Class 4
Inertia and Responding To Climate Change

Climate Change

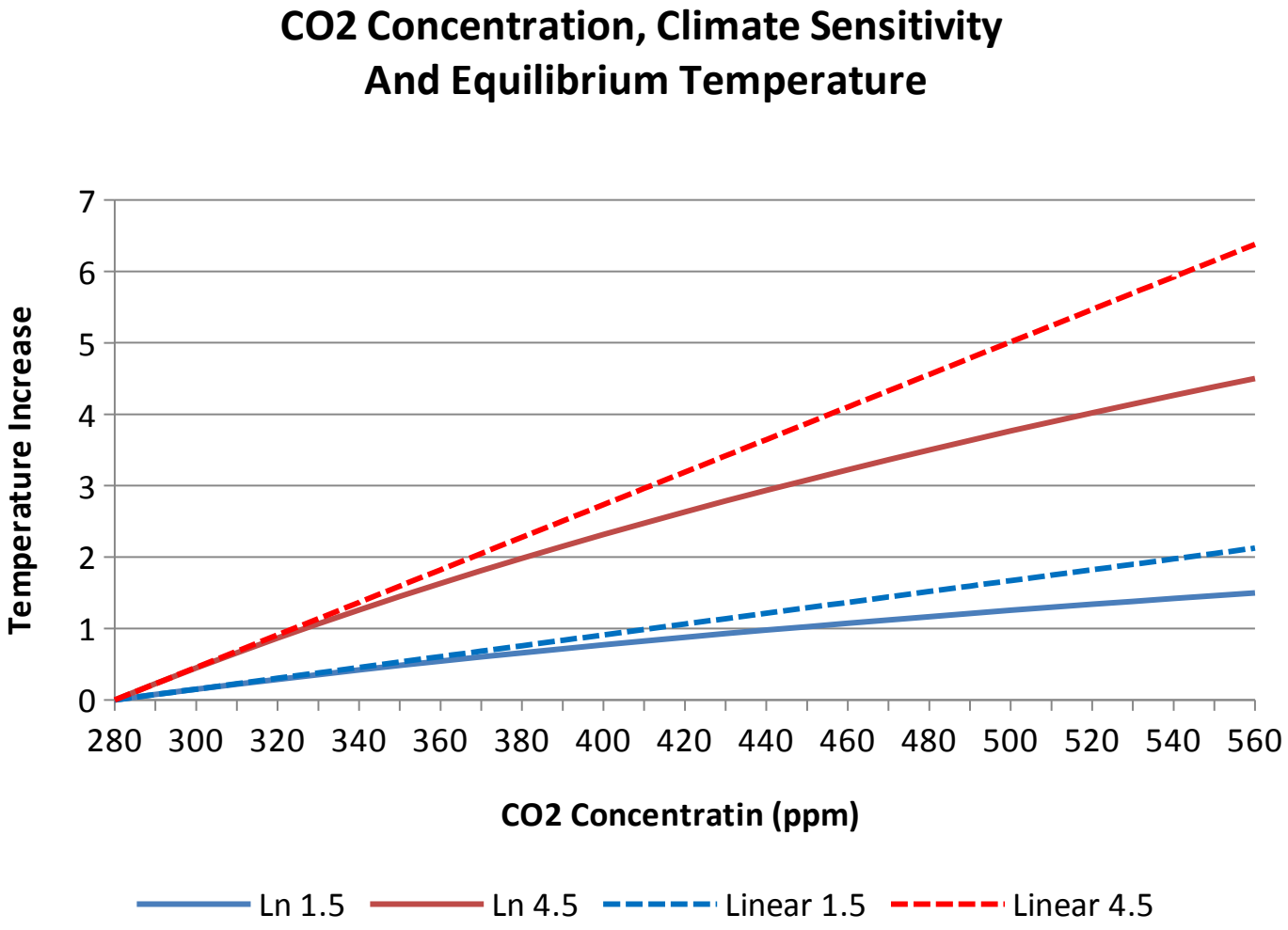
OLLI Summer 2013

Increase in Equilibrium Temperature Due to Increase in CO2 Concentration from 280 ppm

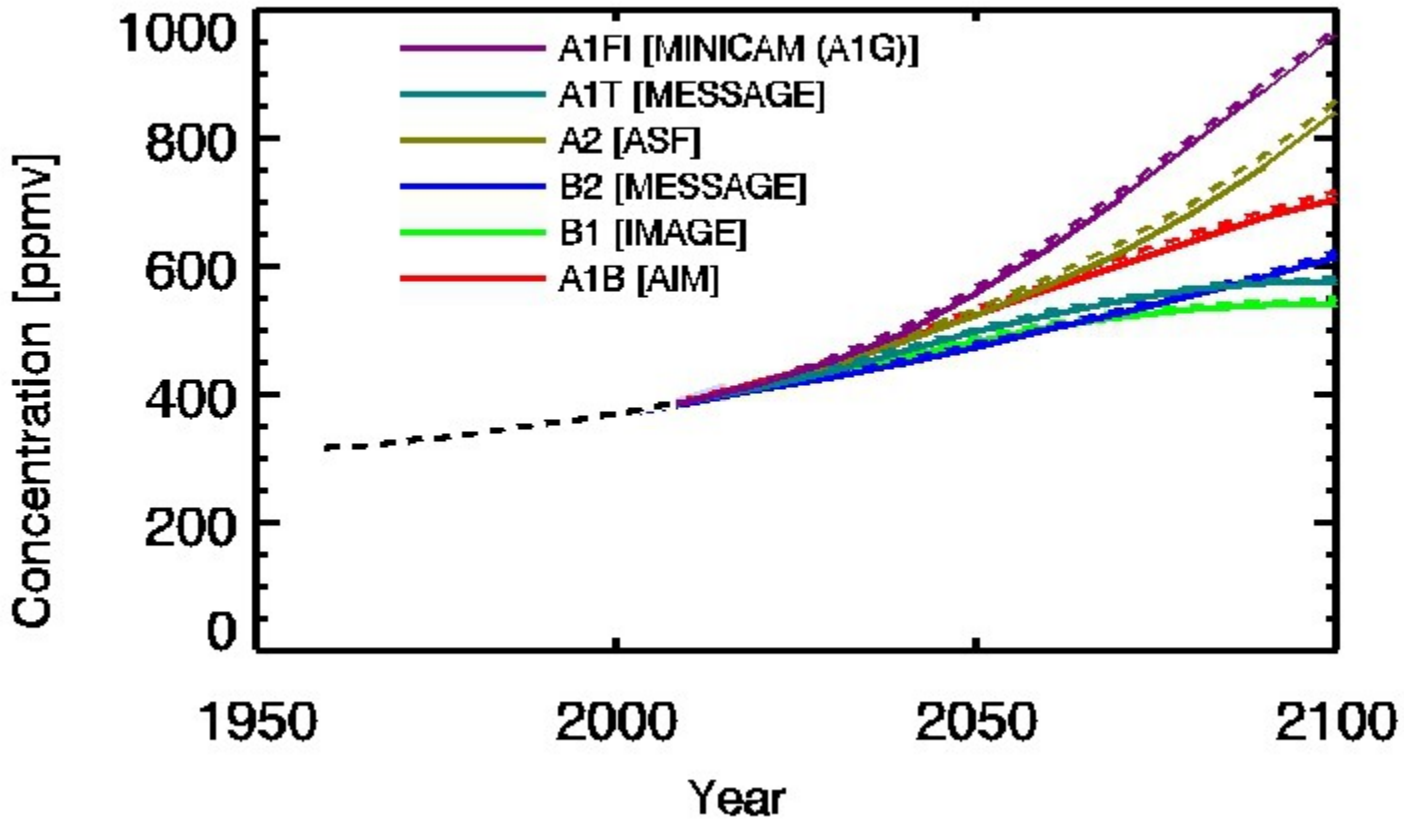
$$\Delta T = \Delta T2X * Ln(\text{new } CO2 \text{ concentration}/280 \text{ ppm concentration})/Ln(2.0)$$

$$Ln(2.0) = 0.69$$

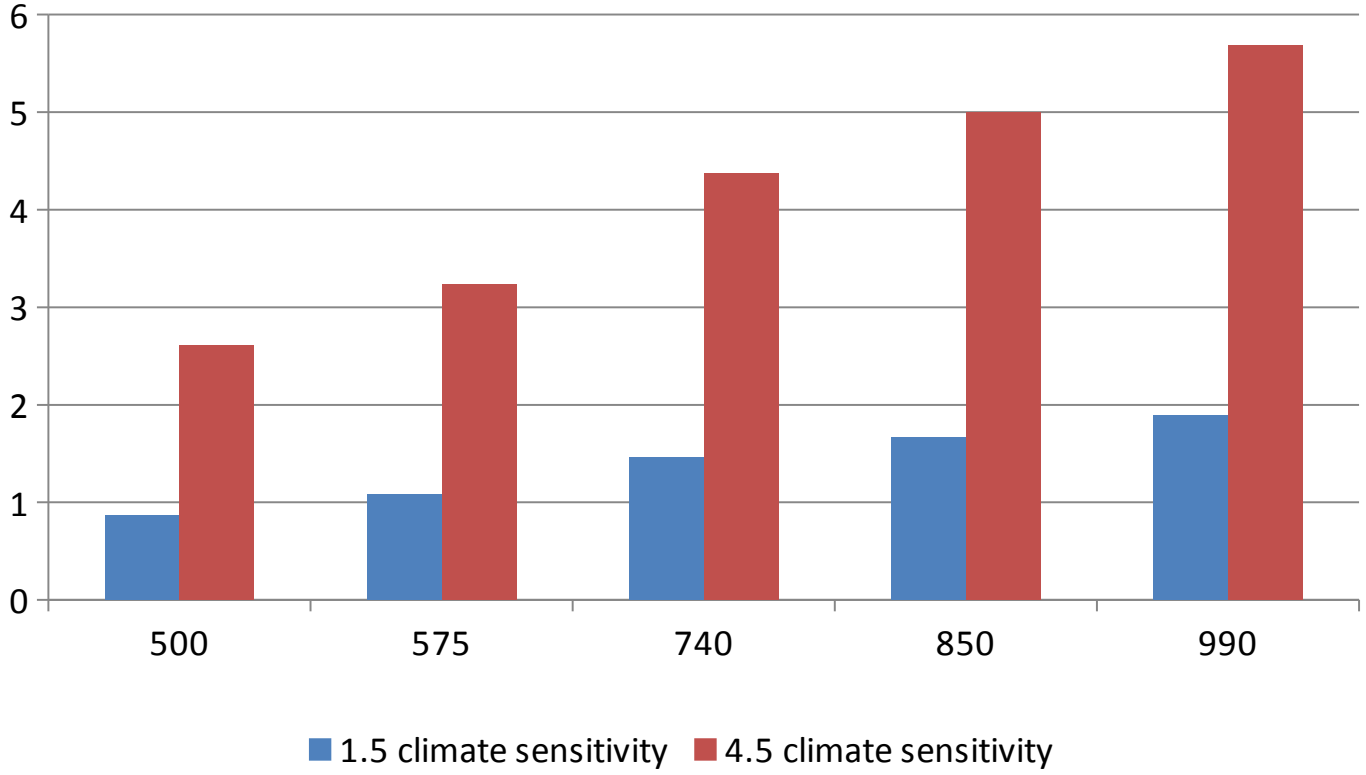
Current sensitivity estimate:
1.5o to 4.5o


CO2 Concentration, Climate Sensitivity
And Equilibrium Temperature
Temperature Increase
0
1
2
3
4
5
6
7
280
300
320
340
360
380
400
420
440
460
480
500
520
540
560
CO2 Concentratin (ppm)
Ln 1.5
Ln 4.5
Linear 1.5
Linear 4.5

2007 IPCC CO2 Scenario Projections



2100 Equilibrium Temperature Increase From Pre-industrial Level For Five IPCC Scenario CO2 Projections



What equilibrium temperature means: 740 ppm example

- Transient temperature
  - Temperature when concentration reaches 740 ppm

- Equilibrium temperature
  - Temperature when radiative forcing is zero at 740 ppm
  - Thermal radiation plus reflected solar radiation equals incoming solar radiation

