A Conspectus on US Energy

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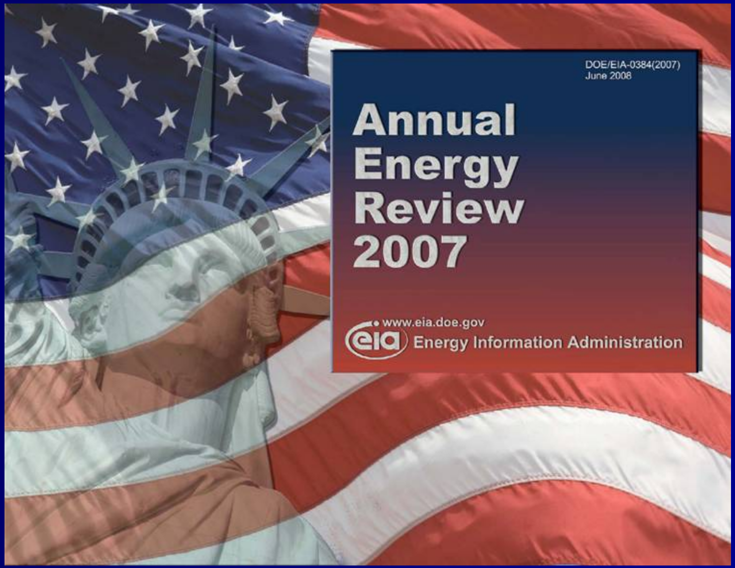
Great source of data

- www.eia.doe.gov
- Look up aer2007 (Annual Energy Review, and pick your year)



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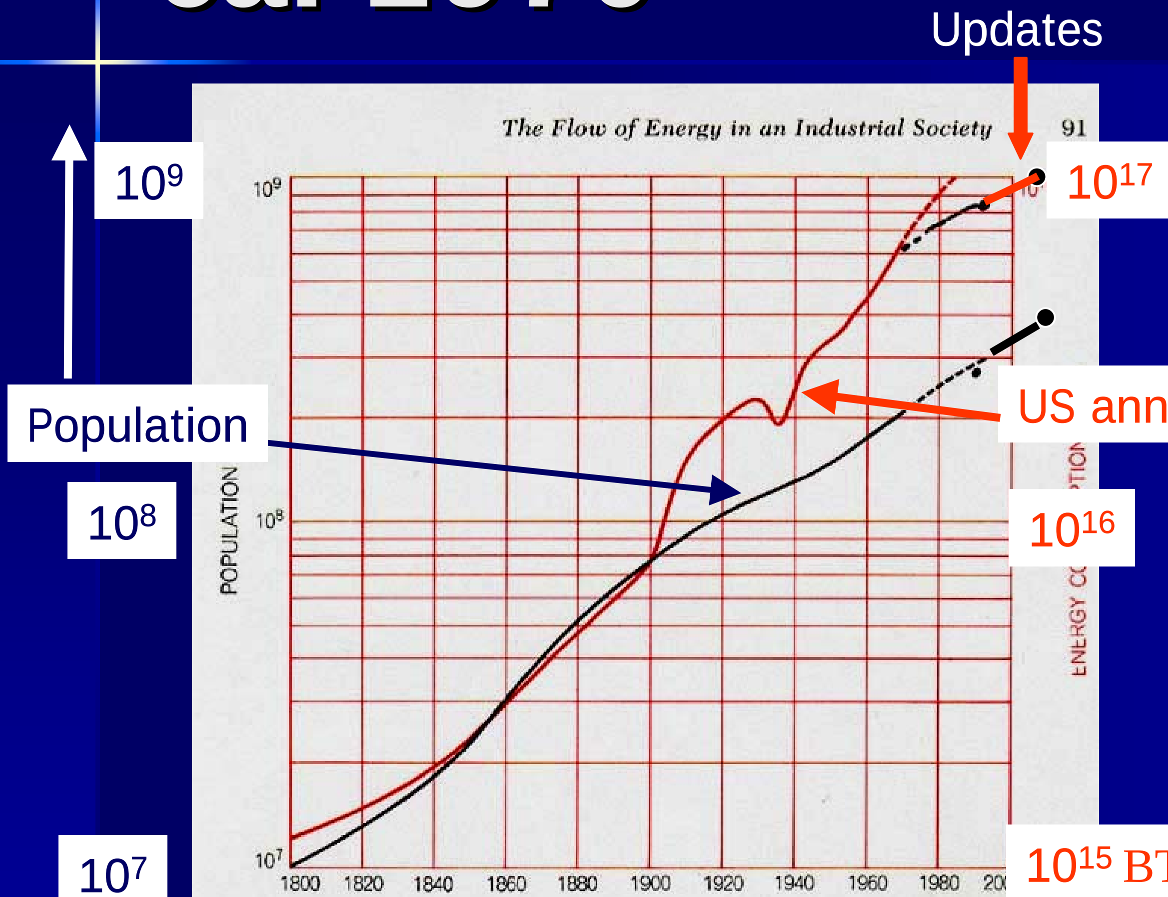
From Scientific American ca. 1970



U.S. ENERGY-CONSUMPTION GROWTH (*curve in color*) has outpaced the growth in population (*black*) since 1900, except during the energy cutback of the depression years.

2007: 101.5 quads = 107 EJ

3.39 TW_t (all energy)

US Population 2007 298 million

11.4 kW_t /capita

10^{15} BTU = 1 quad

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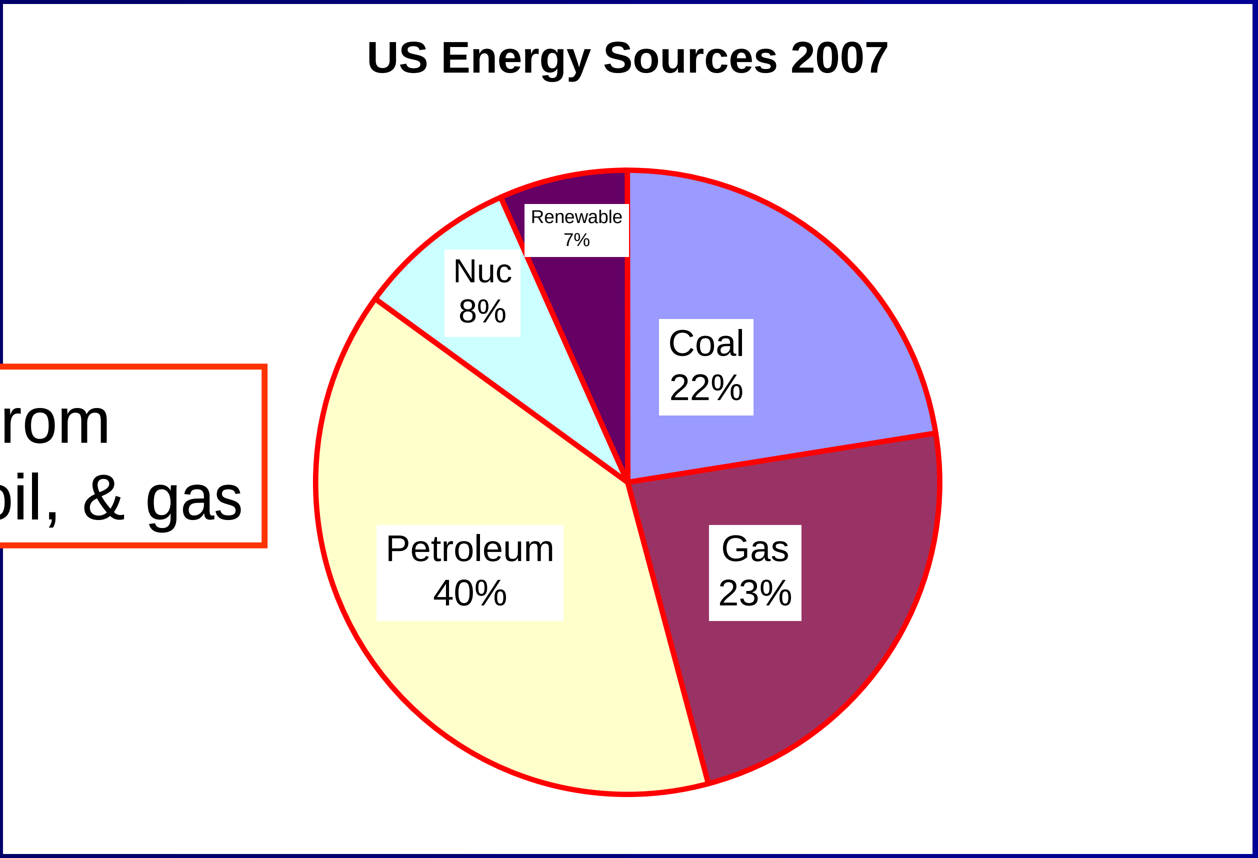
All US Energy 2007 = 107 $EJ_{thermal}$



