Welcome to this week's presentation and conversation
hosted by the
Canadian Association for the Club of Rome,
a Club dedicated to intelligent debate and action on global issues.

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

Our speaker today is Dr. Charles AS Hall, PhD (Systems Ecology under Howard Odum, UNC). He was professor at Cornell U, U Montana, & SUNY (Environmental Science & Forestry), & now *Professor Emeritus* in Oregon. He is author or editor of 14 books & 300 articles. He won the Hubbert-Simmons Prize for Energy Education & Lifetime Achievement Award (Int Soc BioPhysical Econ). He is best known for energy return on investment (EROI) & BioPhysical Economics. Today he assesses how much oil remains to be produced & whether this poses a major constraint to global development, delving into the categories & reserves of oil & related liquid fuels. His forecasts indicate that IPCC's high-CO_2 scenarios is not feasible by assuming unrealistic high rates of oil production, but also indicate that considerable oil must be left in the ground if climate change targets are to be met. As the world tries for sustainability, these perspectives on the availability of oil are critical.

The presentation will be followed by a conversation, questions, and observations from the participants.

CACOR acknowledges that we all benefit from sharing the traditional territories of local Indigenous peoples (First Nations, Métis, and Inuit in Canada) and their descendants.

2022 Oct 26

Zoom #120

How much oil remains for the world to produce?

Comparing assessment methods, and separating fact from fiction

CHARLES A. S. HALL

PROFESSOR EMERITUS ,

STATE UNIVERSITY OF NEW YORK ,

COLLEGE OF ENVIRONMENTAL SCIENCE AND FORESTRY

FOR THE CANADIAN ASSOCIATION FOR THE CLUB OF ROME OCTOBER 26, 2022

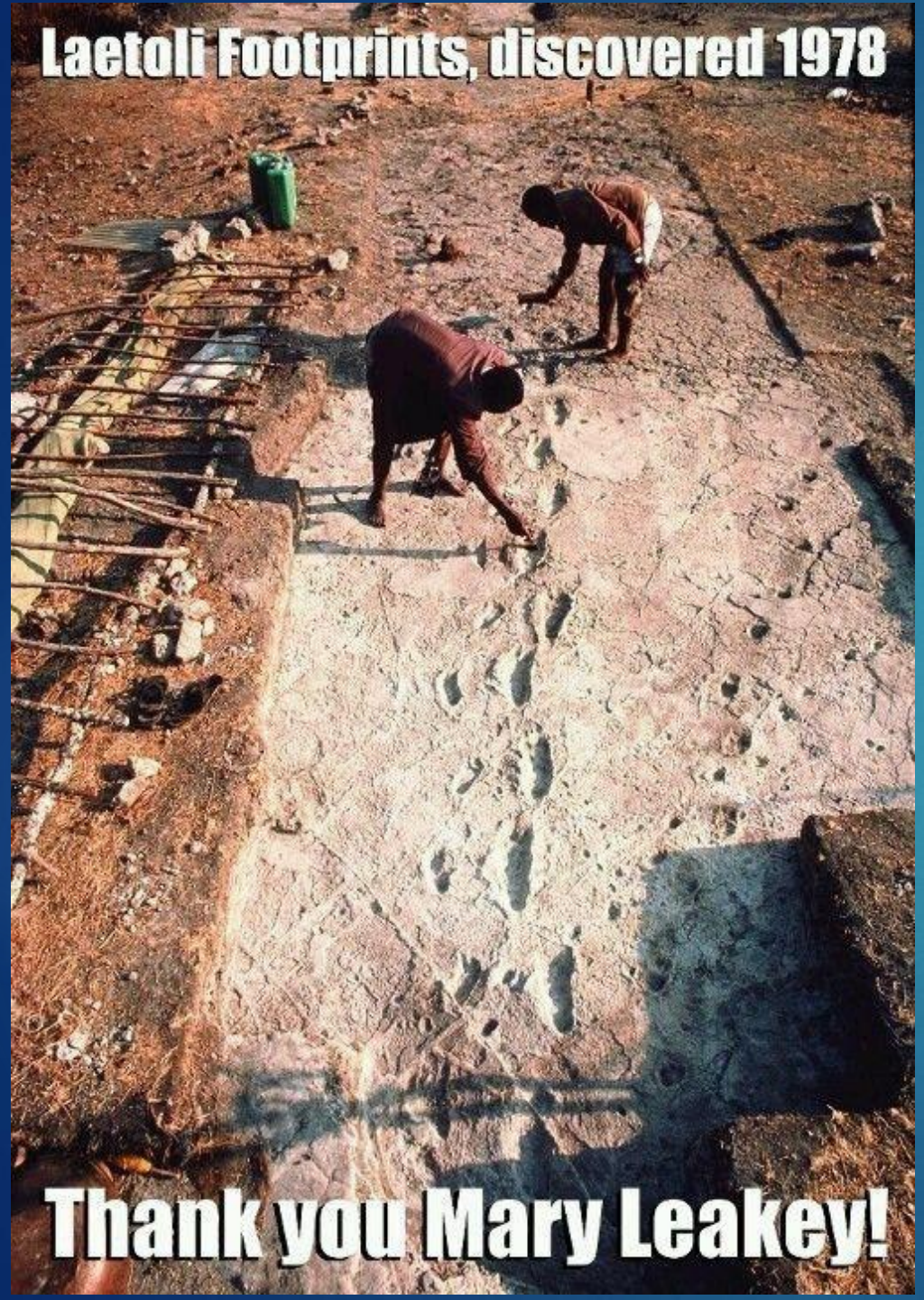
I. Sustainability

- Very sloppy use of the word sustainable
- According to Goodland and Daly (1996) sustainability means at least three things to at least three different groups:
    1) economic (survival of an economy)
    2) social (survival of an ethnic social group or its culture)
    3) environmental (survival of nature, or a part, or our society)

Not only are these three independent, they are often contradictory

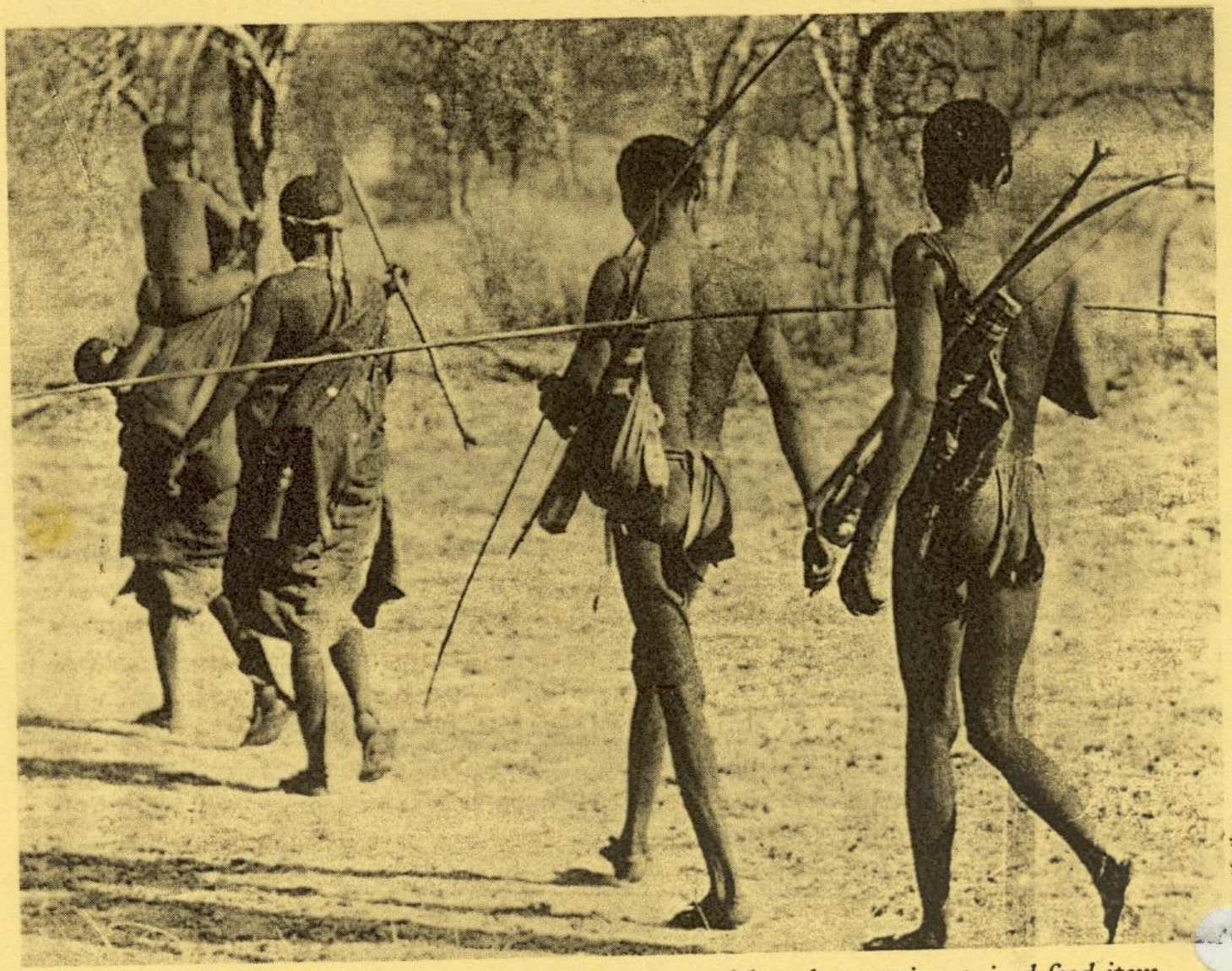
II. Energy: Humanity's critical resource

- ALSO:
- WATER
- ENERGY (INCLUDING FOOD)
- SOIL
- BREATHABLE AIR



~3.6 Mya our early ancestors walked the Rift Valley of East Africa (modern Tanzania)

Reconstruction of our ancestors in their natural environment



!Kung in action. *The !Kung project showed that, although meat is a prized food item, plant foods provided most sustenance.*

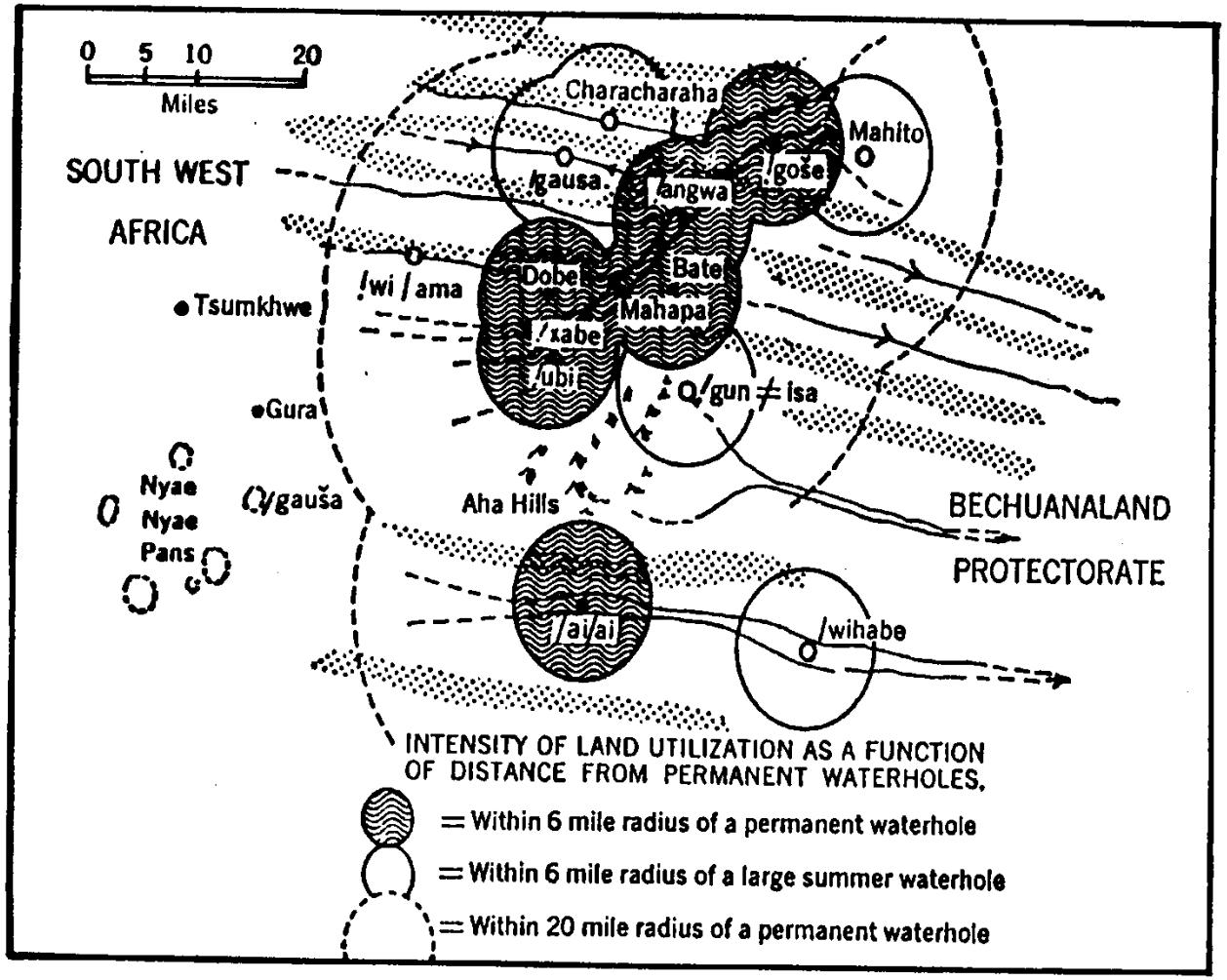
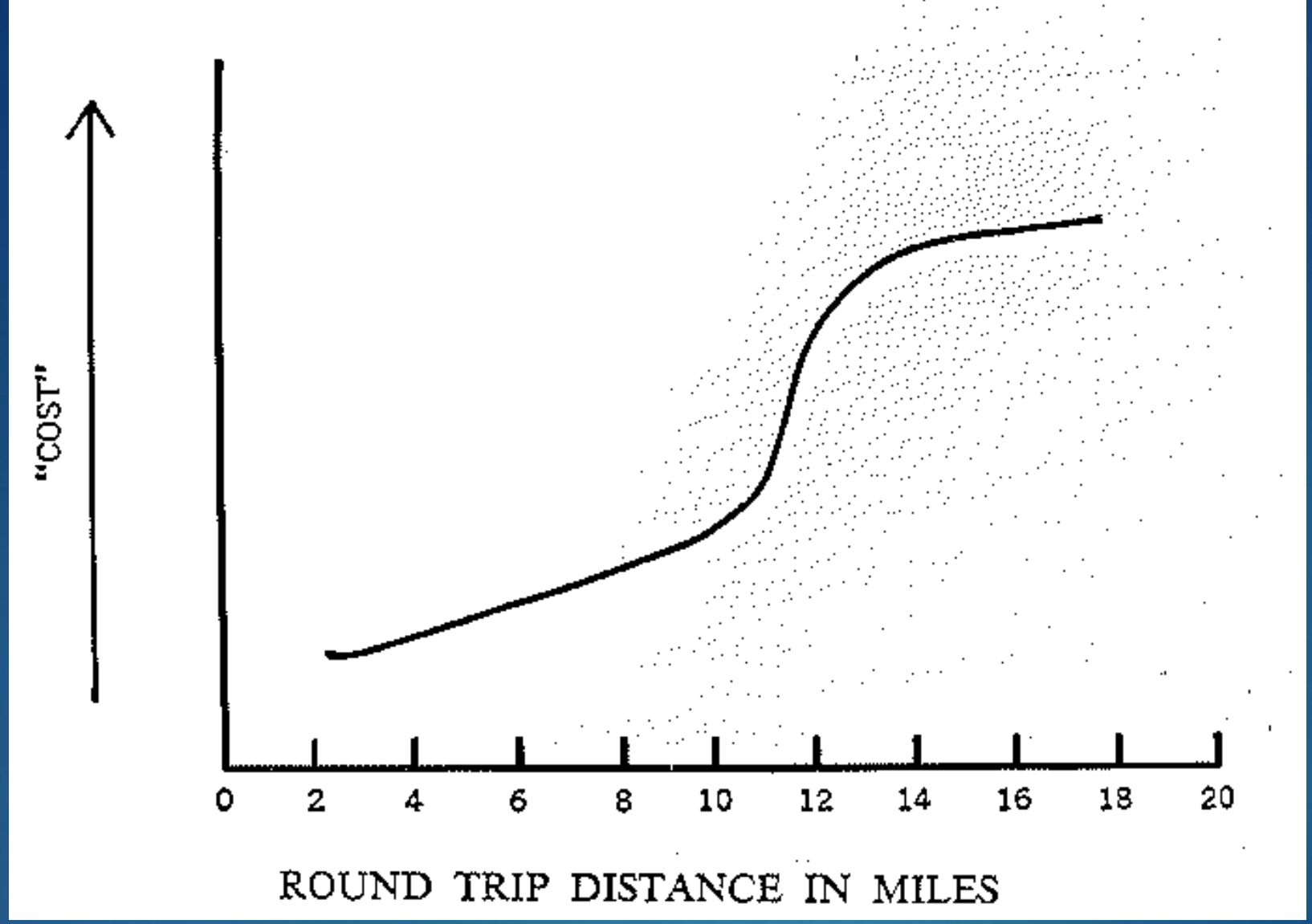
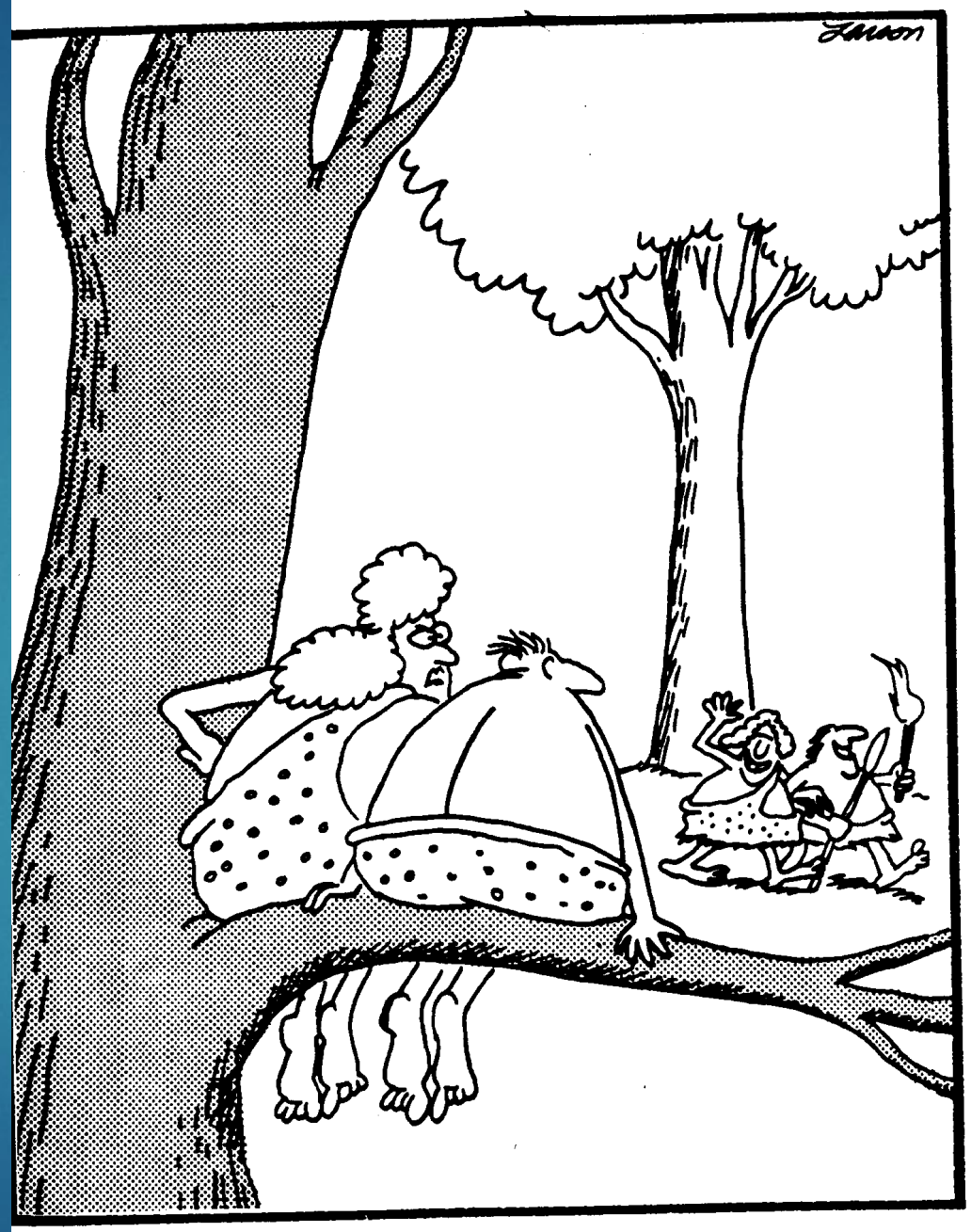


Figure 6.3. Intensity of land utilization by !Kung as a function of distance from permanent water holes. Within six miles of a water hole the food resources can be considered of higher quality and are utilized more intensively, because the energy investment required for exploitation is less. (Map from *Environment and Cultural Behavior* by Andrew P. Vayda. Copyright © 1969 by Andrew P. Vayda. Reprinted by permission of Doubleday & Company Inc.


