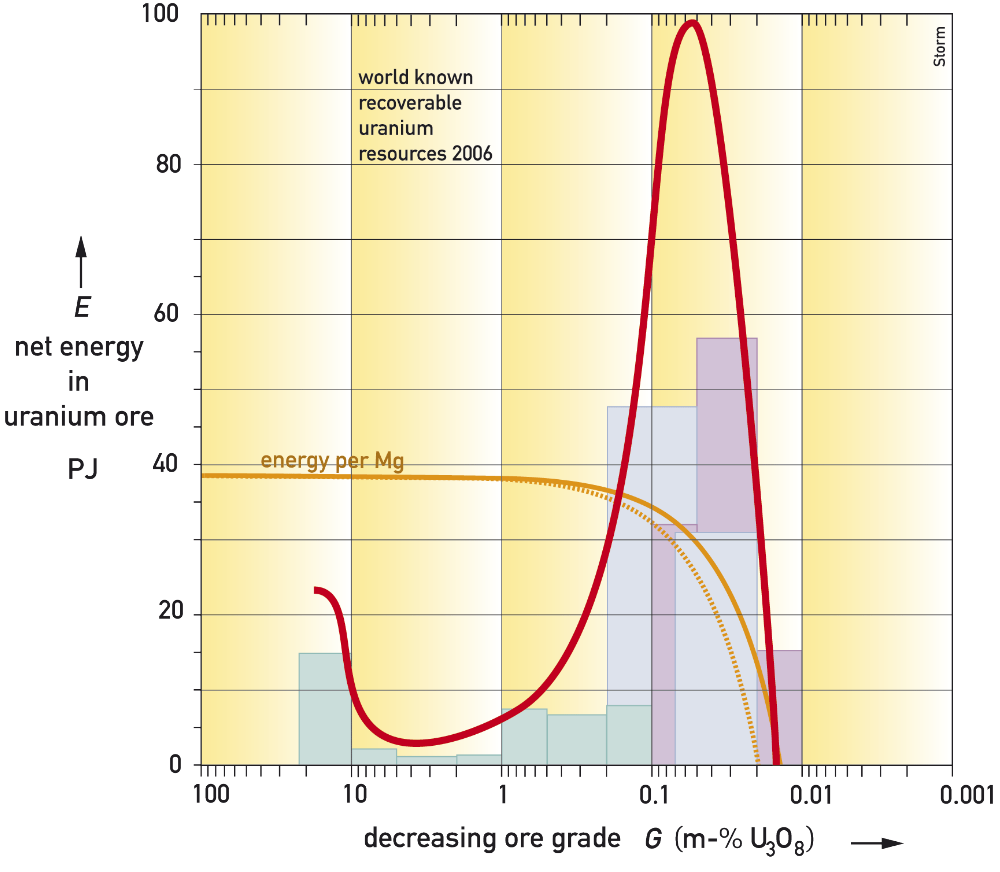
Uranium peak



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Vulnerability of nuclear power

- Large units (1000-1500 MW):
  large reserve capacity,
  heavy grid

Energy supply vulnerable to non-planned outages and terrorist attacks

Vulnerability of nuclear power

- Rich uranium ores depleted in near future
- Energy cliff precludes use of abundant but poor ores

No indications of new rich finds,

may be in 'Uranistan' or Antartica?

Vulnerability of nuclear power

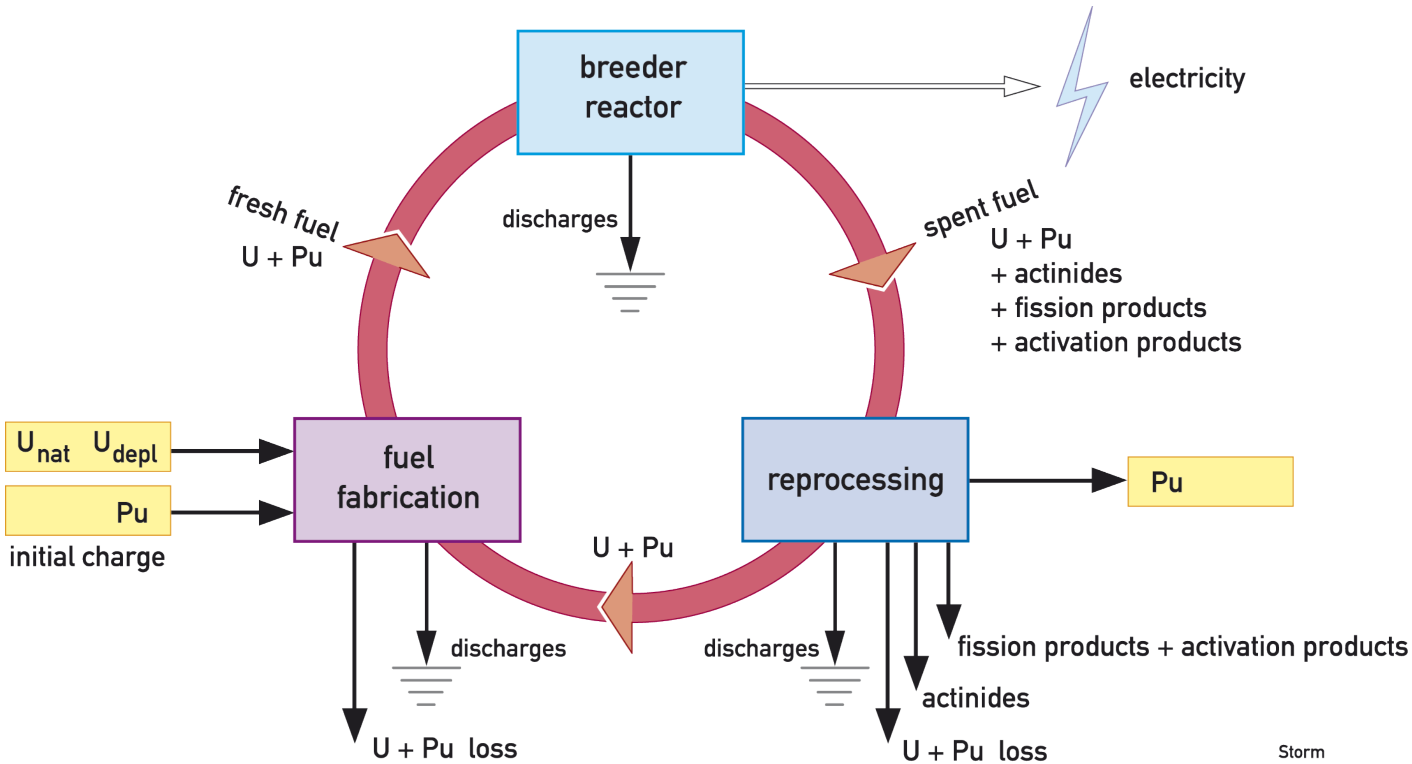
- Spent fuel storage
- retired reactors and
- other radioactive waste

pose an ever increasing risk of accidents and terroristic abuse

Vulnerability of nuclear power

- No nuclear project ever completed from uranium ore through geologic repository.
- Large unknowns of technical feasibilty and economic aspects.
- Energy debt cannot be written off as ‘uncollectable’.
- Energy in the future will likely be more expensive.

