

Growth Has an Expiration Date

“Sustainable” is an appropriate reaction...
...but do we even know what it means?

Tom Murphy: UCSD Physics

Shall We Continue Growth?

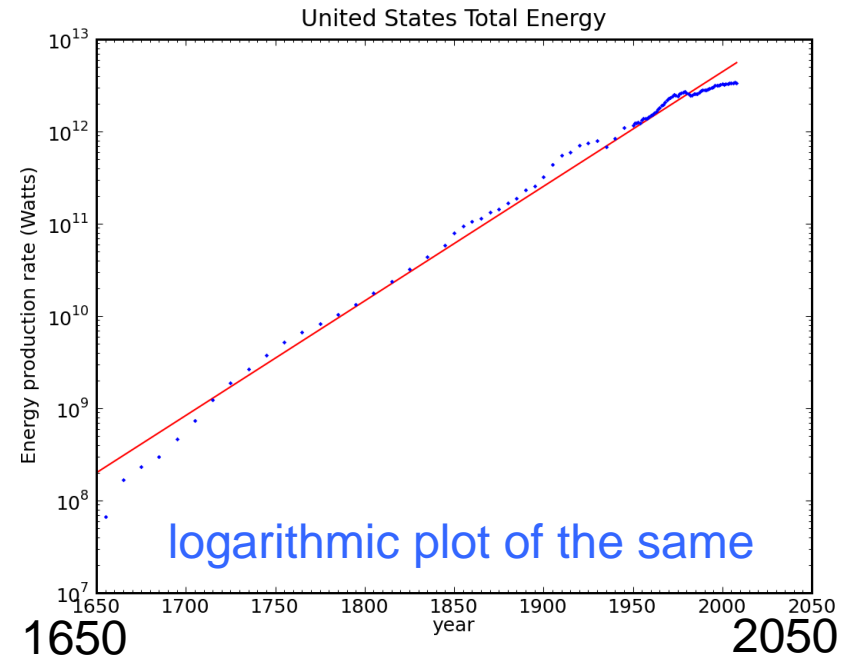
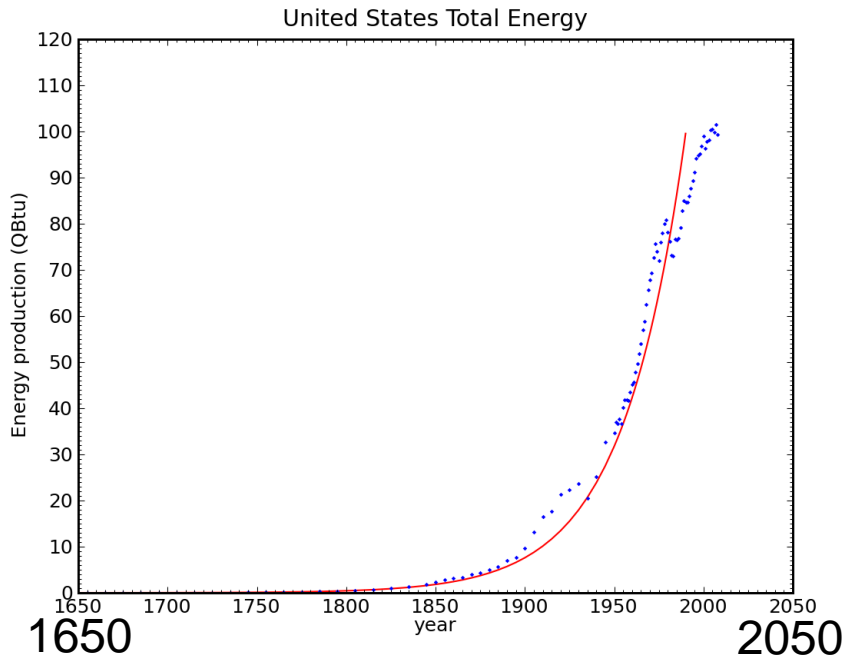
- We associate **growth** with **progress**

- cars, TVs, air travel, iGadgets,...
- quality of life improves
- investment pays interest



- Initially restrict attention to **physical growth** (**energy**)
- **Surplus energy** (beyond the bare amount needed for survival) has translated into:
 - more food available, more people, more industry, economic growth
- Our energy use, now at **12 TW** globally, has historically grown at **>2%** per year
- What will this mean if we continue expanding energy use at this rate?

U.S. Energy Historical Growth: 2.9%

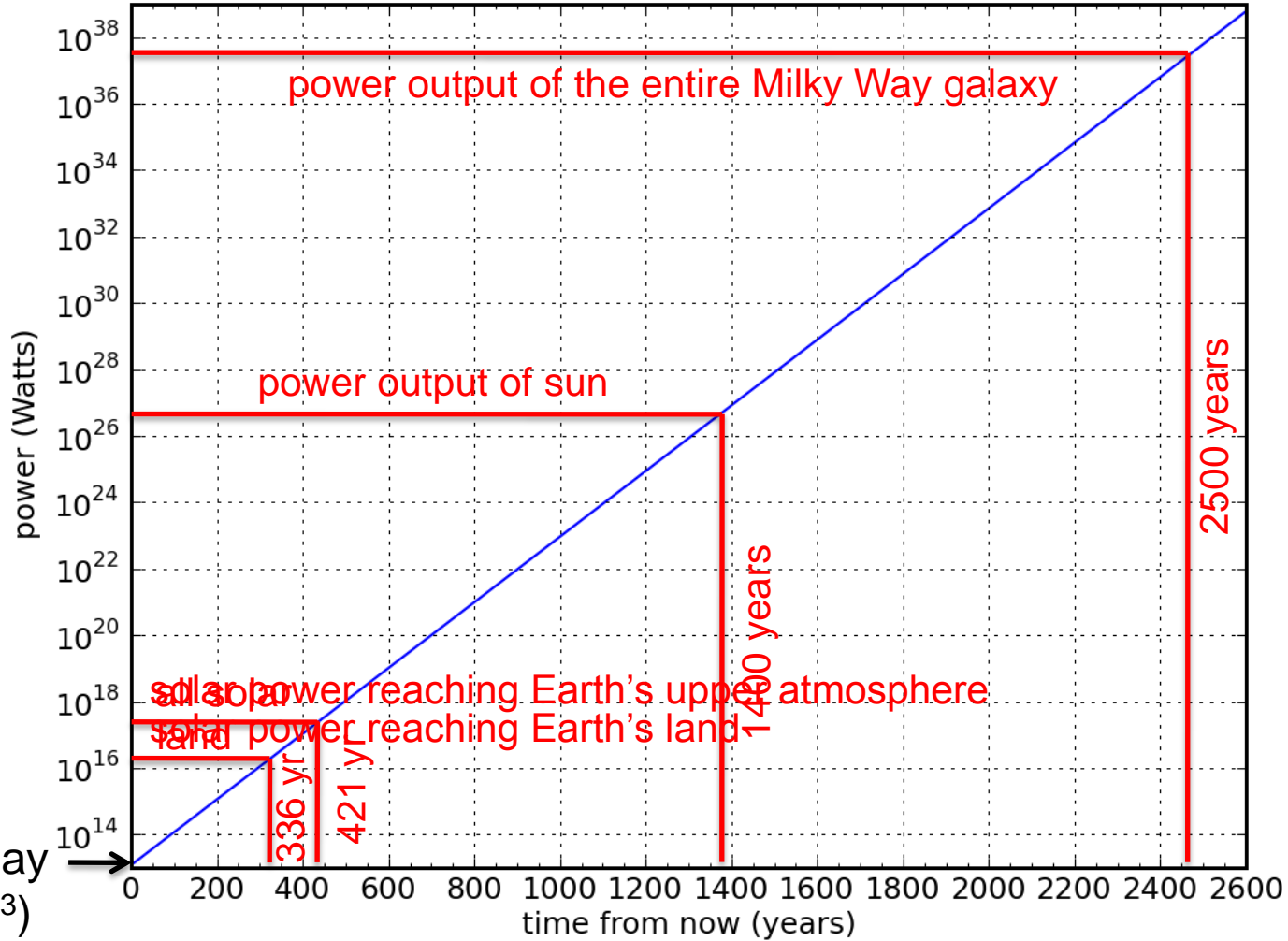


Sum of all forms of energy used in the U.S. (fossil fuels, nuclear, hydro, wood, etc.)

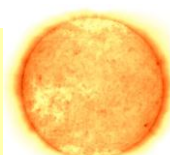
Red curve is exponential at 2.9% per year growth rate

