Clean Coal Technologies

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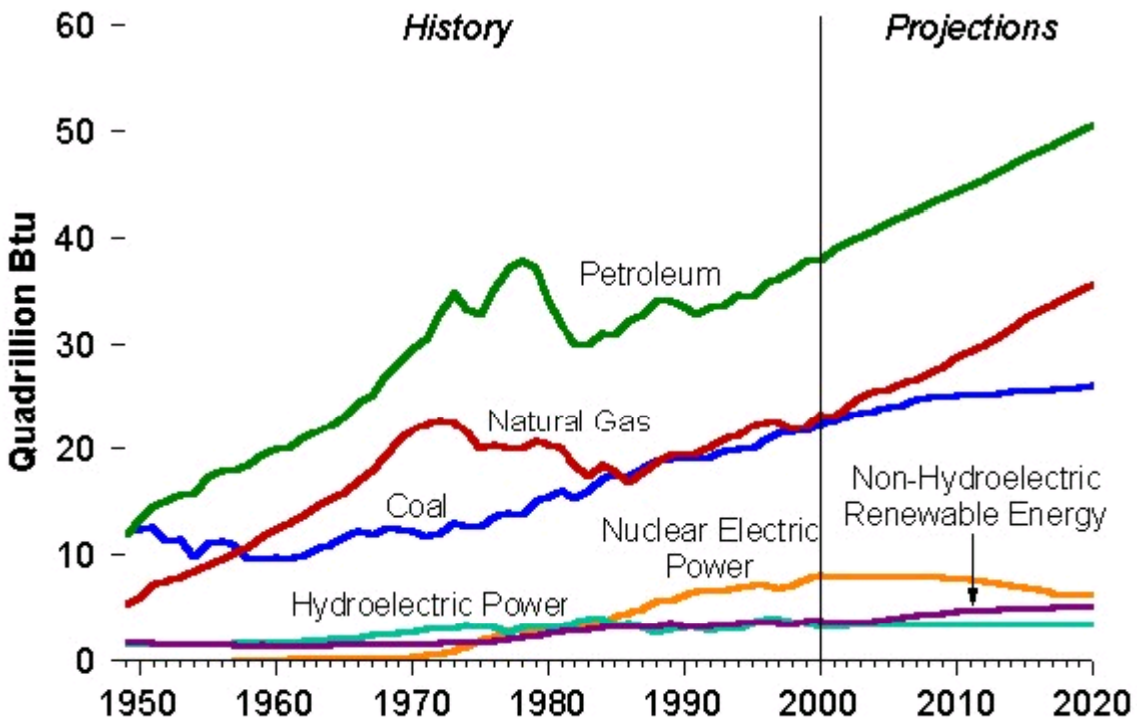
Outline

- Energy Sources
  - History, Projections and Usage
- Coal: Formation and Usage
- Clean Coal
- Options
  - Electricity
  - Liquid Fuels
    - Direct Liquefaction
    - Indirect Liquefaction

