Economic analysis of the integrated bio-methanol production and green hydrogen production process

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1. INTRODUCTION

- Increasing demand for methanol as a marine alternative fuel
- Clean methanol is less than 1% of the methanol supply ⇨ High production costs of clean methanol
- High prices and unreliable supply of renewable energy

Issue 1 **Significant energy consumption** in clean methanol production

- High energy consumption of electrolysis process for green hydrogen production
- High energy consumption due to steam reforming process of biogas

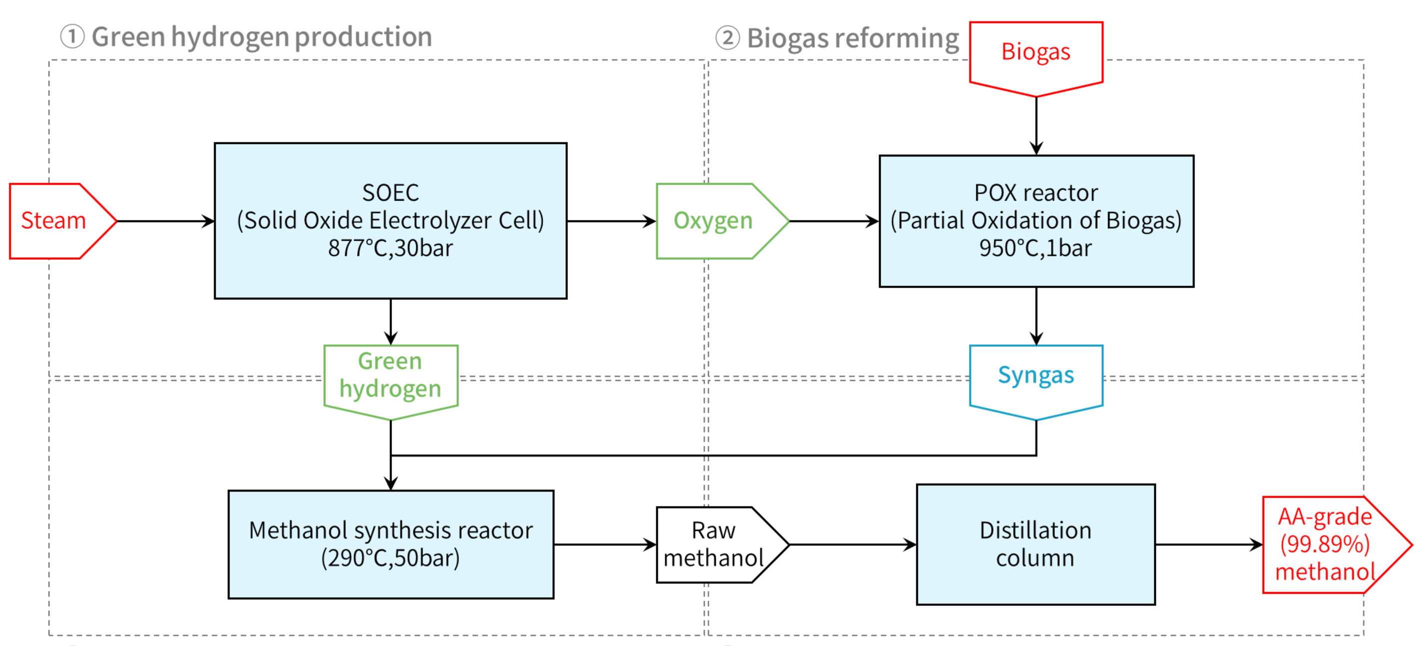
Issue 2 **High hydrogen/carbon losses** from bio-resources

- Hydrogen/carbon loss by (reverse-)Water-Gas Shift (WGS) reaction for achieving molar ratio M

$$M = \frac{H_2 - CO_2}{CO + CO_2} \qquad WGS: CO + H_2O \rightarrow CO_2 + H_2 \qquad r-WGS: CO_2 + H_2 \rightarrow CO + H_2O$$

- In this study,
  1) Direct injection of hydrogen into a methanol synthesis reactor
     ⇨ Achieving the molar ratio M conditions without additional equipment while minimizing hydrogen/carbon losses
  2) Partial oxidation for biogas reforming
     ⇨ Utilization of exothermic energy in the process
  3) Waste heat utilization for steam production
     ⇨ Reducing energy consumption in green hydrogen production processes

