The Future of Coal-Based Power Generation With CCS

UN CCS Summit

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web.mit.edu/coal/

Times Are Changing

As Yogi Berra said:

“The Future Ain’t What It Used to Be”

Overview

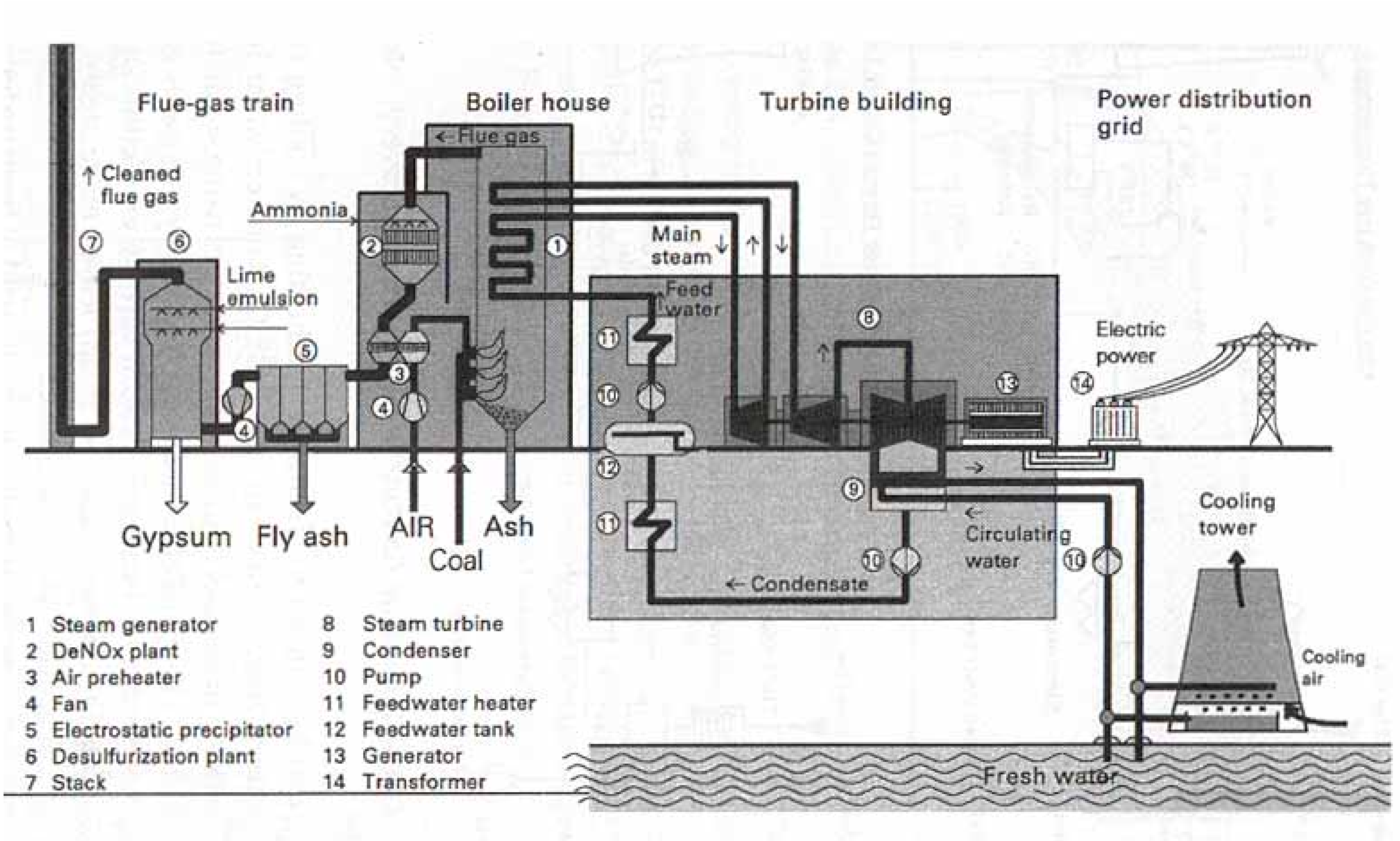
- **Coal-Based Electricity Generating Technologies**
  - Without and with CO_2 capture
  - Criteria emissions performance today and future potential
  - Cost and performance impacts
- **CO_2 Transport and Sequestration**
- **Conclusions**
- **A Forward View**

Coal is and will remain, by necessity, a key component in our electricity generating portfolio for the foreseeable future.

Base Design Conditions for Generation Technologies

- New greenfield unit
- Emissions controlled to below today's best demonstrated performance
- Illinois # 6 high-sulfur bituminous coal
- Used Carnegie-Mellon model for consistent design comparisons
- Costs based on 2000 to 2004 detailed design costs; **indexed to 2007 $ with process construction cost index**
- Integrated existing commercial technology
- Single-condition indicative cost comparisons done; coal type, site, location, etc. will affect cost numbers
- Important issue is comparison among technologies w/o and w CO_2 capture

