Carbon capture for Energy-from-Waste plants: comparison of three appliable technologies

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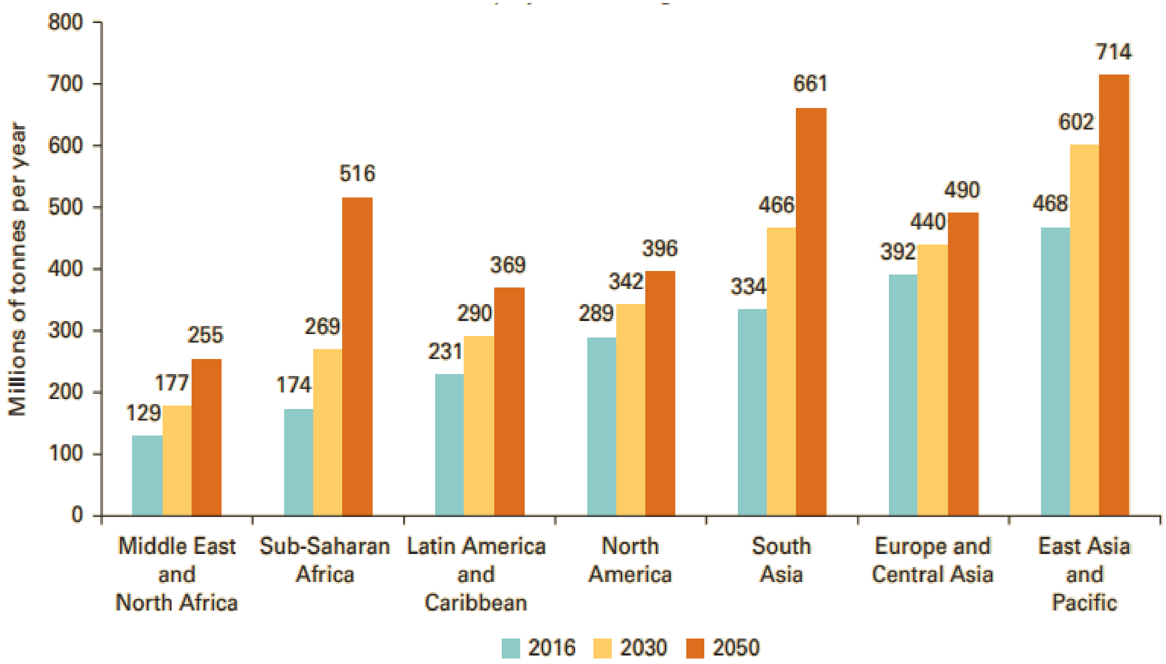
Municipal solid waste potential

3.88 billion tonnes of waste will be generated in 2050 due to rapid population growth.

Each tonne of municipal solid waste burnt typically releases between **0.7 and 1.7 tonnes** of CO_2, considering both the fossil and biogenic parts.

