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Institute for Energy Systems

Waste to Energy with BECCS for the urban environment: Opportunities and challenges for development

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1. Context for Waste-to-Energy and district heating

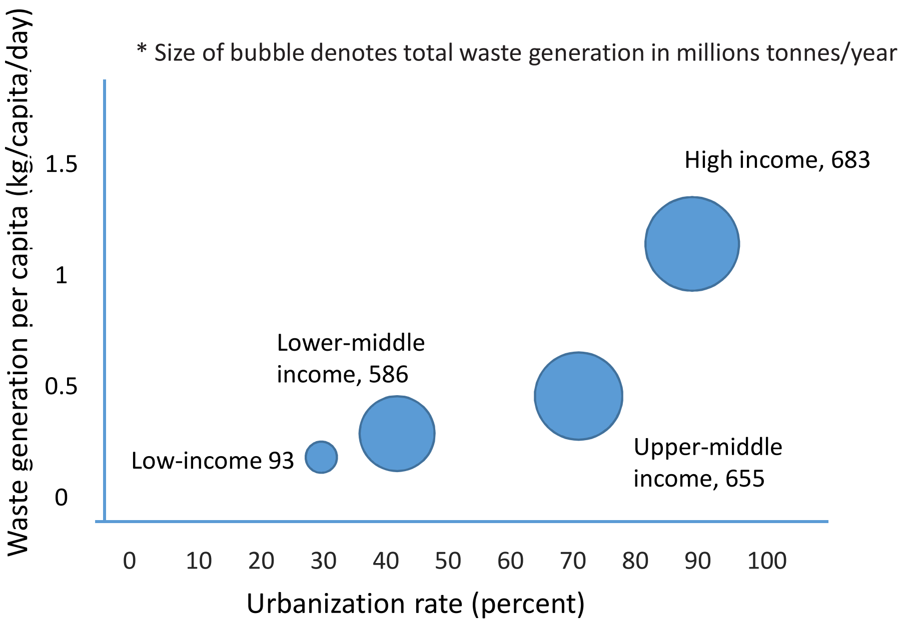


Figure 1. Waste generation and urbanization rate

- With rapid population growth and urbanization, municipal waste generation is expected to rise to 3.4 billion tonnes by 2050. [1]

[1] The World Bank, What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050, 2018;

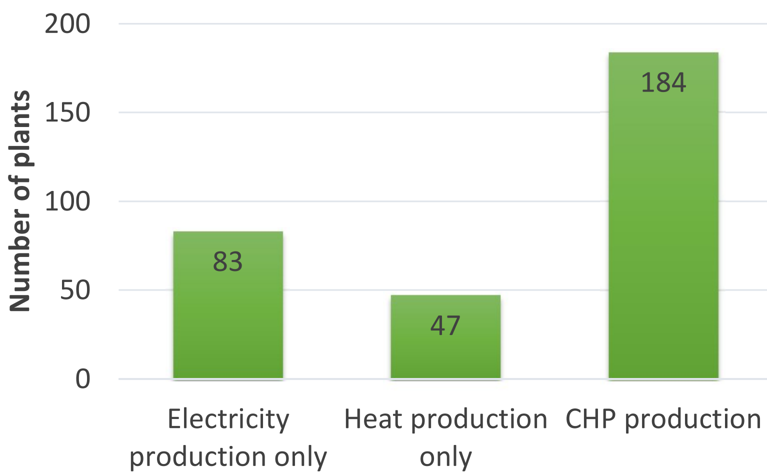


Figure 2. Type of energy recovery from WtE plants in Europe (2010)

- WtE offers an effective way to treat MSW, compares with traditional methods such as landfills;
- However, direct CO_2 emission factor for MSW with LHV of 10 MJ/kg is assumed equal to 0.9875 ton CO_2/t of waste [2];

[2] IEAGHG, "CCS on Waste to Energy", 2020-06, December 2020;

