

# Finite, infinite o rinnovabili?

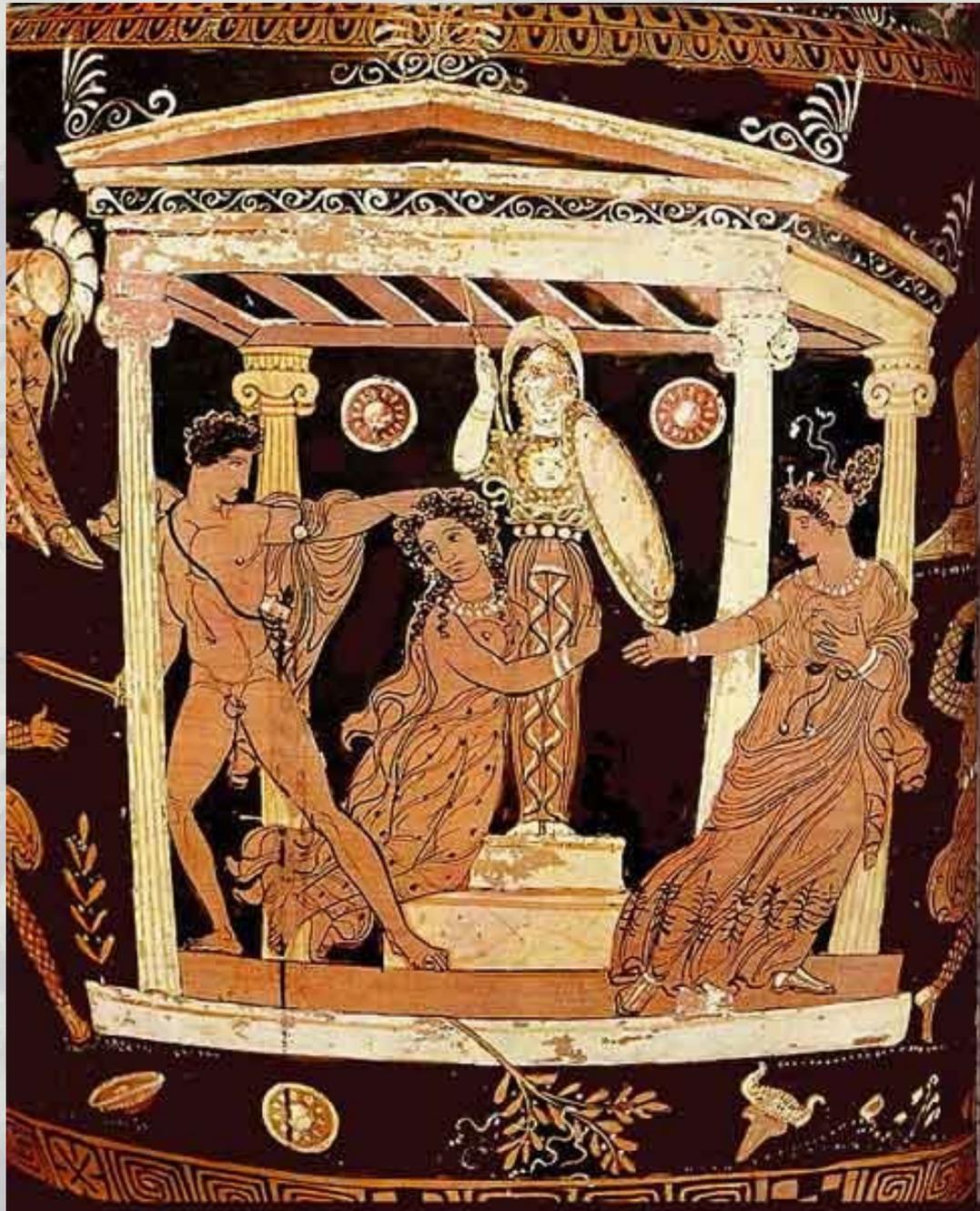
Ugo Bardi  
ASPO-Italia

Università di Firenze

Verbania – 27 Novembre 2009

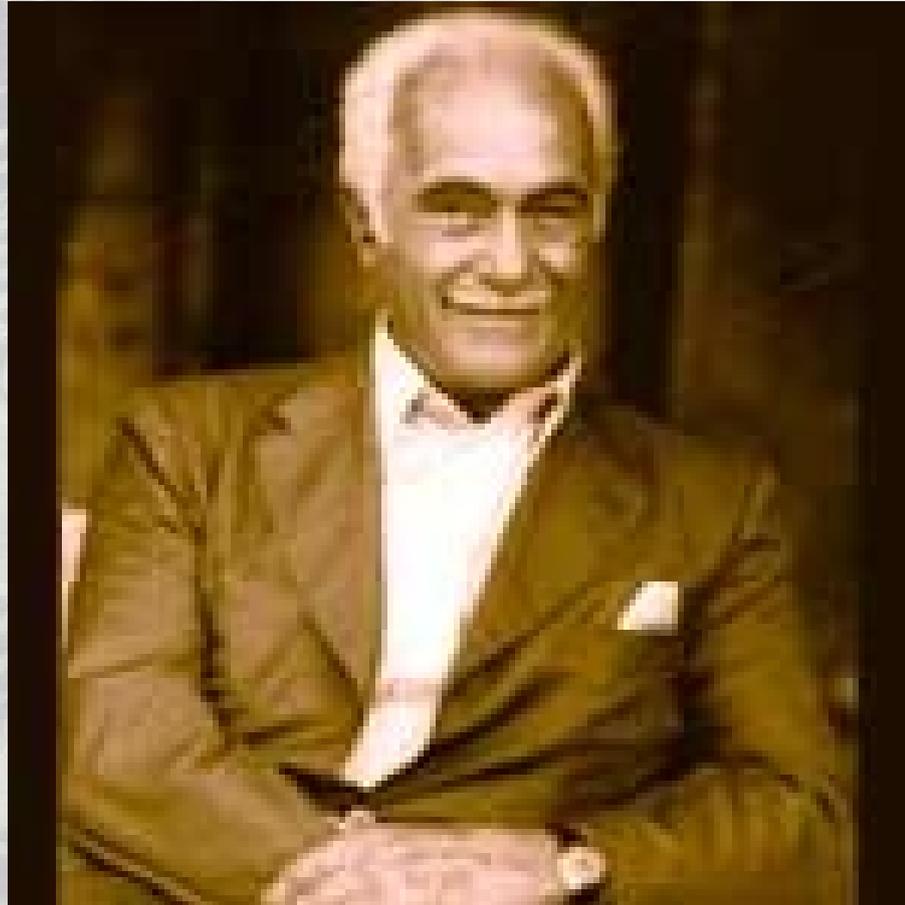


# La Maledizione di Cassandra



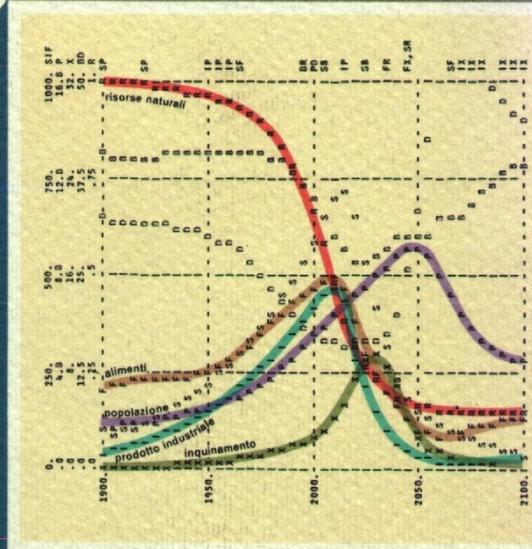


Aurelio Peccei – 1908 -1984



DONELLA H. MEADOWS  
DENNIS L. MEADOWS  
JØRGEN RANDERS  
WILLIAM W. BEHRENS III

prefazione di  
AURELIO PECCEI



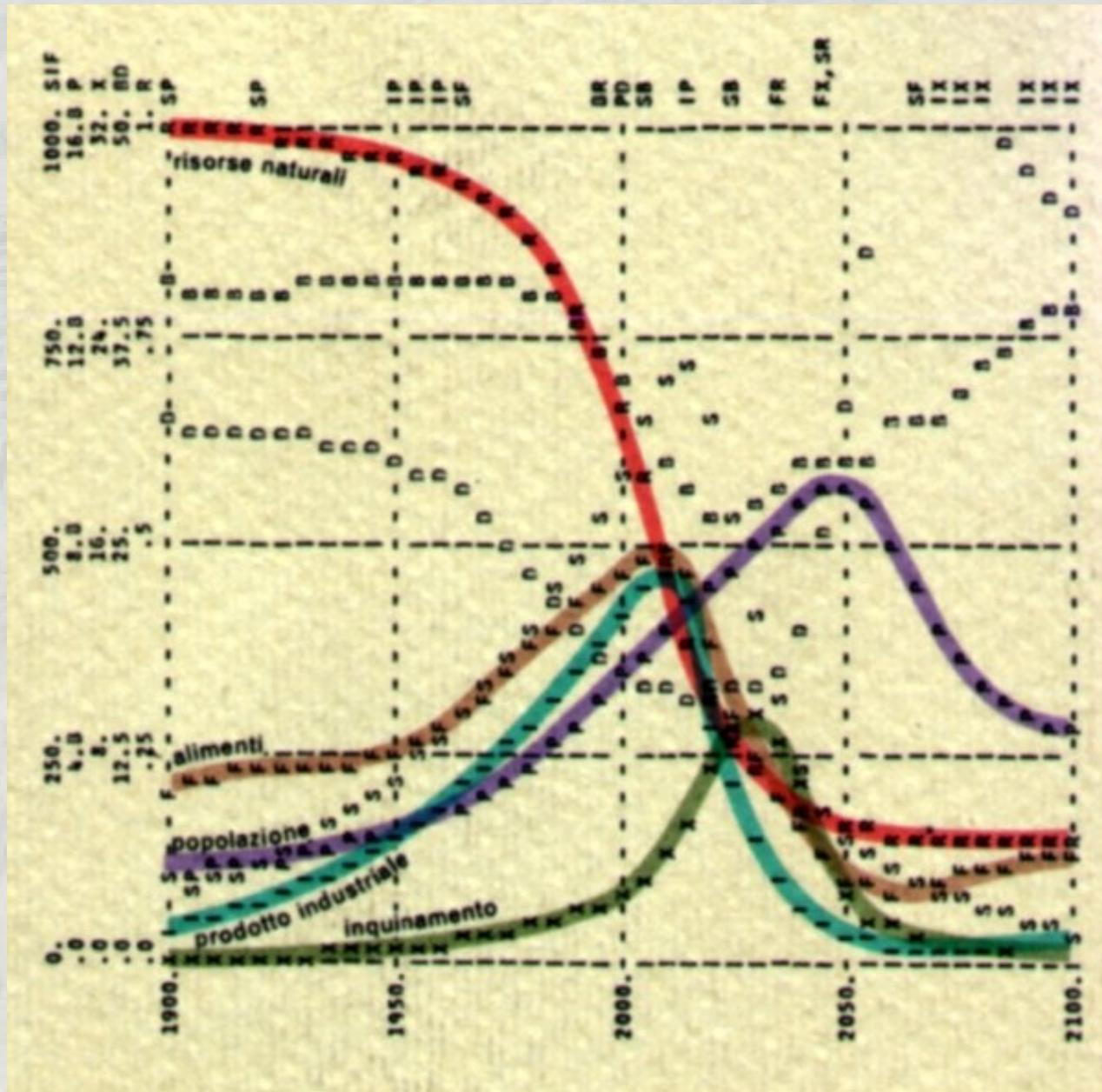
# I LIMITI dello SVILUPPO

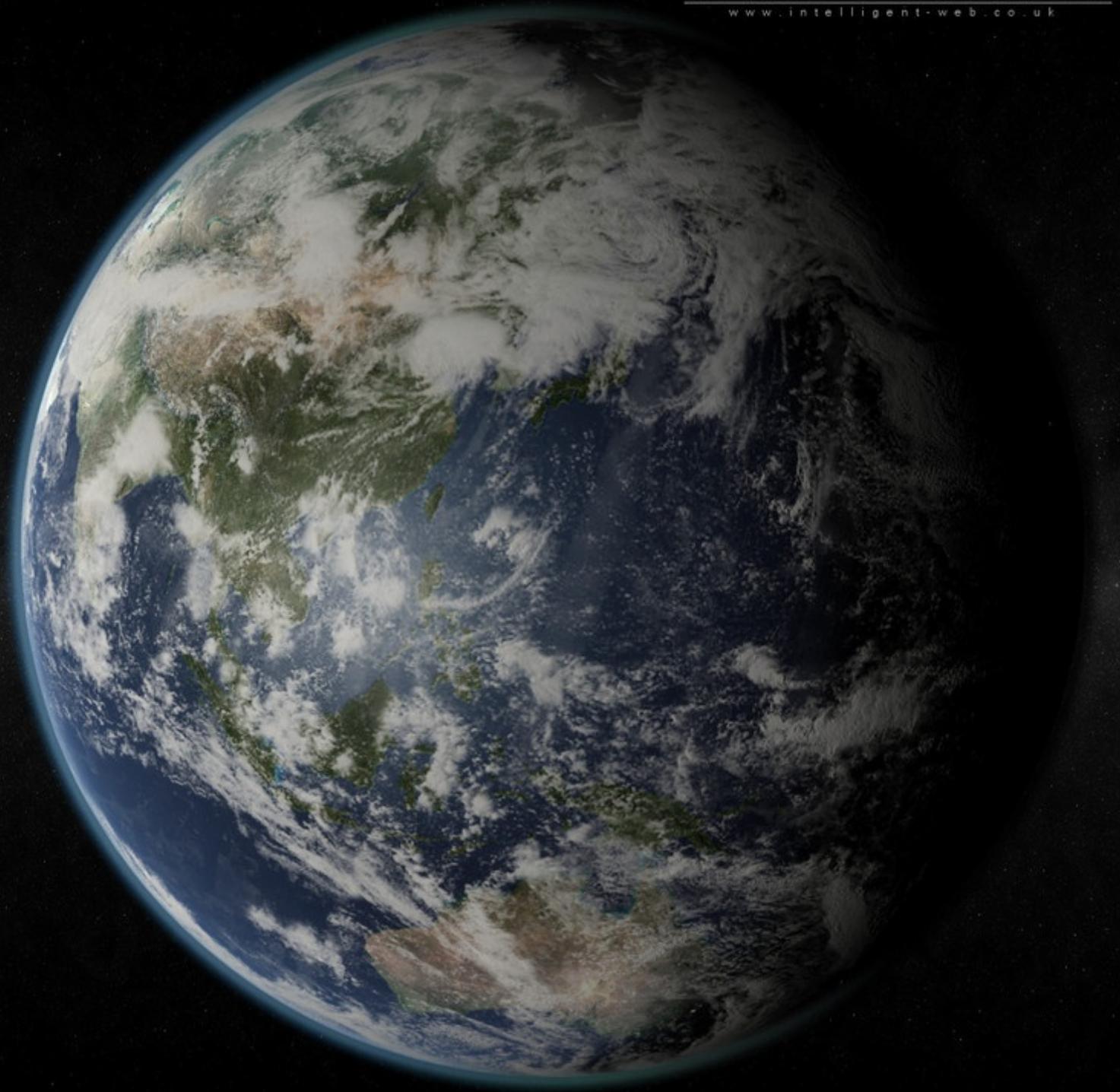
rapporto del System Dynamics Group  
Massachusetts Institute of Technology (MIT)  
per il progetto del Club di Roma  
sui dilemmi dell'umanità

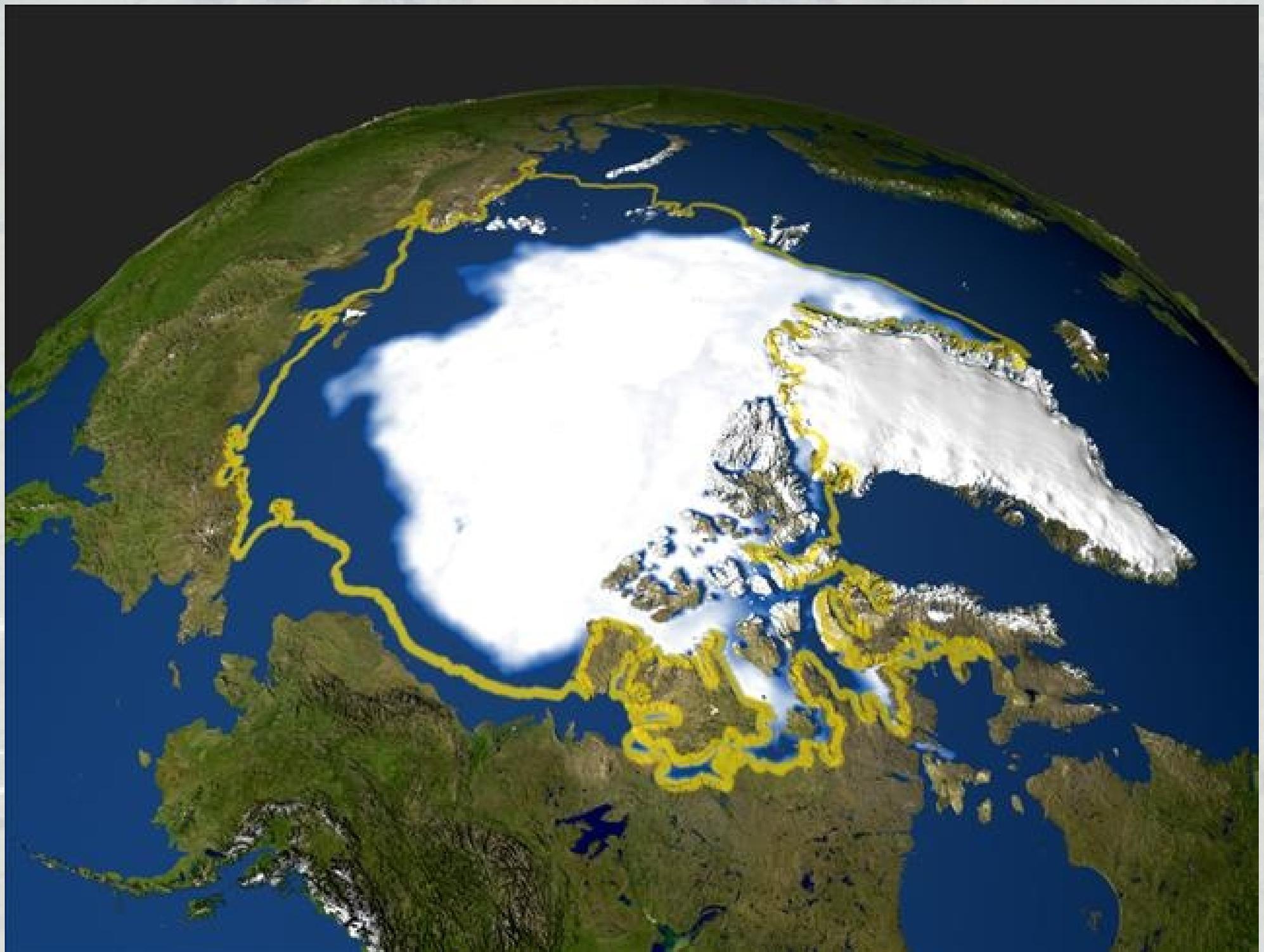
Biblioteca della EST  
EDIZIONI SCIENTIFICHE E TECNICHE  
MONDADORI



# "Limits to Growth", 1972





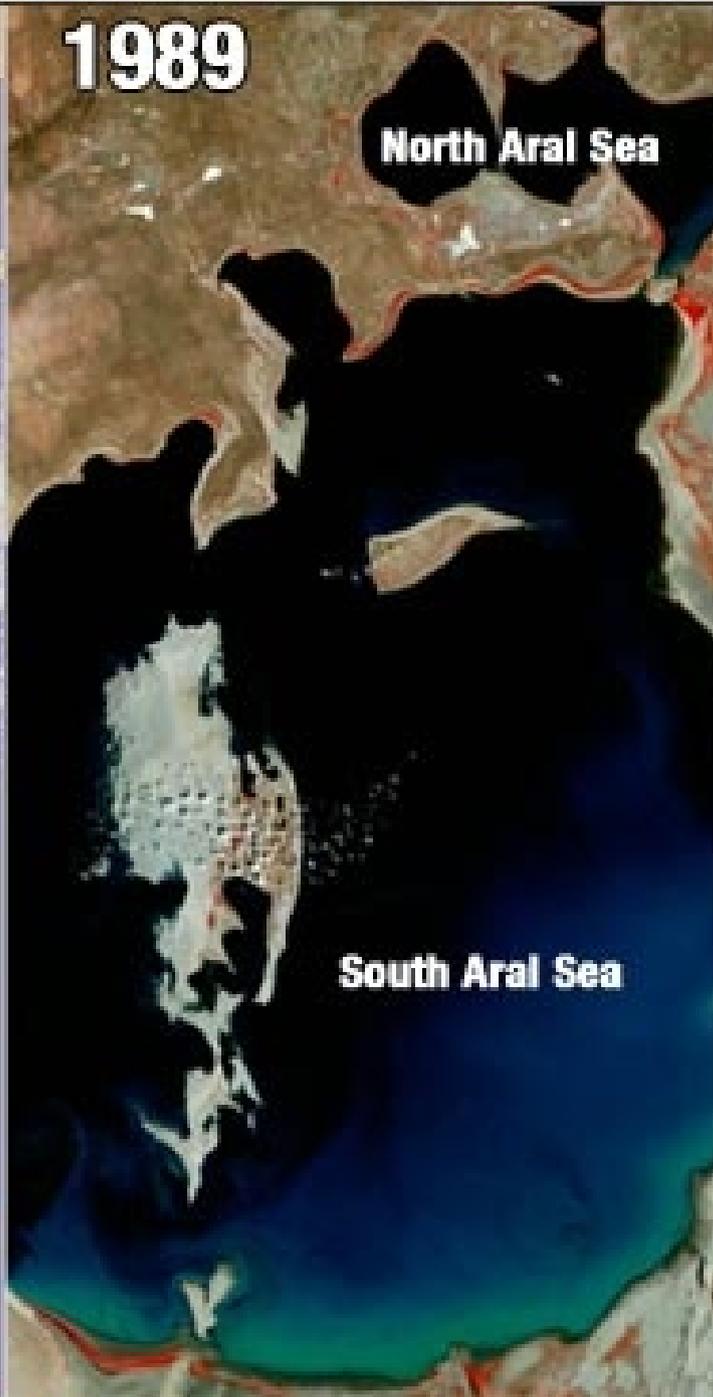




**1977**



**1989**



**2006**





photo by Leonid Ibragimov  
© OrexCA.com







# Morency copper mine, Australia





Chalcopyrite deposits,  $\text{CuFeS}_2$ : 34.5% copper when pure.

Typical ores  $\square$  1% copper in weight

# Mining machines







# Il Petrolio è una cosa importante



- Il 40% di tutta l'energia primaria mondiale viene dal petrolio



- Il 90% di tutta l'energia usata per i trasporti viene dal petrolio



- Il 65% del petrolio viene usato per fare carburanti



- Del restante si fa energia elettrica, asfalti, materie plastiche, fertilizzanti, prodotti chimici e medicinali.



*Senza petrolio saremmo tutti al buio e al freddo e non avremmo neanche da mangiare*

Consumiamo 5 litri di petrolio al giorno a testa



*Consumo di petrolio medio giornaliero per persona in Italia*  
*1 litro di petrolio = 40 Eurocent (100 Dollari/Barile)*  
*5 litri di petrolio = 2 Euro*

# Consumiamo un barile di petrolio al mese



**1 barile=159 litri**

*Consumo di petrolio mensile medio per persona in Italia  
Circa 60 Euro (2009)*



*Consumo di petrolio annuale medio per una famiglia di 4 persone in Italia: 7760 litri*

*Circa 4000 Euro ai prezzi del 2008*



*Il mondo consuma 27 miliardi di barili di petrolio “convenzionale” all’anno.*

*Spesa mondiale: circa 2500 miliardi di dollari, 1600 miliardi di Euro all’anno*

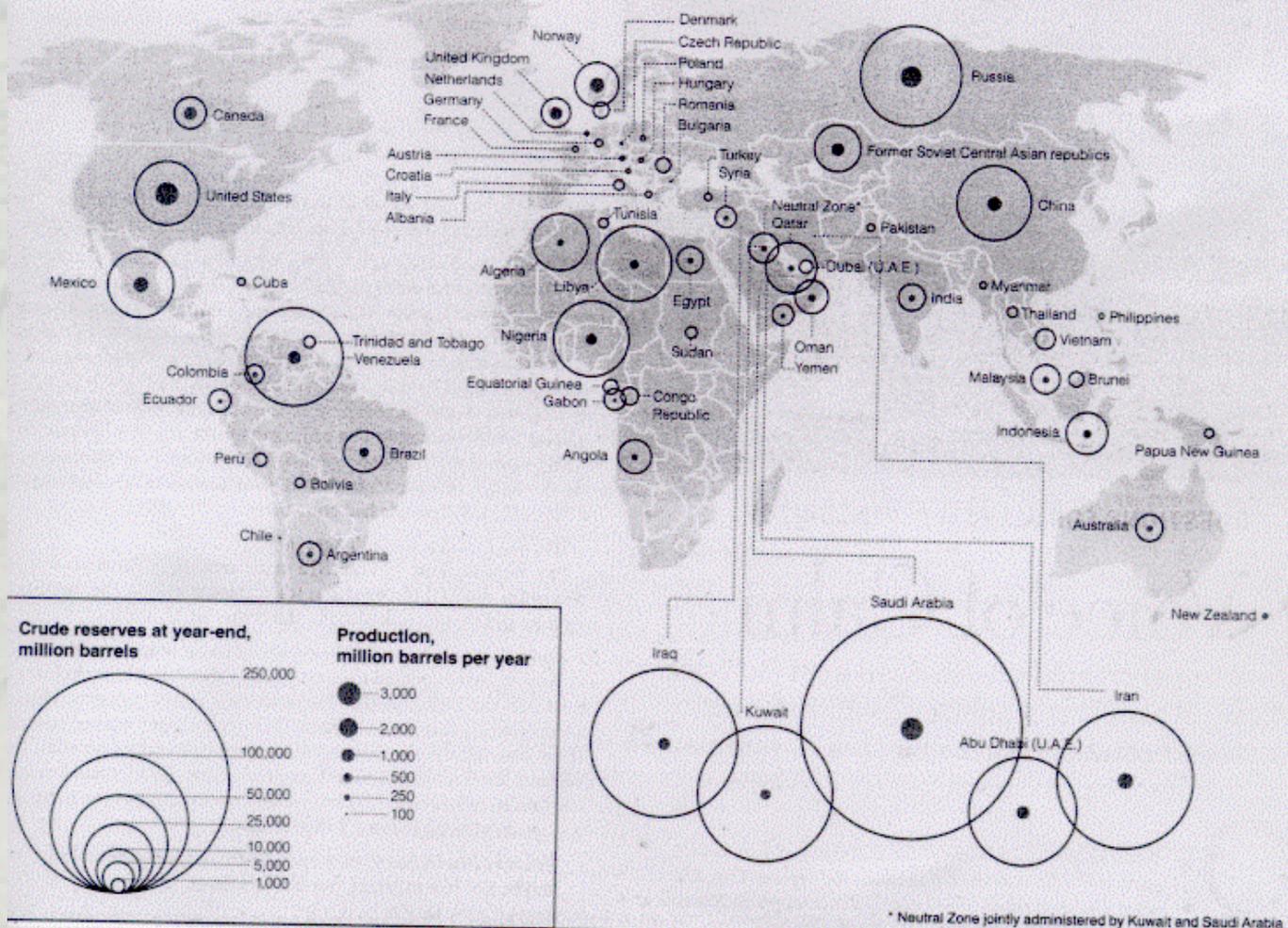






# Where the Oil Is

Is there enough of it elsewhere in the world to wean ourselves from the Persian Gulf? By Noam Scheiber



Sources: WorldOil.com (reserves); International Energy Agency (production).

## Il corridoio del petrolio



## Il Petrolio Del Caspio





# Il greggio e l'economia italiana



**X 700 Milioni**  
(all'anno)

**€ 40 miliardi**  
(prezzi 2009)

**Export Commerciale Italiano =  
280 miliardi di Euro**

**Domanda:** quanto durerà il petrolio?

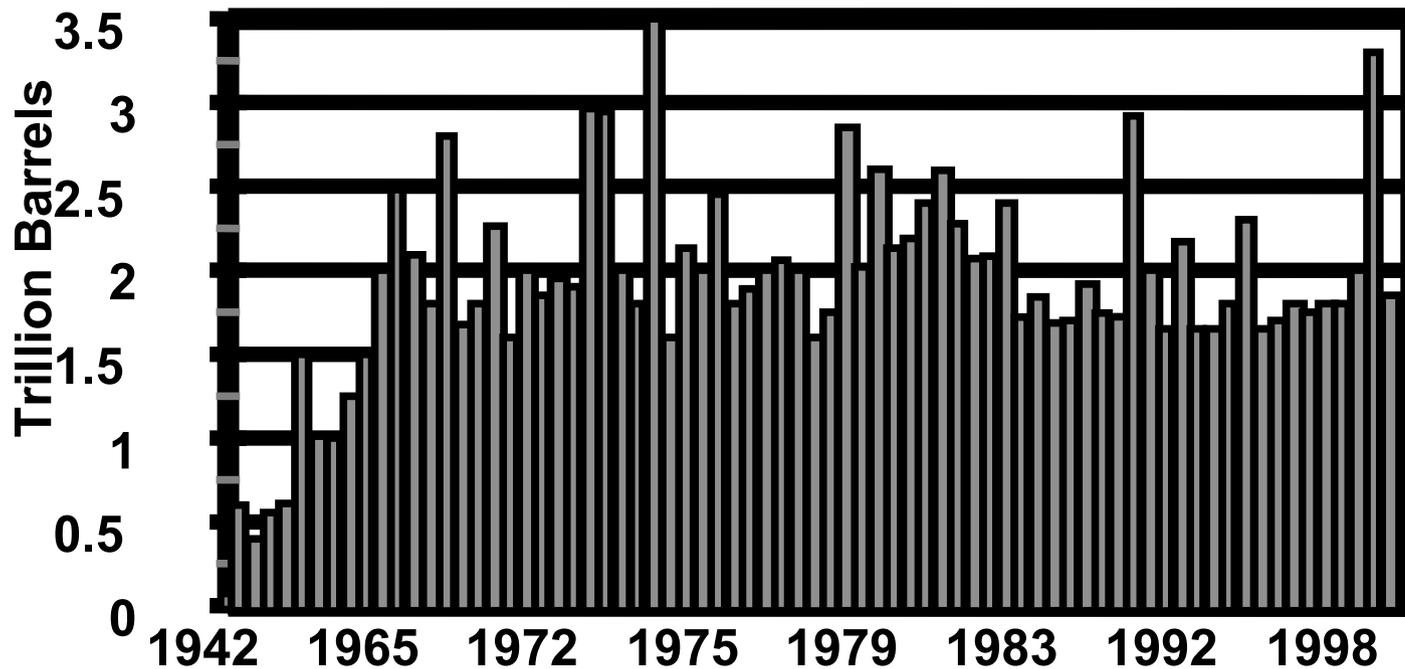
**Risposta:** dipende.

- Dipende da quanto petrolio rimane da estrarre
- Dipende dalla velocità con la quale lo estrarremo.



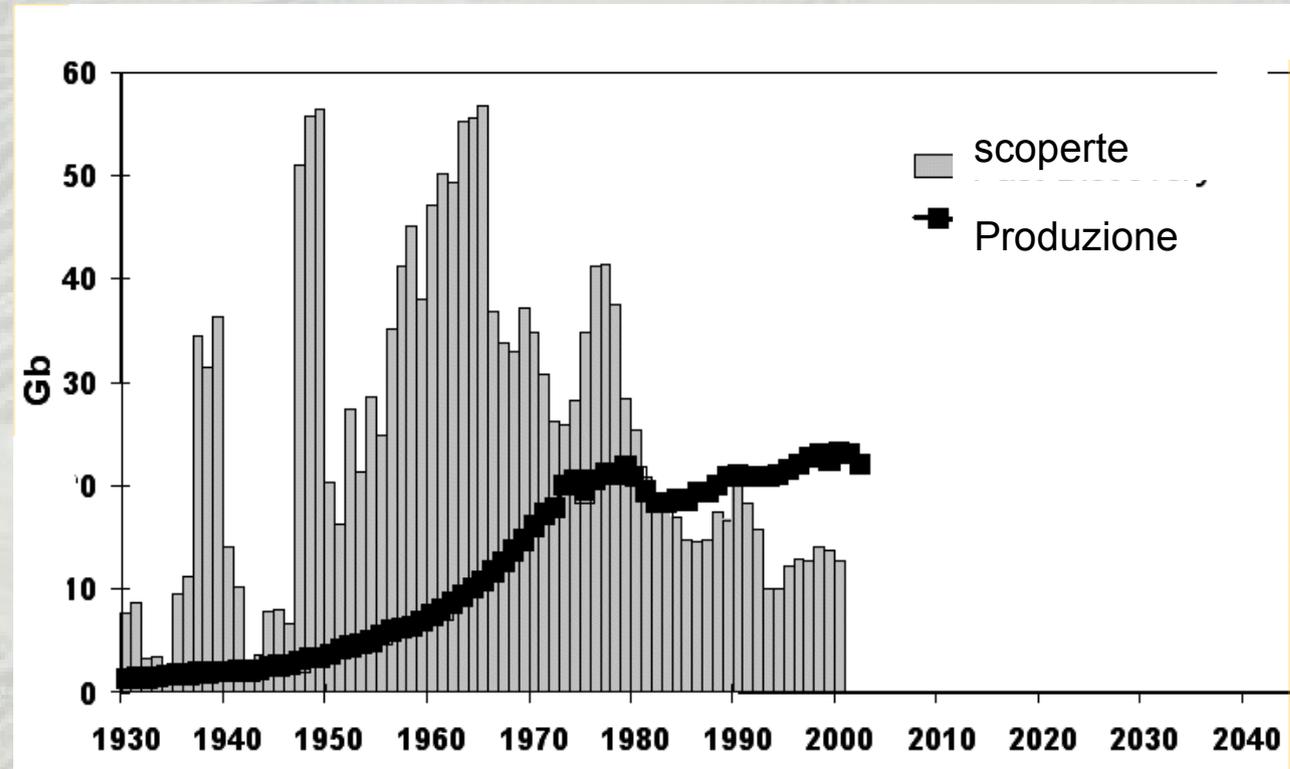
# Siamo partiti con una quantità limitata di petrolio

Le stime della quantità di petrolio presenti in origine nelle viscere del pianeta, in migliaia di miliardi di barili



I dati sono incerti, ma già a partire dagli anni 1960, le stime delle risorse petrolifere globali si erano stabilizzate intorno a un valore medio di circa 2.000 miliardi di barili. Non è vero che al tempo delle crisi del petrolio (1974-1979) si temesse di essere già arrivati alla “fine del petrolio.”

# E ne rimane sempre meno



Le scoperte di nuovi giacimenti hanno raggiunto il loro massimo storico verso la metà degli anni 1960. Da allora sono in declino. E' dal 1985 che si consuma più petrolio di quanto non se ne scopra.

# Un po' di conti

- Il totale estraibile di petrolio convenzionale è intorno ai 2.000 miliardi di barili
- Fino ad oggi, abbiamo estratto circa 1000 miliardi di barili
- Stiamo consumando circa 25 miliardi di barili all'anno
- Dunque, ci rimangono 40 anni

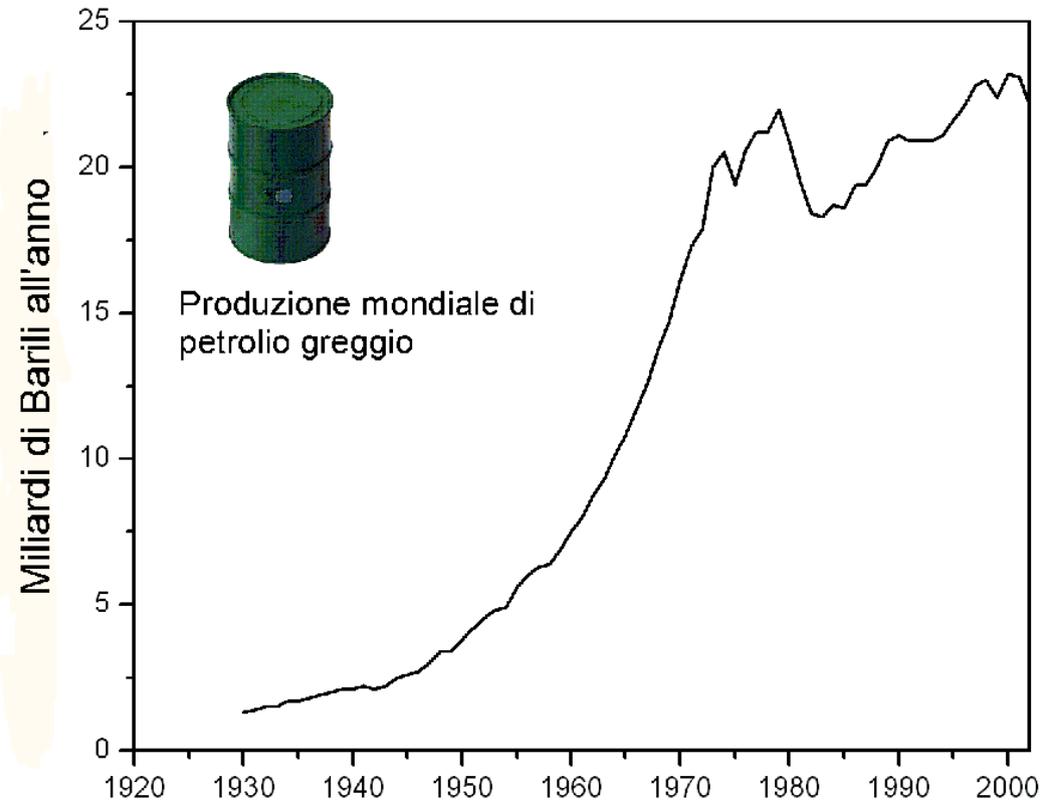
*Giusto?*



# Non è così Semplice

La produzione di petrolio non è mai stata costante nella storia, per cui non ha senso parlare di “40 anni di riserve al ritmo di produzione attuale”

La domanda giusta è, invece: “Quanto petrolio potremo produrre nel futuro e a che costi?”

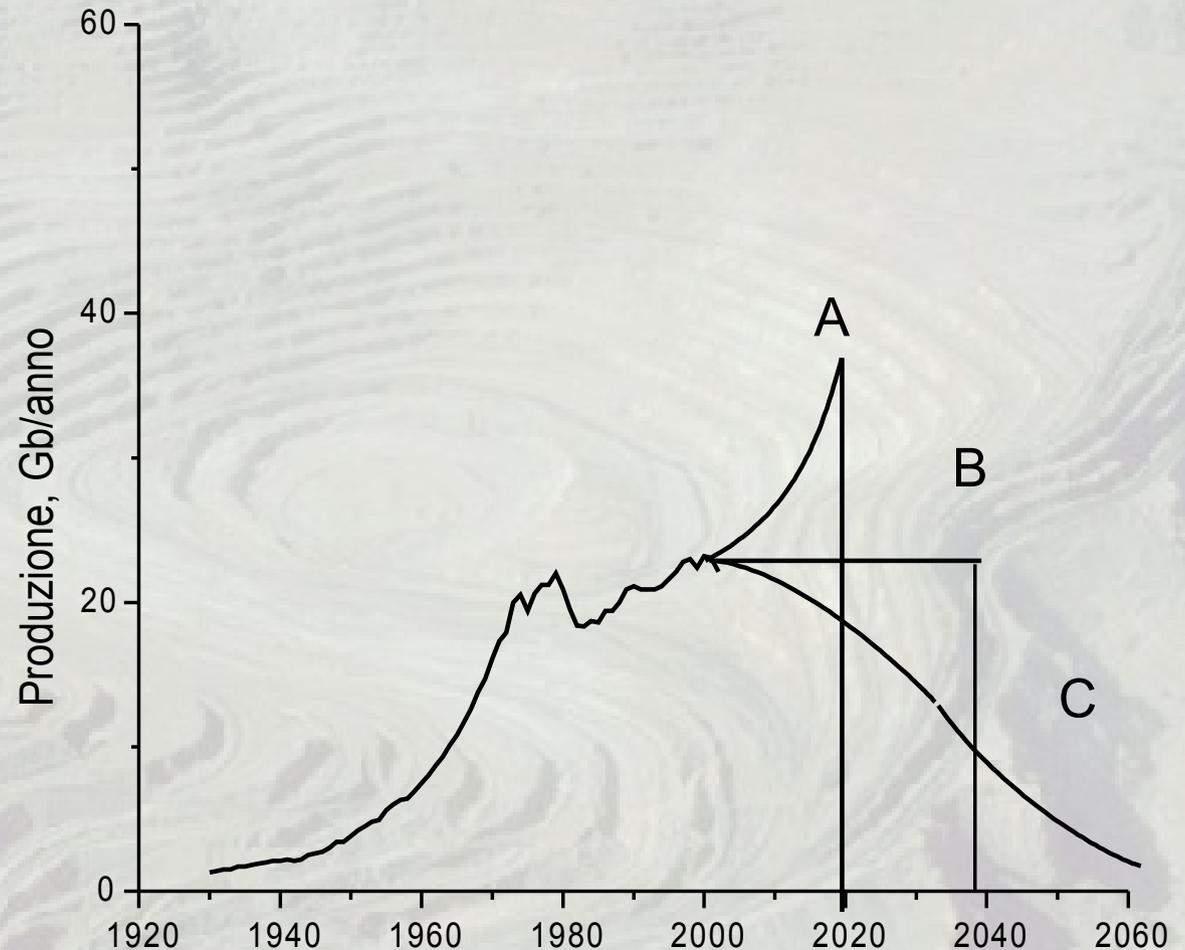


# Cosa Possiamo Aspettarci?

A: Crescita rapida  
seguita da collasso

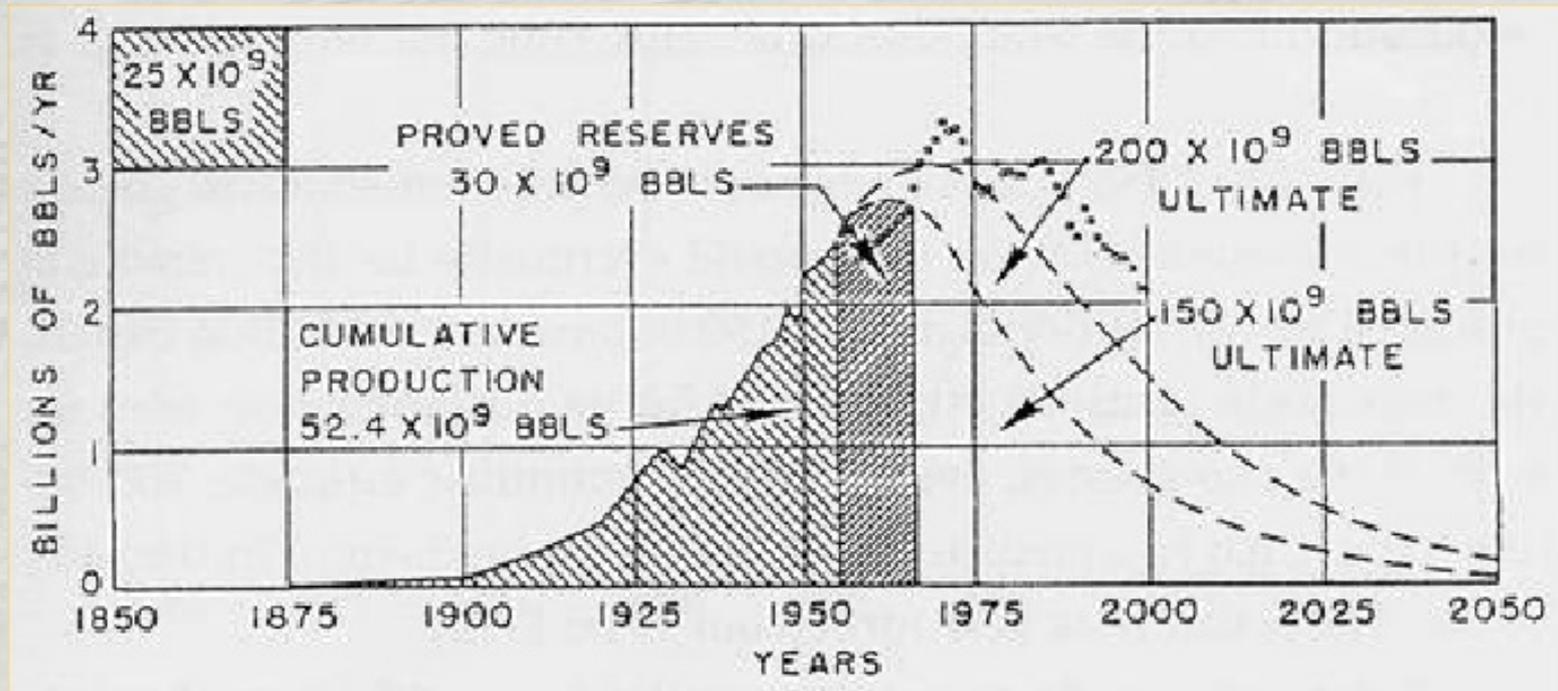
B: Produzione costante,  
seguita da collasso

C: Declino graduale



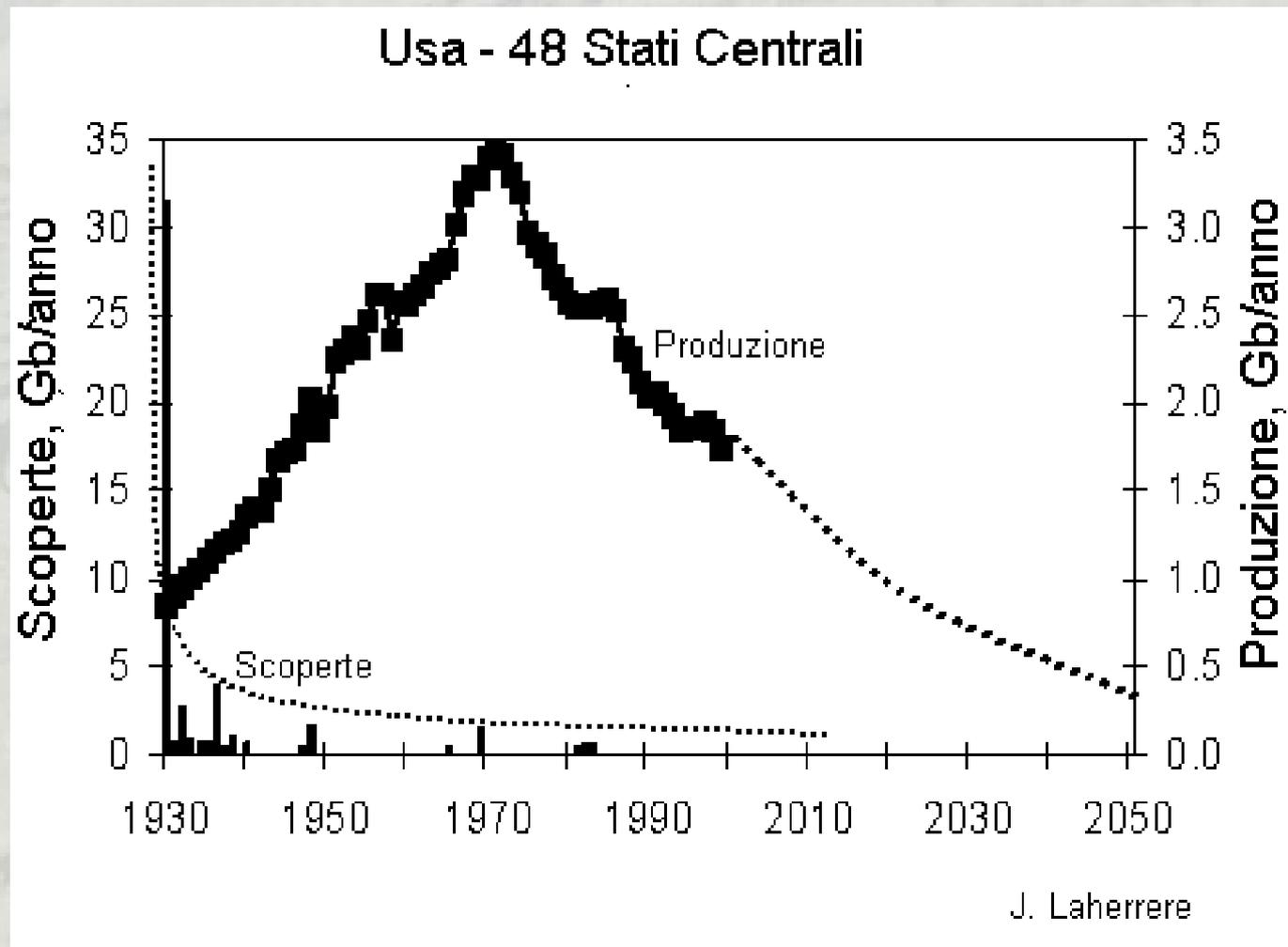
*La risposta la da il “modello di Hubbert”, basato su casi storici: il caso “C” è quello giusto.*

# La scoperta di Hubbert



Questo è il grafico originale che il geologo M. King Hubbert pubblicò nel 1956. Hubbert prevedeva che la produzione di petrolio dai pozzi petroliferi americani avrebbe seguito una “curva a campana” (o gaussiana), passando per un massimo verso il 1971. A quel tempo, nessuno ci credette.

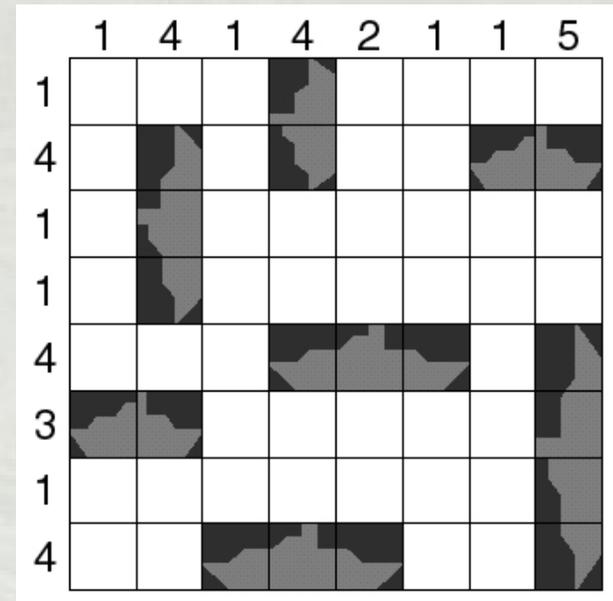
# Hubbert aveva ragione



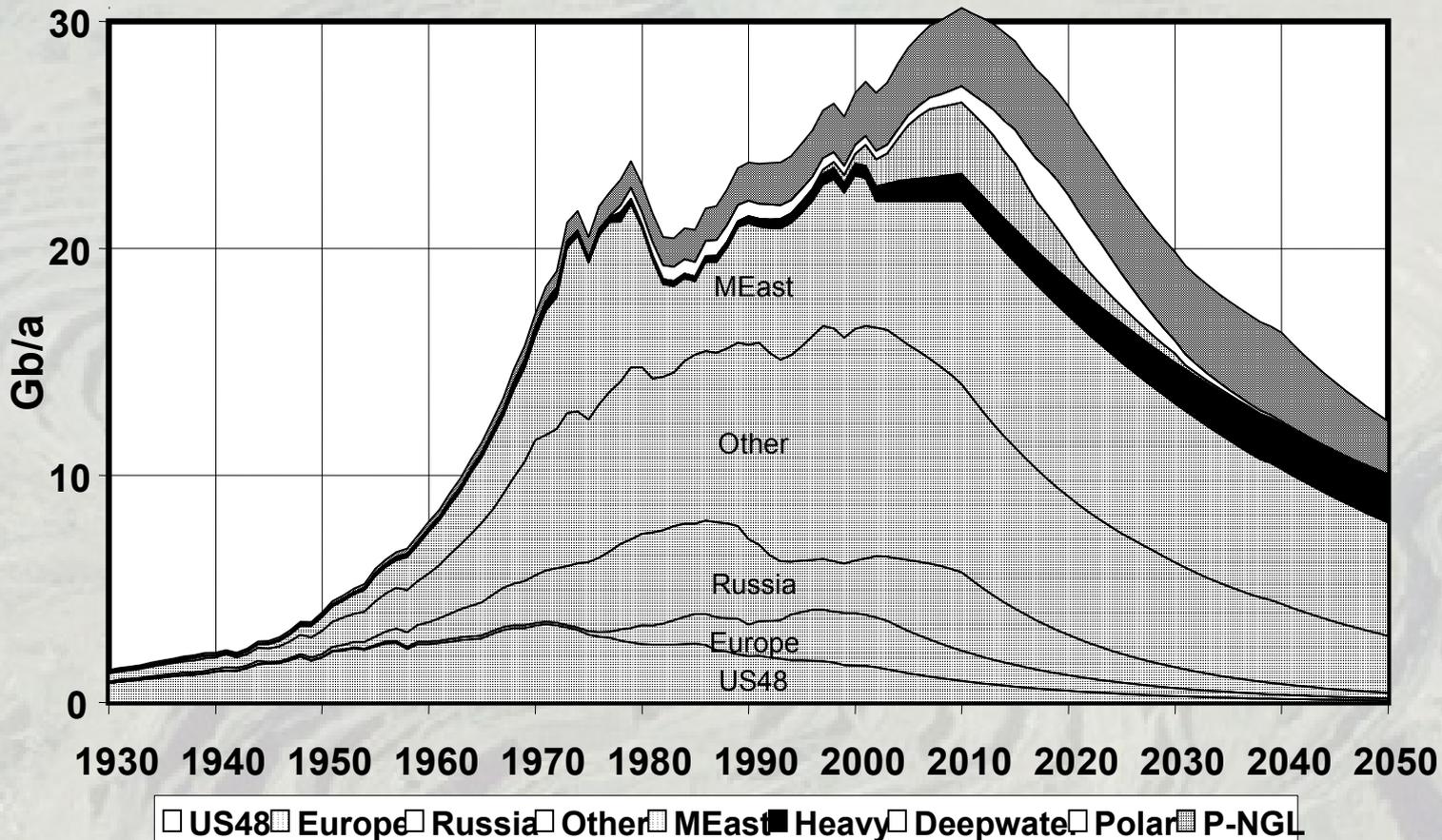
La curva della produzione americana è passata per un massimo nel 1971, proprio come aveva predetto Hubbert. Dopo essere arrivati a produrre quasi 3,5 miliardi di barili (Gb) all'anno, gli stati uniti ne producono oggi circa la metà e sono diventati un paese importatore di petrolio.

# La spiegazione della teoria di Hubbert

- Inizialmente, è facile trovare i pozzi più grandi, un po' come nella battaglia navale si colpiscono più facilmente le navi più grandi.
- Via via che i pozzi grandi si esauriscono, bisogna cercare e sfruttare pozzi piccoli, e questo costa più caro.
- A un certo punto, i costi diventano talmente alti che la produzione comincia a diminuire.
- Questo effetto è la base della **teoria di Hubbert** che dice che la produzione di una risorsa esauribile passa per un massimo e poi tende a calare.

