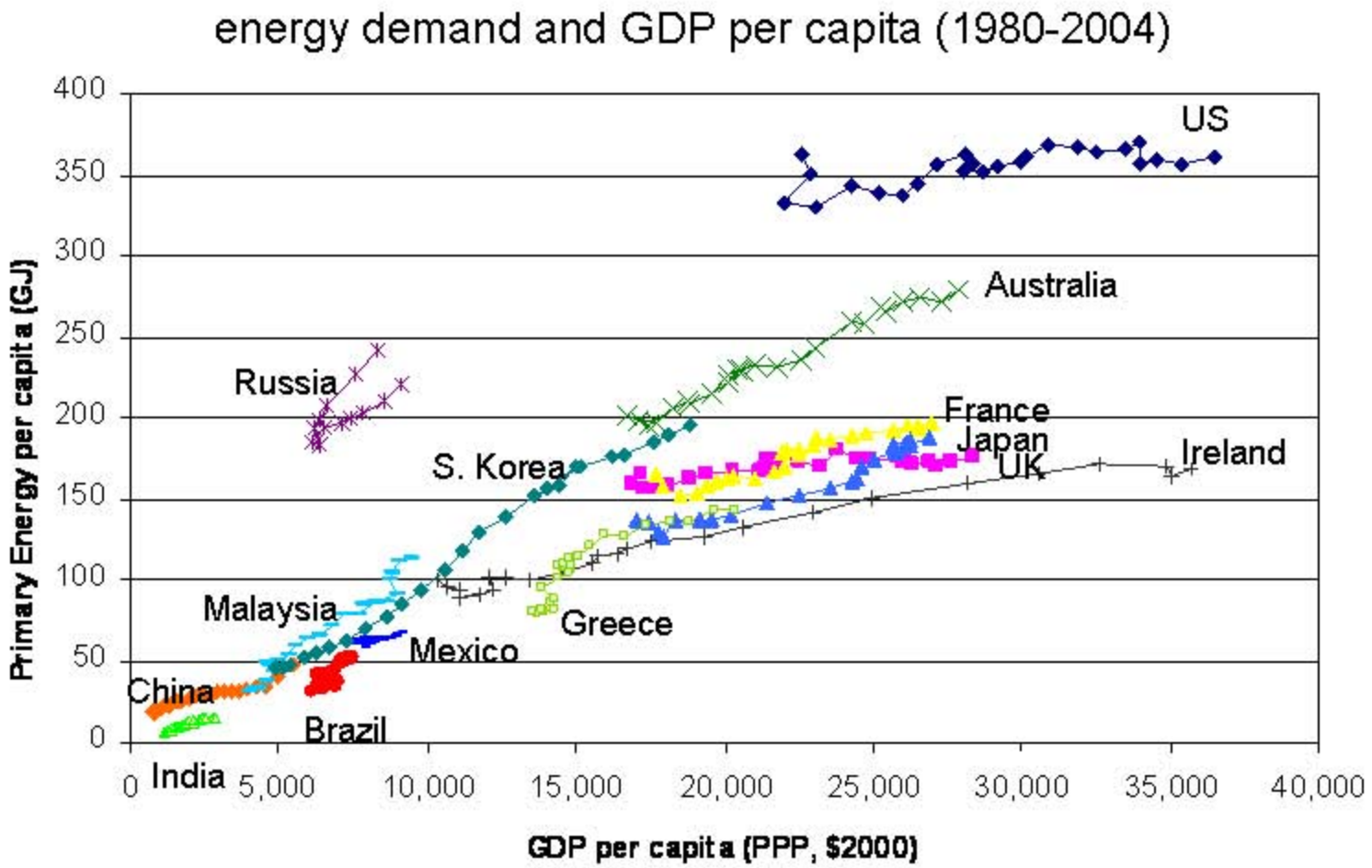
Energy Research: What should be on the agenda and why?

Steven E. Koonin, Chief Scientist, BP plc
Caltech NRG 0.1
October 5, 2007

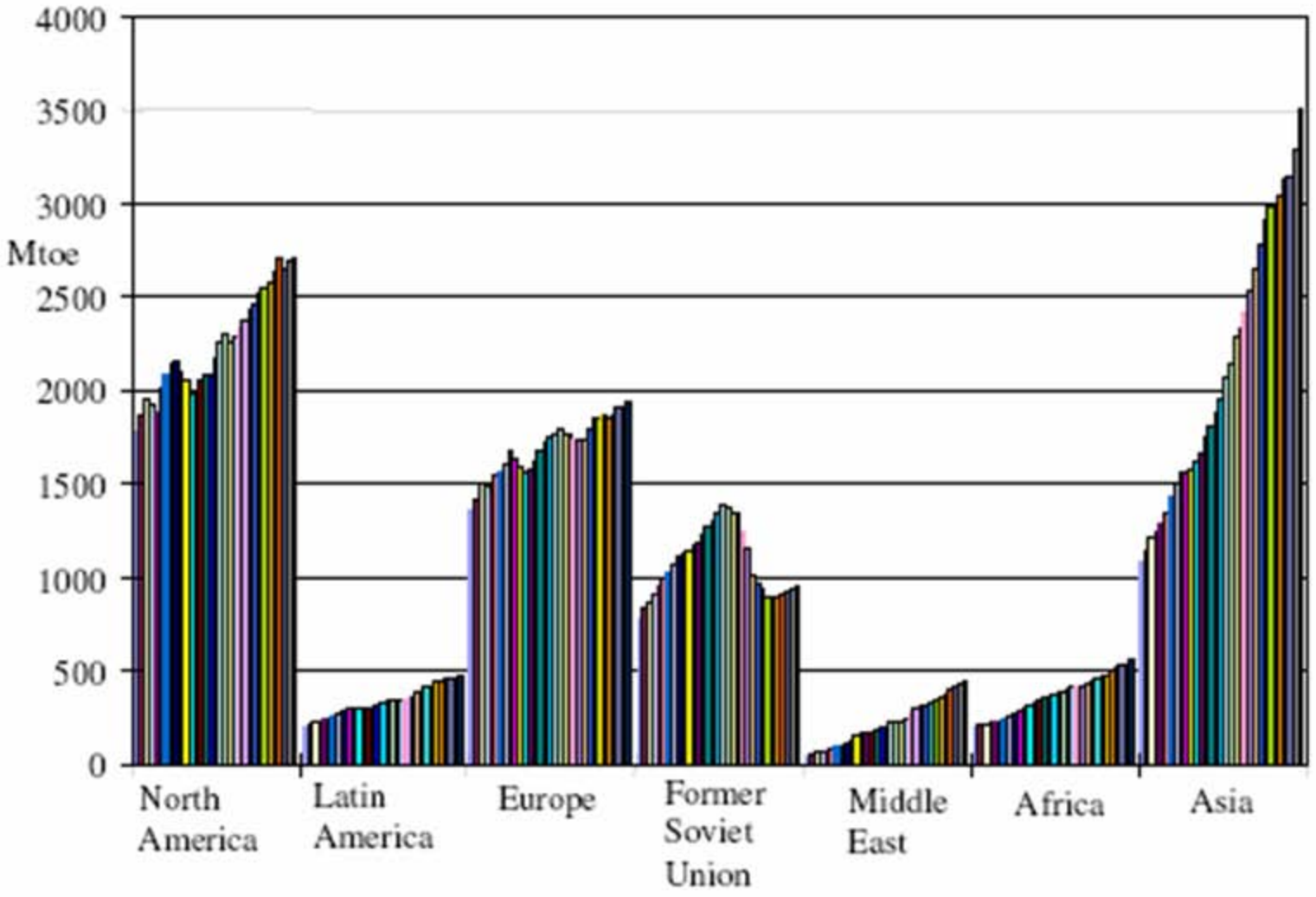
key drivers of the energy future

energy use grows with economic development



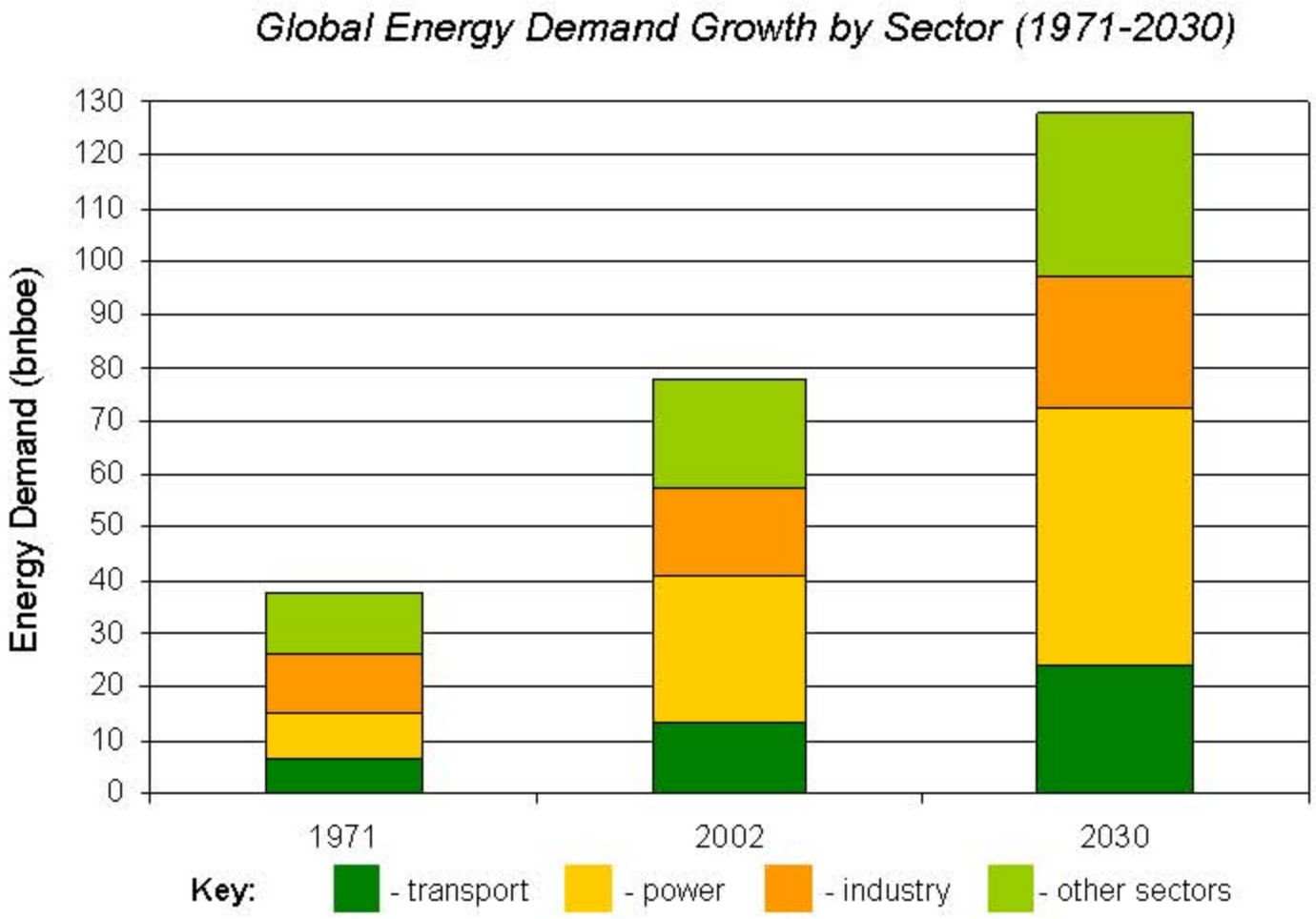
Source: UN and DOE EIA
Russia data 1992-2004 only

annual primary energy demand 1971-2003



Source IEA, 2004 (Excludes biomass)

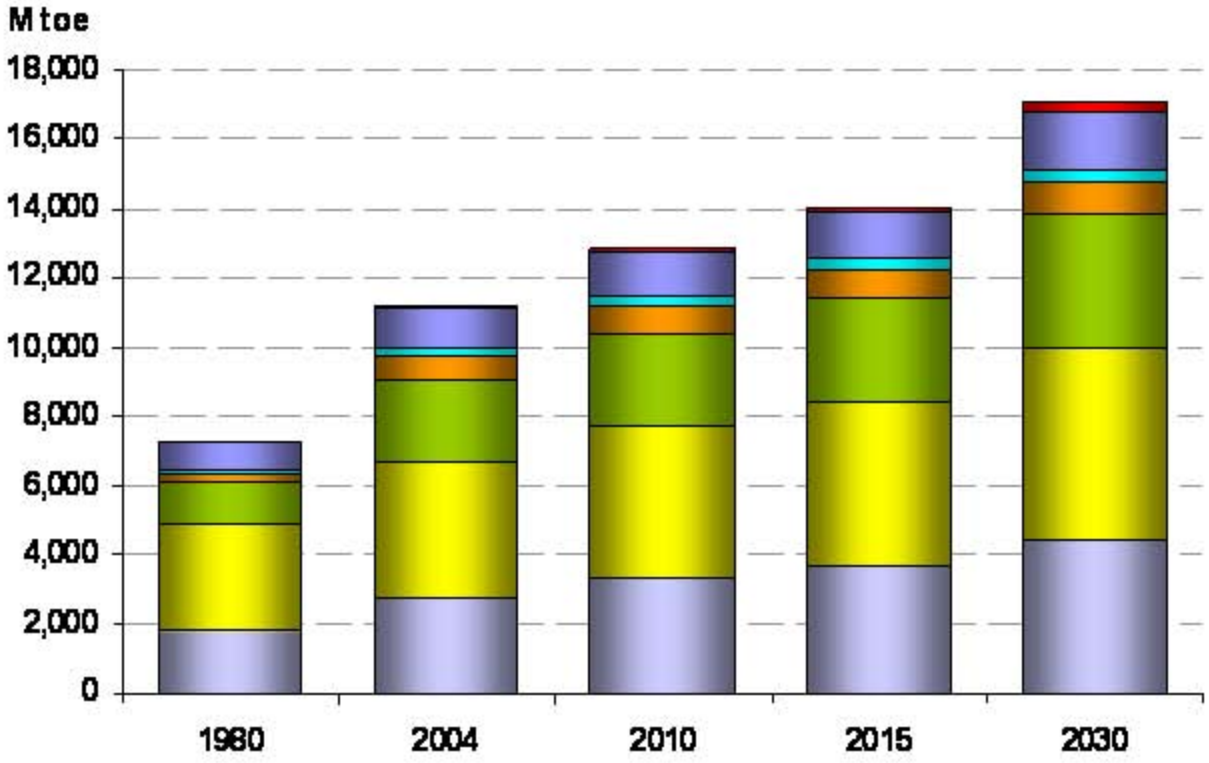
growing energy demand is projected



Notes: 1. Power includes heat generated at power plants
2. Other sectors includes residential, agricultural and service

