Techno-economic analysis of flexible Power & Biomass-to-Methanol plants

A. Poluzzi[1], G. Guandalini[1], S. Guffanti[1], S. Moioli[2], C. Elsido[1], E. Martelli[1], G. Groppi[1], M.C. Romano[1],

[1] Politecnico di Milano, Department of Energy, Via Lambruschini 4, 20156 Milano (Italy)

[2]Politecnico di Milano, Department of Chemistry, Materials and Chemical Engineering «Giulio Natta», Piazza Leonardo da Vinci 32, 20133 Milano (Italy)

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MOTIVATION OF RESEARCH

Biofuel production from second generation biomass gasification is:

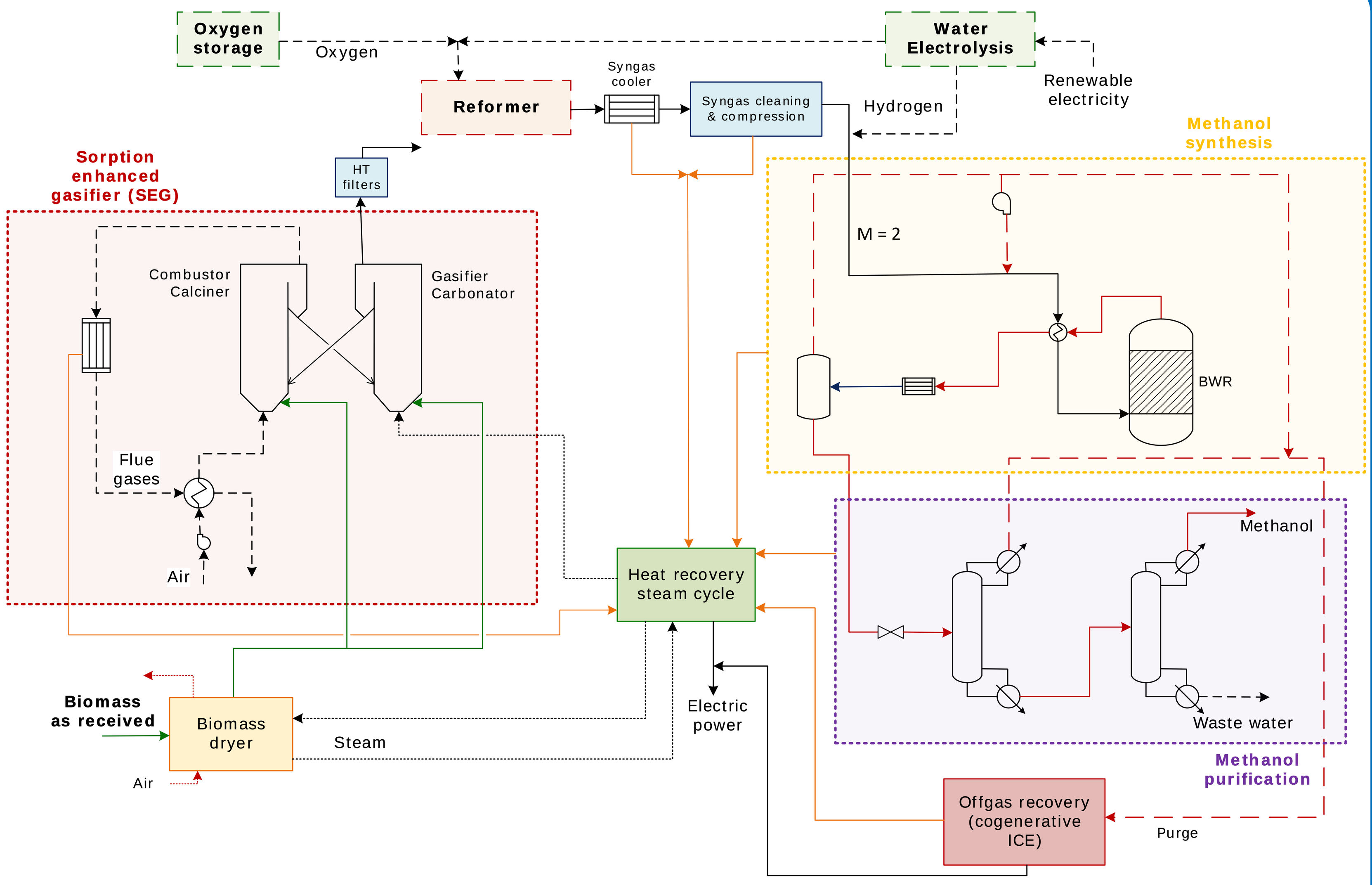
- ✗ Not economically competitive with the current market conditions and regulations;
- ✗ Inefficient in terms of carbon efficiency: <50% of the feedstock carbon is retained in the biofuel.

