Université Paris Cité

What geo-bio-physical criteria will it take to invent technologies with a very long-term future?

José Halloy

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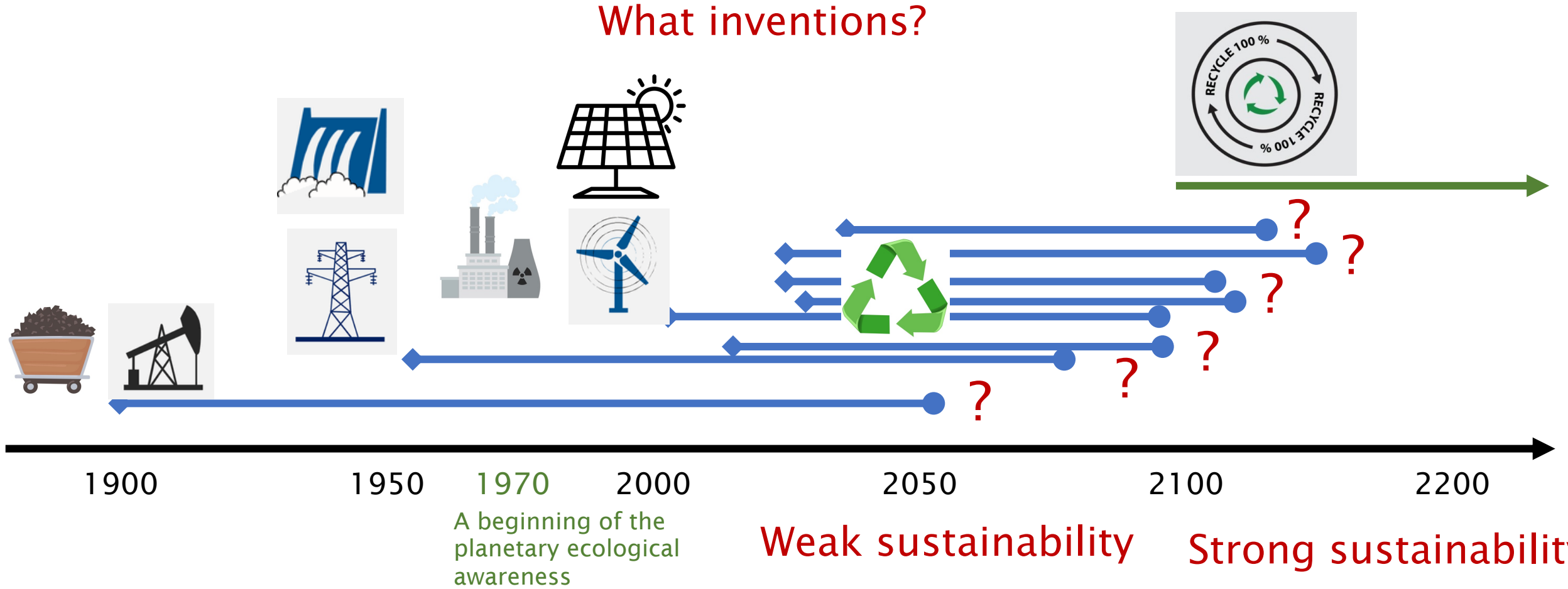
Successions of inventions whose sustainability is increasing?



Inventing sustainable technologies according to what criteria?

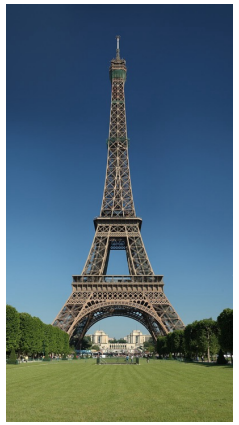
Technical systems

Materials and energy sources are interdependent.

The use of fossil fuels changes the nature of materials and the quantities produced, due to interactions between materials, power (W,concentrated energy), techniques and new socio-economic systems.







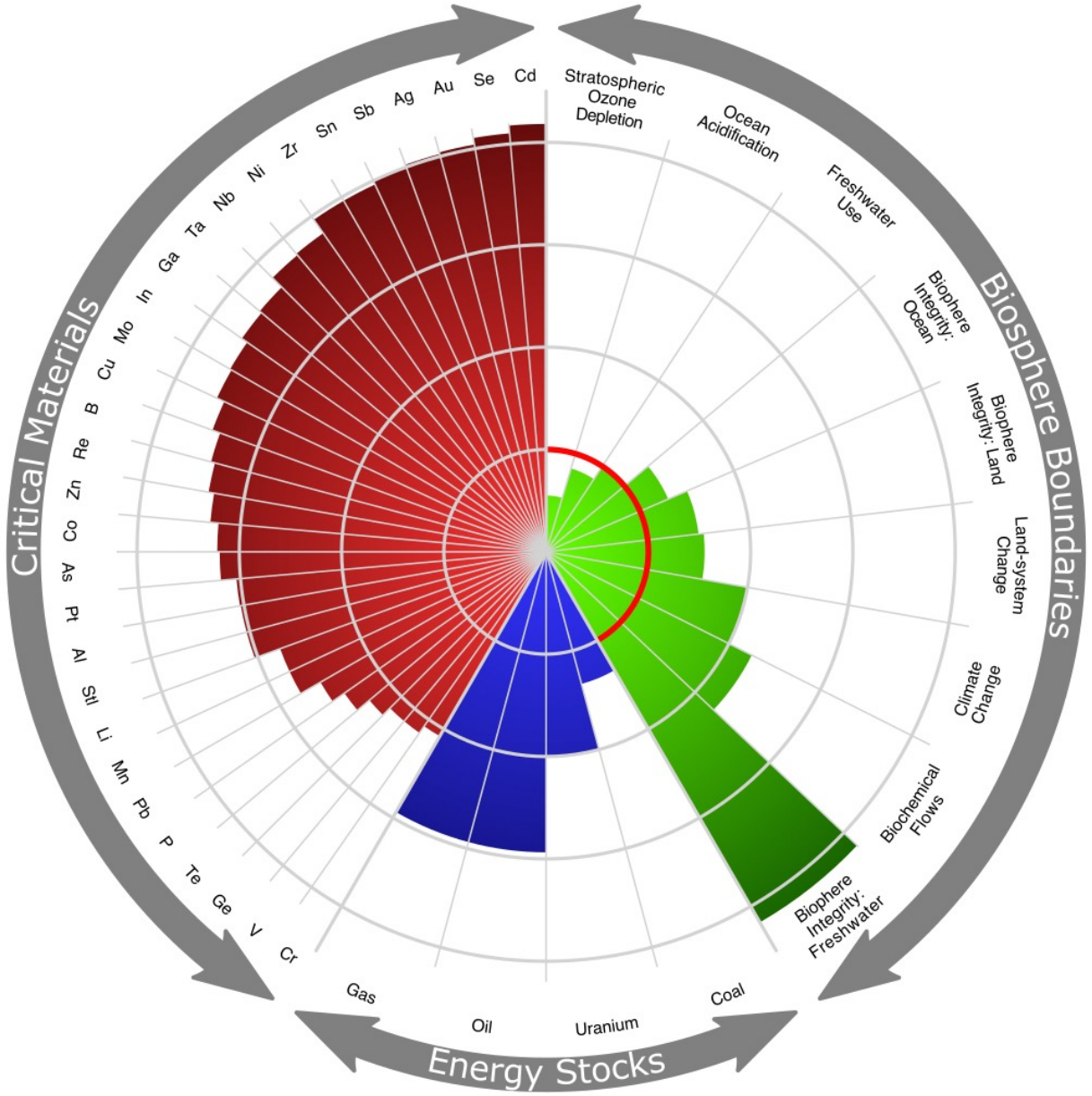


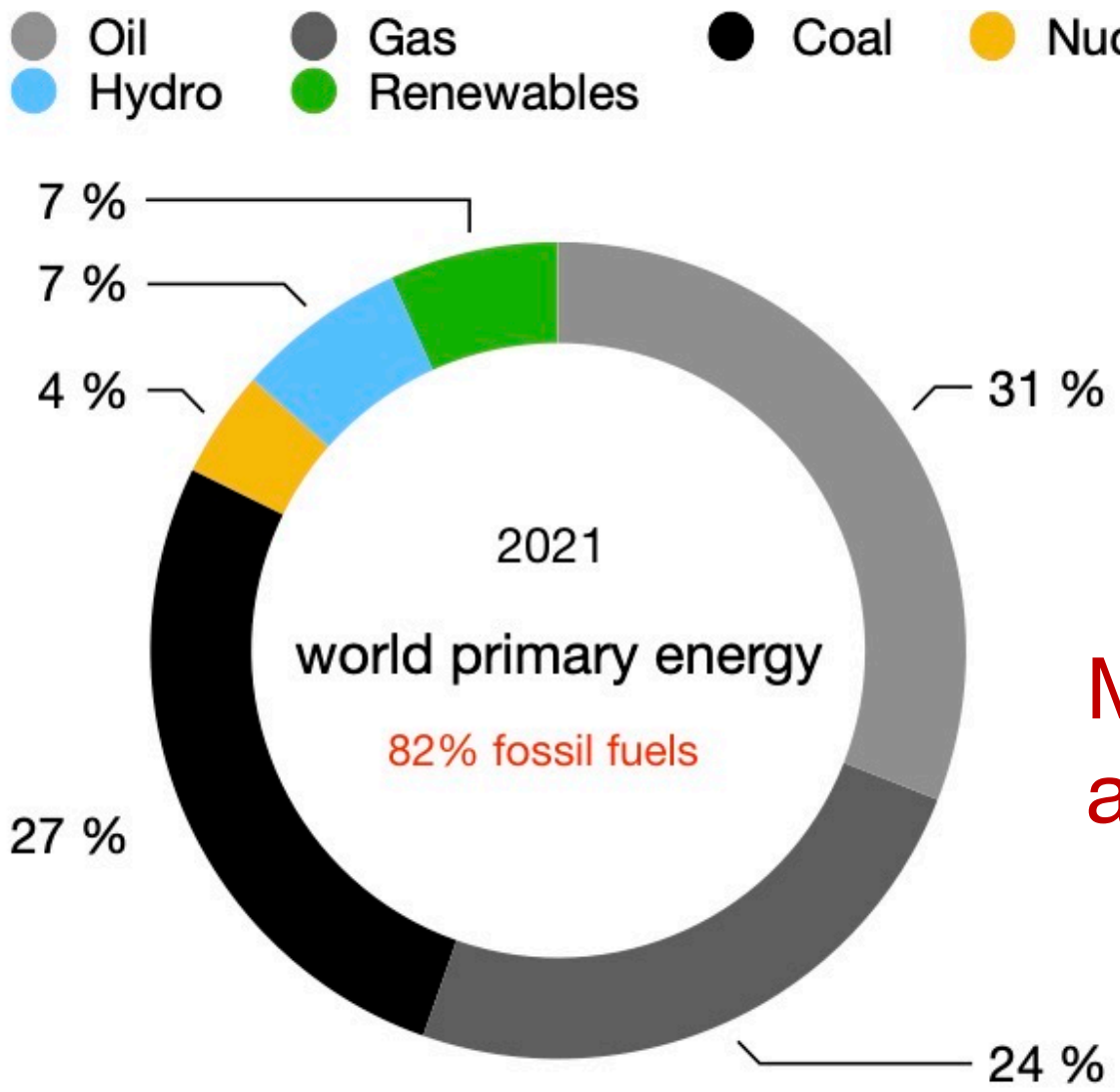




Materials, energy, the biosphere, the technosphere and the planet form systemic interactions.

How can we define technologies that preserve the habitability of the planet for humankind?

