“Conventional” Energy Technologies:
What does the future hold?

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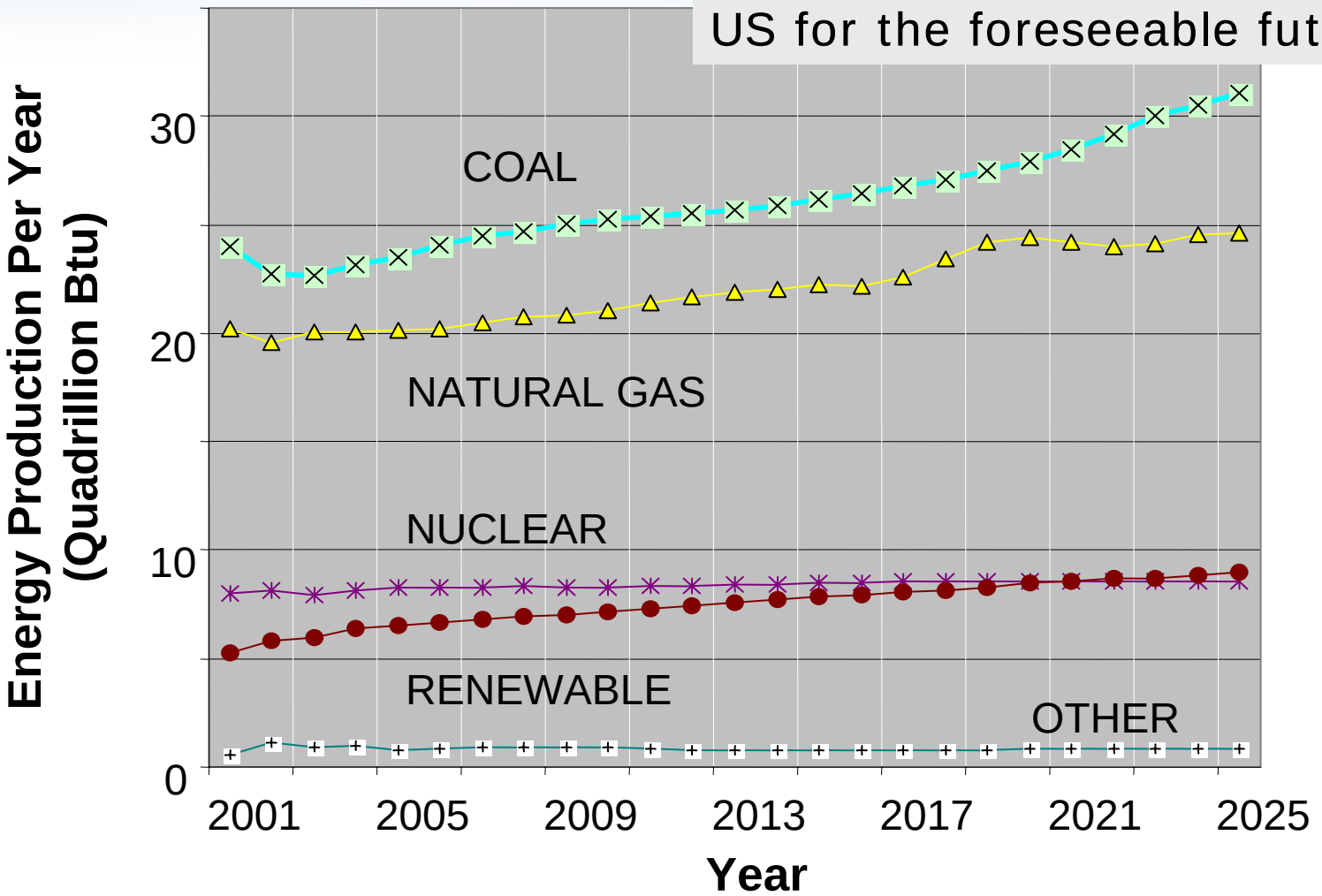
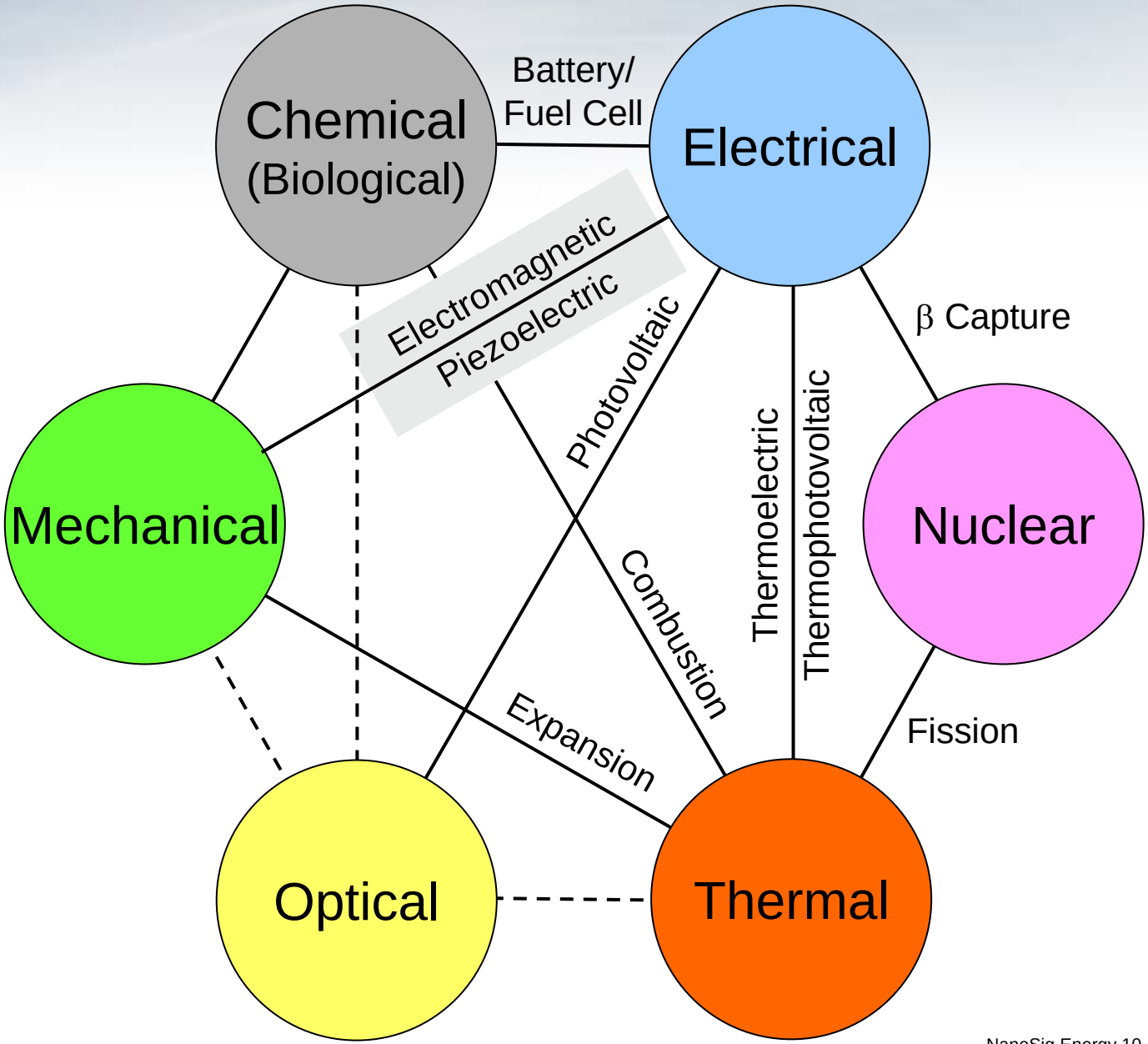
The United States Energy Market

