Sustainable Materials and the Circular Economy

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JCH Industrial Ecology Ltd

Structure

- What is sustainability?
- Growth and sustainability
- Stocks and flows
- Why haven’t we run out of resources?
- Economic growth and decoupling
- The Circular Economy

What is Sustainability?

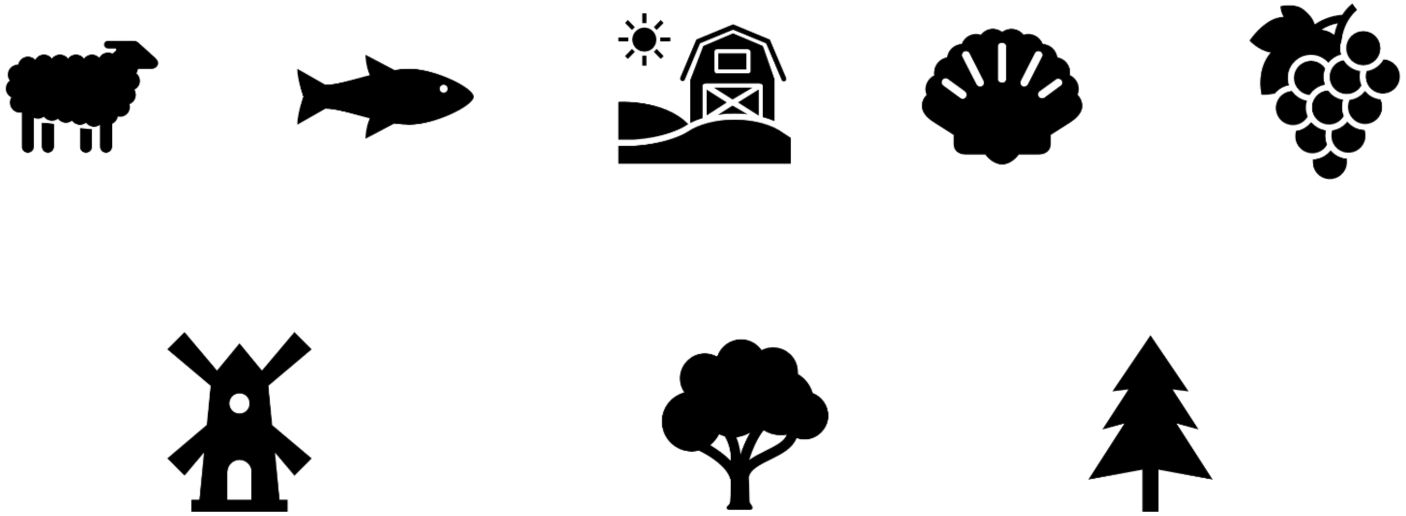
‘Meeting the needs of the current generation without compromising the ability of future generations to meet their own needs’

Or similar….

Over 200 definitions!

Renewable resources

- A sustainable yield is one that is available in perpetuity



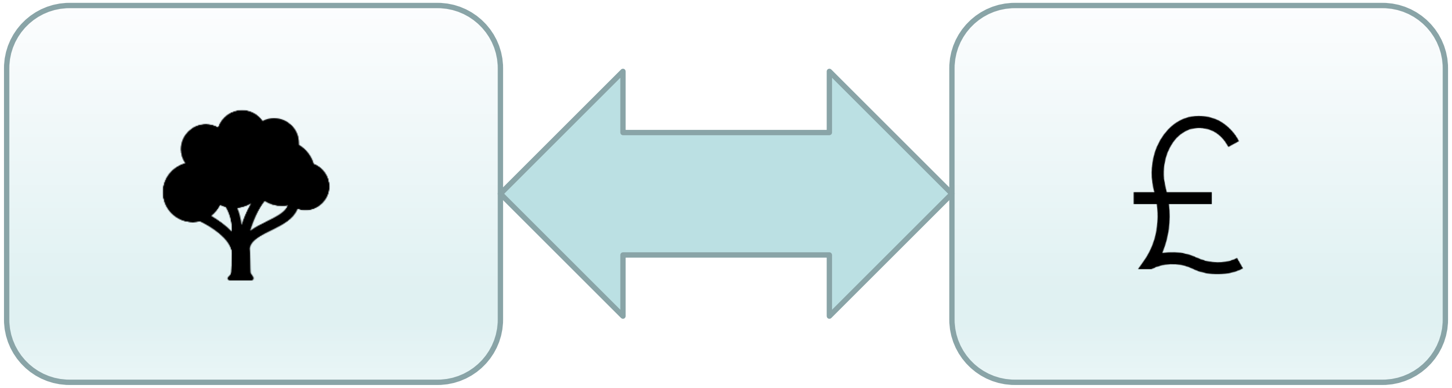
- There is a limit to the ***RATE*** at which we can exploit renewable resources

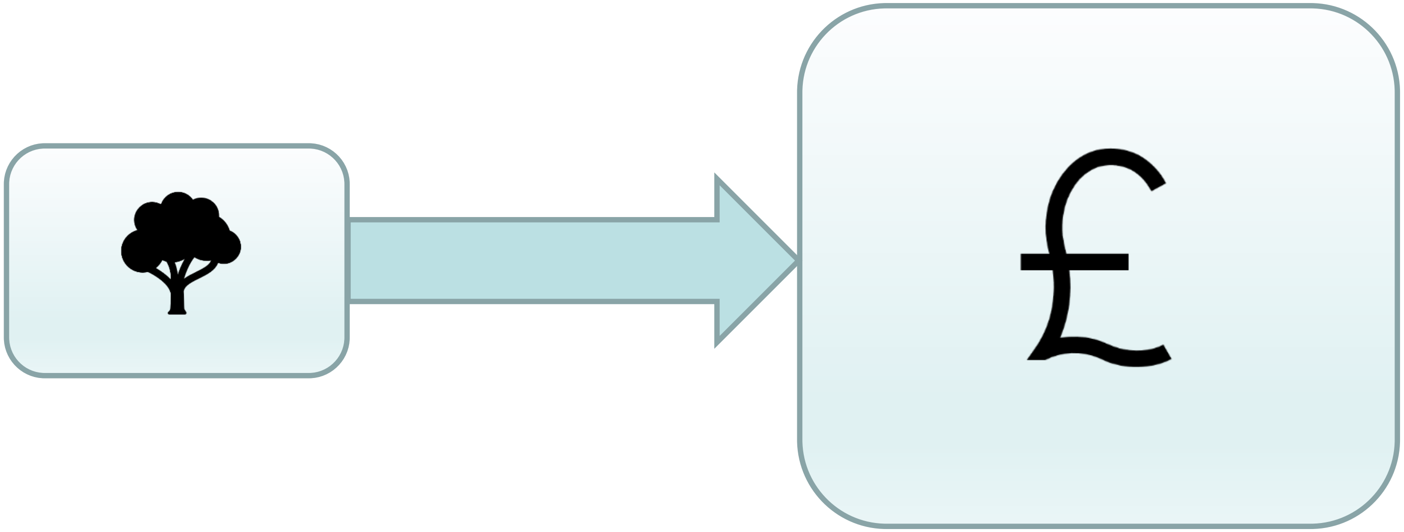
Sustainability is best understood in terms of capitals

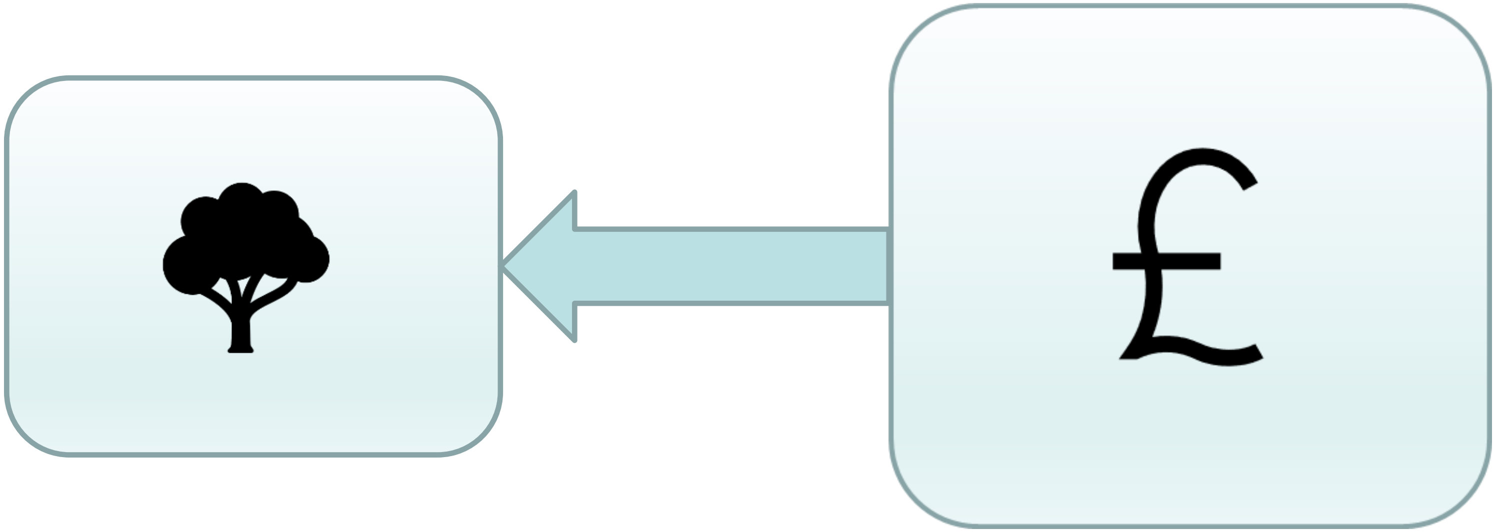
The five capitals

- **Financial** (money)
- **Natural** – resources (renewable, non-renewable, replenishable) – sinks (recycle and absorb wastes) – processes (e.g., climate regulation)
- **Human** (health, knowledge, skills, motivation)
- **Social** (families, schools, libraries, etc.)
- **Manufactured** (material goods, fixed assets such as buildings)

https://www.forumforthefuture.org/







Definitions of sustainability

- Absurdly strong – no change in stocks is allowed
- Strong – all capital assets must be kept intact, but can be substituted
- Pragmatic – thresholds are set below which a capital must not fall
- Weak – all capitals can be exchanged

Growth and Sustainability

Malthusian world view

- *An Essay on the Principle of Population* – Thomas Robert Malthus FRS
- *Limits to Growth* – Dennis Meadows, Donella Meadows, Jorgen Randers, William Behrens III
- *The Population Bomb* – Paul Ehrlich (Anne Ehrlich)