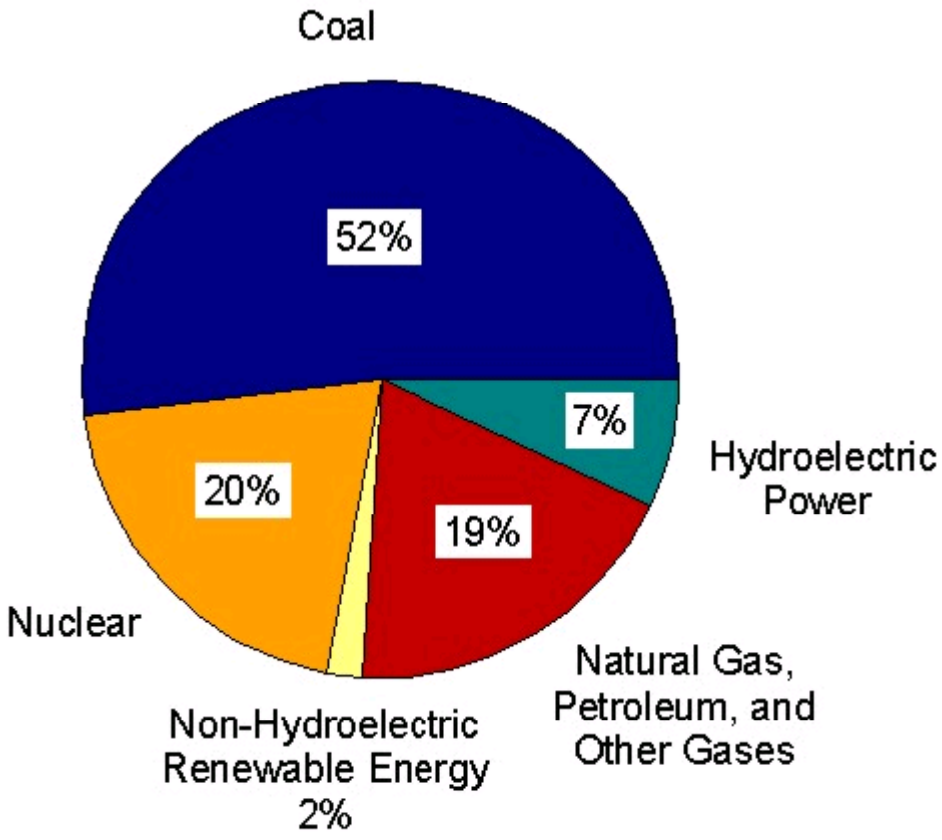
*UDEI as of July 1, 2010

Trends in US Energy Consumption



http://www.eia.doe.gov/emeu/aer/eh/frame.html

US Electricity Generation By Source

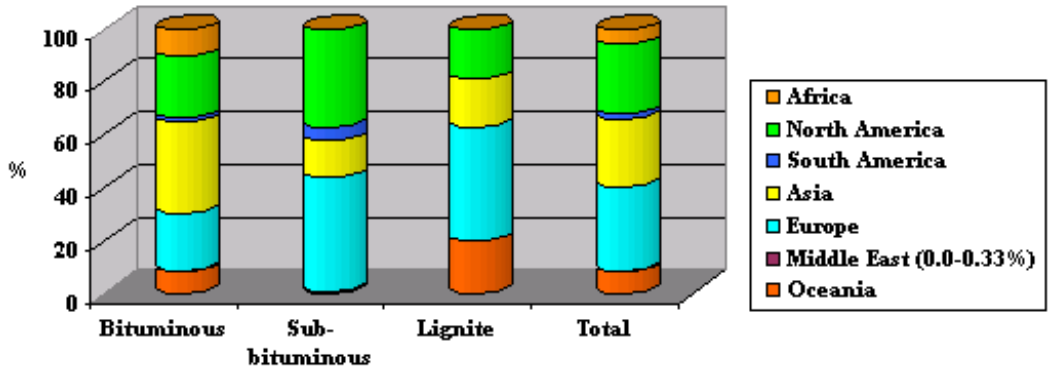


http://www.eia.doe.gov/emeu/aer/eh/frame.html

Coal

- Is strategic*
  - 25% of world's supply in USA
  - USA coal content greater than world's reserves of oil
  - 250-300 year supply
- Is the workhorse of US electric power industry
  - Provides greater than 50% of US electricity

