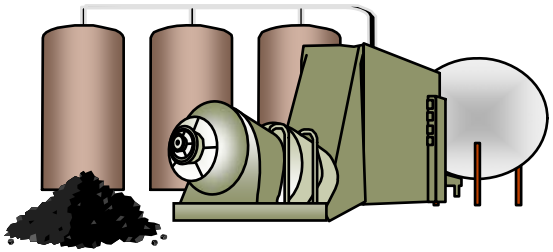
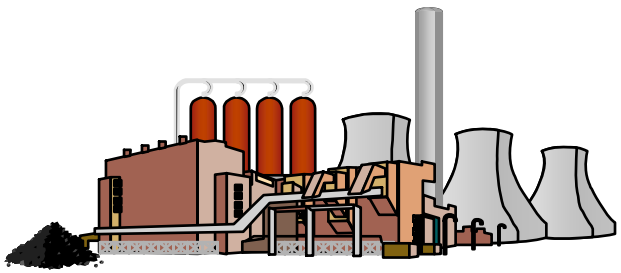


IGCC + CO_2 Capture



Ultrasupercritical

+ CO2 Capture

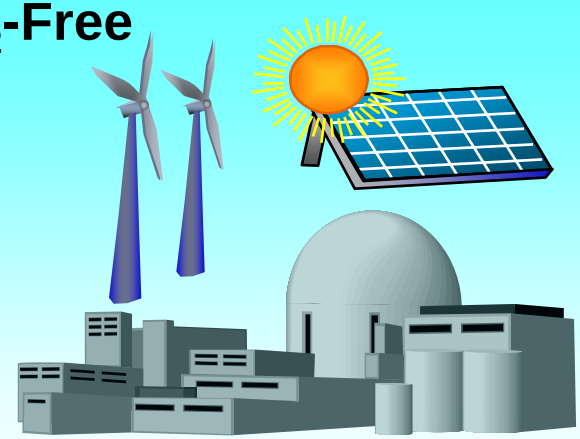
Overview of Advanced Coal Technology for Electric Power Generation

Stu Dalton
Director, Generation
John Novak
Executive Director of Federal Industry Activities

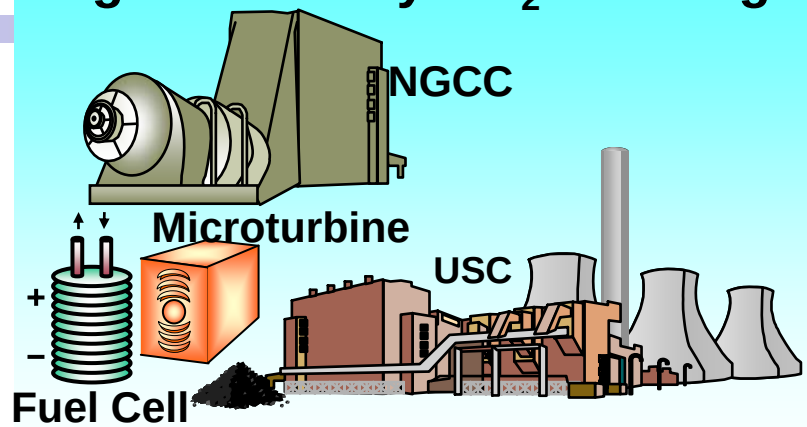
EPA Advanced Coal Technology Work Group
Washington DC January 8, 2007