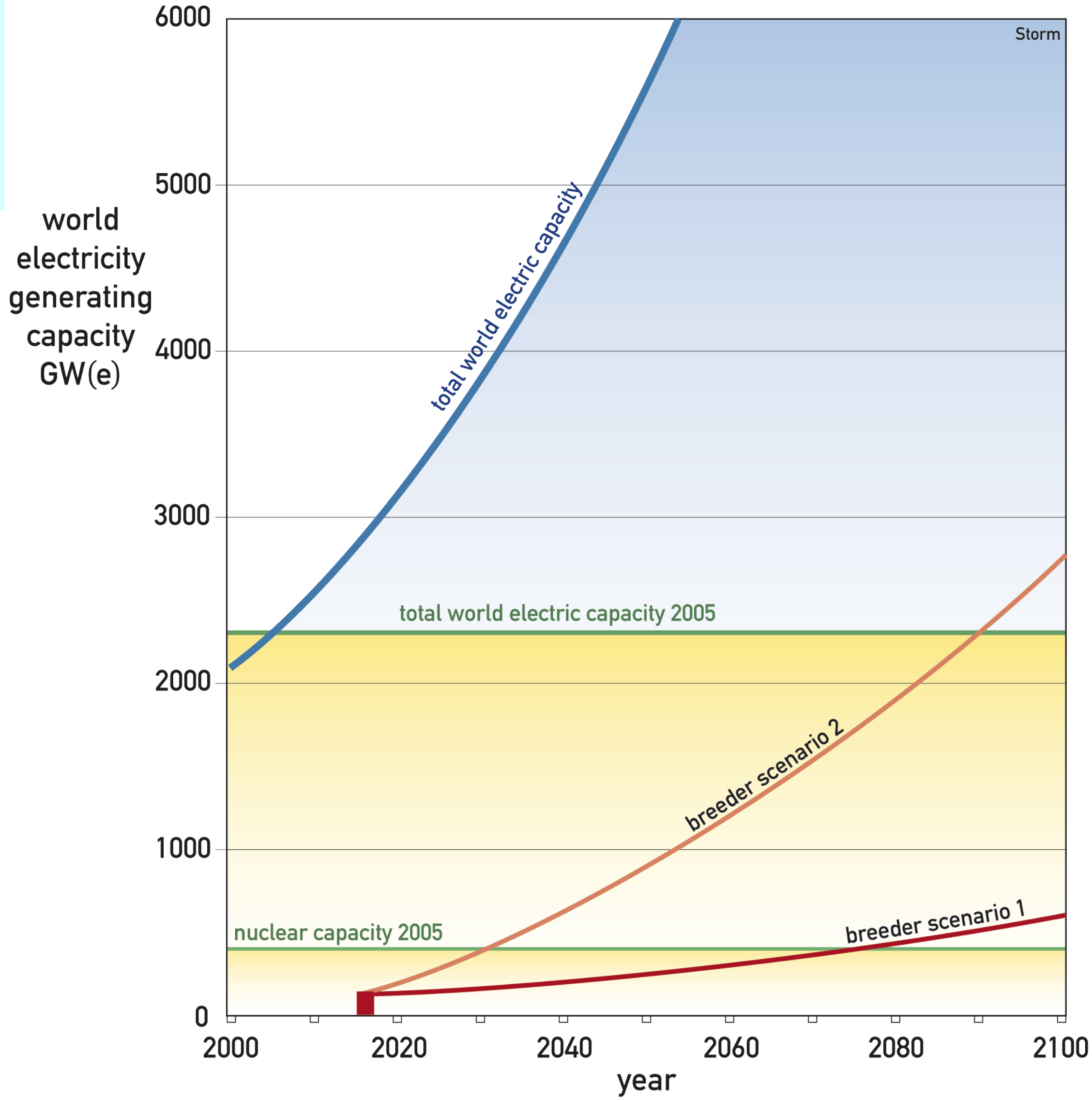
Breeder cycle



Breeder scenarios: assumptions

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

Breeder scenarios



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Thorium breeder

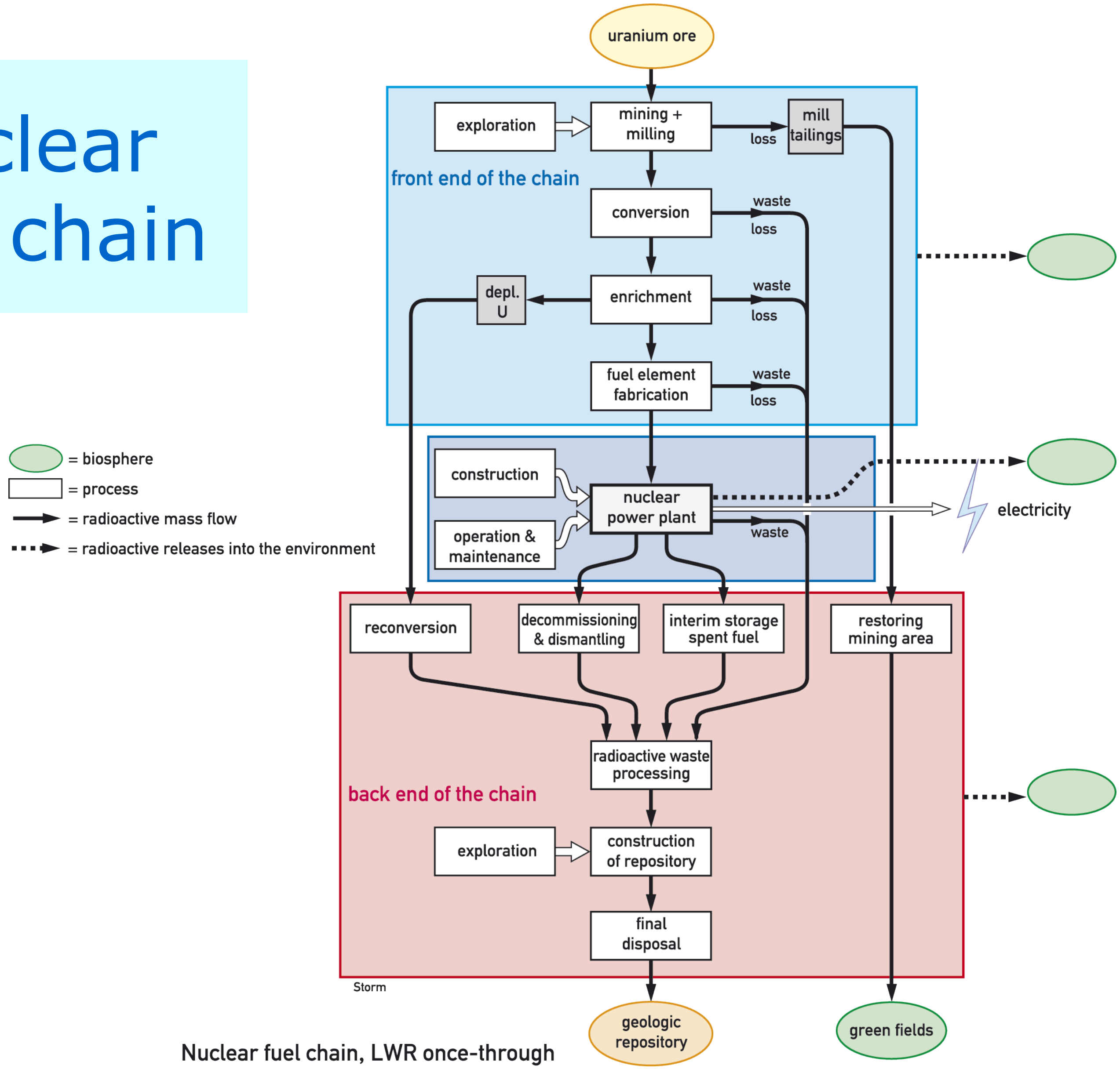
- based on Th-232 –> U-233
- Th-U breeder system more remote
- no U-233 in stock