2. PROCESS DESCRIPTION

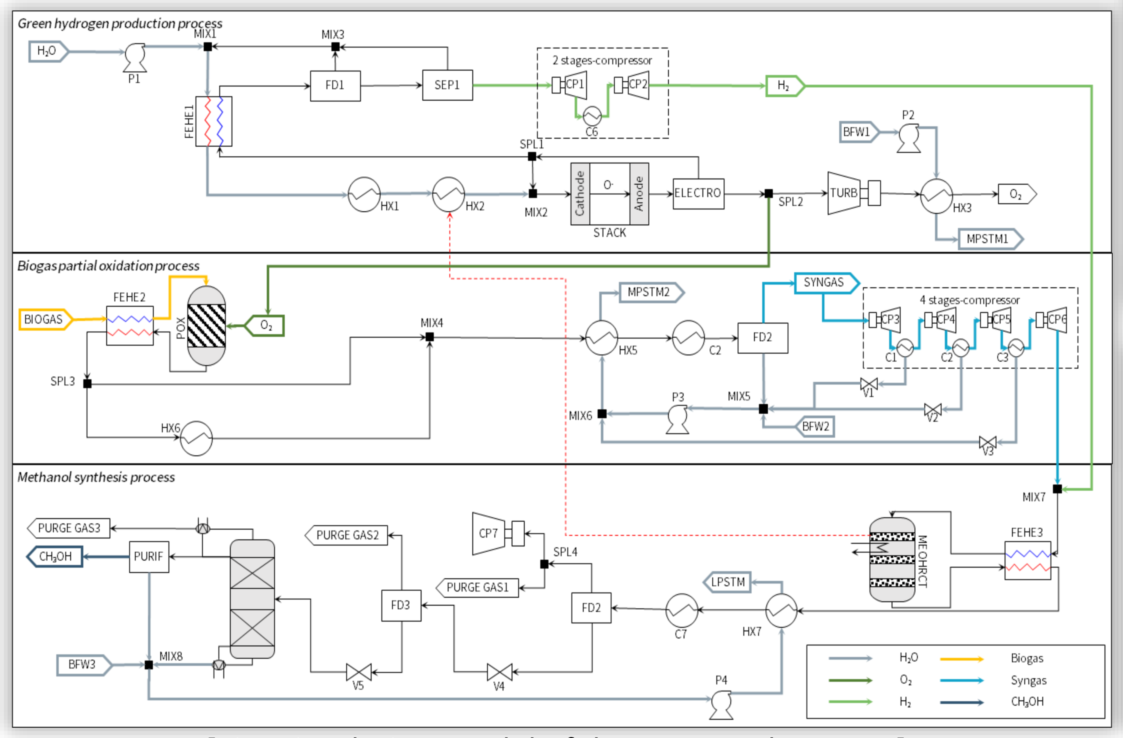


[Fig. Schematic diagram of the proposed process]

