Emerging Energy Issues and New Technologies

University of Kentucky
Center for Applied Energy Research

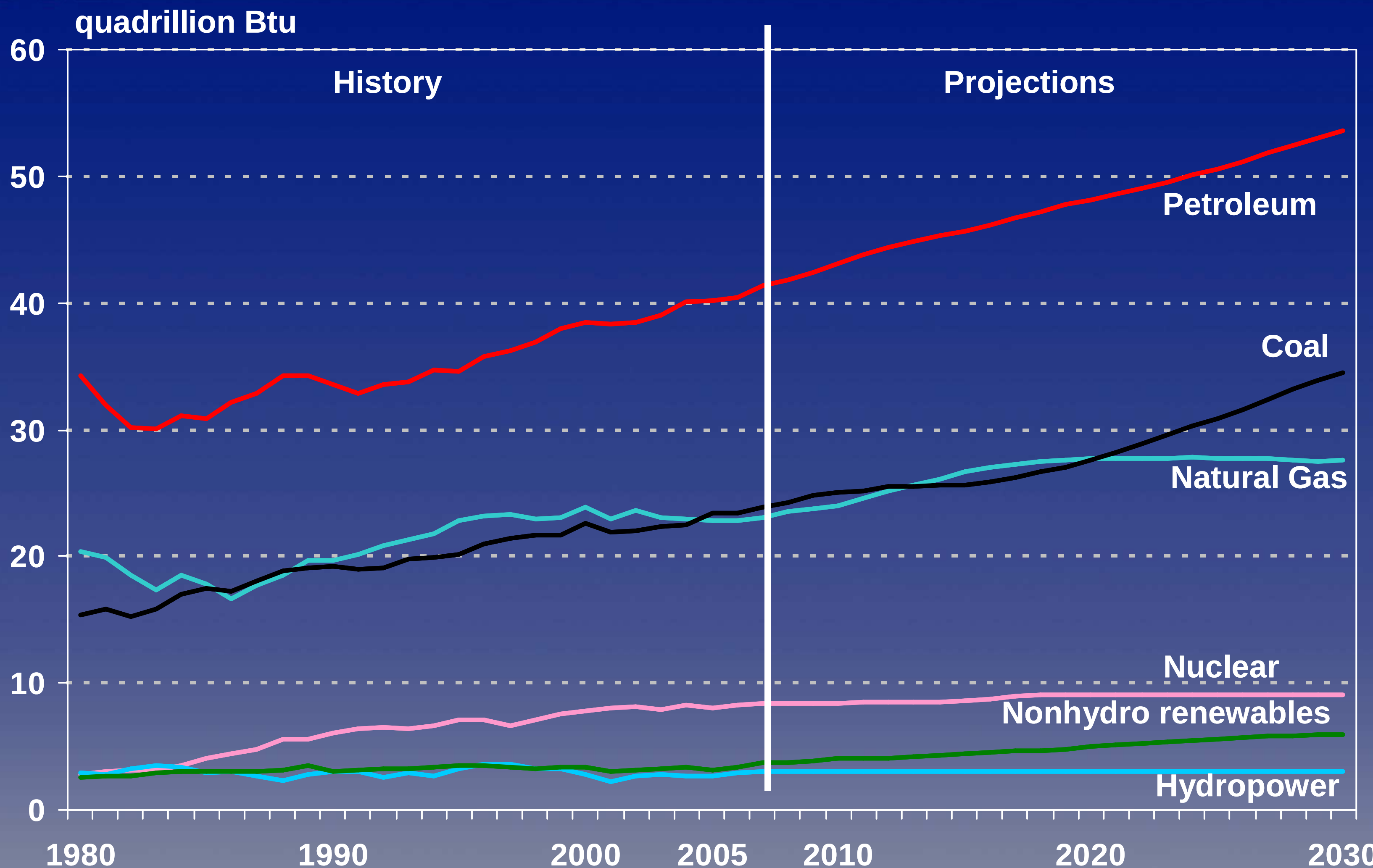
Rodney Andrews
Director
Email: andrews@caer.uky.edu
Tel: 859/ 257-0306

Agenda

- Energy Demand and Availability
- Coal Conversion Technologies
  - – Gasification
  - – Coal to liquids / gas
- Carbon Management
- Future Directions and Impacts

Photo art: A. Benlow

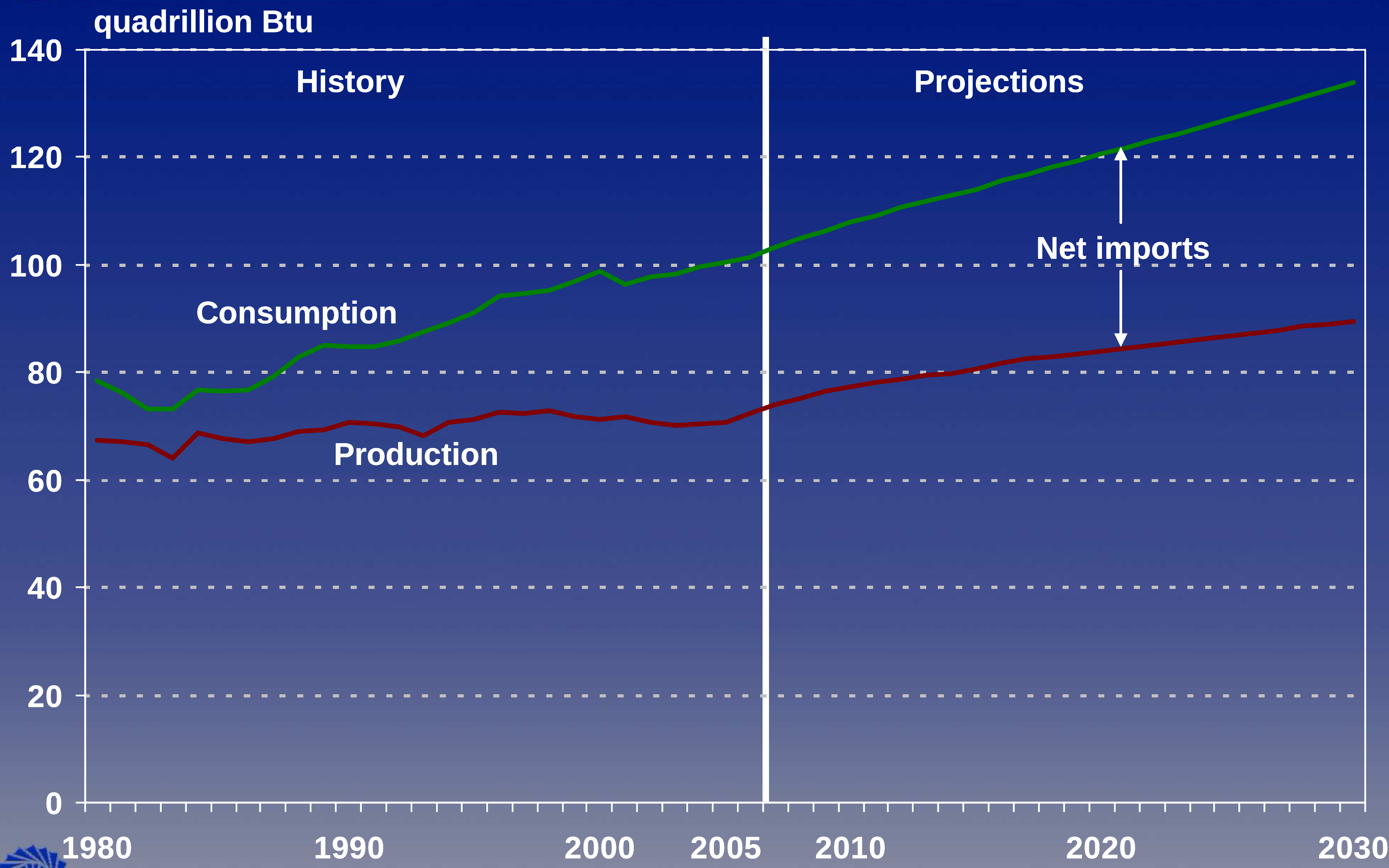
USA Energy Consumption



Center for Applied Energy Research

Source: AEO 2007
DOE/EIA-0383(2007)

US Production and Consumption



Center for Applied Energy Research

Source: AEO 2007
DOE/EIA-0383(2007)

