Sustainable Use and Depletion of Natural Resources: Lessons for the Energy System

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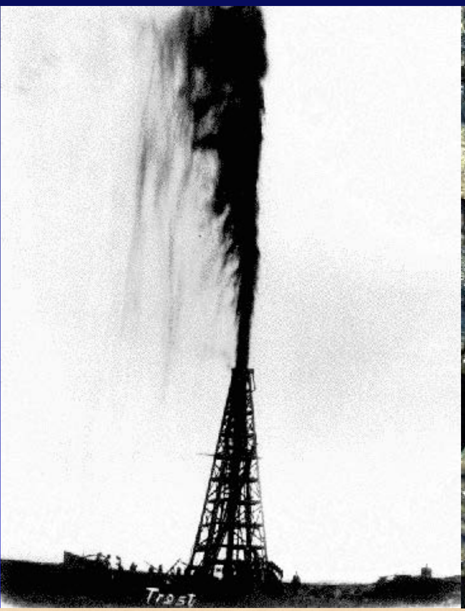
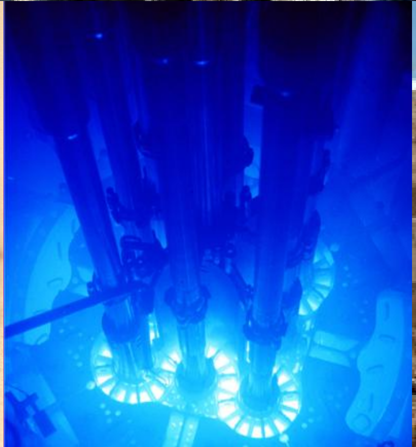
Framework

- What resources are inexhaustible or truly renewable?
- Visualizing stocks, flows, and prices – the theory
- Special Model 1. Sustainable use of renewables
  - A narrow range of conditions, bounded by restrained use
- General Model 2. Unrestrained use and depletion
  - General dynamics of stock, flow, and price
  - Identifying the peak/plateau of flow; implications
  - Applies to non-renewables and renewables
- What to do when a resource is depleted?
  - Making substitution happen
  - The arrow of innovation
  - A system for technological innovation
- For energy, there are only a <u>few</u> good choices!
  - Wind, geothermal, ocean, non-food biofuels, solar
- Pushing the learning curve
- Building the infrastructure

What is an exhaustible natural resource?

- **What about non-renewable resources?**
- **All NRR are exhaustible, only the depletion rate can be managed .**





What's an inexhaustible natural resource?

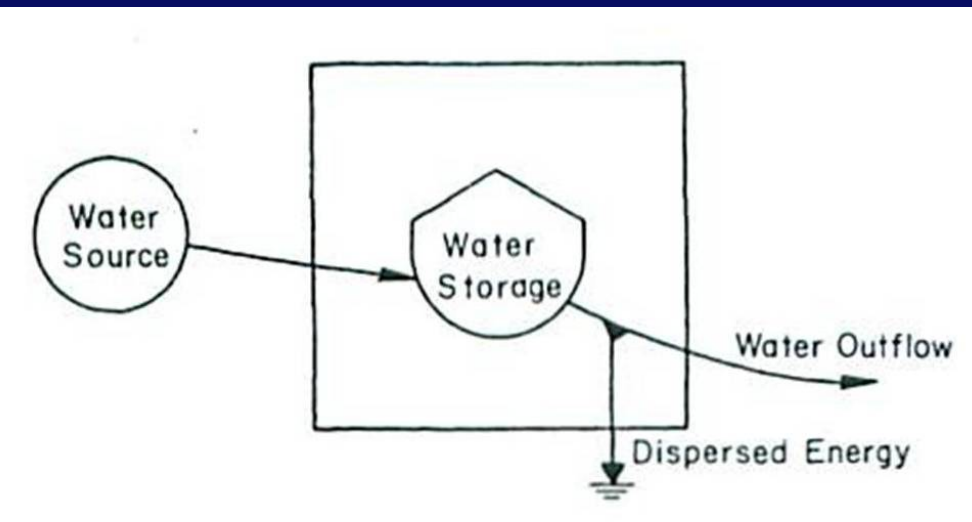
- Renewable resources can be used sustainably
- But only some RR are inexhaustible. Which ones?
- What happens when RR are used unsustainably?

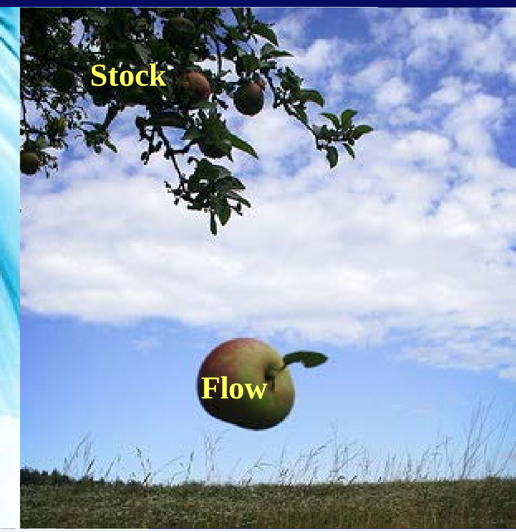




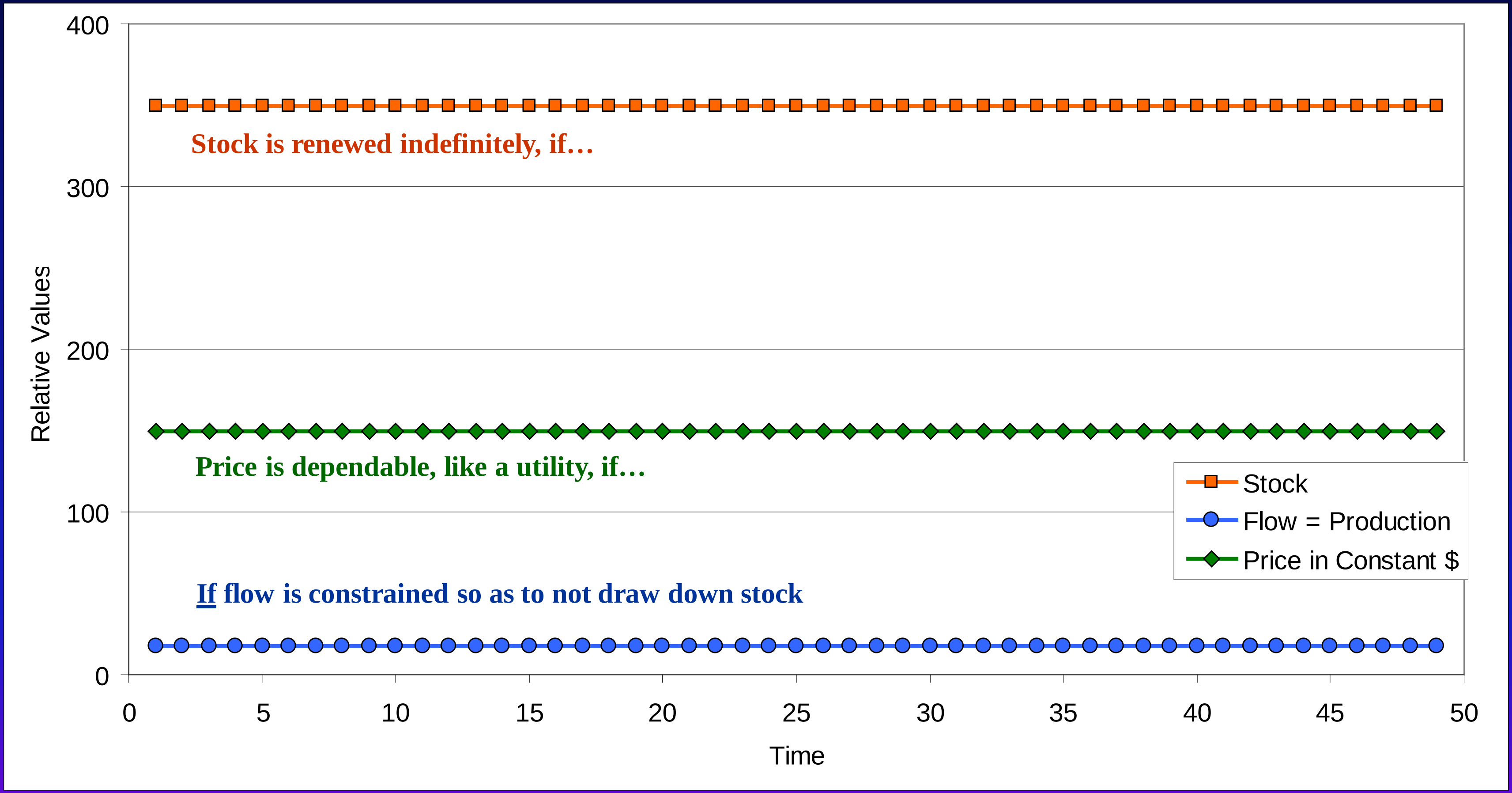

Key insight: distinguishing stock and flow

- The supply in "supply and demand" is not a resource stock!
- Supply is <u>flow</u>, or periodic production from stock
- <u>Stock</u> is the resource that may be used sustainably or exhausted



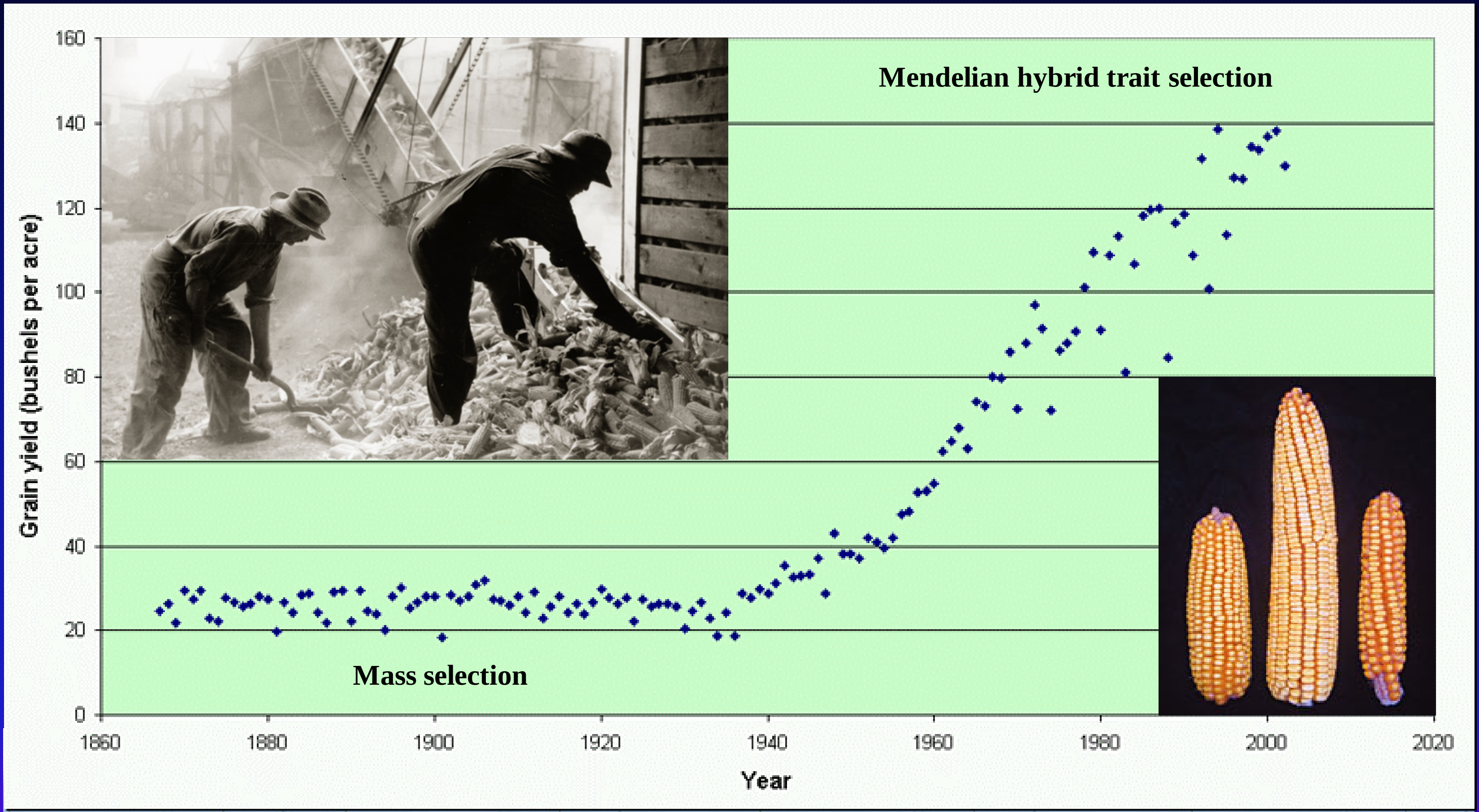


Special Model 1: sustainable use of a renewable resource



Shows 5% harvest, conditions unchanging, variation ignored. The sustainability model is simple but crucial to visualize.

