RETE ALTA TECNOLOGIA EMILIA-ROMAGNA HIGH TECHNOLOGY NETWORK
TECNOPOLO PIACENZA
LEAP FOUNDED IN 2005 BY POLITECNICO DI MILANO

10th CEWEP Congress

Technical Seminar

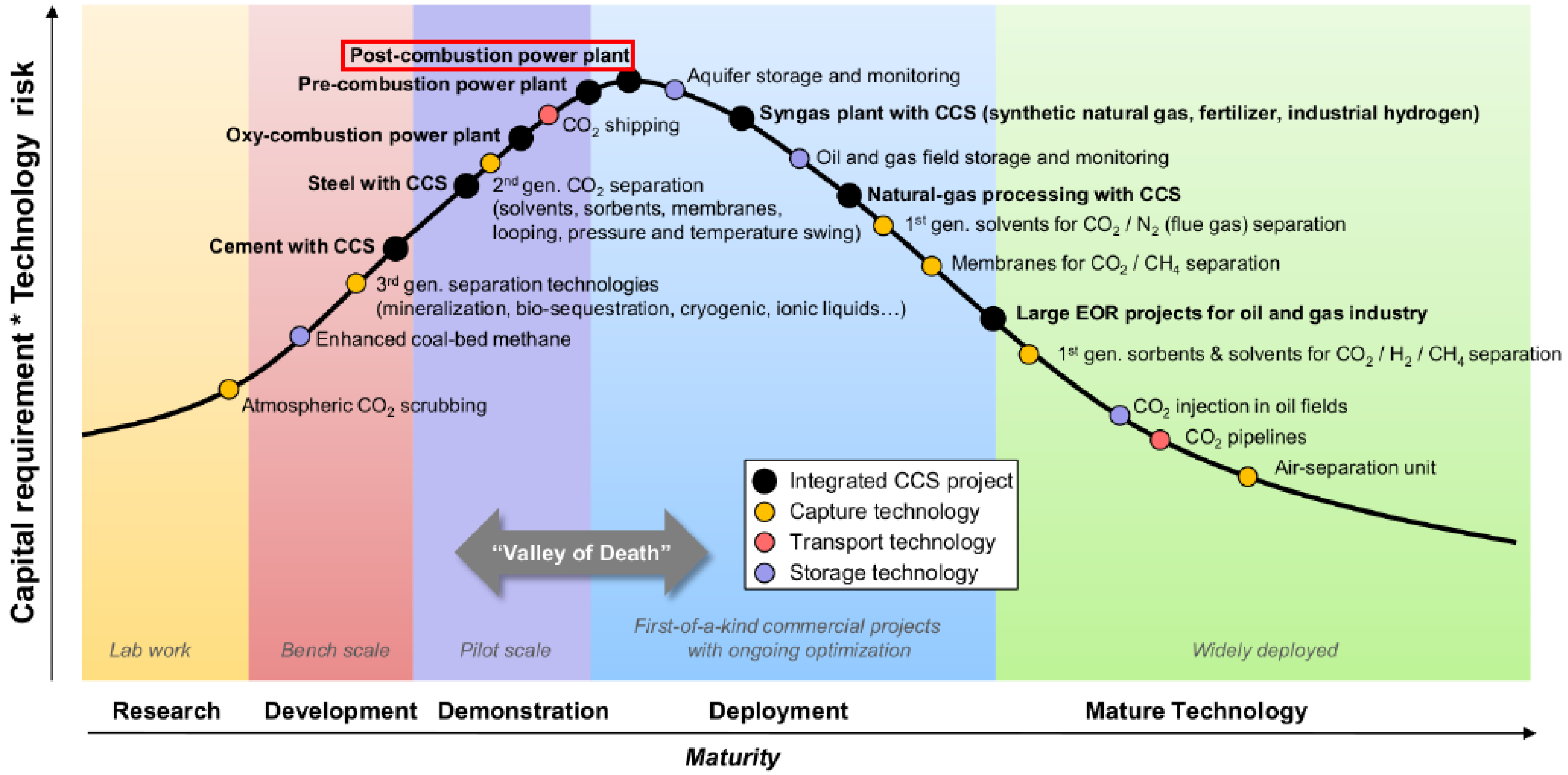
Overview of CO_2 capture technologies for WtE: current perspective and future possibilities

Federico Viganò[1,2], Letizia Cretarola[1,2], Gabriele Mazzolari[2], Edoardo De Lena[2], Maurizio Spinelli[2], Stefano Consonni[1,2]

[1] *Dep. Of Energy – Politecnico di Milano*

[2] *LEAP Scarl*

Carbon capture and associated technologies



CC technologies potentially appliable to EfW

LEAP & IREN Innovazione - evaluation of **different CC solutions for EfW** (case study: 200kt/y)

Solvent

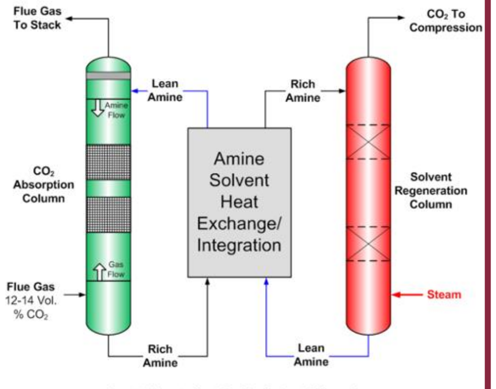
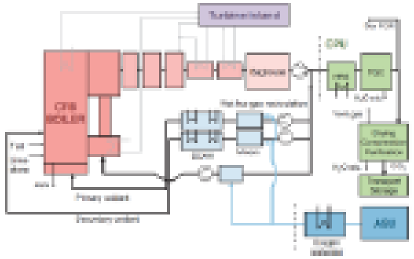
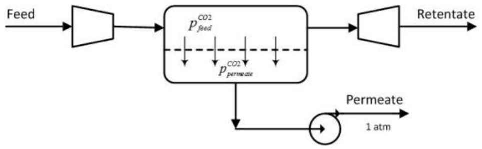


Figure 1-3. Schematic of Amine-Based Post-Combustion CO_2 Capture Process

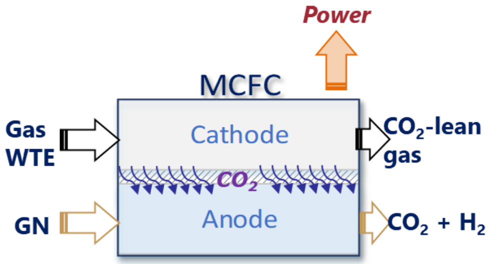
Oxyfuel



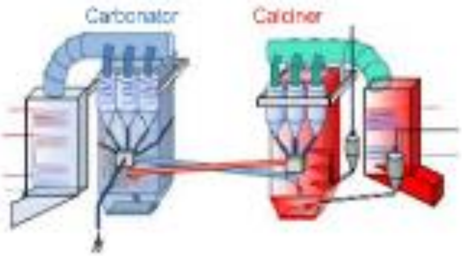
Membranes



MCFC



Calcium Looping



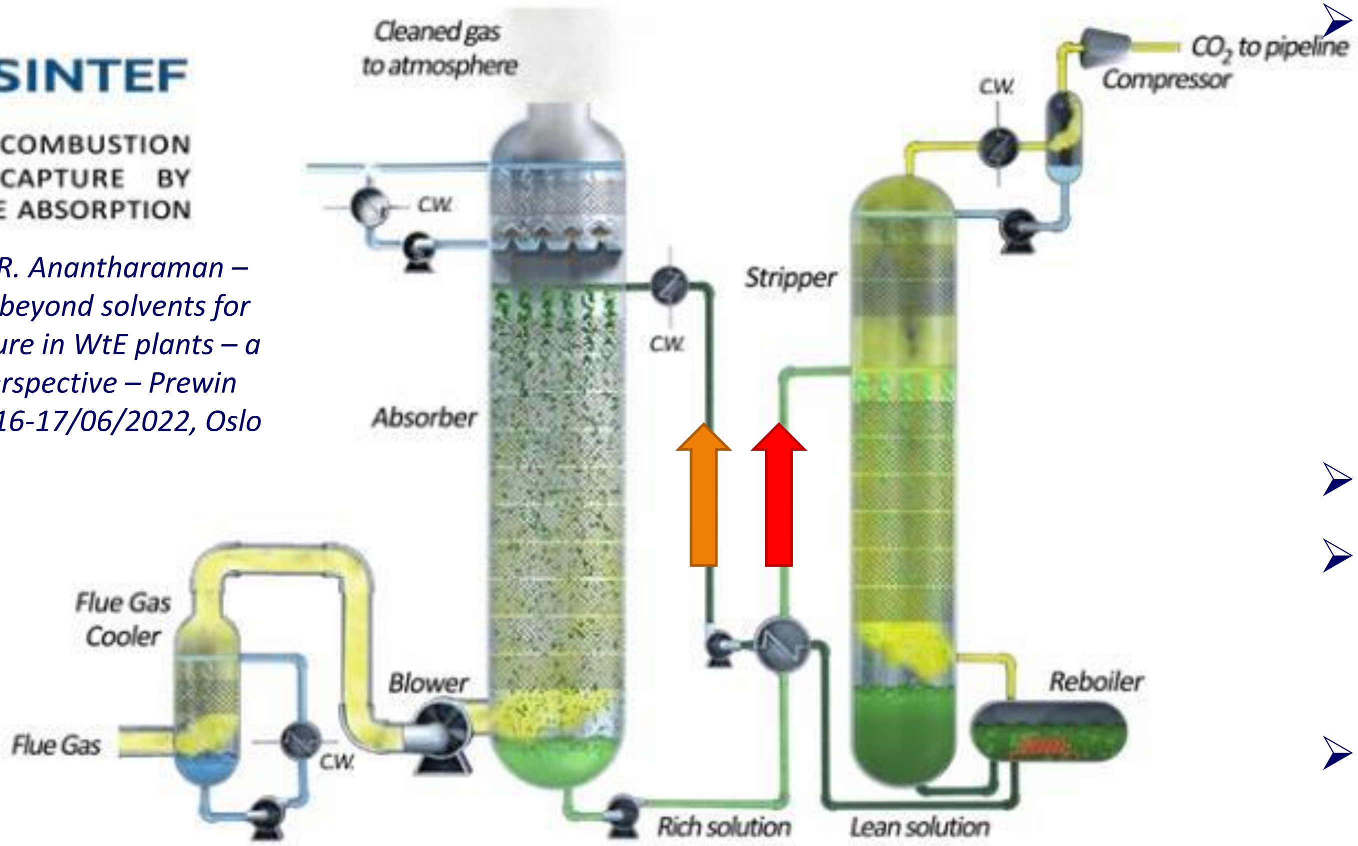
Preliminary **technical, economical and environmental** characterization based on literature data/ LEAP previous works