Source: IEA WEO 2004

BAU projection of primary energy sources

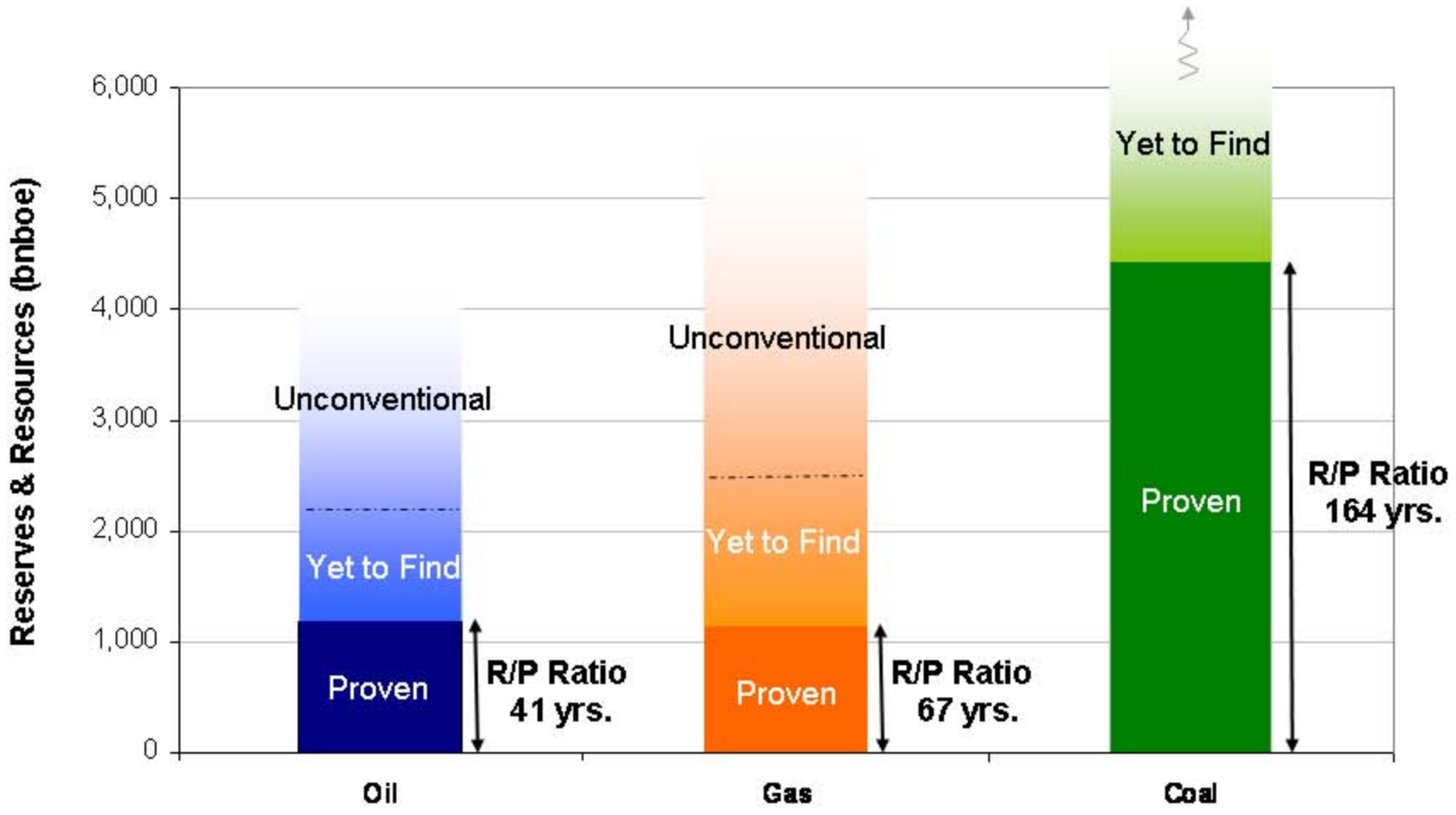


	'04 – '30 Annual Growth Rate (%)
Other Renewables	6.5
Biomass & waste	1.3
Hydro	2.0
Nuclear	0.7
Gas	2.0
Oil	1.3
Coal	1.8
Total	**1.6**

Note: 'Other renewables' include geothermal, solar, wind, tide and wave energy for electricity generation

Source: IEA World Energy Outlook 2006 (Reference Case)

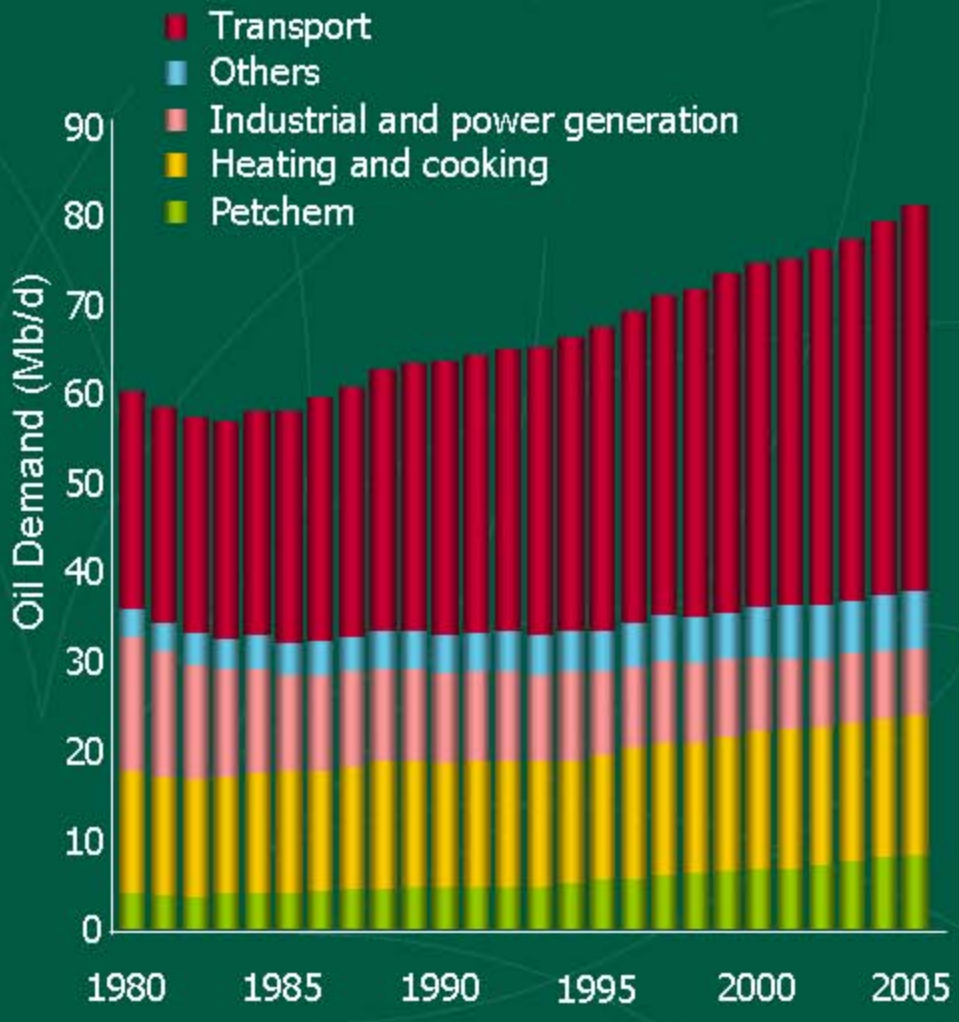
substantial global fossil resources



Source: World Energy Assessment 2001, HIS, WoodMackenzie, BP Stat Review 2005, BP estimates

6bn of us want mobility

"There is no fuel like an old fuel…"

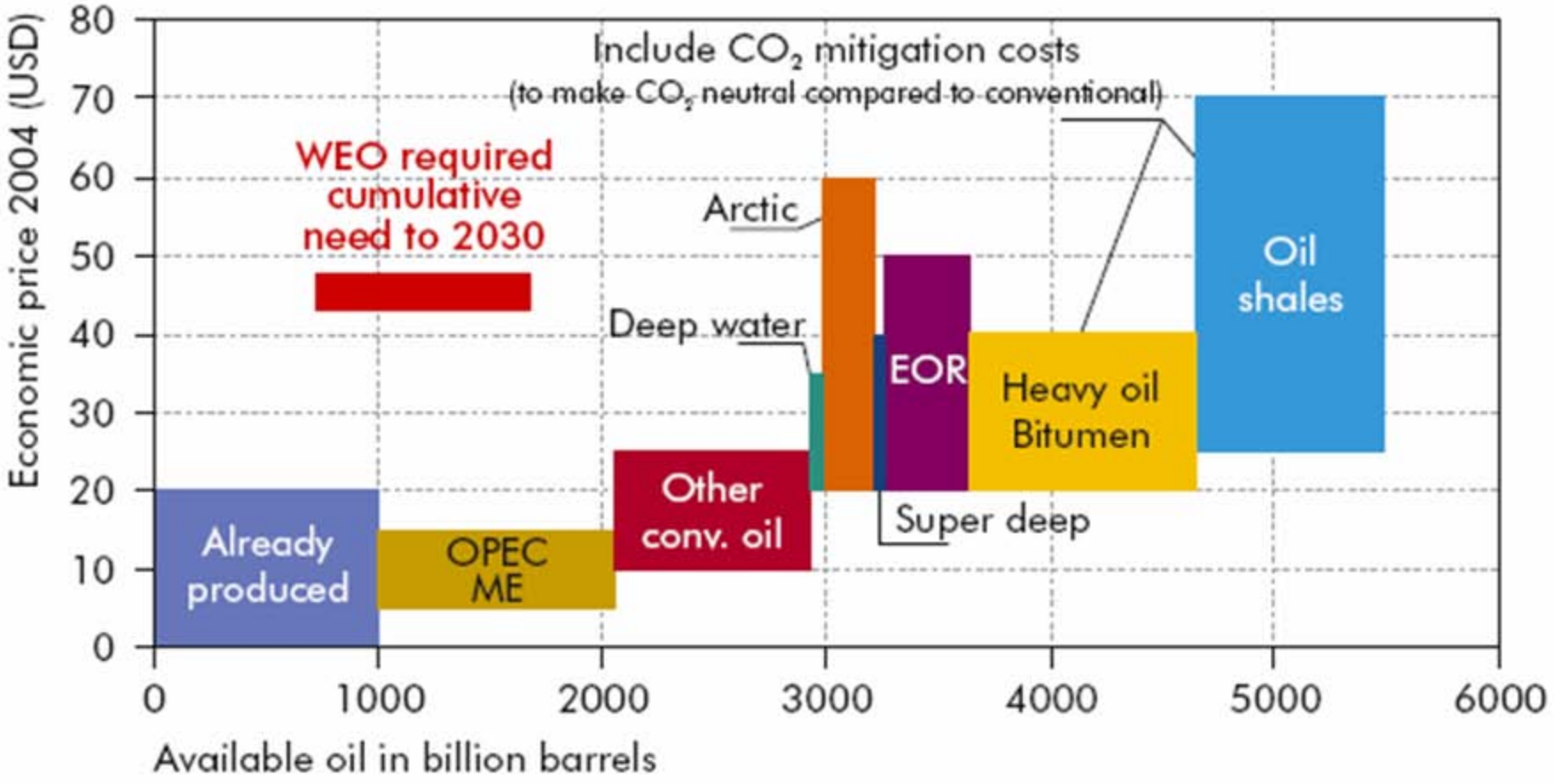


The not so distant past….

The present ….

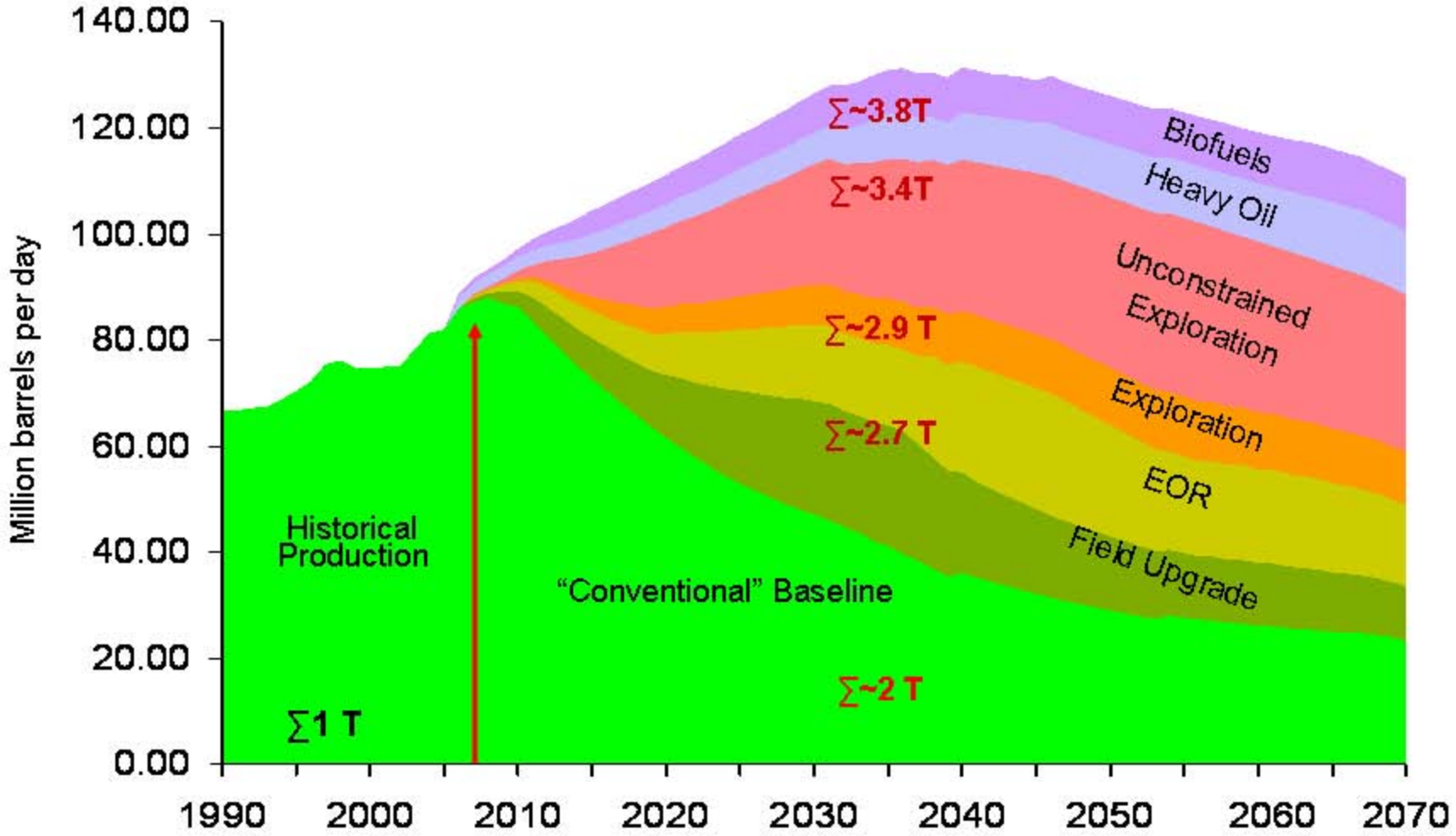
oil supply and cost curve

Availability of oil resources as a function of economic price

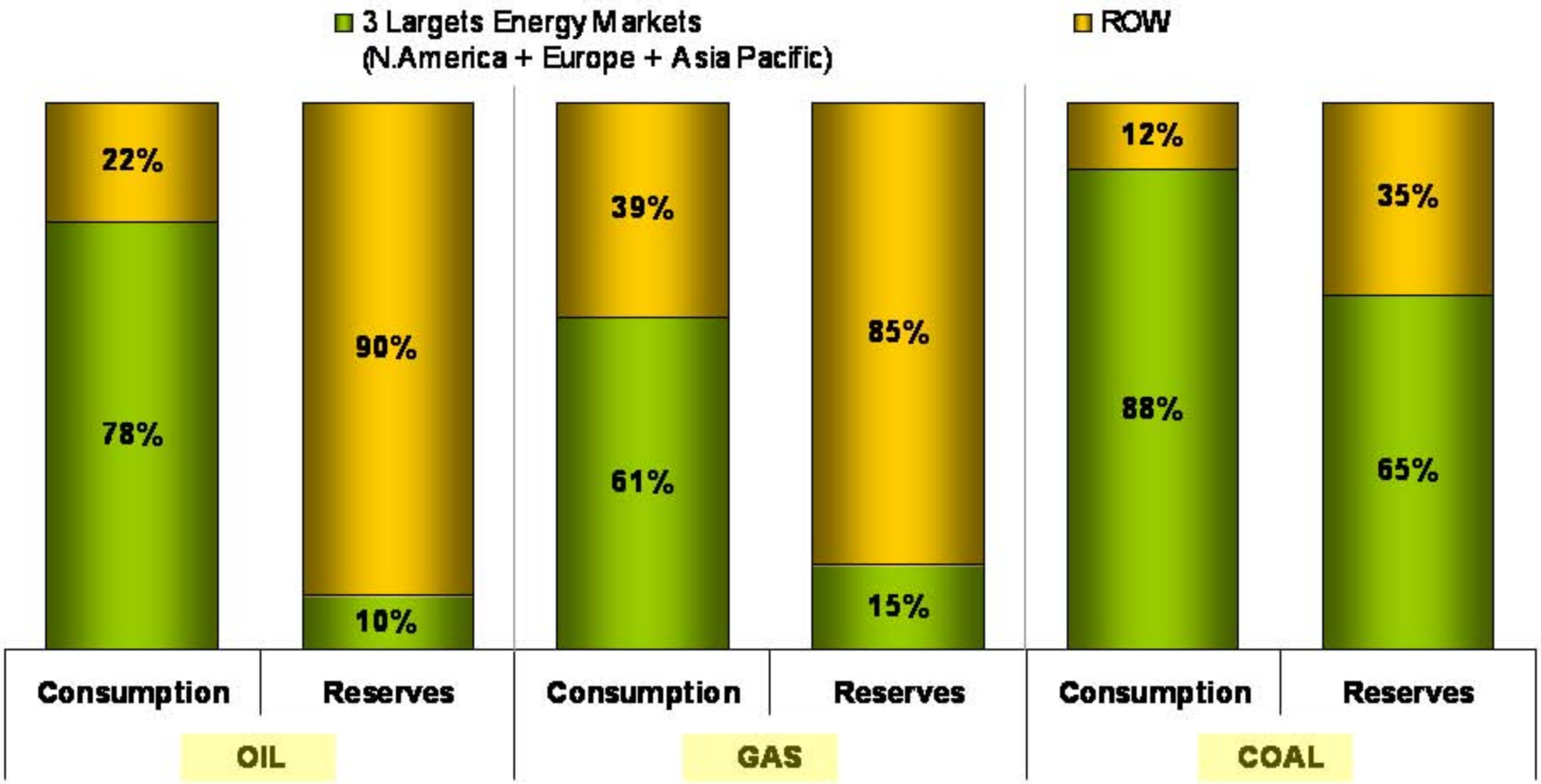


Source: IEA (2005)