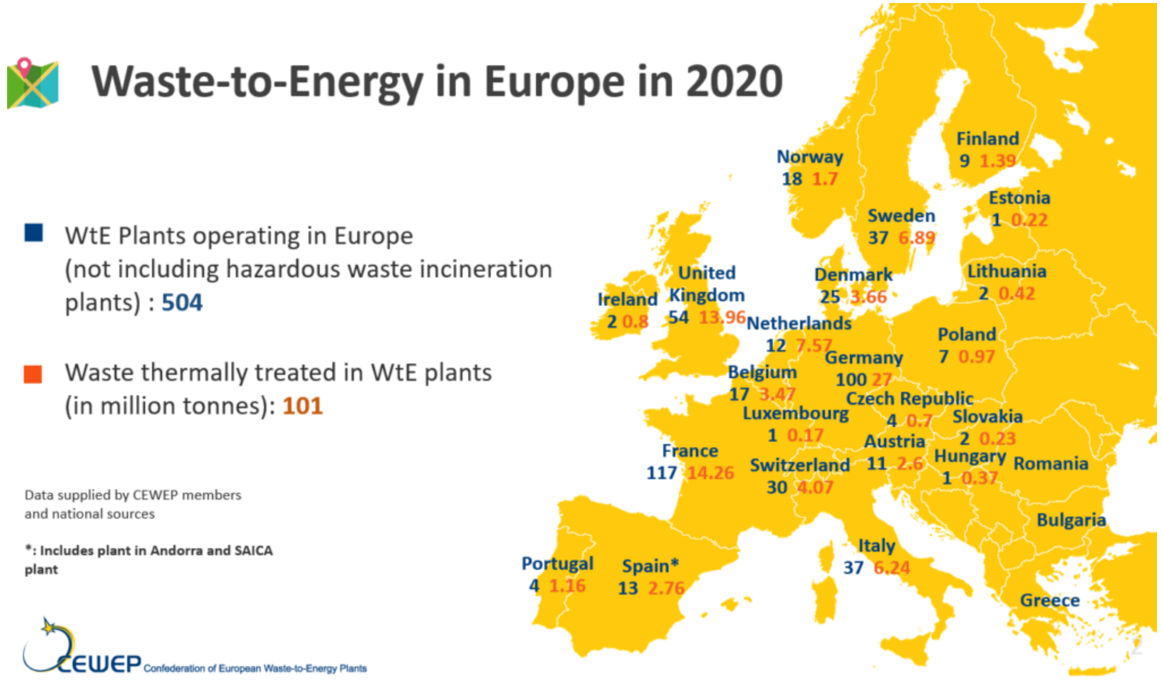


https://openknowledge.worldbank.org/handle/10986/30317

Energy-from-Waste potential

EfW plants in Europe can provide electricity and heat to 18 million and 15 million inhabitants respectively, avoiding the emission of **24-49 million tonnes** of CO_2.

In existing European EfW plants there is a potential to capture **60-70 million tons** of CO_2 per year.



https://www.cewep.eu/what-is-waste-to-energy/

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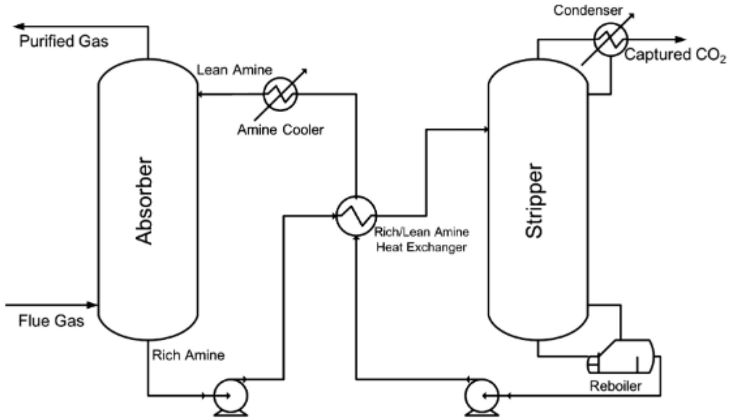
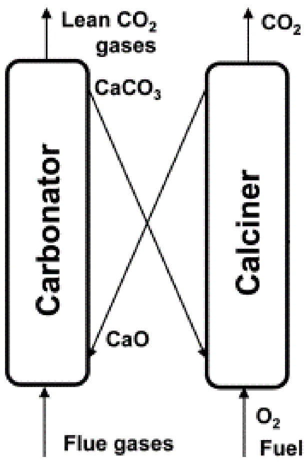
MonoEthanolAmine



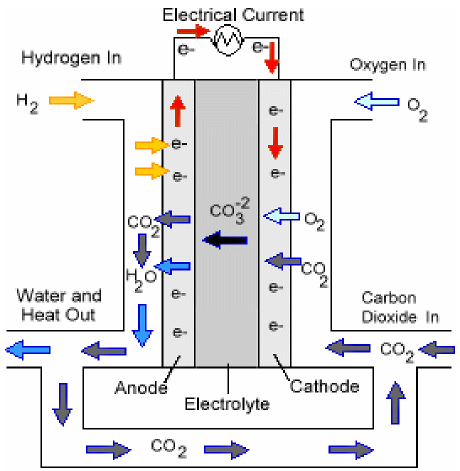
- ⊕ **TRL**: 9 (commercial full scale)
- ⊕ **Retrofittability**: end-of-pipe
- ⊖ **High heat requirement** for regeneration (~ 4 GJ/ tonCO_2)
- ⊖ **Solvent degradation**

Calcium Looping



- ⊕ Possibility of **thermal recovery**
- ⊕ **Lower energy penalty**
- ⊖ **Loss of CO_2 carrying capacity** due to unwanted reactions
- ⊖ Only **pilot plant** demonstration

Molten Carbonate Fuel Cell



- ⊕ **Additional** energy production
- ⊕ **Retrofittability**: end-of-pipe
- ⊖ Additional **natural gas** consumption
- ⊖ High **uncertainty** on cost and degradation

