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Thermodynamic performance of IGCC with oxy-combustion CO_2 capture

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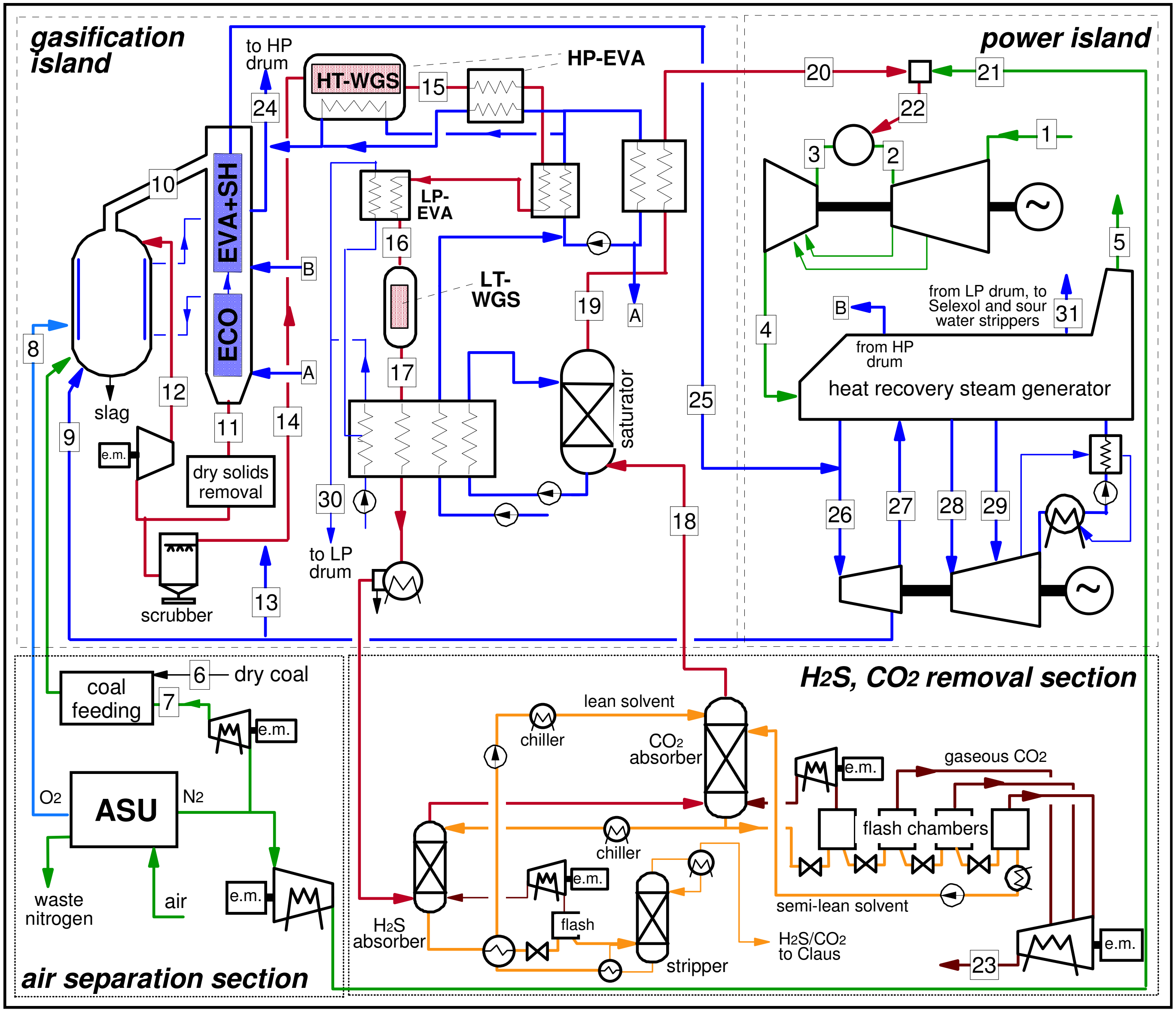
Purpose of the study

- CO_2 capture from coal power plant. Configurations proposed:
  - USC with amine capture or with oxy-combustion
  - IGCC with pre-combustion capture
- Investigate novel plant configurations, to obtain better thermodynamic and environmental performance
- Near-term solutions requiring the development of components not available in today's marketplace, <u>but not requiring unproven technologies</u>
- Investigated configurations:
  - Reference IGCC, without and with capture
  - Oxy-combustion, with semi-closed H_2O-CO_2 power cycle, present technology
  - Oxy-combustion, with co-capture CO_2-SO_2, advanced technology
  - Oxy-combustion, Hot Gas Desulfurization, advanced technology
- Detailed thermodynamic analysis and optimization