Amines adsorption

SINTEF

POST-COMBUSTION CO_2 CAPTURE BY AMINE ABSORPTION

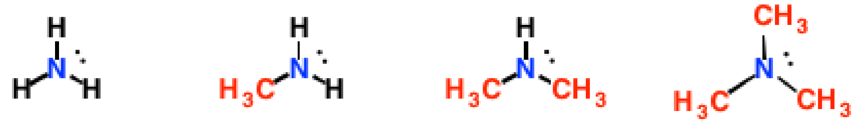
Source: R. Anantharaman – Looking beyond solvents for CO_2 capture in WtE plants – a R&D perspective – Prewin meeting 16-17/06/2022, Oslo



Poor solvent (clean) to the absorber

Rich solvent (CO_2 loaded) to the stripper

- Commercial solvents: amines

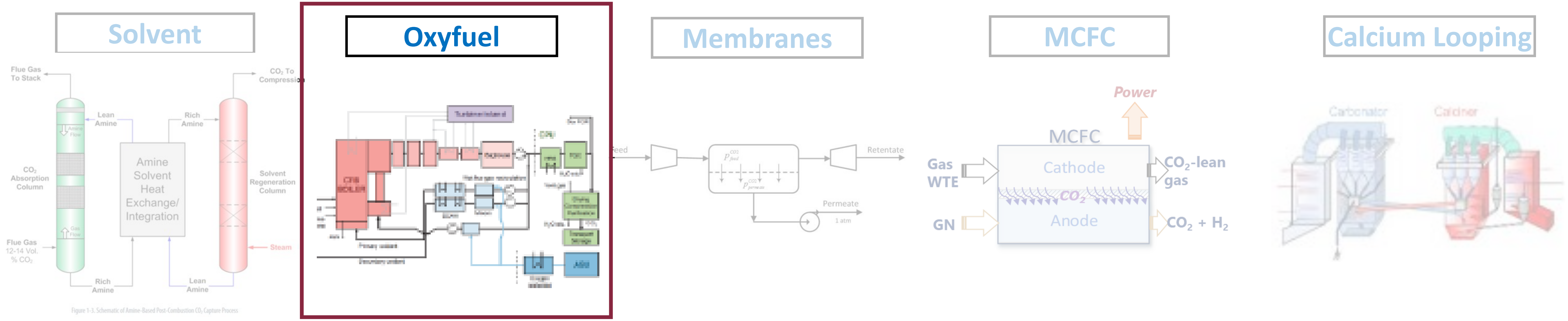


0 carbons	1 carbon directly attached	2 carbons	3 carbons
Ammonia (unique)	Primary (1°) amine	Secondary (2°) amine	Tertiary (3°) amine

- *Trade-off* between *reaction rate* and *CO_2 loading*
- Commercial solvents contain additives to **optimise performances, limit degradability,** volatility and corrosivity
- Research for new solvents is focused on **reducing regeneration heat** (e.g., potassium carbonate, K_2CO_3)
- The steam for solvent regeneration is extracted from the steam turbine (ST) -> **reduction of electric production and cogeneration capability**

Oxyfuel

LEAP & IREN Innovazione - evaluation of **different CC solutions for EfW** (case study: 200kt/y)

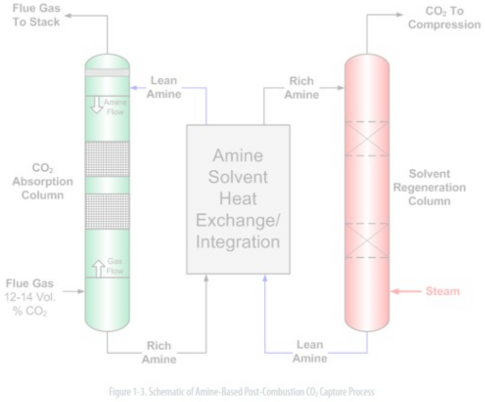


- Simple concept: waste combustion is switched **to oxyfuel mode, to produce flue gas rich in CO_2** and H_2O (water is then separated by condensation)
- Requires huge modifications to EfW plant and an **Air Separation Unit (ASU)** for O_2 production **(high energy penalty)**

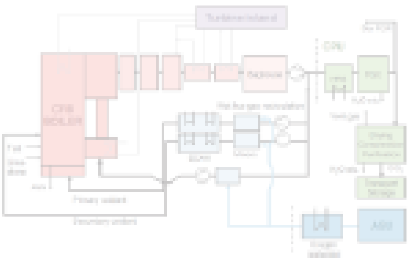
Membranes

LEAP & IREN Innovazione - evaluation of **different CC solutions for EfW** (case study: 200kt/y)

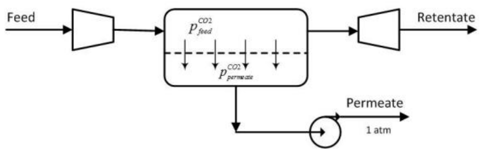
Solvent



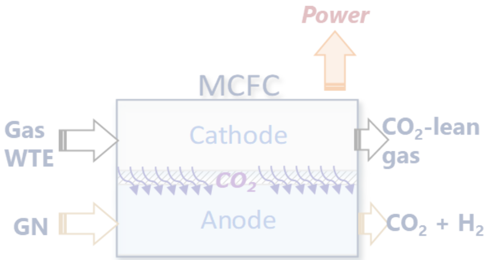
Oxyfuel



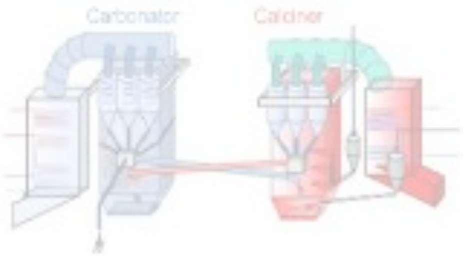
Membranes



MCFC

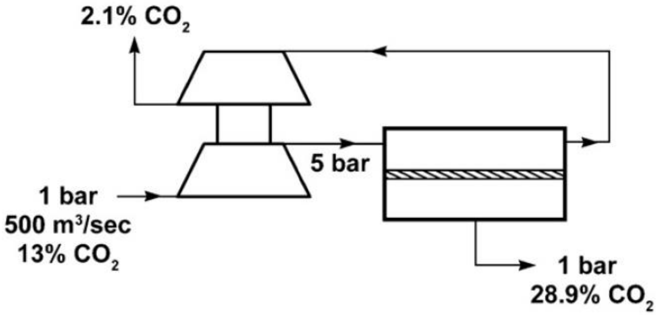


Calcium Looping



- **Membranes separate selectively specific components from mixtures (e.g., CO_2/N_2)**
- Pre/Oxy/**Postcombustion membranes (Polymeric)**: CO_2 is adsorbed over membrane surface and then diffuses through the polymeric film, exploiting its higher **affinity** and shorter **free path** (compared to N_2)
- Significant **energy consumption** especially for low CO_2 concentrations in the feed (the **driving force** of the process in the partial **pressure ratio** across the membrane)

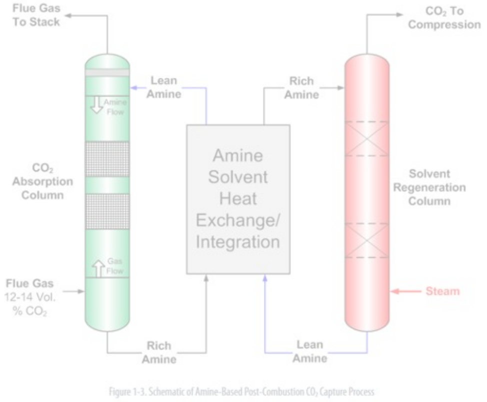
(a) Single-step membrane process with feed compression