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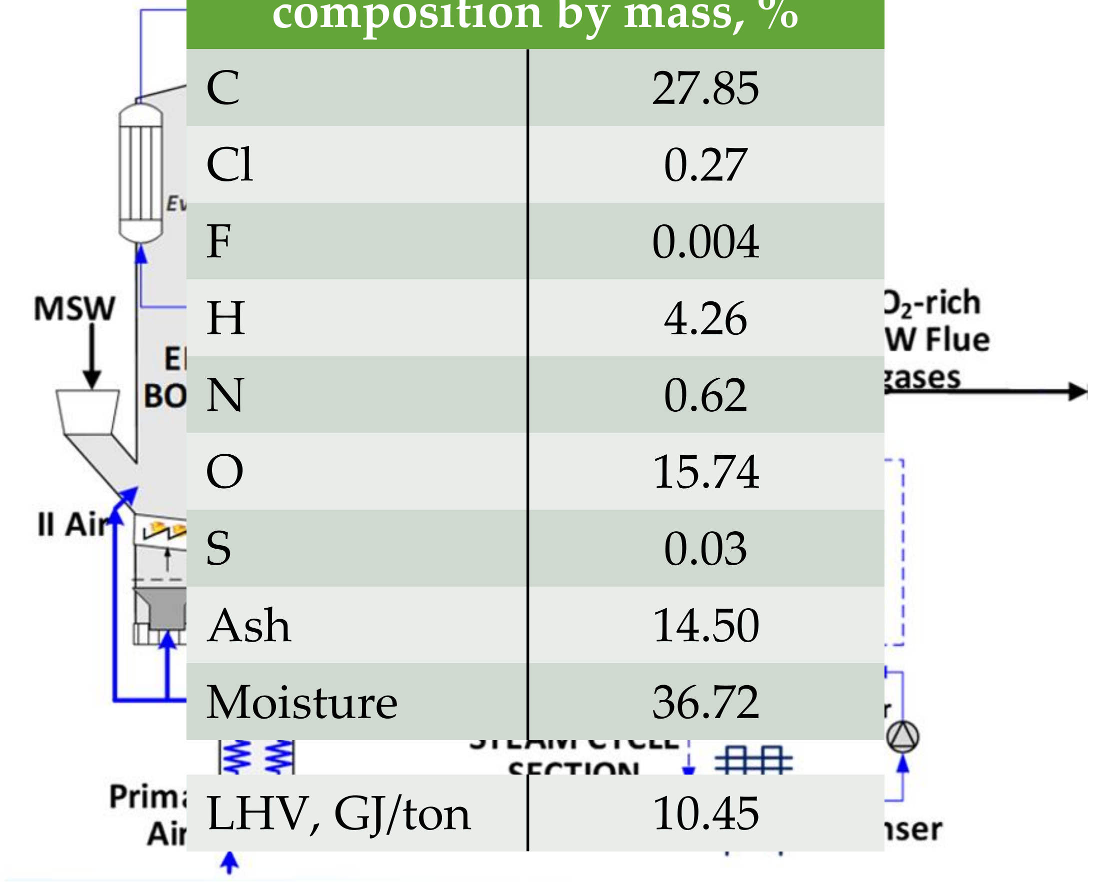
Reference waste and EfW plant



Ultimate waste composition by mass, %	
C	27.85
Cl	0.27
F	0.004
H	4.26
N	0.62
O	15.74
S	0.03
Ash	14.50
Moisture	36.72
LHV, GJ/ton	10.45

