The raw materials - energy nexus

The crucial role of "structural raw materials" to the energy transition and social development

Olivier Vidal, CNRS, Isterre
olivier.vidal@ujf-grenoble.fr

Rapport Ressources minérales - Energie

http://www.allianceenergie.fr/page000100dc.aspx?card=1293

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- Cadre général et enjeux
- Besoins en ressources minérales pour la transition énergétique: trois scénarios (2050)
- Mise en regard par rapport aux besoins mondiaux et capacités de production estimées – focus sur les ressources “de base”
- Les besoins énergétiques pour leur production
- Les futurs possibles: les couplages production I – recyclage - énergie-économie
- Recommendations Ancre, groupe sol & sous-sol

35 diapos, environ 45 minutes

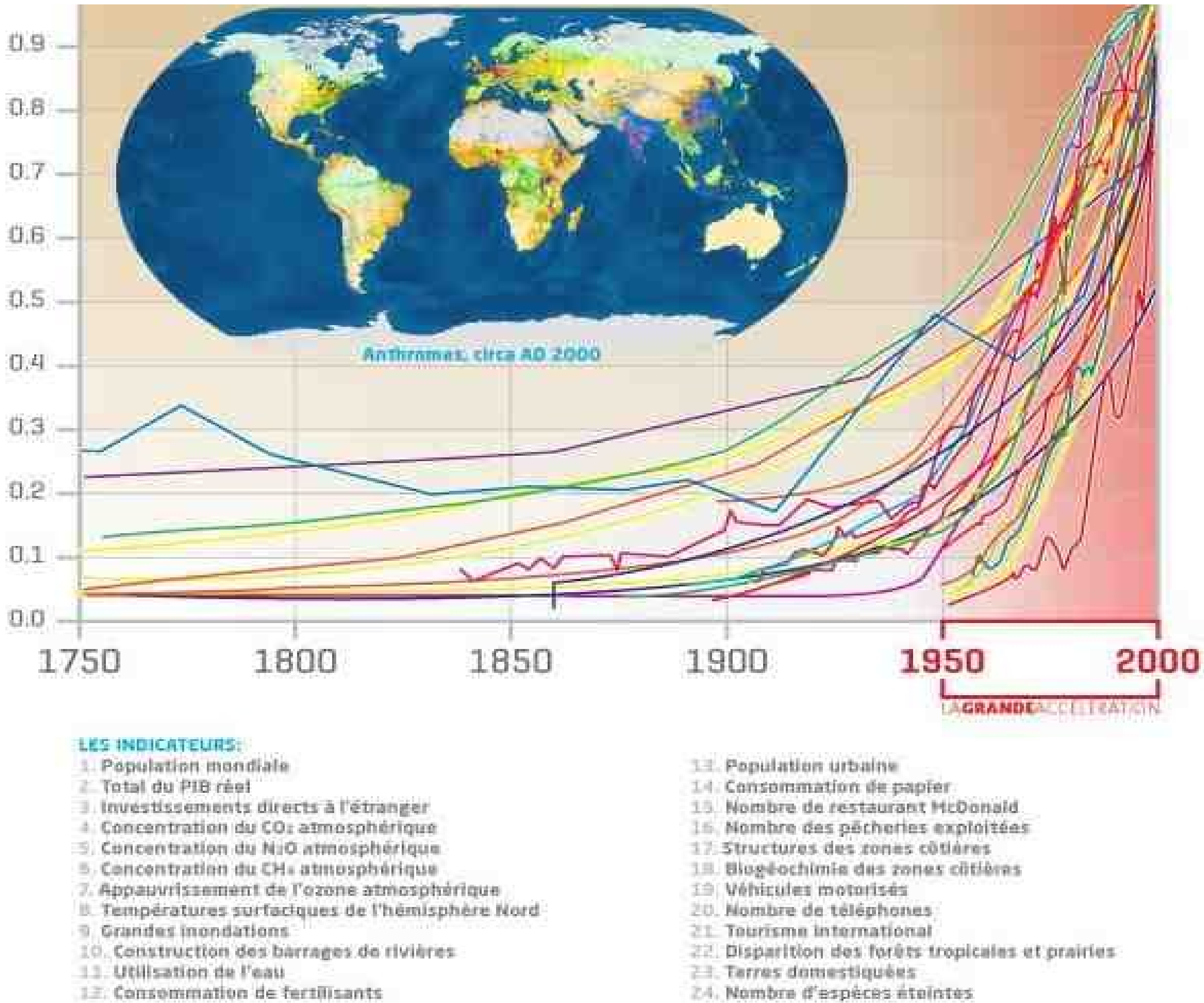
Mineral resources for the transition to low-carbon energy

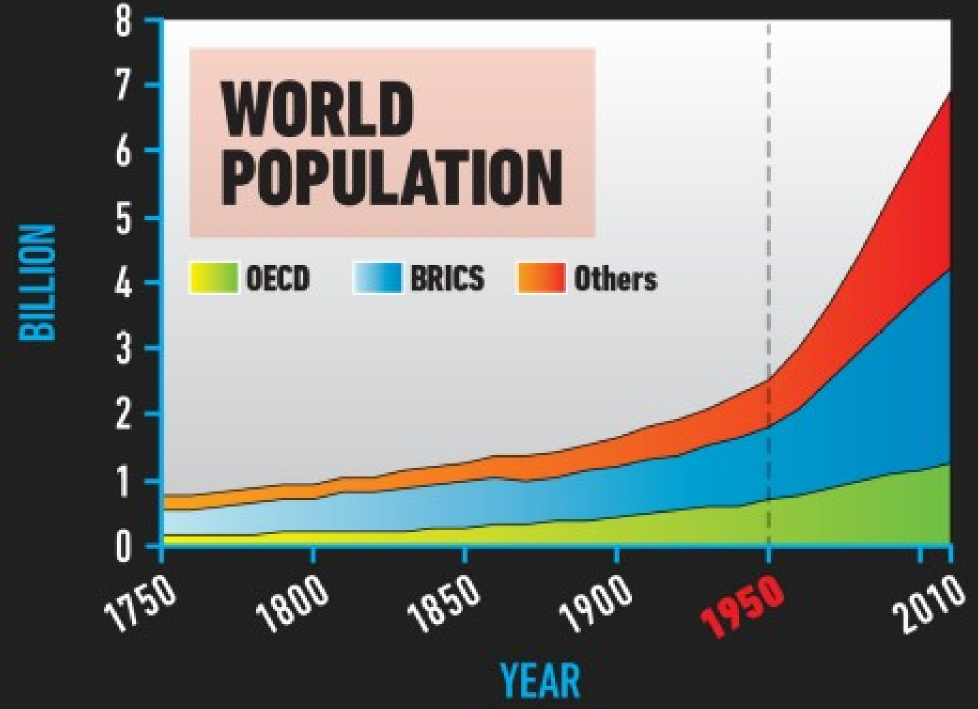
The COP21 Paris agreements foresee reaching the "carbon neutrality" worldwide by 2050.

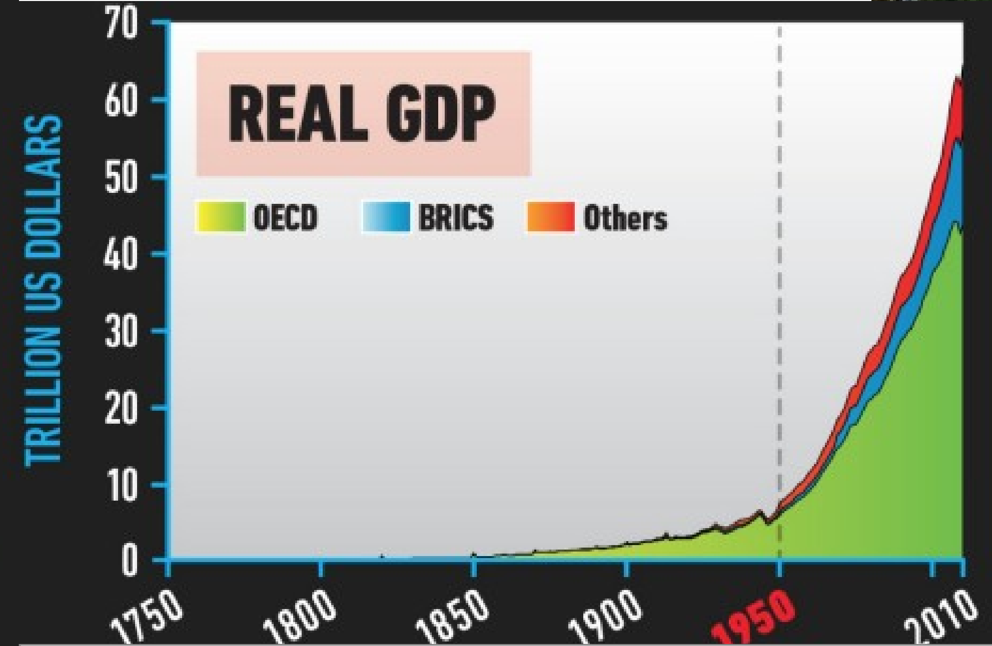
This implies transforming in 40 years the existing (fossil fuels based) system of energy generation, transport, distribution and use.

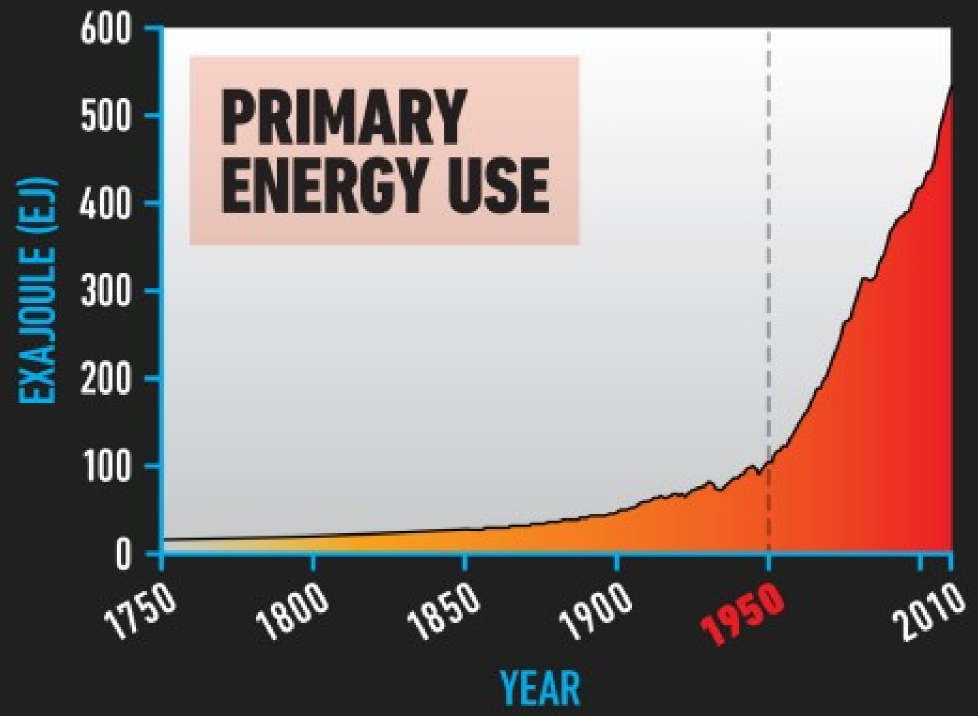
… In a context of growing raw materials and fossil energy demands worldwide

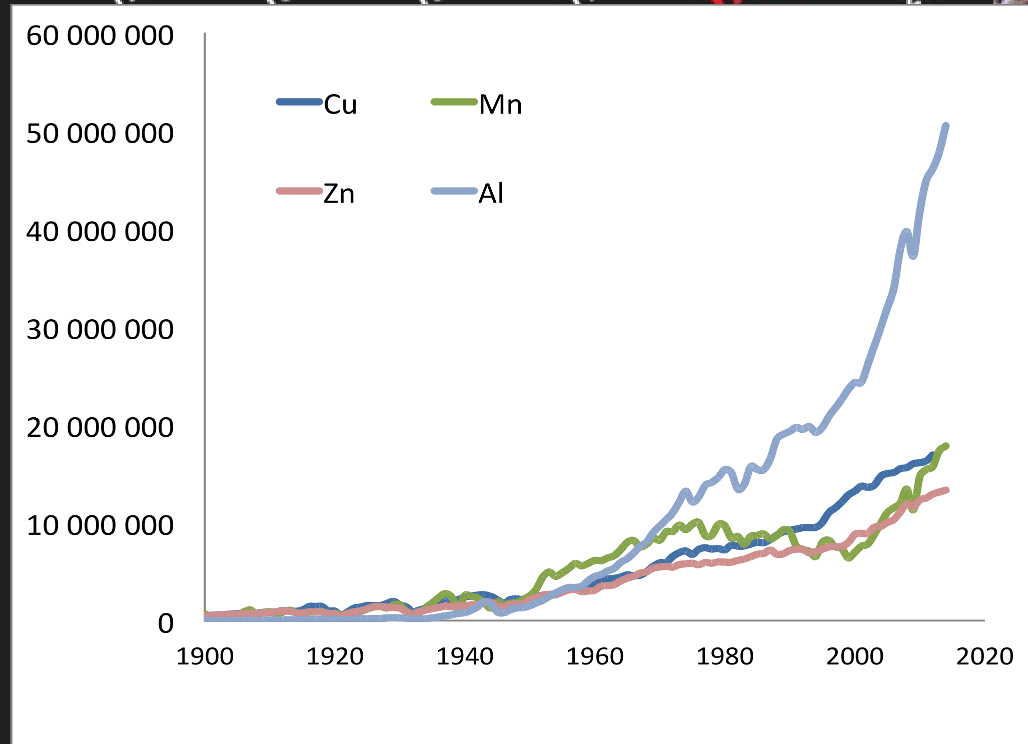
Adapted from Steffen *et al.* (2015)**The trajectory of the Anthropocene: The Great Acceleration** (*Anthropocene Review)*









