The US Energy Sector and Climate Change: The Scale of the Problem and Prospects for Progress

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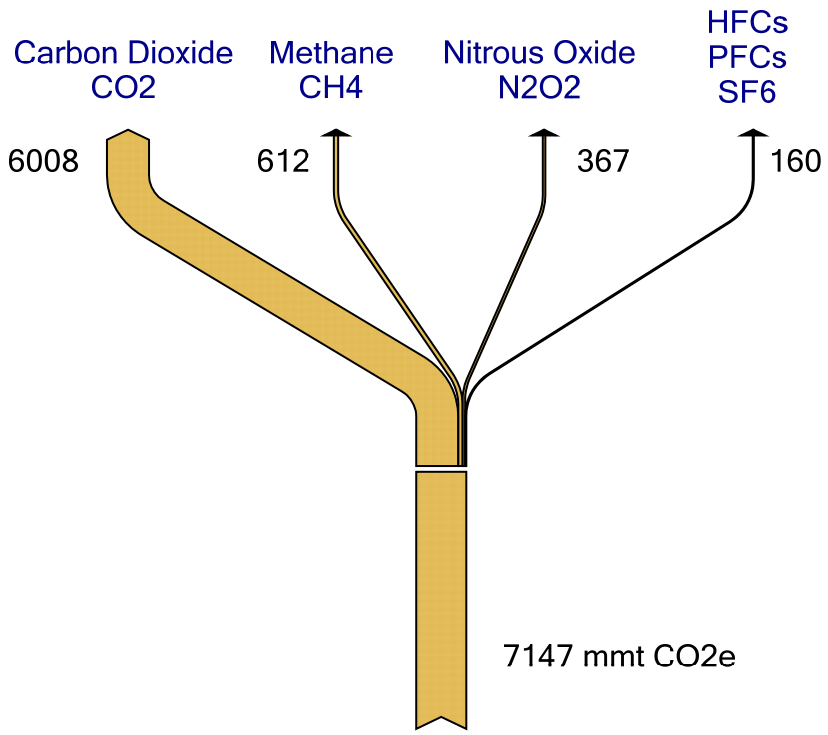
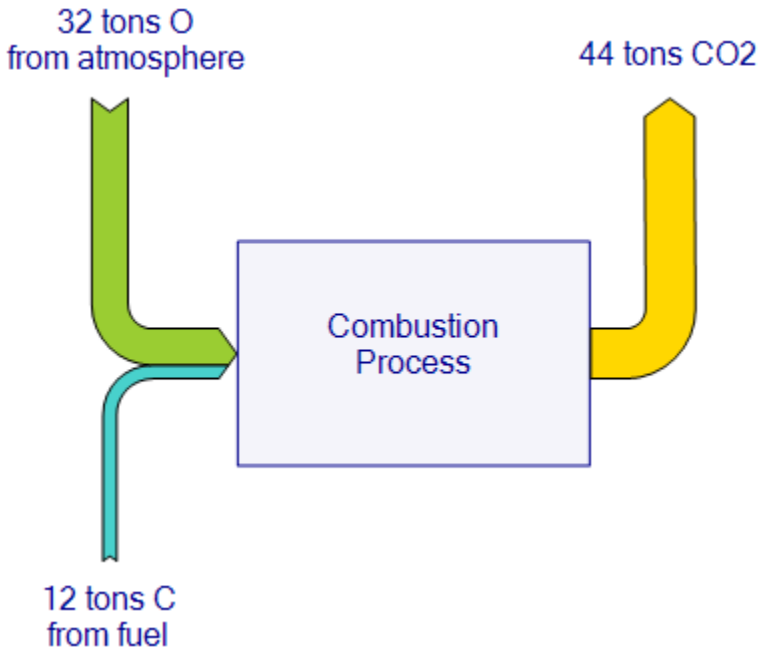
US greenhouse gas emissions in 2005

- Units
  - *Amount of CO2 for equal warming*
  - *Million metric tons*
- Percentages by gas
  - *84% CO2*
  - *9% methane*
  - *5% nitrous oxide*
  - *2% other*
- Key problem is CO2
  - *6008 mmt CO2e*
  - *6 gigatons CO2e*



CO2 originates from combustion

- Typical activities
  - *Electricity generation*
  - *Transportation*
- Problem is fossil fuels
  - *Coal, oil, natural gas*
  - *Add carbon to the biosphere*



Fuel use and energy units

- National fuel use is measured in quads
  - *1 quad = 1 quadrillion BTU (10^15)*

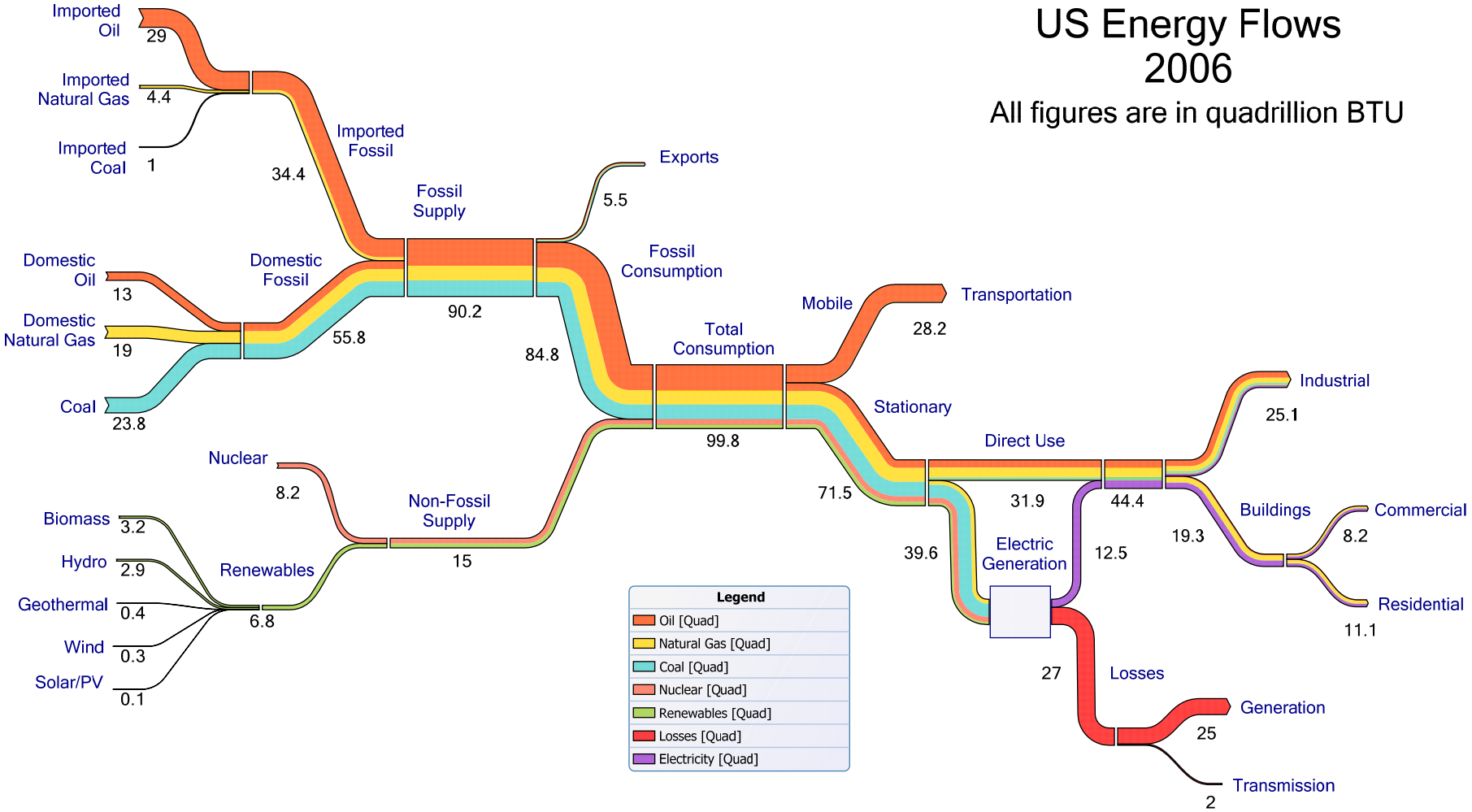
- How large is a quad?
  - *Coal "unit trains": 100 cars, about 1 mile long*
  - *1 train fuels a 300 MW power plant for about 3 days*
  - *1 quad = 4,500 unit trains*

How large is the energy sector?