A Future: ~ 3.5 Trillion bbls



dislocation of fossil fuel supply & demand



Source: BP Statistical Review 2006

Crucial facts about CO_2 science

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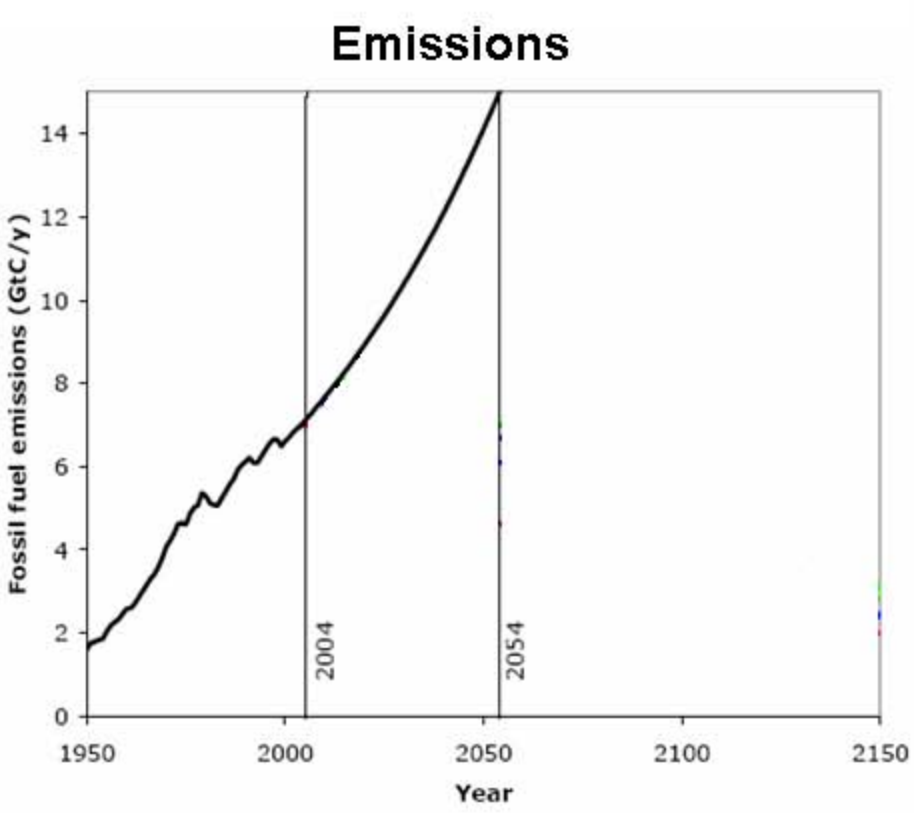

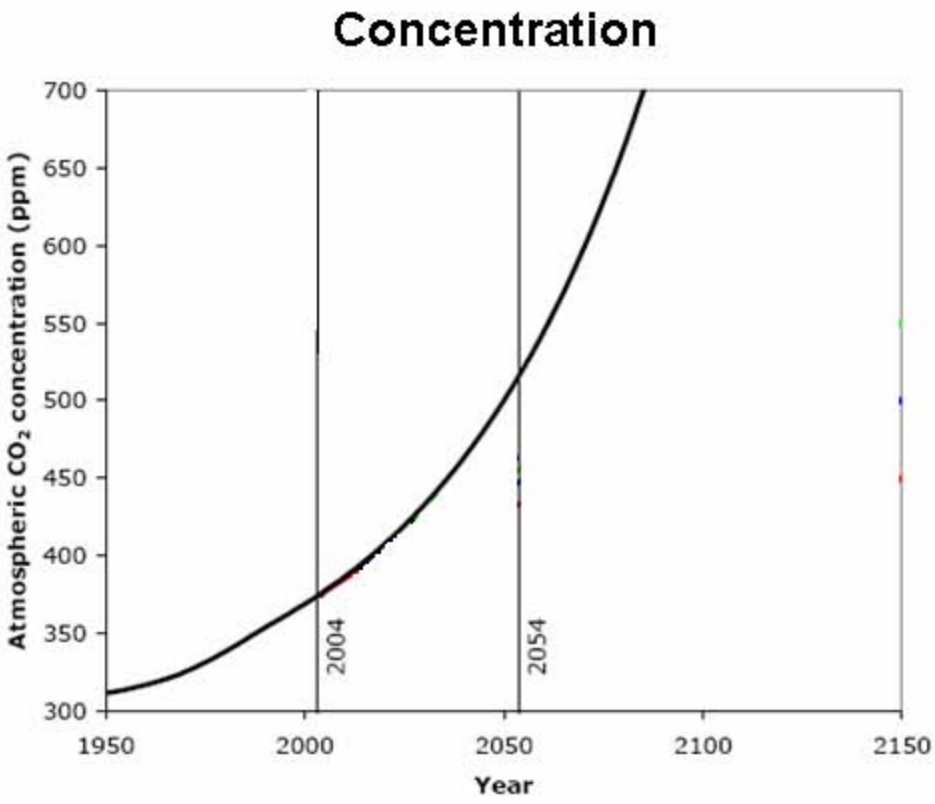

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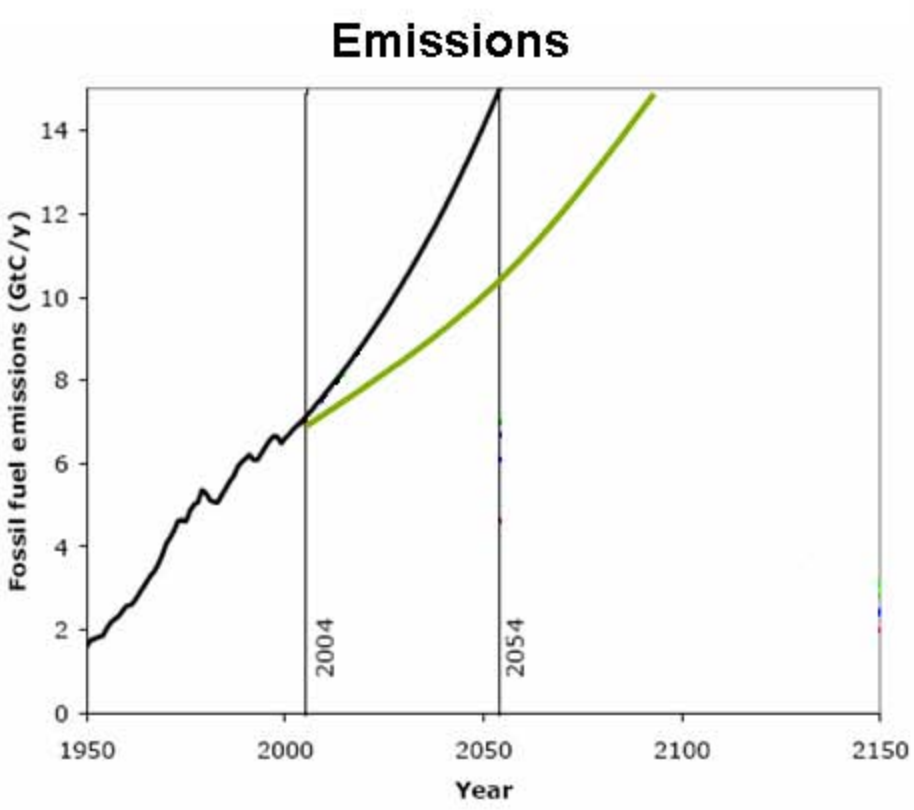

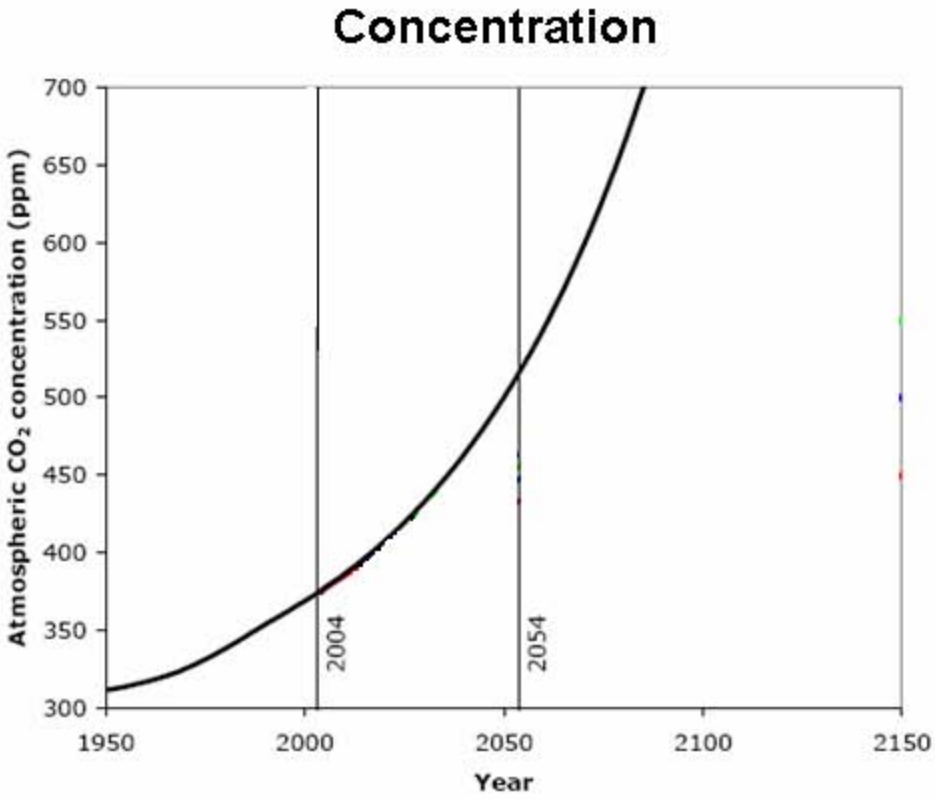

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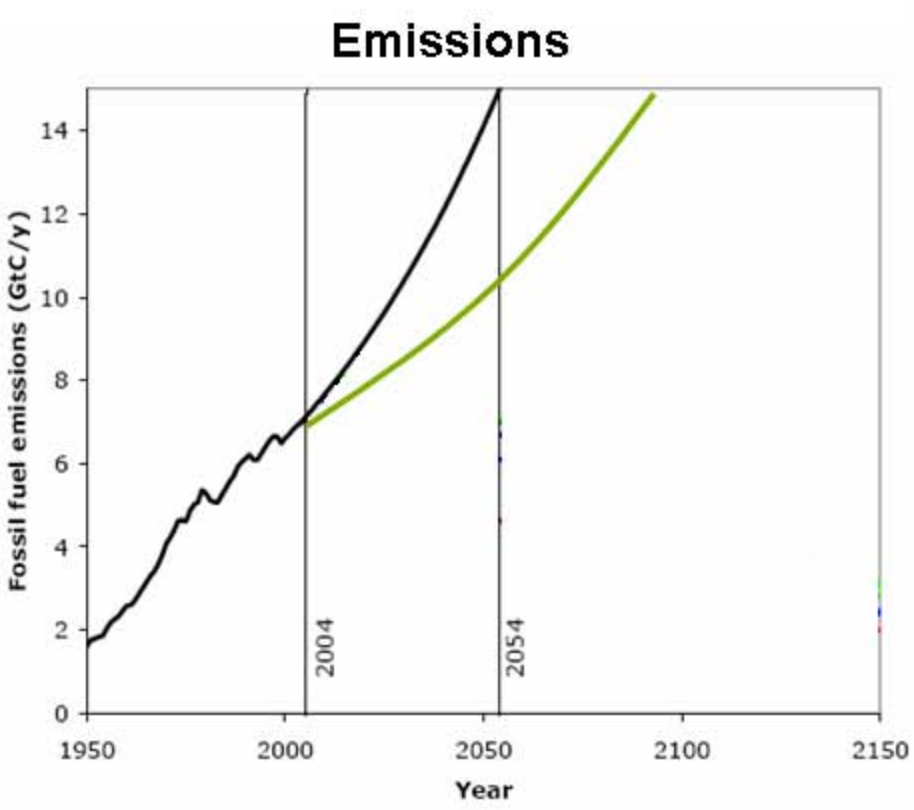

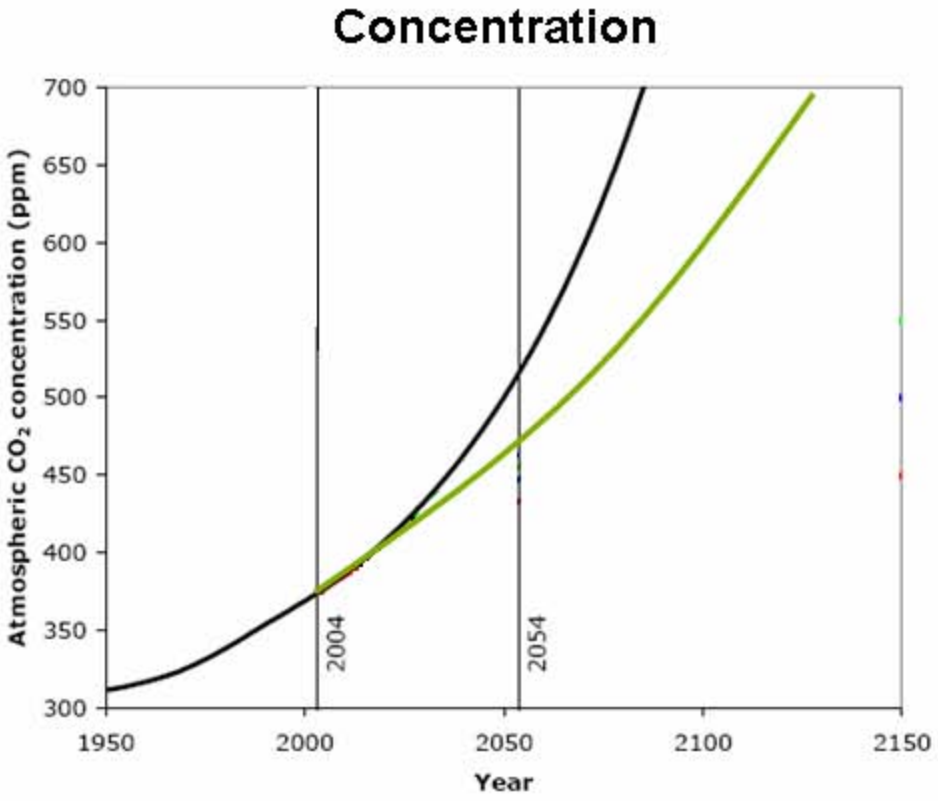

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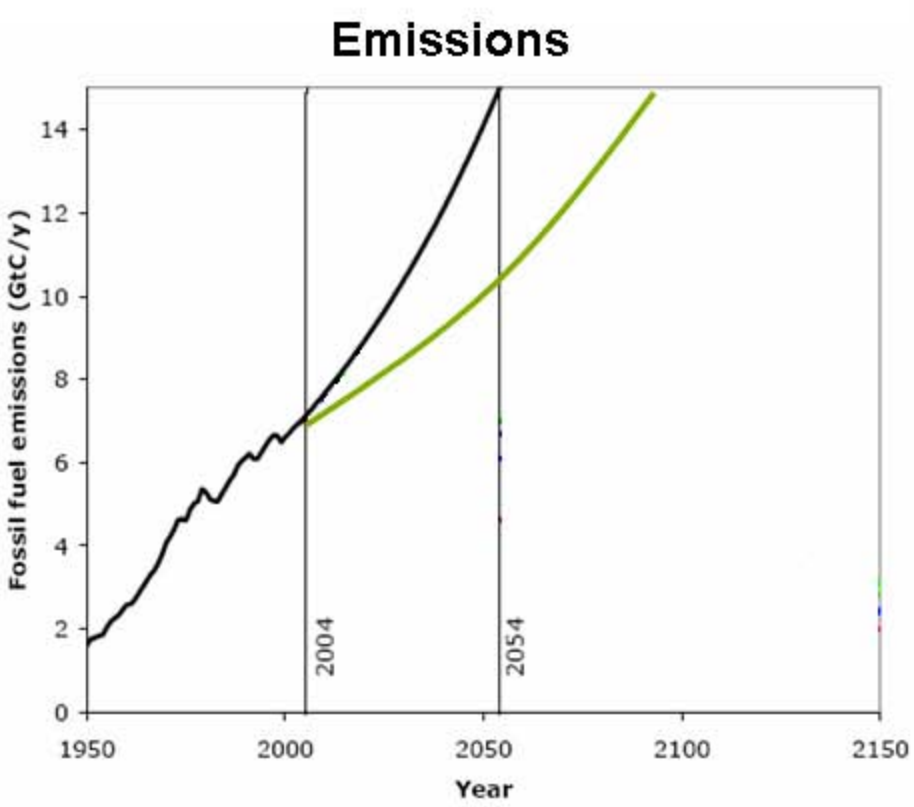