Power Company Carbon Management Options

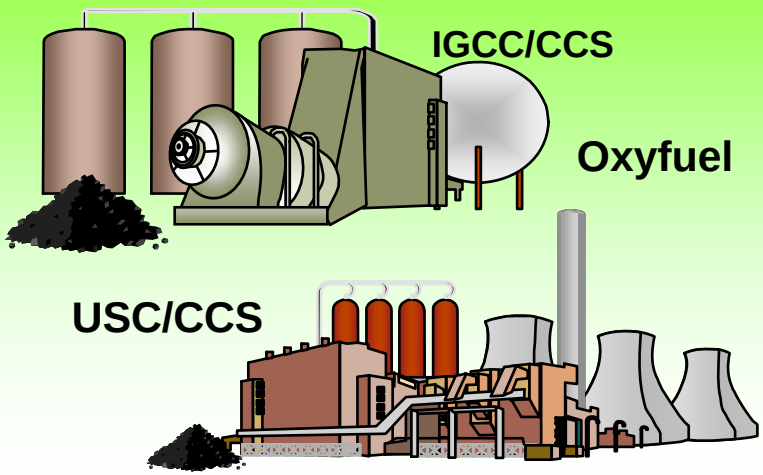
CO_2-Free



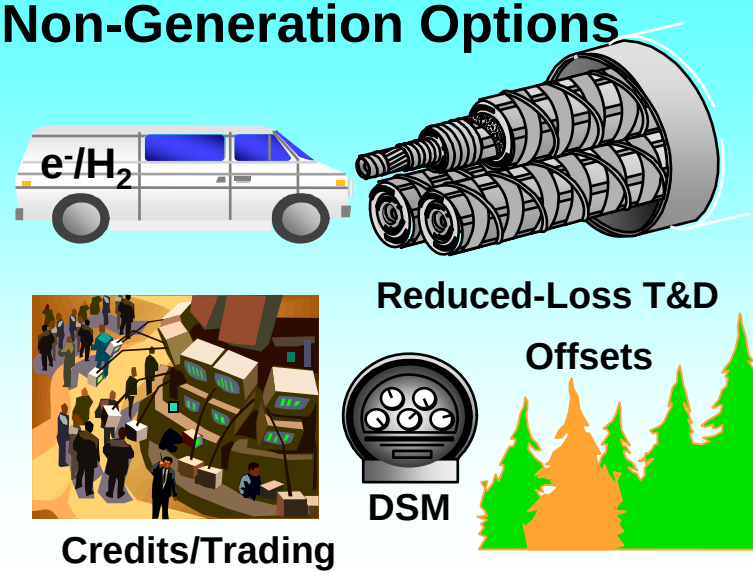
High-Efficiency CO_2-Emitting



CO_2- with Capture Technology



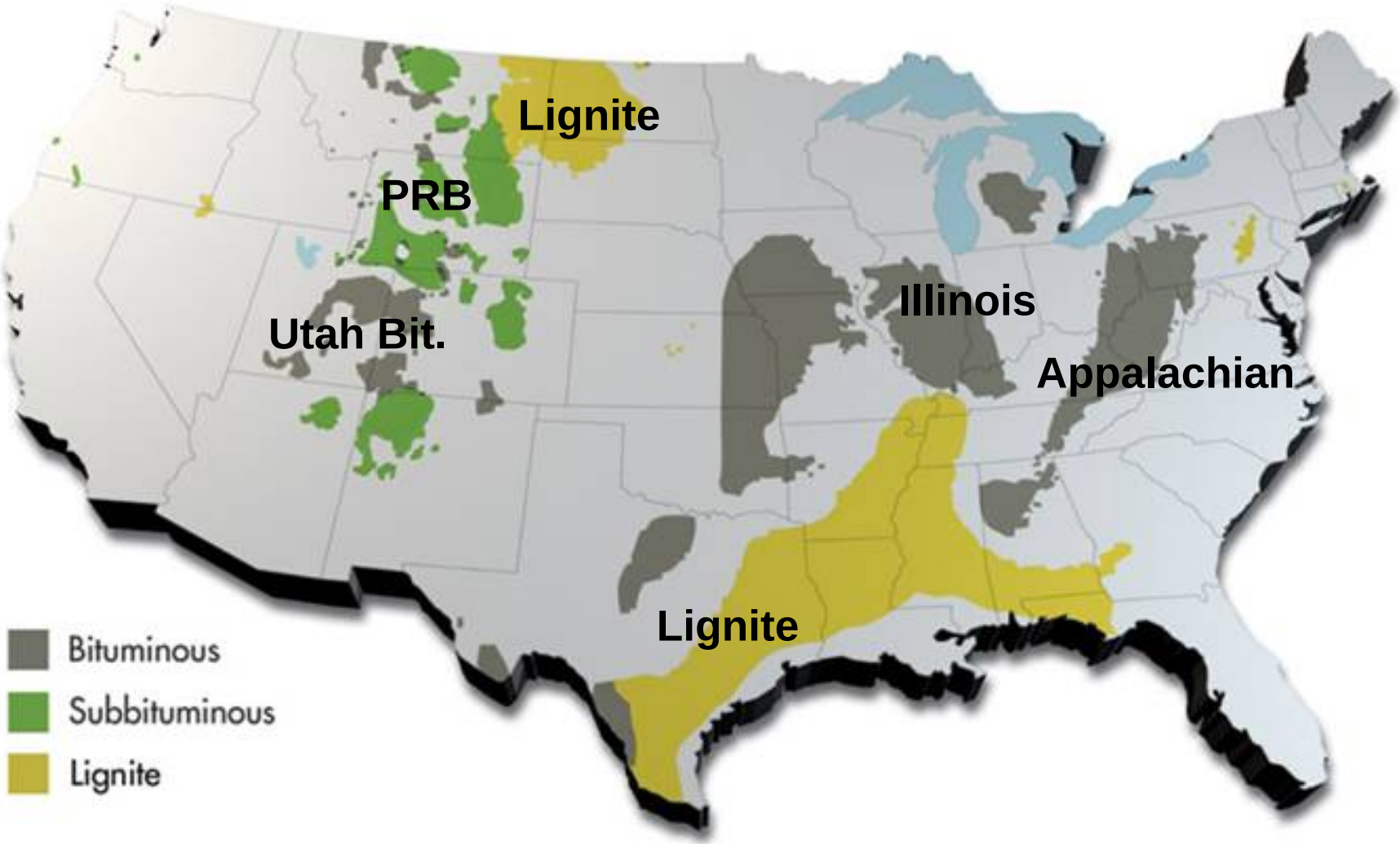
Non-Generation Options



What is coal???

- Carbon
- Ash (rock)
- Sulfur
- Nitrogen
- Hydrogen
- Water
- Trace Elements, e.g. mercury

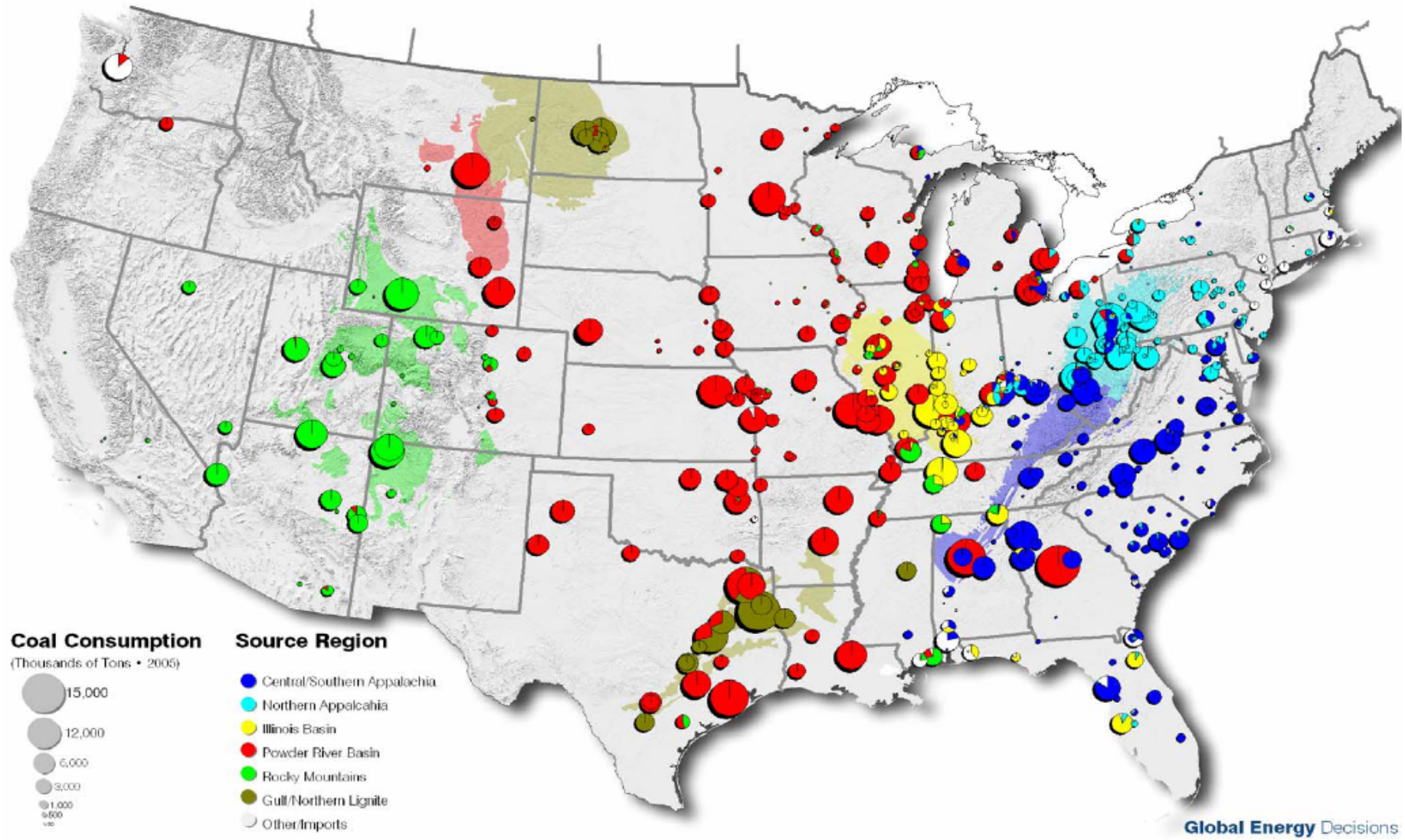
U.S. Coal Types and Basins



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

	Pittsburgh	Illinois	Wyoming	Texas
	#8	#6	PRB	Lignite
Ultimate Analysis				
Moisture	5.2	12.2	30.24	33.03
Carbon	73.8	61.0	48.18	35.04
Hydrogen	4.9	4.25	3.31	2.68
Nitrogen	1.4	1.25	0.70	0.77
Chlorine	0.07	0.07	0.01	0.09
Sulfur	2.13	3.28	0.37	1.16
Oxygen	5.4	6.95	11.87	11.31
Ash	7.1	11.0	5.32	15.92
Higher Heating Value as received (Btu/lb)	13,260	10,982	8,340	6,010

