Understanding the Scale of the Problem: US Energy Sources and CO2 Emissions

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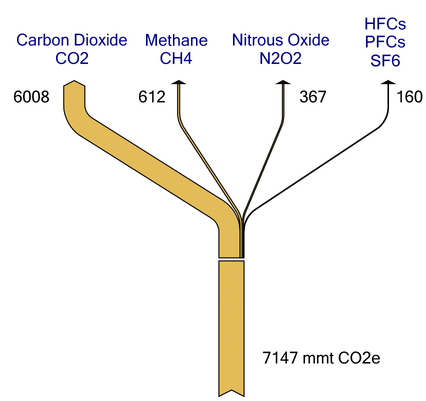
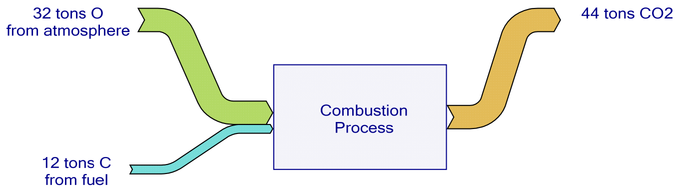
US greenhouse gas emissions in 2005

Gas	mmt	mmt CO2e
Carbon Dioxide	6008	6008
Methane	27	612
Nitrous Oxide	1.2	367
Halocarbons	--	160



mmt = 1 million metric tons = 10^9 kg; CO2e = CO2 equivalent

Where does the CO2 originate?



- Equivalent measures: 12 tons of carbon ⇔ 44 tons of CO_2

Controlling CO2 emissions

- Natural result of combustion
  - *Not an impurity like sulfur*
  - *Not from poor combustion (ozone, NOx, particulates)*
- Reductions require either or both of the following
  - *Reduction in fuel use*
  - *Capture and sequestration of CO2*

Fuel use and energy units

- National fuel use is measured in quads
  - *1 quad = 1 quadrillion British Thermal Units (BTU)*
  - *quadrillion = 10^15*
  - *1 quad = 10^15 BTU = about 1 exajoule (10^18 J)*

Putting a quad in perspective ...

- Coal delivered by “unit trains”
  - *100 cars, about 1 mile long*
- 1 train = 10,000 tons of coal
  - *Fuels a 500 MW power plant for about 2.5 days*
- 1 quad = 4,500 unit trains
- Powder River Basin in WY:
  - *60 trains a day*

Photo: University of Wyoming

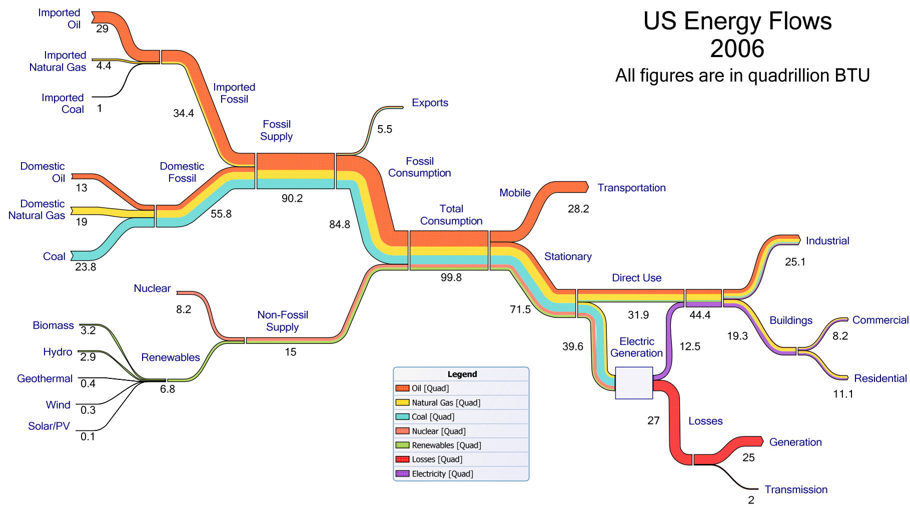
How many supertankers?