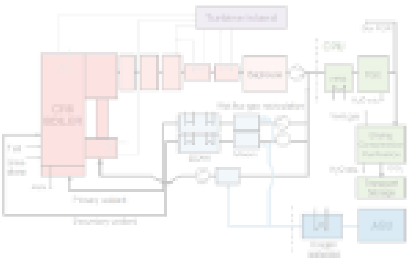
[Power plant post-combustion carbon dioxide capture: An opportunity for membranes | 2010]

LEAP & IREN Innovazione - evaluation of **different CC solutions for EfW** (case study: 200kt/y)

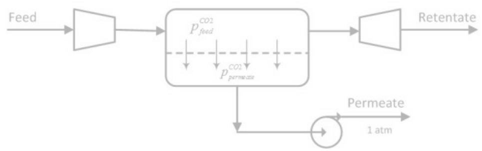
Solvent



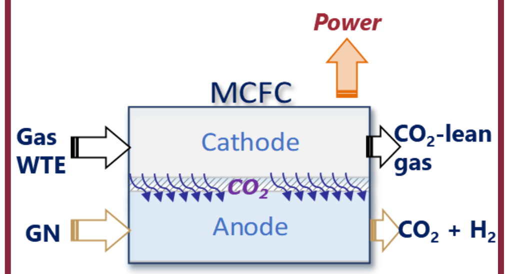
Oxyfuel



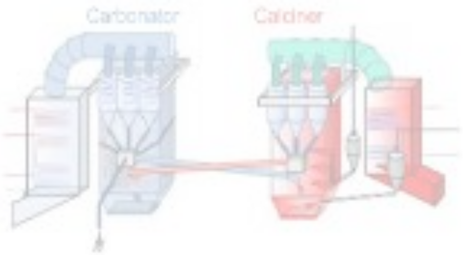
Membranes



MCFC

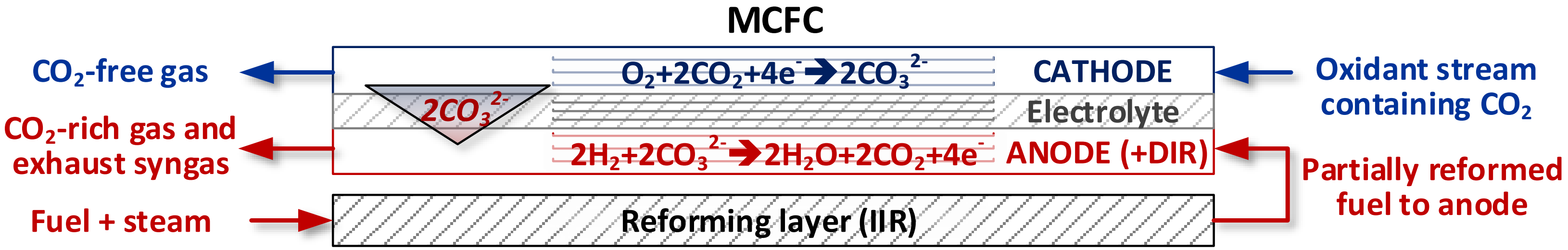


Calcium Looping

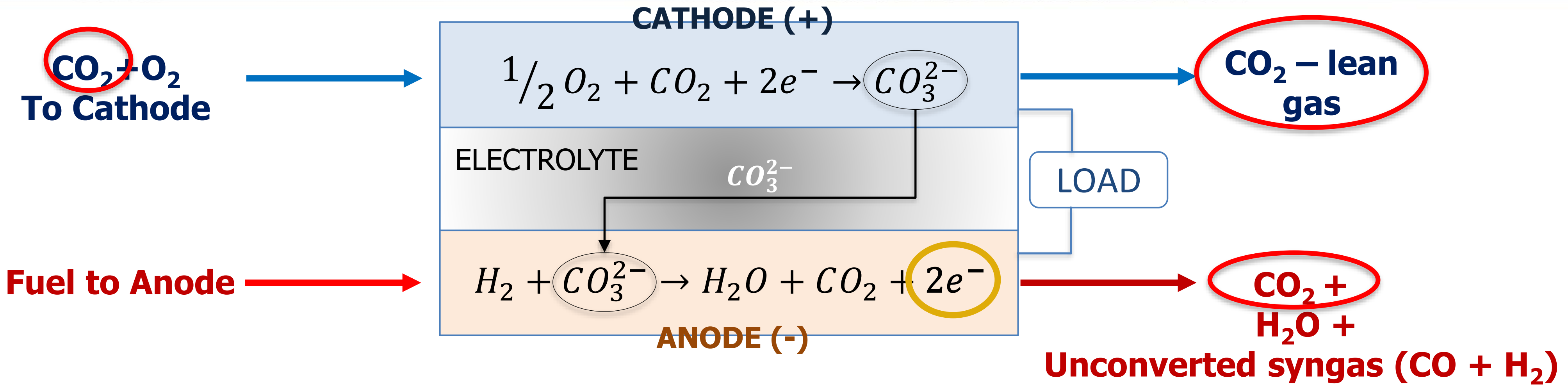


Molten Carbonate Fuel Cells -> ***electrochemical* membranes** operating at high temperature

Peculiar feature: they require to be **fed with CO_2 to produce electricity**

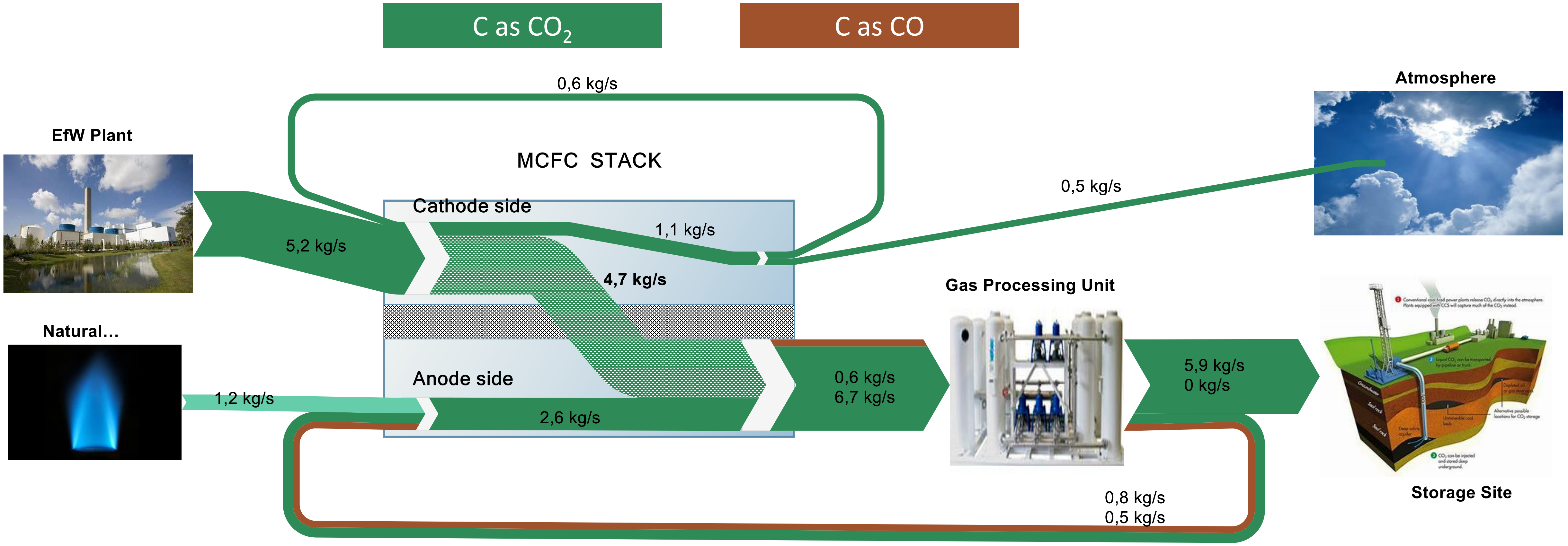


MCFCs

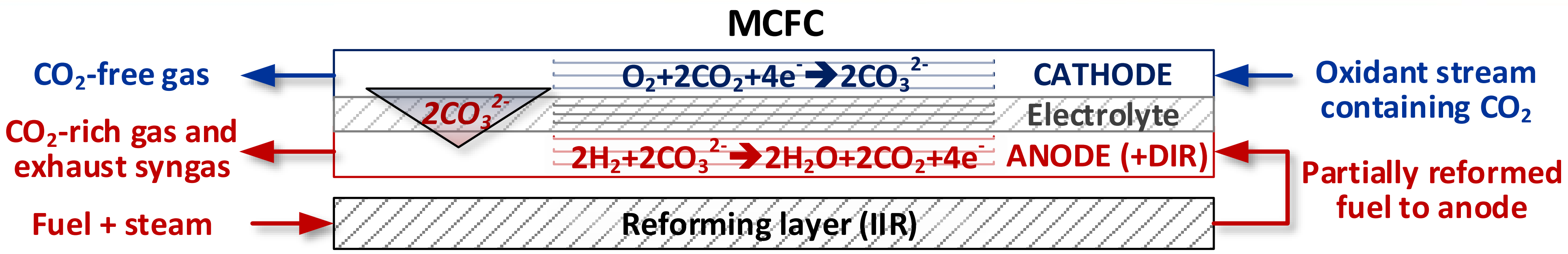


- ✓ MCFCs are fed by **natural gas** (NG) or other gaseous fuels converted into H_2 and electricity with **high efficiency** (up to~50%)
- ✓ They require a simple **CO_2 purification unit** (**CPU**) for (i) separating unconverted syngas and (ii) reaching CO_2 purity specifications
- ✓ With further NG consumption, they can also produce **blue hydrogen** (-> CO_2 from NG is 100% captured)
- ✓ Waste carbon content can potentially be captured to 90%, while **enhancing electrical and thermal output** of the host plant
- ✓ **Active NO_X separation**, driven by secondary electrochemical reactions
- They have been lab tested for CO_2 capture from flue gas of coal- and NG-fired plants, but never on flue gas from WtE plants
- ✗ Low tolerance against side pollutants (e.g. SO_2, metals)
- ✗ They feature very **high CAPEX and OPEX*** and there is only one industrial-scale manufacturer (Fuel Cell Energy)

