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Calcium looping combustion for high-efficiency low-emission power generation from coal,

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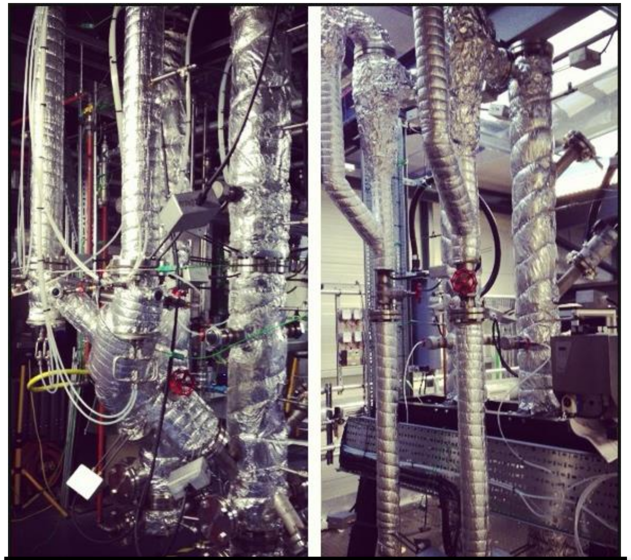
Research interest of *Thermal and Chemical Process Engineering Group*

- CO_2 capture, transport and storage
- CO_2 utilisation
- Energy storage
- High-efficiency low-emission power generation
- Novel combustion and gasification processes
- Sustainable energy systems
- Alternative fuels
- Novel materials for CO_2 capture



Outline

1. Background
2. Calcium looping
3. Calcium looping combustion based power plants
4. Techno-economic performance assessment
5. Conclusions

Background

To reduce the risks and impacts of climate change, the temperature increase needs to be kept well below 2°C compared to pre-industrial levels - Power sector accounts for a third of total greenhouse gas emissions.

- A large share of global electricity produced from coal (~28.1%) [1];
- Low average thermal efficiency of the power plant fleet;
- Low price of coal-based power generation.