Coal Consumption Patterns - 2005



Technology Costs and Emissions

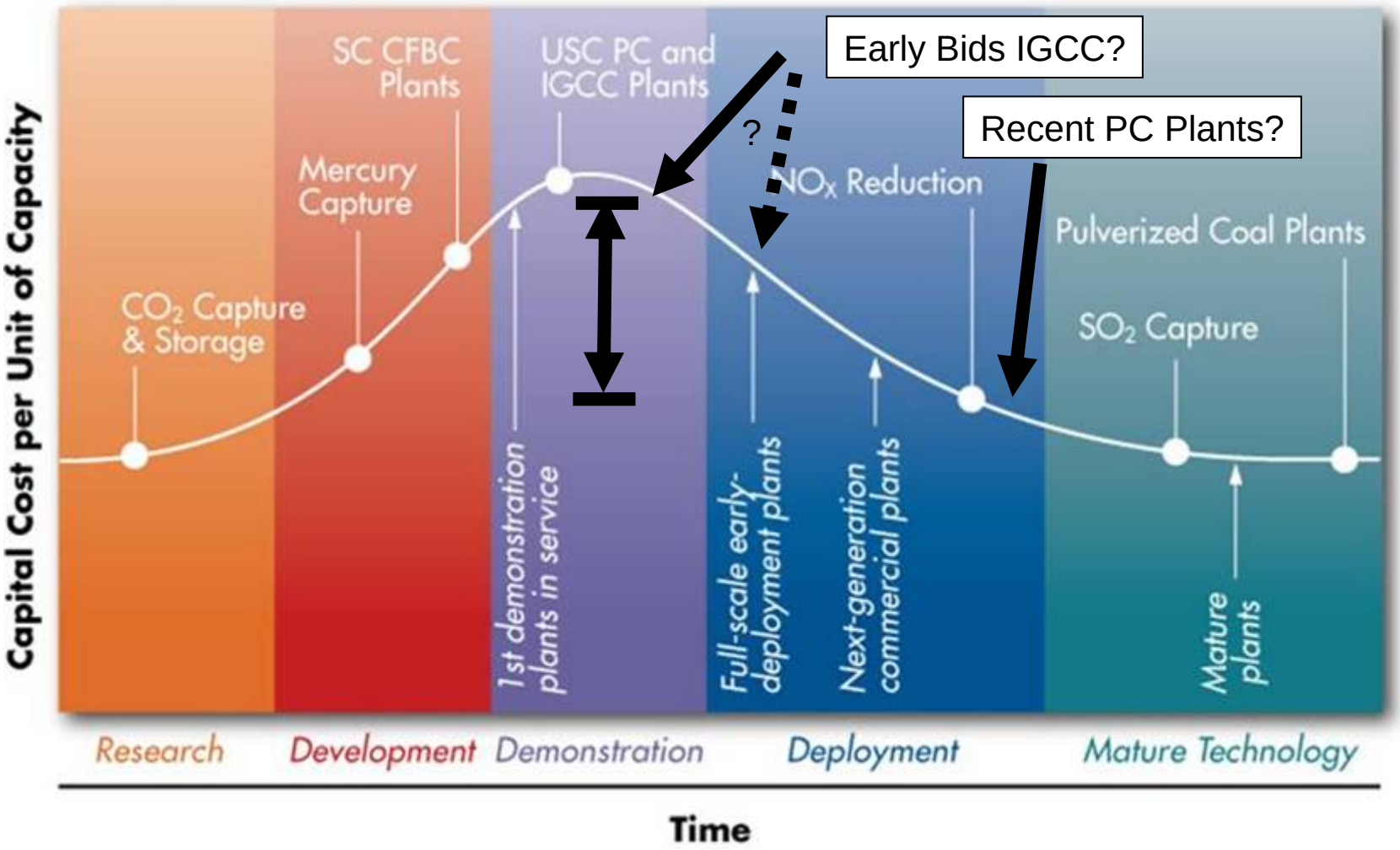
- Technology Costs
  - Maturity and cost for FOAK plants
  - Construction Indices
  - Reported Costs show cost significant growth

Costs are up – especially for IGCC

- Emissions (NOx & SOx)
  - Existing and Planned IGCC & PC

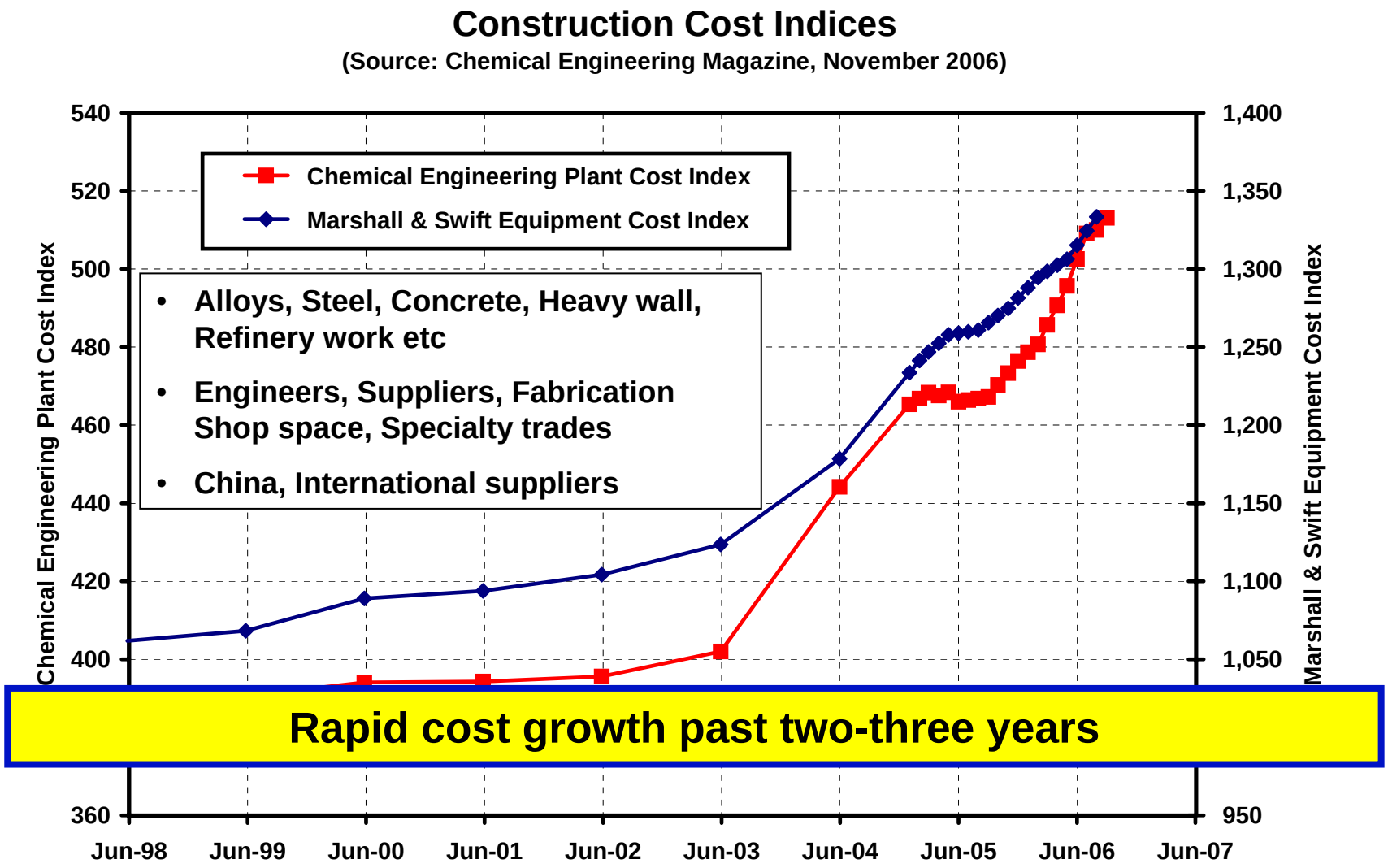
All coal plants are reducing emissions in permits – all very low

Costs of First of a Kind Technology vs. More Mature Technology?



