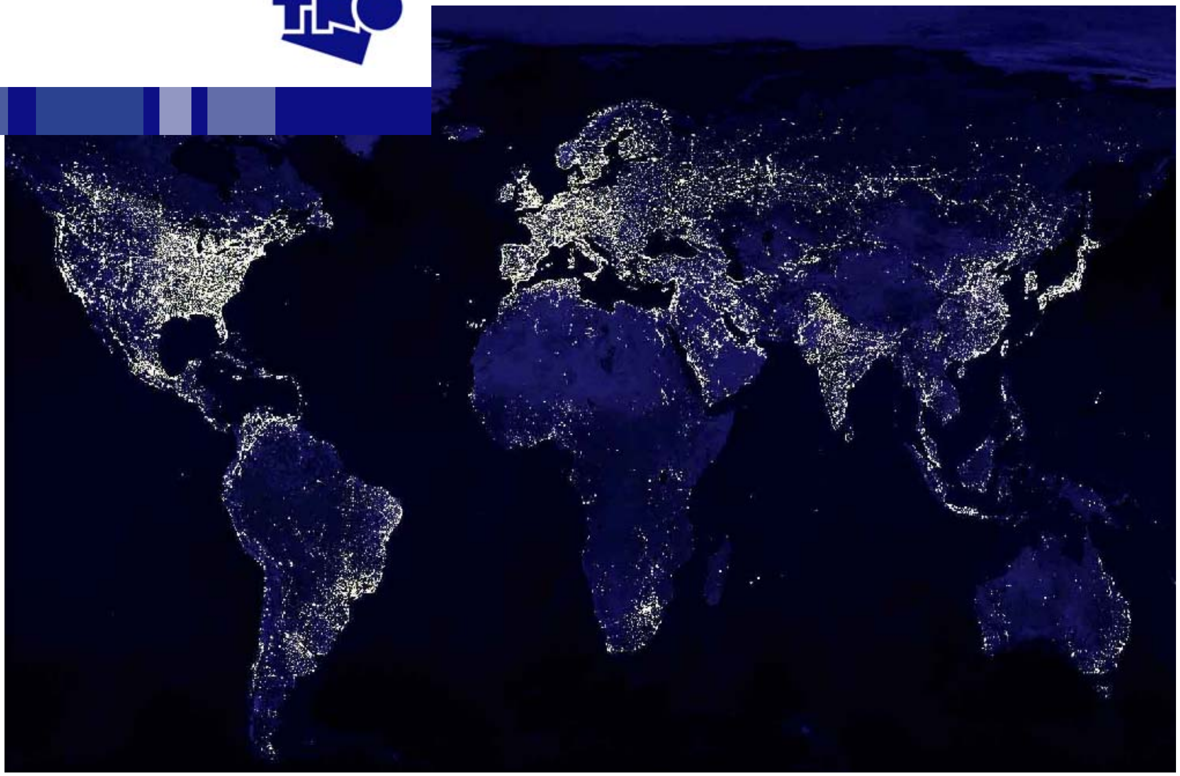
Implications of a resource-poor future for armour materials

October 13, 2008

LWAG 2008, Rijswijk, The Netherlands

TNO | Knowledge for business



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Outline

Exponential demand growth

Global resource depletion

→ **the "big picture"**

Energy scarcity

Minerals scarcity

Aggravating conditions

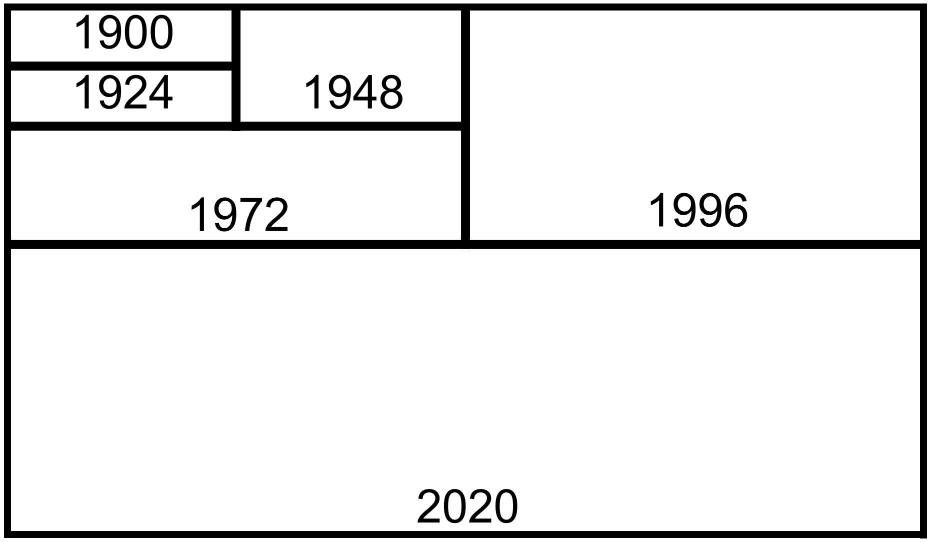
→ **scarcity of materials**

Implications for armour materials

→ **planning ahead**

Exponential demand growth

growth rate (% per year)	doubling time (years)
2	36
3	24
4	18
5	14
6	12
7	10
10	7



