CO_2 Capture Technologies

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CO2Capture Technologies

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- Technology Descriptions
- DOE Program
- Wrap Up

CO_2 Capture Technologies

- CO_2 has been captured from natural gas processing facilities since the 1950s, at least.
- The most prominent technology has been Monoethanol Amine (MEA) as the scrubbing solution.
- The size equivalent has been roughly 25 MW.
- There have been 3 commercial power plants in operation since the late 80s, 2 on coal and 1 on gas.

CO_2 Capture Technologies

- Capture technologies are usually divided into 3 categories:
  - Post combustion capture (like MEA scrubbing)
  - Pre combustion capture (ie gasification)
  - Oxy firing (combustion with relatively pure oxygen)

CO2 Capture Technologies

- Technologies to be covered:
  - MEA Scrubbing
  - Chilled Ammonia Scrubbing
  - Oxygen Firing
  - IGCC
  - Chemical Looping

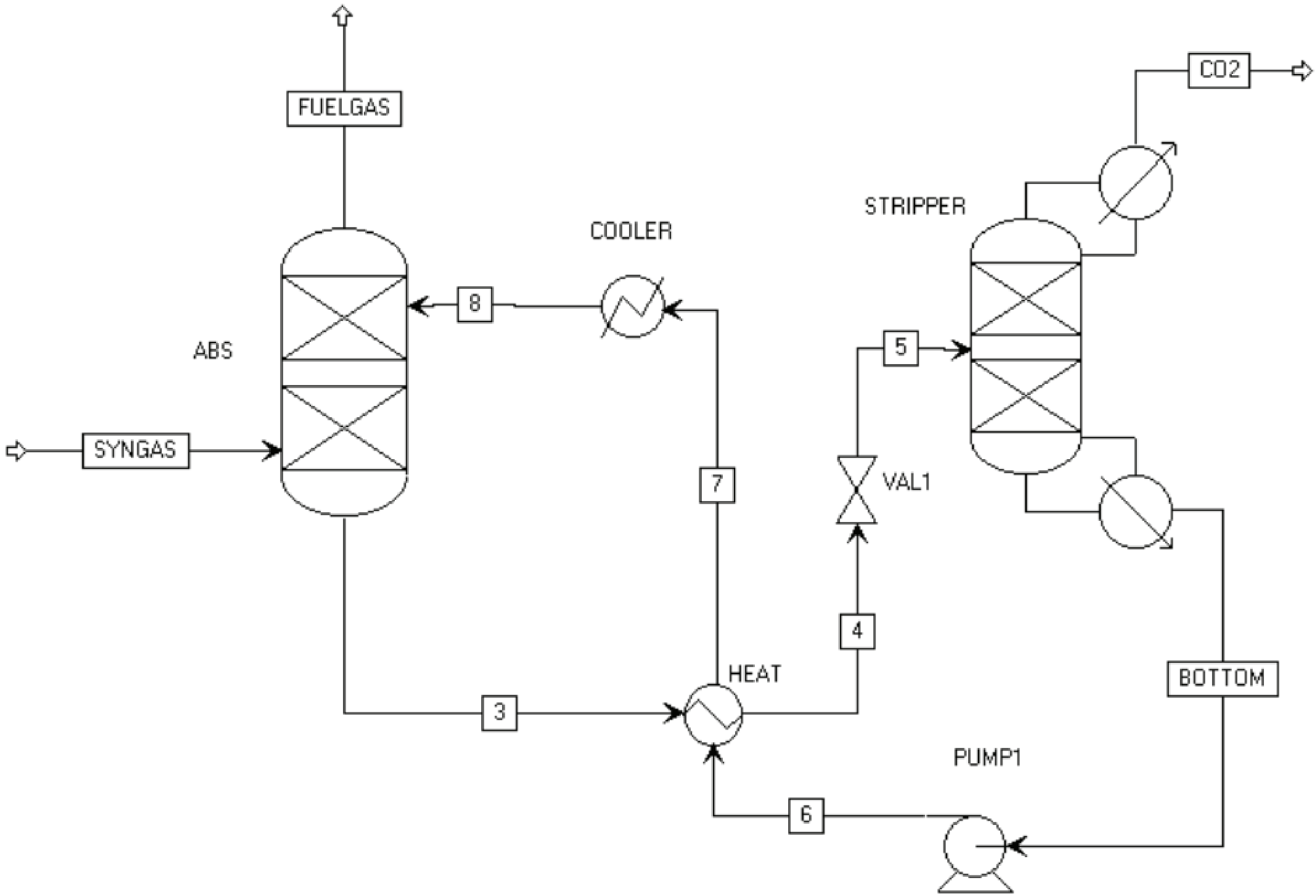
CO_2 Capture Technologies

Process	Technical Status	Cost	CO_2 Reduction	CO_2 Quality
Amine Scrubbing	110 MW	\$60 – 80/ton	90%	Food Grade
NH_3 Scrubbing	30 MW	\$60 – 80/ton	90%	Food Grade
Oxygen Firing	30 MW	\$60 – 80/ton	100%	EOR
IGCC w/CO_2	500 MW	\$90 +/ton	90%	Food Grade
Chemical Looping	3 MW(th)	\$20 – 25/ton	90%	Food Grade

Amine Scrubbing

- Amine solutions are selective to acid gases.
- Amine solutions are degraded by oxygen.
- MEA has been the most common scrubbing solution, but R&D has been underway to reduce the energy penalty for regeneration of the scrubbing solution.
- MEA has had the most operating experience in a power plant environment.

Amine Scrubbing



Amine Scrubbing

- Absorber Operating Conditions
  - 100 F inlet
  - 160 F outlet
  - Atmospheric Pressure
  - CO_2 concentrations as low as 2 - 3%