2. Integration of WtE with CCS

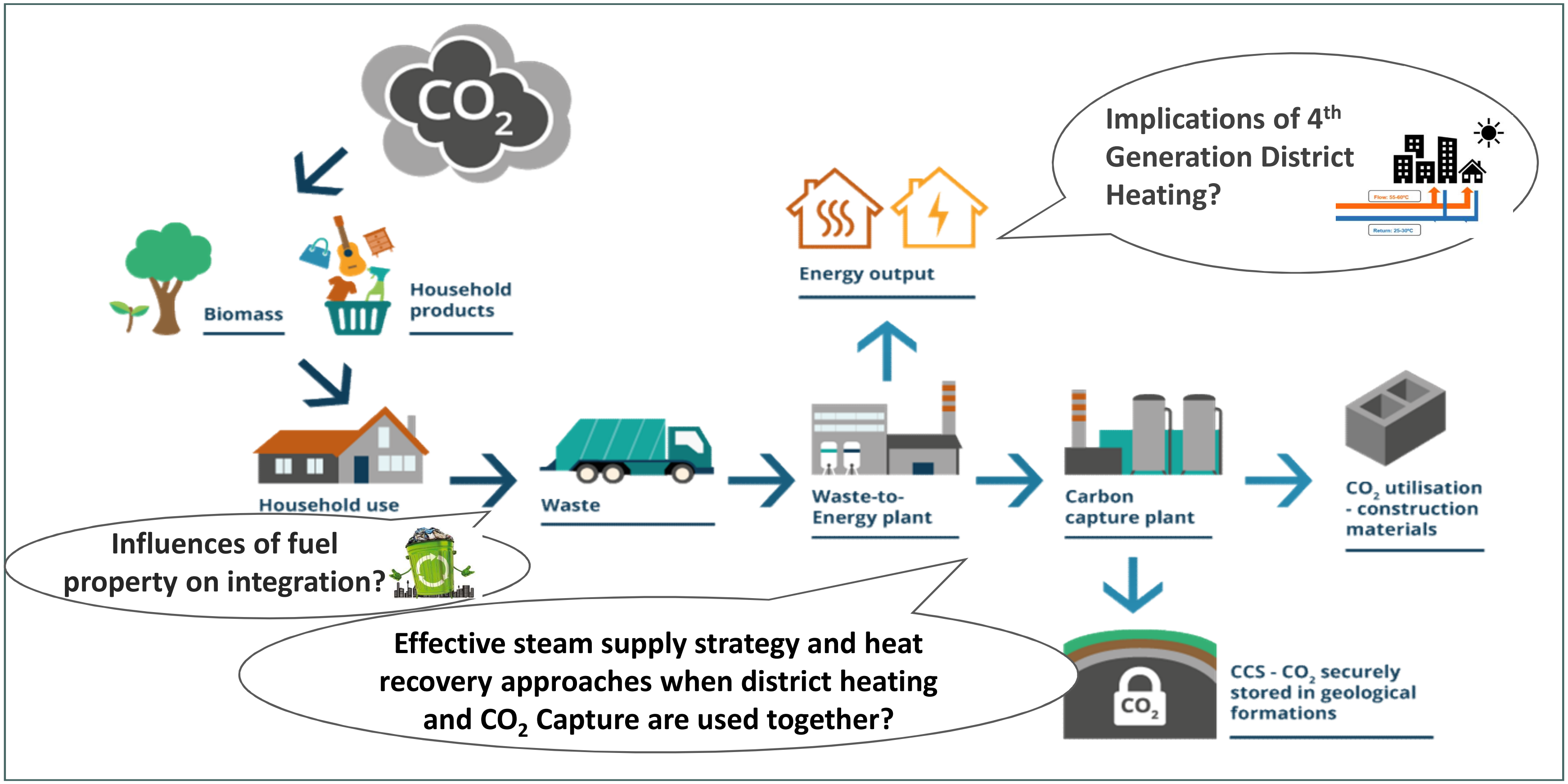
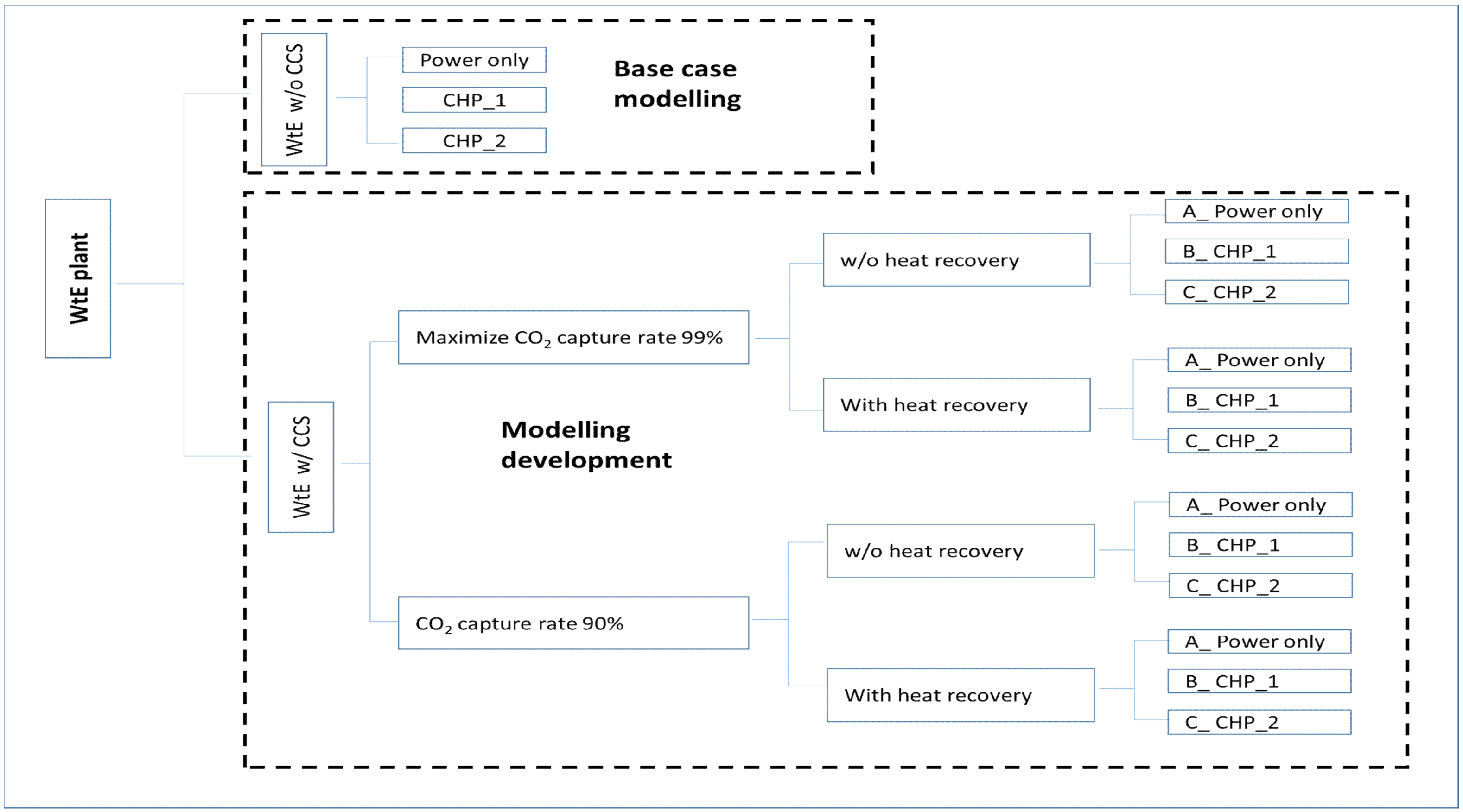


