The mineral resources - energy nexus in the context of energy transition

Dynamic modeling of

1) mineral resources demand and energy cost, emitted CO2 for three energy scenarios 2060

2) future price of commodities and capacities of production

3) level of sustainability until 2200

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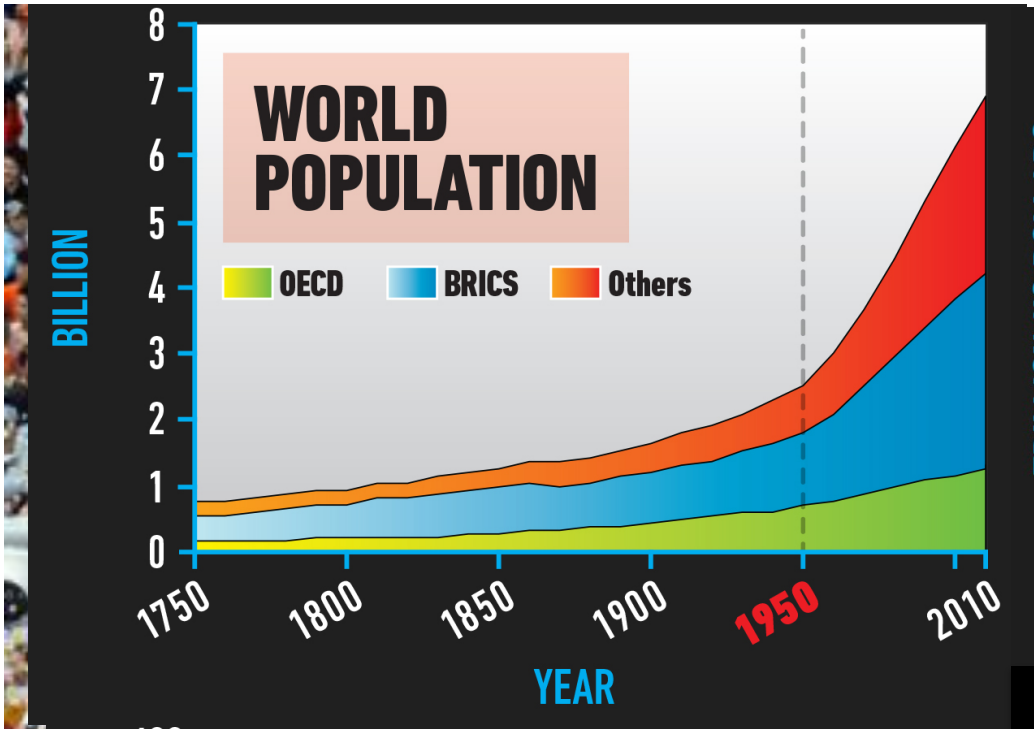
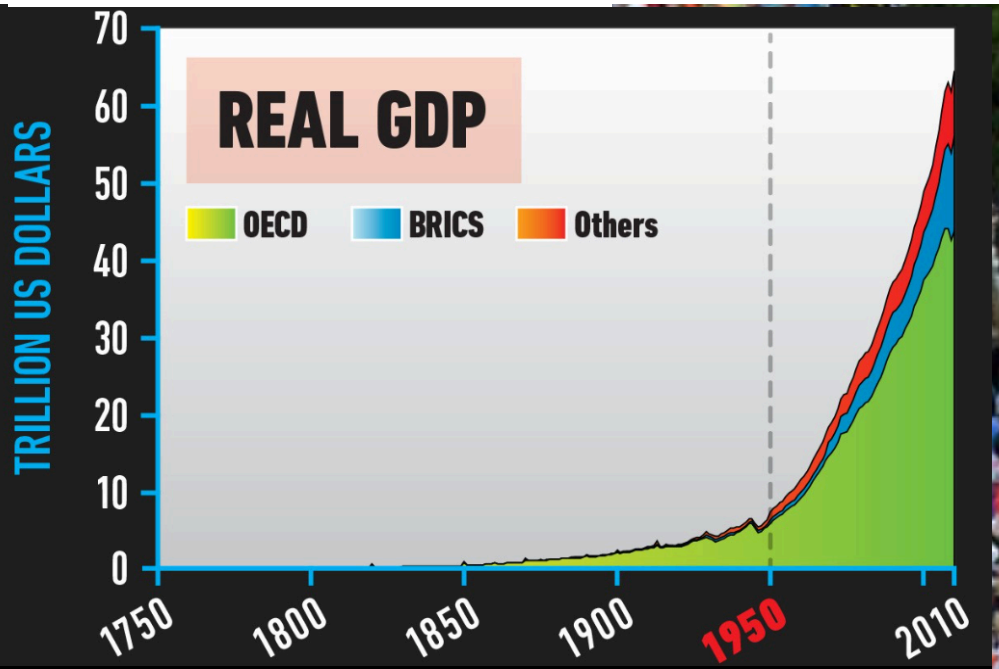
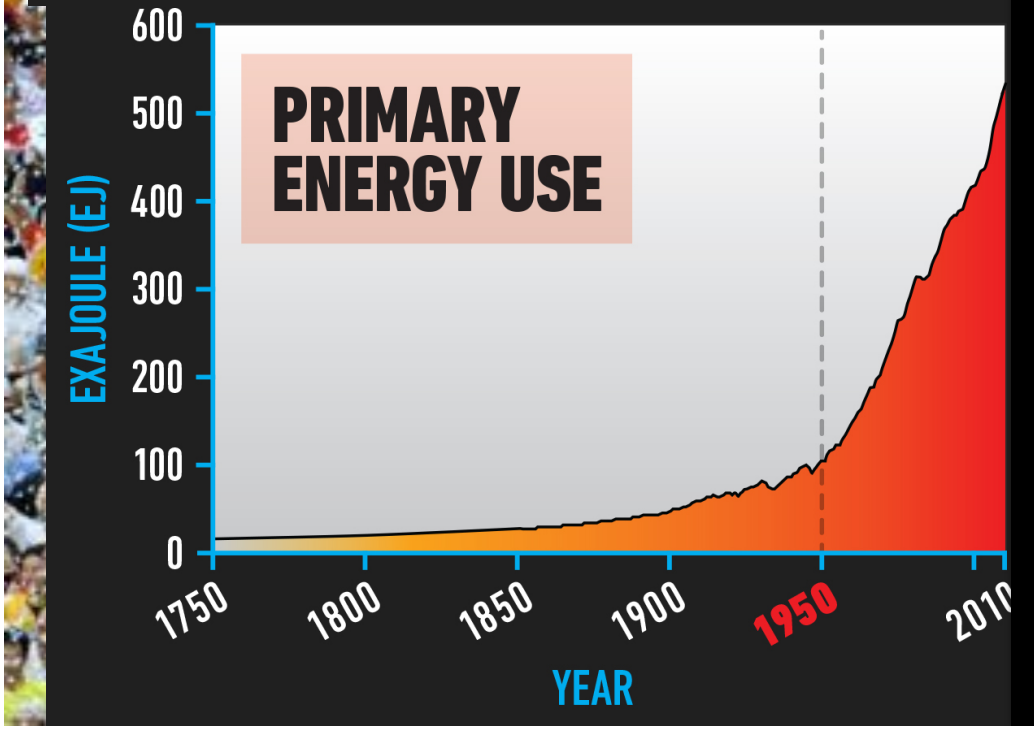
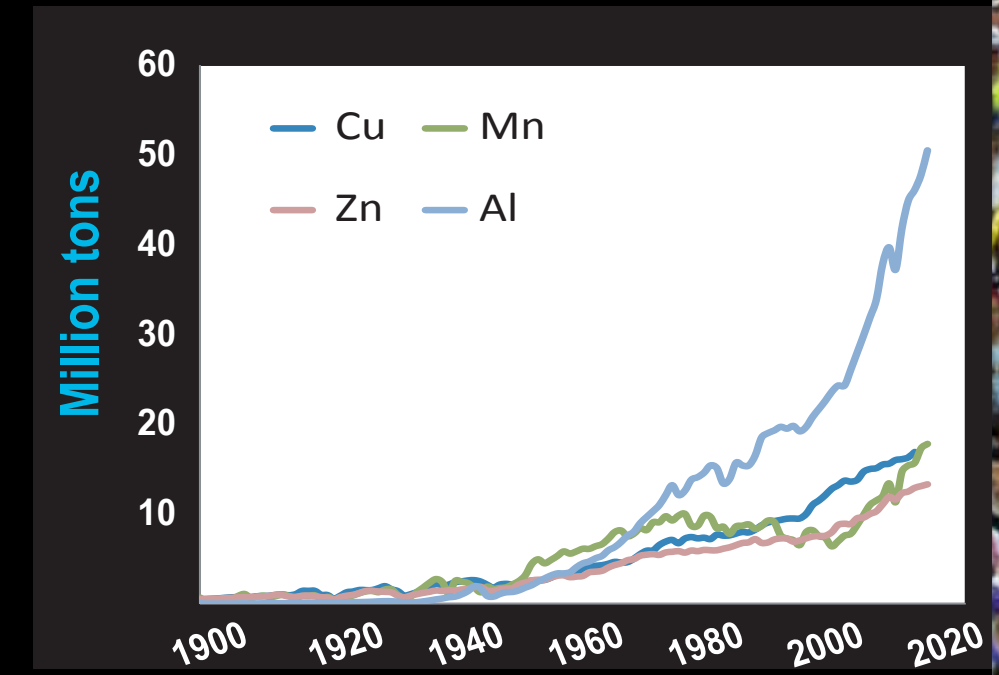
ISTerre
Institut des Sciences de la Terre


WORLD POPULATION
OECD
BRICS
Others
BILLION
0
1
2
3
4
5
6
7
8
1750
1800
1850
1900
1950
2010
YEAR


REAL GDP
OECD
BRICS
Others
TRILLION US DOLLARS
0
10
20
30
40
50
60
70
1750
1800
1850
1900
1950
2010


PRIMARY ENERGY USE
EXAJOULE (EJ)
0
100
200
300
400
500
600
1750
1800
1850
1900
1950
2010
YEAR


Cu
Mn
Zn
Al
Million tons
10
20
30
40
50
60
1900
1920
1940
1960
1980
2000
2020

The reduction of GHG emissions is a big challenge of the XXIst century

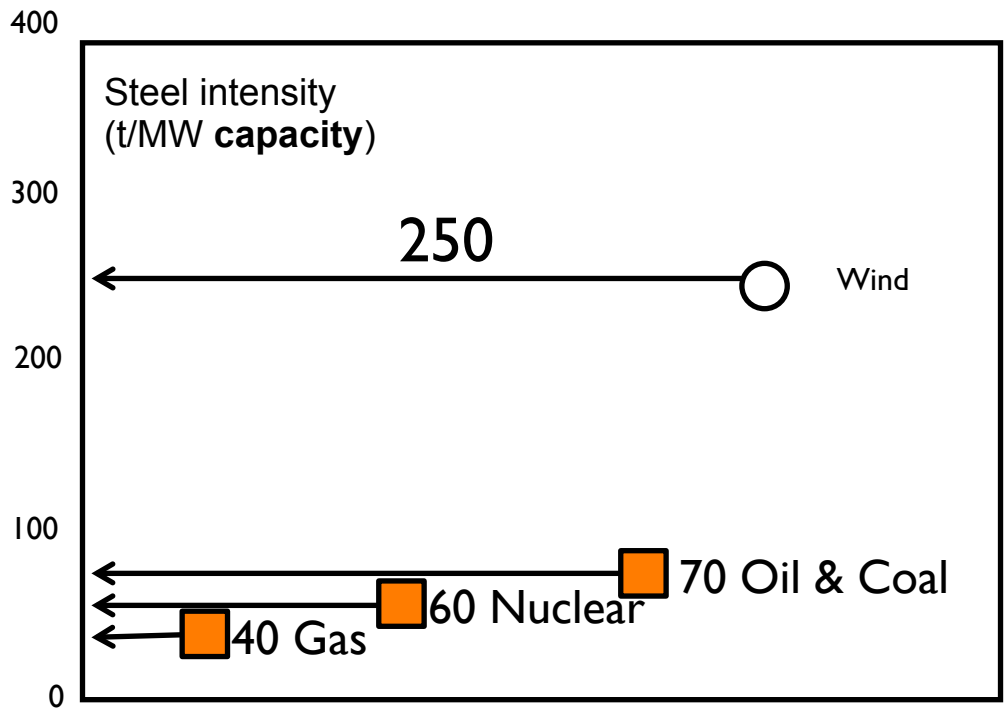
The COP21 Paris agreements : 30% reduction of global emissions and achievement of "carbon neutrality" worldwide by 2050+. This implies:

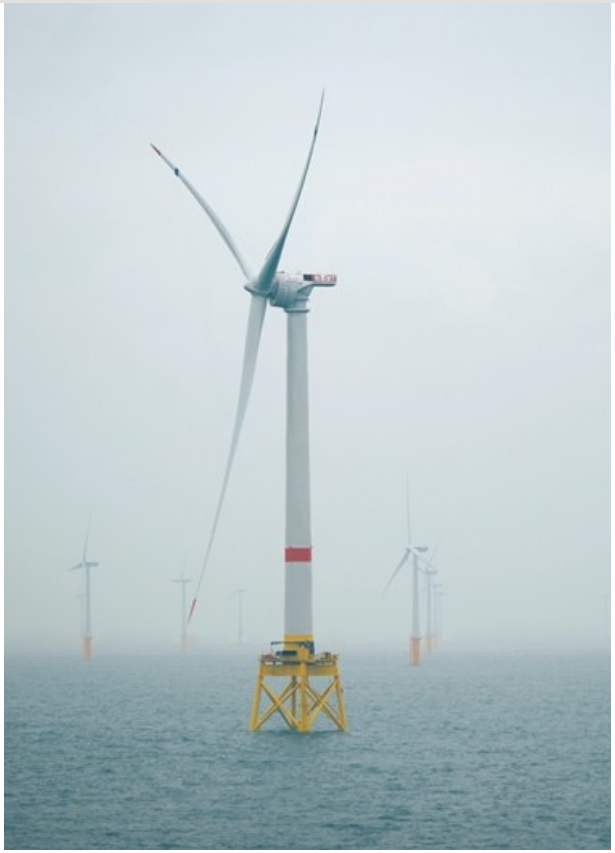
- To replace in 40 years the existing fossil fuels based system of energy generation, storage, transport, distribution and use

- To shift from **stocks** of concentrated fossil energies to **intermittent flows** of diluted renewable energies

Renewable energies are diluted => large infrastructures are required

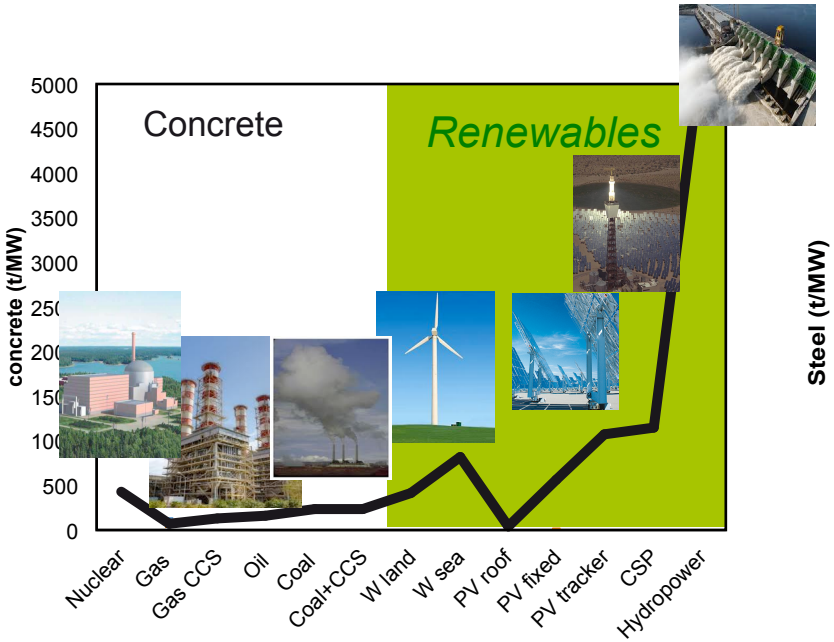
6 Mw, > 150 m, *1500 t steel*
3t permanent magnet, *1t REE*
(Nd, Dy, *Sm, Gd, or Pr)*