The reference cases

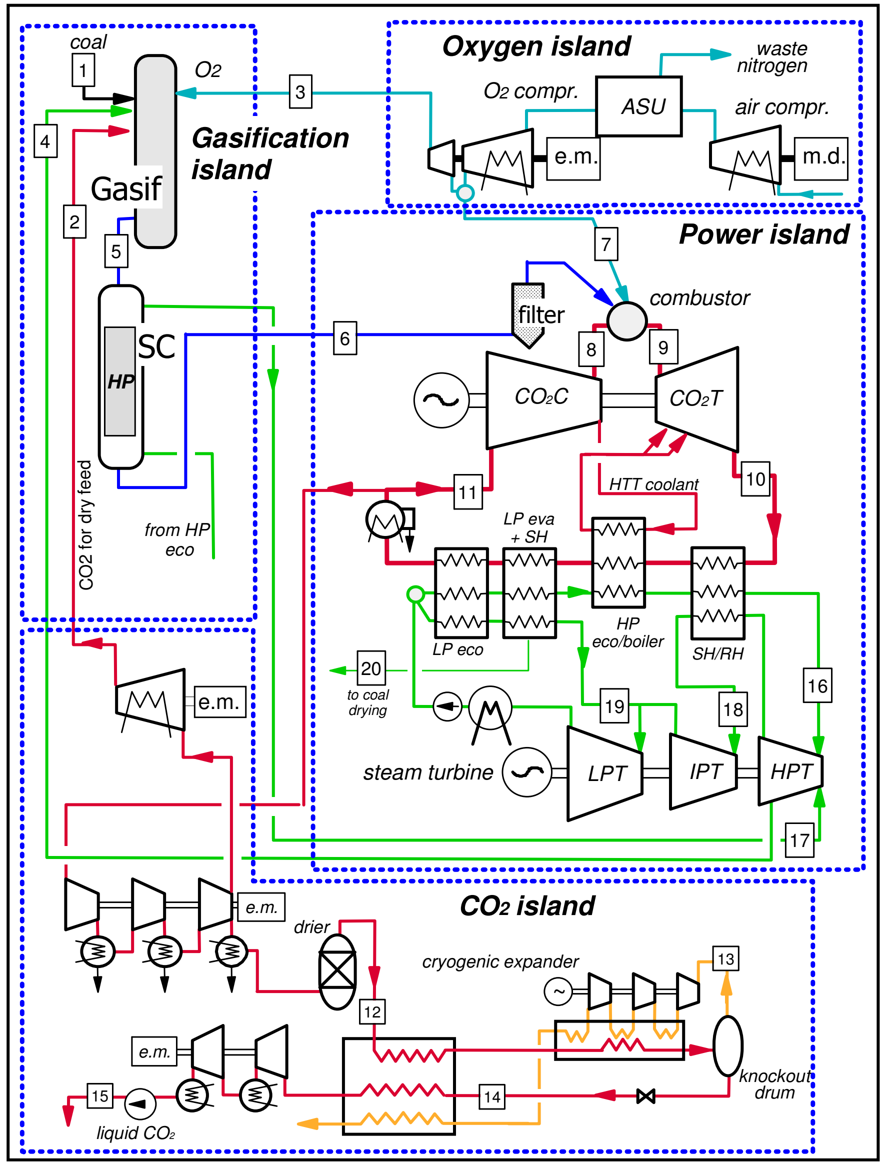
- Calculations by means GS code, developed in our Department and used for power plant on-design performance prediction
- No capture: A status-of-the-art IGCC combined cycle based:
  - An oxygen-blown dry-feed entrained-flow gasifier (Shell type)
  - Syngas cooling by syngas quench and HP steam gen.
  - Power cycle based on a FB-technology gas turbine
- With pre-combustion capture:
  - Same basic plant configuration and calculation assumptions
  - CO conversion to hydrogen by means of two Water-Gas-Shift reactors (HT: bulk conversion, LT: 'finishing')
  - H_2S/CO_2 removal by Selexol in two separate absorbers; largest solvent fraction for CO_2 removal with pressure-swing regeneration; smaller fraction for H_2S removal with stripper regeneration.