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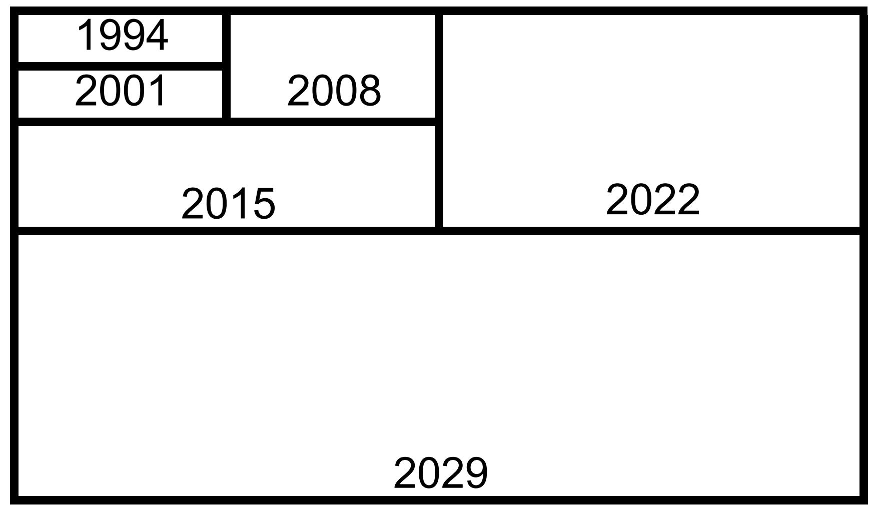
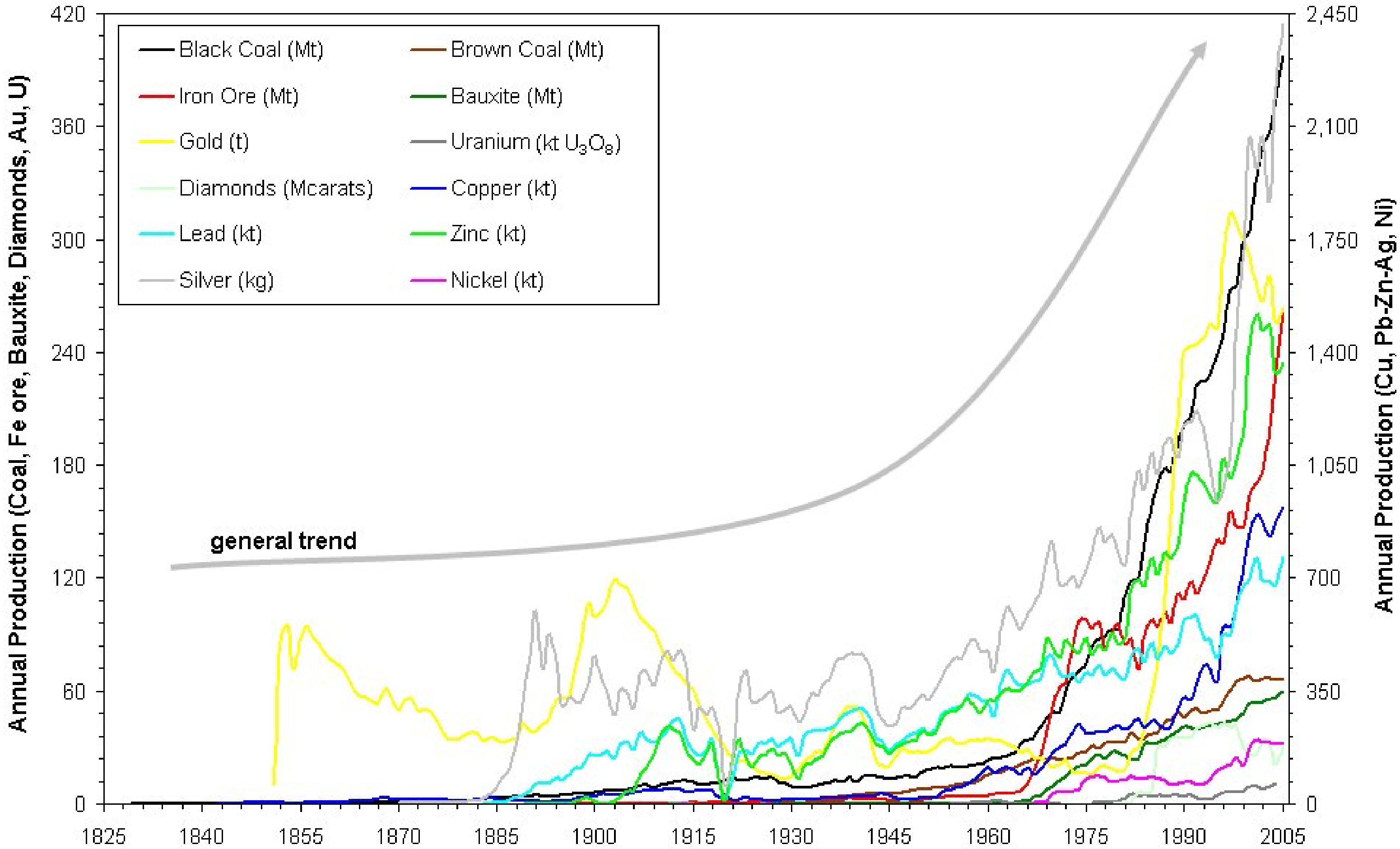


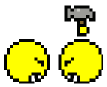
Example of exponential demand growth: mining in Australia



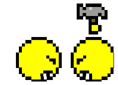
Source: Monash University, October 2007

Global resource depletion

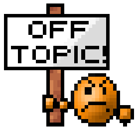
Inconvenient truth: **global resource depletion** (fossil fuels, food/fertilizer/arable land, potable/fossil water, minerals, ….)



→ huge global potential for escalating resource conflicts



(to be compounded by other non-negligible global risks ….)



← are you sure?

Simple observation: we are using too much resources with too many people much too fast on a global scale

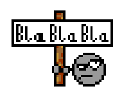
↑ number is steadily increasing!

Global resource depletion

- Not something of the future, it is happening **NOW**
- We no longer live in a normal world, we should let go of many "normal" notions

- The aggregate implication of global resource depletion is collapse

- **Collapse is** not an event but **a decades-long process**, therefore not clear to recognize whilst in it → denial 

- Collapse is <u>unevenly distributed</u>, one region can be in collapse whilst another region prospers → denial 

- Change during collapse is <u>non-linear</u>: the fact that current change is happening quickly doesn't mean that it will continue to happen at the same pace, or even in the same direction → denial 

Global resource depletion

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Preliminary conclusion:

Optimism is a sympathetic form of stupidity

The need for ***affordable*** solutions

Global resource depletion →

- Steady cost (value) increase of virtually everything
- Economic stagnation / recession / depression
  (note: non-linear distribution around globe)

The need for ***available*** solutions

Global resource depletion →

- Resource nationalism / export restrictions
- Stagnating supply, spot shortages
- Rationing of commodities (fuels first)
- More corruption as a consequence of scarcity

Free markets do not always work when demand outstrips supply

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Free markets do not work when demand outstrips supply

hope for the best,
prepare for the rest

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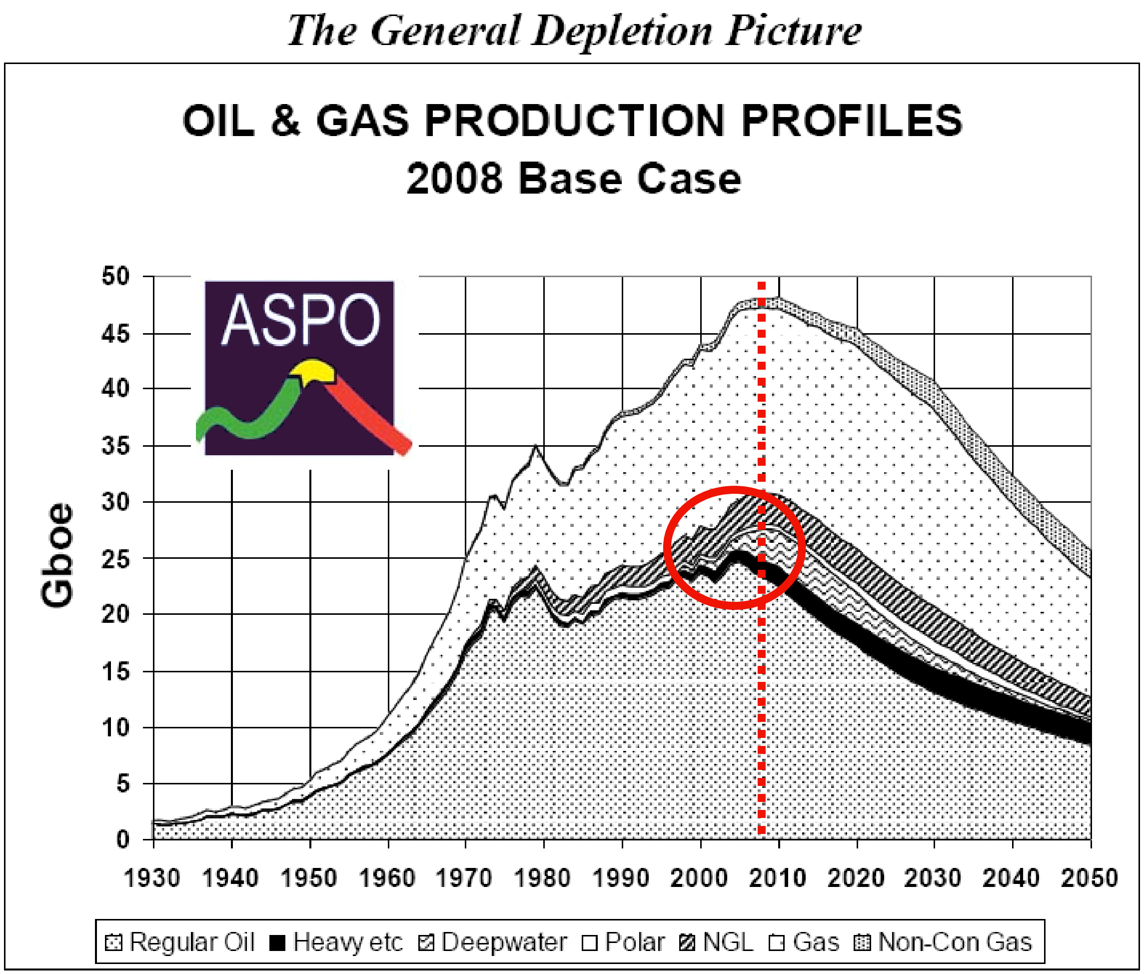
Worldwide, regular oil has already peaked (circa 2005) and natural gas is estimated to peak in 2020