85% from coal, oil, & gas

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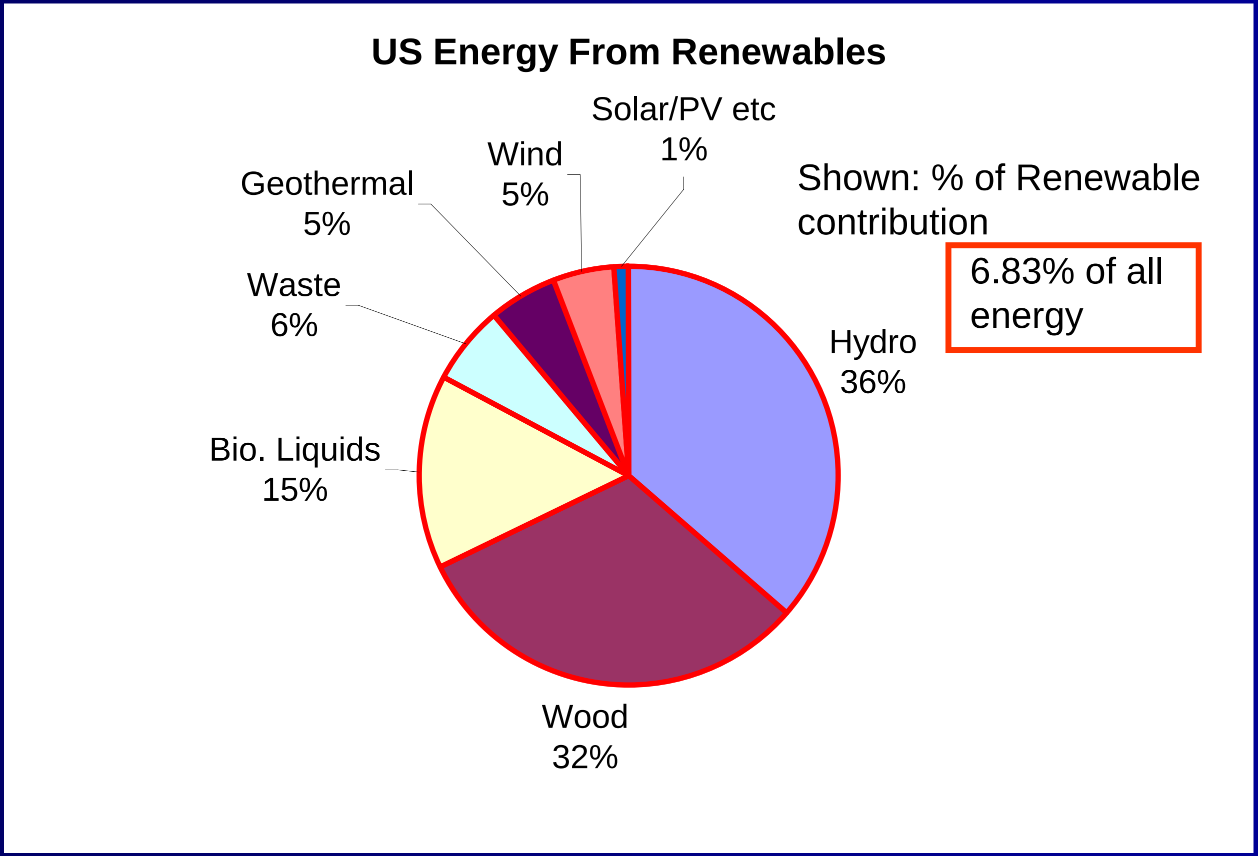
All 2007 Renewables = 7.2 EJ_t



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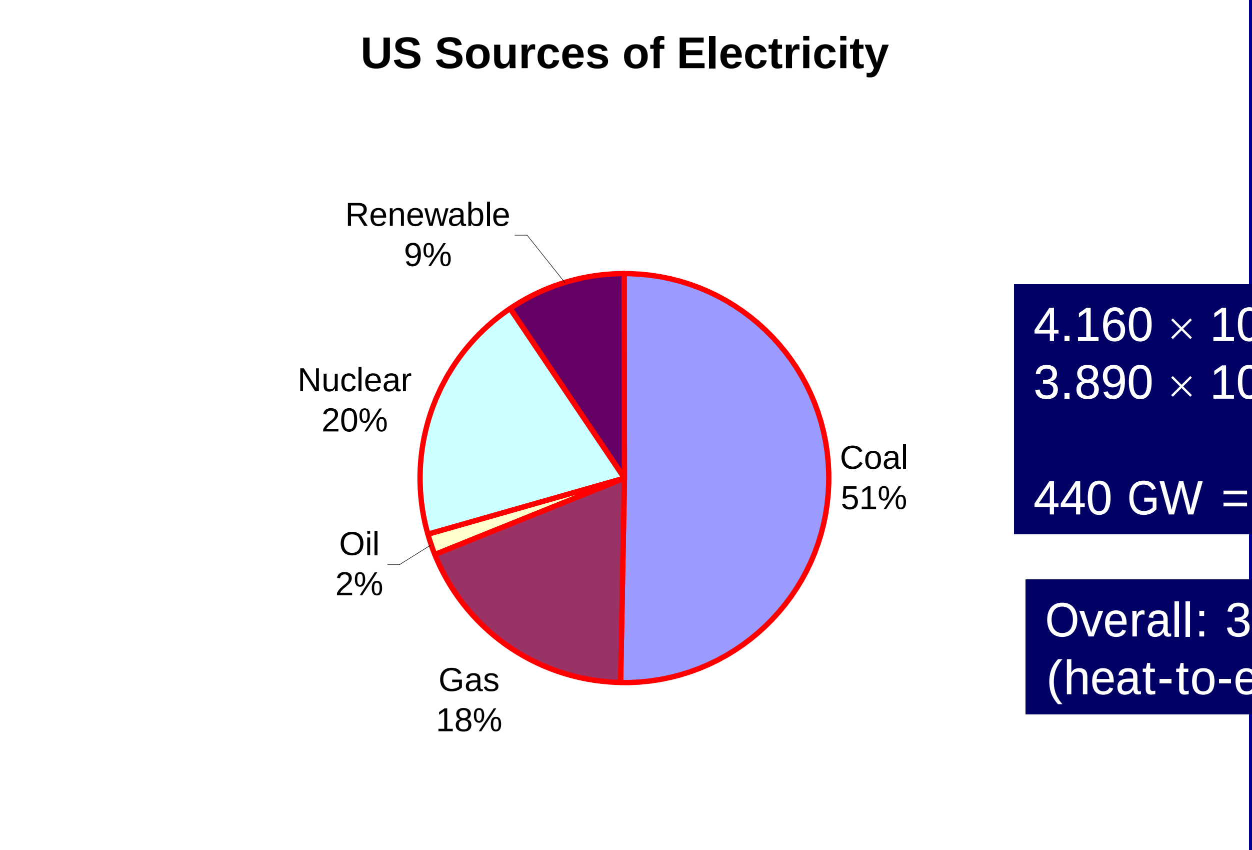
All 2007 US Electricity from 44.4 EJ_t



