# A Historical Perspective on Global Energy Transitions

"Modeling the Oil Transition"
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# Energy Transitions

- Change in one state of an energy system to another one, in terms of:

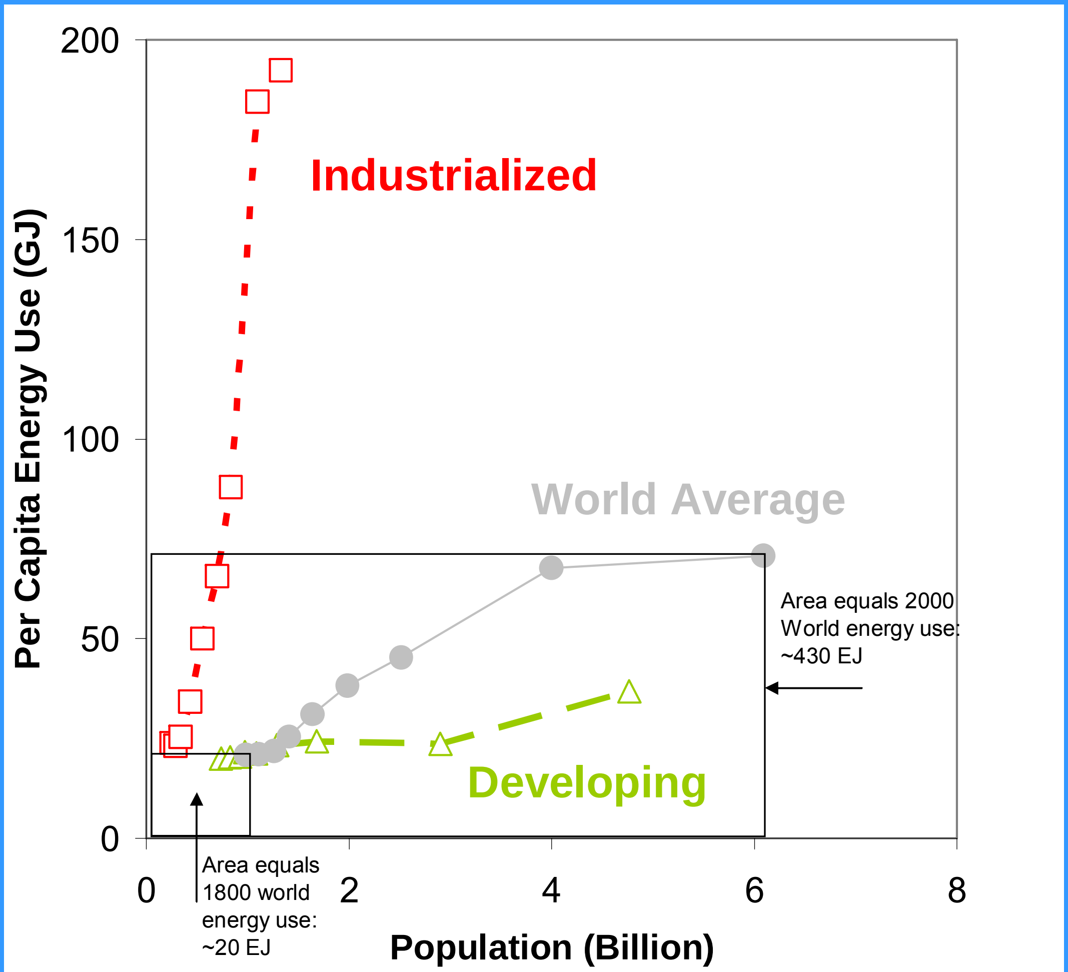
  -- Quantity
  -- Structure of end-use and supply
  -- Quality

- With due regard to differences in
  -- space: “where”
  -- time: “when”

# Main Energy Transitions: History

- Non-commercial → commercial
- Renewable → fossil
- Rural → urban
- South → North → South
- Low exergy → higher exergy (H:C ratio↑)
- Improved efficiency/productivity
- Conversion deepening
  (e.g. electrification)
- Increasing supply/demand density
- Desulfurization, Decarbonization

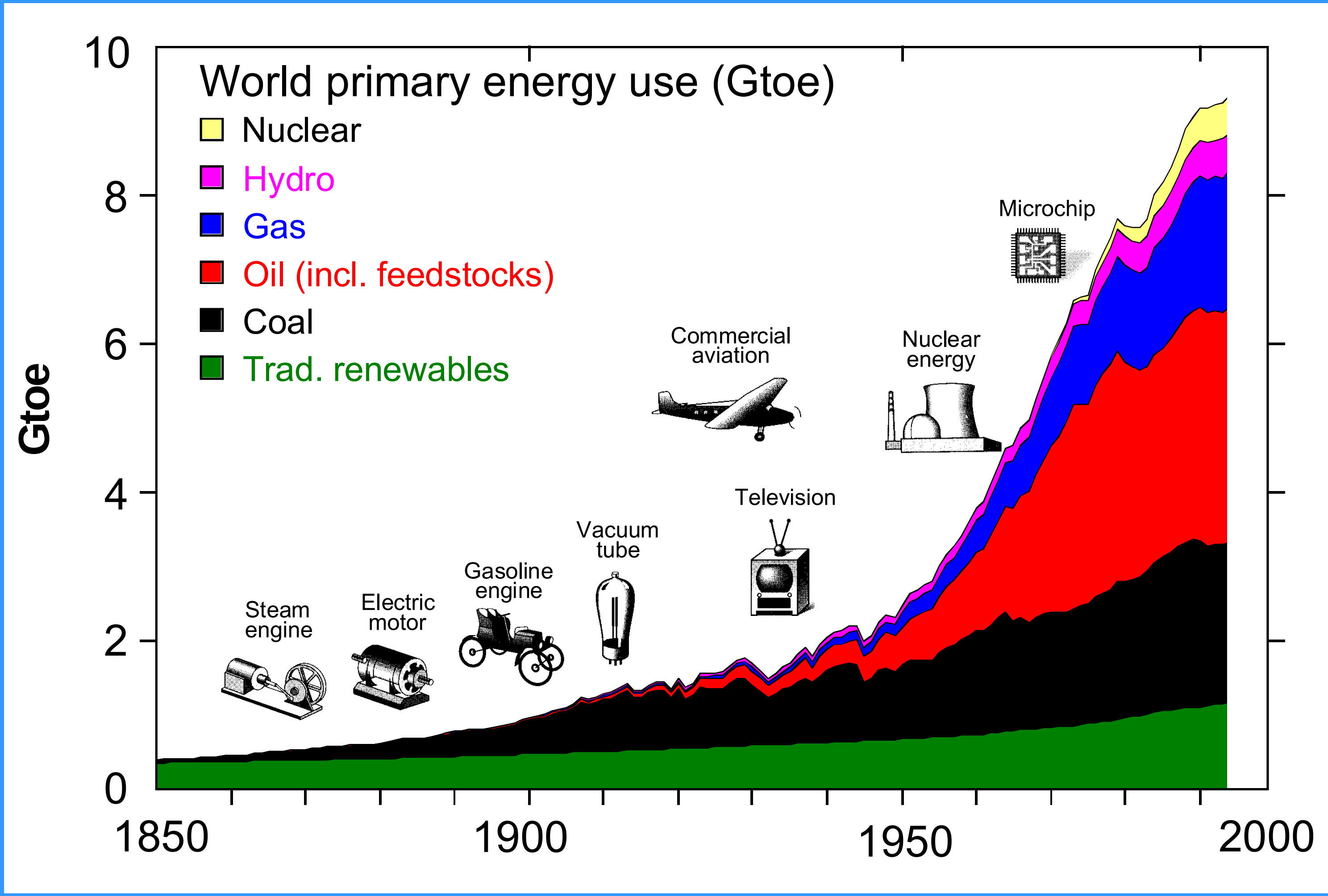
# World Primary Energy Demand
## 1800-2000 in 25 yr intervals