Figure 1.1: Proved coal reserves at end-1999 - regional distribution **

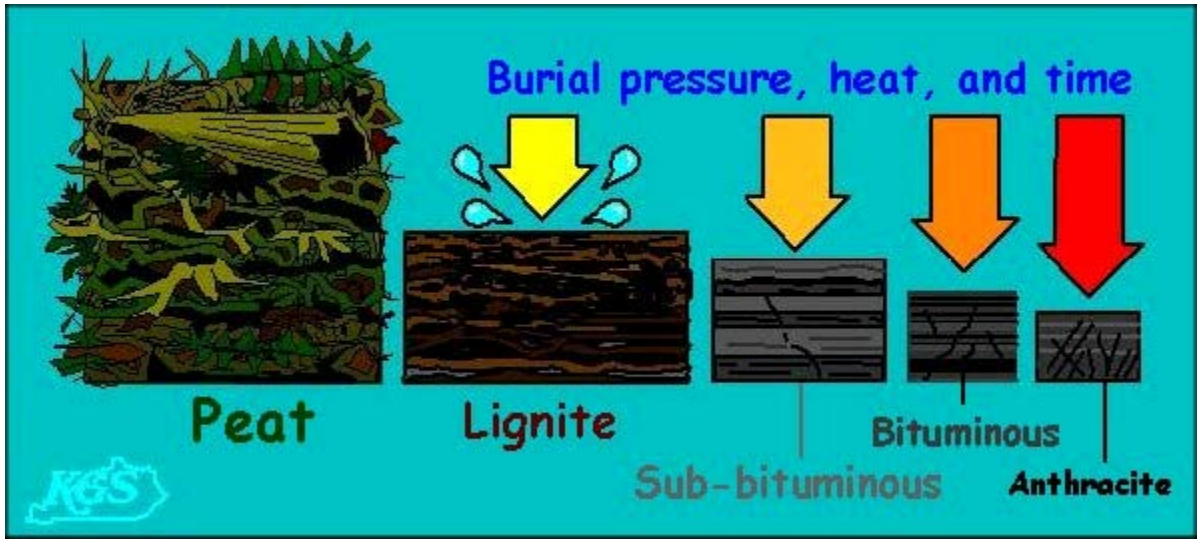


**www.chemistryexplained.com/Ce-Co/Coal

*US DOE www.energy.gov/energysources/coal

Coal Origins and Structure

- 250-300 million years ago:
  - Forests and plant material died and sank under earth's wet surface
  - Cellulose and hemi-cellulose decayed
  - Lignin (more resistant to microbial decay) concentrated and transformed
  - With prolonged exposure to T and P:

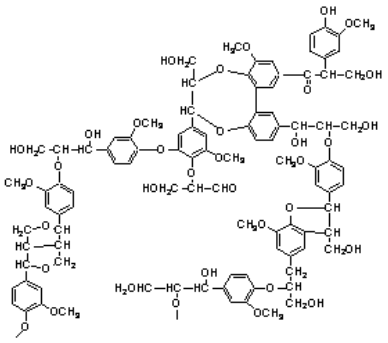


www.chemistryexplained.com/Ce-Co/Coal

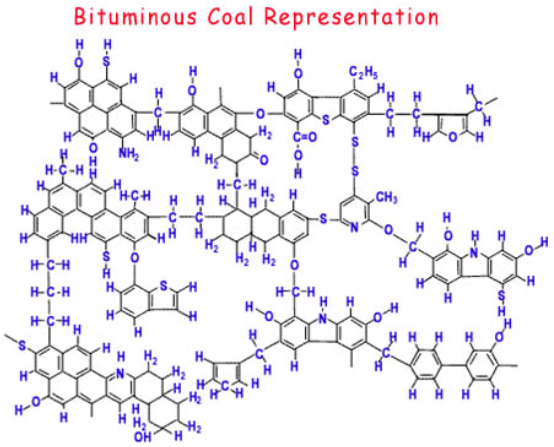
Key Structural Features of Coal

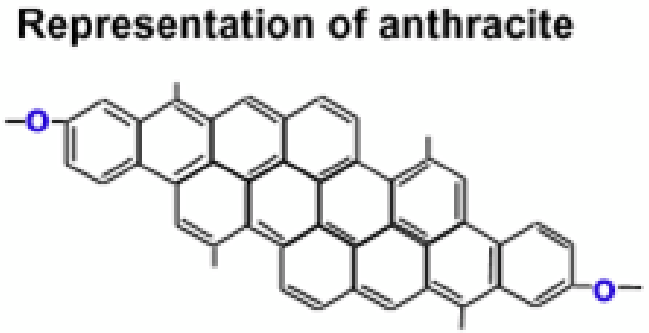
- PNA structures: 1-N aromatic (benzenoid) rings
- Heteroatoms: S, N, O, metals, ash
- Macromolecular Structure
- C/H ratio

$$\frac{C}{H}_{Coal} > \frac{C}{H}_{Oil}$$



Lignin

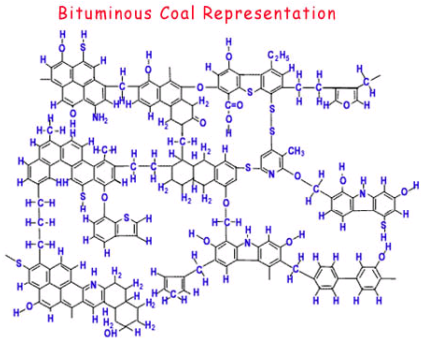




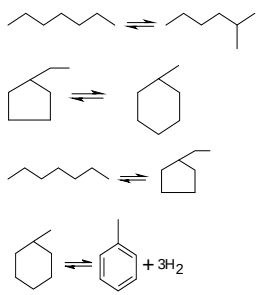
www.chemistryexplained.com/Ce-Co/Coal

Coal Utilization Options

- Combustion for Electricity*
- Indirect Liquefaction*
  - Reaction of coal with oxygen
  - Coal transformed to CO, H2 and other small gases
  - Petroleum-like molecules synthesized via catalytic Fischer-Tropsch process
  - Very flexible (can burn product “synthesis gas” for electricity)
- Direct Liquefaction
  - Fragments coal macrostructure
  - Preserves building blocks that are similar to petroleum molecules
  - Process involves thermal treatment in hydrogen donor around 400°C
  - Products could be sent to refinery



