

Technologies for Energy Production and Utilization in a Carbon Constrained World



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Director

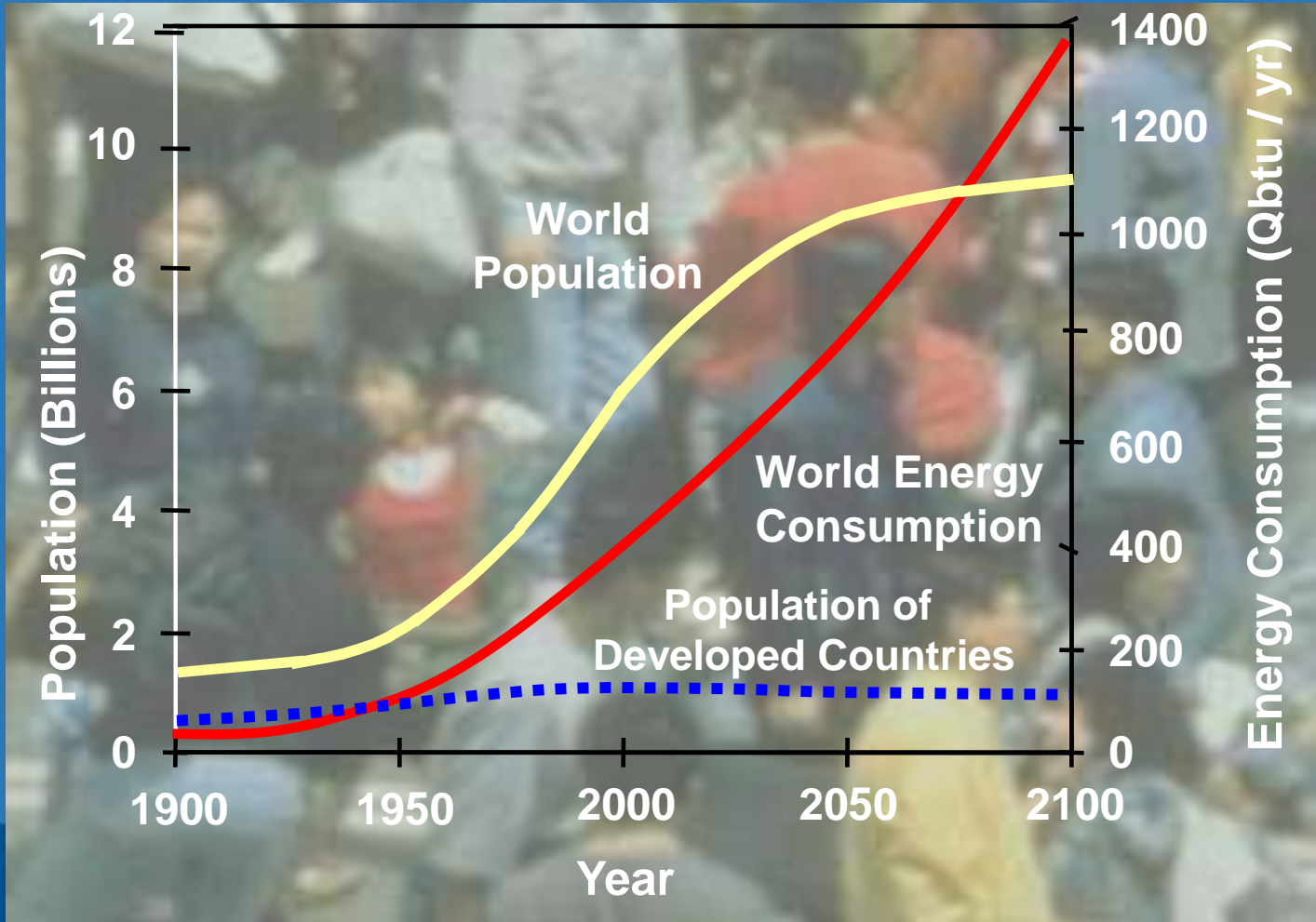
Center for Applied Energy Research

University of Kentucky

UK
UNIVERSITY OF
KENTUCKY
see blue.