"COST"
0
2
4
6
8
10
12
14
16
18
20
ROUND TRIP DISTANCE IN MILES

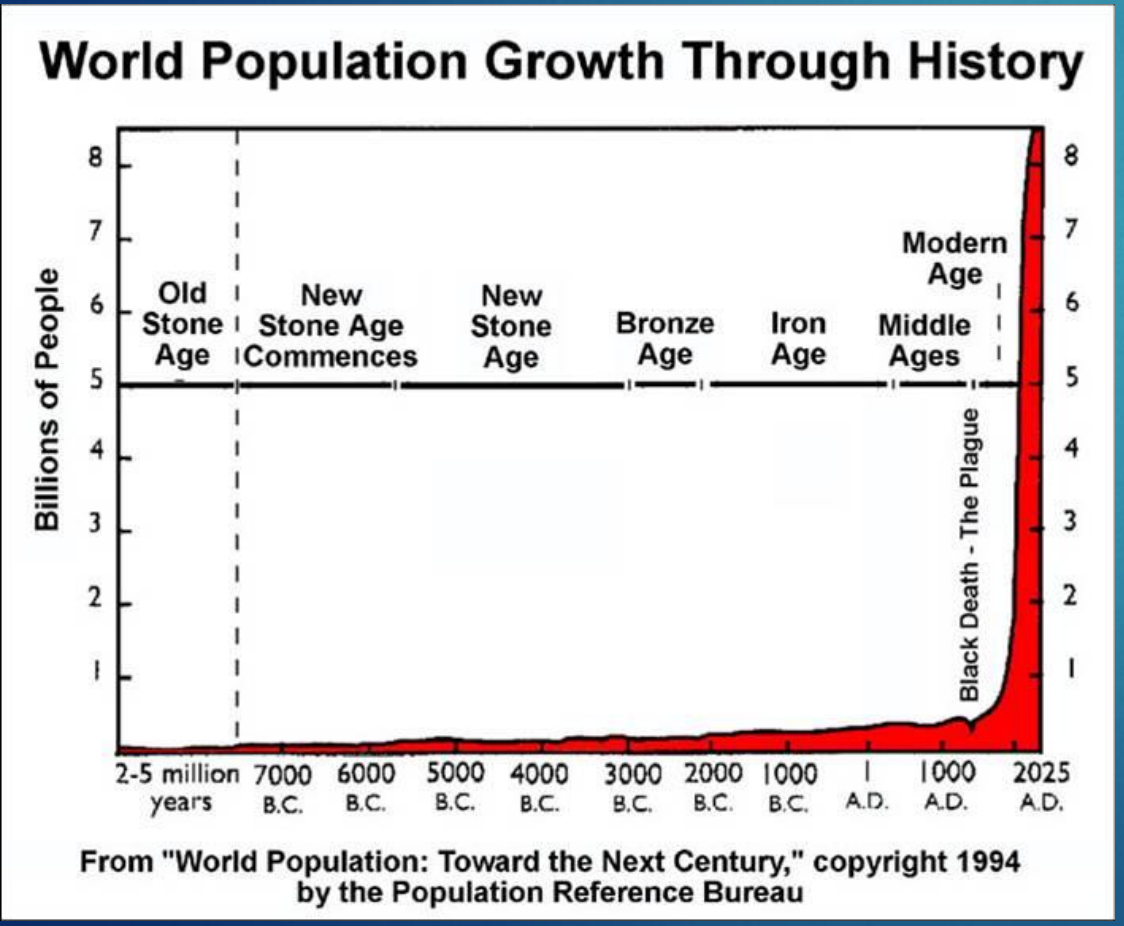
Left behind in an energy race?

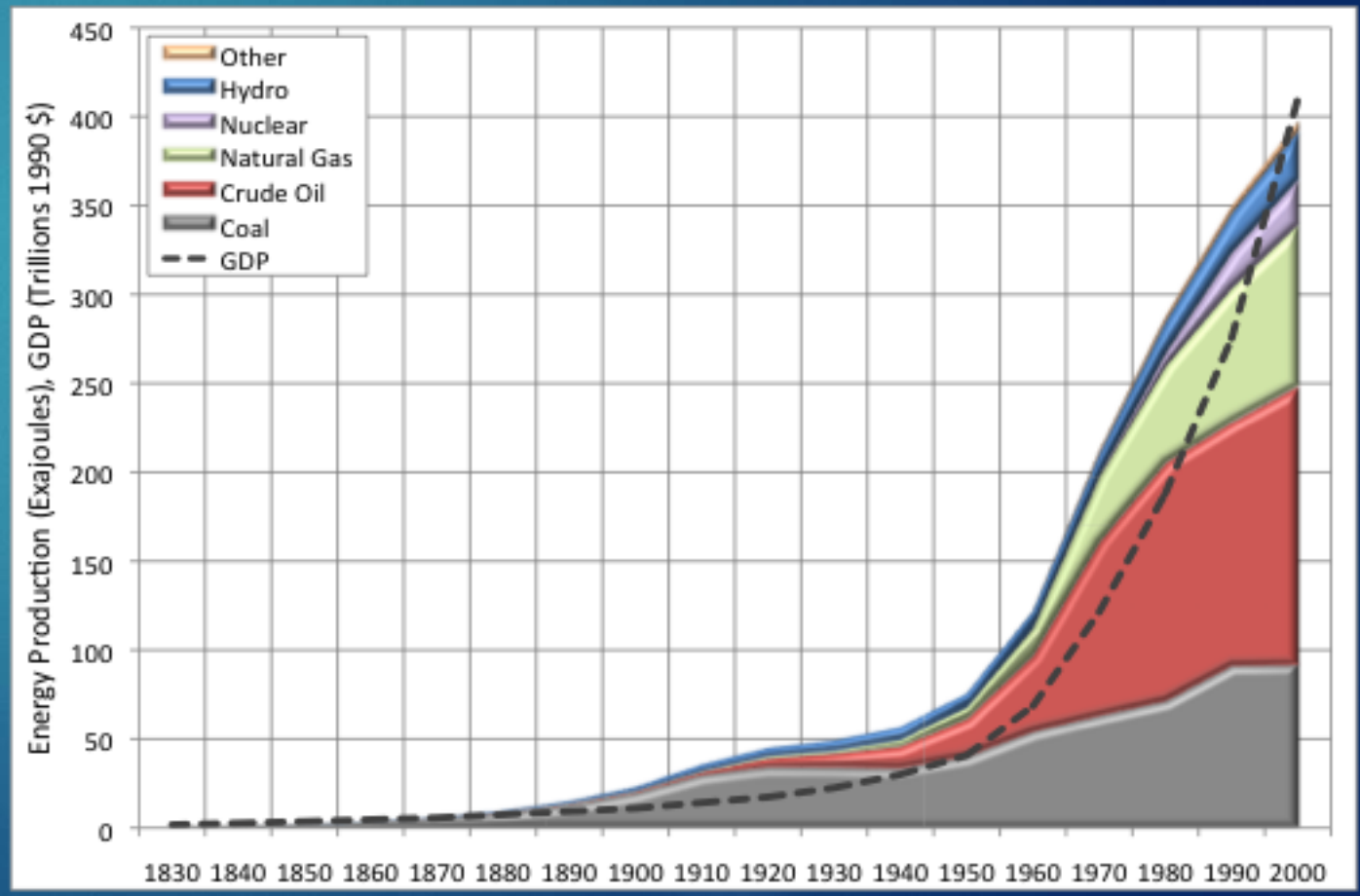


"And now there go the Wilsons! . . . Seems like everyone's evolving except us!"

Evolution of agriculture increased Energy Return on Energy Invested, EROI, And allowed the development of cities

III. The impact of petroleum discovery and increase





33 HP animal power (controlled by 5 workers plus)

Land for feed, Human work, Water and soil, Stables

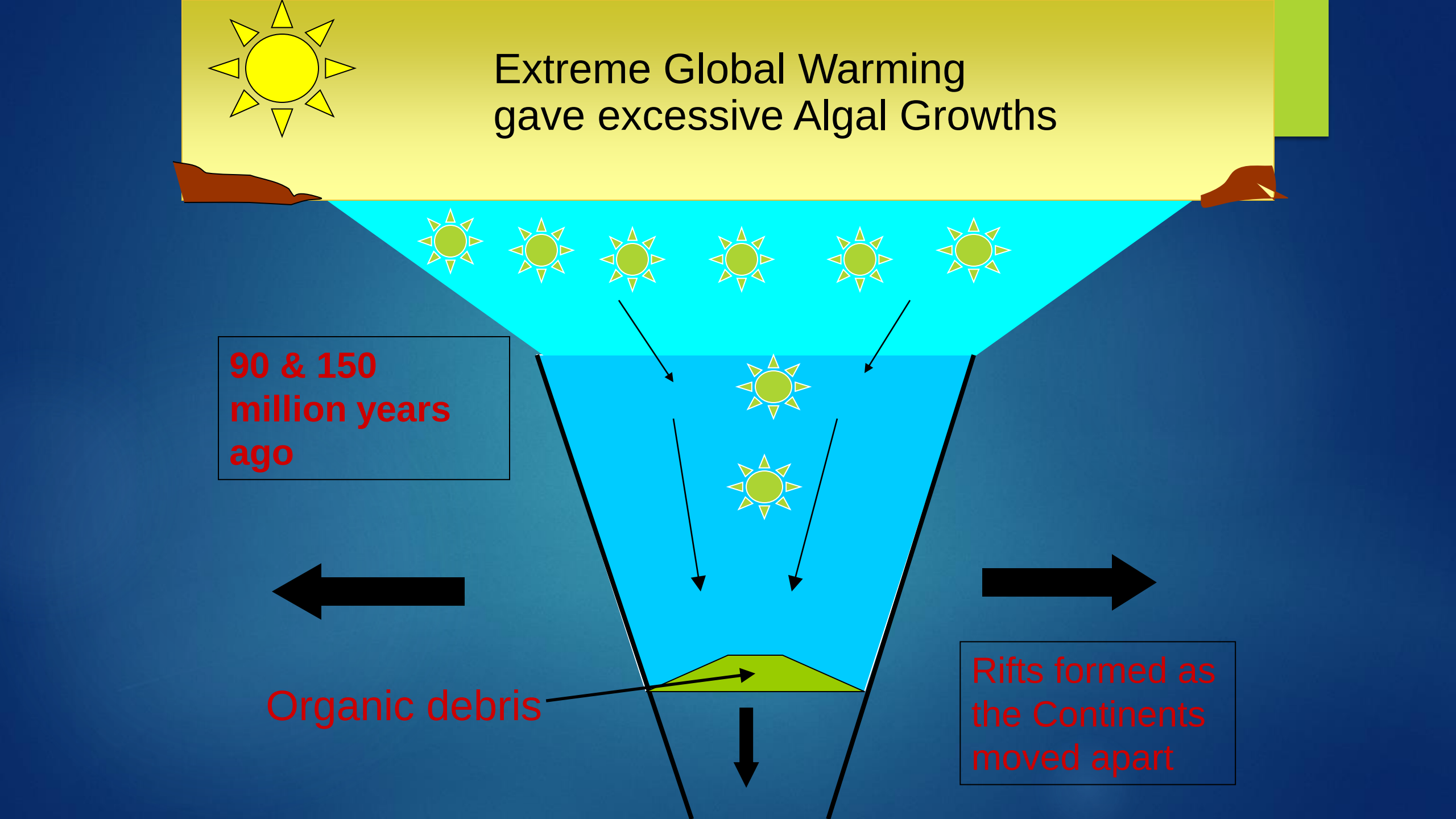
200 HP mechanical power (controlled by 1 worker)

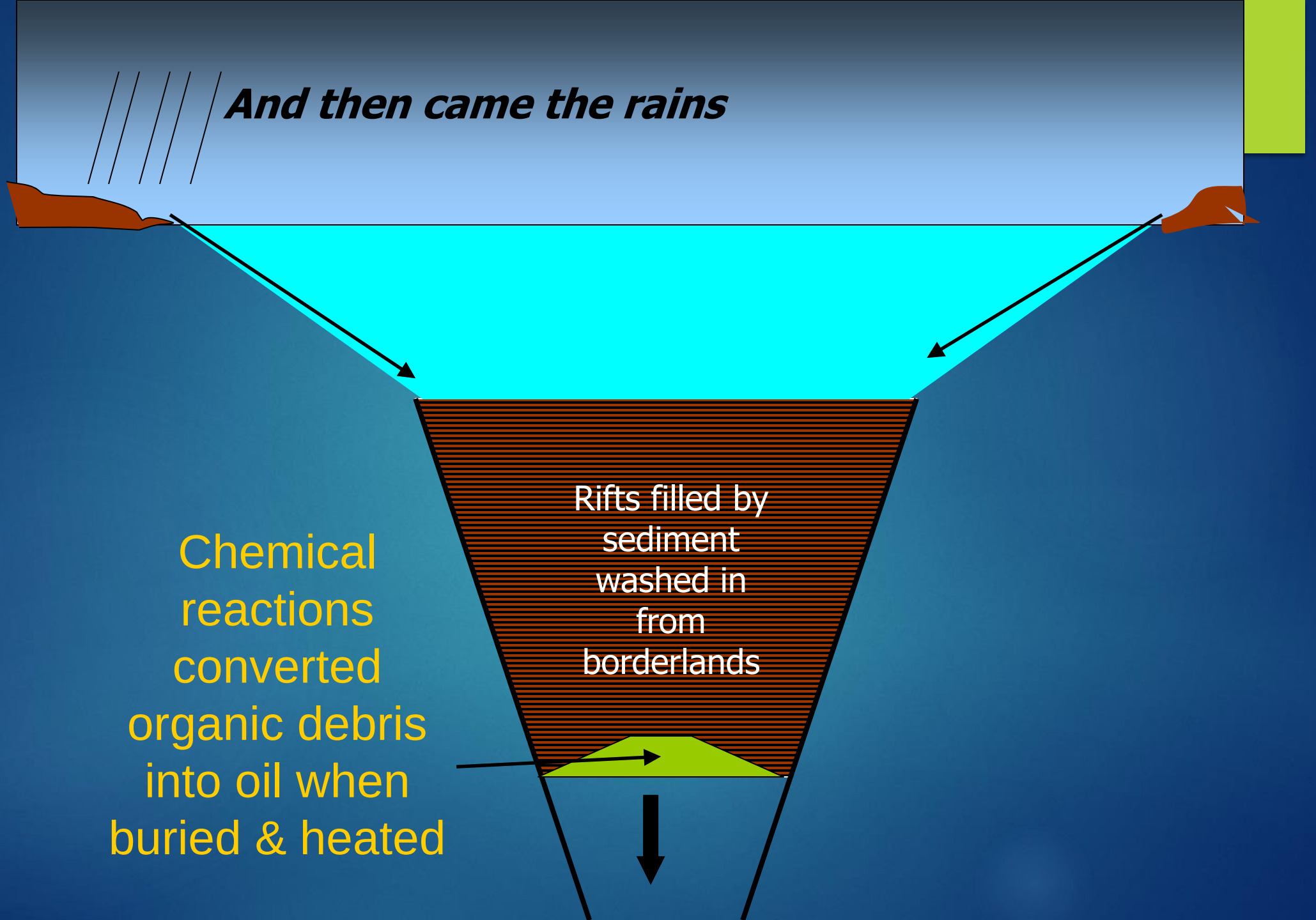
- The use of fossil (old) energy creates an entirely new resource for humans:

- enormously greater than in the past

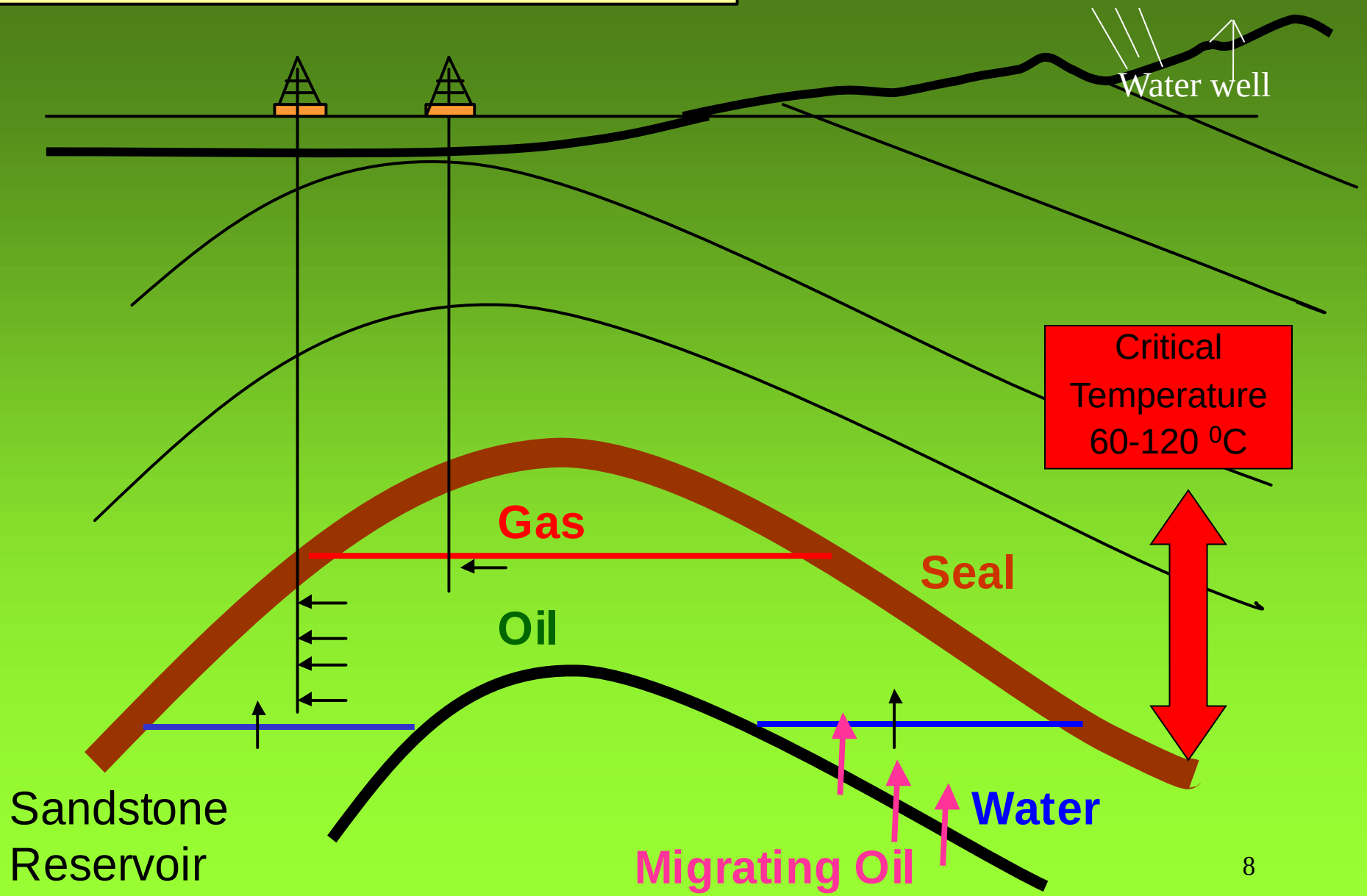
IV. PETROLEUM GEOLOGY in 3 Minutes

(Thanks to Colin Campbell)


Extreme Global Warming
gave excessive Algal Growths
90 & 150
million years
ago
Organic debris
Rifts formed as
the Continents
moved apart


And then came the rains
Rifts filled by sediment washed in from borderlands
Chemical reactions converted organic debris into oil when buried & heated

Geology of an Oilfield



- The important thing for today is that, geologically, this is a relatively rare event

