Research Needs for Carbon Capture and Mitigation

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Center for Applied Energy Research

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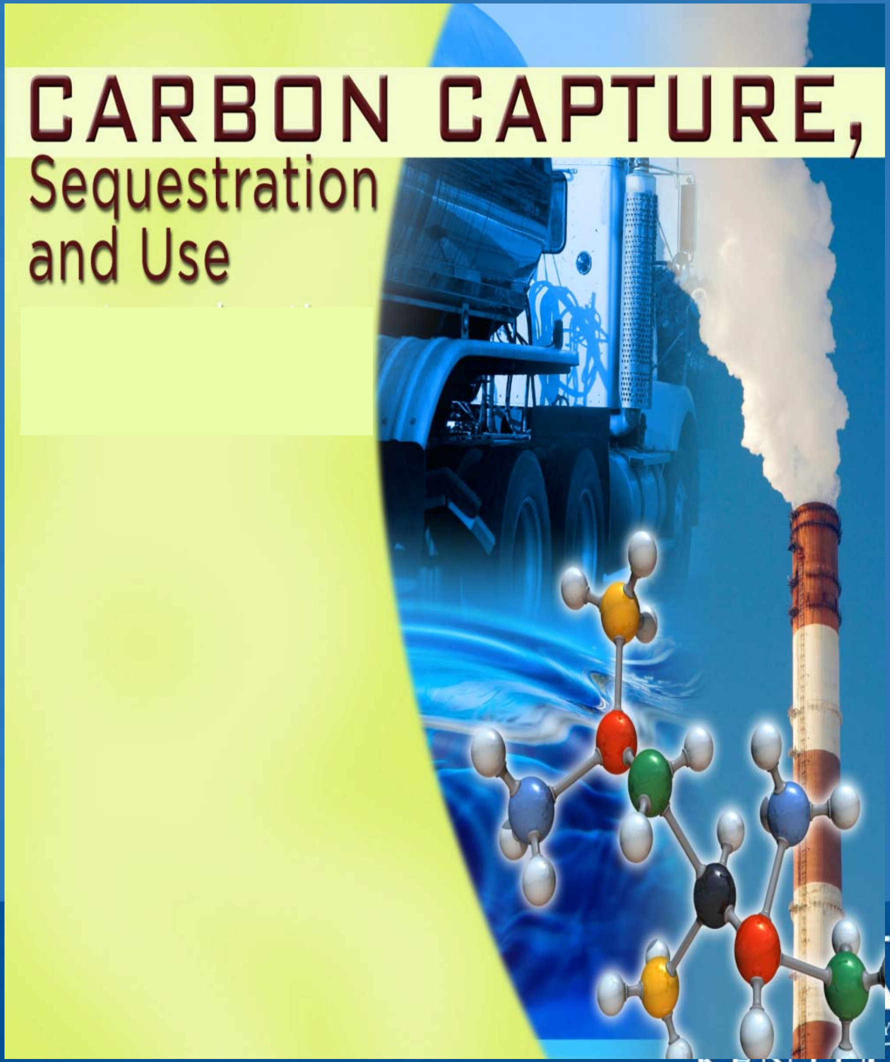
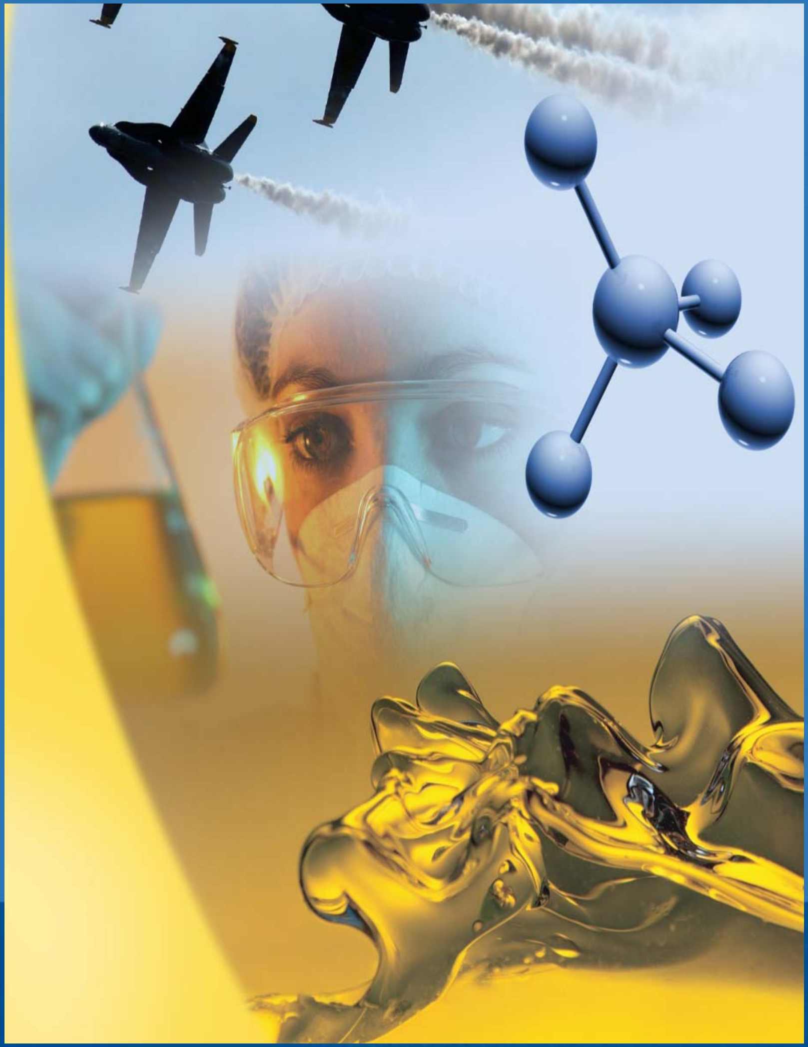