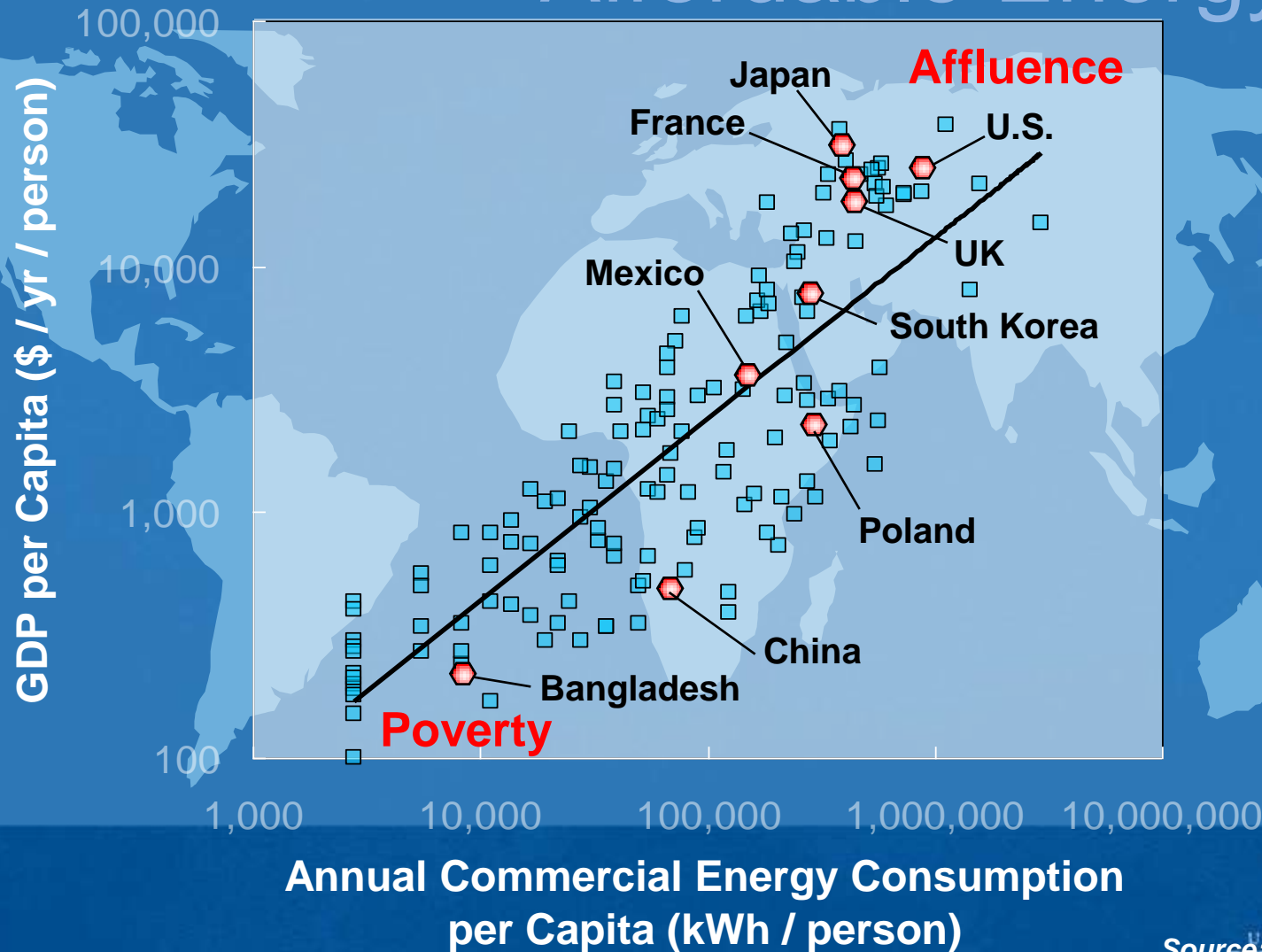
World Energy Use

Growing Dramatically with Population



Source: USDOE

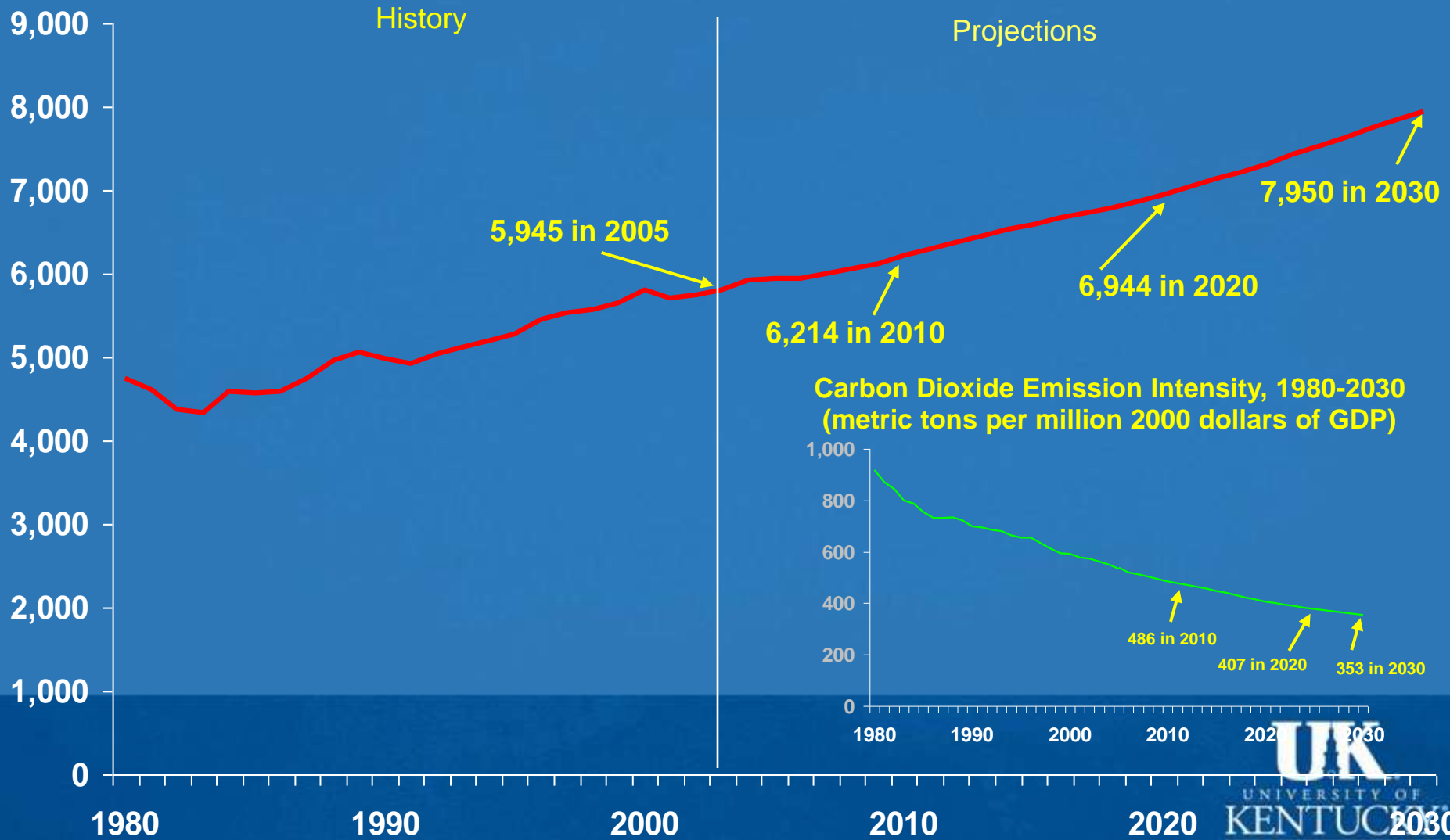
Universal Need for Affordable Energy



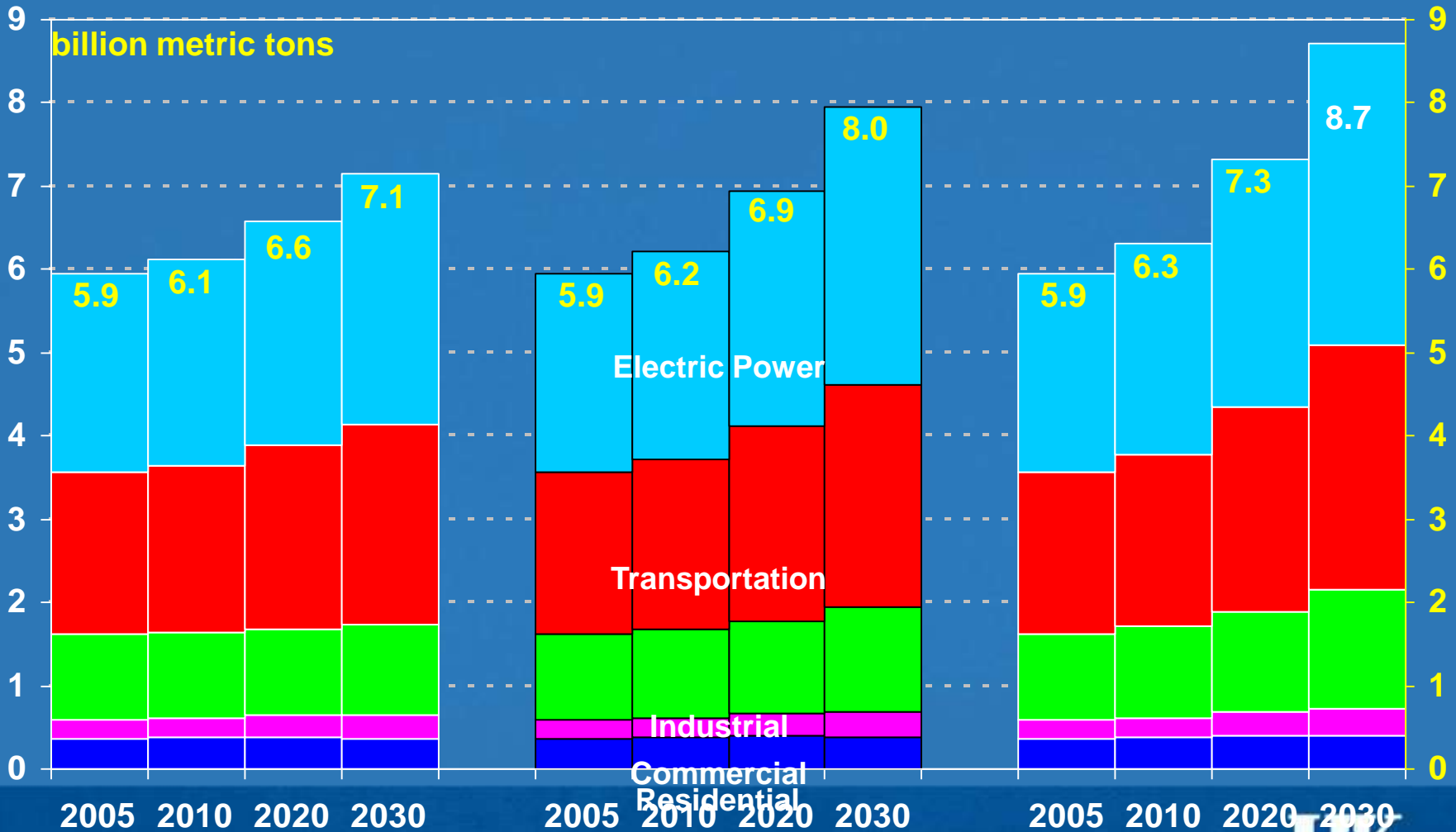
CARBON CONSTRAINTS

The world is getting smaller, and fossil energy is a bigger target

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



