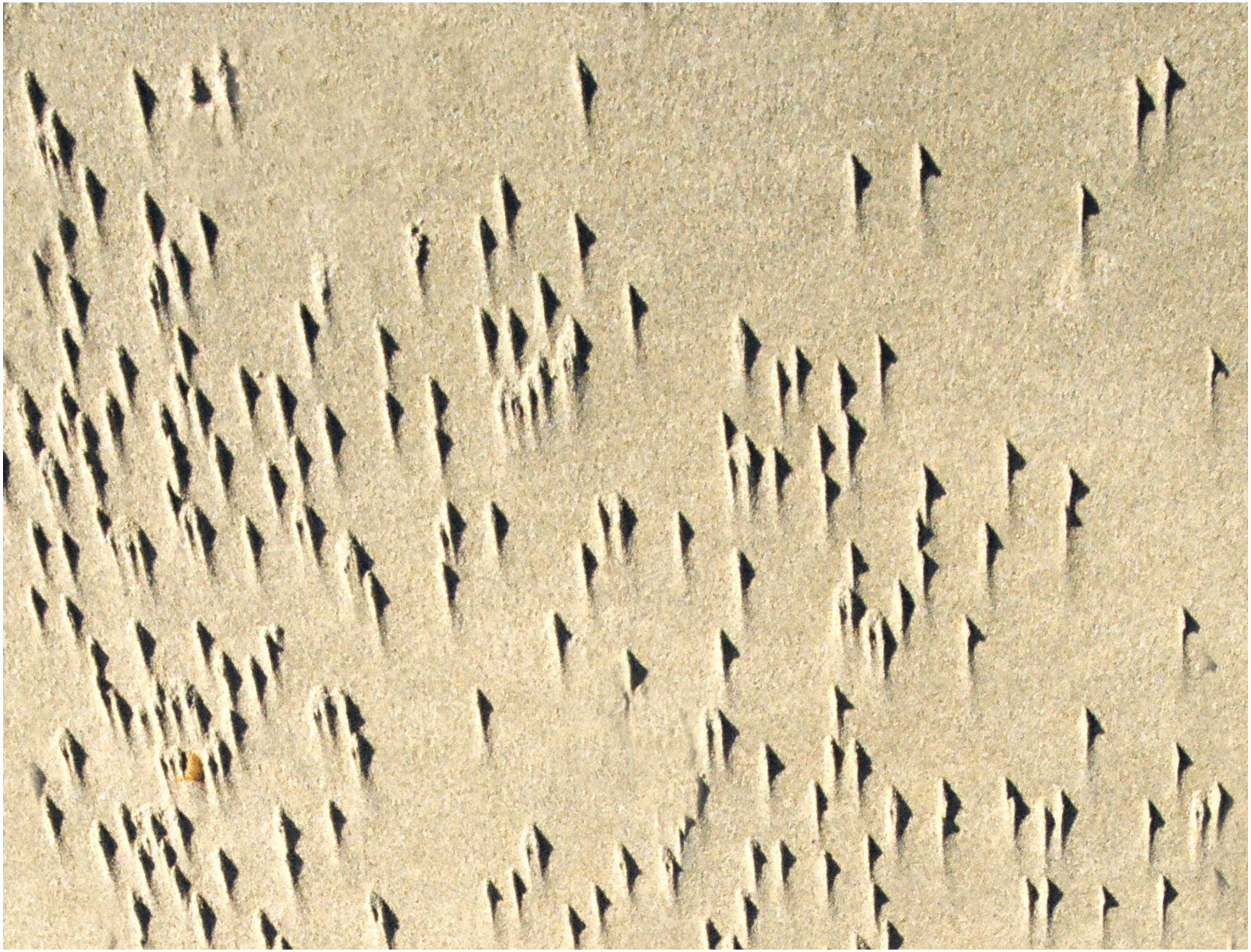


Climate change and nuclear power

J.W. Storm van Leeuwen

storm@ceedata.nl

2006

Nuclear power – the energy balance

by

J.W. Storm van Leeuwen and P.B. Smith

August 2005

www.stormsmith.nl

Nuclear power – the energy balance

History of the study

About the study

Data:

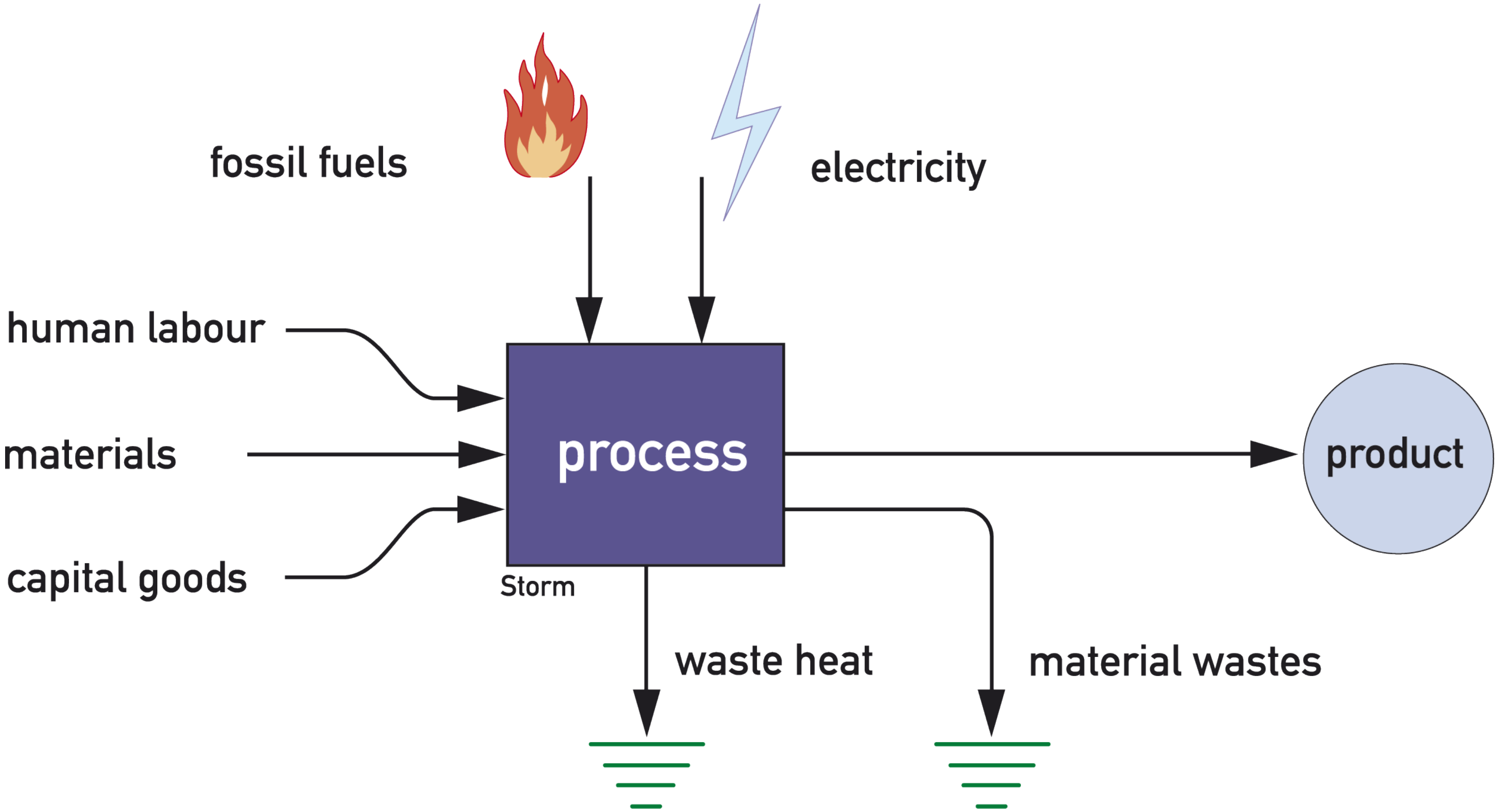
exclusively from nuclear industry itself

About the study

Methodology:

- physical relationships and quantities:
  mass and energy
- life cycle assessment (LCA)
- process analysis
- energy analysis of complex systems
  methods validated during the
  1970s and 1980s

Process analysis



Unique features of our study

- Exhaustive analysis
- Energy debt
  - construction
  - dismantling
- Ore grade – energy relationship
- Empirical figures where possible
- Large database, recent data

Key points

- Nuclear and greenhouse gases
- Nuclear share
- Uranium: how much energy?

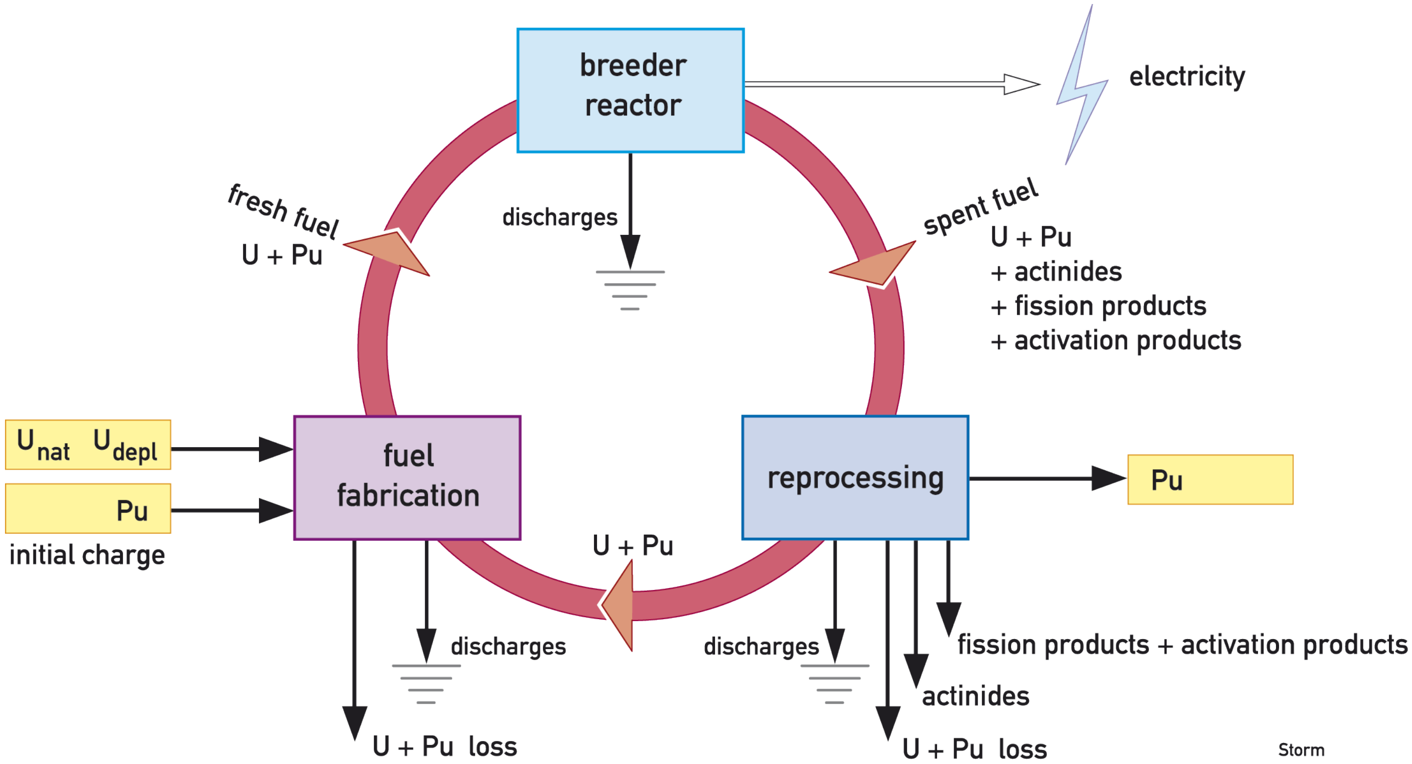
Contents

- Reactor technology
- Energy for energy
- Greenhouse gases
- Nuclear share
- Energy from uranium
- Conclusions