Choice for the next decades

Thermal neutron reactors:
mainly LWR

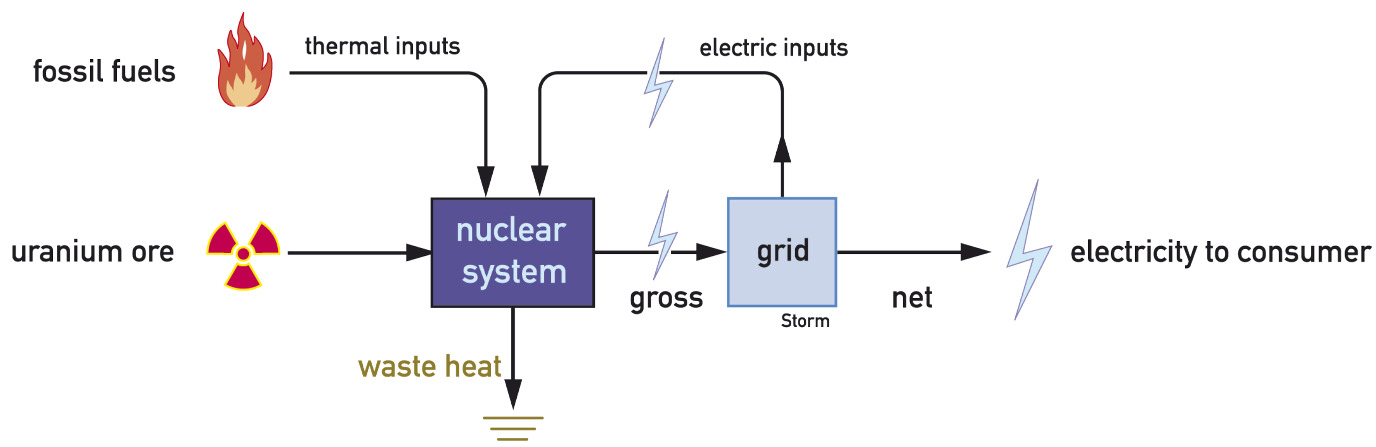
Once-through fuel cycle

Full nuclear process chain



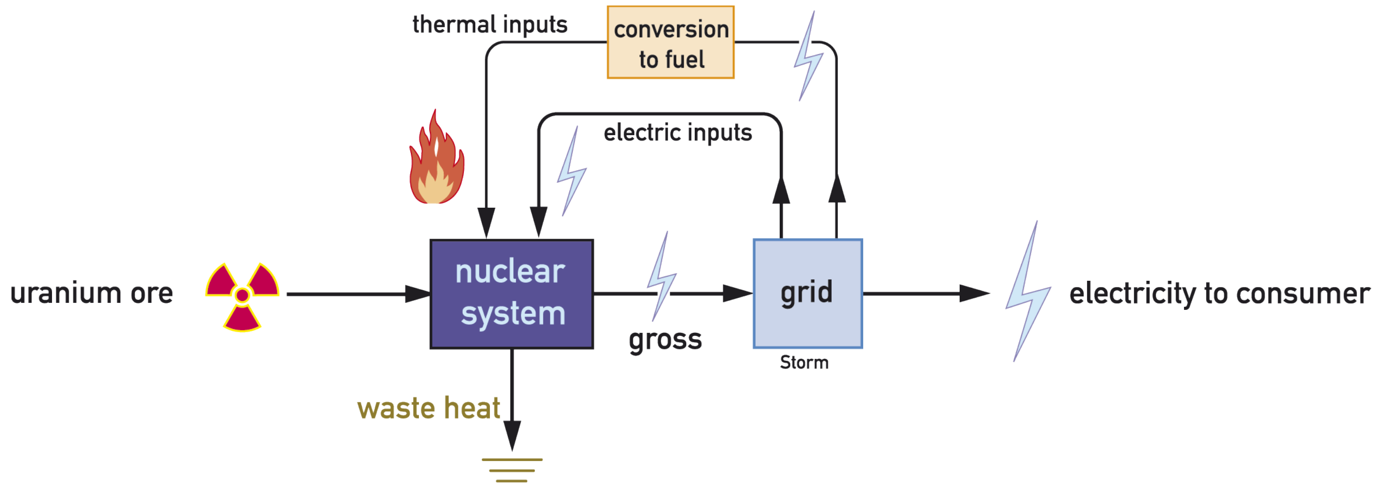
Nuclear fuel chain, LWR once-through

Energy flows of the nuclear system



Fossil fuel-assisted system (current situation)