[1] Key World Energy Statistics, 2017, Rapport, International Energy Agency

Background

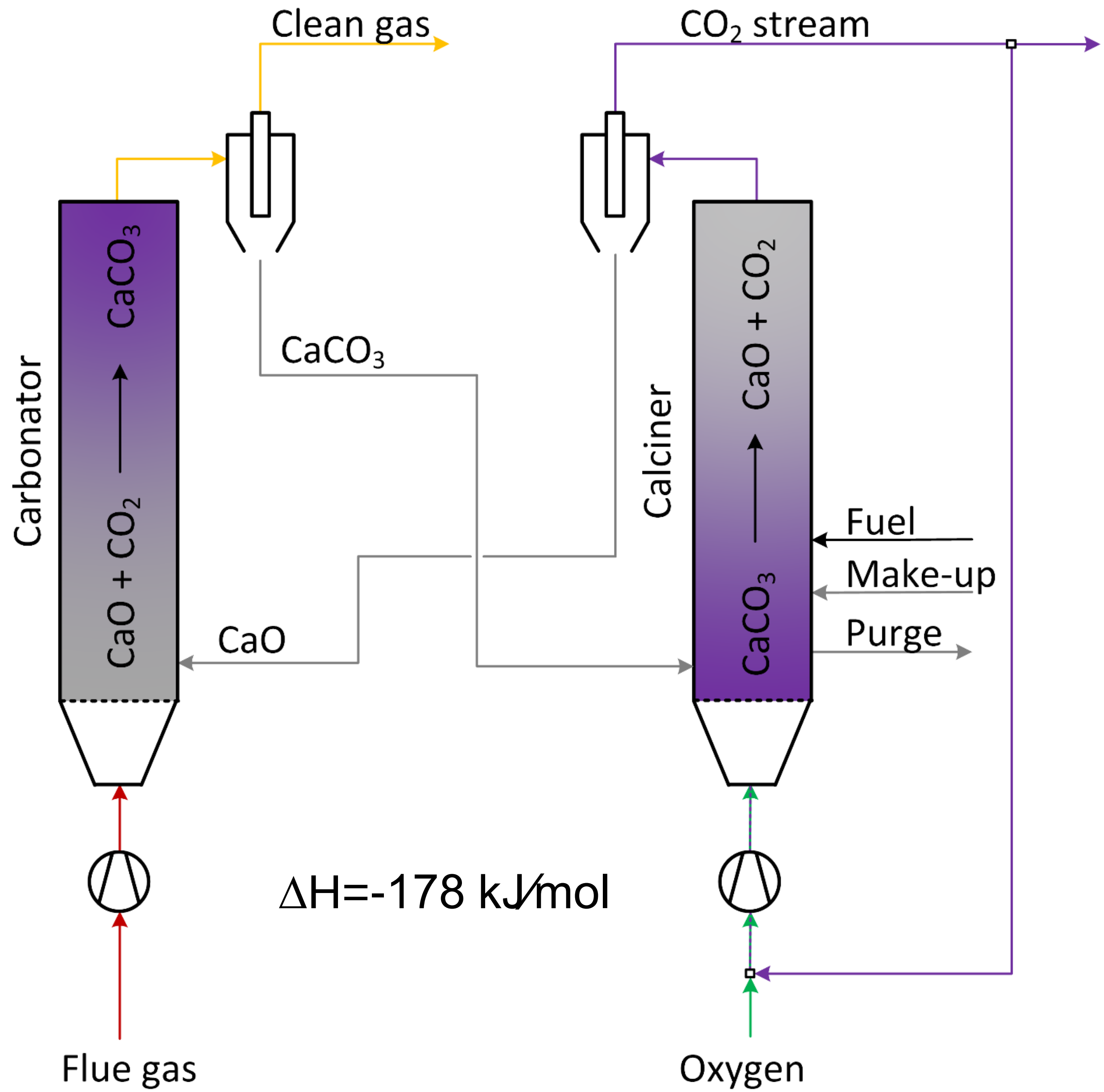
The power sector can be decarbonised via portfolio of measures, such as:

- Renewable energy sources (linked with energy storage technologies);
- Nuclear power systems (lack of social consent and flexibility);
- Carbon capture and storage:
  - Oxy-combustion and chemical solvent scrubbing - 7-13% points efficiency drop[1];
  - Calcium looping retrofit - 5-8% points efficiency drop[2].

[1] Boot-Handford, M.E., Abanades, J.C., Anthony, E.J., Blunt, M.J., Brandani, S., Mac Dowell, N., Fernandez, J.R., Ferrari, M.C., Gross, R., Hallett, J.P., Haszeldine, R.S., Heptonstall, P., Lyngfelt, A., Makuch, Z., Mangano, E., Porter, R.T.J., Pourkashanian, M., Rochelle, G.T., Shah, N., Yao, J.G., Fennell, P.S., 2014. Carbon capture and storage update. Energy Environ. Sci. 7, 130-189

[2] Hanak, D.P., Anthony, E.J., Manovic, V., 2015. A review of developments in pilot plant testing and modelling of calcium looping process for CO_2 capture from power generation systems. Energy Environ. Sci. 8, 2199-2249.