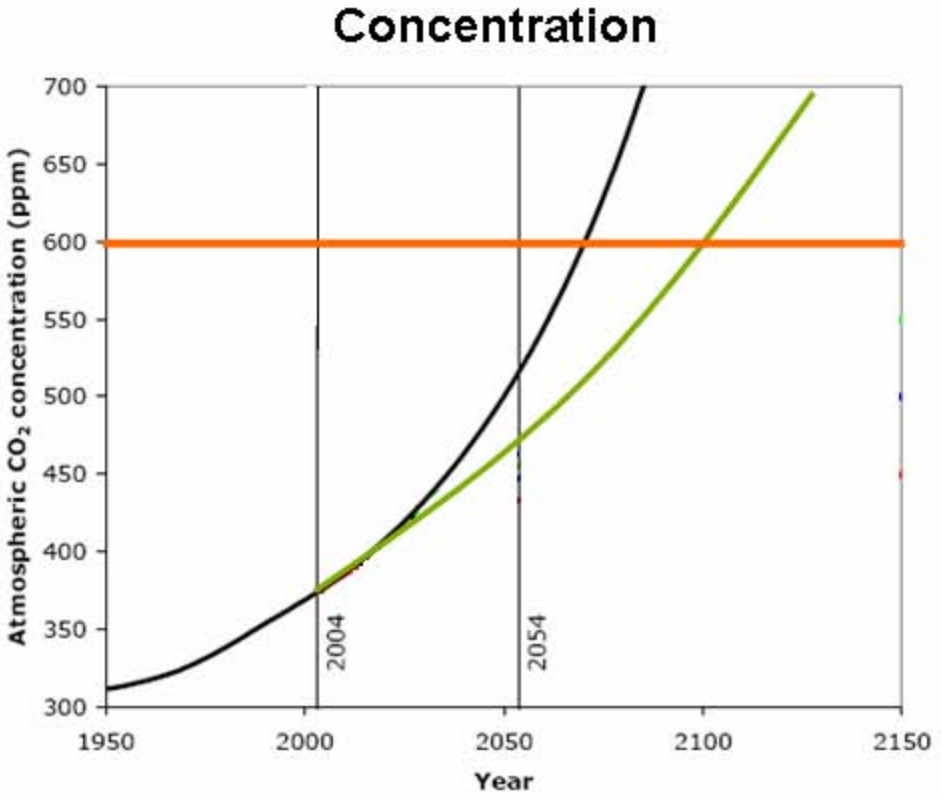

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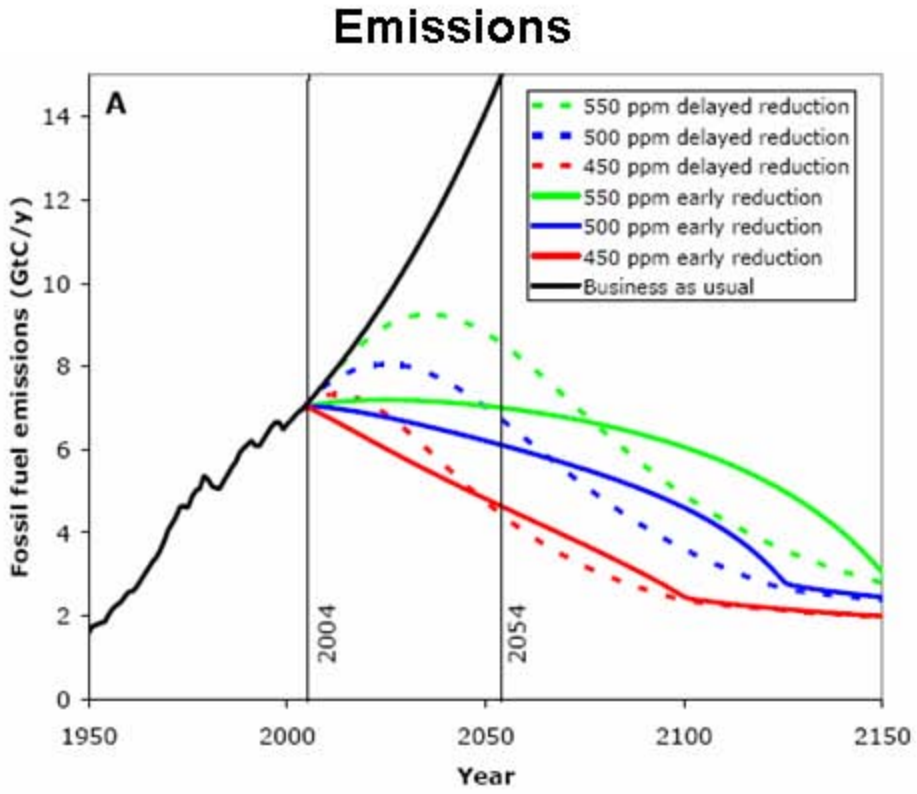

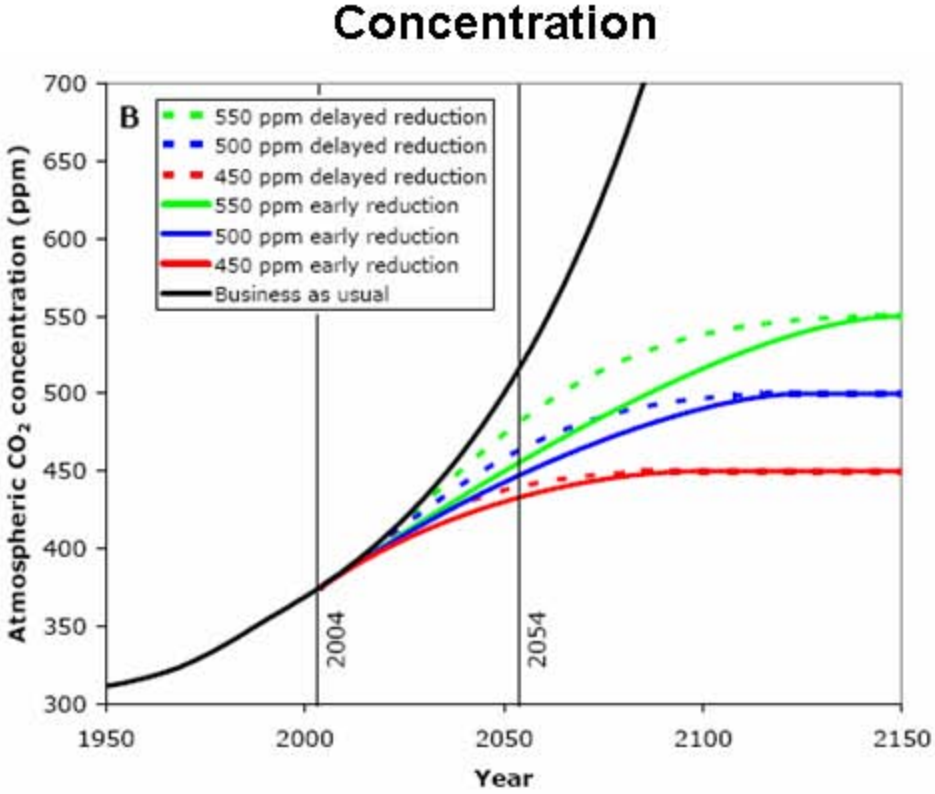

social barriers to meaningful emissions reductions

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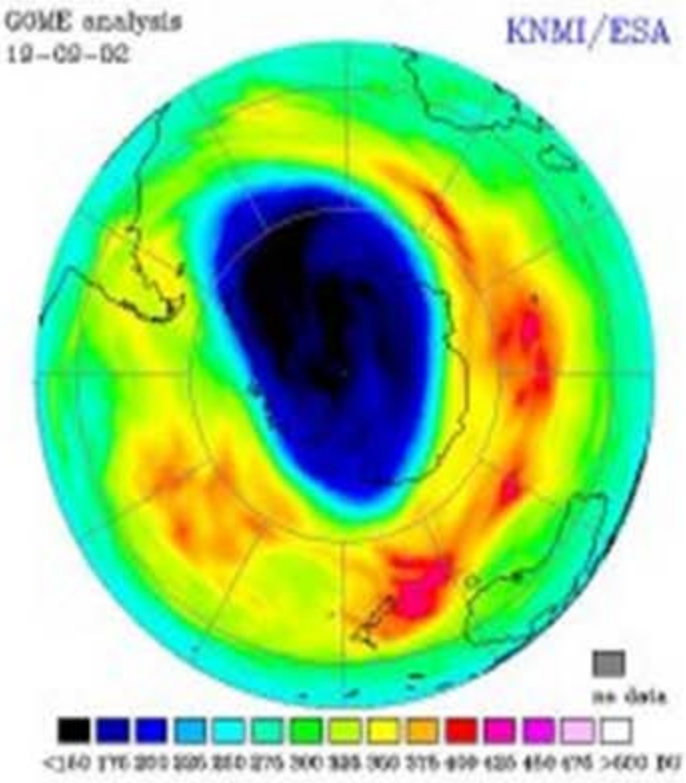

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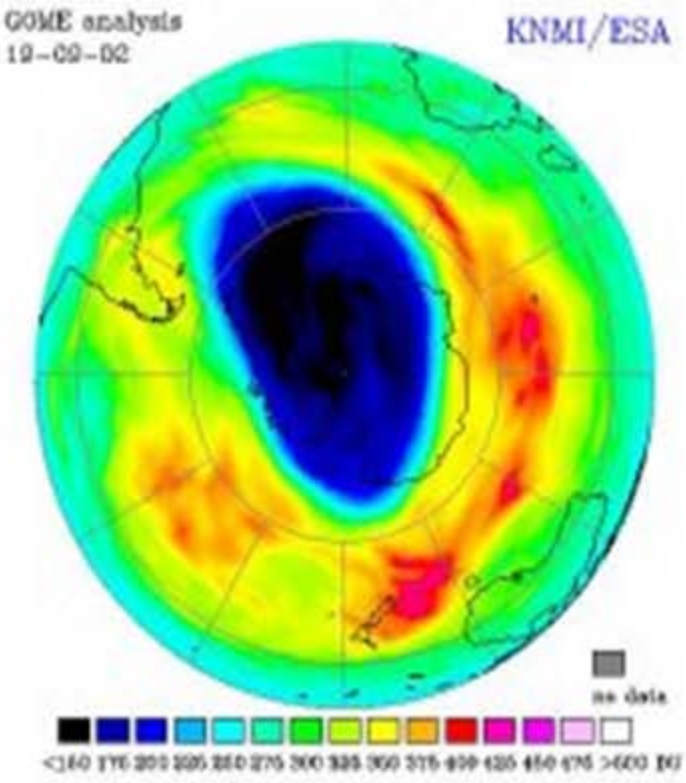

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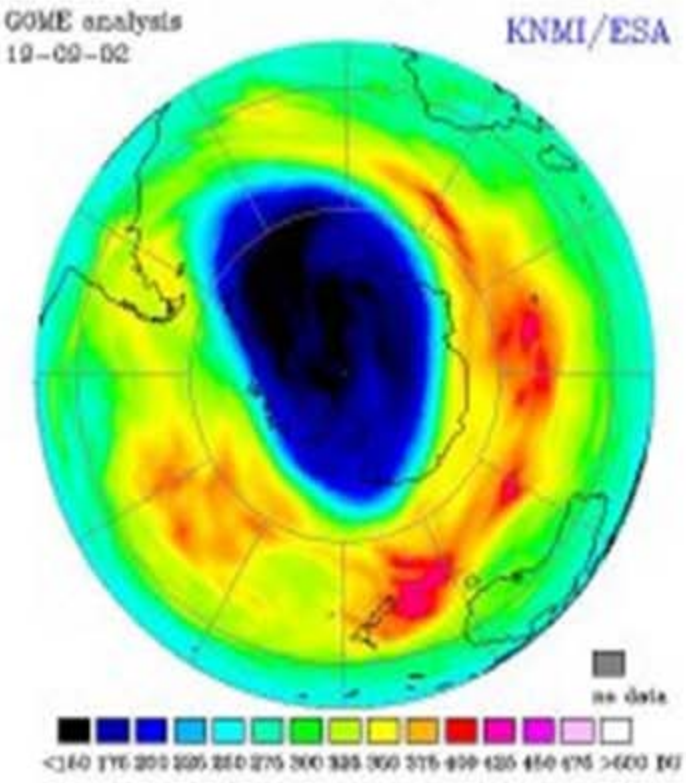
  - Political cycle is ~6 years; news cycle ~1 day



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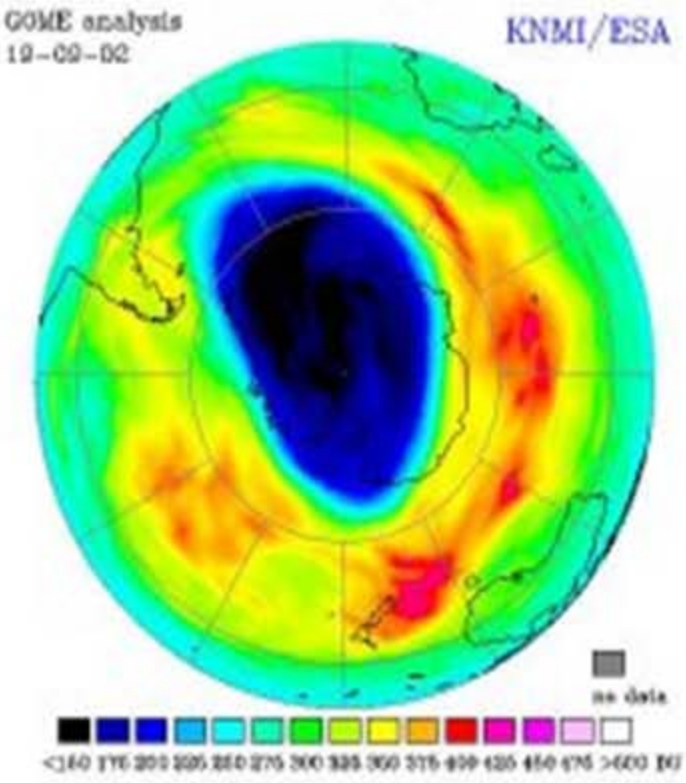