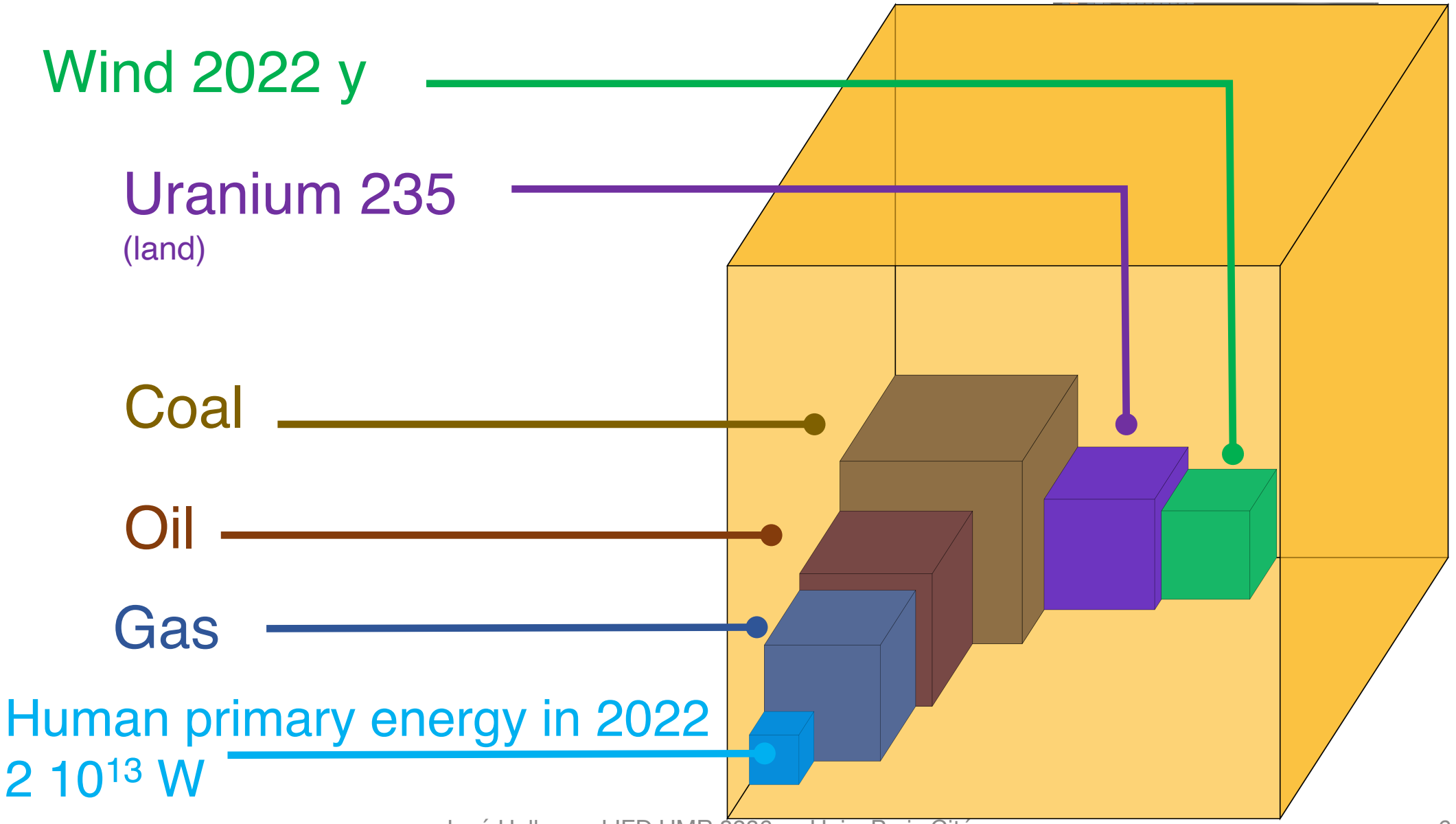


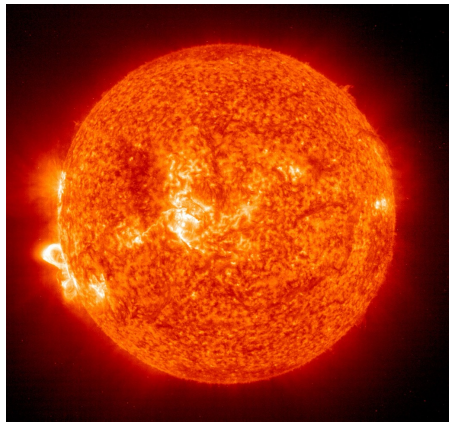


82% fossil fuels

Major inequalities within and between countries

Solar 2022 y: 2.3 10^{16} W



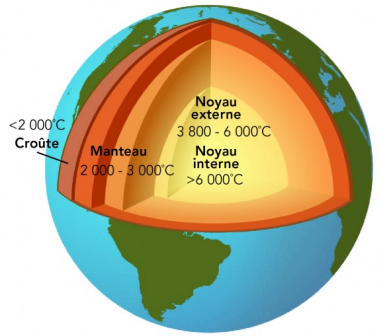


➕ gravitation ➡️ Hydroelectricity

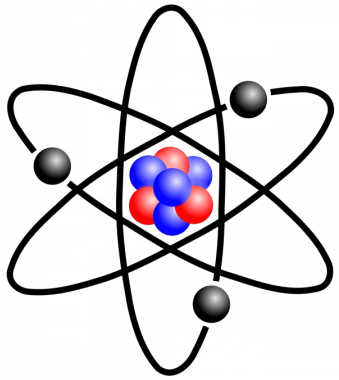
Wind power, solar heat (furnace, water heater)

Photosynthesis (light converted into chemical bonds)
➡️ Vegetal materials
➡️ Fossil fuels (stock of sunlight)

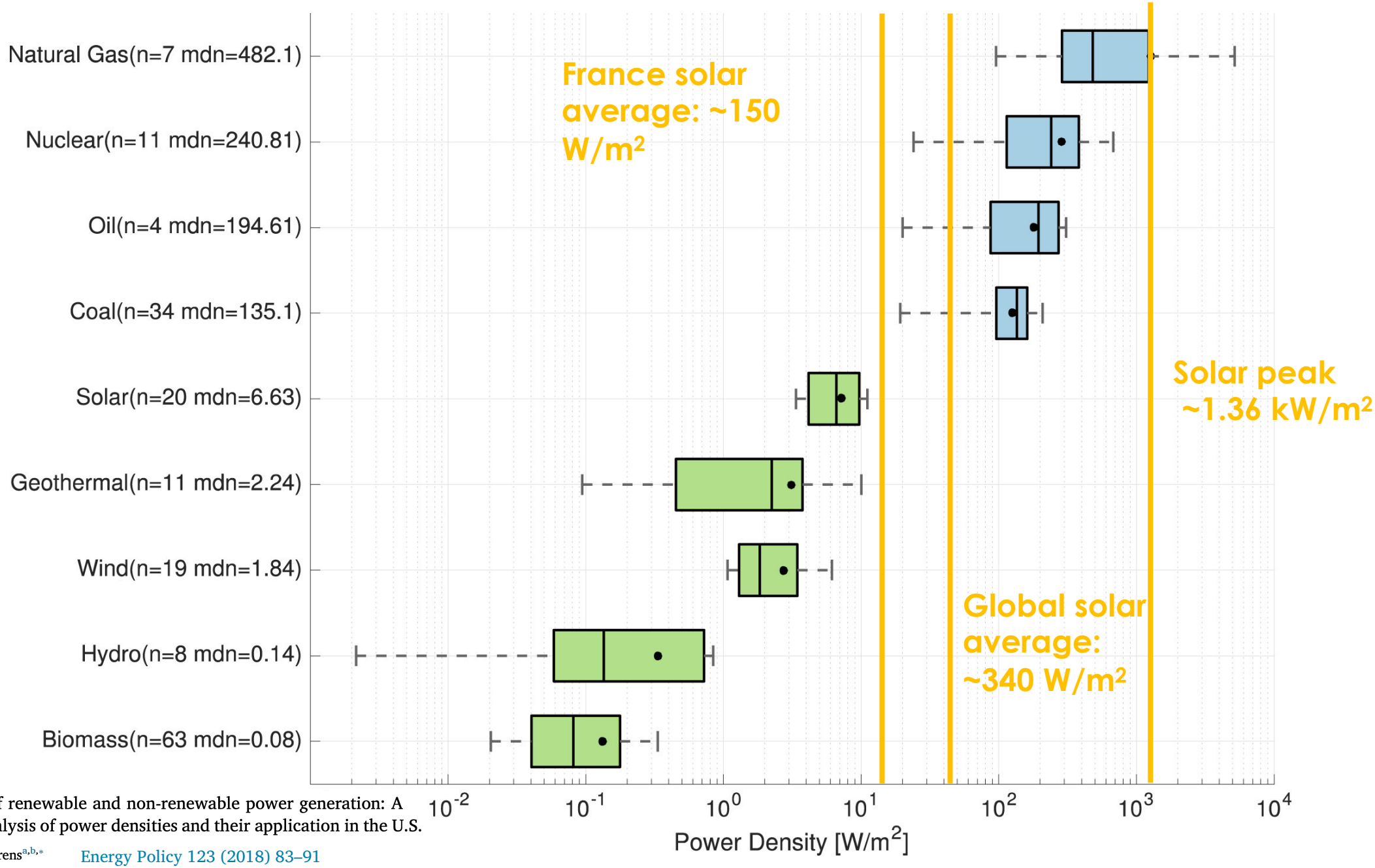




Geothermal
➕ gravitation plate tectonics, rocks and minerals



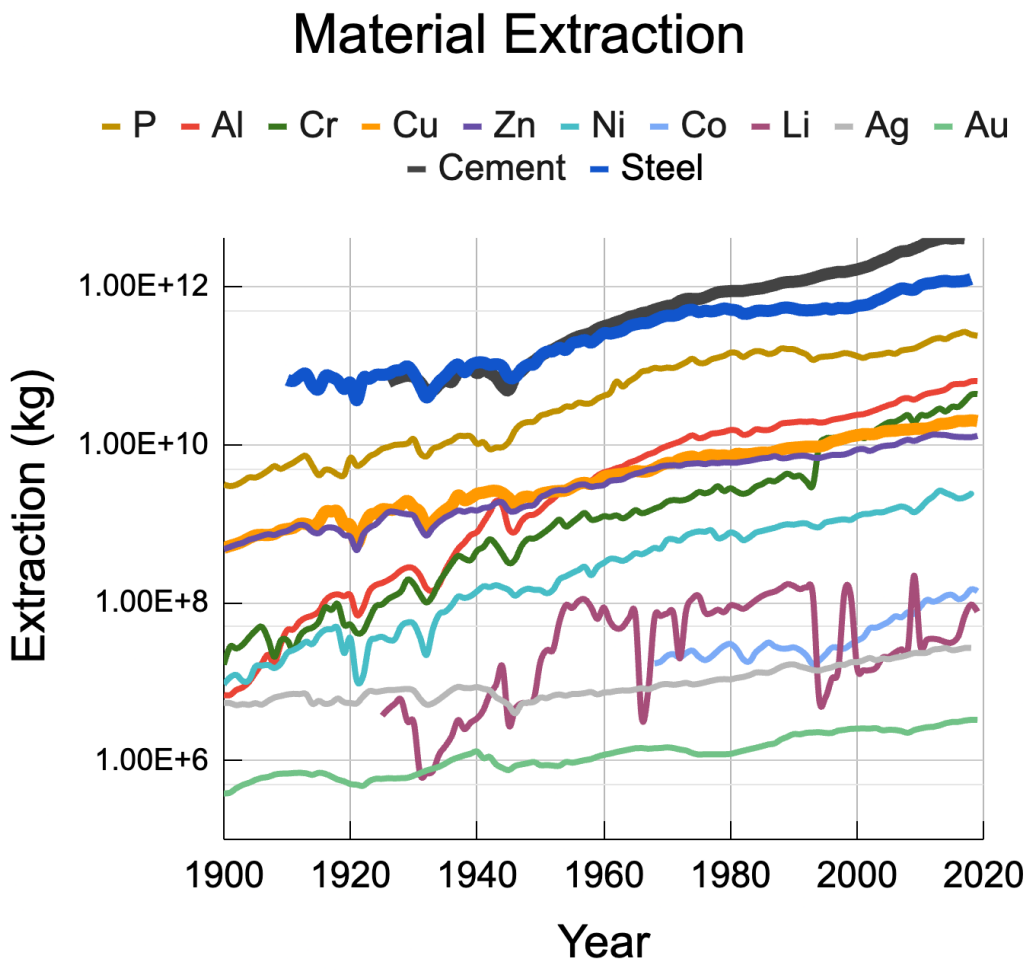
Thermonuclear ➡️ electricity (uranium 235 stock)

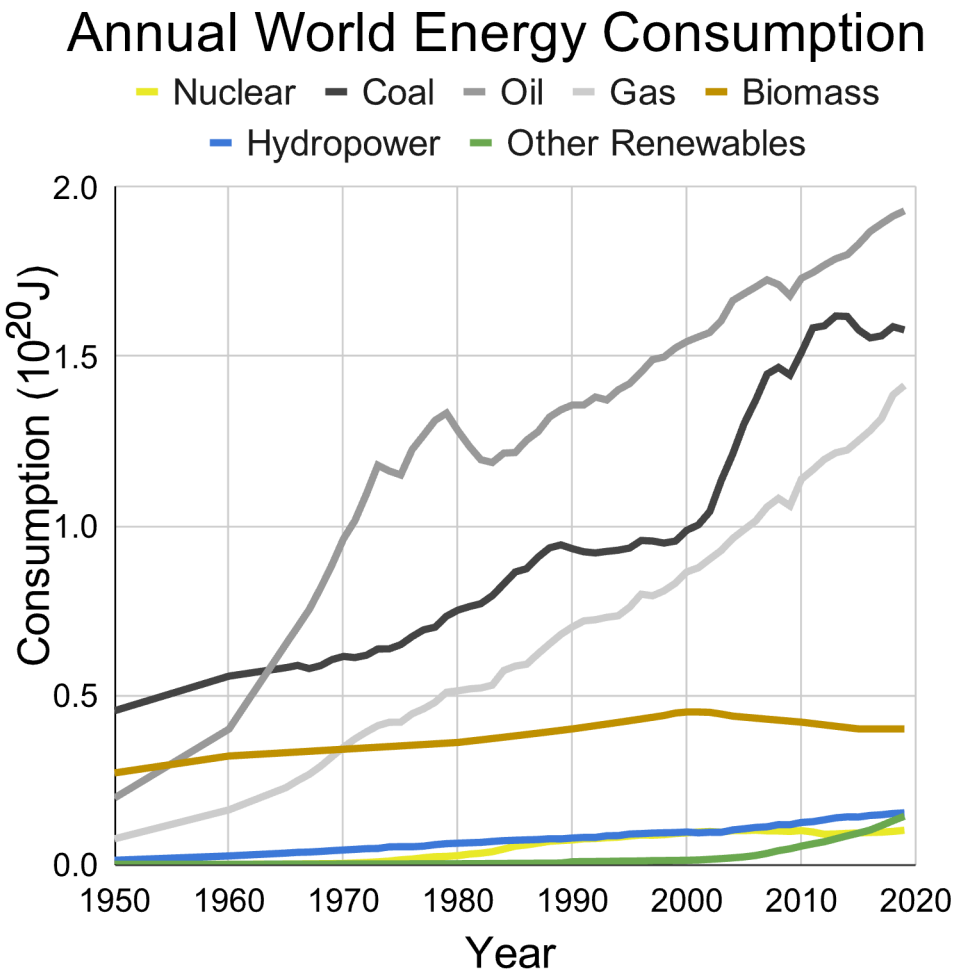


The spatial extent of renewable and non-renewable power generation: A review and meta-analysis of power densities and their application in the U.S.