Ehrlich-Commoner Equation

$$I = P \times A \times T$$

Ehrlich-Commoner Equation

$$I = P \times A \times T$$

ENVIRONMENTAL IMPACT

Ehrlich-Commoner Equation

$$I = P \times A \times T$$

POPULATION

Ehrlich-Commoner Equation

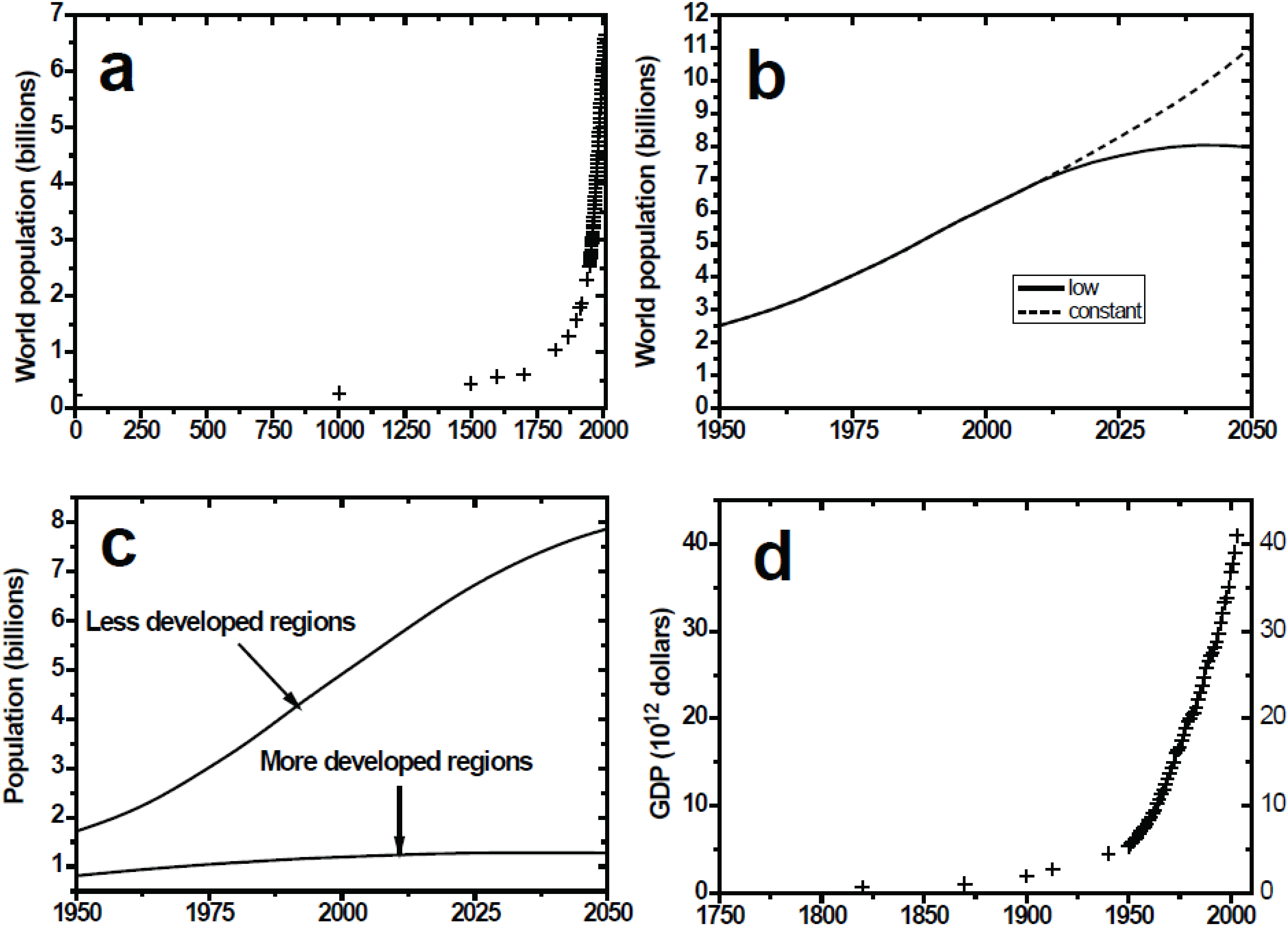
$$I = P \times A \times T$$

ECONOMIC ACTIVITY

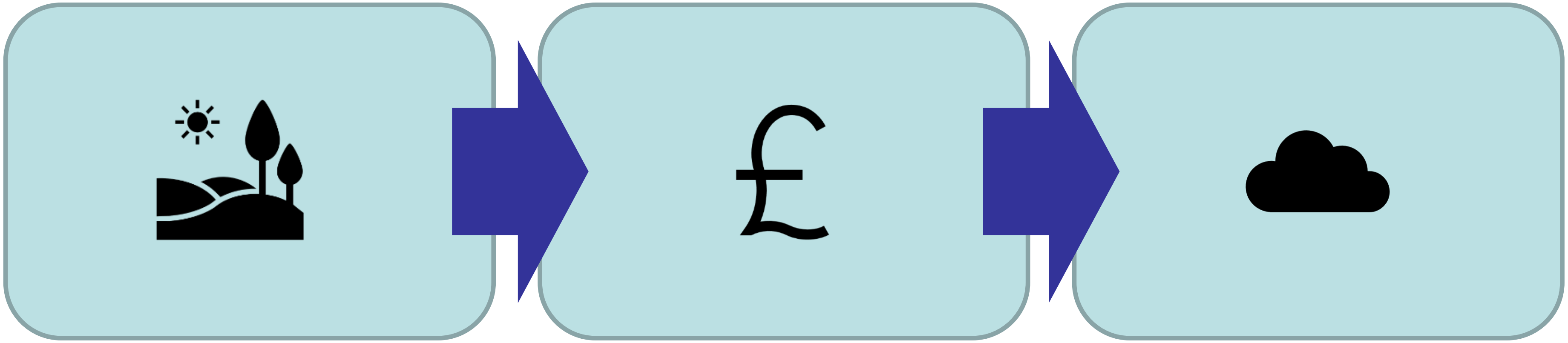
Ehrlich-Commoner Equation

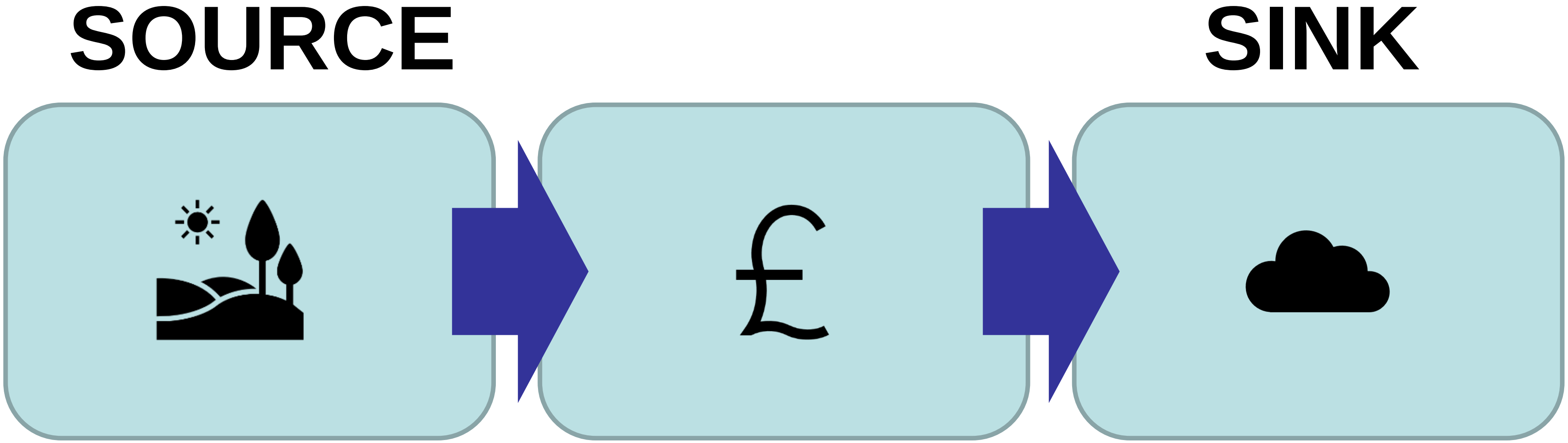
$$I = P \times A \times T$$

TECHNOLOGY FACTOR


a
World population (billions)
0
1
2
3
4
5
6
7
0
250
500
750
1000
1250
1500
1750
2000
b
World population (billions)
0
1
2
3
4
5
6
7
8
9
10
11
12
1950
1975
2000
2025
2050
low
constant
c
Population (billions)
1
2
3
4
5
6
7
8
Less developed regions
More developed regions
1950
1975
2000
2025
2050
d
GDP (10^{12} dollars)
0
10
20
30
40
1750
1800
1850
1900
1950
2000

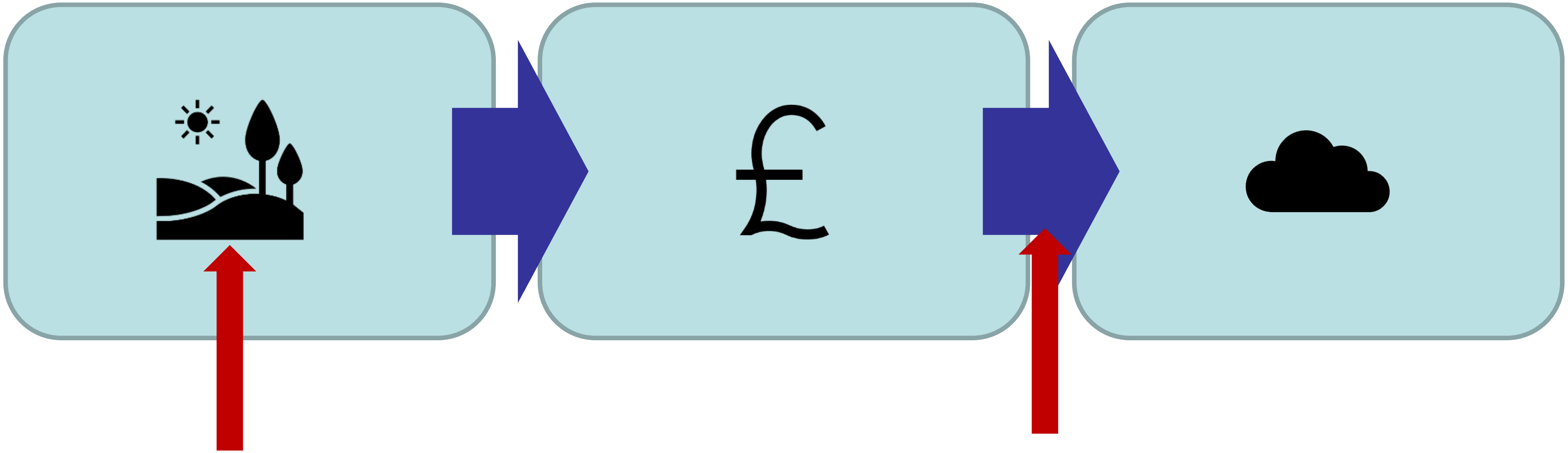
THE WAY WE DO THINGS





SOURCE

SINK



STOCK

FLOW

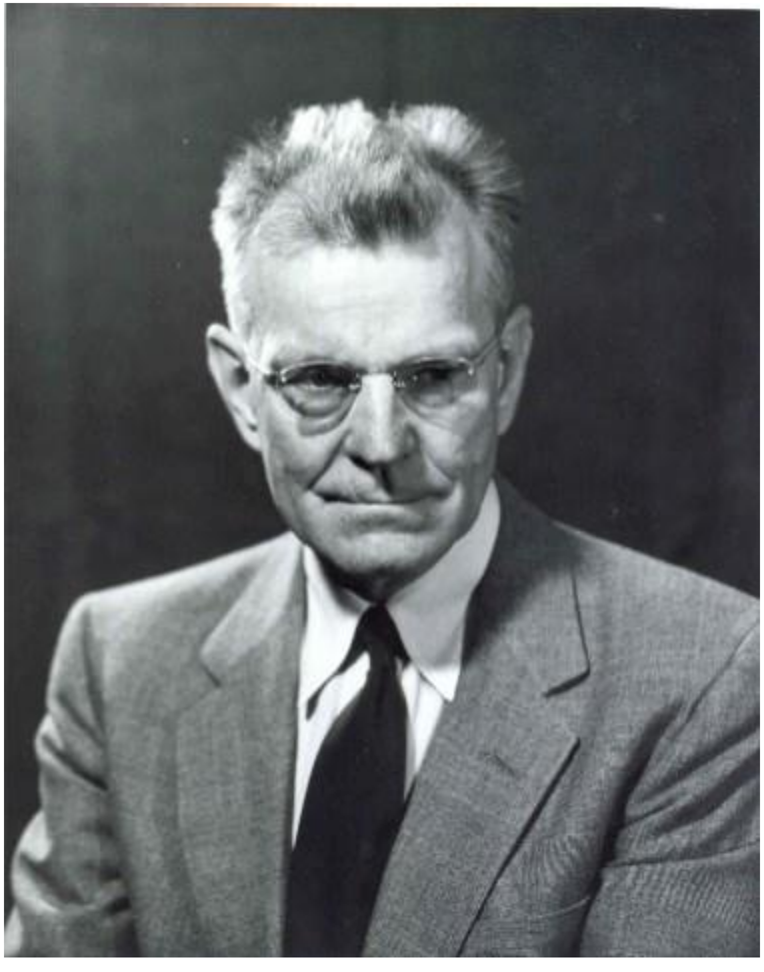
Assumptions

- **The ability of the source to provide is infinite**
- **The capacity of the sink to absorb is infinite**

Resources – are we running out?