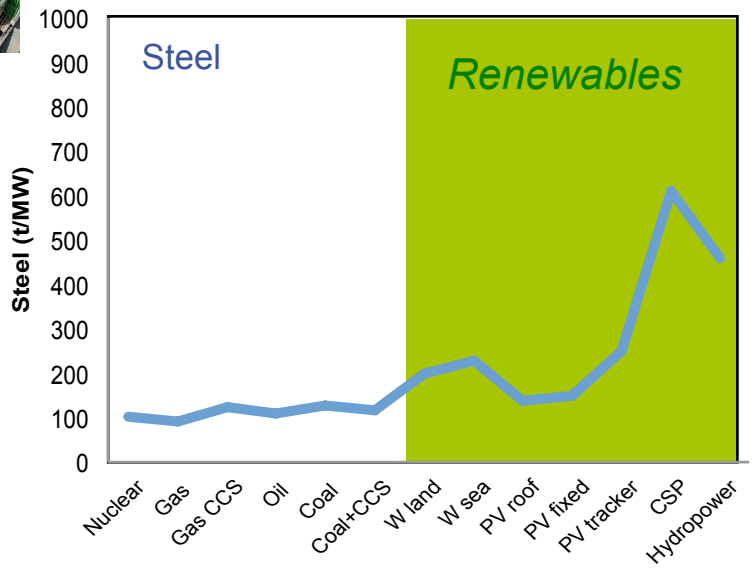


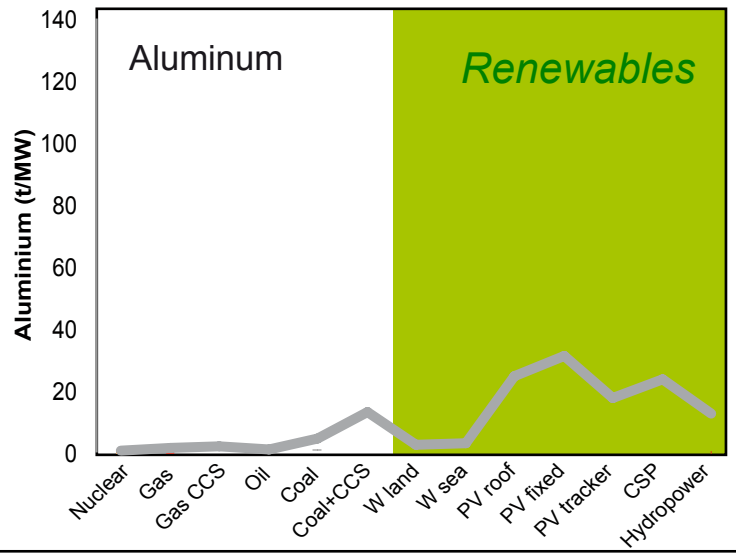


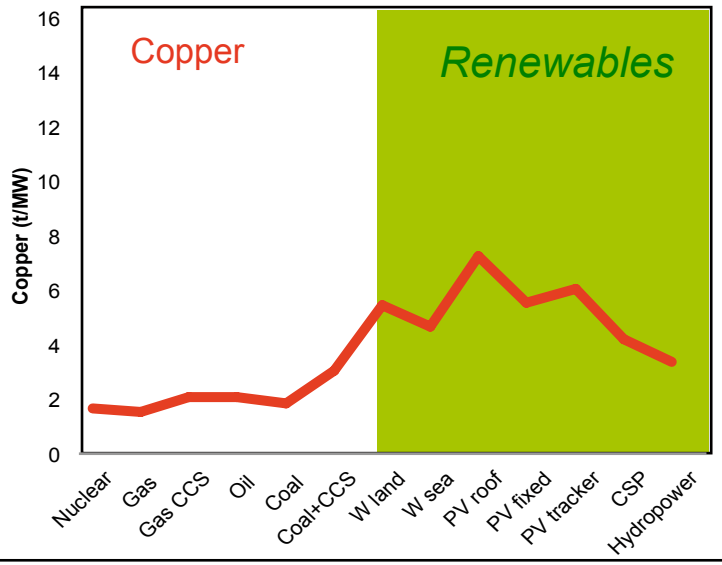
700 wind turbines to produce the same annual energy (Wh) as a 1300 MW nuclear power plant

Material intensity of electricity-generation facilities (t/Mw)









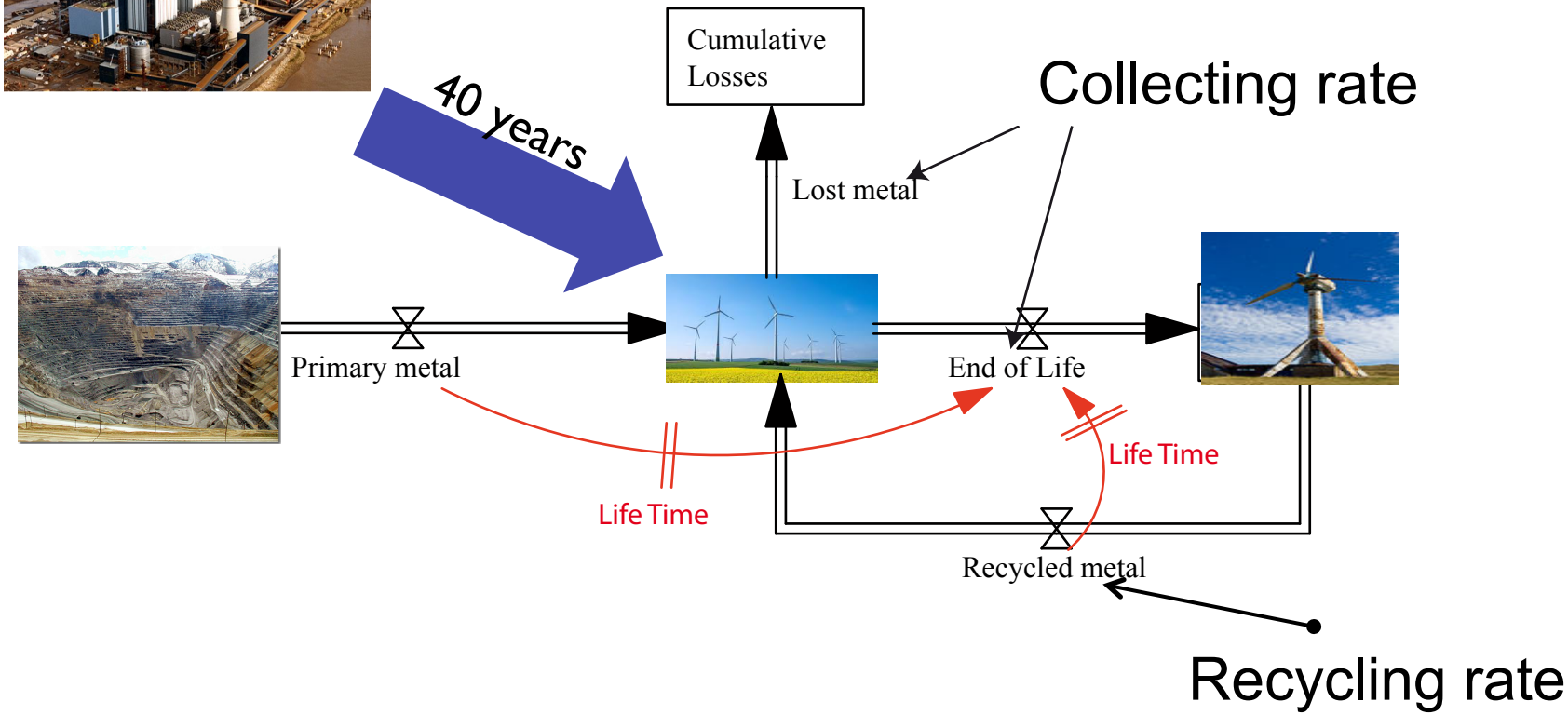
The transition towards low-carbon energy requires large amounts of mineral resources

- How much primary metal ? (scenario and technology dependent)
- Are they available ?
- What are the environmental impacts of their production ?

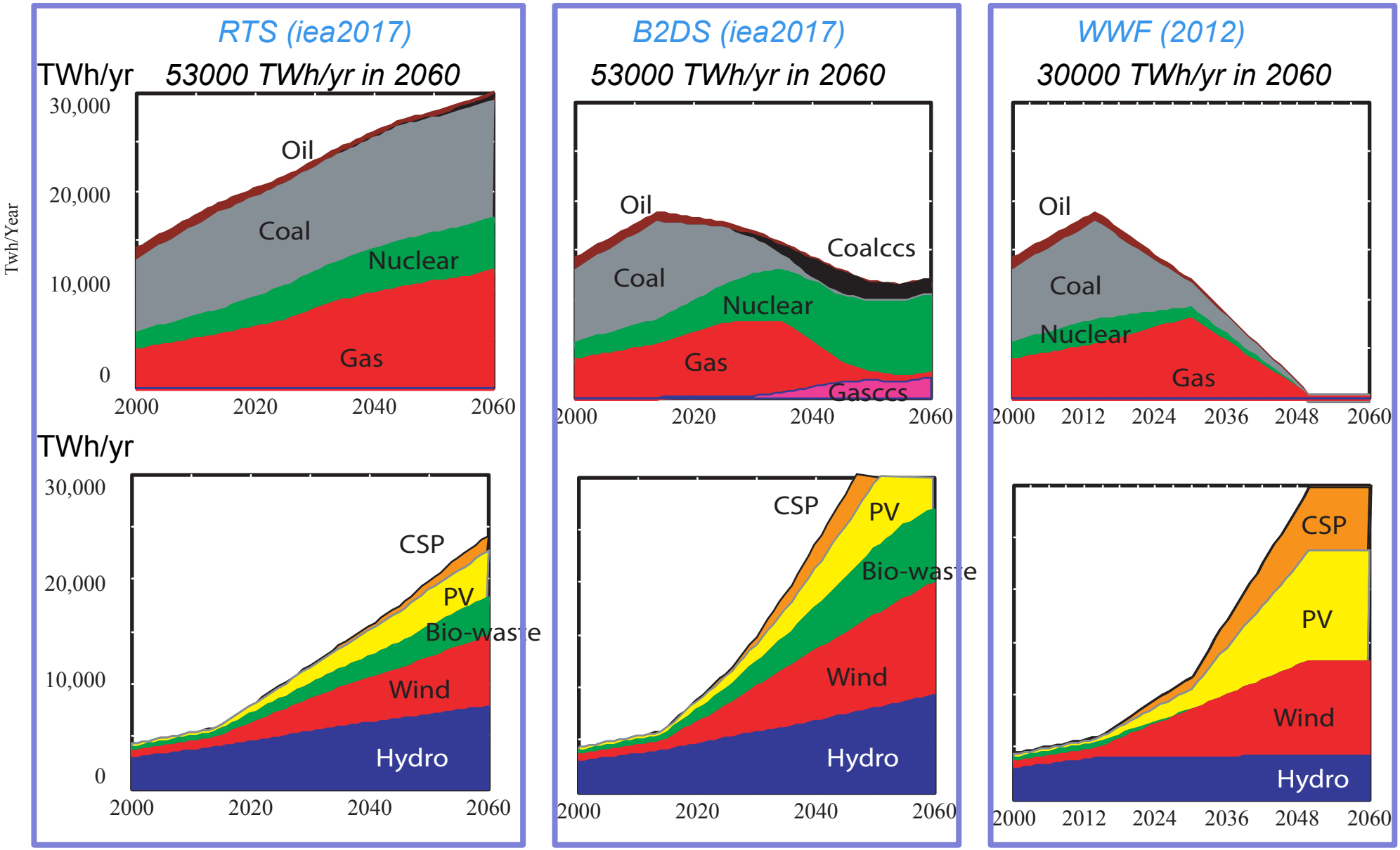
Dynamic modeling

Raw Materials and energy requirements: a stock and flow problem…

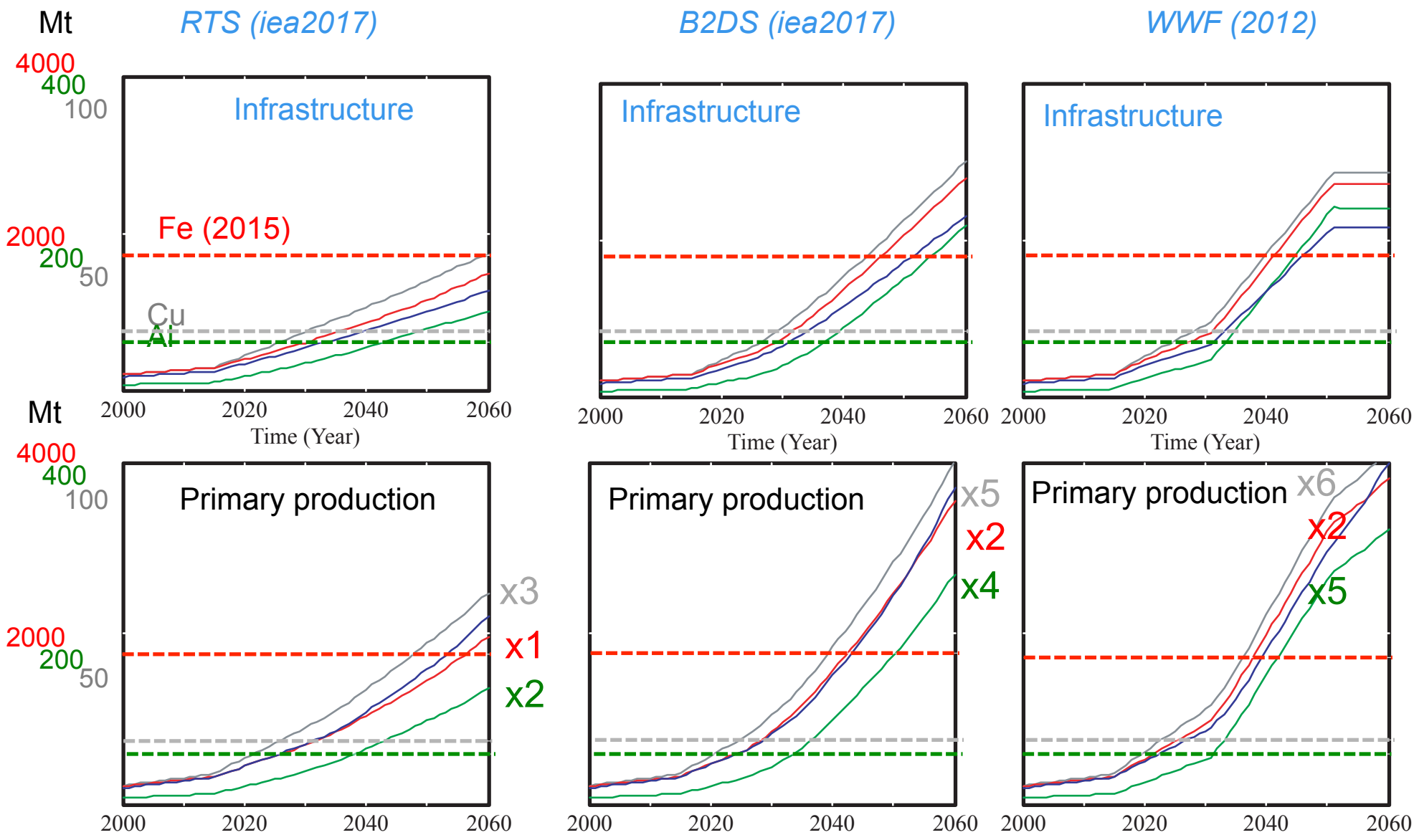
$\int$ primary production > stock in infrastructure



Generated electricity



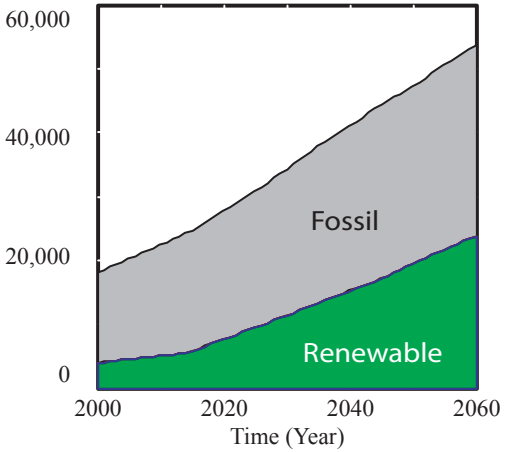
Cumulative needs in Fe, Al & Cu (Mt)



Cumulative needs in Fe, Al & Cu (Mt)

RTS (iea2017)