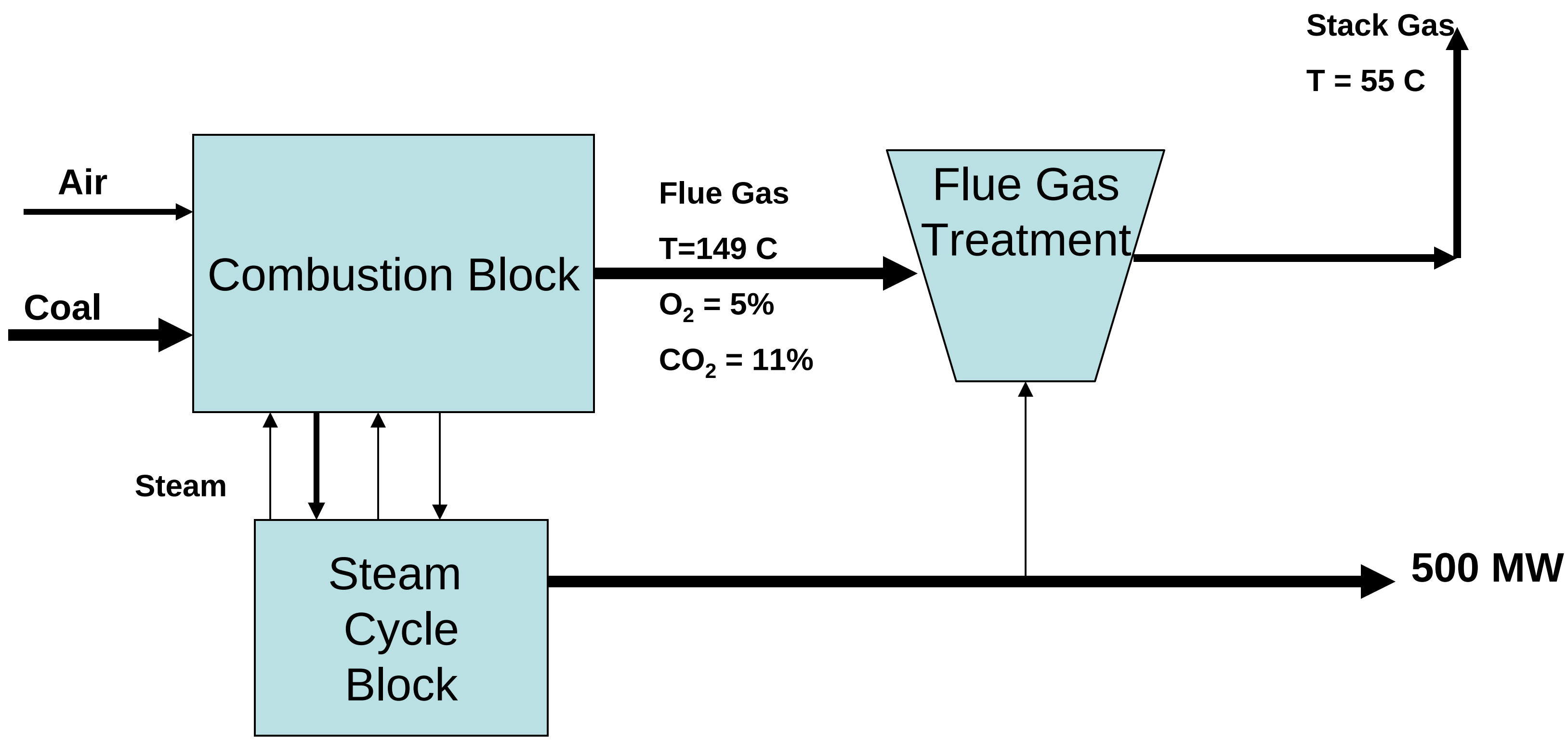
Advanced PC Power Plant



The New Generation of Power Plants

Neideraussem Lignite-fired Power Plant, 965 MWe (net), 43.3% (HHV)