Anecdotal IGCC costs not as low as expected >20% gap

Plant Construction Costs Escalating



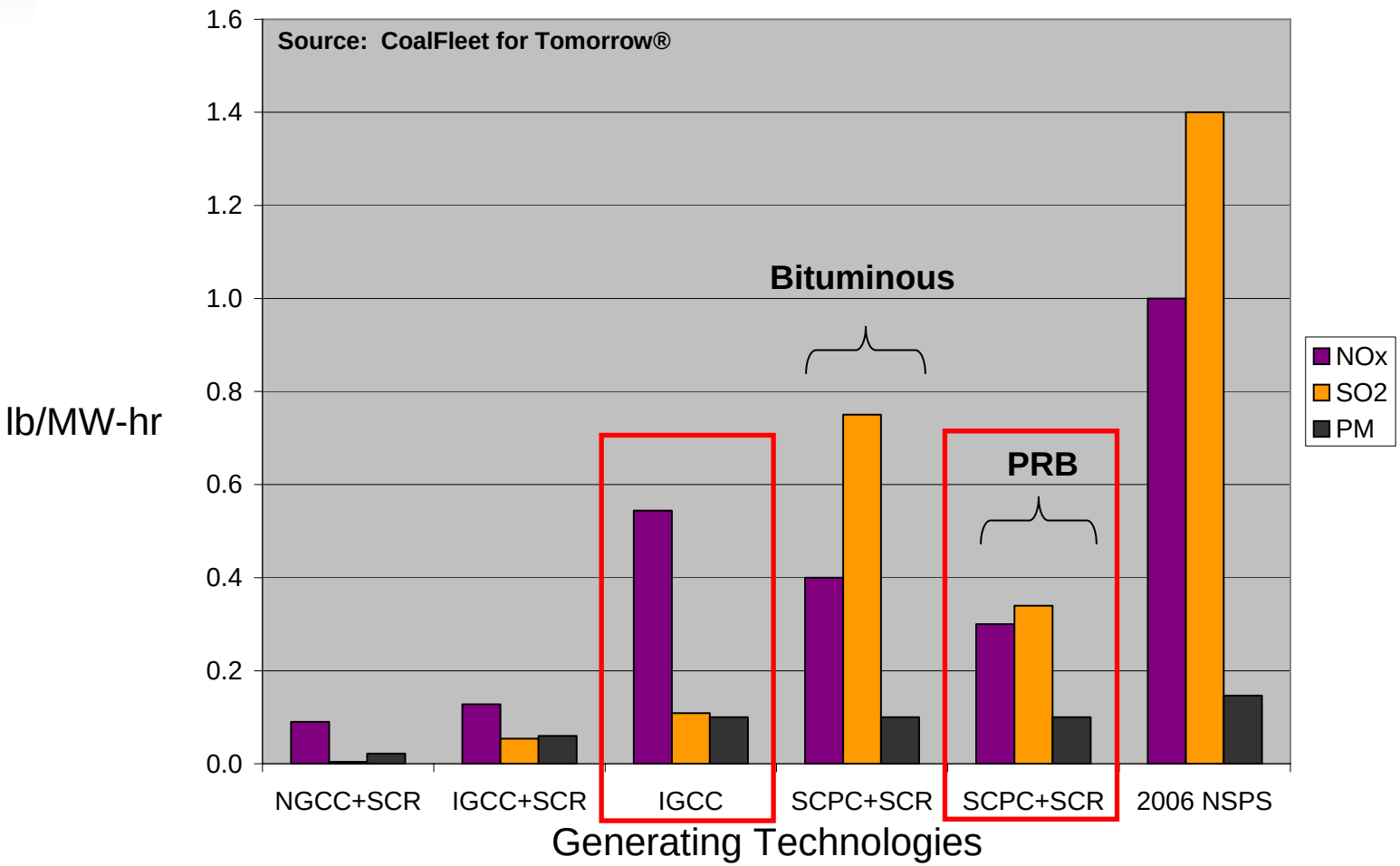
Recently Reported Costs

Owner	Plant Name /location	Net MW	Technology/Coal	Reported Capital $ Million	Reported Capital $/kW
AEP SWEPCO	Hempstead, AR	600	USC PC/PRB	1300	2167
AEP PSO/OGE	Sooner, OK	950	USC PC/PRB	1800	1895
AEP	Meigs County, OH	630	GE RQ IGCC/ Bituminous	1300	2063
Duke Energy	Edwardsport, IN	630	GE RQ IGCC/ Bituminous	1300-1600	2063-2540
Duke Energy	Cliffside, NC	2 x 800	USC PC/ Bituminous	3000	1875
NRG	Huntley, NY Montvale, CT Indian river, DE	620	Shell IGCC/ Bituminous, Pet Coke and PRB	1466	2365
Otter Tail/GRE	Big Stone, SD	620	USC PC/PRB	1500	2414

Source: CoalFleet for Tomorrow® EPRI Report 1012224

Costs Up Even with Minimal or No Provisions for CO_2 Capture

Emissions Comparison – Technology Capability



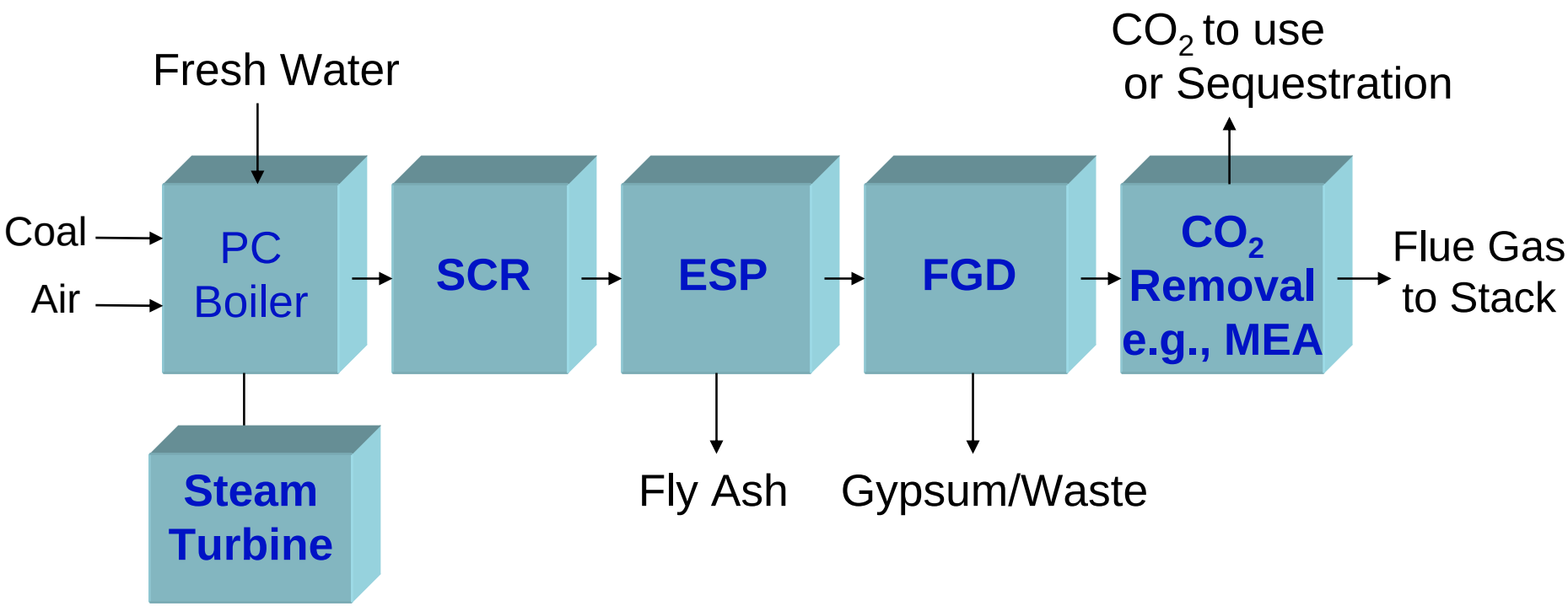
Minimal or No Provisions for CO_2 Capture

CO_2 Capture - Technology Options, Status, Costs, Issues

- Gasification and CO_2 removal are both offered commercially but not integrated or mature
  - **Big issues IGCC Cost, Integration, H_2 Turbines and CO_2 Storage**
- Advanced PC and CO_2 post combustion are each offered commercially but CO_2 not at scale or integrated
  - **Big Issues CO_2 Capture Cost, Integration and CO_2 Storage**
- **Oxyfuel Combustion is not as advanced**
- **Many promising options are under development (DOE, EPRI, others)**