Why the lag?
Near-term answer: Feedbacks

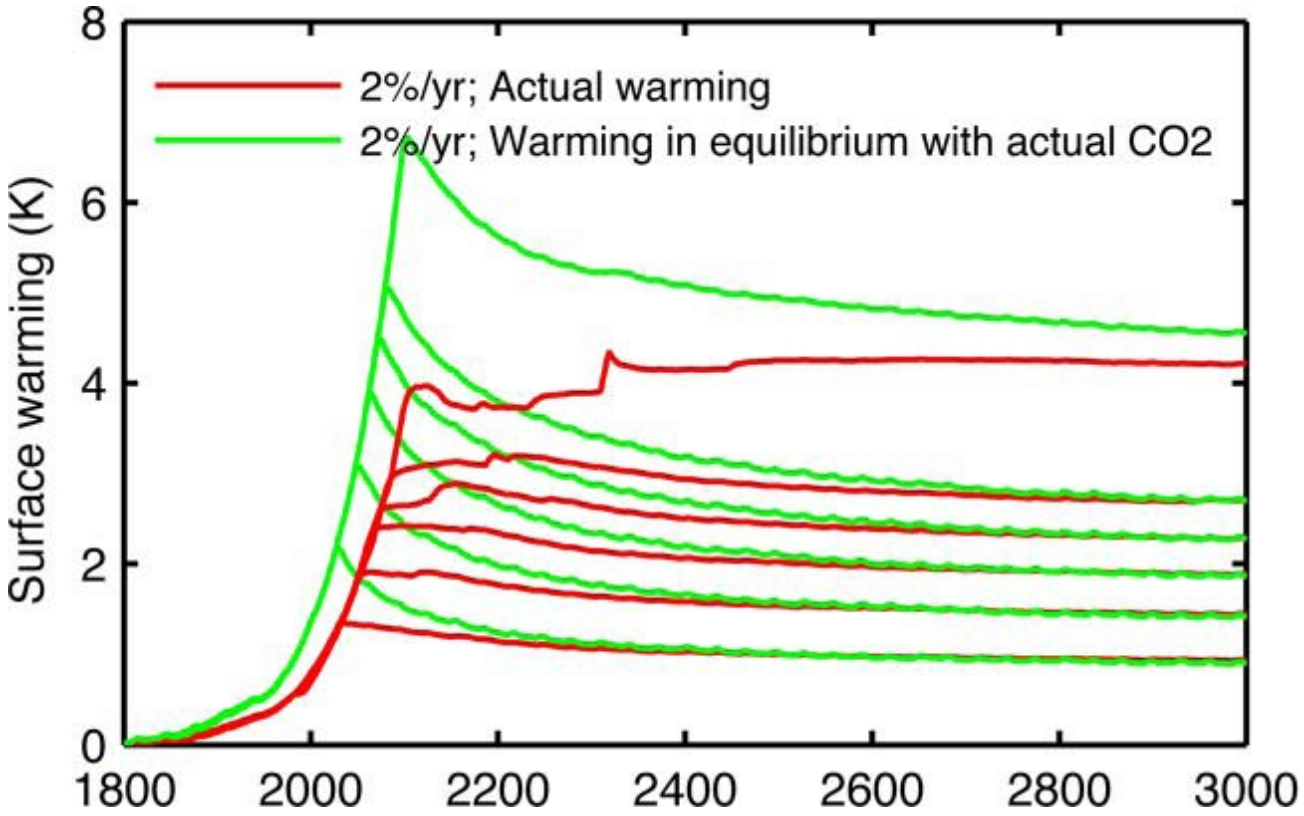
- Water vapor: near-instantaneous

- Longer: years to decades
  - Vegetation
  - Snow and ice cover
  - Carbon pools:
  - Soils and permafrost
  - Methane hydrates???

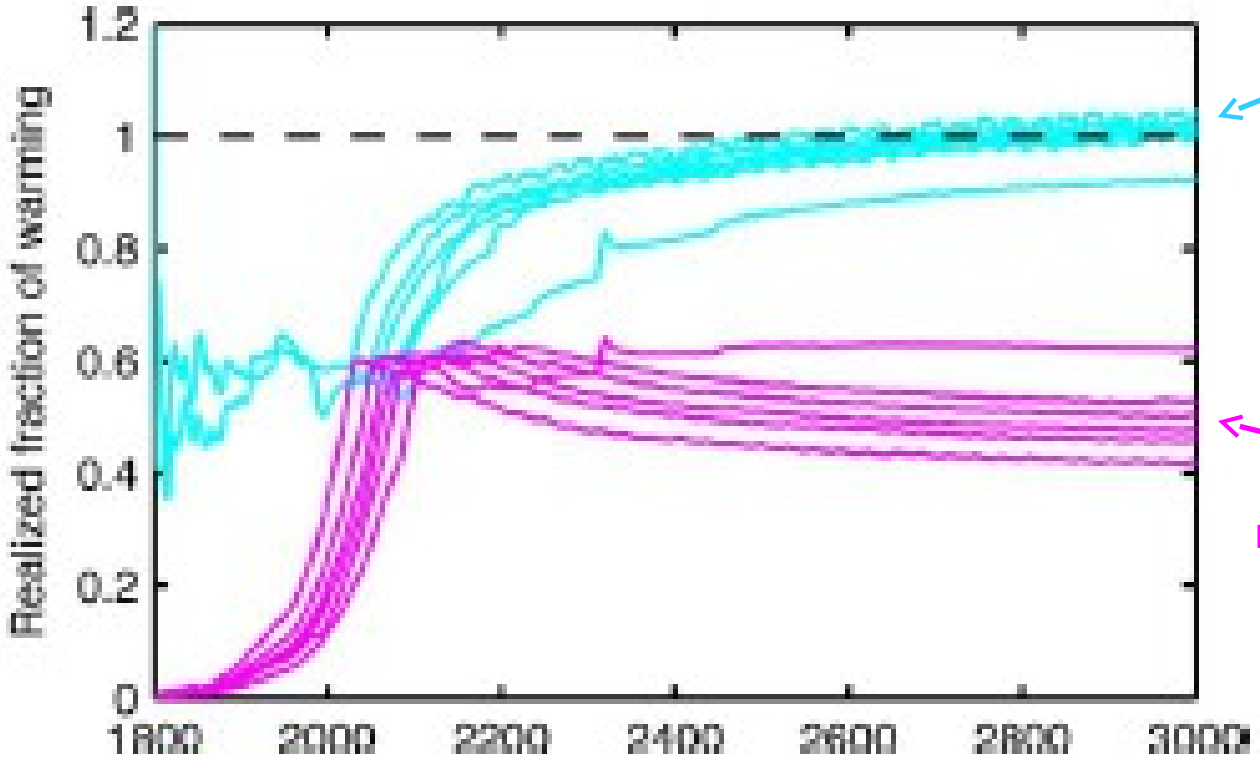
Long-Term Answer

- Time needed to achieve equilibrium between surface and deep ocean

- Necessary for both CO2 and temperature



Curves represent peak CO2 of 450, 550, 650, 750, 850 and 1200 ppm



Transient T/equilibrium T ratio

Ratio of temperature to equilibrium temperature for peak CO2

What's Happening?

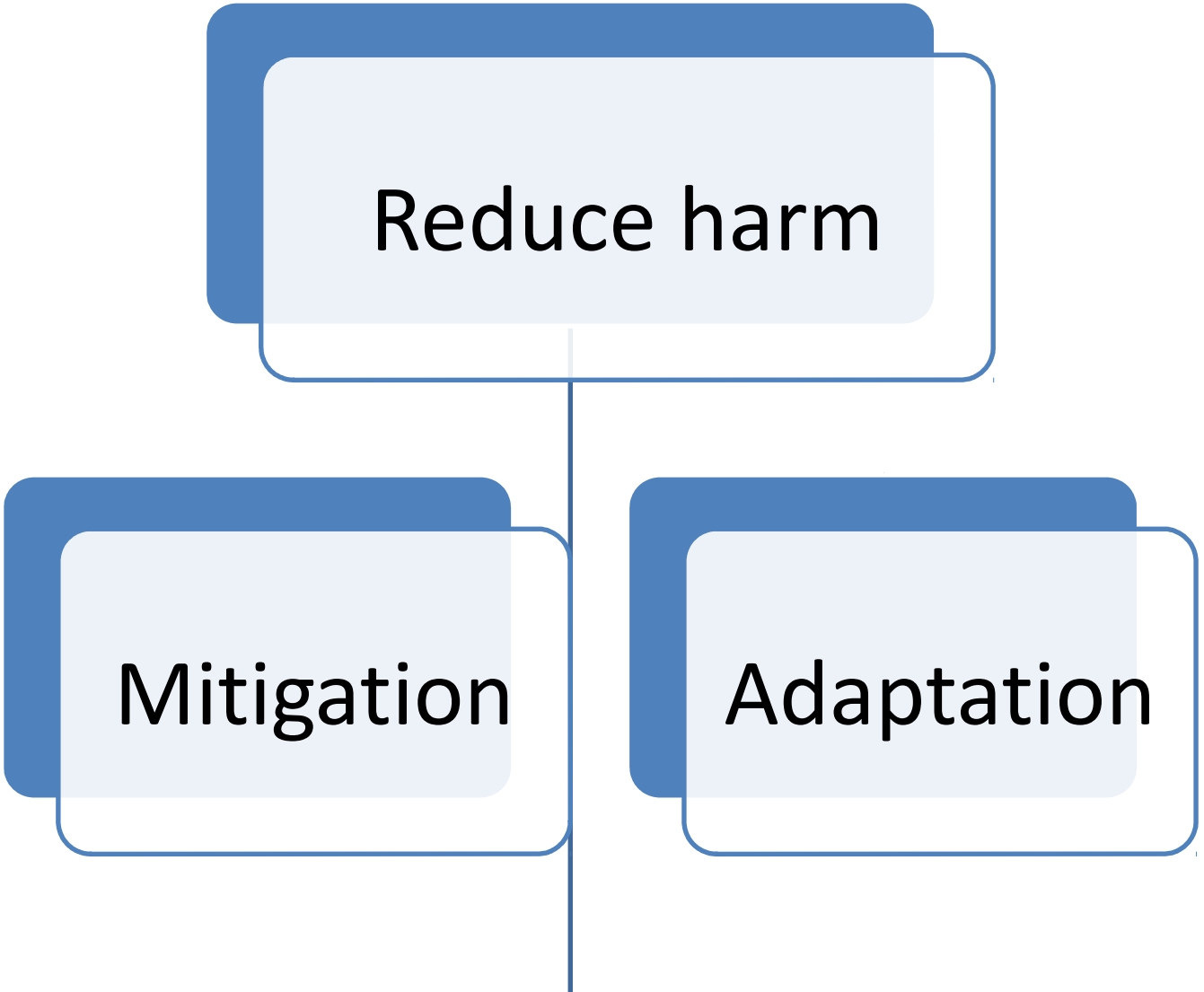
- At millennial time scale, CO2 largely equilibrates between ocean (~80%) and atmosphere (~20%)
  - Result: Radiative forcing reduced from peak
- But oceans gradually warm
  - Result: reduced transfer of heat to ocean
- Net result: near-constant temperature over millennium

What does 1000 years mean?