Reactor technology

- Thermal neutron reactors
  - LWR
  - other (‘advanced’)
- U-Pu breeder
- Th-U breeder

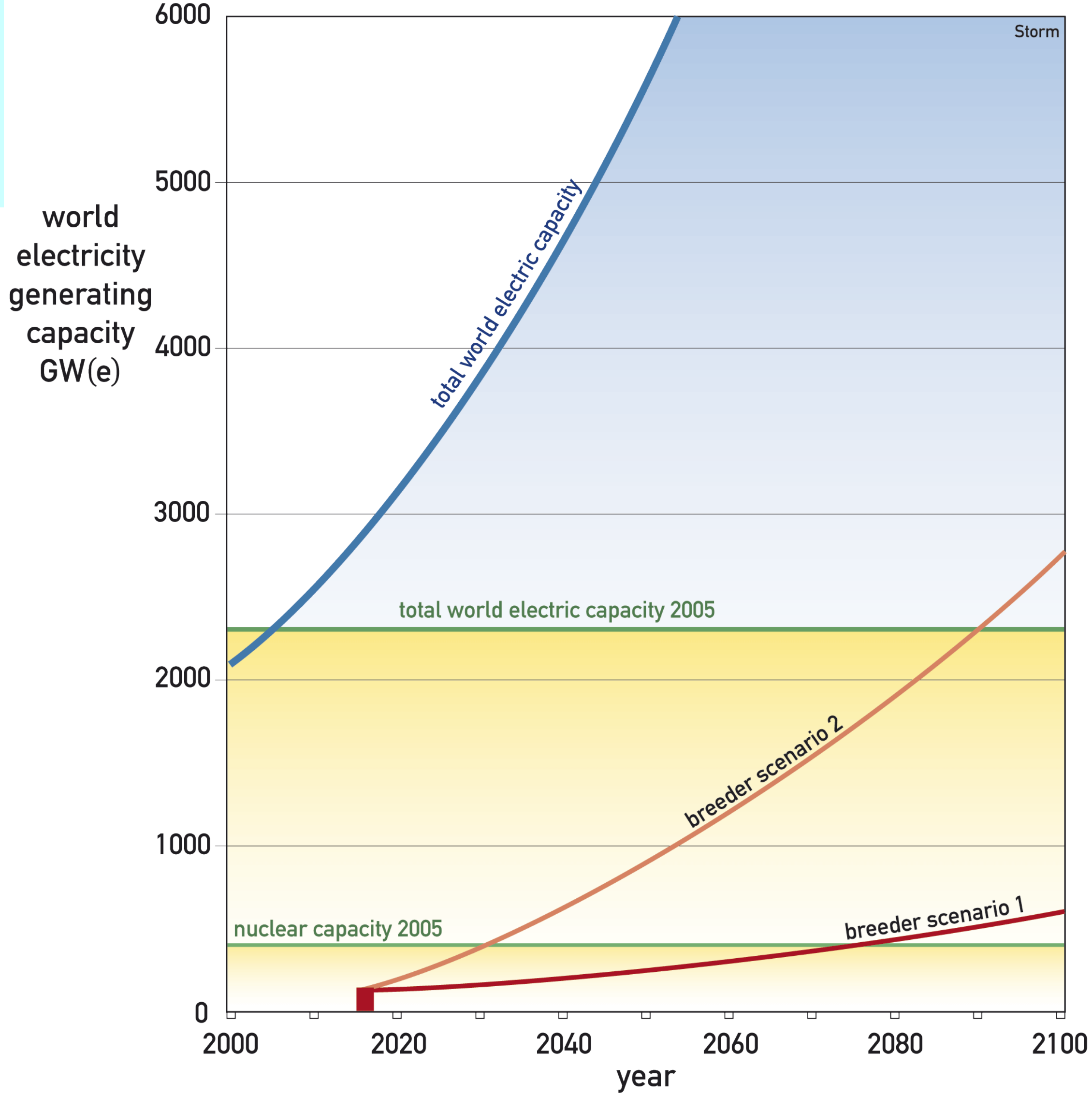
Breeder cycle



Breeder scenarios: assumptions

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

Breeder scenarios



J.W. Storm van Leeuwen 2006

Thorium breeder

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

Choice for the next decades

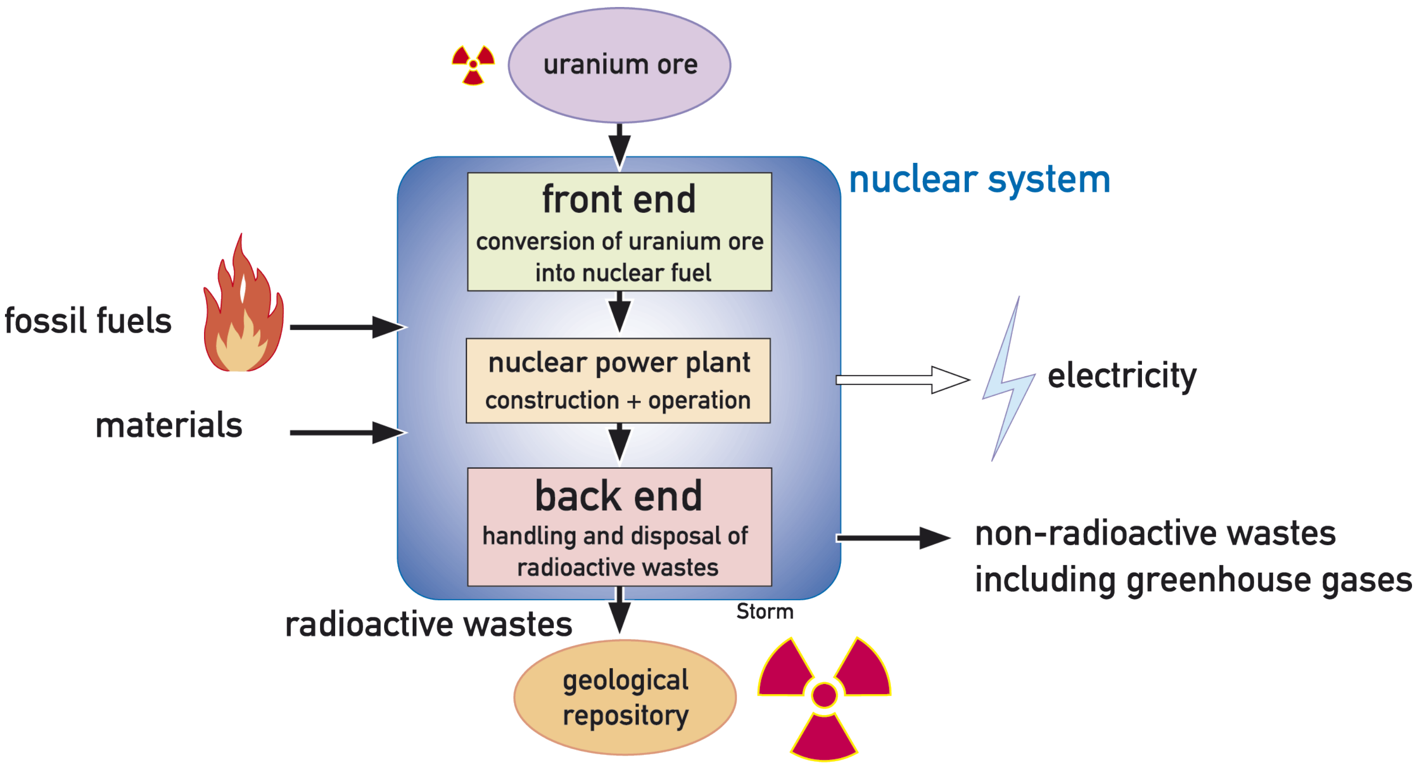
Thermal neutron reactors:
mainly LWR

Once-through fuel cycle

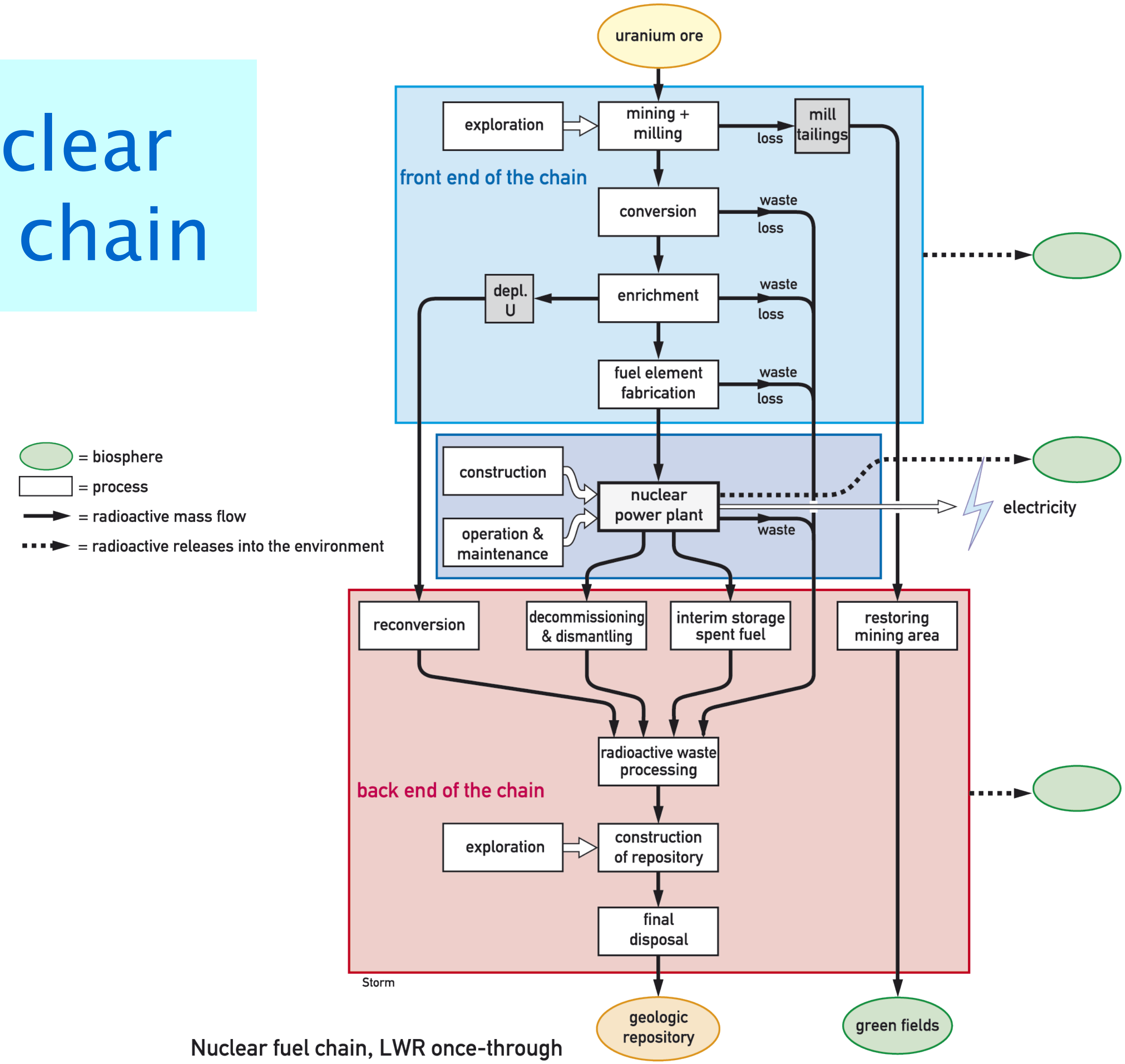
Energy for energy

- Releasing useful energy from uranium costs energy
- Nuclear reactor part of a complex system
- Nuclear process chain: conventional industrial and nuclear operations