Photo art: A. Benlow

Agenda



- ✐Extent and Sources of CO_2 Emissions
- Management & Capture
- Research Needs

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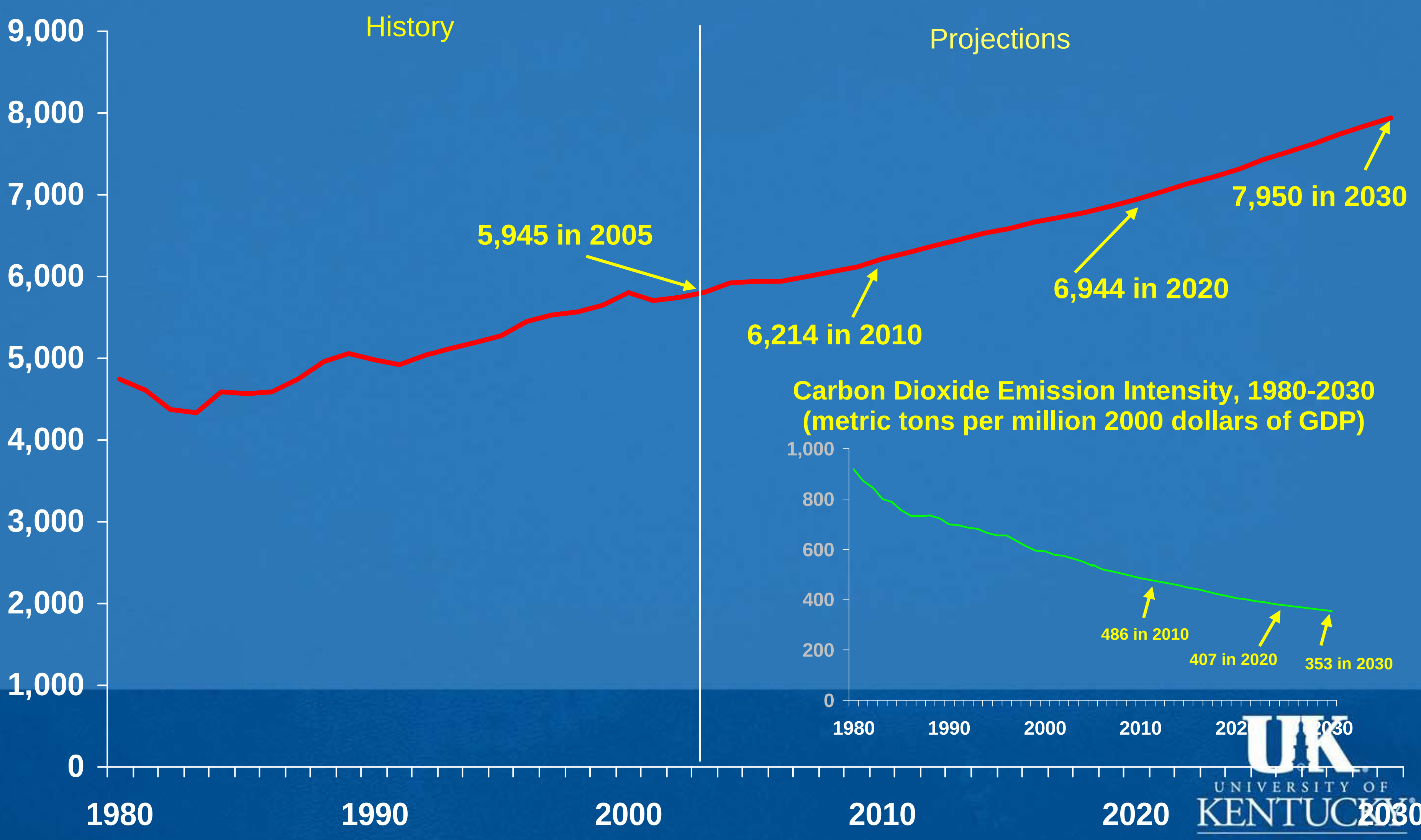
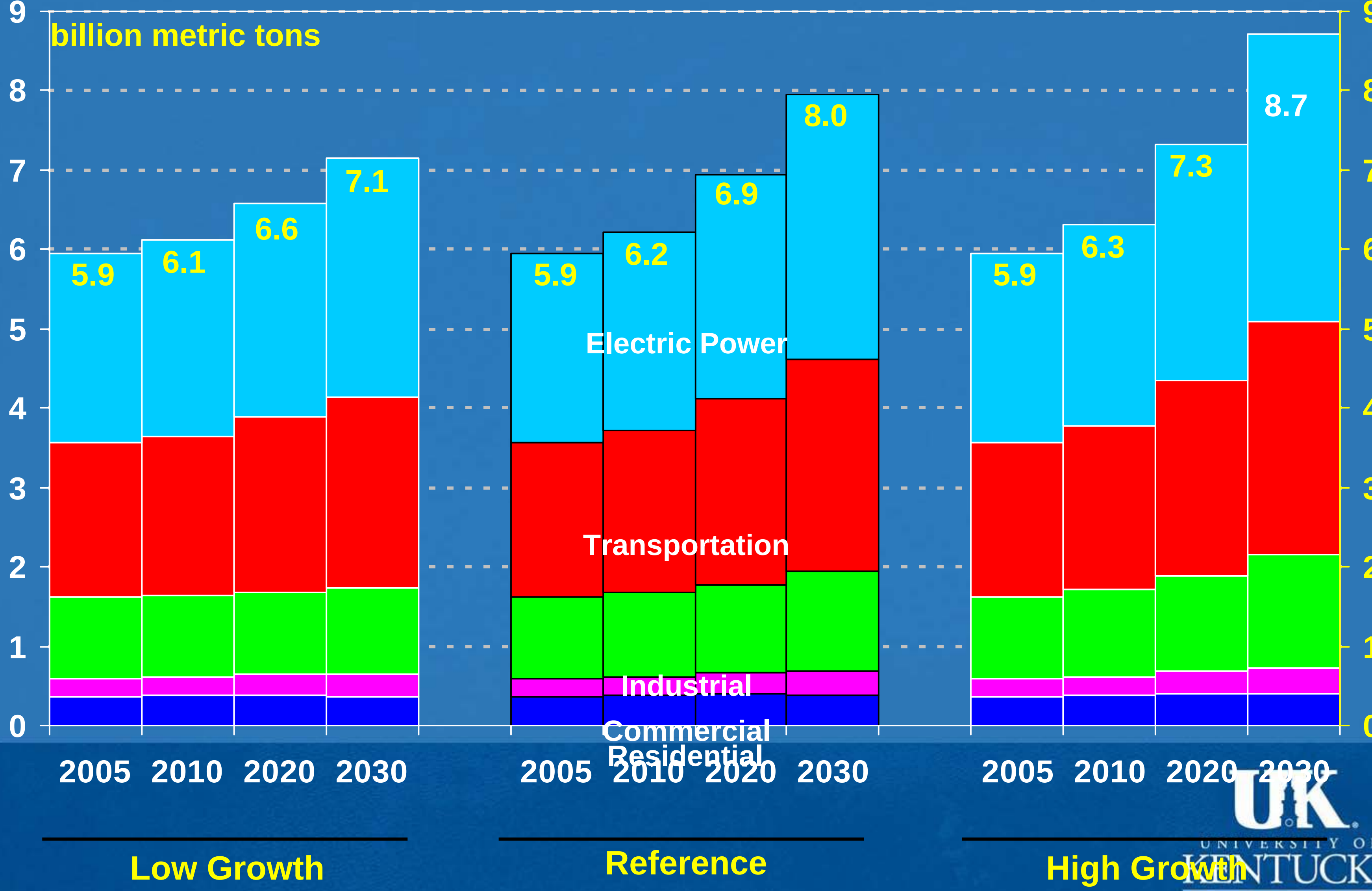
U.S. Energy-Related Carbon Dioxide Emissions, 1980-2030 (million metric tons)



Annual Energy Outlook 2007

Carbon Dioxide Emissions



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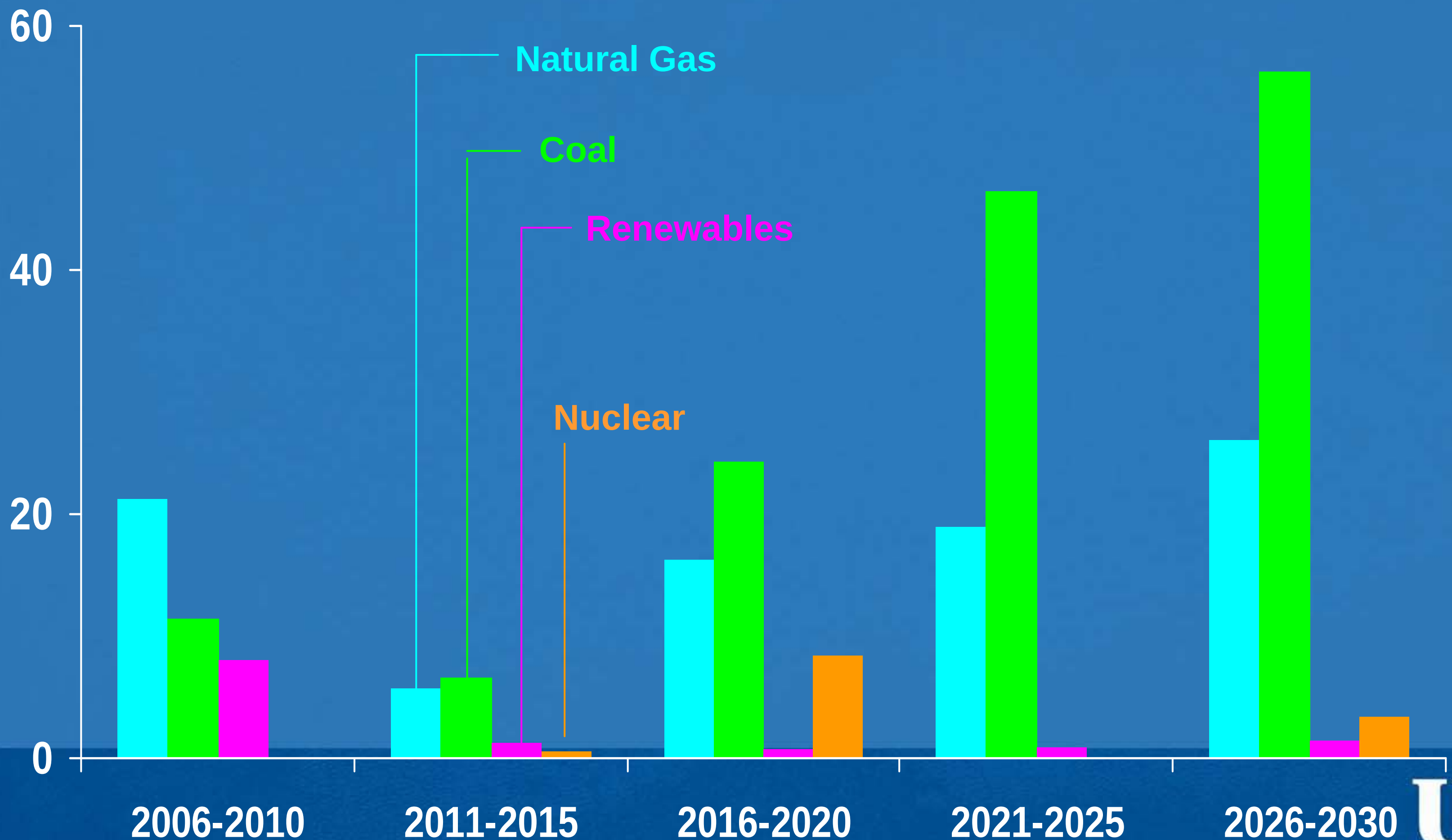
Needed: 1,300 New Power Plants