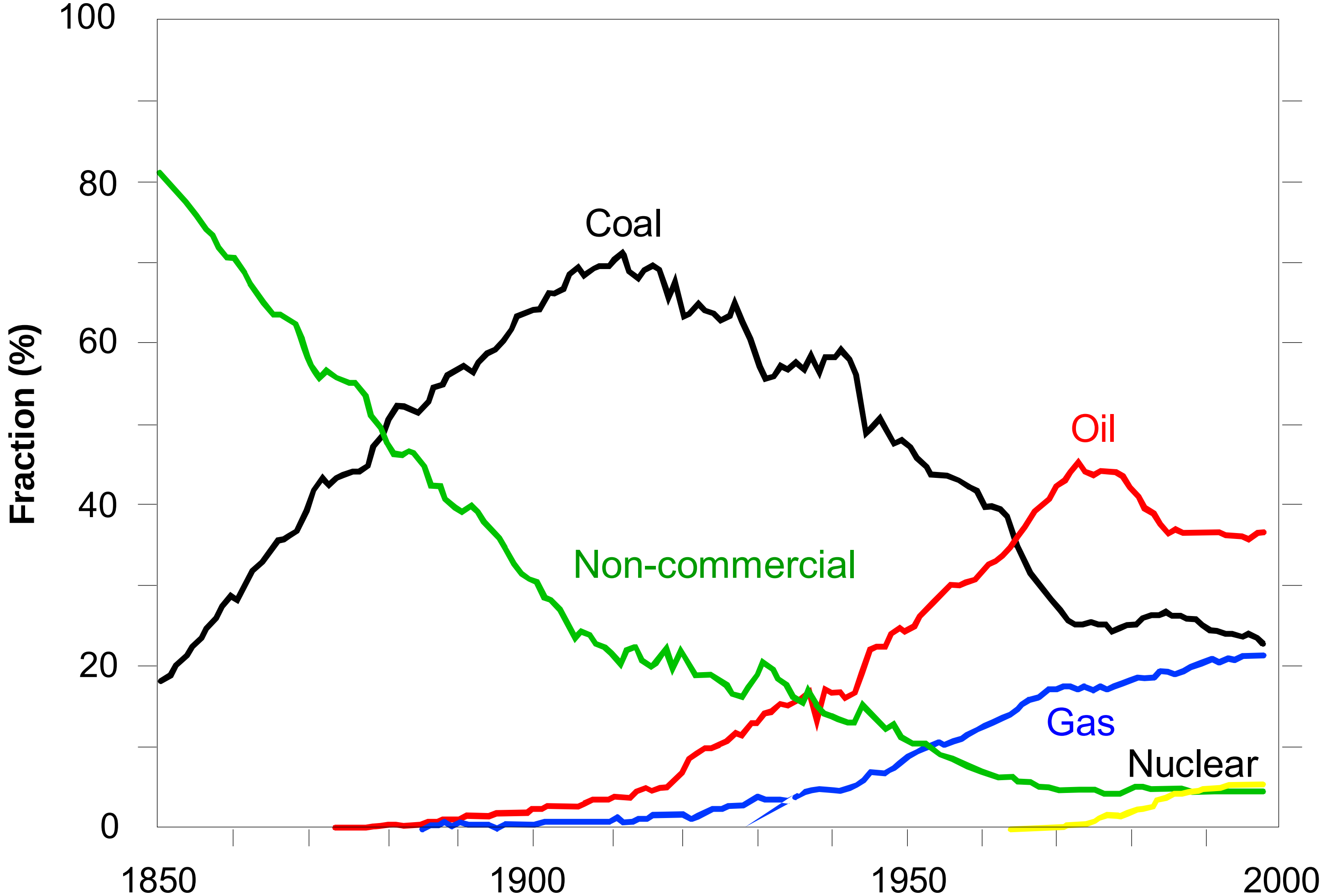

IND:
"take-off" ~1850
"plateau" ~1975

DEV:
"take-off" ~1975
"plateau" ??