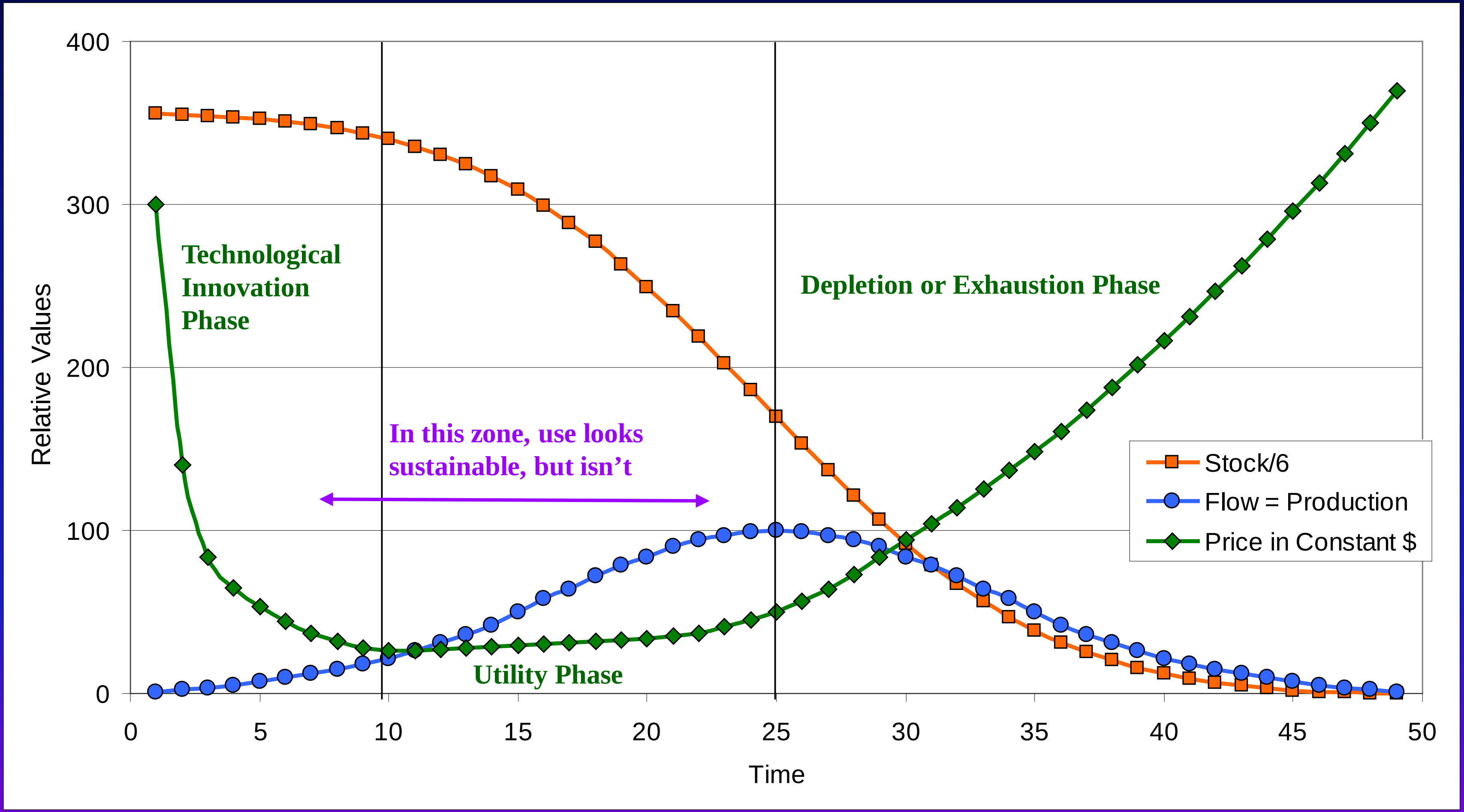
Corn: sustainable use, disruptive tech



Is modern corn agriculture sustainable?

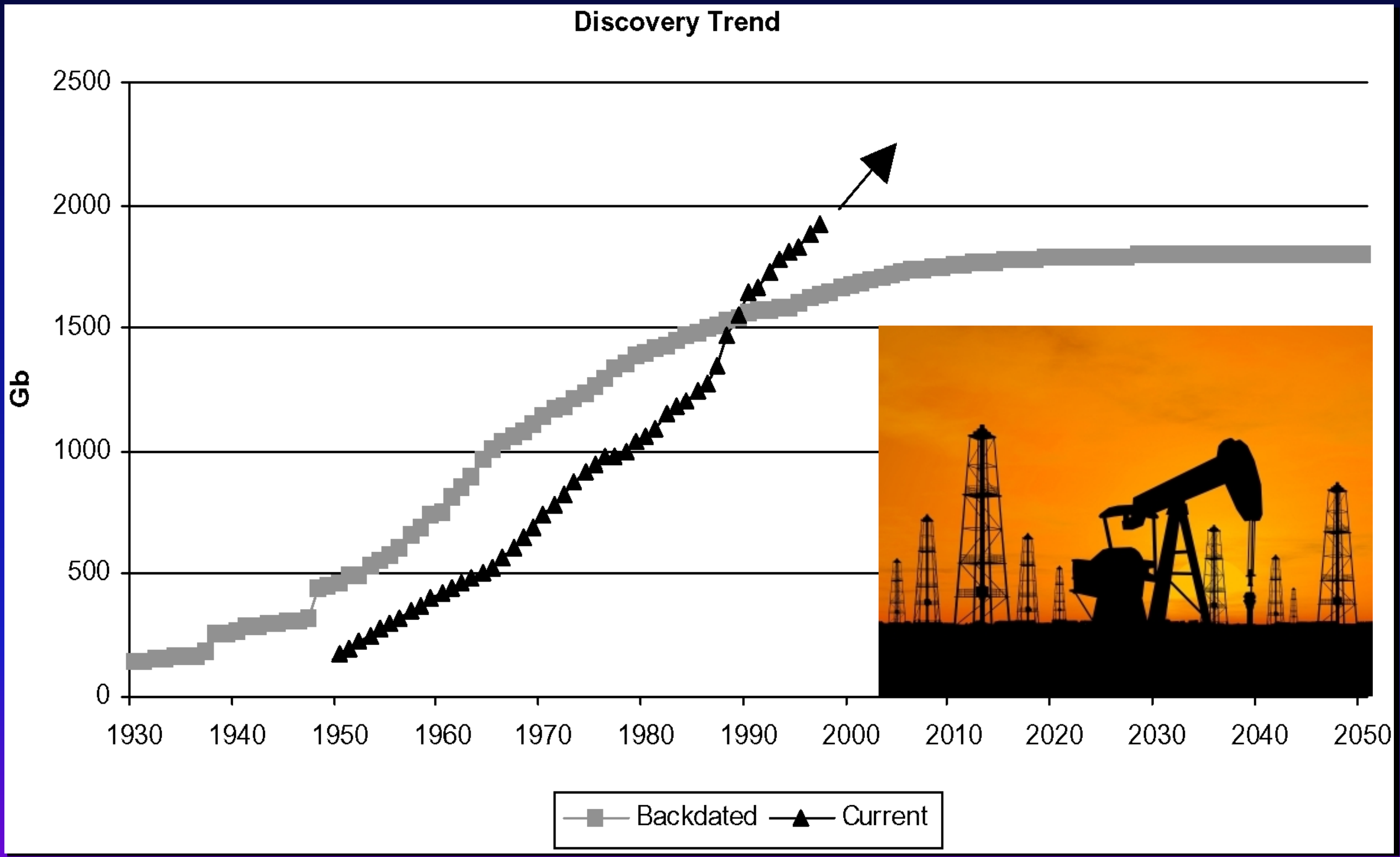
Are the renewable inputs used renewably?
Do the non-renewable inputs have substitutes?

General Model 2: non-renewable resource with high demand and no substitute



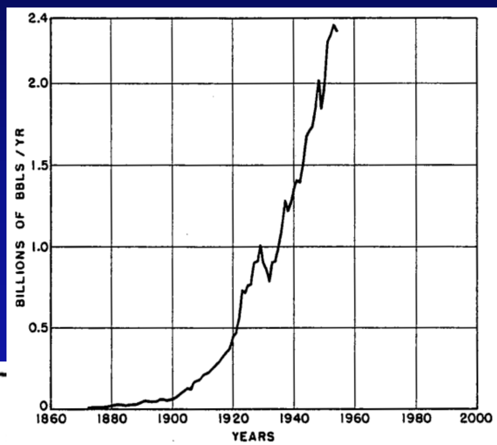
Stock is steadily depleted, flow rises-peaks-drops, and price drops-bottoms-rises; use seems sustainable temporarily

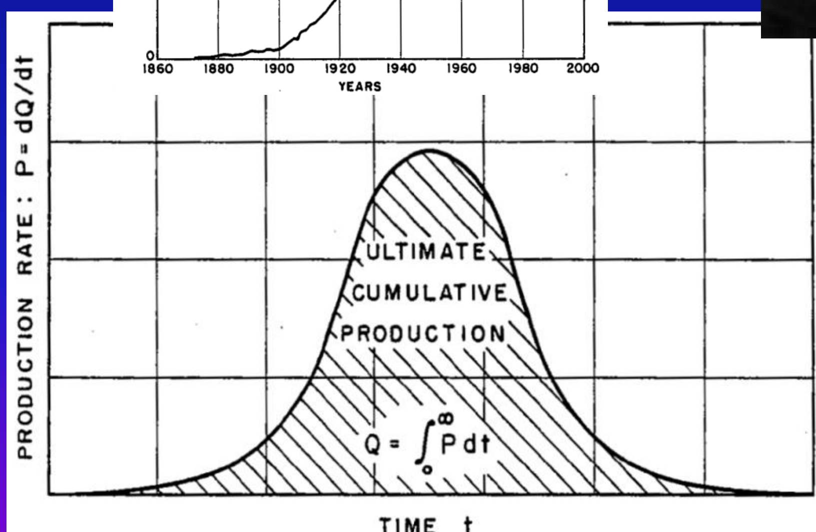
Inferring **stock** is the most difficult step.
Ex: cumulative world oil & gas discoveries

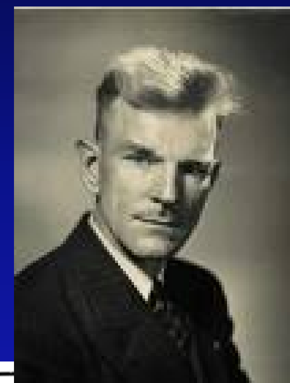


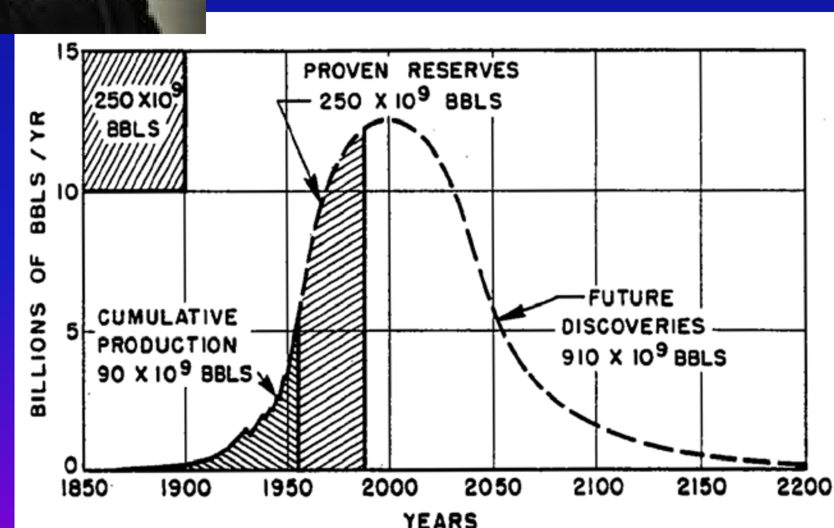
Backdating corrects errors in reporting date and reserve estimates

Flow is seen empirically, see Hubbert's 1956 data on US oil produced; reserves allow inferring US & world production