Basic nuclear process chain



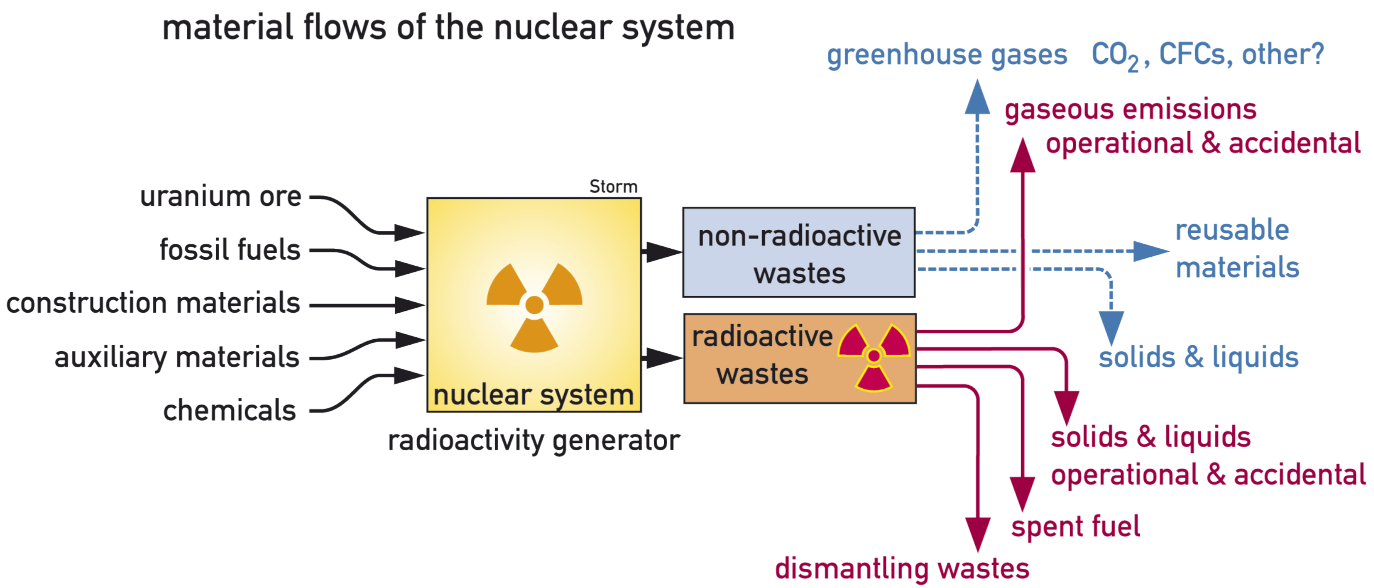
Full nuclear process chain



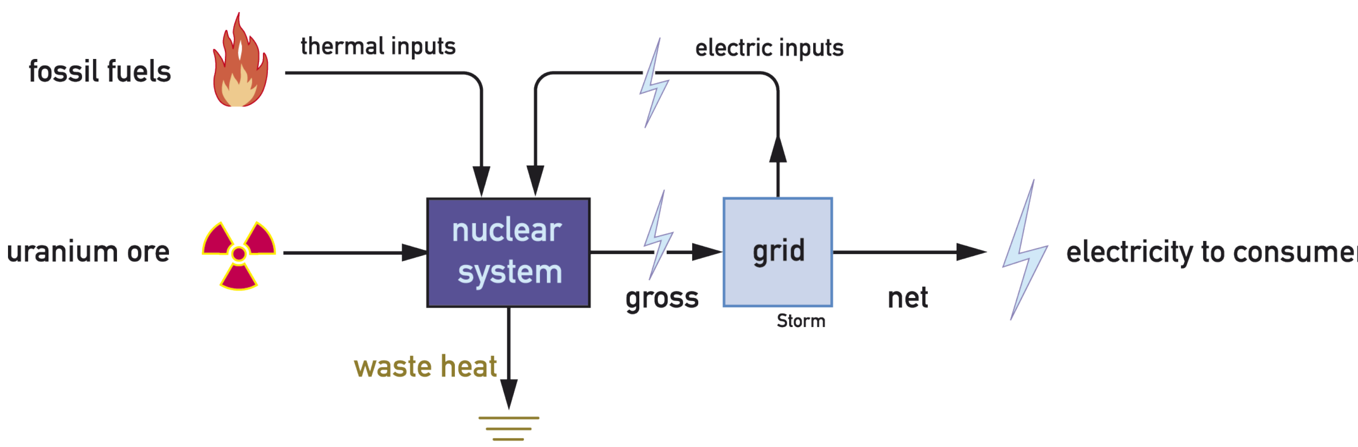
Nuclear fuel chain, LWR once-through

J.W. Storm van Leeuwen 2006

Waste flows of the nuclear system

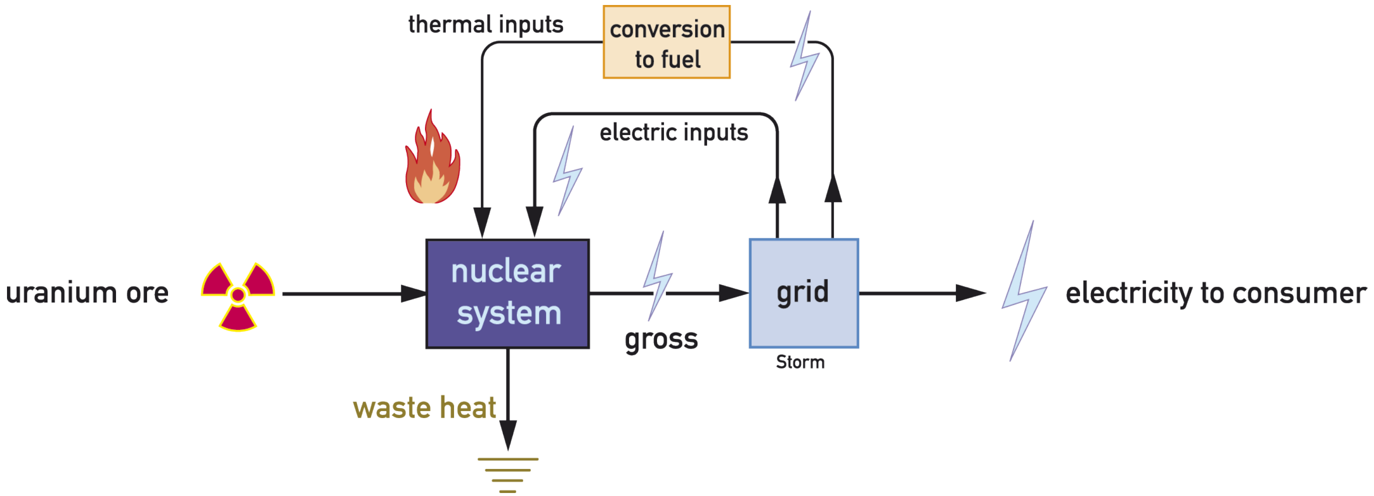


Energy flows of the nuclear system



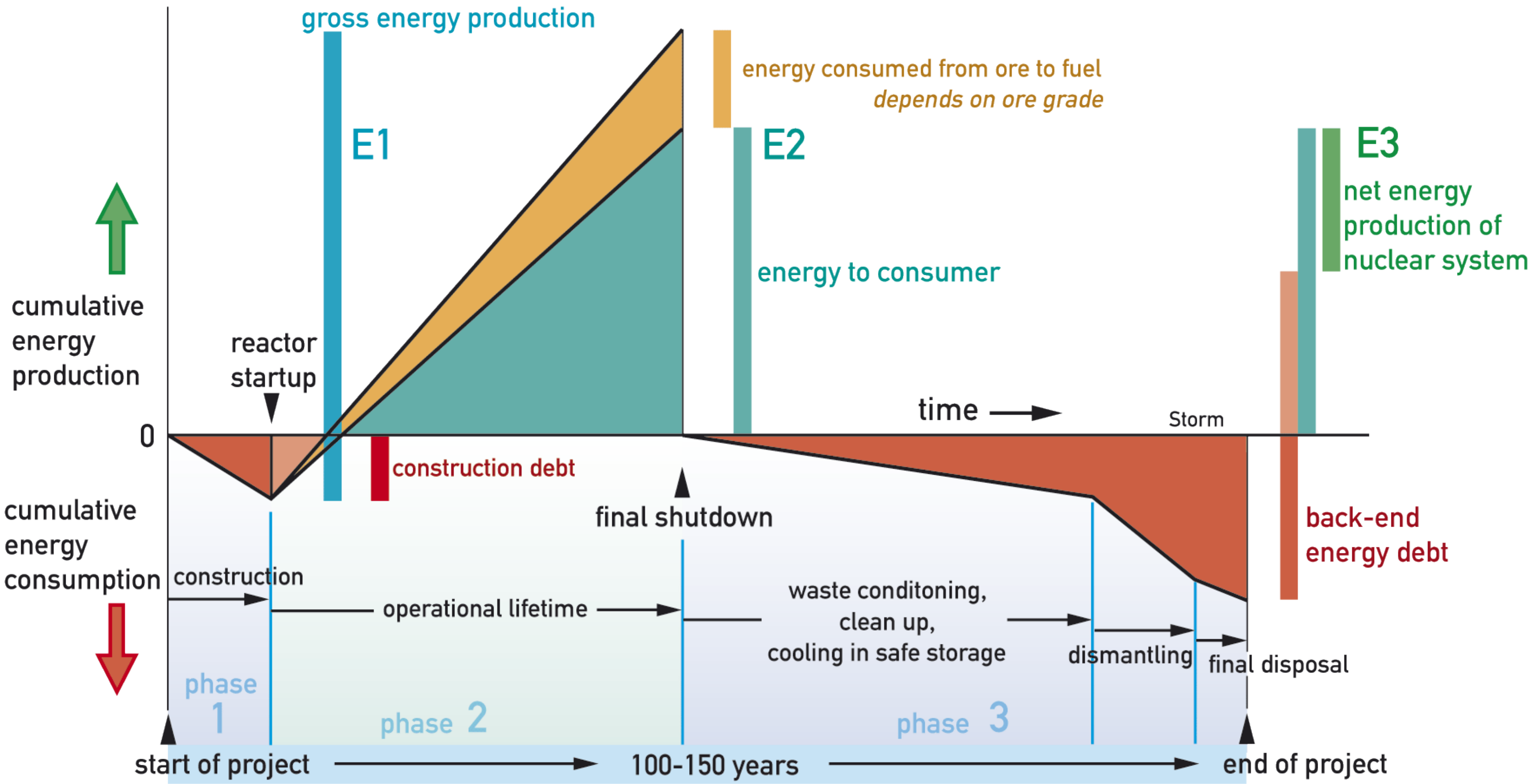
Fossil fuel-assisted system (current situation)