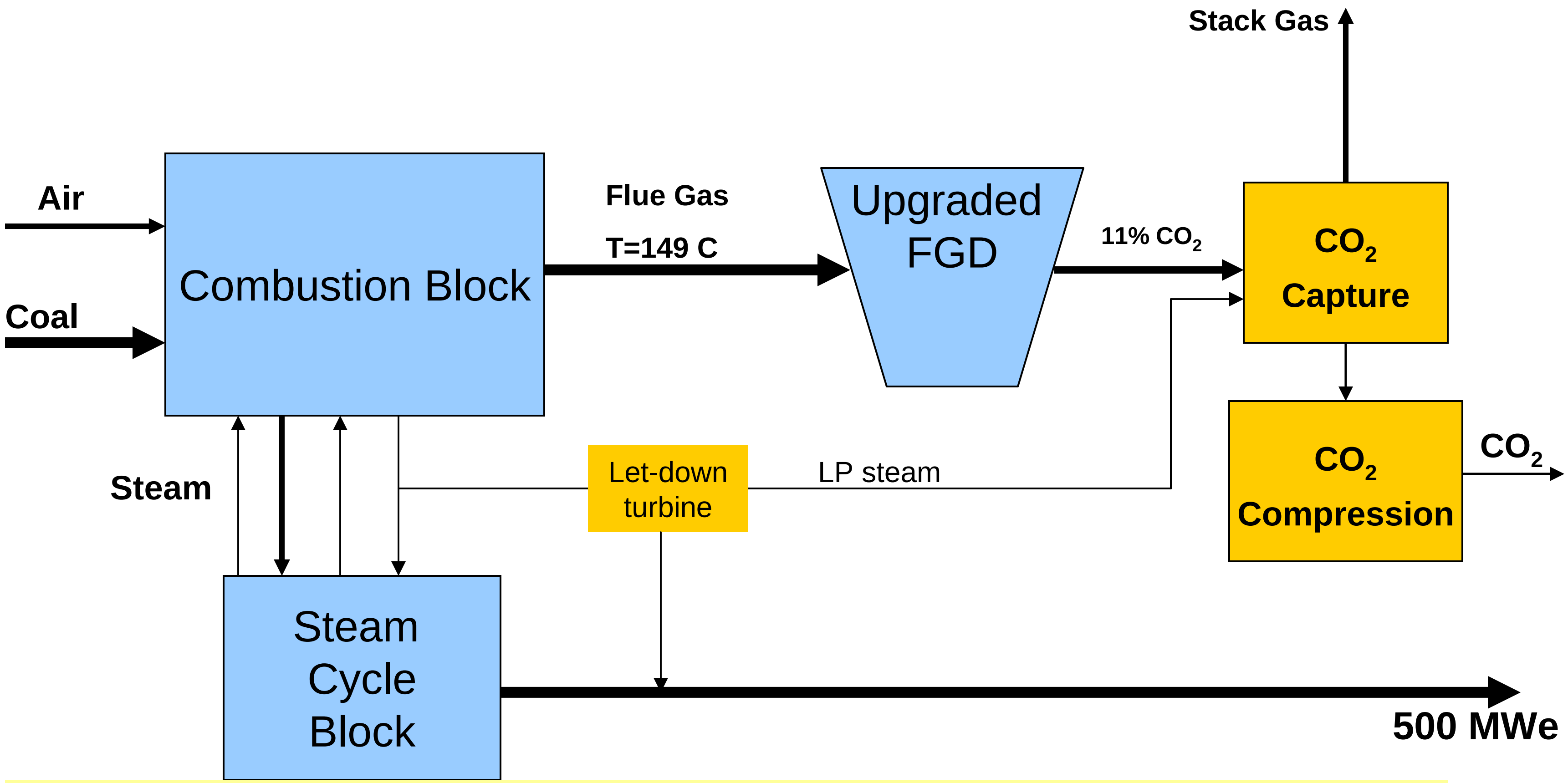
PC Power Plant Schematic



PC Thermal Efficiencies

- **Sub-Critical Unit**
  - Operation to 1025 ^oF and 3200 psi
  - **33 to 37 % (HHV)**
- **Supercritical Unit**
  - Typical operation 1050 ^oF and 3530 psi
  - **37 to 42 % (HHV)**
- **Ultra-Supercritical Unit**
  - Typical 1110-1140 ^oF and 4650 psi
  - **42 to 45 % (HHV)**

PC Plant with Amine-Based CO_2 Capture



- **Generating efficiency is 29.3% for new supercritical plant with CO_2-capture; down from 38.5 % for supercritical no-capture plant; a 9.2 percentage point drop.**
- **To maintain constant electrical output requires 32% increase in coal consumption**