- 1 tanker = 1 million barrels of oil

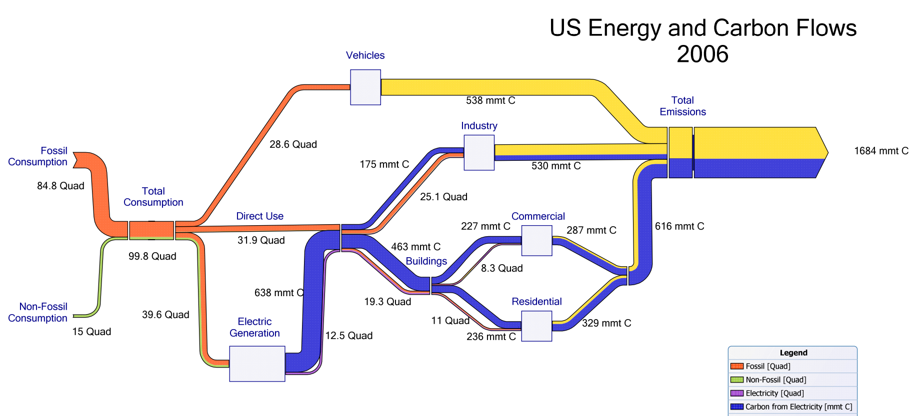
- 1 quad = 170 tankers
- US used 21 million barrels *per day* (57% imported) in 2005

How much energy is used?

- World energy consumption
  - *400 quads per year*
  - *1 quad every 22 hours*
- US consumption
  - *100 quads per year*
  - *25% of the world total*



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



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A very large problem ...

- US fossil energy
  - *86 quads*
- US emissions
  - *6 billion tons of CO_2 or 1.7 billion tons of C*
- Limiting temperature increase to 2° C
  - *Need to bring CO_2 down by more than 80%*
  - *Obama Administration's goal: 83% reduction by 2050*

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Four options for abatement

- Fuel switching
  - *Shift to fuels with lower CO_2 for given energy*
    - Example: coal to gas for electricity
- Improve efficiency
  - *Use fuels more efficiently to produce lighting, heating, etc.*
    - Example: better lights
- Reduce energy services
  - *Use less lighting, heating, etc.*
    - Example: turn lights off
- Capture and sequester CO_2
  - *Store in old oil reservoirs or saline aquifers*