4.160×10^{15} Wh *produced*
3.890×10^{15} Wh end use

440 GW = $< P >_{\text{end use}}$

Overall: 31.3% efficient (heat-to-electricity)

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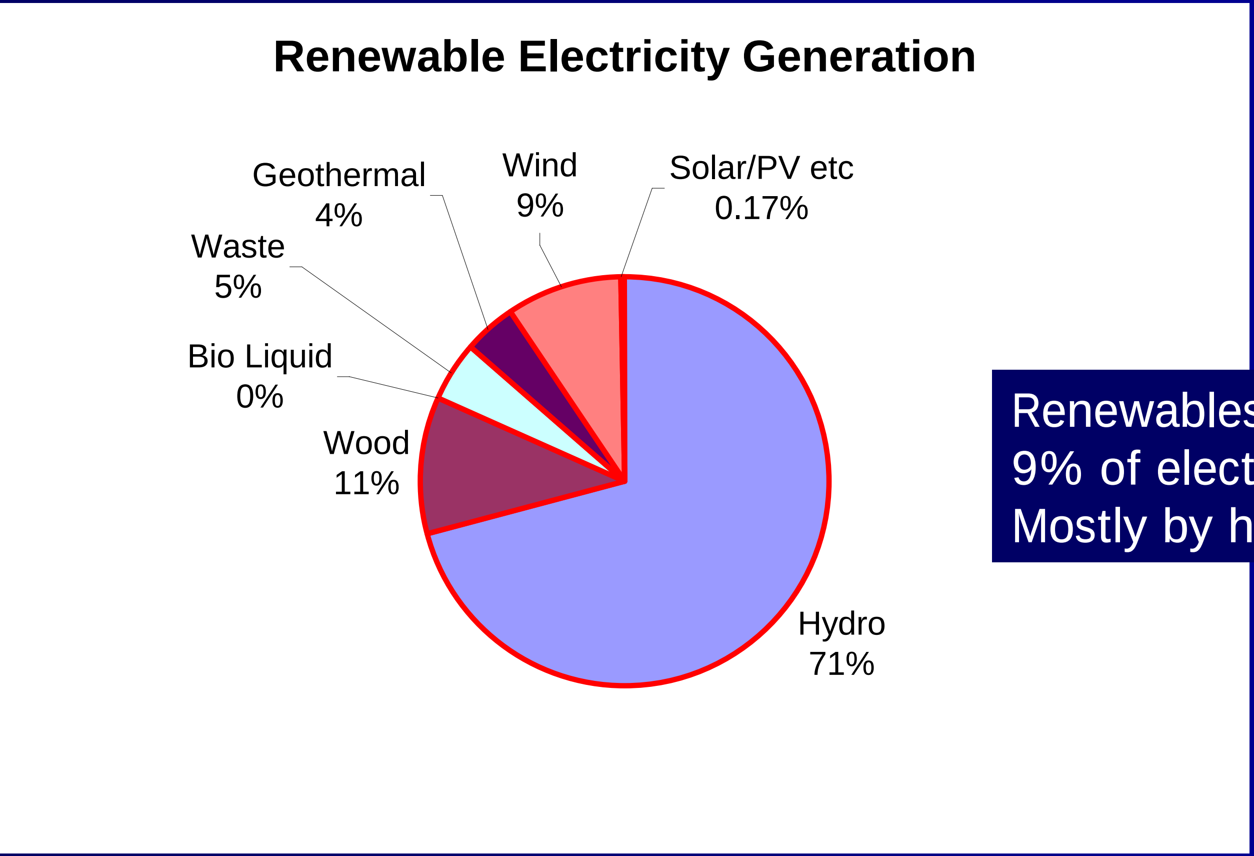
Electricity from Renewables = 0.35×10^{15} Wh



Renewables produce 9% of electricity
Mostly by hydro

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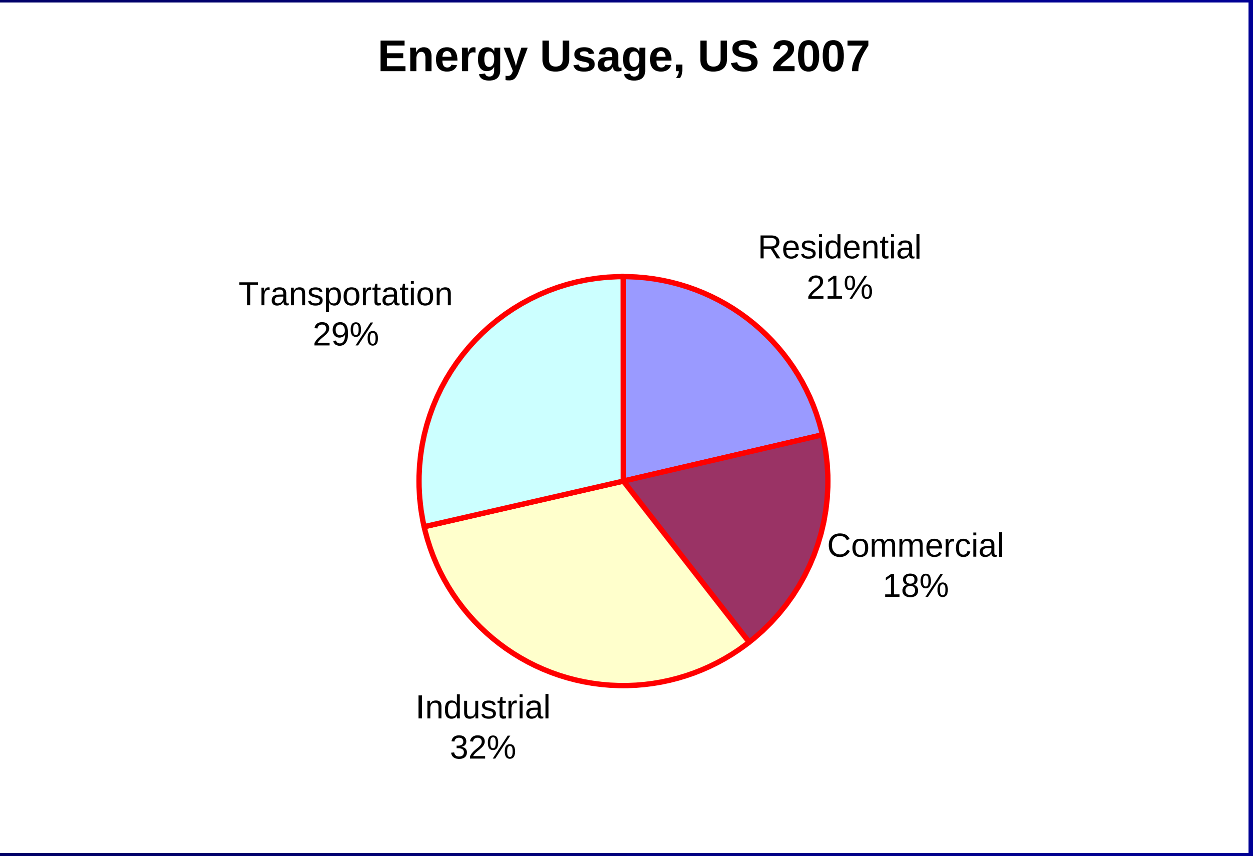
US Energy Usage