A Conservative Estimate

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

Source: EIA/DOE

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



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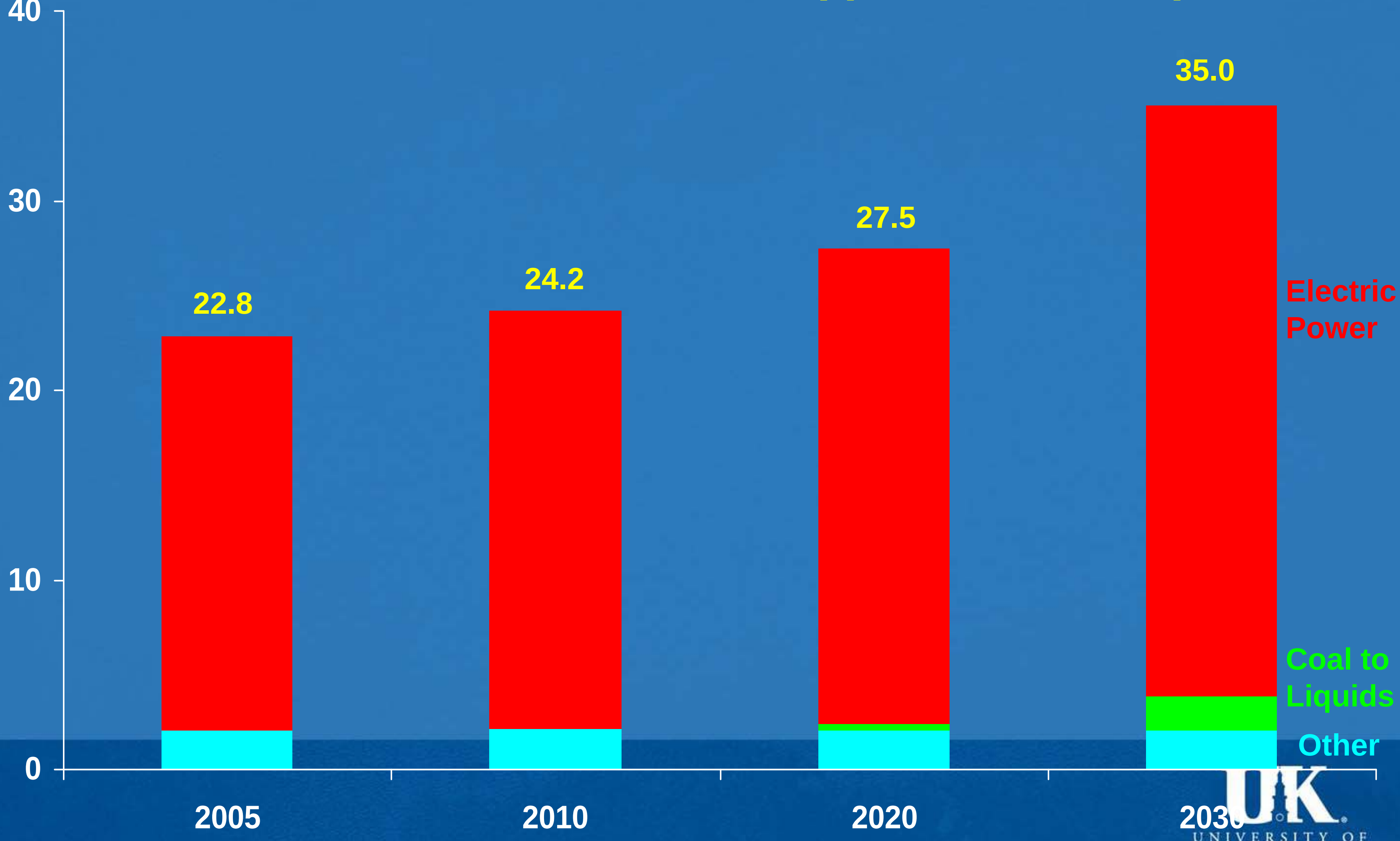
U.S. Coal Consumption by Sector, 2005, 2010, 2020, and 2030 (quadrillion Btu)



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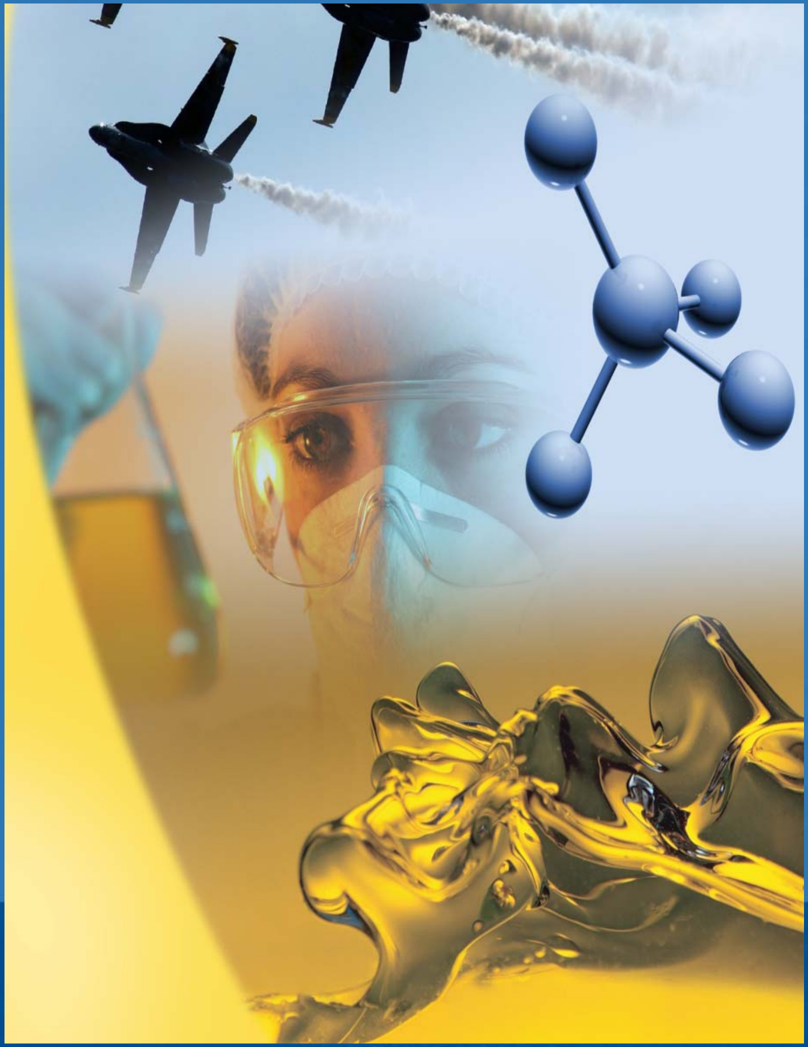

- Extent and Sources of CO_2 Emissions
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Technology and Innovation

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

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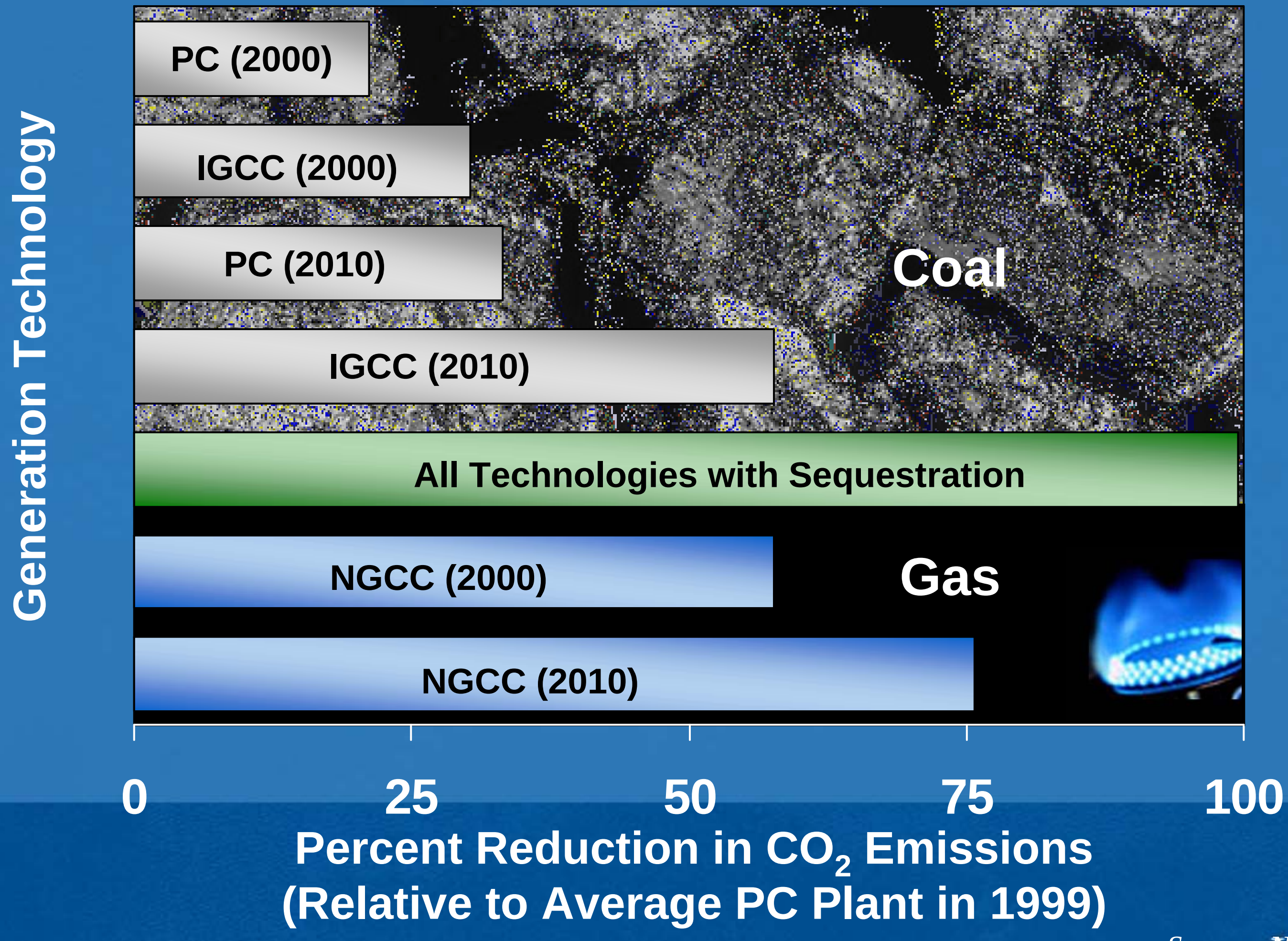
Reductions in Carbon Emissions
By Adoption of New Power Generation Technologies



Source: NETL, Scott Klara

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Reductions in Carbon Emissions
By Switching to Natural Gas

Era of "Cheap" Gas May Be Over

- **Supply cushion since mid-1980's eroded**
  - US supply flat past 5 years
  - Rapid decline curves for new wells
  - Canadian gas/LNG imports up from 4% in mid-1980s to 15%
- **Spot Market Prices up 4-fold**
- **Projected 2-3% annual growth – up 60% thru 2020**
- **T&D infrastructure stressed**
  - Need $120-150B investment to expand system