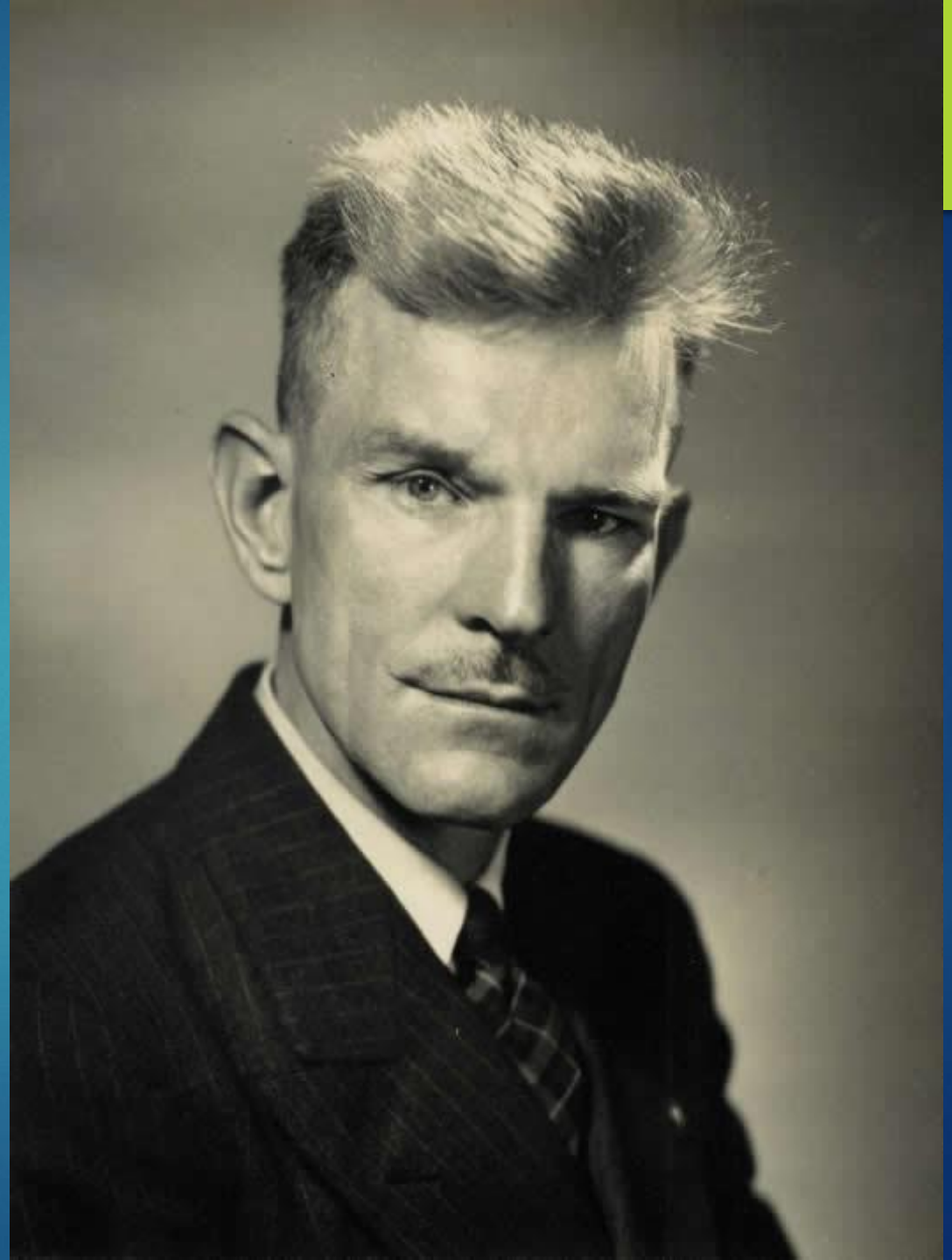
V. PATTERN OF USE OVER TIME

M. King Hubbert

1903-1989

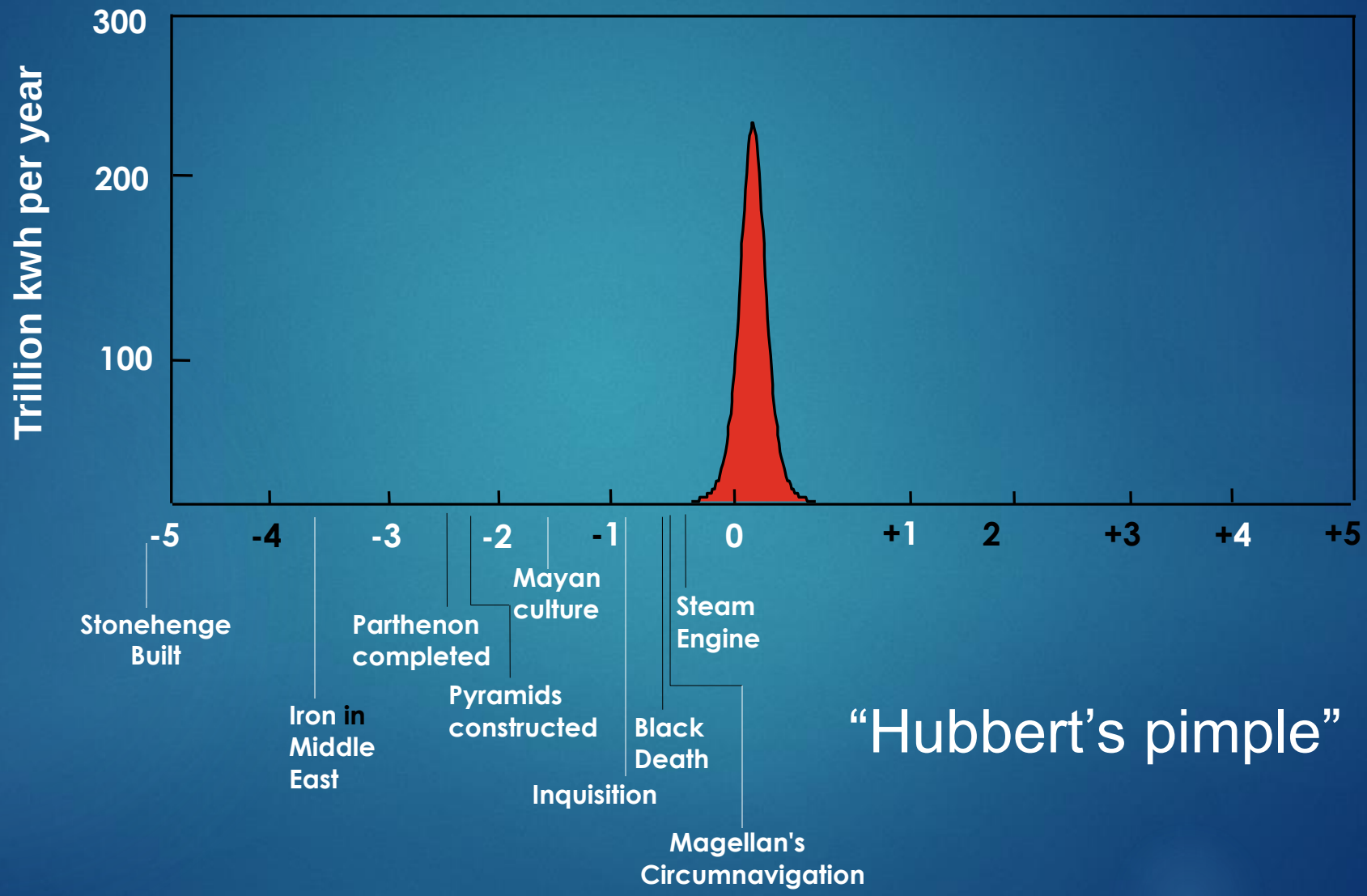
America's greatest Scientist?

- Geophysicist at the Shell lab in Houston, Texas
- In 1956, he wrote a paper with predictions for the peak year of US oil production



The Epoch of Fossil Fuel Exploitation

(after Hubbert, 1969)



"Hubbert's pimple"

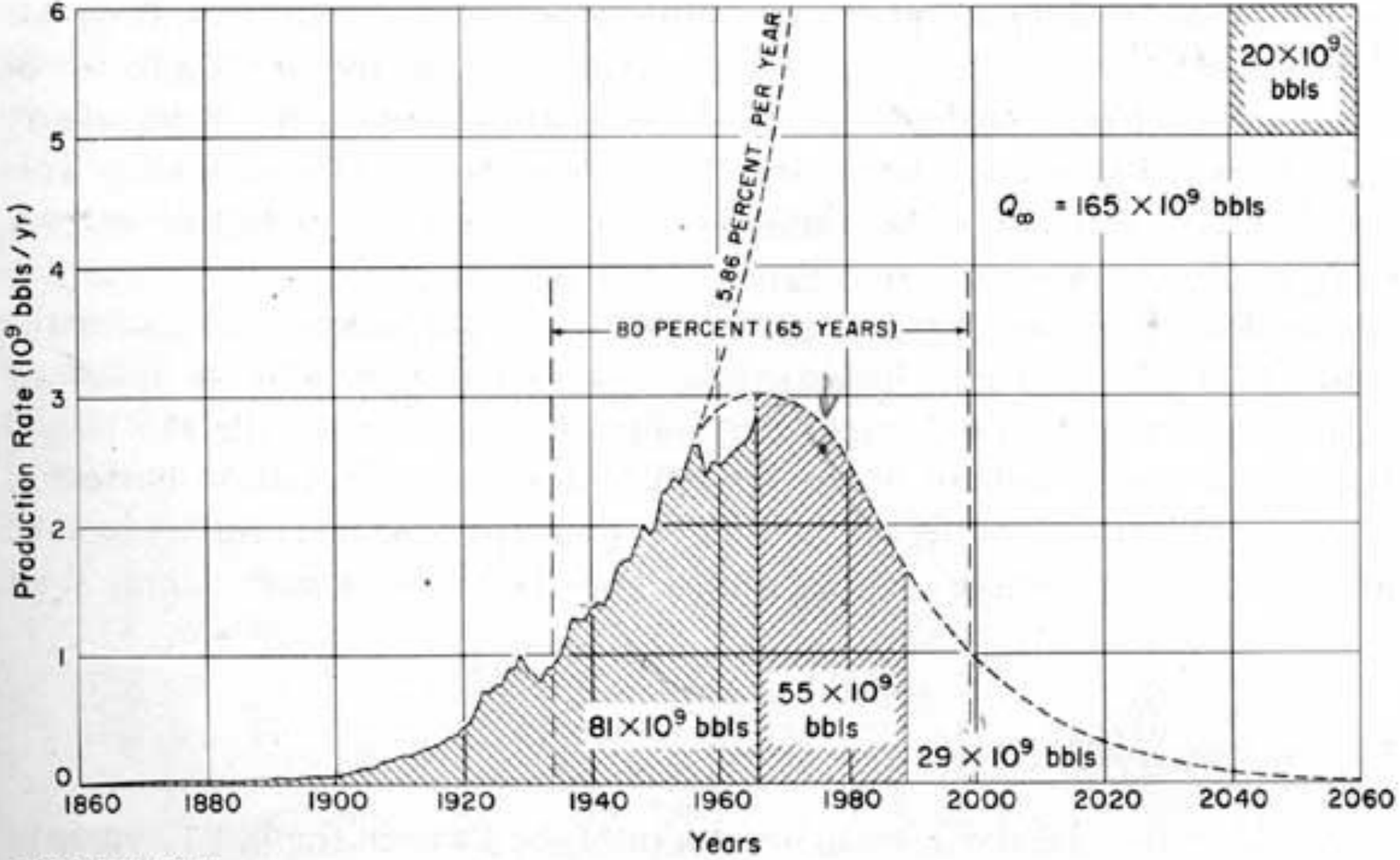
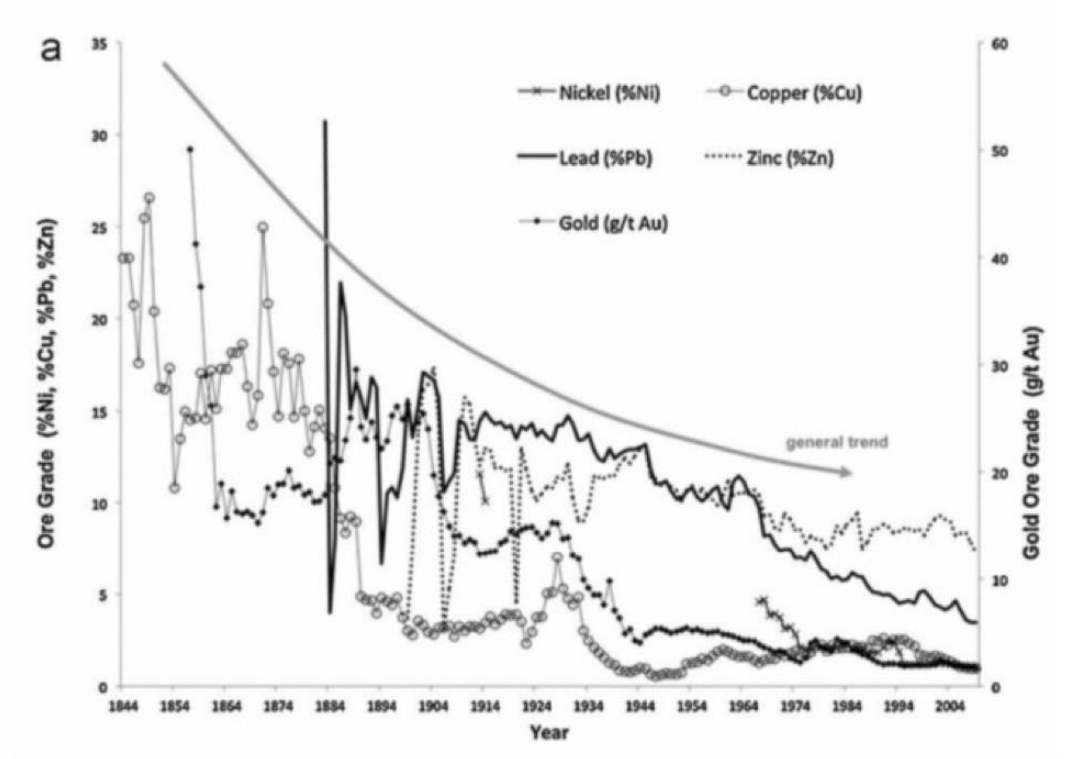


FIGURE 8.17
Complete cycle of crude-oil production in the United States and adjacent continental shelves, exclusive of Alaska.

Depletion

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

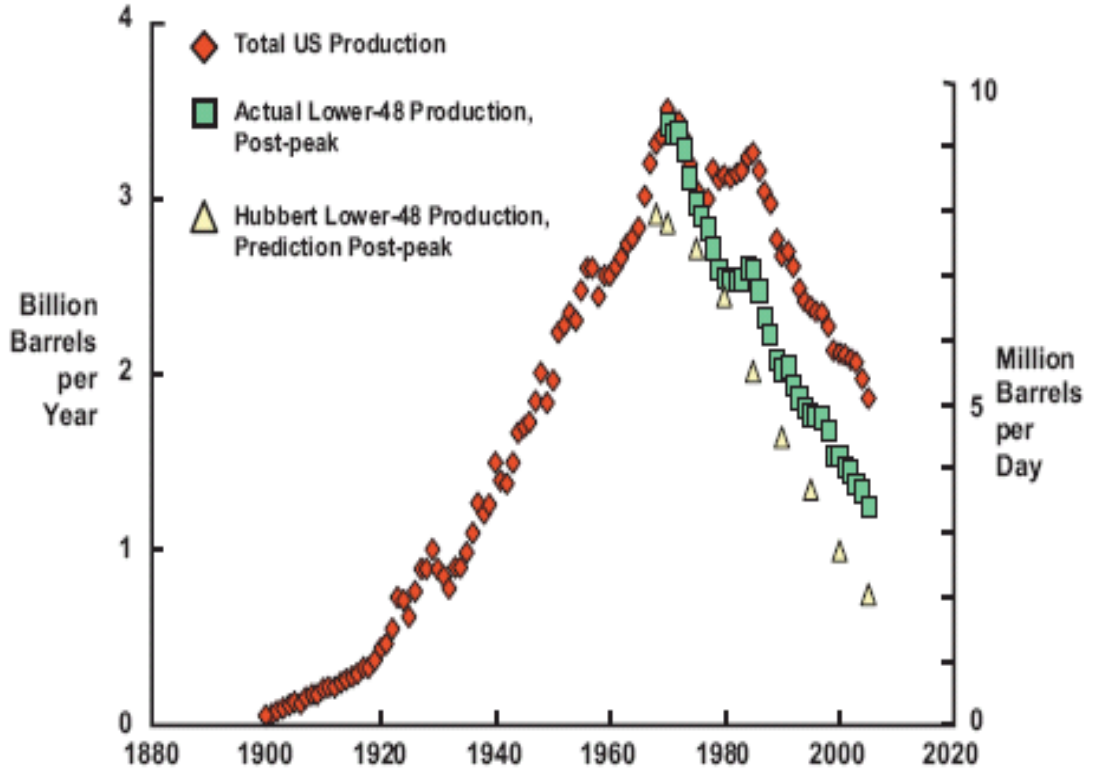


r, T., Giurco, D., Mudd, G., Mason, L., Behrisch, J. 2012) Diagram reproduced by permission o

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

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

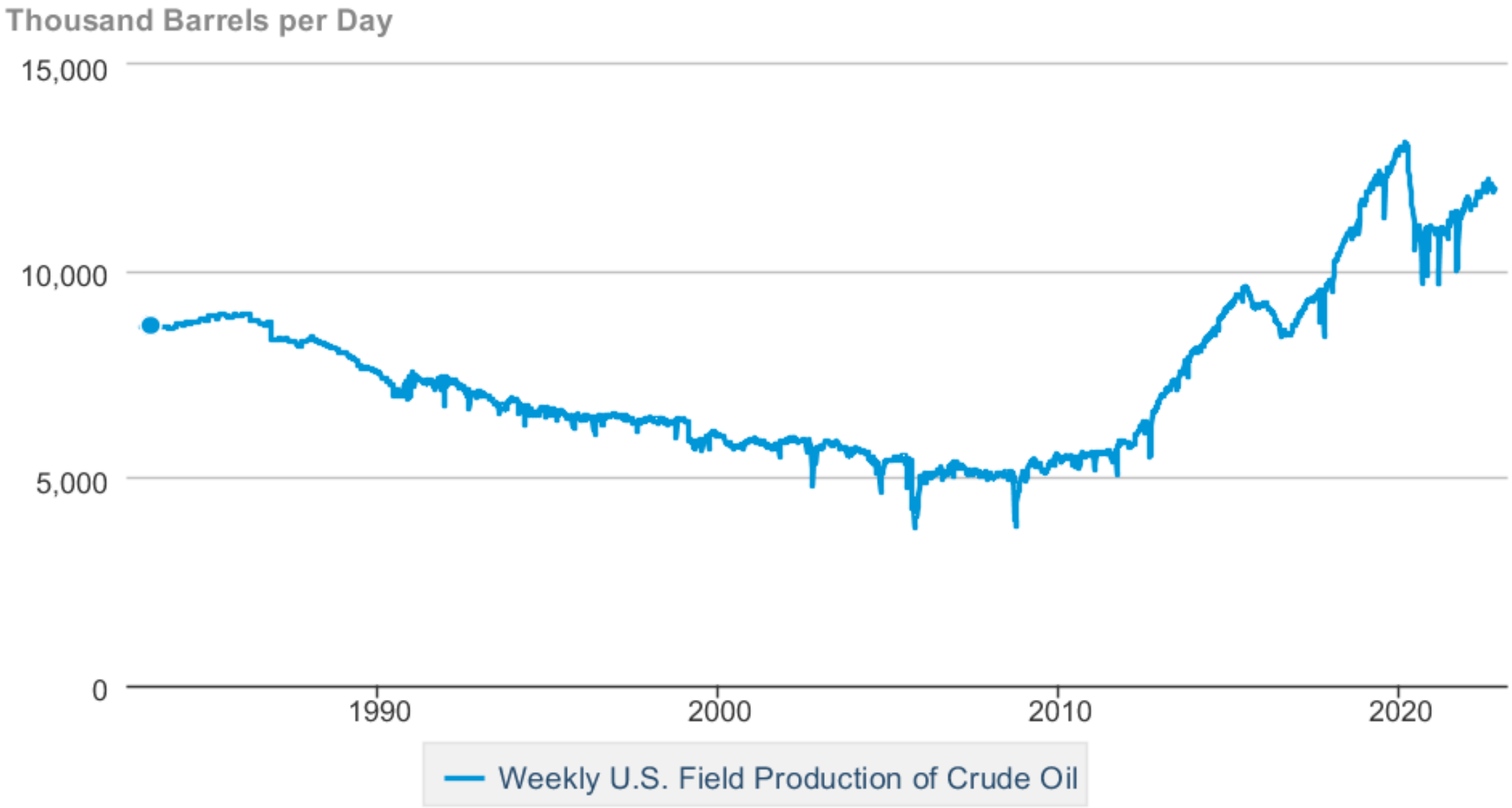
United States Production, Hubbert versus Actual



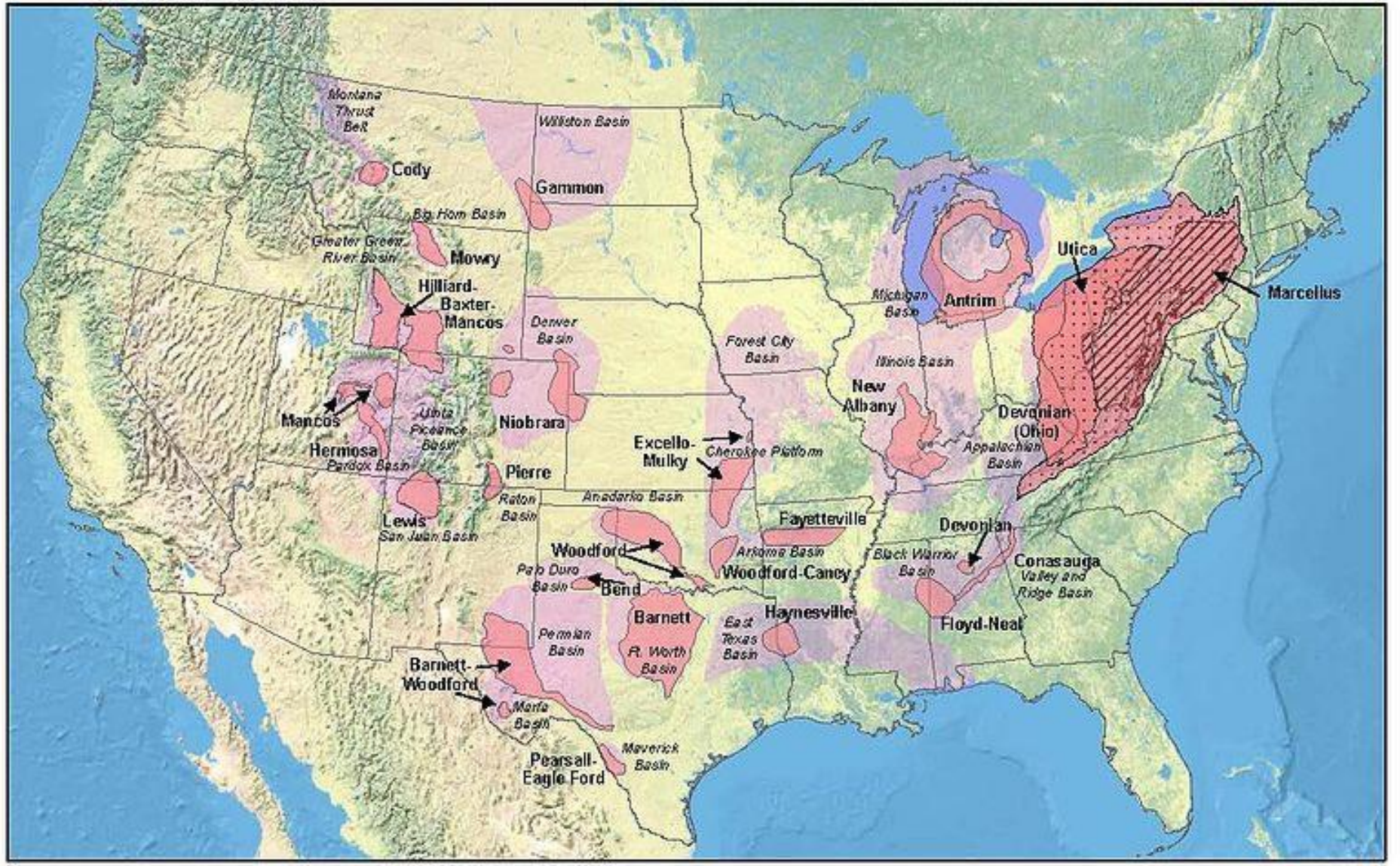
Source: Cambridge Energy Research Associates.
61019-1

But what about fracking?