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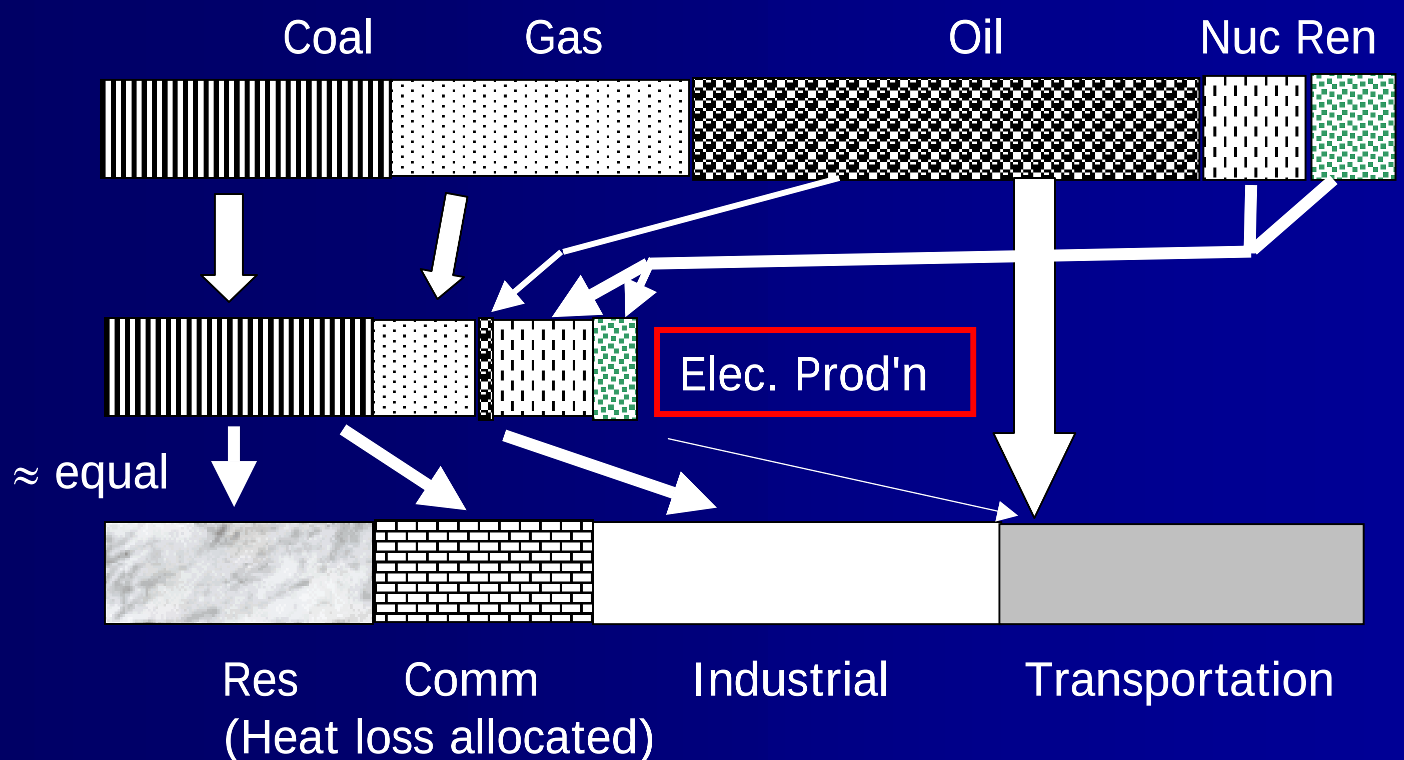
Sources, Dist., & Sinks



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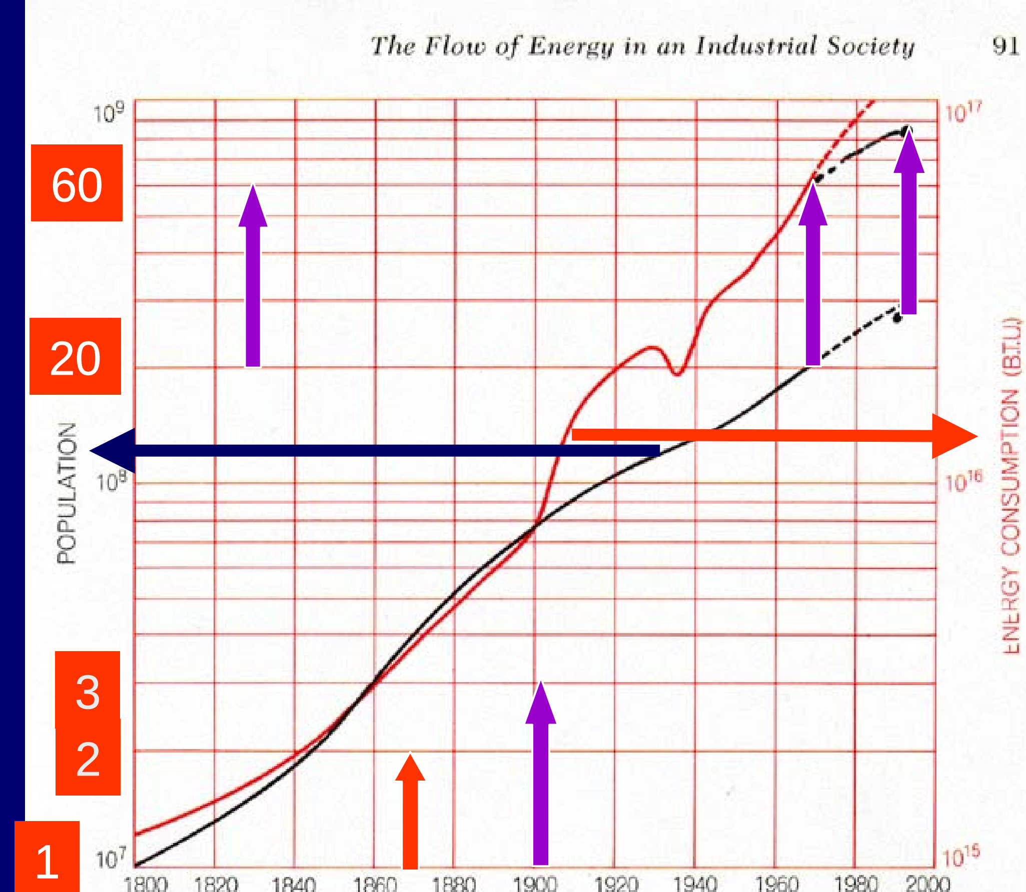
Scientific American (1968)