Carbon Dioxide Emissions



Low Growth

Reference

High Growth



**Figure 7. Electricity generation by fuel, 1980-2030
(billion kilowatthours)**

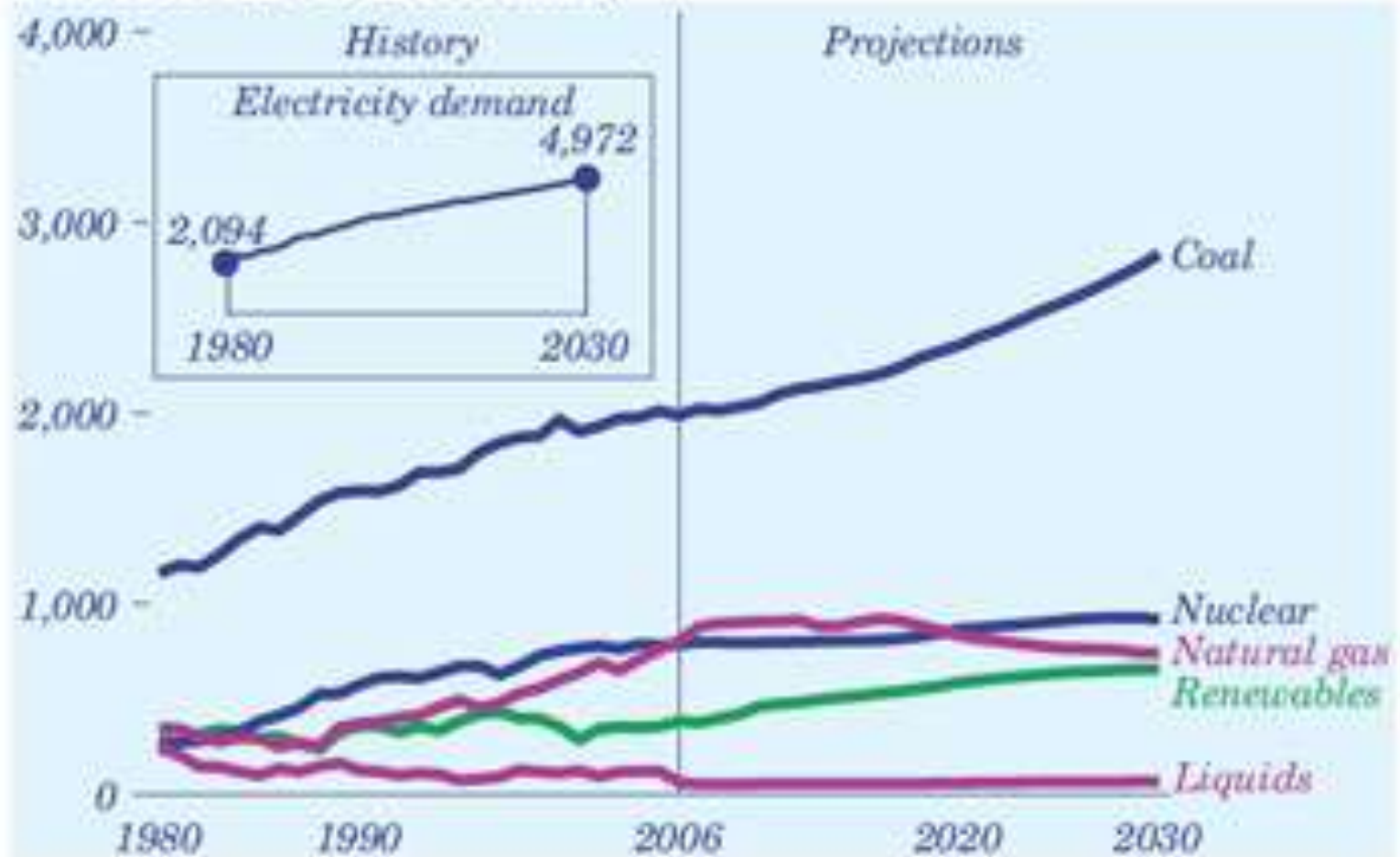


Figure 62. Electricity generation capacity additions by fuel type, including combined heat and power, 2007-2030 (gigawatts)

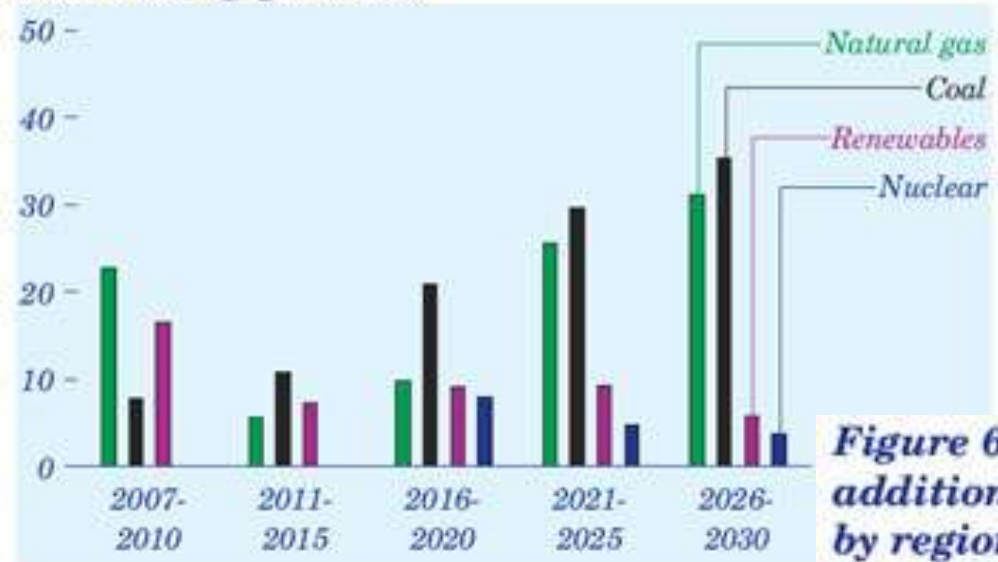
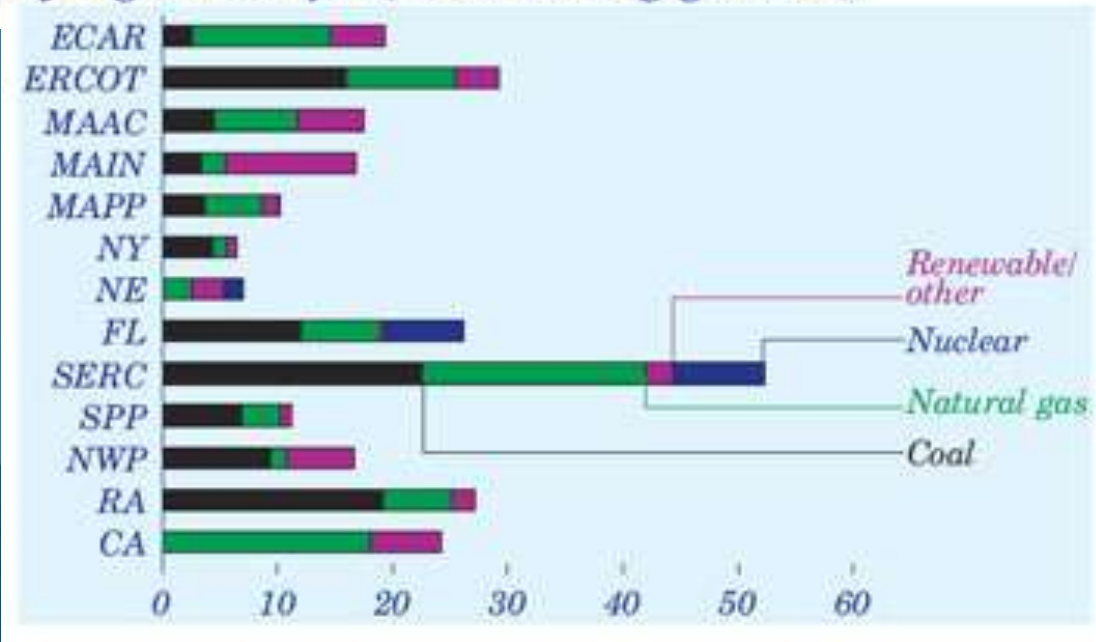