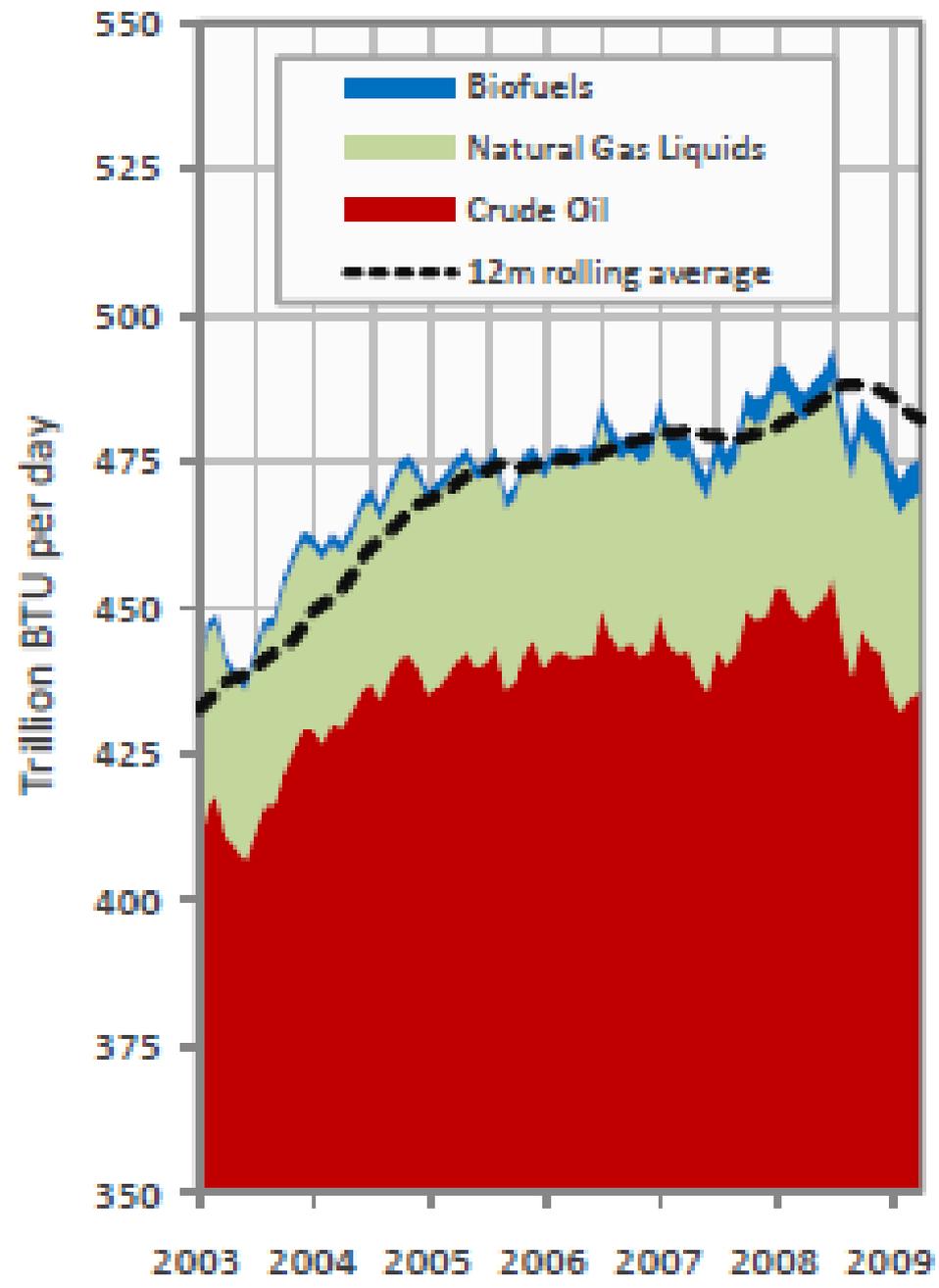


# Previsioni Globali



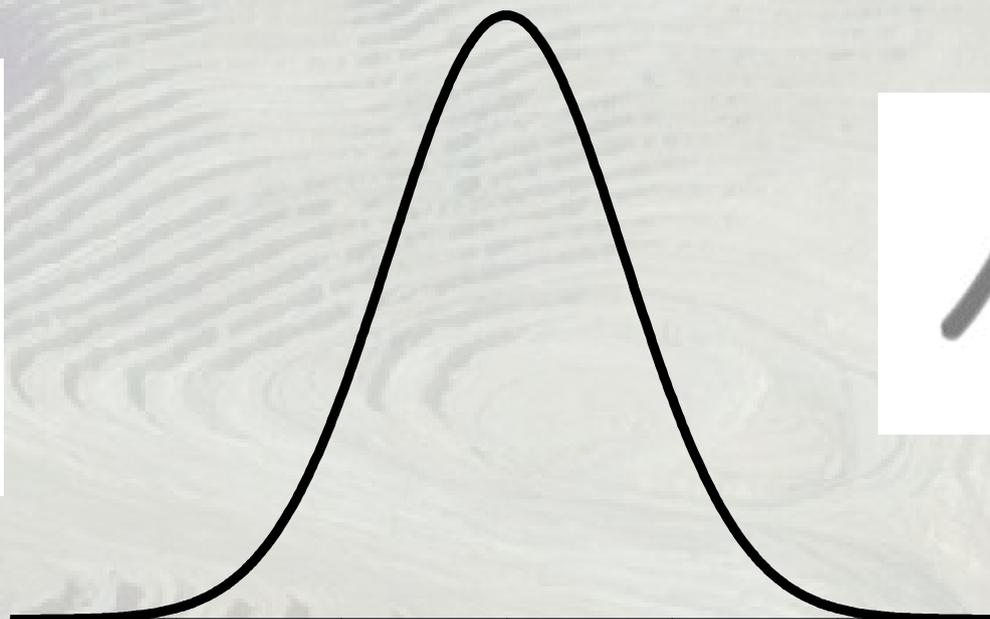
Il modello di Hubbert può essere utilizzato per prevedere l'andamento della produzione mondiale di petrolio. Si prevede che il massimo (il "Picco di Hubbert") si verificherà verso il 2007 per il petrolio "convenzionale" (aree a trattini). Altri tipi di petrolio (pesante, profondo, ecc.) sposteranno il picco di poco in avanti.

Chart 7: World Production In BTU Jan. 2003 - July 2009



Source: International Energy Agency

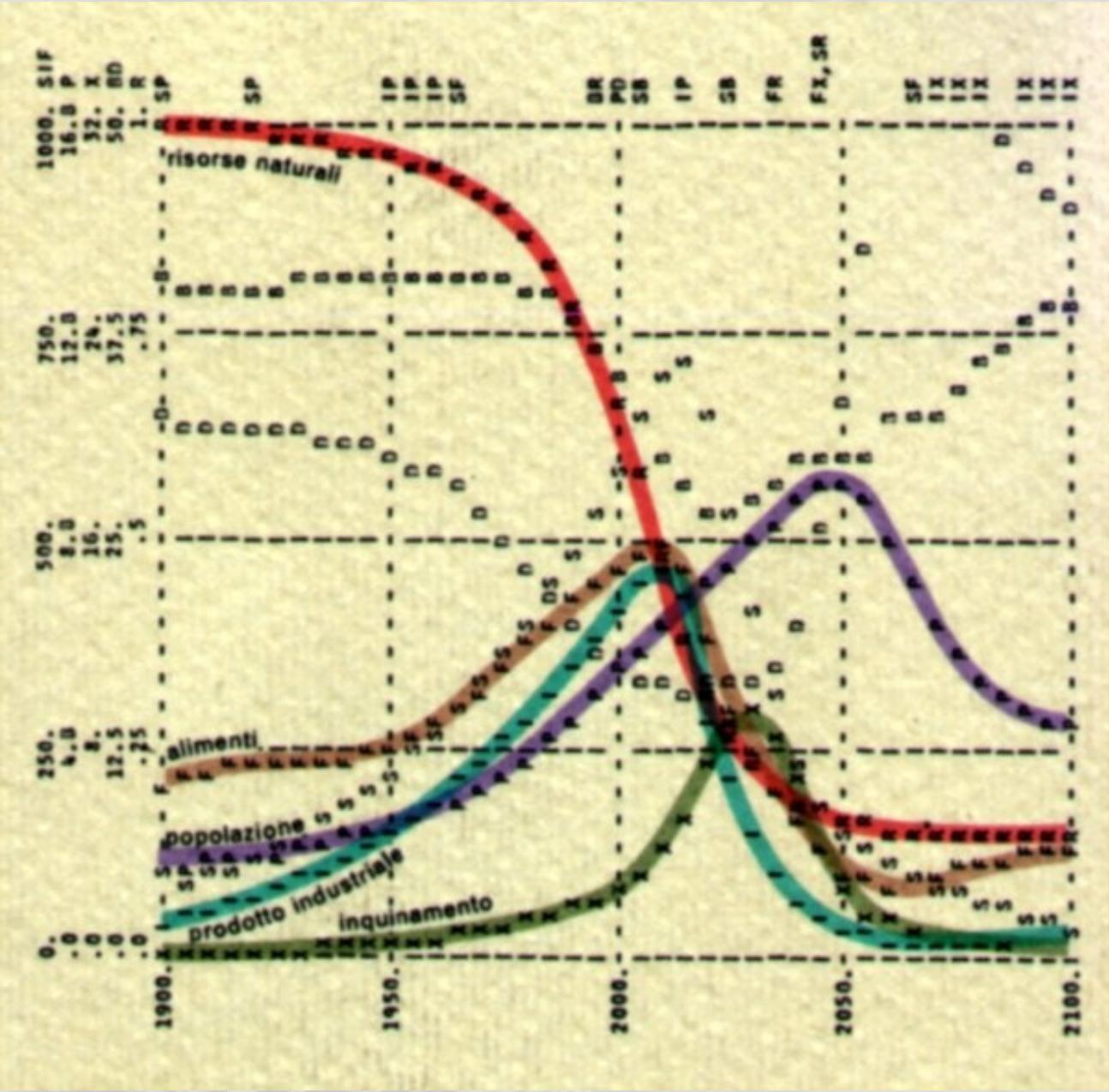
# Vacche Grasse e Vacche Magre



Prima del picco: l'offerta prevale sulla domanda: bassi prezzi, crescita economica, globalizzazione

Dopo il picco: la domanda prevale sull'offerta: alti prezzi, recessione economica, guerre per le risorse

# “Limits to Growth”, 1972



**Teutoburgo, 11 Sett, 9 A.D.**





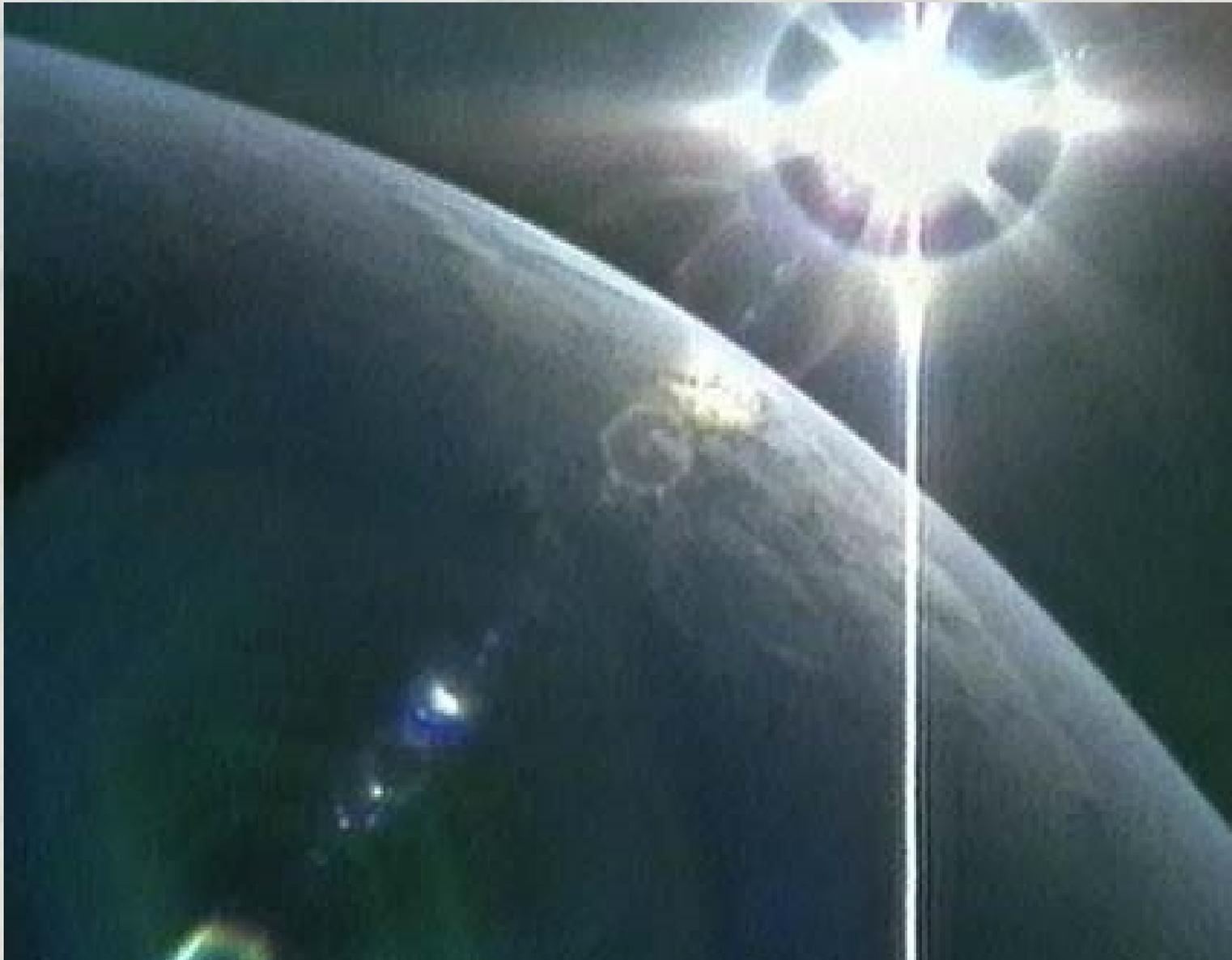








Il primo passo per risolvere un problema è rendersi conto che esiste

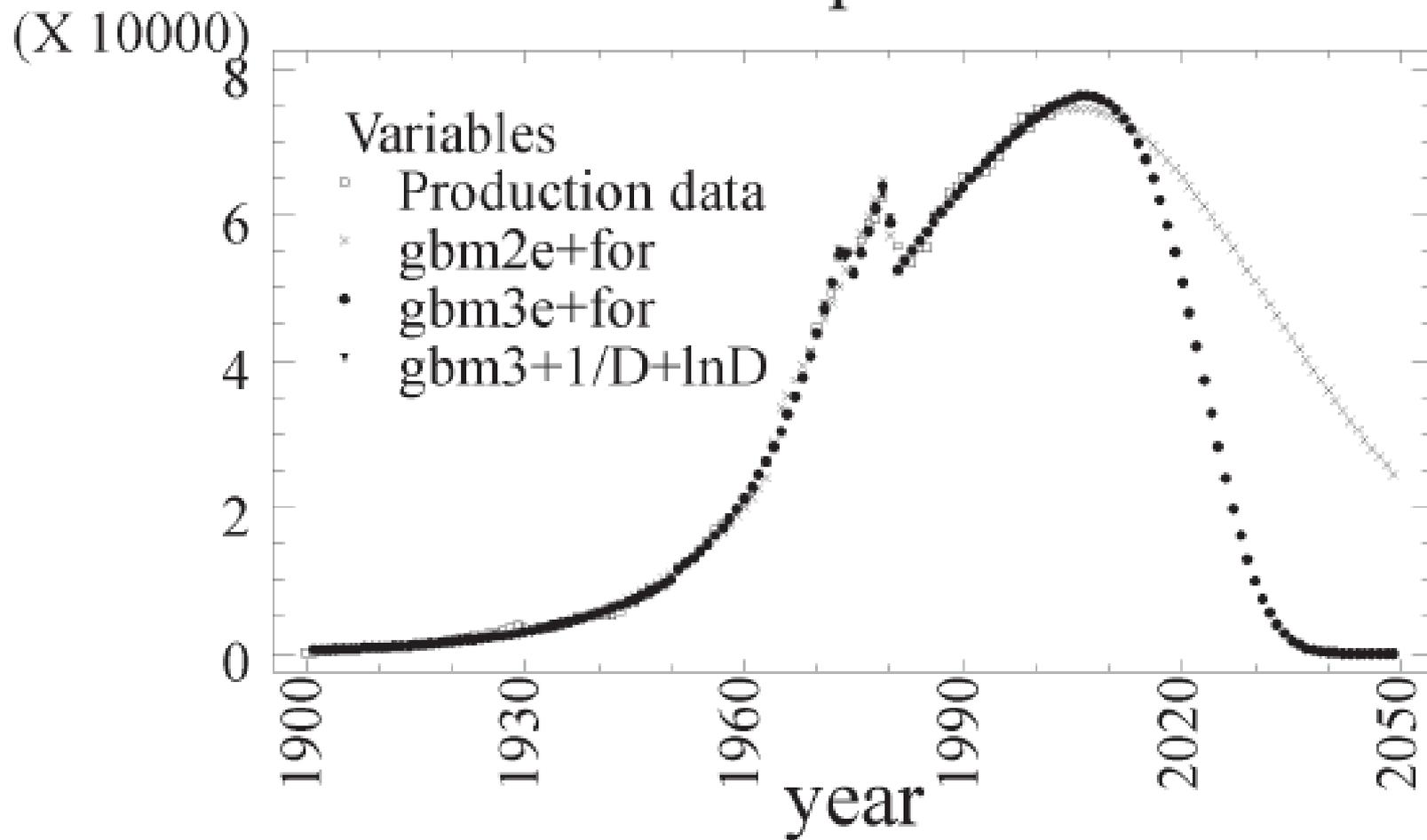




# Vacche Grasse e vacche magre



# World Oil Depletion Models



Guseo et al. 2005

Generalized Bass Model

URR ~ 1600 Gb

**MOD** (mispercezione della dinamica)

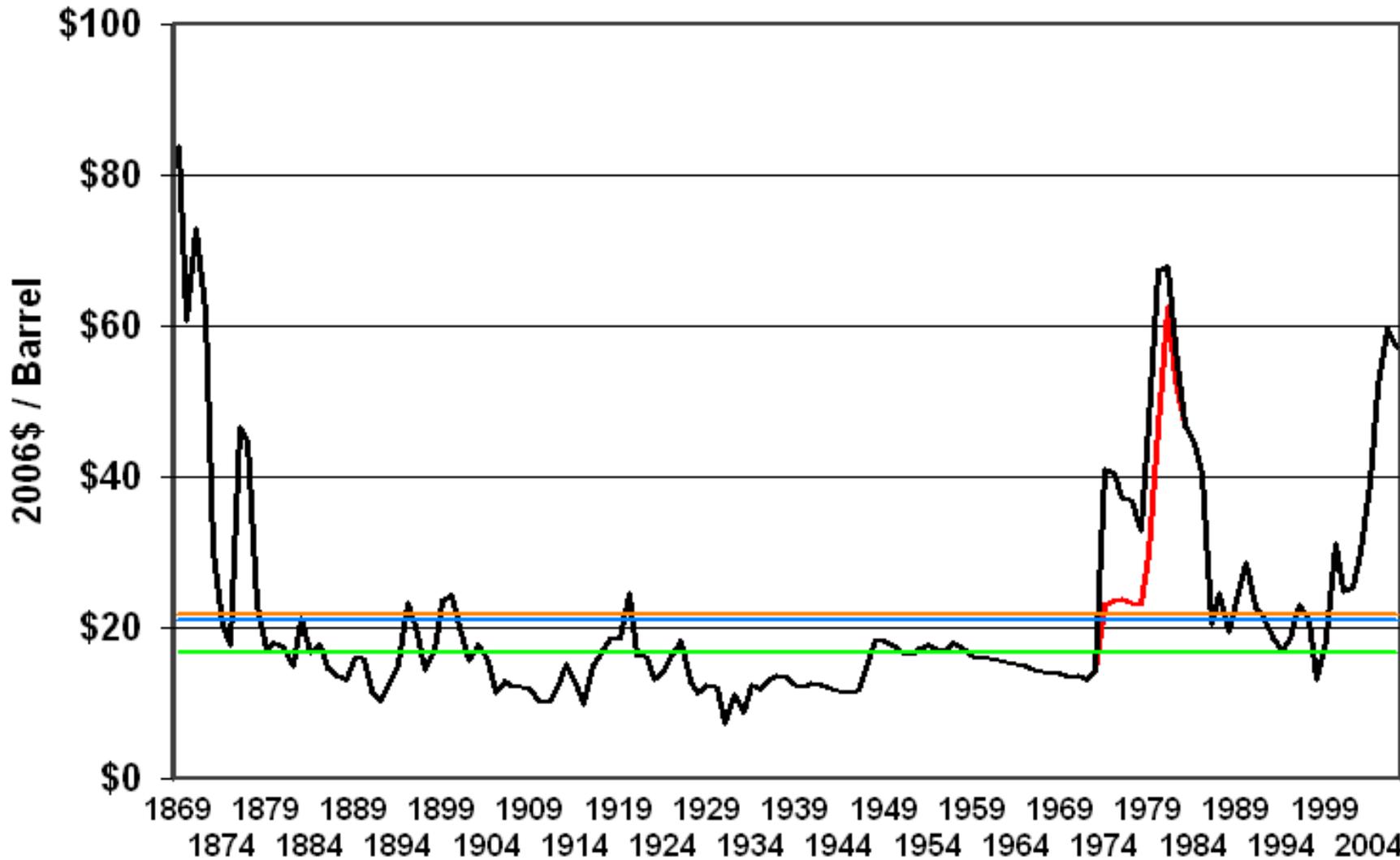
Incapacità di percepire la variazione rapida  
di certe variabili del sistema



**Discounting** (deprezzamento). Considerare il presente di valore maggiore del futuro



CRUDE OIL PRICES  
2006 DOLLARS



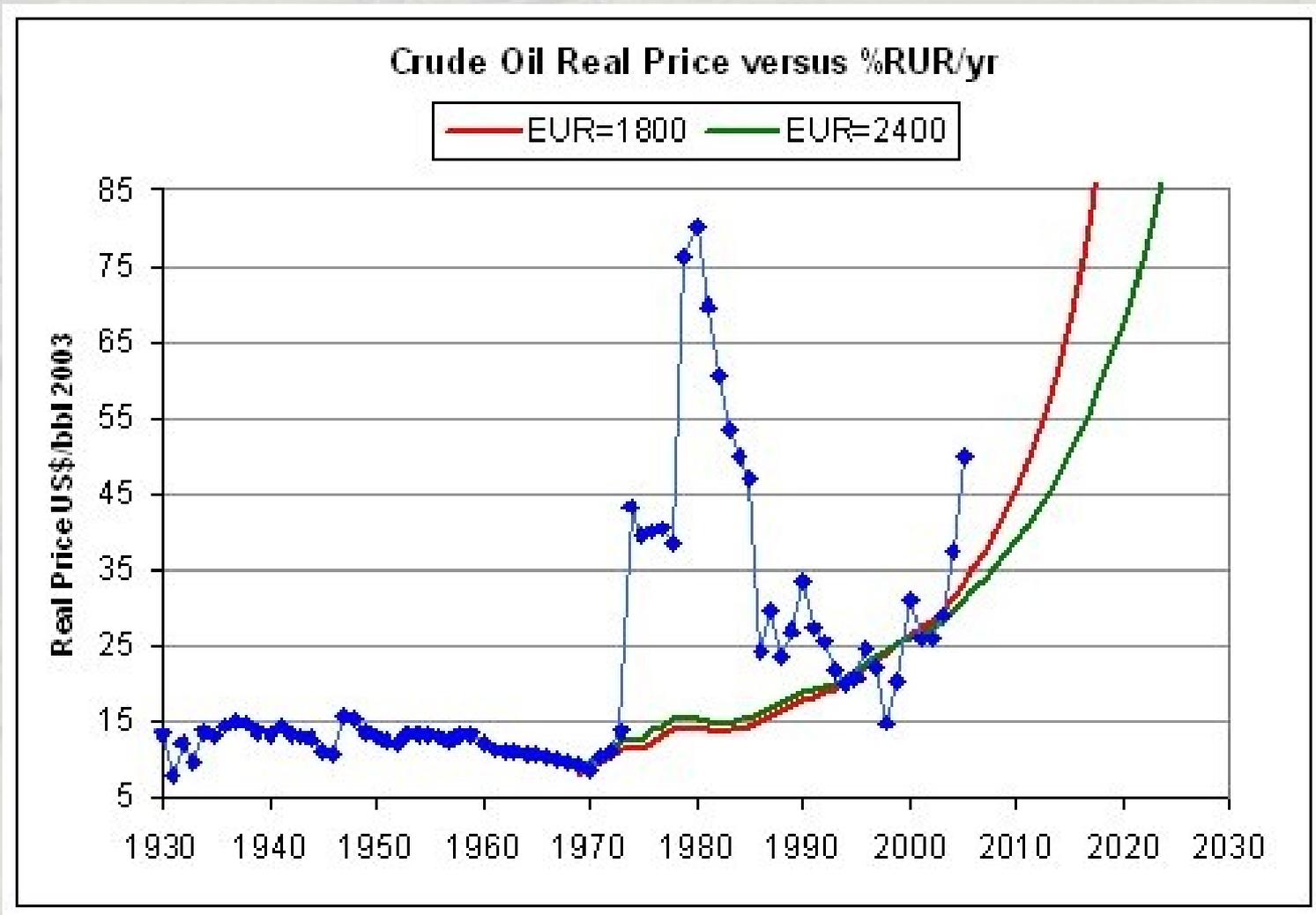
1869 1879 1889 1899 1909 1919 1929 1939 1949 1959 1969 1979 1989 1999  
1874 1884 1894 1904 1914 1924 1934 1944 1954 1964 1974 1984 1994 2004

1869 - Aug. 2007 WTRG Economics ©1998-2007

www.wtrg.com  
(479) 293-4081

— U.S. FIRST PURCHASE (Wellhead) — World Price\*  
— Avg U.S. \$21.05 — Avg World \$21.66 — Median U.S. & World \$16.71

# Prezzi



# The "WOCAP" Model (Bakhtiari, 2004)

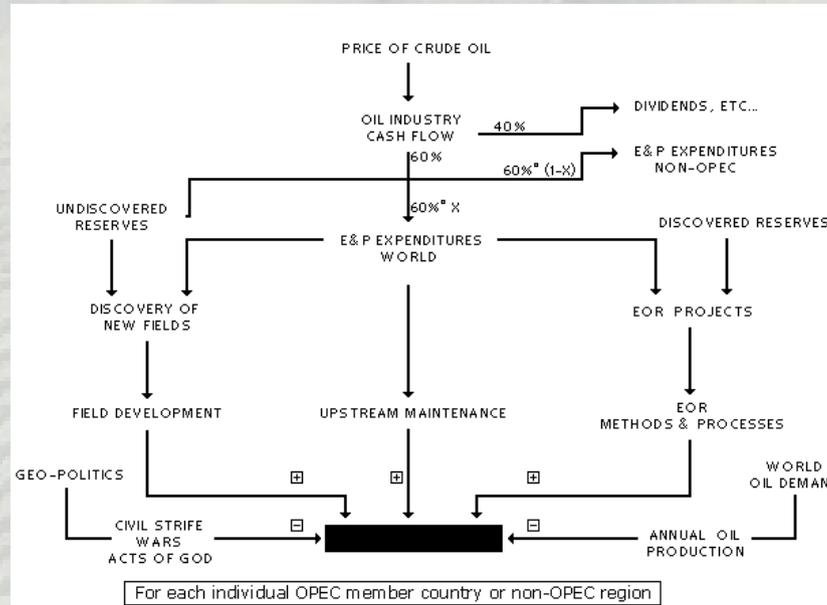


Figure 1. Simplified block-flow diagram of the 'World Oil Production Capacity Model' (WOCAP) --- with its six major influencing factors highlighted.

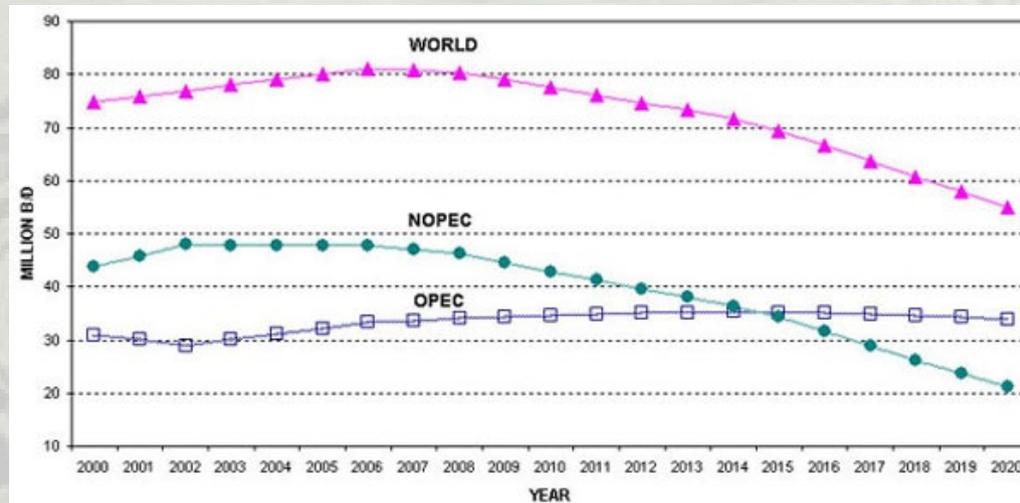
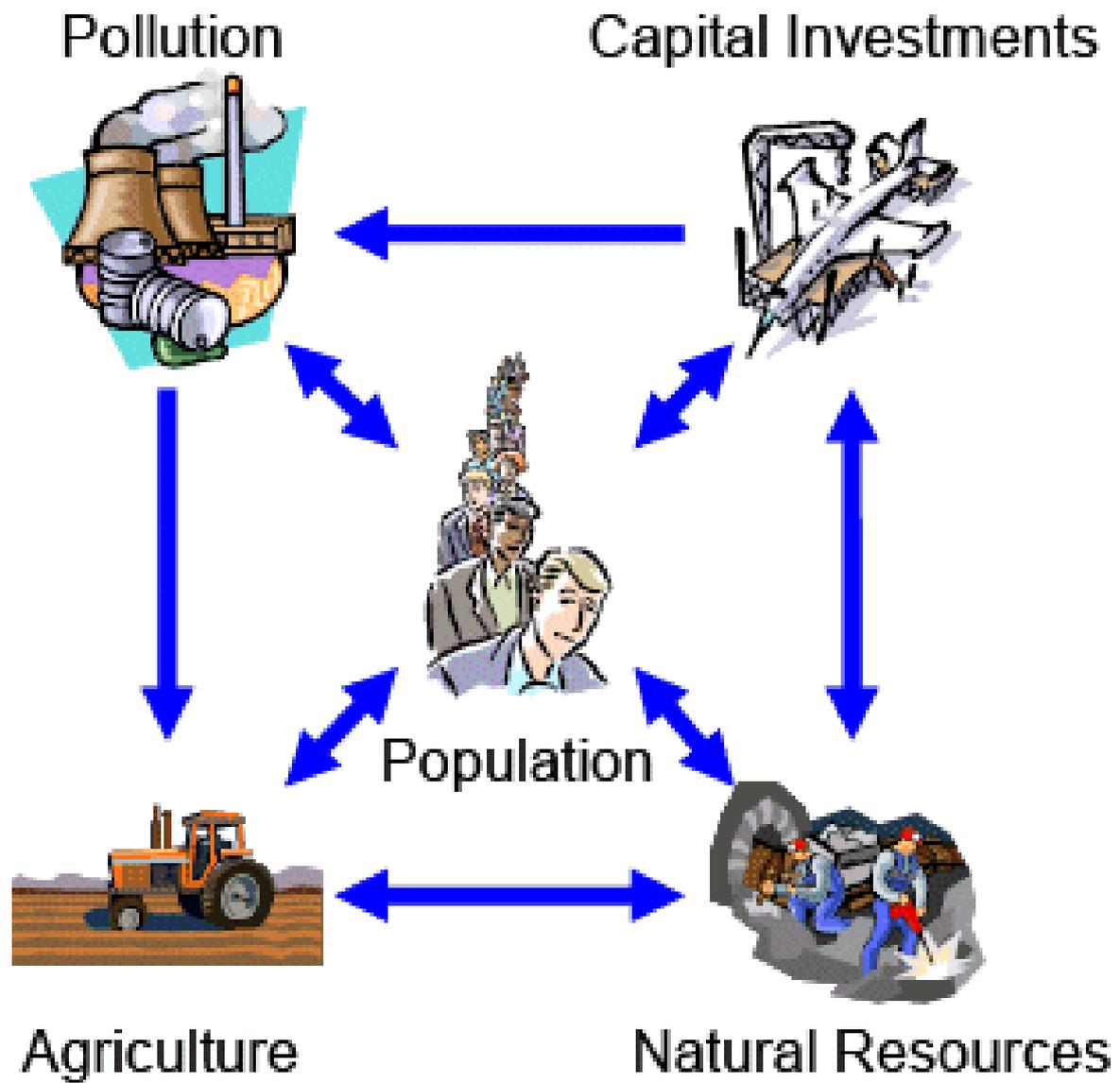


Figure 2. GRAPHICAL REPRESENTATION OF CRUDE OIL PRODUCTION IN OPEC, NON-OPEC (NOPEC) AND WORLD ACHIEVED BY SIMULATING 'WOCAP' MODEL OVER 2003-2020.

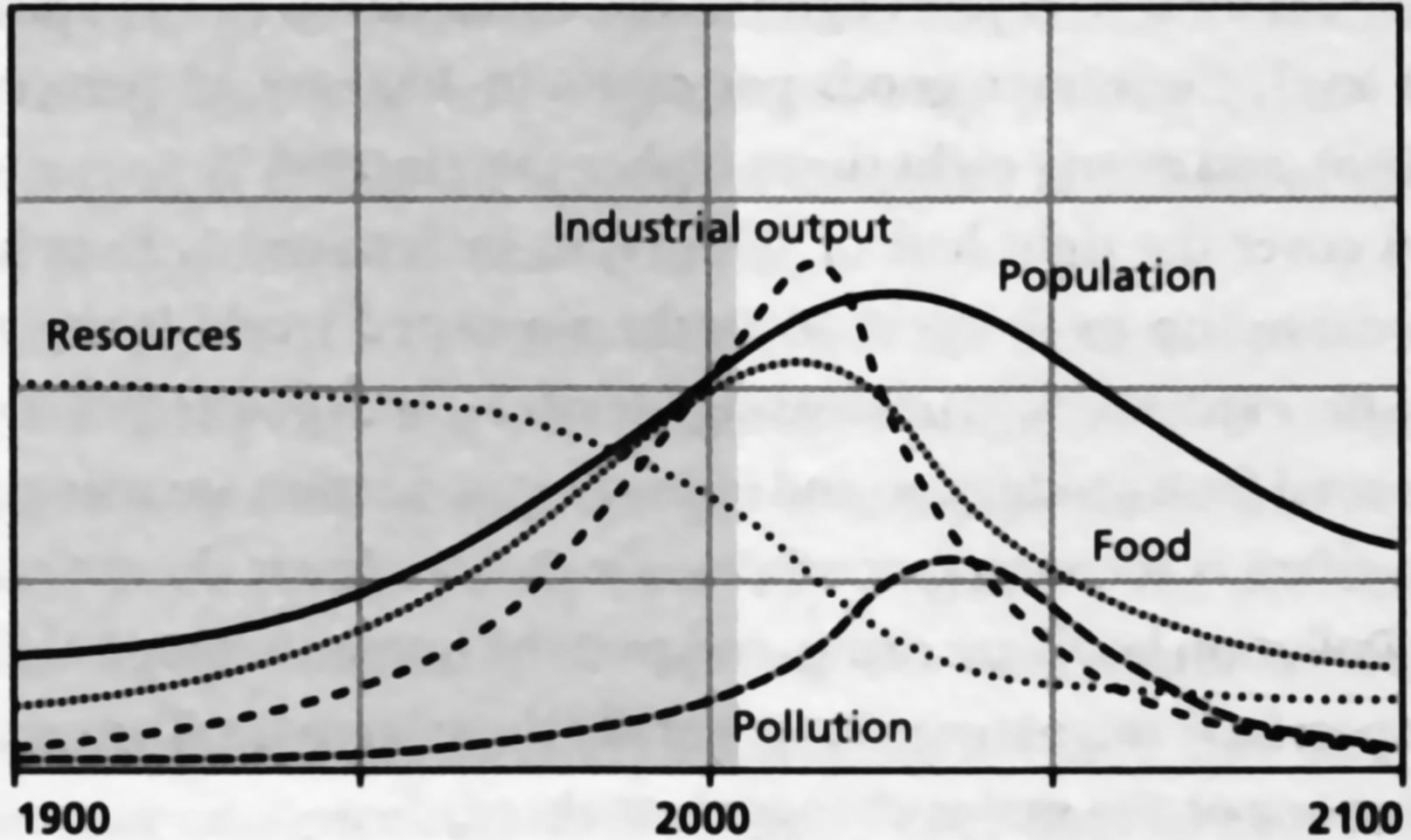


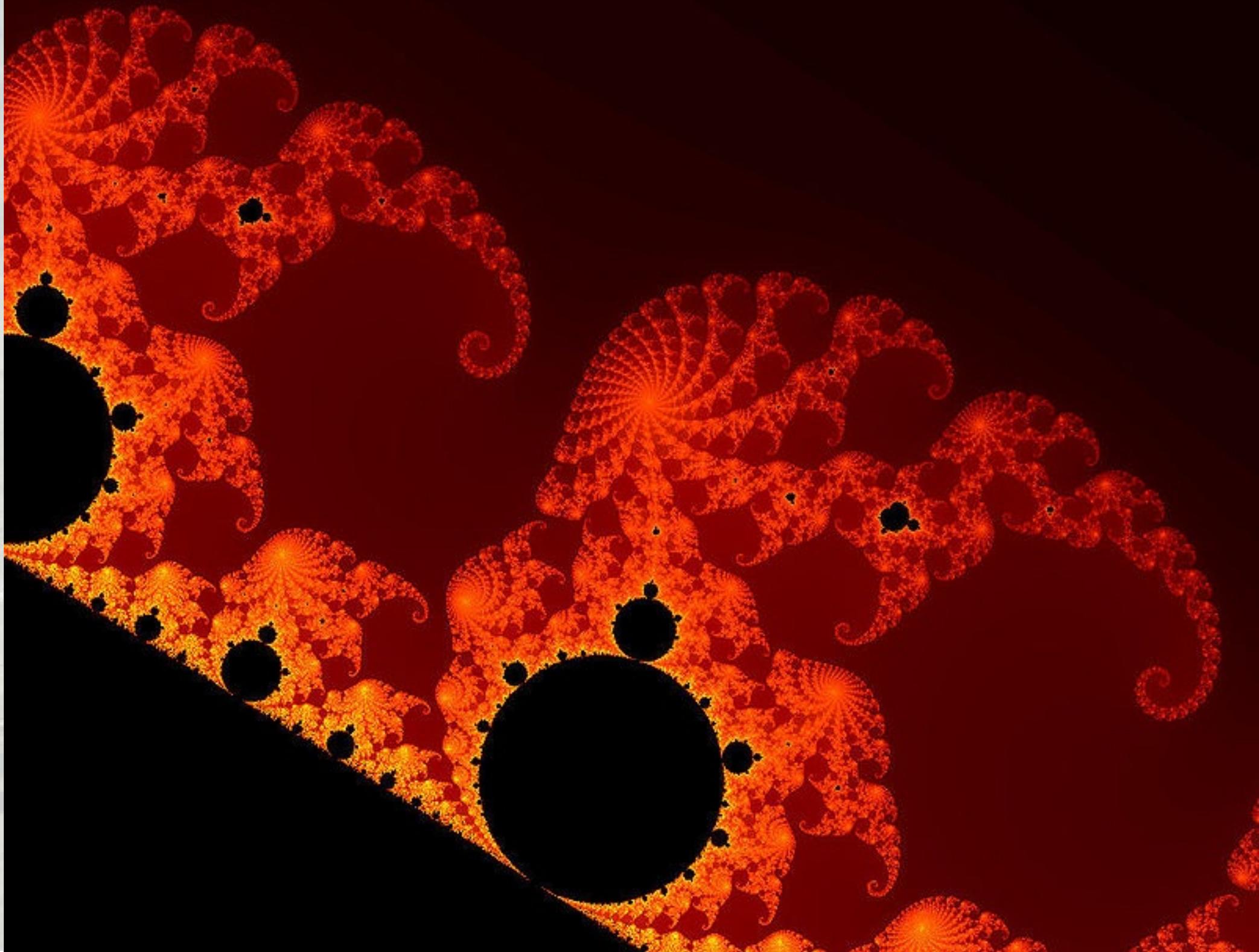




# Limits to growth 2004

## State of the World





## **Complessità secondo J. Tainter (“The Collapse of Complex societies”)**

"Complexity is more challenging to define singularly. As it has become a popular topic in recent years, competing definitions of complexity have made it difficult to clarify the concept. The nuances of these different conceptions are not helpful in understanding the relationship of social complexity to sustainability; those interested may consult the growing literature on this topic. To understand sustainability, it is useful to conceptualize complexity in human social systems as differentiation in both structure and behavior, and/or degree of organization or constraint (Tainter, 1988, 2000b; Allen et al., 2003; see also Allen et al., 1999). Social systems vary in complexity as they diversify or contract in structure and behavior, and/or as they increase or decrease in organizational constraints on behavior."

## **Complessità secondo Kolmogorov-Chaitin (KC complexity):**

“La lunghezza in bit del programma minimo per simulare il sistema”

---

I sistemi complessi:

- Sono fuori dall'equilibrio termodinamico (condizioni di flusso di energia)
- Sono dominati da interazioni di feedback interne al sistema
- Mostrano la proprietà di omeostasi

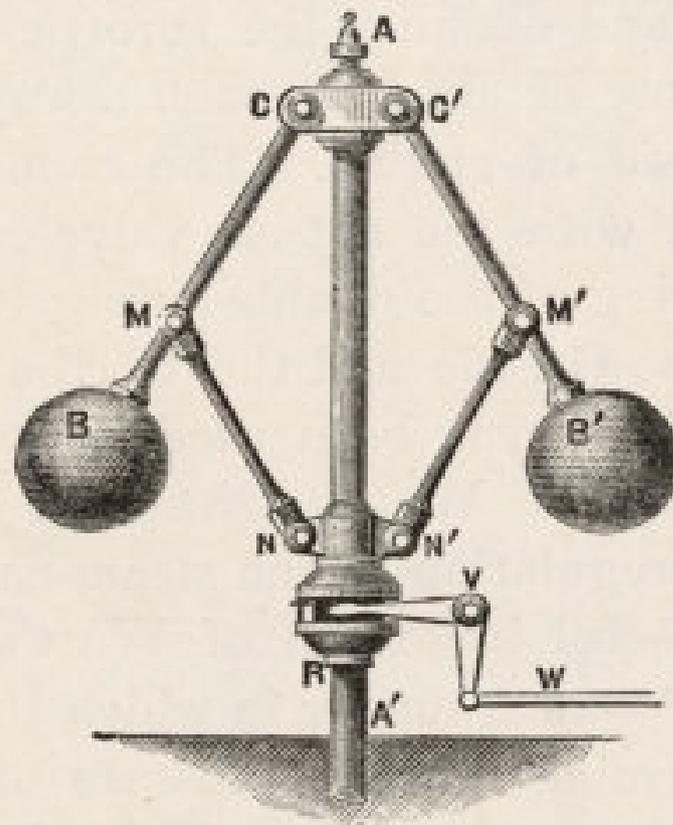
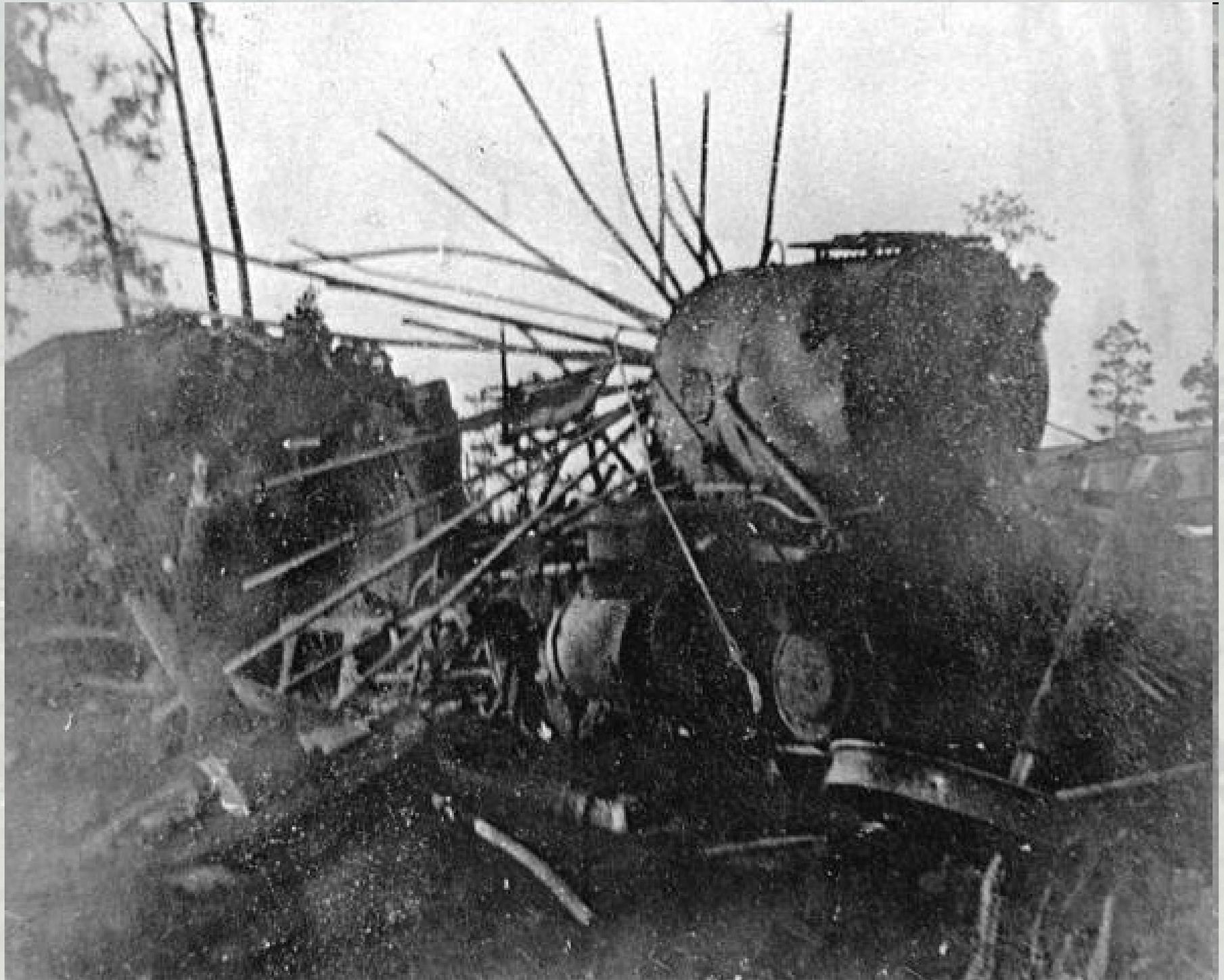
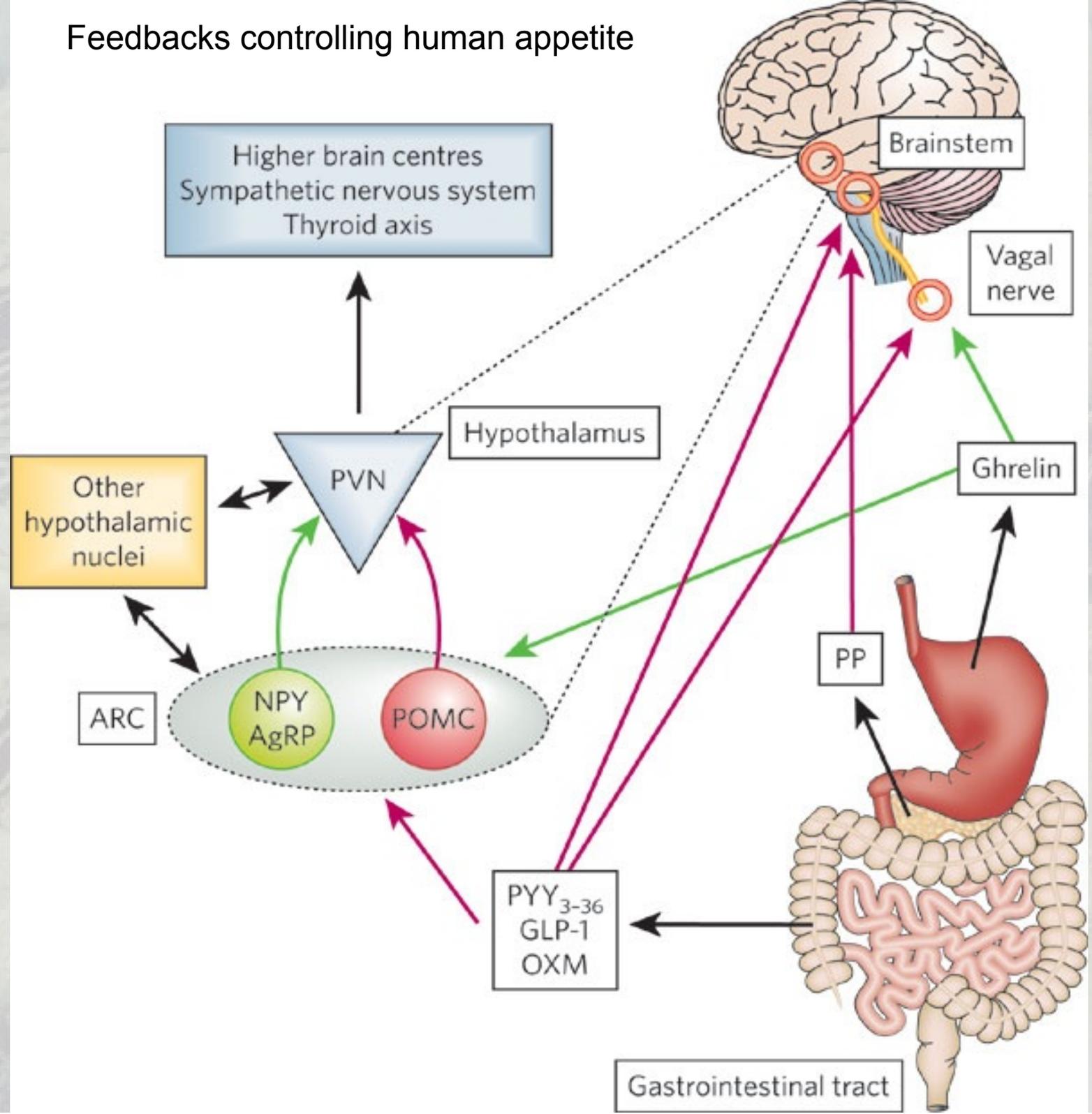


FIG. 29.—The Governor.



# Feedbacks controlling human appetite

PYY<sub>3-36</sub>, GLP-1 and oxyntomodulin (OXM) are released from gut L cells after a meal. They can directly stimulate anorectic pathways in the hypothalamus and brainstem, and may also act through the vagus nerve. Pancreatic polypeptide (PP) is released from the pancreas after a meal and is thought to reduce appetite by directly signalling to neurons in the brainstem. Ghrelin is released from the stomach with fasting and might signal directly to the hypothalamus or through the vagus nerve to stimulate food intake. The ARC is important in integrating gut hormone energy homeostasis signals. NPY/AgRP neurons and POMC neurons signal to the PVN and other hypothalamic nuclei to increase or decrease appetite, respectively. Green arrows indicate orexigenic signals and red arrows indicate anorectic signals.