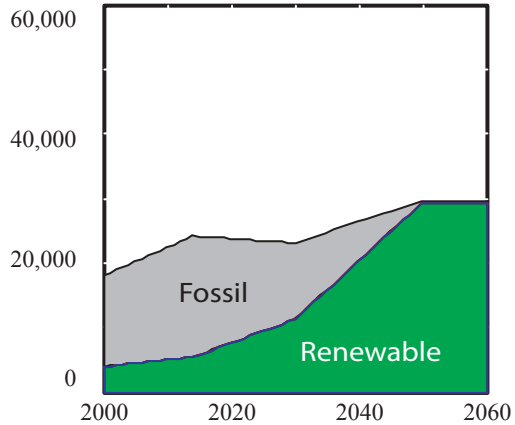
53000 TWh/yr in 2060

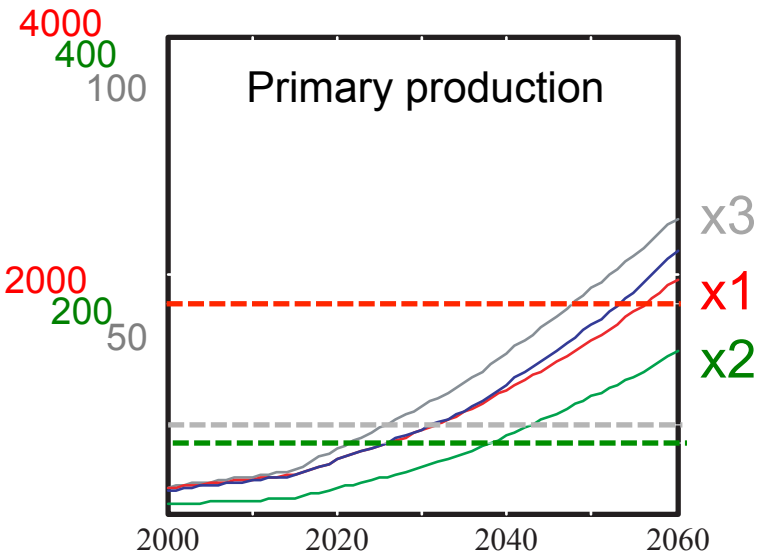


Doubling the needs for half the amount of generated electricity

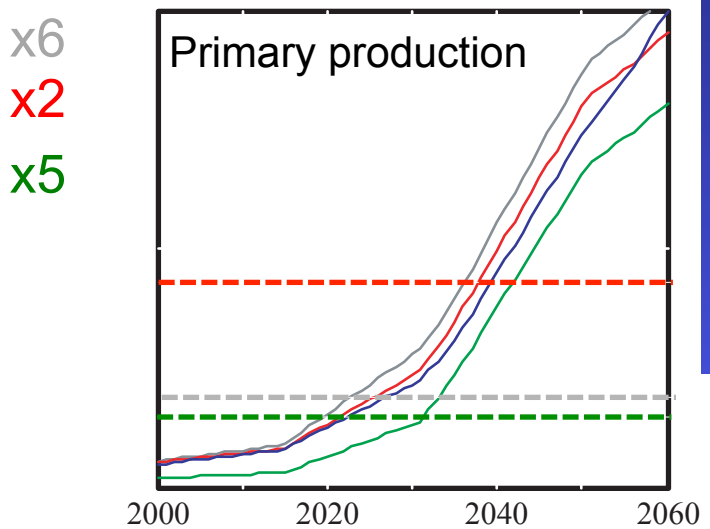
WWF (2012)

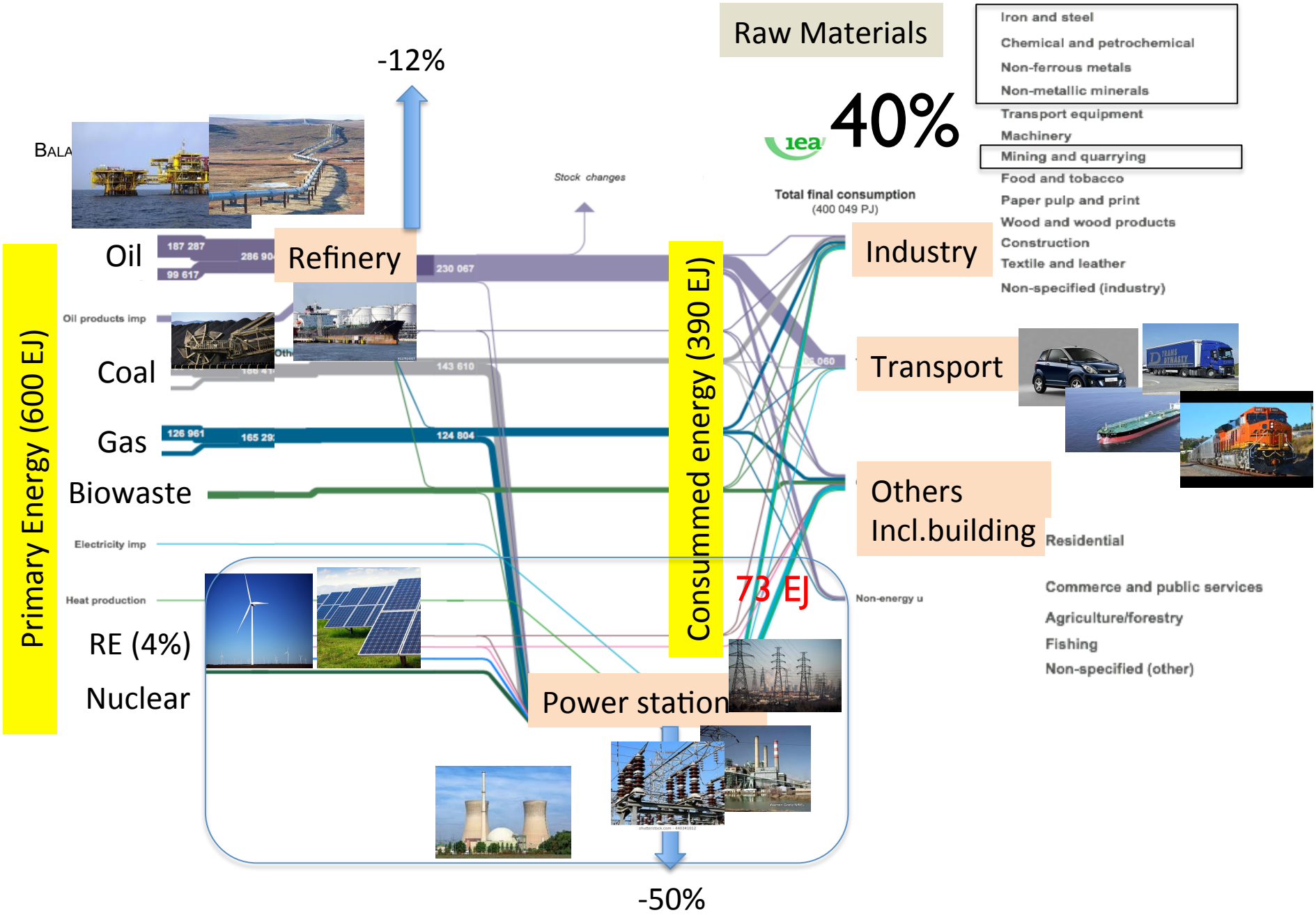
30000 TWh/yr in 2060

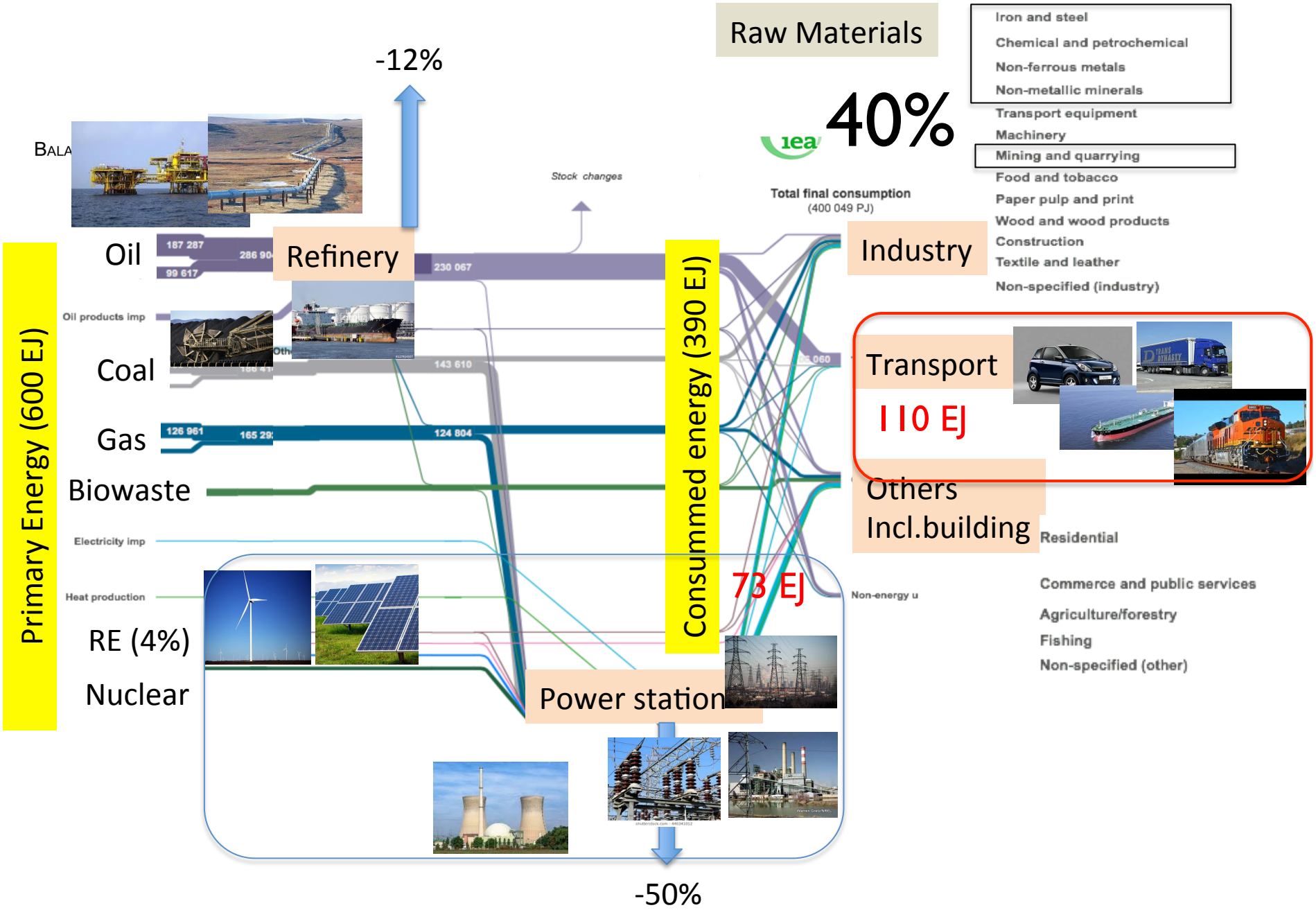




+3%/yr

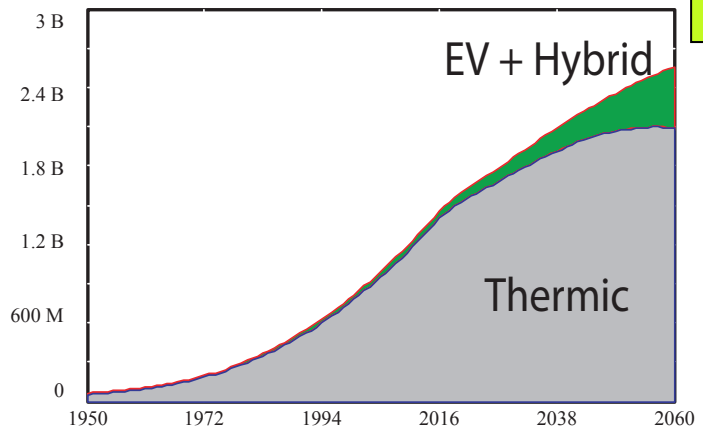



Raw Materials
40%
-12%
Iron and steel
Chemical and petrochemical
Non-ferrous metals
Non-metallic minerals
Transport equipment
Machinery
Mining and quarrying
Food and tobacco
Paper pulp and print
Wood and wood products
Construction
Textile and leather
Non-specified (industry)
Stock changes
Total final consumption
(400 049 PJ)
Primary Energy (600 EJ)
Oil
187 287
286 90
99 617
Refinery
230 067
Oil products imp
Coal
143 610
Gas
126 961
165 29
124 804
Biowaste
Electricity imp
Heat production
RE (4%)
Nuclear
Consummed energy (390 EJ)
Industry
Transport
Others
Incl.building
Residential
Commerce and public services
Agriculture/forestry
Fishing
Non-specified (other)
Non-energy u
73 EJ
Power station
-50%


Raw Materials
40%
Iron and steel
Chemical and petrochemical
Non-ferrous metals
Non-metallic minerals
Transport equipment
Machinery
Mining and quarrying
Food and tobacco
Paper pulp and print
Wood and wood products
Construction
Textile and leather
Non-specified (industry)
-12%
Stock changes
Total final consumption
(400 049 PJ)
Primary Energy (600 EJ)
Oil
187 287
286 90
99 617
Refinery
230 067
Oil products imp
Coal
143 610
Gas
126 961
165 29
124 804
Biowaste
Electricity imp
Heat production
RE (4%)
Nuclear
Consummed energy (390 EJ)
Industry
Transport
110 EJ
Others
Incl.building
Residential
73 EJ
Non-energy u
Commerce and public services
Agriculture/forestry
Fishing
Non-specified (other)
Power station
-50%

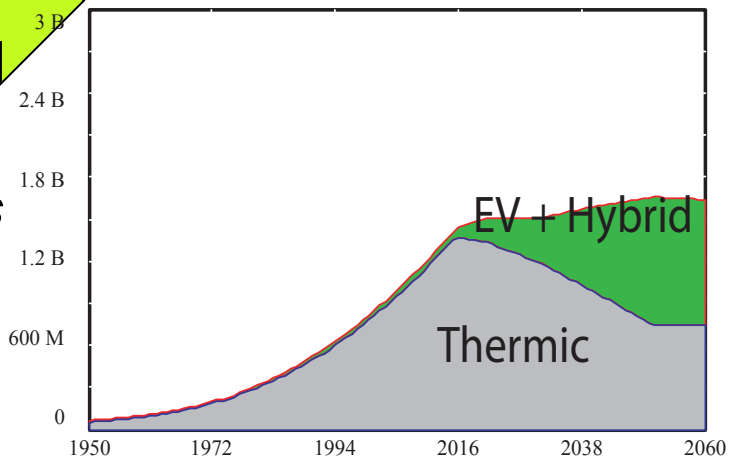
Cumulative need in copper for LDV (2017)

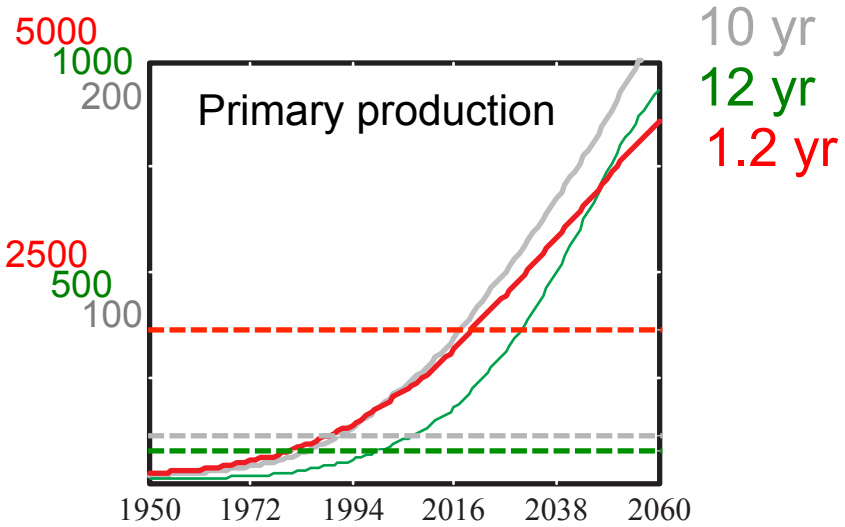
RTS (iea2017)

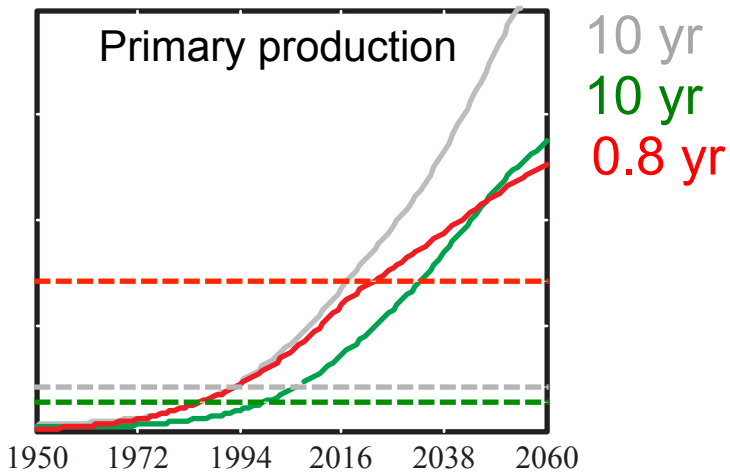


Similar needs of base metals for less vehicles

WWF (2012)







Total needs in copper

200 to 300 Mt Cu are needed for electricity generation and transport, = 10 to15 years of 2015 global production

75-120Mt

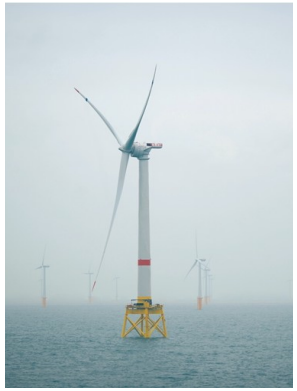
production

3 Mt

storage

>150 Mt Cu

Use



Transport & distribution

10-20 Mt

200 to 300 Mt Cu
400 Mt Al
4000 Mt Fe
For the power sector

Kennecott Copper Mine (Utah) **3.2 x 1.2 x 1.2 km^3** .