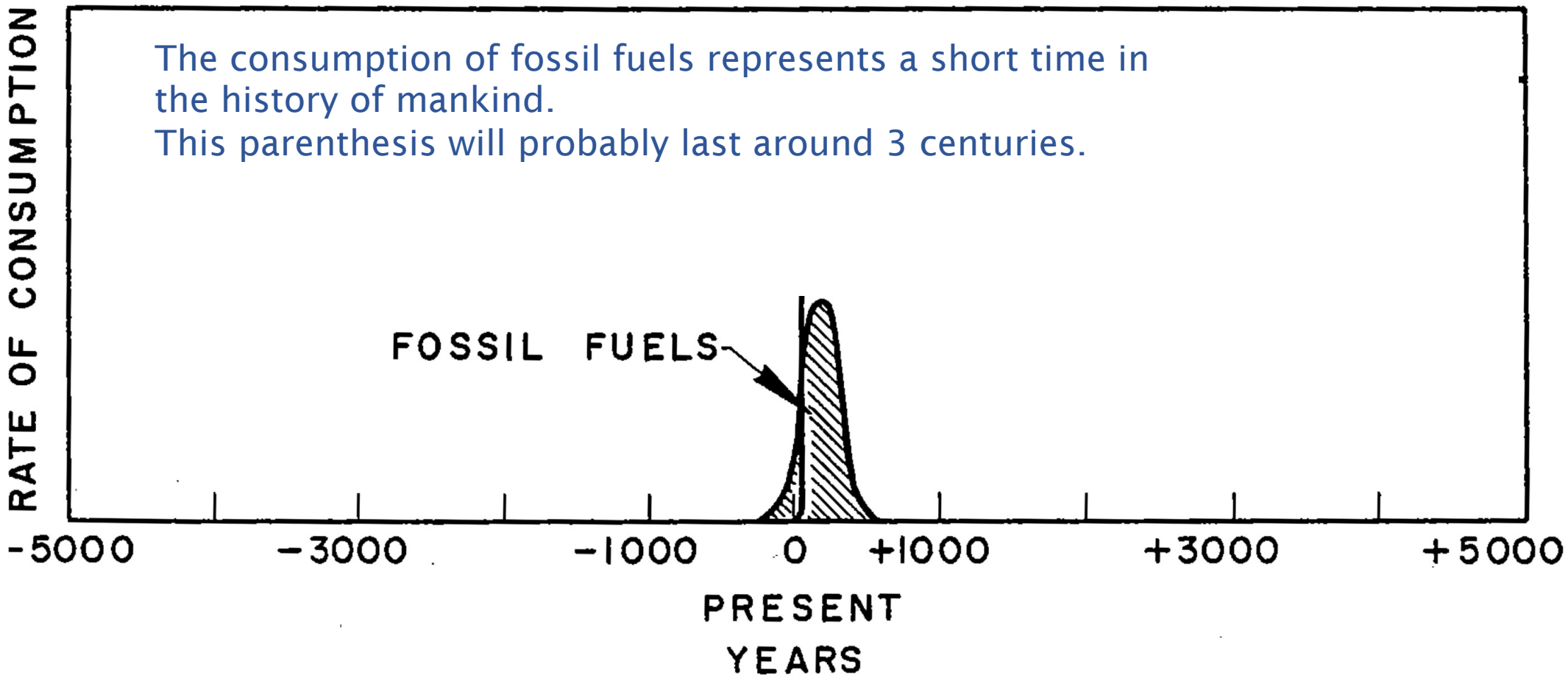
John van Zalk[a], Paul Behrens[a,b,*] Energy Policy 123 (2018) 83–91

Extractivism: massive exploitation of planetary resources





M.K. Hubbert, geologist for the American oil industry, presented this graph at the 1956 meeting of the American Petroleum Institute.

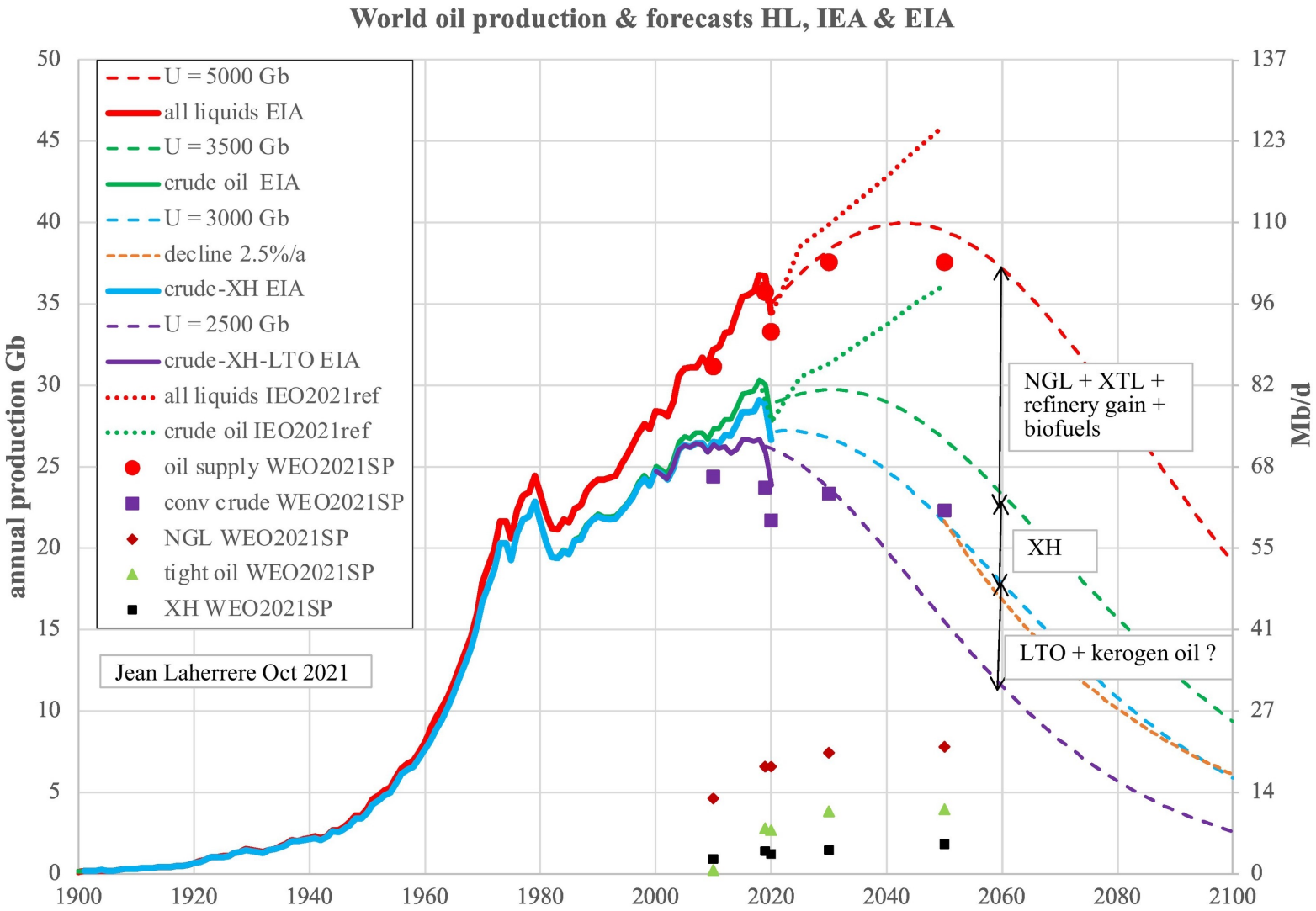


How much oil remains for the world to produce? Comparing assessment methods, and separating fact from fiction

Jean Laherrère [a,d], Charles A.S. Hall [b,*], Roger Bentley [c,e]

[a] Exploration Techniques, Total, France
[b] College of Environmental Science and Forestry, State University of New York, Syracuse, NY, USA
[c] The Oil Age, Petroleum Analysis Centre, Ballydehob, Ireland
[d] President ASPO, France
[e] Former Dept. Cybernetics, University of Reading, UK

Current Research in Environmental Sustainability 4 (2022) https://doi.org/10.1016/j.crsust.2022.100174

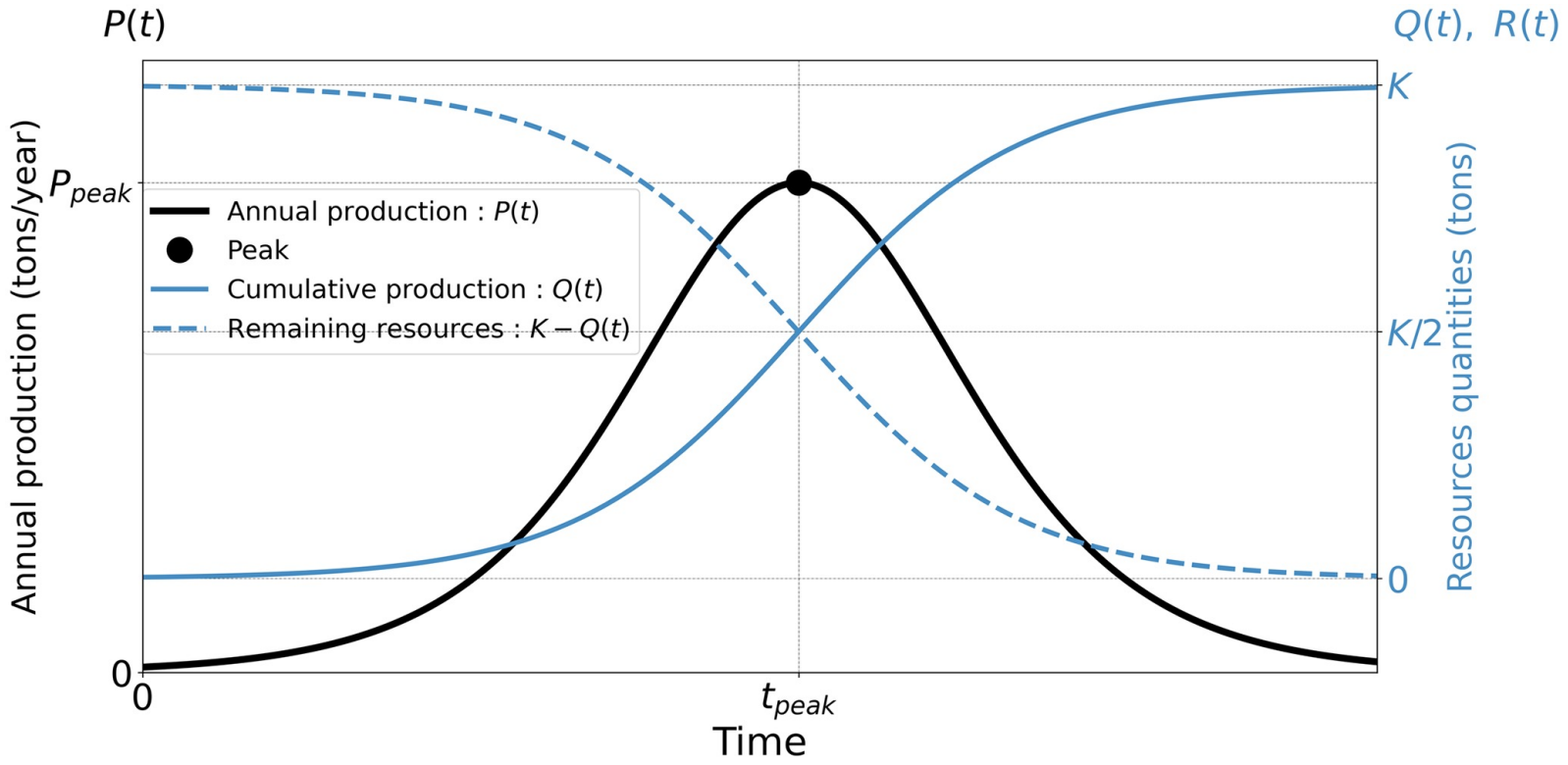


RESEARCH ARTICLE

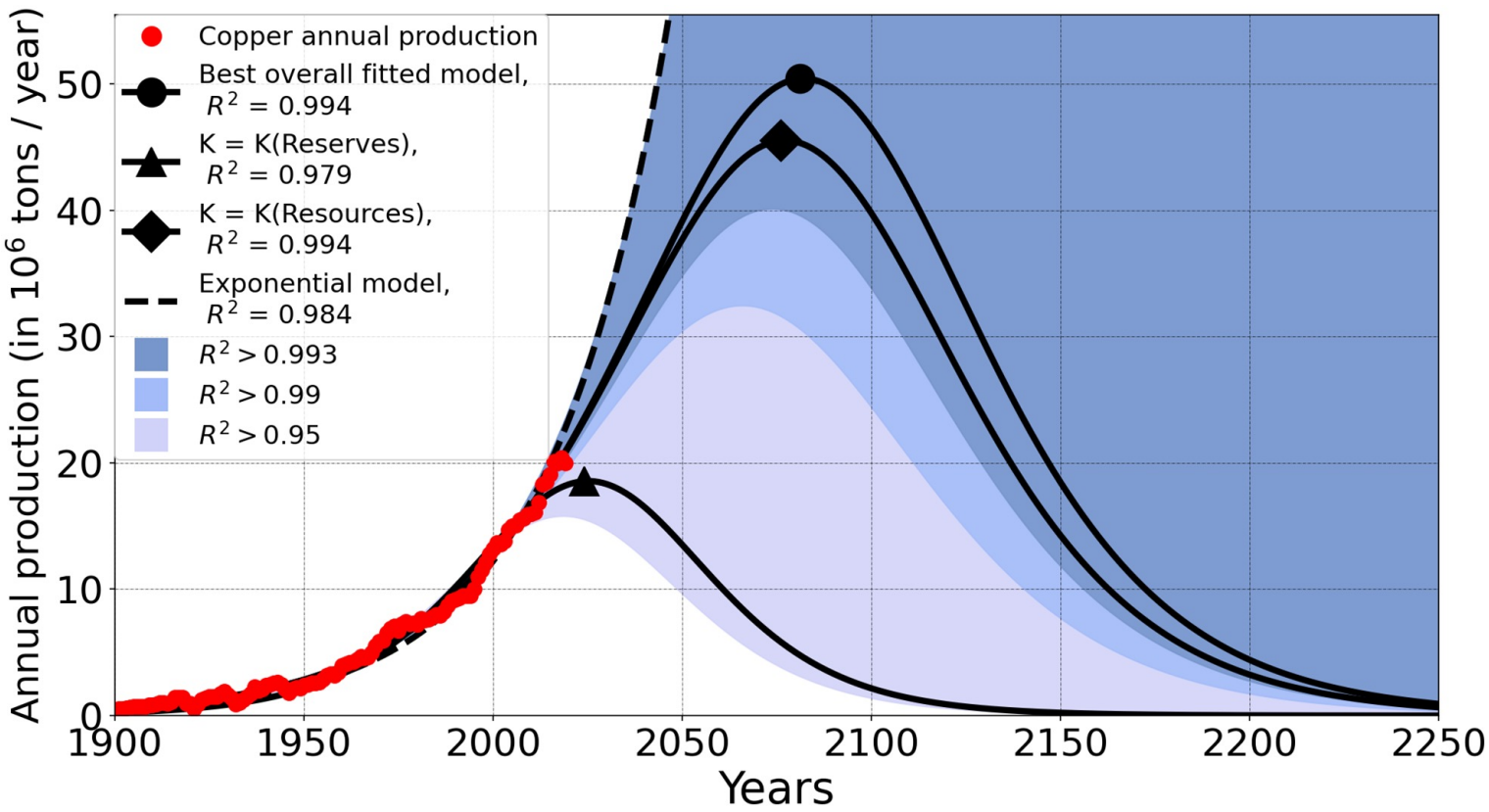
Applicability of Hubbert model to global mining industry: Interpretations and insights

Lucas Riondet[1,2,3]*, **Daniel Suchet**[4], **Olivier Vidal**[5], **José Halloy**[3]*

1 Univ. Grenoble Alpes, CNRS, Grenoble INP, G-SCOP, 38000 Grenoble, France, **2** I2M Bordeaux, UMR 5295, Institut de Chambéry, 73370 Le Bourget du Lac, France, **3** Université Paris Cité, CNRS, LIED UMR 8236, F-75006 Paris, France, **4** Institut du Photovoltaïque d'Ile de France IPVF UMR 9006, CNRS, Ecole Polytechnique, 91120 Palaiseau, France, **5** Univ. Grenoble Alpes, CNRS, Institut des sciences de la Terre, Grenoble, France