- 1000 years ago
  - William the Conqueror not yet born
  - Spanish Reconquista just beginning
- Irreversibility
  - Not technically irreversible: geological cycle
  - Irreversible in human terms
- Possible escapes
  - Net removal of CO2 from atmosphere
  - Radiation management

Doing something

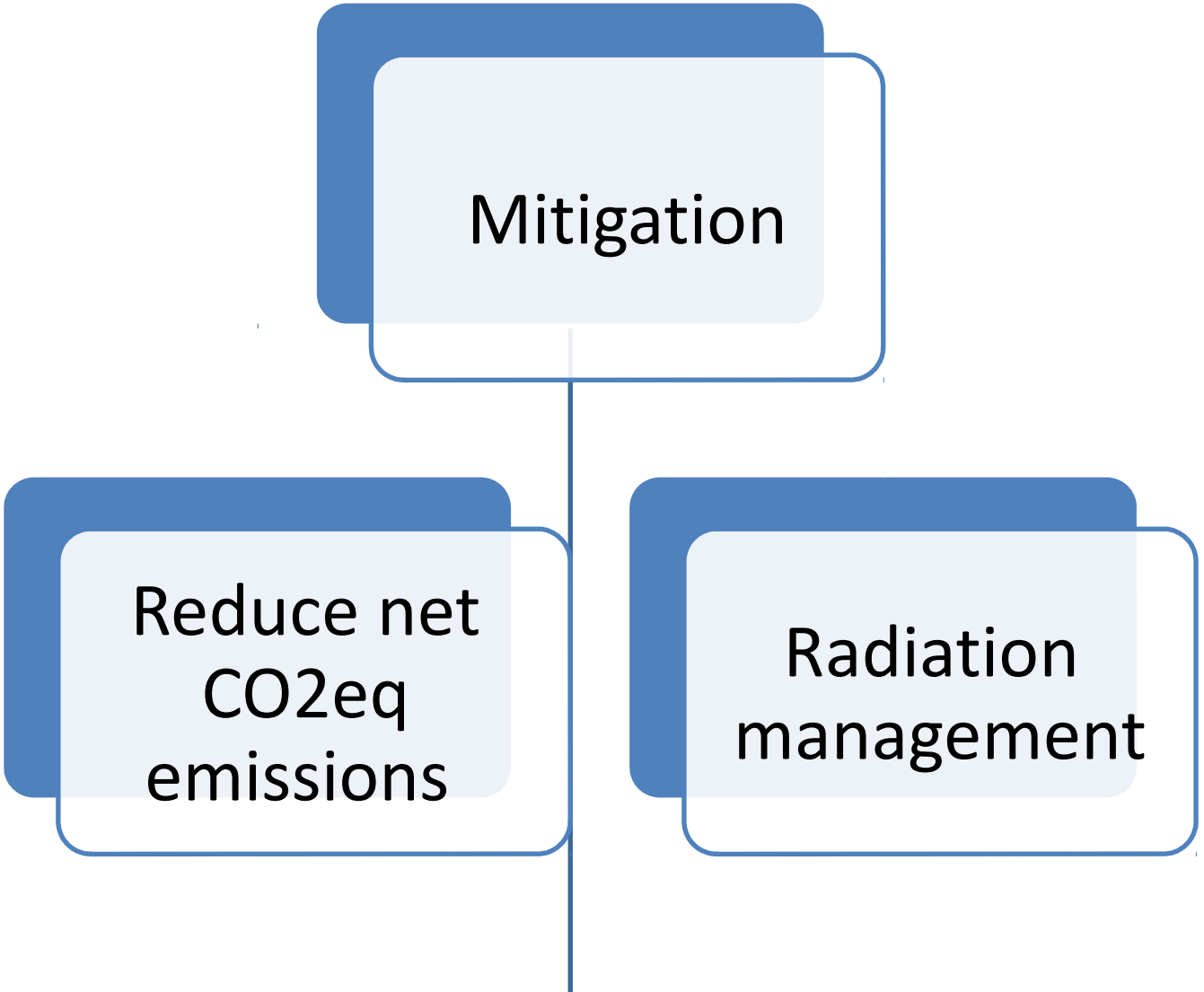
The Basic Alternatives



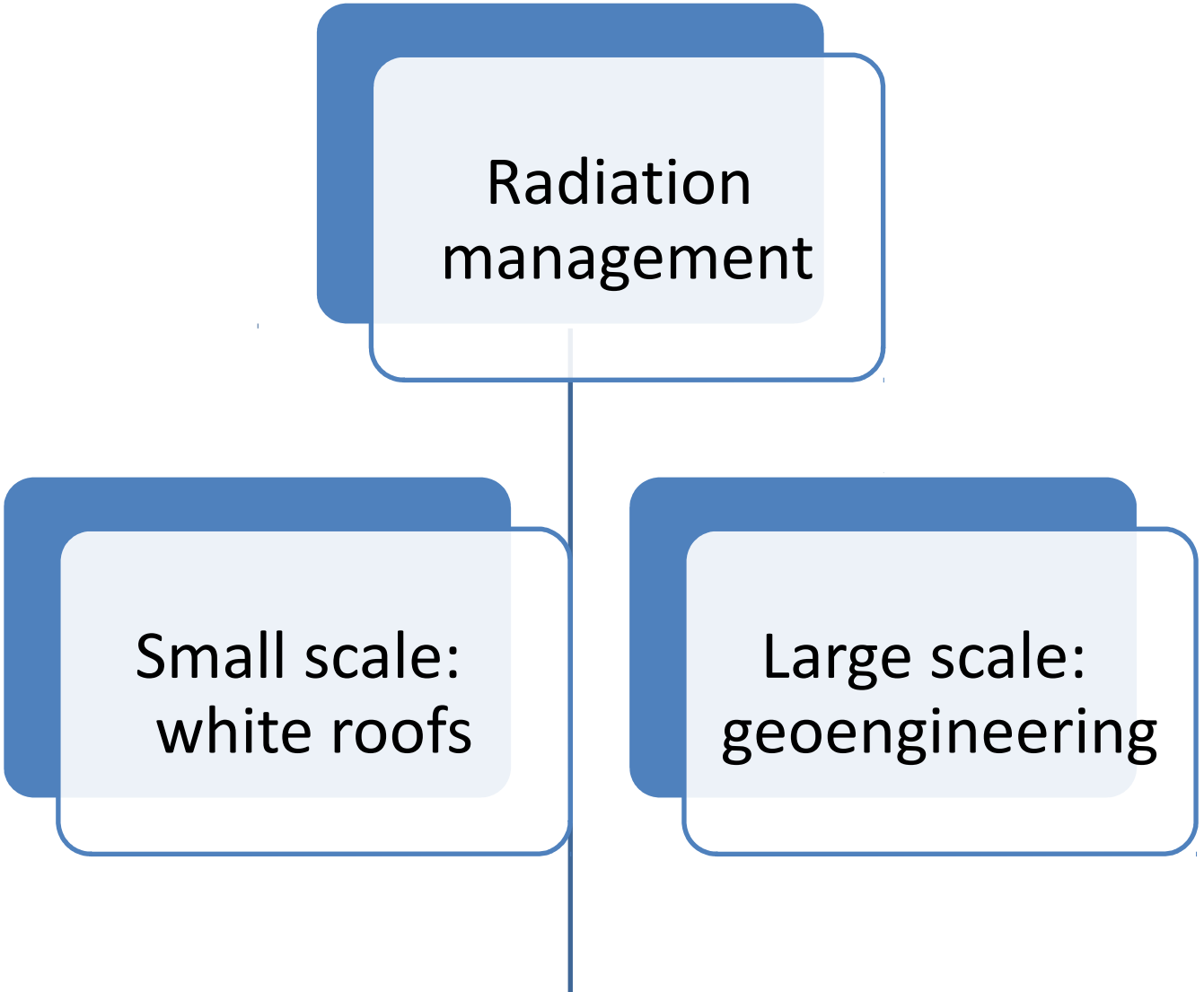
Mitigation Alternatives: Planet Keeling

- Stabilize temperatures
  - Stabilize atmospheric CO2:
  - Emissions must not exceed absorption
  - Natural and anthropogenic on both sides of balance
  - Offset increasing greenhouse effect with increasing albedo: geoengineering
- Undo warming
  - Same tools
  - Must achieve negative radiative forcing

What Actions?



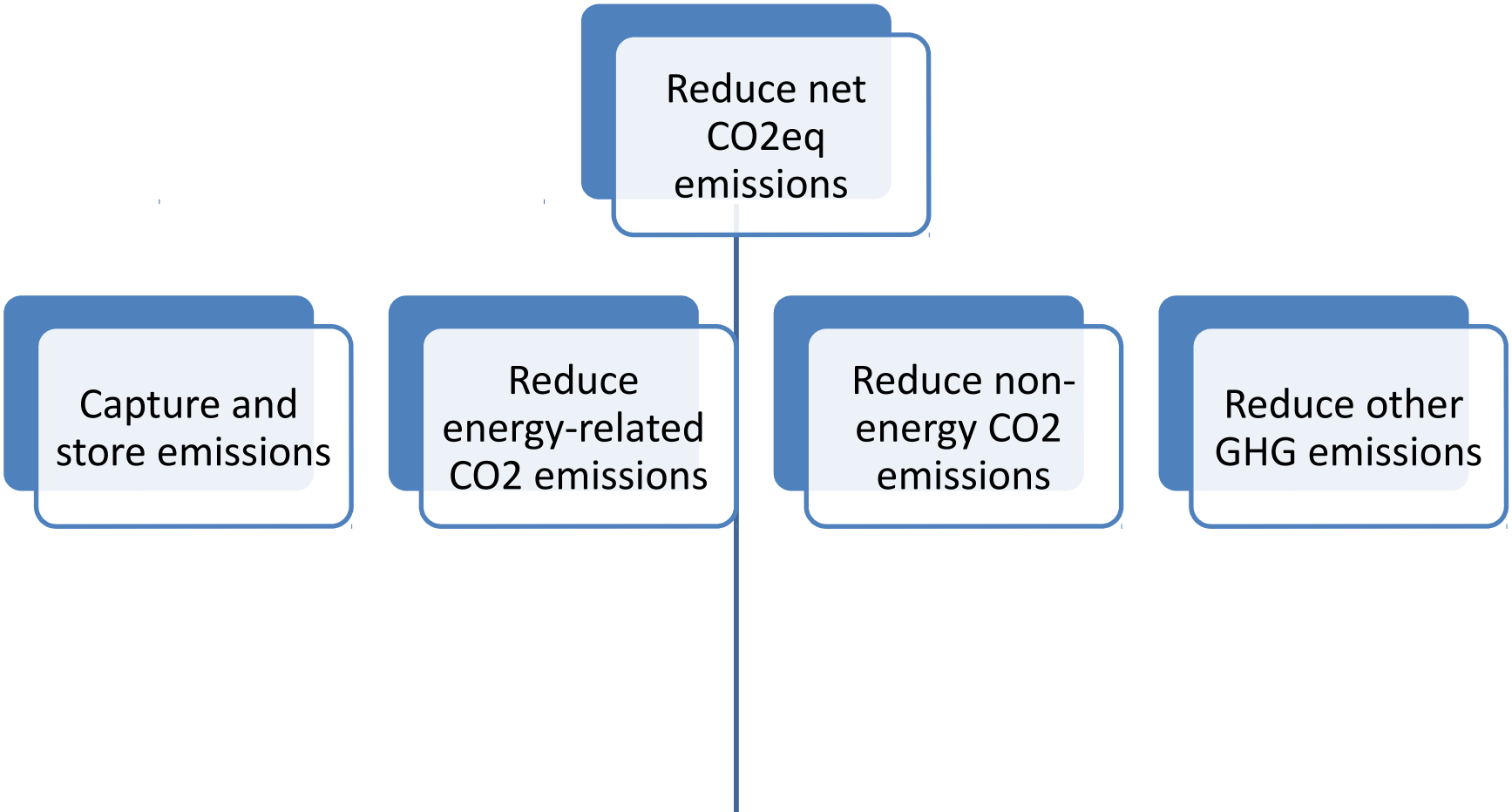
What Actions?