- World energy consumption
  - *400 quads per year*
- US consumption
  - *100 quads per year*
  - *25% of 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
  - *53 mmt CO2 per quad*
    - Lowest carbon per quad of fossil fuels
- Oil
  - *73 mmt CO2 per quad*
    - 38% more carbon than gas
- Coal
  - *95 mmt CO2 per quad*
    - 80% more carbon than gas

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*

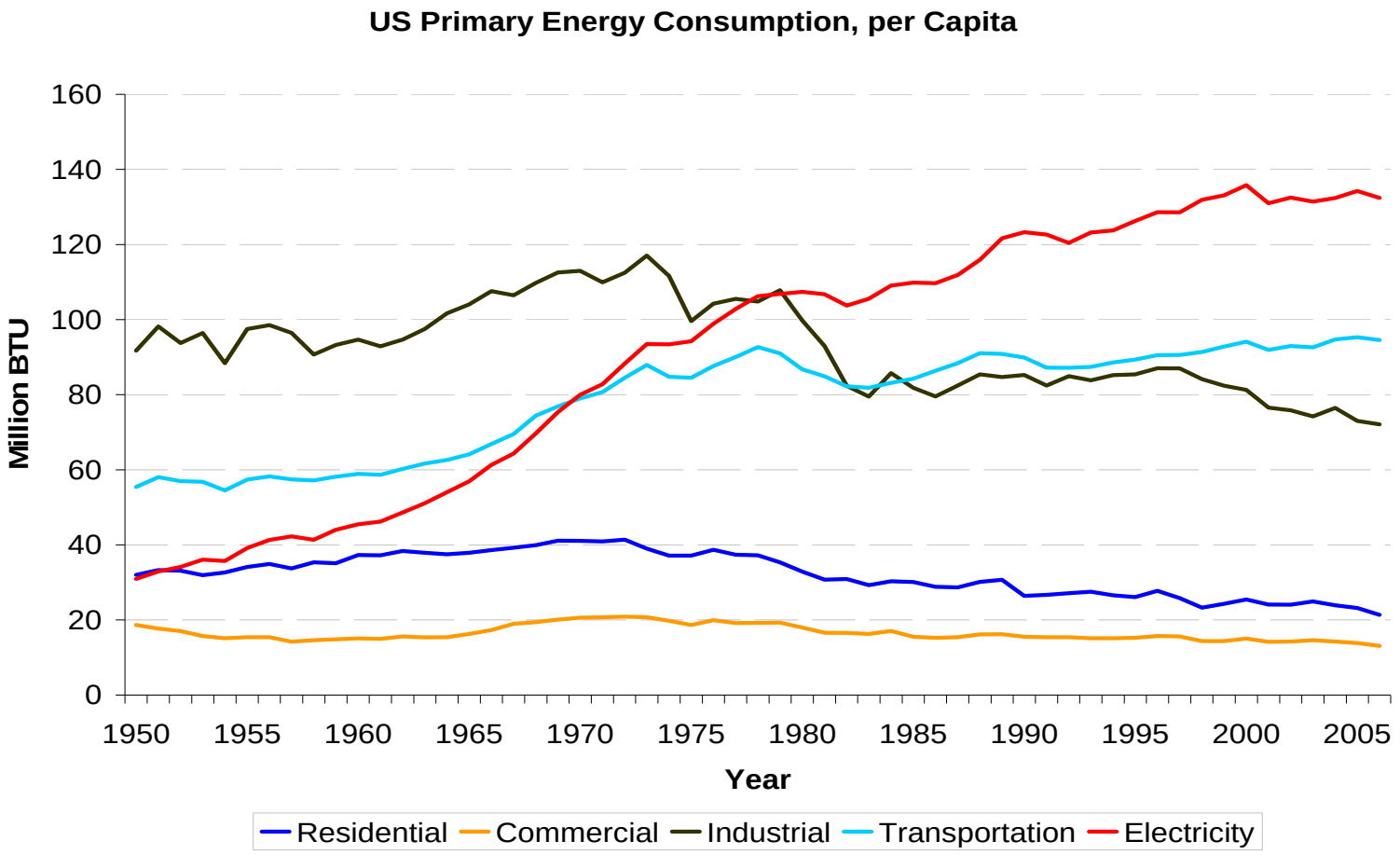
Four options for abatement

- Fuel switching
  - *coal to natural gas*
  - *fossil to non-fossil*
- Improve efficiency
  - *CFL and LED lights*
  - *hybrid vehicles*
- Reduce energy services
  - *turn lights off*
  - *drive fewer miles*
- Capture and sequester CO2
  - *Store underground*
    - old oil reservoirs
    - saline aquifers

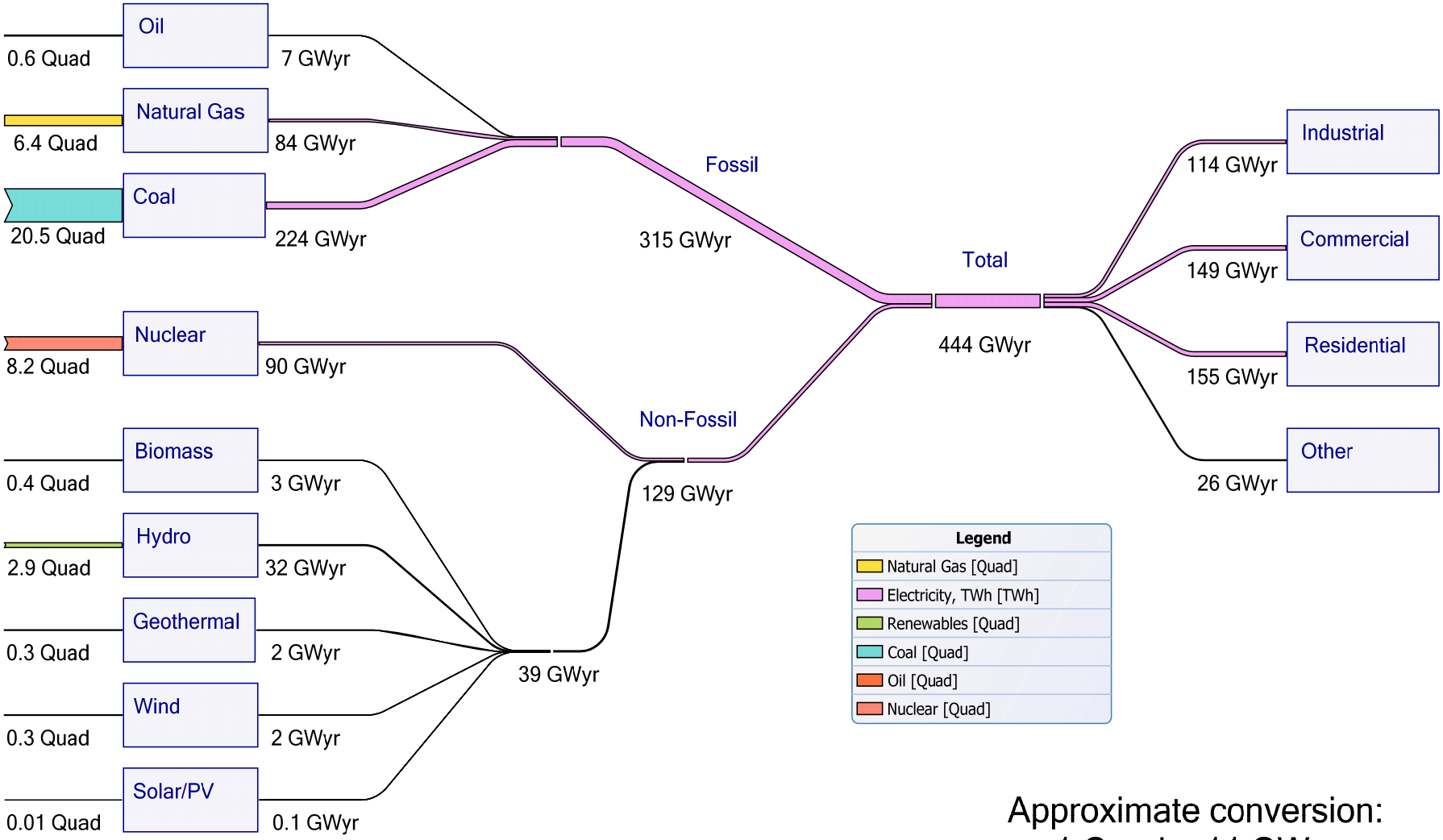
Electric sector is particularly important