Since 1906, six billion tons of rocks have been removed from this pit to extract **18 million tons copper** – equivalent to one year of global primary Cu production

Transport LDV – high tech metals

Conventional vehicule: 20-30 kg Cu /car, EV: 60-80 kg Cu /car

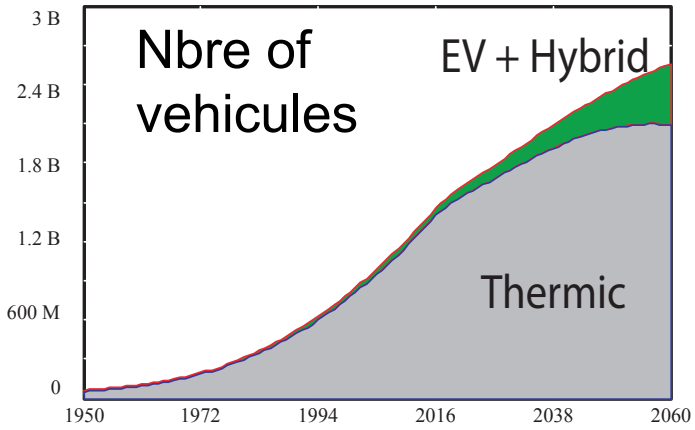
Battery 50 kwh (EV)
=> Li: 6 - 20 kg (100 kWhTesla), Ni: 30 kg, Co: 10 kg, Mn: 10 kg, graphite: 50 kg

Battery PHEV (NiMH)
REE: 10 kg – Prius

Competition with other sectors of uses (ICT)

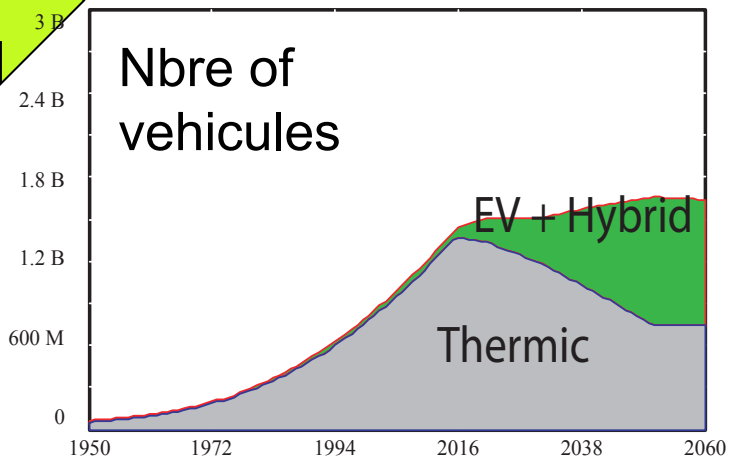
Stock of high tech metals for the batteries of LDV

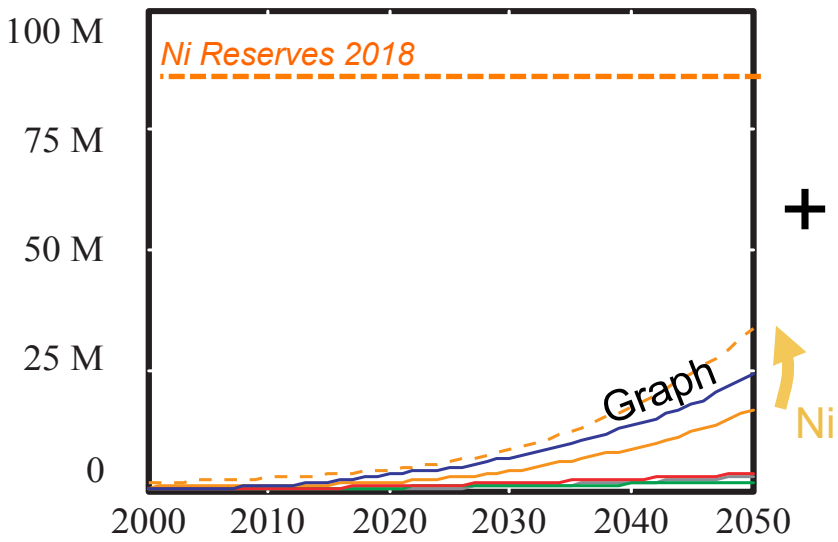
RTS (iea2017)



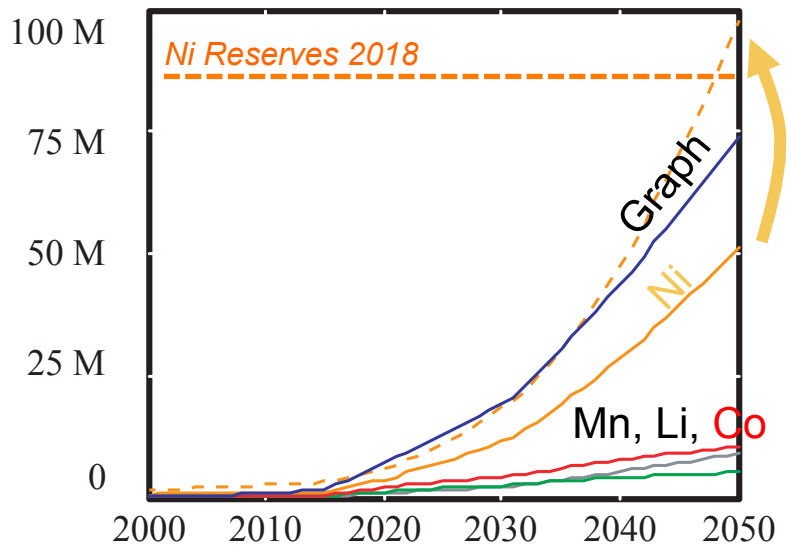
More high-tech metals for less vehicles

WWF (2012)





+10%/yr



Should we worry ?

REUTERS

Business Markets World Politics TV More

DAVOS MAY 3, 2019 / 12:03 PM / A MONTH AGO

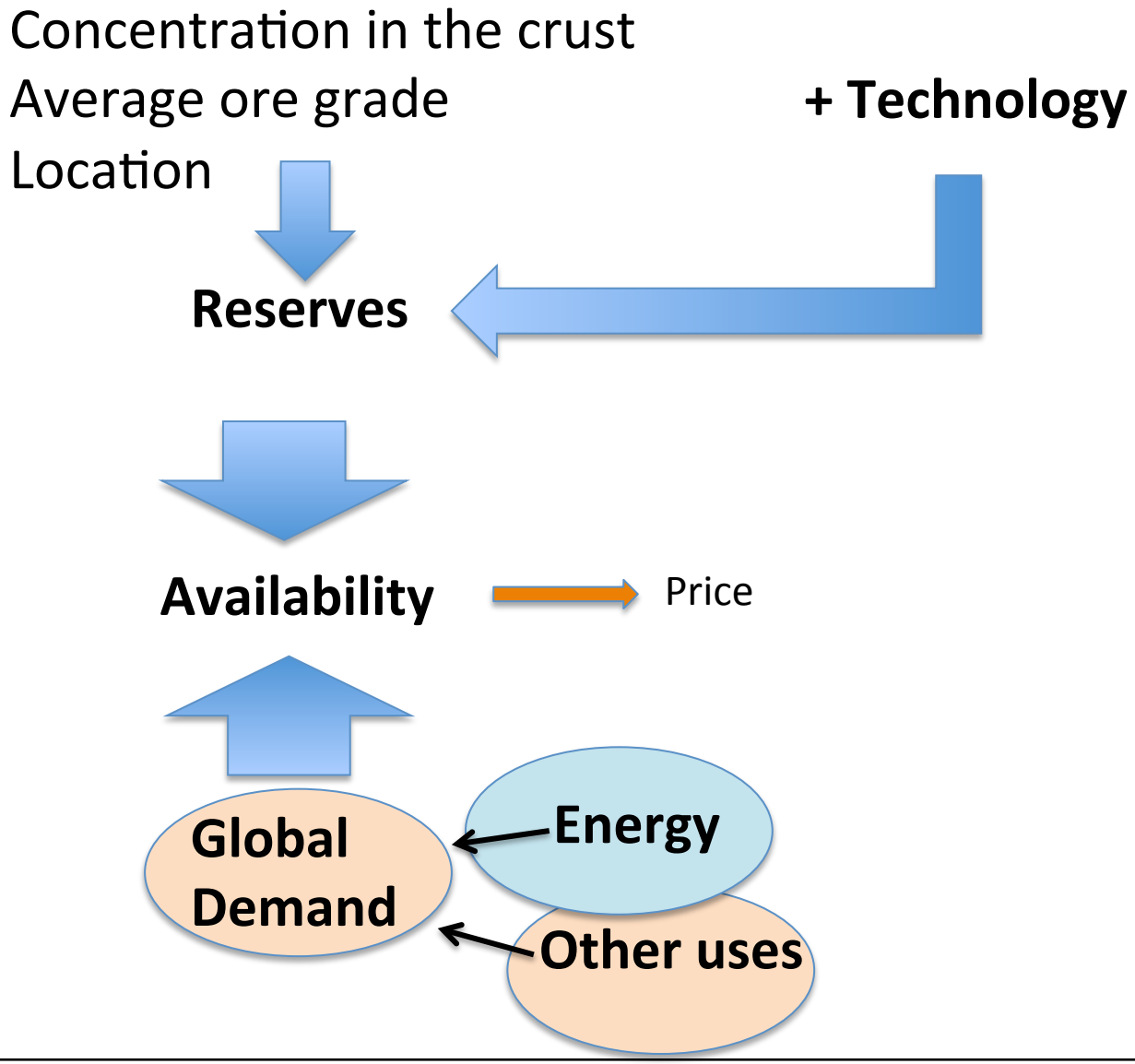
Exclusive: Tesla expects global shortage of electric vehicle battery minerals -sources

Ernest Scheyder

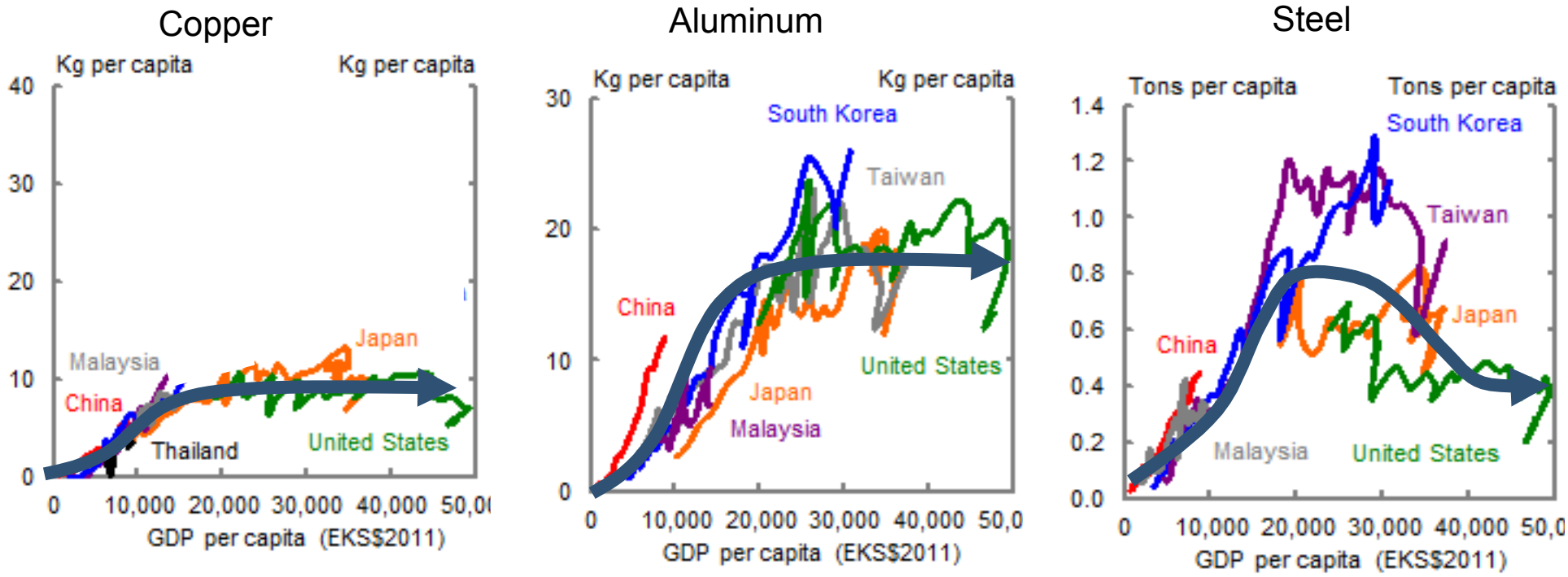
3 MIN READ

WASHINGTON (Reuters) - Tesla Inc expects global shortages of nickel, copper and other electric-vehicle battery minerals down the road due to underinvestment in the mining sector, the company's global supply manager for battery metals told an industry conference on Thursday, according to two sources.

The availability of metals

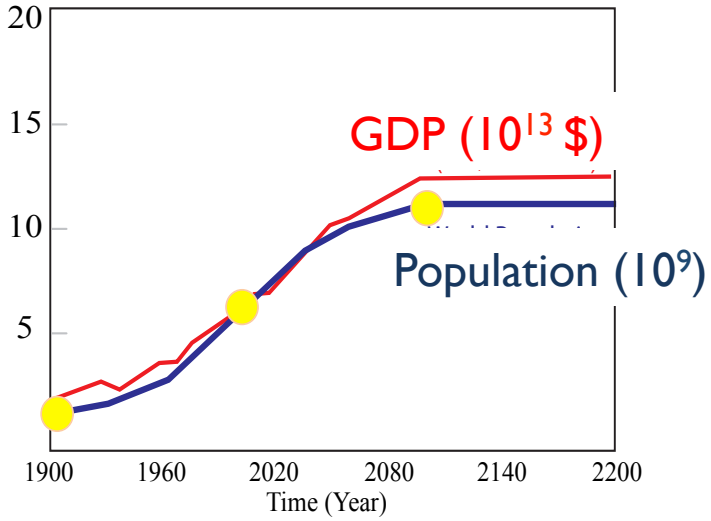


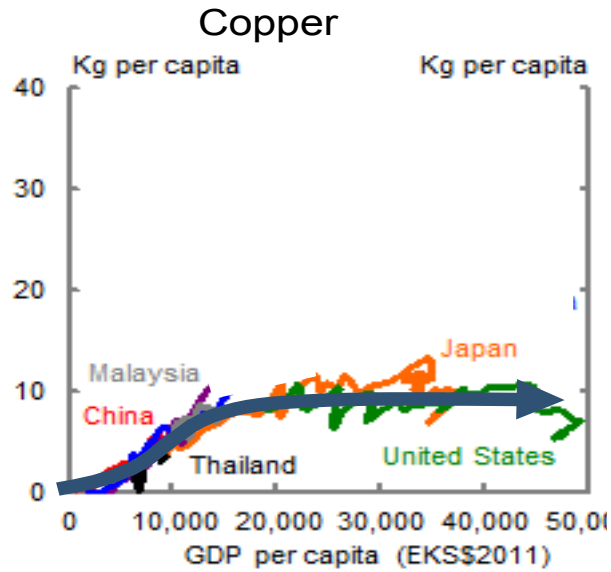
The demand/capita levels off above 15000 $ GDP/capita

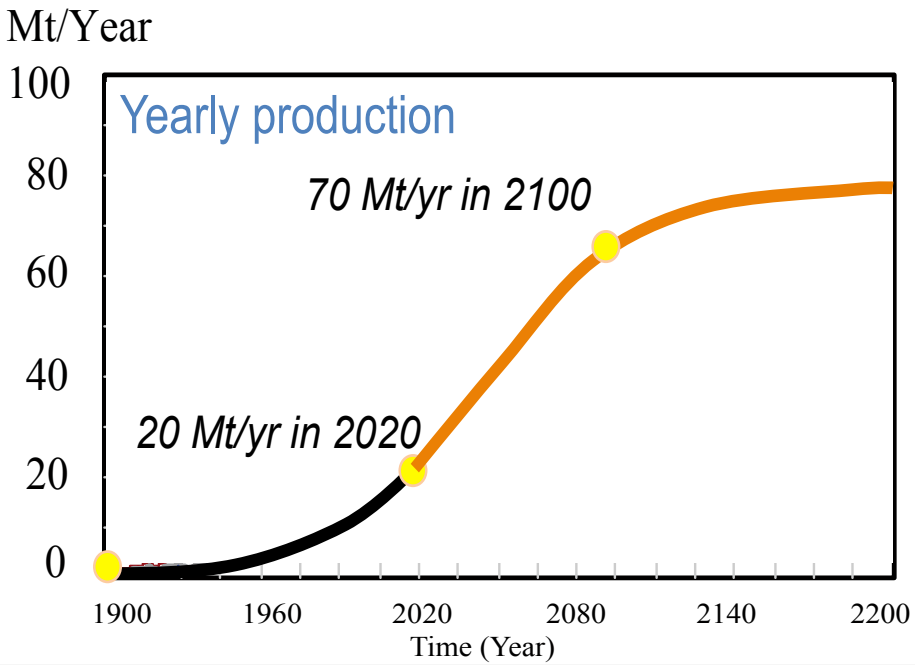


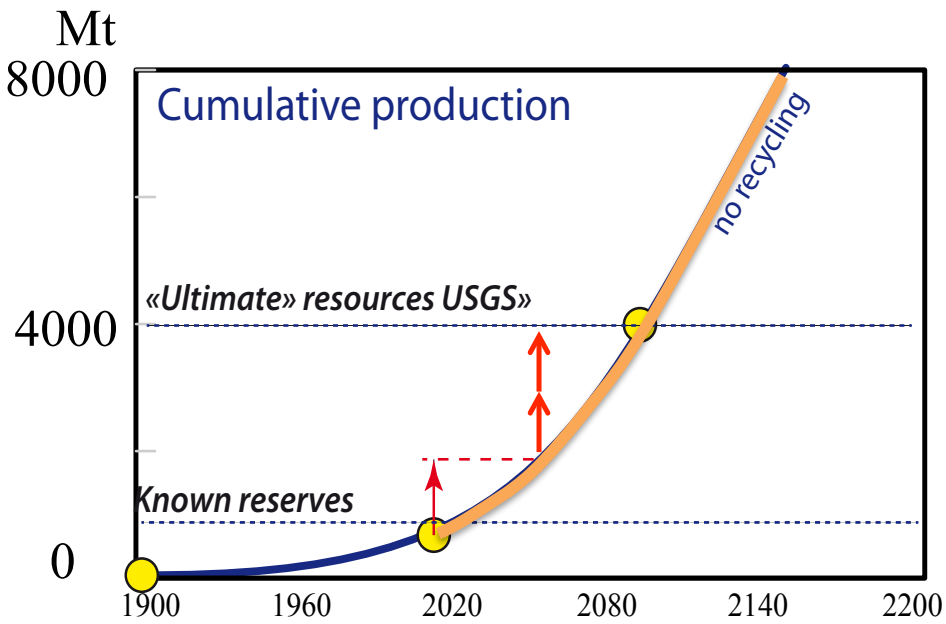
ABARES *Australian Commodities*; *World Metal Statistics*, various years; BREE *Resources and Energy Statistics* 2011; United Nations *World Population Prospects:The 2010 Revision* and The Conference Board Total Economy Database, January 2012