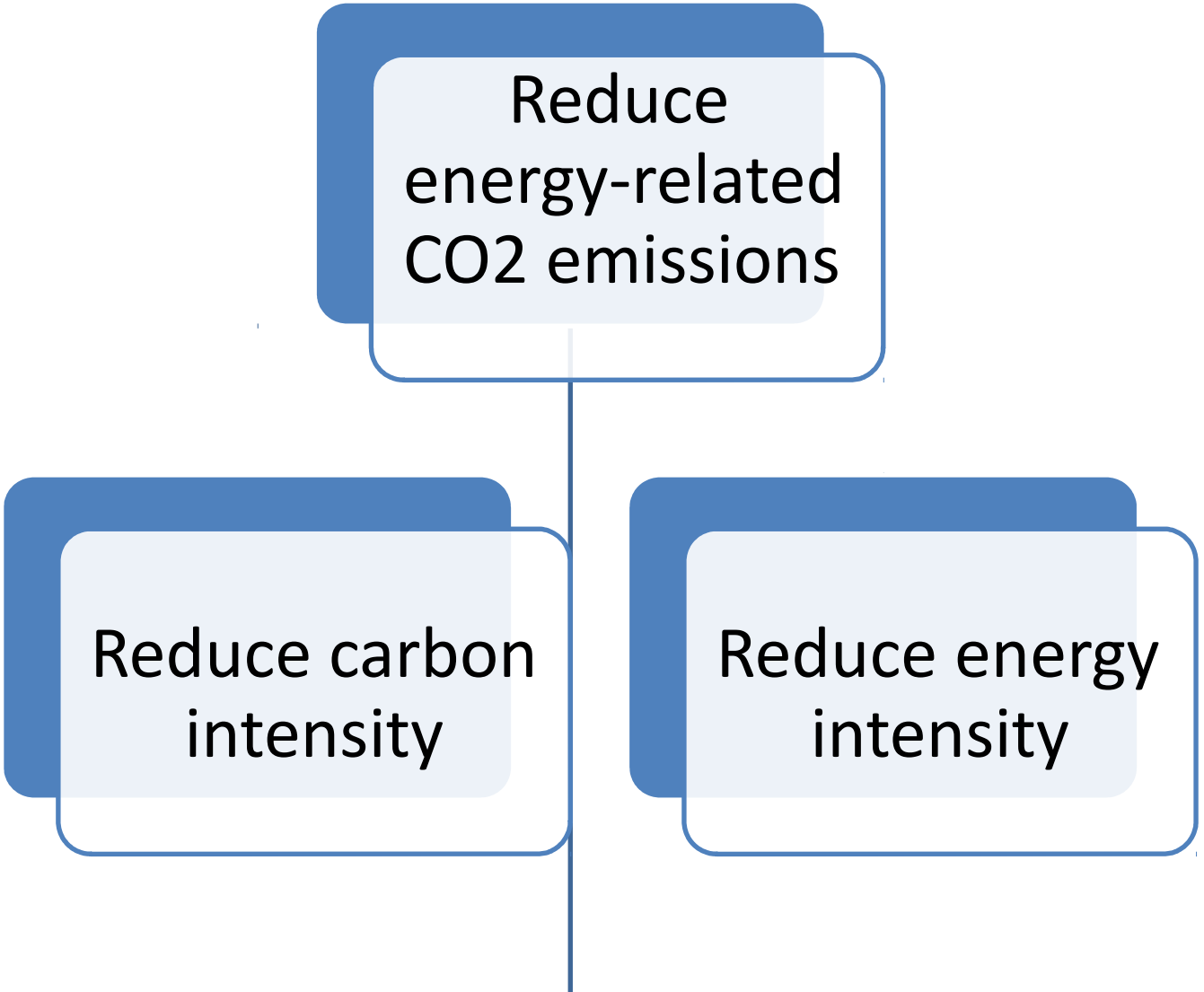
Geoengineering

- Leading candidate: inject sulfate aerosols into stratosphere
  - Like continuous volcanic eruptions
- Advantages
  - Relatively cheap
  - Only known alternative to:
  - Reduce global temperatures on human time scale
  - Quickly stabilize global temperature
- Problems
  - Stabilizes global average temperate
  - Sole reliance creates growing temperature overhang
  - Unknowns

What Actions?



What Actions?



Classifying Determinants of Energy-Related CO2 Emissions

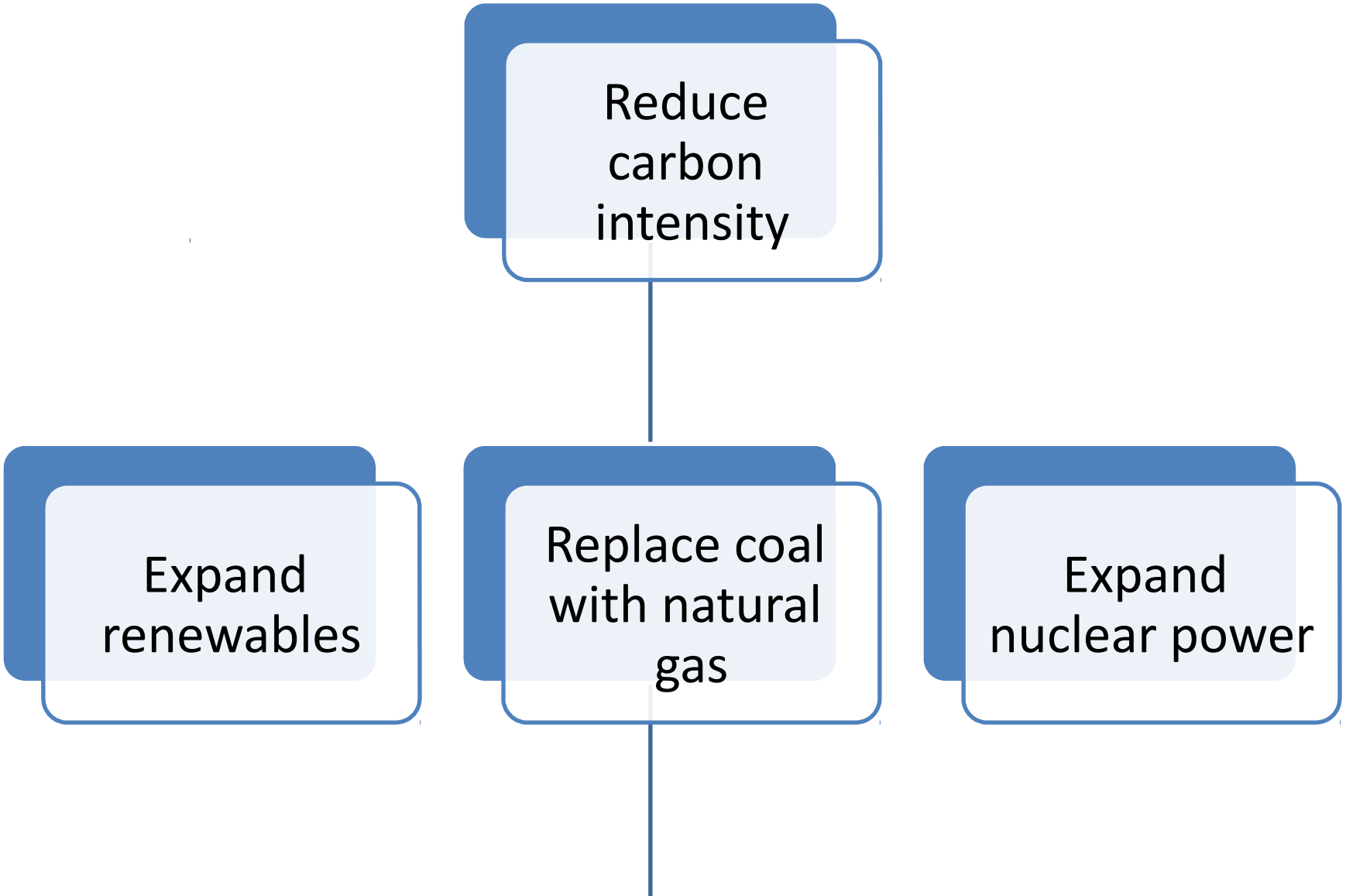
- Energy intensity: (Energy consumed)/(value of output), e.g., Gigajoules/$$

- Carbon intensity: (Carbon emissions)/(energy consumed), e.g., (Kg of CO2)/GJ

Example:
Plug-In Electric Vehicles

- Energy intensity
  - Energy consumed in generating electricity to move vehicle one mile
  - Reduced by more efficient generation or vehicle
- Carbon intensity
  - How is the electricity generated
  - Reduced by replacing fossil fuels with nuclear or renewables or replacing coal with natural gas

What Actions?



Jim Hansen and Nuclear Power

“Can renewable energies provide all of society’s energy needs in the foreseeable future? It is conceivable in a few places, such as New Zealand and Norway. But suggesting that renewables will let us phase rapidly off fossil fuels in the United States, China, India, or the world as a whole is almost the equivalent of believing in the Easter Bunny and Tooth Fairy.”

http://www.youtube.com/watch?v=CZExWtXAZ7M

Expanding Renewables

- The easy part: massive increase in electricity generated by solar and wind

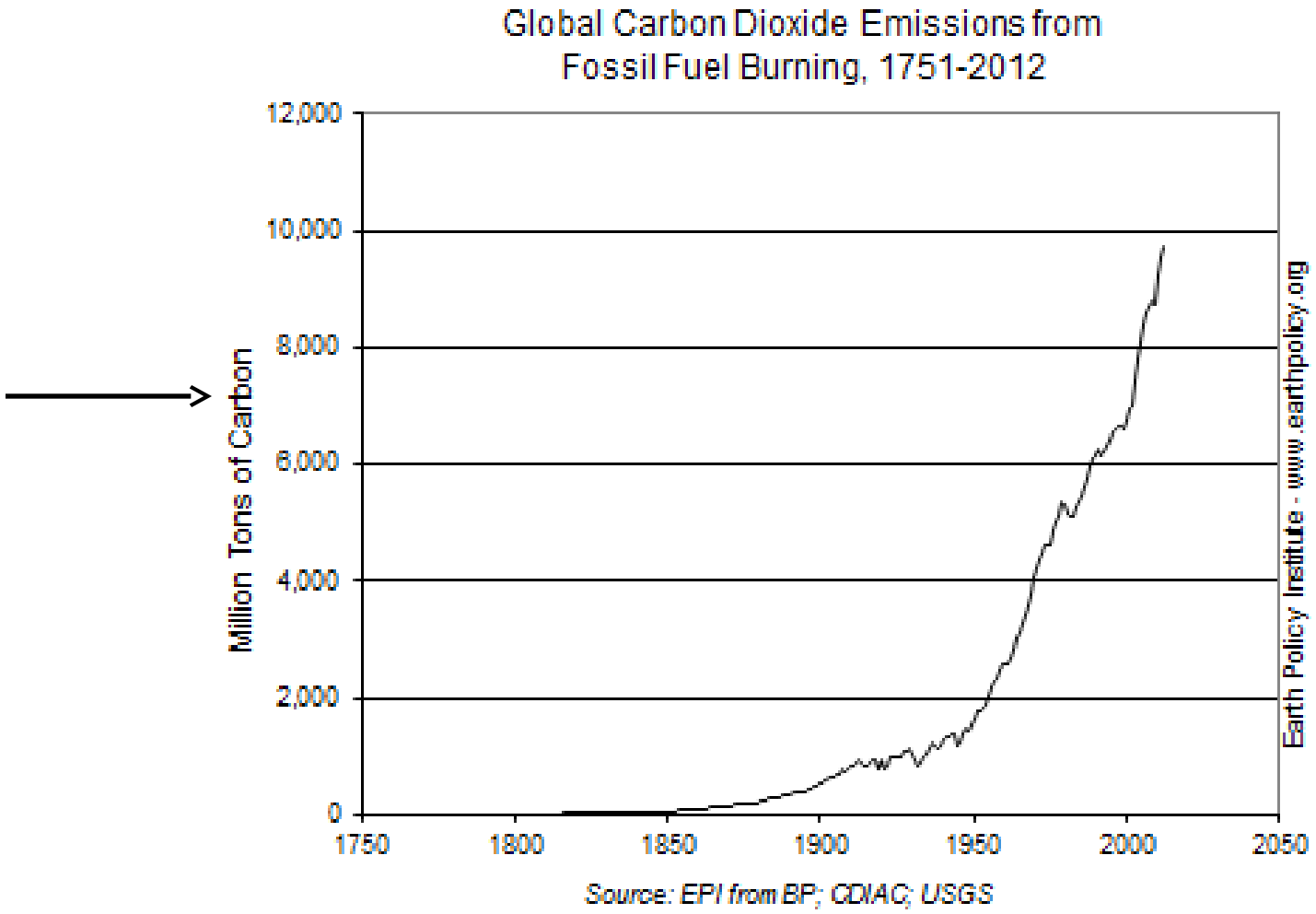
- The hard part: providing
  - Round-the-clock electricity
  - Energy for mobile sources

