Carbon in US Energy Production

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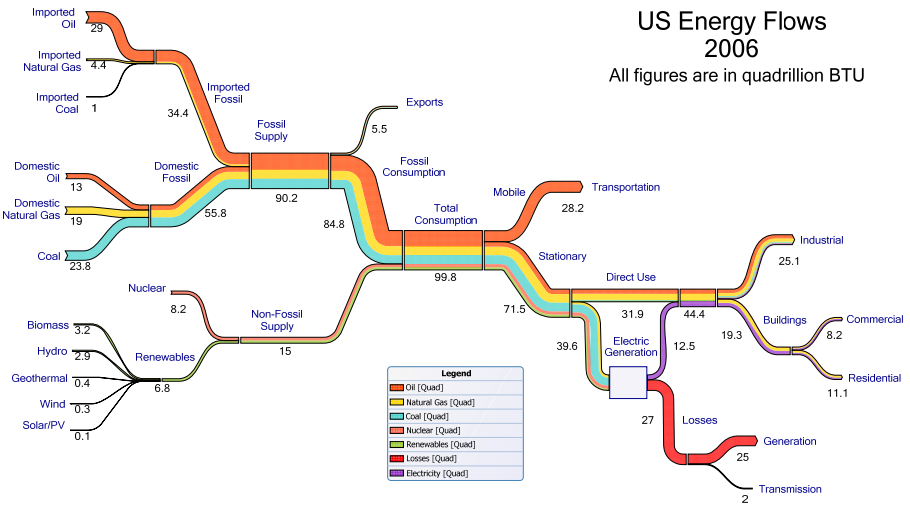
Fuel use and energy units

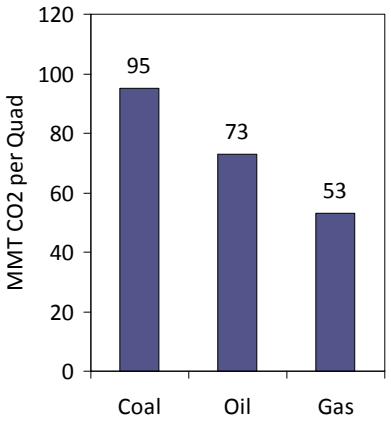
- National fuel use is measured in quads
  - *1 quad = 1 quadrillion BTU (10^15)*
- How large is a quad?
  - *Coal "unit trains": 100 cars, about 1 mile long*
  - *1 train fuels a 300 MW power plant for about 3 days*
  - *1 quad = 4,500 unit trains*



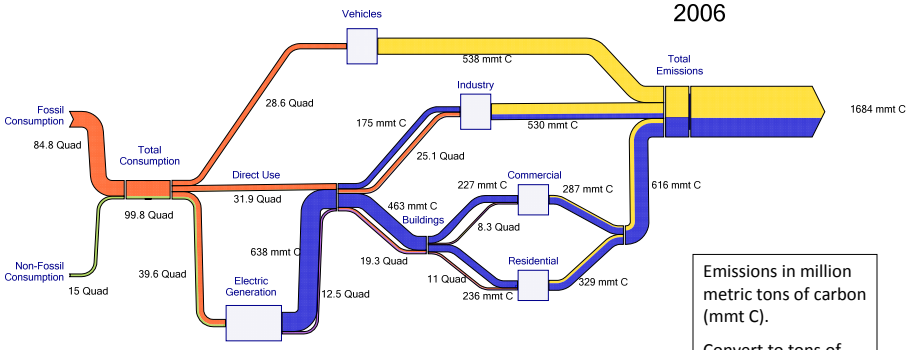
Data source: Annual Energy Review 2006, US Energy Information Administration

Translating energy into CO2

- Fuels differ in carbon intensity
  - *CO2 produced per quad*
- Relative to coal:
  - *Petroleum* ⇩ *23%*
  - *Natural gas* ⇩ *44%*