- 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*

Also, electricity growth has been strong



US Electricity Flows 2006

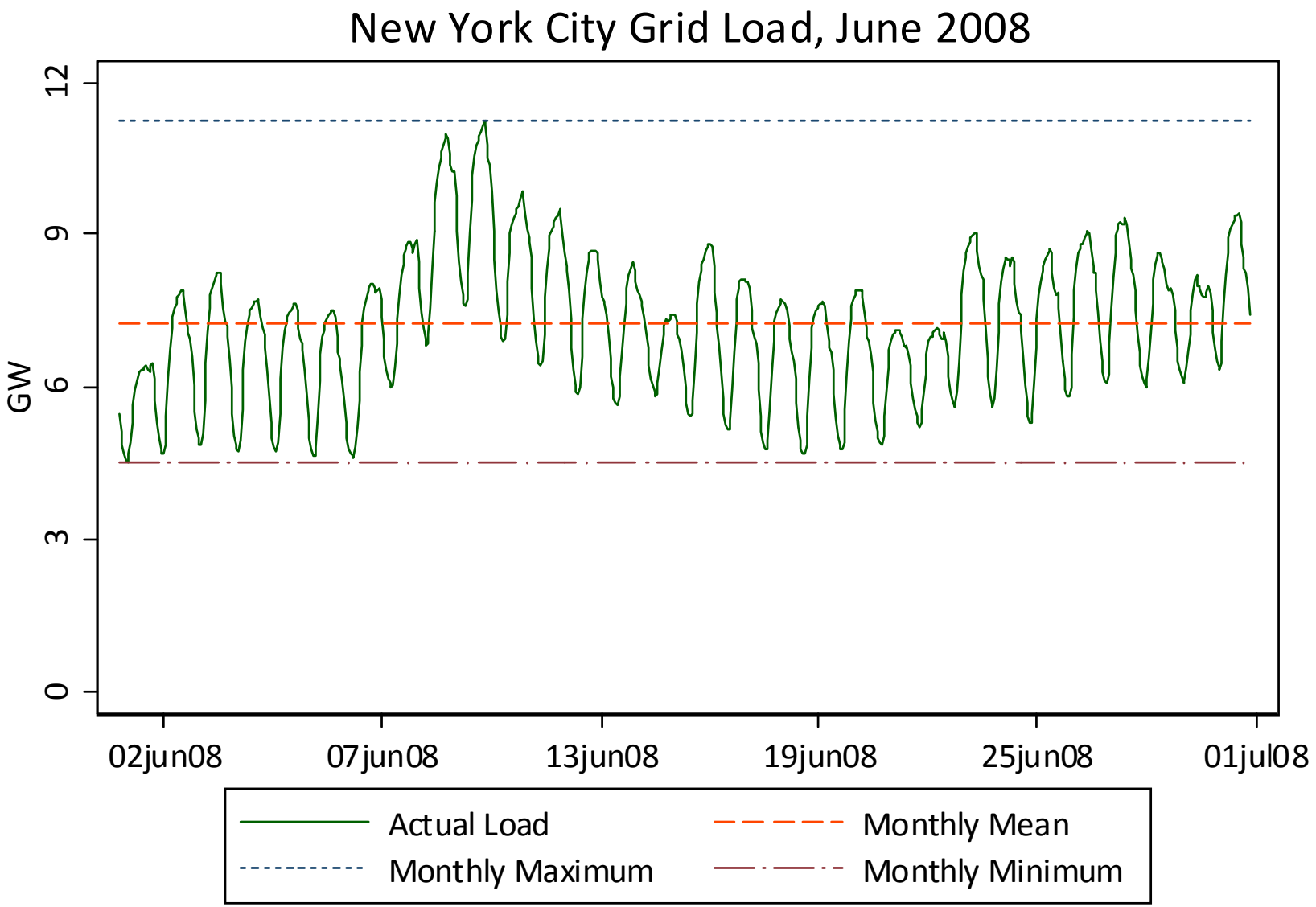


Approximate conversion:
1 Quad = 11 GWyr

Data source: Annual Energy Review 2006, Energy Information Administration

Key problem for power producers...

- Need to follow variations in demand
  - *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*


New York City Grid Load, June 2008
GW
0
3
6
9
12
02jun08
07jun08
13jun08
19jun08
25jun08
01jul08
Actual Load
Monthly Mean
Monthly Maximum
Monthly Minimum

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

- Output in 2005:
  - *91% utilization*
  - *5.2 million MWh*
  - *MWh = megawatt hours*

- Waste:
  - *4.5 mmt CO2*

Photo: NYS DEC

Typical base load nuclear plant

- Nine Mile Point
  - *Northwest of Syracuse*
- Two reactors:
  - *620 MW, 1970*
  - *1138 MW, 1988*
- Output in 2007:
  - *91% cap utilization*
  - *14 million MWh*
- Waste:
  - *0.006 lbs/MWh*
  - *38 mt/year*

Photo: Constellation Energy

Natural gas peaking turbine

340 MW Siemens Gas Turbine

http://www.powergeneration.siemens.com/press/press-pictures/gas-turbines/gas-turbine-1.htm

Intermittent generators: wind turbines

1.75 MW Turbine, Australia

http://www.vestas.com

2 MW Turbine, Wales

http://www.vestas.com

Replacing fossil completely?

- Need about 550 GW total
  - *Peaking: 220 GW*
  - *Base load: 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*

How large is that?

- Approximate cost
  - *$2-$3 trillion*
- For comparison:
  - *US GDP in 2008 = $14 trillion*
  - *US total investment in 2008 = $2 trillion*
  - *Typical investment in generation = $20-$40 billion*
- Roughly 100 times annual investment
  - *Does not include infrastructure*
    - Transmission upgrades, gas pipelines, CO2 pipelines