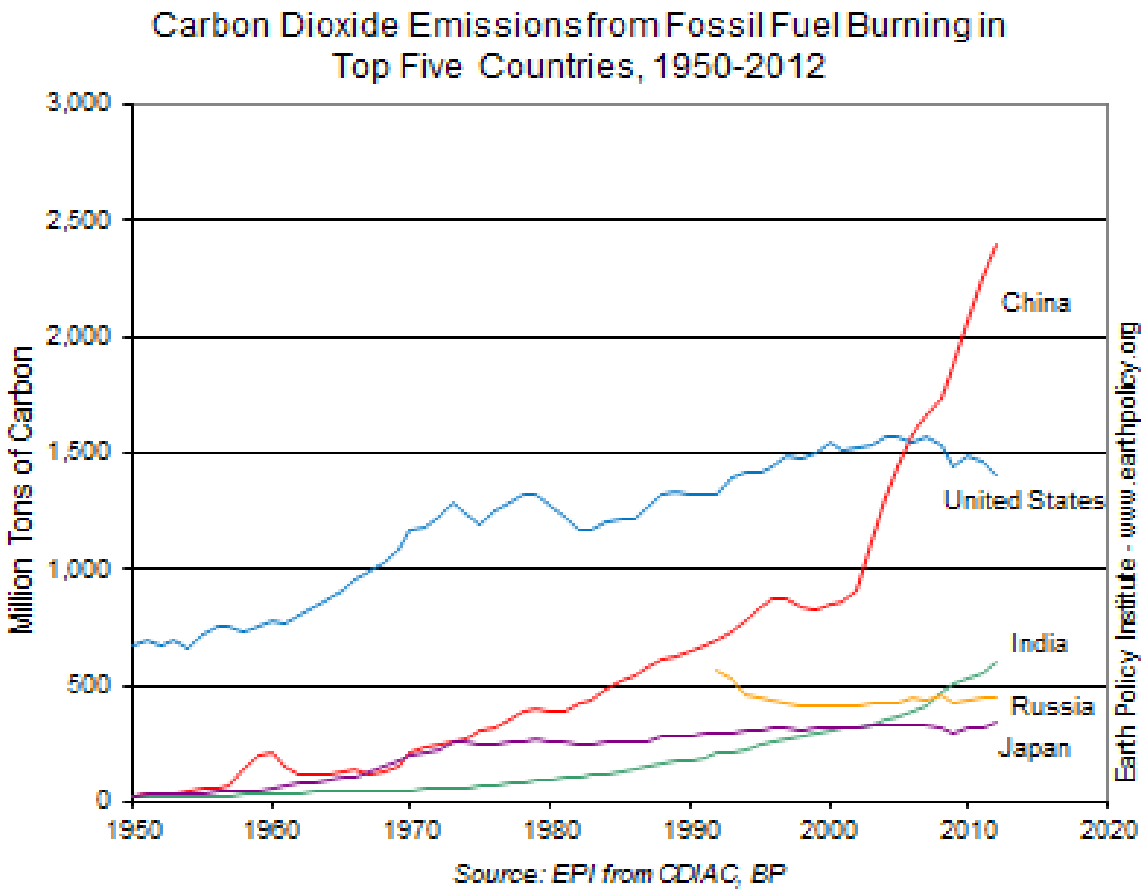
Providing 24/7 Electricity

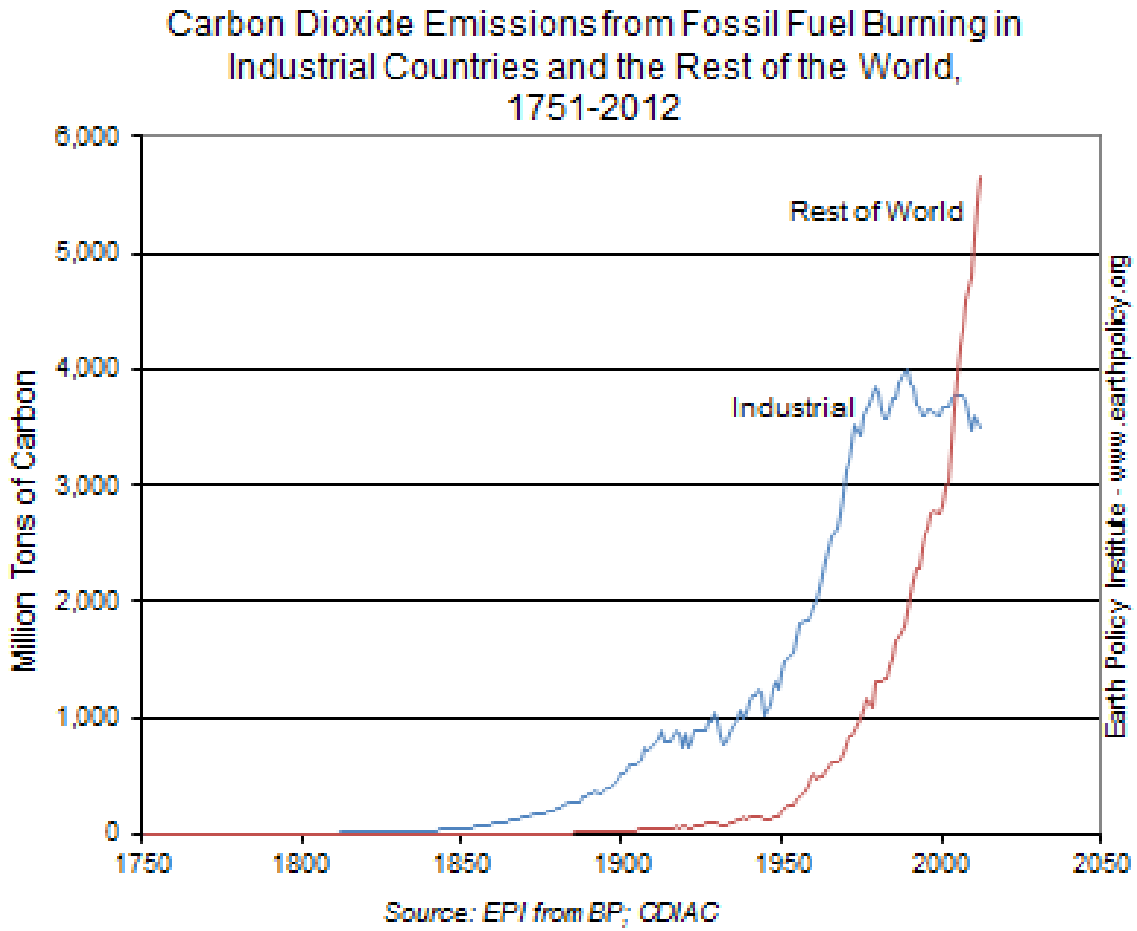
- "Solar (or wind) is cheaper than nuclear" – doesn't address the issue
- Alternatives
  - Wind and solar plus energy storage
  - Fossil fuels plus carbon capture and storage
  - Nuclear power
- Issues:
  - Technical feasibility within the chosen time frame
  - Comparative economic cost
  - Environmental impacts

The International Dimension

- OECD: most atmospheric CO2 inventory
- Non-OECD: largest and growing share of current emissions
- Standard of living – energy – CO2 link


Global Carbon Dioxide Emissions from Fossil Fuel Burning, 1751-2012
Million Tons of Carbon
12,000
10,000
8,000
6,000
4,000
2,000
0
1750
1800
1850
1900
1950
2000
2050
Earth Policy Institute - www.earthpolicy.org
Source: EPI from BP; CDIAC; USGS


Carbon Dioxide Emissions from Fossil Fuel Burning in Top Five Countries, 1950-2012
Million Tons of Carbon
3,000
2,500
2,000
1,500
1,000
500
0
1950
1960
1970
1980
1990
2000
2010
2020
China
United States
India
Russia
Japan
Earth Policy Institute - www.earthpolicy.org
Source: EPI from CDIAC, BP

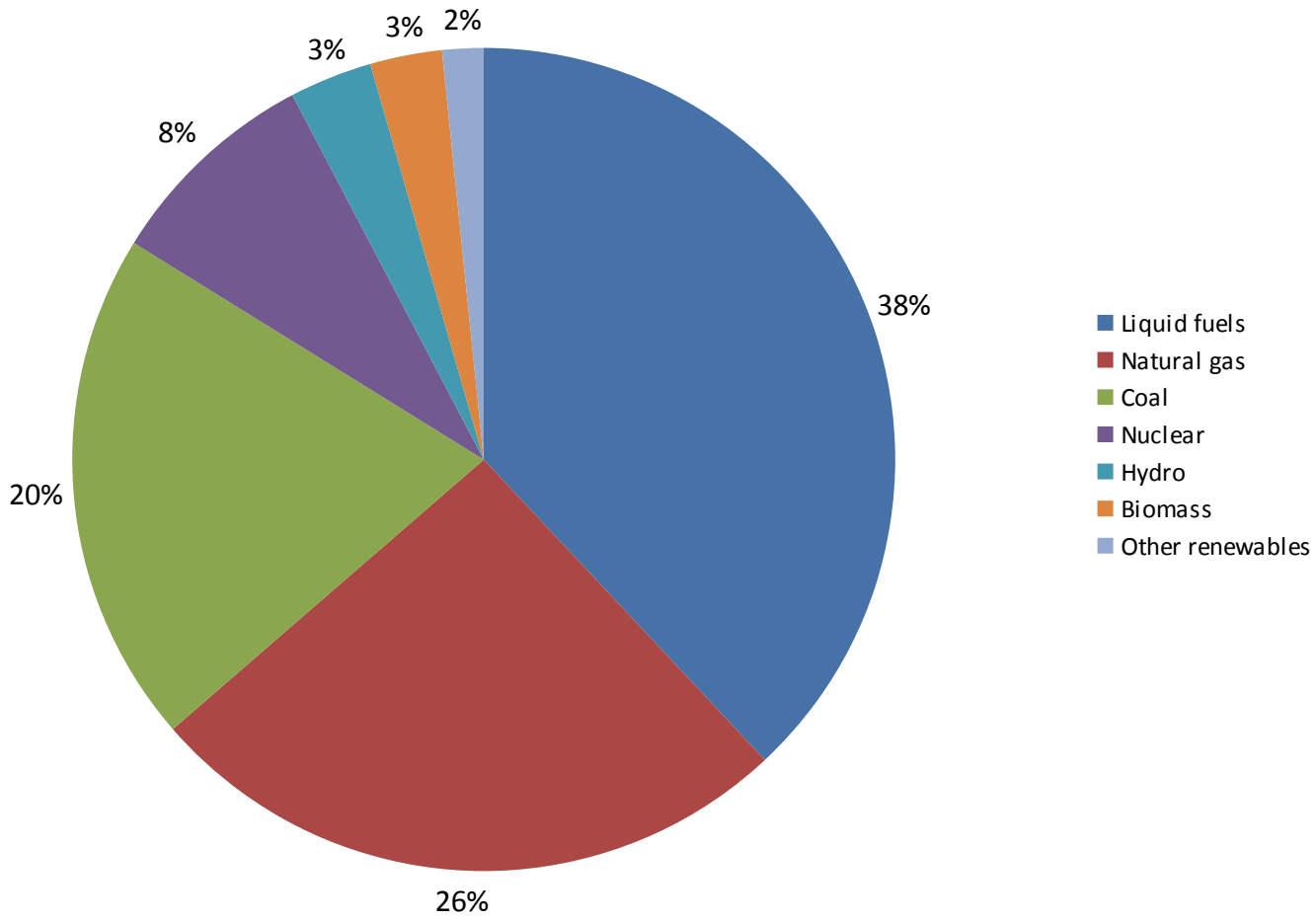

Carbon Dioxide Emissions from Fossil Fuel Burning in Industrial Countries and the Rest of the World, 1751-2012
Million Tons of Carbon
6,000
5,000
4,000
3,000
2,000
1,000
0
1750
1800
1850
1900
1950
2000
2050
Rest of World
Industrial
Earth Policy Institute - www.earthpolicy.org
Source: EPI from BP; CDIAC