Figure 3. Process flowsheet of a WtE plant integrated with CCS
Original Graphic : NEWEST-CCUS, SCCS and Starbit

2. Integration of WtE with CCS



3. Process modelling in gProcess

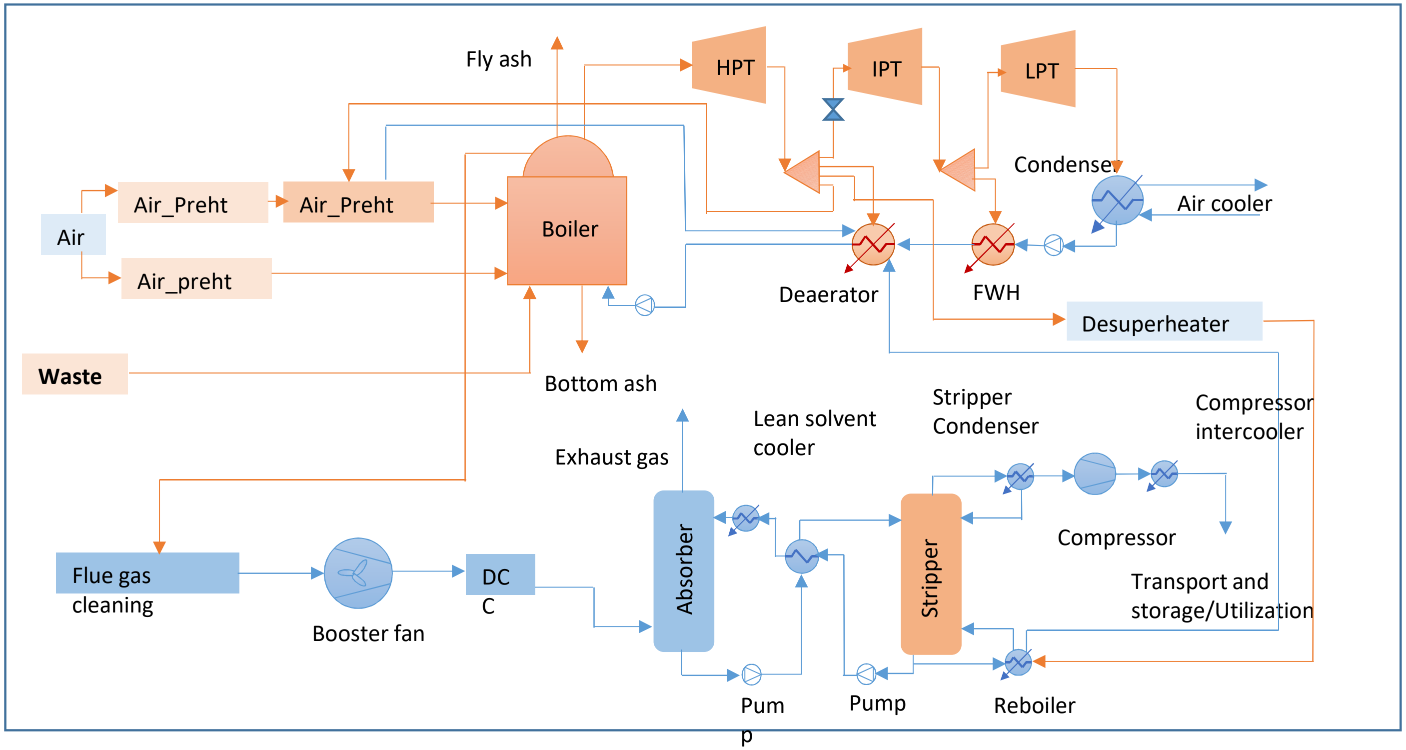


Figure 4. Example of Process flow diagram of a WtE plant integrated with Post combustion CO_2 capture _ Power only

	Unit	gProms modelling
LHV	kj/kg	9300
Waste throughput	t/h	19.4
Primary air into boiler	°C	135
Primary air massflow	kg/s	19.7
Primary air preheating (external)	MW	1.7
Secondary air into boiler	°C	50
secondary air massflow	kg/s	8.5
Secondary air preheating (external)	MW	0
Total air preheating from steam cycle	MW	1.7
Boiler Live steam Temperature	°C	400
Boiler Live steam pressure	bar	60
Boiler Live steam enthalpy	kj/kg	
Boiler Live steam mass flowrate	kg/s	18.2
HP inlet Temperature	°C	400
HP inlet pressure	bar	600
HP inlet enthalpy	kj/kg	
FW return Temperature	°C	137
FW return Pressure	bar	80
FW return mass flowrate	kg/s	18.2
Flue gas Temperature	°C	136
Flue gas pressure	bar	1
O_2 concentration in the flue gas		6.12%
Boier efficiency		88.0%
Total thermal input	MW	52.04
Gross power output	MW	13.6

4. Key performance assessment metrics

- **Efficiency penalty** $\Delta \eta_{Penalty}$

Affected by fuel composition and the heating value

$\Delta \eta_{Penalty} = \eta - \eta^{CCS}$

$$= \frac{Q_{CAP} - (QC - QCCCS) + WACCS}{Q_{IN\_LHV}}$$

$\approx \%_{LHV}$

Small/no significant direct effect

- **Electricity output penalty EOP**

strong function of the post-combustion capture systems

$$EOP = \frac{\Delta \eta_{Penalty}}{\text{Fuel specific emissions}}$$

$$EOP = \frac{\text{Loss of generator output + Compression \& ancillary power}}{CO_2 \text{ mass flow}}$$

- **Coefficient Of Performance for (steam) extraction COP_X [3]**

Equivalent to the COP of a heat pump

$$COP_X = \frac{\text{heat supplied to a PCC plant by steam extraction}}{\text{reduction in work output from that steam cycle}}$$

[3]Lucquiaud, M. and J. Gibbins (2011). "On the integration of CO2 capture with coal-fired power plants: A methodology to assess and optimise solvent-based post-combustion capture systems." Chemical Engineering Research and Design 89(9): 1553-1571.