Needed: 1,300 New Power Plants

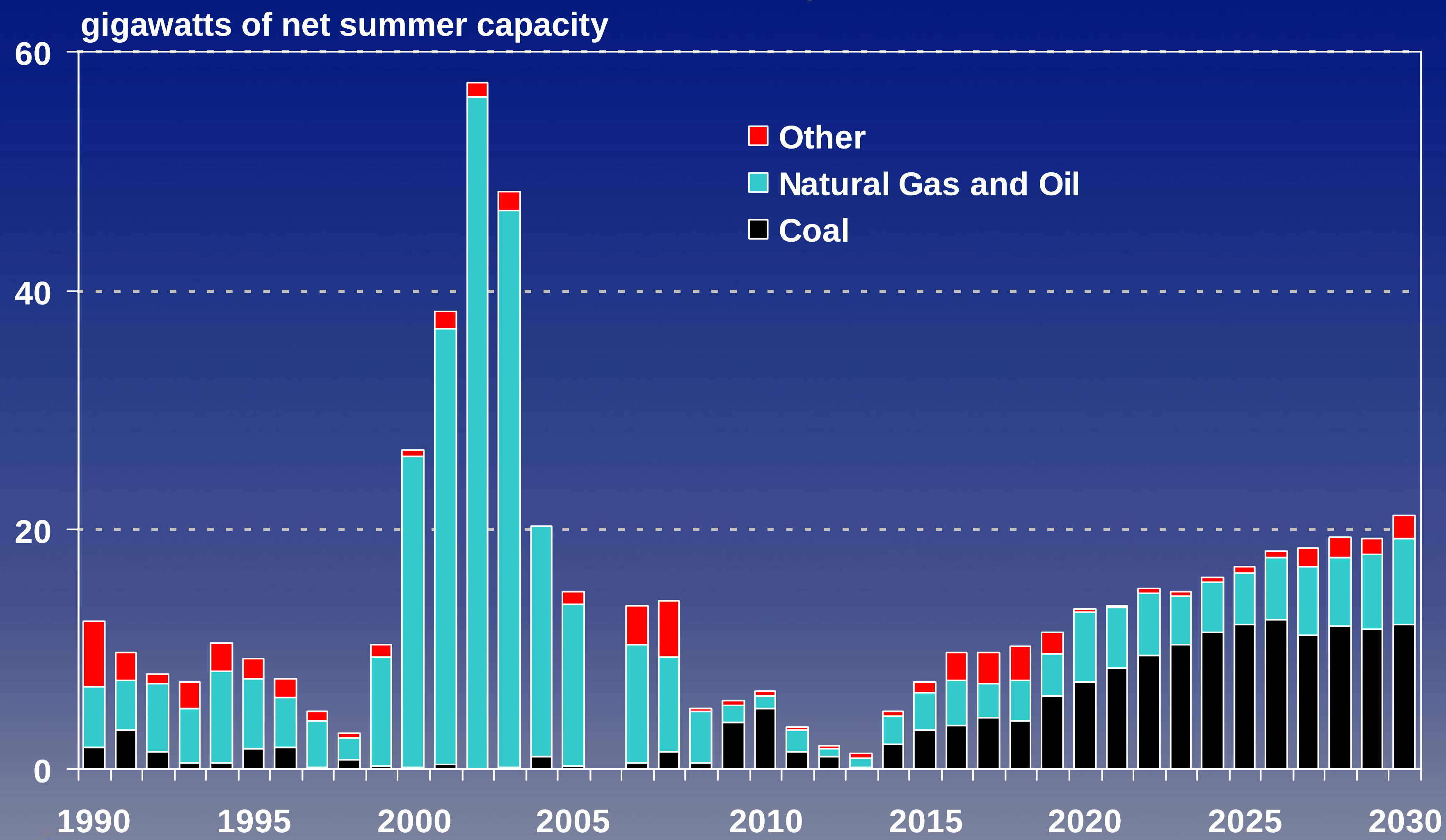
A Conservative Estimate

Nationally Important to Make Right Choices for Infrastructure Investments With 50+ Year Lifetime

Center for Applied Energy Research

Source: EIA/DOE

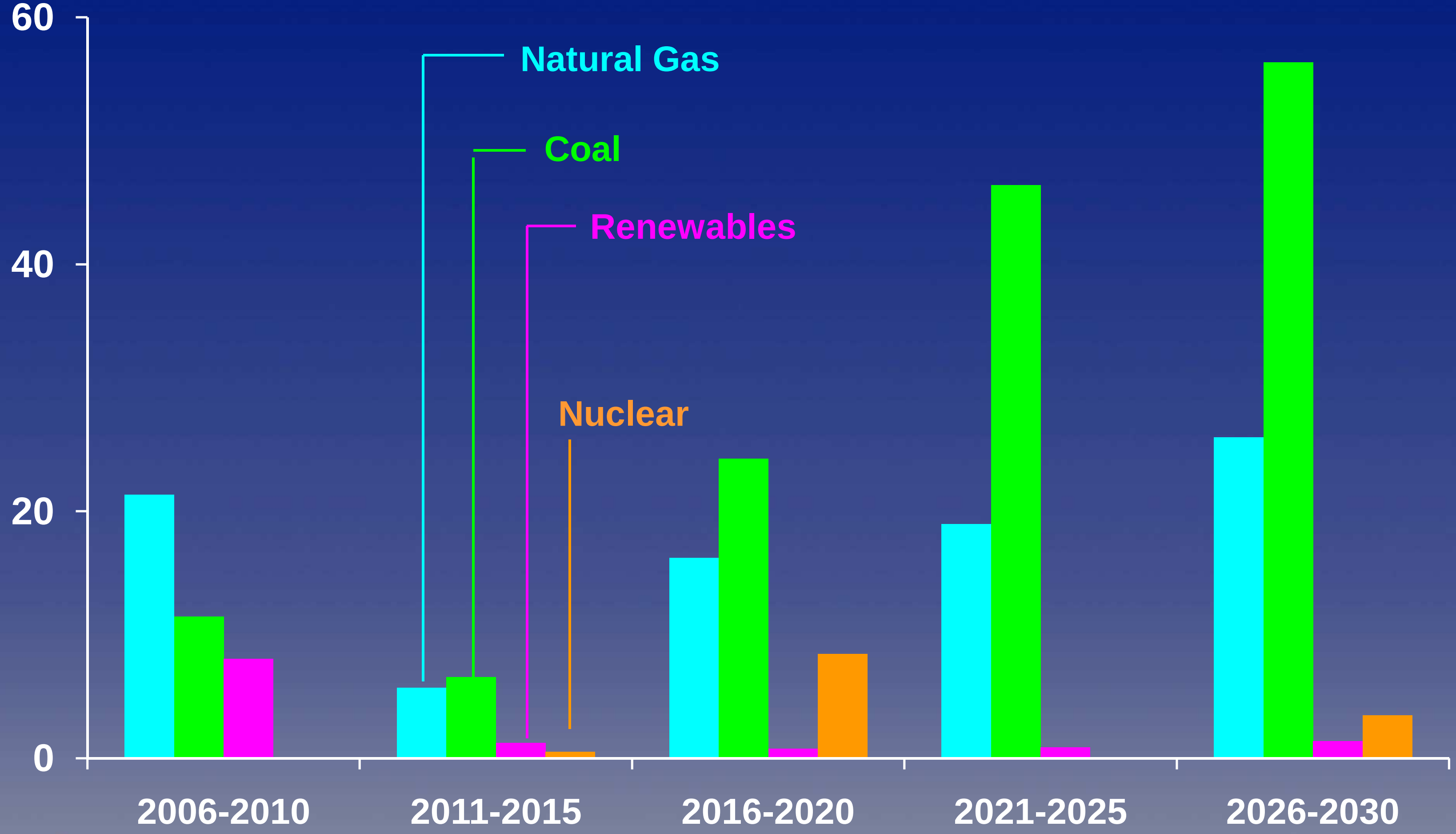
Generation Capacity Growth is Primarily Coal



Center for Applied Energy Research

Source: AEO 2007
DOE/EIA-0383(2007)

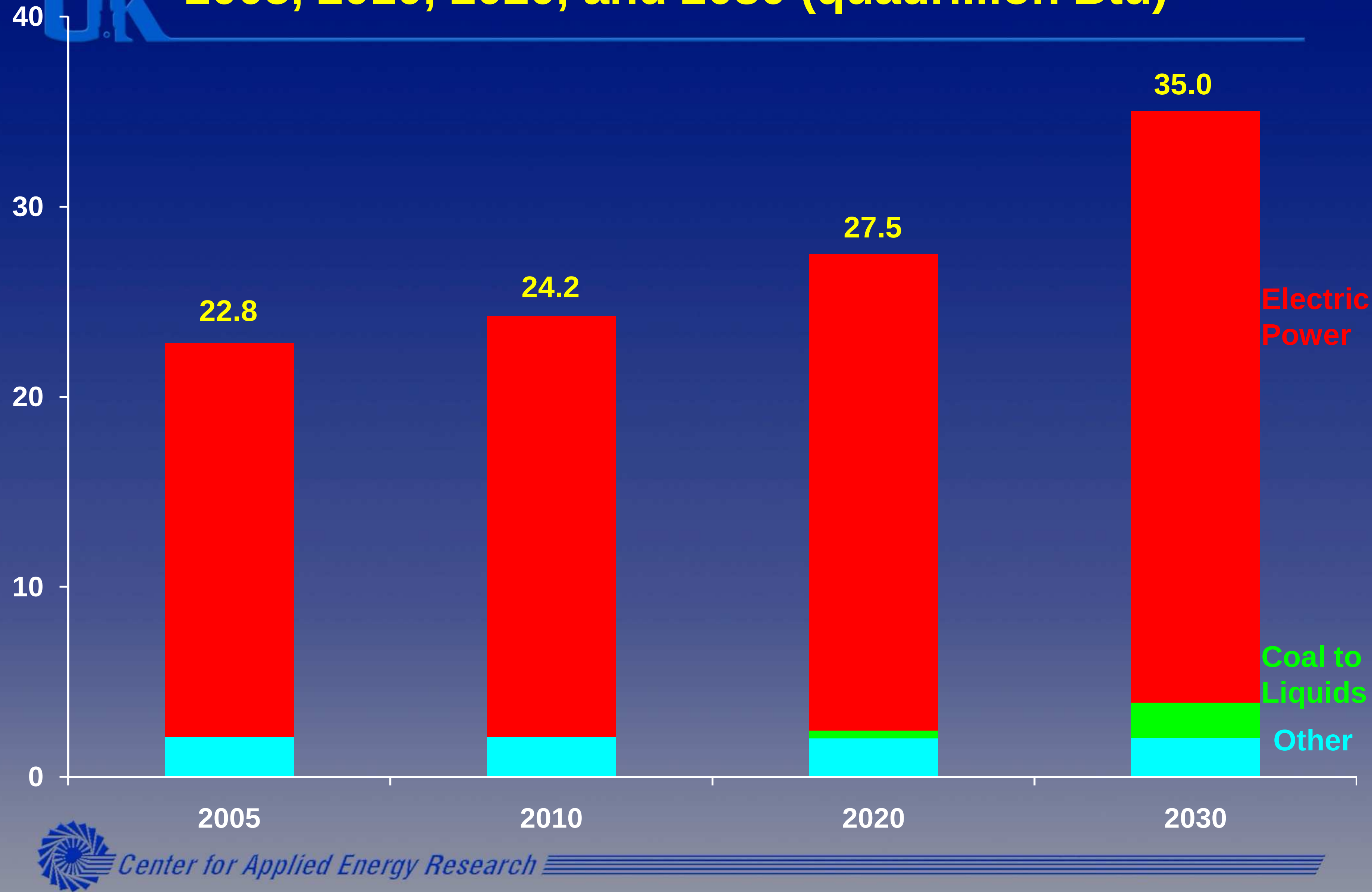
U.S. Electricity Generation Capacity Additions by Fuel, 2006-2030 (gigawatts)



Center for Applied Energy Research

Annual Energy Outlook 2007

U.S. Coal Consumption by Sector, 2005, 2010, 2020, and 2030 (quadrillion Btu)



Annual Energy Outlook 2007

Agenda

- Energy Demand and Availability
- Coal Conversion Technologies
  - Gasification
  - Coal to liquids / gas
- Carbon Management
- Future Directions and Impacts