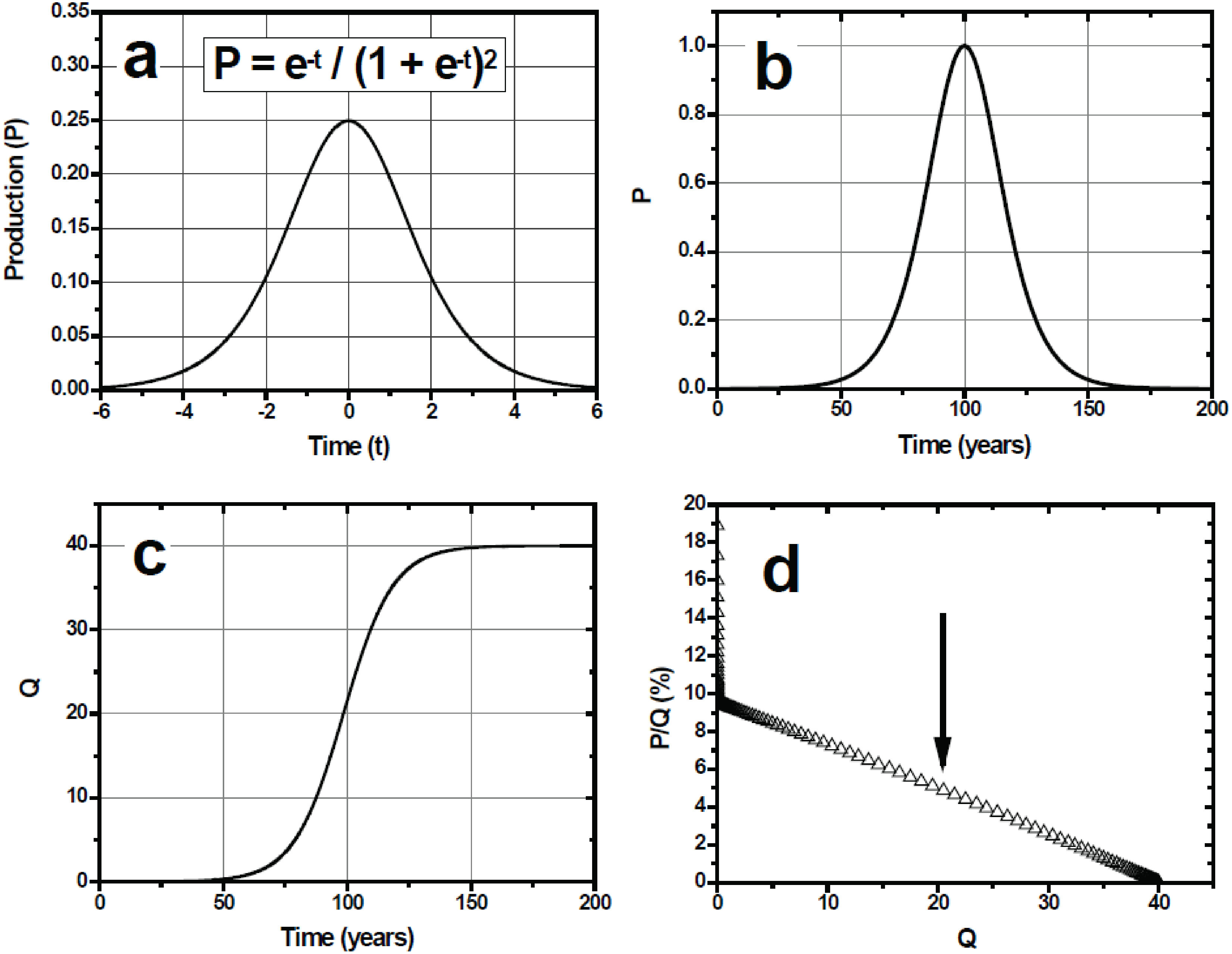
Source is Finite

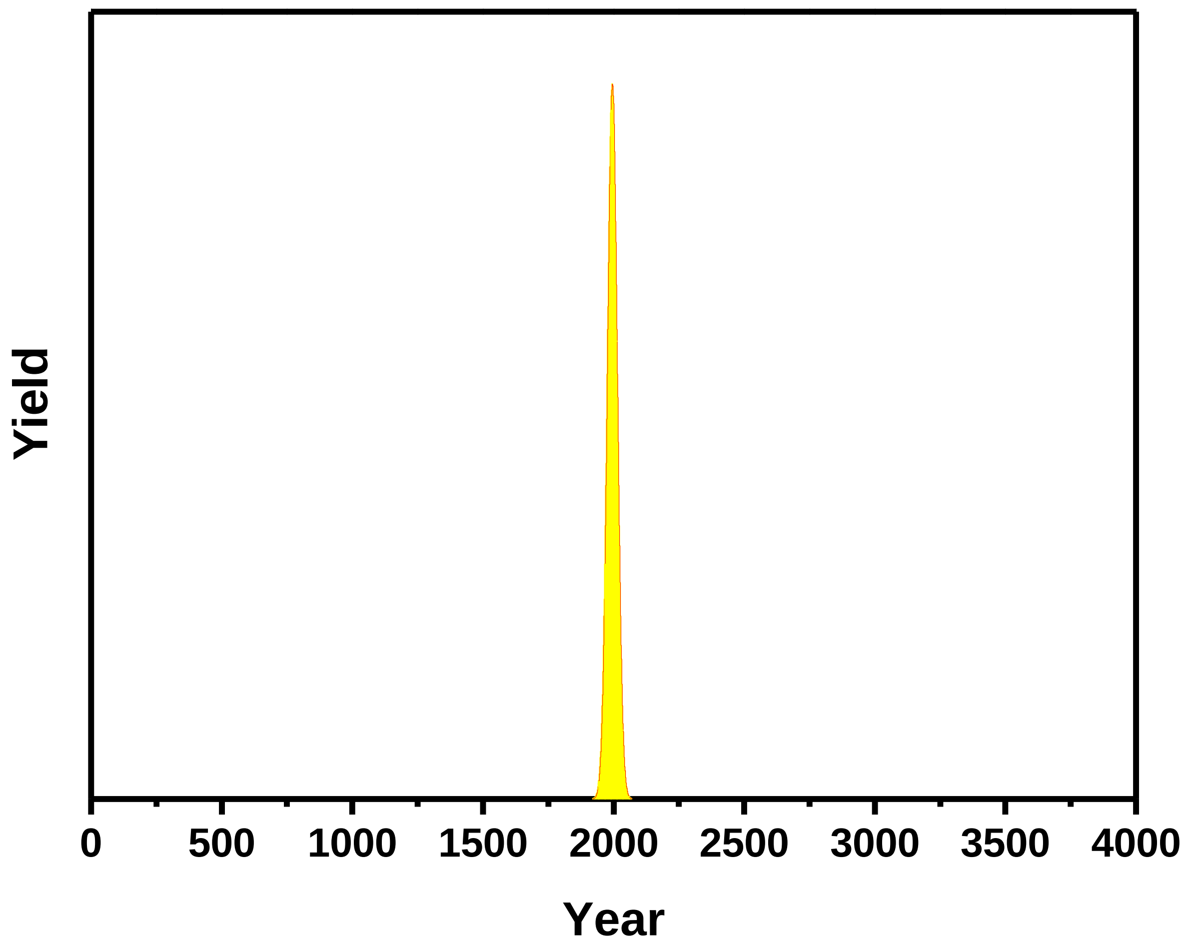
M King Hubbert



Peak oil

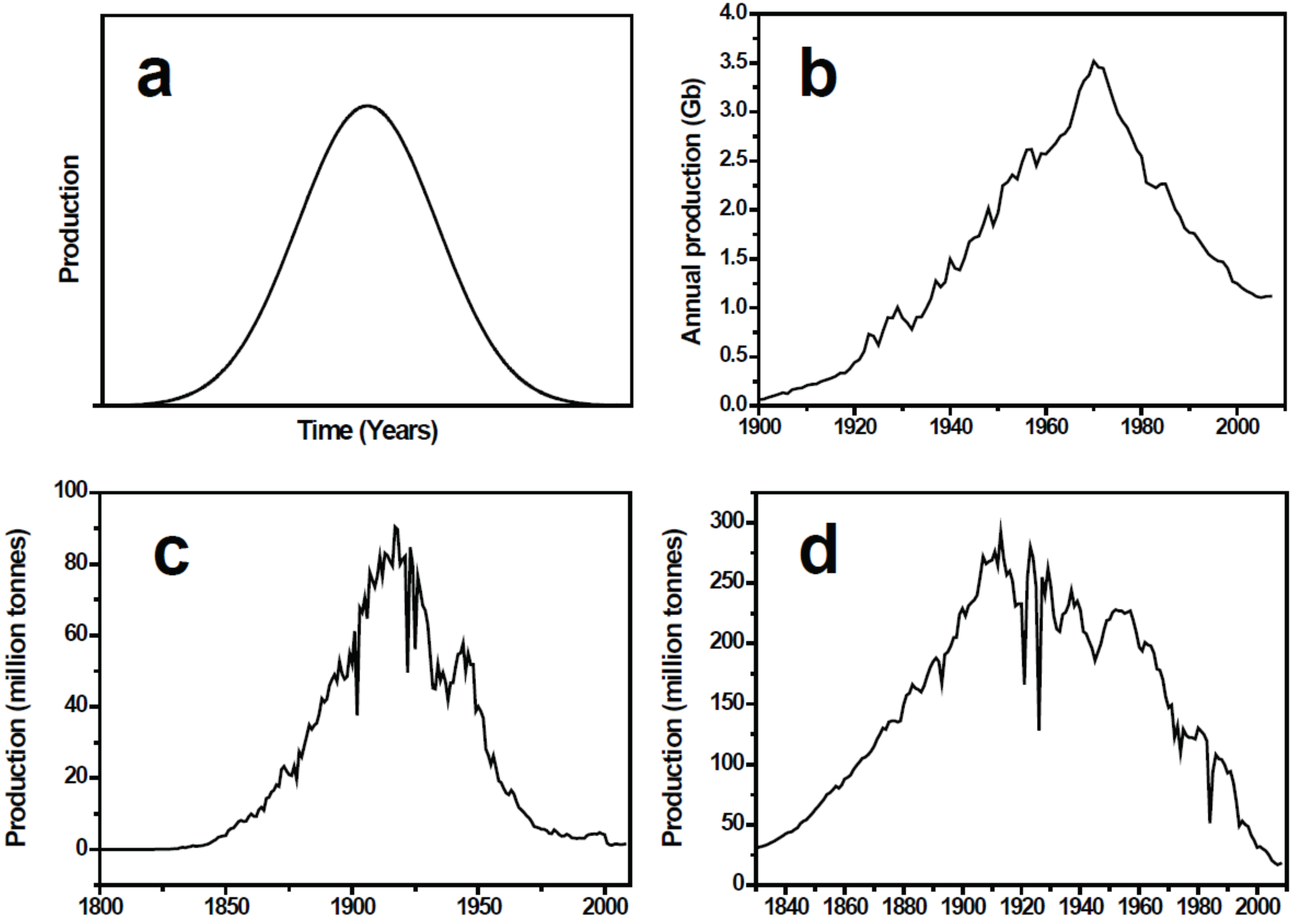
- *Peak Oil* – Matthew Schneider-Mayerson
- *Peak Everything* – Richard Heinberg
- *Twilight in the Desert* – Matthew Simmons


a
P = e-t / (1 + e-t)2
Production (P)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-6
-4
-2
0
2
4
6
Time (t)
b
P
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
Time (years)
c
Q
40
30
20
10
0
0
50
100
150
200
Time (years)
d
P/Q (%)
20
18
16
14
12
10
8
6
4
2
0
0
10
20
30
40
Q

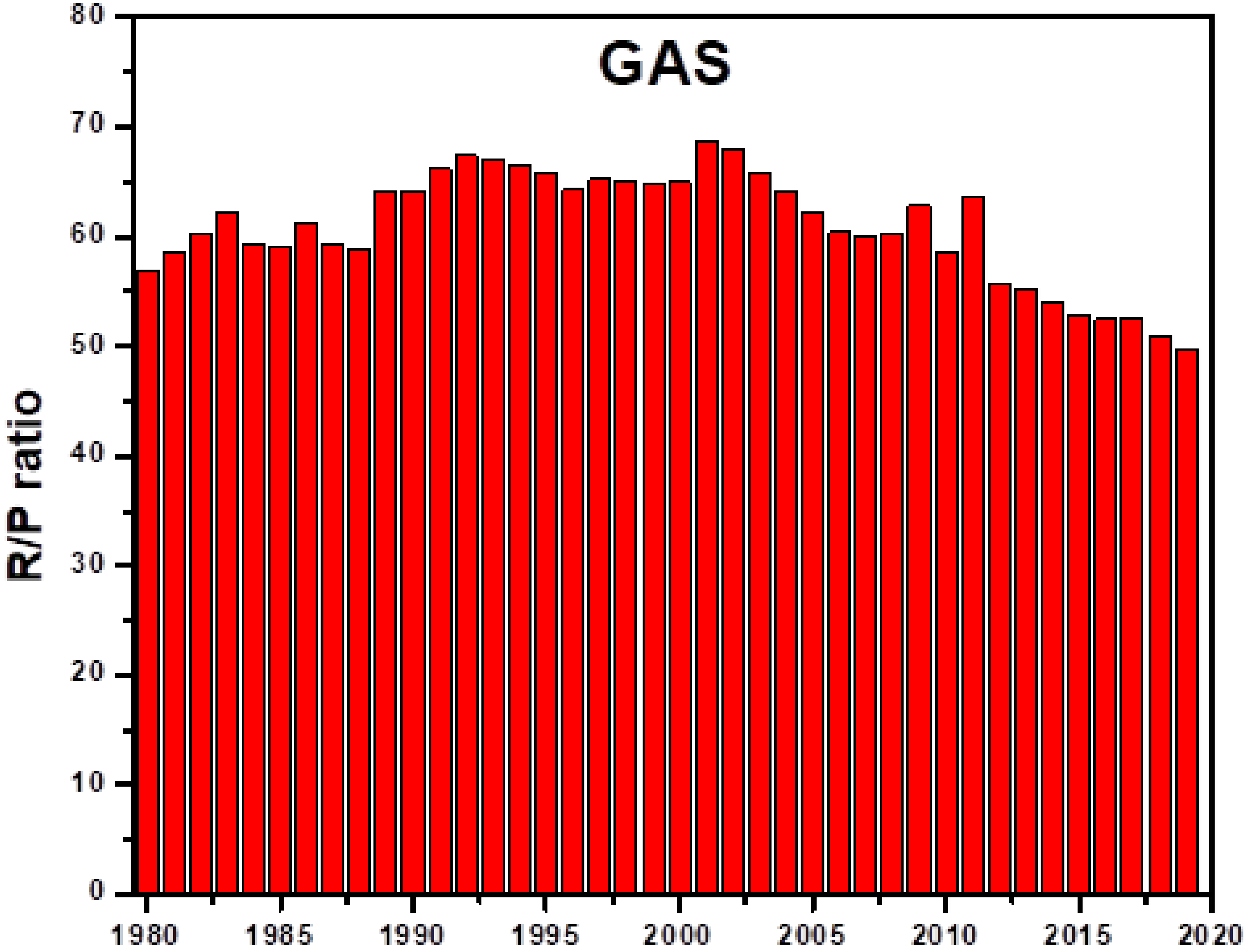


M.K. Hubbert ‘Exponential growth as a transient phenomenon in human history’

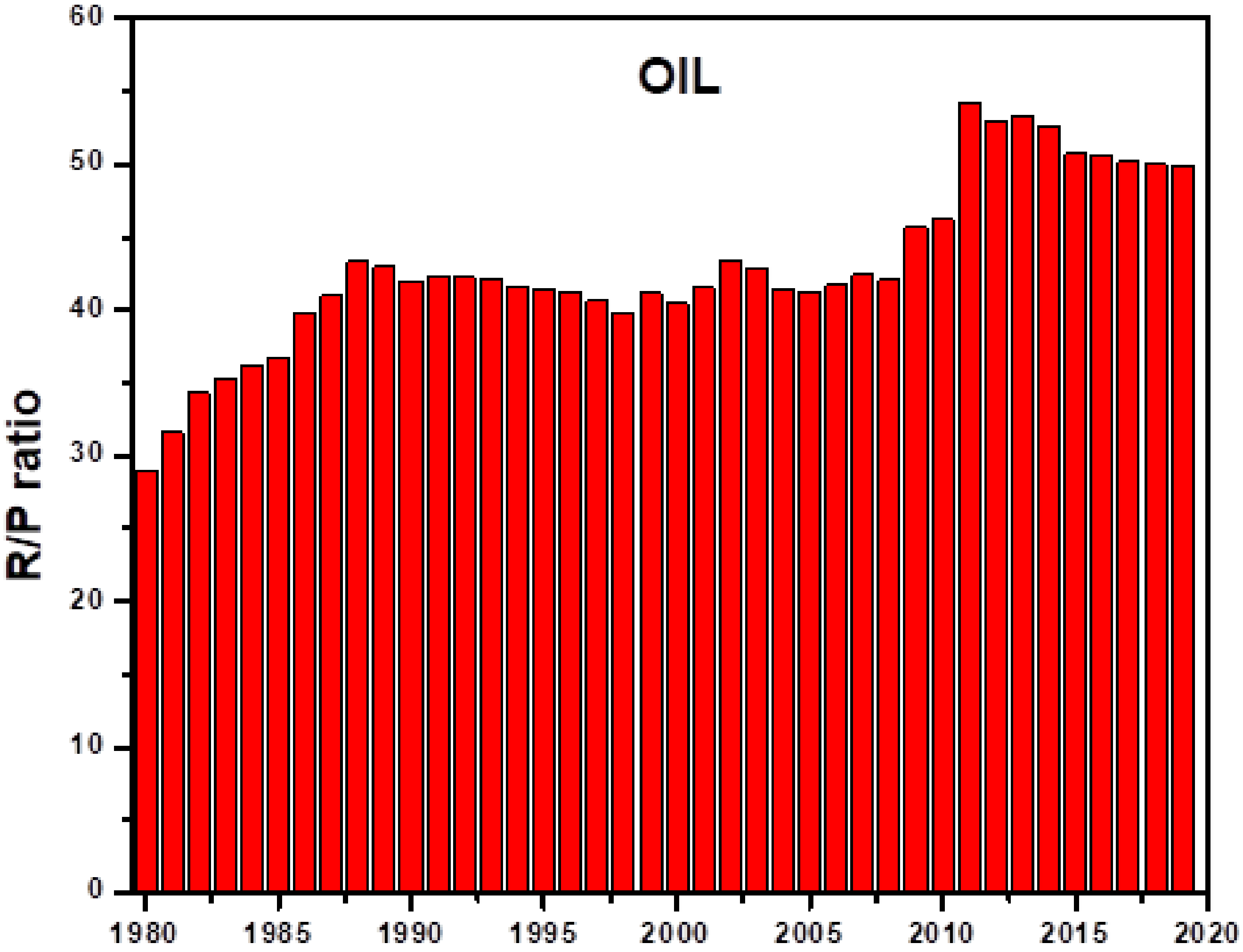
WWF 4th Int. Conf. The Fragile Earth: Strategies for Survival, San Francisco (1976).



