NATIONAL ENERGY TECHNOLOGY LABORATORY

Program Overview – Advanced Turbines

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U.S. DEPARTMENT OF ENERGY

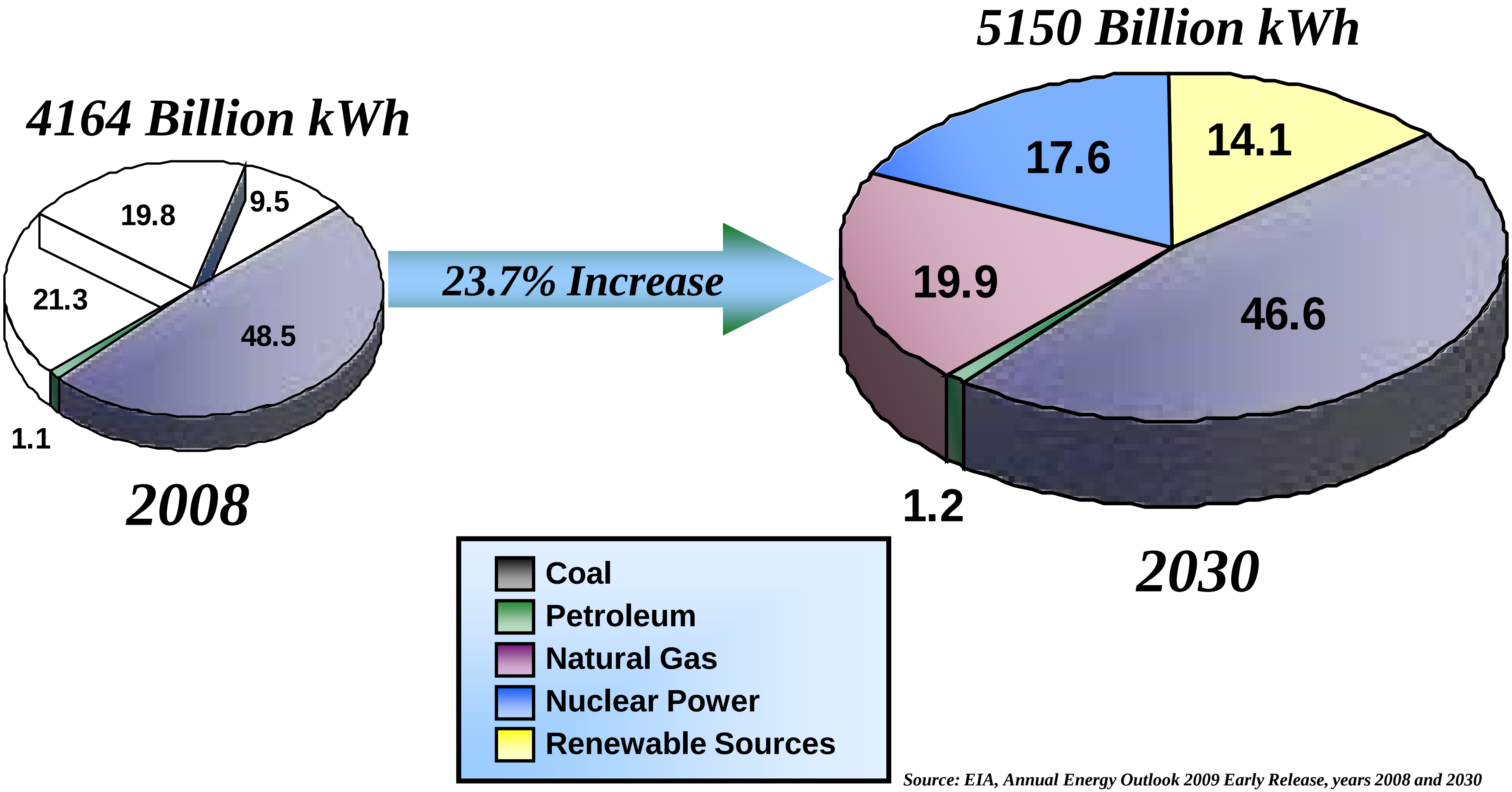
Presentation Outline

- **Drivers for CCS**
  - Need for H2 Turbines
- **DOE's FE Advanced Turbine Program**
  - Hydrogen turbines
- **NGCC Study Overview**
- **Summary**

U.S. Electrical Generation by Fuel Type

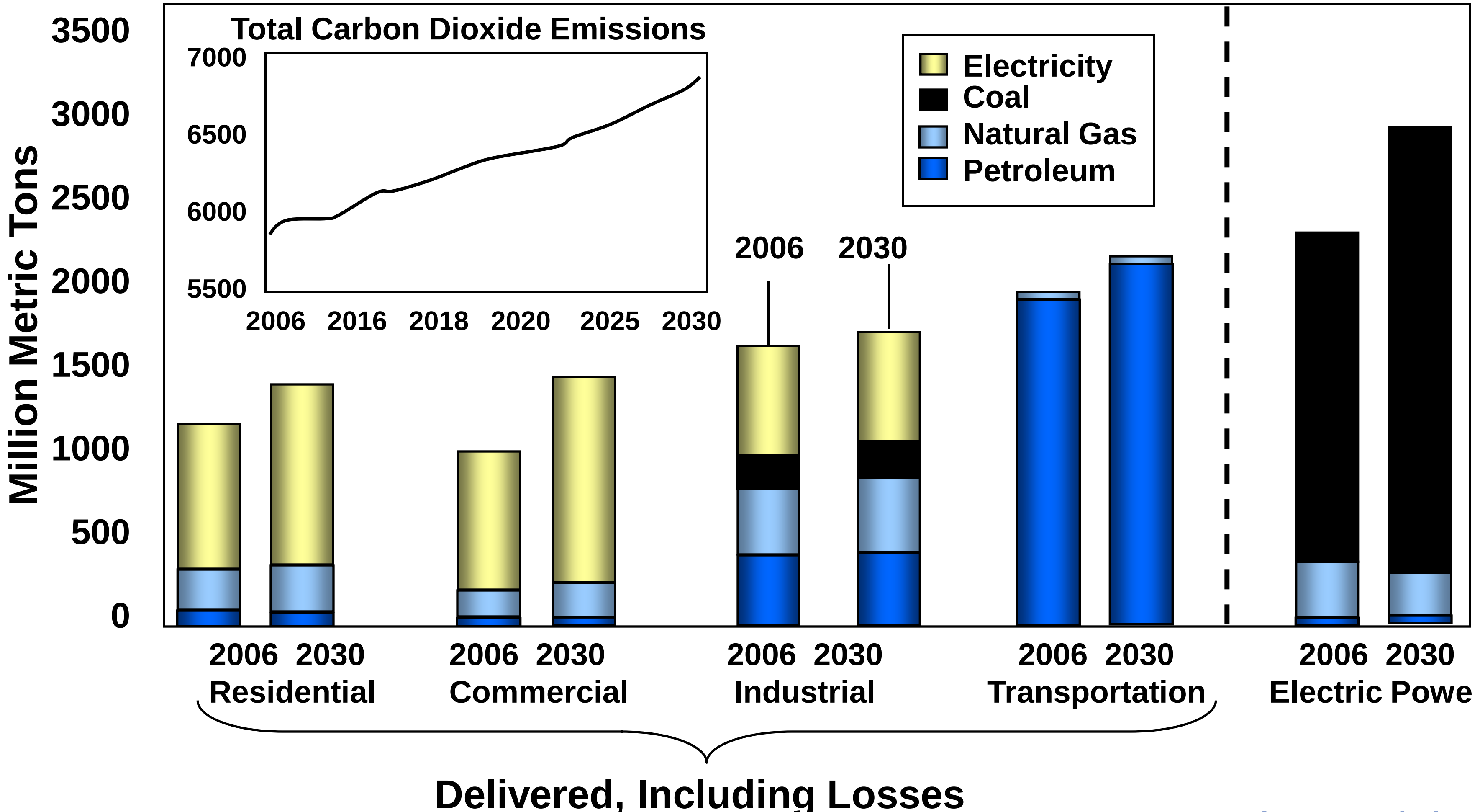
Coal Remains a Dominate Source as Demand Grows