US Energy and Carbon Flows 2006



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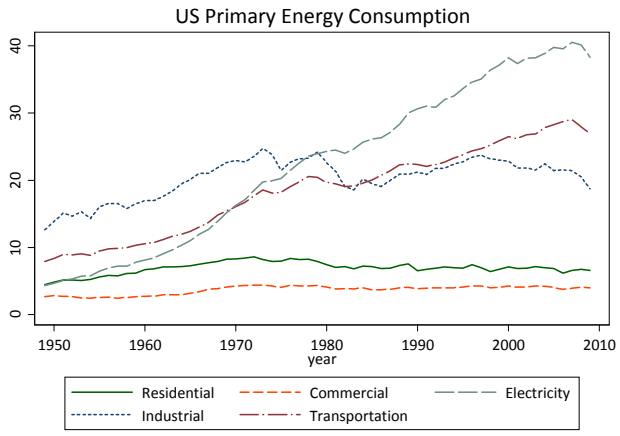
Emissions in million metric tons of carbon (mmt C).

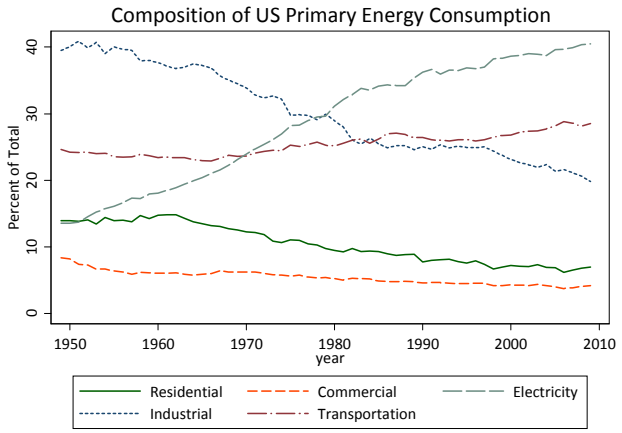
Convert to tons of CO2 by multiplying by 44/12.

Dark blue flows: emissions from power plants. Attributed to end uses in proportion to electricity consumption.

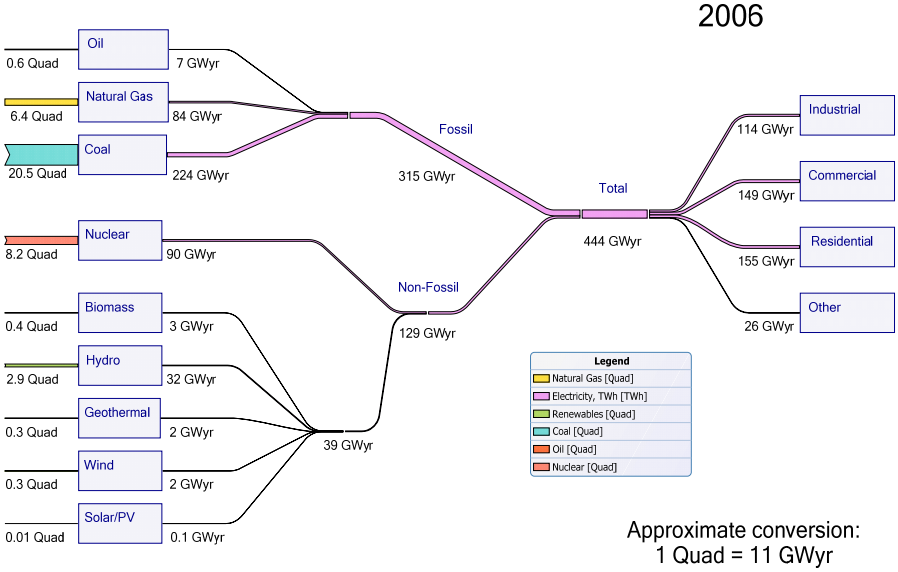
Electricity growth has been particularly strong ...