The Road We're NOT On

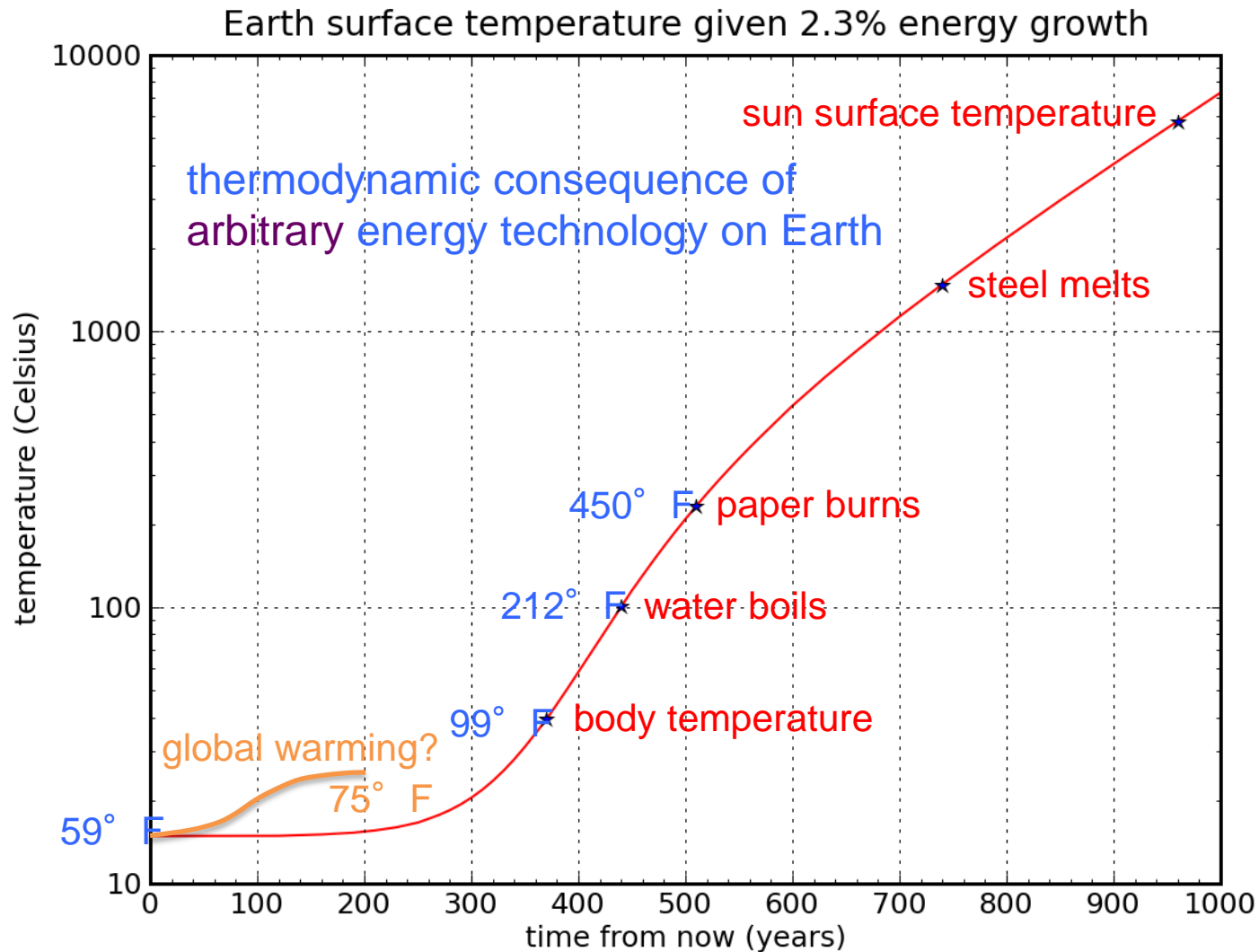
Global power demand at 2.3% growth



12 TW today
(1.2×10^{13})



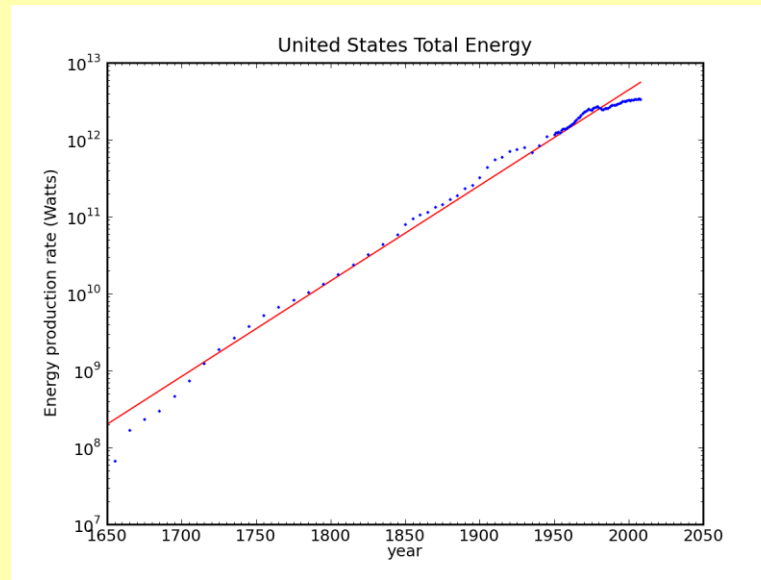
Waste Heat Boils Planet (not Global Warming)



Reality Check

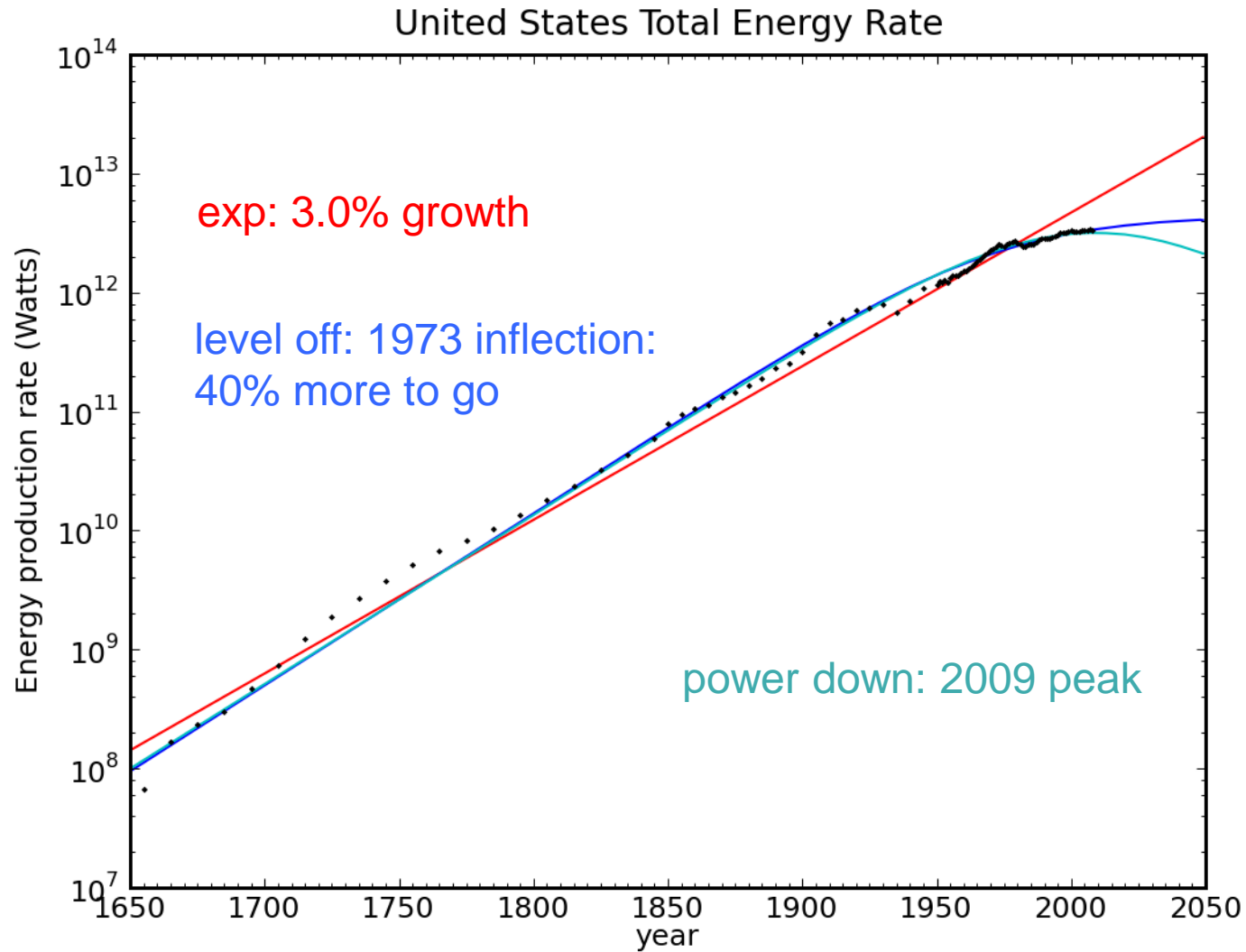
- This calculation shows how **ridiculous, absurd, fantastical** any notion of exponential growth becomes
- Many reasons prevent us from continuing growth trajectory
 - obviously, **we won't cook ourselves**
 - continued growth presupposes **population growth**
 - we certainly can't get far along the curve using **finite fossil fuels**
- The lesson: our future **must abandon growth**, at some point
 - yet most economists and planning commissions **assume** growth

Does the Logistic Shoe Fit?

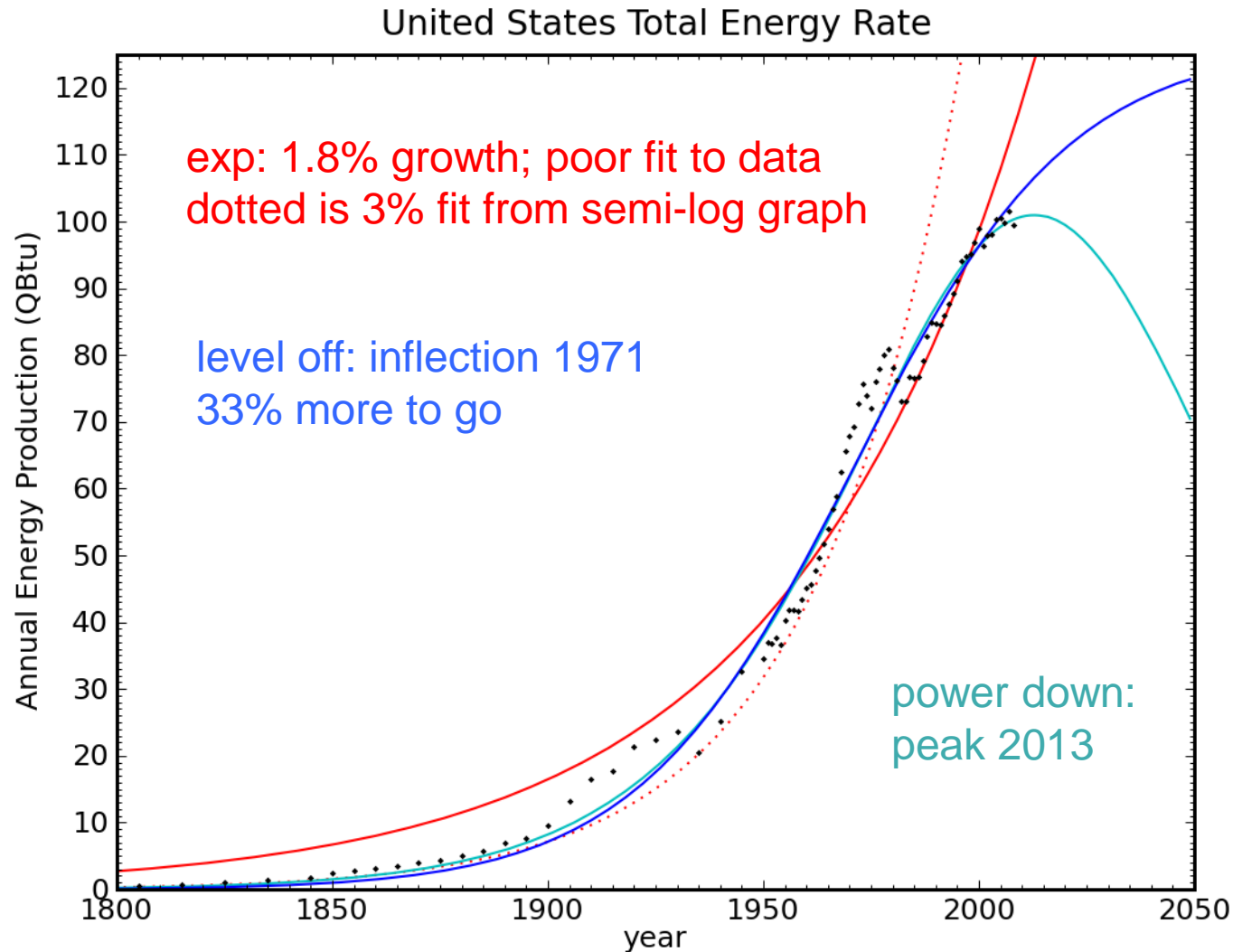


- We fit an exponential to our energy history, but recent decades have seen an underperformance
- Is this better fit by a logistic function?
- Three limiting cases to explore:
 - indefinite exponential growth
 - logistic leveling to constant rate of energy use (renewables)
 - logistic description of finite resource (power down)

Three Cases Fit to U.S. Energy History



On a Linear Scale



The data are not presently able to predict which curve we're on: **both logistics** fit well

The Allure of the Growth Narrative

- Our **narrative** is one of **growth**
- It's what our parents, grandparents, great grandparents, etc. have known: **we are reluctant to give it up**
- We tend to think that even if population levels off, that if energy availability levels off (or even goes down), we can still manage economic growth by:
 - bringing up **standards of living** (even without extra energy)
 - **efficiency gains** (do more with less)
 - **technology innovations** (new gadgets keep economy humming)
- But such things cannot become the **whole** economy
 - at the end of the day, we're tied to the physical/energy streams provided by the natural environment
 - divorcing our economy from physical limits is pure **fantasy**

Snapshot of Current Growth



Before 1950, growth tracked 2.9% energy rate well; souped-up since then

What's in the Gap?