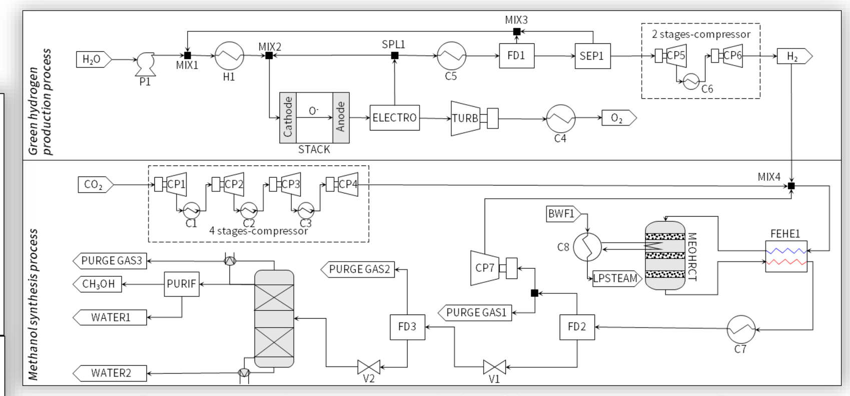
3. METHODOLOGY

3.1. Process simulation

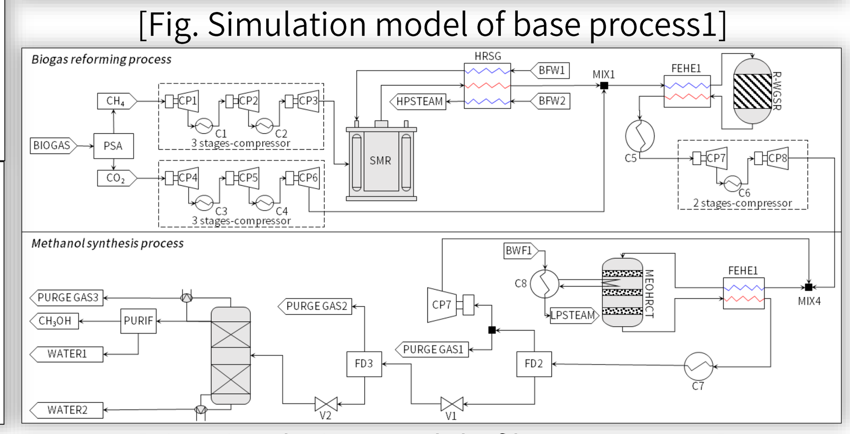
- Simulated by Aspen Plus V11
- Proposed process: methanol production via biogas partial oxidation integrated with green hydrogen production
- Base process1 (BP1): conventional e-methanol production
- Base process2 (BP2): conventional bio-methanol production



[Fig. Simulation model of the proposed process]



[Fig. Simulation model of base process1]



[Fig. Simulation model of base process2]

3.2. Methanol yield

$$\text{Carbon efficiency}^{[1]} = \frac{(F_{CH_3OH})_{out}}{(F_{CO} + F_{CO_2} + F_{CH_4})_{in}}$$

F_{CH_3OH}=Molar flow rate of methanol (kmol/hr)
$F_{CO}, F_{CO_2}, F_{CH_4}$= Molar flow rate of CO, CO_2, CH_4 (kmol/hr)

3.3. Energy efficiency

$$\text{Energy efficiency}^{[2]} = \frac{Q_{MEOH}}{Q + W}$$

Q_{MEOH}=Heat of reaction of methanol(kW)
Q = Heat consumed in the process (kW)
W = Work consumed in the process (kW)

3.4. Levelized cost of methanol (LCOM)

$$\text{LCOM}^{[3]} = \frac{CAPEX \times CRF + OPEX + C_{Carbon\ tax} - R_{revenue}}{P_{methanol}}$$