Photo art: A. Benlow

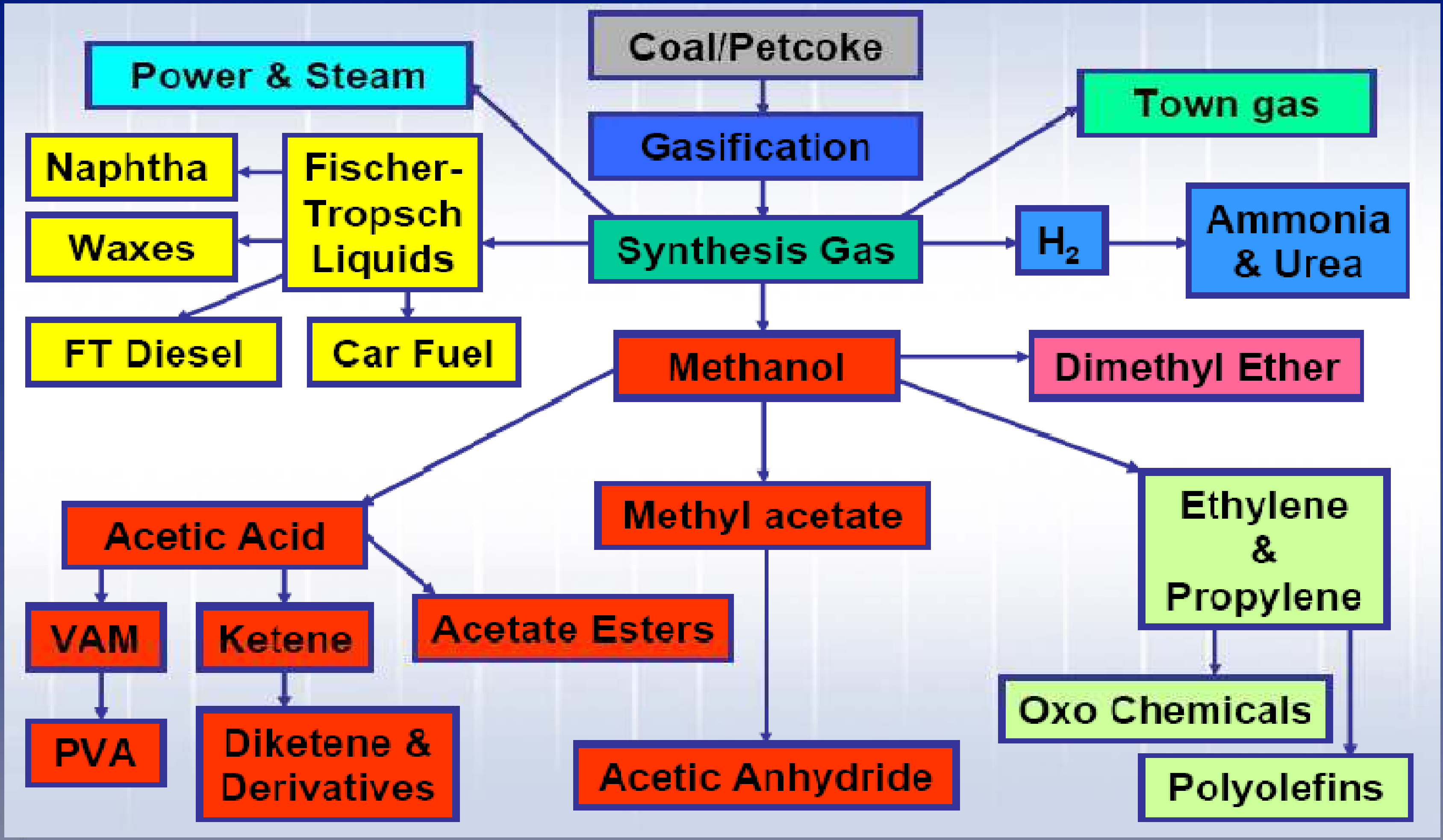
Coal for Power Generation

- Few coal fired power stations built in recent past – gas believed to be cheap, plentiful and clean
- Future: carbon taxes and global warming issues critical
- Nuclear power for power generation (currently about 20%) slow to increase
- More recent combustion technologies:
  - supercritical and ultra-supercritical steam systems for high efficiencies
  - fluidized bed combustors (FBC/CFBC)
- IGCC
- Poly-generation

Coal Conversion

- Combustion to produce steam/power
- Gasification with Combined Cycle (IGCC)
- Gasification to produce syngas (H_2 with CO)
  - Syngas to fuels (indirect liquefaction)
  - Syngas to chemicals, including methanol
  - Syngas to hydrogen
  - Syngas to synthetic natural gas (SNG/CTG)
- Direct coal liquefaction

Gasification: Syngas Uses

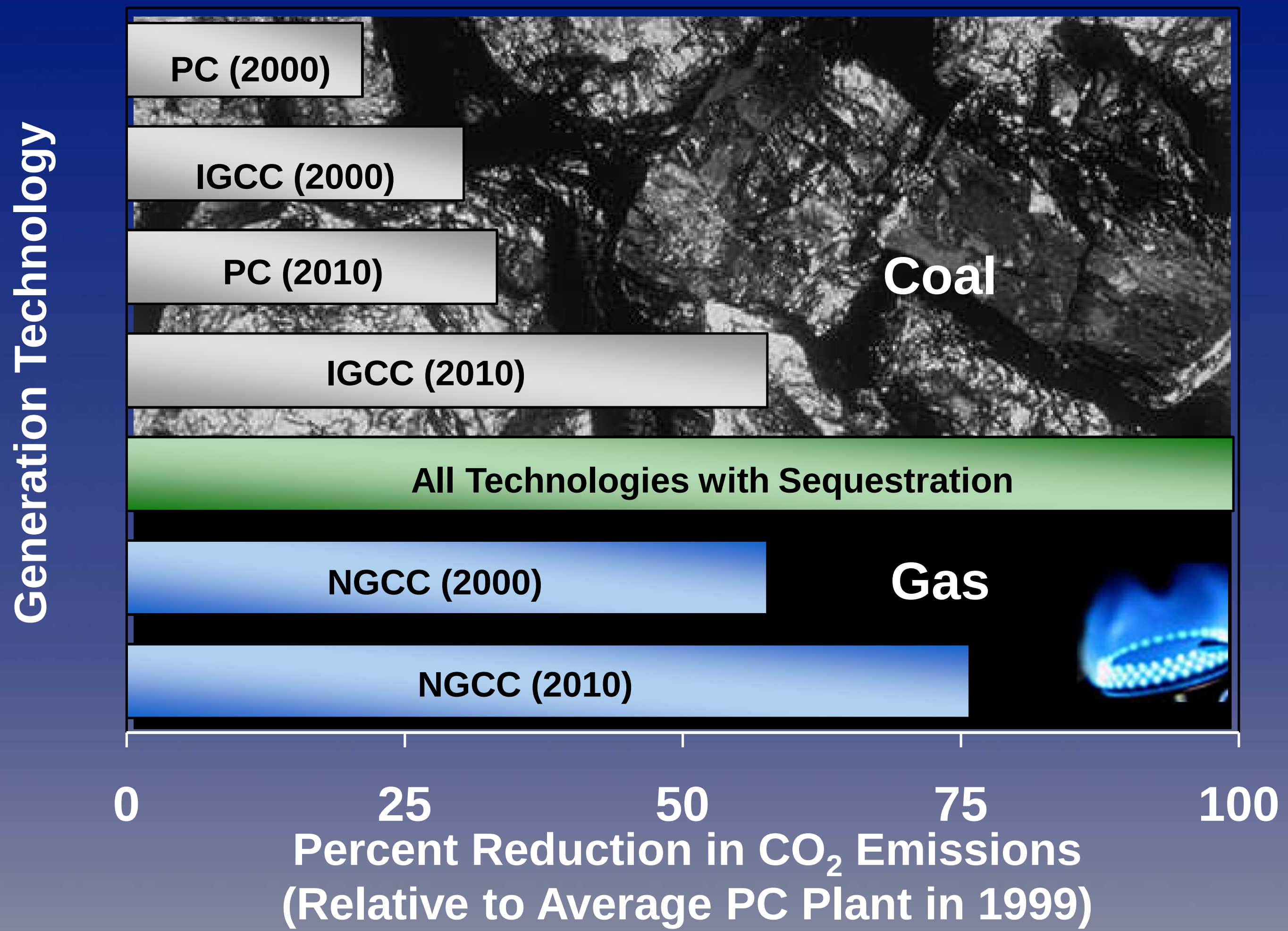


Source: Eastman

Operating Gasifiers

- World-wide about 117 operating plants; 385 gasifiers; 49% coal fed
- Use: 37% for chemicals, 36% for FT, 19% power generation
- Extensive overseas experience
  - South Africa: 97 units – now 80 (sub-bit. coal)
  - China (coal)
  - Europe (coal and biomass)
- USA: Wabash (petcoke), Tampa (petcoke with coal), Great Plains (lignite), Eastman Chemicals (coal)
- Many (~24) US units in planning phase

Reductions in Carbon Emissions By Adoption of New Power Generation Technologies



Source: NETL, Scott Klara

Agenda

- Energy Demand and Availability
- Coal Conversion Technologies
  - Gasification
  - Coal to liquids / gas
- Carbon Management
- Future Directions and Impacts

Photo art: A. Benlow

Alternative Liquid Fuels

- This year's reference case anticipates … ***substantial development of unconventional production*** over the next 25 years. The prices in the AEO2007 reference case are high enough to trigger entry into the market of some alternative energy supplies that are expected to become economically viable in the range of $25 to $50 per barrel. ***They include oil sands, ultra-heavy oils, gas-to-liquids (GTL), and CTL.***