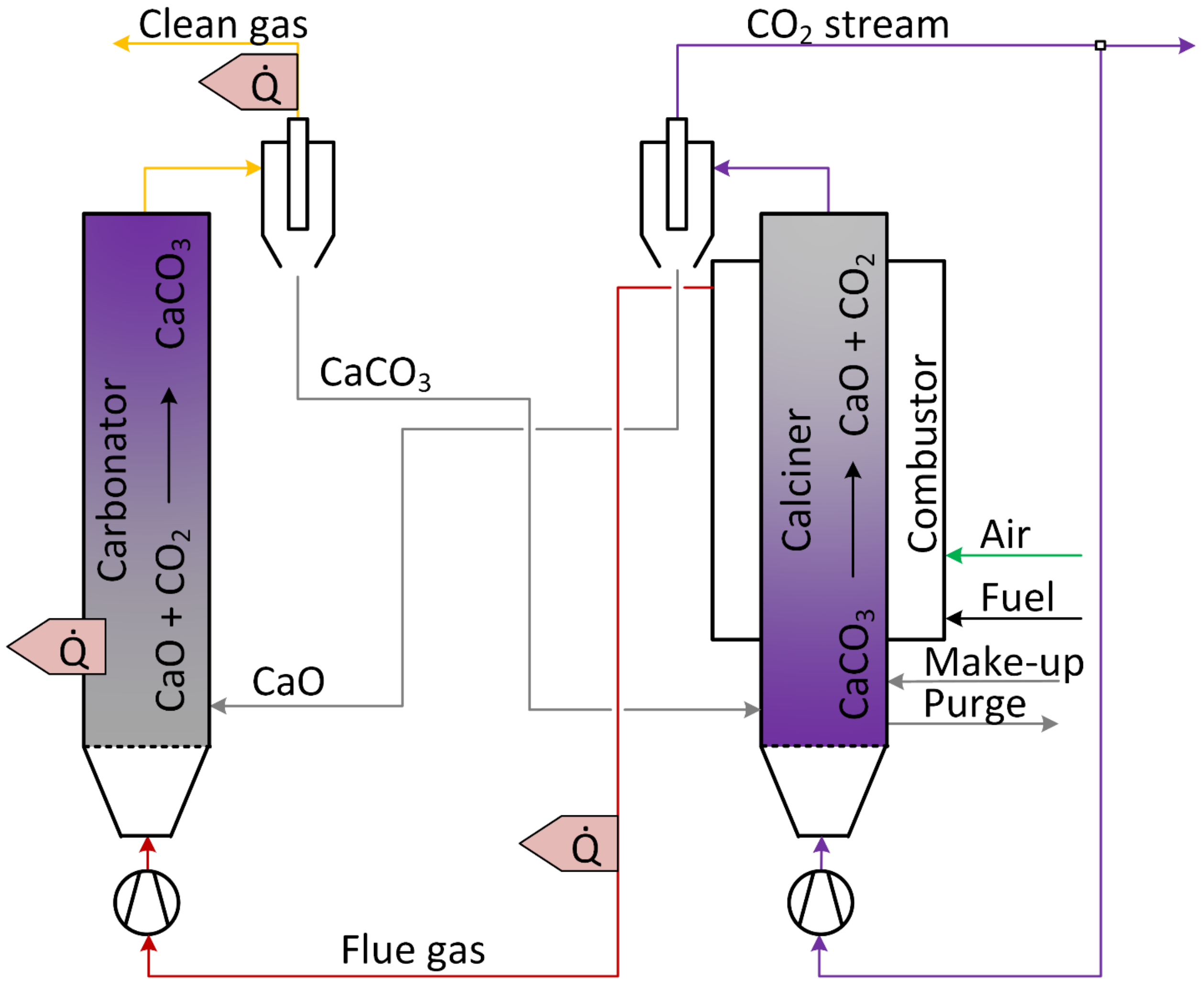
Calcium looping



Process flow diagram of calcium looping – internal combustor

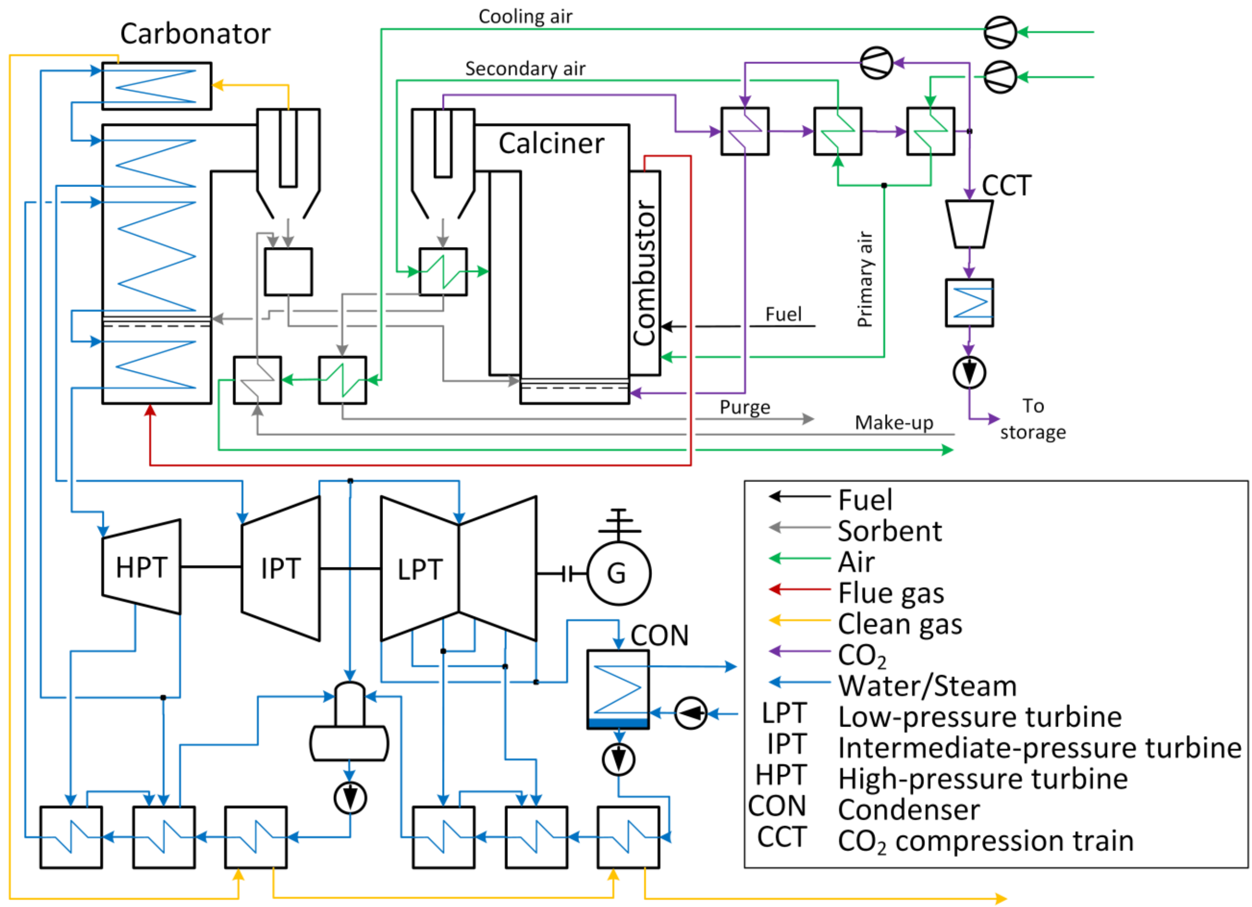
Calcium looping combustion (CaLC)

- Self sufficient heat generation system;
- No need for oxygen production;
- Three high temperature heat sources.



