EROI: The Key Variable in Assessing Alternative Energy Futures?

(and EROI for global oil and gas 1992 - 2005)

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With thanks to John S. Herold, Inc, Jean Laherrere,
and the Santa Barbara Foundation

- Will technology and the market resolve petroleum scarcity issues?

- Perhaps – but technology does not exist in a vacuum, it interacts with depletion and other issues.

- One way of examining the interaction between technology and depletion is by doing time series analyses of EROI.

DEFINITION of EROI (Sometimes EROEI)

Energy return on investment for an activity:

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

Usually consider energy invested *from society*

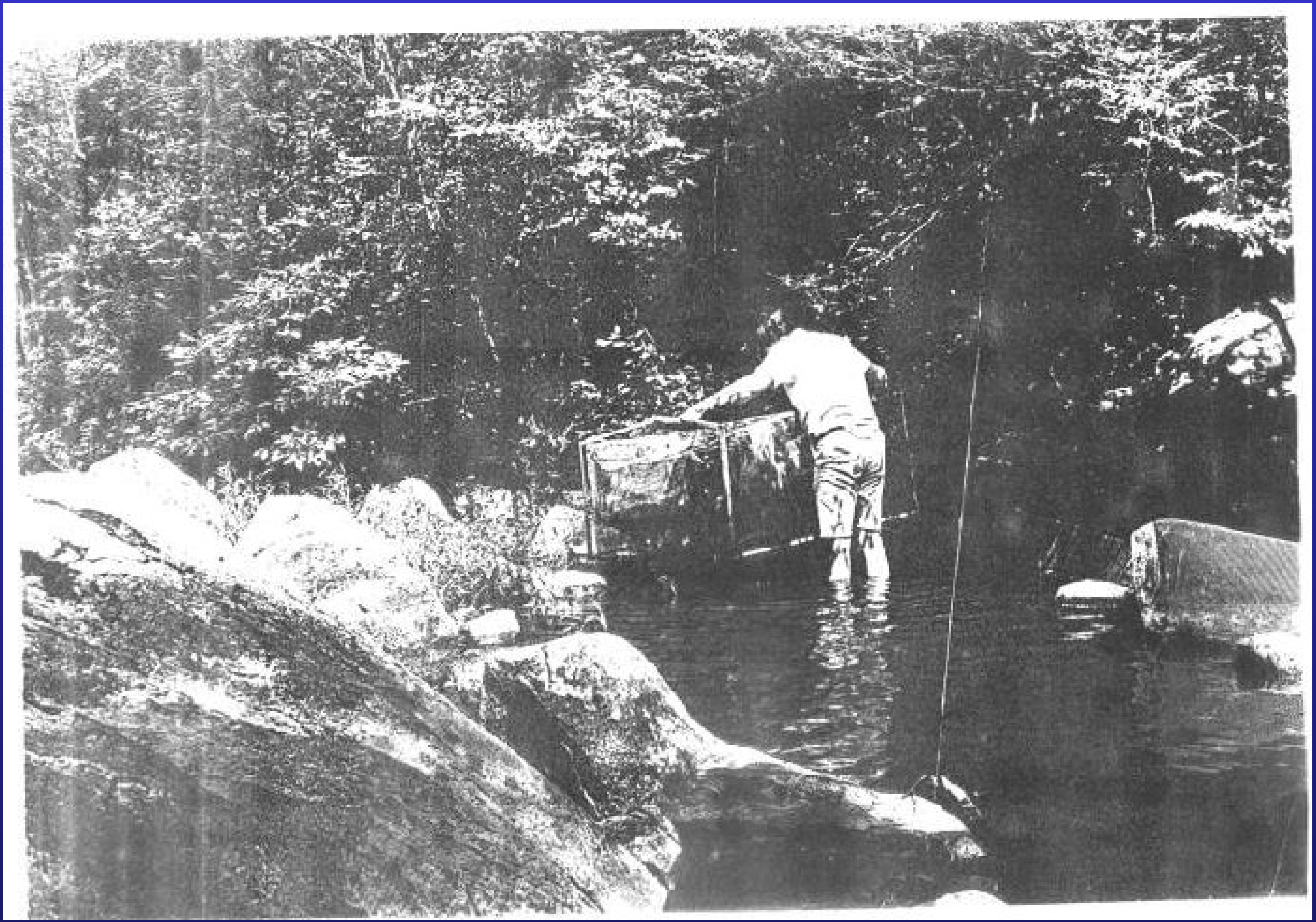
- We believe EROI will be one of the most important defining issues of the future
- Its importance has been submerged by the (inappropriate in our view) increasing dominance of economic cost-benefit analysis

SOME HISTORY

- I am an ecologist, fascinated by energy and natural selection
- A predator, such as a trout or cheetah, cannot expend more energy in chasing prey than it gets from that prey……
- (And it must also pay for its own repair, depreciation, replacement and R&D)

- To my knowledge EROI idea was first formally put forth in my PhD dissertation… for fish migration