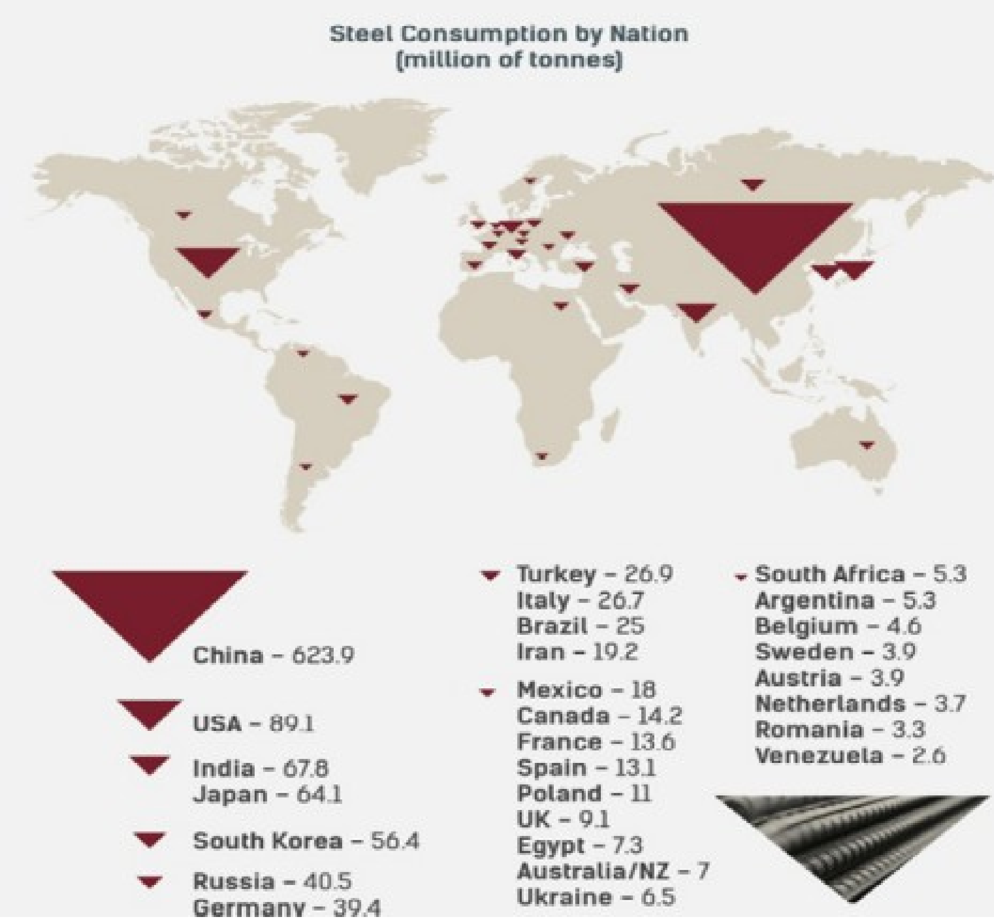


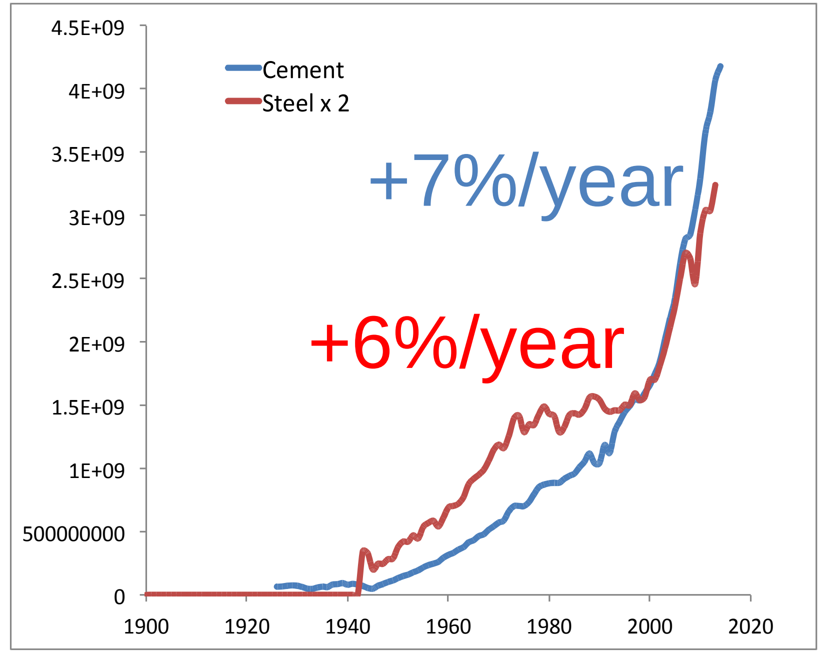
23. Terres domestiquées
24. Nombre d'espèces éteintes

Explosion of structural raw materials consumption – cement, steel, Al, Cu

$(1.06)^{12\text{years}} = 2$

Steel consumption (+ 6%/year 2000-2014)

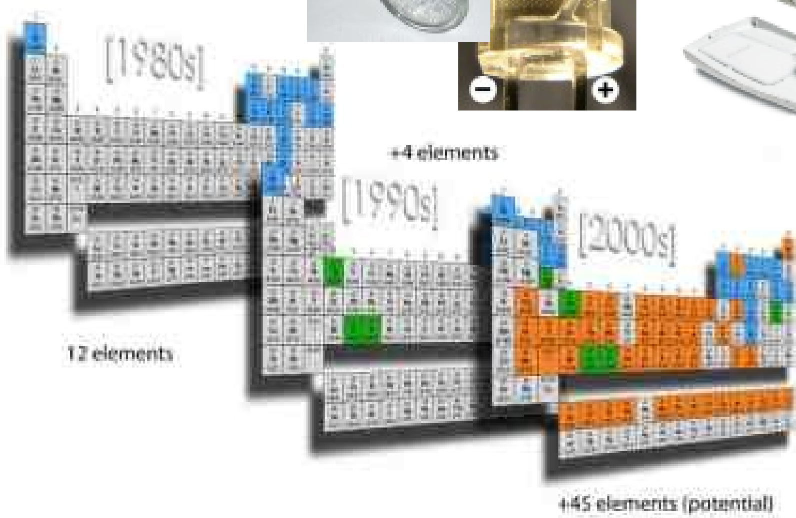




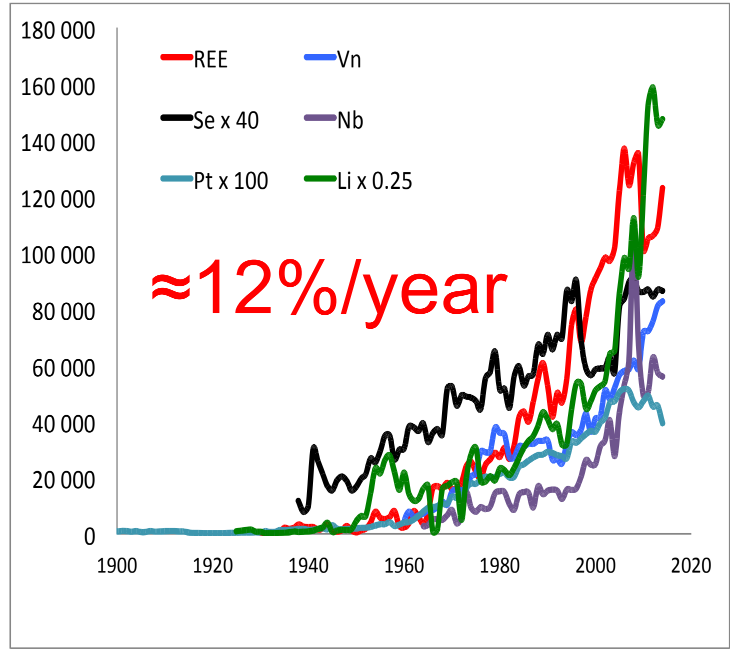
Explosion of « High-tech » metals consumption

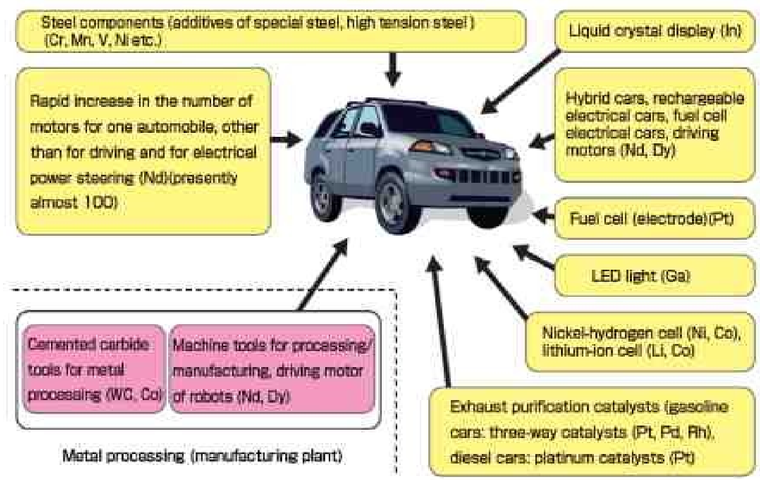
B, Nd, Dy

Ga, In, Se



Co, Ga, In, Nb, Ta,W, PGE, REE, Cu, Ni, Pb, Bi , Li, Ag, Au





The energy-mineral resources Nexus

Increase of energy consumption to produce the raw materials

"> 20 % of the global energy consumed by the industry in 2011 was used for the production of **steel + cement**" *(international energy outlook 2013)* => 50% of the industrial CO_2 emission *(Allwood et al.,2010; IEA, 2010; Carpenter and Center, 2012)*

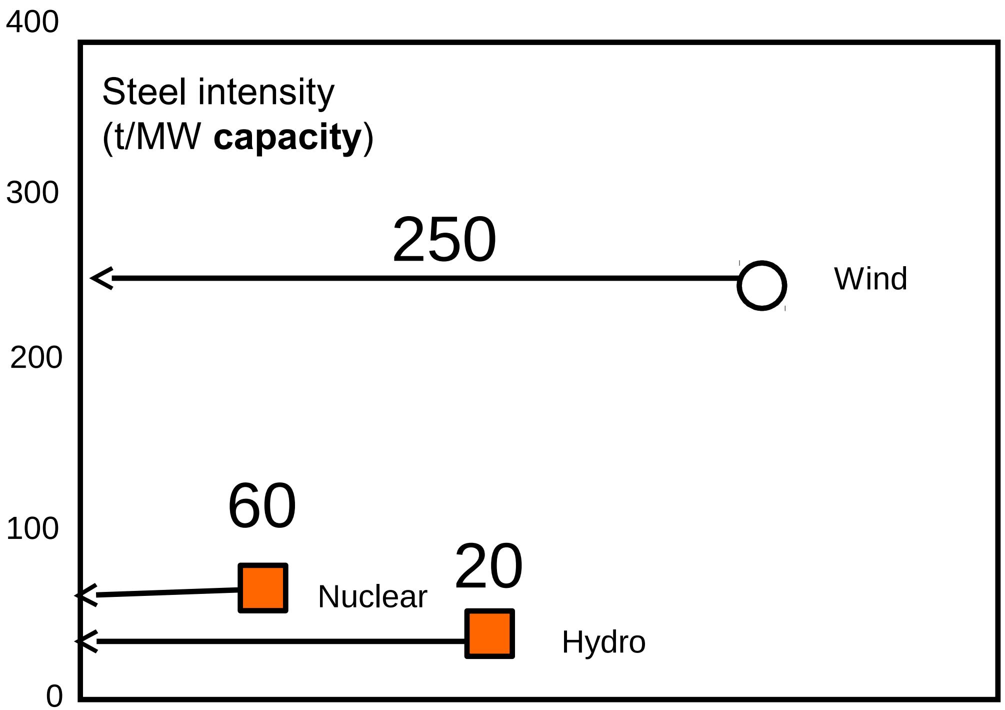
« Energy consumption and intensity in mining and mineral processing is rising at around 6% per annum » *(Australian Bureau of Agricultural and Resource Economics - 2010)*

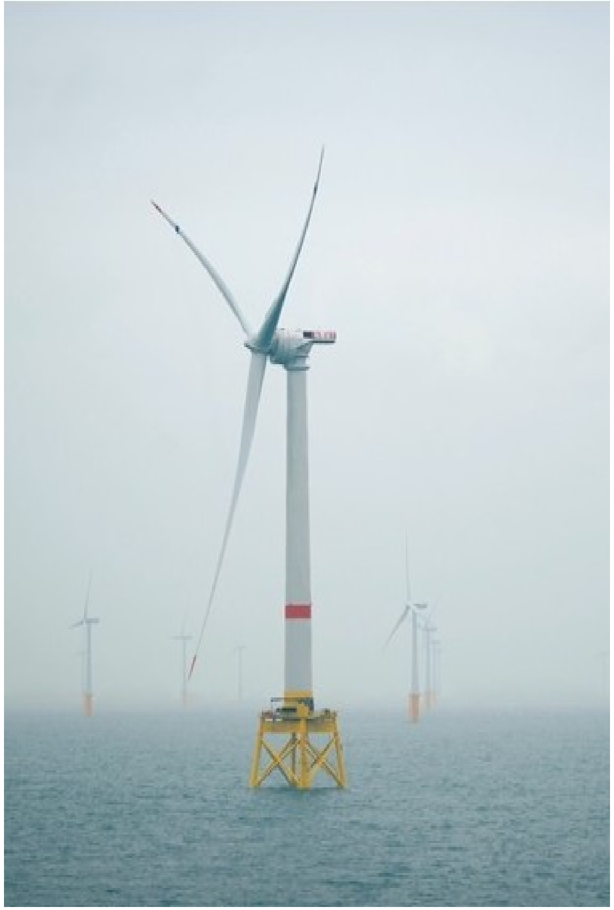
"1 tCO_2 /1t concrete" => 5% of global CO2 emissions *(Natesan et al., 2003)*
2 t CO_2 / t steel => 6-7 % of global CO2 emissions *(Kim & Worrell, 2002)*
66 t CO_2/ t Nd

Increase of raw materials demand to build the future infrastructure of energy

Renewable energy is diluted; it requires large infra-structures to be captured

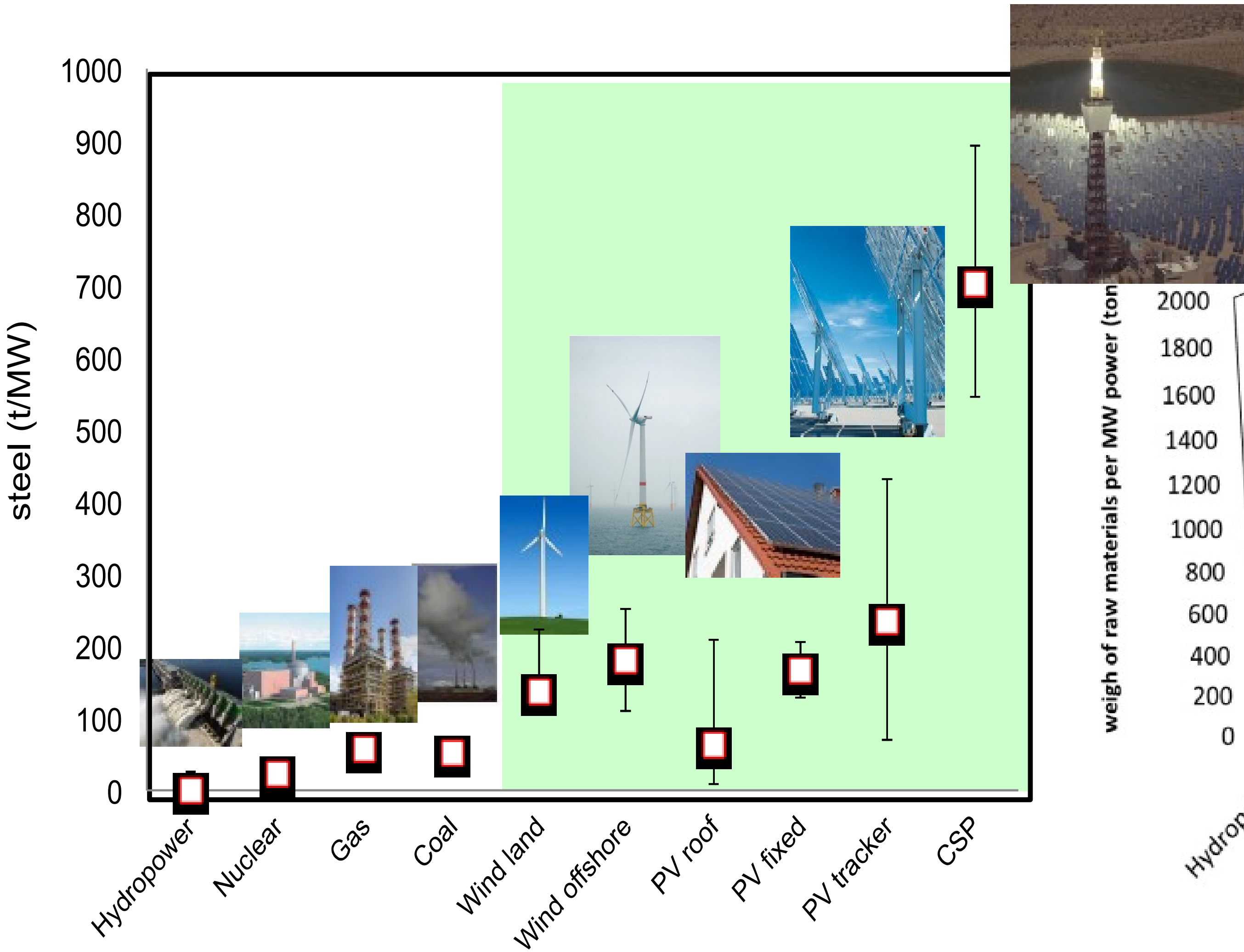
6 Mw, > 150 m high, *1500 t steel,*
Permanent magnet ≈1 t REE (Nd, Dy, *Sm, Gd, or Pr)*

