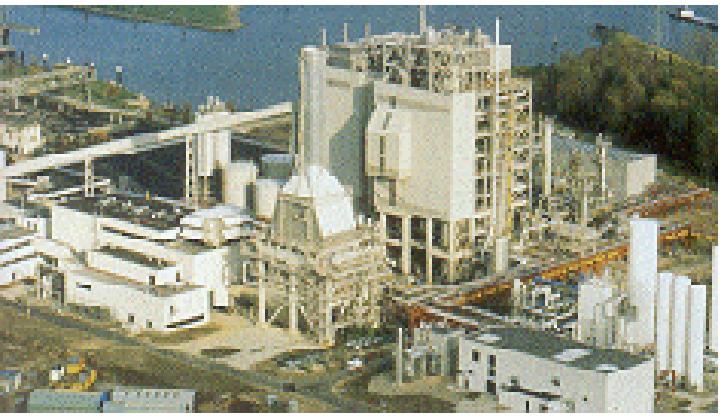

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Coal Gasification 101

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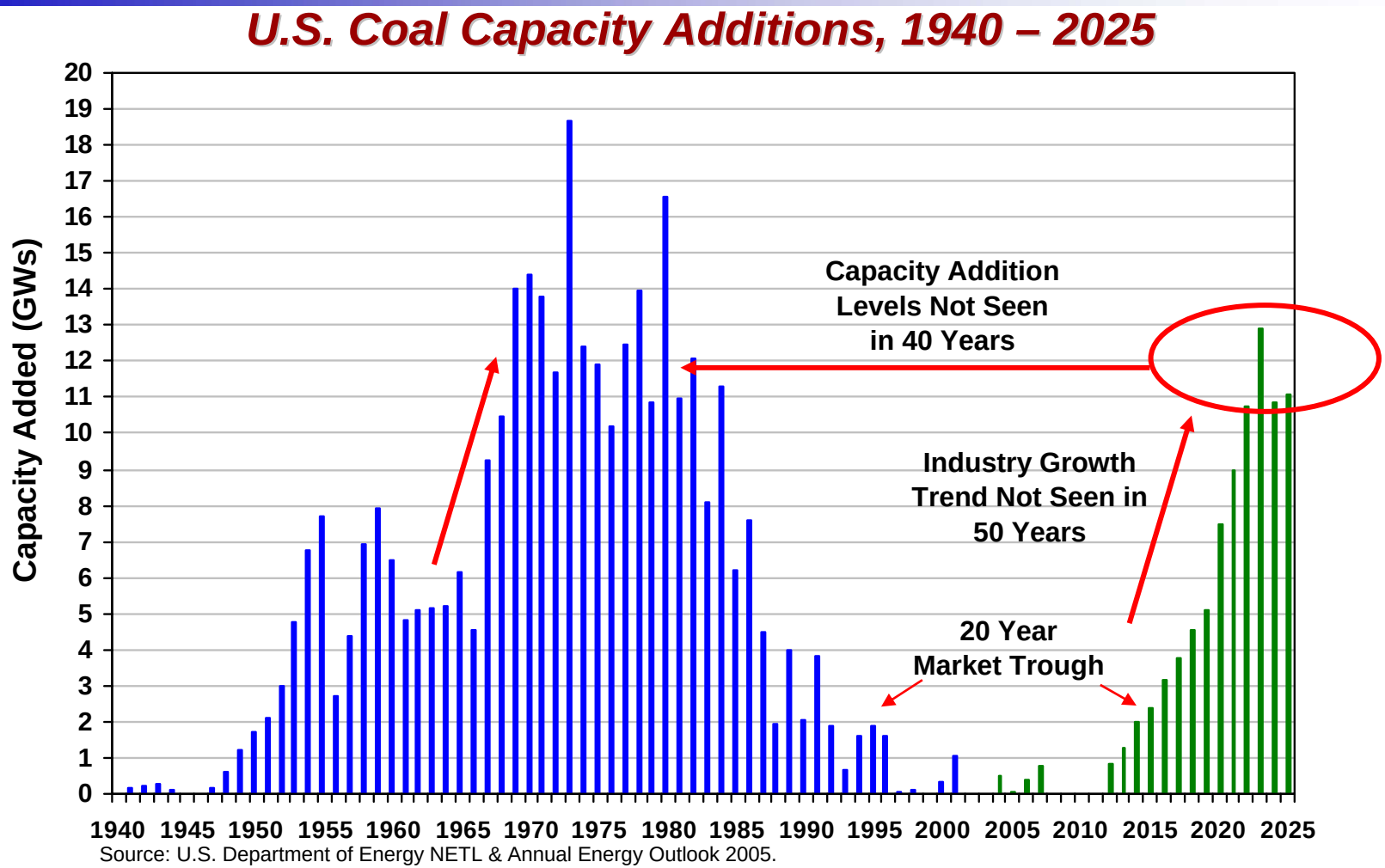
Outline

- What is coal?
- What is coal gasification?
- What can you do with it?
- Gasification-based power plants compared to other fossil fuel power generation options
- A few words on CO_2 capture

U.S. Forecasts Largest Coal Generation Capacity Installation in 40 Years

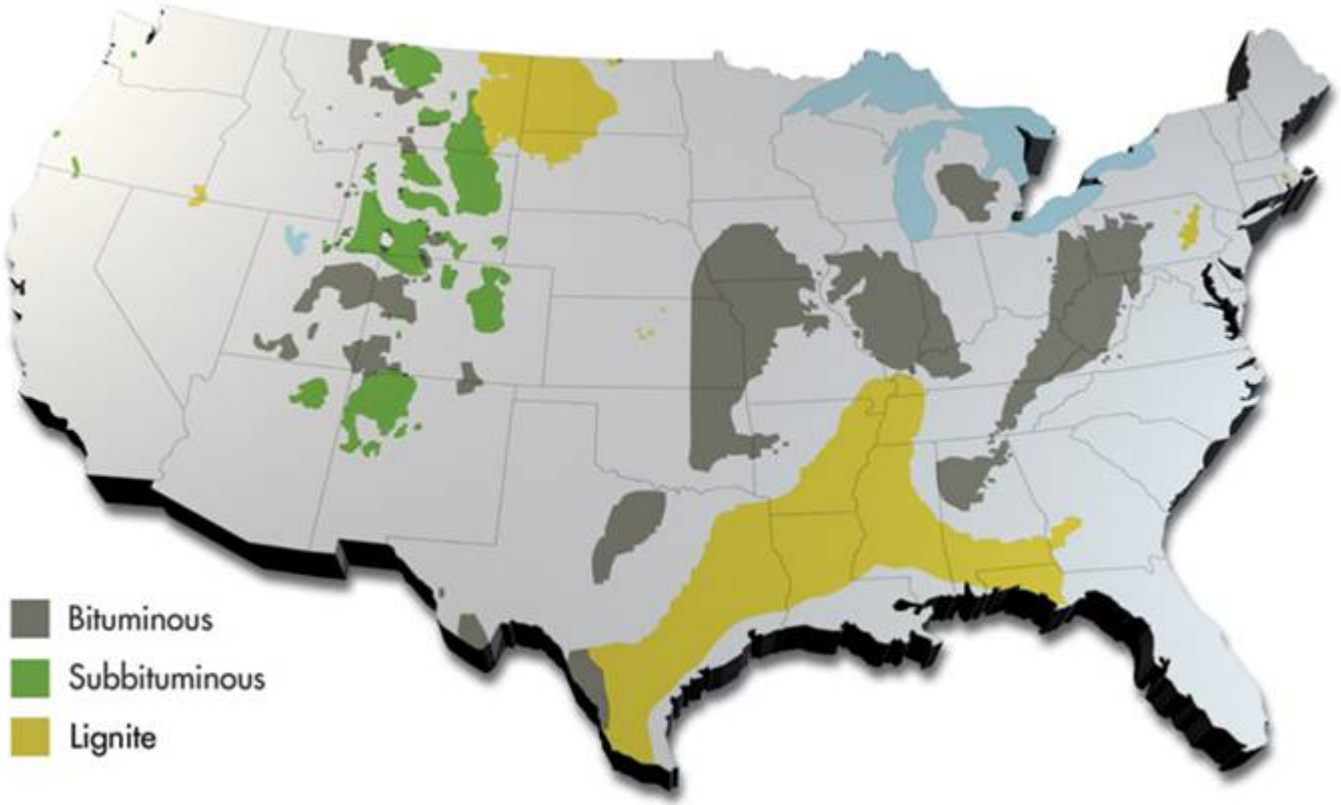


Source: U.S. Department of Energy NETL & Annual Energy Outlook 2005.

What is coal???

- Carbon
- Ash (rock)
- Sulfur
- Nitrogen
- Hydrogen
- Mercury
- Water

U.S. Coal Basins



Typical U.S. Coal Analysis (Coal Properties Differ Markedly)

	Pittsburgh #8	Illinois #6	Wyoming	ND Lignite
Ultimate Analysis				
Moisture	5.2	12.2	30.24	26.80
Carbon	73.8	61.0	48.18	45.82
Hydrogen	4.9	4.25	3.31	3.11
Nitrogen	1.4	1.25	0.70	0.70
Chlorine	0.07	0.07	0.01	N/A
Sulfur	2.13	3.28	0.37	0.69
Oxygen	5.4	11.0	11.87	14.68
Ash	7.1	6.95	5.32	8.20
Higher Heating Value-as Received (Btu/lb)	13,260	10,982	8,340	7,810

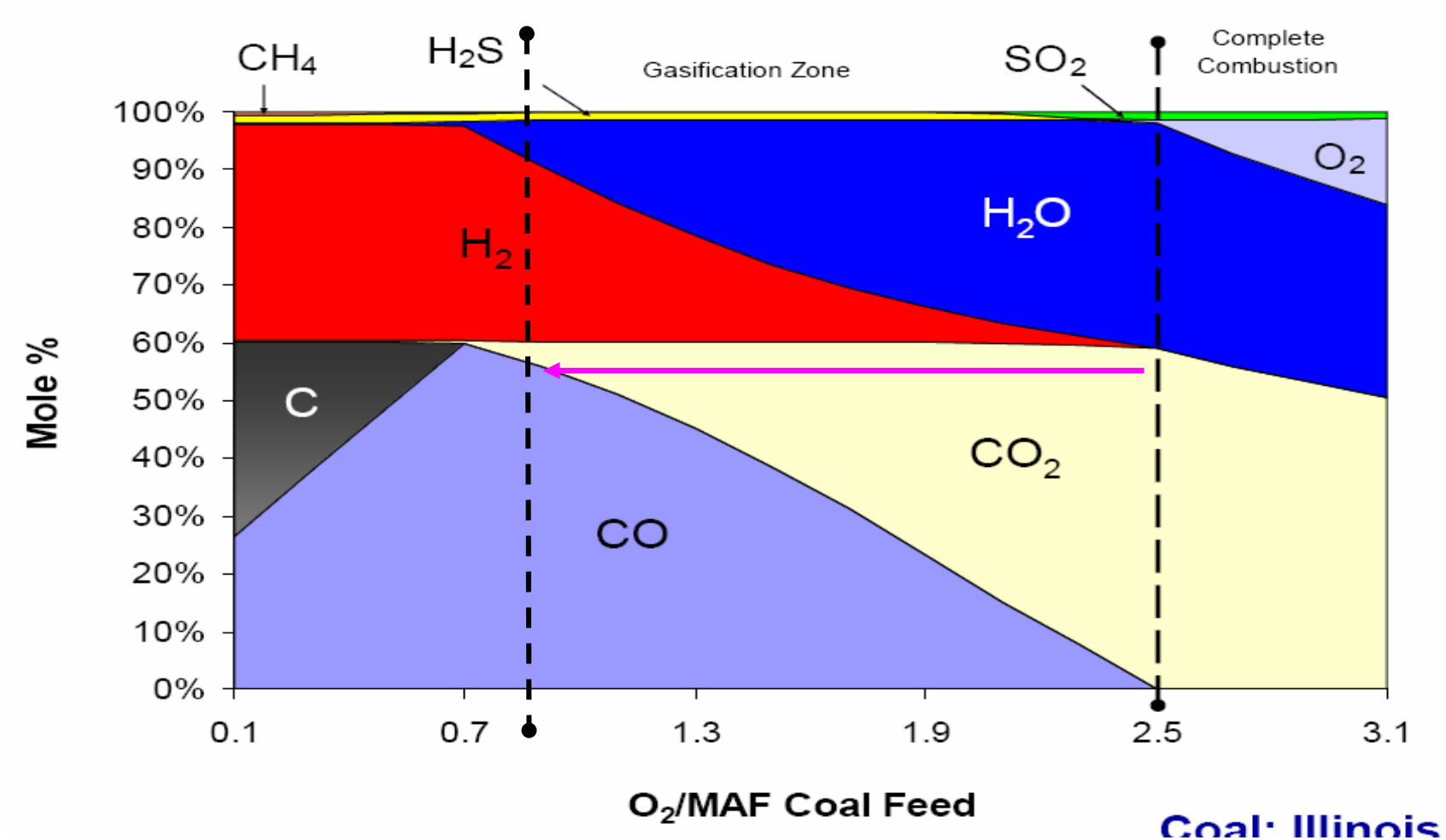
What happens when coal burns?