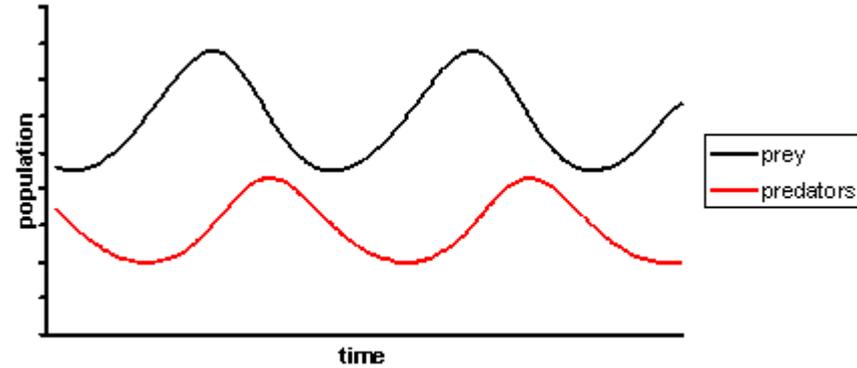




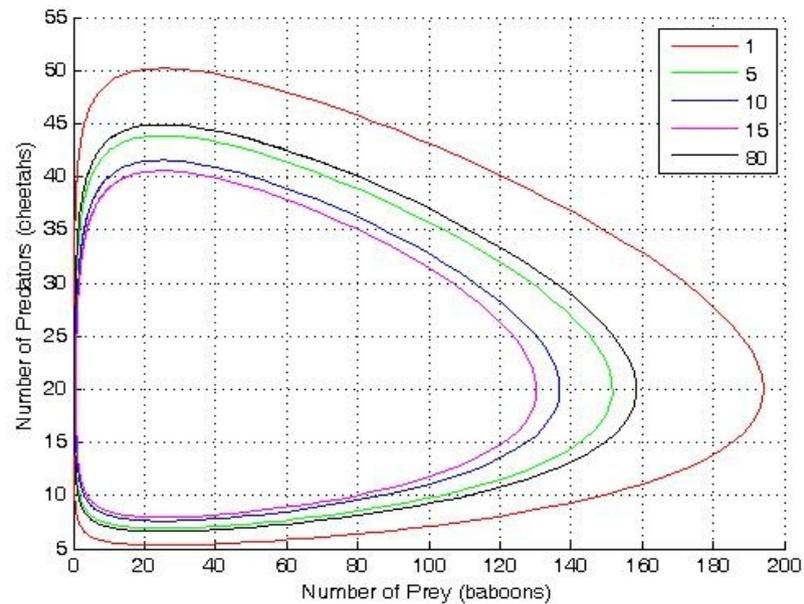
# Modello di Lotka-Volterra (LV)

$$\frac{dx}{dt} = x(\alpha - \beta y)$$

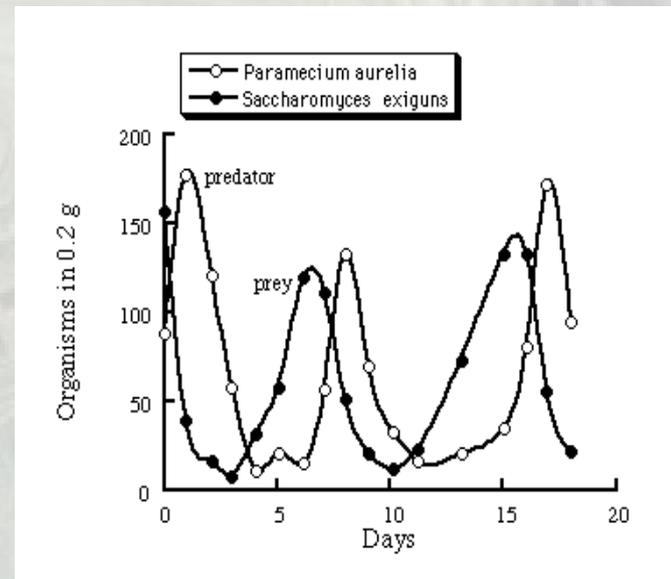
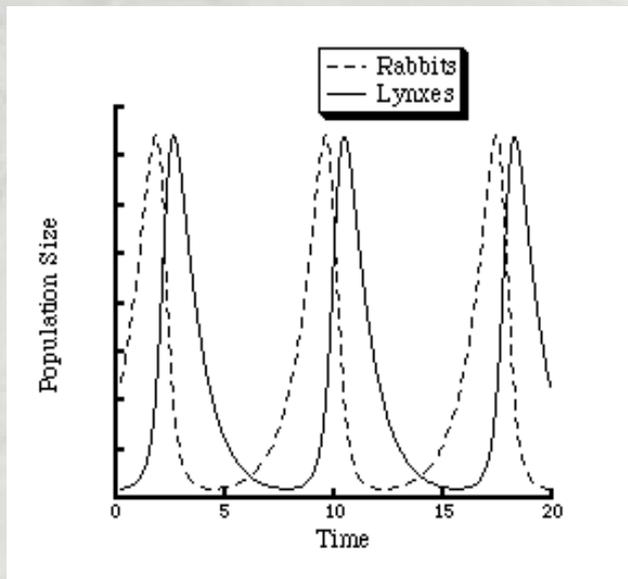
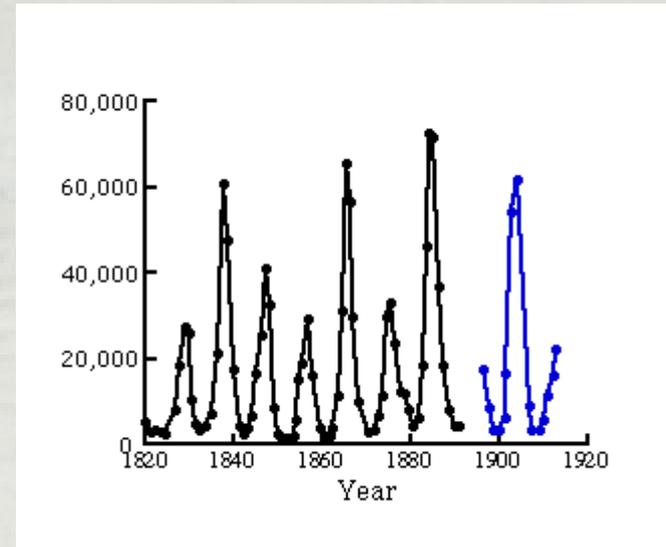
$$\frac{dy}{dt} = -y(\gamma - \delta x)$$



Vito Volterra  
1860-1940



# The Lotka Volterra model: rabbits and lynx



## Modello socio-economico di Lotka-Volterra

$$R' = -k_1 CR$$

$$C' = k_2 CR - K_3 C$$

$R'$  = Produzione

$C'$  = Crescita economica

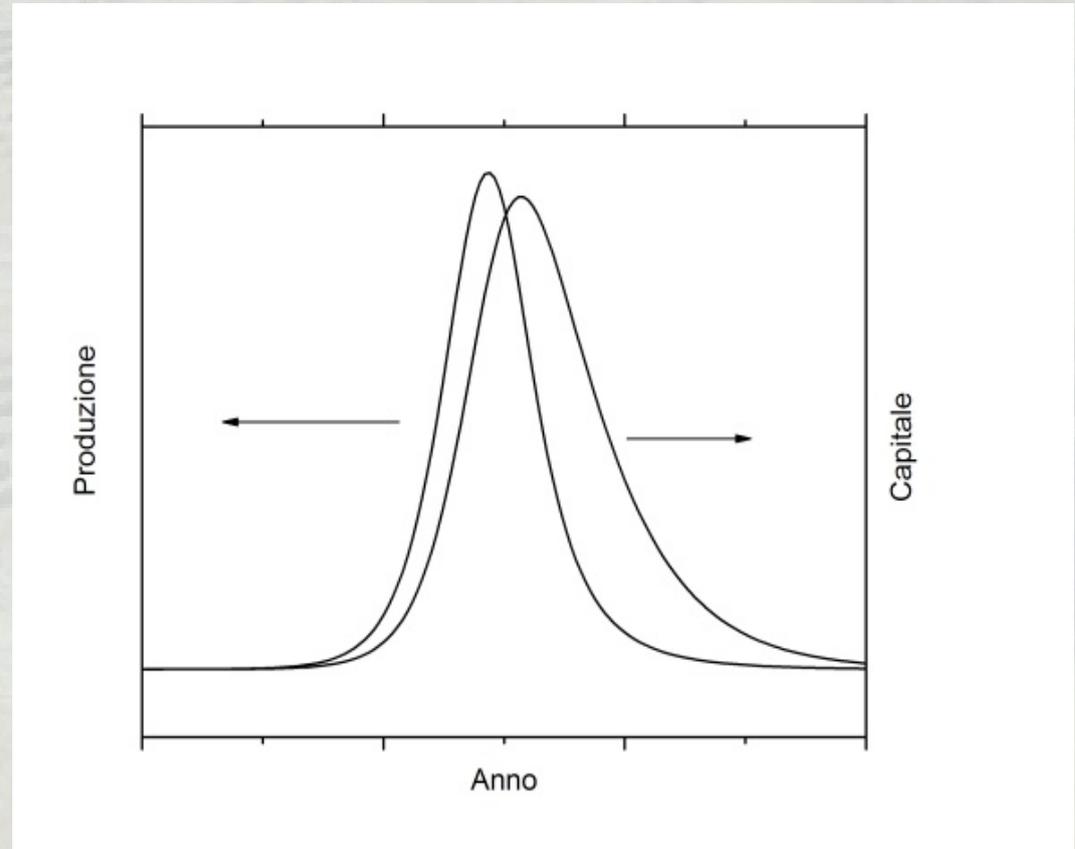
$C$  = Capitale

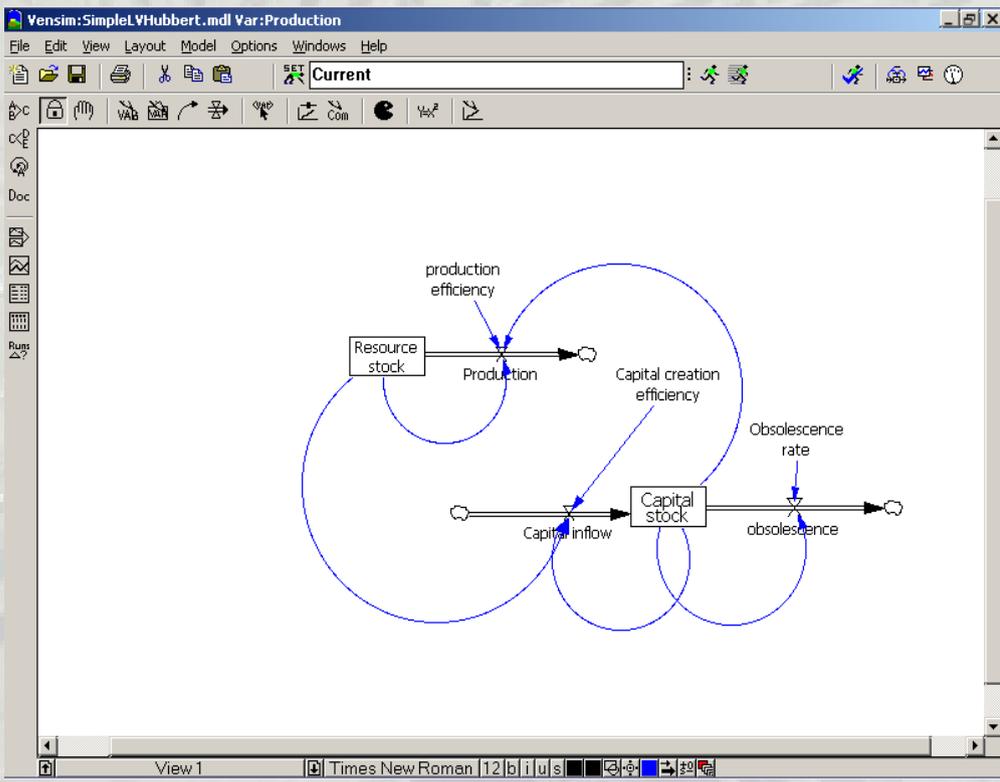
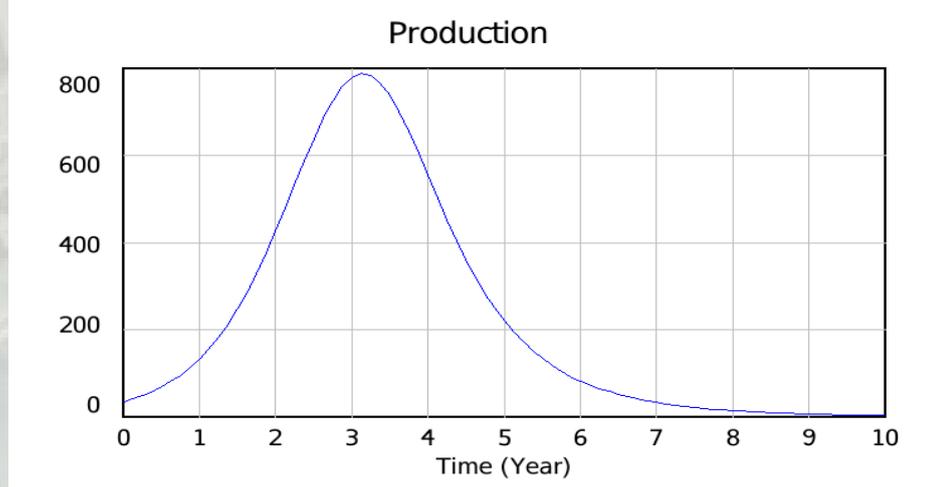
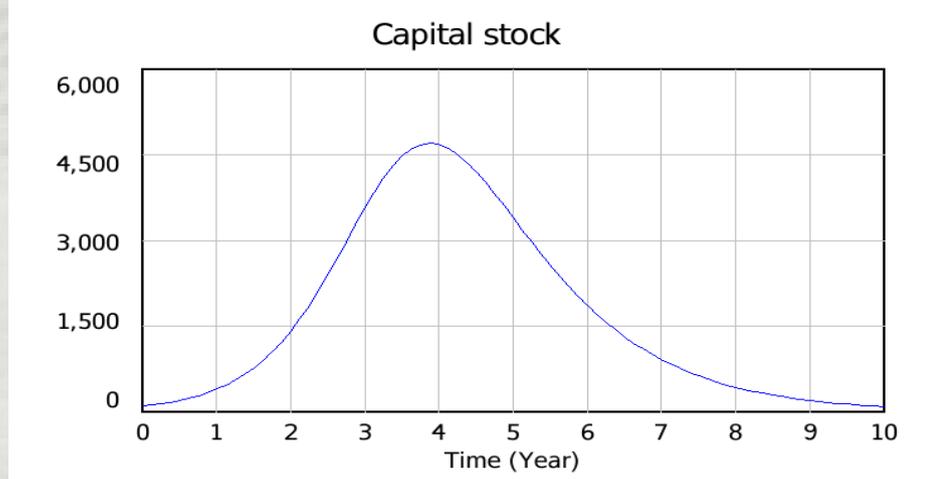
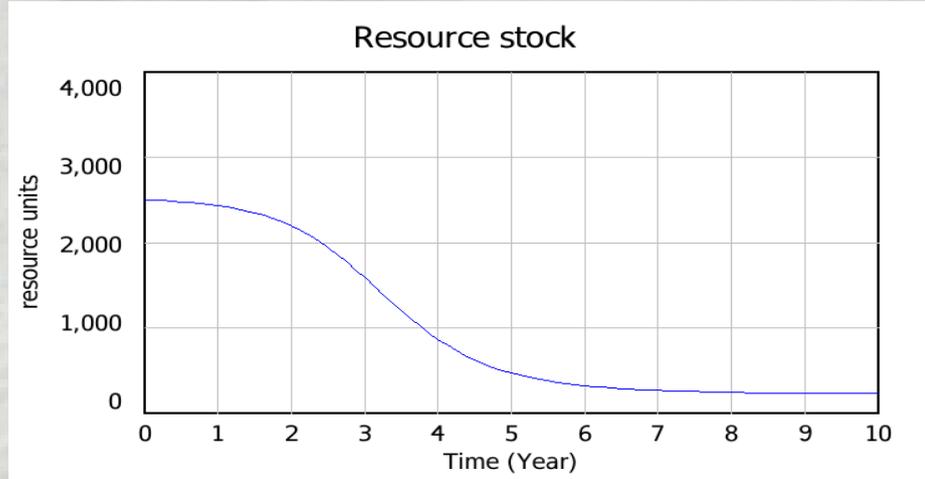
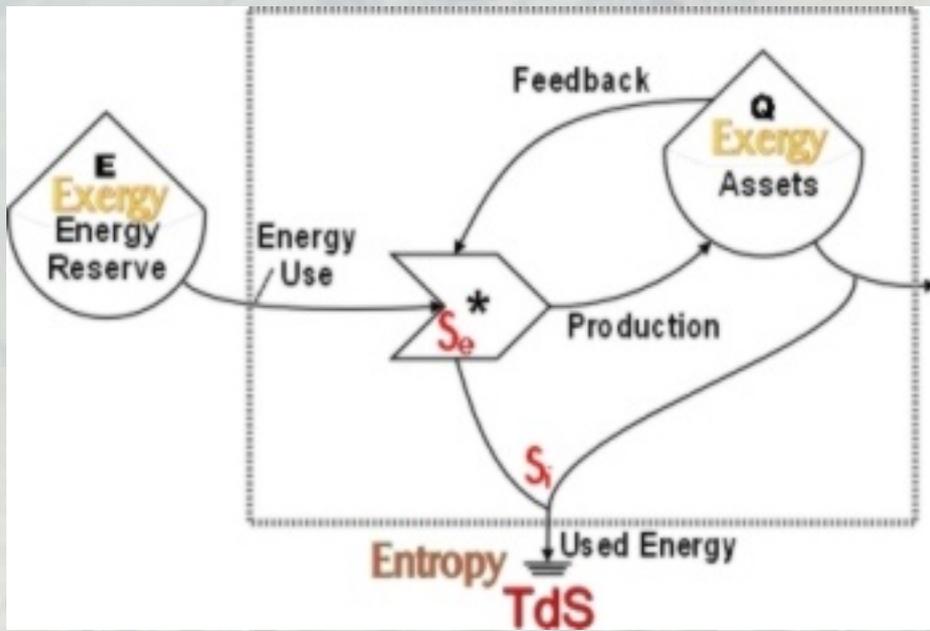
$R$  = Risorse

$k_1$  = Efficienza della trasformazione del capitale in risorse

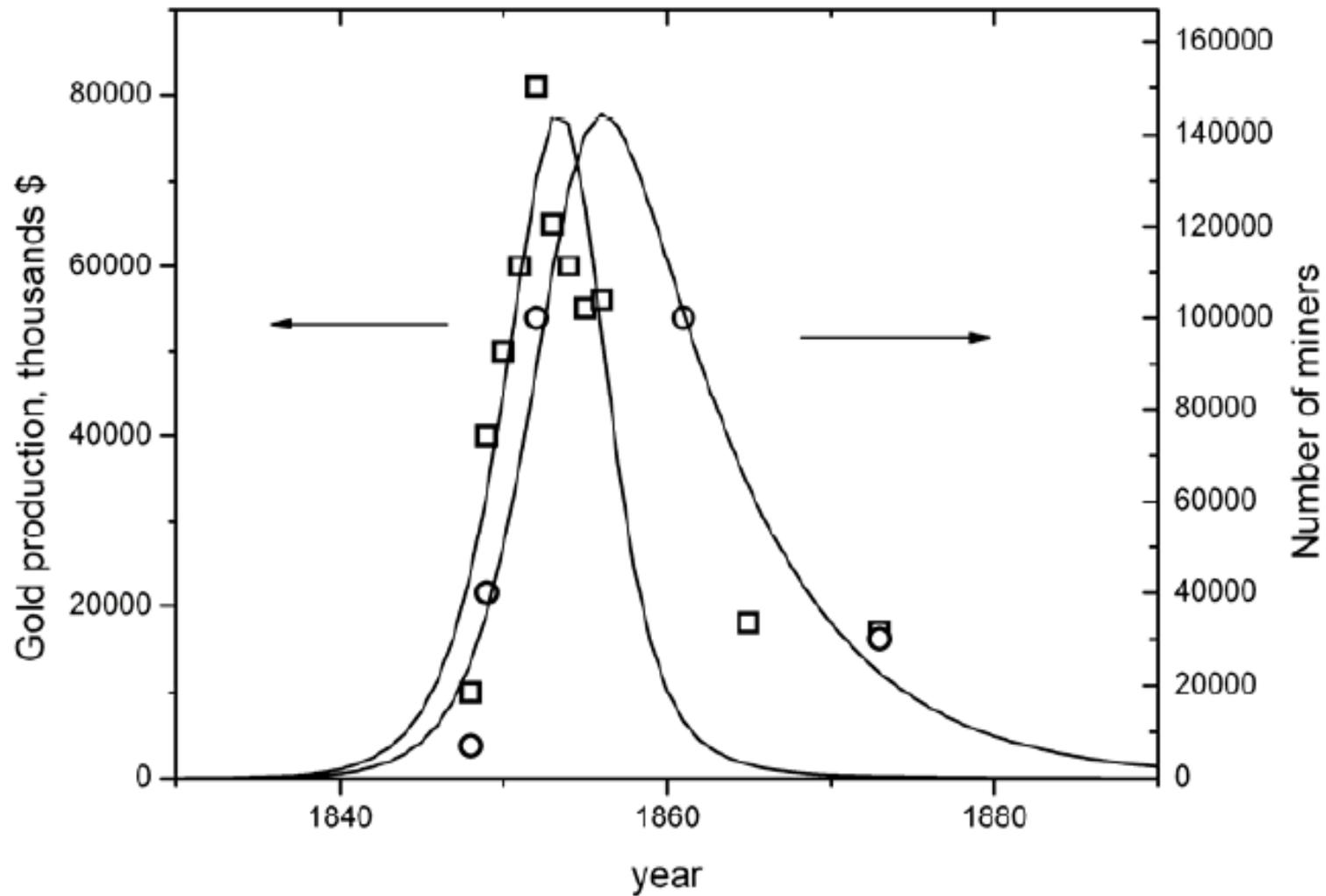
$k_2$  = Efficienza della trasformazione delle risorse in capitale

$k_3$  = Deprezzamento del capitale

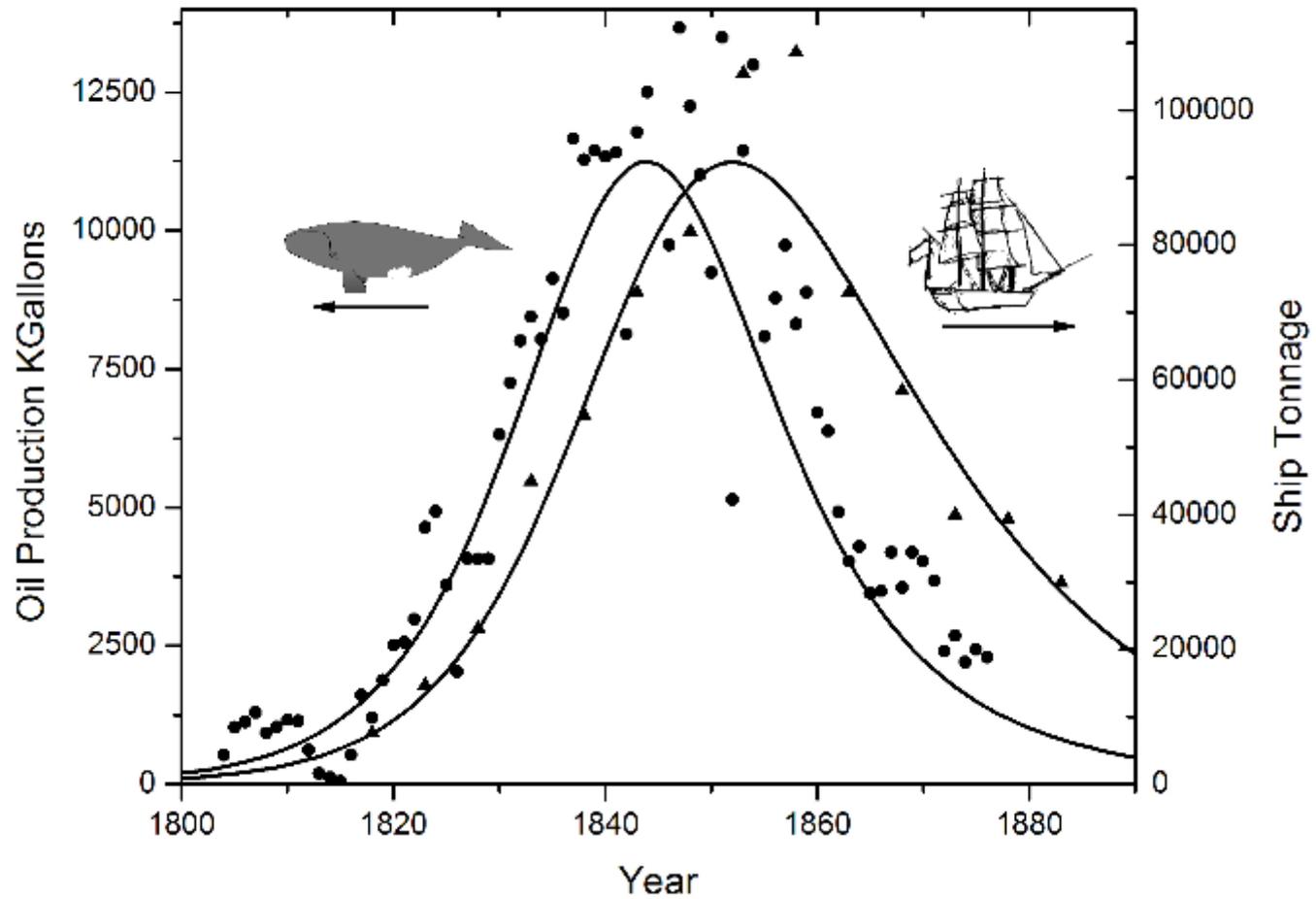




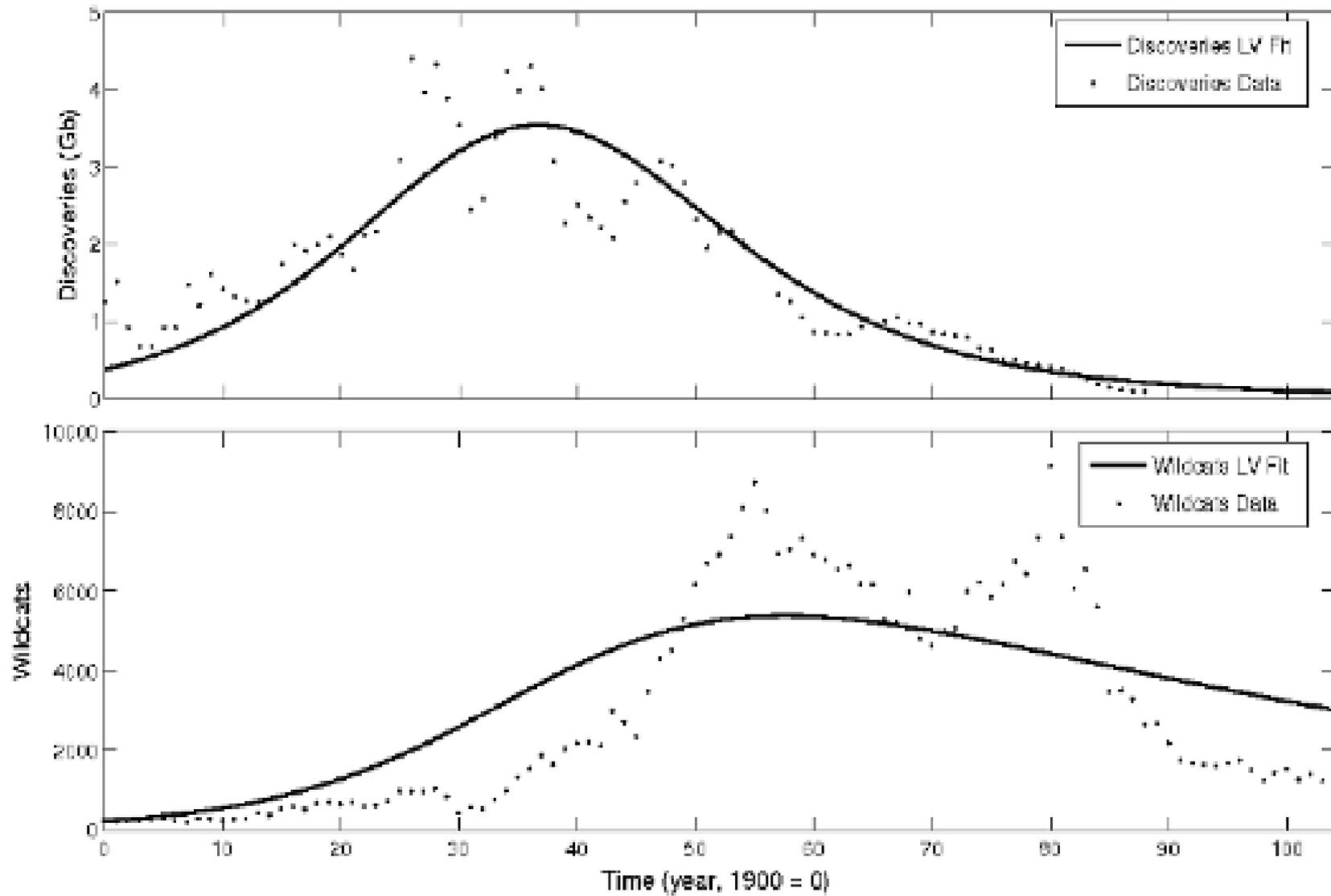
**Figure 3.** Gold production and number of miners during the “Gold Rush” in California fitted using the LV model developed here. The data are from [22].



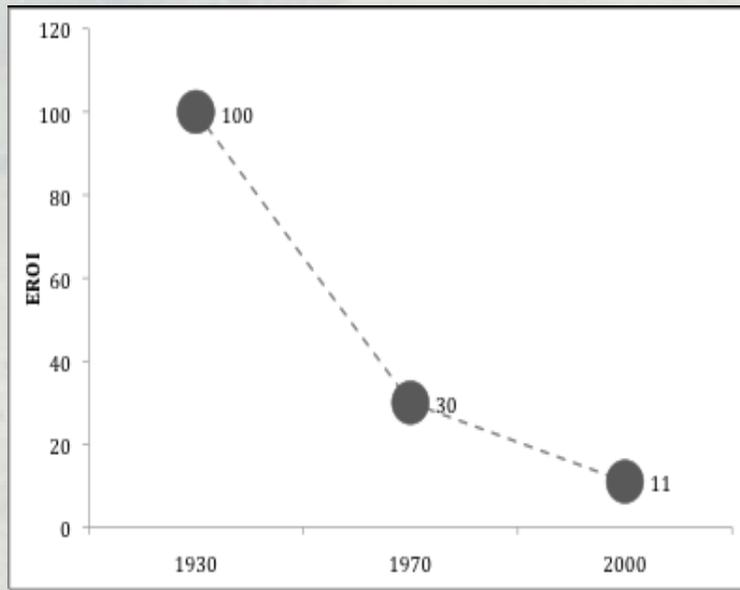
# Whaling in 19th century



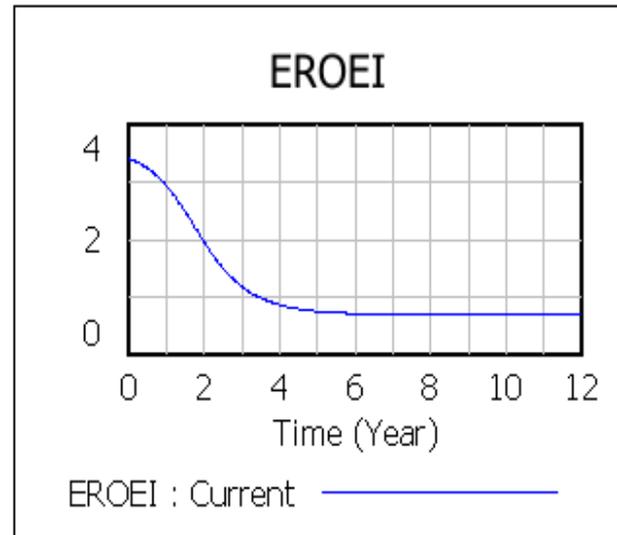
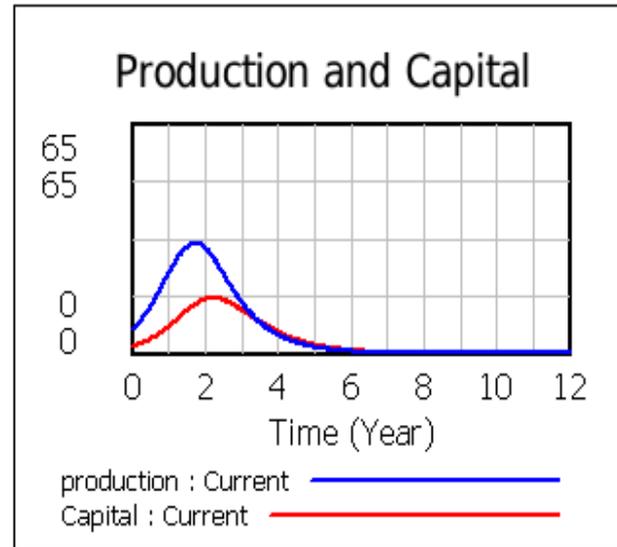
US 48 - Oil Discoveries vs. Wildcats



# Plot of the EROEI of oil extraction in the US.



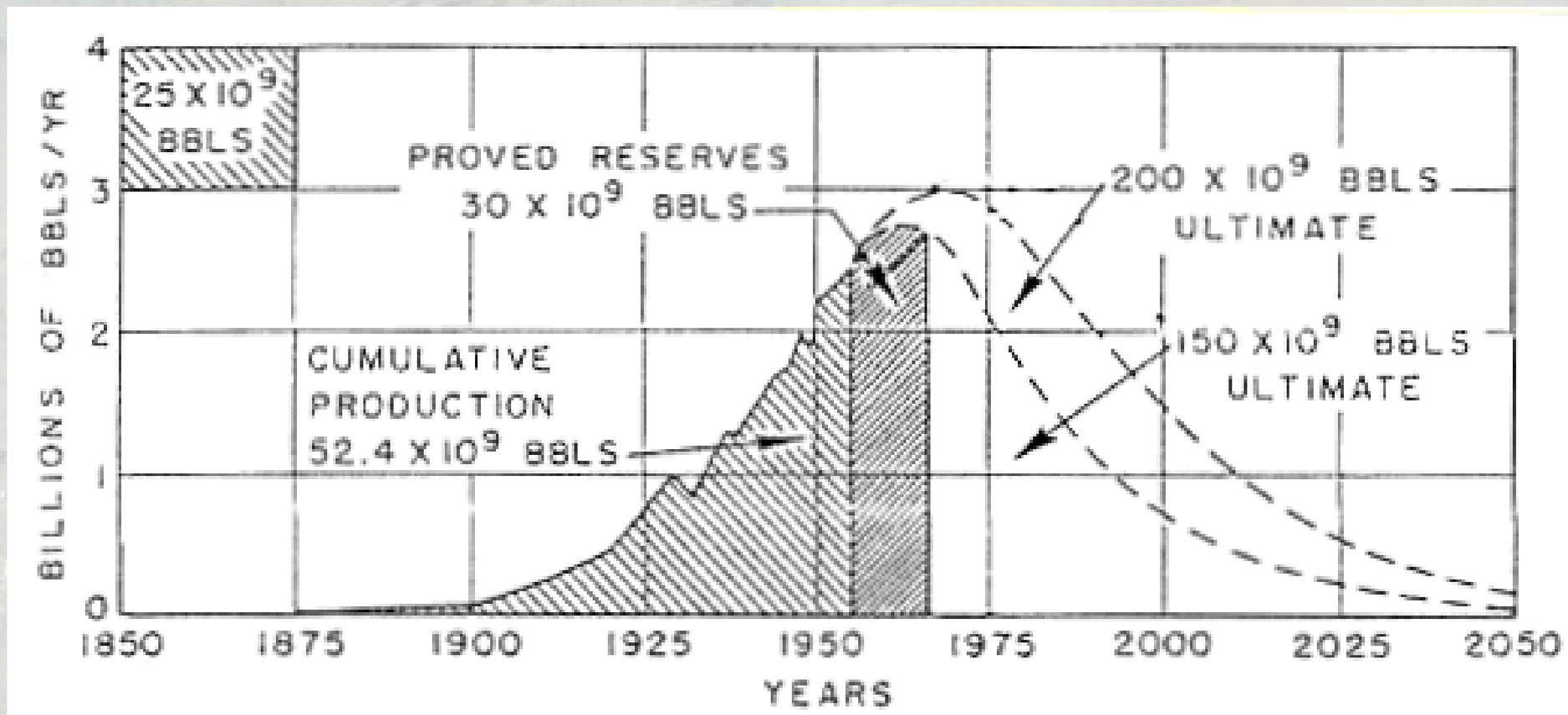
(D. Murphy, TOD, from data of Cutler Cleveland)

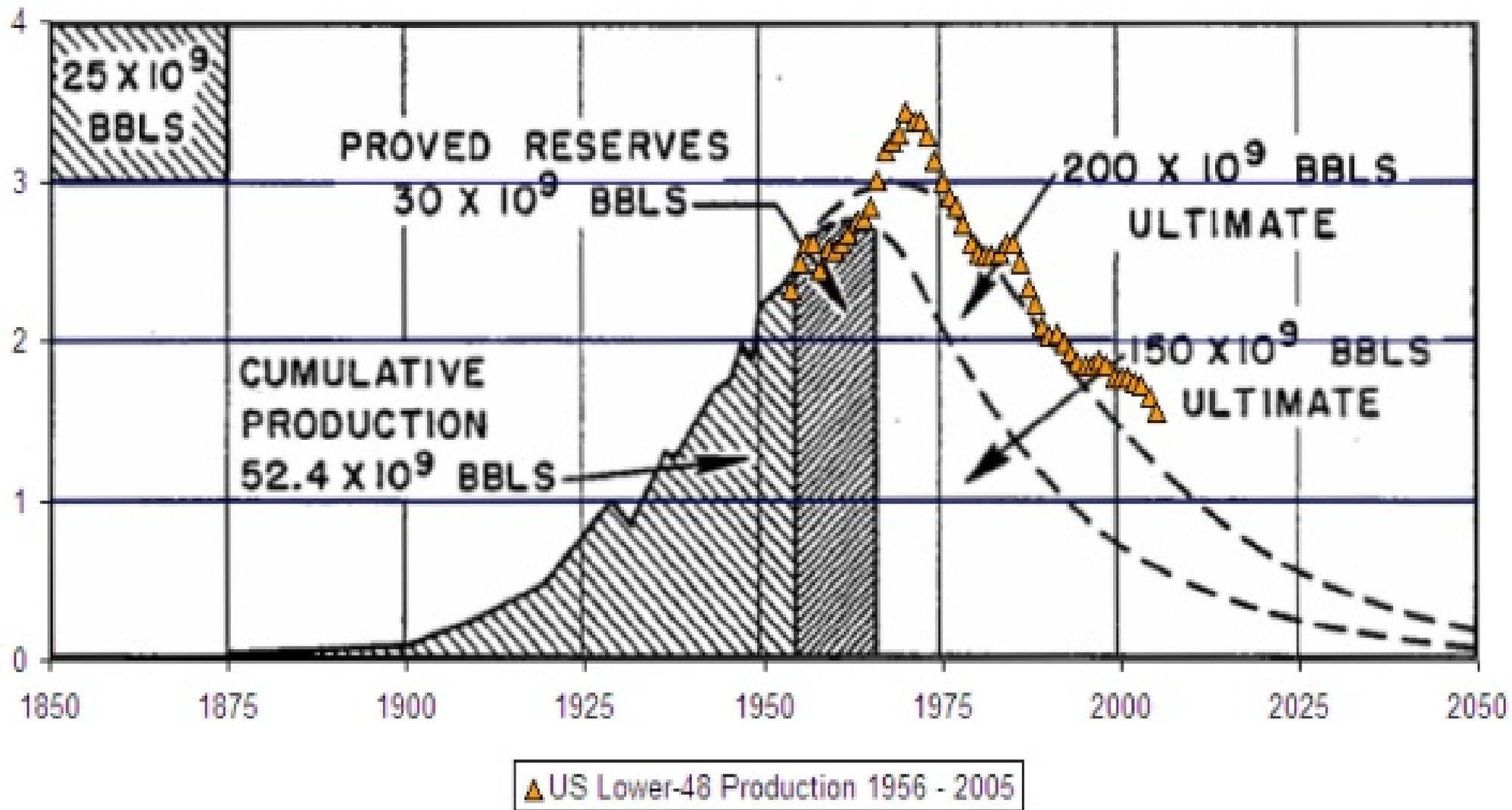


$$EROEI = p/C = k1R$$

LV model

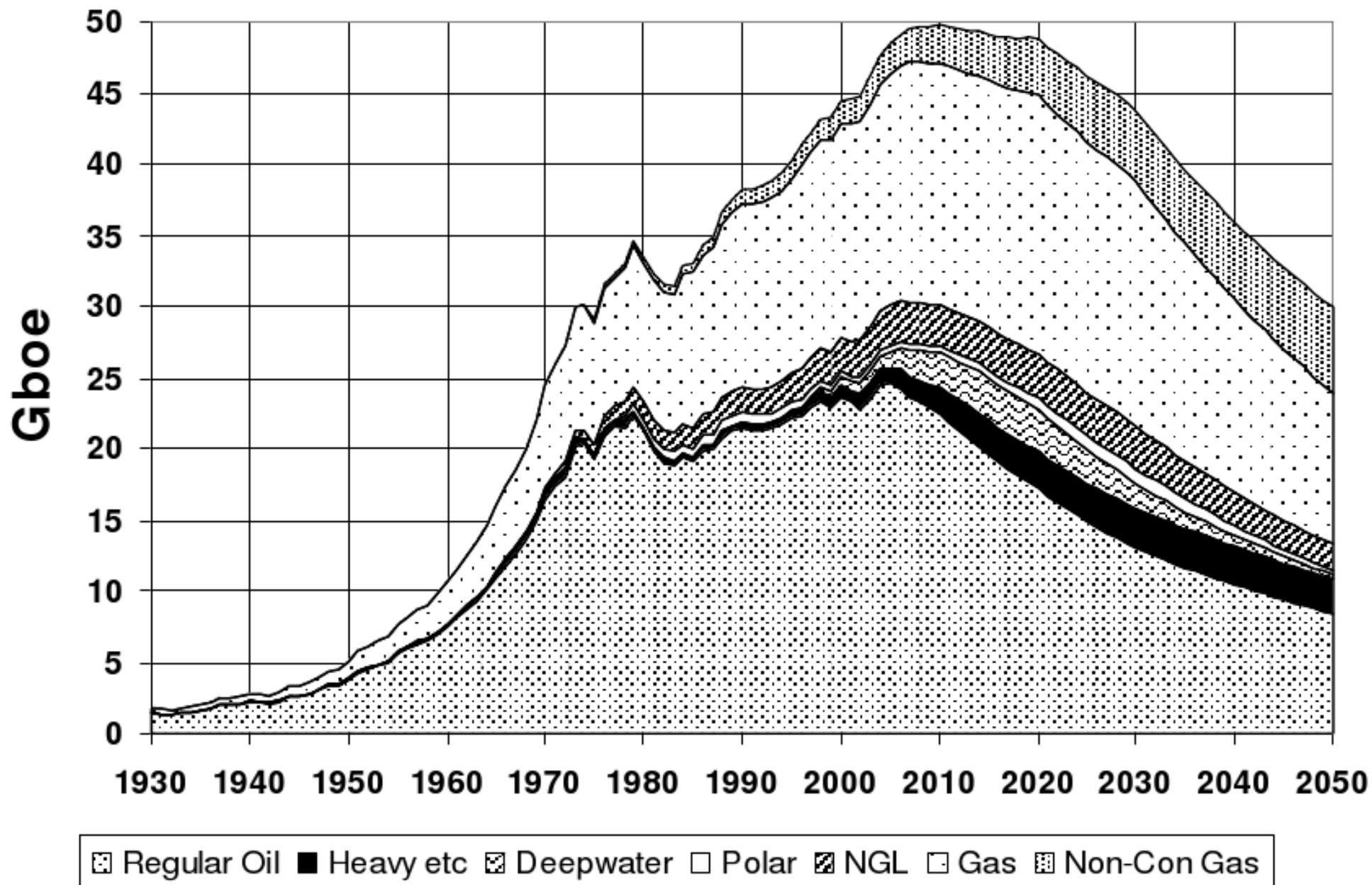
# Hubbert 1956: il "picco del petrolio" nei 48 stati meridionali - USA