Roughly a normal curve, goes parabolic, peaks, then declines with elongated tail

Hubbert's peak prediction: correct

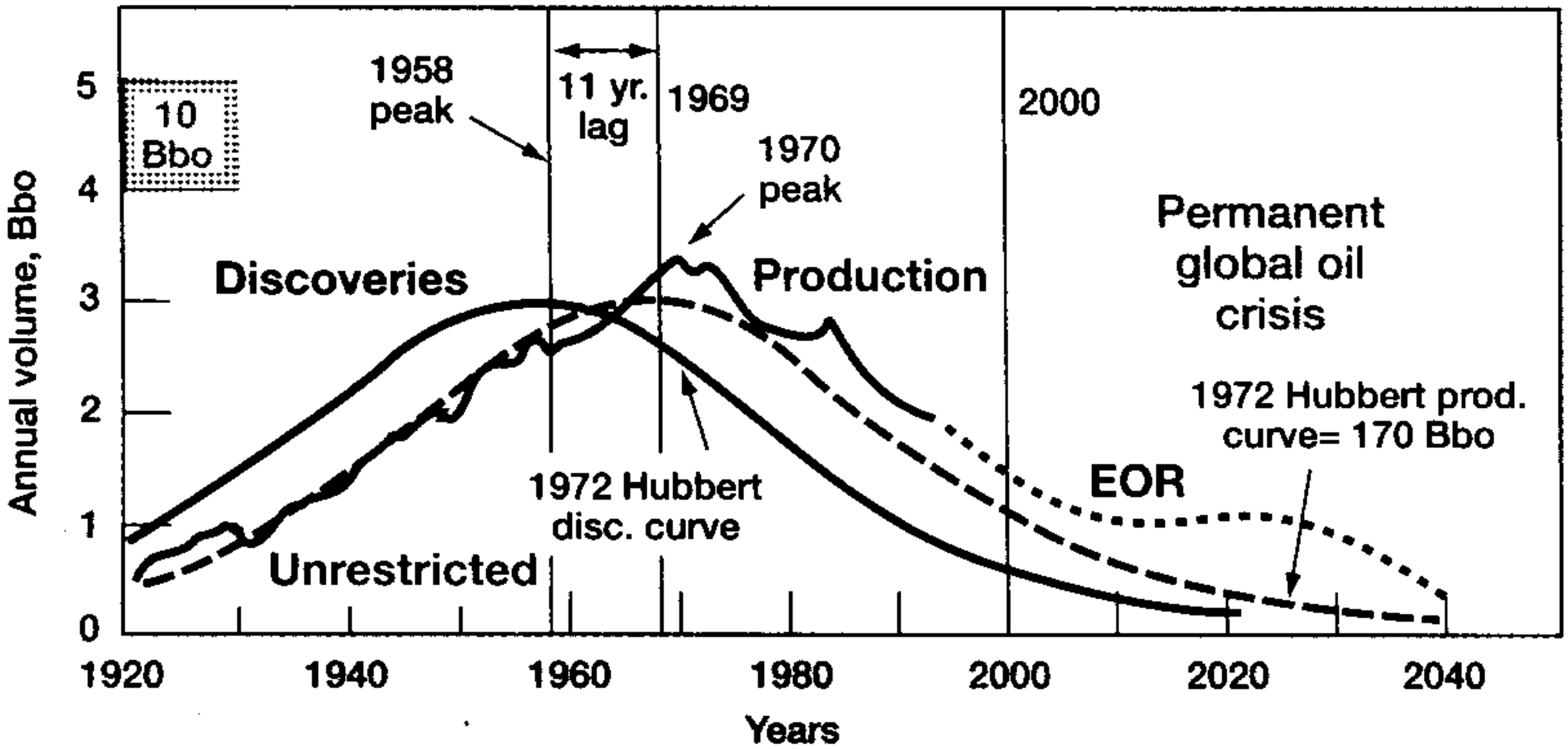
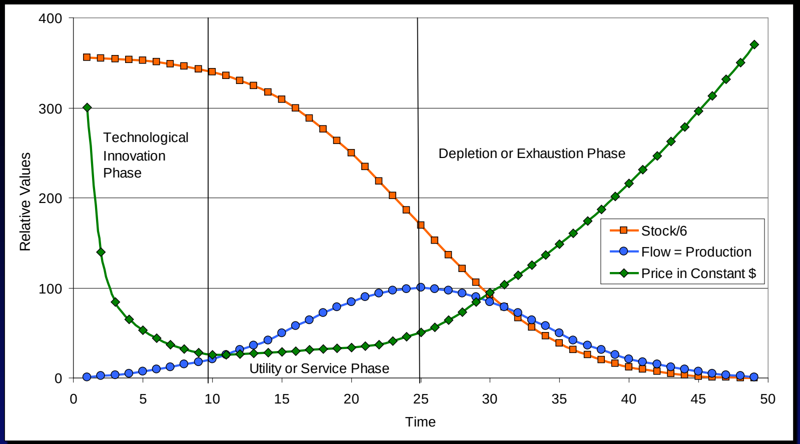


Fig. 4. Hubbert's idealized U.S./48 discovery and projected 1972 production curves, plus actual U.S./48 production. Extrapolations by Ivanhoe show possible increase due to enhanced recovery. After Hubbert 1980.[2]

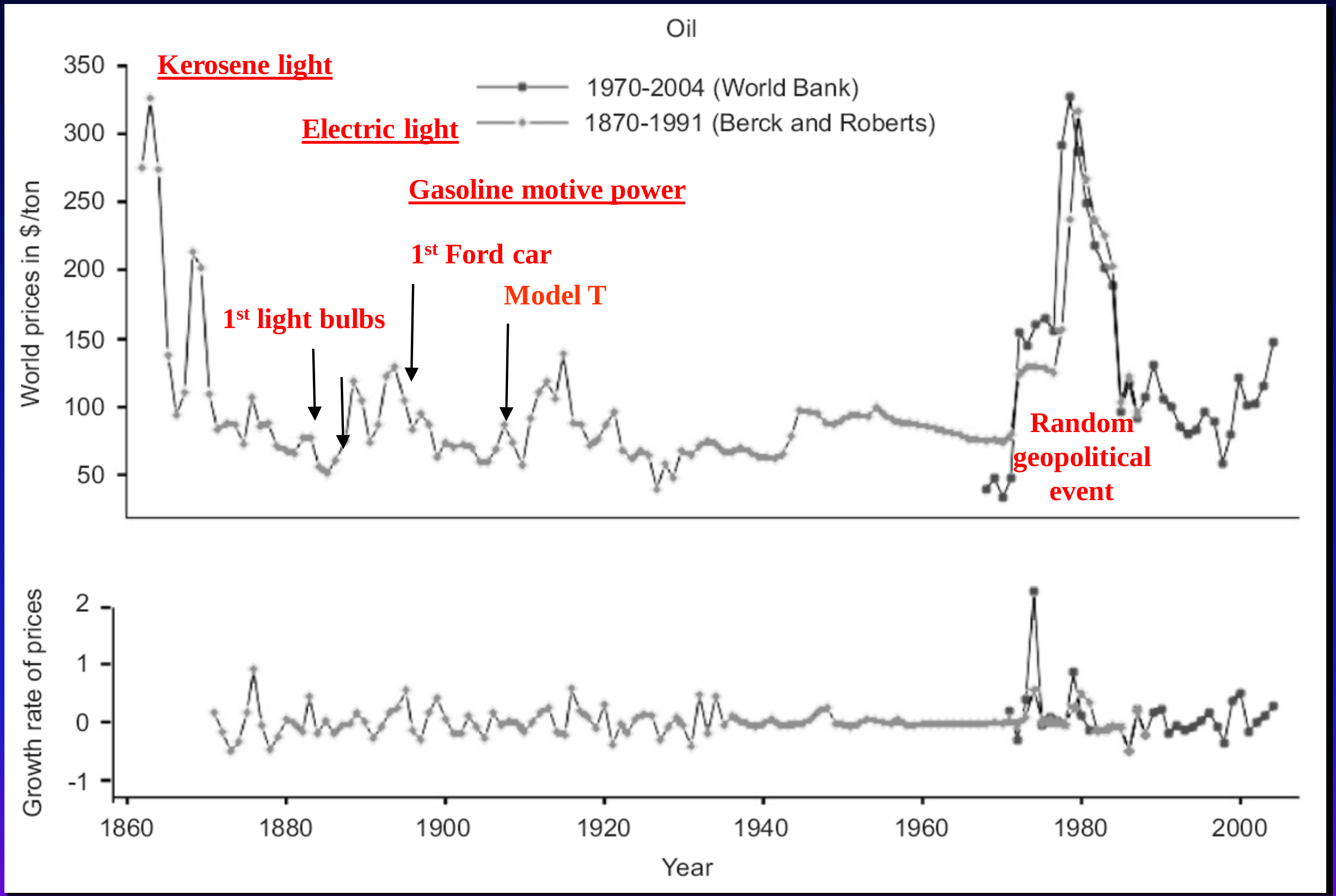
Shows 11-year lag from discovery to production, flow varies and skews to the right via conservation & more efficient recovery technologies

Why is the price timeline U-shaped?



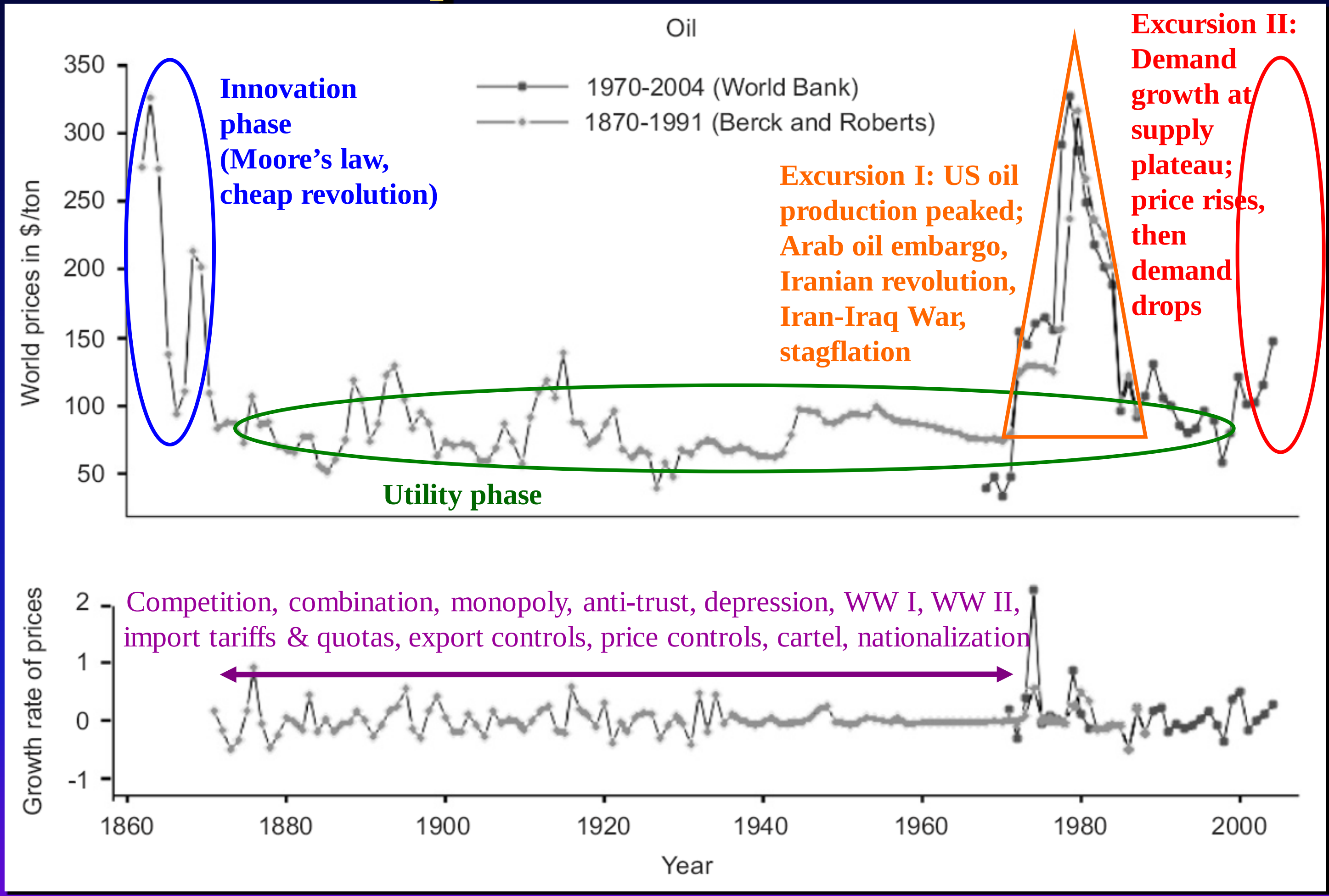
- Tech phase: people innovate to cut costs or find cheaper substitutes
  - So price drops and use rises (“cheap revolution”)
- Utility phase: further innovation is not cost-effective, while use continues
  - So price is low, price and use are steady (utility)
- Depletion phase: supply diminishes while use continues
  - So price rises until resource is exhausted or becomes unaffordable (crisis)
  - Either way, use ceases

World price of oil in constant dollars



This is the left half of the U-shaped price curve

Phases of the resource development-depletion model



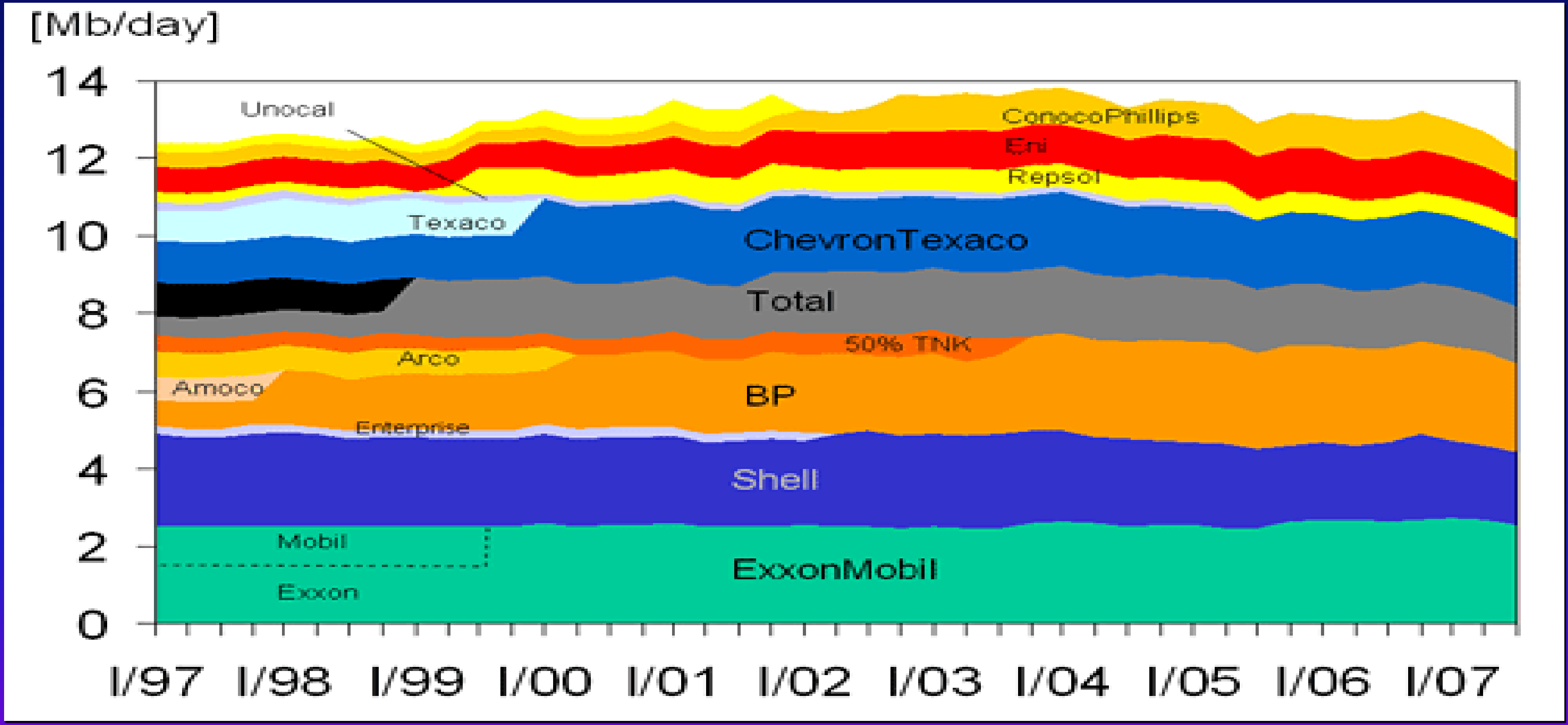
Prior to peak, price is robust to practices-policies-events, because supply is elastic; but when demand exceeds supply, look out!