5. Current Results from Process modelling: Model Validation

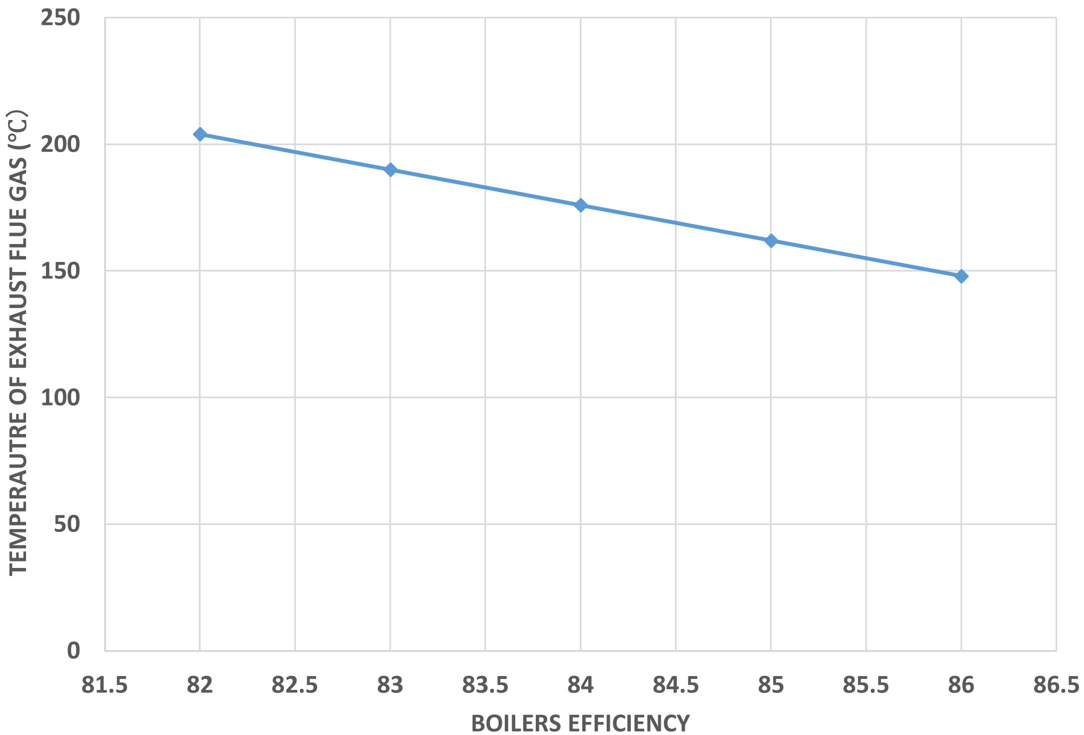


Figure 5 Variation of boiler efficiency with exhaust flue gas temperature

- Heat loss from flue gas, takes the largest share of the heat losses from the boiler, approximately 10% of the total heat input to the boiler
- For every 1% increase of boiler efficiency, the exhaust flue gas temperature decreases by ~14℃
- Modelling results agree well with data from public literature, contribute to the validation process of the process modelling;

5. Current Results from Process modelling: Impact of Fuel Composition

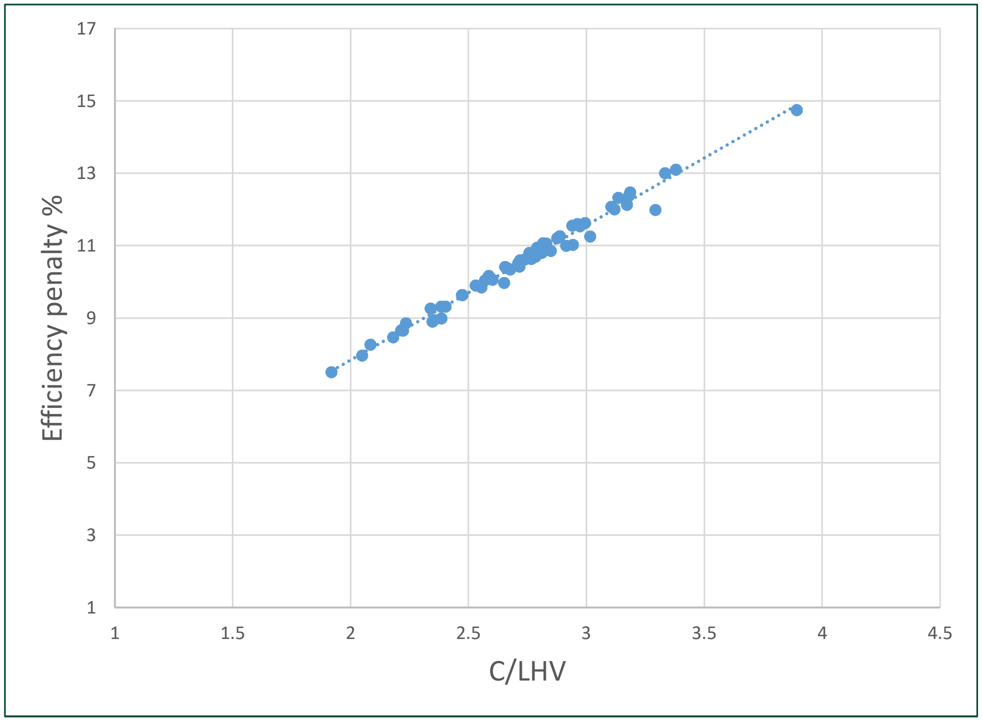


Figure 6. C/LHV vs Efficiency penalty due to CO_2 capture
C is Carbon content in %, LHV is in MJ/kg, as received
(99.5% CO_2 capture rate, 3.5GJ/tCO_2 solvent heat of regeneration, 60bar/400degC steam, 88% boiler efficiency)