Estimating peak copper



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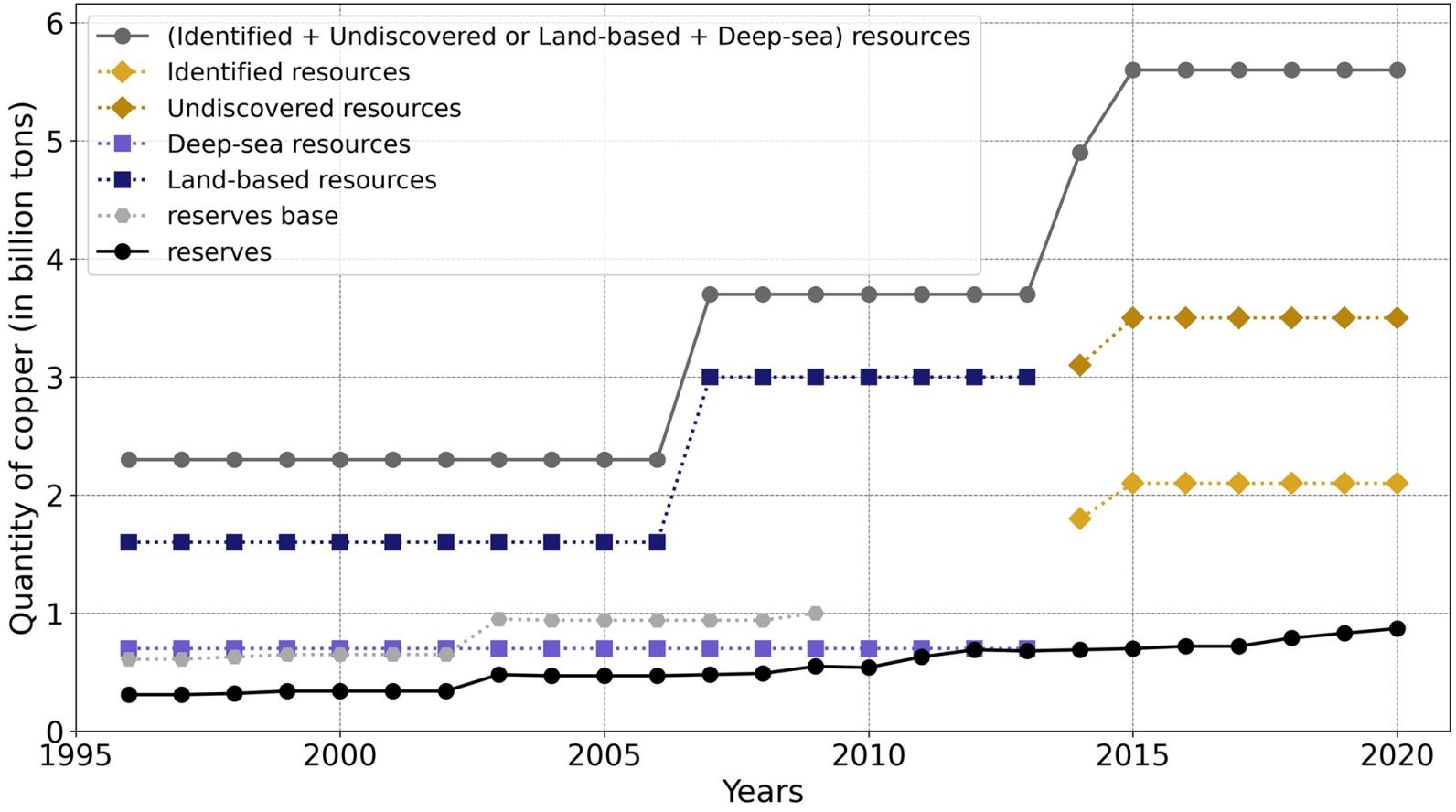
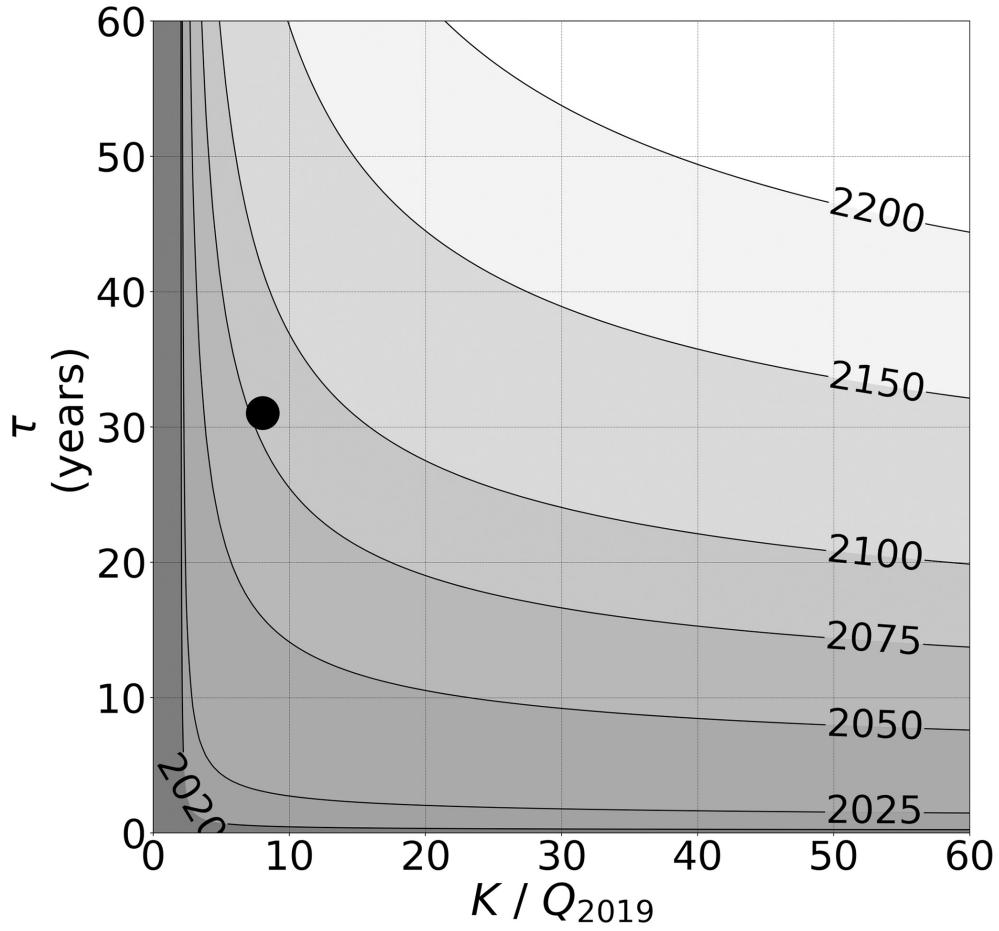
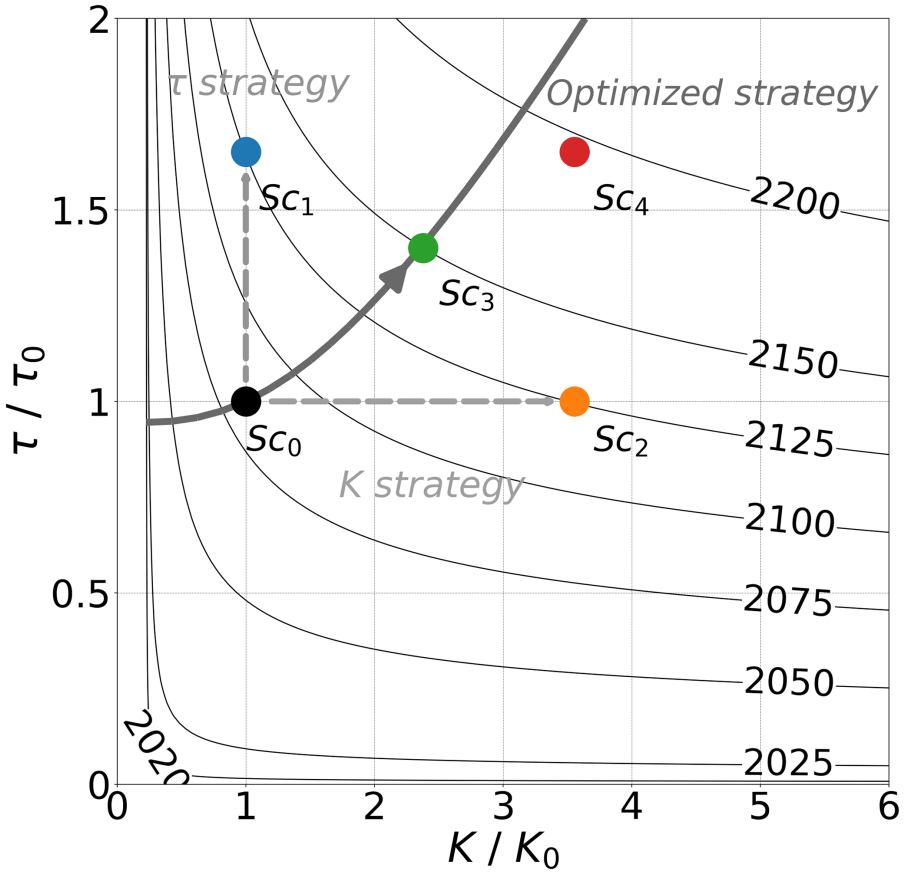
13

Temporal evolution of the world mining industry's estimate of exploitable copper resources



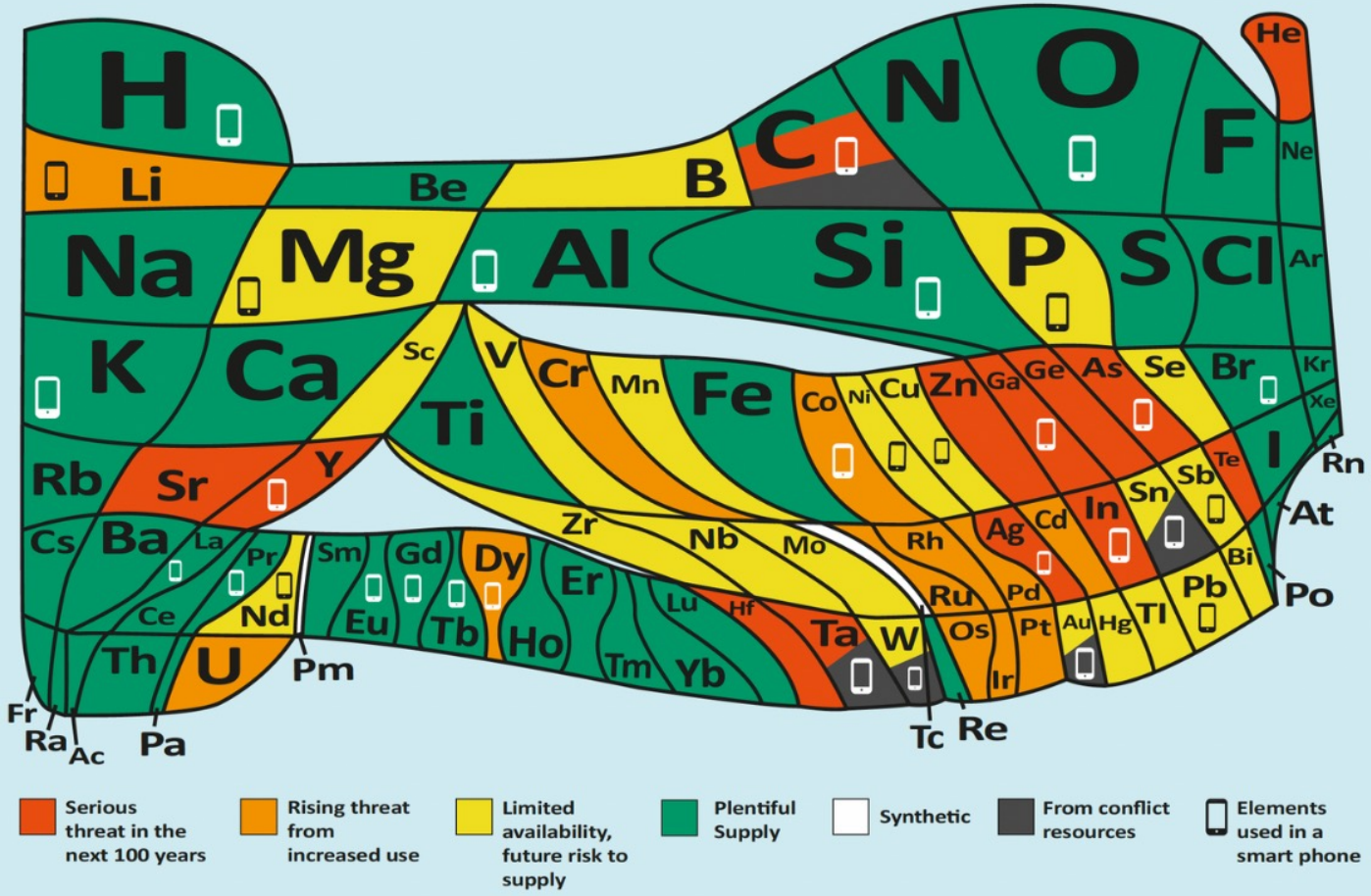
Finding new mines or slowing down extraction?





The 90 natural elements that make up everything

How much is there? Is that enough? Is it sustainable?