# World Primary Energy Supply

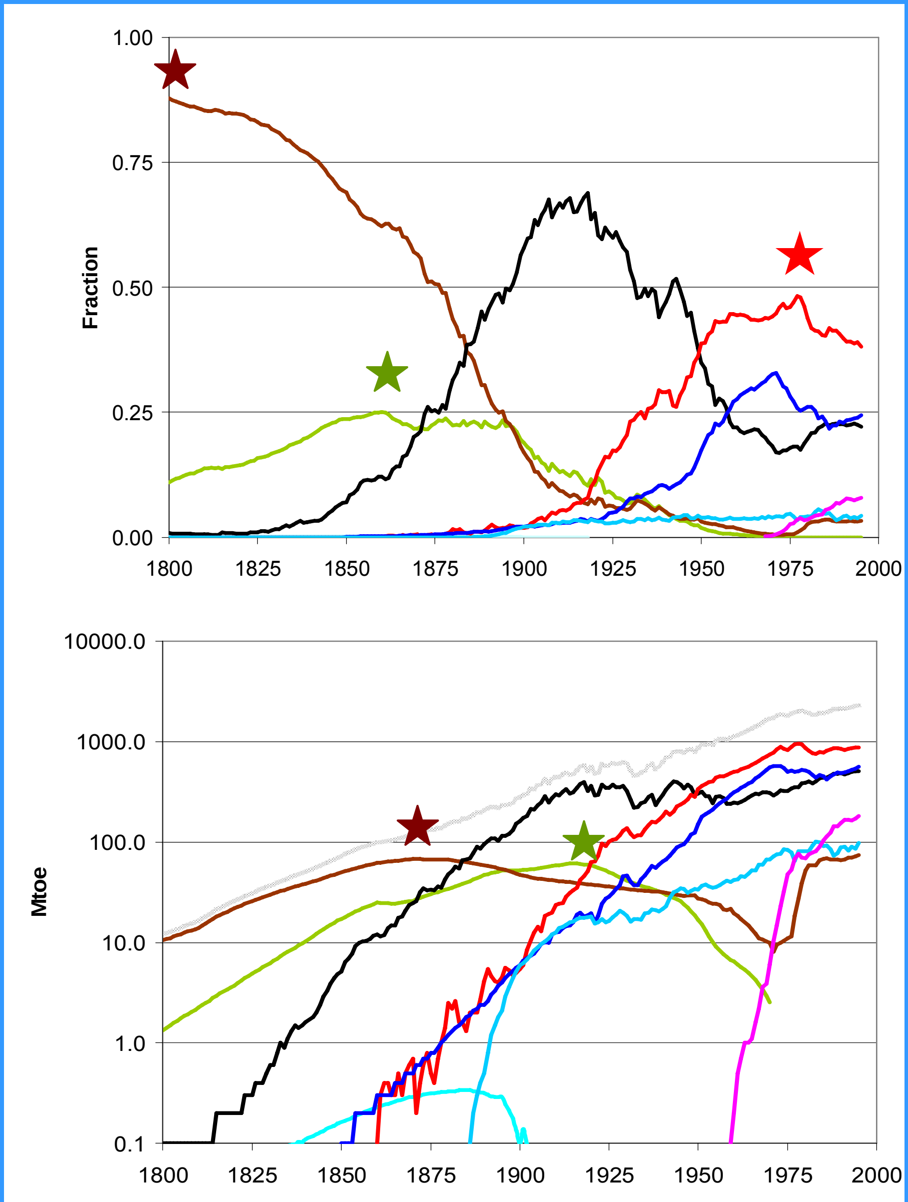


# World Primary Energy Substitution



# Measuring US Energy Transitions

**by rel. market shares (top) and absolute amounts (bottom) of primary energy use**



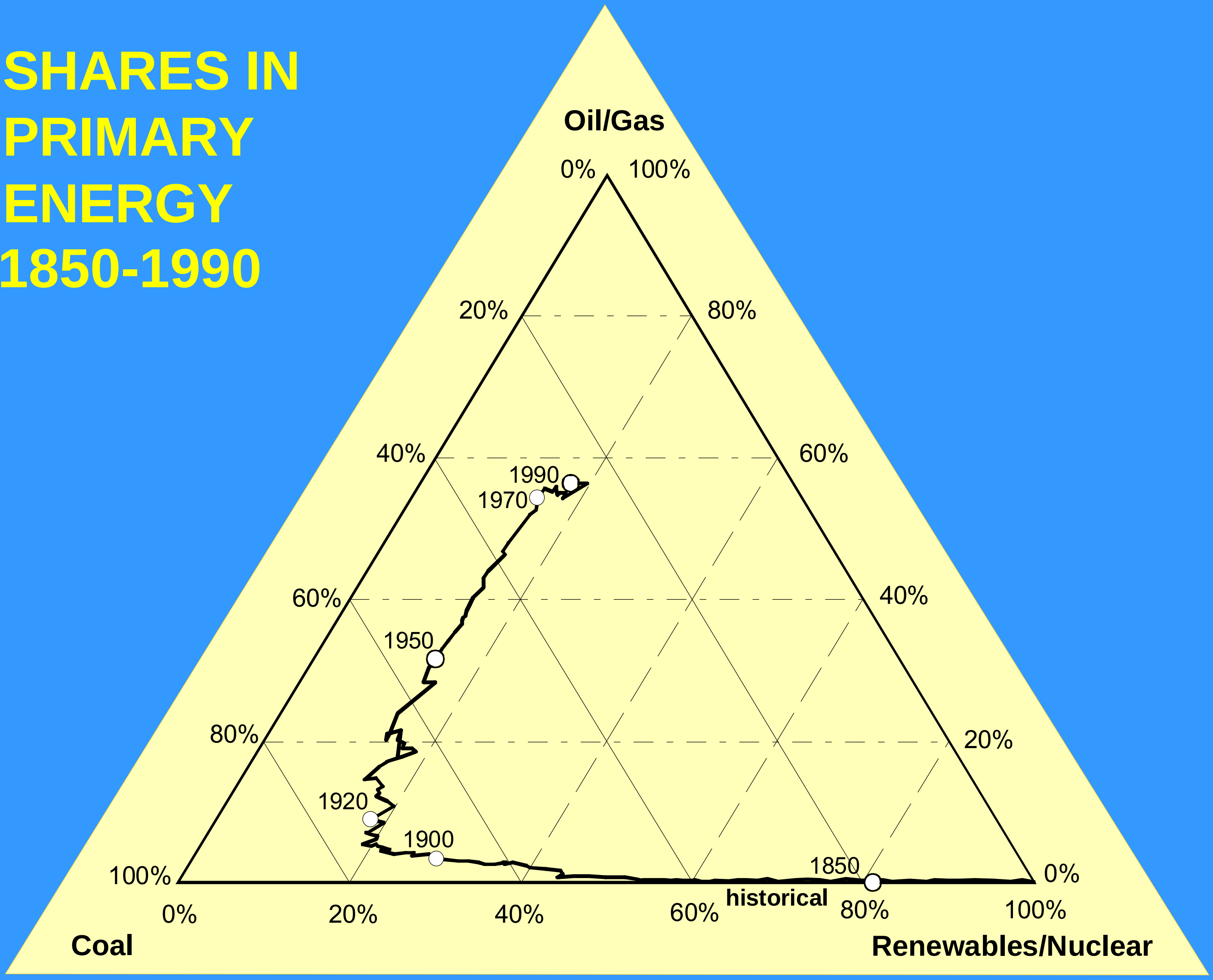

★

**Peak in market share precedes absolute production peak by ~60 years:**

**Wood 1800/1860**
**Feed 1860/1920**
**Oil 1975/??**

# World - Two “Grand” Transitions

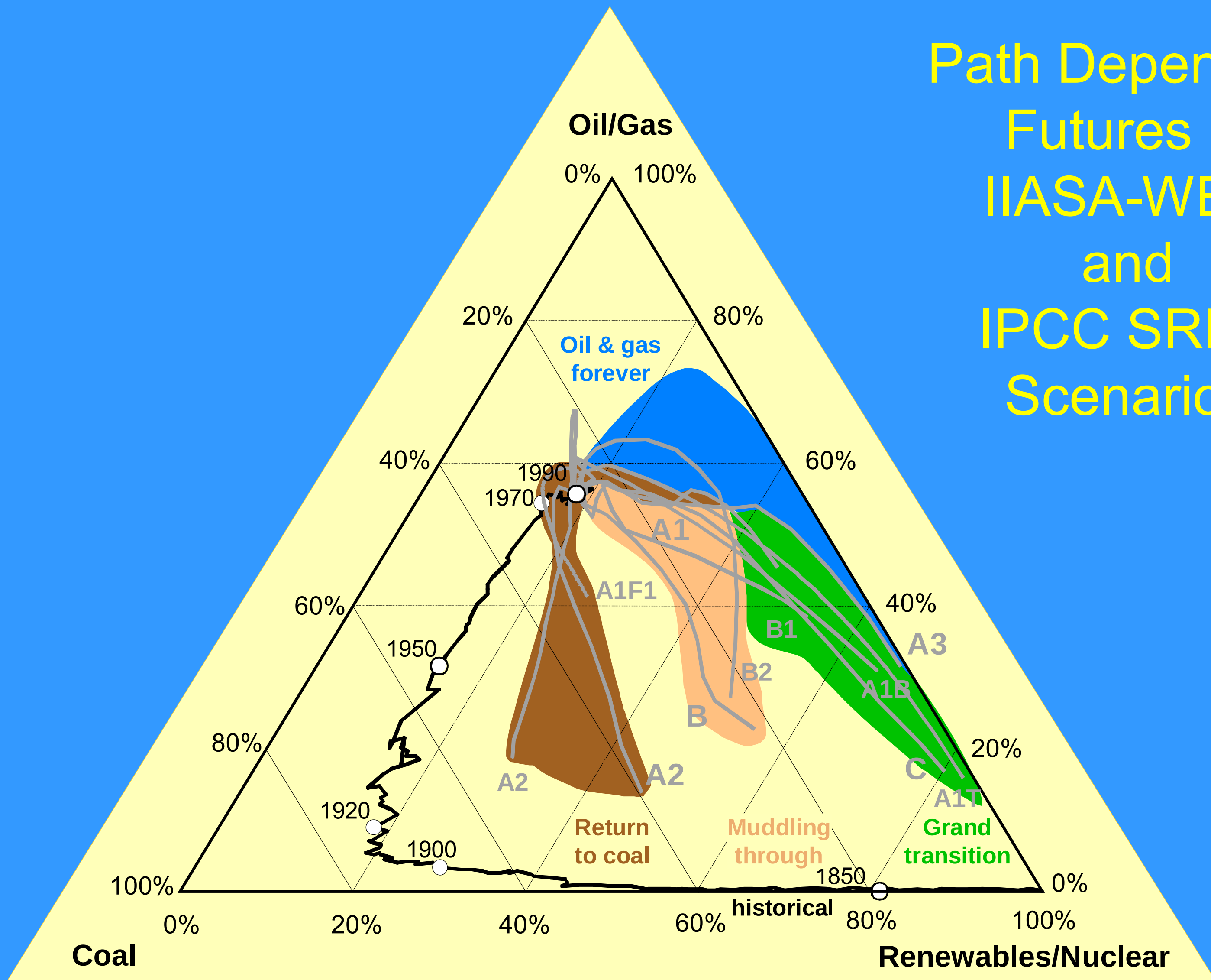
**SHARES IN PRIMARY ENERGY 1850-1990**




Historical Energy Transitions

Arnulf Grubler

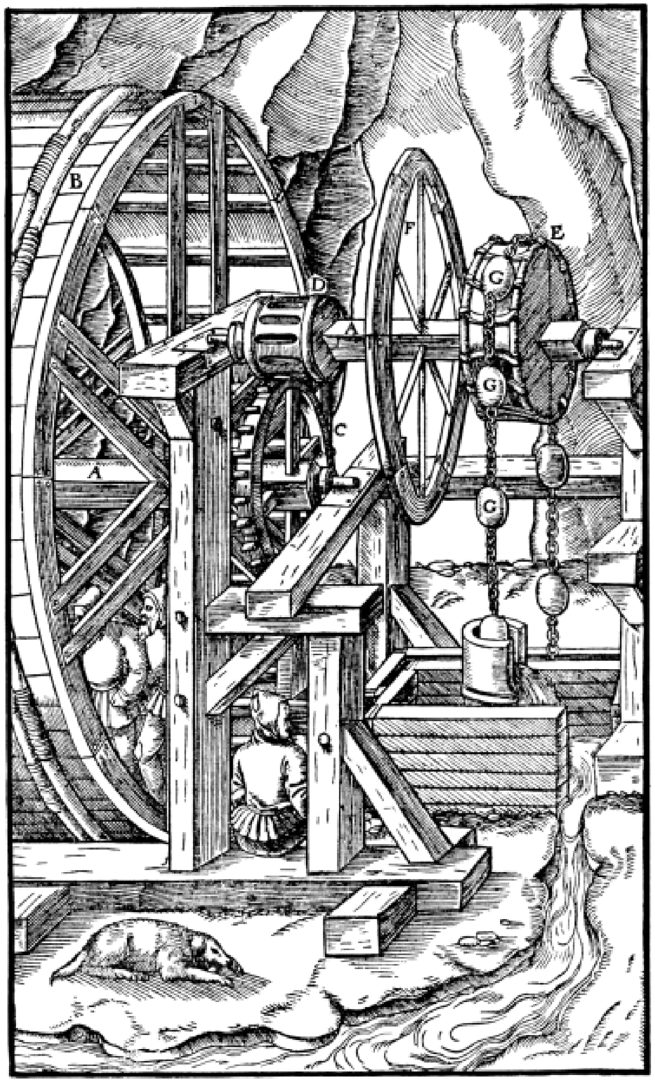
# Path Dependent Futures in IIASA-WEC and IPCC SRES Scenarios