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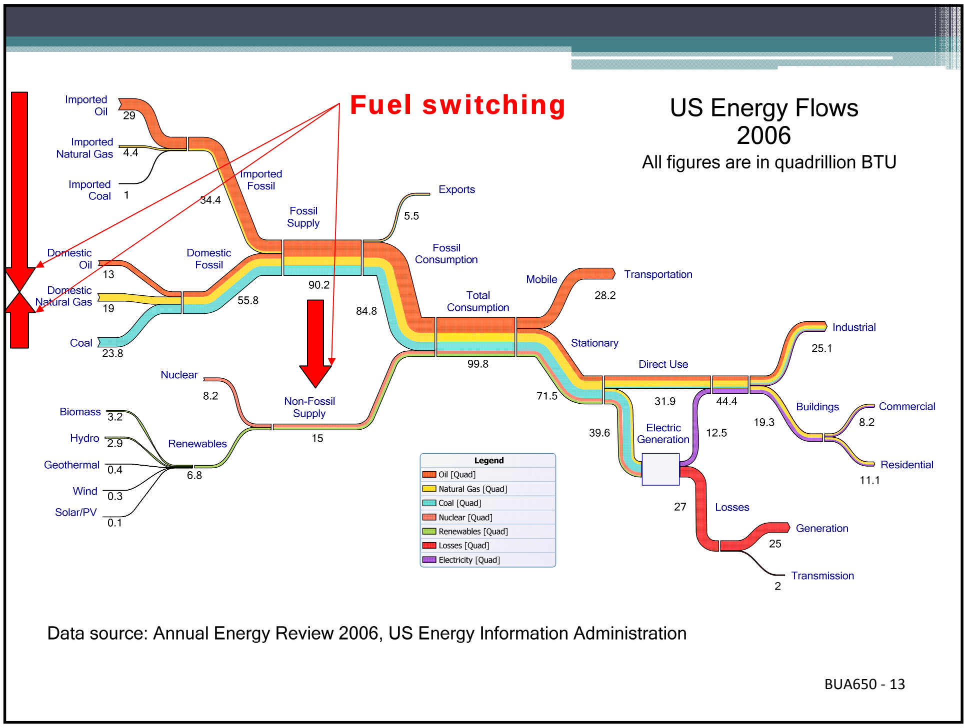
Fuel switching
US Energy Flows
2006
All figures are in quadrillion BTU
Imported Oil
29
Imported Natural Gas
4.4
Imported Coal
1
Imported Fossil
34.4
Fossil Supply
90.2
Exports
5.5
Domestic Oil
13
Domestic Natural Gas
19
Coal
23.8
Domestic Fossil
55.8
Fossil Consumption
84.8
Total Consumption
99.8
Mobile
Transportation
28.2
Stationary
71.5
Direct Use
31.9
44.4
Industrial
25.1
Buildings
19.3
Commercial
8.2
Residential
11.1
Electric Generation
39.6
12.5
27
Losses
Generation
25
Transmission
2
Nuclear
8.2
Non-Fossil Supply
15
Biomass
3.2
Hydro
2.9
Geothermal
0.4
Wind
0.3
Solar/PV
0.1
Renewables
6.8
Legend
Oil [Quad]
Natural Gas [Quad]
Coal [Quad]
Nuclear [Quad]
Renewables [Quad]
Losses [Quad]
Electricity [Quad]
Data source: Annual Energy Review 2006, US Energy Information Administration
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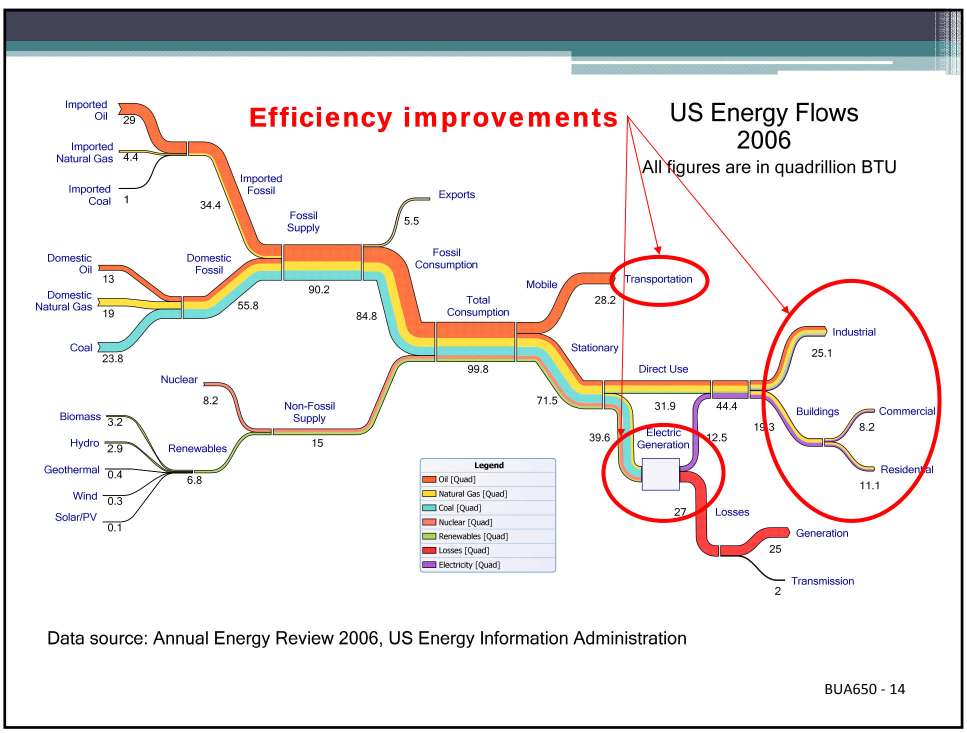
Efficiency improvements
US Energy Flows
2006
All figures are in quadrillion BTU
Imported Oil
29
Imported Natural Gas
4.4
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Electricity [Quad]
Data source: Annual Energy Review 2006, US Energy Information Administration
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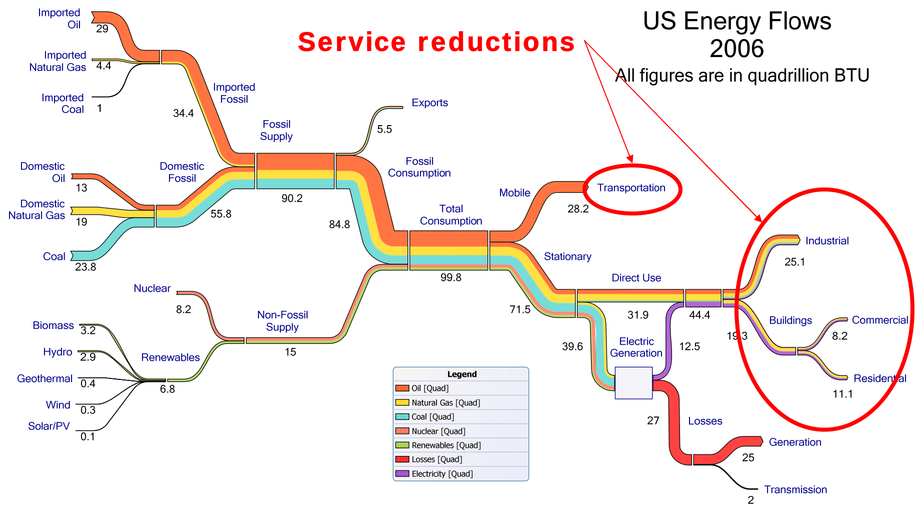
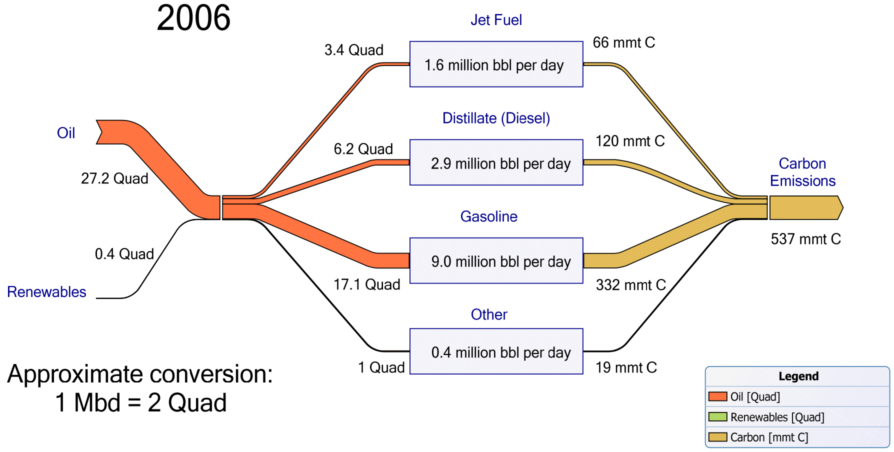


