Gasification & IGCC – Design Issues & Opportunities

Neville Holt – Technical Fellow, EPRI

Presented at the
GCEP Advanced Coal Workshop
Provo, Utah
March 15-16, 2005

Options for CO_2 Response (The Stabilization Wedge & Slices)

- Conservation (Yes - but Rest of the World?)
- Renewables (Yes - but not enough)
- Nuclear (Ultimately Yes – but implies wide Proliferation)
- Adaptation (Probably Yes – we always do)
- Switch from Coal to Natural Gas (Maybe but not enough NG)
- CO_2 Capture and Sequestration –CCS (Maybe but site specific & costly)

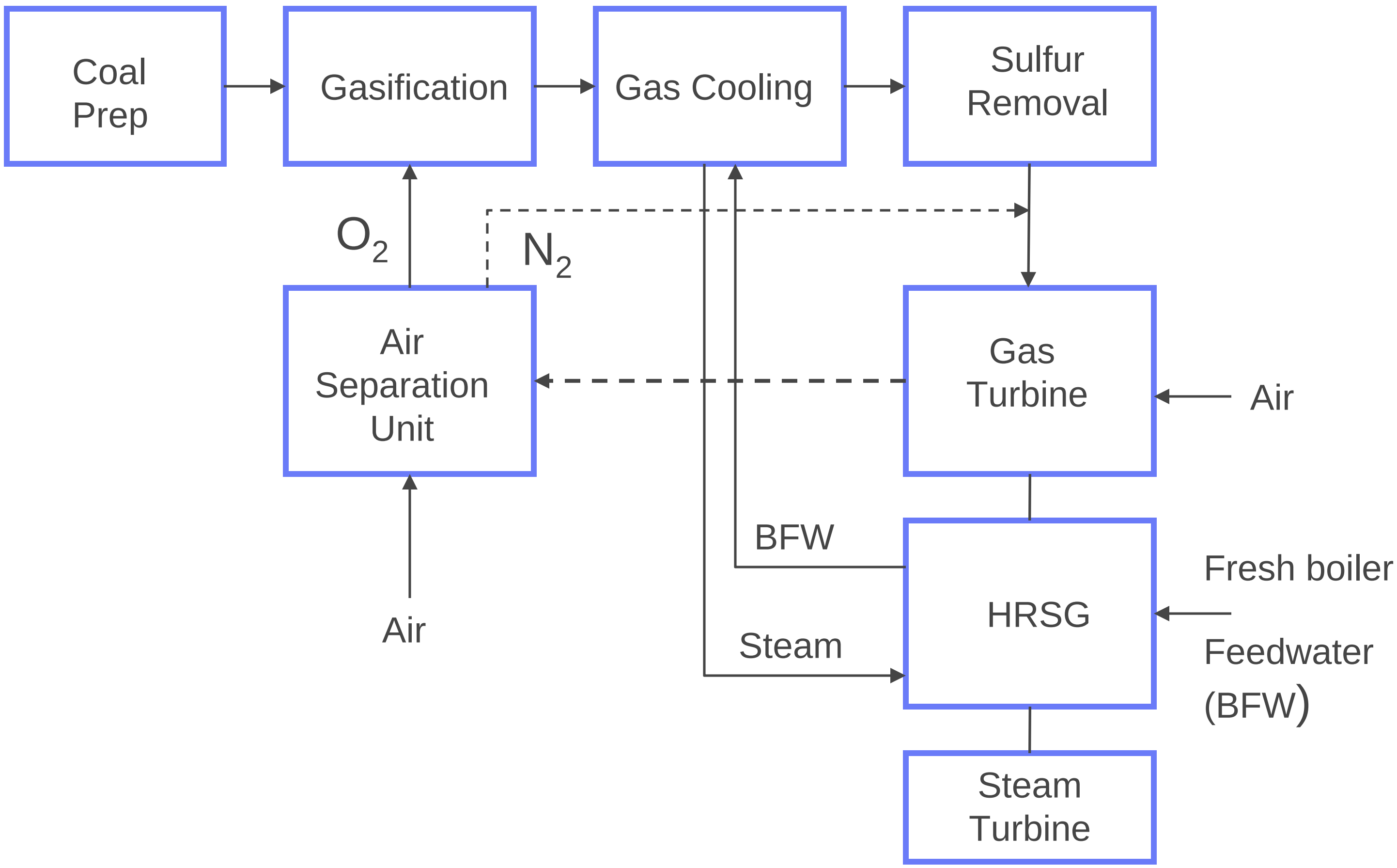
Notes :

US Coal Power Plants emit > 2 billion metric tons of CO_2/yr (~31% of US and 8% of World CO_2 emissions).