- Idea was implicit in writings of Kenneth Boulding, H.T. Odum, others



Reprint Series
6 February 1981, Volume 211, pp. 576–579

SCIENCE

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

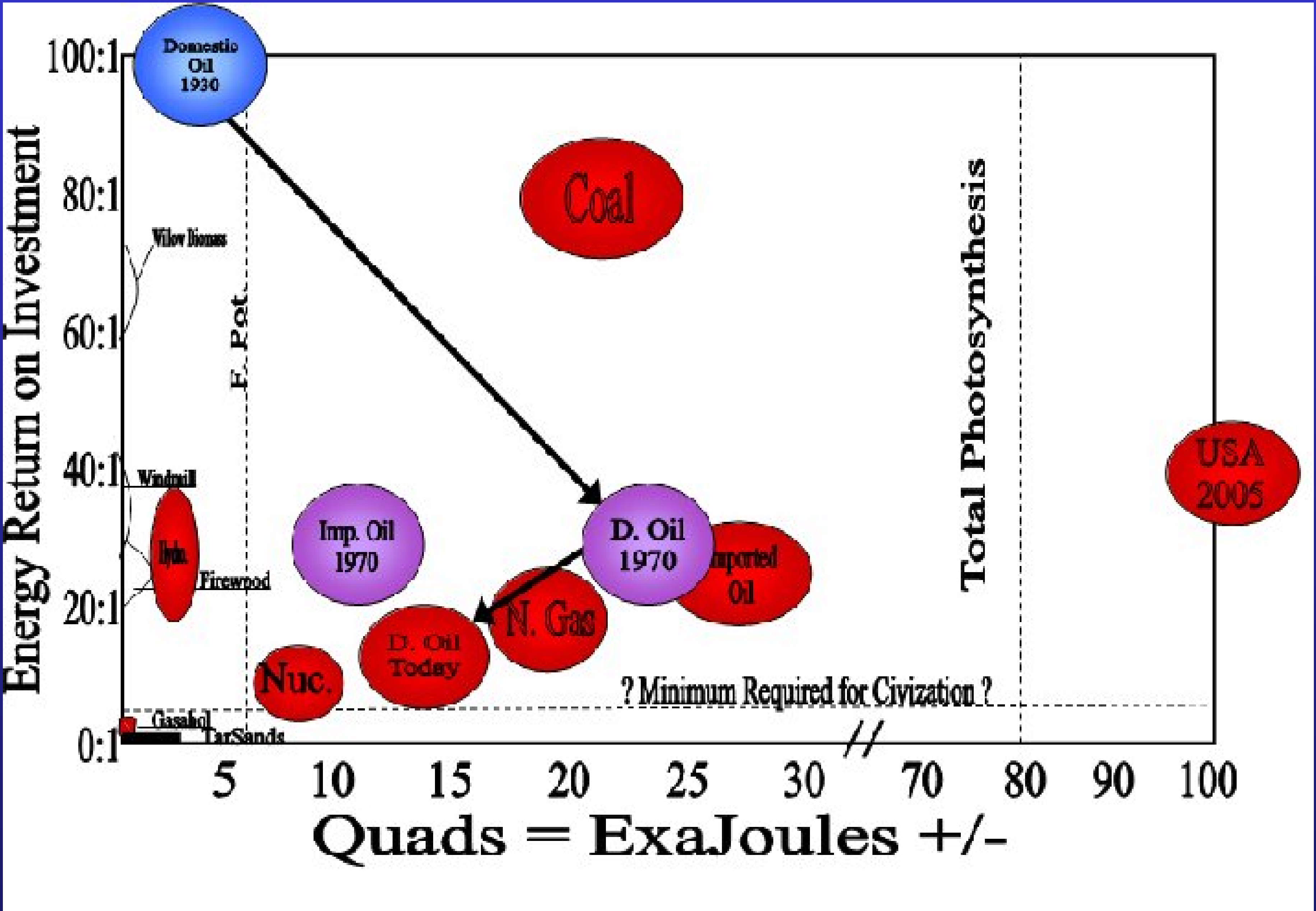
0036-8075/81/0206-0576$00.75/0

We used Yield per Effort concepts from fisheries…..

- We believe that ultimately EROI will be the most important determinant of the availability and price of oil and gas.

- The next slide shows our educated guesses as to the EROIs and quantities of major energy sources for the United States, some from 1930 to today.

- (From Hall and Cleveland, 1981; Cleveland et al., 1984; Hall et al., 1986; Cleveland 2005)



Domestic Oil 1930
Coal
Wilow Biomass
E. Pot.
Total Photosynthesis
USA 2005
Windmill
Hydro.
Firewood
Imp. Oil 1970
D. Oil 1970
Imported Oil
N. Gas
D. Oil Today
Nuc.
? Minimum Required for Civization ?
Gasahol
TarSands
Energy Return on Investment
100:1
80:1
60:1
40:1
20:1
0:1
5
10
15
20
25
30
70
80
90
100
Quads = ExaJoules +/-

- It is curious that we do not have similar information for the entire world.

- We next attempt to derive EROI for global oil and natural gas production

- We seek your criticisms, ideas, input, DATA, whatever.
- We think that in time and with better data we can do this very well

Hypothesis

- Technology is compensating for depletion with respect to EROI for oil and gas
- Barnett and Morse, Lynch, etc
- Testable hypothesis

Methods

We tested our hypothesis by deriving time series of:

$$\text{EROI} = \frac{\text{Energy Output}}{\text{Energy Input}}$$

For global oil and natural gas production

The Rub: Data

INPUT

- Herold (Global, US, North Sea)
- US Government
  - Census of Mineral Industries
  - Bureau of Economic Analysis
- UK Government
  - Department of Trade and Industry

OUTPUT

- Herold (Global, US, North Sea)
- 2006 BP Statistical Review of World Energy
- Oil and Gas Journal
- Jean Laherrere

Output: Easy in Principle

Energy output =

- Barrels of oil times 6164 MJ/barrel
- Cubic feet of gas times 1.09 MJ/ft^3

Input: Difficult in principle

- The few private sets are very expensive and not clearly appropriate
- No public data kept on energy costs except in US and UK (to our knowledge)
- Herold “upstream” $ data very useful but universe is limited to publicly traded firms (1/3 to 1/2 total)

Dollar Cost as Proxy

- Correlation between inflation-corrected dollars spent and energy used

- Improvements:

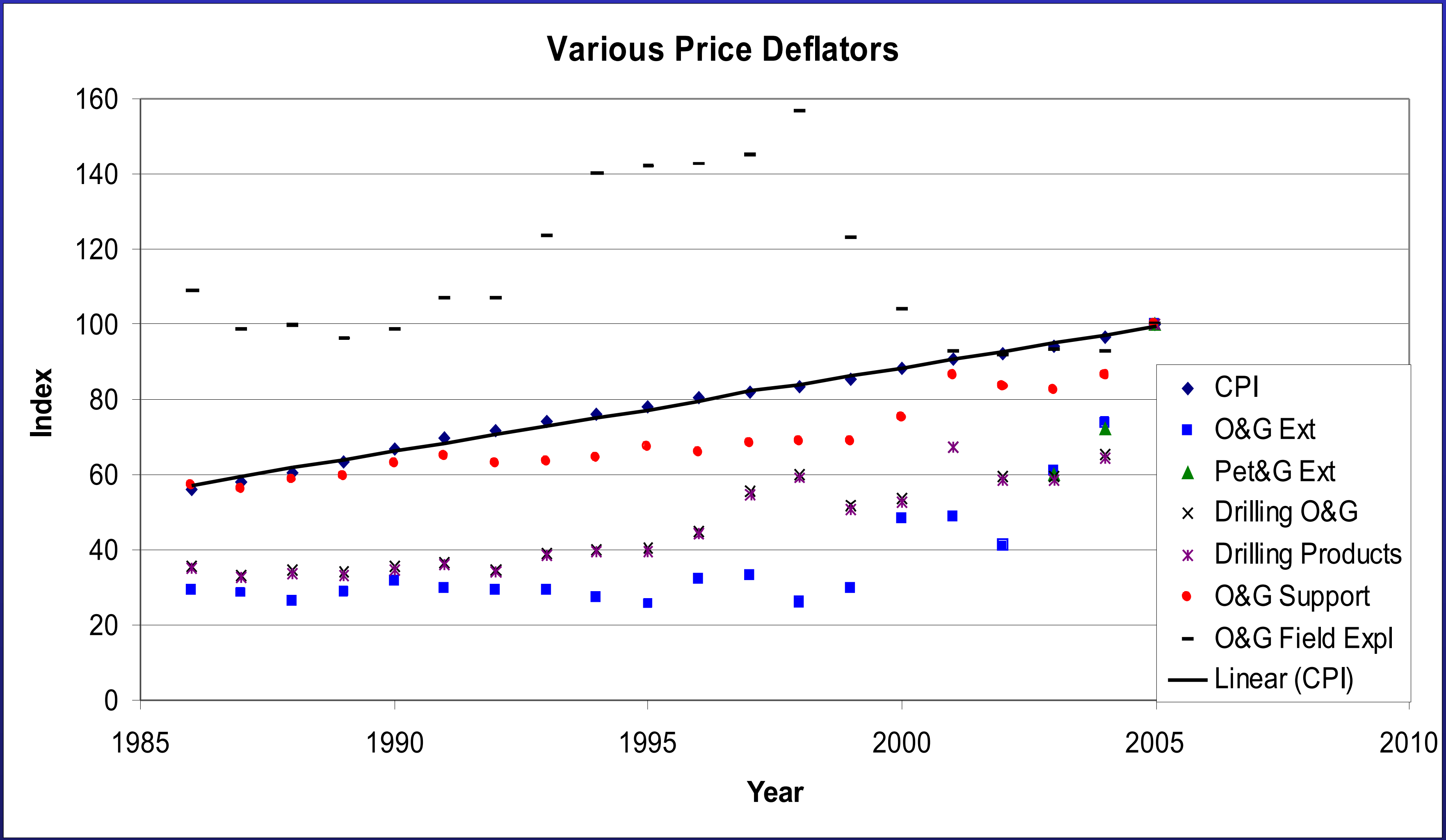
    a) Industry-specific

    b) Input-output analyses

Problems

- Inflation: general vs. “crisis”
- How to relate dollars to energy?
- Leontief I-O approach – very tight for 1970s but has not been done fully since.
  - University of Illinois – Hannon, Bullard, Herendeen
  - Carnegie Mellon
  - All are basically resolvable but uncertainties remain.

Correcting for Inflation- Which index??



Preliminary Estimate of Input

- Annual global expenditures reported by Herold (inflation corrected to 2005 USD)
- Exploration + Development + Production
- We converted dollars to energy