Data source: Annual Energy Review 2006, US Energy Information Administration

US Transportation Sector 2006



Approximate conversion:
1 Mbd = 2 Quad

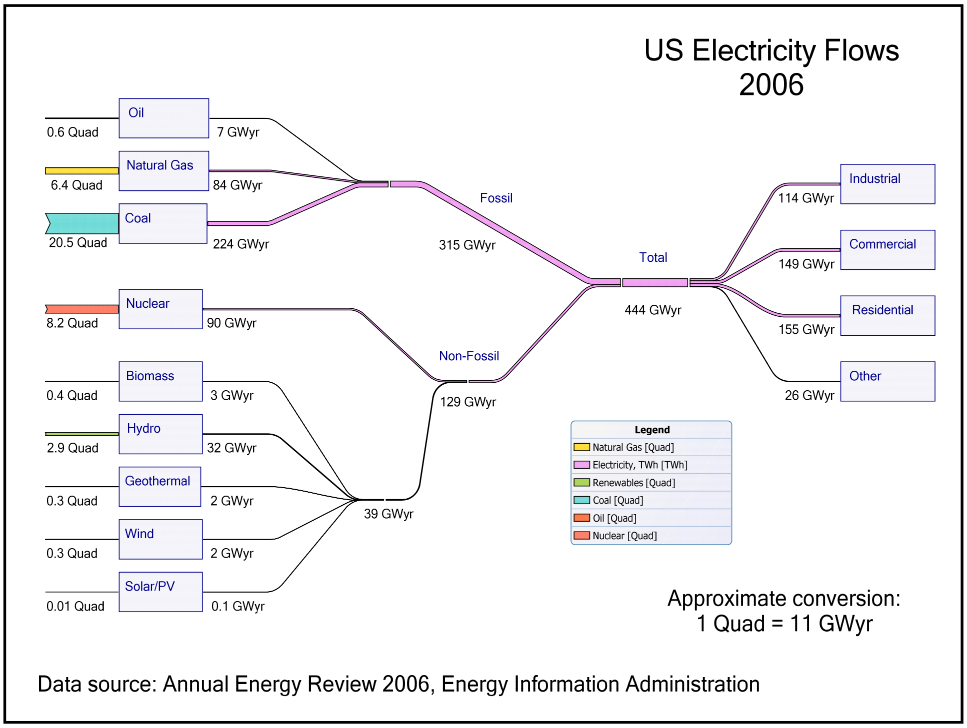
Data source: Annual Energy Review 2006, US Energy Information Administration