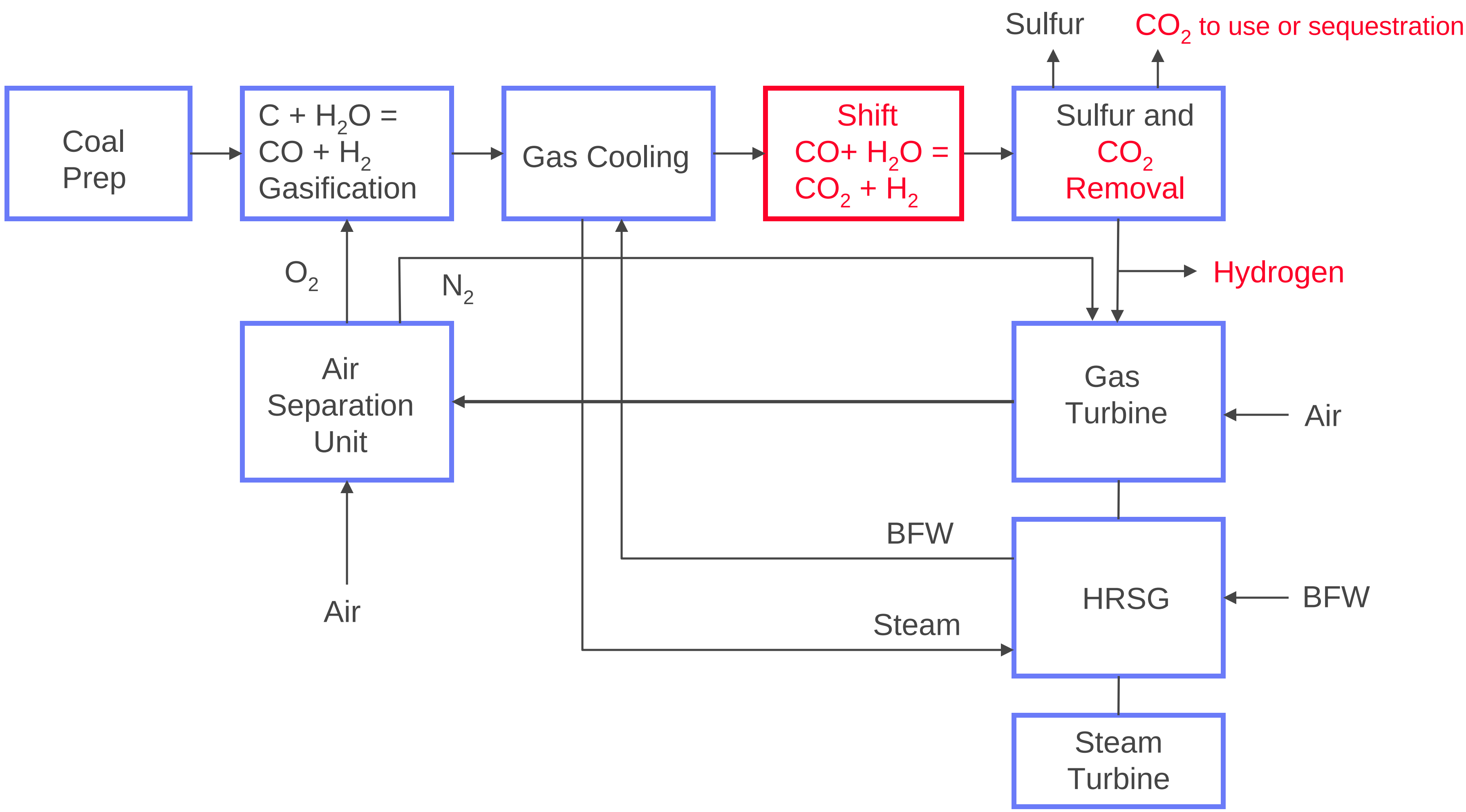
1 billion metric tons/yr = ~25 million bpd of supercritical CO_2