- 59 sets of MSW quality referenced from public literature for process modelling in gProcess builder software;
- C% ranges from 11.37% to 73%;
- LHV ranges from 4 MJ/kg to 35 MJ/kg;
- Heat required for solvent regeneration is extracted from crossover pipeline between IP and LP turbines @3.5 bar, superheated condition;

$$\Delta \eta_{Penalty} = \eta - \eta^{CCS}$$

$$= \frac{Q_{CAP} - (QC - QCCCS) + WACCS}{Q_{IN\_LHV}}$$

$$\approx \%_{LHV}$$

Small/no significant direct effect

5. Current Results from Process modelling: EOP

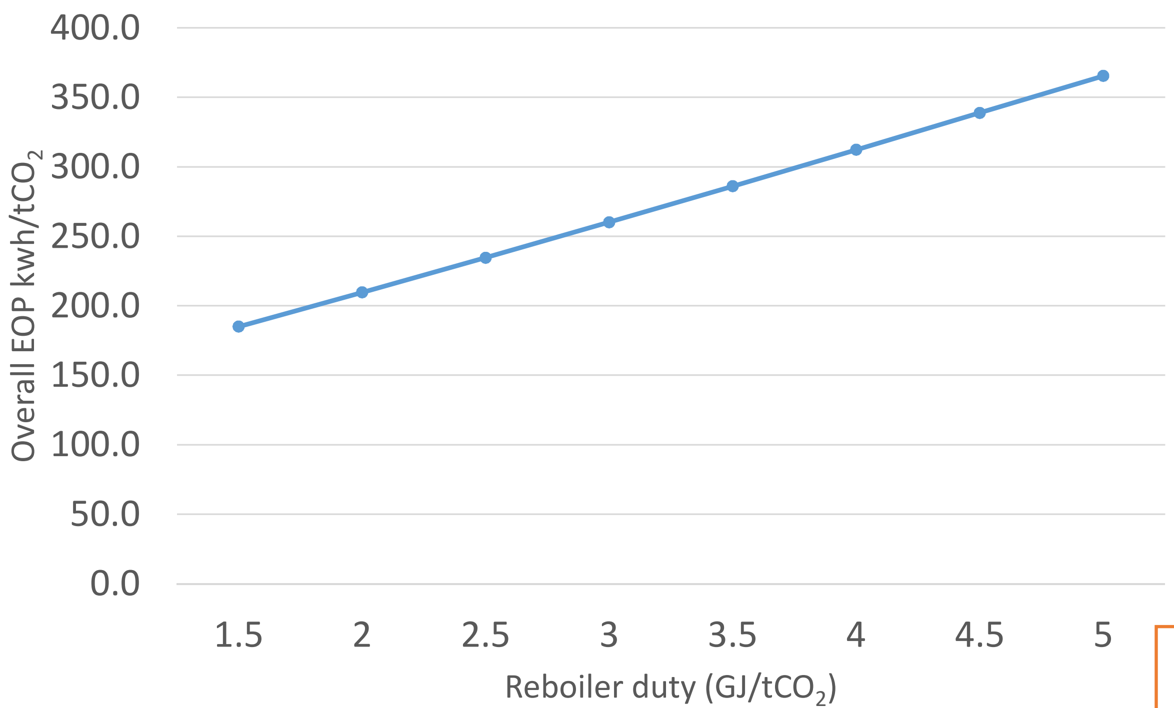


Figure 7. Overall EOP of CO_2 capture for a range of reboiler duty

- EOP of CO_2 capture is strongly affected by the reboiler duty of CO_2 capture facility;
- Site specific parameters, fuel condition also affects…
- …but the influence is relatively small compared to the absolute value of the EOP (~10 kWh/tCO_2 for the modelled cases).

$$EOP = \frac{\Delta\ \eta_{Penalty}}{\text{Fuel specific emissions}}$$

$$EOP = \frac{\text{Loss of generator output + Compression \& ancillary power}}{CO_2 \text{ mass flow}}$$

