The Development of Clean Coal Technology in the US

Jhih-Shyang Shih
Fellow
Resources for the Future

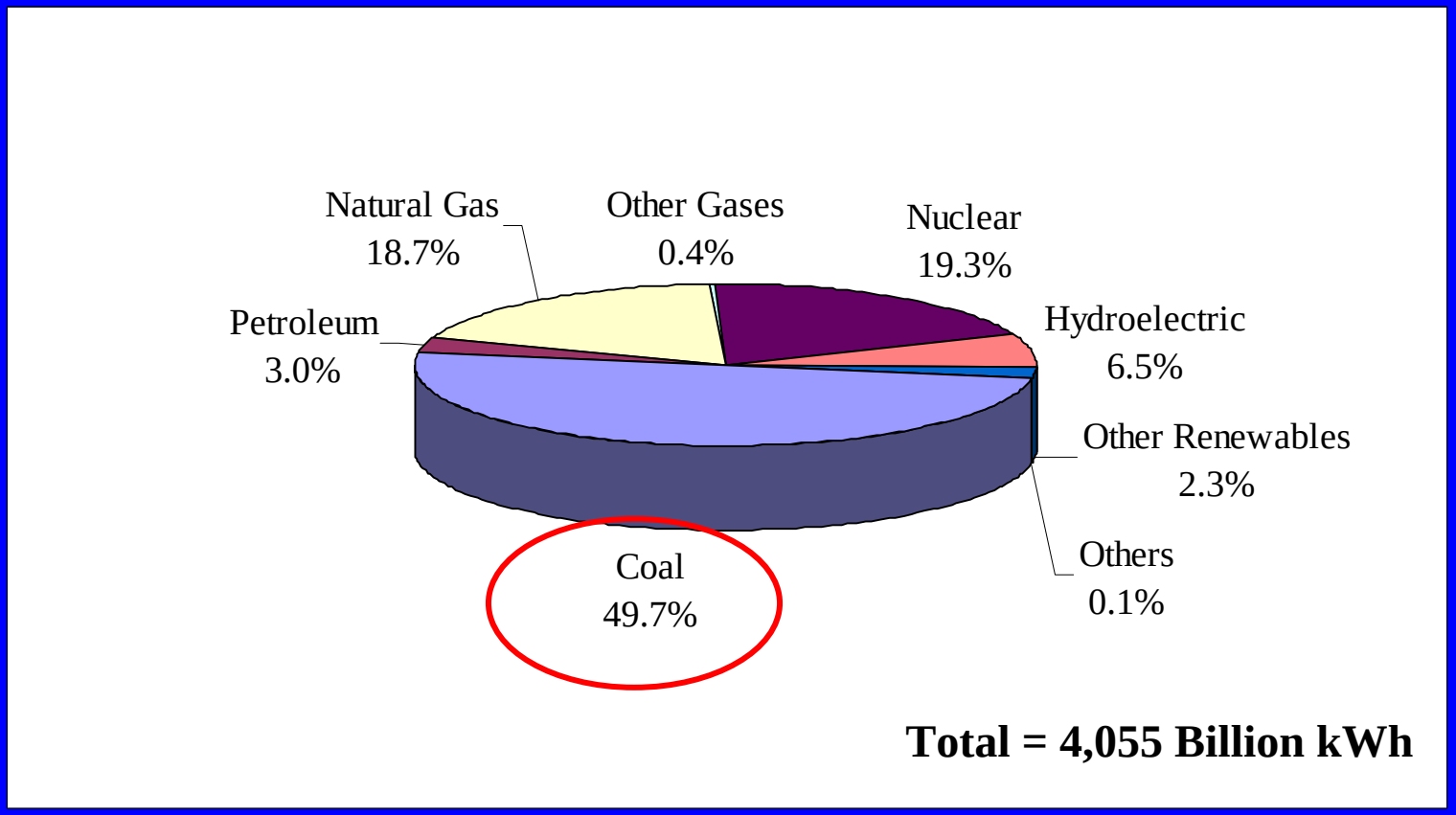
CTCI Foundation Environmental & Energy Convention
Taipei, Taiwan, ROC
January 16, 2007

Overview

- Coal and Electricity
  - Electricity Demand
  - Electricity Supply
- Strategic Drivers for Clean Coal
  - Economics, Energy Security and Environment
- Clean Coal Technology
  - Coal Liquefaction, Combustion Technology, Carbon Capture, and Emission Control Technology
- Cost and Performance Comparison
- Policies/Programs and CCT
- Summary

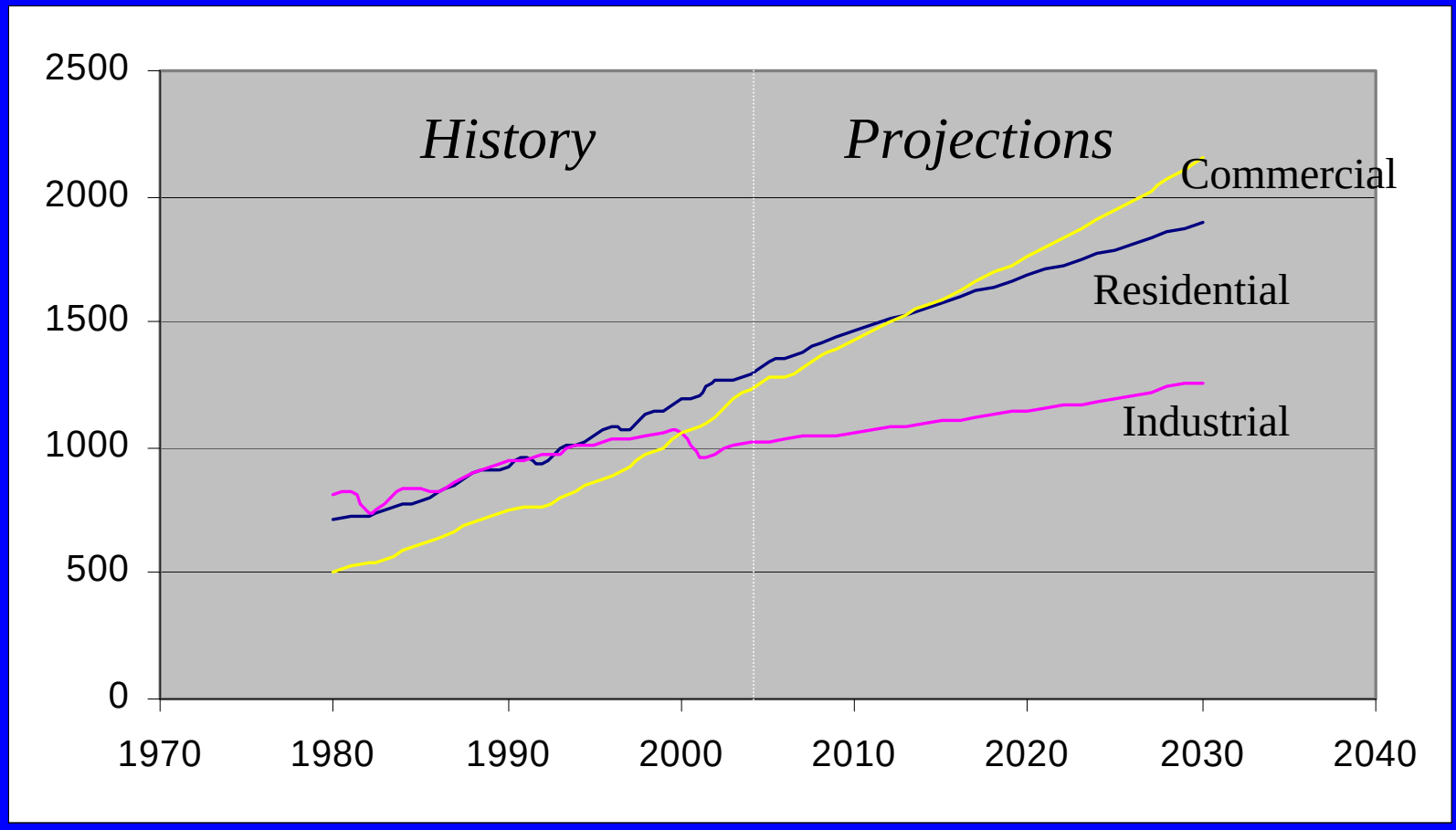
Coal and Electricity

US Electric Power Generation (2005)