The future global demand in copper









With recycling

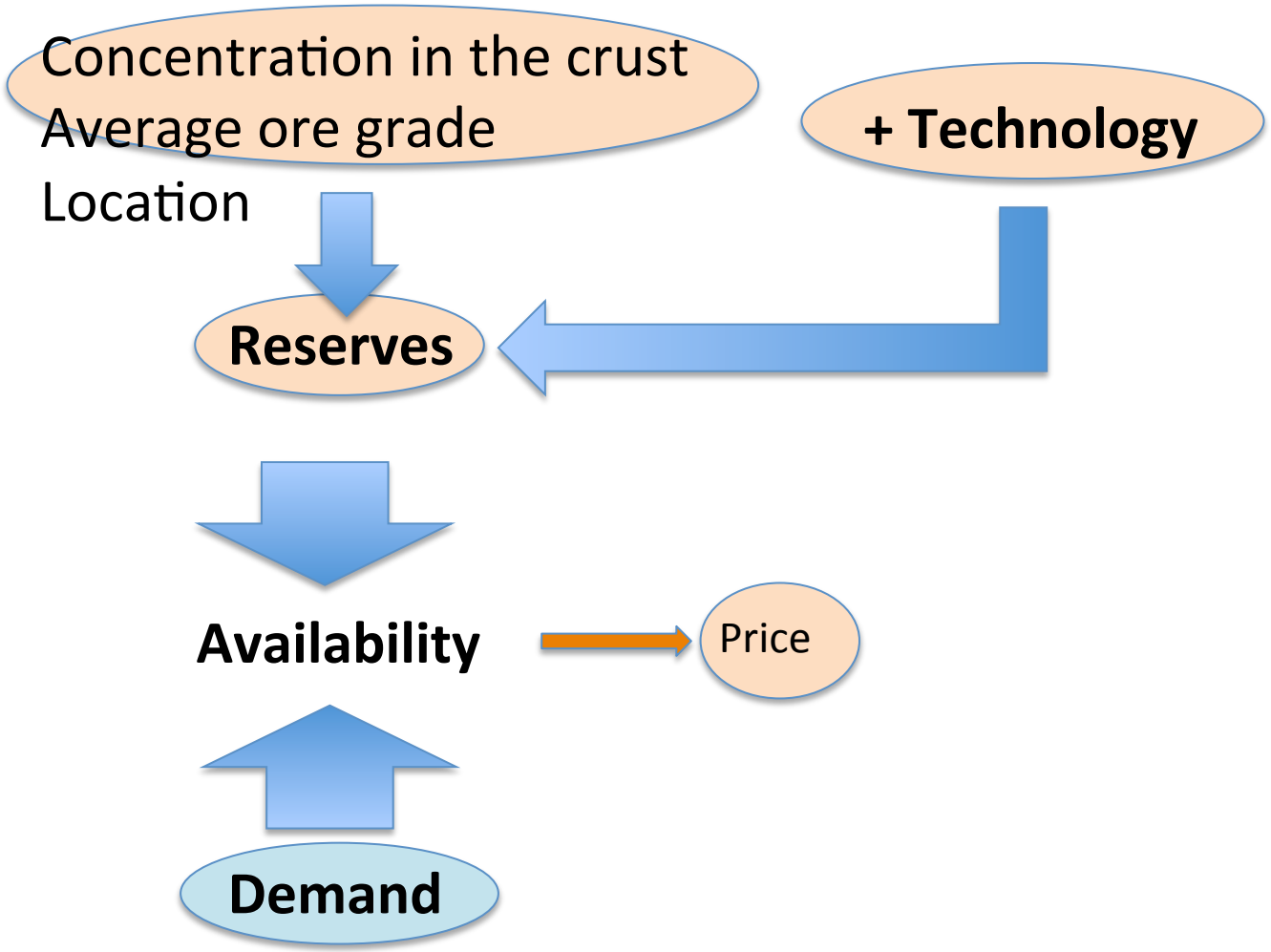
x 45 in 2050
x 150 in 2100
x 275 in 2200

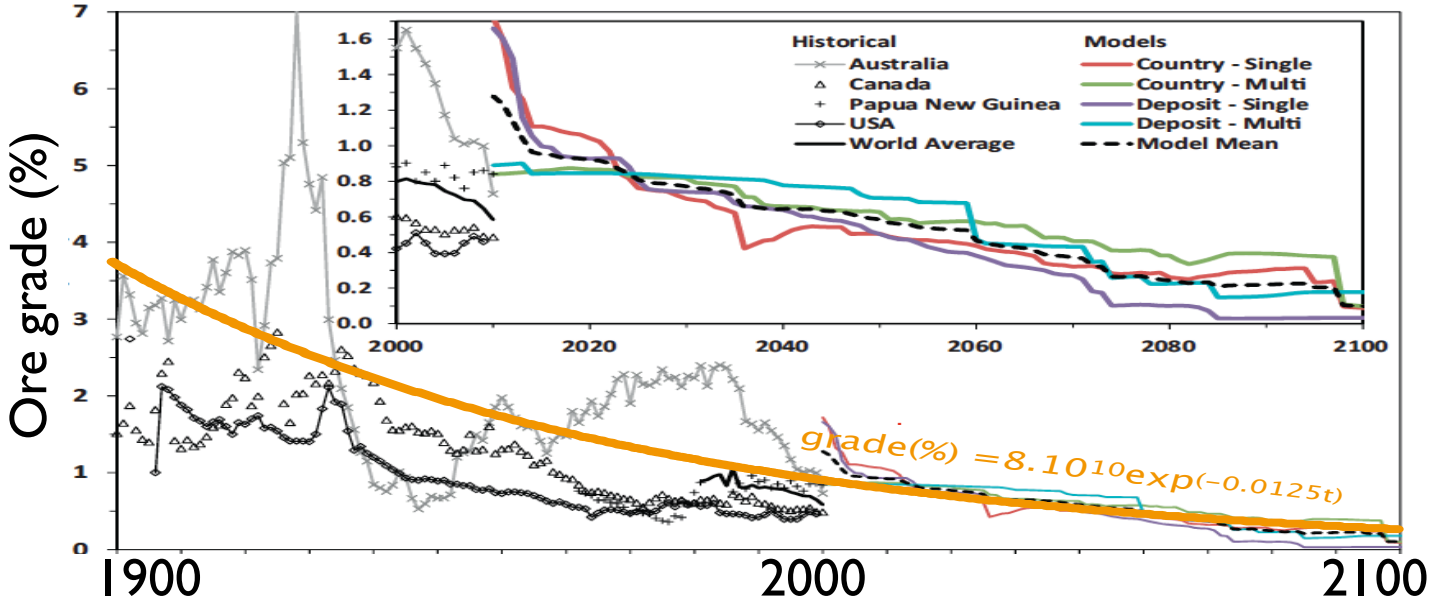
and so forth...

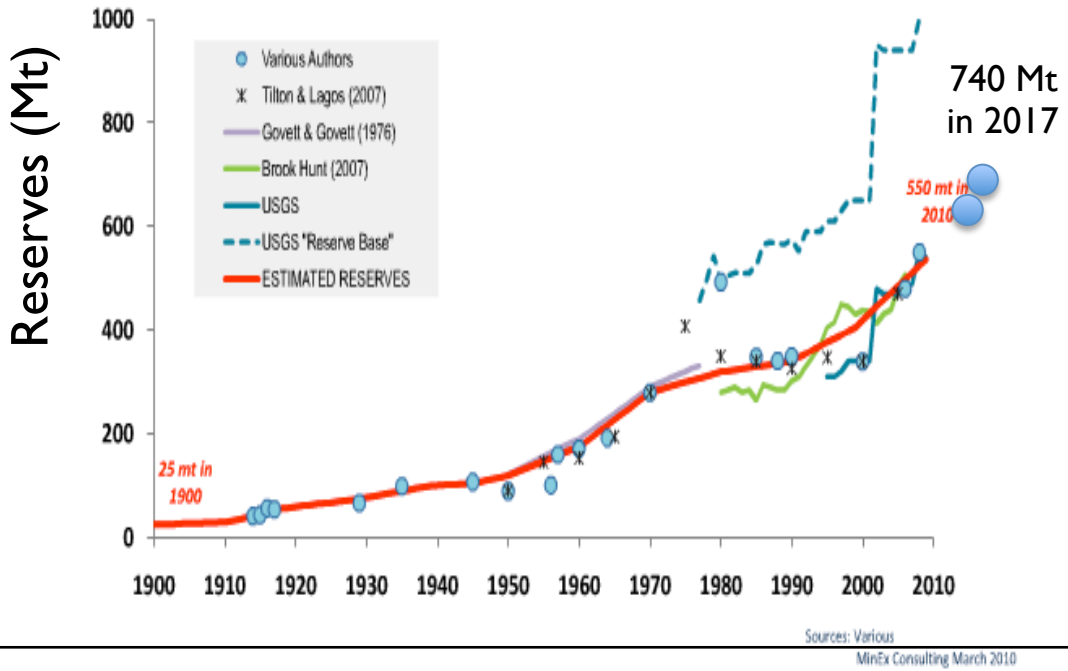
One year of production

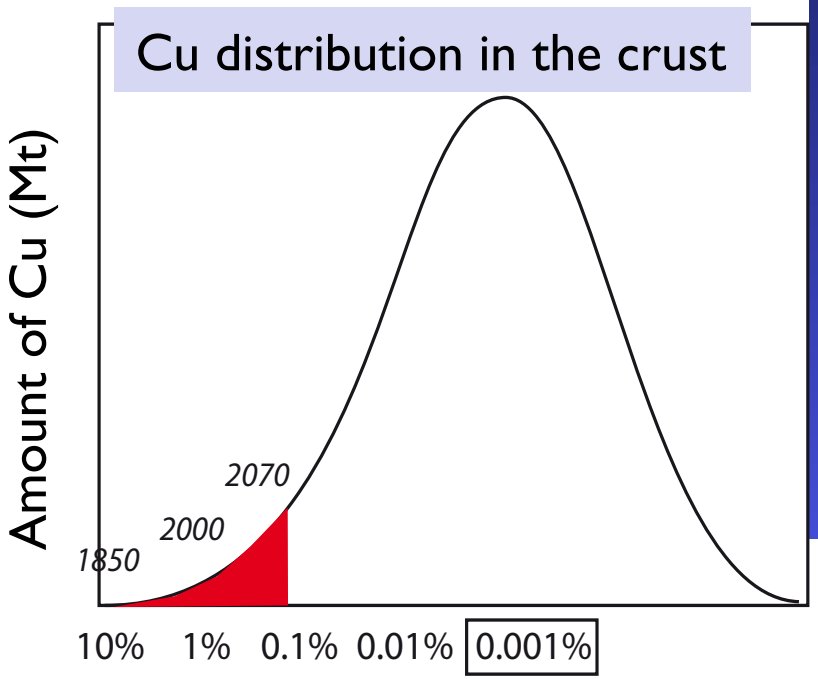
Kennecott Copper Mine (Utah) **3.2 x 1.2 x 1.2 km^3**

The availability of metals

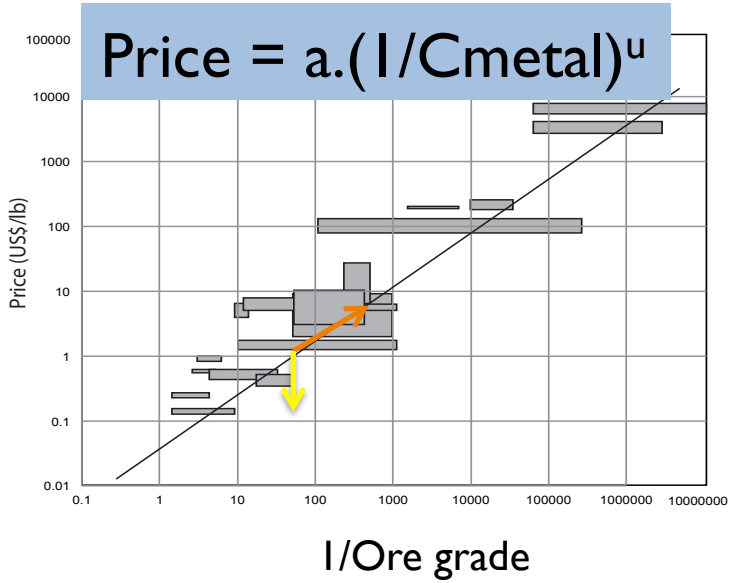


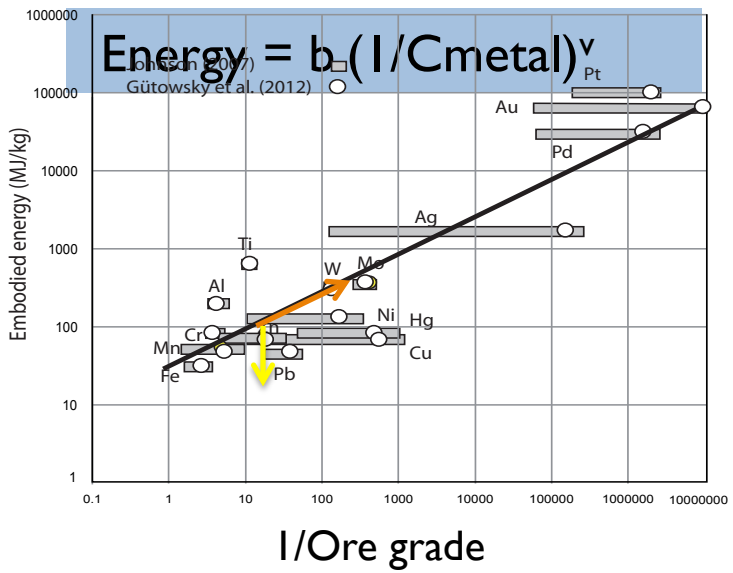

Ore grade (%)
Historical
Australia
Canada
Papua New Guinea
USA
World Average
Models
Country - Single
Country - Multi
Deposit - Single
Deposit - Multi
Model Mean
grade(%) =8.1010exp(−0.0125t)
1900
2000
2100