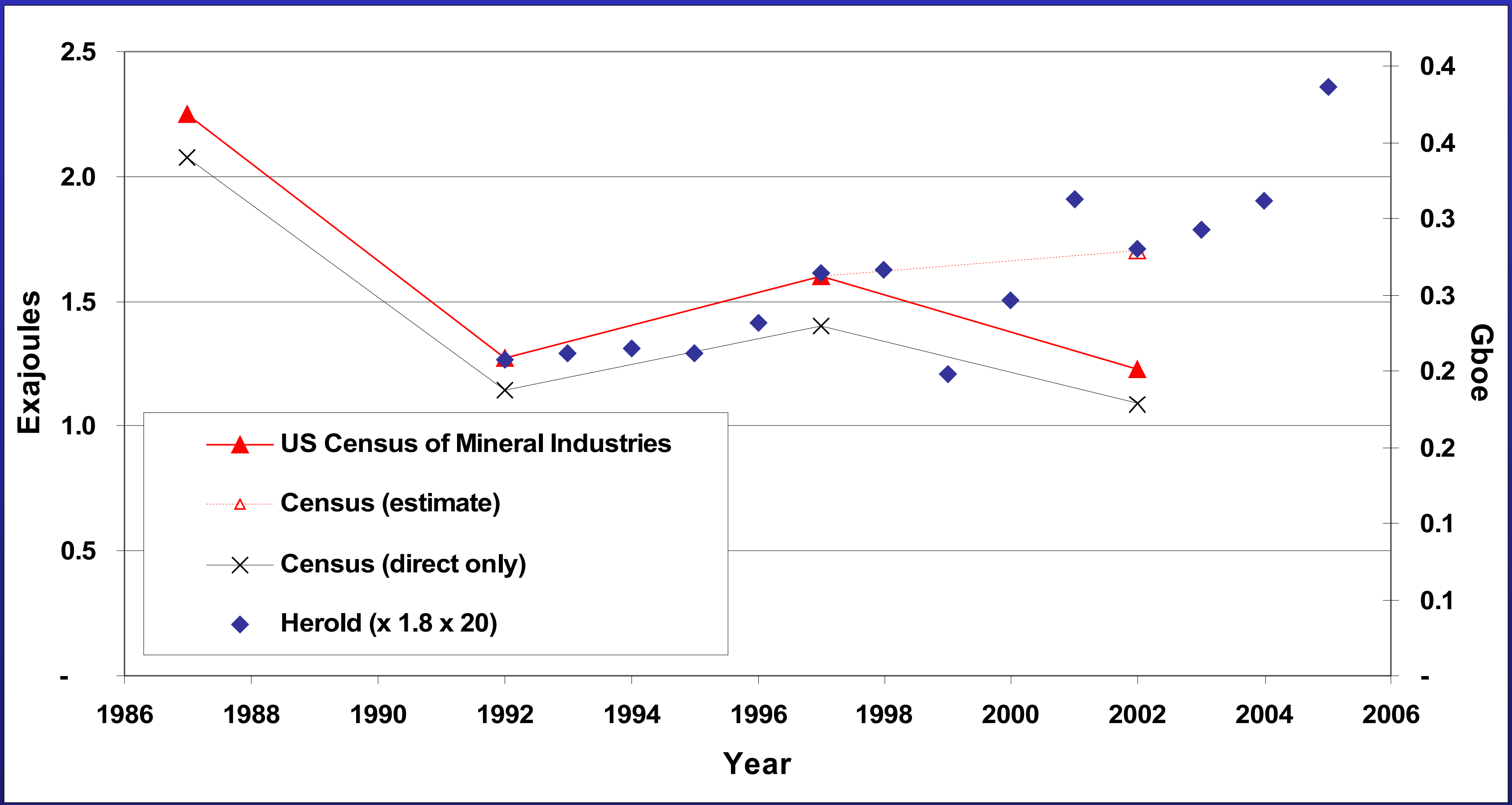
Energy Use per Dollar

- Mean of heavy construction
  - 13.3 MJ per dollar (Carnegie Mellon and Herendeen)
  - Thought to be low - energy companies presumably are able to buy energy cheaply
- Can we calibrate this ratio?

Calibration for US

- US Government Data
  - Direct - energy costs reported by industry
  - Indirect - dollar costs for materials & supplies converted to energy using CMU model
- Compared to Herold Data on Input $ Costs
  - Prorated to reflect entire US industry
  - This allowed us to derive an energy cost of 20 MJ per dollar

US Calibration

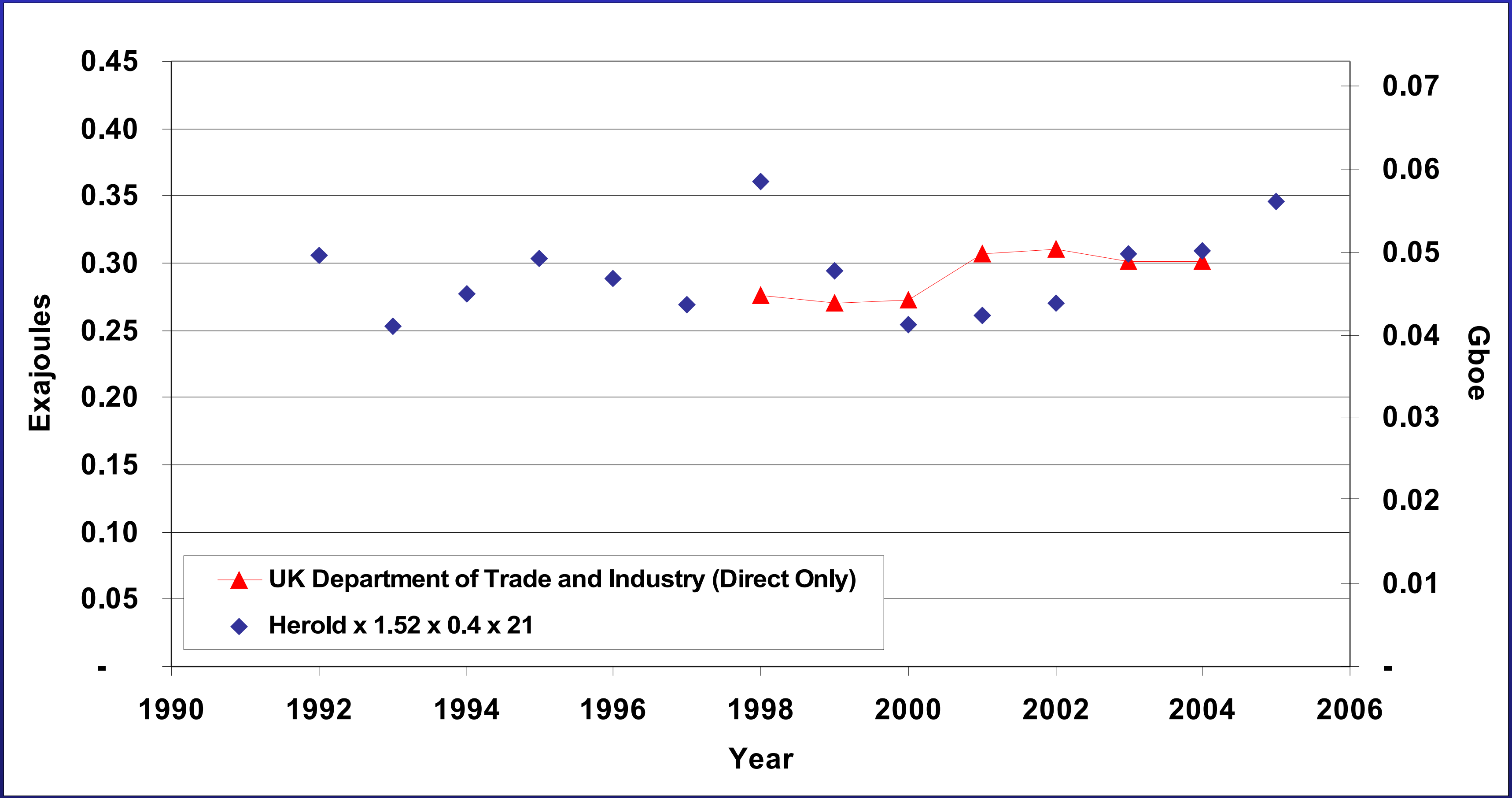


Conclusion: 13.3 is too low – 20 is better

UK Calibration

- UK Government Data
  - Direct - costs already in energy terms
- Herold Data
  - Prorated to reflect all of North Sea
  - Then prorated to reflect UK only
  - Converted to energy at 21 MJ per dollar

UK Calibration



Conclusion: 13.3 is too low – 21 is better

So….

