ASCENT – Performance criteria and benchmarking (WP1)

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Scope of the activity

To perform process integration study and techno-economic analysis of Ascent technologies in full scale power plants and hydrogen plants and compare with benchmark technologies.

Summary of the presentation

- **Benchmark power plants and hydrogen plants**
- **Process integration and simulation of Ascent technologies**:
  - SER process in SOFC-based power plant
  - SER process in combined cycle power plant
  - Ca/Cu process in combined cycle power plant
  - C-Shift process in combined cycle power plant
- **Preliminary economic evaluation of power plants:**
- **Conclusions and next activities**

Benchmark power plants and hydrogen plants

Benchmark plants for power and hydrogen production:

No Capture CO_2 Capture

Combined cyle power plants:

1. **NGCC** (Natural Gas Combined Cycle) - *EBTF*
2. **NGCC+MEA** (NGCC with post-combustion capture by MEA) - *EBTF*
3. **ATR+MDEA** (Autothermal refomrer+pre-combustion capture)

Coal power plants:

4. **IGCC** (Integrated Gasification Combined Cycle) - *EBTF*
5. **IGCC+Selexol** (IGCC with pre-combustion capture by Selexol) - *EBTF*

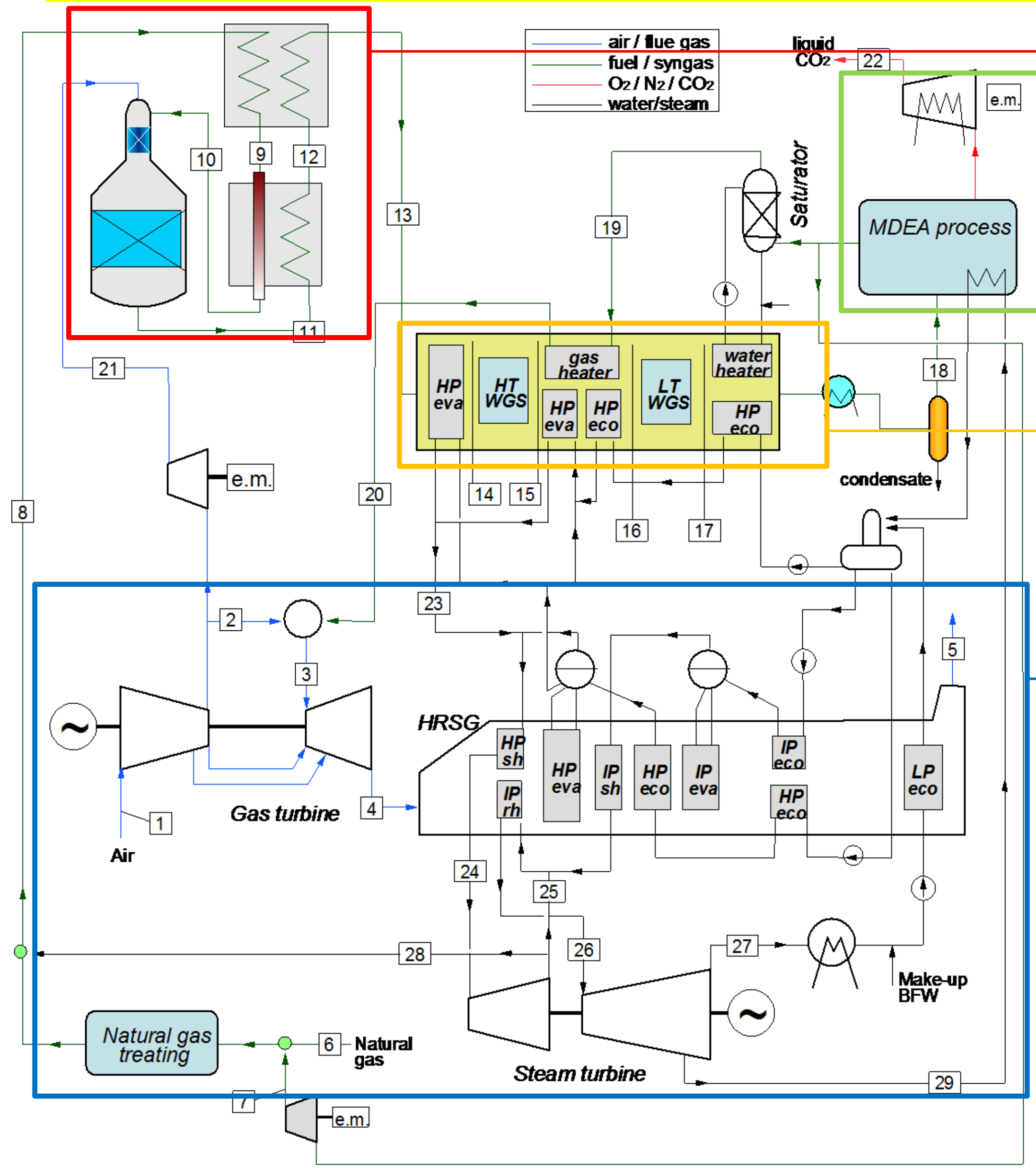
SOFC power plants:

6. **ATM w/o CCS** (Atmospheric SOFC without capture)
7. **ATM with CCS** (With cryogenic CO2 separation)
8. **PRESS w/o CCS** (Pressurized SOFC without capture)
9. **PRESS with CCS** (With cryogenic CO2 separation)

H_2 production plants:

10. **FTR** (Fired Tubular Reformer)
11. **FTR+MDEA** (FTR with CO2 medium capture by MDEA)
12. **FTR+MDEA** (FTR with CO2 high capture by MDEA)

