ON THE INTEGRATED CLIMATE IMPACT OF RESOURCES AND ENERGY EXTRACTION AND USE IN SOCIETY

Professor Dr. Harald U. Sverdrup

Industrial Engineering, University of Iceland, Reykjavik, Chemical Engineering, Lund University, Sweden,

With assistance from

Deniz Koca (Lund University), Martin Hirschnitz-Garbers (Ecologic), Martin Distelkamp (GWS), Mark Meyer (GWS),

Kristin Vala Ragnarsdottir (University of Iceland) and Susanne Langsdorf (Ecologic)

UNDERLYING UFOPLAN RESEARCH PROJECT

- Models, potential and long-term scenarios for resource efficiency (SimRess),
  - FKZ 3712 93 102
- Main project objectives
  - To simulate the potential effects of resource policy mixes on relevant resource use and environmental indicators in Germany until 2050; using an multiregional input-output model (GINFORS) and a system dynamics model (WORLD).
  - To discuss options to elaborate an integrated systemic modelling framework that compares model findings and improves information flow between them
- Selected project achievements
  - Establishing a learning soft link between GINFORS and WORLD
  - Comparing and improving model findings through exchange of information on demand and prices

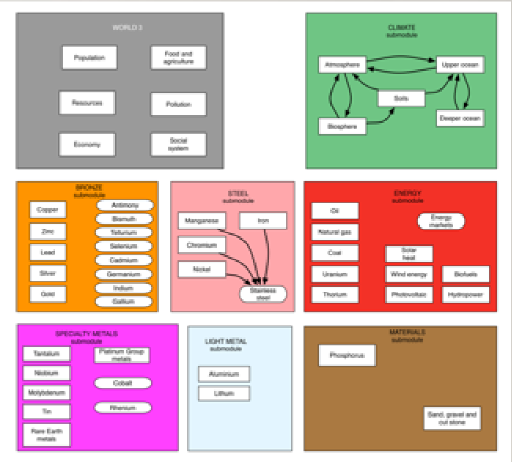
DEFINING SCARCITY

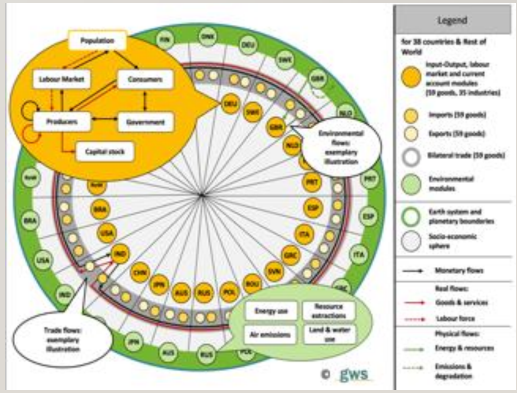
- Soft scarcity
  - Demand is decreased because of higher prices, when demand outmatches supply. The diagnostic indicators are:
    - Reduced demand, with less increase in supply, resulting in reduced consumption and higher prices.

- Hard scarcity
  - Monetary scarcity: The price increases because of supply shortage and society or parts thereof runs out of money to pay. The diagnostic indicators are:
    - Less provision at higher price
    - Structural or functional simplification in society (Tainter 1989)
    - Economic stress or crisis reoccurring
    - Problems making business profits, increased number of bankruptcies, degrowth
    - Difficulties in developing businesses and new products
  - Physical scarcity: The material is physically unavailable demanded volumes regardless of price. The diagnostic indicators are:
    - Substitution with other materials when possible
    - Loss of functionality
    - Loss of efficiency and resilience
    - Failure of provision

A DOUBLE GLOBAL MODEL ASSEMBLY

- **WORLD 6** model
  - System dynamics model
  - Global level, top-down, society system model, linked supply of materials, metals, phosphorus, food, energy and economy
  - Demographics, social dynamics, population
  - Global market supply-side and market price estimation
- **GINFORS**[3] model
  - Account-based transaction matrix model
  - Bottoms-up regional aggregation
  - Commodity transactions (60) and services (40) model, globally agglomerated from 40 regional sub-models.
  - Bottom-up demand-side estimation



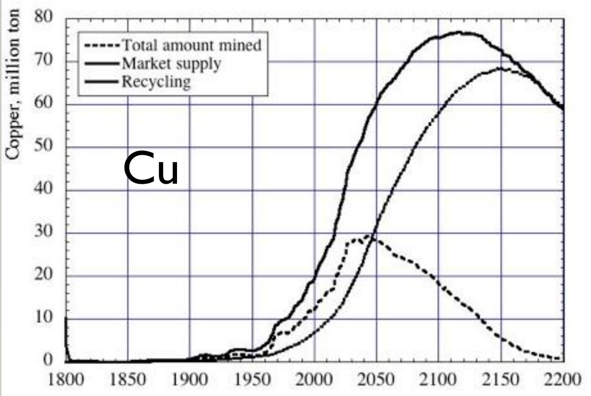


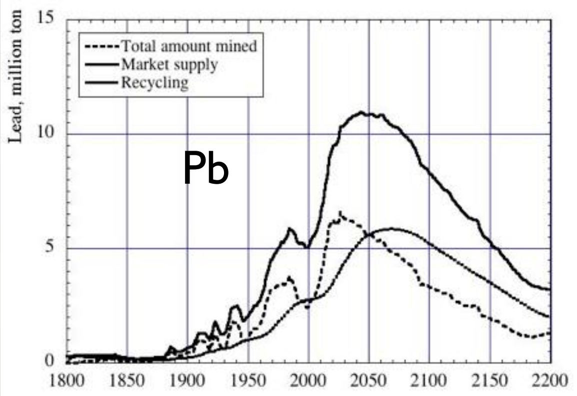
THE SELECTION OF ENERGY, METALS AND MATERIALS MODELLED IN THE WORLD 6 MODEL

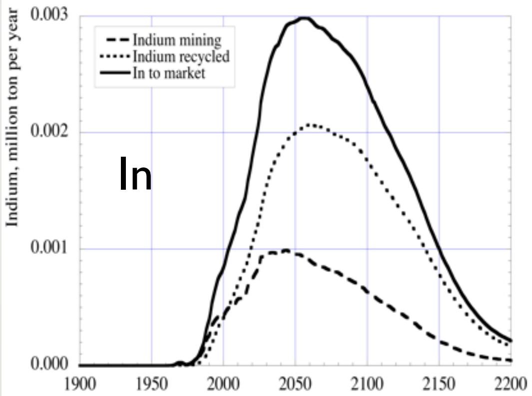
(IN ADDITION TO POPULATION, DEMOGRAPHICS, SOCIETY, ENVIRONMENT AND ECONOMY)

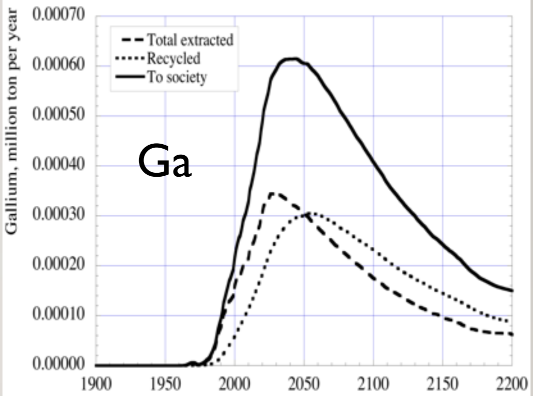
- STEEL module:
  - **Steel** materials: iron, stainless steels, carbon steels (manganese, chromium, nickel)
- BRONZE module:
  - **Base metals** (copper, zinc, lead)
  - **Technology Metals** (indium, germanium, gallium, tellurium, cadmium, bismuth, antimony, tin, selenium)
  - **Superalloys** (molybdenum, niobium, tantalum, rhenium)
  - **Precious metals** (gold, silver, platinum, palladium, rhodium)
- The ALUMINIUM module:
  - **Light metals** (aluminium)
  - **Technology Metals** (gallium)
- The FOSFOR module
  - **Rock phosphate** for fertilizer
- The MATERIALS module
  - Sand, gravel and cut stone
  - Cement and mortar
  - WorldWood (paper, wood, biofuels and wood materials)
- The FOSSIL module
  - **Fossil energy** (hydrocarbons, nuclear)
  - **Renewable energies** (Biofuels, photovoltaic, wind, hydro, geothermal)
- The CLIMATE module
  - Global average temperature
  - Atmospheric CO2 content