$$CRF = \frac{1}{A_{t,r}}$$

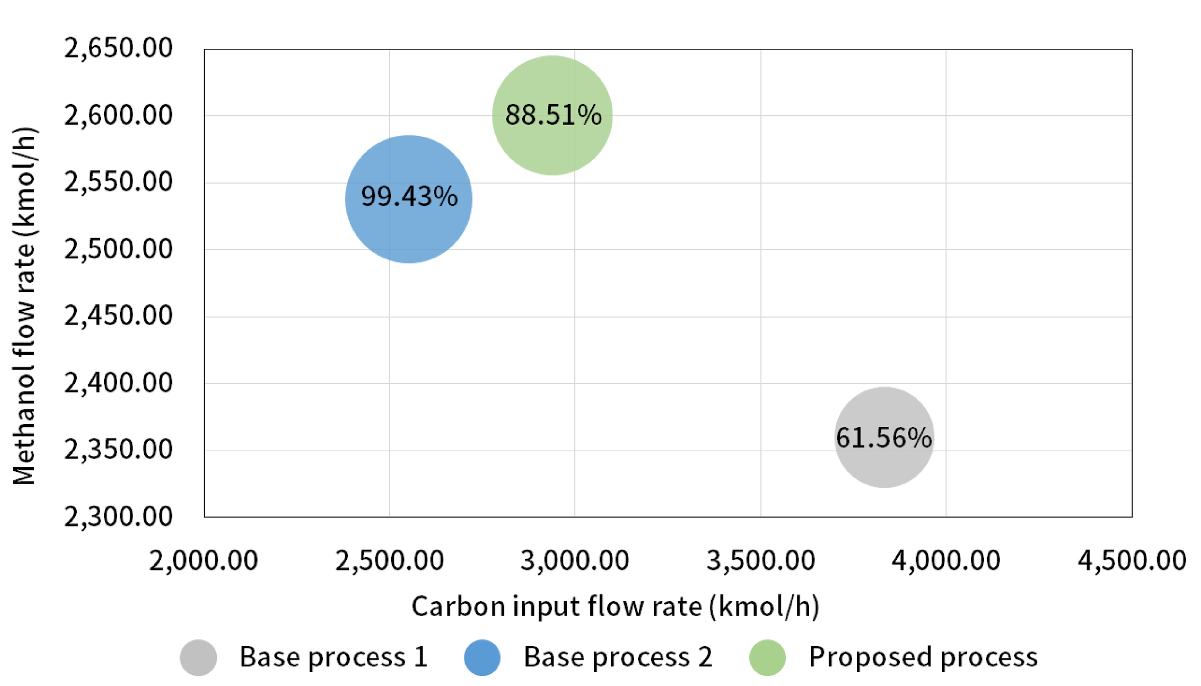
$$A_{t,r} = \frac{1 + (1+r)^{-t}}{r}$$

$LCOM$=Levelized cost of methanol (USD/tonne MEOH)
$CAPEX$ =Capital expenditures (USD/y)
$OPEX$ =Operating expenditures (USD/y)
$C_{Carbon\ tax}$ =Carbon tax of the process (USD/y)
$R_{revenue}$ =Revenue (USD/y)
CRF =Capital recovery factor
$A_{t,r}$ =Annuity factor
t =Operating times (8,322 h/y)
r =Tax rate (5%)
$P_{methanol}$ =Methanol production (tonne/y)

4. RESULTS

4.1. Methanol yield

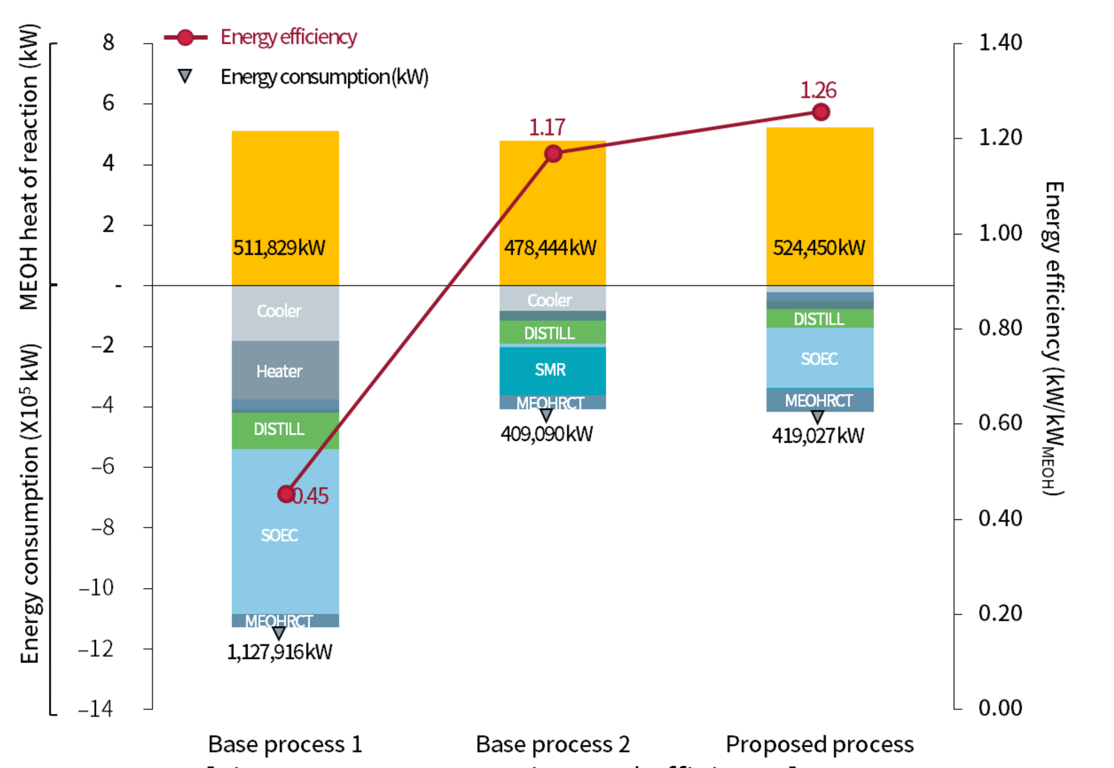
- The proposed process (PP) involves injecting hydrogen directly into a methanol synthesis reactor, reducing carbon losses and resulting in higher methanol yields compared to BP2.
- Although BP1 achieves the highest methanol yield, it is necessary to consider the high energy consumption of steam electrolysis.