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

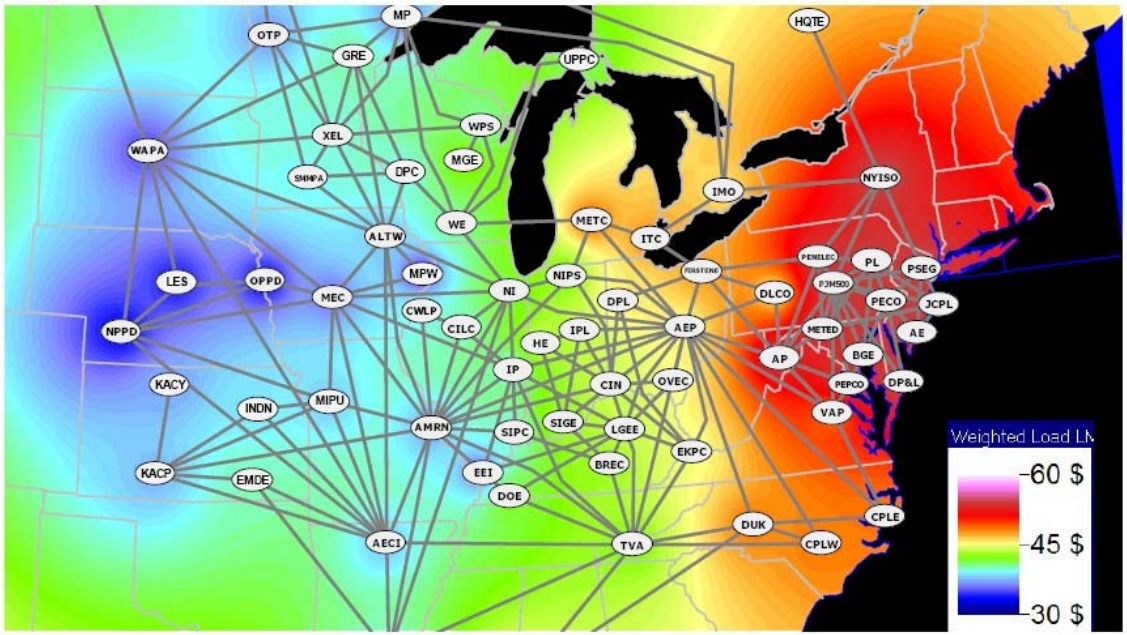


Figure 2.2-3 Contour Map of Annual Load Weighted LMP

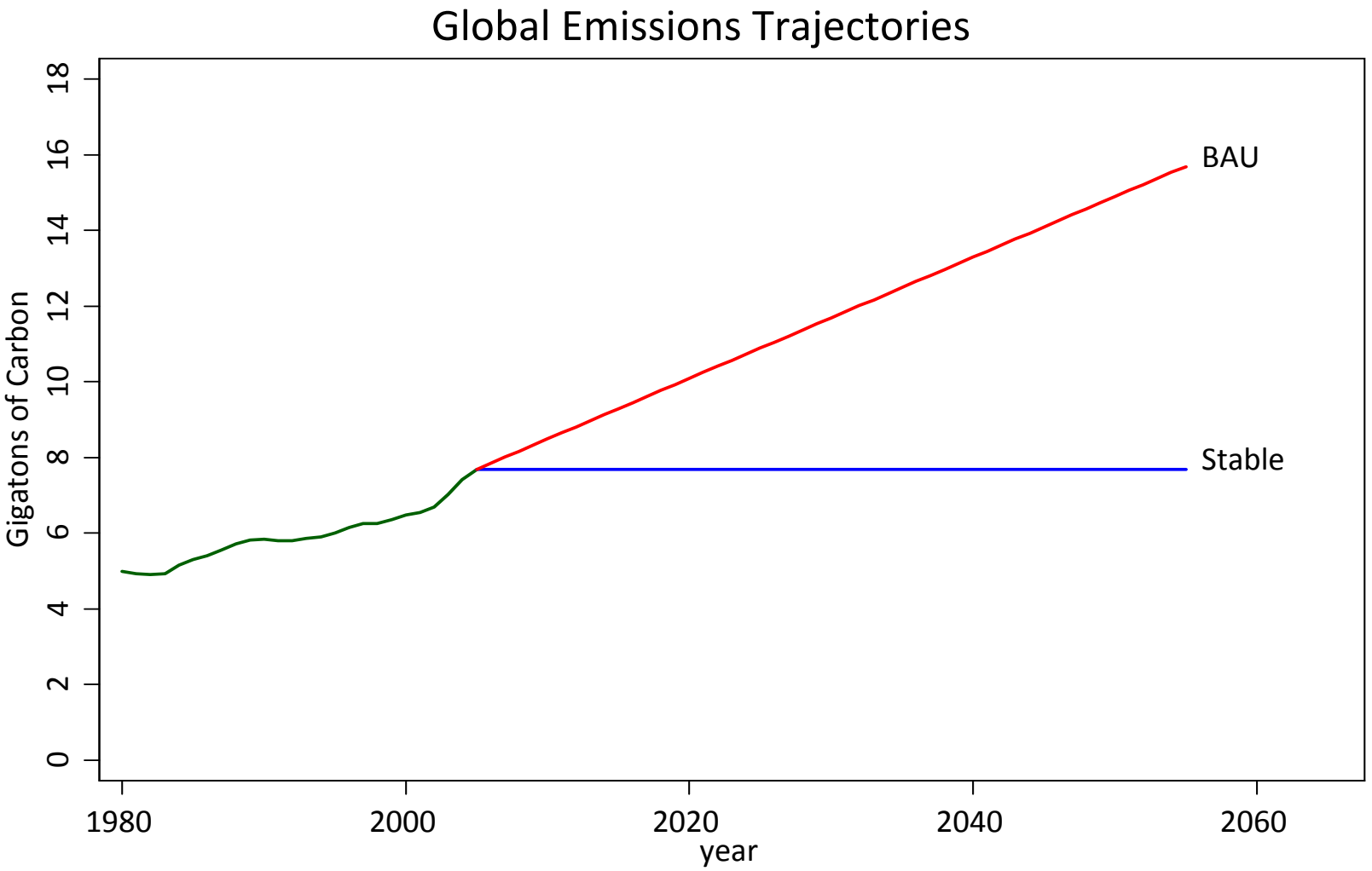
From “2006 Midwest ISO-PJM Coordinated System Plan (CSP),” December 2006.

Silver bullets, silver buckshot

- Will a single technology solve the problem?
  - *Sliver bullet: carbon free, cheaper than fossil*
  - *Does not look likely at the moment*
- Need to use a portfolio of technologies
  - *Silver buckshot*
- Pointed out vividly by Pacala & Socolow
  - *"Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies", Science 13 August 2004.*

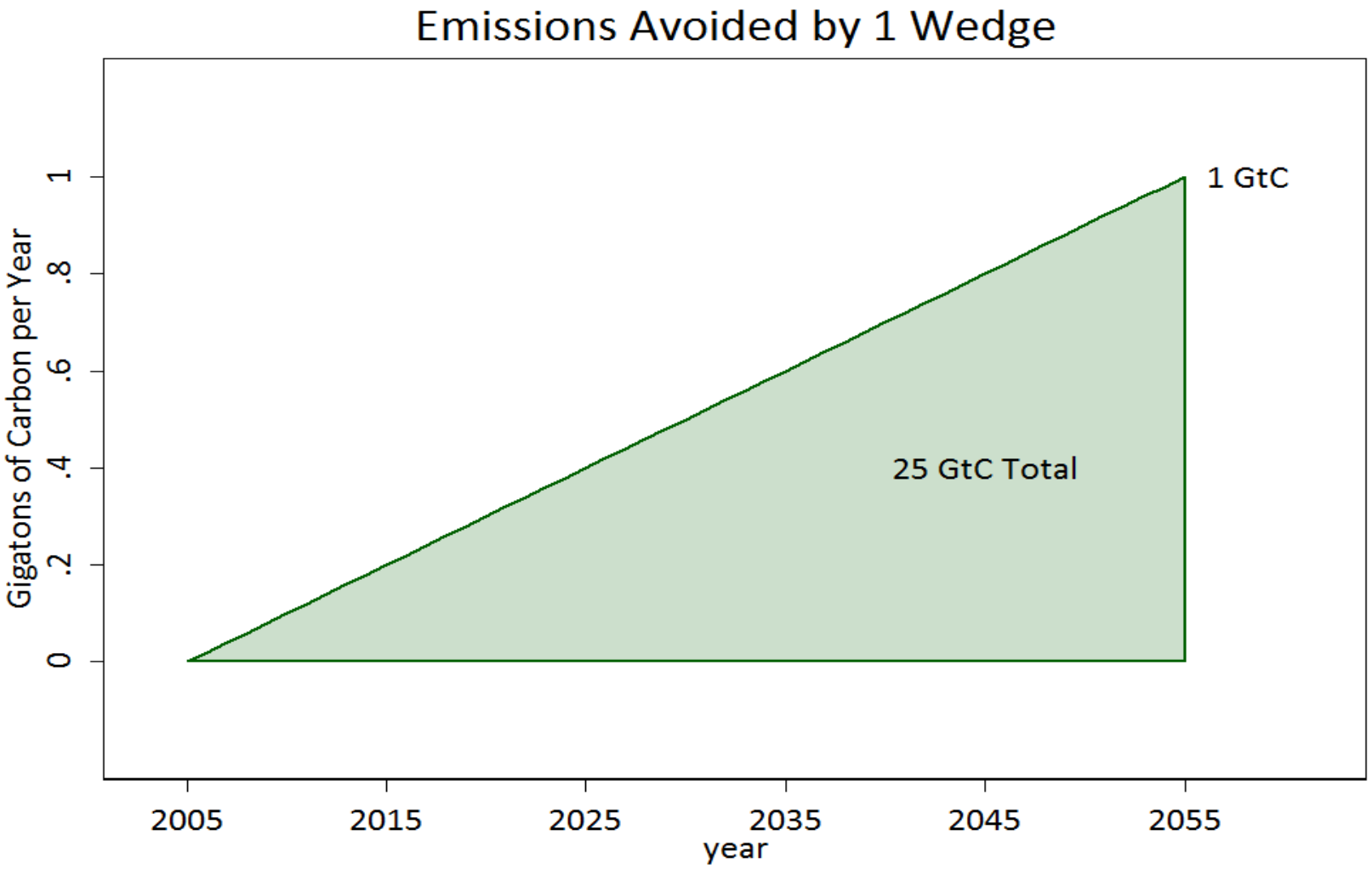
Basic idea ...

