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

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Focus the Nation
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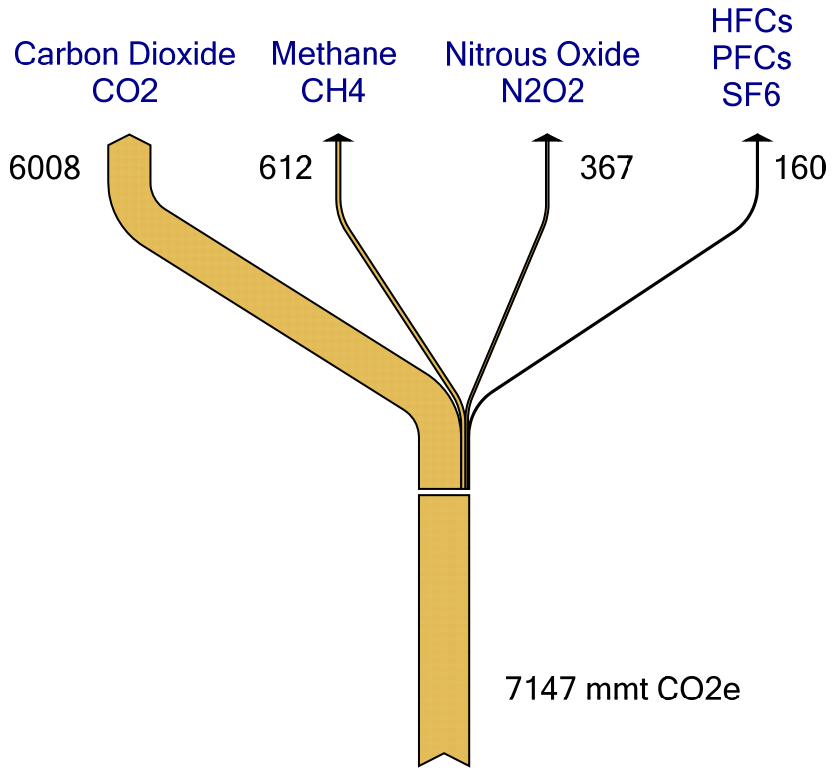
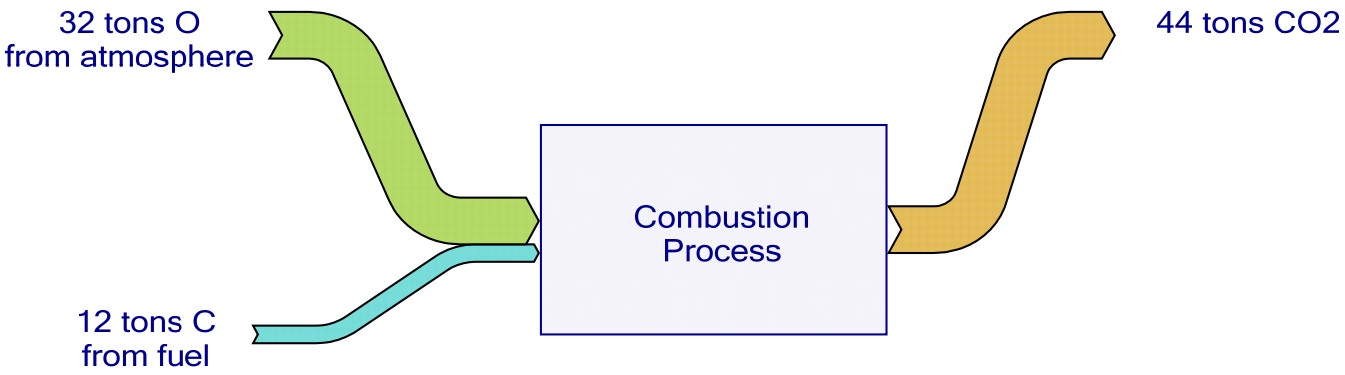
US greenhouse gas emissions in 2005

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

Where does the CO2 originate?



- Equivalent measures: 12 tons of carbon ⇔ 44 tons of CO2

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 300 MW power plant for about 3 days*
- 1 quad = 4,500 unit trains

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

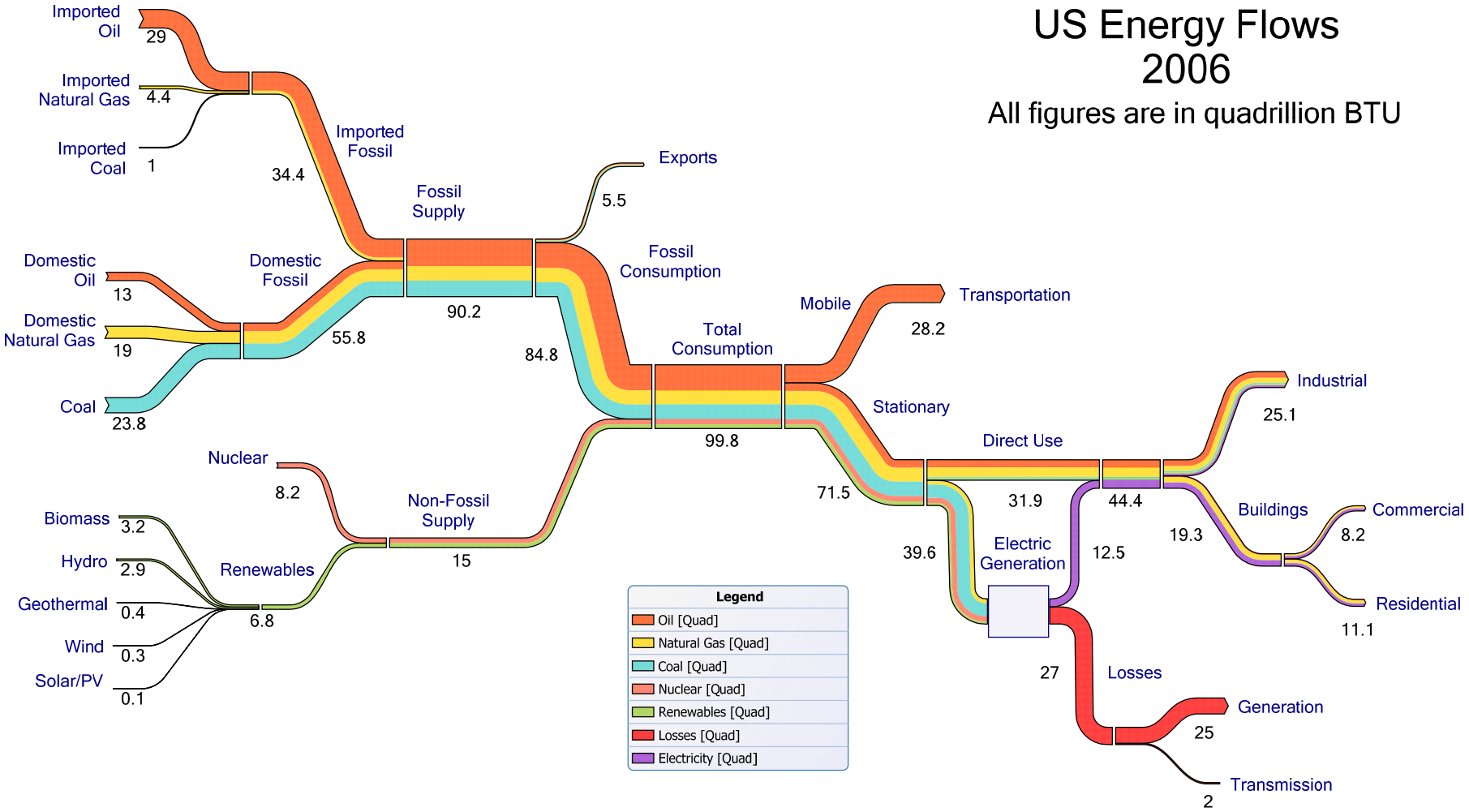
How much energy is used?