Petroleum Naphtha Molecules and Reactions



*Clean Coal

Clean Coal

- Designed to preserve/enhance this vital source of energy
- “Clean Coal Technology” describes a new generation of energy processes that reduce air emissions and other pollutants from coal-burning power plants
  - Sulfur and nitrogen oxides combine with water vapor: acid rain
  - CO2: greenhouse gas emissions
  - Mercury
  - Particulates
- More broadly, Clean Coal Technologies can describe environmentally friendly, sustainable use of coal for energy and fuels

US DOE www.energy.gov/energysources/coal

Clean Coal Technologies

- NOx Formation (NO_2, N_2O and NO)
  - Thermal NOx: reaction of N_2 and combustion air (~25% in coal unit*)
  - Fuel NOx: reaction of Coal-N with O_2 (~75% in coal unit)
  - Formation highly sensitive to reaction temperature, time and turbulence
- NOx Reduction Technologies
  - Combustion modification (addressing the three t's)
    - Low Nitrogen Oxide Burners:
      - On 75% of existing coal power plants
      - 25 million ton reduction in US NOx emissions
    - Fluidized Bed Combustion (FBC)
      - Highly commercialized
      - Inherently low NOx emitting (T range)
      - Allows contact with S-adsorbing material
      - Very flexible with regard to feedstock
  - Selective Catalytic Reduction
    - NOx reductions of 80-90% or higher
    - In about 30% of coal plants
    - 300 < T < 400 C,
    - Cat typically Vanadium/Titanium based

$$4NO + 4NH_3 + O_2 \xrightarrow{cat} 4N_2 + 6H_2O$$

$$2NO_2 + 4NH_3 + O_2 \xrightarrow{cat} 3N_2 + 6H_2O$$

$$NO_2 + NO + 2NH_3 \xrightarrow{cat} 2N_2 + 3H_2O$$

*NETL

Clean Coal Technologies*

- Flue Gas Desulfurization (FGD)
  - Wet scrubbing is the predominant technology (SO_2 removals of 95%+ are typical)
    - Slurry of alkaline sorbent contacts flue gas
    - Sorbent typically limestone or lime
    - Typical reaction: $CaCO_3(s) + SO_2(g) \rightarrow CaSO_3(s) + CO_2(g)$
  - Spray-dry scrubbing
  - Many other FGS variants
- Particulates
  - From mineral matter and formation reactions
  - Appear as “Bottom Ash”: discharged from the bottom of furnace
  - Appear as “Fly Ash”: suspended in Flue Gas
  - Electrostatic precipitators (ESP) and fabric filters are highly efficient (99.5% +)