Energy flows of the nuclear system



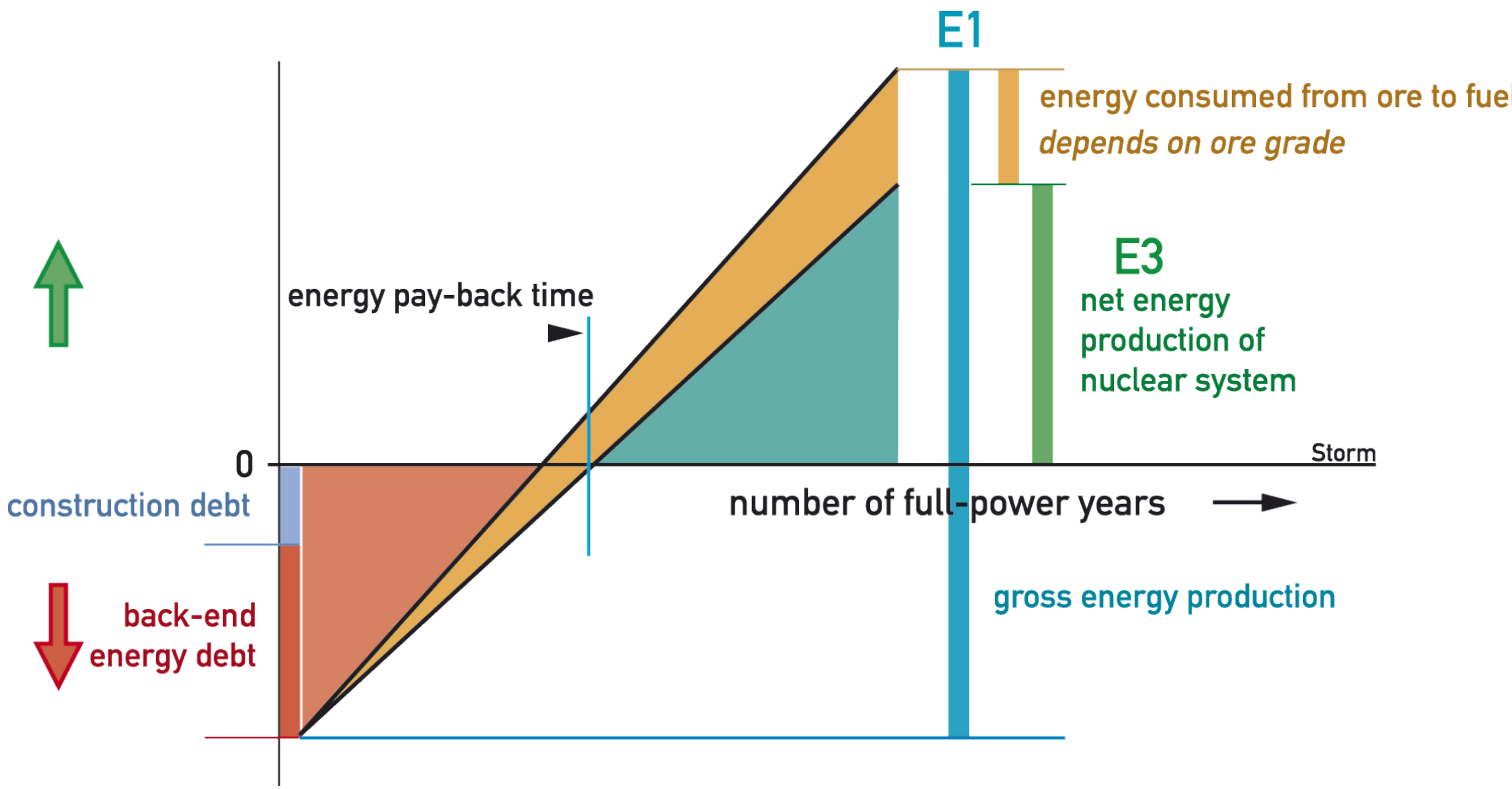
All-nuclear system (comparable to renewables)

Energy debt



J.W. Storm van Leeuwen 2006

Energy debt 'capitalized'



Greenhouse gases

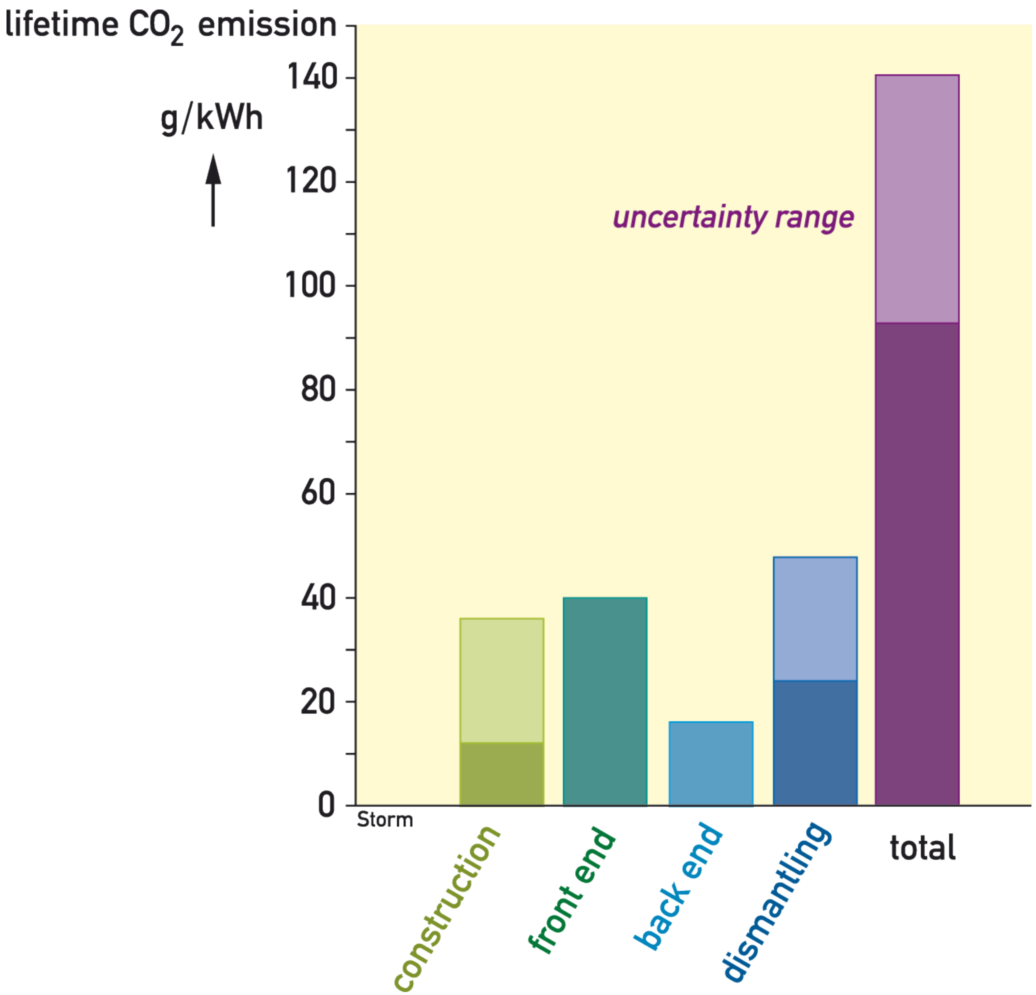
- Carbon dioxide CO_2
- Other greenhouse gases

Only carbon dioxide emisions analyzed

CO_2 emission from construction

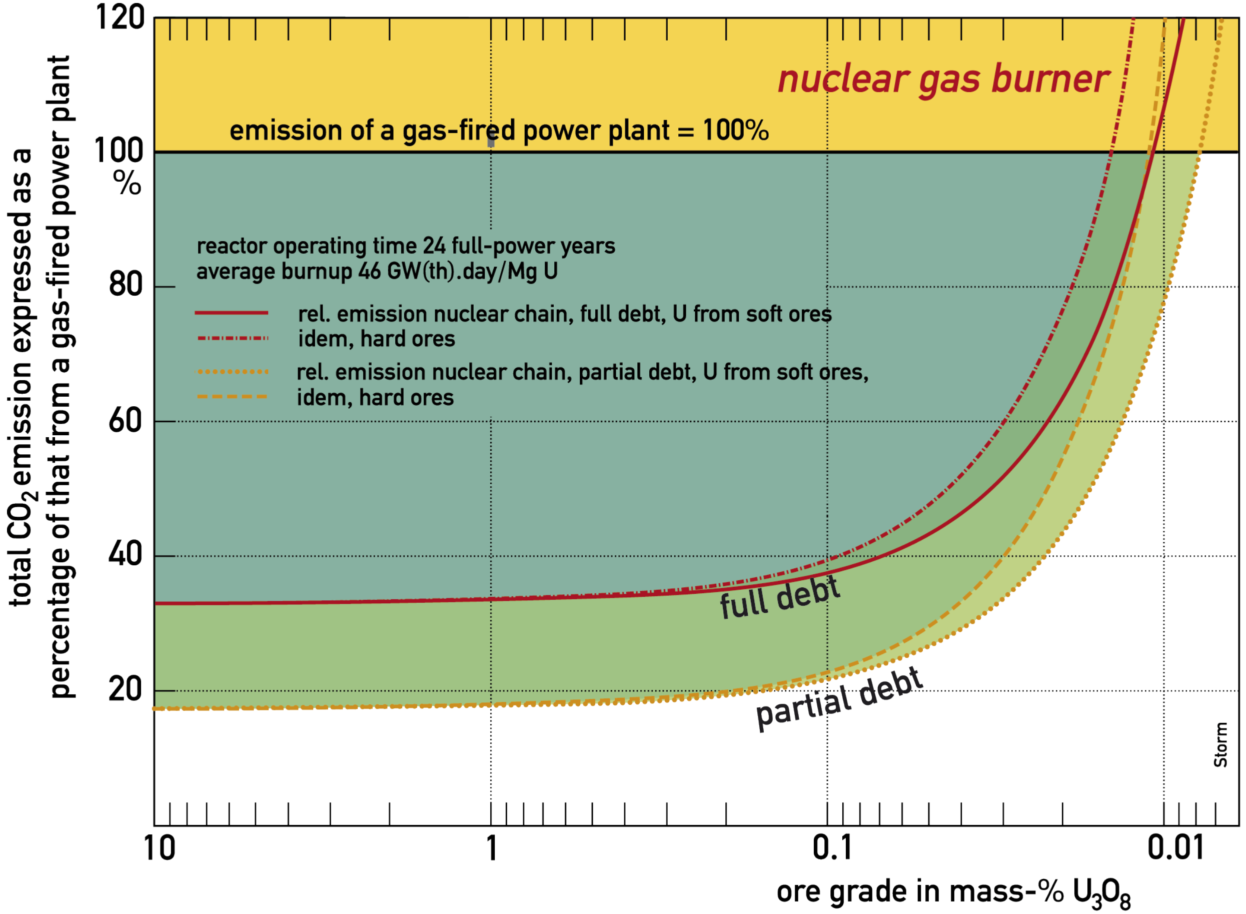
	our study		Sizewell B
	low	high	
total CO_2, Tg	2.5	7.5	3.74
spec CO_2, g/kWh	12	35	14

CO_2 emissions



J.W. Storm van Leeuwen 2006

Specific emission of CO_2 vs ore grade



J.W. Storm van Leeuwen 2006

Emission of other greenhouse gases

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

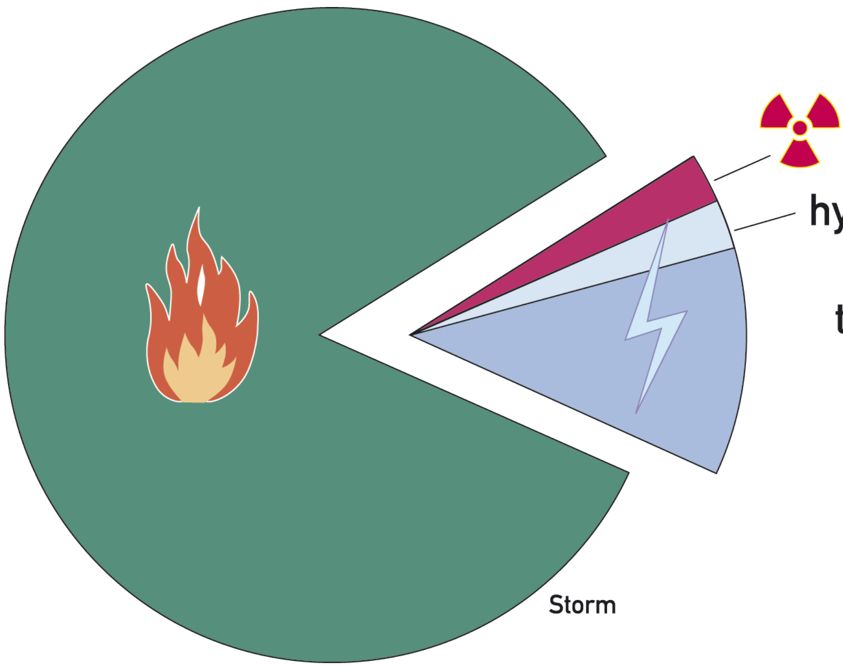
- Other greenhouse gases?
- All nuclear-related processes?

- Ever investigated and/or published?