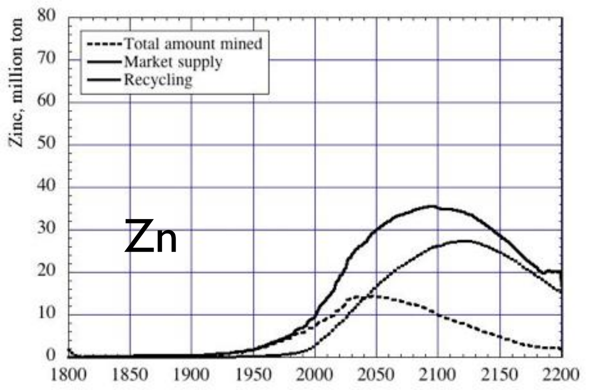
EXTRACTION, SUPPLY, RECYCLING AND DEMAND FOR DIFFERENT IMPORTANT METALS

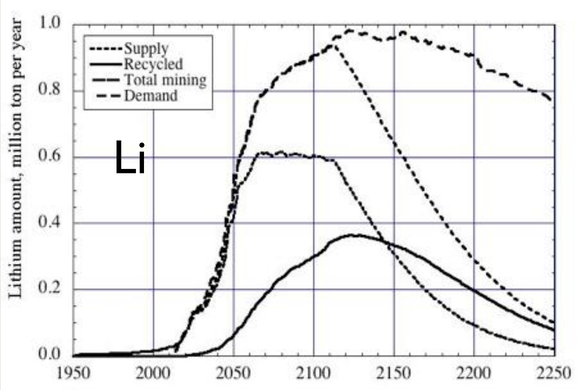


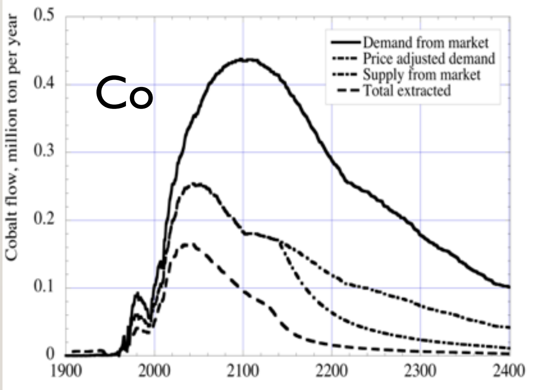


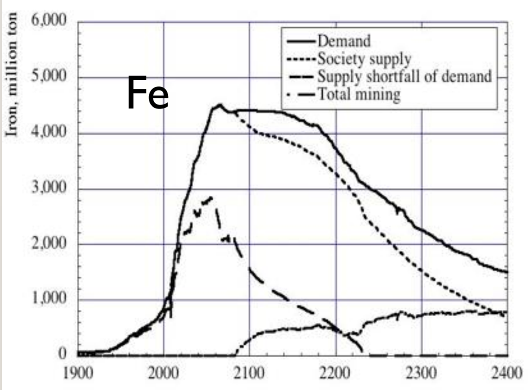




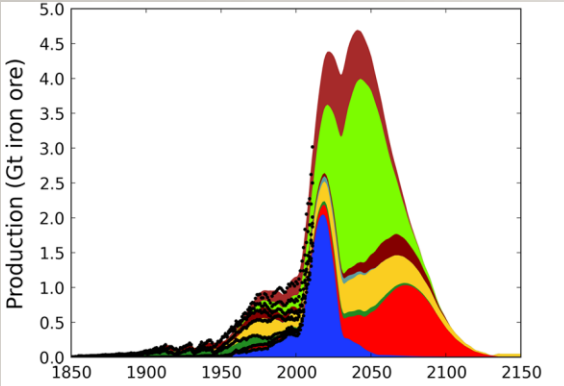


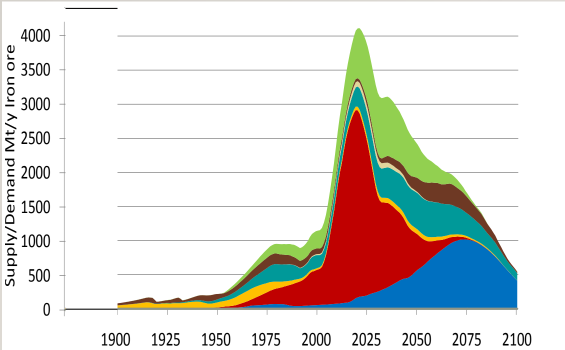


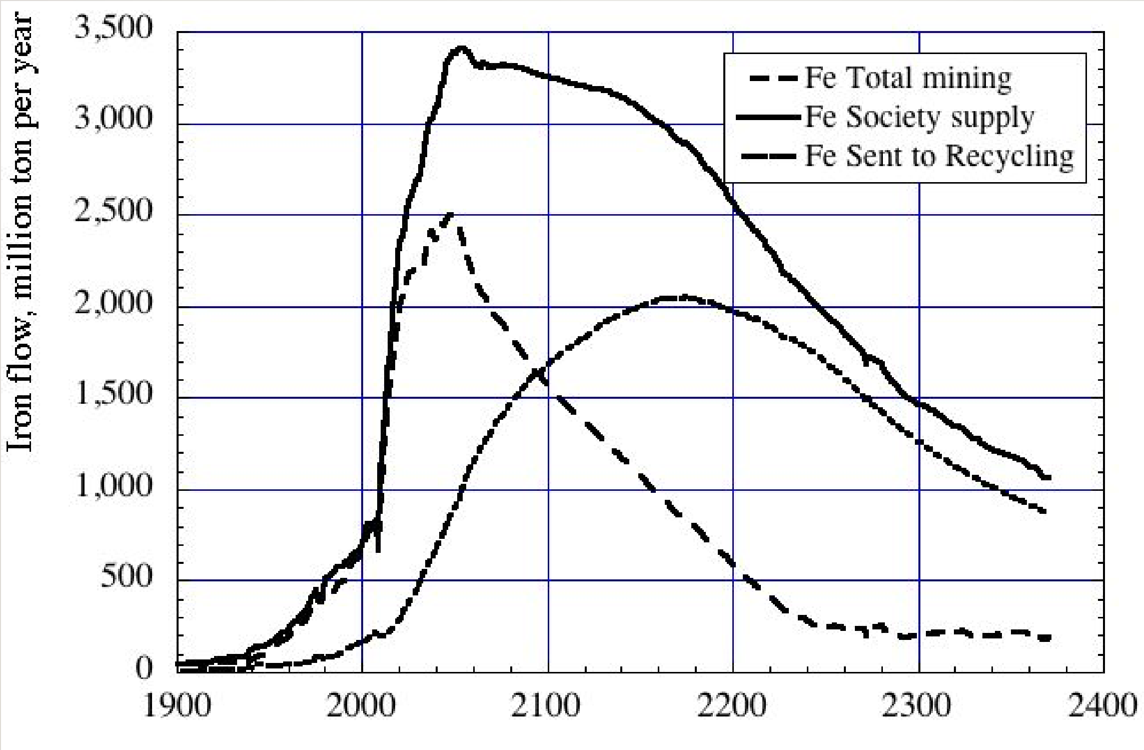


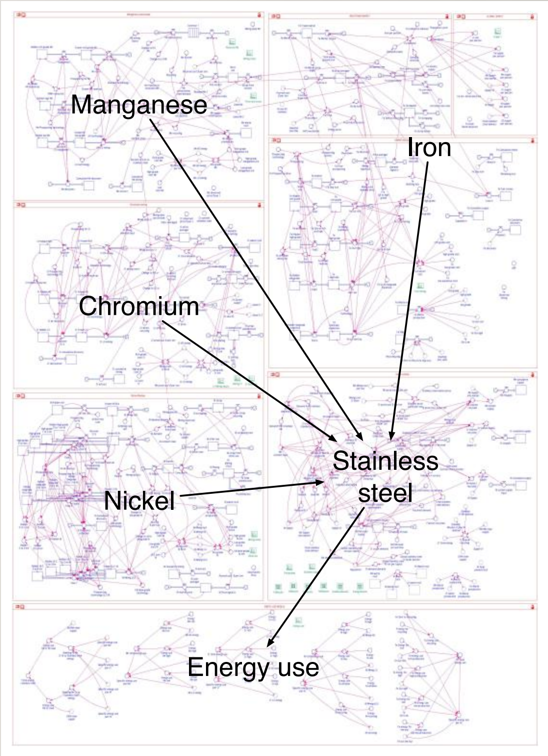