Benchmark power plants – ATR+MDEA



ATR + Gas-heated pre-reformer

CO_2 absorption and compression

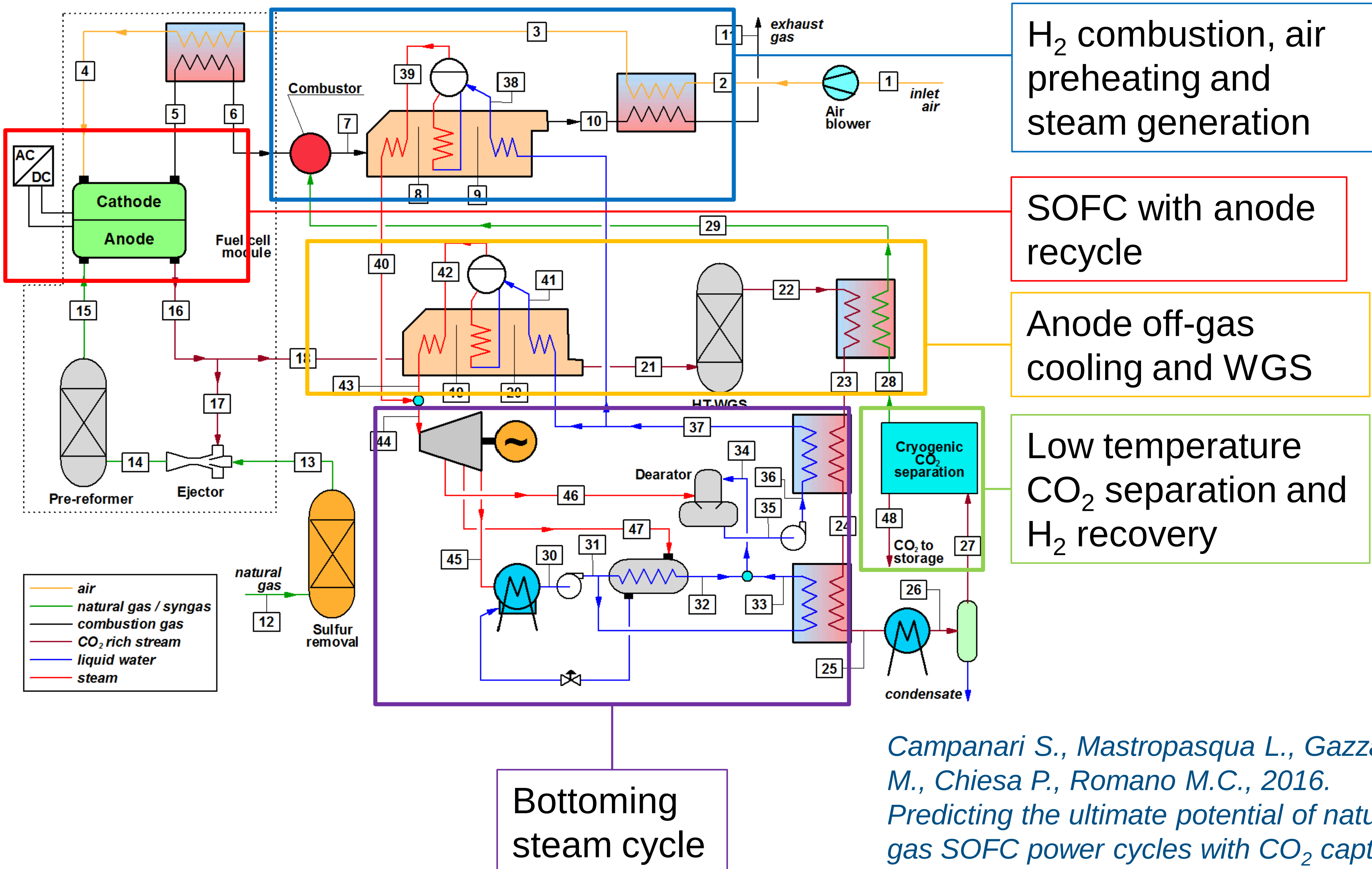
Syngas cooling and conditioning

H_2-fired combined cycle

Adapted from:

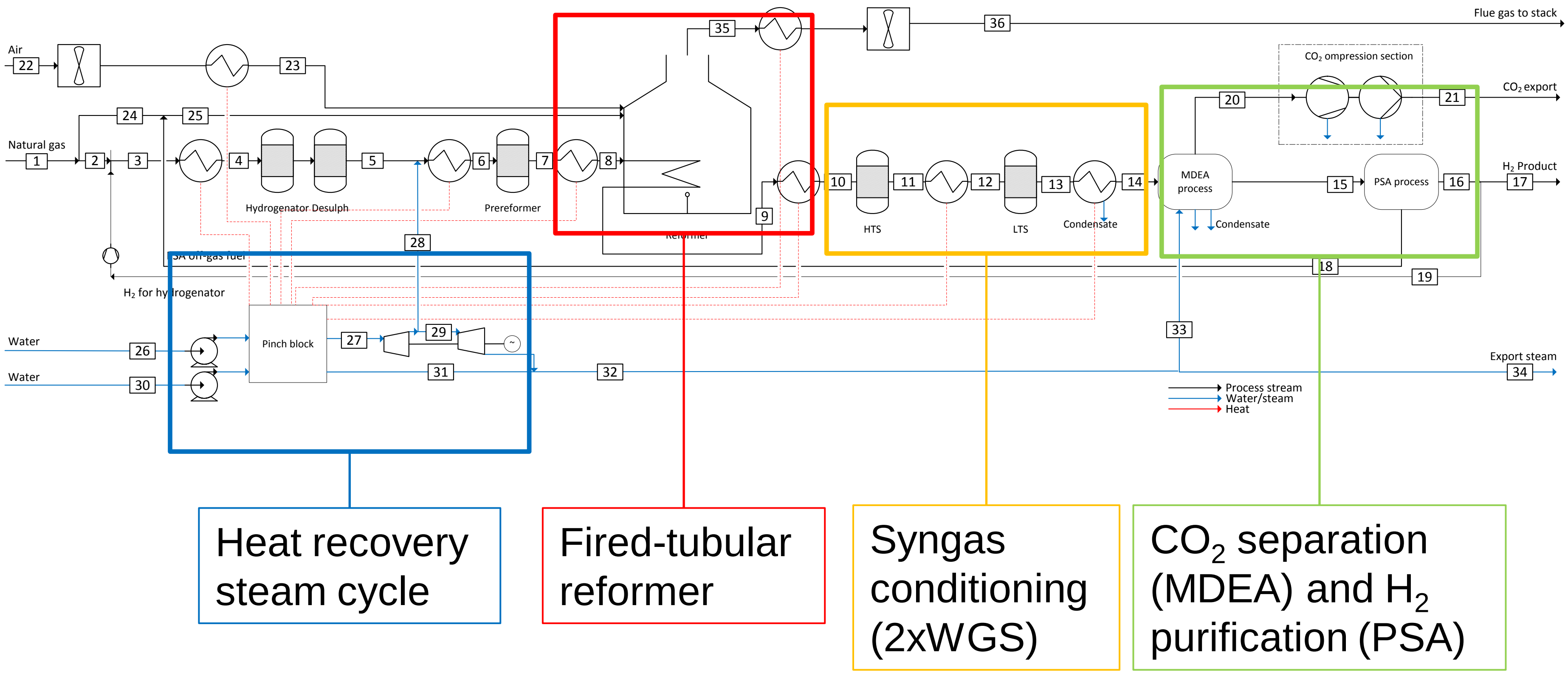
Romano M.C., Chiesa P., Lozza G., 2010. Pre-combustion CO_2 capture from natural gas power plants, with ATR and MDEA processes; Int J Greenh Gas Control, 4, 785-797.