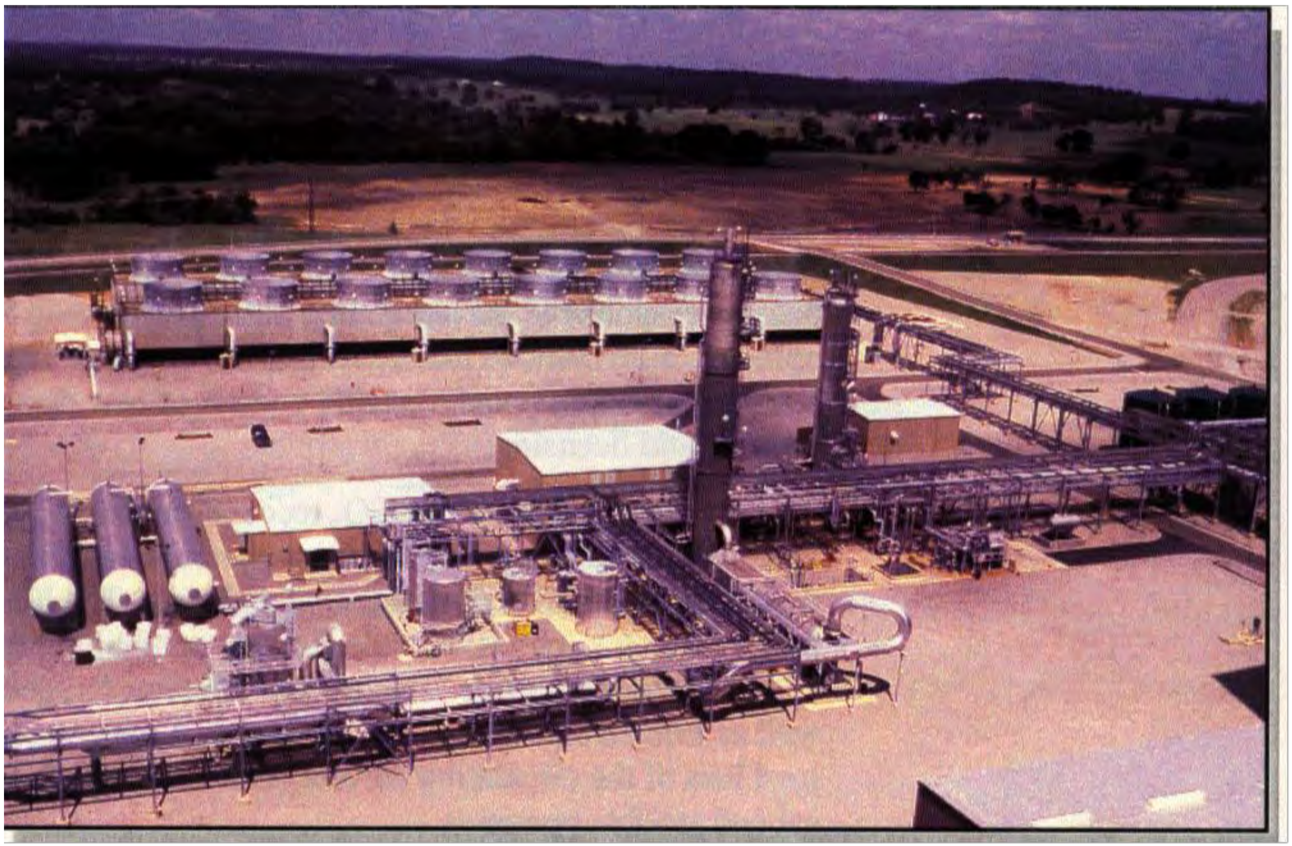
Amine Scrubbing

- Stripper Operating Conditions
  - 175 F Solution Inlet
  - 235 F Stripper Bottom
  - Atmospheric Pressure
  - Steam required for reboiler
  - Steam required for steam stripping (to assist in the release of CO2)
  - Total steam requirement (about 1/3 of the steam flow in the low pressure steam turbine.

Amine Scrubbing

- The CO_2 leaving the stripper is saturated with water vapor, which must be condensed and removed.
- The CO_2 must be compressed to the level required by its final use. For pipeline transport, this is typically 1500 psi – 2000 psi.
- The total energy penalty is currently in the range of 20 – 25% of the plant output.
  - About 55% from the capture plant
  - About 45% from the compression