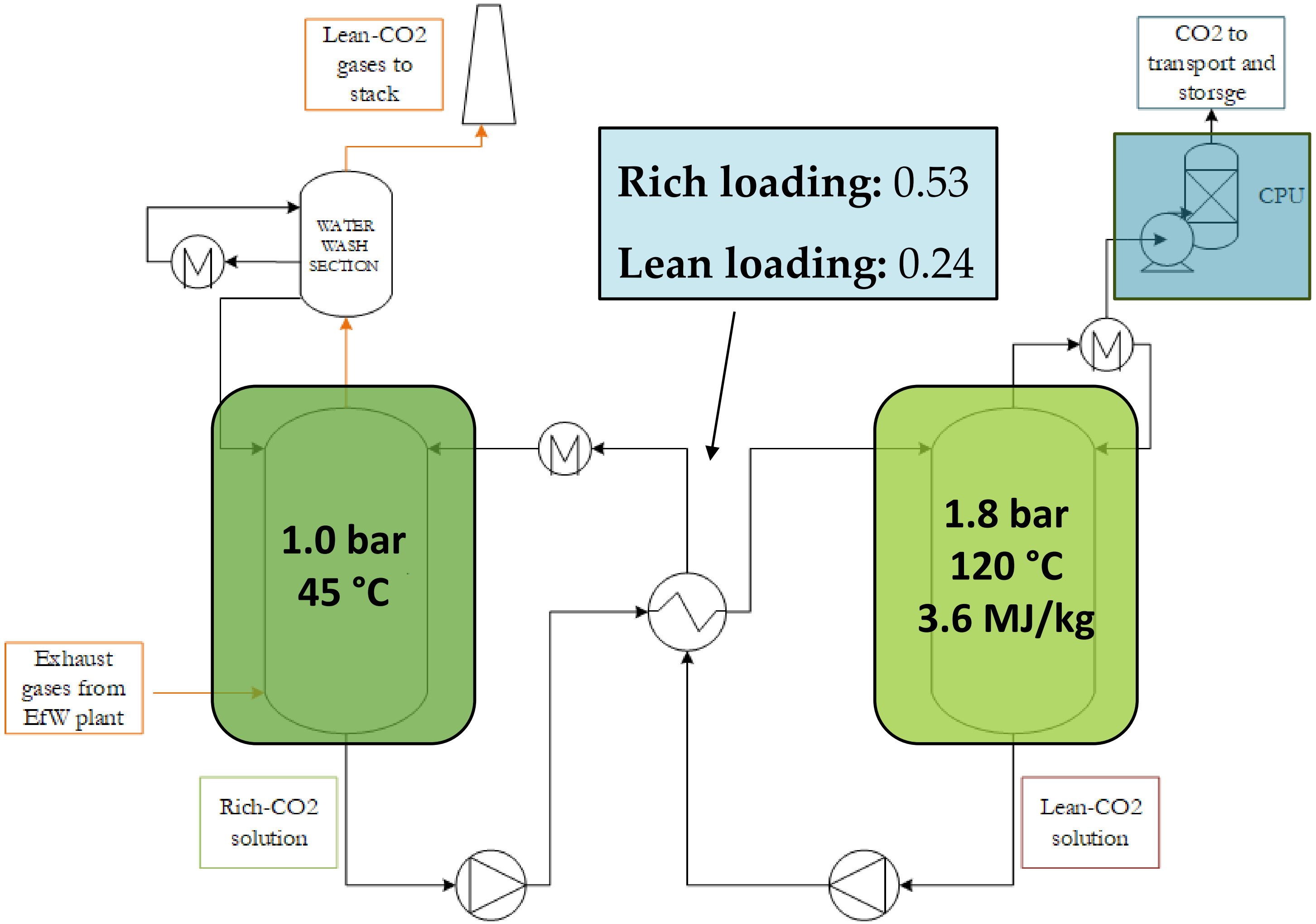
The EfW plant is inspired by the Parma plant in Emilia Romagna (Italy), which consists of 2

… and can treat **160'000 tons of waste per year.**

CO_2 emission factors

- Overall CO_2: 97.69 kg/GJ_{LHV}
- Biogenic CO_2: 49.63 kg/GJ_{LHV} (share: 50.8%)
- Fossil CO_2: 48.06 kg/GJ_{LHV}