US crude oil production from the 48 contiguous states showing a decline starting after 1973 (b), US anthracite production (c) and UK coal production (d)



Source: BP Statistical Review of World Energy


OIL
R/P ratio
0
10
20
30
40
50
60
1980
1985
1990
1995
2000
2005
2010
2015
2020

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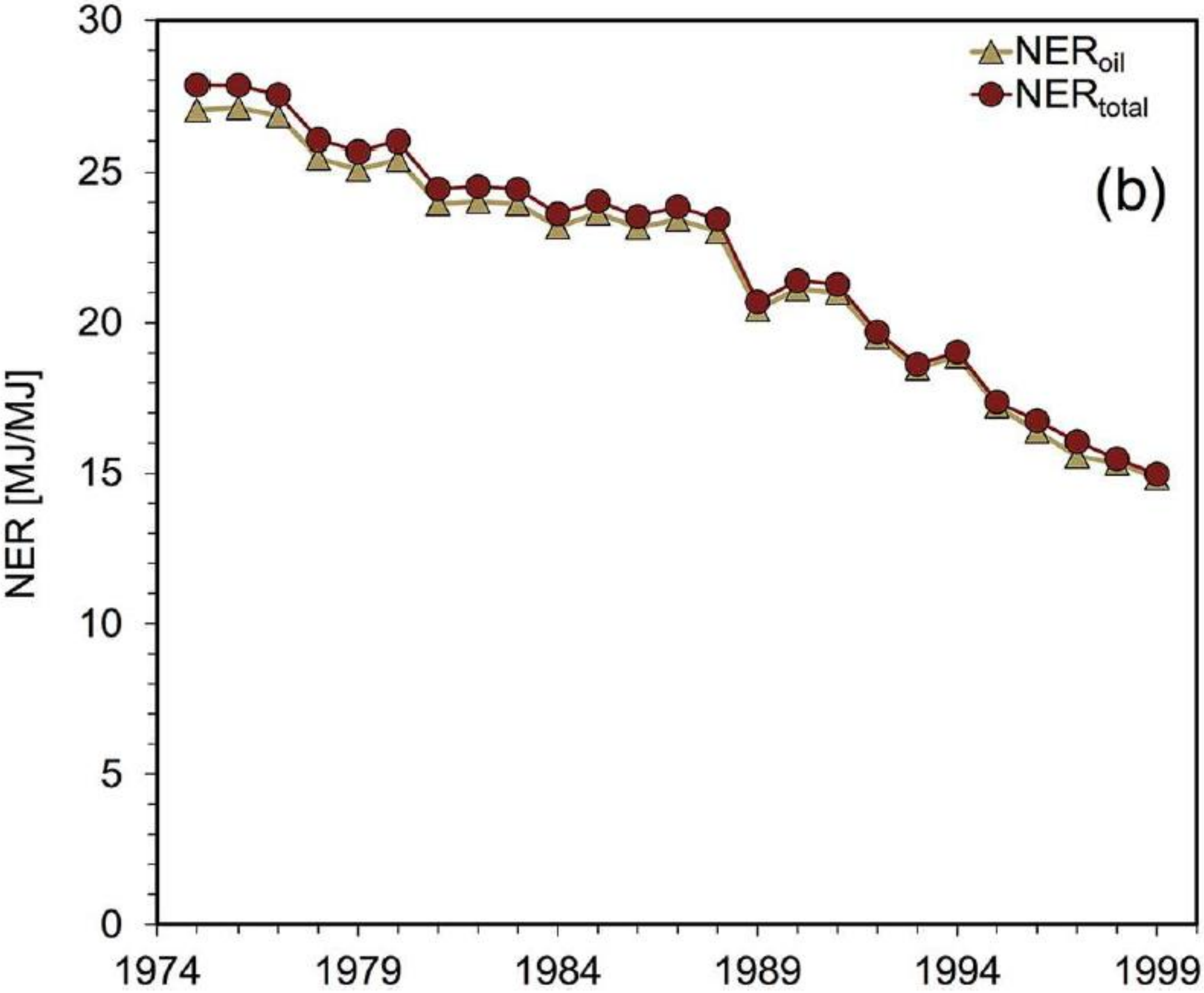
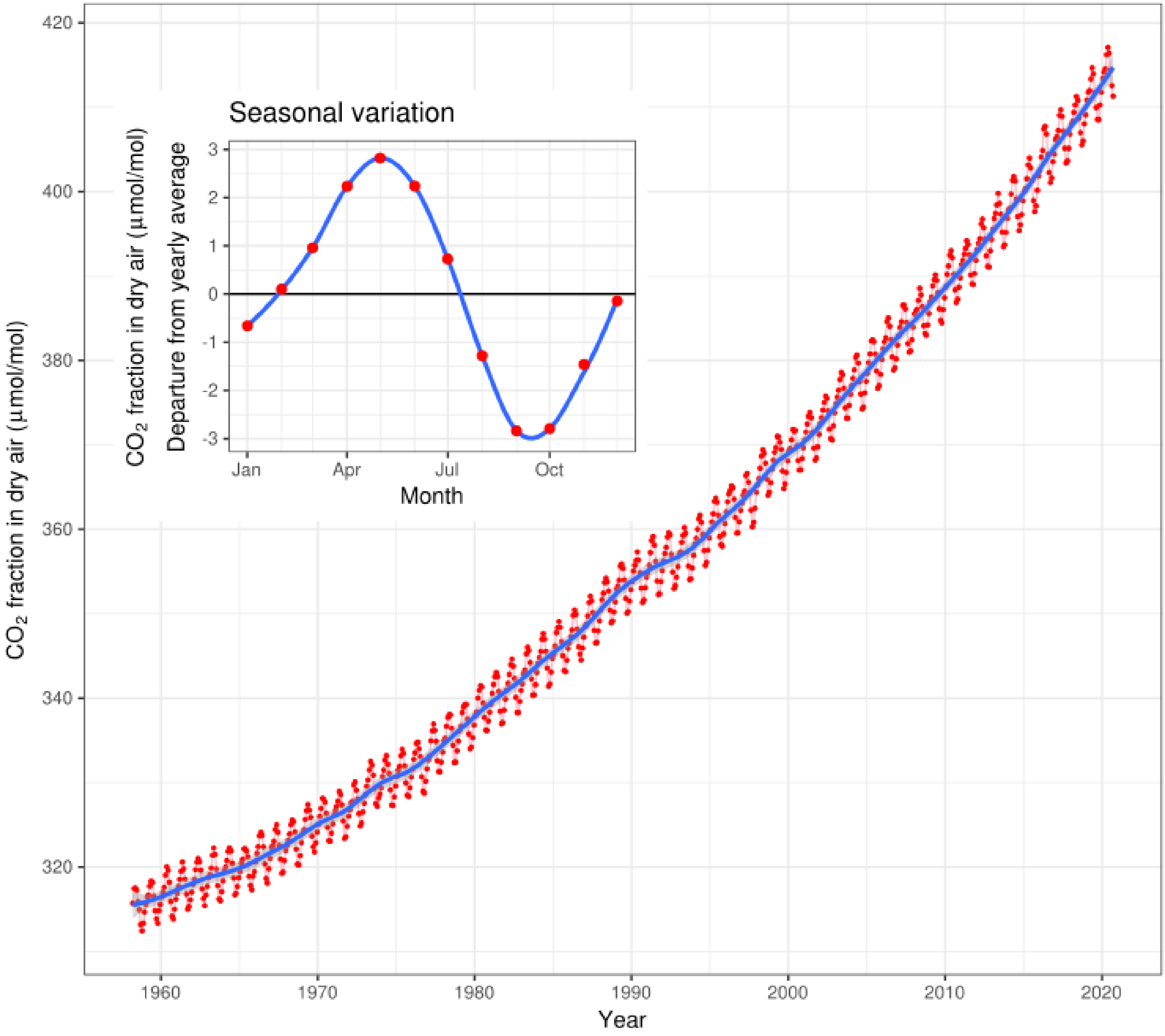


Source: Tripathi and Brand, (2017) PLoS ONE, 12(2), e0171083.