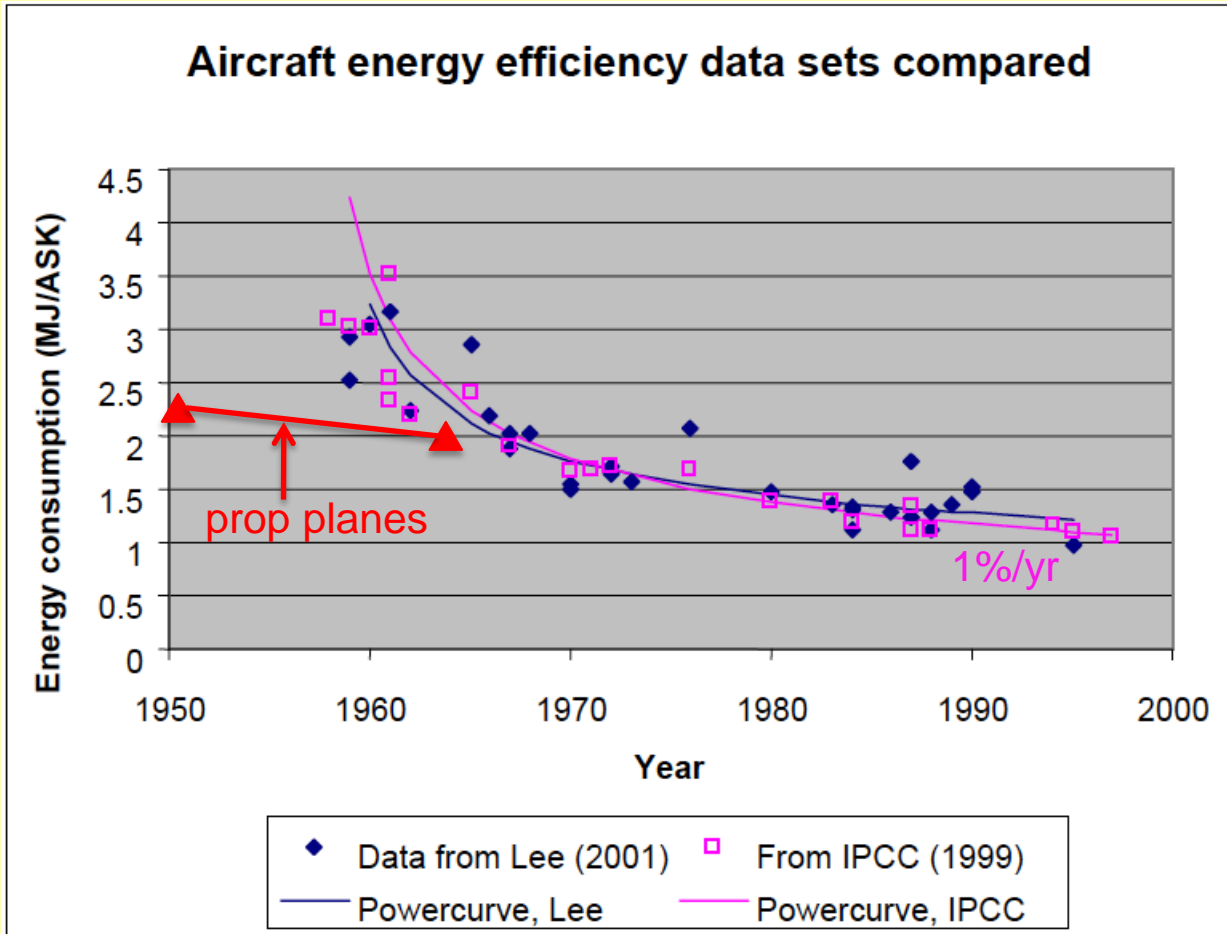
- That the economic scale outpaces the energy scale over the past half-century is a **triumph**
 - does it portend the future?
 - especially in the context of declining fossil fuel availability?
- The gap is in part due to **increased energy efficiency**
 - doing more with less (details on next slide)
- The other part is **growth in the “service” sector**
 - loose term encompassing innovation, office work, selling each other houses, iGadget consumer wave, psychotherapy, economics, etc.
 - low-energy activities **clearly exist**, and can increase for a time

How much can efficiency improve?

- The shining examples are **refrigerators** and **cars**
 - doubling efficiency in **35 years** means **2% per year** improvement
- But not all examples are shining
 - power plants, air travel → only **1%/yr** improvement over 40 years
- And some things don't change
 - heating a liter of water 1° C will always take 1 kilocalorie of energy
 - electric motors (fans, pumps, etc.) are pretty saturated above 80%
 - moving a family down the road at freeway speeds fights air resistance
- Efficiency is a hat with **only one or two bunnies in it**
 - thermodynamic limits, 100% cap means only factor of two across the board is realistic
- Adopt model where **1%** can continue until another **factor of two** is achieved across the board (on average)

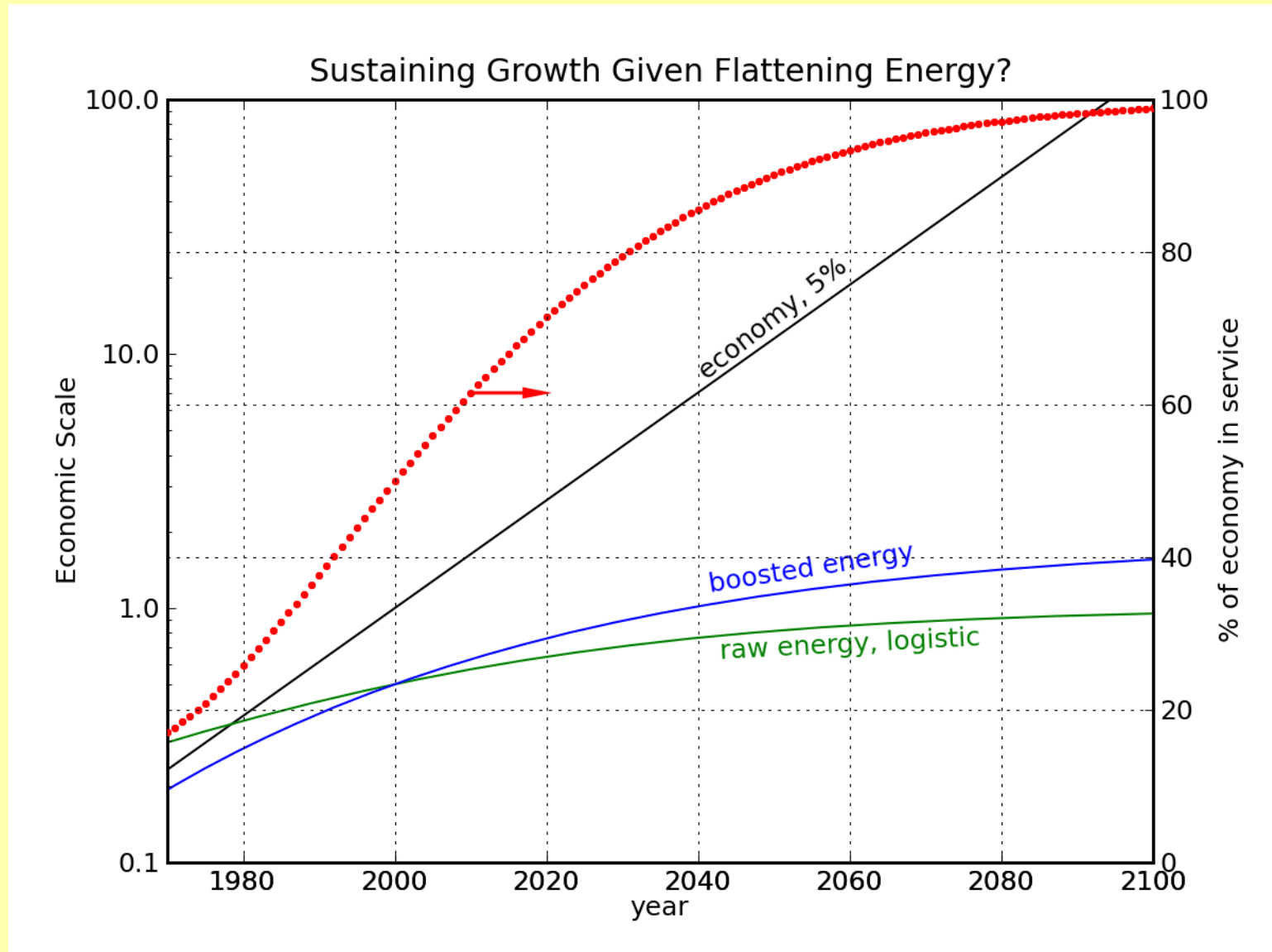


Air Travel Efficiency Gains (Jets)



Despite aggressive campaign to improve efficiency, 1% per year is typical

Leveling Energy/Efficiency → Service Ho!



If energy levels out, and efficiency saturates, “**service**” levels would become silly by mid-century to keep the 5% growth train rolling

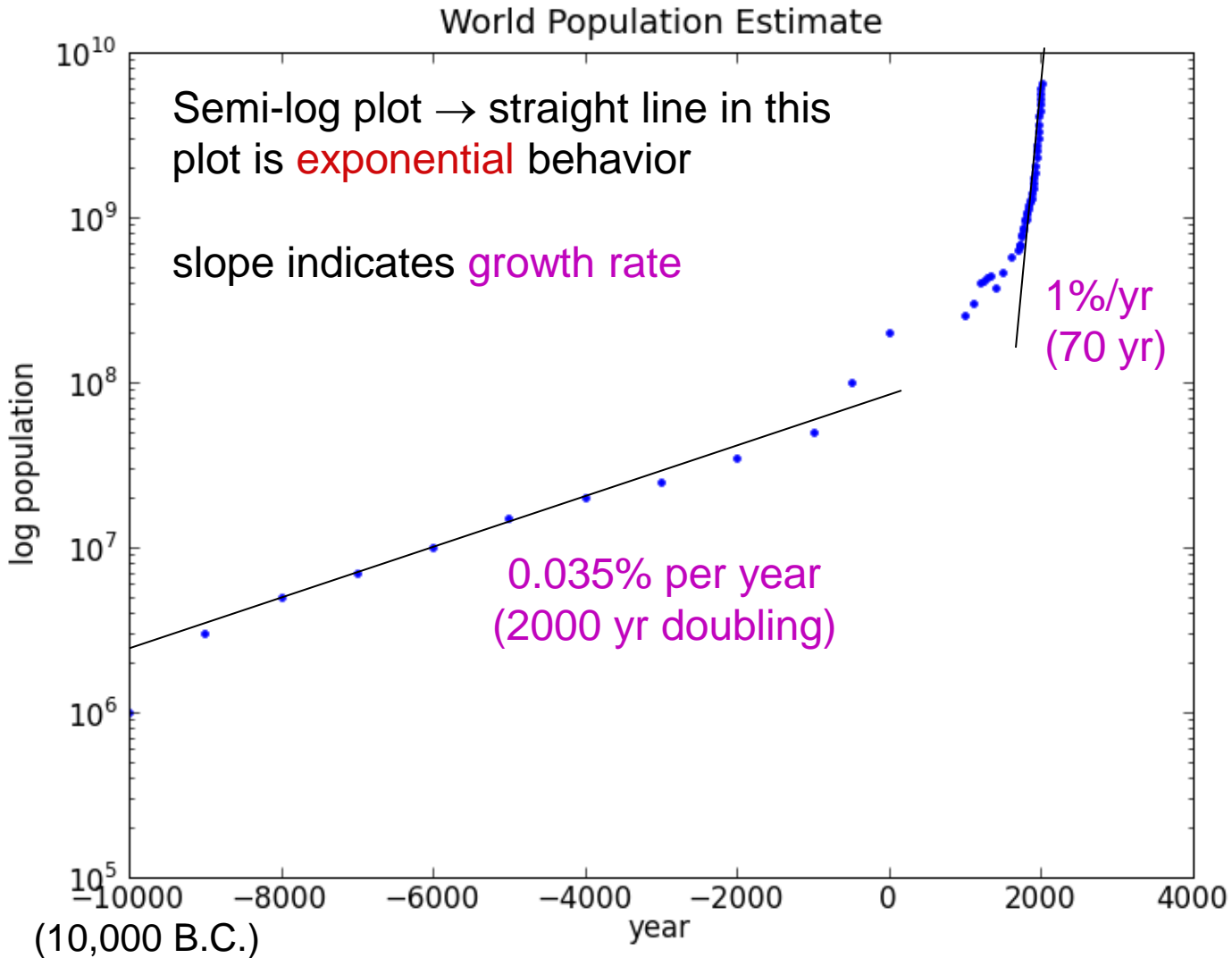
Yup, There is an End to Growth!