Amine Scrubbing

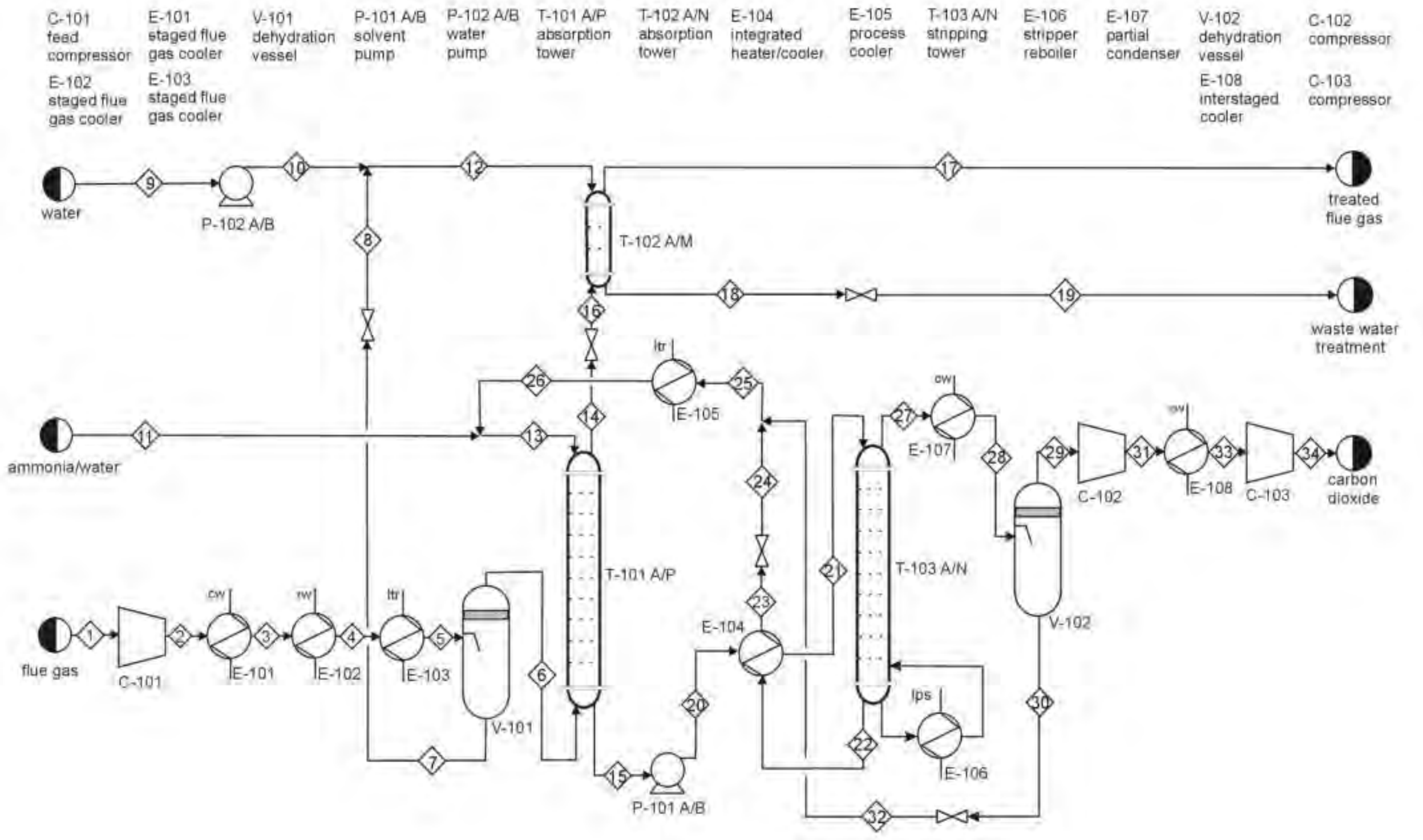


AES Shady Point Amine Scrubbing System

Chilled Ammonia Process

- The Chilled Ammonia Process was designed to take advantage of the lower energy requirement to regenerate the solution.
- Ammonia can absorb CO2 to form ammonium carbonate and ammonium bicarbonate. The sodium version of this process is used to make Alka Seltzer.
- The scrubbing solution is chilled to improve the absorption of CO2.
- The rich solution can be regenerated at pressure to reduce the compression work.

Chilled Ammonia Process



Chilled Ammonia Process

- Absorber Operating Conditions
  - 40 F Scrubber Inlet
  - Atmospheric Pressure
  - Water wash at the top to minimize ammonia losses
    - Less than 10 ppm in the exhaust gas
  - Impurities are less of a problem
    - SO2, SO3, NOx, O2 do not degrade the ammonia
  - Ammonia is cheaper than MEA and already used in power plants.

Chilled Ammonia Process

- Stripper Operating Conditions
  - 300 F
  - 1000 – 1200 psi
  - Still requires some steam for heating the solution
  - Also requires a water wash to minimize ammonia losses.

Chilled Ammonia Process

- The product CO2 is still saturated with water.
- The product CO2 is already at some higher pressure. The compression work is about half.
- Less steam is required.
- Although the target energy penalty is in the range of 10 – 12%, the current value is in the range of 18 – 20%.
- There are start up issues with the crystallization of some ammonia salts before the process is up to temperature in the stripper.