Factor of 2

Factor of 3



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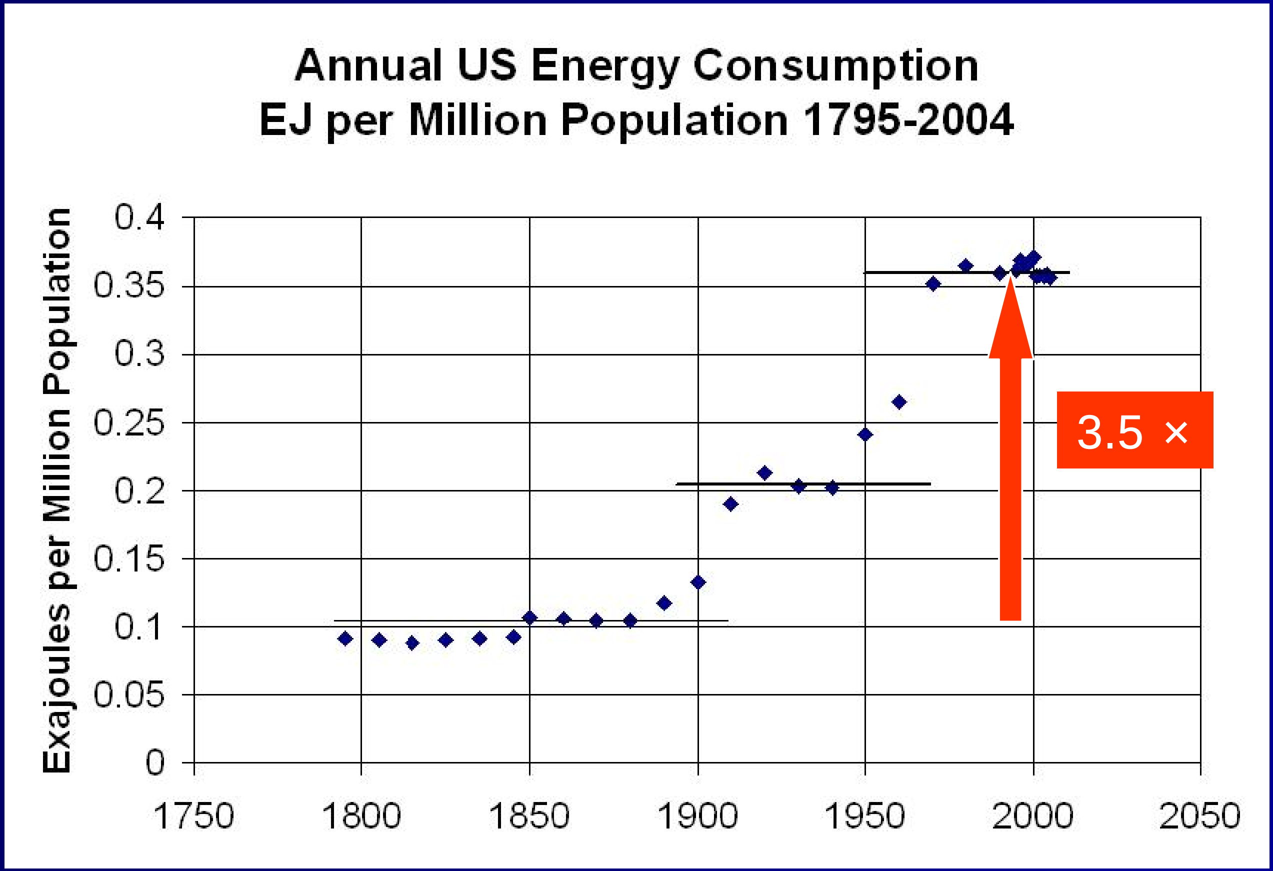
U.S. Per-capita energy consumption



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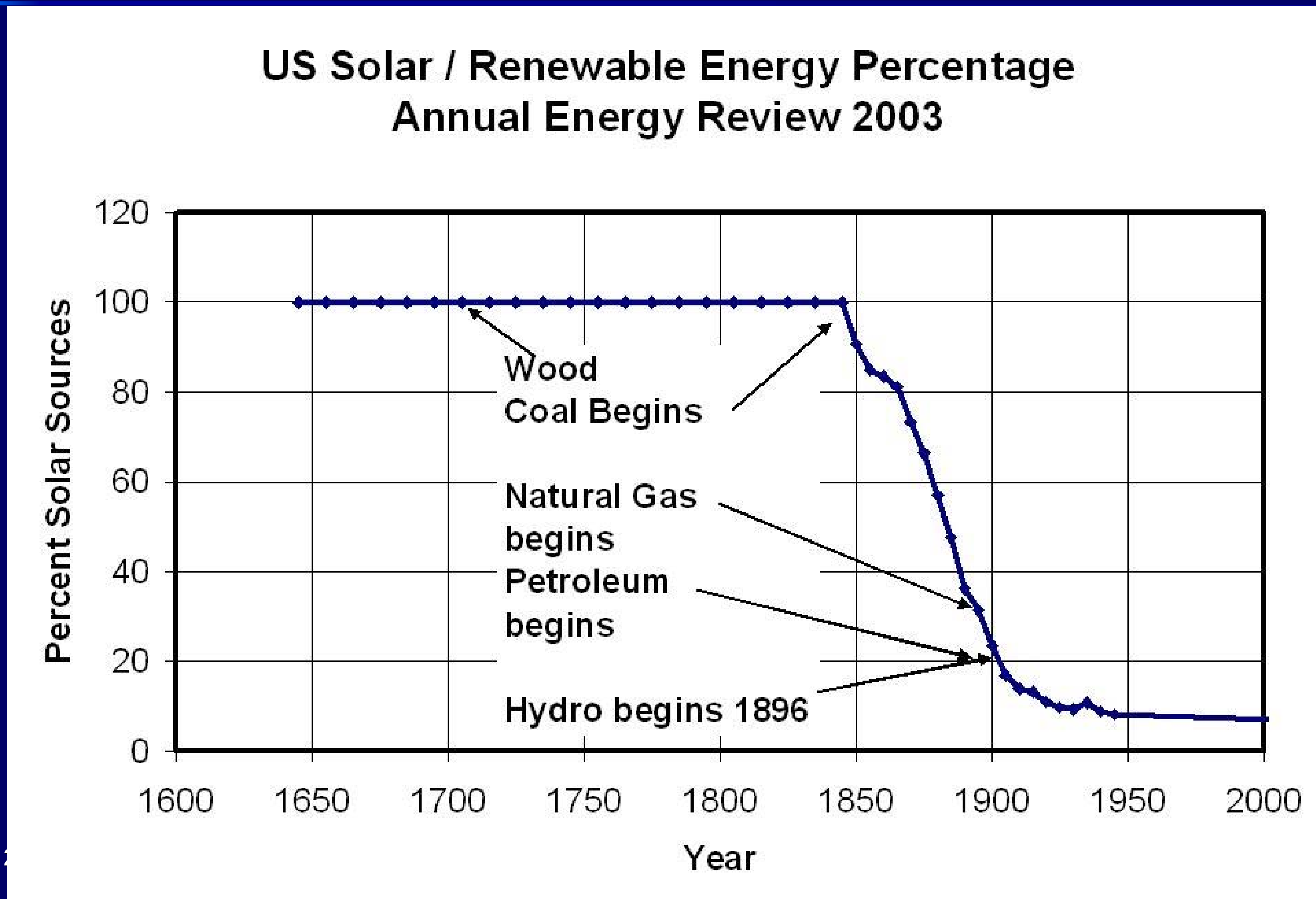
History of Renewables: The Decline from 100 %



Virtually all solar energy comes from two sources

Hydro

Biomass

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Solar Intensity

- Above atmosphere ➔ 1368 W/m^2
- Surface, noon clear sky, sun overhead ➔ 950 W/m^2
- Average 24/7/365 ➔ 200 $W/m^2 \pm$ 20% (covers most of US)
- Note: All solar systems should be expressed in W/m^2 (save, perhaps, hydro)

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Note on hydro & wind.

