Les enjeux matière et énergie dans un monde en transition

- Evolutions démographique, technologique, économique
- Hausse des prix uniquement conjoncturelle ? ou signal long-terme indiquant une difficulté systémique d'approvisionnement ?

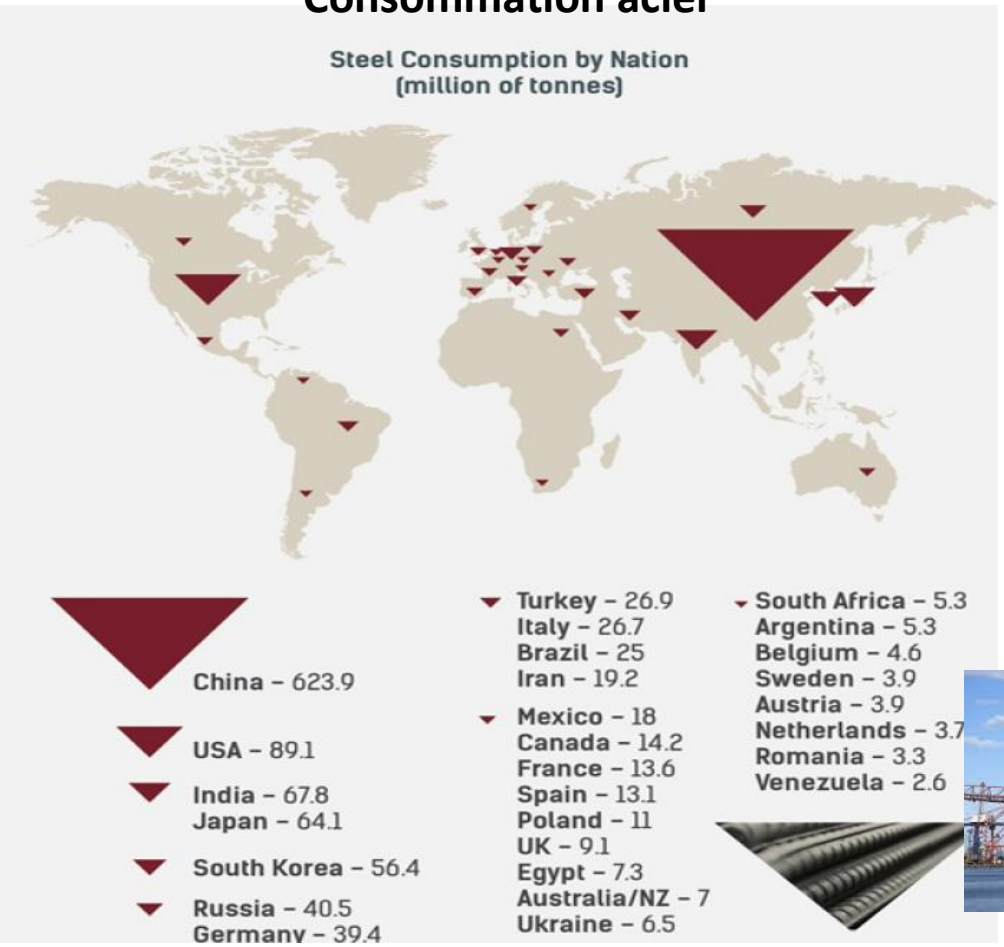
Olivier Vidal, CNRS, Isterre olivier.vidal@univ-grenoble-alpes.fr

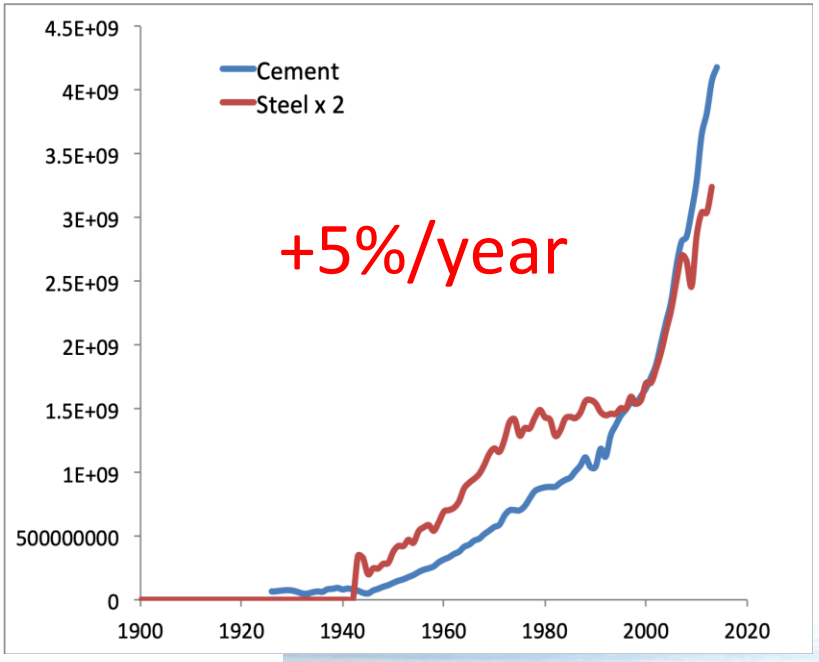
cnrs
dépasser les frontières

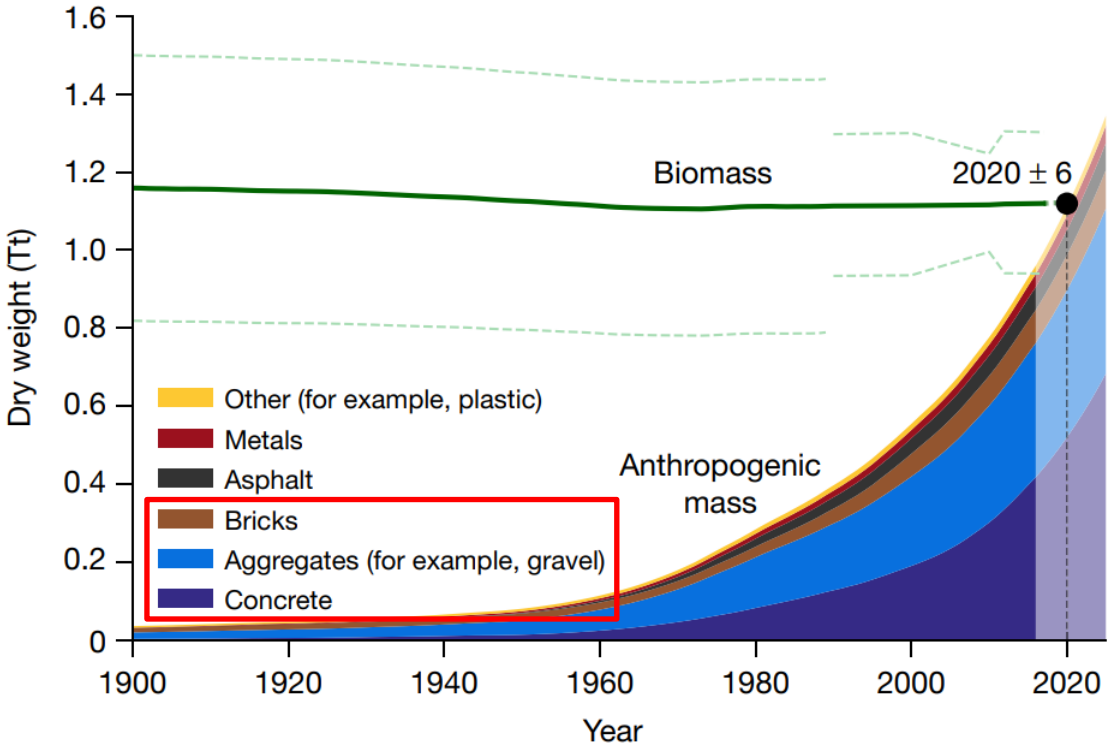
ISTerre
Institut des Sciences de la Terre

Matières "structurelles" – ciment, acier & alliages, Al, Cu > 1Mt/an

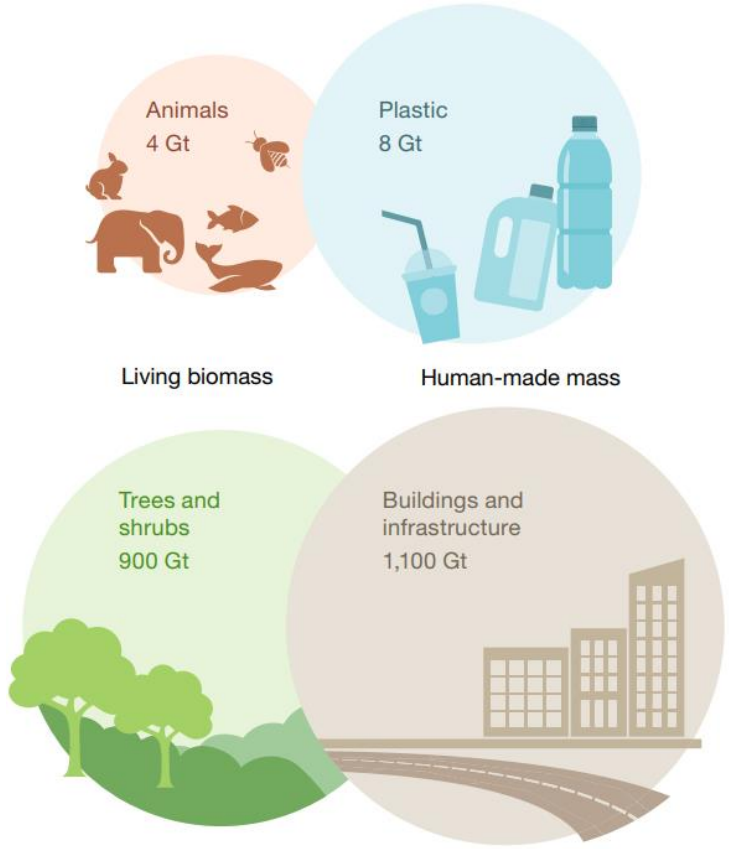
Consommation acier



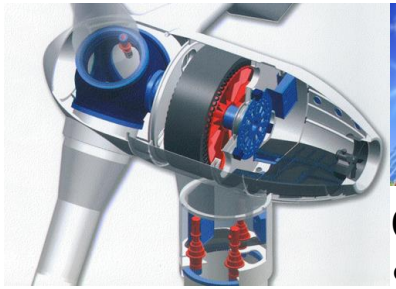




Source: Elhacham et al. 2020



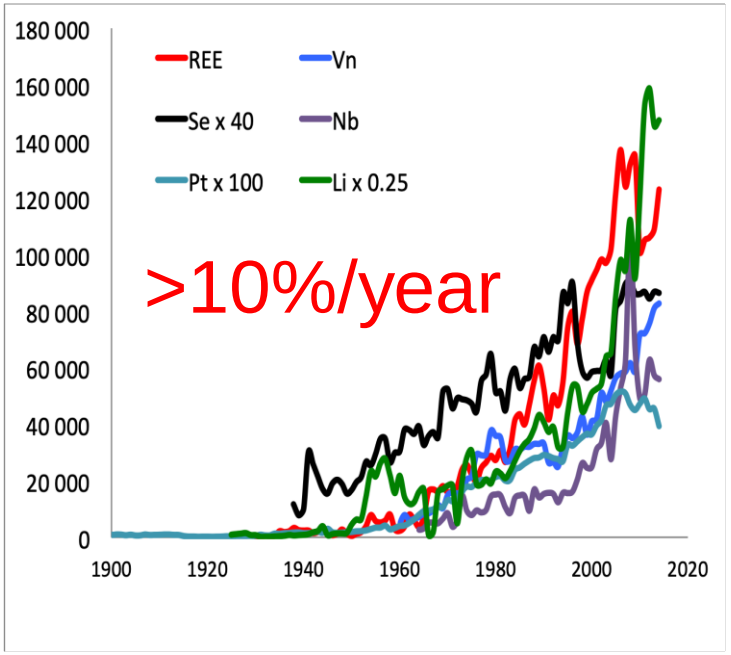
Métaux "technologiques" (< 0.5 Mt/an)

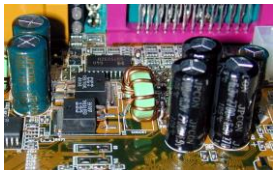


Nd, Dy, Pr, Tb

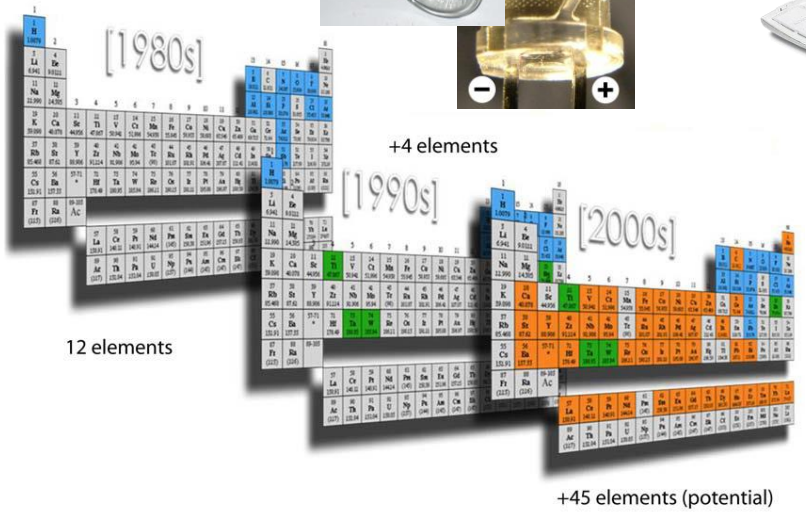
Ga, In, Se
Si, Ag

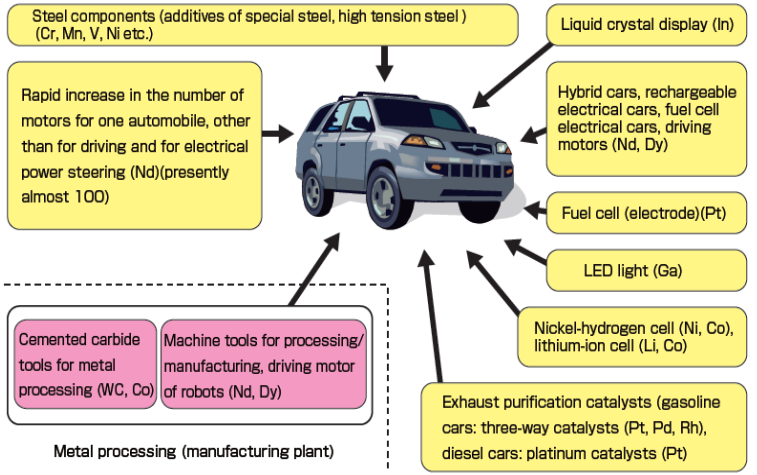
Li, Co, Graph





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





une demande qui augmente dans un contexte de transition énergétique

Métaux : les besoins colossaux de la transition énergétique

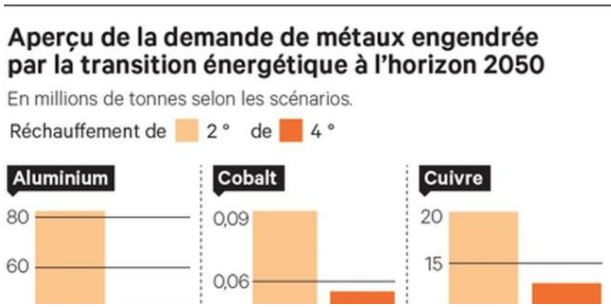
¤ Les technologies requises pour limiter le réchauffement du climat feront grimper la demande de ressources naturelles. ¤ C'est, selon la Banque mondiale, un risque majeur pour l'environnement.

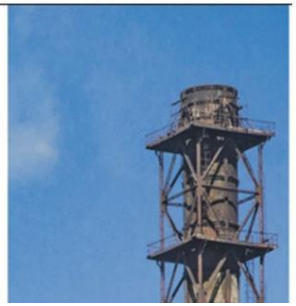
Lire plus tard | 07 | Commenter

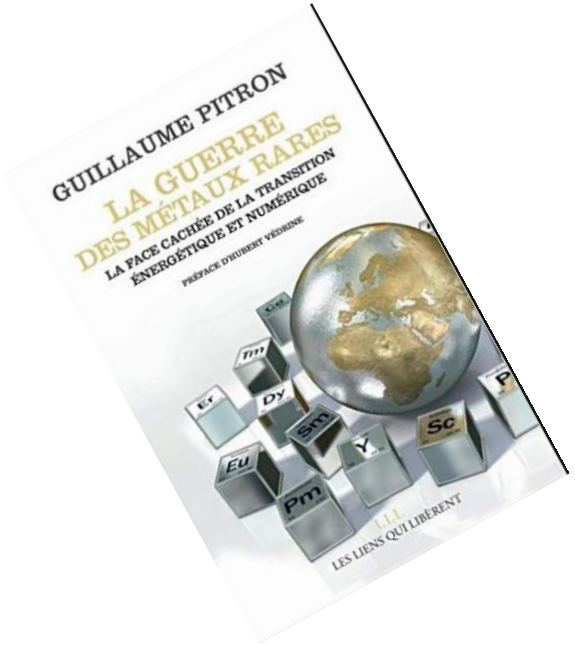
Aperçu de la demande de métaux engendrée par la transition énergétique à l'horizon 2050

En millions de tonnes selon les scénarios.