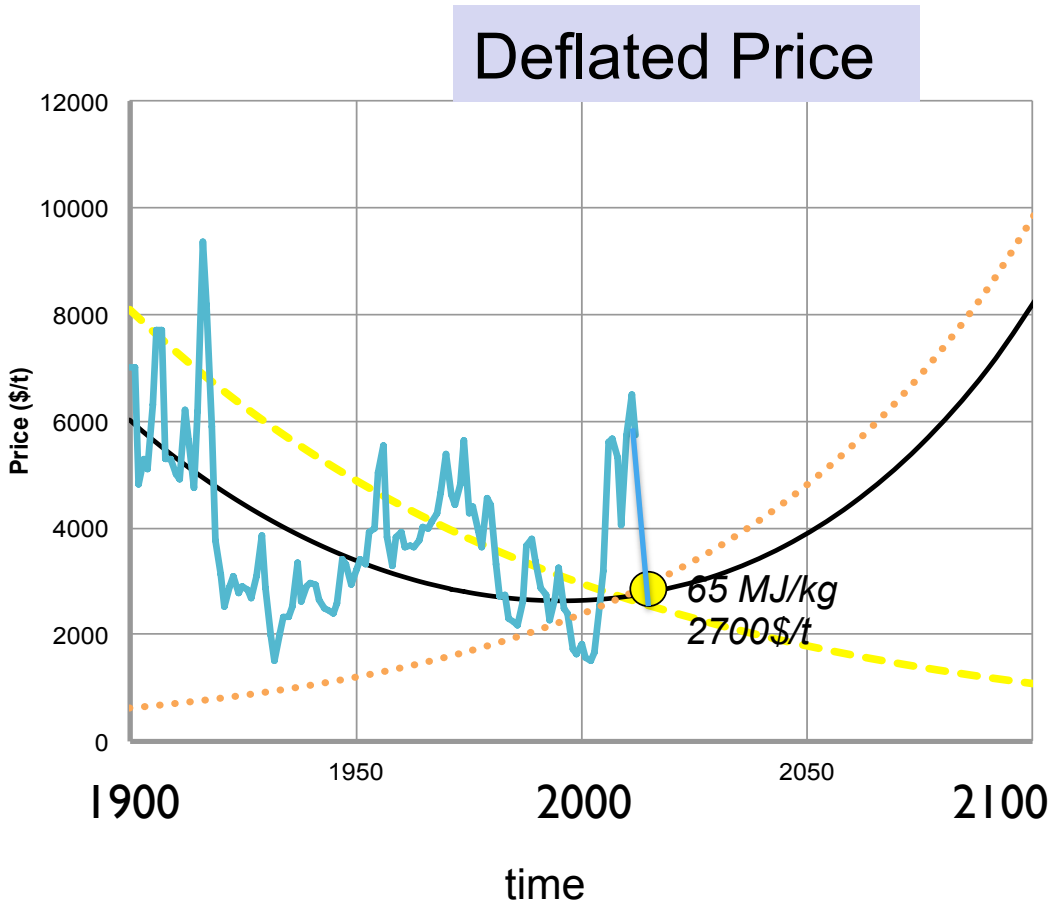

Reserves (Mt)
Various Authors
Tilton & Lagos (2007)
Govett & Govett (1976)
Brook Hunt (2007)
USGS
USGS "Reserve Base"
ESTIMATED RESERVES
740 Mt in 2017
550 mt in 2010
25 mt in 1900
Sources: Various
MinEx Consulting March 2010

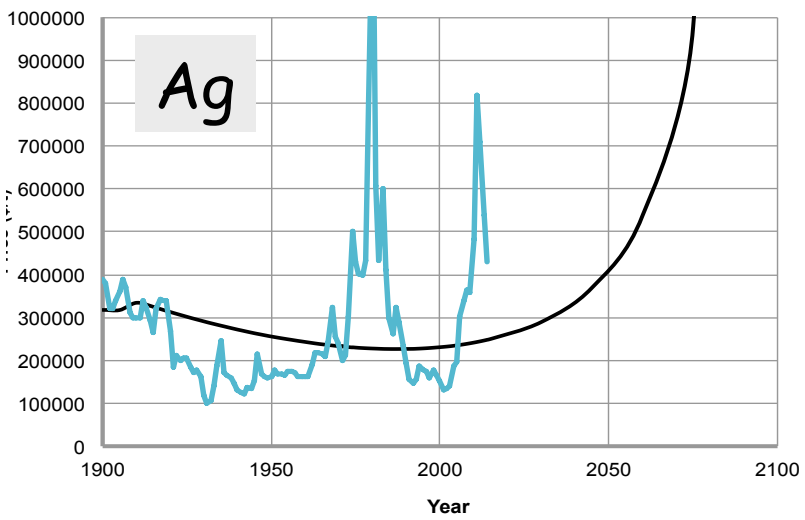

Cu distribution in the crust
Amount of Cu (Mt)
1850
2000
2070
10%
1%
0.1%
0.01%
0.001%

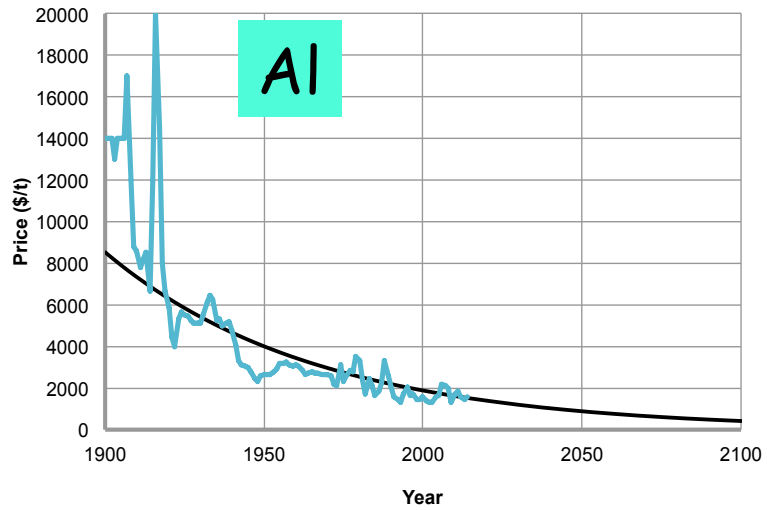
Embodied energy and price

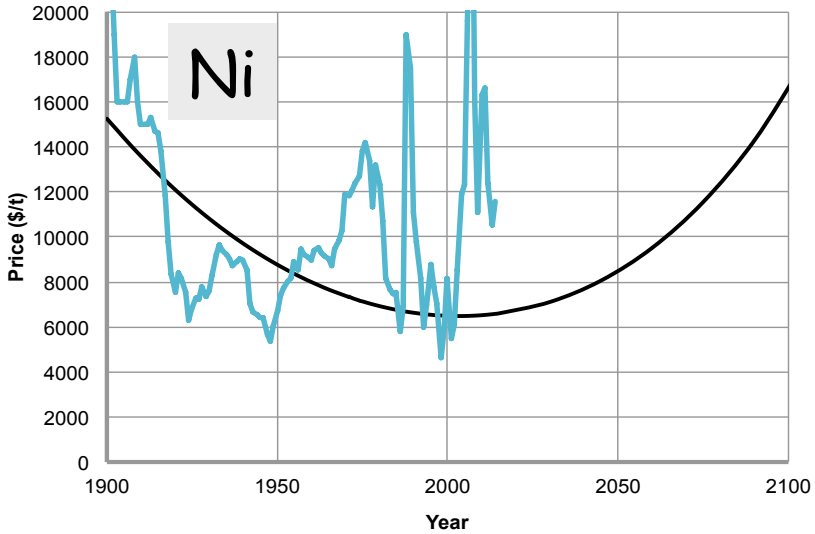


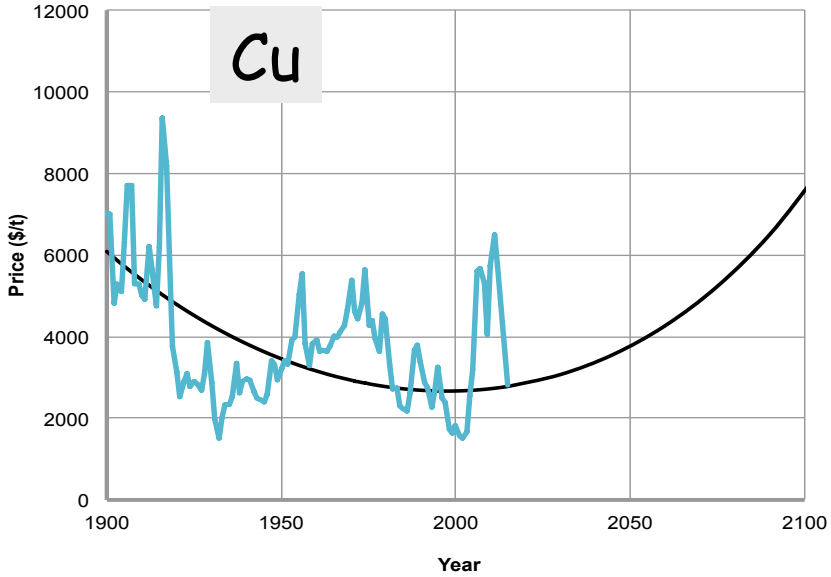




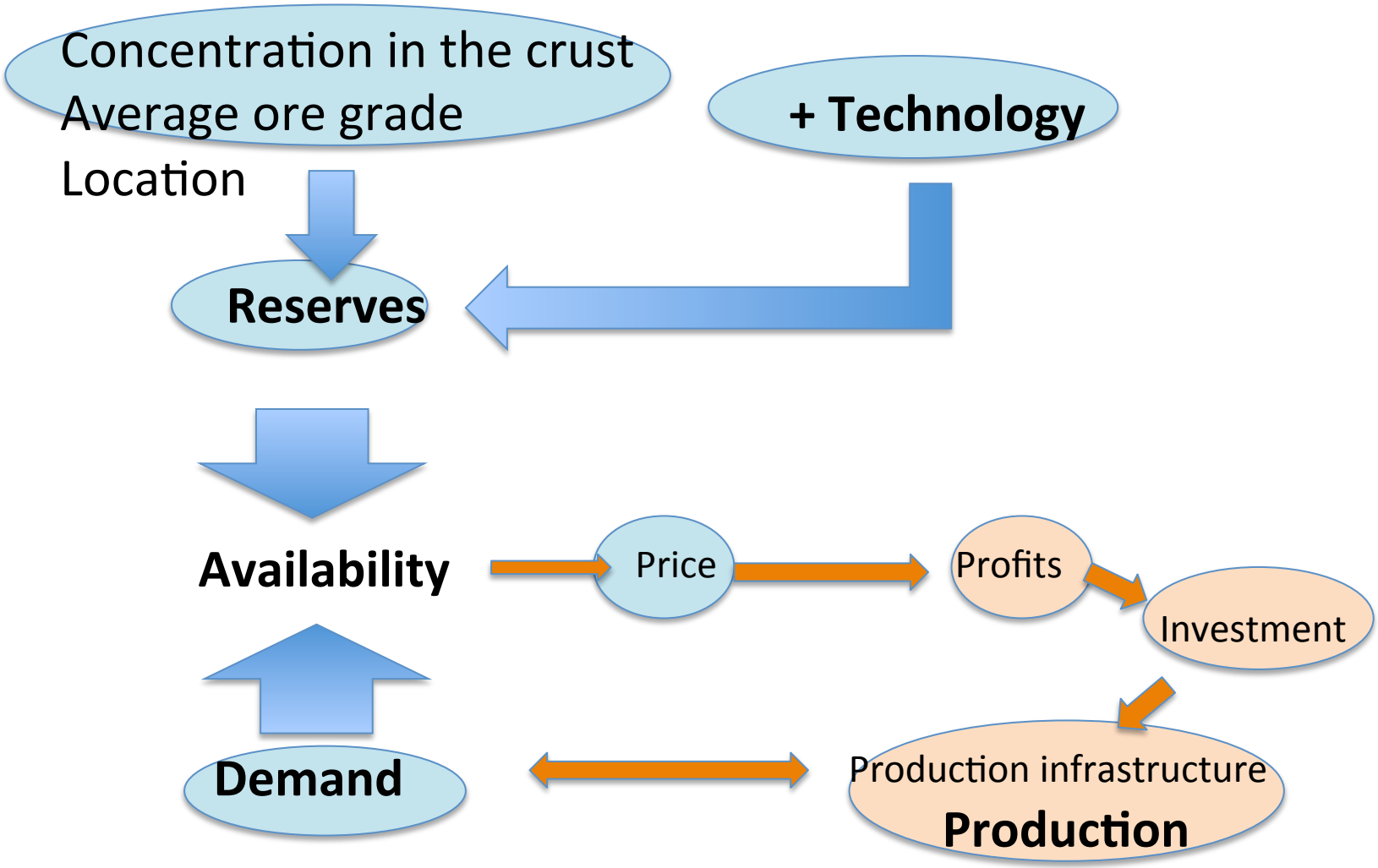

Ag
1000000
900000
800000
700000
600000
500000
400000
300000
200000
100000
0
1900
1950
2000
2050
2100
Year

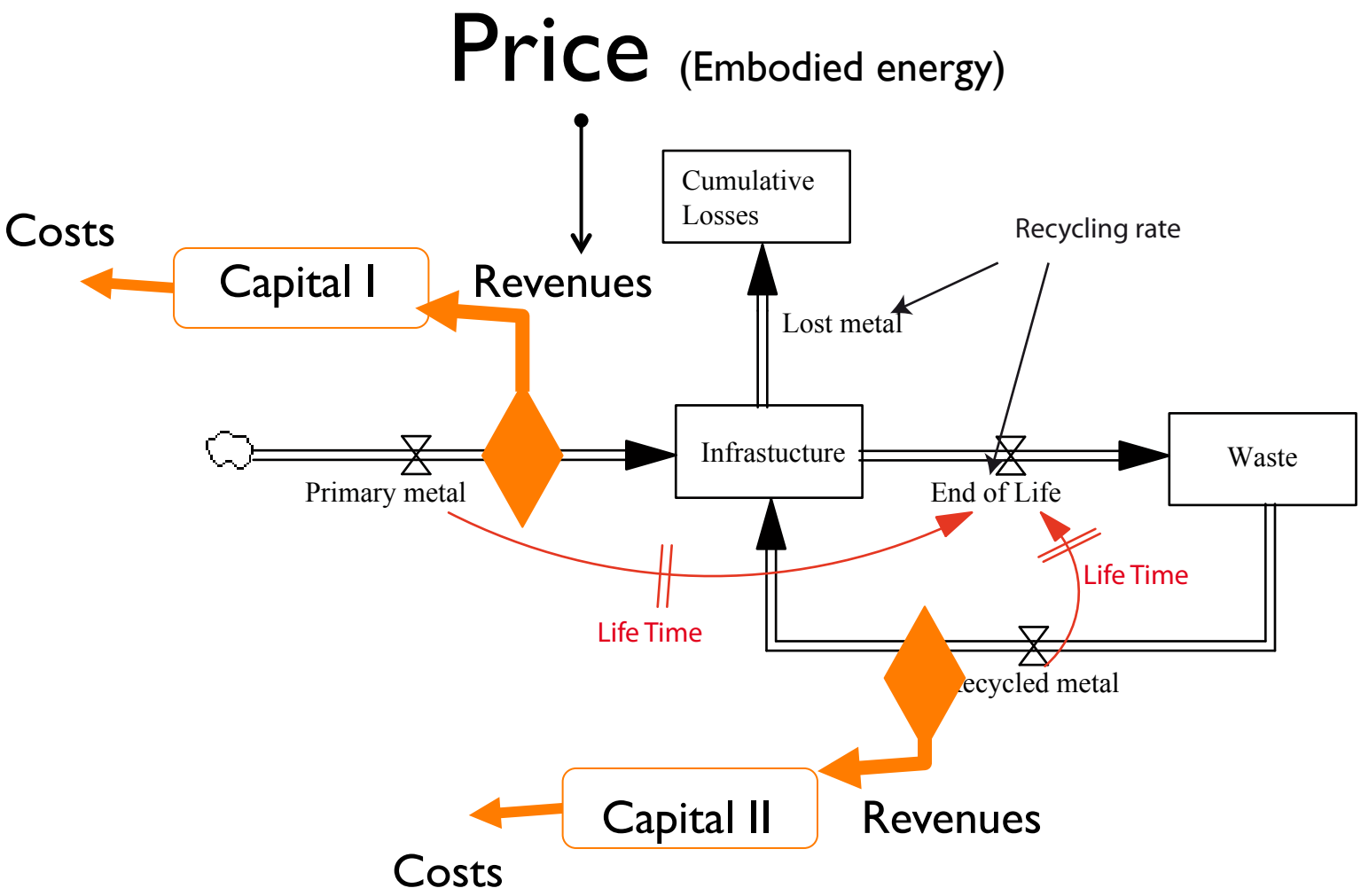

Al
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Price ($/t)
1900
1950
2000
2050
2100
Year

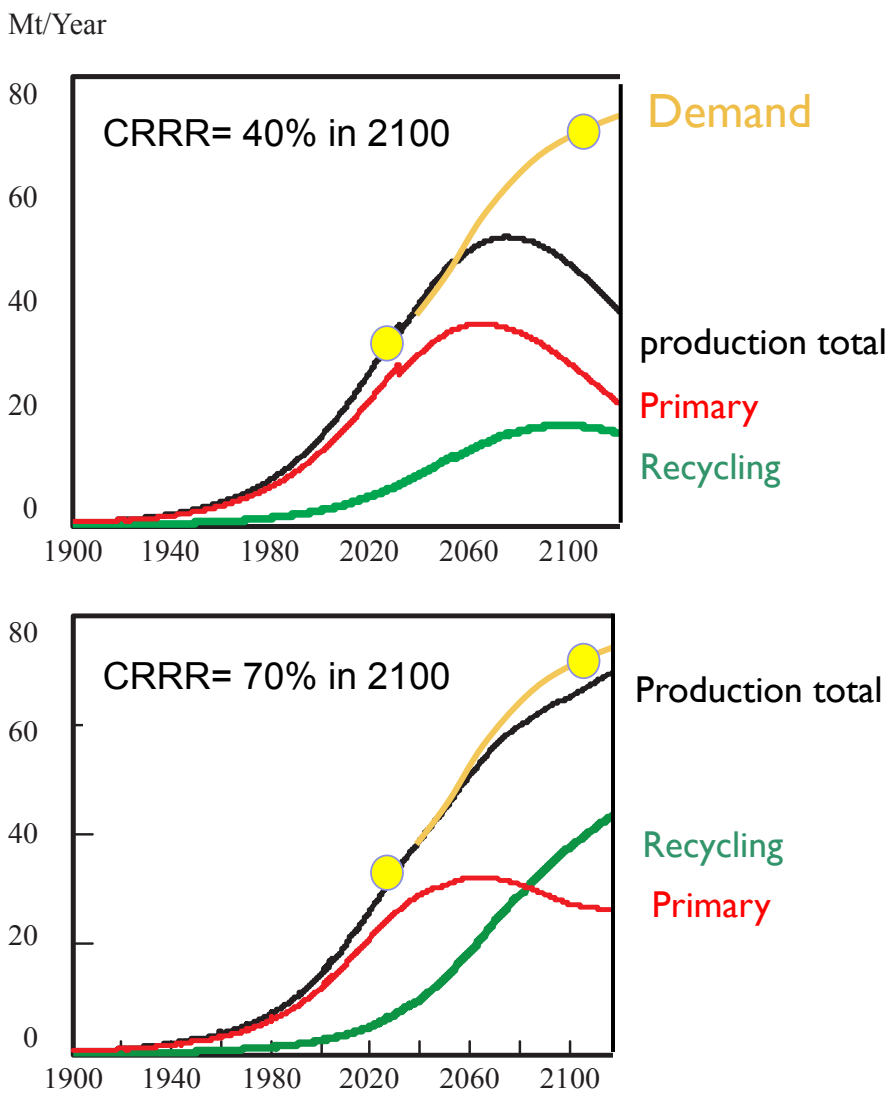

Ni
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Price ($/t)
1900
1950
2000
2050
2100
Year