Benchmark power plants – Low press. SOFC with CCS



Campanari S., Mastropasqua L., Gazzani M., Chiesa P., Romano M.C., 2016. Predicting the ultimate potential of natural gas SOFC power cycles with CO_2 capture; Journal of Power Sources, 324, 598-614. Journal of Power Sources, 325, 194-208.

Benchmark hydrogen plants – FTR with CCS



Martínez I., Romano M.C., Fernández J.R., Chiesa P., Murillo R., Abanades J.C., 2014. Process design of a hydrogen production plant from natural gas with CO_2 capture based on a novel Ca/Cu chemical loop. Applied Energy, 114, 192-208.
Martínez I., Romano M.C., Chiesa P., Grasa G., Murillo R., 2013. Hydrogen production through sorption enhanced steam reforming of natural gas: thermodynamic plant assessment; International Journal of Hydrogen Energy, 38(35), 15180-15199.

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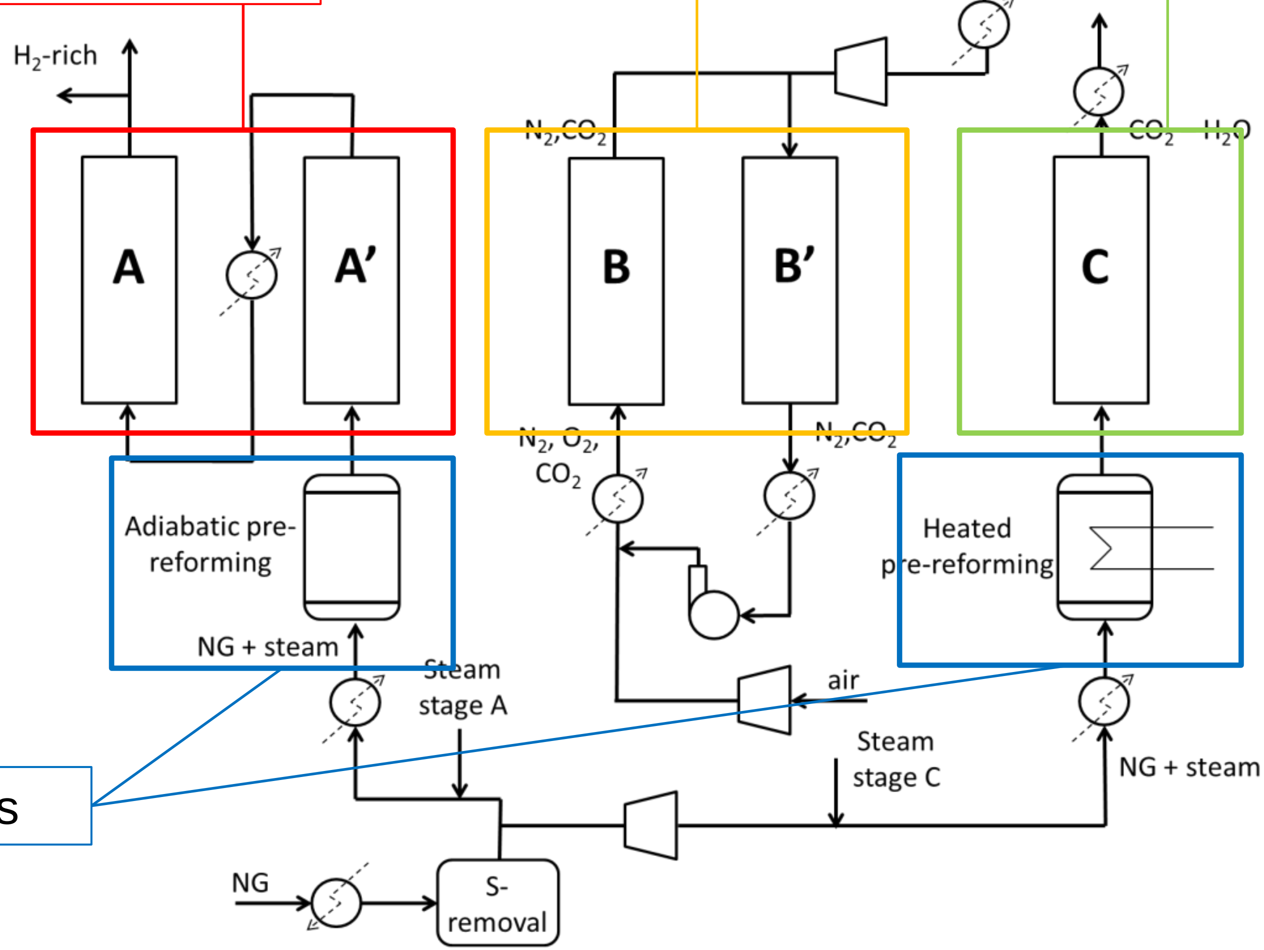
Ca-Cu process for NGCC power plant

Step A (~20 bar, S/C=5):
$CH_4+2H_2O \rightarrow CO_2+4H_2$
$CaO+CO_2 \rightarrow CaCO_3$
(Cu)

Step B (~20 bar):
$Cu+1/2O_2 \rightarrow CuO$
($CaCO_3$)