Réchauffement de 2 ° de 4 °







Le boom des batteries va entraîner une ruée sur les métaux critiques

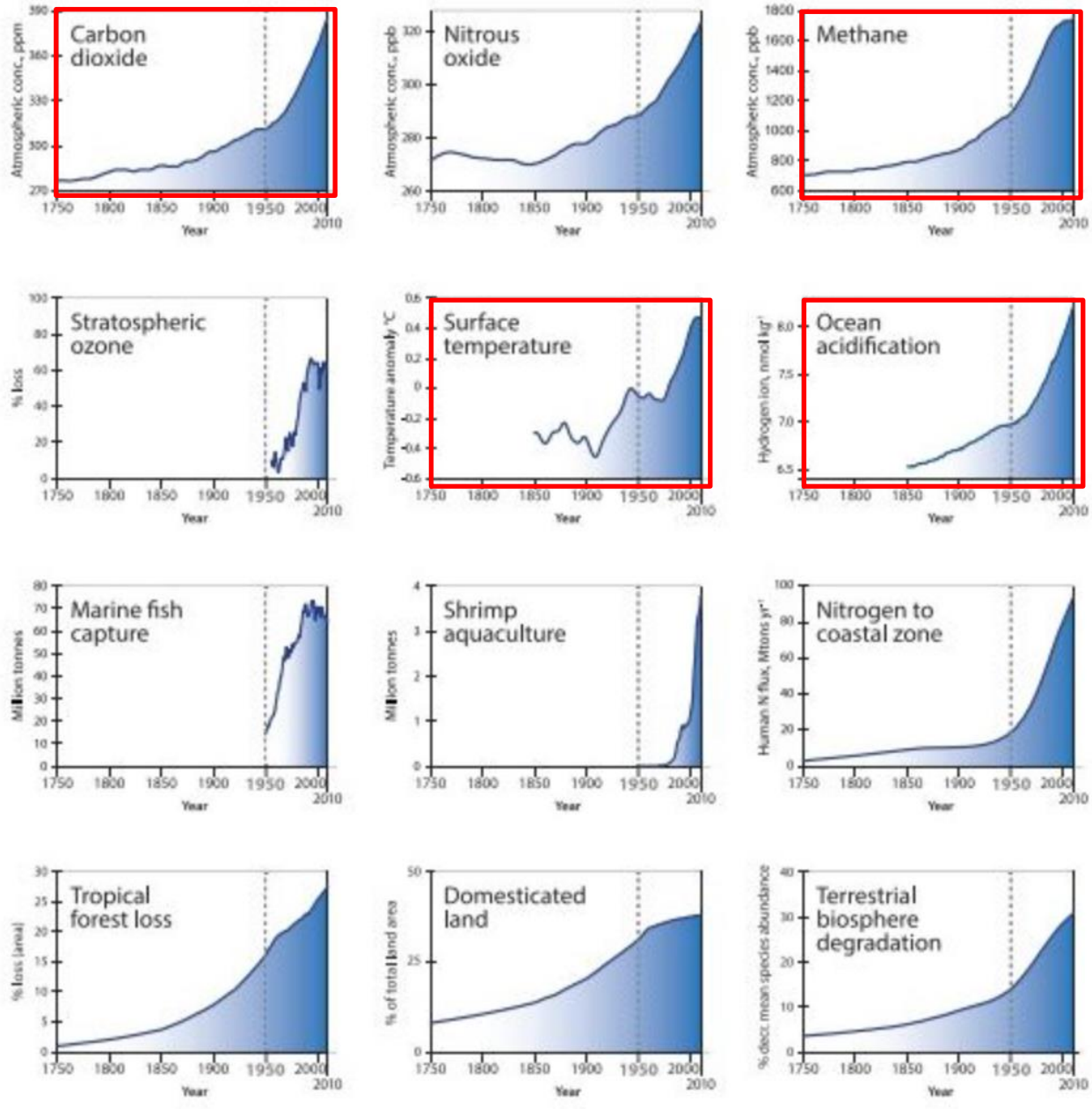
Dans un monde 100 % véhicule électrique, la demande de lithium serait multipliée par trente, celle de cobalt par vingt. Pour y répondre, les mines manquent.

Lire plus tard | 09 | Commenter

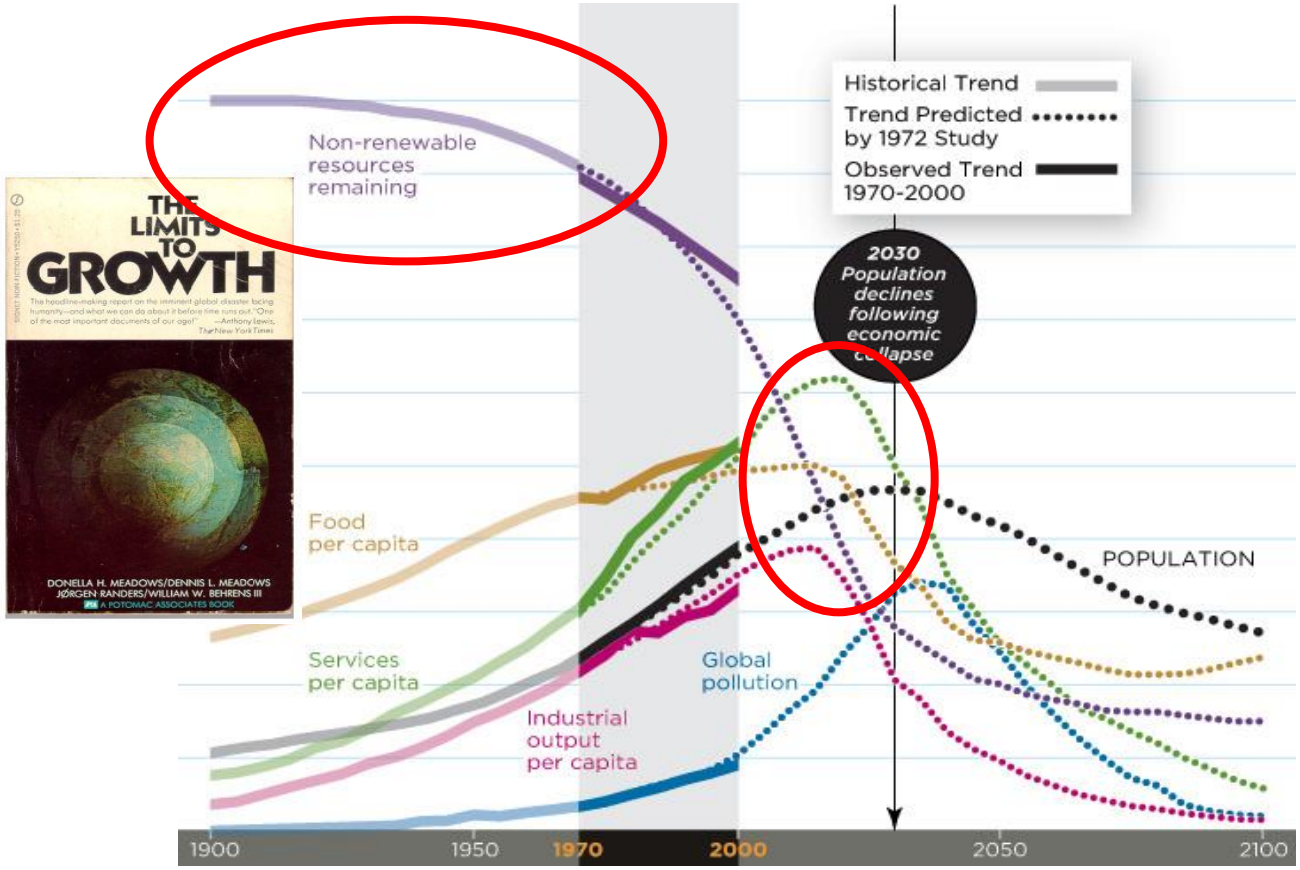
Des impacts environnementaux inquiétants

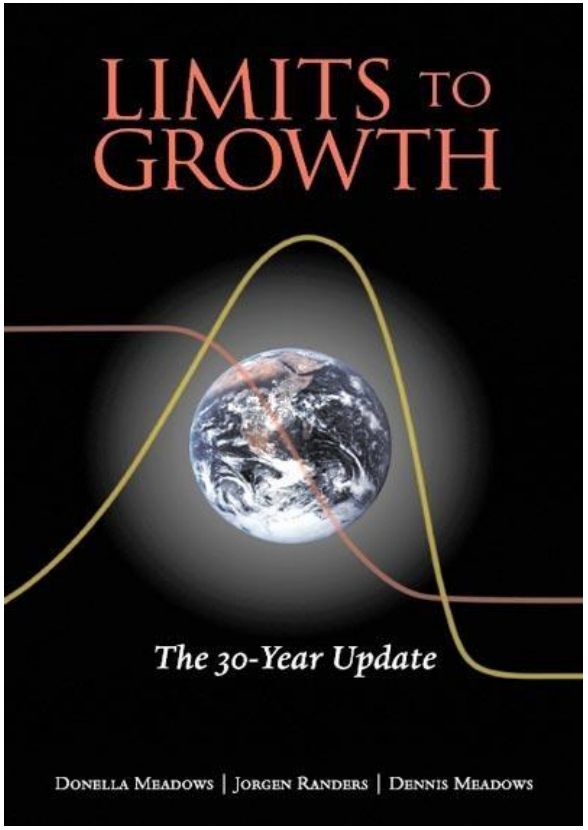
Production de matières premières

- 35% de la consommation industrielle mondiale d'énergie
- 50% des émissions de CO2 de l'industrie



Climat anxiogène qui nous renvoie aux prévisions catastrophiques du club de Rome (1972)





Evolution future ?

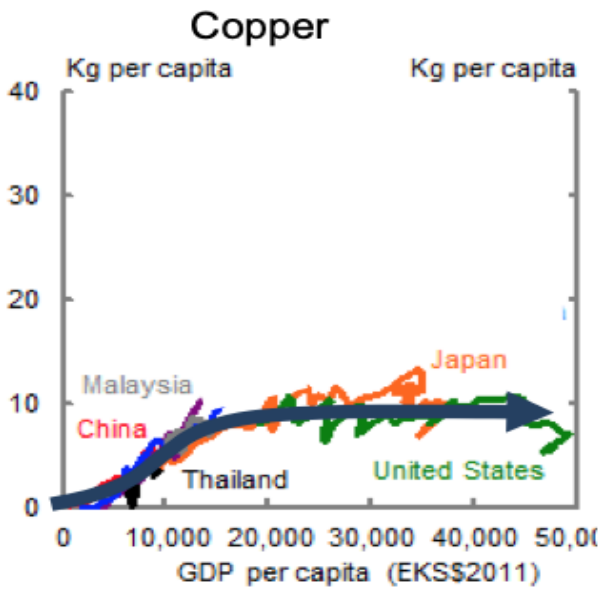
Estimation

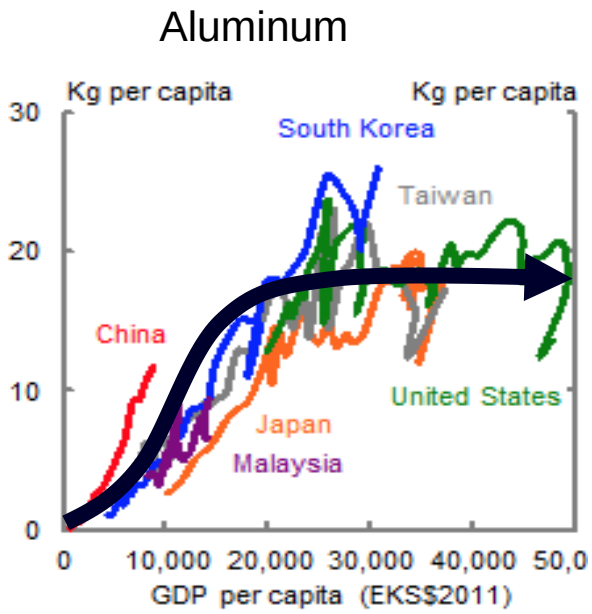
- de la *demande* en ressources et énergie,
- des capacités de *production* primaire (+ recyclage pour métaux),
- de la substitution pour chaque ressource dans chaque technologie, par pays

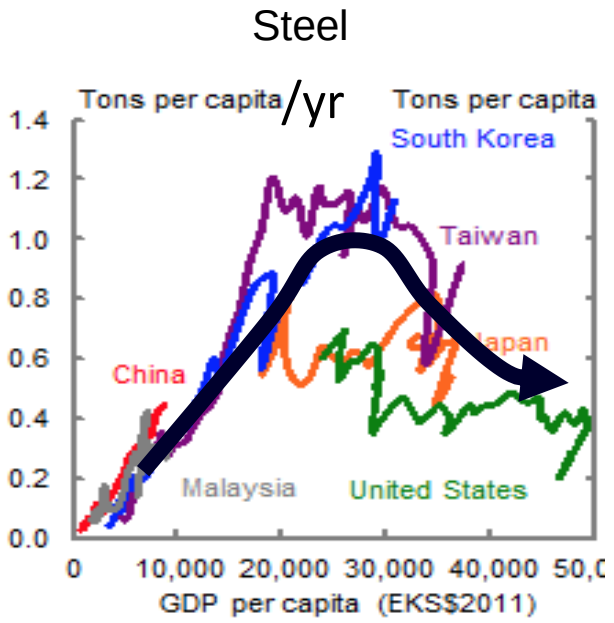
...dans un *système dynamique*: monde en évolution et en « transition", mondialisé, avec de forts contrastes entre les pays

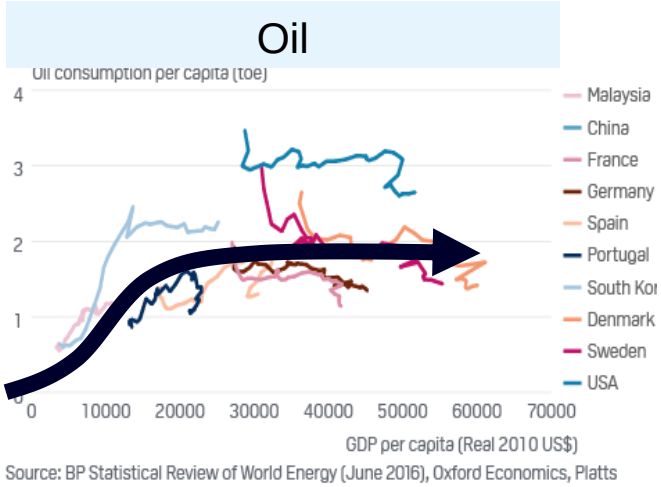
La demande

Le premier moteur de la consommation est l'augmentation de la population et du PIB

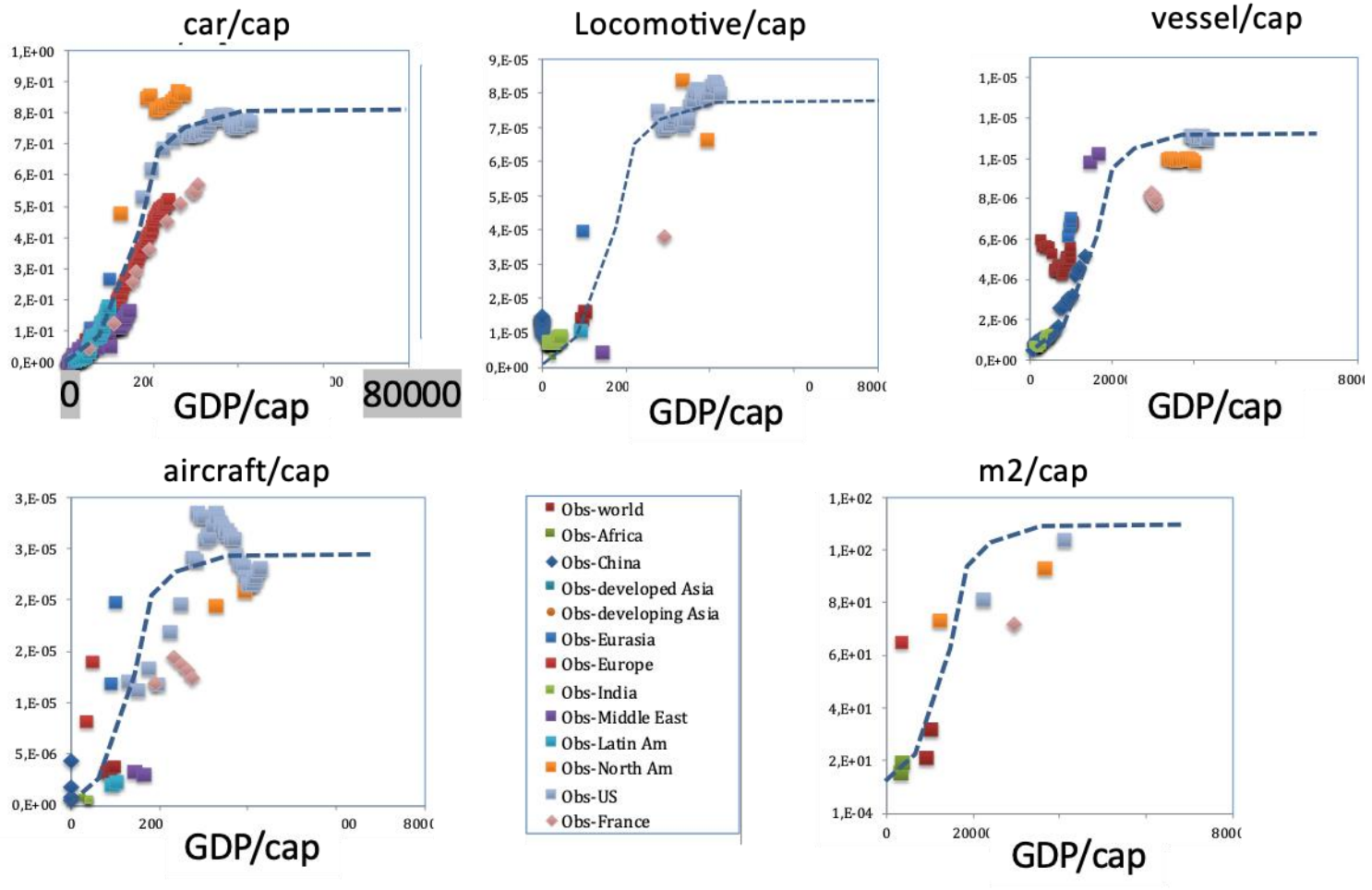








L'évolution ***tendancielle*** de l'infrastructure/hab est proportionnelle au PIB/hab