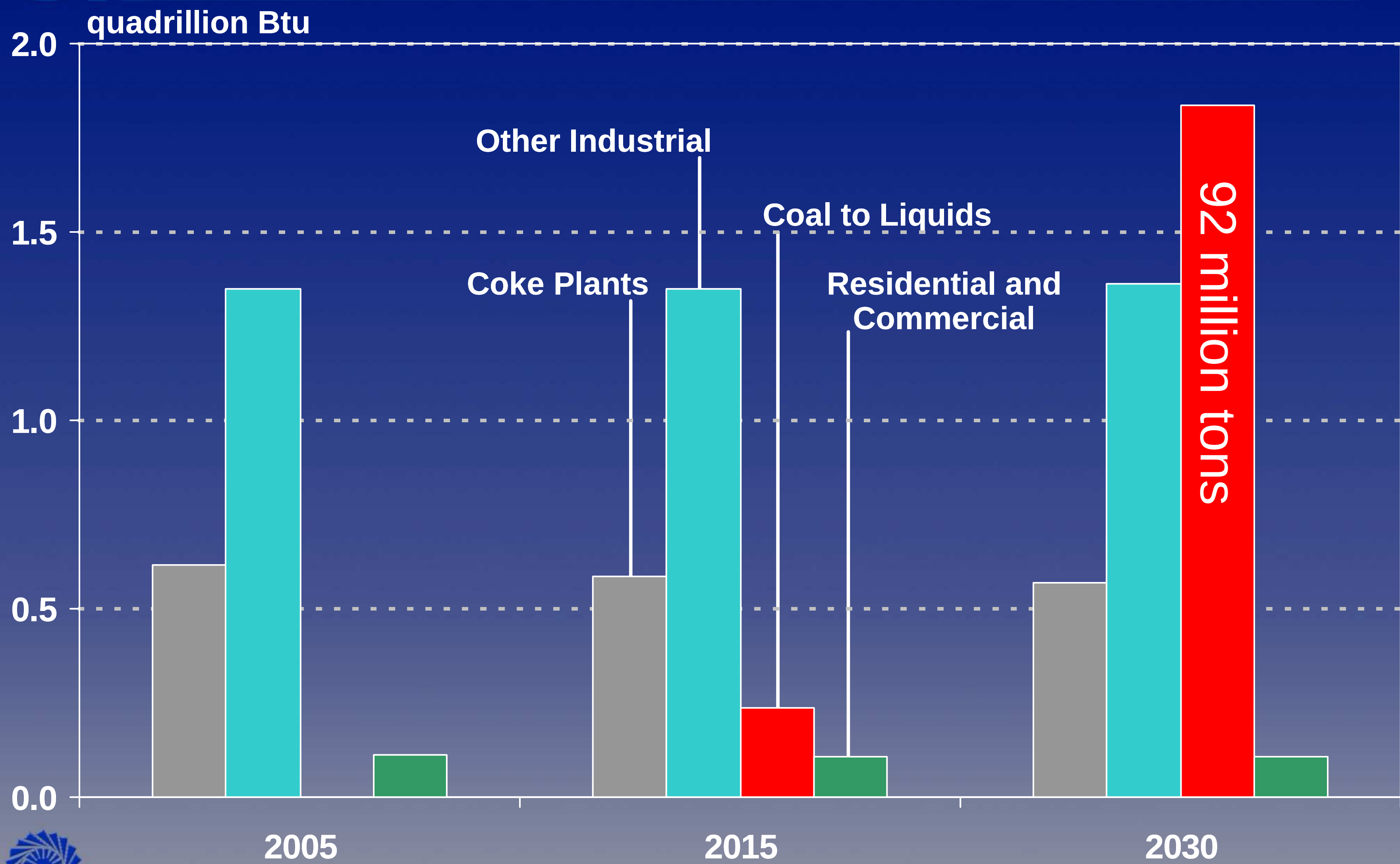
- *AEO2007* includes, for the first time, a reorganized breakdown of fuel categories that reflects the increasing importance, both now and in the future, of conversion technologies that can produce liquid fuels from natural gas, coal, and biomass.

Coal to Liquids (FT)

- Need for liquid fuels to accommodate projected growth, especially in transportation
- Strong growth and US driving preferences (compare with Europe)
- High crude prices
- US per capita one of the highest energy users
- Favorable coal reserves
- Uncertain time line for H_2 economy

- Growing crude imports and strategic concerns
- Competition from China and India

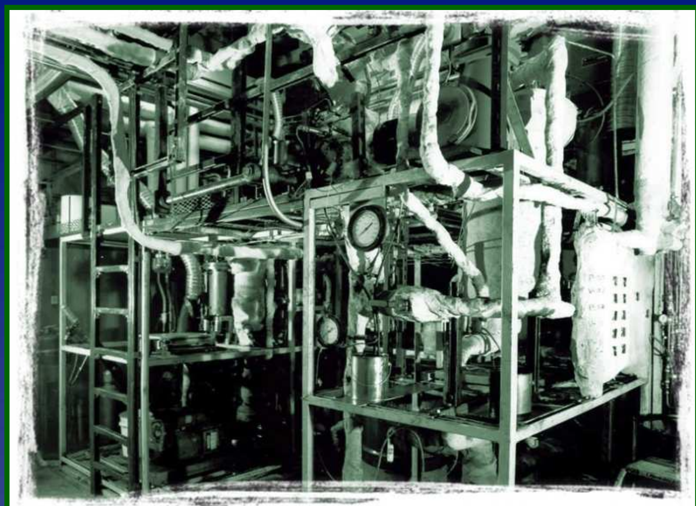
Demand for Coal to Liquids will Dominate Non-Electric Coal Use



Center for Applied Energy Research

Source: AEO 2007
DOE/EIA-0383(2007)

Coal Liquefaction: Two Methods



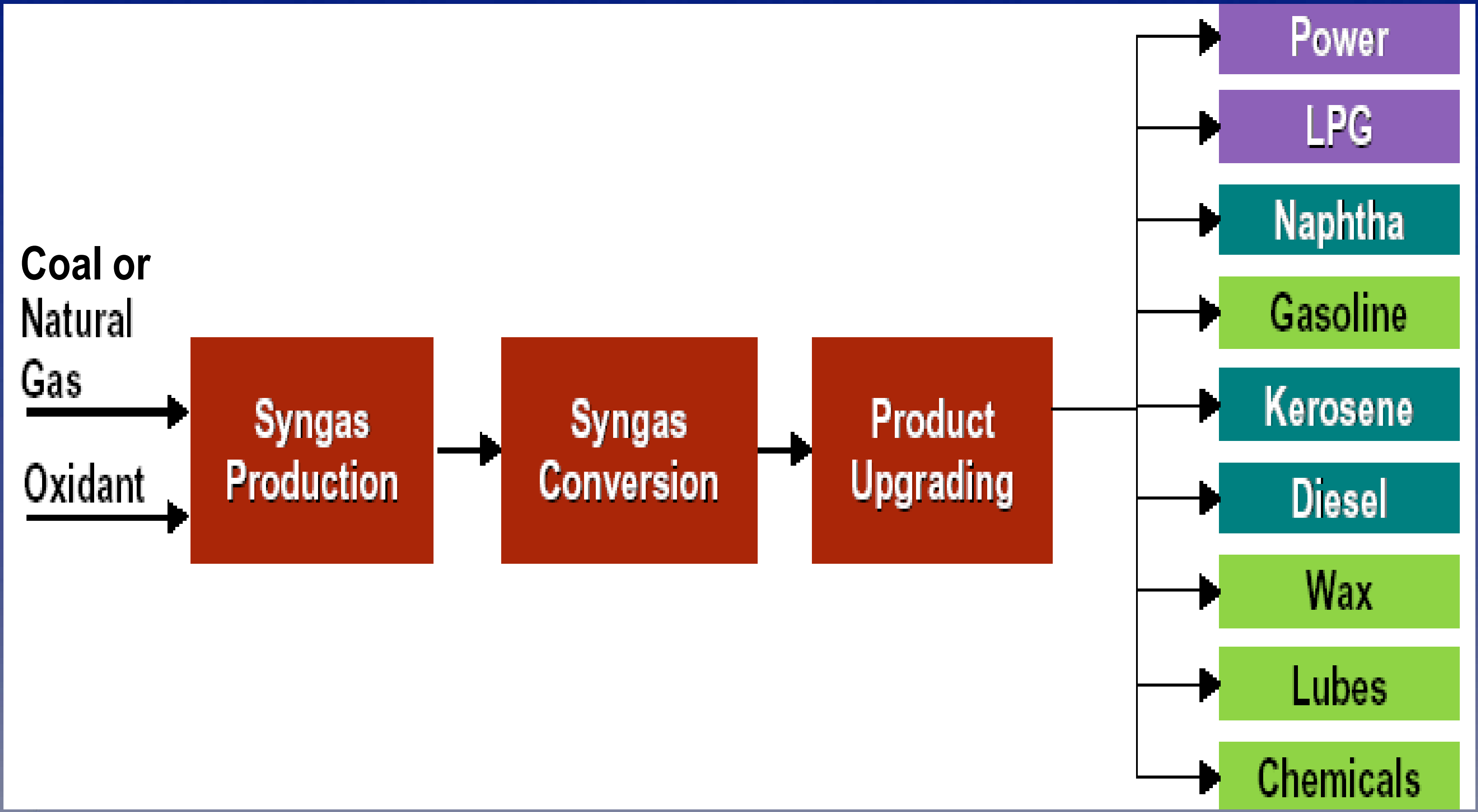
Indirect: coal gasified with steam and oxygen and resultant CO and H_2 (syngas) is catalytically converted to liquid hydrocarbons at about 375psi (25 bar) and 400-630℉ (200-340℃)

Direct: fine low-ash coal with catalyst; high pressure (3500psi/230 bar+) and temperature (750℉/400℃) reacts with hydrogen to produce liquid hydrocarbons and char-like residue