Abating vehicle emissions

- Shift fuel mix -- less CO2 per unit of energy, less imported oil
  - *Toward natural gas*
  - *Toward biofuels (really feasible?)*
  - *Toward electricity with sequestration*
- Improve fuel efficiency -- less energy per mile
  - *Hybrids*
  - *Advanced diesel*
  - *Public transportation*
- Reduce driving -- fewer miles
  - *Live closer to work*
  - *Change habits*

Electric sector has multiple roles

- Adapting to climate change
  - *Higher summer temperatures*
  - *Potentially greater peak demand for electricity*
- Implementing climate policies
  - *Generation and delivery of renewable power*
  - *Replace on-site fuel use in order to sequester carbon*
  - *Support plug-in hybrids*
- Implications
  - *Even greater role for the grid*



Key problem for power producers...

- Need to follow variations in demand
  - *Electricity essentially non-storable at the grid level*
- Power demand varies strongly over the day
  - *Higher during the day than at night*
- Also varies strongly over the year
  - *Higher in the summer due to air conditioning*

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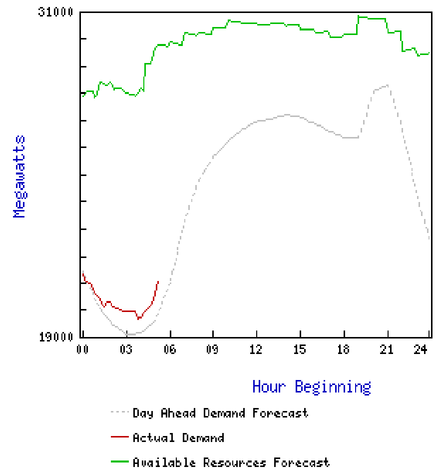
California load curve

- Independent System Operator
  - *CAISO*
  - *Operates part of the electrical grid*
- Data for March 22, 2010
- Demand (red curve):
  - *Min at 3:30 am, 19 GW*
  - *Max at 9:00 pm, 28 GW*
  - *Max is 47% higher*
- Capacity (green curve):
  - *28–31 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*

Typical base load coal plant

- AES Somerset on Lake Ontario
- 655 MW capacity
- 91% utilization in 2005
- 5.2 million MWh
- 4.5 mmt CO_2

Photo: NYS DEC

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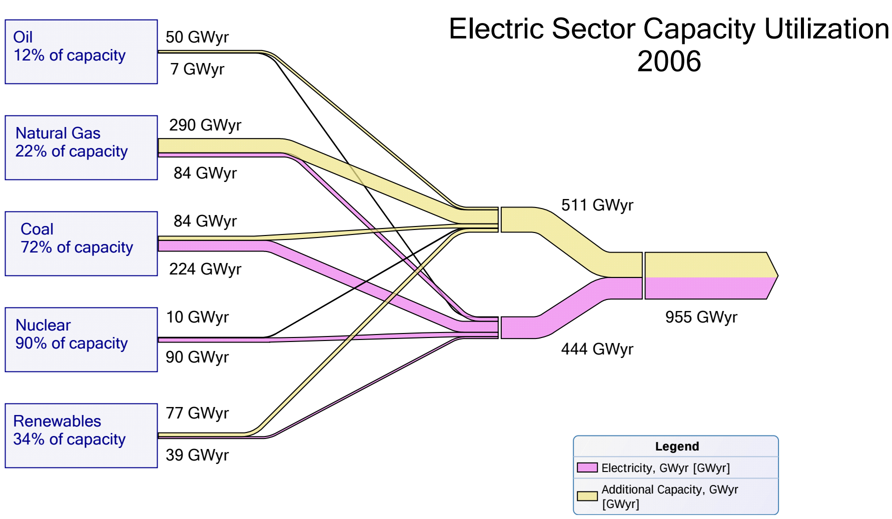

