



Limits to Growth at 50 years: Brief history and present implications

CHARLES A. S. HALL

PROFESSOR EMERITUS

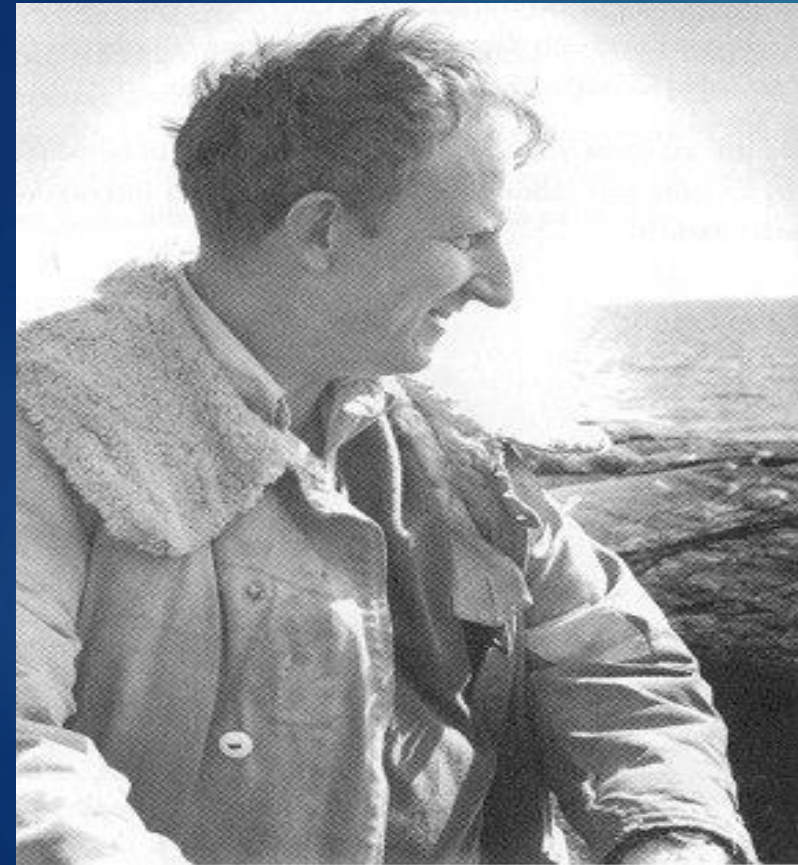
STATE UNIVERSITY OF NEW YORK

COLLEGE OF ENVIRONMENTAL SCIENCE AND FORESTRY

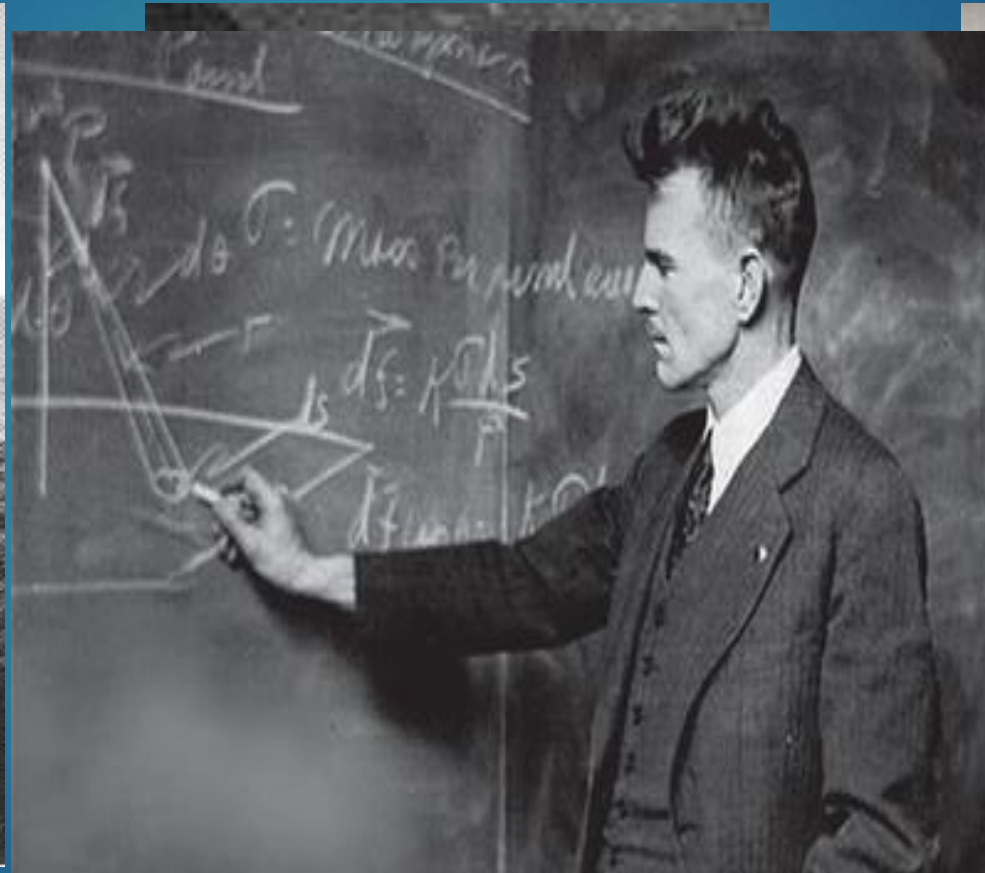
I. History



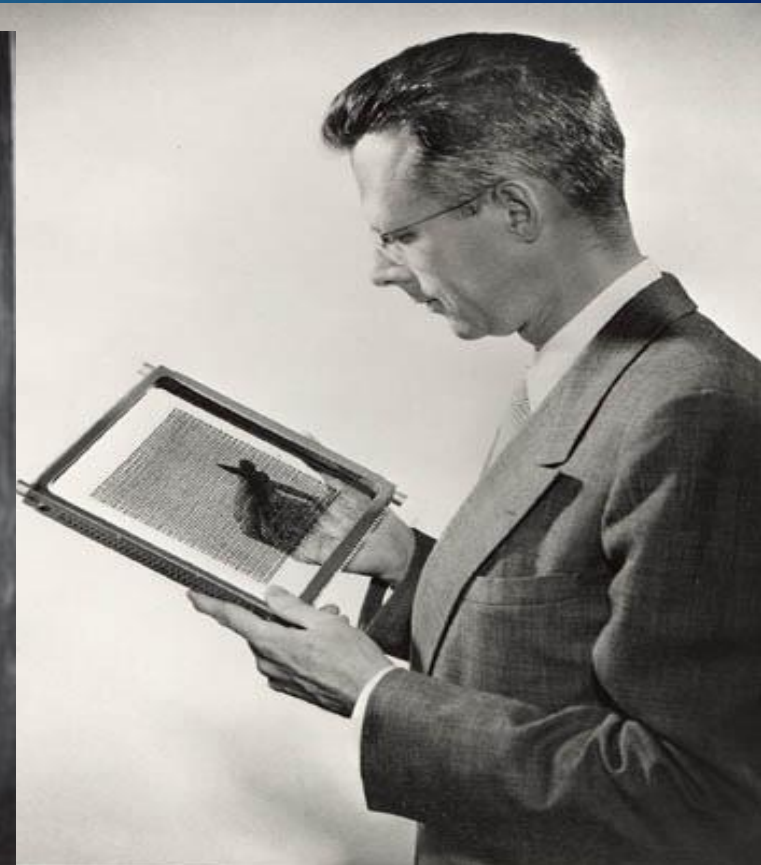
My major influences during graduate school/PostDoc



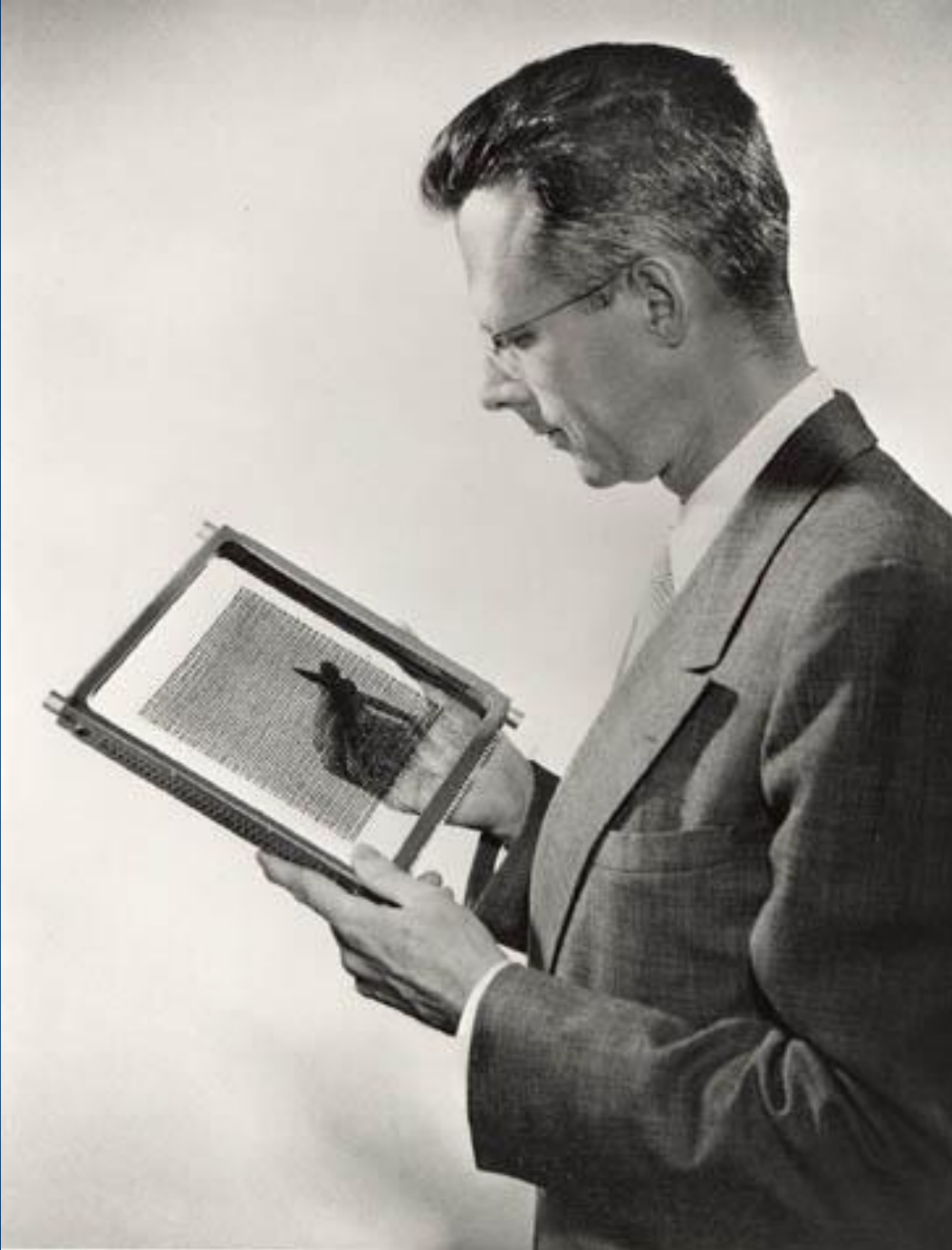
H. T. Odum



M. King Hubbert



Jay Forrester



Jay Forrester

Inventor of:
RAM,
Systems Dynamics,
Limits to growth

“The counterintuitive
behavior of social
systems”
(Technology Review
1971)

El libro fue comisionado por el [Club de Roma](#) y escrito por [Donella H. Meadows](#), [Dennis L. Meadows](#), [Jorgen Randers](#), and [William W. Behrens III](#).



Donella H. Meadows



Dennis L. Meadows



Jorgen Randers

THE LIMITS TO growth

Donella H. Meadows

Dennis L. Meadows

Jørgen Randers

William W. Behrens III

*A Report for THE CLUB OF ROME'S Project on the
Predicament of Mankind*



A POTOMAC ASSOCIATES BOOK

\$ 2.75

Forrester turned the project over to his grad students and Donella Meadows, post doc at Harvard

- ▶ What, basically, does the LtG model say?
- ▶ Let's call a spade a spade

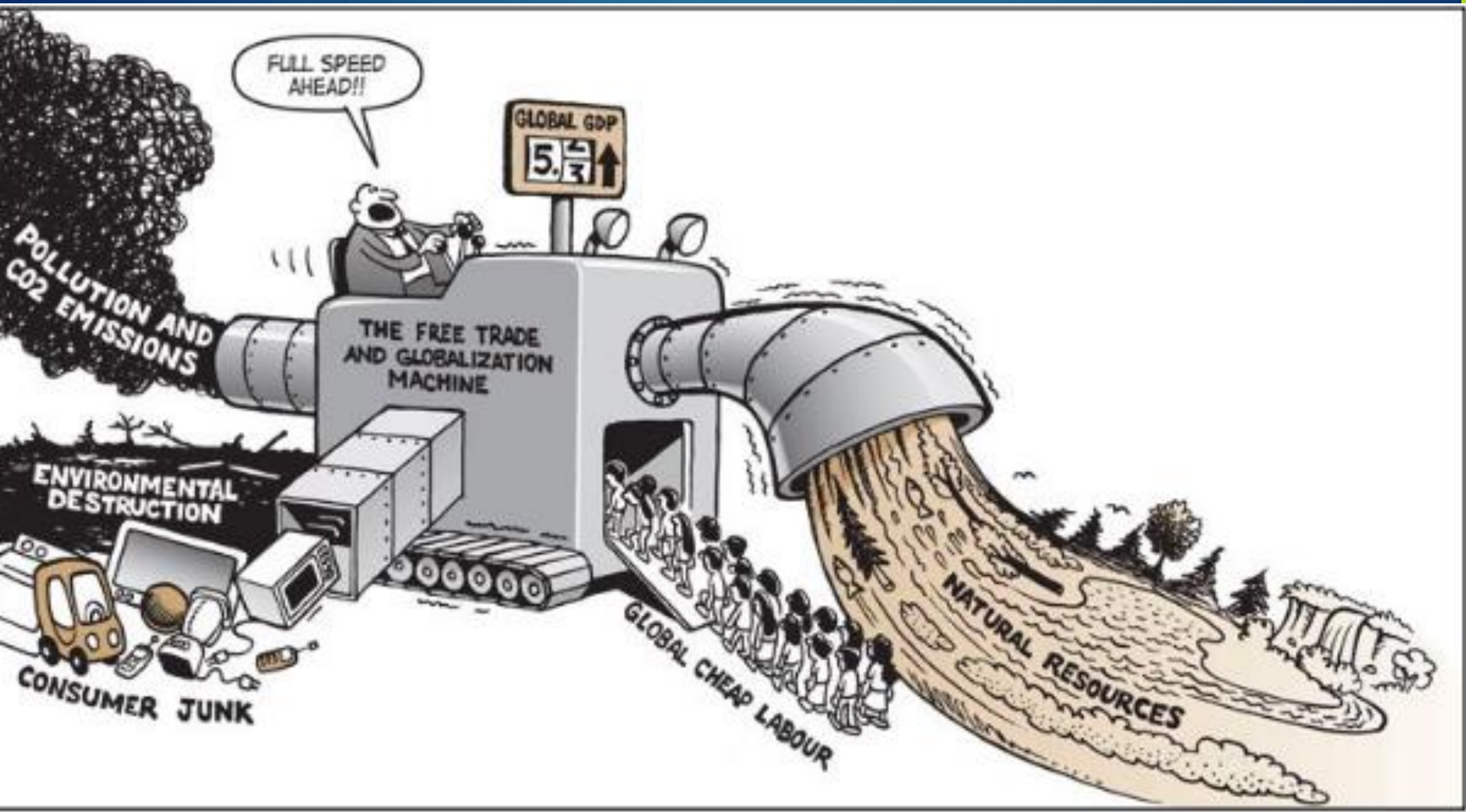
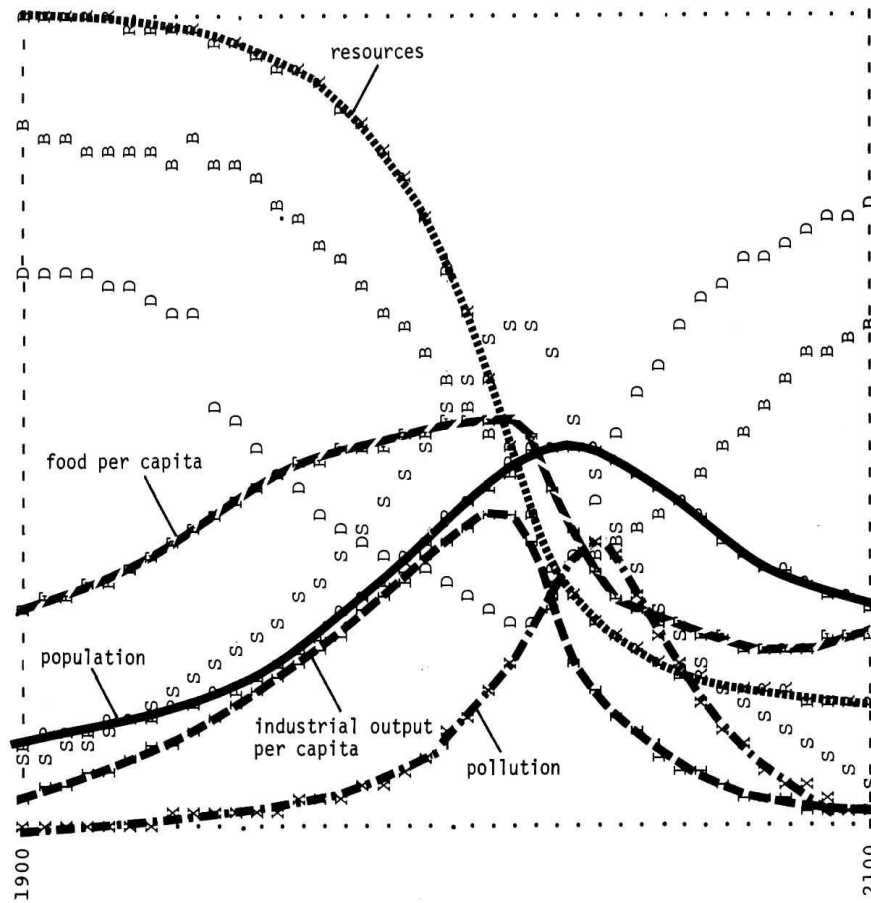