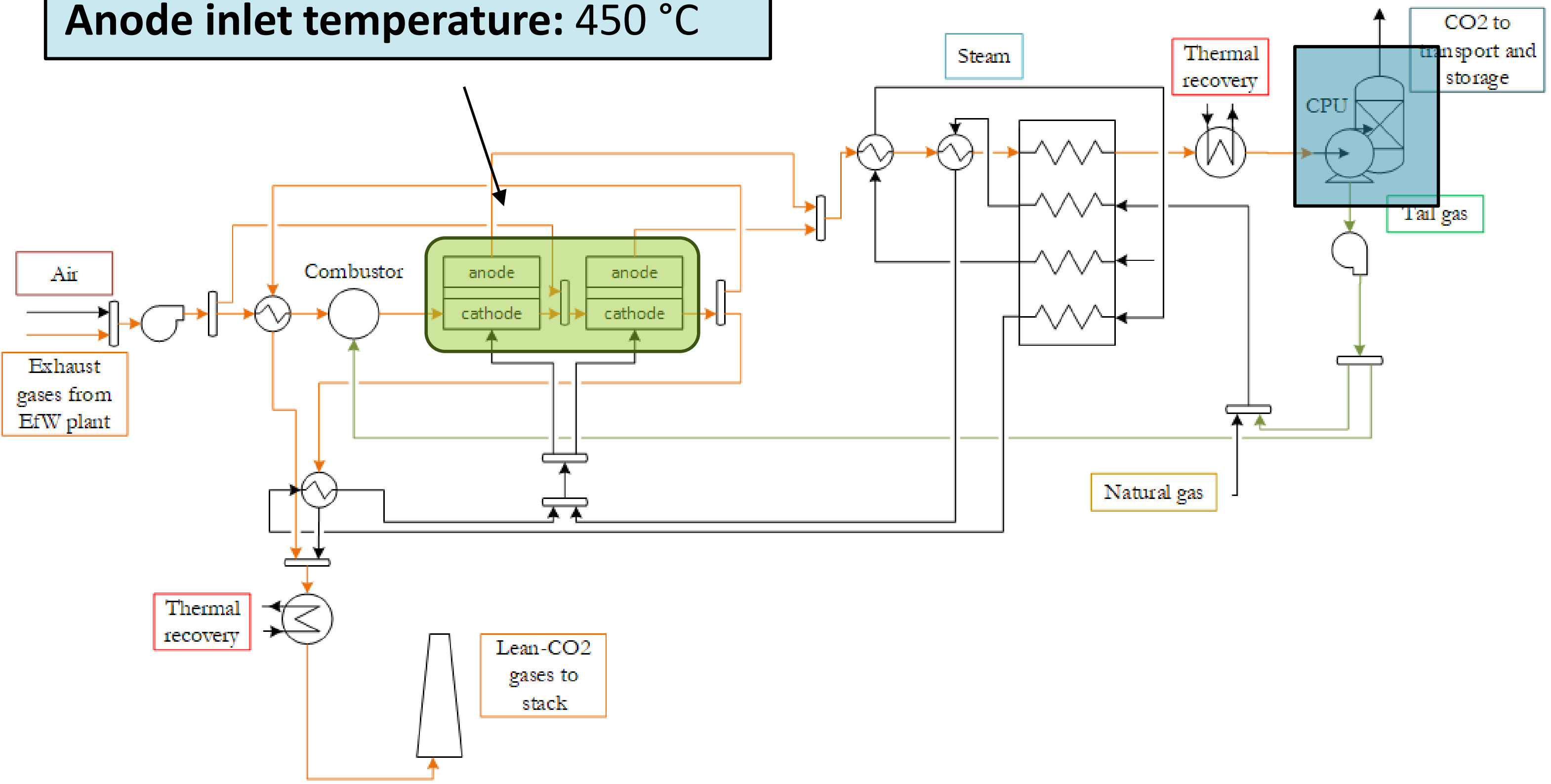
MEA-based CC section



- Two main reactors: the **absorber** and the **stripper**, equipped with the reboiler for the regeneration of the solvent.
- **Compression and Purification Unit**: a series of inter-refrigerated compressors to bring the CO_2 – flow to 110 bar.