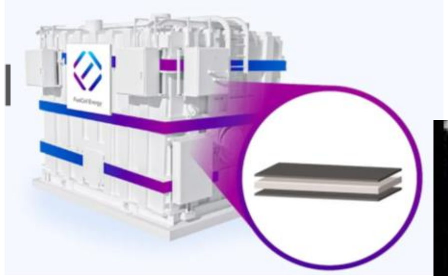
* High OPEX are related to the limited durability of the active layers of MCFC stacks, that must be substituted every 5-7 years



The combination between **MCFC & CPU maximizes** (i) **the fuel utilization** (the unconverted syngas relased by MCFC anode is separated in the CPU and recycled back) and (ii) the **carbon capture rate**, which overcomes **90%.**



FuelCell Energy



Source: https://www.fuelcellenergy.com

CapLab

ELECTROCHEMICAL CELLS FOR CARBON CAPTURE & ENERGY TRANSITION

Università di Genova

ECOSPRAY technologies for the planet

Source: https://ecospray.eu

Calcium Looping (CaL)

LEAP & IREN Innovazione - evaluation of **different CC solutions for EfW** (case study: 200kt/y)

Solvent

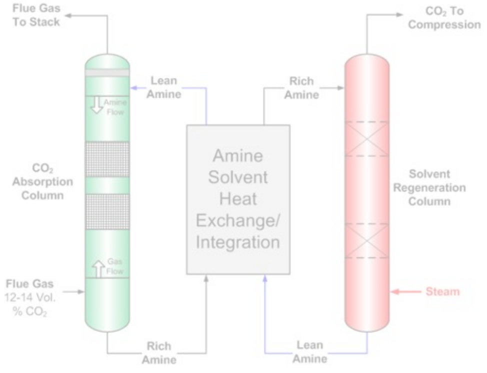
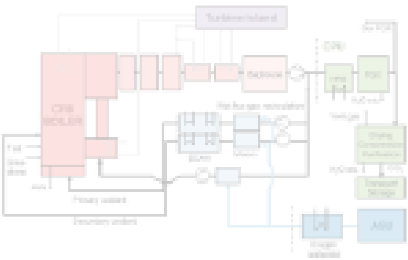
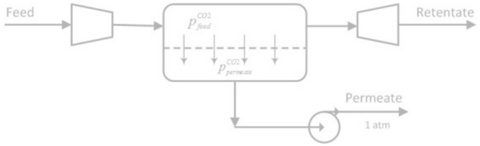