Cu
12000
10000
8000
6000
4000
2000
0
Price ($/t)
1900
1950
2000
2050
2100
Year

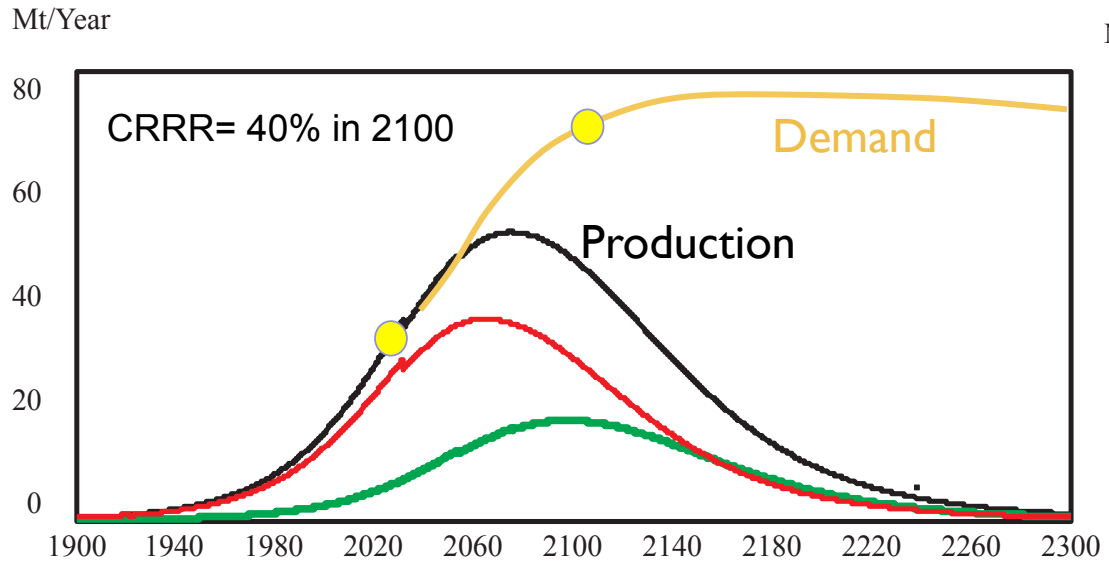
The availability of metals

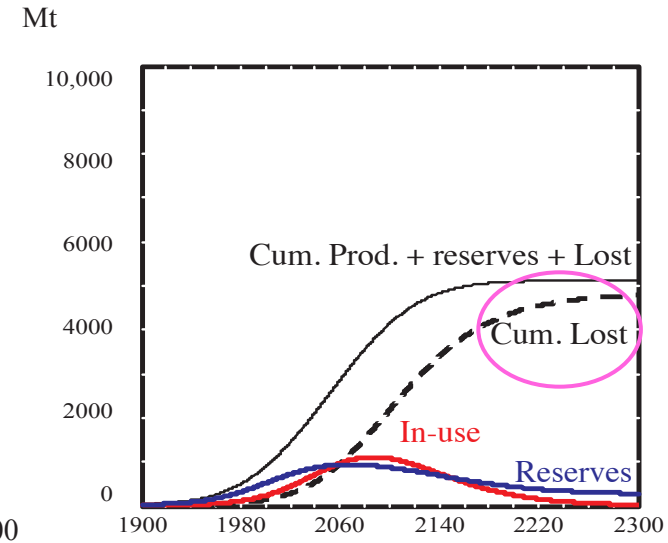


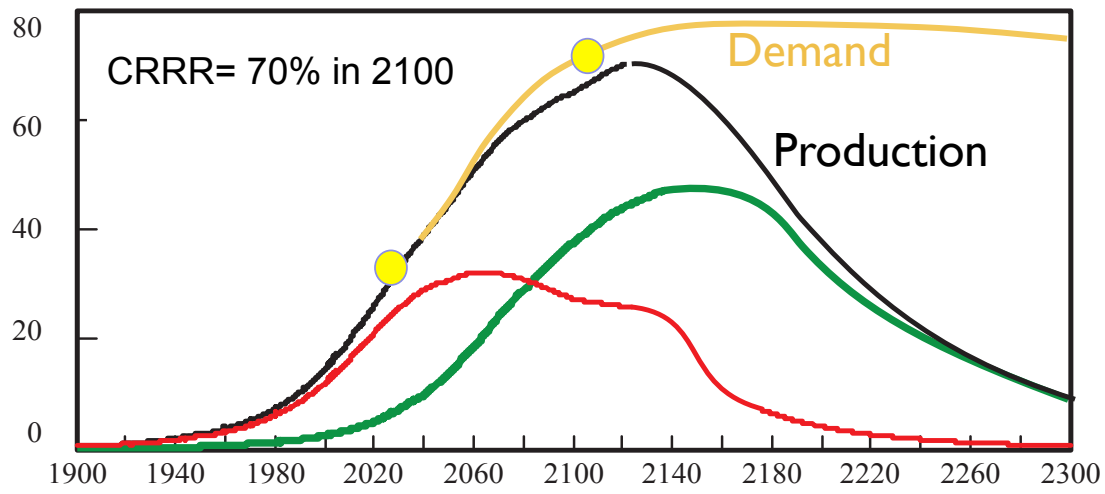

Price (Embodied energy)
Costs
Capital I
Revenues
Cumulative Losses
Recycling rate
Lost metal
Infrastucture
Waste
Primary metal
End of Life
Life Time
Life Time
ecycled metal
Capital II
Revenues
Costs

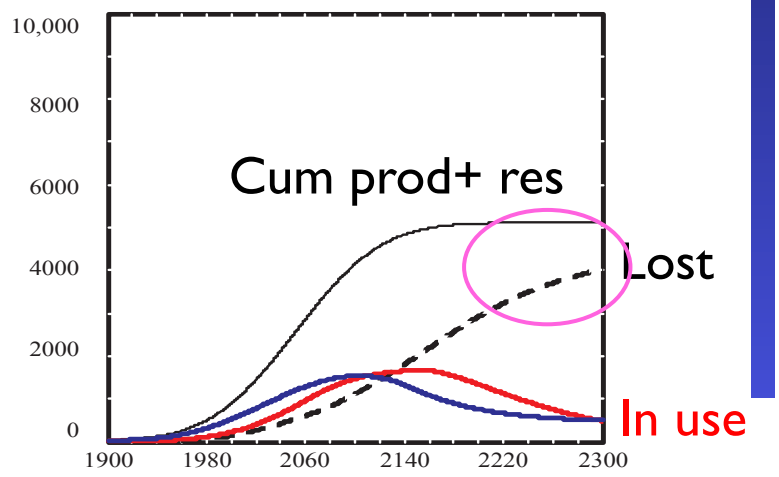


Doubling the recycling rate is necessary to meet the expected demand in 2100

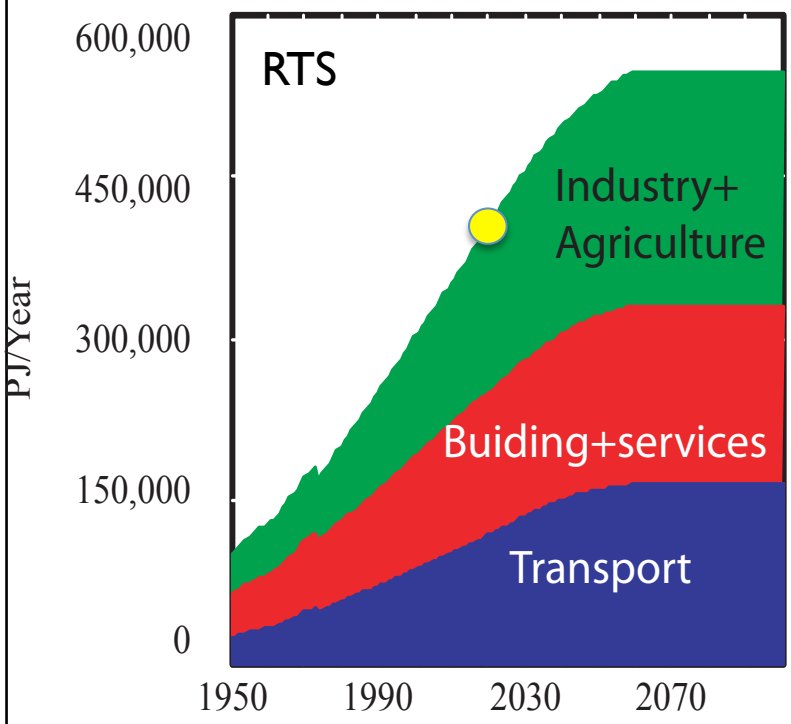

Mt/Year
CRRR= 40% in 2100
Demand
Production
80
60
40
20
0
1900
1940
1980
2020
2060
2100
2140
2180
2220
2260
2300

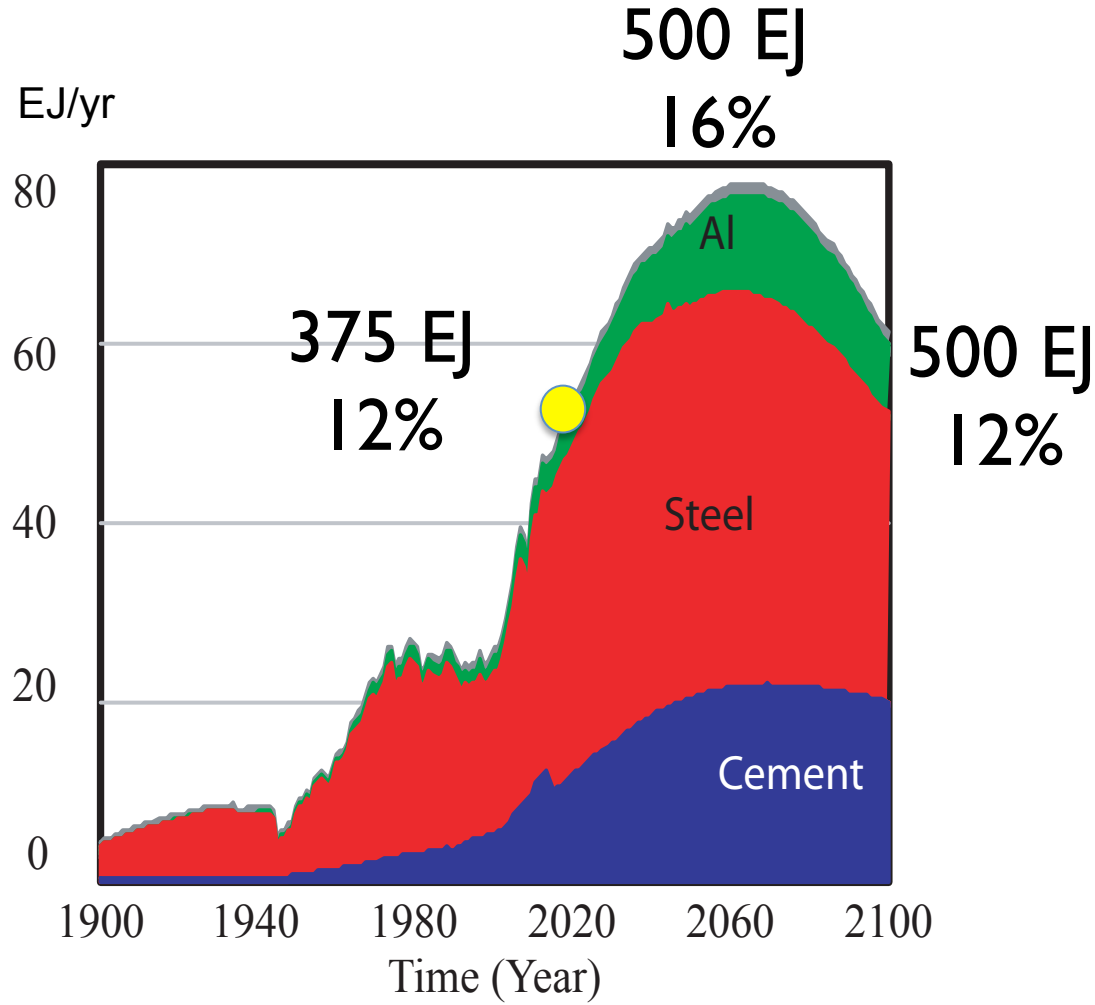

Mt
Cum. Prod. + reserves + Lost
Cum. Lost
In-use
Reserves
10,000
8000
6000
4000
2000
0
1900
1980
2060
2140
2220
2300


CRRR= 70% in 2100
Demand
Production
80
60
40
20
0
1900
1940
1980
2020
2060
2100
2140
2180
2220
2260
2300

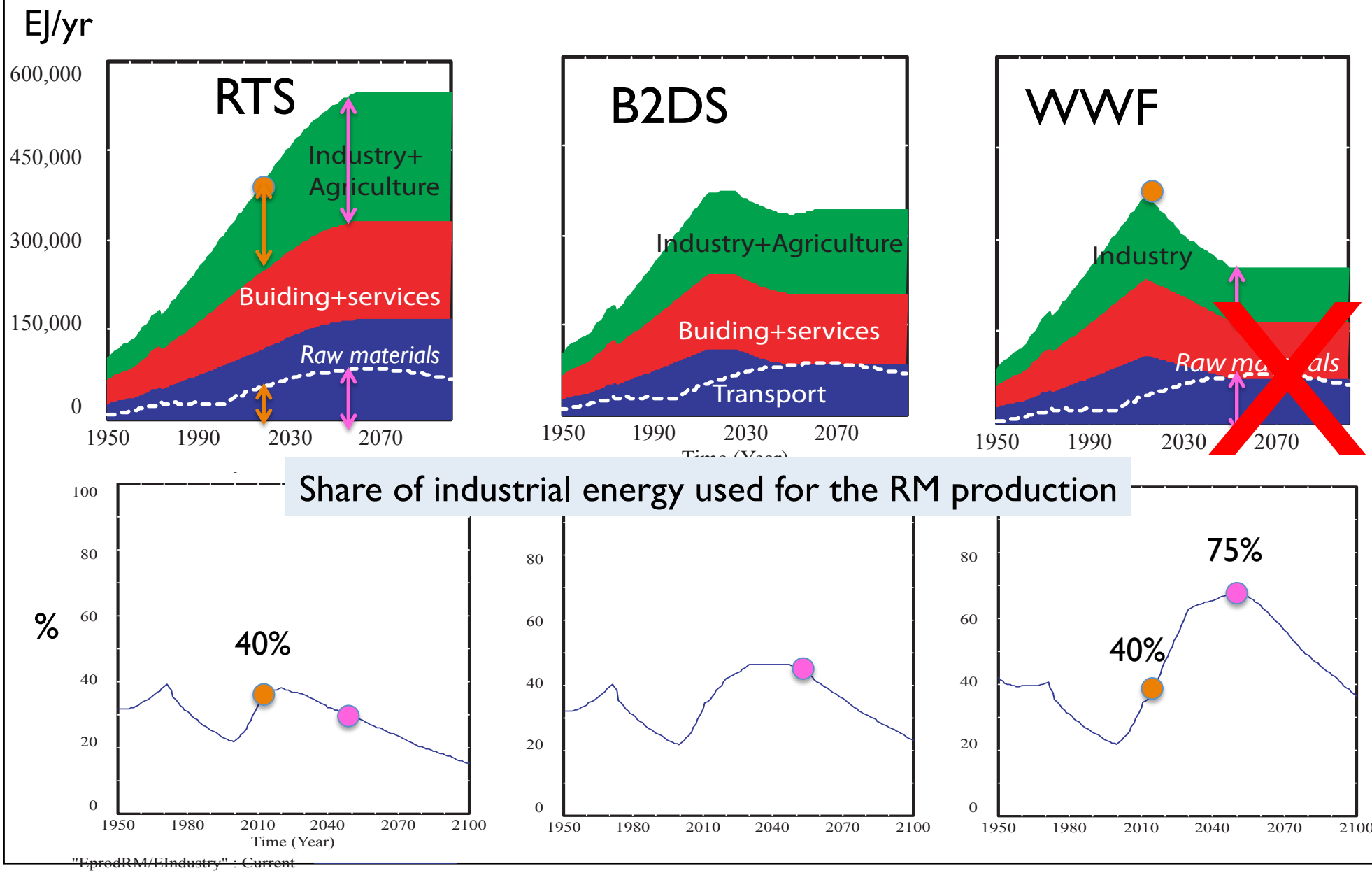

Cum prod+ res
Lost
In use
10,000
8000
6000
4000
2000
0
1900
1980
2060
2140
2220
2300