When will world oil production peak?

- US Department of Energy data:
  - world oil production peaked in 2005
- International Energy Agency data:
  - world oil production peaked in 2006
- EnergyWatchGroup: oil peaked in 2006
  - (independent advisor to German Parliament)
- National Petroleum Council 2007: "Facing hard truths"
- Dr. Sadad Al-Husseini: "the oil boom is over"
  - (former Saudi Oil Minister)
  - capacity outlook: 10-year production plateau
- Association for the Study of Peak Oil: "2010"
- Shell CEO van der Veer: "2015"
- International Energy Agency 2008: "trends in energy supply and consumption are patently unsustainable"

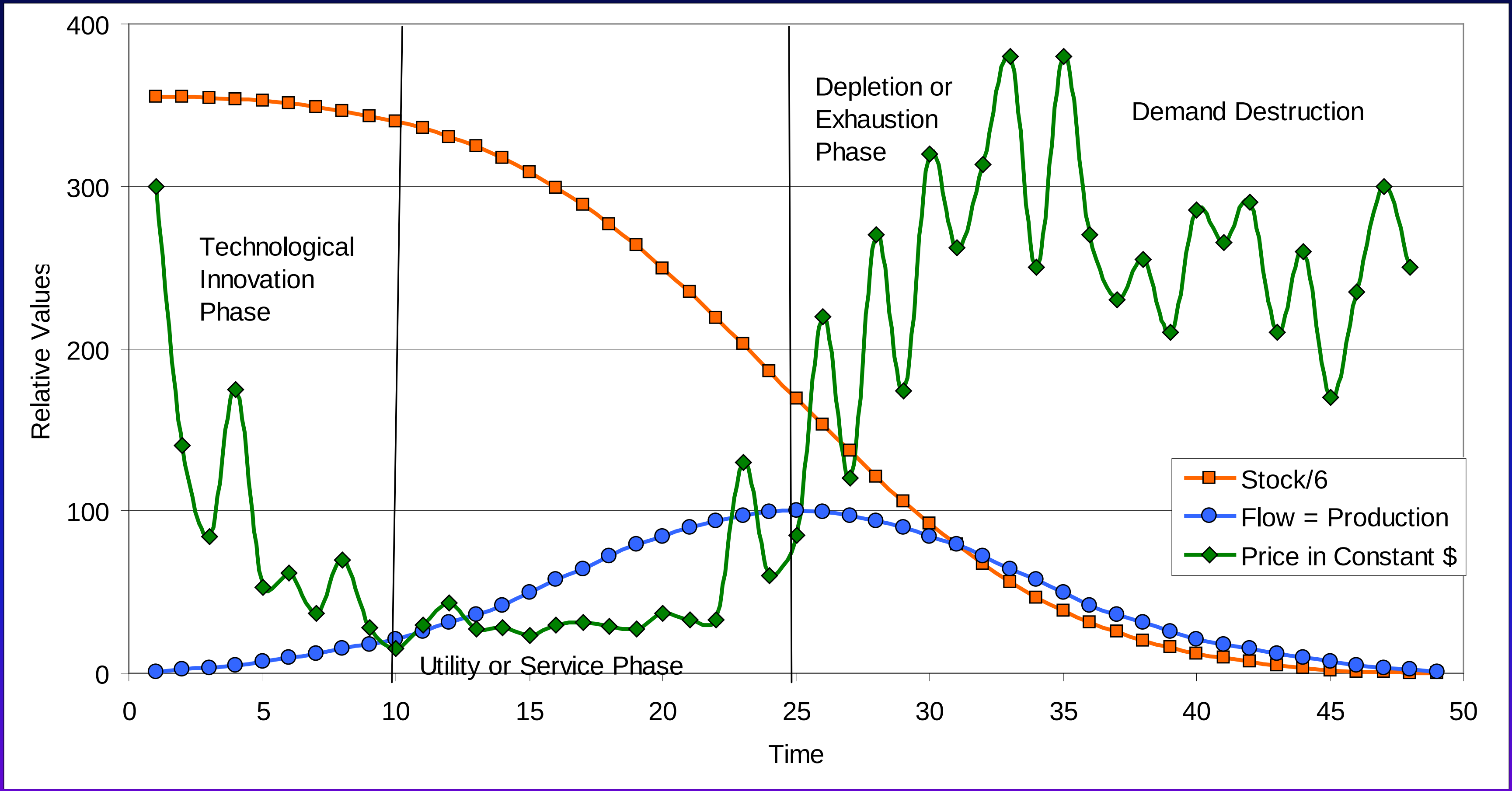
Opinions vary about the timing, but not about the outcome!

Plateau Oil or Peak Oil? World oil production by the independent oil companies



We are beginning a long, slow emergency

Adding plausible price volatility to the life span of an exhaustible resource

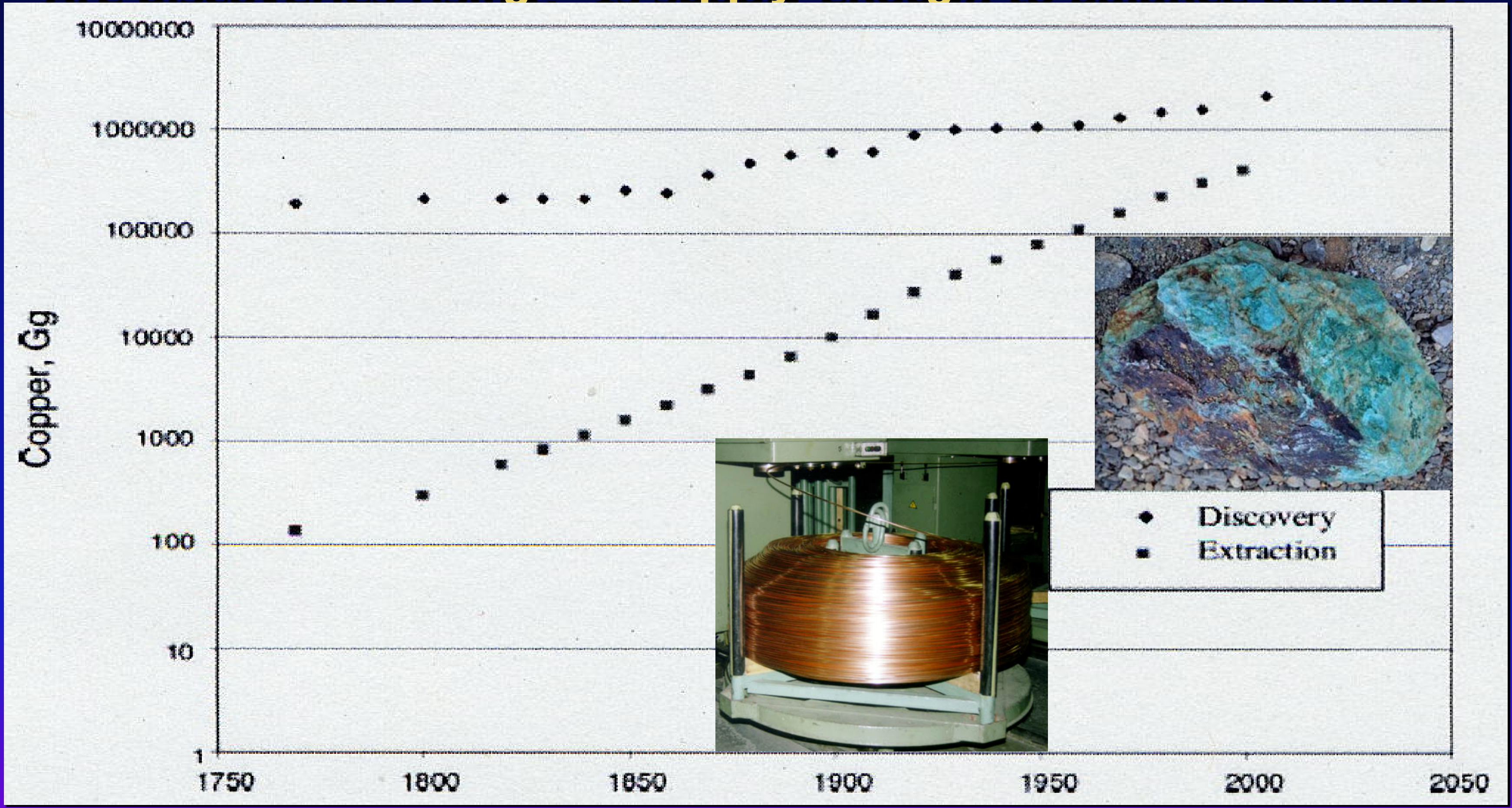


The left half was fun; the right half will be terrible.

Cycles make the depletion trend easy to miss or deny.

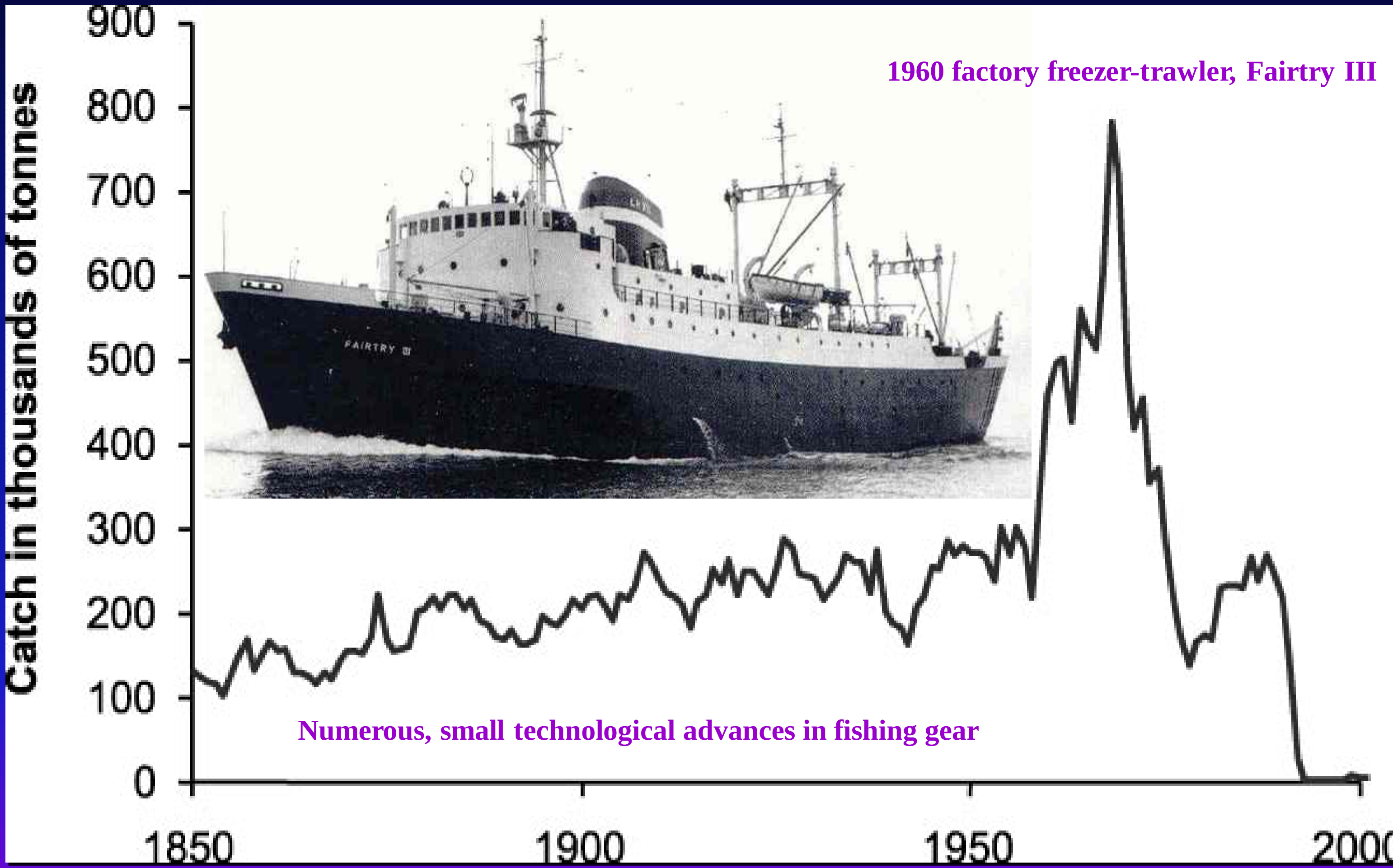
Ecologist & economist bet that prices of 5 metals would be lower in 10 years.