- EIA / DOE reckons heat in BTU
- EIA / DOE reckons electricity in millions (or billions) of kWh
- 1 kWh = 3413 BTU (direct conversion)
- But steam engines typically require about 10,000 BTU to get 1 kWh.
- For wind & hydro, EIA / DOE multiplies kWh by ≈ 3 for "replacement" purposes

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EIA example

- Hydro:
  - 2.46×10^{15} BTU
  - 248.3 billion kWh
    - ➔ 9,910 BTU / kWh instead of 3413 (direct)

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Solar Math:
Find the largest

- A. 11,700 calories per square centimeter during one month
- B. 254 BTU per square foot per minute
- C. 2 MWe generated per 130 acres of solar collector
- D. 1/2 cord of white oak per acre per year
- E. 397 Langleys per day

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Which is largest?

- A: 45 W/m^2
- B: 89 W/m^2
- C: 800 W/m^2
- D: 15 W/m^2
- E: 0.05 W/m^2

N.B. Use a consistent system of units.

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The Fair-haired boys

- Corn ➔ ethanol
  - ➢We'll ignore this abomination
- Wind (0.3% of U.S. energy)
- Solar-thermal (the largest)
  + Solar-thermal/electric
  + Photovoltaics
  $\cong$ 0.07% of U.S. energy
- Wind $\approx$ 50 $\times$ Solar / PV (electricity)

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Wind

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Power from Wind

- Proportional to R^2
- Proportional to v^3
- $v_{tip} \approx 6 \times v_{wind}$
- Separation of adjacent turbines typically 10 diameters

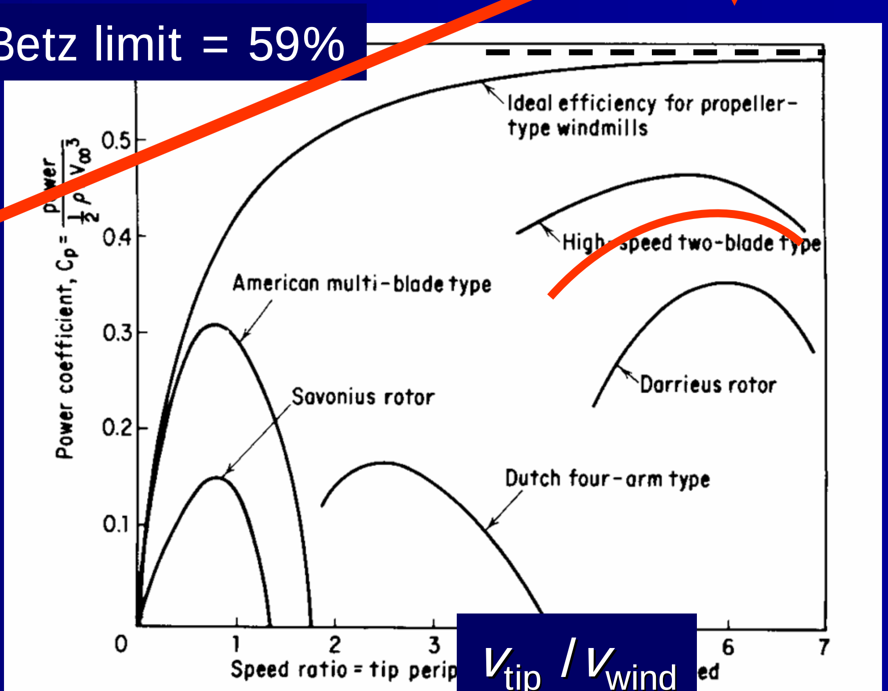

Fig. 5. Typical performance of wind power machines.

$$P\text{ (watts)} \cong 0.8*[R\text{ (meters)}]^2 \times [v\text{ (meters/sec)}]^3$$

at maximum possible efficiency

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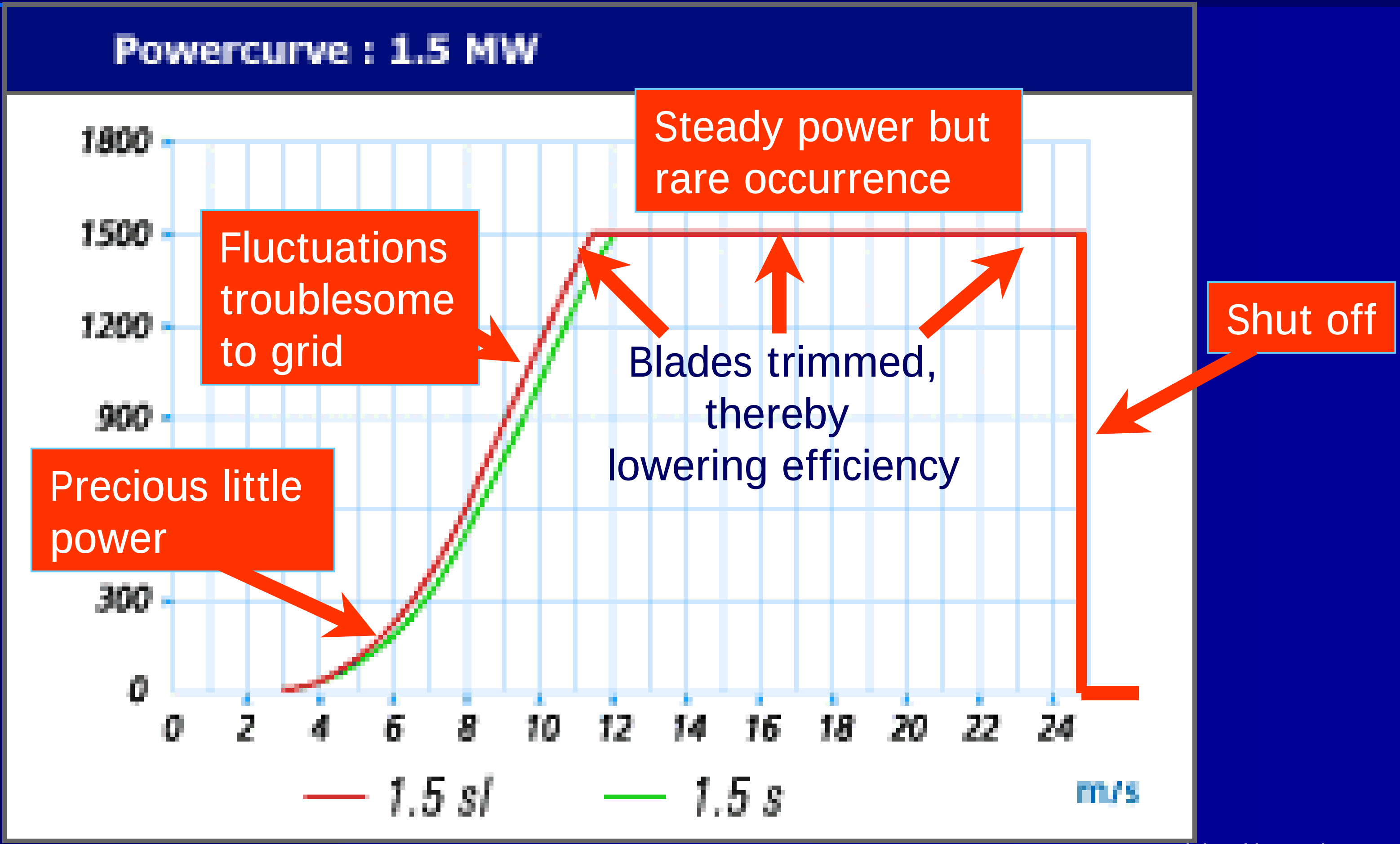
Power from Wind:
Output Power *versus* Wind speed