(2009 Data)



Source: EIA, Annual Energy Outlook 2009 Early Release, years 2008 and 2030

U.S. CO_2 Emissions by Fuel and Use



Source: EIA, Annual Energy Outlook 2008

Technological Carbon Management Options

Reduce Carbon Intensity

- Renewable
- Nuclear
- Fuel Switching

Improve Efficiency

- Demand Side
- Supply Side

Sequester Carbon

- Capture & Store
- Enhance Natural Processes

All options needed to:

- **Supply energy demand**
- **Address environmental objectives**

DOE Office of Fossil Energy (FE) Advanced Power Systems Goals

- **2010: R&D Focus**
  - 45- 47% Efficiency (HHV)
  - $1,600/kWe capital cost
  - 99% SO_2 removal
  - NOx< 0.01 lb/MM Btu
  - 90% Hg removal

- **2015: Technology Ready for Demonstration w / CCS**
  - *90% CO_2 capture*
  - *<10% increase in cost of electricity (COE) with carbon sequestration*

- **2020: Technology Ready for Deployment**

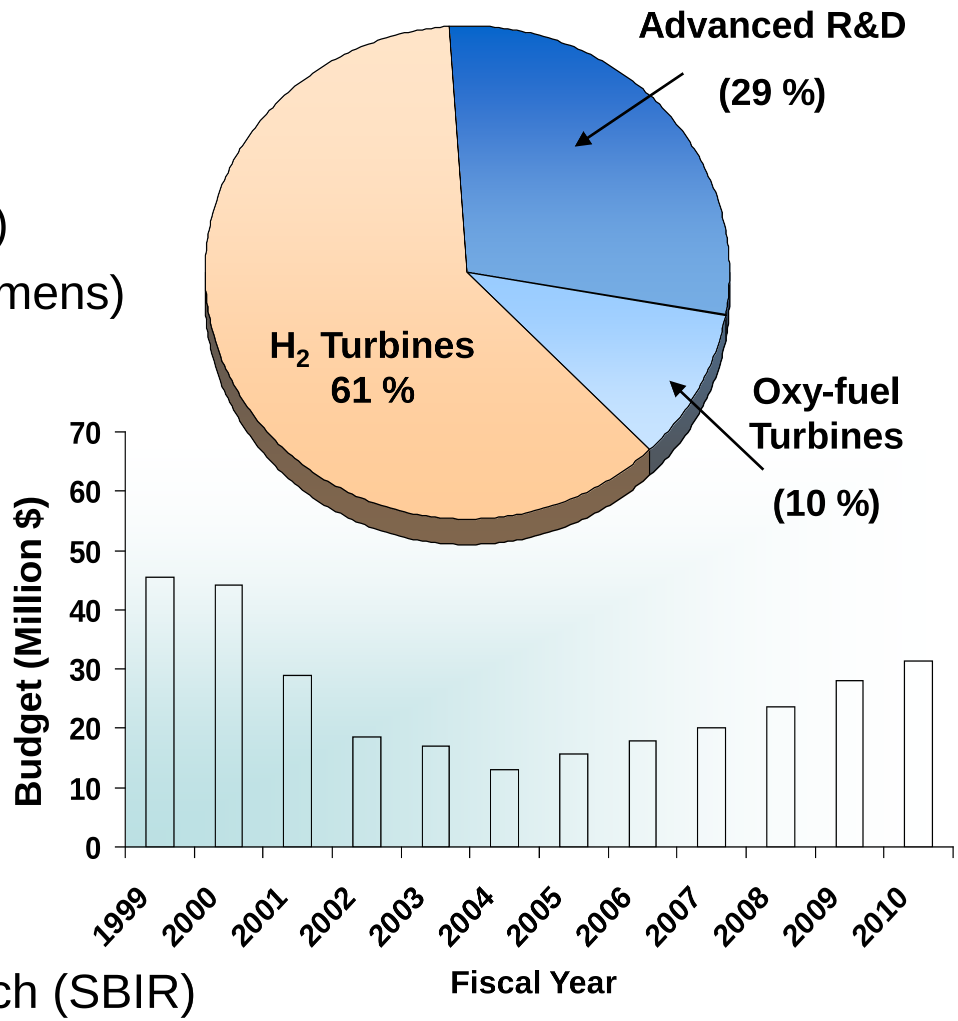
DOE FE programs address these goals:

- **Advanced Turbines**
- **Gasification**
- **Advanced Research**
- **Fuel Cells**
- **Innovations for Existing Plants**
- **Sequestration**
- **Fuels from Coal**

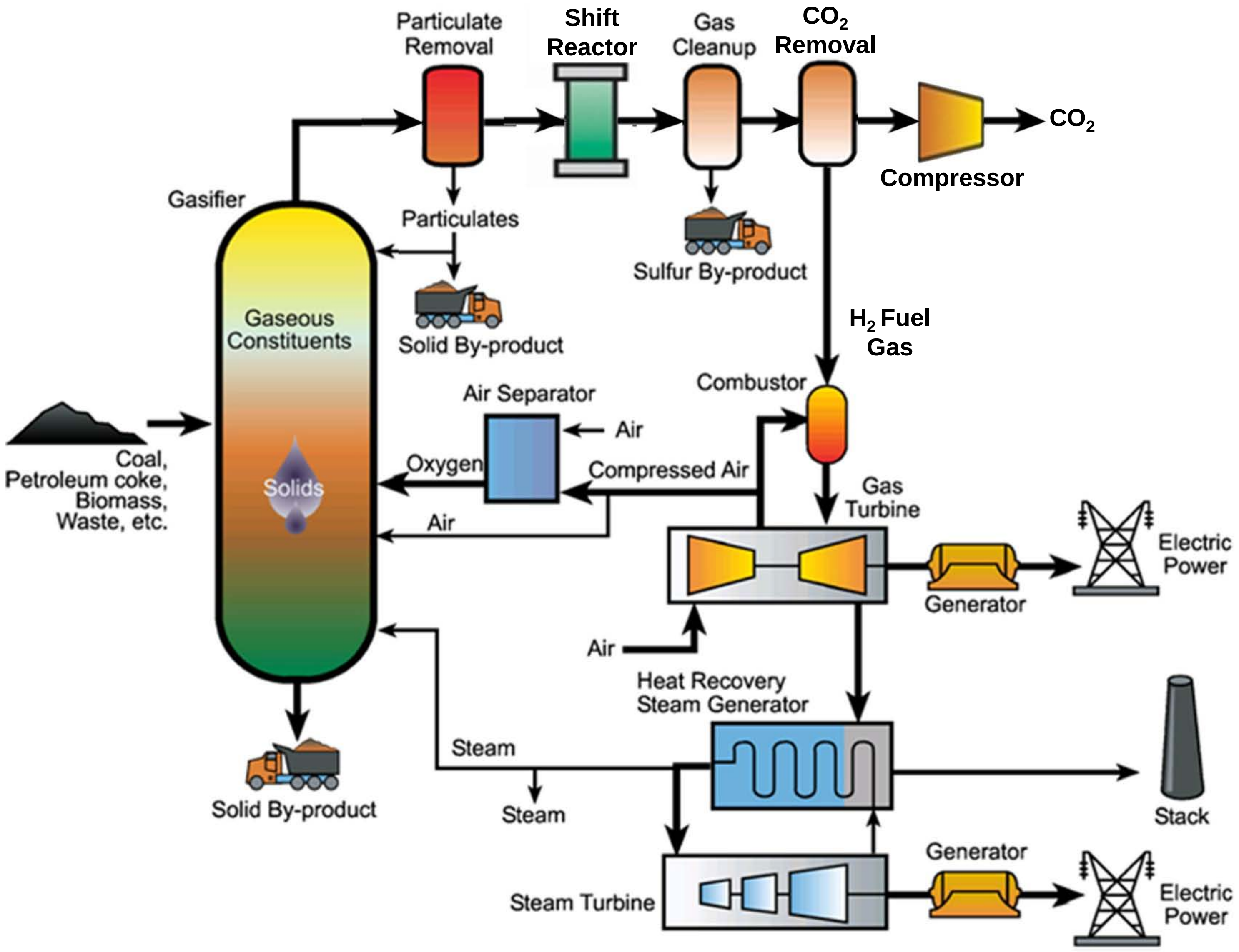
FE Advanced Turbines Budget by Focus Area

