8.21 The Physics of Energy
Fall 2009

8.21 Lecture 1

The Physics of Energy:

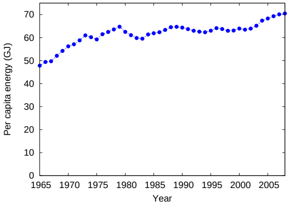
Introduction to Course

September 9, 2009

Energy issues seem to be everywhere

Economics	Volatile oil prices Corn-based ethanol & rising food prices Cape wind & property values
Politics	Iraq and Middle East politics Russian Gazprom cuts natural gas to Ukraine Offshore drilling
Environment	Global warming from CO_2 →Pressure on many ecosystems, species →Sea level rise →Floods, hurricanes, drought Mercury from coal plants

We use more and more energy



Energy use/person

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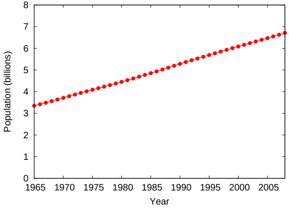

World Population

[Data from U.S. Census bureau]

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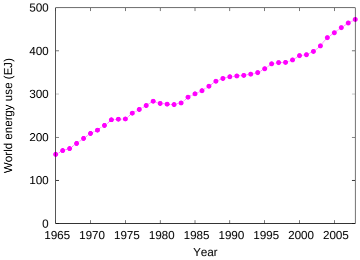
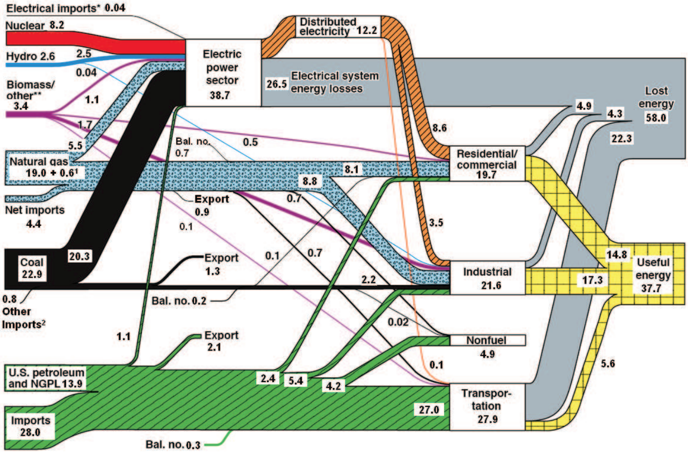


Global energy use

[data from BP]

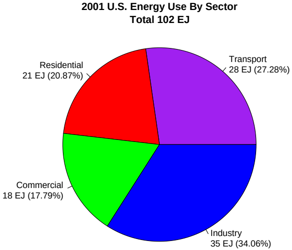
But resources are limited



[image: EIA]

Energy flow from sources to uses is COMPLEX

In this class, we'll use physics to understand Energy:



[data: EIA]

U.S. energy use

∼28%	transport	(mechanics)
∼40%	heating/AC	(thermodynamics)
∼3%	lighting	(EM)

Physical requirements: ?How much energy do we need to use?

Physical limitations: ?How much energy is available for use?

?How efficiently can we use energy?

Physical consequences: ?Can we limit side effects?

Energy Sources

Currently about 85% of U.S. energy from fossil fuels

Photo courtesy of Rennett Stowe on Flickr.

Coal (23%)

Photo courtesy of craig1black on Flickr.

Petroleum (40%)

Many issues:

- Political: Foreign sources
- Economic: Increased global demand, limited resource
- Environmental: CO_2 warming, NO_x smog

Alternative Energy Sources

Solar	solar thermal [thermo] PV [quantum]	• Ultimate source of most E • Vast potential • Issues: efficiency, scaling, distribution
Nuclear	fission, fusion [quantum]	• Vast potential • Issues: safety, waste, security, technology
Other renewables	wind, waves, hydro, tides, [fluid mech] ocean, geothermal [thermo]	• Clean energy sources • Substantial potential in wind, geothermal; others more limited • Study physics of each

Some course objectives

Overview of natural and human earth energy systems

–Underlying physical processes
–Order of magnitude quantities + efficiencies
–Example: energy flow from sun → this slide → space

New physics relevant for energy

–Thermodynamics
–Quantum mechanics
–Fluid mechanics

Abstract theoretical principles → concrete energy applications

–Principles → order of magnitude estimates
–Learn to estimate or look up details

8.21: Not just a class It's an Adventure!