2-MCFC-based CC section

Cathode inlet temperature: 570 °C
Anode inlet temperature: 450 °C

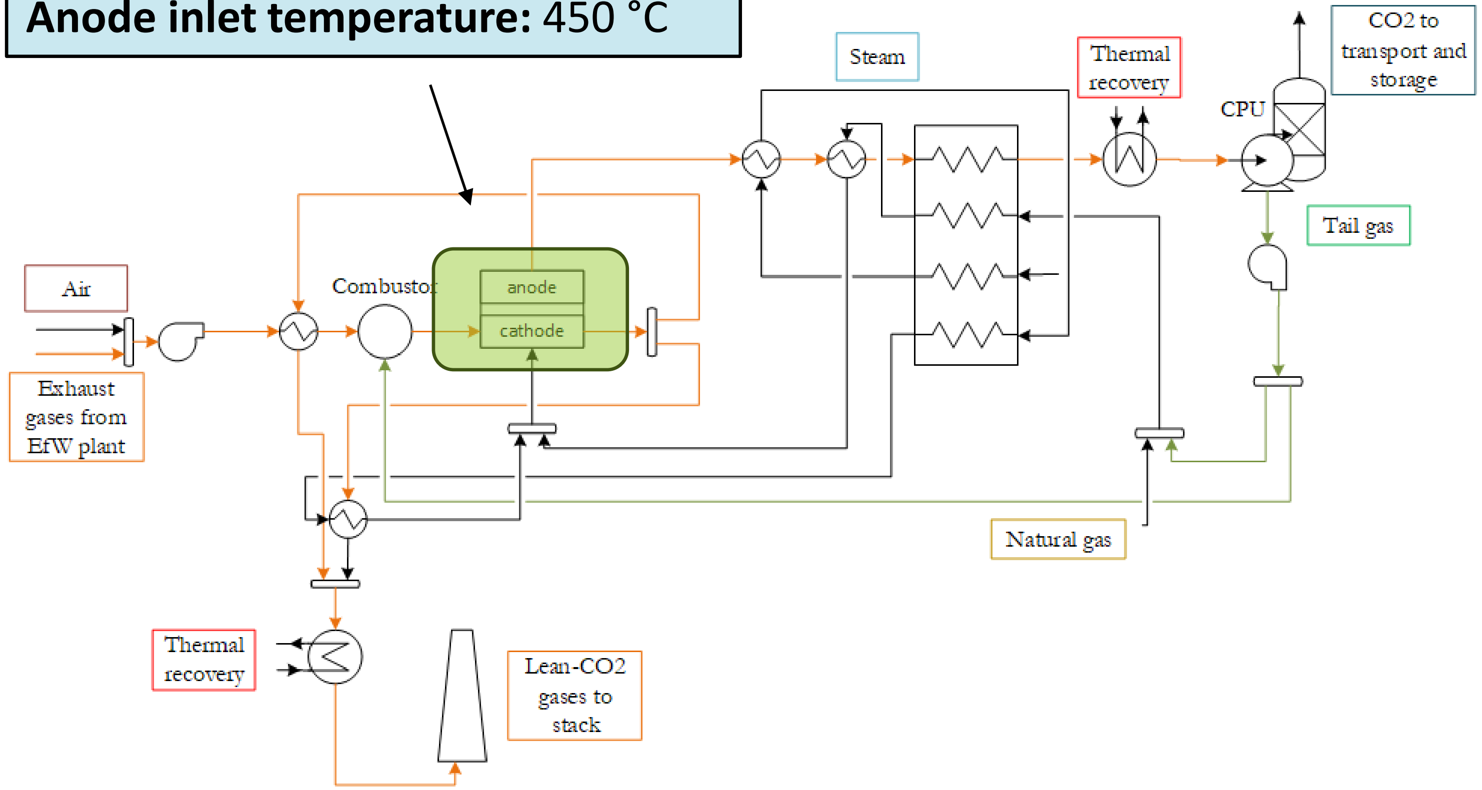


- **Cathode side connection**: series/parallel mixed, to ensure the inlet temperature of 570 °C and the maximum temperature difference across the cell.

- **Compression and Purification Unit**: necessary to separate the tail gas from the pure CO_2-flow.