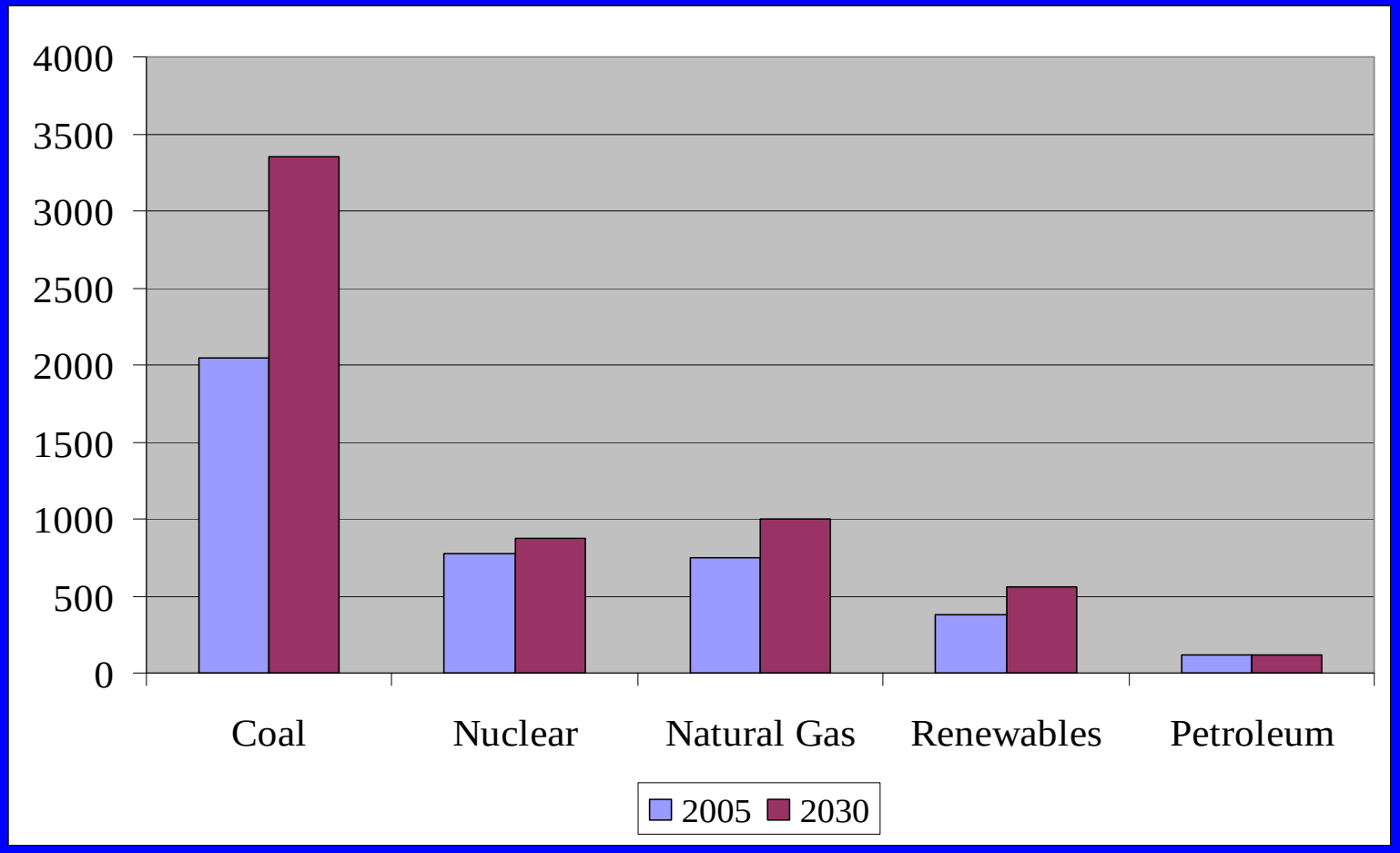
Data Source: EIA, Electric Power Annual

Annual Electricity Sales by Sector (billion kWh)



Data Source: AEO 2006

Electricity Generation by Fuel 2005 and 2030 (billion kWh)



Data Source: AEO 2006

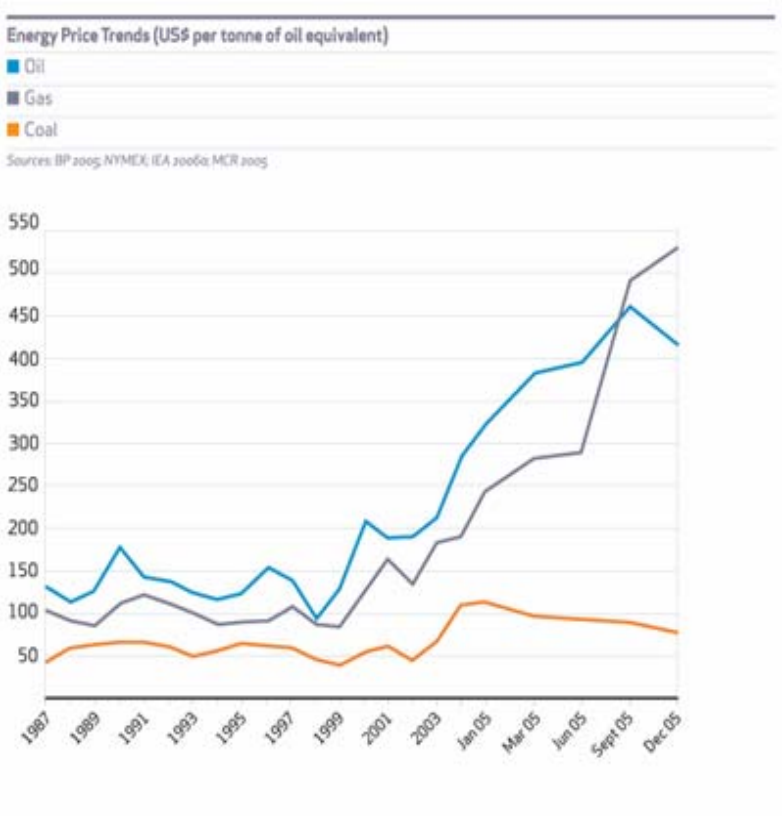
Coal Generation Demand by 2030

- 154 gigawatts of new coal capacity are projected to be needed (EIA).
- 153 new coal-fired plants (93 gigawatts) are under consideration.

Strategic Drivers for Clean Coal

- what are the drivers for coal?
- why do we need clean coal?

Economics: Coal Market and Price



Source: World Coal Institute

- Coal is readily available from a wide variety of sources in a well-supplied worldwide market.
- Coal prices have historically been lower and more stable than oil and gas prices.
- Coal is likely to remain the most affordable fuel for power generation in many developing and industrialized countries for several decades.