We are teaching
this course
for the second time,
learning as we go

We will cover
more material
than you can absorb
Focus on core,
rest is optional.

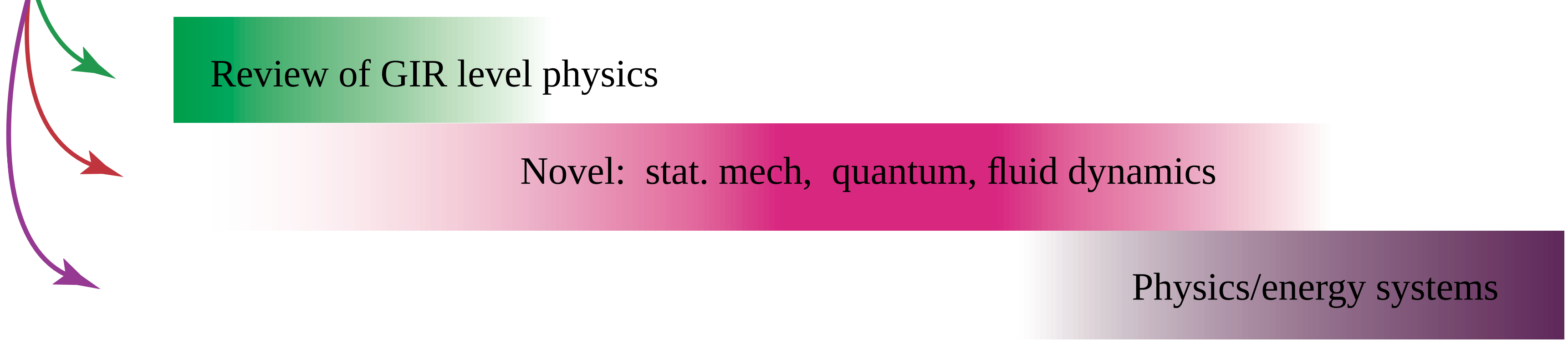
You are invited to
participate
in optimizing the course.
We want your Feedback!
Ask questions!

Give us comments!
What works,
what doesn't?
Find errors in notes, and
other material
–There will be **prizes!**–

Now over to BOB

The Big Picture

- Uses (12 lectures)
- Sources (19 lectures)
- Environmental physics and systems (7 lectures)



What's the physics?

- Mechanics
- Electricity and magnetism
- Heat
- Energy in chemical processes

- Statistical physics
  - Thermodynamics, entropy, efficiency, cycles, phase changes, thermal radiation
- Quantum physics
  - States, probabilities, wave functions, eigenenergies and eigenstates, tunneling, radiation
- Fundamental physics
  - Particles and forces, the Standard Model, origins and flow of energy in the Universe

- Nuclear physics
  - Nuclear structure, nuclear binding, stability and decays, radiation
- Condensed matter physics
  - Electrons in matter, bands and gaps, semiconductors, radiation absorption
- Fluid dynamics
  - Fluid flow, pressure, viscosity, Bernoulli's law, drag, lift