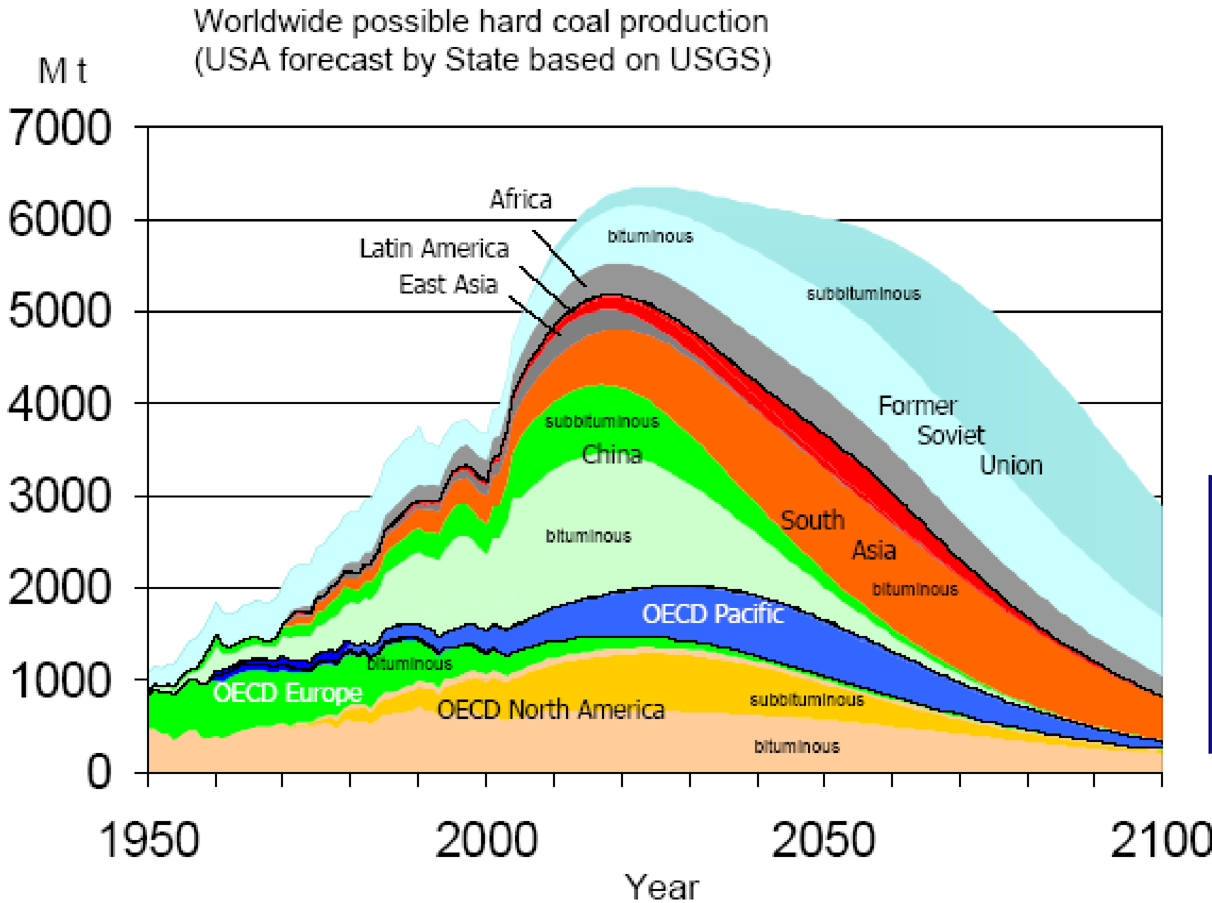


Peak = maximum possible rate of production, when supply can no longer grow

consequence:
soaring energy value

ENERGYWATCHGROUP

Worldwide, “Peak coal” is estimated to occur between 2025 and 2030



Peak = maximum possible rate of production, when supply can no longer grow

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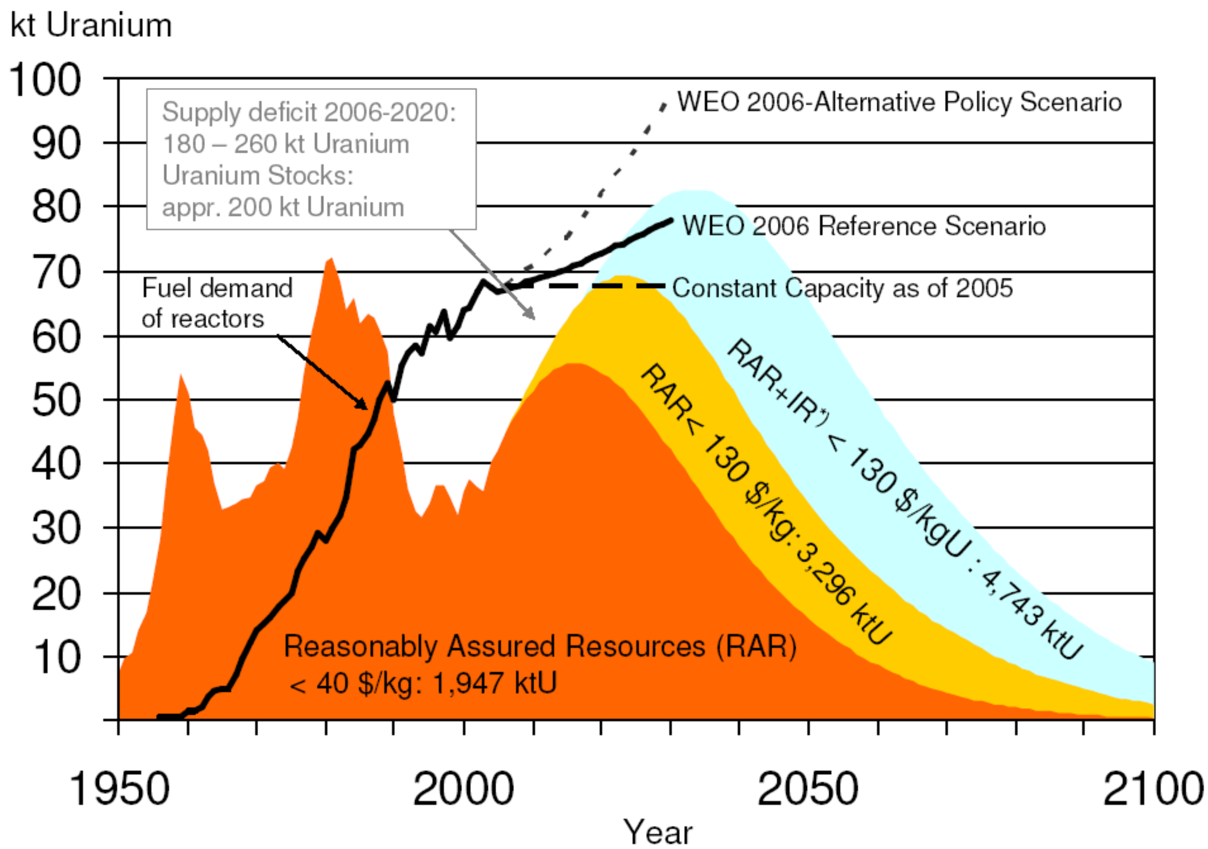
Source: EWG-report, March 2007