Source: USDOE

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Reductions in Carbon Emissions By Switching to Renewables

- Wind, hydro, and geothermal - Not enough
- Biomass - Transportation, land use, expense
- Solar - Land use, capital cost, storage

Needed: An Affordable, Clean, and Abundant Energy Source
No Known Source Meets These Criteria

Source: USDOE

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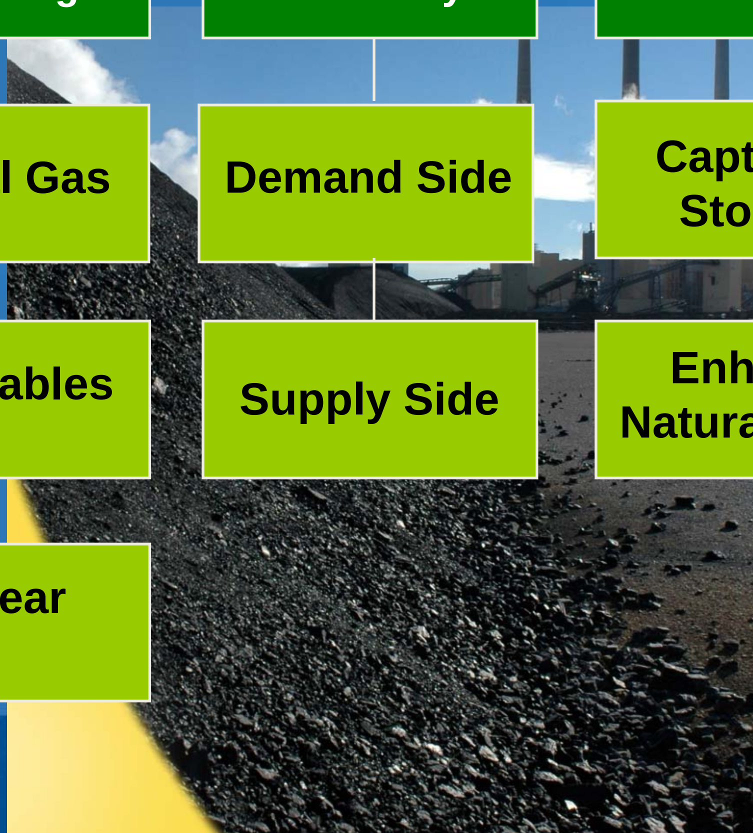

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Reductions in Carbon Emissions
By Demand-side Efficiency

- *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"*

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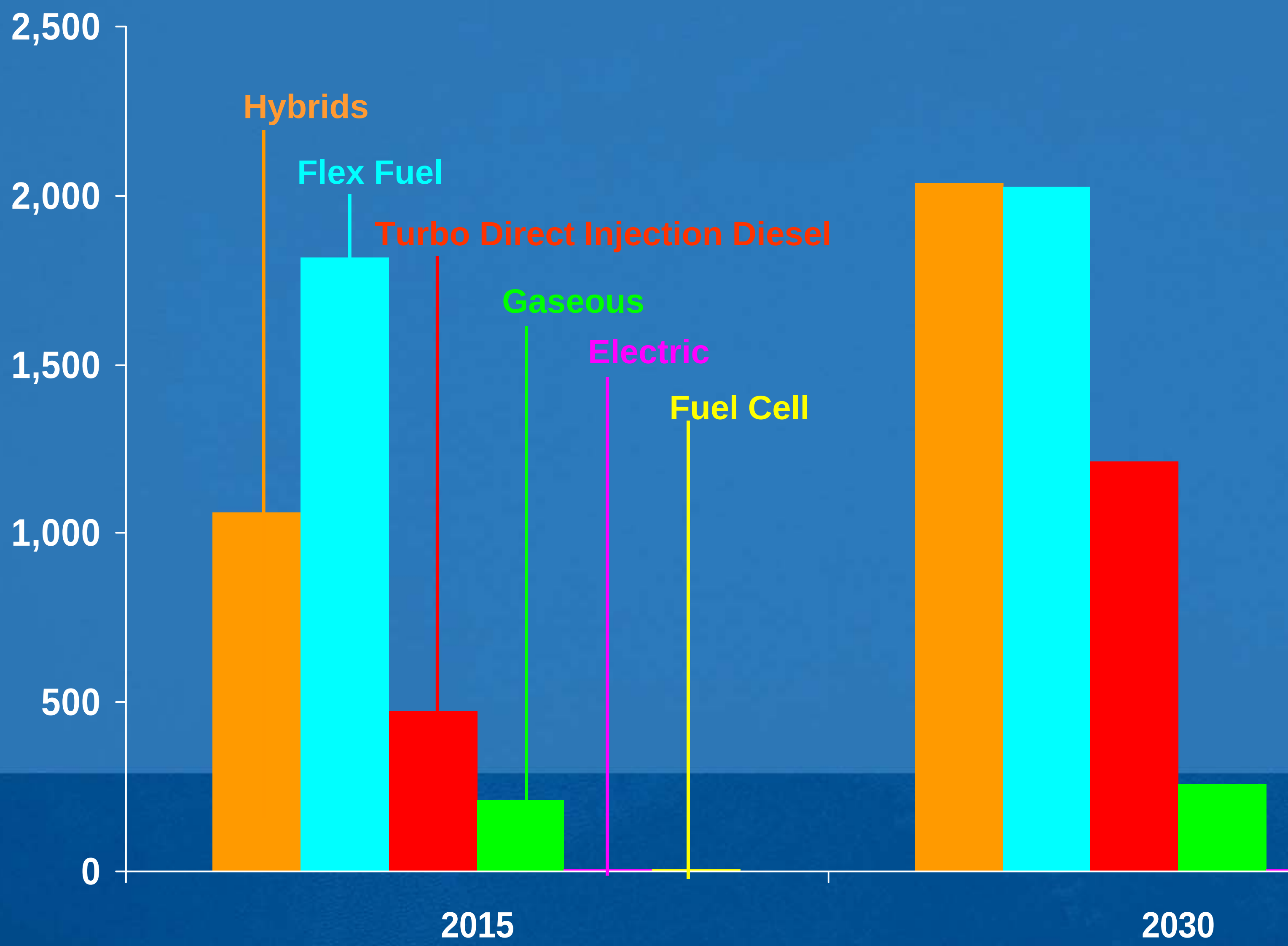
U.S. Sales of Unconventional Light-Duty Vehicles, 2015 and 2030 (thousand vehicles sold)



Annual Energy Outlook 2007

Reductions in Carbon Emissions By Greater Supply-side Efficiency

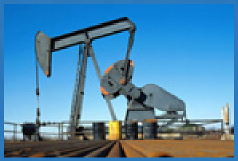
Electric Power

Coal Production

Power Delivery

Power Generation

Petroleum



Exploration & Production

Refining & Delivery

Transportation

Natural Gas

Exploration & Production

Pipelines & Storage

Distributed Power Generation

Source: USDOE

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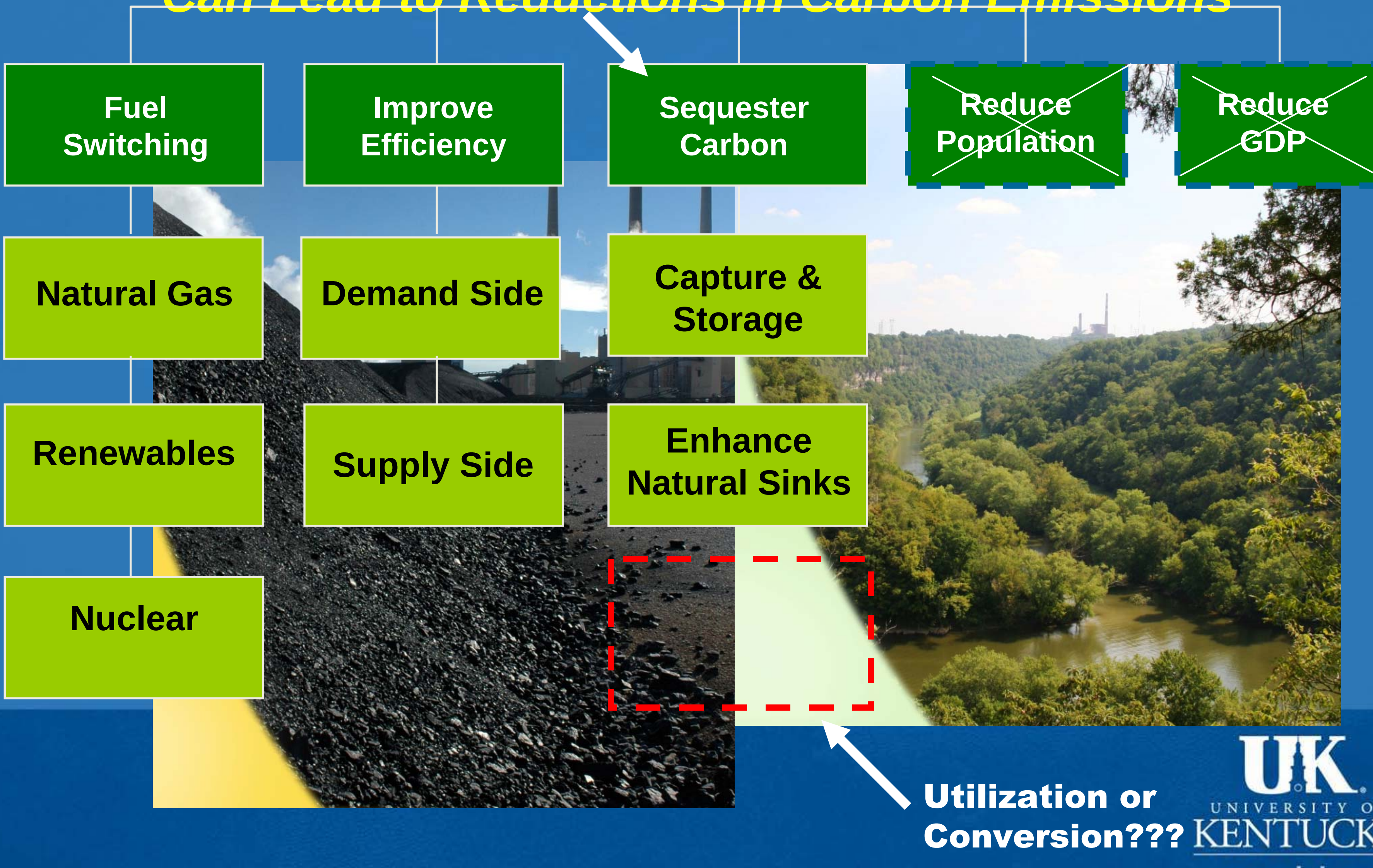