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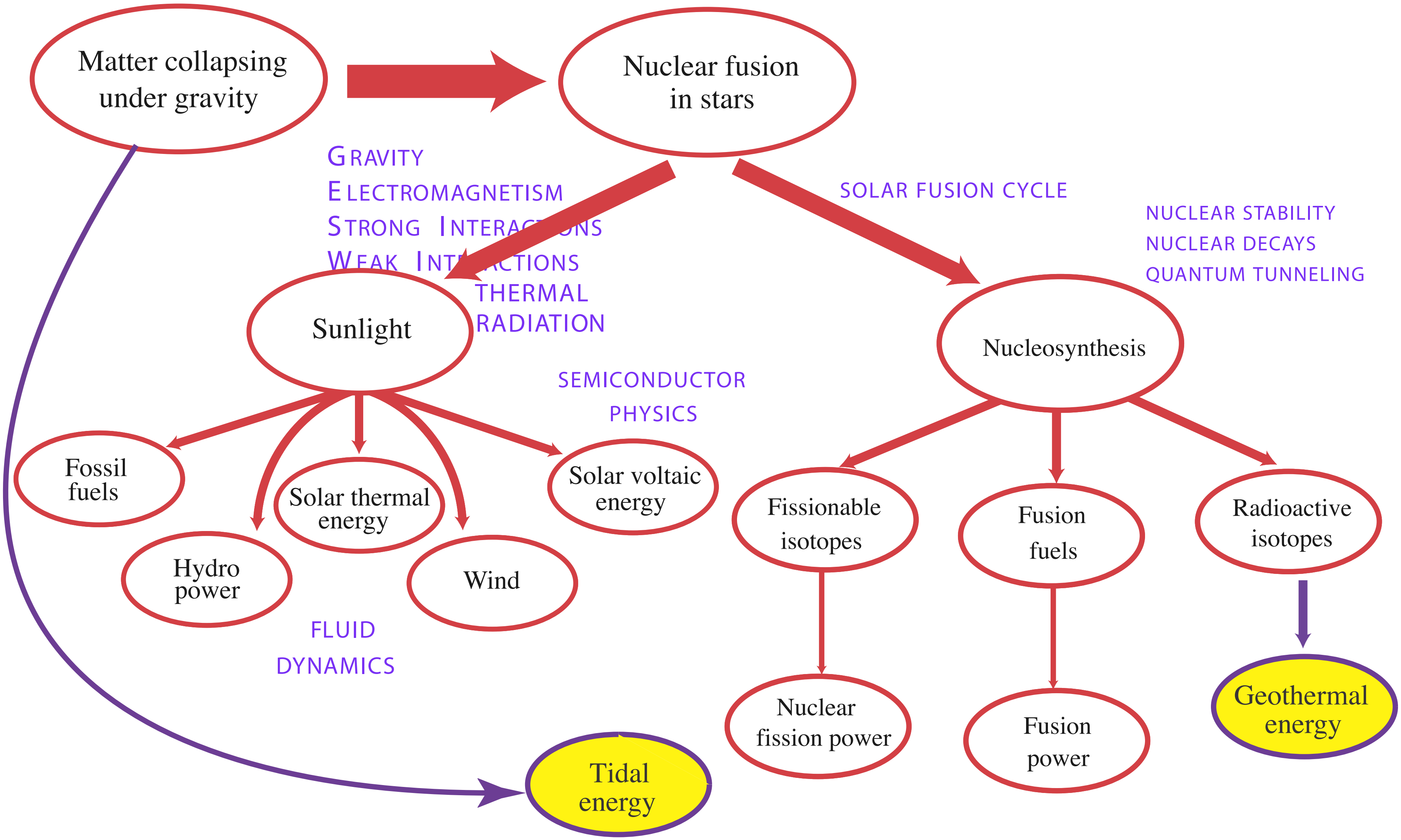
- Nuclear fission reactor design, dynamics, stability, and safety
- Solar voltaic energy flow, thermodynamics, and efficiency
- Wind power potential, aerodynamics, design
- Atmospheric energy flow and climate change
- Environmental radiation
- Energy storage
- Conservation

Ambitious!!


Matter collapsing under gravity
Nuclear fusion in stars
GRAVITY
ELECTROMAGNETISM
STRONG INTERACTIONS
WEAK INTERACTIONS
SOLAR FUSION CYCLE
NUCLEAR STABILITY
NUCLEAR DECAYS
QUANTUM TUNNELING
THERMAL RADIATION
Sunlight
Nucleosynthesis
SEMICONDUCTOR PHYSICS
Fossil fuels
Solar thermal energy
Solar voltaic energy
Hydro power
Wind
Fissionable isotopes
Fusion fuels
Radioactive isotopes
FLUID DYNAMICS
Nuclear fission power
Fusion power
Geothermal energy
Tidal energy

To whet your appetite

- Why a rare isotope of *lithium* is a key player in the future of nuclear fusion power.

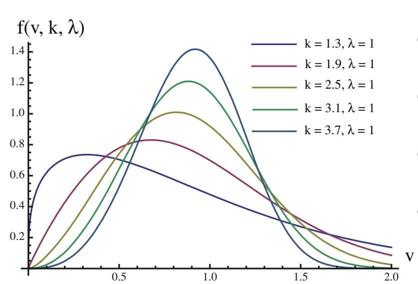
It's the fundamental fuel because tritium is made from it.