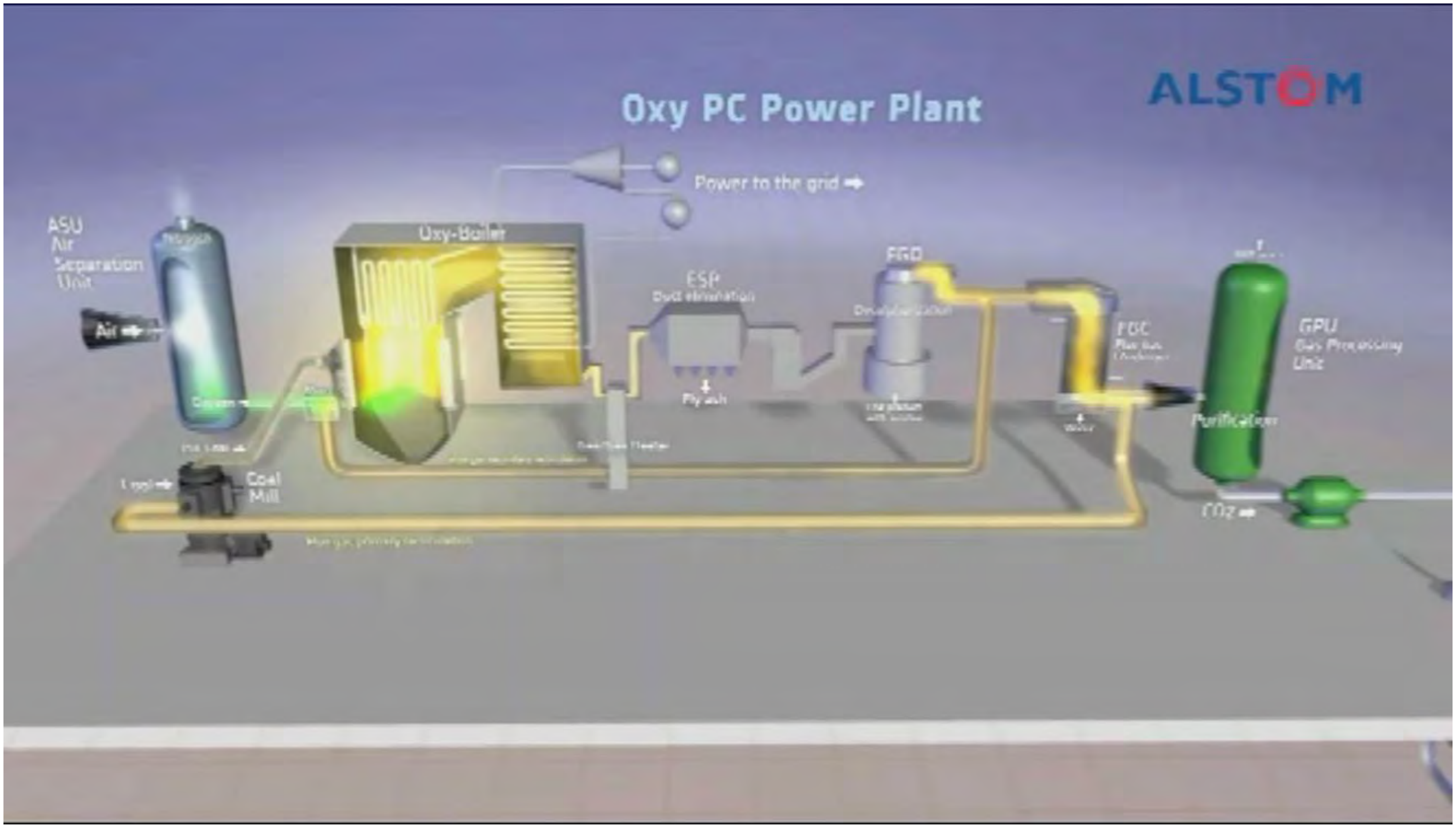
Chilled Ammonia Process

AEP Mountaineer CAP Slip Stream Plant

Oxygen Firing

- Oxygen firing involves the use of pure oxygen to burn the fuel in order to make a concentrated stream of CO_2.
- An air separation plant is required for the oxygen.
- Flue gas recirculation is required to create a synthetic air with 22 – 25% O_2 and the rest CO_2.
- No pressure part modifications are needed for the boiler.

Oxygen Firing



Oxygen Firing

- The air separation plant with current technology needs 200 kwhr/ton of O_2 (8 – 10% of the energy in the coal).
- The optimized purity level is 96.4% O_2.
- There are benefits from integration of the ASU and the power plant.
- The flue gas can be sequestered directly (ie a zero emissions power plant).
- If high purity CO_2 is required, more gas processing is needed.

Oxygen Firing

- The overall energy penalty is still in the range of 20 – 22%.
- Retrofit of an existing plant is considerably easier, as no pressure part modifications are required and very little back end equipment is needed.
- FutureGen 2.0 in the US (B&W) and White Rose in the UK (Alstom) are planned for scale up.