Figure 35 WORLD MODEL STANDARD RUN



The "standard" world model run assumes no major change in the physical, economic, or social relationships that have historically governed the development of the world system. All variables plotted here follow historical values from 1900 to 1970. Food, industrial output, and population grow exponentially until the rapidly diminishing resource base forces a slowdown in industrial growth. Because of natural delays in the system, both popu-

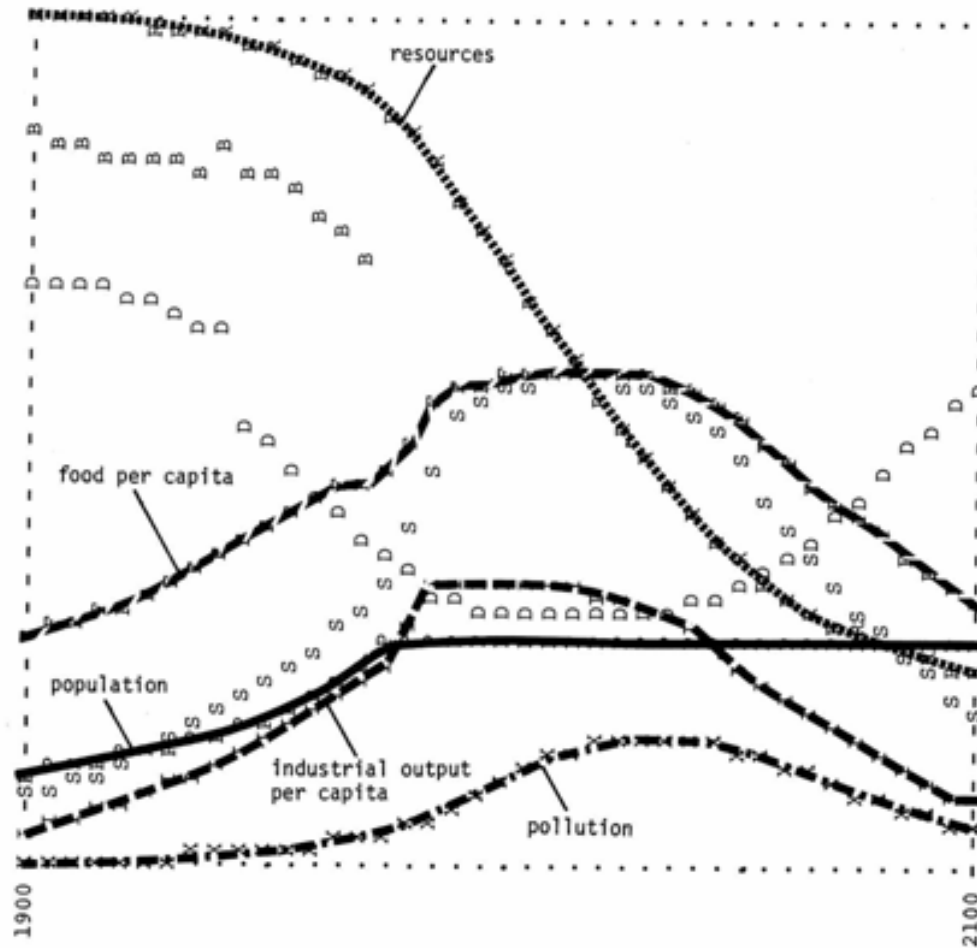
The model showed violent changes in the conditions of humanity

Many variants of the model were
tried to seek a “sustainable” future




THE STATE OF GLOBAL EQUILIBRIUM

Figure 45 WORLD MODEL WITH STABILIZED POPULATION AND CAPITAL





The only way to stabilize the model was to stabilize population and reduce/eliminate investment beyond covering depreciation!

- 
- ▶ Then came the oil price shocks of the 1970's
 - ▶ The price of oil went up (twice) from \$3.50 a barrel to \$3.50 a gallon in today's prices ...
 - ▶ There were huge, previously unseen economic problems... “stagflation” etc.
 - ▶ The LtG models seemed to be validated....

II. THE NEGATION

- ▶ The mainstream economists did not like any of this
- ▶ They found three torpedoes:
 - ▶ 1) Economists' arguments
 - ▶ 2) Paul Ehrlich's stupid bet
 - ▶ 3) The price of oil receded

- 
- ▶ Many economists HATED the limits to growth study
 - ▶ They believed in “technology”, “That spark of human ingenuity”
 - ▶ It is a fundamental issue: are humans constrained by nature’s laws and properties?



“ A close look by economists has led many competent independent analysts to conclude that the underlying assumptions are pure fantasy”

“...did not refer to a single scientific study ... There is a clear possibility that the development of nuclear fusion will open up a vast and perhaps enormously cheap source of power ...”

“There are no inventions .. Output per unit input has been rising between one and one half and three percent (Denison)... “

15. Leonard M. Ross/ Peter Passell

Professors Leonard M. Ross and Peter Passell were interviewed simultaneously since they coauthored (with Marc Roberts, another Columbia University economics professor) a devastating critique of *Limits to Growth*, as well as Jay W. Forrester's two books, *World Dynamics* and *Urban Dynamics*, in the April 2, 1972, New York Times Book Review.

Leonard M. Ross was born in Los Angeles, California, in 1945. Both he and his colleague Peter Passell studied at Yale University in New Haven, Connecticut. Ross went to Yale Law School, while his friend Passell got a Ph.D. in economics at Yale in 1970. Professor Ross is completing his economics degree at Yale as well. They both teach at Columbia University. Together they recently published *Affluence and Its Enemies*, The Viking Press (New York, 1973).

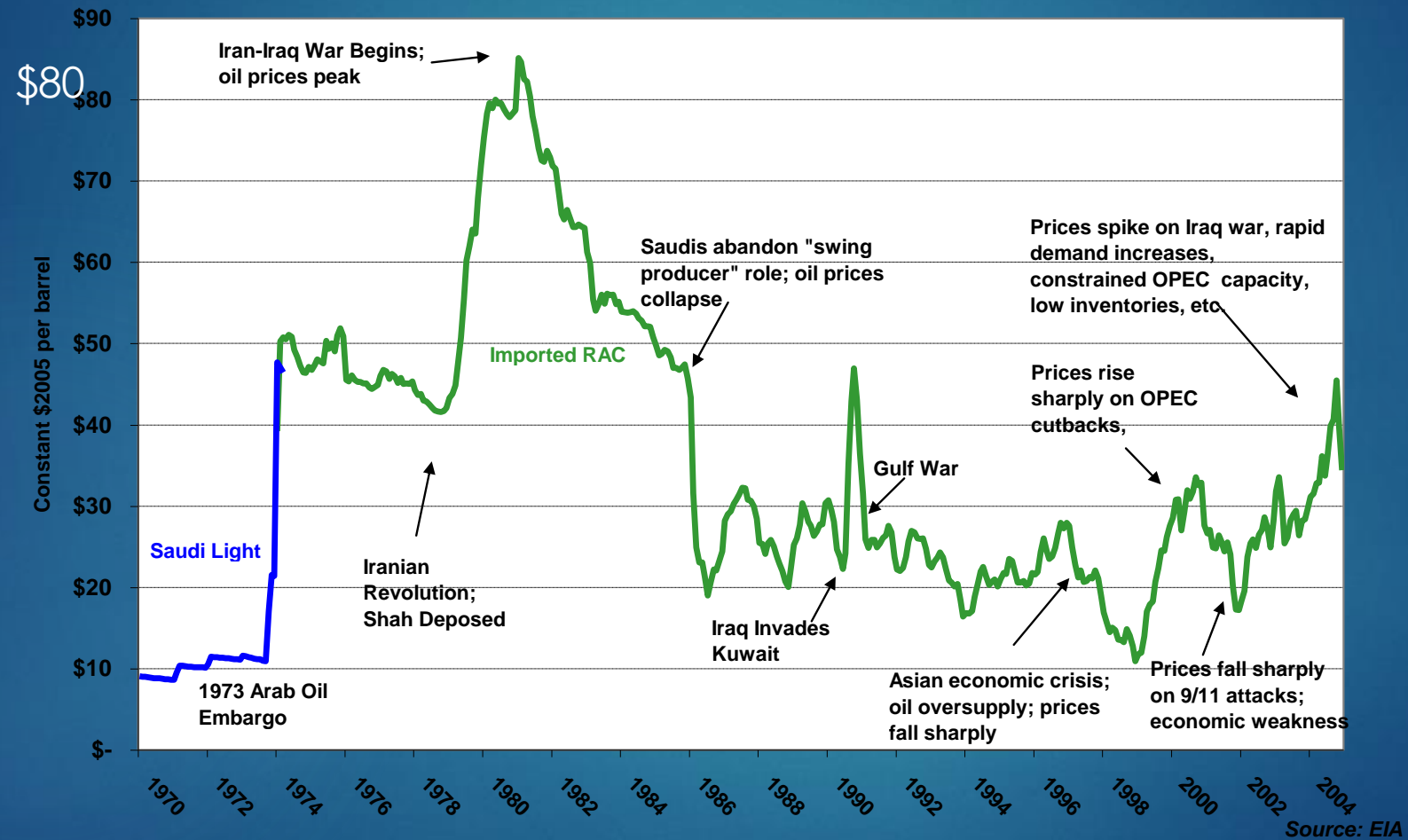
Professor Ross, you have been one of the critics of Limits to Growth, in the New York Times, for instance.

Professor Ross: Our basic feeling was that it was a bold and ambitious attempt but one with very negative consequences. We thought it so far

The price of oil receded

Major Events and Real World Oil Prices, 1970-2005

(Prices adjusted by CPI for all Urban Consumers, 2005)



► Paul Ehrlich's (one of my heroes) stupid bet

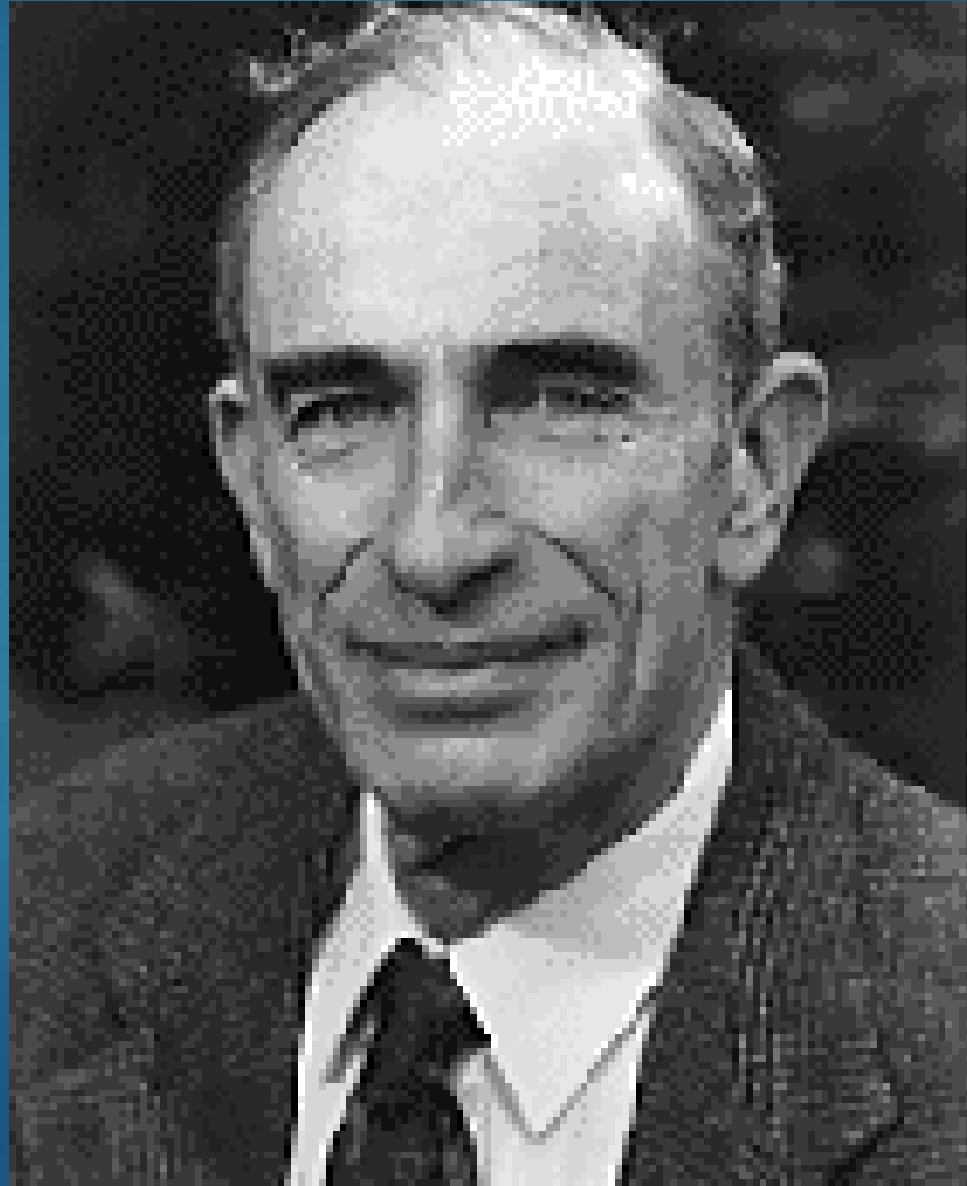
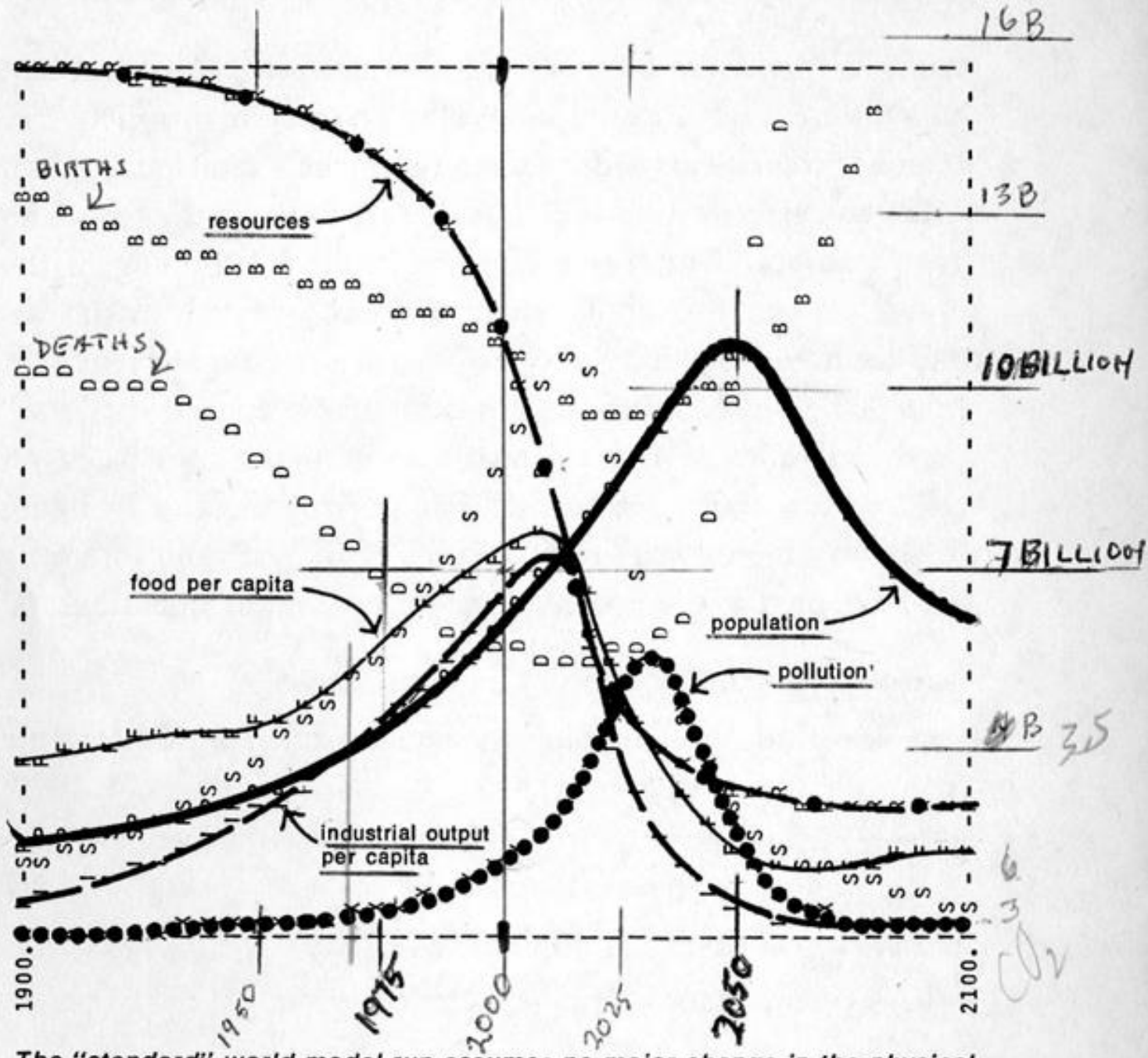