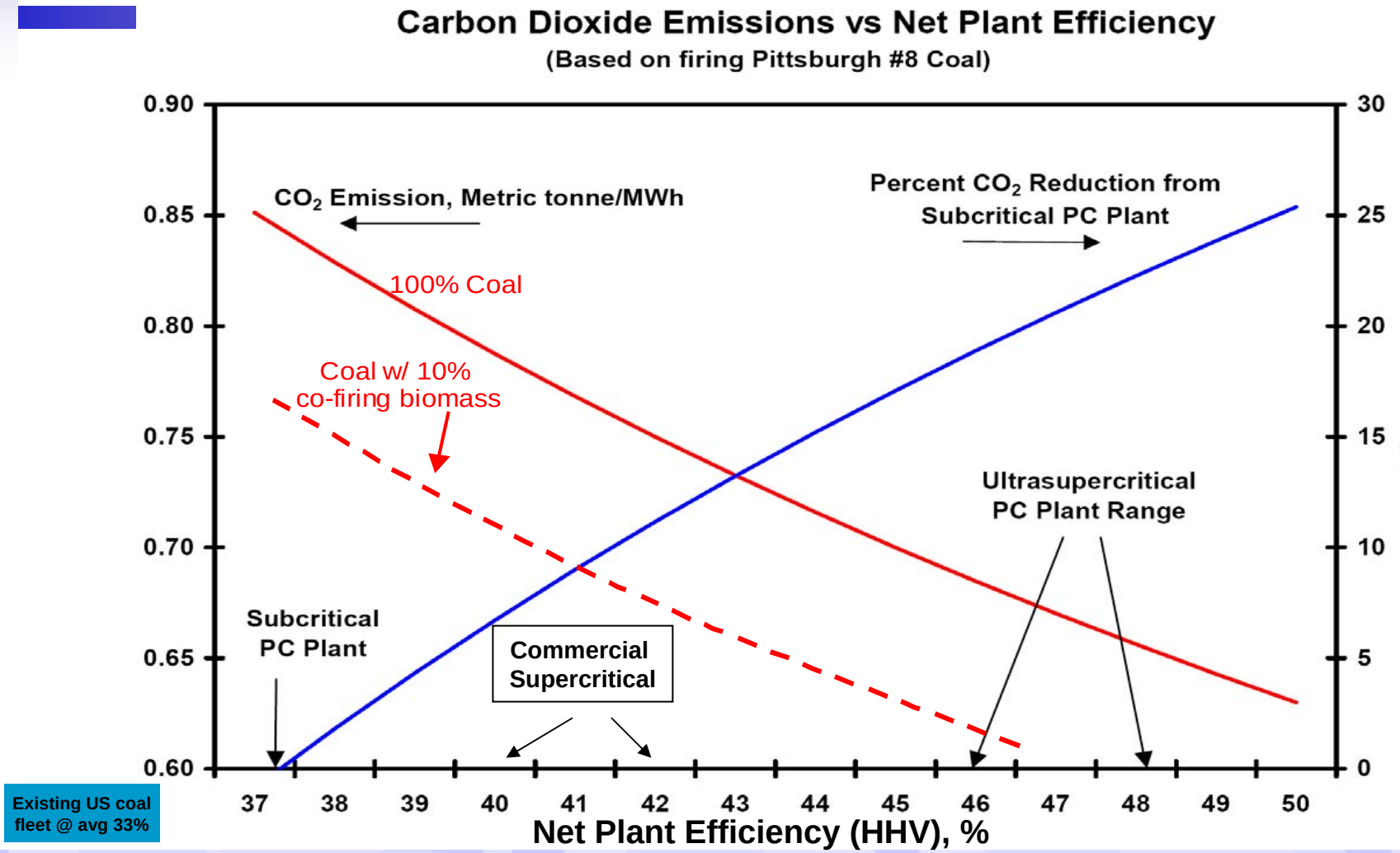
Gasification and Combustion Needed With CO_2 Options

Pulverized Coal (PC) with CO_2 Removal



CO_2 Capture = $, Space, Ultra Low SO_2, and Lots of Energy

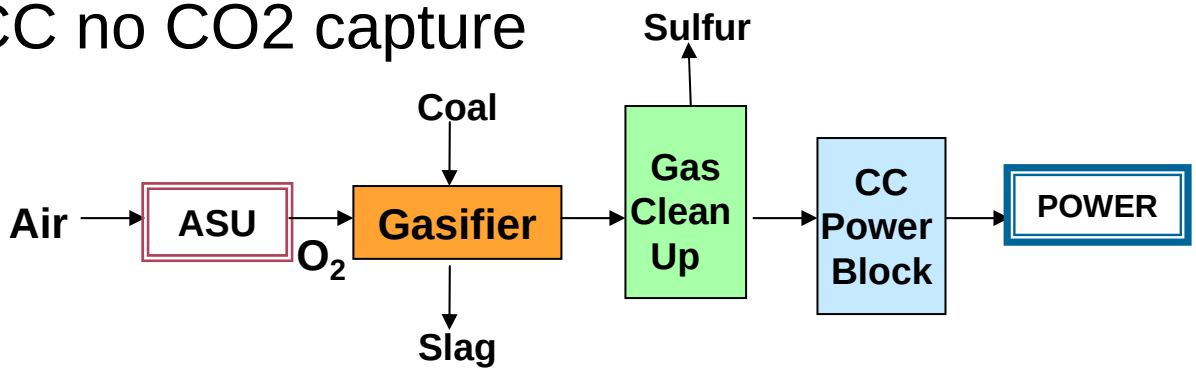
Effects of Efficiency on CO_2 (Alstom Slide)



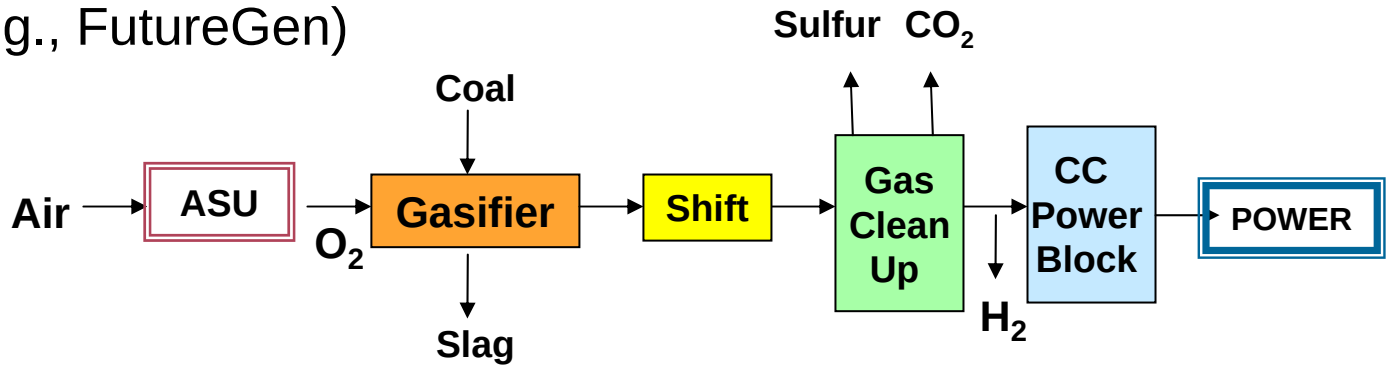
Efficiency increase from Subcritical to USC can, for example, yield up to 25% CO_2 reduction

IGCC with and without CO_2 Removal

IGCC no CO2 capture



H_2 & CO_2
(e.g., FutureGen)



CO_2 Capture = $, Space, Shift, H_2 Firing, CO_2 Removal, Energy

Combustion vs Gasification

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

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
- **Make Hydrogen**
  - FutureGen project will set the stage for production of H_2 from coal