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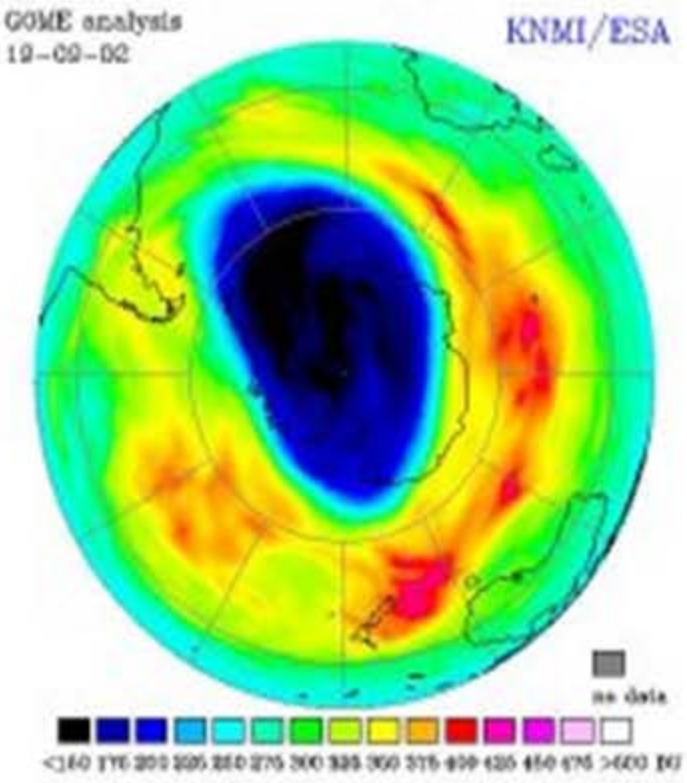
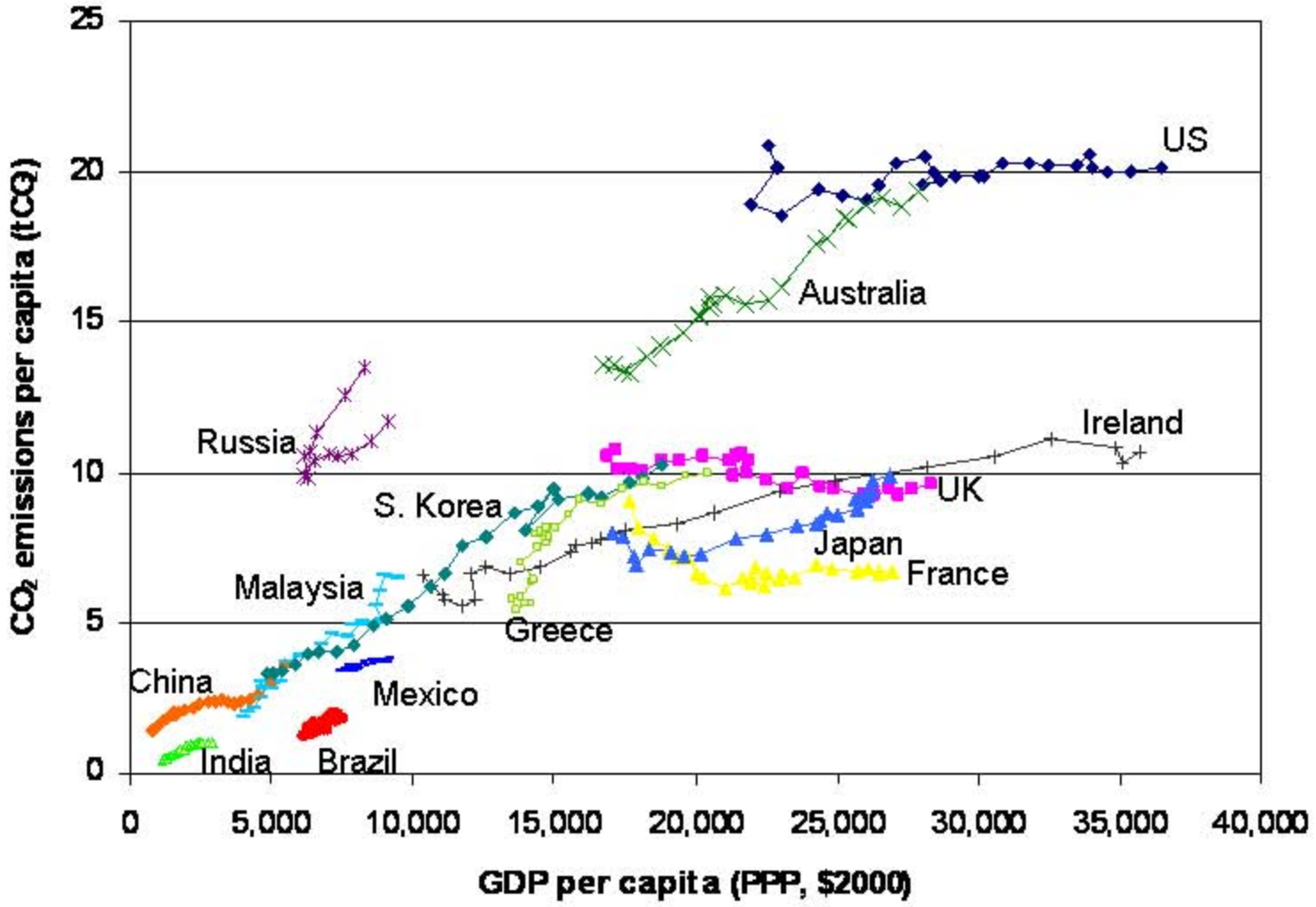
- **Emissions, economics, and the priority of the threat vary greatly around the world**



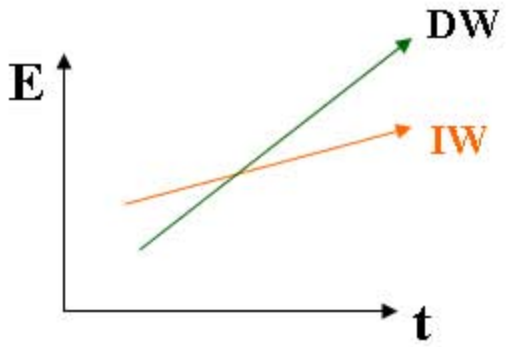
CO_2 emissions and GDP per capita (1980-2004



Source: UN and DOE EIA
Russia data 1992-2004 only

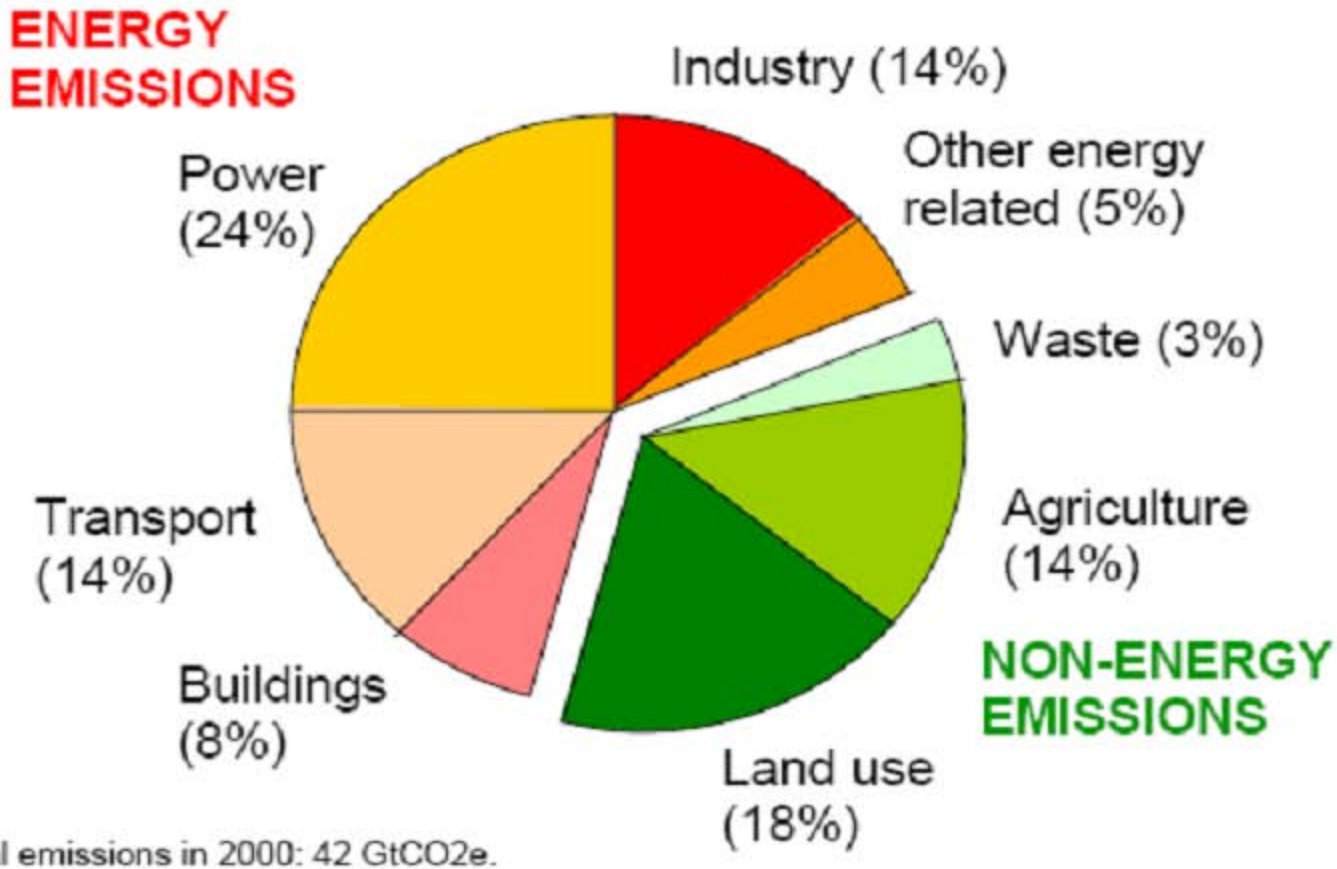
implications of emissions heterogeneities

- **21st Century emissions from the Developing World (DW) will be more important than those from the Industrialized World (IW)**
  - DW emissions growing at 2.8% vs IW growing at 1.2%
  - DW will surpass IW during 2015 - 2025



- **Sobering facts**
  - When DW ~ IW, each 10% reduction in IW emissions is compensated by < *4 years* of DW growth
  - If China's (or India's) per capita emissions were those of Japan, global emissions would be 40% higher
- **Reducing emissions is an enormous, complex challenge; technology development will play a central role**

greenhouse gas emissions in 2000 by source

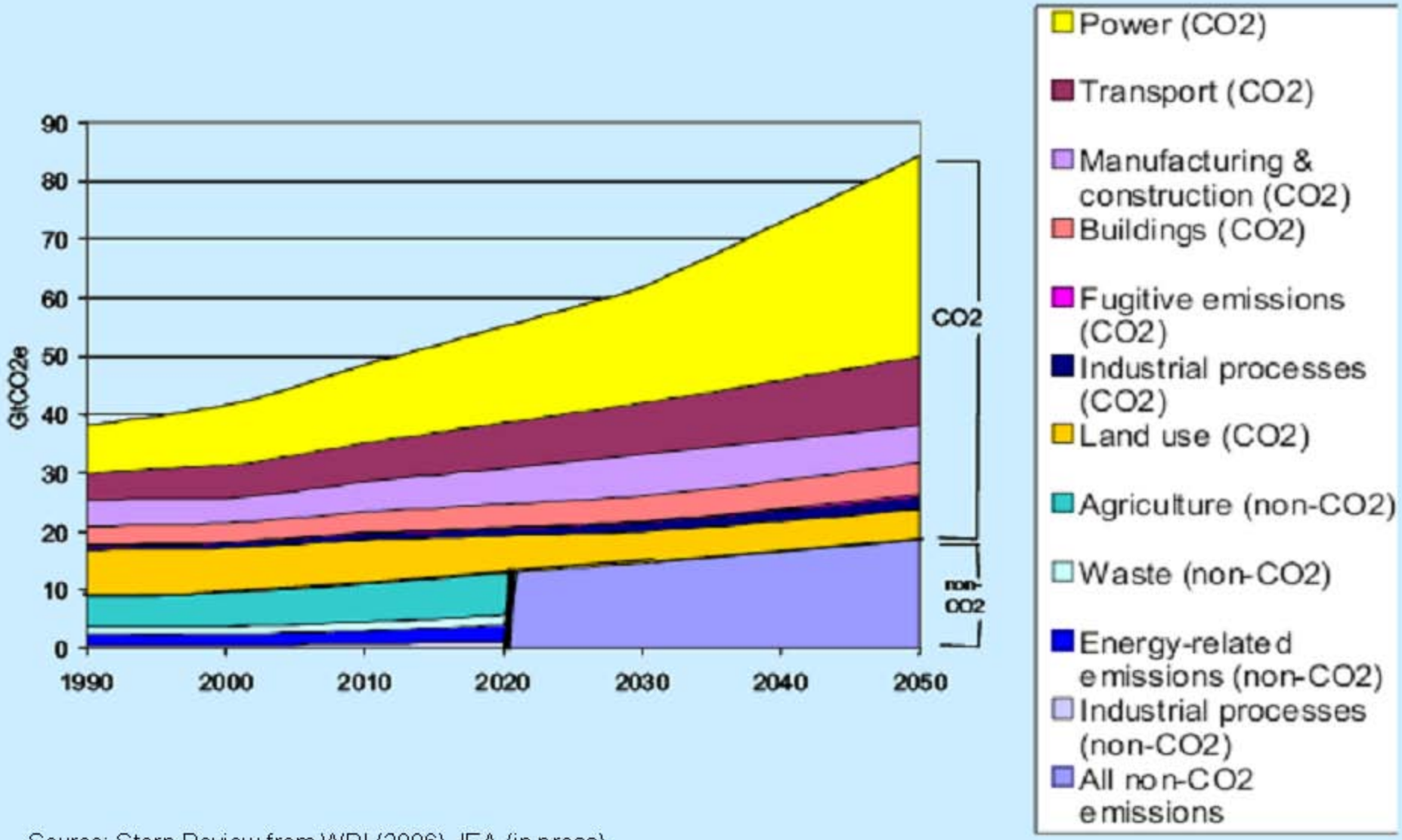


Total emissions in 2000: 42 GtCO2e.

Energy emissions are mostly CO_2 (some non-CO_2 in industry and other energy related).
Non-energy emissions are CO_2 (land use) and non-CO_2 (agriculture and waste).

Source: Stern Review, from data drawn from World Resources Institute Climate Analysis Indicators Tool (CAIT) on-line database version 3.0

historical and projected GHG emissions by sector



Source: Stern Review from WRI (2006), IEA (in press), IEA (2006), EPA (forthcoming), Houghton (2005).

Distinguishing aspects of energy technologies

- **Scale**
  - Large infrastructure, amounts of material, numbers of units
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- **Incumbency**
  - New energy technologies must compete on cost
  - May not provide any qualitatively new service to the end-user

some energy technologies

Primary Energy Sources:

- Light Crude
- Heavy Oil
- Tar Sands
- Wet gas
- CBM
- Tight gas
- Nuclear
- Coal
- Solar
- Wind
- Biomass
- Hydro
- Geothermal

Extraction & Conversion Technologies:

- Exploration
- Deeper water
- Arctic
- LNG
- Refining
- Differentiated fuels
- Advantaged chemicals
- Gasification
- Syngas conversion
- Power generation
- Photovoltaics
- Bio-enzyimatics
- H_2 production & distribution
- CO_2 capture & storage

End Use Technologies:

- ICEs
- Adv. Batteries
- Hybridisation
- Fuel cells
- Hydrogen storage
- Gas turbines
- Building efficiency
- Urban infrastructure
- Systems design
- Other efficiency technologies
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There are no "silver bullets"
But some have a larger calibre than others !

evaluating energy technology options

- Current **technology status** and plausible **technical headroom**
- **Budgets** for the three E's:
  - **Economic** (cost relative to other options)
  - **Energy** (output how many times greater than input)
  - **Emissions** (pollution and CO2; operations and capital)
- **Materiality** (at least 1TW = 5% of 2050 BAU energy demand)
- **Other costs** - reliability, intermittency etc.
- Social and political **acceptability**