Energy flows of the nuclear system

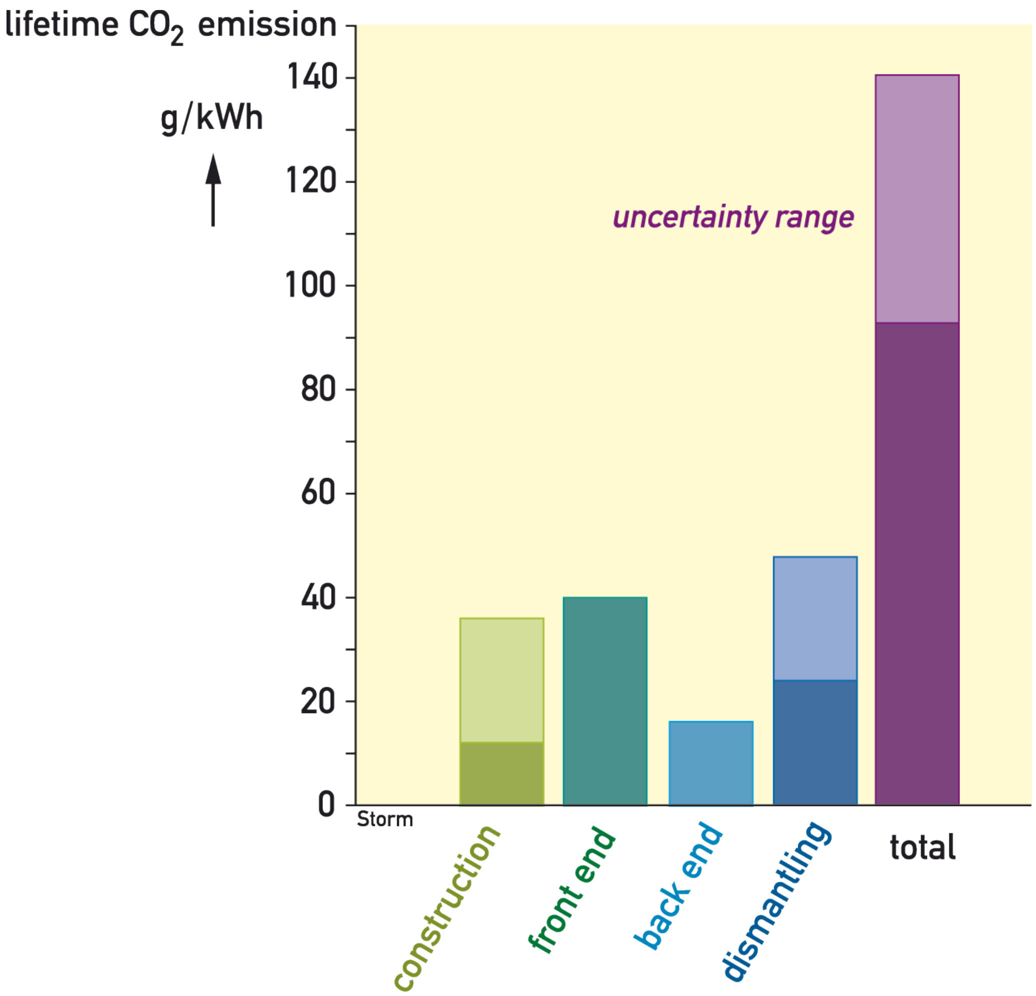


All-nuclear system (comparable to renewables)

CO_2 emission from construction

	our study		Sizewell B
	low	high	
total CO_2, Tg	2.5	7.5	3.74
spec CO_2, g/kWh	12	35	14

CO_2 emissions



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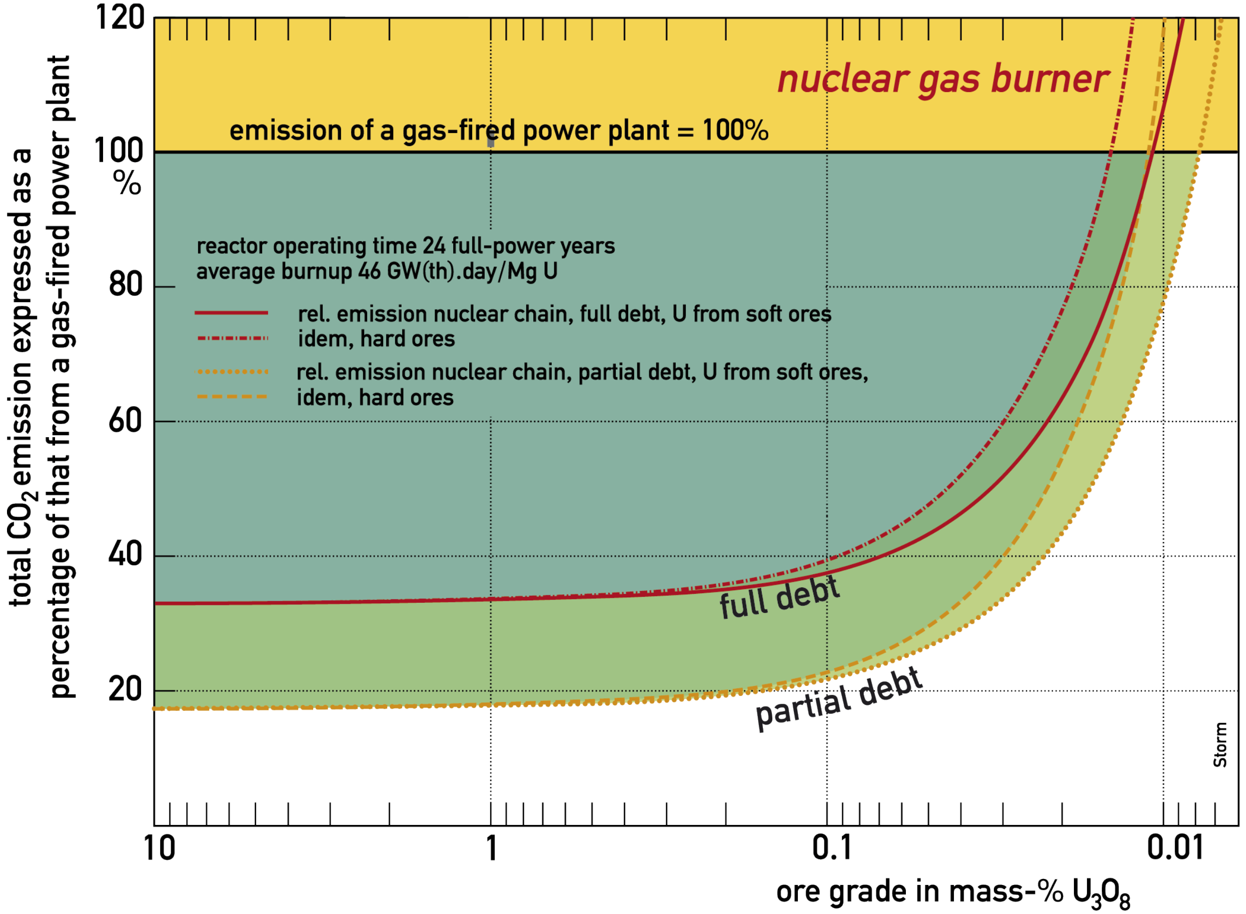
Specific emission of CO_2 vs ore grade