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Designing the Capacity Factor

- Huge generator on a pinwheel
  - 0% annual C.F.
- Huge blades driving 1-watt generator
  - Near 100% annual C.F.
- Choose an engineering compromise
  - Now designed for 35% annual C.F.
    - Most places don’t reach it.
- Wind electricity is not dispatchable

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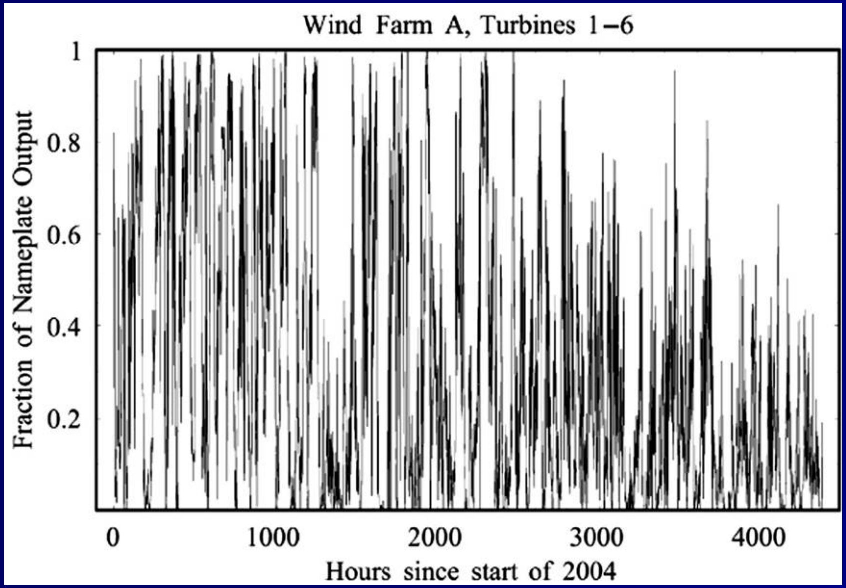
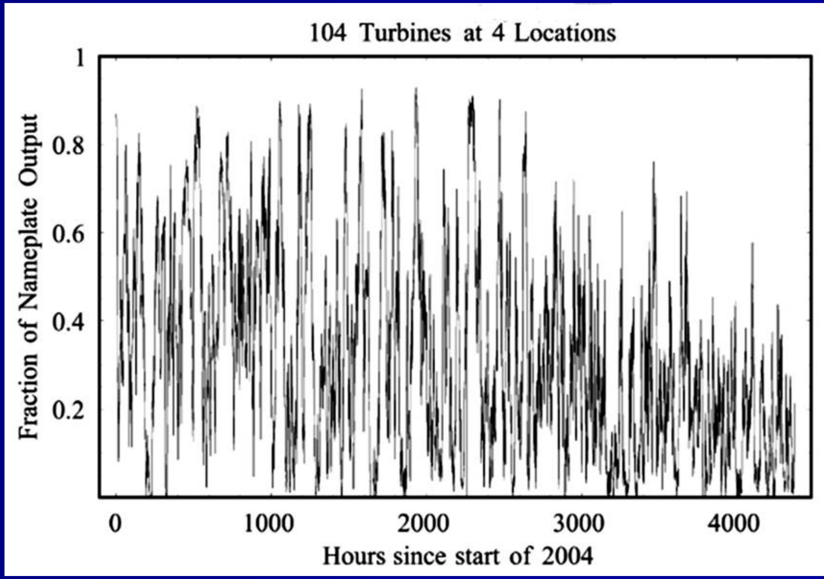
Wind Power (%), 1-hr intervals



6 turbines



104 turbines, 4 locations

Jay Apt, *J. Power Sources* **169** (2007), 369-374

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Power from Wind: Land requirements

- Power output *per unit land area* of wind farm is independent of R
  - $P \propto R^2$; $D_{separation} \propto R$; P/A_{land} = const
- Actual results of year-round average power production from wind farms
  - About 12.5 kW/ha (5 kW per acre)
    - 770 km^2 (300 mi^2) for 1000 MW
- Will environmentalists tolerate it?

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Solar Electricity

- Solar-thermal electricity
  - 2-angle tracking (Field of mirrors)
  - 1-angle tracking (Parabolic mirrors)
- Photovoltaics

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Solar-2
(Field of 2-axis mirrors)

- 10 MW *peak* on 53 hectares

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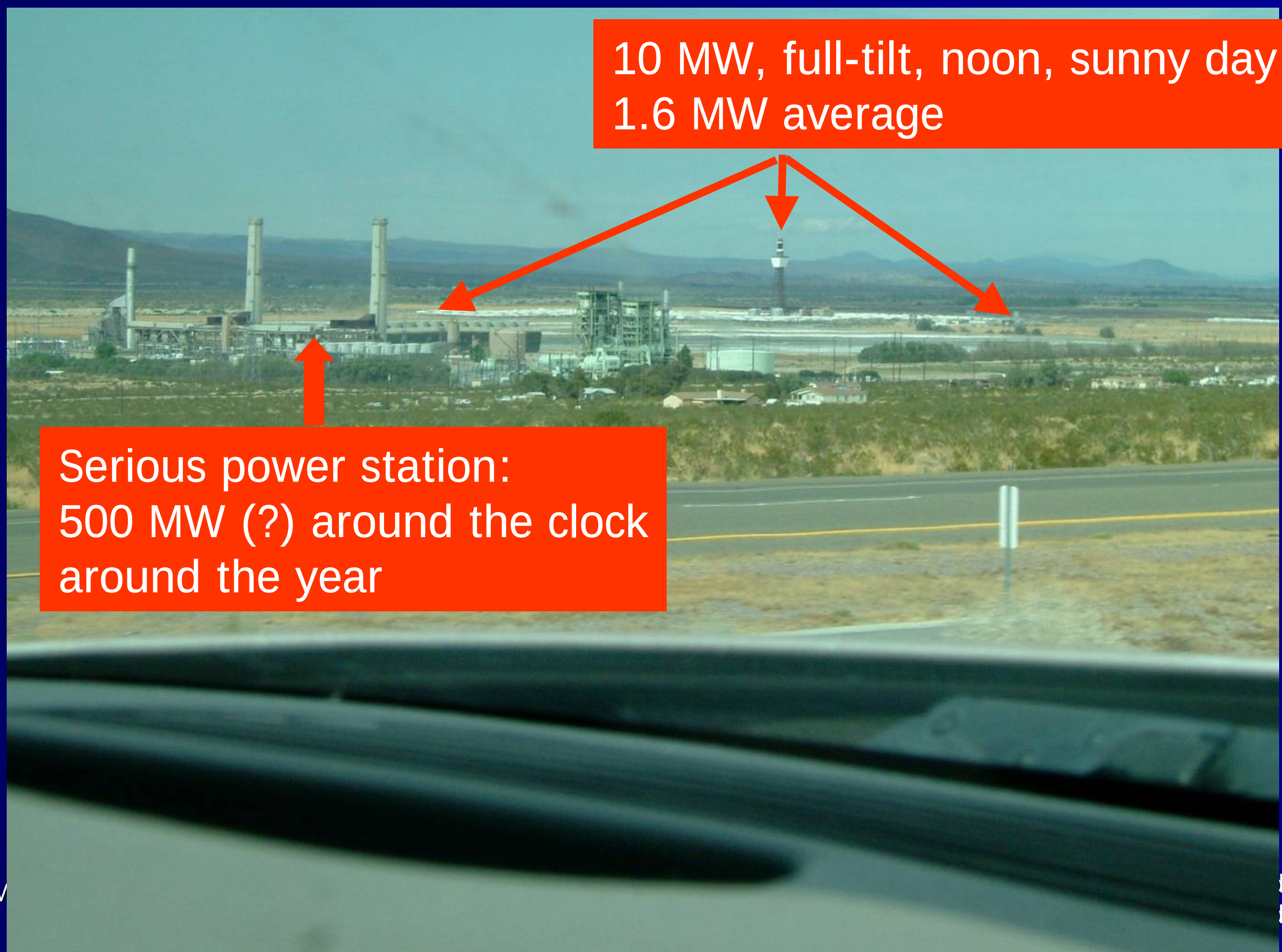
Solar-II (in Mojave Desert)



