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# Energy Perspectives on Sustainability

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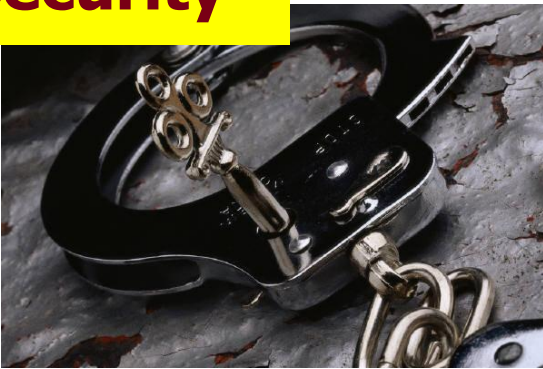
# The Perfect Storm

## Supply



- Energy supply and demand
- Energy and security
- Energy and the environment

## Security



## Impacts

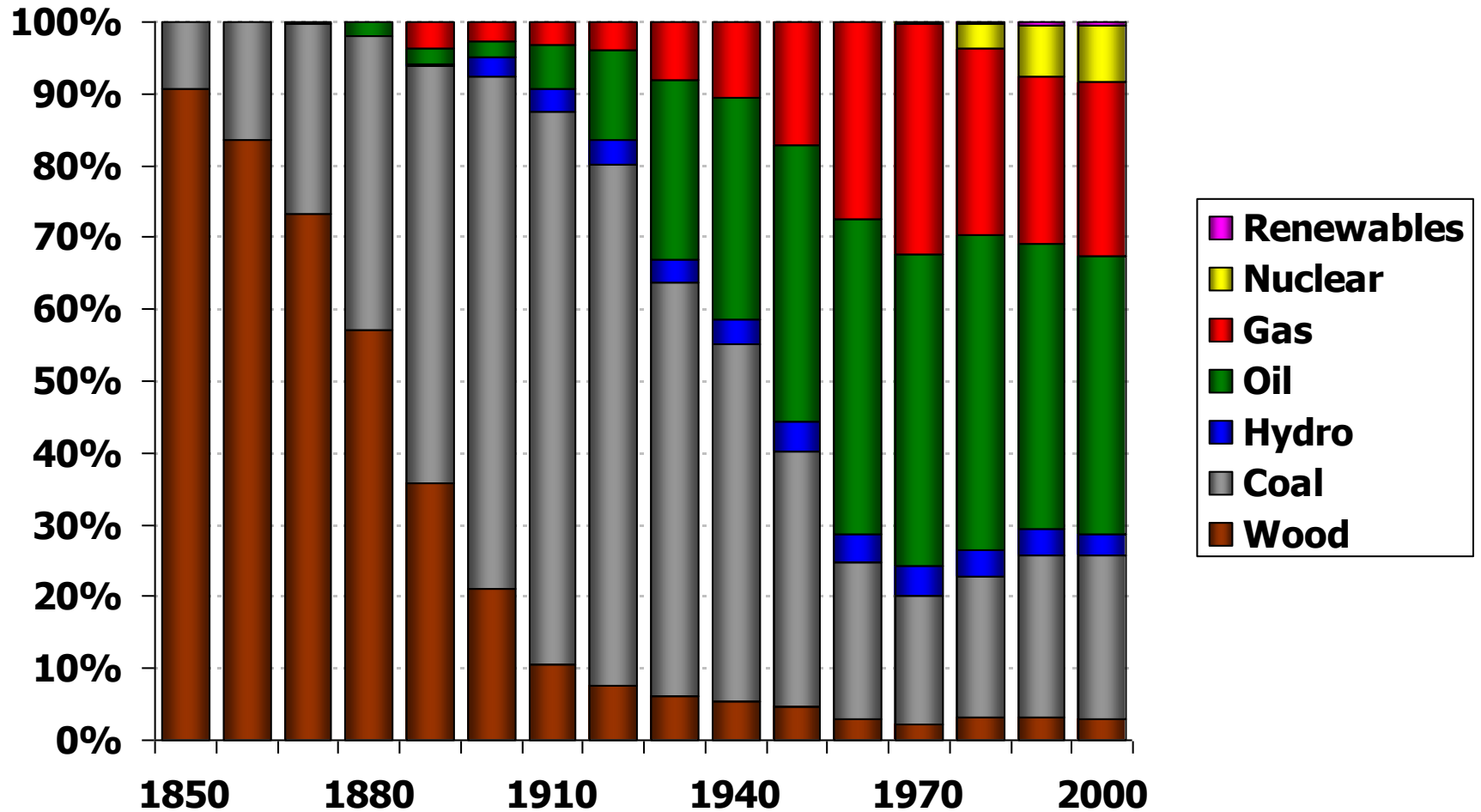


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# The “Perfect Storm”

- Energy supply and demand
  - 450 EJ/year (14.2 TW)/16 T kWh-electric/year
  - Projected doubling of energy use and tripling of electricity use by 2050 in business as usual
  - 1.4 Billion people without electricity in 2030
  - 80+% fossil fuel/enough oil?
  - 50 year time scale for major shifts in energy

