Energy from uranium

Uranium supply and the future of nuclear power

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Outline

- Part 1 Introduction
- Part 2 Nuclear system
- Part 3 Key points
- Conclusions

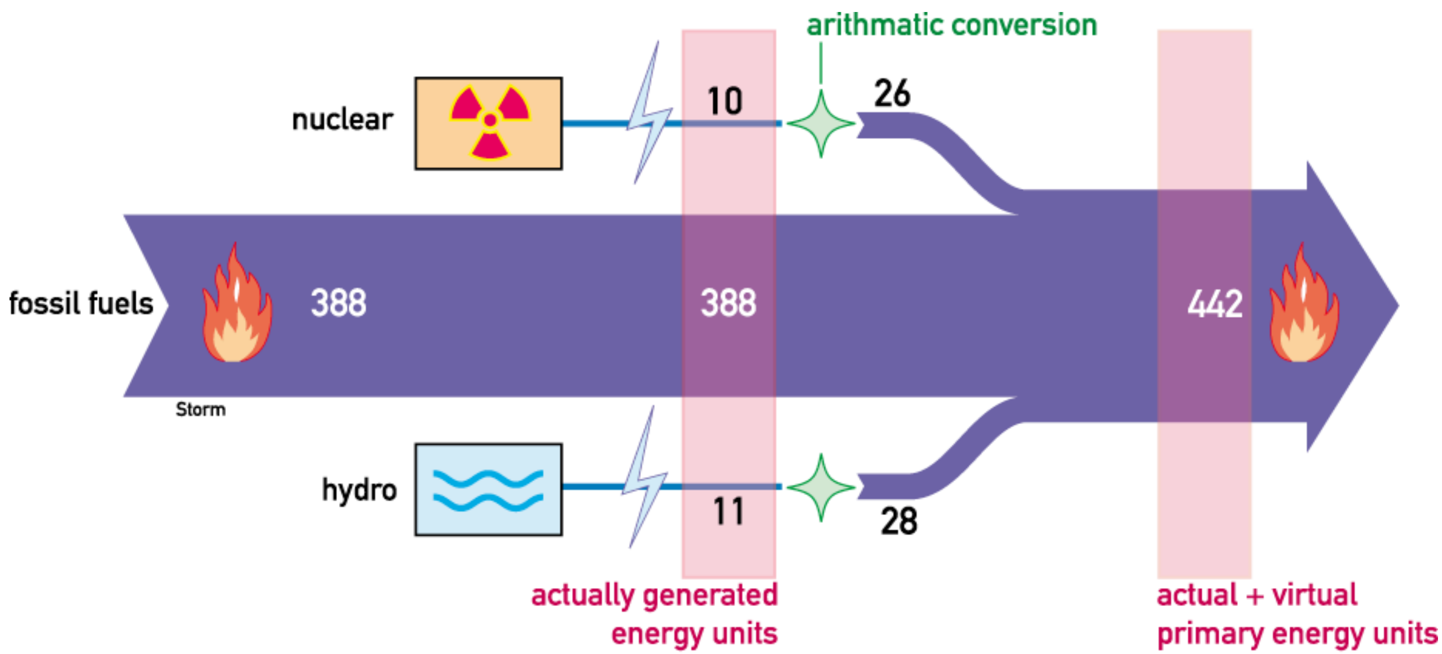
Part 1
Introduction

- Nuclear power in the world energy supply: current situation.

- Which reactor type for the future?