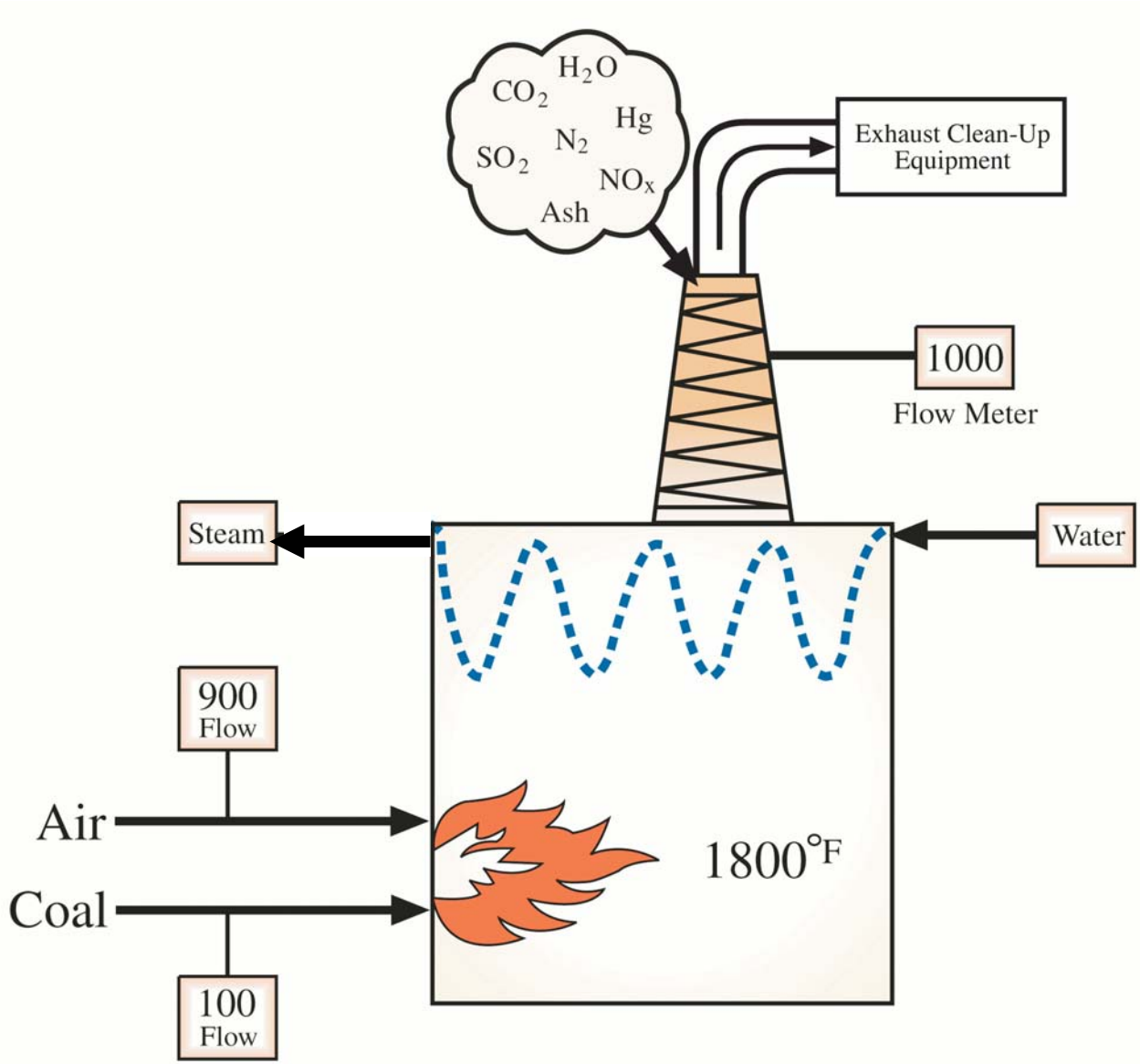
- Carbon => CO_2 (carbon dioxide)
- Ash => flyash
- Sulfur => SO_2, SO_3 (SOx)
- Nitrogen => N_2 and NOx
- Hydrogen => H_2O
- Mercury => Hg, $HgCl_2$
- Water => water vapor (H_2O)

What is gasification?

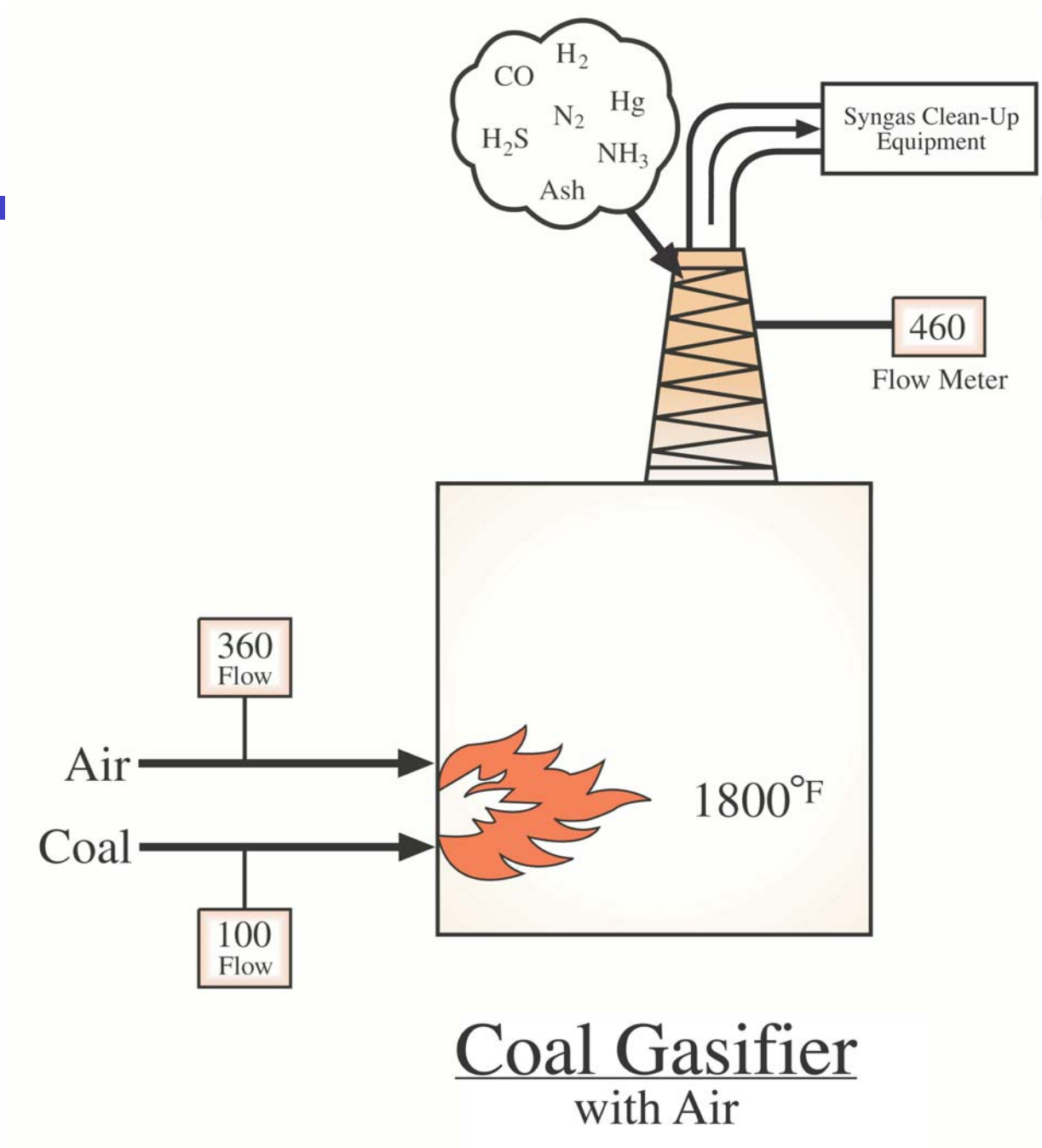
- Similar to combustion (burning) but with less than half the amount of oxygen needed to fully burn the coal
- Combustion: excess air
- Gasification: excess fuel (by a lot!!)