- Physical growth is undoubtedly bounded
 - independent of energy technology: thermodynamic conclusion
- There *are* viable mechanisms for economic growth requiring little or no physical growth
 - examples abound (and bubble and burst sometimes)
- But their reach is limited; can't skip off into la-la land forever
 - existence of examples does not mean that 99.99999% of our economy could be driven by non-energy activities (making *limited* energy ~free!)
 - meanwhile, *everything* takes *some energy*: physical limits don't disappear
- Therefore: Economic Growth Must End
 - failure to adopt steady-state economy results in overshoot/collapse

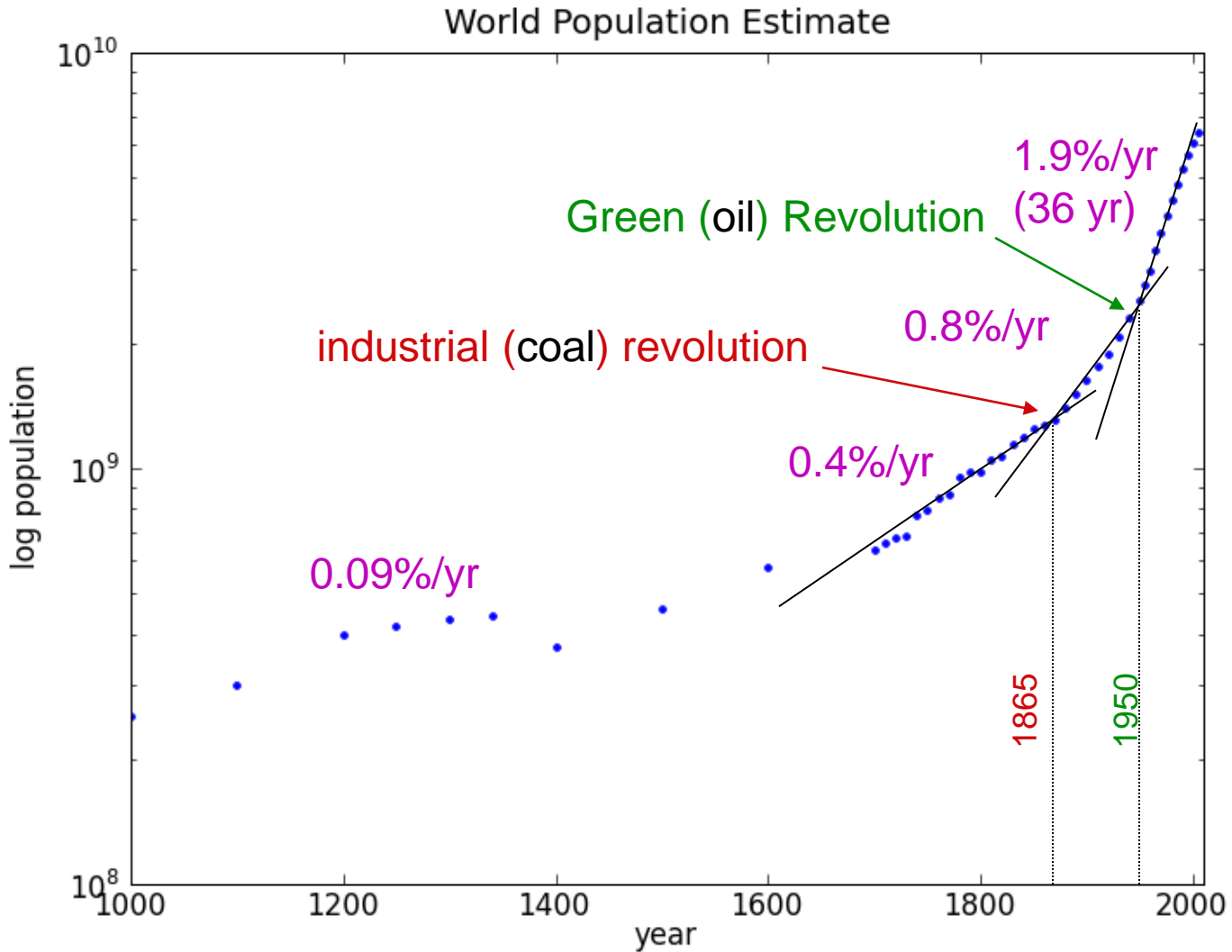
Stop Growth, or Suffer Overshoot

- If we do not **deliberately** stop the growth goal, the dynamic system is **fated** to overshoot
- Negative feedback mechanisms are **unavoidably delayed** compared to the here-and-now positive feedback of growth
 - population, pollution, depletion, etc. created *now*; consequences *later*
- A **universal consequence** is overshoot, followed by crash
- Driving blindfolded, receiving directions from a passenger introduces **delay** to corrective (negative feedback) measures
 - the **only safe state** is slow and steady (**no acceleration, please!**)
- Yes, our smarts *can* save us, but only if applied to the fundamental problem: **STOP THE GROWTH TRAIN!**
 - **desperately need transition to steady-state economy**

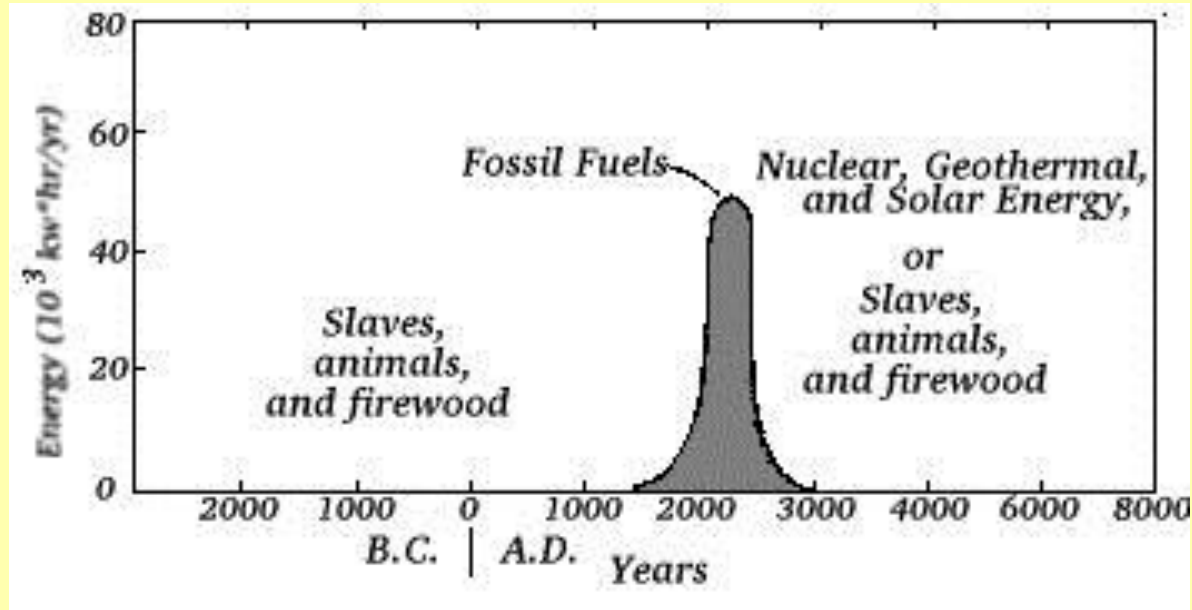
A Look at Population



Surplus Energy Grows Babies



Perspective on Our Joy Ride



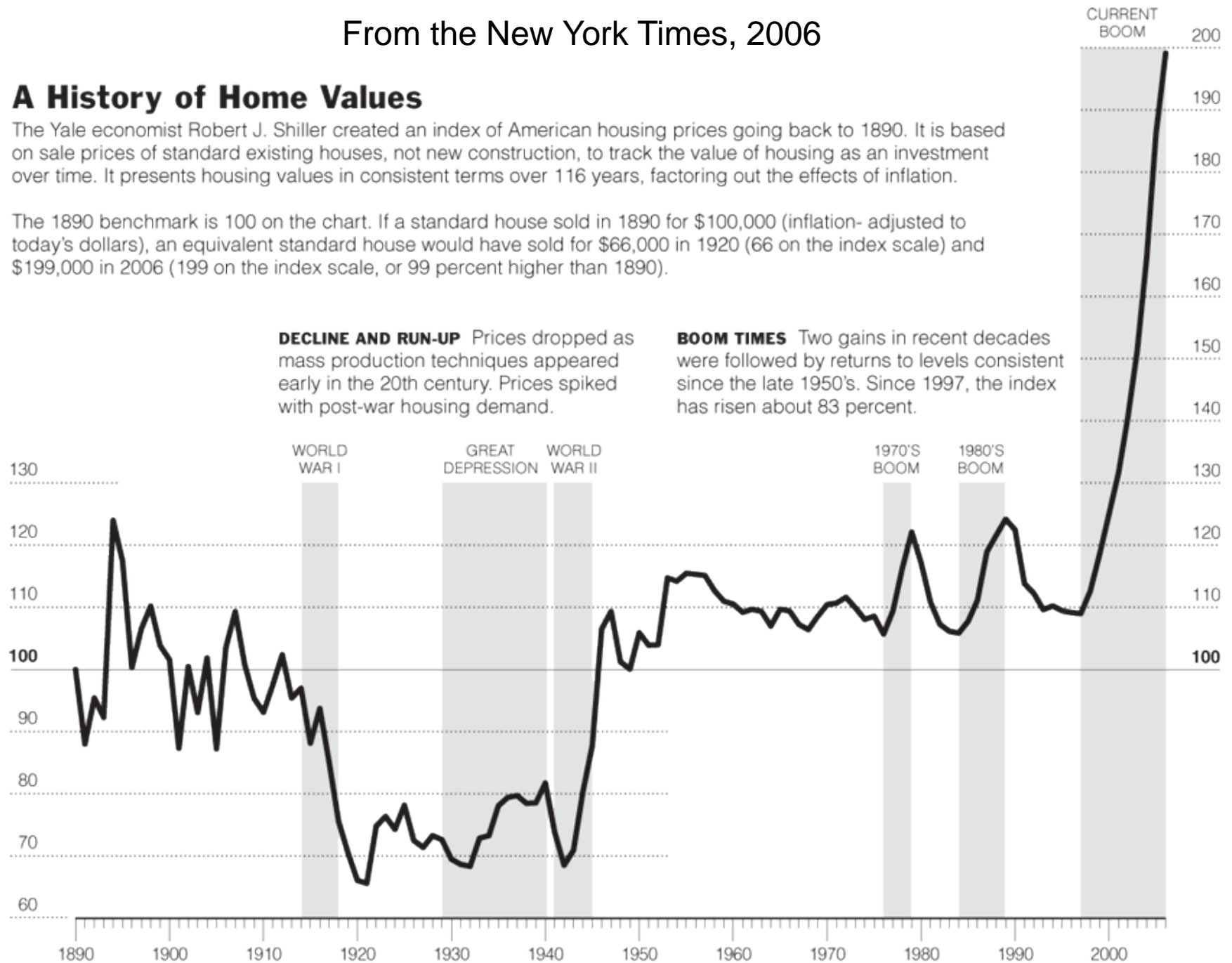
- This cartoon is from an energy/environment textbook, pointing out how **special** this moment in history really is
- We found the **Earth's battery**, expending it **as fast as we can**
- Treating the last 200 years as “normal” is **perilous**

From the New York Times, 2006

A History of Home Values

The Yale economist Robert J. Shiller created an index of American housing prices going back to 1890. It is based on sale prices of standard existing houses, not new construction, to track the value of housing as an investment over time. It presents housing values in consistent terms over 116 years, factoring out the effects of inflation.