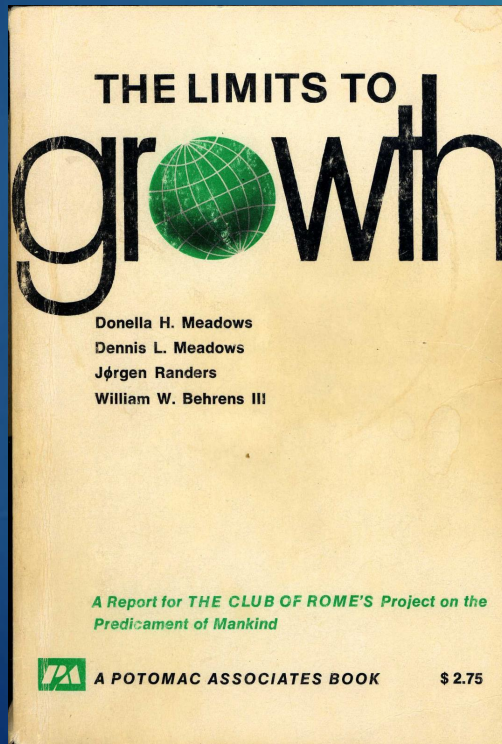
Figure 35 WORLD MODEL STANDARD RUN




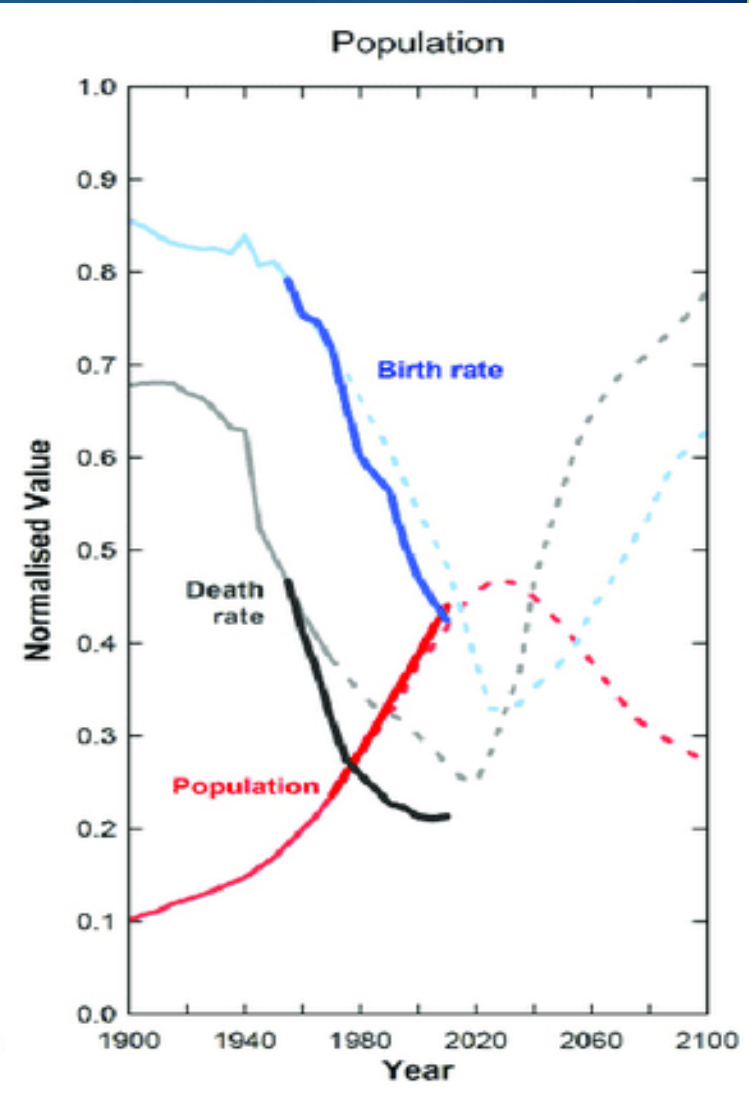
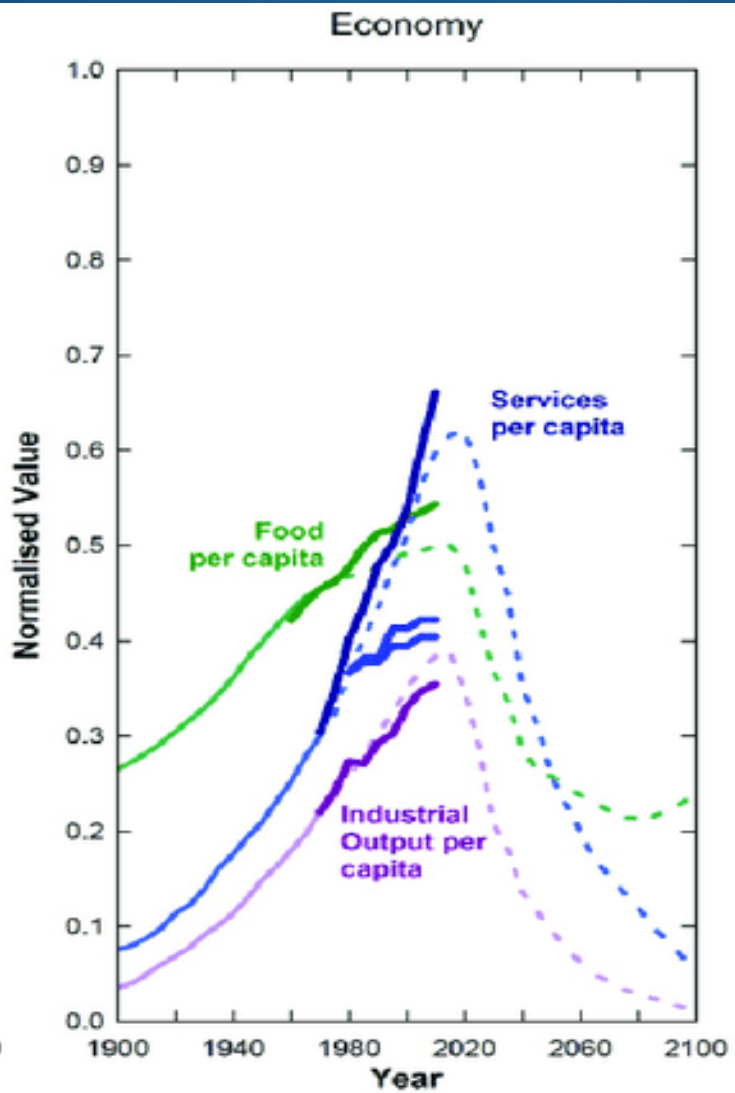
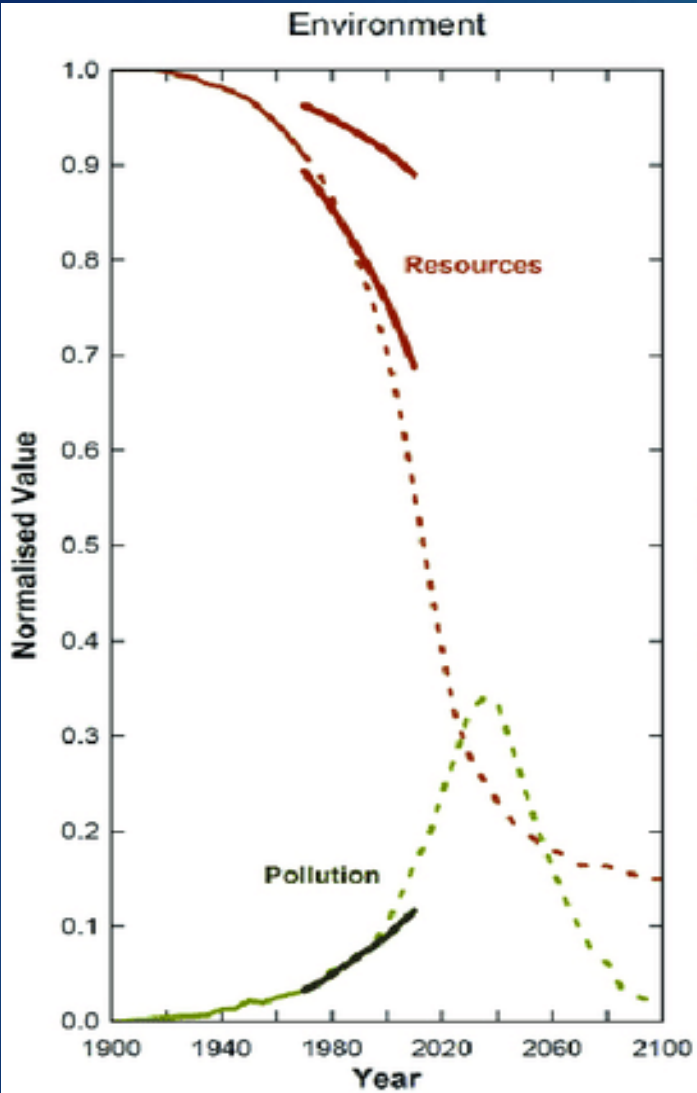
The model was often misunderstood as an explicit predictor and the technology of the time did not allow the labeling of the time intervals

III. WAS THE MODEL WRONG?

Present state of the LtG “Predictions”



- 
- ▶ The output graphs produced from the World3 model are predictive “only in the most limited sense of the word. These graphs are not exact predictions of the values of the variables at any particular year in the future. They are indications of the system’s behavioural tendencies only.” (Meadows et al., 1972, pp. 92–93)..
 - ▶ **Nevertheless** they have hardly been demonstrated incorrect... quite the contrary.
 - ▶ what economic model is still “correct” 50 years later?



A comparison of The Limits to Growth with 30 years of reality Graham M. Turner
 CSIRO Sustainable Ecosystems, Global Environmental Change 18 (2008) 397–411

IV. Shift gears: my personal story

... HAS BEEN DEVOTED TO TRYING TO
UNDERSTAND HOW ENERGY WORKS IN
NATURAL SYSTEMS AND (LATER) SOCIETY



Systems ecologist Howard Odum was my PhD advisor at the University of North Carolina



I was
obsessed
with water,
fish,
ecology,
stuff like
that

New Hope
Creek



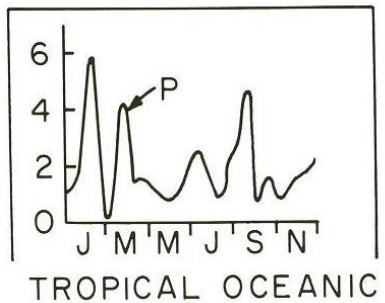
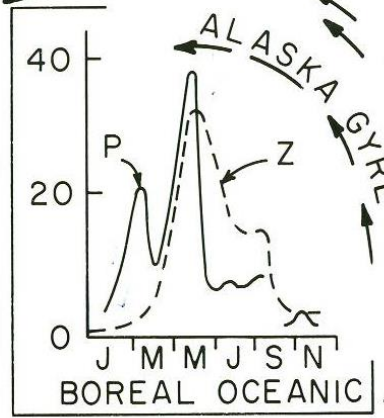
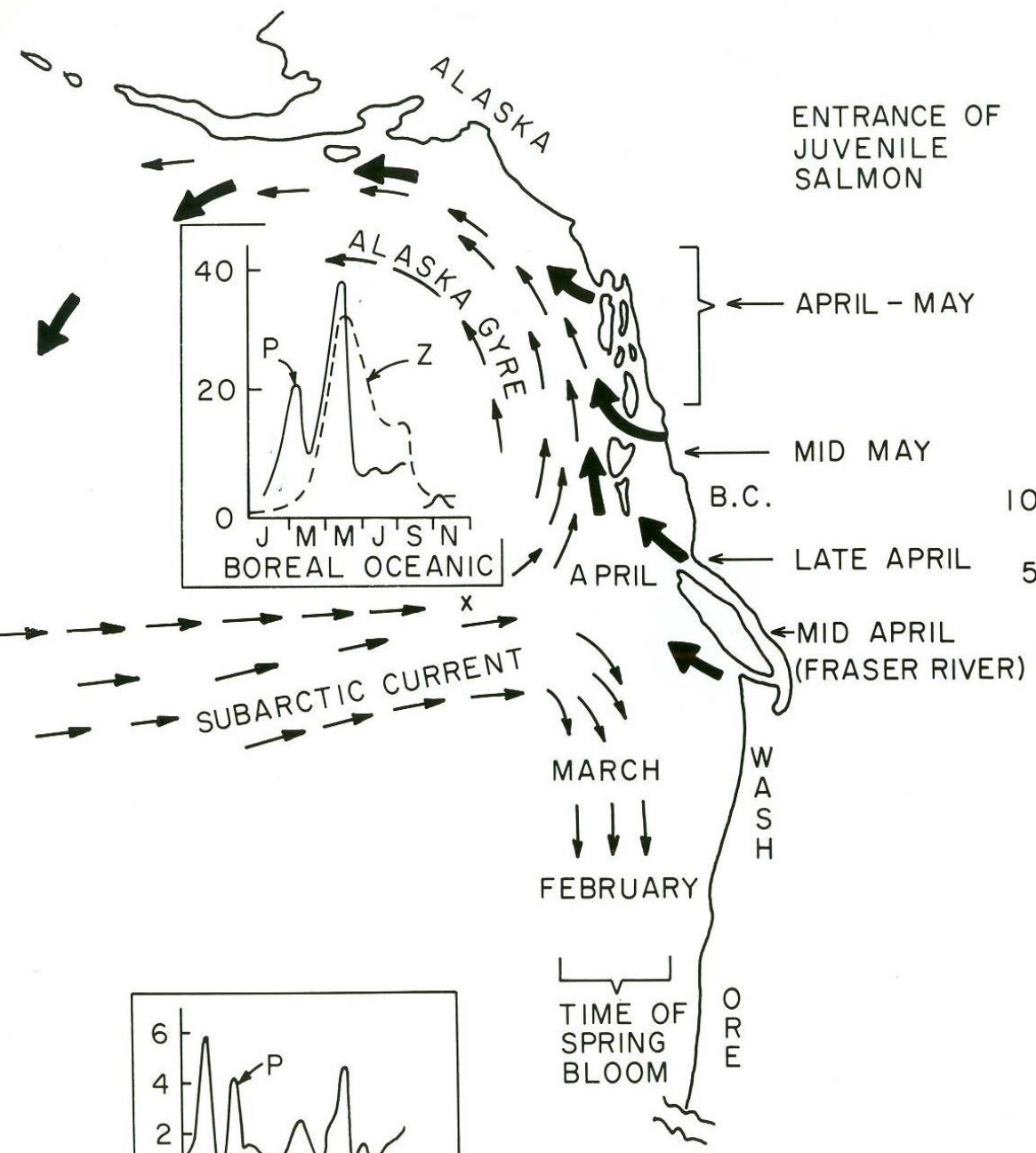
I devised
weirs and
traps to study
fish migration

During my dissertation work I came up with the idea of EROI

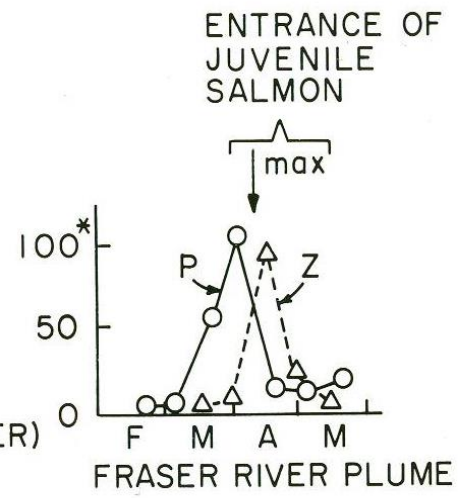
Energy return on investment for an activity:

$$\text{EROI} = \frac{\text{Energy delivered to society (or organism)}}{\text{Energy put into that activity}}$$

Usually consider energy invested *from society* (organism)



THE PATTERN FOR THE FRASER RIVER



LEGEND

—	PRIMARY PRODUCTION
—○—	ZOOPLANKTON STANDING CROP
—△—	OCEANIC CURRENTS
→	MOVEMENTS OF YOUNG SALMON

I spent years studying salmon migrations



Sockeye salmon that migrated came back much larger than their brothers and sisters that did not (foreground)

But energy in society kept gnawing at me ...

Howard Odum was just beginning to write on this....

From Odum I learned of the incredible importance of fossil fuel energy
Few environmentalists today know how to deal with this issue well

Why do we do so much on environment and so little on resources?