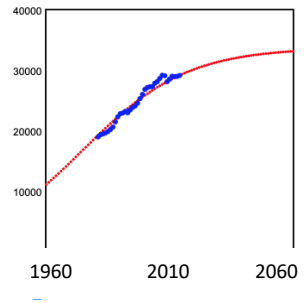


L'évolution est la même pour tous les pays

Evolution ***tendancielle*** de l'infrastructure - **FRANCE**

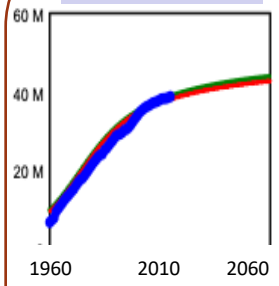
Population & PIB

PIB/hab

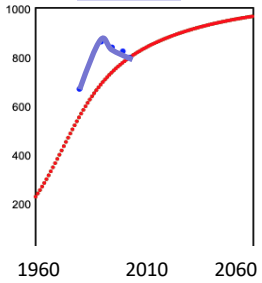


Infrastructure

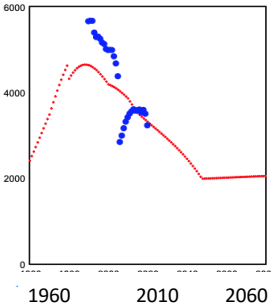
Automobiles



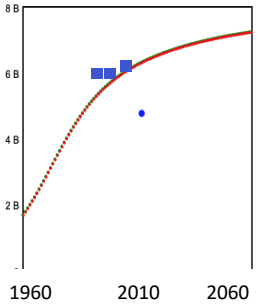
Avions



Locomotives



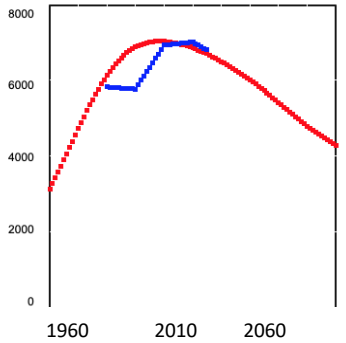
m2 batiment



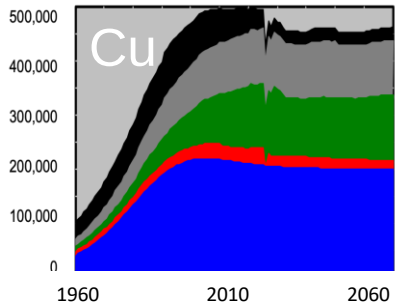
Appareils domestiques, réseaux, etc

Ressources

Energie (PJ/yr)



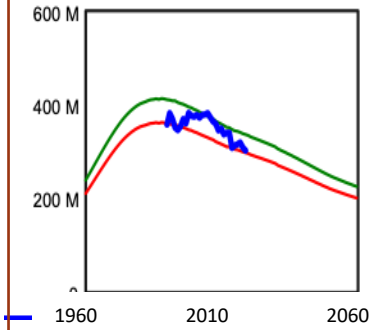
Matières (t/yr)



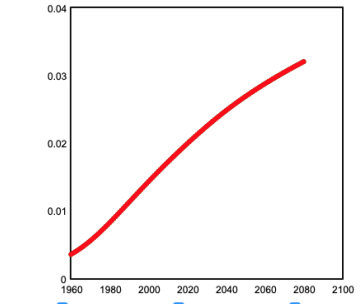
Autres ressources

Impacts

CO2 (Mt/yr)



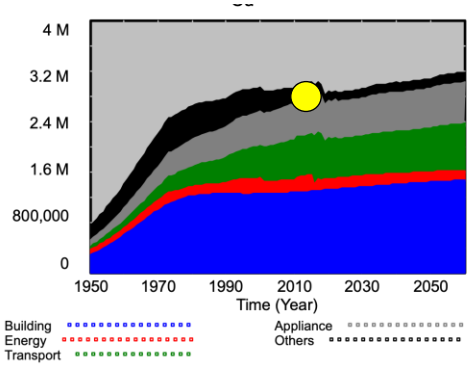
Local contribution to global warming



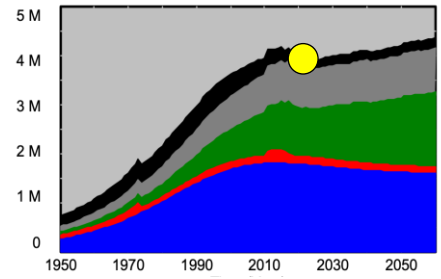
l'évolution ***tendancielle*** mondiale de consommation en cuivre

Developed countries

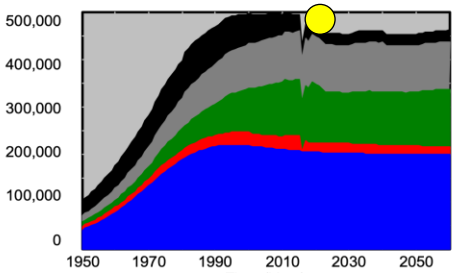
US



Europe



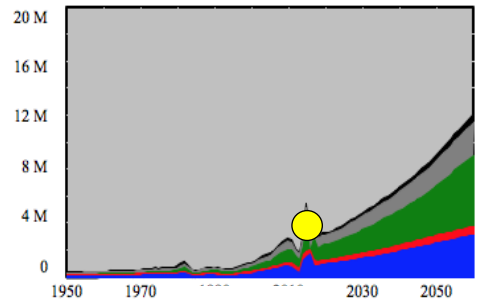
France



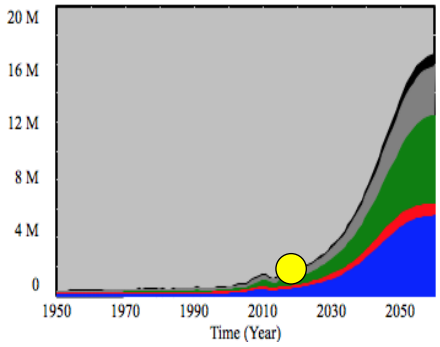
+

Developing economies

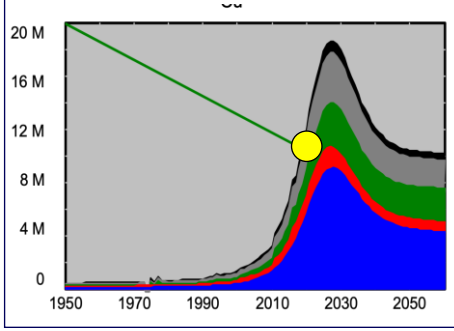
Africa



India

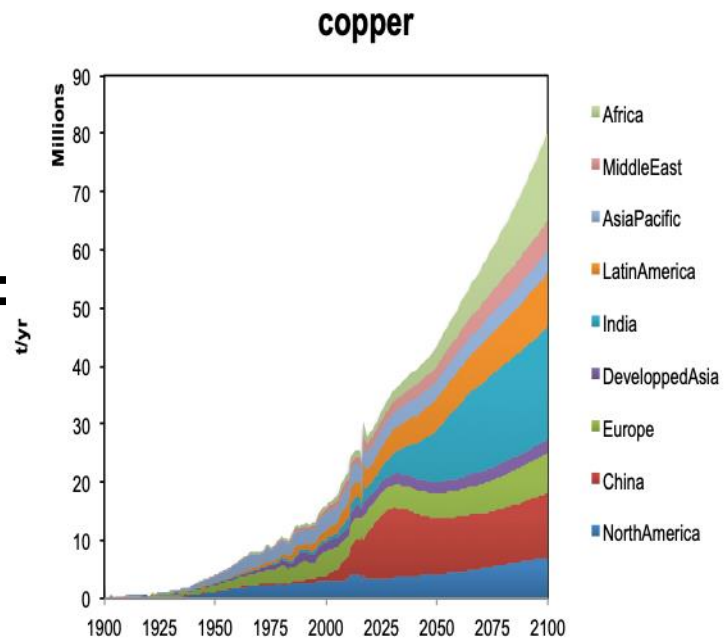


China

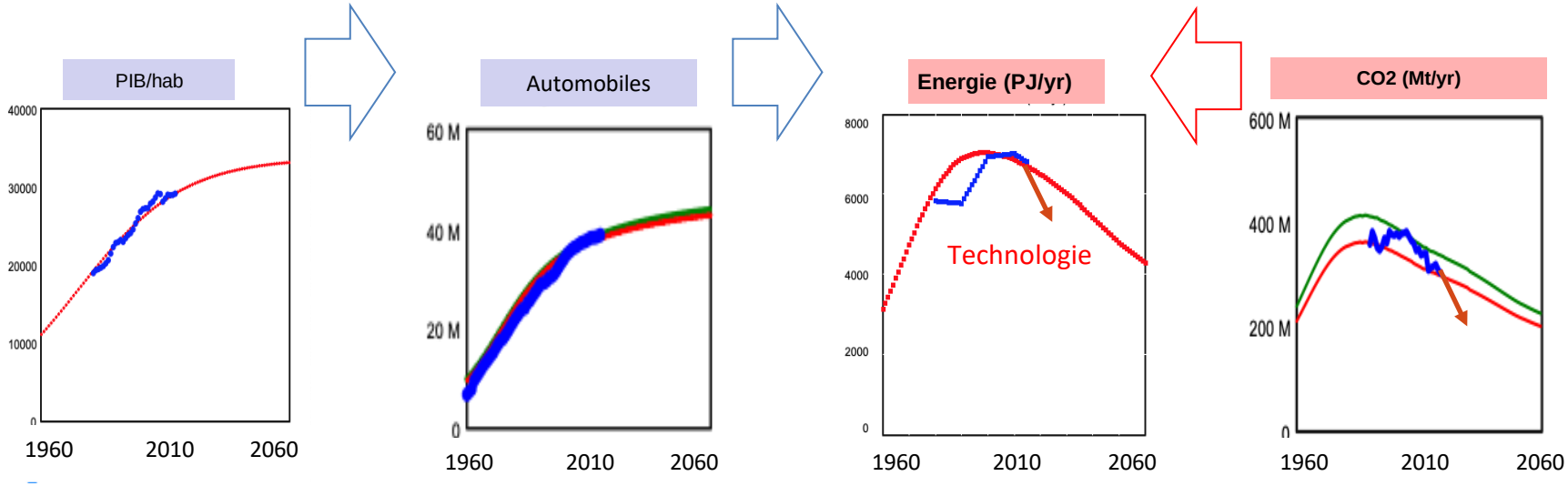


=

World

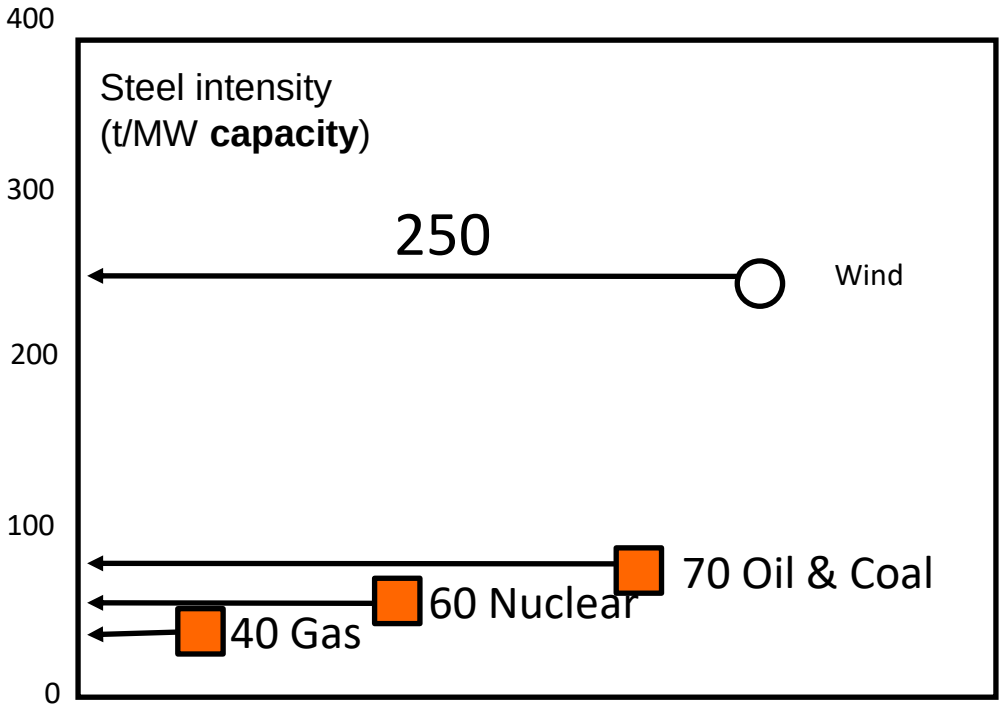


Pour s'*écarter des évolutions tendancielles* : technologies de rupture

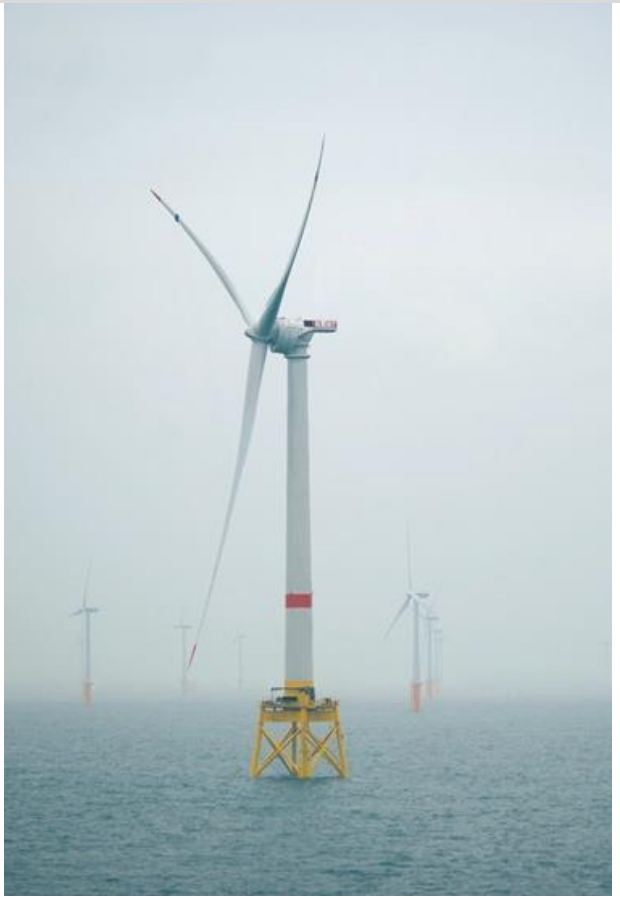


Nouveaux besoins en ressources, impacts et prix

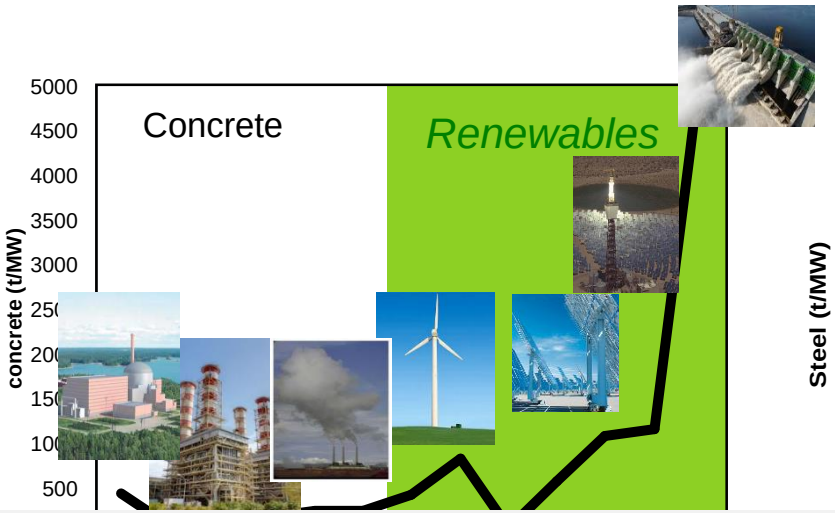
Les énergies renouvelables sont diluées => de grandes infrastructures sont nécessaires