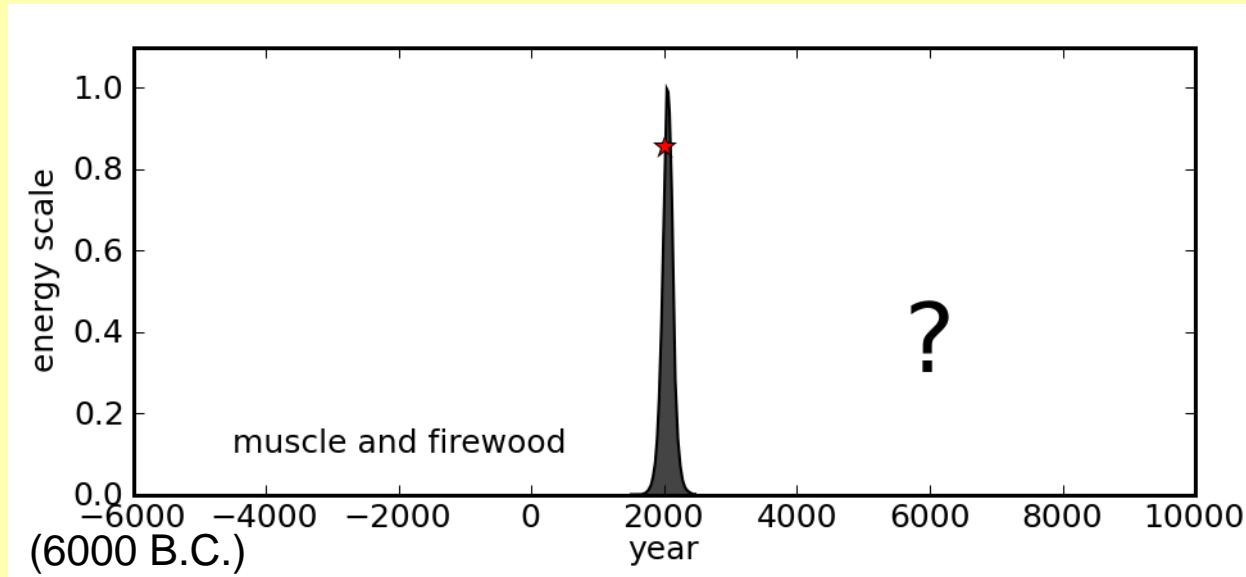
The 1890 benchmark is 100 on the chart. If a standard house sold in 1890 for \$100,000 (inflation-adjusted to today's dollars), an equivalent standard house would have sold for \$66,000 in 1920 (66 on the index scale) and \$199,000 in 2006 (199 on the index scale, or 99 percent higher than 1890).



DECLINE AND RUN-UP Prices dropped as mass production techniques appeared early in the 20th century. Prices spiked with post-war housing demand.

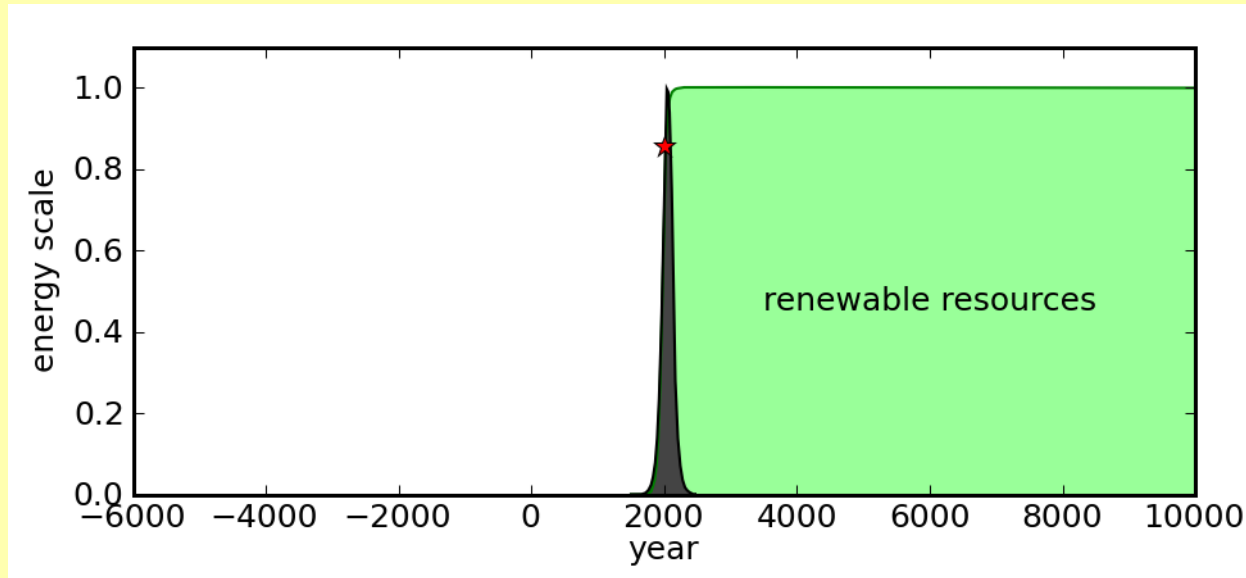
BOOM TIMES Two gains in recent decades were followed by returns to levels consistent since the late 1950's. Since 1997, the index has risen about 83 percent.

What Happens Next?



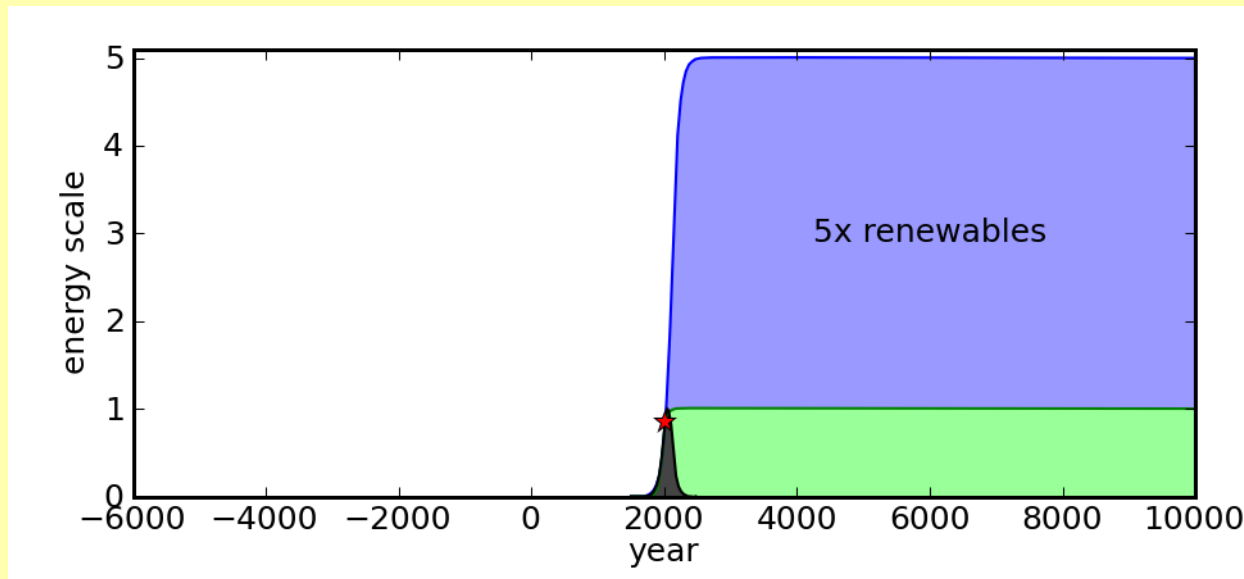
- The future beyond our fossil fuel surge is **not written**
- A return to more primitive ways is a **distinct possibility**
 - most say 2200 will be as **unimaginable** to us as 2000 would be in 1800
 - I agree: who could have imagined we'd be clubbing each other over the heads with half-gnawed bones 200 years after the height of the fossil fuel age?!
 - let's have some **humility**, and not be unjustifiably asymmetric

Sustainable Option 1: Level Out Here



- Leveling out at today's scale means roughly **1/5 U.S. standard**
 - because U.S. is **5%** of population, **25%** of energy
 - inequalities are difficult to justify in no-growth world
- Could we even sustain **today's** physical throughput?
 - pollution, fisheries, rain forests, soil quality, aquifers, minerals, etc.

Sustainable Option 2: Everyone Lives Large



- If we wanted the world to live like Americans, we need $10 \times$
 - $5 \times$ for today's population at today's standards, $10 \times$ for a bit of growth in both aspects
- Pull back to $5 \times$ to allow efficiency, etc.
- Makes the amazing **fossil fuel ride** look like a blip
- What makes us think we can do this?

Stepping Up

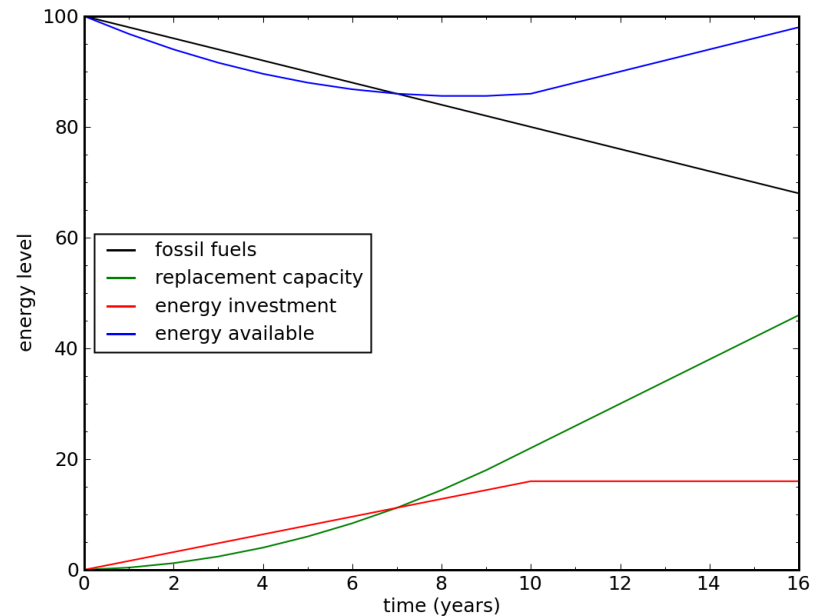
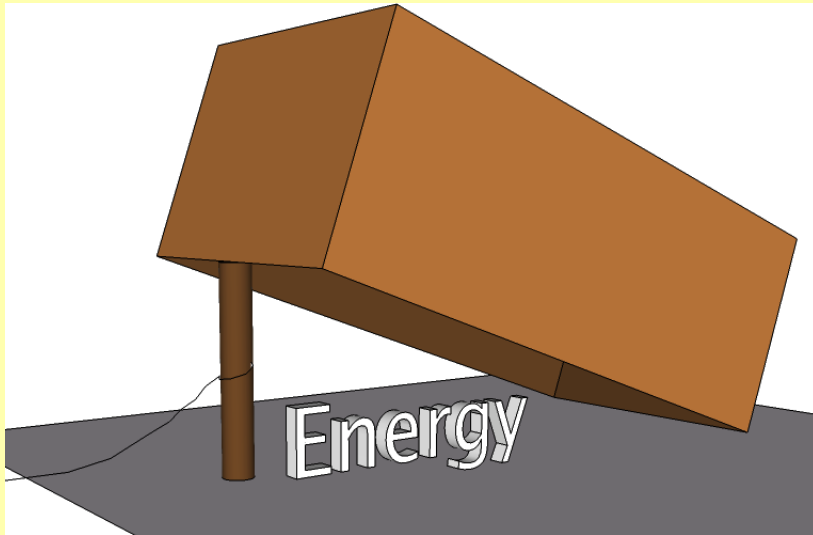
- A kid might *really* want a pet pony
- A smart parent might approach the problem step-wise