Energy Security: Coal Reserve

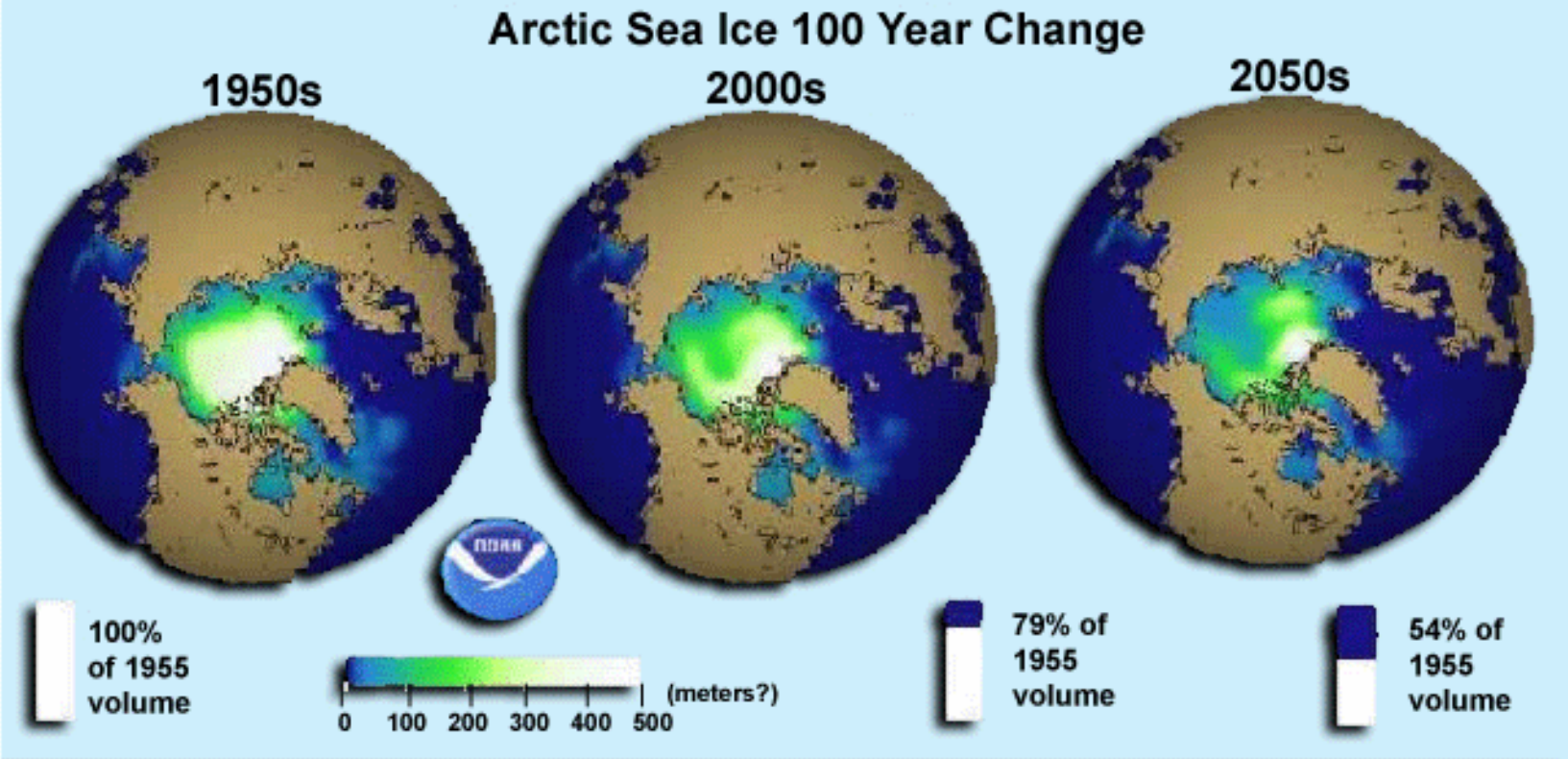
Source: World Coal Institute

- Total recoverable reserves of coal around the world are estimated at 1,001 billion tons—enough to last approximately 180 years (compared to 41 years for oil and 65 years for gas).
- 67 percent of the world's recoverable reserves are located in four countries: the United States (27 percent), Russia (17 percent), China (13 percent), and India (10 percent).

Environment

- **Coal Use & the Environment**
  - Coal is the major emitter of CO2, a greenhouse gas.
  - Coal is also an emitter of particulate matters, SOx and NOx, and mercury.
- **Coal Mining & the Environment**
  - land disturbance, mine subsidence, acid mine drainage, dust & noise pollution.
  - Rehabilitation.

Global Warming



This chart compares the actual loss of Arctic Ice Cap volume between the 1950s and 2000, and the projected loss by 2050. The more ice that is lost, the faster the ice cap shrinks due to the loss of albedo, the amount of light energy that is normally reflected back out into space by the ice cap. (Image: NOAA)

Challenges of Power Generation Using Coal

The electricity is a major contributor to economic and social development. However, electricity generation using coal faces many challenges in this century:

- To continue to supply secure and affordable electricity in the face of growing demand.

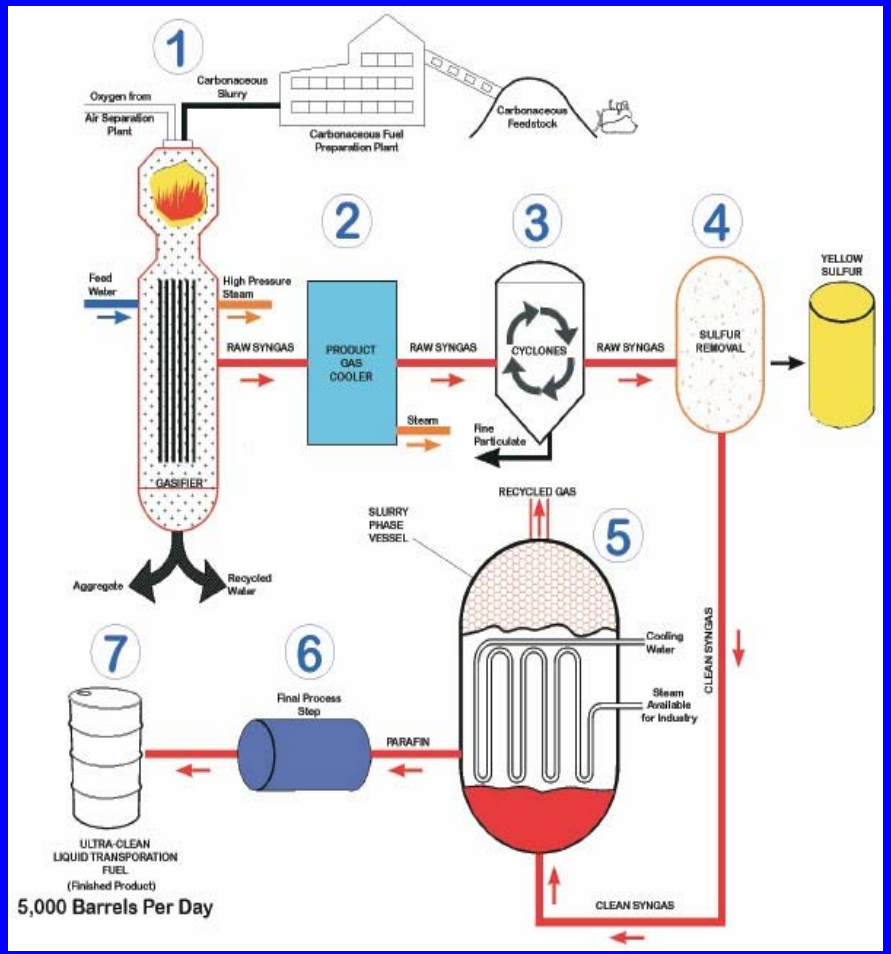
- To provide more efficient energy, reducing pollution, and increasing the emphasis on environmental sustainability.