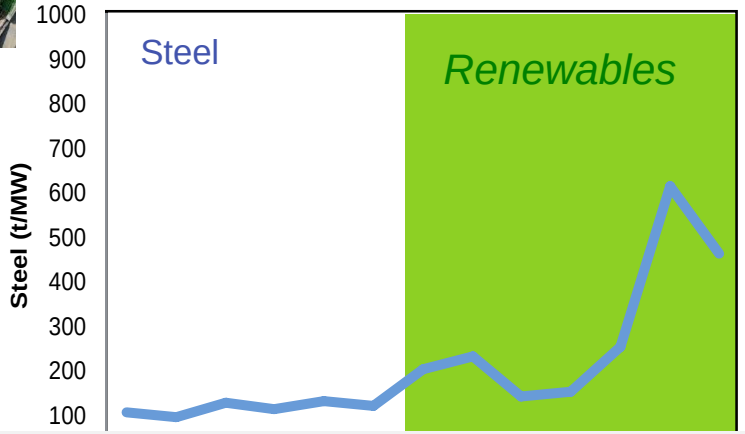


6 Mw, > 150 m, *1500 t steel*
3t permanent magnet, *0.5t REE*

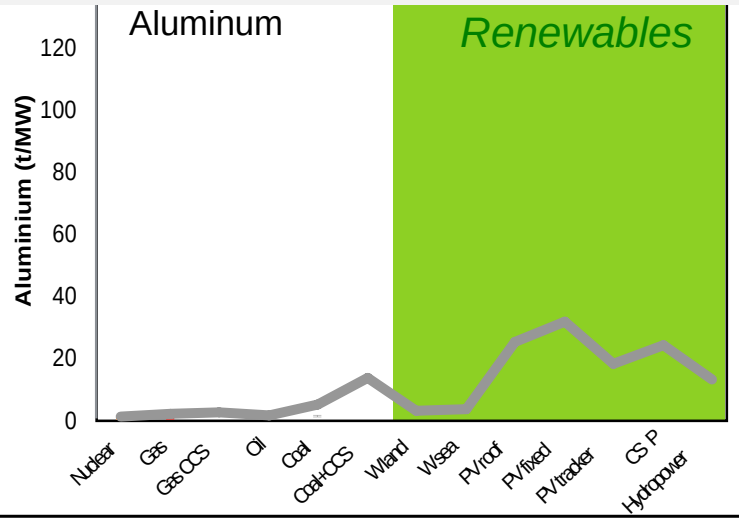


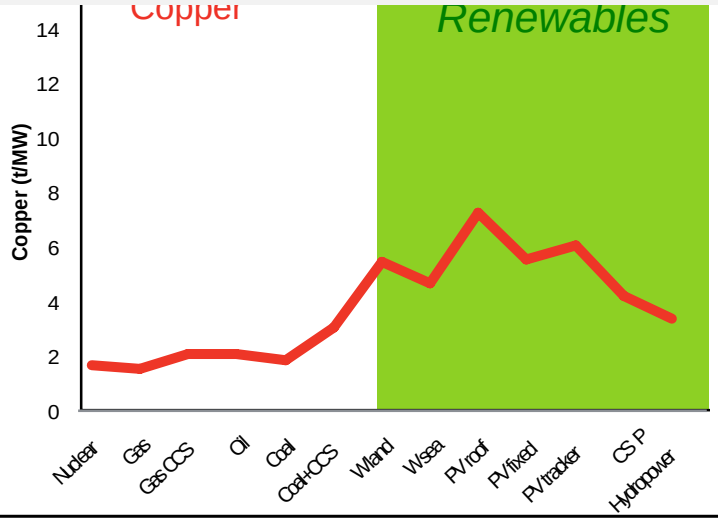
Material intensity of power plans (t/Mw)





Material intensity of renewables (t/MWh) = 5 to 10 x classical power plans

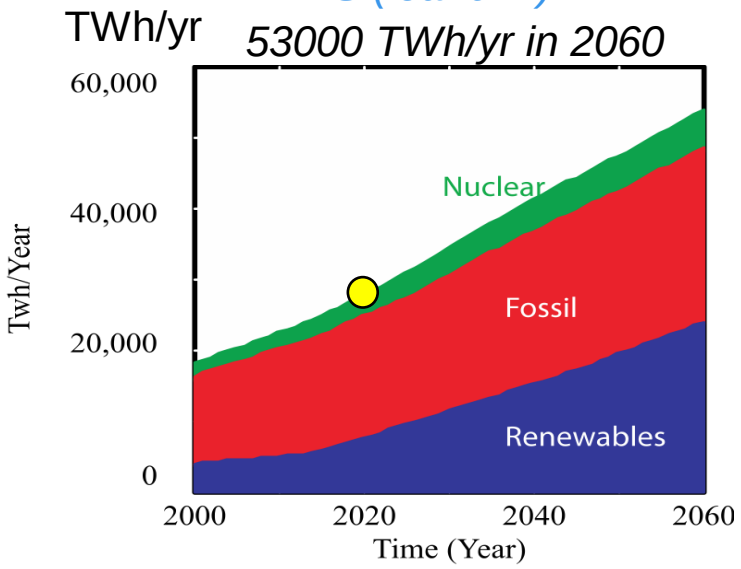




Exemple: la production d'électricité - monde

RTS (iea2017)

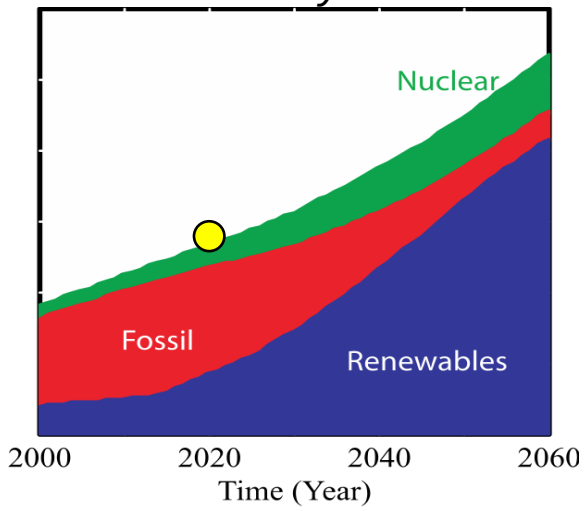
53000 TWh/yr in 2060



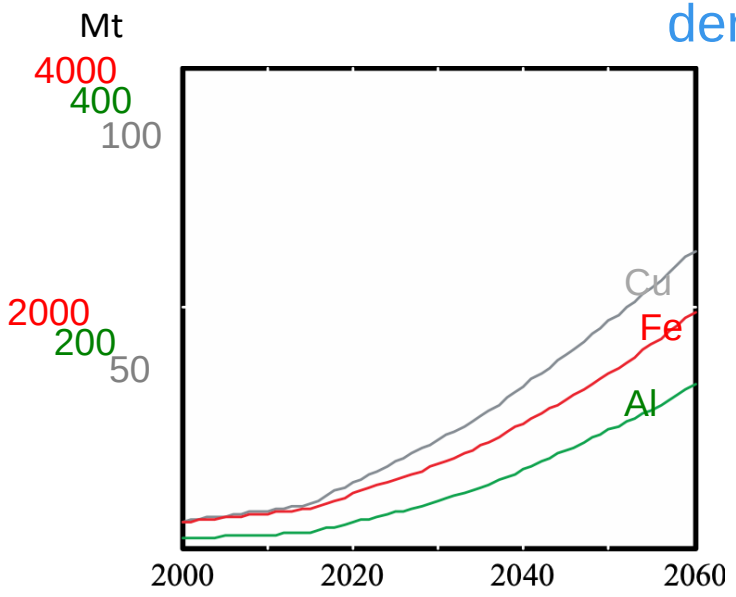
PIB & population

B2DS (iea2017)

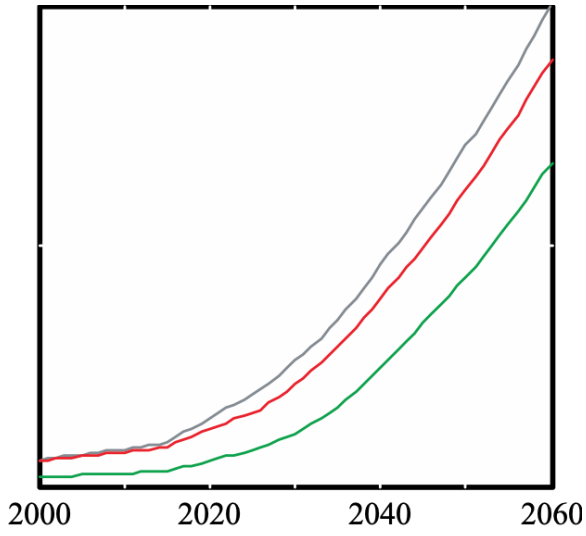
53000 TWh/yr in 2060



demande cumulée

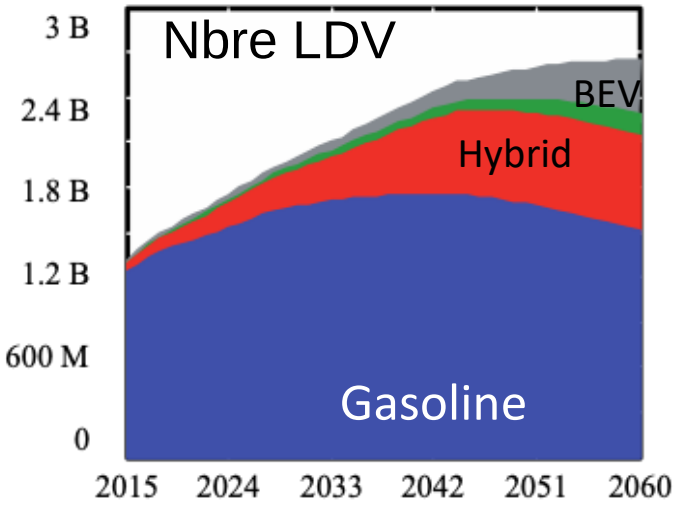


X 2

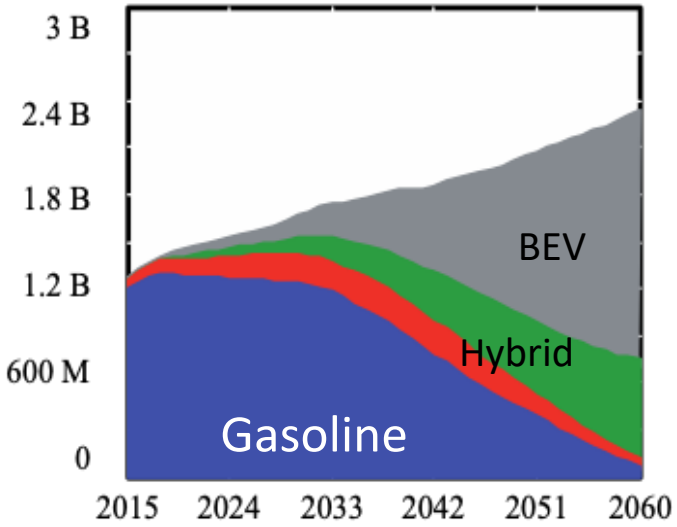


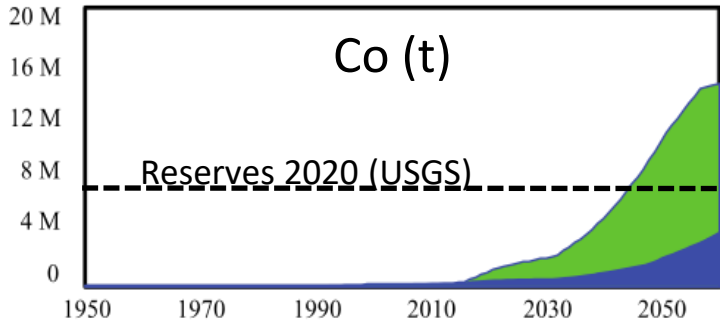
Transport routier – cobalt ds batteries Li-ion

RTS (iea2017)



B2DS (iea2017)

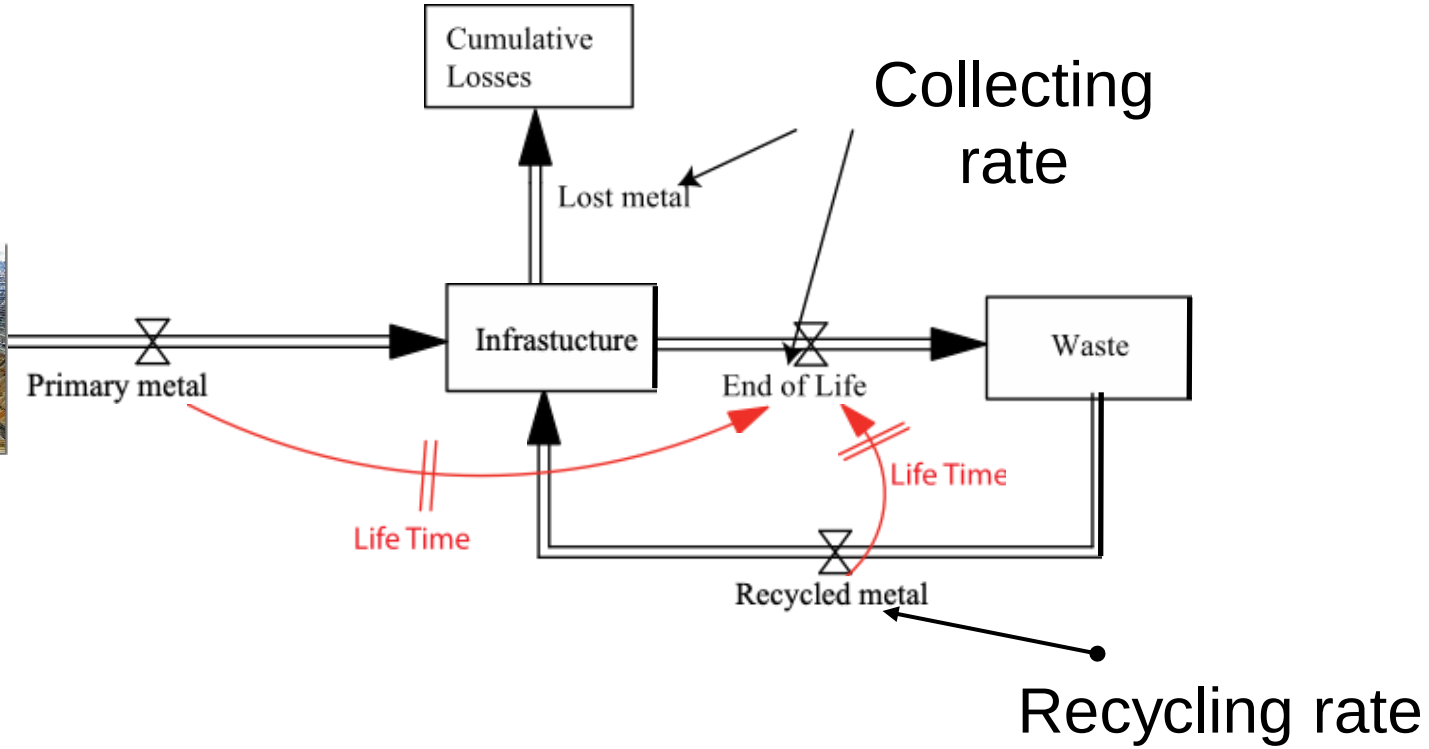




B2DS

RTS

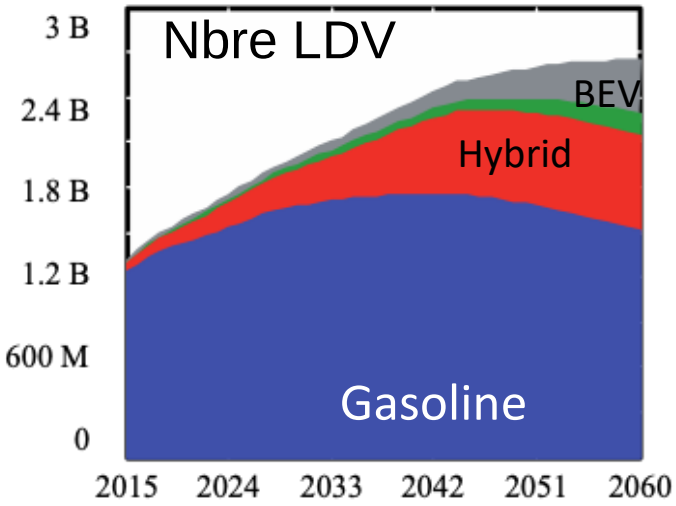
A stock and flow problem



1) ∫ primary production > stock in infrastructure
2) the recycling flow depends on the total consumption