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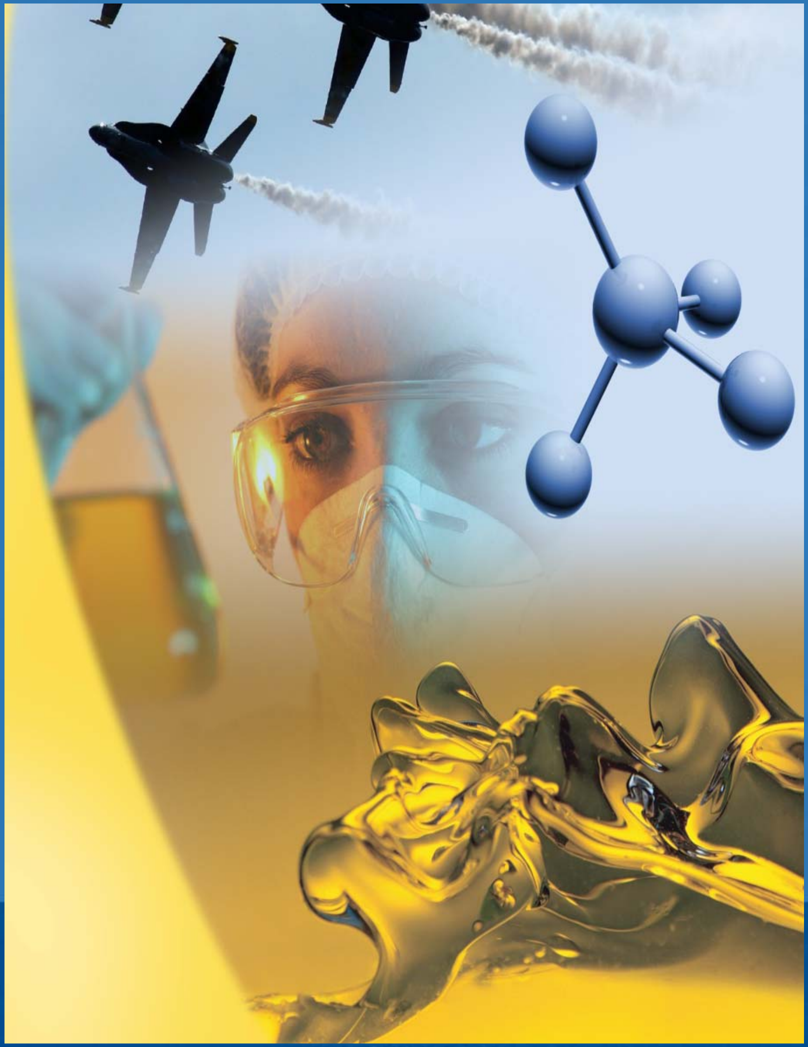

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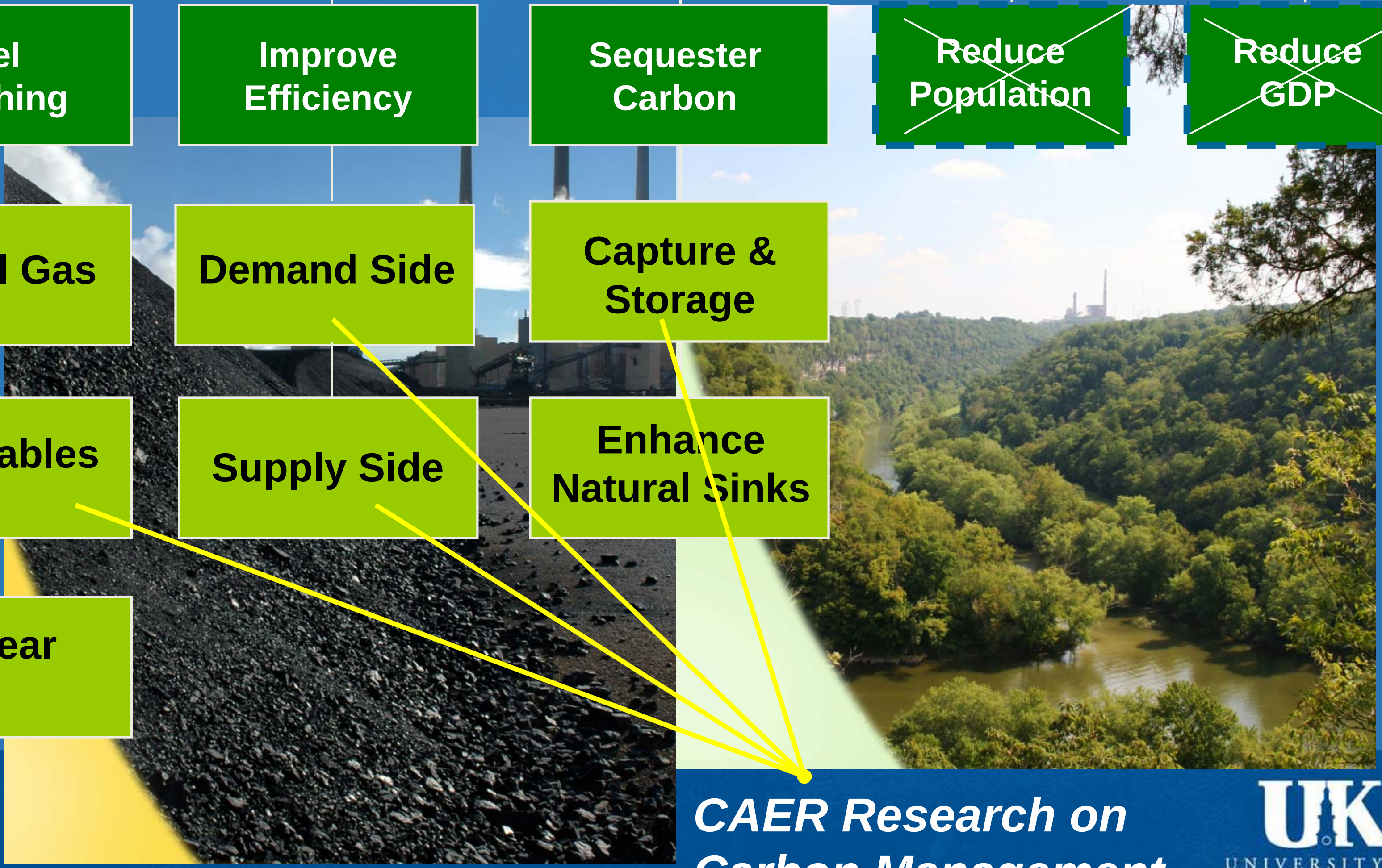

CAER Research on Carbon Management

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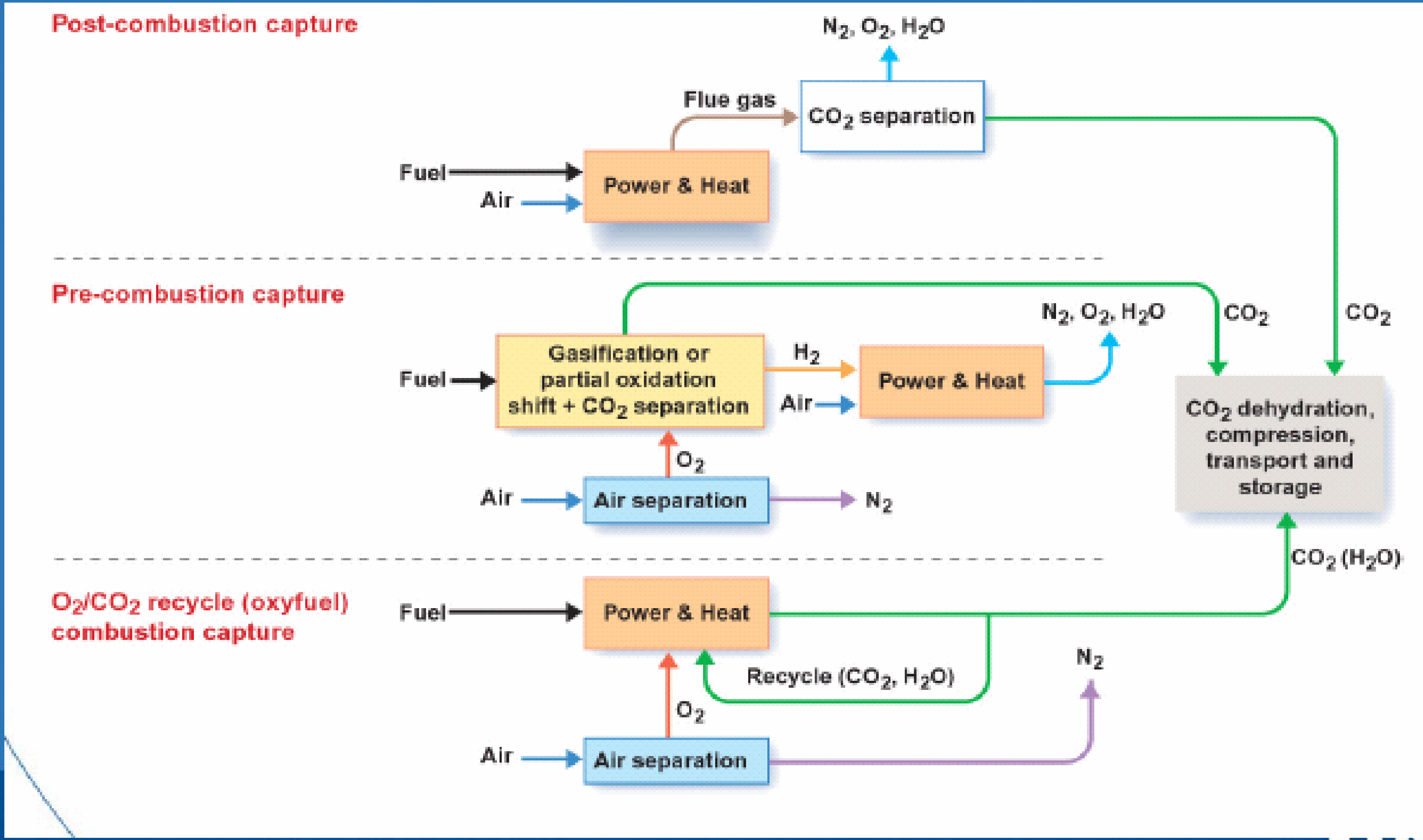
CO_2 Capture from Electricity Generation