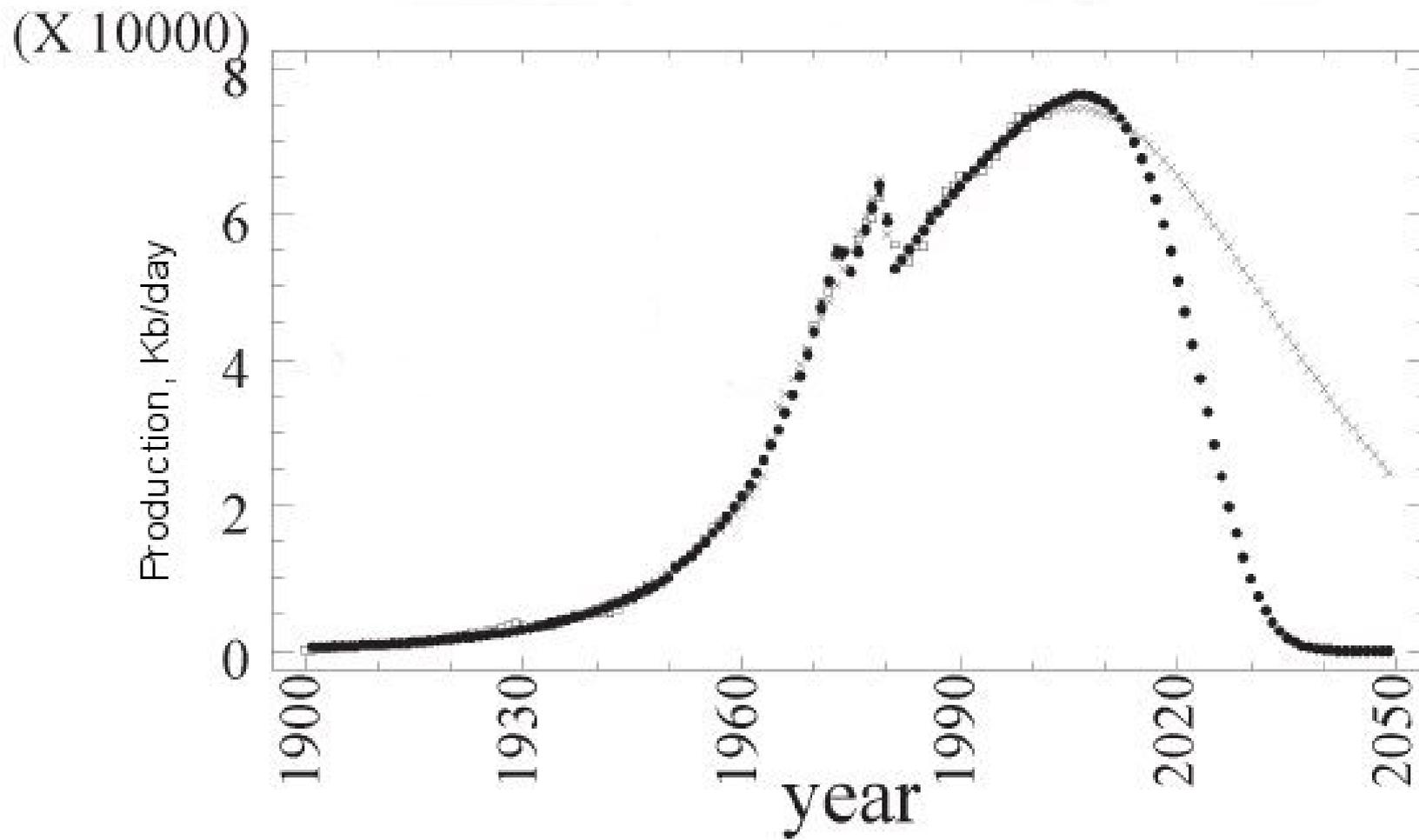


# OIL & GAS PRODUCTION PROFILES

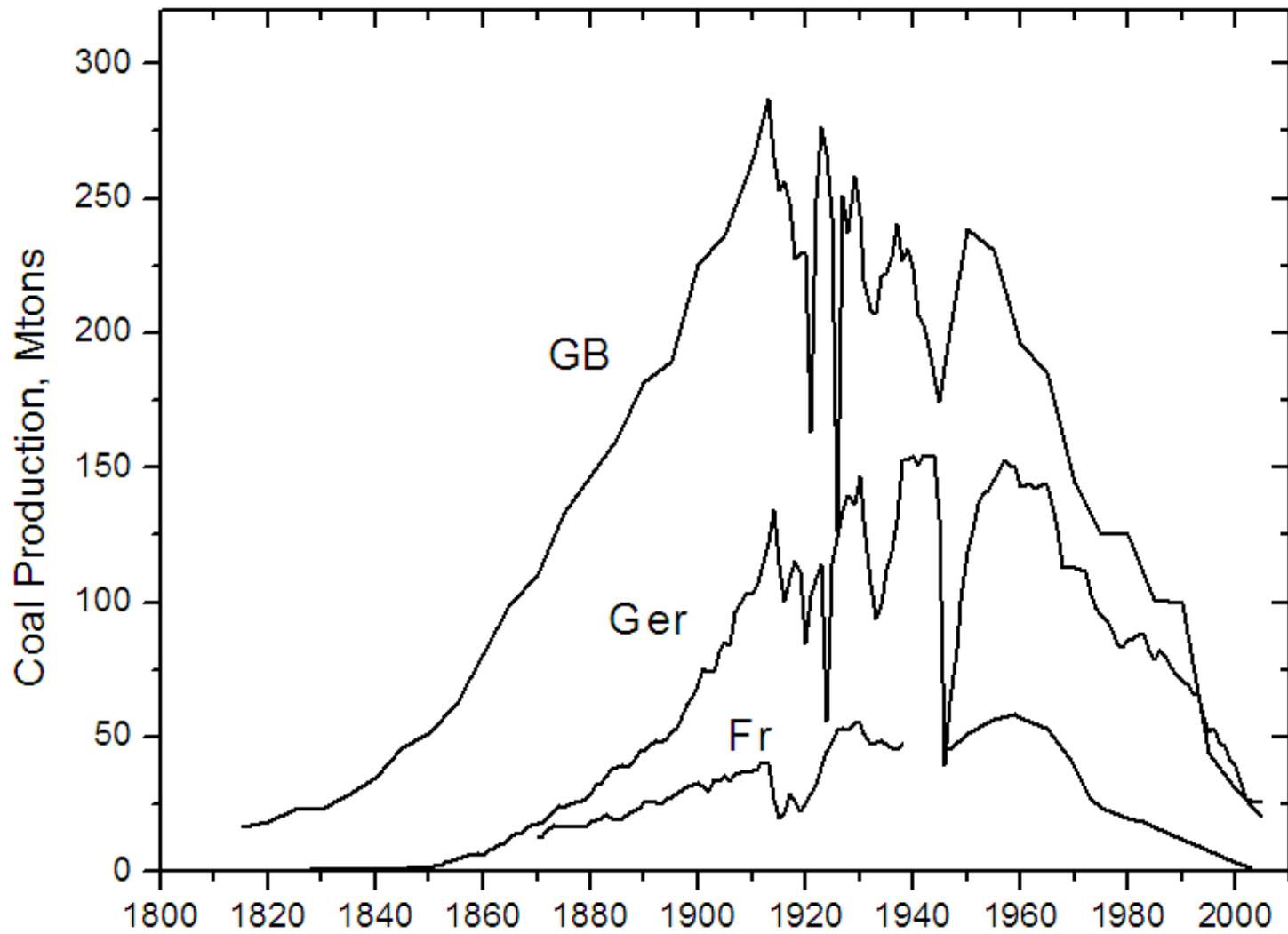
## 2008 Base Case



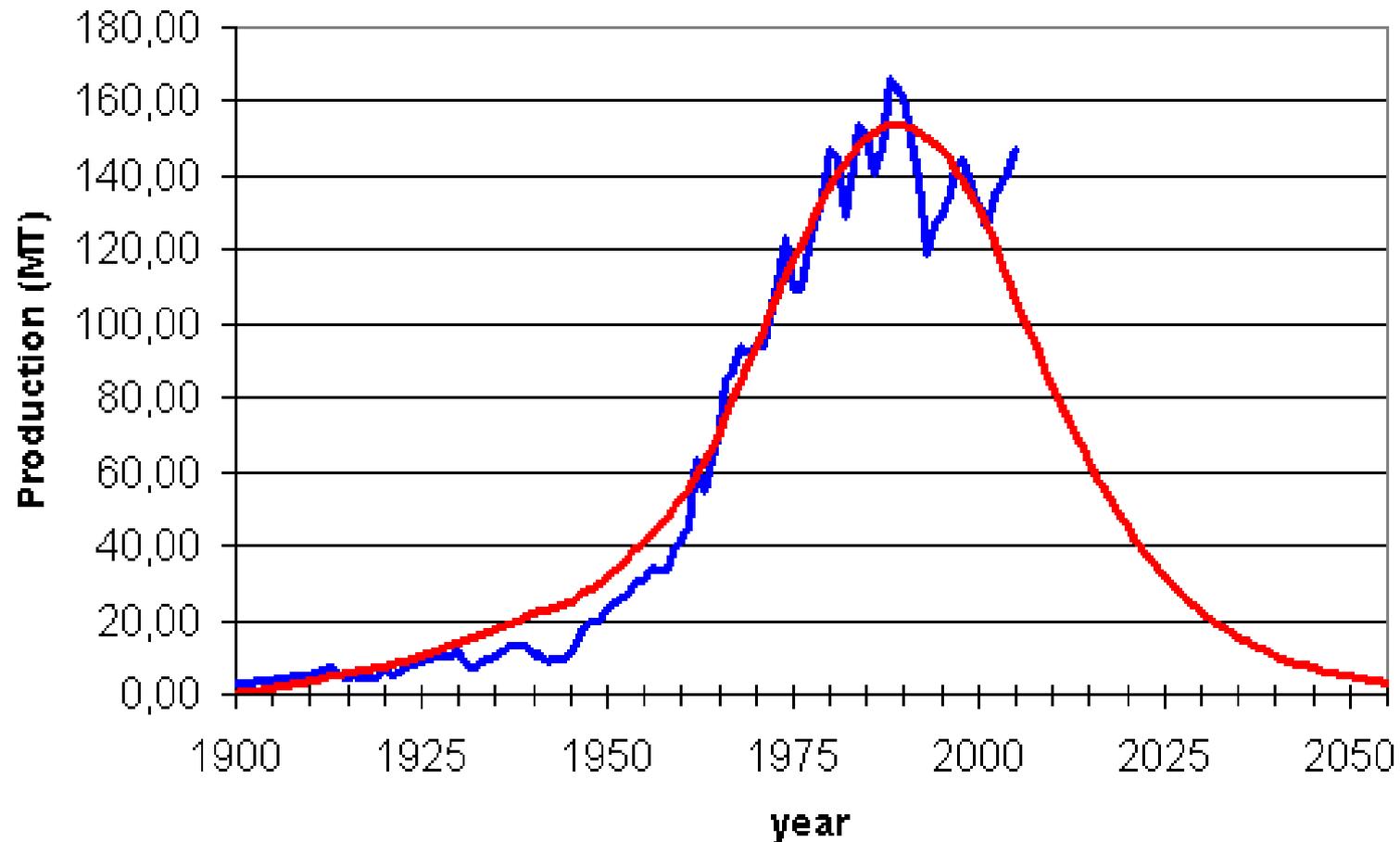
## Generalized Bass Model



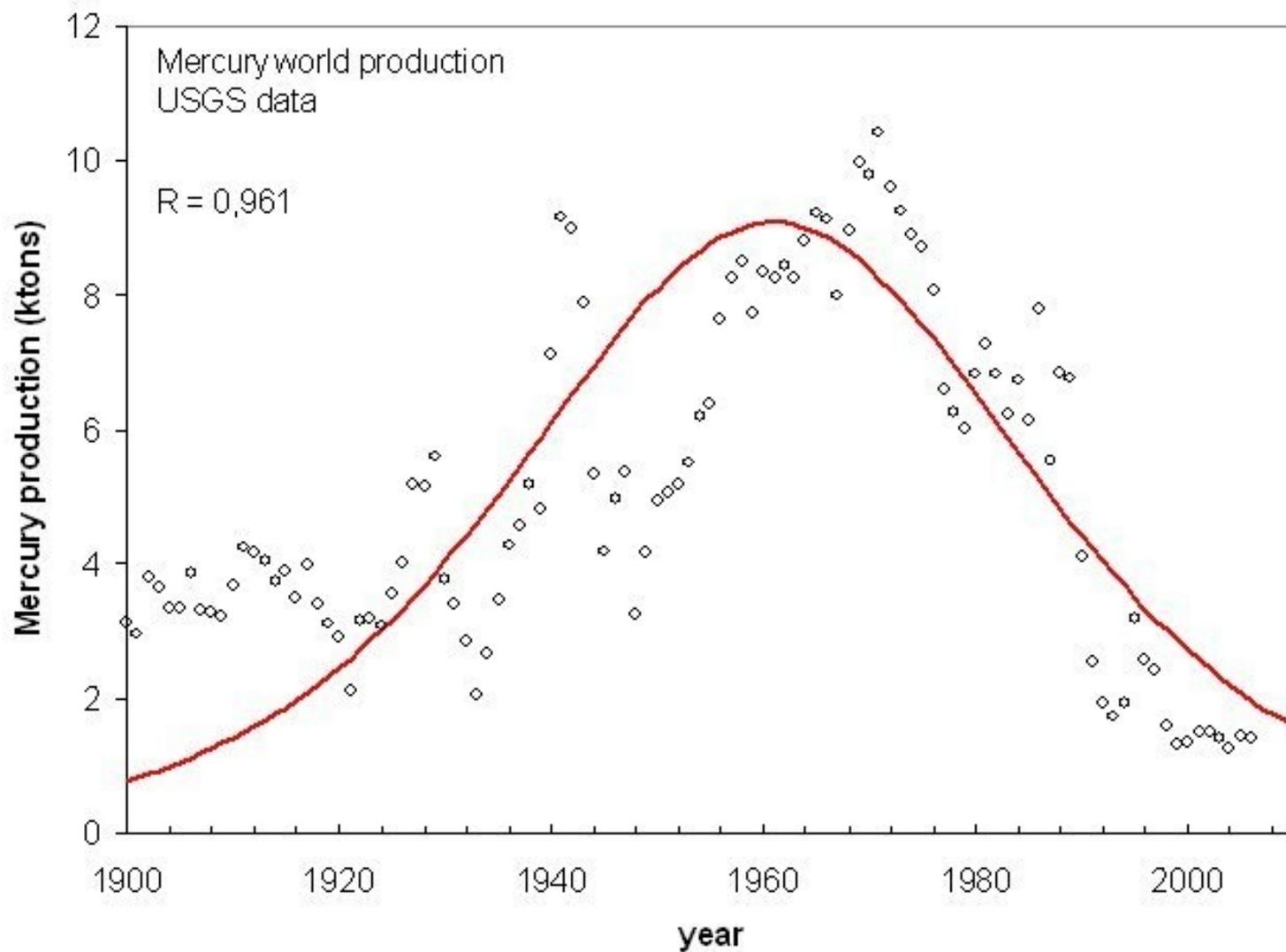
# Historical Coal Production: Europe



## World rock phosphate production

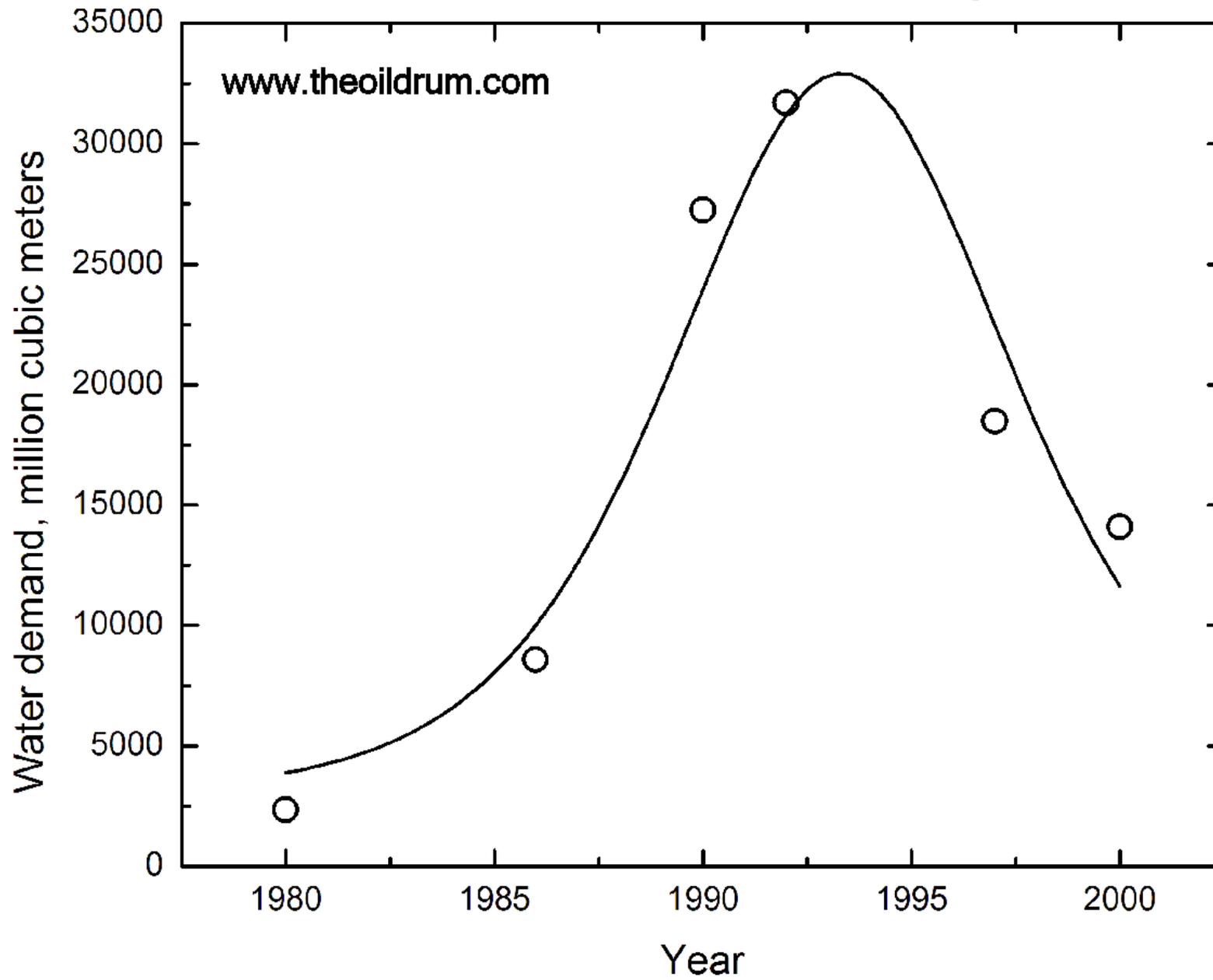


Dery and Anderson, The Oil Drum  
<http://www.theoil drum.com/node/2882>



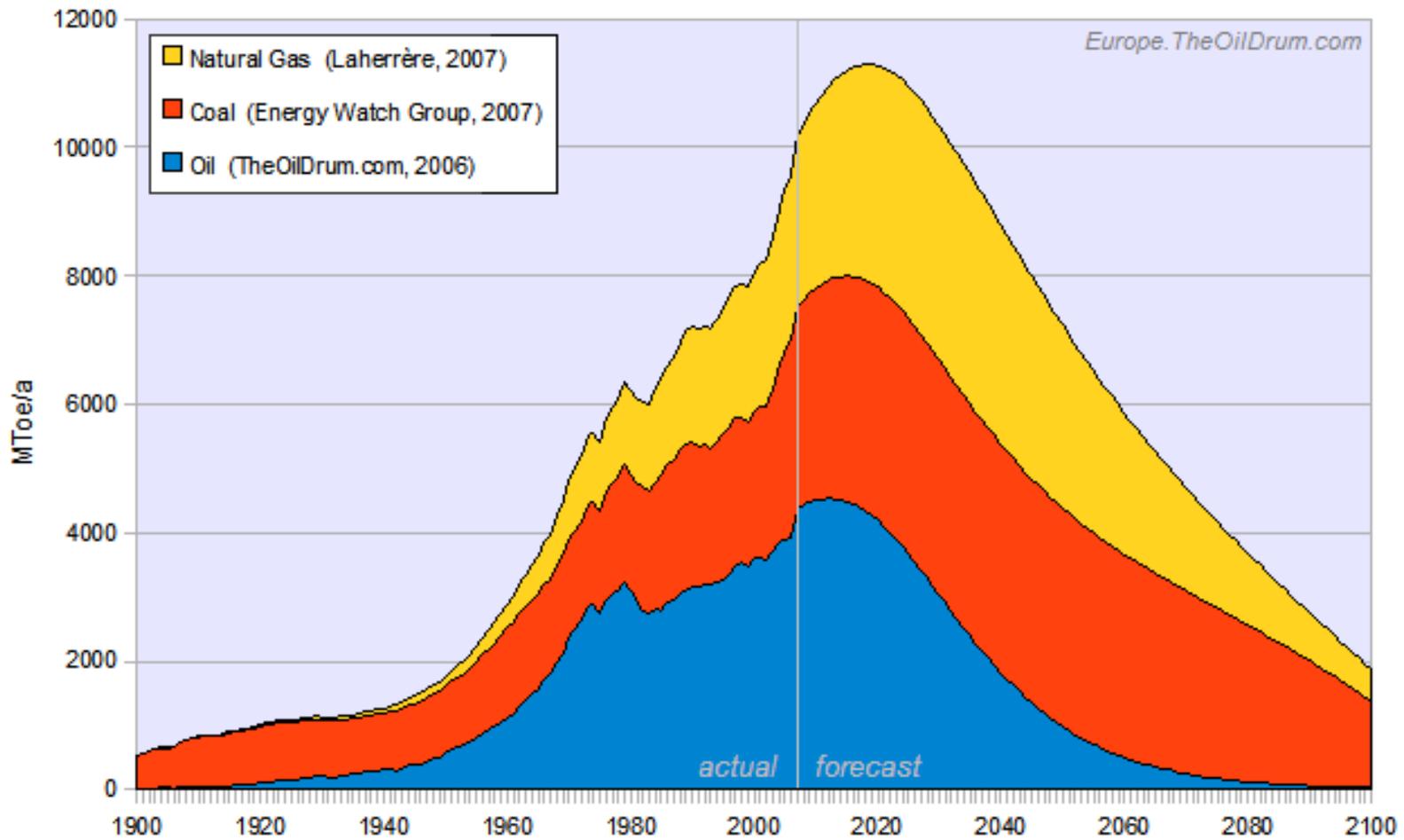
Bardi and Pagani, TOD 2007  
<http://europe.theoil drum.com/node/3086>

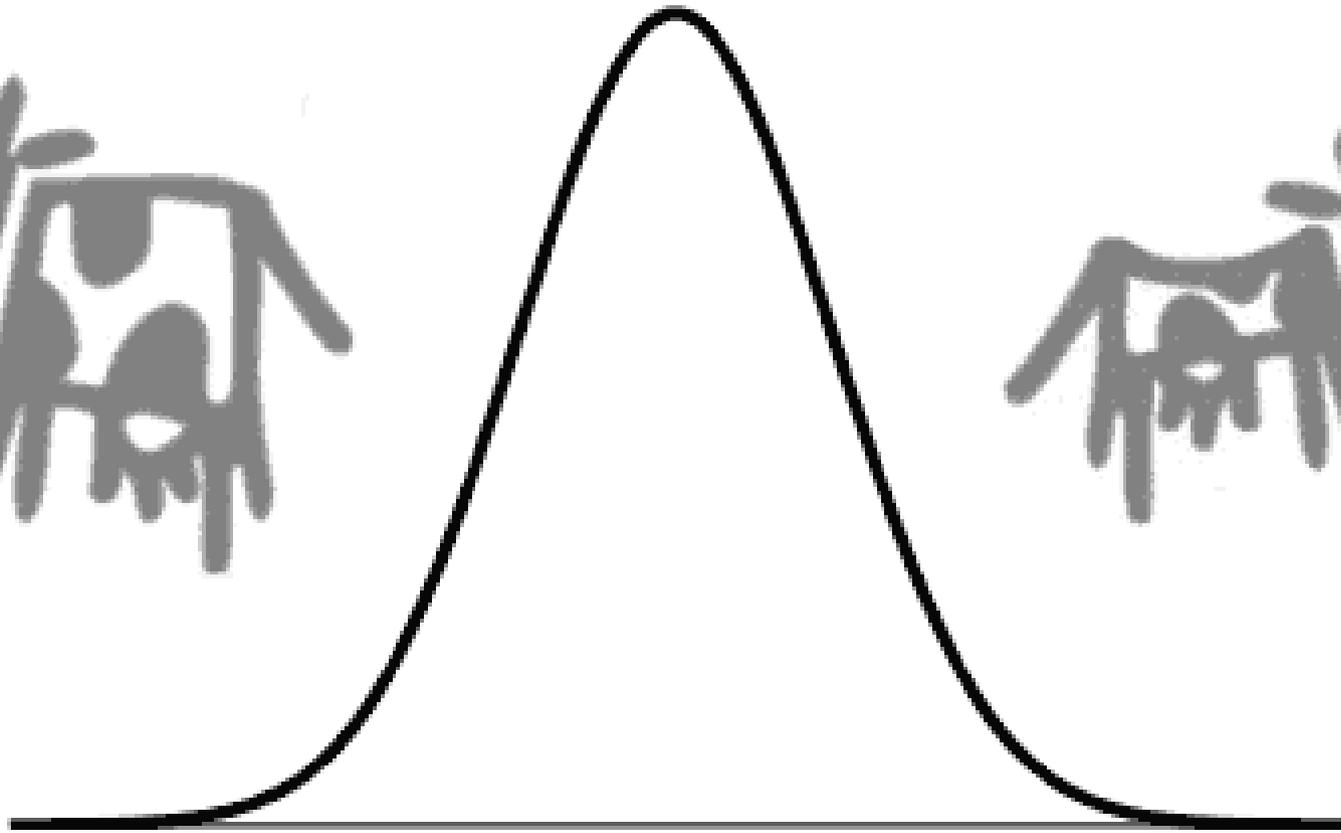
# Saudi Arabian Water Supply



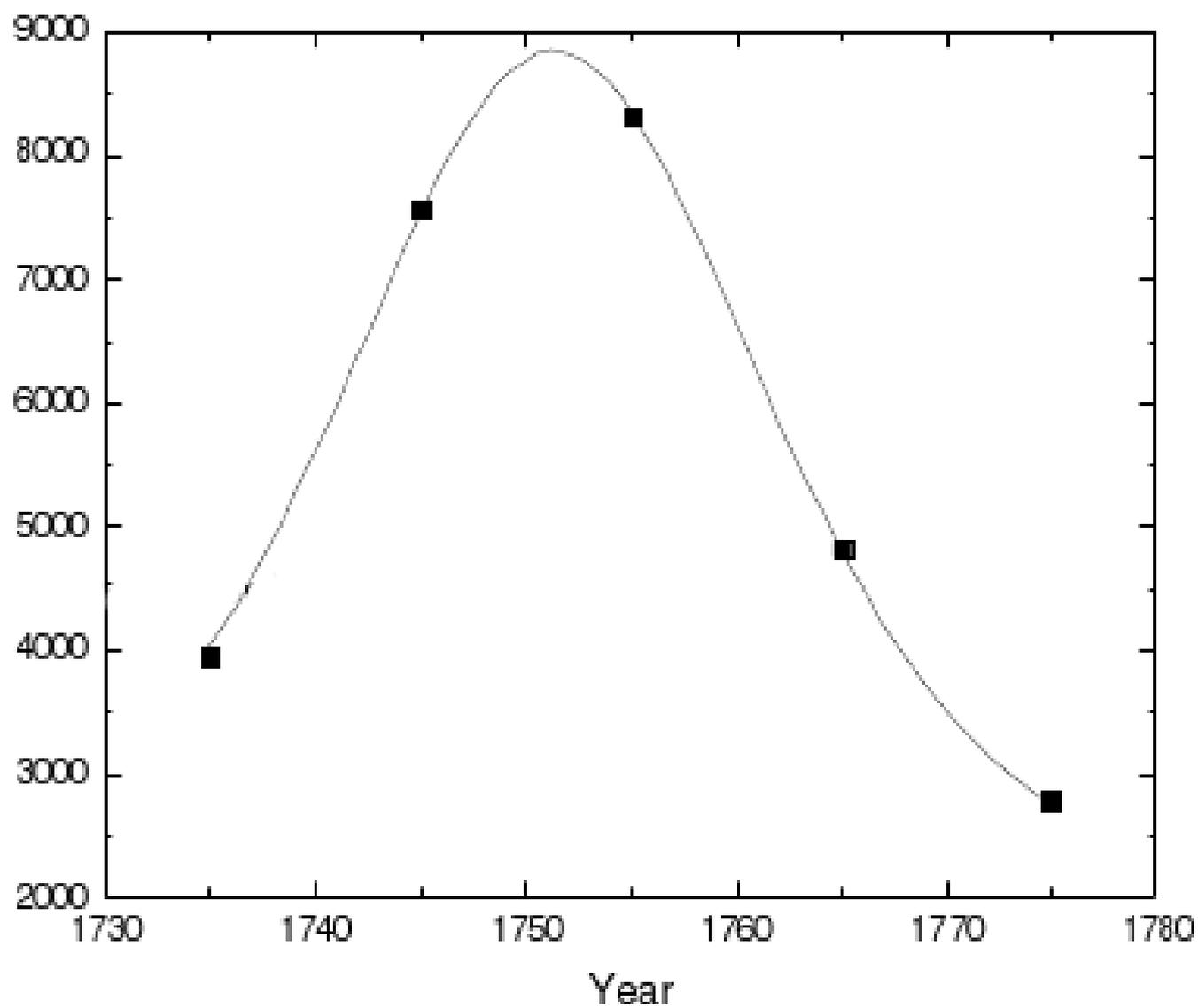
Data from Abderrhaman, [http://www.idrc.ca/en/ev-93954-201-1-DO\\_TOPIC.html](http://www.idrc.ca/en/ev-93954-201-1-DO_TOPIC.html)

## Conventional Fossil Fuels



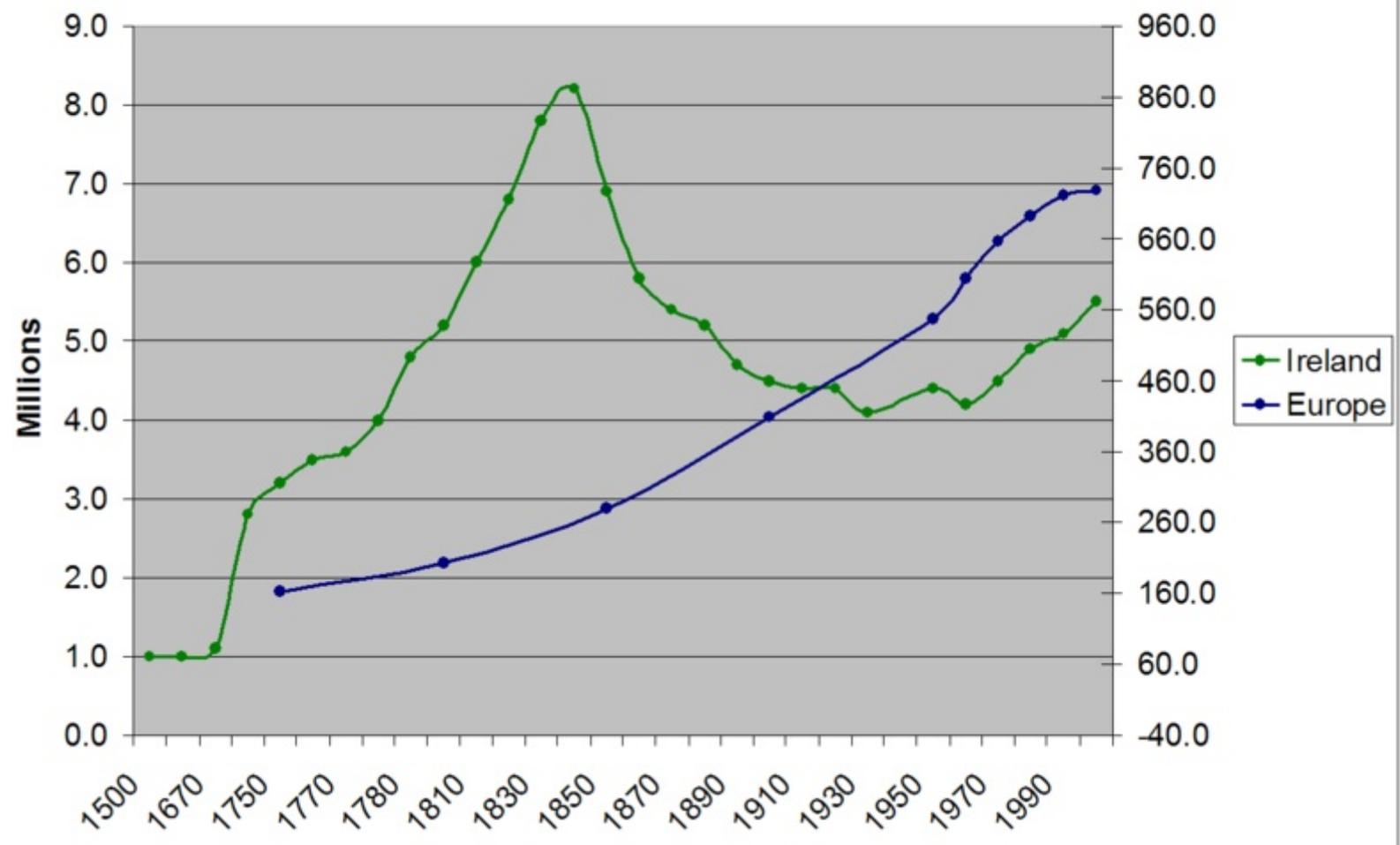


## Acreage for sale in Ireland

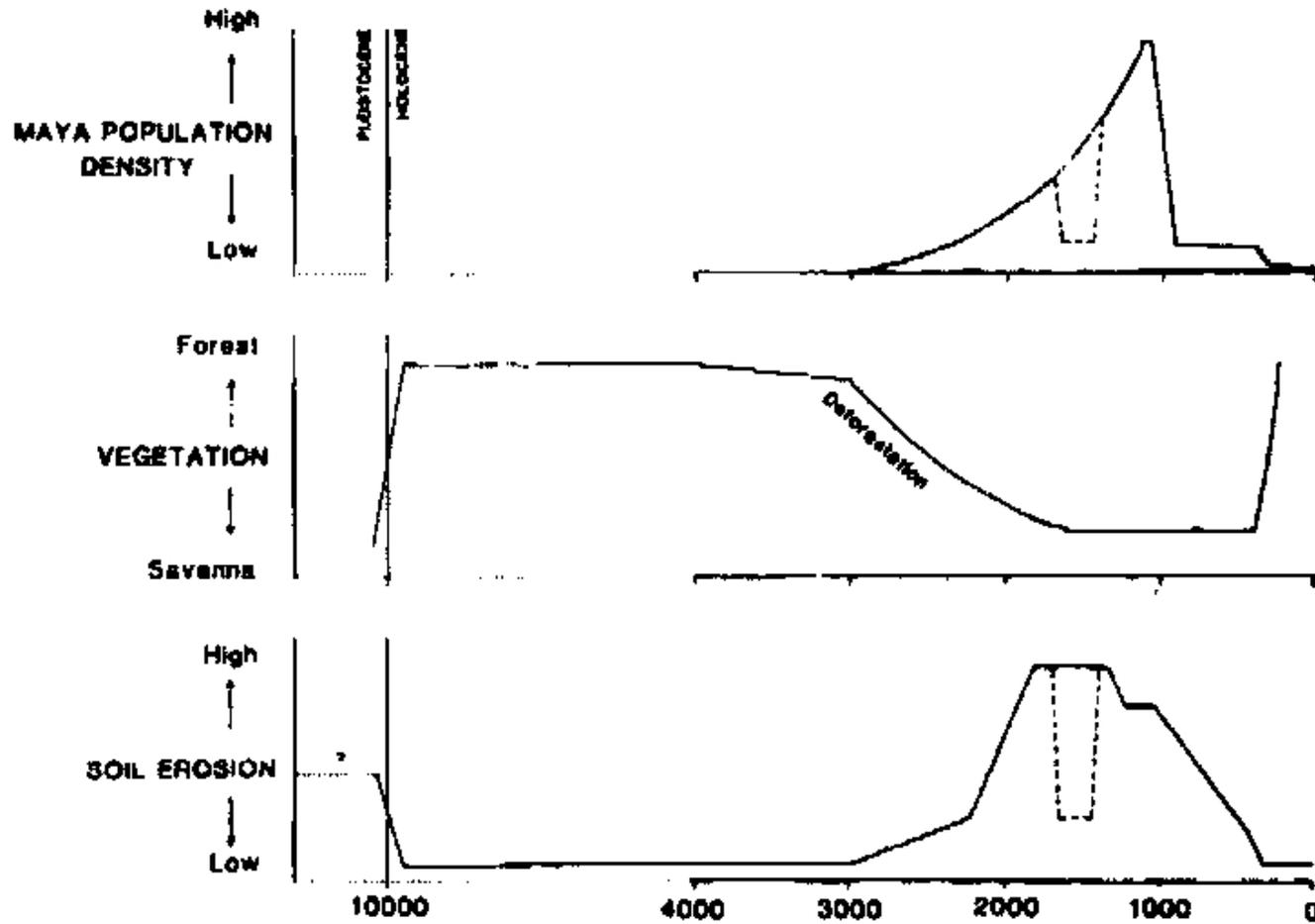


data from, McCracken 1972

### Population of Ireland and Europe

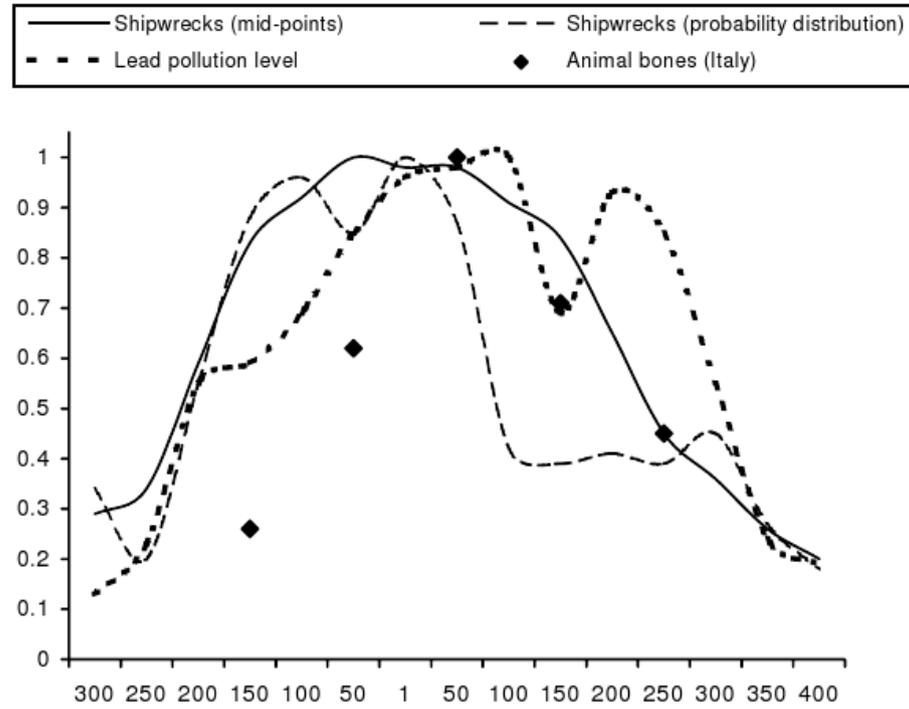


# The collapse of the Mayan Civilization



# The fall of the Roman Empire

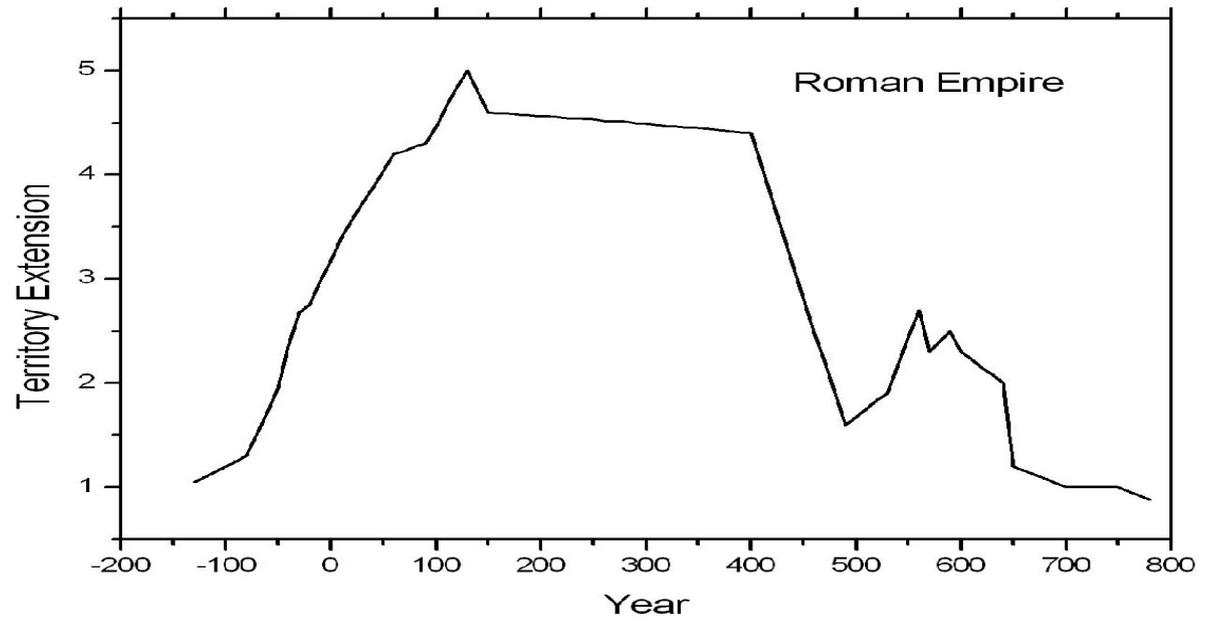
In search of Roman economic growth, W. Scheidel, 2008



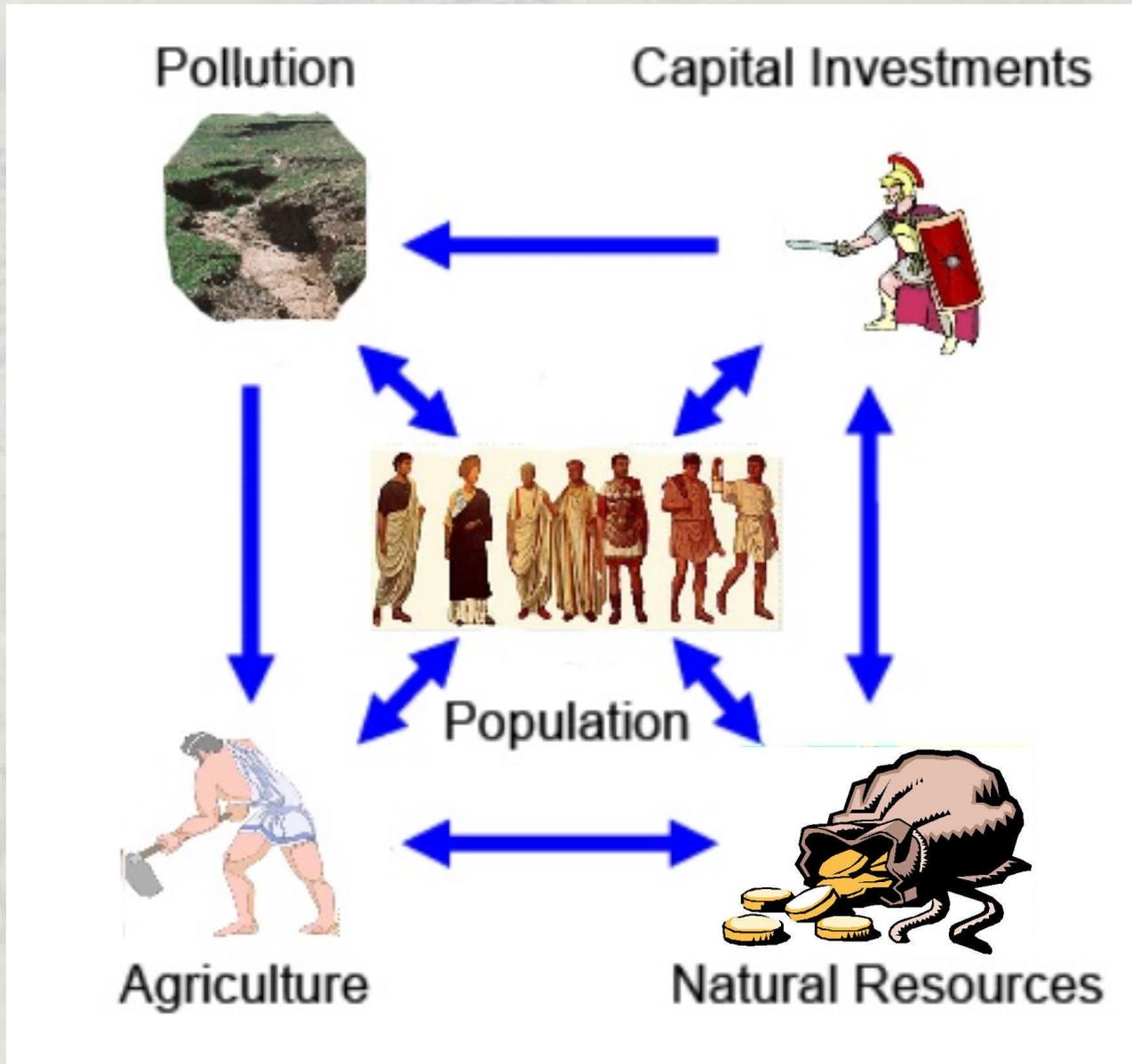
Production

Capital

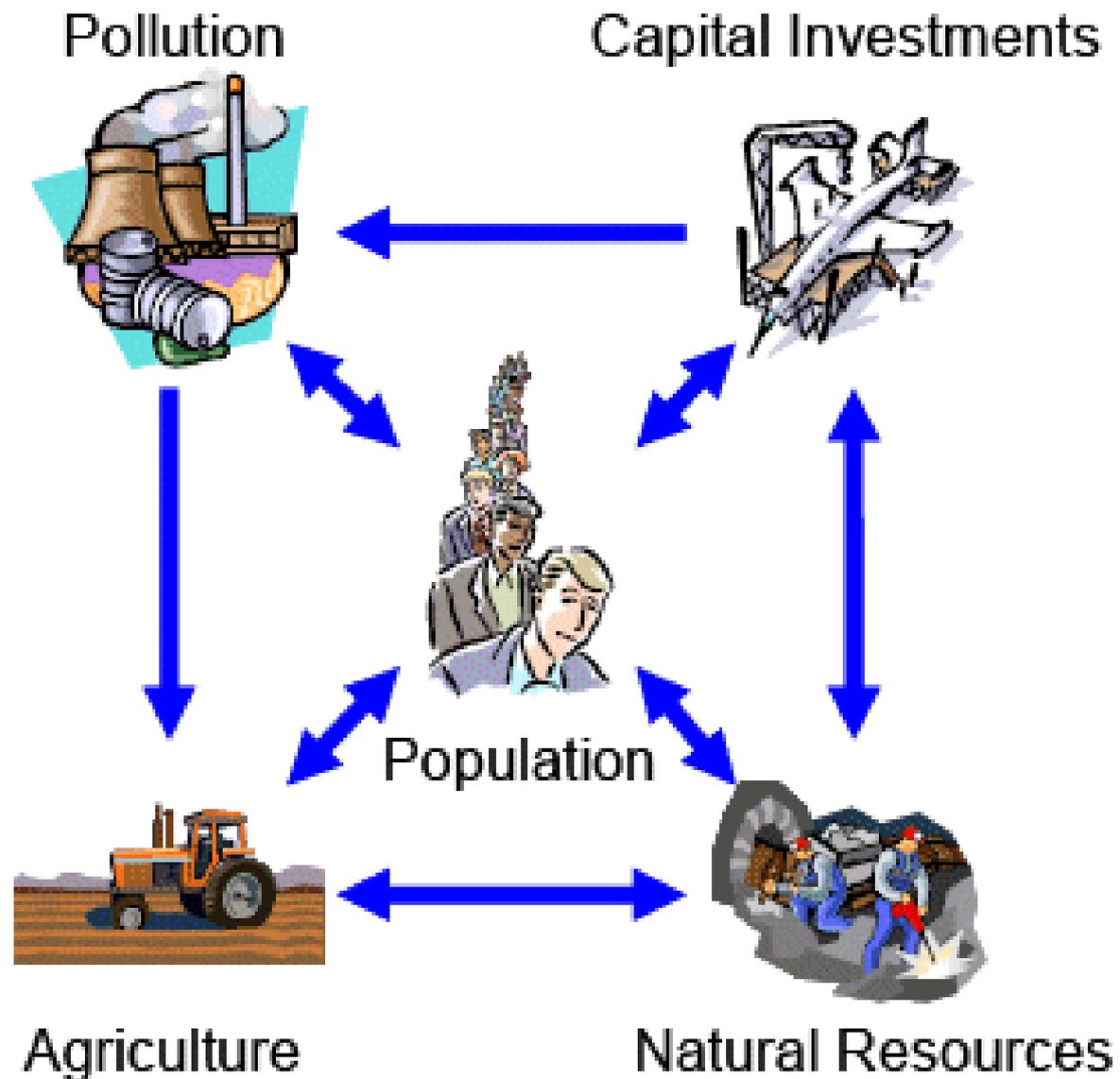
Taagenpere, 1968



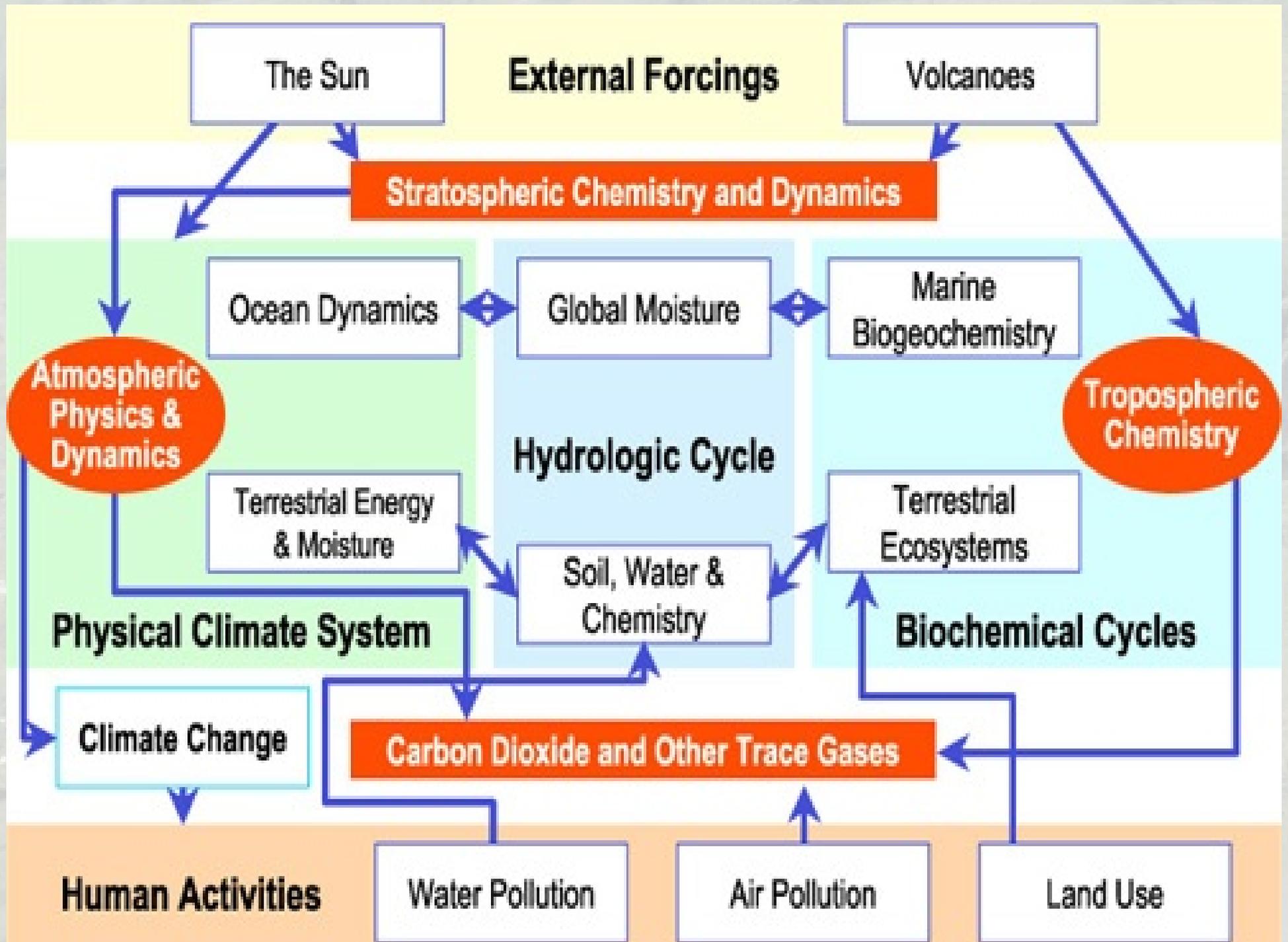
# Roman World Model

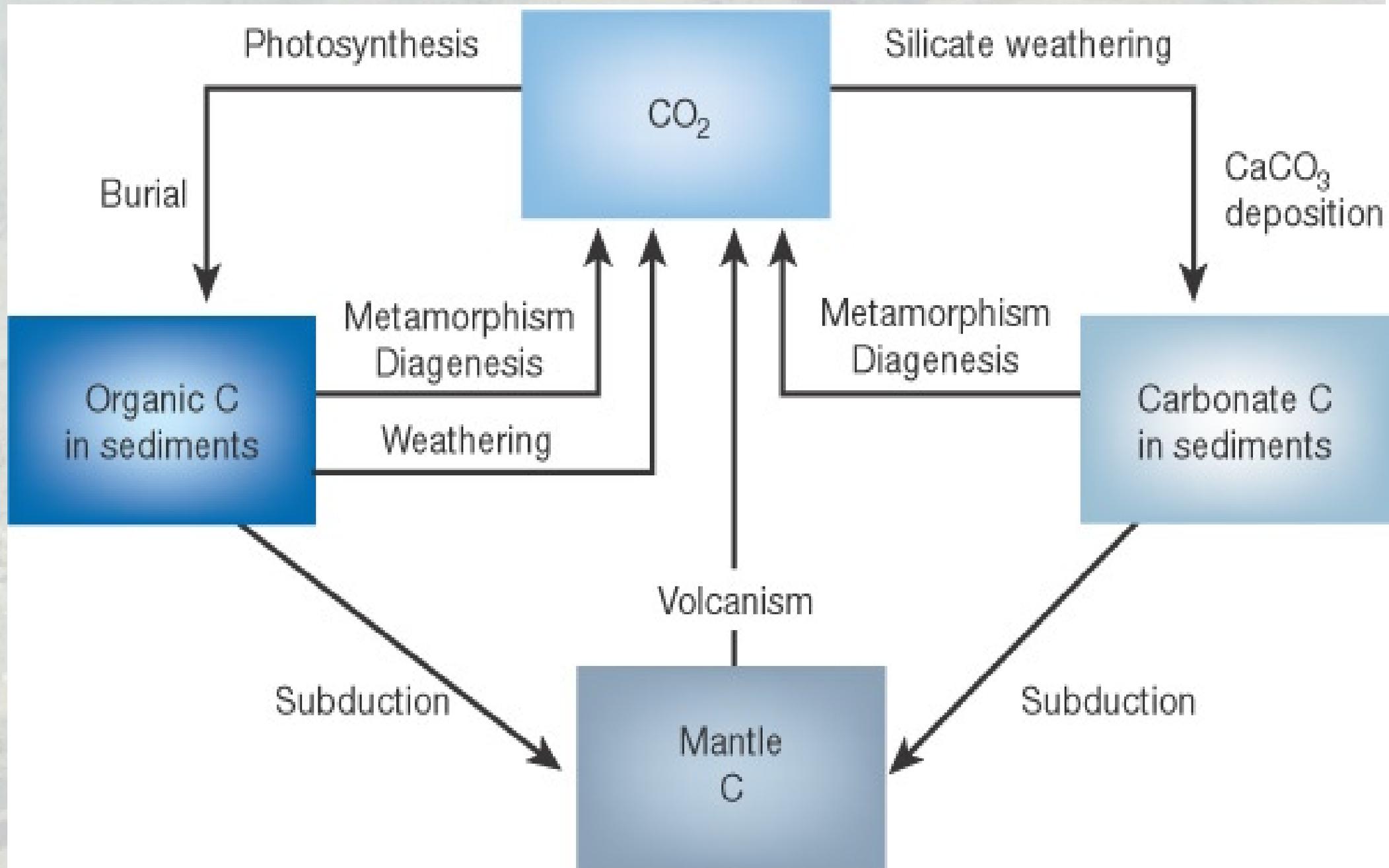


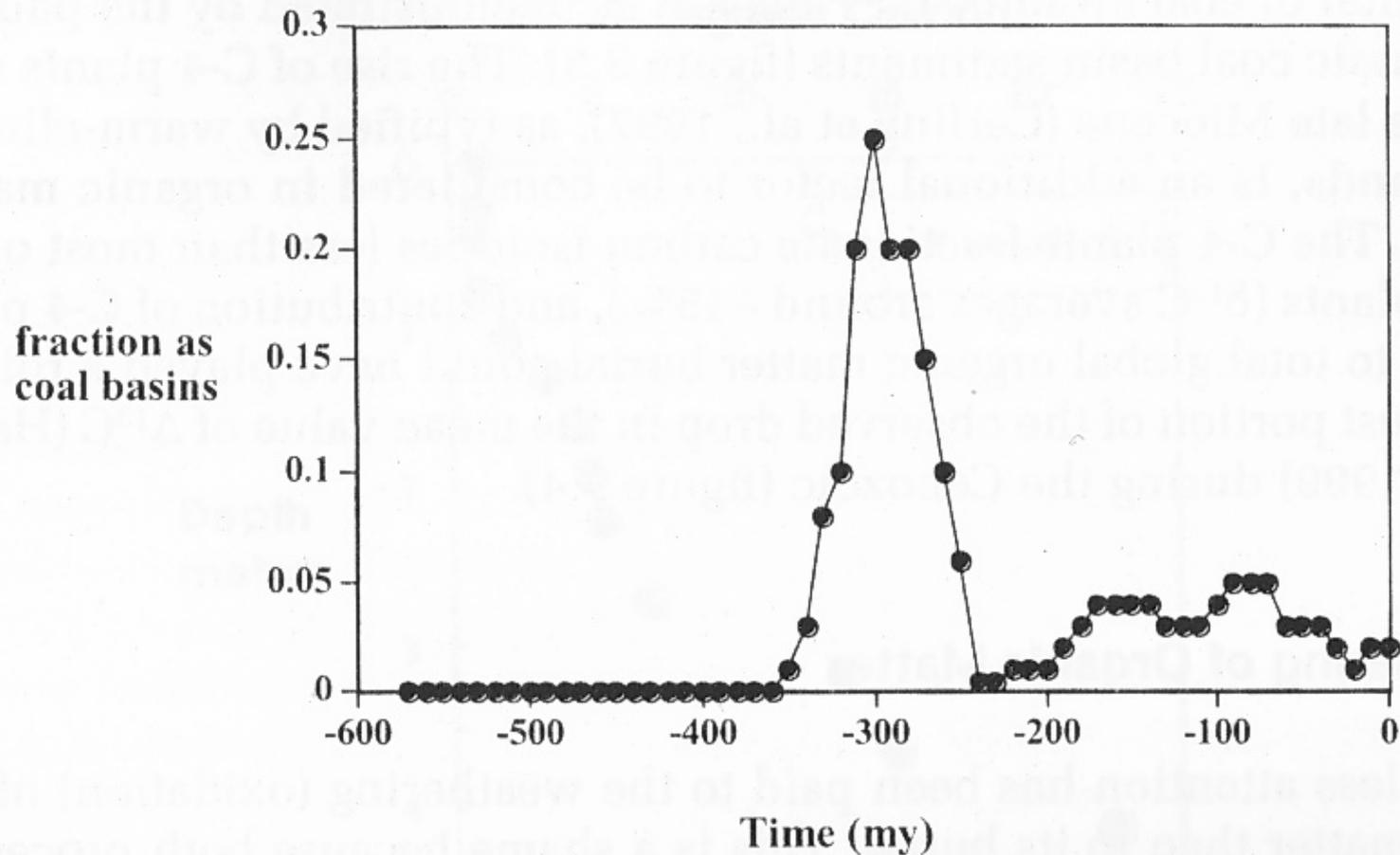
## The Limits to Growth (1972), World model



How the planet works – Come funziona il pianeta

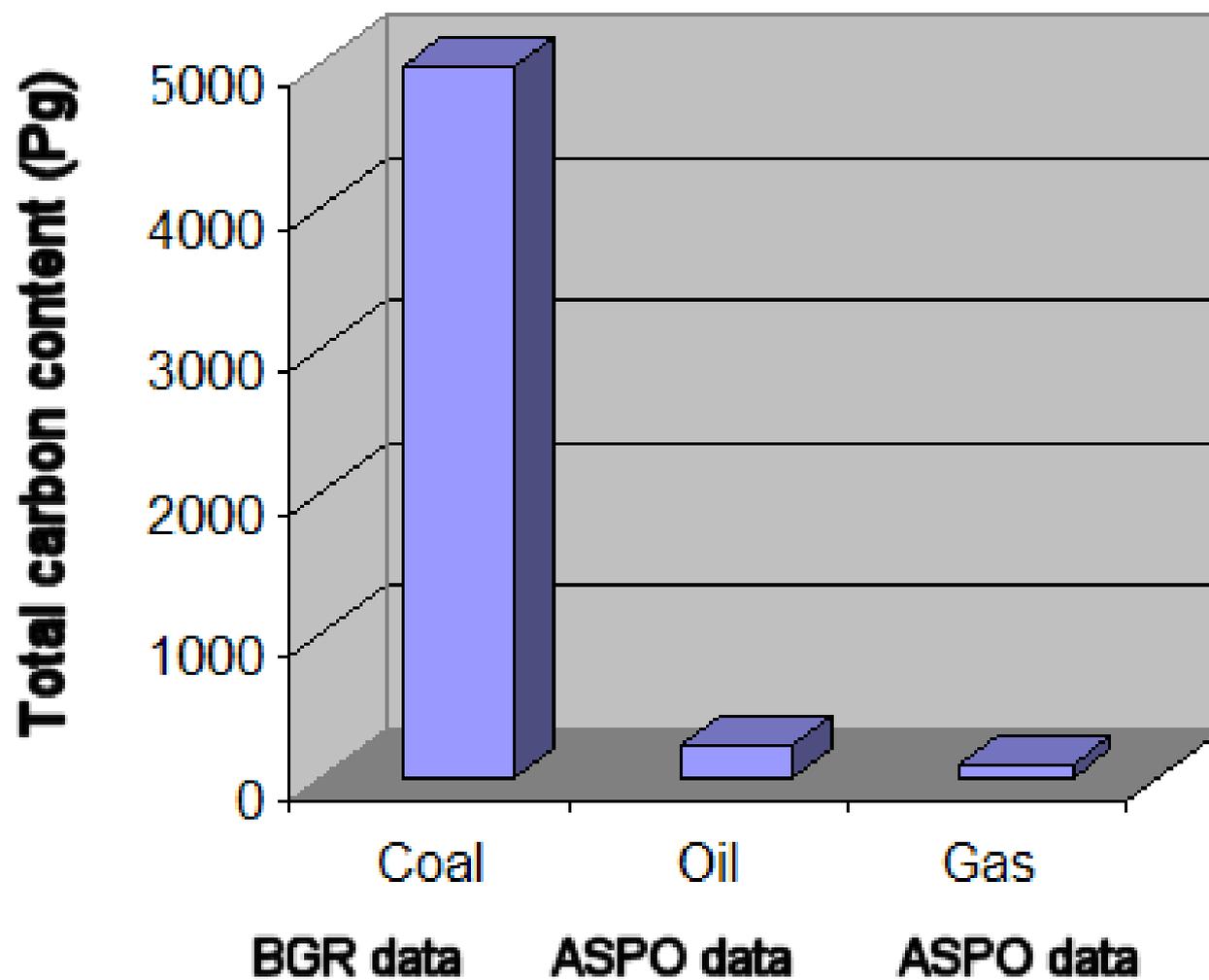






**Figure 3.5.** Abundance of coal basin sediments as a function of time expressed as a fraction of total terrigenous sediments (sandstones and shales). (Data from Ronov, 1976.)