Nuclear share in the future

- Current share
- Nuclear scenarios
- World energy scenarios
- Uranium requirements

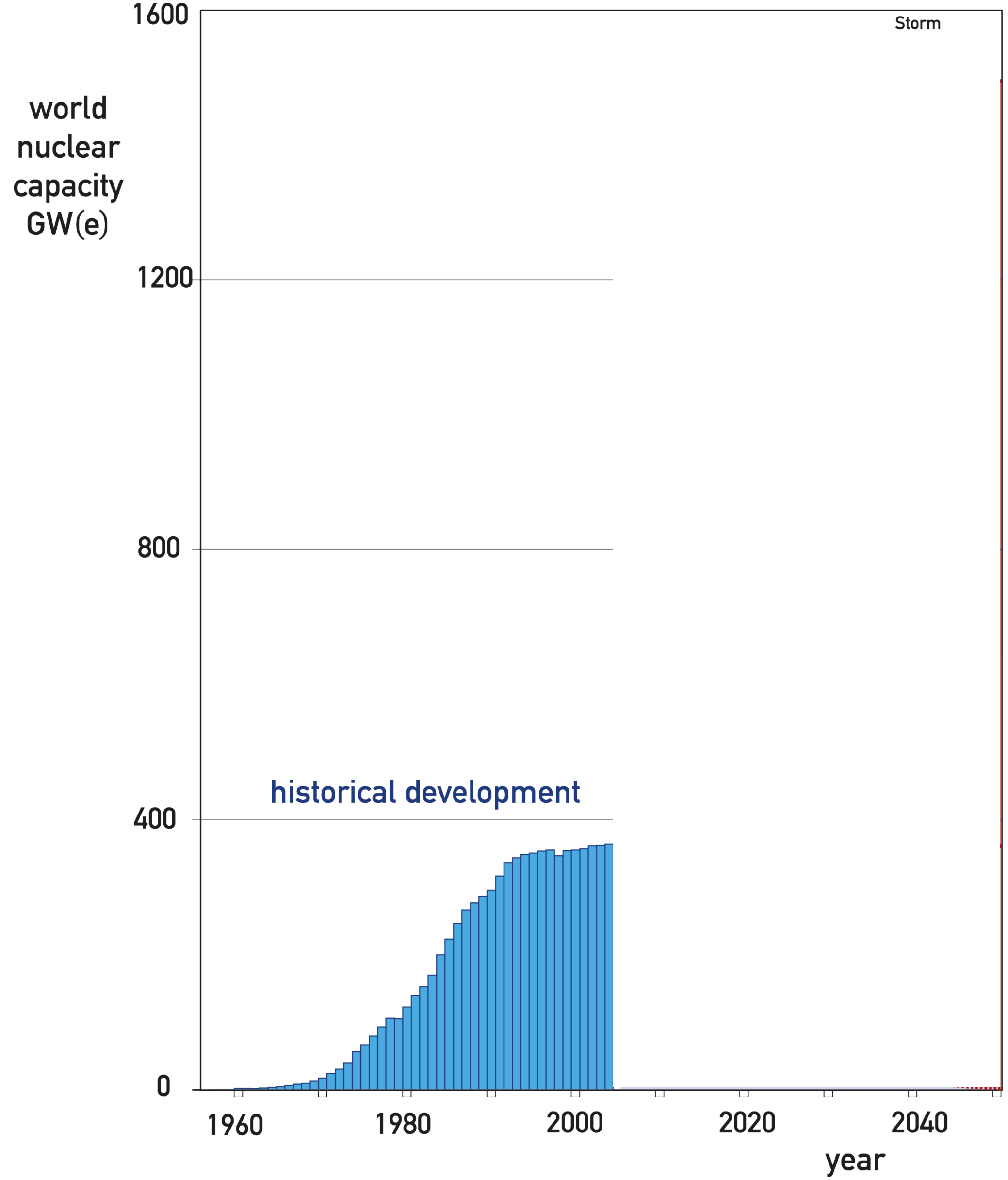
Current nuclear share



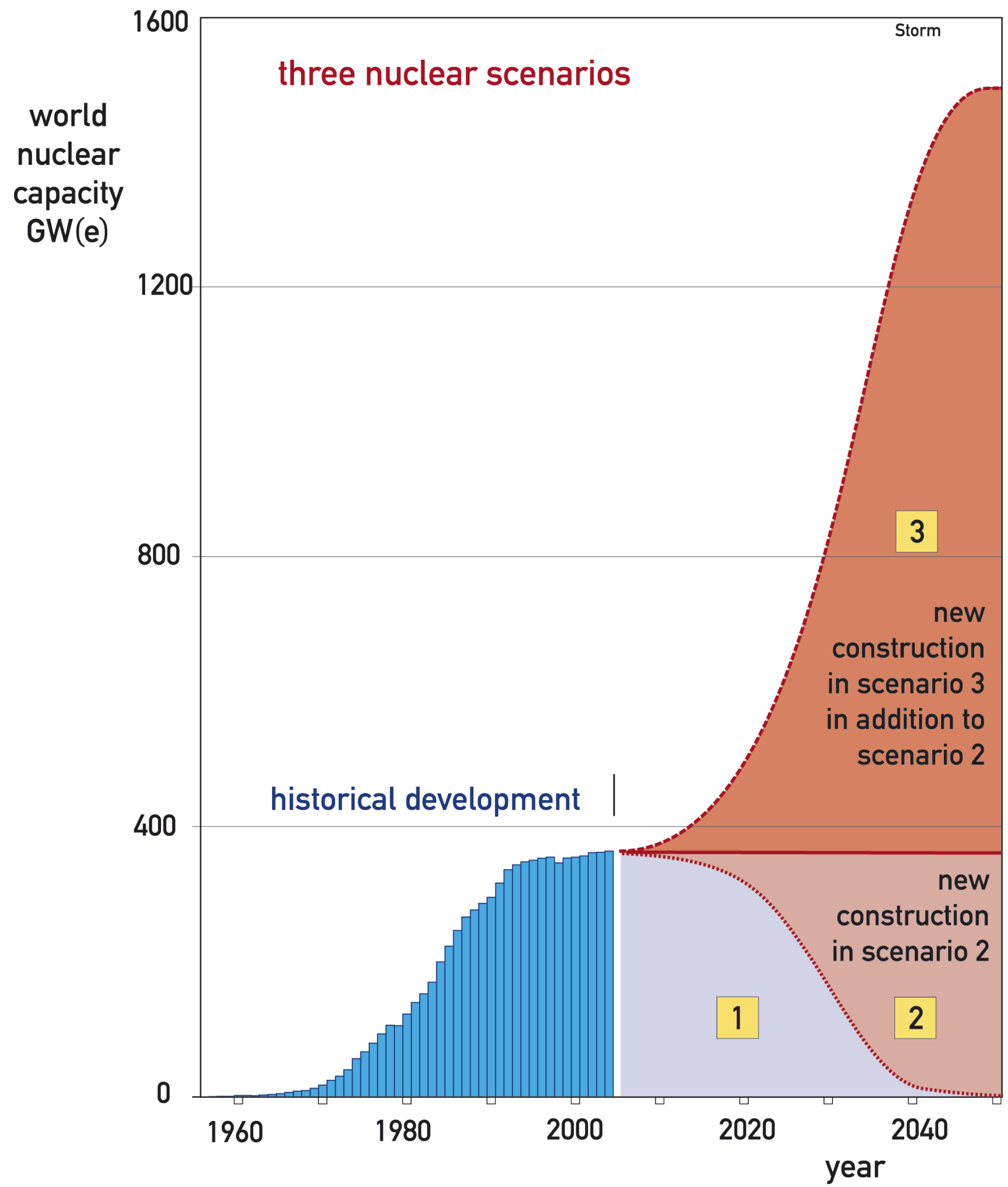
total world electricity in 2004:
17500 billion kWh (62.8 EJ)