THE IRON SUPPLY, FOUR DIFFERENT STUDIES (MOHR, NICKLESS, GUIRCO, SVERDRUP), SAME CONCLUSION





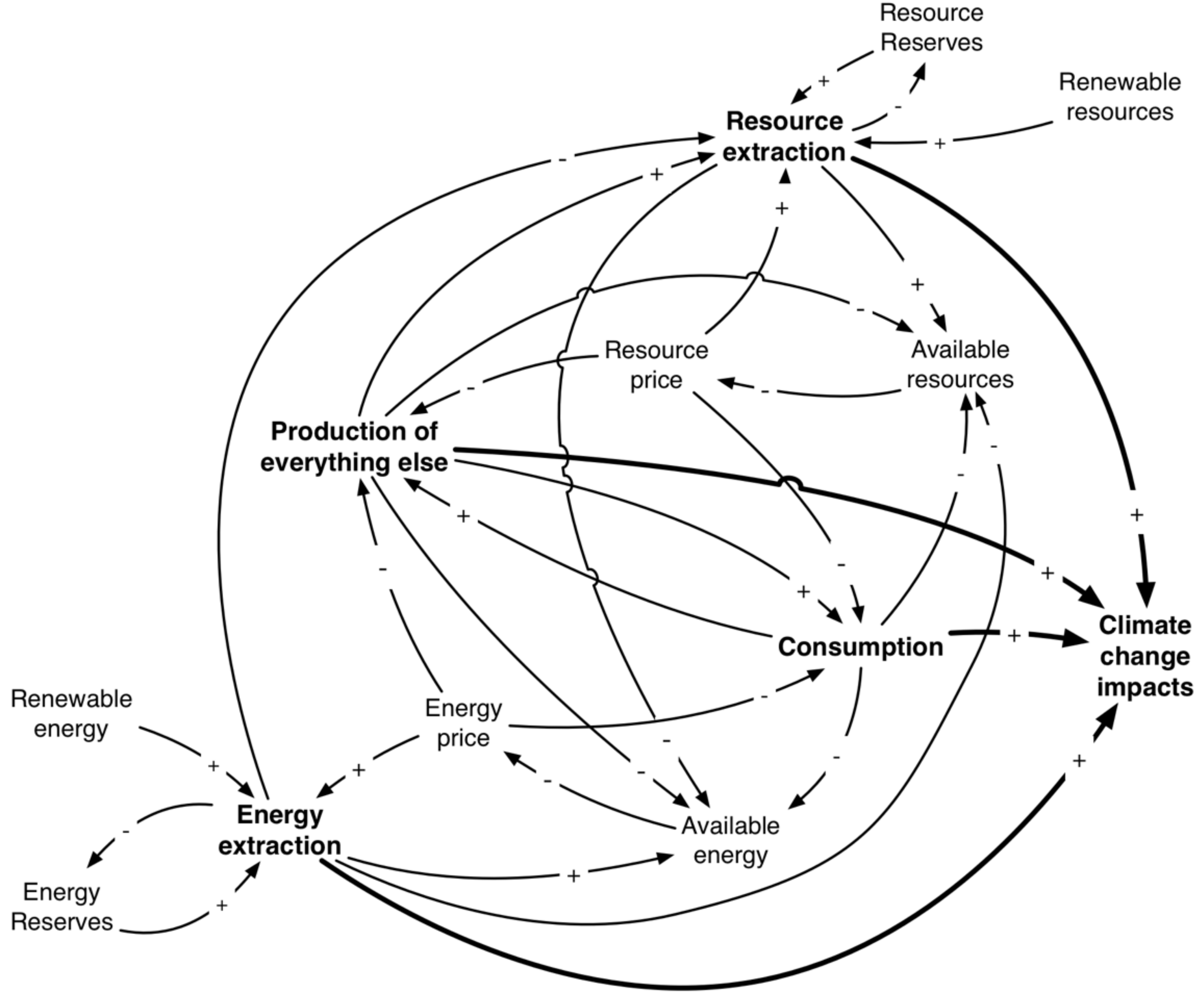




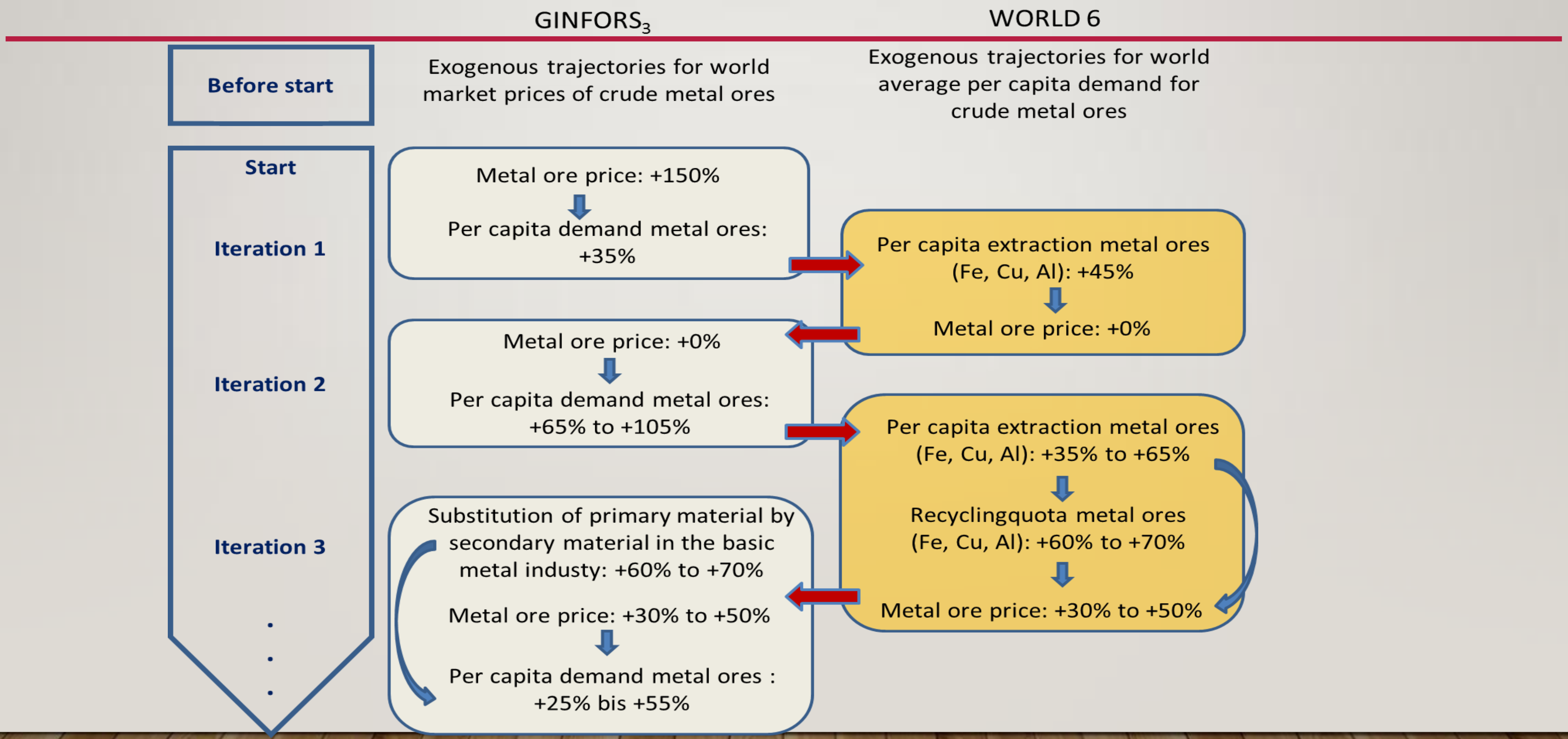
CO_2 EMISSIONS

IN **WORLD 6** ARE CAUSALLY CROSS-LINKED TO EXTRACTION AND CONSUMPTION OF:

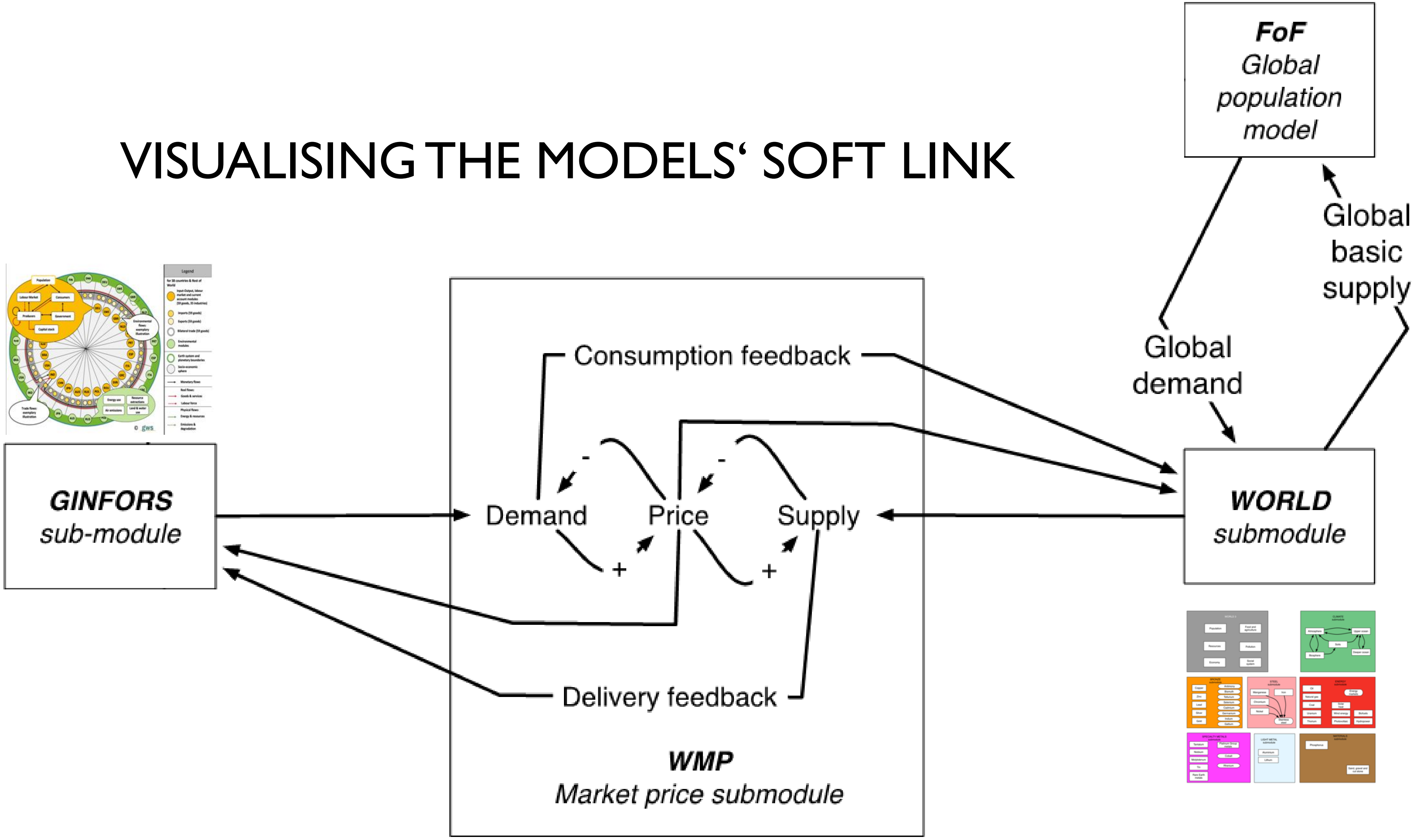
ENERGY,
MATERIAL RESOURCES,
PRODUCTION OF GOODS AND SERVICES
AND
GENERAL CONSUMPTION