*iea-coal.org.uk; NETL

Clean Coal Technologies

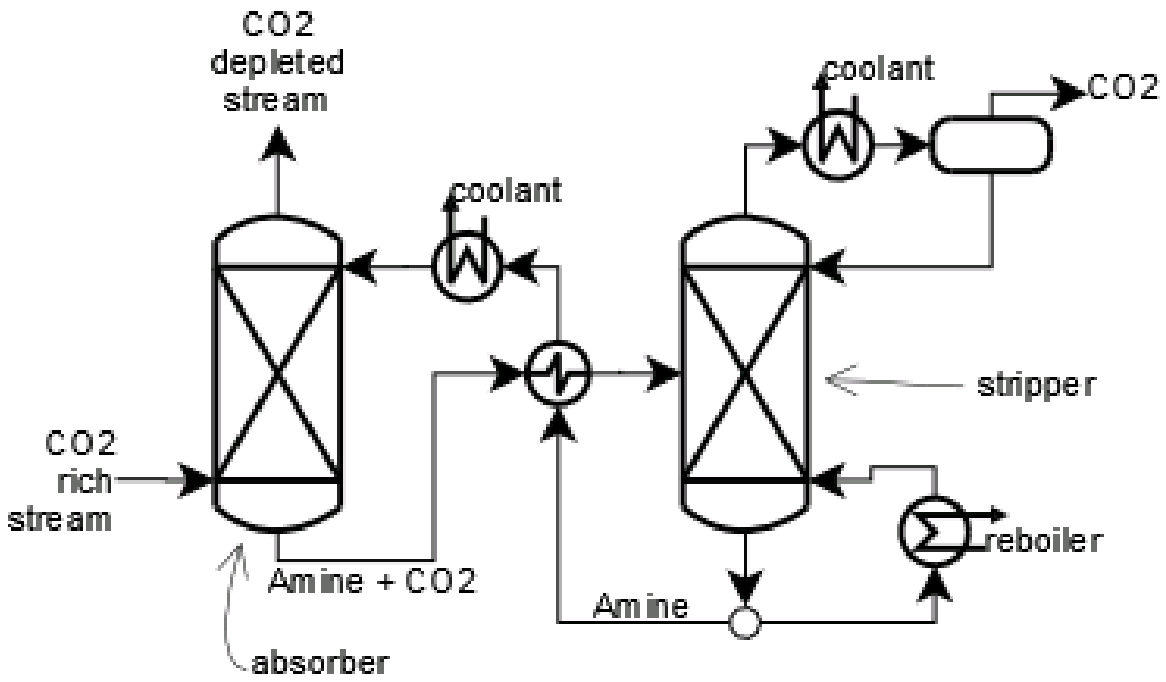
- Mercury*
  - Hg volatilized during combustion, converted to gaseous elemental Hg^o
  - Subsequent cooling and reactions produces flue gas with:
    - Hg^P: Particulate-bound mercury, and therefore handled with particulate control device (ESP, fabric filter)
    - Hg^{2+}: gaseous oxidized form, is water soluble and portions can be captured in wet FGD process
    - Hg^o: is captured by sorbent injection technology
  - Sorbent injection technology
    - Activated carbon injection
    - Partially reacted coal (e.g., Nalco Mobotec-NETL "Thief" technology)