Oxygen Firing

Test Boiler

Test Equipment at Schwarze Pumpe

Oxygen Firing

Specifications

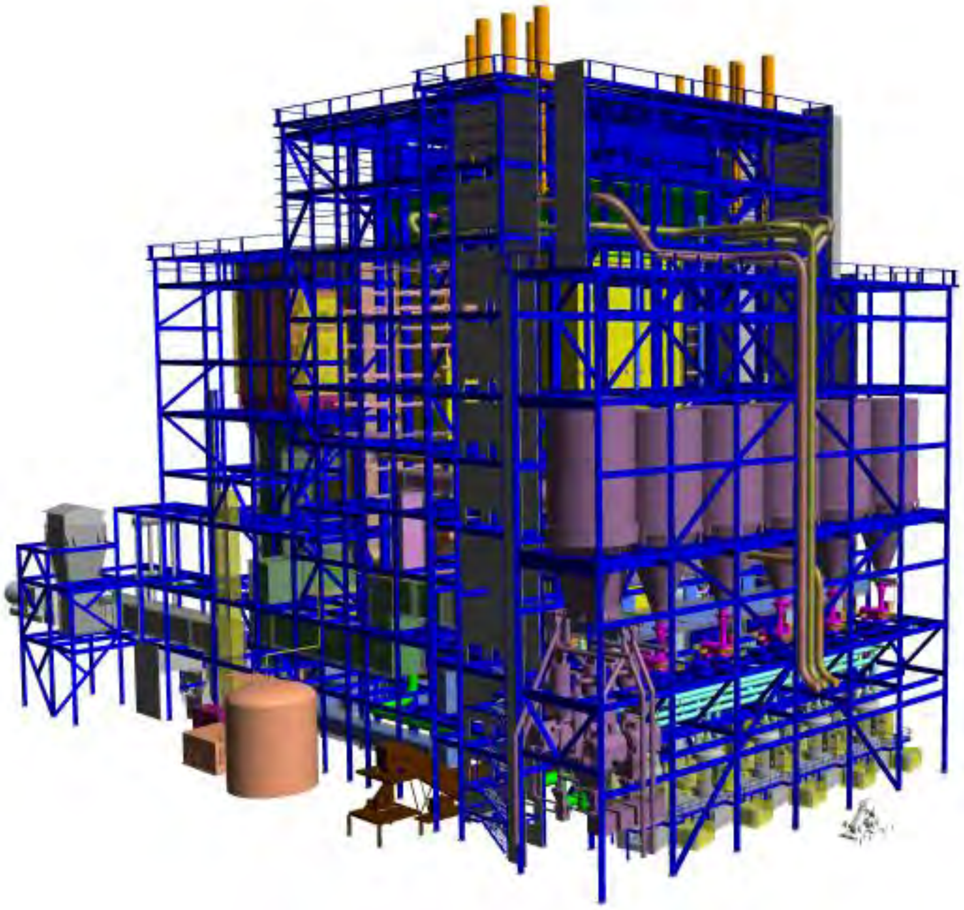
- **426 MWe gross**
- Ultra-Supercritical, sliding pressure with spiral wall evaporator
- USC – 279/52 bar, 600/620°C
- Direct pulverized coal firing, Tilting-tangential firing system

Design Fuel

- Range of Bituminous Coals

Operation

- Dual 100% Air / 100% Oxy
- Cycling load operation
- Min. Load 25%



White Rose 426 Mw

IGCC

- Integrated Gasification Combined Cycle plants have been under development since the 70s.
- The first demonstration was the Coolwater plant in 1984 (about 100 MW). Dow also built a plant at Plaquemine of similar size. Eastman Chemical built a plant for chemical production.
- Two demonstrations were built in the mid 90s at 250 MW. Polk station is still in operation.
- Edwardsport (520 Mw) was started up last year.
- Kemper County (520 Mw) will start up in 2016 and has 65% CO2 capture.

IGCC

- IGCC works by converting the coal into a fuel gas.
  - The coal is reacted with oxygen at half the stoichiometric amount to make CO rather than CO_2.
  - The resulting gas is a mixture of CO, H_2, CO_2, and H_2O and is referred to as water gas.
  - When the water and CO_2 are removed, the mixture is now CO and H_2, which is referred to as synthesis gas, or syngas. With syngas, it is possible to make any hydrocarbon with the right catalyst.
  - The Great Plains Gasification plant makes methane, or synthetic natural gas, SNG