Calcium looping combustion (CaLC) – steam cycle

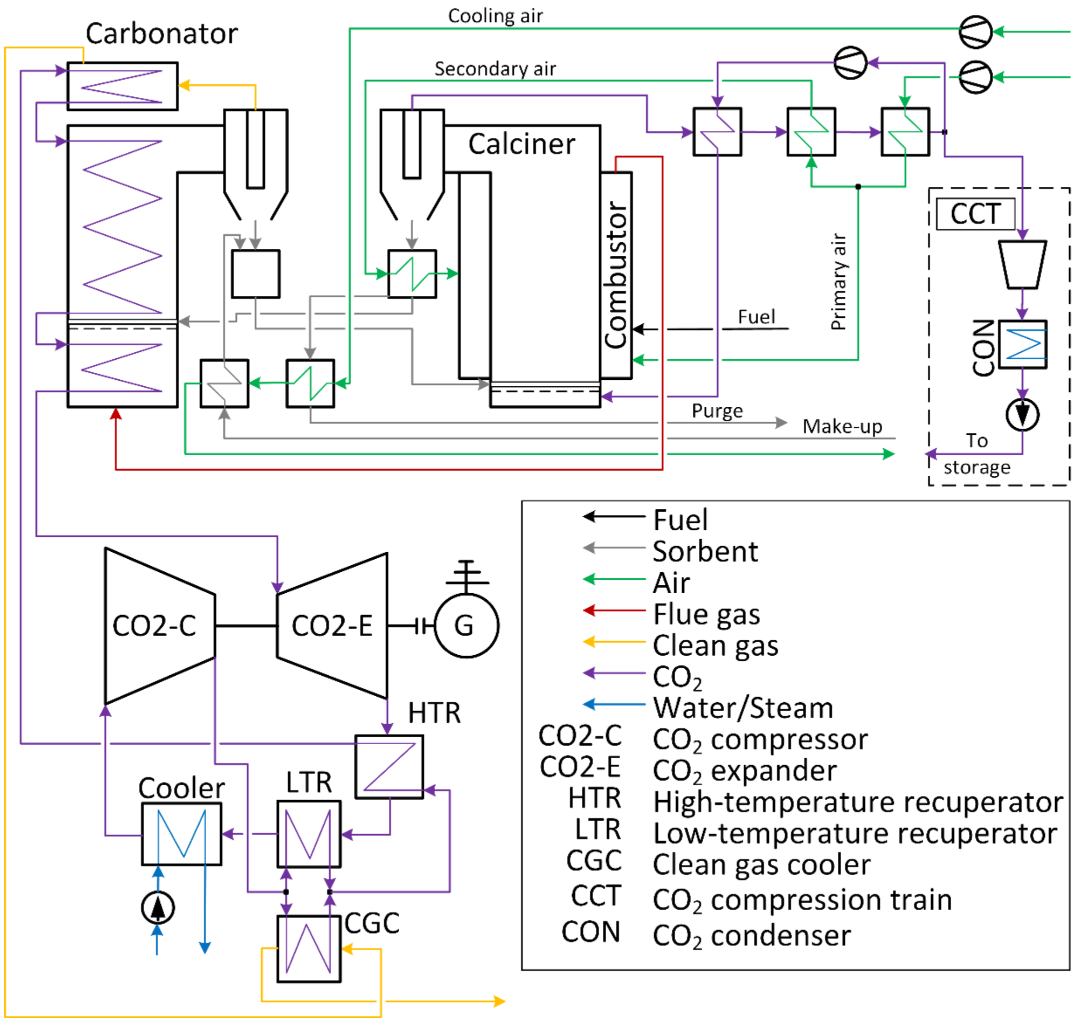
- Working temperature of Calciner - 900°C and Carbonator - 650°C
- Gross electrical power 592.7 MW_{el}
- Live steam parameters 593.3°C/24.23 MPa
- Reheated steam par. 593.3°C/4.9 MPa