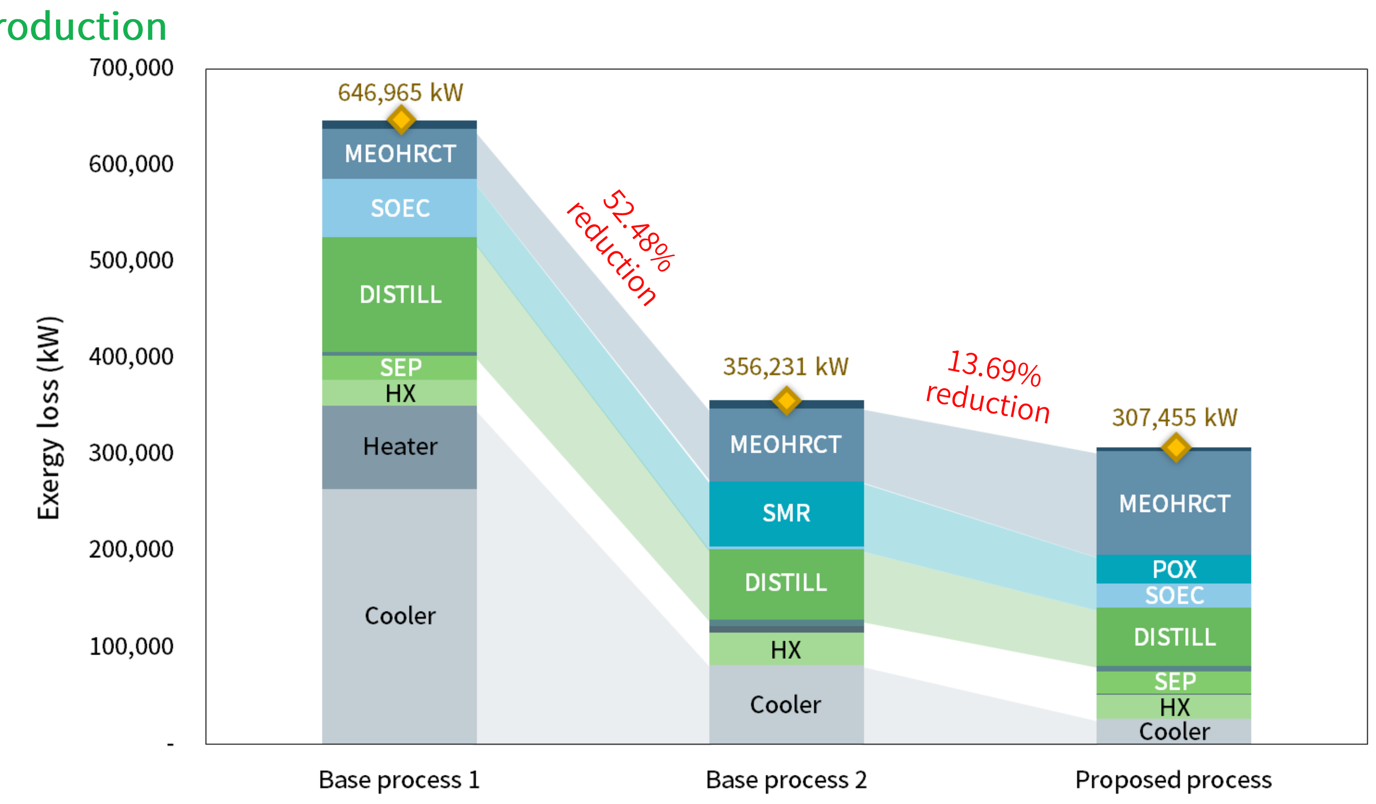
[Fig. Comparison of methanol yield of base process1, 2, and the proposed process]