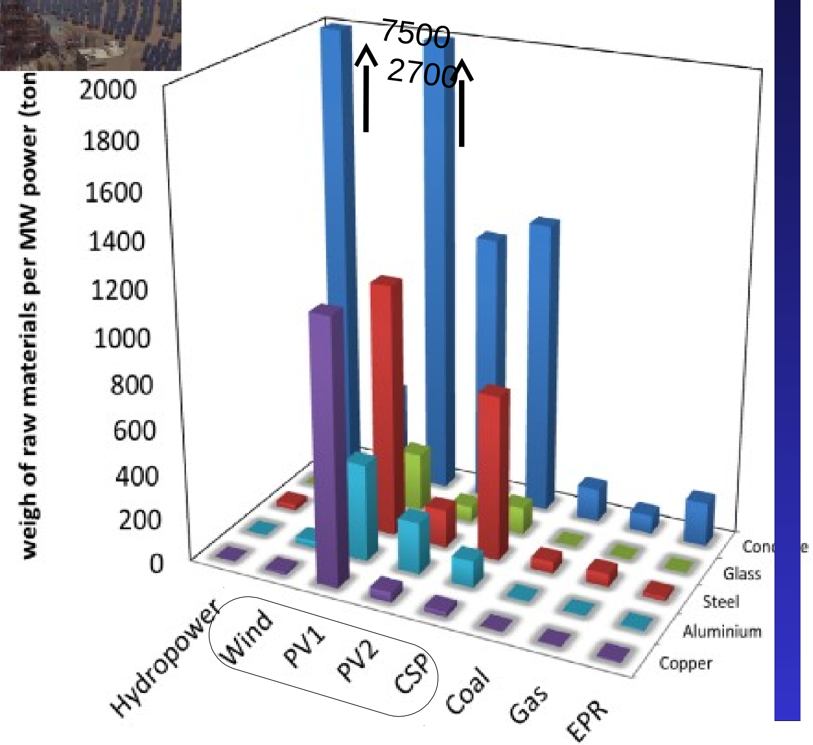




600 wind turbines to produce the same energy (Wh) as a nuclear power plan 1300 MW

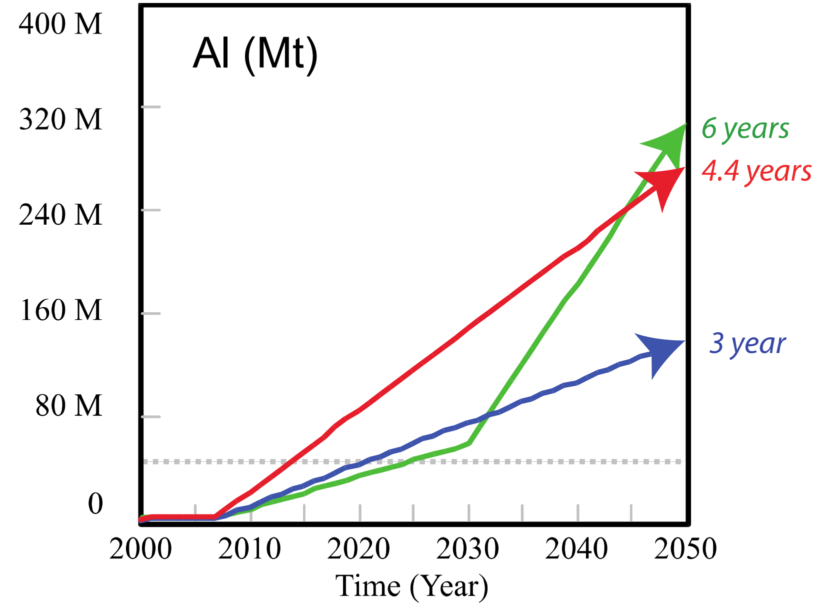
Material intensity of electricity generation

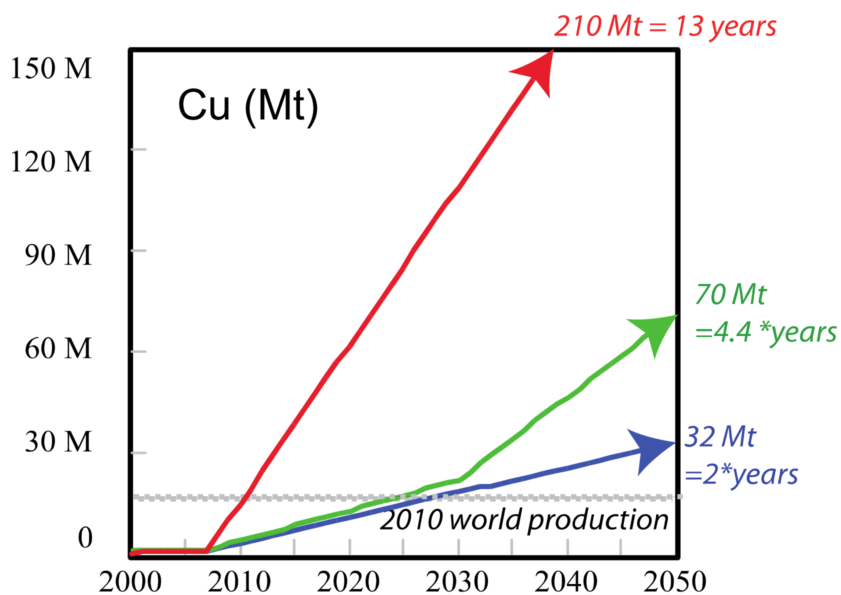


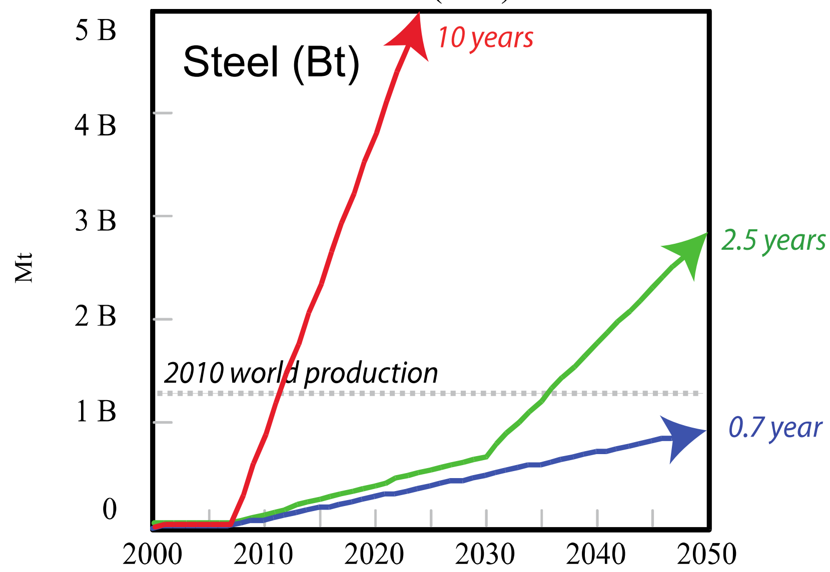


Cumulative amount of metals in the infrastructure of electricity generation

2050: Blue Map IEA (2010)
36 PWeh, *42% renewables*
2050: Ecofys-WWF (2012)
29 PWeh, *100% renewable*
2050: Garcia-Olivares (2013)
109 PWeh, *100% renewable, only electricity*