Weekly U.S. Field Production of Crude Oil



eia Source: U.S. Energy Information Administration



United States Shale Gas Plays

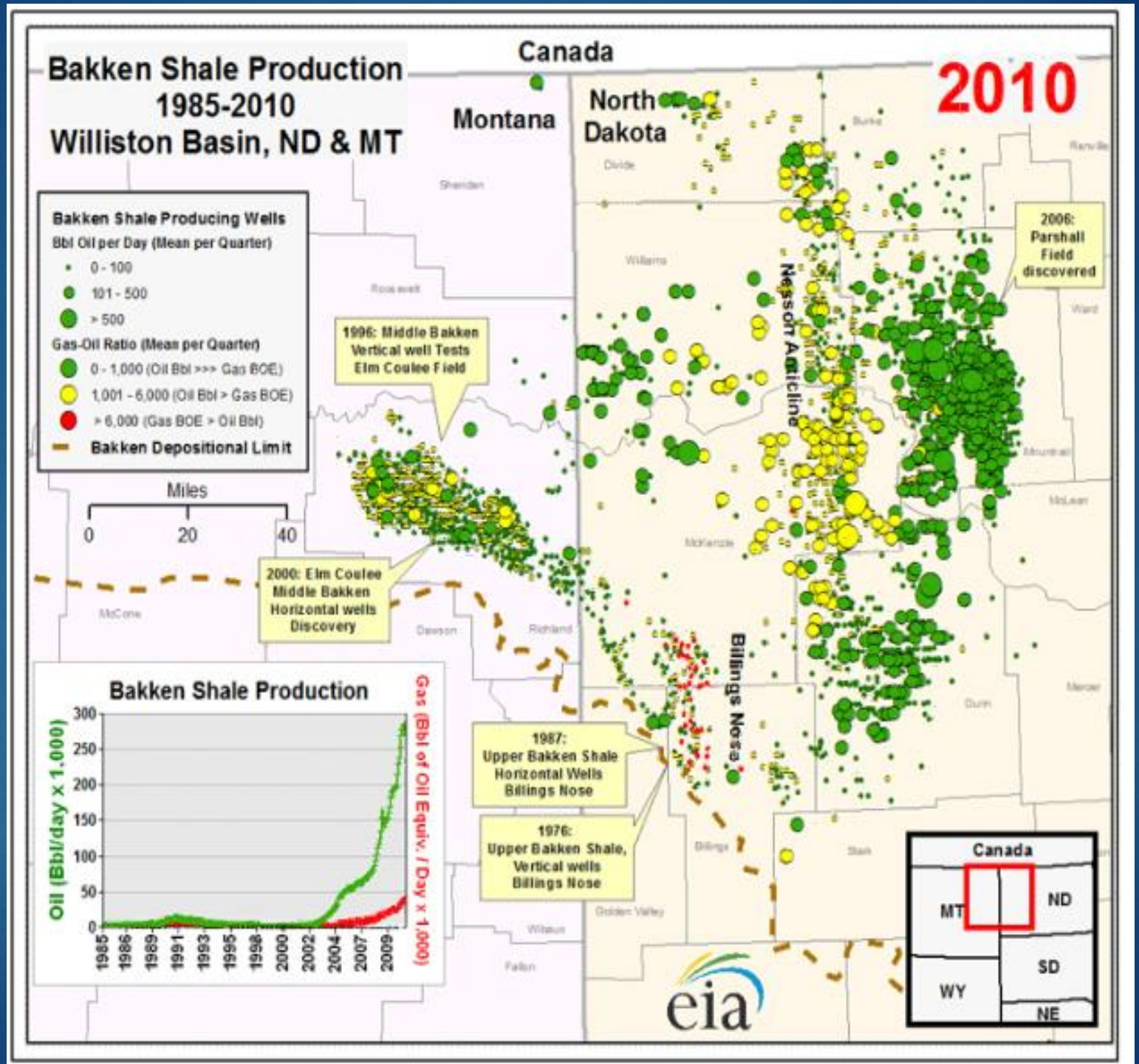
www.eia.doe.gov
Energy Information Administration
Office of Oil and Gas

Shale Gas Plays
Basins

Stacked Appalachian Plays
Marcellus
Utica
Devonian (OH shale)

November 2008
Miles
0 150 300 600

N

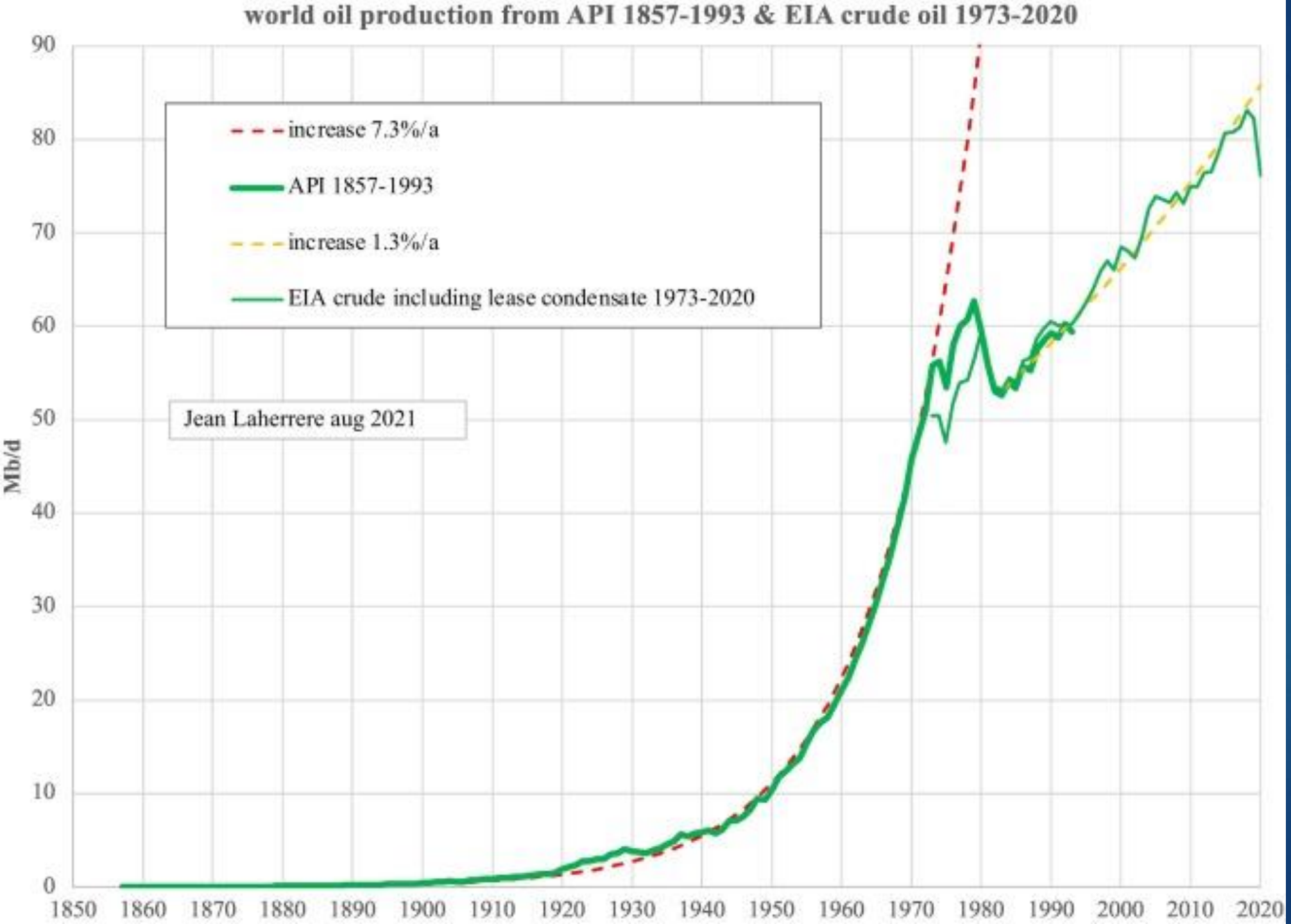

Bakken Shale Production
1985-2010
Williston Basin, ND & MT
Canada
Montana
North Dakota
2010
Bakken Shale Producing Wells
Bbl Oil per Day (Mean per Quarter)
0 - 100
101 - 500
> 500
Gas-Oil Ratio (Mean per Quarter)
0 - 1,000 (Oil Bbl >>> Gas BOE)
1,001 - 6,000 (Oil Bbl > Gas BOE)
> 6,000 (Gas BOE > Oil Bbl)
Bakken Depositional Limit
Miles
0
20
40
1996: Middle Bakken Vertical well Tests Elm Coulee Field
2006: Parshall Field discovered
Nesson Anticline
2000: Elm Coulee Middle Bakken Horizontal wells Discovery
Billings Nose
1987: Upper Bakken Shale Horizontal Wells Billings Nose
1976: Upper Bakken Shale, Vertical wells Billings Nose
Bakken Shale Production
Oil (Bbl/day x 1,000)
Gas (Bbl of Oil Equiv. / Day x 1,000)
300
250
200
150
100
50
0
1985
1986
1989
1991
1993
1995
1998
2000
2002
2004
2007
2009
Canada
MT
ND
SD
WY
NE
eia

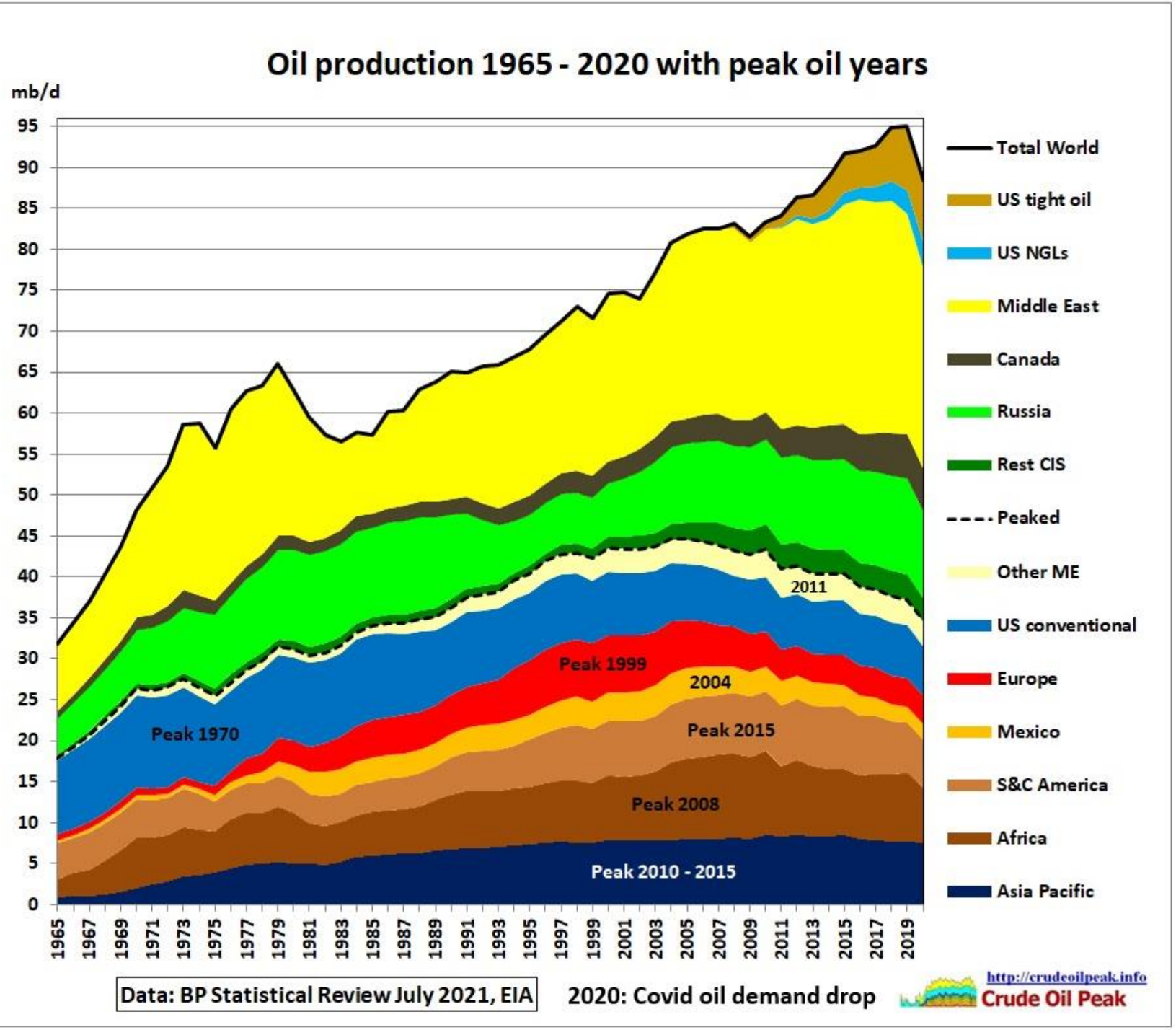
The “sweet spots “ are pretty much all developed

VI. Our new study:

- **How much oil remains for the world to produce? Comparing assessment methods, and separating fact from fiction**
- Jean Laherrère, Charles A.S.Hall, Roger Bentley

- Current Research in Environmental Sustainability
- Volume 4, 2022, 100174


world oil production from API 1857-1993 & EIA crude oil 1973-2020
increase 7.3%/a
API 1857-1993
increase 1.3%/a
EIA crude including lease condensate 1973-2020
Jean Laherrere aug 2021
Mb/d
90
80
70
60
50
40
30
20
10
0
1850
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020



- Peak oil has occurred already for Asia, Africa, Europe, S&C America… all but NA & ME
- Also, for some 36 of 44 oil producing nations (Hallock et al. 2014)

What is oil?

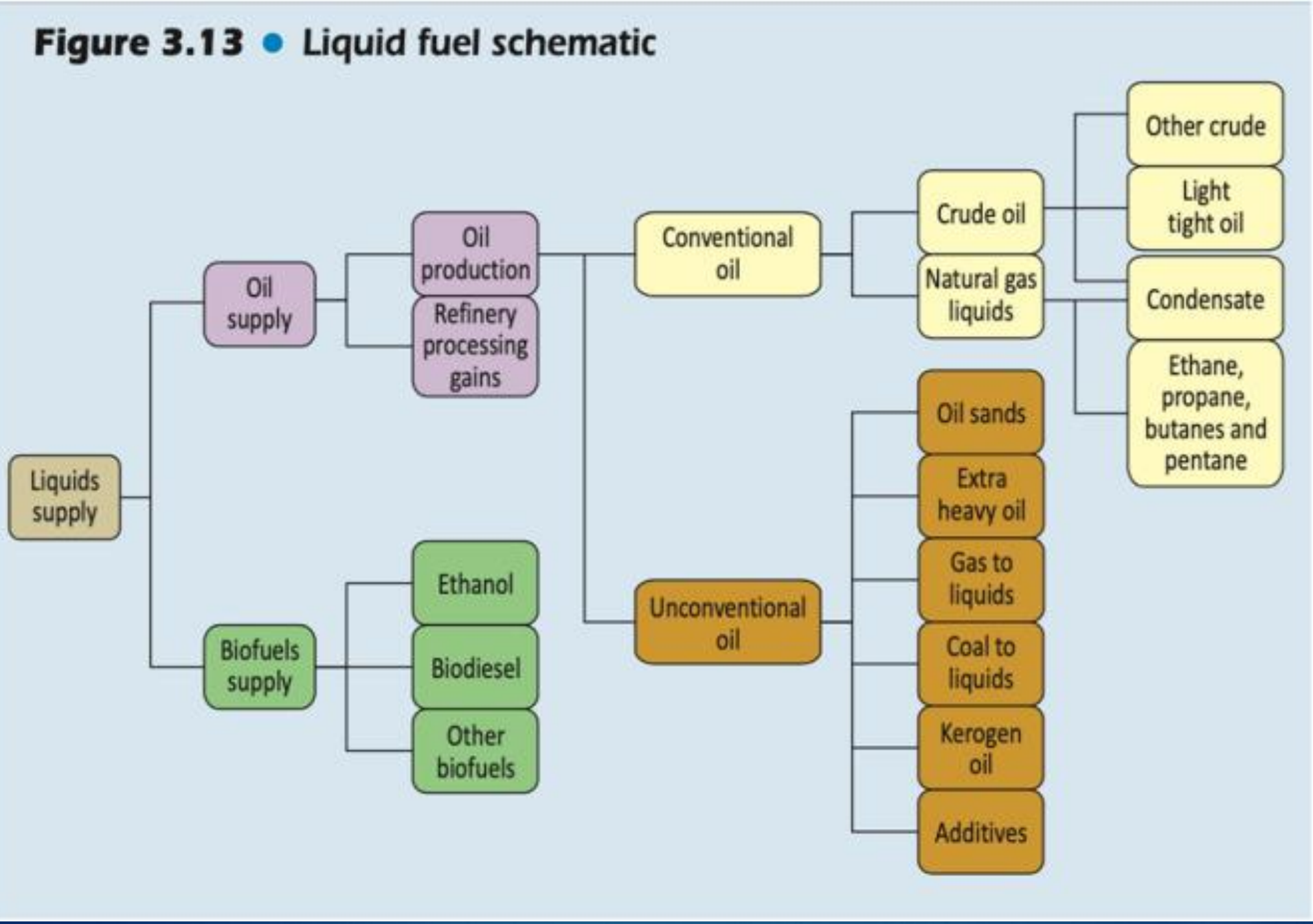
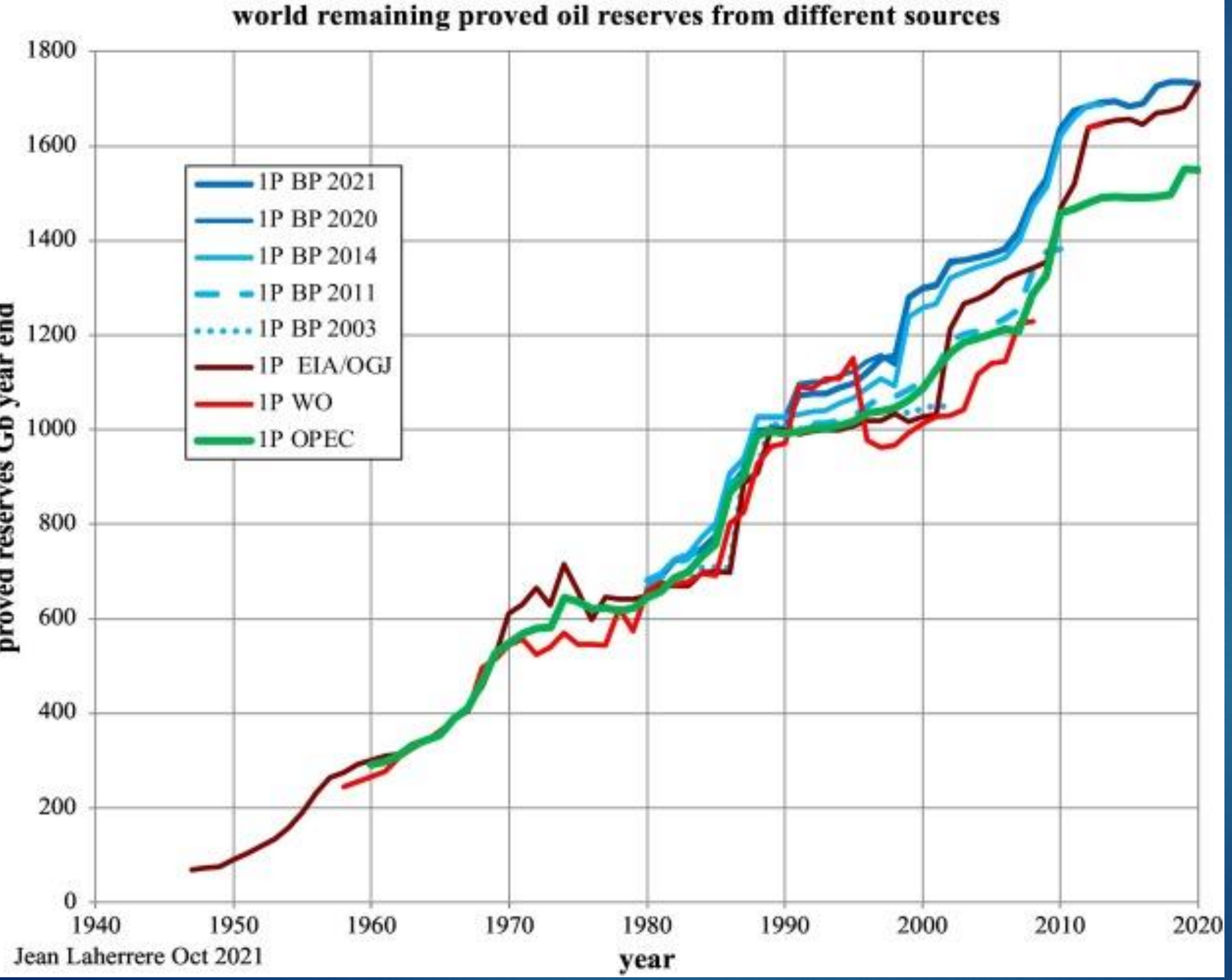


Figure 3.13 • Liquid fuel schematic
Liquids supply
Oil supply
Oil production
Refinery processing gains
Biofuels supply
Ethanol
Biodiesel
Other biofuels
Conventional oil
Unconventional oil
Crude oil
Natural gas liquids
Other crude
Light tight oil
Condensate
Ethane, propane, butanes and pentane
Oil sands
Extra heavy oil
Gas to liquids
Coal to liquids
Kerogen oil
Additives