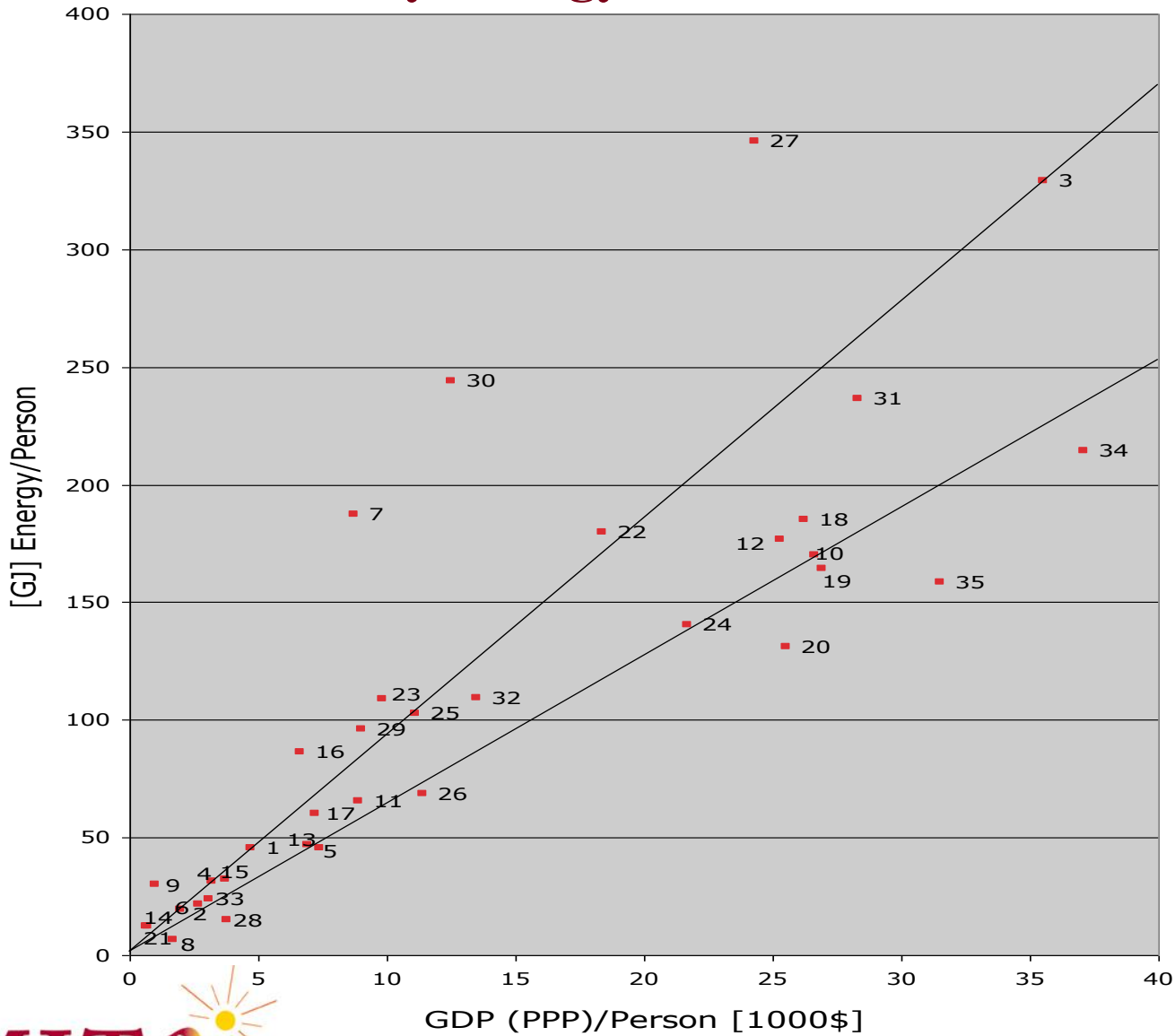
# US Energy Supply Since 1850



Author: Koonin

Source: EIA

# Primary Energy Use Per Person

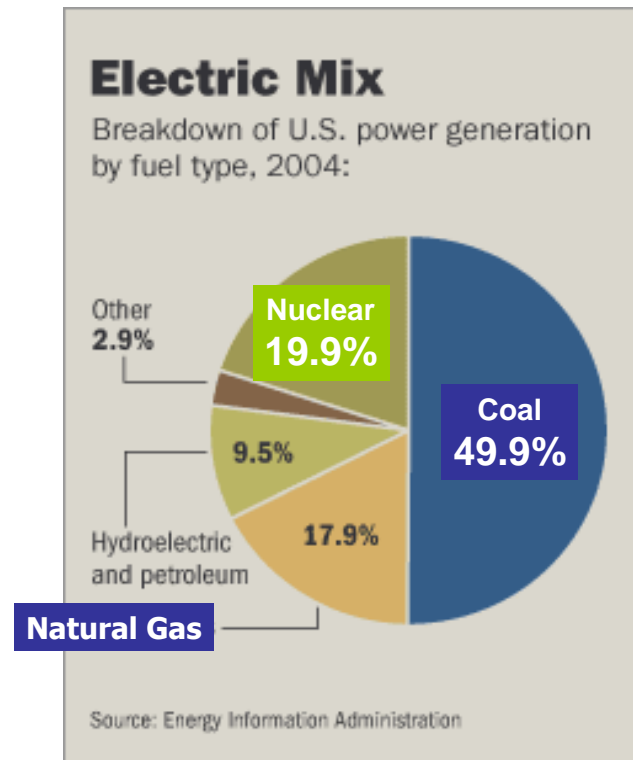


- 1 China
- 2 India
- 3 US
- 4 Indonesia
- 5 Brazil
- 6 Pakistan
- 7 Russia
- 8 Bangladesh
- 9 Nigeria
- 10 Japan
- 11 Mexico
- 12 Germany
- 13 Turkey
- 14 Ethiopia
- 15 Egypt
- 16 Iran
- 17 Thailand
- 18 France
- 19 UK
- 20 Italy
- 21 Dem Rep. Congo
- 22 South Korea
- 23 South Africa
- 24 Spain
- 25 Poland
- 26 Argentina
- 27 Canada
- 28 Morocco
- 29 Malaysia
- 30 Saudi Arabia
- 31 Australia
- 32 Hungary
- 33 Nicaragua
- 34 Norway
- 35 Ireland