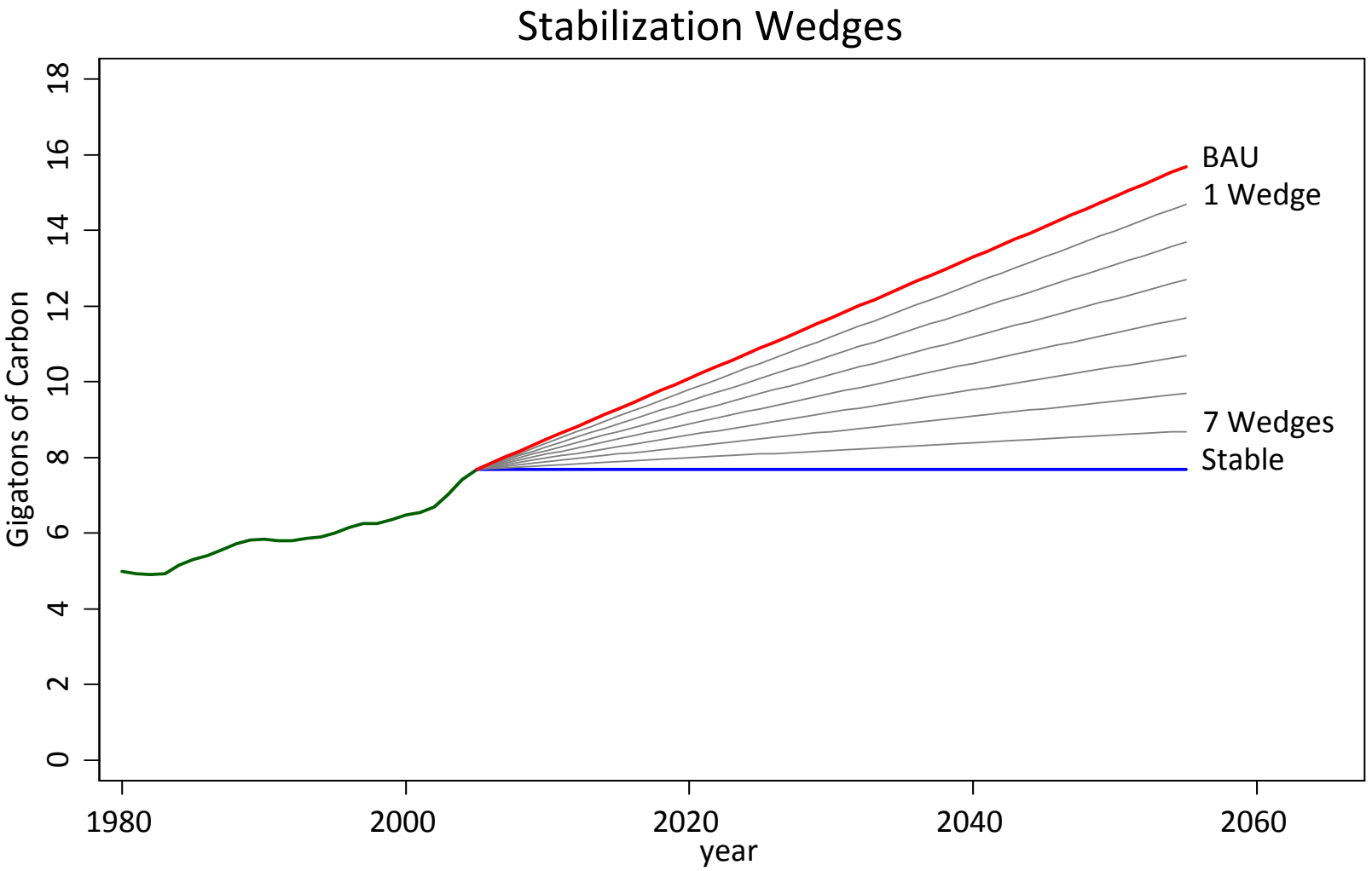
- Stabilize world emissions
  - *Would slow but eliminate warming*
- World emissions now:
  - *Approx 8 gigatons C (29 gigatons CO2)*
- Emissions in 50 years without action:
  - *Approx 16 gigatons C*
- To stabilize:
  - *Avoid increase of 8 gigatons C*


Global Emissions Trajectories
Gigatons of Carbon
0
2
4
6
8
10
12
14
16
18
1980
2000
2020
2040
2060
year
BAU
Stable

Silver buckshot

- Break task in to smaller pieces
  - *No single approach will be adequate*
- Divide into 8 wedges
  - *Each slows emissions growth a little*
- Each wedge:
  - *Phased in gradually*
  - *After 50 years, annual emissions lower by 1 GtC*
  - *Cumulative emissions lower by 25 GtC*


Emissions Avoided by 1 Wedge
Gigatons of Carbon per Year
0
.2
.4
.6
.8
1
1 GtC
25 GtC Total
2005
2015
2025
2035
2045
2055
year


Stabilization Wedges
Gigatons of Carbon
0
2
4
6
8
10
12
14
16
18
1980
2000
2020
2040
2060
year
BAU
1 Wedge
7 Wedges
Stable

Fuel Switching

Photo by J.C. Willett (U.S. Geological Survey).

Substitute 1400 natural gas electric plants for an equal number of coal-fired facilities

A wedge requires an amount of natural gas equal to that used for all purposes today

Nuclear Electricity

Triple the world's nuclear electricity capacity by 2055

Graphic courtesy of NRC

The rate of installation required for a wedge from electricity is equal to the global rate of nuclear expansion from 1975-1990.

Wind Electricity

Photo courtesy of DOE

Install 1 million 2 MW windmills to replace coal-based electricity,

OR

Use 2 million windmills to produce hydrogen fuel

A wedge worth of wind electricity will require increasing current capacity by a factor of 30