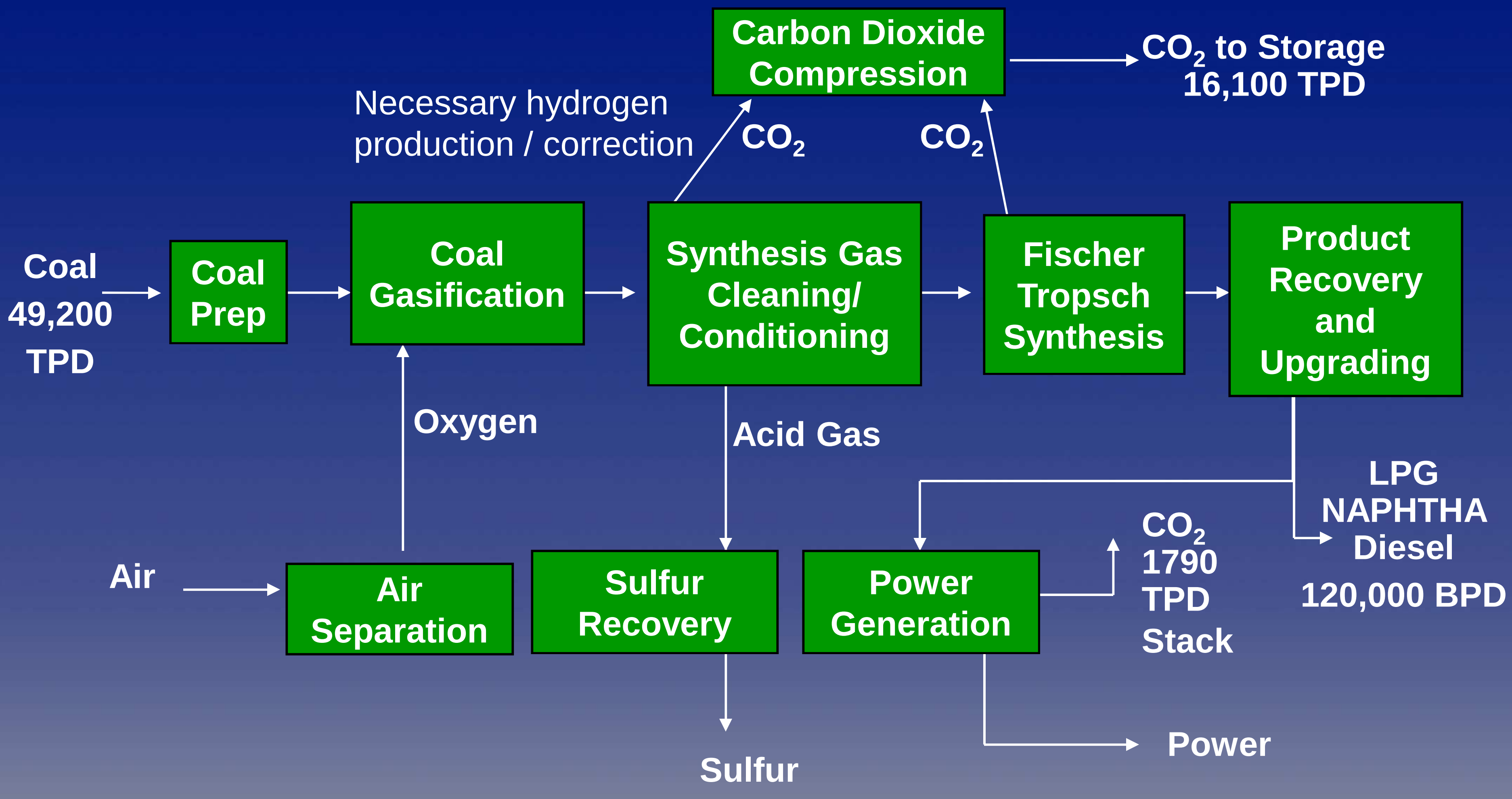
Indirect Liquefaction: Fischer-Tropsch (FT)

- Invented in 1920's
- Developed pre WW II Germany
- Commercialized in South Africa 1955 and again late 70's/early 80's
- Other ventures based on natural gas built and more in progress
- Coal based: capital significantly higher than natural gas based – but: cost of coal versus natural gas

FT Products and Characteristics



Coal-to-Liquids



Hurdles to Implementation

- Lack of domestic familiarity
  - Not a power plant, not a refinery
- Capital Investment
  - 10,000 bbl/day: $1 billion
  - 30,000 bbl/day: $2.5 billion
  - 60,000 bbl/day: $4 billion
- Volatility in the cost of petroleum and gas

Work Force Issues for Coal-to-Liquids and Coal-to-Gas

- No trained workforce exists
  - Seen as barrier to construction and operation of CTL
- Wyoming / Rentech Project Example
  - 10,000 bbl/day CTL plant
  - Staffing estimate
    - 23 professionals
    - 112 operators
    - 47 other
- Extrapolate to 5 to 8 million bbl/day
  - 10,000 to 20,000 new engineers and scientists
  - chemical, mechanical, electronics, petroleum, and industrial engineering, chemists
  - PLUS skilled operators and technicians

Sasol Plants At Secunda ~ 1985

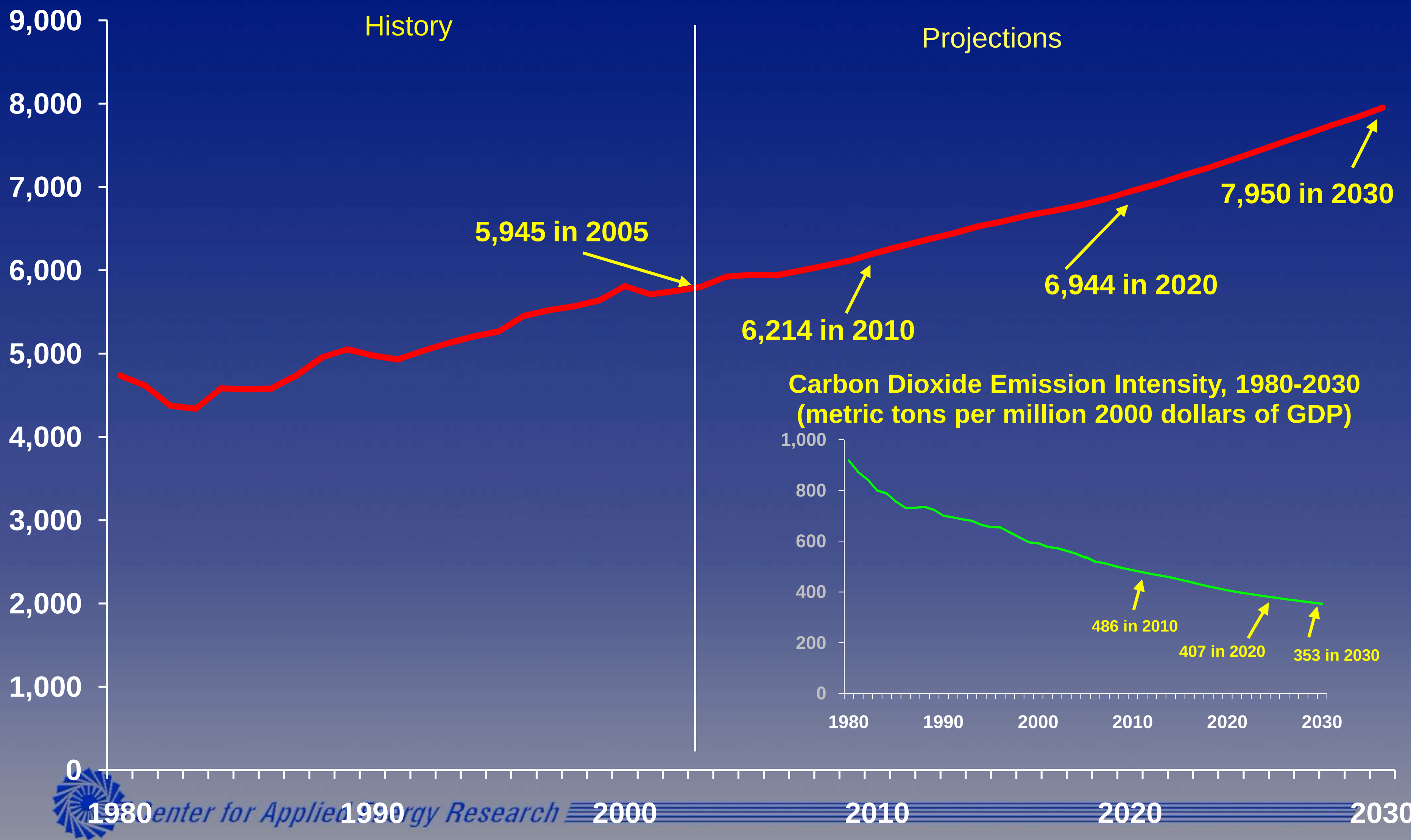
Initial capacity: 2 x 50,000 bbl/d, Then 40% of SA's fuel needs, now 28%; Cost $6bn; Site 13 km^2 (~3,200 acres)
Two plants built sequentially with $500m saving
Construction work force 28,700 from 39 nationalities
250 million man-hours.   Now 160,000 bbl/d

Agenda

- Energy Demand and Availability
- Coal Conversion Technologies
  - Gasification
  - Coal to liquids / gas
- Carbon Management
- Future Directions and Impacts