FY 2010 Budget $31M

- **Hydrogen Turbines ($19,080 K)**
  - Adv. H_2 Turbine Development (GE)
  - Adv. H_2 Turbine Development (Siemens)
- **Oxy-fuel turbine ($3,057 k)**
  - Oxy-Fuel Combustor (CES)
  - Oxy-fuel Turbine (Siemens)
- **Advanced Research ($9,162 k)**
  - UTSR (Various Universities)
  - US National Laboratories
    - **System Studies (NETL)**
    - **Combustion (NETL and LBNL)**
    - **HX Analysis (Ames and NETL)**
    - **Materials (ORNL and NETL)**
  - Small Business Innovative Research (SBIR)



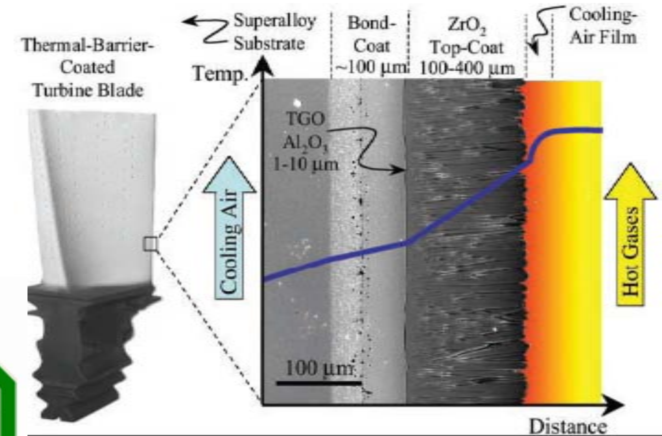
Plant Overview – IGCC with CCS



R&D Areas Advance Turbine Performance

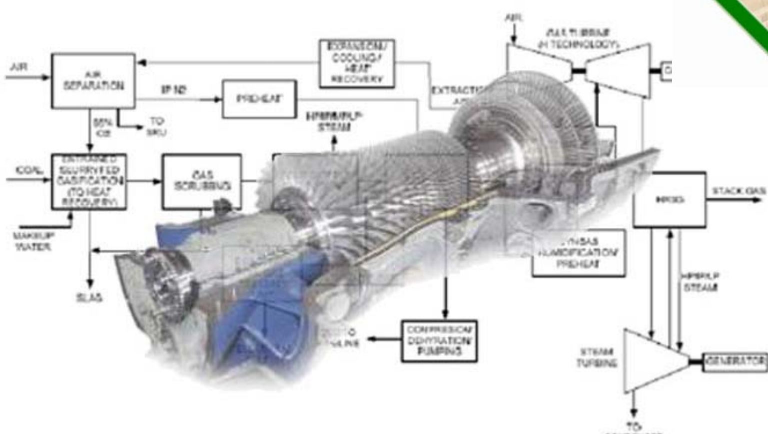
Combustion

Materials

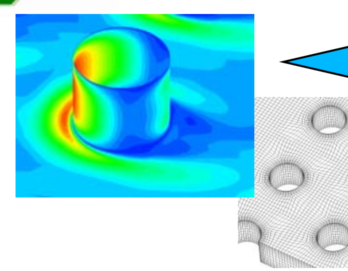


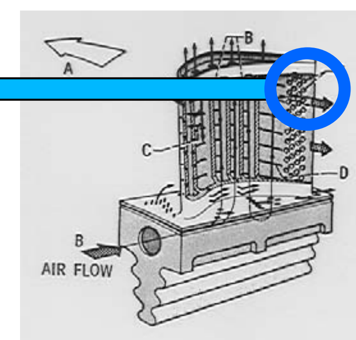
Cost
Power
Efficiency
Emissions

System Design

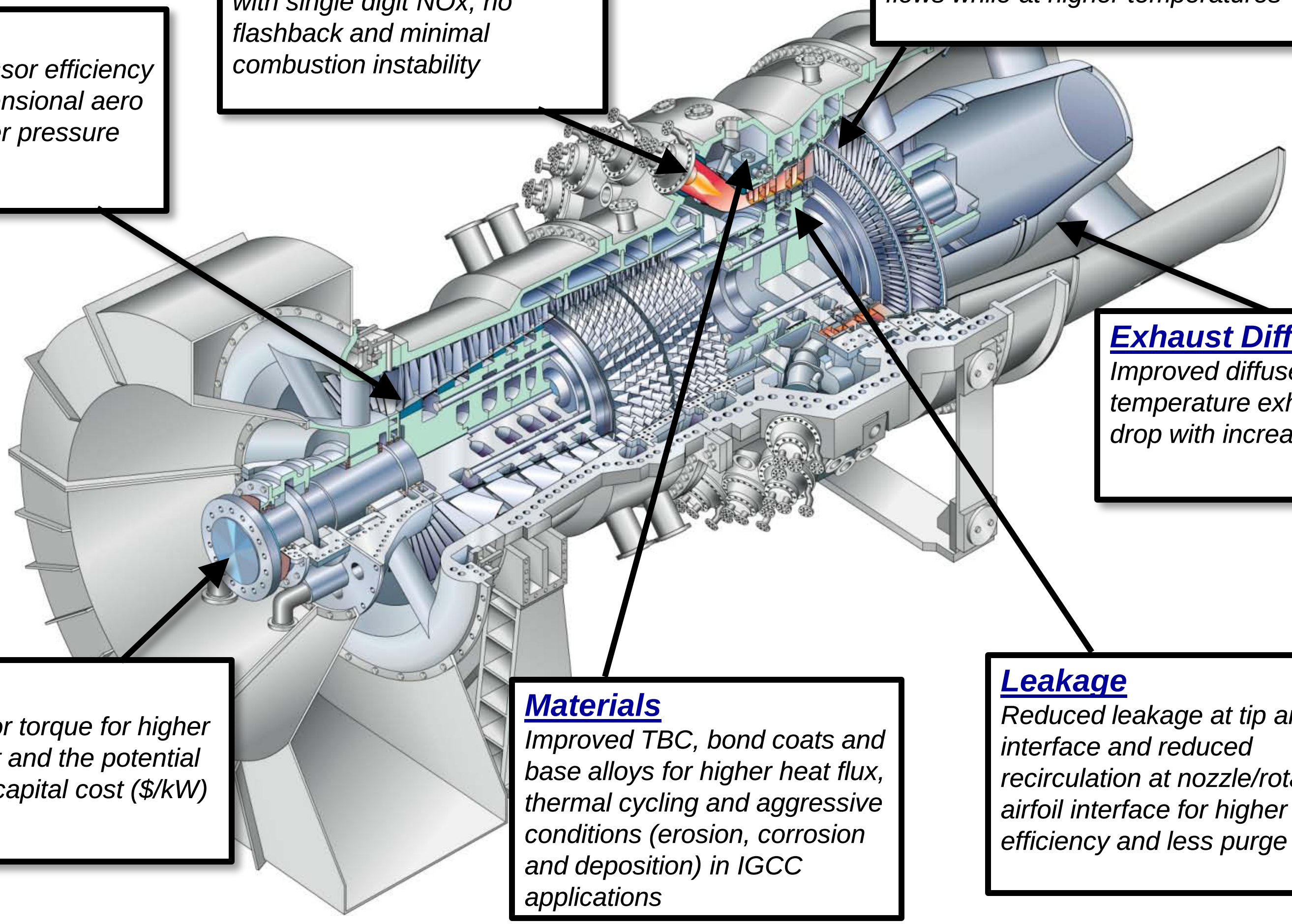


Aerodynamics & Heat Transfer





Targeted Areas for H2 Turbine Improvement



Turbine
Improved aerodynamics, longer airfoils for a larger annulus / higher mass flow and improved internal cooling designs to minimize cooling flows while at higher temperatures