... especially as a share of the total



US Electricity Flows 2006

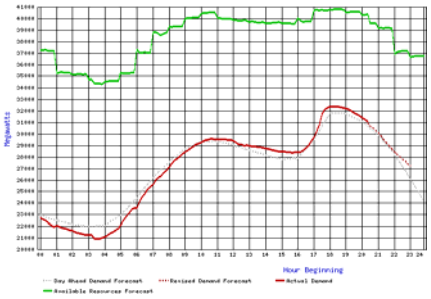


Approximate conversion:
1 Quad = 11 GWyr

Data source: Annual Energy Review 2006, Energy Information Administration

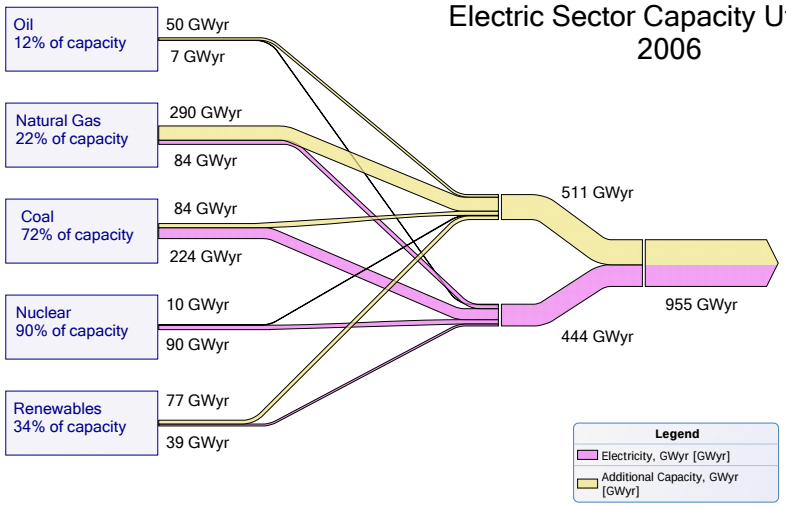
California load curve

- Independent System Operator (ISO)
  - *Operates part of the electrical grid*
- Data for January 21, 2008
- Demand (red curve):
  - *Min at 3:30 am, 21 GW*
  - *Max at 6:30 pm, 32.5 GW*
  - *Max is 55% higher*
- Capacity (green curve):
  - *34.5–41 GW*

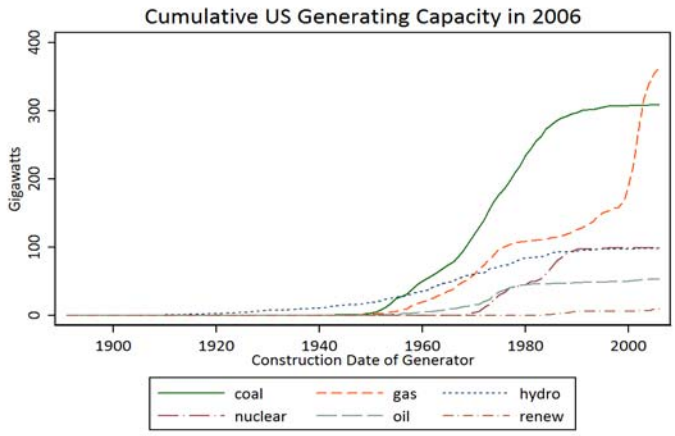


Types of plants

- Base load
  - *Run almost all the time*
  - *Expensive to build, slow start, cheap to run*
  - *Coal, nuclear*
- Peaking
  - *Run during peak periods*
  - *Cheap to build, quick start, expensive to run*
  - *Gas, oil, hydro*
- Intermittent
  - *Weather dependent: wind, solar*

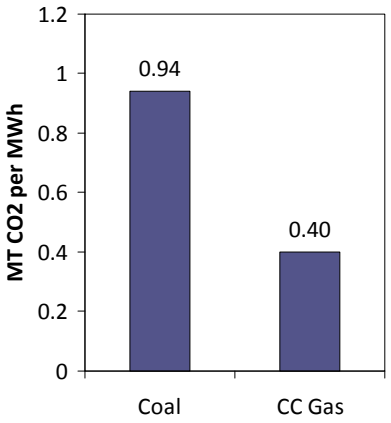


When were plants built?



Potential gains from fuel switching

- Carbon intensity of fuels
  - *Gas: 44% less CO2 per quad*
- Efficiency in generation
  - *Pulverized coal ≈ 34%*
  - *Combined cycle gas ≈ 46%*
- CO2 per MWh relative to coal:
  - *Natural gas ⇩ 57%*



Leading options for replacing fossil

- Integrated gasification combined cycle coal (IGCC)
  - *With carbon capture and sequestration (CCS)*
- Combined cycle gas
  - *With CCS*
- Nuclear
- Renewables

Replacing fossil completely?