World energy supply

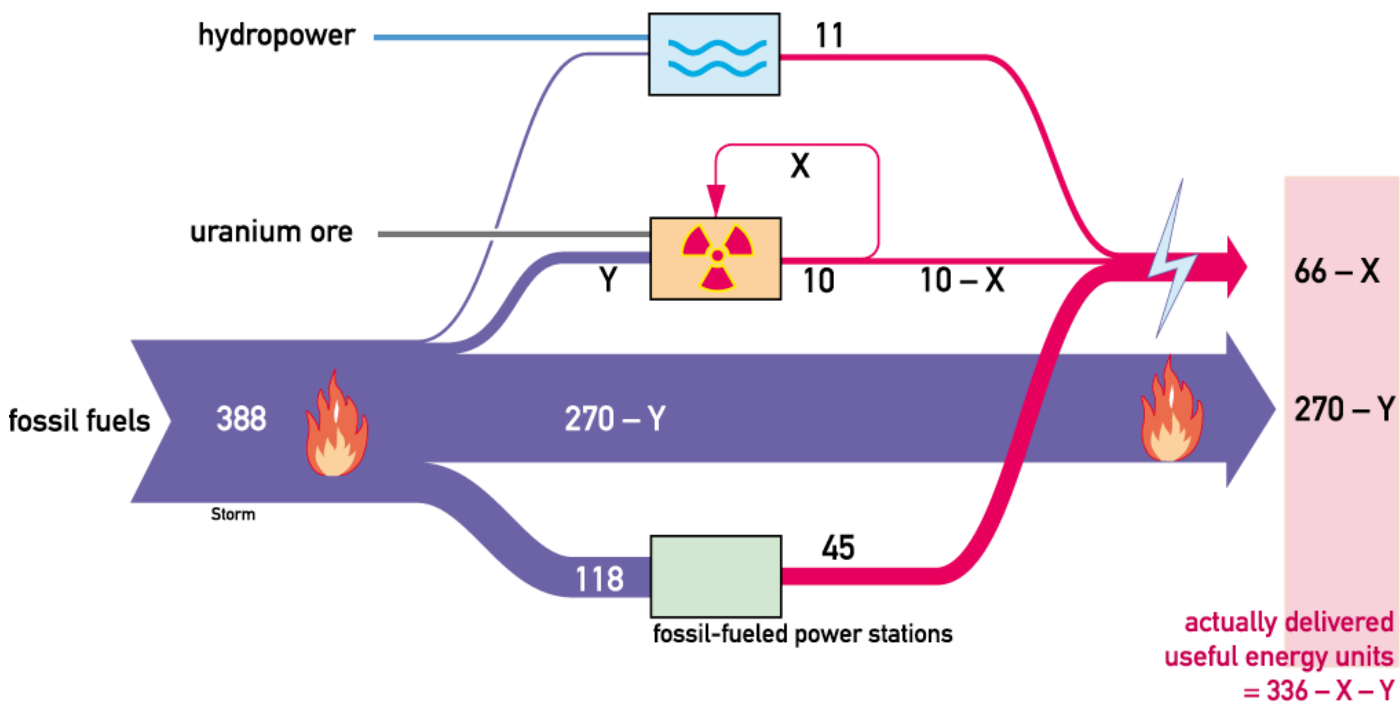
statistical view: primary energy units



World energy consumption 2005, statistical view

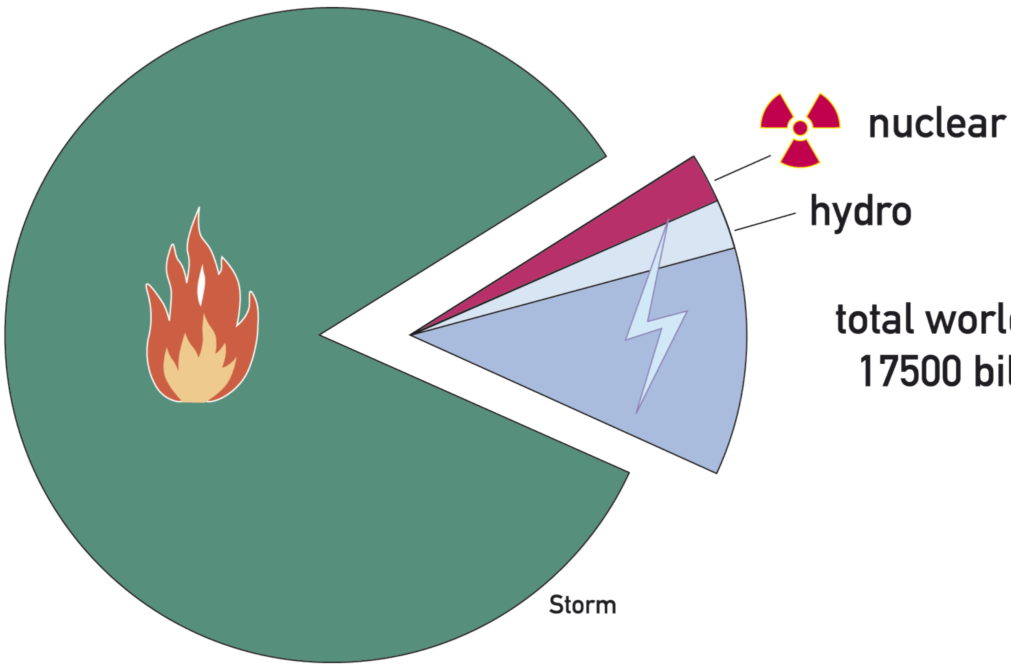
World energy supply

physical view: physical energy units



World energy consumption 2005, physical view

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

Which reactor technology?

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

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

Choice for the next decades

Thermal neutron reactors:
mainly LWR

Once-through fuel cycle

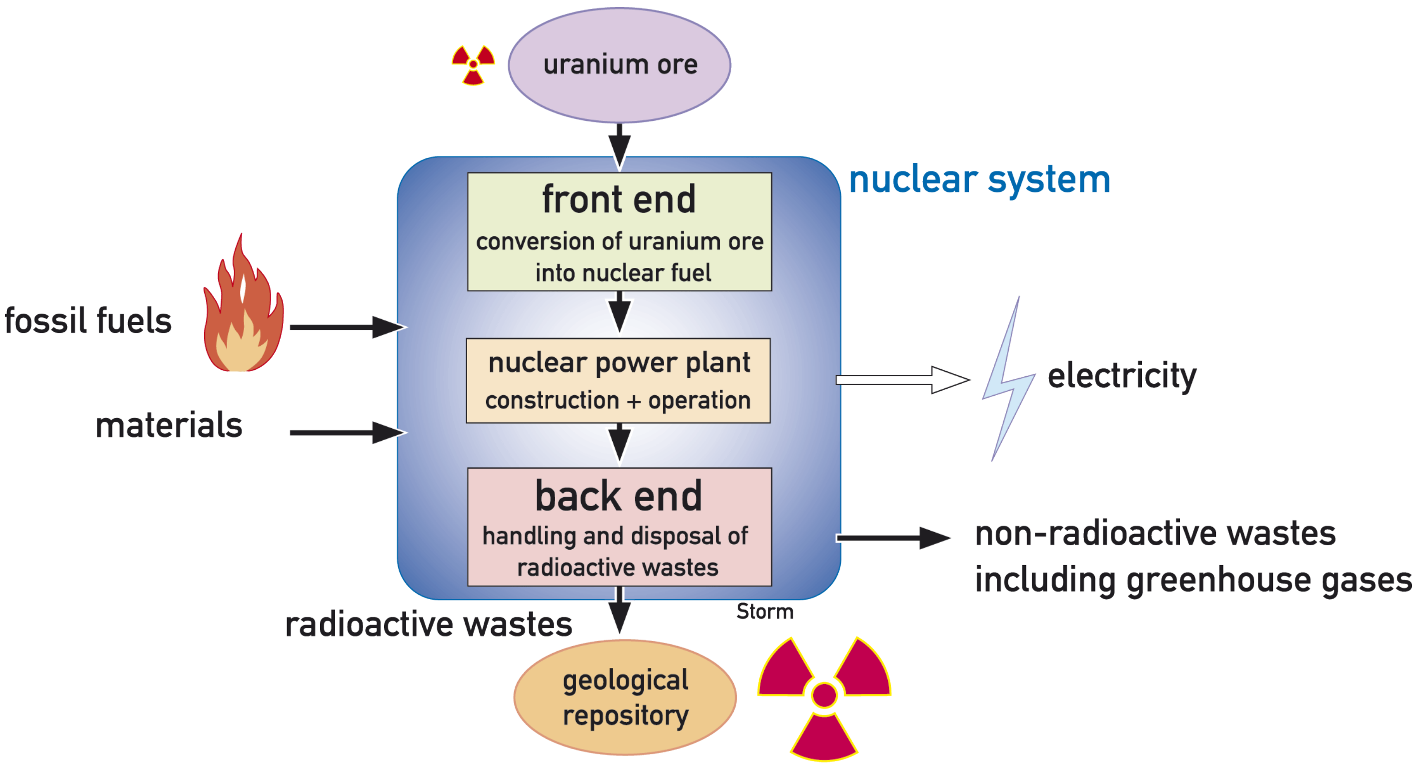
Part 2
Nuclear system

- Nuclear process chain
- Energy costs energy
- Energy debt

Energy costs 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



Time scale

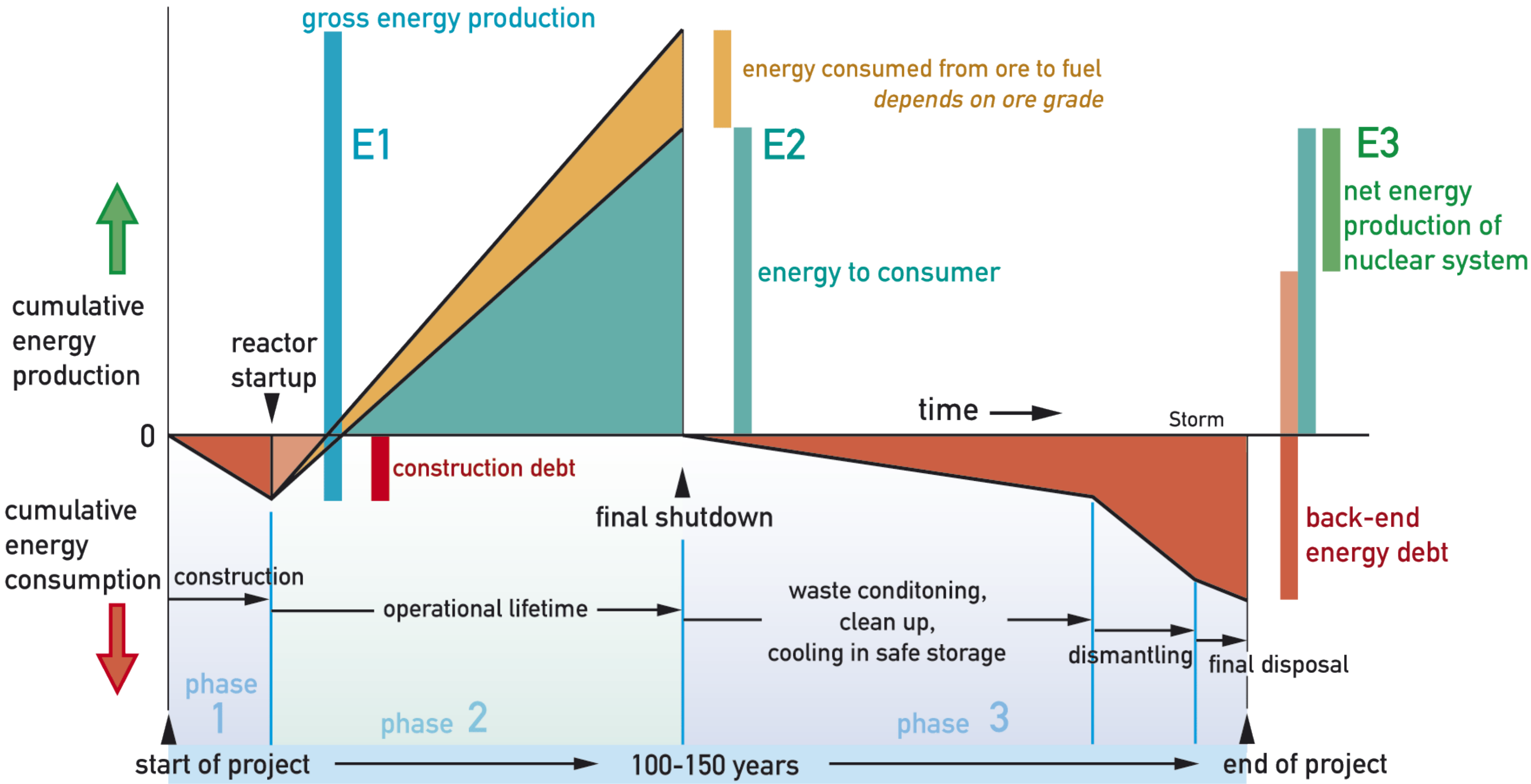
• Construction of NPP + development time	10 years
• Operational life	40 years?
• Aftermath, back end no empirical data	30-100 years?
• Total time scale	80 - 150 years