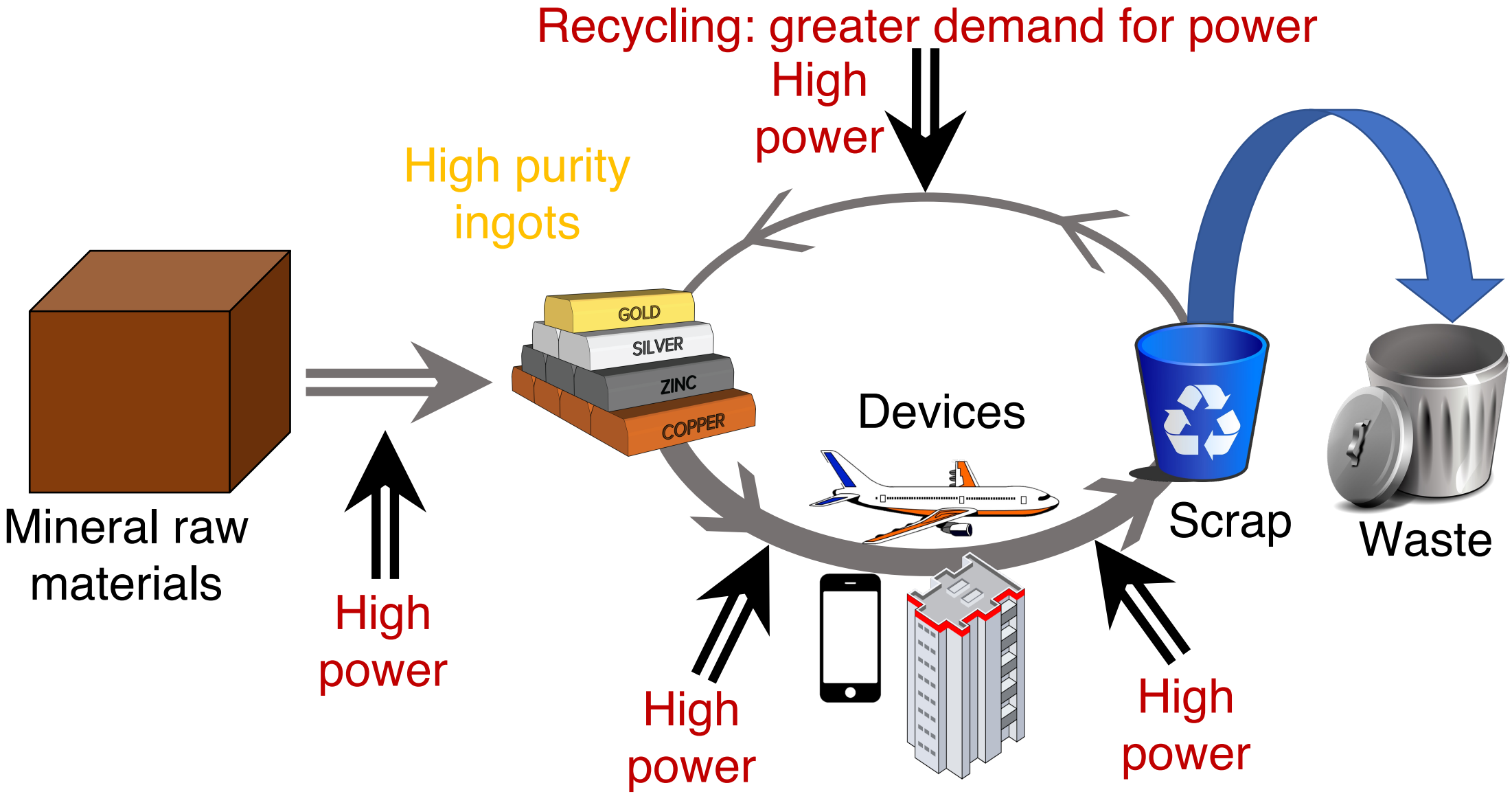
Read Support Notes and play the video game **http://bit.ly/euchems-pt**

Inspired by WF Sheehan's 'A Periodic Table with Emphasis' published in Chemistry, 1976, 49, 17-18'

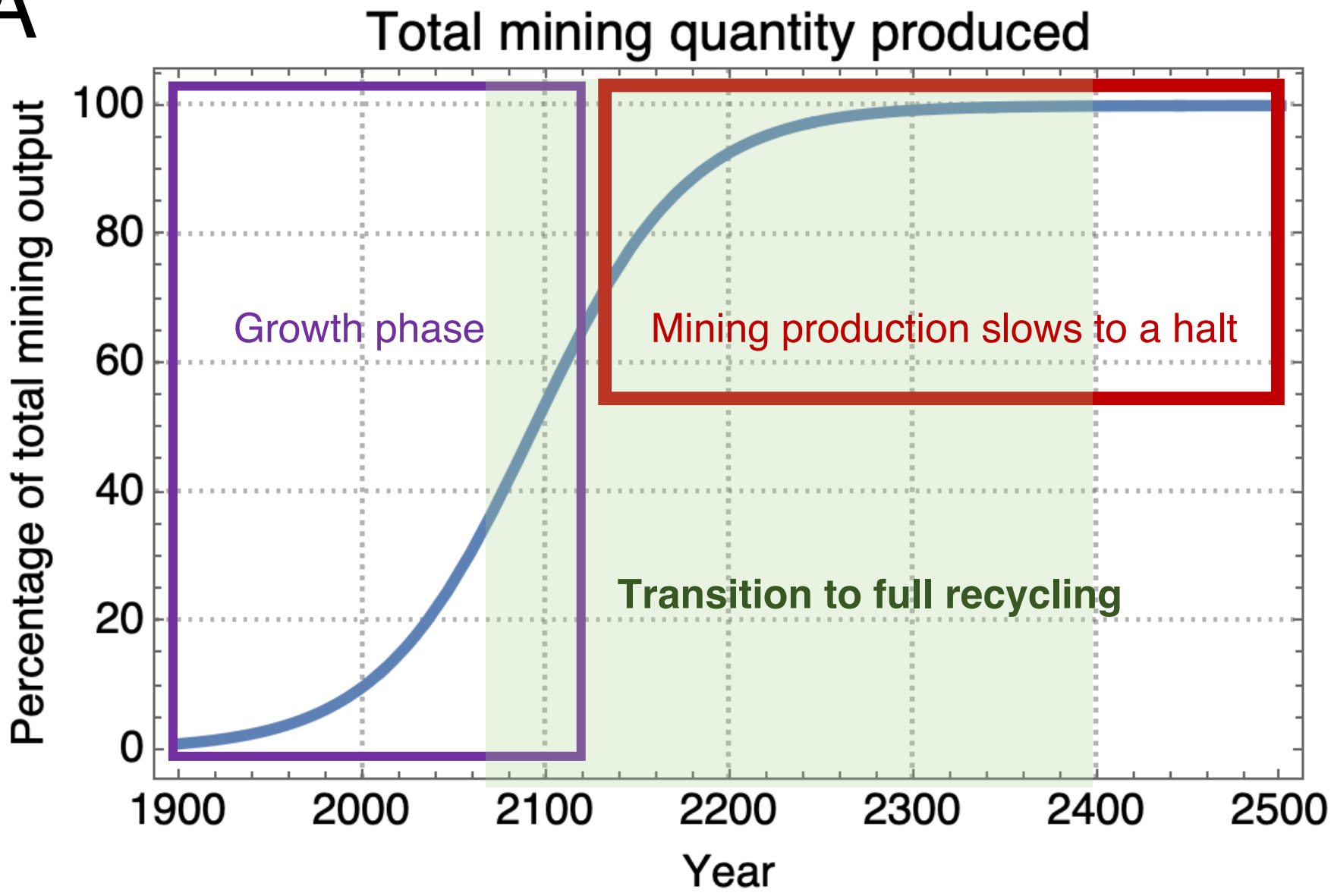
Edition 3 (2023)

EuChemS
European Chemical Society

Technological systems



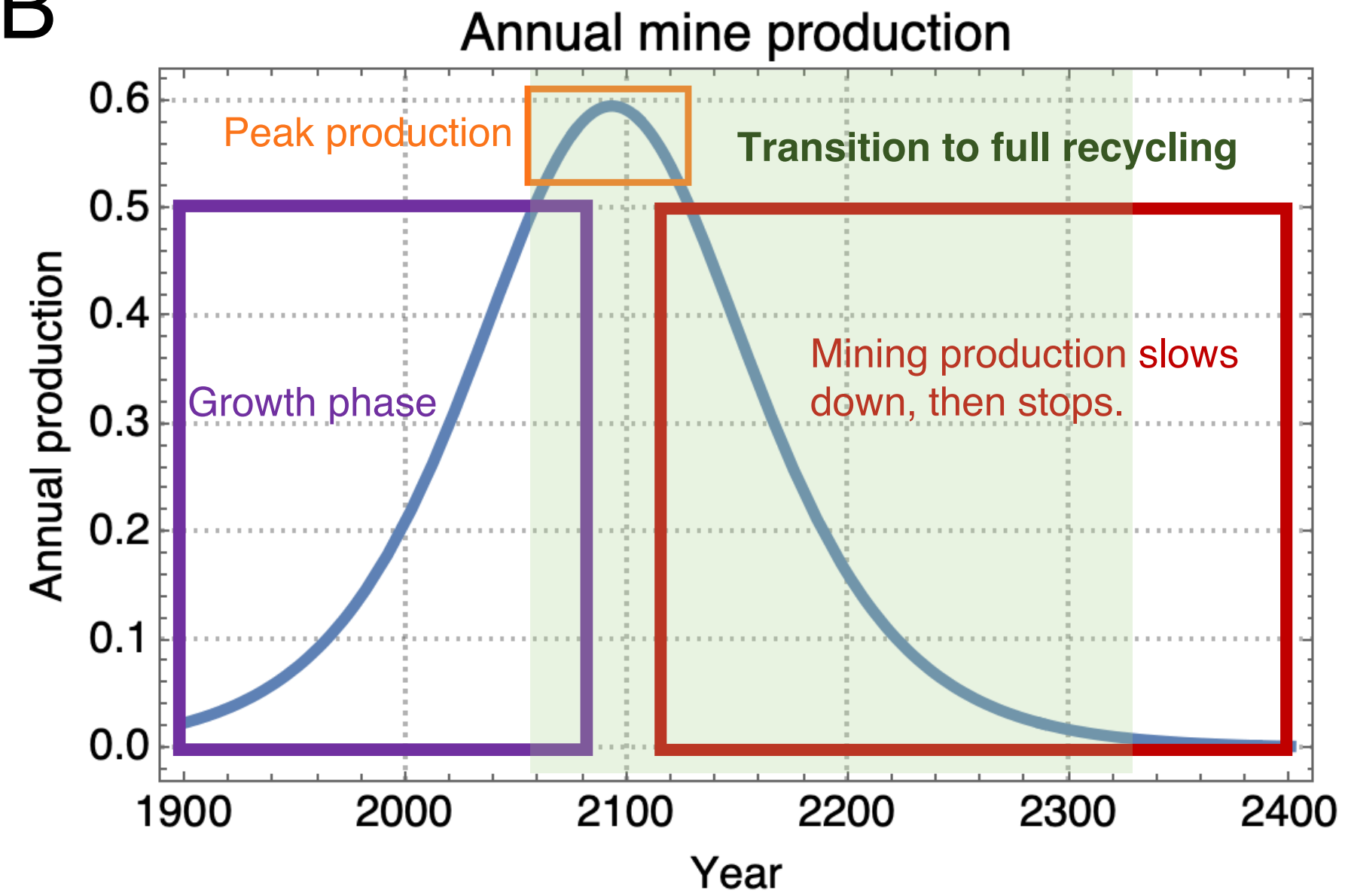
A



Recycling must take over to maintain metal supplies.

Recycling then becomes the only source of concentrated metals.

B


Annual mine production
Peak production
Transition to full recycling
Growth phase
Mining production slows down, then stops.
Annual production
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1900
2000
2100
2200
2300
2400
Year

I consider current technologies to be dead by the yardstick of strong sustainability, but they continue to invade the world to the detriment of humanity and part of the living world, I call them "zombie technologies". They are zombies for three main reasons:

they depend on fossil fuels to manufacture and operate;

they are based on materials that are not designed to be recycled, creating scarcity by depleting resources, or requiring even more power to recycle them;

they produce ecological disasters to the detriment of humanity and ecosystems.

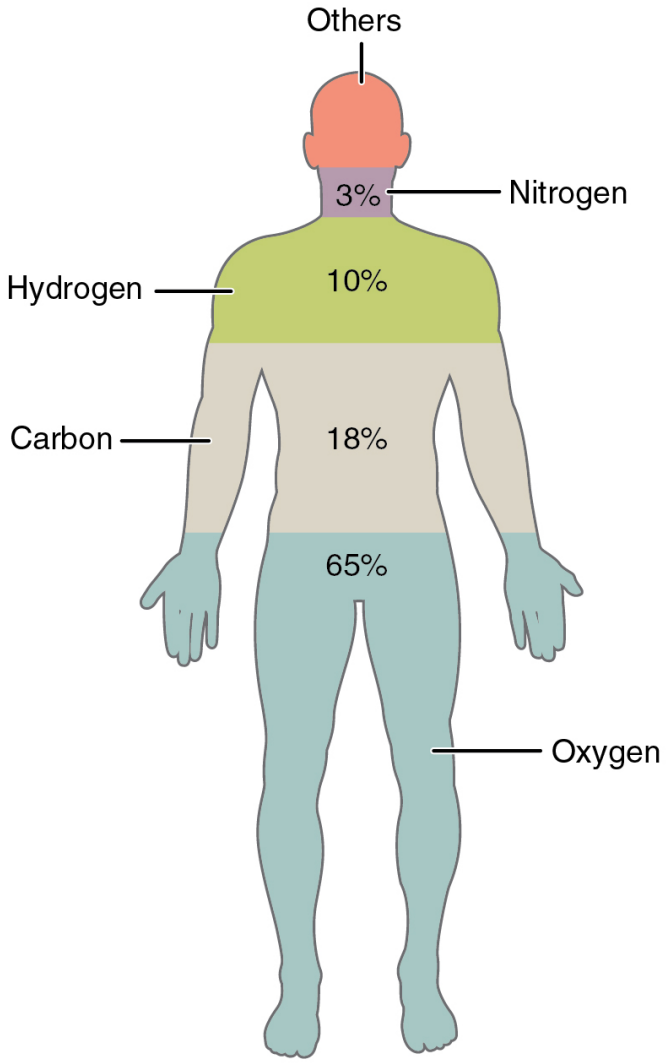
Three criteria favor zombification:

(i) the use of finite stocks, which by definition impose a limit on activity ;

(ii) the use of power that exceeds the capacity of the environment in which the technique is used;