1) ∫ primary production > stock in infrastructure

RTS (iea2017)

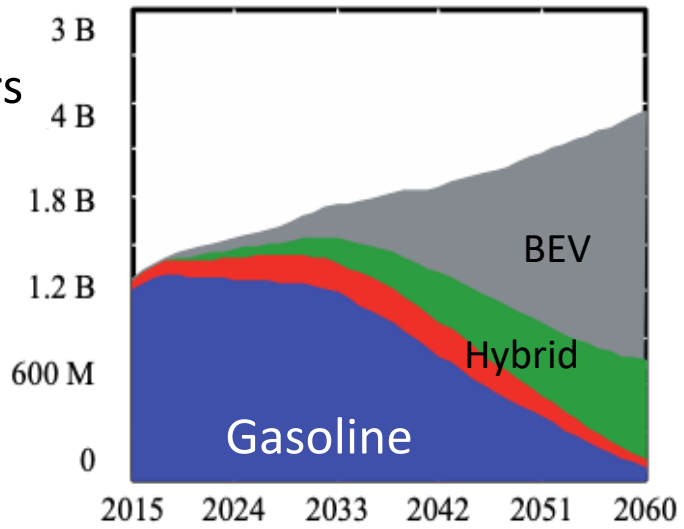


6kg/EV

RR = 0.5 in 2050

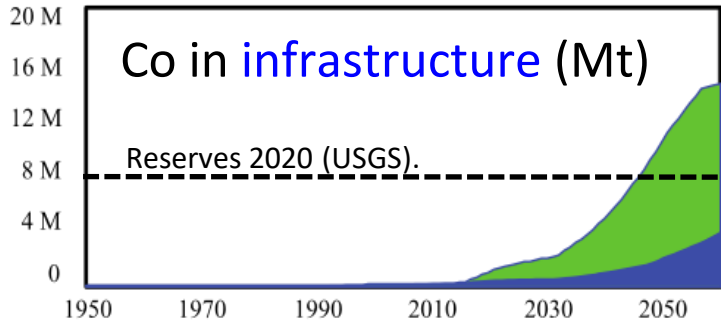
Lifetime = 10 years

B2DS (iea2017)



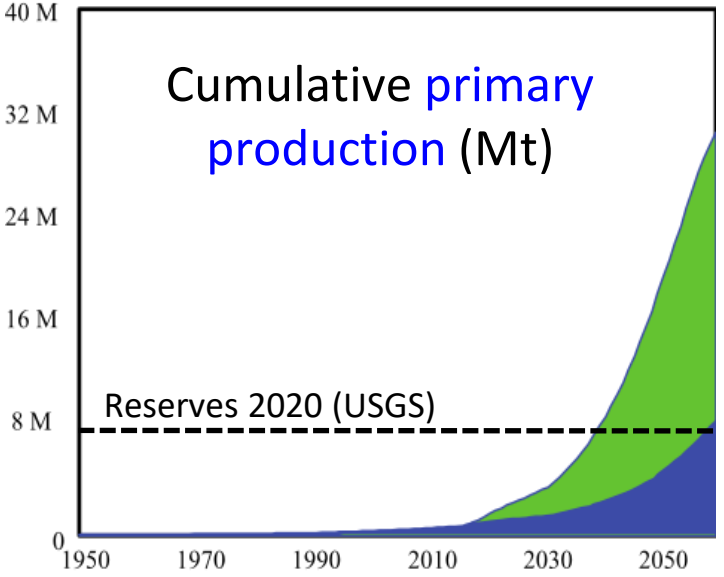
Technologies will change

Reserves will change



B2DS

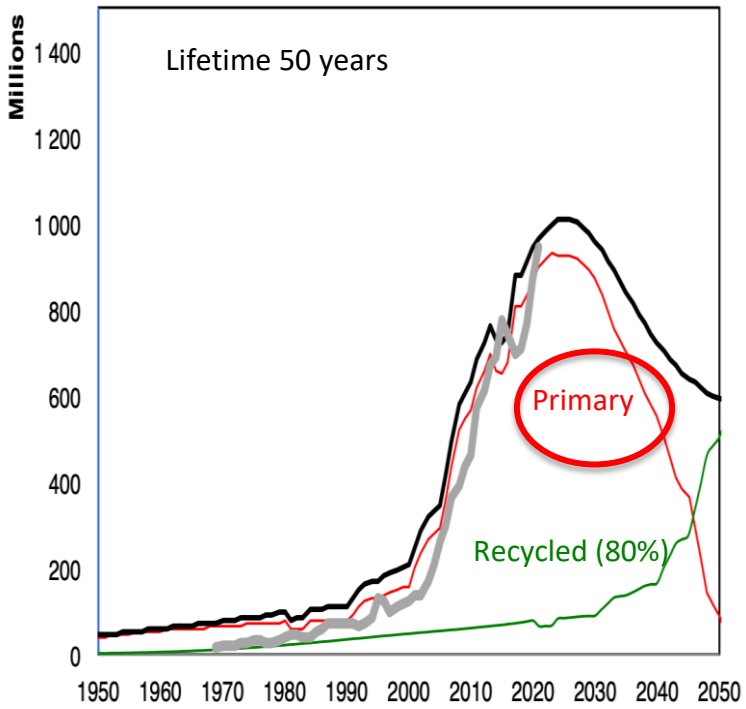
RTS



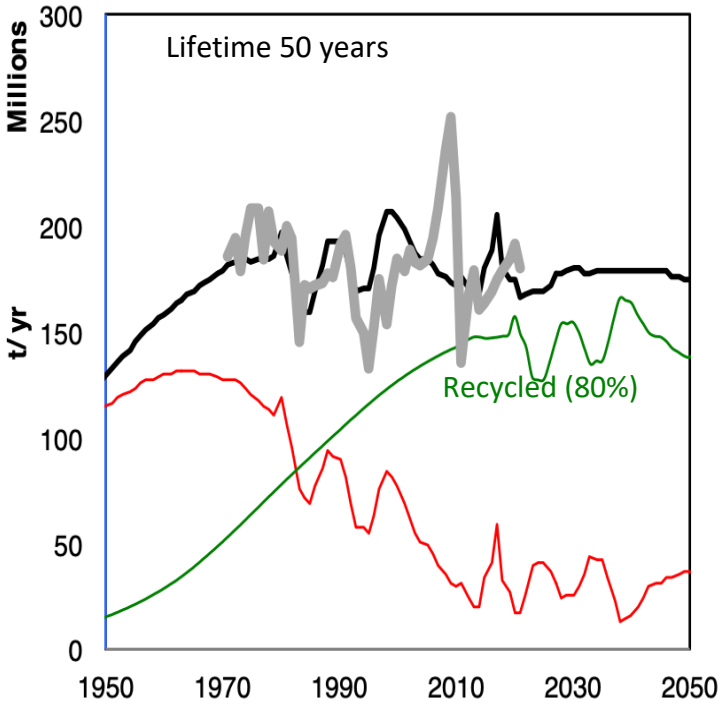
2) Des situations contrastées entre pays riches et en développement pour le recyclage

Steel

China

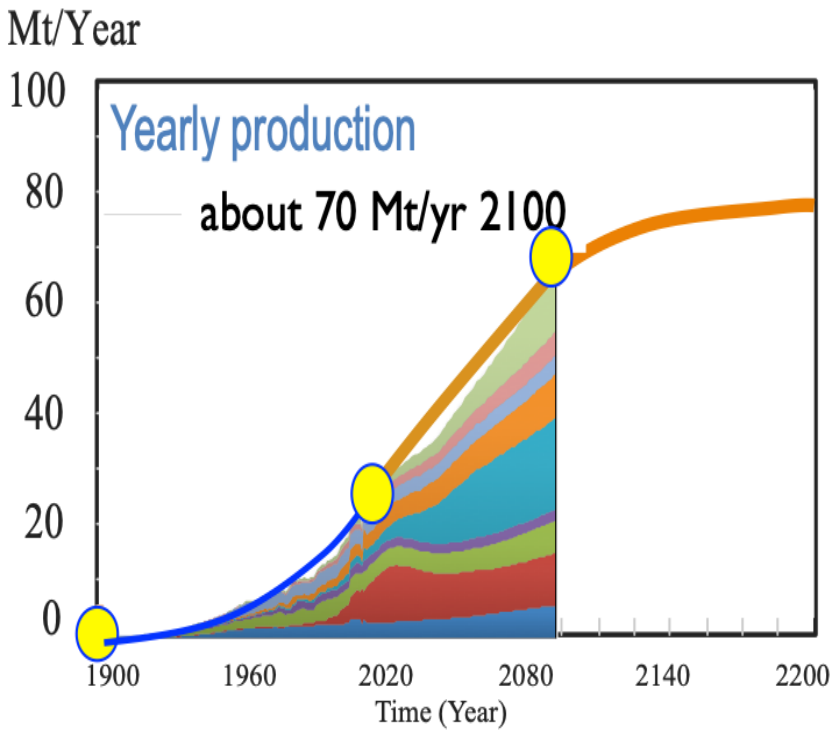


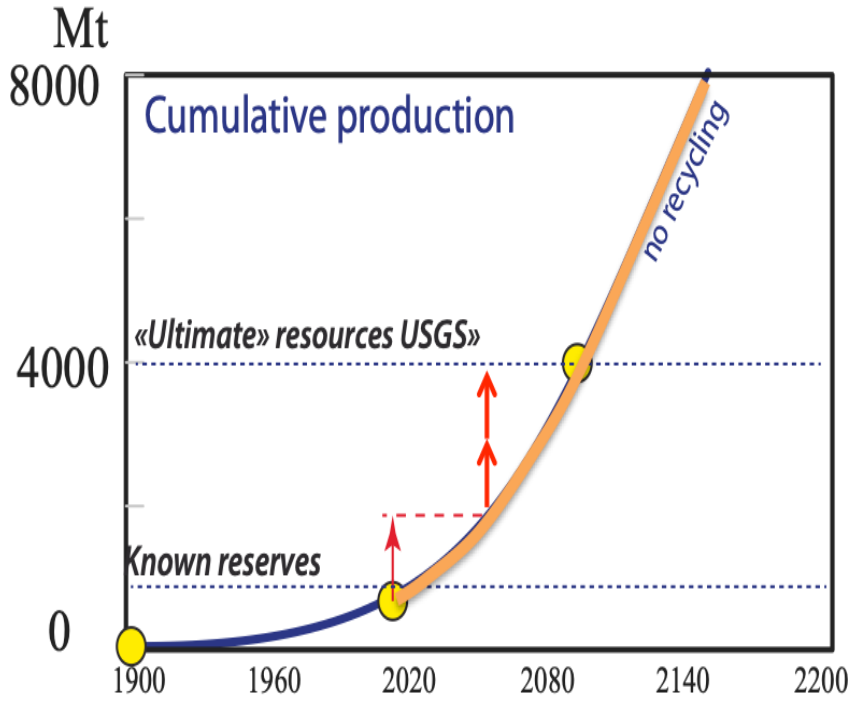
Europe



Quelles capacités de production ? = quelle disponibilité à quel prix ?

Demande future en cuivre pour un scénario BAU





Quantité cumulée (Cu)

44 en 30 ans

130 en 80 ans

272 en 180 ans

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

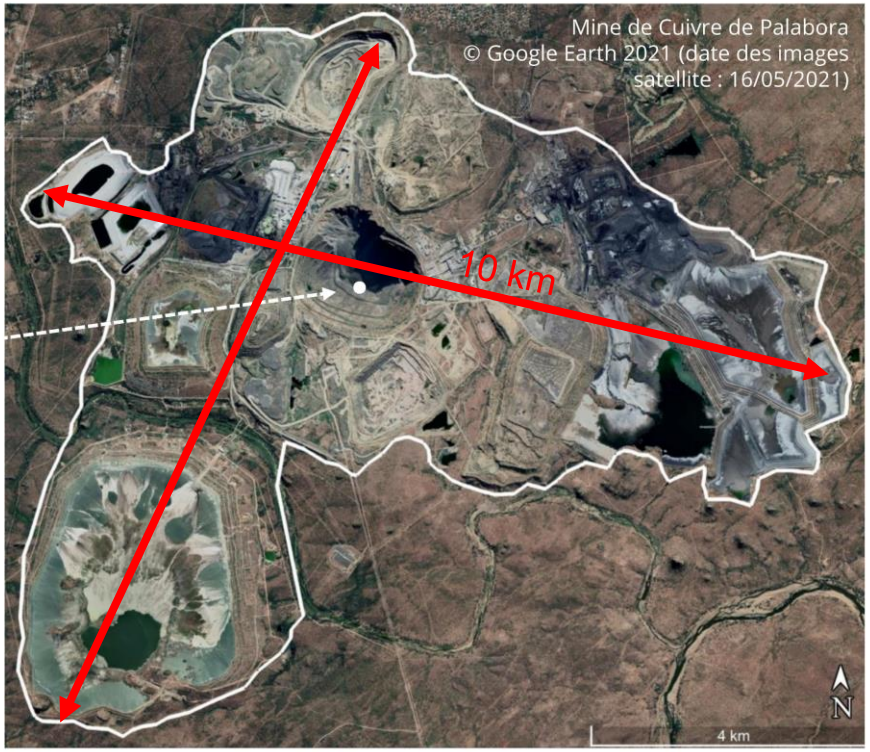
(Chile)

ake in 30 years

ng)

Hormis l'accès à la ressource, limite = les impacts environnementaux

Palabora (afrique du sud) => 4 millions de t de cuivre en 40 ans (16% de la consommation mondiale 2020)



Volume of waste

Visual Capitalist:
[All of the World's Mine Tailings, in One Visualization (visualcapitalist.com)]

Limite 1: Les impacts environnementaux => opposition sociale

The Guardian: 30/03/2017

El Salvador makes history as first nation to impose blanket ban on metal mining

PRESS RELEASE: Colombians threatened with death for opposition to mega-mining project as defenders visit UK

Ecuador's rising opposition to mining may thwart exploration boom – by Cecilia Jamasmie (Mining.com – January 6, 2019)

January 7, 2019 in Canadian Media Resource Articles, Copper, Gold and Silver, Latin America Mining, Mining Conflict and Opposition

The Chilean government is taking on a U.S. mining company in a spat that could rattle the electric-car industry.

Penhalonga and Tsvingwe Community Opposition to Destructive Mining Impacts

Financial Time: 17/02/2019

Australian coal industry jolted as 'climate change' ruling blocks mine

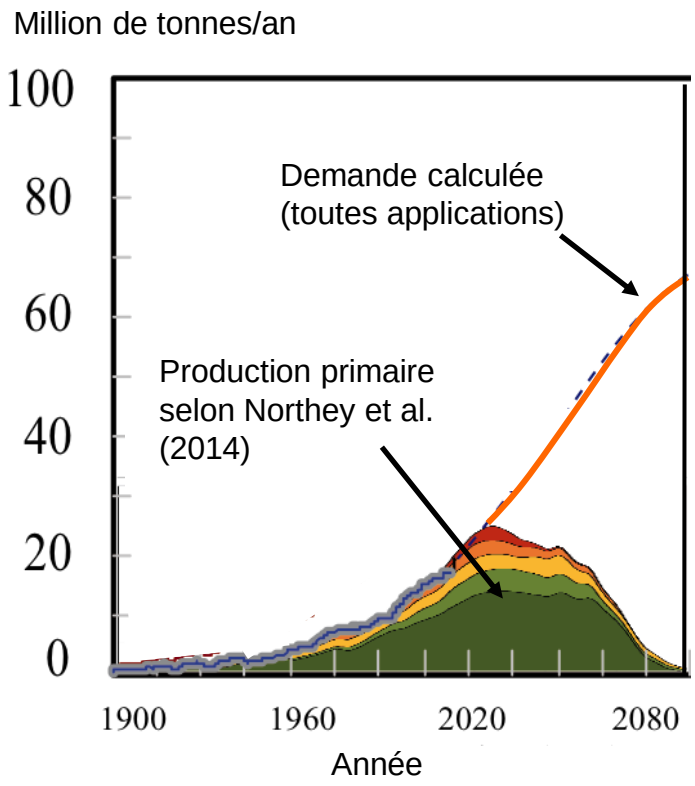
PNG government rethinking China mining deal after opposition

Mining Technology: 17/01/2017

While in Africa, formerly considered one of the continent's brightest mining prospects, investment in Tanzania's mining industry has slowed due to a crackdown on firms by the government as it attempts to reap greater benefits from the sector.

Limite 2: Epuisement des réserves (peak oil, peak metals) ?