Figure 1-3. Schematic of Amine-Based Post-Combustion CO_2 Capture Process

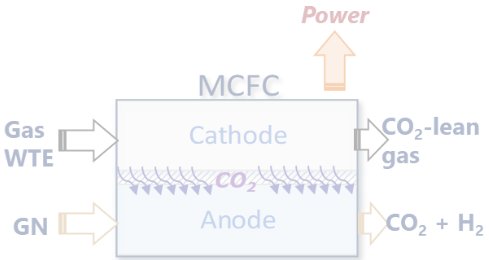
Oxyfuel



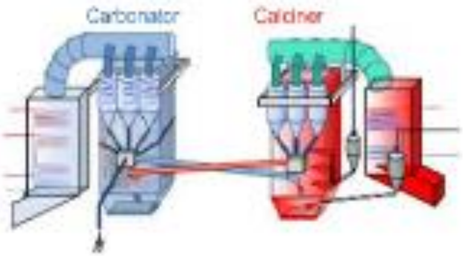
Membranes



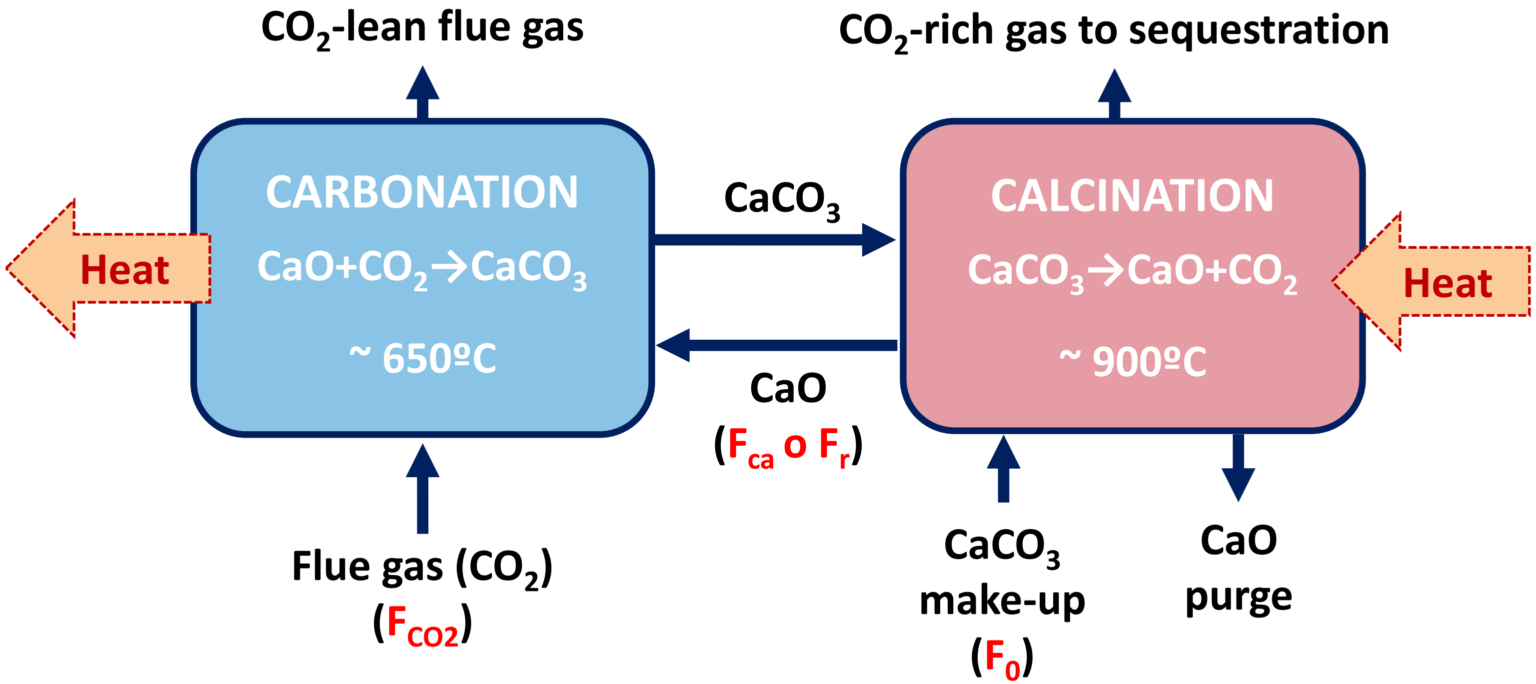
MCFC

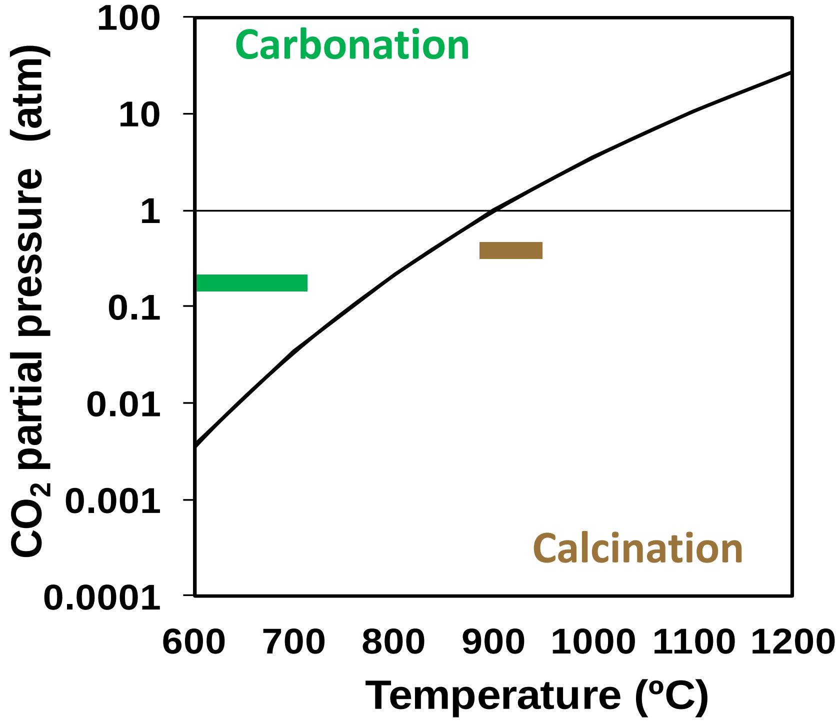


Calcium Looping



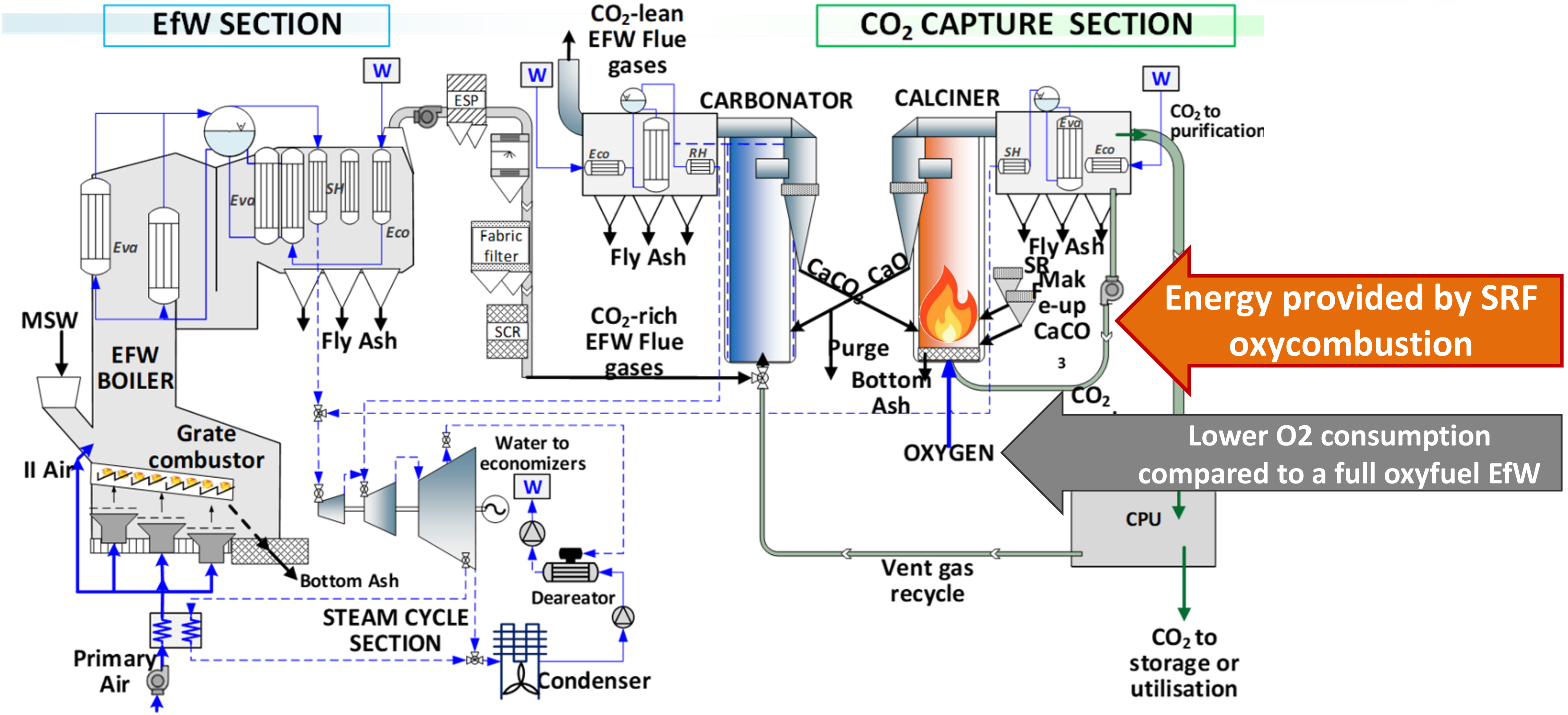
CaL



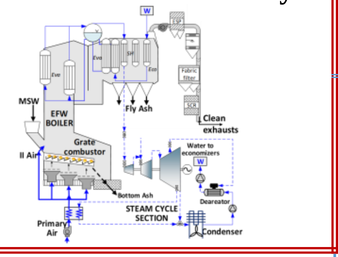
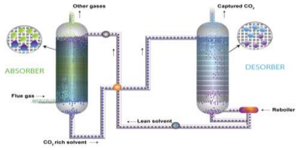
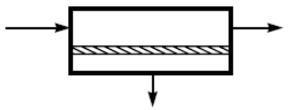
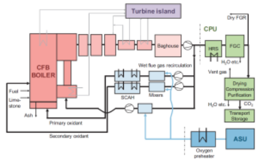
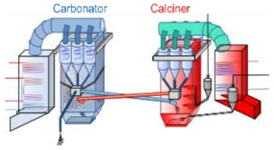


$CaO + CO_2 \longleftrightarrow CaCO_3$ $\Delta H_{298\,K}$=-178 kJ/mol (or 4.04 MJ/kg_{CO2})

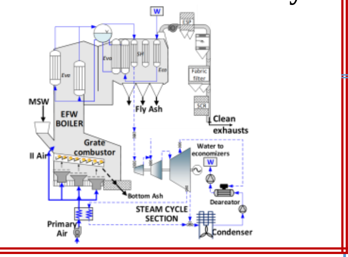
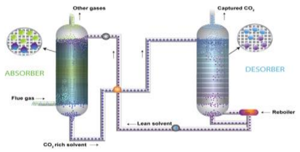
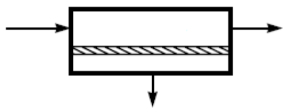
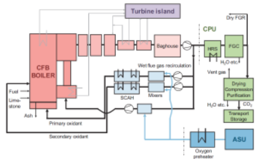
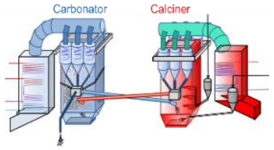
- Based on the capability of calcium oxide (CaO) to react with CO_2, generating calcium carbonate ($CaCO_3$)
- The **sorbent is regenerated** by the reverse reaction (**calcination**, $CaCO_3$+heat -> CaO + CO_2) sustained by oxyfuel combustion
- A continuous sorbent make-up (and a corresponding purge) is required to keep high reactivity and low ash build-up
- The high quality CaO-rich purge can be valorized as raw material for the production of clinker, cement or binders


EfW SECTION
CO₂-lean EFW Flue gases
CO₂ CAPTURE SECTION
W
ESP
CARBONATOR
CALCINER
CO₂ to purification
Eco
RH
SH
Eva
Fabric filter
Fly Ash
CaCO₃
CaO
SRF
Make-up CaCO3
MSW
EFW BOILER
SCR
CO₂-rich EFW Flue gases
Purge
Bottom Ash
CO₂
Energy provided by SRF oxycombustion
Grate combustor
II Air
Water to economizers
OXYGEN
Lower O2 consumption compared to a full oxyfuel EfW
CPU
Bottom Ash
Deareator
Vent gas recycle
STEAM CYCLE SECTION
Primary Air
Condenser
CO₂ to storage or utilisation

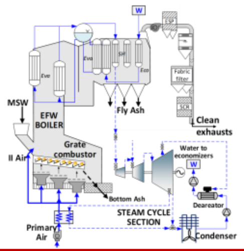
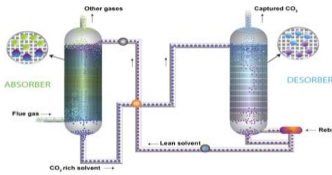
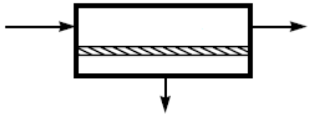
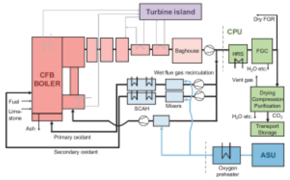
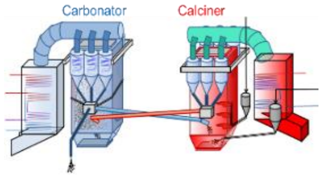
CC technologies potentially appliable to EfW

Ref. EfW : 200 ktUrw/y	EfW ref	Solvents (MEA)	Membranes + CPU	MCFC+CPU	Oxycombustion +CPU	Ca-Looping+CPU
	200kt/y URW					
$\varepsilon_{CO2,\ captured}$	-					
Power output [MW_e]	20					
Fuel Input [MW_{LHV}]	82					
Net electric efficiency [%]	24.4					
Electric energy for CO_2 capture [GJ_e/t_{CO2}]	-					
Thermal energy for CO_2 capture [GJ_t/t_{CO2}]	-					
Cost of CO_2 avoided [€/tCO2]	-					
TRL	-					
Technological maturity	-					
Retrofitability	-					
Impact on host plant operation	-					