CO_2 Capture from Gasification-based coal power plants - US

- No coal gasification-based power plant (IGCC) currently recovers CO_2 from the process
- Three non-power facilities in the US recover CO_2
- The recovered CO_2 from the Great Plains plant is used for enhanced oil recovery 2.7 MTY~ 300 MWe if it were an IGCC

The Great Plains Synfuels Plant
http://www.dakotagas.com/Companyinfo/index.html

Weyburn pipeline
http://www.ptrc.ca/access/DesktopDefault.aspx

CO_2 Capture from "Conventional" Pulverized Coal Power Plants

- Three US small plants in operation today on coal – MEA based
- The CO_2 is sold as a product or used
- CO_2 recovered is 300 metric tons/day ~15 MWe power plant equivalent at largest plant
- Many pilots planned over the next few years
  - e.g., 5 MW Chilled Ammonia Pilot at We Energies EPRI/Alstom with testing

AES Cumberland ~ 10 MW

5 MW Chilled Ammonia CO_2 Capture Pilot

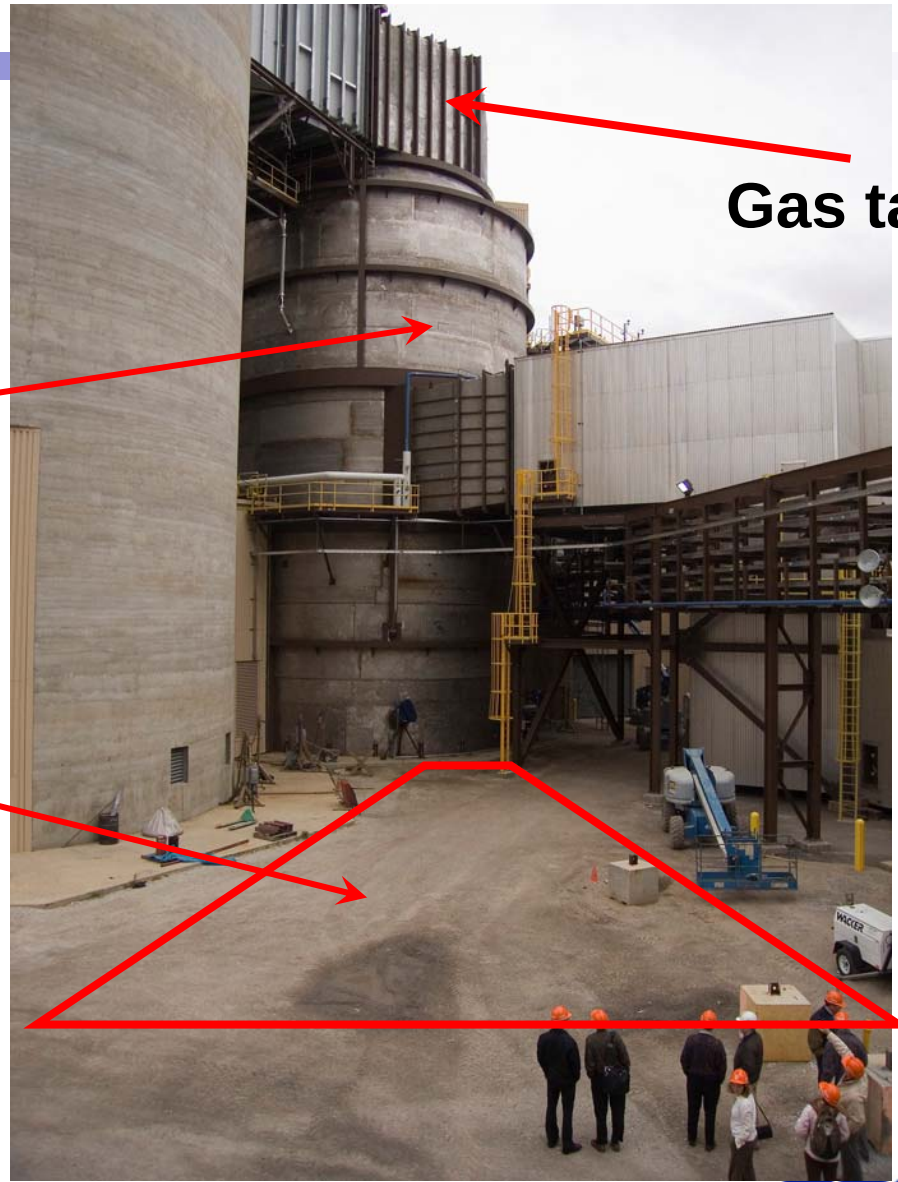
- Alstom and EPRI have agreed to jointly fund a 5 MW pilot
- Site Selection Complete
  - WE Energies Pleasant Prairie Power Pla
- $11 million for construction, operation for one year, data collection and evaluation
  - Alstom will design, construct and operate
  - EPRI will collect data and provide evaluation
- 24 firms have agreed to fund EPRI testing with more being added
- Operations beginning in the 3rd Quarter of 2007

5 MW Chilled Ammonia CO_2 Capture Pilot Participants

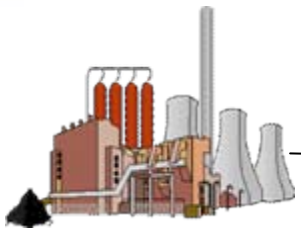
AEP
Ameren
CPS Energy
Dairyland
DTE Energy
Dynegy
E.ON U.S.
Exelon
First Energy
Great River Energy
Hoosier
KCPL
MidAmerican
NPPD
Oglethorpe
PacifiCorp
PNM
Sierra Pacific
SRP
Southern Co
Tri-State
TXU
TVA
We Energies

Red = New Participants

5 MW Chilled Ammonia CO_2 Pilot Capture Pilot



RTI's Post-Combustion CO_2 Capture Thermal-Swing Process using Dry, Regenerable Sorbents



Fossil Fuel Combustion Facility

Carbonation Reactor

Sorbent Transfer

Decarbonation Reactor

Water Condenser

CO_2-Free Stack Gas

Stack

CO_2 (≥ 99% Pure)