- World energy consumption
  - *400 quads per year*
  - *1 quad every 22 hours*

- US consumption
  - *100 quads per year*
  - *25% of the world total*

US Energy Flows 2006

All figures are in quadrillion BTU

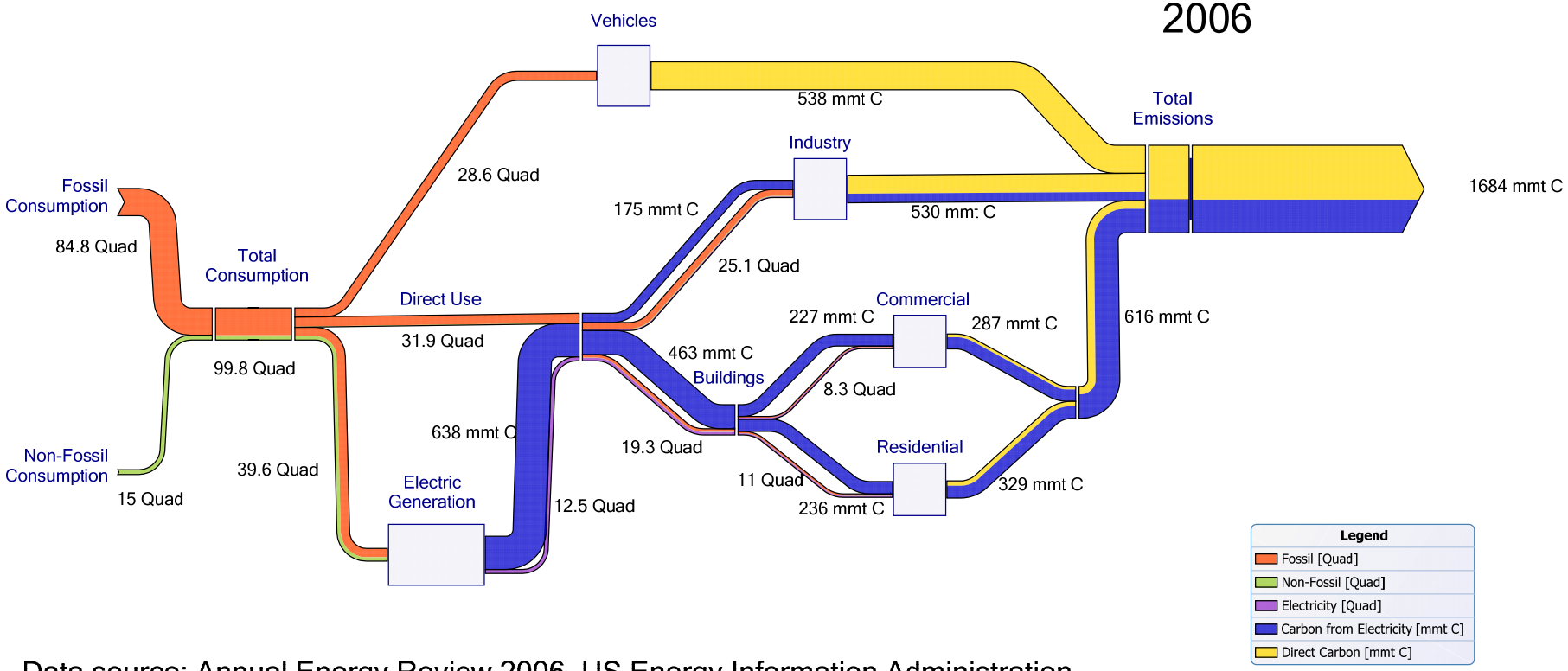


Data source: Annual Energy Review 2006, US Energy Information Administration

Translating energy into CO2

- Natural gas
  - *14.5 mmt C per quad*
  - *Lowest carbon per quad of fossil fuels*
- Oil
  - *About 20 mmt C per quad*
  - *38% more carbon than gas*
- Coal
  - *26 mmt C per quad*
  - *80% more carbon than gas*