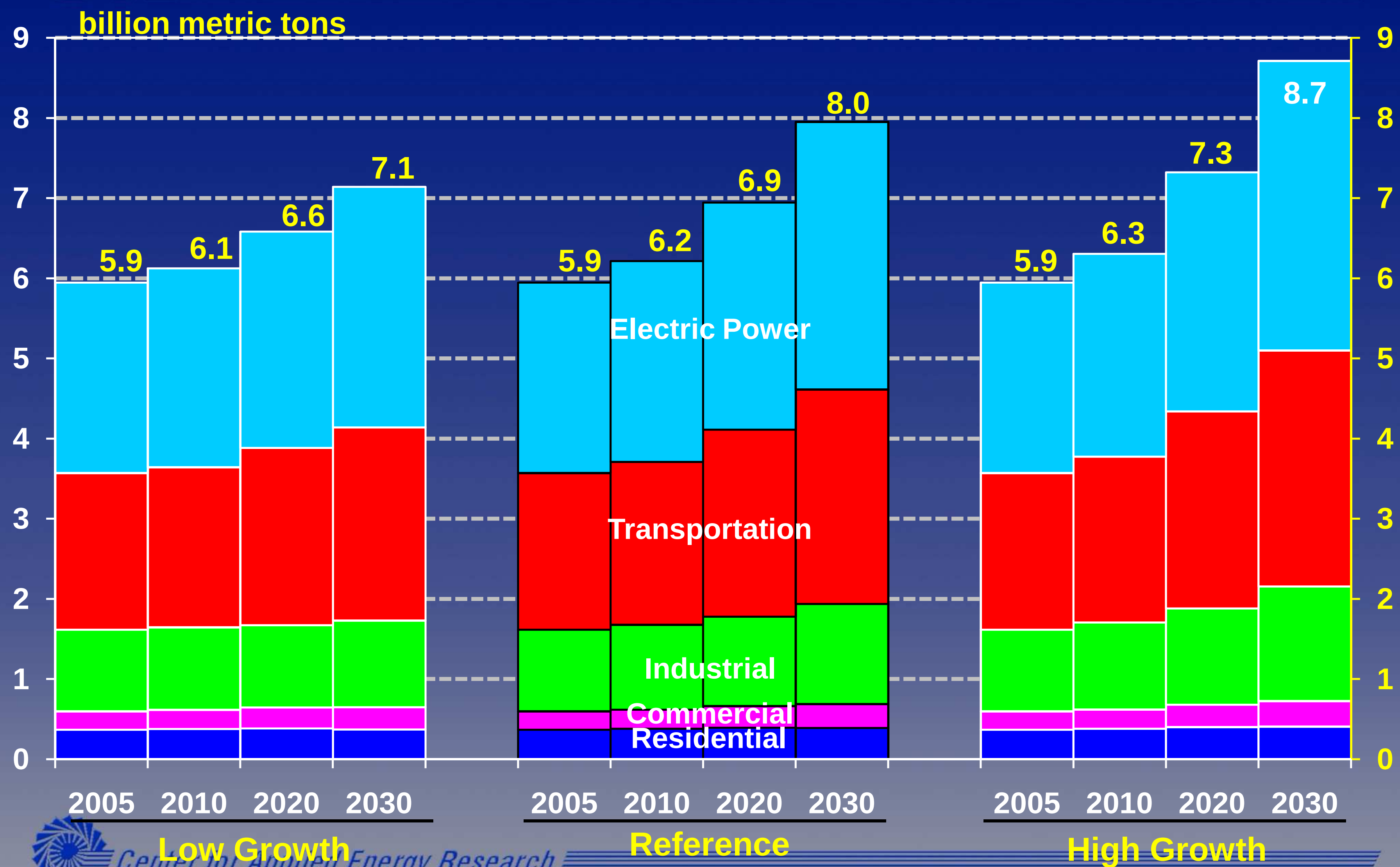
Photo art: A. Benlow

U.S. Energy-Related Carbon Dioxide Emissions, 1980-2030 (million metric tons)



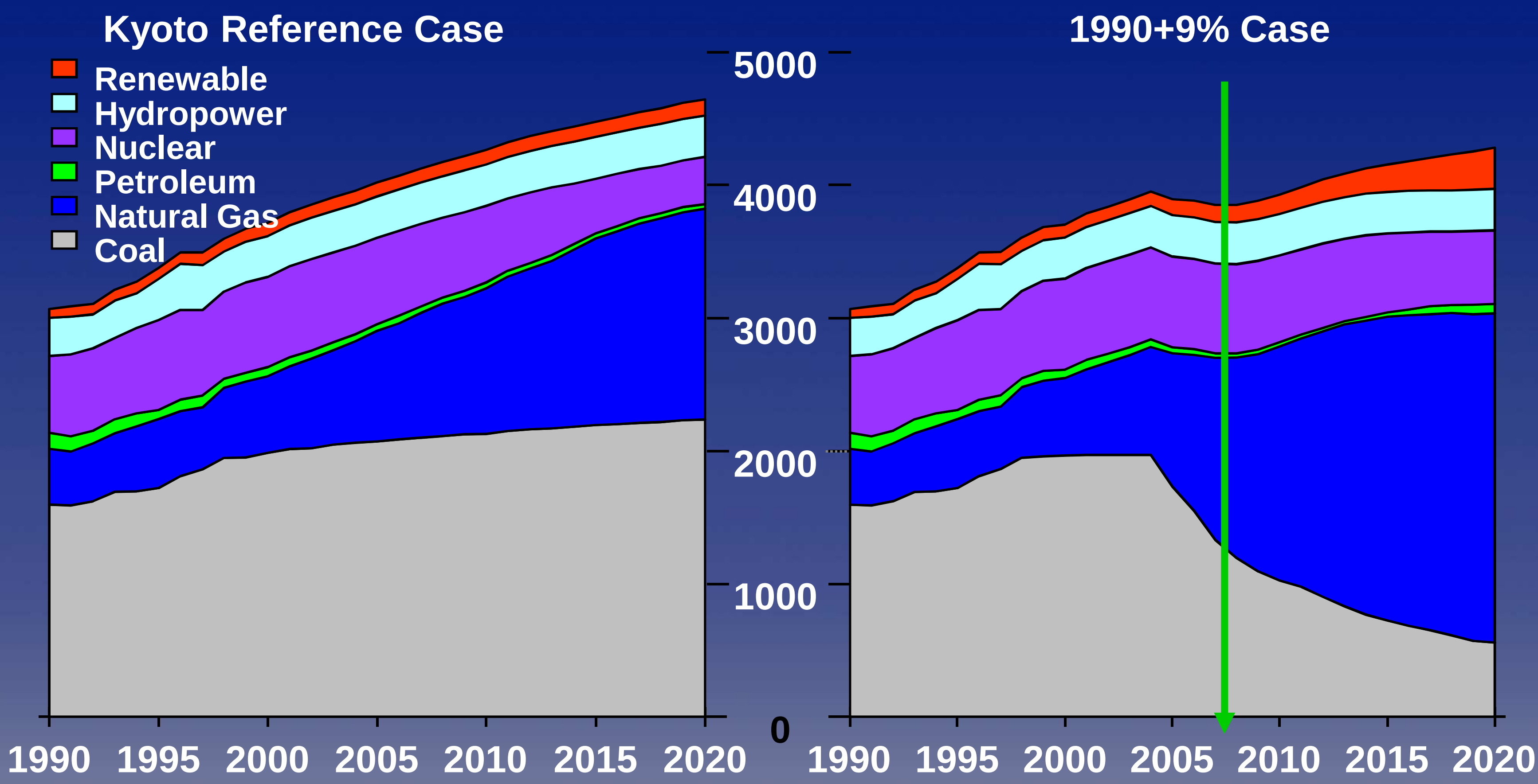
Annual Energy Outlook 2007

Carbon Dioxide Emissions



Annual Energy Outlook 2007

Electricity Generation by Fuel in Two Cases, 1990-2020 (billion kilowatt-hours)



2000 EIA *Administration Response to Unratified Kyoto Treaty*

Technology and Innovation

Can Lead to Reductions in Carbon Emissions

- **Fuel Switching**
  - Natural Gas
  - Renewables
  - Nuclear
- **Improve Efficiency**
  - Demand Side
  - Supply Side
- **Sequester Carbon**
  - Capture & Storage
  - Enhance Natural Sinks
- ~~Reduce Population~~
- ~~Reduce GDP~~

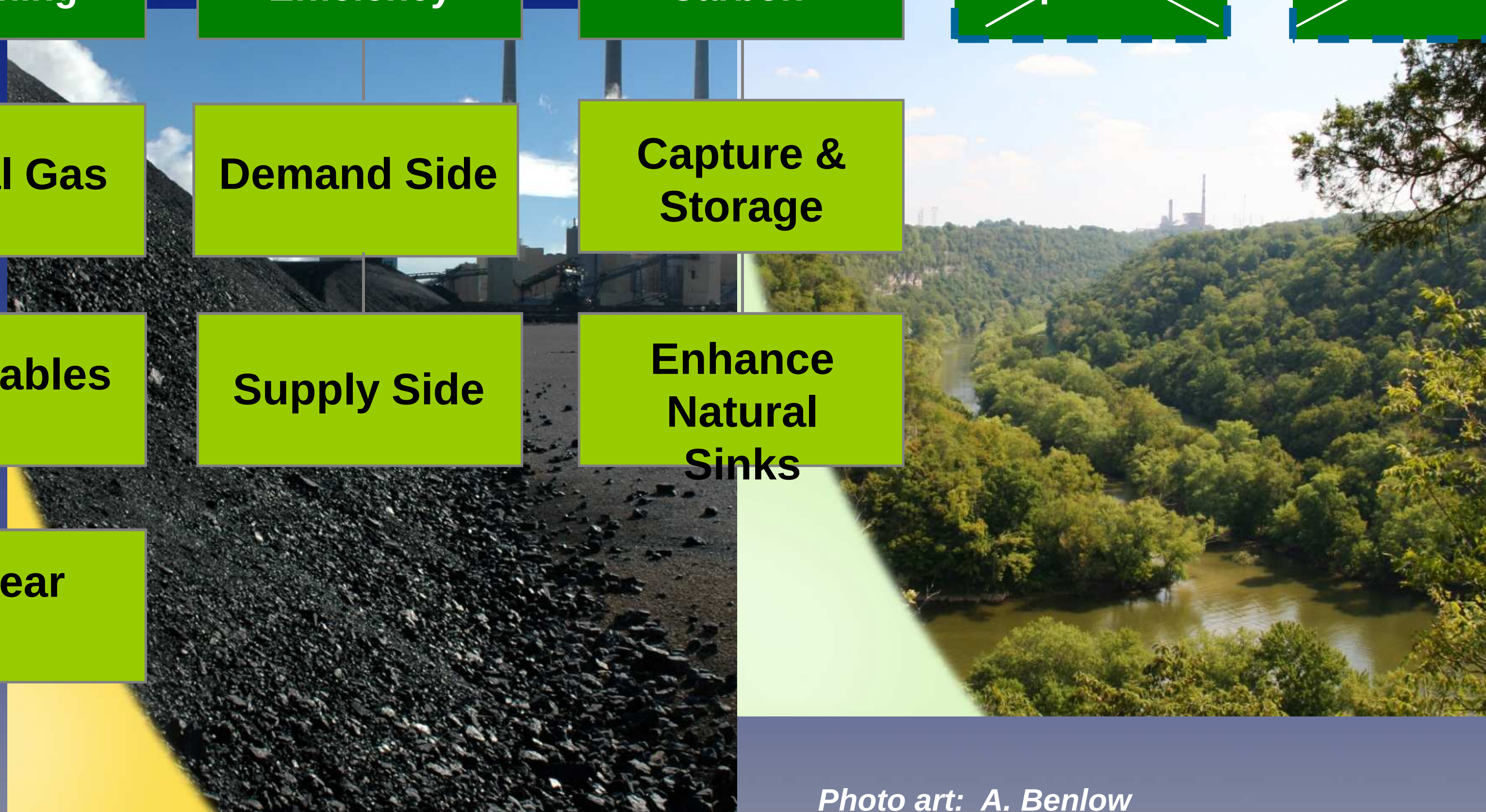


Photo art: A. Benlow

Reductions in Carbon Emissions By Demand-side Efficiency

- *Insulate your house*
- *Thermal windows*
- *High efficiency appliances*
- *Water-saving devices*
- *Natural lighting/solar mass*