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Research directed to Lowering Energy Penalty of CO_2 Capture Options

- 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

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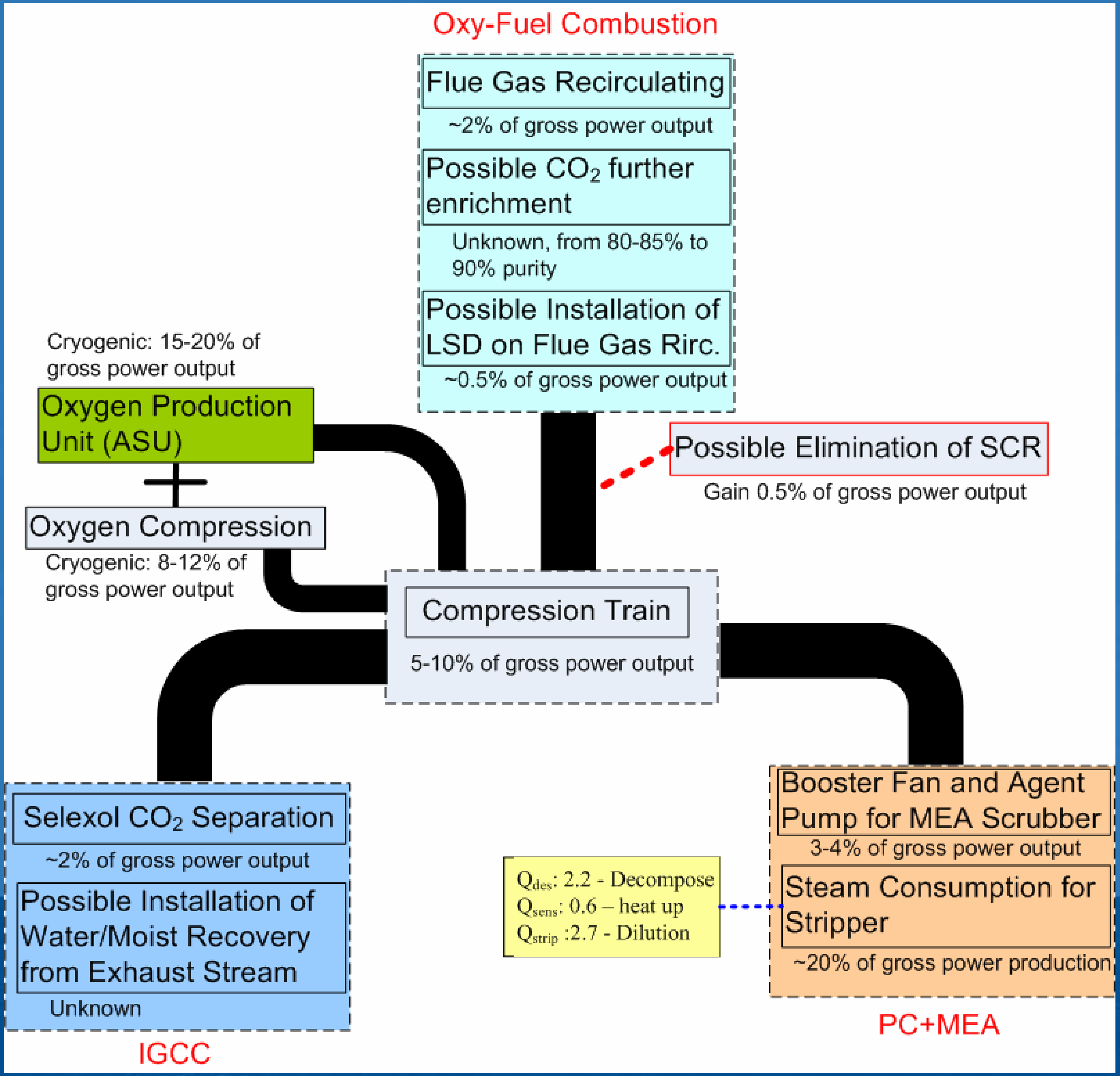
Possible Choices for CO2 Management



Current Status of IGCC

- Mature technology for gasifier
- New wave pushed by GE, Shell and ConocoPhillips
- OEMs teamed with engineering companies to wrap
- RD&D
  - New catalyst/shift-reactor process to reduce H_2O/CO ratio
  - Membrane separation
  - Sorbent development
  - Process integration
  - Oxygen production

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Current Status of Oxy-Fuel

- Oxyfuel -- Commercial available for glass, steel and other sectors
  - Demo
    - Praxair & Foster Wheeler
      - Bahamas project
      - Fundación Ciudad de la Energía (CIUDEN)
    - B&W and Air Liquide
      - SaskPower (terminated?)
      - AEP
    - Alstom
      - Vattenfall
  - Ongoing RD&D for Utility
    - Vattenfall 30MWe plant
    - Air Liquide/B&W 4MMBtu and 40MMBtu plant
    - Alstom (3MWth FBC)
    - Universität Stuttgart (0.5MWth PC)
    - CANMET (0.3MWth PC and 1.0MWth FBC)
  - Air Separation Unit
    - Ion transport membrane (ITM) (Air Products, Praxair)
    - Ceramic autothermal recovery (CAR) (BOC Gases)

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Post CO_2 Capture Process

- Absorption Processes (Liquid & Solid)
- Adsorption Process (Solid Surface, Ionic Liquid)
- Physical Separation (Membrane, Cryogenic Separation)

- Hybrid Solution (Mixed Physical - Chemical Solvent)

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Post Combustion Scrubbing in Fossil Power Plants

- Challenges:
  - Low CO_2 partial pressure
    - 5-15 vol%
  - Low System Pressure
  - 25-35% of plant output for auxiliary power.

- Capital Costs $500/kW
  - Three absorbers with same diameter as FGD, 50 ft packing.
  - Strippers somewhat smaller.

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Physical Absorption

- Physical solvent processes use organic or inorganic solvents to physically absorb acid gas components rather than react chemically.

- Removal of CO_2 by physical absorption processes based on the solubility of CO_2 within the solvents.

- The solubility of CO_2 depends on the partial pressure and on the temperature of the feed gas.

- Regeneration of the spent solvent can be achieved by flashing to lower pressure or by stripping with vapor or inert gas.

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Chemical Absorption

- Chemical absorption processes are based on exothermic reaction of the solvent with the CO_2 in the feed gas stream.

- Chemical reaction must be reversible. The reactive solvent removes CO_2 in the absorber at low temperature. The reaction is then reversed by endothermic stripping process at high temperature and low pressure.

- Majority of chemical solvent processes use either an amine or carbonate solution.