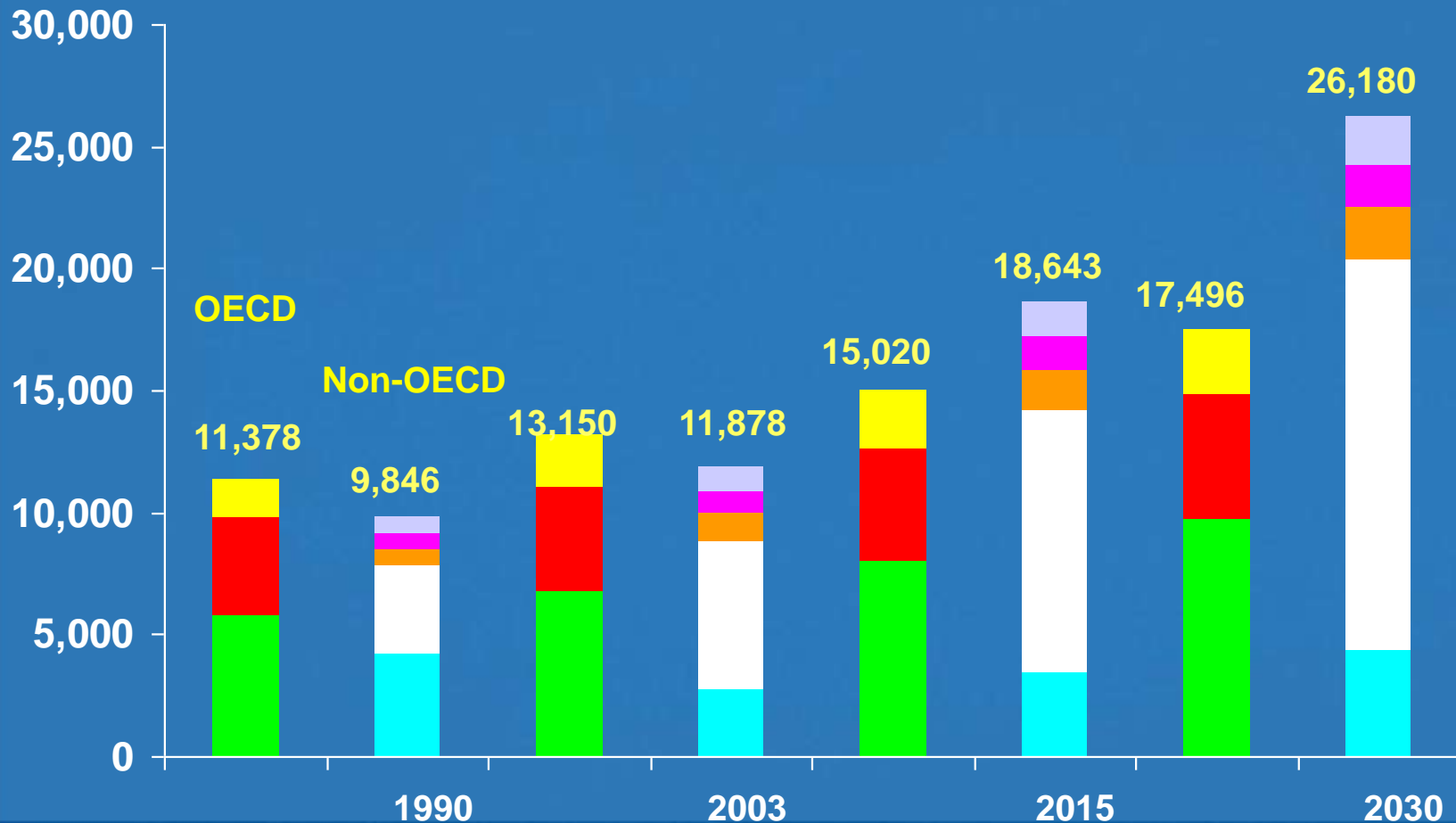
Figure 64. Electricity generation capacity additions, including combined heat and power, by region and fuel, 2007-2030 (gigawatts)



AEO 2008

World Energy-related Carbon Dioxide Emissions

1990-2030 (million metric tons)



■ North America
■ OECD Asia
■ Non-OECD Asia
■ Africa

■ OECD Europe
■ Non-OECD Europe & Eurasia
■ Middle East
■ Central & South America

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What about Kentucky?

- 92% of Ky electricity from coal
- 32 plants in KY and Ohio River Valley
 - ~ 33 GW total coal-fired
 - ~ 16 GW in Kentucky



CARBON MANAGEMENT

Can technology keep up with political reality?

Technology and Innovation

Can Lead to Reductions in Carbon Emissions

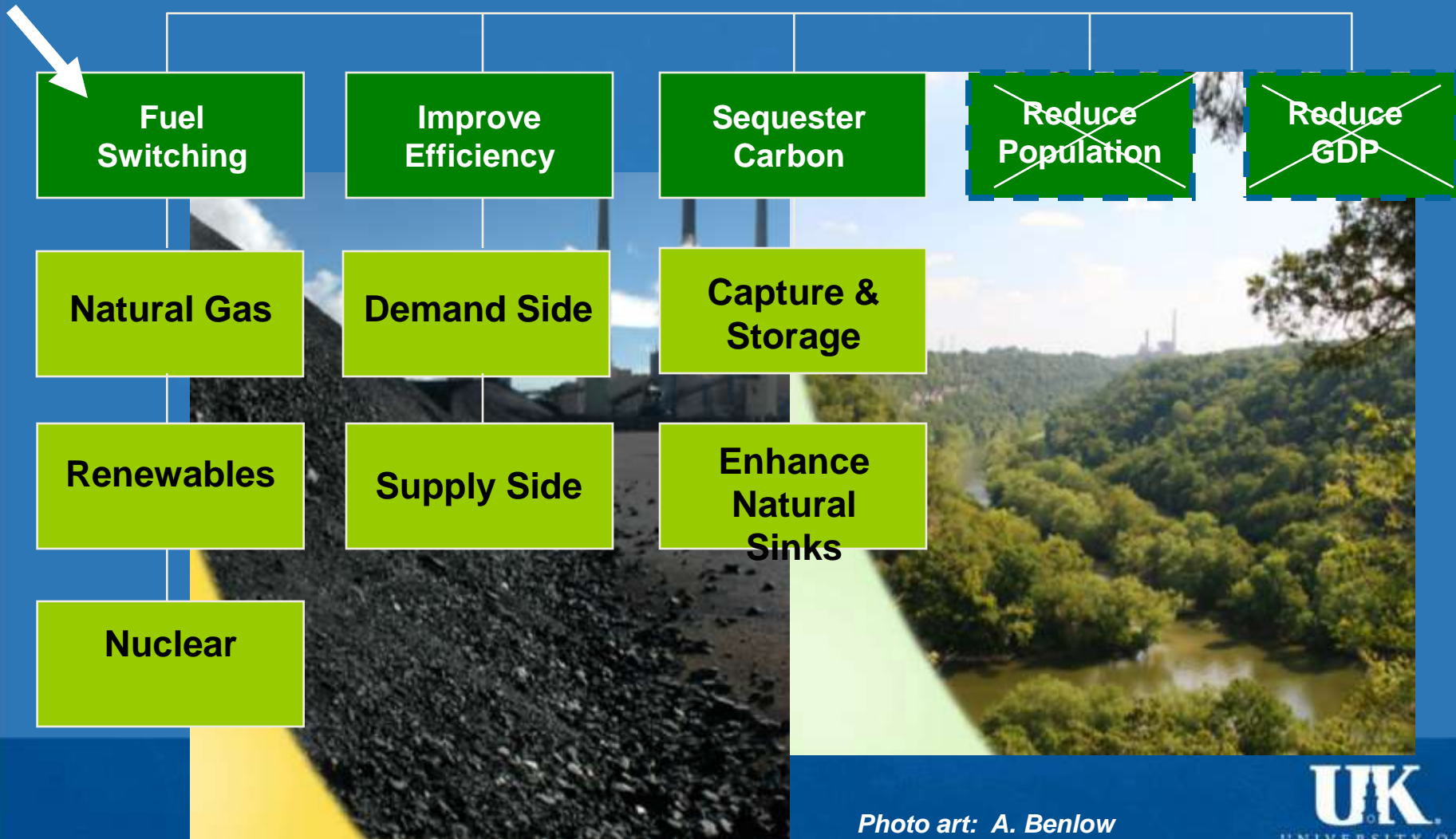
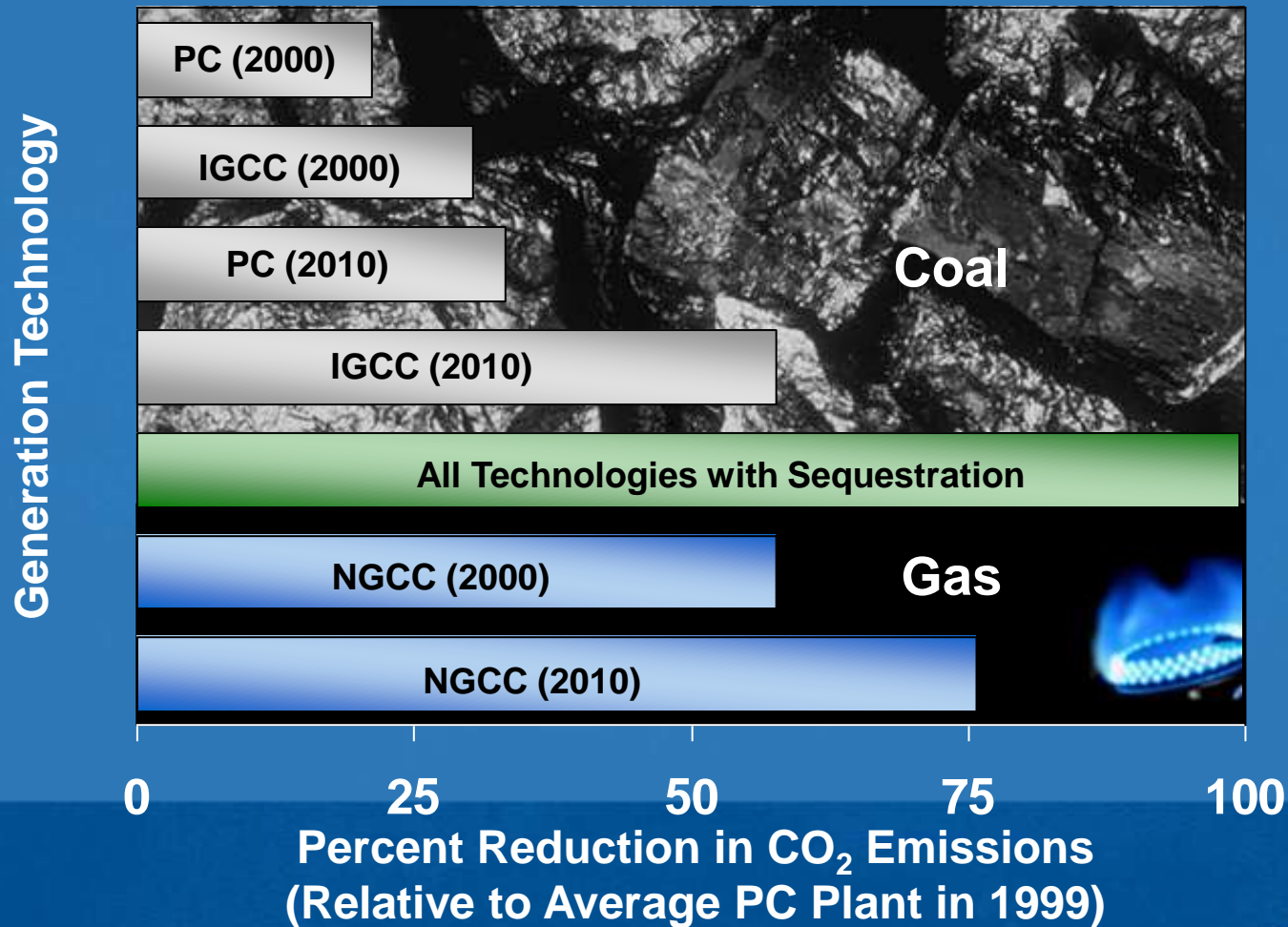