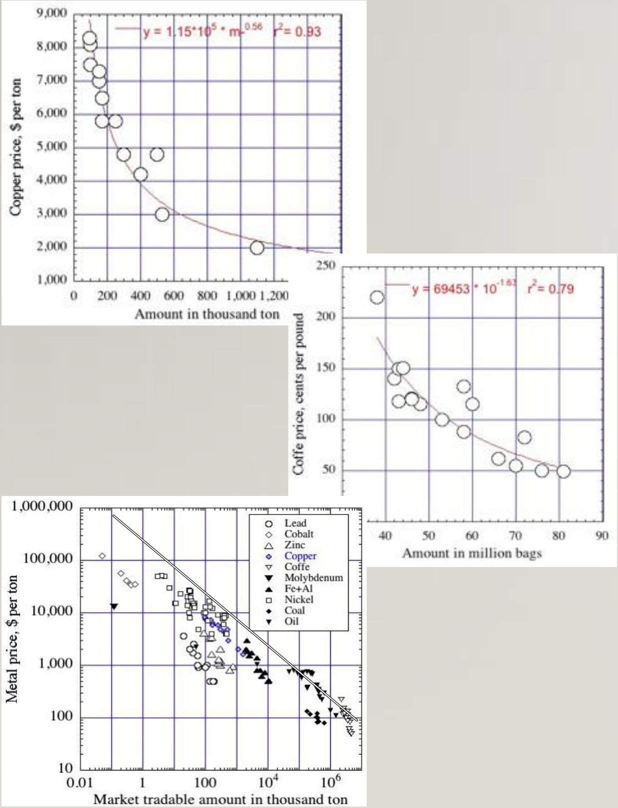
VISUALISING THE MODELS‘ SOFT LINK

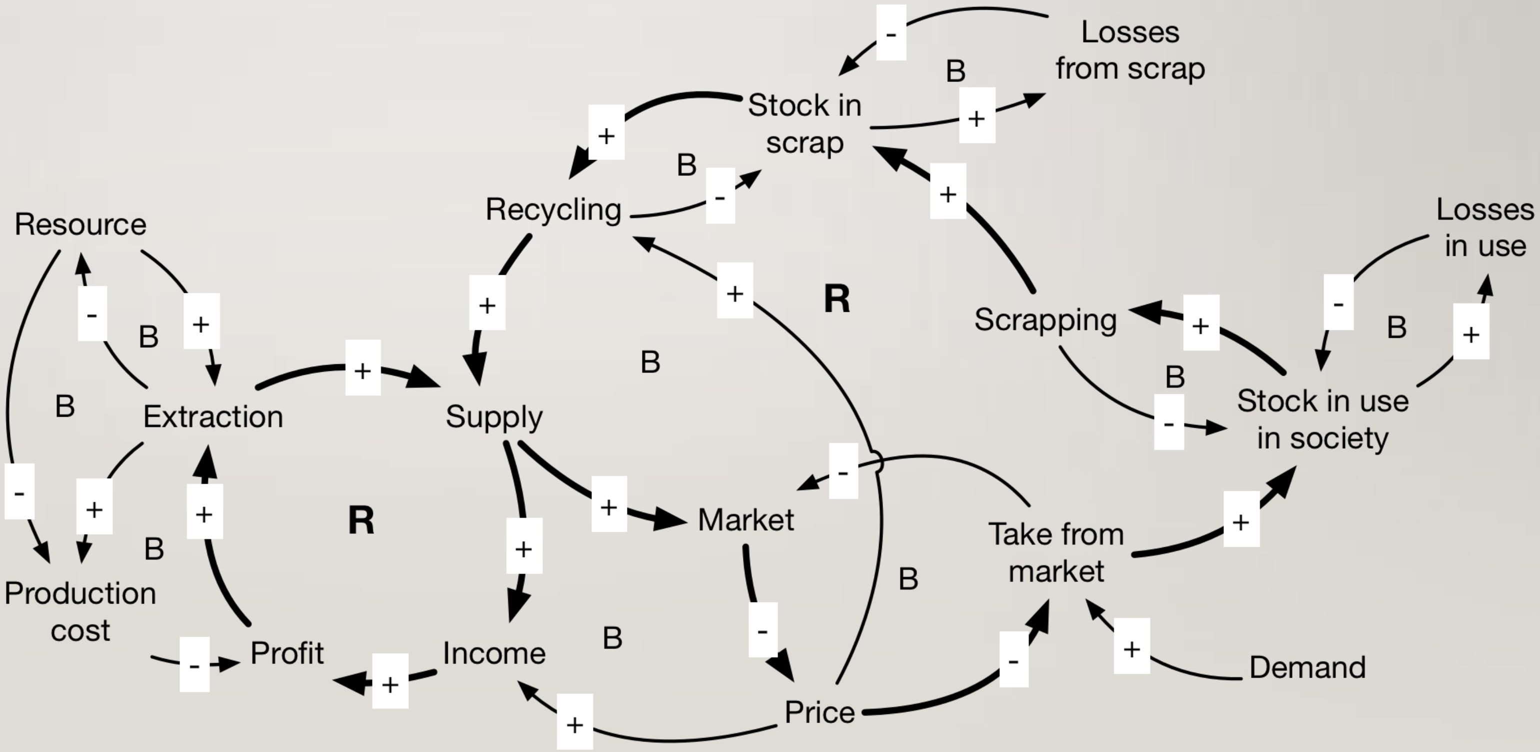


VISUALISING THE MODELS‘ SOFT LINK

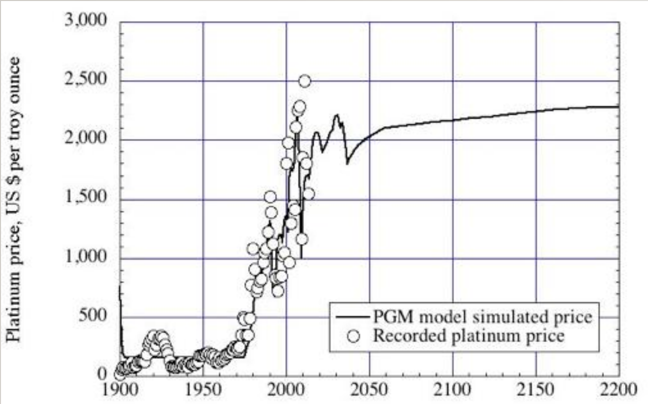


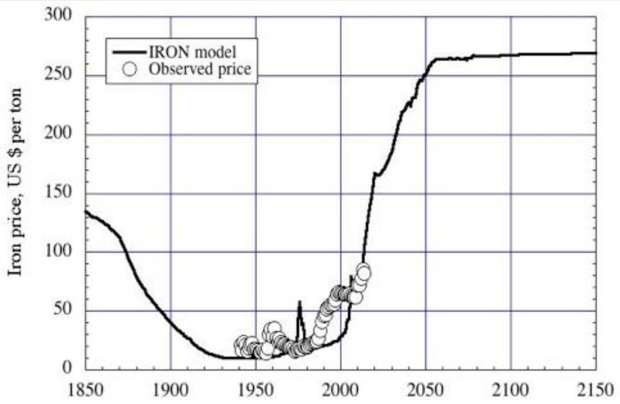
WORLD 6 MODEL; THE MARKET PRICE FROM CAUSALITIES; FEEDBACK EFFECTS ON SUPPLY, DEMAND AND CONSUMPTION