We're Not Taking Care of Our Gerbil

- We're having tremendous difficulty managing the 1 × case
 - we have not demonstrated that we can take care of our gerbil
 - pollution, CO₂, fisheries, rain forests, soil erosion, aquifer depletion, etc.
- What makes us think we **deserve** a pony?
 - are we deluding ourselves about our capacity to manage?
- Do we then **deserve** to be brandishing the word “**sustainable?**”
 - we have *no clear idea what it means*, or at *what level* we can expect to operate
- This fossil fuel joy ride has **clouded our judgment**
 - we tend to attribute our progress to **our smarts**, not to **surplus energy**

The Energy Trap



- Once we begin a fossil fuel decline, we hit a **trap**
 - a **new energy infrastructure** requires up-front **energy investment**...
 - ...*exactly* the thing that is in **short supply**
 - we must intentionally **make decline worse**; politically untenable
 - 10:1 EROEI and 40 year lifetime → **1 unit** of energy/year **costs 4** up front
 - nature provides **no energy financing**: can't build windmill on **promised** energy
 - instant relief by abandoning crash program is **too tempting**

Summary

- **Physical growth will end on Earth**, independent of technology
- Economic growth cannot continue for long without energy growth
 - we should begin taking **steady-state economics** seriously
- We have no idea what a **sustainable existence** really means
 - and our gerbil performance **has not deserved us the pony we want**
- **The Energy Trap** builds in severe FF withdrawal symptoms
 - largely unappreciated, politically ruinous
- Let's not be glib. We're not as clever as we look in the mirror.

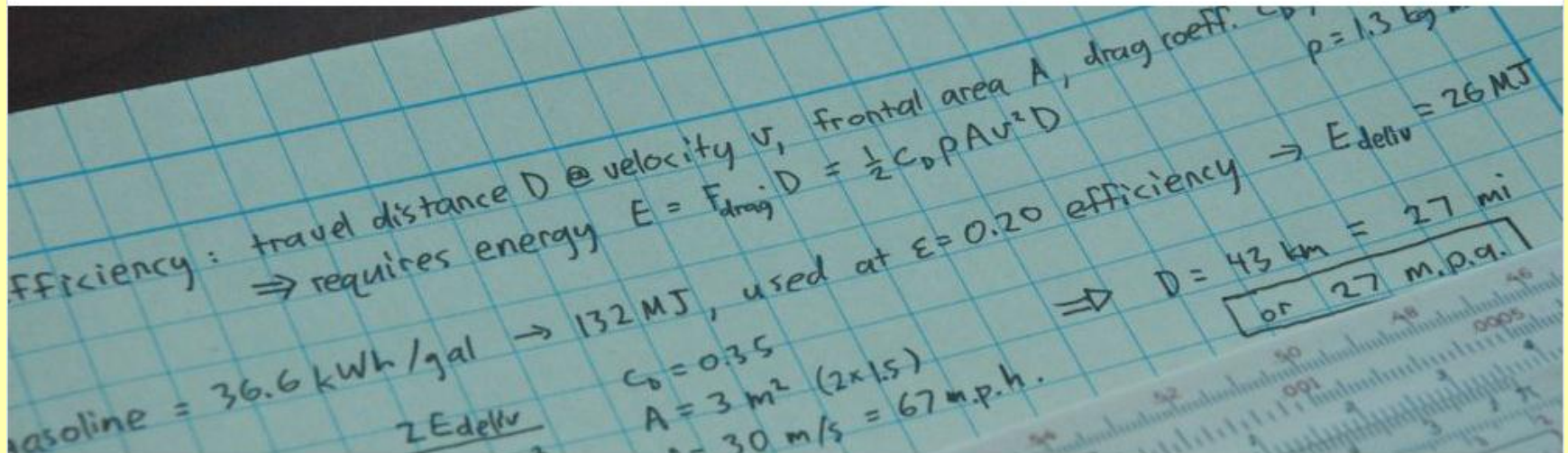
Learn more at my new blog: Do the Math

Do the Math

Using physics and estimation to assess energy, growth, options—by Tom Murphy



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physics.ucsd.edu/do-the-math/

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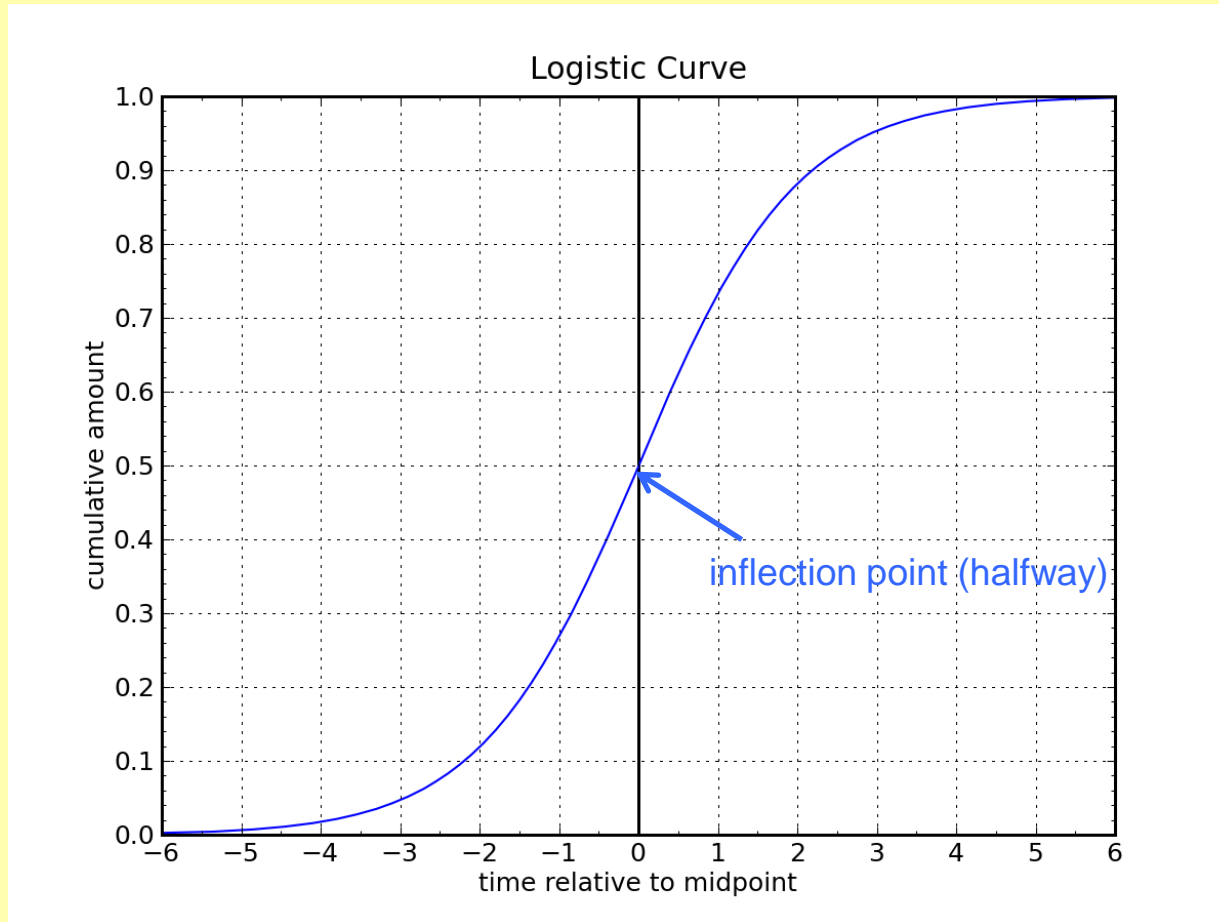
Google: do the math

also check out:

Ecological Economics (textbook by Daly and Farley)

Pile of Extra Slides

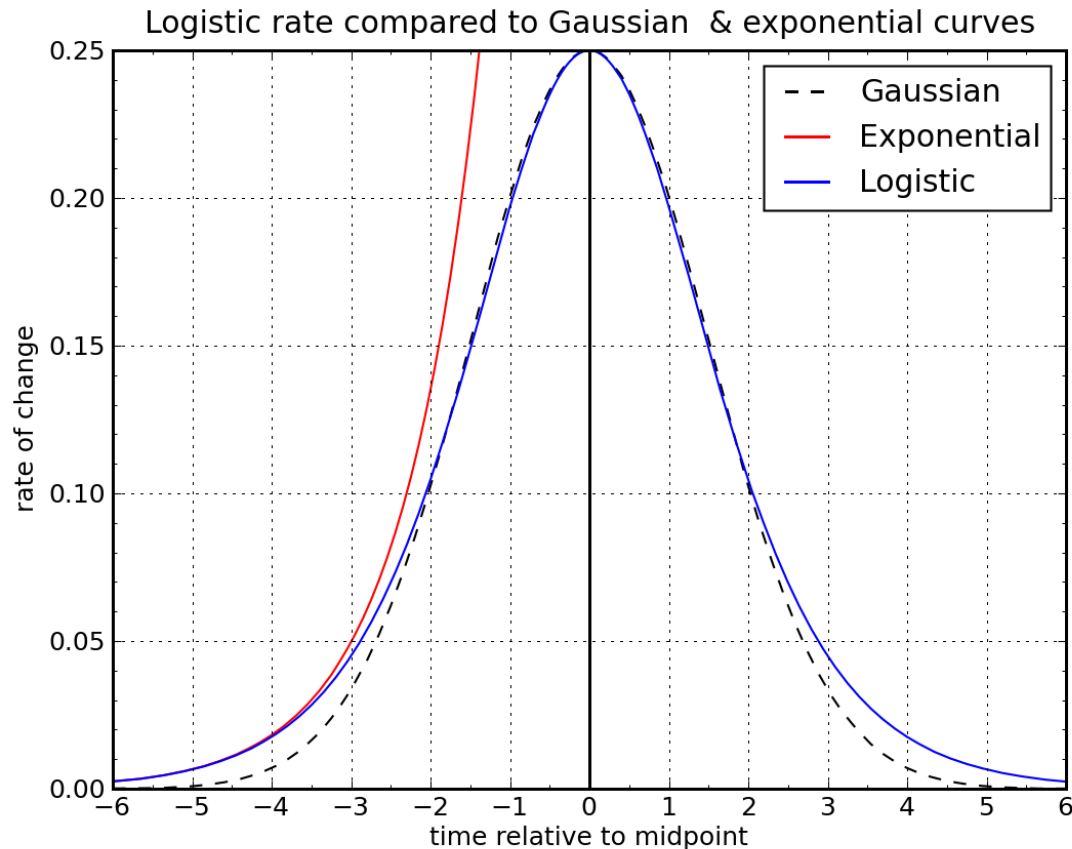
Finite resource, no overshoot → Logistic



$$P(t) = \frac{1}{1 + e^{-t}}$$

Starts off like exponential, but inflects and then levels off.
Still growing at halfway (inflection) point, but linearly, before rolling over