- *Large uncertainties*

Sustainability

A philosophy of
'*Après nous le déluge*'
is not consistent
with any sustainability principle

Lifetime costs: energy debt



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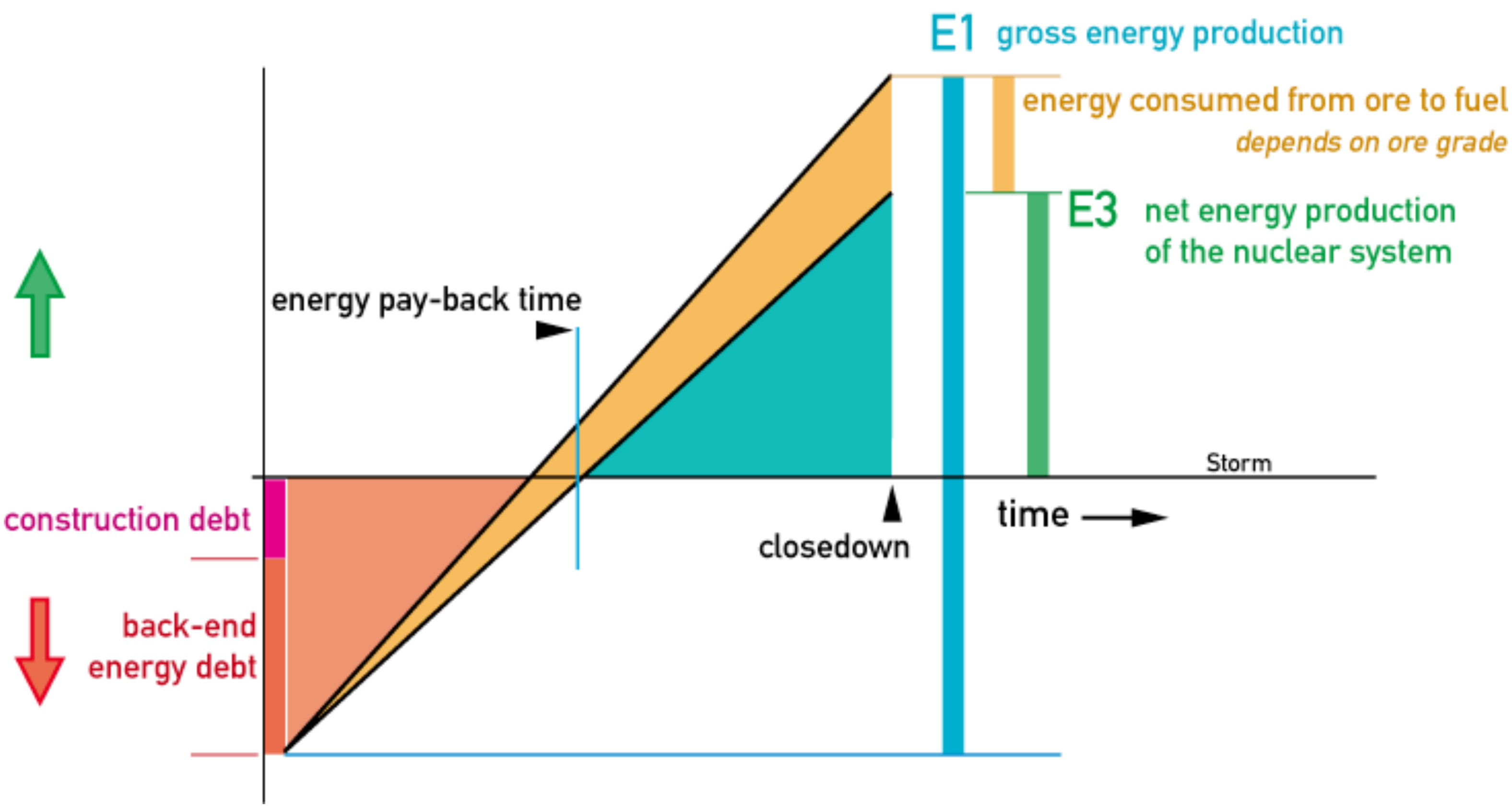
Energy debt 'capitalized'