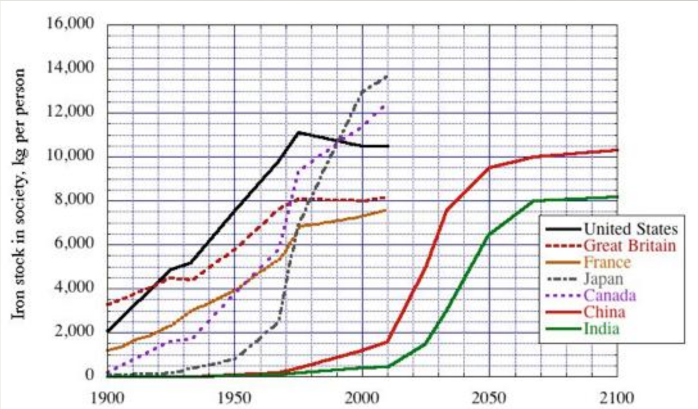


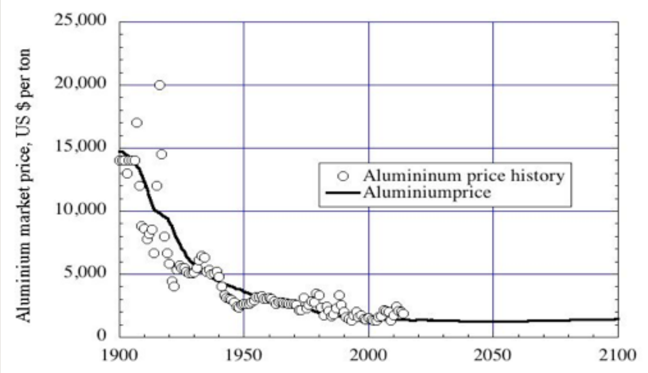


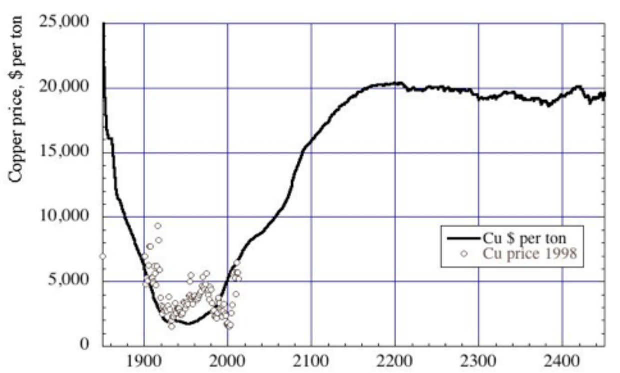
DEMAND, SUPPLY, MARKET PRICES AND REALITY







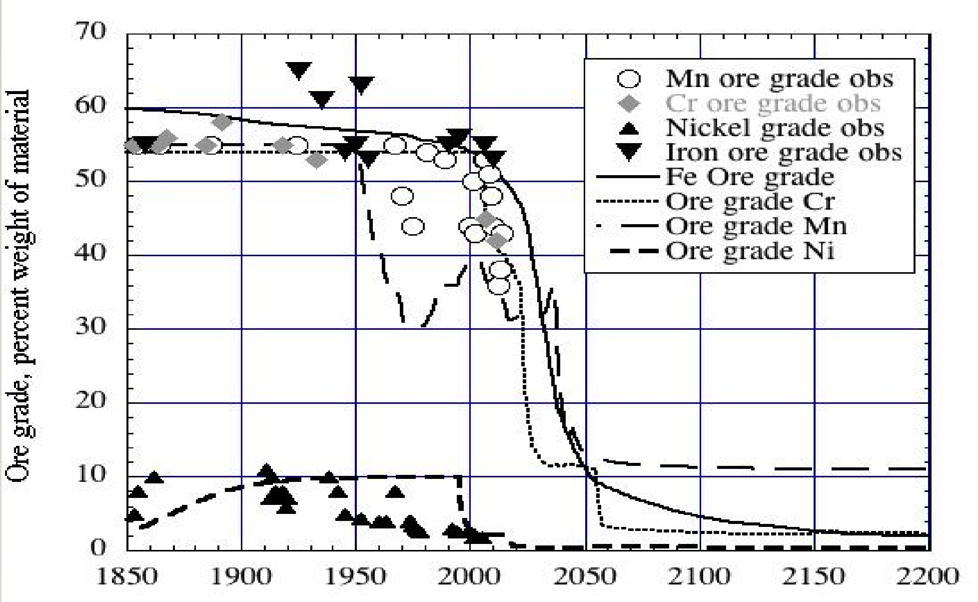




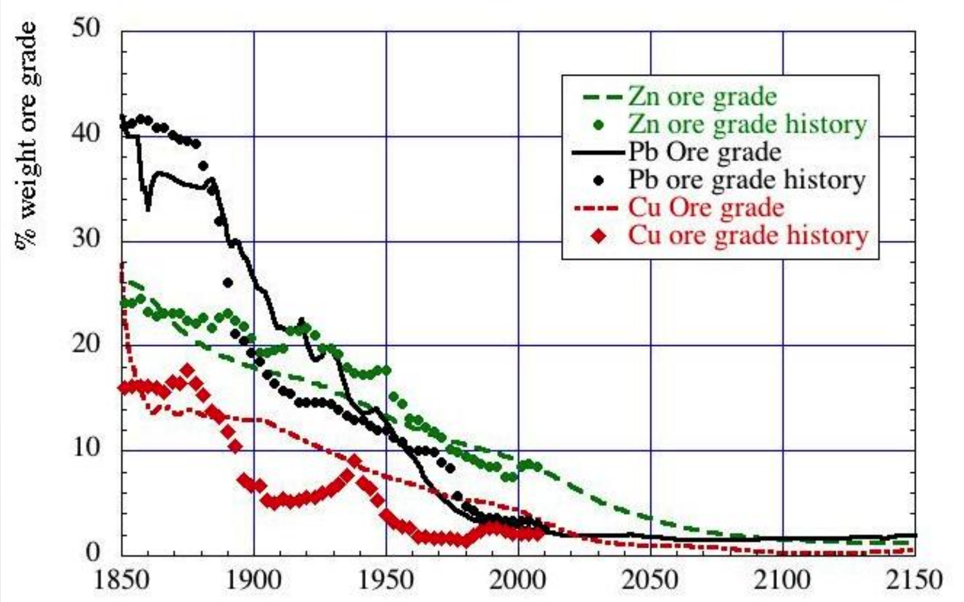
Further simulated market prices for;
oil, shale oil, coal, bitumen, peat, carbon shales,
natural gas, shale gas, tar,
nickel, tantalum, silver, molybdenum, cobalt, zinc, lead,
gold, indium, germanium, gravel, sand, cut stone,
phosphorus, coffee, niobium, rhenium, tin, antimony,
uranium, manganese, stainless steel