Chemical Absorption Processes

- **Potassium Carbonate.**

  $K_2CO_3 + CO_2 + H_2O \leftrightarrow 2KHCO_3$

- **Monoethanolamine (MEA)**

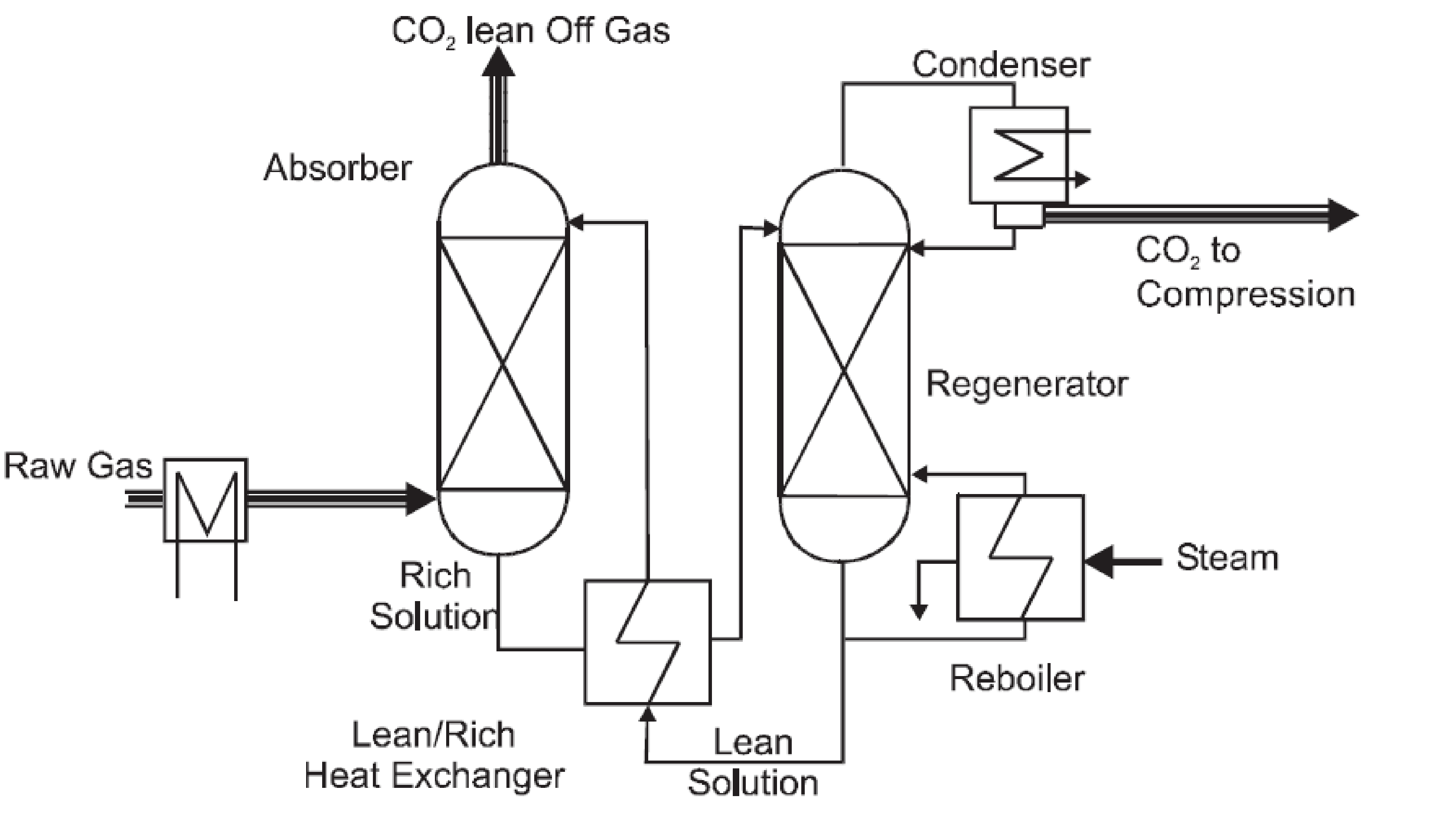
  $2\ HO\text{-}CH_2\text{-}CH_2\text{-}NH_2 + CO_2 \leftrightarrow$

  $HO\text{-}CH_2\text{-}CH_2\text{-}NH\text{-}COO^- + MEAH^+$

- **Ammonia**

  $2NH_3 + CO_2 \leftrightarrow NH_2COO^- + NH_4^+$

Chemical Absorption Scrubbing



Reagent Properties Affecting Makeup

	Cost $/lbmol	$P_{amine, 40C}$ atm x 10^3	Degradation	Corrosion
MEA	40	0.1	High	High
NH_3	5	200	None	High
PZ	300	0.1	Moderate	High
MDEA	300	0.003	Moderate	Moderate
K_2CO_3	40	0	None	High

Source: Rochelle, 2007

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Current Status of Aqueous Scrubbing

- Amine: commercial-implementation on NG, food and chemical production
  - Kerr-McGee/ABB Lummus Crest Process
  - Fluor Daniel ECONAMINE FG Process
  - MHI's KM-CDR process with KS solvent
  - Ongoing RD&D for utility flue gas
    - University of Texas at Austin
    - European Union integrated project "CO_2 from Capture to Storage" (CASTOR)
    - International Test Center (ITC) at University of Regina, Canada
    - MHI
    - UK CAER
- Ammonia: Commercial for fertilizer production
  - Ongoing RD&D for Utility's flue gas
    - Alstom/EPRI 5MWth pilot plant at WE Energy - Pleasant Prairie Plant
    - Powerspan/NETL 1MWth slipstream at FirstEnergy's Burger station
    - UK CAER/E-ON US 0.1MWth pilot plant

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CAER CO_2 Capture Research

- **Two Supported by E-ON US:**
- ***Post-Combustion Process**
  - Solvent-based CO_2 capture technologies
  - New concept development
    - Solid additives
    - Membrane for solution separation
- ***In-situ process (No external ASU)**
  - Pressurized Chemical Looping Combustion Combined Cycle (PCLC-CC)
- **Two for existing PC supported by GOEP**
  - Feasibility Study on Using Algal Capture and Utilize CO_2 Source from Kentucky Power Plants
  - Development of Liquid Membrane for Solvent-Based Post-Combustion CO_2 Scrubber
- **One for IGCC supported by CAER**
  - Activated Carbons for CO_2 Capture from Coal-derived Pitch/Polymer Blends

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Solvent-based CO_2 Capture Pilot-plant Objectives

- Provide a flexible pilot-scale platform to study a variety of CO_2 scrubbing processes for existing power stations.
- Study and optimize the power requirements for CO_2 scrubbing technologies.
- Solvent development and solvent management protocol (impact from coal impurities).
- Material Corrosion

0.1MWth Post-combustion CO_2 Capture Pilot Plant

- **Scrubber with height of 22-25 ft:**
  - 10” bottom tank, a 4” reaction zone, and a 8” reaction zone
  - Flexible configuration (open, tray-type or packed column)

- **Stripper with height of 15ft**
  - 8” for reboiler section, 4” tower
  - 400^{o}F and 450 psia (max)
- **Range of gas flows: 10-50 scfm**
- **L/G range: 50 to 200**
- **Simulated flue gas**
  - **mixed from N_2, air, CO_2, HCl and SOx tanks.**
- **Will work on coal-derived flue gas**
- **generator**

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Research Progress

- Completed commissioning using K2CO3 Solvent
  - -Easy solvent
  - -Under utility flue gas cond., the CO2 removal efficiency at 3%-10%
- Pre-trail Study using K_2CO_3/Piperizane (PZ)
  - \- solution preparation difficult (solved)
  - \- low PZ solubility in lean solution (Precipitation of PZ at low Temp)
  - \- 100 hrs run using 1.5m K_2CO_3/PZ
- Baseline Testing using 30% MEA
  - -Over two-month with 32 runs using ceramic packing
  - -foaming in stripper
  - -MEA degradation vs. stripping temperature
  - -Metal concentration profile