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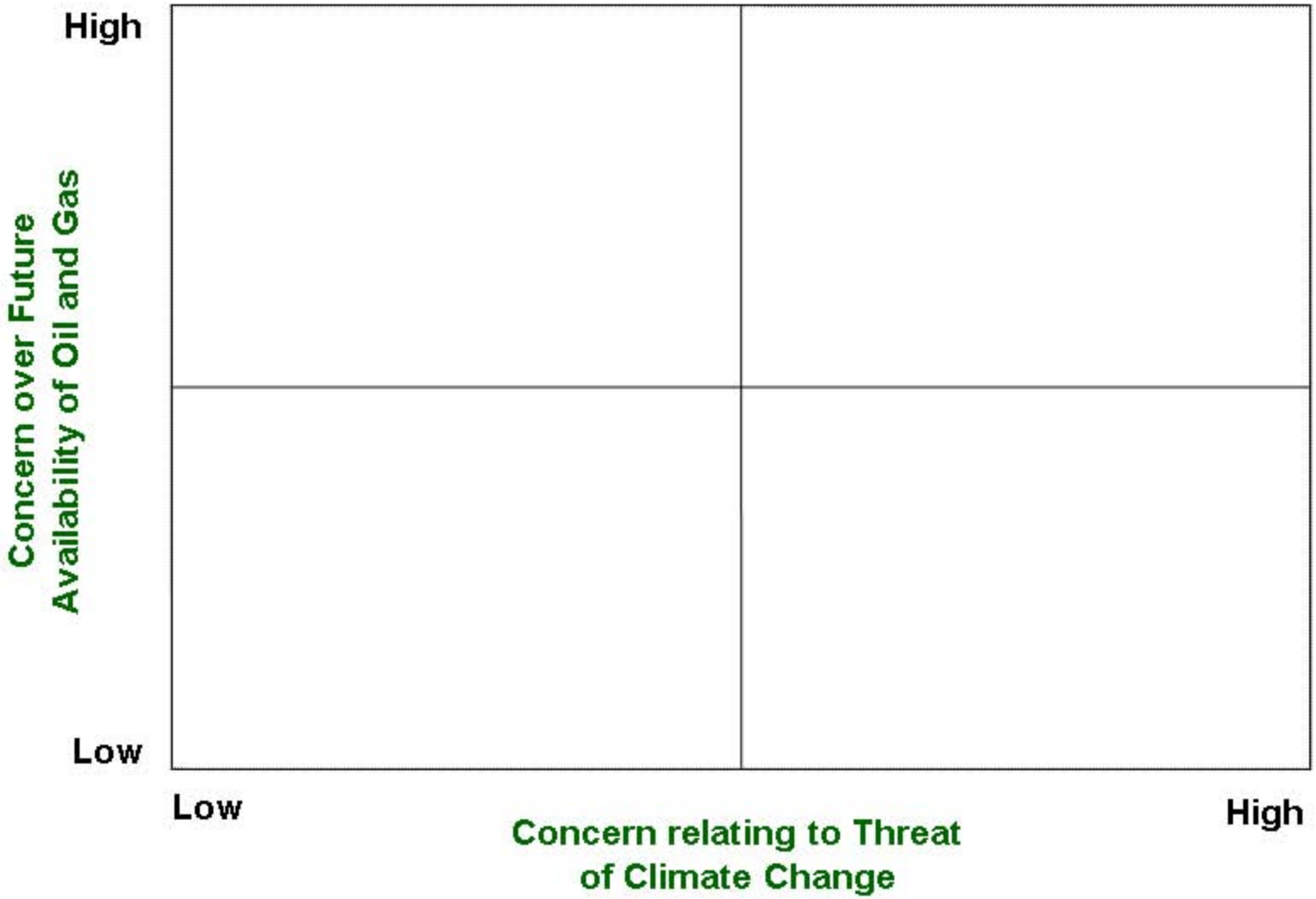
we also must know what problem we are trying to solve

two key energy considerations – security & climate



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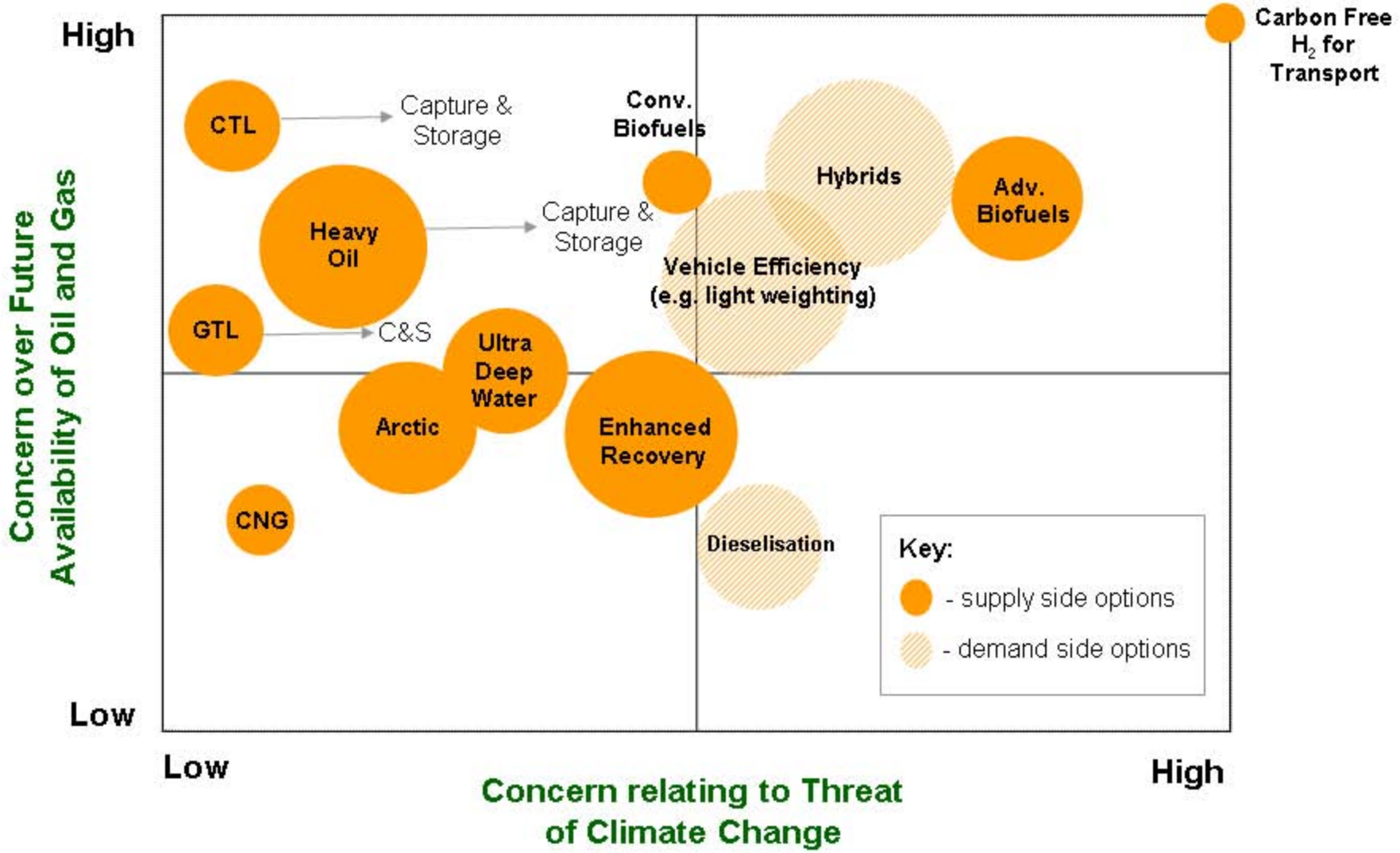
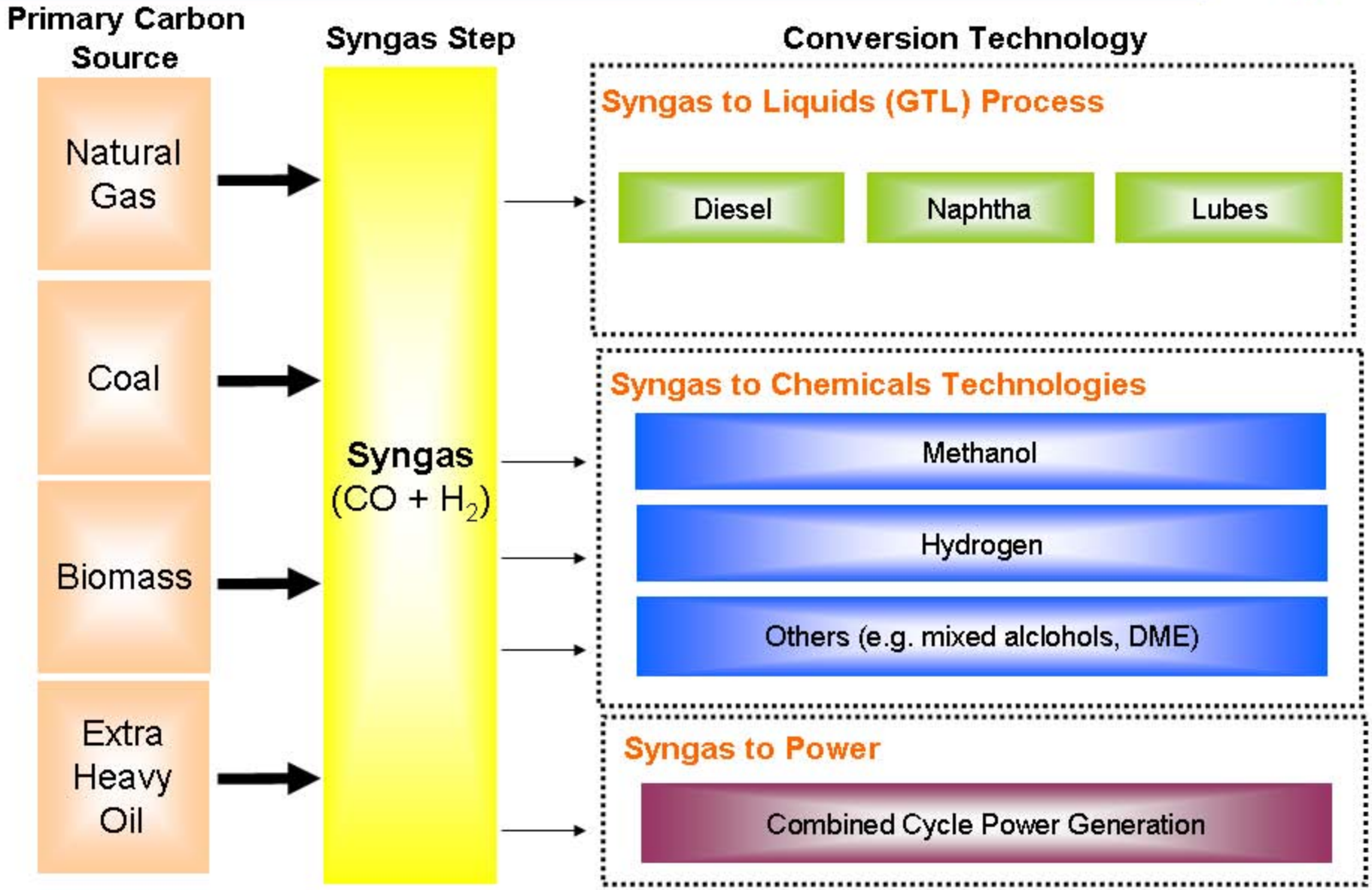
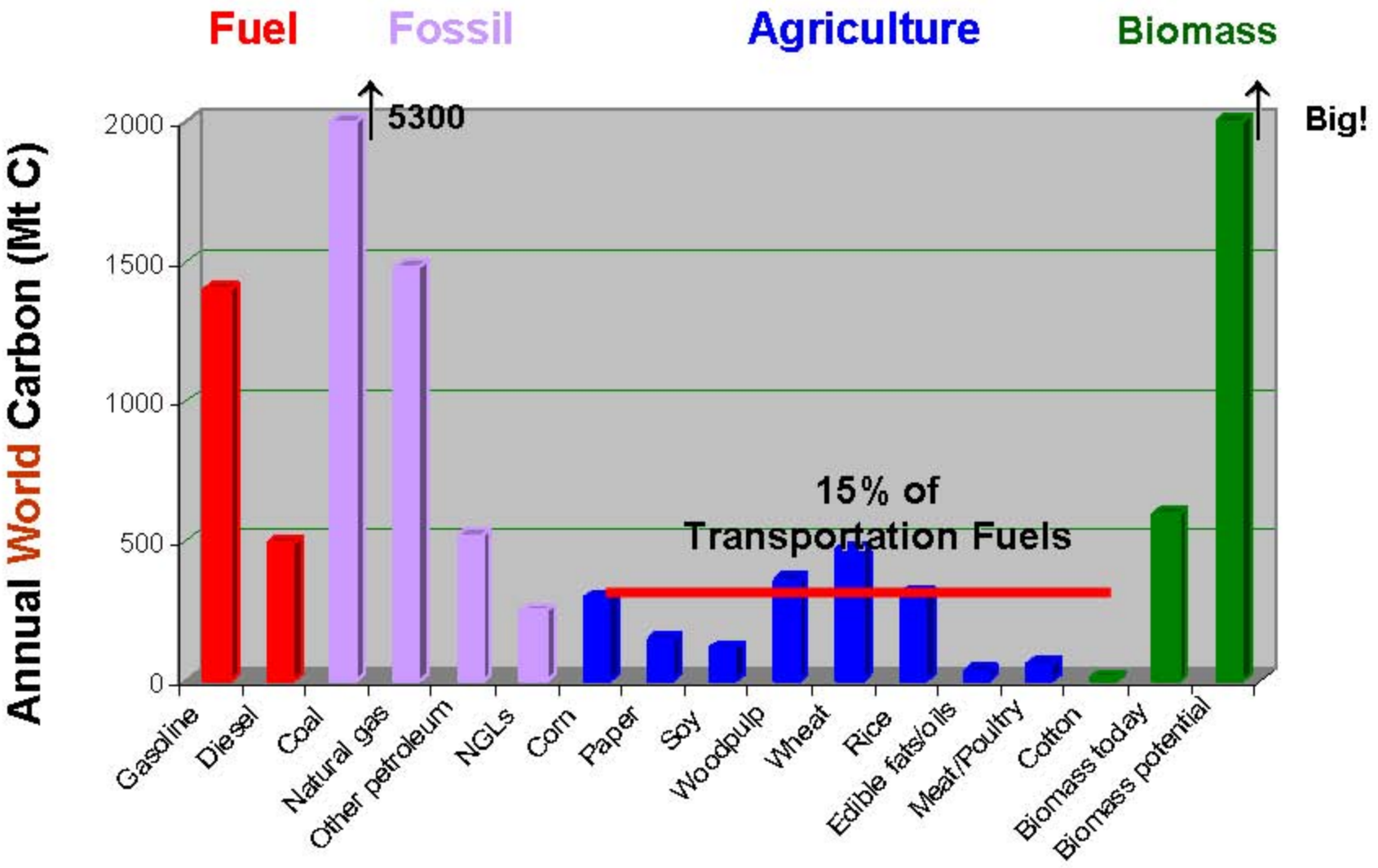