Photo art: A. Benlow

Reductions in Carbon Emissions By Adoption of New Power Generation Technologies



Reductions in Carbon Emissions By Switching to Renewables

Wind, hydro, and
geothermal - Not
enough

Biomass -
Transportation,
land use, expense

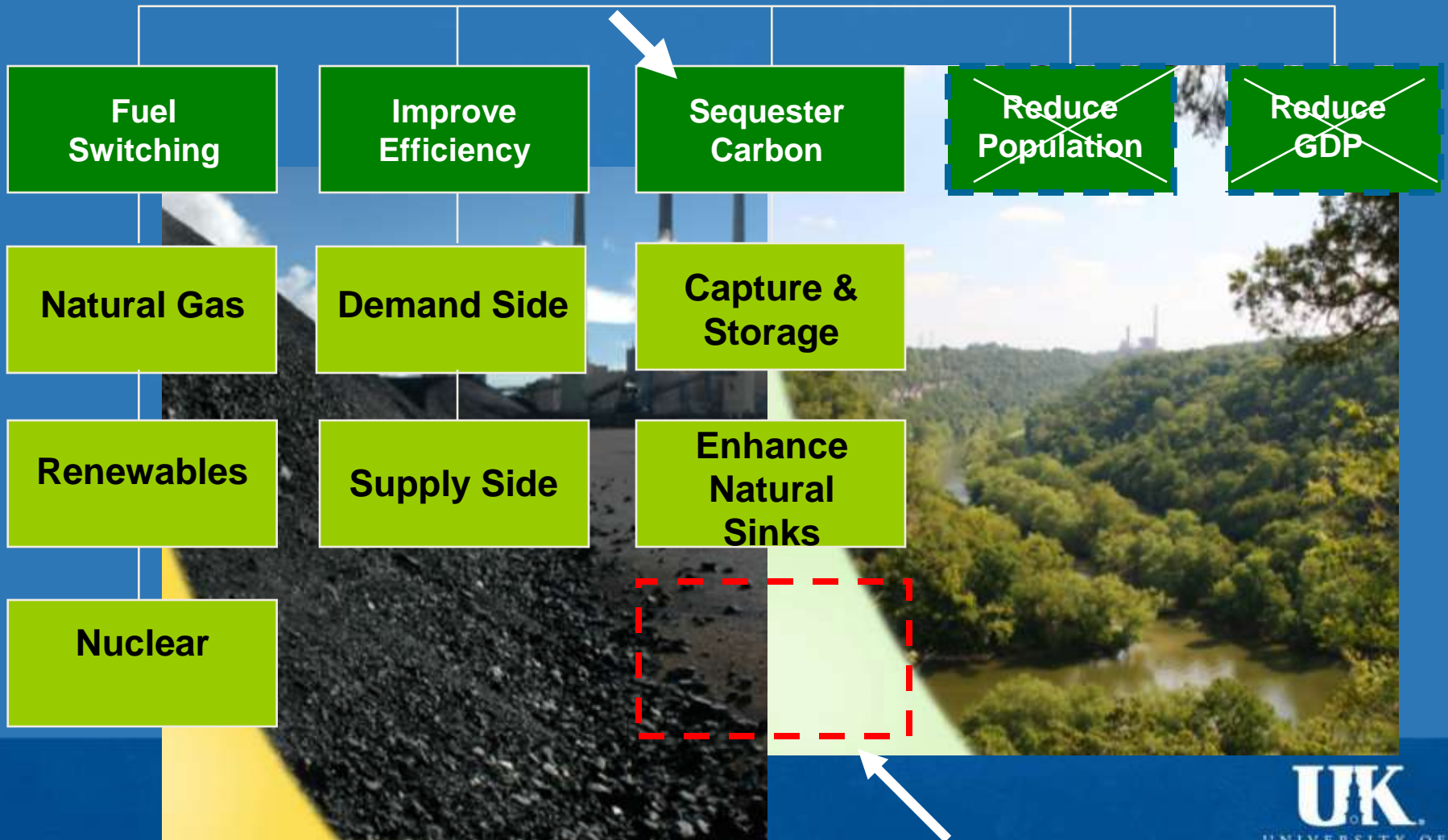
Solar - Land use,
capital cost,
storage



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

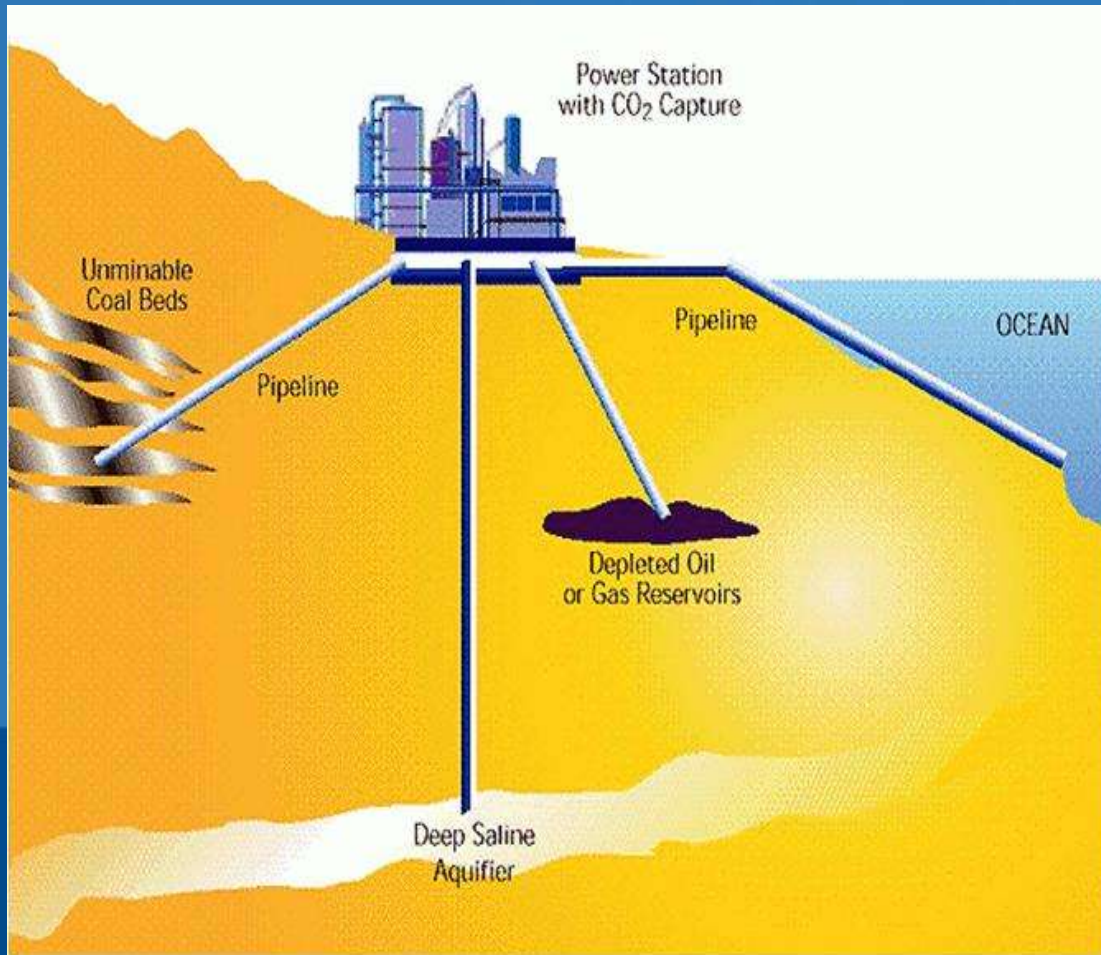
Technology and Innovation

Can Lead to Reductions in Carbon Emissions



Utilization or Conversion???

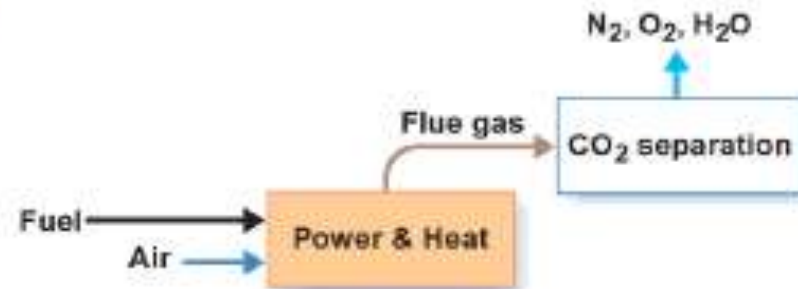
CARBON CAPTURE FROM FOSSIL FUEL POWER PLANTS



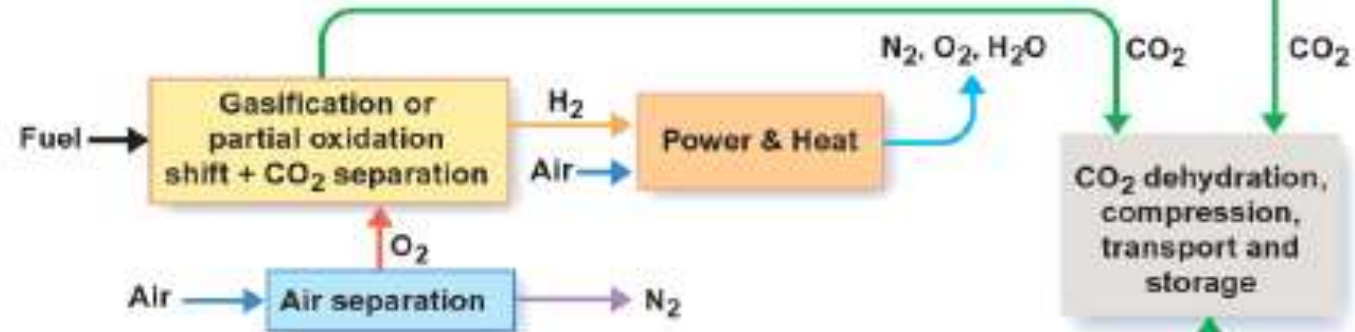
Algae Farm

CO₂ Capture from Electricity Generation

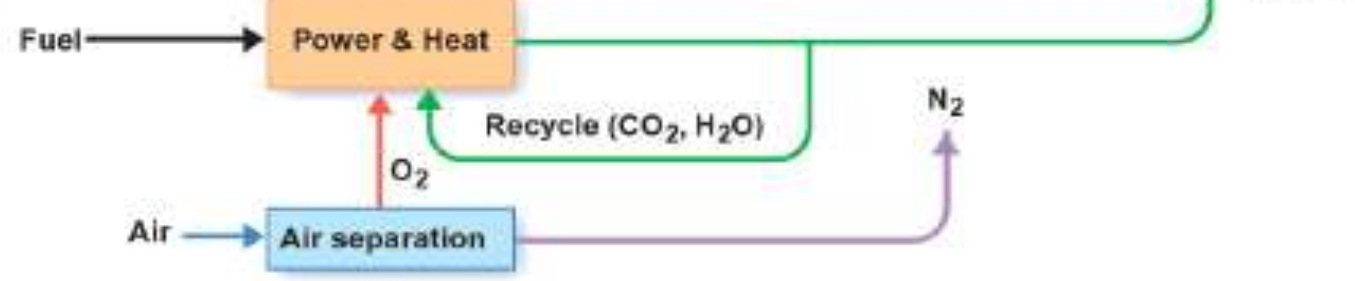
Post-combustion capture



Pre-combustion capture



O₂/CO₂ recycle (oxyfuel) combustion capture



Lowering the Energy Penalty of CO₂ 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 CO₂ 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**

Cost Related to CCS
Capture: 60%
Transport: 20%
Injection & Storage: 20%

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 H₂O/CO ratio
 - Membrane separation
 - Sorbent development
 - Process integration
 - Oxygen production

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)

Current Status of 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 “CO₂ 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

CAER's Post-combustion CO₂ Capture Pilot Plant

- Initiated by EON-US
 - \$1.5 million grant
- 0.1 MW(th) Pilot Scrubber System
 - Largest at a university
- Platform for testing
 - New chemistries
 - New scrubber designs
- Focus on lower energy penalty
 - Estimates of 60% cost increase
 - 1/3 power output of plant



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
- EON US, Duke, AEP/KP, EKPC, EPRI

Expected Output from CMRG

- **Guidelines for technology selection for specific sites**
 - **Technical insight**
 - Current developed by OEM