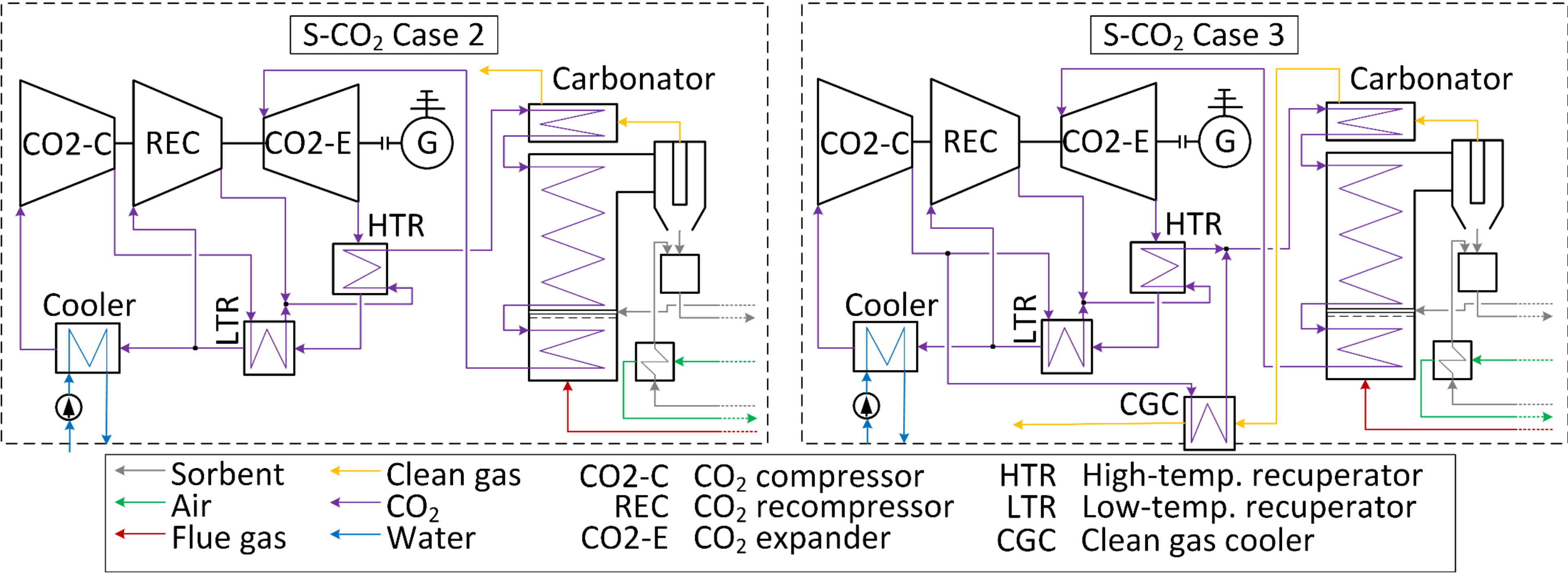
Hanak, D. P. and Manovic, V. (2017) 'Calcium looping combustion for high-efficiency low-emission power generation', Journal of Cleaner Production, 161, pp. 245–255. doi: 10.1016/j.jclepro.2017.05.080.

Calcium looping combustion (CaLC) – s-CO2 Case 1

- Working temperature of Calciner - 900°C and Carbonator - 650°C
- Gross electrical power 563.4 MW_{el}
- Live CO2 stream temperature 675°C
- CO_2 compressor outlet pressure 27 MPa



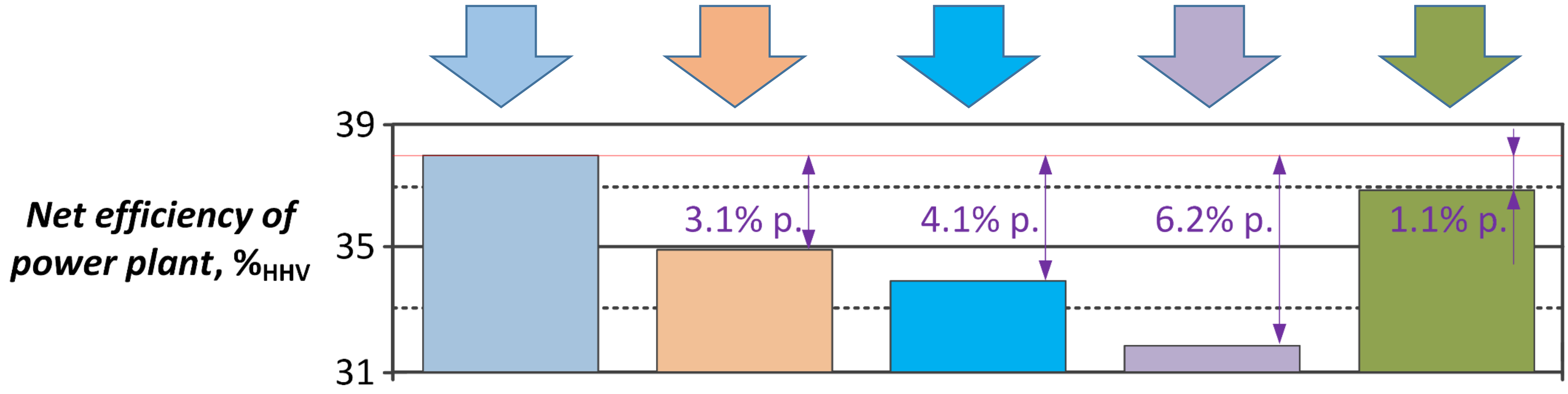
Calcium looping combustion – s-CO2 Case 2 and Case 3