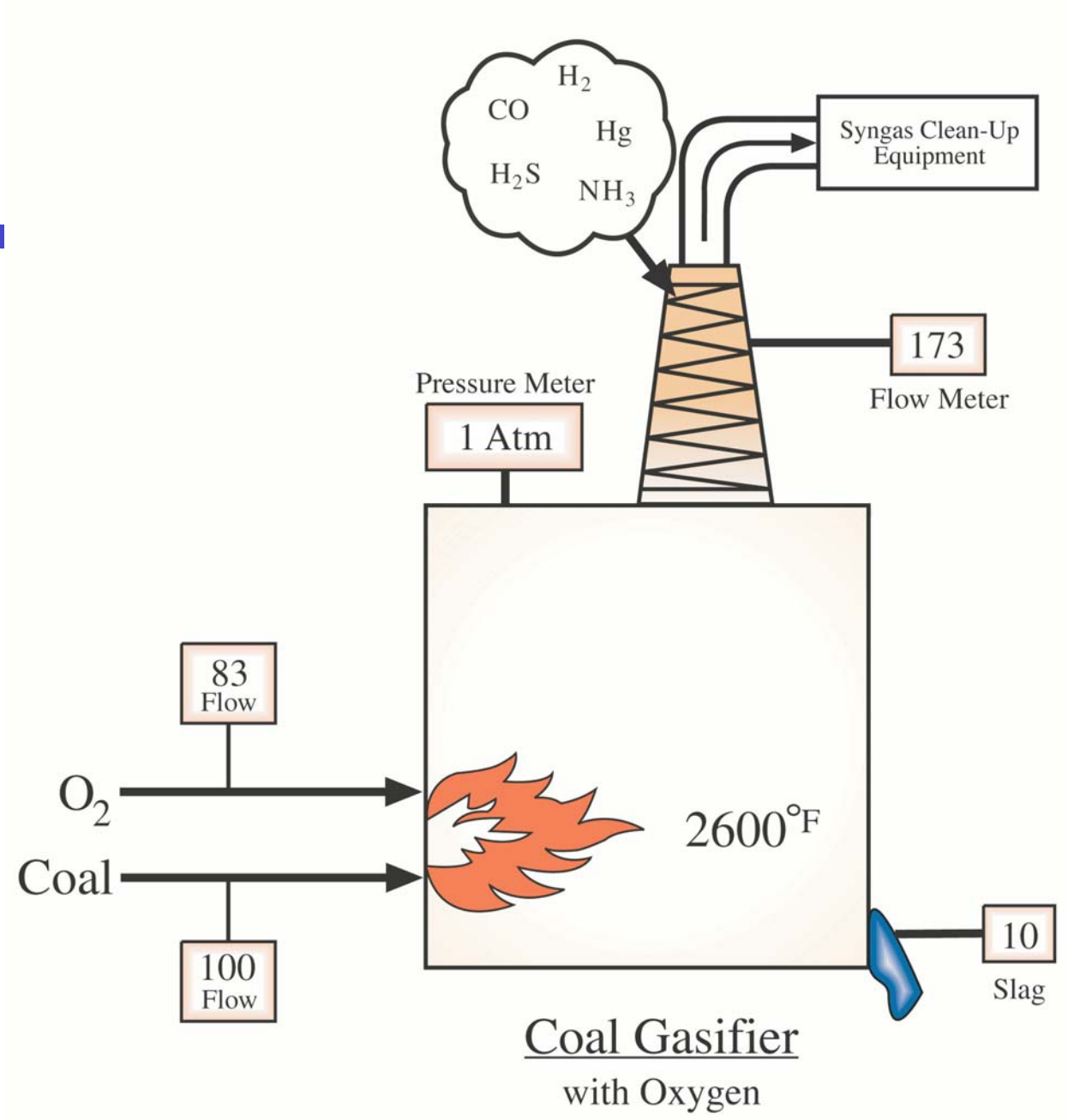
Combustion & Gasification Products

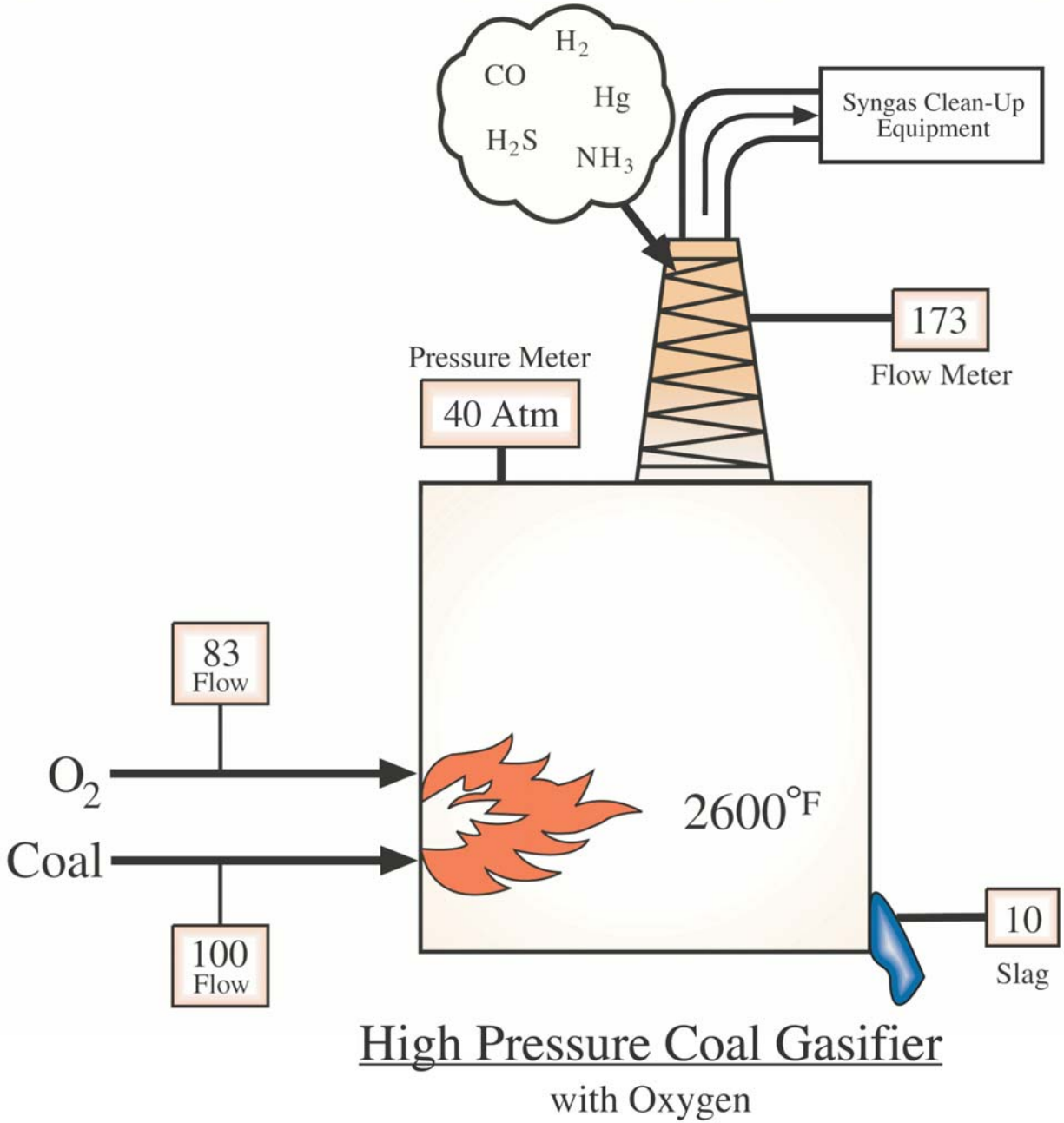




Coal Boiler







High Pressure Coal Gasifier

with Oxygen

Combustion vs Gasification

- SO_2 & SO_3 is scrubbed out of stack gas – reacted with lime to form gypsum
- NOx controlled with low NOx burners and catalytic conversion (SCR)
- Large volume of flyash & sludge
- Hg can be removed by contacting flue gas with activated carbon
- H_2S & COS are easily removed from syngas and converted to solid sulfur or sulfuric acid
- NH_3 washes out of gas with water, thermal NOx controlled by diluent injection in GT
- Ash is converted to glassy slag which is inert and usable
- >90% of Hg removed by passing high pressure syngas thru activated carbon bed

Vapor-Phase Mercury Removal

>94% Removal

Demonstrated for 21 years at Eastman !

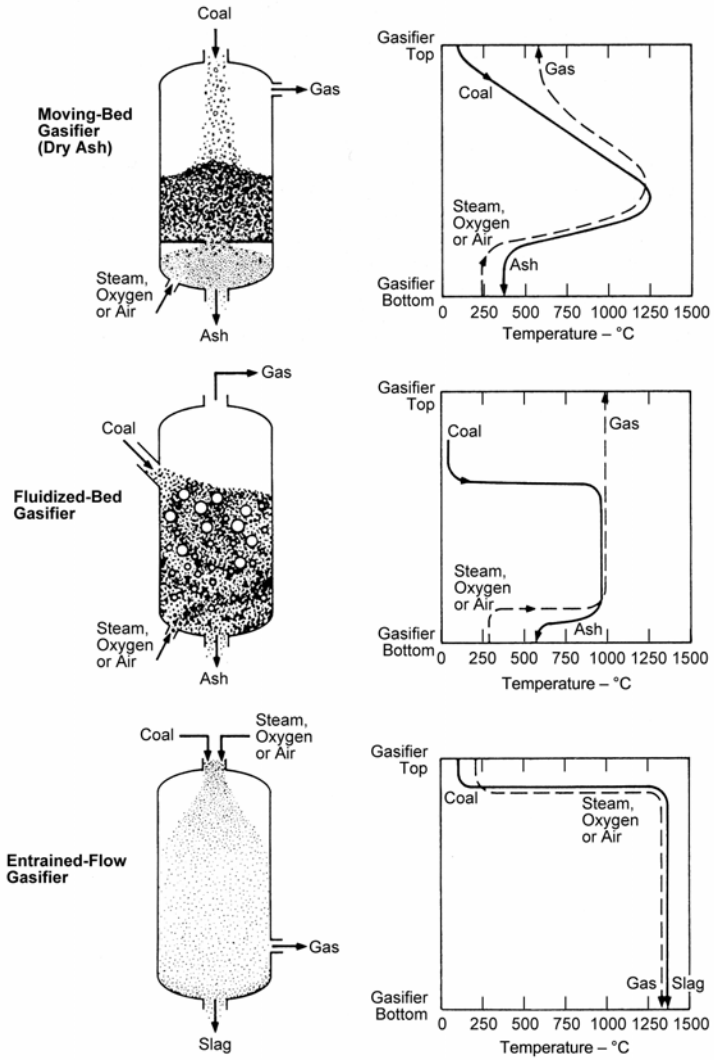
The cost of volatile mercury removal by IGCC is estimated to be < $0.25/MWh, almost an order of magnitude lower than for PC technologies using activated carbon, according to a 2002 DOE report by Parsons (DOE Report, "The Cost of Mercury Removal in an IGCC Plant", September, 2002).

Dakota Gasification Gasifier

- The dry ash (non-slagging) Lurgi gasifier is used in Dakota Gasification's lignite-to-natural gas plant
- The Lurgi process was developed in the 1930s, and was the only "mature" gasification process available when the Dakota project was initiated (circa 1980)
- The Lurgi process operates at relatively low temperature and has some undesirable characteristics
  - Cannot handle coal fines, produces tars & phenols as well as syngas, bottom ash instead of slag
- Since 1980 several "second generation" gasification processes have been developed which avoid some of the Lurgi process' undesirable characteristics

The 3 Major Types of Gasification Processes

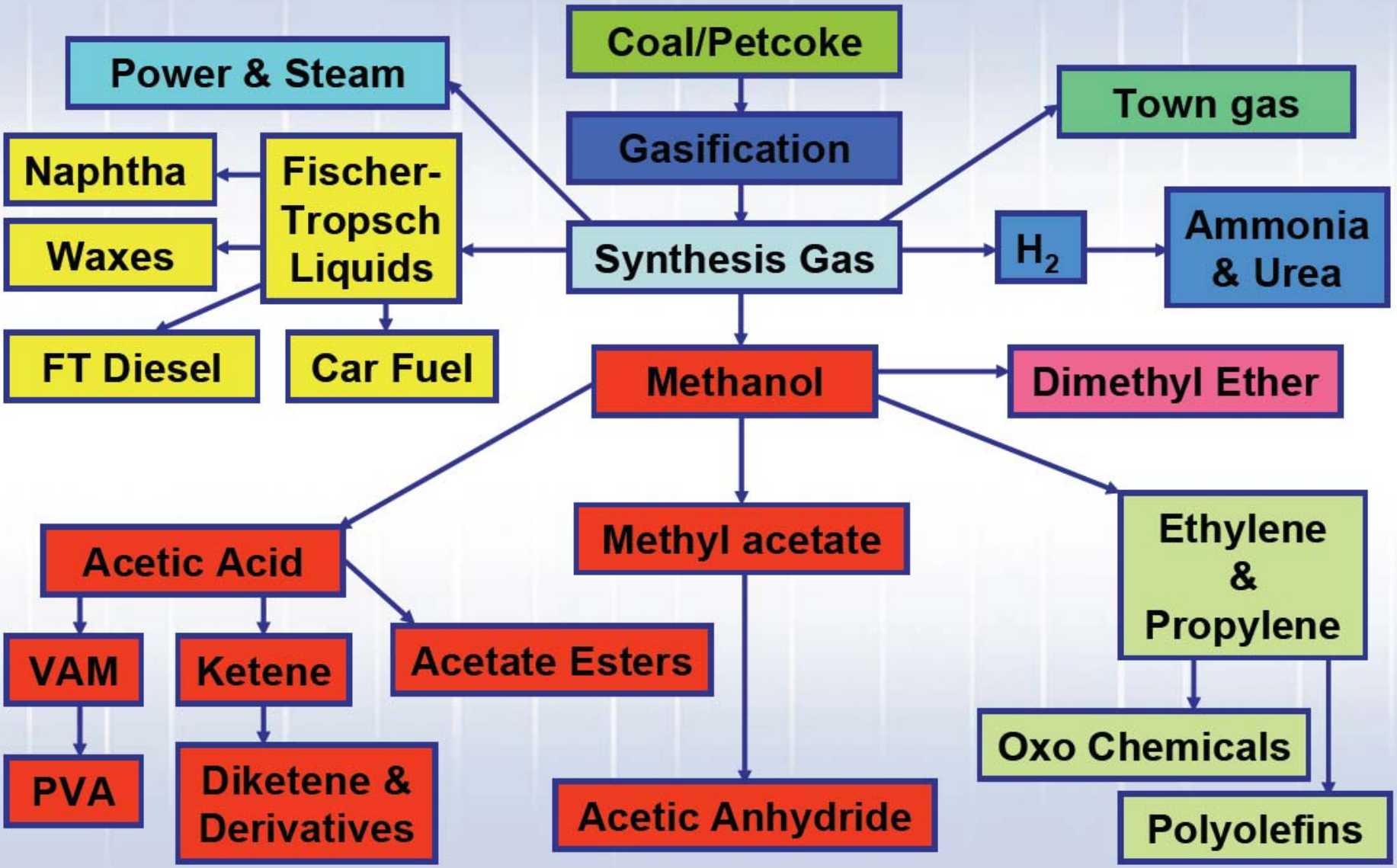
1. **Moving-Bed Gasifier (e.g., Lurgi)**
2. **Fluidized-Bed Gasifier (e.g., KBR/Southern)**
3. **Entrained-Flow Gasifier (e.g., GE Energy, ConocoPhillips, Shell, Siemens)**



What can you do with coal gasification?