Effort Required for CCS Slice- World-wide build or replace 8 GW of Coal Power plants with CCS every year and maintain them until 2054

IGCC Block Flow Diagram (State-of-the Art)



IGCC with CO_2 Removal and Hydrogen Co-Production



Gasification Process Selection

- Selection depends upon:
- Application – Hydrogen only, Power only, or both?
- Coal types or range
- Overall Plant/Project Objectives

  - Lowest Cost-of-Electricity (COE) ?
  - Highest Efficiency?
  - Maximum CO_2 capture?
  - Near Zero (Minimal) Emissions?

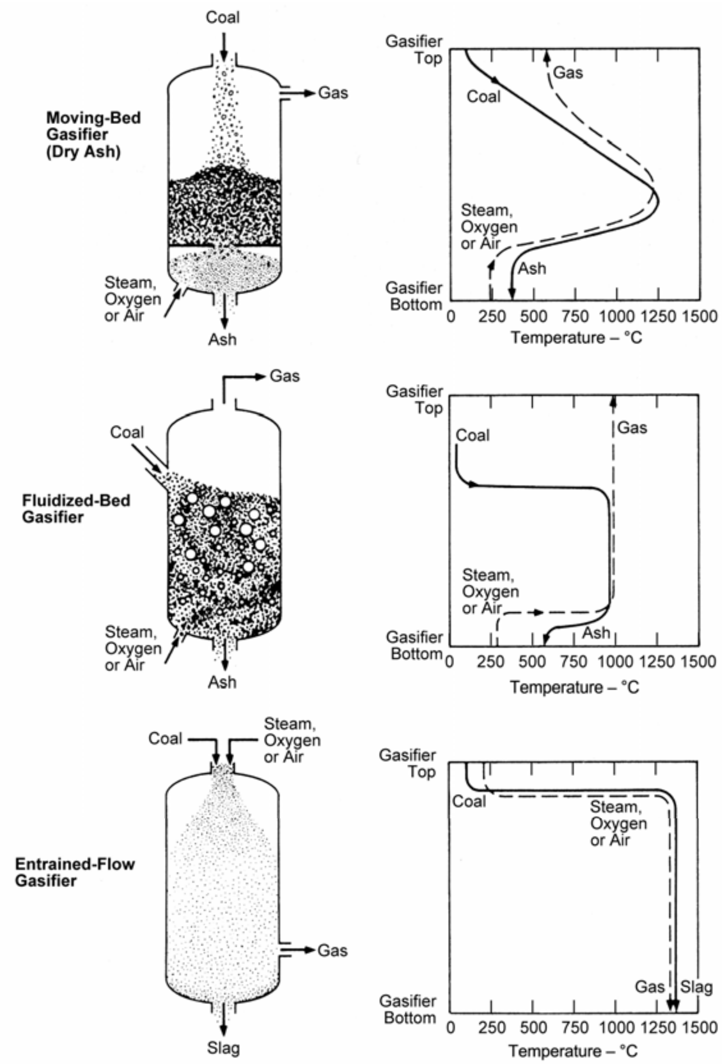
Chemistry & Reactions

The following reactions are important in coal gasification:

Coal Devolatilization = CH_4 + CO + CO_2 + Oils + Tars + C (Char)	
$C + O_2 = CO_2$	(exothermic – rapid)
$C + 1/2O_2 = CO$	(exothermic – rapid)
$C + H_2O = CO + H_2$	(endothermic – slower than oxidation)
$C + CO_2 = 2CO$	(endothermic – slower than oxidation)
$CO + H_2O = CO_2 + H_2$	Shift Reaction (slightly exothermic– rapid)
$CO + 3H_2 = CH_4 + H_2O$	Methanation (exothermic)
$C + 2H_2 = CH_4$	Direct Methanation (exothermic)

The 3 Major Types of Gasification Processes

1. Moving-Bed Gasifier (Dry Ash)
2. Fluidized-Bed Gasifier
3. Entrained-Flow Gasifier



Methane Formation in Gasifiers

- CH_4 is produced by:

  - Devolatilization of the Coal's Volatile Matter. Survival of this CH_4 depends on temperature and kinetics. Lower outlet temperature yields more CH_4. Moving bed and Fluid bed gasifiers have lower outlet temperatures than single stage Entrained gasifiers and higher CH_4 (typically 10-15% of the coal's carbon content at 400-500 psig).