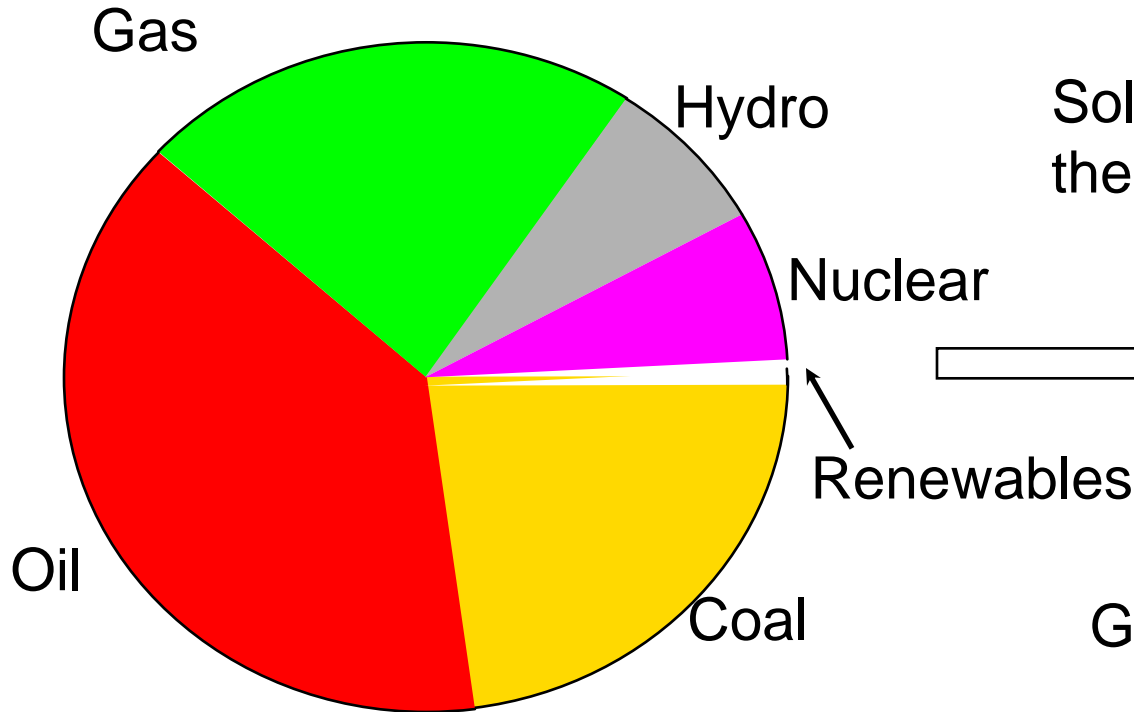
# Scale Issues – Magnitude of Problem

- World wide consumption of oil ~ 1000 barrels per second
- CO2 emissions from coal is ~9 Giga Tons per year
- China currently building the equivalent of two 500 MW power plant per week
- China growth rate for coal consumption is twice the US rate
- Time constant for energy infrastructure changes in the US is O(50 years)
- Average age of US power plants is over 30 years

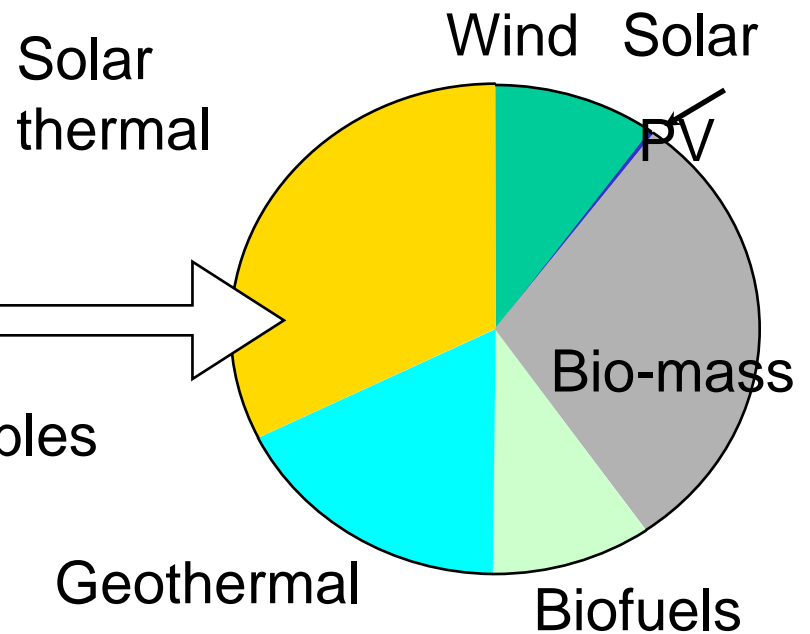


# Scale Issues – Renewable Sources

Total primary energy: 410 EJ/year



Renewables: 4 EJ/year



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# The “Perfect Storm”