total world final energy consumption in 2004: ~400 EJ

Nuclear scenarios

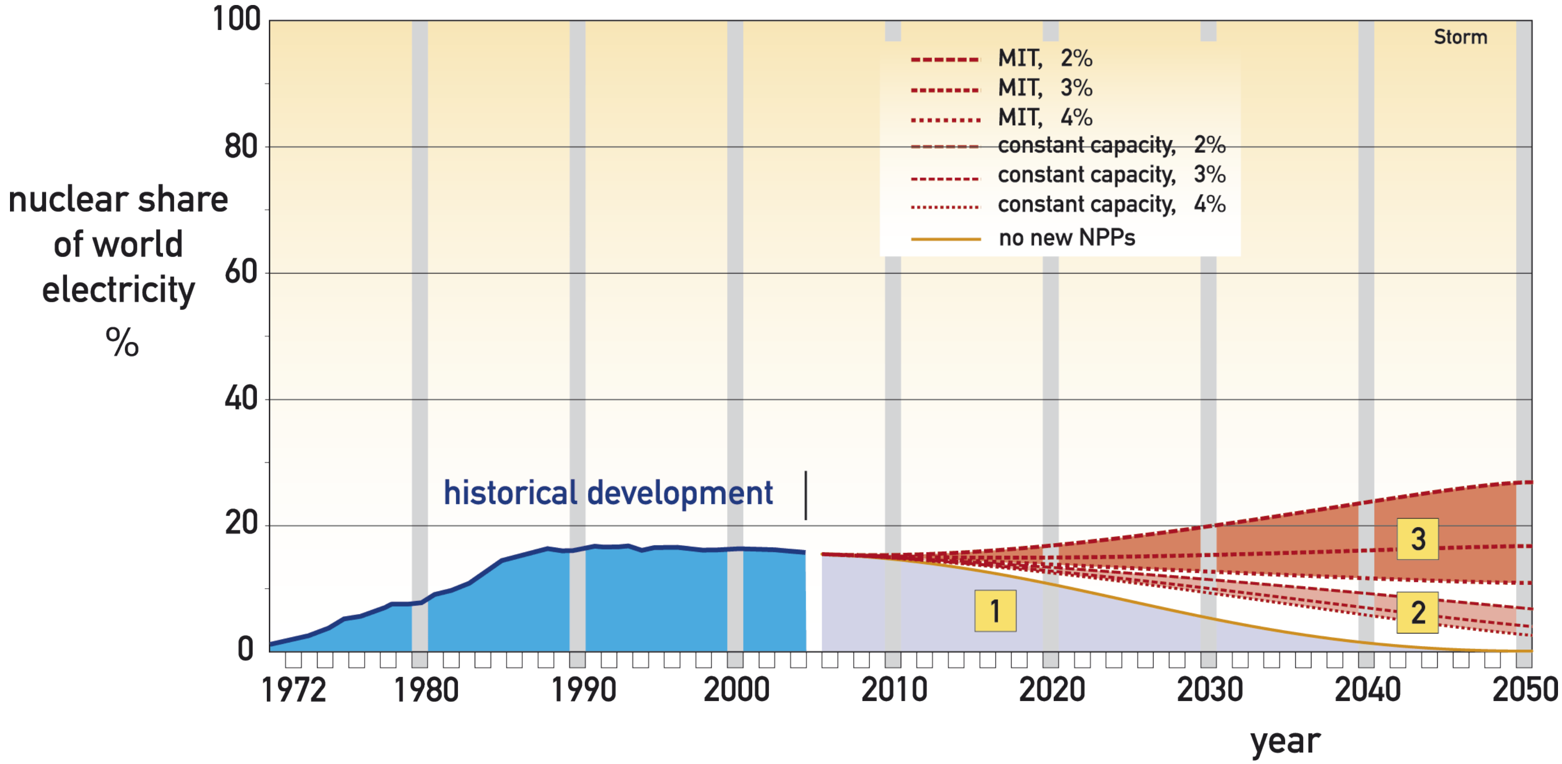


Nuclear scenarios



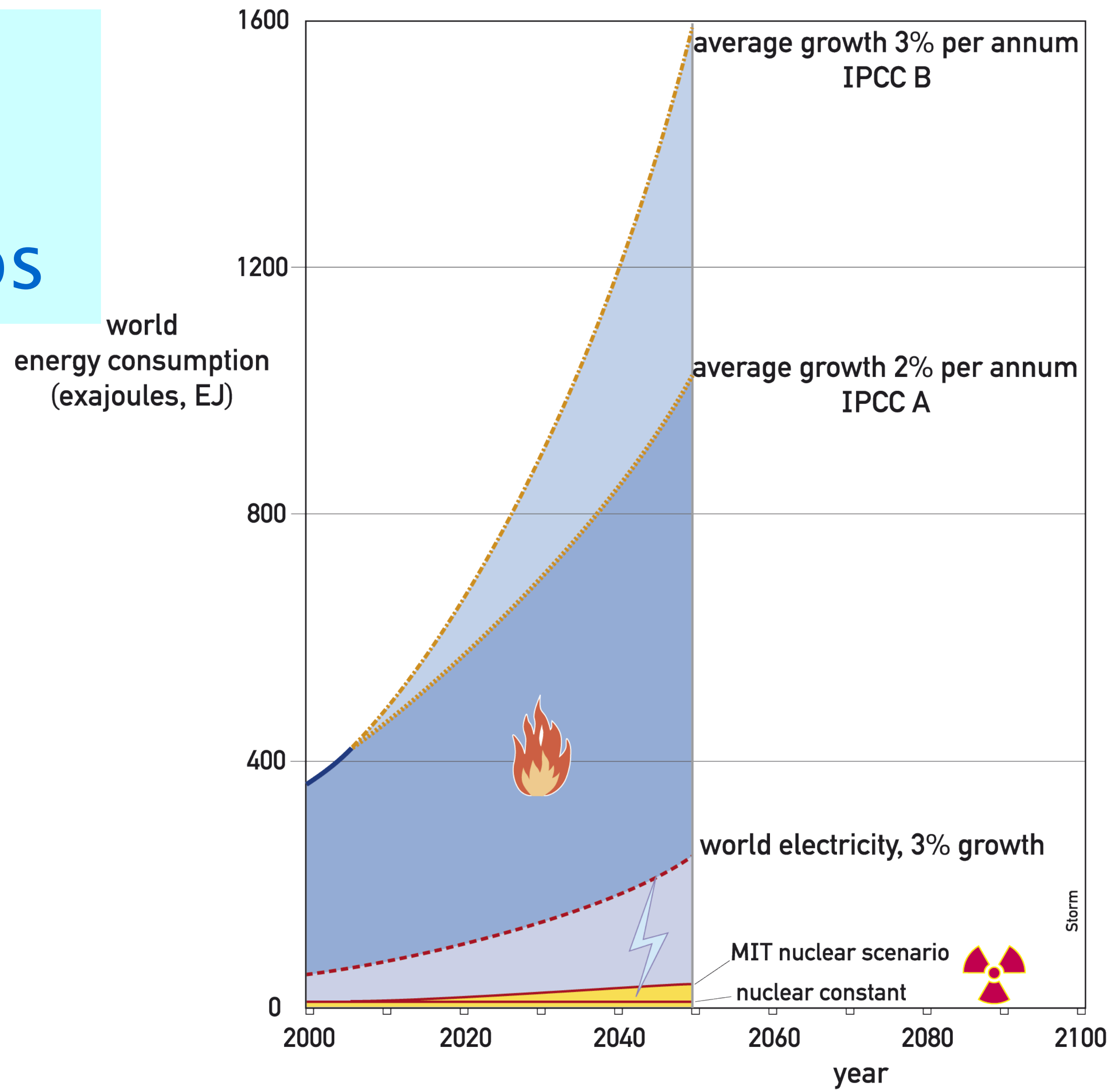
J.W. Storm van Leeuwen 2006

Nuclear share of world electricity



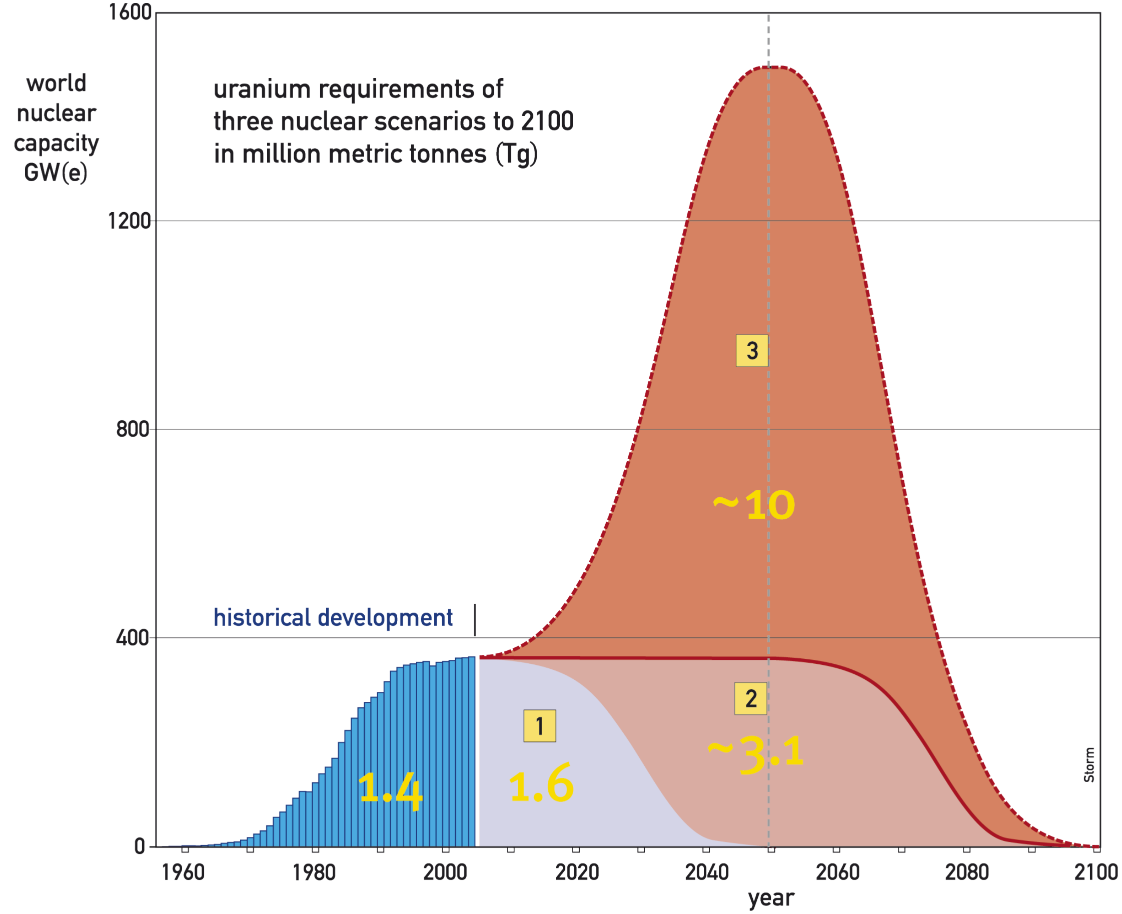
J.W. Storm van Leeuwen 2006

World energy scenarios



J.W. Storm van Leeuwen 2006

Uranium requirements



J.W. Storm van Leeuwen 2006

Energy from uranium

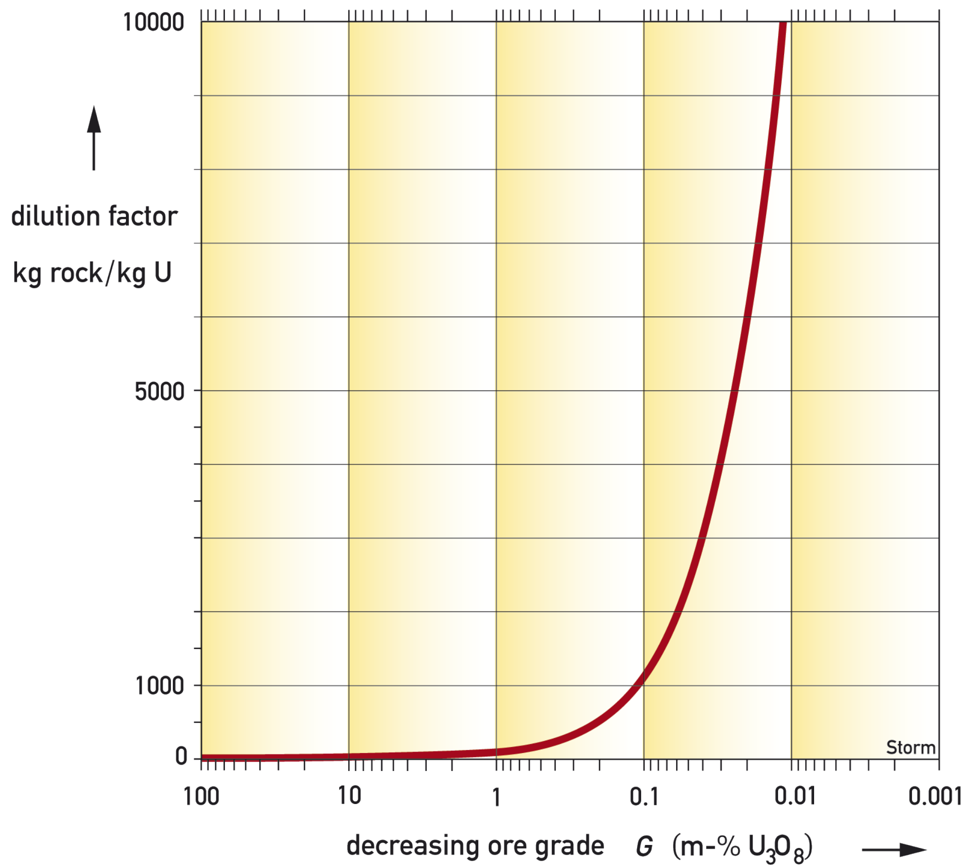
- Uranium extraction from ore:
  - dilution factor
  - extraction yield