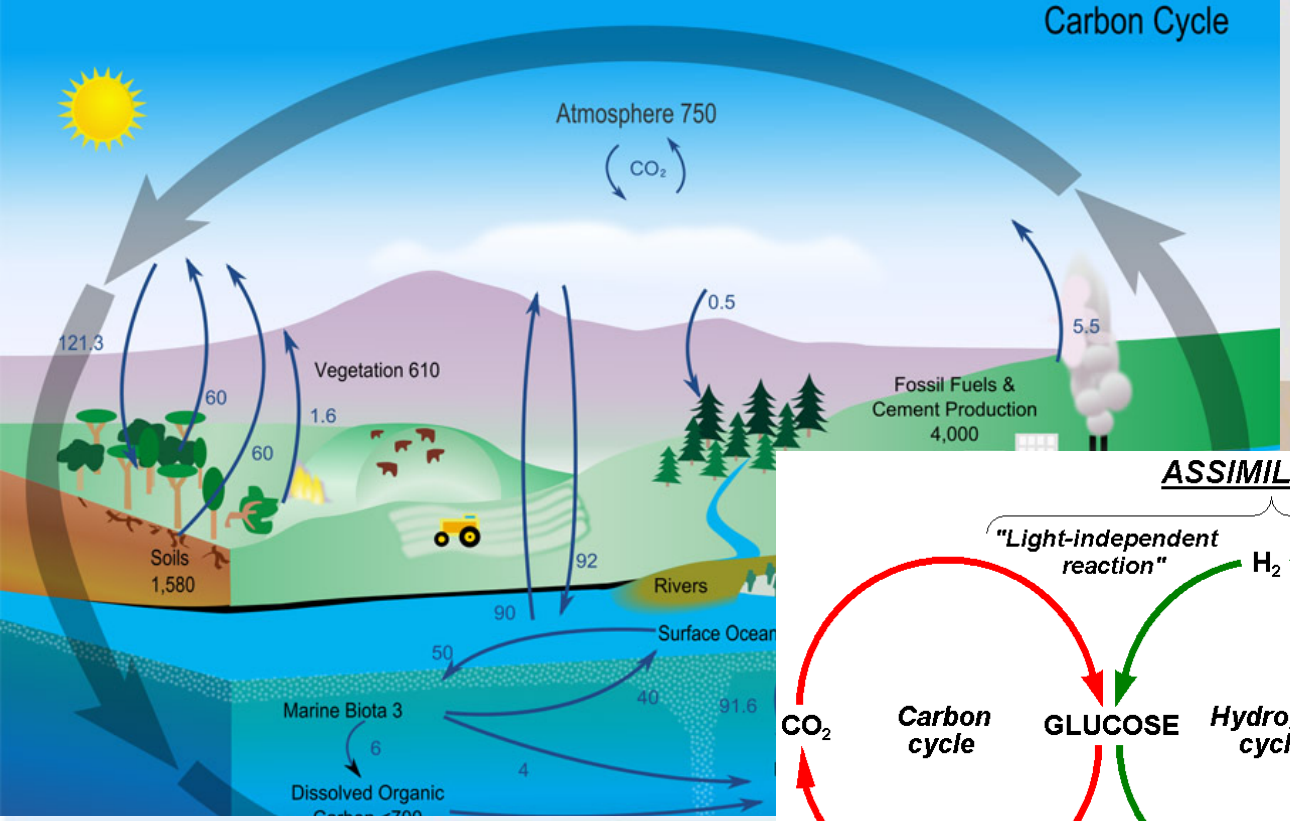
(iii) the generalization of these characteristics on a large scale..

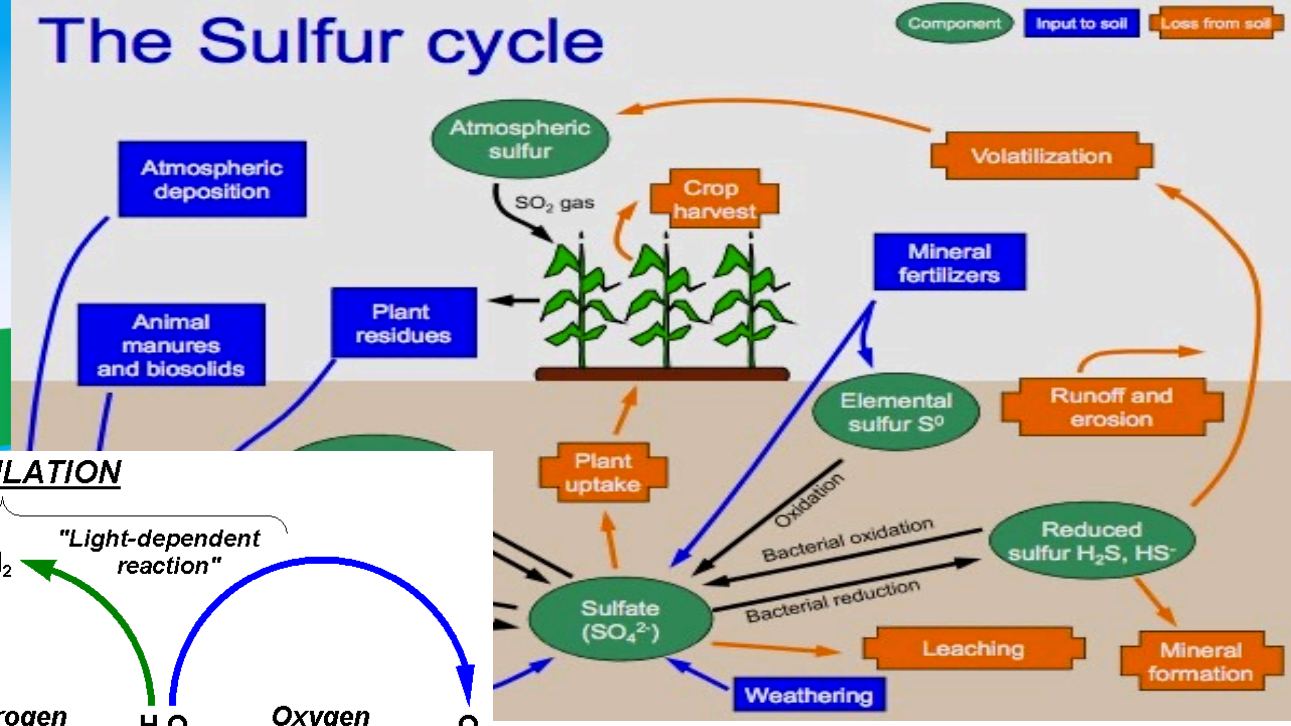
CHON-CHNOPS

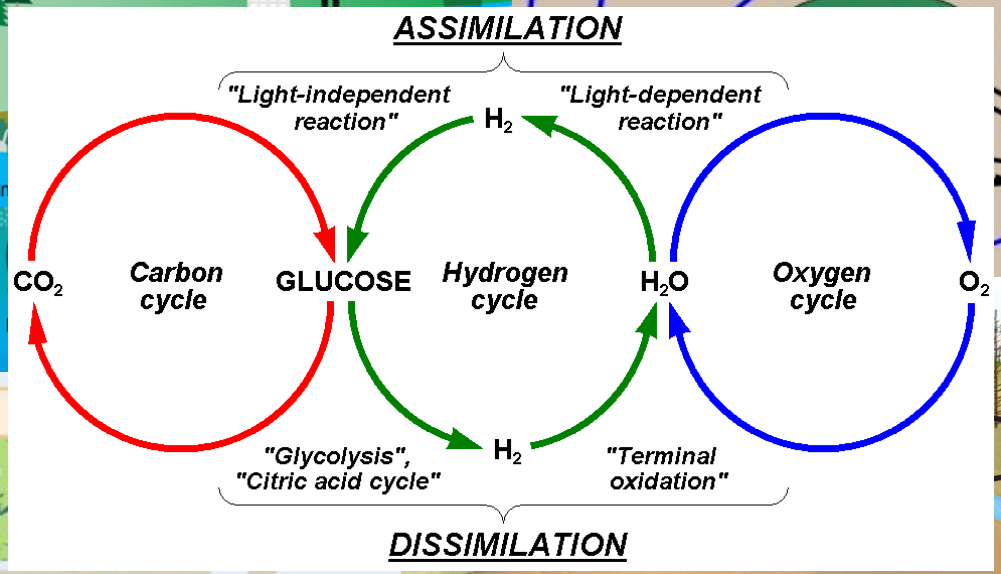


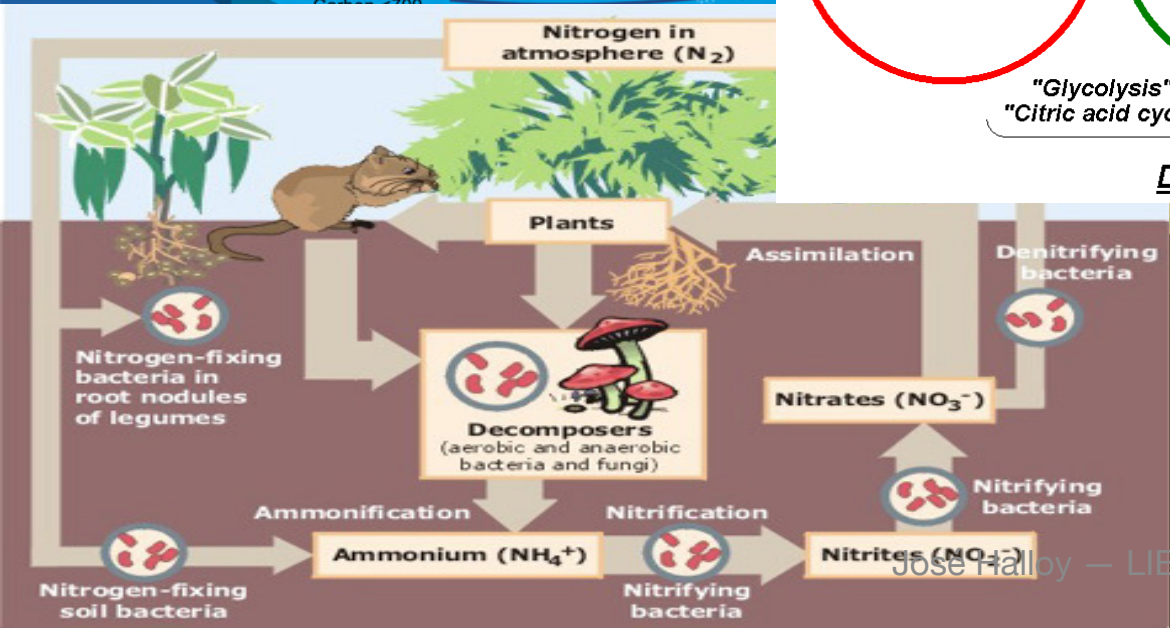
Element	Symbol	Percentage in Body
Oxygen	O	65.0
Carbon	C	18.5
Hydrogen	H	9.5
Nitrogen	N	3.2
Calcium	Ca	1.5
Phosphorus	P	1.0
Potassium	K	0.4
Sulfur	S	0.3
Sodium	Na	0.2
Chlorine	Cl	0.2
Magnesium	Mg	0.1
Trace elements include boron (B), chromium (Cr), cobalt (Co), copper (Cu), fluorine (F), iodine (I), iron (Fe), manganese (Mn), molybdenum (Mo), selenium (Se), silicon (Si), tin (Sn), vanadium (V), and zinc (Zn).		less than 1.0

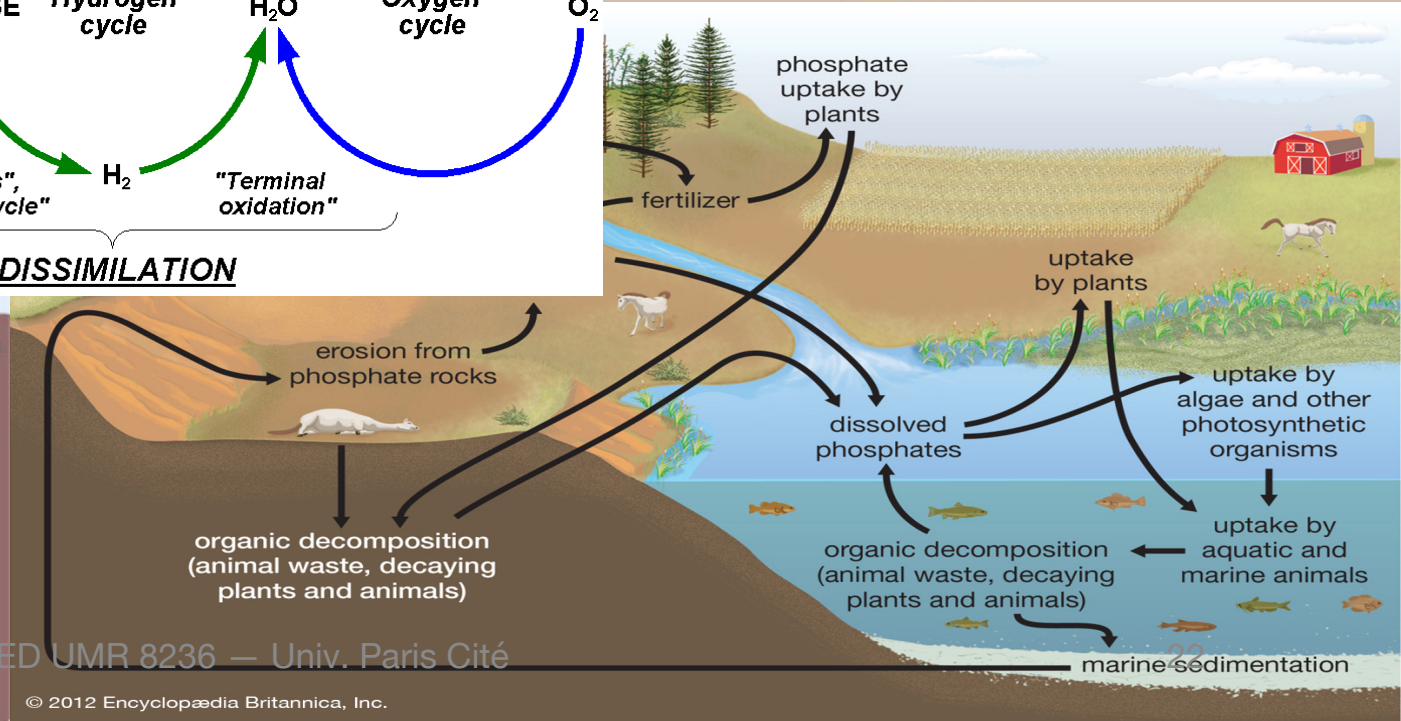
Diluted minerals


Carbon Cycle
Atmosphere 750
CO_2
121.3
60
60
Vegetation 610
1.6
0.5
5.5
Fossil Fuels & Cement Production 4,000
Soils 1,580
92
Rivers
90
Surface Ocean
50
40
91.6
Marine Biota 3
6
4
Dissolved Organic