- **Produce Electricity**
  - In a Gas Turbine-based Combined Cycle power plant
  - Emissions approaching that of a natural gas fired power plant
- **Make Fuels**
  - Sasol has been making gasoline from coal since the 1950s in Republic of South Africa
  - Dakota Gasification has been making “synthetic’ natural gas from lignite since the 1980s
- **Make Chemicals**
  - Eastman Chemicals has been doing this since 1980s
- **Make Fertilizer**
  - Coffeyville Resources in Kansas makes ammonia-based fertilizer from petroleum coke

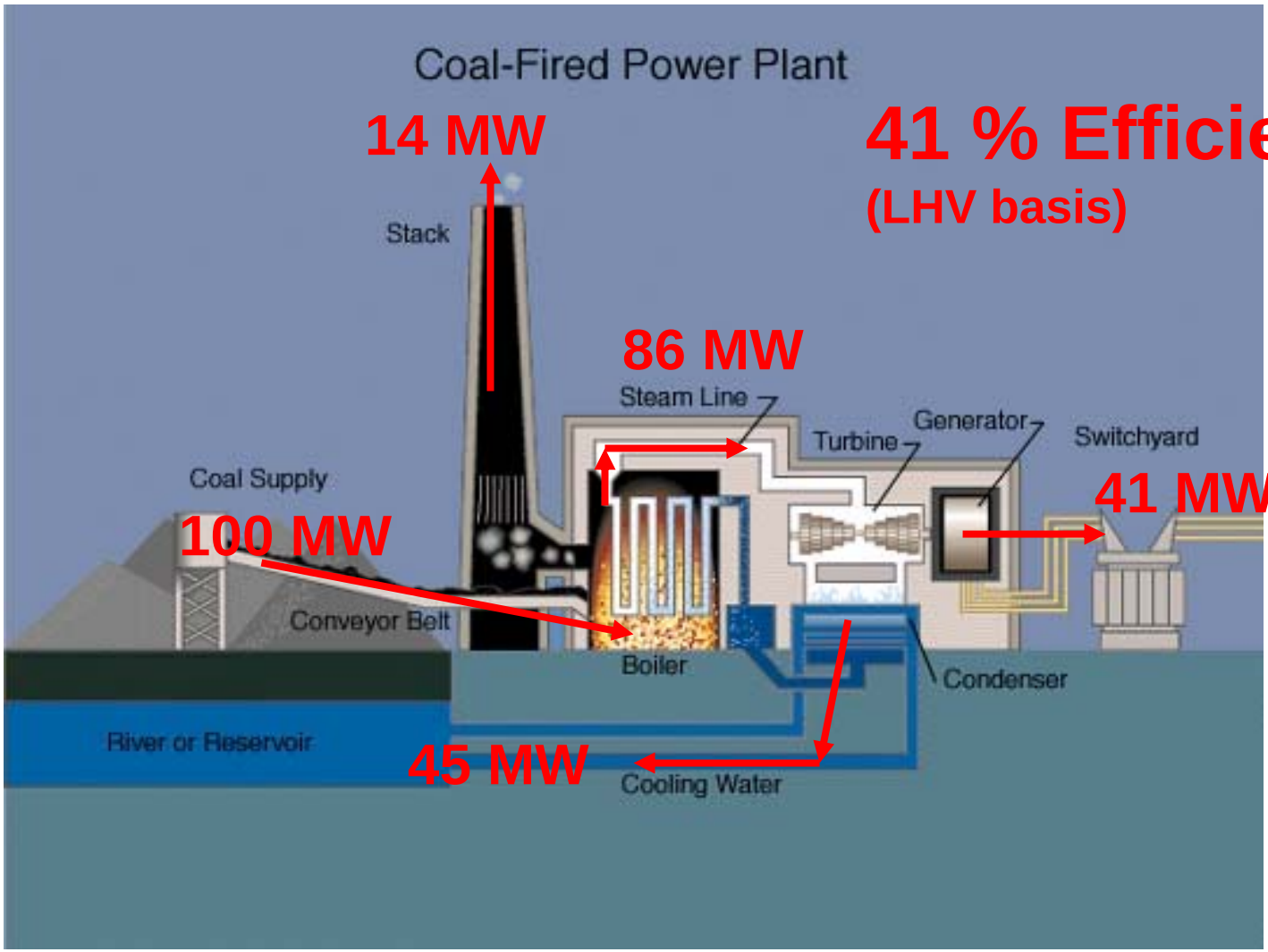
Improved Economics via Polygeneration



Steam Cycles vs “Combined” Cycles

- Steam Cycles have
  - a boiler
  - a steam turbine
    - Referred to as “Rankine” cycle, fossil boiler, “fossil steam” plant, “conventional coal” plant
- Combined Cycles (the “CC” in IGCC) have
  - a Gas Turbine
  - a “heat recovery steam generator” (HRSG)
  - a steam turbine

Conventional Coal Plant



Gas Turbine

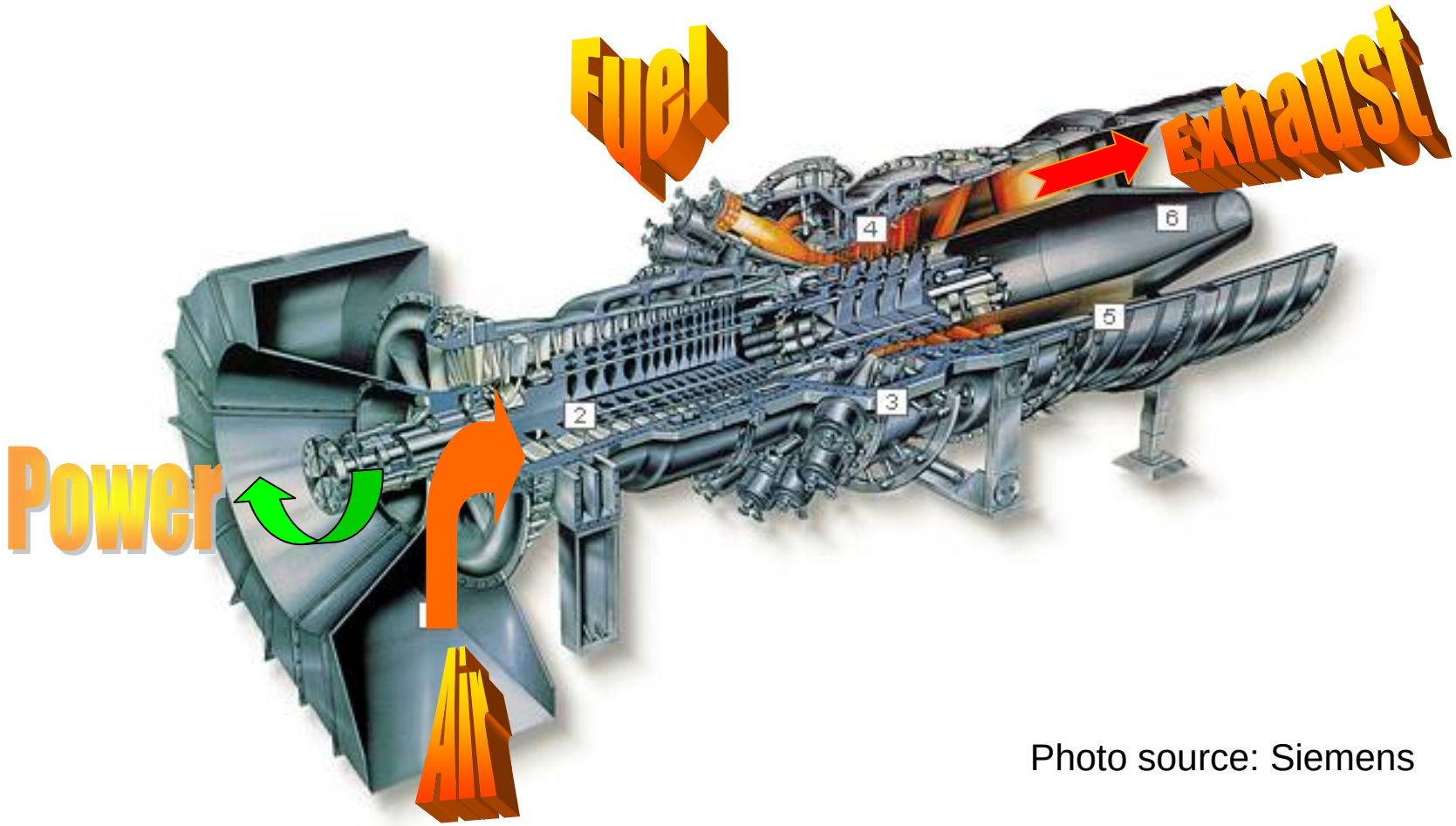
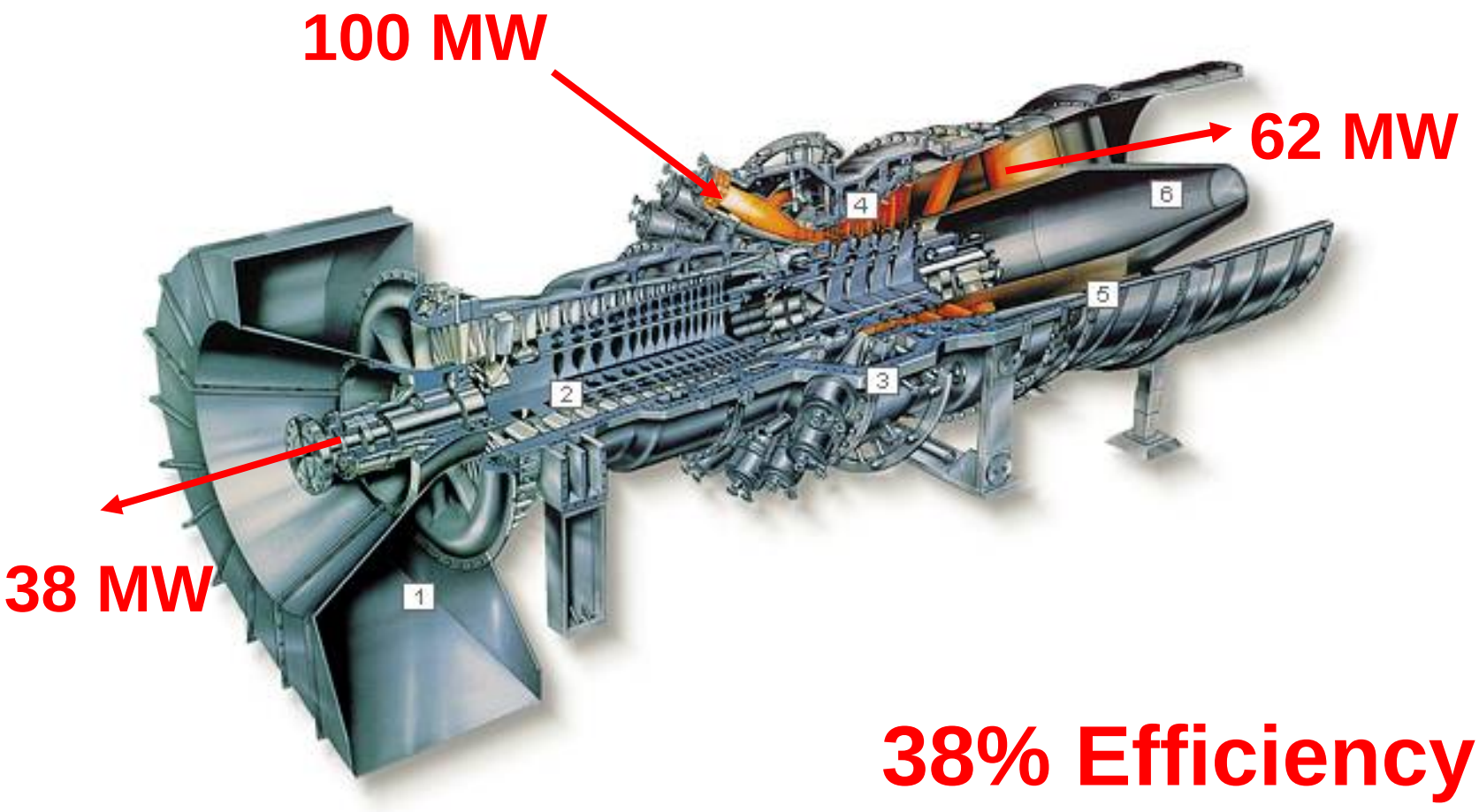