- Energy and security
  - Geological and geopolitical realities of oil and gas supply
  - Oil (and natural gas) adequate and reliable supply
  - Vulnerability of extended energy delivery systems
  - Nuclear weapons proliferation facilitated by worldwide nuclear power expansion
  - Dislocation from environmental impacts, such as from climate change

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# Oil and Energy Security

- Core Issue: inelasticity of transportation fuels market, together with geographical and geophysical realities of oil
- Addressing sudden disruptions
  - Strategic reserves
  - Well-functioning markets
- Increasing and diversifying supplies
  - Enhanced production from existing fields
  - Arctic E&P
  - “Unconventional” oil (tar sands,...)
- Weakening the “addiction”
  - Very efficient vehicles
  - Alternative fuels (coal, NG, biomass)
  - New transportation paradigm (electricity as “fuel”? H2?)

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# The “Perfect Storm”

- Energy and environment
  - Risk of climate change
  - 50+ years of CO<sub>2</sub> “emissions budget”
  - “De-carbonizing” of energy?

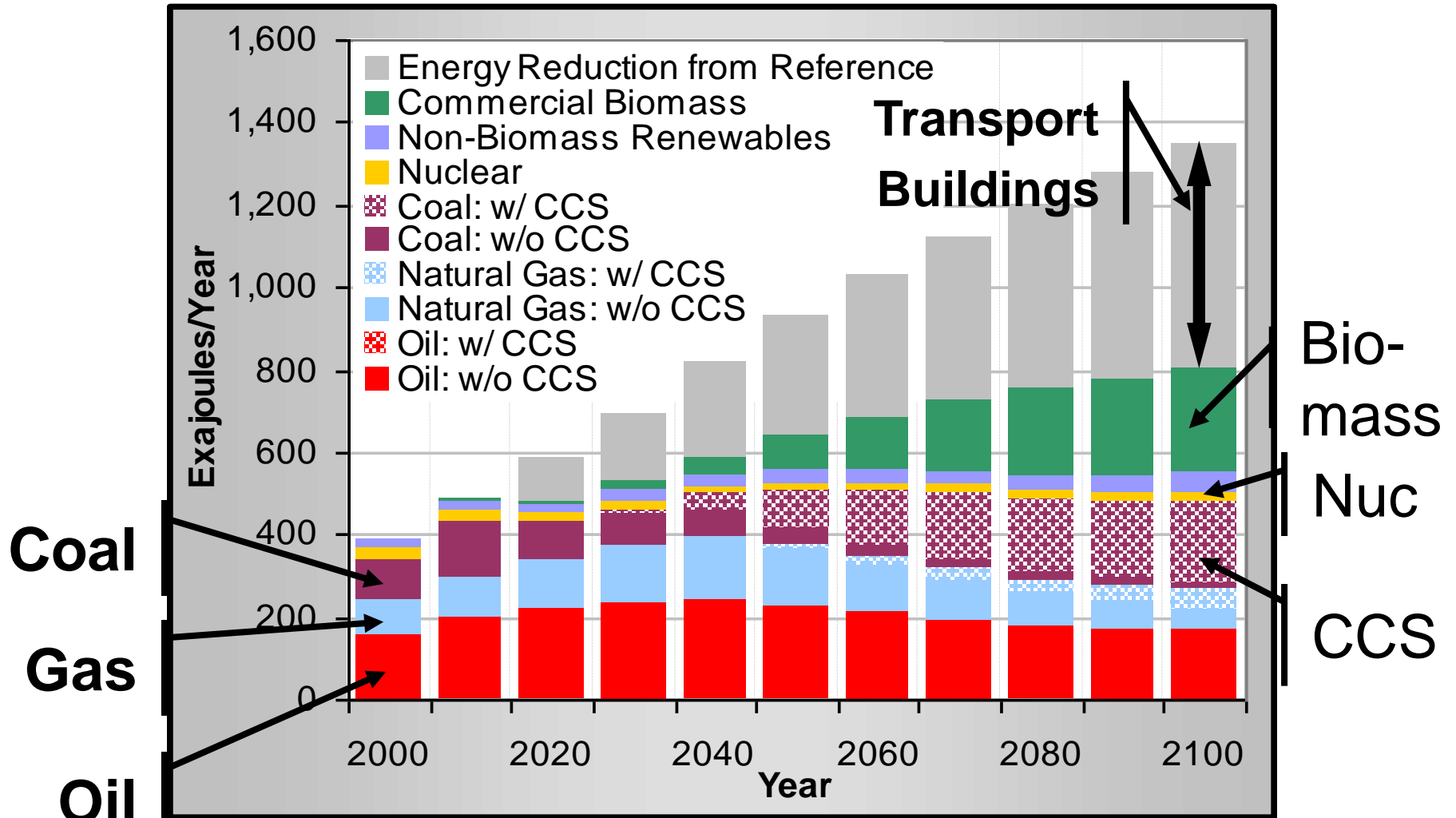
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# Climate Change Technology/Policy Pathways