United states

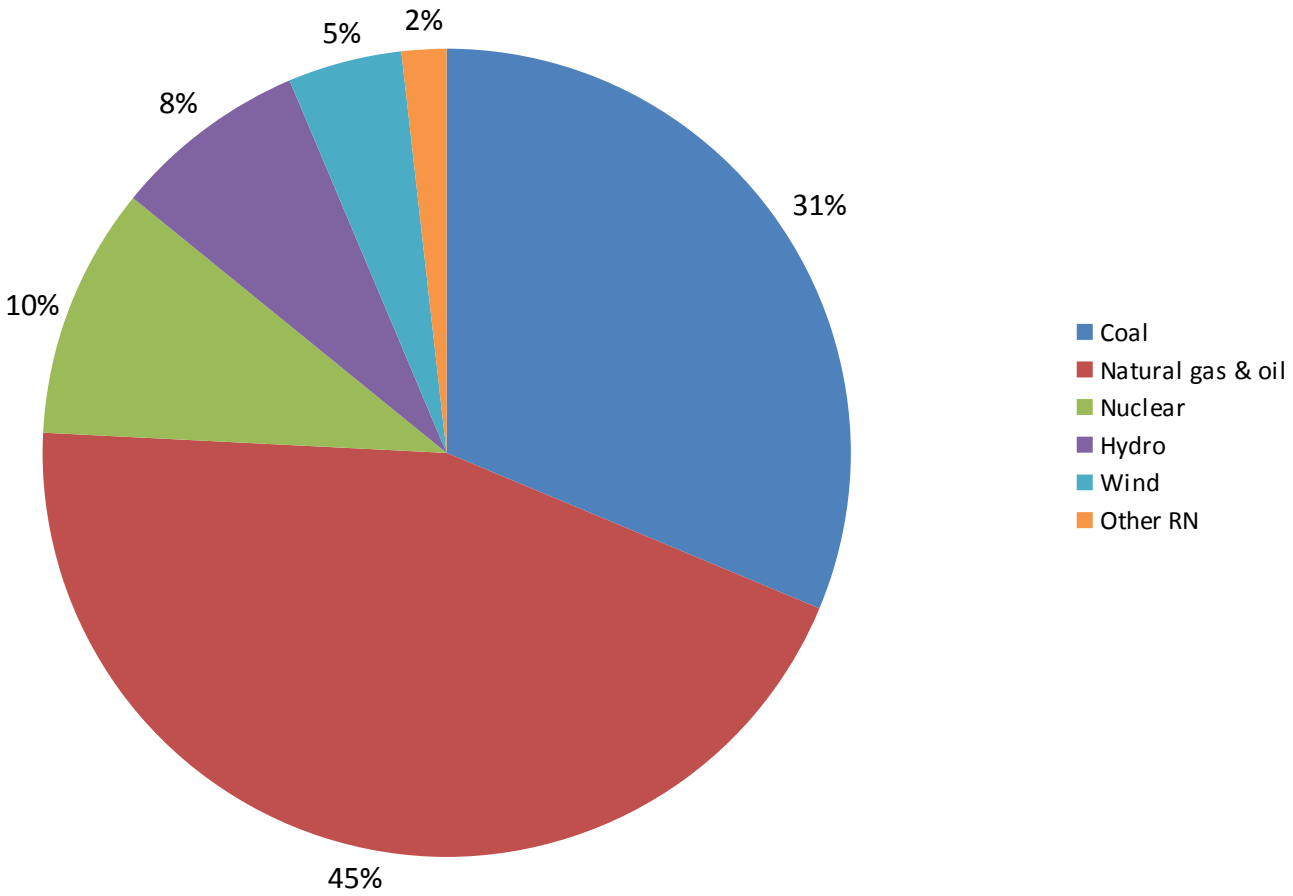
U.S. Compared with. World

- CO2
  - More important: 85% vs. 77%
  - Larger share from fossil fuels
  - Land use changes not a net source
  - Cement production less important
- Methane (CH4) and nitrous oxide
  - Less important – linked to agriculture's smaller role
- The moral: For US, primary focus on fossil fuels

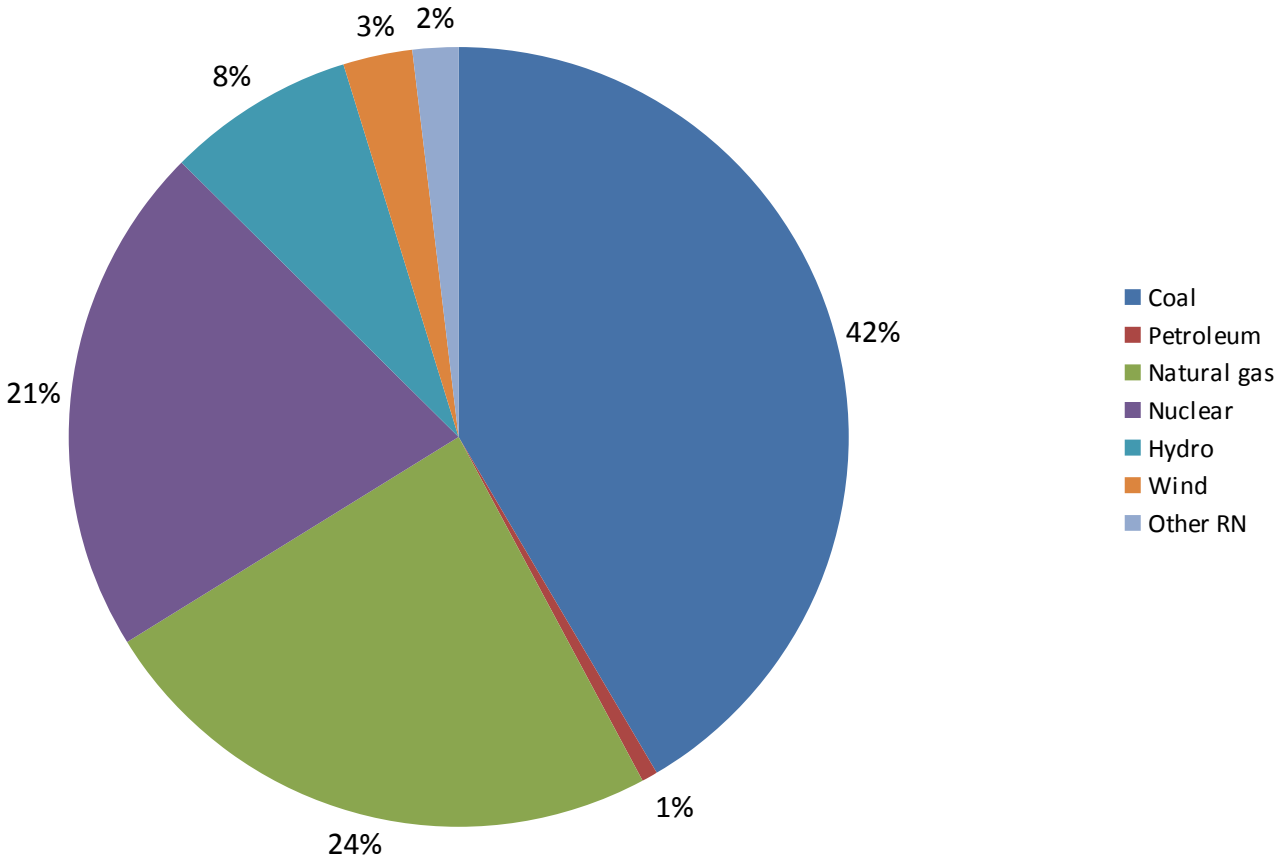
2011 Share of Primary Energy



2011 Share of Generating Capacity



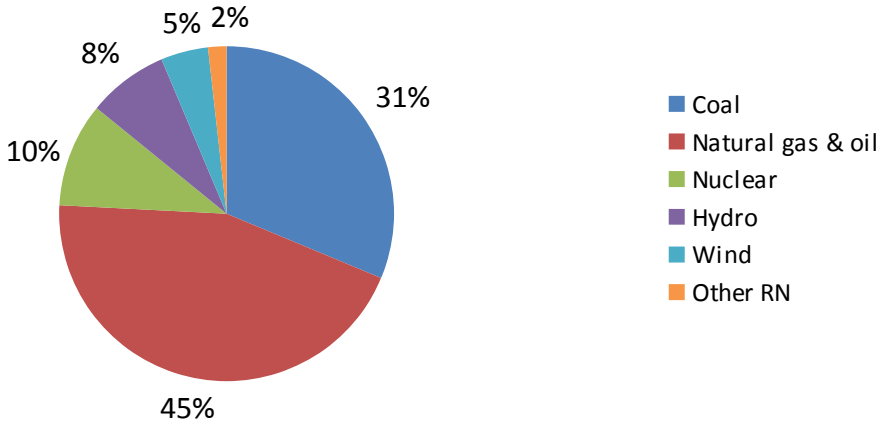
2011 Share of Generation

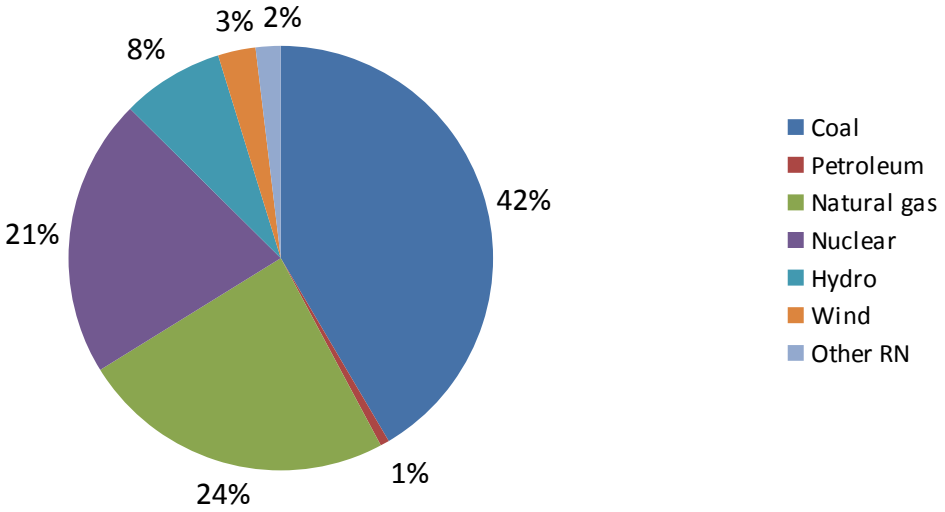


Points To Note

- Renewable sources' importance in economy and in electricity
- Technologies' shares of capacity and generation
- Petroleum's tiny role: price determined by superiority as transportation fuel