Step C (1 bar):
$4CuO+CH4 \rightarrow CO_2+2H_2O$
$CaCO_3 \rightarrow CaO+CO_2$



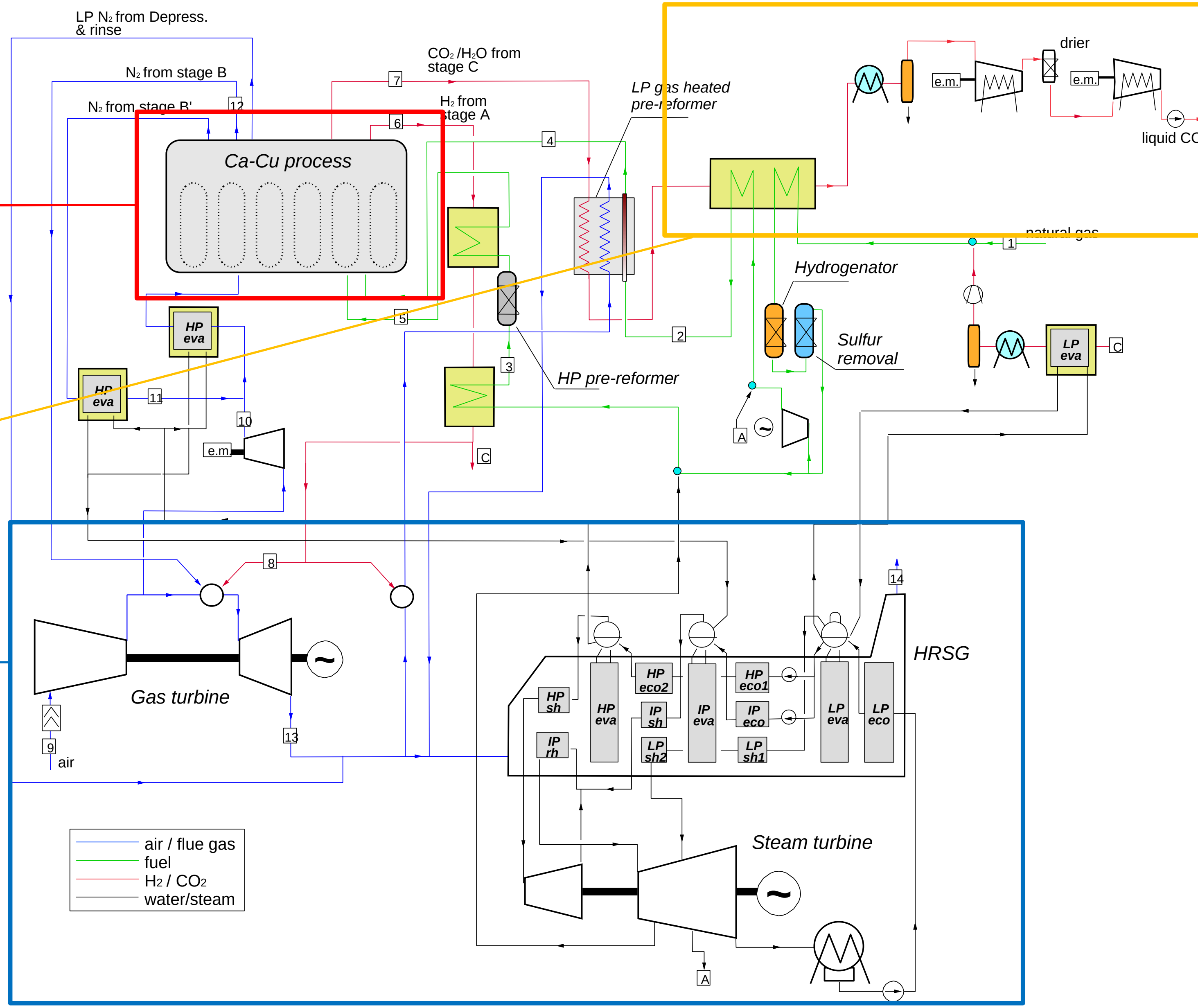
Pre-reformers

Ca-Cu process for NGCC power plant

Ca-Cu process

CO_2 cooling and compression

H_2-fired combined cycle



SER for SOFC-based power plant

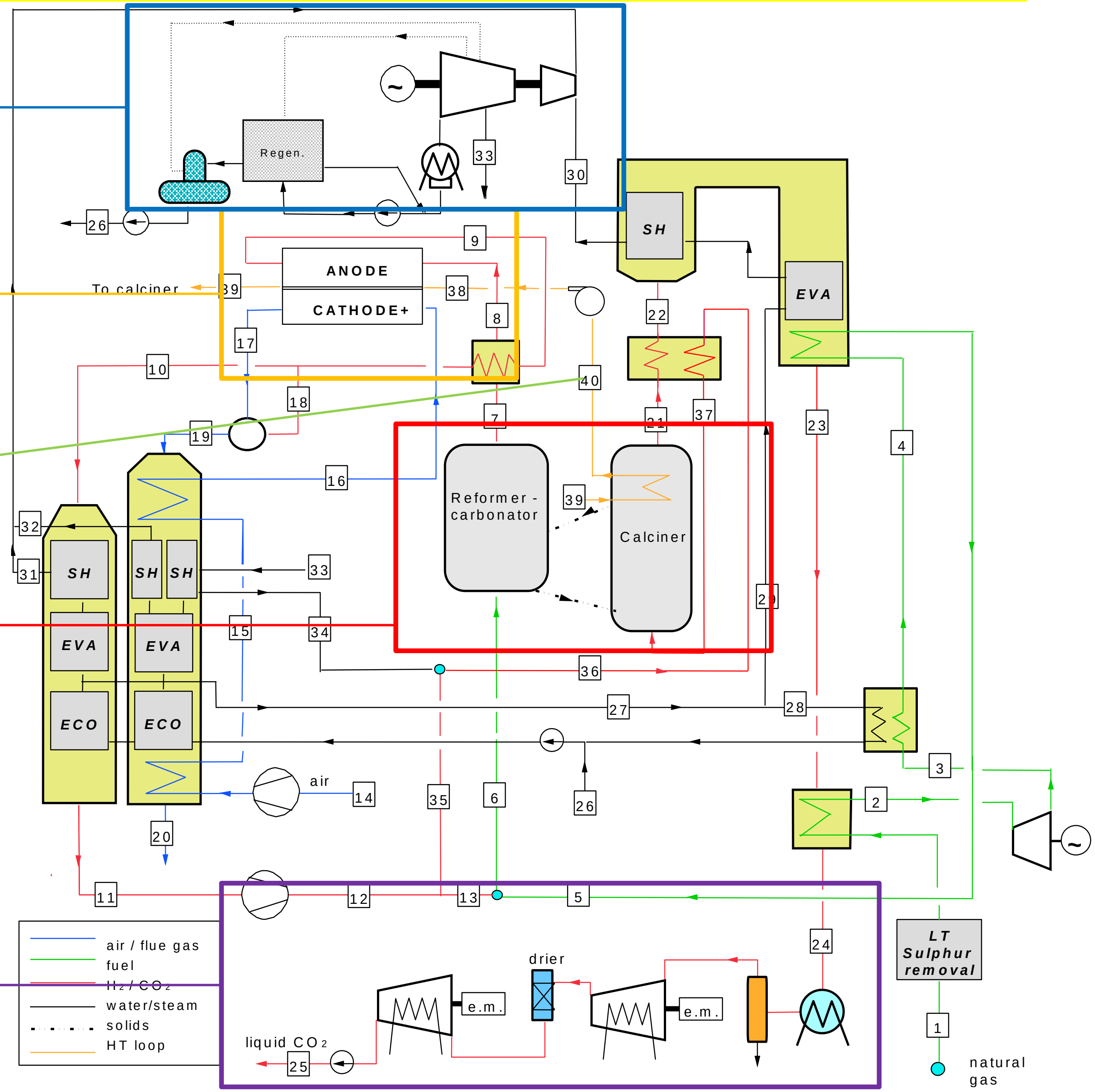
Bottoming steam cycle

High temperature (~1000°C) SOFC

High temperature heat transfer loop

SER process:
- Adiabatic reformer-carbonator at 635°C
- Externally heated calciner at 865°C