US Energy and Carbon Flows 2006



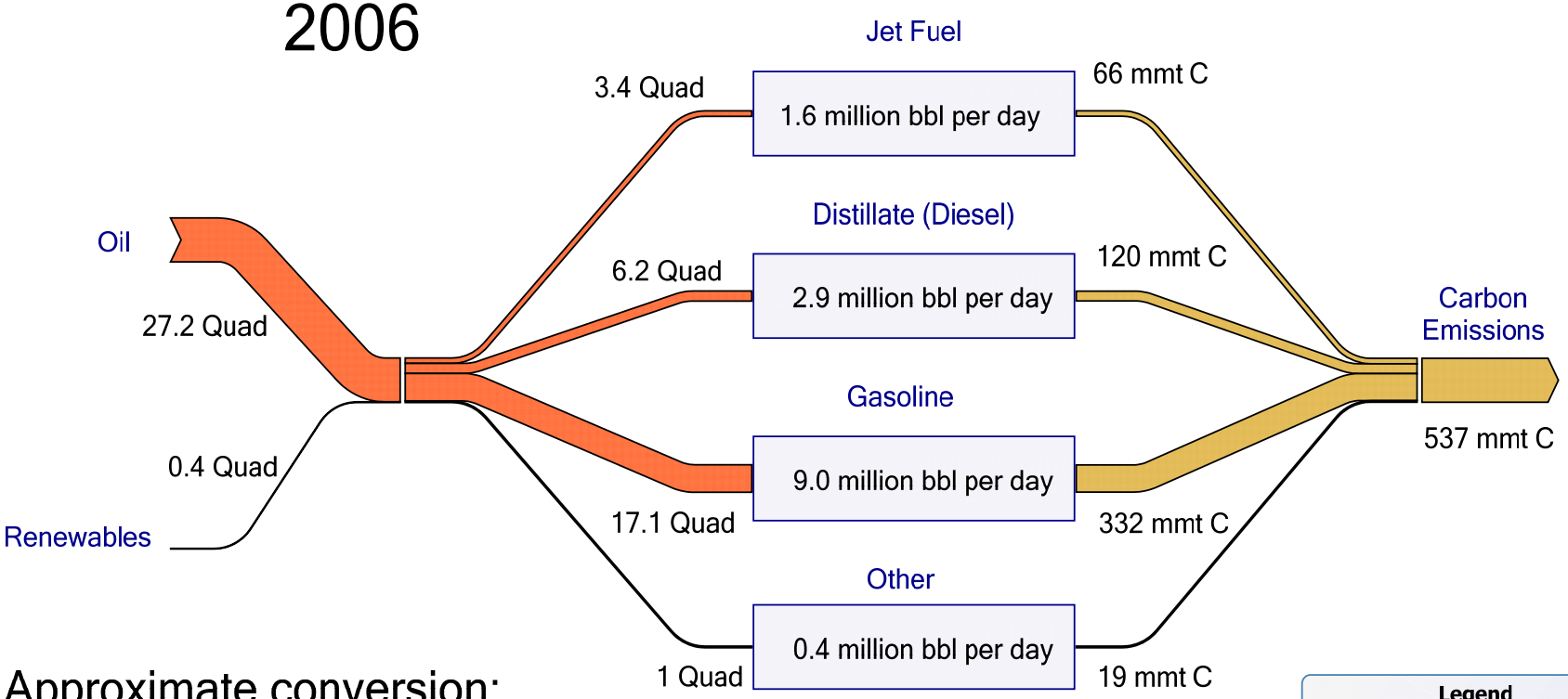
Data source: Annual Energy Review 2006, US Energy Information Administration

A very large problem ...

- US fossil energy
  - *86 quads*
- US emissions
  - *6 billion tons of CO2 or 1.7 billion tons of C*
- To limiting temperature increase to 2° C
  - *Need to bring CO2 down by more than 80%*
  - *Obama Administration's goal: 83% reduction by 2050*