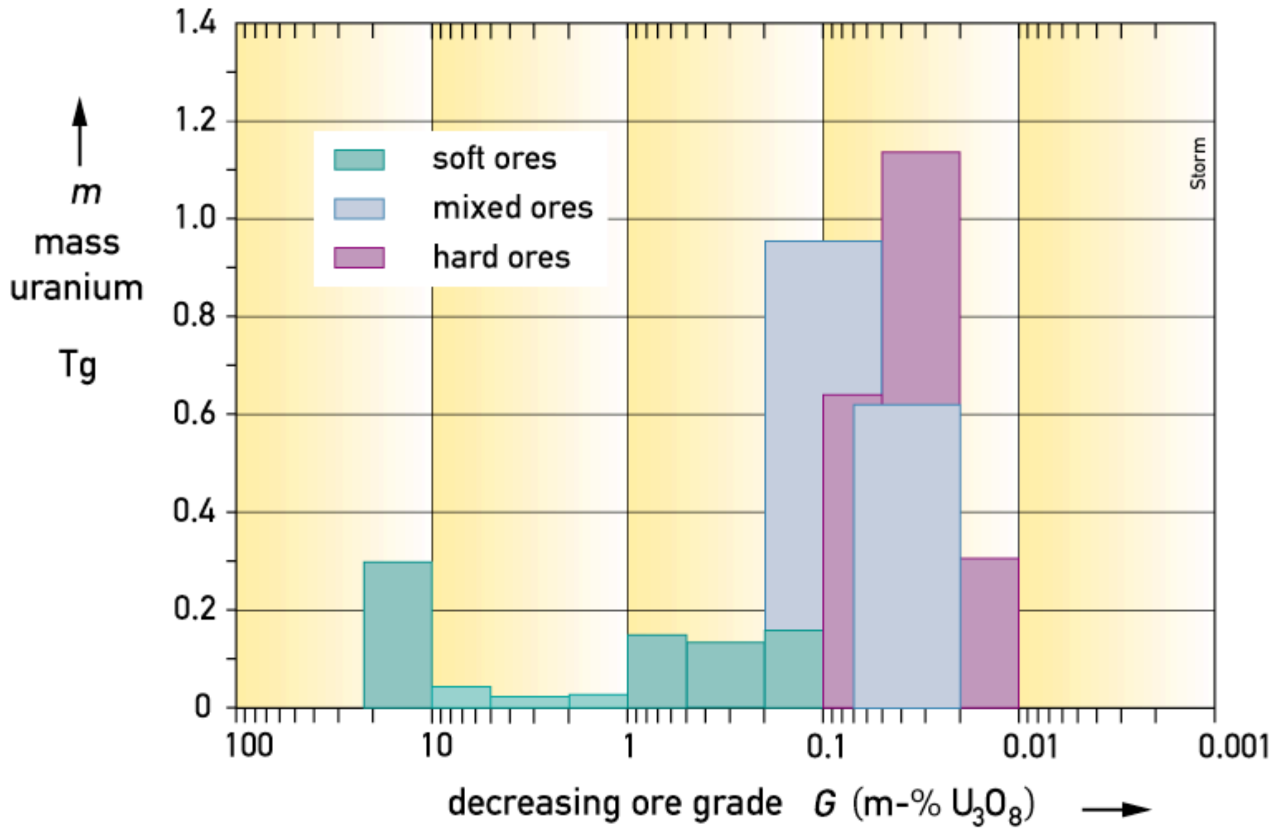
Energy pay-back times

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

Part 3
Key points

- uranium resources
- energy cliff
- uranium peak
- CO_2 emissions by nuclear power
- nuclear energy resources
- depletion scenario

World known recoverable uranium resources 2006



New uranium resources, yet to be discovered

- Easily discoverable and mineable resources: *already known and in production*.
- New large and rich uranium deposits: *no indications known*.
- Nuclear industry refers to unconventional uranium resources: shales, phosphates and seawater.

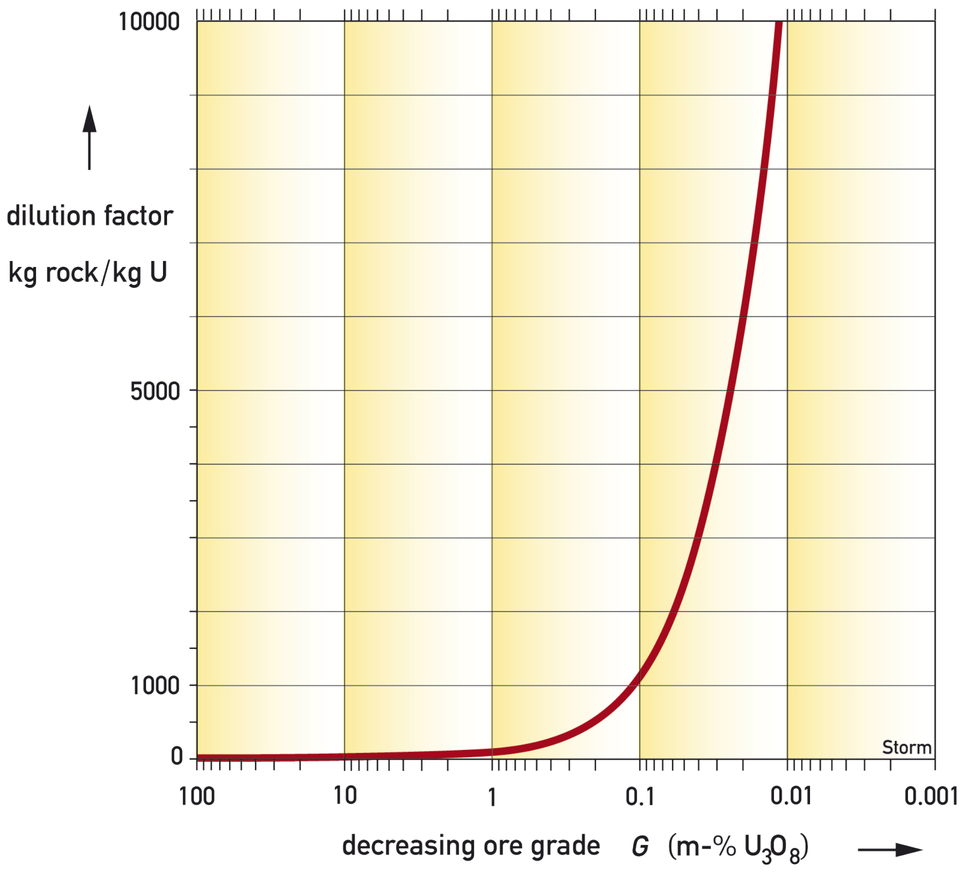
  These are beyond the energy cliff.