RESOURCE QUALITY IS CONSISTENTLY DECLINING FOR ALL RESOURCES

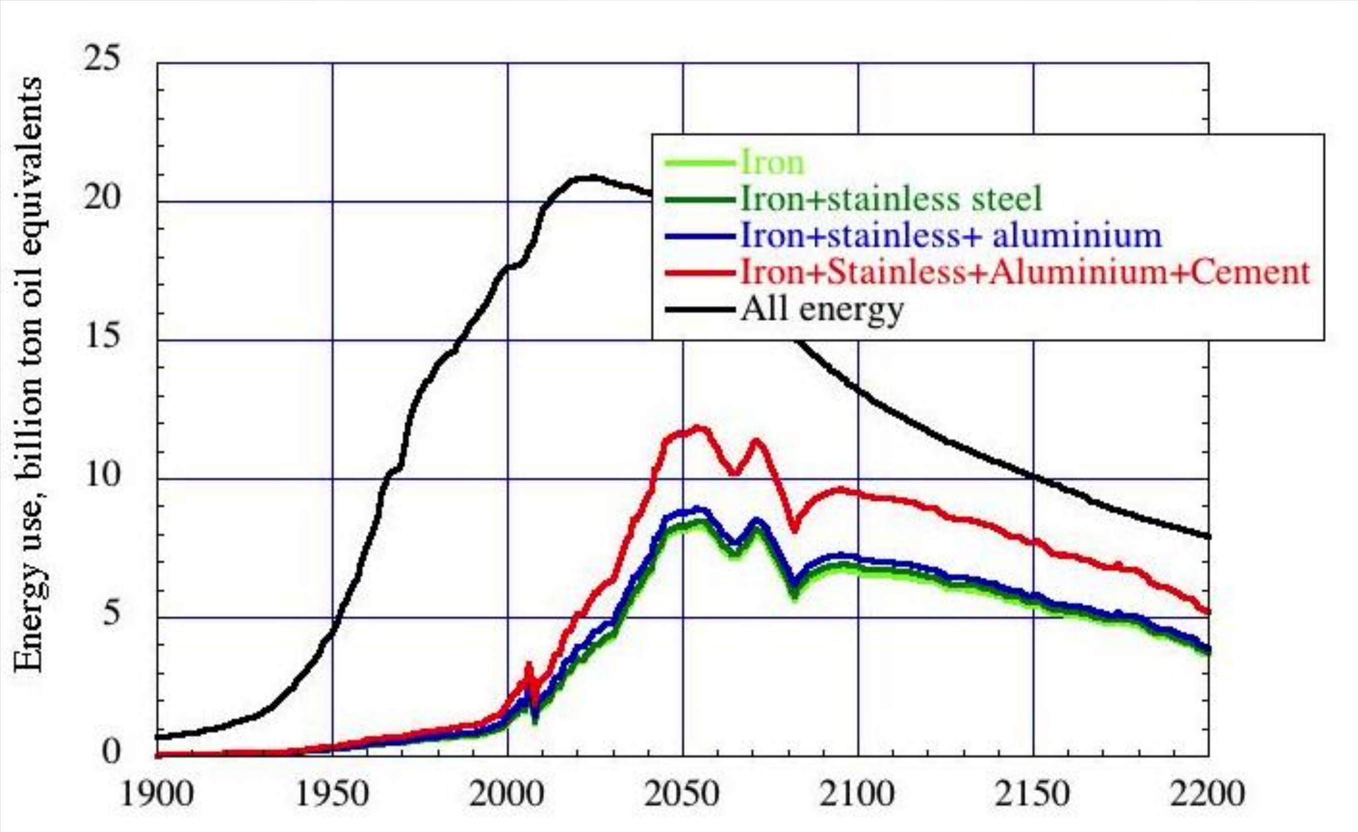
Iron, Manganese, Chromium, Nickel



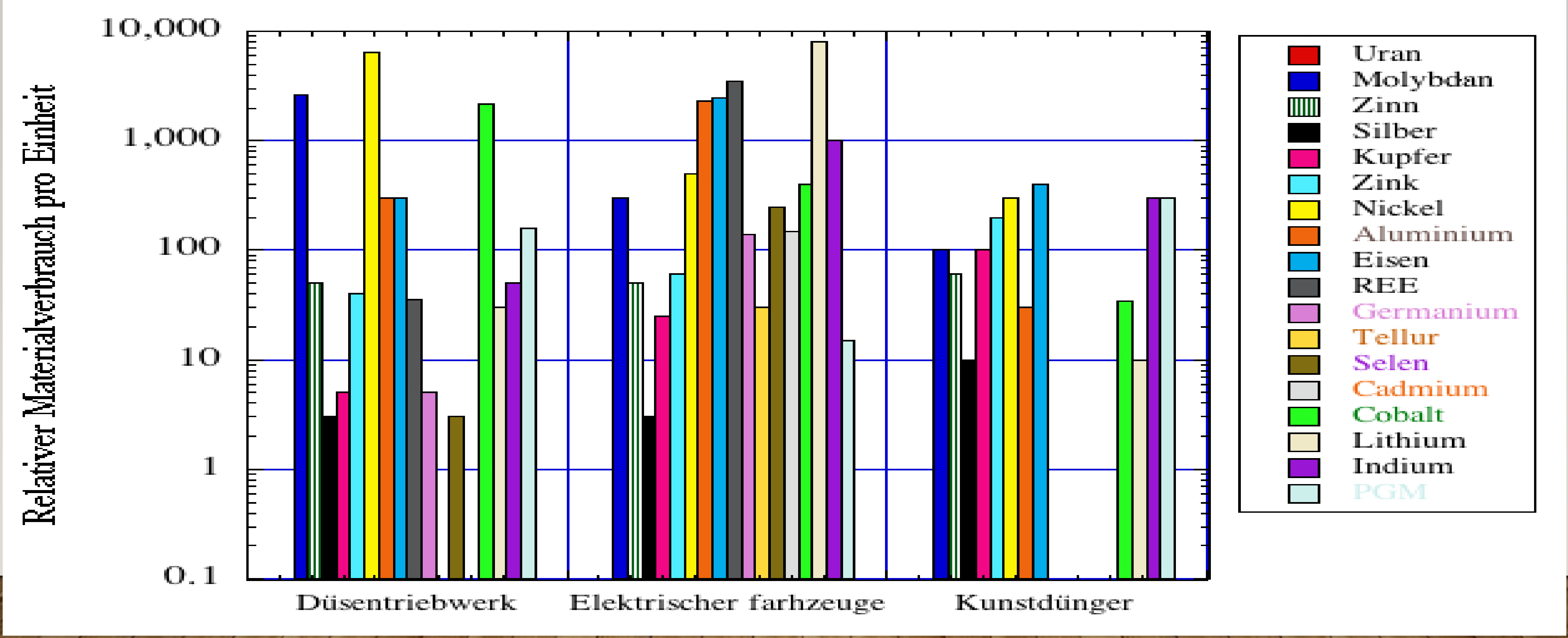
Copper, Zinc, Lead

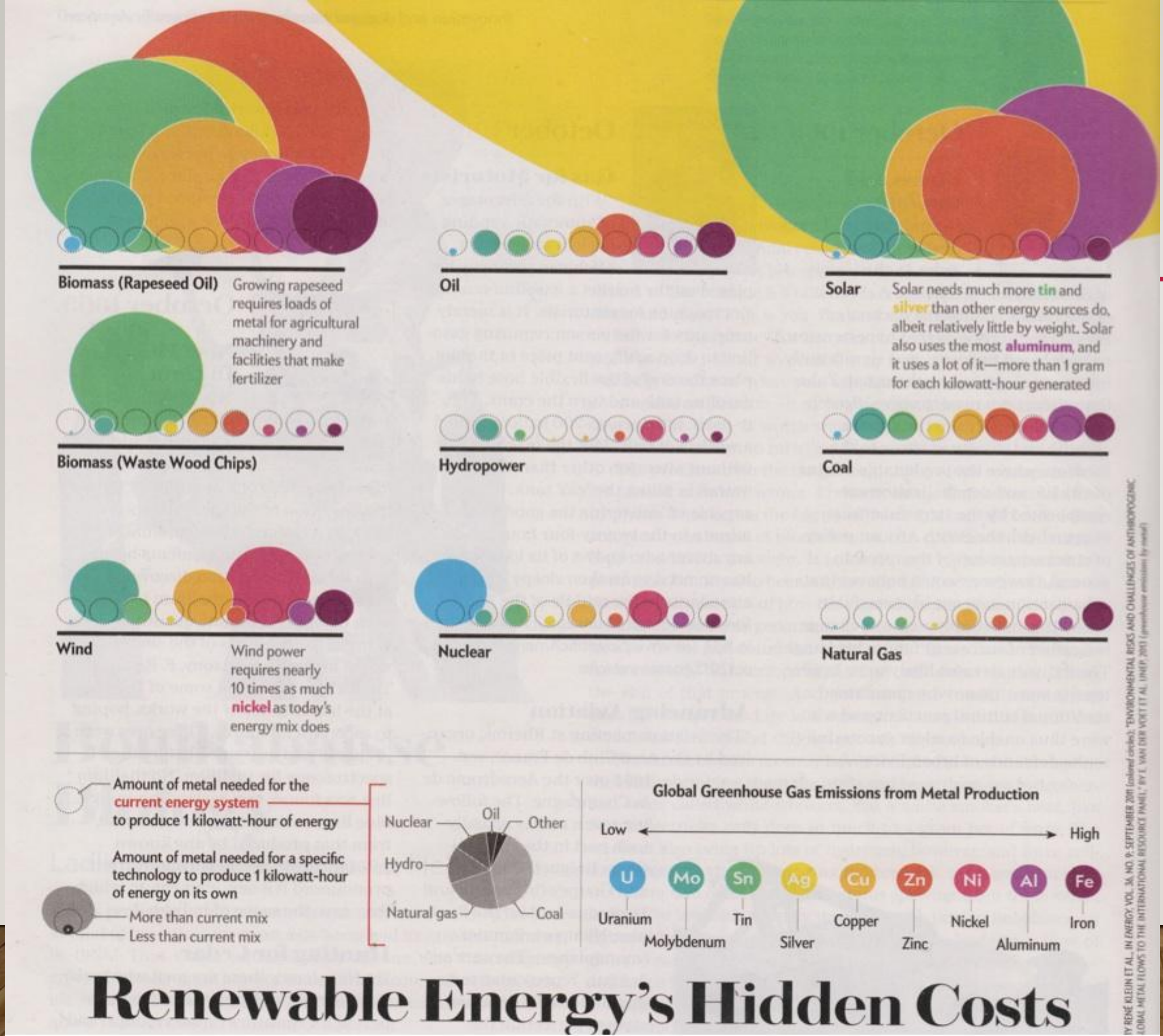


% OF TOTAL AVAILABLE GLOBAL ENERGY DEMANDED BY METALS AND CEMENT PRODUCTION AND USE



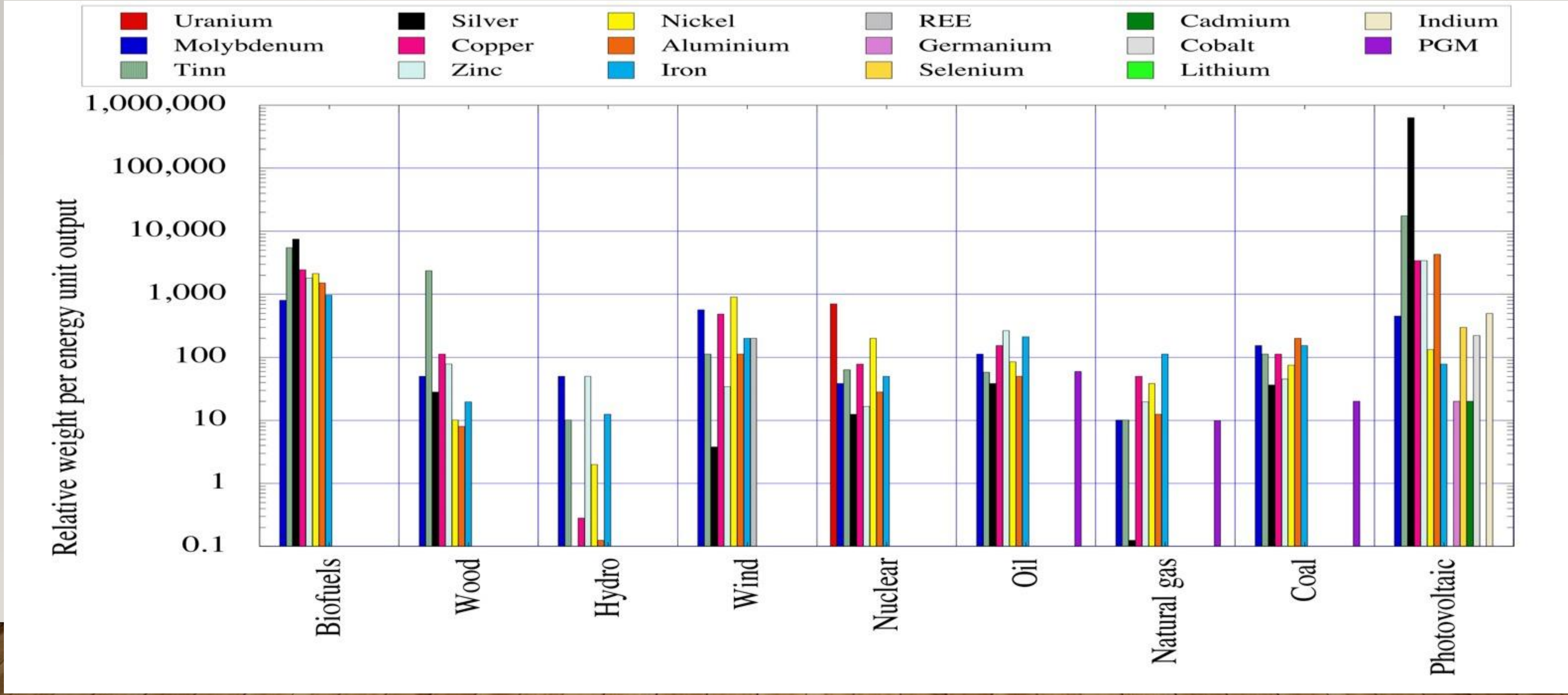
RELATIVE MATERIAL CONSUMPTION FOR JET ENGINES, ELECTRIC VEHICLES AND INDUSTRIAL FERTILIZERS