Summary of generation mix

Fuel	Capacity (GW)	Generation (GWyr)	Fossil Fuel Use (Quads)	Carbon (Mmt C)
Oil	57	7	0.6	13
Gas	374	84	6.4	93
Coal	310	224	20.5	532
Fossil total	741	315	27.5	638
Nuclear	100	90	--	--
Renewables	116	39	--	--
Total	958	444	27.5	638

Leading options for replacing fossil

- Integrated gasification combined cycle coal (IGCC)
  - *With carbon capture and sequestration (CCS)*
- Combined cycle gas (CC)
  - *With CCS*
- Nuclear
- Renewables
  - *Biomass*
  - *Hydro*
  - *Wind*
  - *Solar thermal, photovoltaic*

Advanced coal power plants

Integrated gasification combined cycle (IGCC)

IGCC plant at Puertollano, Spain

http://www.powergeneration.siemens.com/press/press-pictures/igcc/igcc-puertollano1.htm

Cost of building new power plants

Technology	Capital cost per GW of capacity
Coal	$2.1 B
IGCC	$2.4 B
IGCC with CCS	$3.5 B
Nat Gas CC	$0.9 B
CC with CCS	$1.9 B

Technology	Capital cost per GW of capacity
Adv Nuclear	$3.3 B
Biomass	$3.8 B
Hydro	$2.2 B
Onshore Wind	$1.9 B
Solar Thermal	$5.0 B
Solar/PV	$6.0 B

Replacing fossil completely?

- Need about 550 GW total
  - *Peaking: 220 GW*
  - *Baseload: 330 GW*
- All cases at right assume gas is used for peaking

- Fossil with carbon capture
  - *410 GW of advanced coal*
  - *80% utilization*
  - *Total = $1.8T*
- Nuclear
  - *367 GW advanced nuclear*
  - *90% utilization*
  - *Total = $1.2 T*
- Intermittent renewables
  - *1300 GW of wind*
  - *25% utilization*
  - *Total = $2.9 T*

Very important implication

- Would be less expensive if demand were lower
- Need to reduce fuel use on the demand side

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*

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More grid capacity needed for wind

Variation in wholesale electricity prices due to grid congestion

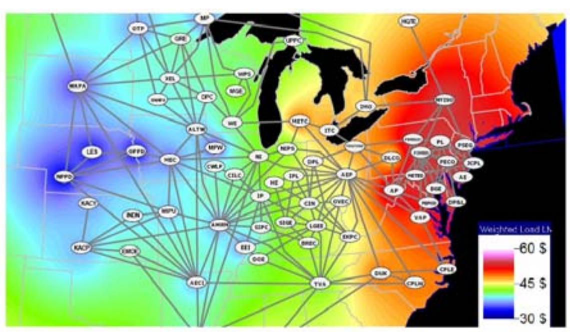

Figure 2.2-3 Contour Map of Annual Load Weighted LMP

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

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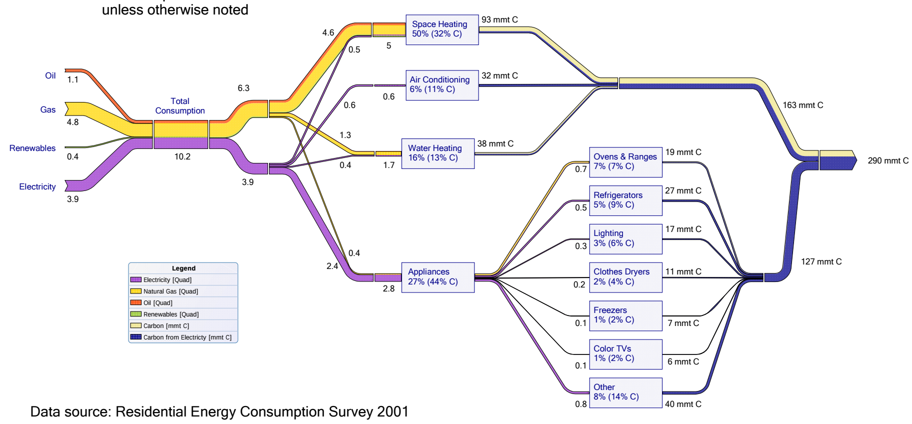
Reducing demand?