Are discoveries rising? Is supply enough to balance demand?



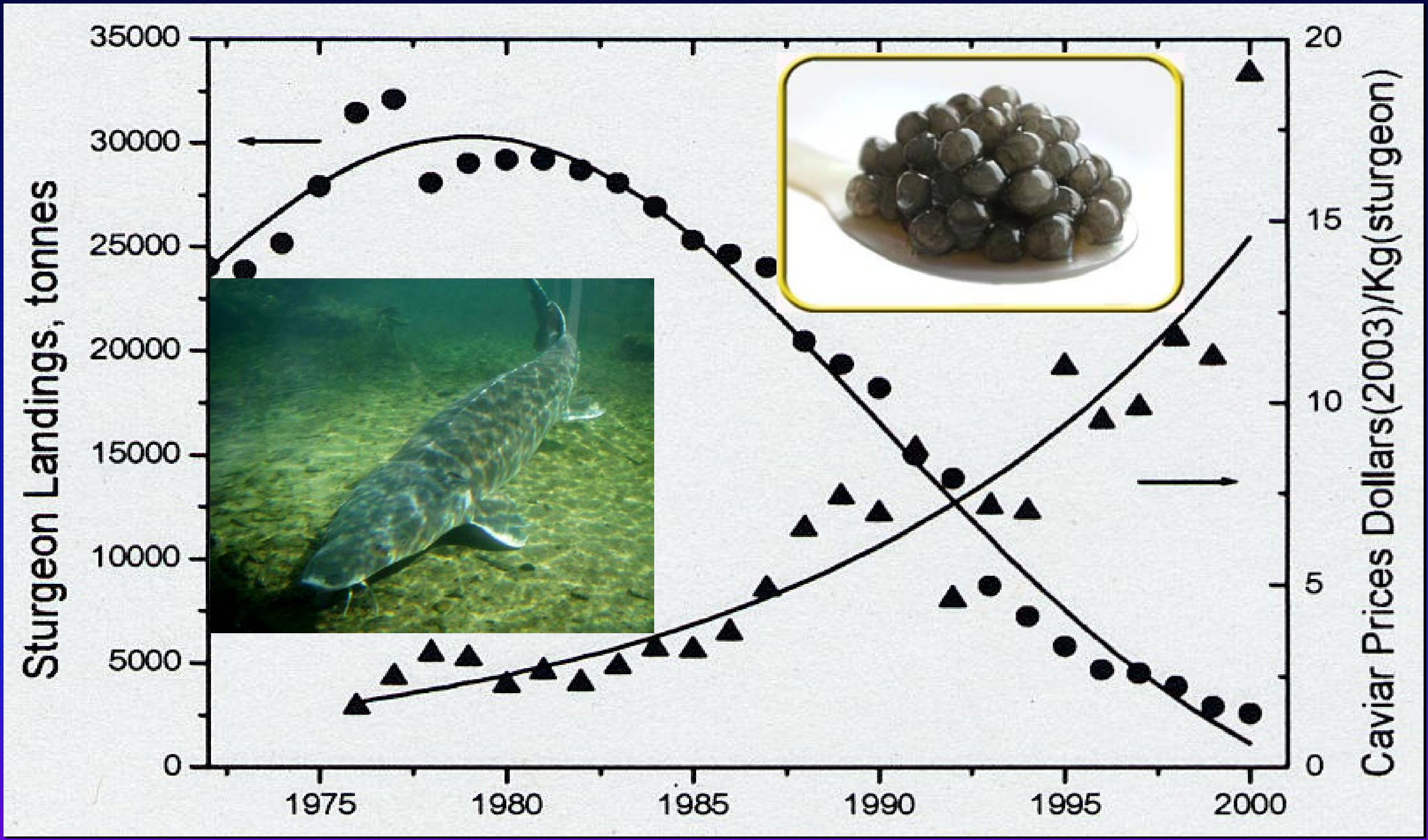
With data on cumulative discoveries & extraction, you can infer stocks, assess position in the resource-use life cycle

Northern Cod: sustainable use, disruptive tech, rapid depletion



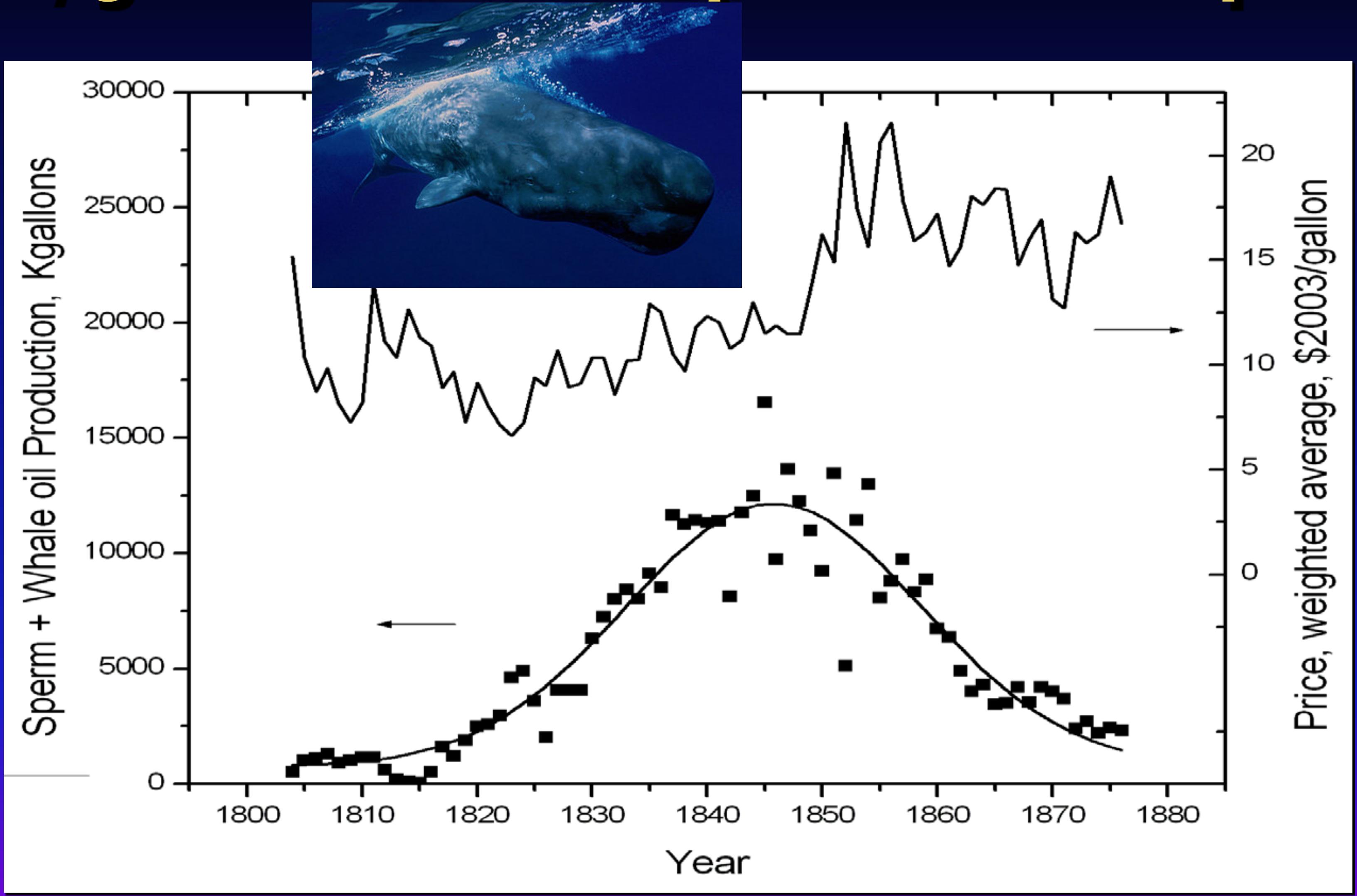
Shifted from Model 1 to Model 2; ecosystem no longer supports a large cod population or fishery

Caspian sturgeon landings & caviar price



High demand and unsustainable harvest easily can exhaust a renewable resource

US/global whale oil production & price

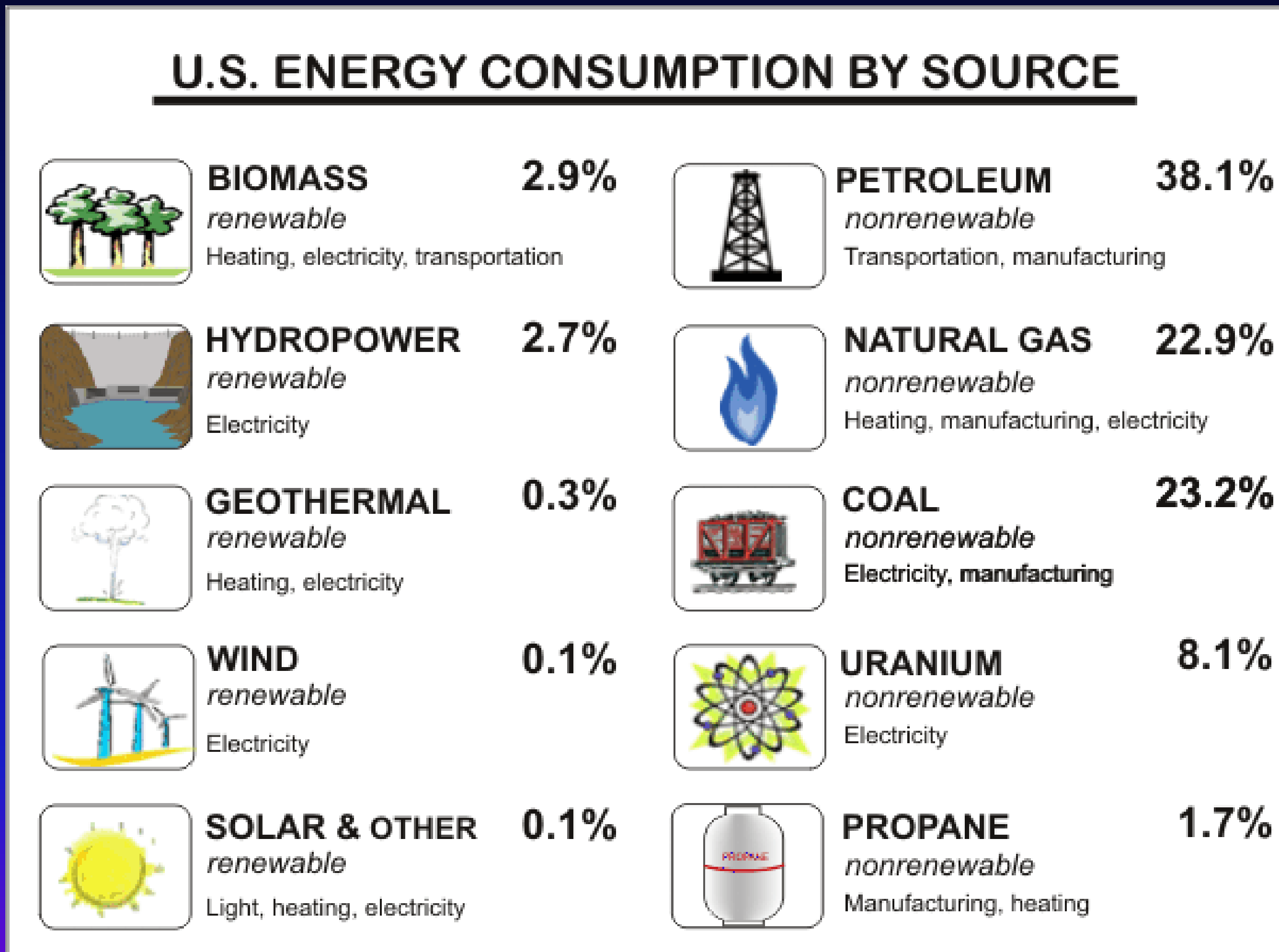


Also renewable but used unsustainably, so follows model 2; note the demand destruction by kerosene after 1859