Combustor
Combustion of hydrogen fuels with single digit NOx, no flashback and minimal combustion instability

Compressor
Improved compressor efficiency through three dimensional aero dynamics for higher pressure ratio

Exhaust Diffuser
Improved diffuser designs for higher temperature exhaust, lower pressure drop with increased mass flow

Rotor
Increase rotor torque for higher power output and the potential for lowering capital cost ($/kW)

Materials
Improved TBC, bond coats and base alloys for higher heat flux, thermal cycling and aggressive conditions (erosion, corrosion and deposition) in IGCC applications

Leakage
Reduced leakage at tip and wall interface and reduced recirculation at nozzle/rotating airfoil interface for higher turbine efficiency and less purge

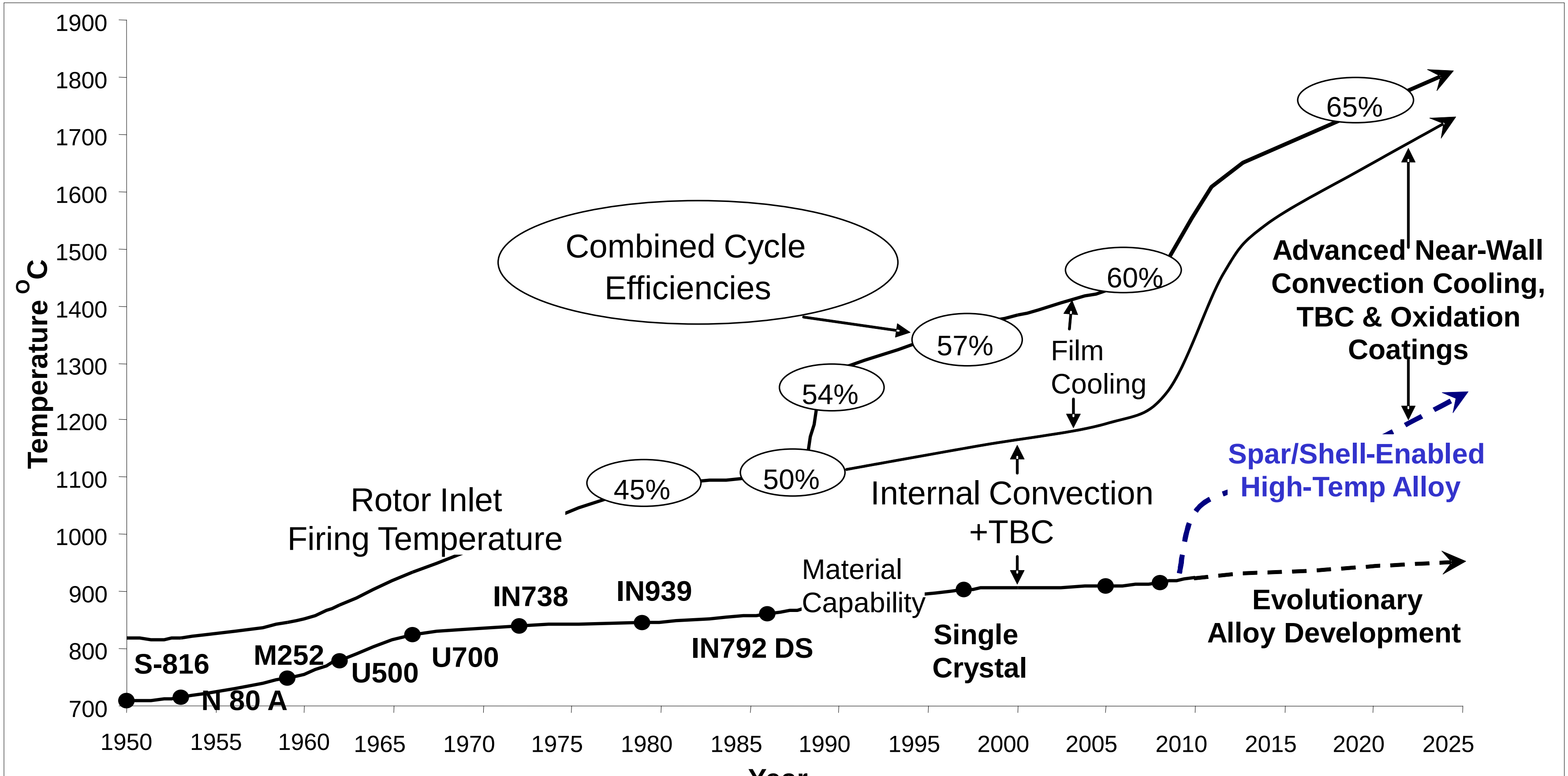
Photo courtesy of Siemens Energy

H_2 Properties Impacts Turbine Combustion

- **Low density of hydrogen (7.6 X< natural gas (NG))**
  - Reduces momentum of injected fuel to promote mixing
- **Low energy density (3.2 x< NG)**
- **H_2 has broad flammability limits 4 – 75 % versus 5 – 15 % for NG in air**
  - H_2 more likely to combust in undesirable locations
- **Laminar flame speed of H_2 ten times faster than NG**
  - Promoting flash back and flame holding
- **H_2 diffuses three times as fast as NG in air**
- **Minimum ignition energy 17 times lower than NG**

High Inlet Temperature Key to Efficiency

Made Possible by Advanced Materials and Cooling Technology



Data up to 1992 based on graph published by Schilke teal.

Status Of H2 Turbine Projects

- **Projects awarded in October, 2005**
  - Two recipients
    - GE Energy
    - Siemens Energy
  - Total Project Value: ~$90M/project
    - 30% recipient cost share
  - 7 year, 2 Phase efforts
    - Phase I – (10/1/2005 – 9/30/2007)
    - Phase II – (10/1/2007 – 9/30/2012)
- **Phase I – Conceptual Design and R&D Implementation Plan (Oct, 2005 – Sep, 2007)**
  - Completed September 2007
  - Resulted in conceptual design and down selection of key technologies for the advanced H2 turbine.

Status Of H2 Turbine Projects

- **Phase II – Detailed Design and Validation Test Program (Oct, 2007 – Sep, 2012)**
  - Combustion – Conducting Syngas and H_2 full can combustion tests at advanced conditions
  - Materials - Developing advanced coating systems and enhanced alloys for higher temperature performance.
  - Turbine –Increase turbine efficiency including: increased annular area, reduced cooling requirements, advanced sealing technologies and hardware geometries.
  - Systems – GE and SE predicting efficiency improvements that meet or exceed goals.
- **Exploring options for Phase III – H-Class H2 Turbine Development**

System Study Results

- **Recipients system study results have demonstrated the ability to meet program goals**
  - 5 percentage points improvement in the CC performance above base line
    - Now need R&D to be successful
- **Advanced H2 turbine improves IGCC performance**
  - Expected to recover a significant amount of the efficiency penalty due to CCS
  - When combined with other balance of plant improvements and other successful FE R&D all efficiency penalties should be recovered
  - In a 2 on 1 configuration all cost penalties may be recovered