Clean Coal Technology

Clean Coal Technology

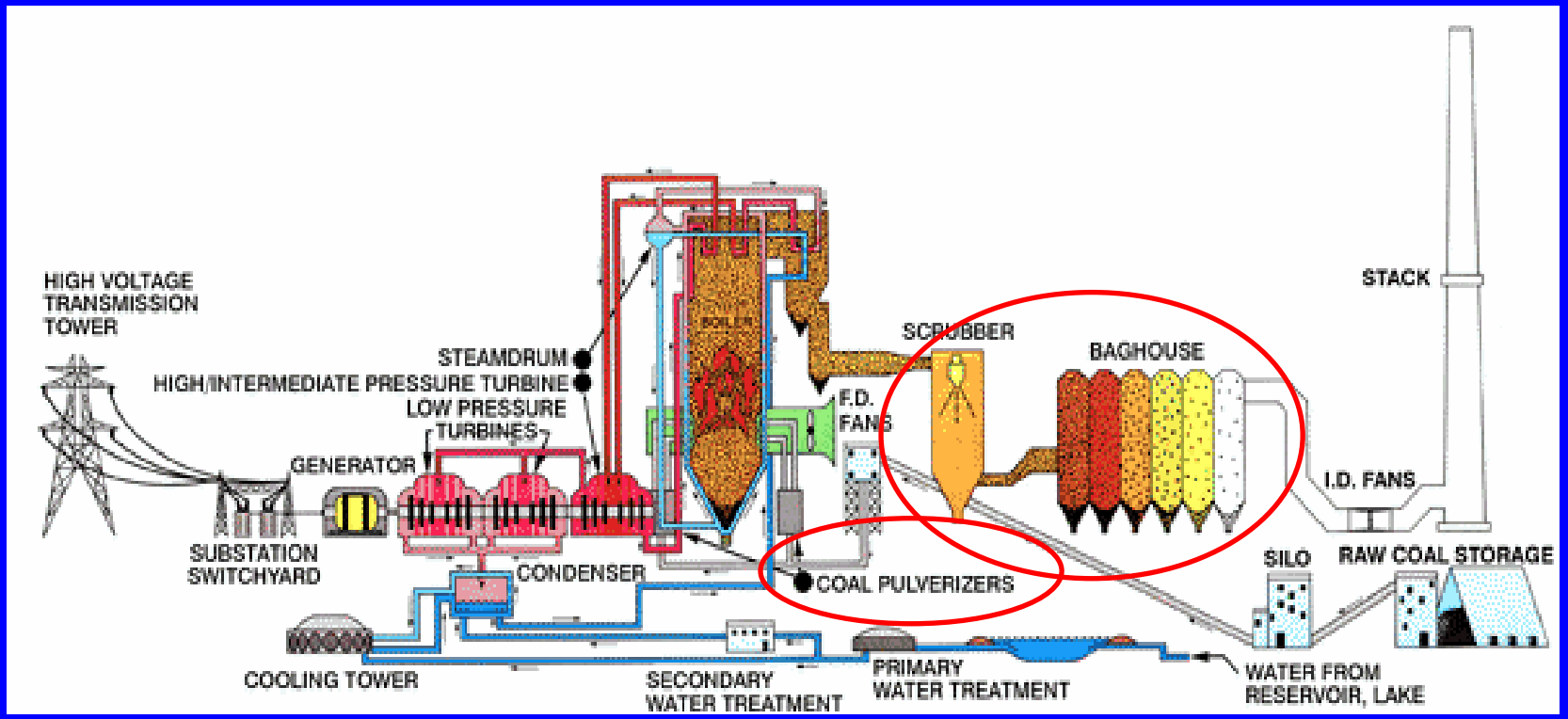
- Coal Liquefaction
  - Coal to Liquid (CTL)
- Combustion Technology
  - Pulverized Coal (PC) combustion
  - Advanced PC technology
    - Supercritical PC (SCPC) combustion
    - Ultra-supercritical PC (USCPC) combustion
  - Fluidized Bed Combustion (FBC)
  - Integrated Gasification Combined Cycle (IGCC)
- Carbon Capture
- Emissions Control Technology

Coal Liquefaction



- Coal liquefaction is the conversion of coal into a synthetic oil in order to supplement natural sources of petroleum.
- Coal liquefaction and heavy oil refining were potentially the two largest sources of transportation fuels that could be used to mitigate the peaking of conventional oil.

Pulverized Coal (PC) Combustion



Source: IEA

Coal-fired electricity generation today normally uses conventional subcritical pulverized coal (PC) combustion.

Advanced PC Combustion Technology

- Two types: supercritical (SC) & ultra-supercritical (USC)
- Power plants operate at high temperatures and pressures. This results in higher efficiencies – up to 46% for supercritical and 50% for ultra-supercritical
- Lower coal consumption and pollutant emissions than conventional PC plant
- Advancements in materials, controls and temperature mixing led to improved performance and reliability

Pulverized Coal Technology

	Conditions	Net Energy Efficiency	Heatrate HHV
Subcritical	2,400 psig	35%	9,751 Btu/kWh
Supercritical	3,500 psig	37%	9,300 Btu/kWh
Ultra-Supercritical	5,500 psig	44%	7,757 Btu/kWh

Source: Supercritical Plant Overview

Subcritical vs. Supercritical

	Subcritical	Supercritical
Heatrate Efficiency	34-37% HHV	36-44% HHV
Boiler Capital Cost	Base	0-9% Higher
Plant Capital Cost	Base	1-6% Higher
Non-Fuel O&M	Base	0-2% Higher
Fuel Cost	Base	Lower
US Operating Units	1,338 Units	117 Units

Source: Supercritical Plant Overview

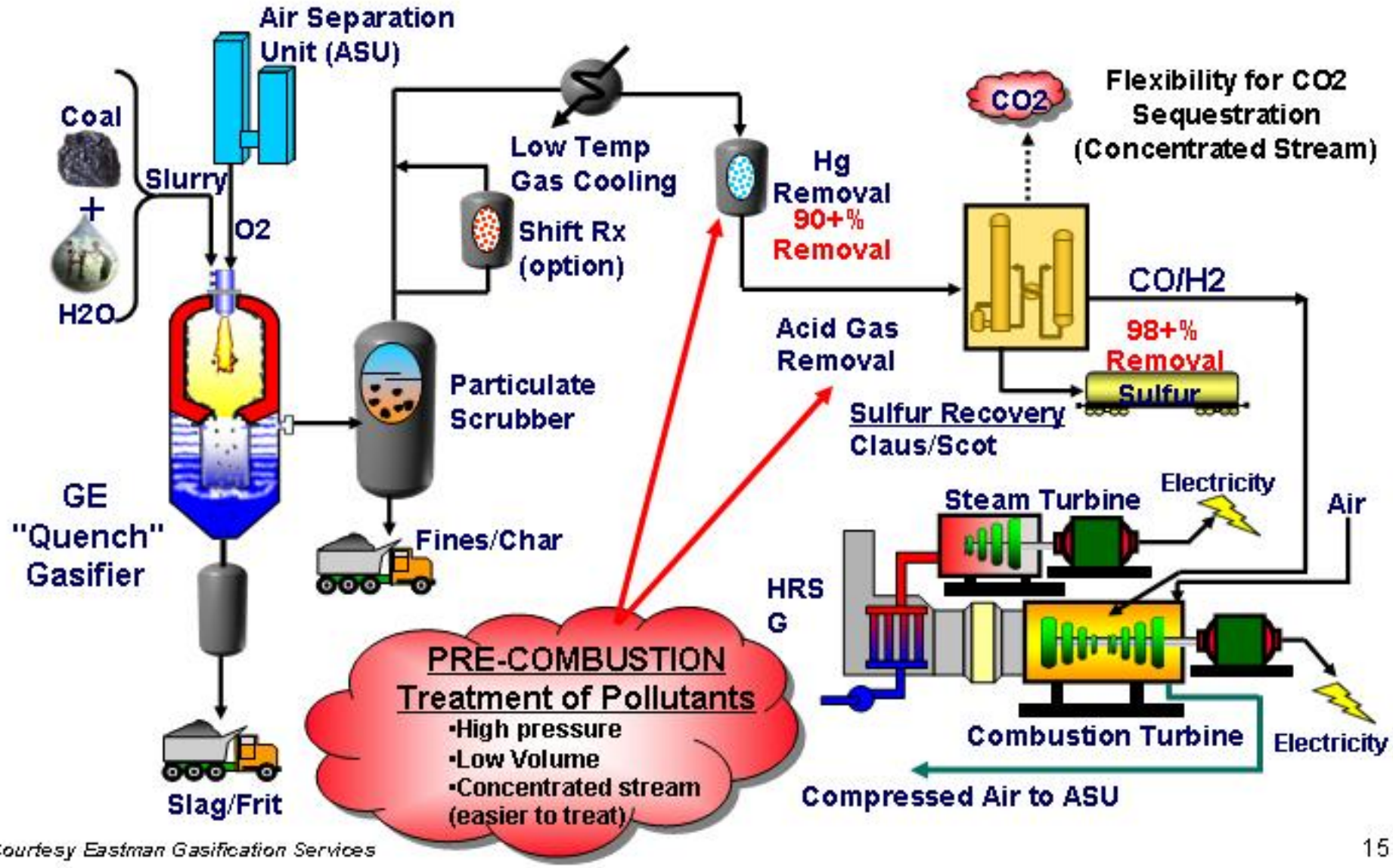
Fluidized-Bed Combustion (FBC)

- Fluidized beds suspend solid fuels on upward-blowing jets of air during the combustion process.
- The technology burns fuel at temperatures of 1,400 to 1,700 degrees F, well below the threshold where nitrogen oxides form.
- Limestone can be added to control sulfur with 95% removal rate.
- Greater fuel flexibility.
- Currently, 104 Boilers-8,900 MW in operation and up to 320 MW size range offered.