Mixing H_2 from *water electrolysis* with carbon-rich syngas from biomass gasification leads to [1]:

- ✓ Increase of biogenic carbon utilization and product yield;
- ✓ Opportunity of additional revenues from electric grid services through power-to-X energy storage.

The electrolyzer can be turned on only when the electricity price is sufficiently low. Therefore:

- The plant must be designed for flexible operations, taking into account intermittent H_2 addition;
- The system has to be designed and operated to work efficiently in the enhanced operation (with hydrogen addition) and in the baseline operation (without hydrogen addition).



Block diagram of the Power & Biomass-to-Methanol plant

POWER & BIOMASS-TO-METHANOL PLANT

- **Belt dryer** for biomass drying.
- **Sorption-enhanced-gasification** flexibly produces a tailored syngas for the downstream synthesis, without any additional conditioning unit. By controlling the gasification temperature, the gasifier yields a syngas with module $M=(H_2-CO_2)/(CO+CO_2)$ close to 2 in baseline operation and lower than 1 in enhanced operation. In the latter condition, the syngas retains the maximum amount of carbon, to be combined with the downstream added hydrogen.
- **O_2-blown autothermal reformer** converts tar, methane and higher hydrocarbons in the syngas into useful reactants (i. e. CO and H_2).
- **Oxygen storage** allows to store intermittent O_2 from electrolysis and provide a stable flow to the reformer. The minimum capacity factor of the electrolyzer needed to produce the needed O_2 without external import or back-up ASU is 18%.
- **Boiling water methanol synthesis reactor** keeps high methanol productivity in both the operating conditions by controlling the recycle of unconverted reactants back to reactor.
- **Methanol purification** section is designed to manage the different operating mass flow rates, to avoid flooding and to guarantee the final product specification (>99% wt.) during the operation of the plant.
- **Heat recovery steam cycle** is designed by using a systematic optimization-synthesis method which takes into account the optimal heat integration of the plant.
- **Cogenerative ICE** burns the off-gas of the methanol synthesis and purification.

RESULTS OF TECHNO-ECONOMIC ANALYSIS

Performance indexes for the analysis are the biomass and H_2 to MeOH efficiency (η_{fuel}), the power to MeOH efficiency (η_{P2MeOH}) and the carbon efficiency (CE).

$$\eta_{fuel} = \frac{\dot{m}_{MeOH} \cdot LHV_{MeOH}}{\dot{m}_{biomass} \cdot LHV_{biomass} + \dot{m}_{H_2} \cdot LHV_{H_2}} \qquad \eta_{P2MeOH} = \frac{(\dot{m}_{MeOH} \cdot LHV_{MeOH}) - (\dot{m}_{MeOH} \cdot LHV_{MeOH})_{w/o\ H_2}}{E_{el}} \qquad CE = \frac{F_{C,MeOH}}{F_{C,biomass}}$$