Water

Carbonation: $Na_2CO_3 + H_2O + CO_2 \leftrightarrow 2NaHCO3$

Decarbonation: $2NaHCO_3 \leftrightarrow Na_2CO_3 + CO_2 + H_2O$

CO_2 Generation

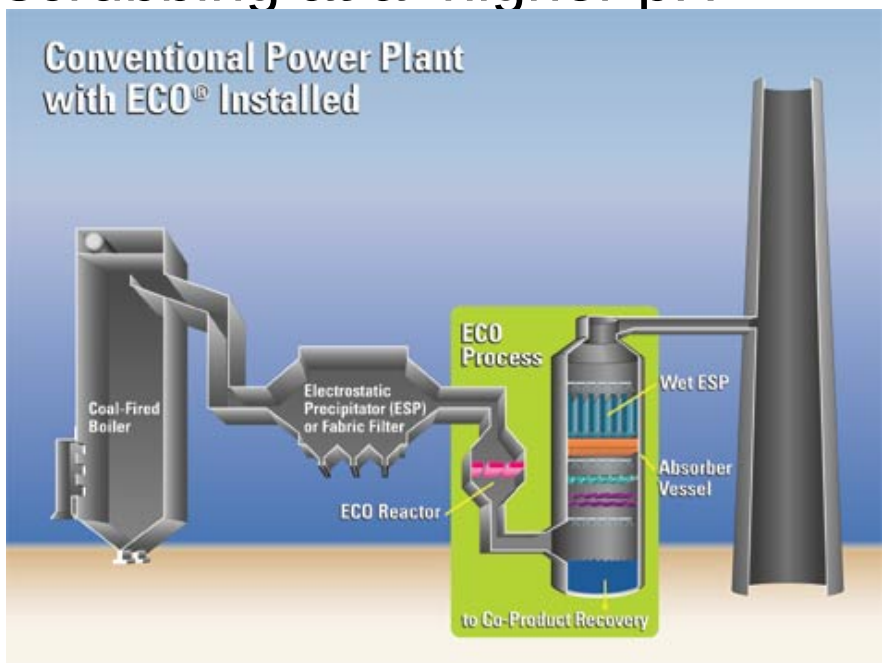
CO_2 Separation

CO_2 Sequestration

ECO_2™ Process for CO2

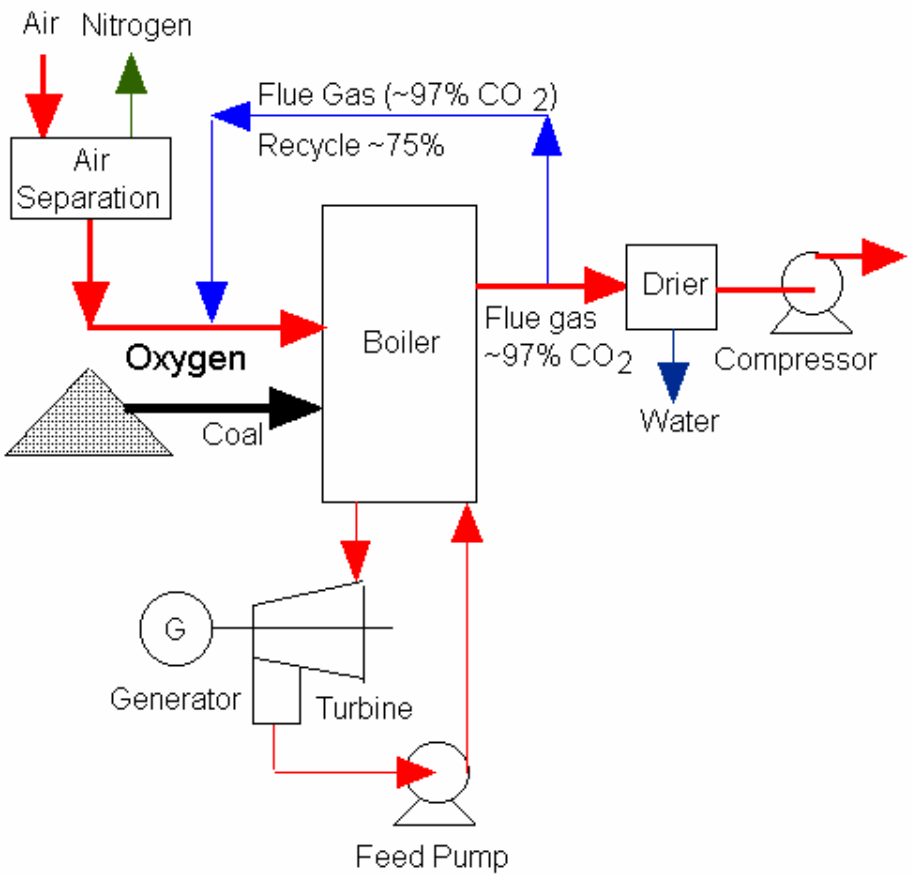
- POWERSPAN® developed the ECO™ process for SOx, NOx and Hg capture
- They have a variation planned for a CO2 capture called ECO_2™ using ammonia scrubbing at a higher pH

50 MW ECO pilot



http://www.powerspan.com/technology/eco_overview.shtml

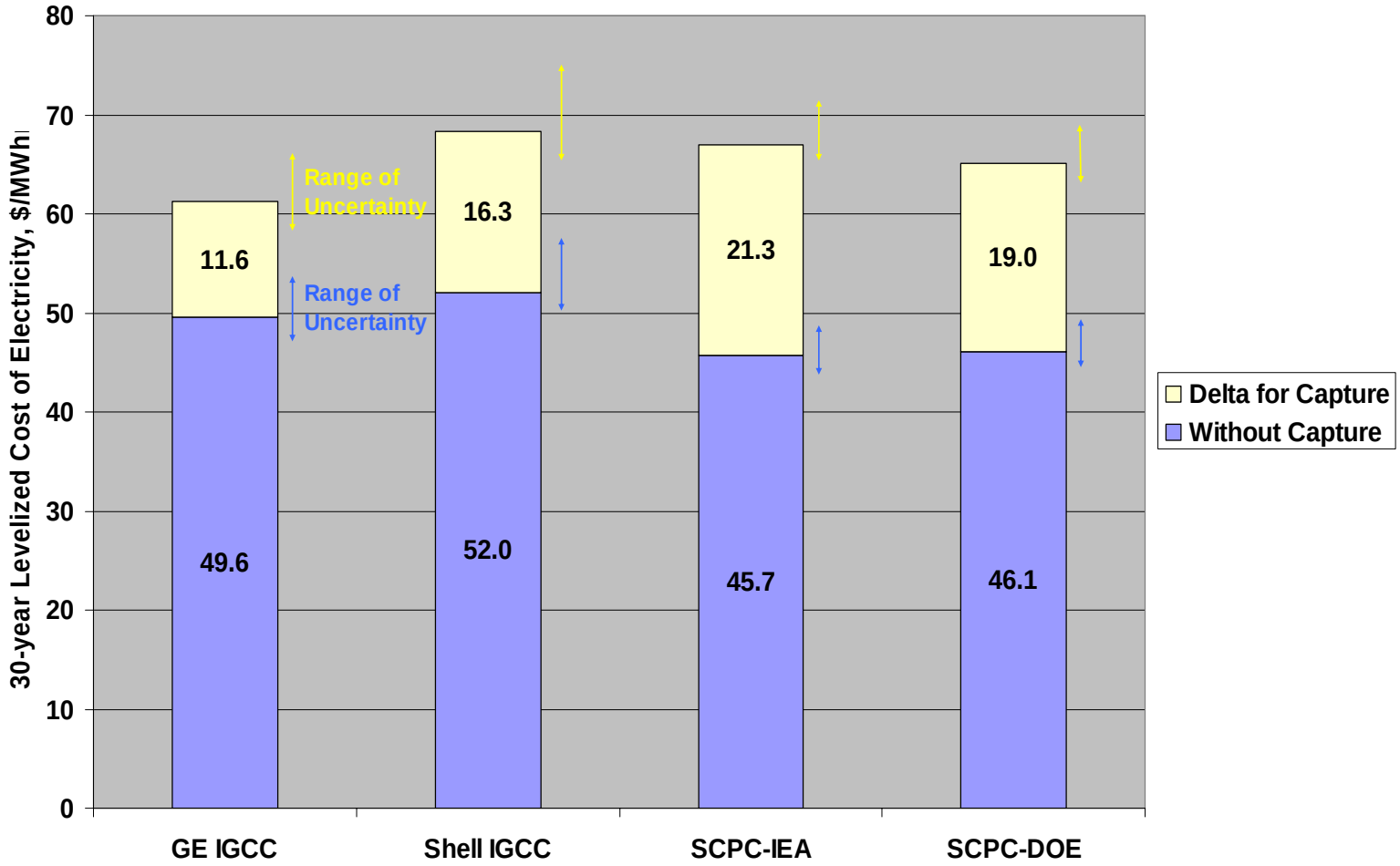
CO_2 Capture by O_2/CO_2 Combustion (Oxyfuel)



- Small test facilities at Canmet, B&W, Alstom big Canada Demo planned
- Reuse existing boiler equipment?
  - » Pulverizers, air heaters, etc.
  - » Potential “retrofit kit”
- CO_2 recycled for temp. control
- SO_2 removed from purge stream
  - » If higher purity CO_2 reqd.
- Large auxiliary power requirement
  - » Large net output reduction
- Issues –
  - Cost
  - 3x Oxygen of IGCC
  - Oxygen and moisture?
  - Dual firing designs?