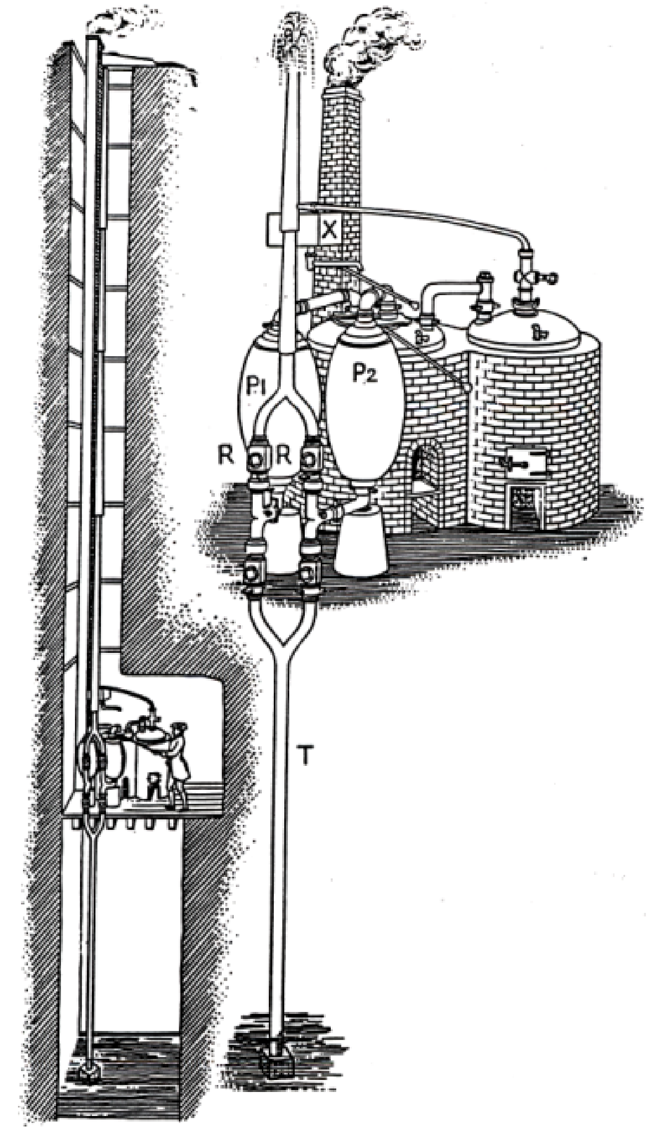
# Drivers of Historical Energy Transitions

- Technological change in end-use: steam engines, automobiles, electric motors and lights
- Supply: no evidence of resource scarcity, but plenty of evidence of TC
  (coal chemistry, offshore and "unconventionals", nuclear
- Price volatility (recurring): trigger of TC and structural change
- Policy: few success stories, lots of failures (Project Independence, breeders)
- Quality matters: electrification, decarbonization

# Dewatering Coal Mines



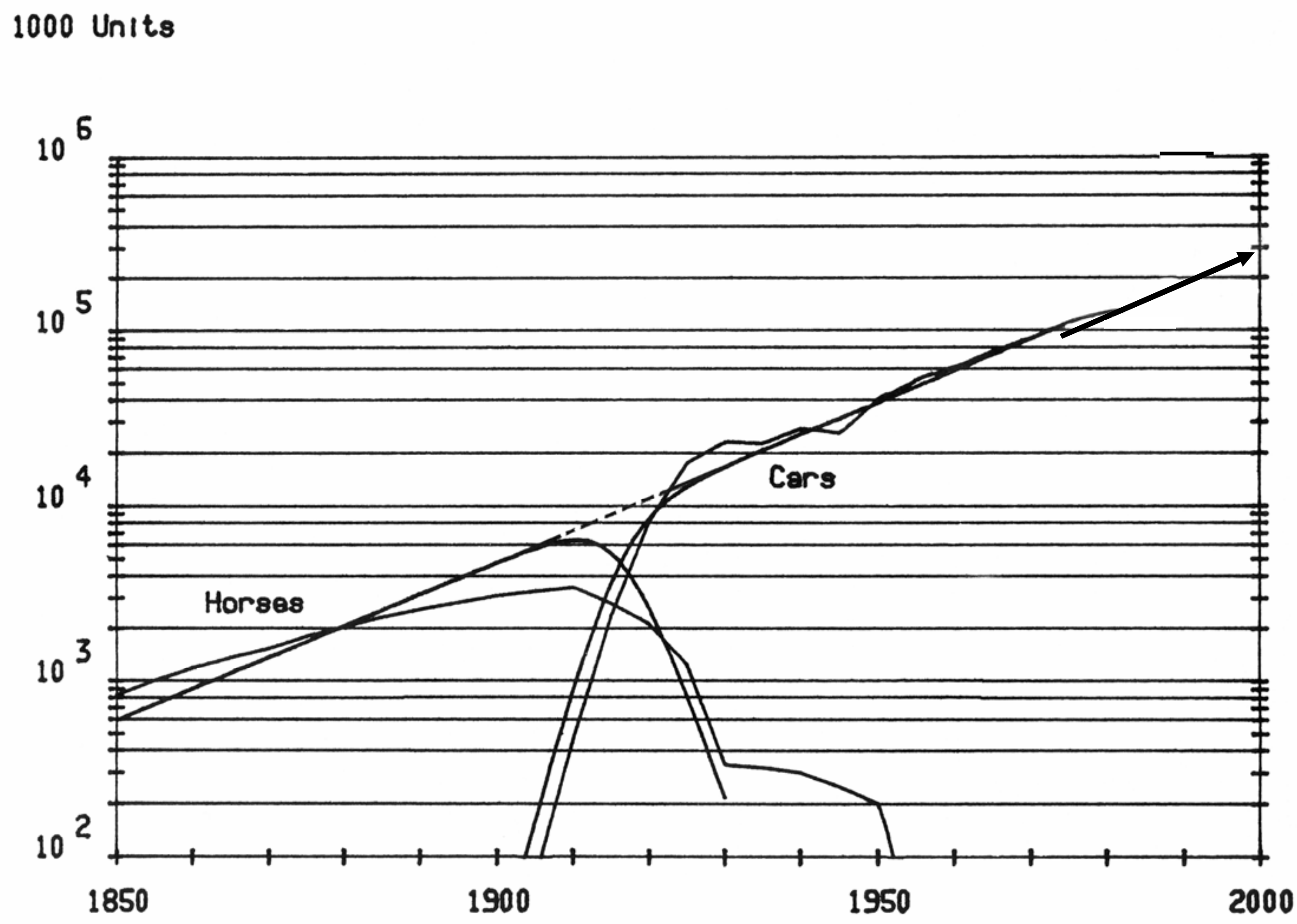

A—Axles. B—Wheel which is turned by treading. C—Toothed wheel. D—Drum made of rundles. E—Drum to which are fixed iron clamps. F—Second wheel. G—Balls.



# Technology Transitions are also Social Ones

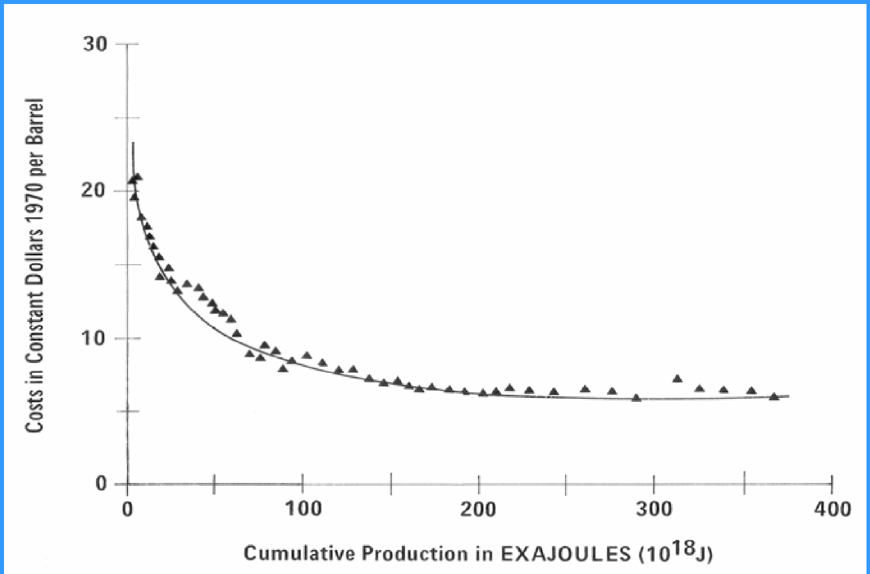
## 1838: Resistance to New Technology (Railways)

# Technological Change in US Road Vehicles

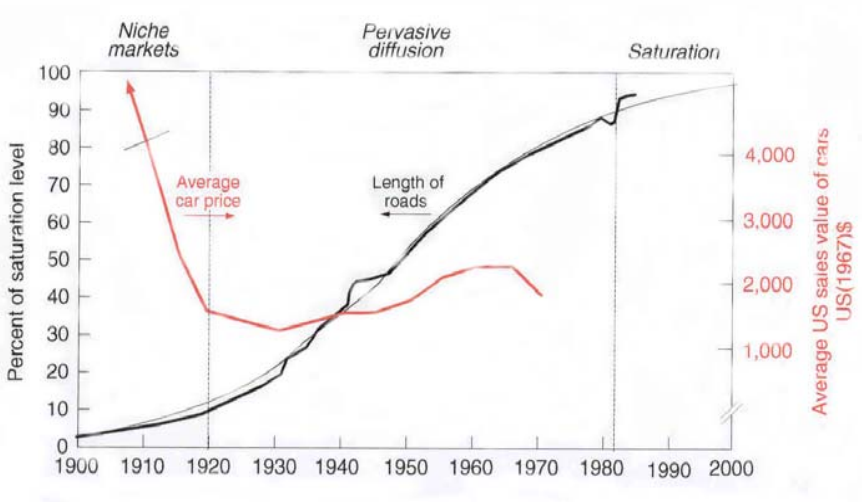



Source: N. Nakicenovic, 1986.