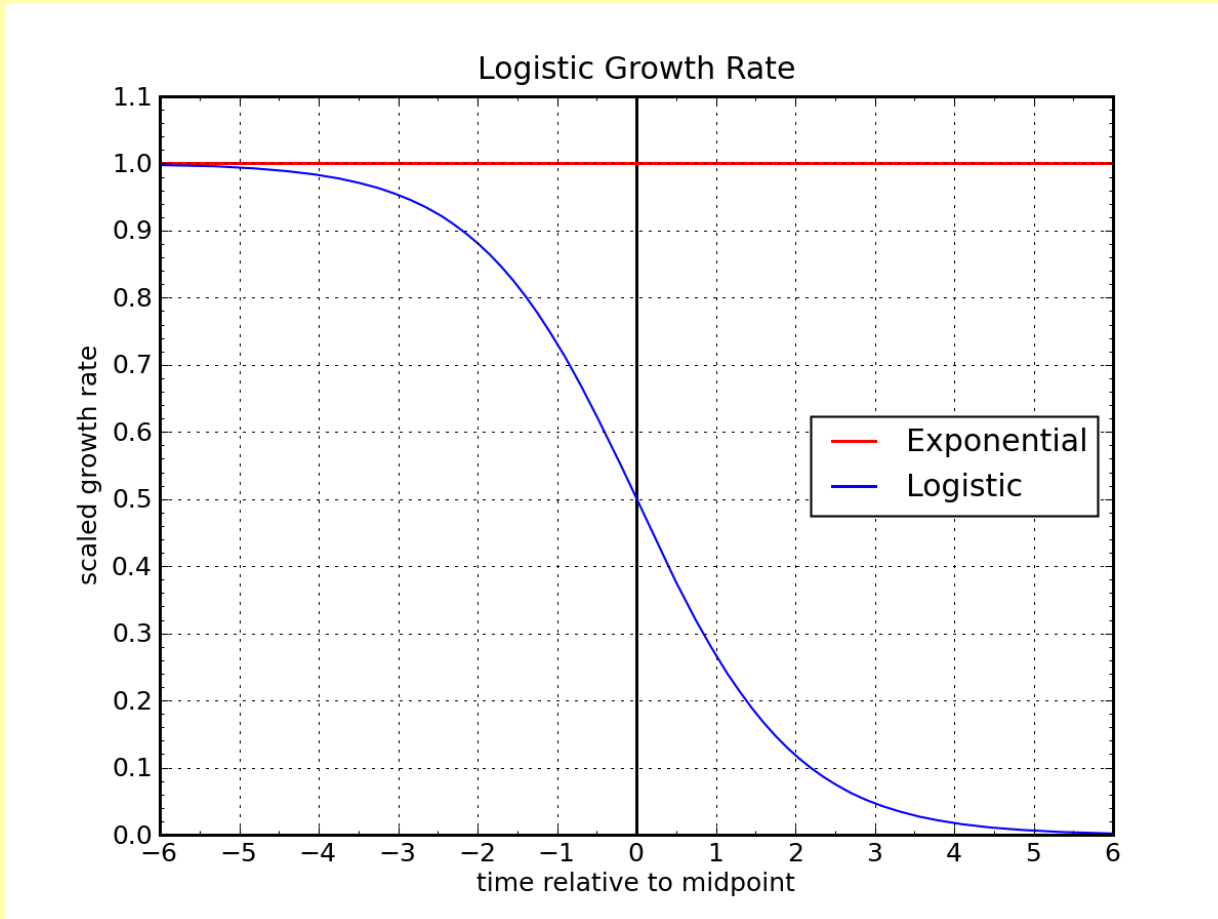
Rate of expansion/production



$$\text{rate} = \frac{e^{-t}}{(1 + e^{-t})^2}$$

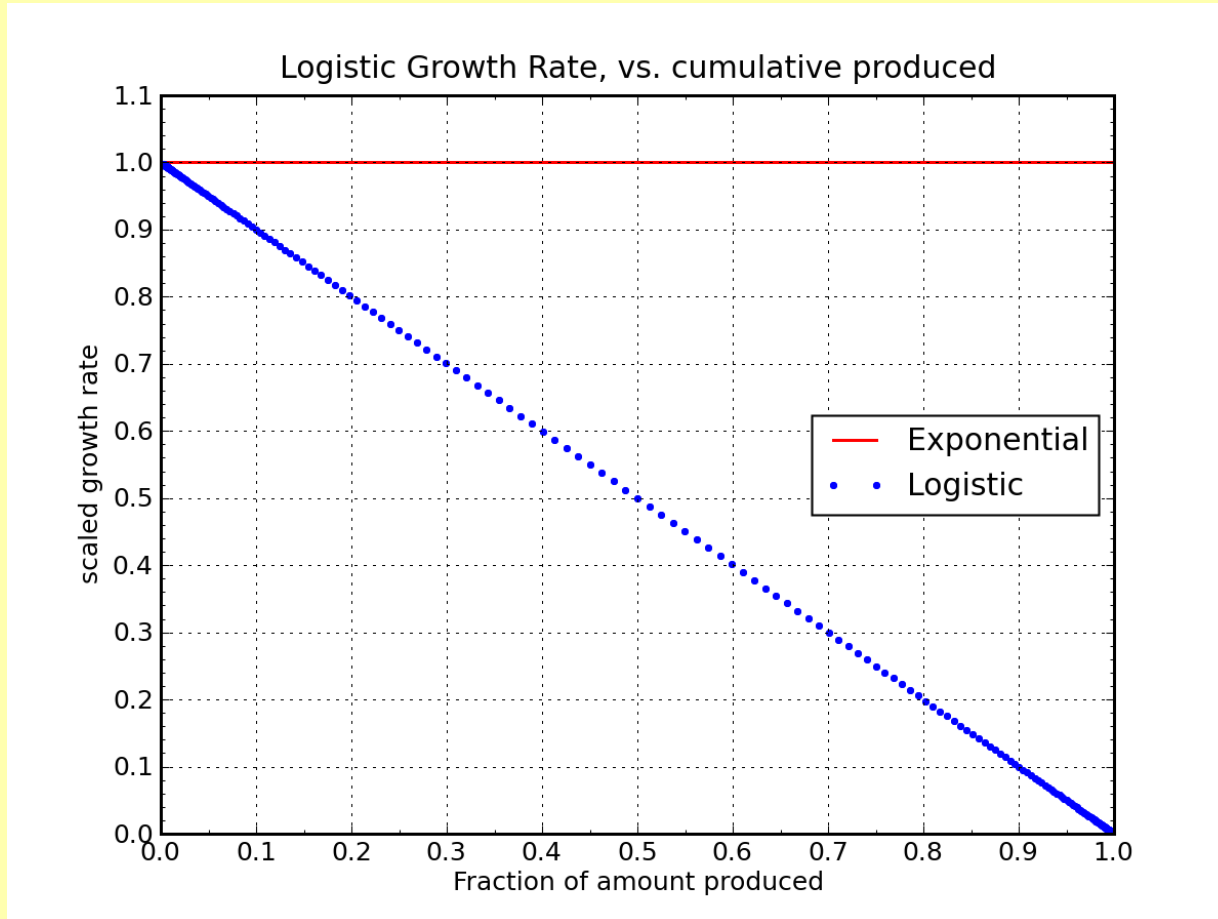
The **slope** of the **logistic curve** follows a bell-shape.
Initially looks like an **exponential**.
But not exactly the Gaussian (usual) bell-shape.

Growth rate declines with time



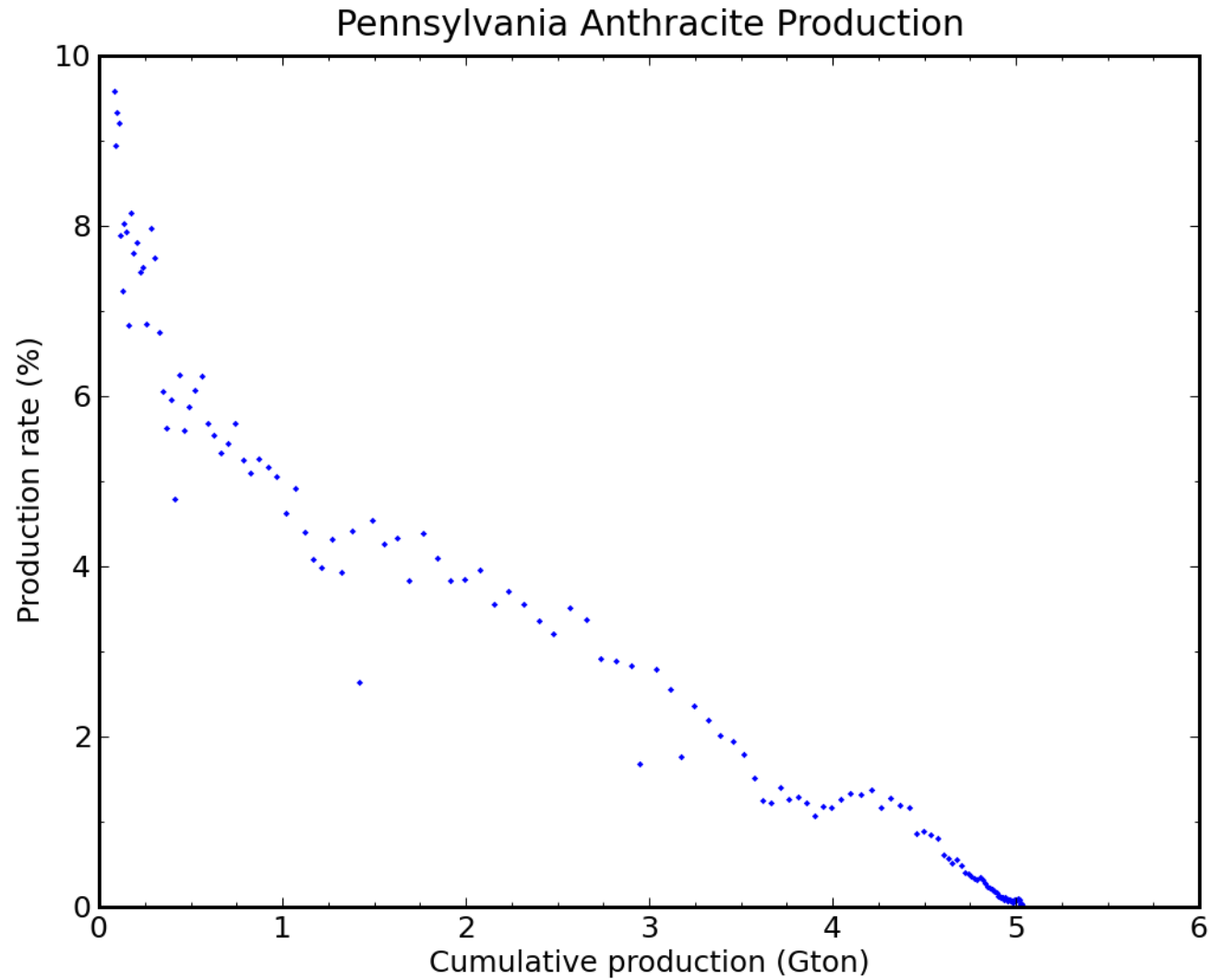
For **logistic curve**, the fractional growth (amount produced **relative to total**) declines, whereas the same measure for **exponentials** is constant (flat).
At the midpoint, the fractional growth is down to half (even while rate is maximum)