Solar Electricity

Photos courtesy of DOE Photovoltaics Program

Install 20,000 square kilometers for dedicated use by 2054

A wedge of solar electricity would mean increasing current capacity 700 times

Biofuels

Scale up current global ethanol production by 30 times

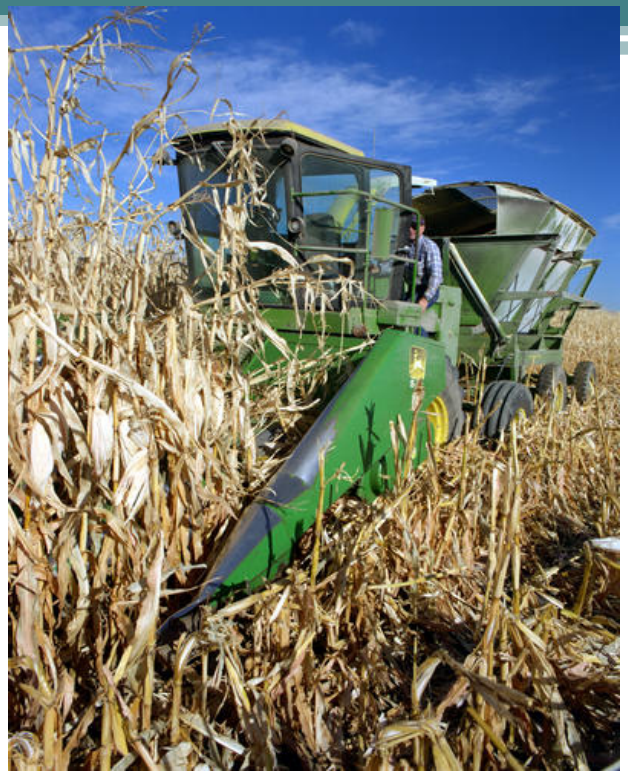


Photo courtesy of NREL

Using current practices, one wedge requires planting an area the size of India with biofuels crops

Efficiency

Double the fuel efficiency of the world's cars or halve miles traveled

There are about 600 million cars today, with 2 billion projected for 2055

Produce today's electric capacity with double today's efficiency

Average coal plant efficiency is 32% today

Use best efficiency practices in all residential and commercial buildings

Replacing all the world's incandescent bulbs with CFL's would provide 1/4 of one wedge

Natural Sinks

Eliminate tropical deforestation

OR

Plant new forests over an area the size of the continental U.S.

OR

Use conservation tillage on *all* cropland (1600 Mha)

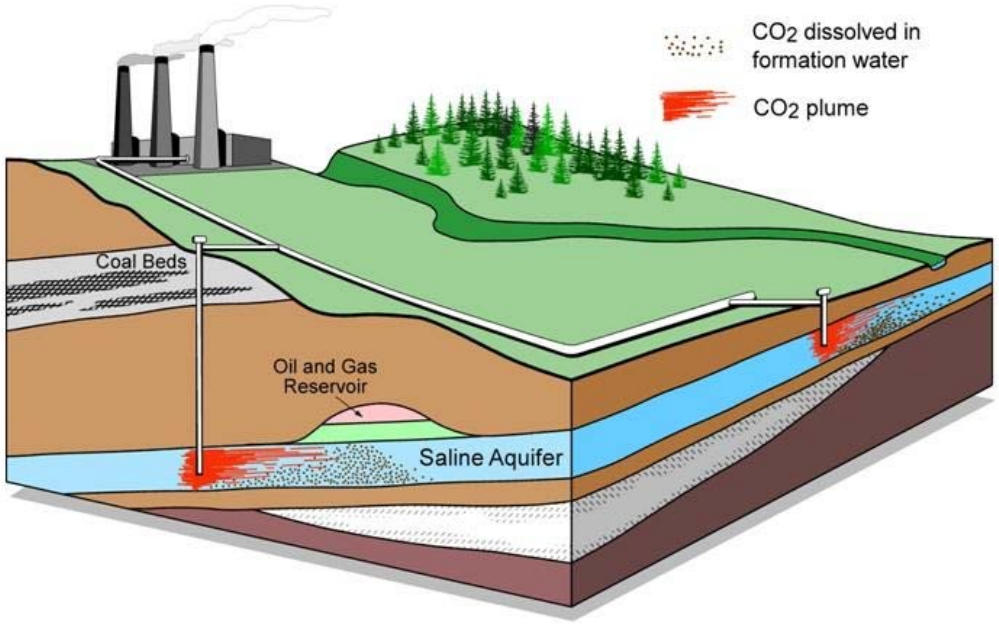
Conservation tillage is currently practiced on less than 10% of global cropland

Photos courtesy of NREL, SUNY Stonybrook, United Nations FAO

Carbon Capture & Storage

Implement CCS at

- **800 GW coal electric plants or**
- **1600 GW natural gas electric plants or**
- **180 coal synfuels plants or**
- **10 times today's capacity of hydrogen plants**



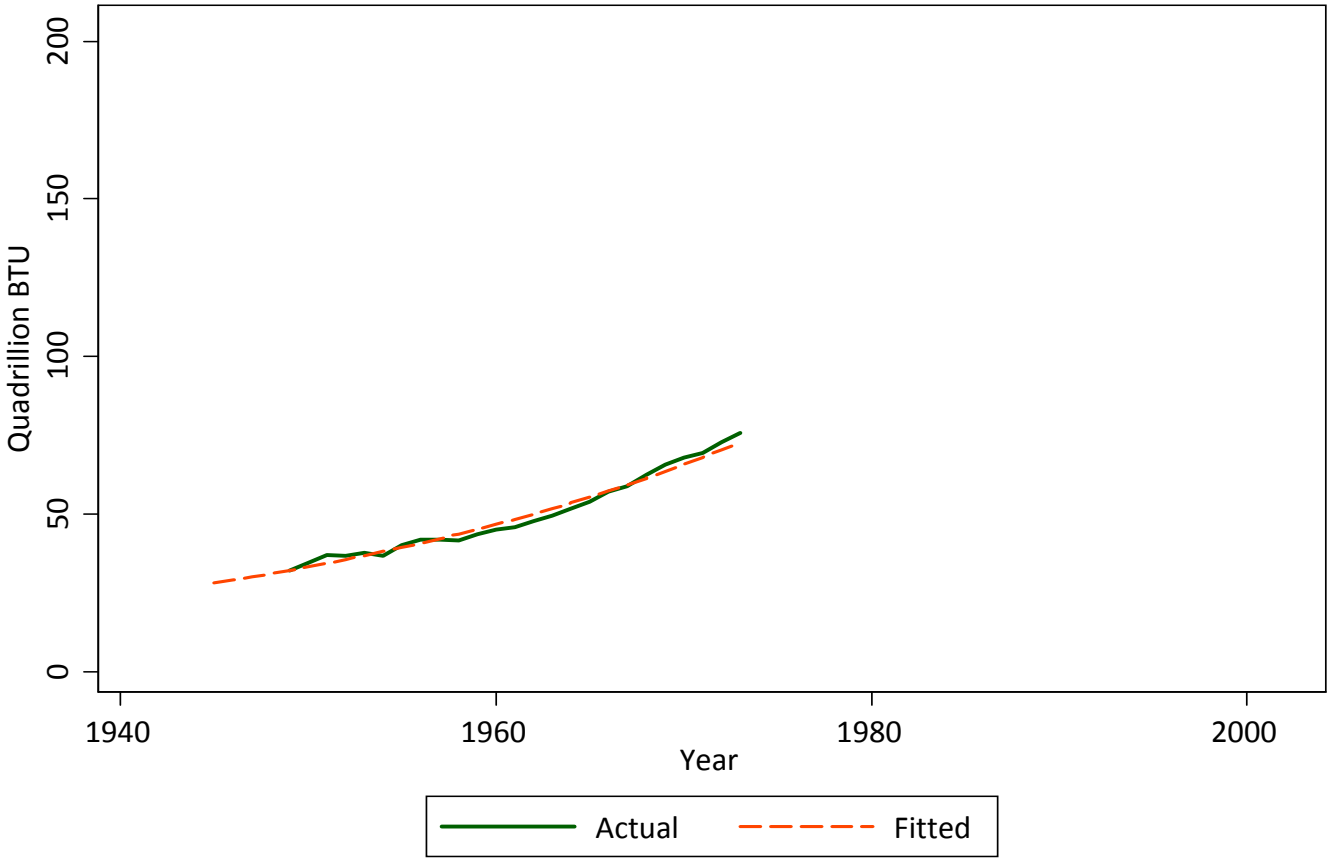
Graphic courtesy of Alberta Geological Survey

There are currently three storage projects that each inject 1 million tons of CO_2 per year – by 2055 need 3500.