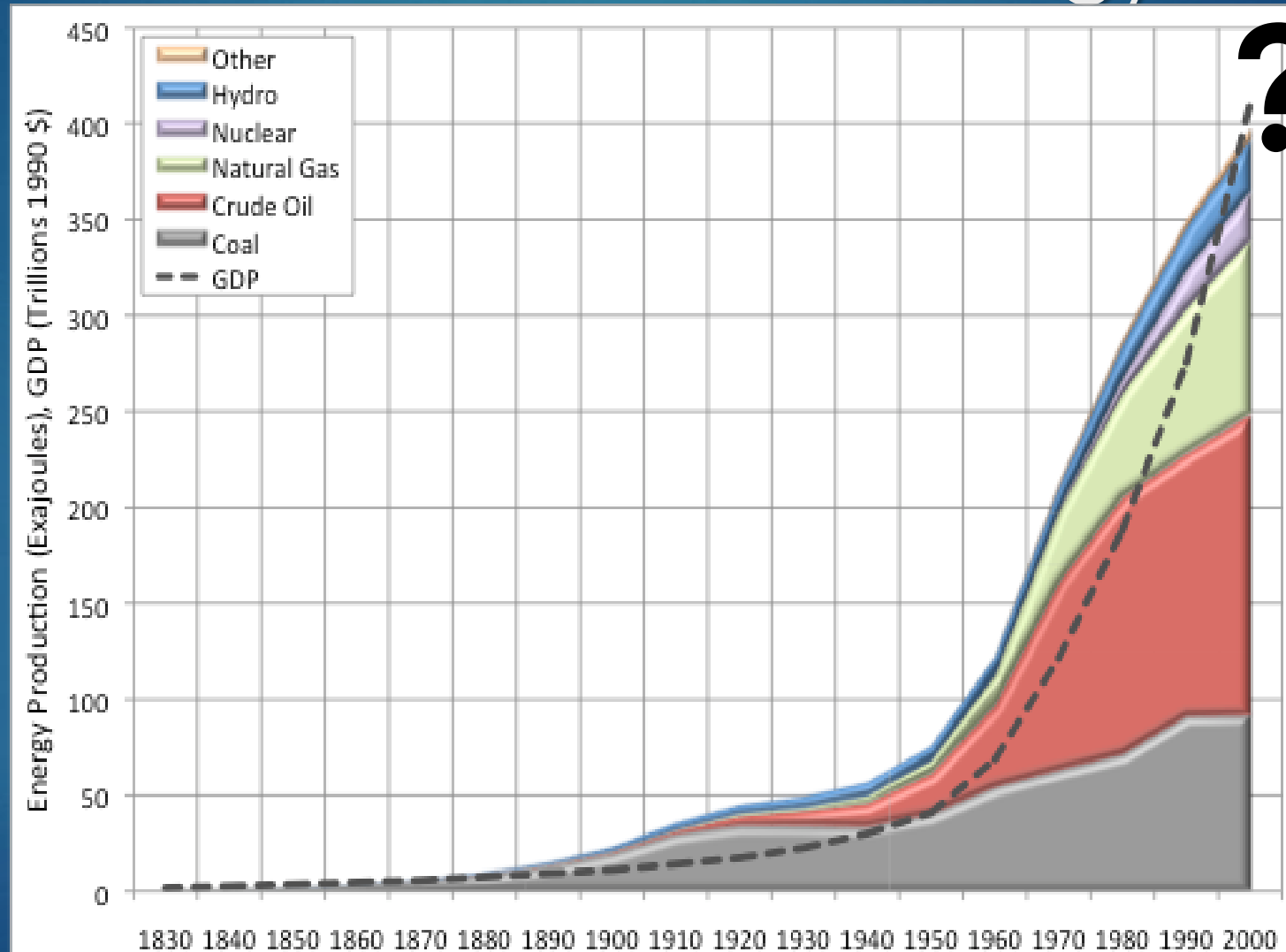


33 HP animal power (controlled by 5 workers plus
Land for feed, Human work, Water and soil, Stables

200 HP mechanical power (controlled by 1 worker)



The dirty secret to wealth production: Use more energy



Petroleum Drilling and Production in the United States: Yield per Effort and Net Energy Analysis

Abstract. For the past three decades the quantity of petroleum (both oil and oil plus gas) found per foot of drilling effort in the United States for any given year can be expressed as a secular decrease of about 2 percent per year combined with an inverse function of drilling effort for that year. Extrapolation of energy costs and gains from petroleum drilling and extraction indicates that drilling for domestic petroleum could cease to be a net source of energy by about 2004 at low drilling rates and by 2000 or sooner at high drilling rates, and that the net yield will be less at higher drilling rates.

Production and reserves of U.S. liquid and gaseous petroleum peaked in the early 1970's and generally have declined since then despite considerable increases in drilling effort. Continued increases in effort are likely in the near future because imports carry a heavy economic and political price and because recent increases in oil prices have given petroleum corporations considerable quantities of new working capital. But the Carter Administration and Congress have imposed a large "windfall profits tax" on petroleum corporations, which will decrease the capital available for additional exploratory effort. On the other hand, oil industry advertisements and some politicians have promised large new exploratory efforts and oil supplies if government decreases regulation and

Hall and Cleveland 1981

We applied EROI and
Yield per Effort (concepts
from fisheries) to oil

**Energy and the U.S. Economy:
A Biophysical Perspective**

Cutler J. Cleveland, Robert Costanza, Charles A. S. Hall, and Robert Kaufmann

We got
lots of
papers
into “The
best”
Journals

31 August 1984 • Vol. 225 • No. 4665

\$2.50

SCIENCE


AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE



I may be the only person ever to be denied tenure at an Ivy League University on the week I had the cover issue of Science!

IV. ENERGY WAS NOT CONSIDERED EXPLICITLY IN LtG

- ▶ I had always thought that “resources” applied to energy , but Dennis Meadows has told me recently that resources did not in their minds particularly mean energy, and that I had made useful contributions to the implications of LtG by analyzing energy explicitly


- 
- ▶ So my goal today is to add in what energy might mean for LtG today
 - ▶ 1) Universal resource – allows production of other resources and avoidance of pain
 - ▶ 2) Causes dependency
 - ▶ 3) Is finite: in both supplies and EROI

So, with respect to energy, what kind of a future do I envision?

I don't know!

There are many unknowns and many
degrees of freedom,

BUT,,,,,,



**We face six basic problems that
must be overcome if we are to
successfully navigate the future**

The first is climate change, which I will not discuss further

With the exception of climate change these issues are basically not considered by the “sustainability” community.

The second is depletion of our basic fossil fuels.

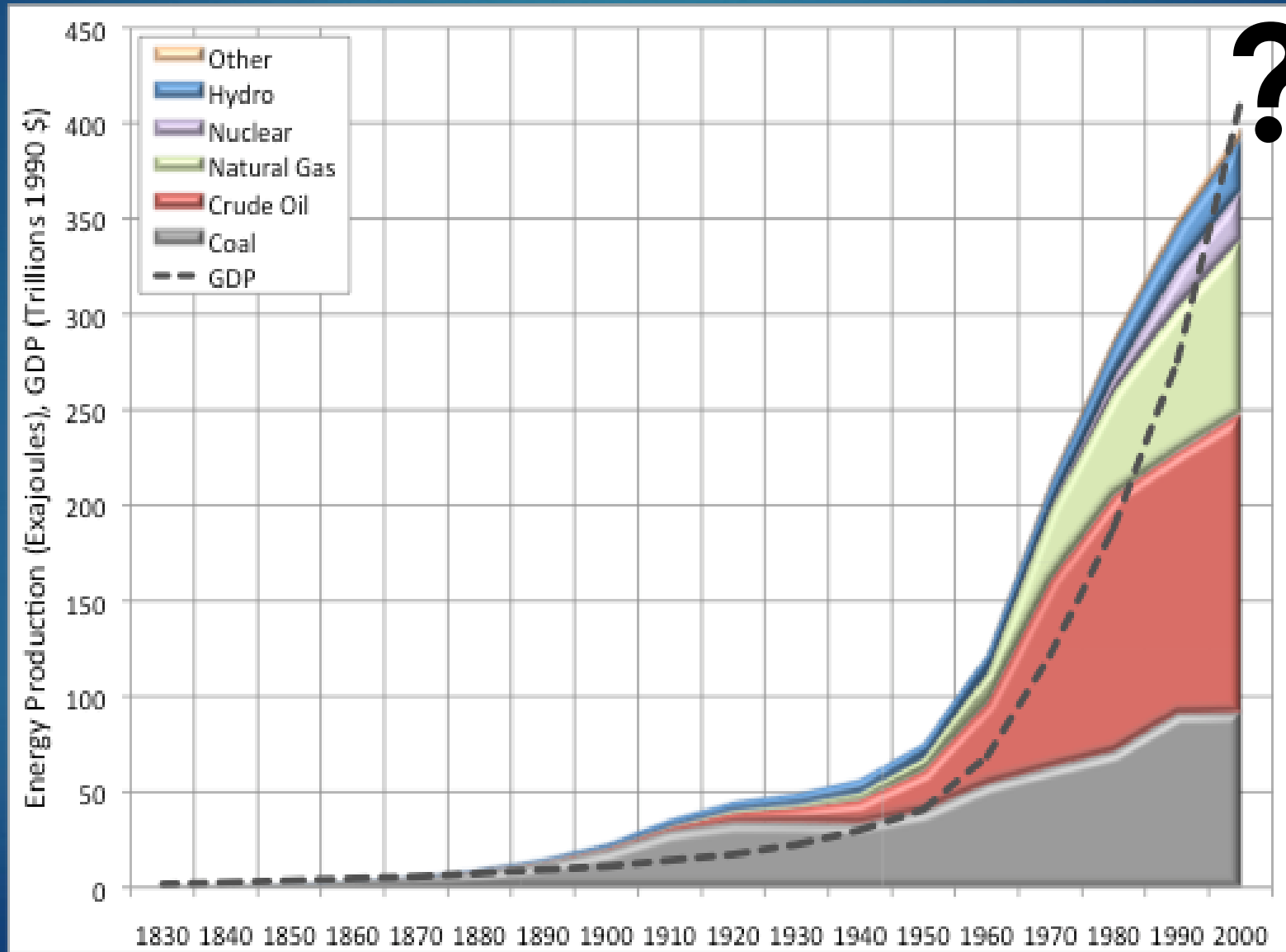
Fossil (old) fuels are the basis of our modern economies, wealth, food supply, health, education and so on.

DEPLETION



CO2

The dirty secret to wealth production: Use more energy



?

Global GDP
and global
energy use

Depletion is Easy to Grasp

As every beer drinker knows:

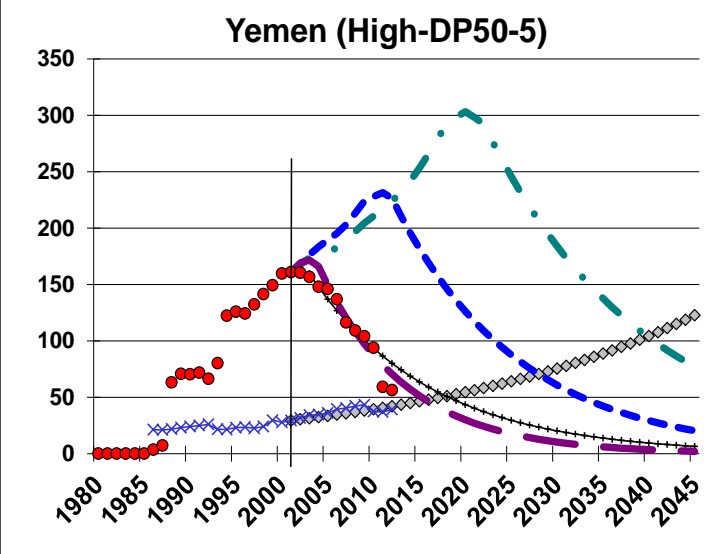
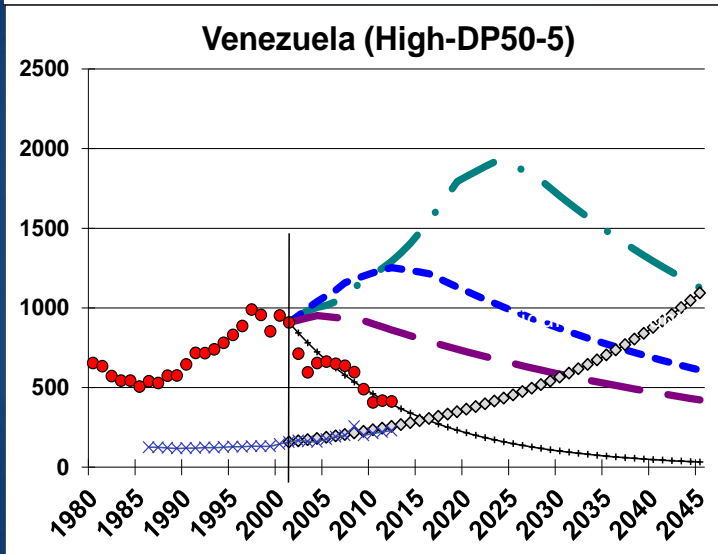
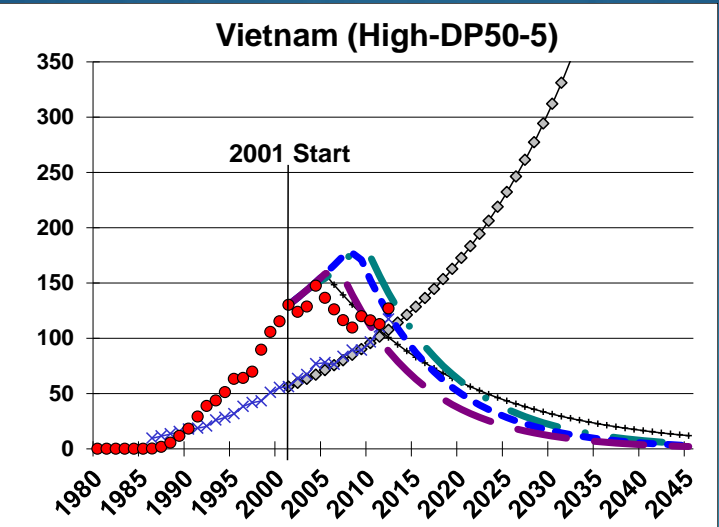
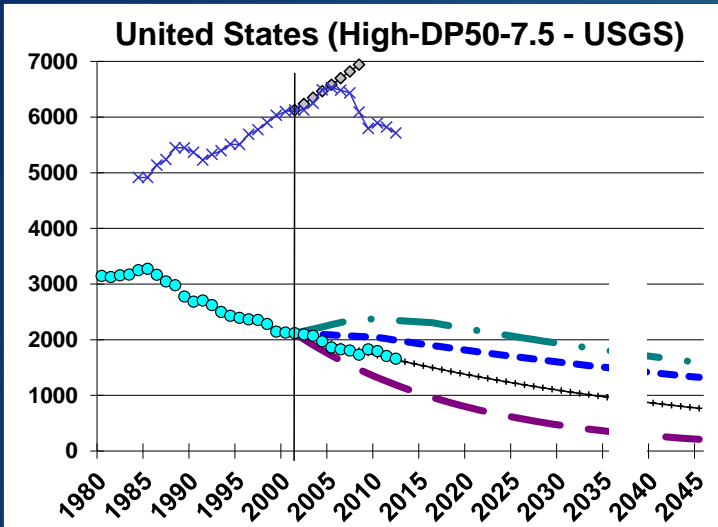
“Glass starts full, and ends empty”

- ▶ The quicker you drink it, the sooner it is gone
- ▶ The same principle applies to oil and gas

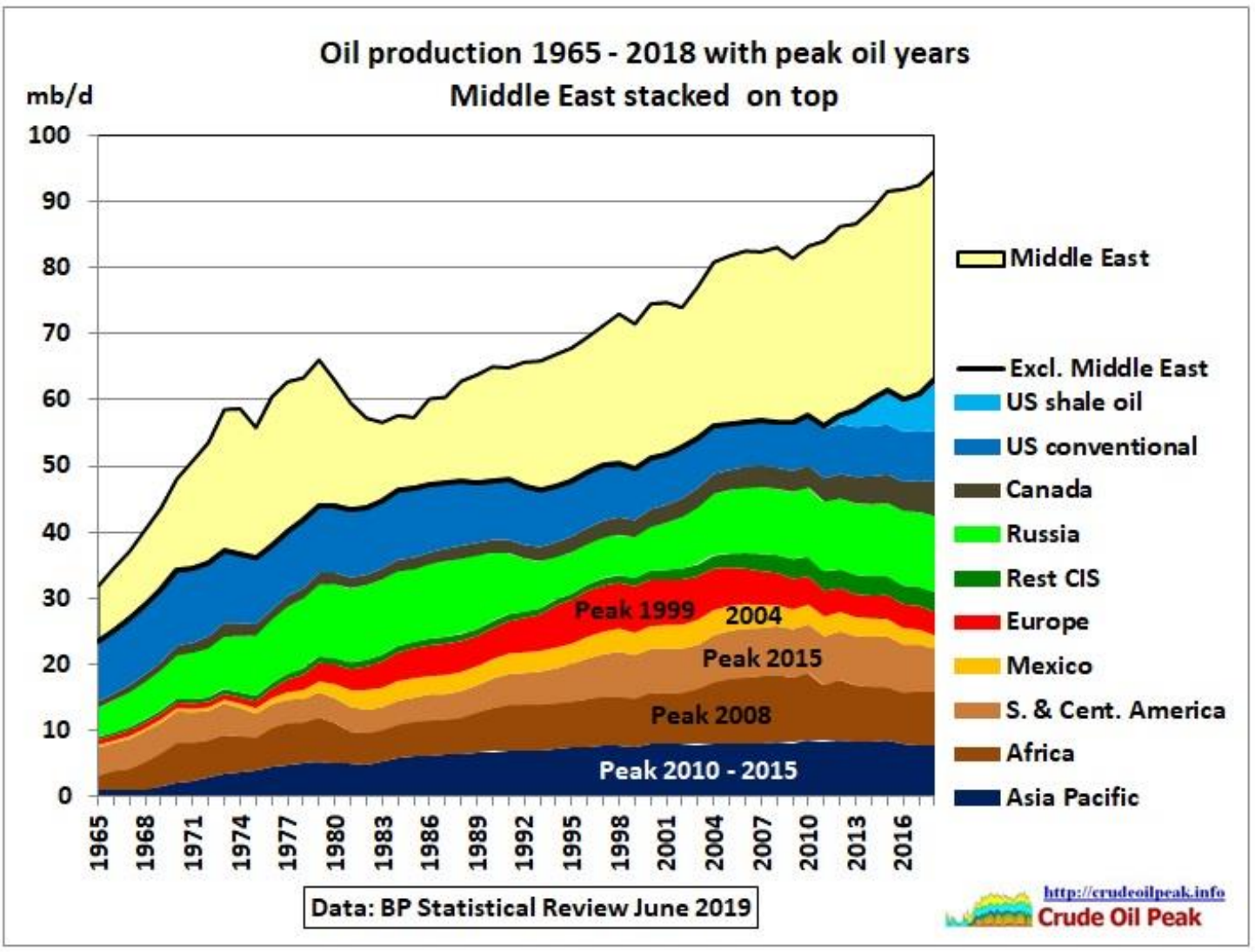
How has this self-evident reality been
concealed ?