The embodied energy and CO2 emissions of recycling are much lower than those of primary production



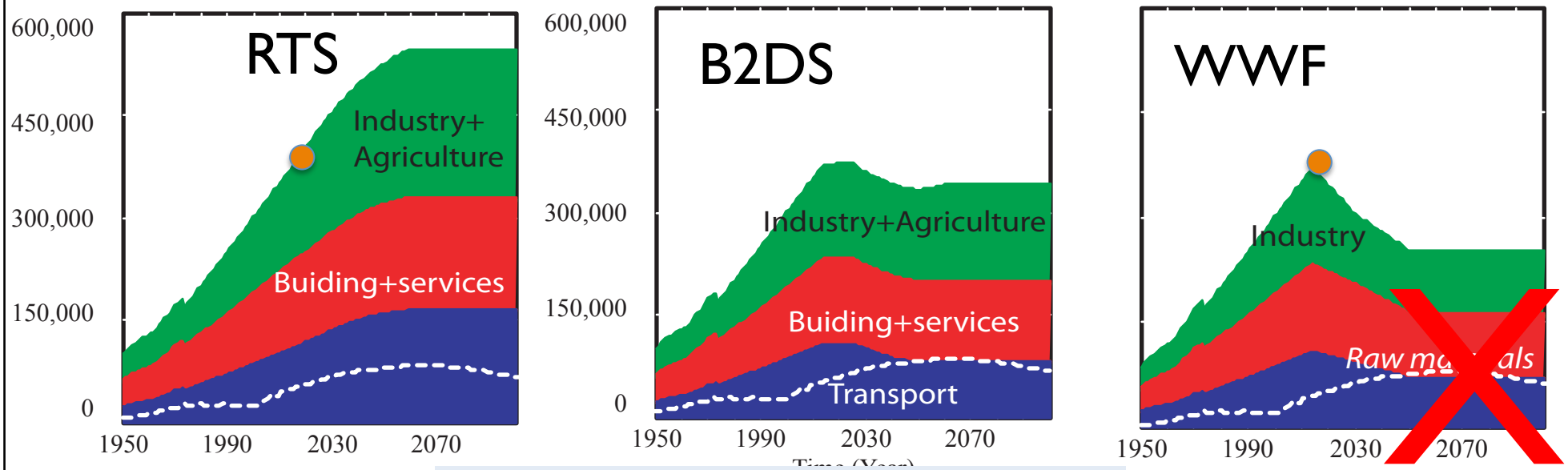


Total energy & energy for raw materials

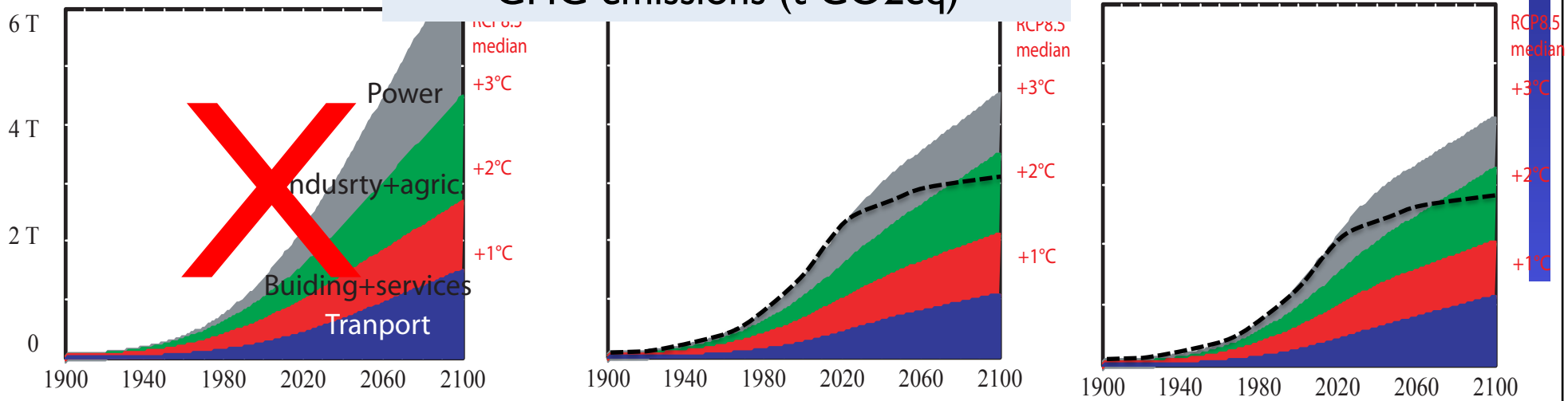


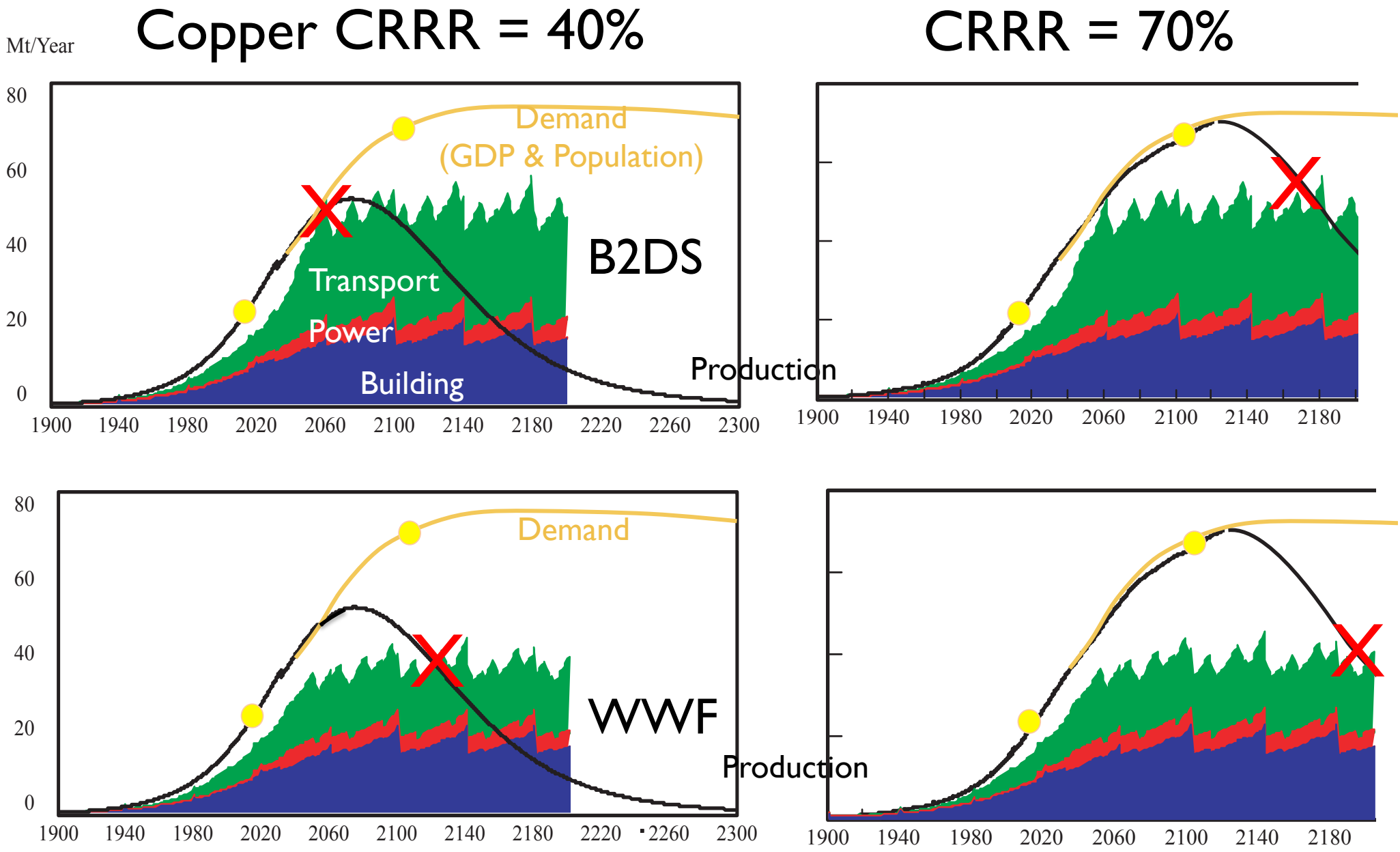
"EprodRM/EIndustry" : Current

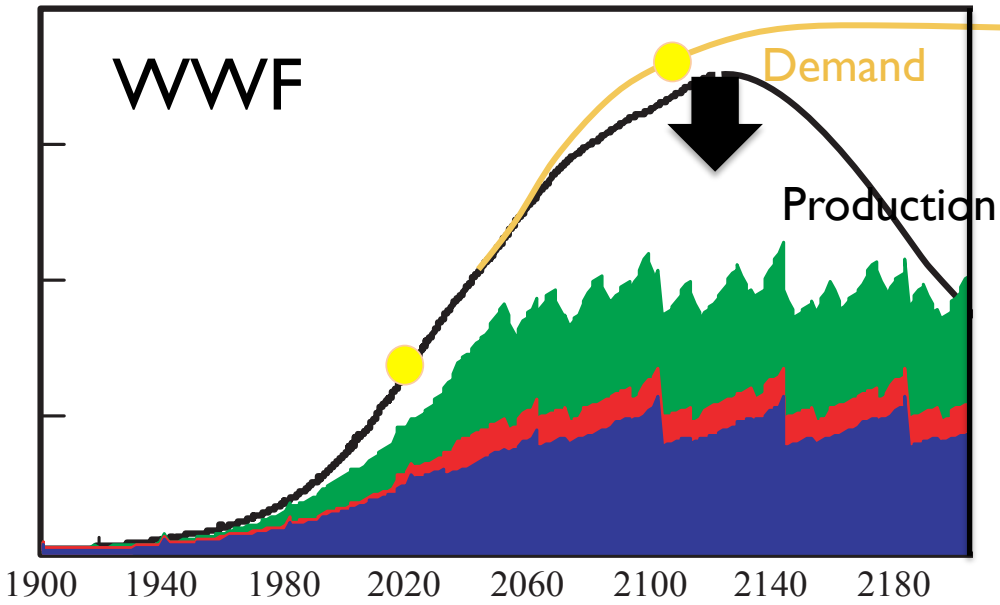
Total energy & GHG emissions

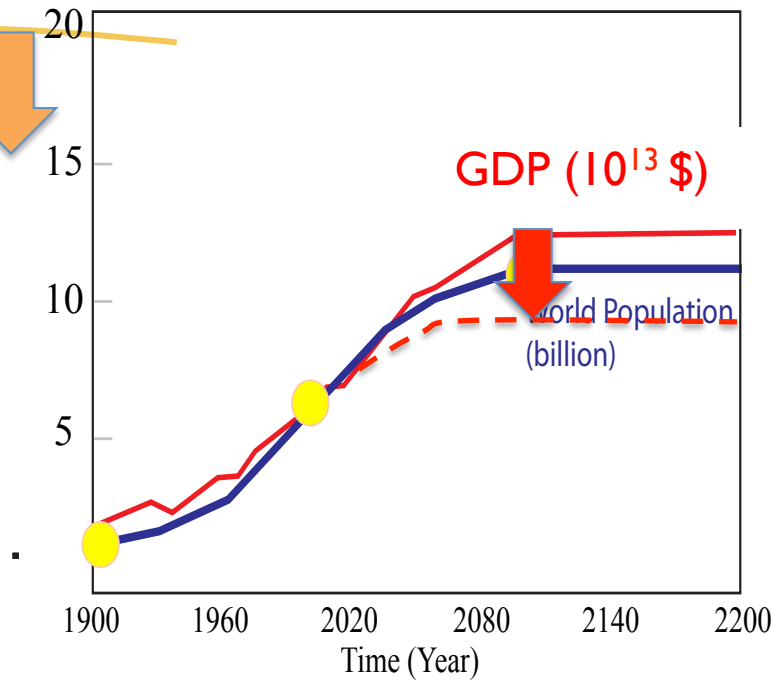


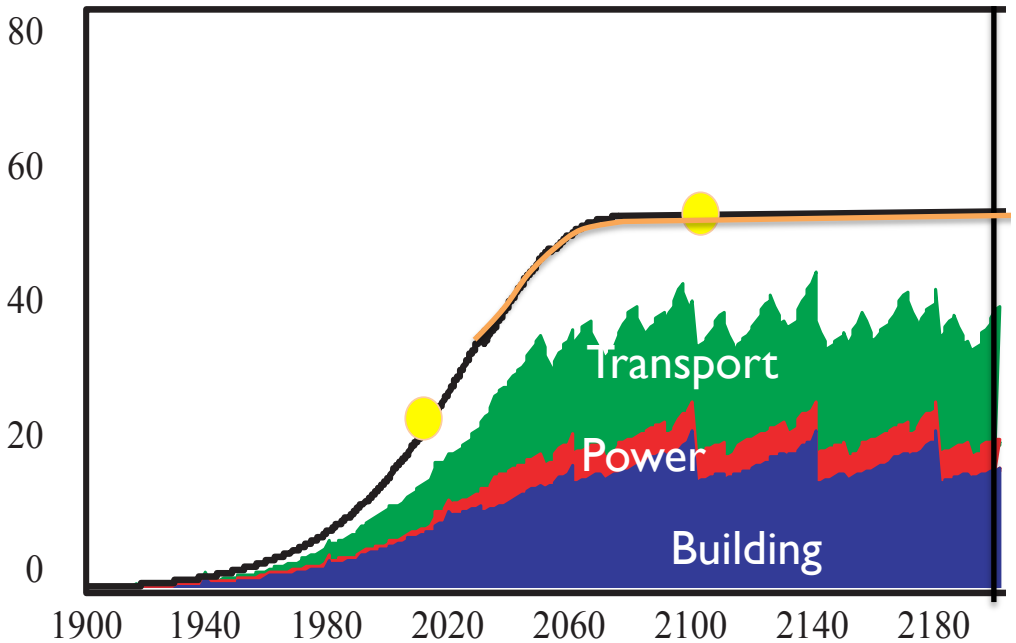
GHG emissions (t CO2eq)




Copper CRRR = 40%
CRRR = 70%
Mt/Year
80
60
40
20
0
Demand
(GDP & Population)
Transport
Power
Building
B2DS
Production
1900
1940
1980
2020
2060
2100
2140
2180
2220
2260
2300
Demand
WWF
Production







The only path to sustainability is sobriety => lower increase of GDP (or population) with time

Sobriety...

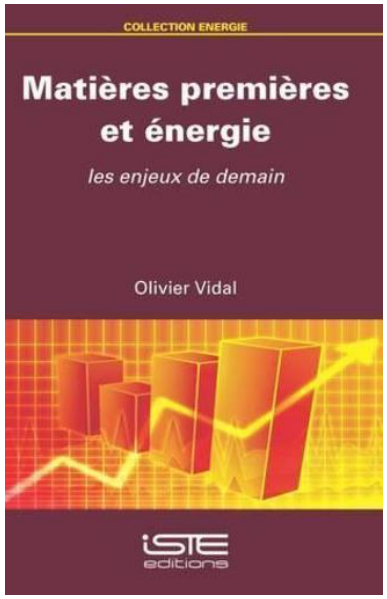
230-250 km/h

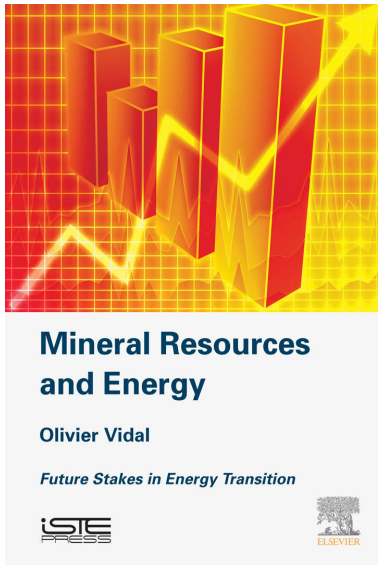
2100-2500 kg

18 kWh/100 km
@ 90 km/h

	RTS (iea2017)	*B2DS (iea2017)*	*WWF (2012)*
Energy consumption	Increase	Reduction	Reduction
RM demand for energy	Increase	**>> BAU + High Tech**	Increase + **High tech**
RM global demand	Increase	**> BAU**	< BAU
GDP	Increase	Increase	**< BAU**
Temperature increase	**+4 to 6°C**	+1.5 to 2.5°C	+1.5 to 2°C
	Crash before 2100	**Crash before 2200**	**Sustainable until 2200**

Thank you for your attention !





Cumulative need in copper for LDV (2017)