Photo source: Siemens

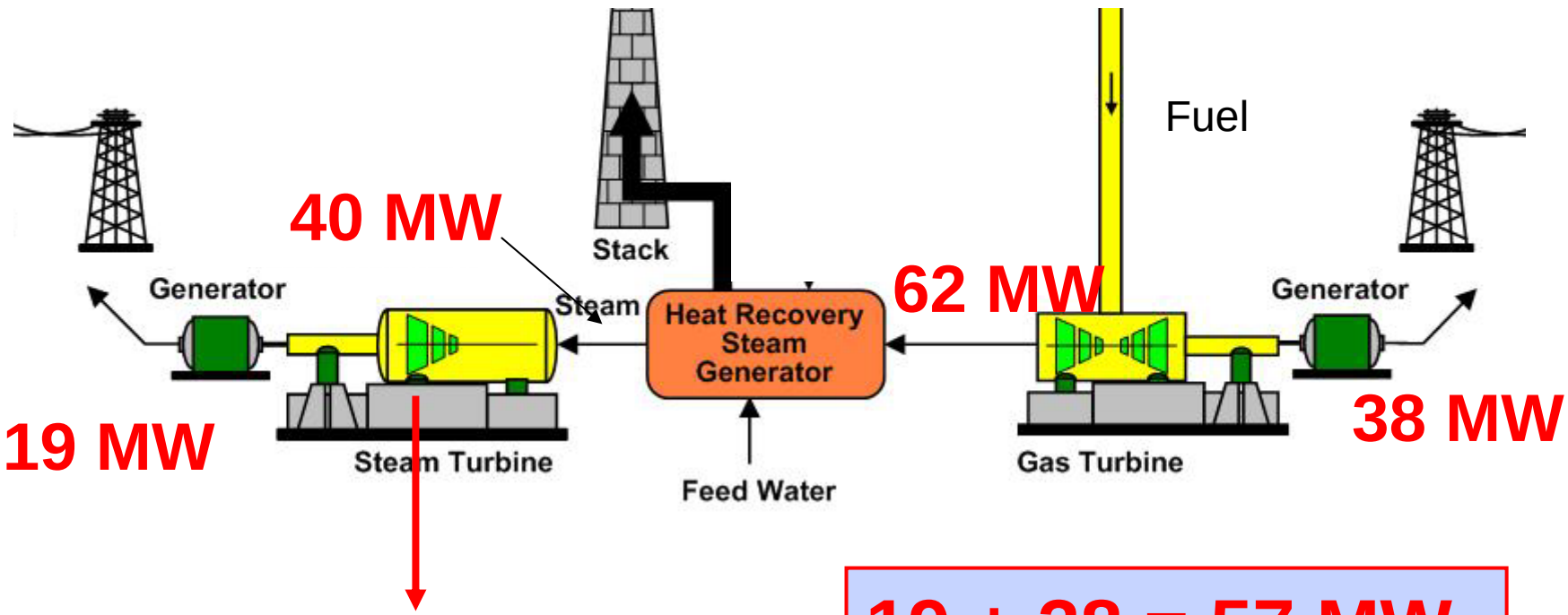
Gas Turbine “simple cycle”



38% Efficiency

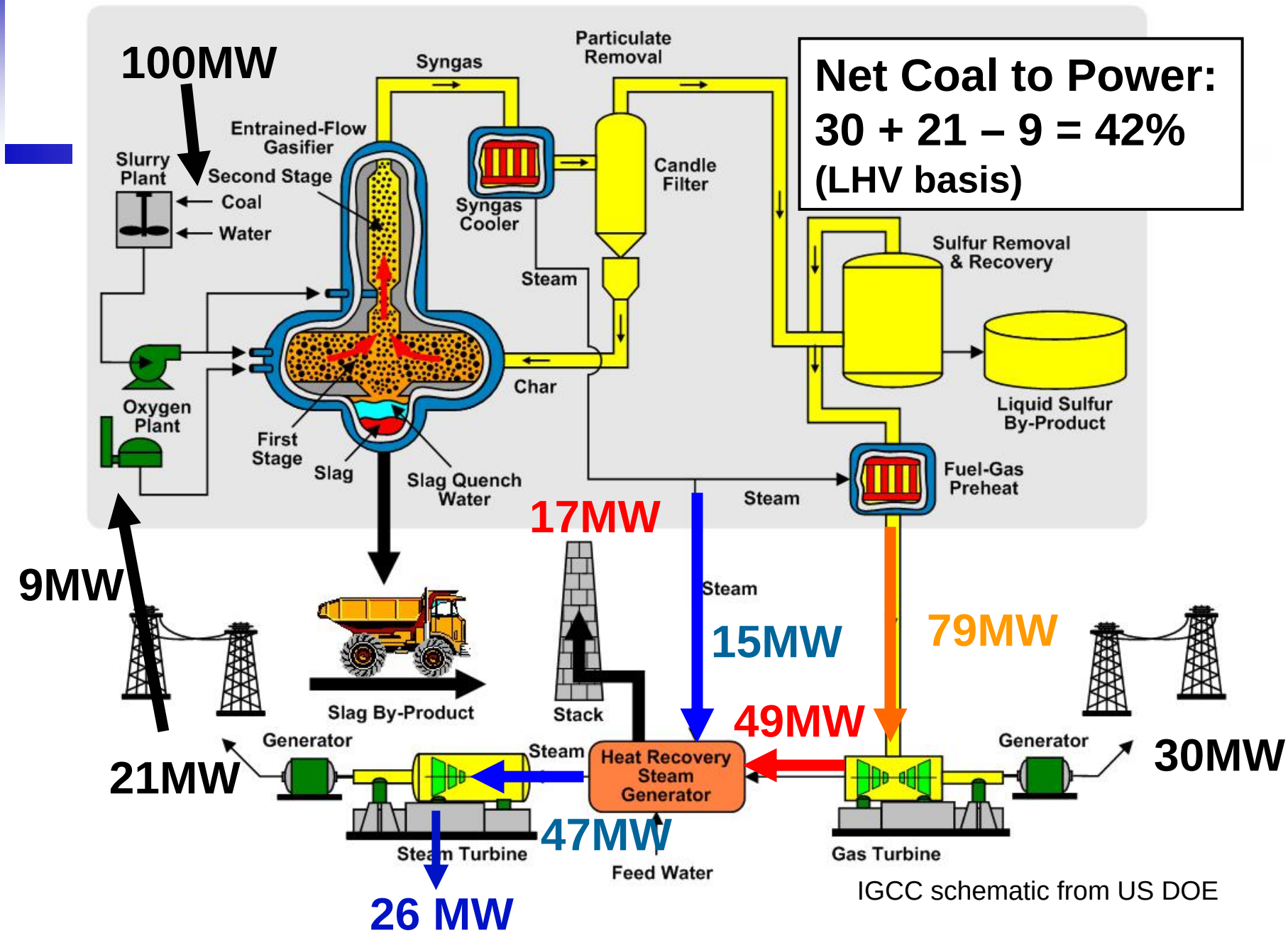
(LHV basis)

Combined Cycle



21 MW to condenser

19 + 38 = 57 MW
57% Efficiency!
(LHV basis)