Transportation

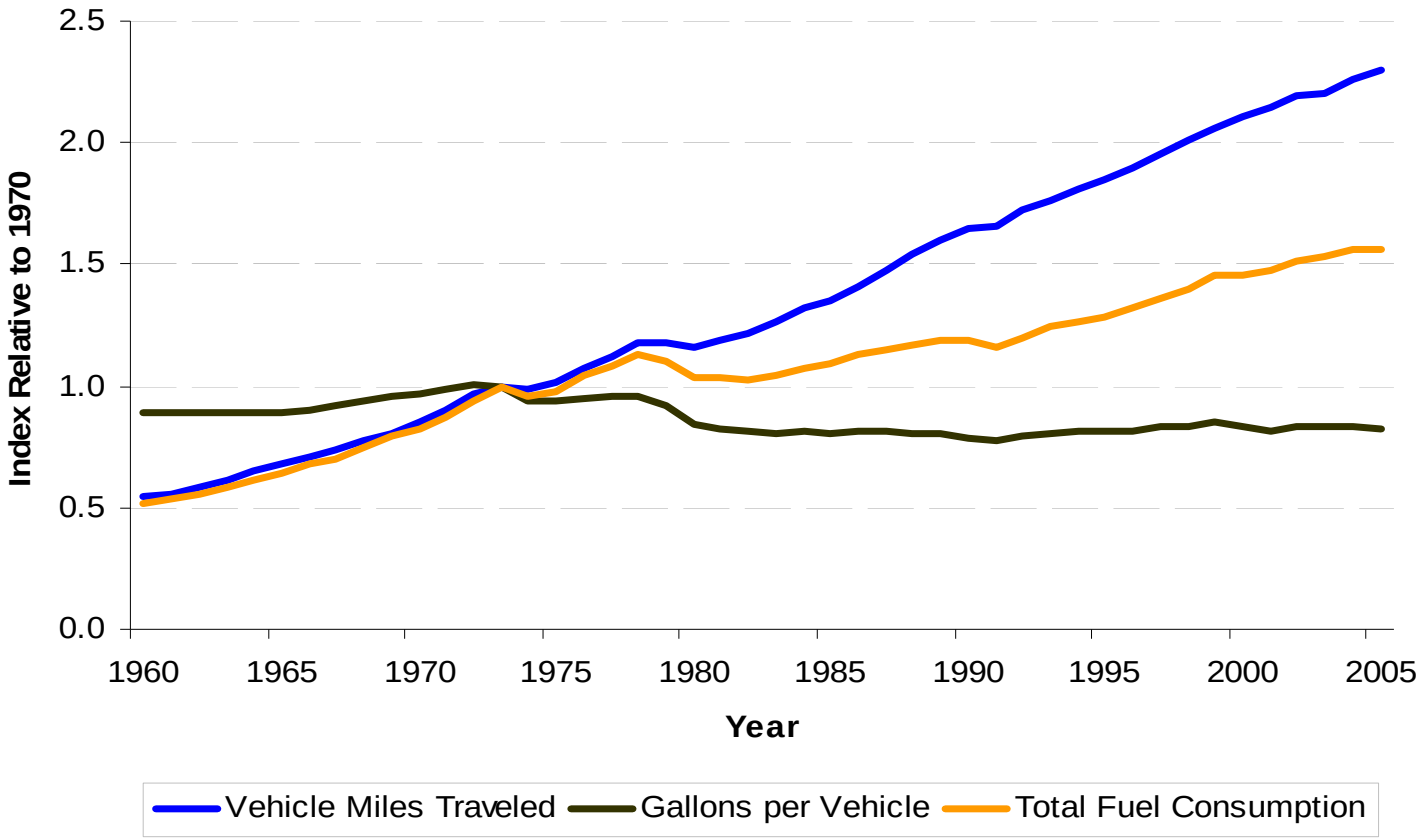
US Transportation Sector 2006



Approximate conversion:
1 Mbd = 2 Quad

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

Slightly better cars but a lot more driving



Abating vehicle emissions

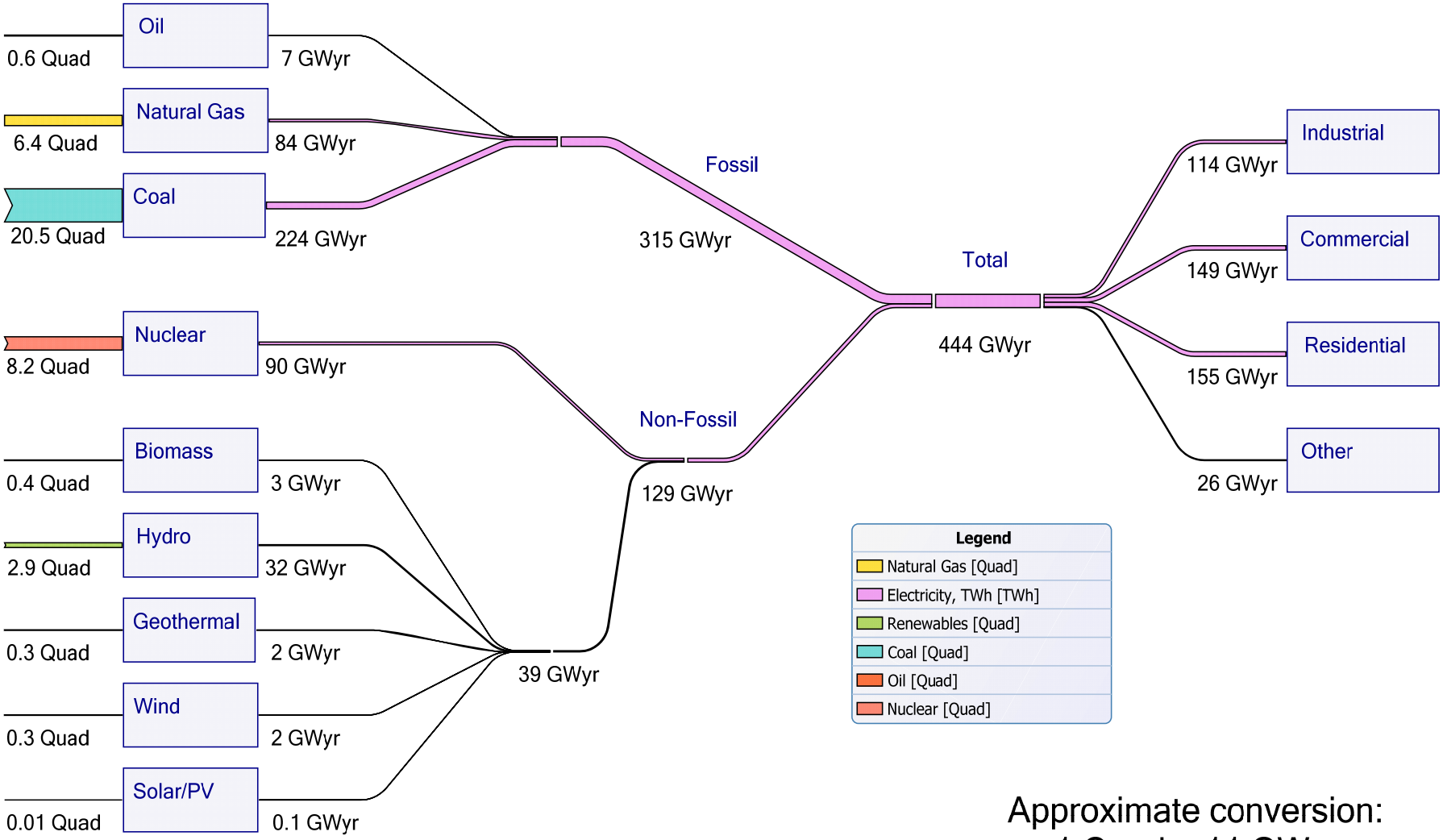
- Shift fuel mix -- less CO2 per unit of energy, less imported oil
  - *Toward natural gas*
  - *Toward biofuels (really feasible?)*
  - *Toward electricity with sequestration*
- Improve fuel efficiency -- less energy per mile
  - *Hybrids*
  - *Advanced diesel*
  - *Public transportation*
- Reduce driving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

Electricity

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*

US Electricity Flows 2006



Approximate conversion:
1 Quad = 11 GWyr

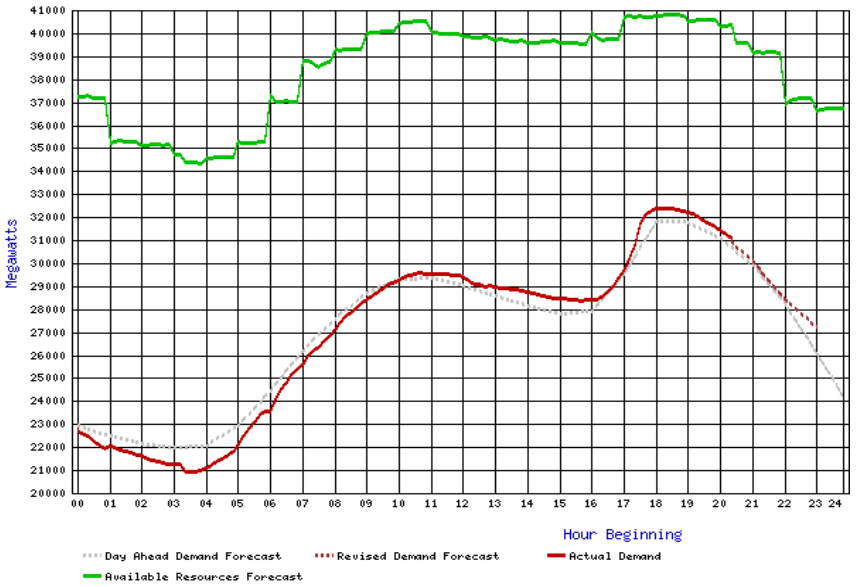
Data source: Annual Energy Review 2006, Energy Information Administration

Key problem for power producers...

- Need to follow variations in demand
- 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*

California load curve

- Independent System Operator (ISO)
  - *Operates part of the electrical grid*
- Data for January 21st
- 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*