# Drivers of Transitions (US cars): Continued Improvements and Complementary Infrastructures:




**Cost declines of gasoline refining, T&D**
**Source: Fisher 1974 and EIA, 1985**




**Cost declines of cars**
**and increases in road infrastructures**
**Source: Grubler, 1990.**

# Energy Efficiency (%) and Emissions (g/km) for Horses, and Early and Contemporary Automobiles

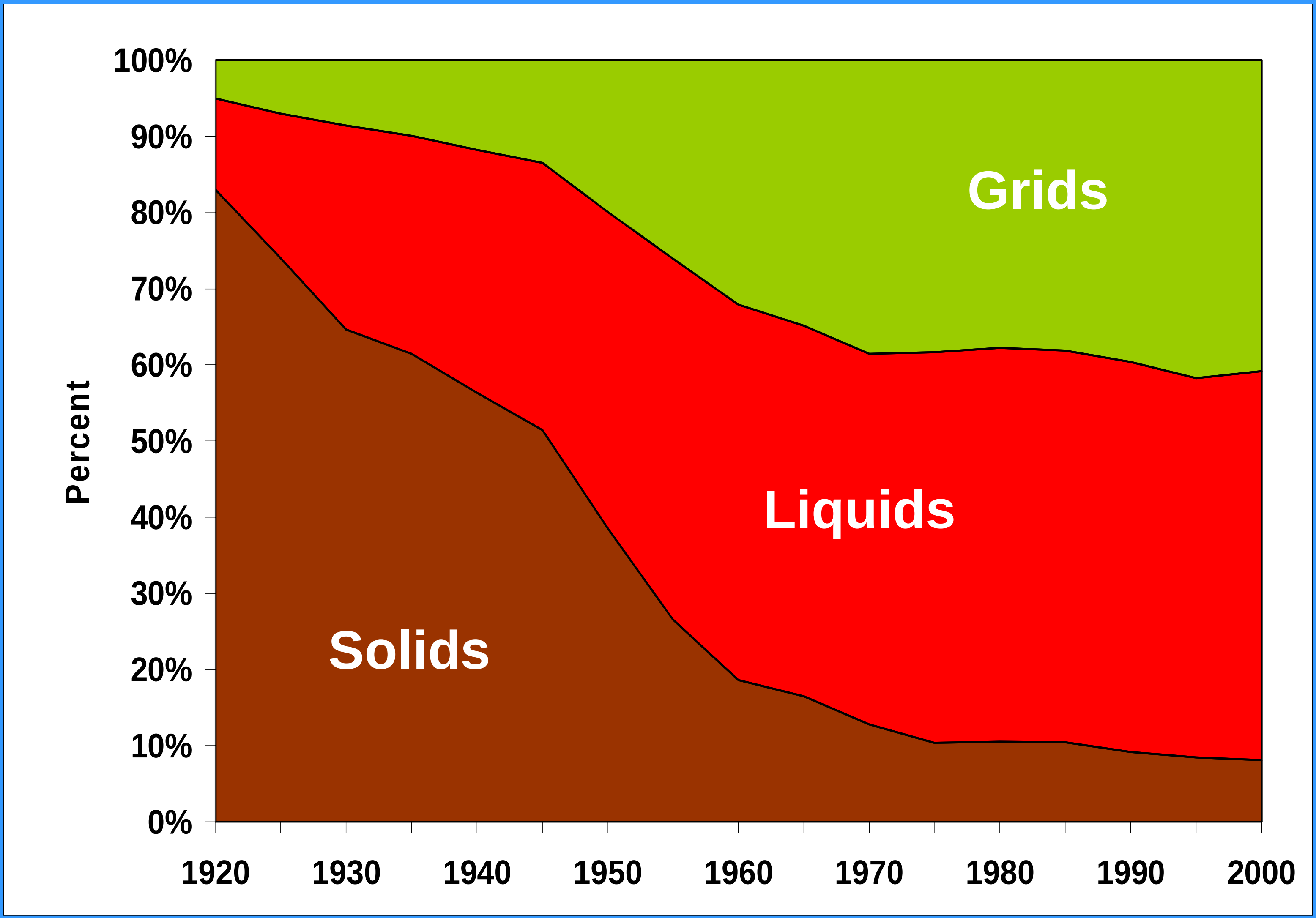
| | Horses | Cars (ca. 1920) | Cars (1995) |
|---|---|---|---|
| Engine efficiency, % | 4 | 10 | 20 |
| Wastes | | | |
| Solid | 400 | – | – |
| Liquid | 200 | – | – |
| Gaseous, | | | |
| Carbon ($CO_2$)[a] | 170 | 120 | 70 |
| Carbon (CO) | – | 90 | 2 |
| Nitrogen ($NO_x$) | – | 4 | 0.2 |
| Hydrocarbons | 2[b] | 15 | 0.2 |

*a* Total carbon content of fuel
*b* Methane

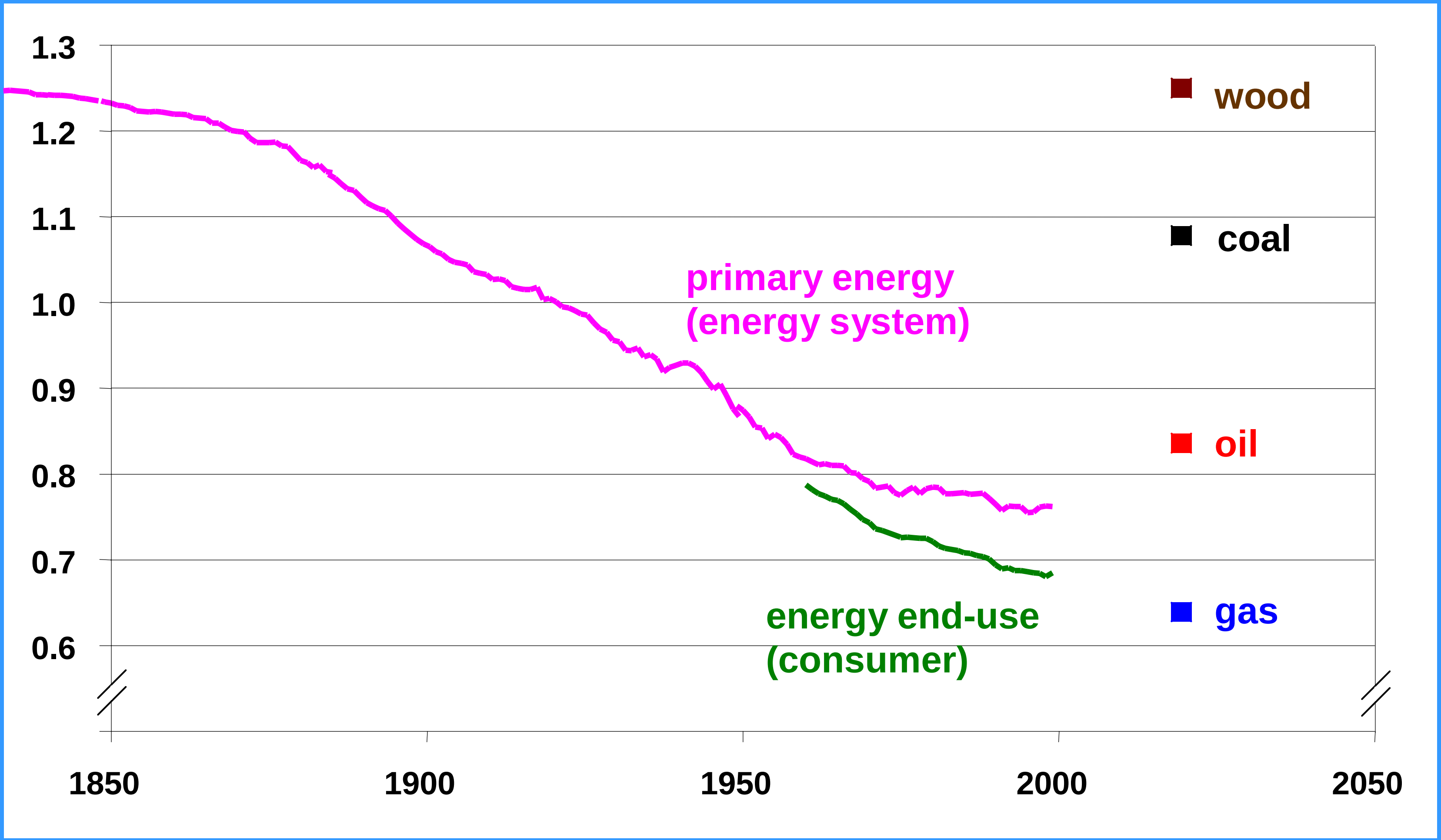
# Energy Quality

- Multiple dimensions:
  -- exergy or form value
  -- H/C ratio
  -- emissions (particulates, sulfur)
- Few studies and largely ignored in models
- Tradeoffs between quality and price initially resolved <u>in favor of quality</u> (subsequent cost declines via “learning-by-doing”)
- Quality trends more pronounced at end-use (supply improves only via structural change and regulation)