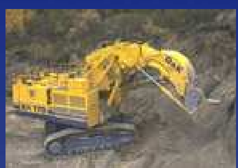
- *Eat lower on the food chain*
- *Get close to your food*

- *Encourage industrial efficiency*
- *"Green" chemistry*
- *Recycle your waste*

- *Park your SUV*
- *Take the Bus*
- *Higher Price at the Pump*
- *Demand CAFÉ*
- *Buy the "Hybrid"*

Reductions in Carbon Emissions By Greater Supply-side Efficiency

Electric Power



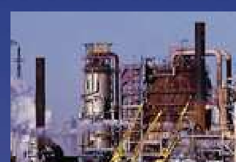
Coal Production

Power Delivery

Power Generation

Petroleum

Exploration & Production

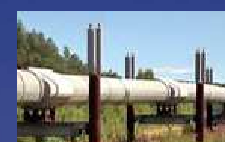


Refining & Delivery

Transportation

Natural Gas

Exploration & Production

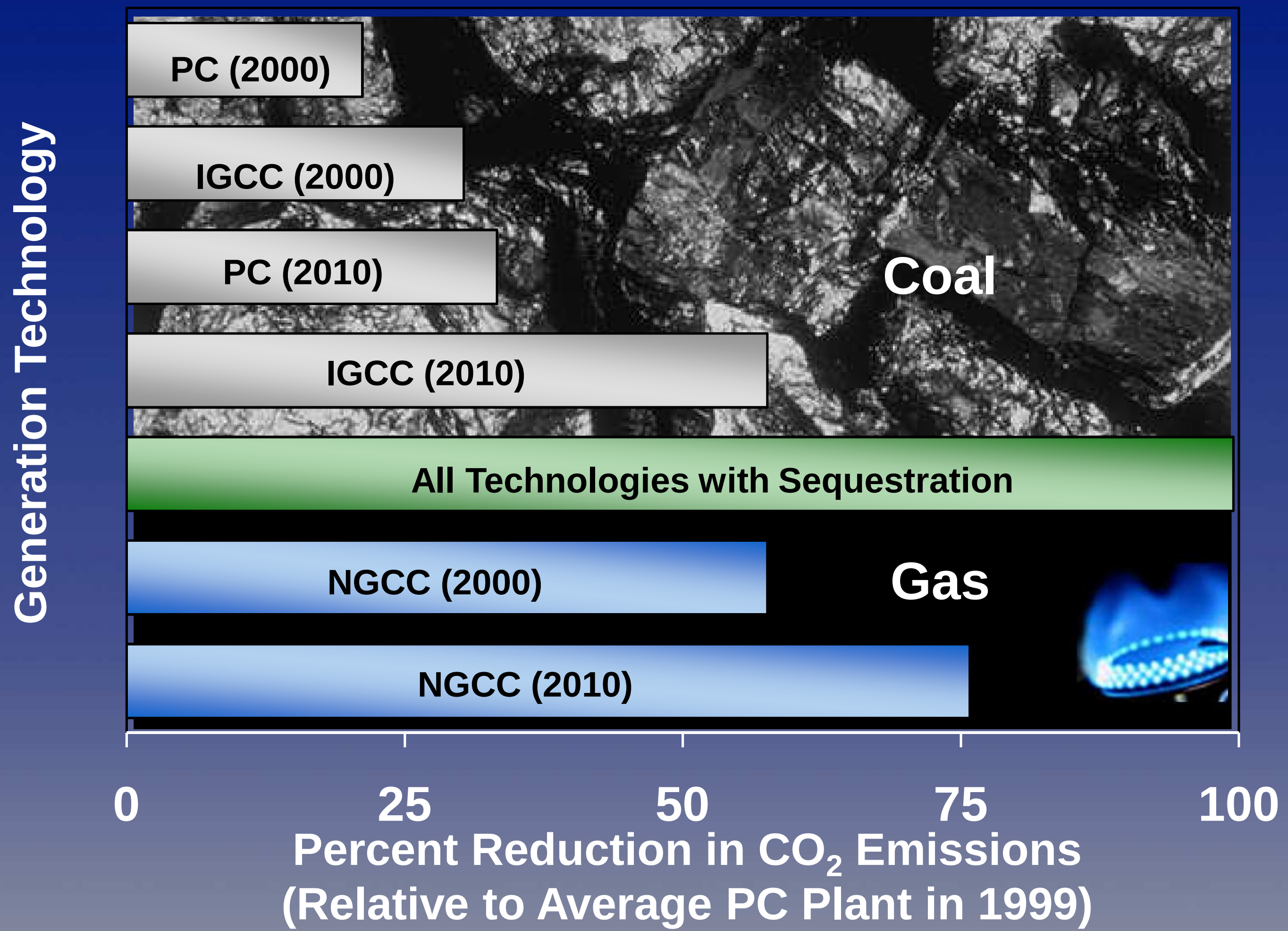


Pipelines & Storage

Distributed Power Generation

Source: USDOE

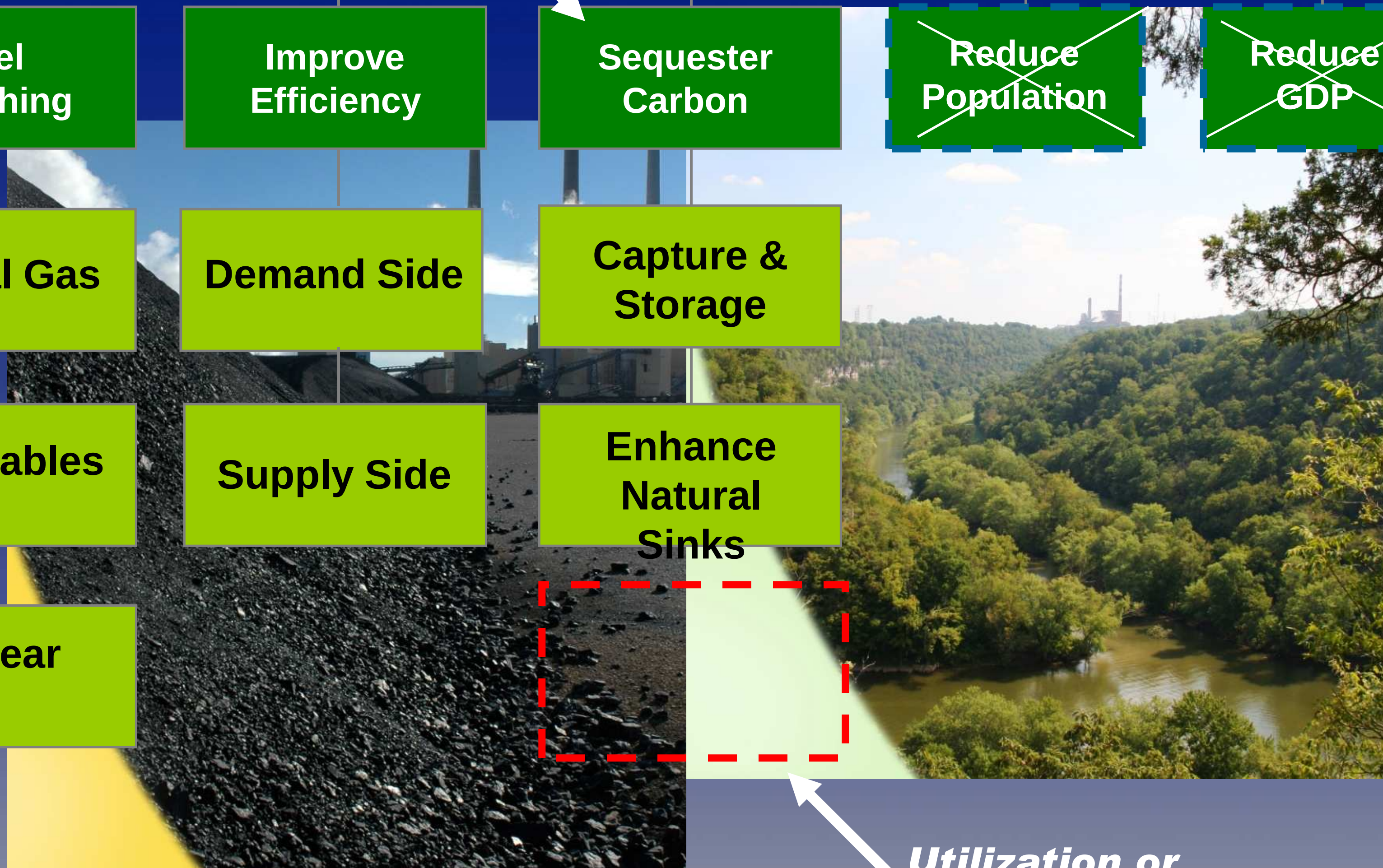
Reductions in Carbon Emissions By Adoption of New Power Generation Technologies