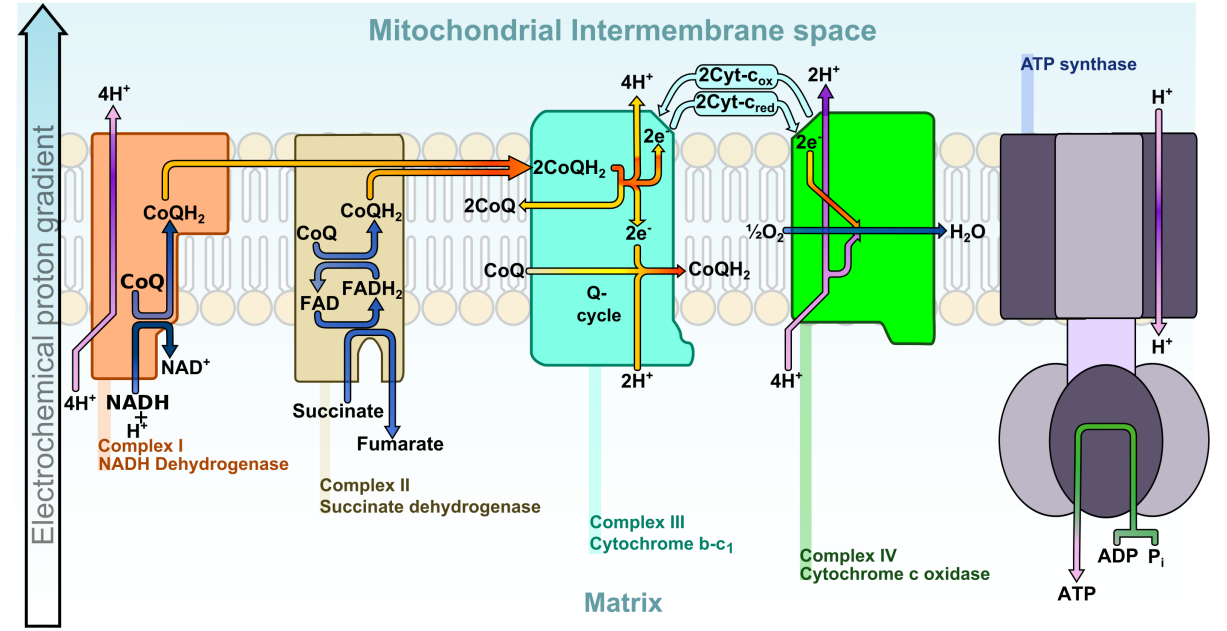

The Sulfur cycle
Component
Input to soil
Loss from soil
Atmospheric deposition
Atmospheric sulfur
SO_2 gas
Crop harvest
Volatilization
Mineral fertilizers
Animal manures and biosolids
Plant residues
Elemental sulfur S^0
Runoff and erosion
Plant uptake
Oxidation
Bacterial oxidation
Reduced sulfur H_2S, HS^-
Bacterial reduction
Sulfate (SO_4^{2-})
Leaching
Mineral formation
Weathering


ASSIMILATION
"Light-independent reaction"
H_2
"Light-dependent reaction"
CO_2
Carbon cycle
GLUCOSE
Hydrogen cycle
H_2O
Oxygen cycle
O_2
"Glycolysis", "Citric acid cycle"
H_2
"Terminal oxidation"
DISSIMILATION


Nitrogen in atmosphere (N_2)
Plants
Assimilation
Denitrifying bacteria
Nitrogen-fixing bacteria in root nodules of legumes
Decomposers (aerobic and anaerobic bacteria and fungi)
Nitrates (NO_3^-)
Nitrifying bacteria
Ammonification
Nitrification
Ammonium (NH_4^+)
Nitrites (NO_2^-)
Nitrogen-fixing soil bacteria
Nitrifying bacteria

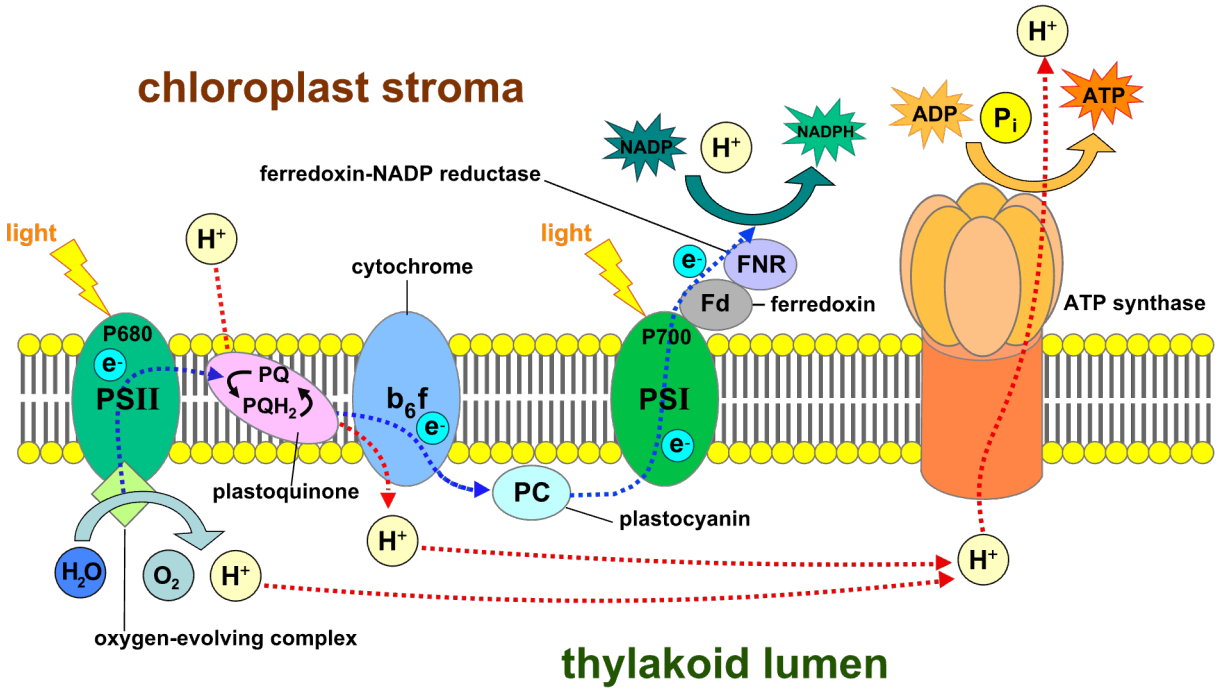

phosphate uptake by plants
fertilizer
uptake by plants
erosion from phosphate rocks
dissolved phosphates
uptake by algae and other photosynthetic organisms
organic decomposition (animal waste, decaying plants and animals)
uptake by aquatic and marine animals
organic decomposition (animal waste, decaying plants and animals)
marine sedimentation
© 2012 Encyclopædia Britannica, Inc.

Mitochondrion



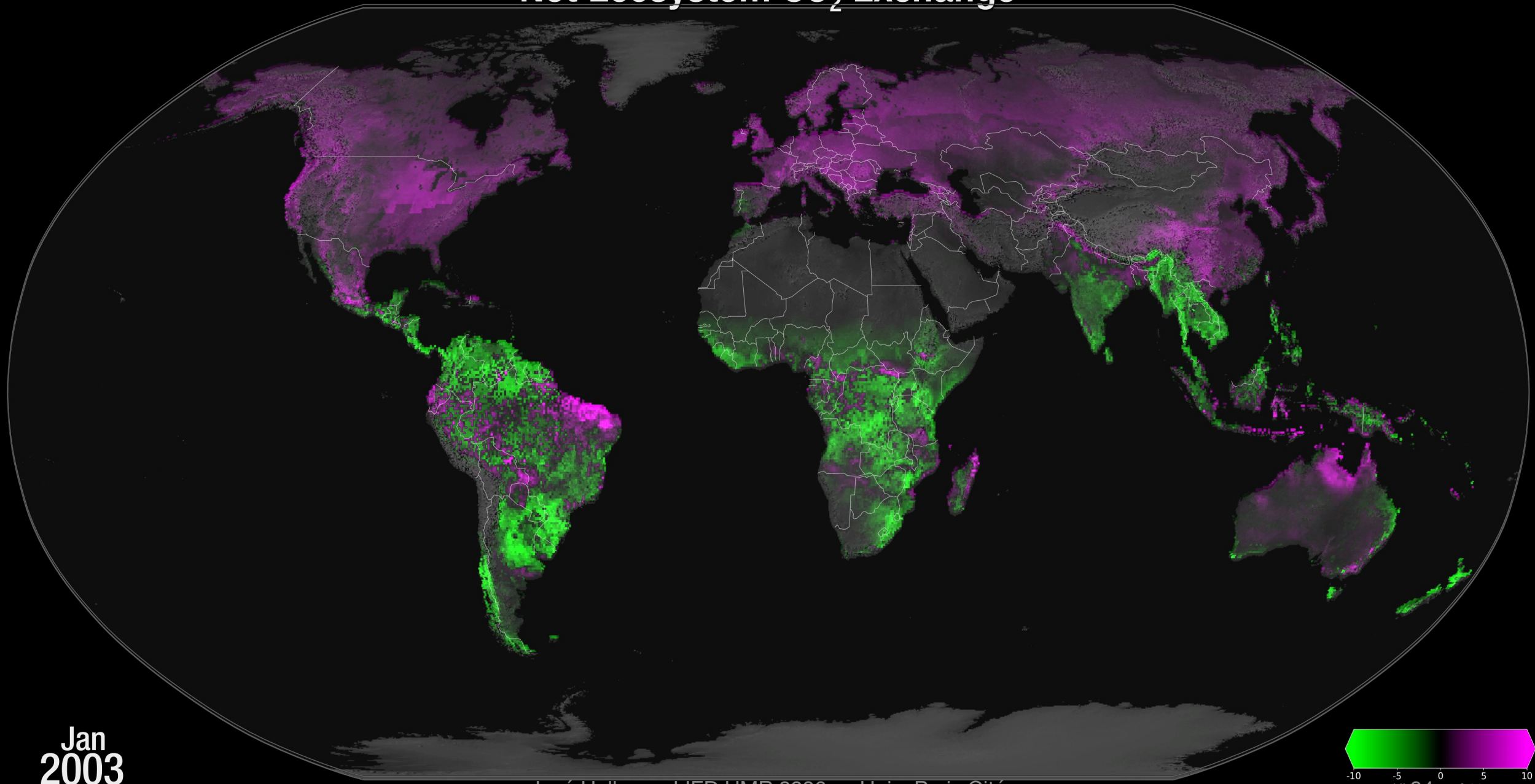
The most important roles of the mitochondria are the production of the cell energy currency, ATP through respiration, and the regulation of cellular metabolism.

Chloroplast, thylakoids



The thylakoids are the site of photosynthesis, which converts electromagnetic energy (light) into chemical energy (covalent bonding). These reactions oxygen production, proton pumping across thylakoid membranes coupled to the electron transport chain, and ATP synthesis using the generated proton gradient.

Net Ecosystem CO_2 Exchange



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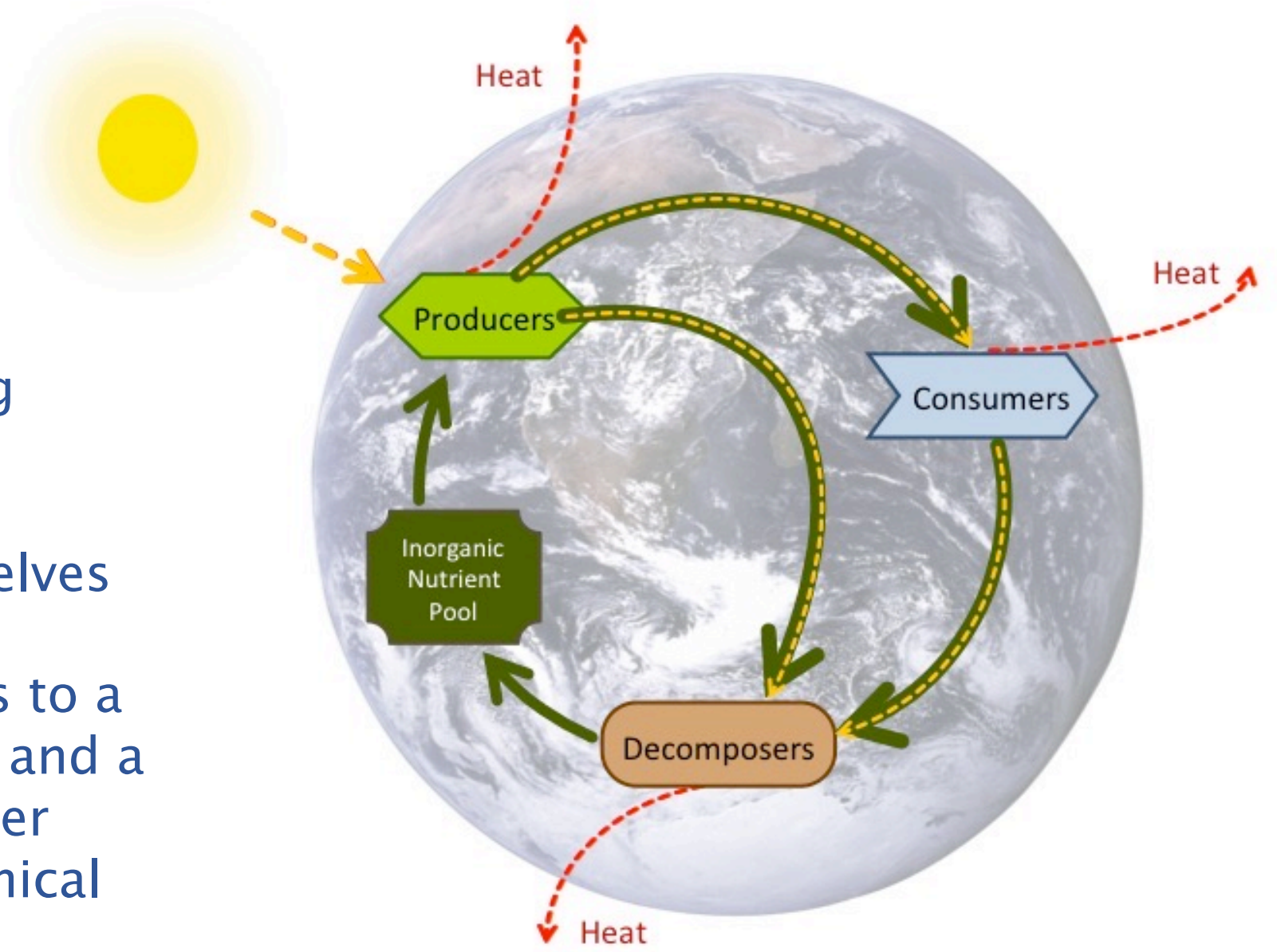
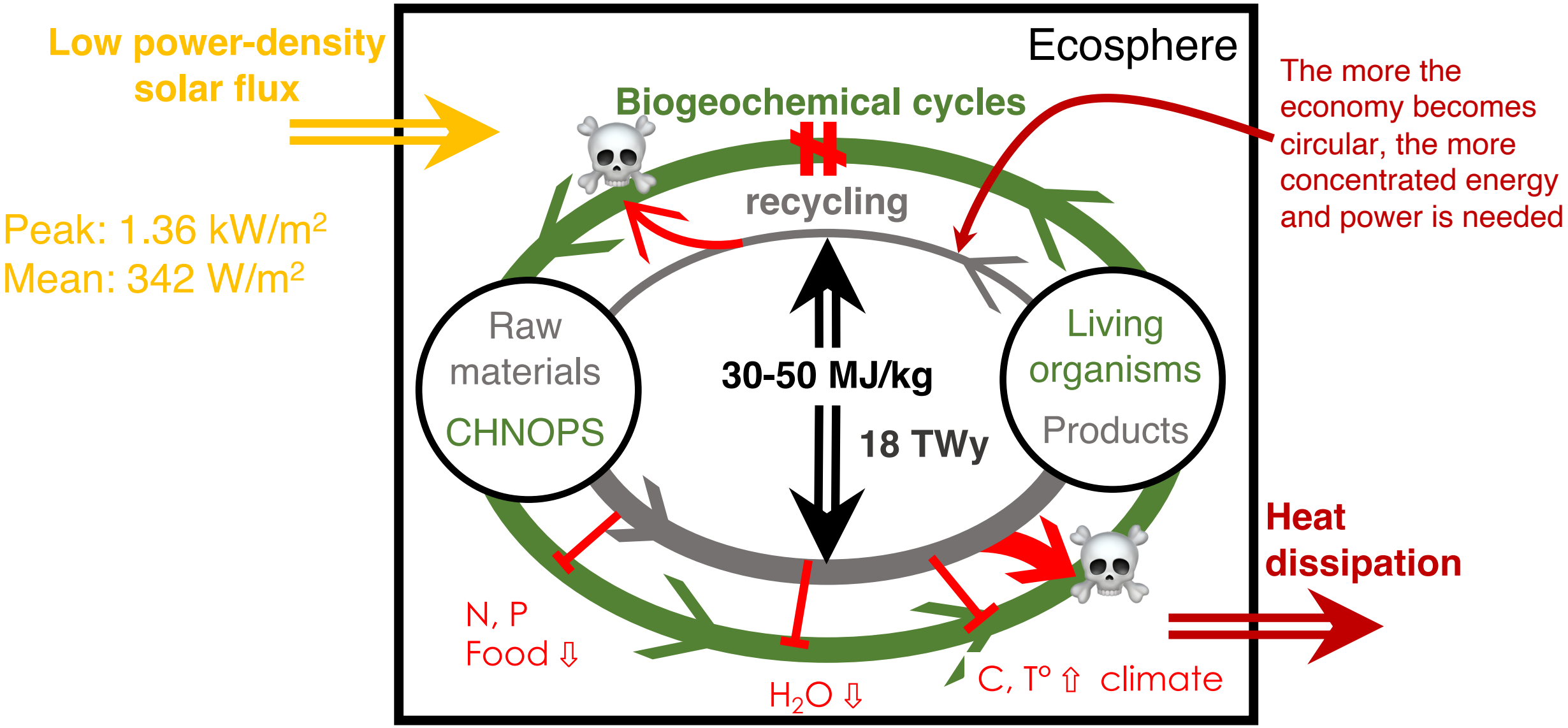
Low power-density solar flux