CC technologies potentially appliable to EfW

Ref. EfW : 200 ktUrw/y 	EfW ref	Solvents (MEA)	Membranes + CPU	MCFC+CPU	Oxycombustion +CPU	Ca-Looping+CPU
	200kt/y URW					
$\varepsilon_{CO2, captured}$	-	90%	50-90%	92%	90%	94%
Power output [MW_e]	20	10	3- 9	33	8	24
Fuel Input [MW_{LHV}]	82	82	82	82 + 32.6 (NG)	82	82+80 *(line replacement)*
Net electric efficiency [%]	24.4	12.2	3.6-11.0	28.8	9.9	14.8
Electric energy for CO_2 capture [GJ_e/t_{CO2}]	-	-0.36	-1.26 ÷ -1.94	-0.66 **CPU+MCFC auxiliaries*	-1.35 **CPU+ASU*	-0.82 **CPU+ASU+auxiliaries*
Thermal energy for CO_2 capture [GJ_t/t_{CO2}]	-	-3	-	-	-	-
Cost of CO_2 avoided [€/tCO2]	-	*200-230*	*200-730*	-	-	*119-168*
TRL	-	9	<5 (not tested for EfW applications)	<5 (not tested for EfW applications)	<4	6
Technological maturity	-	Available for full scale application	Tested with gas from coal/NG combustion – still to test with EfW effluents and pollutants	Lab tests with variable CO_2 concentrations and variable pollutants concentrations	Very low (demonstrated only in CFB applications)	Tested to capture CO_2 from coal-fired boiler and with SRF combustion in the calciner
Retrofitability	-	«End-of-pipe» (*possible modifications to ST*)	Possible «End-of-pipe» Even if for high capture rate, slective flue gas recirculation is required, with heavy boiler modifications	«End-of-pipe» (NG required)	Greenfield application. The retrofit option would require significant modification to boiler, heat transfer surfaces, ST and gas treatment line	One line replacement or addition («End-of-pipe»), with modification to gas treatment line and steam cycle
Impact on host plant operation	-	Impact on district heating	Impact on power production	Increase in electricity and heat output	ASU consumption (only partially compensated by higher gross power output	High integration with steam cycle, higher efficiencies

CC technologies potentially appliable to EfW

Ref. EfW : 200 ktUrw/y	Solvents (MEA)	Membranes + CPU	MCFC+CPU	Oxycombustion +CPU	Ca-Looping+CPU
					
PRO	- **mature technology**, market-ready (max TRL) - **limited footprint** 0.2-0.8 m^2/Nmc/s (e.g., **1000 m^2** - without including the compression unit - for a 20 MW_{el} EfW)	- conceptually simple and **modular technology** - no chemicals - **limited footprint** – 1500 - 2000 m^2 for the reference EfW	- available on the market - high **electric efficiency** - suitable for the coproduction of power, hydrogen and heat - **modular and flexible,** suitable for many sectors(e.g., NGCC, EfW)	- conceptually simple - high CO_2 concentration reachable only without air infiltrations	- CFB reactors familiar to EfW sector - Moderate energy penalty - Possible increase of thermal power output - **sinergy processes** – CaO recovery - **CFB reactors re-usable** for gasification
CONS	-**significant energy penalty associated to solvent regeneration** ➔ impact on cogenerative plants -solvent degradation (make-up) -side species emissions, to be evaluated with long tests	-**high electric consumptions for gas compression**, especially for high CC efficiency -uncertainties related to materials degradation -low technology maturity for EfW	-**use of NG-deep gas polishing** is required -low durability, **high costs** -**large footprint** (800 m^2 for a 2 MW module in CC configuration, including BOP) ➔8000 m^2 for the reference EfW plant	-significant uncertainties related to **air-in leakages** -high energy penalty due to high ASU consumption (small size) -no **retrofit** – EfW plant must be re-built	-calciner fed with SRF -high solid amounts to be handled -high footprint -**cyclone selectivity (high efficiency for CaO, low efficiency for ash)** for avoiding sorbent losses and ash build-up

Some remarks

- Even if Amines absorption is the closest to market post-combustion CO_2 capture technology also for EfW plants, several other possibilities are currently under development
- Some of these offer interesting energy performances, with possible beneficial effects on OpEx
- In particular, MCFCs and CaL seems very promising options
- MCFCs feature rather high efficiency in converting NG to electricity, thus offsetting part of the energy cost of CO_2 capture
- Their main problem, currently, is their very high CapEx
- CaL requires relevant interventions on the EfW section of the plant: a partial substitution or a significant capacity expansion
- An additional drawback is the very significant amount of solid sorbent handled in the plant
- Energy performances of both MCFCs and CaL are better than those achieved by (reference) Amines
- MCFCs and CaL do not penalise the cogeneration capacity of the plant (differently from Amines)
- However, this can be a real advantage only when the EfW plant is coupled with a very large DH network

In the backup slides:

Preliminary comparison of three technologies based on energy performances

Focus on a plant treating 160 kt/y of MSW

Reference case: grate-based EfW plant without capture

Benchmark case: MEA CO_2 capture

MCFC case with two sets of MCFCs (see Viganò et al., 2022)

MCFC case with only one set of MCFCs and reduced performances

CaL case

Thanks for your attention!

Contact:
federico.vigano@polimi.it

POLITECNICO
MILANO 1863

RETE ALTA TECNOLOGIA
EMILIA-ROMAGNA
HIGH TECHNOLOGY NETWORK
TECNOPOLO PIACENZA

LEAP
FOUNDED IN 2005 BY
POLITECNICO DI MILANO

Backup slides

Reference waste & reference plant

Data from Consonni & Viganò, 2011 – Waste sent to energy recovery from a collection area featuring 65% source separation

Waste fraction	% by mass
Paper and cardboard	20.62
Wood	3.02
Plastics	22.56
Glass and inerts	2.76
Ferrous metals	3.09
Non-ferrous metals	0.32
Food waste	24.38
Green waste	10.08
Organic fines	8.31
Inert fines	4.86

Ultimate 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
Biogenic C	14.15
Fossil C	13.70

LHV = 10.45 GJ/t

CO_2 emission factors:

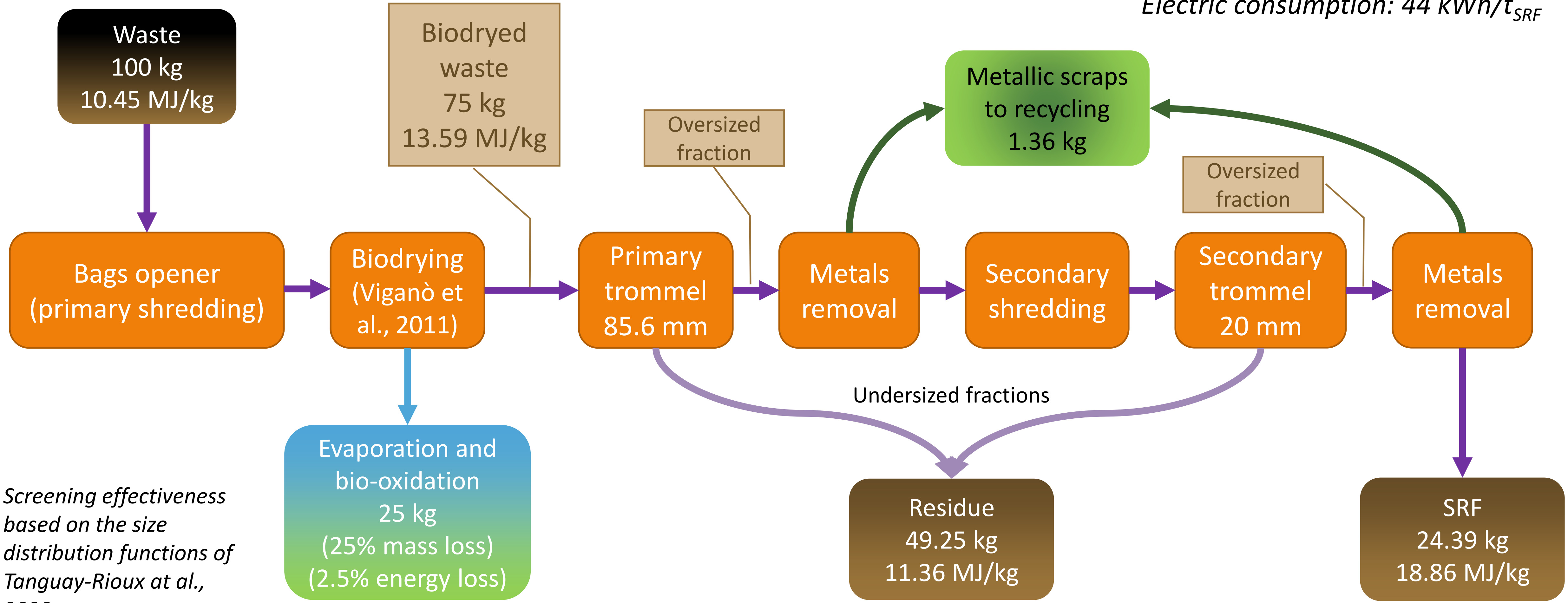
- Overall CO_2 97.69 kg/GJ_{LHV}
  1.021 t/t
- Biogenic CO_2 49.63 kg/GJ_{LHV}
  0.519 t/t
- Fossil CO_2 48.06 kg/GJ_{LHV}
  0.502 t/t