2014



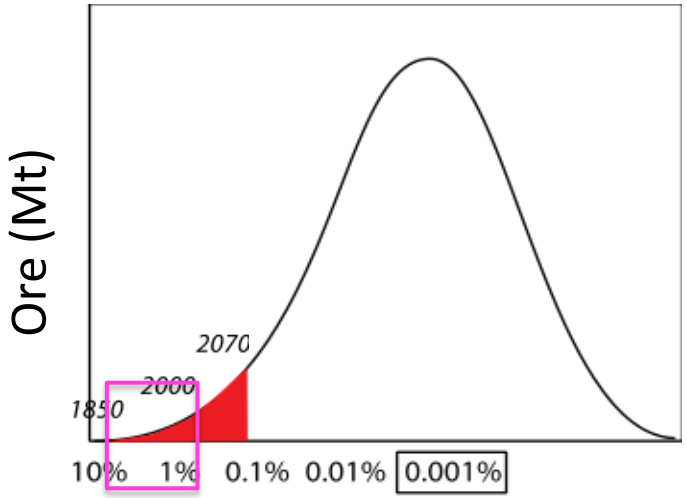
1924

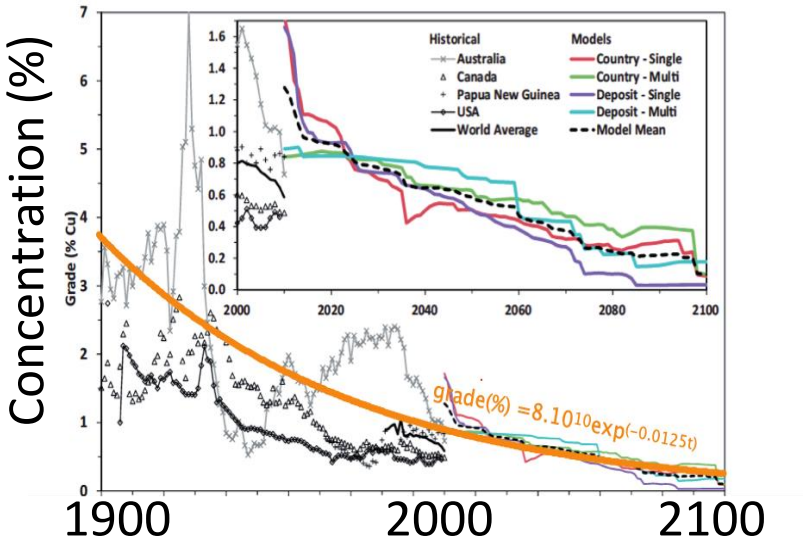
Copper and Electricity to Vanish in Twenty Years?

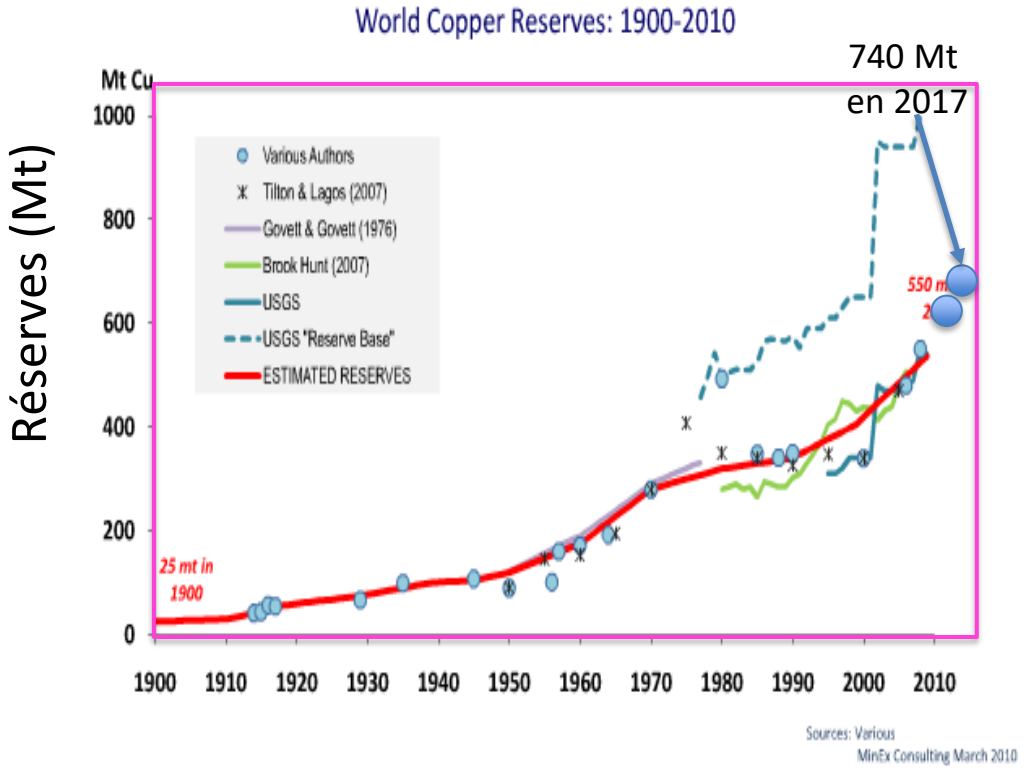
LAST WEEK we reprinted part of an address made by Ira B. Joralemon before the Commonwealth Club of California, in which he stated that "the age of electricity and of copper will be short. At the intense rate of production that must come, the copper supply of the world will last hardly a score of years. . . . Our civilization based on electrical power will dwindle and die." We are rather surprised that a geologist of Mr. Joralemon's standing cannot use his imagination a little more than this, but no doubt he was painting the picture as black as possible so that copper miners would wake up to the fact that they are rapidly wasting a valuable natural resource with little or no profit to themselves. Known deposits of copper ores of a present commercial grade are limited, as Mr. Joralemon says, and it might be possible that in twenty years electrical requirements will have milked most of them dry. But metallurgical methods will advance; likewise prices, we hope; so that it will pay to mine lower grade deposits of which there is a tremendous tonnage available, and also deeper deposits such as our friends in Michigan have. And we can hardly believe that all the copper resources of the world are known. Twenty years ago, for example, who would have classed such deposits as those at Chuquicamata and Bingham Canyon as important factors, even with the price of copper somewhat higher than it is now?

As to the electrical industry, we can hardly believe that all our electricity will go back into the clouds where Franklin found it, just because copper is scarce. Maybe copper won't be required at all for transmission purposes; we may just use the ether.

En réalité, les réserves de tous les métaux n'ont cessé d'augmenter depuis 1900...







OUI MAIS...
les coûts énergétiques et économiques ?

Limite 2: Les limites thermodynamiques

1/efficacité

$$E = \eta.(\Delta \mathbf{G_f}^\circ + \frac{0.2}{\bar{C}})$$

Métallurgie

Broyage

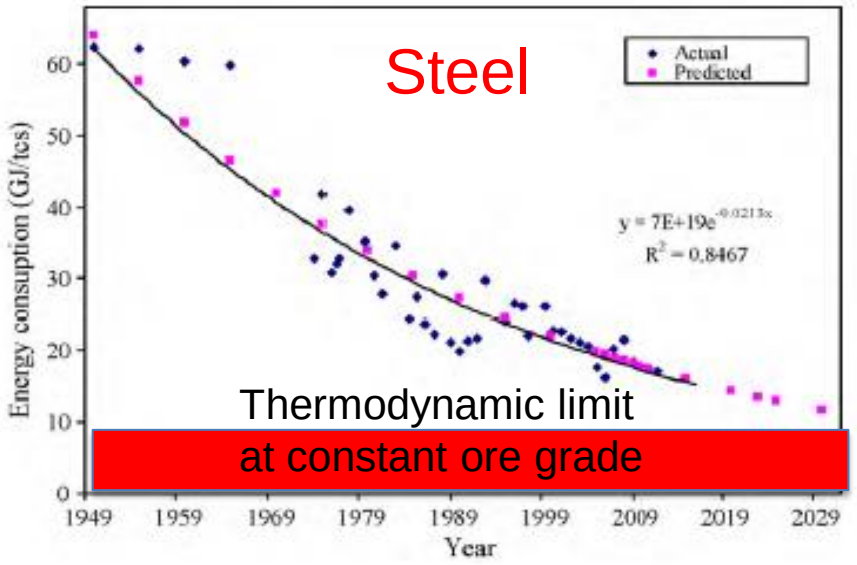


Fig. 5. Actual and projected specific energy consumption in the steel industry (world average).

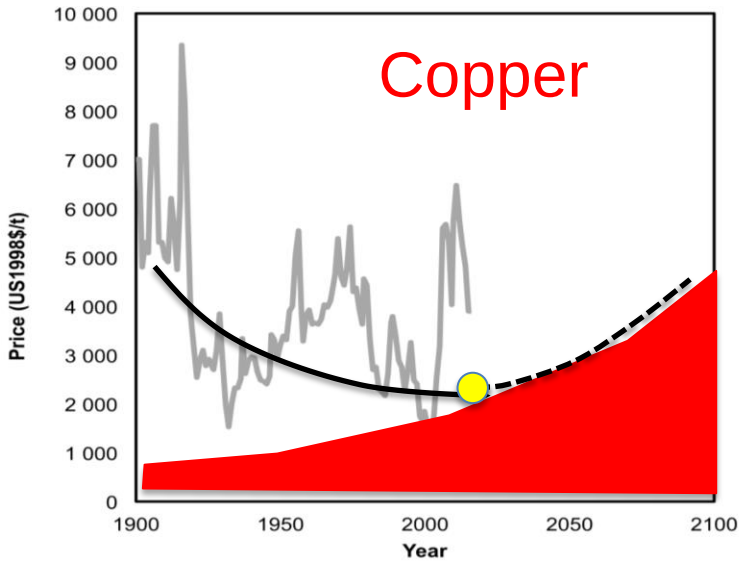
Le potentiel d'amélioration technologique est contraint par une limite thermodynamique

Limite 2: Les limites thermodynamiques

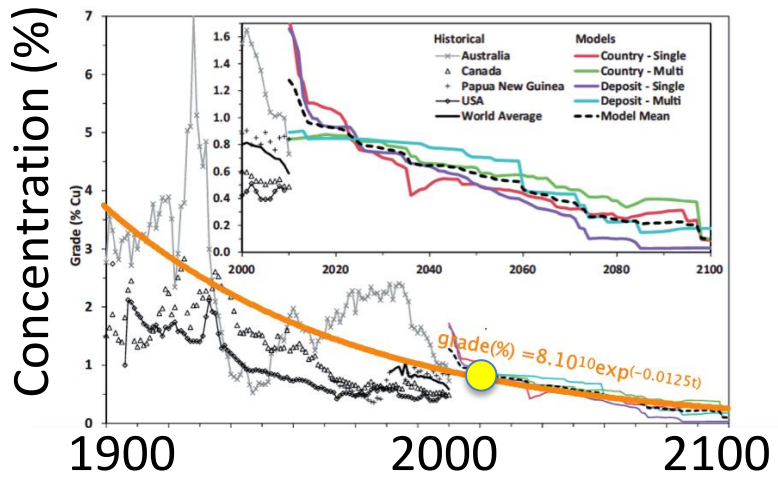
1/efficacité

$$E = \eta.(\Delta G_f^\circ + \frac{0.2}{\bar{C}})$$

Métallurgie — Broyage

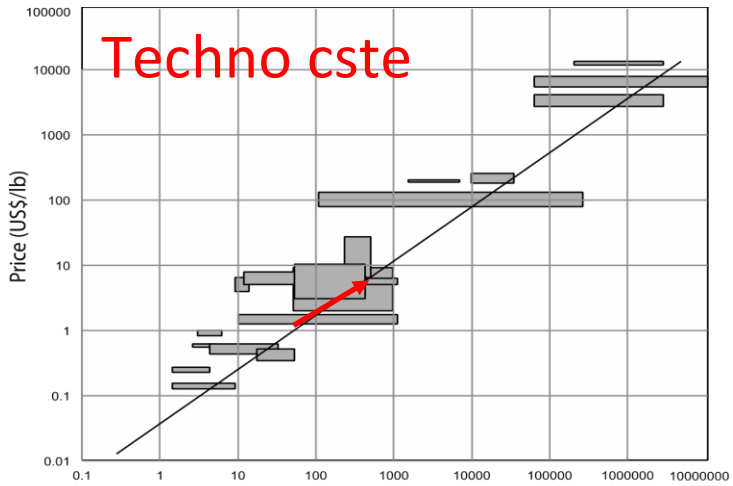


L'amélioration technologique est limitée par une limite thermodynamique



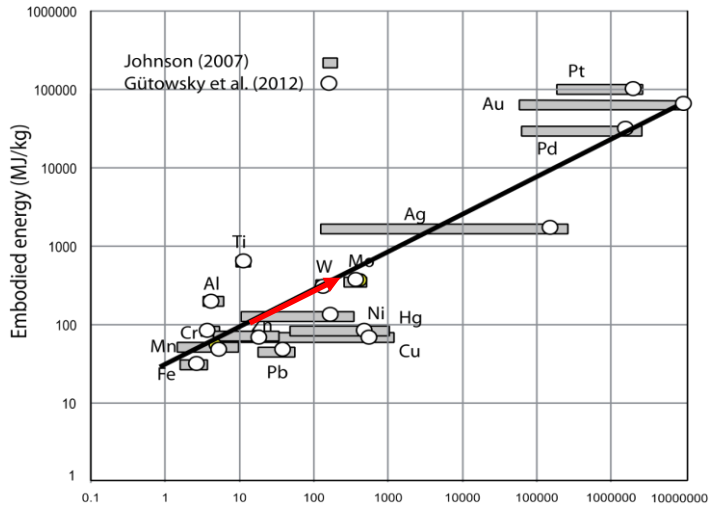
Limite 2 : la relation énergie -concentration-prix

Prix = a.(1/Cmetal)^{u}



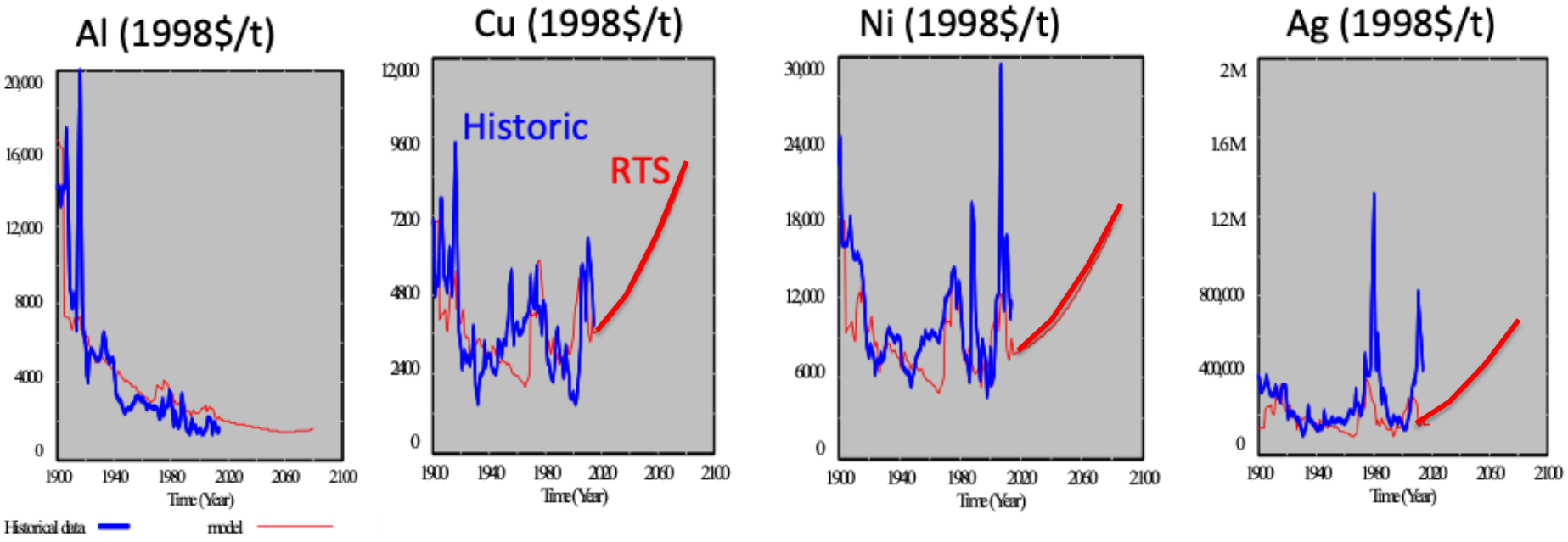
1/Concentration

Energie = b.(1/Cmetal)^{v}



1/Concentration

Limite 2: Potentiel d'amélioration technologique limité par la physique qui contrôle l'économie (et pas l'inverse)



La disponibilité future est fonction du prix que l'on sera prêts à payer, des impacts que l'on est prêt à accepter... et du prix de l'énergie

Contrainte 3: géopolitique

L'europe consomme 15% des métaux produits mondialement, elle en produit environ 3%

Nbre de CRM Europe
2011: 14
2014: 20
2017: 27
2020: 30

Figure E: Countries accounting for largest share of EU sourcing of CRMs

Cela est vécu comme une risque nouveau, pourtant la situation est similaire depuis plusieurs décénnies pour les hydrocarbures et l'uranium

Contrainte 3: géopolitique
Le poids de la Chine existe aussi sur les métaux de base...