Capacity Share vs. Generation Share

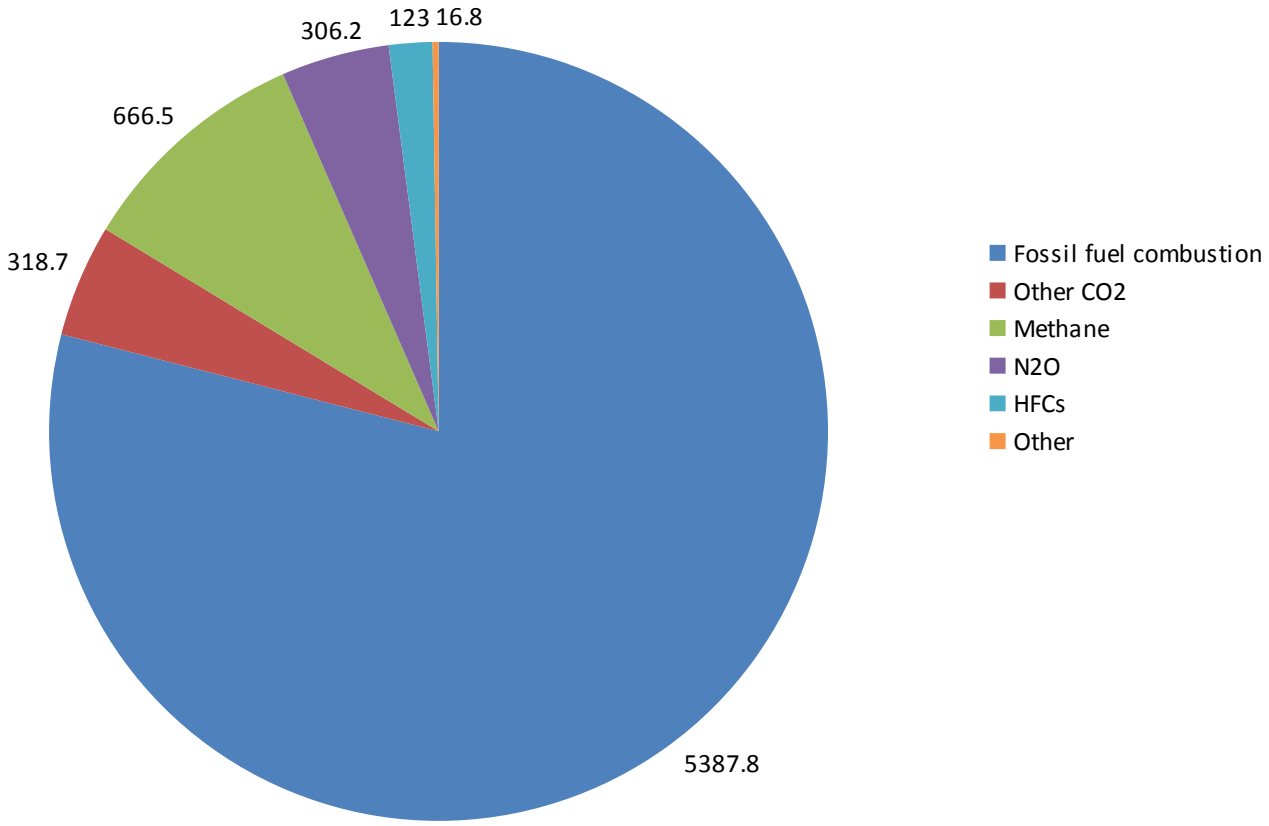


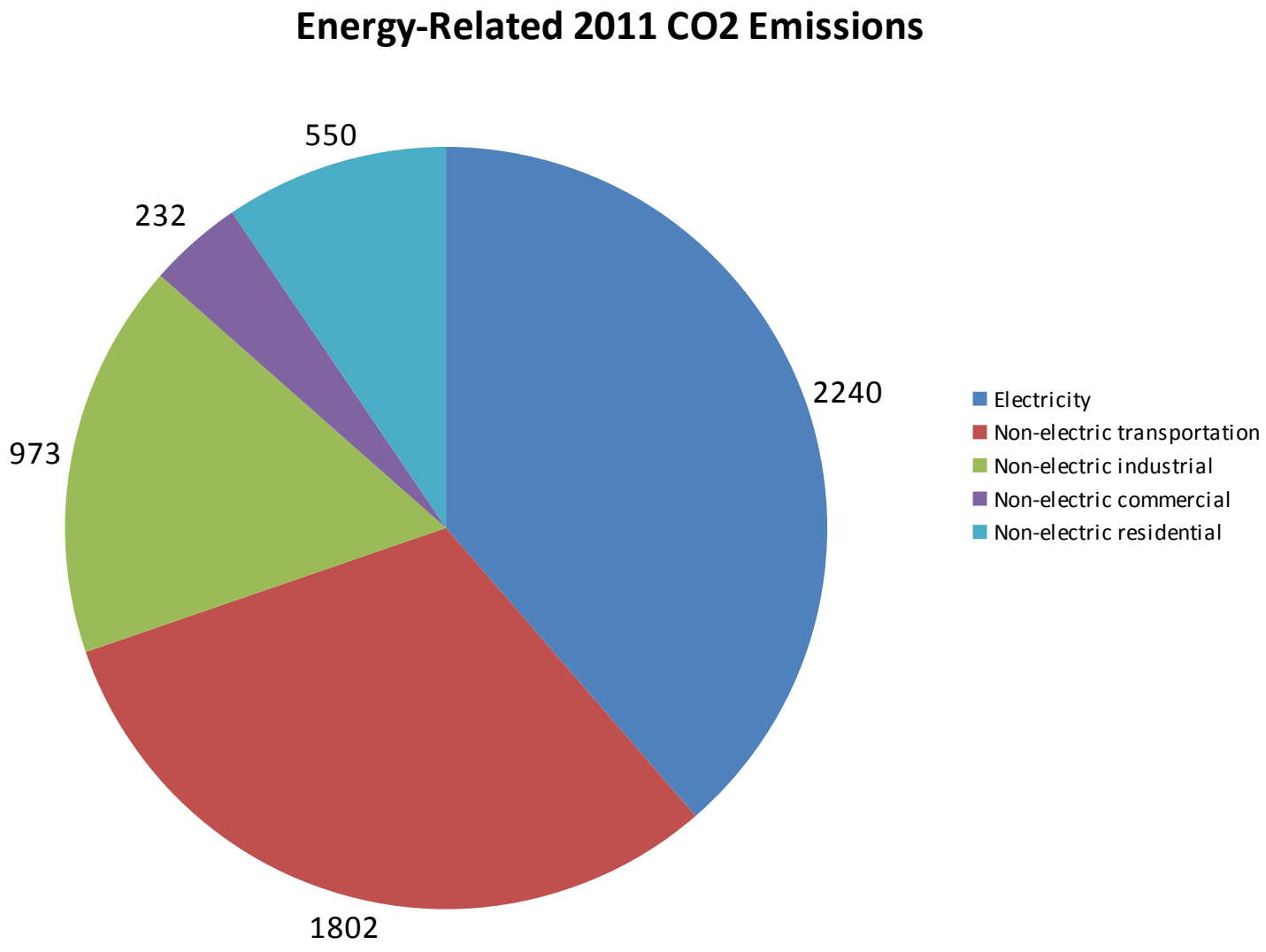


2006-2011 Growth

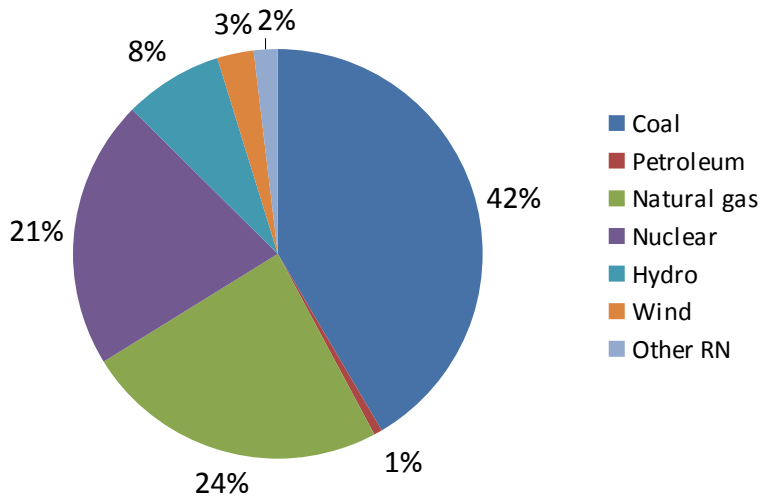
	Billions of kWh	Annual growth rate
Total generation	42.00	0.2%
RN generation	150.16	7.0%
Hydro	39.26	2.6%
Wind	94.02	35.9%
PV	5.24	66.8%

US GHG Emissions 2010: Gigatons

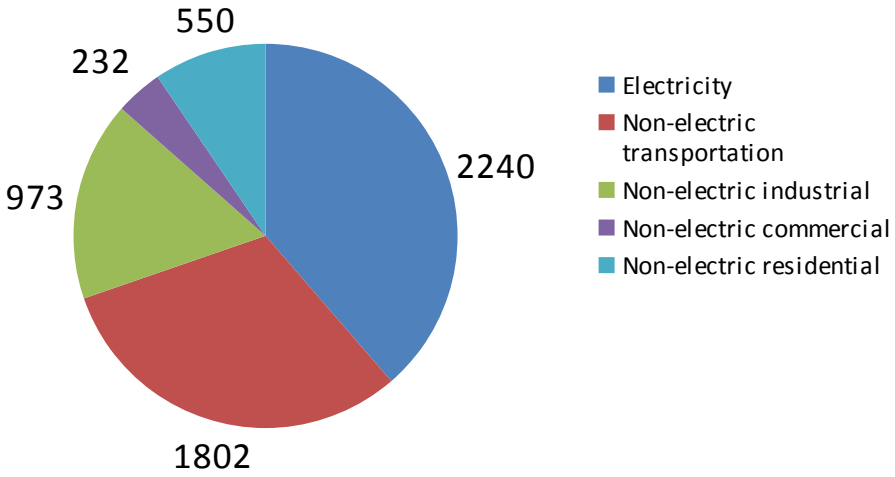



Energy-Related 2011 CO2 Emissions
550
232
2240
973
1802
Electricity
Non-electric transportation
Non-electric industrial
Non-electric commercial
Non-electric residential

Electricity Generation vs. Emissions

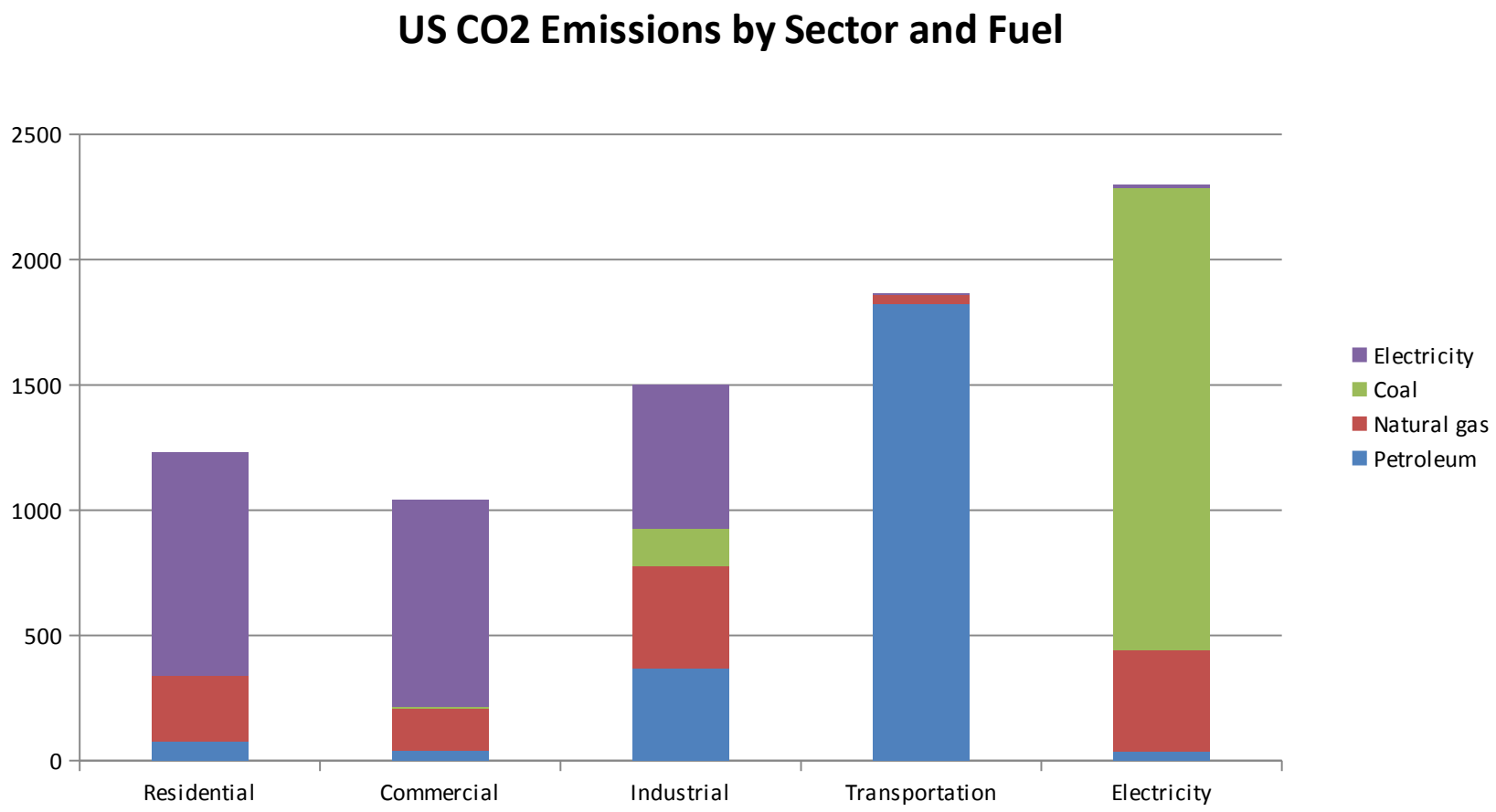


Energy-Related 2011 CO2 Emissions



Energy carrier: electricity

Primary Energy: coal, natural gas, petroleum



electricity as a solution

Climate Policy Goal

- Stable temperature needs stable GHG concentration
- Stable concentration needs zero net emissions
- Problem: Reconcile goal with modern energy services
- Zero/near-zero net emission alternatives
  - Renewables
  - Nuclear
  - Fossil fuels with CCS