4.2. Thermodynamic analysis

- The PP demonstrates the highest energy efficiency
  : By injecting hydrogen directly into a methanol synthesis reactor and meeting the methanol synthesis conditions, it achieves a 7.53% increase in energy efficiency compared to BP2 due to higher methanol yields.
- The PP significantly reduces exergy loss due to excessive driving forces in coolers and heaters
  : By utilizing waste heat to progressively heat water for steam production



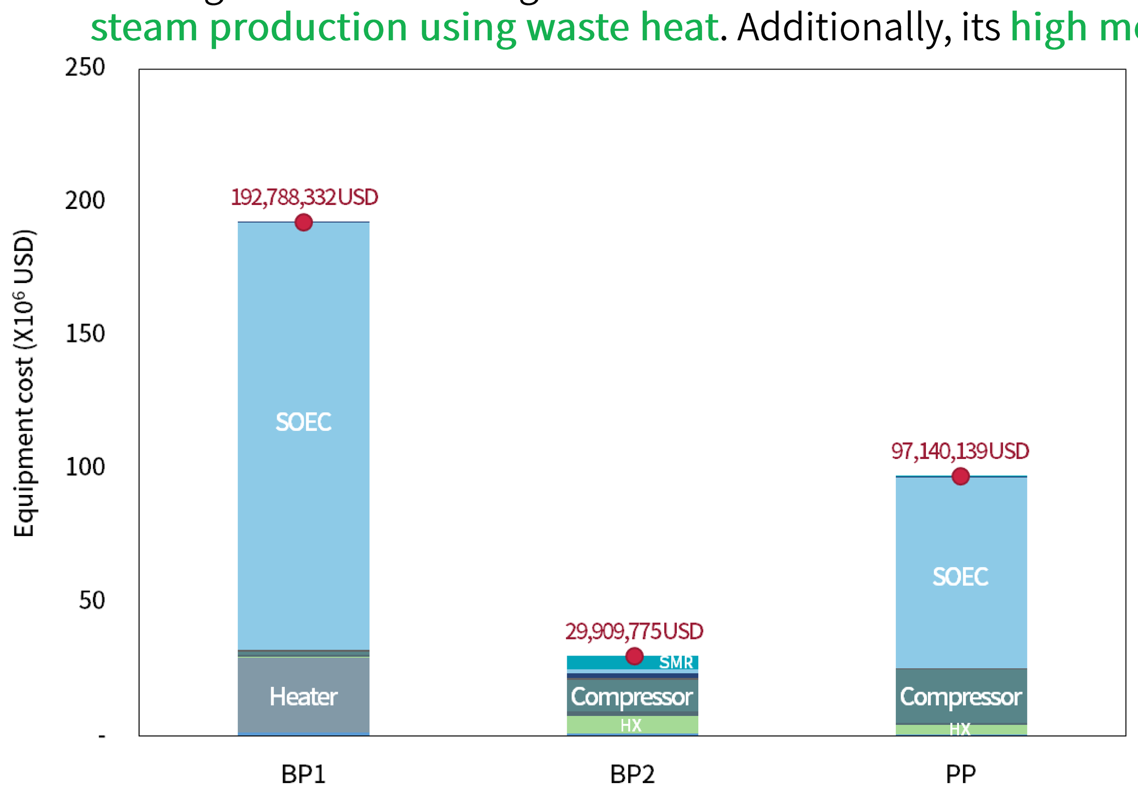
[Fig. Energy consumption and efficiency]