 - **Solvent/process development**
 - Keep power plant as usual, not a chemical plant conversion
 - **Advance technology for electricity generation**
- **First-hand experience on CO₂ capture**
 - **Workforce training**
 - **Student training**

ALGAE SYSTEMS FOR SCRUBBING COAL-FIRED POWER PLANTS

Center for Applied Energy Research
Biosystems and Agricultural Engineering



Algae for Carbon Capture

- Uses CO₂ as feedstock
 - Improved CO₂ footprint for coal
- Robust and easily produced
- High solar efficiency
- May have a high oil (lipid) content
 - As high as 65% by mass (dry)
 - Converts to biodiesel

FOSSIL GENERATION PLANT WITH BIOREACTOR

The bioreactor contains cyanobacteria (referred to here as algae) that metabolize carbon dioxide to biomass with the help of a slug flow reactor that provides needed ions. Light, which is necessary for the process of photosynthesis, is transmitted through special solar collectors via large core fiber optic cables.

STEAM

Steam produced by the furnace powers high-pressure turbines and generators to produce electricity.



FOSSIL-FIRED FURNACE

Coal is ground into very fine powder, which makes it easier to burn. The heat produced converts water to steam.

ELECTROSTATIC PRECIPITATOR

Metal plate filters "catch" electrically charged fly ash as it passes through.

TRANSLATING SLUG FLOW REACTOR

Gas travels very rapidly through tubes of running water.

TUBES

Gas from the furnace and water from the cooling tower pass through numerous tubes inside the translating slug flow reactor.



1 ANNULAR FLOW

Gas rapidly passes through the tubes, forcing water to the outside of the tubes, forming a ring of water.



2 SLUG FLOW

Water forms slugs due to friction, inclination, and flow properties, creating a turbulent mixing zone that maximizes the absorption of carbon dioxide in water.



COOLING TOWER

Hot water from the slug flow reactor must be cooled to increase the ability of the water to transport bicarbonate.