- Very quick overview of energy use
- Residential and commercial
  - *Heating*
  - *Air conditioning*
  - *Water heating*
  - *Appliances*
- Industry
  - *More difficult due to accounting for feedstocks*
  - *Mostly in the production process*
  - *Most of that is heating*

US Residential Energy Consumption
2001

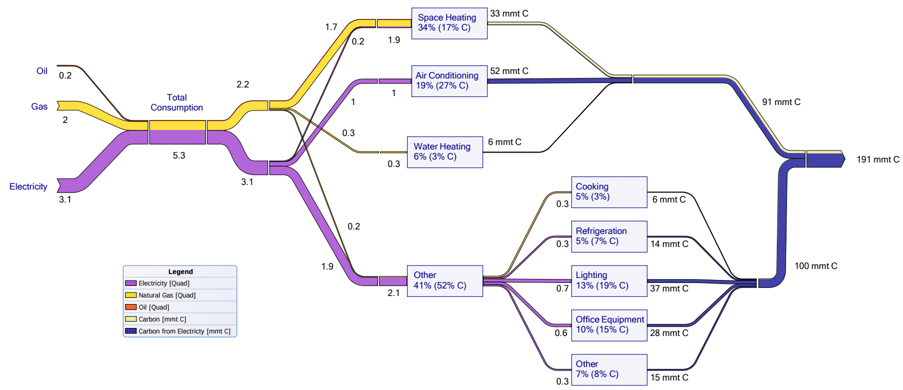
Values in quadrillion BTU
unless otherwise noted



Data source: Residential Energy Consumption Survey 2001

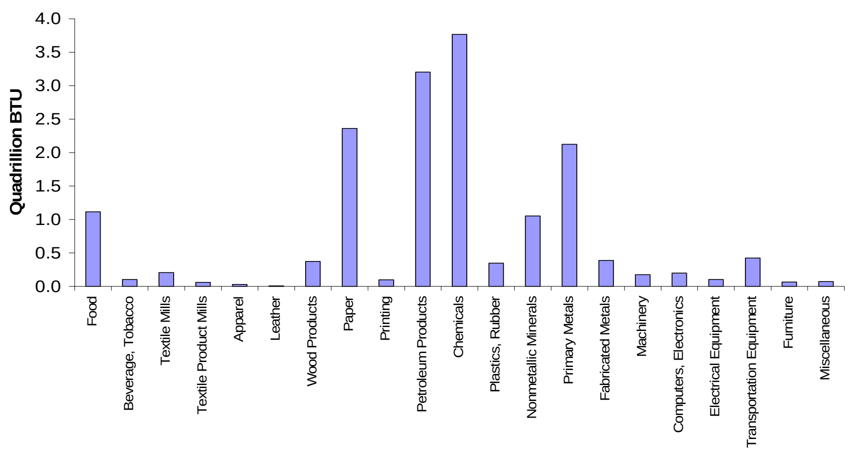
US Commercial Building Energy Consumption 1999

Values in quadrillion BTU unless otherwise noted



Data source: Residential Energy Consumption Survey 2001

US Manufacturing Energy Consumption, 2002



Historical perspective?

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

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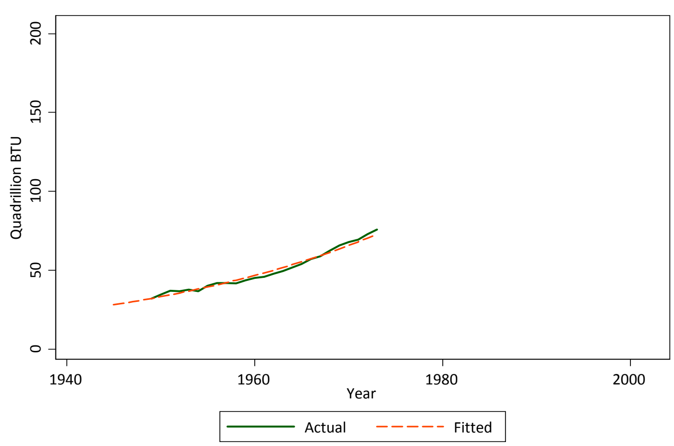
Exponential growth after WW II (3.4%)