Integrated Gasification Combined Cycle (IGCC)

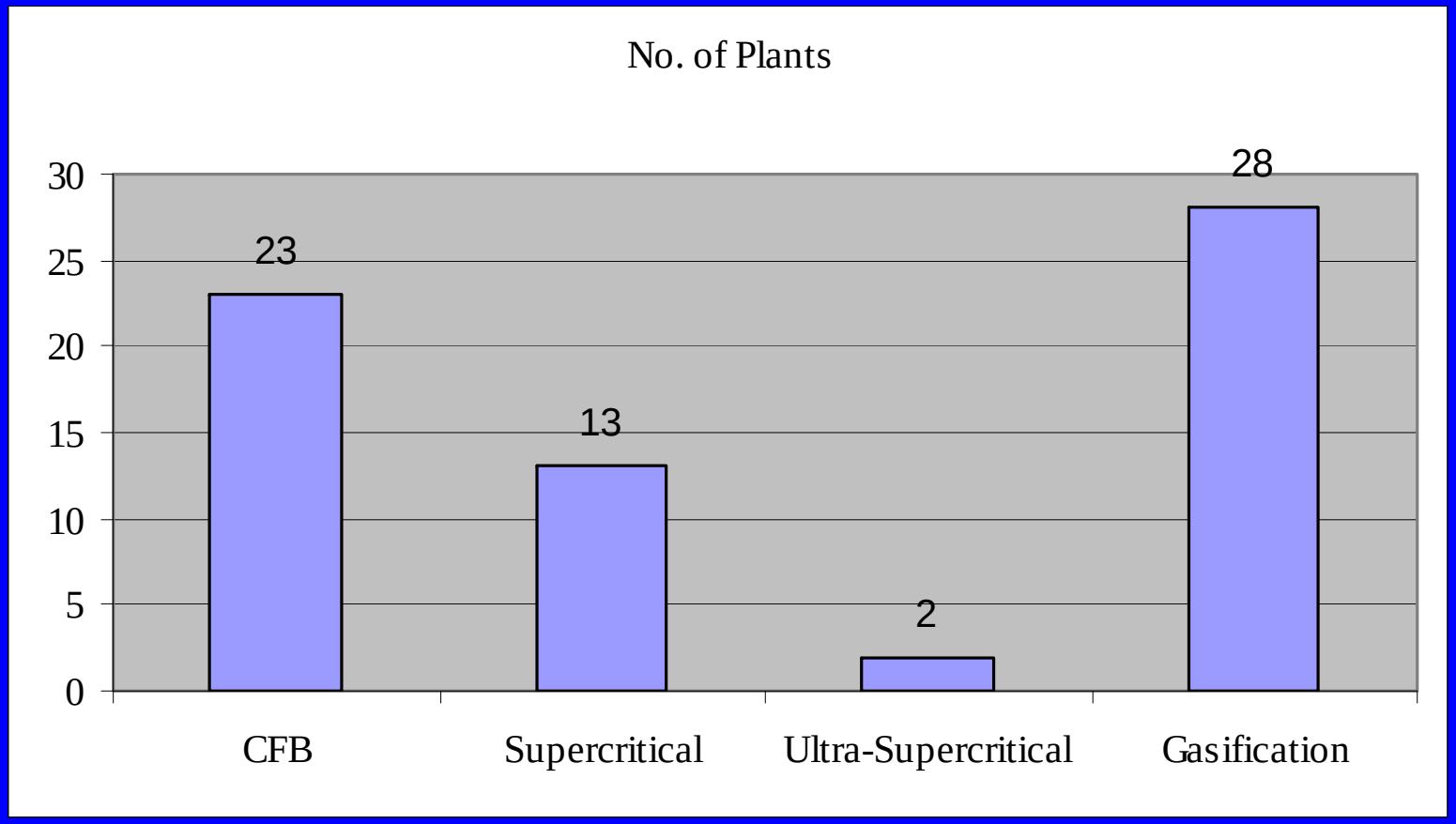
- Coal and other hydrocarbons have been gasified for the production of chemicals, fertilizers, and synthetic fuels for more than half a century.
- 117 plants with 385 gasifiers in operation in 2004. These facilities produce mostly chemicals (37%), gas (36%) or power (19%).
- Current IGCC power technology applications focus on producing CO rich syngas that can be burned in turbines.
- Future IGCC technologies maybe developed to produce hydrogen rich syngas with maximum carbon capture (“zero emission” IGCC).

IGCC Overview



Courtesy Eastman Gasification Services

Planned Coal-Fired Power Plants as of 2006



Data Source: NETL

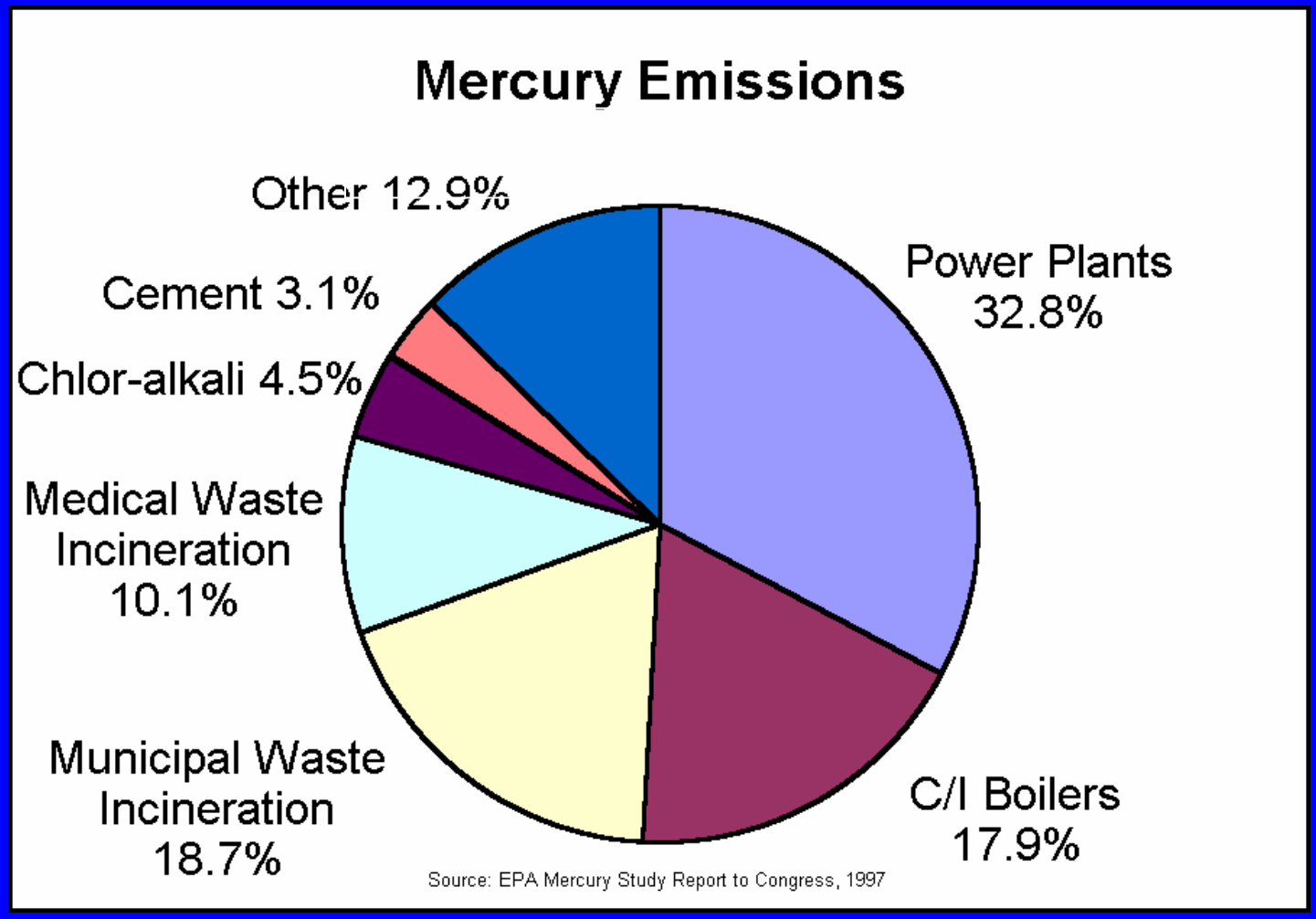
Carbon Capture

- There are a number of options for the capture of CO_2:
  - ***Post-combustion***: CO_2 is captured from the flue gas at atmospheric pressure and at low concentration.
  - ***Pre-combustion***: CO_2 can be captured from a syngas (coming out of the coal gasification reactor) before it is mixed with air in a combustion turbine.