Base load vs. peaking plants

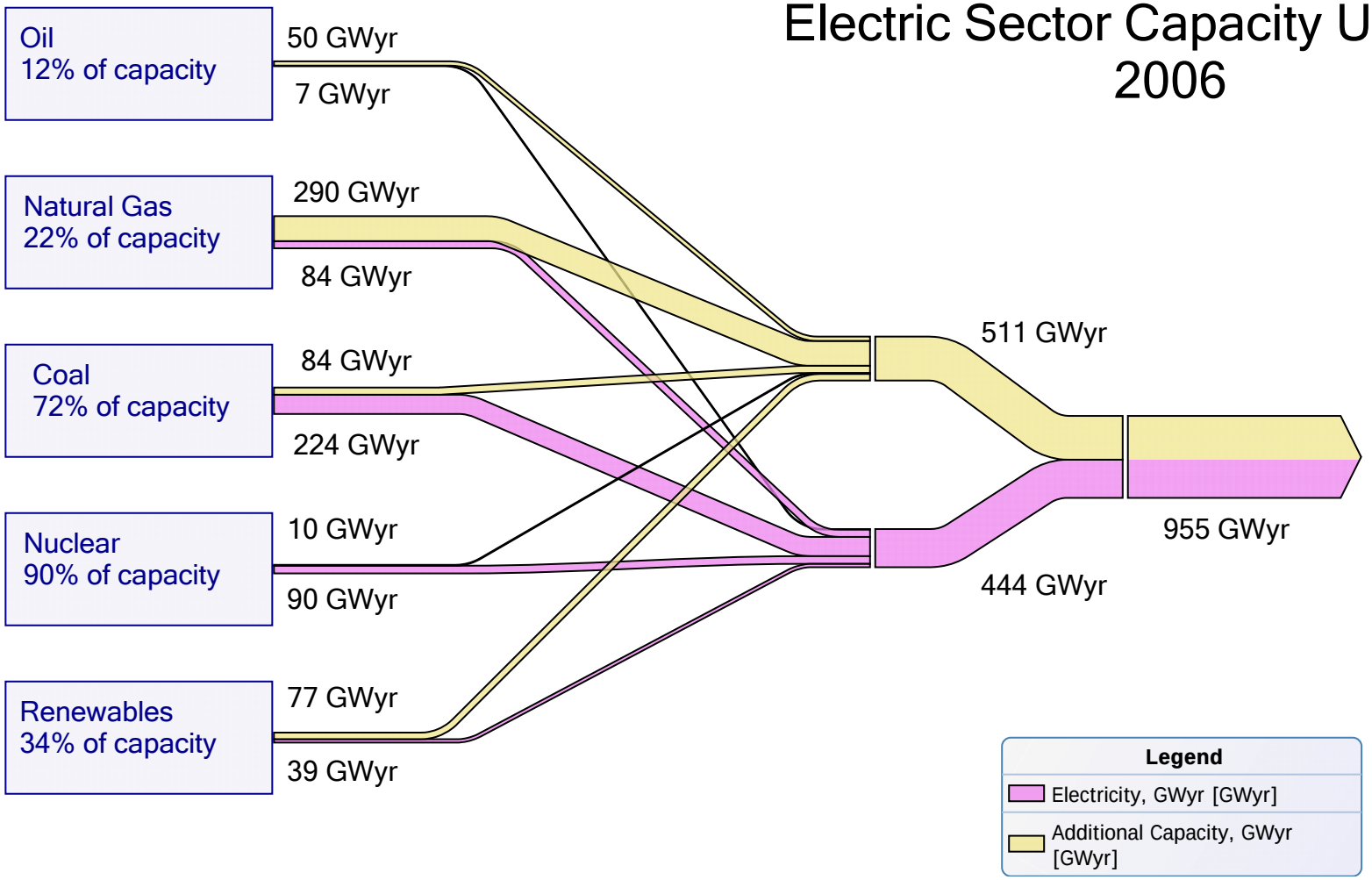
- Generators brought on line as needed
  - *Dispatching order*
- Base load
  - *Run almost all the time*
  - *Expensive to build, slow start, cheap to run*
  - *Coal, nuclear*
- Peaking
  - *Run during peak periods*
  - *Cheap to build, quick start, expensive to run*
  - *Gas, oil, others*

Typical base load coal plant

- AES Somerset on Lake Ontario
- 655 MW capacity
- 91% utilization in 2005
- 5.2 million MWh
- 4.5 mmt CO2

Photo: NYS DEC

Electric Sector Capacity Utilization 2006



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*

Cost of building new power plants

Technology	Capital Cost per kW of capacity
Coal	$1,206
IGCC	$1,394
IGCC with CCS	$1,936
Gas Turbine	$400
Combined Cycle	$550
CC with CCS	$1,055

Technology	Capital Cost per kW of capacity
Adv Nuclear	$1,802
Biomass	$1,714
Hydro	$1,364
Wind	$1,127
Solar Thermal	$2,675
Solar/PV	$4,114

Replacing fossil capacity

- Summer fossil capacity now 741 GW

- Replace with IGCC CCS coal plants?
  - *$2000 per kWh*
  - *Per GW: $2 billion*
  - *Current capacity: 741 GW * $2 B = approx $1.5 T*
  - *For comparison: US GDP approx $13 T ($2 T investment)*

- Not impossible but definitely expensive
- Also, very uncertain: no large scale CCS plants
- Population growth makes things worse

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*

More grid capacity needed for wind

Variation in wholesale electricity prices due to grid congestion

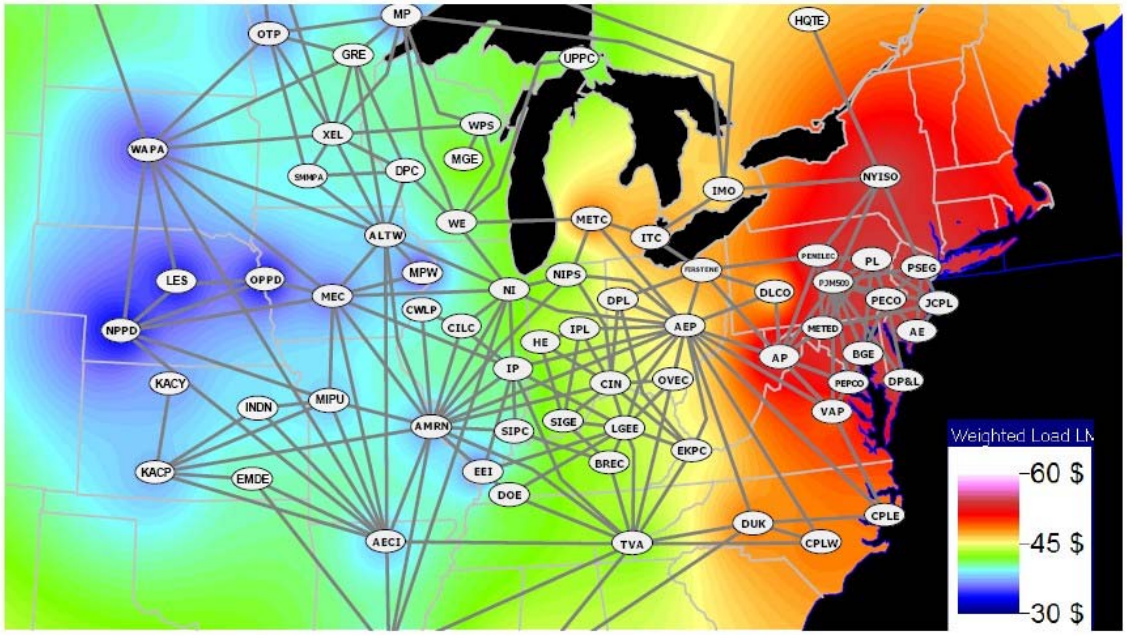


Figure 2.2-3 Contour Map of Annual Load Weighted LMP

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

Reducing demand?