# US - Final Energy Structure



# USA - Decarbonization (tC/toe)

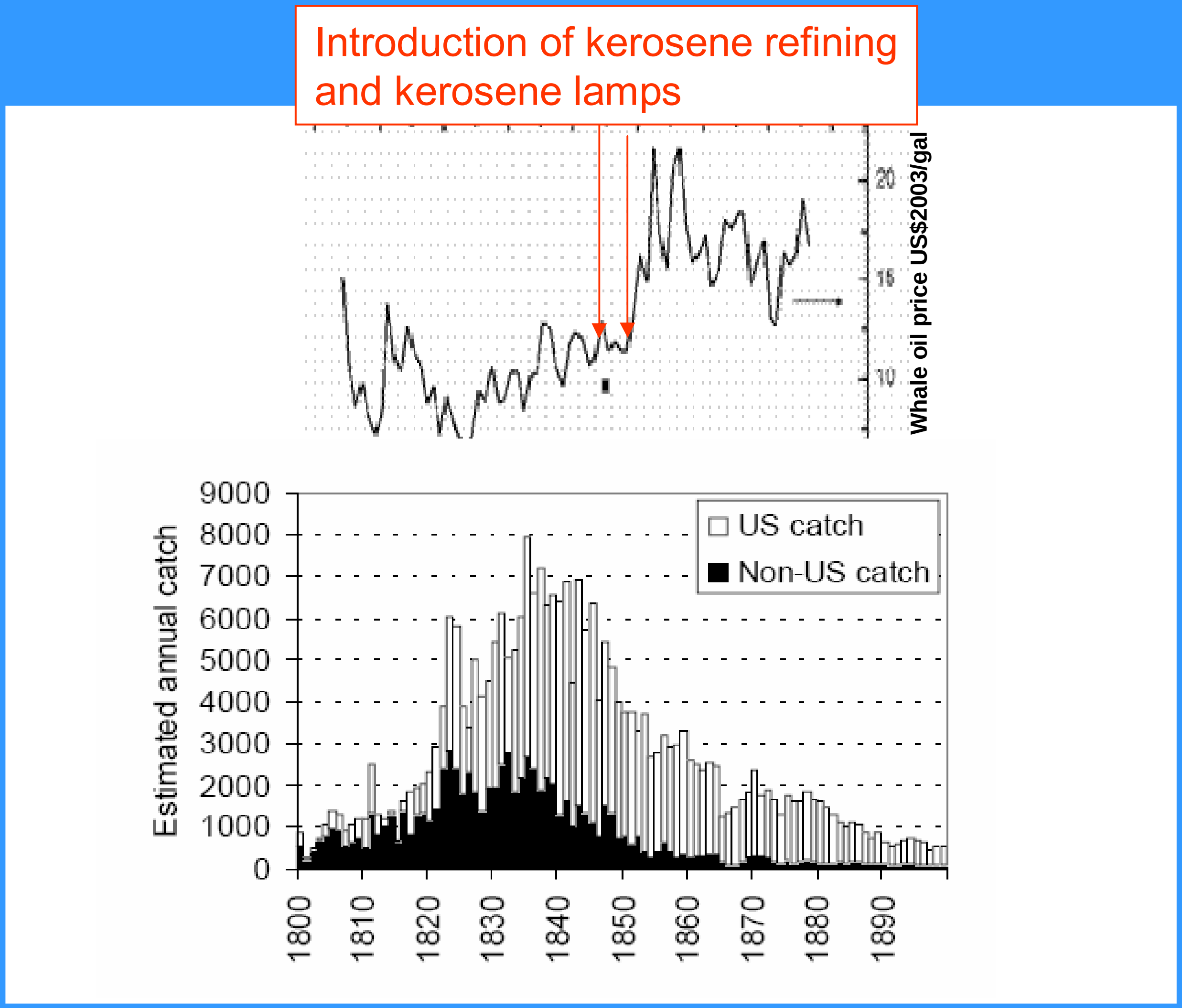



Data Source: US DOE EIA (2001): 1960-1999; Grubler (1998): <1960.

# On Hubbert Curves

- Sparse historical evidence (whale oil)
- Assumed symmetry condition neither empirically or theoretically confirmed
- Continued uncertainty: “Ultimately recoverable reserves” change with exploration and new technologies
- Interaction (market response, i.e. demand & substitution) ignored or underestimated
- Economic implications of “peaking” not rigorously argued or tested

# Whale Catch and Whale Oil Prices




Source: Sperm catch: P. Best, 2002, IWC SC/56/IA5; Prices: U. Bardi, 2004, based on Starbuck, 1878.

# An Early "Hubbert Peak"

*"…the data at hand in regard to the gas still available underground … make it probable that the annual output will never be very much more than it was during the period 1916 - 1920."*

R.S. McBride and E.G. Sievers (USGS),

Mineral Resources of the United States, 1921, p.340.

US gas production:

22 Mtoe in 1920

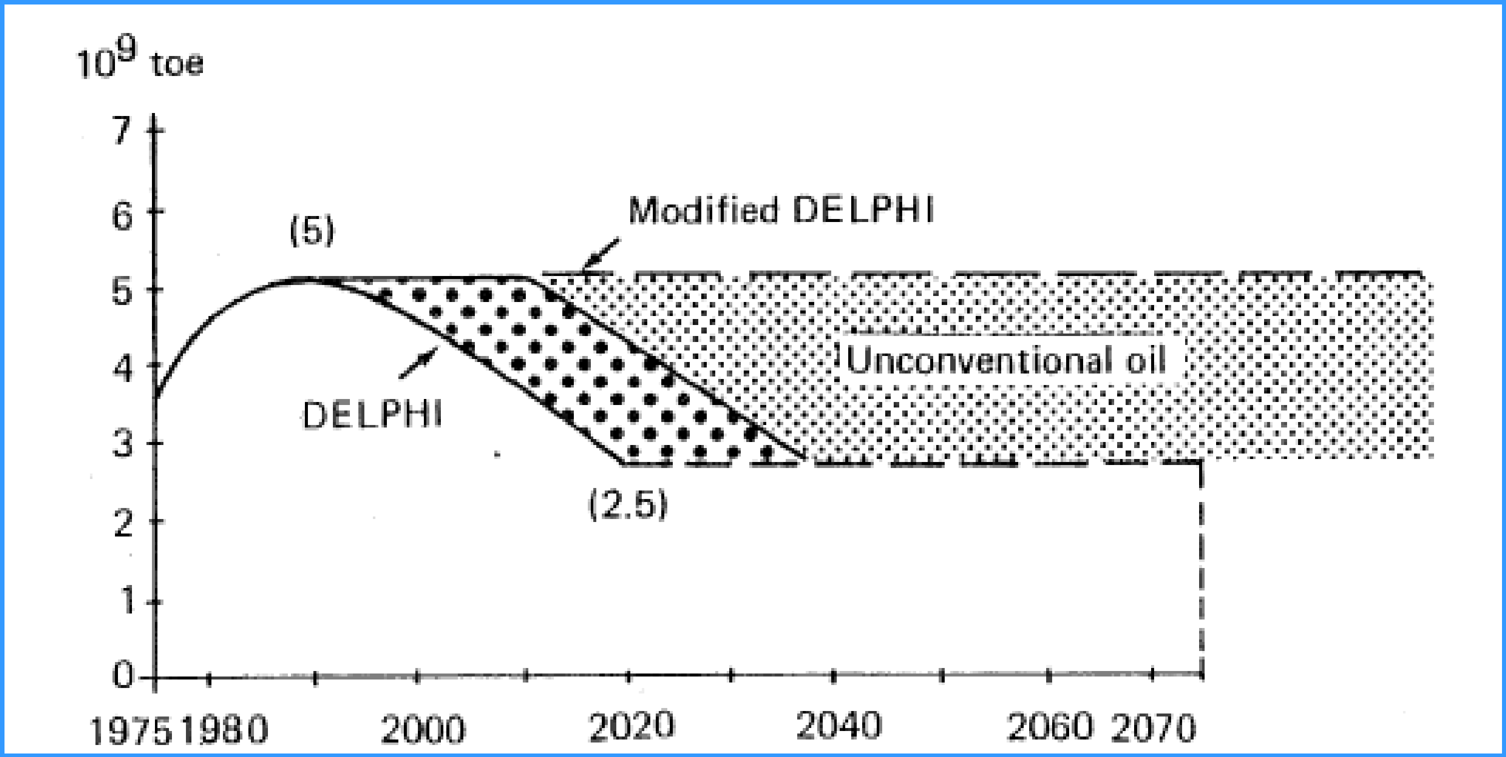
100 Mtoe in 1995

# Recurring Perceptions of Geological and Environmental Limits

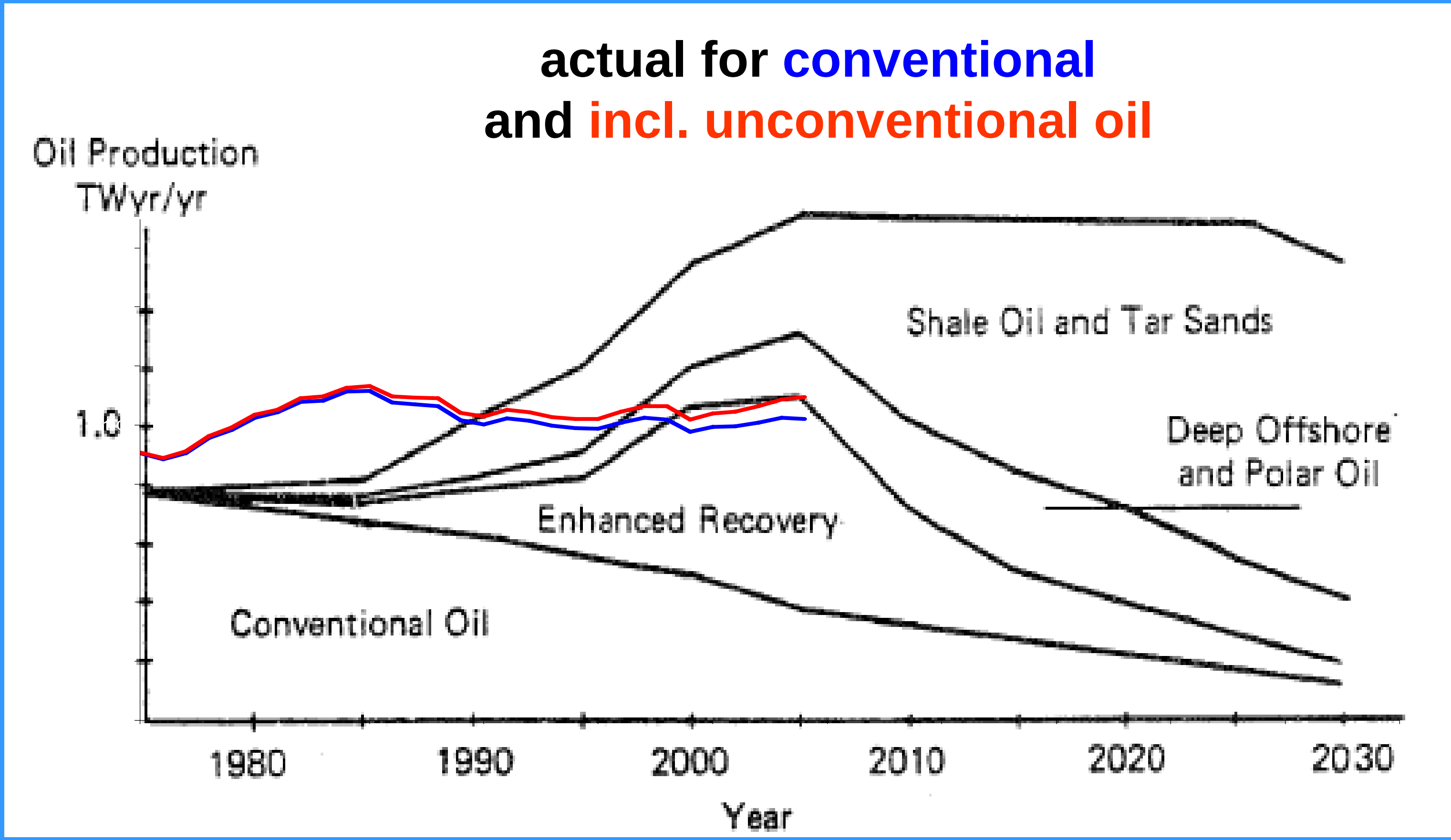
- 1865: W.S. Jevons *The Coal Question*
- 1884: J. Ruskin *Storm Cloud of the 19th Century*
- 1919-22: Oil rationing and scarcity fears in US
- 1970s: *Limits to Growth* and "energy gap" studies
- 1980s: First globally balanced supply-demand
  *Energy in a Finite World (1981)*
  Oil price collapse and expansion
  of non-OPEC production (>1986)
- 1990s: Interest shifts to climate change

# Energy in a Finite World (Haefele et al., 1981):

**Conventional Wisdom of the 70s (rapid demand growth, supply peak in 1990s) New Information: Uncertainty of reserves and importance of unconventional oil**