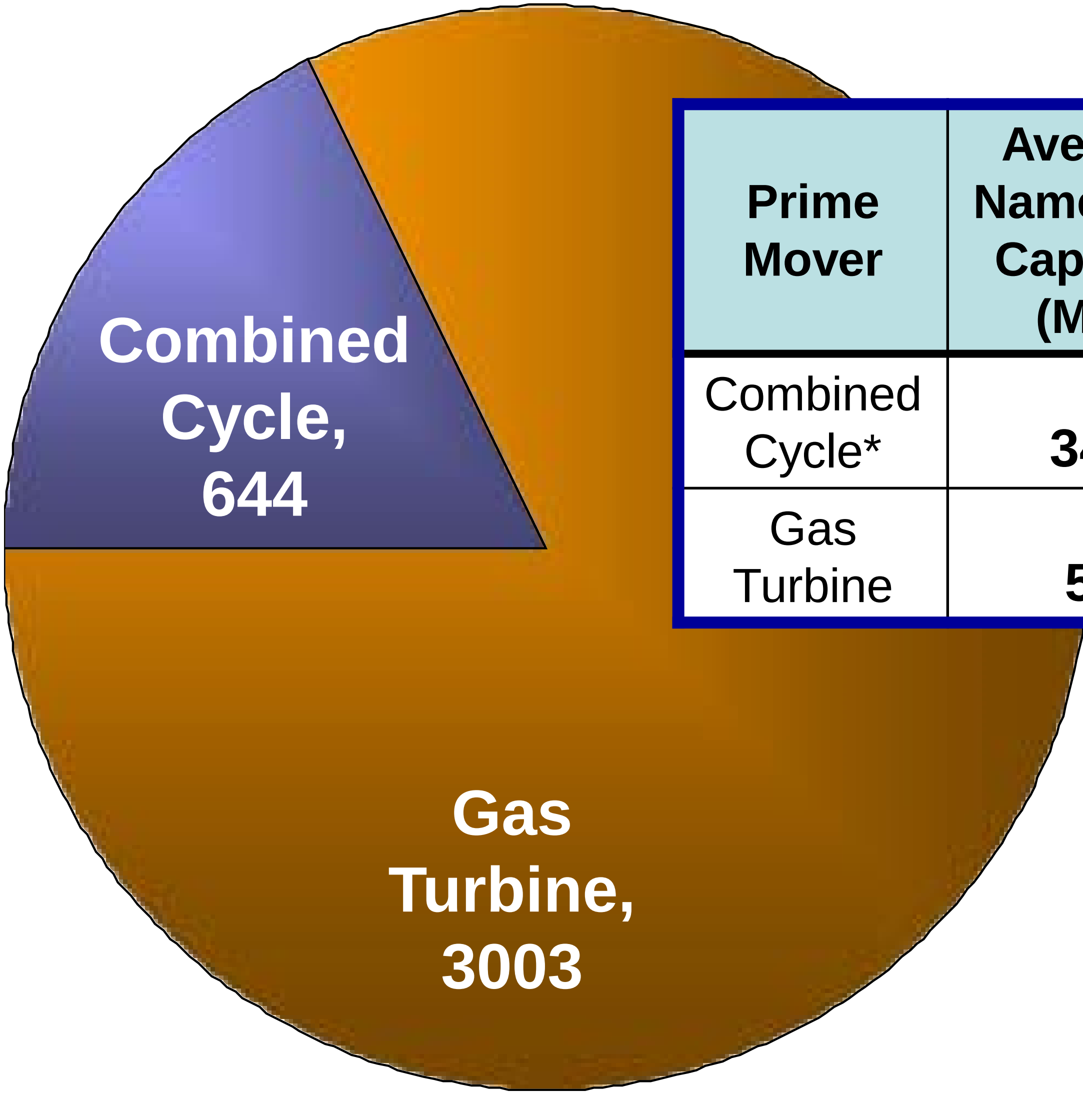
OVERVIEW OF NGCC

Demographics of GT Power Generation

Data overview

- **Energy Velocity "Unit Capacity" query**
  - Sources: EIA 860, NERC ES&D, CFE, StatsCanada, CEMS, U.S. Federal and State Agencies, ISOs, Unit Owner and/or Operator Websites, Global Energy Primary Research
- **6,104 total units with Gas Turbine or Combined Cycle prime movers**
- **5,710 in U.S.**
- **3,647 of these listed as *operating*, *mothballed* or *cold standby* (*retired*, *canceled* and *planned* were filtered out)**

Number of units by prime mover

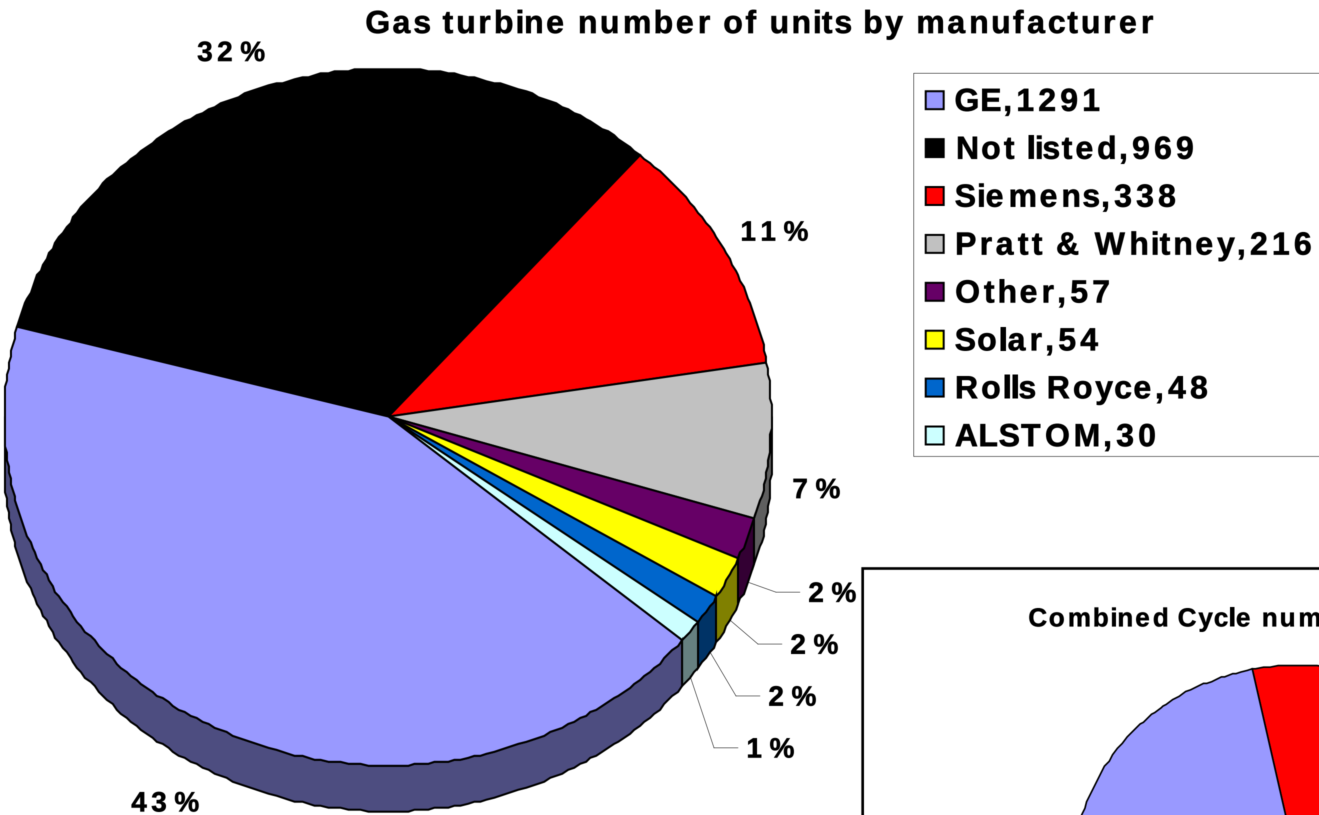


Prime Mover	Average Nameplate Capacity (MW)	Average Heat Rate (Btu/kWh)
Combined Cycle*	**343**	**9,254**
Gas Turbine	**52**	**15,270**