Review of concept

Intermission

Focus: transforming the energy system

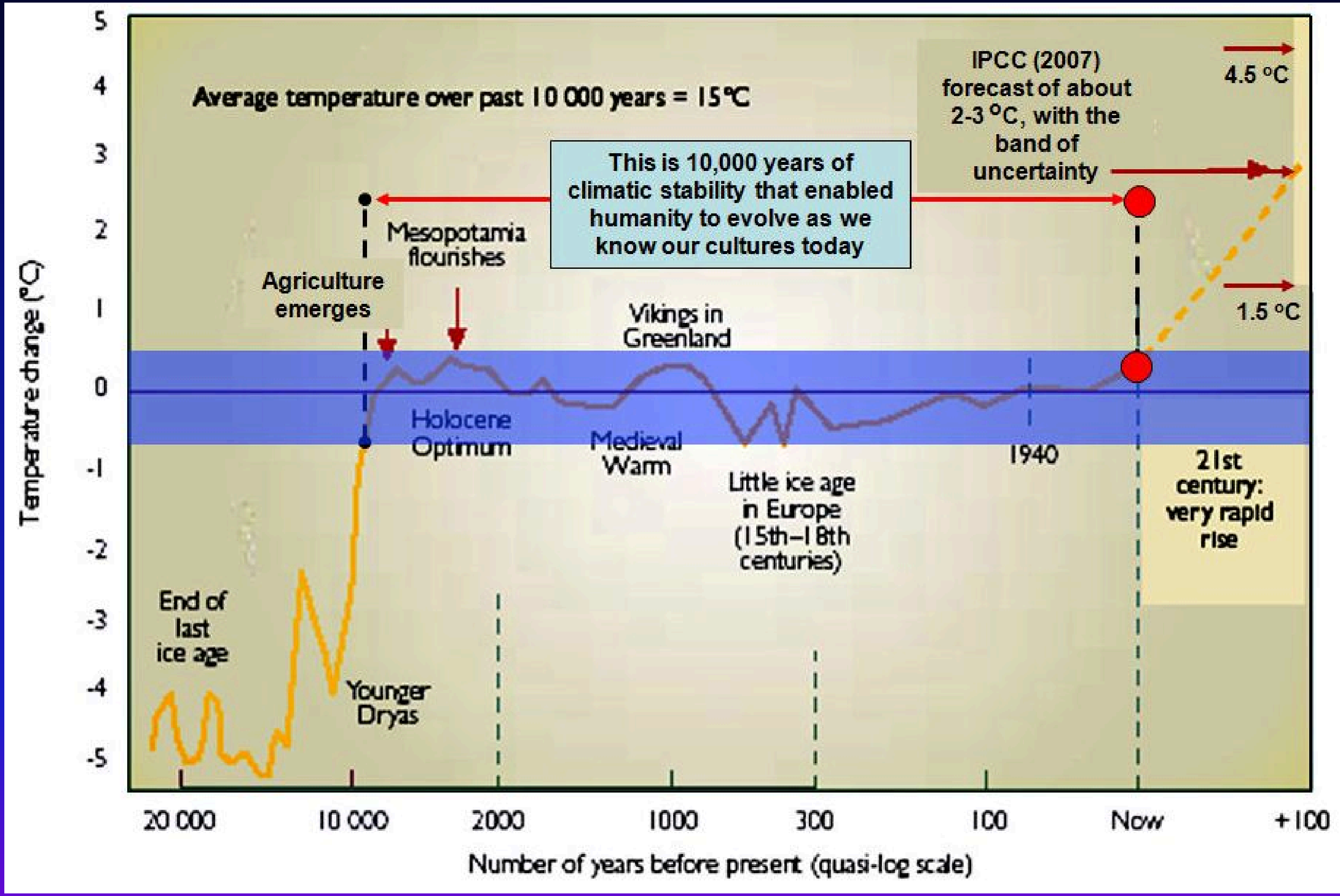


Reason #1: energy services provided by natural resources are literally the basis of our industrial economy

Focus: transforming the energy system

Reason #2: we've run out of cheap oil, "practical peak oil."

Focus: transforming the energy system



Reason #3: greenhouse gases from fossil fuels are changing climate, an existential threat to civilization.

Focus: transforming the energy system

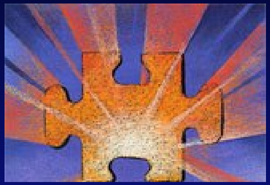


Reason #4: Release of carbon from fossil fuels, forests, and sediments must be halted and reversed.

So, what to do when oil costs too much?

Economic theory and experience foretell substitution via new technology.
We should set about to make this happen.

The substitution puzzle (Solow 1974)



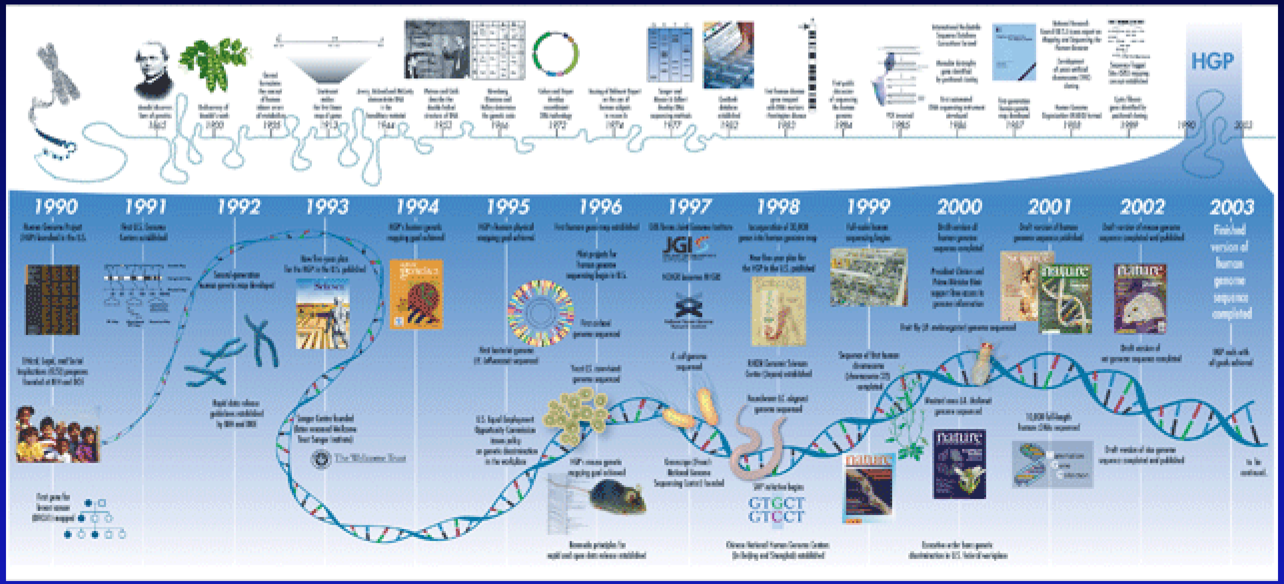
If we can easily substitute other factors for natural resources, then we can "…get along without natural resources, and exhaustion is just an event, not a catastrophe."

But, if no substitute is found, catastrophe is unavoidable.

In between are many cases where the problem is real, interesting, and not foreclosed.

So, substitution needs <u>disciplined thinking</u>, puzzling out Solow's uncertain outcomes by focusing on innovation.

The Arrow of Innovation –
takes vision, leadership, intellect, risk, money, hard work

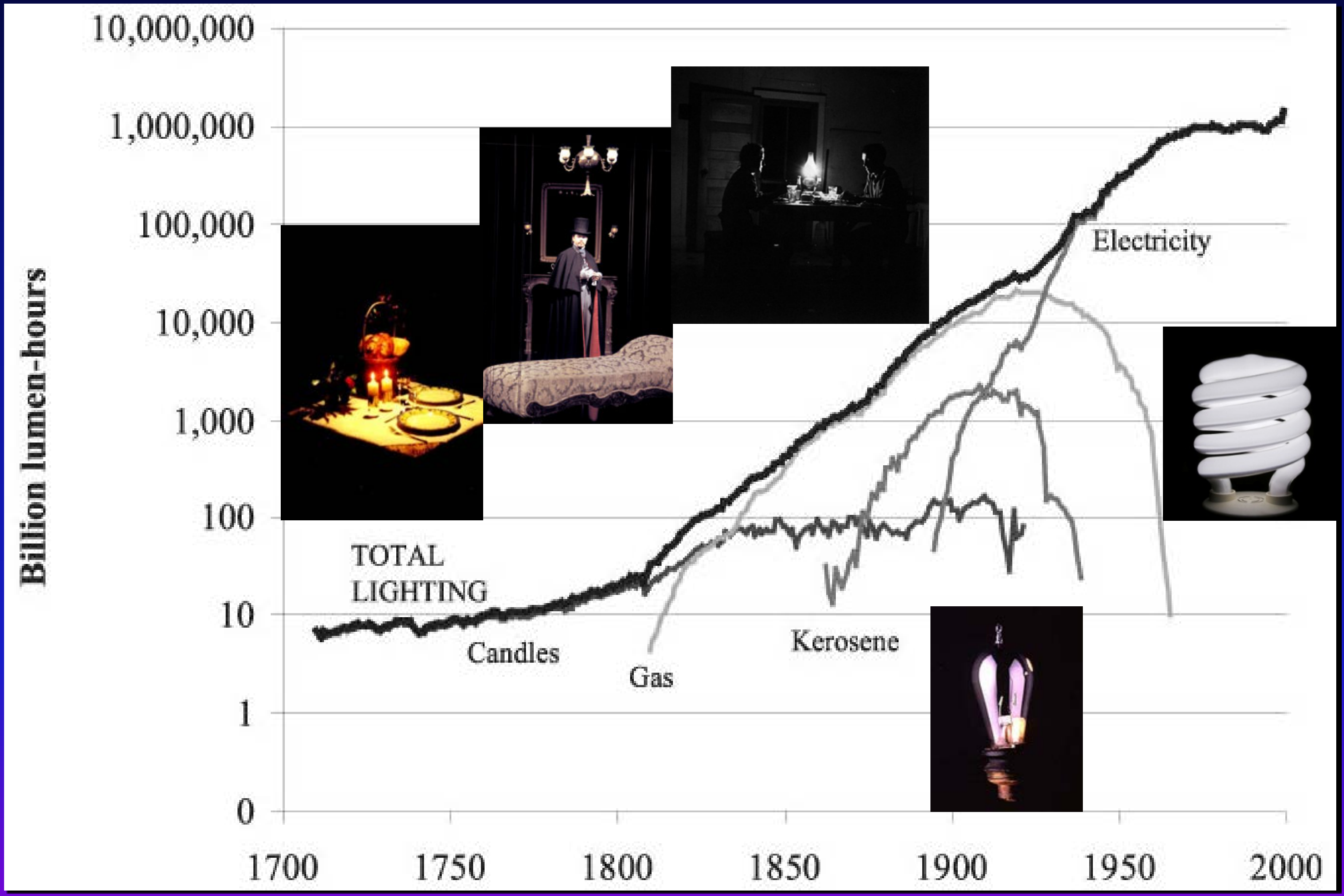


- Water wheels
- Railroads
- Electricity
- Automobiles
- Hydro dams
- Logging systems
- Fishing boats & gear
- Airplanes & airports
- Telegraphy & telephony

- Communication satellites
- Microprocessors
- Internet
- Biotechnology

Tech innovations drive rapid economic & GDP growth

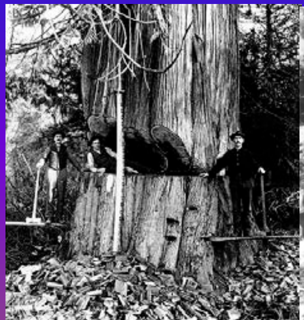
The Arrow of Innovation - consumption of light in the UK



Flow as a service based on successive natural resources.

The Arrow of Innovation - Lumber

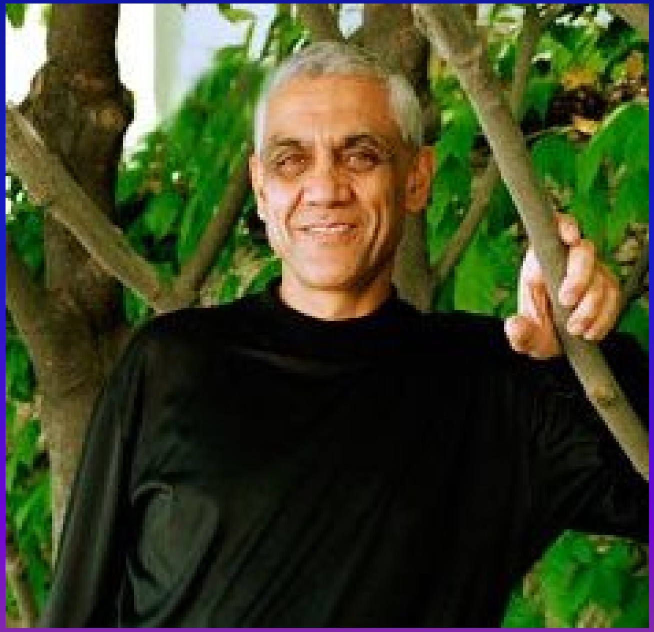
- Hand logging, crosscut saw, oxen & horses, rivers – limited to flat ground near streams
- Steam engine for ground-lead logging, woods railroads – increased mobility
- Overhead spar and lead-line logging – large clearcuts
- Chain saw, diesel yarder, logging truck, caterpillar tractor – maximum mobility
- Feller-buncher and loading grapple – maximum efficiency