Peak: 1.36 kW/m²
Mean: 342 W/m²

Photosynthetic living beings have been emerging and perpetuating themselves for 3 billion years, sustainable!!, thanks to a flow of solar energy and a circular flow of matter through biogeochemical cycles.




Low power-density solar flux
Peak: 1.36 kW/m²
Mean: 342 W/m²
Ecosphere
Biogeochemical cycles
recycling
Raw materials
CHNOPS
30-50 MJ/kg
18 TWy
Living organisms
Products
The more the economy becomes circular, the more concentrated energy and power is needed
Heat dissipation
N, P
Food ⇩
H2O ⇩
C, T° ⇧ climate

AlphaGo defeated Lee Sedol

Not the same chemistry
Not the same physics

Only one is sustainable because it is compatible with Earth metabolism

~ 155 kW (low estimate)
Up to 500kW

130 GJ = 9.7 days

Brain ~ 20 W
2500 kCal/day
Human ~ 120 W

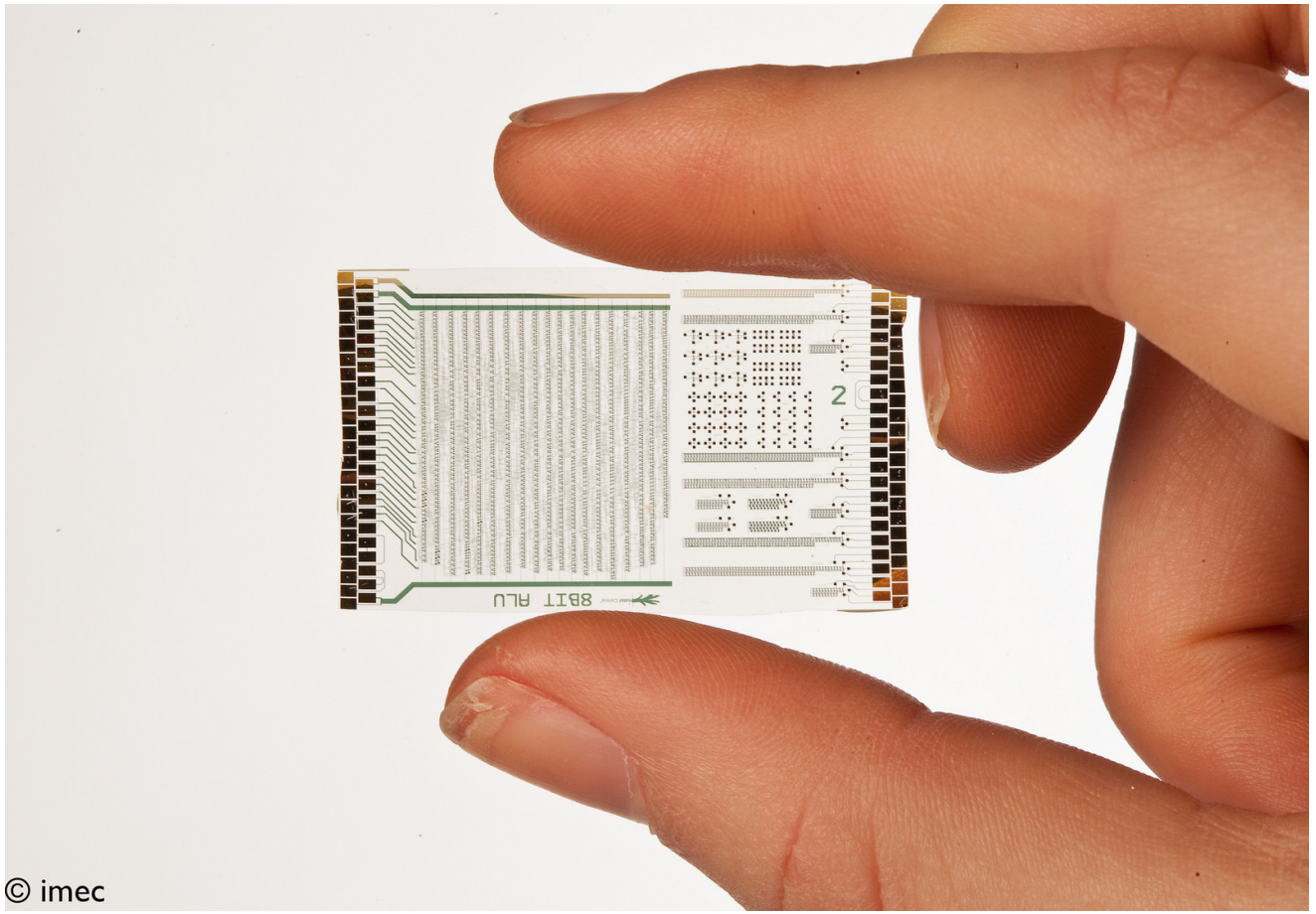
34 years = 130 GJ

An 8-Bit, 40-Instructions-Per-Second Organic Microprocessor on Plastic Foil

Kris Myny, *Student Member, IEEE*, Erik van Veenendaal, Gerwin H. Gelinck, Jan Genoe, *Member, IEEE*, Wim Dehaene, *Senior Member, IEEE*, and Paul Heremans

IEEE JOURNAL OF SOLID-STATE CIRCUITS, VOL. 47, NO. 1, JANUARY 2012

Mostly organic materials (carbon based)
Au for gates



An 8-Bit, 40-Instructions-Per-Second Organic Microprocessor on Plastic Foil

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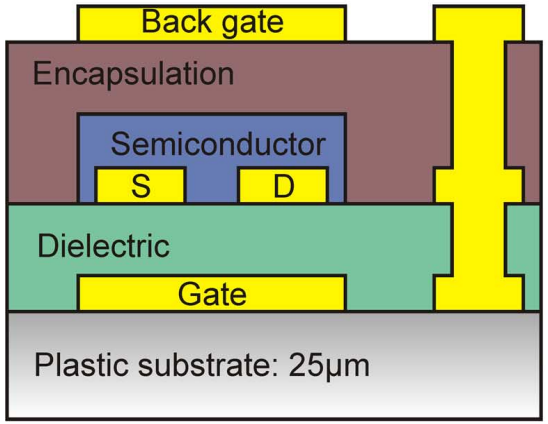
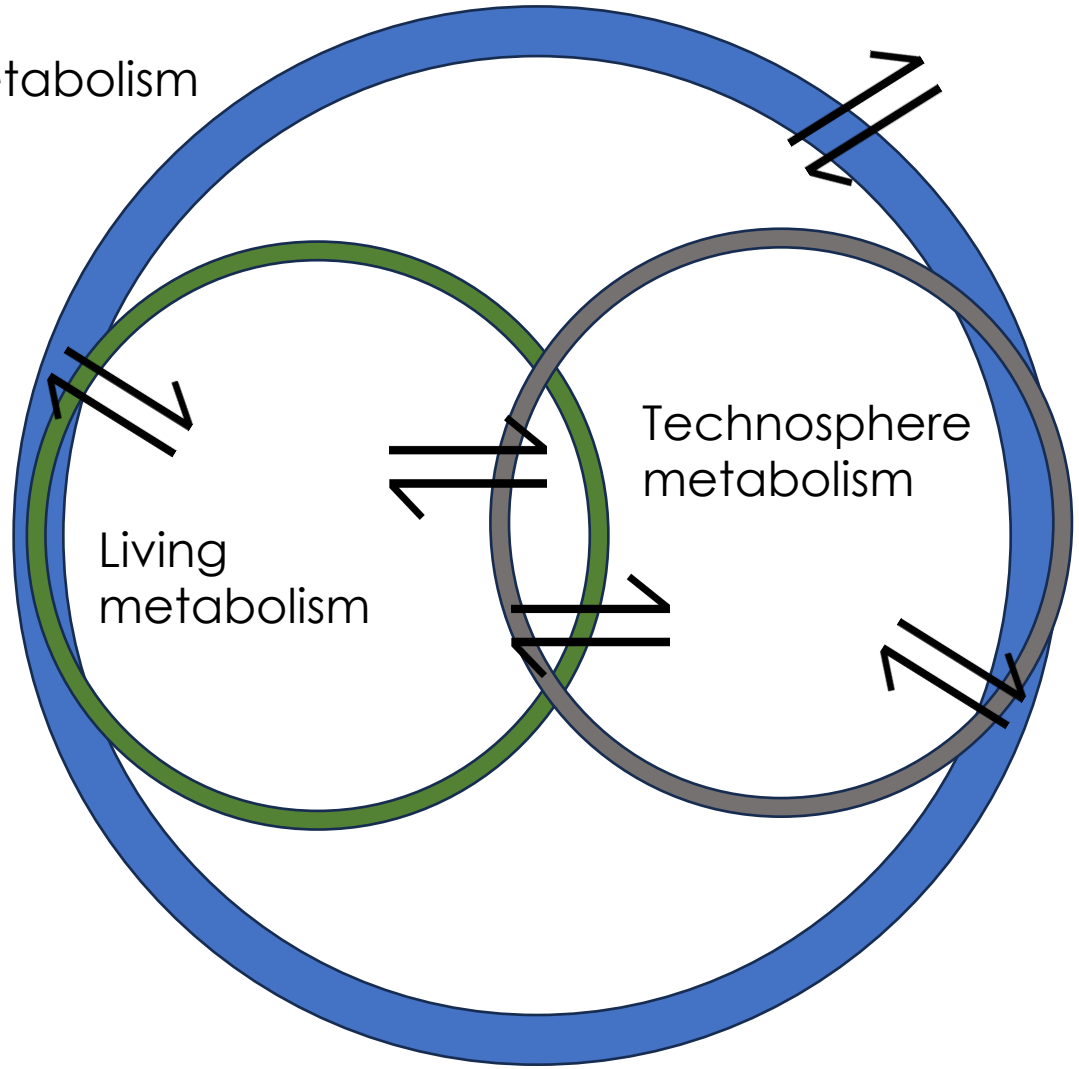


	Plastic microprocessor	Intel 4004
Transistor-count	3381	2300
Area	1.96 x 1.72 cm^2	3 x 4 mm^2
Pin-count	30	16
Power supply voltage	10 V	15 V
Power consumption	92 µW	1 W
Operation speed	40 operations/second	92000 operations/second
Semiconductor	Pentacene	Silicon
P-type mobility	~0.15 cm^2/Vs	~450 cm^2/Vs
Logic family	P-type	P-type
Operation	accumulation	inversion
Technology	5 µm	10 µm
Bus width	8 bit	4 bit
Production year	2011	1971
Wafer scale	6″	2″
Substrate	flexible	rigid

Principle for new technologists



The technosphere metabolism must be chemically and physically compatible (CHNOPS), and correctly connected to the metabolism of the living planet.

Principle for new technologists

If the power required to manufacture and operate a technology is greater than the solar irradiance, this raises questions and problems.

How will you get such power?

Three missions for the new technologists

Mission 1

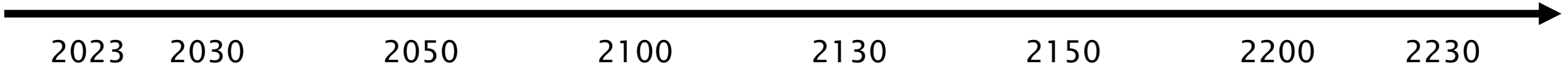
Manage existing systems, close, redirect

Mission 2

Using existing technologies to achieve weak sustainability

Mission 3

Inventing strong sustainability based on new technological metabolism



Low sustainability duration circa century

Strong sustainability lasting centuries or more

It is not climate change, it is everything change