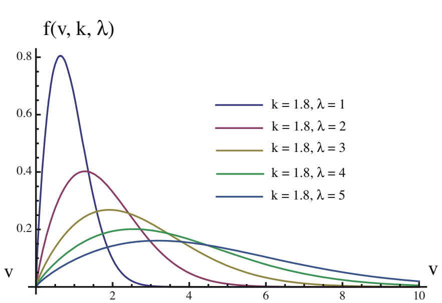
$$d + t \rightarrow {}^4\text{He} + n \qquad n + {}^6\text{Li} \rightarrow {}^4\text{He} + t$$

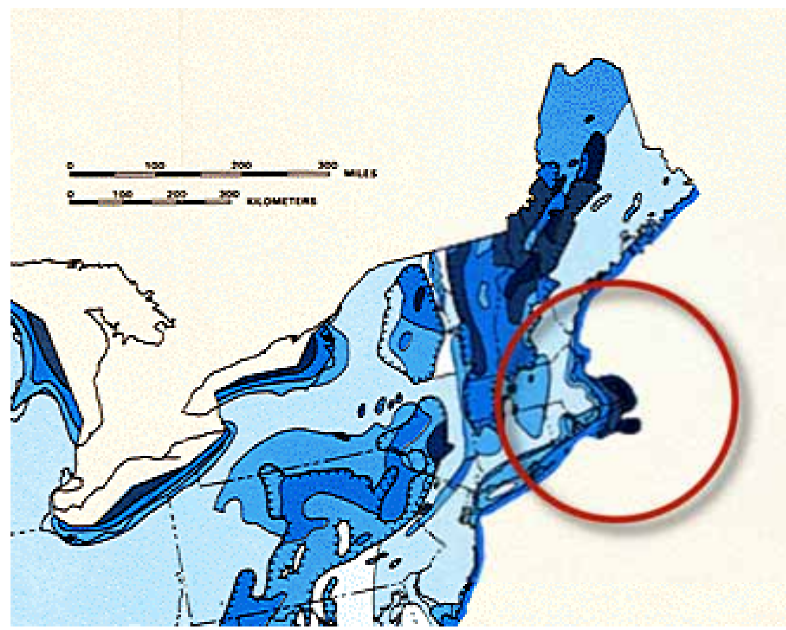
And tritium is the fuel for fusion energy for the foreseeable future.

- Why is coastal Massachusetts prime *wind power* real estate.

Wind power class 6 near population centers is a winning combination.







http://rredc.nrel.gov/wind/pubs/atlas/

To whet your appetite (II)

- Why is geothermal energy a form of nuclear energy?
  What does it have to do with refrigeration?
  - Because the ultimate heat source is radioactive decay of potassium, thorium and uranium in the earth's interior.
  - Perhaps the most promising exploitation of geothermal energy is through the use of heat pumps, which are basically refrigerators run backwards.

- Is the role of hydrogen more similar to ??
  - a flywheel?
  - methane?

  - Answer: a flywheel! Methane (Natural gas) is a naturally occurring energy source that can be used as a fuel. Hydrogen would also be *fuel* if it occurred as molecular hydrogen (H_2) in nature. Instead it is always found tightly bound to other elements. It always takes more energy to liberate they hydrogen than it will generate when it is used (2nd law of thermodynamics), so hydrogen is *an energy storage device* like a flywheel (and not, at present, a very efficient one).

To whet your appetite (III)

- What is a *fission poison* and why is it important for power grid operation?
  - It is a fission product that continues to be created after a reactor is turned off. A fission poison absorbs neutrons and prevents the reactor being restarted for several days.

- What is the difference between solar thermal energy and solar voltaic energy, and what are the roles of each in our energy future?
  - The differences are huge:
    - Solar Thermal: thermal fluid power technology resembling fossil fuel and nuclear plants, relatively mature technology, few exotic materials, promising storage options, significant economies of scale suggest commodity applications.
    - Solar Voltaic: solid state electrodynamics unlike other energy sources, rapidly developing technology, rare and exotic materials, storage issues, relatively efficient at small scales suggesting end user implementation.

  I wish I knew!

What we do not cover in 8.21

- A lot!
- All of the crucial economic, political, and policy issues.
- Chemistry and biology of energy
  - Coal! Carbon capture and sequestration, coal gasification.
  - Biofuels. . . cellulosic ethanol, advanced biofuels
  - "Artificial" photosynthesis
  - Fuel cells
- And, of course, everything at an advanced level!