Rene Klein et al., 2011
Energy vol 36

MATERIAL USE FOR DIFFERENT ENERGY PRODUCTION PATHWAYS



Estimation of sustainable mine extraction of different metals in ton per year.					
Metal	Primary production 2012, ton/year	Sustainable use in % of todays use, Time horizon applied, years			
		10,000	5,000	1,000	500
Iron	1,400,000,000	1.6%	3.2%	16%	31%
Aluminium	44,000,000	4.3%	8.6%	43%	86%
Manganese	18,000,000	0.6%	1.1%	5.5%	11%
Chromium	16,000,000	0.3%	0.5%	2.5%	5%
Copper	16,000,000	0.4%	0.7%	3.5%	7%
Zinc	11,000,000	1.0%	2%	10%	20%
Lead	4,000,000	1.7%	3.4%	17%	34%
Nickel	1,700,000	0.6%	1.1%	5.5%	11%
Magnesium	1,000,000	surplus	surplus	surplus	surplus
Tin	300,000	2.5%	5%	25%	50%
Titanium	283,000	surplus	surplus	surplus	surplus
Molybdenum	280,000	0.8%	1.6%	8%	16%
Antimony	180,000	0.4%	0.8%	4%	8%
Rare Earths	120,000	18%	36%	surplus	surplus
Cobalt	110,000	0.1%	0.2%	1%	2%
Tungsten	80,000	0.9%	1.8%	3.6%	7.2%
Vanadium	70,000	2.7%	5.4%	27%	54%
Niobium	68,000	0.6%	1.2%	6%	12%
Lithium	37,000	9.5%	19%	95%	surplus
Silver	23,000	0.6%	1.1%	5.5%	11%
Bismuth	7,000	0.5%	72	360	720
Selenium	2,200	0.8%	1.6%	8%	16%
Gold	2,600	0.5%	1%	5%	10%
Indium	670	0.7%	1.4%	7%	14%
Tantalum	600	1%	2%	10%	20%
Gallium	280	0.2%	0.4%	2%	4%
Palladium	220	1.6%	3.2%	16%	32%
Platinum	180	2.4%	4.8%	24%	48%
Germanium	150	0.9%	1.8%	9%	18%
Tellurium	120	0.9%	1.8%	9%	18%
Rhenium	50	0.8%	1.6%	8%	16%

SUBSTITUTION HAS LIMITATIONS BECAUSE OF DIFFERENCES IN SUPPLY VOLUMES

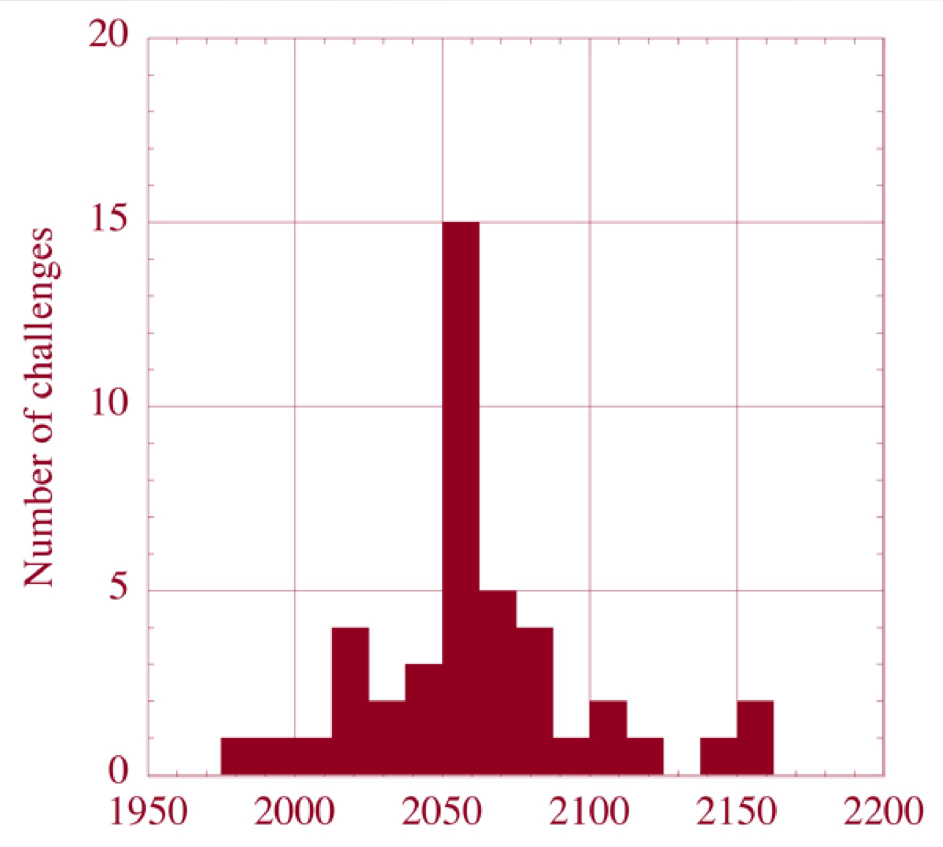
And

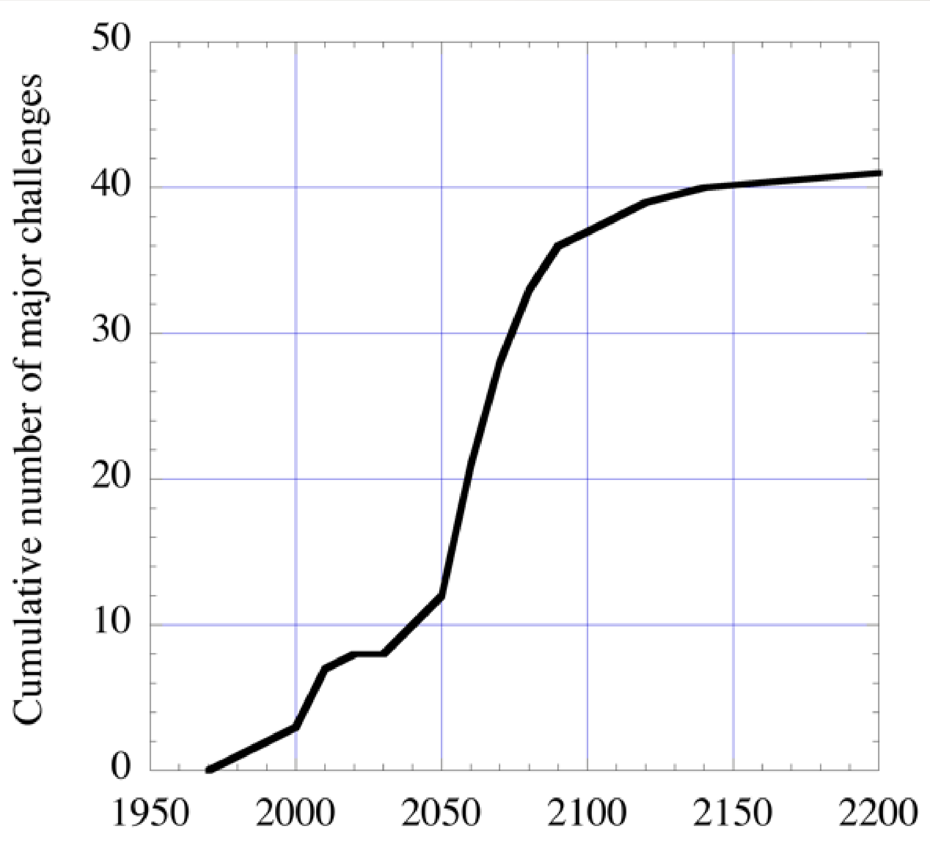
Because it excludes something else

WHEN DO RESOURCE EXTRACTION, PRODUCTION AND SUPPLY REACH MAXIMUM?