Coal and natural gas will remain key sources of electricity in the US for the foreseeable future



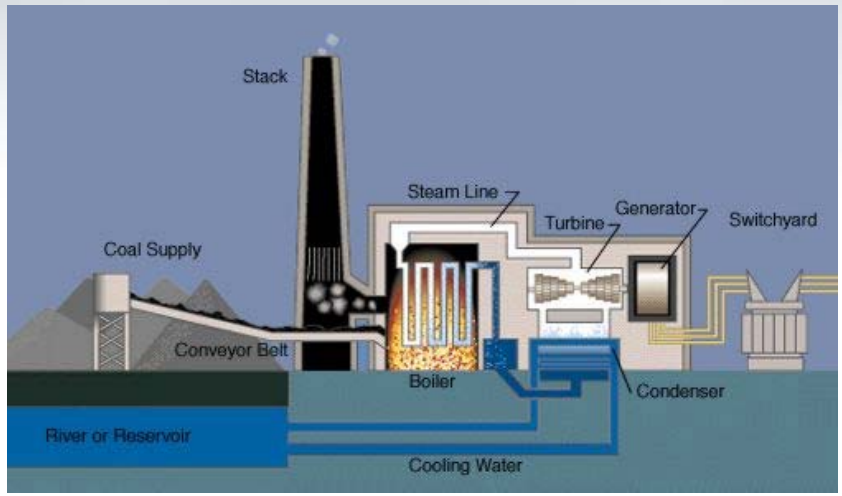
Energy Information Administration/US Department of Energy (2003)