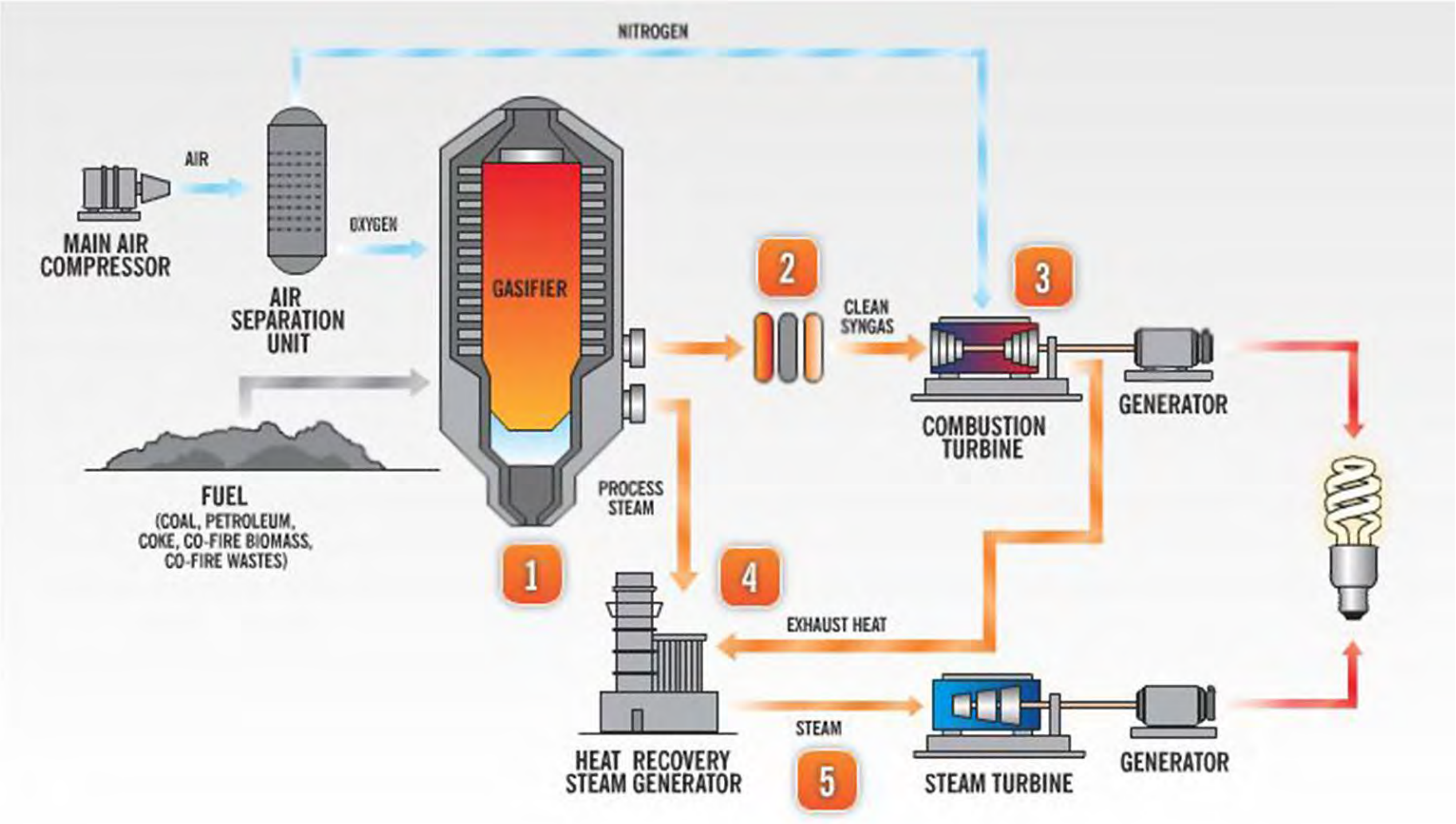
IGCC

- Once water gas is produced, the mixture can be adjusted by the water gas shift reaction to favor hydrogen production.
  - $CO + H_2O = CO_2 + H_2$
- With the addition of a shift reactor, the majority of the CO can be shifted to CO_2 leaving H_2 behind. The CO_2 can be scrubbed using "conventional" technology. The hydrogen then provides fuel for a gas turbine. The combustion product is water vapor.

IGCC

- The original goal of the IGCC plant was to take advantage of the higher efficiency of the combined cycle plant by providing a fuel gas that was cleaned prior to combustion.
- Since CO2 would have to be scrubbed anyway, the overall energy penalty was assumed to be less.
- The CO2 still needs to be compressed.
- In general, the overall efficiency gains have not been realized and the cost has been too high (about double the cost of a conventional plant).

IGCC


NITROGEN
AIR
MAIN AIR COMPRESSOR
OXYGEN
AIR SEPARATION UNIT
GASIFIER
2
CLEAN SYNGAS
3
COMBUSTION TURBINE
GENERATOR
FUEL
(COAL, PETROLEUM, COKE, CO-FIRE BIOMASS, CO-FIRE WASTES)
PROCESS STEAM
1
4
EXHAUST HEAT
HEAT RECOVERY STEAM GENERATOR
STEAM
5
STEAM TURBINE
GENERATOR