A different view of growth rate

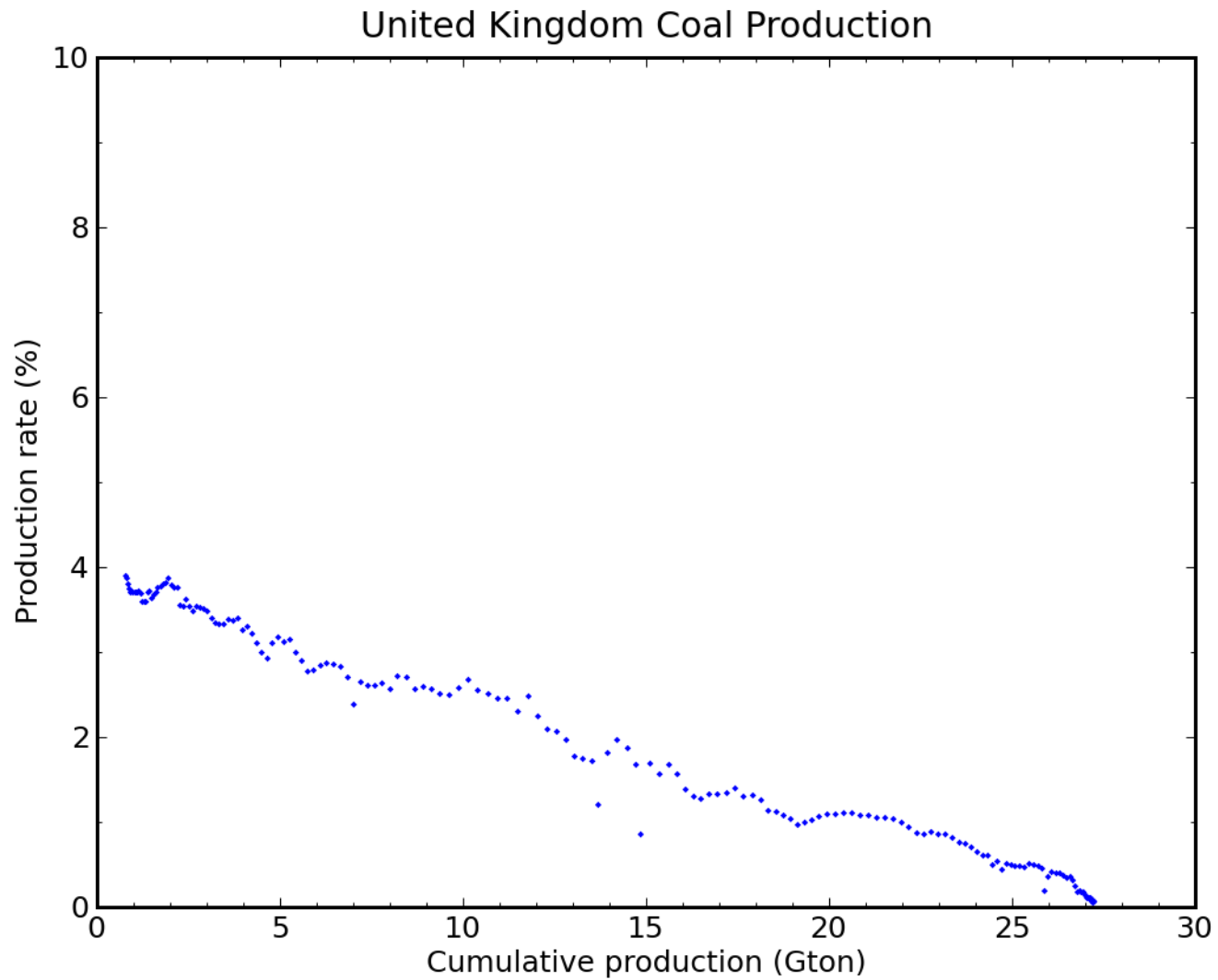


Plotting against *cumulative amount* rather than time, the decline is *linear*. Individual points are *equally spaced in time*: dwell on ends; fly through middle part. Can be used to *anticipate* ultimate production, before the end

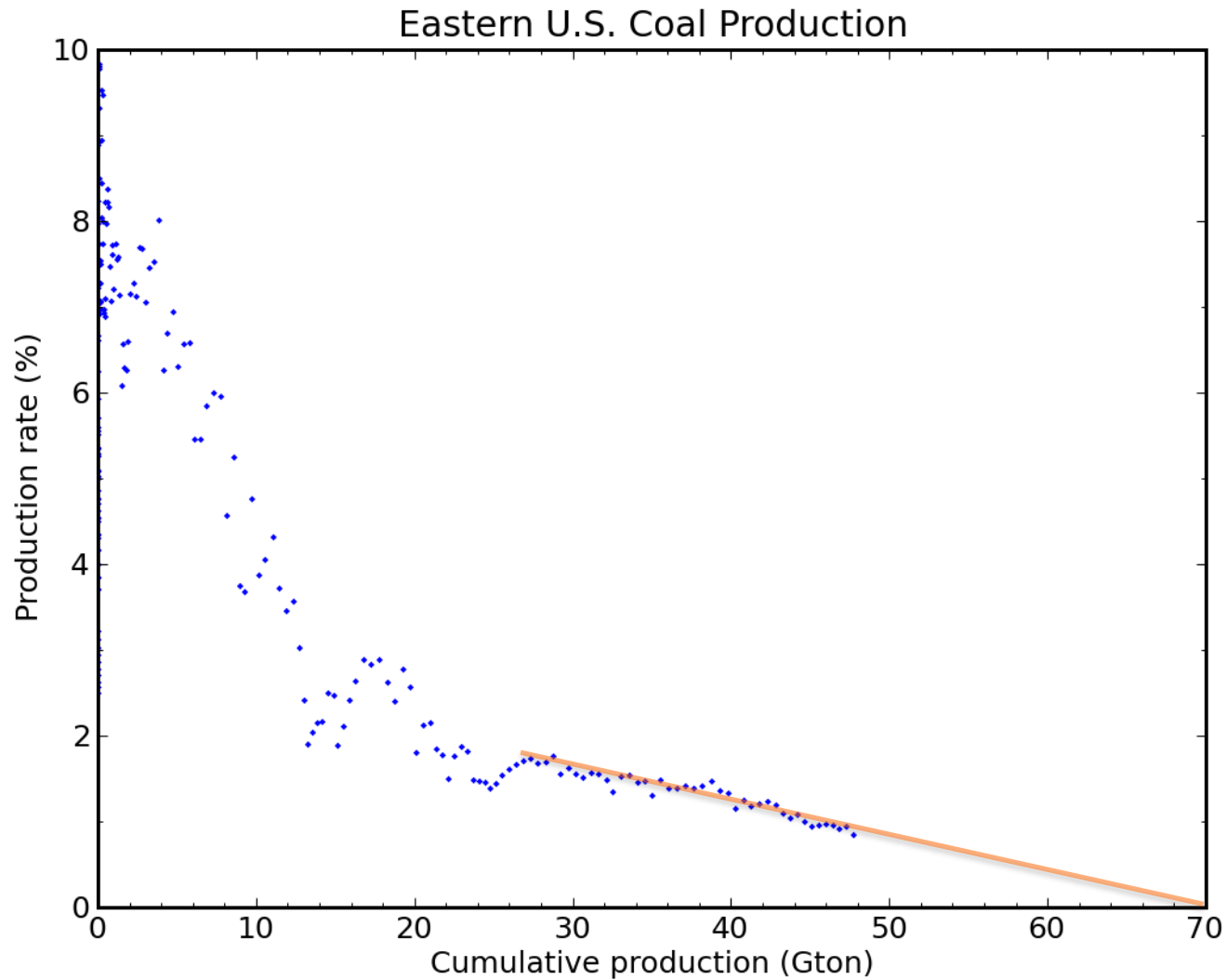
Done Deals, Logistically



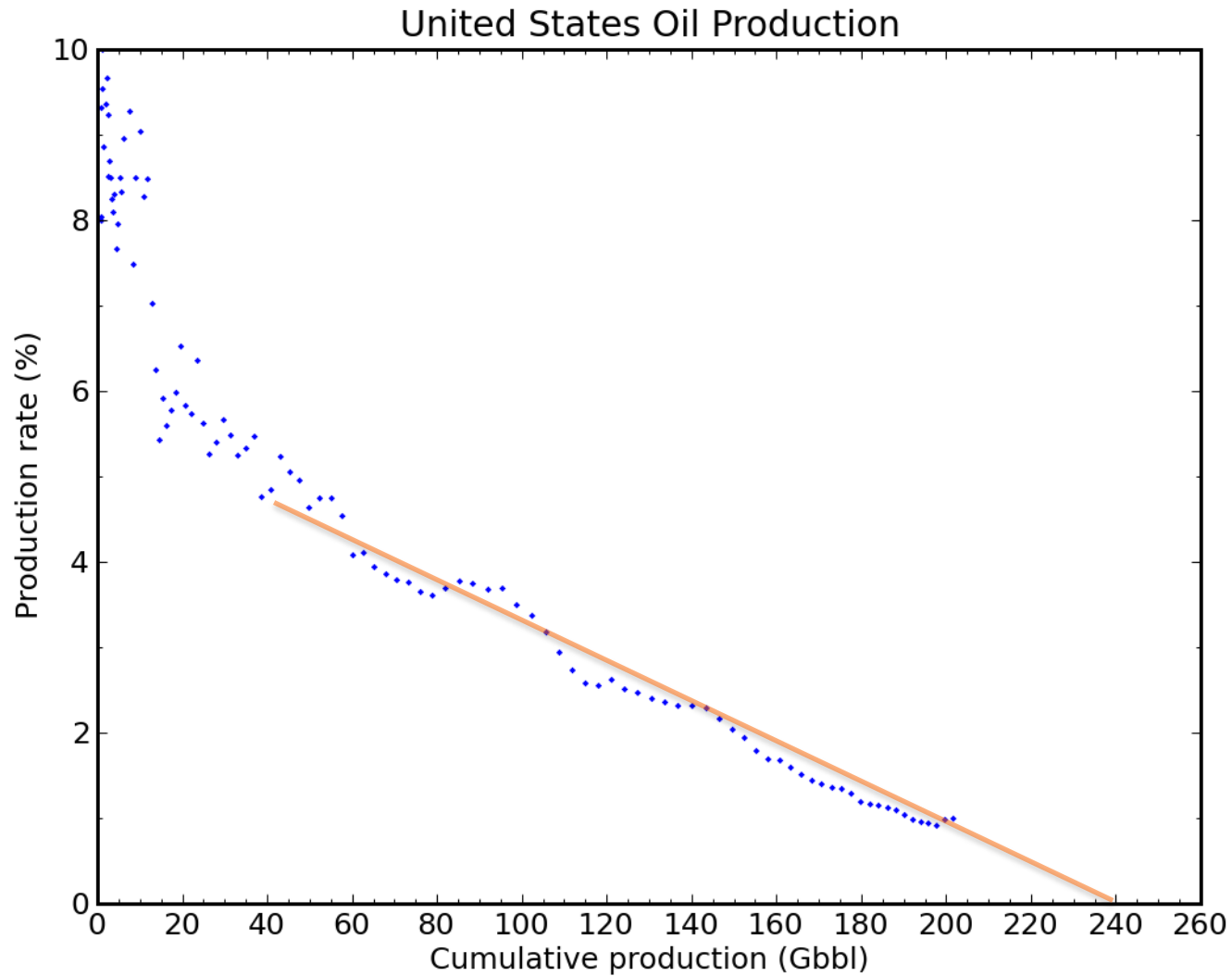
British Coal: Fueling an Empire



Eastern U.S. Coal: Not dead yet...



U.S. Oil: In the End Game



World Oil: Halfway Through?