Bruciare 5000 ton di carbone: 2000 ppm CO2 nell'atmosfera ( oggi 380 ppm)

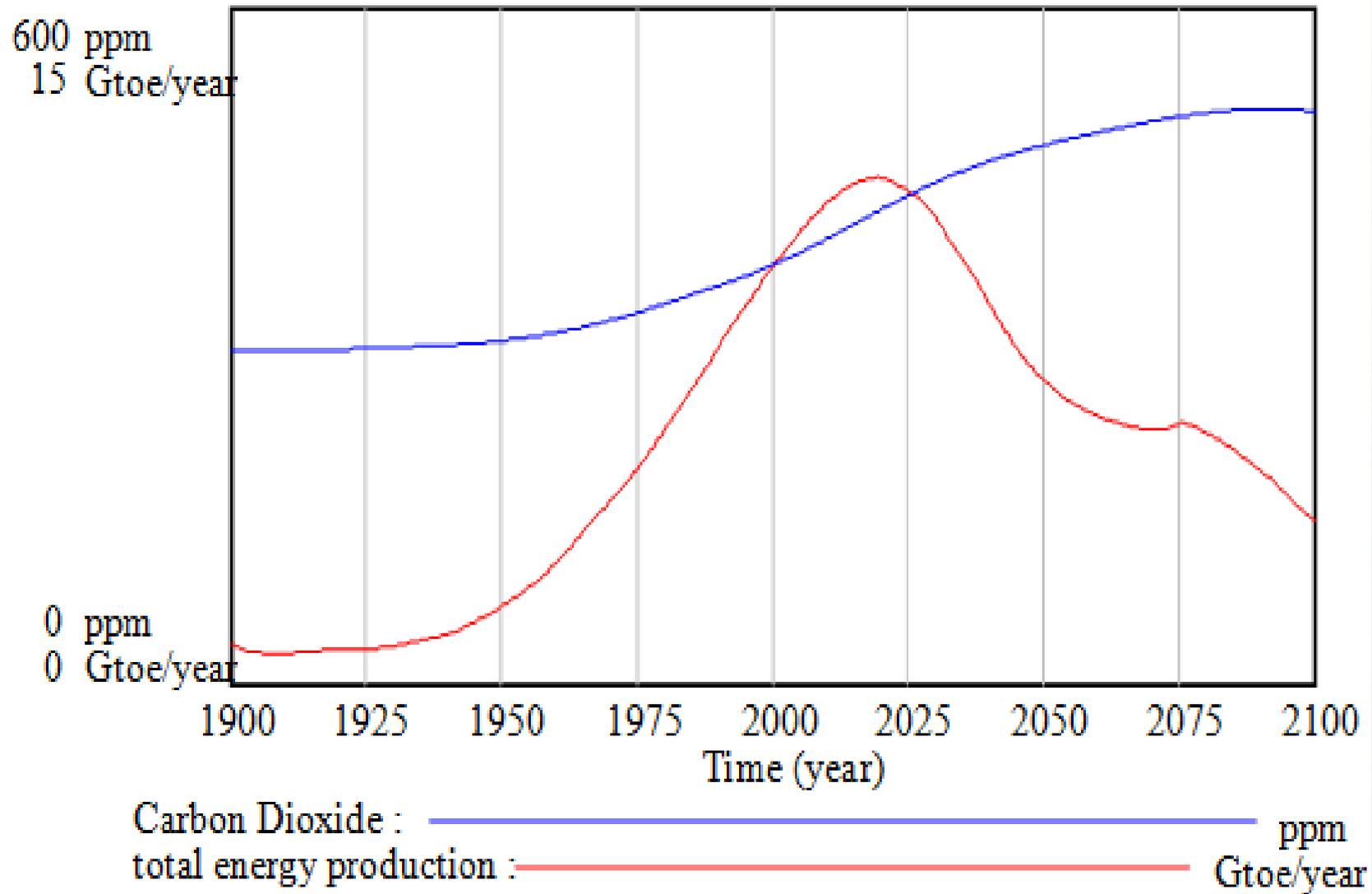


# Carbonio terrestre

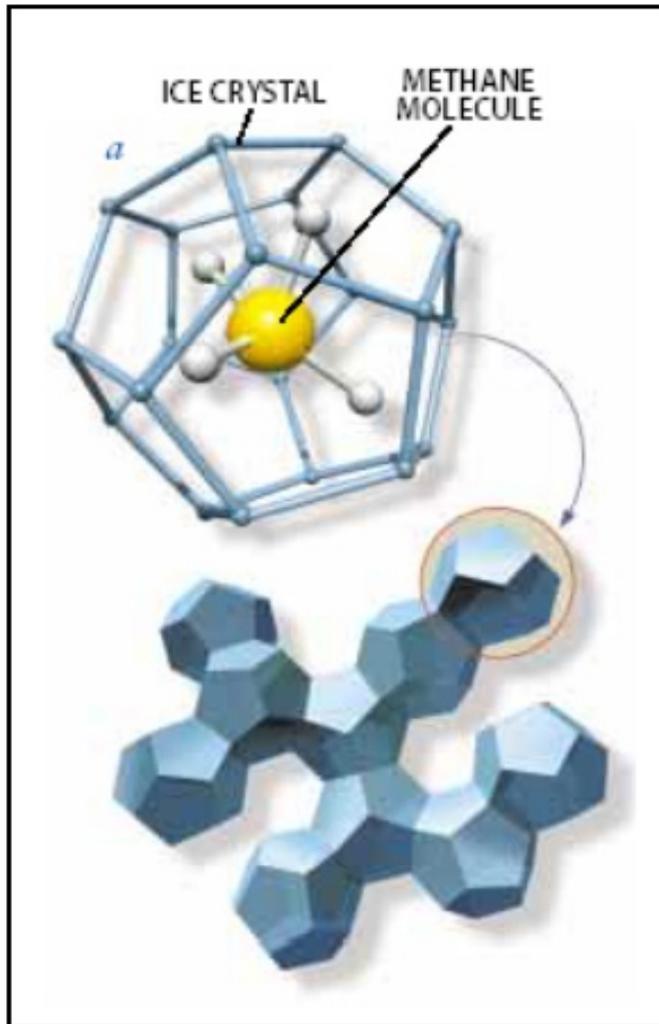
(Pg,  $gx10^{15}$ )

• Atmosfera	750	(380 ppm)
• Petrolio	170	
• Gas naturale	100	
• Biosfera	600	
• Humus	1000-2500	
• Carbone	5000-6000	
• Idrati di metano	$10^4$ - $10^6$ (?)	
• Oceano	$3.5 \times 10^4$	
• Kerogene	$10^6$	
• Carbonati	$10^7$	
• Massa totale dell'atmosfera	$2 \times 10^6$	

## Carbon dioxide and energy

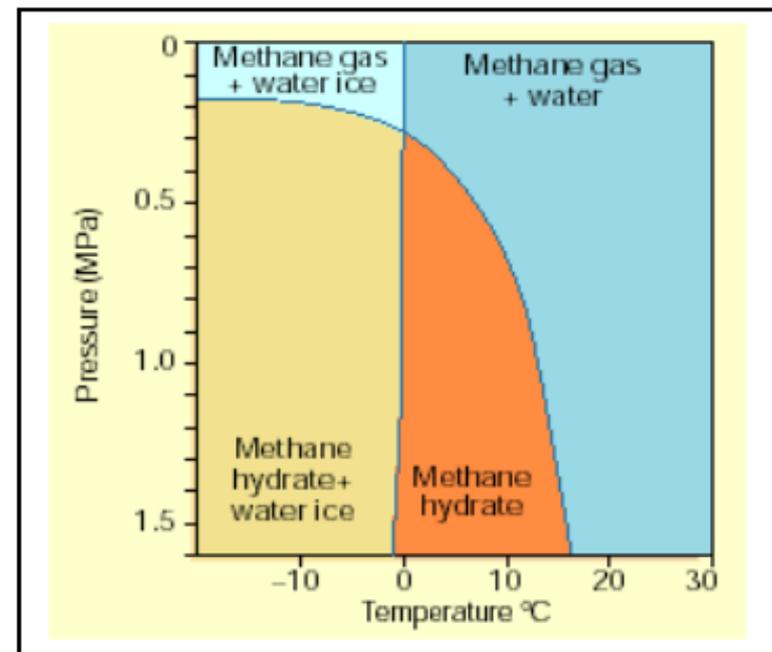


10.000 ton CH<sub>4</sub> nell'atmosfera sono equivalenti a circa 100.000 ppm CO<sub>2</sub> (10% in peso)nell'atmosfera ( oggi 380 ppm)



**Figure 1: The structure of a CH<sub>4</sub> hydrate compound. A CH<sub>4</sub> molecule is caged within a cubic H<sub>2</sub>O crystalline structure to form the building block (top). Multiple blocks link together to form the clathrate compound. (From Suess 1999.)**

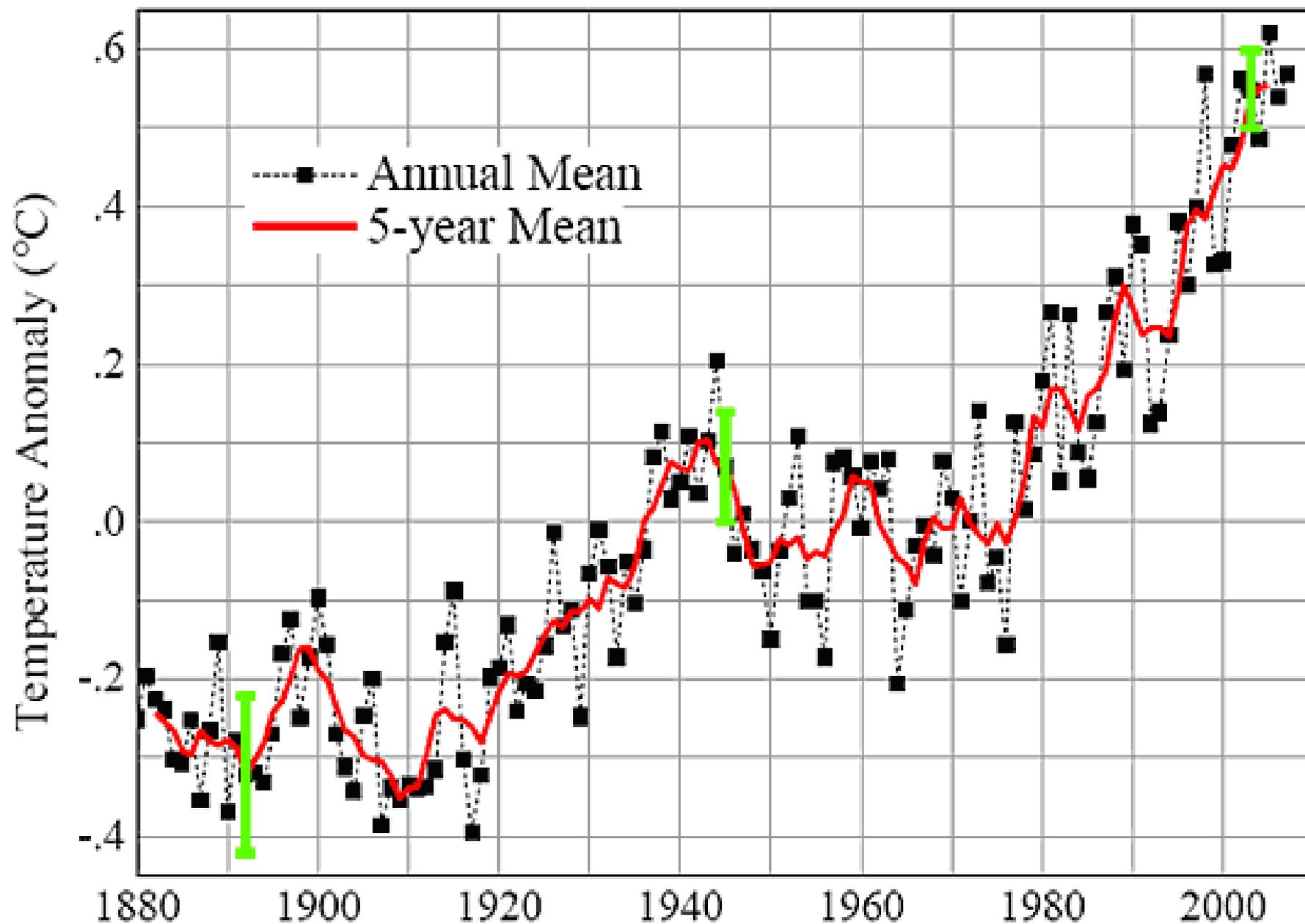
La molecola più pericolosa che esiste.



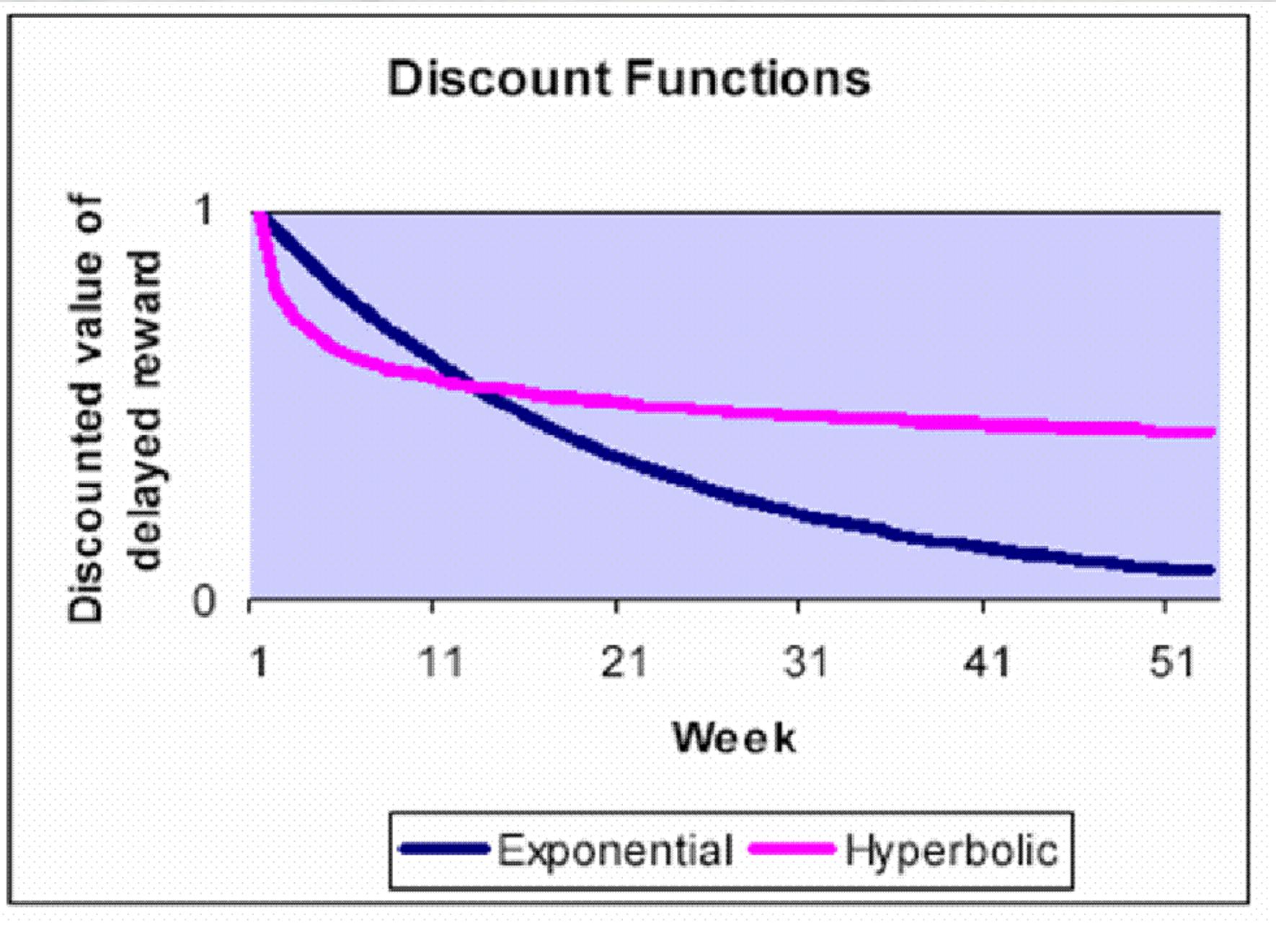
**Figure 2: Phase chart for a mixture of methane and water. Pressure and temperature increase with subterranean depth. (From Adams 2002)**

1 atm □ 0.1 MPa

# Global Temperature Land-Ocean Index



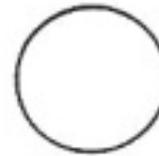




# Odum's Notation

Source of External Energy

Sun, moon, human energy, . . .



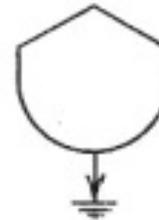
The Heat Sink

The loss of energy from a system or its units.



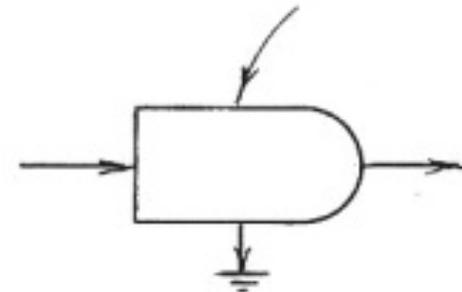
Storage Tank

Battery, bank account, soil, . . .



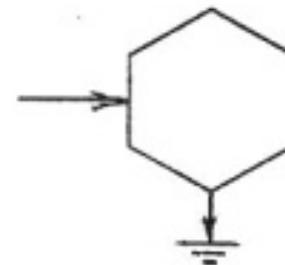
Primary Production Unit

Bacteria, green plants.



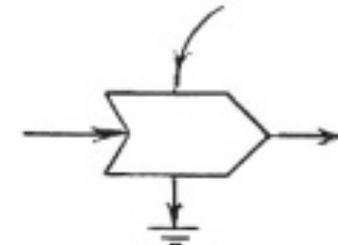
Consumption Unit

Animals, industry.

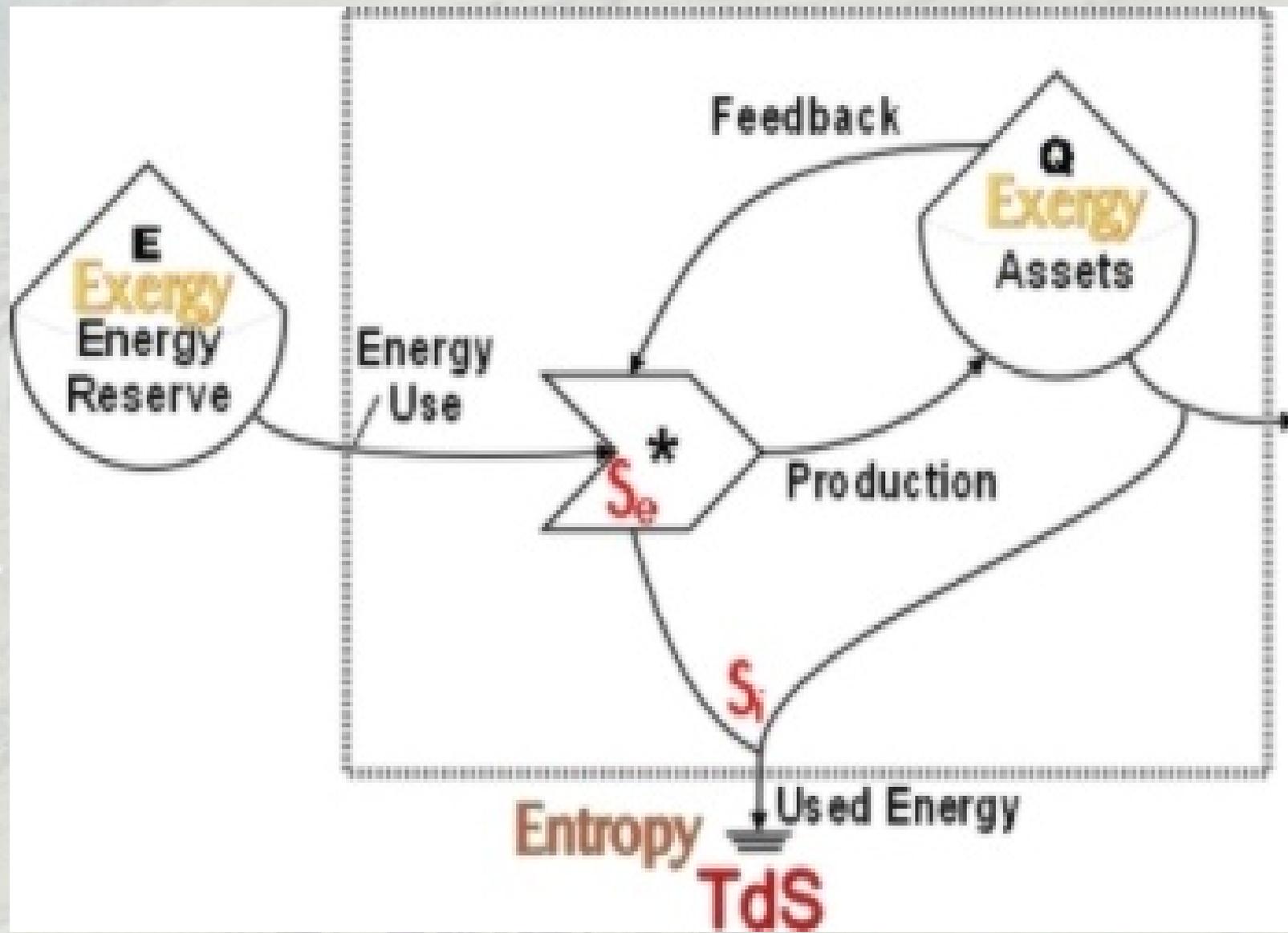


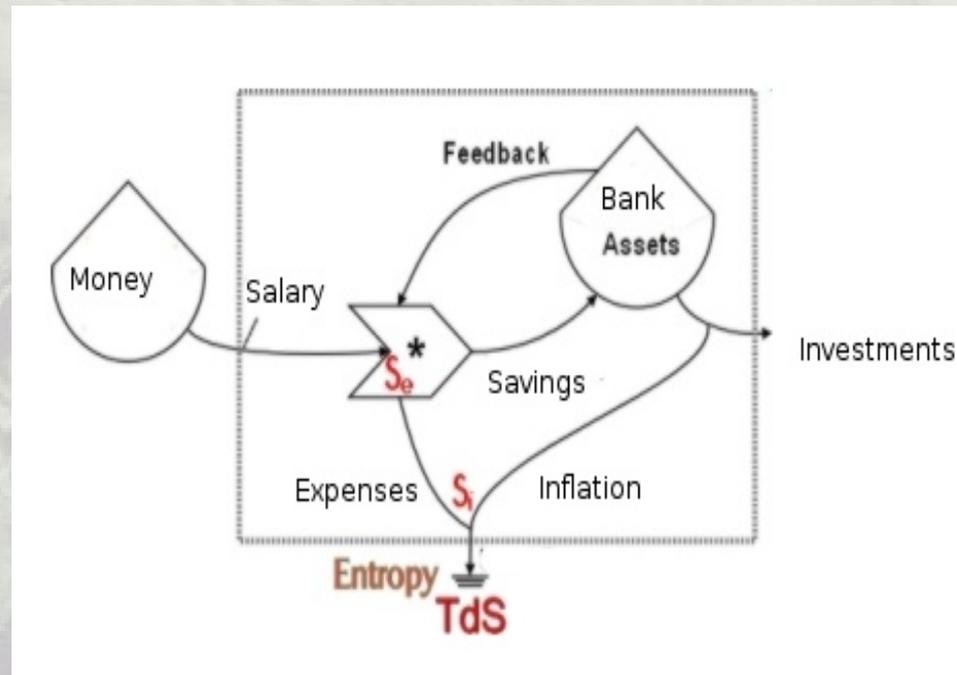
Energy Mixer or Work Gate

Animal, engine, . . .

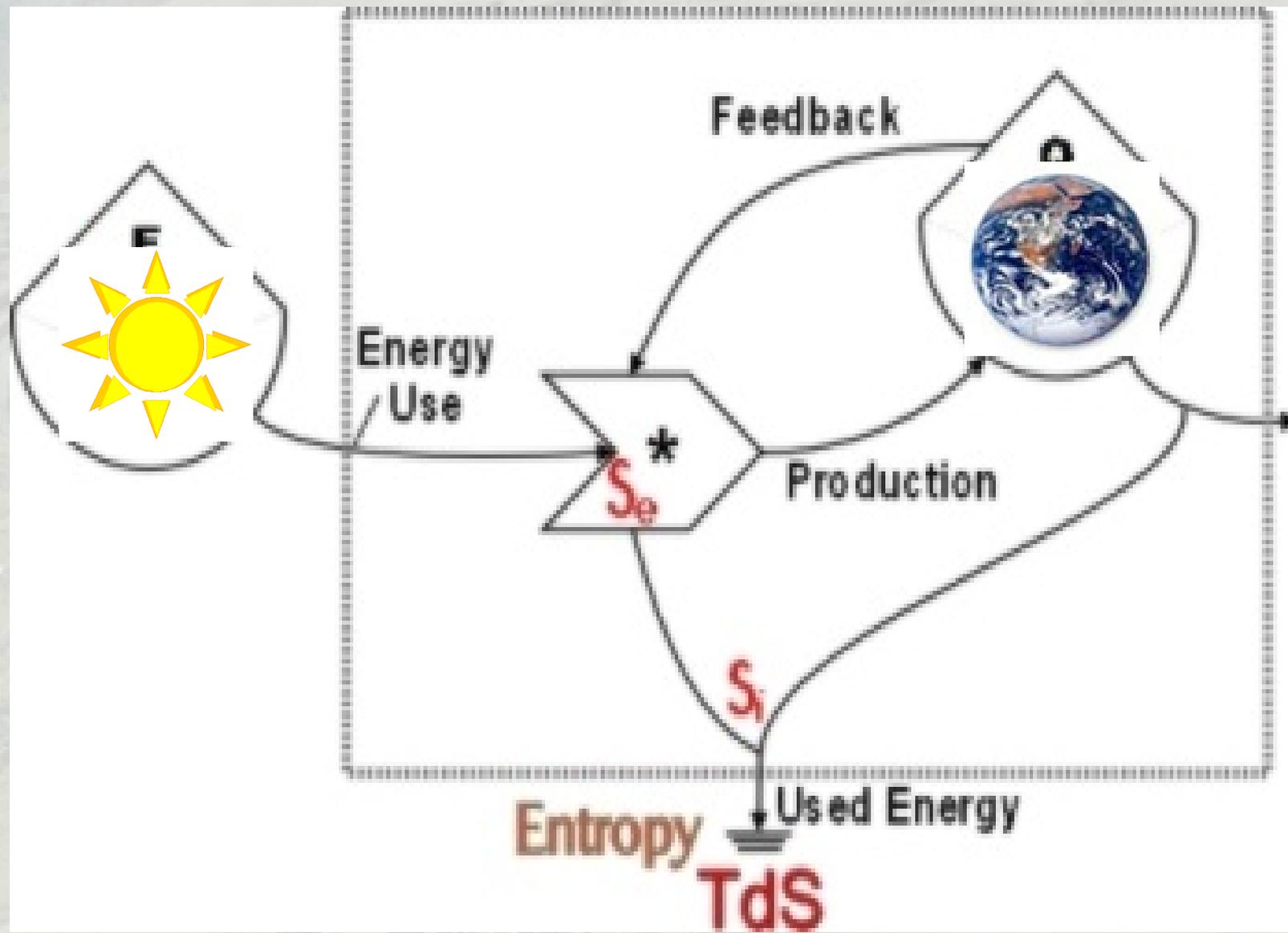


# Omeostasi

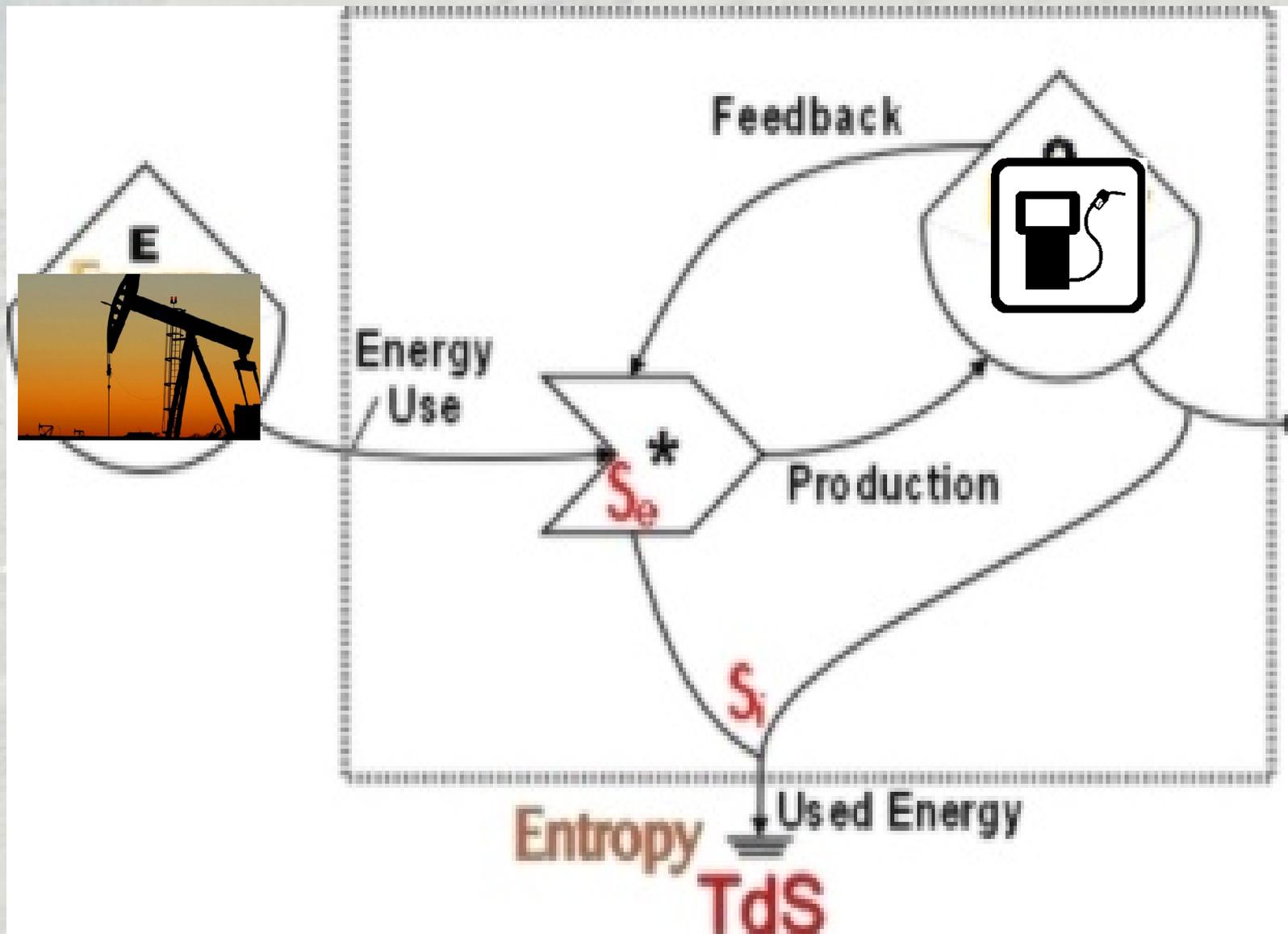


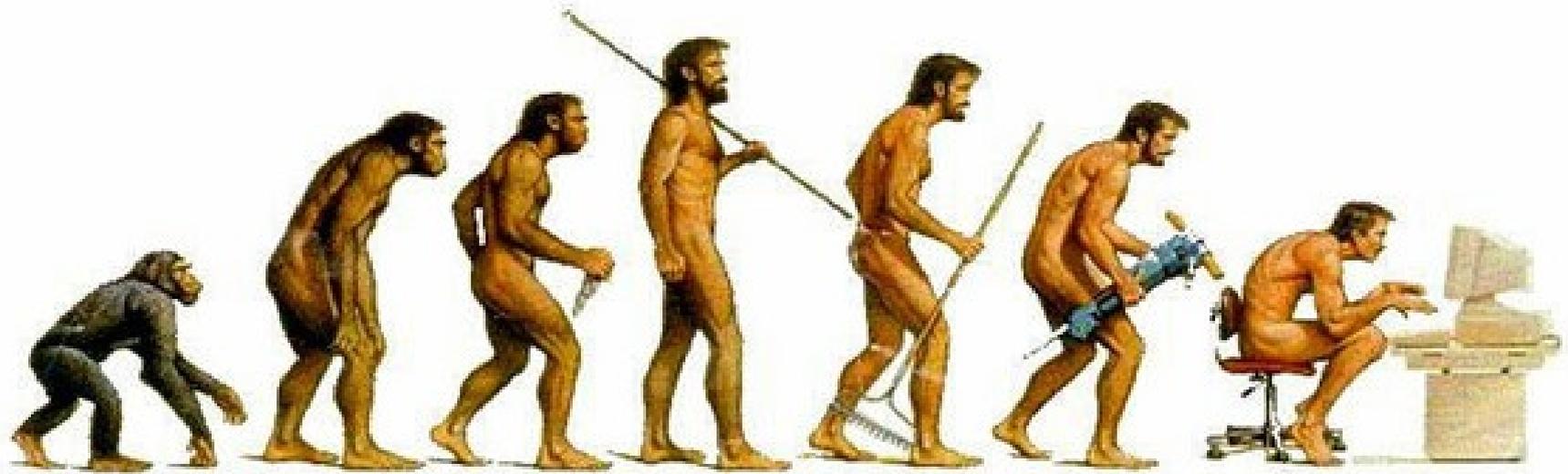


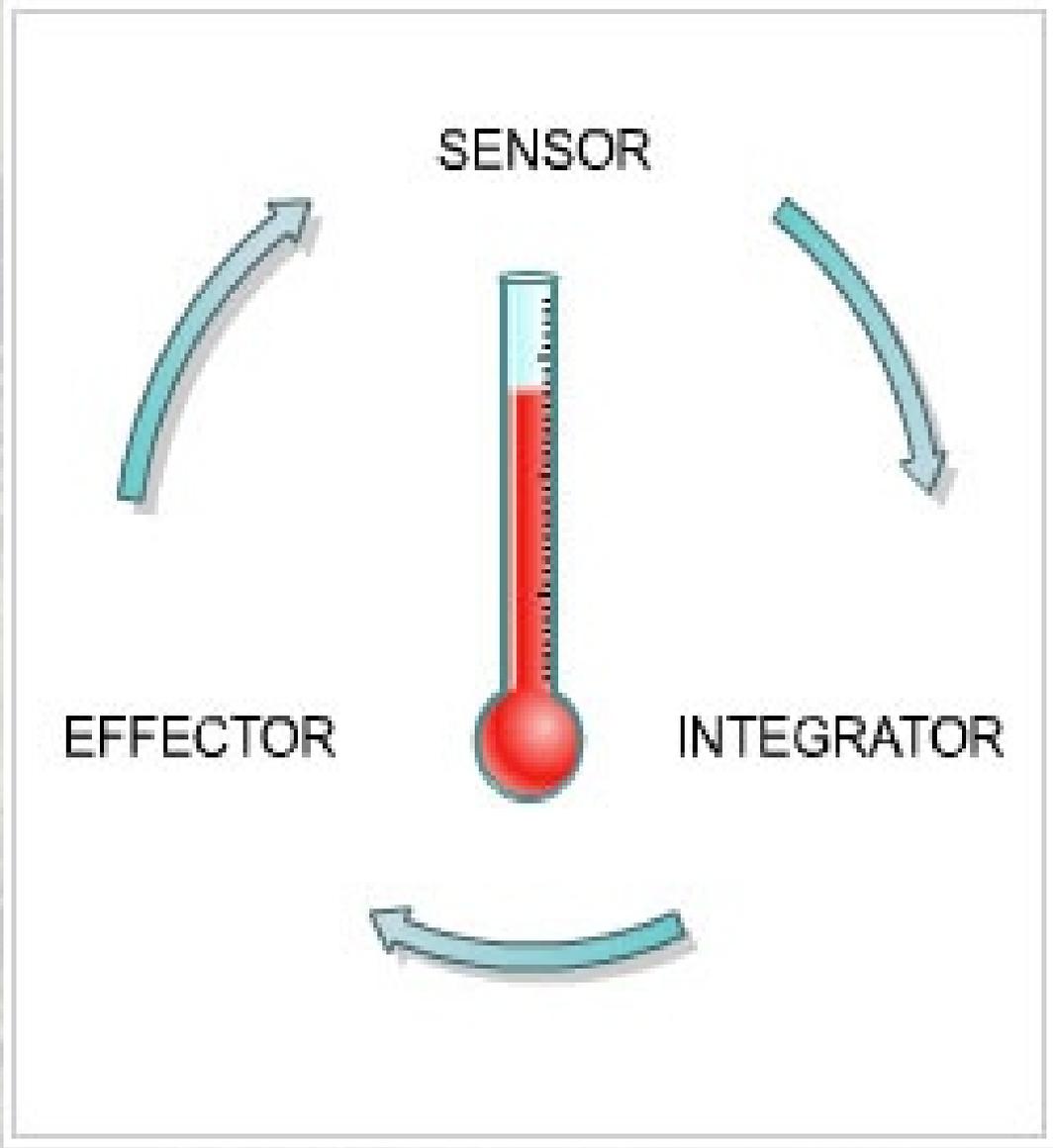
# Omeostasi



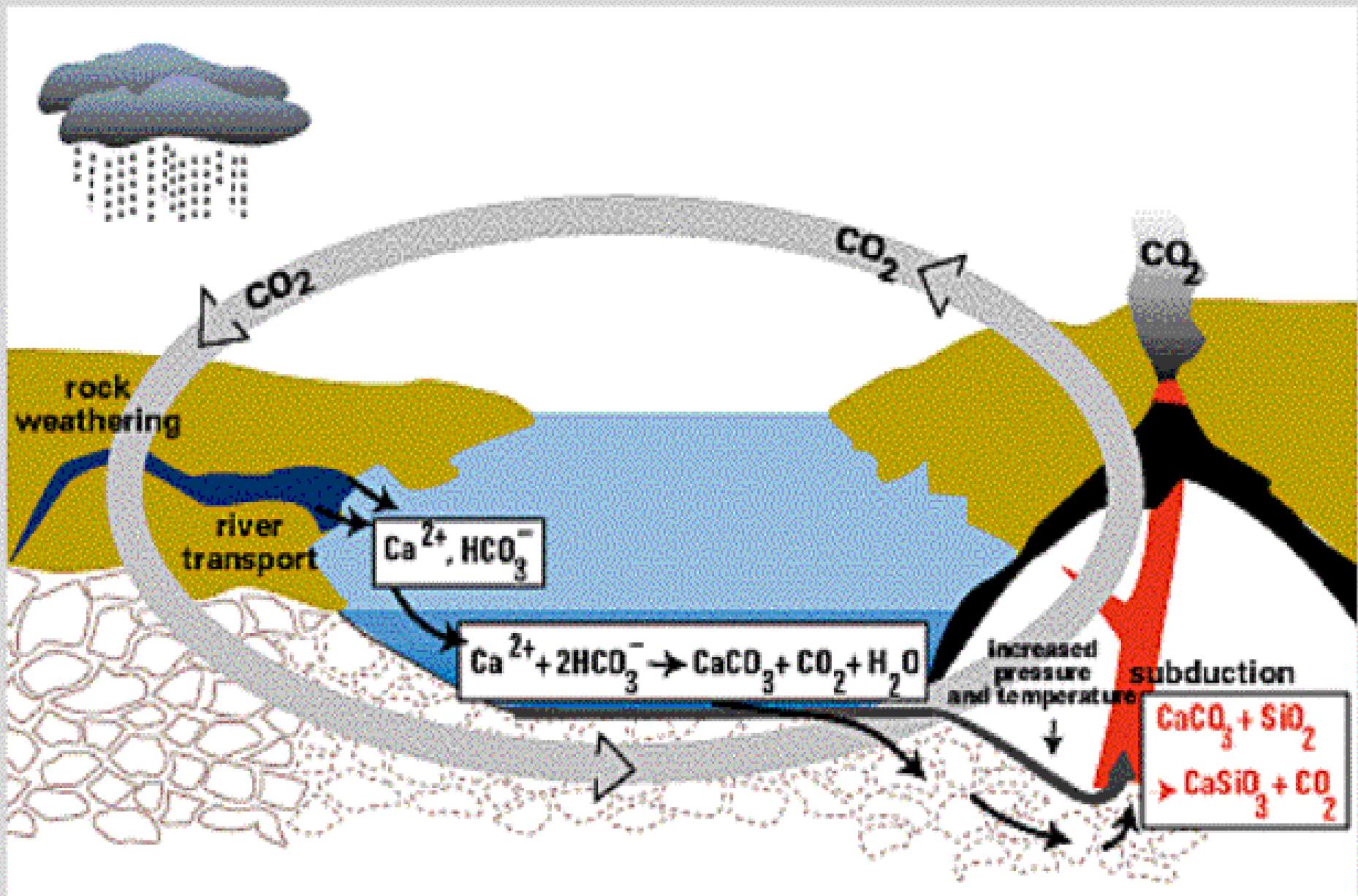
# Omeostasi petrolifera?



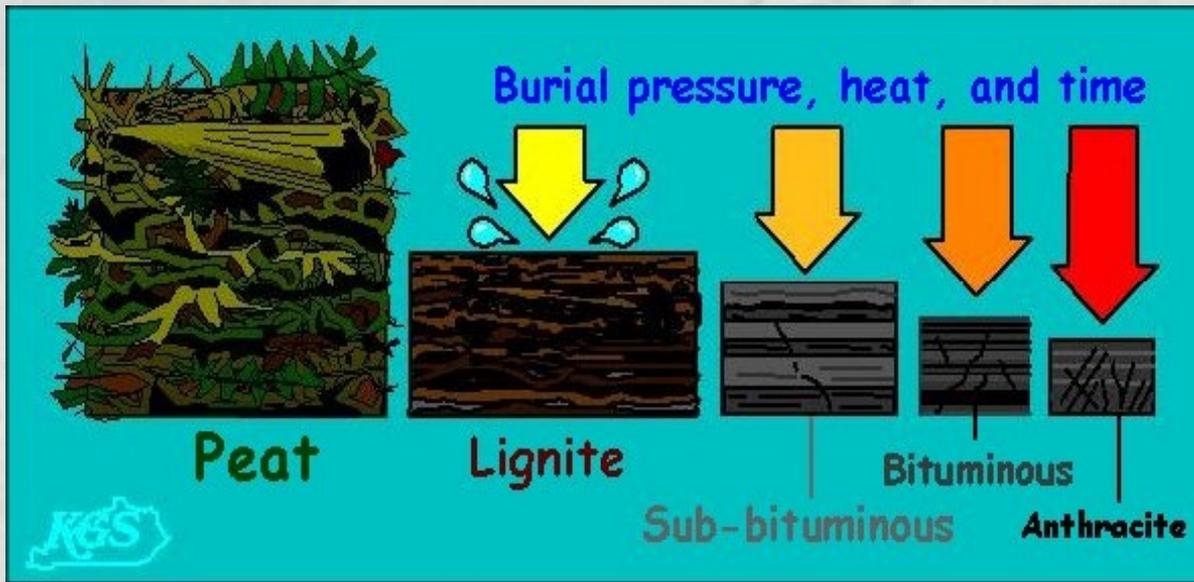




Carbon's "long" cycle – Il ciclo "lungo" del carbonio (t= ca. 1 My)

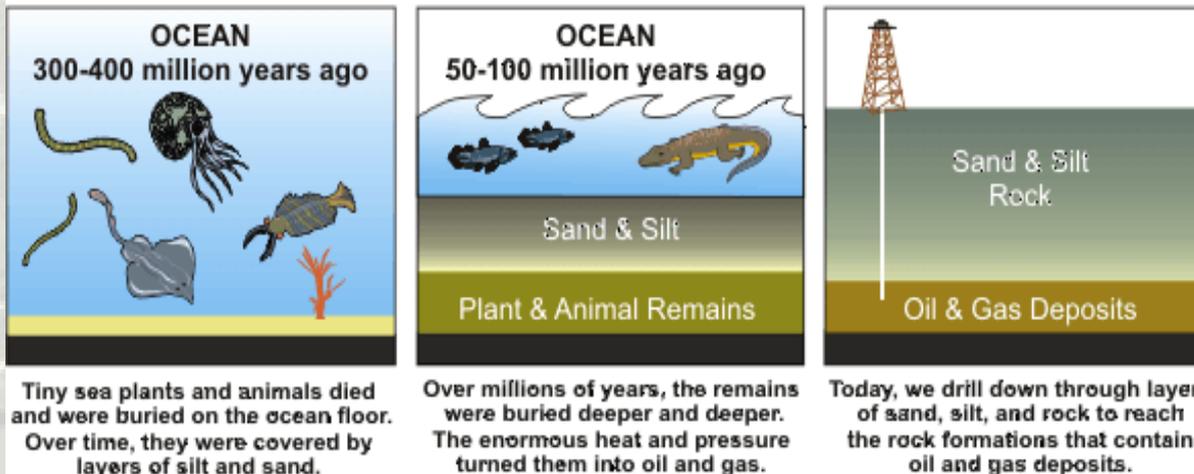


# Formazione dei Combustibili Fossili



Carbone

## PETROLEUM & NATURAL GAS FORMATION



Petrolio e gas

**PETROLIO** (secondo i dati ASPO)

**Restano da bruciare:** □ 1300 Gb ▪ 170 Pg

**Carbonio nel petrolio:** □ 85%

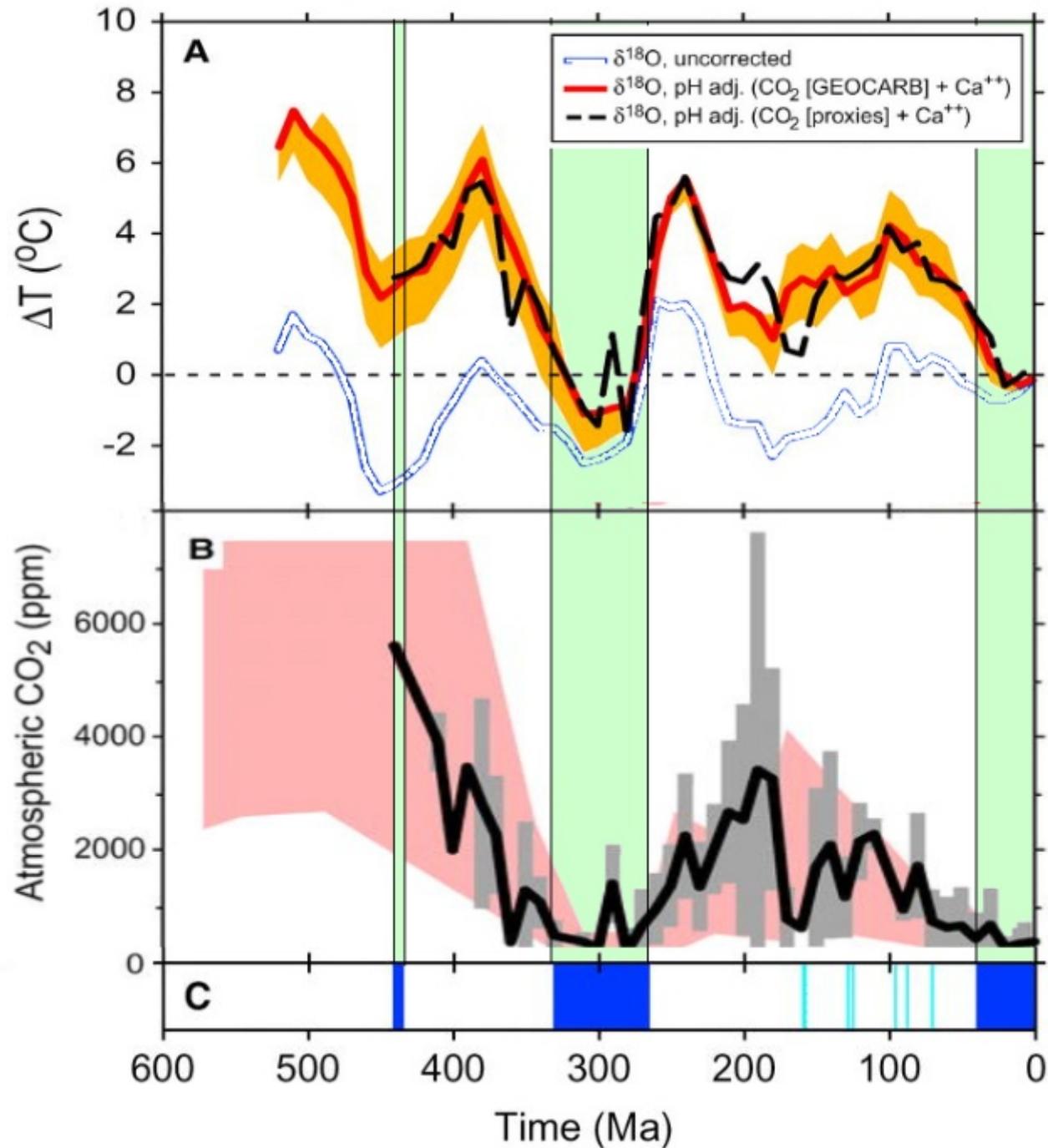
**Extra carbonio nell'atmosfera:** ▪ ▪ 150 Pg ▪ 75 ppm

**Valore attuale = 380 ppm**

**Valore finale = 455 ppm**

**“Tipping Point” secondo James Hansen** □ □ ~ ~ **450 ppm**

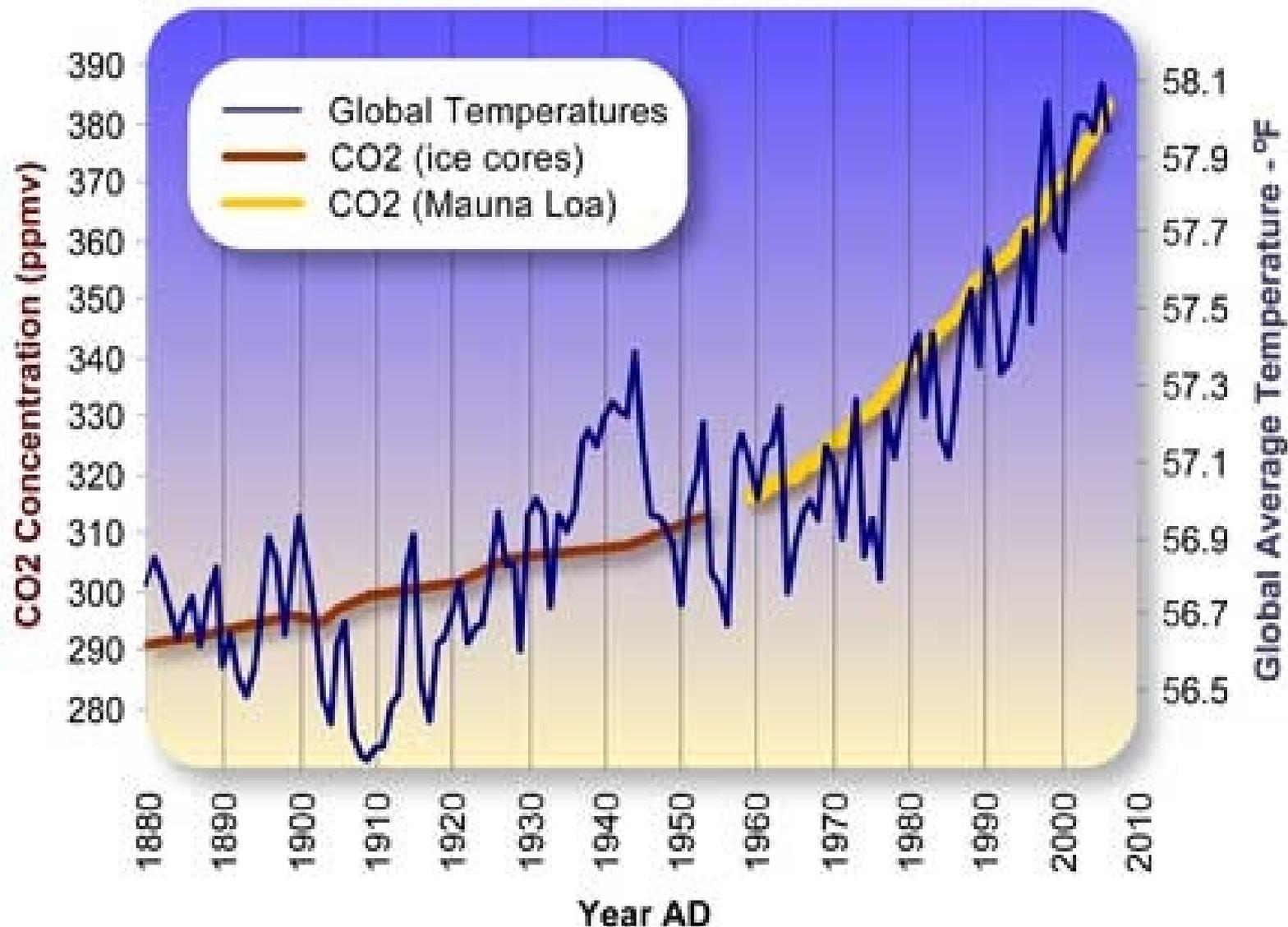
# Phanerozoic Climate and CO<sub>2</sub> (Royer et al)



Technosphere - Tecno



# Global Average Temperature and Carbon Dioxide Concentrations, 1880 - 2006



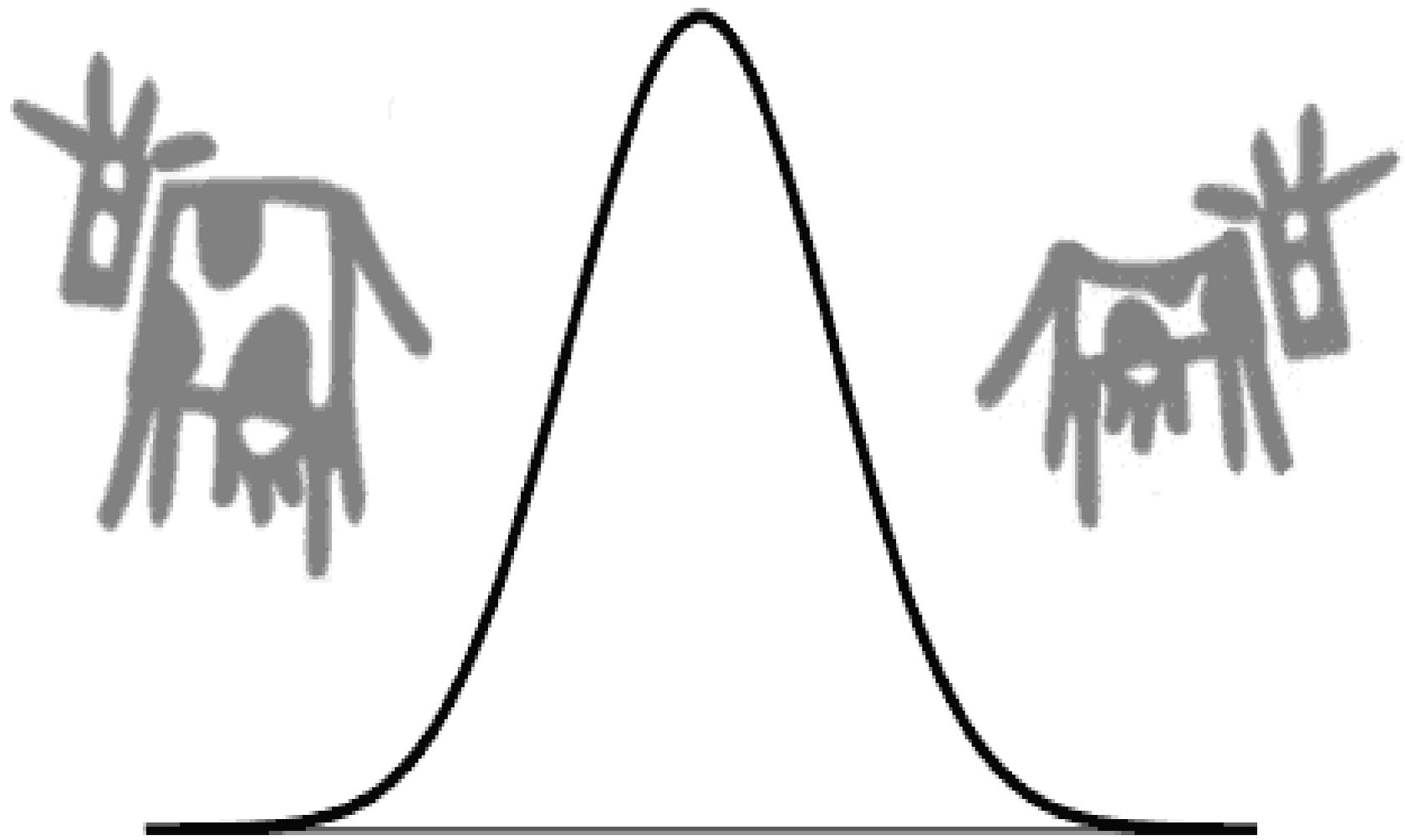
Data Source Temperature: [ftp://ftp.ncdc.noaa.gov/pub/data/anomalies/annual.land\\_and\\_ocean.90S.90N.df\\_1901-2000mean.dat](ftp://ftp.ncdc.noaa.gov/pub/data/anomalies/annual.land_and_ocean.90S.90N.df_1901-2000mean.dat)

Data Source CO2 (Siple Ice Cores): <http://cdiac.esd.ornl.gov/ftp/trends/co2/siple2.013>

Data Source CO2 (Mauna Loa): <http://cdiac.esd.ornl.gov/ftp/trends/co2/maunaloa.co2>  
& [http://www.esrl.noaa.gov/gmd/webdata/cogg/trends/co2\\_mm\\_mlo.dat](http://www.esrl.noaa.gov/gmd/webdata/cogg/trends/co2_mm_mlo.dat)

Graphic Design: Michael Ernst, The Woods Hole Research Center







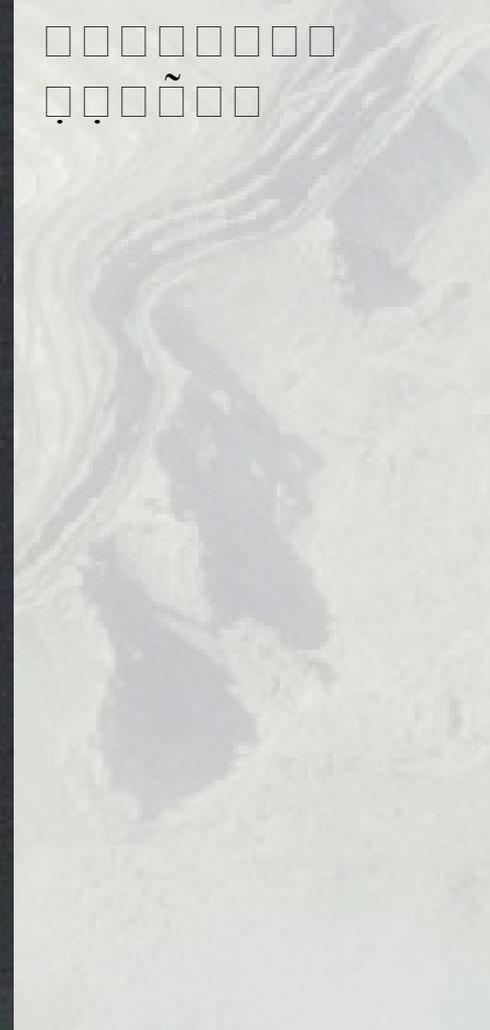
Venere

Calcolata  
(senza gas serra)

$T_{\text{eff}} \approx 230 \text{ K}$

$\rho_{\text{atm}} \approx 93 \text{ kg m}^{-3}$

$\mu \approx 0.046 \text{ kg mol}^{-1}$



## Native metals



Native copper



Meteoric iron



Gold nugget

The future of mining?