- Our two independent estimates indicate that, as we had thought, the value of 13.3 MJ per dollar is somewhat too low

- Thus a value of 20 +/- 1 looks pretty good

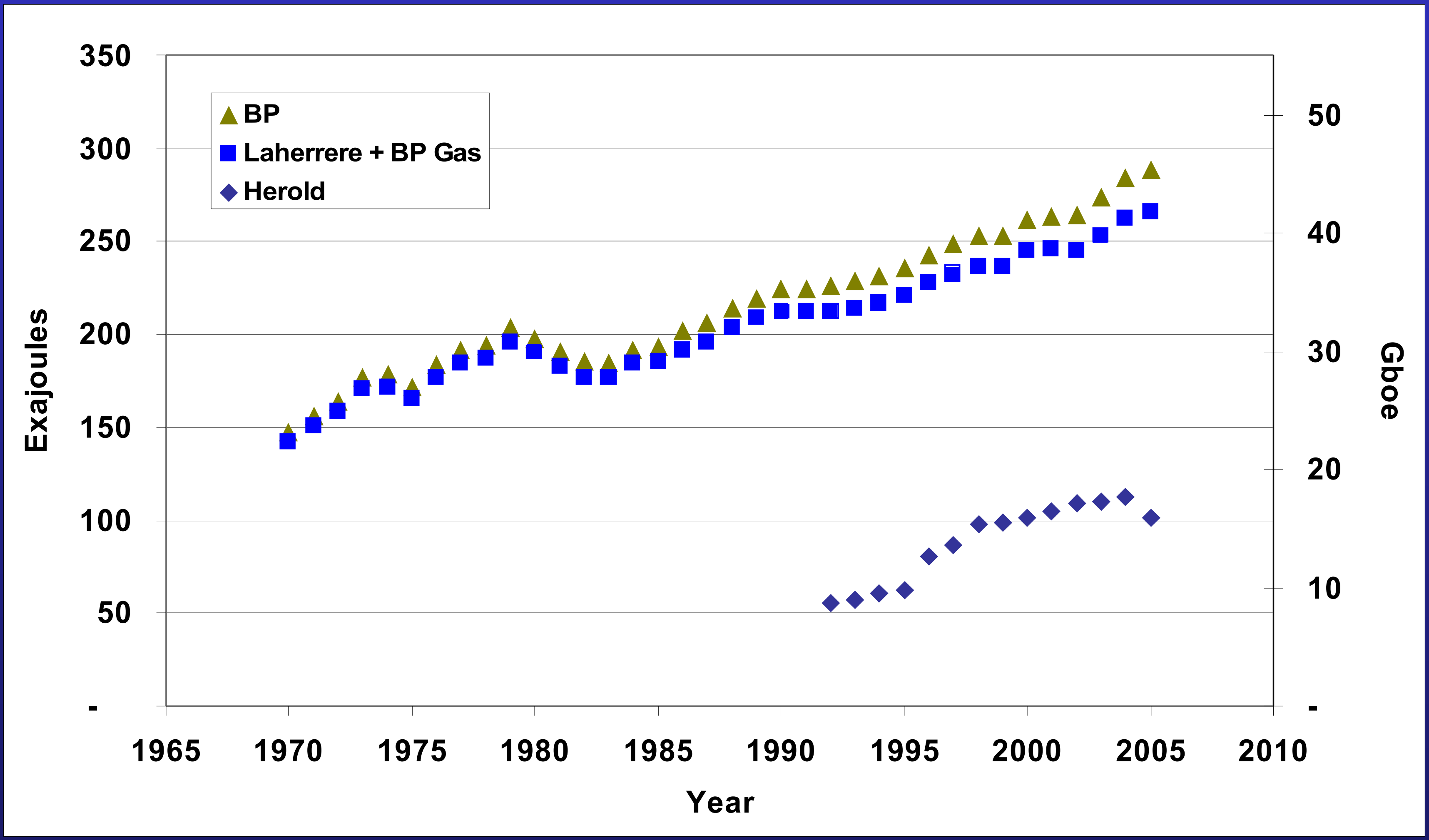
- And we use it

Critical Assumptions

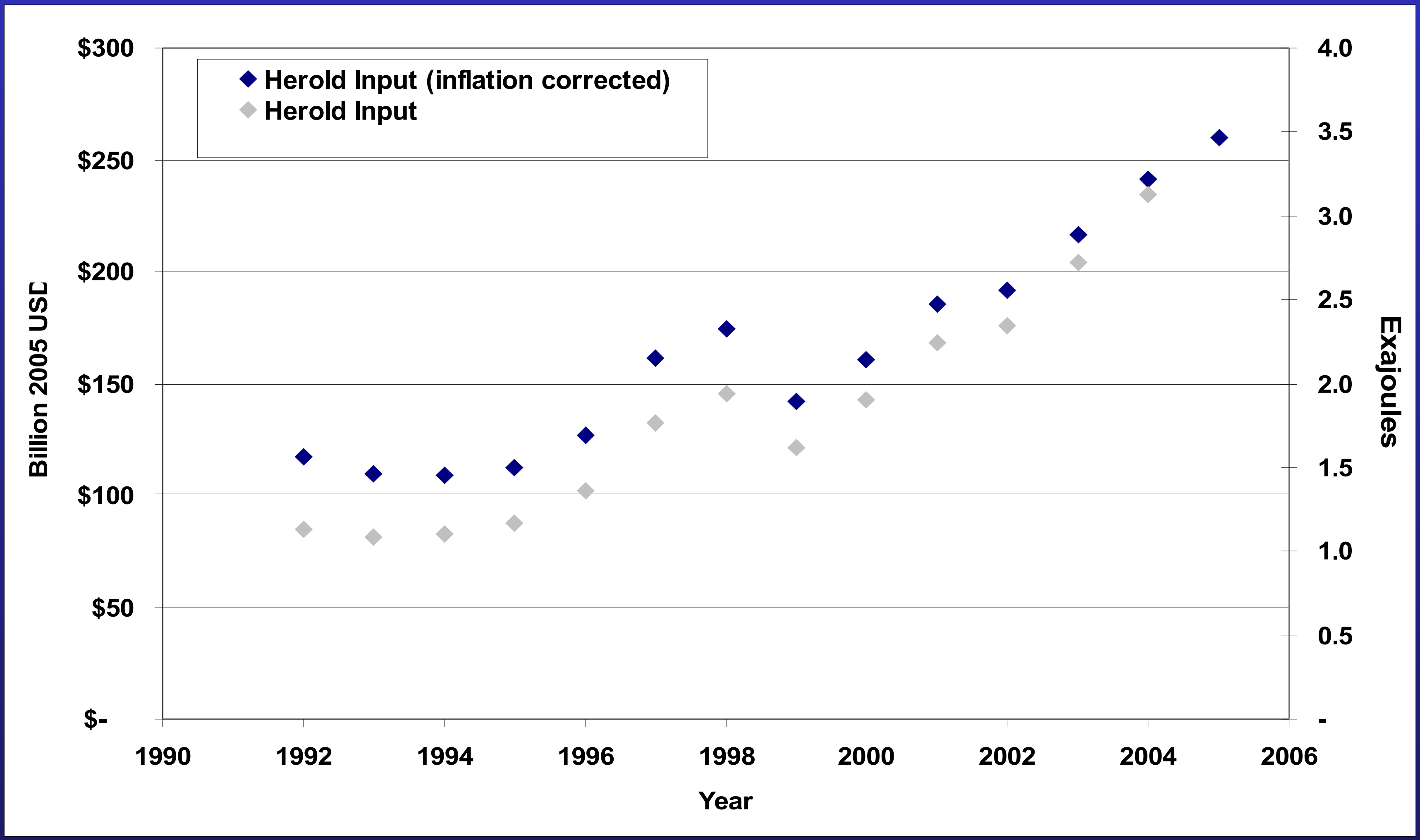
- Costs per barrel and per cubic foot same outside Herold universe as inside
- Data adequate at face value
- Sensitivity analysis – different data sets