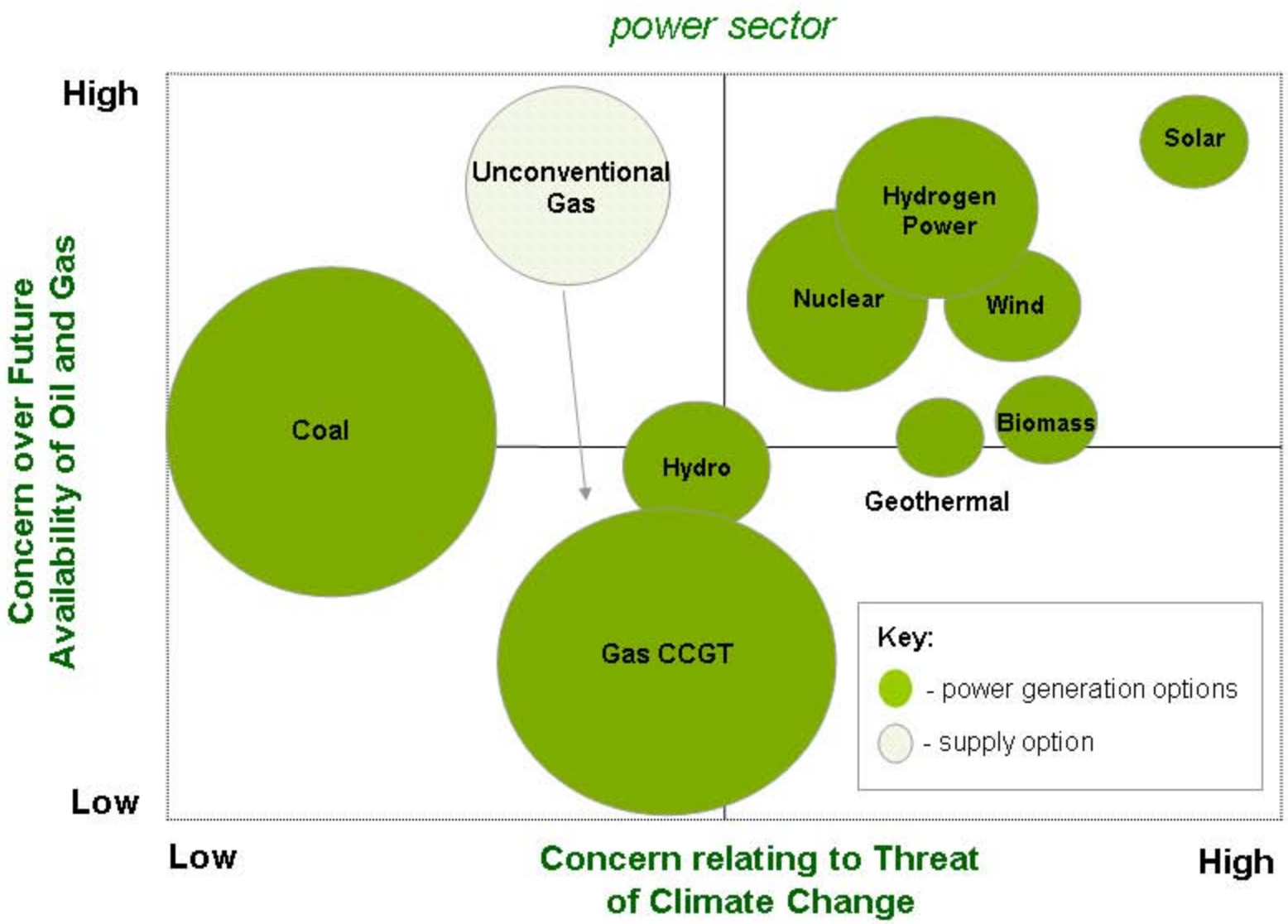
the fungibility of carbon



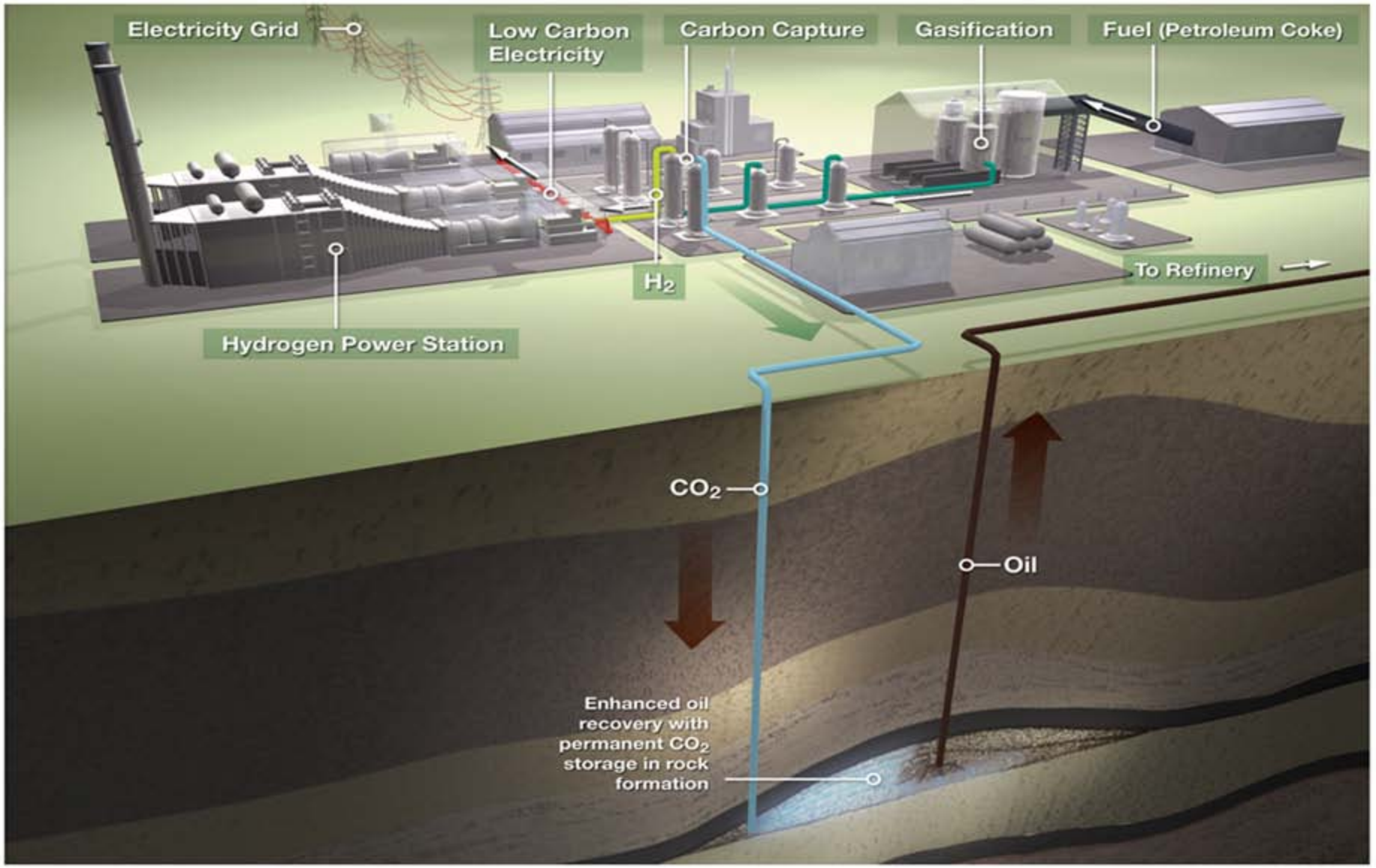
what carbon “beyond petroleum”?



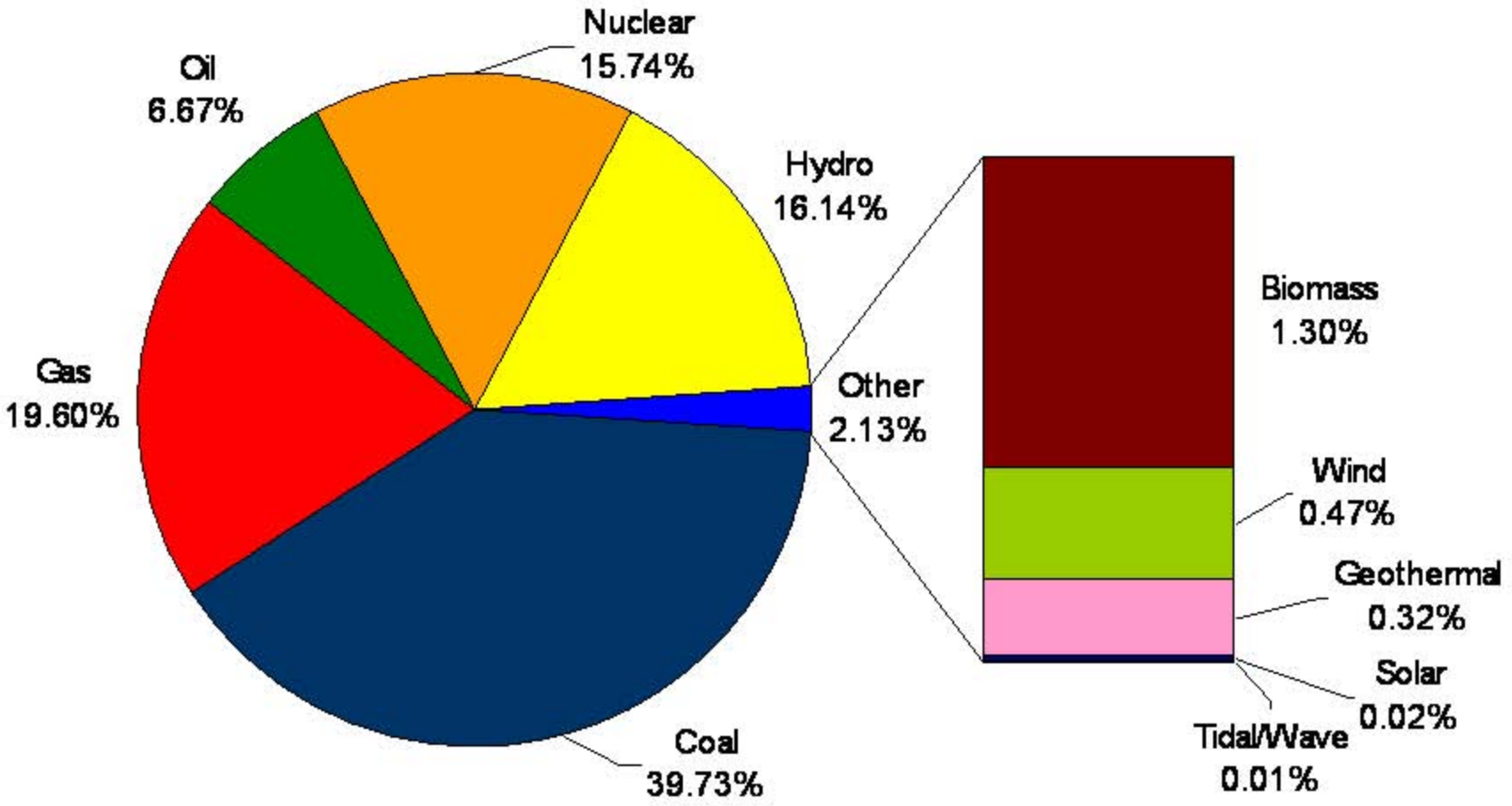
evaluating power options



hydrogen power project – California

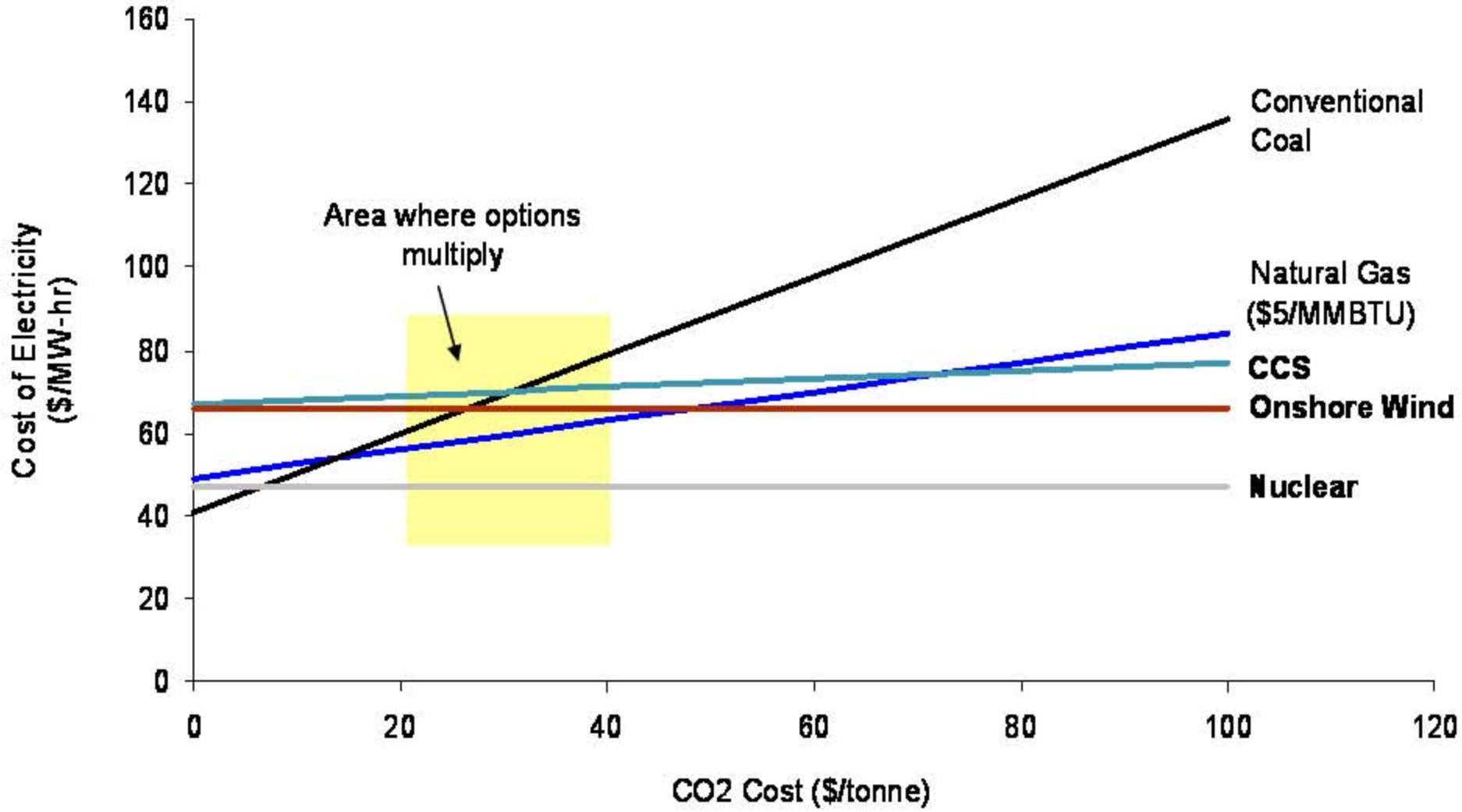


electricity generation shares by fuel - 2004



Source: IEA WEO 2006

impact of CO_2 cost on levelised Cost of Electricity



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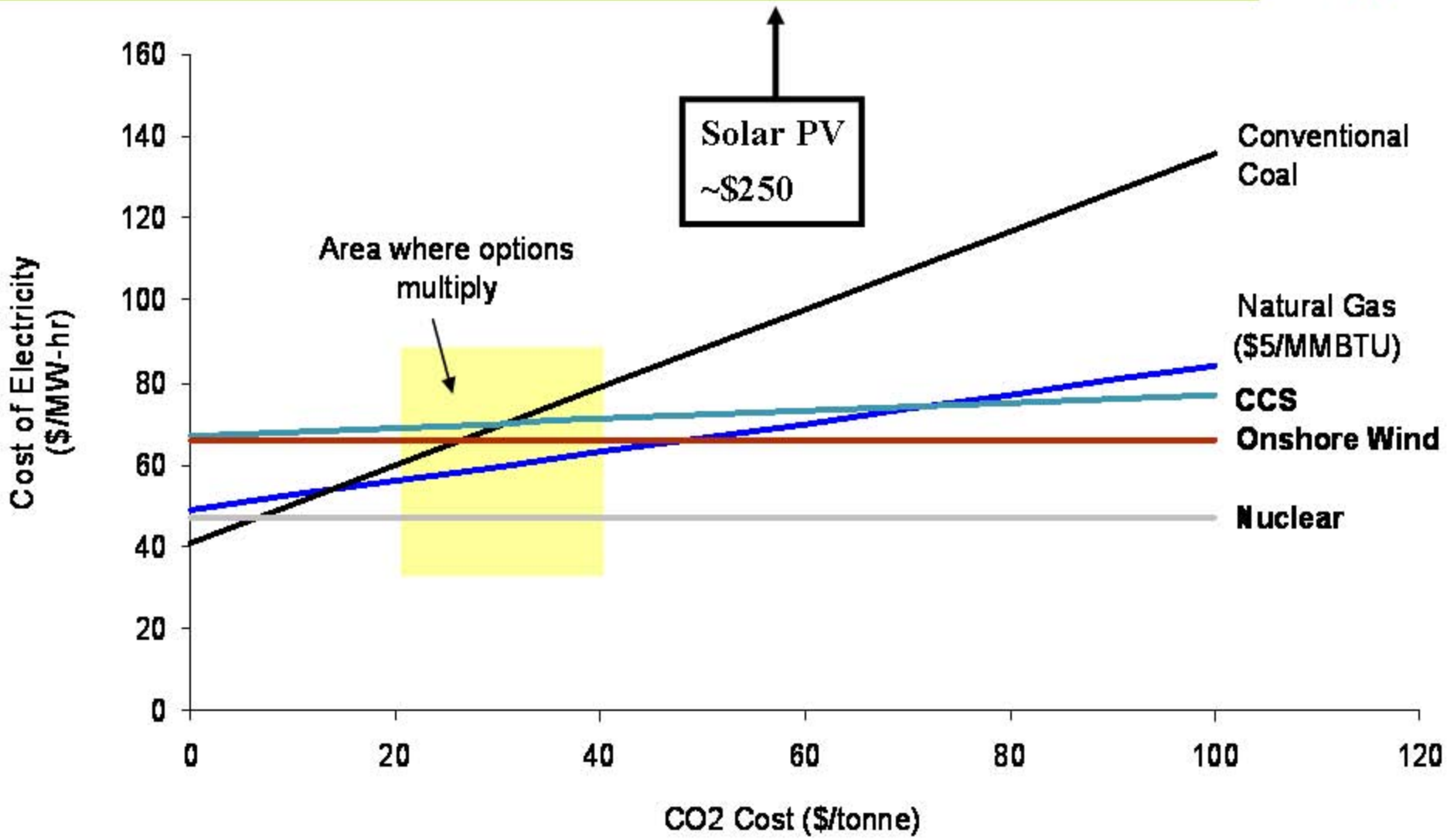