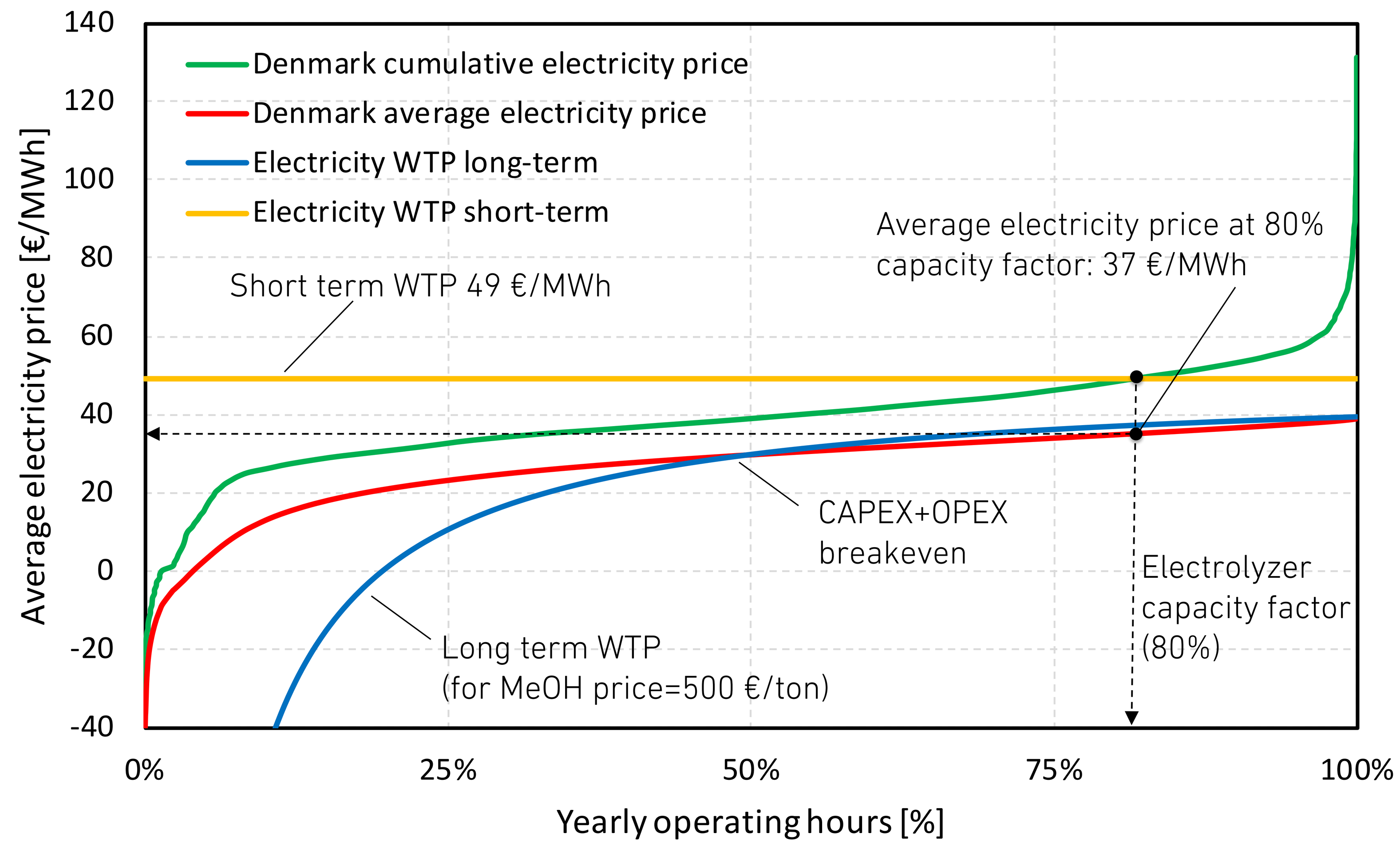
Results for a lignocellulosic biomass input of 100 MW_{LHV} (as-received, moisture 45%)

Performance indexes	Enhanced operation	Baseline operation
Gasifier temperature [°C]	771.8	714.2
M at gasifier outlet	0.71	2.24
M at reformer outlet	0.93	2.04
Electricity input to electrolyzer [MW]	68	-
Carbon yield MeOH synthesis [%]	96.3	97.9
Number of tubes MeOH synthesis reactor	7583	7583
MeOH production [kg/s]	4.97	3.12
MeOH production enhancement [%]	59.4	-
Power to MeOH efficiency [$MW_{LHV,MeOH}/MW_{el}$][(1)]	54.1	-
Biomass (and H_2) to MeOH efficiency [%]	68.8	62.0
Carbon efficiency [%]	64.4	40.3

(1) Electricity to hydrogen LHV efficiency of 64% [2]

Economic analysis (willingness to pay –WTP approach [3])

- **Cumulative electricity price** during the year (green line).
- **Average electricity price** vs. capacity factor (red line).
- **Short term willingness to pay** (yellow line). Breakeven OPEX: revenues from methanol selling = cost of electricity + cost of water.
- **Long term willingness to pay** (blue line). Maximum electricity price to breakeven the total costs: revenues from methanol selling = electrolyser CAPEX (assumed 630 €/kW [2]) + OPEX.



CONCLUSIONS

- ✓ The integration with water electrolysis allows to decrease the biogenic carbon loss during the production process, as shown by the higher carbon efficiency in the enhanced operation.
- ✓ The enhanced operation is generally more efficient than the baseline and the power to MeOH efficiency expresses the effectiveness of the integration with the electrolyzer.
- ✓ The electrolyzer will be turned on for electricity prices lower than OPEX breakeven (short term WTP, 80% h/y), also covering the investment cost (long term WTP).

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