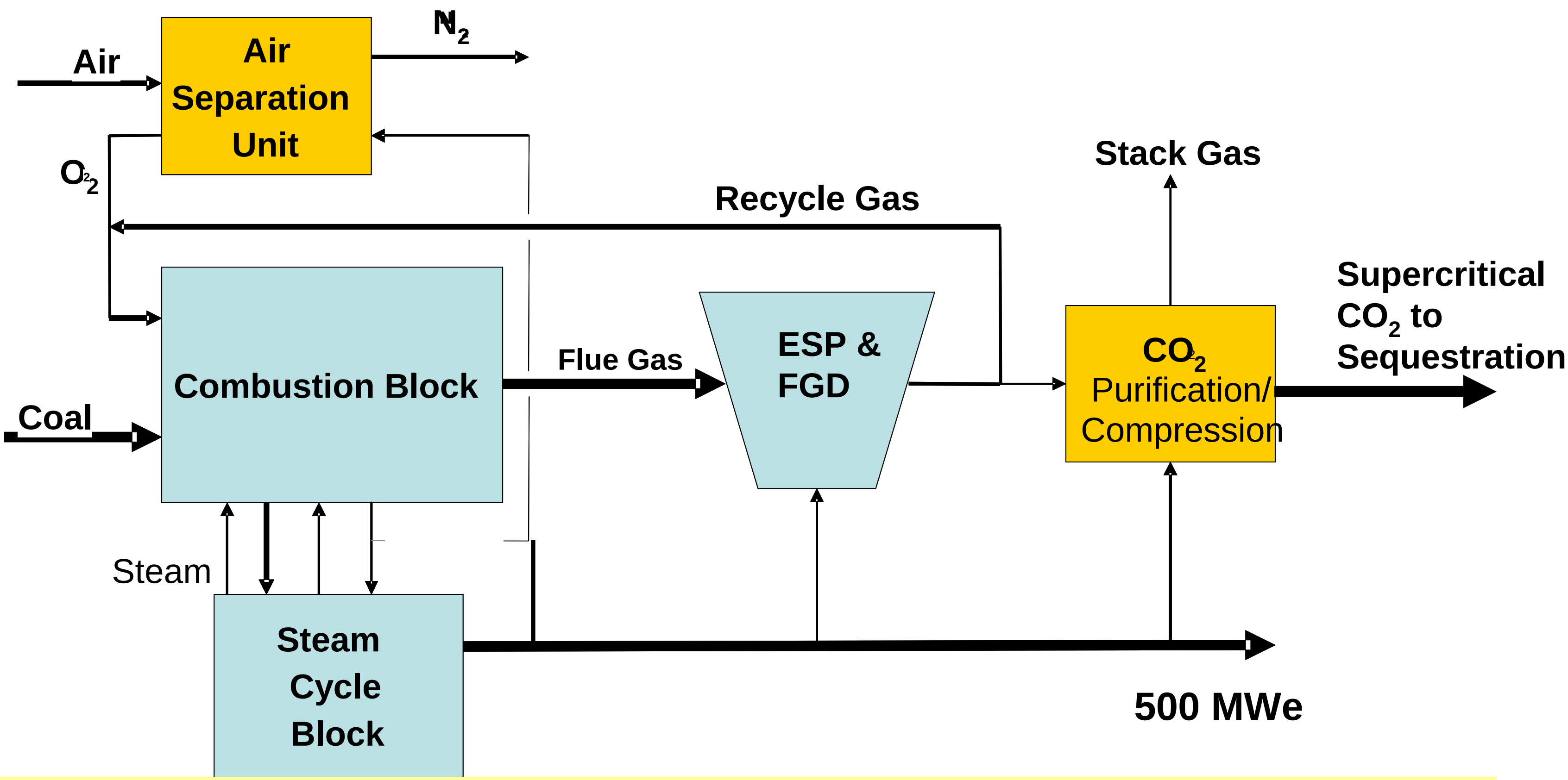
Oxygen-Driven Power Generation

Issue: Low flue-gas CO_2 concentration due to high nitrogen dilution causes large impact of capture

- **Solution: Substitute oxygen for air eliminating the nitrogen dilution, compress flue gas directly [Oxy-fuel PC combustion]**

- **Solution: Gasify the coal and remove the CO_2 at high pressure [IGCC]**

Oxy-Fuel PC Generation/Capture



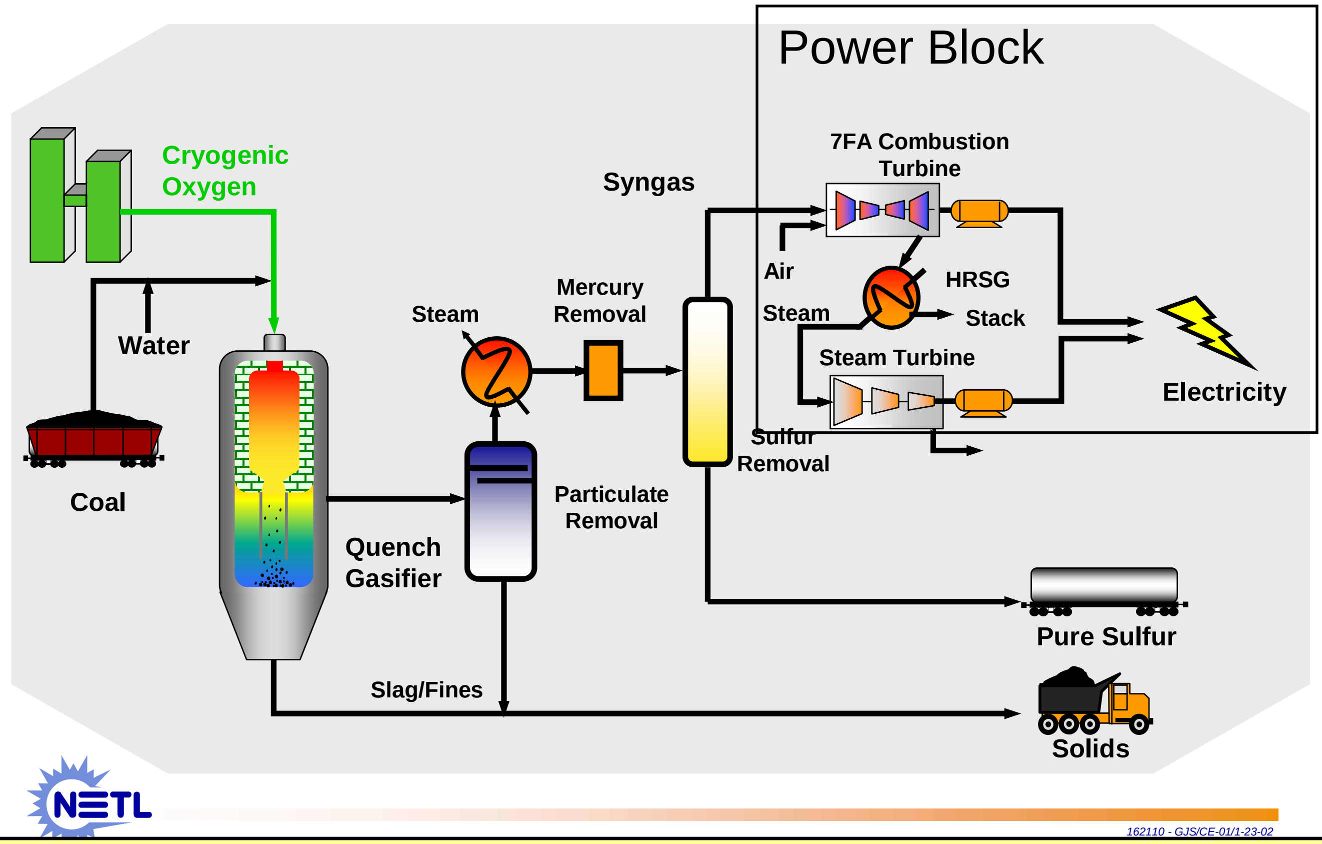
- Of interest only for CO_2 capture for sequestration
- Addresses the issue of high energy costs for capture and recovery
- Requires air separation unit and associated energy usage

Oxy-Fuel PC Generation/Capture

- Current Status
  - Active pilot-scale development
  - Vattenfall planned new 30 MW_{th} CO_2-free coal steam plant with 2008 start-up in Germany
  - Hamilton, Ohio planning 25 MW_e 1963 power boiler retrofit, 2009 start-up