- ▶ It is so obvious yet it is a

DEVASTATING REALISATION



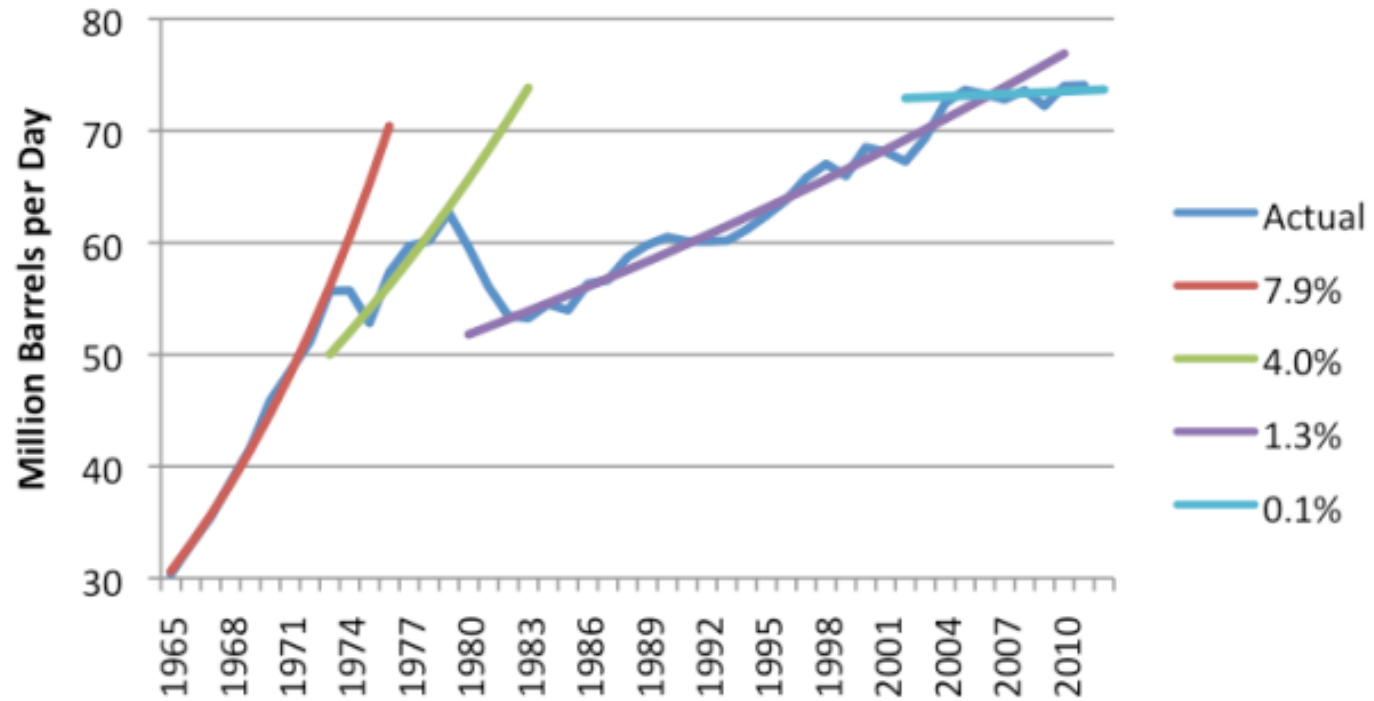
Some 36 of 44 oil-producing countries have already experienced “peak oil” ...
Hallock et al

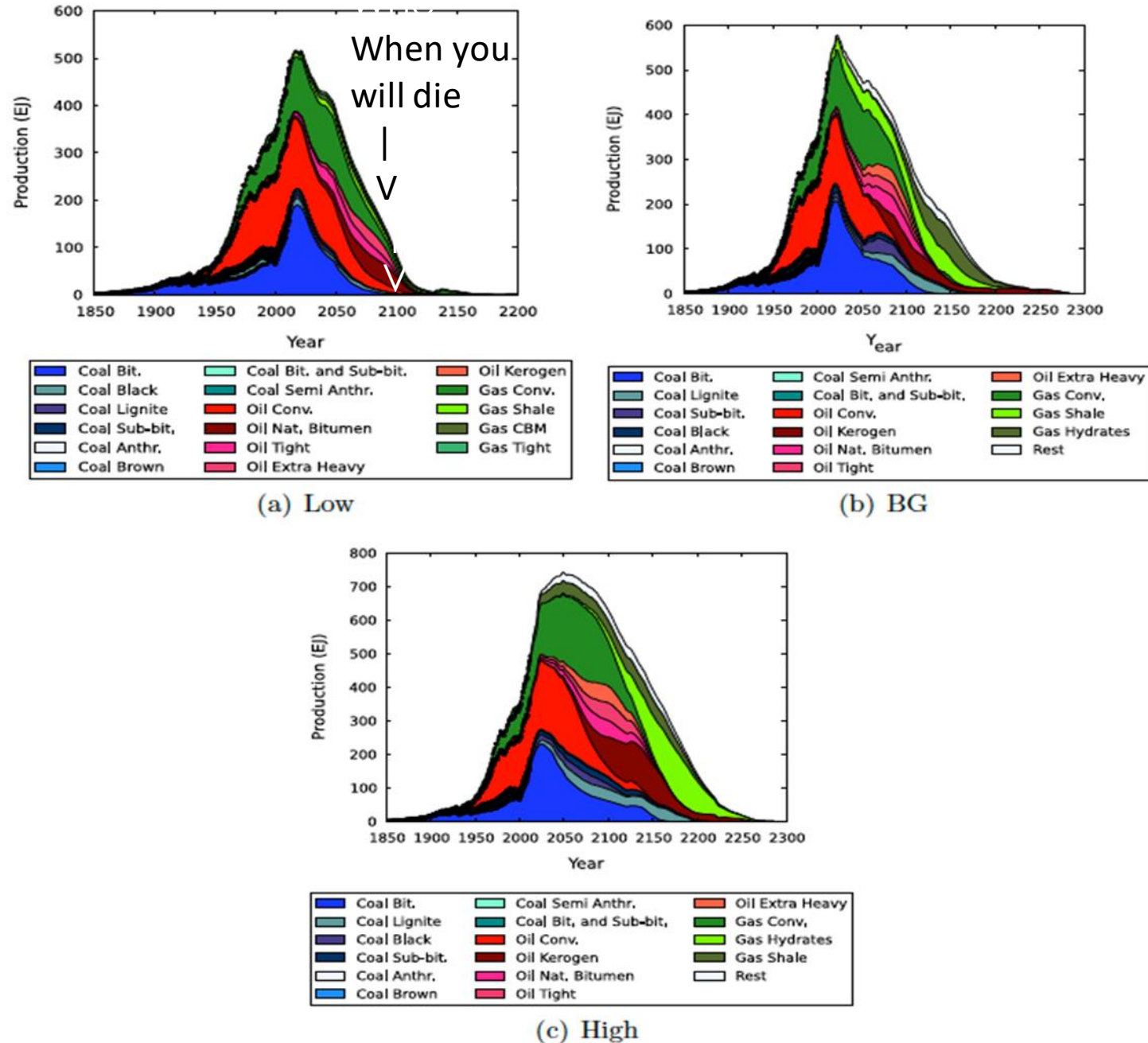


PEAK OIL* HAS OCCURRED ALREADY FOR ASIA, AFRICA, EUROPE, SOUTH & CENTRAL AMERICA ..ALL BUT NORTH AMERICA & MIDDLE EAST

(* = "ALL LIQUIDS")

World Crude Oil Production & Fitted Growth %





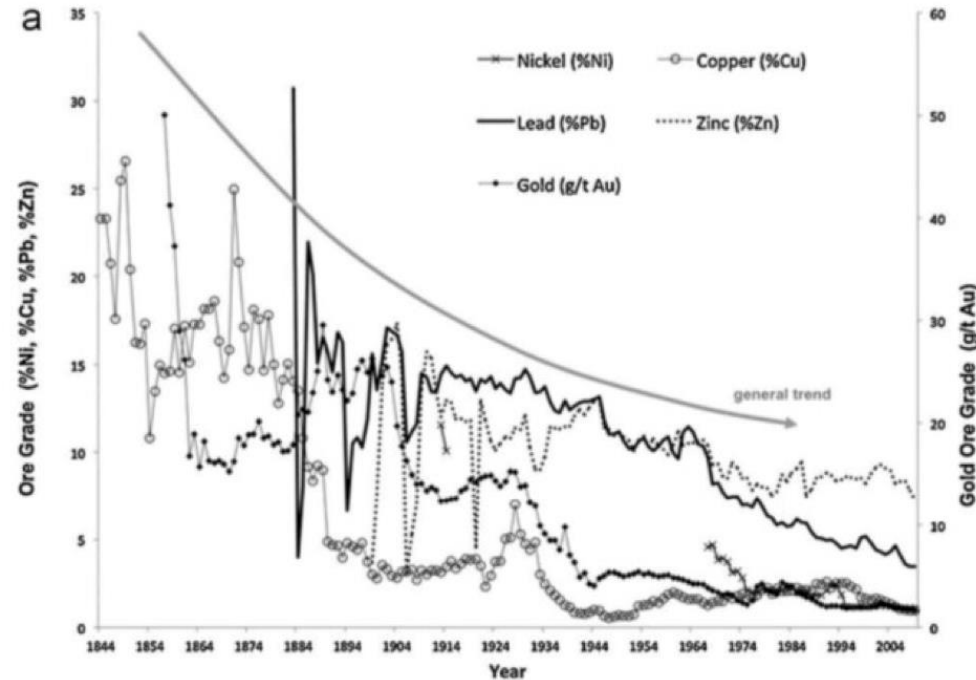
The future is likely to be severely constrained by “peak oil” and other energy resources

From : Mohr et al. 2015
 Future of all fossil fuels.
 Low, “Best Guess” and High estimates

Fig. 6. Fossil fuel projection by mineral type (black dots represent actual historical production).

Depletion

- Depletion of renewables if over sustainable harvest
- Depletion of minerals and non-renewables unless replaced by renewables



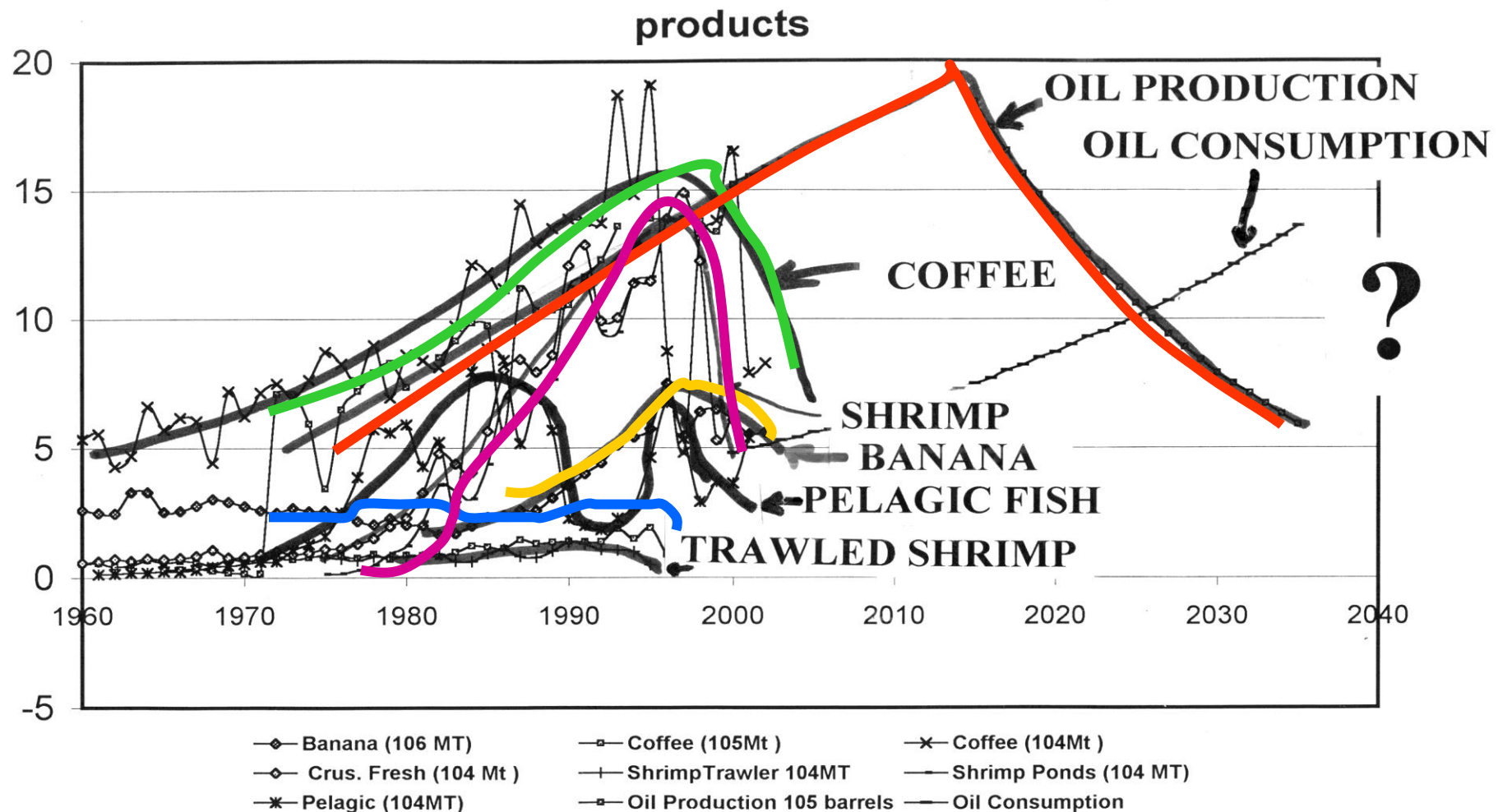
(r, T., Giurco, D., Mudd, G., Mason, L., Behrisch, J. 2012) Diagram reproduced by permission of

- Declining ore grades mean more energy and wastes
- Depletion = increasing raw materials costs

▶ Ore grade mined for most of our resources is declining as the best resources are depleted, requiring more energy per ton delivered.

▶ See also Calvo et al).

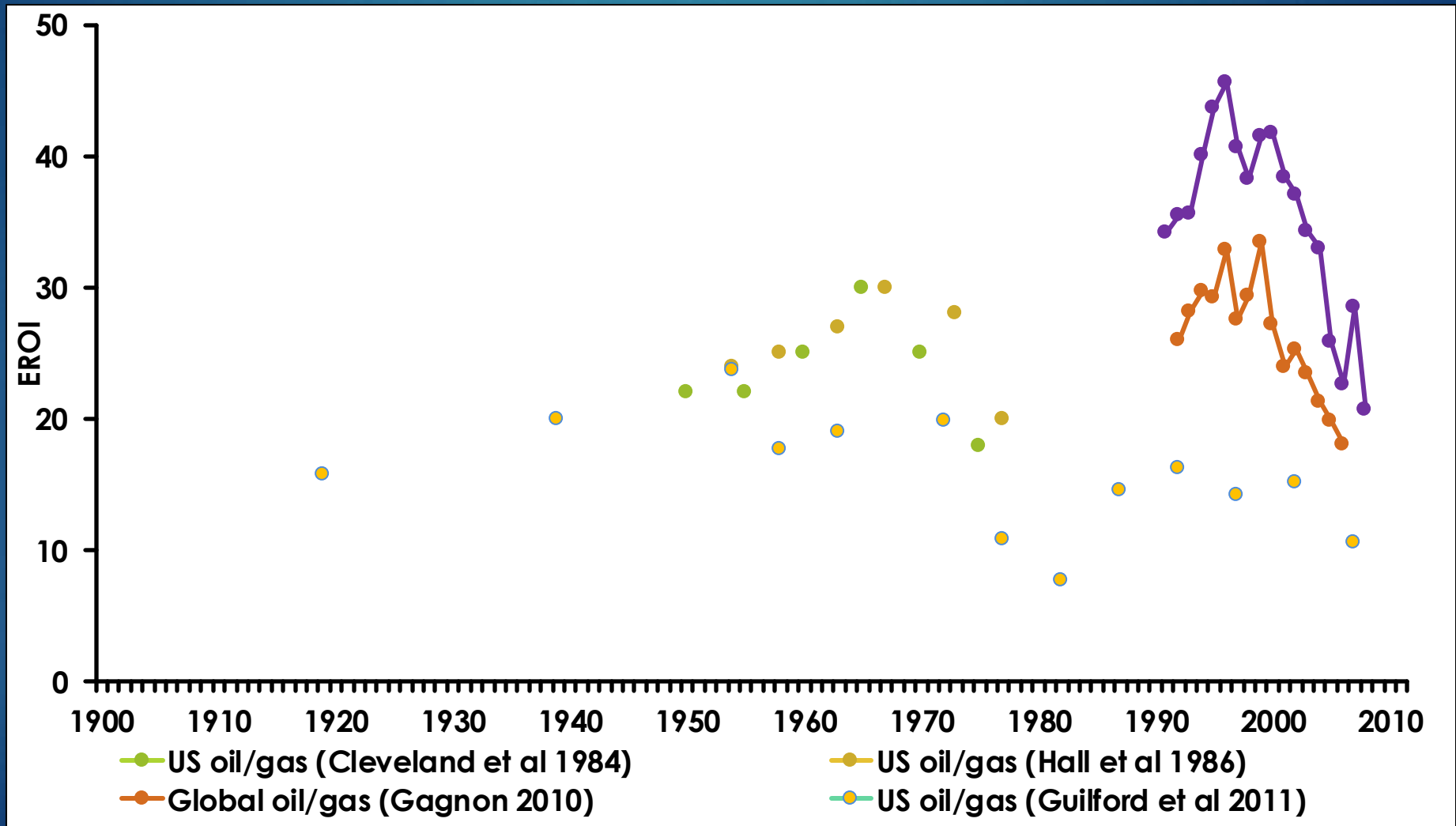
Exploitation cycles (Ecuador)