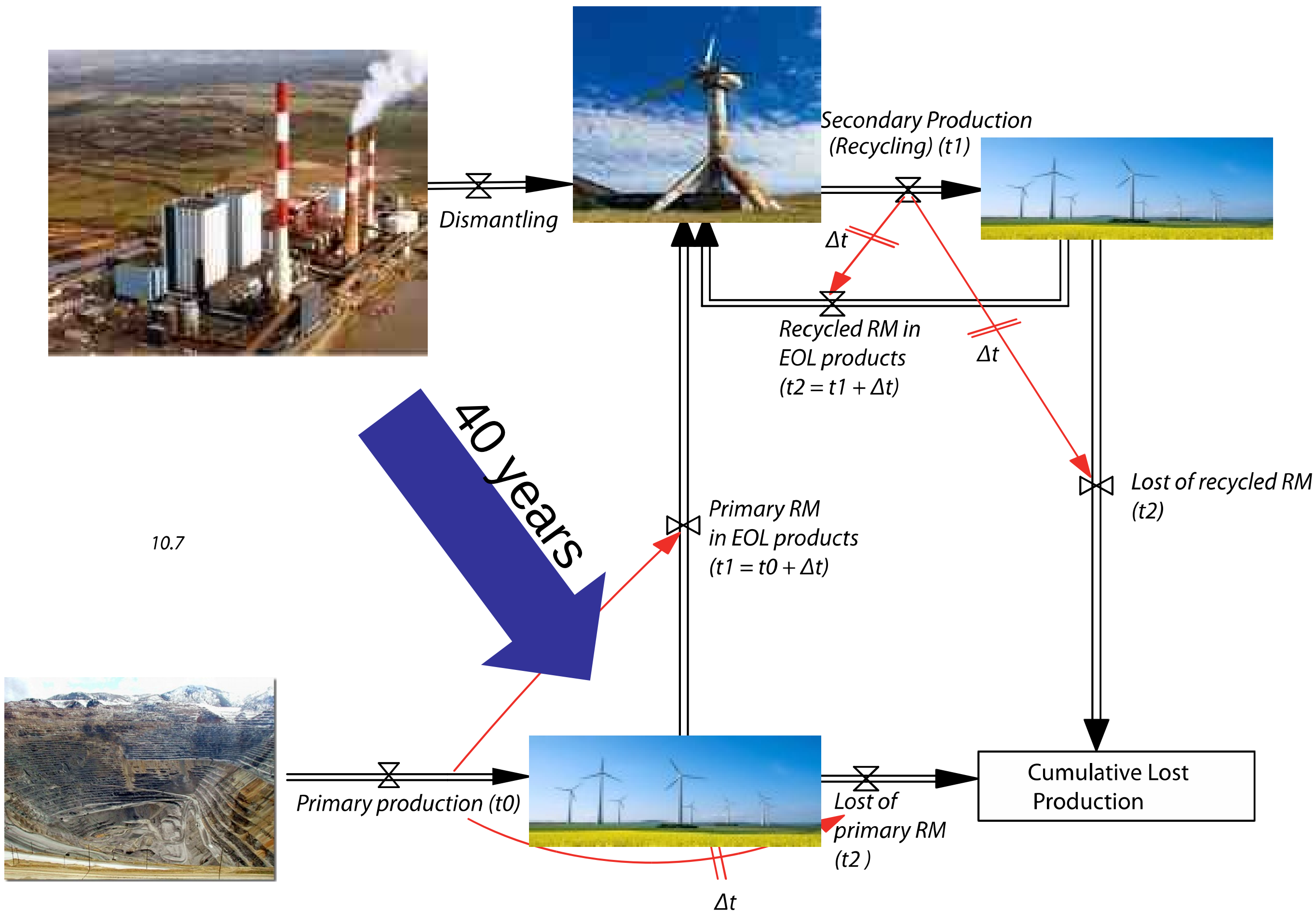


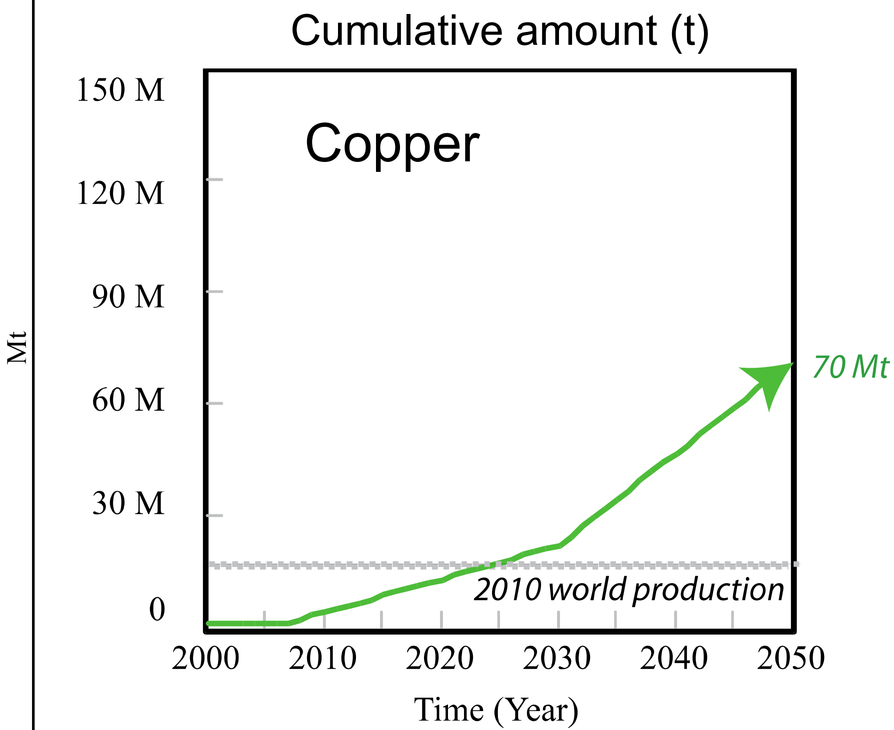


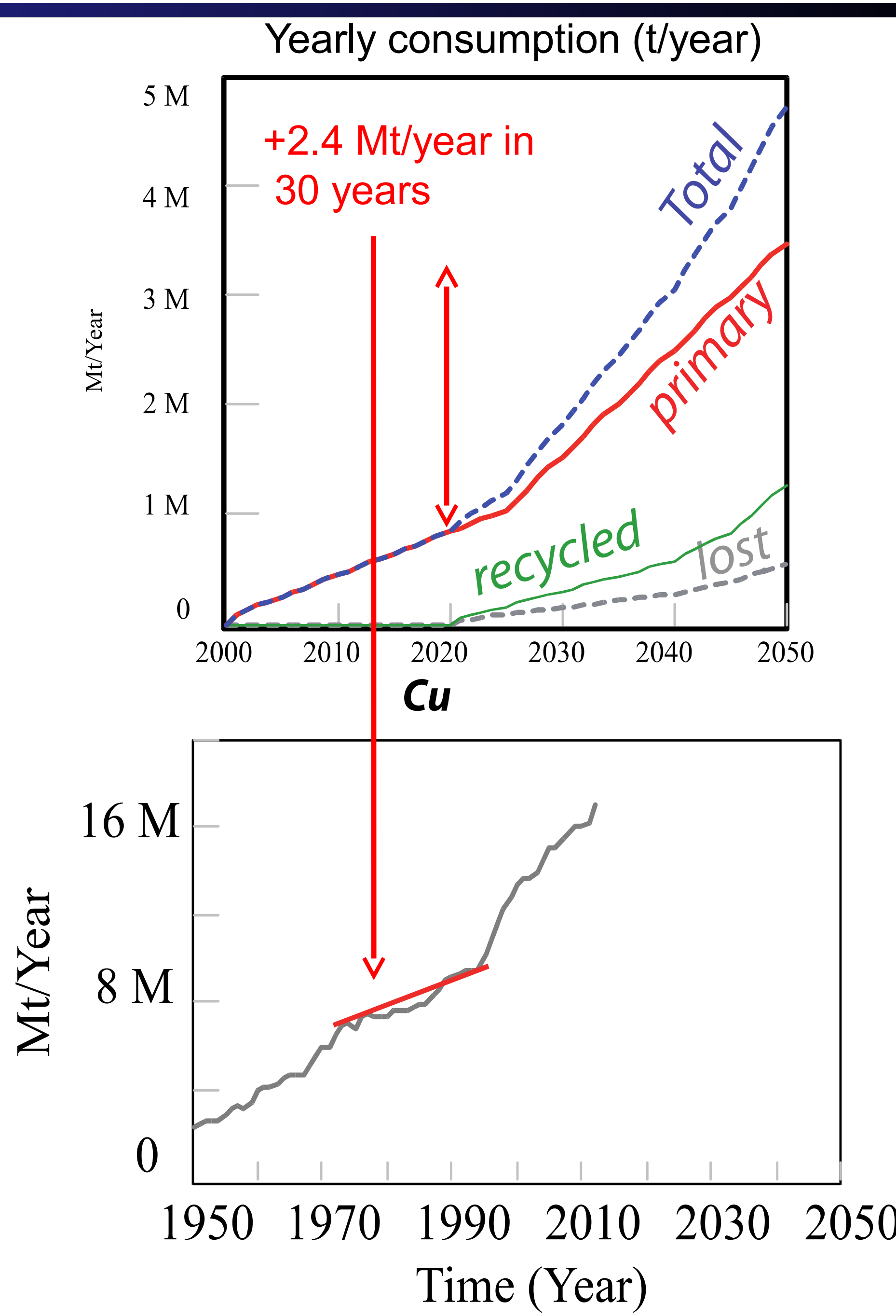


In 2050, the **cumulative** amount of steel, Al, Cu sequestered in hydropower, wind and solar facilities could be up to 13 times the global 2010 production

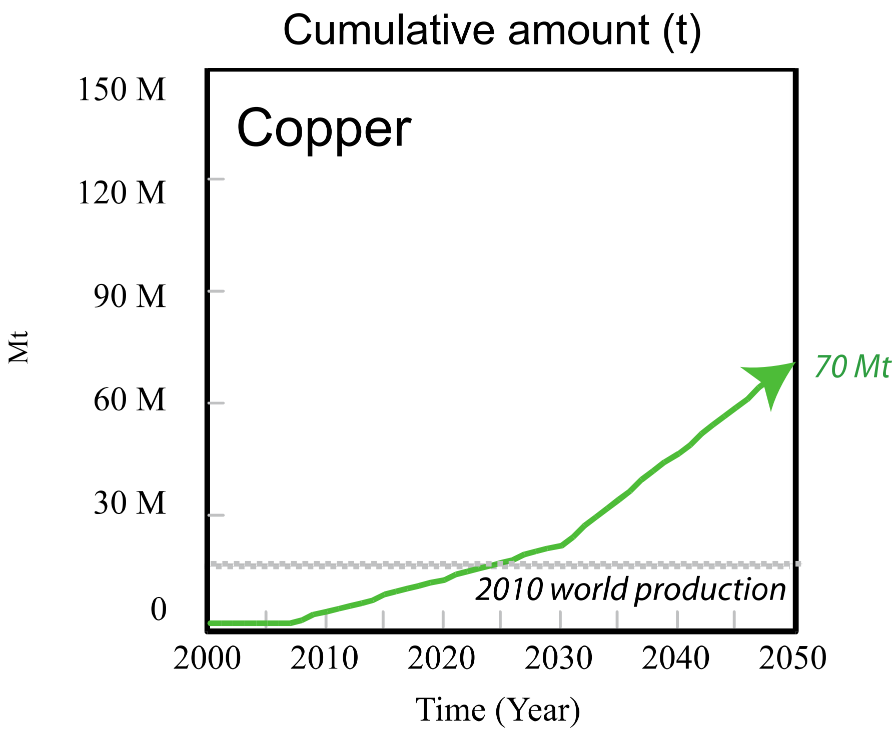
Dynamic stock & flow problem







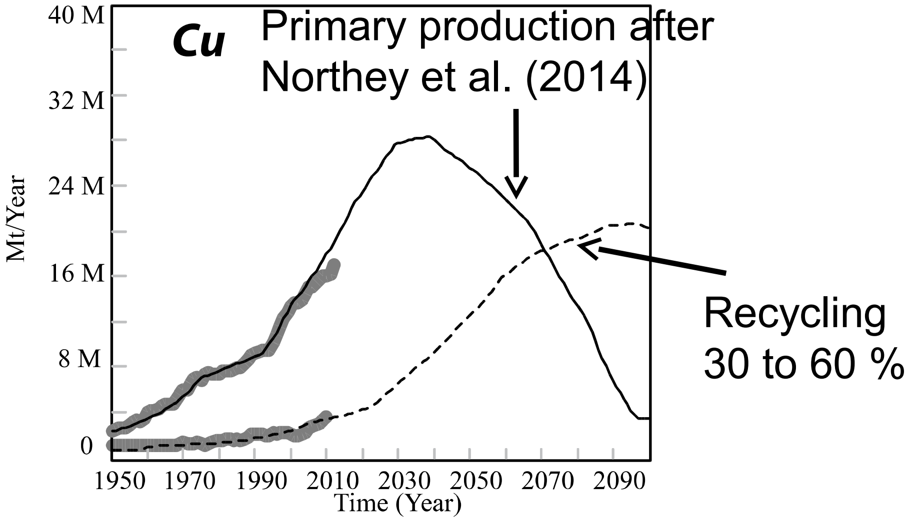
The increase of primary Cu, Fe, Al, cement production for the infrastructure of energy generation ***only*** is equivalent to the 1970-2000 growth of global production (all applications)



The largest human excavation on Earth: Kennecott Copper Mine (Utah) **3.2 x 1.2 x 1.2 km³** . It is, along with Great Wall of China, one of only two man-made objects distinctly visible from space

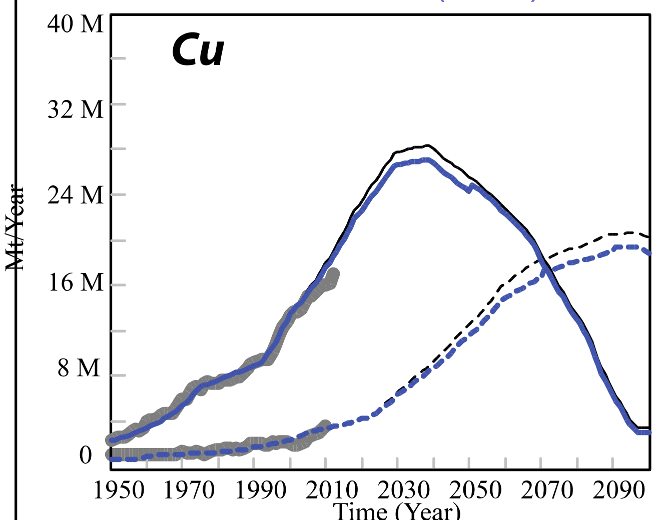
Since 1906, six billion tons of rock have been moved from this pit to extract **18 million tons of copper** – equivalent to the 2010 global production

Comparison with forecasted global production

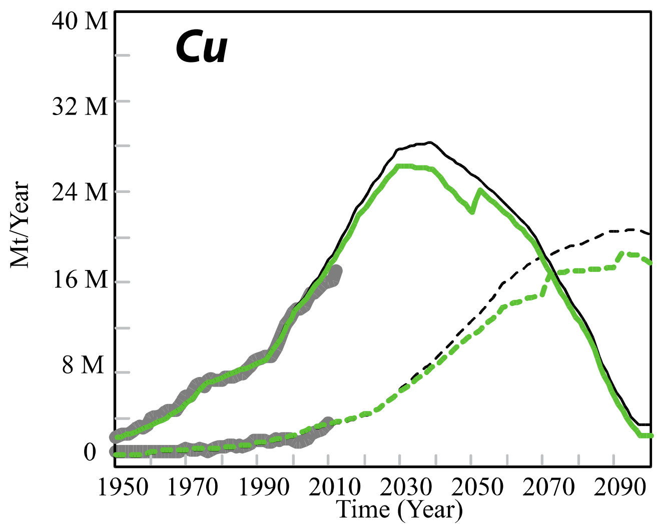


- Highest demand in copper at the forecasted production peak
- Even though recycling increases significantly after 2030

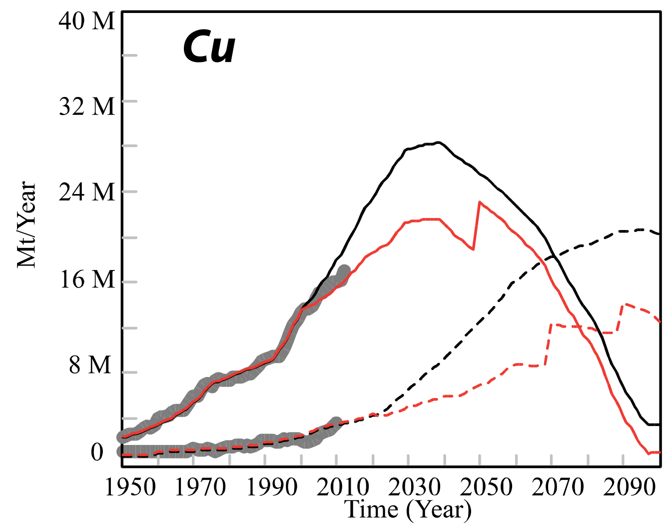
36500 TWeh BM (2010)

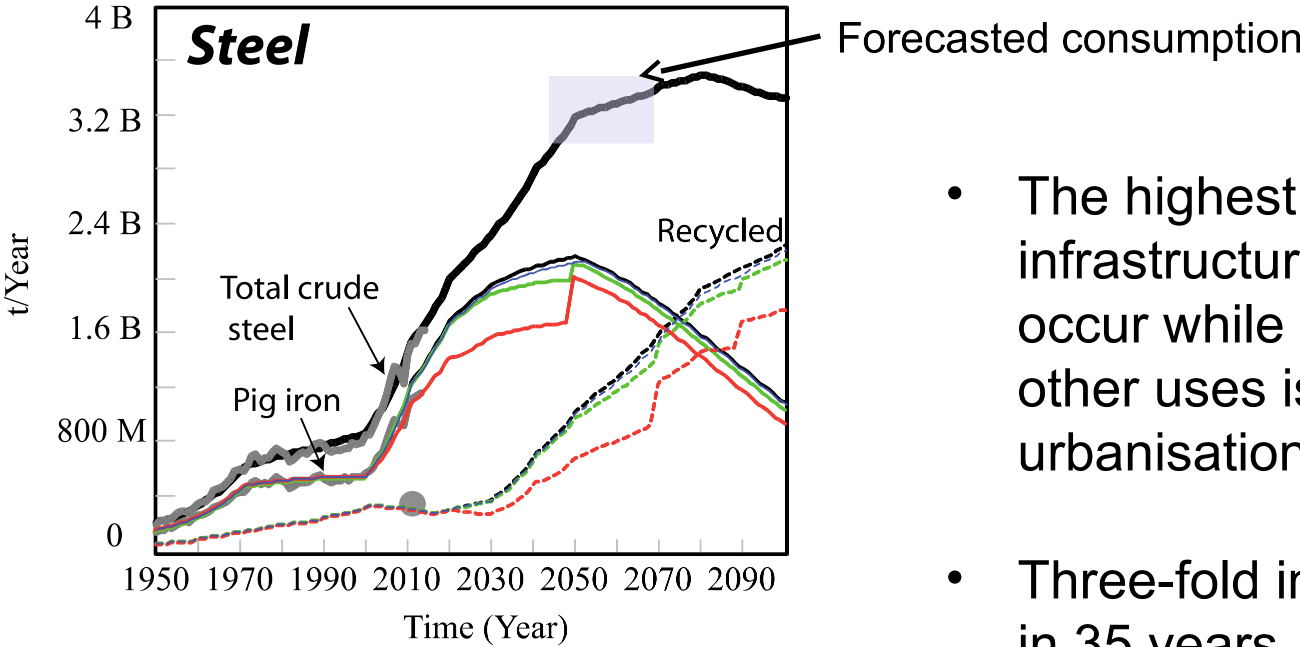


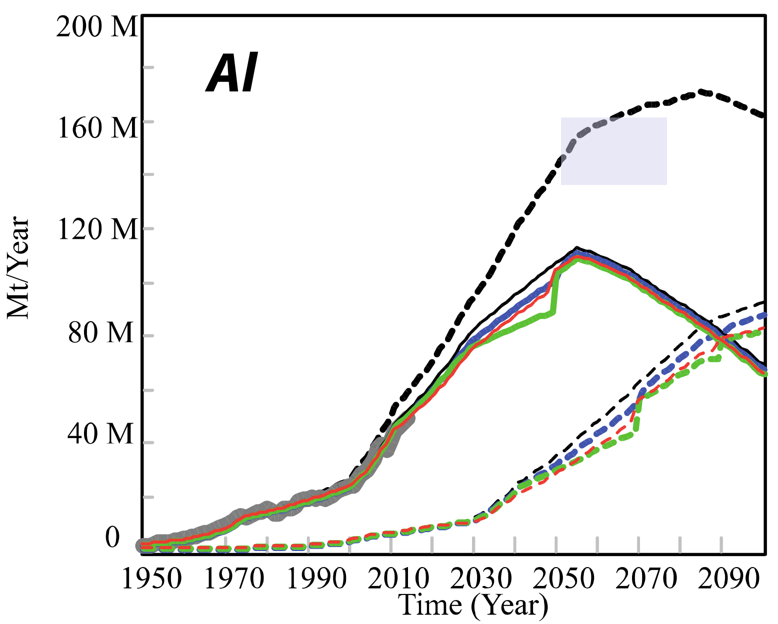
29300 TWeh Ecofys-WWF (2012)



108800 TWeh Garcia-Olivares (2013)







- The highest demand to built the infrastructure of energy will occur while the demand for other uses is maximum (strong urbanisation).