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Solar / thermal-electric One-axis parabolic mirrors

SEGS at Kramer Junction, CA, in the Mojave Desert

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Solar Energy Generating System (SEGS)

- 355 MW *peak* on ~ 725 hectares

Human

~ $10 W/m^2$ (100 kW/ha) on 24/7/365 basis

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Solar / thermal-electric

- This California system produces almost all solar electricity in the US --- 616 GWh 2006
- PV is so insignificant that the US Energy Information Agency (www.eia.doe.gov) doesn't bother keeping track of it separately from solar/thermal-electric.

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Photovoltaics

- Main Problem #1:
  - Asking a broad spectrum to do a quantum job
- Main Problem #2
  - Sunlight is dilute
- Main Problem #3
  - You can collect solar energy only where you put collectors

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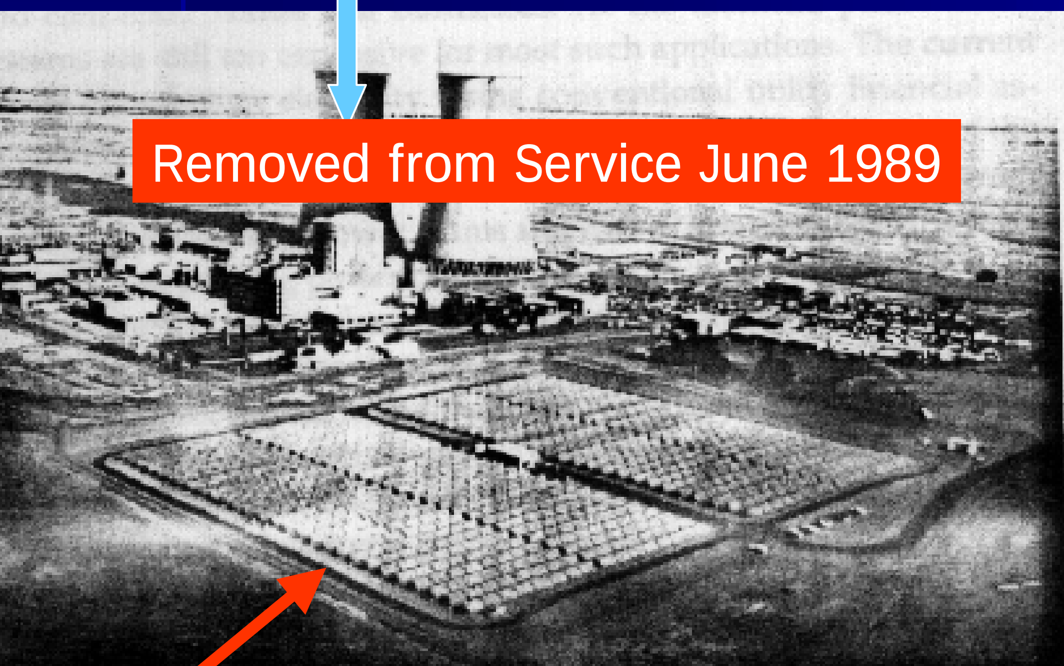
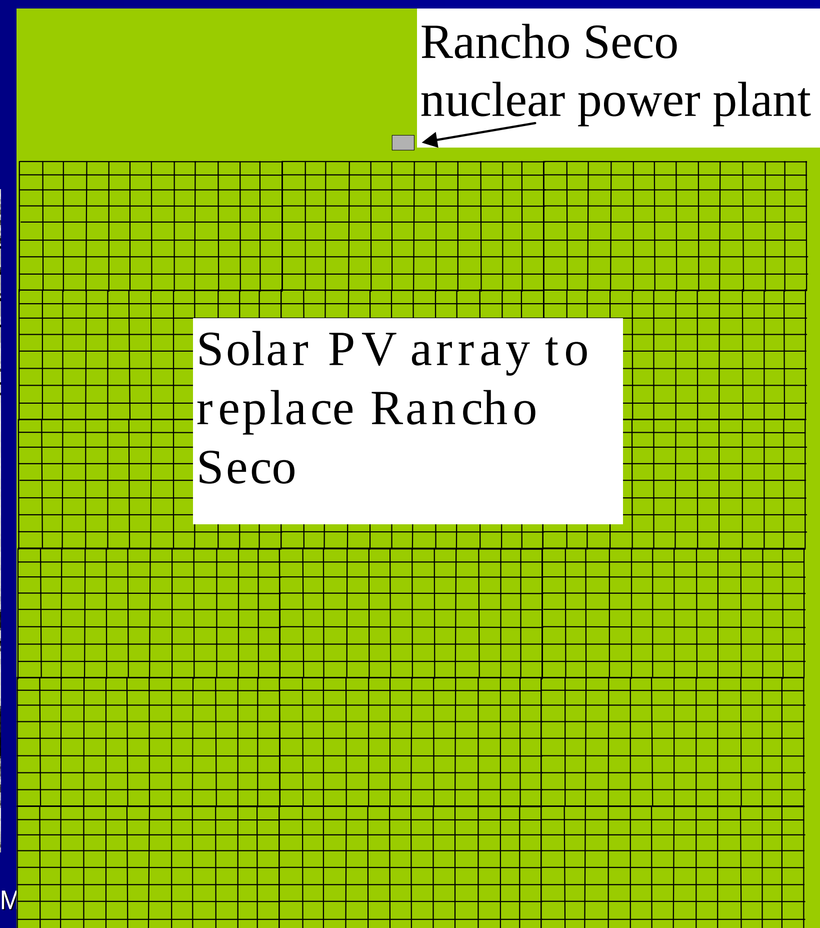
Solar PV Replaces Nuclear?

Rancho Seco 900 MW nuclear power station



2 MW *peak* PV farm



Biomass

- Open-field growth
  - Plant small seeds, get big plants
- Closed-environment growth
  - Must build structure
  - Better control
- Chlorophyll absorbs 6.6% of the solar spectrum.
- $< P_{\text{thermal}} / A >$ $\approx$ $\text{wind}_{\text{elec}}$, *at best* (with good water, fertilizer, weed control, insect control…)
- Always competes with food production
  - 'Nuff said

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Q&A

- It's your turn

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