Pre-combustion CO_2 capture



Oxy-fuel IGCC

- Syngas from conventional gasification is burnt with high-purity oxygen in a semi-closed CO_2-H_2O Joule cycle:
  - CO_2 to lock-hoppers.
  - A CO_2 compressor recycles CO_2 to the oxy-combustor
  - Larger pressure ratio to optimize cycle efficiency
- A CO_2 cryogenic purification system is needed to eliminate incondensable gases during compression

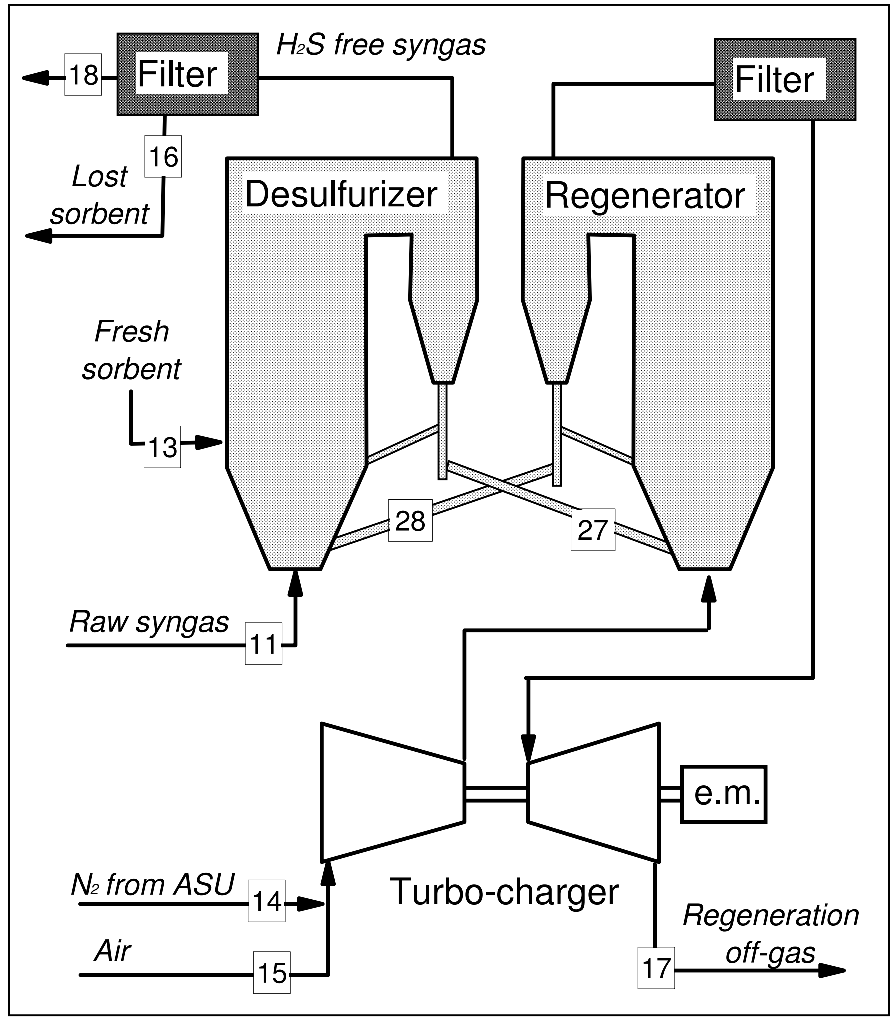


Oxy-fuel IGCC: present vs. advanced technology

- The gas turbine must be re-designed, using known methodologies and present technology. Large development costs can be anticipated.
- Present technology:
  - Conventional gasification with H_2S separation by Selexol
- Advanced technology with CO_2-SO_2 co-sequestration:
  - High pressure gasifier
  - Hot Gas Filtration (550°C)
  - H_2S not separated (sent to burner)
  - Improved gas turbine, due to the mid-long term application
  - Blade coolant cooling to improve TIT

Hot Gas Desulfurization

- To avoid Co-sequestration of CO_2 and SO_2
- Reactions
  - $ZnO + H_2S \rightarrow ZnS + H_2O$
  - $ZnS + 3/2\ O_2 \rightarrow ZnO + SO_2$
- Desulpurization @550°C
- Regeneration @750°C
- Regeneration gas with 2% O_2 to avoid $ZnSO_4$ formation



Calculation method and assumptions

- Performance calculated by GS code, developed at Energy Dept, Politecnico di Milano
- Used since two decades to calculate the performance of any type of power plant
- Built-in correlations for components' efficiency prediction
- GT blade cooling models
- Assumptions from literature and industrial experience

Gasification and ASU		*Gas turbine and steam cycle*	
Gasification pressure, bar	44	Fuel temperature, °C	250
Gasification temperature, °C	1550	GT turbine inlet temperature, °C	1335
Heat losses, % LHV	0.7	GT pressure ratio	17
Carbon conversion	99.0	Pressure levels, bar	130/36
Temperature of O_2 to gasifier, °C	15	SH/RH temperature, °C	565
Moderator steam, kg_{H2O}/kg_{coal}	0.06	Pinch point/sub-cooling ΔT, °C	10/5
N_2 to lock hoppers, $kg/kg_{dry\text{-}coal}$	0.22	Condensing pressure, bar	0.04
Quenched syngas temperature, °C	900	Minimum stack temperature, °C	115
Cold recycle syngas temperature, °C	200	*CO_2 compression*	
Min. ΔT in syngas coolers, °C	20	Number of inter-cooled stages	5
Oxygen purity, % mol.	95	Inter-cooling temperature, °C	25
ASU electric consumption, kWh/t_{O2}	325	Inter-coolers pressure loss, %	1
		Compressors isentropic efficiency, %	82

Table 1 – Assumptions for the reference IGCC plants, present technology.