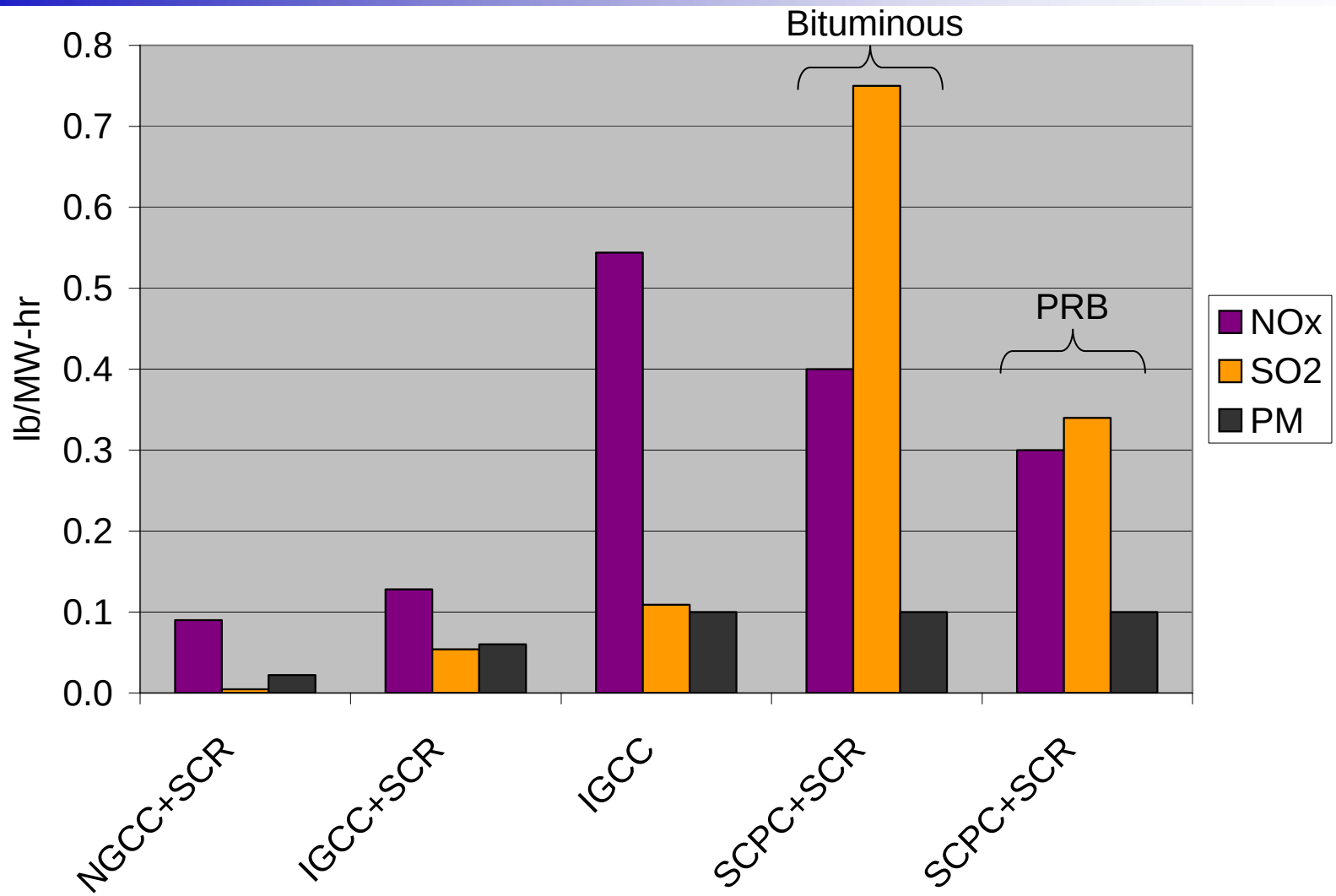
IGCC schematic from US DOE

Comparison to other fossil fuel power generation options

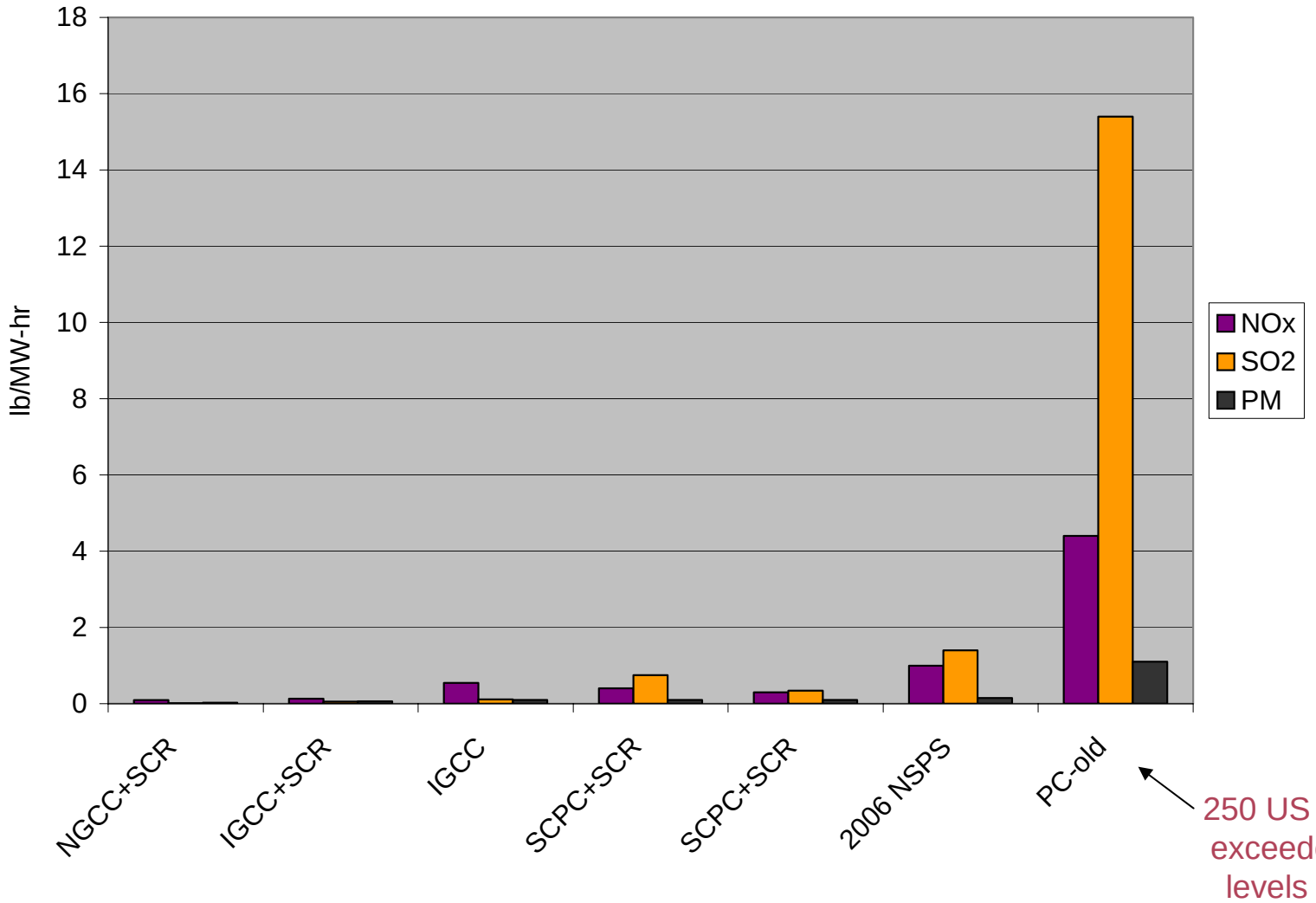
- Emissions
- Greenhouse gases
- Cost of Electricity

Emissions Comparison – State-of-the-Art Coal Combustion, IGCC, and NGCC

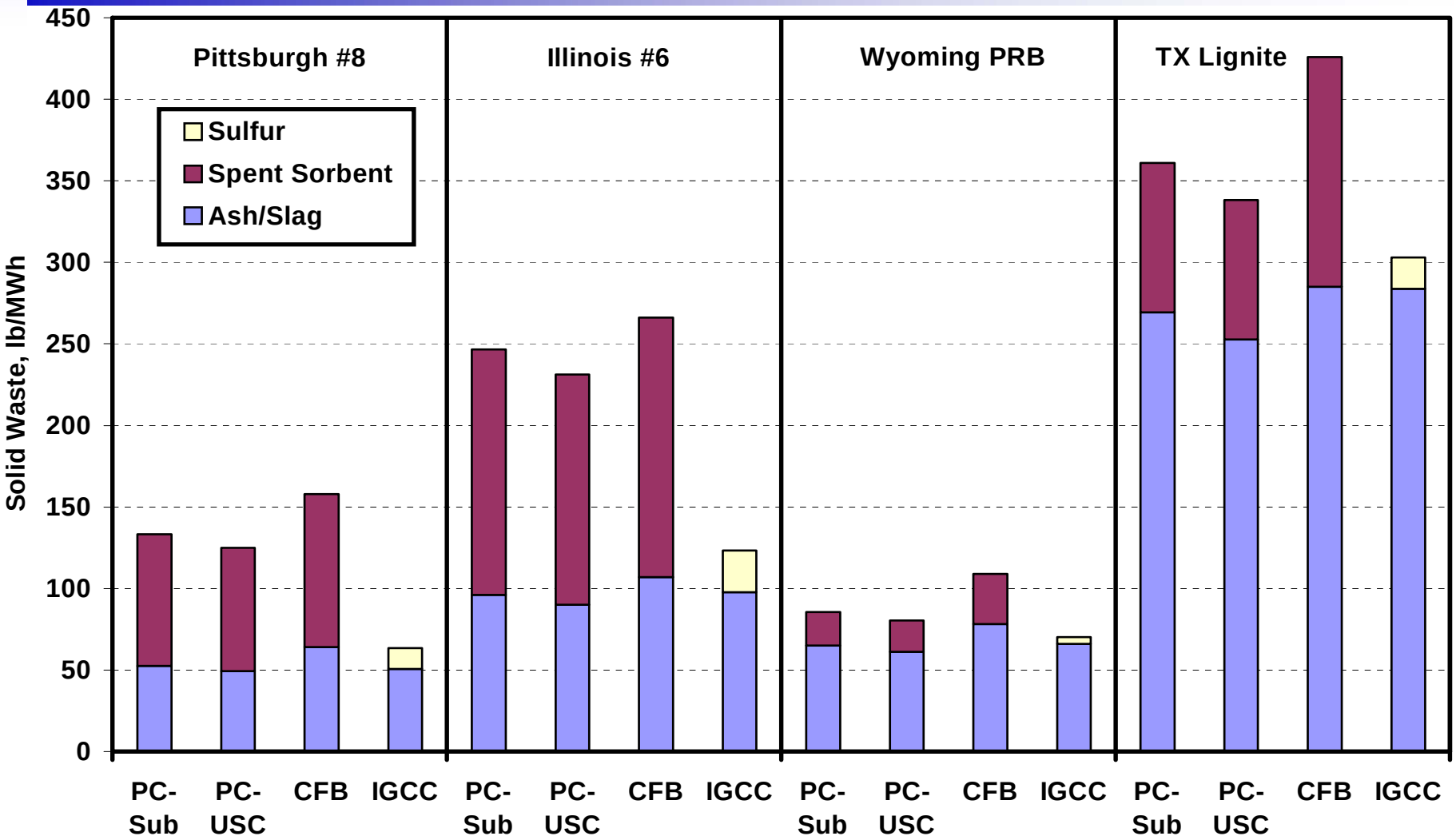
Values represent technology capability, not permit levels



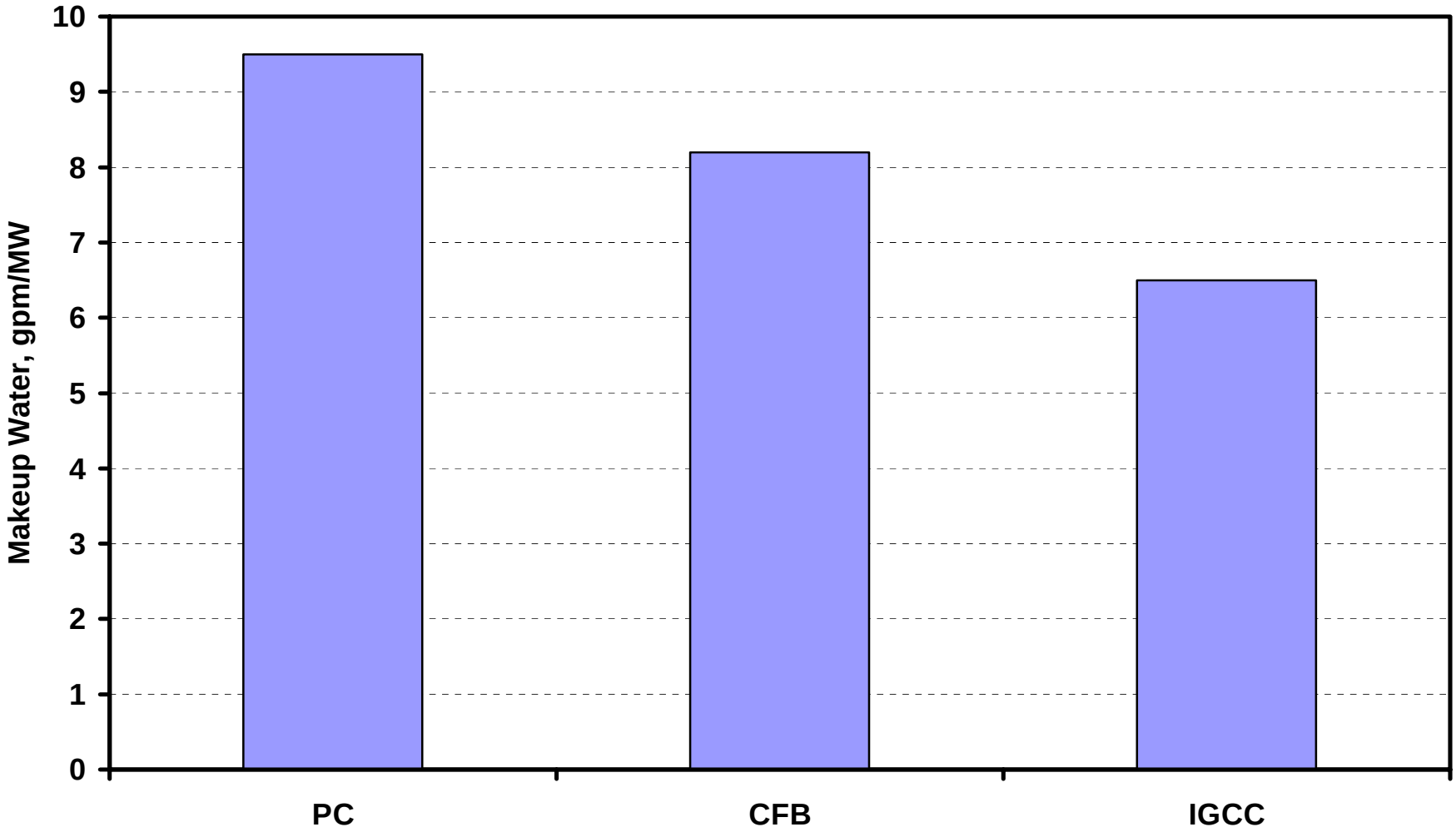
Emissions Comparison with Older Coal Plants and Federal Standards