- Efficiency
- Low carbon or “carbon-less” technologies/fuels
  - Fuel switching, e.g., coal to natural gas
  - Nuclear power (fission, possibly fusion in long term)
  - Renewables (wind, geothermal, solar,...)
    - Note: scale matters
- Carbon dioxide capture and sequestration

Climate control policy is not new. As early as 1306 Edward I of England prohibited the burning of coal in craftsman’s furnaces. Later Elizabeth I banned burning of coal in London while Parliament was in session.

# Global Primary Energy: 550 ppmv



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# Major technology and policy challenges to realization of this scenario - scale

Capture and sequestration of about 15 billion tonnes of CO<sub>2</sub> per year

- Billion barrels/50 yrs for 600 MWe
- About 200 million barrels/day of supercritical CO<sub>2</sub>
- Alternatives? Nuclear, wind, solar,....

About 50 million barrels/day of biofuels (3.5 TW)

- Systems challenges (land, water, fertilizer,...)?
- Alternatives? Hybrids, electric vehicles, fuel cell vehicles/H<sub>2</sub>,...

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# Uncertainty on a 50-year Time Scale

- Future scenarios highly uncertain on mid-century time scale
  - 50-year time scale characteristic of significant change in energy infrastructure, of greenhouse gas concentrations approaching twice pre-industrial,...
- Multiple uncertainties
  - Resource availability?
    - fossil fuels, land for renewables, effects of renewables at scale...
  - Science and technology advances?
    - technology breakthroughs, climate change impacts
  - Geopolitical considerations?
    - Middle East, climate protocol participation,...
- Broad response pursuing multiple technology and policy options is needed