The Electrification Imperative

- Alternatives ill-suited for directly supplying energy services

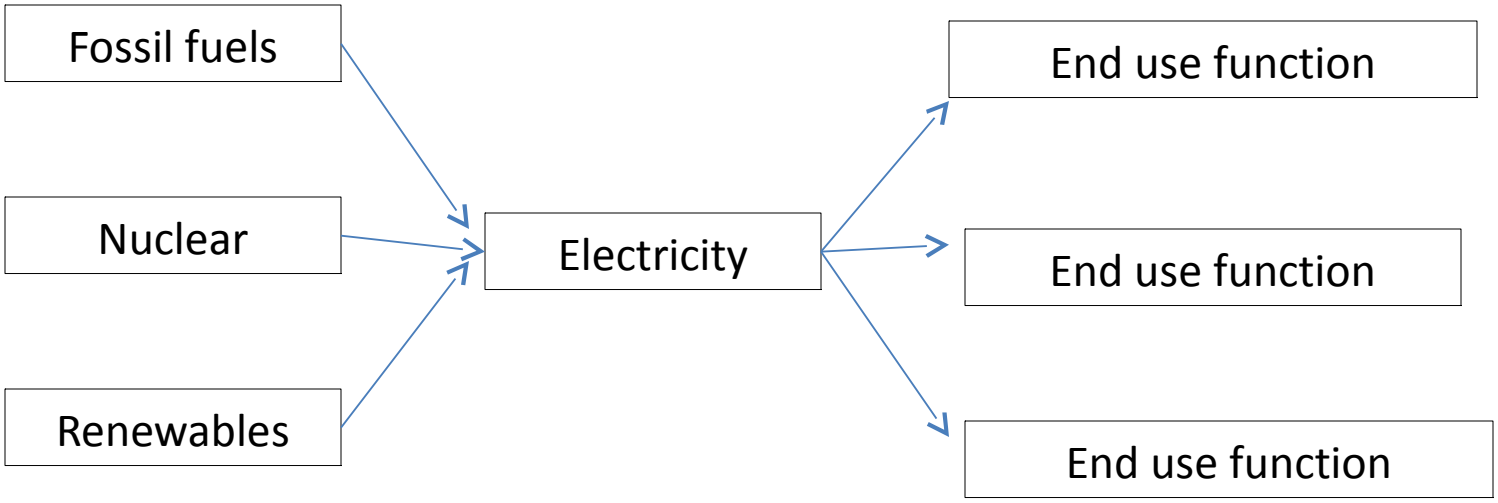
- Require an intermediate energy carrier
  - Electricity
  - Hydrogen

- Implication: Near-zero net emissions requires delivery of most energy in form of electricity

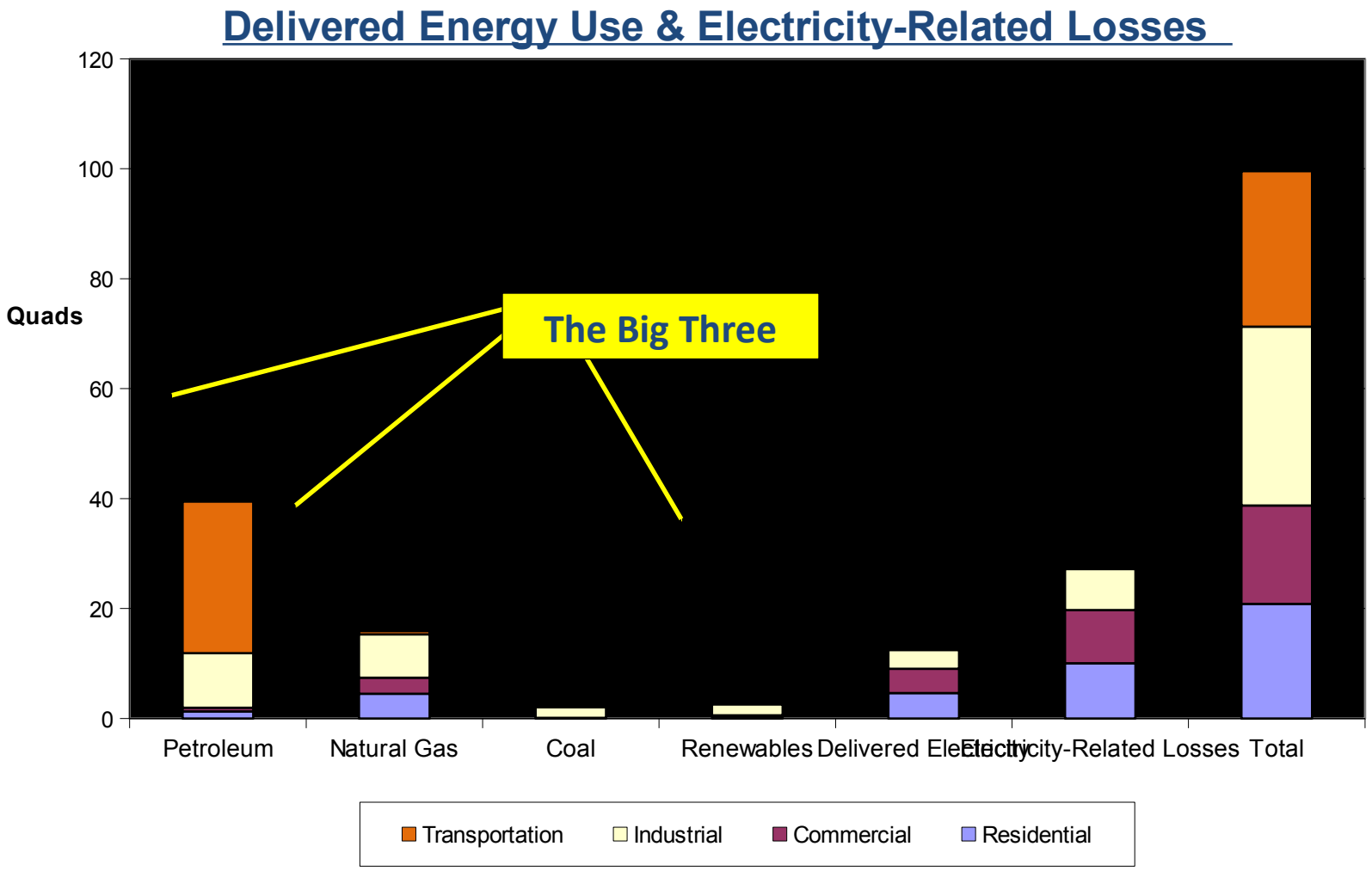
Direct Use of Non-Carbon Energy

Primary Energy	Electricity Generation	Transportation	Thermal
Hydro	X		
Wind	X		
Biomass	X		X
Biofuels	X	X	X
Solar thermal	X		X
Solar PV	X		
Geothermal	X		X
Nuclear	X		
Carbon capture & storage	X		

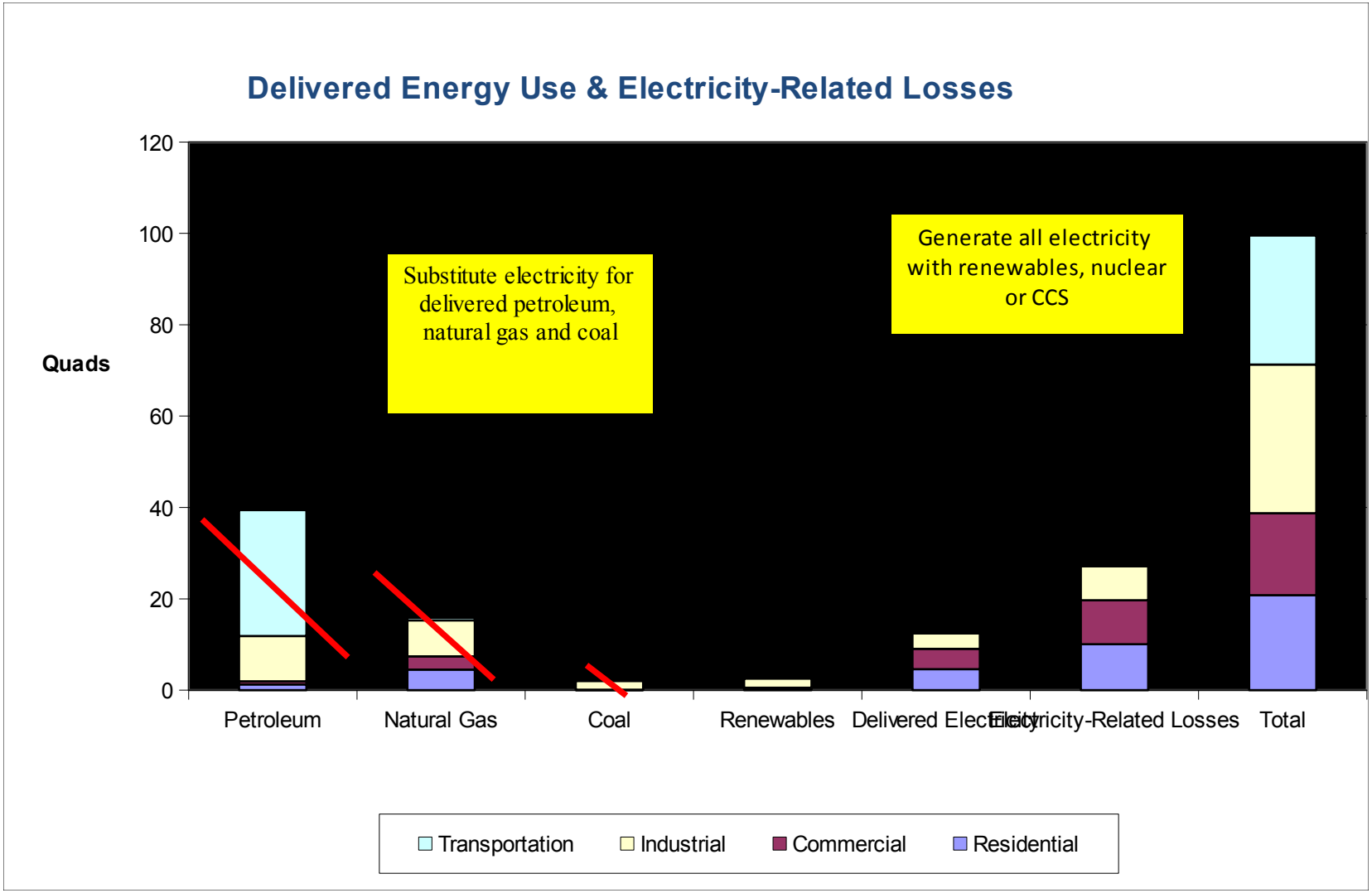
Electricity:
The Universal Energy Carrier



How We Receive Energy Today



Two Changes to Stabilize Temperatures



Biomass

- Often efficient for space heating
- Limited alternative for electricity generation
- Alternative for transportation
  - Biofuels vs. EVs/fuel cells with non-CO2 electricity
  - Liquid fuel vs. batteries or on-board hydrogen
  - Need biofuels that don't compete with food: cellulosic ethanol and algae-based fuel