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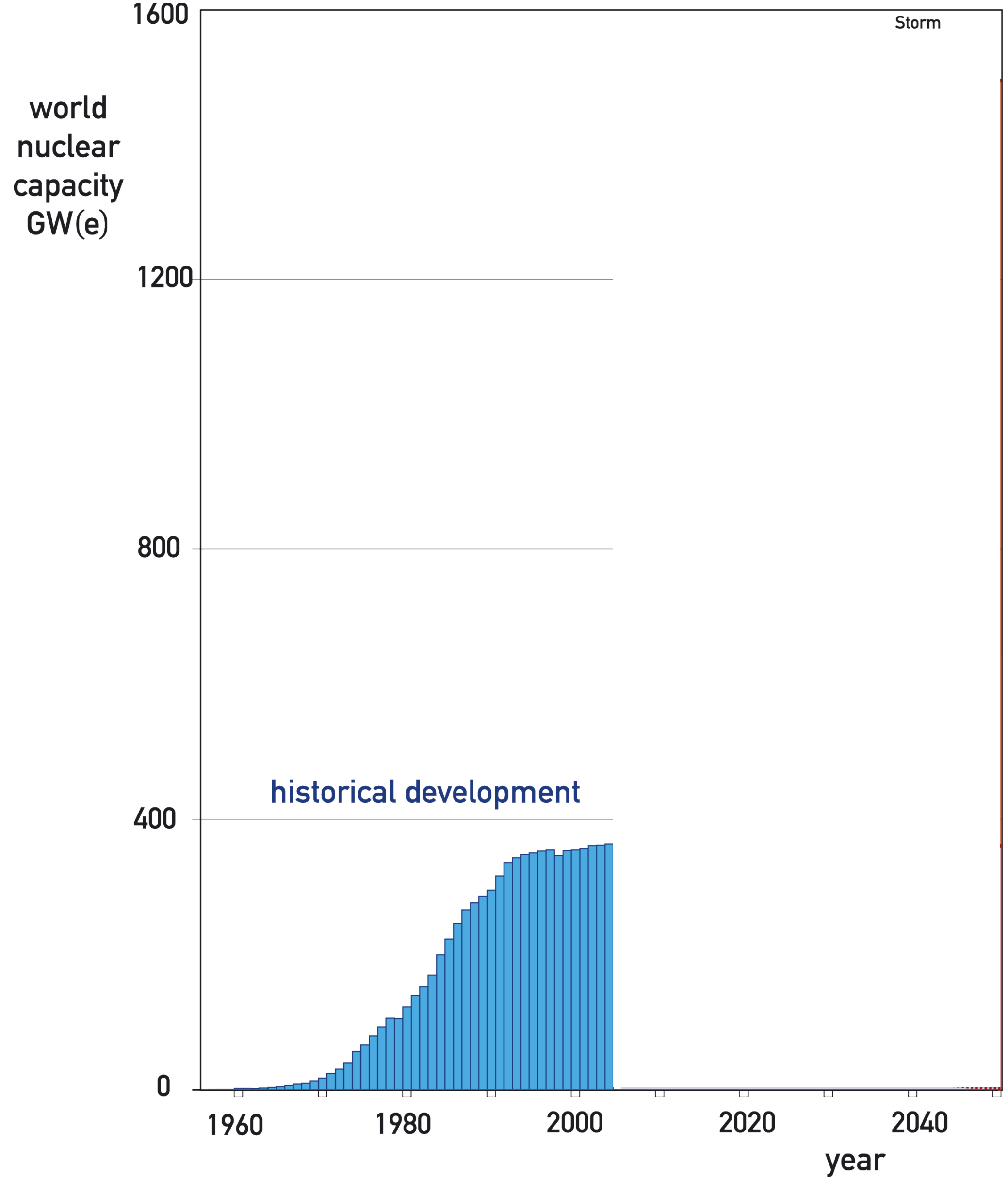
Emission of other greenhouse gases

- Enrichment ~5 g CO2-eq/kWh freon-114.

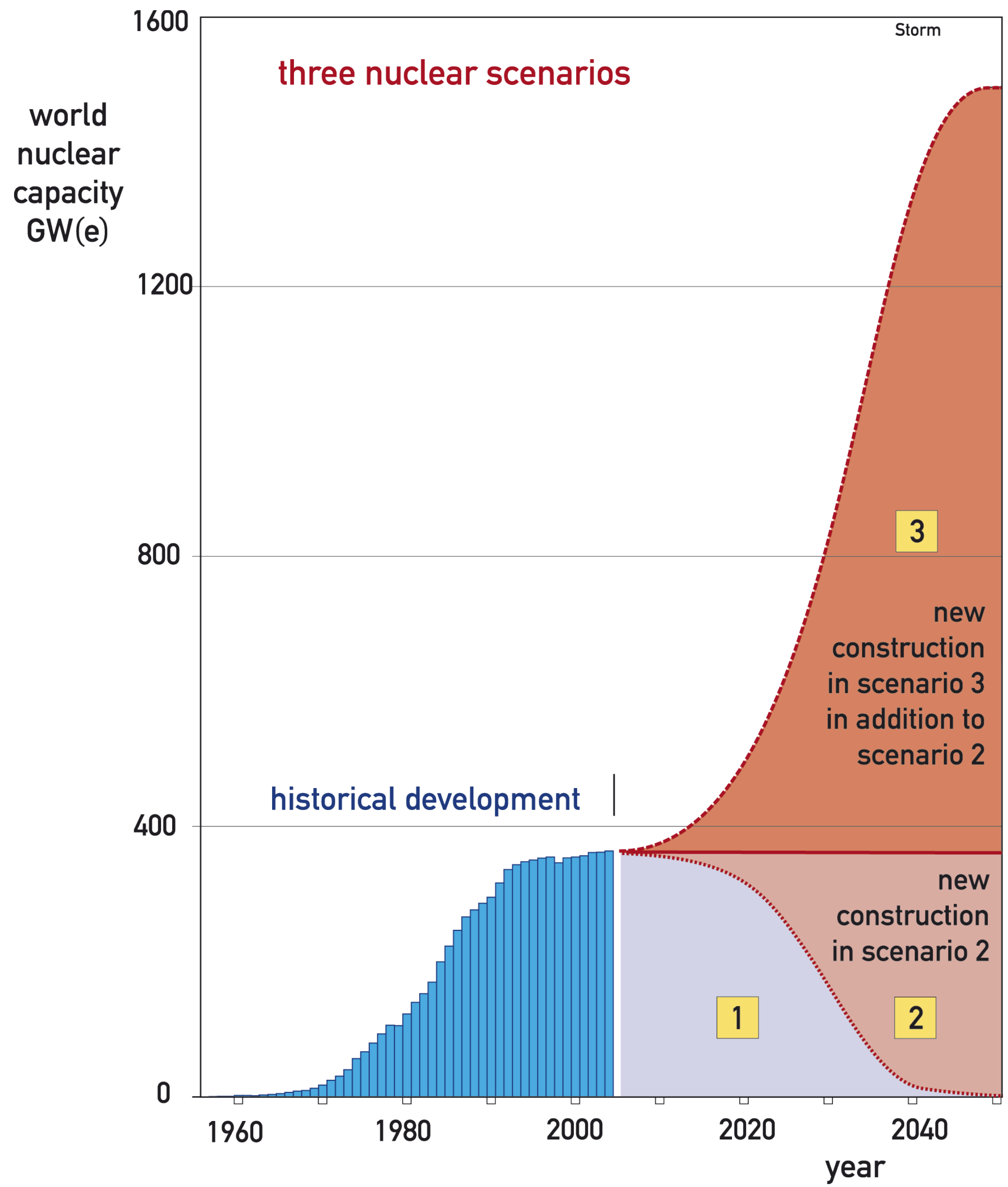
- Other greenhouse gases?
- All nuclear-related processes?