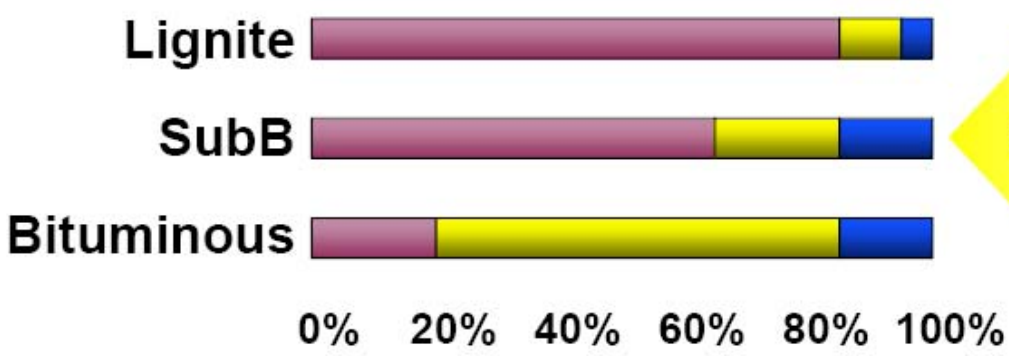
Emissions Control Technology

- In the last three decades, control technologies have been developed to capture conventional pollutants contained in the exhaust systems from coal combustion.
- Pollutants that can be removed include sulfur oxides, nitrogen oxides, and particulates.
- Mercury has been regulated since March 15, 2005.
- The technologies that can be utilized to remove these pollutants are:
  - Sulfur Oxides: Wet and Dry Flue Gas Desulfurization Plant
  - Nitrogen Oxides: Low NOx burners, Post Combustion Catalytic Reduction Systems
  - Particulates: Electrostatic Precipitator, Fabric Filters
  - Mercury: Activated Carbon Injection Systems

Mercury Emissions



Hg Speciation by Coal Rank



% Hg Species in Flue Gas

- Elemental Hg
- Oxidized Hg
- Particulate Hg

Other Influences

- Time
- Temperature
- Gas composition
- Catalysts

NETL

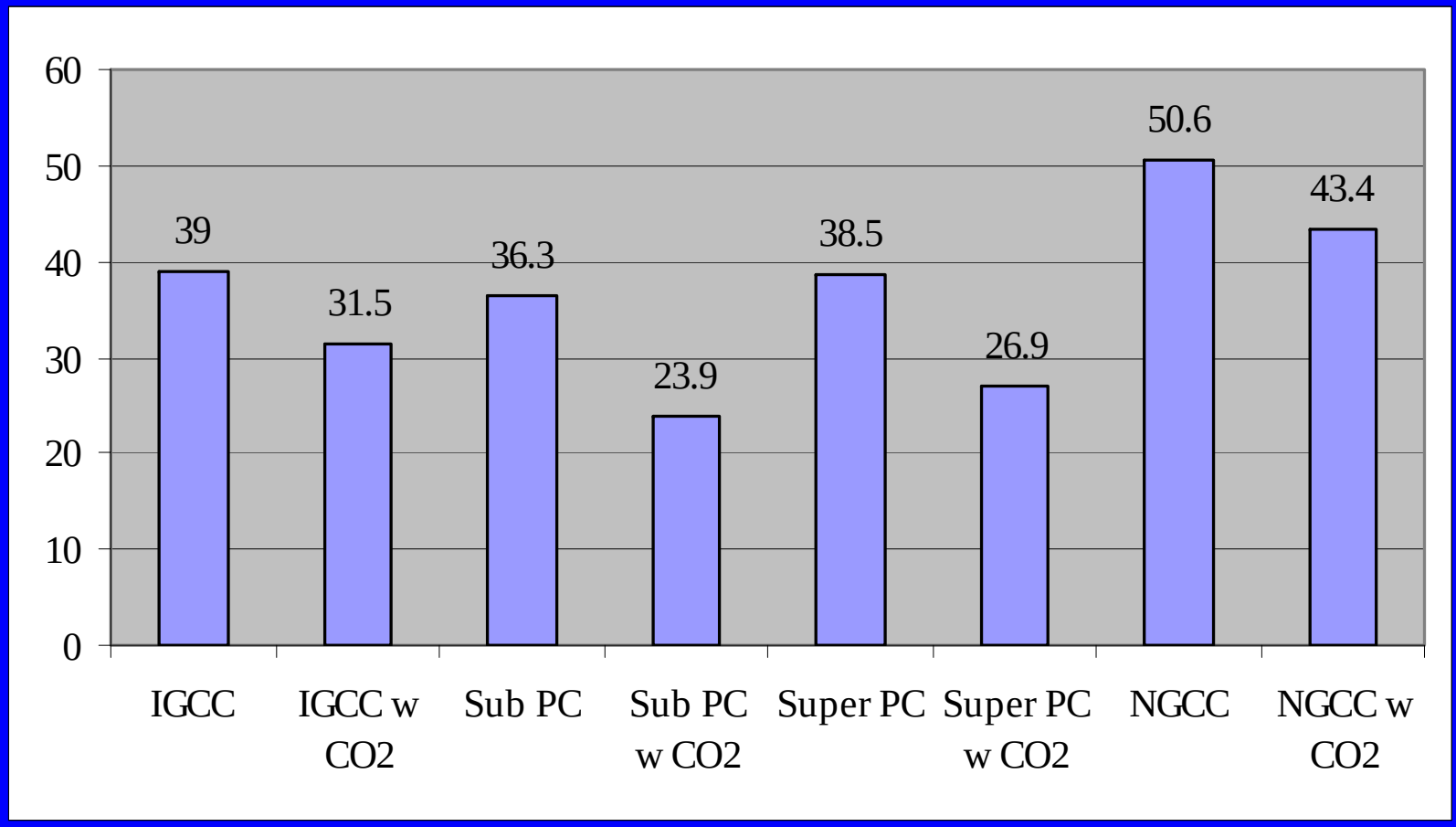
T. Feeley Nov. 2005

Mercury Control

- Oxidized mercury: water soluble, high removal with FGD
- Elemental mercury: non-water soluble, can be removed by activated carbon injection
- Particulate mercury: can be removed by existing particulate controls