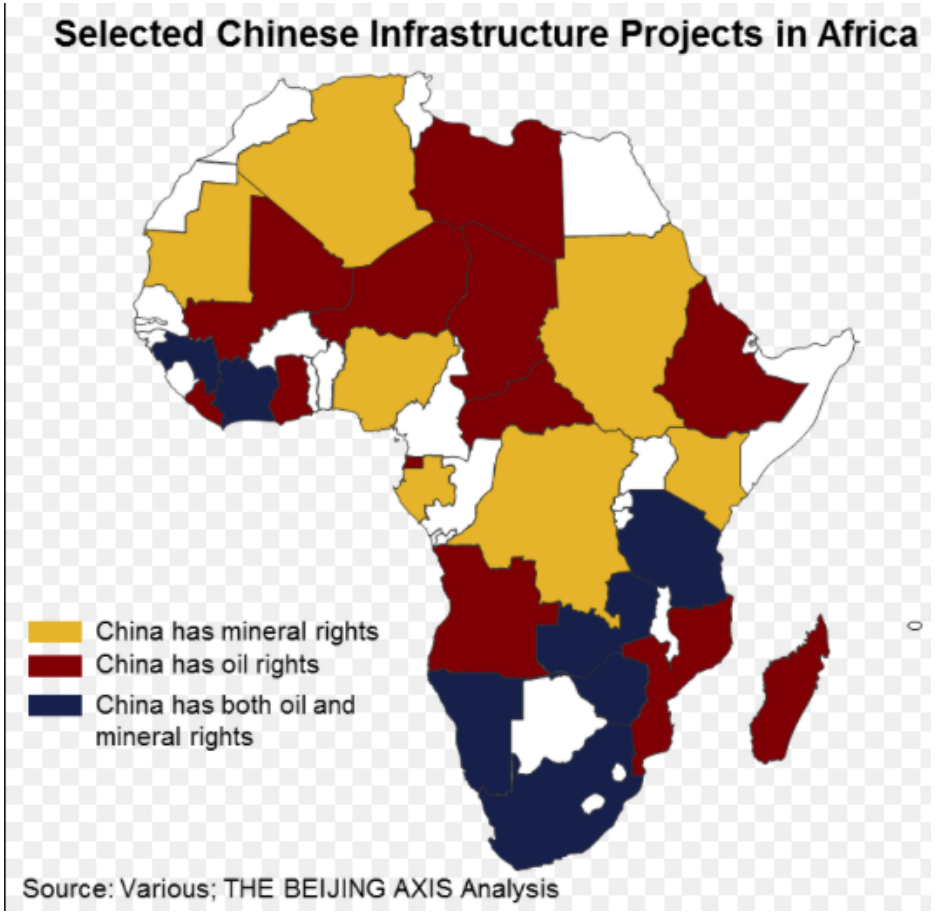
En 2018, la Chine a produit 45% de l'aluminium, plomb, acier, cuivre, nickel, zinc et étain raffinés mondialement.

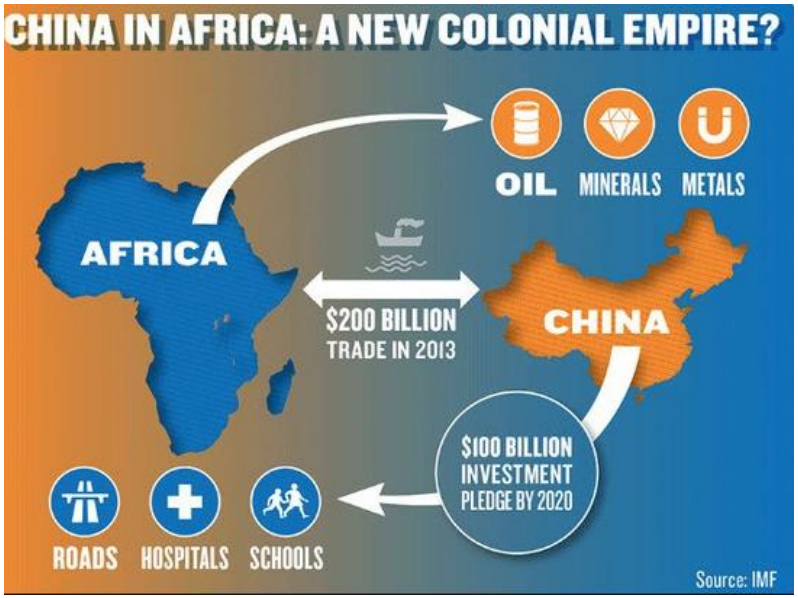
L'Europe et les US ont consommé 14% and 8% de ces métaux raffinés, leur production domestique étant largement inférieure.

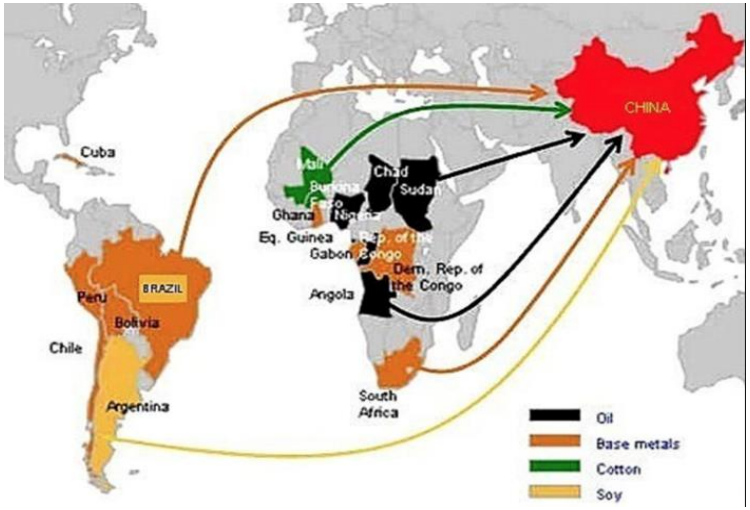
Cette position dominante de la Chine sur les métaux de base lui donne un pouvoir très important de contrôle des prix et de l'approvisionnement

Contrainte 3: géopolitique

La Chine va aussi chercher ailleurs ses matières premières...







- Les ressources minérales sont aussi centrales que l'énergie.

La minimisation de l'utilisation et la maximisation du recyclage sont cruciales

- L’absence de pénurie n’est pas un signe d’abondance, c’est un signe de progrès technologique qui masque la dégradation des ressources.

Que se passe-t’il quand la limite thermodynamique est atteinte ?
Peut-on envisager de nouvelles ressources « non conventionnelles » ?
Peut-on (doit-on) envisager une relocalisation de la production ?

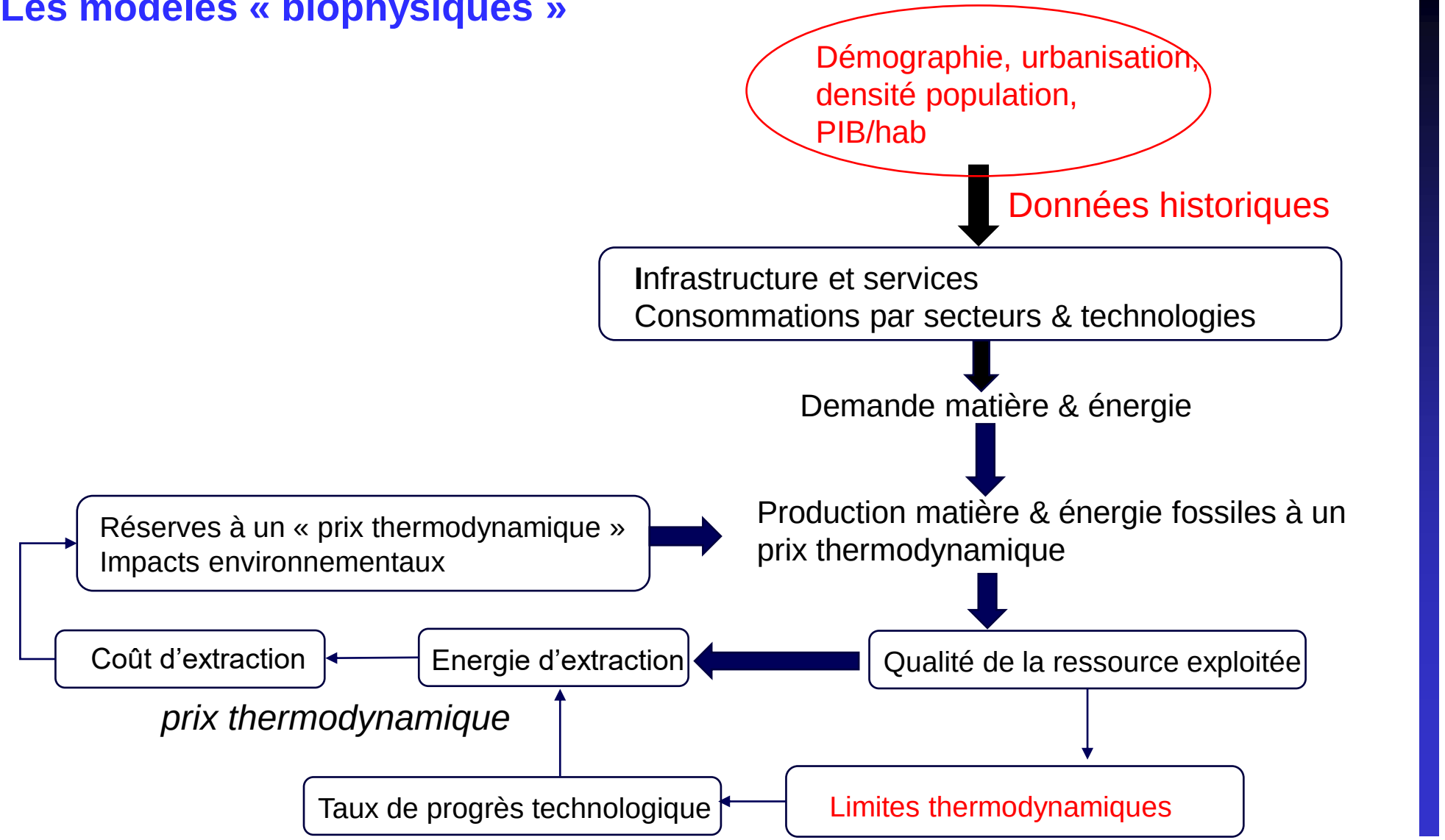
- La demande et l'approvisionnement dépendent de scénarios technologiques et économiques + dimensions géologique, géopolitique, environnementale et "sociale"

Pas de chemin unique, le futur sera différent du passé
La transition énergétique est-elle compatible avec la croissance des pays riches ?

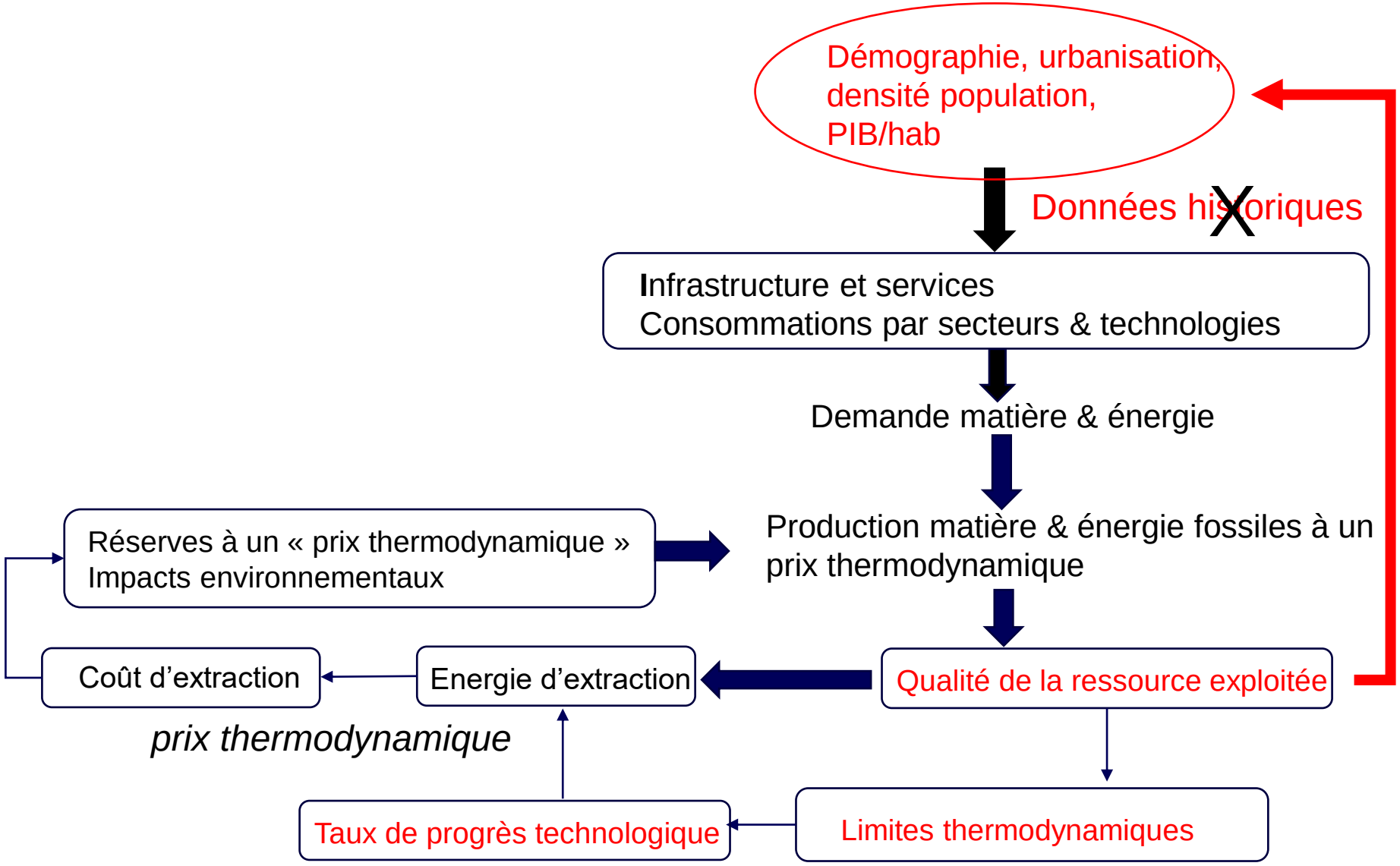
- La coopération internationale est essentielle.

Comment évaluer les flux futurs de ressource et d’énergie ?
Quels modèles de flux basés sur les dimensions « physiques » ? - rente naturelle non uniforme
Tester des scénarios de coopération (ou pas)

Les modèles « biophysiques »



Les modèles « biophysiques »



Les modèles IAM (économistes) – groupe 3 du GIEC

Pas de back-testing

Démographie,PIB/hab,
structuration du marché

Politiques publiques +
économie (prix)

Infrastructure et services
Consommations par secteurs & technologies

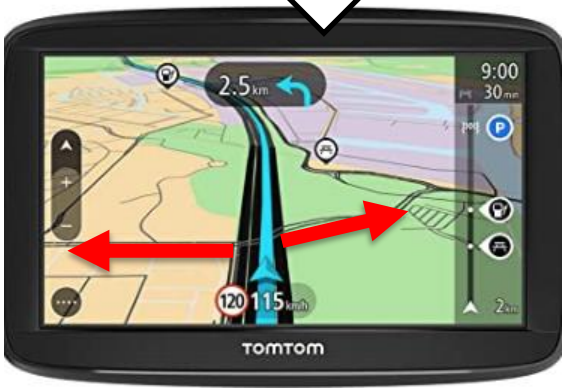
Les ressources et les infrastructures n'existent pas

- *Pas de cohérence assurée entre flux et stocks, entre monnaie et unités physiques,*
- *Equilibre (no crisis) et autres difficultés (Grandjean and Giraud, 2017)*
- *Equations non physiques => manque de robustesse*

Le GPS = Le Gros Problème des Scénarios

Le GPS = Le Gros Problème des Scénarios

Decision des acteurs (industrie, politiques locaux/nationaux, ONG, citoyens, etc)

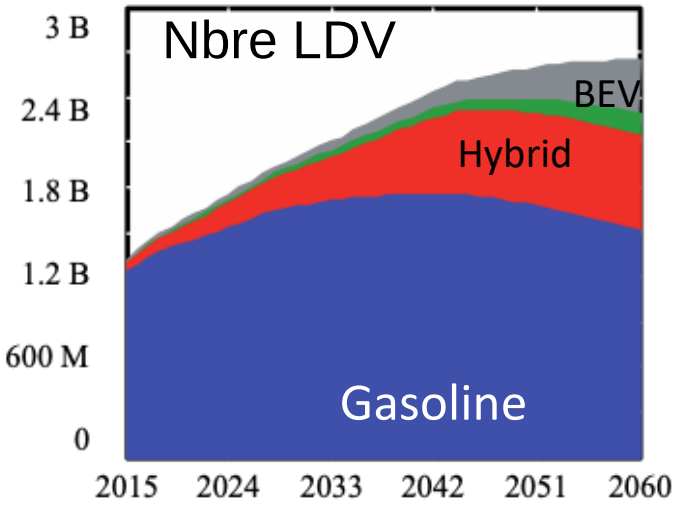


Intégrer la dimension humaine pour *anticiper les difficultés qui ne sont pas uniquement technico-économiques*