ENERGYWATCHGROUP

Nuclear fission: “peak uranium” could already be reached within the next decade



Peak = maximum possible rate of production, when supply can no longer grow

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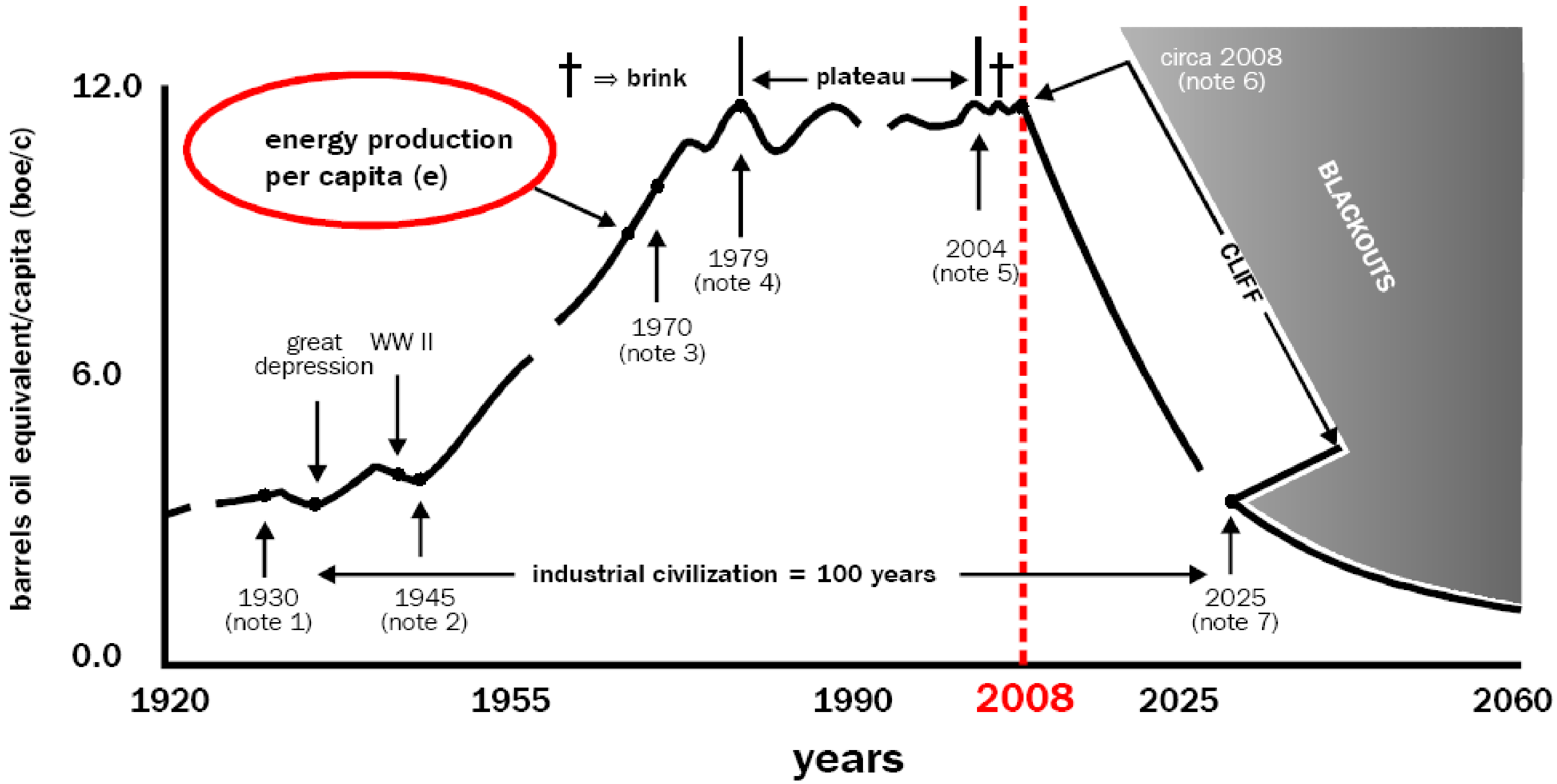
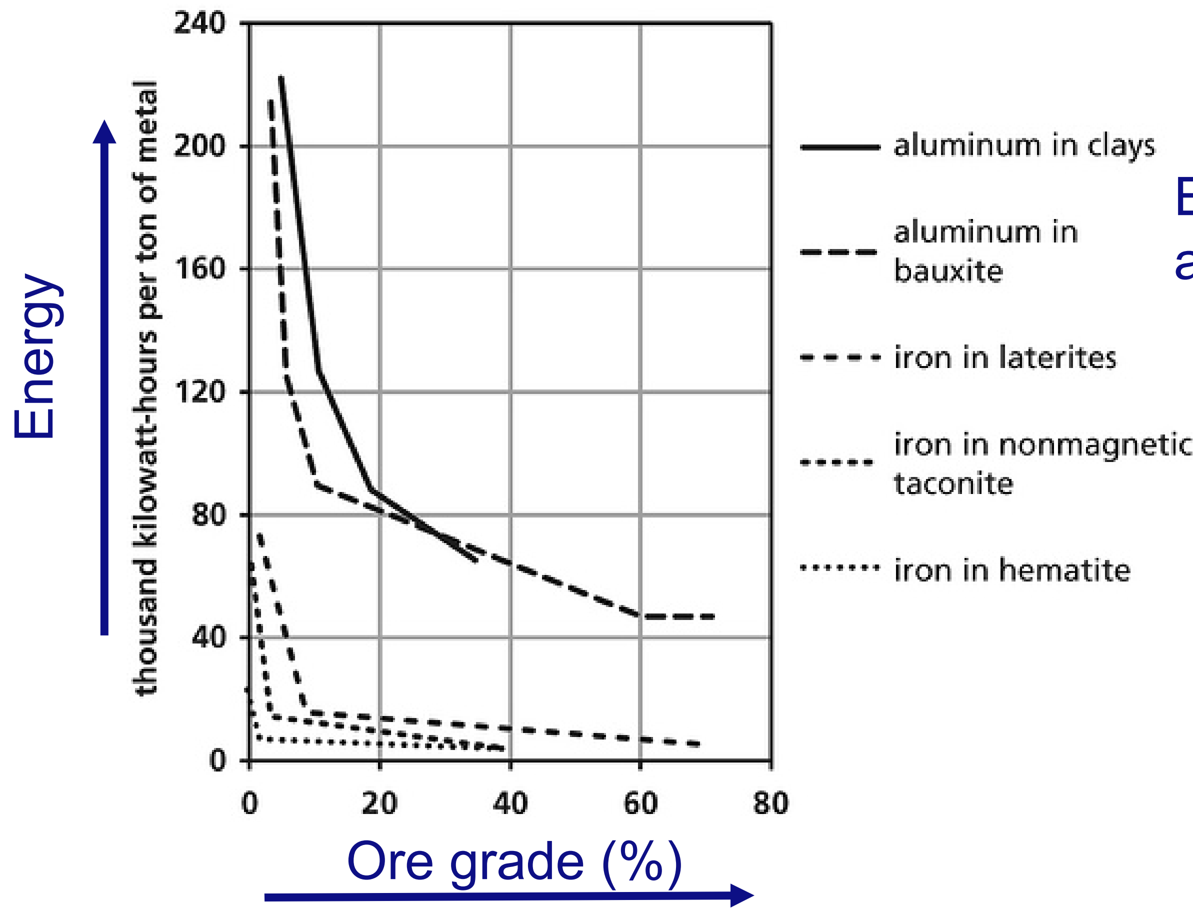
Source: EWG-report, December 2006 ENERGYWATCHGROUP