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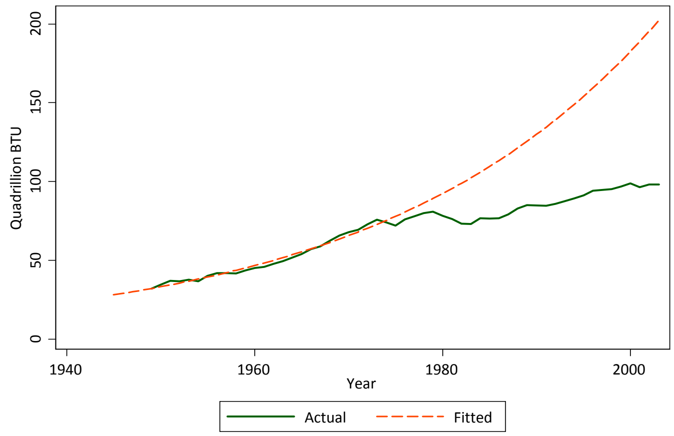
Sharp change after the energy shocks!



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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%*

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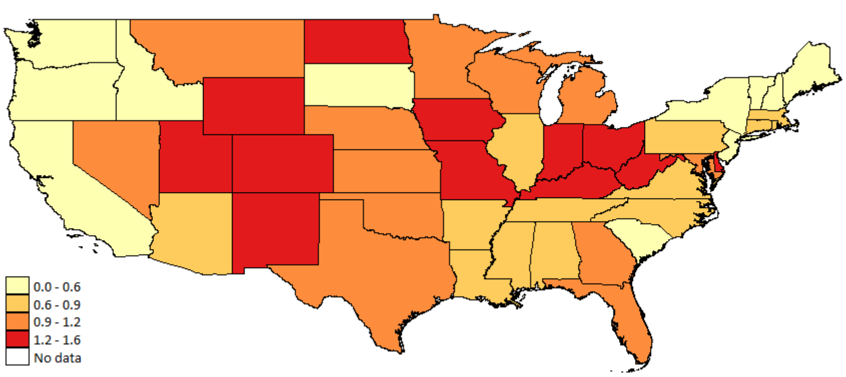
Policy option: carbon tax

- Tax fossil fuels based on the carbon emitted when burned
  - *Example: $15 per ton of CO_2*
- Raises price of natural gas, gasoline and electricity
  - *Gasoline*
    - 13 cents per gallon
  - *Natural gas*
    - 82 cents per 1000 cubic feet
  - *Electricity*
    - 0 to 1.6 cents per kWh
  - *In general, about a 6% increase*

Cents per kWh due to a $15 CO_2 fee



National average price is now about 9 cents per kWh

What political problems arise?

- Large energy taxes may not be politically viable
  - *Not possible to discuss seriously?*
  - *Pressure to repeal every year*
- Main policy question becomes
  - *Can we get similar incentives with a different policy?*

Alternative: a cap and trade system

- Fuel users must own 1 permit per ton of CO_2
- Limit the number of permits
- Allow owners to buy and sell them
- Market price of a permit provides incentives
  - *Example: $15 per ton*
  - *Non-owners must buy; incentives similar to a carbon tax*
  - *Owners who can cut emissions for $10: profitable to cut and sell*

Problem with permits

- Guarantees emissions but does not limit costs
  - *Market price may be very high if policy is unexpectedly stringent*
- Congress likely to require cost containment provisions
  - *A price ceiling or price collar*

Other policies: efficiency regulations

- Appliance standards
  - *Energy ratings, Energy Star program*
- Building codes
  - *Insulation*
  - *Windows*
- CAFE standards
  - *Vehicle fuel efficiency requirements*

Other policies: technology subsidies

- Subsidies for hybrid cars
- Subsidies for alternative fuels
  - *Corn-based ethanol not a good solution*
  - *Cellulosic ethanol great but expensive to produce*
- Subsidies for R&D
  - *A Manhattan Project for energy ?*
- Carbon capture and sequestration
  - *Would allow coal use without climate damage*
  - *Basic technologies are known*
  - *Need large scale demonstration projects*

No matter what, need fossil fuel prices to rise

- Fossil fuels are currently very cheap
- Technology policies alone won't be enough
  - *Unlikely to produce a "silver bullet" technology that would be cheaper than fossil fuels and also carbon-free*