- Energy cliff
- Uranium resources
- Nuclear energy resources

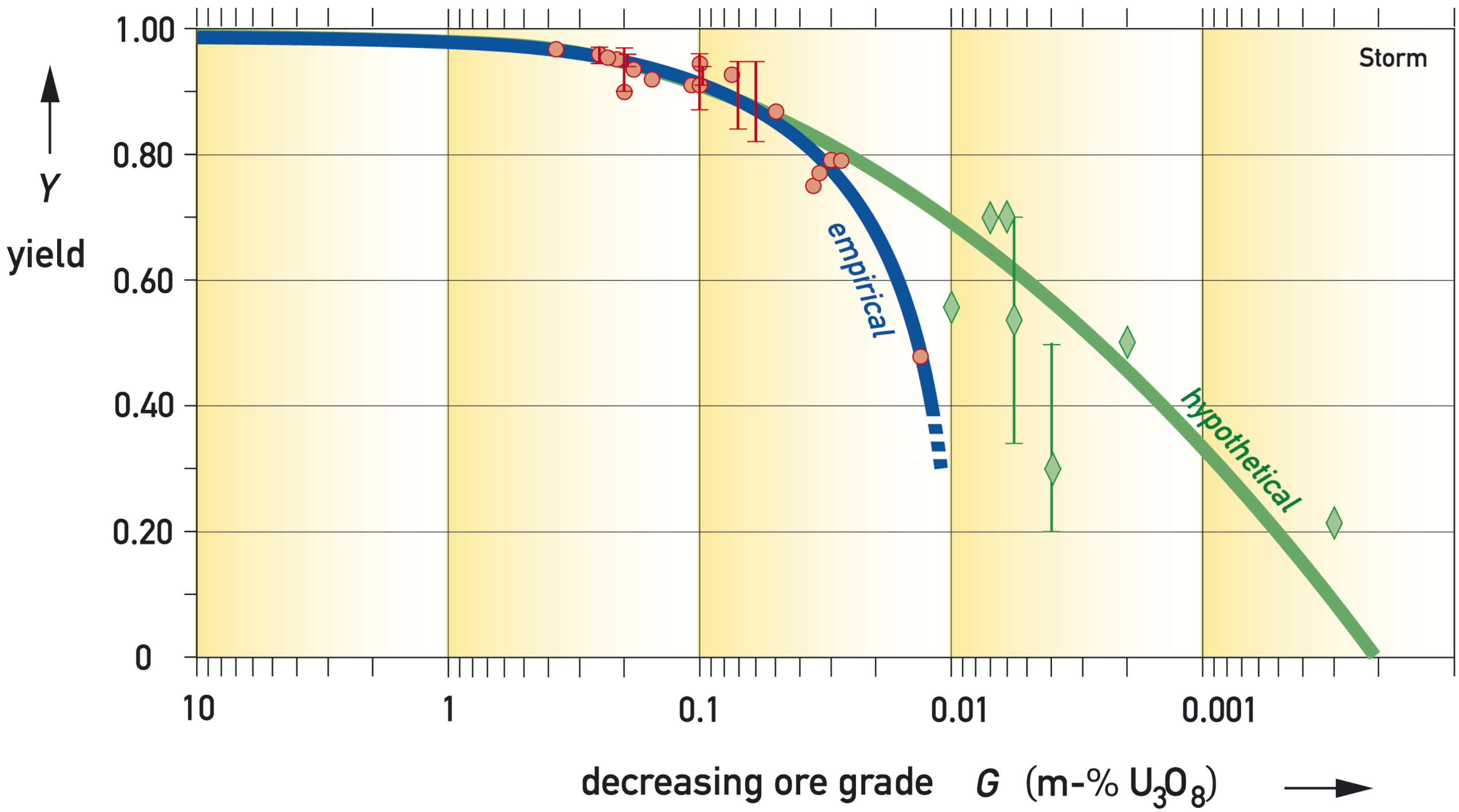
Extraction of uranium from ore

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

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

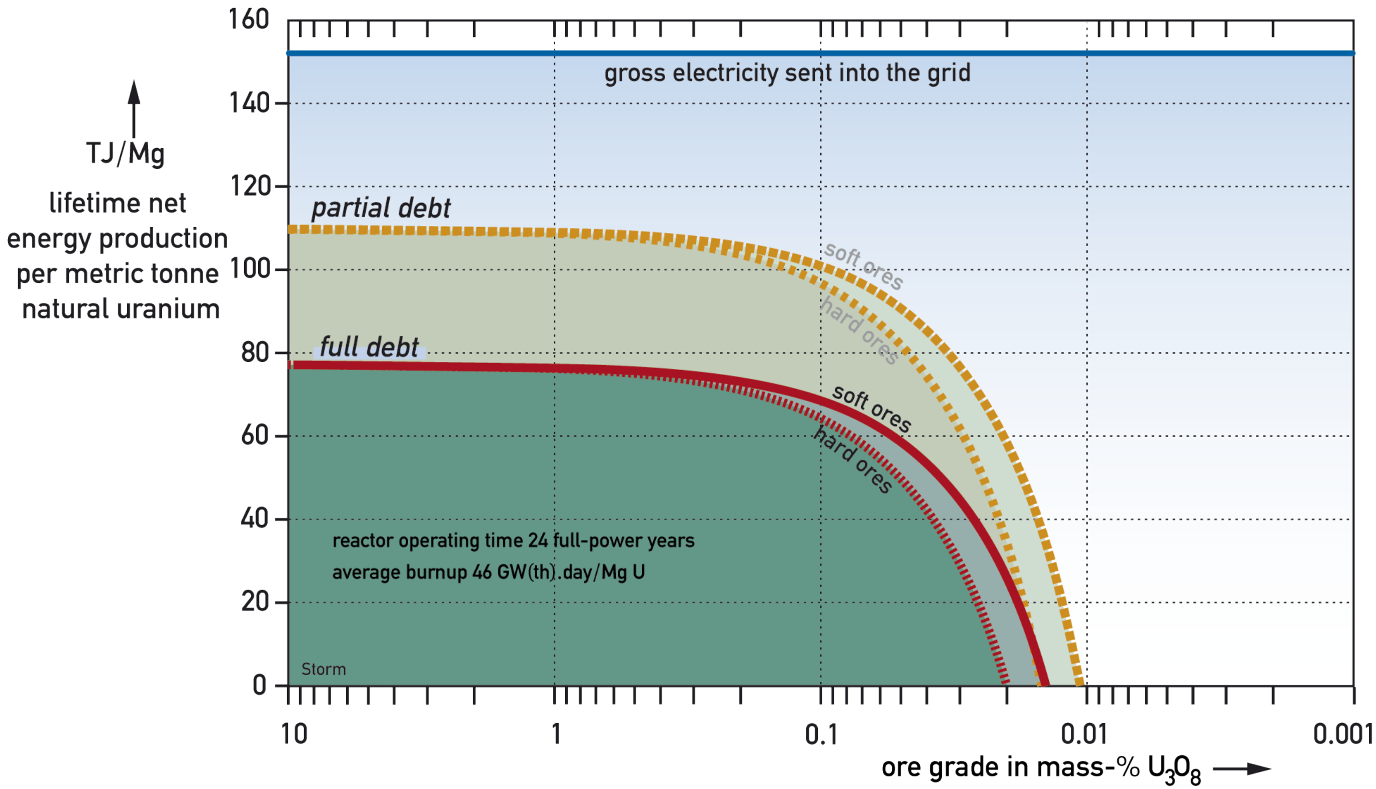


Extraction yield $Y = mU_{ex} / mU_{rock}$



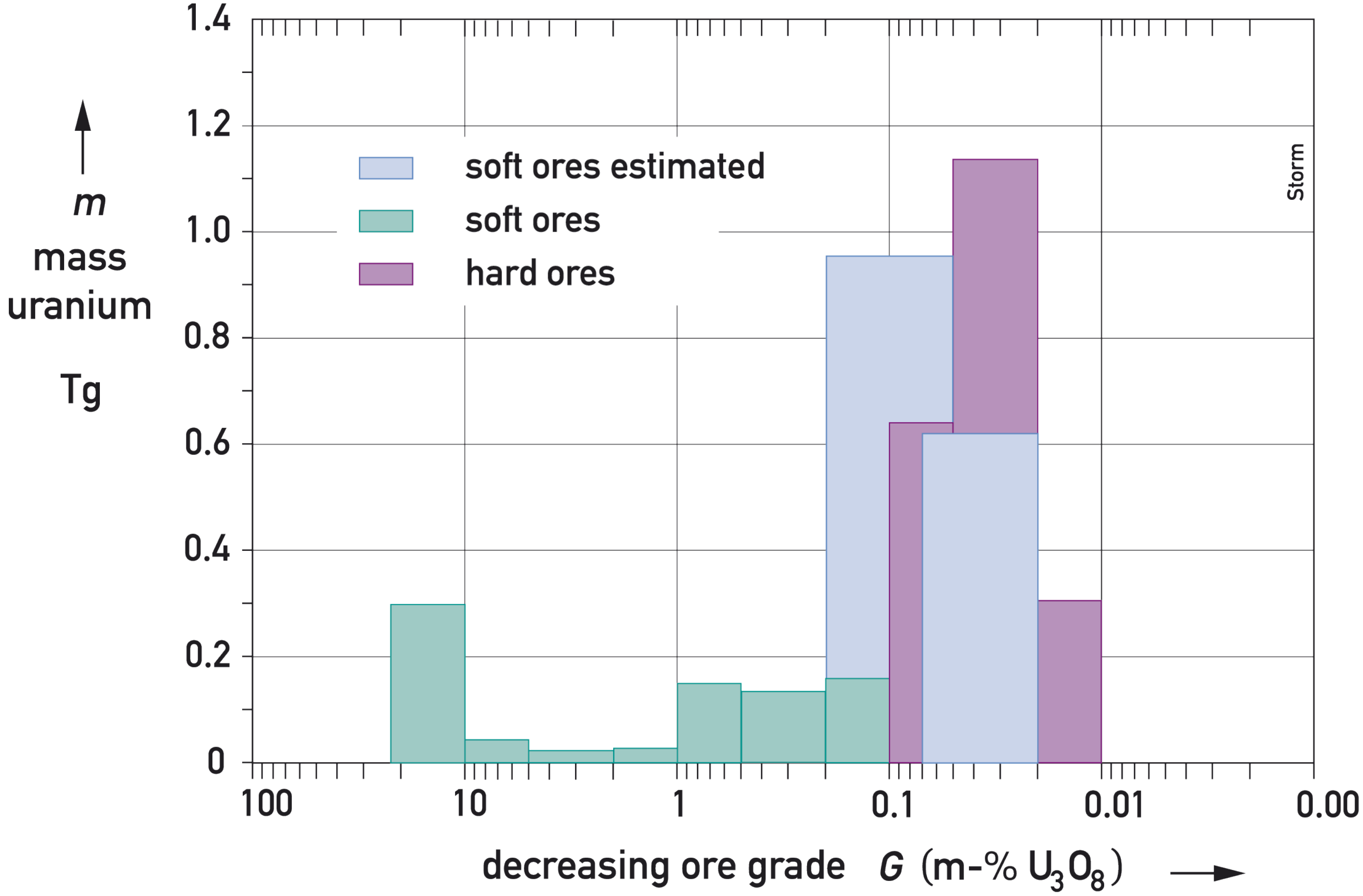
J.W. Storm van Leeuwen 2006

Energy cliff



J.W. Storm van Leeuwen 2006

Quantities of available uranium depend on ore grade



J.W. Storm van Leeuwen 2006

Uranium in the future: ***economic view by WNA***

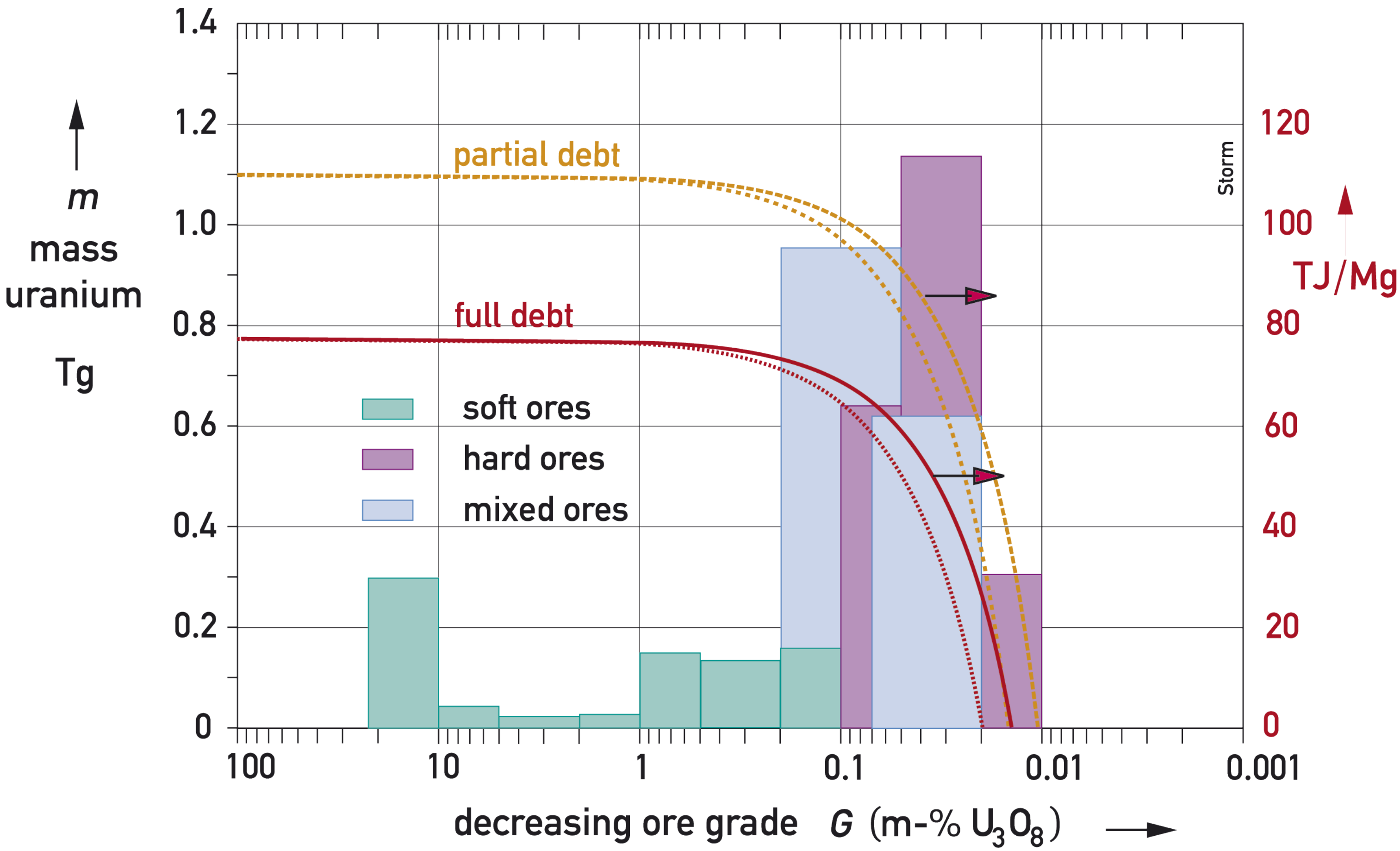
- Higher prices ->
- More exploration, advanced techniques ->
- More discoveries, lower costs ->
- More resources.