- Need about 550 GW to eliminate fossil
  - *330 GW base load*
  - *220 GW peaking*
- Fossil with CCS
  - *410 GW of IGCC CCS coal (80% utilization) = $1.4 T*
  - *Add CCS to 220 GW of combined cycle gas = $220 B*
    - Total = $1.6T
- Intermittent renewables
  - *1300 GW of wind (25% utilization) = $2.5 T*
  - *Add CCS to 220 GW of combined cycle gas = $220 B*
    - Total = $2.7 T

Transmission grid

- Can we get power where it's needed?
- Especially important for wind and solar
  - *Best locations are far from cities*
  - *Need geographic dispersion*

More grid capacity needed for wind

Variation in wholesale electricity prices due to grid congestion

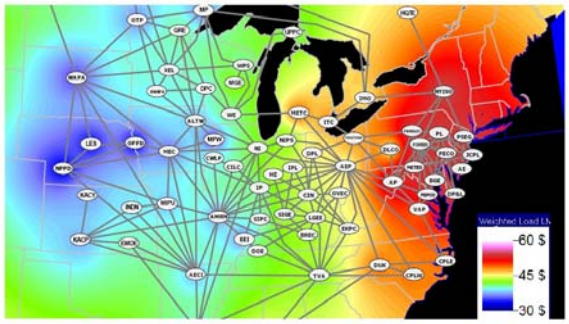


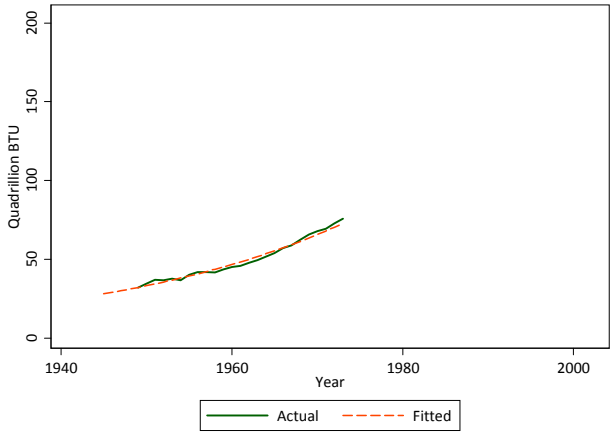
Figure 2.2-3 Contour Map of Annual Load Weighted LMP

From "2006 Midwest ISO-PJW Coordinated System Plan (CSP)," December 2006.

Historical perspective?

- Does fuel use rise inexorably no matter what?
- What do we know from history about fuel use?

Exponential growth after the war (3.4%)



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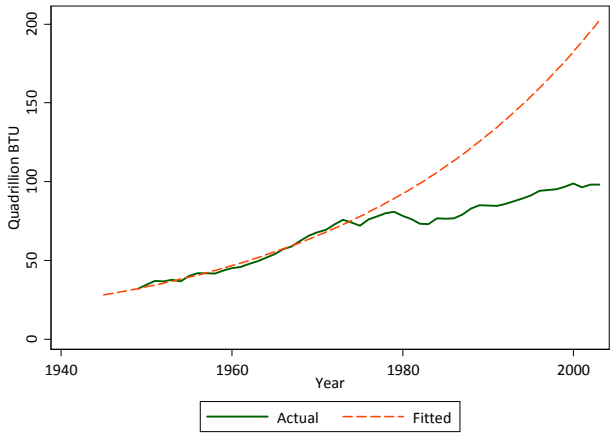
Sharp change after the energy shocks!



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Energy prices matter!

- Stabilized US energy consumption
  - *Flat for about 20 years*
- GDP growth was a little slower
  - *About 0.2% per year: from 3.2% to 3.0%*

A very large problem ...

- Currently:
  - *86 quads of fossil fuels*
  - *6 gigatons of CO2 emissions*
- To limit temperature increase to 2° C:
  - *Need to bring CO2 down by more than 80%*
- Rough targets by 2050:
  - *16 fossil quads* ⇩*70 quads*
  - *1 gigaton CO2* ⇩ *5 gigatons*
- Will be very difficult without a rise in fossil prices