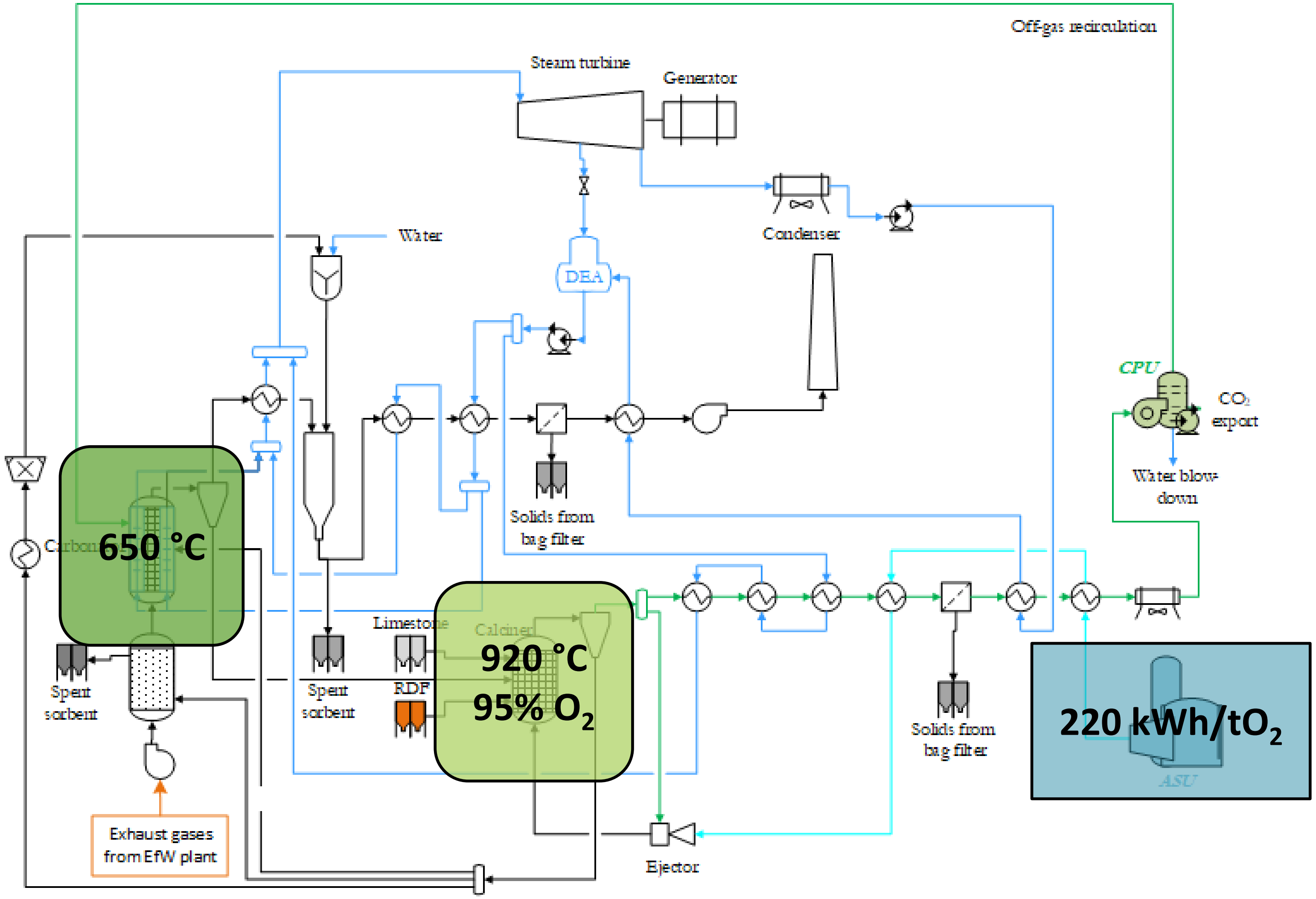
1-MCFC-based CC section

Cathode inlet temperature: 570 °C
Anode inlet temperature: 450 °C



- **Same layout** in terms of main components and operating conditions, except for splitters for flue gases and natural gas which are not necessary.

CaL-based CC section

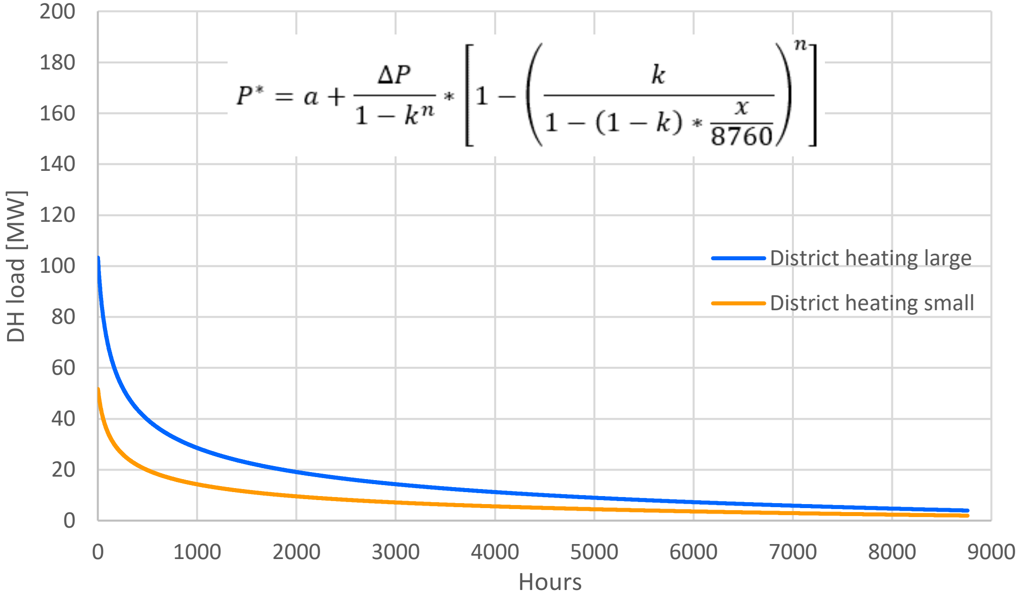


- Two main reactors: the **carbonator** and the **calciner**, equipped with the SRF combustion.
- Oxygen for oxy-combustion is produced on-site, thanks to the **Air Separation Unit**.

DH network

- Two coupling situations can be considered: small and large DH.
- The load duration curve is modelled analytically.