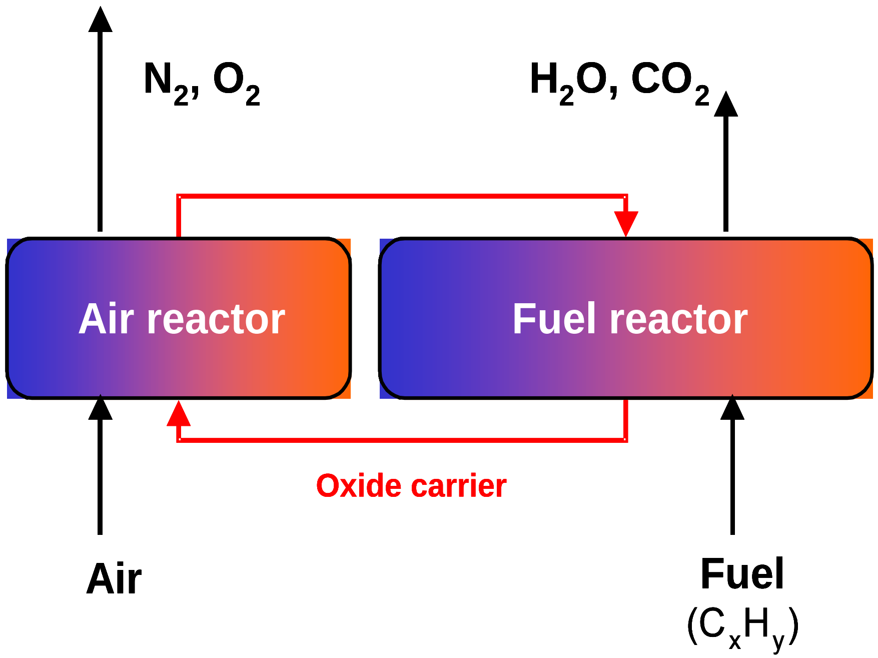
IGCC

Kemper County IGCC w/65% CO_2 Capture

Chemical Looping

- Chemical Looping is a second generation process that facilitates CO_2 capture.
- In its simplest form, chemical looping combustion (CLC) uses a solid oxygen carrier to move oxygen from one reactor to another where the fuel can accept it to produce CO_2 without the dilution of nitrogen.
- The spent oxygen carrier is returned to the first reactor where air is used to regenerate the solid

Chemical Looping



Chemical Looping

- The main advantage of chemical looping is that the two reactors operate at temperatures above the steam temperature.
  - The fuel reactor runs at about 1800 F
  - The air reactor runs at about 2000 F
- With these operating temperatures, any inefficiencies end up in the steam.
- CLC effectively provides oxygen firing without the air separation plant

Chemical Looping

- Oxygen carriers have typically been metal oxides, with copper, nickel, and iron being prime candidates.
- Alstom US is developing a system using $CaSO_4$ as the oxygen carrier. With this material, sulfur capture is achieved without the need for an SO_2 scrubbing system (ie like a CFB). $CaSO_4$ is over 42% oxygen.

Chemical Looping

- Chemical Looping is in the small pilot stage. The largest unit is 3 Mw(th) at Alstom's test facility in Windsor, CT. There are a few 1 Mw(th) test units in Europe.
- Solids handling and side reactions are key development issues for this technology.
- Not only chemicals have to participate in the looping, but also heat.

Chemical Looping

Item	Base Plant*	Base Plant with MEA**	CDLC
Gross Power, MW	580	663	657
Auxiliary Power, MW	30	113	107
Net Power, MW	550	550	550
Net Efficiency, %	39.3	28.4	35.8
Carbon Capture Efficiency, %	0	90	97
First-Year COE, $/MWh	81.0	132.6	104.3
Increase in First-Year COE, %	---	63.7	28.8

B&W Economic Analysis for Chemical Looping

Chemical Looping

Item	Base Plant*	Base Plant with MEA**	Case 1	Case 2	Case 3	Case 4	Case 4A
Reactor Type	---	---	Trans	CFB	Trans	Trans	Trans
Steam Cycle	SC	SC	SC	SC	A-USC	A-USC	A-USC
Net Power, MW	550	550	550	550	550	550	550
Net Efficiency, %	39.3	28.4	35.8	35.8	41.1	42.7	42.0
Investment Cost, $/kW	2452	---	2795	2801	2944	3067	2978
CO_2 Avoided Cost, $/ton-$CO_2$	---	---	27.0	27.3	24.2	26.5	23.4
Carbon Capture, %	0	90	97	97	98	96	97
First-Year COE, $/MWh	81.0	132.6	96.7	96.8	95.1	96.0	94.6
Increase in First-Year COE, %	---	63.7	19.5	19.6	17.5	18.5	16.9

Alstom Economic Analysis for Chemical Looping

DOE Program

- The DOE CCS program is currently focused on reducing the cost of CO_2 captured to the point where it can be competitive in EOR applications.
  - The cost of capture has gone from \$100/ton down to \$60/ton today, with a goal of \$40/ton or less by 2025
  - The long run goal is more like \$25/ton
- DOE's ultimate goal is to combine 2cd generation capture technology with advanced generation technology to reach cost parity with today's conventional power plant technology without capture.