The third is declining EROI of our most important fuels

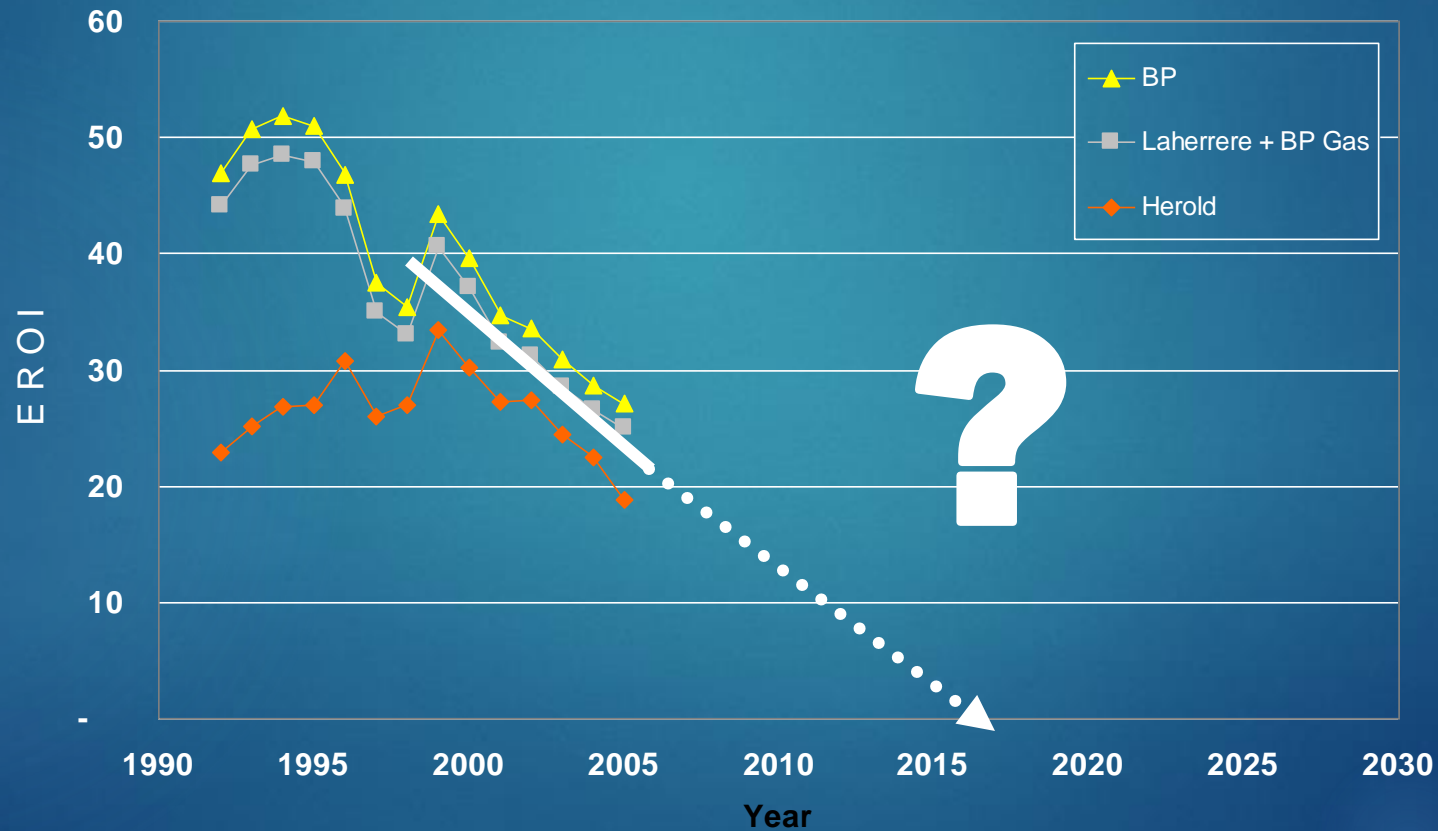


EROI for Oil: US and other



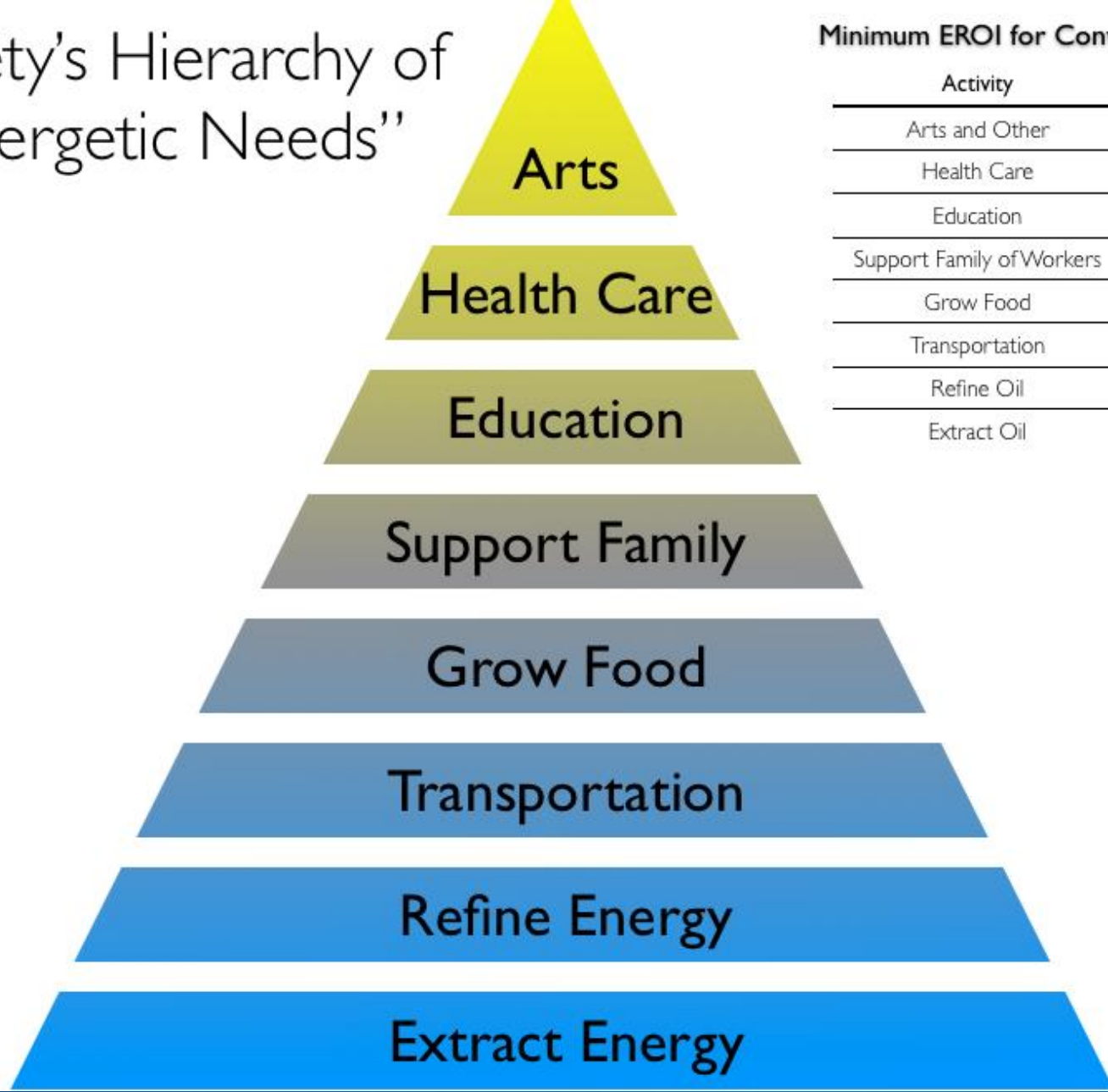
Time: series & projections

EROI for Global Oil and Gas



Gagnon, Hall
and Brinker 2009

Society's Hierarchy of "Energetic Needs"



Minimum EROI for Conventional Sweet Crude Oil

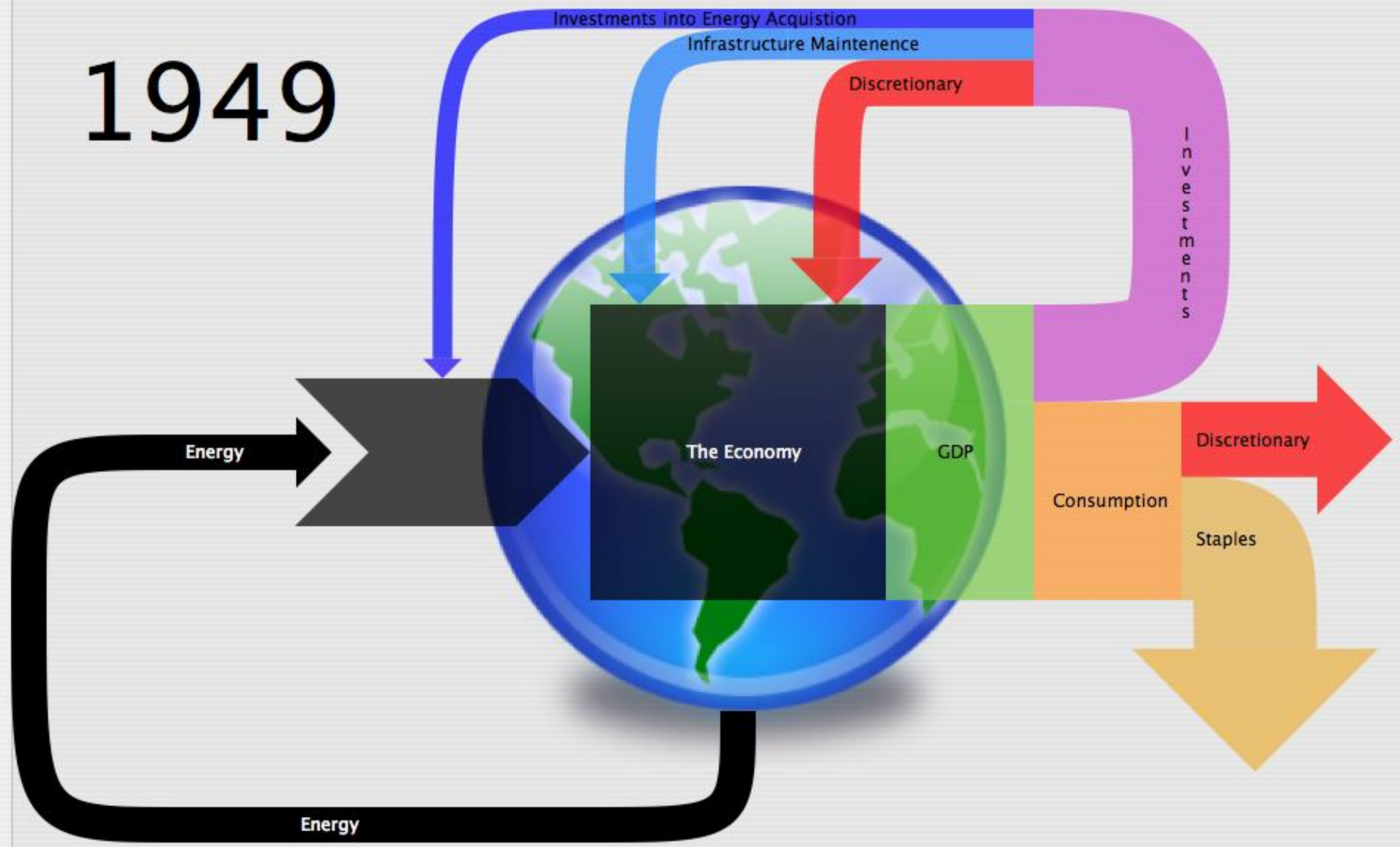
Activity	Minimum EROI Required
Arts and Other	14 : 1
Health Care	12 : 1
Education	9 or 10 : 1
Support Family of Workers	7 or 8 : 1
Grow Food	5 : 1
Transportation	3 : 1
Refine Oil	1.2 : 1
Extract Oil	1.1 : 1

My colleague Jessica Lambert will talk more about the need for high EROI next week

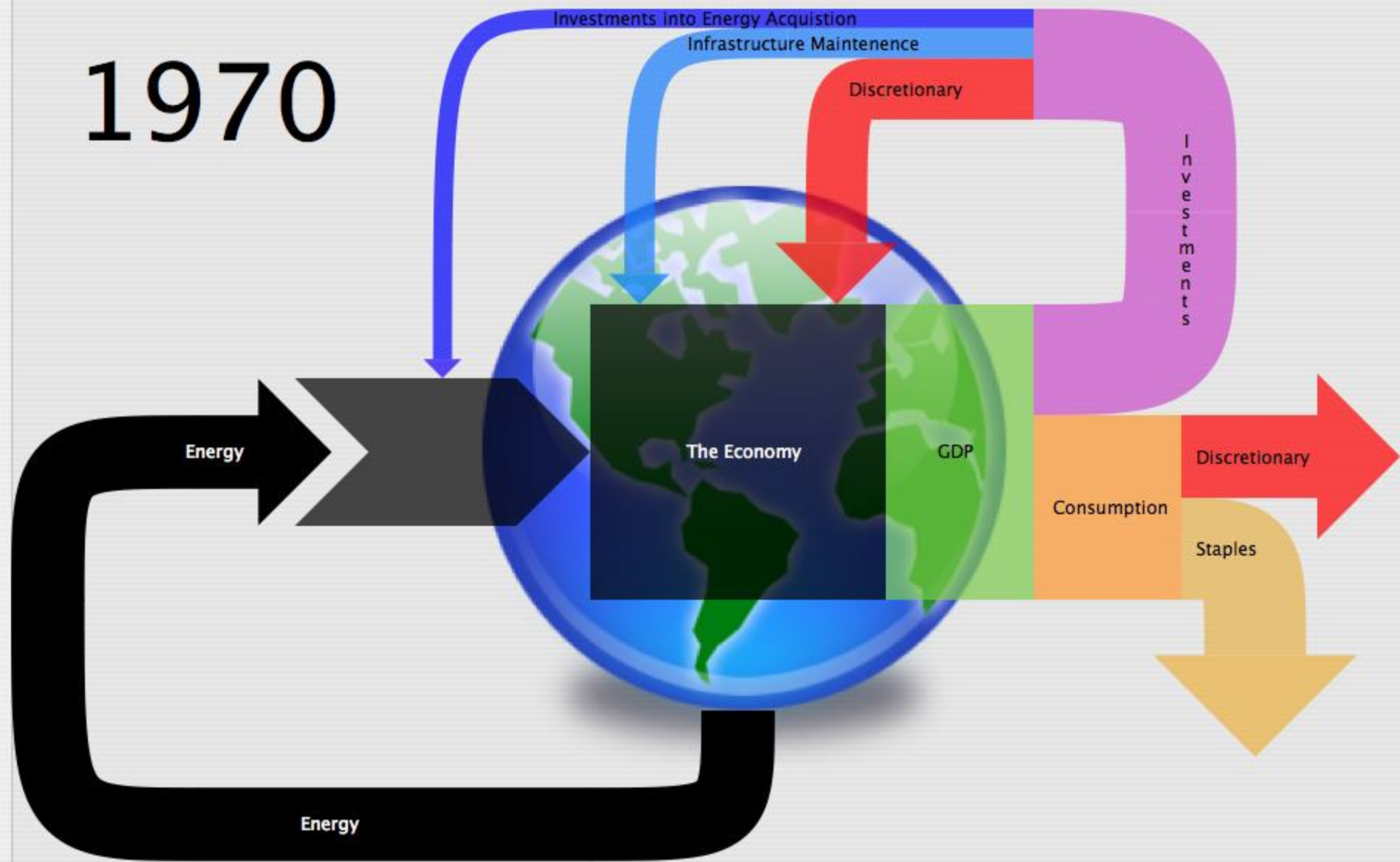
The situation is perhaps best summarized in the “cheese slicer” model

Hall, Powers Schoenberg 2009

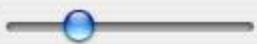
1949



1970

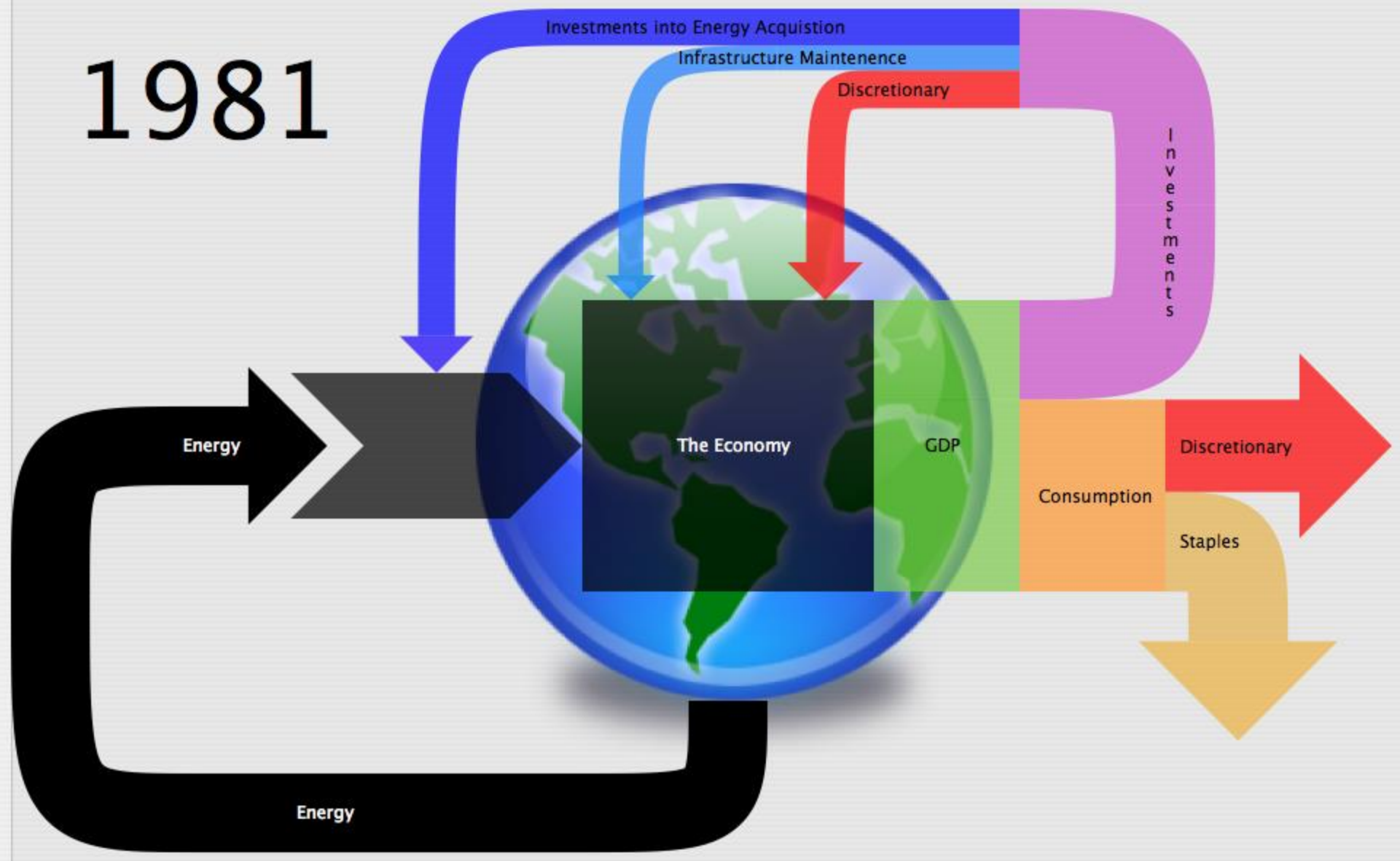


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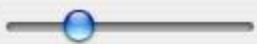