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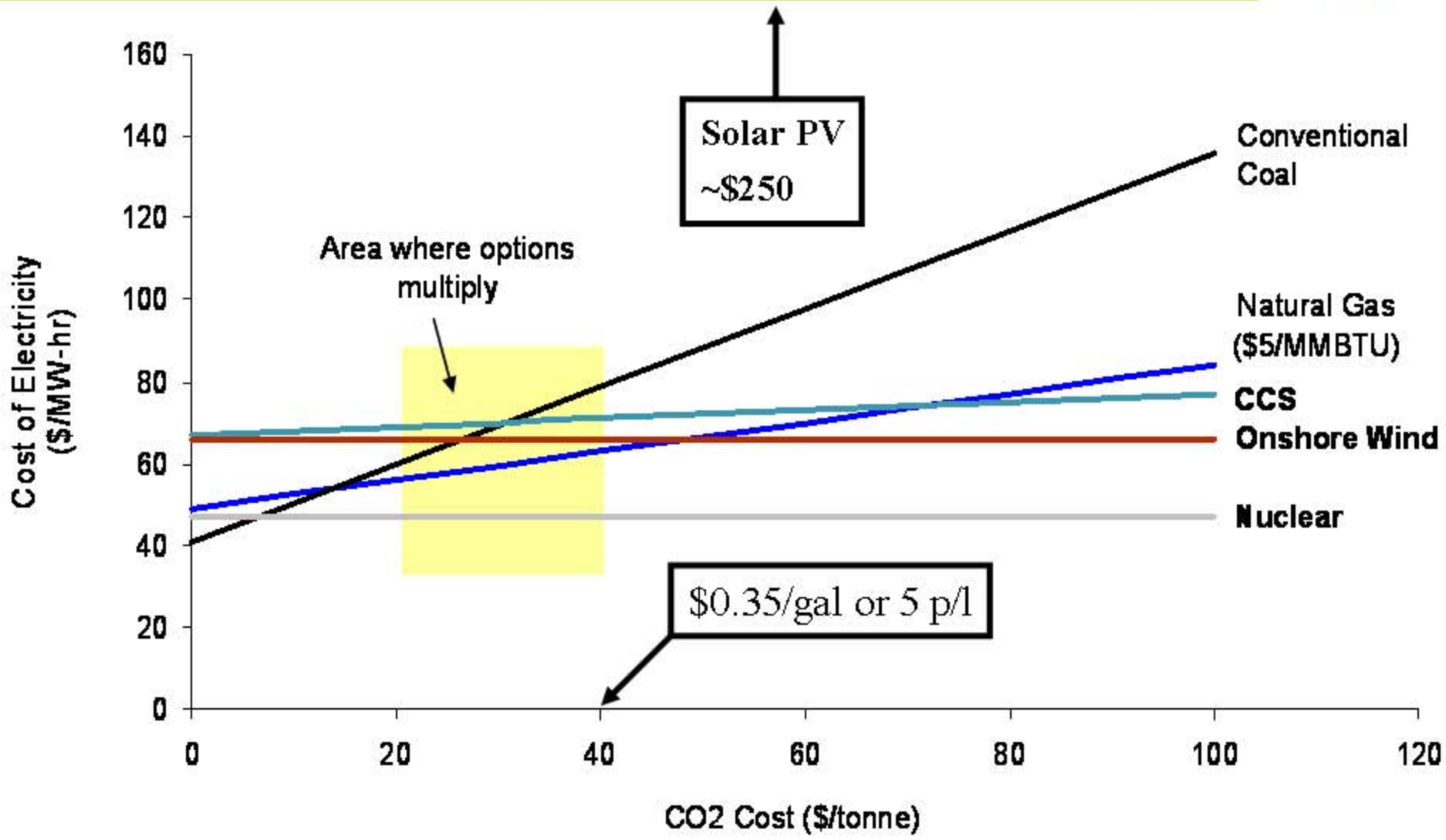

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The (supply) research agenda

Fossil fuel technologies

- Operation in the Artic, extreme deepwater (>6000 ft)
- Subsalt seismic and Controlled Source ElectroMagnetics
- Extreme pressures/temperatures (10 km, 1000 atm, 200C)
- Improved Oil Recovery/Mature basin management
- Heavy/shale/tarsand oil
  - production, refining
- Tight gas/Coal Bed Methane
- Underground Coal Gasification
- Conversion + sequestration for power, fuels, chemicals
  - Gasification, catalysts, membranes

Alternatives, renewables, exotica

- Energy-bio connection
  - Advanced biofuels, conversion, sequestration
- Energy storage
  - batteries, capacitors, flywheels, phase change, H2?
- Power transmission
- Advanced photovoltaics
- Methane hydrates
- Next and (Next + 1) generation fission
  - Fission heat
- Fusion (magnetic and inertial)

potential of demand side reduction

Low Energy Buildings

- Buildings represent 40-50% of final energy consumption
- Technology exists to reduce energy demand by at least 50%
- Challenges are consumer behaviour, policy and business models

Urban Energy Systems

- 75% of the world's population will be urbanised by 2030
- Are there opportunities to integrate and optimise energy use on a city wide basis?

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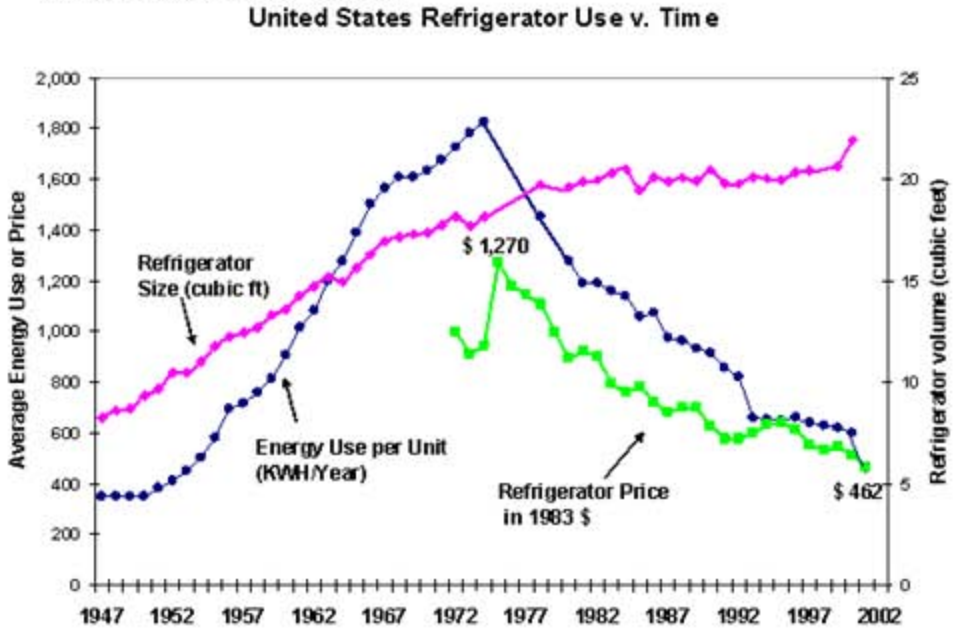

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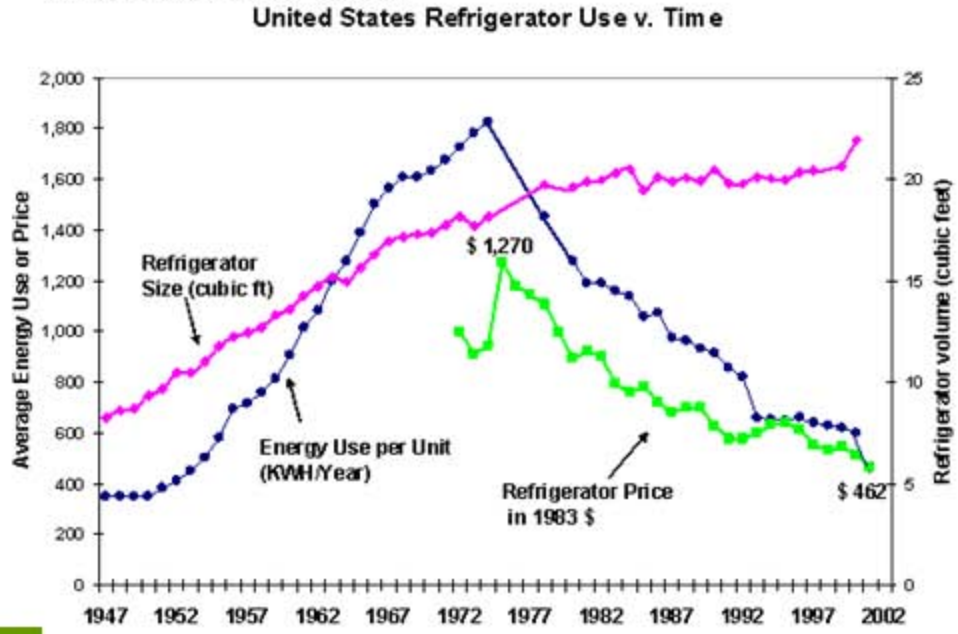

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- engine efficiency:	***+23.0%***
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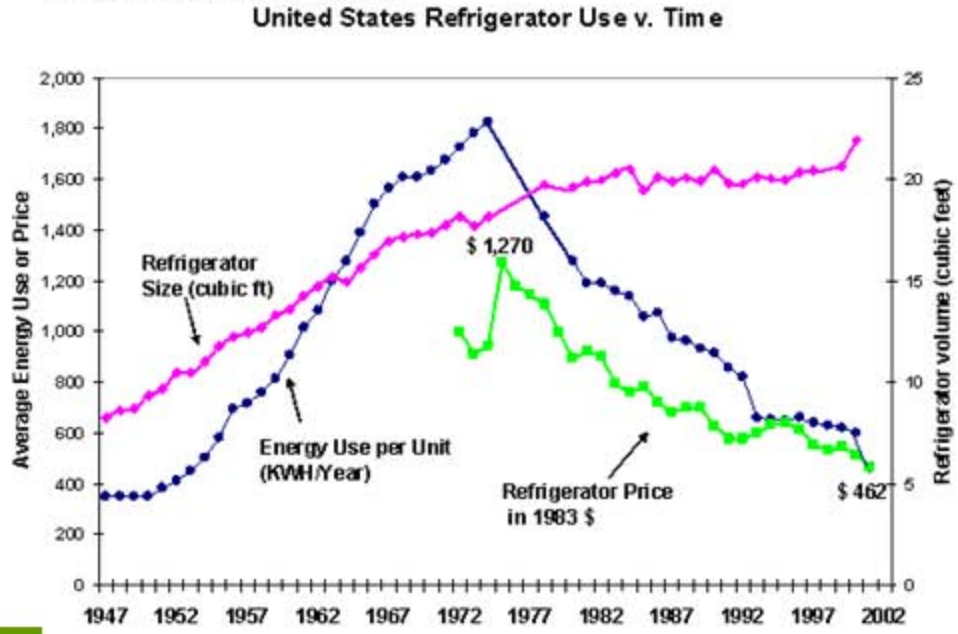

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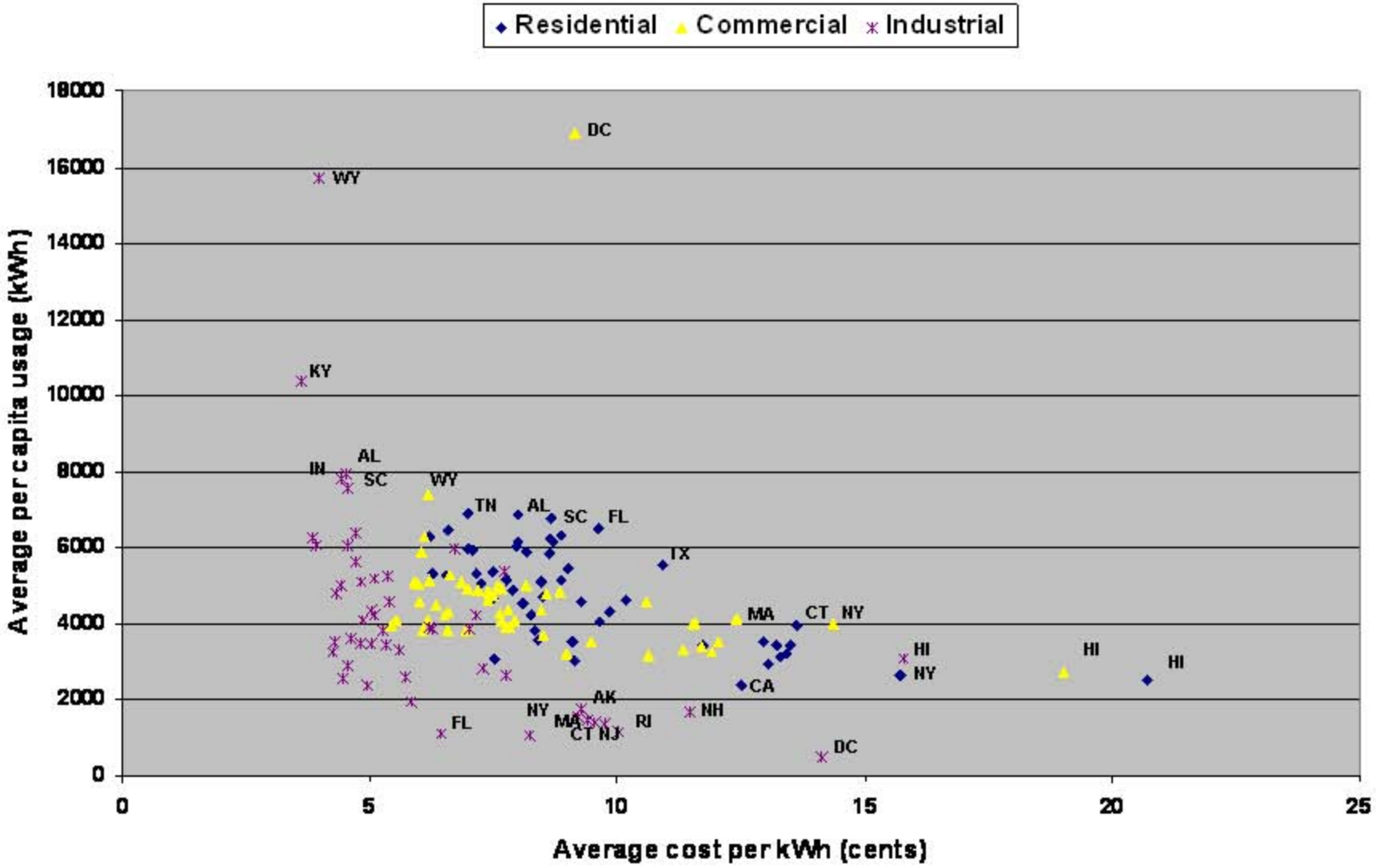
- Price and/or policy are the surest ways to induce conservation
- Either is politically difficult

per capita US electricity by state



likely 30-year energy future

- **Hydrocarbons will continue to dominate transportation (high energy density)**
  - Conventional crude / heavy oils / biofuels / CTL and GTL ensure continuity of supply at reasonable cost
  - Vehicle efficiency can be at least doubled (hybrids, plug-in hybrids, HCCI, diesel)
  - local pollution controllable at cost; CO_2 emissions now ~20% of the total
  - Hydrogen in vehicles is a long way off, if it's there at all
    - No production method simultaneously satisfies economy, security, emissions
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- **CO_2 emissions (and concentrations) continue to rise absent dramatic global action**

necessary steps around the technology

- **Technically informed, coherent, stable government policies**
  - Educated decision-makers and public
  - Focus on the most material/lowest-cost measures
  - For short/mid-term technologies
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- **Universities/labs must recognize and act on importance of energy research**
  - Technology and policy

What is Plan B for climate change?

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- **Geoengineering is a last resort if things get really bad**
  - Albedo modification (need only to go from 0.30 to 0.31)
    - In space, in the atmosphere, at the surface
  - Removal of GHGs from the atmosphere (probably biological)
    - Annual natural carbon exchange with the atmosphere is ~200Gt
    - Fossil fuel increment is currently ~6Gt

Questions/Comments/Discussion