Results

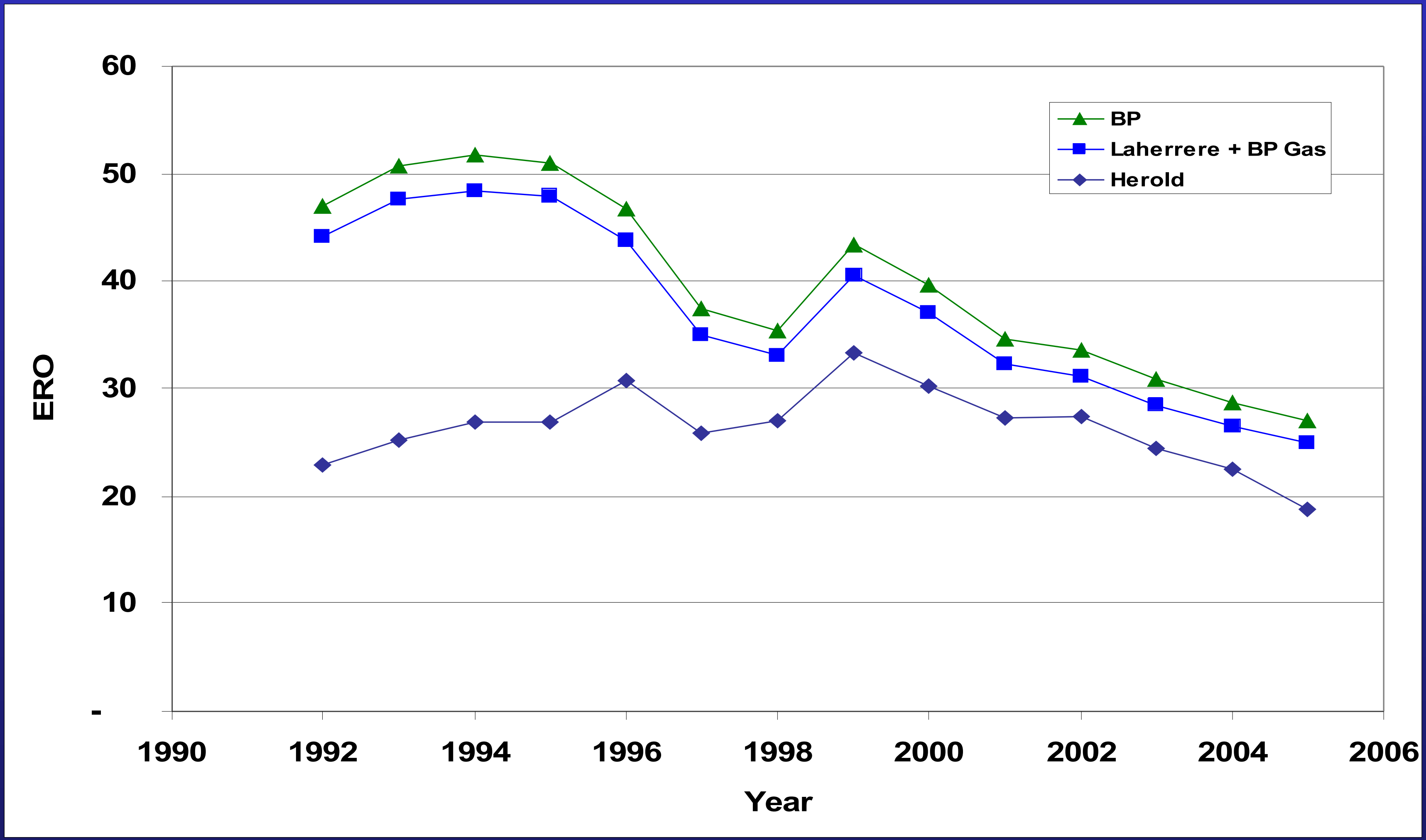
Annual Oil and Gas Production



Total Upstream Expenditure - Herold