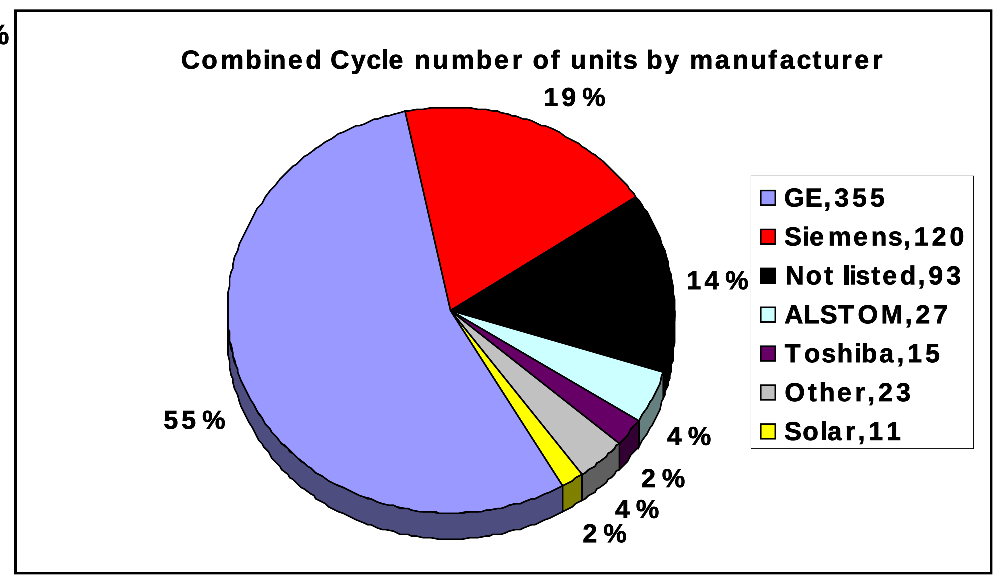
*** Combined cycle units include the entire generating package, e.g. two GT's and one ST**

Data source: analysis and synthesis of Energy Velocity database, "Capacity by unit" and "generation by unit" queries filtered for status and prime mover

Manufacturer distribution

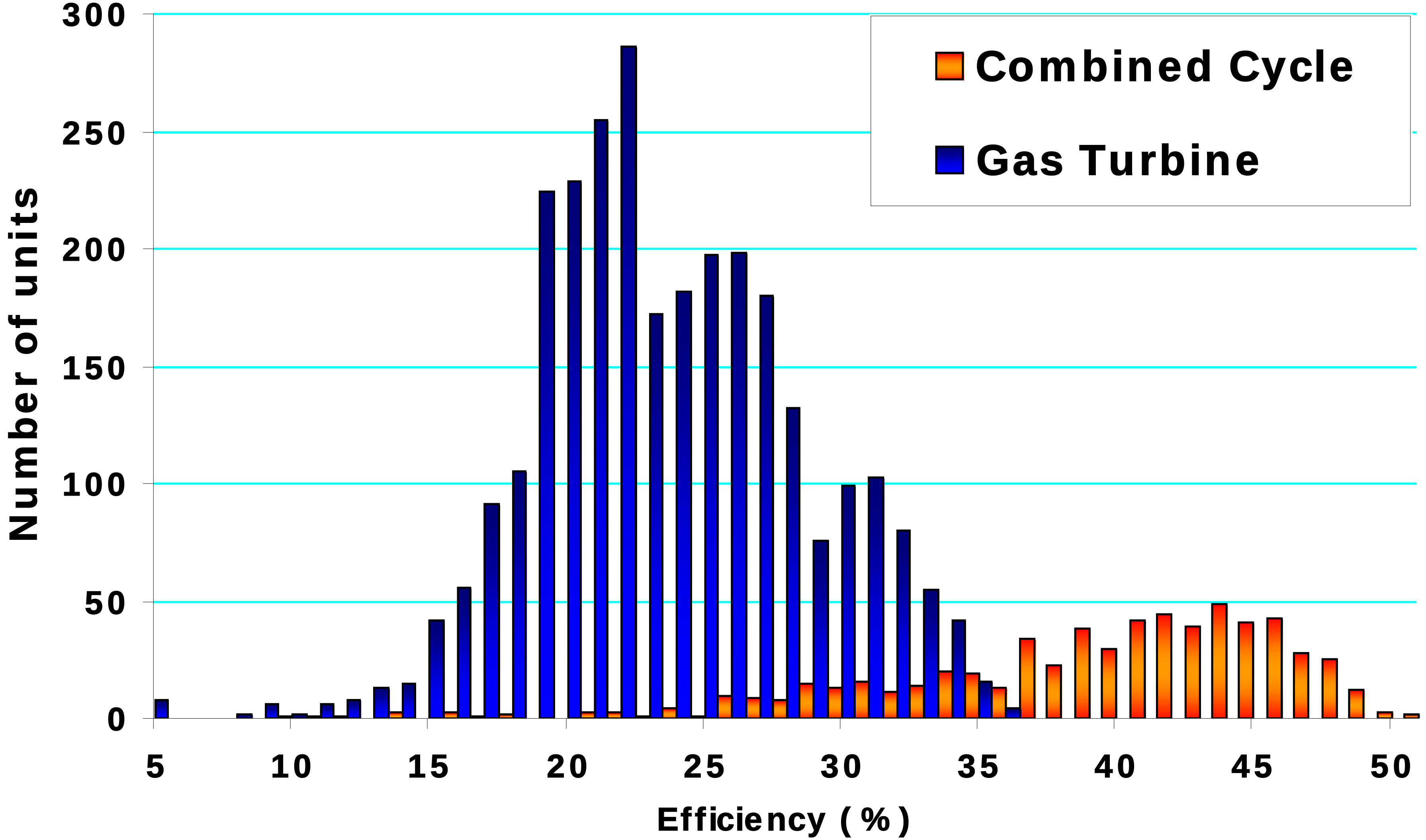


GE dominates both GT and CC markets…



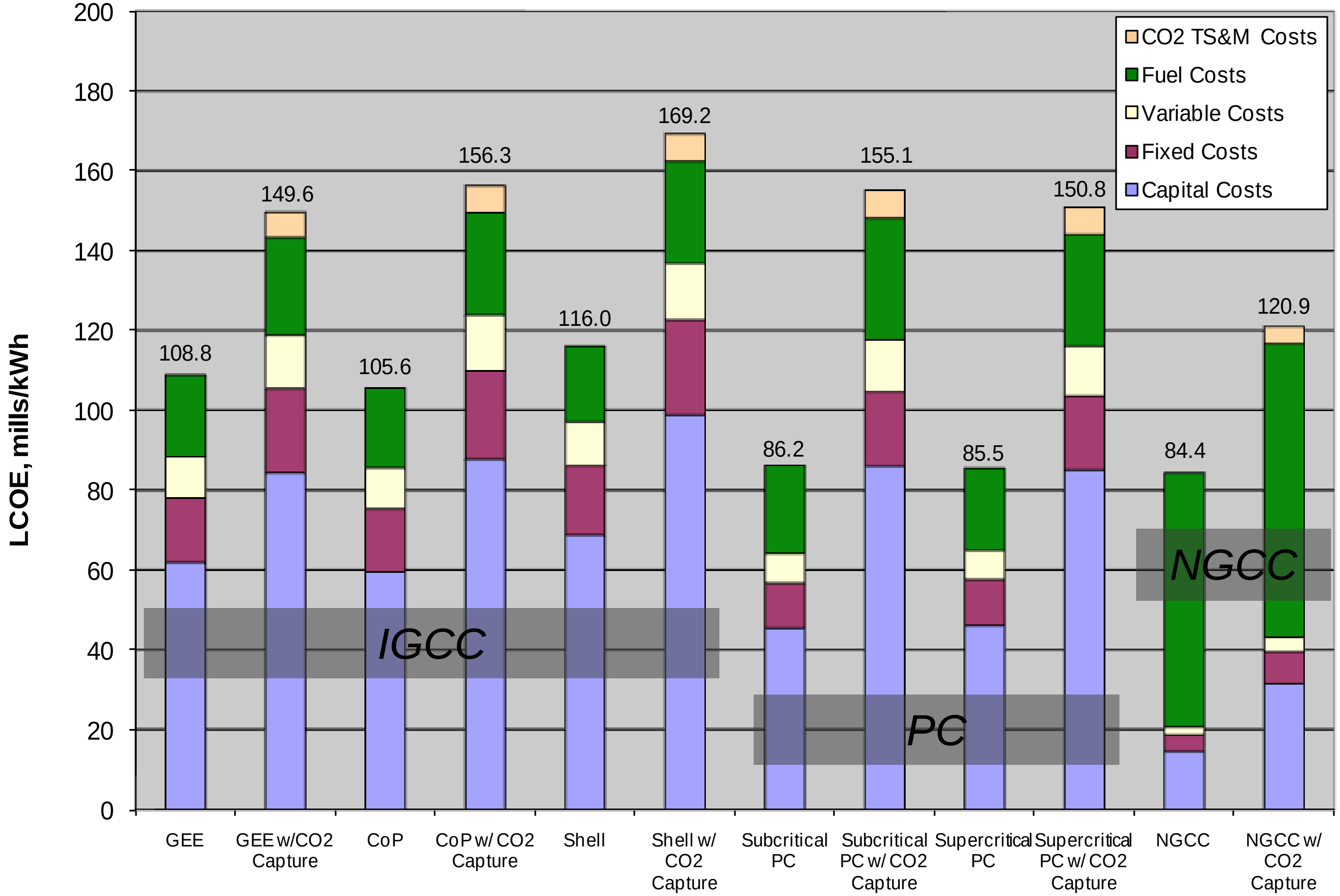
…but there are many "not listed" entries in the database