Quantity, Unit	Calcium looping combustion power plant	
	S-CO$_2$ Case 2	S-CO$_2$ Case 3
Working temperature of Calciner/Carbonator, °C	900/650	900/650
Gross electrical power, MW_{el}	535.5	610.1
Live CO_2 stream temperature, °C	675	675
Main CO_2 compressor outlet pressure, MPa	27	21

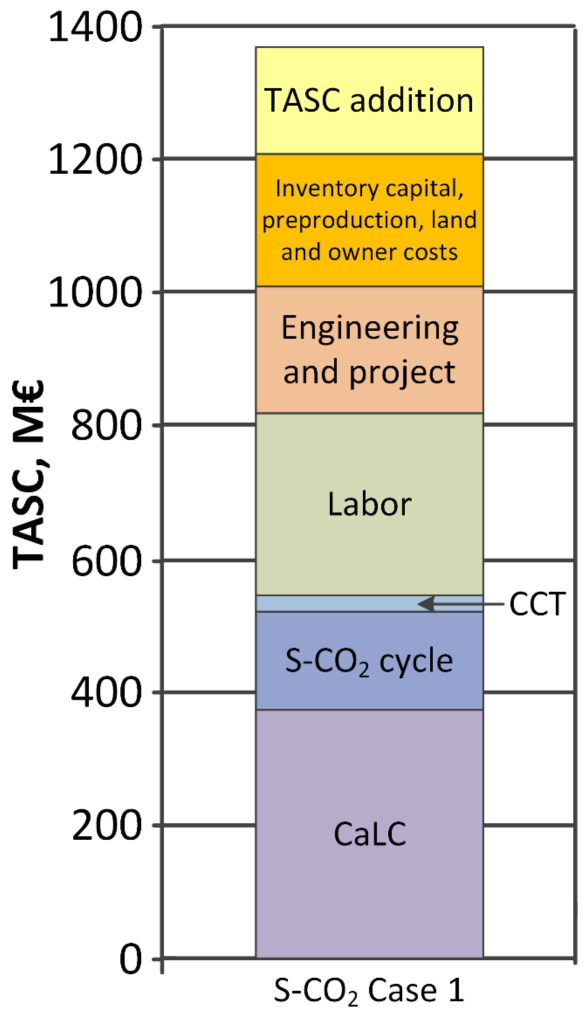
Techno-economic performance assessment

Quantity, Unit	Conventional coal-fired power plant	Calcium looping combustion power plant			
		Steam cycle	s-CO_2 Case 1	S-CO_2 Case 2	S-CO_2 Case 3
Heat input from coal combustion, MW_{th}	1452.6	1452.6	1452.6	1452.6	1452.6
Gross power output, MW_{el}	580.4	592.7	563.4	535.5	610.1
Net power output, MW_{el}	552.7	507.3	492.6	462.2	535.3
Boiler thermal efficiency, $\%_{HHV}$	85.2	88.3	86.4	73.1	86.0
Specific CO_2 emission, $g/kW_{el}h$	796.8	102.1	105.1	112.1	96.7



Techno-economic performance assessment

- Newly developed method to calculate investment cost:
  - Cost of individual components are calculated based on their scale parameters (thermodynamic parameters);
  - Total as spent cost division based on the DOE/NETL rapport[1];