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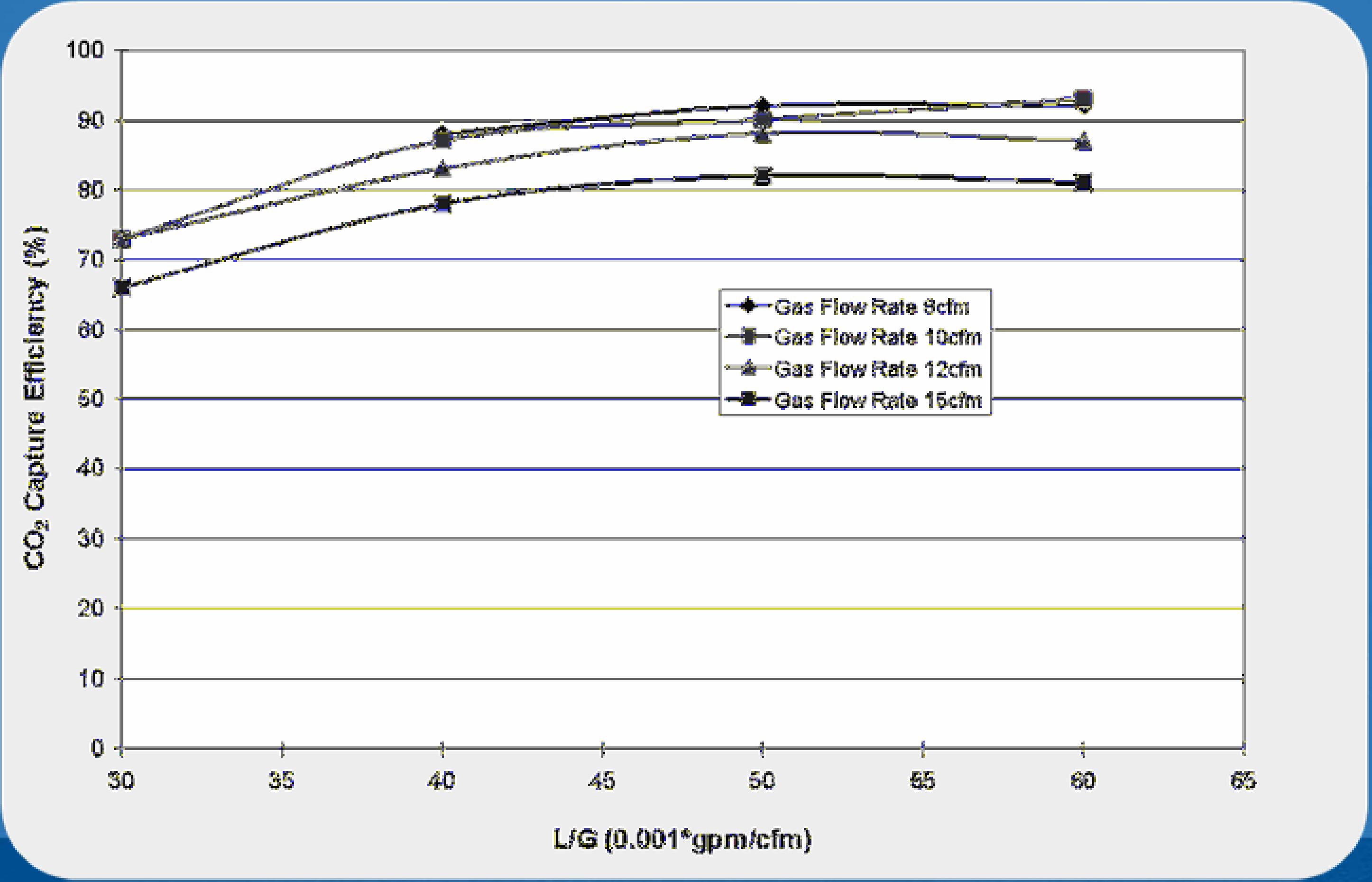
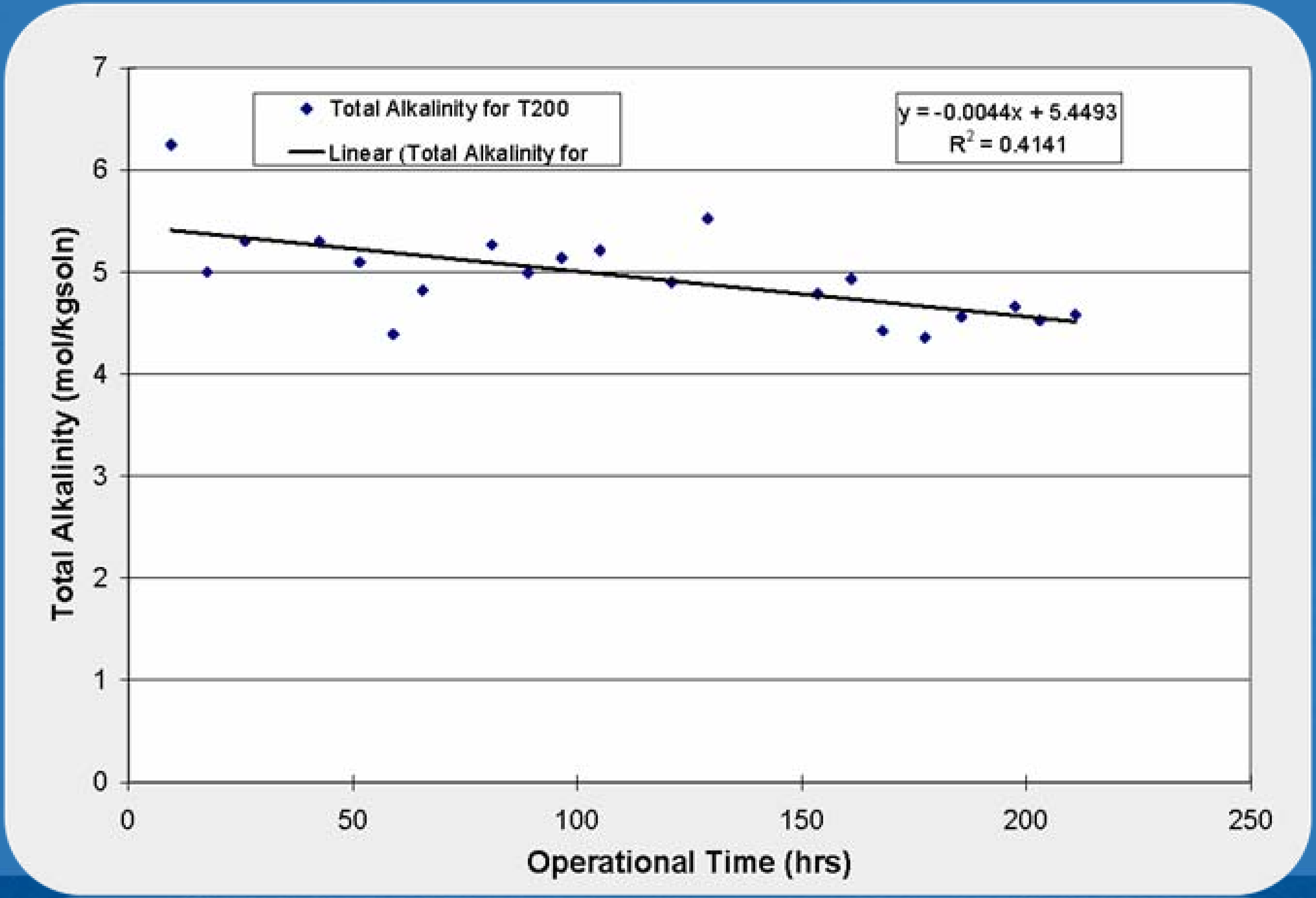
CO_2 capture vs. L/G Ratio



MEA Degradation vs. Time



Carbon Management Research Group

- State-UK-Industry consortium
- Build on E-ON US investment in carbon management and emissions control
- Develop more energy and cost effective carbon management technologies
- Address specific materials, controls and waste management solutions
- Allow early adoption of technologies by Kentucky's electric utilities
- $1 Million/yr match provided by State.

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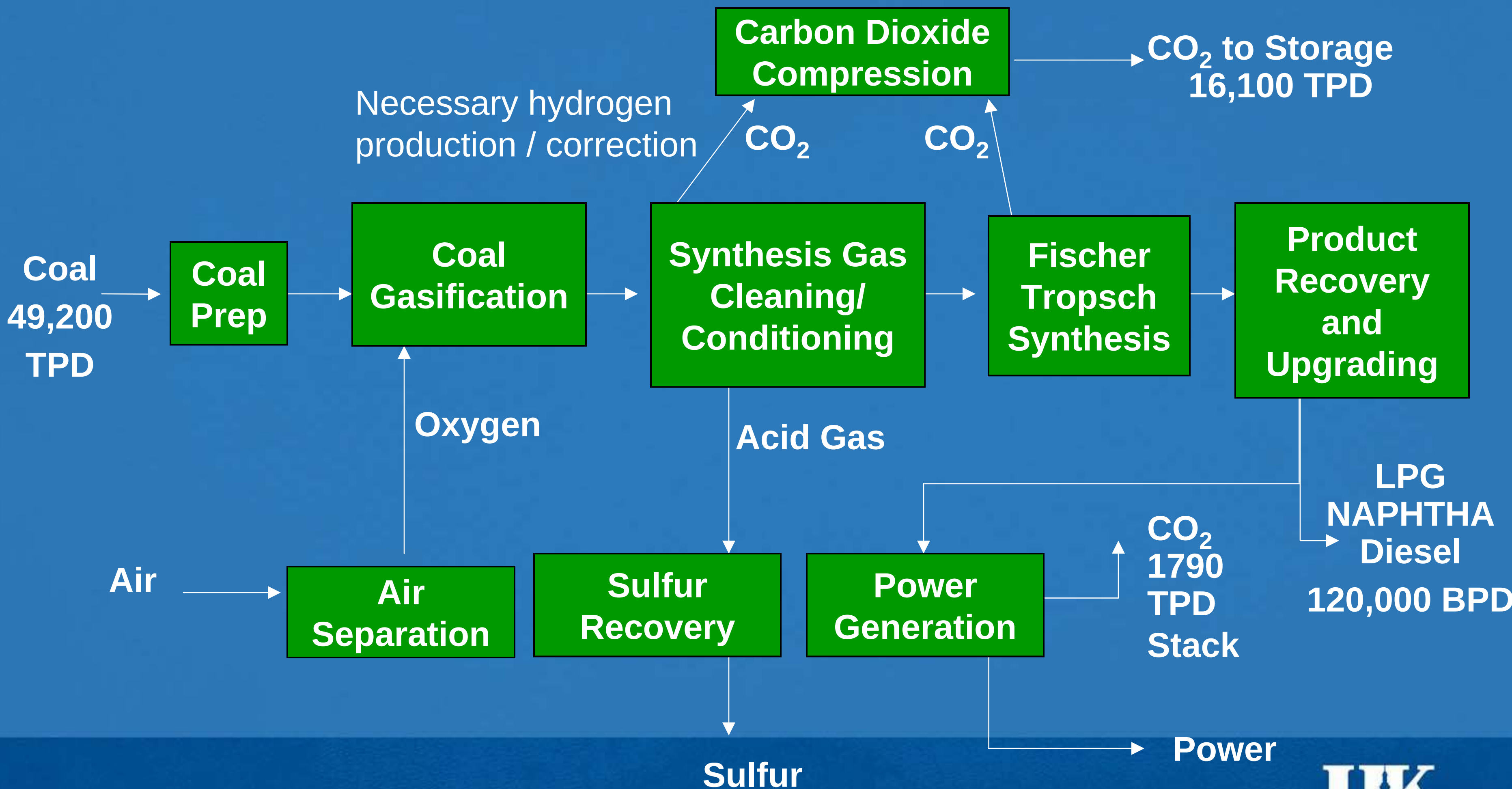
CO_2 Capture from Coal-to-Liquids



Mitigating Carbon Impact from the Production of FT Fuels

- Enhanced modular reactor systems
- Improved catalysts for water-gas-shift
  - Reduce unwanted CO2 formation
- Use of biomass in FT processes
  - Biomass gasification
  - Gas cleaning
  - Utilization of biomass as hydrogen source
- Co-feed of Coal and Biomass for CTL

Questions?

Graphic: Future Gen, US DoE

Photo art: A. Benlow