*NETL

CO_2 Capture and Storage

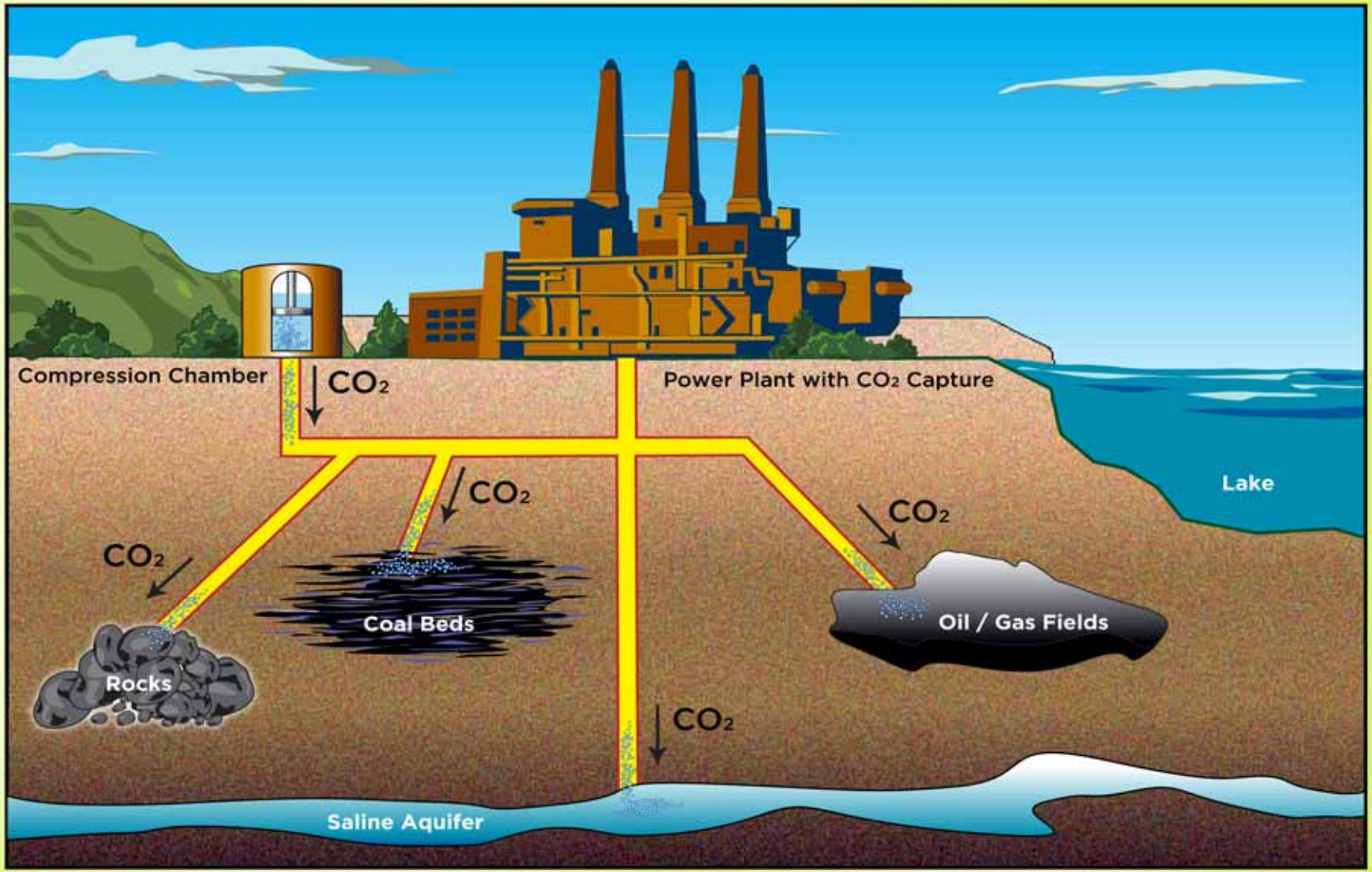
- Pre-combustion (e.g., in a gasification scheme)
  - Remove CO_2 from synthesis gas before combustion
  - Takes advantage of the relatively higher CO_2 concentration
  - Selexol commercial process
  - Current research includes membranes, ionic liquids, etc.
- Post-combustion CO_2 Capture
  - Challenges due to low pressure (1 atm) and low concentration (10-15 vol%)
  - CO_2 compression costs large
  - Trace impurities reduce effectiveness of CO_2 reduction process
- Oxy-Fuel Combustion
  - Uses oxygen rather than air
  - Off gas is mainly H_2O and CO_2

