Lecture 2

Human energy use cont.,
Earth’s energy flows
Agenda for this lecture

- Review: units, laws of thermodynamics, human energy use
- Definition of efficiency
- Lessons from quizzes: core principles of physics and environmental science
- Earth’s 3 energy flows
Technology has allowed us to increase primary energy use

THEN

Hunter-gatherers – 100 W / person is food requirement

NOW

Americans – 10,000 W / person  (...100 servants)
Wealth is strongly predicted by energy use

Sample shown: all countries other than
- < 4M pop.
- major oil producers
- former Soviet Union or East bloc or China
- sub-Saharan Africa

Energy use is total primary energy usage (not just electricity), in common units of Watts per person.

For these “normal” countries, energy use predicts GDP to x3 lines $3-9/yr GDP / Watt

Relationship holds across countries and across time for a given country, over x 100

Data: World Bank, ~1960-2011, 2005 USD
Development = greater energy use

Data: World Bank, ~1960-2011, 2005 USD
FSU and East bloc were wasteful, now recovering

Data: World Bank, ~1960-2011 2005 USD

Power use per capita (1000 W)

GDP<sub>PPP</sub> ($1000)

$9/yr/W

$3/yr/W

Data: World Bank, ~1960-2011 2005 USD
Some sub-Saharan countries are regressing

Many sub-Saharan countries fall below “normal zone”, but direction of movement can differ

DRC is dropping below the “normal zone” over time

Mozambique is recovering toward the “normal zone”

Data: World Bank, ~1960-2011 2005 USD
China has entered the normal zone now.

Data: World Bank, ~1960-2011 2005 USD

China was below “normal zone” from 1980-2000

Inflection point is ~ 2001
France and the Netherlands grew by x 10 from 1800-1900 and energy usage increased correspondingly.

In last few decades wealth has risen without much change in energy use. (This is common in high-income countries.)

Data:
World Bank, ~1960-2011 2005 USD
www.energyhistory.org, converted to 2005 USD
Britain and the U.S. initially “wasteful”

1800-1900 Britain: doubling energy = doubling wealth.

Both Britain (and U.S.) historically were “wasteful” energy users – excess energy used per GDP – and are more “normal” now.

U.S. note: one datapoint per 10 years til 1949

Data:
World Bank, ~1960-2011 2005 USD
www.energyhistory.org, converted to 2005 USD
U.S. data from EIA
Only 3 primary sources for energy in Earth system
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Solar radiation (nuclear fusion in sun)
Only 3 primary sources for energy in Earth system

Solar radiation (nuclear fusion in sun)

Geothermal heat:
- nuclear fission of radiogenic elements
- residual heat

$^{238}\text{U} \rightarrow ^{206}\text{Pb}$
Only 3 primary sources for energy in Earth system

- Solar radiation (nuclear fusion in sun)
- Geothermal heat: nuclear fission of radiogenic elements + residual heat
- Rotational kinetic energy (source of tidal energy)
What happens to incoming solar energy?

Solar radiation (nuclear fusion in sun)
Solar energy undergoes transformations before being ultimately dissipated as heat.

Solar radiation in (visible) → Thermal radiation out (mid-infrared)
Solar energy undergoes transformations before being ultimately dissipated as heat.

- Solar radiation in (visible)
- Latent heat transport
- Gravitational potential energy of water
- Hydrological cycle: Large fraction of incoming power.. But we can’t extract it all
Solar energy undergoes transformations before being ultimately dissipated as heat.

Solar radiation in (visible) goes to kinetic energy, which can be converted to wind. Wind has a smaller fraction than hydrological, but it is still substantial. Note that waves come from wind and are associated with thermal radiation out (mid-infrared).
Solar energy undergoes transformations before being ultimately dissipated as heat.

Solar radiation in (visible) -> Chemical energy

Photosynthesis

Thermal radiation out (mid-infrared)
Solar energy undergoes transformations before being ultimately dissipated as heat.

Solar radiation in (visible) leads to photosynthesis, which stores chemical energy. Only very little biological material is buried and preserved. Carbon burial occurs with thermal radiation out (mid-infrared).