Looking at a global scale: energy production related to world population



Source: The Olduvai Theory by Richard C. Duncan, 2005/2006

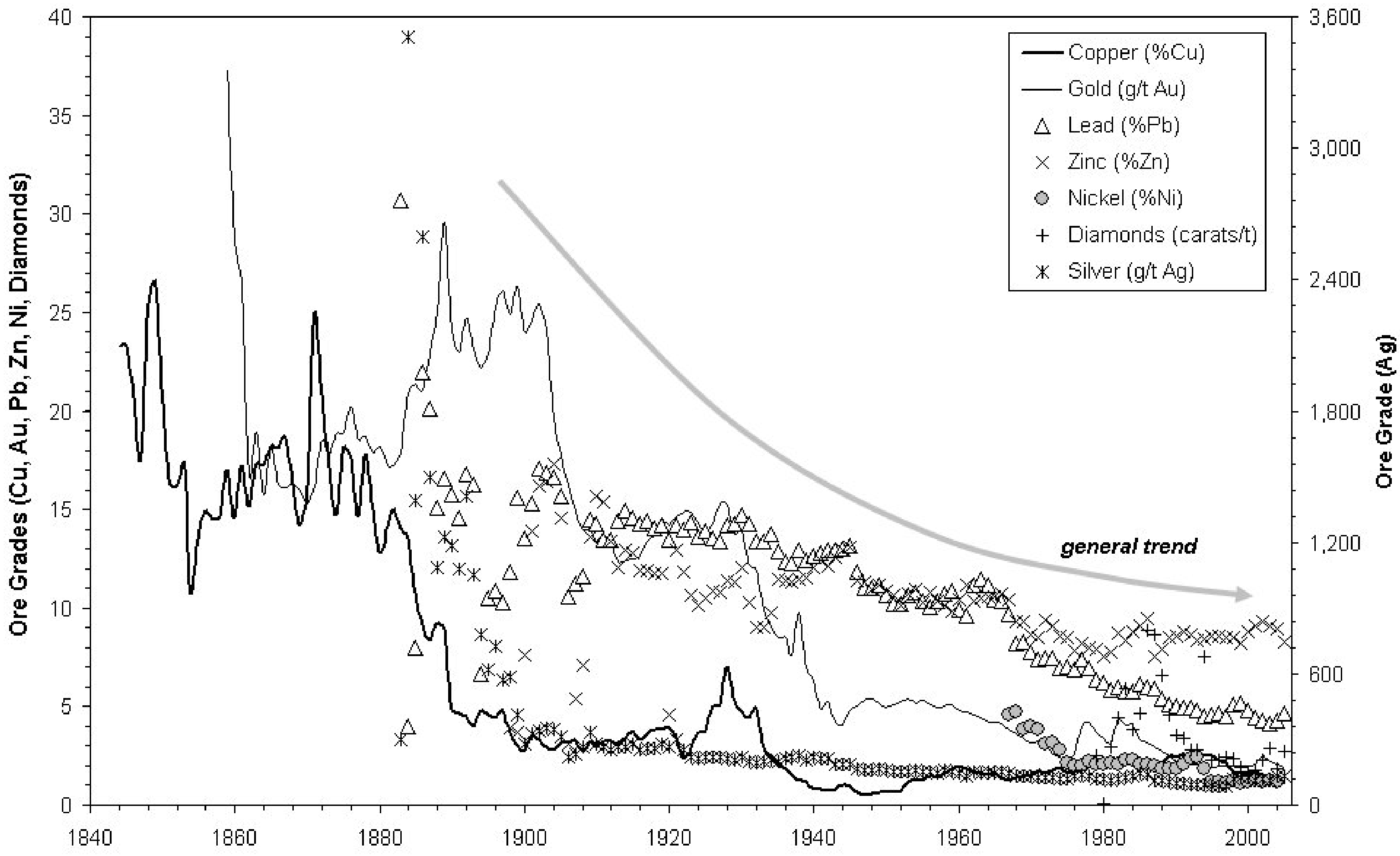
Lower ore grades require exponentially larger amounts of energy for metal extraction



Example:
aluminium and iron

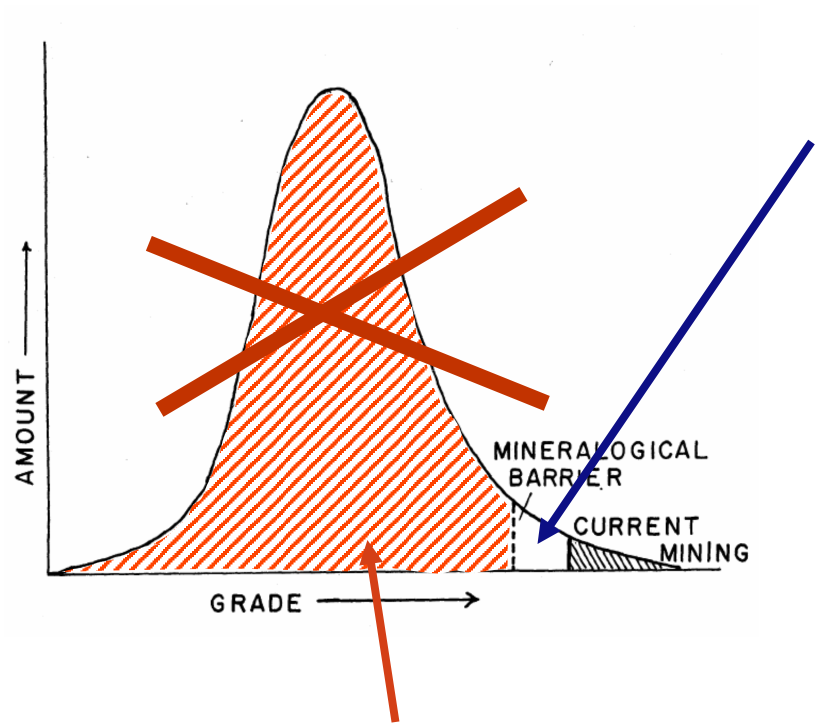
Source: Limits to growth – the 30-year update, Meadows et al, 2004

Example of lower ore grades: mining in Australia



Source: Monash University, October 2007

Mineralogical barrier for elements ≥ 0.1% (by weight) of the Earth's crust

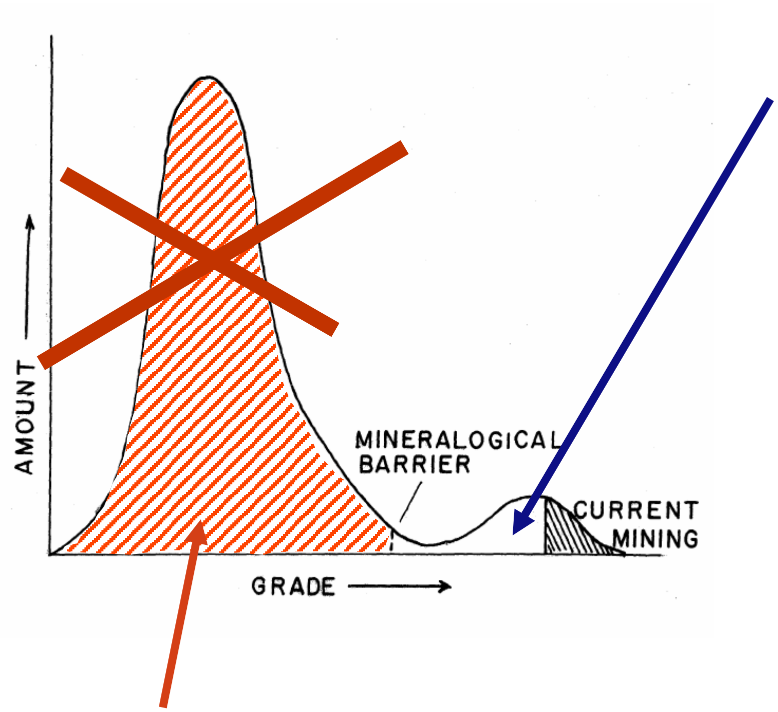


remaining reserves of **aluminium, iron, magnesium and titanium (, …..)**

Extremely energy intensive to extract

Source: "Exploring the resource base" by Brian J. Skinner, Yale University, 2001

Mineralogical barrier for elements < 0.1% (by weight) of the Earth's crust



remaining reserves of
other minerals
(V, Cr, Mn, Co, Ni, Cu, Zn, Y, Zr, Nb, Mo, Cd, Sn, Sb, Ta, W, Pb, Bi, U, ….)