Energy Transformation Mechanisms



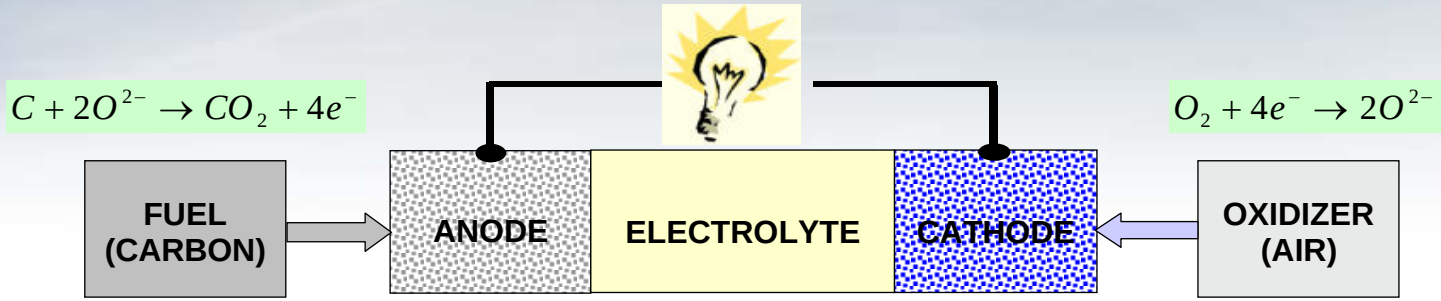
Why Coal?

- Energy generation cost is low and the price of coal is stable
  - Coal: $1.20 / million BTU (23 of the 25 power plants with the lowest operating costs burn coal)
  - Natural gas: $4.30 / million BTU
  - Oil: $4.45 / million BTU



- US has more than a 250-year supply of coal, which contains more energy than that of all the world's oil reserves
  - *US can become an energy exporter*
- Despite its abundance and low cost, coal is a major source of greenhouse gases and heavy metal pollutants
  - Government has pledged $2 billion over 10 years to advance clean coal technology

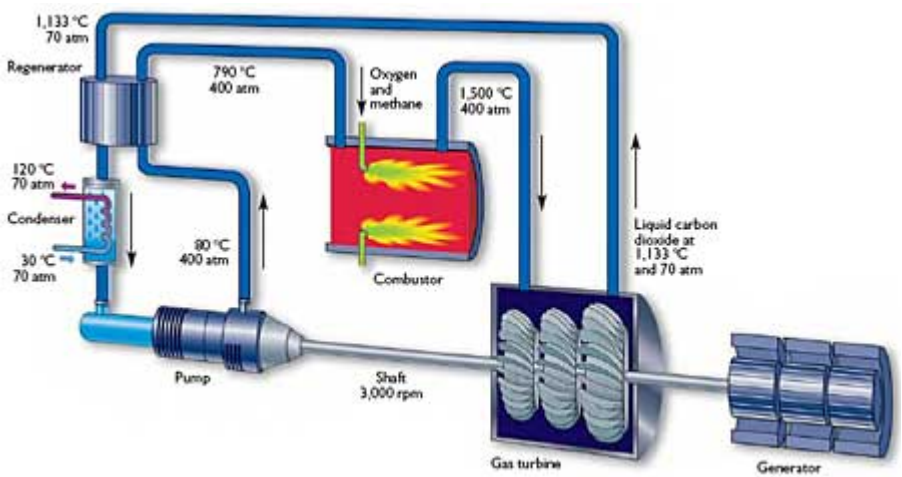
Direct Carbon Fuel Cell (DCFC)



- Direct conversion of carbon to electricity – *no combustion*
- Efficient (>70% efficient, 2X conventional coal-fired plants)
- Inherently reliable (few moving parts)
- Quiet
- Zero air emission
  - High-purity by-product CO_2 stream is captured internally for use or disposal – less greenhouse gases than natural gas fired plants
- Cost-competitive with coal fired power plants
  - Scalable, factory-built modules

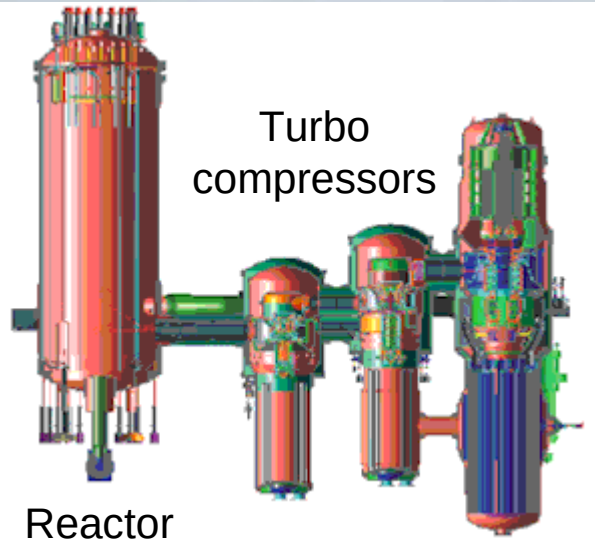
High-Temperature and High-Pressure Natural Gas Fired Turbine