Efficiency distribution



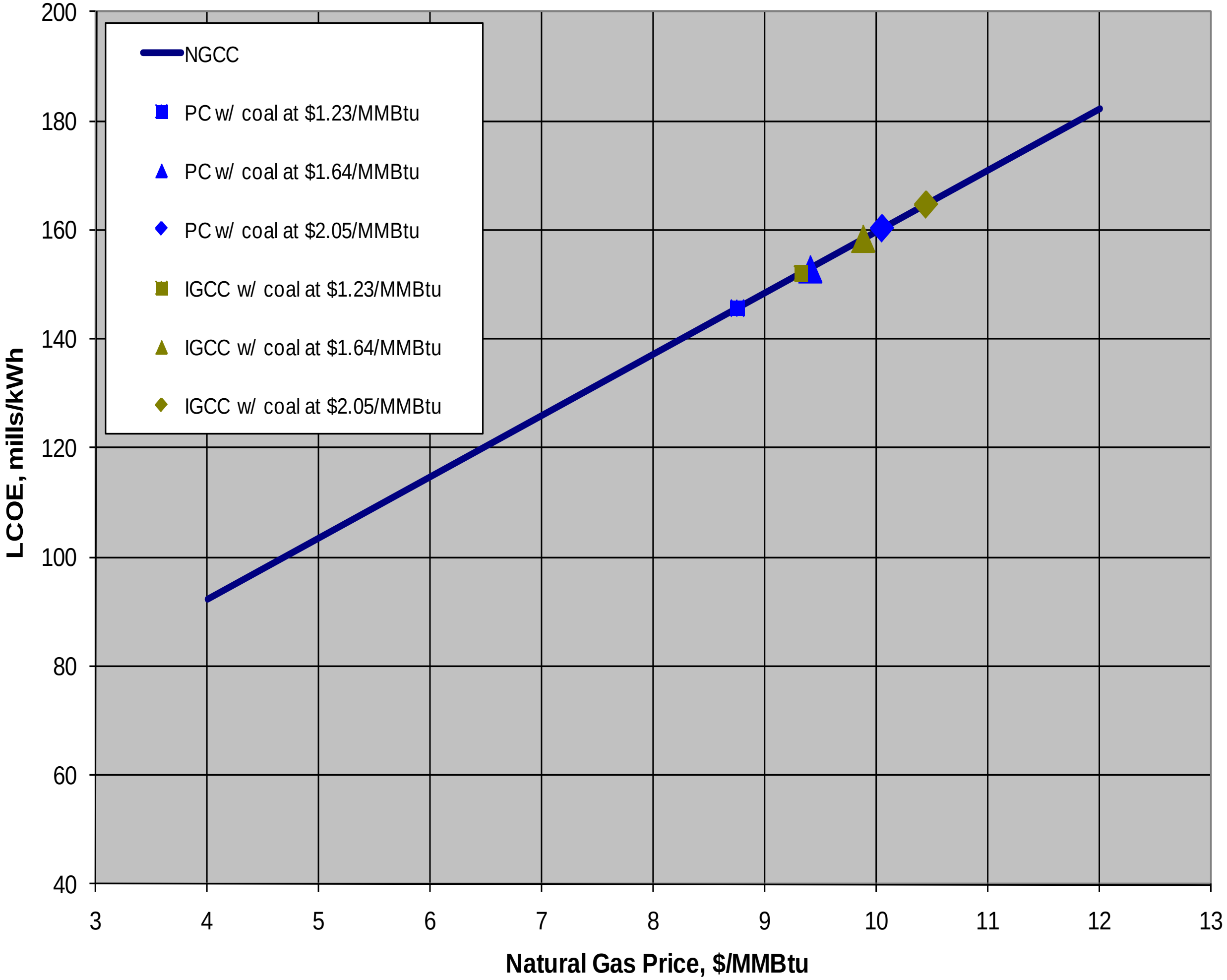
Cost of CCS in Fossil Fuel Power Systems

(from DRAFT "Cost and Performance Baseline for Fossil Energy Plants" DOE/NETL 2010)