Monthly mean CO_2 concentration

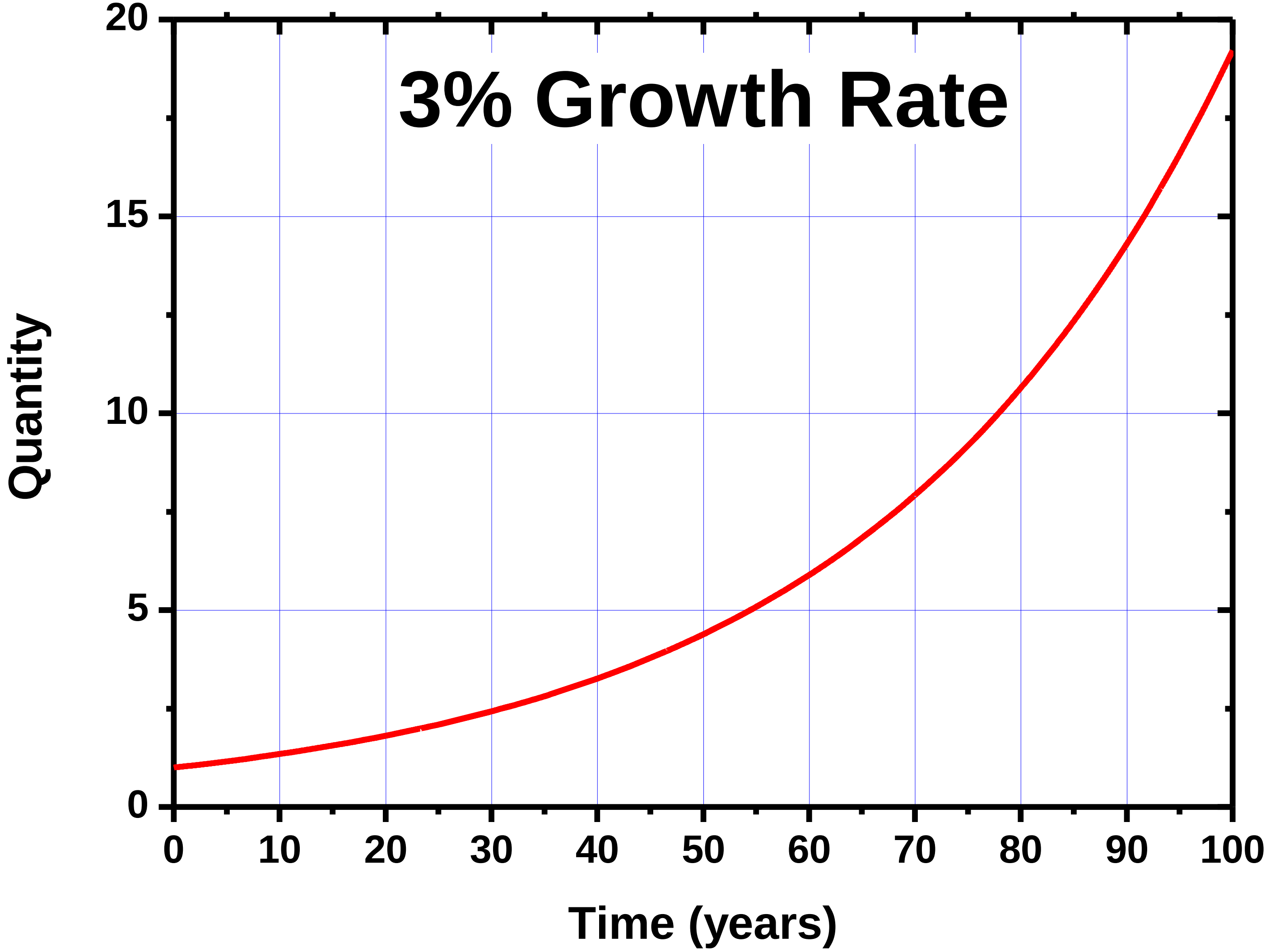
Mauna Loa 1958 - 2020

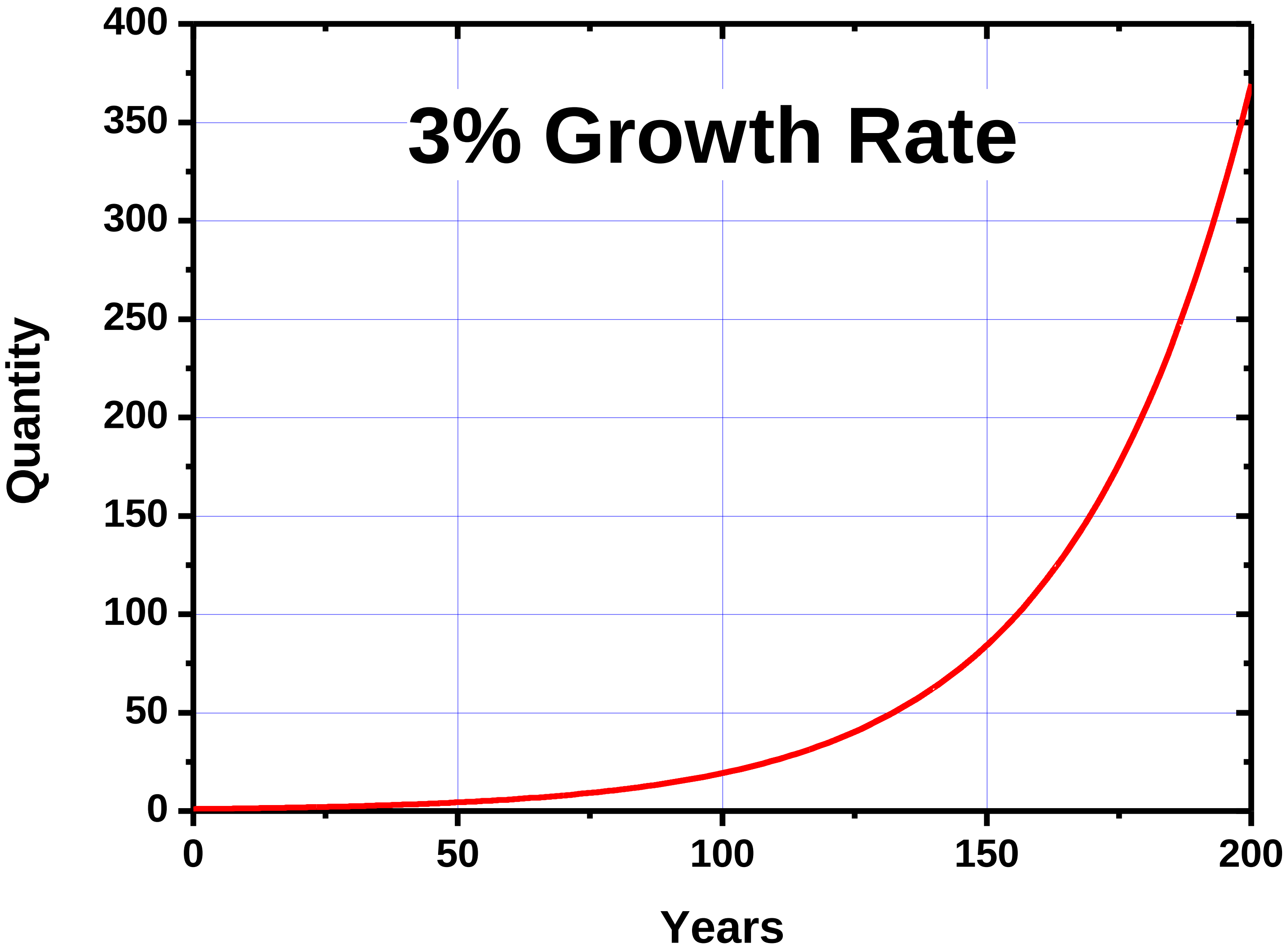


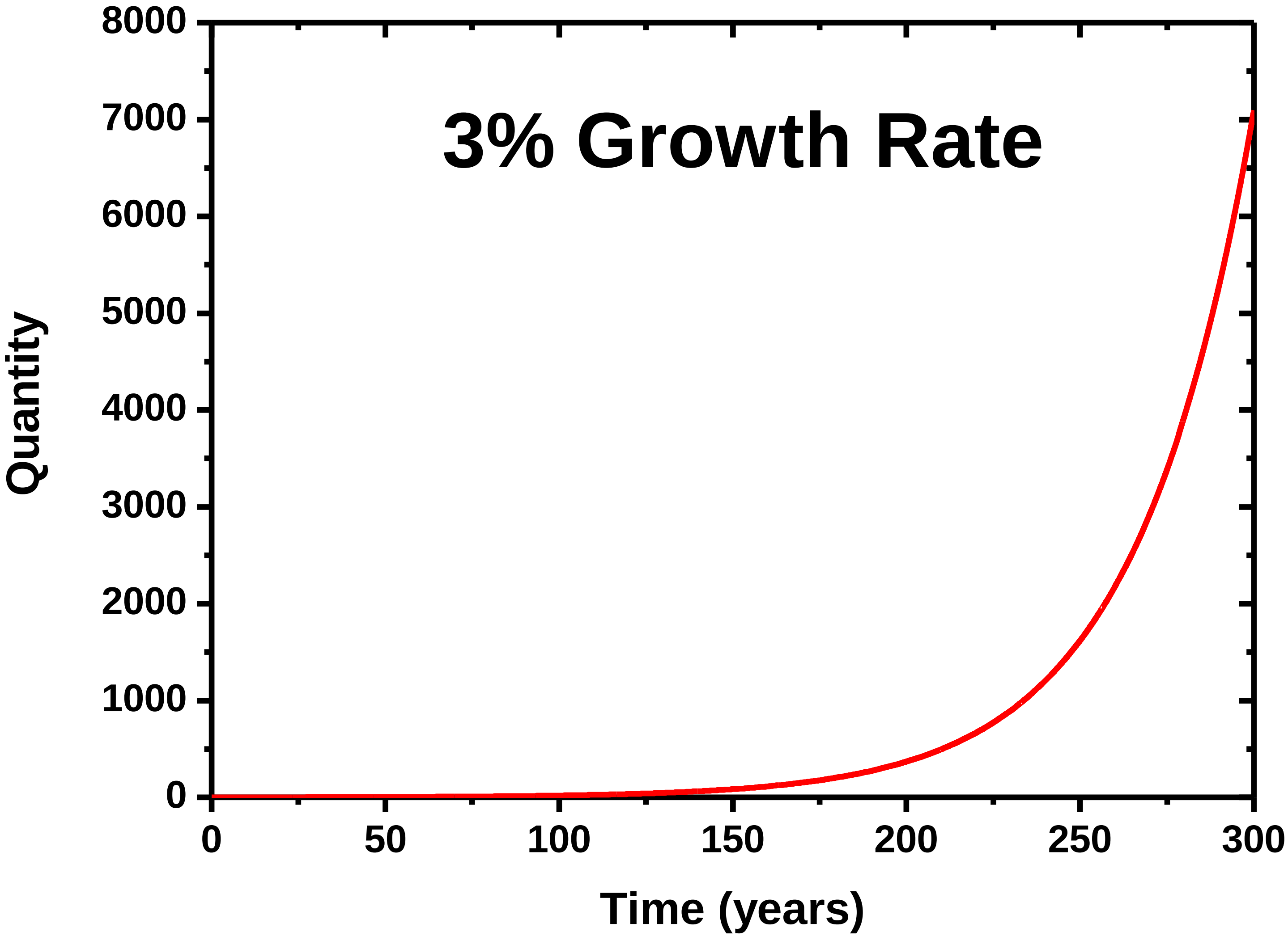
Data : Dr. Pieter Tans, NOAA/ESRL (www.esrl.noaa.gov/gmd/ccgg/trends/) and
Dr. Ralph Keeling, Scripps Institution of Oceanography (scrippsco2.ucsd.edu/). Accessed 2020-10-31

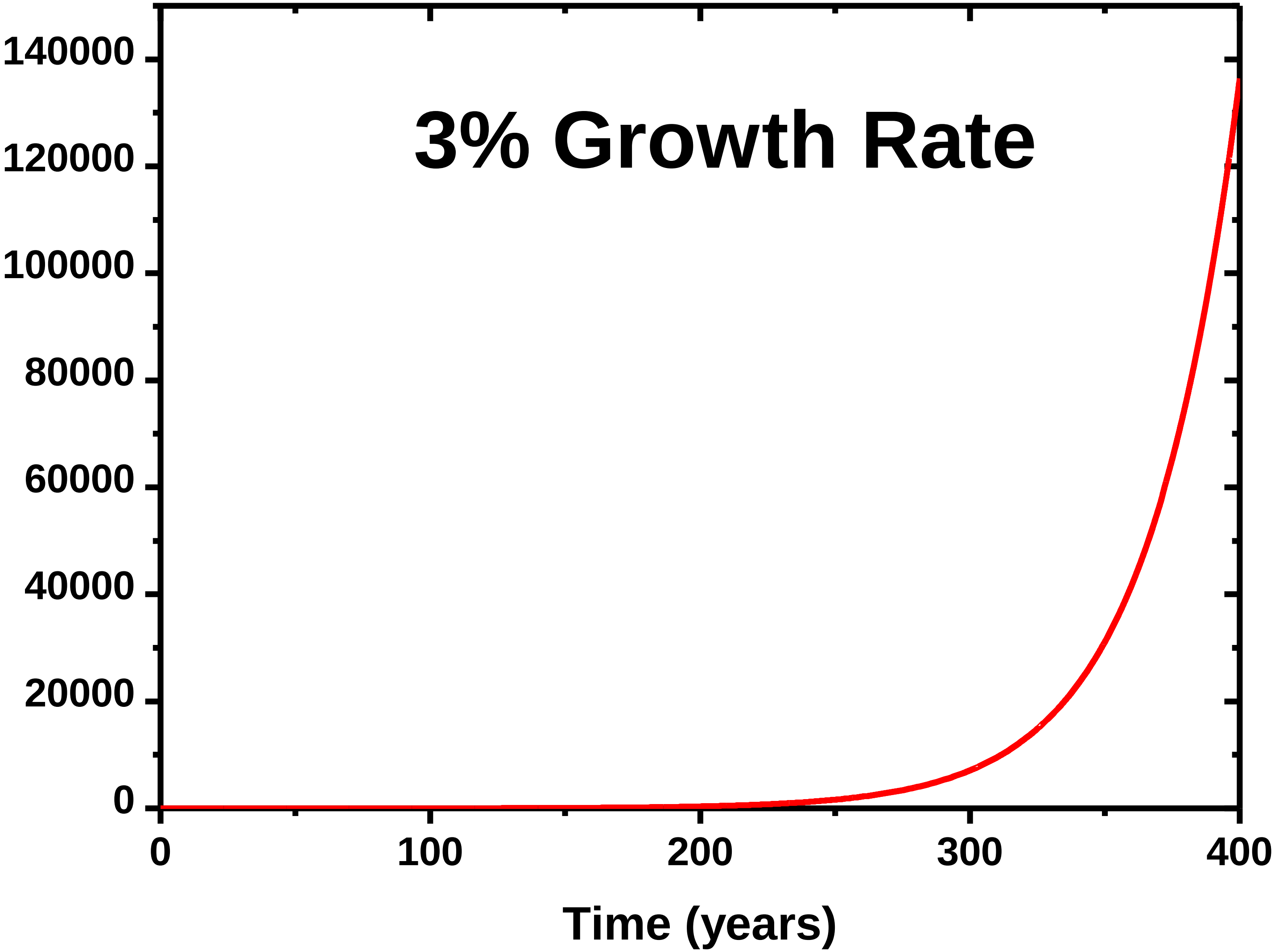
Economic Growth

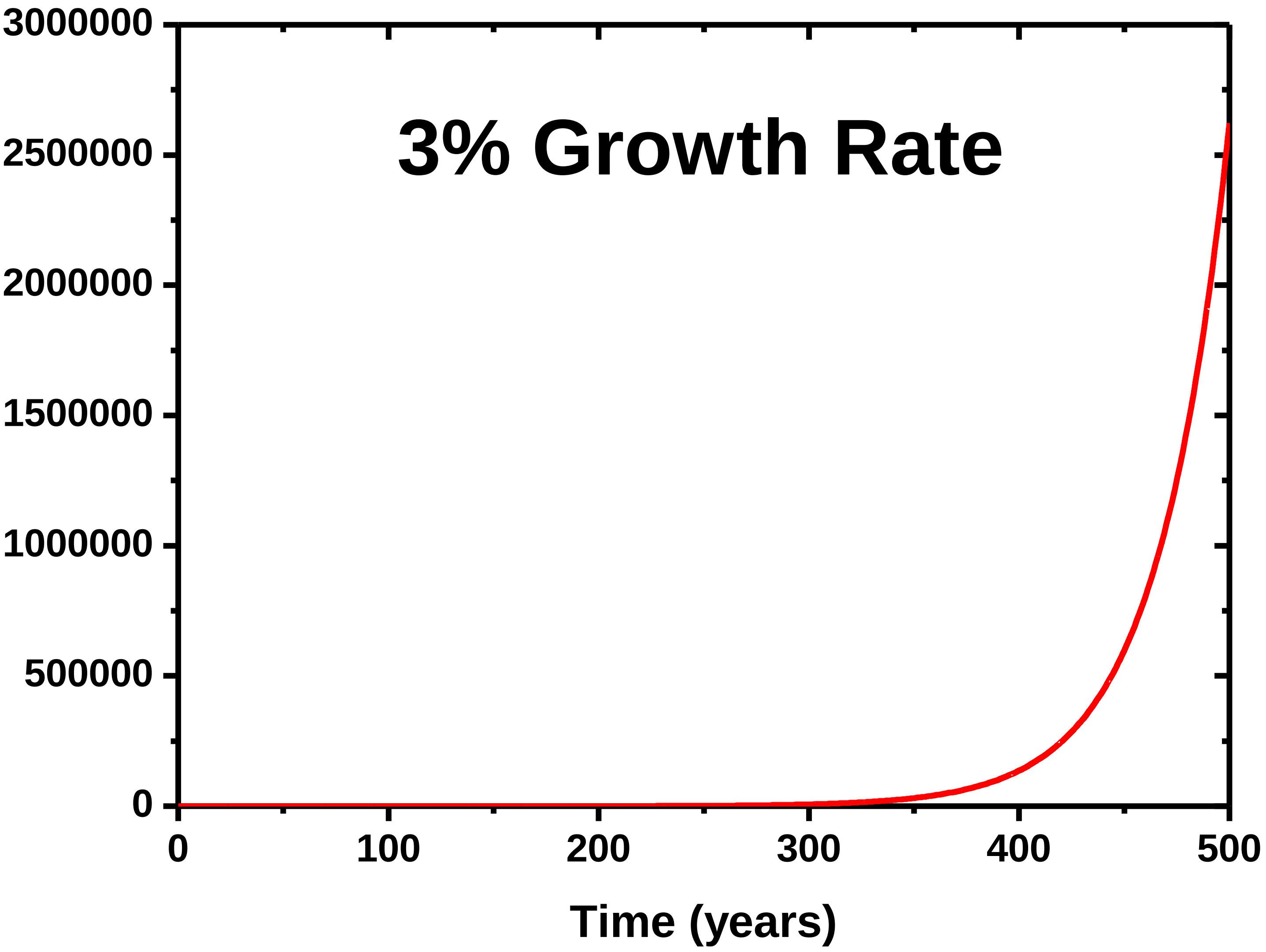
Sustainable?

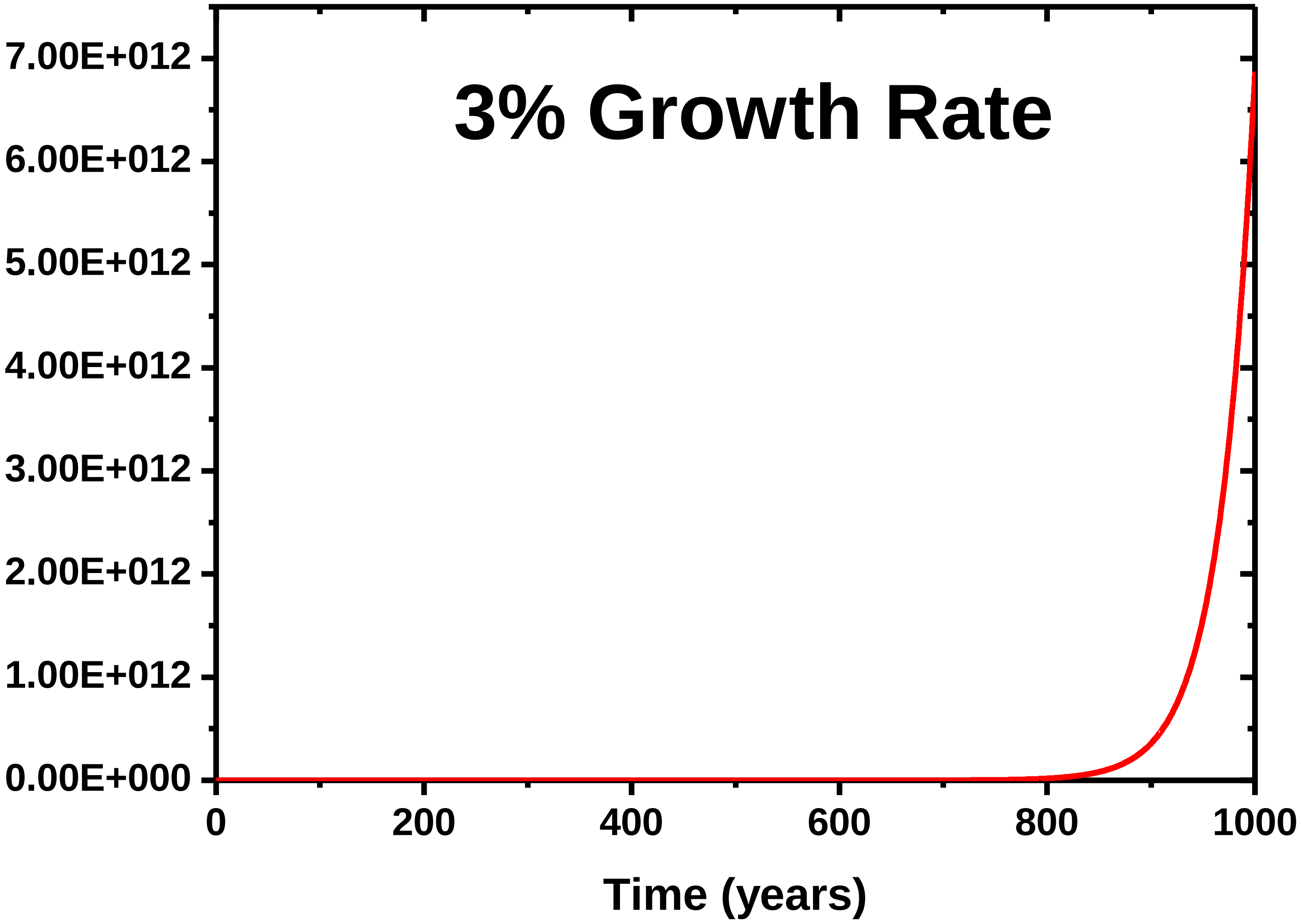

3% Growth Rate
Quantity
0
5
10
15
20
0
10
20
30
40
50
60
70
80
90
100
Time (years)