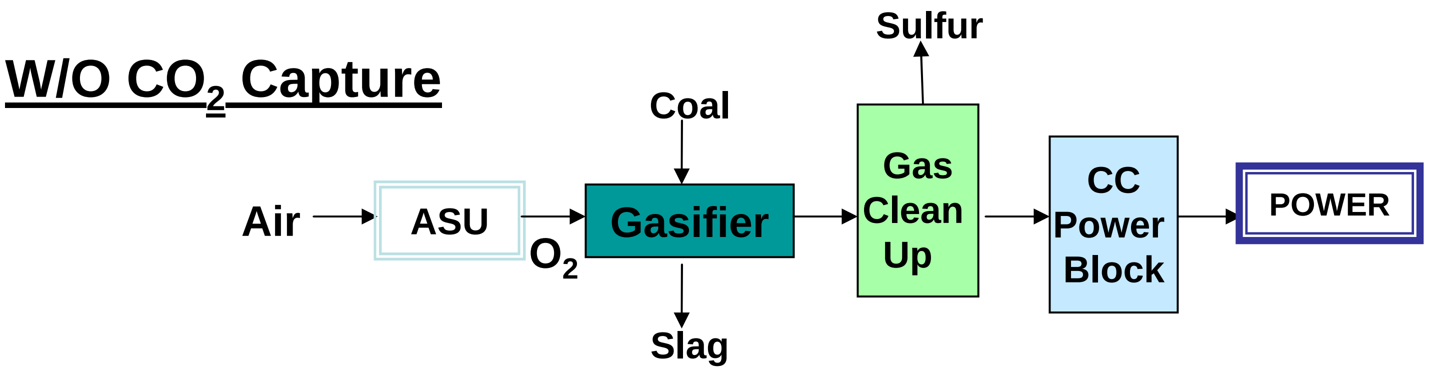
- Oxy-Fuel PC shows potential of lower COE and lower CO_2 avoided cost than other PC capture technologies

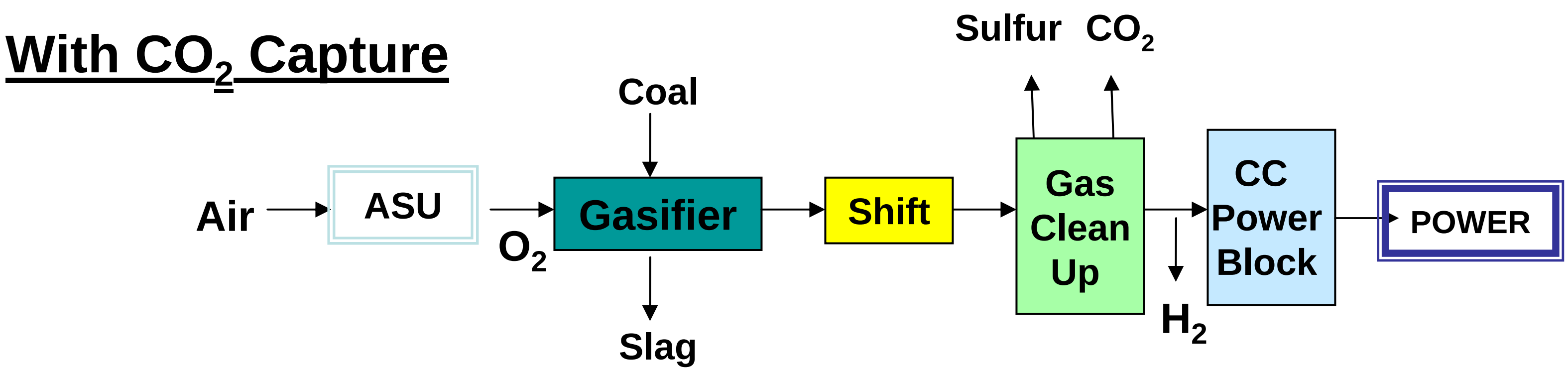
IGCC Plant



- **Gasifier type is biggest variable:**
- **Texaco & E Gas: slurry feed & higher pressure, ~39% efficiency potential**
- **Shell: dry feed and lower pressure, more costly, ~41% efficiency potential**

IGCC without and with CO_2 Capture





The Shift reaction converts CO to CO_2 & hydrogen; the CO_2 is then removed.

Performance and Costs of Generating Technologies

	Subcritical PC		Supercritical PC		Oxy-Fuel PC	IGCC	
	w/o capture	w/ capture	w/o capture	w/ capture	w/capture	w/o capture	w/capture
PERFORMANCE							
Heat Rate, Btu/kWe-h	9,950	13,600	8,870	11,700	11,200	8,890	10,900
Efficiency (HHV)	34.3%	25.1%	38.5%	29.3%	30.6%	38.4%	31.2%
CO_2 emitted, g/kWe-h	931	127	830	109	104	824	101
COSTS							
Total Plant Cost, $/kWe	$1,580	$2,760	$1,650	$2,650	$2,350	$1,770	$2,340
Cost of Electricity							
Inv. Charge, ¢/kWe-h @ 15.1%	3.20	5.60	3.35	5.37	4.77	3.59	4.75
Fuel, ¢/kWe-h @ $1.50/MMBtu	1.49	2.04	1.33	1.75	1.67	1.33	1.64
O&M, ¢/kWe-h	0.75	1.60	0.75	1.60	1.45	0.90	1.05
COE, ¢/kWe-h	**5.45**	**9.24**	**5.43**	**8.72**	**7.89**	**5.82**	**7.44**
Cost of CO_2 avoided vs. same technology w/o capture, $/tonne		47.1		45.7	34.0		22.3

Basis: 500 MWe plant. Illinois # 6 coal, 85% capacity factor, COE at bus bar. Based on design studies between 2000 and 2004, a period of cost stability, indexed to 2007 $ using construction cost index.