- Ever investigated and/or published?

Nuclear scenarios



Nuclear scenarios



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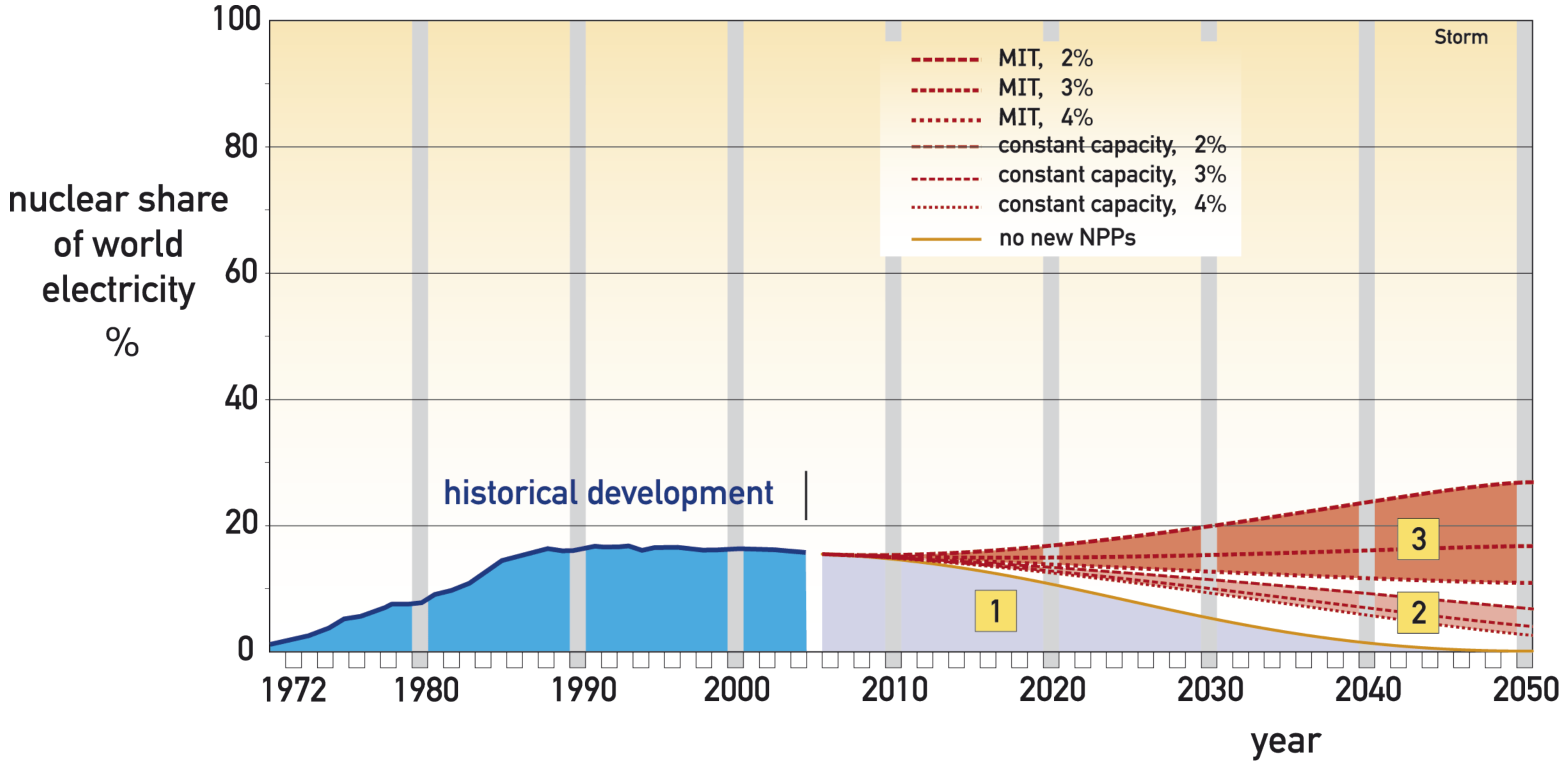
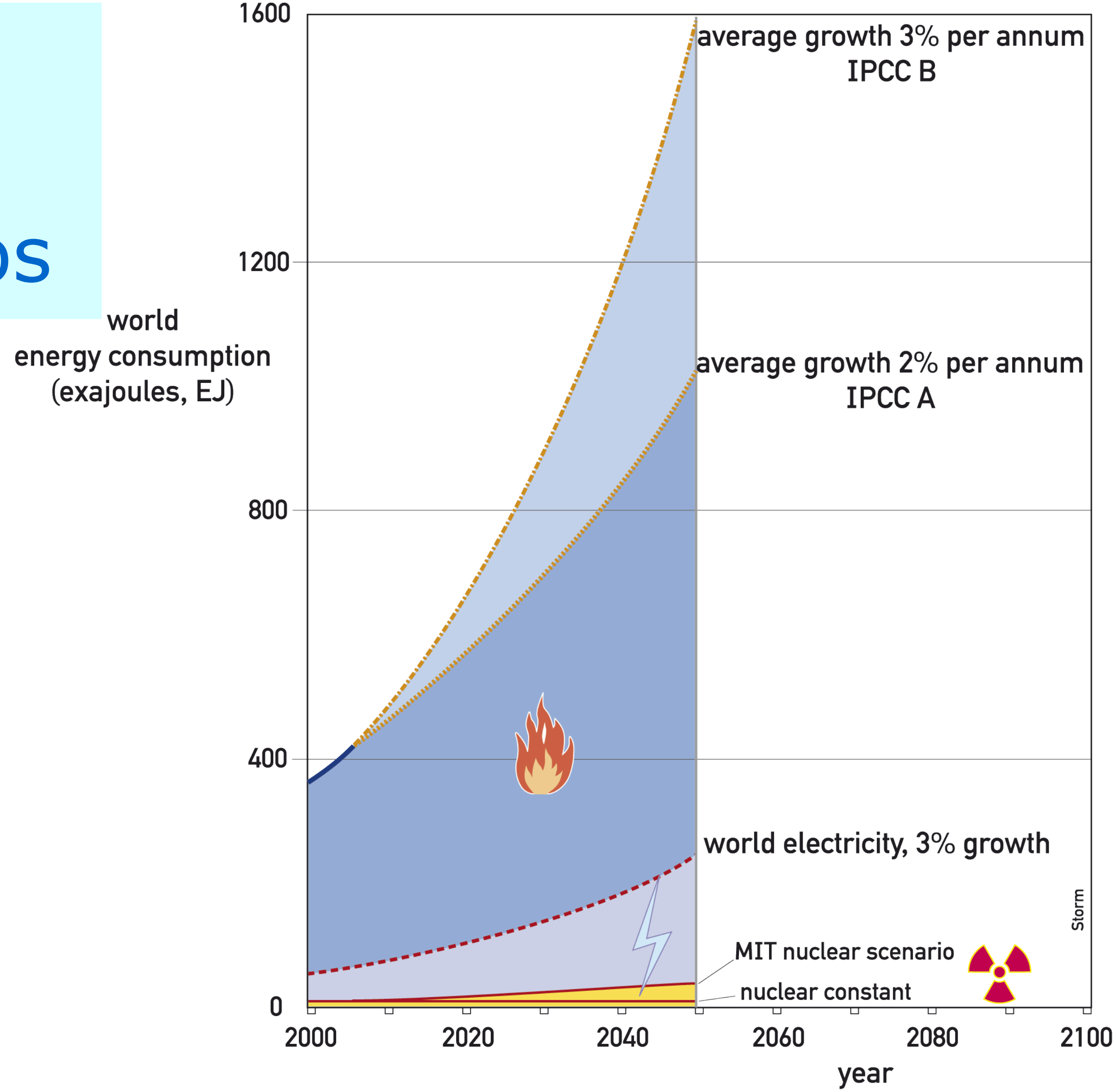
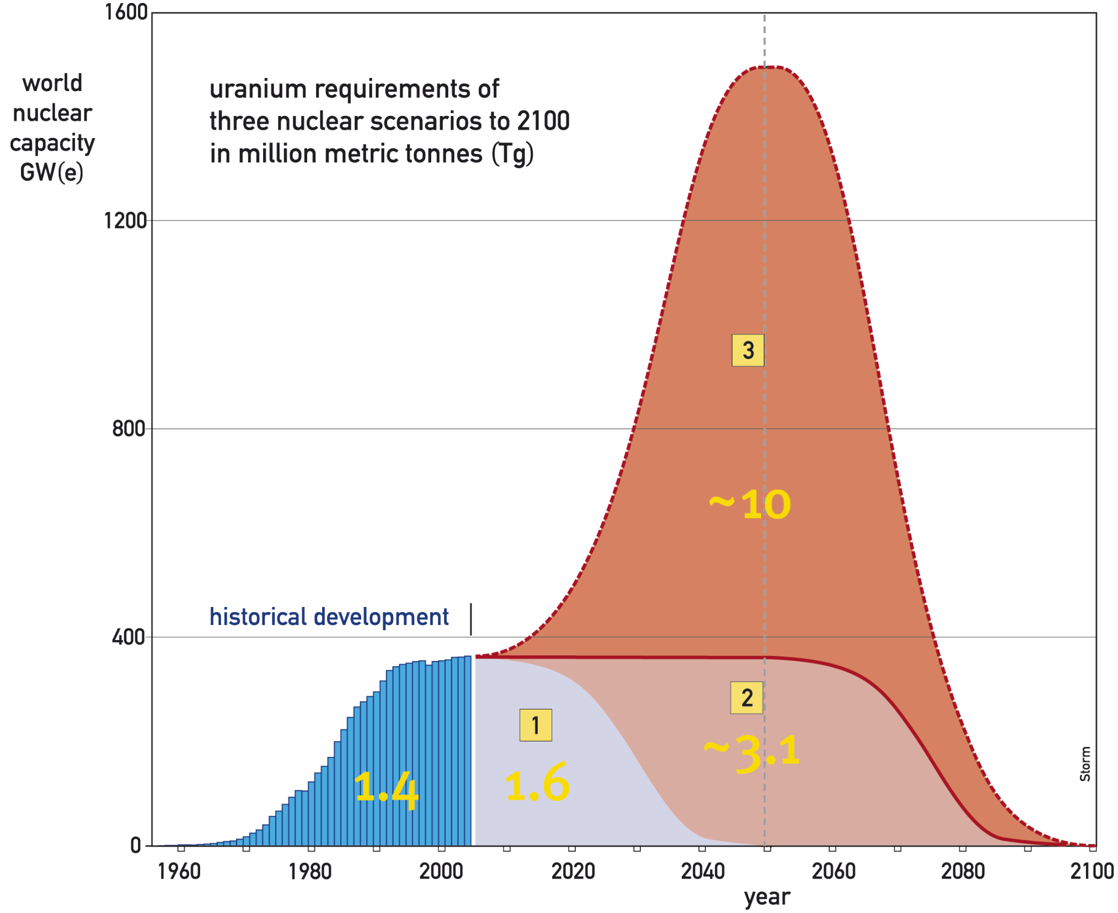
Nuclear share of world electricity