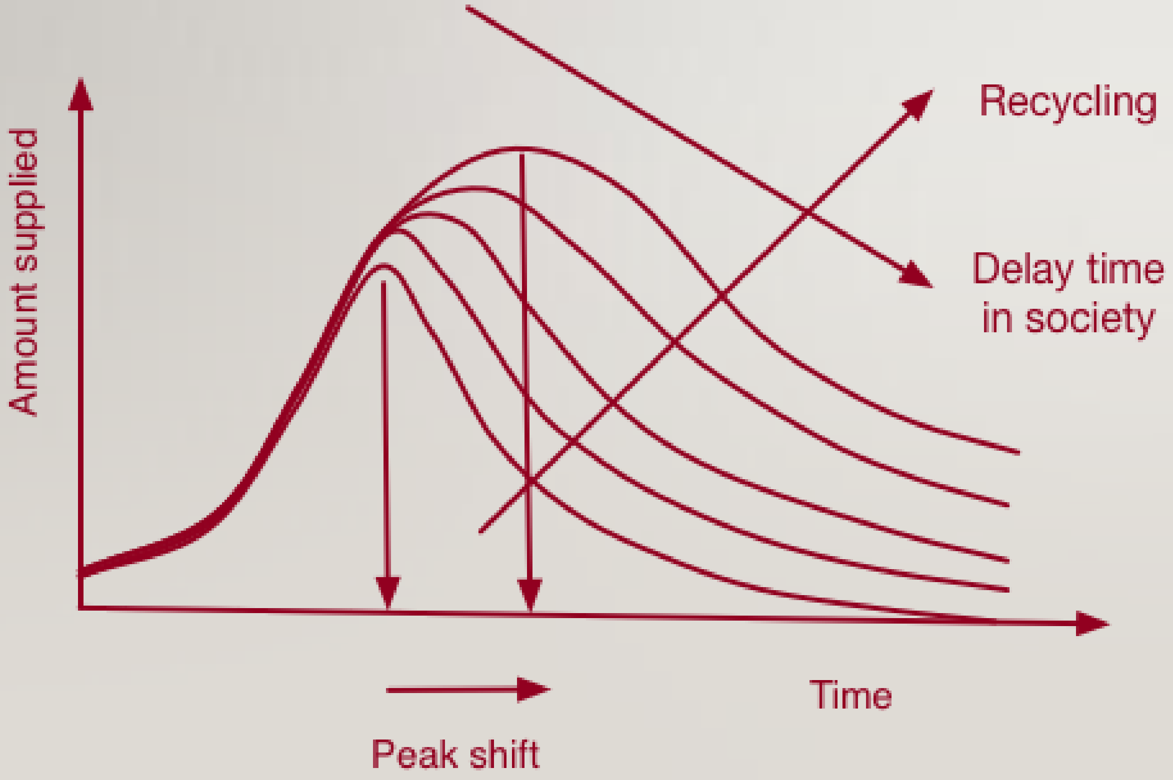
Metal	Extraction peak year	Supply peak year	Recycling degree (%)	Metal	Extraction peak year	Supply peak year	Recycling degree (%)
Oil	2012	2014	0	Titanium	2038	2060	40
Gas	2016	2016	0	Tellurium	1984	2060	0
Coal	2020	2018	0	Phosphorus	2035	2060	16-25
Cadmium	2010	2020	80	Palladium	2042	2065	60
Gold	2016	2036	85-90	Aluminium	2030	2070	75
Cobalt	2026	2040	40	Iron	2052	2072	60
Gallium	2026	2042	5-15	Stainless steel	2052	2070	65
Silver	2038	2045	70	Manganese	2053	2072	45
Selenium	2042	2050	0-5	Tantalum	2035	2078	60
Cut stone	2040	2050	20	Molybdenum	2038	2080	40
Lead	2041	2051	65	Rhenium	2042	2080	40
Niobium	2045	2052	60	Uranium	2035	2080	50
Tin	2046	2055	40	Zinc	2046	2090	20
Antimony	2048	2056	5-15	Chromium	2051	2110	22
Indium	2042	2055	20-40	Copper	2044	2120	60
Rhodium	2034	2058	60	Lithium	2060	2142	10-20
Germanium	2042	2058	20-30	Sand	2075	2150	30
Bismuth	2044	2059	5-15	Gravel	2130	2150	20
Nickel	2028	2060	50-60	Rare Earths	2045	2280	15
Platinum	2036	2060	70	Thorium	2090	2400	90

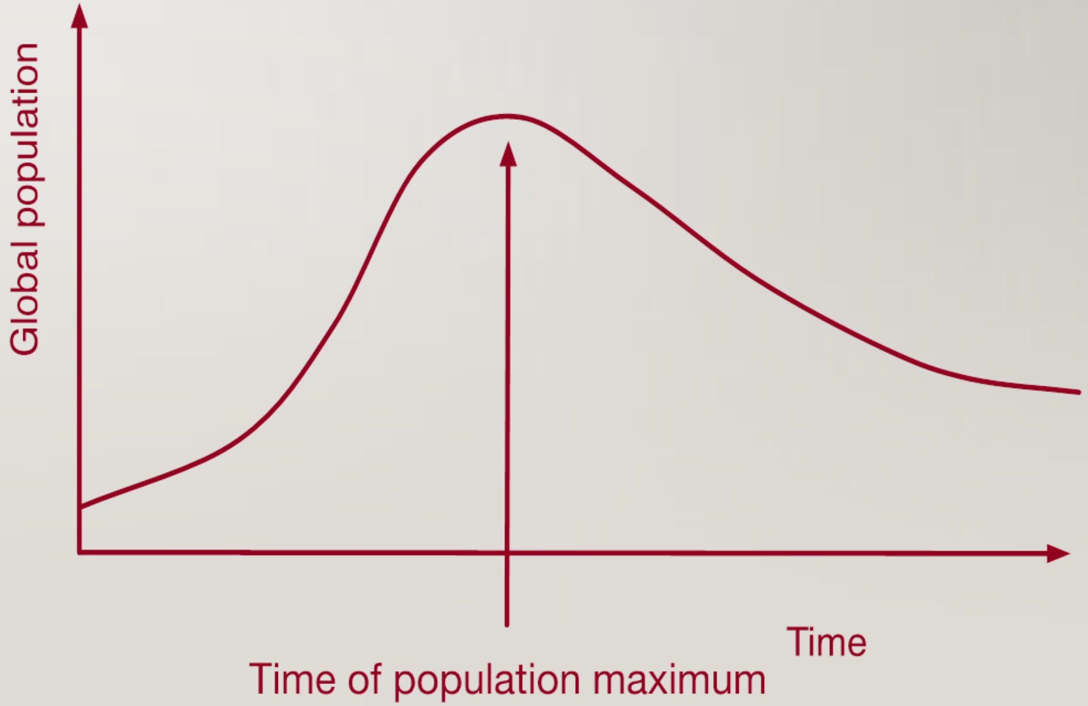
CHALLENGES PILE UP UNDER BUSINESS-AS-USUAL TOWARDS 2040 - 2100





WHAT CAN WE DO?
RECYCLING AND DELAY-TIMES SYSTEM DYNAMICS OF THE SUPPLY MAXIMUM





WHAT ARE THE POSSIBILITIES FOR METALS AND MATERIALS?

- **Efficiency**
  - Manufacturing use efficiency
- **Recycling, losses** and **reuse**
  - Recycling materials from use and waste
  - Reuse and retrofitting existing items
  - Limit irreversible losses
- **Delay times** in society
  - Longer use for required installations
  - Efficiency of recycling of redundant infrastructures and consumables
- **Consumption**
  - Less consumption overall
  - Better consumption utility efficiency
  - Less wasteful consumption
  - Behavioural patterns, social norms and prioritizations change
- **Governance** and **management**
  - Price interventions, taxations, limits
  - Promotions, education, public insights
  - System optimization

ASSESSING SUSTAINABILIY ASPECTS OF BEST AVAILABLE TECHNOLOGY ENERGY PRODUCTION METHODS

Extraction or production method	Energy source is sustainable?	Materials use is sustainable?	Environmentally sustainable?	Production and use is socially sustainable?	Totally sustainable?
Hydrocarbons	No	Yes	No	Yes	No
Biofuels	Can be by design	Yes	Can be by design	Can be by design	Can be by design
Wood	Can be by design	Yes	Can be by design	Yes	Can be by design
Wind energy	Yes	Limits	Can be by design	Can be by design	Limits
Photovoltaic	Yes	Limits	Yes	Yes	Limits
Uranium energy	No	No	No	Nuclear arms risks	No
Thorium energy	Limits	No	Has issues	Can be by design	No
Fusion	Unknown	No	Unknown	Unknown	Unknown
Hydropower	Yes	Yes	Can be by design	Yes	Can be by design
Solar heat	Yes	Yes	Yes	Yes	Yes
Geothermal heat	Yes	Yes	Can be by design	Yes	Can be by design
Geothermal to electricity	No	Limits	No	Yes	No
Fuel cells	By design	No	Has issues	Yes	No
Electric vehicles	By design	Limits	Can be by design	Yes	Limits

INSIGHTS

- All material resources will get into soft scarcity. Some key materials may get into physical scarcity, all fossil fuels have a quantifiable end date.
- Substitution has significant limitations, no substitute for phosphorus exists
- Resource shortages may cause economic crisis. Economic crisis may cause risk for social stresses and problems for governance. The economic system may have problems before the physical systems.
- Business-as-usual is the most dangerous policy
- **Business-as-unusual** has large possibilities for change of trajectory

CONCLUSIONS

- A systemic approach is a condition for resolving the challenges.
  - Narrow sectorial appoaches are neither systemic, nor sufficient, it is not about adjusting the parameters of the present system, feedbacks co across sectors
  - The circular economy is systemic in nature and must be designed as such
  - Potentially, many goal conflicts are possible that must be solved at systemic level

---

- Systemic changes need to be multi-sectorial, causally linked and pervasive
  - **Energiewende** is linked to a **Ressourcewende**
  - Both are about rearranging the basic **structure of the systems** and resetting parameters
  - It involves **all fundamental systems**; industrial, economic and social dynamics
  - It may imply **transformative changes** to existing society and existing power-structures
  - Unresolvable **goal conflicts** will lead to difficult choices
- Transformative changes take time,
  - Plan with at least **20 years** from start to full implementations (Ref; LRTAP protocol, IPCC progress)
  - **Start**ing is needed **at once** (2017+20 = 2037)

DISCUSSING FINAL SIMRESS PROJECT RESULTS

- Invitation to joint final workshop of SimRess and DeteRess projects
- Two consecutive workshop days
  - Resource conservation and resource productivity: modelling approaches for assessment of economy-wide material flows and potential policy impacts
    – 7 December 2016, Berlin (Workshop language: English)
  - Resource conservation and resource productivity: Drivers, long-term development and policy options
    – 8 December 2016, Berlin (Workshop language: German)
- Please see for more information: http://simress.de/en/events