- Three-fold increase of recycling in 35 years.
  - *The infrastructure of recycling must be scaled up rapidly*
  - *The cost of recycling must be competitive/ primary production*

The energy-RM-**economy** nexus: the case of recycling

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EXPERT SOLUTIONS FOR YOUR RECYCLING NEEDS

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Solvay Opens Rare Earth Metals Recycling Plants in France

European chemical company invests $19.5 million in two facilities.

October 3, 2012

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Solvay Group, a chemical group headquartered in Brussels, has officially opened two rare earth metals recycling plants in France. The two plants are designed to allow the company to diversify its supply of rare earth metals and preserve resources.

Solvay says it has developed a process to recover rare earth metals from end-of-life products, such as light bulbs, batteries and magnets.

Research into and development of the process began in 2007 and tool two years, followed by two years of industrialization studies and site selection, according to the company. The investment was officially approved in 2011.

Solvay says it focused initially on low-energy light bulbs because the recovery channels already existed. The light bulbs have an ample amount of six different rare earths—lanthanum, cerium, terbium, yttrium, europium and gadolinium—which Solvay it is in position to recycle while preserving 100 percent of their

Hua adds, "The launch of these units illustrates our tangible contribution as a chemical manufacturer to sustainable development."

2016: Solvay Ferme ses usines de recyclage

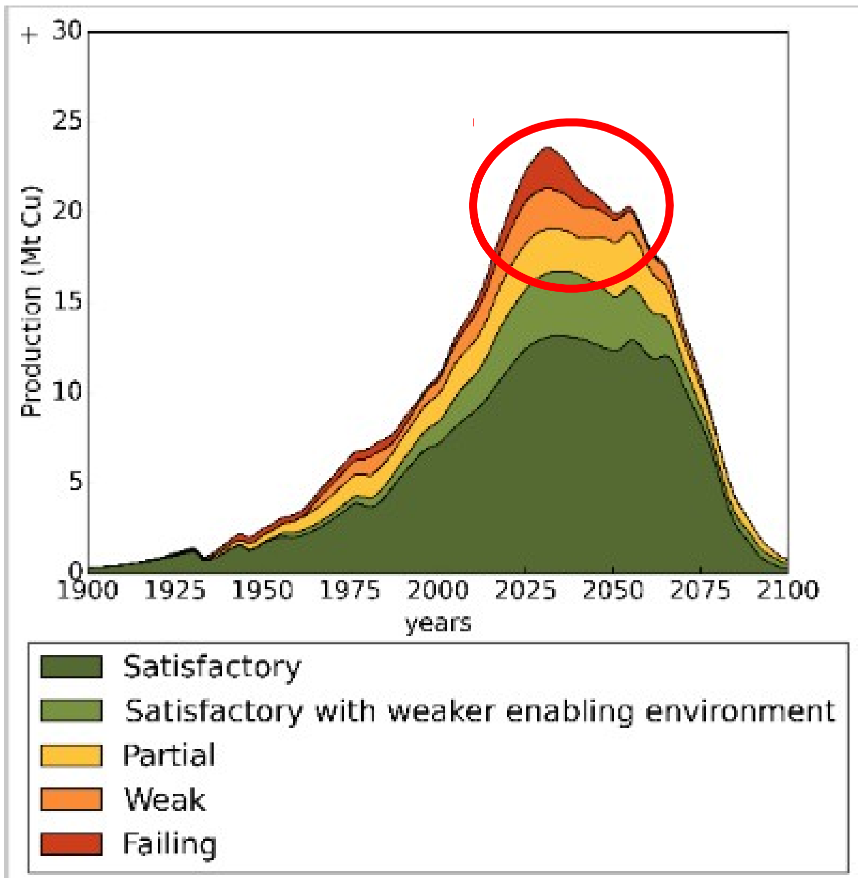
-> La coût de production est trop élevé au prix actuel des REE

2016: Fer primaire Chinois (charbon) compétitif / acier recyclé Européen (électricité)

2016: Première usine française de recyclage des pneus en hydrocarbure et charbon

The energy-RM-economy-**geopolitics** nexus

Resources ordered according to the quality of resource governance as measured by the Natural Resource Governance Index of 2014: « Institutional and Legal Setting; Reporting Practices; Safeguards and Quality Controls, and Enabling Environment »

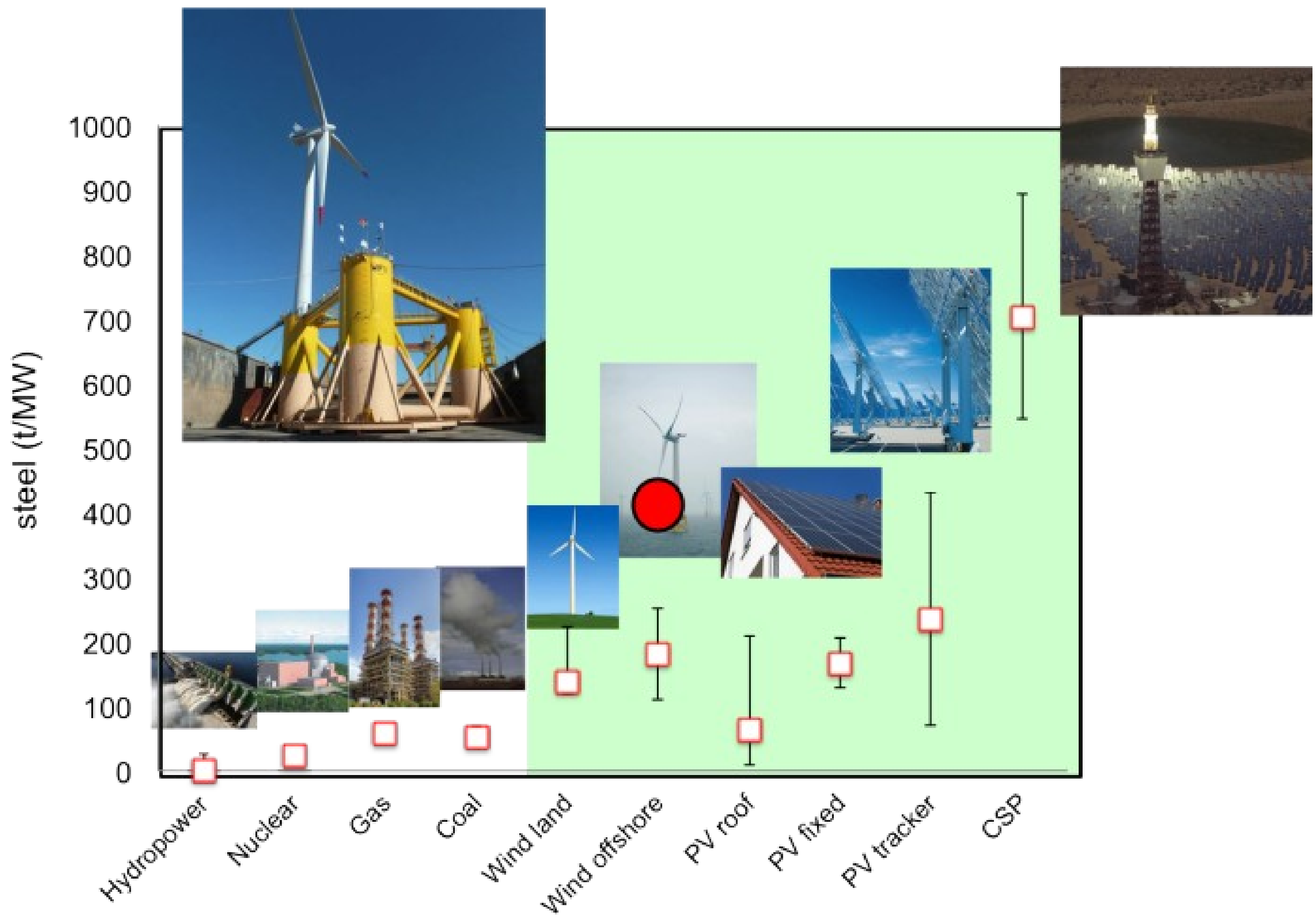


A third of known Cu resources are in countries with less than satisfactory governance…This adds a further risk, if production from these countries is to be needed to meet global demand

Northey et al. (2014), Ali et al. (2016)

These situation could become worse…

New intensive technologies

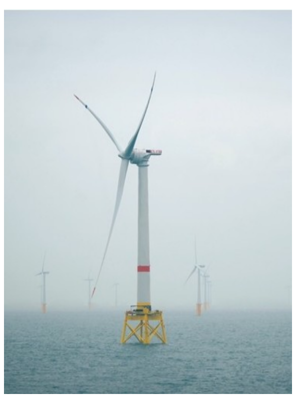


Additional needs

100 and 300 Mt Cu are needed: 6 to18 x 2010 global production

70 Mt Cu

production



1 Mt Cu

storage

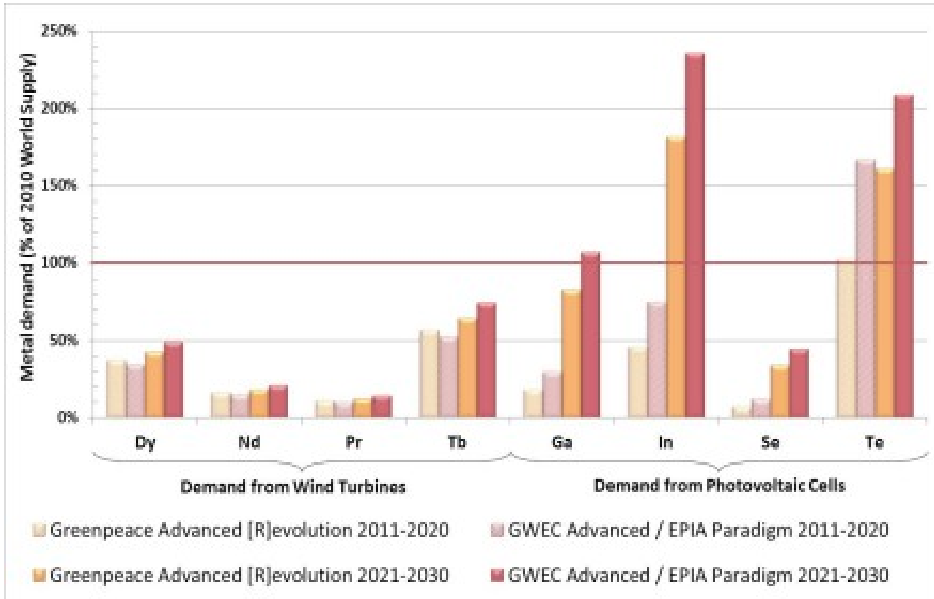
Transport & distribution

5 Mt Cu

30 Mt Cu

Use

The situation for mineral commodities used in the « high technologies » is more worrying **on the short term**



Until 2030, the yearly global demand in Ga, In, Se, Te, Dy, Nd, Pr and Tb for PV cells and wind turbines will be boosted to 10 to 230% of the 2010 world supply (Öhrlund, 2011)

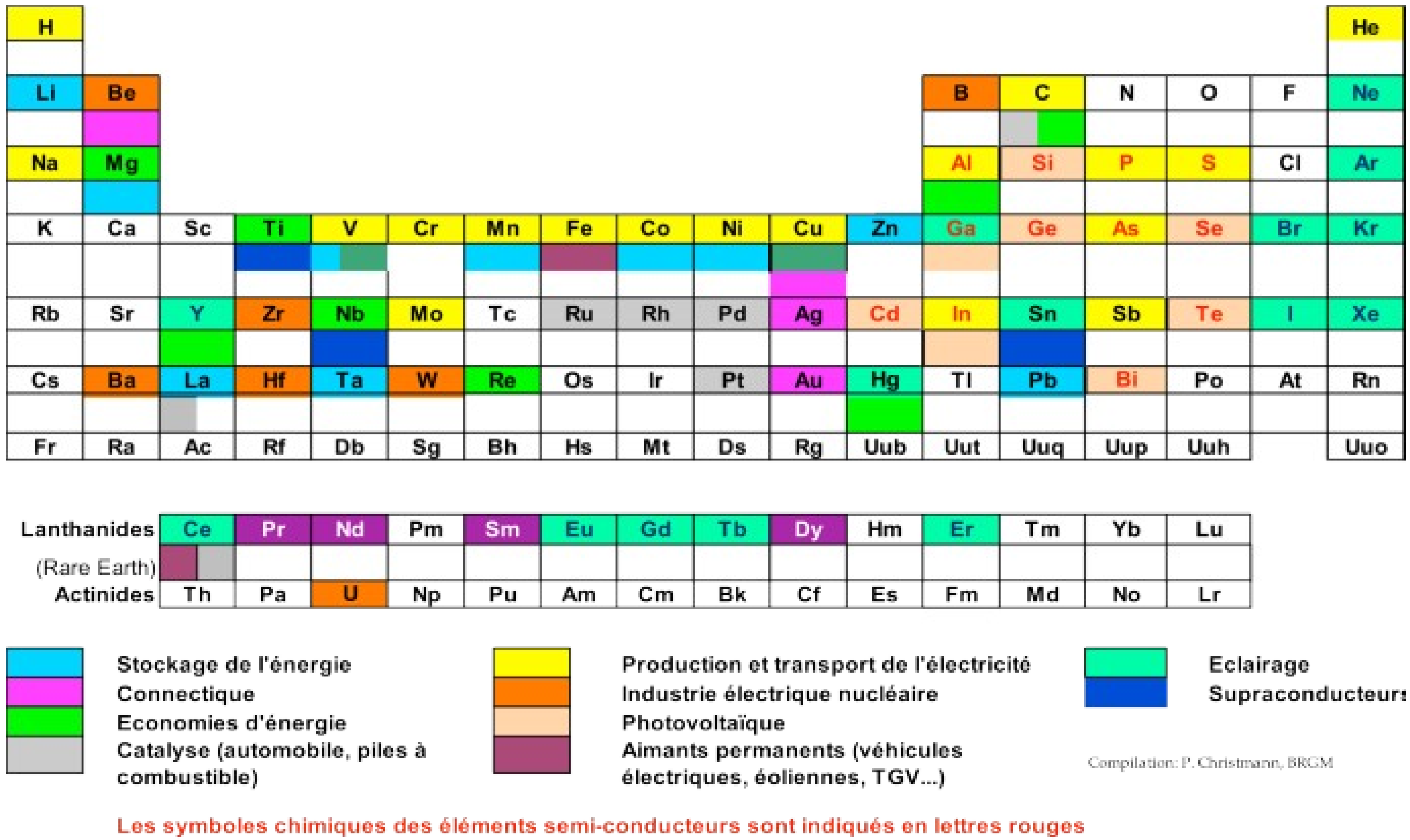
- Their production requires much less energy than structural raw materials

- Economy of use is possible, efficiency can be improved:

- *High-efficiency permanent magnet with no REE (Hitachi, 2012).*
- *Reluctance motors using electro instead of permanent magnets are an option for electrical vehicles.*
- *Two-fold increase of Net Energy Ratio of PV in 10 years (Koppelaar et al., 2016)*

⇒ Innovation is likely to "solve" the problem. **This is not the case for steel, Al, Cu, concrete**

Additional needs



Should we worry ?