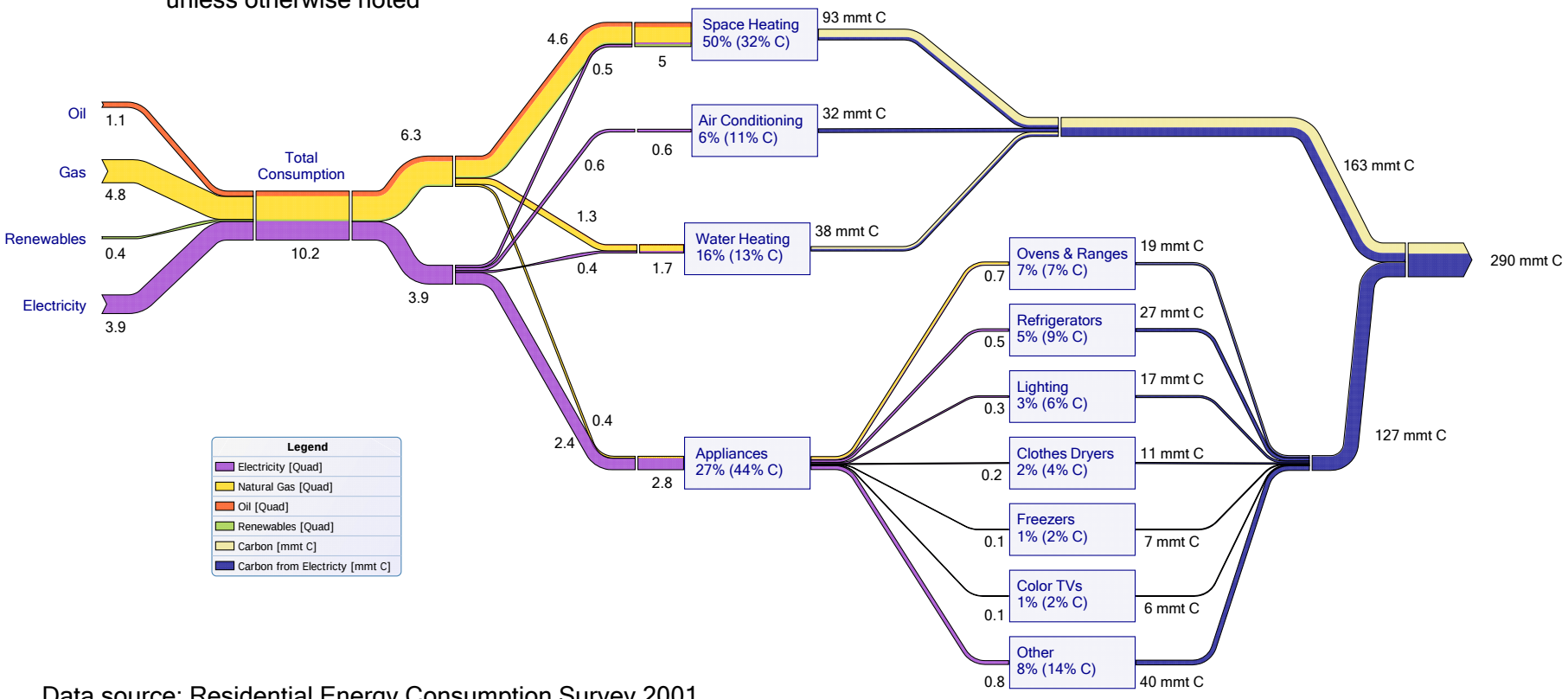
- Very quick overview of energy use

- 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

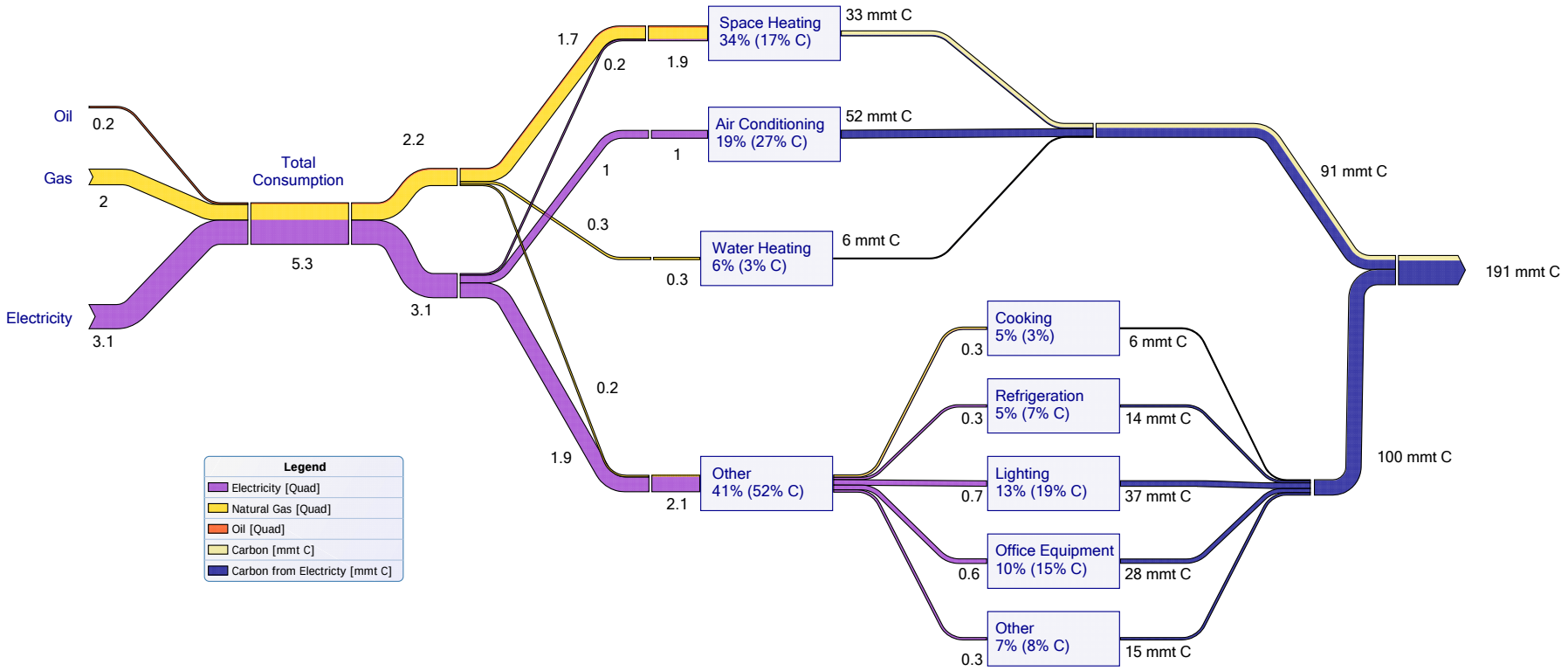
Values in quadrillion BTU unless otherwise noted