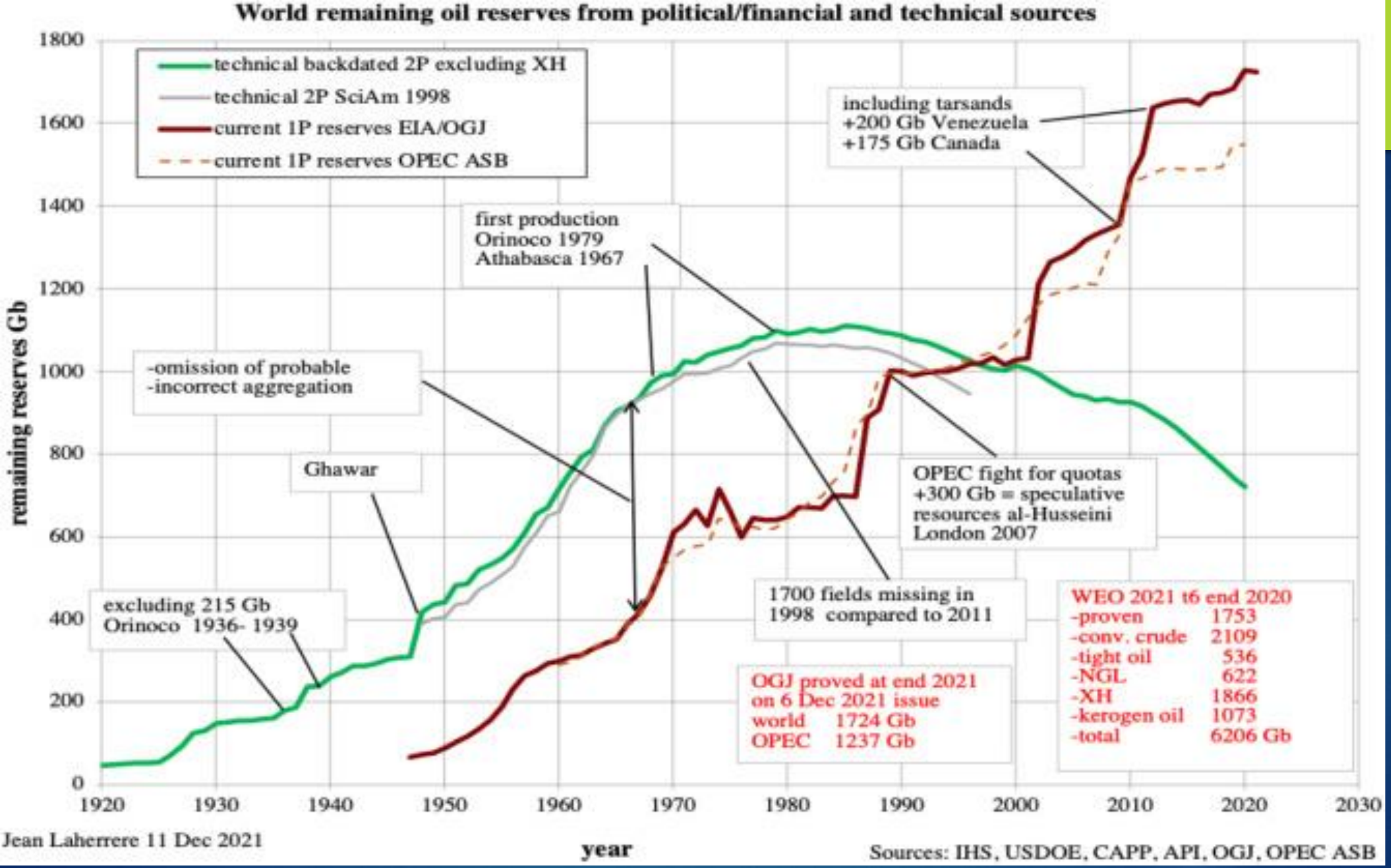
Official estimates of remaining oil are reassuring

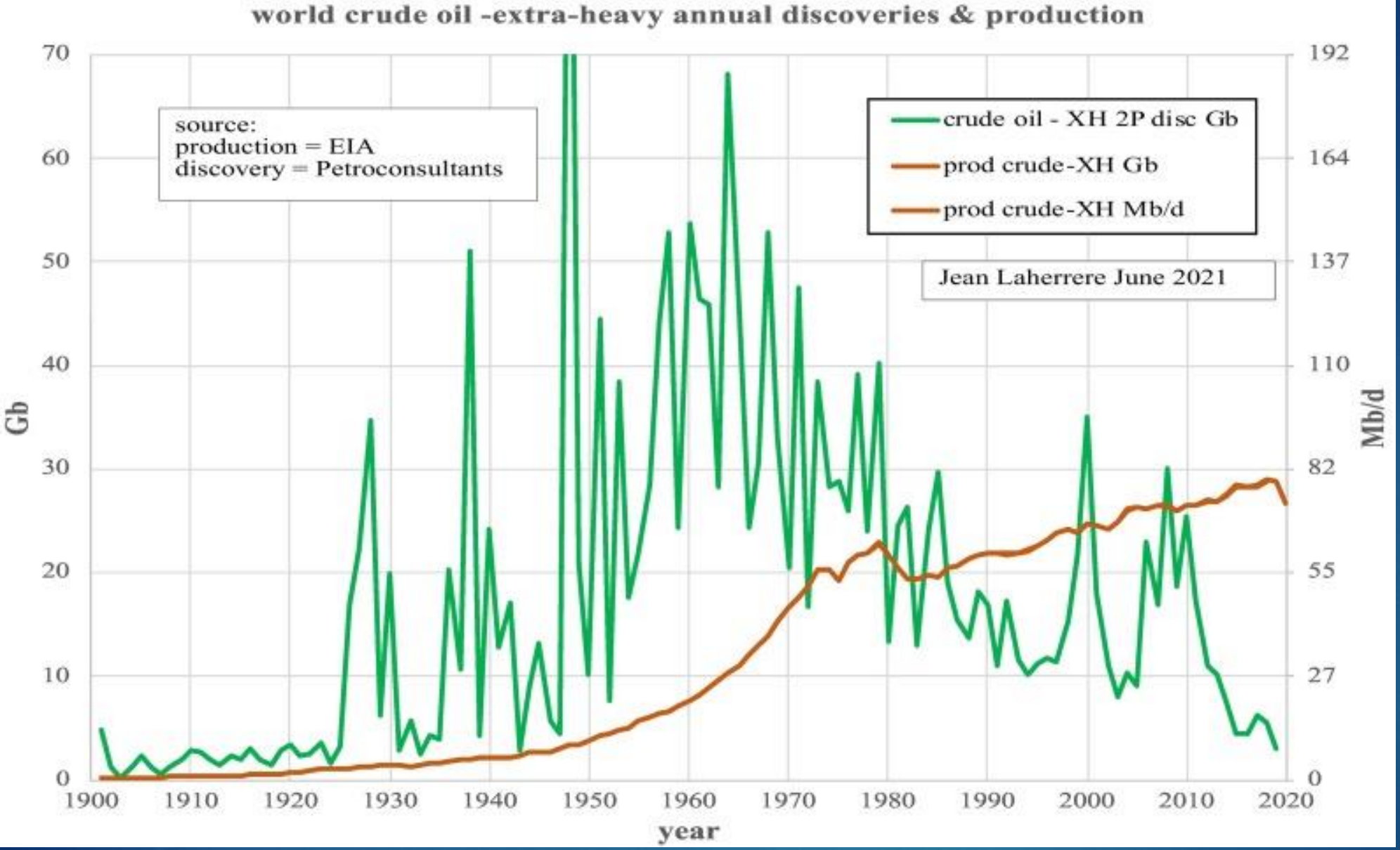
- But how are these estimates obtained?

The critical issue of year of attribution

Most “new” oil is in fact a “revision” or “extension” of an earlier find….

…often decades earlier


World remaining oil reserves from political/financial and technical sources
technical backdated 2P excluding XH
technical 2P SciAm 1998
current 1P reserves EIA/OGJ
current 1P reserves OPEC ASB
including tarsands
+200 Gb Venezuela
+175 Gb Canada
first production
Orinoco 1979
Athabasca 1967
-omission of probable
-incorrect aggregation
Ghawar
OPEC fight for quotas
+300 Gb = speculative
resources al-Husseini
London 2007
excluding 215 Gb
Orinoco 1936- 1939
1700 fields missing in
1998 compared to 2011
WEO 2021 t6 end 2020
-proven 1753
-conv. crude 2109
-tight oil 536
-NGL 622
-XH 1866
-kerogen oil 1073
-total 6206 Gb
OGJ proved at end 2021
on 6 Dec 2021 issue
world 1724 Gb
OPEC 1237 Gb
remaining reserves Gb
year
Jean Laherrere 11 Dec 2021
Sources: IHS, USDOE, CAPP, API, OGJ, OPEC ASB


world crude oil -extra-heavy annual discoveries & production
source:
production = EIA
discovery = Petroconsultants
crude oil - XH 2P disc Gb
prod crude-XH Gb
prod crude-XH Mb/d
Jean Laherrere June 2021
Gb
Mb/d
year
70
60
50
40
30
20
10
0
192
164
137
110
82
55
27
0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

How about undiscovered oil?

A “new” tool: Hubbert Linearization

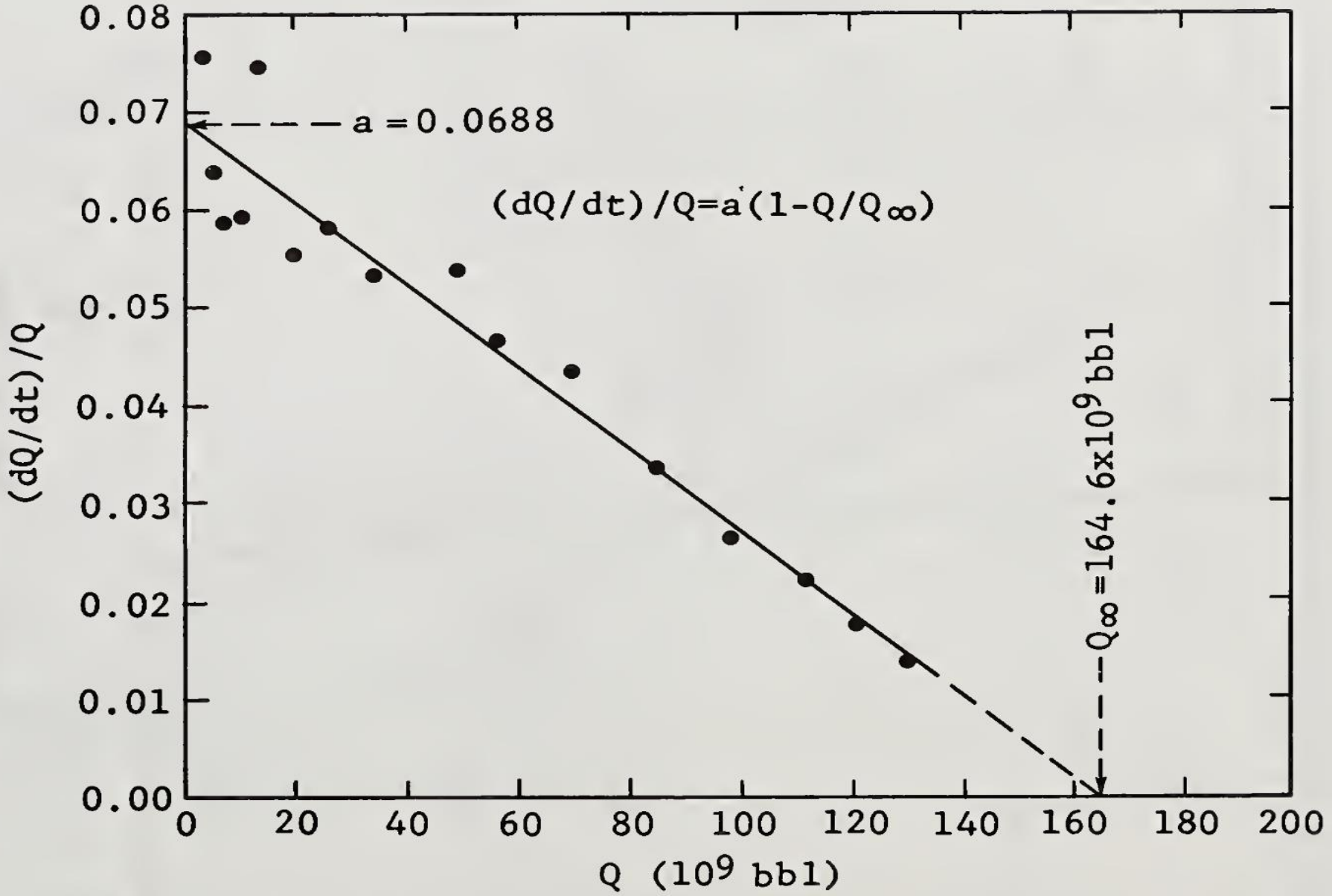
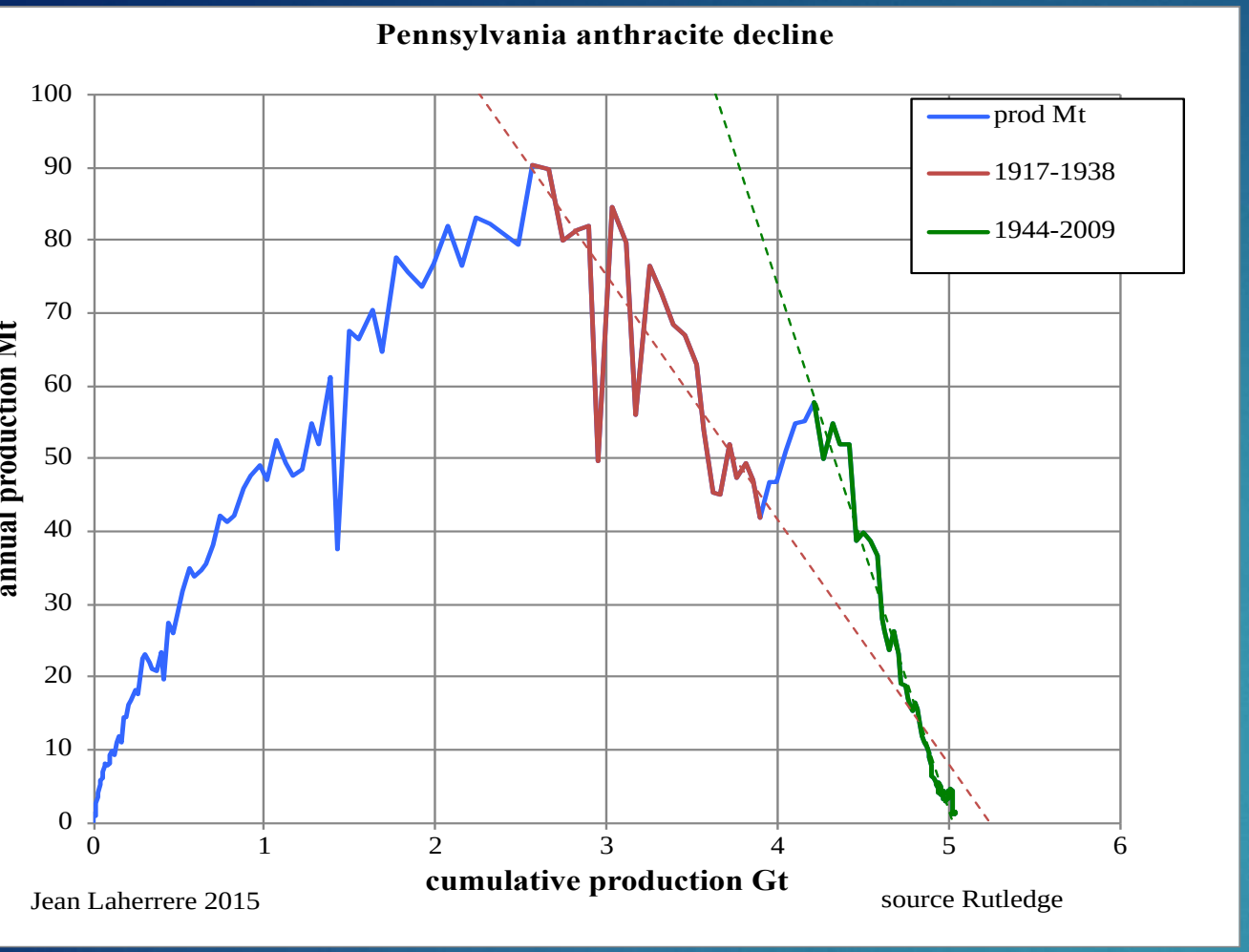
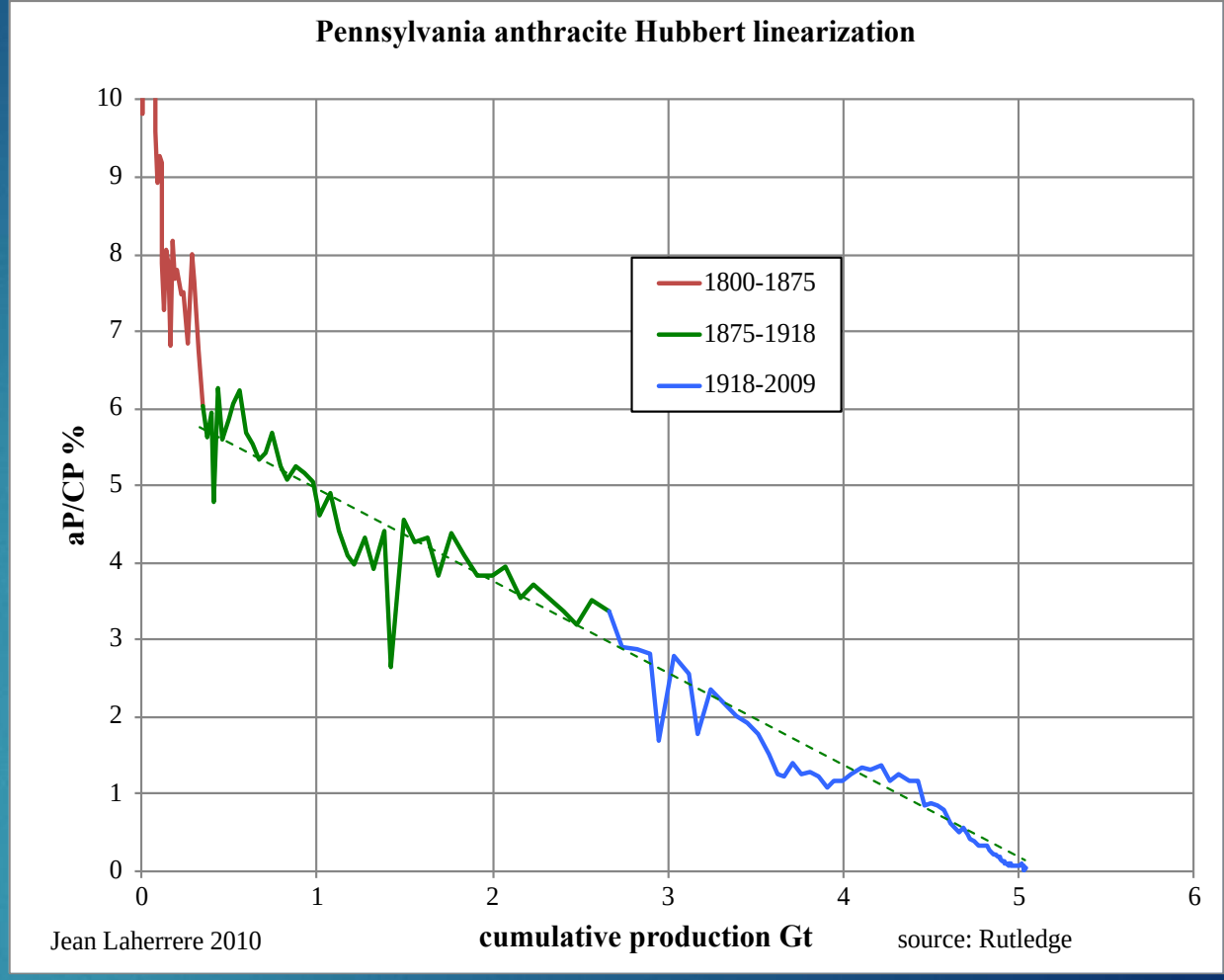


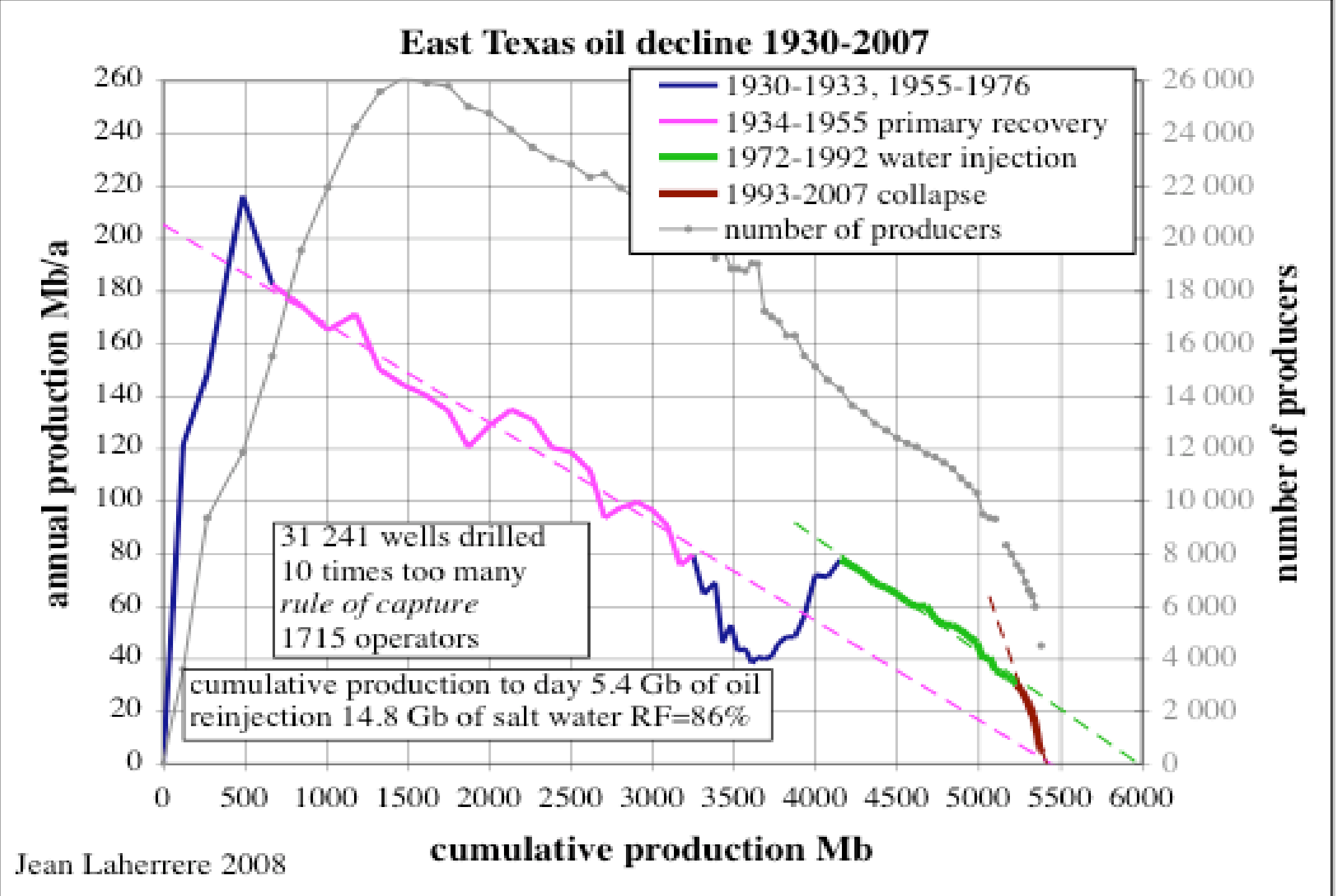
Fig. 32 - Determination of logistic-equation constants for U.S. cumulative proved crude-oil discoveries, 1860-1975, by the technique of $(dQ/dt)/Q$ versus Q.