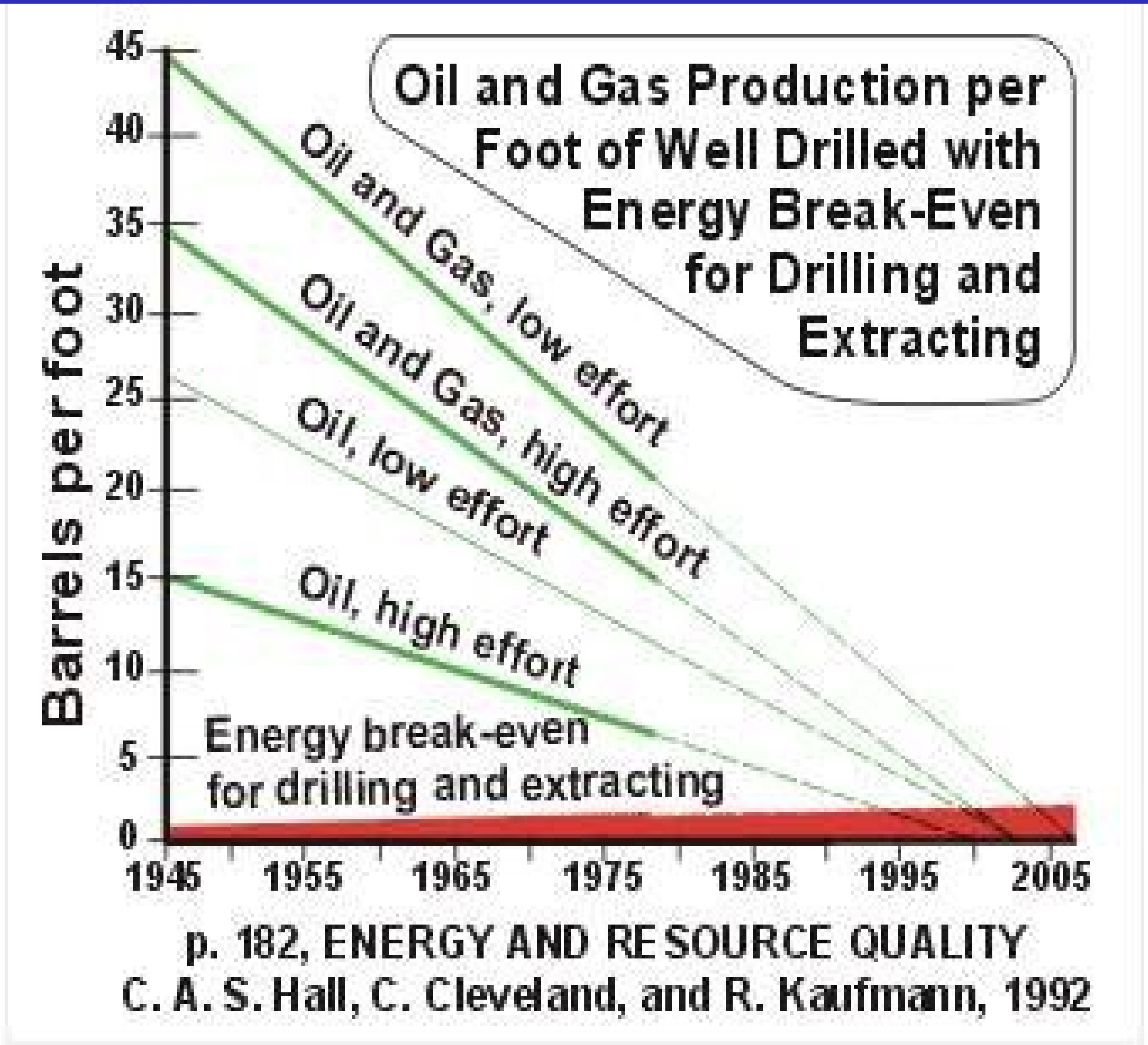


EROI for Production



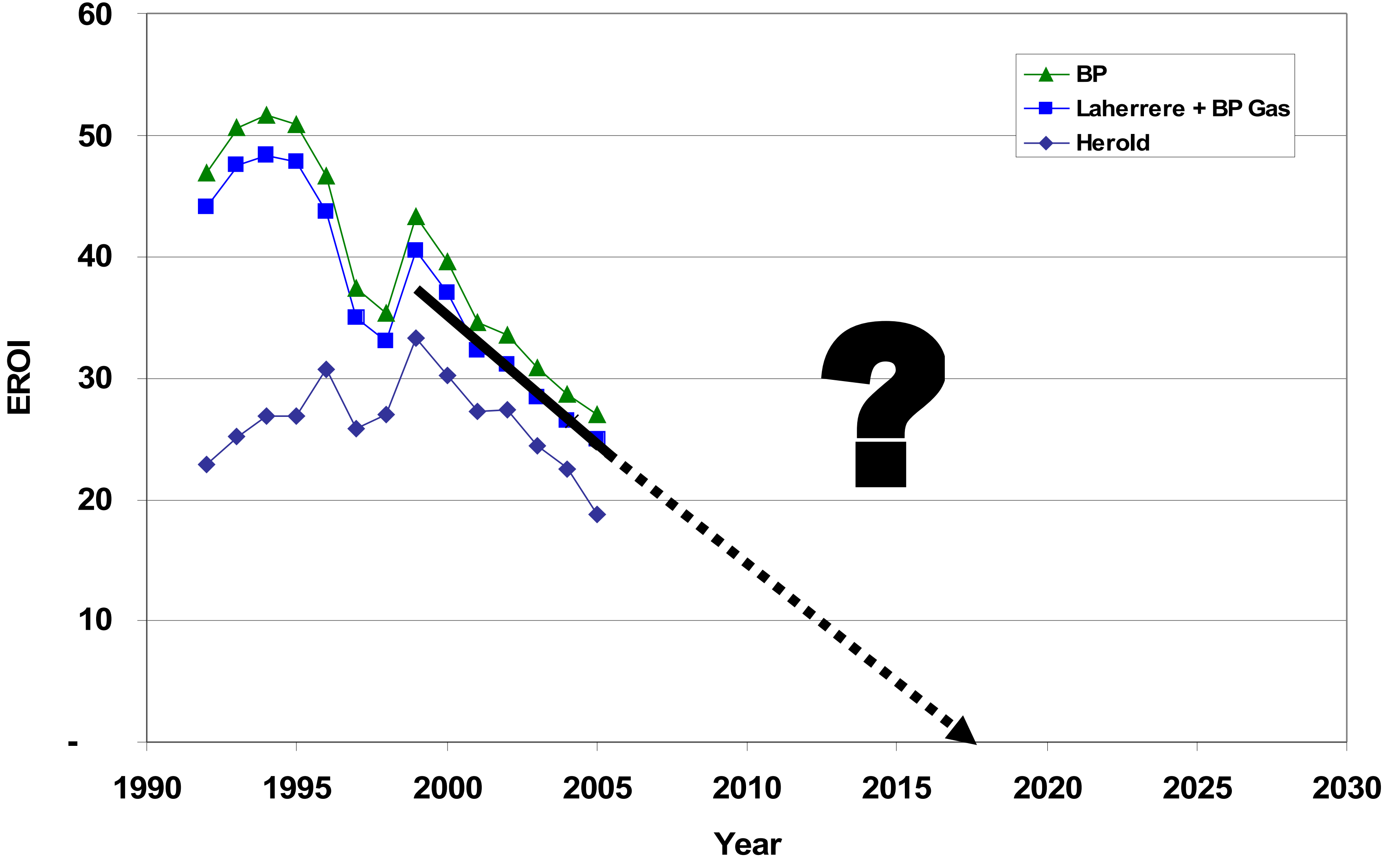
The Future?