- Conclusion: uranium is a sustainable energy resource

Uranium in the future: ***physical facts***

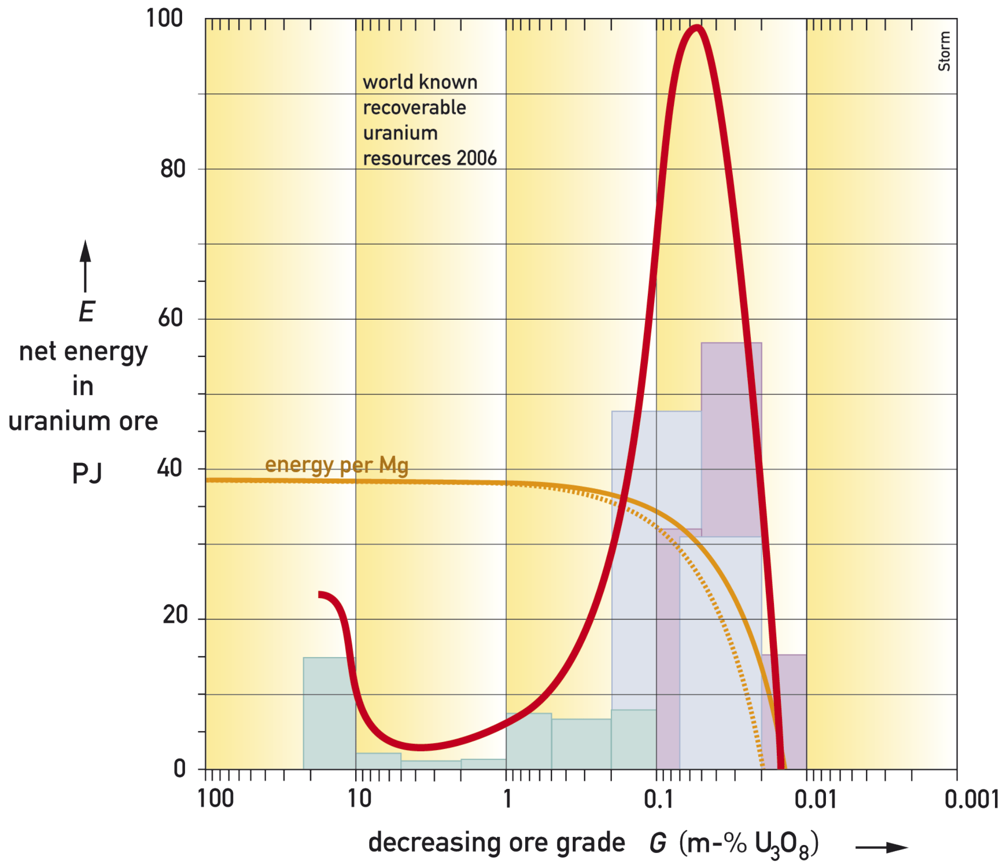
- The larger amount of U in rock, the lower its grade.
- Easily discoverable and mineable uranium resources are already in production.
- Physical laws stay in force, cannot be circumvented by economics.

Nuclear energy resources



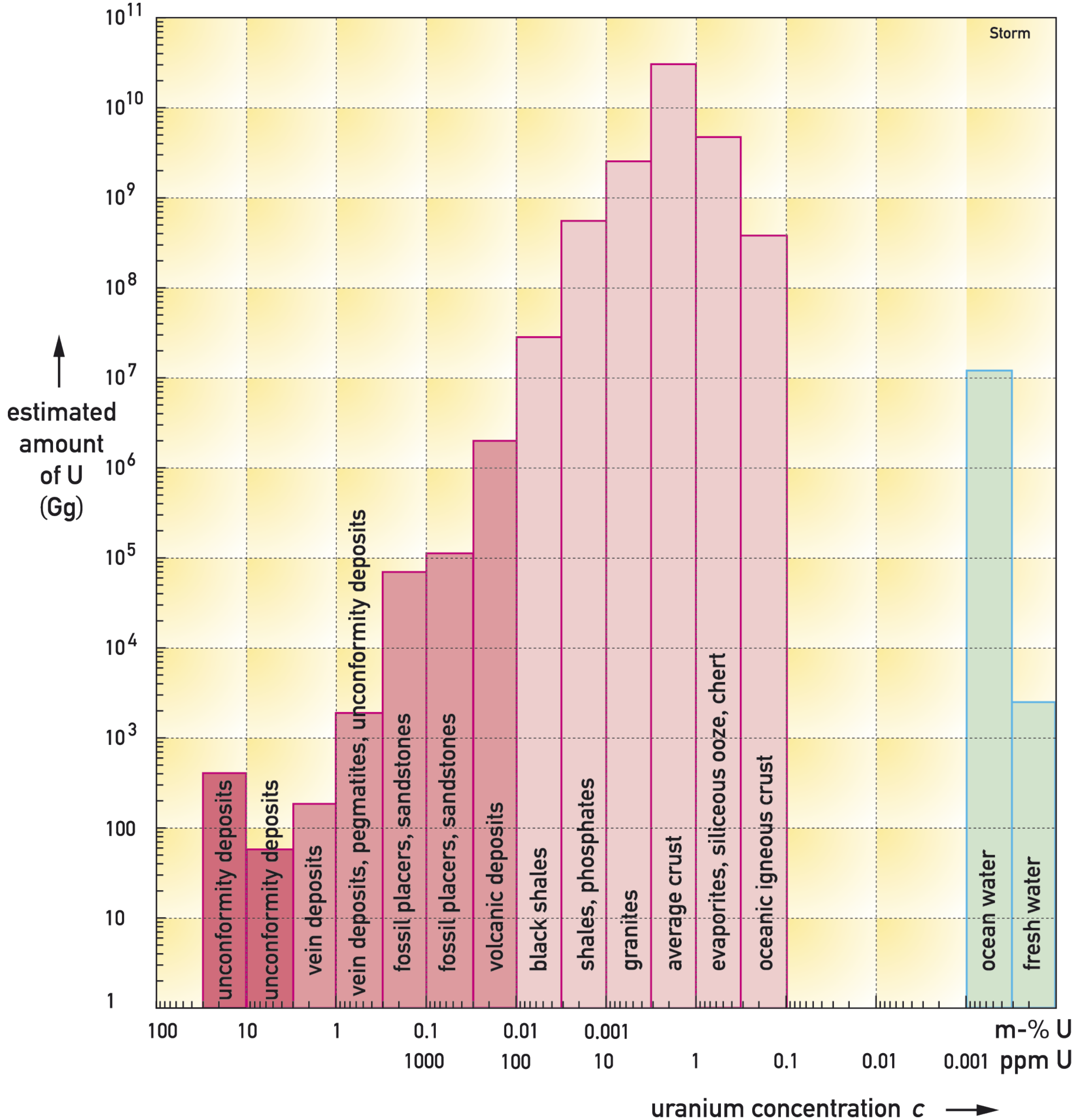
J.W. Storm van Leeuwen 2006

Uranium peak



J.W. Storm van Leeuwen 2006

Uranium in the earth's crust



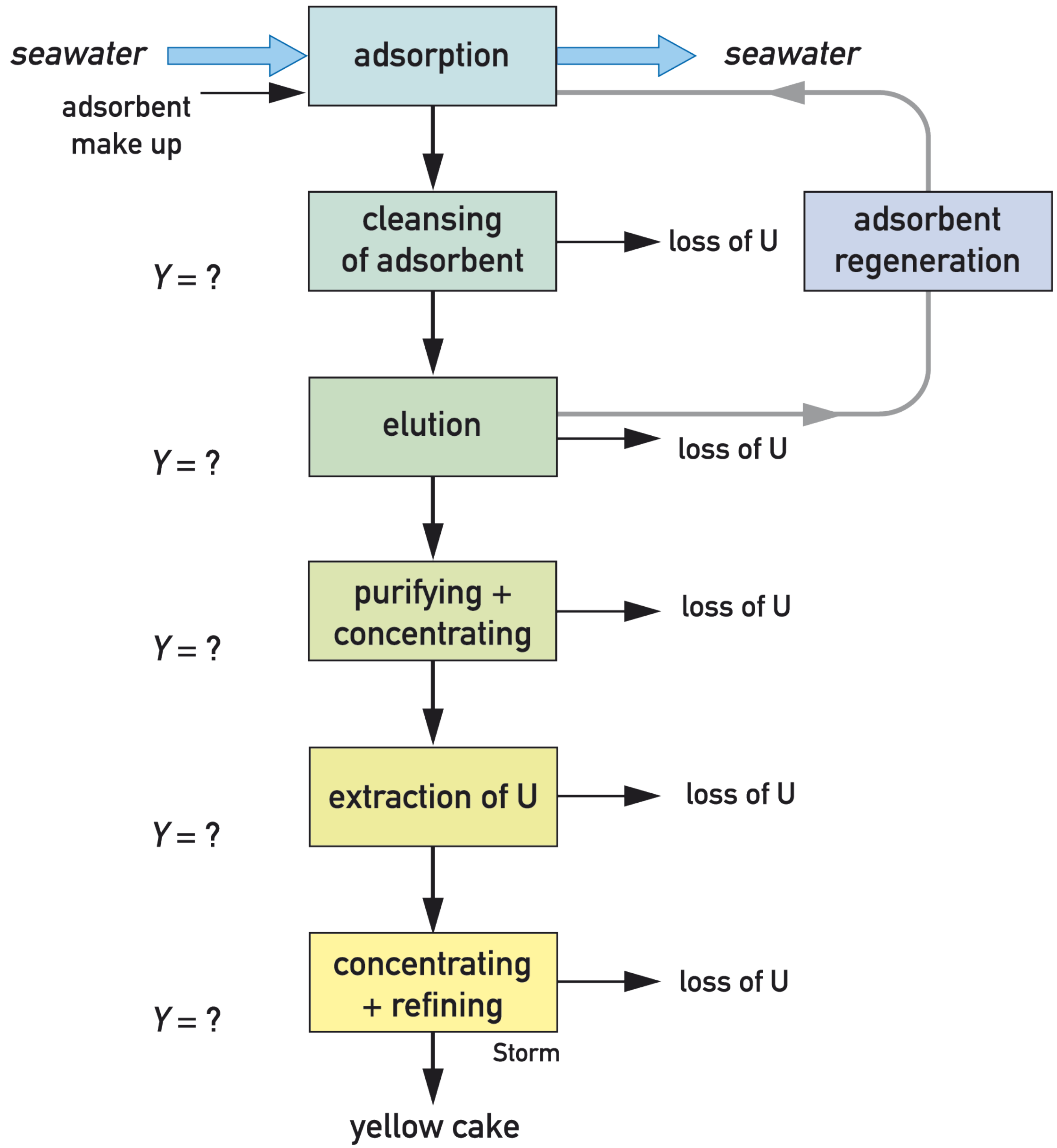
J.W. Storm van Leeuwen 2006

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

Conclusions

- Greenhouse gas emissions by nuclear?
  Yes, carbon dioxide and other
- Nuclear share in the future?
  Marginal
- Availability of nuclear energy from uranium?
  Serious misconceptions
  Very large uncertainties

Concluding remarks

The industrial society meets the thermodynamic limits in drawing its energy needs from mineral resources.

The time has come to divert to the only entropy-free energy source: the sun.


sun, sand and wind