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Developing Exponential Intuition

- When the rate of increase depends directly on how much stuff there is, we get exponential growth
 - interest earned depends on balance
 - more bacteria or rabbits are born if the population is larger
- Important concept is doubling time
 - A 1% yearly increase doubles in 70 years
 - $1.01^{70} = 2.0$
 - A 5% increase doubles in 14 years
 - $1.05^{14} = 2.0$
 - Law of 70: doubles in $(70 / \% \text{ rate})$ periods

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Bacteria in Jar

- Imagine bacteria with a doubling time of one minute
 - a little fast, but still: one splits to two every minute
- Start the jar with just enough bacteria to completely fill the jar in exactly 24 hours
 - provide adequate food, etc.
- Start culture at exactly midnight (12:00 AM)
 - so jar reaches full at midnight on next day
- At what time is the jar half full?

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We're going to need more jars

- When the jar is 1/16th full (at 11:56 PM), some visionary (laughed at for predicting full jar) decides to strike out on a quest to find more jars
- Good news! Three empty jars available!
- After 24 hours, and 1440 generations in this stinking jar, we're *saved!*
- Okay, but for how many more minutes?

- And how many more Earths do you think we've got available this century?

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A note on graphs: log vs. linear

- Many graphs in the book are on logarithmic scales
- This condenses wide-ranging information into a compact area
- Pay attention, because you could warp your intuition if you don't appreciate the scale
- Log scales work in *factors of ten*
- A given vertical span represents a constant ratio (e.g., factor of ten, factor of two, etc.)
- An *exponential increase* looks like a *straight line* on a logarithmic scale

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Example Plots

linear scale

log scale

Exponential plot is curved on linear scale, and straight on a logarithmic scale

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Shall We Continue Growth?

- We associate **growth** with **progress**
 - cars, TVs, air travel, iGadgets,...
 - quality of life improves
 - investment pays interest
- Let's look at **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?

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U.S. Energy Historical Energy Growth: 2.9%

United States Total Energy

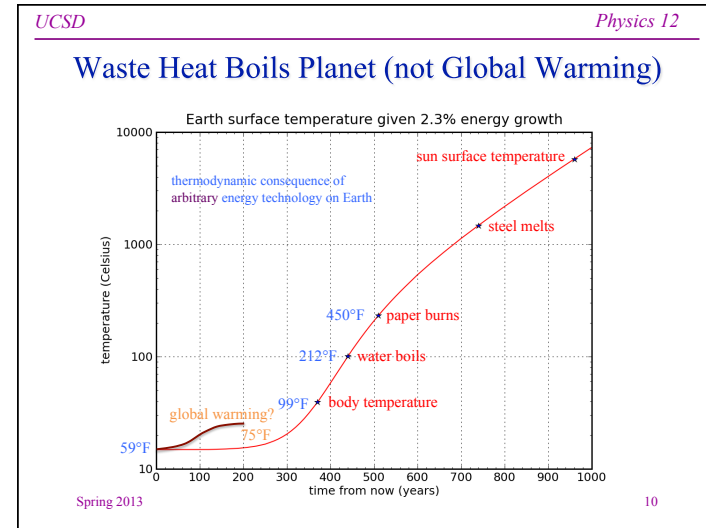
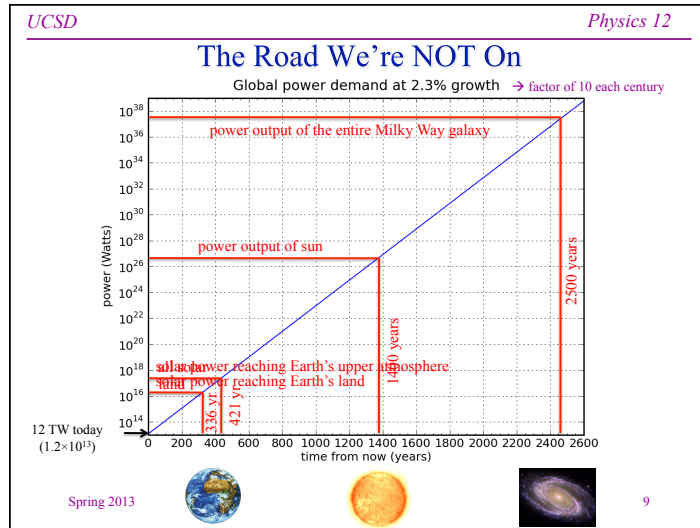
United States Total Energy

logarithmic plot of the same

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

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- ### 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
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- ### 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**
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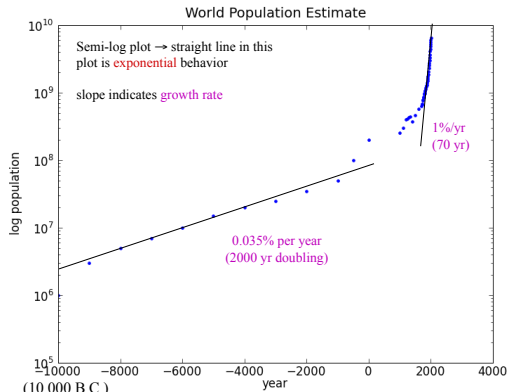
Yup, There is an End to Growth!

- 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
 - Adam Smith saw growth as a transient phase, until all land was used

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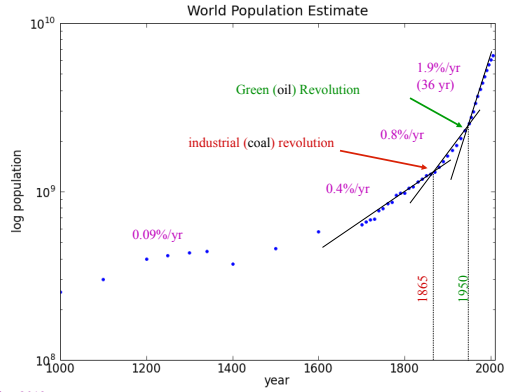
A Look at Population



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Surplus Energy Grows Babies



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Our Problem: Approaching “Full Earth”

- The Frontier Earth model no longer applies
 - imagine building an interstate system from scratch today in the U.S. (was possible 50 years ago)
 - now everything we try to do hits constraints
- Not surprising: we’ve populated ourselves into a crowded, resource-constrained existence
- Earth has a finite “carrying capacity”
 - we may well have exceeded it in an overshoot mode
 - estimates range from 1 billion humans to over 10 billion

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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**
 - effectively a **short circuit**
- Treating the last 200 years as “normal” is **perilous**

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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

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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.

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Sustainable Option 2: Everyone Lives Large

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

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Stepping Up

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

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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*

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Breaking News: NYT Science Screenshot

- From April 3, 2013
 - ahem: today
- Not unusual for energy stories to dominate science news
- This isn't going to go away
 - as this century progresses, we'll be ever-more tuned in to energy news

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Announcements/Assignments

- Reading:
 - Chapter 1 of Ristinen and Kraushaar
 - also read the Appendix
- Optional Reading from Do the Math (DtM)
 - Galactic Scale Energy (#1)
 - Can Economic Growth Last? (#2)
 - numbers refer to chronological list on Guide to Posts page
- First homework will be due Friday, April 12
 - see main course website for assignment
- First quiz by Friday (midnight), April 12
- Transmitter use (iClicker) starting Friday, April 5
- Discussion Session today (I'll join partway through)
- Matt's office hours: Thursday 2:30–3:50, SERF 434

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