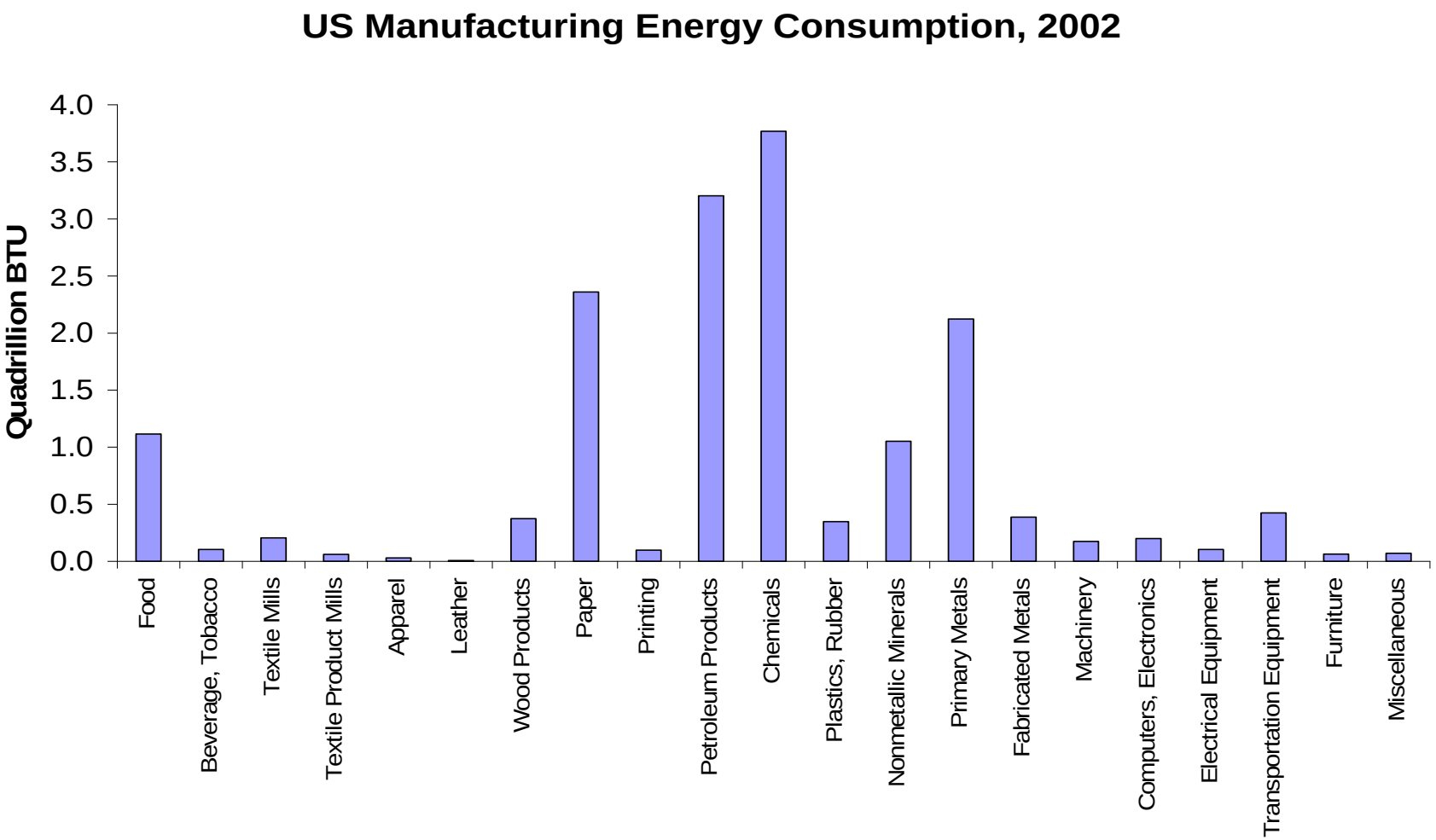
Data source: Residential Energy Consumption Survey 2001

US Commercial Building Energy Consumption 1999

Values in quadrillion BTU unless otherwise noted



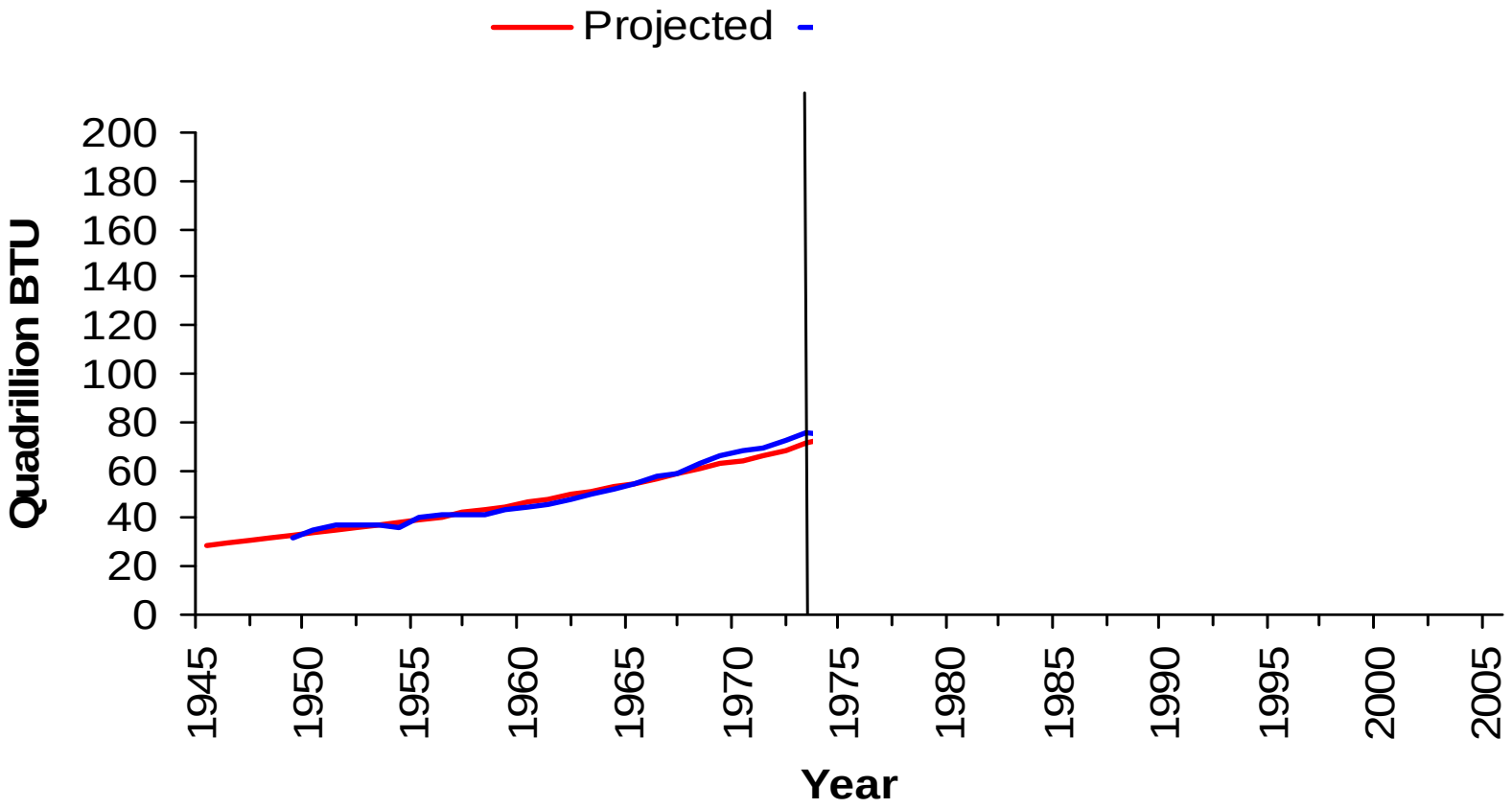
Data source: Residential Energy Consumption Survey 2001