  - Methanation reactions
  CH_4 increases at higher pressures
  (See subsequent Table)

  - In a two stage entrained gasifier CH_4 will also increase as a higher proportion of the feed coal is fed to the 2nd stage

Methane Formation in Gasifiers – Trade-Offs and Ironies

- CH_4 in the Syngas results in higher Gasifier efficiency and lower Oxygen usage
- CH_4 in the Syngas reduces % of the coal's carbon that can be captured via the Shift reaction and subsequent CO_2 removal
- Increased pressure further increases CH_4 and Gasifier efficiency and further reduces oxygen usage – and reduces the achievable % of coal's carbon that can be captured
- Increased pressure decreases the cost of CO_2 removal and compression through use of a physical absorption system (e.g. Selexol) where solvent recovery is largely achieved through depressurization and without large steam (energy) penalty.

Fluid and Moving Bed Coal Gasification Processes - Syngas Compositions

(Mol % Clean Dry Basis – Typical Bituminous Coal)

Type	Moving Dry ash	Moving Slagging	Moving Slagging	Fluid KRW	Fluid Transport	Fluid Synthane
Pressure PSIG	400	400	1000	450	450	1000
H_2	40	28	25	34	34	32
CO	17	59	59	45	22	13
CH_4	9	7	10	7	9	15
CO_2	32	3	3	12	33	36
N_2 + A	2	3	3	2	2	4

Entrained Coal Gasification Processes
- Syngas Compositions
(Mol % Clean Dry Basis – Typical Bituminous Coal)

Stages/ Feed	Single/ Slurry	Single/ Dry	Two/ Slurry	Two/ Slurry	Two/ Dry
Pressure PSIG	1000	500	450	450	1000
H_2	37	28	33	30	32
CO	47	64	54	49	29
CH_4	< 0.1		1	6	15
CO_2	14	2	10	12	22
N_2 + A	2	6	2	3	2

Gasifier Selection for Synthesis, Hydrogen and Maximum CO_2 Capture

- If the goal is >90% capture of the coal's carbon content as CO_2 for Sequestration and production of Hydrogen then a single stage entrained gasifier at high pressure operating in the Quench mode is preferred.
- The Quench mode is the lowest cost method of putting the moisture in the raw syngas needed for the Shift reaction. Other configurations would add expensive steam raising equipment and/or rob the steam cycle.
- High pressure operation lowers the cost of CO_2 removal and compression.
- Single stage entrained gasifiers operate at high temperature and produce very little CH_4.
- If the Syngas to be used exclusively for Synthesis (Methanol, Fischer-Tropsch etc) CH_4 should be minimal (avoids inerts build up in the synthesis loop)

Key Gasifier Design Features for CCS (or for Liquid Synthesis and Hydrogen)

- High pressure ~1000 psig (69 barg). Single stage entrained flow gasifier. Advantageous for CO_2 capture, liquid synthesis and Hydrogen
- Dry coal feed. Fuel flexibility. Coal pump particularly important for low rank coals. Replaces lock hoppers. Reduces required residence time for high carbon conversion
- Cooled refractory liner (membrane wall). Avoids costly periodic refractory replacement. Improved availability.
- Partial water quench to temperature for gas filter. Lowest cost provision of moisture for the shift reaction.
- Hot or warm gas filter for slag/ash removal. Eliminates high maintenance carbon scrubber
- Continuous slag removal. Replace lock hoppers.
- Further direct quench as required for shift. Also removes chlorides and ammonia

New IGCC RD&D Developments

- Stamet Posimetric pump tested (DOE) to 560 psig (38 Bar). Aim is to go up to 1000 psig. Potentially important development for all dry coal fed gasifiers (Shell, KBR, Noell, Eagle, Boeing Rocketdyne etc
- Boeing Rocketdyne new gasifier design (dry coal fed,single stage entrained, high pressure, short residence time, cooling screen, Quench) potentially overcomes most of the drawbacks of current commercial entrained gasifier designs. EPRI has NDA with Boeing Rocketdyne. Great interest from DOE, Eastman, GE Energy etc. With further enhancements e.g. Jacobs desaturator, this could be the best gasifier for CO_2 Capture and even without capture the heat rate could be close to gasifiers with full heat recovery.