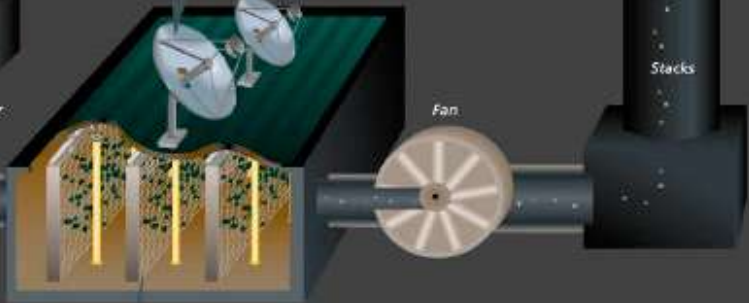


SOLAR COLLECTORS

Special parabolic dishes collect light that is transmitted via fiber optic cables to the bioreactor.

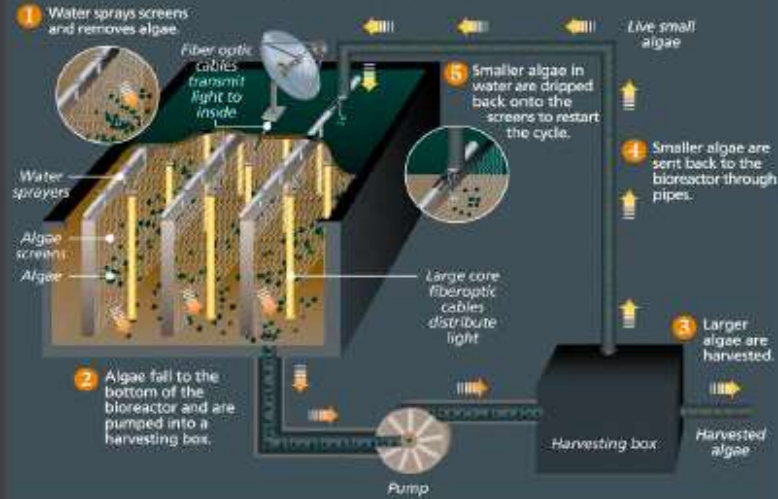


White cloud-like discharge



BIOREACTOR

Algae grow on screens with the assistance of water pipes that spray the screens and large fiberoptic tubes that provide light. The algae grow and are recycled in a continuous process:



Graphic by Christina Ullman

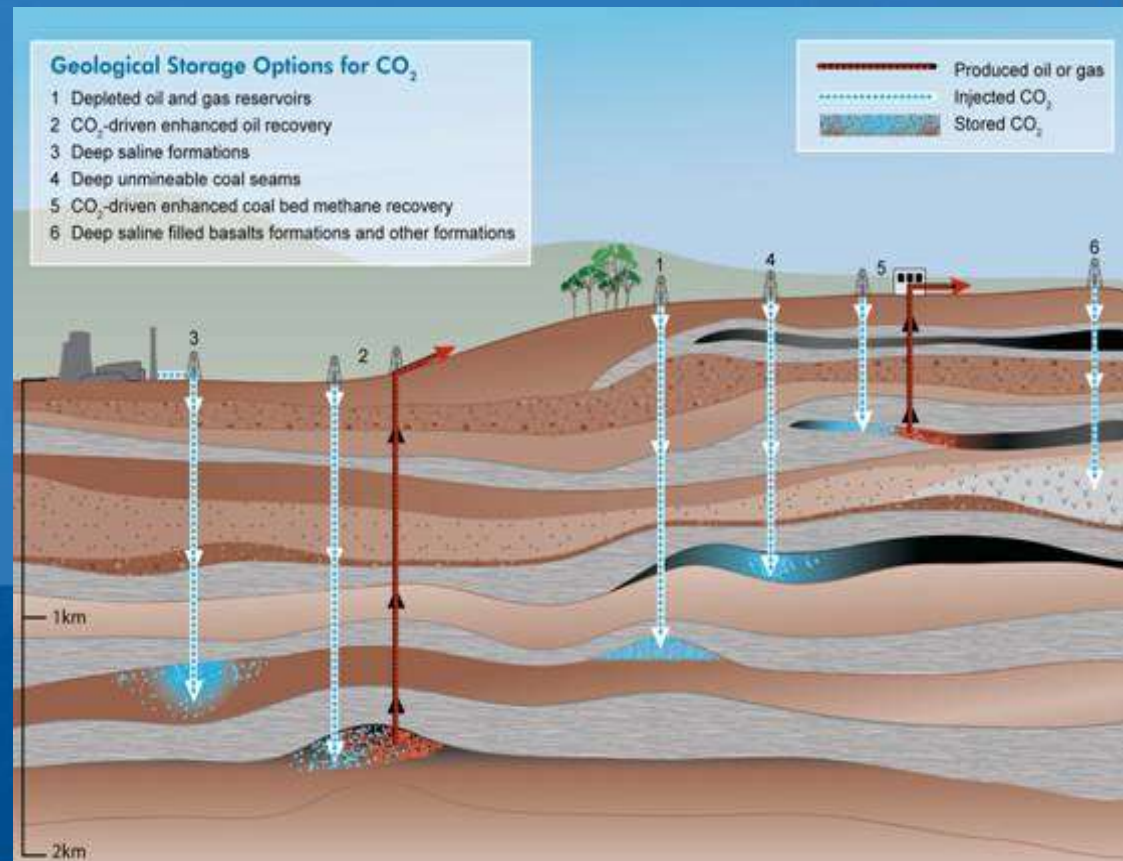
<http://www.ent.ohiou.edu/~ohiocoal/projects/algae.pdf> (Dr. Dave Bayless)

Development of an Algae System for Mitigation of CO₂ from Coal-Fired Power Plants

- KY Department of Energy Development and Independence
 - \$3.5 million / 3 years + industry support
- Focus on coal-fired utilities
 - Avoid energy penalty from chemical capture
- Three phases
 - YR 1: 0.1 MW thermal system
 - YR 2: 1 MWth, modular system for scaling
 - YR 3: 10 MWth demo
- Working with several utilities to host
- Offers alternative to storage alone