Cost of Electricity w/ and w/o CO_2 Capture

IEA & US DOE bituminous coal adjusted to standard EPRI economic inputs: $2/MMBtu coal, 85% capacity factor, 2005 USD,

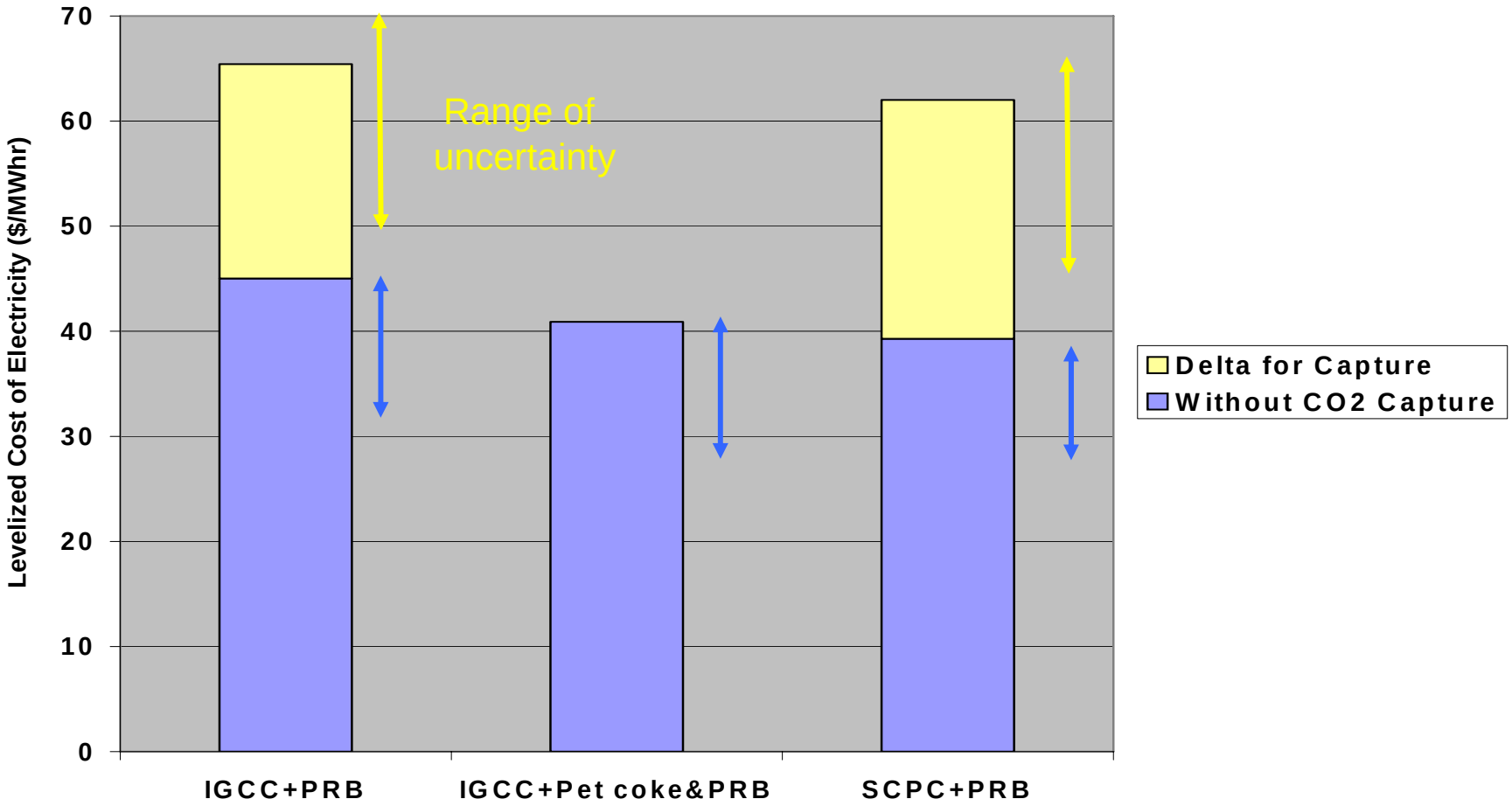


Most Estimates - IGCC 15-20% Premium but Better with Capture

EPRI ELECTRIC POWER RESEARCH INSTITUTE

Low Rank Coal Study IGCC & PC w and w/o Capture

2006 EPRI study (1014510) Texas location and municipal utility financing



PRB Estimate Shows Even with Capture PC May be an Option

EPRI ELECTRIC POWER RESEARCH INSTITUTE

Cost and Performance Summary - New Public CPS Report on PRB (EPRI report 1014510)

Notes: • All analysis at 73 ^{0}F. • 50%/50% PRB-Petcoke blend by weight	IGCC 100% PRB	IGCC 50%/50% PRB/ Pet C	SCPC 100% PRB	IGCC 100% PRB CO_2 Capt	SCPC 100% PRB CO_2 Capt
Gas Turbine Output (MW)	**450**	**453**		**427**	
Steam Turbine Output (MW)	**260**	**258**	**615**	**203**	**521**
Gross Plant Output (MW)	**710**	**711**	**615**	**630**	**521**
Auxiliary Load (MW)	**157**	**158**	**65**	**217**	**132**
Net Plant Output (MW)	**553**	**553**	**550**	**413**	**390**
Net Heat Rate, HHV (Btu/kWh)	**9,220**	**9,070**	**9,150**	**12,800**	**12,911**
EPC (Overnight) ($/kW)	**2,390**	**2,330**	**1,950**	**3,630**	**3,440**
20-yr LCOE ($/MWh) (Constant 2006$) municipal Financing	**45.0**	**40.9**	**39.2**	**65.4**	**62.0**
Cost of CO_2 Avoided ($/tonne CO_2)				**26.3**	**29.6**

IGCC for Western Coal?

CPS Environmental Performance Summary Source EPRI Report 1014510

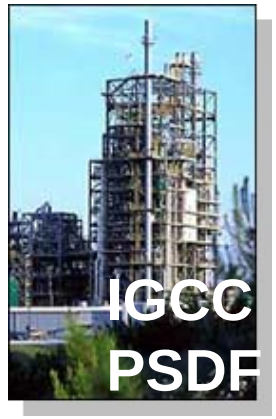
Notes: **1. All analysis at 73 ^{0}F.**	**IGCC 100% PRB No SCR**	**IGCC 50%/50% PRB/Pet C**	**SCPC 100% PRB SCR**	**IGCC 100% PRB CO_2 Capt**	**SCPC 100% PRB CO_2 Capt**
NO_X, lb/mmBtu, (HHV)	0.063	0.062	0.050	0.061	0.045
lb/MWh (Net)	0.581	0.562	0.458	**0.781**	**0.581**
ppmvd @ 15% O_2	15	15	N/A	15	N/A
SO_2, lb/mmBtu, (HHV)	0.019	0.023	0.060	0.004	0.0003
lb/MWh (net)	**0.173**	0.210	**0.549**	**0.051**	**0.003**
CO_2, lb/mmBtu, (HHV)	215	213	215	22	22
lb/MWh (net)	1,985	1,934	1,967	276	278
Total Makeup Water (acre-ft/yr) (85% CF)	6,830	7,170	7,950	**8,430**	**10,640**

Surprisingly low SO_2 and NO_X from PC with CCS

Conclusions

- EPRI believes All the generation options (Coal Natural Gas, Nuclear, Renewables) will be needed in a Carbon Constrained World
- Costs for new coal plants are up (first of a kind IGCC plant costs up even more?)
- Emissions for all new coal plants are down approaching "near zero" without CO_2 capture
- CO_2 Capture is costly for both IGCC and PC plants and probably feasible but integration and costs are still uncertain
- EPRI believes PC and IGCC will compete in the future even with capture for some coals and conditions
- CO_2 Storage demonstrations needed soon at large scale

Questions?



Post Combustion

CO2 Capture