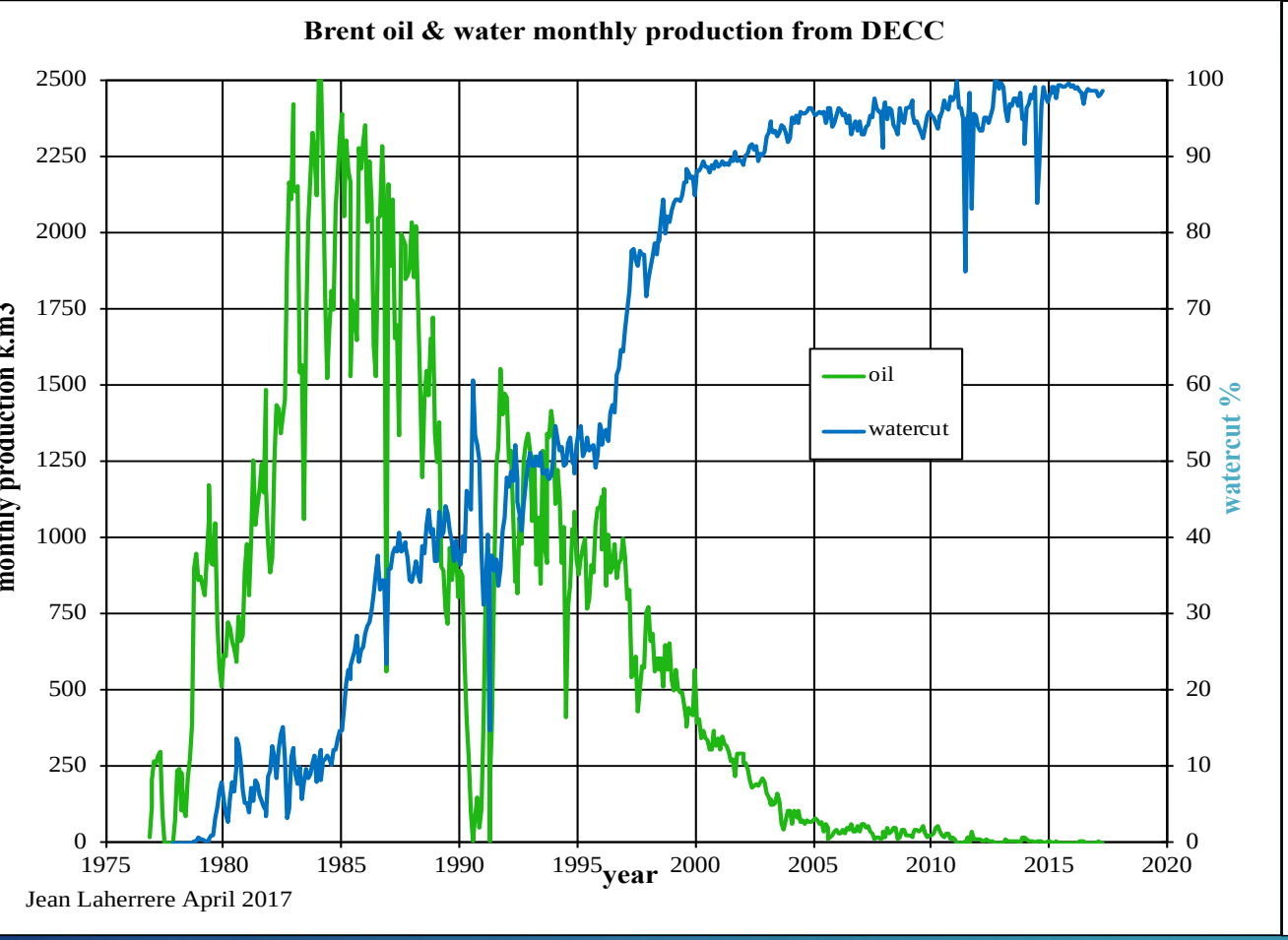
How well does it work for plays that are depleted to exhaustion?

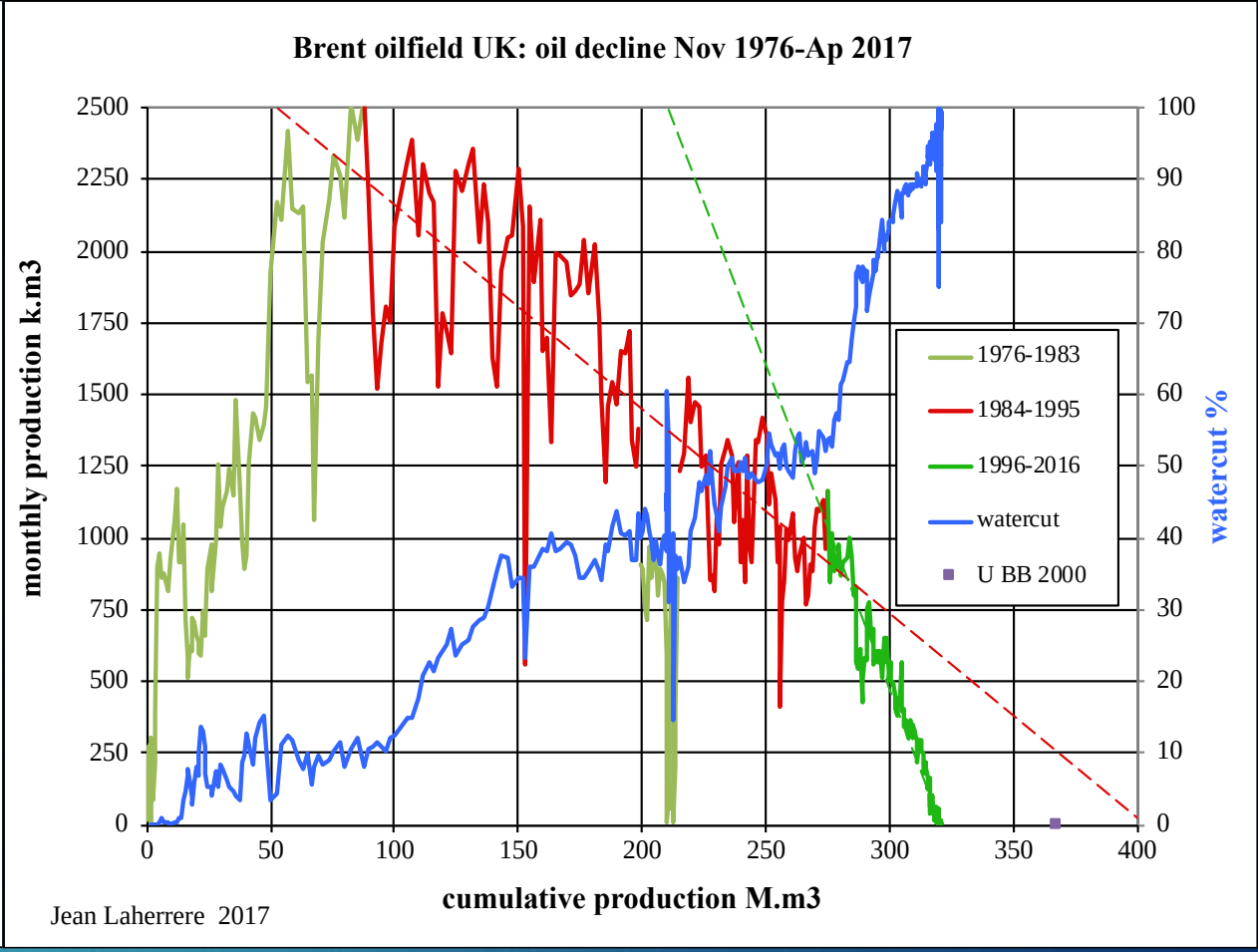




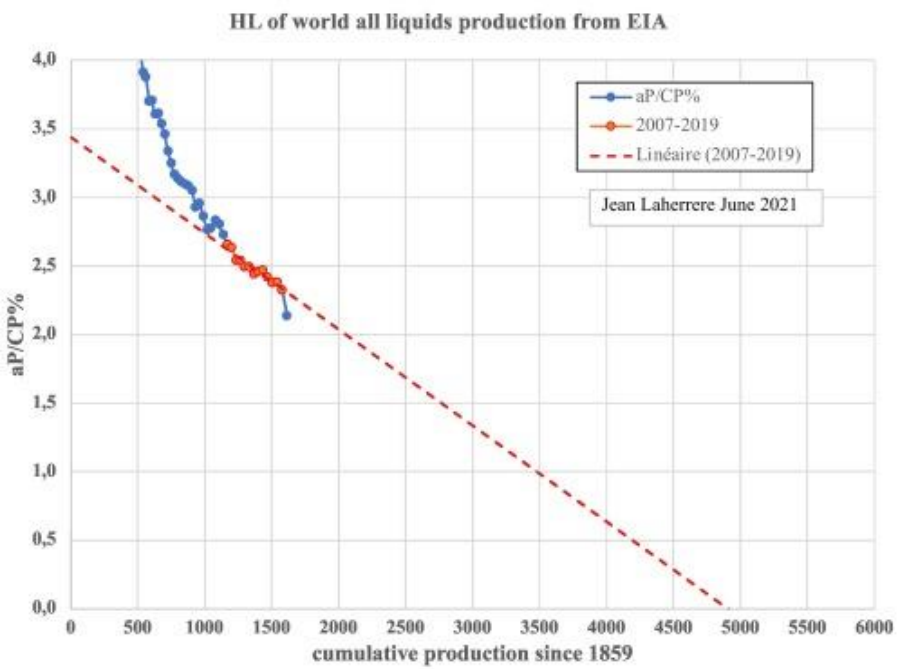
For Pennsylvania Anthracite -- perfectly

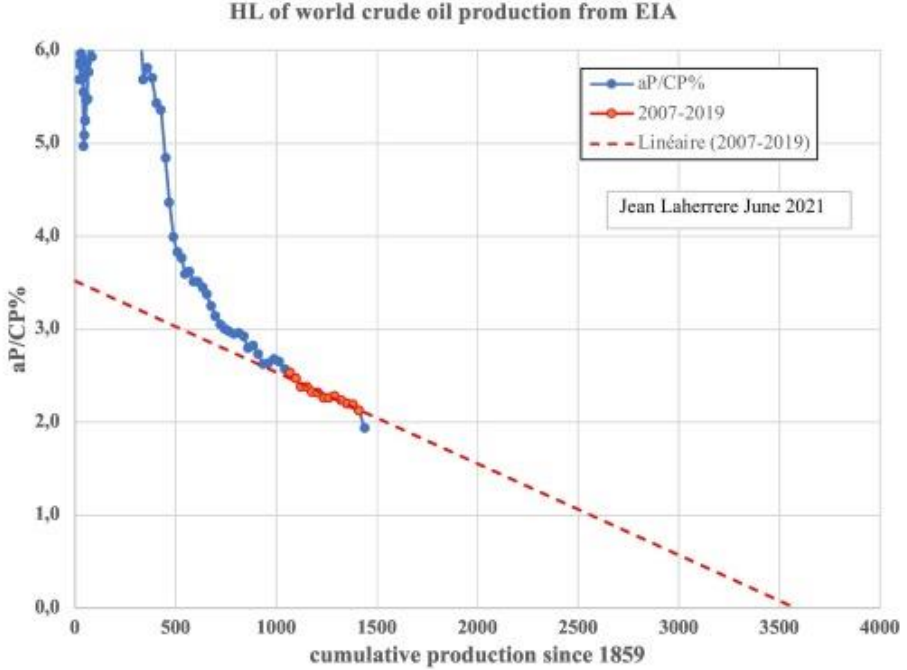

East Texas oil decline 1930-2007
1930-1933, 1955-1976
1934-1955 primary recovery
1972-1992 water injection
1993-2007 collapse
number of producers
31 241 wells drilled
10 times too many
rule of capture
1715 operators
cumulative production to day 5.4 Gb of oil
reinjection 14.8 Gb of salt water RF=86%
annual production Mb/a
number of producers
cumulative production Mb
0
20
40
60
80
100
120
140
160
180
200
220
240
260
0 2 000 4 000 6 000 8 000 10 000 12 000 14 000 16 000 18 000 20 000 22 000 24 000 26 000
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000
Jean Laherrere 2008

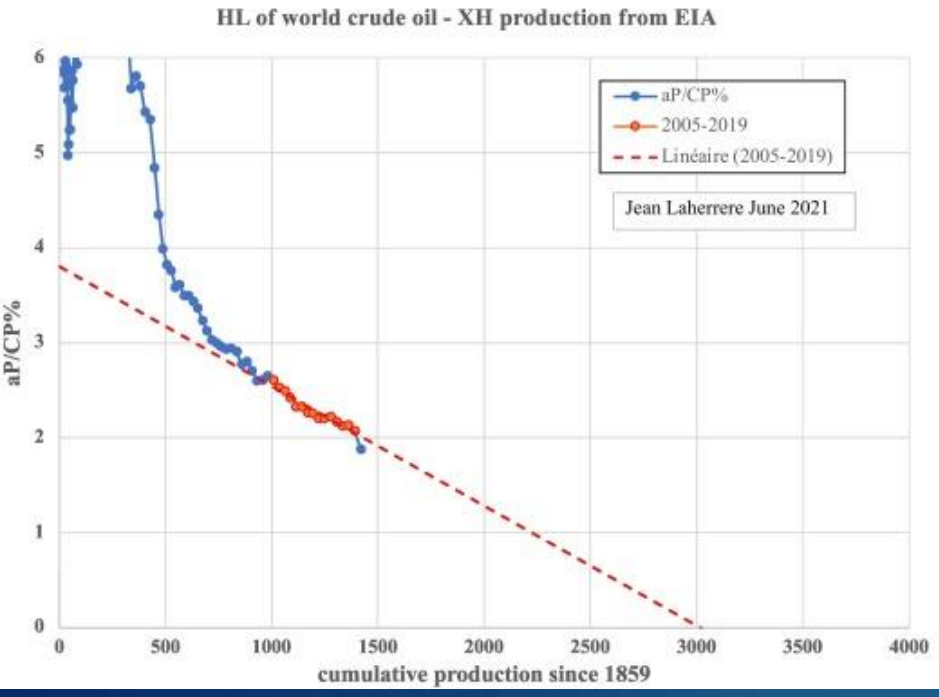


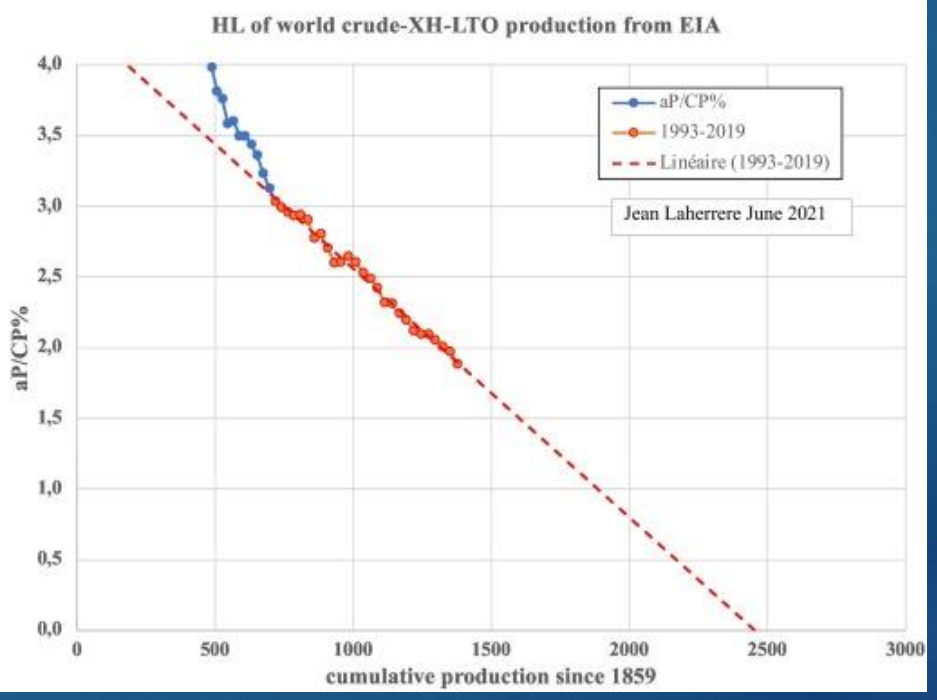


Hubbert Linearization predicts depletion


HL of world all liquids production from EIA
aP/CP%
2007-2019
Linéaire (2007-2019)
Jean Laherrere June 2021
aP/CP%
cumulative production since 1859


HL of world crude oil production from EIA
aP/CP%
2007-2019
Linéaire (2007-2019)
Jean Laherrere June 2021
aP/CP%
cumulative production since 1859

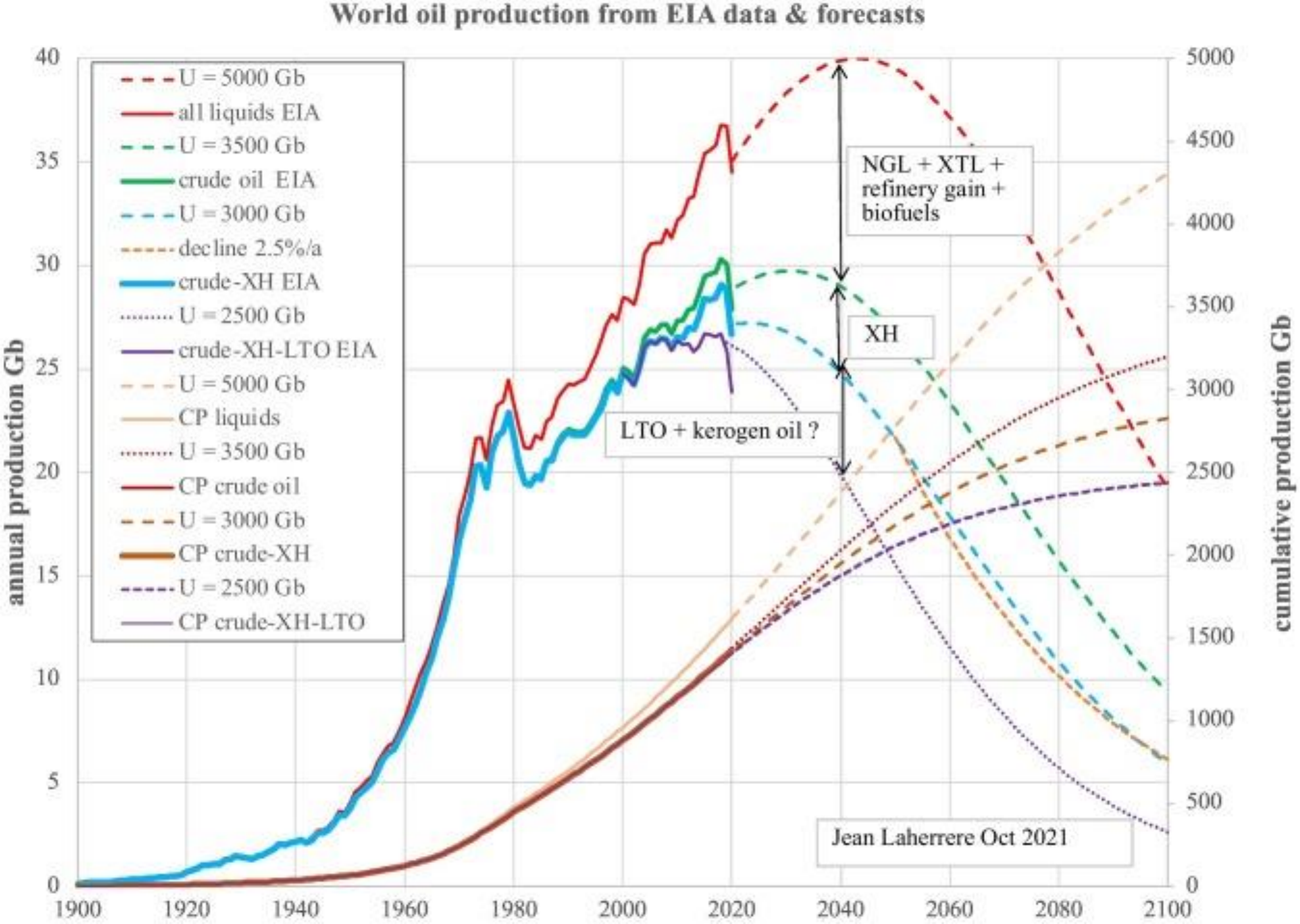

HL of world crude oil - XH production from EIA
aP/CP%
2005-2019
Linéaire (2005-2019)
Jean Laherrere June 2021
aP/CP%
cumulative production since 1859


HL of world crude-XH-LTO production from EIA
aP/CP%
1993-2019
Linéaire (1993-2019)
Jean Laherrere June 2021
aP/CP%
cumulative production since 1859

Summarizing

(Data in Gb)	Cum. prodn. to end-2020	Estd. HL ultimate	Already discovered	Yet to find	Estd. yet to produce
All-liquids	1615	5000	-	-	~3400
Crude oil	1440	3500	-	-	~2100
Crude less XH	1420	3000	-	-	~1600
Conventional oil (i.e., crude oil less XH less LTO)	1400	2500	2150	350	~1100
Hence:					
NGLs + other liquids	175	*	-	-	
XH	20	*	500	-	~480
LTO	20	55**	?	-	~35**

Note: All data approximate.