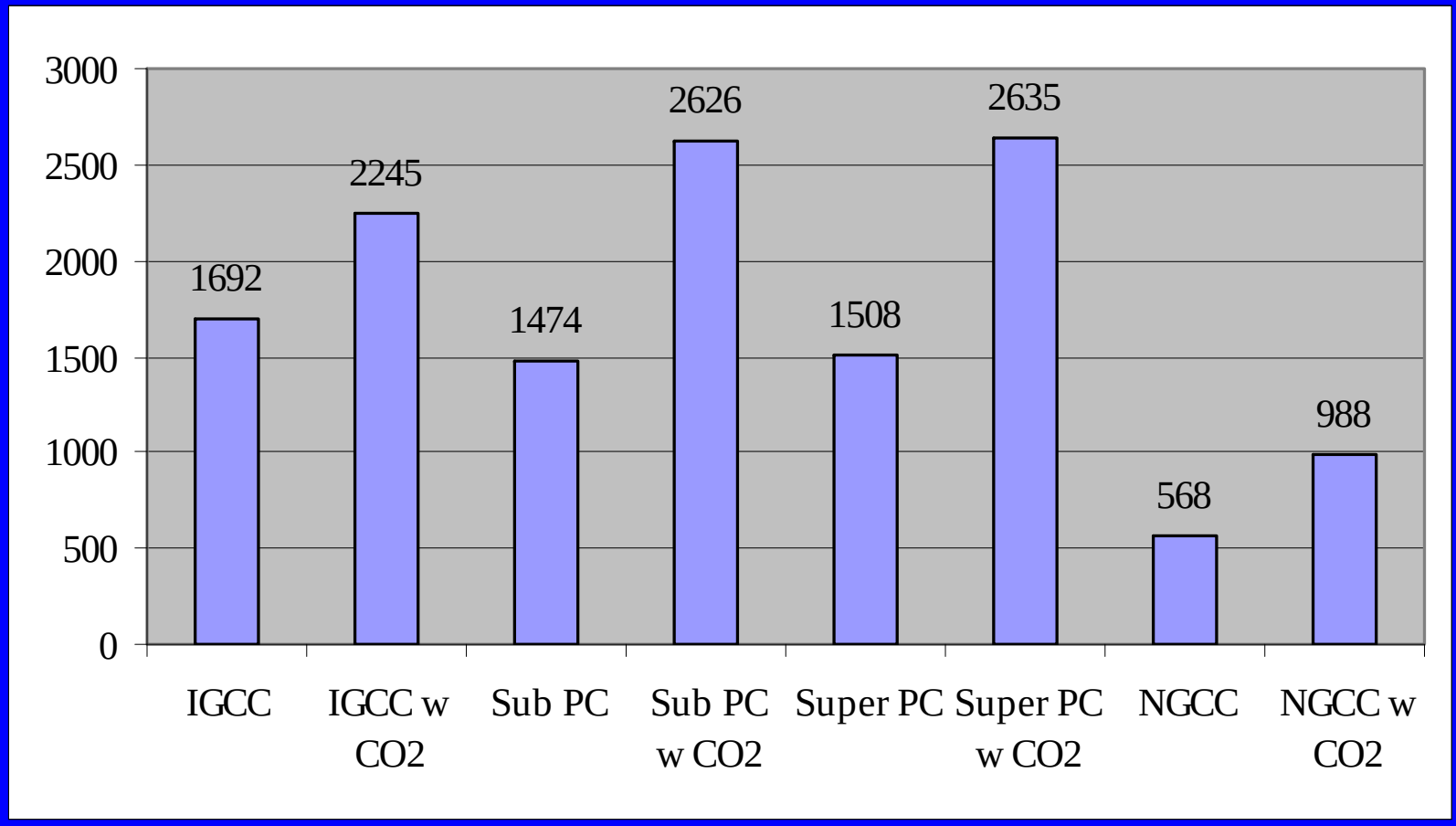
Performance and Cost

HHV Efficiency (%)



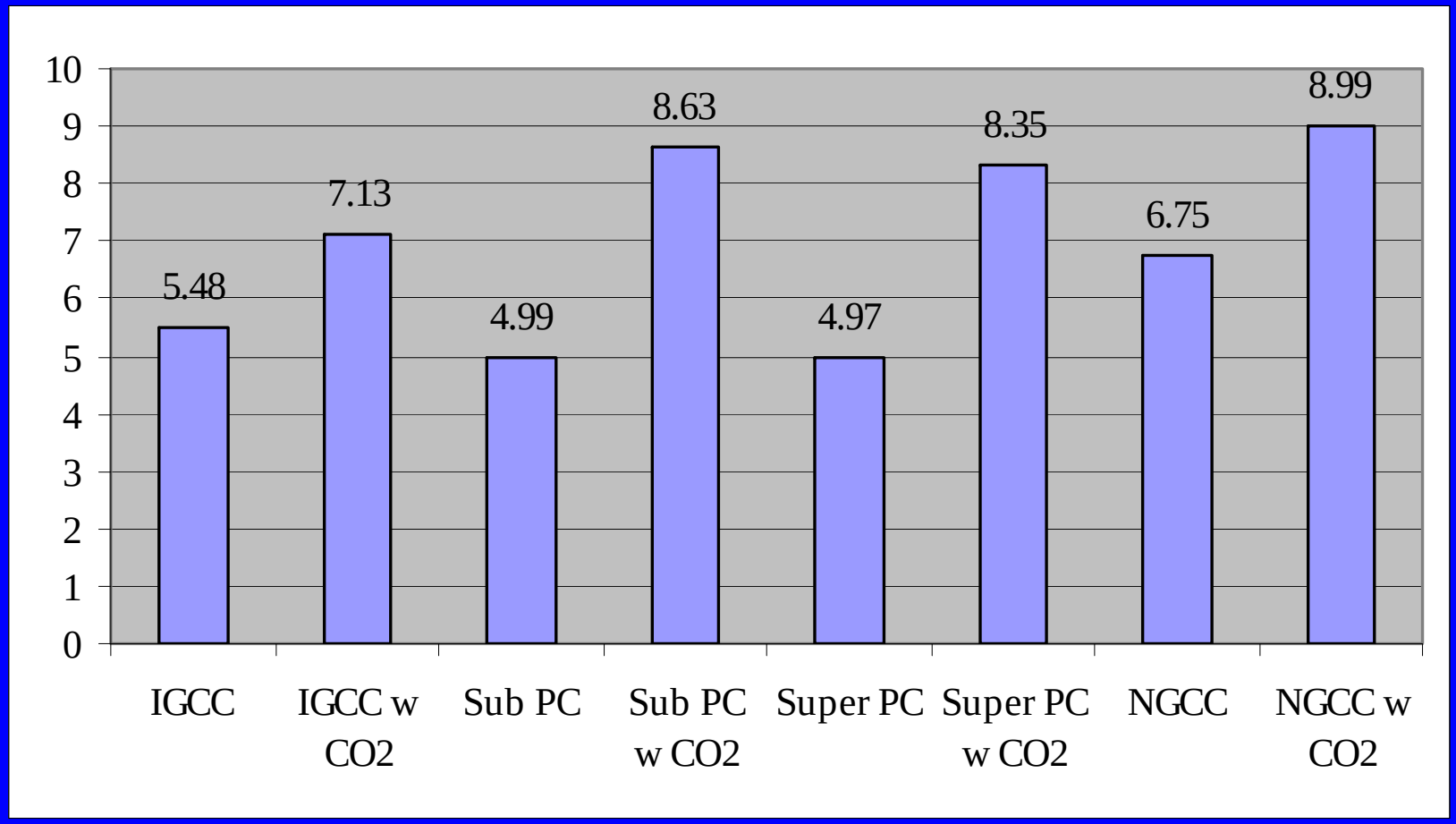
Source: NETL

Total Capital Requirement ($/kW, 2006 dollars)



Source: NETL

Cost of Electricity (cents/kWh, 2006 dollars)



Source: NETL

Performance and Cost of Hg Emissions Control

- Mercury removal performance has been observed to vary between 70% and 98% using sorbent technology.
- The range of sorbent consumption costs is quite large, depending on the combustion technology.
- According to an NETL report, the estimated cost of mercury removal from an IGCC plant was $3,412 per pound of mercury, compare to $37,800 per pound of mercury removal from a PC plant.

Policies/Programs and CCT

Relevant Policies

- Energy Policy Act of 2005
  - Provide many incentives: authorization, tax incentives and loan guarantees. The Energy Policy Act of 2005 (EPAct) authorized the Department of Treasury to provide tax credits as incentives to move advanced technologies to the marketplace. EPAct focuses on clean energy, efficient energy use, energy conservation, and advanced technologies.
  - Energy and Treasury Secretaries announce the award of $1 billion in Tax Credits to Promote Clean Coal Power Generation (11/30/2006).