US Manufacturing Energy Consumption, 2002
Quadrillion BTU
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Food
Beverage, Tobacco
Textile Mills
Textile Product Mills
Apparel
Leather
Wood Products
Paper
Printing
Petroleum Products
Chemicals
Plastics, Rubber
Nonmetallic Minerals
Primary Metals
Fabricated Metals
Machinery
Computers, Electronics
Electrical Equipment
Transportation Equipment
Furniture
Miscellaneous

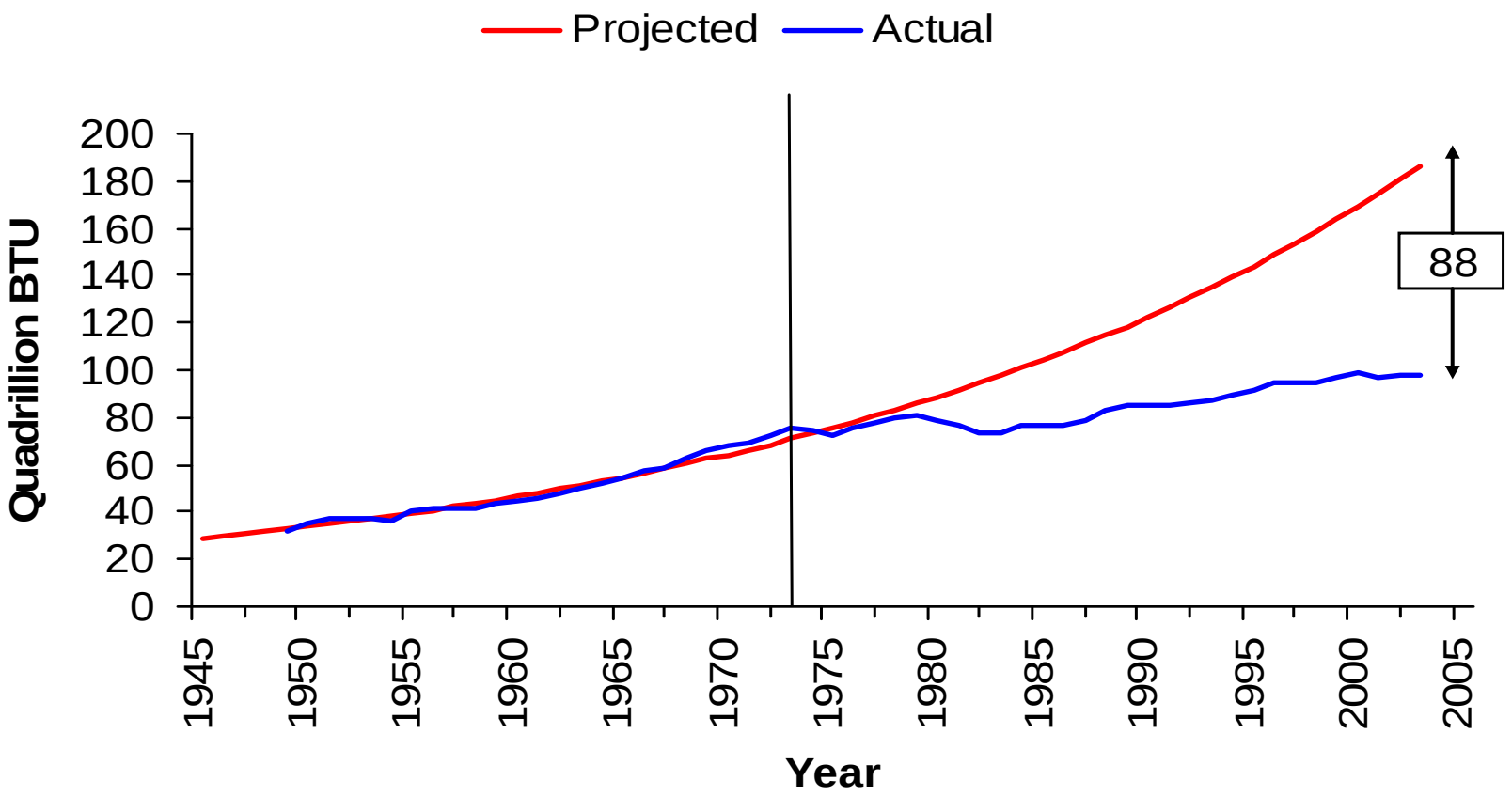
Historical perspective?

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

US Energy Consumption, 1949-2003



US Energy Consumption, 1949-2003



Energy prices matter!

- Price spikes stabilized US energy consumption for about 20 years
- GDP growth was a little slower: about 0.2% per year

Carbon tax

- Tax on fossil fuels in proportion to carbon content
- Would reduce emissions substantially
  - *Powerful incentive to reduce fuel use*
  - *Incentive to adopt alternative technologies*
  - *Incentive for R&D on alternative technologies*
  - *Consistent with historical evidence on energy prices*
- Would reduce imports of oil

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?*

Alternatives to a tax

- Tradable emissions permits
  - *Issue a limited number of permits to burn fossil fuels*
  - *Allow owners to buy and sell*
  - *Would raise fuel prices*
  - *Costs may be very high*

- Hybrid policy
  - *Some tradable permits*
  - *Tax provision for exceeding permits*
  - *Raises fuel prices with fewer political problems*

Efficiency regulations

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

Technology policies

- 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*