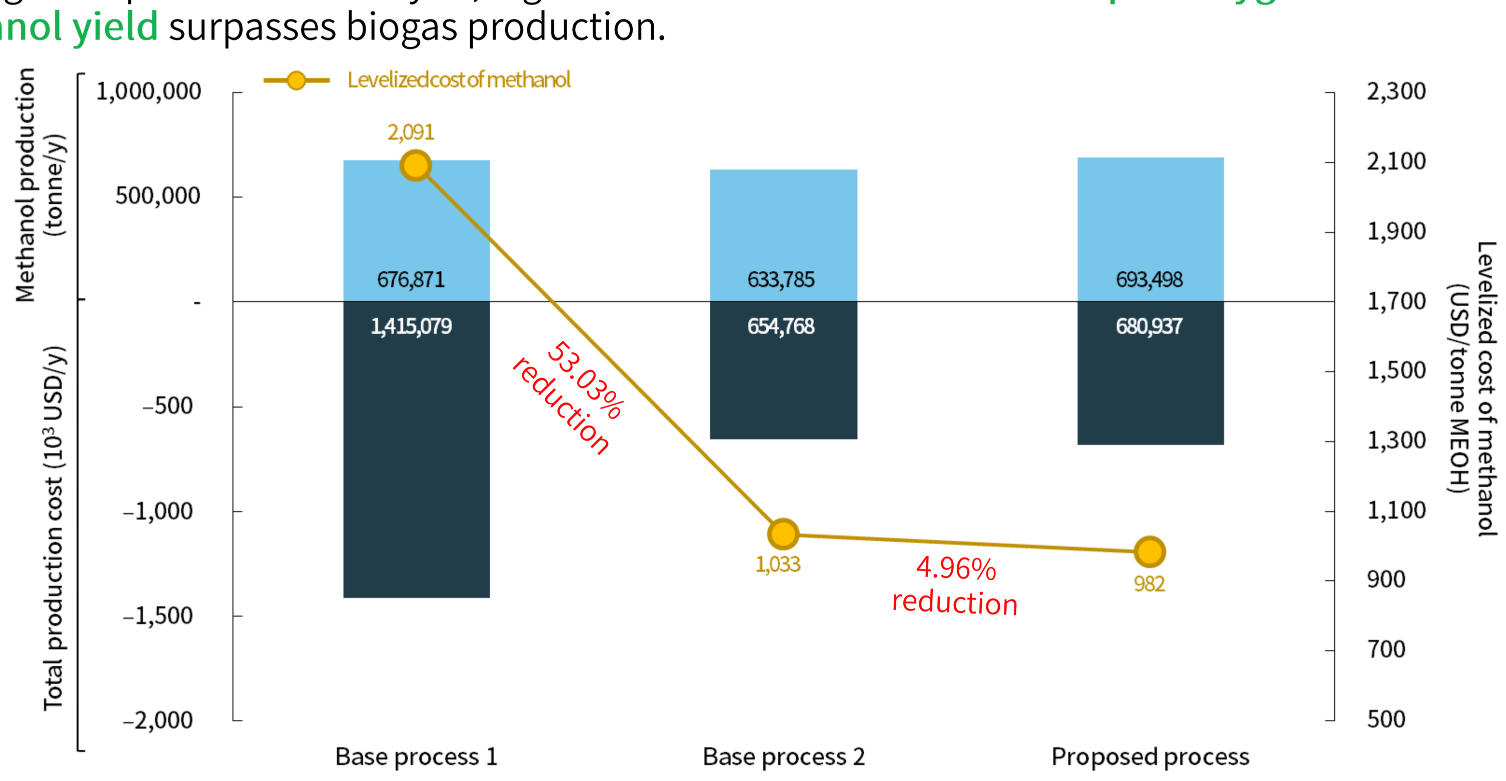
[Fig. Comparison of exergy loss for each piece of equipment]

4.3. Techno-economic analysis

- BP1 exhibits the highest total product cost: High capital and electricity costs associated with high-temperature electrolysis.
- Although the PP incurs higher CAPEX and OPEX than BP2 due to high-temperature electrolysis, it generates more revenue from surplus oxygen sales and steam production using waste heat. Additionally, its high methanol yield surpasses biogas production.



[Fig. Comparison of equipment cost]



[Fig. Comparison of levelized cost of methanol (LCOM)]

5. CONCLUSION

Integration of green hydrogen production	BP1	BP2	PP	
Methanol yield	99%	62%	89%	Methanol production maximization with minimal renewable energy supply

Steam production utilized waste energy	BP1	BP2	PP	
Energy efficiency	0.45	1.17	1.26	Electricity cost reduction by minimizing energy consumption

High methanol production via surplus oxygen & steam revenue	BP1	BP2	PP	
LCOM (USD/t)	2,091	1,033	982	Achieving lower production costs compared to conventional processes

Sustainable clean methanol production

Reference

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[2] Kim, J., Henao, C. A., Johnson, T. A., Dedrick, D. E., Miller, J. E., Stechel, E. B., & Maravelias, C. T. (2011). Methanol production from CO2 using solar-thermal energy: process development and techno-economic analysis. Energy & Environmental Science, 4(9), 3122-3132.
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