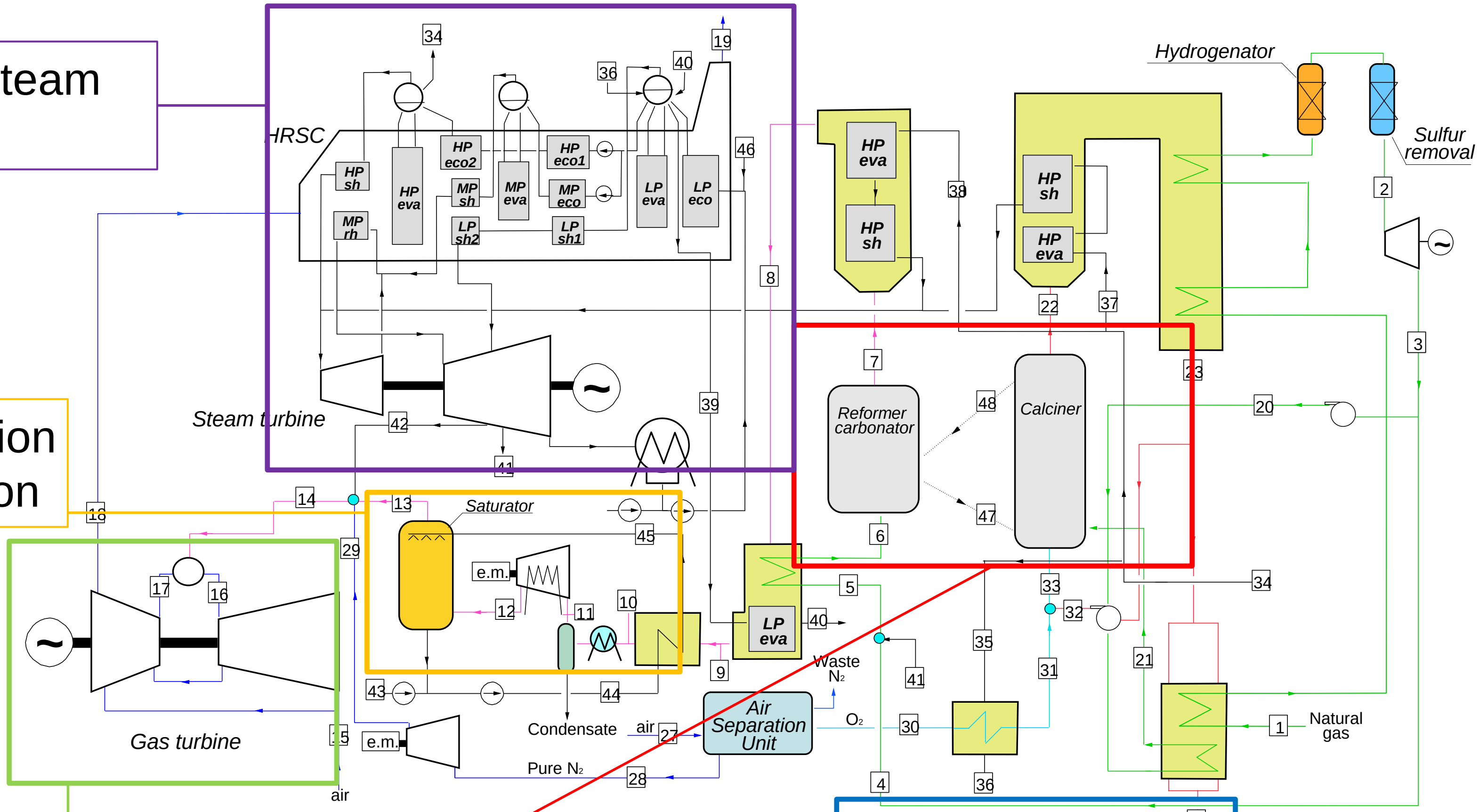
CO_2 compression



SER for NGCC-based power plants

Bottoming steam cycle

H_2 compression and saturation



H_2-fired gas turbine

SER process:

- Adiabatic reformer-carbonator at 635°C
- Oxy-fired calciner

CO_2 compression

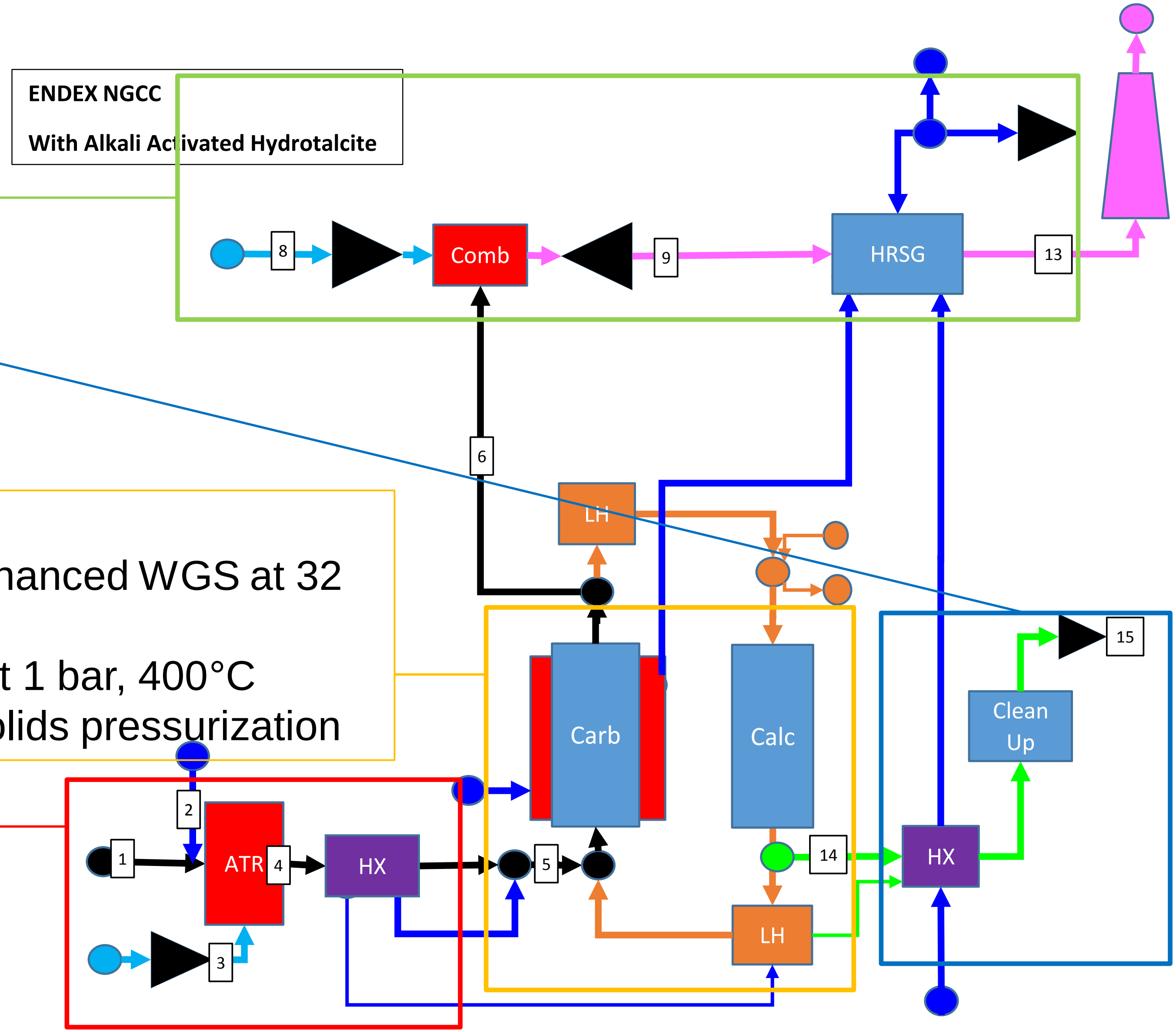
C-Shift process for NGCC power plant

H_2-fired combined cycle

CO_2 cooling and compression

C-Shift process:
- Cooled sorption-enhanced WGS at 32 bar, 440°C
- Adiabatic calciner at 1 bar, 400°C
- Lock-hoppers for solids pressurization

Air-blown ATR



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TRL of Ascent power plants

A direct comparison and ranking of Ascent technologies is premature: the different power plants include technologies other than the Ascent ones with very different level of maturity.

Low TRL components in Ascent power plants

Ascent technology and component	Comments
All Ascent processes (except SER-SOFC plant)	
H_2-fired gas turbine	No industrial application use hydrogen as GT fuel today. However, significant experimental tests on commercial GT machines have been performed with research purposes. → under proper market conditions, commercial GTs may operate using hydrogen as fuel, after modifications of the combustor, the fuel system and possibly slightly modifying the firing temperature with respect to the corresponding NG-fired machine.
Ca-Cu process	
No novel unit, too far from current industrial practice.	-

Low TRL components in Ascent power plants

Ascent technology and component	Comments
SER-SOFC process	
Cooled SOFC	No tests reported high temperature SOFC with external cooling circuit. Tests on externally cooled FC performed on PEM FC, operating at much lower temp..
High temperature heat transfer loop and calciner heat exchanger	Lab-scale tests on the externally heated calciner performed at IFE. The heat transfer loop also includes high temperature piping and a high temperature fan. The operating temperature of these components is ~900°C, which is close to the temperature required in fired tubular reformer tubes. Duration tests to verify the resistance of such material at the specific conditions of the SER unit (high steam concentration, erosion by impacting solids, but low pressure differences) are needed.
SER-NGCC process with externally heated calciner	
High temperature heat transfer loop and calciner heat exchanger	Same considerations of the SER-SOFC system, except that no high temperature blower is needed, since gas pressure drops are balanced by GT compressor.
SER-NGCC process with oxyfuel calciner	
No novel unit, too far from current industrial practice.	-

Low TRL components in Ascent power plants

Ascent technology and component	Comments
C-Shift process	
High temperature lock hoppers	Lock hoppers are commercially available devices. However, operating conditions in the C-Shift process are more severe than in conventional applications, involving the pressurization and depressurization of solids at high temperatures.

Performance of Ascent CC power plants

	NGCC w/o capture	ATR + MDEA	Ca-Cu CC	Oxy-SER CC	HE-SER CC	C-Shift CC
Electric efficiency, $\%_{LHV}$	58.42	47.12	47.78	46.3	46.1	51.2
Carbon capture ratio, %		91.56	87.34	92.1	86.5	88.3
Specific emissions, kg/MWh	350.6	36.66	56.70	32.1	59.9	46.9
CO_2 avoided, %		89.54	83.83	90.8	82.9	86.6
SPECCA, MJ_{LHV}/kg_{CO2}		4.71	4.67	5.04	5.67	2.85
Presence of additional low- TRL components	-	-	-	-	High temp. heat transfer loop	High. temp. lock hoppers

Performance of Ca-Cu and oxy-SER cases is similar to benchmark ATR+MDEA plant.

Margins exist for improving Ca-Cu plant performance.

Advantages on the economic side are however possible for both processes.

Promising performance, much better than the benchmark, for the C-Shift process. More detailed modelling of the reactors is needed to confirm these performance.

Performance of Ascent SOFC power plant

	Atmospheric SOFC w/o capture	Atmospheric SOFC with capt.	SER-SOFC
Electric efficiency, $\%_{LHV}$	76.14	72.48	**70.58**
Carbon capture ratio, %	-	84.87	**93.90**
Specific emissions, kg/MWh	269.36	42.66	**17.70**
CO_2 avoided, %	-	84.16	**93.43**
SPECCA, MJ_{LHV}/kg_{CO2}	-	1.05	**1.48**
Presence of additional low- TRL components	**-**	**-**	**Cooled SOFC & high temp. heat transfer loop**

Performance of SER-SOFC plant slightly worse than the SOFC-benchmark in terms of SPECCA. Performance improvement is possible if sorbent performance is improved.

Advantages on the economic side are anyway possible.