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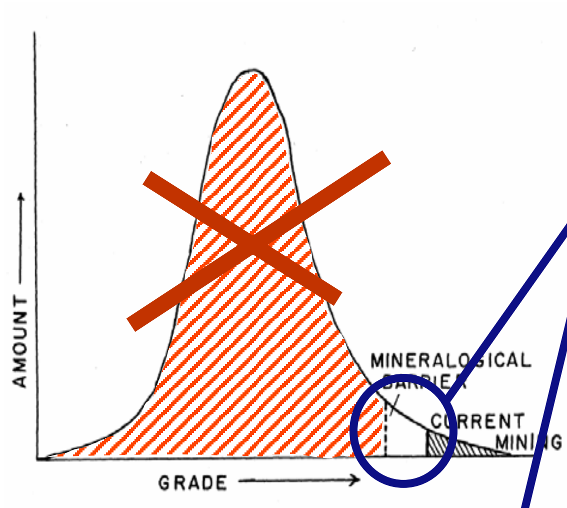
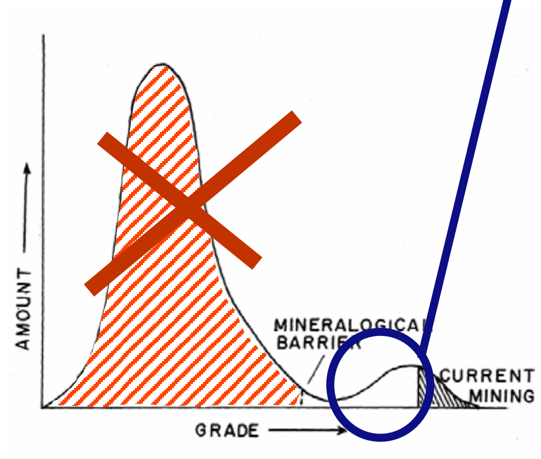
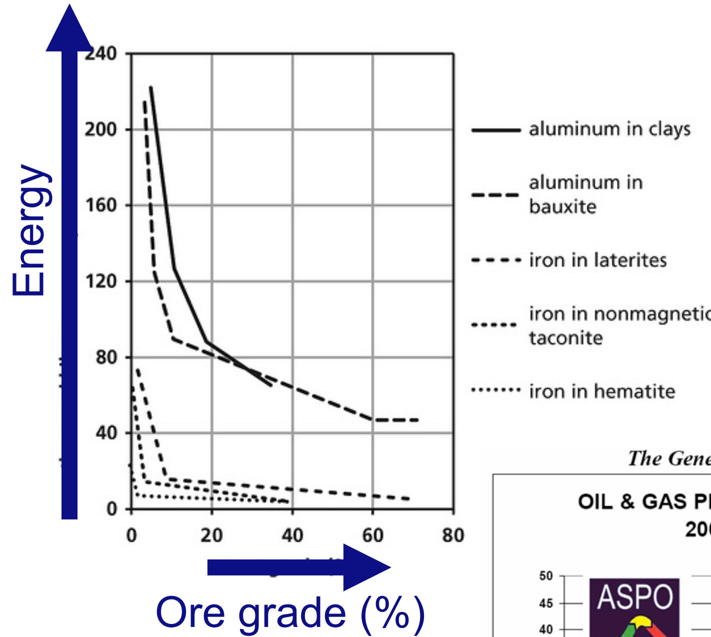
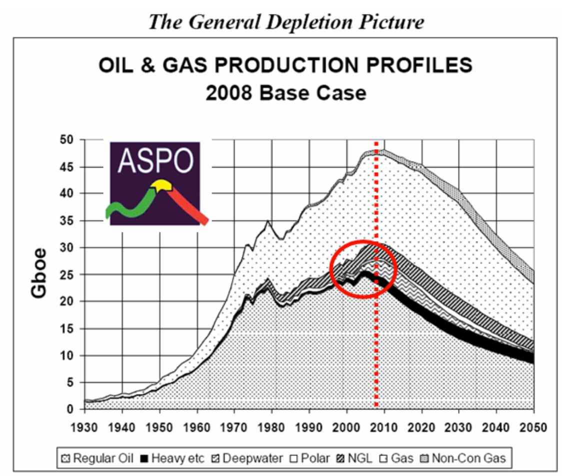








consequence:

soaring material value

Resources run short: aggravating conditions

- Substitution problems
  - Global economy: nowhere to run
  - Magnitude of global energy and resource consumption: cascade of supply shortages among alternatives
  - Oil, gas and coal are – besides an energy source – an essential raw material

- Just-in-time economy and free market economy → less strategic supplies in Western world (contrary to Cold War period and some time thereafter)

- Remaining reserves are increasingly concentrated outside Western world, sometimes in just a few countries

- Exportcrisis preceeds actual physical shortages due to increasing internal consumption of exporting nations, profiteering and geopolitical factors