5. Current Results from Process modelling: COPx

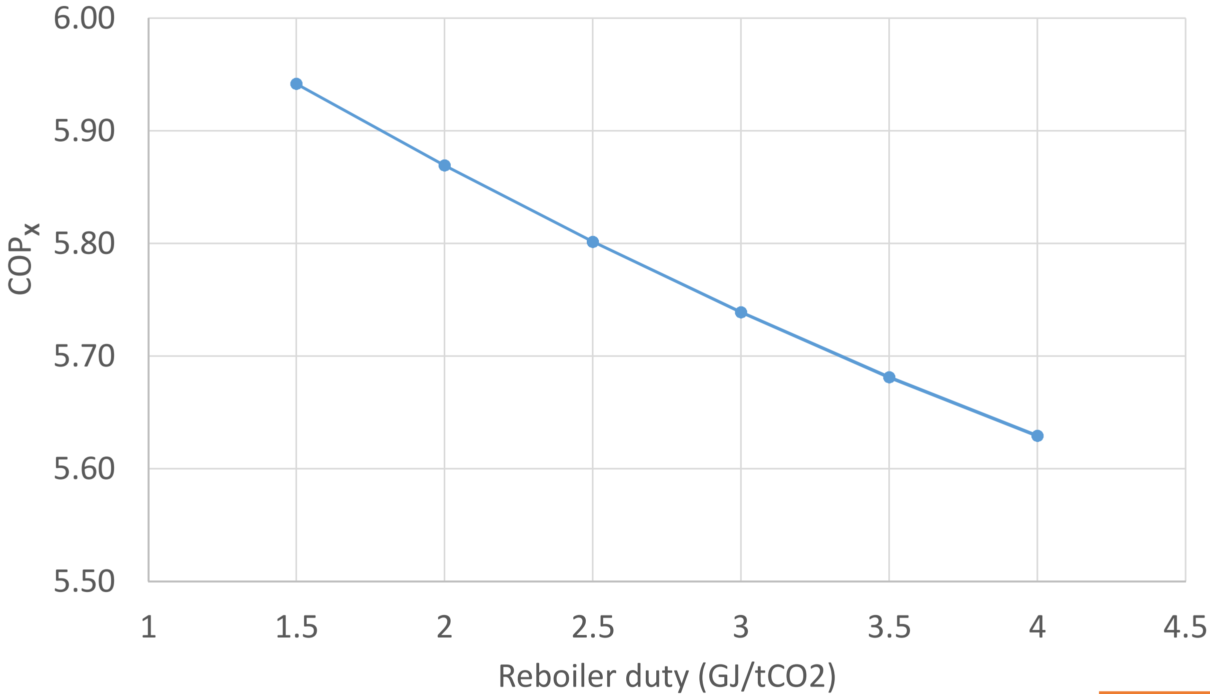


Figure 8. COPx for a range of reboiler duty

- COP_x of CO_2 capture is strongly affected by the reboiler duty of CO_2 capture facility;
- COP_x of CO_2 capture is in general higher than a 'equivalent' heat pump producing the same output temperature and recover heat at temperature equal to the steam cycle condensing temperature;

$$COP_X = \frac{\text{heat supplied to a PCC plant by steam extraction}}{\text{reduction in work output from that steam cycle}}$$

5. Current Results from Process modelling: Preliminary Heat Network Analysis

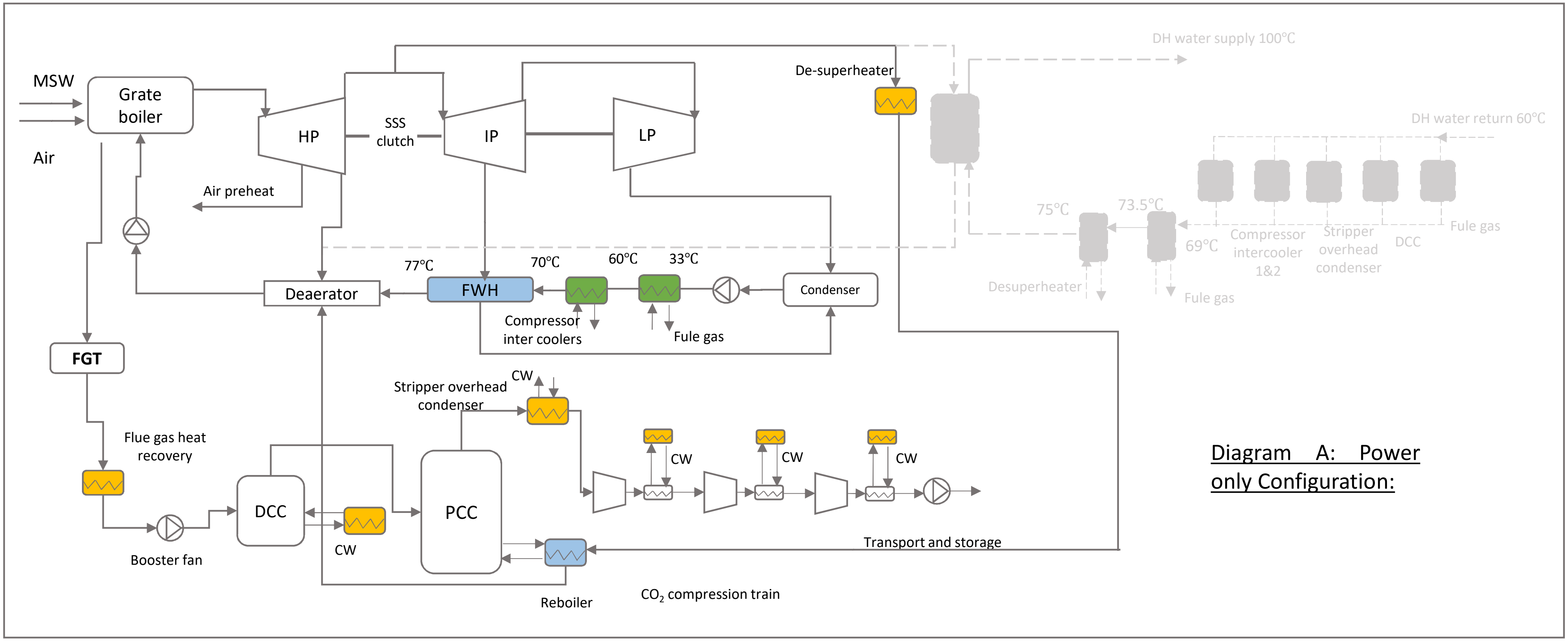


Diagram A: Power only Configuration:

5. Current Results from Process modelling: Preliminary Heat Network Analysis

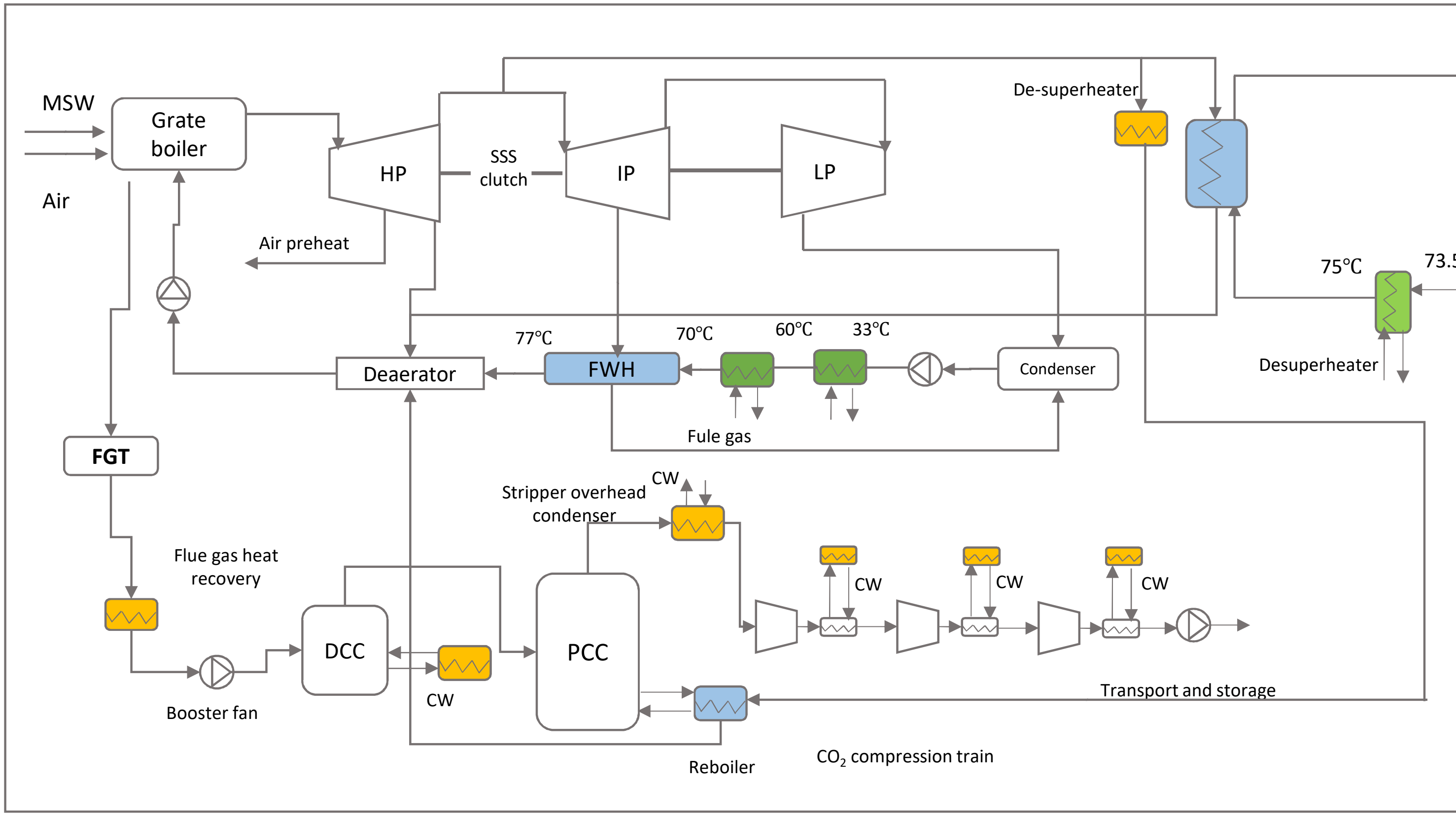


Diagram B: Configuration of CHP 1: medium scale District heating capacity (operate as an extraction and condensing turbine)