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Economic analysis – first approach

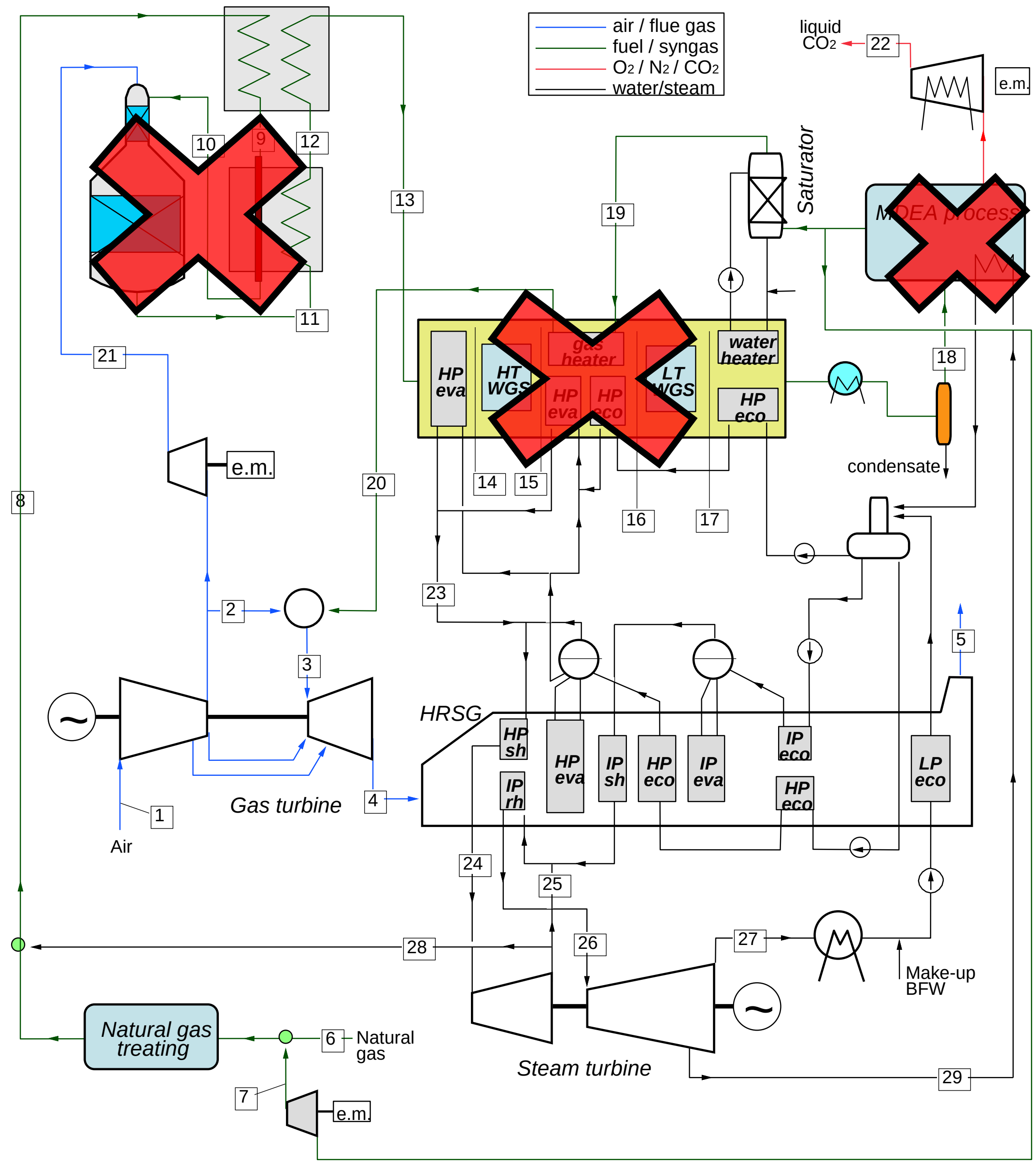
Due to the high uncertainty in estimating several components of novel Ascent processes, a differential economic analysis has been initially performed.

→ definition of an area of economic competitiveness for Capex and Opex of novel components/processes.

Economic analysis – example of the CaCu plant

With respect to the benchmark ATR-NGCC power plant with CO_2 capture, CaCu plant features:

- No conventional reforming section → saving in Capex and opex for catalyst replacement
- No WGS reactors → saving in Capex and opex for catalyst replacement
- No CO_2 absorption process → saving in Capex and opex for solvent make-up
- Different size of steam cycle and cooling water system



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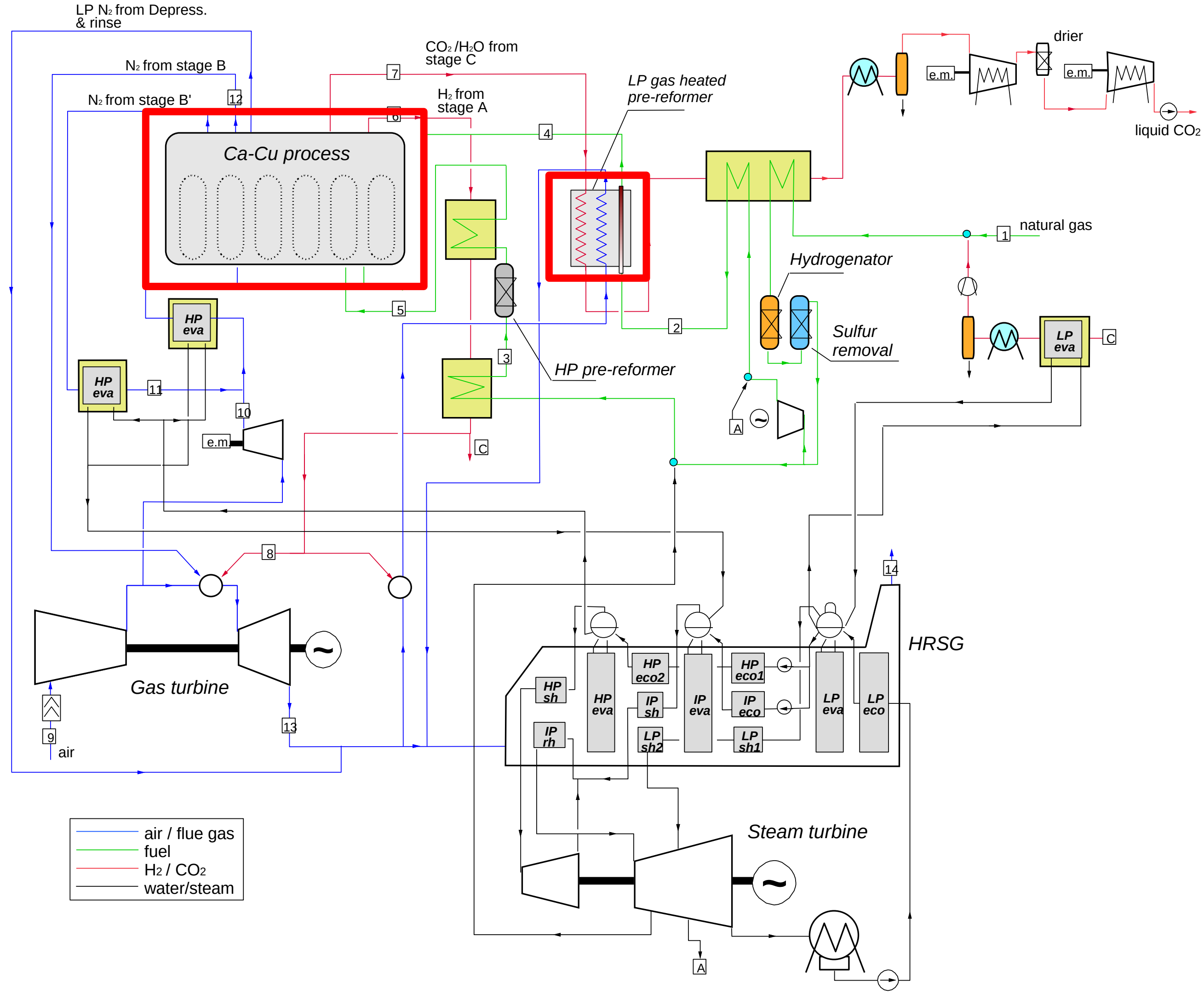
Economic analysis – CaCu plant