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1981

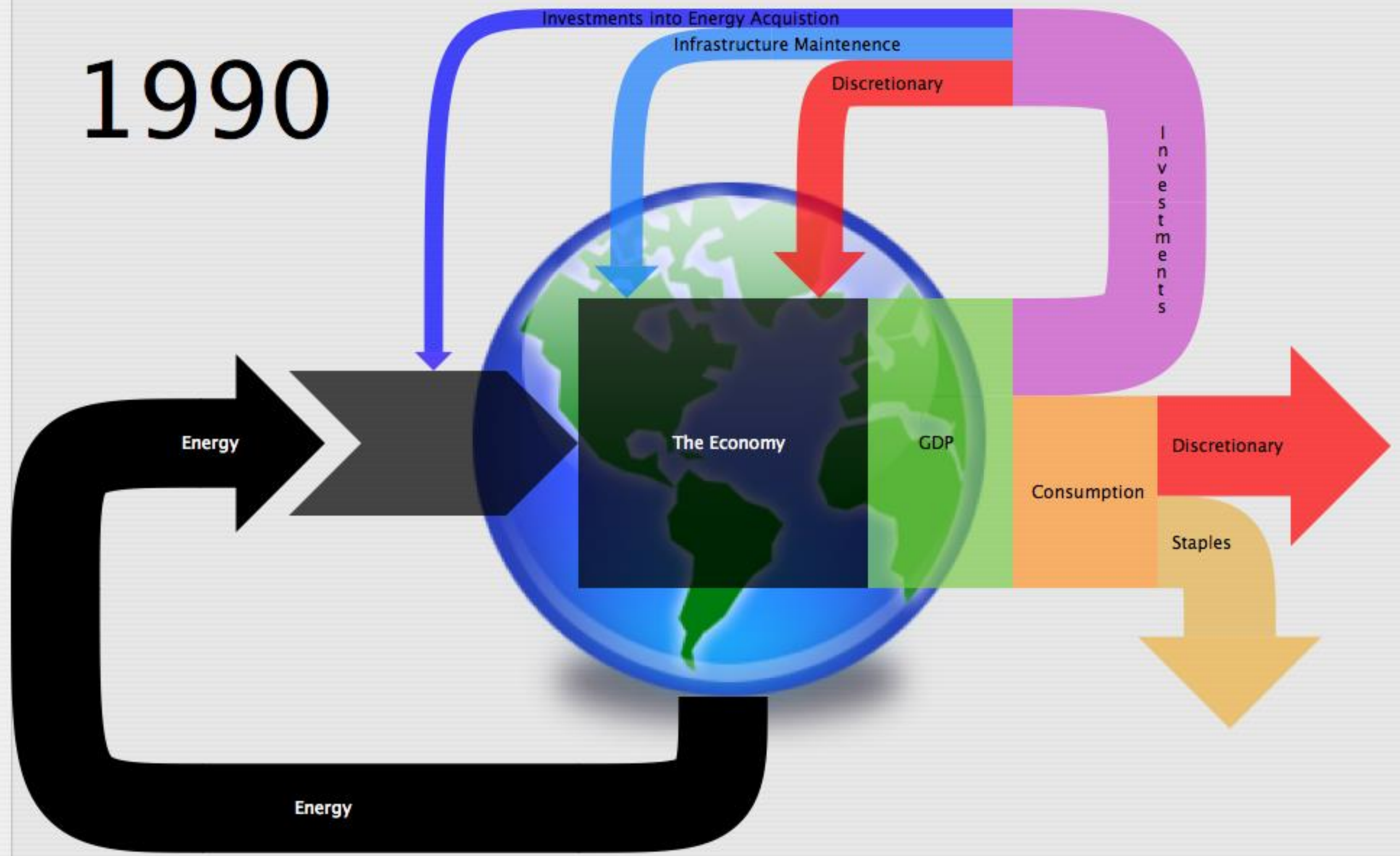


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1990

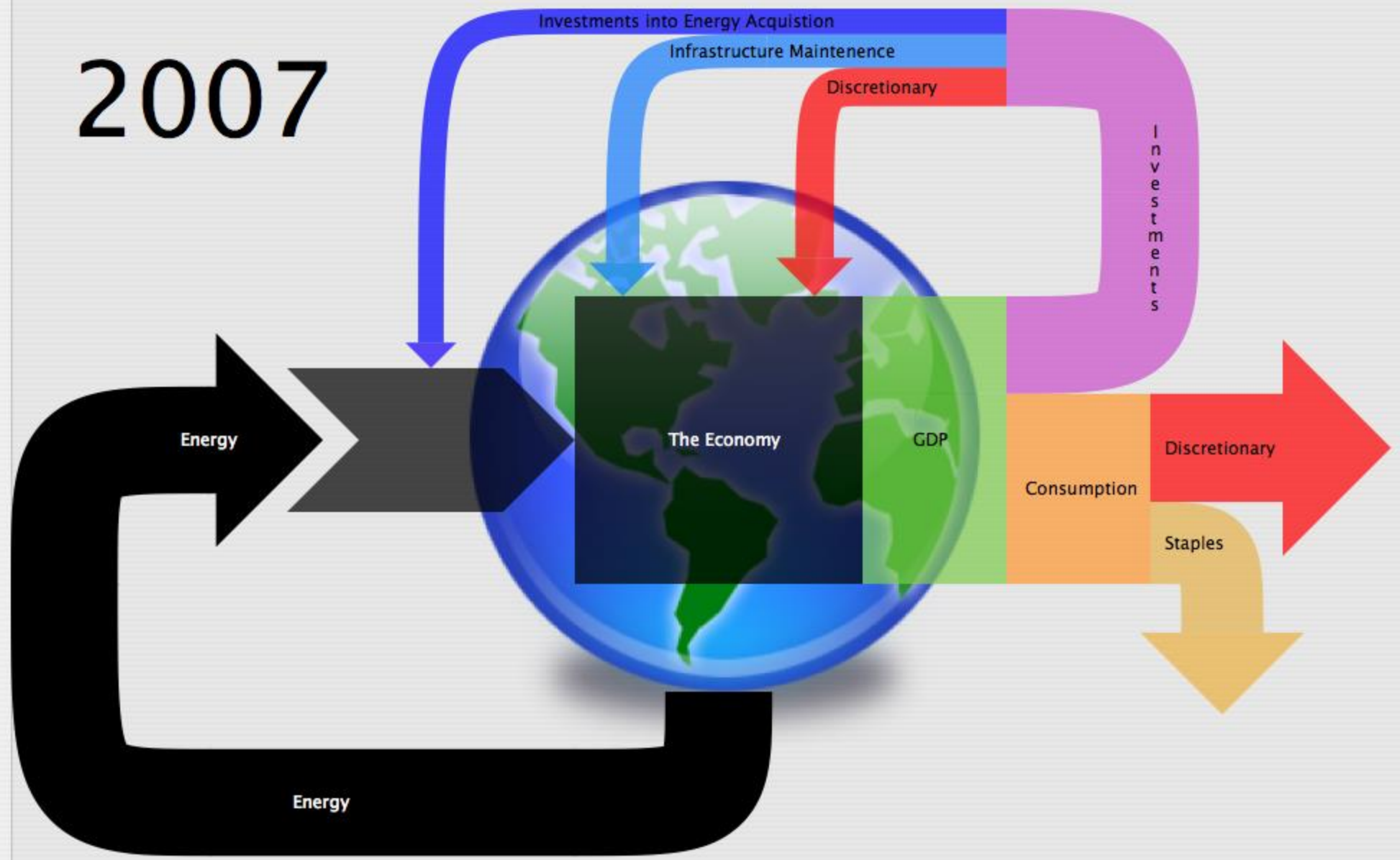


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2007

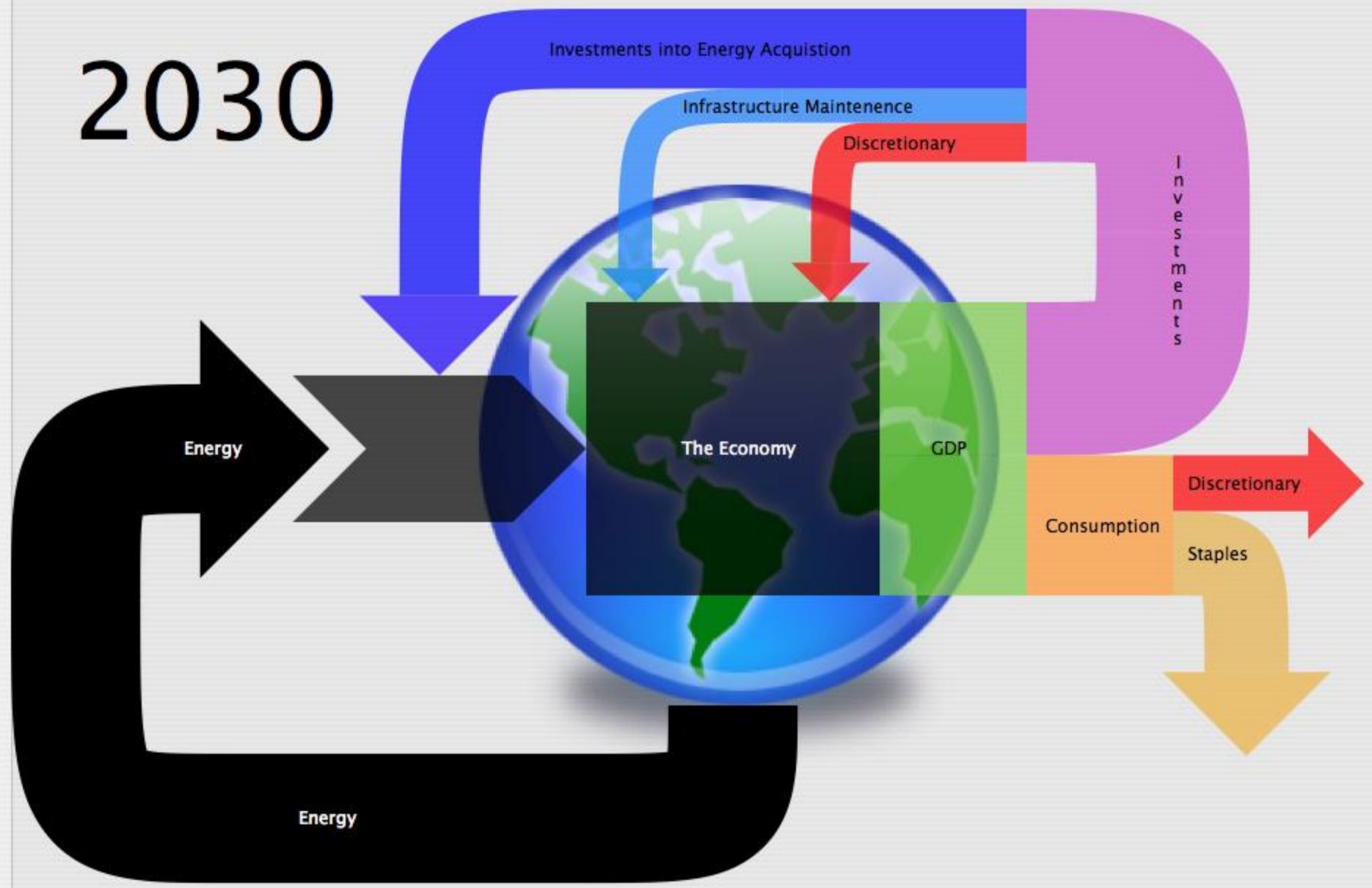


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2030

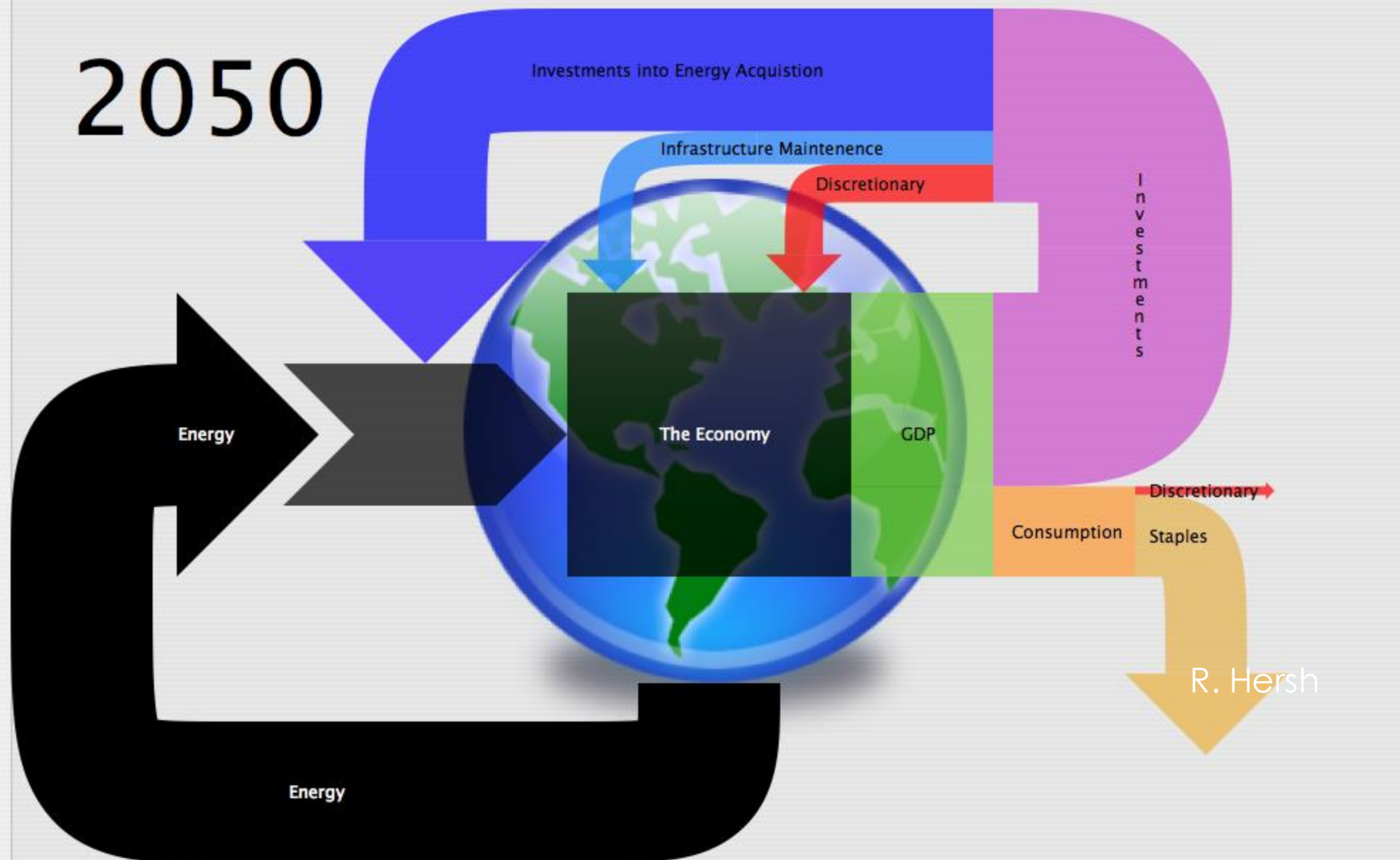


start!



Load Data

2050



R. Hersh

Analysis by Capellan Perez et al. suggests that if we switch to a 50% or 100% renewable system then the EROI for society will decline to as low as 4:1, or even 2:1. This would probably make modern industrial society impossible.

b

Dimmi

EROIst system





First, make sure you have done your homework thoroughly !