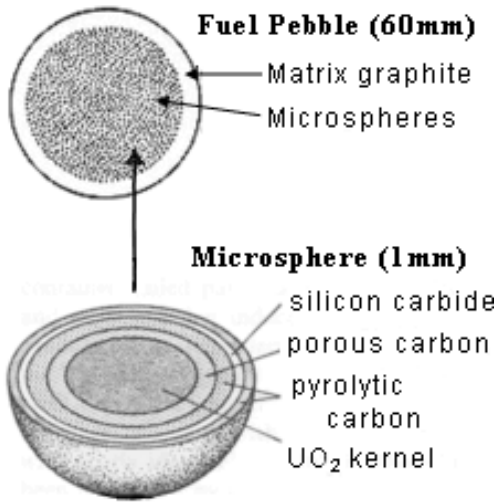
- Burns methane and oxygen
  - Highest heating value of any hydrocarbon
  - Contaminant free fuel
- Clean combustion
  - Near zero emissions (no NOx, SOx, etc.)
  - Pure CO_2 product can be readily sequestered
- High efficiency (>50% possible) due to high operating temperature (1500 ºC) and pressure (>400 atm)



Advanced Modular Pebble Bed Reactor for Nuclear Power Generation

- Low enrichment (8%) SiC/UO_2 fuel pellets
  - Lower cost
  - Reduces proliferation threat
  - Spent fuel more easily stored
- 1000°C core temperature for high efficiency operation
  - High fuel burnup minimizes fuel reprocessing
- Inherently safe design using He gas
  - Stable
  - Cannot “melt-down”
- Cost competitive with natural gas (3.3 vs. 3.4 ¢/kWh)
  - Modular factory construction
  - Refueled by adding “pebbles” ⇒ high up-time
  - Low manpower and operation and maintenance costs

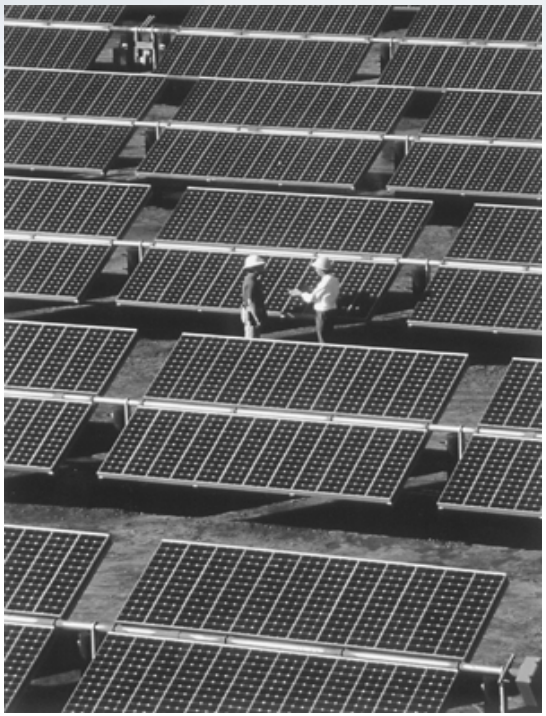




Challenges Ahead

- Research, development and demonstration costs
  - High temperature, corrosion-resistant materials
  - System integration, system demonstration
- Fuel sources
  - Nuclear proliferation
  - Drilling / digging for coal, natural gas
- Environmental concerns
  - Greenhouse and toxic gas emissions
  - Toxic and hazardous waste disposal
- Realistic, profitable business model

Challenges with Renewable Technologies for *Large-Scale* Power Generation



- Citing
  - 1000 MW_e plant requires 2500 km^2 of biomass or a 750 km^2 wind farm or 150 km^2 of photovoltaic cells
  - Power distribution
- Materials cost
  - Natural gas-fired plant uses 3 m-tons of steel and 27 m^3 of concrete/Mw_e vs. 460 m-tons of steel and 870 m^3 of concrete for a comparable wind energy system
- Energy payback time
  - >5 years for silicon photovoltaic cells
- Research and development costs, business model, etc.

Industrial Physicist (2004)

Can Nanotechnology Help?

- Lightweight, high-strength, high-temperature materials for turbines, heat exchangers, packaging, etc.
- High performance, corrosion-resistant coatings for turbines, heat exchangers, packaging, ….
- Advanced materials for improved fuel cell catalysts, electrolytes, separator plates, seals, ….
- Selective catalysis for more energy efficient processing (e.g., improved yield, higher selectivity, ….)
- Membranes for gas separation, purification, ….
- Nanomaterials for CO_2 and hazardous waste sequestration
- Nanoenabled sensors for environmental, safety and process monitoring
- Etc.