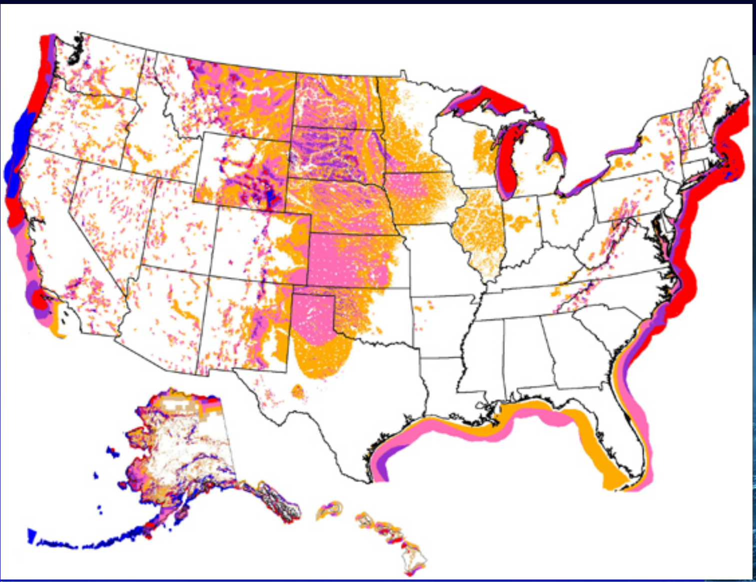

Vinod Khosla's system for driving innovation/adoption of energy tech

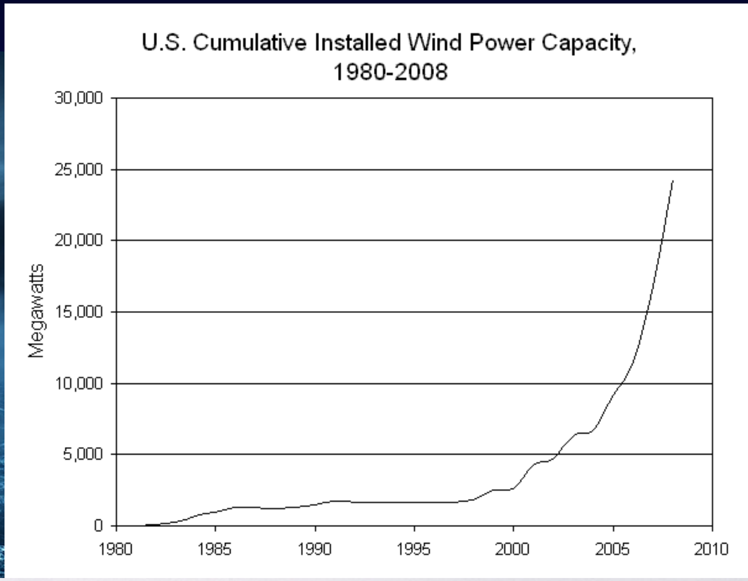
- Principles: promising technologies must be:
  - Inexhaustible or truly renewable
  - Affordable, low start-up cost, short innovation cycle
  - Capable of scaling up to demand, w declining costs
  - Competitive without subsidy in ~10 years
  - Not energy intensive
- Policies: government must:
  - Encourage capitalists to invest
  - Subsidize next-least-cost tech
- See khoslaventures.com

innovate
a podcast about innovation and entrepreneurship



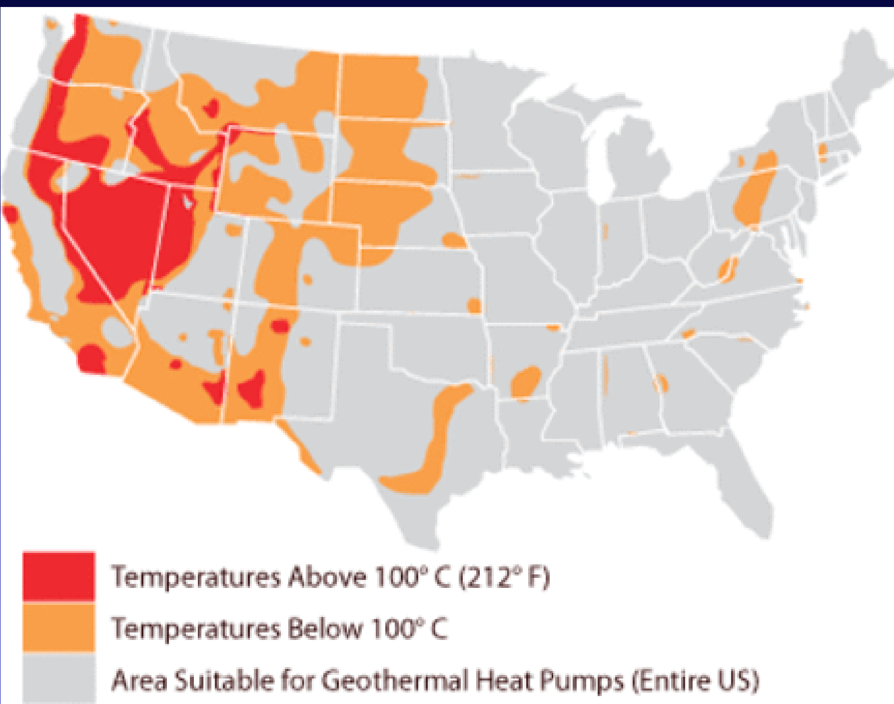
Only a <u>few</u> good choices:
Wind

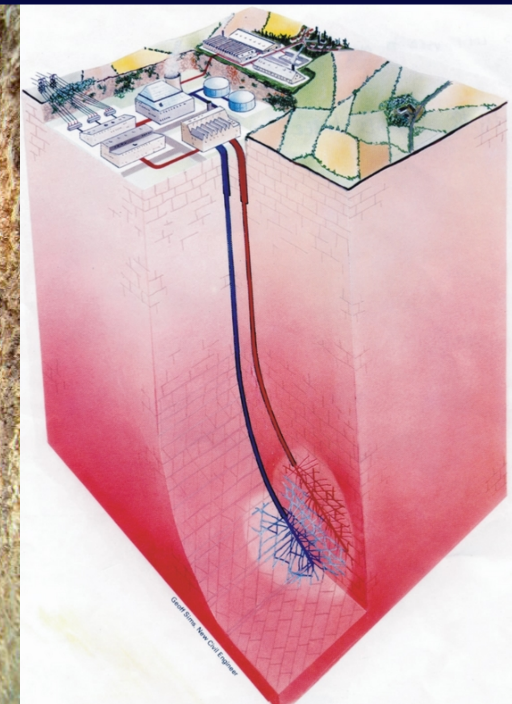




Only a few good choices:

Geothermal

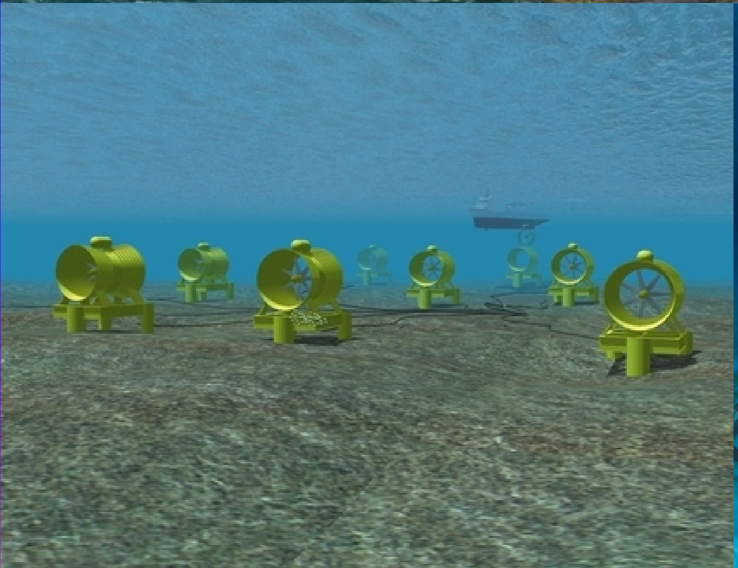
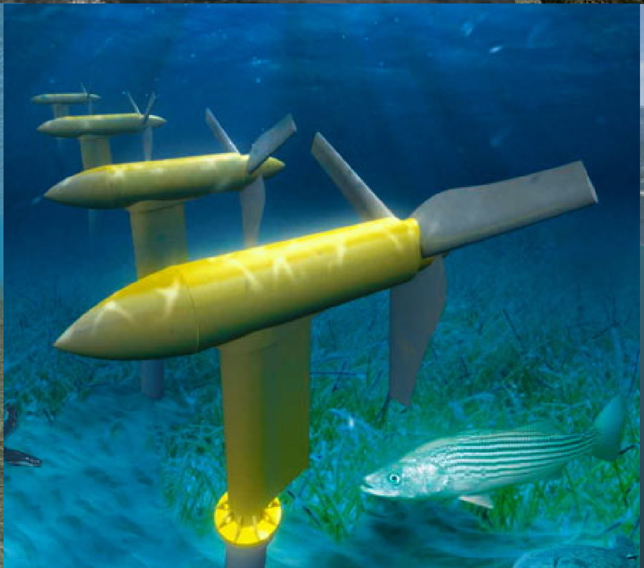
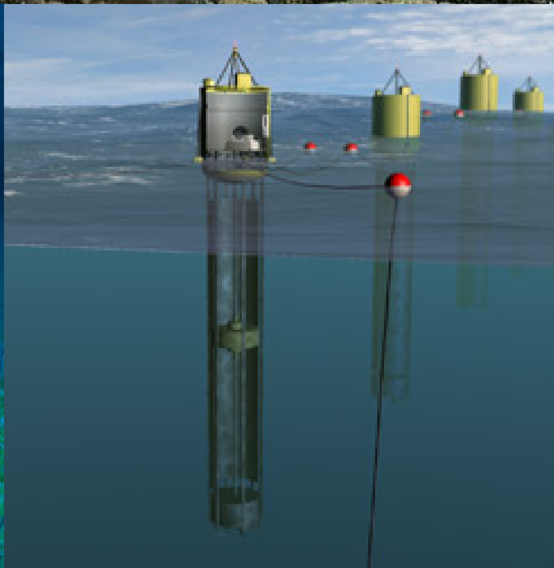




Only a <u>few</u> good choices:

Ocean wave/current/tide/thermal



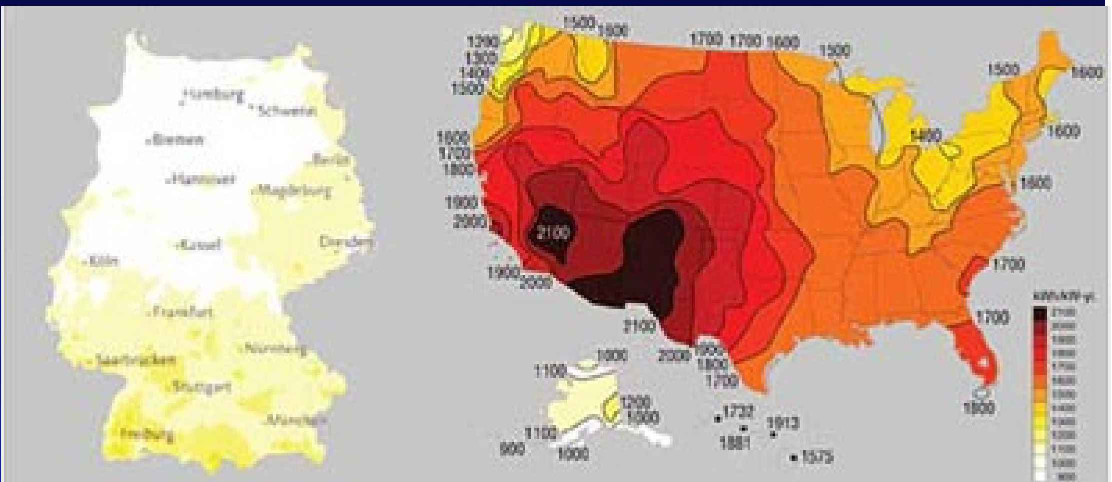





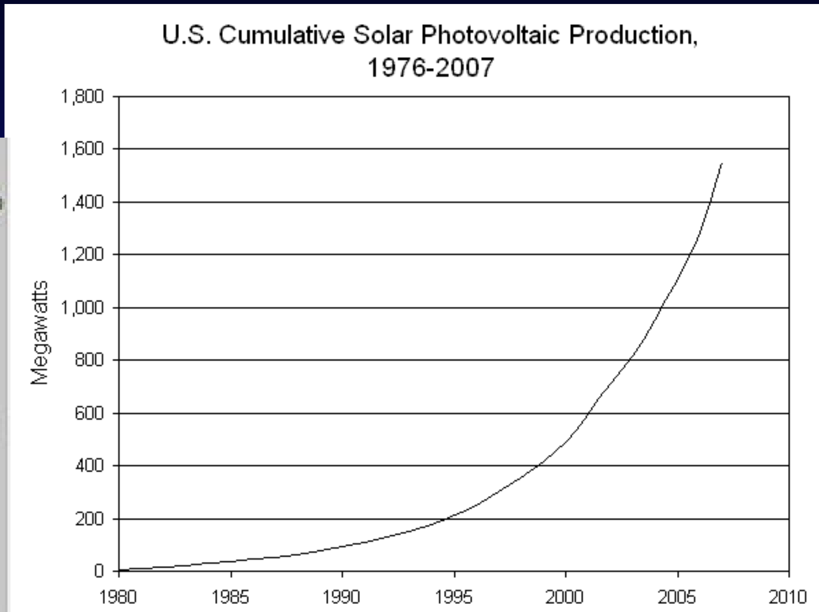
Only a <u>few</u> good choices:

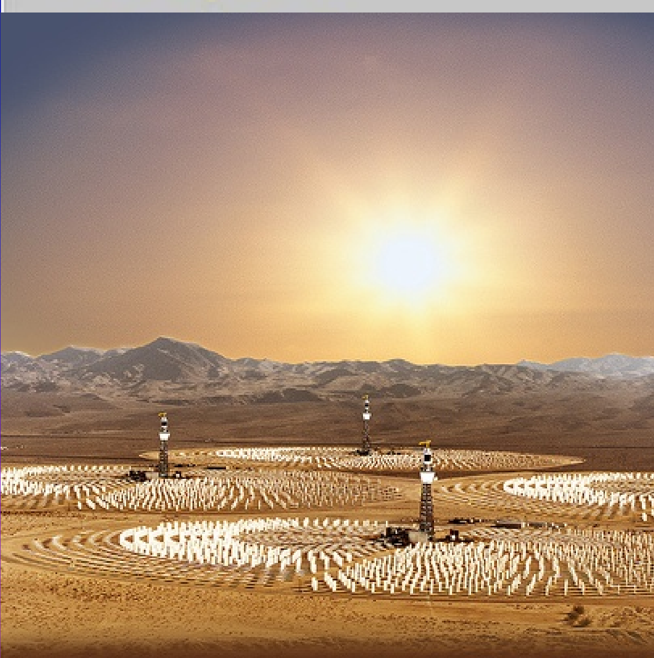
Biofuel (cellulosic ethanol, butanol, algae)