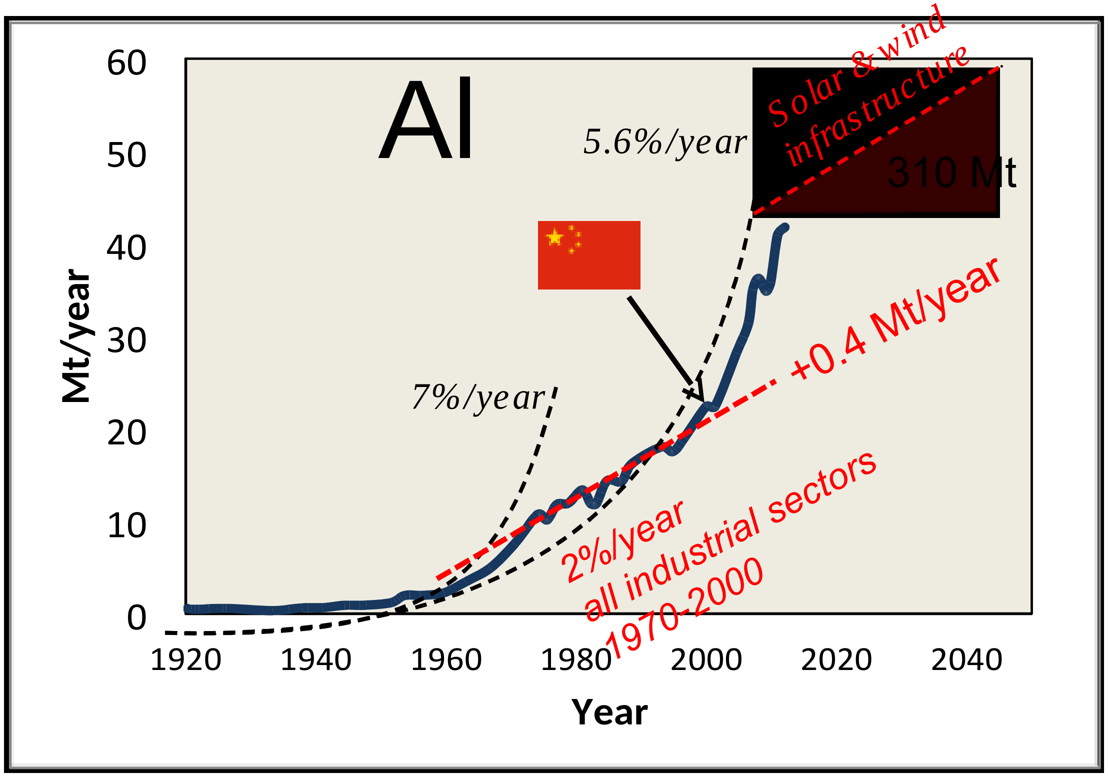
The **most exigent** scenario (Garcia-Olivares et al., 2013) requires by 2050:

300 Mt Cu: 18 years of present production, 40% of known reserves
8 Mt Li: 190 years of production, 200% of known reserves
66 Mt Ni: 40 years, 95% of known reserves
31 Mt Pt: 19 years, 44% of known reserves

…and a considerable amount of energy to produce these raw materials in equally considerable amounts…

But other more realistic scenarios are available and part of these raw materials will be provided by recycling

The energy cost of raw materials production



Energy requirement

Primary Al production: 210 GJ/t
(Drezet, 2014
http://ecoinfo.cnrs.fr/article329.html)

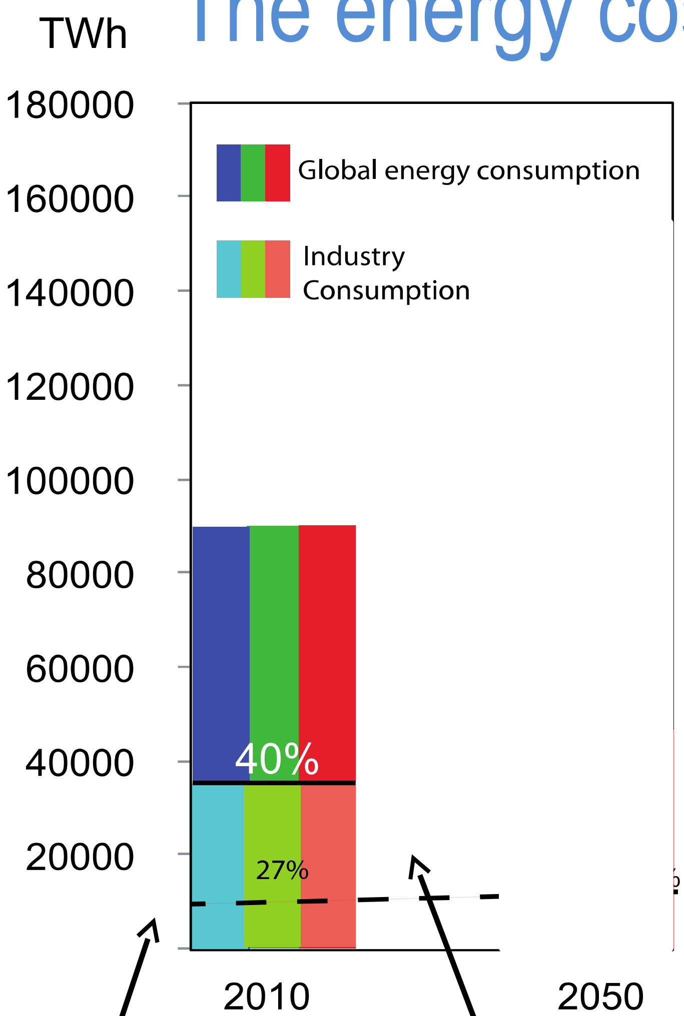
10.10^9 Barels of Oil Equivalent

5 months of crude oil global production

With concrete and steel: energy equivalent to 1.5 years of crude oil production

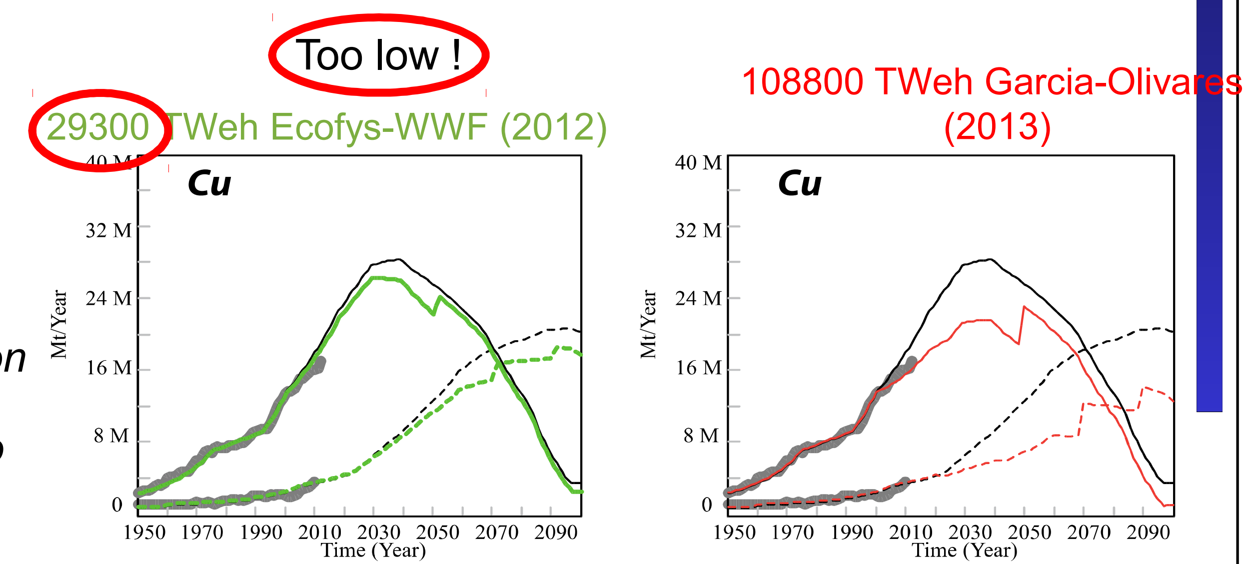
The energy cost of raw materials production

A global drop of energy consumption is unlikely in in view of the growing needs for structural raw materials.



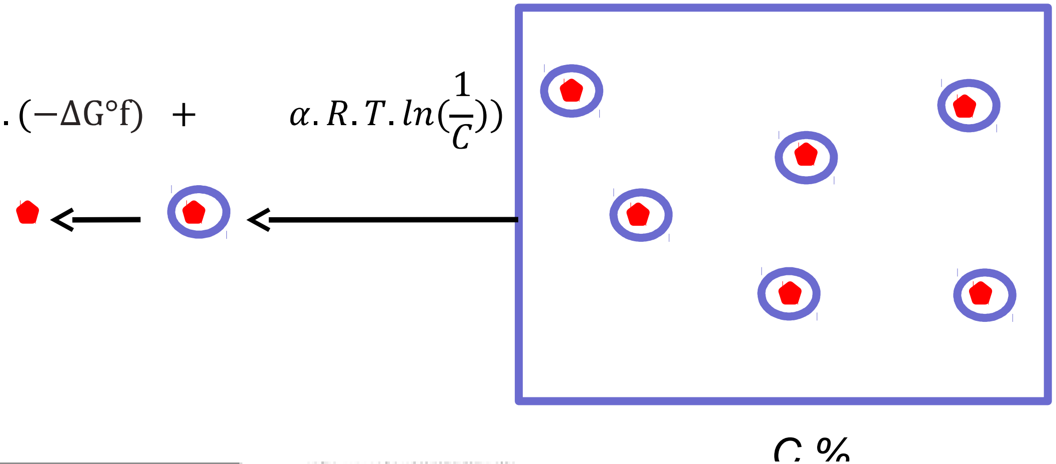
Share of industry consumption

Share of industry consumption used to produce of steel, concrete, Al, Cu

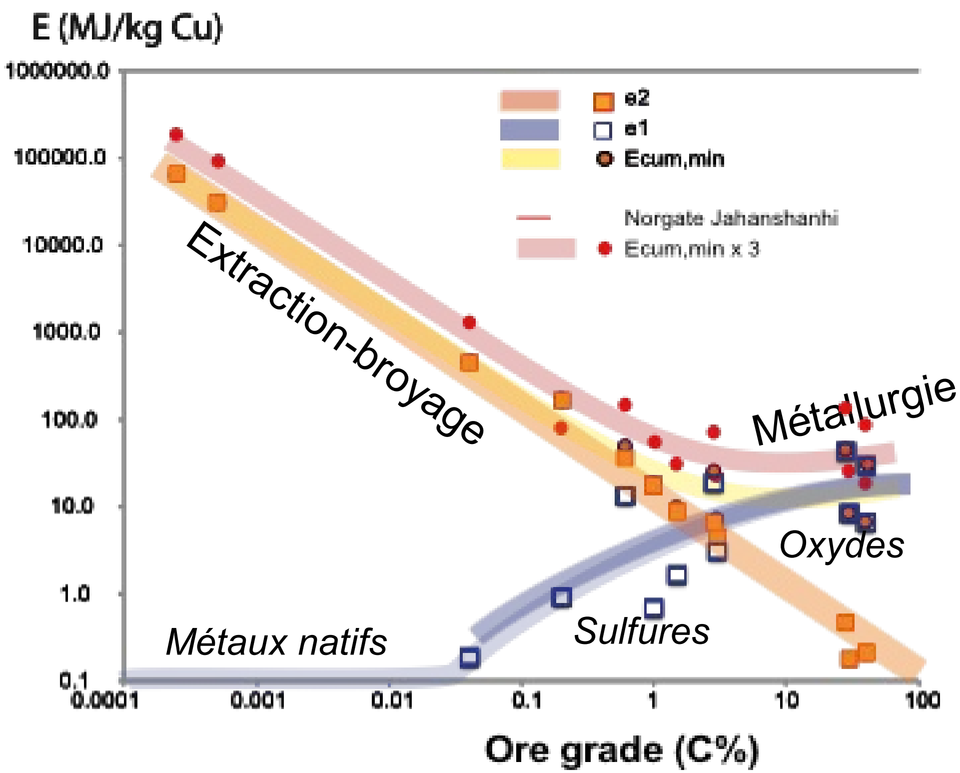


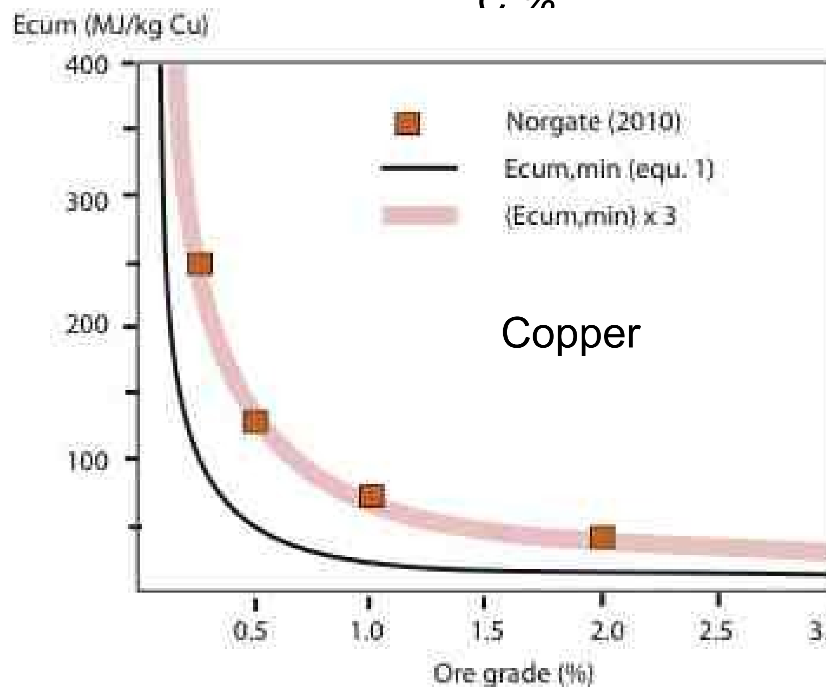
The energy cost of primary raw materials production

$$\text{Ecum, min (MJ/kg)} = \frac{1}{Mm.n.1000}.(-\Delta G°f) + \alpha.R.T.ln(\frac{1}{C}))$$