World energy scenarios



Uranium requirements



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Uranium in the future: *economic view by WNA*

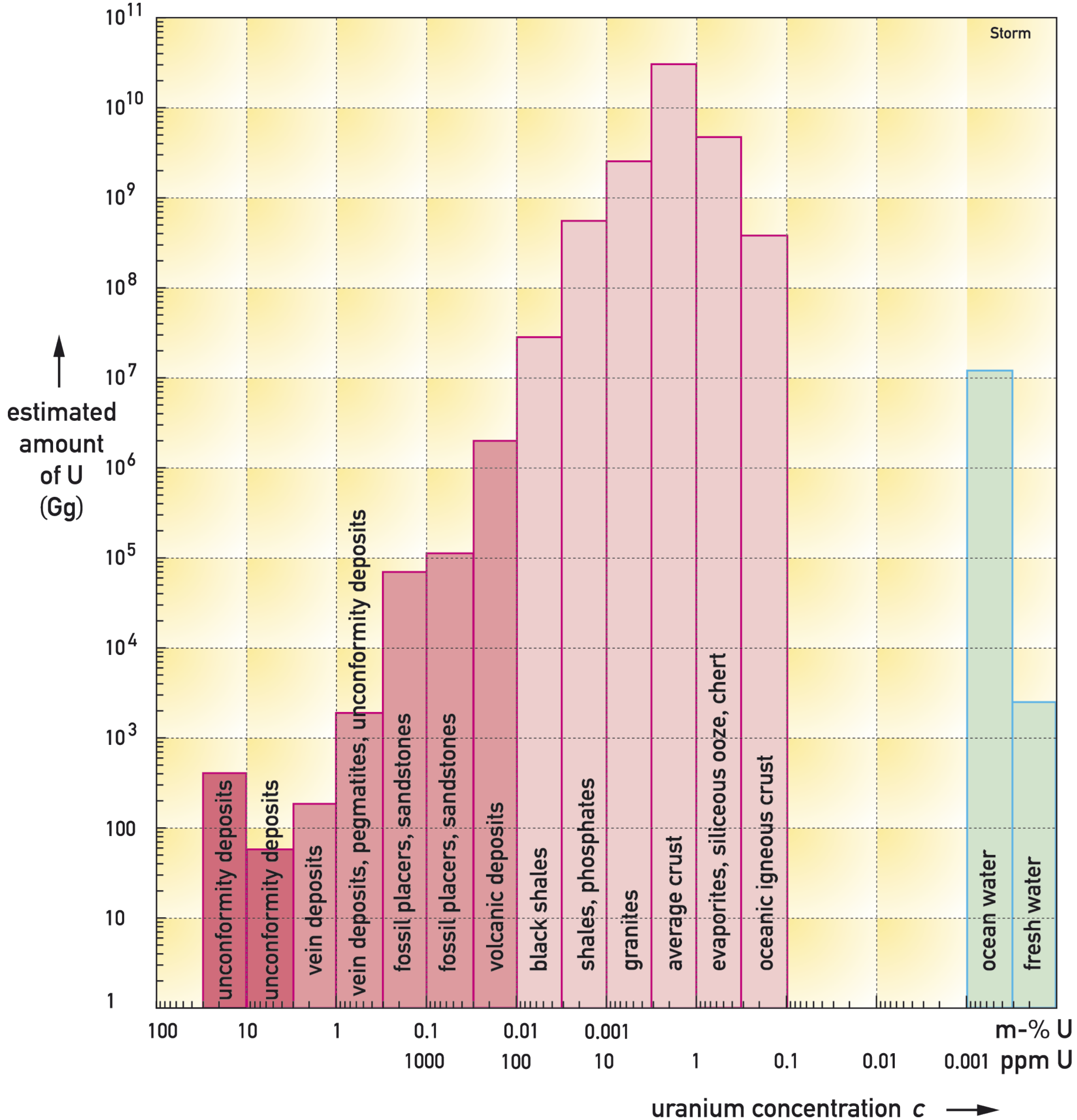
- Higher prices –>
- More exploration, advanced techniques –>
- More discoveries, lower costs –>
- More resources.

- Conclusion: uranium is a sustainable energy resource

Uranium in the future: *physical facts*

- The larger amount of U in rock, the lower its grade.
- Easily discoverable and mineable uranium resources are already in production.
- Physical laws stay in force, cannot be circumvented by economics.

Uranium in the earth's crust



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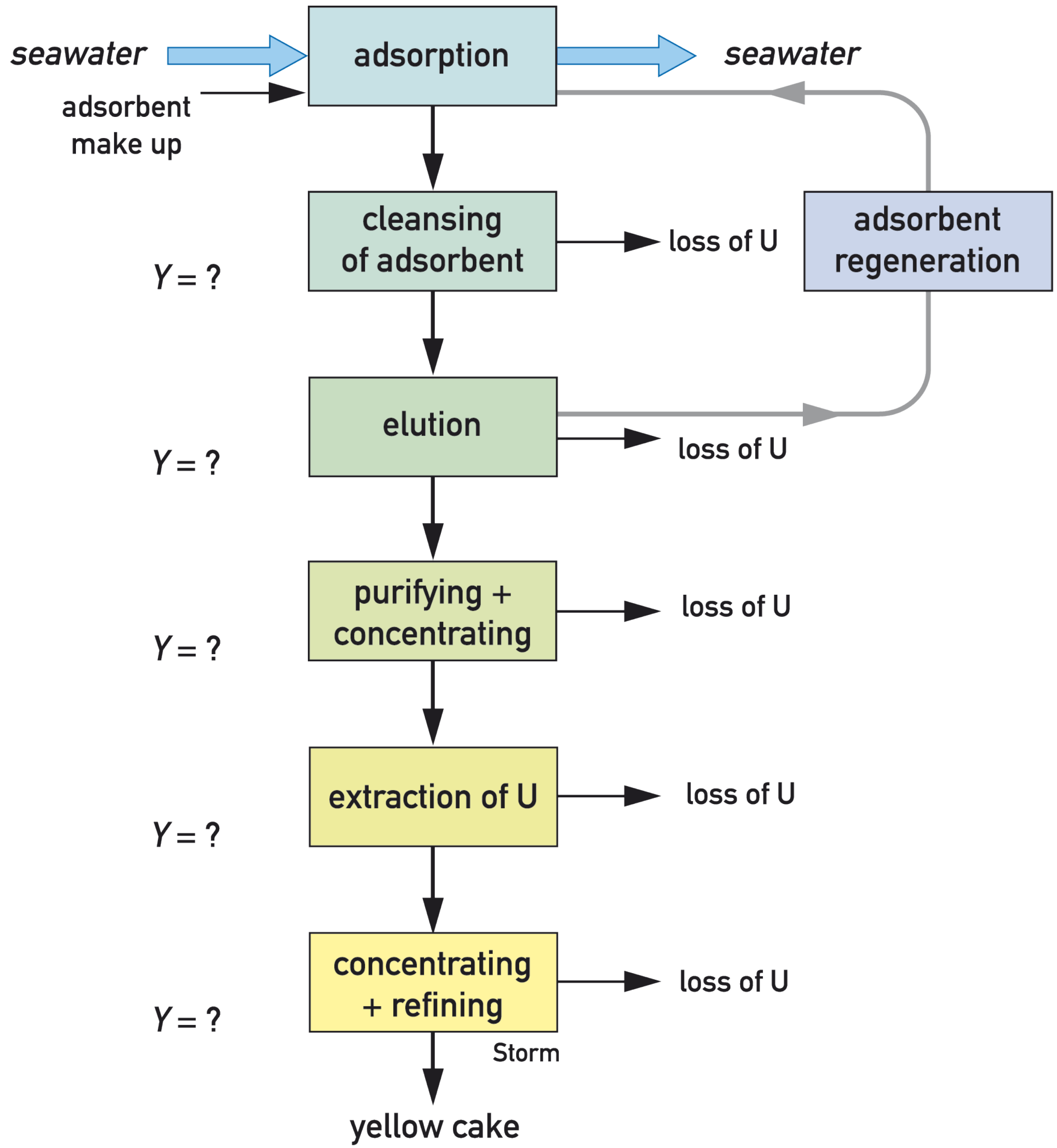
Uranium in seawater

- Dissolved uranium in seawater:
  3.34 milligram per cubic meter
- 1.37 billion km^3 seawater
- 4.5 billion metric tonnes uranium in the oceans

- *A net energy resource?*

Uranium extraction from seawater



Uranium extraction from seawater

- 162 Mg natural uranium per year per GW
- Overall extraction yield = 17%
  (excluding the first stage)
- 285 km^3 seawater per year per GW = = 90400 m^3 per second per GW
- 428000 km^3 per year in MIT scenario = = 14 million m^3 per second