Emissions Performance

Technology	Case	Particulates	SO_2	NO_x	Mercury
		lb / MM Btu	lb / MM Btu	lb / MM Btu	% removed
PC Plant					
	Typical	0.02	0.22	0.11	
	Best Commercial	0.015 (99.5%)	0.04 (99+%)	0.03 (90+%)	90
	Design w CO_2 Cap.	0.01 (99.5+%)	0.0006 (99.99%)	0.03 (95+%)	75-85
IGCC Plant					
	Best Commercial	0.001	0.015 (99.8%)	0.01	95
	Design w CO_2 Cap.	0.001	0.005 (99.9%)	0.01	>95

PC emissions control technology continues to improve; further, emissions reductions potential exists. Design case with CO_2 capture from recent EPRI evaluation.

IGCC emissions performance (best commercial) is well below current requirements and can be further improved; should be similar to NGCC

Incremental Costs of Advanced PC Emissions Control Vs. No-Control

	Capital Cost* [$/kW$_e$]	O&M [¢/kW$_e$-h]	COE** [¢/kW$_e$-h]
PM control	50	0.18	**0.28**
NO_x	32	0.11	**0.17**
SO_2	190	0.22	**0.60**
Incremental control cost	273	0.51	**1.05*****

* Incremental capital costs are for a new-build plant

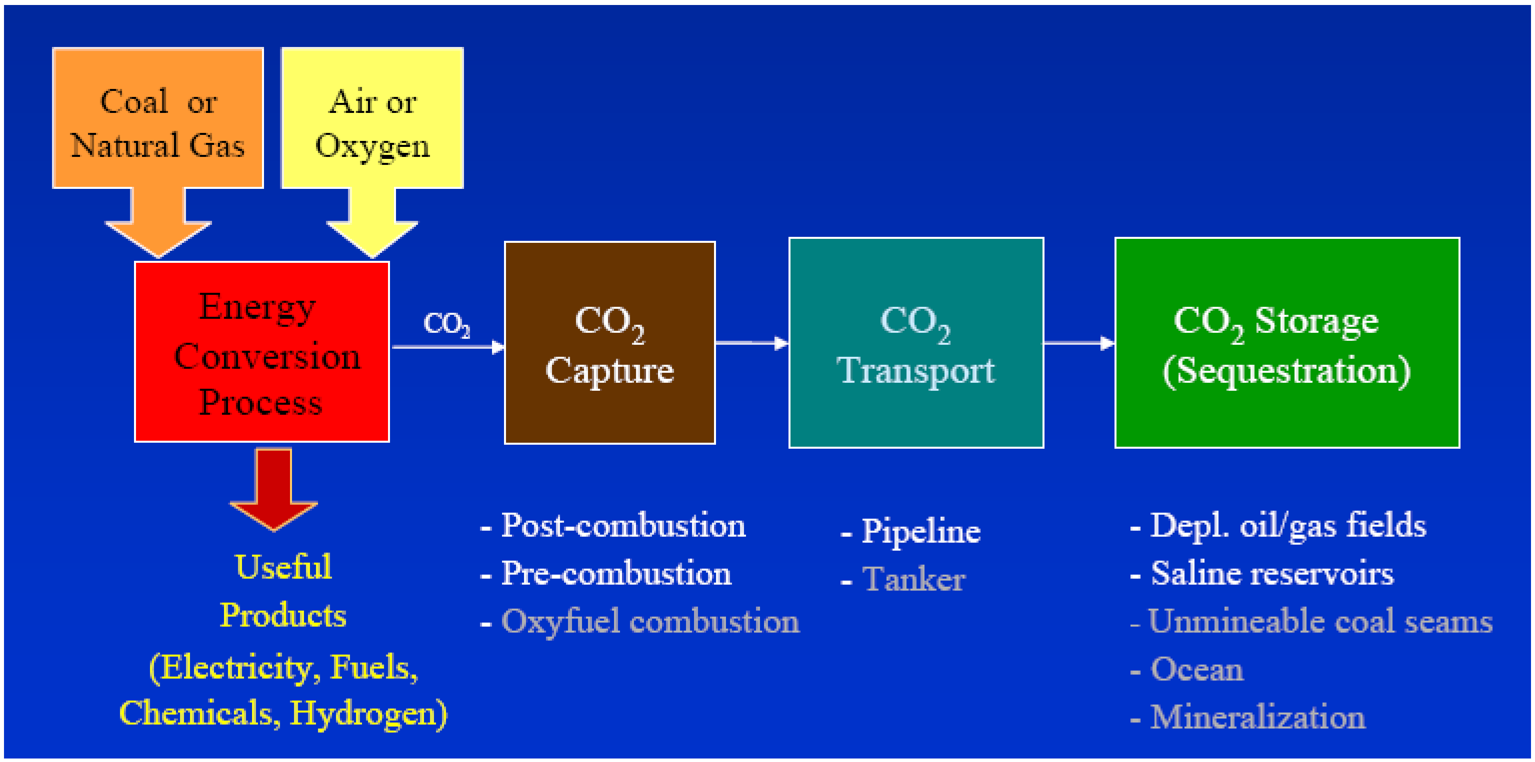
** Incremental COE impact for Illinois #6 coal with 99.3 % PM reduction, 99.4% SOx reduction, and >90 % NOx reduction.