<b>Metal</b>	<b>Specific production energy MJ/kg</b>	<b>World production (Mtons/year)</b>	<b>Total energy used (EJ)</b>
<b>Steel</b>	22	1100	24
<b>Aluminium</b>	211	33	6.963
<b>Copper</b>	48	15	0.72
<b>Zinc</b>	42	10	0.42
<b>Nickel</b>	160	1.4	0.224
<b>lead</b>	26	3	0.078

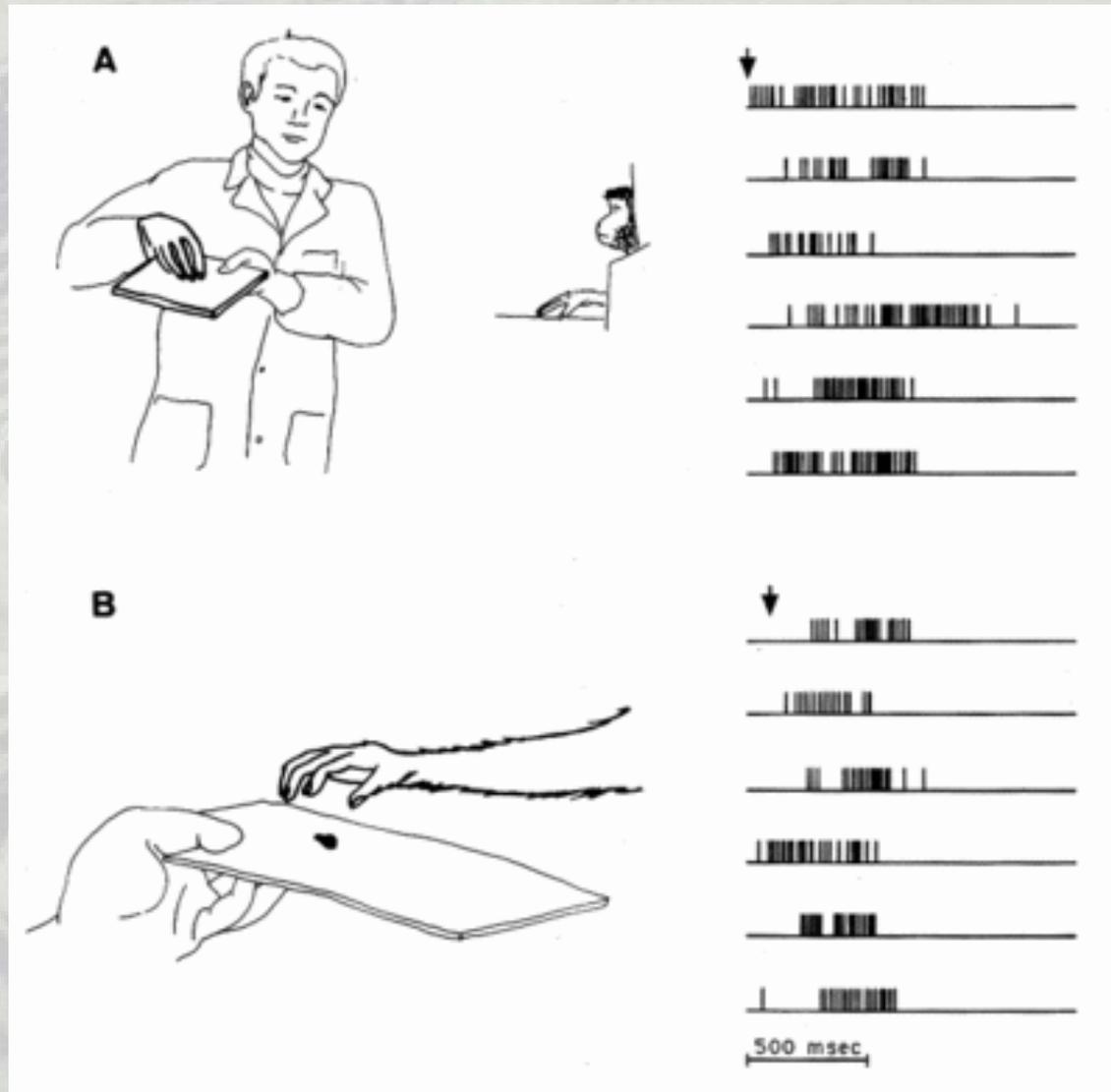
**Total world primary energy produced per year: ca. 400 EJ**

Data from Norgate and Rankin (2002) and from USGS (2005)

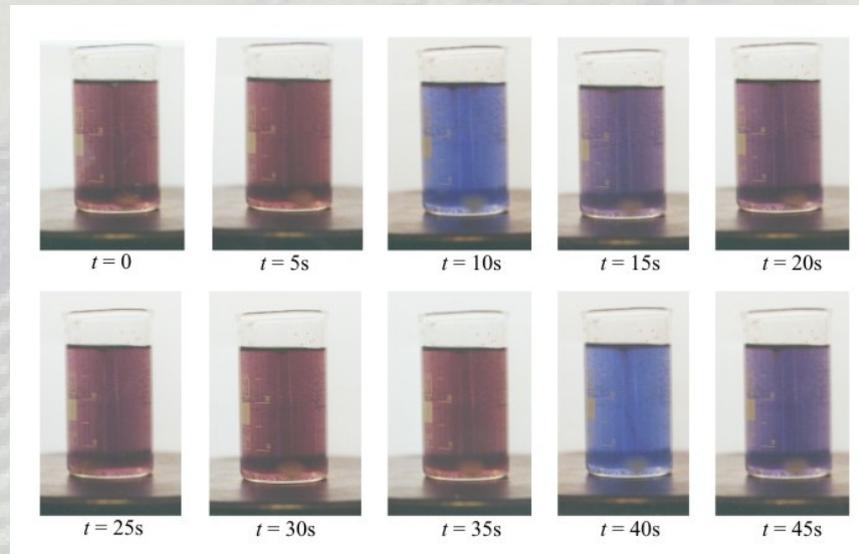
# La barriera narrativa

- Le fogne di New York sono piene di coccodrilli ciechi che sono cresciuti dai piccoli di coccodrillo che la gente buttava nelle fogne non sapendo come disfarsene altrimenti
- Le difficoltà economiche che abbiamo oggi sono il risultato della speculazione che si è verificata con l'introduzione dell'Euro
- Il picco del petrolio è un complotto delle multinazionali per farci pagare più cara la benzina
- Se non fosse stato per un gruppo di ambientalisti esagitati, oggi avremmo le centrali nucleari in Italia e non ci sarebbe un problema energetico
- Nel 1972, un gruppo di pazzoidi che si facevano chiamare “Il Club di Roma” si sono resi ridicoli facendo delle previsioni catastrofiche che poi non si sono avverate.
- Il clima è sempre cambiato: l'idea che dovremmo smettere di bruciare i combustibili fossili è una panzana inventata dai catastrofisti

# Mirror neurons – Neuroni specchio



# Belousov–Zhabotinsky reaction



8650

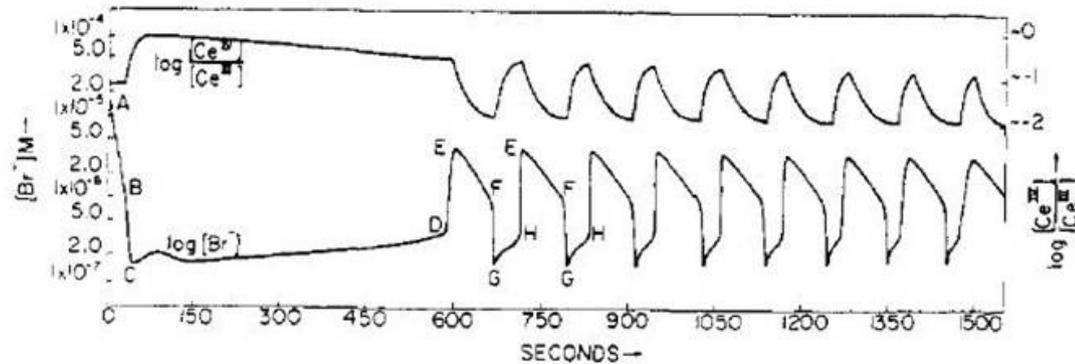
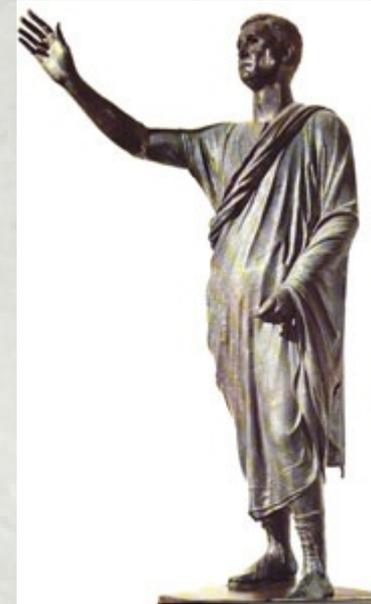
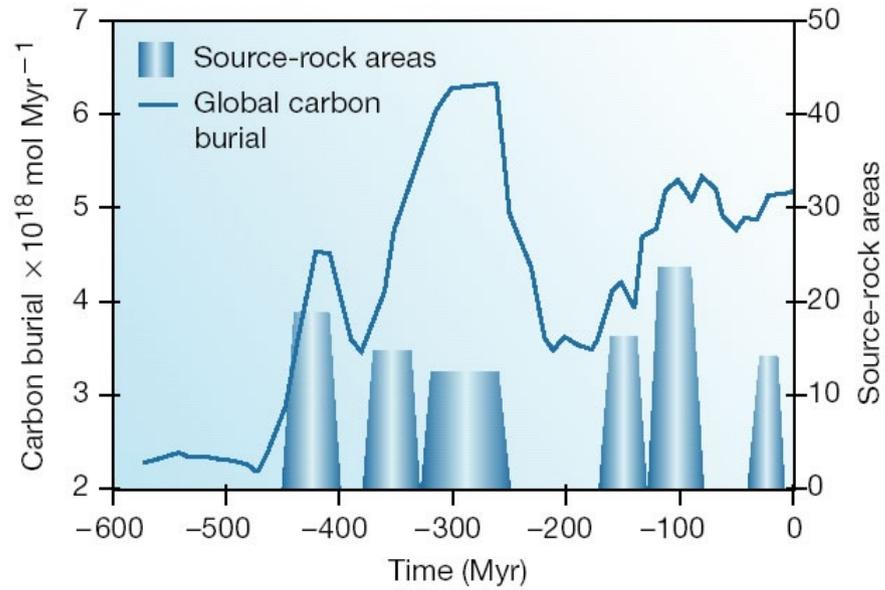


Figure 1. Potentiometric traces of  $\log [\text{Br}^-]$  and  $\log [\text{Ce(IV)}]_i / [\text{Ce(III)}]$  for a representative reaction exhibiting all six periods. Initial concentrations were  $[\text{CH}_2(\text{COOH})_2]_0 = 0.032 \text{ M}$ ,  $[\text{KBrO}_3]_0 = 0.063 \text{ M}$ ,  $[\text{KBr}]_0 = 1.5 \times 10^{-5} \text{ M}$ ,  $[\text{Ce}(\text{NH}_4)_2(\text{NO}_3)_5]_0 = 0.001 \text{ M}$ ,  $[\text{H}_2\text{SO}_4]_0 = 0.8 \text{ M}$ .

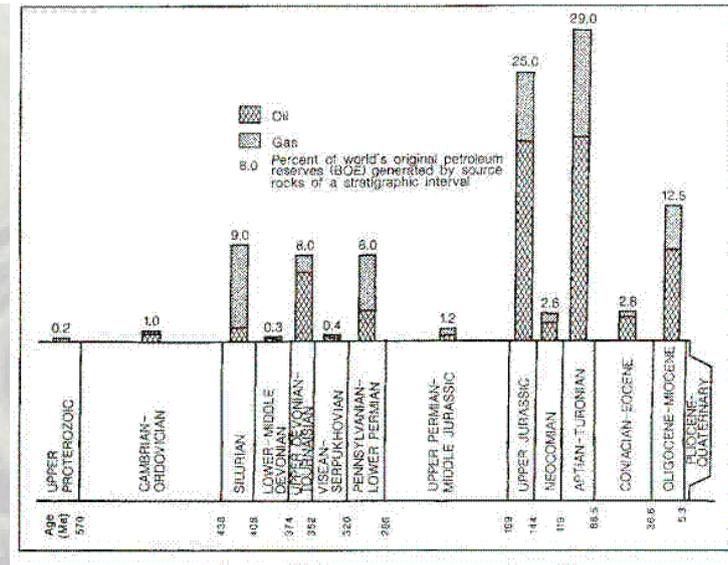
## Neuroni Specchio



Cesare Augusto  
Re Kamehameha  
L'Arringatore  
Benito Mussolini

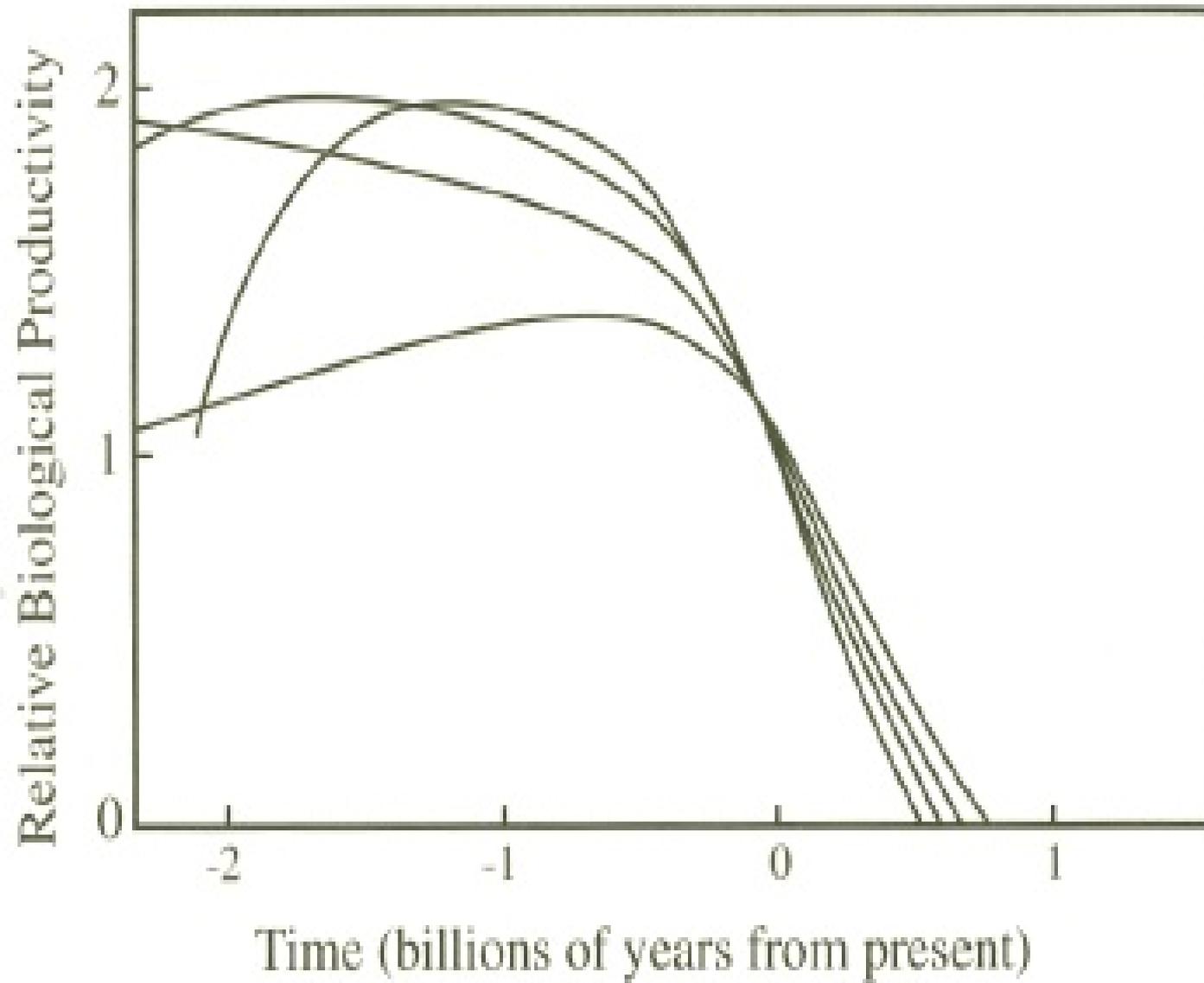


Berner 2003



Klemme and Ulmishek 1991



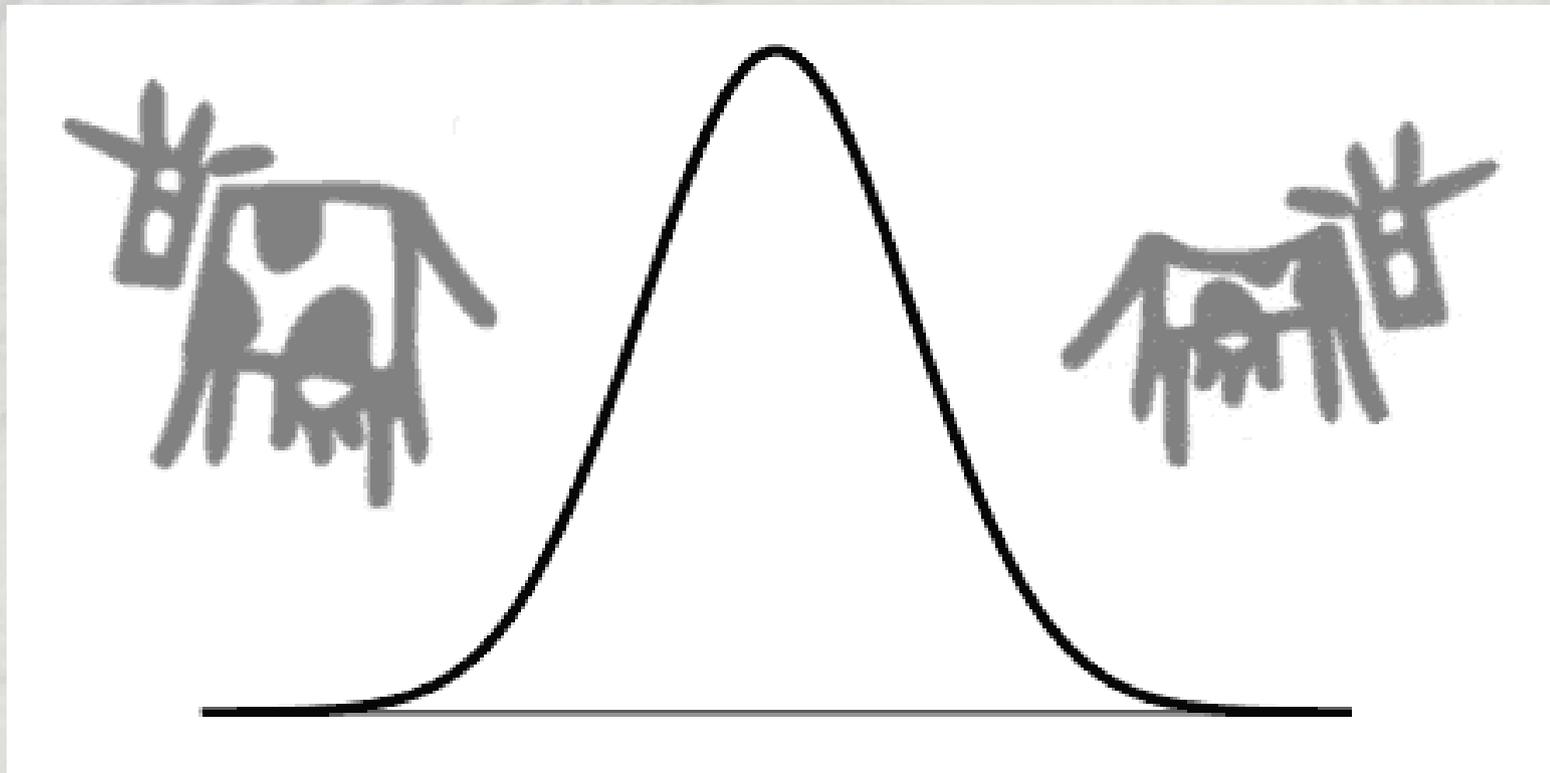


La regola d'oro della sopravvivenza

## **“Pensare dinamicamente**

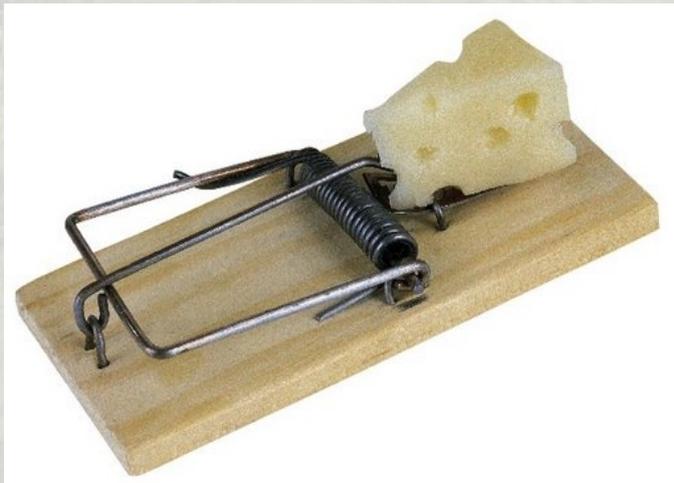
Ovvero:

**“Nei sistemi complessi non esistono cause ed effetti, solo forzanti e feedback”**





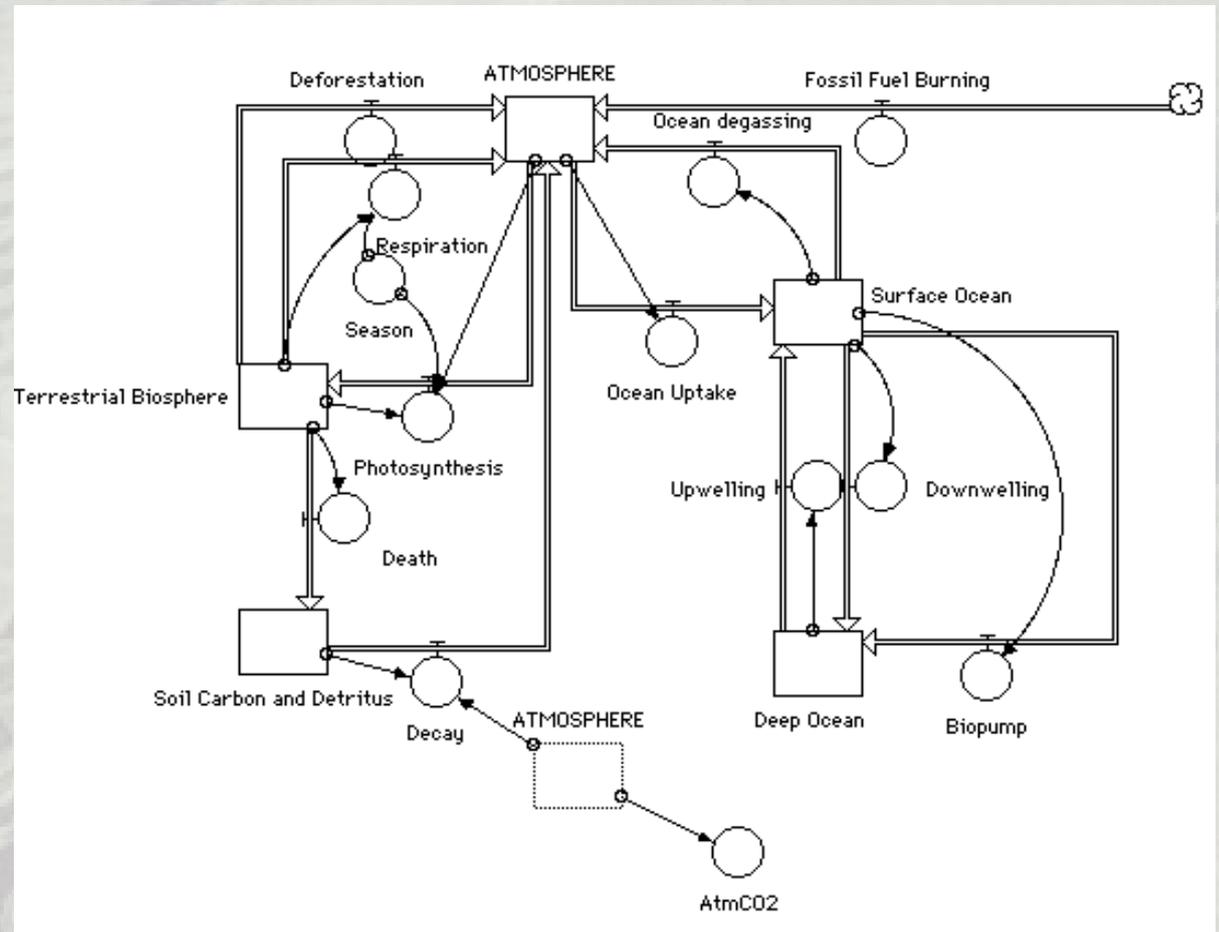
Pensiero lineare



Pensiero dinamico

# Alcuni cicli terrestri

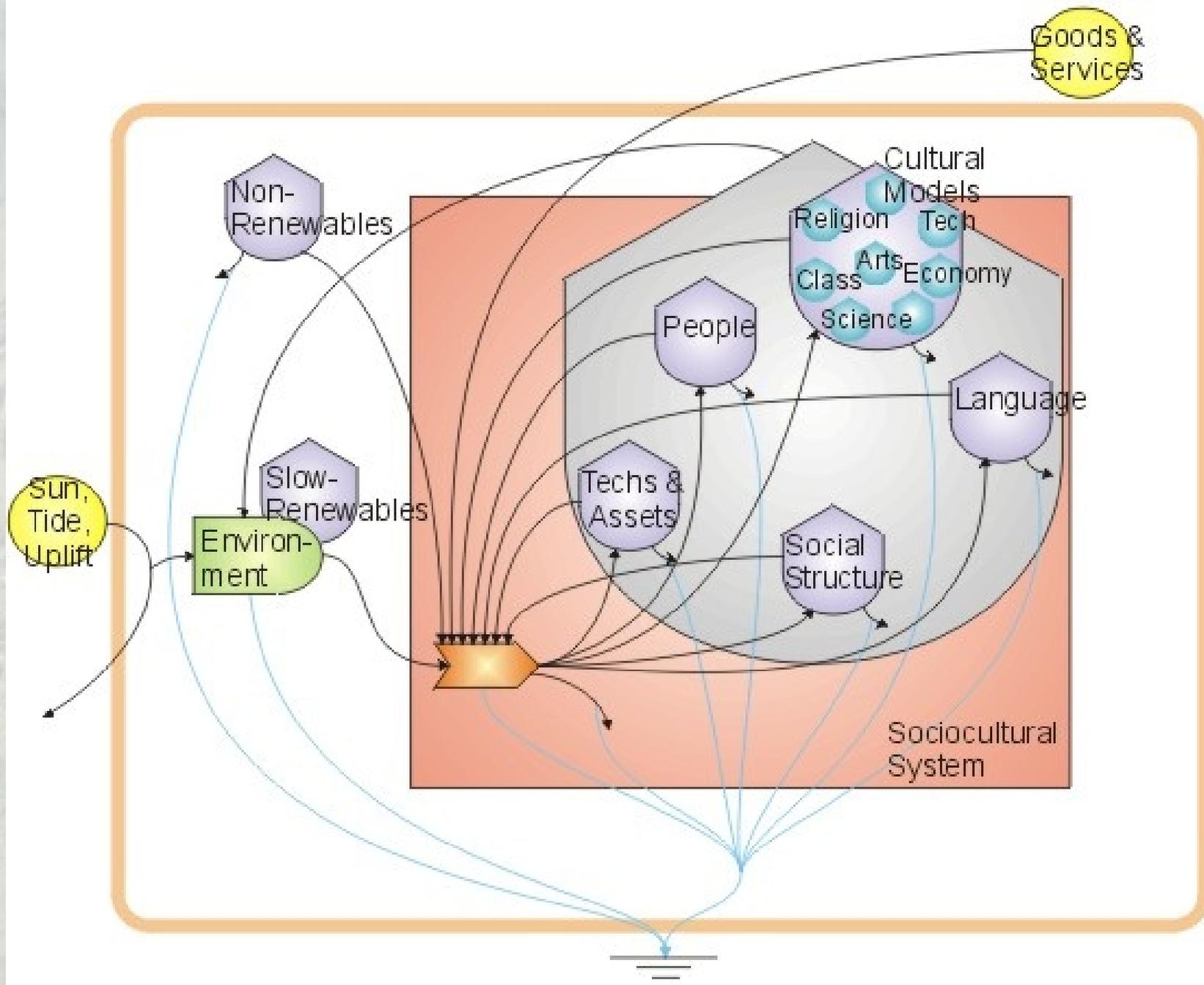
- Acqua
- Azoto
- Carbonio
- Metalli
- Fosforo

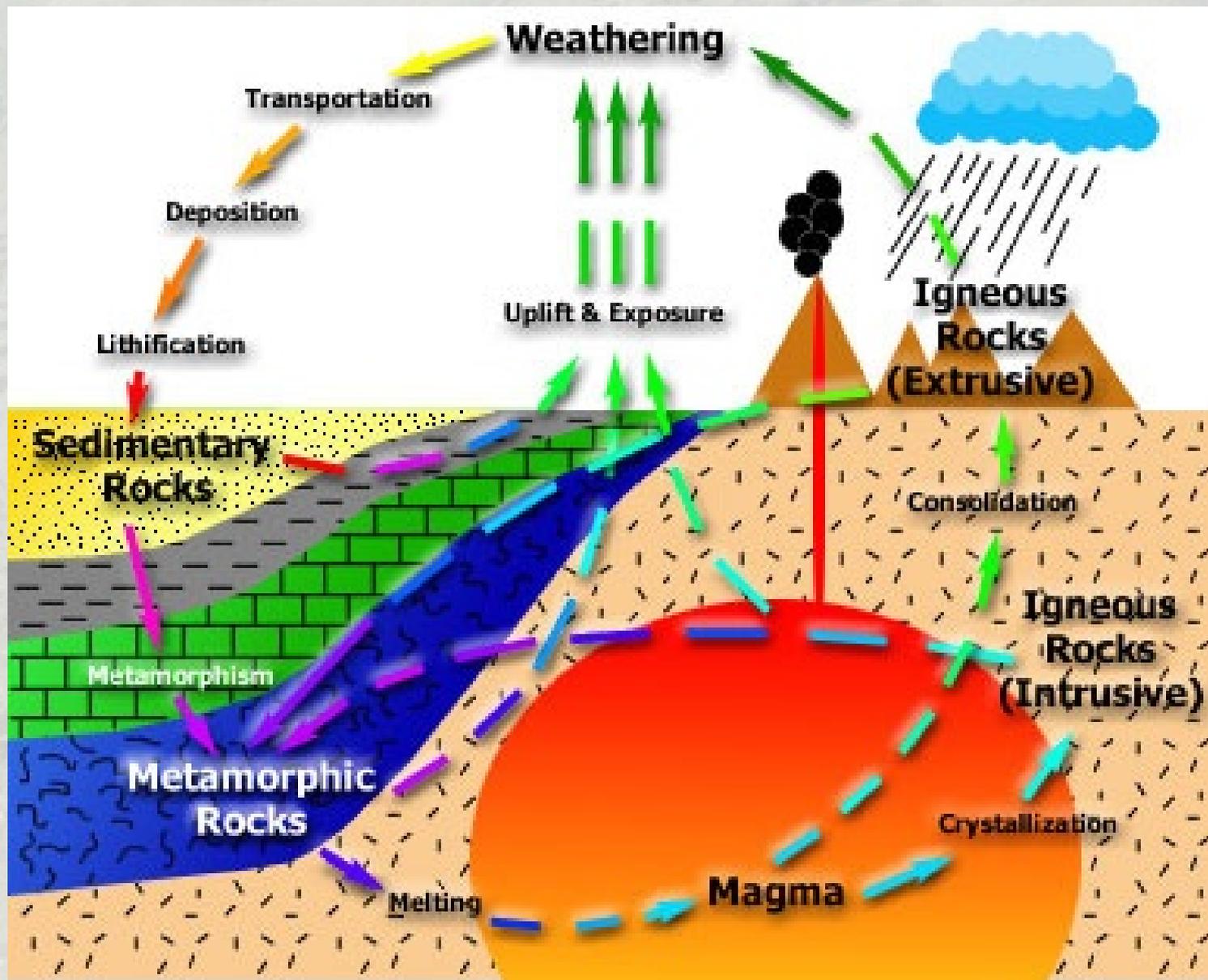


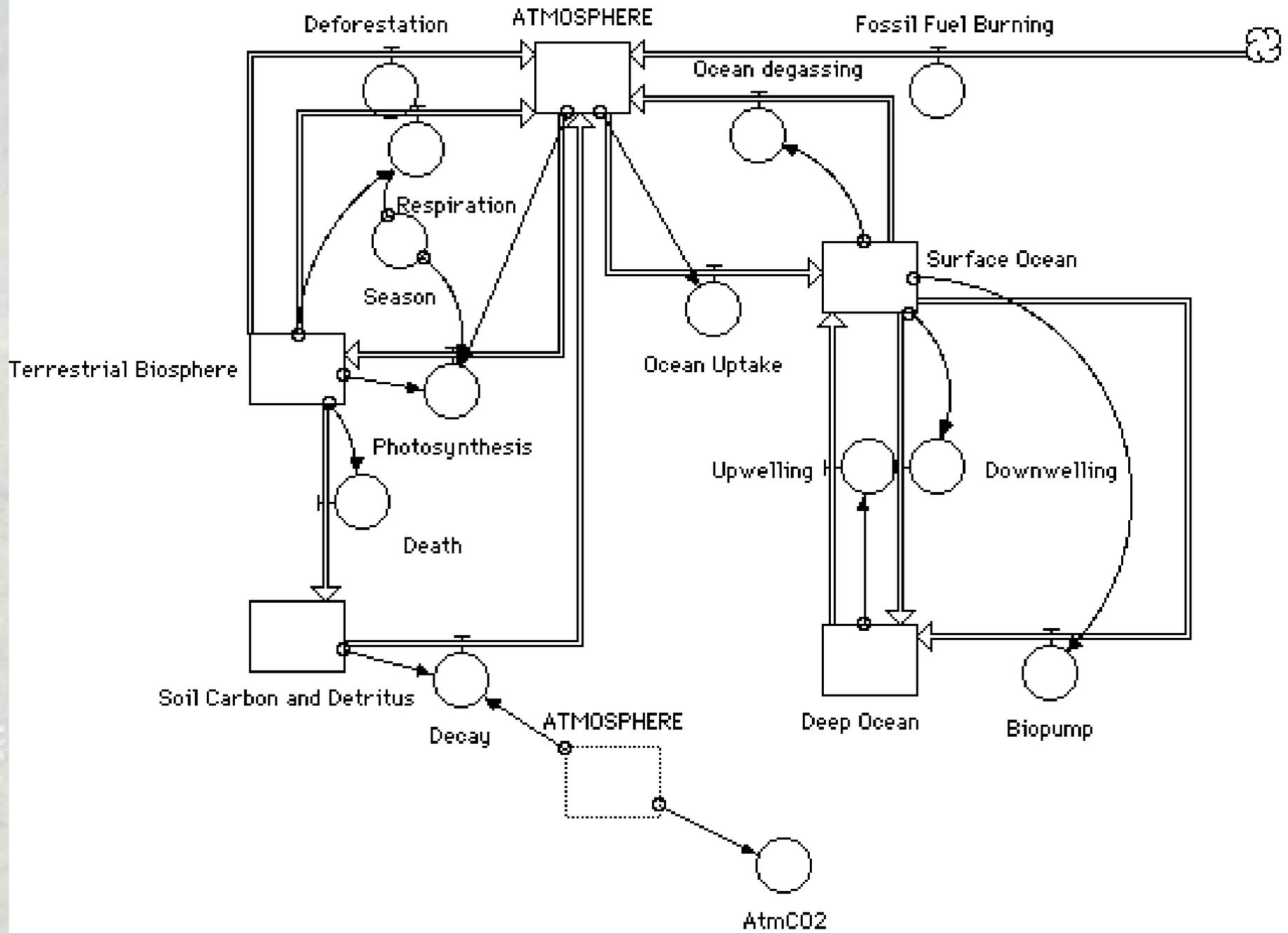
« Mi hai dato perfezione di sensibilità,  
prontezza di intelligenza, forza di memoria;  
mi hai dato la possibilità di esprimermi con  
scioltezza, di esporre piacevolmente i miei  
pensieri, di insegnare in modo convincente,  
di attuare i miei propositi, di comportarmi  
gradevolmente, di progredire negli studi, di  
raggiungere i miei progetti; mi hai dato  
conforto nelle avversità, cautela nelle  
circostanze felici »

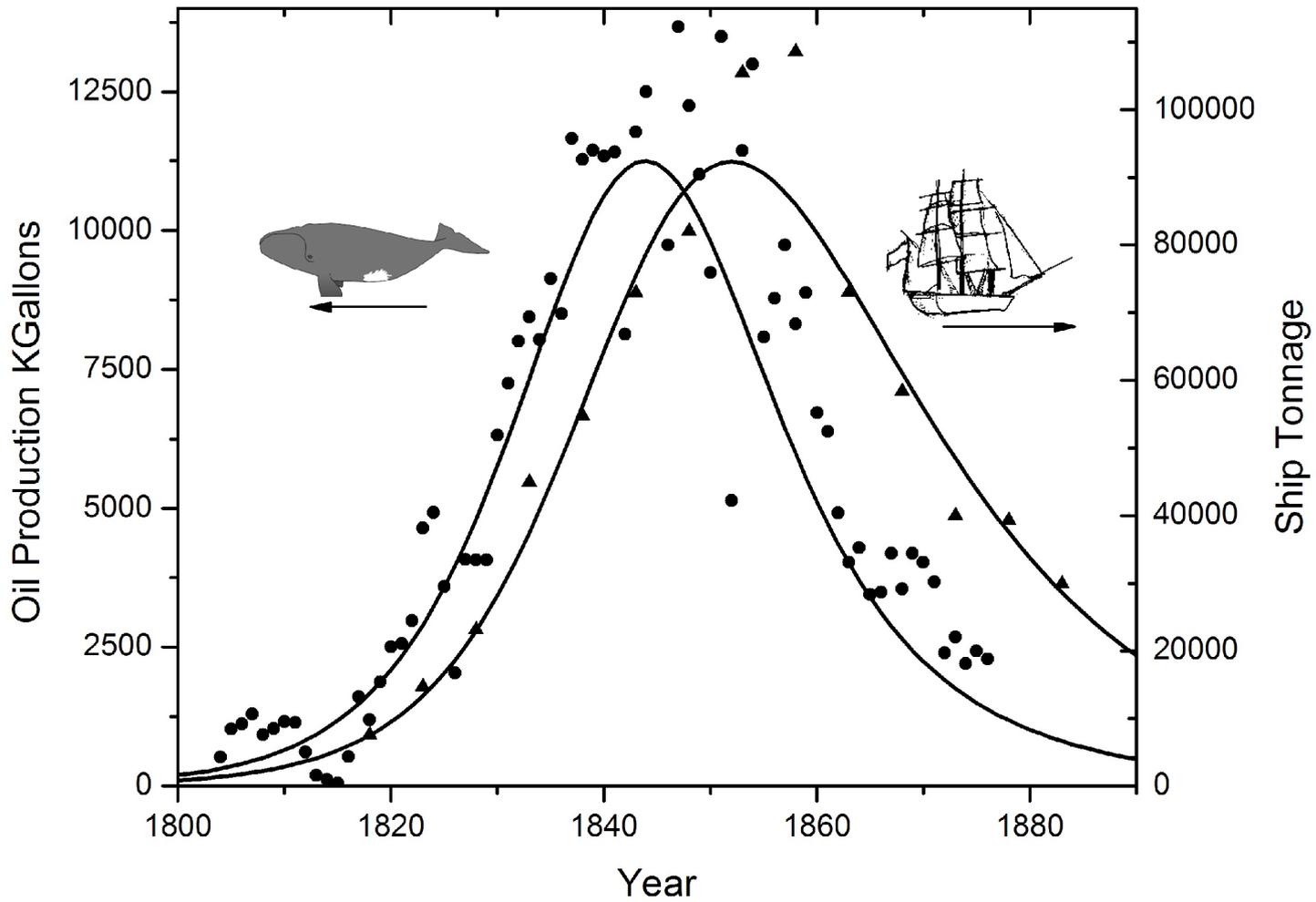
(Ugo di San Vittore, Soliloquium de arrha  
animae – circa 1120)

# Simbologia secondo Odum



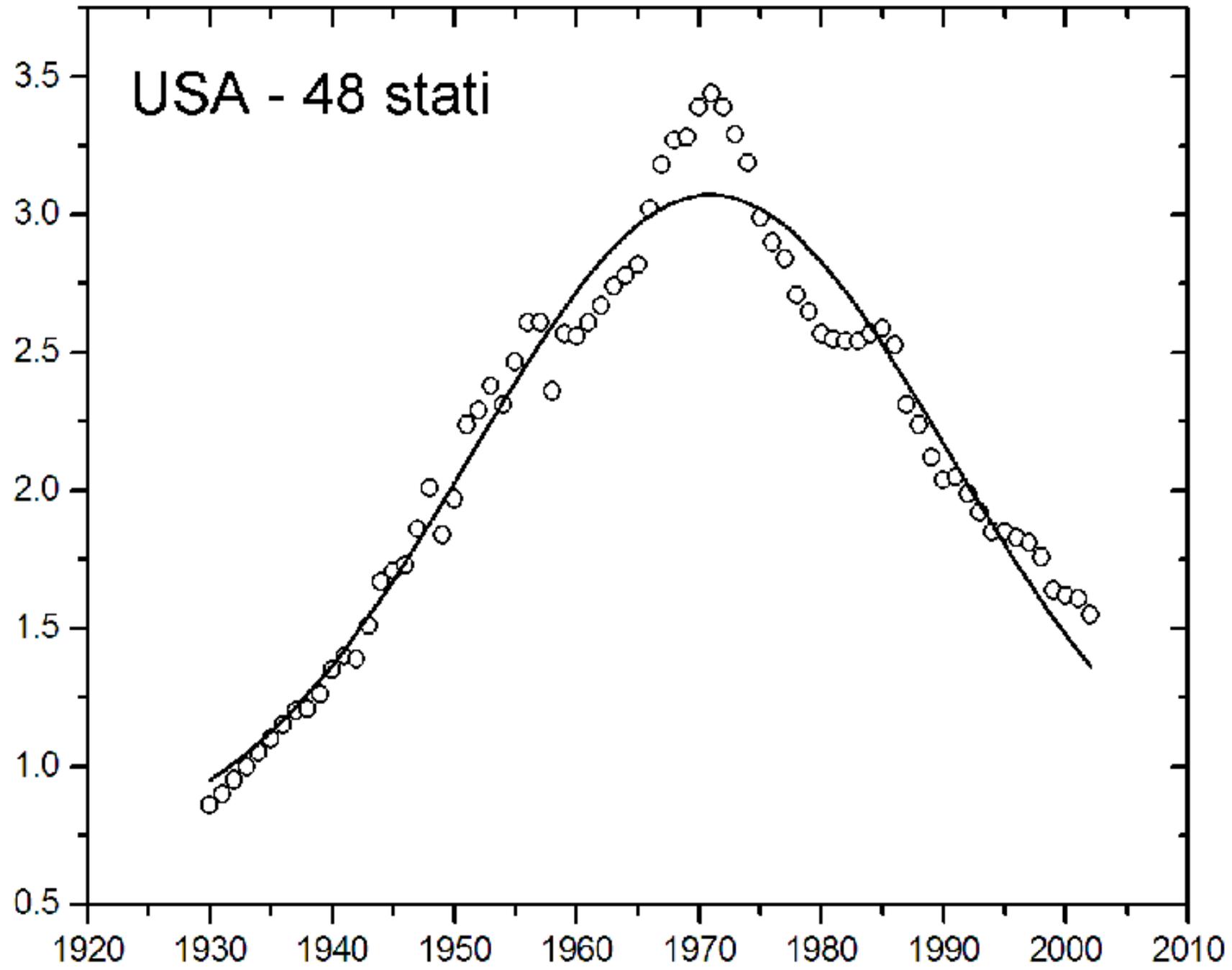






Produzione, gigabarili/anno

USA - 48 stati



Anno

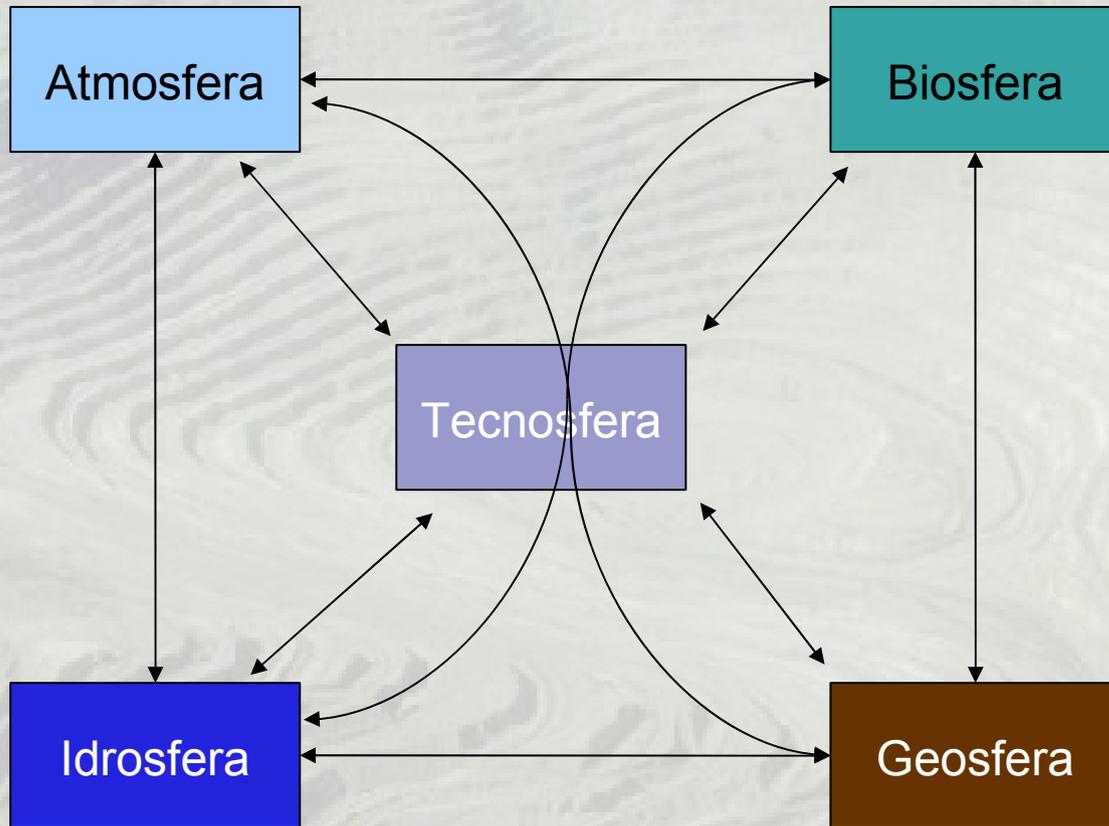
## **Ambientalismo tradizionale:**

Enfasi sul risparmio e l'efficienza (tappare i buchi nel secchio)



## **Il Nuovo Ambientalismo**

Enfasi sul riciclo e sull'uso dell'energia rinnovabile (riempire il secchio)





**Una persona produce:**

ca. 150 W,  
ca. 1 kWh al giorno

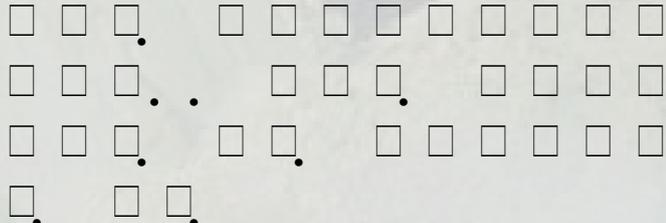
**Ha bisogno di**  
2500 kcal alimentari/giorno  
2.8 kWh

**Luce solare su un metro quadro:**

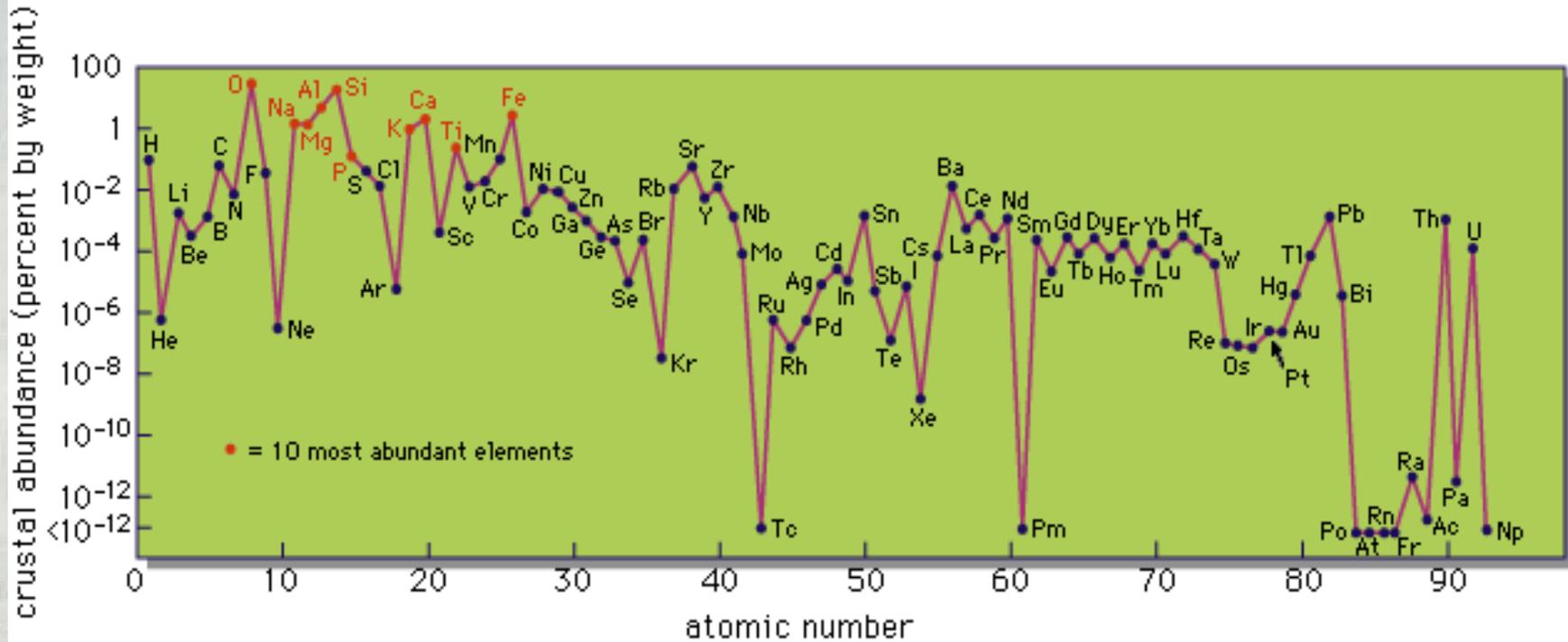
1000 W in media, ovvero  
24 kWh/giorno

**Resa dei cereali**

- 10<sup>7</sup> kcal/ettaro
- 10<sup>4</sup> kWh/ettaro
- 60 kWh/ettaro/giorno
- 6x10<sup>-3</sup> kWh/m<sup>2</sup>/giorno



# Crustal abundance of the elements



©1994 Encyclopaedia Britannica, Inc.