$$\text{For } \alpha = \frac{1}{C.Mm.n.1000}.$$





The energy cost of raw materials production is **dynamic**

ergy increase by reduction of concentration

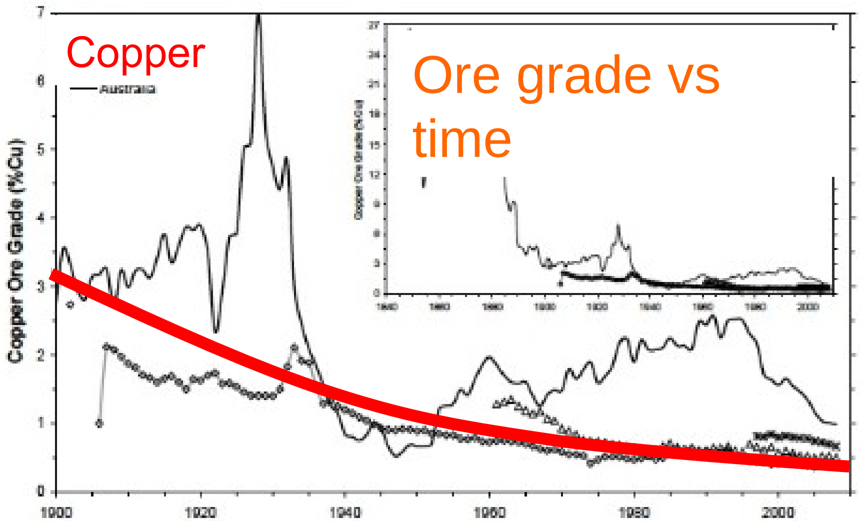
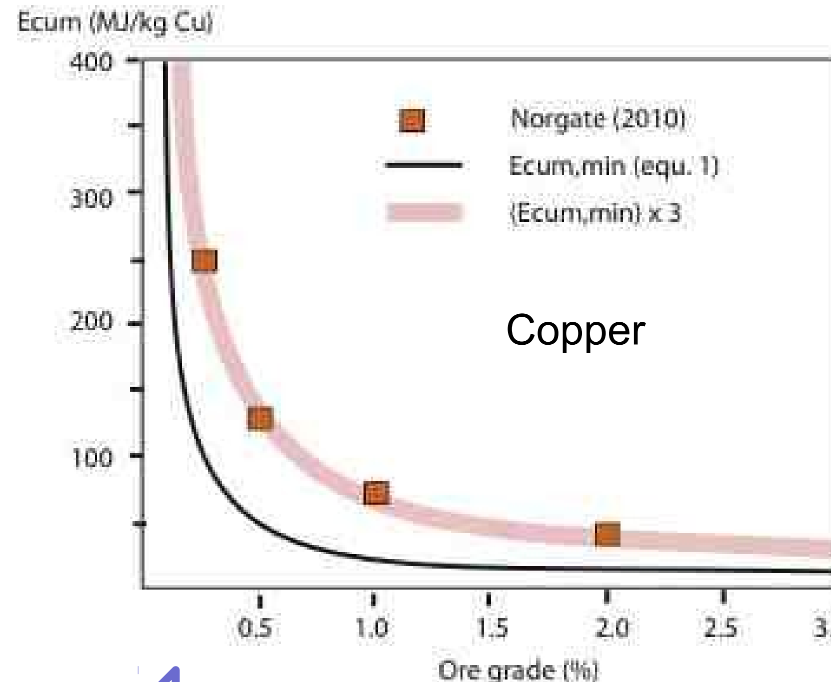


Figure 2 – Copper ore grades over time by country and approximate world average



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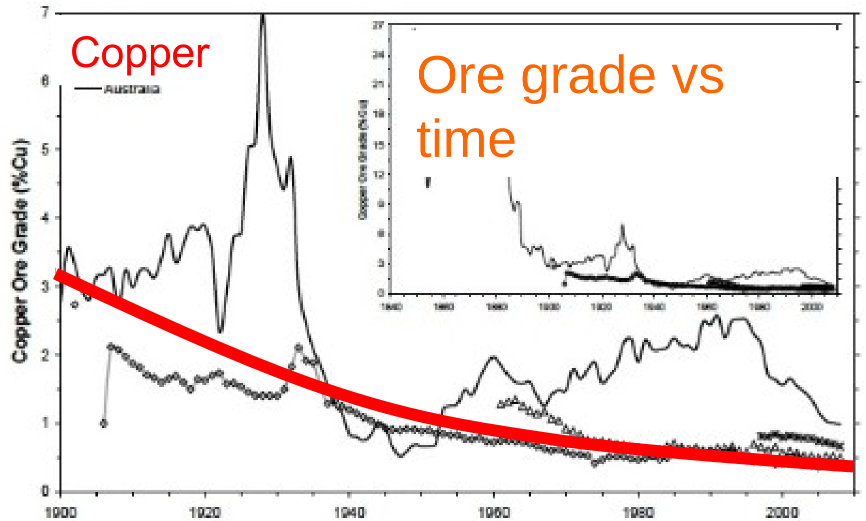
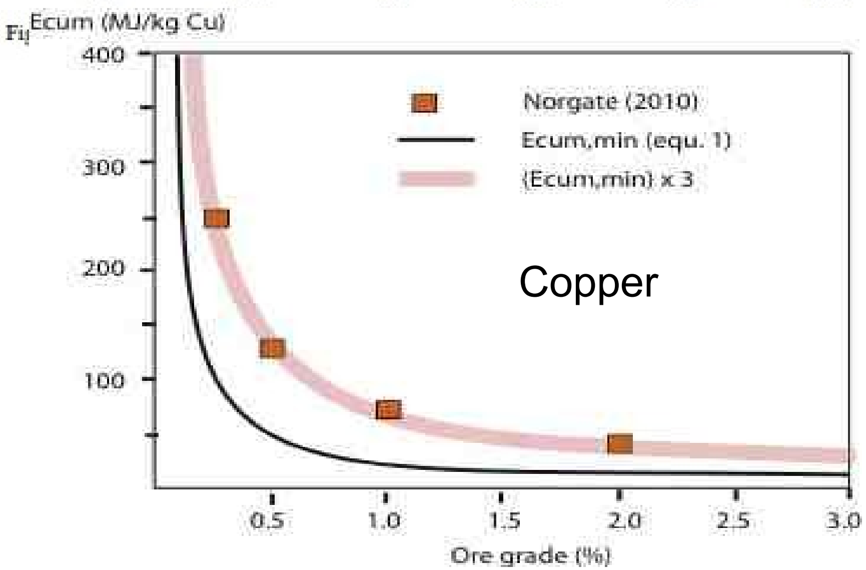




Energy saving by technological improvement

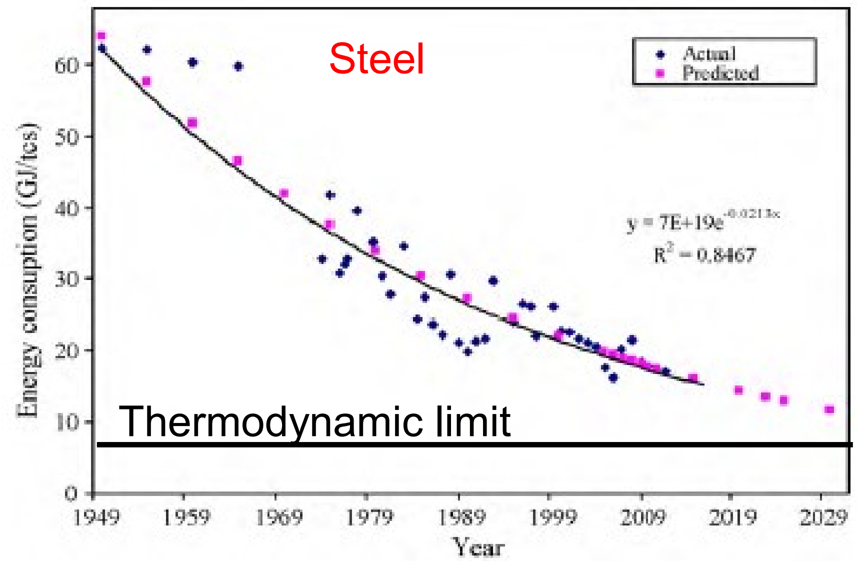
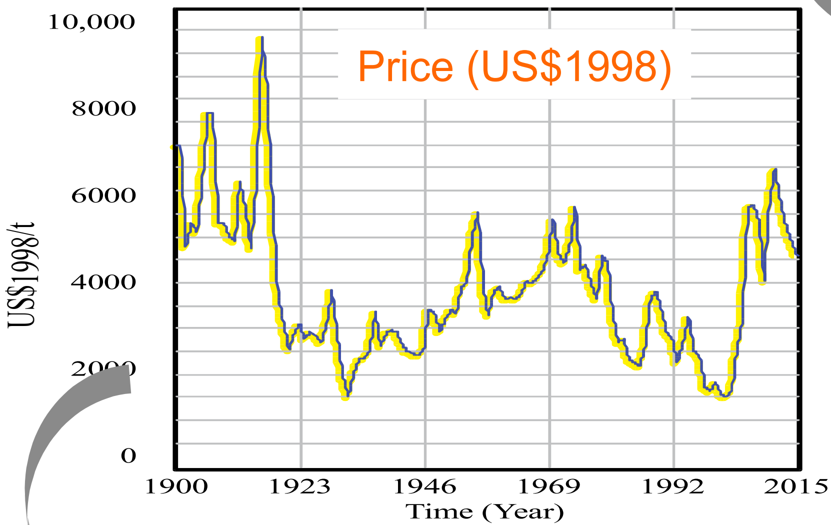
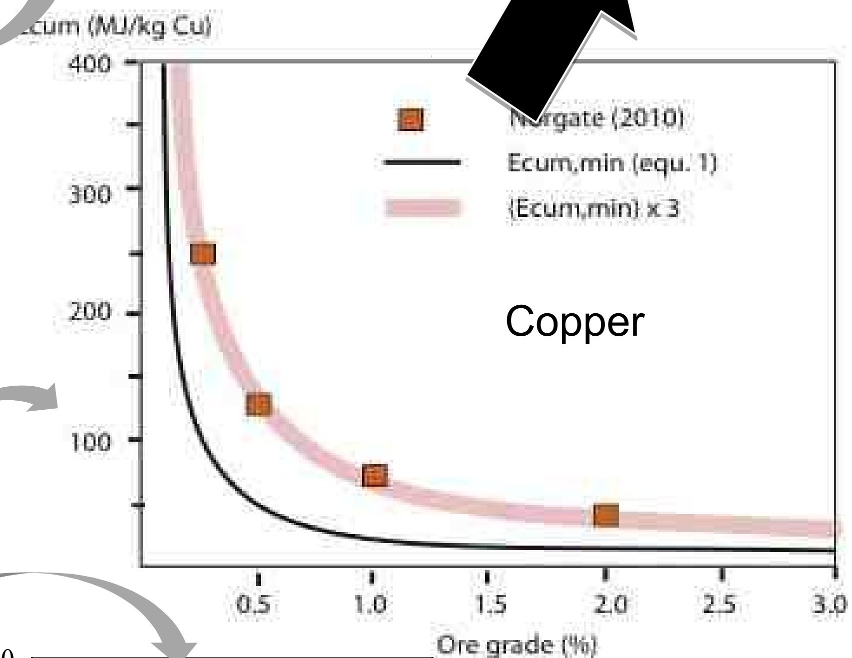


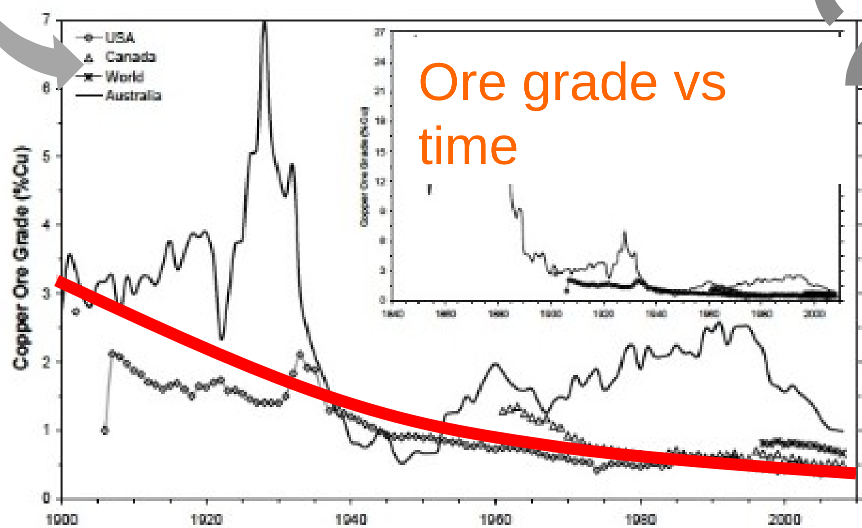
Fig. 5. Actual and projected specific energy consumption in the steel industry (world average).

But in the meantime, « technical » and energy intensive steels have been developped, e.g. steel in automative industry: 52 MJ/kg, stainless steel: up to
300 MJ/kg