DH load duration curves



DH parameters

	Small DH network	Large DH network
a, MW	2.0	4.0
ΔP, MW	50.0	100.0
k, -	165	
n, -	0.3	

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Energy balances – minimum cogeneration

	Reference	MEA	2 MCFC	1 MCFC	CaL
Energy potential of treated waste, MW_{LHV}	71.32	71.32	71.32	71.32	66.60
NG input to MCFCs, MW_{LHV}	-	-	32.88	35.37	-
Grate combustor(s) input, MW_{LHV}	71.32	71.32	71.32	71.32	35.66
SRF calciner input, MW_{LHV}	-	-	-	-	29.31
Energy lost for SRF production, MW_{LHV}	-	-	-	-	1.63
Steam cycle electric power output, MW_{EL}	16.49	12.29	16.36	16.40	16.13
MCFCs electric power output, MW_{EL}	-	-	20.17	20.24	-
Auxiliaries of EfW section, MW_{EL}	2.96	3.00	3.01	3.01	3.00
Auxiliaries of CC section, MW_{EL}	-	2.58	4.38	4.26	6.23
Consumption for SRF production, MW_{EL}	-	-	-	-	0.25
Net electric power outcome, MW_{EL}	13.53	6.71	29.14	29.37	6.65
Thermal power required by CC section, MW_{TH}	-	*23.11*	-	-	-
Thermal power recovery from CC section, MW_{TH}	-	*0.55*	*0.85*	*0.81*	*0.00*
Thermal power adjustment (from steam cycle), MW_{TH}	-	*0.00*	*0.70*	*0.49*	*0.00*
Minimum cogenerated thermal power (70-120°C), MW_{TH}	*0.00*	*0.55*	*1.55*	*1.31*	*0.00*
Overall net electric efficiency, %LHV	18.97	9.40	27.97	27.54	9.99
Overall net thermal efficiency, %LHV	0.00	0.77	1.49	1.22	0.00

CO_2 capture performances

Treated waste: 160’000 t/y

	Reference	MEA	2 MCFC	1 MCFC	CaL
CO_2 emission from EfW plant, kt/y	163.25	15.84	16.50	23.71	6.39
CO_2 emission from SRF production, kt/y	-	-	-	-	11.14
Overall CO_2 emissions, kt/y	163.25	15.84	16.50	23.71	17.53
Overall fossil CO_2 emissions, kt/y	80.37	-64.53	-63.88	-56.66	-62.85
Overall CO_2 capture efficiency, %	-	90.30	92.04	88.73	89.26
Capture efficiency of CO_2 from NG, %	-	-	100.00	90.00	-
Capture efficiency of CO_2 from waste, %	-	90.30	89.90	88.37	89.26

SPECCA index

For EfW + CCS plants, it is necessary to define a **modified SPECCA** that takes into account the fixed amount of burned waste and the change in efficiency due to the capture section.

$$SPECCA = -\frac{\Delta EP}{\Delta CO_2} = -\frac{E_{NG} - \frac{\Delta E_{el}}{\eta_{STD,el}} - \frac{\Delta E_{th}}{\eta_{STD,th}}}{CO_{2,waste} + CO_{2,CCS} - \Delta E_{el} * e_{el,STD} - \Delta E_{th} * e_{th,STD}}$$

	NGCC without CC (a)	NGCC with CC (b)
Net electric efficiency, %	58.3	49.9
Specific CO_2 emissions, kg/kWh	351.8	36.2
Marginal ratio cogenerated heat / electricity lost	7.7	

Energy performances - coupling with DH network

Small DH network

	Reference	MEA	2 MCFC	1 MCFC	CaL
Annual saleable thermal energy, GWh_{TH}	56.82	52.07	56.85	56.85	58.53
Annual saleable electricity, GWh_{EL}	69.95	31.35	163.09	164.18	32.24
Annual SPECCA[(a)], MJ/kg_{CO2}	-	2.03	0.73	1.05	1.80
Annual SPECCA[(b)], MJ/kg_{CO2}	-	2.16	0.16	0.71	1.94

Large DH network

	Reference	MEA	2 MCFC	1 MCFC	CaL
Annual saleable thermal energy, GWh_{TH}	106.71	84.74	106.32	107.06	110.35
Annual saleable electricity, GWh_{EL}	61.79	26.00	155.00	155.96	23.76
Annual SPECCA[(a)], MJ/kg_{CO2}	-	2.00	0.73	1.05	1.81
Annual SPECCA[(b)], MJ/kg_{CO2}	-	2.13	0.16	0.71	1.94

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01 **Introduction**

02 **Carbon Capture technologies for EfW plants**

03 **Methodology for CC implementation**

04 **Results**

05 **Conclusions**

MEA-based carbon capture has the highest TRL at the moment. However, **MCFC-based** and **CaL-based** carbon capture systems prove to be much more competitive from the electrical and thermal performance point of view.

A properly defined **SPECCA index** can be a suitable KPI to quantify the energy performance of different carbon capture options.

In terms of SPECCA index, no difference is appreciated between coupling with a small or large **DH network**.

Thank you for your attention!

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