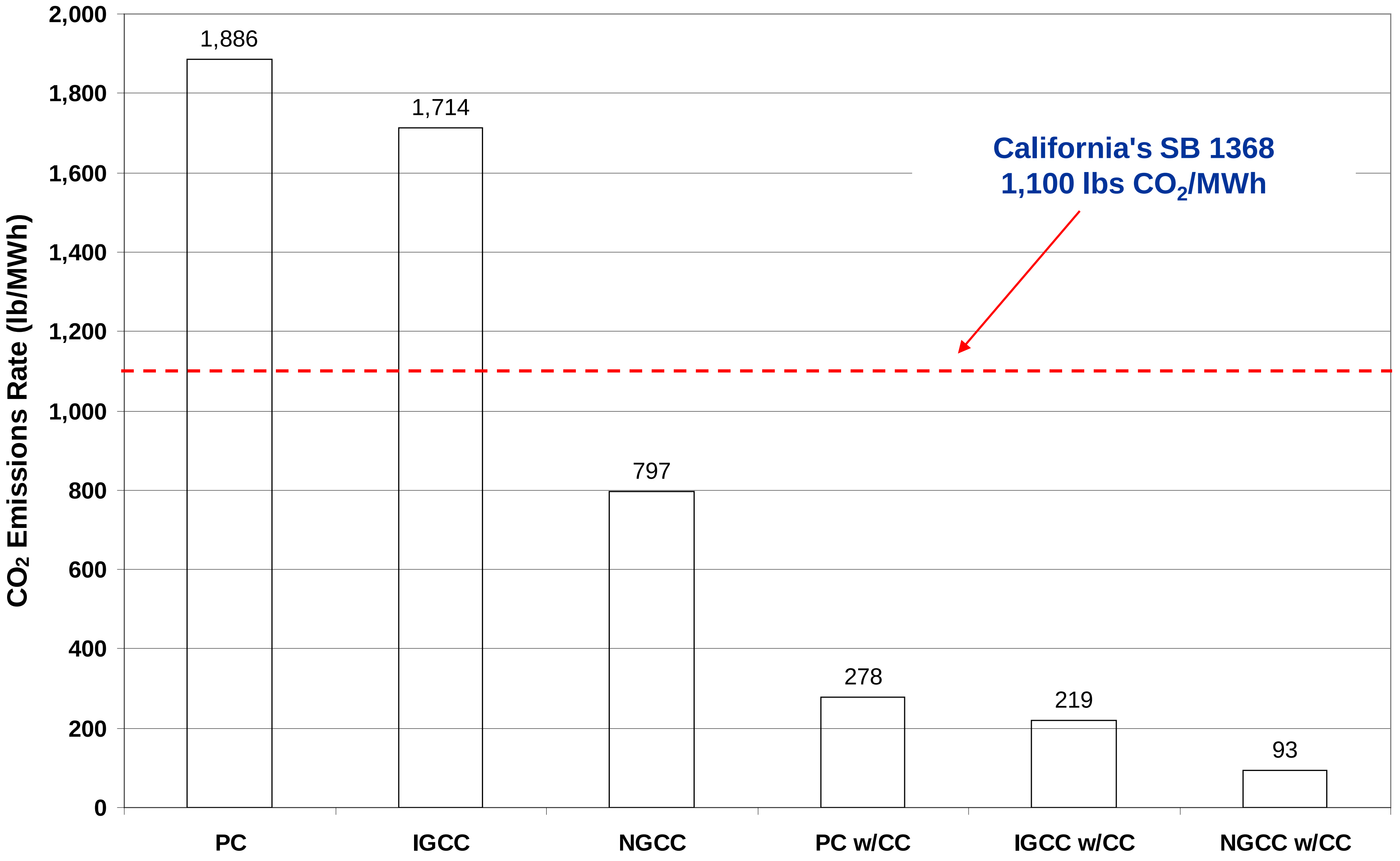


NGCC COE as a Function of Fuel Cost

(from DRAFT “Cost and Performance Baseline for Fossil Energy Plants” DOE/NETL 2010)



CO_2 Emissions



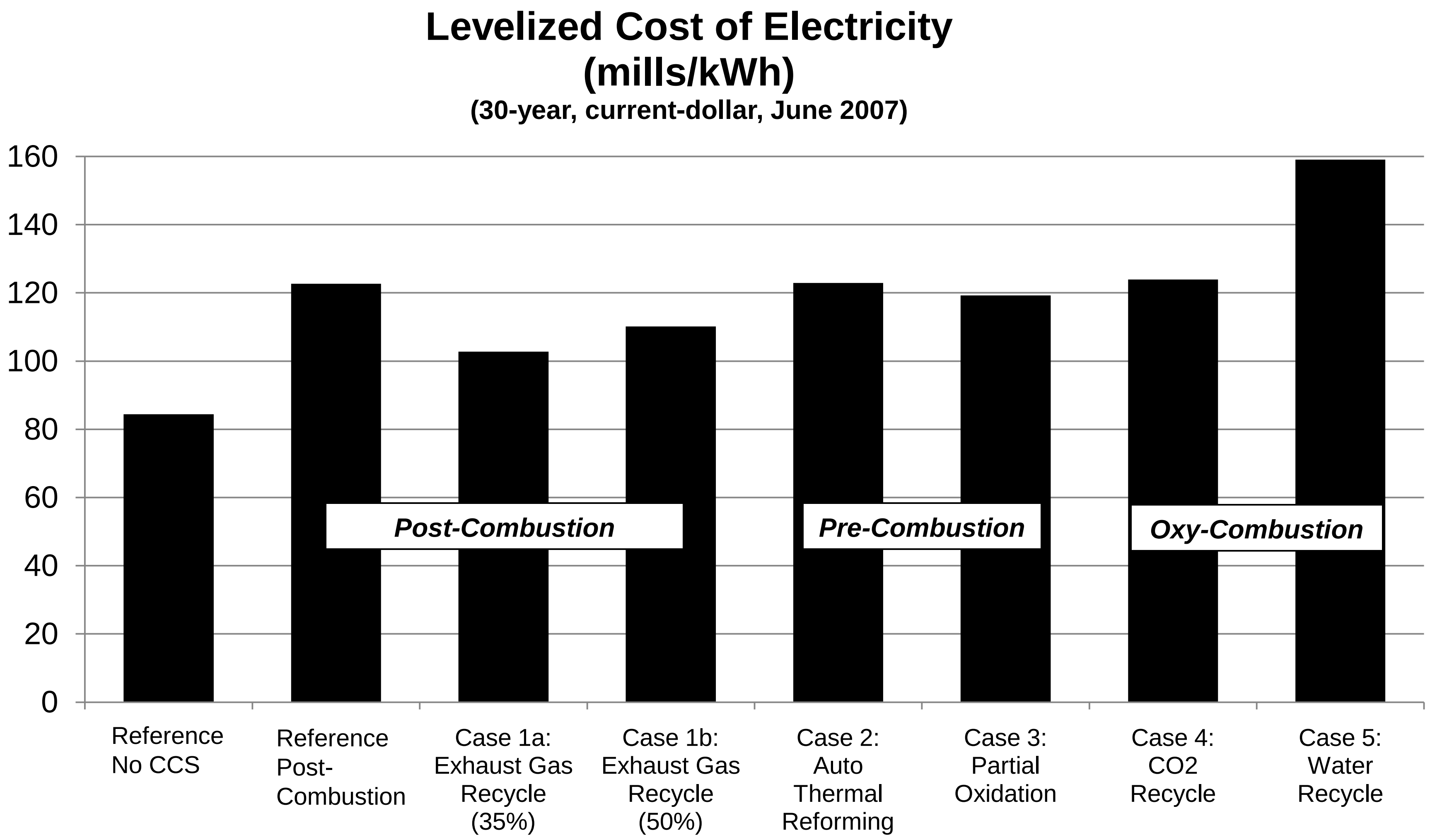
Source: Cost and Performance Baseline for Fossil Energy Power Plants study, Volume 1: Bituminous Coal and Natural Gas to Electricity; NETL, May 2007.

Project Cases

Study Matrix

Case	Description	Steam Cycle, psig/°F/°F	Combustion Turbine	Steam Generation	Oxidant	NOx Control	CO_2 Separation	CO_2 Capture Target
Ref non-capture	No capture	2400/1050/ 1050	Advanced F Class	HRSG	Air	LNB and SCR	N/A	90%
Ref capture	Post-Combustion	2400/1050/ 1050	Advanced F Class	HRSG	Air	LNB and SCR	MEA	90%
1	Post-Combustion with exhaust gas recycle	2400/1050/ 1050	Advanced F Class	HRSG	Air	SCR	MEA	90%
2	Pre-Combustion ATR	2400/1050/ 1050	Advanced F Class	HRSG	Air	SCR	MDEA	90%
3	Pre-Combustion high pressure POX	2400/1050/ 1050	Advanced F Class	HRSG	Air	N/A	MDEA	90%
4	Oxy-Combustion with CO_2 recycle	2400/1200/ 1200	High Pressure Ratio Combustion Turbine	HRSG	O_2	N/A	Oxy-fuel	>99%
5	Oxy-Combustion with water/steam recycle	CES design	CES design	N/A	O_2	N/A	Oxy-fuel	>99%

Preliminary Cost Results



- Assumes $6/MMBtu NG price

- All cost estimates are presently being revised based on final versions of the simulation models

Summary

- **Coal is projected to be a major energy resource for the U.S. and the world**
- **Majority of planned US power plants are NGCC**
- **Effective CO2 management will require a multi facetted approach – including CCS**
- **For new coal plants IGCC is the best approach for CO_2 capture**
  - CO_2 capture and geologic sequestration is a viable option for reducing carbon intensity
  - IGCC creates new pathways for energy production, lower emissions and higher efficiency
- **DOE's Turbine program is addressing opportunities for IGCC with CO_2 capture**
  - Excellent progress in efficiency, power output, materials and combustion with reduced emissions
- **On track to meet program goals**