Outlook for minerals: available but much more expensive

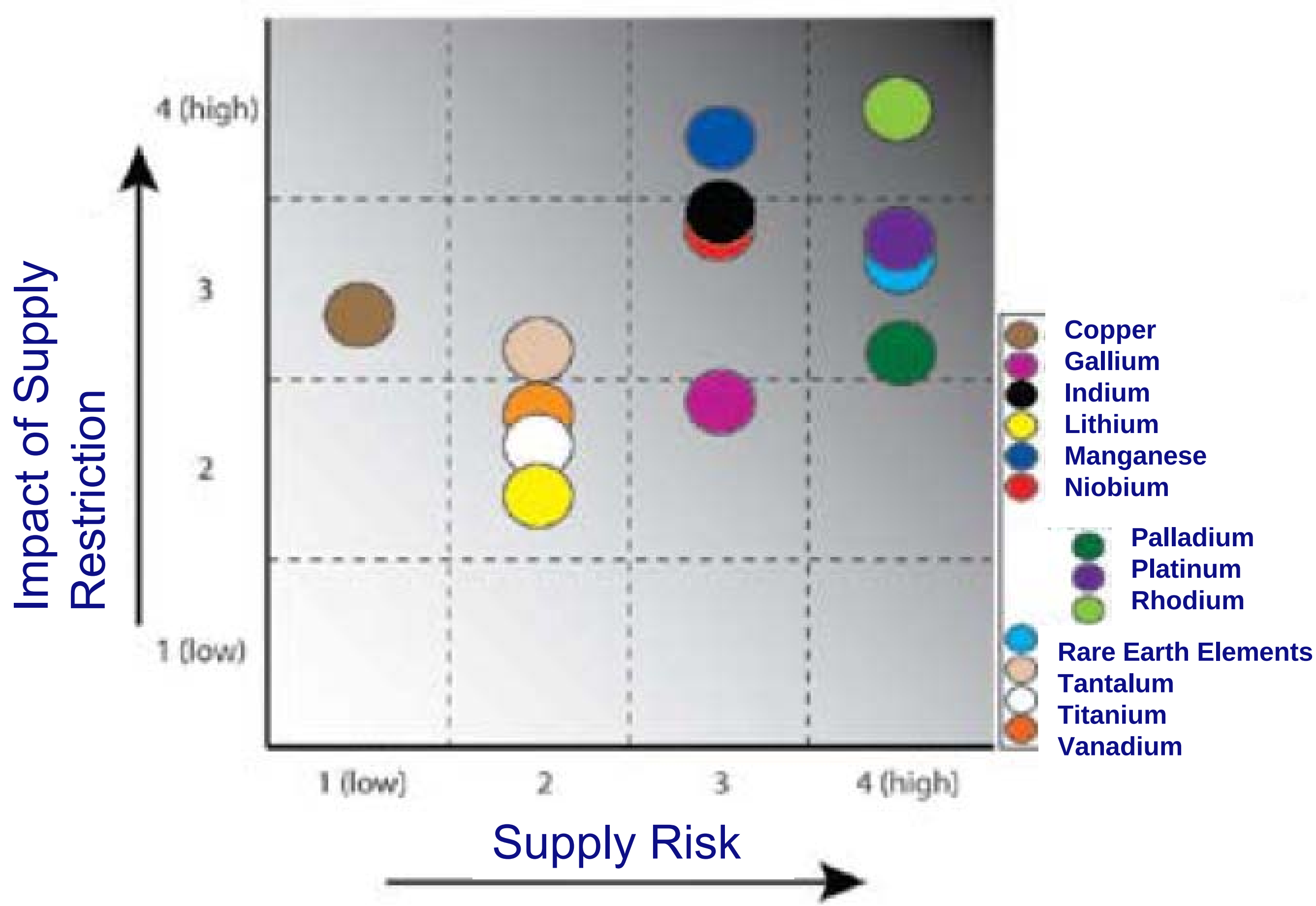
- Earth's crust still holds enough deposits above mineralogical barrier for primary production

- More energy required for extracting lower grade ores (or deeper mining)
- Energy gets more and more expensive (valuable)
- Exponential demand growth

} ➡

➡ **minerals become exponentially more expensive (valuable), starting with the rare and with the difficult to substitute ones**

Supply risk is being acknowledged by authorities



Source: US National Materials Advisory Board, October 2007

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Planning ahead

1. Reinstate strategic stockpiles

2. Substitution: yes, and:
   - Alternatives usually cost more energy
   - Hard to imagine scale of materials use (worldwide, various industry sectors) leads to cascade of substitutions

3. Recycling and reuse: yes, and:
   - Always losses (< 100% recycling) and degradation
   - Recycling currently of the order of 30% or more
   - Extreme recycling unlikely until crisis really hits
   - Costs energy, although much less than primary production

4. Use less (unlikely until crisis really hits)

Lessons from a less affluent past: steel armour

- World War 1: 8-14 mm thickness
- World War 2: up to 250 mm thickness (and yet a useful toughness)
- 1960s: 4340 electro slag remelted

All of these: >94% iron

German Jagdtiger, World War 2

Lessons from a less affluent past: aluminium armour

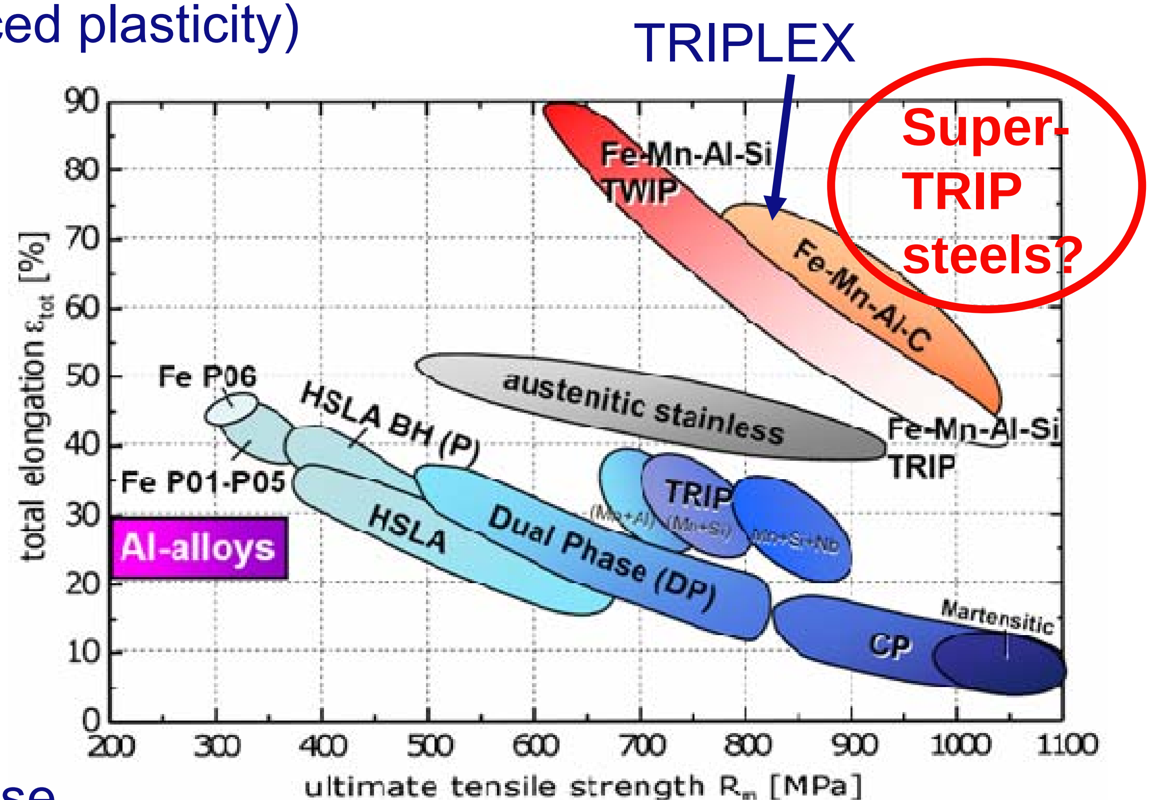
- 1950s/1960s: aluminium 5083 (± 4.5% magnesium)
- No better ***overall*** aluminium armour yet

Israeli M113
(shown with reactive add-on armour)

Austenitic steel armour for *thin* plates?

- TRIP (transformation induced plasticity)
- TWIP (twinning induced plasticity)
- TRIPLEX (3 phases)

Source: Max-Planck-Institut für Eisenforschung GmbH

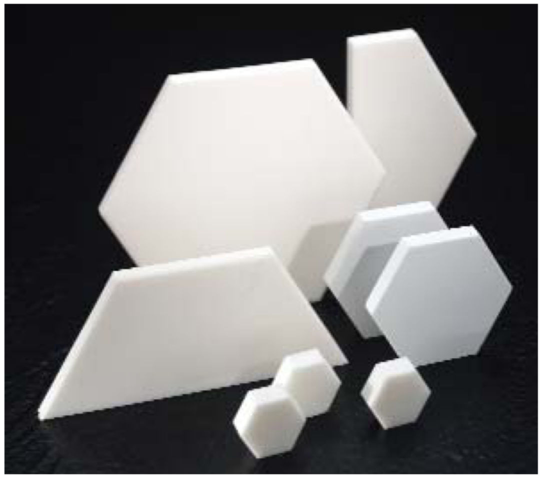


- Super-TRIP steels:
  - 14-18% manganese
  - 2-12% aluminium
  - <5% chromium, vanadium and/or molybdenum