=> mise en situation
=> prise en compte des *spécificités locales*
=> imaginer le meilleur compromis: *vision systémique de la region au monde*

1) ∫ production primaire > stock dans l'infrastructure

RTS (iea2017)

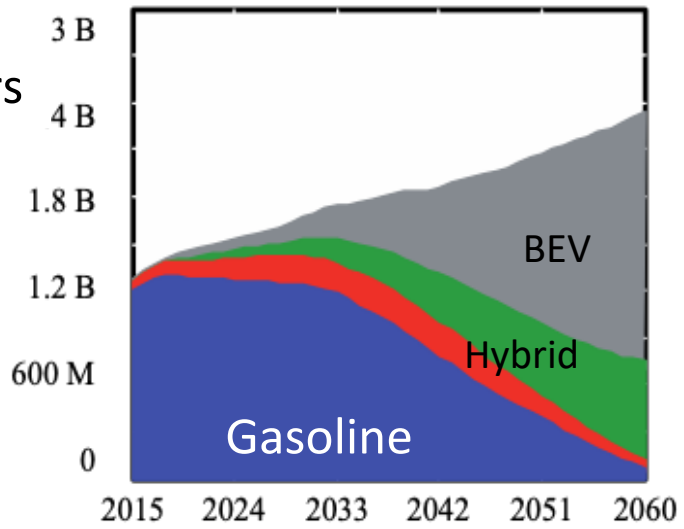


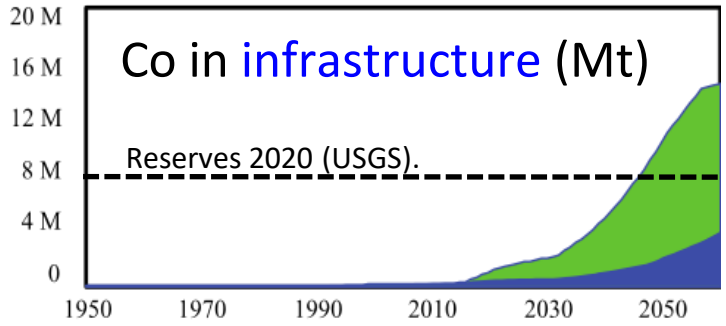
6kg/EV

RR = 0.5 in 2050

Lifetime = 10 years

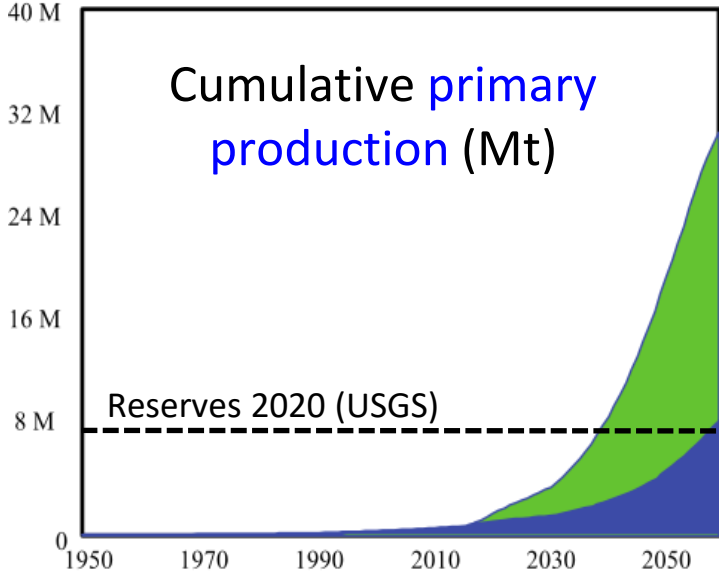
B2DS (iea2017)



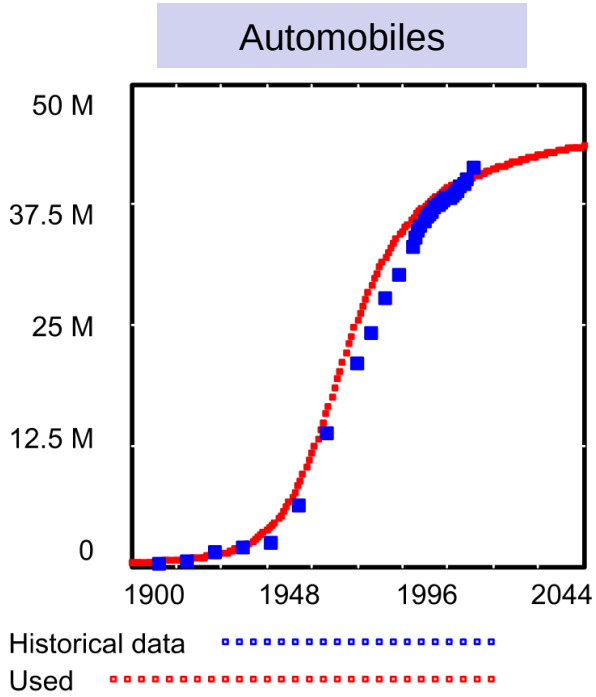


B2DS

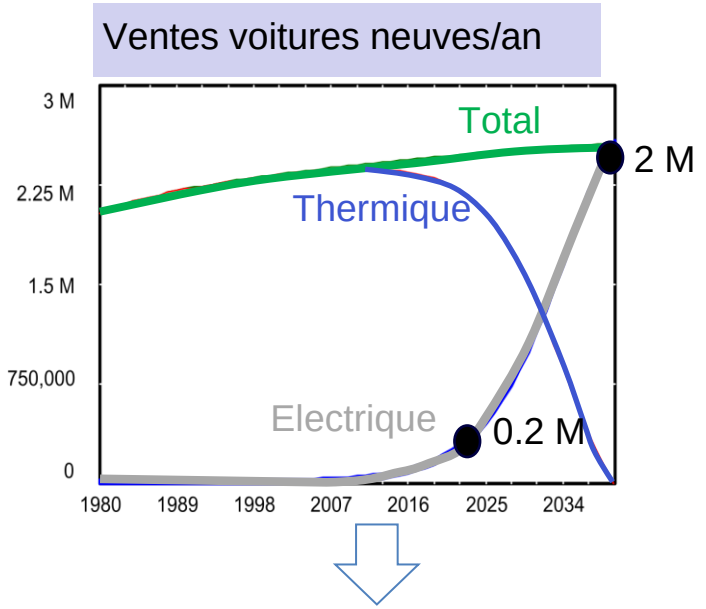
RTS

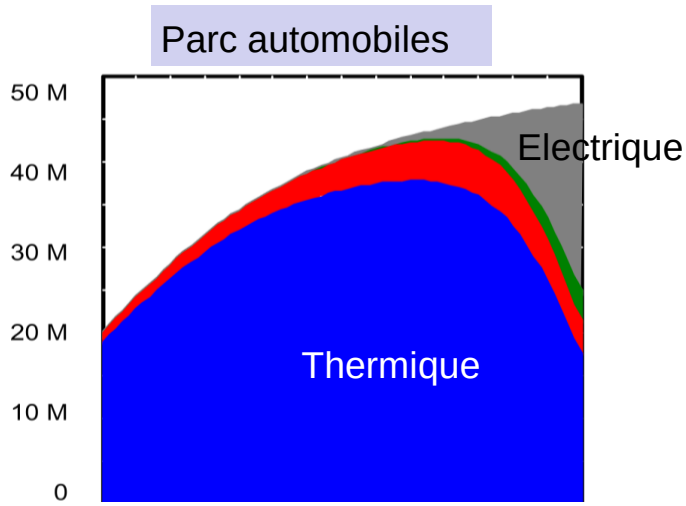


Exemple: le parc automobile - France



durée de vie
= 15 ans

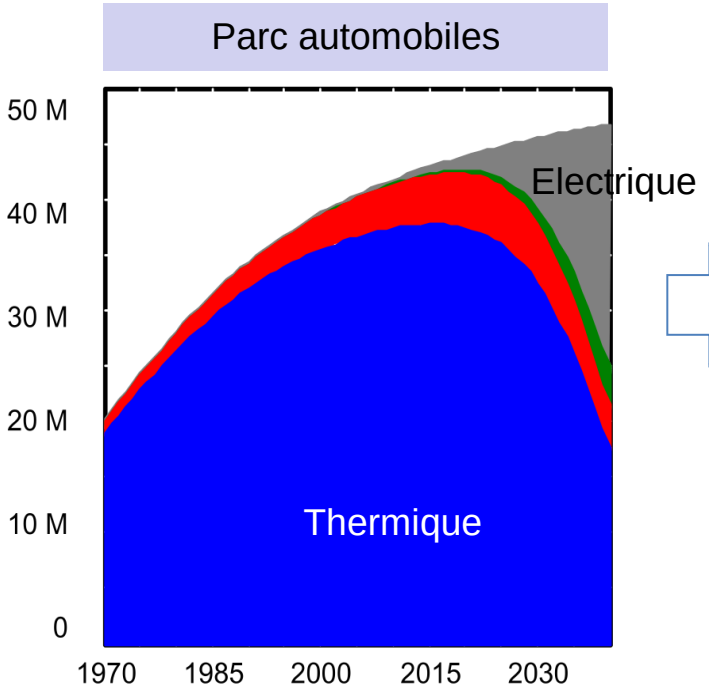


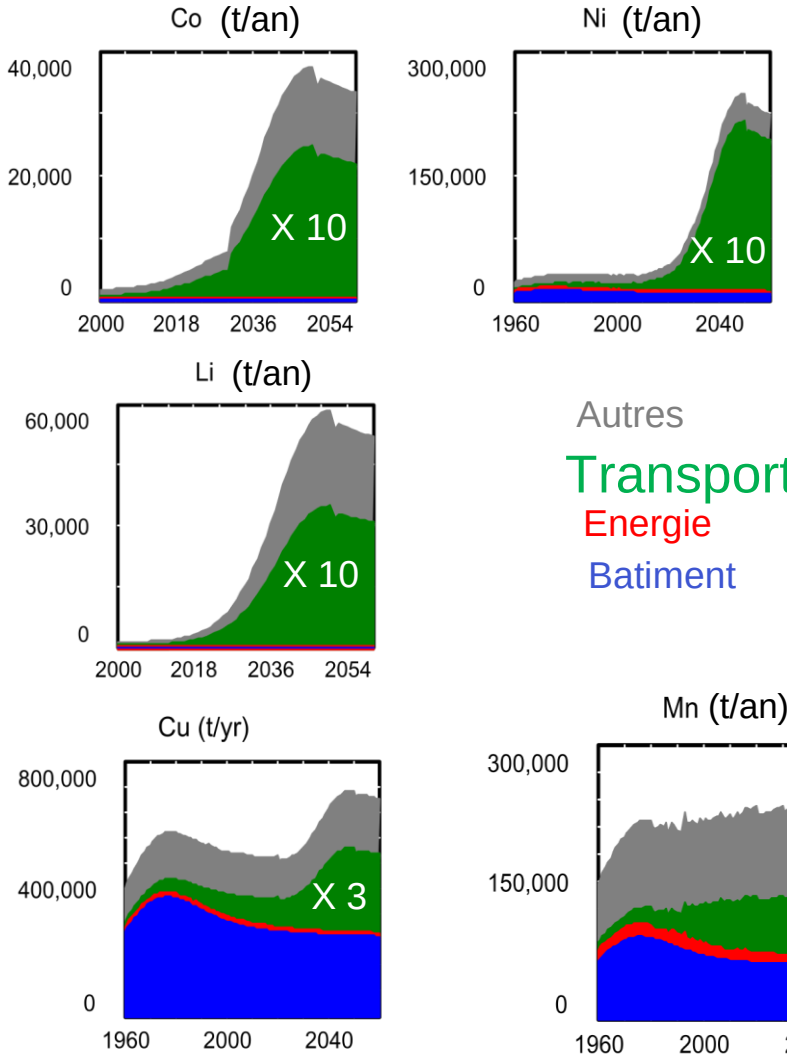


Hybrid

BEV

Besoins matières pour les VE (*technos actuelles*, 50 kWh) - France



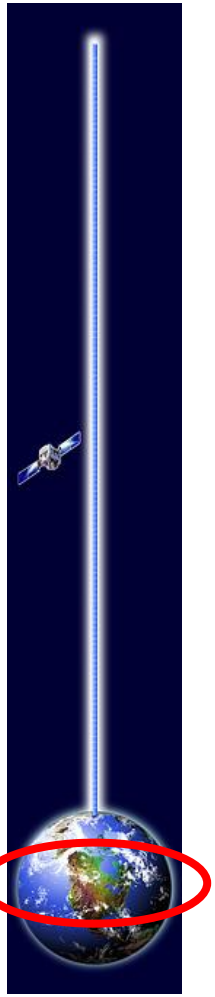


Attention: les technos évoluent !

Consommation mondiale de pétrole

Production mondiale: 100 millions barils/jour
Baril de pétrole =159 litres: 50 x 80 cm

Terre-Lune en 5 jours : 384 400 km

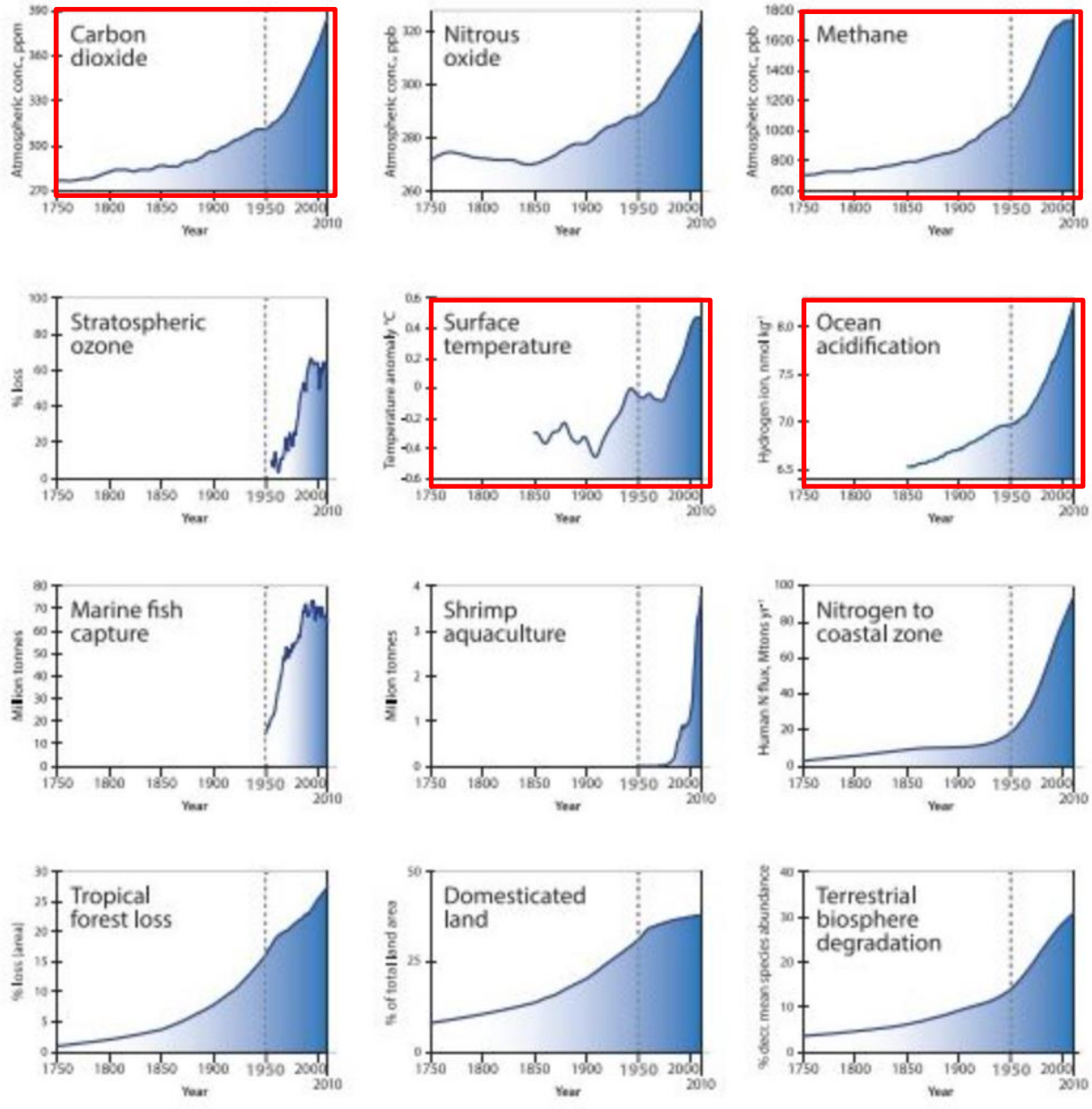


1.2 fois le tour de la Terre chaque jour

Des impacts environnementaux inquiétants

Production de ciment + acier + Al + Cu

- 35% de la consommation industrielle mondiale d'énergie
- 50% des émissions de CO2 de l'industrie



Climat anxiogène qui nous renvoie aux prévisions catastrophiques du club de Rome (1972)