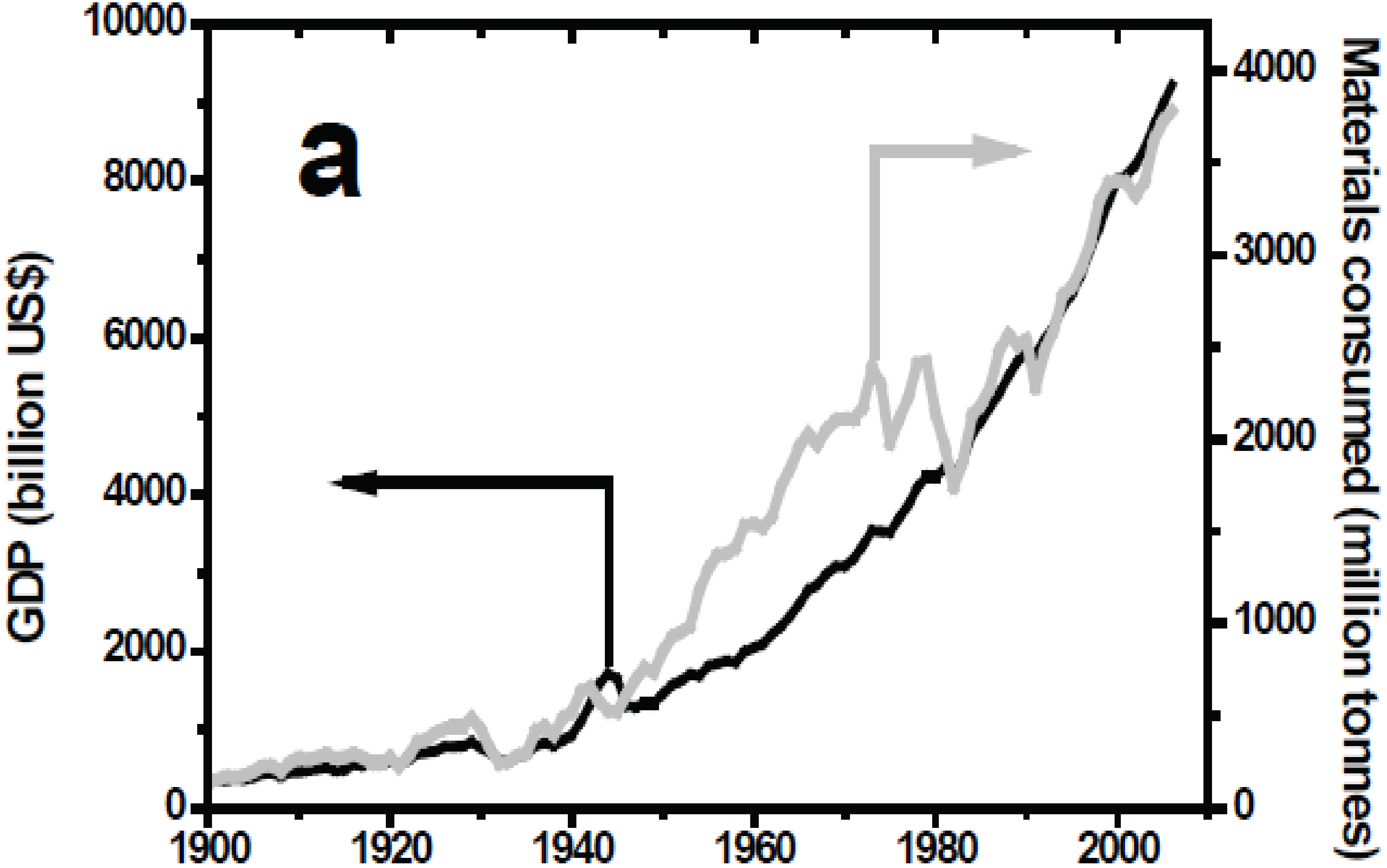

3% Growth Rate
Quantity
Years
400
350
300
250
200
150
100
50
0
0
50
100
150
200


3% Growth Rate
Quantity
8000
7000
6000
5000
4000
3000
2000
1000
0
0
50
100
150
200
250
300
Time (years)


3% Growth Rate
140000
120000
100000
80000
60000
40000
20000
0
0
100
200
300
400
Time (years)


3% Growth Rate
3000000
2500000
2000000
1500000
1000000
500000
0
0
100
200
300
400
500
Time (years)


3% Growth Rate
7.00E+012
6.00E+012
5.00E+012
4.00E+012
3.00E+012
2.00E+012
1.00E+012
0.00E+000
0
200
400
600
800
1000
Time (years)


a
GDP (billion US$)
10000
8000
6000
4000
2000
0
Materials consumed (million tonnes)
4000
3000
2000
1000
0
1900
1920
1940
1960
1980
2000

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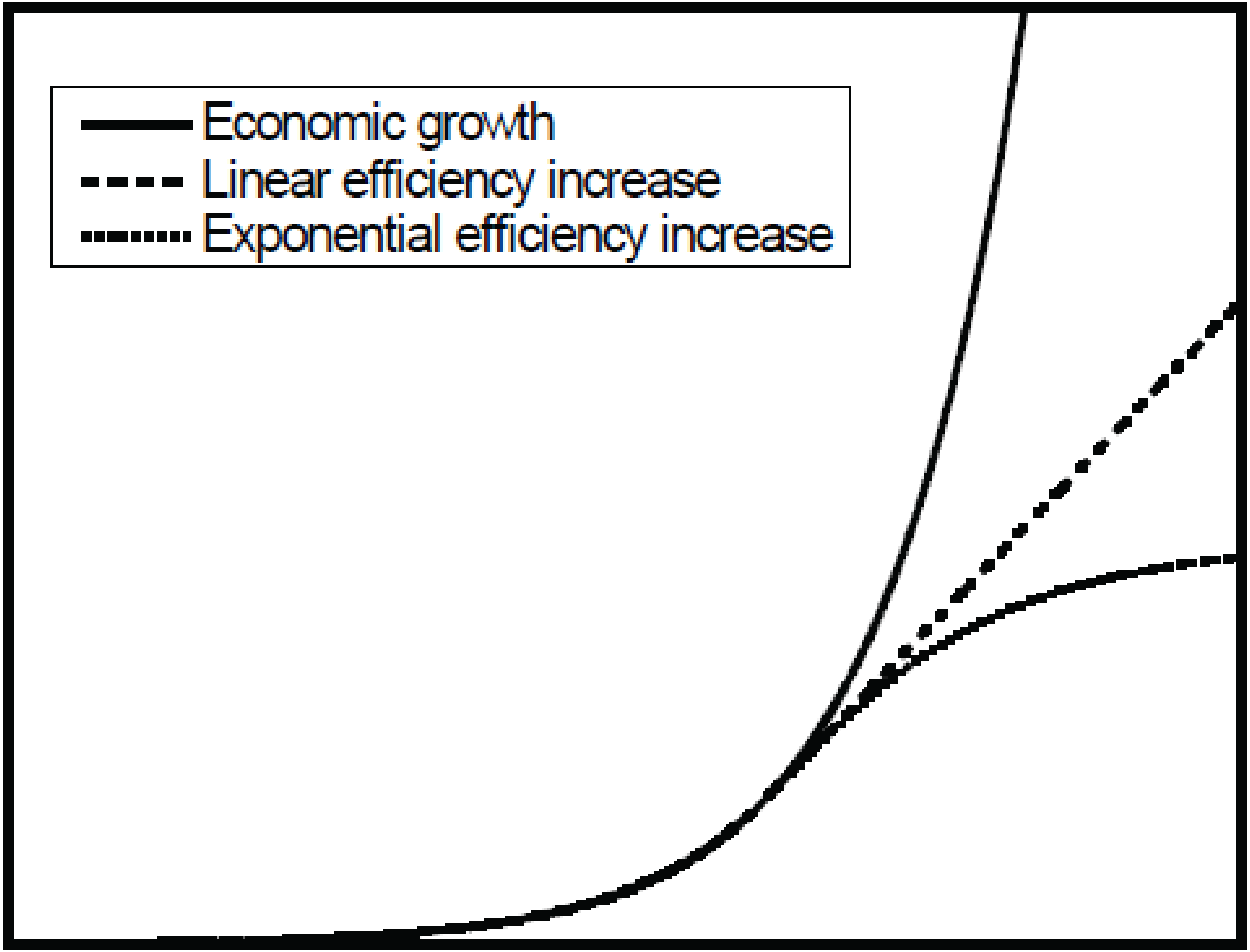
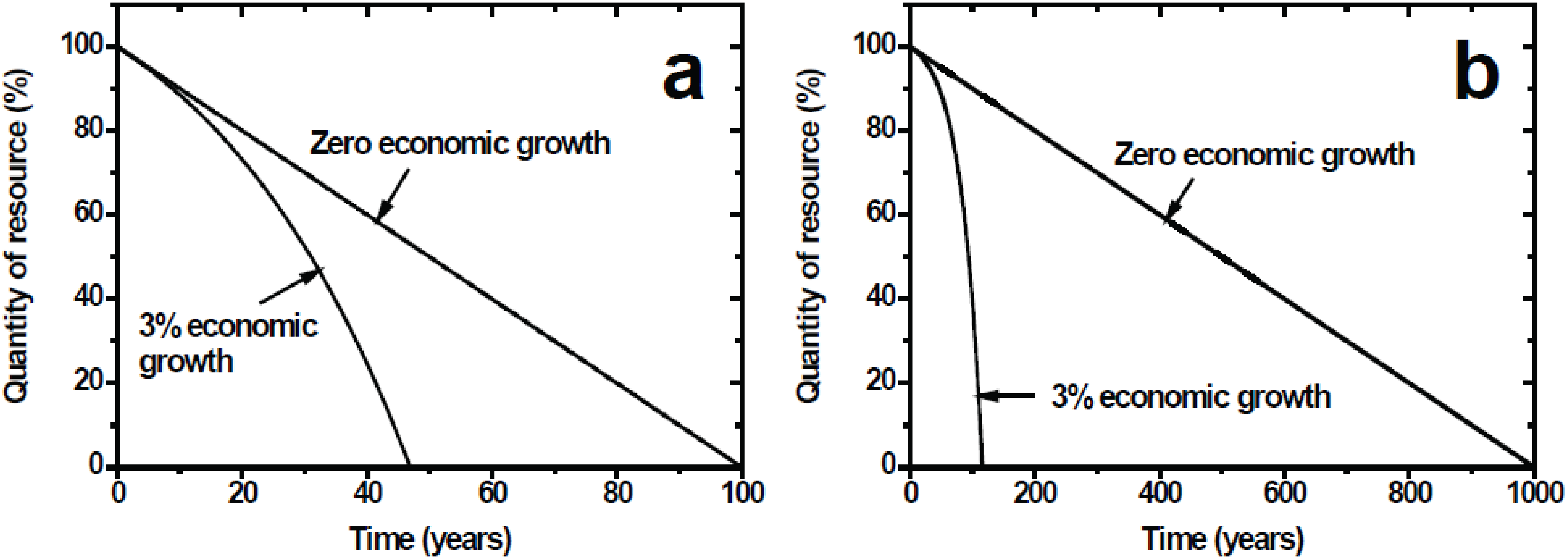
Technology will save us?

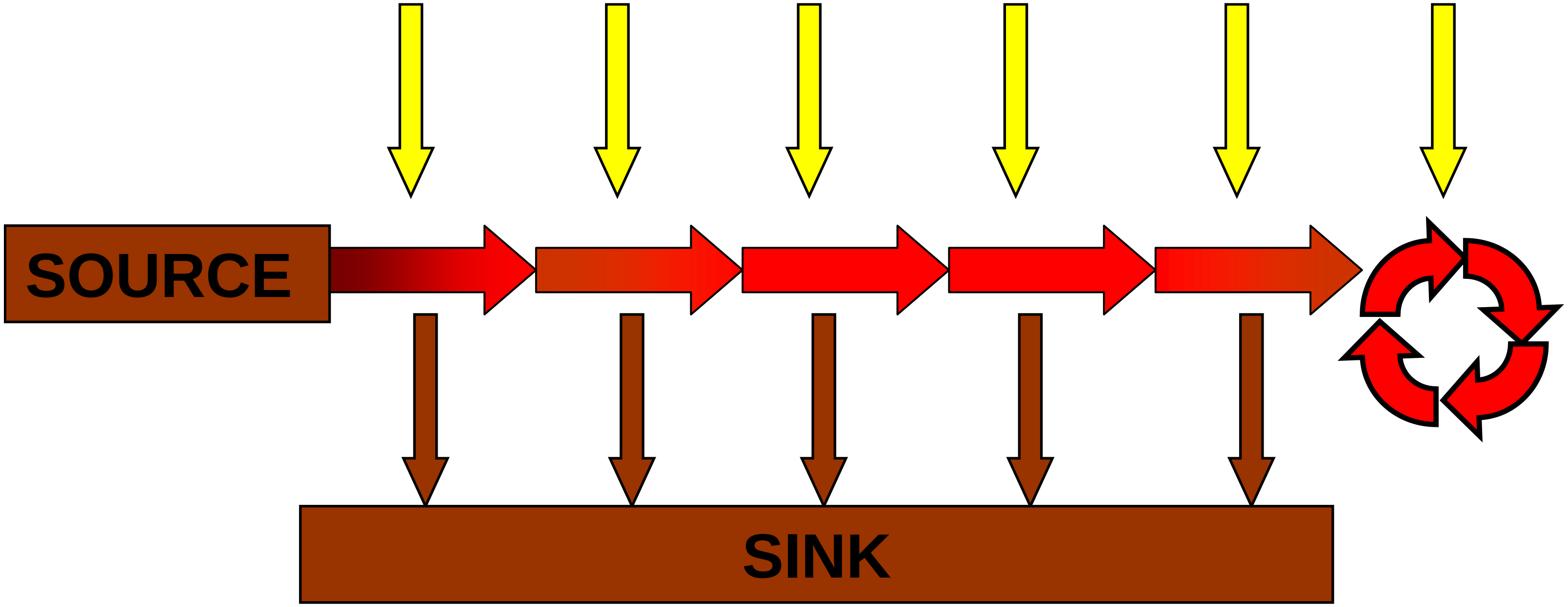
- *Factor Four* – Ernst von Weizsacker
- *The Ultimate Resource* – Ted Simon
- *The Solar Economy* – Hermann Scheer