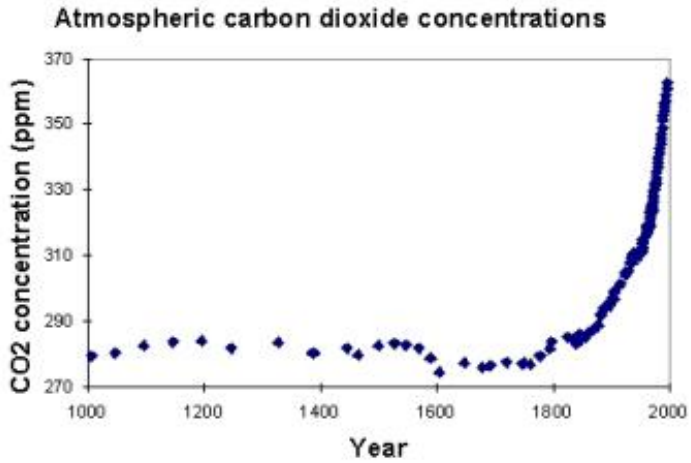
Solid Waste Comparison
(Based on nominal 500 MW plant size)



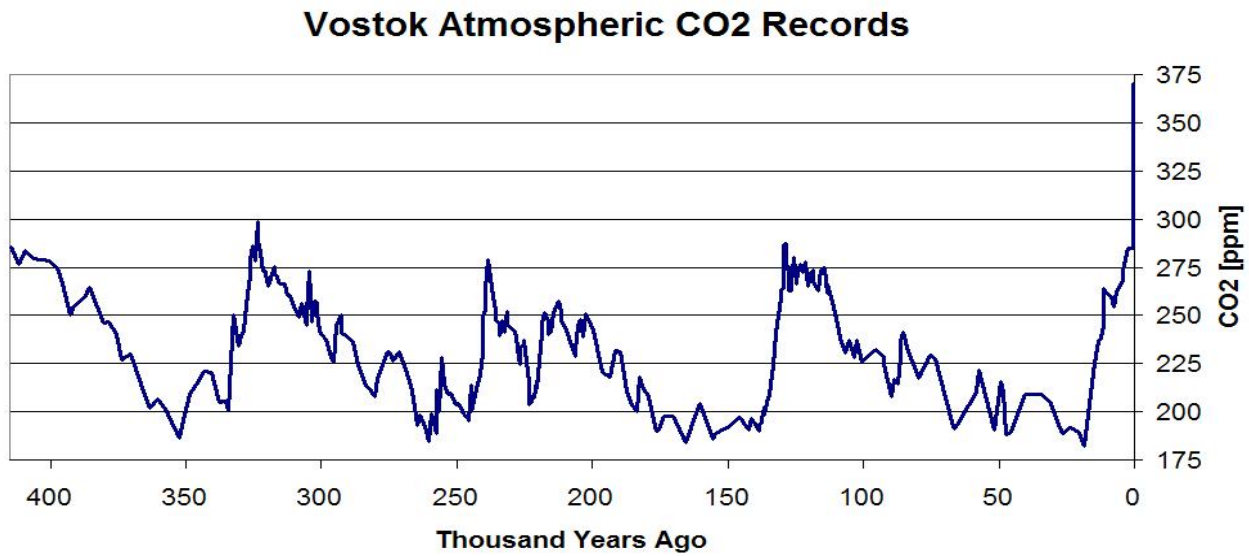
Makeup Water Comparison



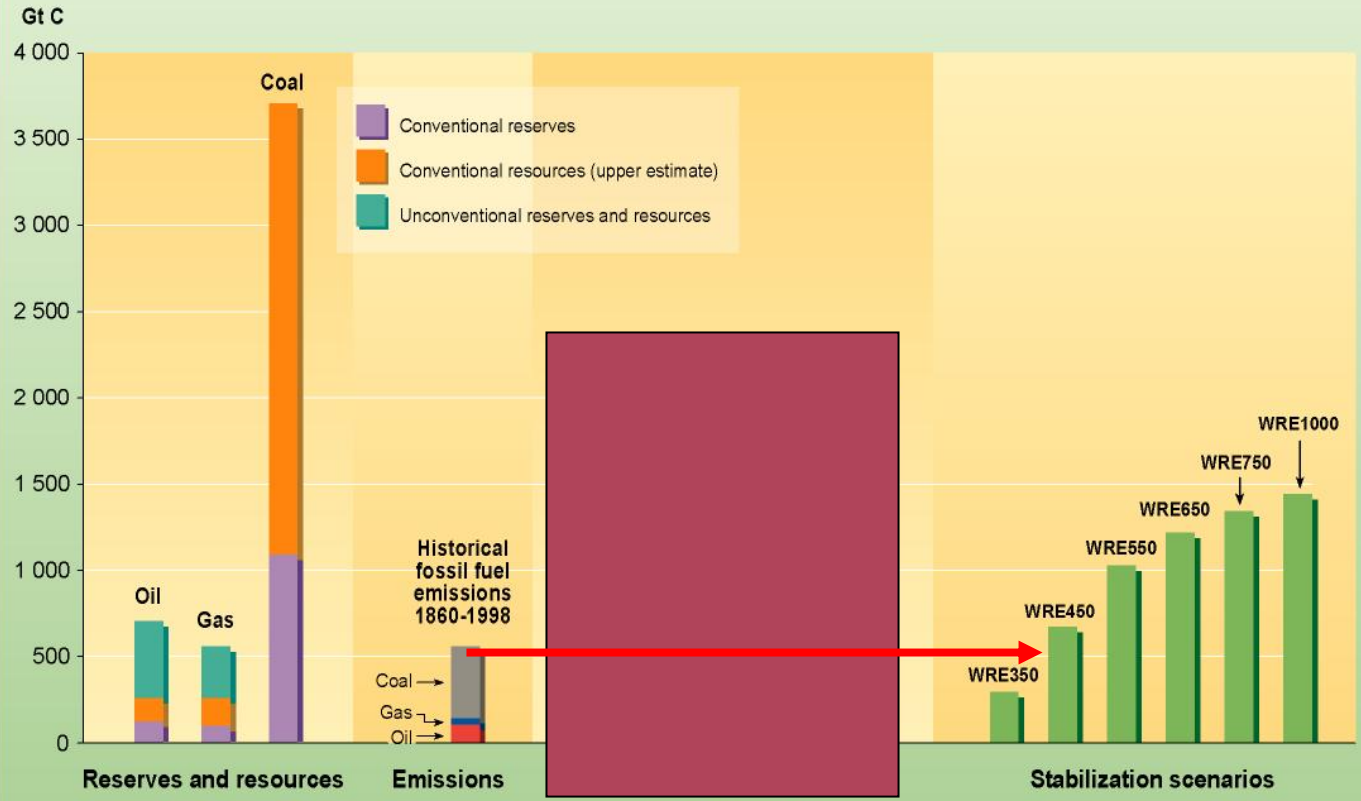
Atmospheric CO2 Trends



Source: CSIRO Atmospheric Research, www.cmar.csiro.au

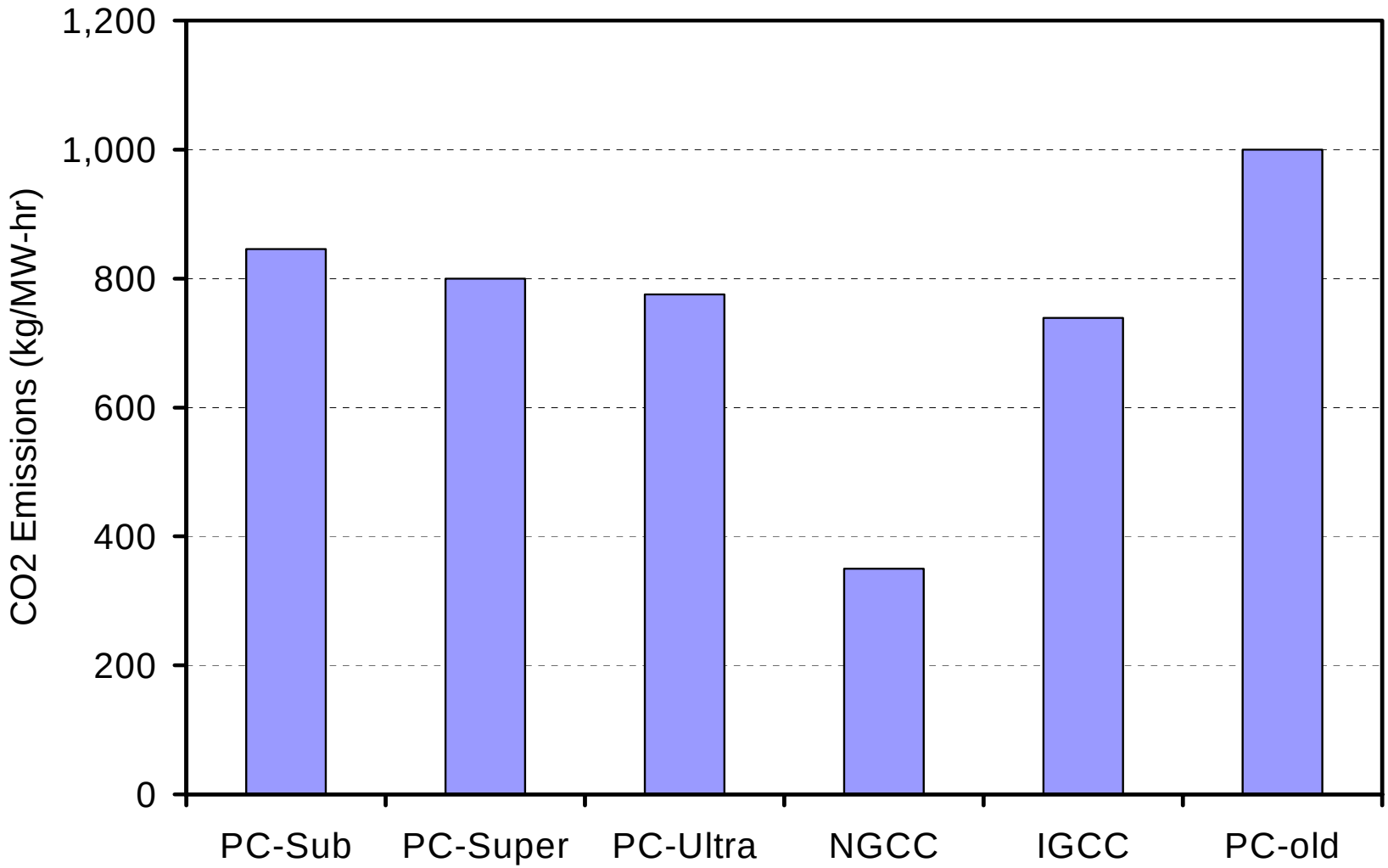


Carbon in fossil fuel reserves and resources compared with historical fossil fuel carbon emissions, and with cumulative carbon emissions from a range of SRES scenario and TAR stabilization scenarios up until the year 2100