Entrained Flow Gasifiers RD&D Needs

Candidate Improved Design Features

Improvement/Technology	*Shell/Prenflo*	*Texaco*	*E-Gas*	*Mitsubishi*	*Noell/GSP*
HP Dry Feed System	✔	✔	✔	✔	✔
Add 2nd Stage	✔	✔			✔
Reduce Gas Recycle	✔				
Partial Quench	✔	✔	✔	✔	✔
Fire Tube SGC	✔	✔		✔	✔
Continuous Slag Removal	✔	✔		✔	✔
High Pressure Design	✔		✔	✔	✔
Other		Dry Dust Removal	Cylindrical Design	Use O_2	

EPRI

Economics of IGCC and USC PC with CO_2 Capture. (Gasification Technologies are not all alike!)

Nominal 450 MW net Plants Pittsburgh #8 Bituminous Coal, All IGCC with spare gasifiers Caution :2002 data. Needs updating. New improved designs are now being offered)

Technology	IGCC GE Quench	IGCC GE Radiant SGC	IGCC E-Gas	IGCC Shell	PC Ultra Supercritical
MW no capture	512	550	520	530	600
TPC $/KW no capture	1300	1550	1350	1650	1235
COE $/MWh no capture	50.1	55.7	50.2	57.2	45.0
MW with capture	455	485	440	465	460
TPC $/kW with capture	1650	1950	1900	2200	2150
COE $/MWh with capture	62.7	69.6	68.9	75.1	76.2
Avoided Cost of CO_2 $/mt	18	22	29	29	42

GE Quench IGCC (~500 MW) Costs and Power
(Where can costs and power consumption be reduced?)

Plant Section	No Capture Cost $ Million	Capture Cost $ Million	No Capture Power Use MW	Capture Power Use MW
ASU	100	110	-86	**-105**
Gasification Island	130	134	-2	-2
Gas cooling & cleanup	100	130	-4	**-14**
CO_2 Compression		40		**-24**
Power Island	210	220	604	597
General Facilities	160	166	-2	-2
Total	700 (1372$/kW)	800 (1778 $/kW)	Net 510	Net 450

IGCC Improvement Opportunities
(Besides those for the gasifier previously listed)

- Reduce ASU power consumption. New ASU – Ion Transfer Membrane (ITM)? An ASU nearer to ambient temperature would be nice.
- Gas separation membranes and processes that can operate at warmer temperatures and that can also reduce the auxiliary power requirements for separation and compression.
- Gas turbine redesign to recover the derating, lost performance and efficiency with syngas and hydrogen firing.
- Longer term possibilities such as Clean Power Systems and Solid Oxide Fuel Cell with Oxygen Transfer Membrane on Anode gas would eliminate the need for shift and CO_2 removal from the syngas since the flue gas is essentially CO_2 and water.

Is 90% Capture really Necessary?

- Perhaps 90% carbon capture is not really necessary in all cases. Maybe 70-80% is OK? If so this opens up the choice of gasifiers to include more efficient fluid bed or two stage entrained gasifiers.
- In a Polygeneration or Co-production mode the plant configuration could then feature Shift and CO_2 removal, Hydrogen production from some of the syngas by PSA and power generation in a power block firing H_2/CH_4 and with the PSA filtrate returned to the power block either compressed and added to the H_2/CH_4 or duct fired in the HRSG.
- If some Synthesis is required (Methanol, Fischer-Tropsch) a once-through synthesis reactor could be used and the methane would pass through as partial fuel to the power block (as above)
- If developed successfully some future power blocks (Clean Energy Systems, SOFC + OTM) could use any clean syngas including those with methane and produce a concentrated CO_2 stream