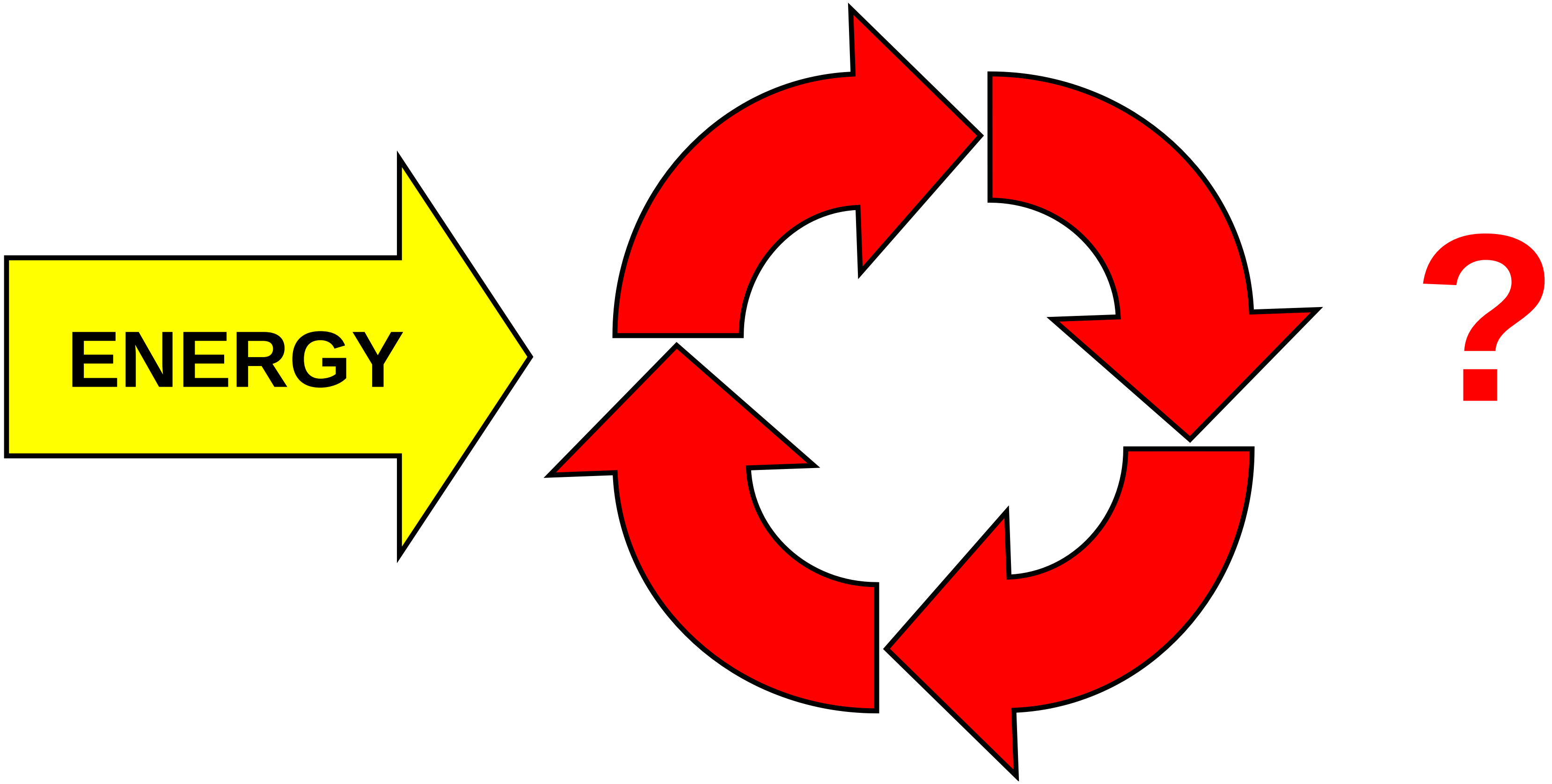

Economic growth
Linear efficiency increase
Exponential efficiency increase



x10 efficiency gain

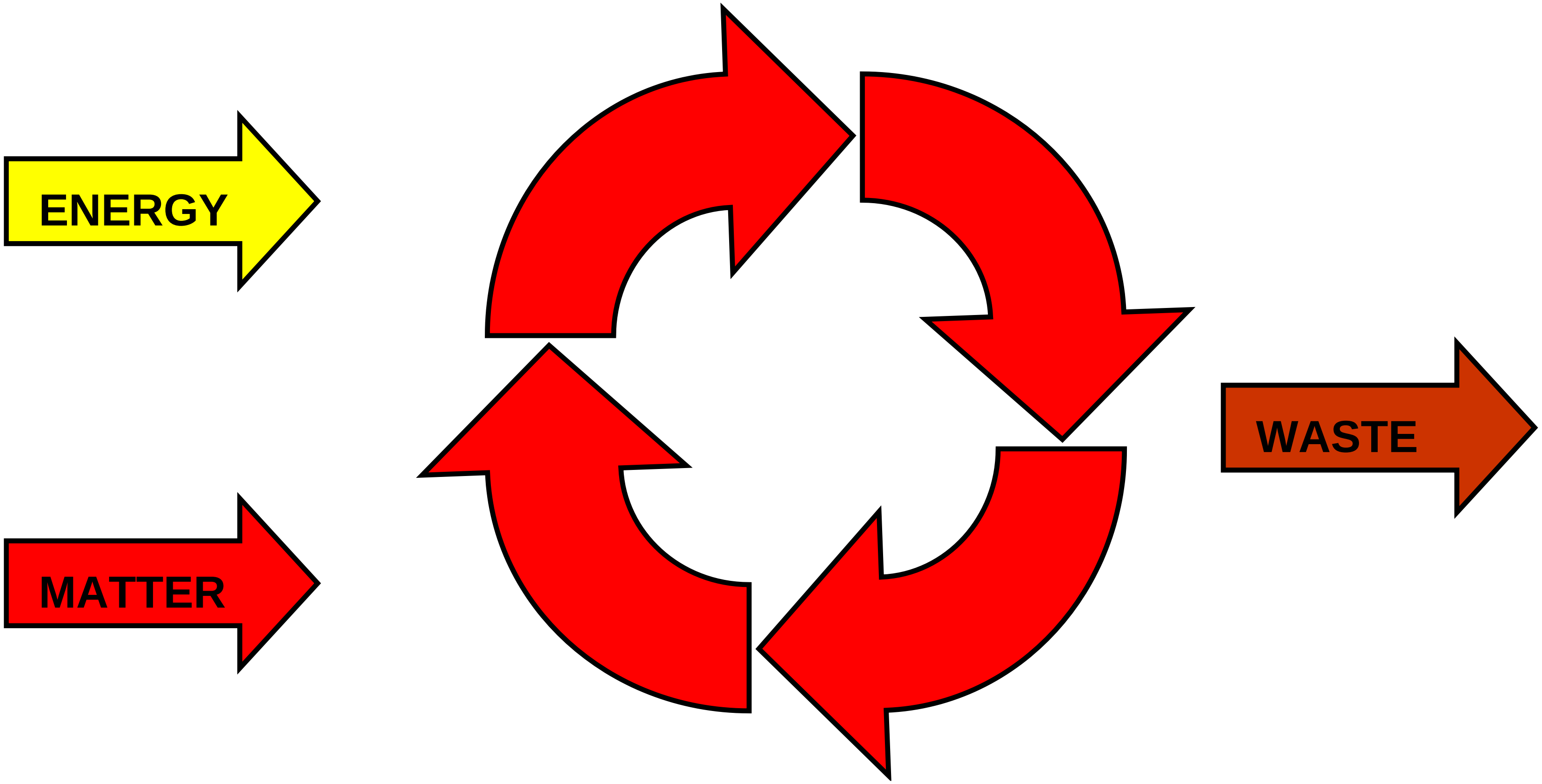
The Circular Economy


SOURCE
SINK



ENERGY

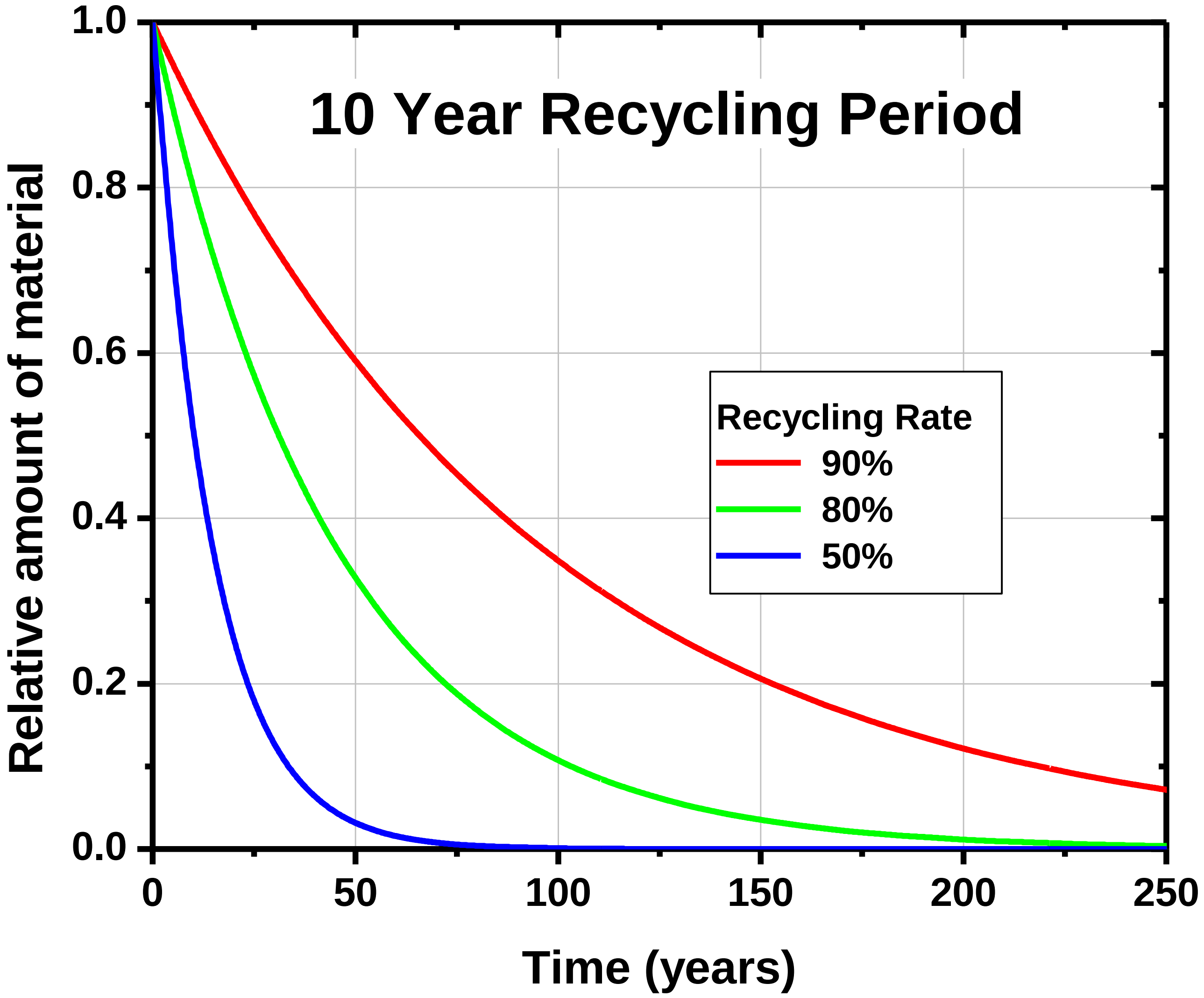
?

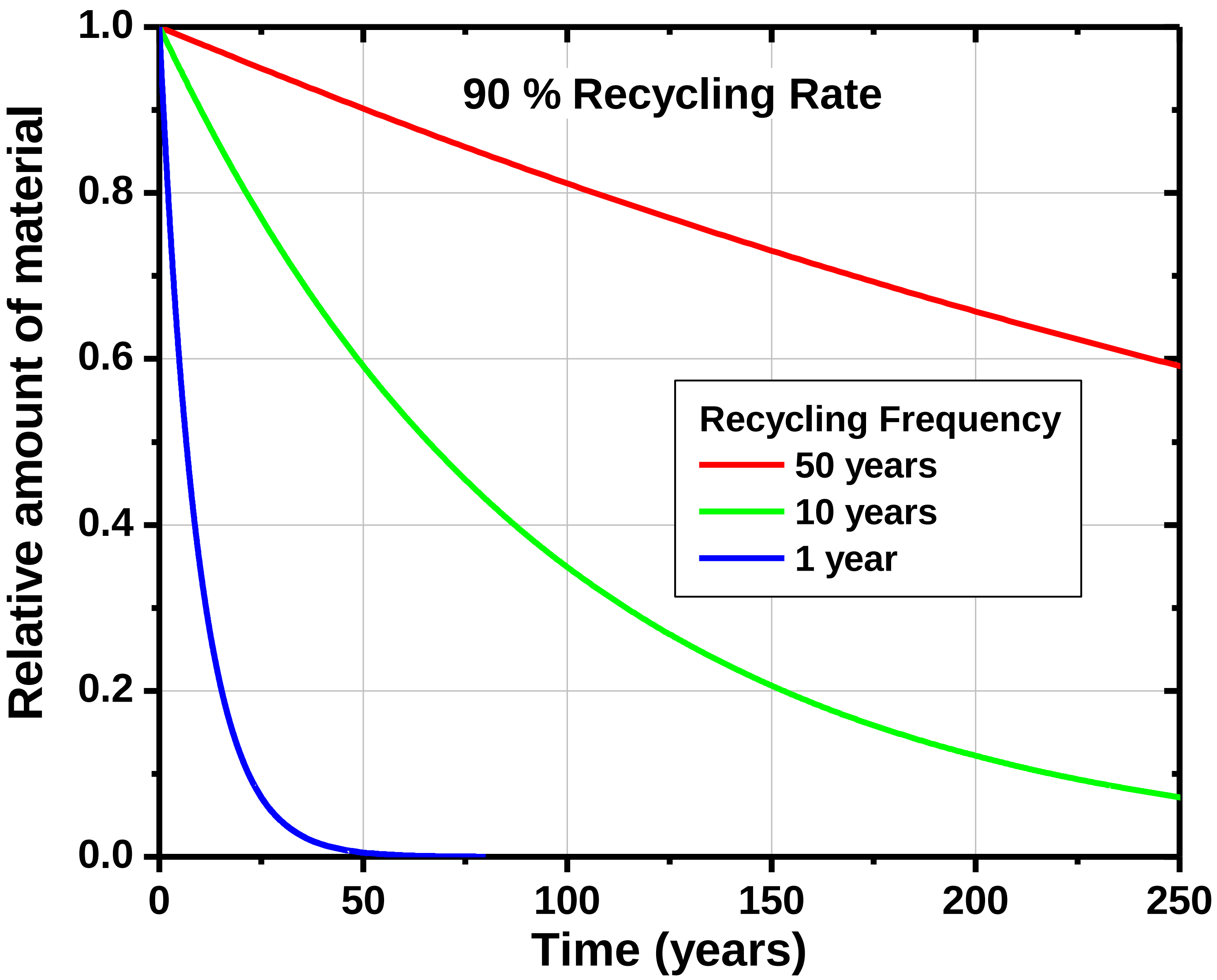


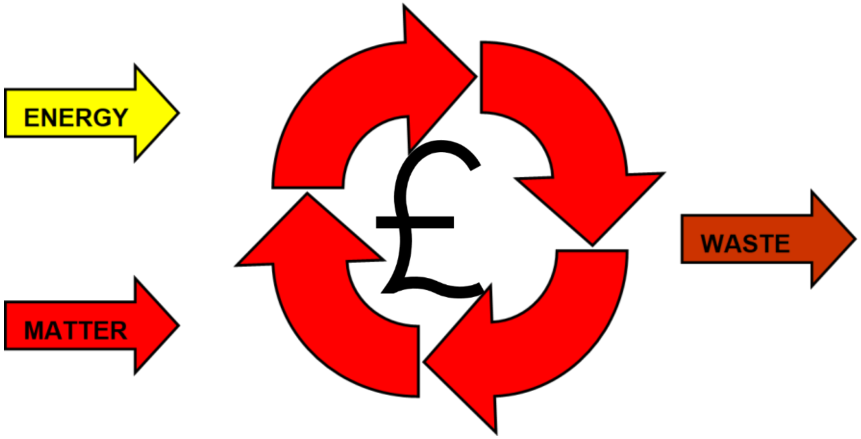
ENERGY

MATTER

WASTE


10 Year Recycling Period
Relative amount of material
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
250
Time (years)
Recycling Rate
90%
80%
50%