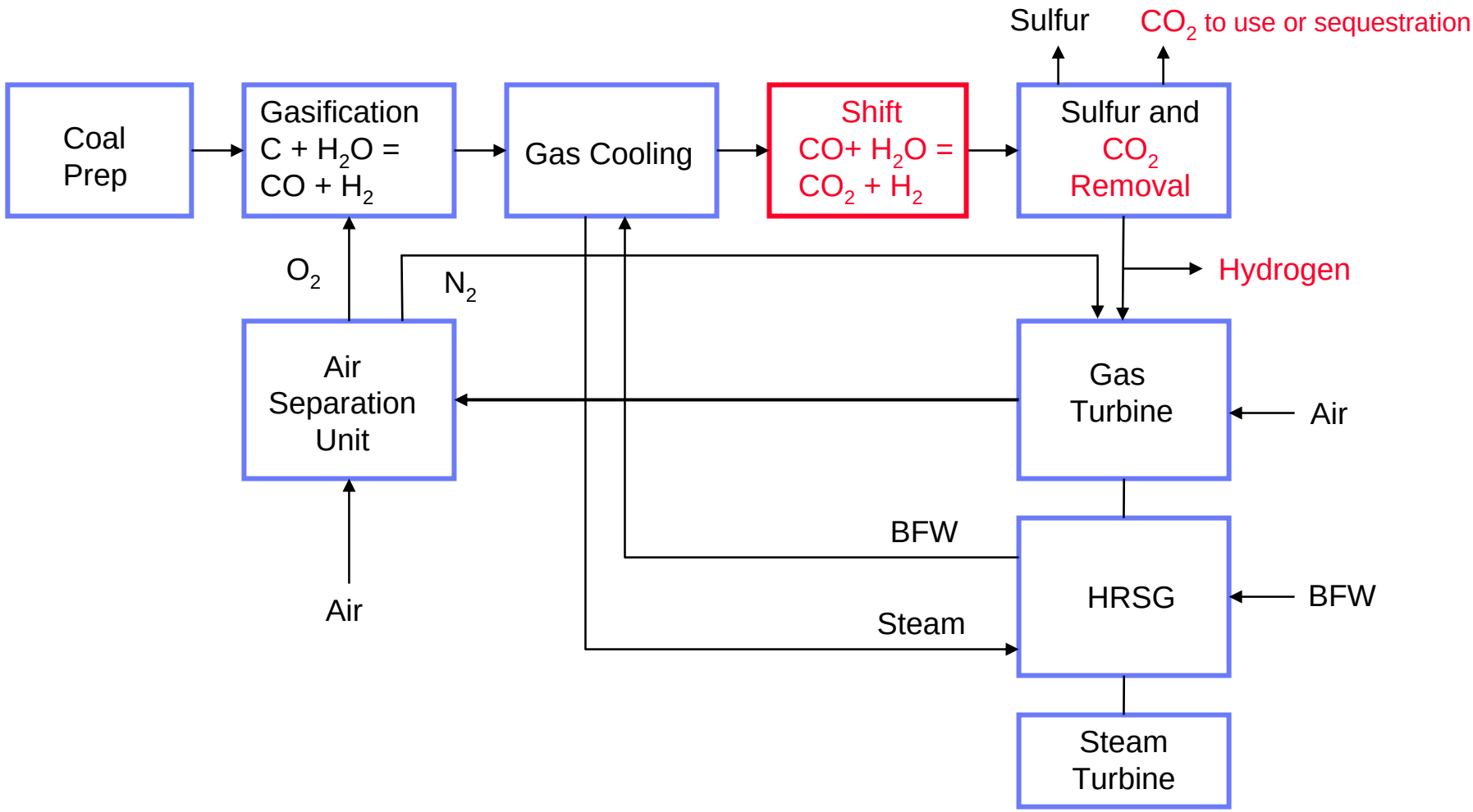


SYR - FIGURE 7-5

CO_2 Emissions without CO_2 Capture



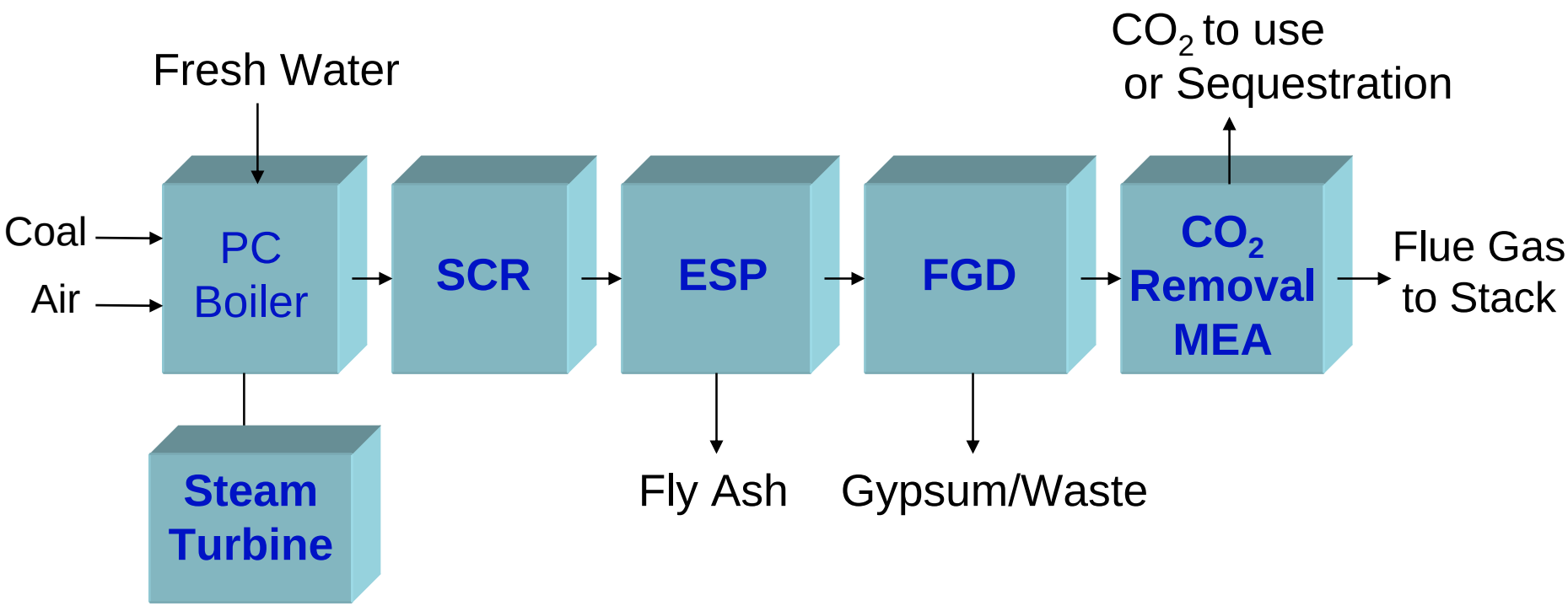
IGCC with CO_2 Removal and Optional Hydrogen Co-Production



FutureGen Project

- A 275 MW (nominal) IGCC with CO_2 capture and H_2 export
  - Coal gasification followed by water-gas shift reaction
  - 90% of CO_2 will be removed from syngas, compressed to circa 2000 psia and injected into deep geologic formations for sequestration
  - Remaining syngas will be primarily H_2
    - Small slipstream will upgraded to high purity H_2 and sold "over the fence"
    - Balance will be fired in an advanced combined cycle
- Site selection RFP issued in March 2006
- Operation targeted to begin in 2012

Pulverized Coal (PC) with CO_2 Removal

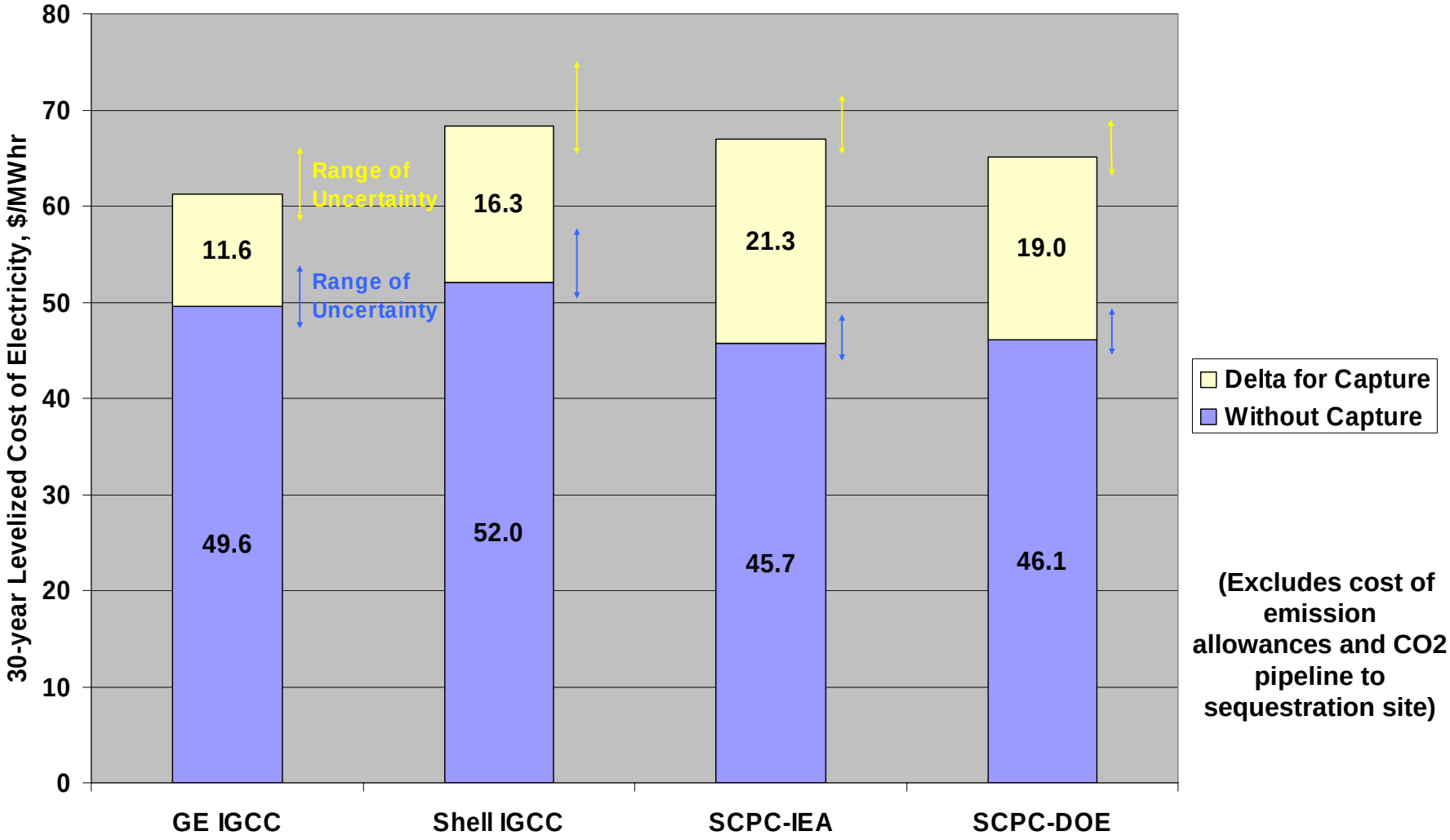


CO_2 Capture Comparison

	Exhaust or Syngas Pressure	CO_2 Volumetric Concentration	CO_2 Partial Pressure
Natural Gas Combined Cycle Exhaust	14.7 psia	4%	0.6 psia
Supercritical Coal Boiler Exhaust	14.7 psia	13%	1.9 psia
IGCC Syngas	825 psia	40%	330 psia

Impact of CO2 Capture

Results from recent IEA & US DOE studies on bituminous coal adjusted to standard EPRI economic inputs, $2/MMBtu coal, 85% capacity factor, 2005 USD



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The End