The prices, reserves and costs are dynamic and coupled







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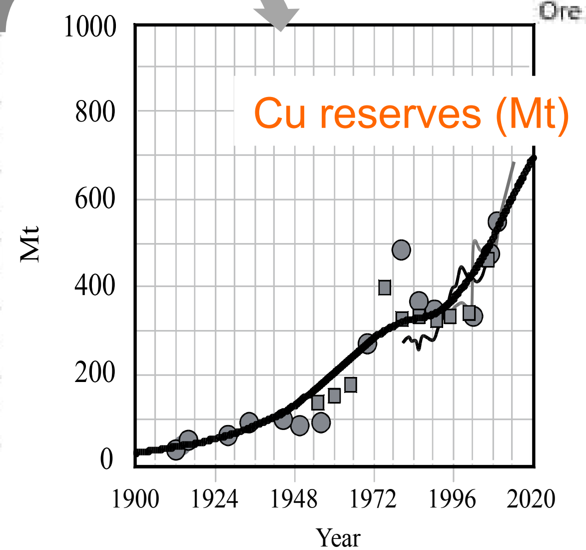
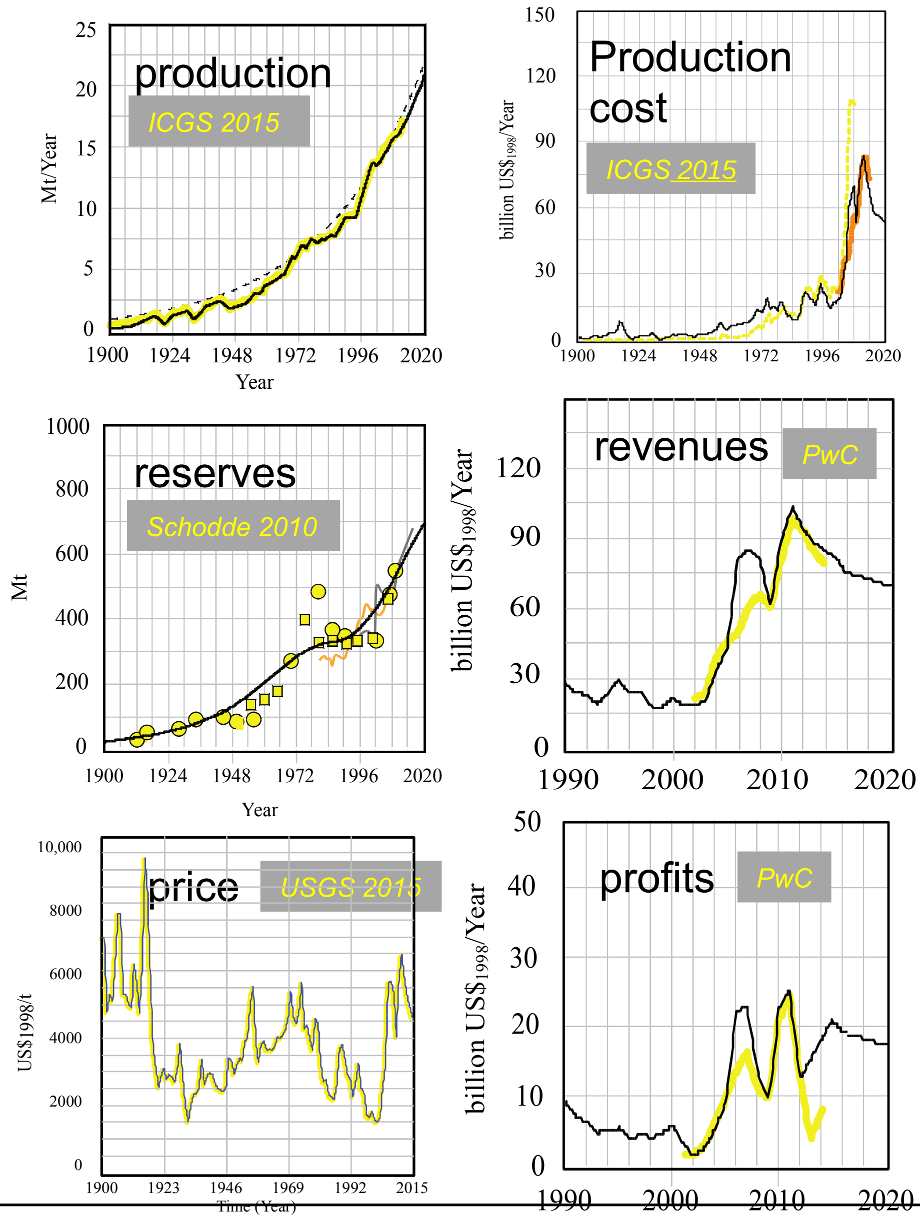
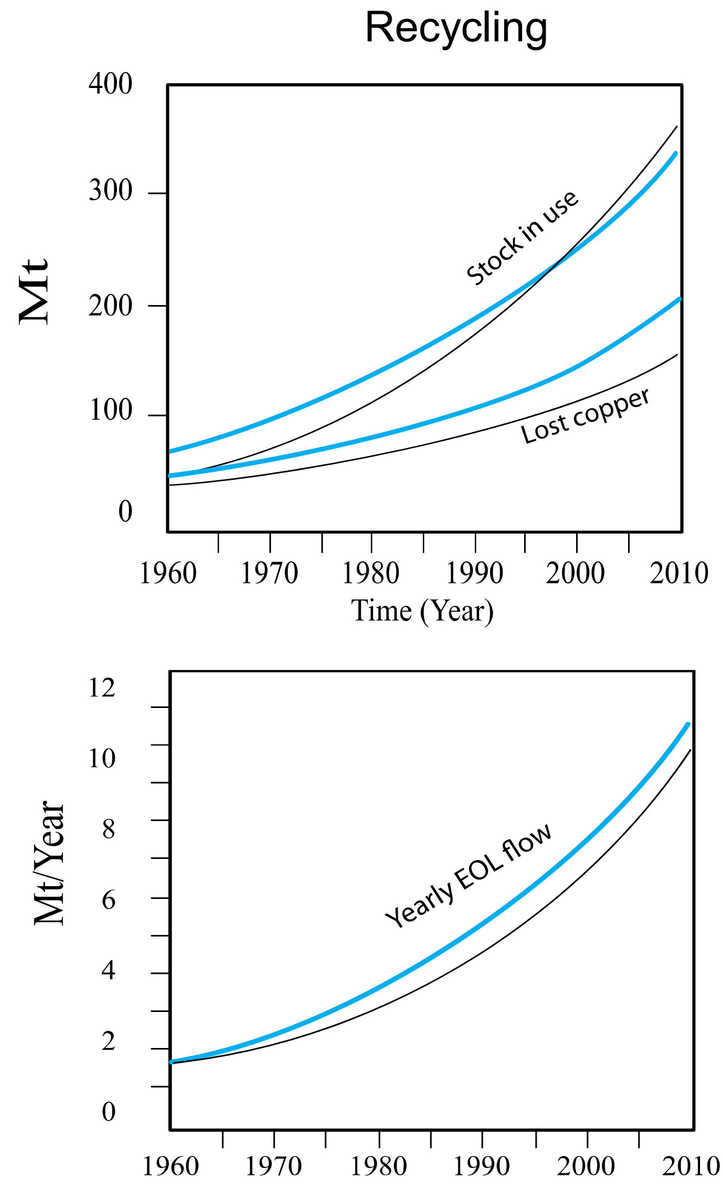


The prices, reserves, costs, demand and production, energy intensity, share of recycling *vs* primary production, technologies and basic knowledge, geopolitical issues and environmental impacts are dynamic and coupled parameters

Discussing the future of raw materials & energy requires dynamic and non-empirical models integrating all these aspects and **capable of reproducing historic trends**

Constrains: Global historical trends of Copper production



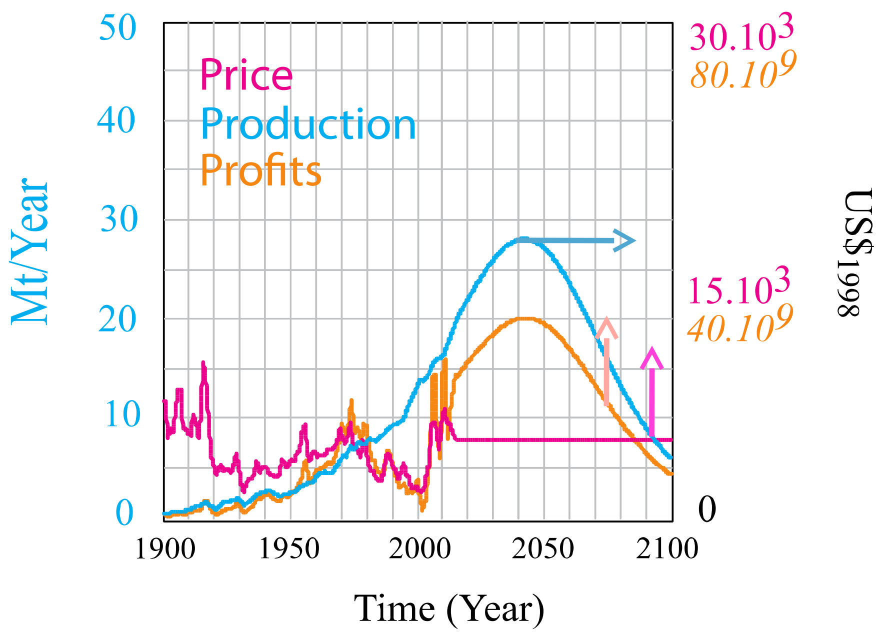


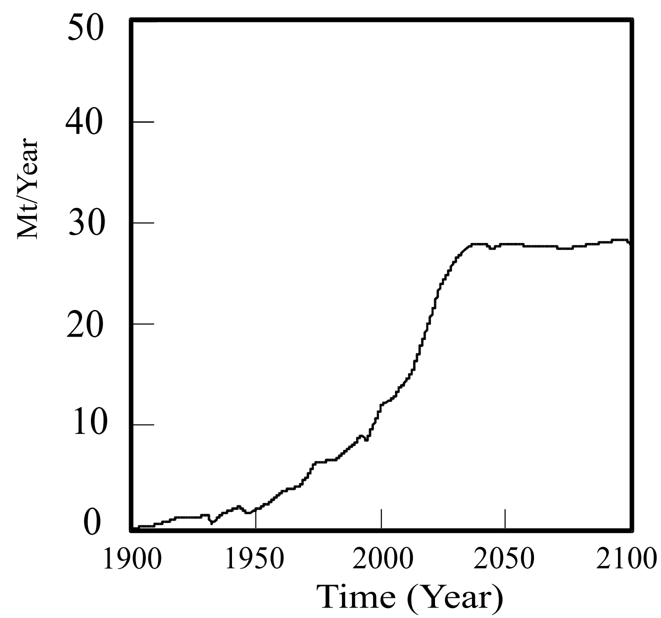
Glöser et al. (2013)

Of course we should worry, but not for bad reasons…

Scenario 1 (BAU, constant deflated price and *increase of costs with decreasing ore grade*)

Scenario 4b (stable demand, *decrease of costs to maintain the prices and profits at decreasing ore grade and increasing reserves*





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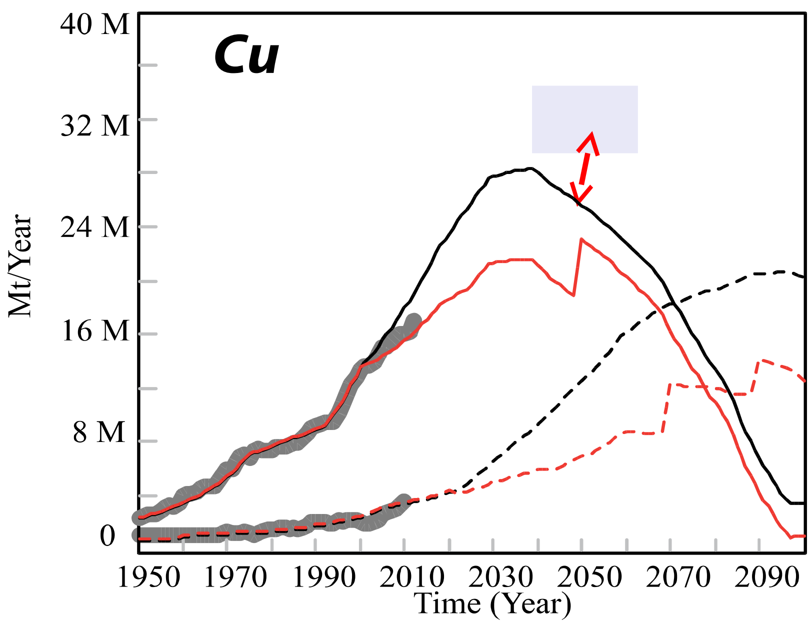
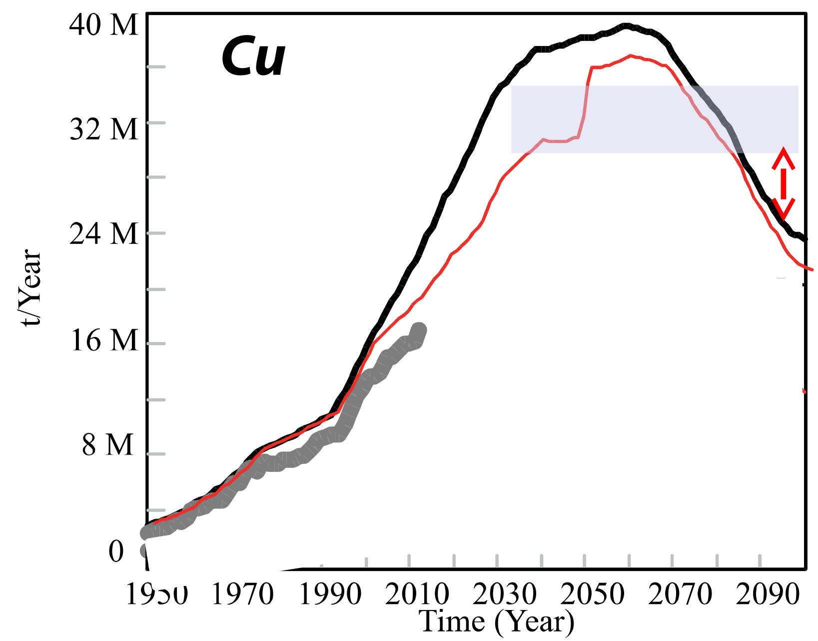
Share of Primary & secondary production



Primary + secondary production



In the future, recycling will become the most important source of metal because the stock will be available. The question is where ?

Export of e-waste

http://www.tradingeconomics.com/china/imports-of-copper-waste-scrap

China import of scrap and waste Cu : about 3 Mt/a (global EOL flow = 10 Mt/a)

Chinese refinery devoted to the extraction of copper from e-waste.

http://shanghaiscrap.com/2013/09/page/2/

it is still cheaper to export e-waste to developing countries than it is to locally recycle.

- *In 2005, inspections of 18 European seaports found that approximately 47% of exported waste was illegal*
- *75% of the exported e-waste are working machines*

Conclusion 1/2

14 “**critical” raw materials** identified by the EC in 2010 and 20 in 2014 (criticality = importance for the industry x supply risk ≈ scarcity).

- **Poorly known reserves**. They are often by-products of base metals production
- No or limited recycling
- Used in fast-evolving high-technologies, so that their use depends on technological innovation and they present the highest potential of substitution and reduction of use

Structural raw materials and big metals show no sign of reserves depletion (except Cu ?) and show high recycling rate => low criticality

- Produced in huge amounts with **major environmental impacts and energy requirements**…
- No or very limited potential of substitution

The major issue on the long term ?

Conclusion 2/2

Achieving the transition toward low-carbon energy is a crucial challenge of the 21st century but it has a cost (energy, GHG emission, resources).

- This cost must be evaluated in regards to the availability of raw materials, energy and water and environmental impacts associated to their production. What is the best scenario ?
- What has been possible in the past (e.g. doubling the production of metals every 20 years) will not be necessarily possible in the next decades. It is not only a matter of reserves, but also a matter of social, environmental and economic implications.
- We should anticipate and be prepared for massive recycling and keep our waste at home instead of exporting them abroad.

Address these issues as well as their couplings in a comprehensive and global framework

- Modelling to avoid blind driving. *At yet, lack of predictive models able to link natural resources production-reserves-recycling-demand-price-cost of production and able to reproduce historic data…*

Que faire ?

Des pistes de recherche sont proposées à la fin de chaque chapitre et dans un chapitre dédié.

Il existe déjà beaucoup de documents sur le sujet e.g. « roadmap for research » d'ERA-MIN et documents Européens issus de l'initiative « raw materials ». Réflexions également au niveau National (COMES) mais déclinaison (très) partielle notamment dans le défi 1 ANR. KIC raw materials pour TRL élevés uniquement

- Les moyens nationaux restent très faibles au regard des enjeux, peu de vision long-terme et holistique des enjeux
- Manque de recherche intégrée (ST-Chimie/matériaux-environnement-SI-SHS).
- Pas d'anticipation des contraintes MP-énergie-technologies vs prix du Kwh.
- Focalisation sur l'otimum techno-économique court terme.

Thank you for your attention !