90 % Recycling Rate
Relative amount of material
Time (years)
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
250
Recycling Frequency
50 years
10 years
1 year

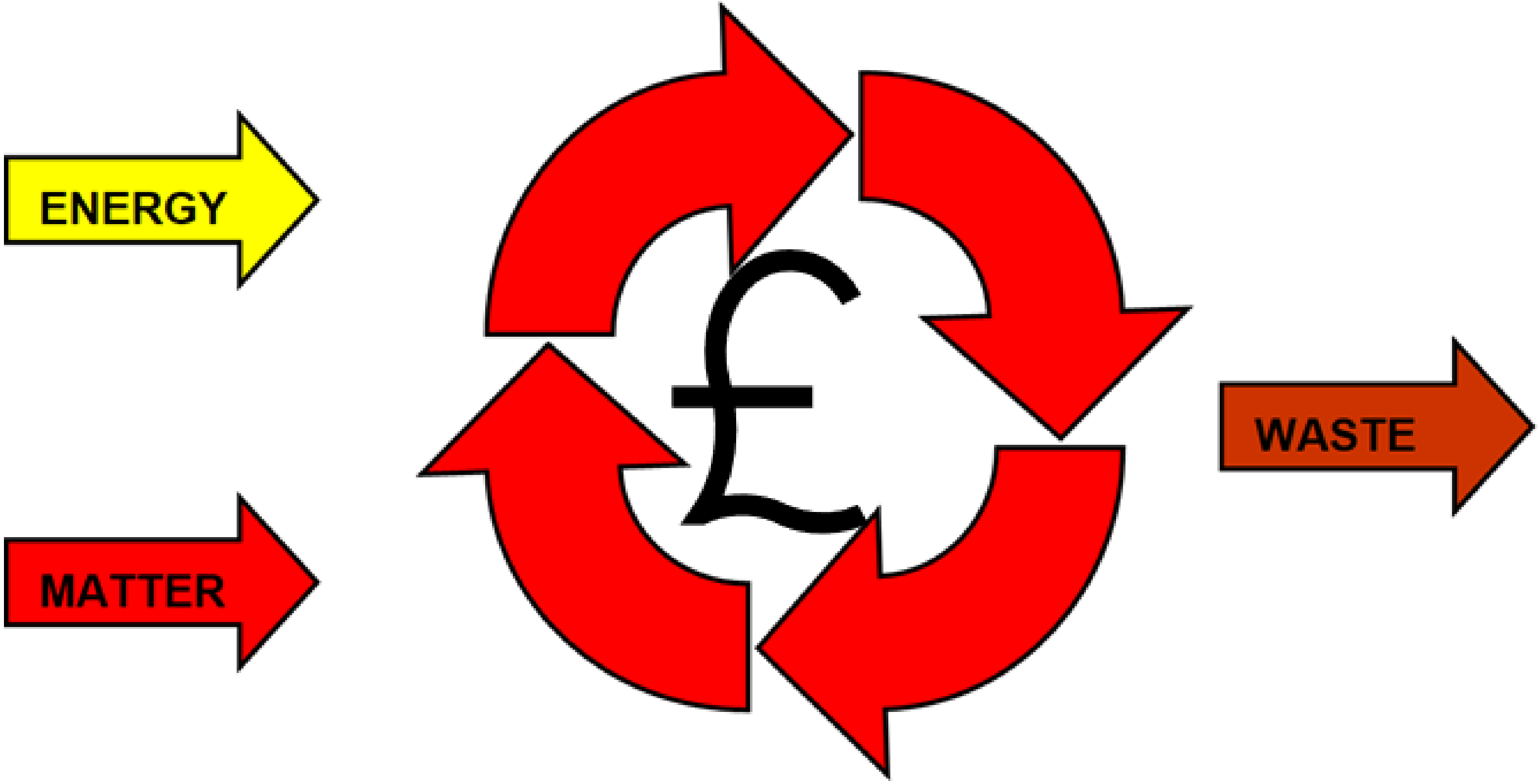


ENERGY

MATTER

£

WASTE



ENERGY

MATTER

£

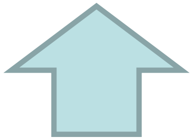
WASTE

$$I = P \times A \times T$$

$$I = P \times A \times T$$

↑

$$I = P \times A \times T$$



$$I = P \times A \times T$$

↑

?

nature sustainability

PERSPECTIVE
https://doi.org/10.1038/s41893-019-0462-4

Buildings as a global carbon sink

Galina Churkina[1,2]*, Alan Organschi[3,4], Christopher P. O. Reyer[2], Andrew Ruff[3], Kira Vinke[2], Zhu Liu[5], Barbara K. Reck[1], T. E. Graedel[1] and Hans Joachim Schellnhuber[2]

The anticipated growth and urbanization of the global population over the next several decades will create a vast demand for the construction of new housing, commercial buildings and accompanying infrastructure. The production of cement, steel and other building materials associated with this wave of construction will become a major source of greenhouse gas emissions. Might it be possible to transform this potential threat to the global climate system into a powerful means to mitigate climate change? To answer this provocative question, we explore the potential of mid-rise urban buildings designed with engineered timber to provide long-term storage of carbon and to avoid the carbon-intensive production of mineral-based construction materials.

During the Carboniferous period, giant fern-like woody plants grew in vast swamps spread across the Earth's surface. As successions of these plants grew and then toppled, they accumulated as an increasingly dense mat of fallen plant matter. Some studies have suggested that this material resisted decay because microbes that would decompose dead wood were not yet present[1], while others have argued that a combination of climate and tectonics buried the dead wood and prevented its decomposition[2]. Over millions of years, geological pressures and temperatures transformed that accretion of organic matter into fossil fuel deposits (Fig. 1, left panel). Since the advent of the industrial revolution in the mid-nineteenth century, these deposits have been continuously extracted and burned to fuel the industrialization required to meet the demands for products and infrastructure of a burgeoning population, leading to substantial increases in atmospheric concentrations of carbon dioxide (CO_2) (Fig. 1, middle panel).

High atmospheric CO_2 concentrations, longer growing seasons, warmer temperatures, forest regrowth and increasing nitrogen mineralization have been identified as the main drivers of current increases in the productivity of vegetation globally[3–5]. In recent decades, the world's forests have served as a net sink of carbon (1.1 ± 0.8 GtC yr^{-1}) with living tree biomass accumulating most of it[6]. While local[7] and global[8] studies suggest that climate change will likely enhance forest growth in the future, it remains unclear how long CO_2 fertilization effects, especially in nitrogen-limited forests, will persist[9] and continue mitigating climate change. Enhanced carbon sequestration in forests may be reinforced, counteracted or even offset by concurrent changes in surface albedo, land-surface roughness, emissions of biogenic volatile organic compounds, transpiration and sensible heat flux[10]. Moreover, storing carbon in forests over the long term becomes less reliable because of the changing dynamics of forest disturbances such as fire, wind and insect outbreaks, which are closely linked to climate change[11,12] and can decrease forest growth and storage of carbon in forests[13]. For example, droughts and frequent heat waves have been shown to reduce forest productivity and net carbon uptake[14,15].

The organic deposits of modern forests will not accumulate in large quantities underground as in the Carboniferous period, nor replenish the underground carbon pool naturally because soil microorganisms, plant species and Earth's climate have inevitably evolved. Furthermore, current rates of fossil fuels combustion have far exceeded carbon sequestration rates in forests creating the need for national governments to submit reduction targets for CO_2 emissions to the United Nations Framework Convention on Climate Change (UNFCCC) as part of their obligations under the Paris Agreement[16]. However, even if all governments were to achieve their commitments, anthropogenic CO_2 emissions would exceed the carbon budget range associated with the agreement[17]. The mitigation pathways presented by the Intergovernmental Panel on Climate Change (IPCC)[18] try to account for this dilemma by introducing large-scale carbon extraction schemes, mainly based on bioenergy with carbon capture and storage, which are supposed to reconcile the budget. These schemes convert biomass to heat, electricity, or liquid or gas fuels and couple that activity with storing the CO_2 on land or in the ocean. Such an approach poses socio-economic risks[19] and threats to natural ecosystems[20,21].

Barring global-scale disasters of natural and human-caused origin, the coming decades will be characterized by demographic and economic growth in many parts of our planet. This will result in accelerated urbanization—UN projections foresee 2.3 billion new urban dwellers by 2050[22]—and entails the production of an enormous volume of housing and infrastructure. We propose to exploit this projected demand for urban buildings as a means to mitigate climate change. By employing bio-based materials, technologies and construction assemblies with high carbon storage capacity and low embodied carbon emissions, we can create a durable, human-made global carbon pool while simultaneously reducing CO_2 emissions associated with building sector activities (Fig. 1, right panel). Embodied energy or carbon emissions refer to energy or emissions associated with building construction, including extracting, transporting and manufacturing materials.

The problem

A recent study concluded that if the global population increases to 9.3 billion by 2050[23], then the emissions from the development of new infrastructure could claim 35–60% of a remaining carbon budget[24] based on limiting a global temperature increase to 2 °C. Further reductions in the energy demands and associated greenhouse gas emissions associated with the manufacture of mineral-based construction materials will be challenging, as these industries have already optimized their production processes. Future improvements in energy efficiency

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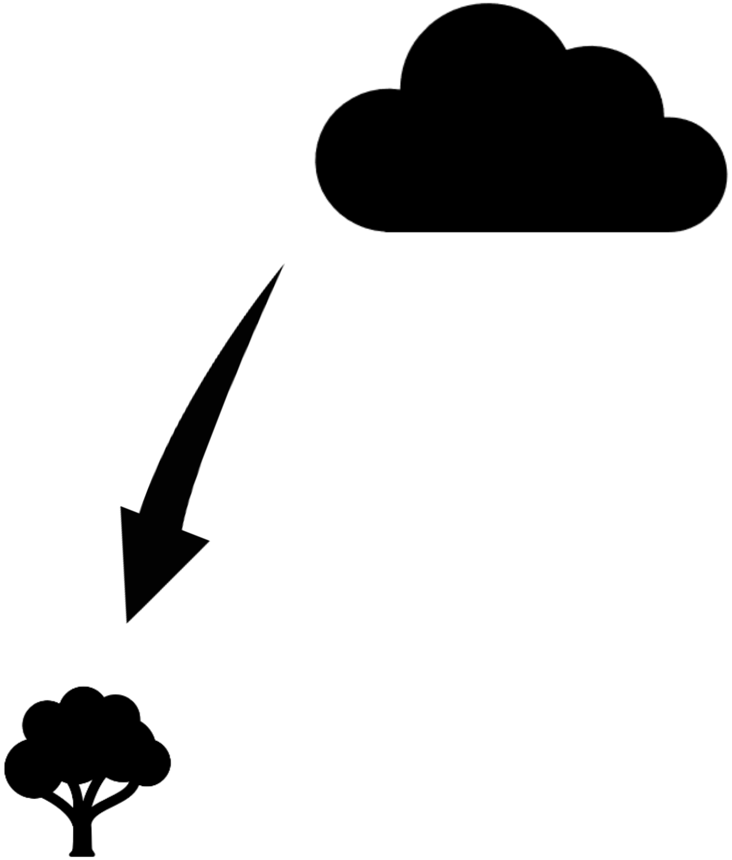
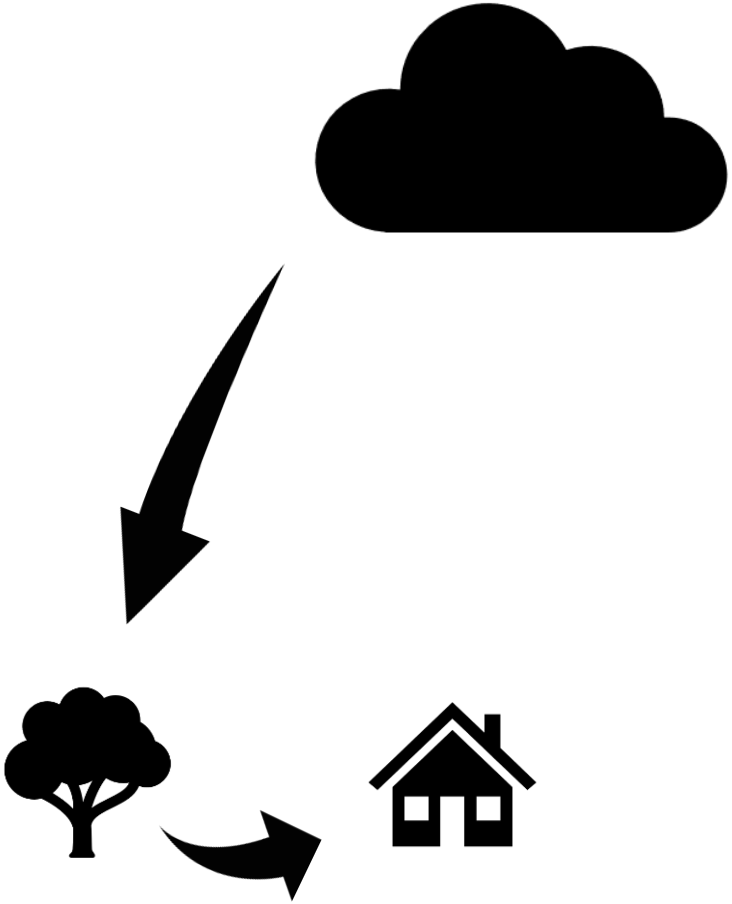
[1] School of Forestry and Environmental Studies, Yale University, New Haven, CT, USA. [2] Potsdam Institute for Climate Impact Research, Member of the Leibniz Association, Potsdam, Germany. [3] Gray Organschi Architecture, Timber City Research Initiative, New Haven, CT, USA. [4] School of Architecture, Yale University, New Haven, CT, USA. [5] Department of Earth System Science, Tsinghua University, Beijing, China. *e-mail: galina@churkina.org





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- *The Population Bomb* – Paul Ehrlich (Anne Ehrlich)
- *Factor Four* – Ernst von Weizsacker
- *Energy in Nature and Society: General Energetics of Complex Systems*– Vaclav Smil
- *The Solar Economy* – Hermann Scheer