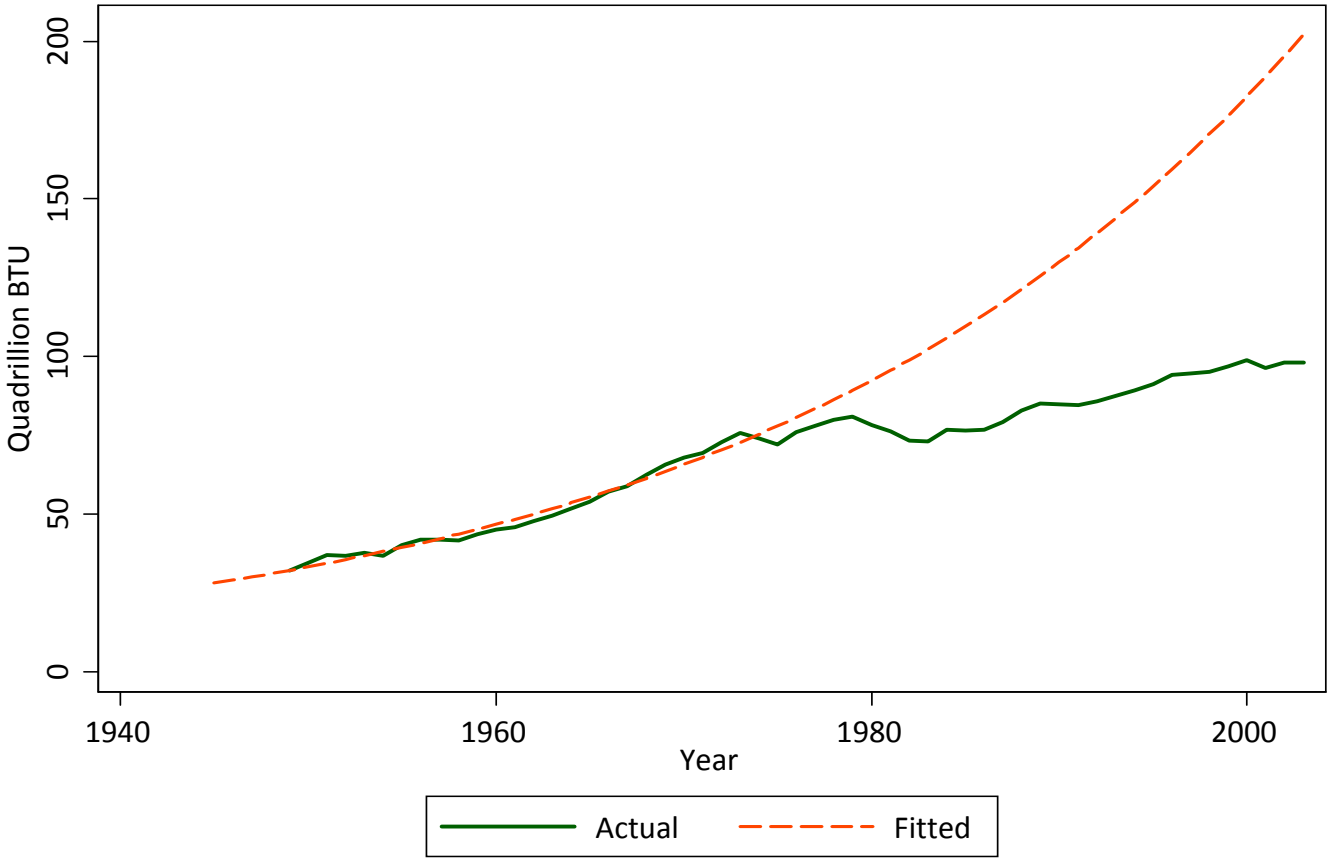
Historical perspective?

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

Exponential growth after WW II (3.4%)



Sharp change after the energy shocks!



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%*

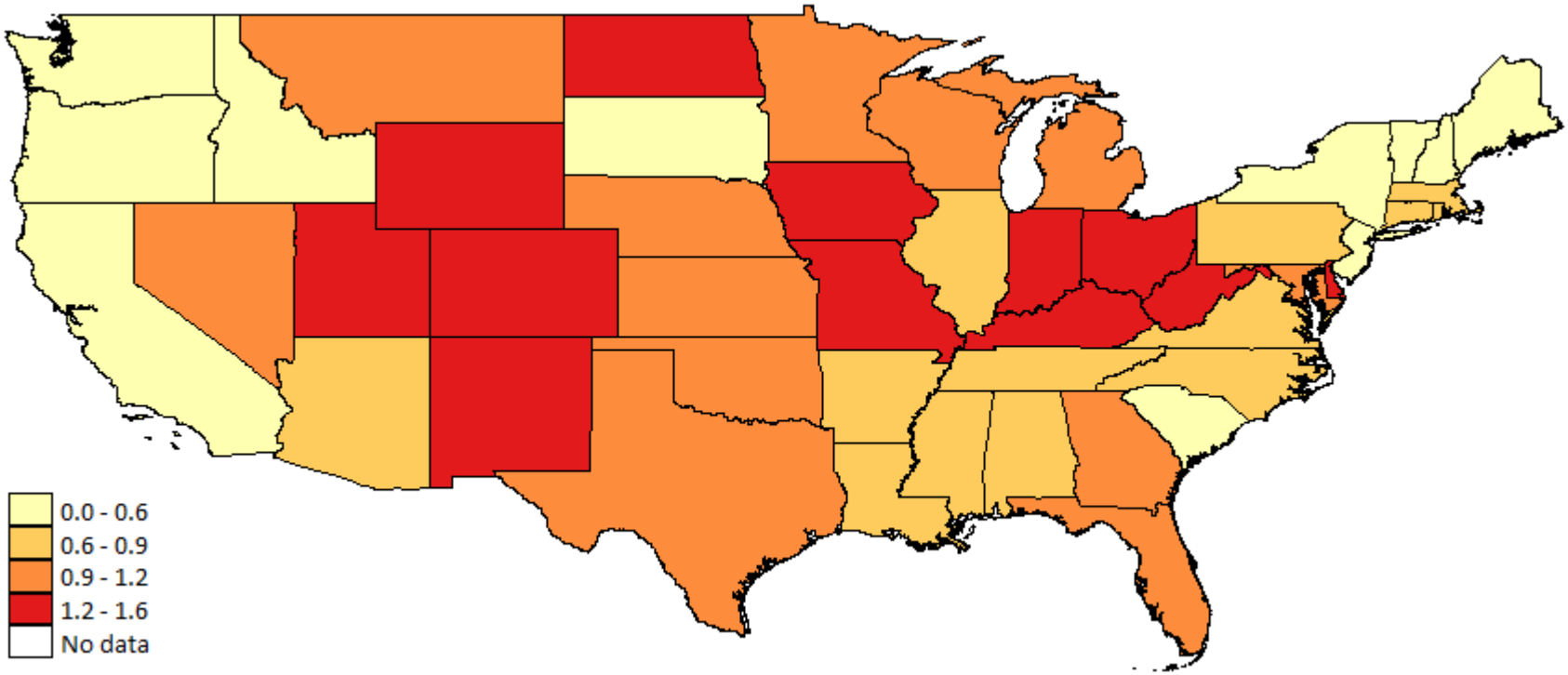
Using the price mechanism: a carbon tax

- Tax fossil fuels based on the carbon emitted when burned
  - *Example: $15 per ton of CO2*