For the past three years the expenditures to look for oil have been greater than the dollar returns!



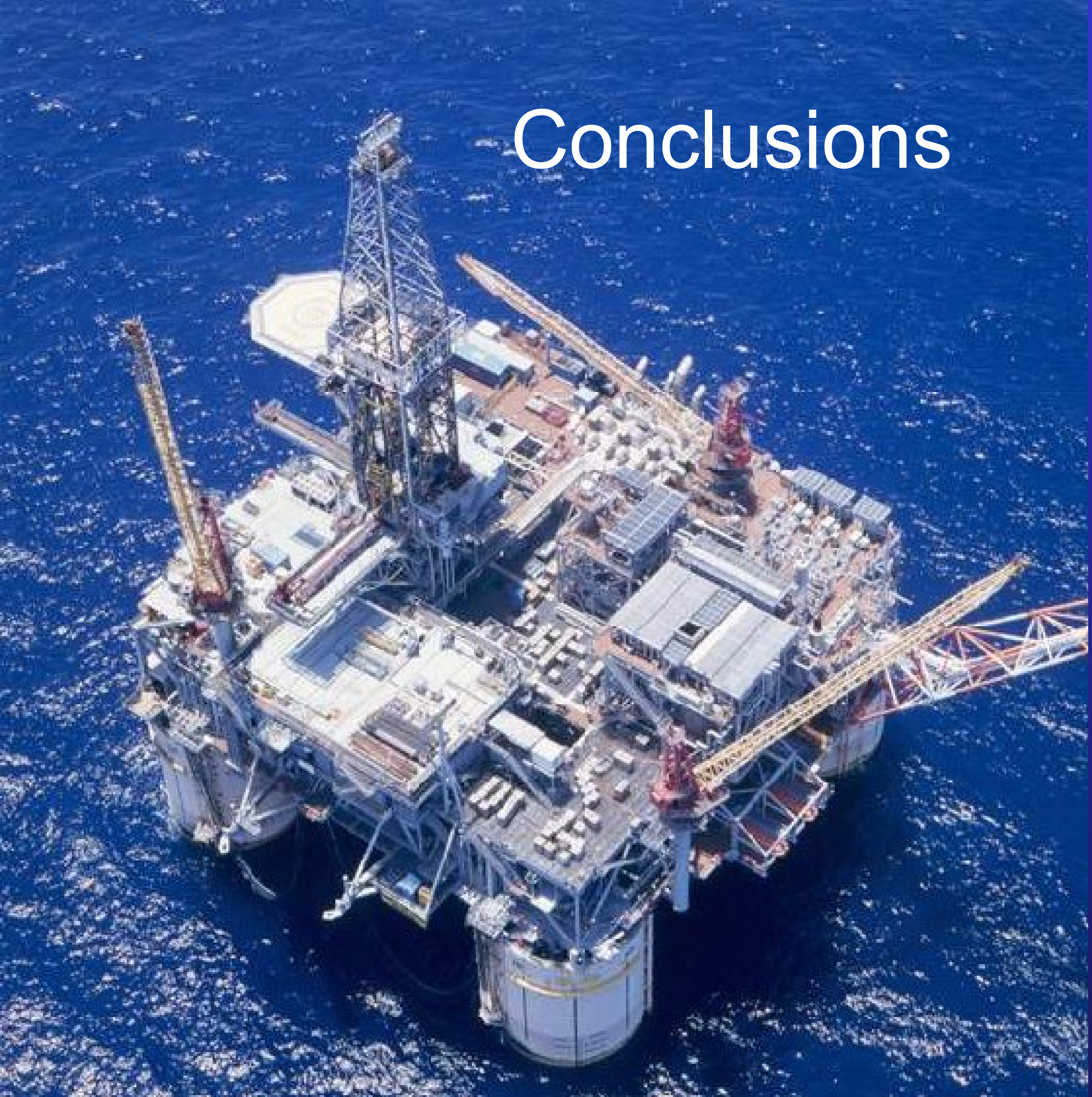
NY Times Oct 10, 04

Hall & Cleveland 1981 Science



60
50
40
30
20
10
-
EROI
1990
1995
2000
2005
2010
2015
2020
2025
2030
Year
BP
Laherrere + BP Gas
Herold
?

Conclusions



The energy cost of getting the next barrel is going way up

- Our hypothesis that technology compensates for depletion with respect to EROI was not supported.
- Depletion appears to be trumping technological change, at least so far.

More Conclusions

- Oil and gas EROI still better than most alternatives
- EROI influenced by effort
- Global EROI for oil and gas declining
- Decline in EROI for production appears very strong
- If true, this makes discovery less important

Caveats

- All assumptions must be tested
- Peak oil theory is based on Laherrere’s data

What We Need

- Far better and more public data on energy cost of the industry because we do not know if $ proxy analyses is adequate to determine trends.

The End

My final professional goal