AND... a typical regular car uses 21 KG of copper, an electric car 80 KG

- 
- ▶ And we need to talk about population
 - ▶ And water
 - ▶ And soil
 - ▶ and resources/capita

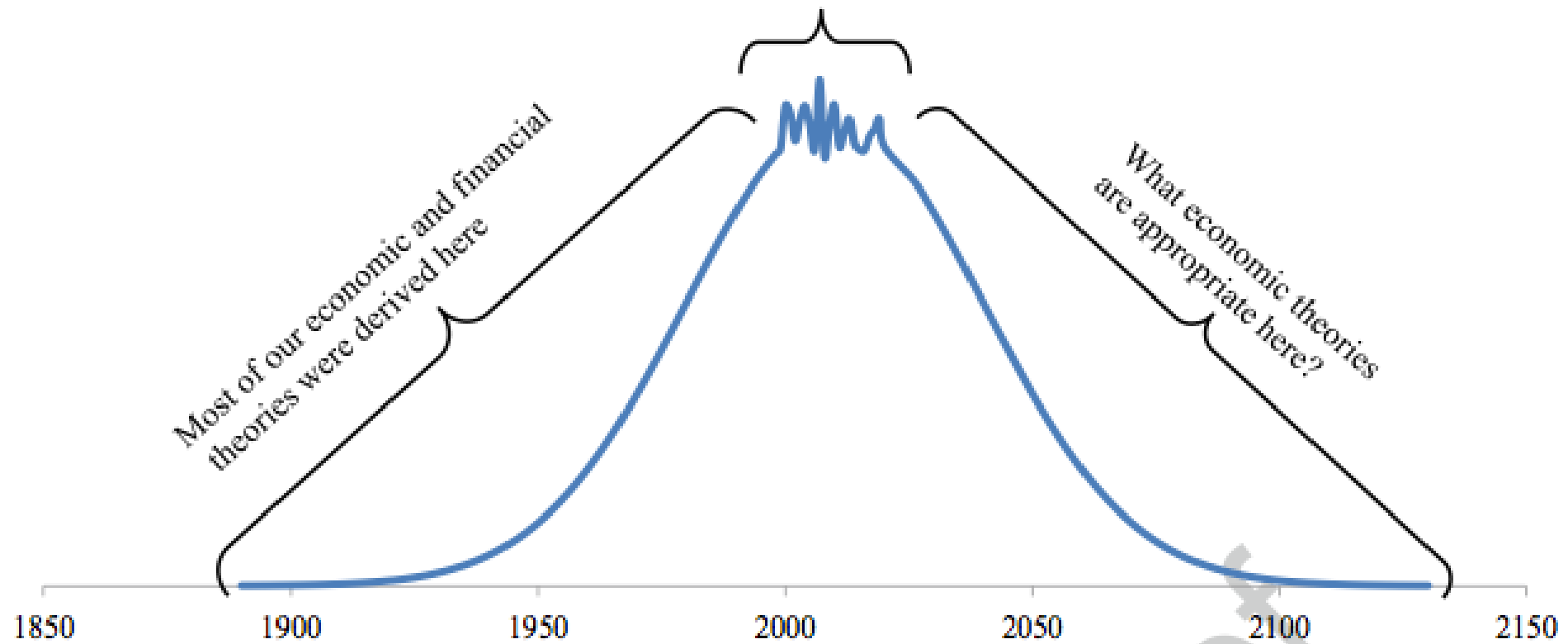
The fourth is Jevon's paradox

- ▶ The most common response: technology , often meaning increasing efficiency
- ▶ “When, to save coal, the efficiency of steam engines (in 1800) was increased they became cheaper, more uses was found for them, and the rate of coal use increased” Stanley Jevons, in The Coal Question 1856
- ▶ Efficiency is the basic mantra/method of the modern green movement
- ▶ Example (one of many) : Since 1995, aviation fuel use/passenger-mile is down 70 percent, air traffic rose more than 10-fold, and global aviation fuel use rose over 50 percent.

The fifth is the suite of myths usually called conventional or neoclassical economics

- ▶ Basically NCE is based on a set of premises that break the basic laws of thermodynamics, conservation of matter etc etc. Their models cannot exist in the real world.
- ▶ NCE gives money little importance because its price is low, e.g. it is only 5-10% of GDP. In fact the present reality that energy is cheap is WHY it is so important for our society.
- ▶ Add in energy to your production function and the “Solow residual” (i.e. technology) disappears.

Current U.S. and Global Oil/Energy Situation



Charles A.S. Hall
Kent Klitgaard

Energy and the Wealth of Nations

An Introduction to Biophysical Economics
Second Edition



Springer

- ▶ There is an antidote to all this:
- ▶ BioPhysical Economics
- ▶ This exists in a number of venues:
 - ▶ 1) The International Society of BioPhysical Economics
 - ▶ 2) The Journal BioPhysical Economics and Sustainability
 - ▶ 3) Many academic publications
 - ▶ ←including textbook
 - ▶ 4) The new think tank
 - ▶ www.BPEInstitute.org
- ▶ If you want more: email chall@esf.edu

The sixth is the most difficult and most important: Social Response





SPRINGER BRIEFS IN ENERGY

Nafeez Mosaddeq Ahmed

Failing States,
Collapsing
Systems
BioPhysical
Triggers of Political
Violence

 Springer

The Limits to Growth is playing out
Nation by Nation

Peak and then
decreasing oil, nation
by nation, generates
extreme social unrest.
This is the real problem

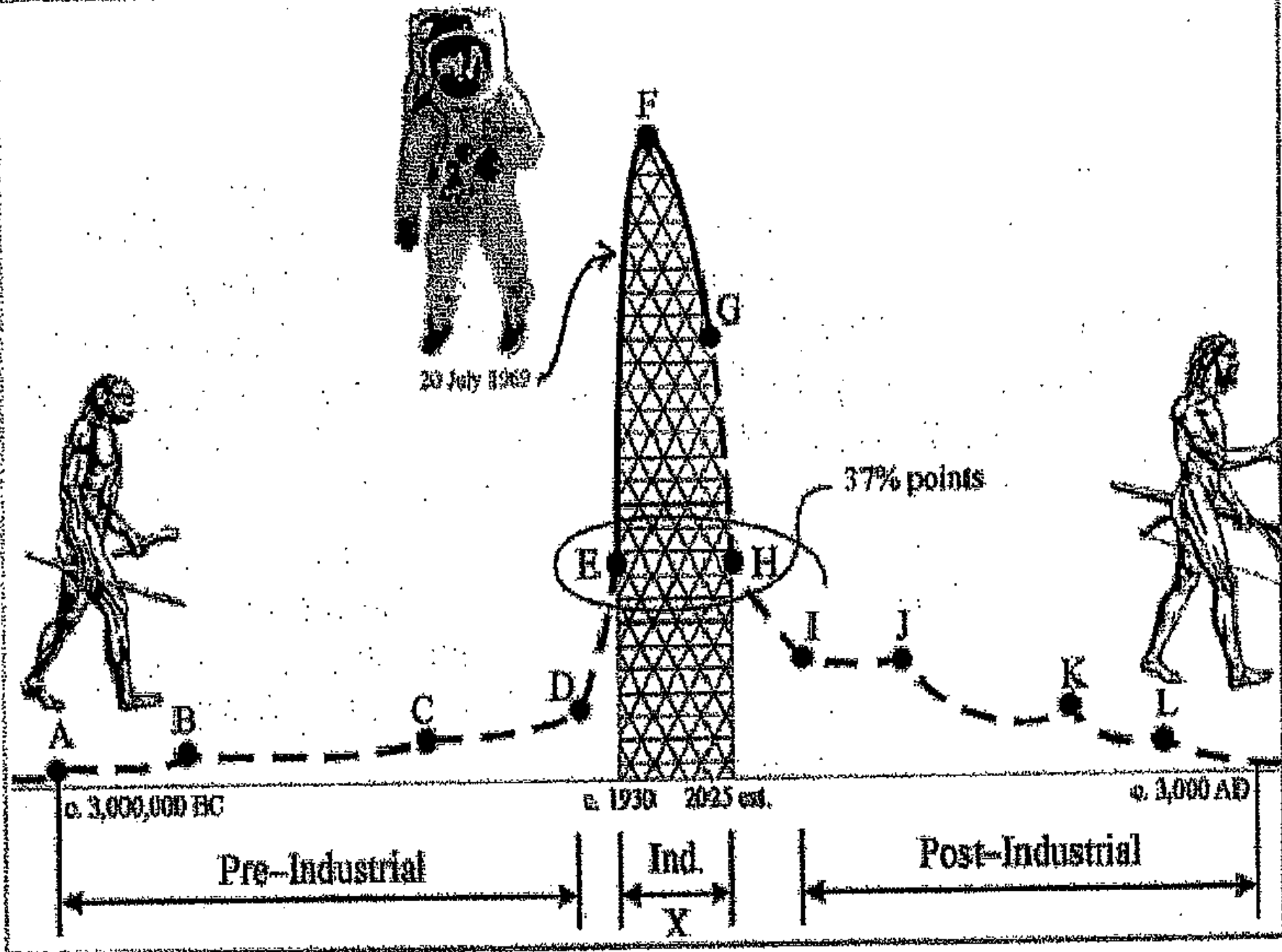
Good BioPhysical analysis
explains many things:
Such as Tump's nominal
economic success

The LtG model asked the right questions, and no newer approach has asked them any better

CONCEPTUALLY IT WAS BRILLIANT AND ITS TRACK RECORD SO FAR IS GOOD

Further thoughts on Limits to Growth today:

- ▶ Dennis Meadows said in the “30 year update to LTG” that we had lost thirty years by doing nothing”. Now we have lost 50
- ▶ We have not examined today their conclusions --that we need to stabilize populations and stop investments to generate stability.
- ▶ **Technology that does not lead to Jevon's paradox?**
- ▶ Nearly all “green” solutions that are offered are not (e.g. June Sekera's study).
- ▶ The governmental data/institutions required to understand these issues is increasingly not maintained. (Leave it to the market!)
- ▶ Science is used increasingly to defend positions, rather than test hypotheses.
- ▶ **It's a great time to think about redistribution !**

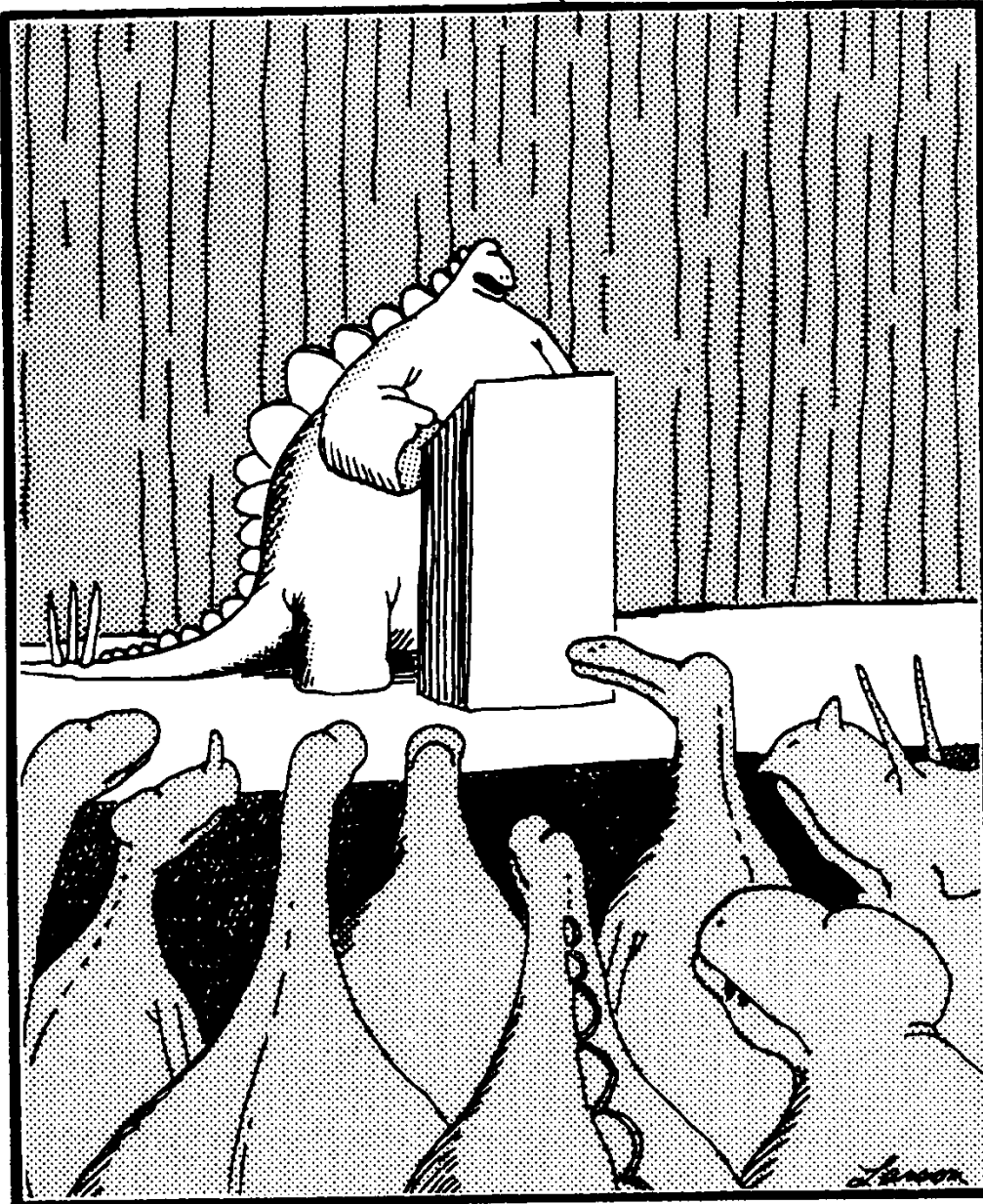


► One possible future ???

IT OFFENDS THE HUMAN EGO THAT
NATURE IS INDIFFERENT TO US.



- ▶ If you do not have enough energy no other sustainability issues matter



"The picture's pretty bleak, gentlemen. ... The world's climates are changing, the mammals are taking over, and we all have a brain about the size of a walnut."


My final professional goal



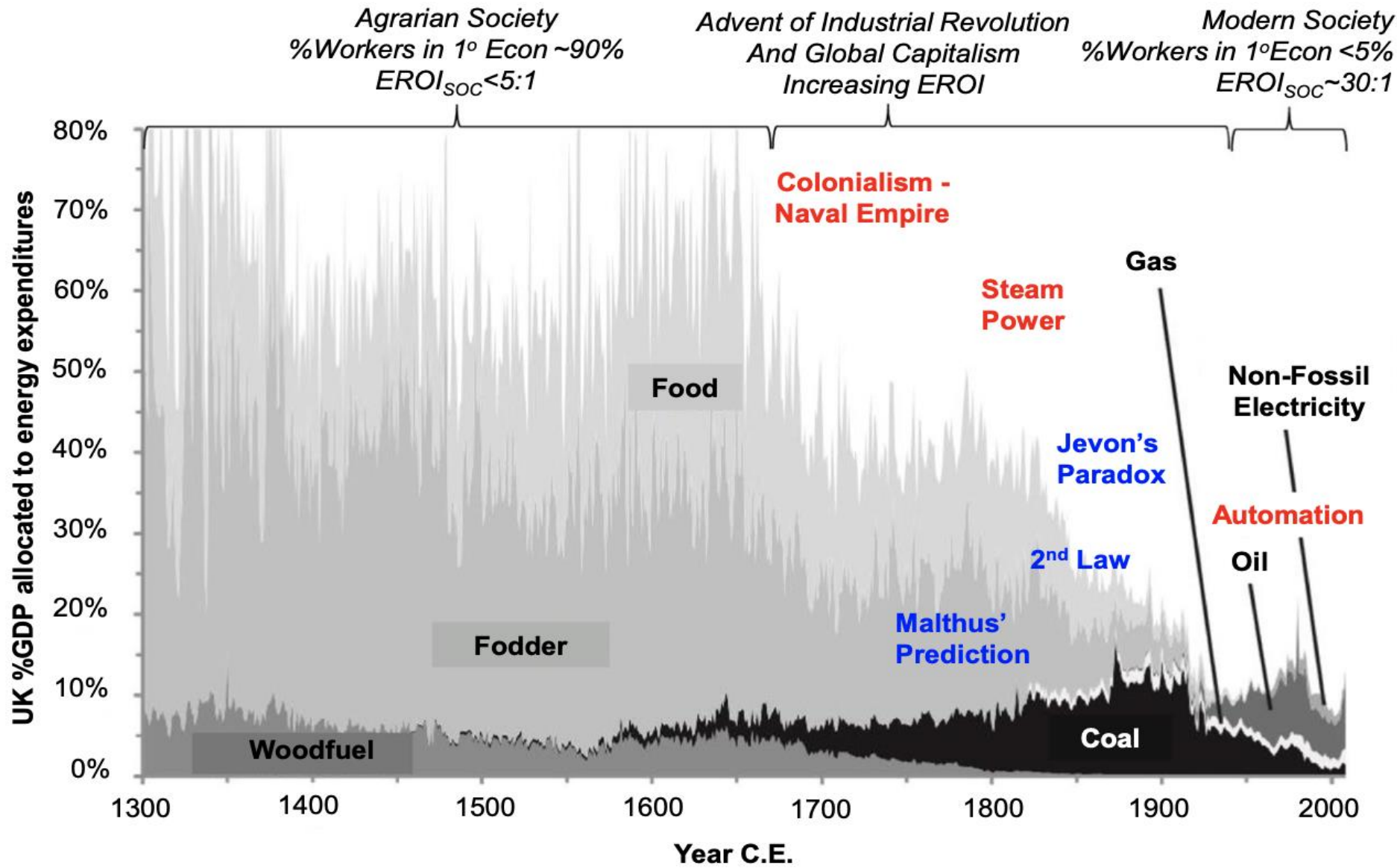
**Neoclassical
economics**

THE END





Since ours is a formal, or mathematical, model it also has two important advantages over mental models. First, every assumption we make is written in a precise form so that it is open to inspection and criticism by all. Second, after the as-sumptions have been scrutinized, discussed, and revised to agree with our best current knowledge, their implications for the future behavior of the world system can be traced without error by a computer, no matter how complicated they become;



Key: Energy Source, Intellectual Paradigm, Net Energy Keystones