Uranium resources are not the same as energy resources

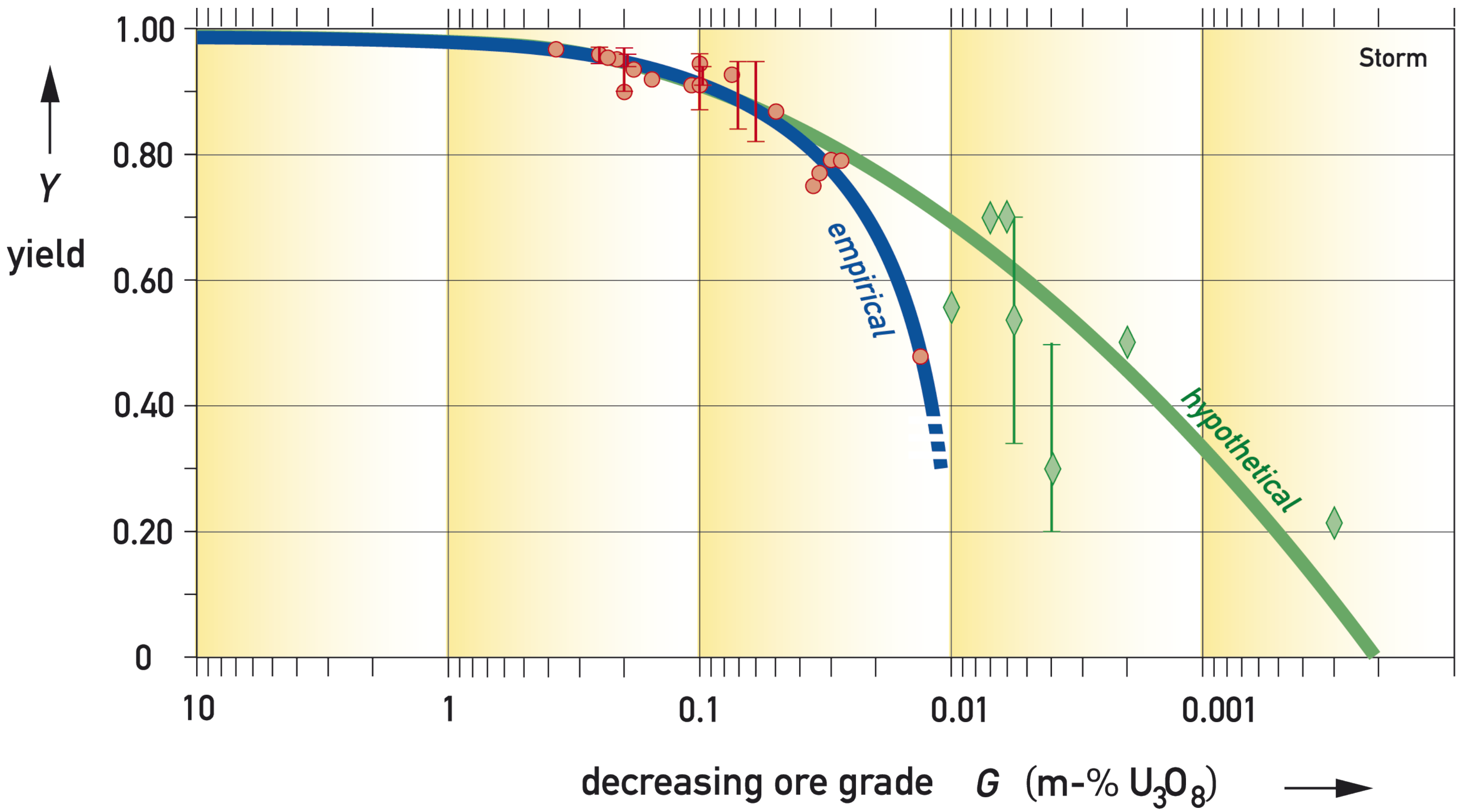
Energy from uranium

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

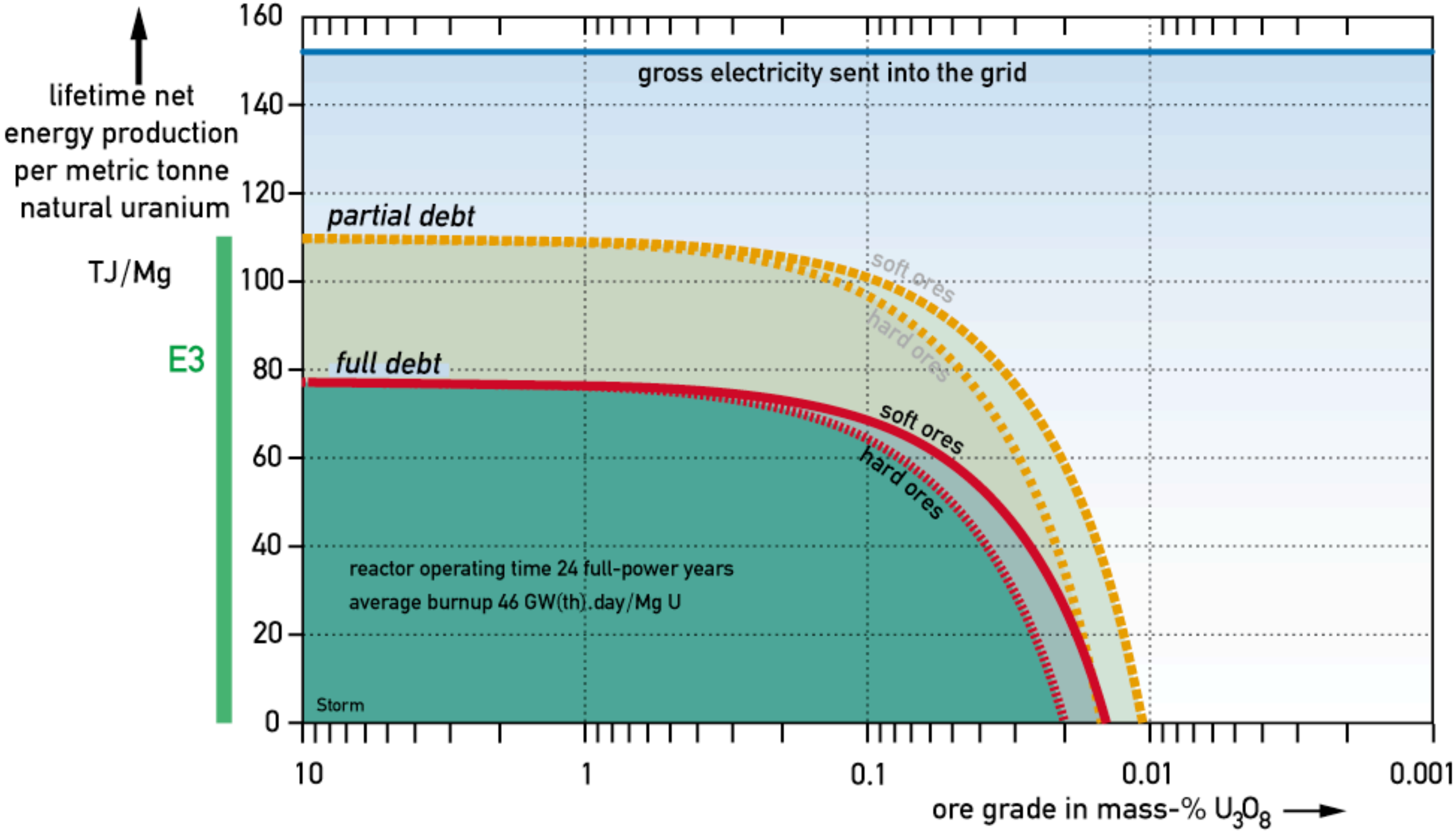
Dilution factor = kg(rock)/kg(U)



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



Energy cliff



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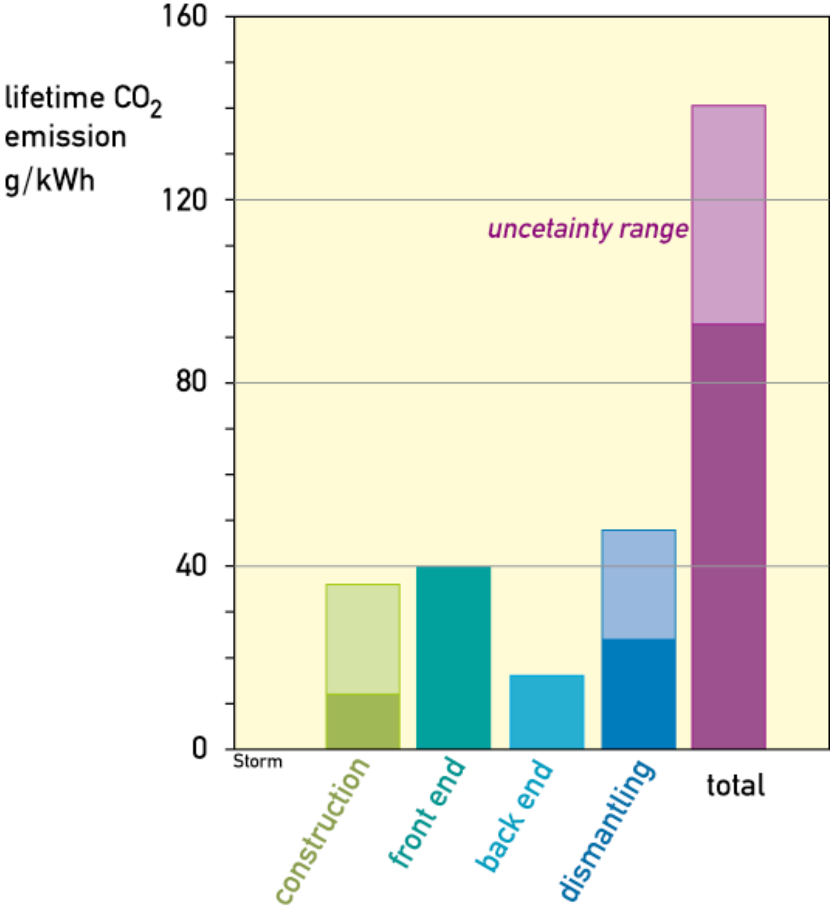
Greenhouse gases from nuclear power