With respect to the benchmark ATR+NGCC power plant with CO_2 capture, CaCu plant features:

- CaCu chemical island → additional Capex and opex for catalyst, sorbent and oxygen carrier replacement
- LP gas heated pre-reformer → additional Capex and Opex



Economic analysis – CaCu plant

Cost of electricity and cost of CO_2 avoided:

	Benchmark NGCC w/o capture €/MWh	Benchmark ATR-NGCC with capture €/MWh	CaCu (zero CaCu cost) €/MWh	CaCu (breakeven Capex) €/MWh	CaCu (breakeven Opex) €/MWh
Capital cost	11.72	25.48	19.38	**25.08**	19.50
Natural gas	40.84	50.63	50.45	50.45	50.45
Other variable O&M	0.51	3.58	2.11	2.11	**10.22**
Fixed O&M	5.45	10.90	8.28	10.82	8.28
Cost of Electricity	**58.52**	**90.60**	**80.22**	**88.45**	**88.45**
Cost of CO_2 Avoided, €/ton		**102.1**	**74.0**	**102.1**	**102.1**

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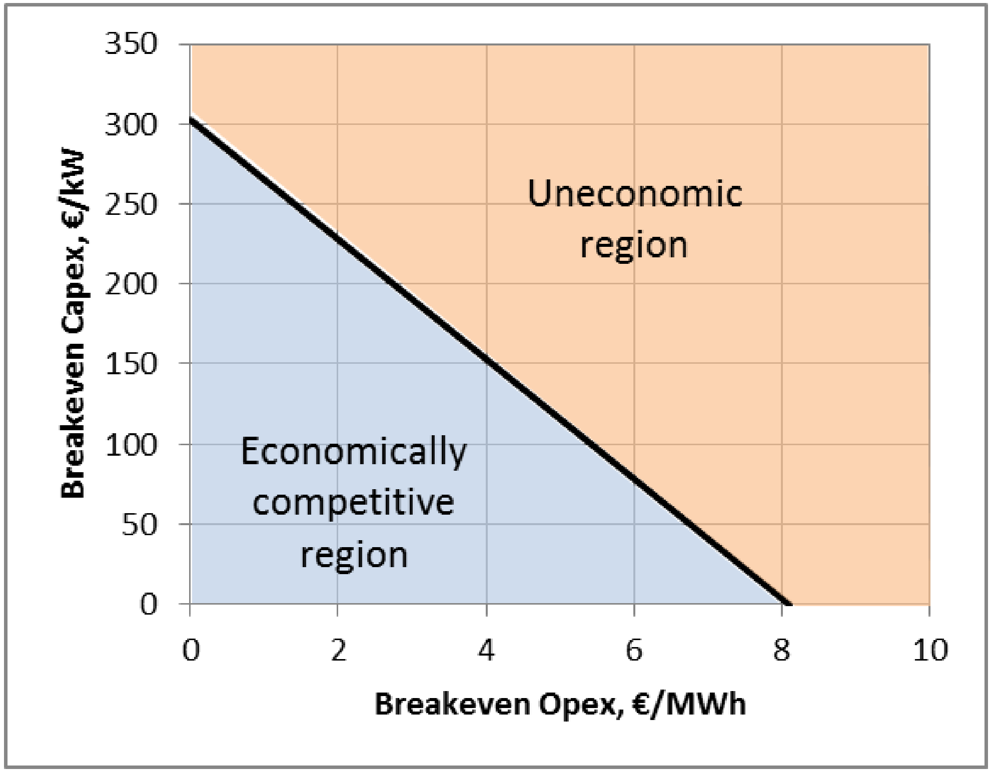
Economic analysis – CaCu plant

Maximum Capex and Opex of novel process units should be in the economically competitive region to make the technology competitive (from the point of view of the cost of CO_2 avoided).



Similar charts have been made for all the other plants, representing target economic performance for the technology developers.

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Conclusions and next activities

- Ca-Cu CC, oxy-SER CC and SER-SOFC power plants show efficiencies and SPECCA in line with the benchmark. Margin exists for improving the integrated processes. Economic benefits over benchmark technologies are possible.
- C-Shift power plants show efficiencies and SPECCA significantly better than the benchmark. Improved reactors modelling is needed to confirm this result. For this technology, the development of high temperature lock-hoppers is needed beyond Ascent.

- Work is ongoing to improve process performance of Ascent technologies in power plants and to include the effects of improved accuracy of the reactors models.
- Work is ongoing on process integration of Ascent technologies in hydrogen and ammonia production plants, with promising results.
- Work is ongoing to complete the economic analysis of Ascent power plants.

Thank you

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