- 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 CO2 fee



National average price is now about 9 cents per kWh

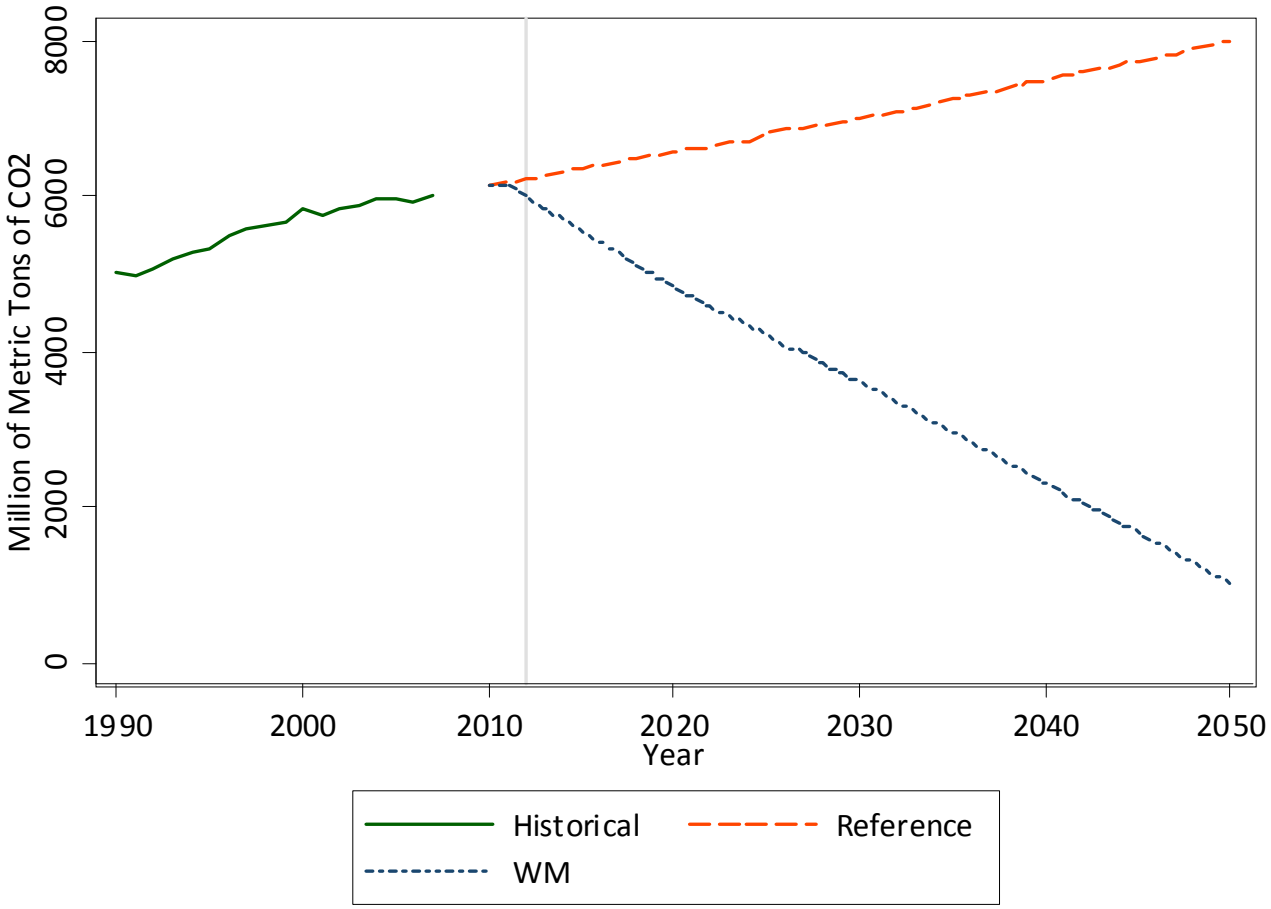
Alternative: a cap and trade system

- Fuel users must own 1 permit per ton of CO2
- Limit the number of permits
- Allow owners to buy and sell them

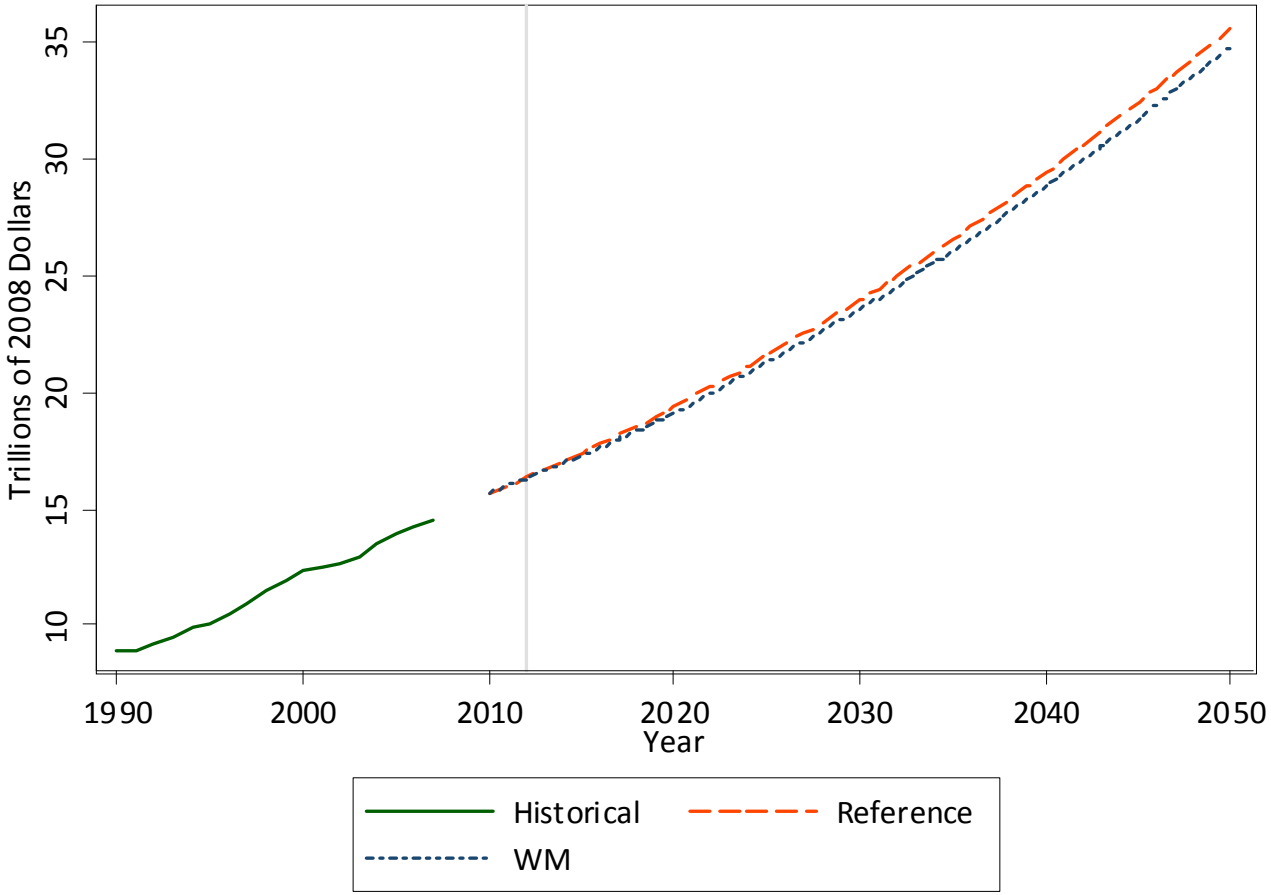
- Market price of a permit provides incentives
  - *Example: $15 per ton*
  - *Non-owners must buy; incentives similar to a carbon tax*
  - *Owners who can cut emissions for $10: profitable to cut and sell*

- 2009 Waxman-Markey House Bill
  - *Would have gradually reduced emissions by 83% by 2050*

Targets in 2009 Waxman-Markey Bill



Effect on GDP



Summary

- Controlling US CO2 emissions
  - *Requires major changes in the energy sector*
    - Eliminate 70 quads of fossil energy (70% of current supply)
    - Reduce emissions by 4.8 gigatons of CO2
- Will require substantial incentives
  - *Increase in fossil fuel prices*
    - Carbon tax
    - Cap and trade program
- Historical evidence is optimistic
  - *Energy prices strongly affect consumption*
  - *Overall economic growth effects are modest*

Where are we now?

- National cap and trade – dead or zombie?
  - *House passed HR 2454 in 2009*
  - *Senate version abandoned its version in 2010*
- Some prospects for limited policies
  - *Renewable electricity standard*
- EPA regulation likely
  - *Authority under the Clean Air Act*
  - *Congress may try to curtail authority or limit funding*
- Regional initiatives
  - *Northeast RGGI, California AB 32*