*** When this is added to the "no-control" COE for SC PC, the total COE is 5.5 ¢/kW$_e$-h.

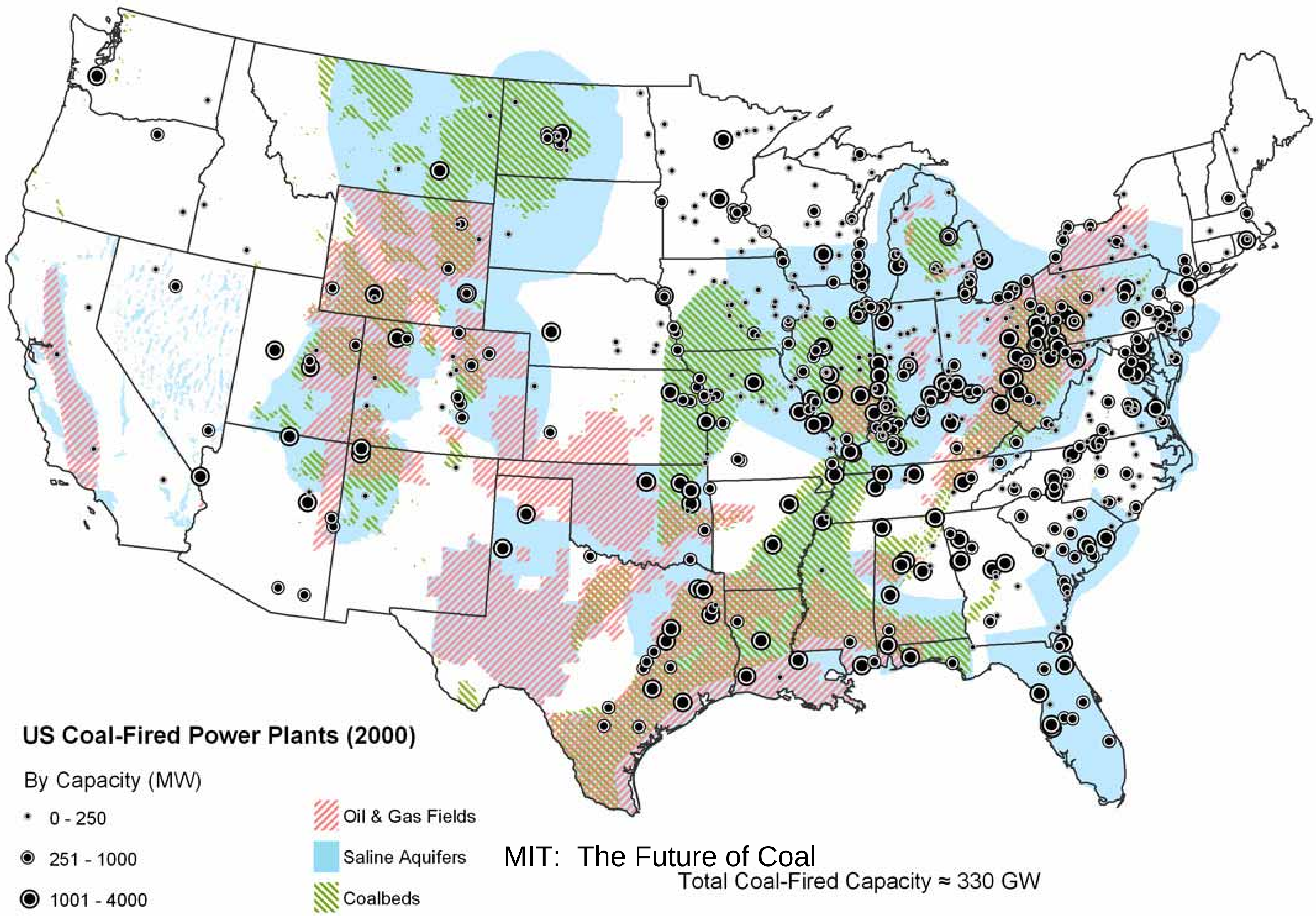
Note: To reduce emissions by a factor of two further would increase the cost by about an additional 0.25 ¢/kW$_e$-h.

Today's high levels of emissions control increase the cost of electricity by ~1 ¢/kW$_e$-h out of about 5.5 ¢/kW$_e$-h or about 20 %.

Carbon Capture and Sequestration (CCS)