Biogenic carbon share: 50.8%

Reference plant:
2 identical grate-based lines
71.32 MW overall combustion power
160.000 t/y waste treated
(@ 10.45 GJ/t → 74.34% load factor)
Cogeneration capacity = 40 MW_{TH}

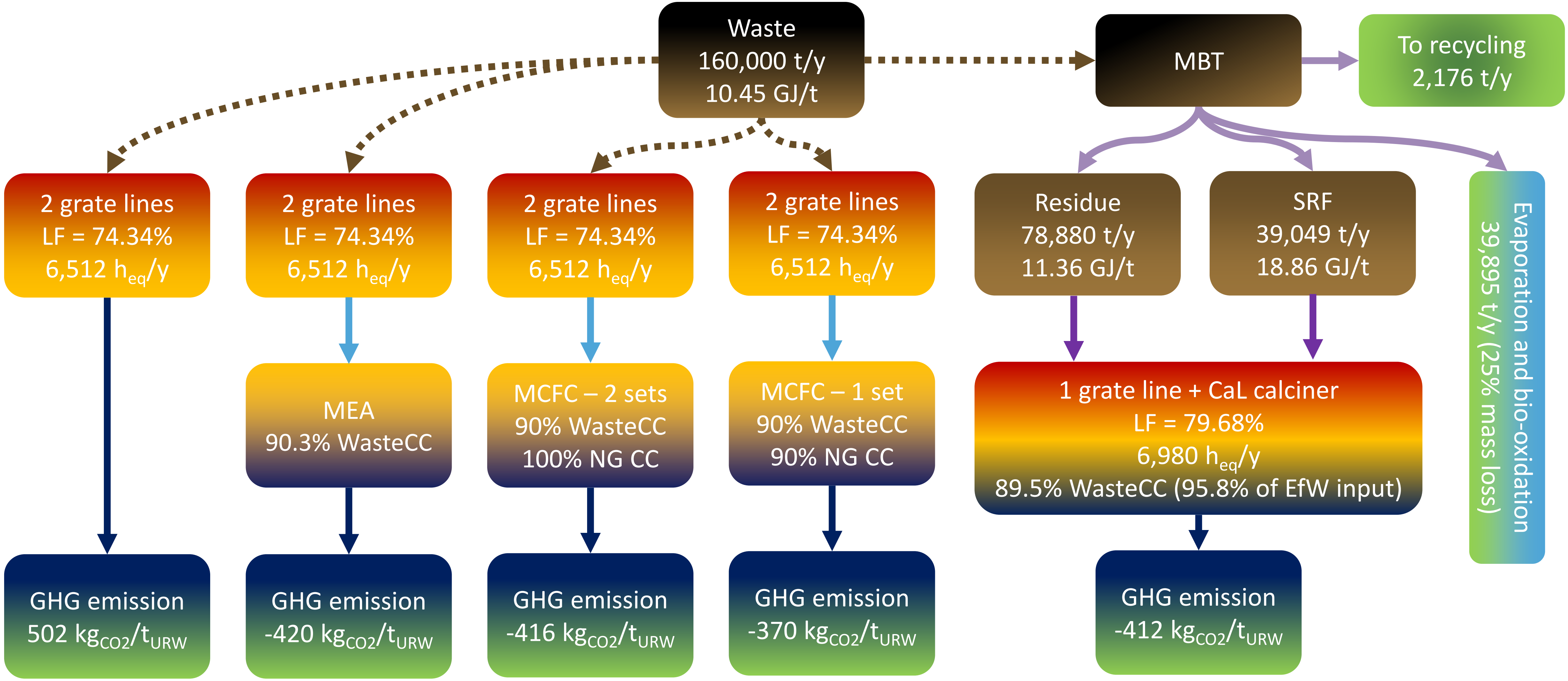
MBT for CaL plant

Electric consumption: 44 kWh/t_{SRF}



Screening effectiveness based on the size distribution functions of Tanguay-Rioux at al., 2020

Scenarios – mass balances



CO_2 capture performances

When treating 160,000 t/y of waste

Plant:	Reference, no CC	MEA	2 MCFC sets	1 MCFC set	CaL
Annual CO_2 emission from EfW plant, kt	163.25	15.84	16.50	23.71	6.39
Annual CO_2 emission from SRF production, kt	-	-	-	-	11.14
Overall annual CO_2 emissions, kt	163.25	15.84	16.50	23.71	17.53
Overall annual fossil CO_2 emissions, kt	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
Efficiency of CO_2 capture section, %	-	90.30	92.04	88.73	95.80

In the case of CaL, (direct) CO_2 emissions from SRF production must also be considered.
In the Table, indirect CO_2 emissions (e.g., due to electricity consumption for SRF production, different electricity outputs from EfW plants) are not considered.

SPECCA: Specific Primary Energy for Carbon Avoided (MJ/kg_{CO2})

$$SPECCA\left[\frac{MJ}{kg_{CO2}}\right] = \frac{\Delta EP_{CCS}\ [MJ]}{\widetilde{CO}_{2,avoided}\ [kg_{CO2}]}$$

For a fossil fuel-fired power plant, producing only electricity, the calculation is straightforward, by simply focusing on a unit product (kWh_{el}):

$$SPECCA\left[\frac{MJ}{kg_{CO2}}\right] = \frac{\left(HR_{w/\_CCS} - HR_{w/o\_CCS}\right)\ [MJ_{LHV}/kWh_{EL}]}{\left(e_{w/o\_CCS} - e_{w/\_CCS}\right)[g_{CO2}/kWh_{EL}]/1000} = 3600 \cdot \frac{\frac{1}{\eta_{w/\_CCS}} - \frac{1}{\eta_{w/o\_CCS}}}{\left(e_{w/o\_CCS} - e_{w/\_CCS}\right)}$$

→ To compensate for the change of efficiency due to carbon capture, a higher/lower fuel consumption is considered.

When the fuel is waste, its availability is constrained, thus it is better to carry out the analysis with reference to a fixed amount of waste to be treated.

→ To compensate for the change of efficiency due to carbon capture, other energy sources must be considered.

Combined Heat and Power (CHP) production makes the situation even more complex.

SPECCA: Specific Primary Energy for Carbon Avoided (MJ/kg_{CO2})

Framework for CHP EfW plants:

A possibility to avoid overestimating the energy performances of EfW+CCS is to consider the best alternative programmable source of electricity and heat: a CHP Natural Gas-fired Combined Cycle (NGCC), in the two versions with and without post-combustion CO_2 capture by MEA (Ref. FP7 CAESAR Project, SPECCA = 3.29 MJ/kg_{CO2}).

Parameter	Without Carbon Capture	With Carbon Capture
Net electric efficiency, $\%_{LHV}$	58.3	49.9
Specific CO_2 emission, kg/MWh_{el}	351.8	36.2
Marginal ratio cogenerated heat / electricity lost	7.7	
Corresponding thermal efficiency, $\%_{LHV}$	448.9	384.2
Corresponding specific CO_2 emission, kg/MWh_{th}	45.7	4.70

When reference is made to the non-decarbonised CHP NGCC (i.e., w/o CC), $SPECCA^{(a)}$ is evaluated.
When reference is made to decarbonised CHP NGCC (i.e., with CC), $SPECCA^{(b)}$ is evaluated.

The considered NG features a carbon intensity of 56.97 kg_{CO2}/GJ_{LHV}.

Scenarios: base performances data

Situation with minimum cogeneration (i.e., thermal power output is set to the minimum allowed by each plant configuration)

Plant:	Reference, no CC	MEA	2 MCFC sets	1 MCFC set	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*

Scenarios: base performances data

Situation with minimum cogeneration (i.e., thermal power output is set to the minimum allowed by each plant configuration)

Plant:	Reference, no CC	MEA	2 MCFC sets	1 MCFC set	CaL
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

Situation with maximum cogeneration (i.e., thermal power output is set to the maximum allowed by each plant configuration)