World oil production from EIA data & forecasts
annual production Gb
cumulative production Gb
U = 5000 Gb
all liquids EIA
U = 3500 Gb
crude oil EIA
U = 3000 Gb
decline 2.5%/a
crude-XH EIA
U = 2500 Gb
crude-XH-LTO EIA
U = 5000 Gb
CP liquids
U = 3500 Gb
CP crude oil
U = 3000 Gb
CP crude-XH
U = 2500 Gb
CP crude-XH-LTO
NGL + XTL + refinery gain + biofuels
XH
LTO + kerogen oil ?
Jean Laherrere Oct 2021
0
5
10
15
20
25
30
35
40
0
500
1000
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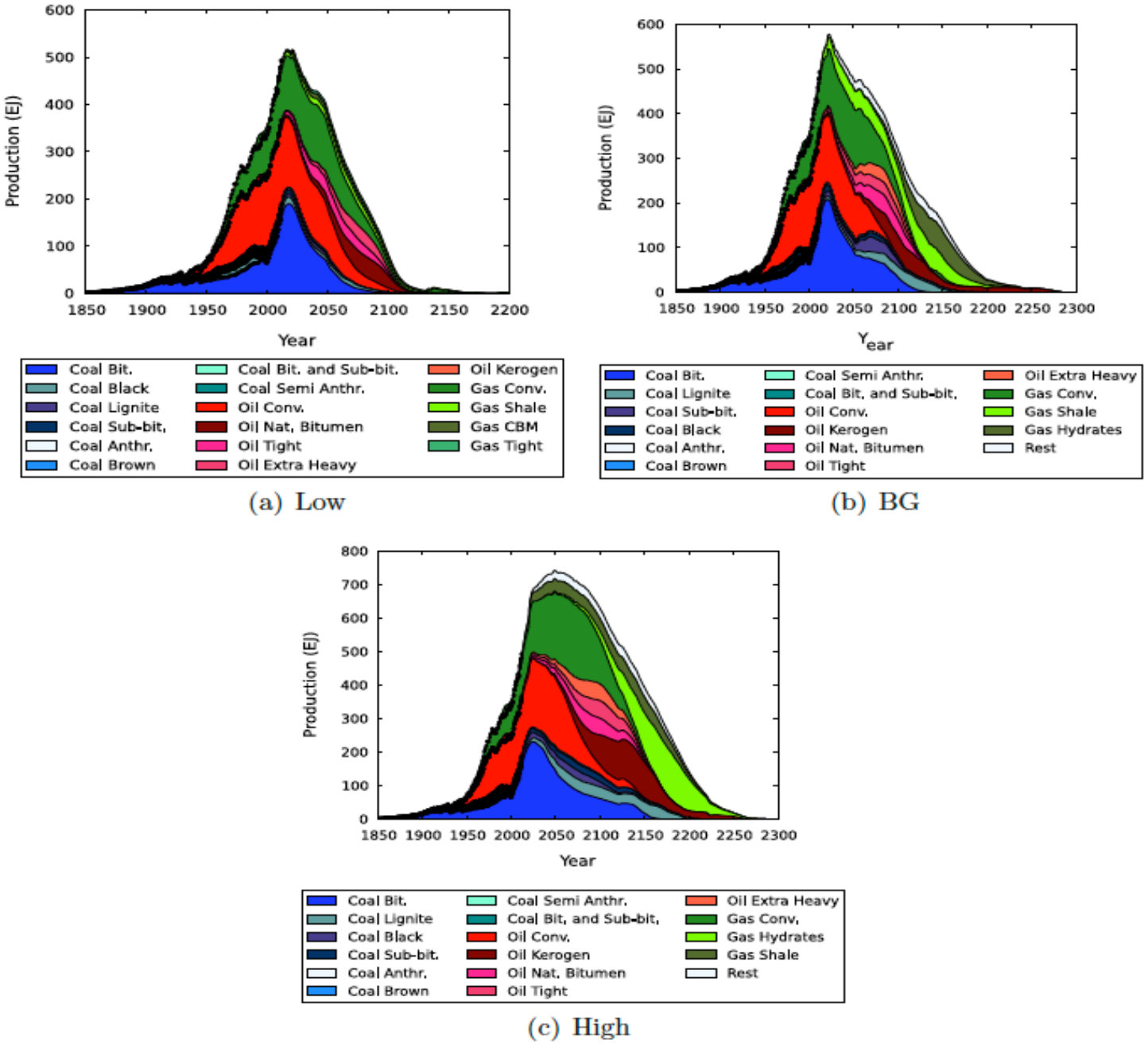


(a) Low

(b) BG

(c) High

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

Uncertainty analysis

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

VII. What does it mean?

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

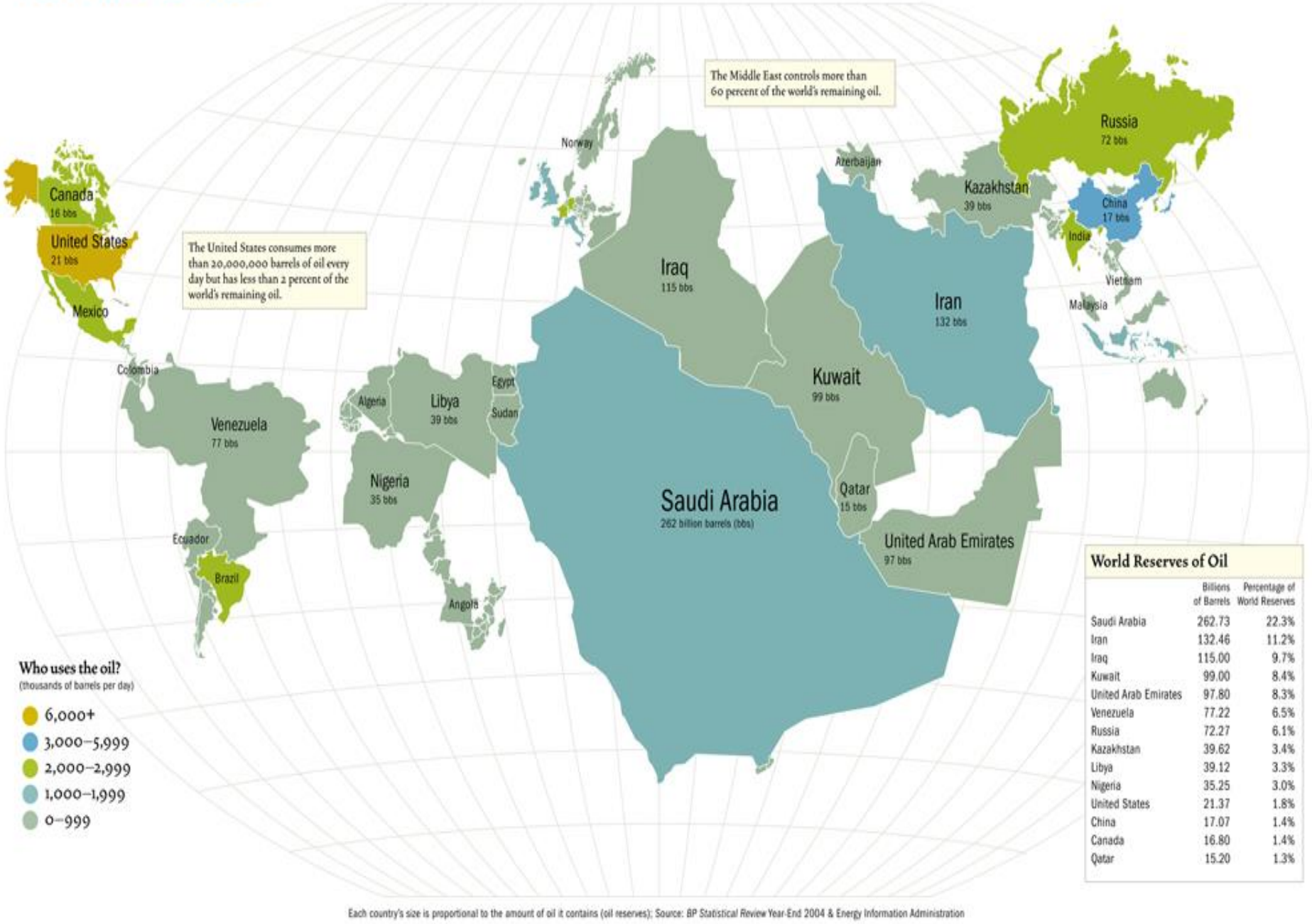
- The same principle applies to oil and gas

How has this self-evident reality been concealed ?

- It is so obvious yet it is a

DEVASTATING REALISATION

Who has the oil?



World Reserves of Oil

	Billions of Barrels	Percentage of World Reserves
Saudi Arabia	262.73	22.3%
Iran	132.46	11.2%
Iraq	115.00	9.7%
Kuwait	99.00	8.4%
United Arab Emirates	97.80	8.3%
Venezuela	77.22	6.5%
Russia	72.27	6.1%
Kazakhstan	39.62	3.4%
Libya	39.12	3.3%
Nigeria	35.25	3.0%
United States	21.37	1.8%
China	17.07	1.4%
Canada	16.80	1.4%
Qatar	15.20	1.3%

Each country's size is proportional to the amount of oil it contains (oil reserves); Source: *BP Statistical Review Year-End 2004* & Energy Information Administration

Geopolitics

THE WALL STREET JOURNAL.

EASTERN EDITION TUESDAY, FEBRUARY 3, 1981 PRINCETON, NEW JERSEY

Increased oil drilling may not be in the national interest, a new study by two Cornell University scientists says. It predicts that industry soon may be finding more energy drilling for oil than it is finding.

(Story on Page 16)

Increased Drilling for Oil May Consume More Energy Than It Gleans, Study Finds

By JERRY E. BISHOP
Staff Reporter of THE WALL STREET JOURNAL

The faster the oil industry drills for new oil in the U.S. the sooner it becomes a losing energy proposition.

That's the conclusion of a new study by two Cornell University scientists. The study appeared in a scientific journal only a few days after President Reagan decontrolled domestic oil prices to stimulate exploration for new oil supplies in the continental U.S.

Unless the oil industry finds a superior way to look for new oil pools, drilling soon will consume more energy than it unearths, the study found. The day soon will come, the researchers explained, when "the energy cost of obtaining a barrel of oil is the same as the energy in that barrel."

This break-even day of reckoning won't come for about 20 years if the industry holds drilling to its 1978 rate, the study predicted. But if that rate continues to increase, "the break-even point for oil could occur in the mid-1980s," the researchers said.

The result of our analysis indicates that the current trend of increasing conventional exploration effort by the oil industry may not be in the best interest of the nation as a whole," Charles A.S. Hall and Cutler J. Cleveland of Cornell's section on ecology and systematics asserted in their study, published in this week's issue of the magazine Science.

The main reason is that the oil industry is becoming less energy-efficient at finding oil, they explained.

Oil observers generally reject this theory of inefficiency, although industry studies have previously demonstrated that oilmen have been finding less oil per foot drilled in recent years. Oil observers maintain that there are a number of factors that could reverse the discovery trend. They cite continuing technological improvements in the search for oil and gas, such as new direct prospecting techniques. Also, industry sources say, there probably are big new oil and gas fields still to be found in the U.S. by new spurts in drilling resulting from rising prices for the fuels.

Statistical Correlation

The Cornell scientists' study statistically correlated the industry's yearly volume of drilling for exploration and development and the amount of oil found. That correlation doesn't show what is commonly assumed, however.

The team found that the amount of oil and gas (measured in equivalents of barrels of oil) discovered per foot of well drilled is dropping precipitously. They cited studies more than a decade ago by M. King Hubbert, an oil exploration consultant to both the industry and the government, that showed the industry in the 1930s extracted about 250 barrels of oil for every foot drilled. This dropped to about 40 barrels per foot drilled in the 1950s.

The trend was reversed briefly in the 1960s, causing many to cast aside Mr. Hubbert's analysis, the researchers noted. The new analysis, they said, shows that the downward trend resumed in the mid-1960s. By the late 1970s, the industry was finding only 10 to 15 barrels of oil for every foot drilled.

"Isn't When the Wells Run Dry"

At the same time, they said, the energy cost of exploring for, extracting and delivery oil has been increasing steadily. It currently equals about 1½ barrels of oil energy for every foot of well drilled.

"The time at which domestic petroleum will no longer, on the average, be a net fuel for the nation isn't when all the wells run dry but rather at some point before that time when the energy cost of obtaining a barrel of oil is the same as the energy in that barrel," they said.

If the yield of oil per foot of well drilled continues to drop—and the energy cost of drilling continues to rise—this break-even point will be reached fairly soon. How soon, they said, depends on how intensively the industry explores for oil.

If the industry slows its drilling rate to about 120 million feet of well a year, the break-even point could be staved off until the year 2004, their analysis found.

"Were we to continue to drill at the 1978 levels of about 200 million feet a year, the linear extrapolations would intersect in 2000," they added. This is for both oil and its equivalent in natural gas. "For oil alone, we could reach the break-even point in about a decade."

If the industry continues to increase its drilling rate at the pace it has in recent years, the break-even point for oil and gas could be reached in the mid-1980s, they concluded.

Reagan Adviser's Challenge

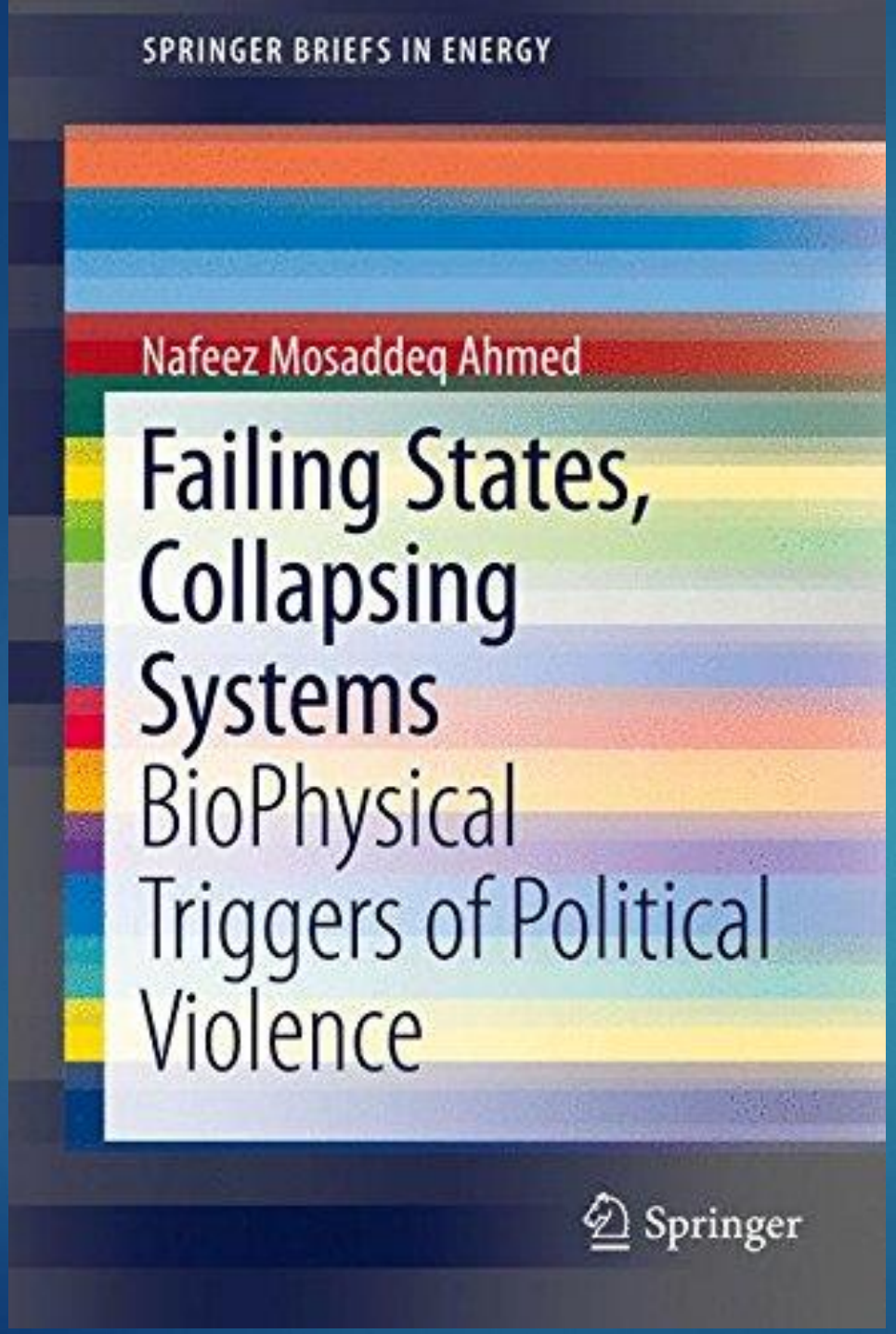
Michel Halbouty, the Houston industry consultant who was President Reagan's chief adviser on energy policies, quickly challenged the Cornell researcher's conclusions. The study, he noted, was based on the industry's drilling record since 1945. But, he said, this drilling record has been distorted by government regulation.

"We've experienced 23 years of controls and regulations that have stymied the exploration effort in this country," he said. Because of such regulation he said, many oil men have been forced to drill near old oil fields where there's a better chance of finding oil. Such drilling, he said, doesn't really add much to new oil reserves. This, he said, was one reason for the decline in the number of new barrels added to reserves per foot of well drilled.

With President Reagan's decontrol order, Mr. Halbouty said, "we're going to see more real wildcatting in the boondocks."

"Most domestic oil (and presumably gas) that is now produced comes from reserves discovered before 1940," the ecologists said. "We see little hope for changing this picture very much through increased conventional drilling effort, and in fact such effort could decrease the total energy delivered to society by the petroleum industry by lowering the efficiency of that energy-intensive industry," they declared.

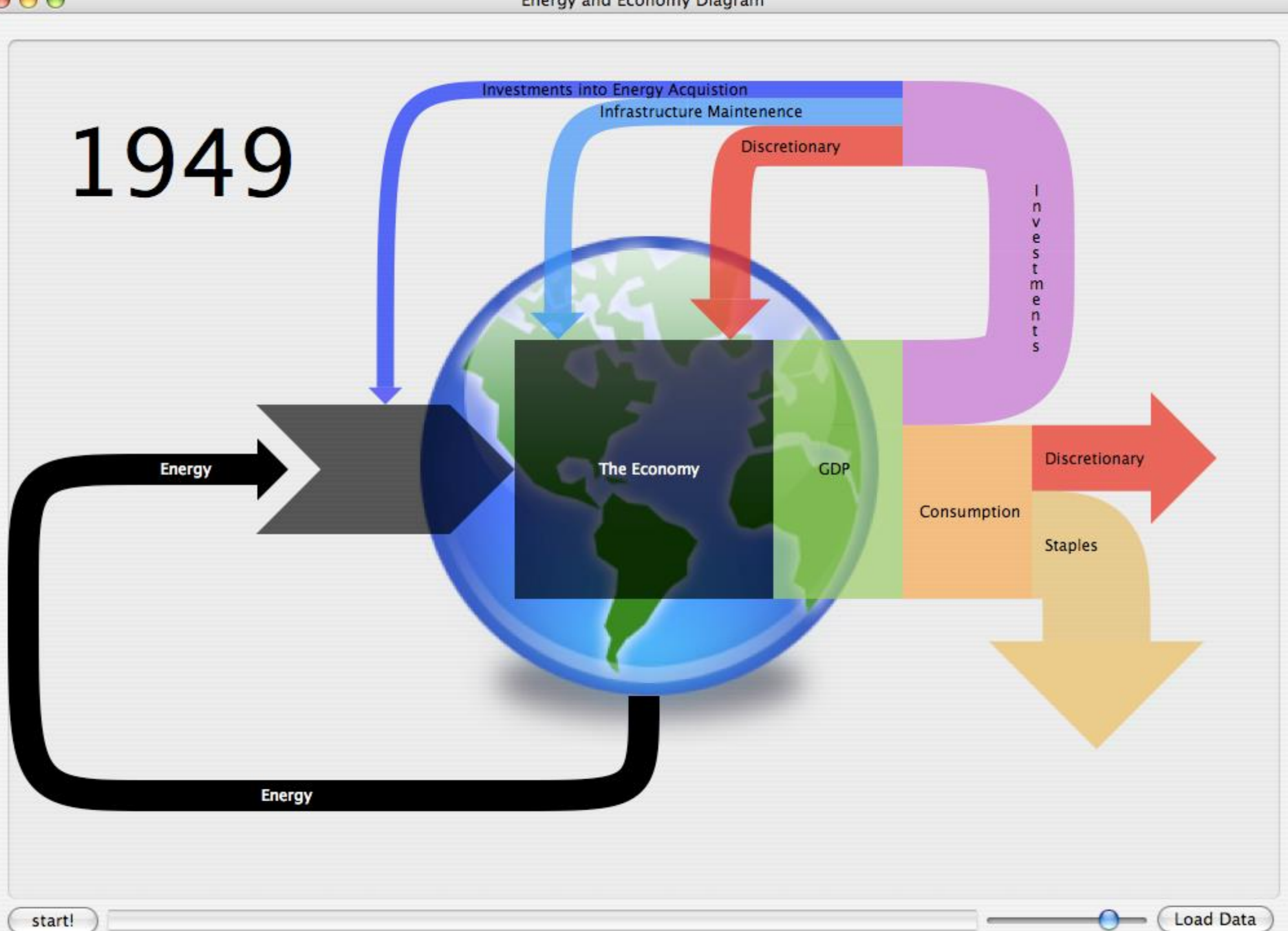
- Declining EROI
- Refutes economist's assertation that there is no issue with depletion because increased prices will bring in increasingly less economic resources
- Applies to Canadian/Venezuelan Heavy oil?