A Conventional Amine Unit

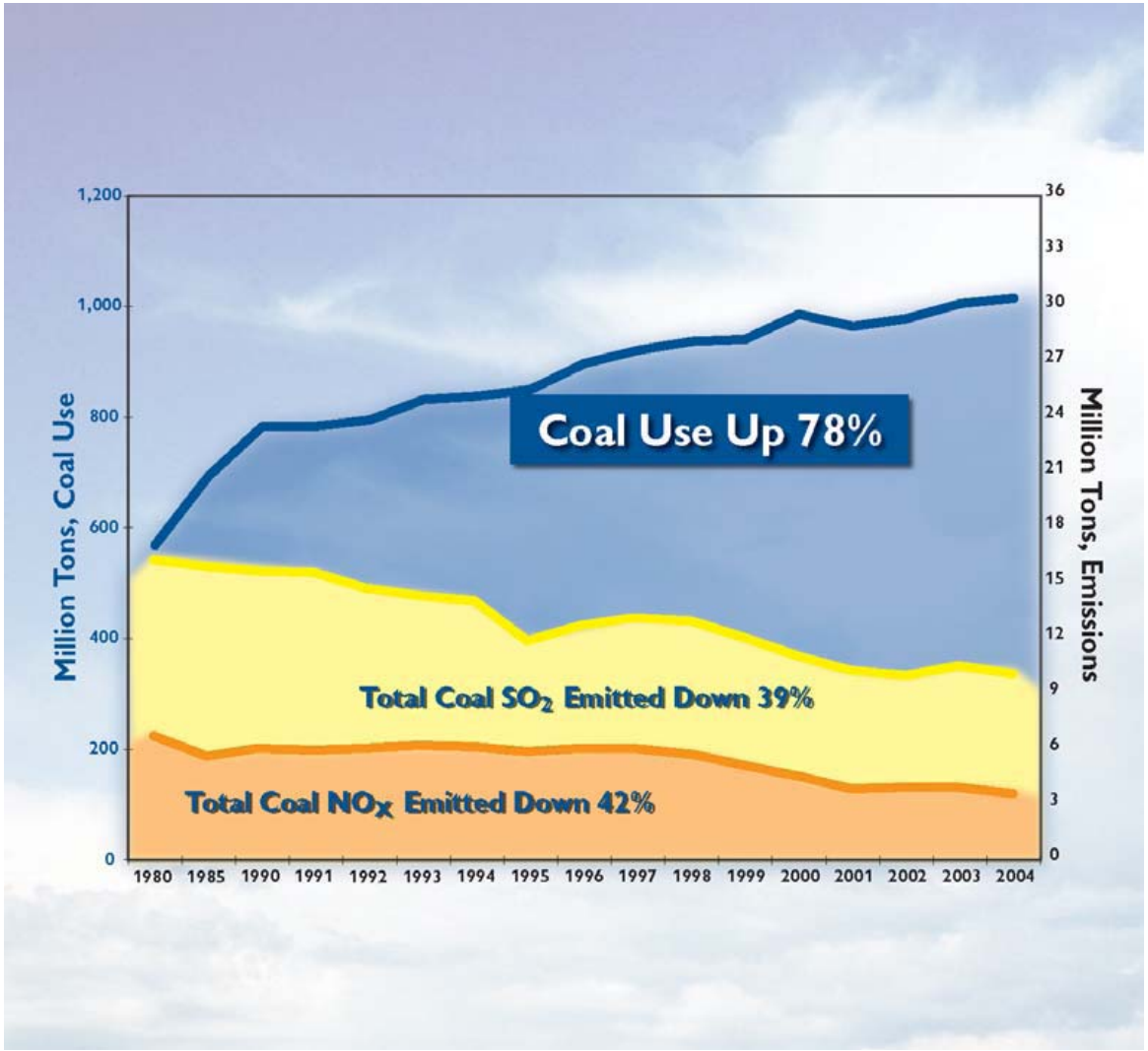


CARBON CAPTURE

and Sequestration/Enhanced Oil Recovery

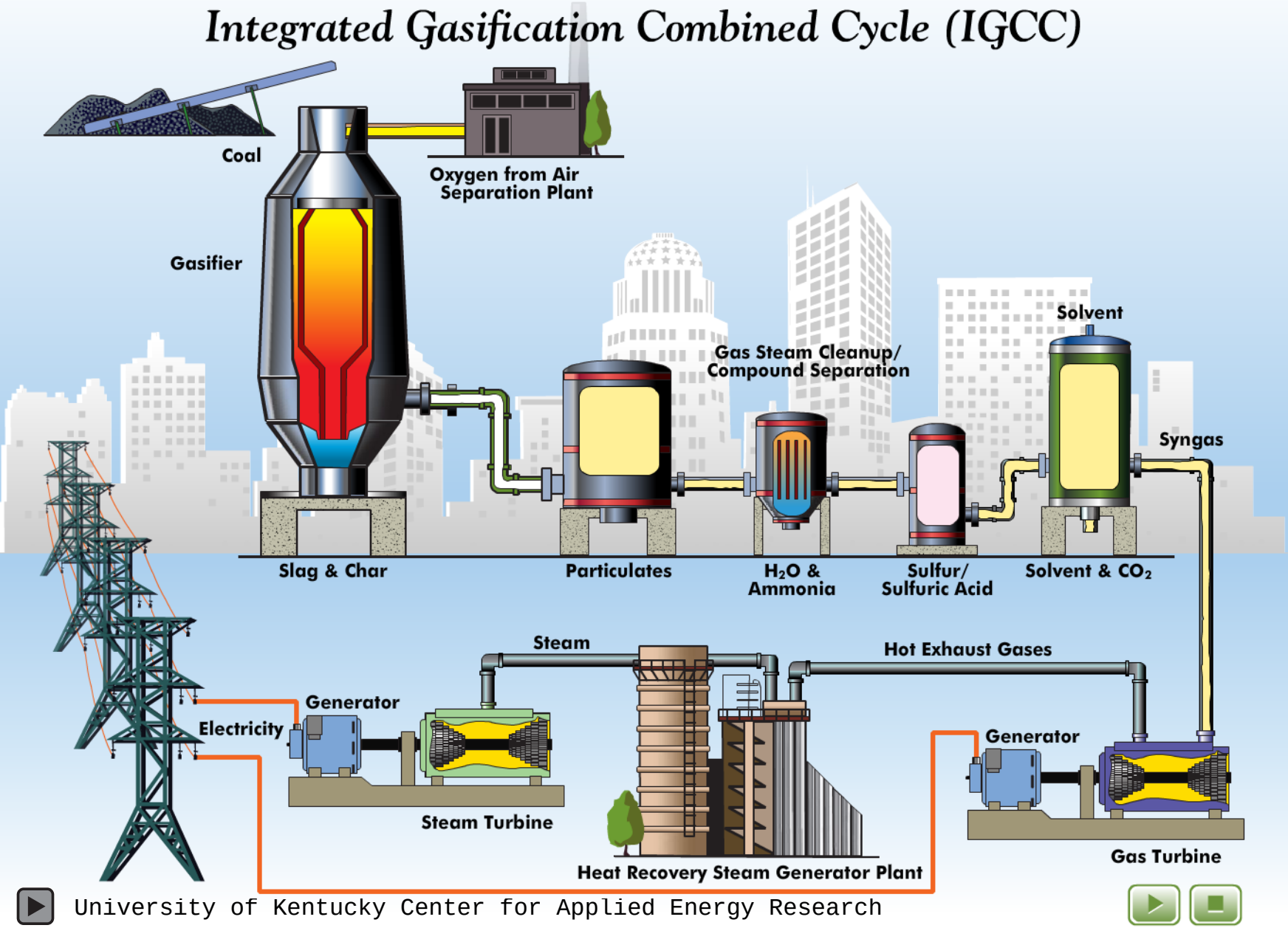


Clean Coal Results*

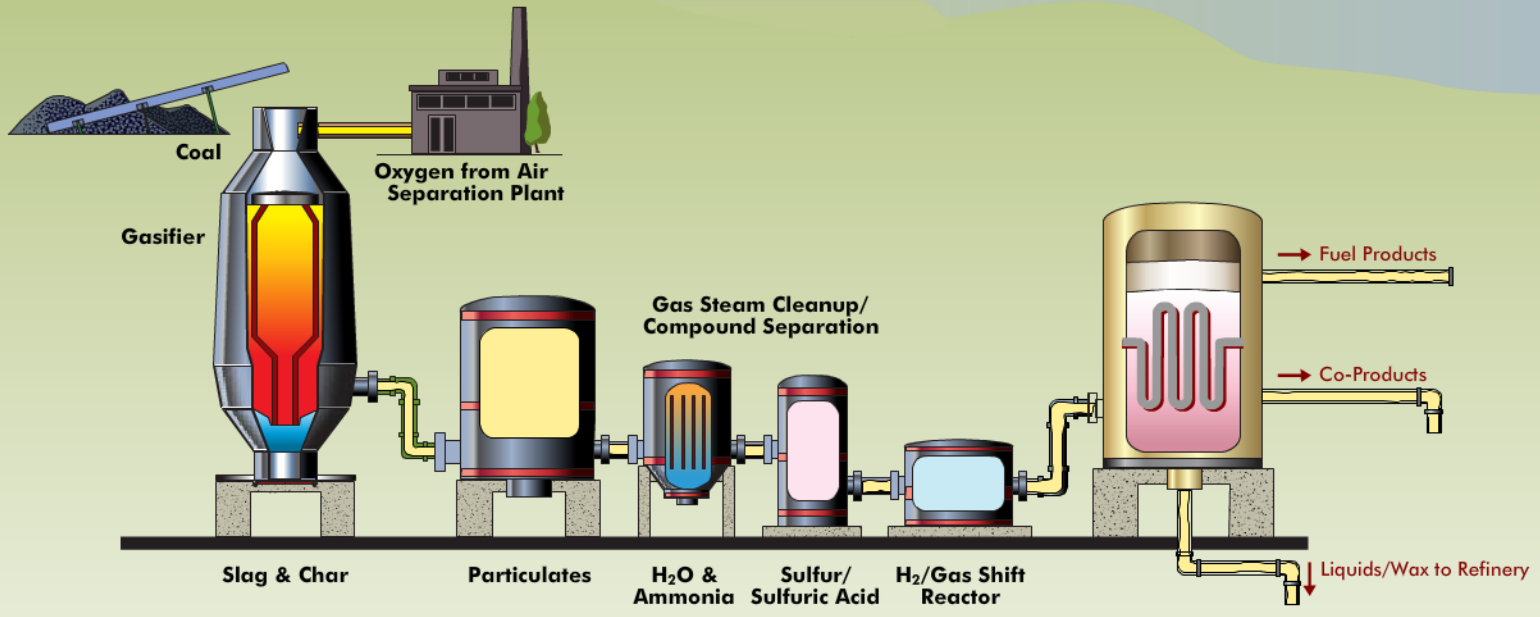


www.fossil.energy.gov.

Integrated Gasification Combined Cycle (IGCC)



COAL TO LIQUIDS



Coal Liquefaction Options

- Indirect Liquefaction
  - University of Kentucky Center for Applied Energy Research
  - Illustrative movies (www.caer.uky.edu/cct/ccthome.html)
  - http://www.caer.uky.edu/cct/Coal-Gasification.swf
  - http://www.caer.uky.edu/cct/CTL.swf
  - http://www.caer.uky.edu/cct/IGCC.swf