- CO_2 emissions
- Emission of other greenhouse gases

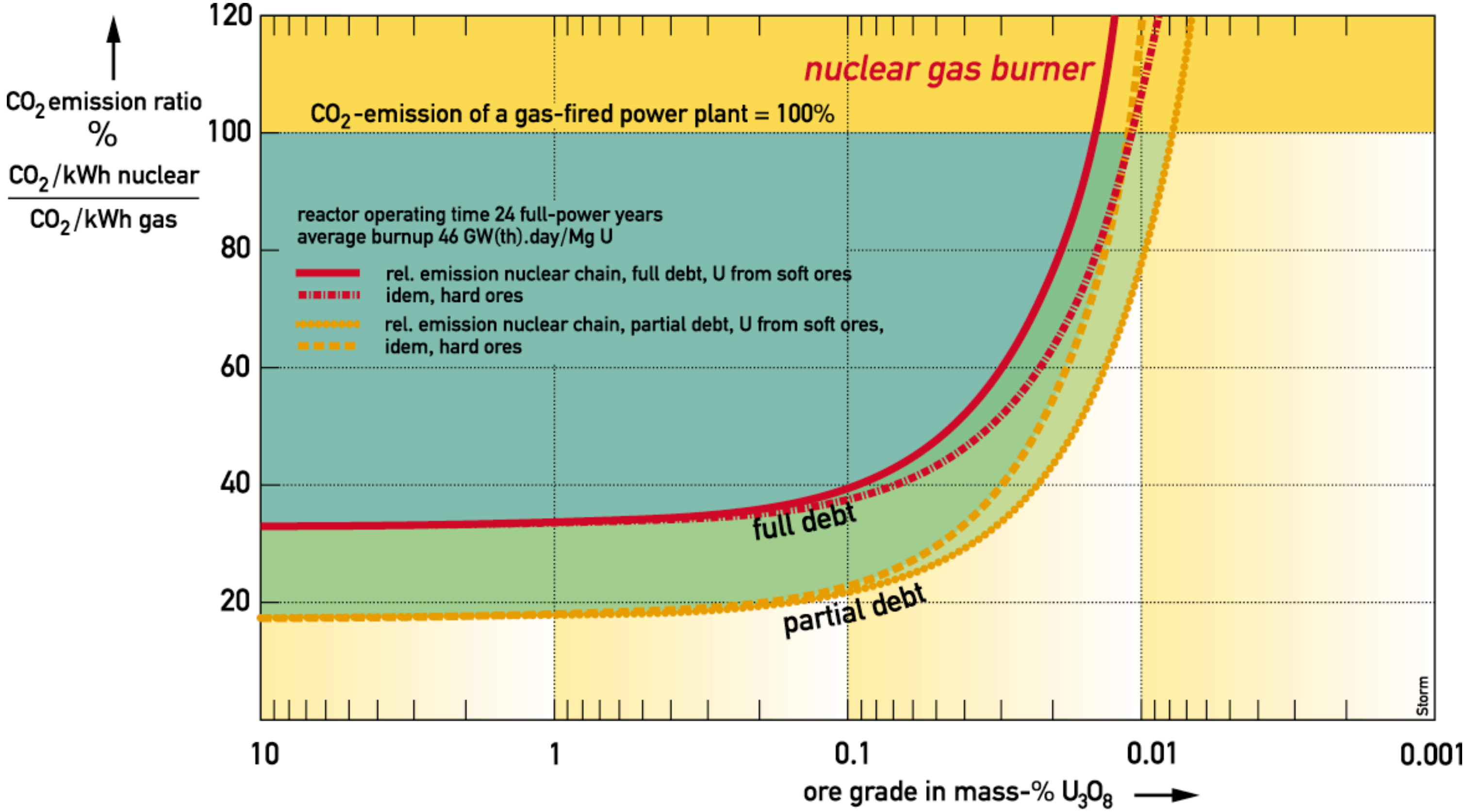
CO_2 emissions



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

Specific emission of CO_2 vs ore grade



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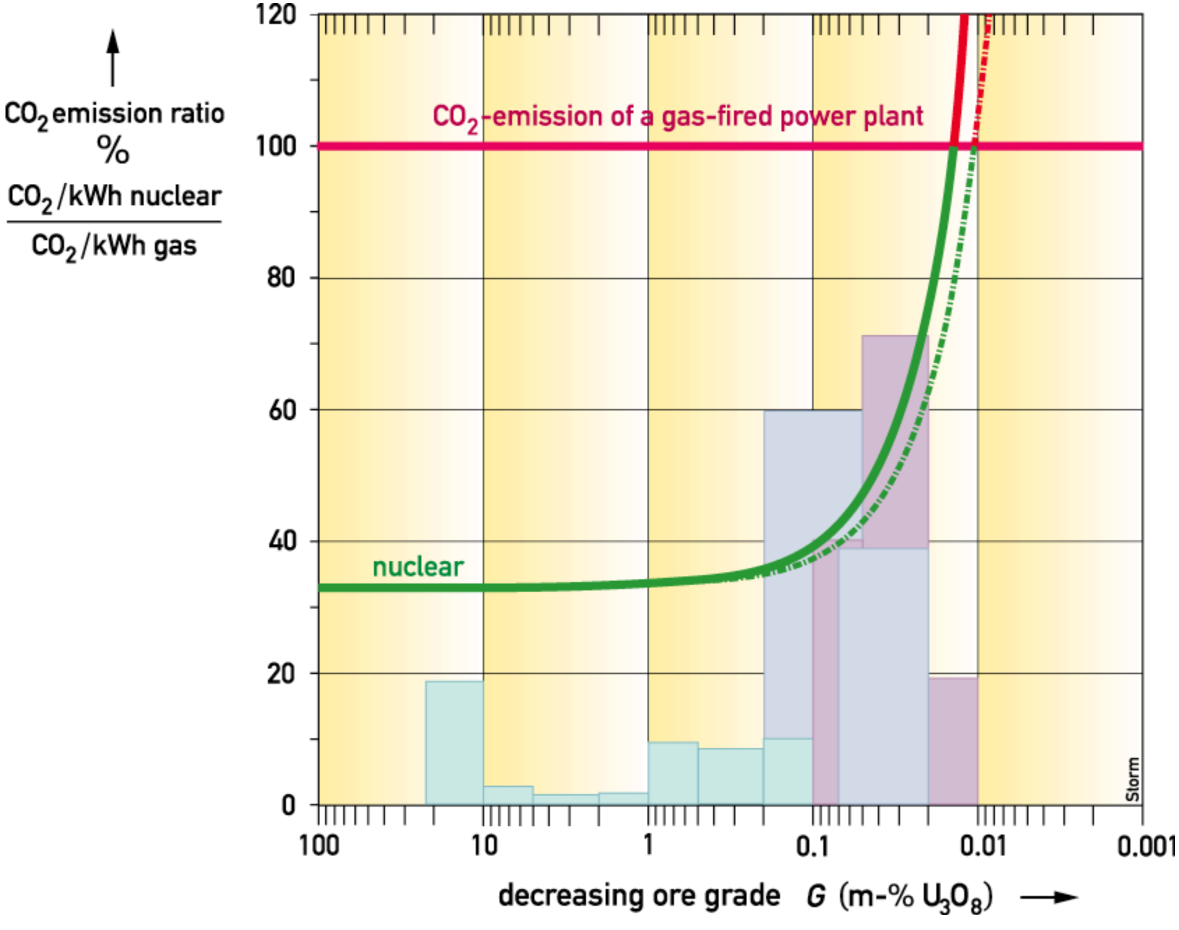
Emission of CO_2 and resources