Water Gas Shift Reactors		*Selexol Plant*	
Steam to carbon at first reactor inlet	1.5	L/G ratio (wt. basis) in H_2S/CO_2 absorption columns	1.1/11.6
HT reactor outlet temperature, °C	400	CO_2 flash tanks pressures, bar	15/8/3.5/1.5
LT reactor outlet temperature, °C	210	Reboiler heat duty, MW_{th}	27

Table 2 – Additional assumptions for the IGCC plant with pre-combustion capture.

CO_2 to gasifier lock hoppers, kg/kg_{coal}	0.35	Fuel side pressure loss at combustor, %	20
GT pressure ratio	40	O_2 content at combustor outlet, % mol.	2

Table 3 – Varied assumptions for the oxy-fuel IGCC plant, present technology.

Gasification temperature, °C	1427	Syngas temperature to GT, °C	550
Gasification pressure,bar	50	Steam pressures HP/RH, bar	247/58
Carbon conversion	99.5	LP evaporation pressure, bar	4
Temperature of O_2 to gasifier, °C	200	SH/RH steam temperature, °C	600/600

Table 4 – Varied assumptions for the oxy-fuel IGCC plant, advanced technology.

ZnO to TiO_2 mol.ratio in fresh sorbent	1	O_2 mol.fraction in regeneration mixture	2%
System pressure, MPa	≈ 5	Regeneration temperature, °C	750
Desulphurization temperature, °C	550	ZnS to ZnO mol.ratio in regen.sorbent	0.1
Sorbent loss, % in wt.	0.1	Pressure loss at the hot gas filter, %	3

Table5 – Assumptions for Hot Gas Desulfurization.

Results of the performance analysis

Case	*Reference IGCC*	*Pre-combustion IGCC*	*Oxy-IGCC*	*Advanced oxy-IGCC*	*Advanced oxy-IGCC + HGD*
TIT, °C	1335	1335	1335	1400	1400
Sulfur co-sequestration	-	no	no	yes	no
Electric/mechanical power MW					
Gas turbine (2 units)	659.4	597.7	609.6	656.5	653.2
GT auxiliaries	-2.34	-2.12	-2.16	-2.30	-2.32
Steam Turbine	420.6	354.0	454.7	510.8	513.6
Steam cycle pumps	-6.53	-6.92	-6.51	-11.60	-11.01
ASU	-72.15	-72.17	-178.17	-188.2	-187.0
Lock hoppers N_2 compress.	-9.11	-9.11	-	-	-
Syngas recycle fan	-2.4	-2.41	-2.42	-	-
Syngas compressor	-	-	-10.79	-	-
N_2 compressor for fuel dilution	-69.13	-51.34	-	-	-
Aux. for H_2S / CO_2 removal	-0.69	-26.16	-0.69	-	-3.40
CO_2 compression	-	-40.80	-83.05	-83.30	-83.30
Auxiliaries for heat rejection	-5.86	-5.18	-8.88	-11.03	-11.03
Miscellaneous BOP	-7.40	-7.38	-7.40	-7.47	-7.45
Net power output, MW_{el}	**904.4**	**728.2**	**764.2**	**863.5**	**861.3**
Fuel input LHV, MW_{th}	1897.6	1897.6	1897.6	1897.6	1897.6
Cold Gas Efficiency, %	78.14	69.63	77.36	83.85	83.31
Net LHV efficiency, %	**47.66**	**38.38**	**40.27**	**45.50**	**45.39**
CO_2 captured, %	0	90.76	97.38	97.38	97.38
CO_2 spec.emissions, g/kWh	**732.1**	**82.3**	**25.1**	**22.2**	**22.3**

Table 6 –Performance of the plants considered in the paper.

Conclusions

- Very interesting performance can be predicted for Oxy-fuel IGCC:
  - Environmental: NOx and SOx not wasted to the atmosphere, but mostly solved within the stream to sequestration
  - Environmental: 95-99% carbon capture, depending on the solutions adopted for incondensable gases stream
  - Efficiency: better than 45% by adopting advanced solutions, specific to oxy-fuel configurations (not applicable to decarbonization):
    - Hot Gas Filtration
    - Co-sequestration of CO2-SO2 or Hot Gas Desulfurization
- Drawbacks: the gas turbine must be re-designed, using known methodologies and present technology.
- A larger attention may be devoted to Oxy-fuel IGCC in the R&D programs

Oxy-fuel CO_2 capture: present technology