IGCC News Announcements 2004-5

- GE Energy acquires Texaco gasification technology from ChevronTexaco and aligns with Bechtel to offer IGCC.
- ConocoPhillips(COP) aligns with Fluor to offer IGCC with E-Gas technology
- Shell/Krupp Uhde align with Black& Veatch to offer Shell IGCC
- The formation of these competing teams is viewed positively for potentially reducing front end development costs and risks for IGCC
- AEP announces plans for 1000 MW IGCC by 2010. Cinergy has similar plans.
- DOE CCPI 2nd Round selects two IGCC projects:
  - Southern/Orlando 280 MW Airblown KBR
  - Excelsior 530MW Oxygen blown E-Gas

CoalFleet Initiative – Genesis & Birth 2004

- 115 New Coal Plants (62 GW) proposed – of which ~33% (20 GW) are more plausible
- Much activity examining incentives for Advanced Clean Coal power plants particularly IGCC – DOE, EPA, Harvard, MIT, GTC, CURC, IGCC Coalition, EPRI CoalFleet
- Harvard Feb.11. W. Rosenberg “3 Party Covenant”
- April 13 EPRI/Power Industry CoalFleet Workshop in Atlanta
- July 29 DOE, EPRI, CINERGY, CURC, EEI and NARUC sponsor “Roundtable on Deploying Advanced Clean Coal Plants” at EEI in Washington,DC
- September 9 AEP hosted meeting on Industry/EPRI Initiative “CoalFleet for Tomorrow”
- November 18 CoalFleet launch meeting Washington,DC
- December NCEP Bipartisan Report recommends additional incentives for IGCC and CCT support

EPRI

CoalFleet Roster (as of 3/10/05)

- AEP
- AES
- Alstom Power
- Ameren
- Associated Electric
- Austin Energy
- B&W
- Calpine
- Cinergy
- City Public Service of San Antonio
- ConocoPhillips
- CSX
- U.S. DOE
- Doosan Heavy Industries (Korea)
- Duke Energy
- Dynegy
- E.ON UK
- First Energy
- Fluor Corporation
- GE Energy
- Great River Energy
- LG&E Energy
- Minnesota Power
- New York Power Authority
- PacifiCorp
- Portland General Electric
- Progress Energy
- Public Service New Mexico
- Salt River Project
- Seminole Electric
- Southern Company
- Southern California Edison
- Tri-State
- TXU
- Wisconsin Public Service

CoalFleet Work Elements

1. **Assess Early Deployment Incentives, Design Impacts on Permitting, and Benefits/Risk Communication Needs**
   Promote regulatory and financial community awareness to support permitting and early deployment of advanced coal plants

2. **Develop Standard Plant Design Guidelines**
   Assure needed plant capabilities and minimize design, permitting, and construction time, costs, and risks through "reference plant" designs. " CO_2 Capture ready"

3. **Accelerate and Augment RD&D**
   Complement existing programs (e.g., DOE) with industry-led projects to support early deployment plants and to hasten commercialization of "next generation" designs

Glossary of Acronyms

- ASU Air Separation Unit
- bpd Barrels per Day
- Canadian CPC Canadian Clean Power Coalition
- CC Combined Cycle
- COE Cost of Electricity
- CT Combustion turbine
- DOE US Department of Energy
- FGD Flue Gas Desulfurization
- GJ Gigajoules
- GW Giga(10^9) watts
- IGCC Integrated Gasification Combined Cycle
- LNG Liquefied Natural Gas
- MBtu Million Btu =1.0548 Gigajoules
- mt Metric ton (2204.6 pounds)
- NG Natural Gas
- NGCC Natural Gas Combined Cycle
- OxyFuel Combustion of coal with O_2 and recycle CO_2
- PC Pulverized Coal
- PRB Powder River Basin (a sub-bituminous coal)
- Q Quadrillion(10^{15})Btu
- SC Supercritical
- SCR Selective Catalytic Reduction (of NOx)
- ST Short tons (2000 pounds)
- STPY Short tons per Year
- TCF Trillion(10^{12}) Cubic Feet
- USC Ultra supercritical