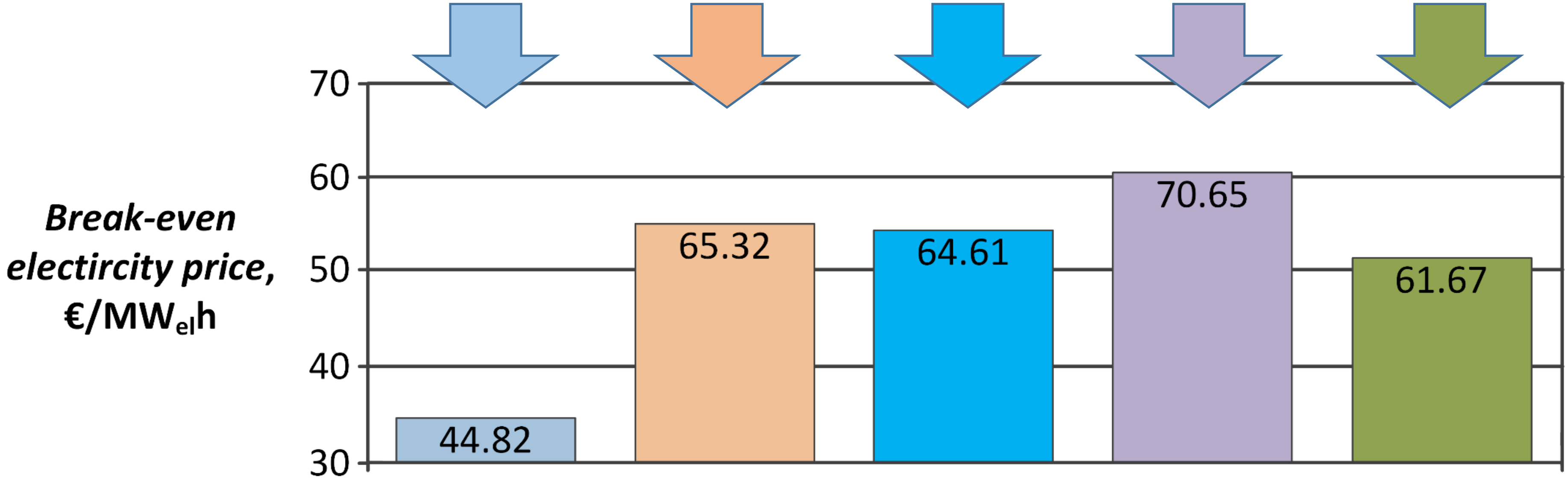
[1] Fout, T. et al. (2015) 'Cost and Performance Baseline for Fossil Energy Plants Volume 1a: Bituminous Coal (PC) and Natural Gas to Electricity Revision 3', National Energy Technology Laboratory (NETL), 1a(May), p. 240. doi: DOE/NETL-2010/1397.

Techno-economic performance assessment

- Break-even price of electricity - method of economic analysis based on the NPV method:
  - Electricity price is changed to value for which the NPV reach zero;
- Assumptions:
  - Discount rate - 6%;
  - Capacity factor - 85%;
  - Building period - 4 years;
  - Exploitation period - 25 years;
  - Commercial loan - 80% of the TASC (interest rate - 6%, repayment time - 15 years)
  - Salvage value - 20% of the TASC.

Techno-economic performance assessment

Quantity, Unit	Conventional coal-fired power plant	Calcium looping combustion power plant			
		Steam cycle	s-CO_2 Case 1	S-CO_2 Case 2	S-CO_2 Case 3
Total as spent cost, M€	1373.5	1533.2	1365.5	1322.4	1362.0
Specific capital cost, €/$kW_{el,gross}$	2366.5	2586.7	2423.7	2469.6	2232.3
CO_2 avoided cost, €/t_{CO2}	-	29.52	28.62	37.73	24.07



Conclusions

- The net efficiency drop of CaLC power plant with steam cycle net is much lower than in other CCS technologies;
- The net efficiency drop for CaLC power plant was reduced by 2% points by implementation of s-CO_2 cycle;
- The CO_2 avoided cost of CaLC power plant with s-CO_2 Case 3 is higher by 2.8 €/t_{CO2} than current value of carbon tax (21.3 €/t – 28/08/2018 [1]).

EPSRC Engineering and Physical Sciences Research Council

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[1] Business Insider (2018) CO_2 European Emission Allowances PRICE Today | Price of CO2 European Emission Allowances and Chart | Markets Insider. Available at: http://markets.businessinsider.com/commodities/co2-emissionsrechte (Accessed: 29 August 2018).