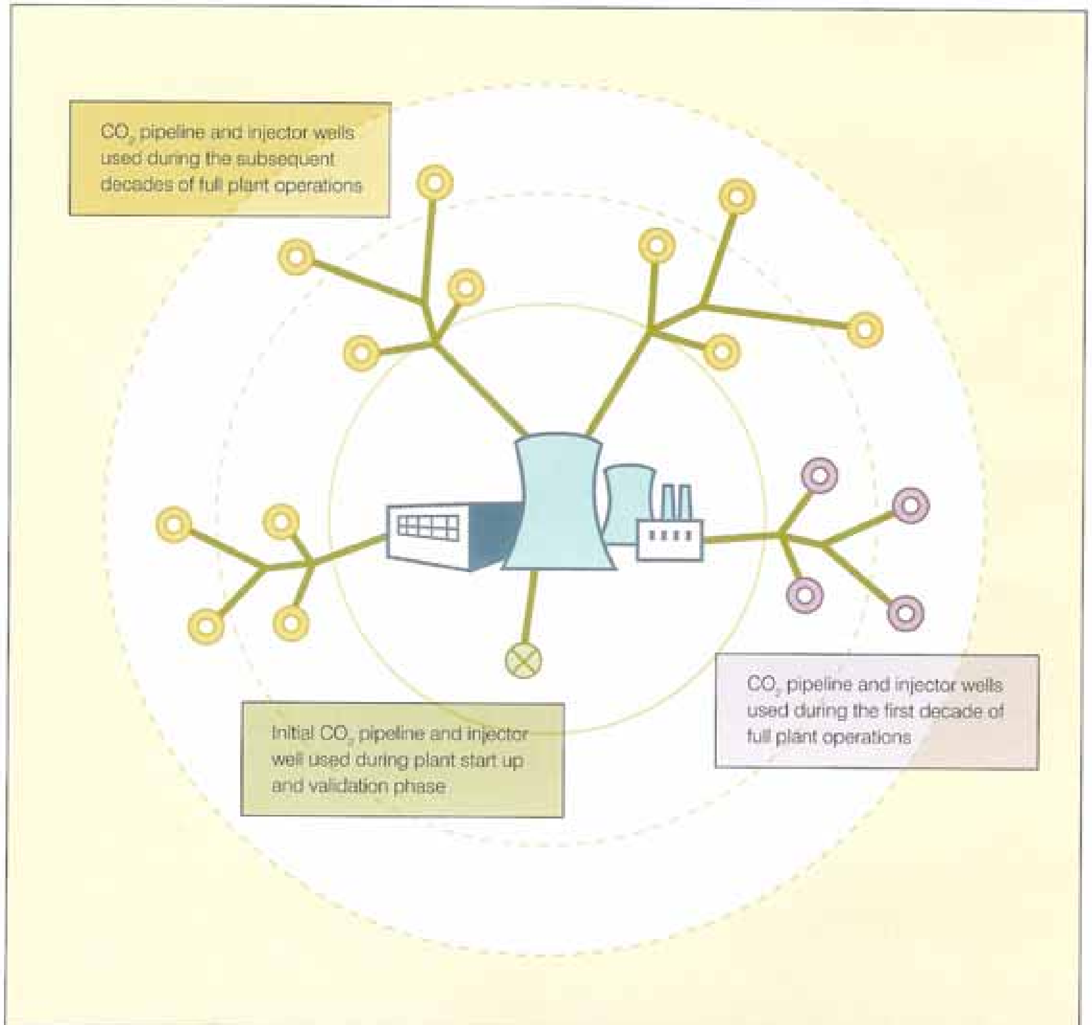


Location of Saline Aquifers, Oil and Gas Fields, and Coal Plants



MIT: The Future of Coal

A Potential CCS Power Plant Project



▲ Planning for a CCS-enabled power plant must include a robust CO_2 storage plan for all phases of the plant's operations over its entire half-century operational lifetime.

From Battelle GTSP Report

CO_2 Capture Through Sequestration*

Technology	PC		IGCC
CCS Step	¢/kW$_e$-h		¢/kW$_e$-h
Capture	2.7		1.21
Compression	0.6		0.4
Transport	0.19		0.18
Injection	0.68		0.64
Totals	**4**		**2.4**

- **There are no apparent technical or economic show-stoppers to CCS today.**
- **Bus Bar COE increase in about 50%.**

* Costs are estimates for existing CCS technology with Illinois #6 Coal; they will vary with coal type, with generating technology, with site and with reservoir properties. Here, they are meant to be indicative of relative magnitude.

The Future of Coal

- Although the COE for IGCC is lower for Bituminous coal, differences narrow for lower rank coals and at elevation; cost improvements for PC could further narrow the gap. Also, Oxy-fuel PC looks competitive.
- It is too early to pick winners for coal-based power generation with capture.
- Emissions from coal-based power generation can be very low; and with CO_2 capture, even lower, to the extent of really being very clean.
- With CO_2 capture and sequestration, coal can provide electricity at a cost competitive with wind and nuclear.
- Thus, coal would appear to continue to be an economic choice for <u>baseload</u> generation of very low emissions electricity, including low CO_2 emissions.

CCS – Findings and Observations

- Technologies for CO_2 capture with generation are all commercial, but will benefit from operation at scale to improve cost/performance
- Current information indicates that it is technically feasible to safely store large quantities of CO_2 in saline aquifers, and the storage capacity of such aquifers is very large. However, there are issues that require resolution
- Broad range of regulatory issues require resolution (permitting, liability, monitoring, ownership,…)
- Need to gain political and public confidence in the safety and efficacy of geologic sequestration

CCS – A Way Forward

MIT Coal Report Recommendations

- Solid technical program to resolve scientific & technical issues associated with injection & storage of Gt quantities of CO_2/yr
- In the U.S., 3 to 5 large-scale CCS demonstration projects of 1 million tonnes CO_2 per year, using different generation technologies, focusing on different geologies, and operated for several years to resolve outstanding technical, scientific, liability, policy, and regulatory issues
- Effectively demonstrate dynamic operation of fully-integrated infrastructure systems including coal conversion, CO_2 capture, CO_2 transport, and CO_2 injection in a continuously operating manner over extended time periods.

This research and demonstration program is needed to develop the required information in a timely manner so that we have robust technology options available to apply when society decides to manage CO_2 emissions from power generation and other major stationary sources.

Thank you