CARBON SEQUESTRATION

James C. Cobb & David C. Harris,
Kentucky Geological Survey

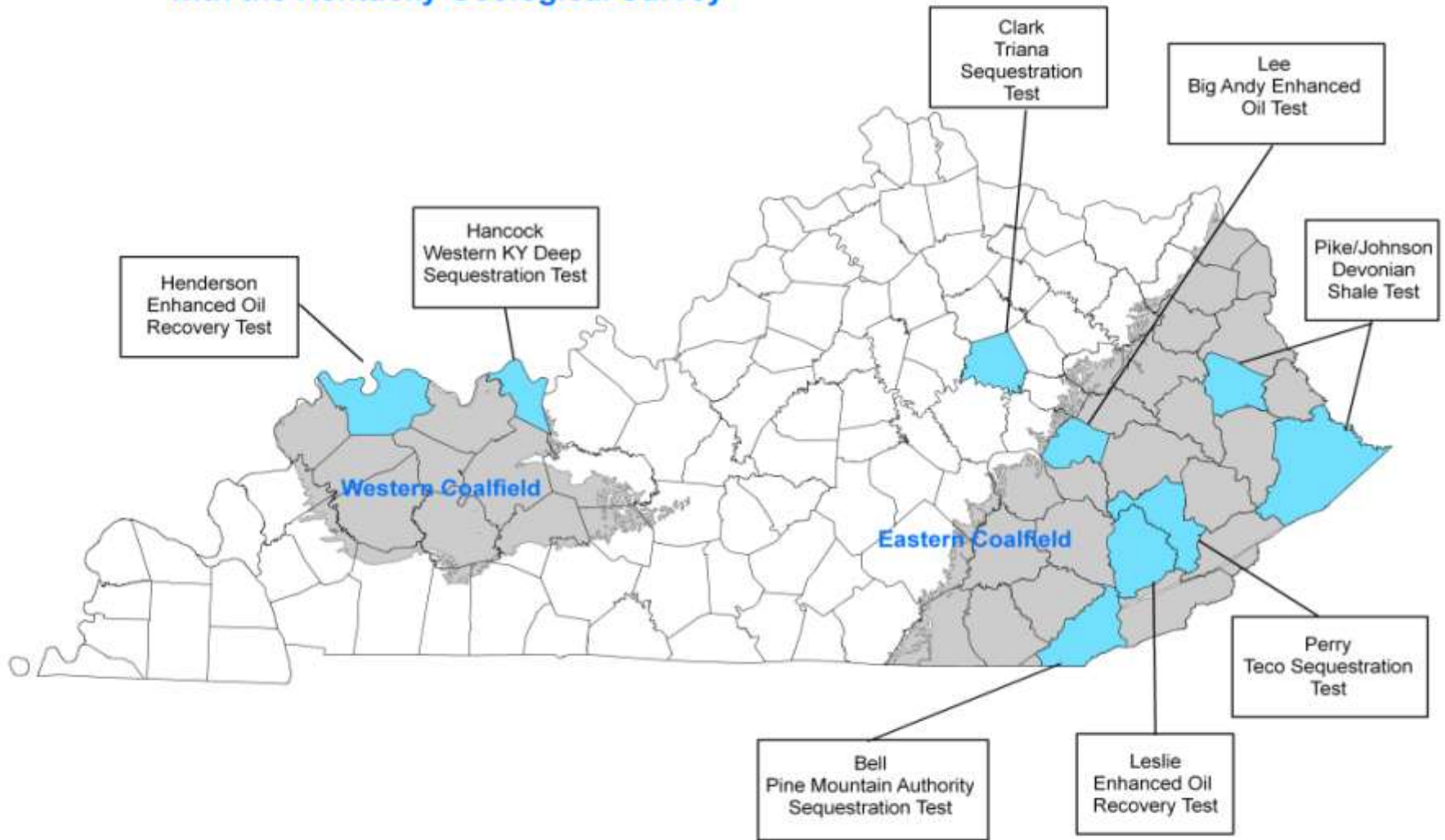


Carbon Sequestration Research

Western KY Seq.	<u>State*</u>	<u>Industry</u>	<u>Other</u>	<u>TOTAL</u>
	\$1.35 M	\$6.0 M	\$0.5 M	\$ 7.85M
Eastern KY Seq.	\$1.35 M	\$1.35 M	\$0.5 M	\$3.2 M
EOR	\$0.85 M	\$0.85 M	\$0.5 M	\$2.20 M
EGR	\$0.85 M	\$0.85 M	\$0.5 M	<u>\$2.20 M</u>
	<u>\$4.90 M</u>			<u>15.45 M</u>

*UK is cost sharing their F & A indirect costs of about \$1.0 million

Kentucky Counties with Active and Proposed HB-1 Projects with the Kentucky Geological Survey



Surface -

1000 -

2000 -

3000 -

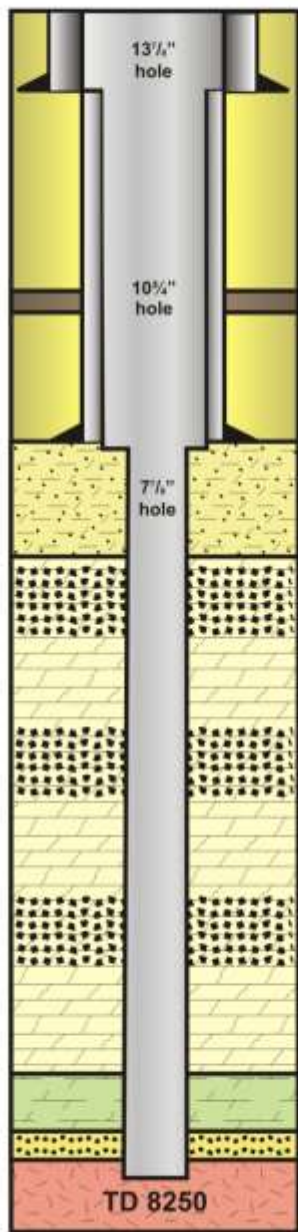
4000 -

5000 -

6000 -

7000 -

8000 -



14 1/2" casing
cemented to surface
at 50 ft in 16" hole

12 1/2" casing
cemented to surface
at 500 ft in 13 7/8" hole

New Albany Shale
Sealing Interval

8 3/8" casing
cemented to surface
at 3000 ft in 10 3/4" hole

Maquoketa Formation
Sealing Interval

Porous Interval

Porous Interval

Knox Dolomite
Test Interval

Porous Interval

Eau Claire Formation
Mt. Simon Sandstone*
Basement Rocks
*If Present

TD 8250

Drilling Program

- Drill to 400 ft and cement casing to protect ground water
- Drill to 3000 ft and cement casing to ensure against any possible leakage to the surface during testing
- Drill to 8250 ft to gather geological, geophysical, and geochemical data to identify and aid the design and evaluation of the intervals to be tested

WHAT DOES THIS MEAN FOR COAL?



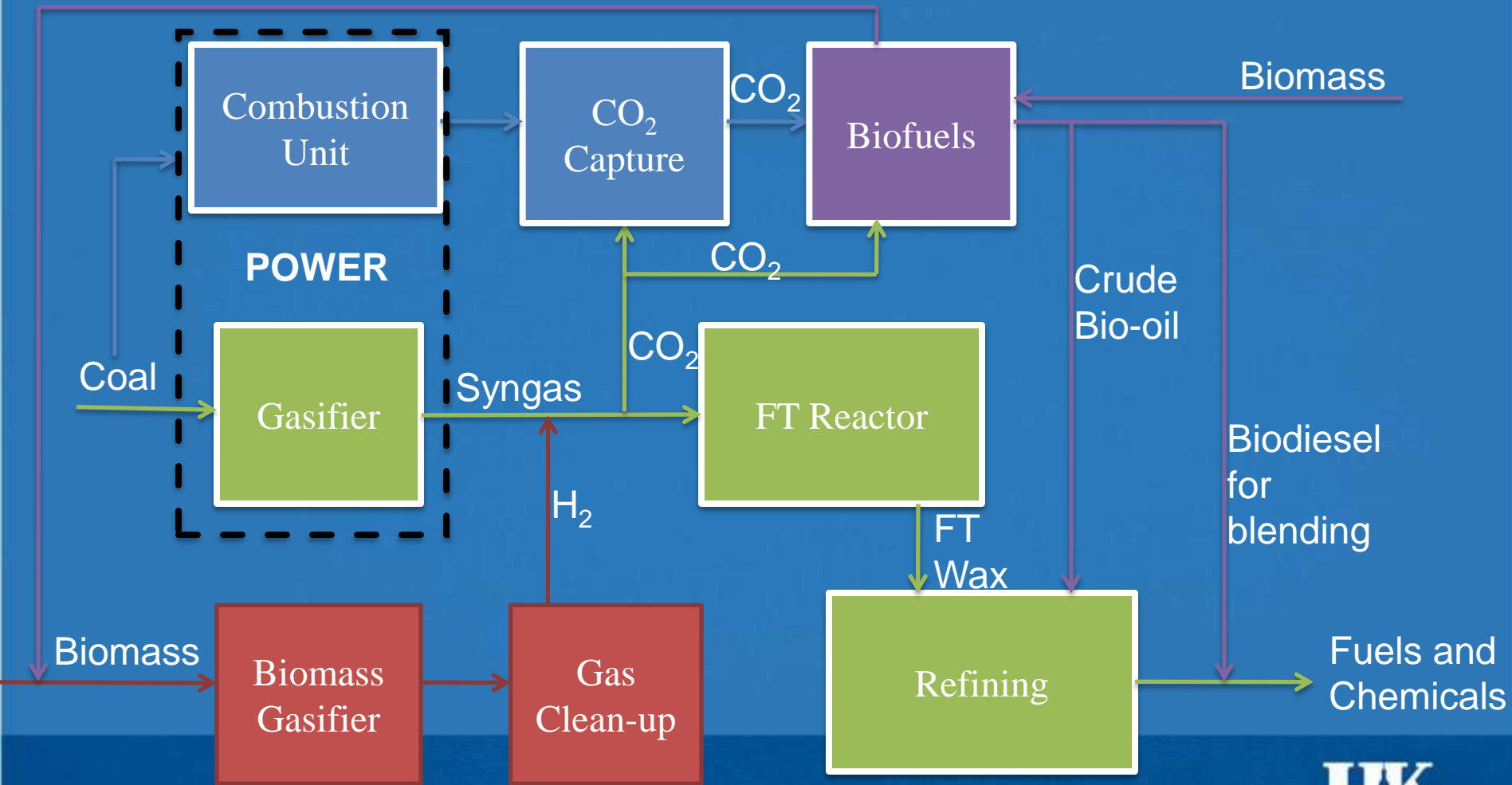
What may happen?

- We pay the penalties
 - 30-40% increase in generation (minimum)
 - 30% more coal mined
 - Delivered cost increases ~60%
- We buy power

What should happen?

- We change our model
 - Base regulation on efficiency
 - Allow “real future cost” in best price option
 - Clean Coal
- We innovate
 - New technologies to deal with carbon
 - Efficiency improvements
 - Renewable and alternative Sources

Integrated Fuels Program



Questions?

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