56 elements listed as being extracted by USGS

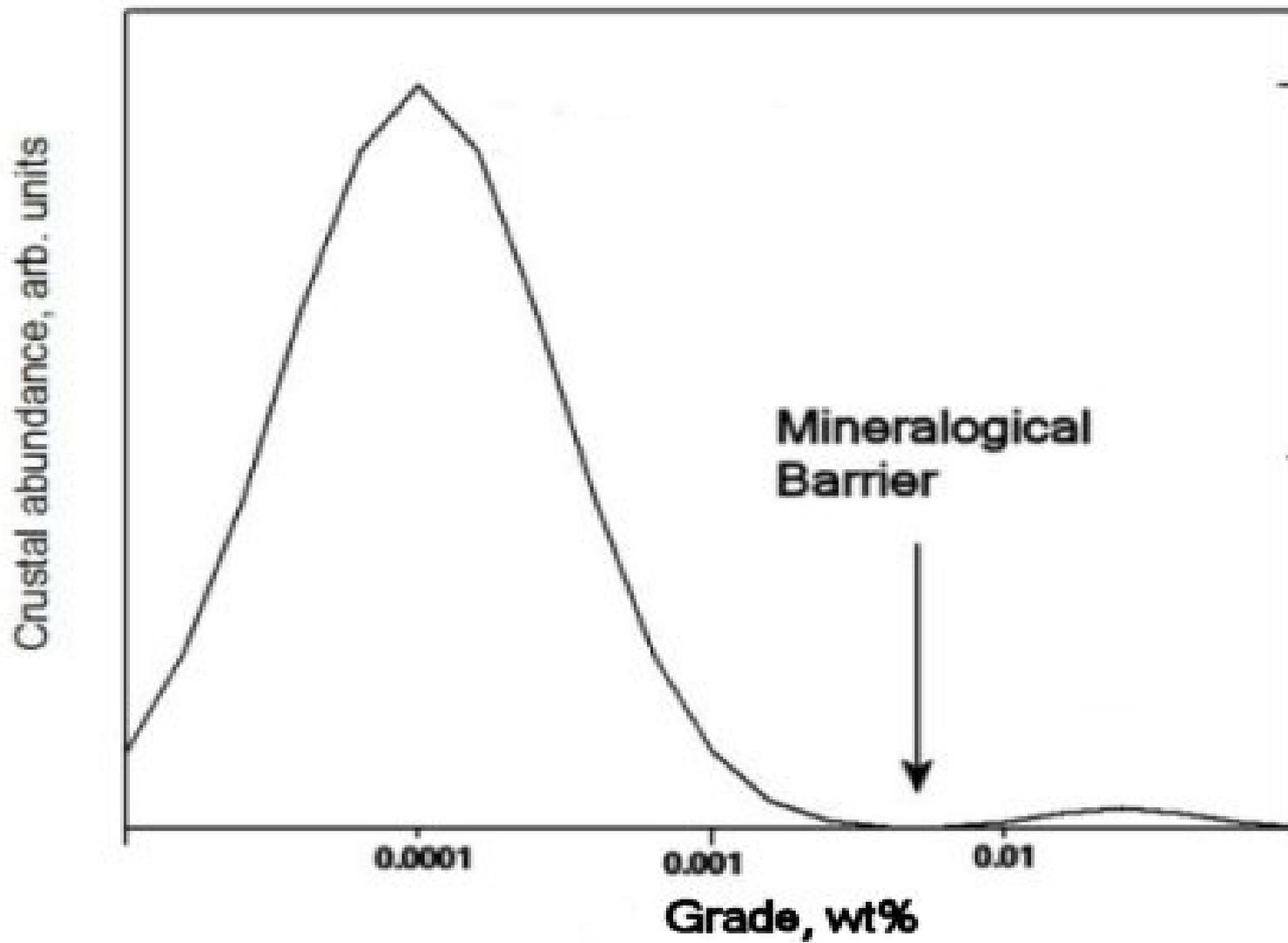
Total mass extracted: ca 10 E+11 tons/year

Total sedimentation in the oceans ca. 2 E+10 tons/year

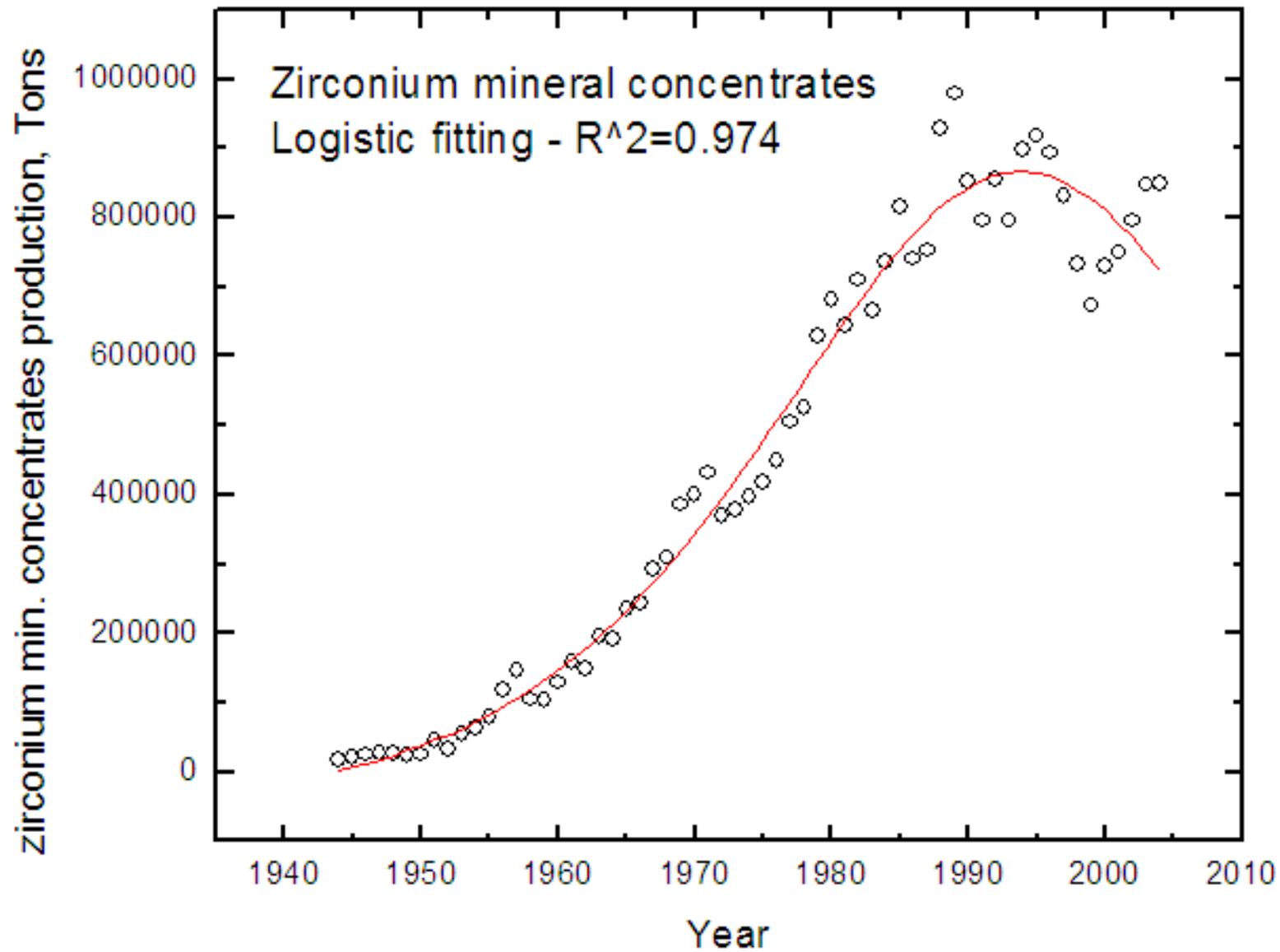
“Common elements”: ca. 1% in weight. Fe, Si, Al, Mg, Ti...

“Rare” elements: 0.01-0.1% weight. Cu, Pb, Zn, Ni, Co .....

“Trace” elements <0.01 in weight. Pt, Ir, Rh, In, Se, Ga.....



The mineralogical barrier according to B.W. Skinner, 1976



Bardi and Pagani, TOD 2007  
<http://europe.theoil Drum.com/node/3086>

Mineral	Peak year (logistic)	URR (tons) from logistic fitting	URR (tons) from USGS: reserves + cumulative production up to 2006
Mercury	1962	$(5.8 \pm 0.4) \cdot 10^5$	$5.9 \cdot 10^5$
Tellurium	1984	$(1.0 \pm 0.4) \cdot 10^4$	$2.8 \cdot 10^4$
Lead	1986	$(3.3 \pm 0.2) \cdot 10^8$	$2.9 \cdot 10^8$
Cadmium	1989	$(1.33 \pm 0.09) \cdot 10^6$	$1.5 \cdot 10^6$
Potash	1989	$(1.54 \pm 0.09) \cdot 10^9$	$9.5 \cdot 10^9$
Phosphate rock	1989	$(8.1 \pm 0.4) \cdot 10^9$	$2.4 \cdot 10^{10}$
Thallium	1995	$(4.7 \pm 0.3) \cdot 10^2$	$7.6 \cdot 10^2$
Selenium	1994	$(1.1 \pm 0.14) \cdot 10^5$	$1.6 \cdot 10^5$
Zirconium minerals concentrates	1994	$(3.9 \pm 0.25) \cdot 10^7$	$6.7 \cdot 10^7$
Rhenium	1998	$(1.0 \pm 0.3) \cdot 10^3$	$3.3 \cdot 10^3$
Gallium	2002	$(2.5 \pm 0.5) \cdot 10^3$	$1.65 \cdot 10^4$ (?)

CRADLE 2

CRADLE

IS A STRATEGY OF

HOPE

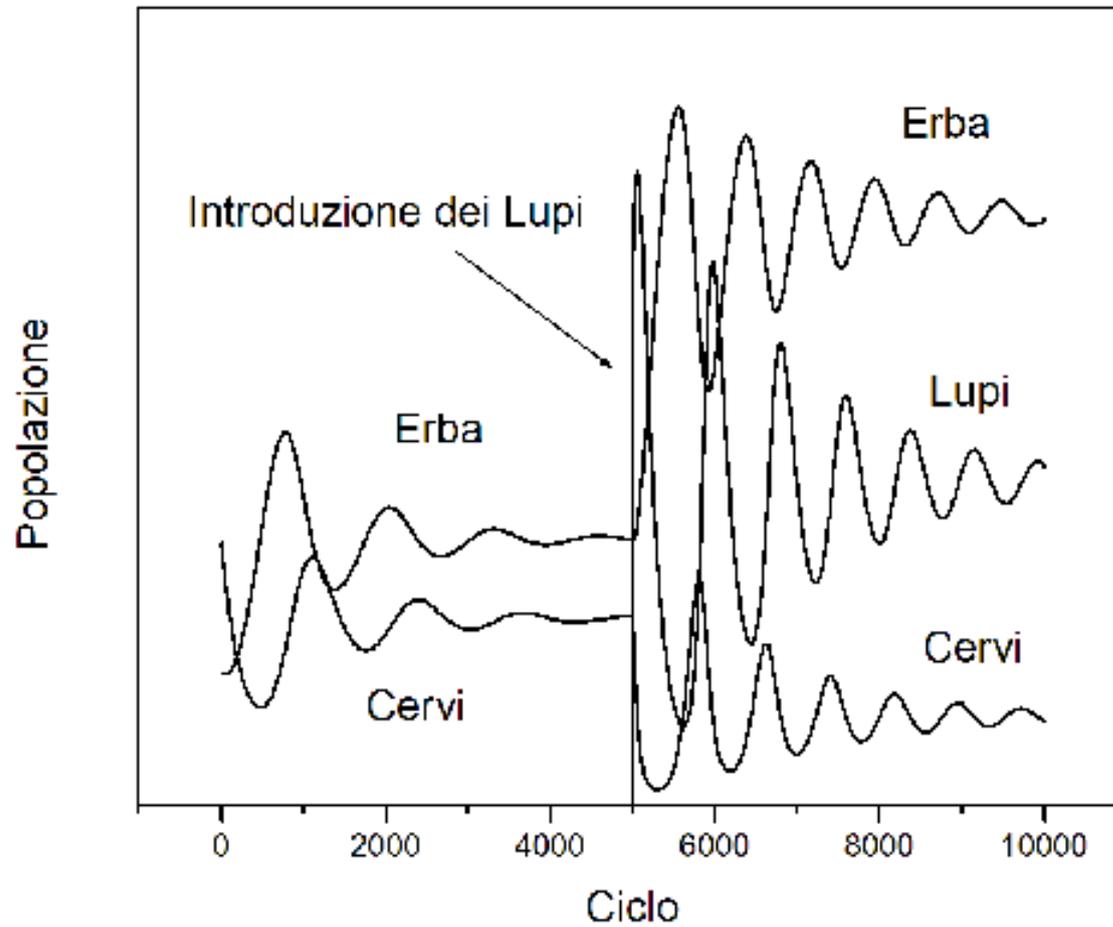
(B.McDonough)

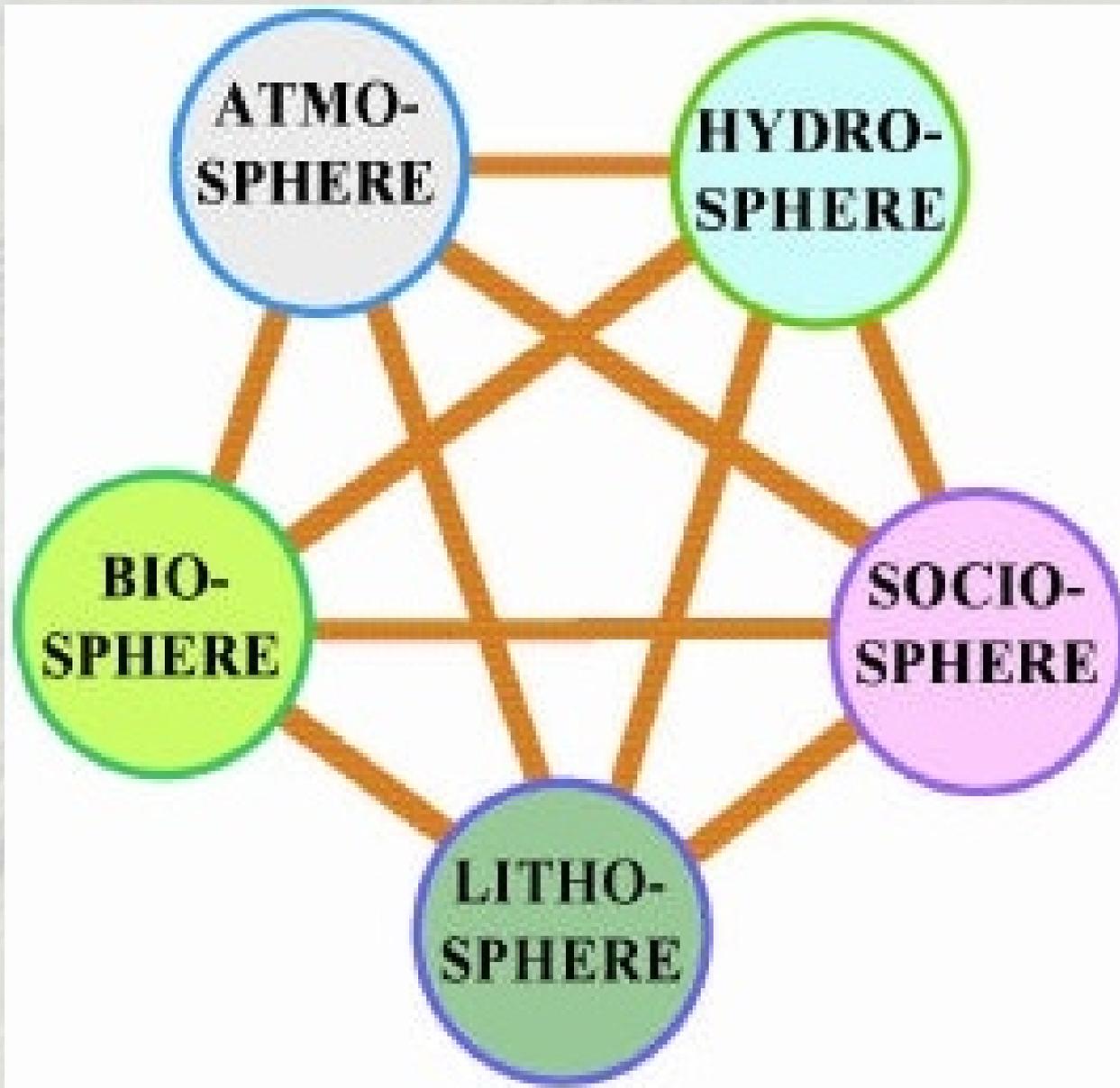


Presentazione di Ugo Bardi, Festival della Creatività, Firenze, Ottobre 2008

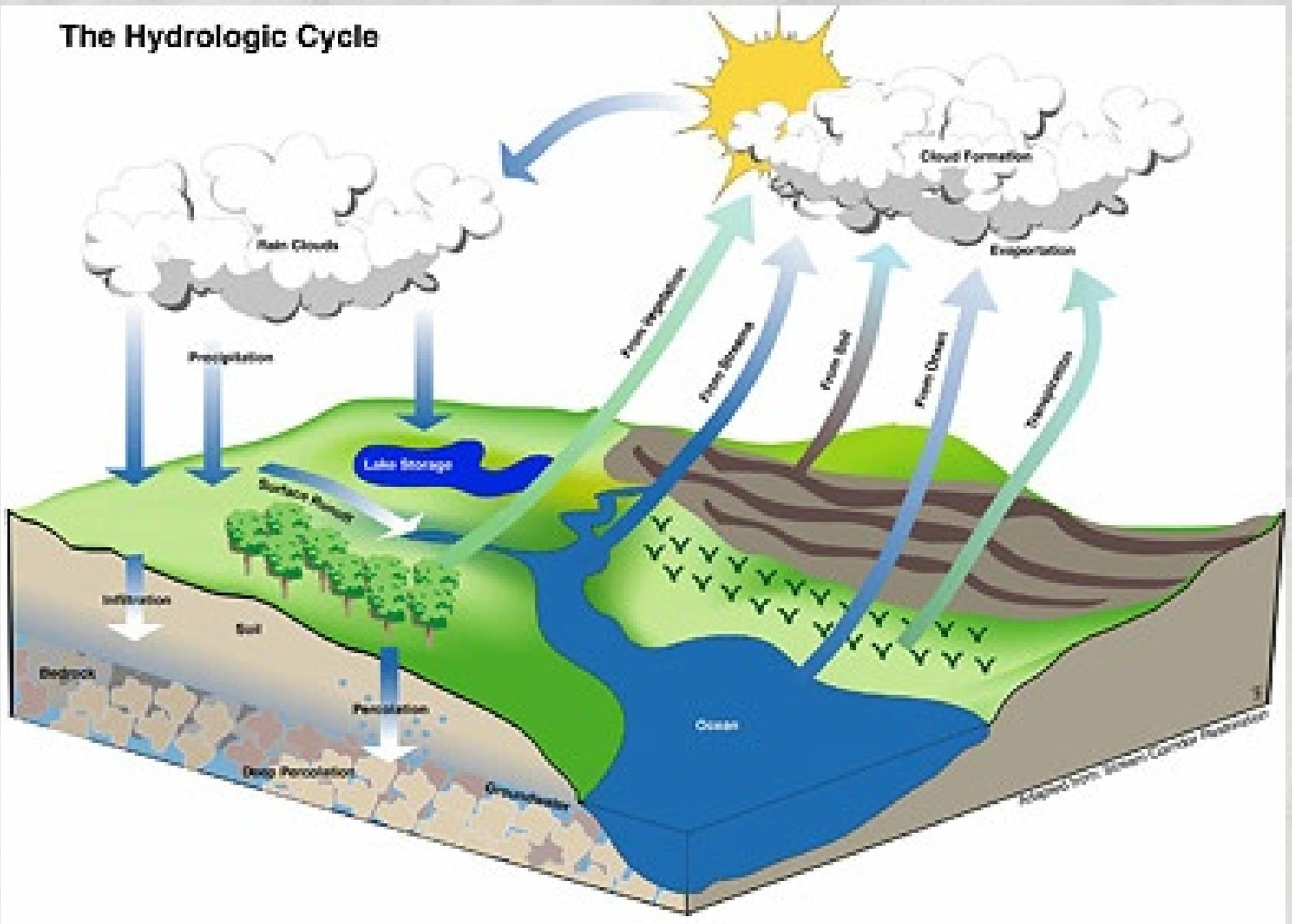
[ugo.bardi@unifi.it](mailto:ugo.bardi@unifi.it)

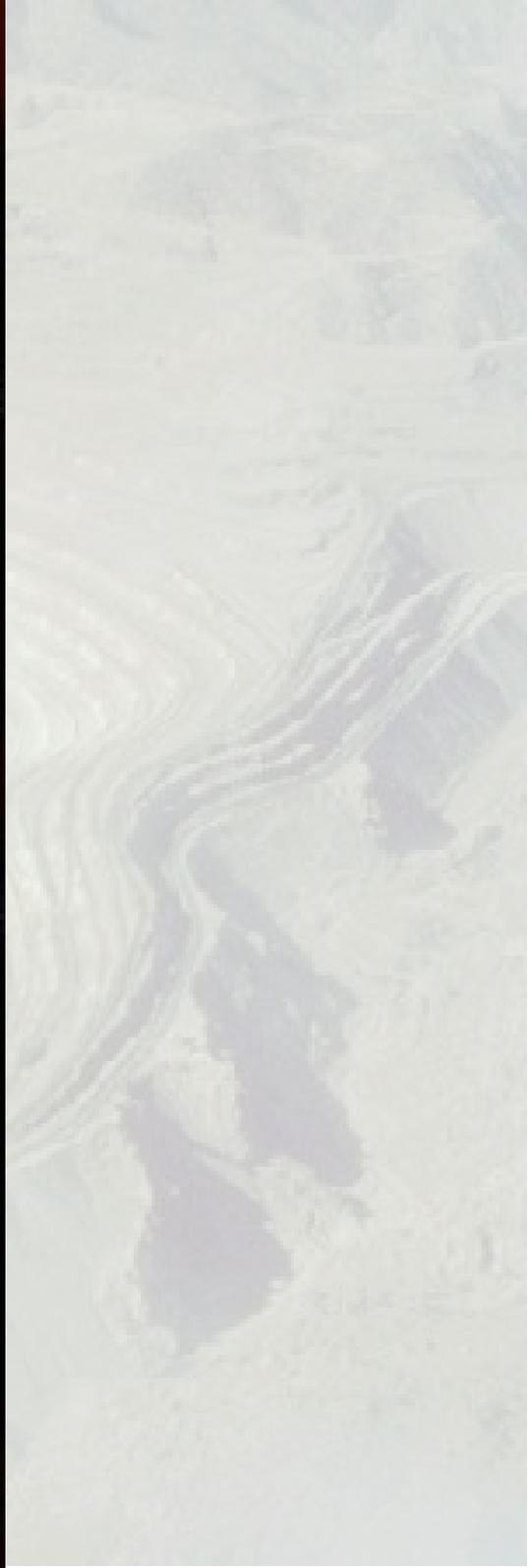
## Omeostasi nel sistema di Lotka-Volterra a tre specie





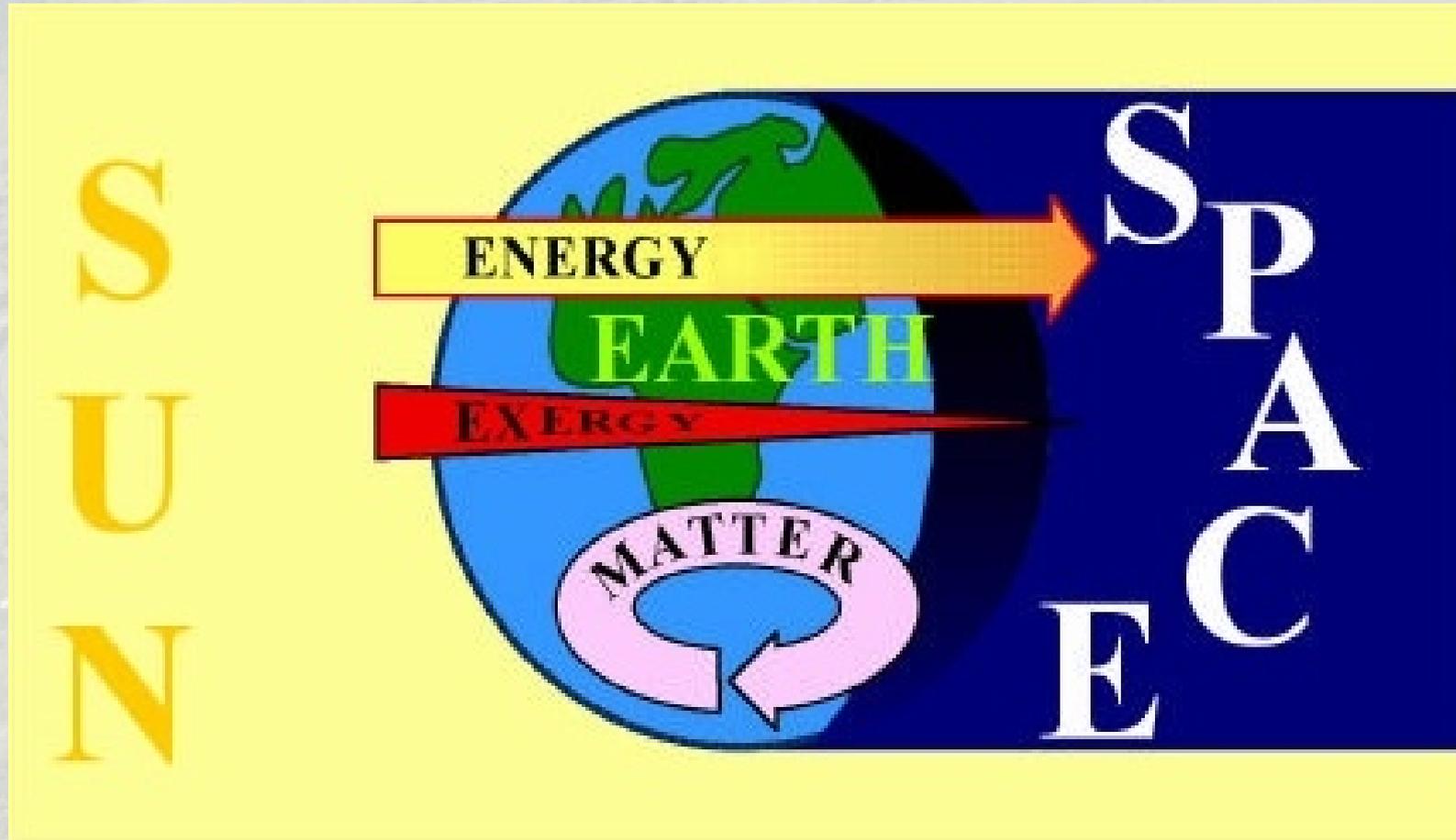
# The Hydrologic Cycle





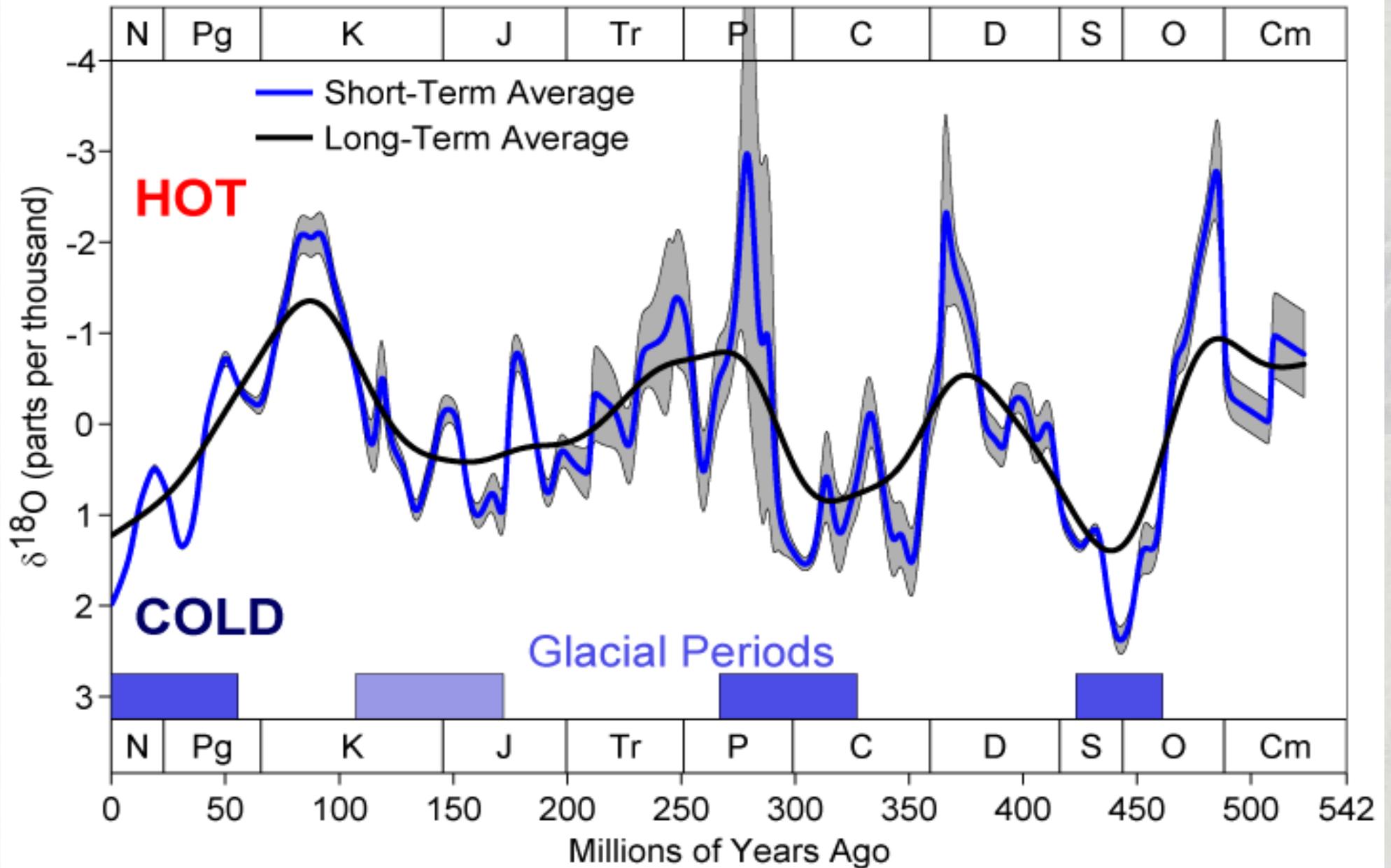


Steady state system – Sistema a stato stazionario

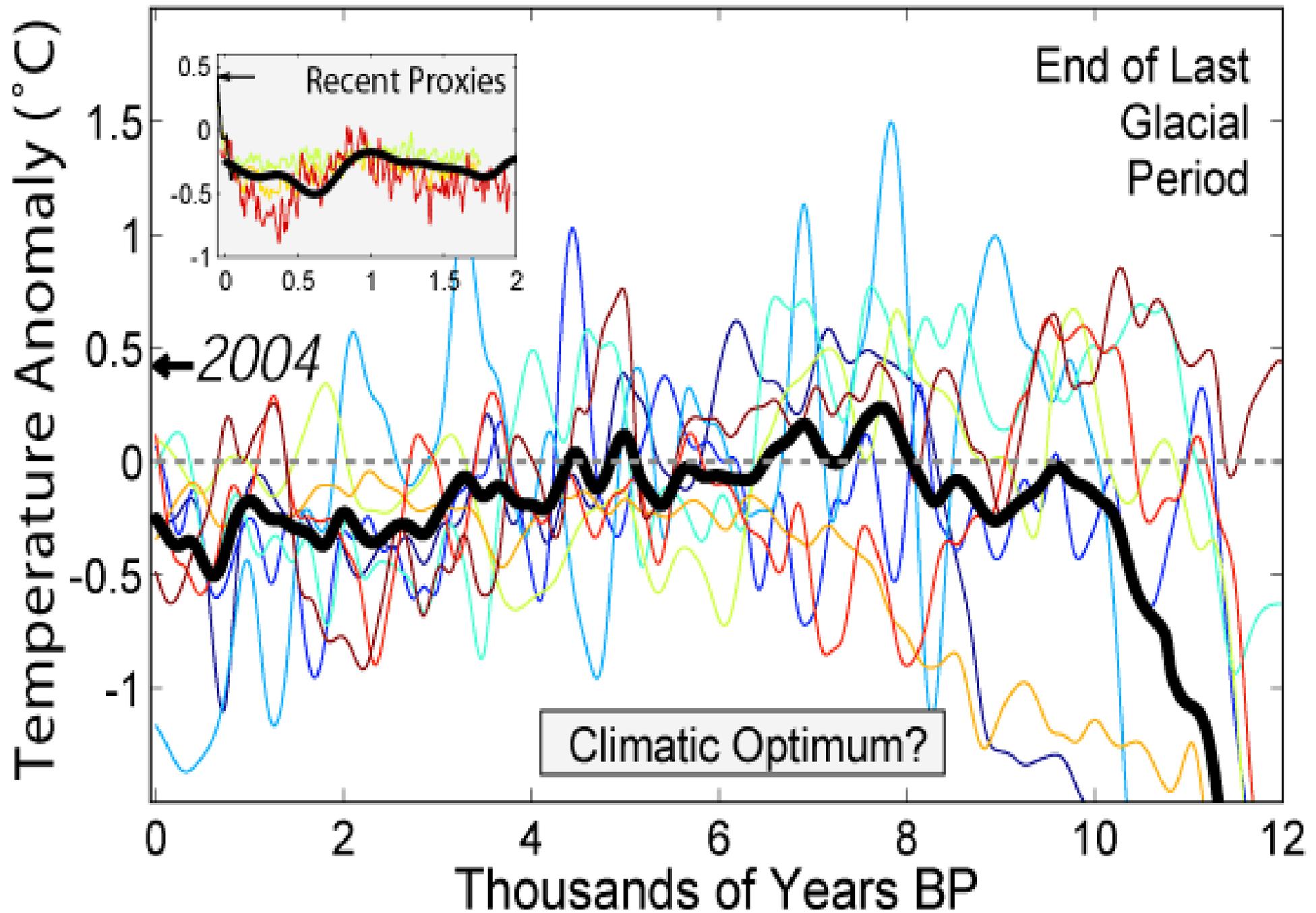


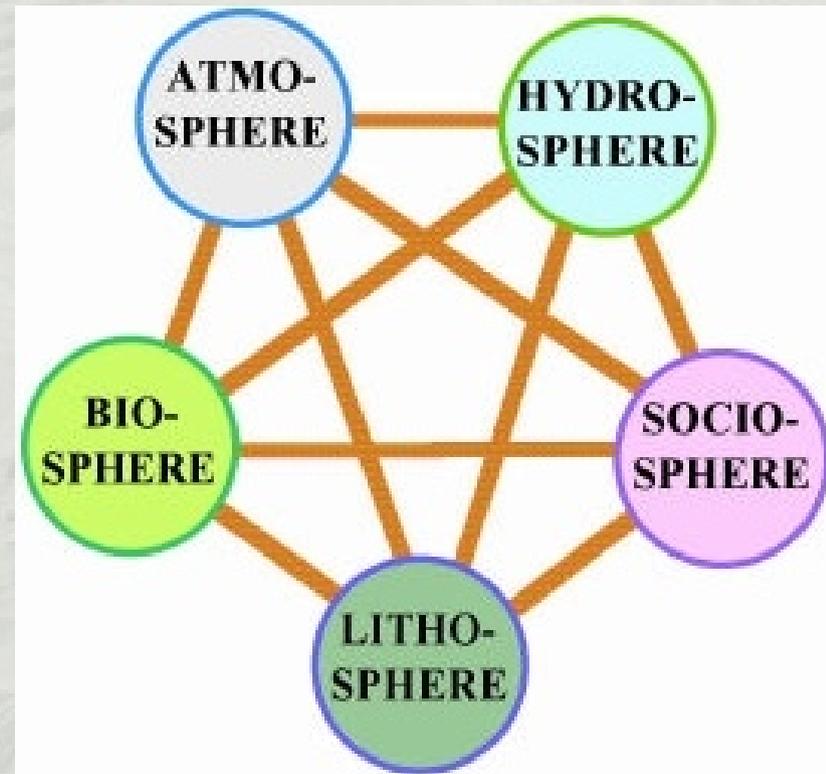
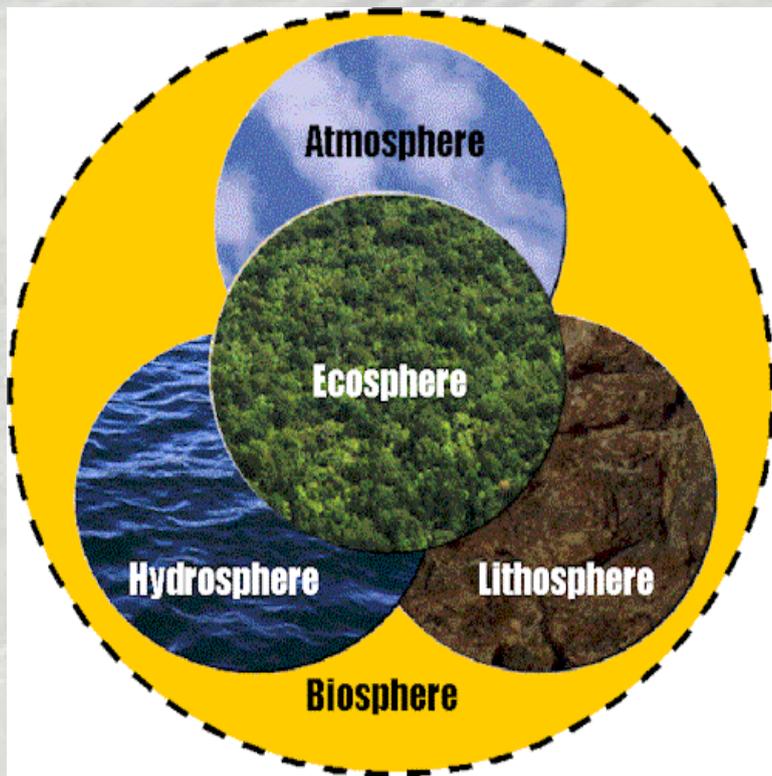
# Temperatura del Fanerozoico

## Phanerozoic Climate Change

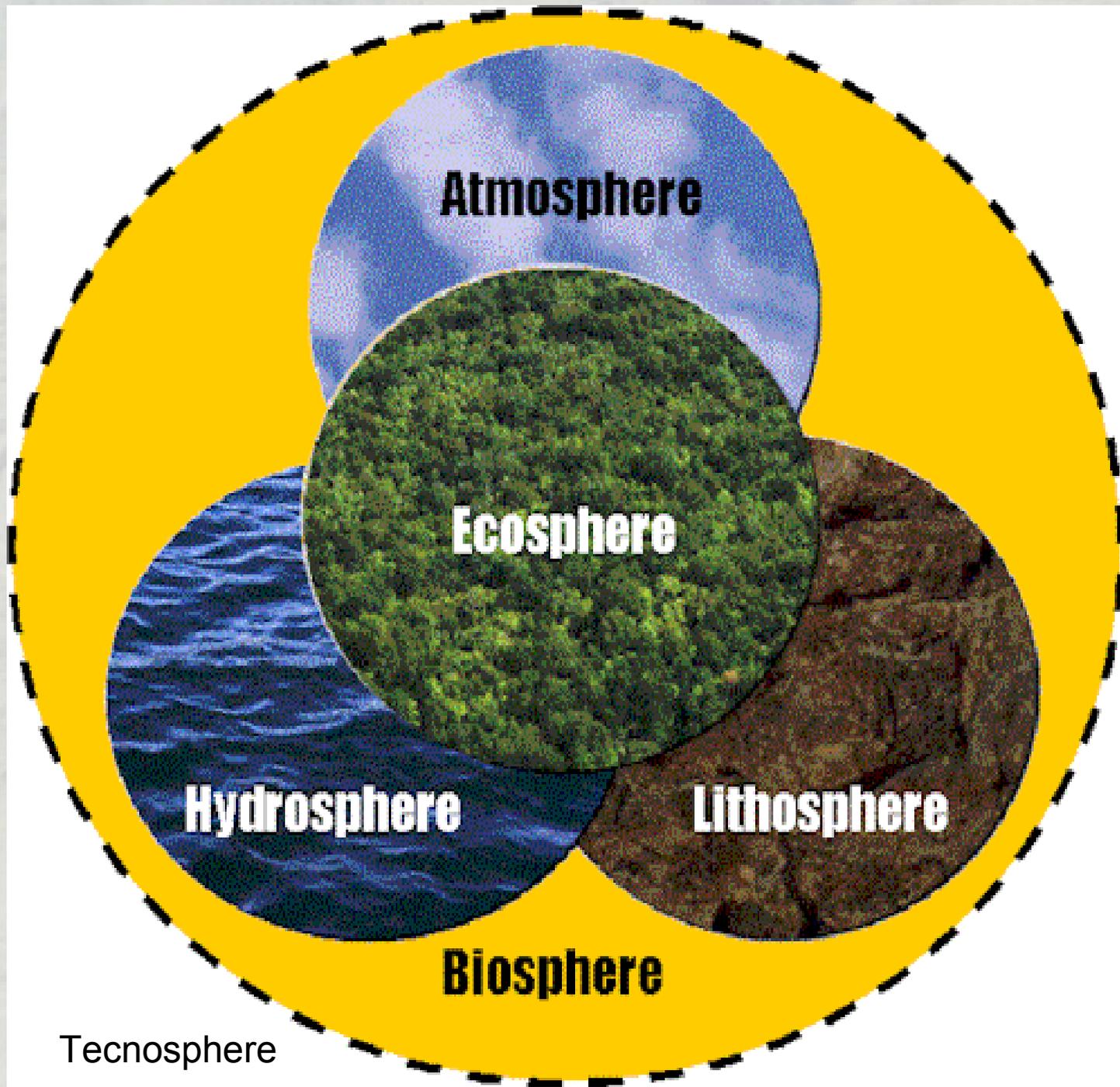


# Holocene Temperature Variations





Element	Concentration in seawater (ppm)	Total oceanic abundance (tons)	Mineral reserves (tons)
Li	0.178000	2.31E+011	4.10E+006
Ba	0.021000	2.73E+010	1.90E+008
Mo	0.010000	1.30E+010	8.60E+006
Ni	0.006600	8.58E+009	6.70E+007
Zn	0.005000	6.50E+009	1.80E+008
Fe	0.003400	4.42E+009	1.50E+011
U	0.003300	4.29E+009	2.60E+006
V	0.001900	2.47E+009	1.30E+007
Ti	0.001000	1.30E+009	7.30E+008
Al	0.001000	1.30E+009	2.50E+010
Cu	0.000900	1.17E+009	4.90E+008
Mn	0.000400	5.20E+008	4.60E+008
Co	0.000390	5.07E+008	7.00E+009
Sn	0.000280	3.64E+008	6.10E+006
Cr	0.000200	2.60E+008	4.75E+008
Cd	0.000110	1.43E+008	4.90E+005
Pb	0.000030	3.90E+007	7.90E+007
Au	0.000011	1.43E+007	4.20E+004



Tecnosphere

<b>Element</b>	<b>Total mass in oceans (tons)</b>	<b>Production in 2007 (tons)</b>	<b>Mass of water to be processed (tons)</b>
Li	2.31E+011	2.50E+004	1.40E+011
Mo	1.30E+010	1.87E+005	1.87E+013
U	4.29E+009	6.65E+004	2.02E+013
V	2.47E+009	5.86E+004	3.08E+013
Cd	1.43E+008	1.99E+004	1.81E+014
Au	1.43E+007	2.50E+003	2.27E+014
Sn	3.64E+008	3.00E+005	1.07E+015
Ni	8.23E+008	1.78E+006	2.81E+015
Cu	1.17E+009	1.56E+007	1.73E+016
Mn	5.20E+008	1.16E+007	2.90E+016
Zn	6.50E+009	1.80E+008	3.60E+016
Al	1.30E+009	3.80E+007	3.80E+016
Cr	2.60E+008	2.00E+007	1.00E+017
Pb	3.90E+007	3.55E+006	1.18E+017
Fe	4.42E+009	2.26E+009	6.65E+017
Ti	1.17E+006	6.10E+006	6.78E+018
Co	8.84E+006	6.23E+007	9.16E+018

**Total mass of the oceans: 1.4 E+18 tons**

**Total volume of water desalinated today: 1.6 E+10 tons**

# ATLANTROPA



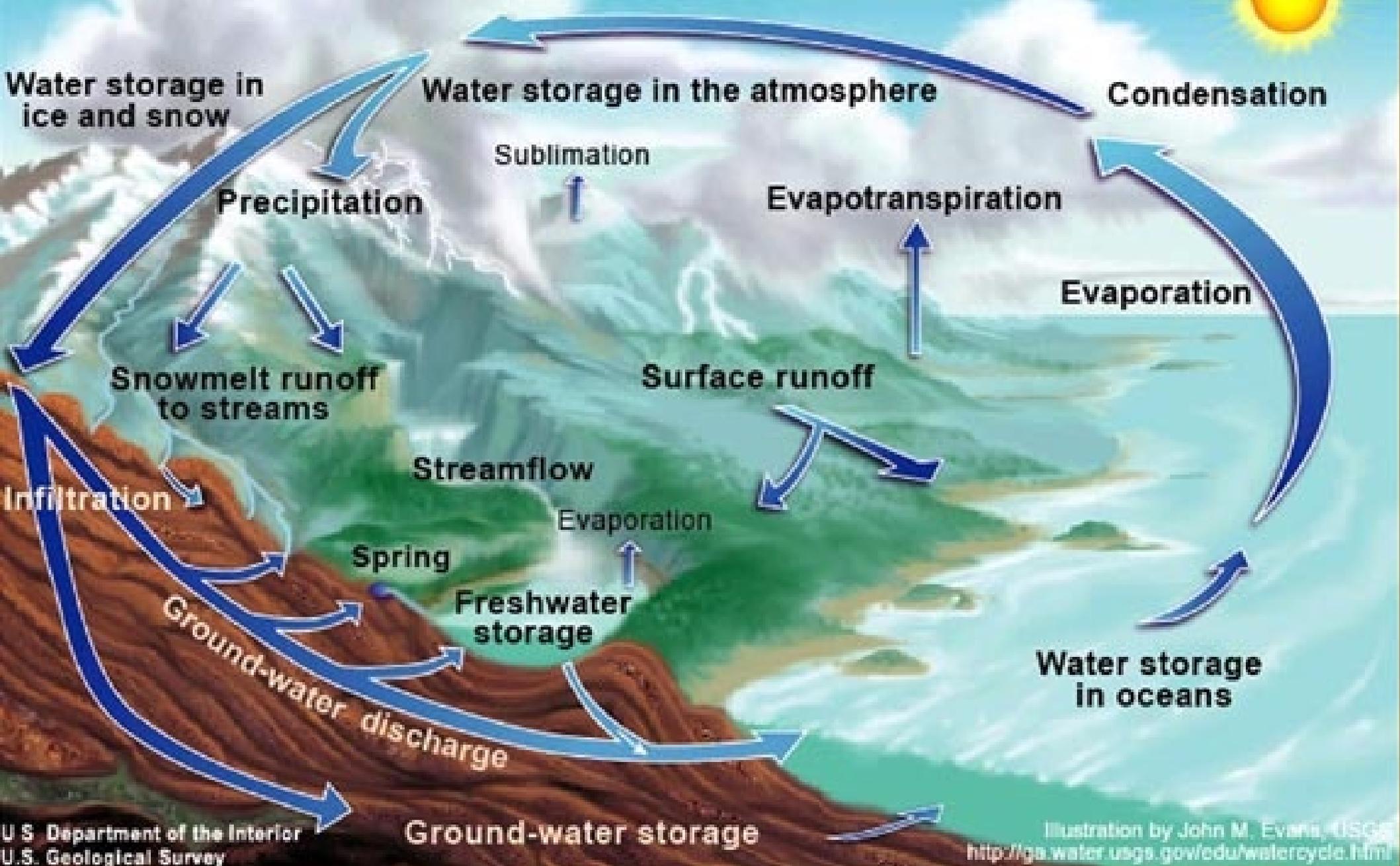
1 “Sverdrup” =  $1 \text{ E}+6 \text{ tons/s}$   
=  $3 \text{ E}+13 \text{ tons/year}$

Strait of Gibraltar = 1 Sverdrup

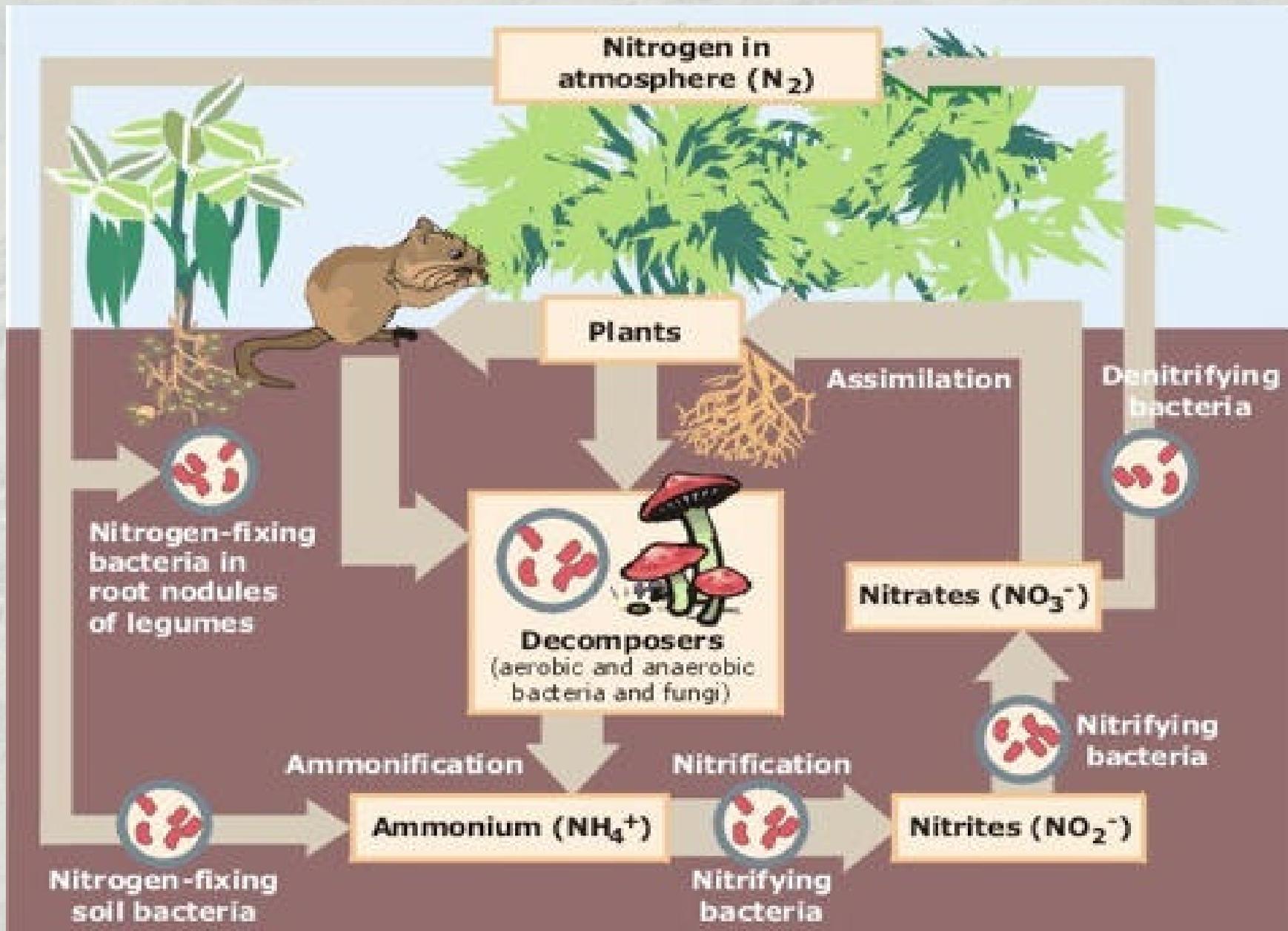
It contains a mass of uranium  
equivalent to today's yearly  
production

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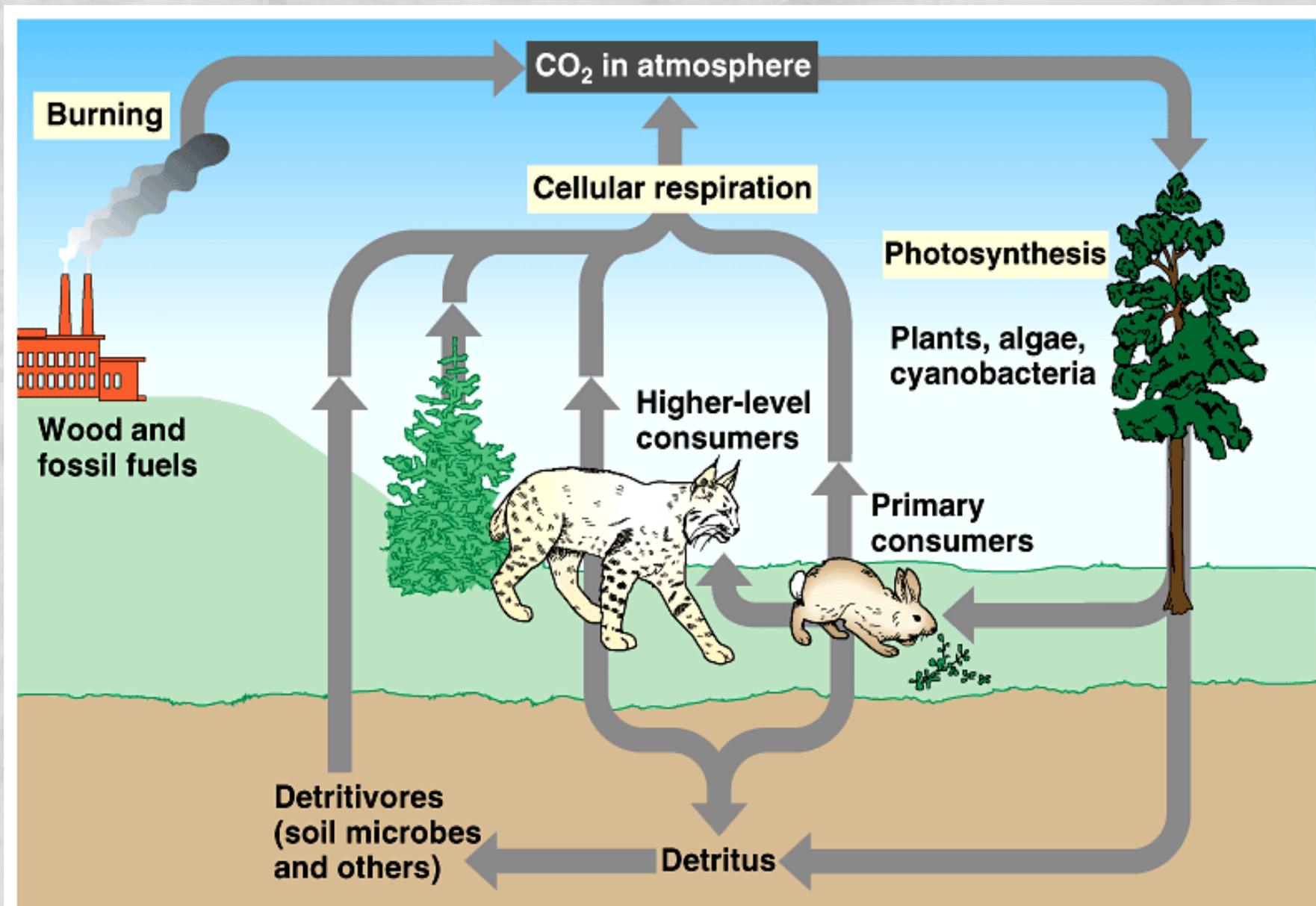
# The Water Cycle