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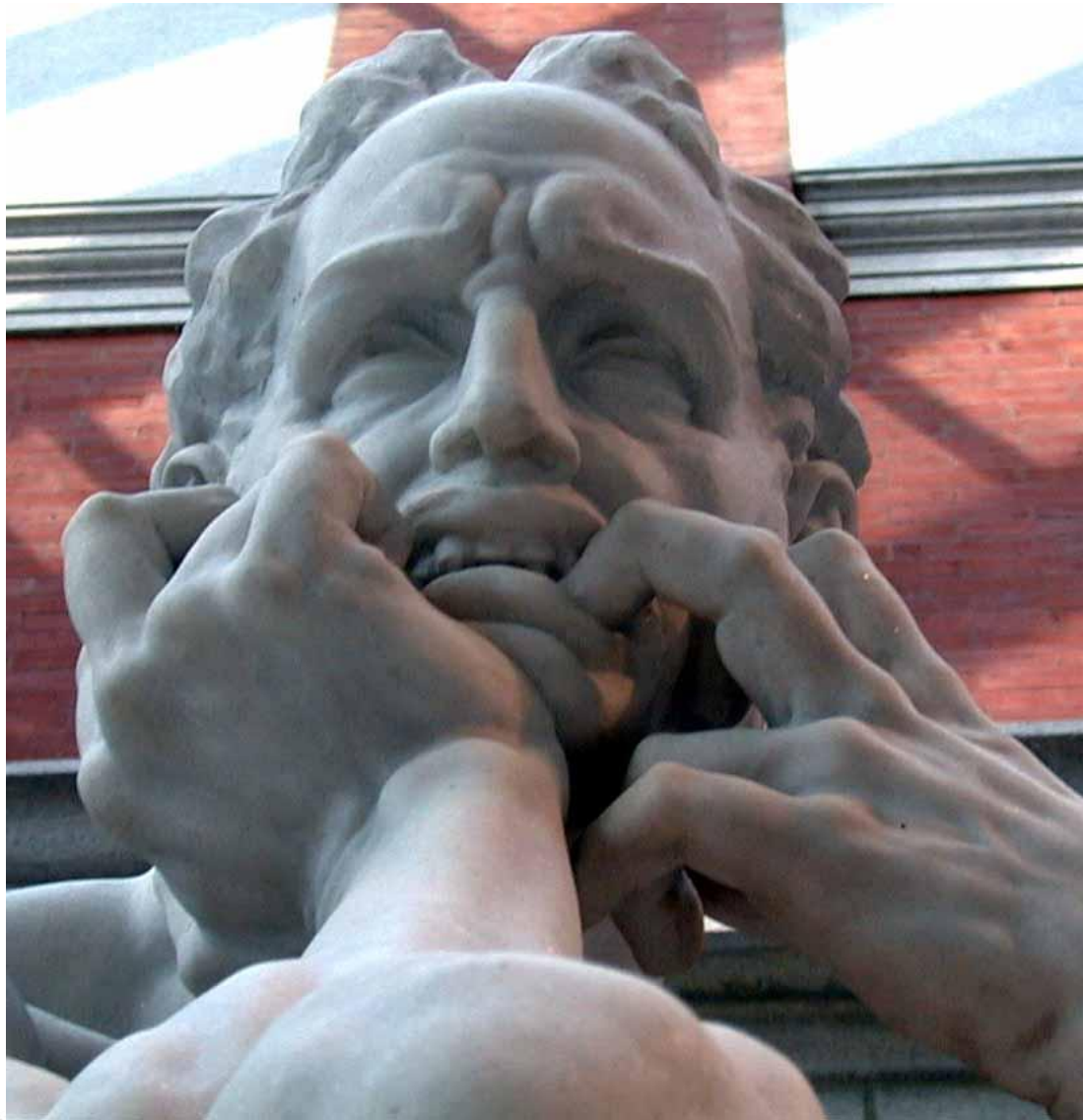
# Key Technology Pathways

- Efficiency (buildings & cities, vehicles & transportation systems, supply chains, industrial processes)
- Alternative transportation fuels (biofuels, electricity, H2?)
- C-“free” electricity (nuclear, coal+CCS, renewables/solar)
- Unconventional hydrocarbon supply (EOR, heavy “oil”, ultradeep)
- Energy delivery systems (storage, high quality power, distributed generation)
- “Managing” global change (mitigation, adaptation, atmospheric “re-engineering”)

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# Closing Thoughts

- This is an enormous problem both in magnitude and time scale
  - To provide 14 TW of carbon-free power by 2050 from nuclear sources
    - ~ 1 GW power plant needs to be built per day
    - What do we do with the nuclear waste?
  - A variety of technology options are needed
  - We must start now
  - At these magnitudes we must do our best to assess impact on our environment before we commit



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**Thank You**

Questions?