5. Current Results from Process modelling: Preliminary Heat Network Analysis

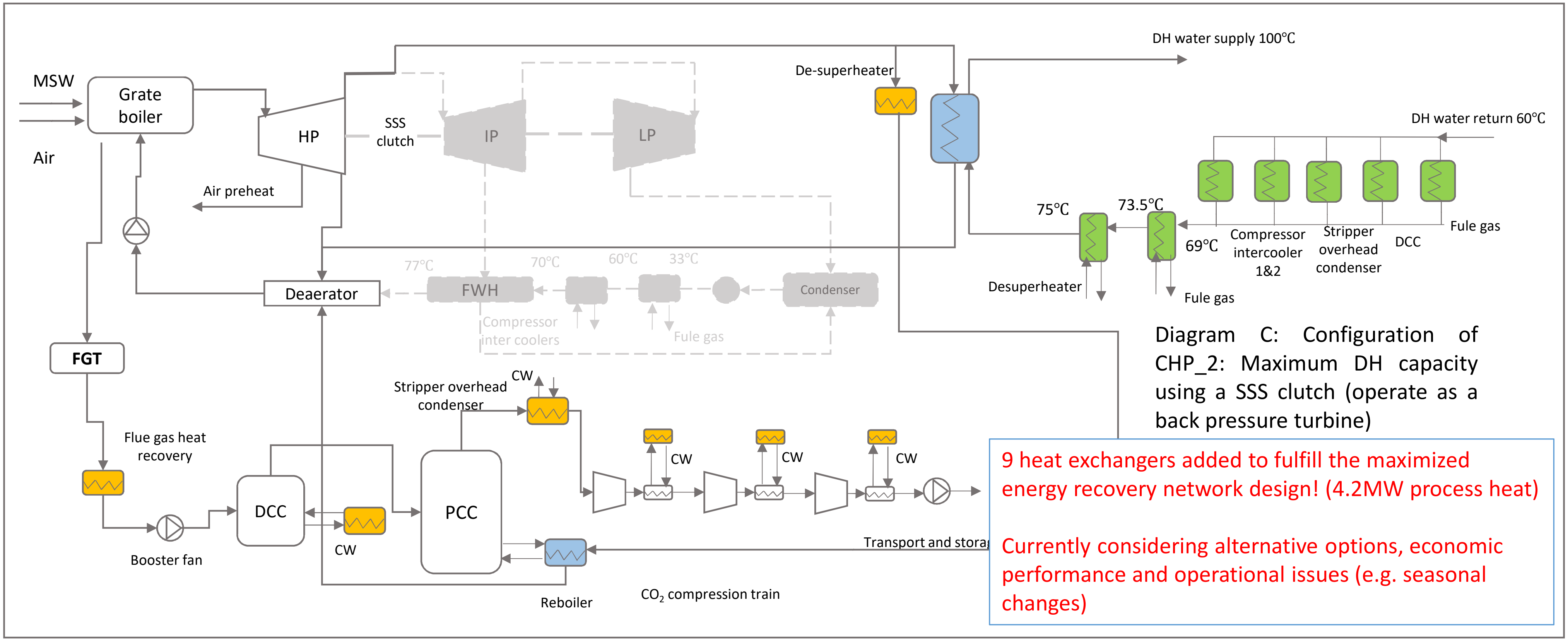


Diagram C: Configuration of CHP_2: Maximum DH capacity using a SSS clutch (operate as a back pressure turbine)

9 heat exchangers added to fulfill the maximized energy recovery network design! (4.2MW process heat)

Currently considering alternative options, economic performance and operational issues (e.g. seasonal changes)

5. Current Results from Process modelling

- Efficiency penalty due to CO_2 capture is strongly affected by composition and the heating value of the fuel;
- Electricity output penalty (EOP) and Coefficient Of Performance for (steam) extraction COPX of CO_2 capture is strongly affected by the reboiler duty of CO_2 capture facility;
- A considerable amount of heat could be recovered from the integration process, thus maximising heat recovery and minimising efficiency penalty;
- Direct heat recovery of process heat appreciable, but need to consider the design of heat exchanger networks to be cost-effective (e.g. more effective heat exchanger network design to minimise number of heat exchangers).

6. Priorities for future work

- Build and complete post-combustion capture model in ASPEN to explore impact of higher capture rates (99%) in more detail (especially solvent energy of regeneration);
- Optimize Heat Exchanger Network considering whole year operation with CO_2 capture and seasonal variation in district heating;
- Consider interim solvent storage in WtE plants with variable heat to power ratio, including sizing of storage tanks and cost benefit analysis.

Acknowledgements

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THANK YOU

Q&A

5. Current Results from Process modelling: Pinch Analysis

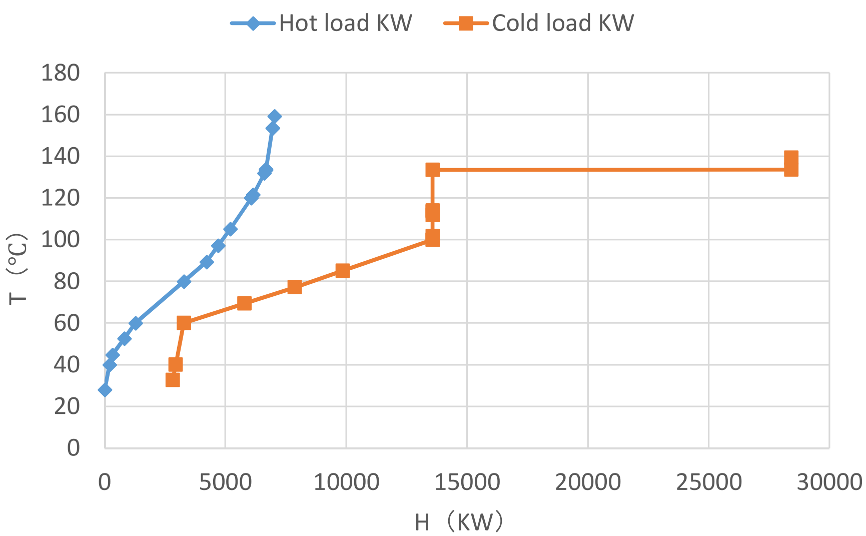

Figure 10. Composite curve of pinch analysis for the in-process heat recovery

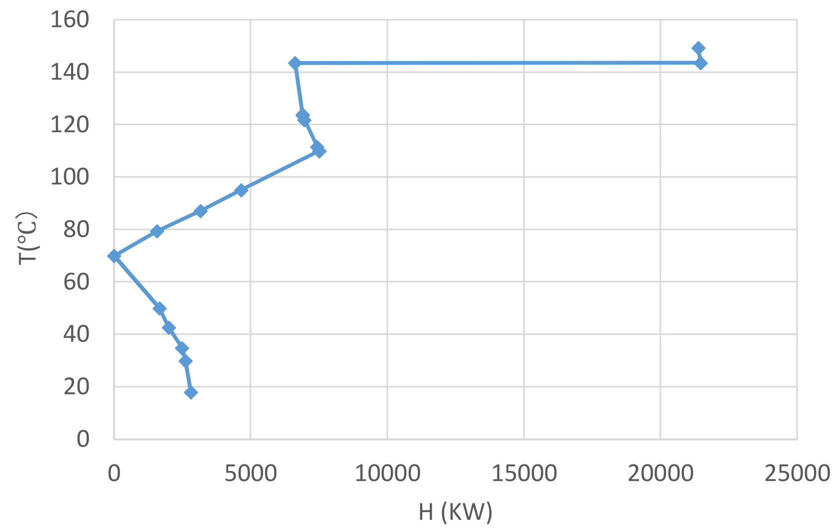

Figure 11. Grand composite curve of pinch analysis for the in-process heat recovery

Heat exchange between hot and cold streams within the process: 4.2MW

Before pinch analysis	
Hot utility KW	Cold utility KW
25599	7046

After pinch analysis	
Hot utility KW	Cold utility KW
21382	2808