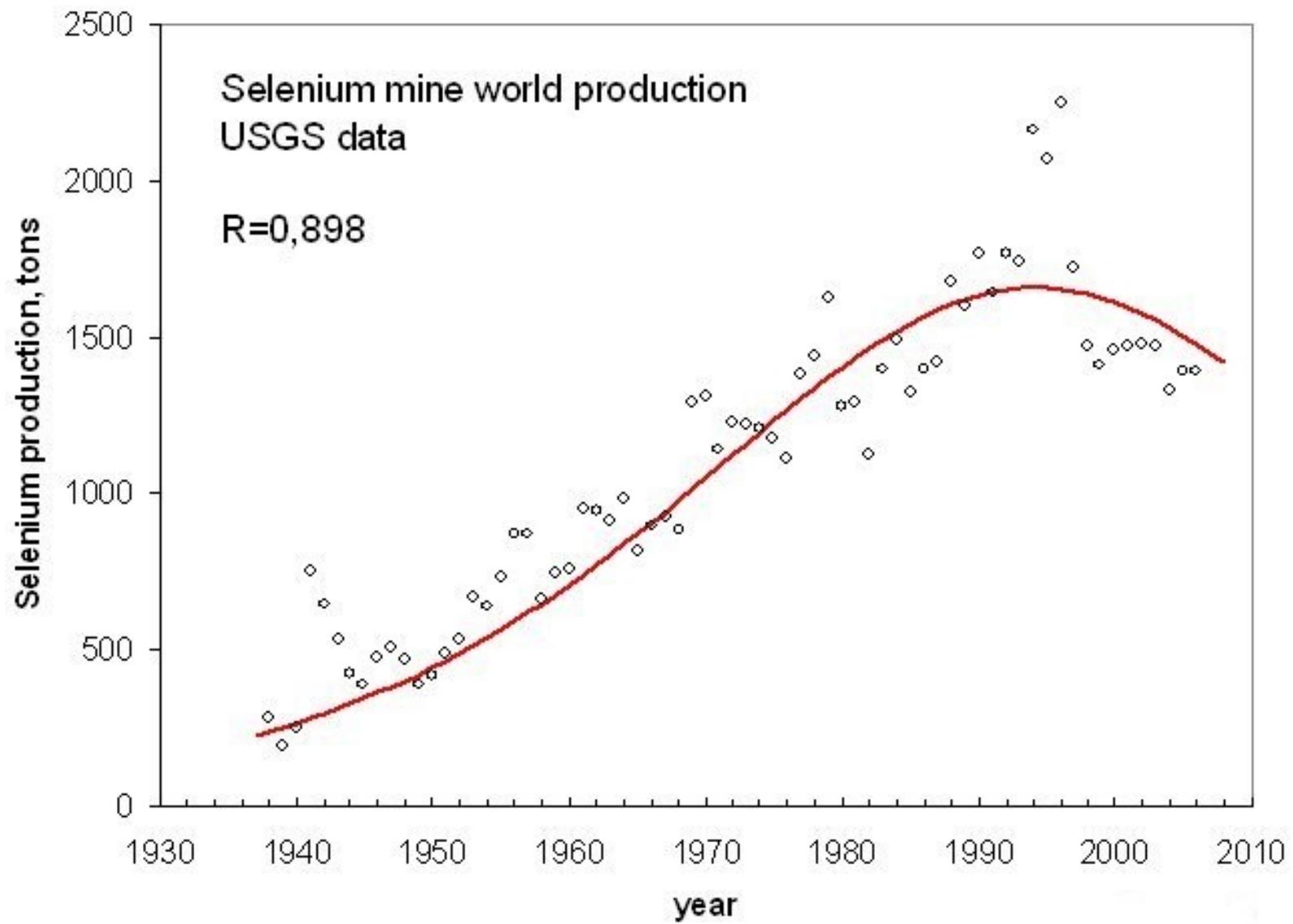
# The nitrogen cycle – Il ciclo dell'azoto

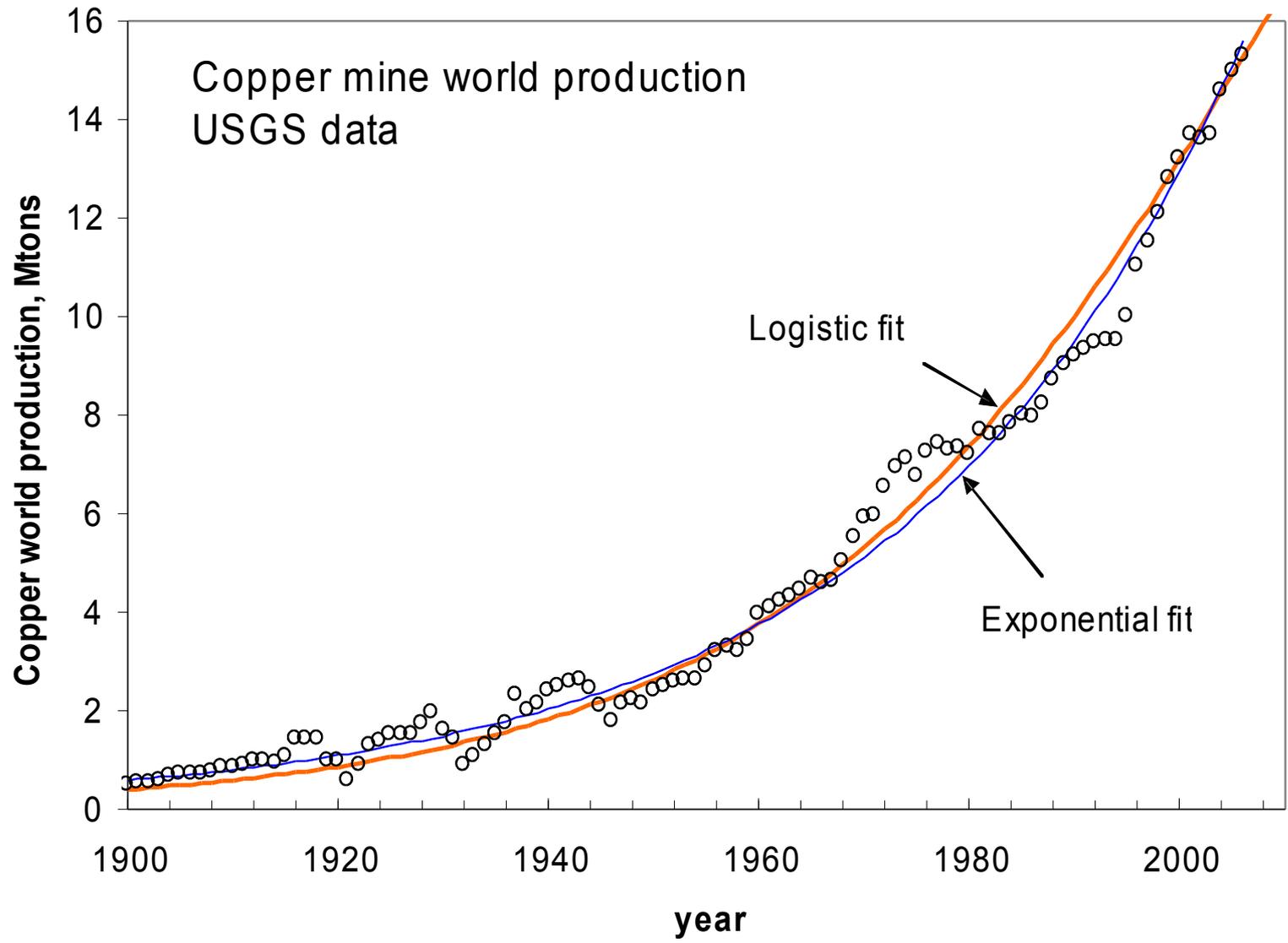


## Carbon's "short" cycle – Il ciclo "corto" del carbonio

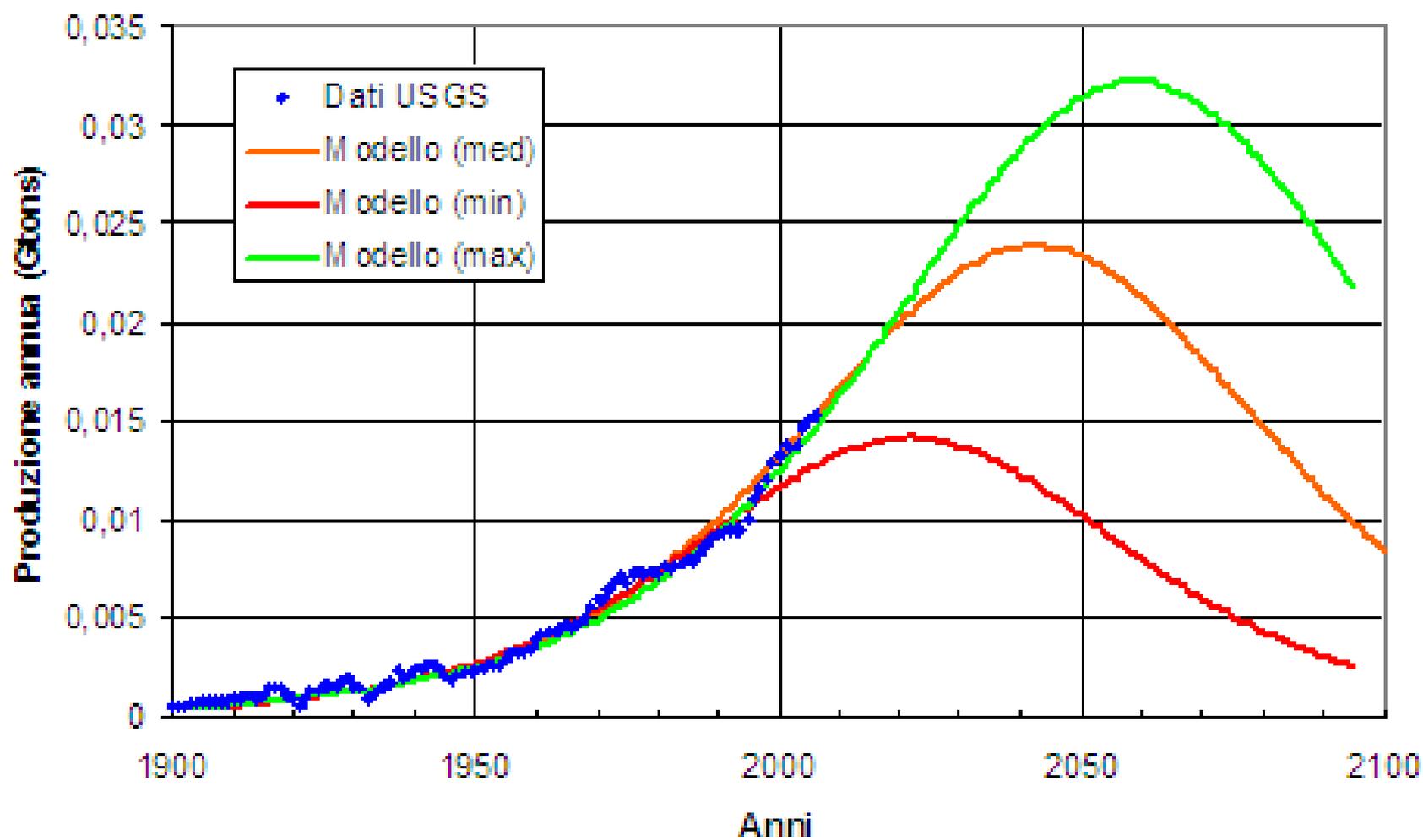


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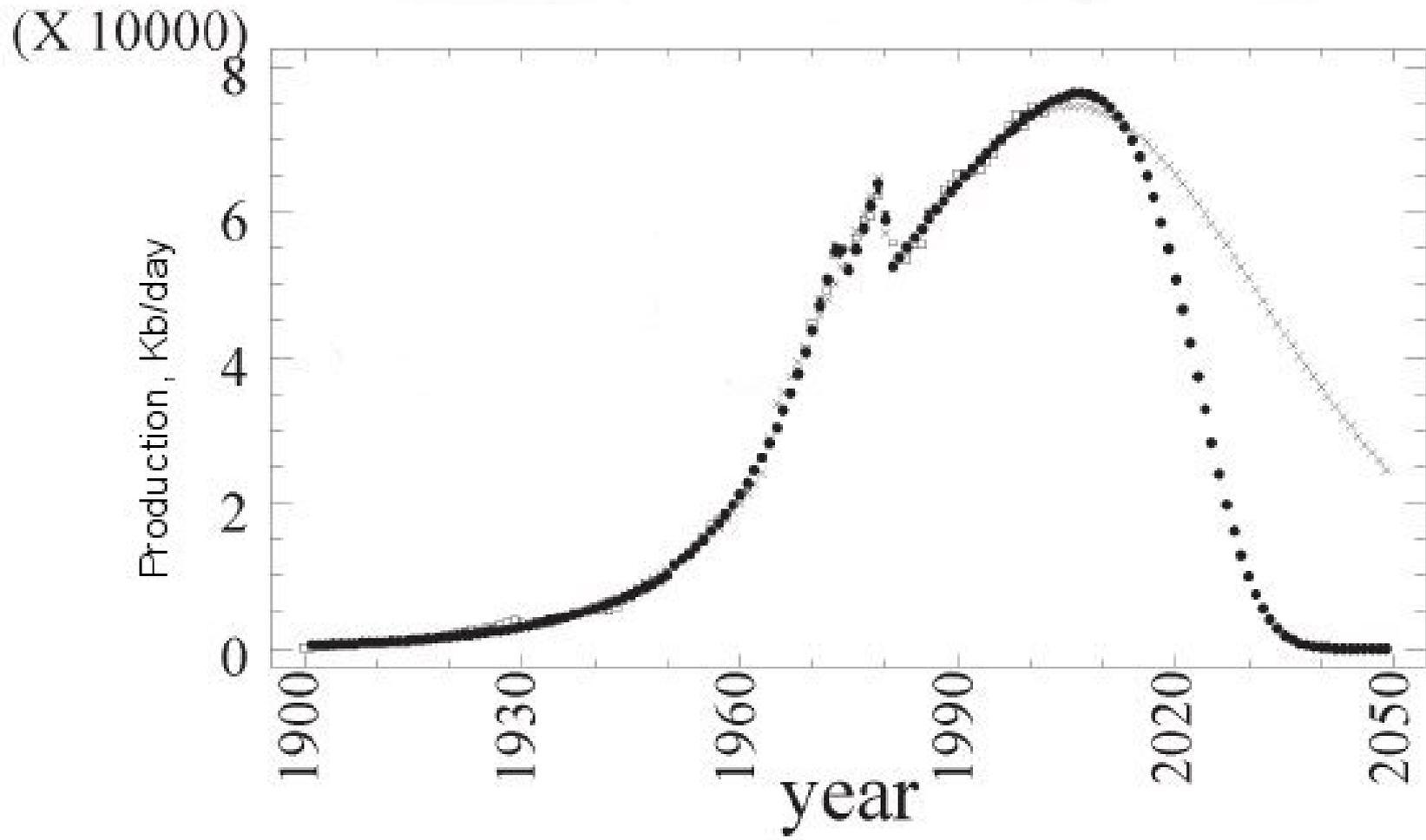




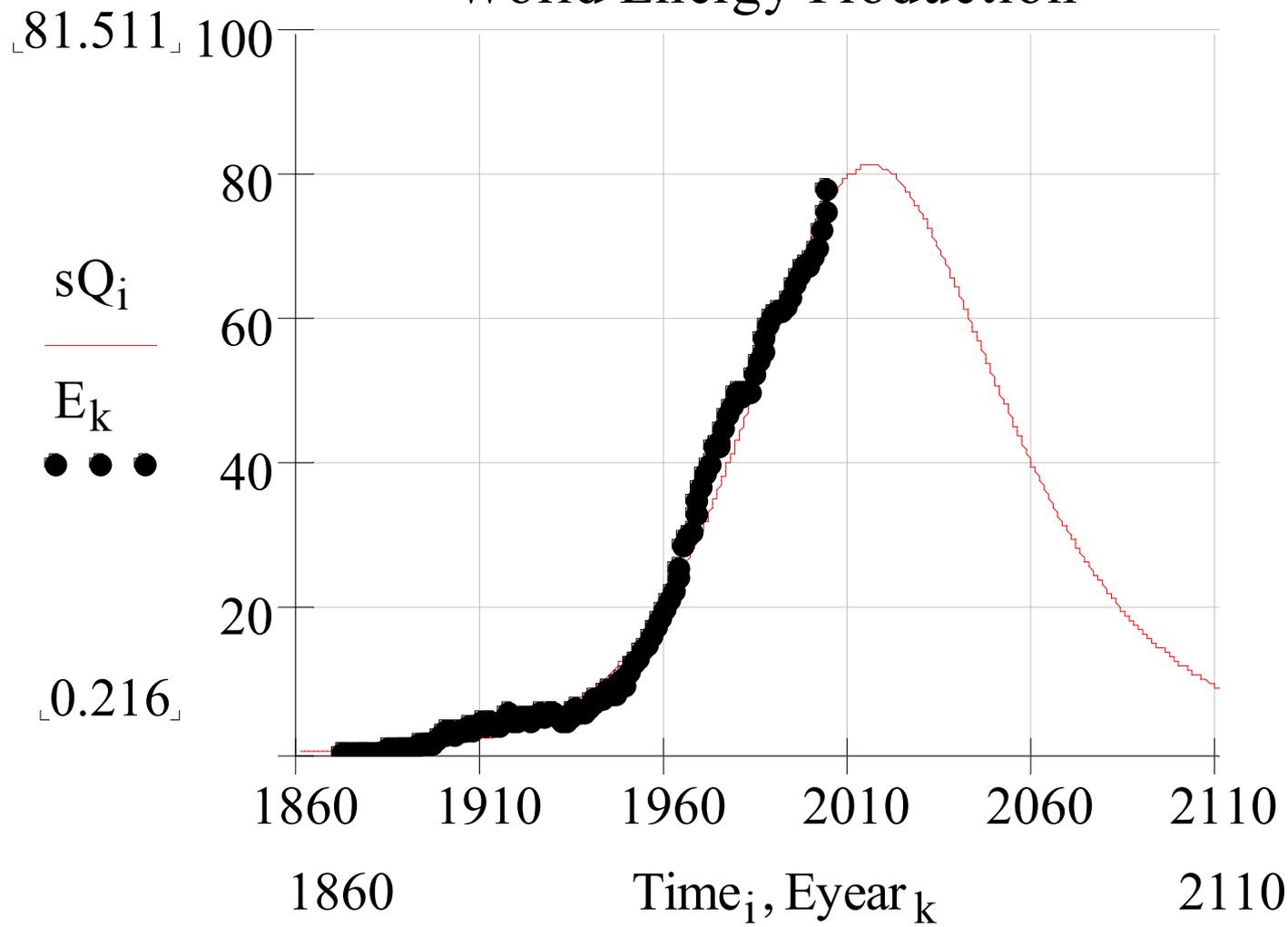
## Produzione *annua* mondiale di rame



# Generalized Bass Model



# World Energy Production



$sQ_i$

$E_k$

0.216

81.511

100

1860

1910

1960

2010

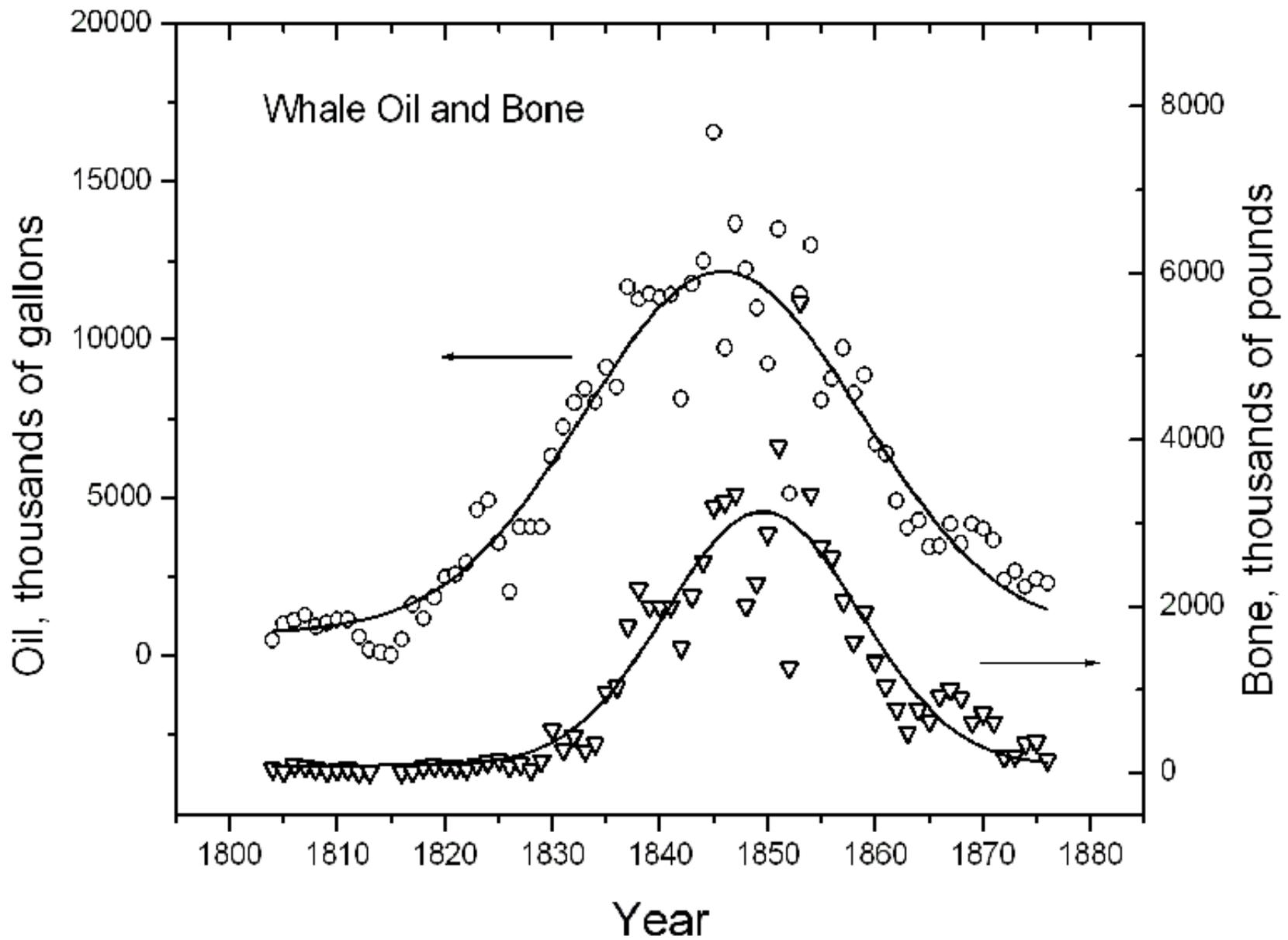
2060

2110

1860

Time<sub>i</sub>, Eyear<sub>k</sub>

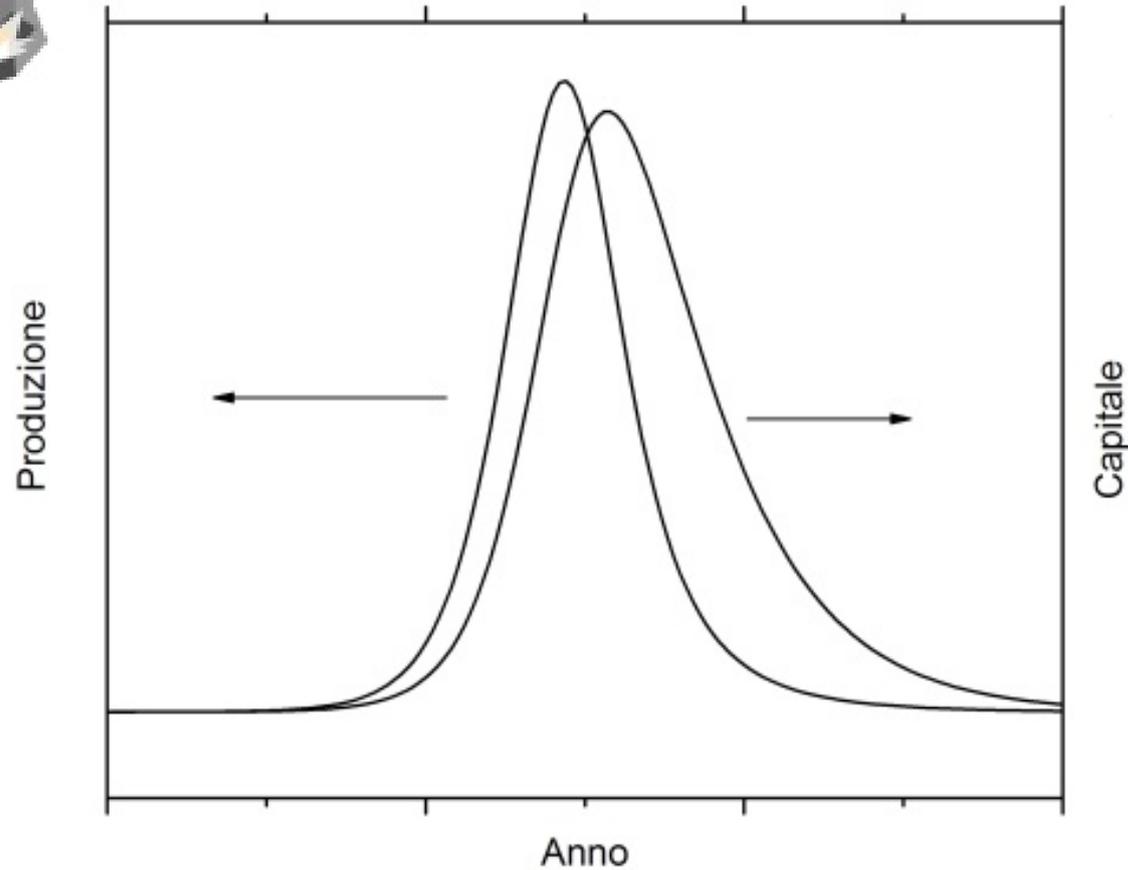
2110



# Dynamic Modelling



$$p = -k_1 CR$$
$$g = k_2 CR - k_3 C$$



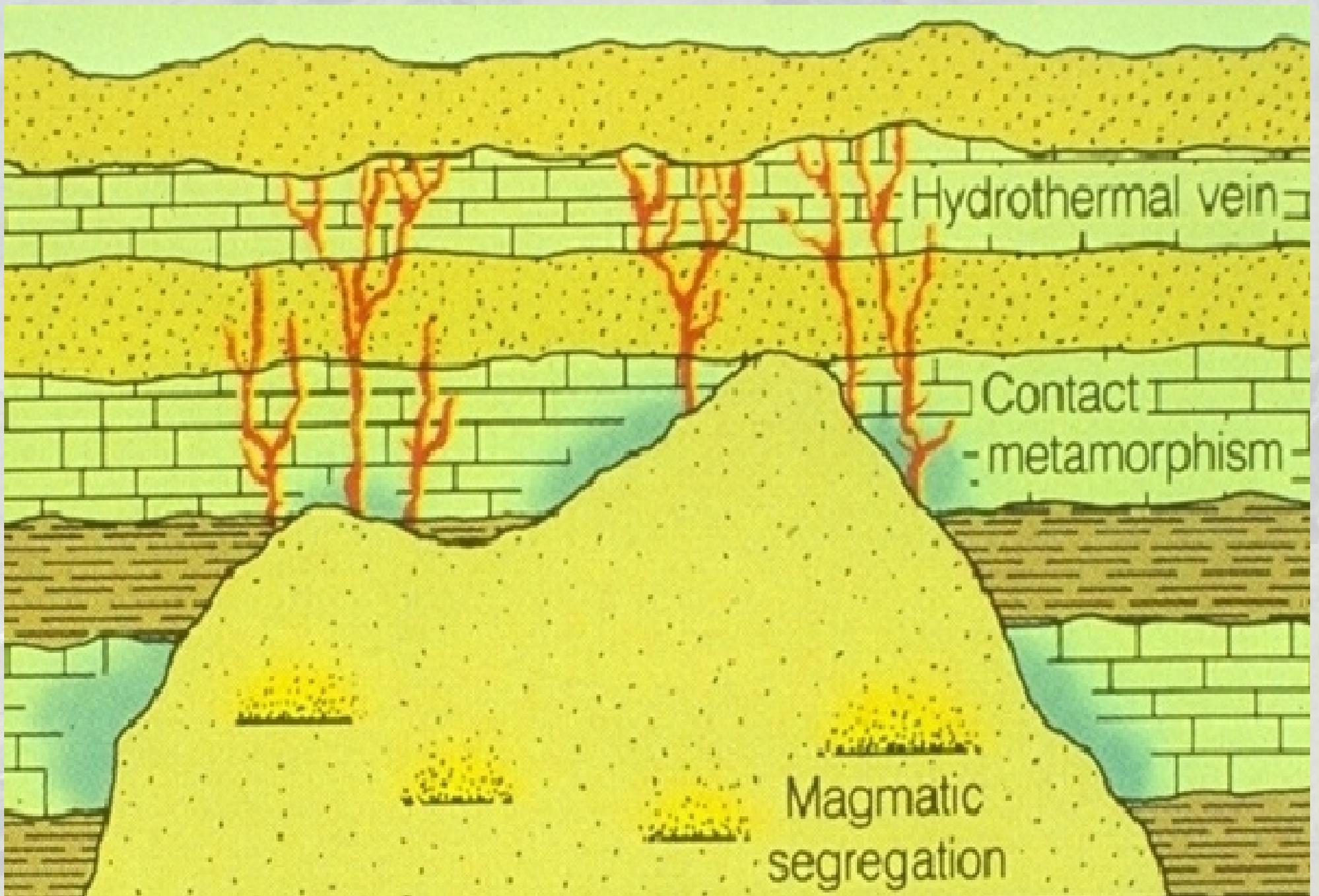
## Prigogine's principle of minimum entropy's production

$$dS = dS_e + dS_i$$

$$P = \frac{dS_i}{dt} = \int \sigma dV \geq 0$$

$dP/dt < 0$  away from steady-state

$dP/dt = 0$  at a steady state.



Formation of copper deposits

Mineral	Peak year (logistic)	URR (tons) from logistic fitting	URR (tons) from USGS: reserves + cumulative production up to 2006
Mercury	1962	$(5.8 \pm 0.4) \cdot 10^5$	$5.9 \cdot 10^5$
Tellurium	1984	$(1.0 \pm 0.4) \cdot 10^4$	$2.8 \cdot 10^4$
Lead	1986	$(3.3 \pm 0.2) \cdot 10^8$	$2.9 \cdot 10^8$
Cadmium	1989	$(1.33 \pm 0.09) \cdot 10^6$	$1.5 \cdot 10^6$
Potash	1989	$(1.54 \pm 0.09) \cdot 10^9$	$9.5 \cdot 10^9$
Phosphate rock	1989	$(8.1 \pm 0.4) \cdot 10^9$	$2.4 \cdot 10^{10}$
Thallium	1995	$(4.7 \pm 0.3) \cdot 10^2$	$7.6 \cdot 10^2$
Selenium	1994	$(1.1 \pm 0.14) \cdot 10^5$	$1.6 \cdot 10^5$
Zirconium minerals concentrates	1994	$(3.9 \pm 0.25) \cdot 10^7$	$6.7 \cdot 10^7$
Rhenium	1998	$(1.0 \pm 0.3) \cdot 10^3$	$3.3 \cdot 10^3$
Gallium	2002	$(2.5 \pm 0.5) \cdot 10^3$	$1.65 \cdot 10^4$ (?)

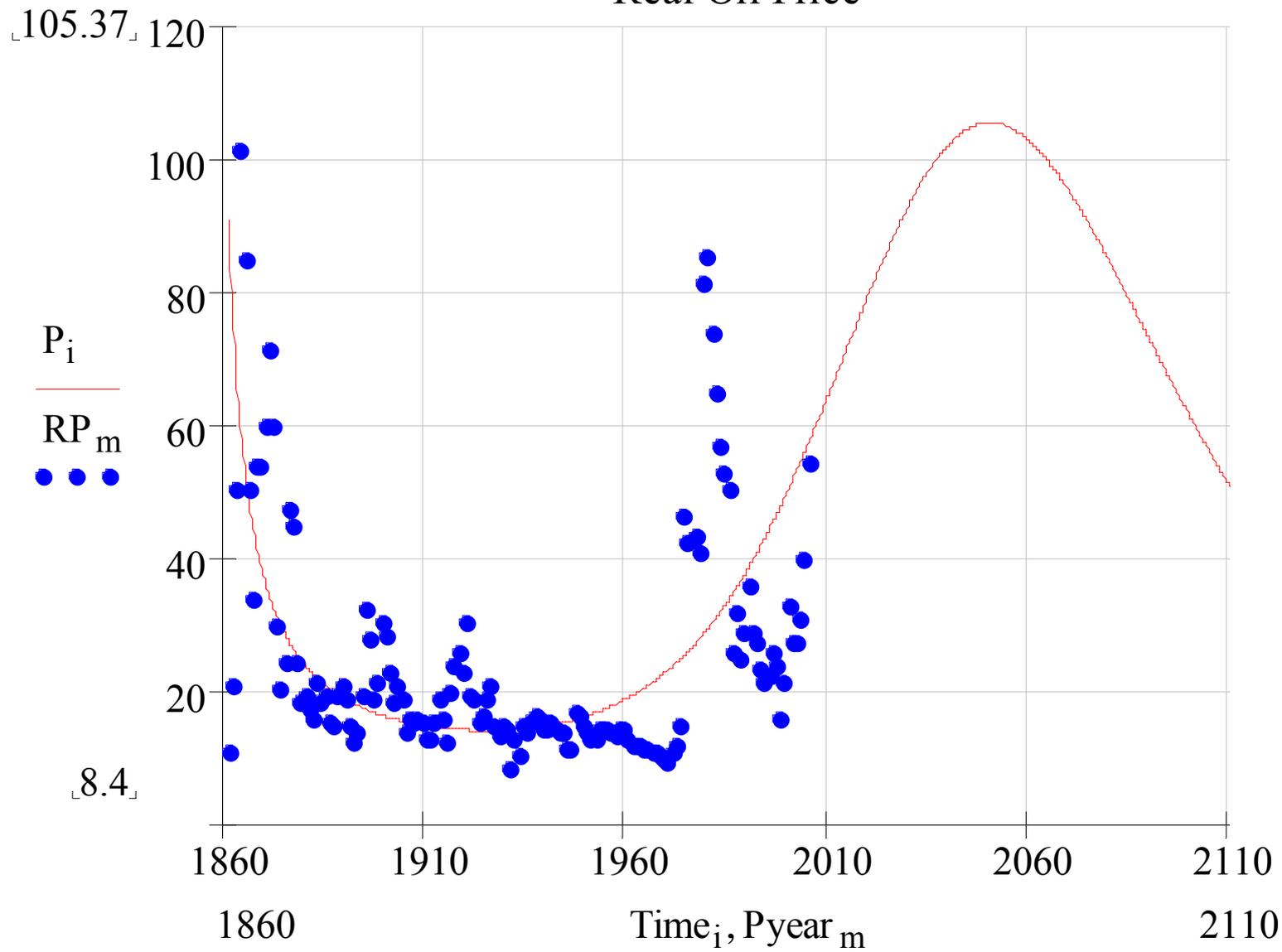


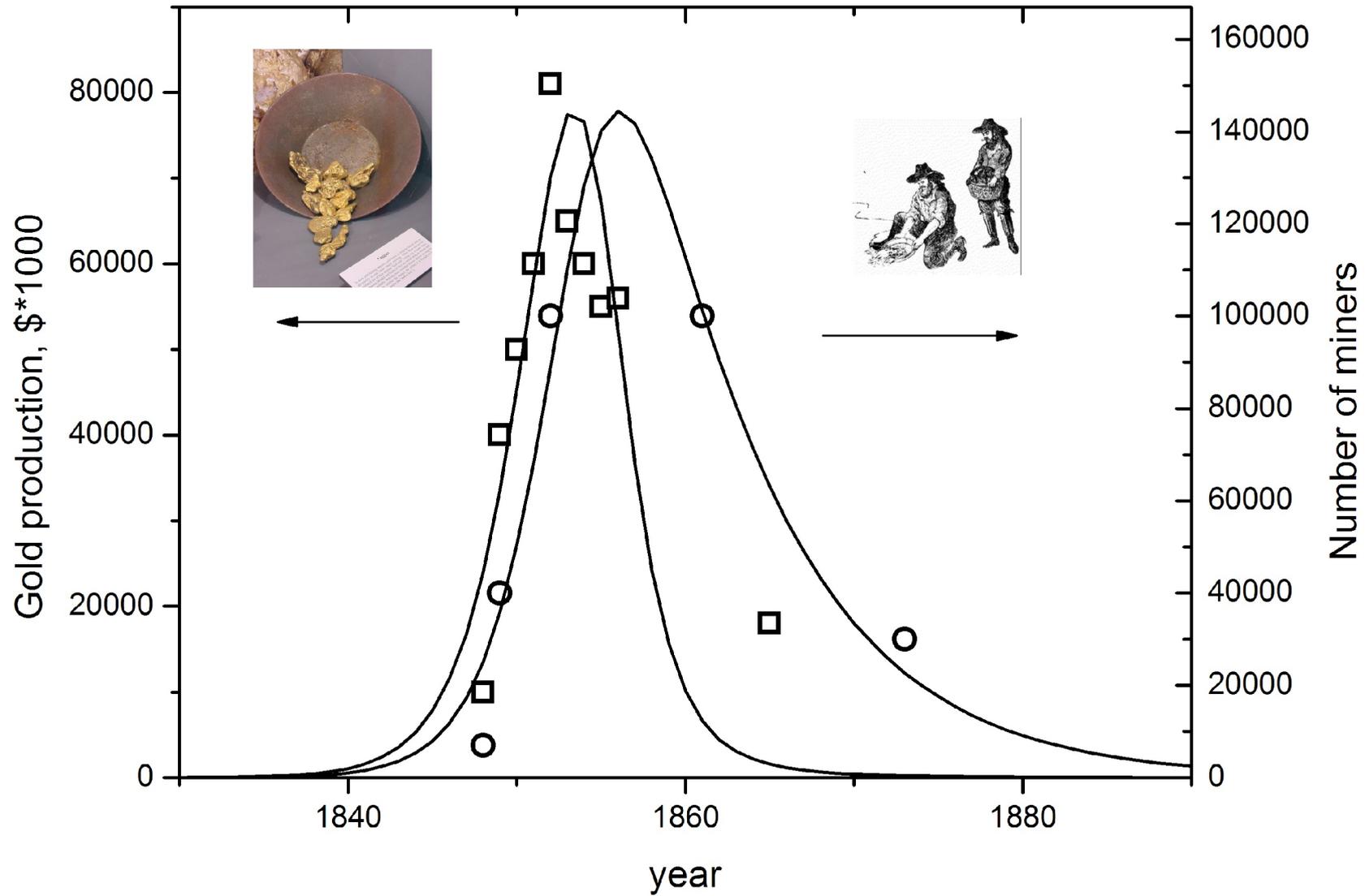
[www.aspoitalia.net](http://www.aspoitalia.net)

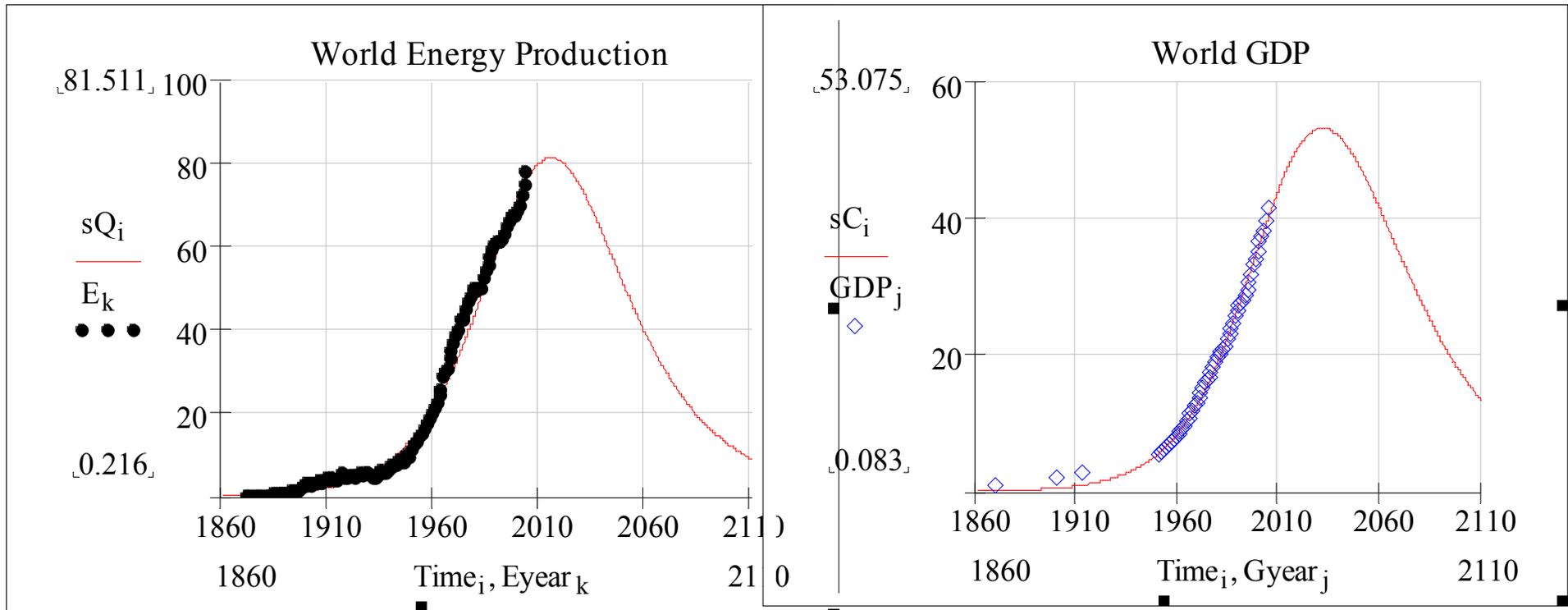
[www.peakoil.net](http://www.peakoil.net)



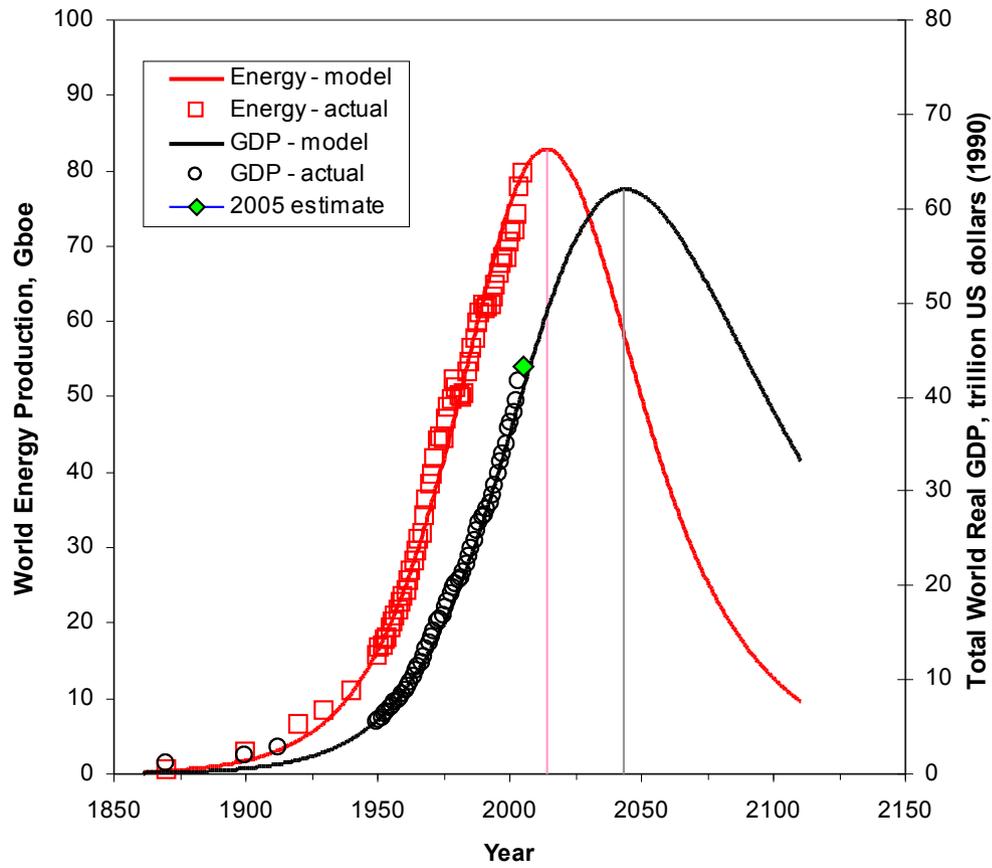
# Real Oil Price



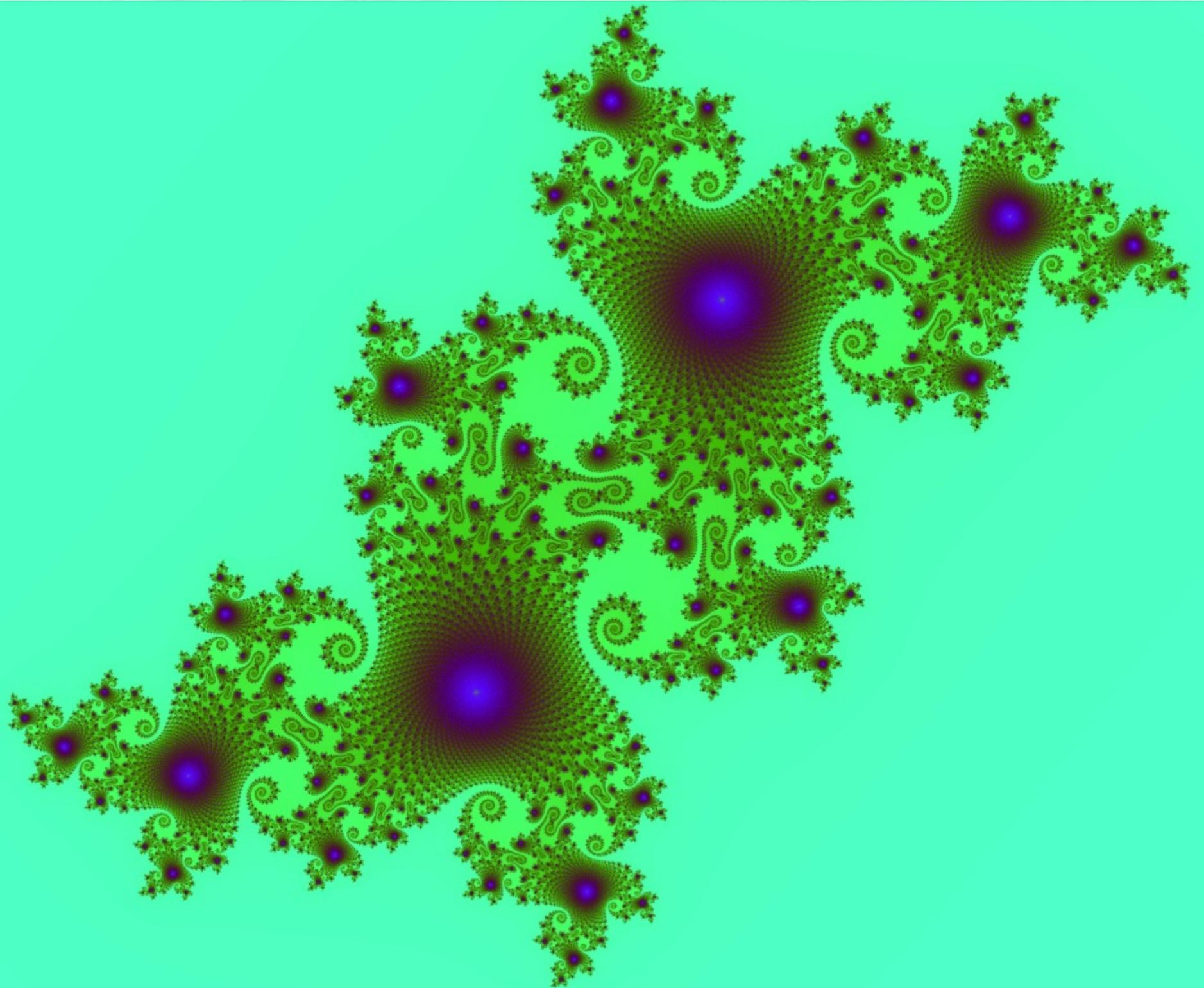




# LV Model - Total World Energy



- Total World Energy Production Peak  $\pm$  2014
- Total World GDP Peak  $\pm$  2044





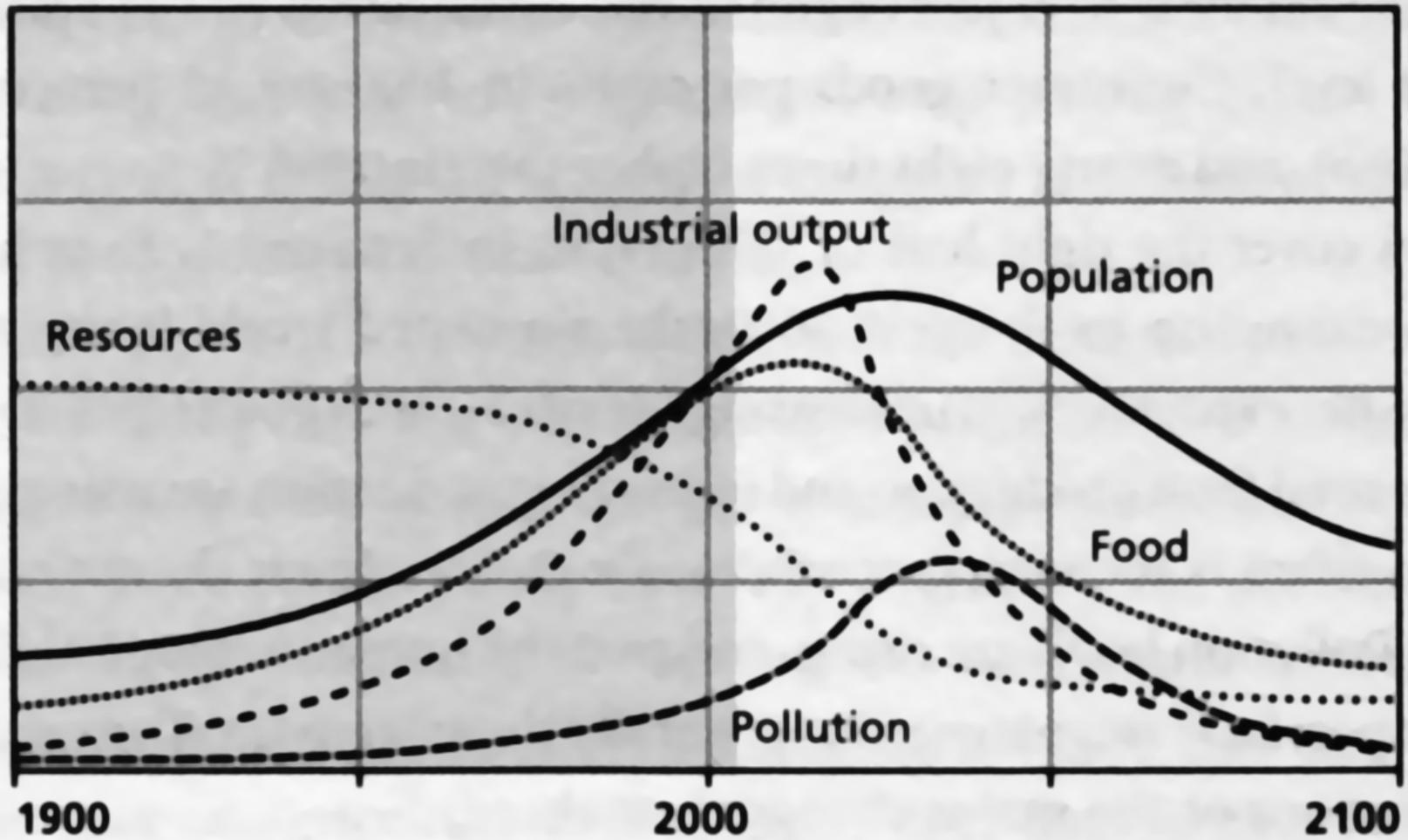
Name	Count	Armies	Cards
Egyptian Alliance	28	73	0
Parthian Empire	15	46	0
Goths and Huns	8	34	0
Germanic Tribes	5	33	0
Roman Empire	27	78	0
Peasants	41	69	0

# ROMAN EMPIRE

SAHARA DESERT

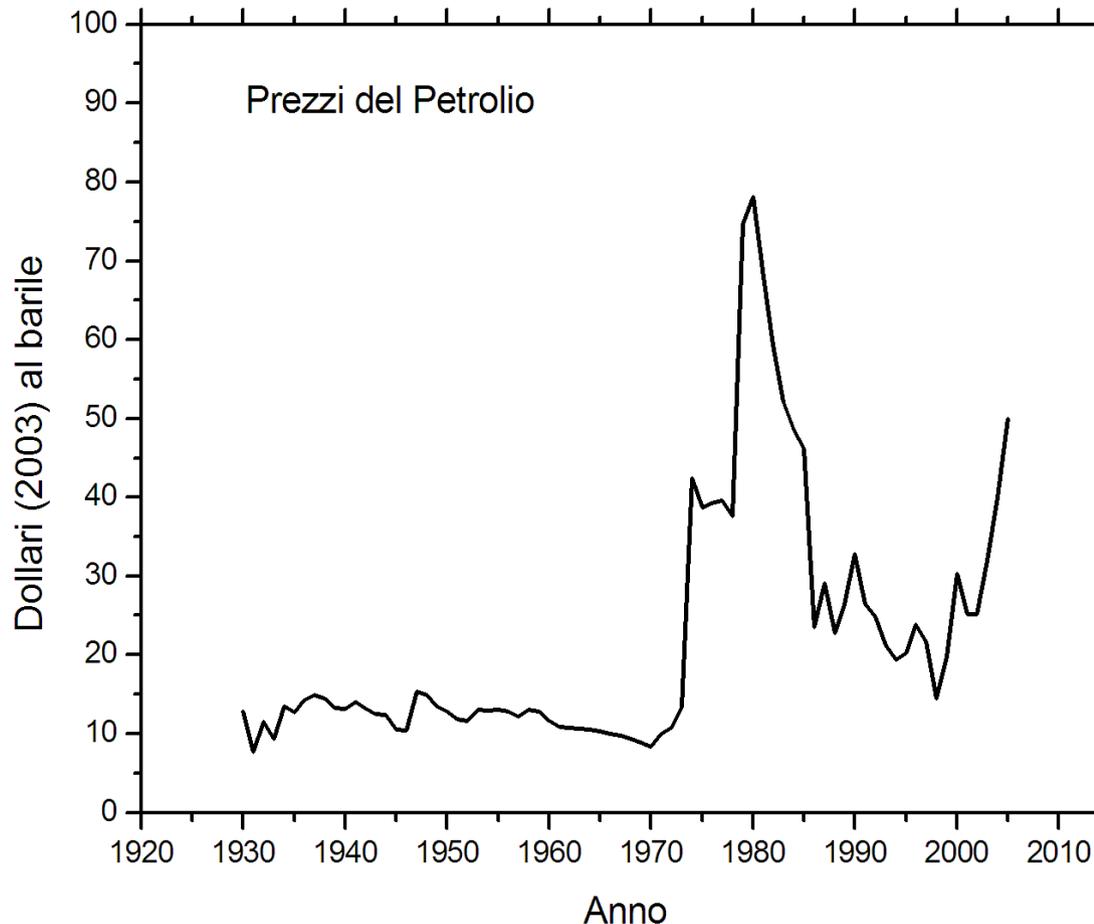
ARABIAN DESERT

# State of the World





# Gli Aumenti dei Prezzi segnalano il Picco



Gli aumenti del prezzo del petrolio segnalano una carenza di produzione. Negli anni delle grandi crisi (1974-1979) questa carenza era temporanea ed era dovuta alla mancanza di infrastrutture per il trasporto di petrolio dai pozzi del Medio Oriente. Oggi, si ritiene comunemente che la carenza sia definitiva: non ci sono nuovi giacimenti da sfruttare e per il futuro non possiamo che aspettarci ulteriori aumenti.