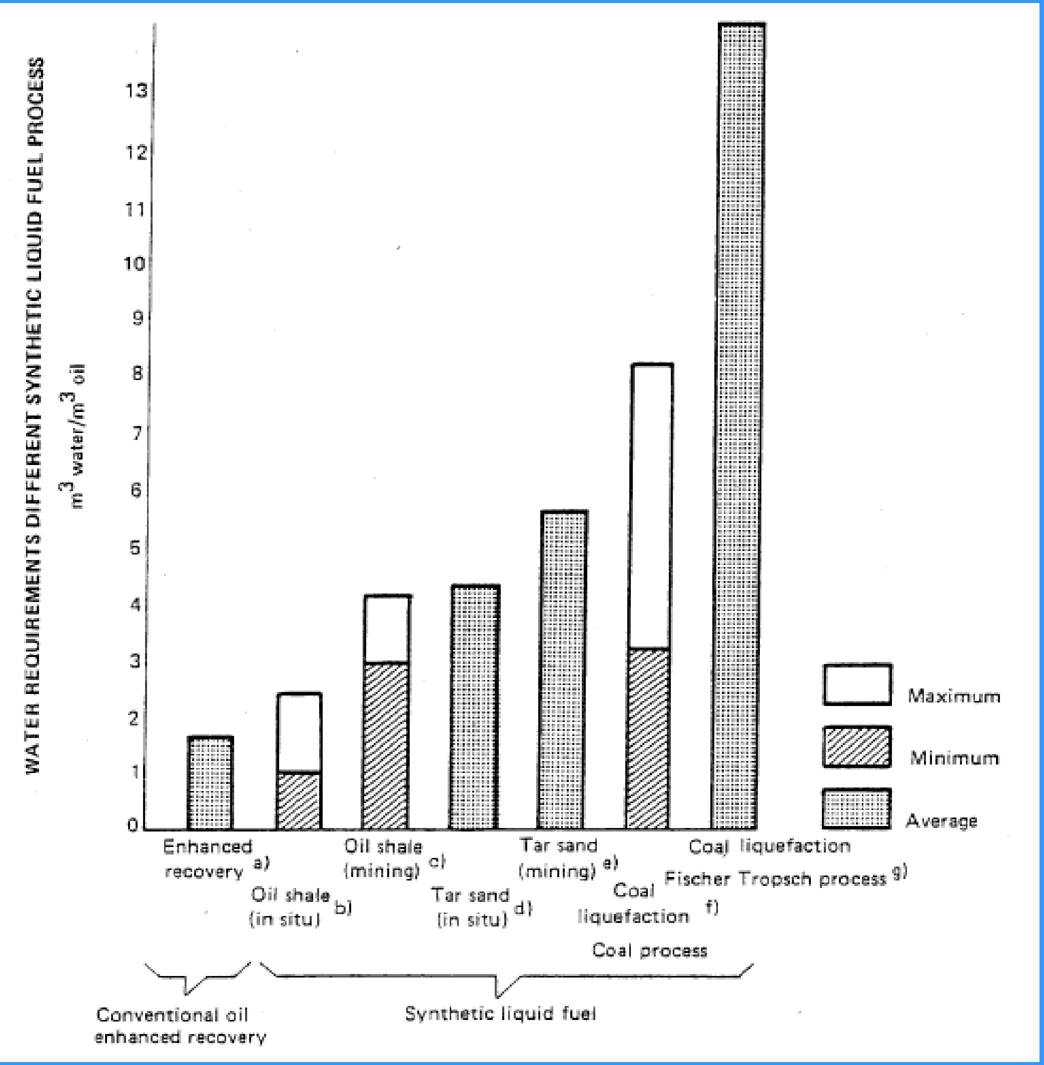


# North America: Estimated Maximum Oil Production (all sources) EiFW, 1981 and actual



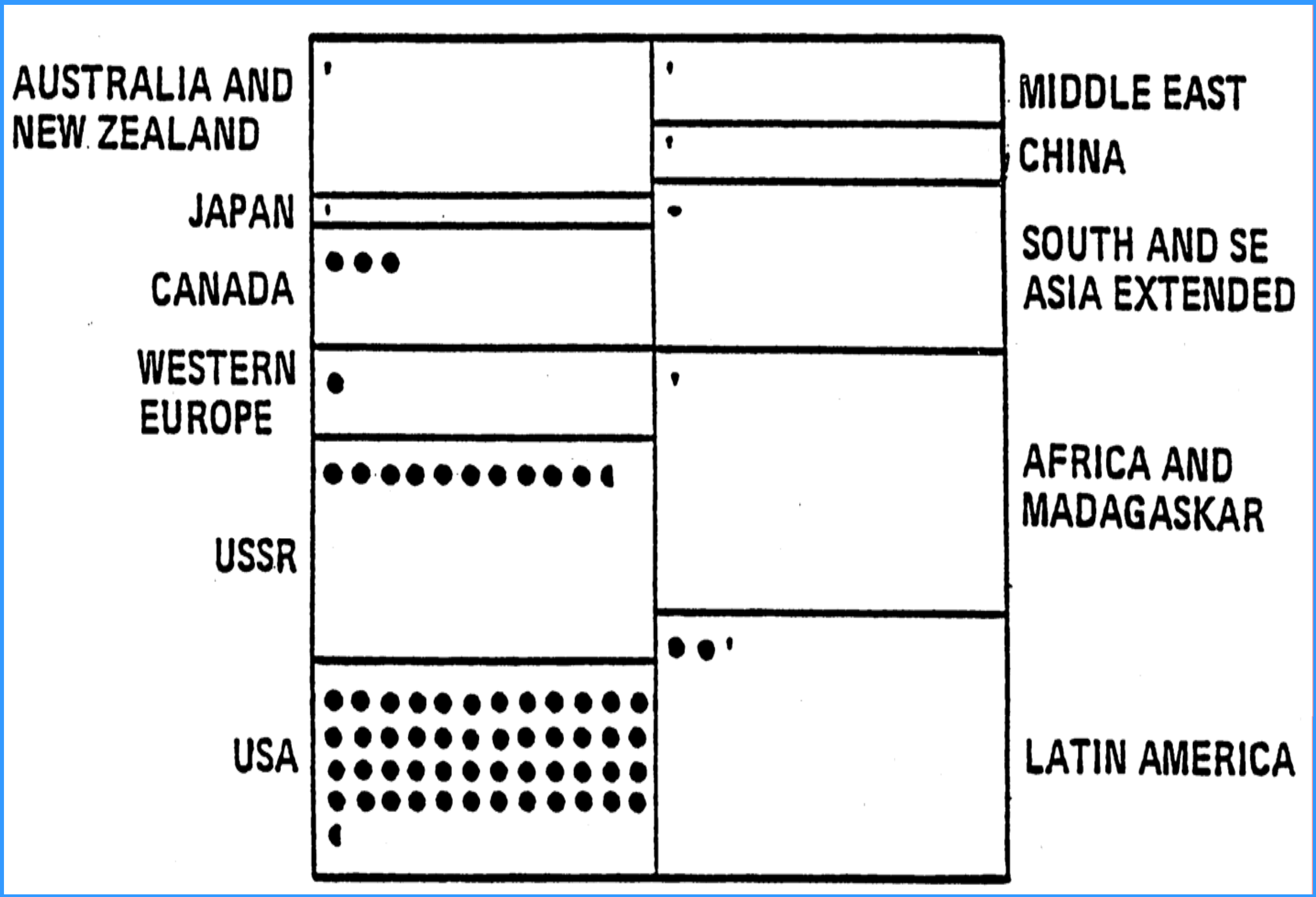
# Resource Constraints Beyond Energy: Estimated Water Use for Synfuel Production.

**Source: EiFW, 1981.**



# OIL: How Much Did We Know?
# Density of Exploratory Drilling per (potentially petroleum bearing) Sedimentary Area

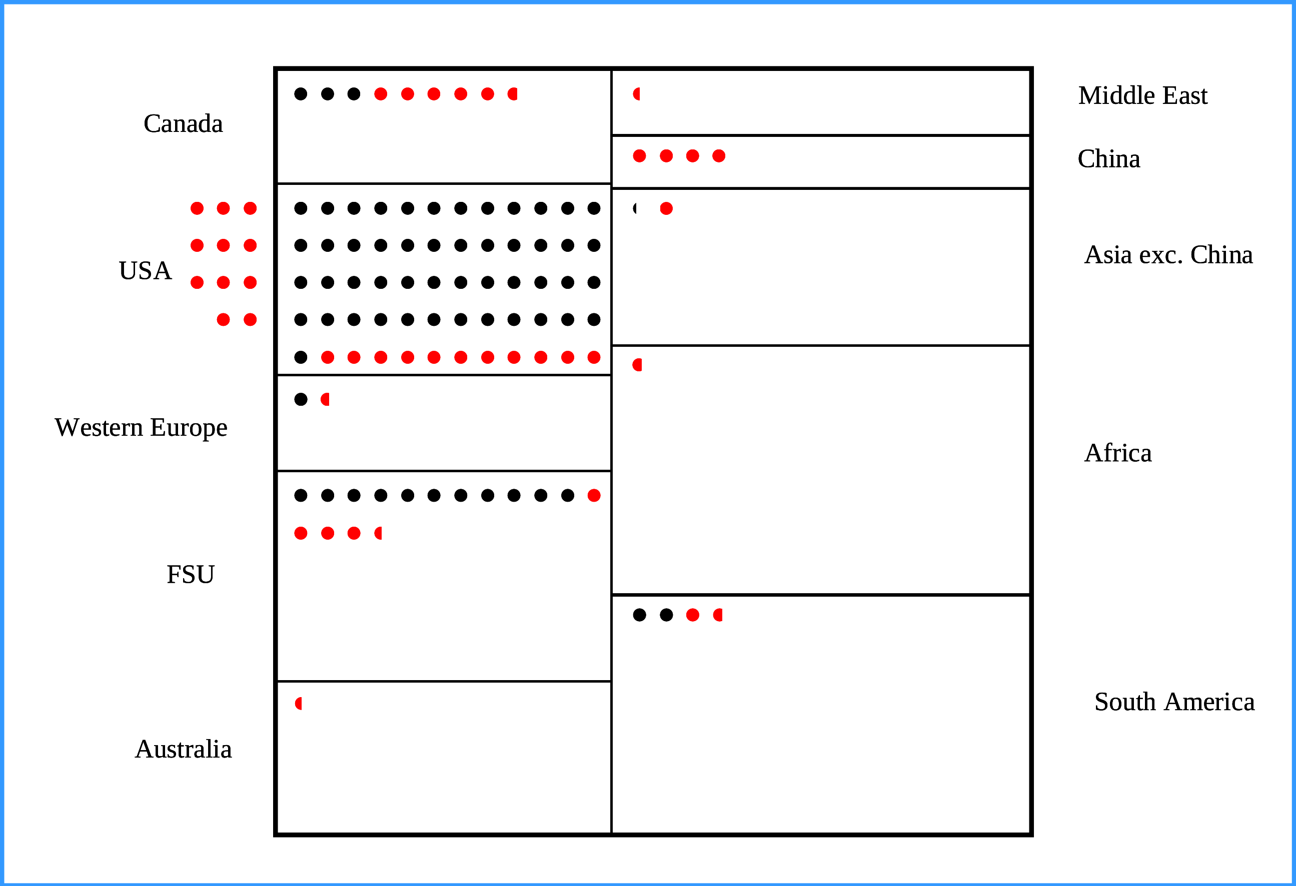
Source: Grossling, 1976.



# OIL: Where Did We Look?

## Prospective Sedimentary Areas and Oil Drilling Densities as per 1975 and per 2003

## Almost inverse relation between potentials and drilling efforts!




Wells drilled through 1975 shown in black. Wells drilled 1976 through 2003 shown in red.
Each circle represents 50,000 wells. Data through 1975 and relative petroleum prospective area from Grossling: "Window on Oil"
Wells drilled 1976 through 2003 per *World Oil*, August issue 1977 through 2003.

**From the 1.9 million wells drilled worldwide since 1975 three quarters were drilled in mature oil provinces (esp. the USA), classified in 1975 as "close to drilling saturation".**

Update courtesy of Jeff Possick, Yale FES, 2004

# Lessons Learned
## (even if sometimes forgotten)

- Resource availability is dynamic, “constructed” by changing economics, technology, and geological knowledge
- Feedbacks and responses often more dynamic than brains or models expect
- Constraints beyond geology important: R&D, capital, environment
- Drivers of Transition: Importance of technological change, esp. in end-use
(weak point in scenarios and models of future transitions)
- Analysis needs to consider all factors
- Geological depletion and “mid-point” studies that ignore(d) potential of alternatives, economics, technology, and behavioral and market responses were both historically wrong and offered bad policy advice
(Project Independence, Synfuels Corporation,…)