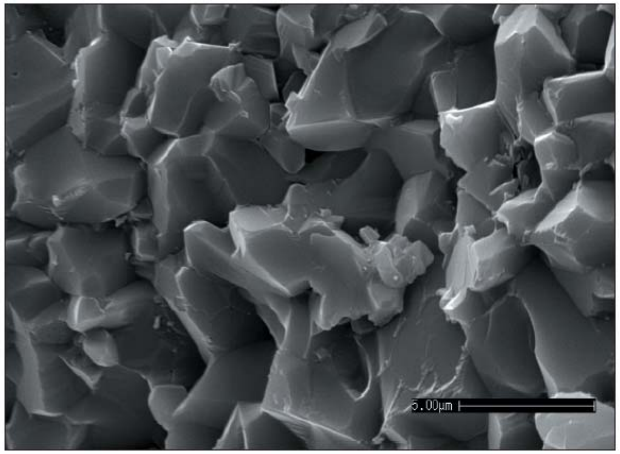
Ceramic armour

selective improvement of bulk materials

- Ceramics are (partly) less susceptible to energy and minerals scarcity
- Alumina (Al_2O_3) does not require an inert gas atmosphere or a vacuum for production
- From most to least energy intensive: pressureless (or liquid phase) sintering, hot-pressing and reaction bonding



- Important development: increased dynamic resistance to fracture **using micron-/sub-micron-/nano-sized reinforcing elements for improved microstructure**



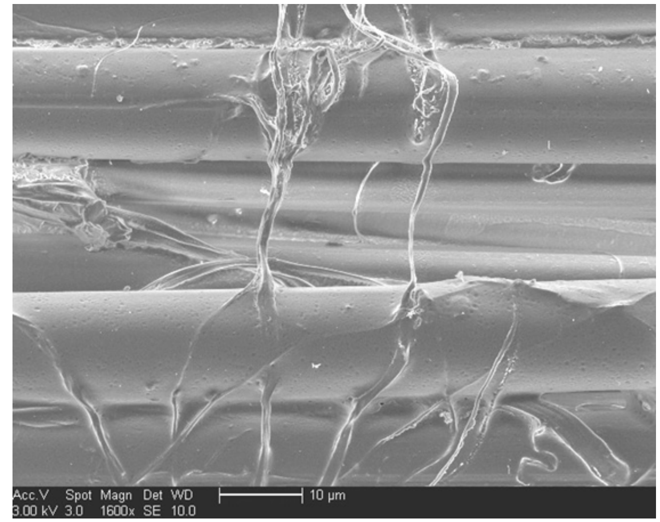
Polymers and carbon structures

- Polymers will suffer double from scarcity of fossil fuels: energy *and* raw material
- Polymers suffer most from degradation → limited recycling

- Important development: **coating of fibers with polymers, carbon, metals or ceramics**

selective improvement of bulk materials

- Carbon fiber reinforced plastic (CFRP) costs huge amounts of energy → restriction to flying platforms or *non-bulk* vehicle applications?

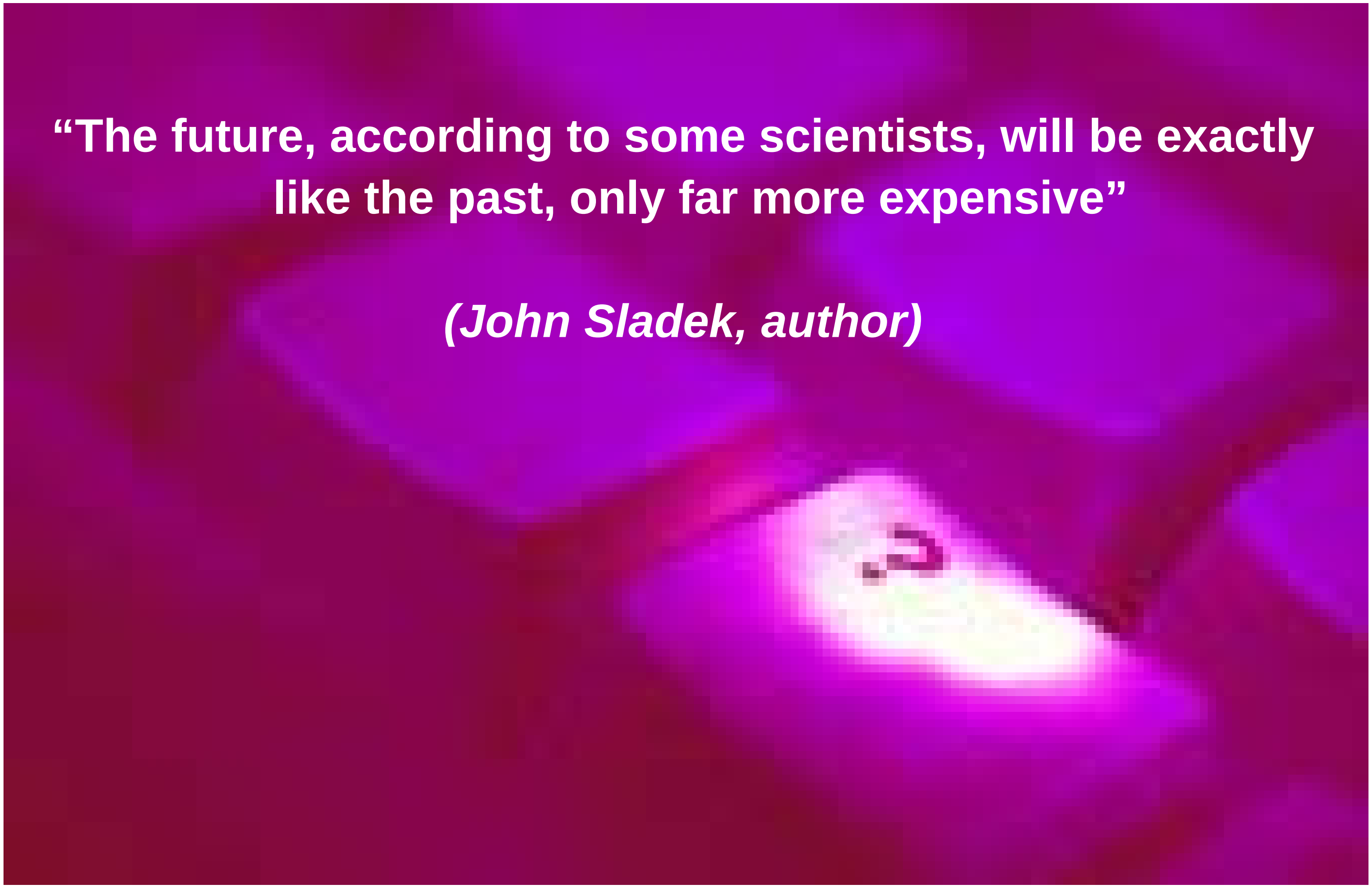


	GJ / ton
construction steel	58
stainless steel	115
aluminium	290
magnesium	415
titanium	560
polyethylene	80
nylon	180
natural rubber	6
synthetic rubber	140
bricks, pantiles	6
glass	24
CFRP	4000

Conclusions

- The permanent and increasing energy and minerals scarcity will be an ever increasing factor co-determining the choice and application of materials for armour
- Those who manufacture and apply armour using less energy and less scarce materials will have a ***growing*** advantage over those who don't
- Newly produced armour will increasingly reuse, combine and improve various existing ("old") solutions springing from a less affluent era
- Part of the improvement of existing solutions is the selective combination of small quantities of "special" materials with large quantities of "cheap" (less valuable) materials

Questions?



“The future, according to some scientists, will be exactly like the past, only far more expensive”

(John Sladek, author)