Peak and then decreasing oil, nation by nation, generates extreme social unrest

This is the real problem

INFLATION……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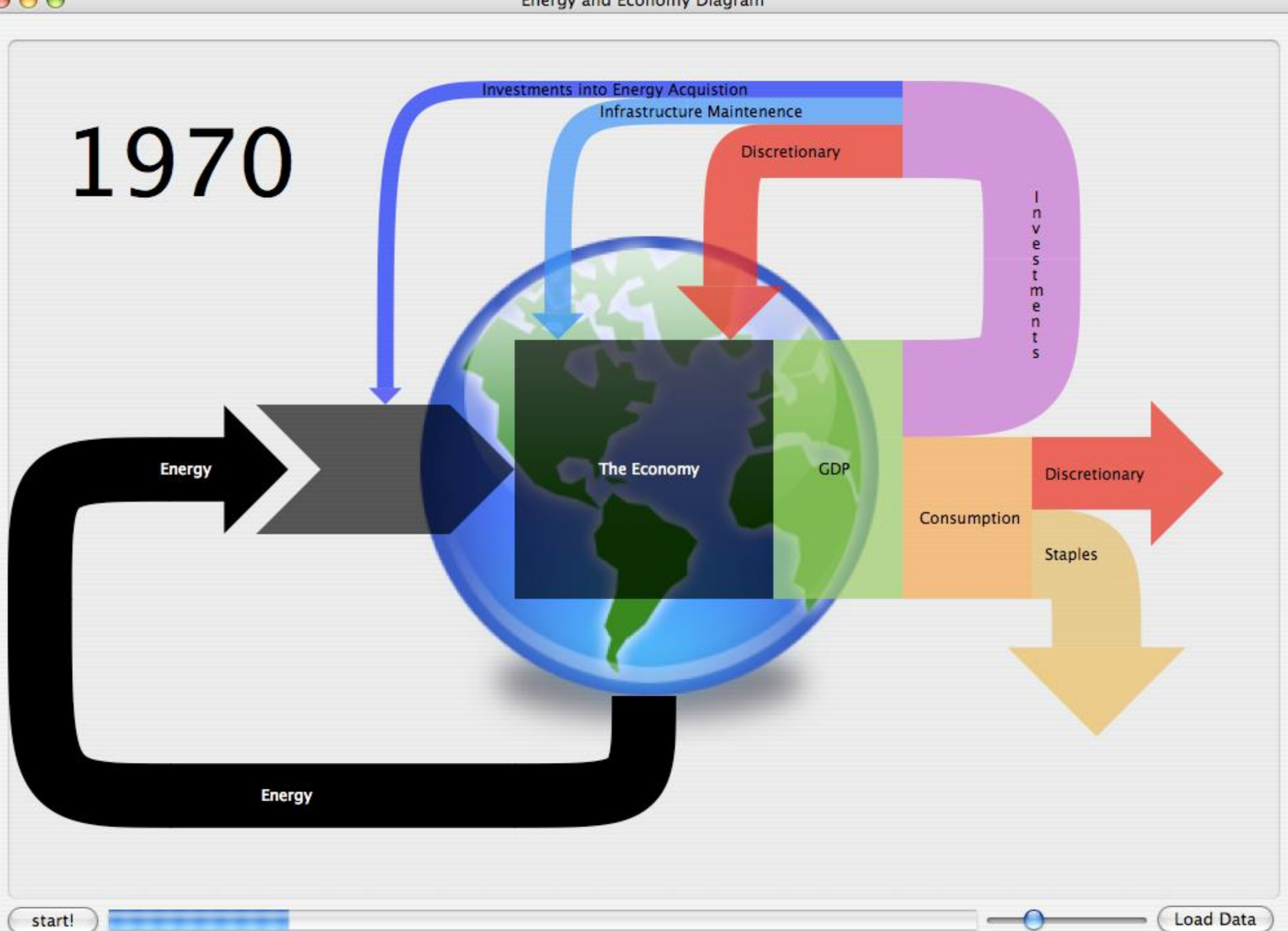
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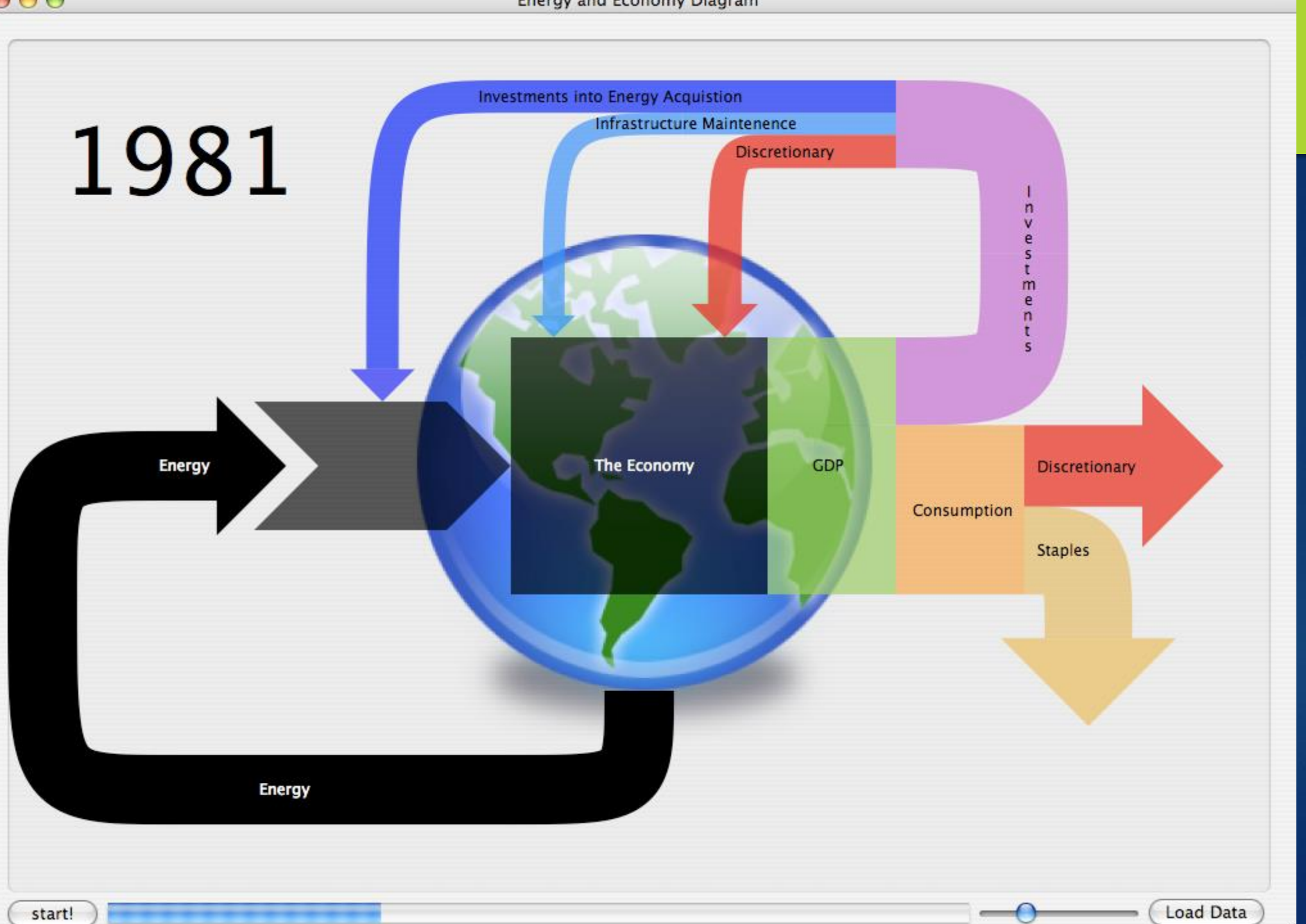
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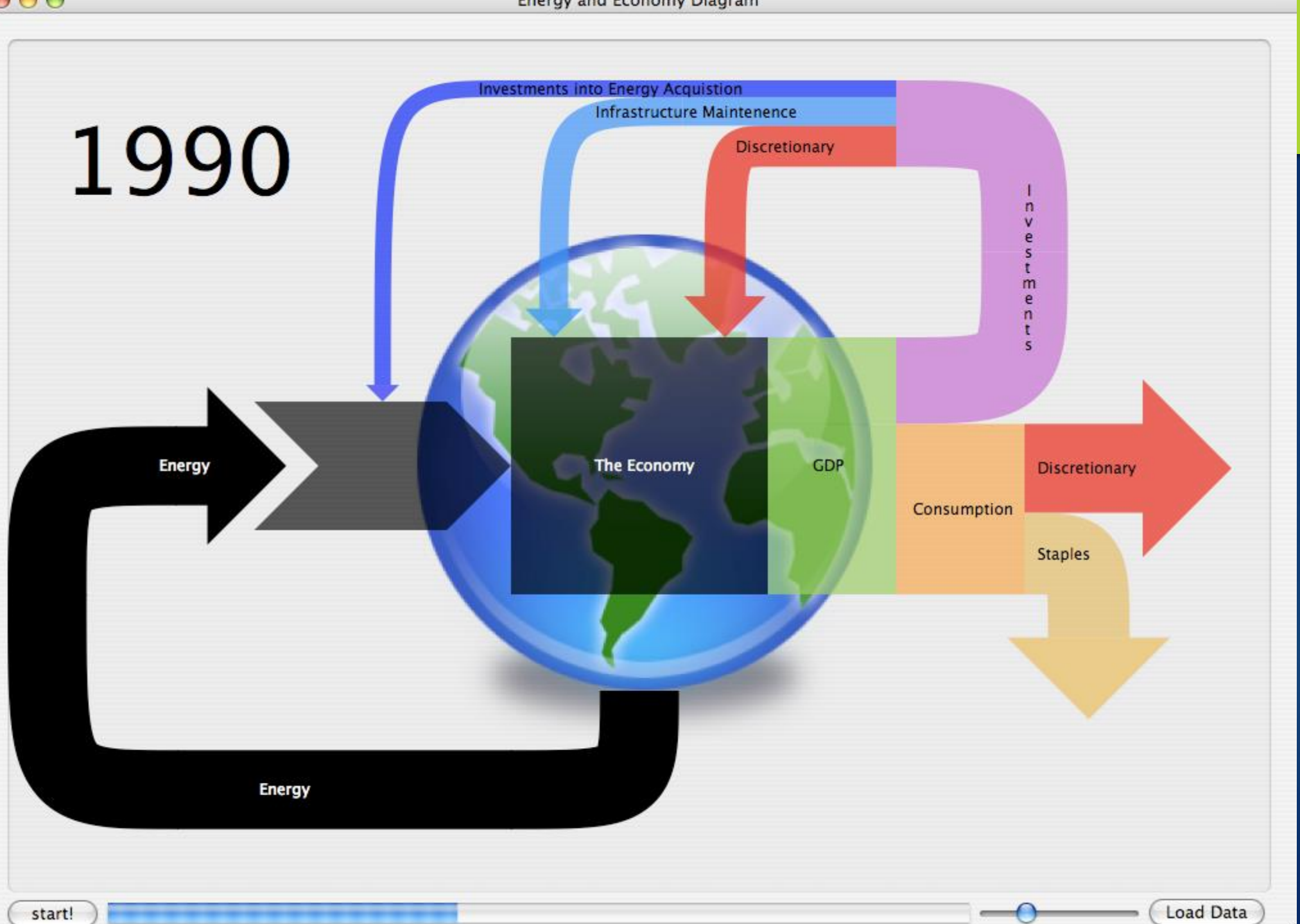
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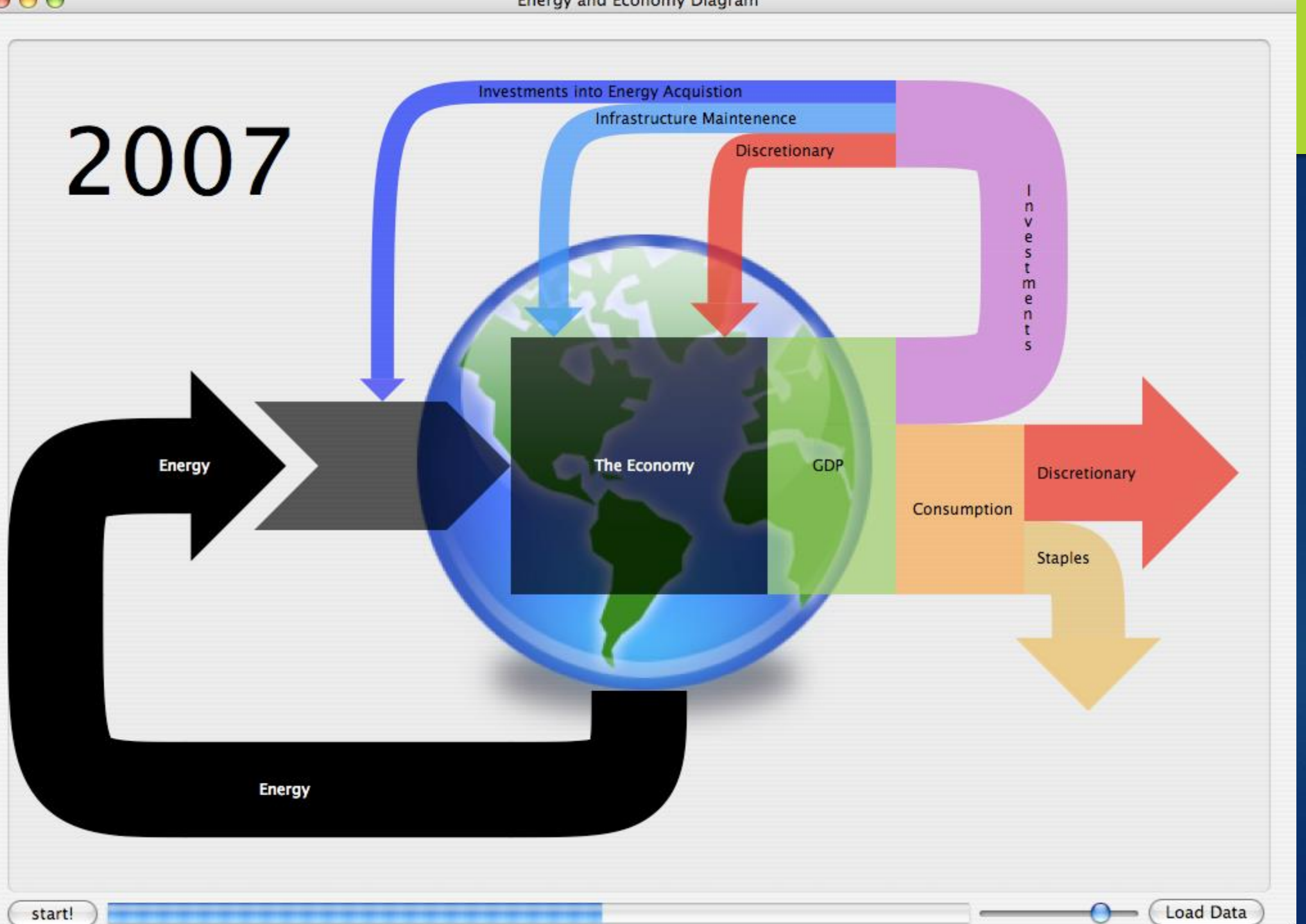
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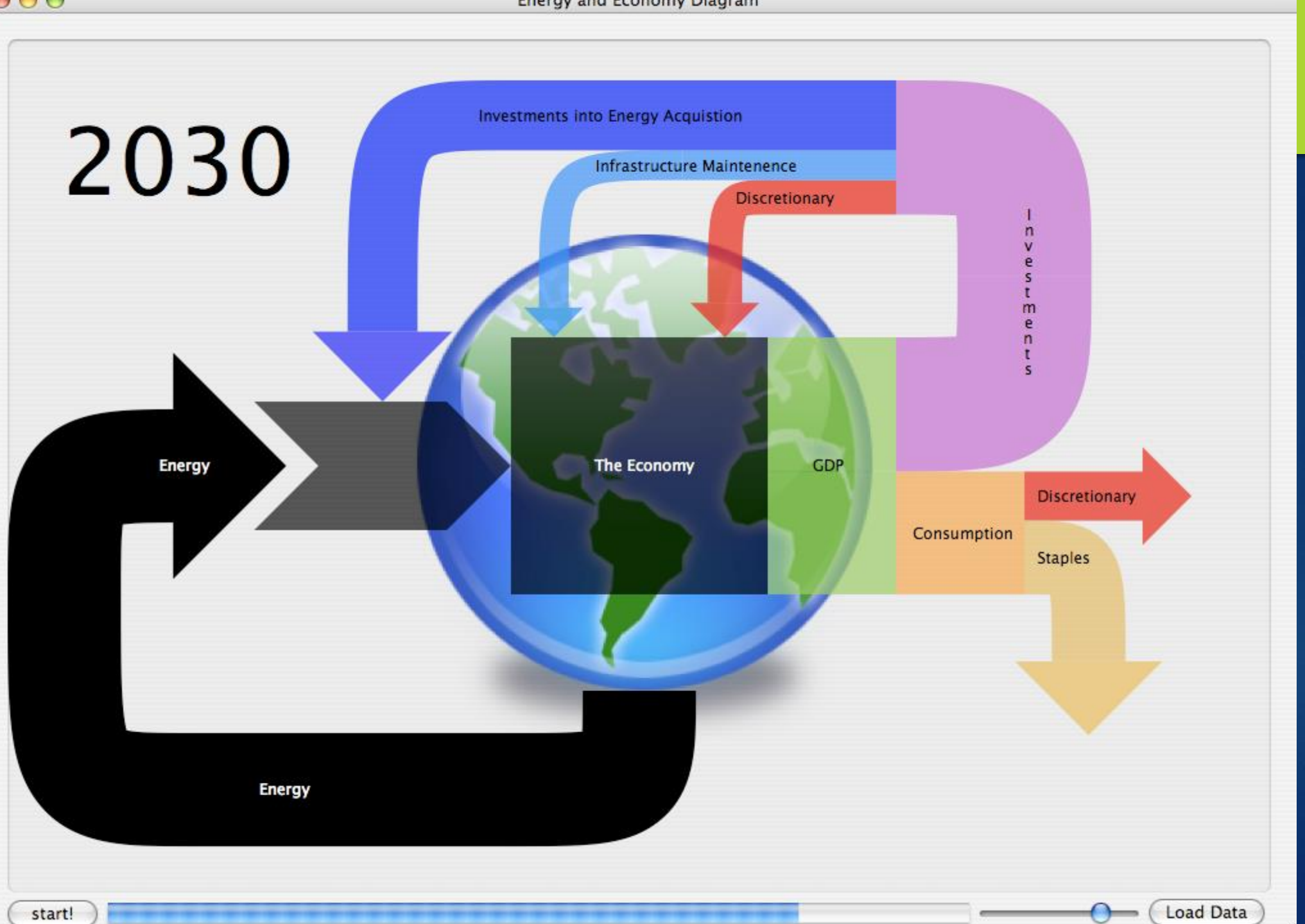
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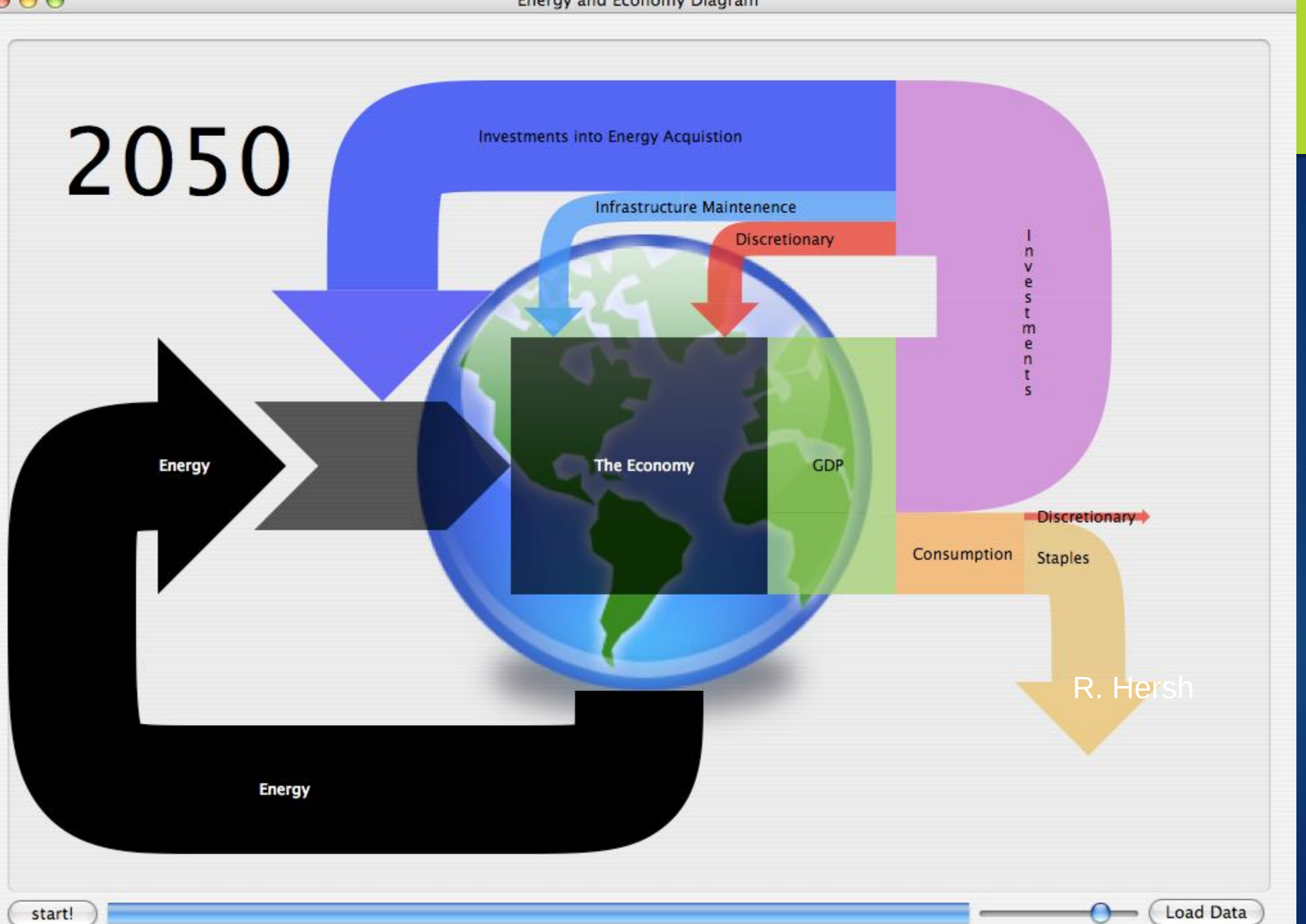
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R. Hersh
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My final professional goal

THE END