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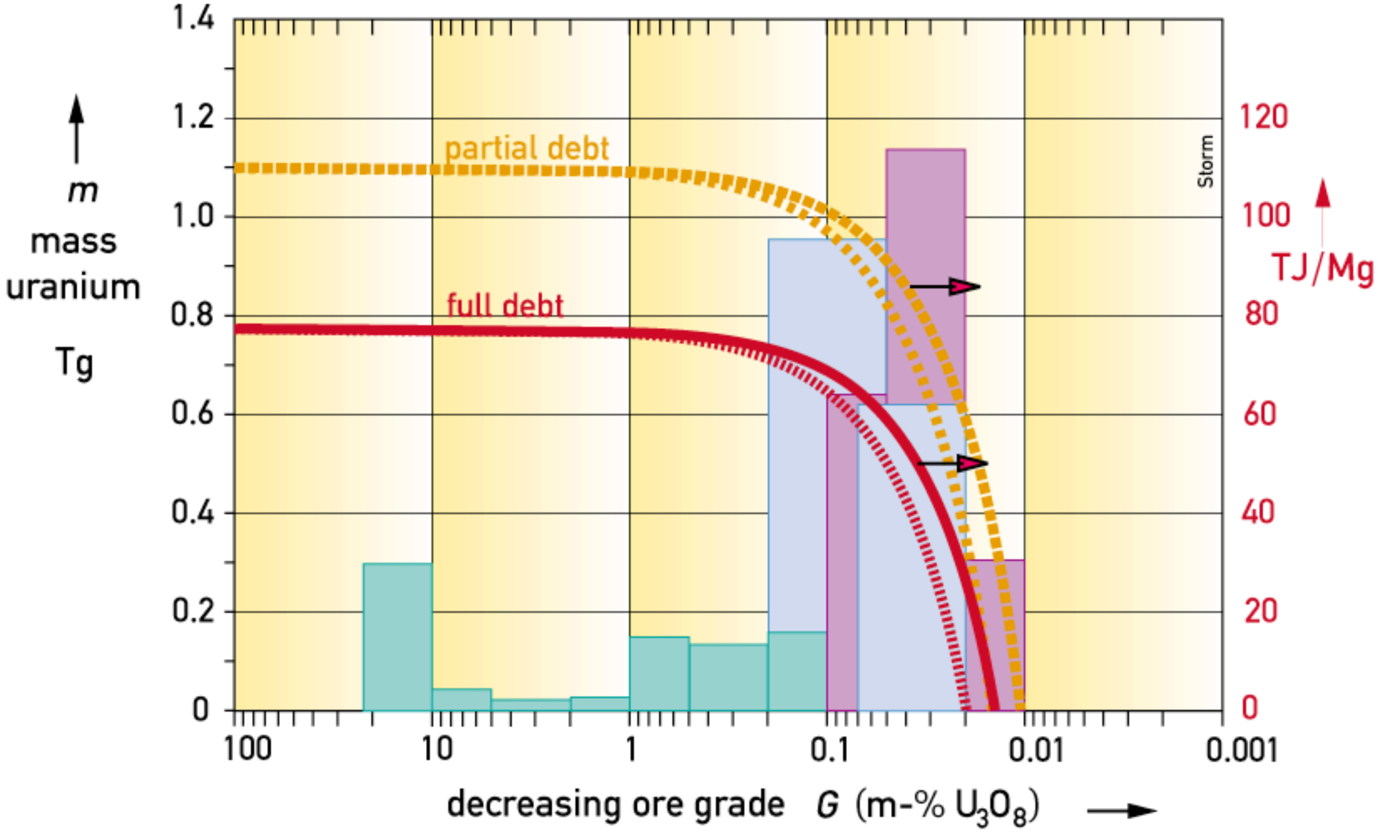
Emission of other greenhouse gases

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

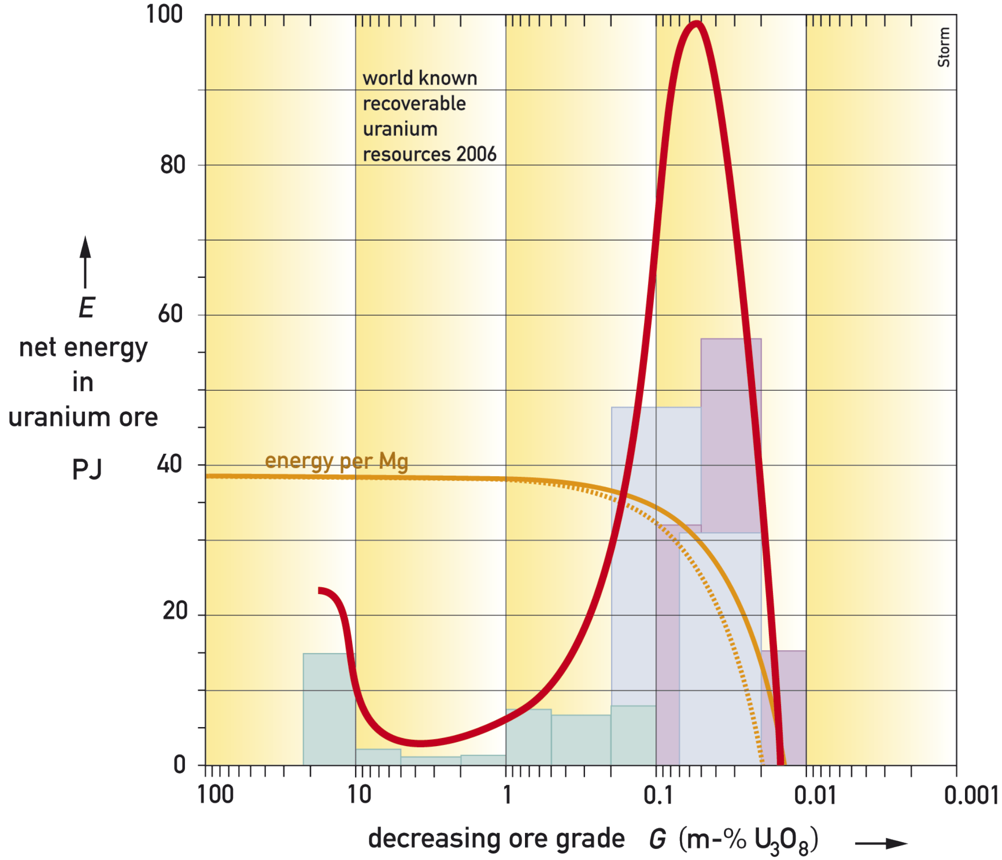
- Other greenhouse gases from nuclear chain?
  Plausible but unknown.

- Ever investigated and/or published?