Source: NETL, Scott Klara

Technology and Innovation

Can Lead to Reductions in Carbon Emissions



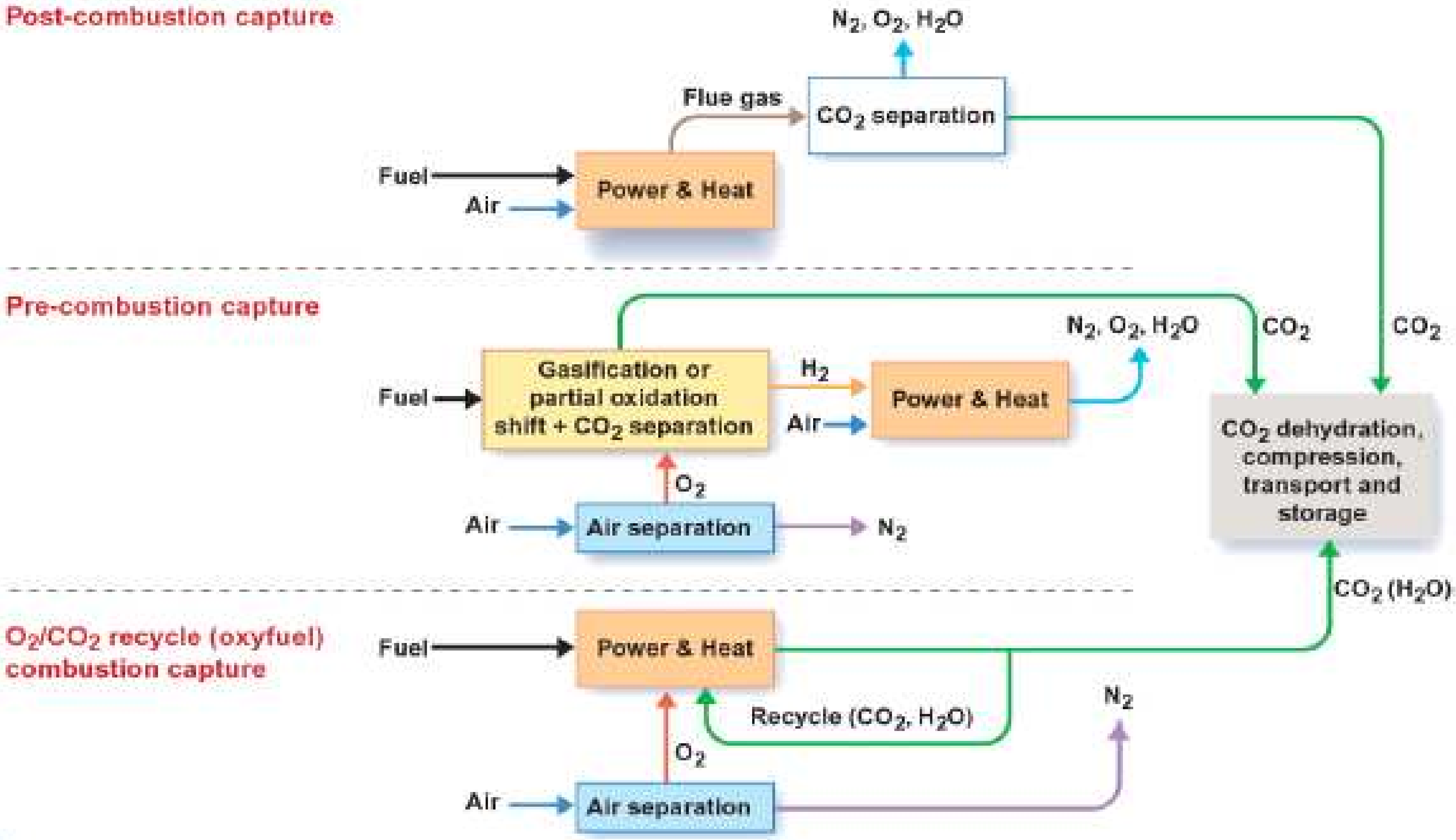
- **Fuel Switching**
  - Natural Gas
  - Renewables
  - Nuclear
- **Improve Efficiency**
  - Demand Side
  - Supply Side
- **Sequester Carbon**
  - Capture & Storage
  - Enhance Natural Sinks
- ~~Reduce Population~~
- ~~Reduce GDP~~

Utilization or Conversion???

Center for Applied Energy Research

Photo art: A. Benlow

CO_2 Capture from Electricity Generation

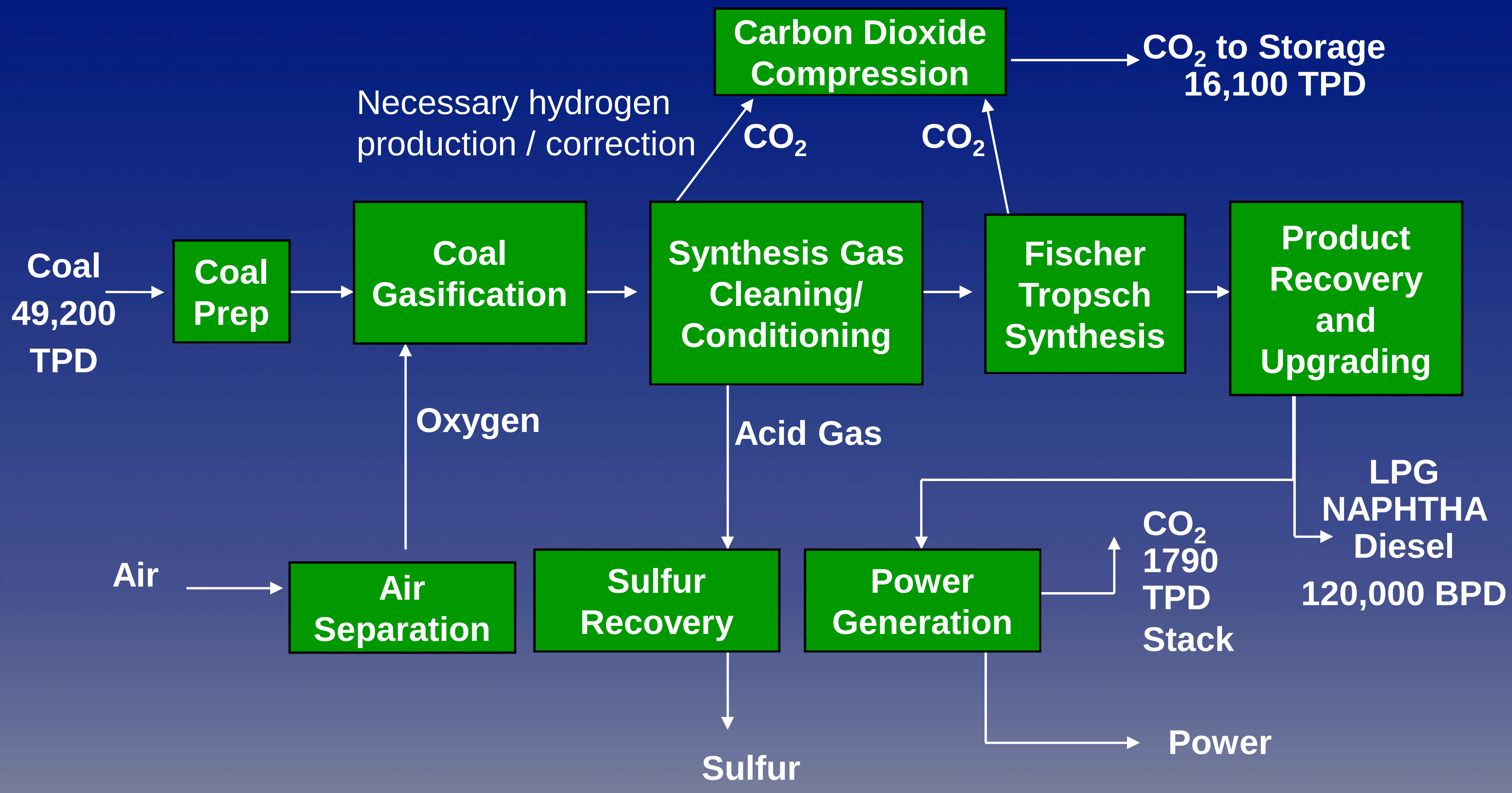


Lowering the Energy Penalty of CO_2 Capture

- Post-Combustion Capture: PC + MEA (28-34%)
  - Steam consumption for stripper: 20% of gross power output
  - Booster fan and agent pump for MEA scrubber: 3-4% of gross power output
- Pre-combustion Capture: IGCC (total 15-24%)
  - ASU + oxygen compression: 8-12% of gross power output
  - Selexol CO_2 separation: 2% of gross power output
- In-situ Capture: Oxy-Fuel Combustion (total 22-32%)
  - ASU: 15-20% of gross power output
  - Flue gas recirculation: 2% of gross power output
  - Possible CO2 further enrichment (unknown)

** Compression Train: 5-10% of gross power output

CO_2 Capture from Coal-to-Liquids



Center for Applied Energy Research

Mitigating Carbon Impact from the Production of FT Fuels

- Gas Cleaning/Conditioning:
  - To reduce the initial make of CO_2
  - To reduce hydrogen demand
- Improved Catalysts
  - Reduce unwanted CO_2 formation (for water-gas-shift)
  - Longer life/aging of catalysts
  - Increased robustness (mechanical attrition resistance)
  - Catalyst for improved product selectivity and conversion
- Use of biomass in FT processes
  - Biomass gasification
  - Gas cleaning
  - Utilization of biomass as hydrogen source
- Co-feed of Coal and Biomass for CTL

Agenda

- Energy Demand and Availability
- Coal Conversion Technologies
  - Gasification
  - Coal to liquids / gas
- Carbon Management
- Future Directions and Impacts

Photo art: A. Benlow

Projections to 2025

Capital Expenditures for Coal Btu Conversion Technologies

	Coal Use Per Year in Million Tons	Capital Expenditures in Billions (2005 Dollars)
Coal-to-liquids	475	$211
Coal-to-gas	340	115
Coal-to-electricity	375	150
Coal-to-hydrogen	70	27
Coal for ethanol	40	12
TOTAL	**1,300**	**$515**

Figure ES.5

- Current coal production about 1.1 billion t/year
- Additional needs 1.3 billion t/year
- Economic multiplier: Over next 20 years it will contribute to
  - 1.4 million new jobs
  - GDP gains of $3 trillion
- Some concerns:
  - Impact on mining
  - Impact on the environment
  - Transportation of coal
  - Labor Force / Skills

National Coal Council Estimates

“Green Coal” Strategies

- Conventional Use of Coal to Lower CO_2 Emissions
  - Replace Natural Gas for Both Peak and Base-load Power Generation
    - More fuel for direct use in the home
    - No transmission losses
  - Displacing Petroleum via Electrification
    - Electrification of Transportation
- New Technologies for Emissions Control
  - Carbon capture and utilization
    - Sequestration??

Energy Urgencies

- Add New (Coal Based) Power Generation
- Develop Incentives to update of coal power fleet
  - Higher efficiency, lower emissions
- Upgrade/strengthen our transmission infrastructure
- Change the way we regulate power generation
  - Include efficiency in the mix
    - i.e. lbs. of SO_2/mmBtu to lbs. SO_2/MW/hr
- Develop a long term coal strategy for Kentucky
  - protect our manufacturing base
  - Coal to synthetic natural gas
  - Coal to liquid fuels
  - Green coal and efficiency
- There is no quick and simple “Fix” for our energy problems
  - Any rational strategy is multi-fuel, multi-sector
  - Any rational strategy must include production and efficiency together

Questions?

Graphic: Future Gen, US DoE

Photo art: A. Benlow