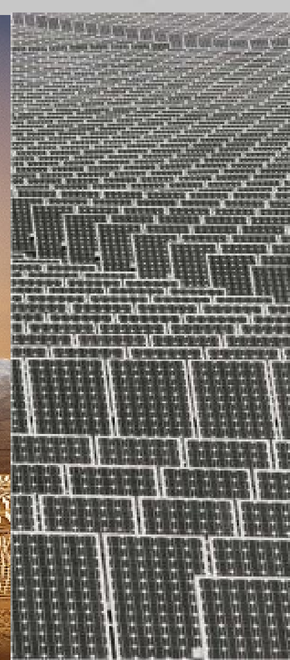
Only a __few__ good choices:

Solar

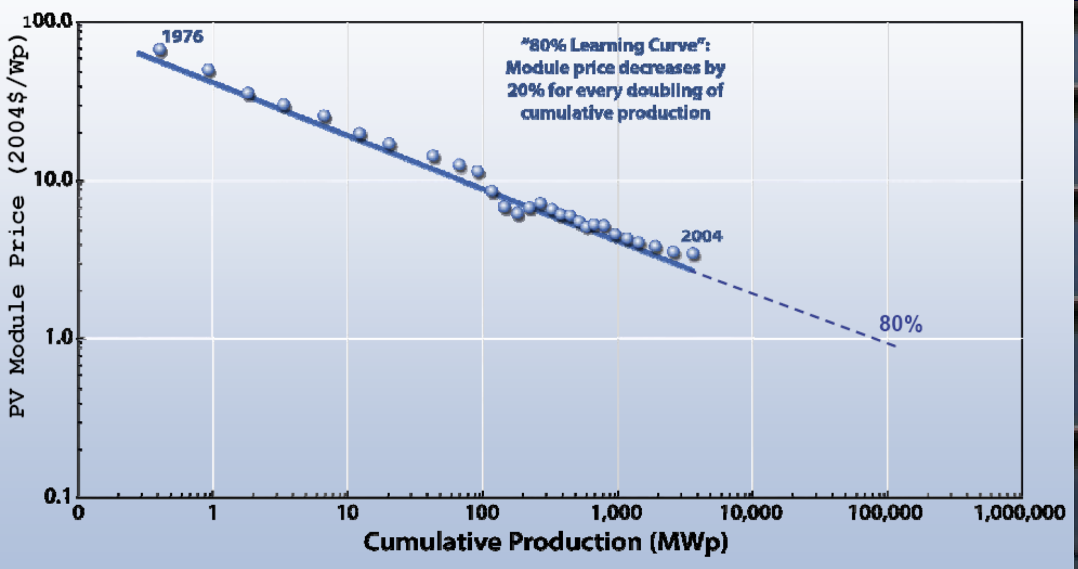


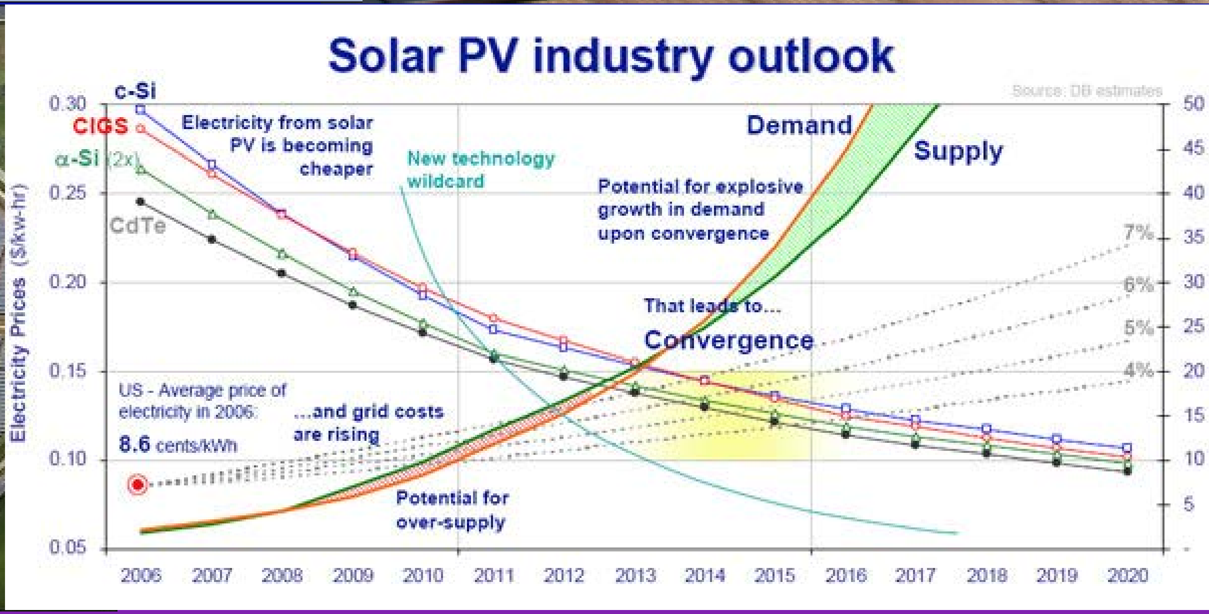




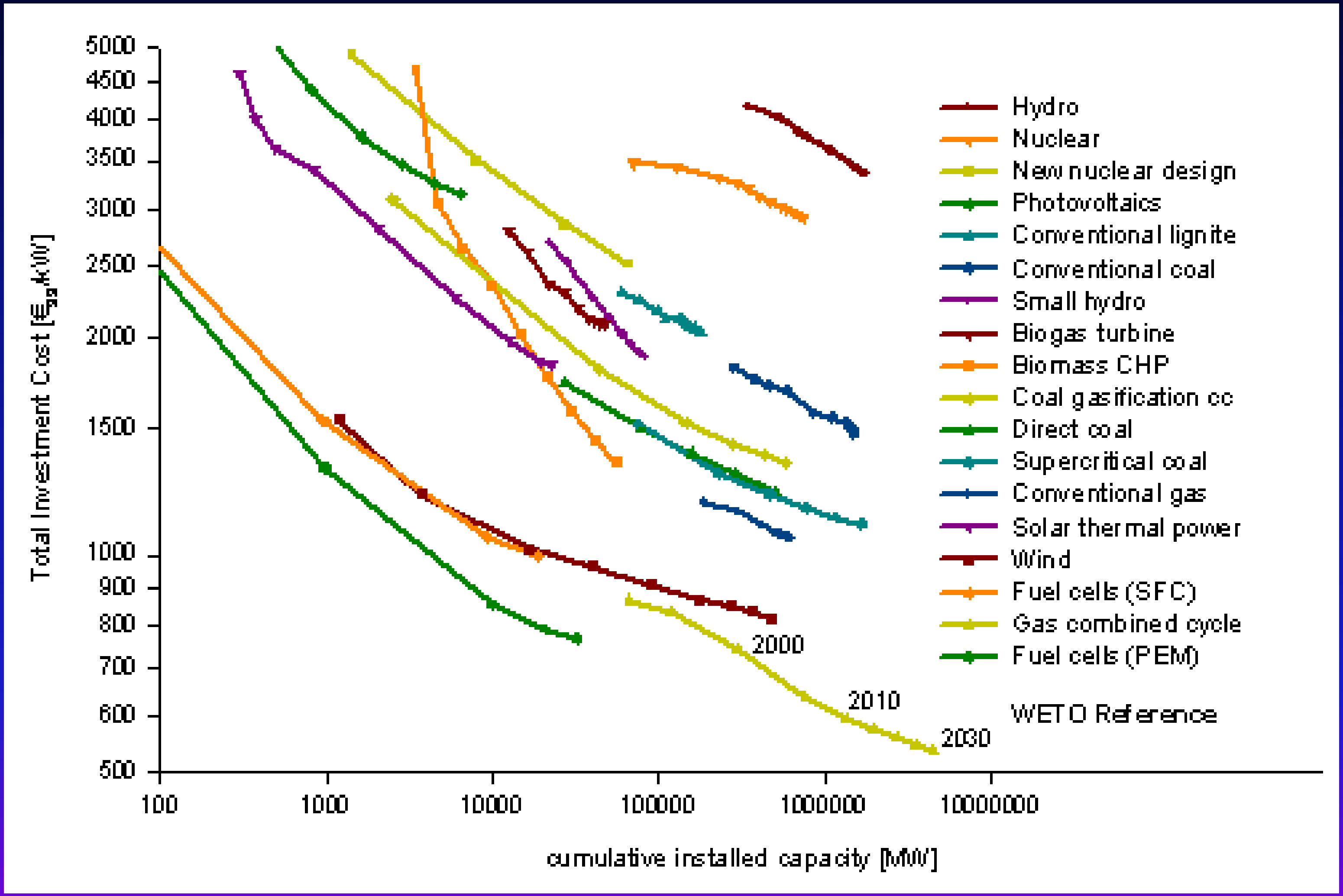


Pushing the learning curve: solar PV cheaper each year, grid parity soon



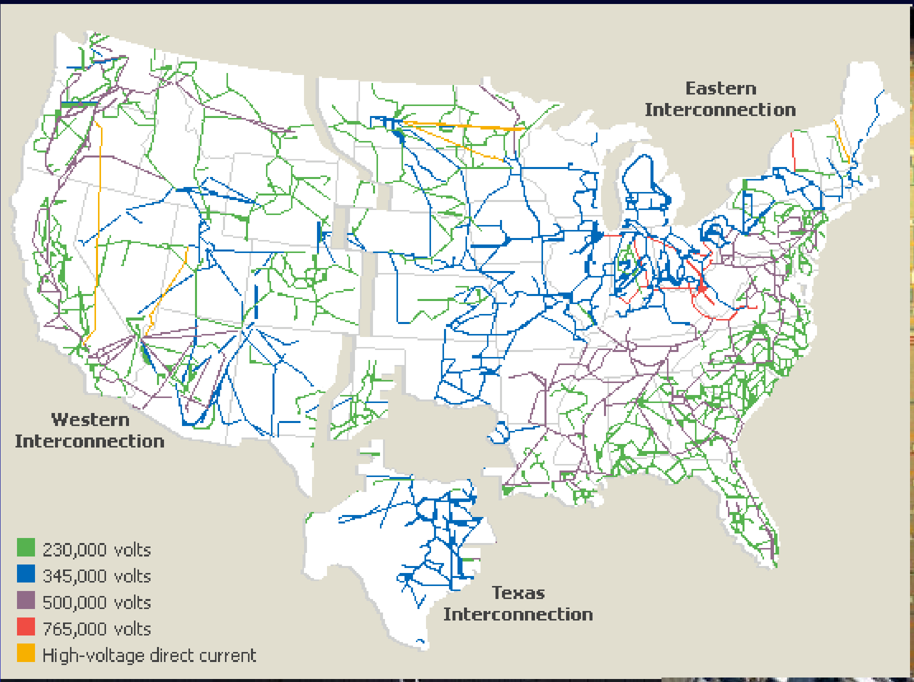


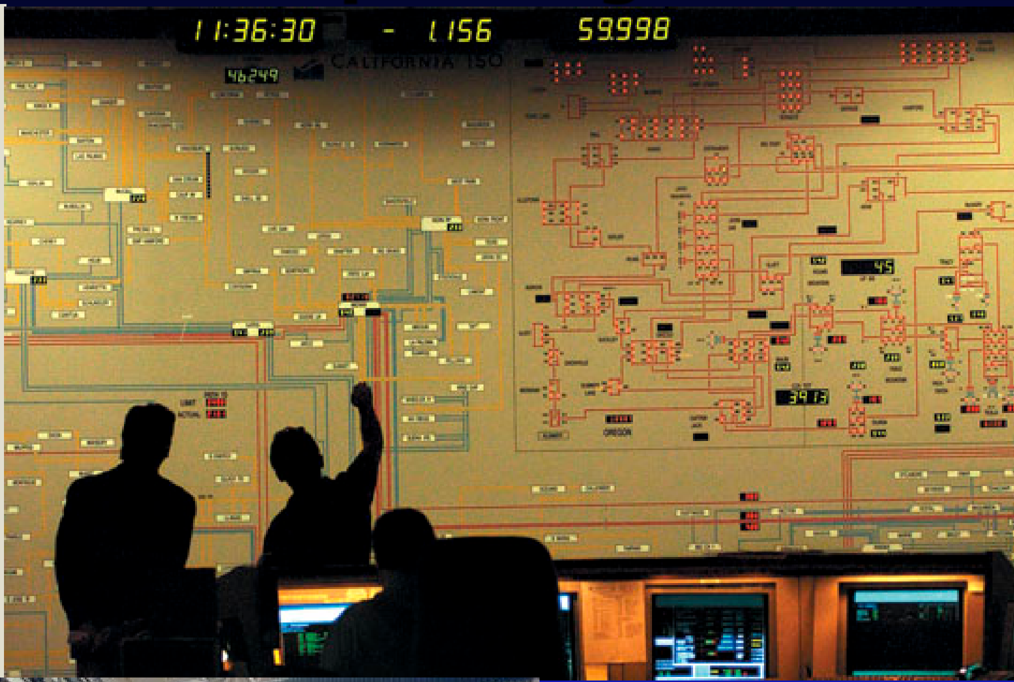
Learning Curves, Electricity Technologies



Steep: biomass combined heat & power.
Cheap: wind, fuel cells, gas combined cycle

Infrastructure needed for all the above, and a new direct-current power grid





1909 Baker Electric Car
--technology not adopted

Questions?