Nuclear energy resources



Uranium peak



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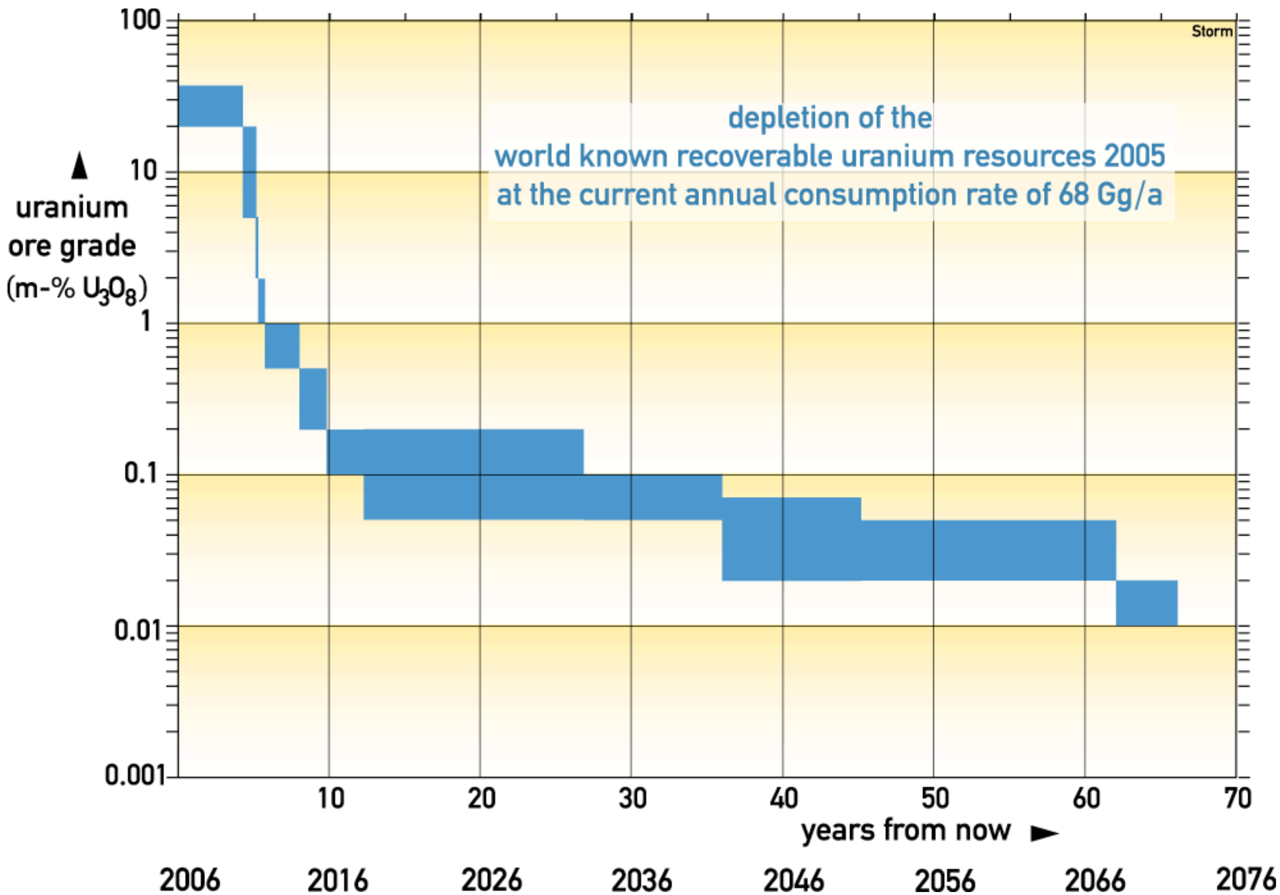
Uranium depletion scenario



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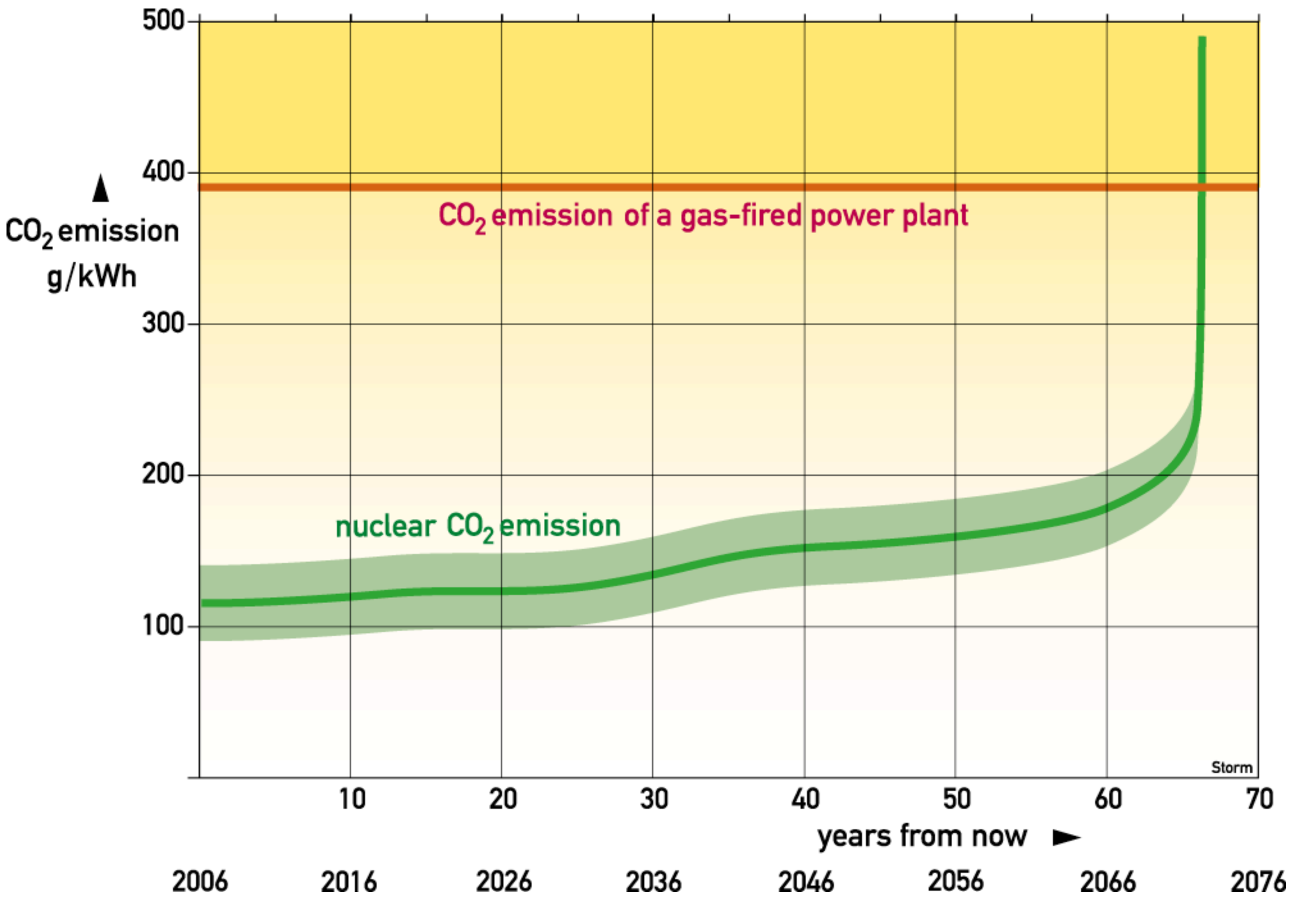
CO_2 emission scenario



Conclusions 1

- Rich known uranium ores depleted by ~2016.
- After ~2034 mean ore grade well below 0.1%.
- By ~2070 currently known resources depleted.
- Chances of new large rich finds unknown.
- New resources less accessible and harder to mine.

Conclusions 2

- Exponential decline of net energy per kg uranium after ~2034.

- Nuclear power falls off the energy cliff by ~2060.

- Exponential increase of CO_2 per kilowatt-hour nuclear electricity after ~2034.

  Nuclear CO_2 emission equals gas-fired power after ~2060.