Relevant Policies

- Clean Air Act
  - **Clean Air Mercury Rule (CAMR) –**It is a mercury cap-and-trade program affecting new and existing coal fired units greater than 25 MW. Phase I starts in 2010 and has a national cap of 38 TPY; Phase II starts in 2018 and has a national cap of 15 TPY. Electricity generators are expected to retrofit coal-fired capacity with ACI technology in order to comply with the CAMR caps.
  - **Clean Air Interstate Rule (CAIR) –**It contains an annual SO2 cap-and-trade program, as well as an annual and Ozone Season NOx cap-and-trade program, for the DC and 28 eastern and midwestern states. Power companies are projected to add FGD and SCR to comply with State and Federal initiatives

Relevant Policies

- Climate Change
  - **Regional Greenhouse Gas Initiative** (**RGGI**) is a regional initiative by states in the Northeastern United States region to reduce greenhouse gas emissions.
  - The RGGI is designing a cap and trade program for emissions from power plants.
  - In August 2005, the RGGI staff working group proposed an emissions reduction program that would start in 2009 and lead to a stabilization of emissions at an average of 2002-2004 levels by 2015.
  - California Governor's Executive Order # S-3-05 (June 1, 2005) and AB 32, the California Global Warming Solutions Act of 2006.

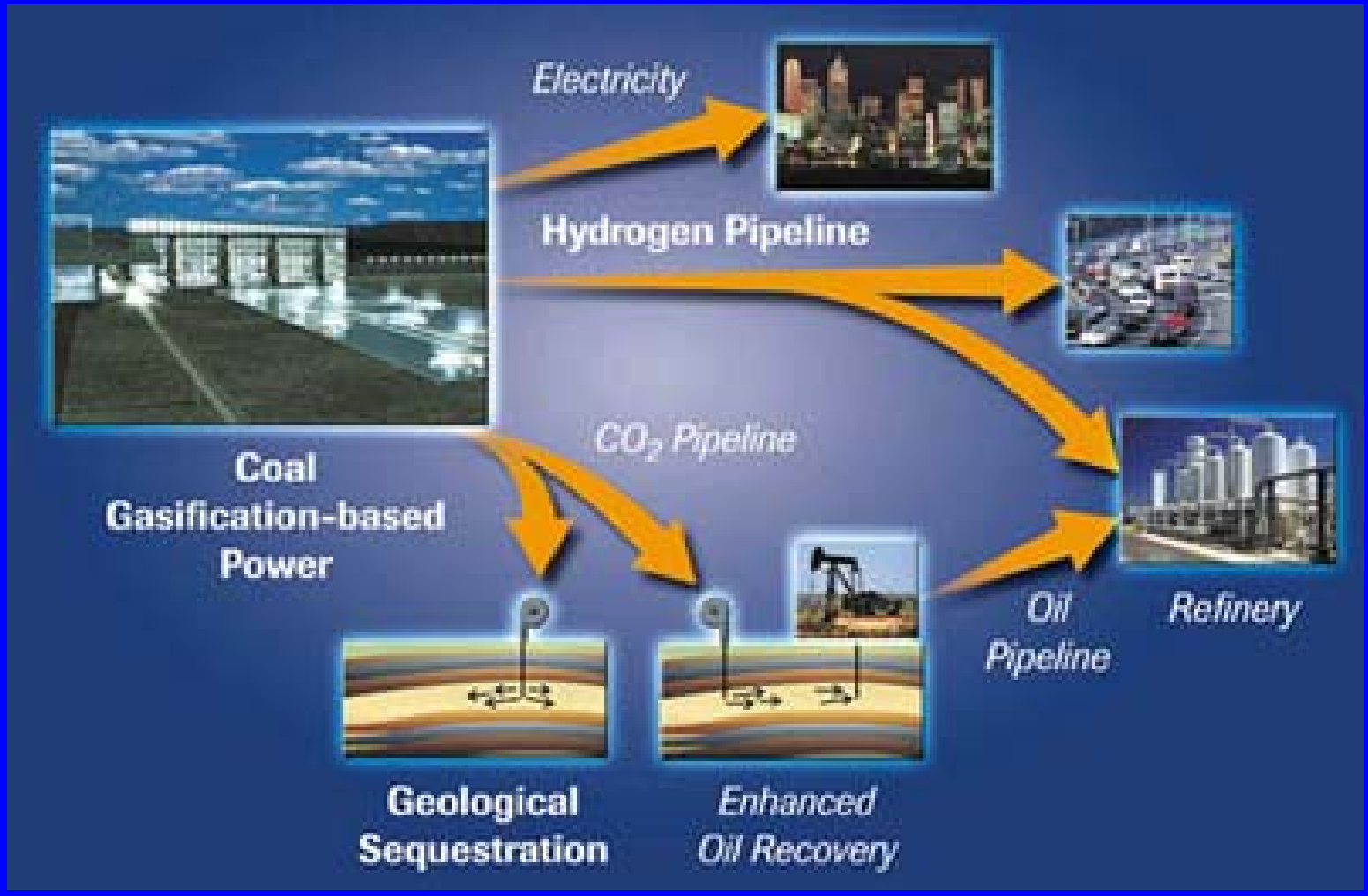
Relevant Programs

- Clean Coal Technology Program (1986-93)
  - 38 projects (18 state)
  - Total investment: $5.2 billion
  - Federal Government: $1.8 billion (34%)
  - Industry/States: $3.5 billion (66%)
- Power Plant Improvement Initiative (2001)
- Clean Coal Power Initiative (2002)
- FutureGen Initiative (2006)

Project	Company	Location
Gas Suspension Absorption	AirPol	W. Paducah, KY
Confined Zone Dispersion	Bechtel	Seward, PA
LIFAC Sorbent Injection	LIFAC	Richmond, IN
Adv. Flue Gas Desulfurization	Pure Air	Chesterton, IN
CT-121 Flue Gas Scrubber	So. Co. Services	Newnan, GA
NOx Control - Wall-Fired	So. Co. Services	Coosa, GA
Coal Reburning	B&W Co.	Cassville, WI
Low-NOx Cell Burner	B&W Co.	Aberdeen, OH
Gas Reburning/Low-NOx Burn.	EERC	Denver, CO
Micronized Coal Reburning	NYSEG	Lansing, NY
Selective Catalytic Reduction	So. Co. Services	Pensacola, FL
NOx Control - T-Fired	So. Co. Services	Lynn Haven, FL
SNOX Flue Gas Cleaning	ABB	Niles, OH
LIMB SO_2/NOx Control	B&W Co.	Lorain, OH
SOx-NOx-ROx Box	B&W Co.	Dilles Bottom, OH
Gas Reburning/Sorbent Inj.	EERC	Two sites - IL
Milliken Clean Coal Project	NYSEG	Lansing, NY
Dry NOx/SOx Control Sys.	Pub. Service CO	Denver, CO
McIntosh PFBC Project (4A)	City of Lakeland	Lakeland, FL
McIntosh PFBC Project (4B)	City of Lakeland	Lakeland, FL
JEA Fluidized Bed Project	JEA	Jacksonville, FL
Tidd PFBC Project	Ohio Power Co.	Brilliant, OH
Nucla CFB Project	Tri-State	Nucla, CO
Kentucky Pioneer Project	Kentucky Pioneer	Trapp, KY
Pinon Pine Power Project	Sierra Pacific	Reno, NV
Tampa Electric IGCC Project	Tampa Electric	Mulberry, FL
Wabash River Repowering	Dynegy/PSI	W. Terre Haute, IN
Clean Coal Diesel	AD Little	Fairbanks, AK
Healy Clean Coal Project	AIDEA	Healy, AK
Liquid Phase Methanol	Air Products	Kingsport, TN
Adv. Coal Conversion	Western Syncoal	Colstrip, MT
Coal Quality Expert	CQ Inc. & ABB	Multiple Sites
ENCOAL Mild Gasification	ENCOAL Corp.	Gilette, WY
Integrated Coal/Ore Reduction	CPICOR	Vineyard, UT
Pulse Combustor	MTCI	Baltimore, MD
Blast Furnace Injection Sys.	Bethlehem Steel	Burns Harbor, IN
Cyclone Combustor	Coal Tech Corp.	Williamsport, PA
Cement Kiln Scrubber	Passamaquoddy	Thomaston, ME

Some successful projects under 1986-1993 Clean Coal Technology Program

FutureGen



Source: NETL

Summary

- Coal plays important role in meeting future energy demand.
- Advanced technology is needed to meet economic and environmental goals.
- Policies and incentives will result in technology innovations and adoptions.

Thank You!

Shih@rff.org