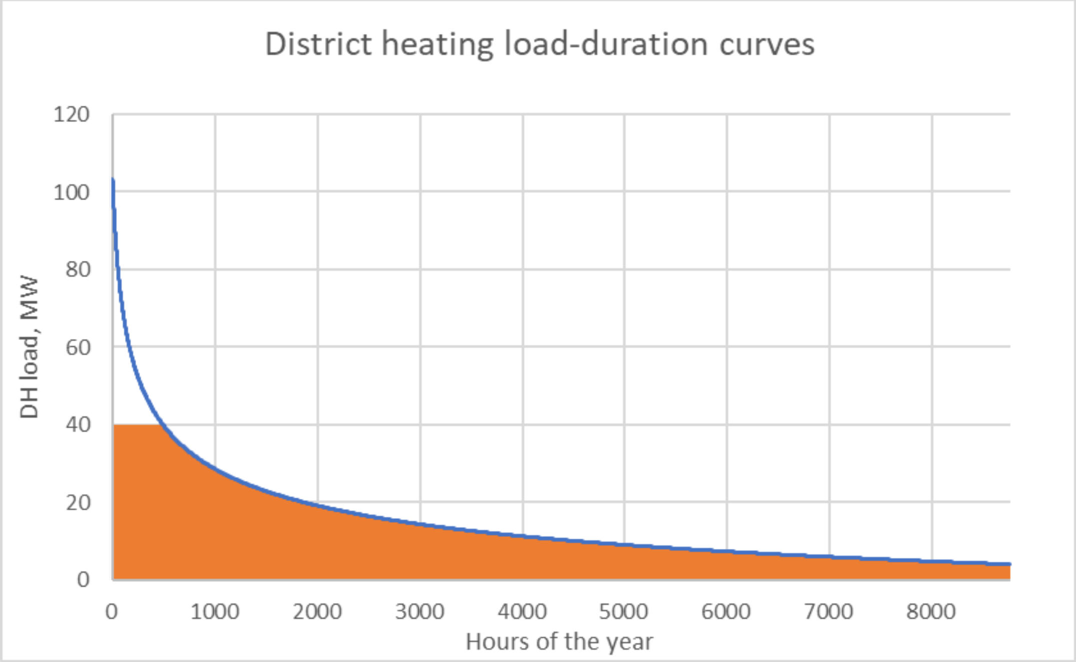
Plant:	Reference, no CC	MEA	2 MCFC sets	1 MCFC set	CaL
Maximum cogenerated thermal power (70-120°C), MW_{TH}	40.00	17.44	40.85	40.81	39.13
Corresponding net electric power output, MW_{EL}	6.26	3.64	22.00	22.19	-0.46
Overall net electric efficiency, $\%_{LHV}$	8.77	5.10	21.12	20.80	-0.69
Overall net thermal efficiency, $\%_{LHV}$	56.09	24.45	39.20	38.26	58.75

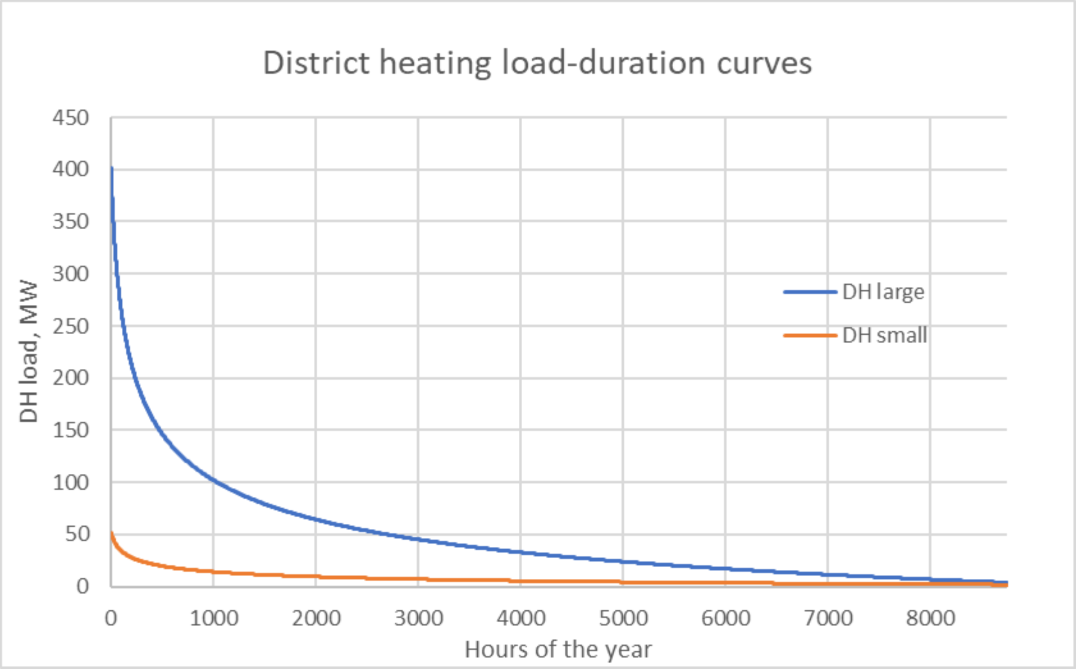
Situation with the same level of cogeneration (on annual basis)

Plant:	Reference, no CC	MEA	2 MCFC sets	1 MCFC set	CaL
Cogenerated thermal power (70-120°C), MW_{TH}	15.00	15.00	15.00	15.00	13.99
Corresponding net electric power output, MW_{EL}	10.80	4.08	26.70	26.89	4.11
Marginal NG conversion efficiency, $\%_{LHV}$	-	-	48.36	45.48	-
SPECCA[a], MJ/kg_{CO2}	-	2.052	0.719	1.035	1.827
SPECCA[b], MJ/kg_{CO2}	-	2.170	0.158	0.514	1.951

Energy performances when considering the coupling with a DH network

Based on the characteristics of both the plant and the DH network, it is possible to evaluate the maximum thermal energy that can be supplied.





$$P = a + \frac{\Delta P}{1 - k^n}\left[1 - \left(\frac{k}{1 - (1 - k)\frac{x}{8760}}\right)^n\right]$$

Two coupling situations can be considered: small and large DH.
The load duration curve can be modelled analytically.
"*a*" and "*a* + ΔP" represent the minimum and maximum power demand.
"*k*" and "*n*" are "shape factors", *k* = 165 and *n* = 0.3 work well.

	Small DH network	Large DH network
a, MW	2.0	4.0
ΔP, MW	50.0	400.0

Energy performances when considering the coupling with a DH network

Annual theoretical thermal energy = Area of the DH load duration curve

Reduction coefficient for thermal energy = 1 – (1 – LF) x 0.5

LF = Load Factor

Plant:	Reference, no CC	MEA	2 MCFC sets	1 MCFC set	CaL
Load factor, %	74.30	74.30	74.30	74.30	79.68
Reduction coefficient for thermal energy, %	87.15	87.15	87.15	87.15	89.84
Waste energy input, GWh_{LHV}	464.20	464.20	464.20	464.20	464.20
NG energy input, GWh_{LHV}	0.00	0.00	214.01	230.21	0.00

Annual saleable thermal energy = Annual theoretical thermal energy x Reduction coefficient for thermal energy

Maximum annual theoretical electricity = Nominal power output x 8,760 x LF

Annual saleable electricity = Krid x [Maximum annual theoretical electricity – (Annual saleable thermal energy – Minimum cogenerated thermal power x 8,760 x LF) / Keq]

Krid = reduction coefficient for off-design operating conditions = 0.9
Keq = thermal equivalent of electricity = 5.5

Krid applies also to the performance of the reference CHP NGCC

Energy performances when considering the coupling with a DH network

Coupling with the SMALL DH network:

Plant:	Reference, no CC	MEA	2 MCFC sets	1 MCFC set	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 mean net thermal efficiency, $\%_{LHV}$	12.24	11.22	8.38	8.19	12.61
Annual mean net electric efficiency, $\%_{LHV}$	15.07	6.75	24.05	23.64	6.95
Annual SPECCA[(a)], MJ/kg_{CO2}	-	2.03	0.73	1.05	1.80
Annual SPECCA[(b)], MJ/kg_{CO2}	-	2.16	0.16	0.51	1.94

Coupling with the LARGE DH network:

Plant:	Reference, no CC	MEA	2 MCFC sets	1 MCFC set	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 mean net thermal efficiency, $\%_{LHV}$	22.99	18.25	15.68	15.42	23.77
Annual mean net electric efficiency, $\%_{LHV}$	13.31	5.60	22.85	22.46	5.12
Annual SPECCA[(a)], MJ/kg_{CO2}	-	2.00	0.73	1.05	1.81
Annual SPECCA[(b)], MJ/kg_{CO2}	-	2.13	0.16	0.51	1.94

Some additional remarks

- A properly defined SPECCA index can be a suitable KPI to quantify energy performances of different options and, therefore, impacts on OpEx
- In terms of such a SPECCA index, EfW appears much more attracting than other technologies for the application of CO_2 capture (i.e., MEA in a NGCC leads to SPECCA = 3.29, in a EfW achieves SPECCA = 2.00)
- In terms of SPECCA index, no differences are appreciated between coupling with a small or large DH network
- In economic terms, this would be different
- MCFC are very performing thanks to their ability of converting NG to electricity with a very high marginal efficiency, which is comparable with that of a decarbonised NGCC

References

- *Consonni, S., and Viganò, F., 2011, "Material and energy recovery in integrated waste management systems: The potential for energy recovery", Waste Management 31, 2074-2084.*
- *Viganò F., Consonni S., Ragazzi M., Rada E. C., 2011, "A model for mass and energy balances of bio-drying", Paper 5457 in Proceedings of NAWTEC19: 19th Annual North American Waste-to-Energy Conference, Lancaster (PA), USA, May 16-18, 2011.*
- *Viganò, F., Cretarola, L., Spinelli, M., 2022, "Molten Carbonate Fuel Cells (MCFC) for the carbon capture in Energy-from-Waste (EfW) plants", Proceedings of Venice 2022: 9th International Symposium on Energy from Biomass and Waste, Venice, Italy, November 21-23, 2022.*