Techno-economic analysis of low-carbon hydrogen production through sorption enhanced steam methane reforming (SE-SMR) processes

Yongliang (Harry) Yan*****, Peter Clough, Vasilije Manovic

Energy and Power Theme, School of Water, Energy and Environment, Cranfield University, Cranfield, Bedfordshire, MK43 0AL, UK.

*** Yongliang (Harry) Yan Email: yongliang.yan@cranfield.ac.uk**

Introduction

- ❑ **Hydrogen**, as a versatile energy source, is widely applied in oil refining, chemical production, and iron and steel production, and has also drawn significant attention to tackle various critical energy challenges
- ❑ **Steam Methane Reforming (SMR)** is the dominant and commercial technology used for decades for hydrogen production, which is also a large emitter of CO_2- around 2.6% of the global CO_2 emissions in 2019.
- ❑ **Sorption Enhanced Steam Reforming (SE-SMR)** is an innovative technology to use the pre-combustion CO_2 capture to produce the decarbonised, high purity H_2.
- ❑ **Techno-economic analysis** of six different SE-SMR configurations has been conducted to evaluate their potential in low-carbon and carbon-negative hydrogen production.

Methodology

Proposed SE-SMR configurations

Case 1A: SE-SMR with indirect air-natural gas combustion calciner

Case 1B: SE-SMR with indirect air-biomass combustion calciner

Case 2A: SE-SMR with indirect oxy-natural gas combustion calciner

Case 2B: SE-SMR with indirect oxy-biomass combustion calciner

Case 3A: SE-SMR with indirect chemical-looping combustion of natural gas calciner

Case 3B: SE-SMR with indirect chemical-looping combustion of biomass calciner

Model development

- ➢The process modelling and mass-energy balance calculations used for the techno-economic analysis were performed by Aspen Plus V10.
- ➢A chemical plant cost estimation methodology developed by Sinnott et al. [1] for calculating the capital and operating costs is employed.

Performance evaluation

Cold gas efficiency: $\eta_{CG} = \left(\frac{\dot{m}_{H_2,product} * LHV_{H_2}}{\dot{m}_{NG,feed} * LHV_{NG} + \dot{m}_{NG/Biomass,additional} * LHV_{NG/Biomass}}\right) * 100\%$

Net efficiency: $\eta_{net} = \left(\frac{\dot{m}_{H_2,product} * LHV_{H_2}}{(\dot{m}_{NG,feed} + \dot{m}_{NG/Biomass,additional}) * LHV_{CH_4} + \frac{P_e}{\eta_{elect}}}\right) * 100\%$

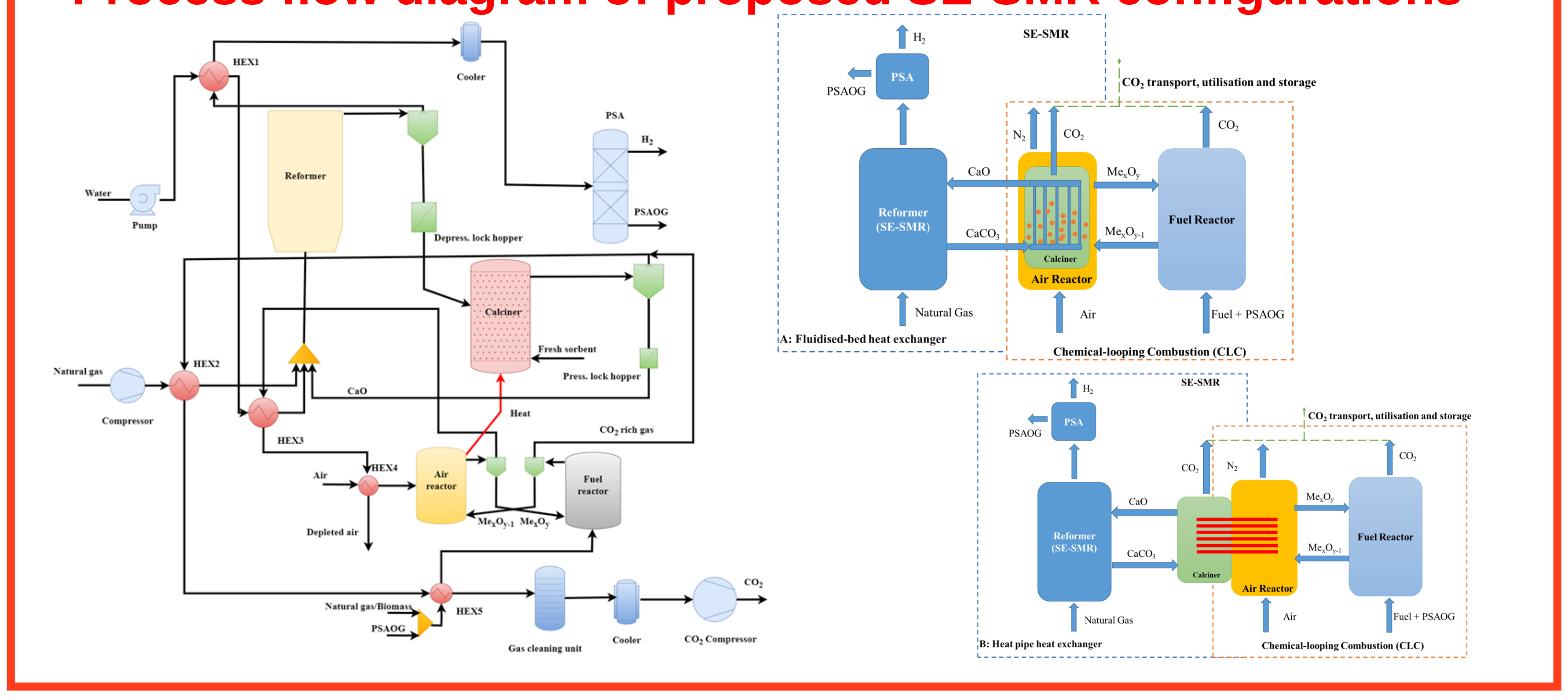
CO_2 capture efficiency: $CO_2\ capture\ efficiency = \left(\frac{n_{CO_2,captured}}{n_{NG,feed} + n_{NG/Biomass,additional}}\right) * 100\%$

Levelised cost of hydrogen: $LCOH = \frac{(TOC * FCF + FOM)}{(CF * 8760)} + (FC * HR) + VOM$

Cost of CO_2 avoided: $CCA = \frac{LCOH_{SE-SMR} - LCOH_{Non\ CCS}}{CO_2\ Emissions_{Non\ CCS} - CO_2\ Emissions_{SE-SMR}}$

Cost of CO_2 removal: $CCR = \frac{LCOH_{SE-SMR} - LCOH_{Non\ CCS}}{CO_2\ Removed_{SE-SMR}}$

Process flow diagram of proposed SE-SMR configurations



Results

Key performance indicators (KPIs)	Case 1A	Case 1B	Case 2A	Case 2B	Case 3A	Case 3B
Net efficiency (%)	77.0	70.5	73.7	66.3	74.1	69.4
CO_2 capture efficiency (%)	60.1	86.1	100.0	100.0	100.0	99.7
Capital costs (£m)	188.7	193.5	248.4	293.0	264.9	284.9
Operating costs (£m)	237.5	252.9	286.0	329.8	277.5	299.0
LCOH (£/kg H_2)	1.90	2.15	2.30	2.80	2.26	2.53
CCA (£/tCO_2)	33.0	45.7	57.3	68.6	54.4	52.9
CCR (£/tCO_2)	57.7	96.9	80.0	106.5	72.7	81.9

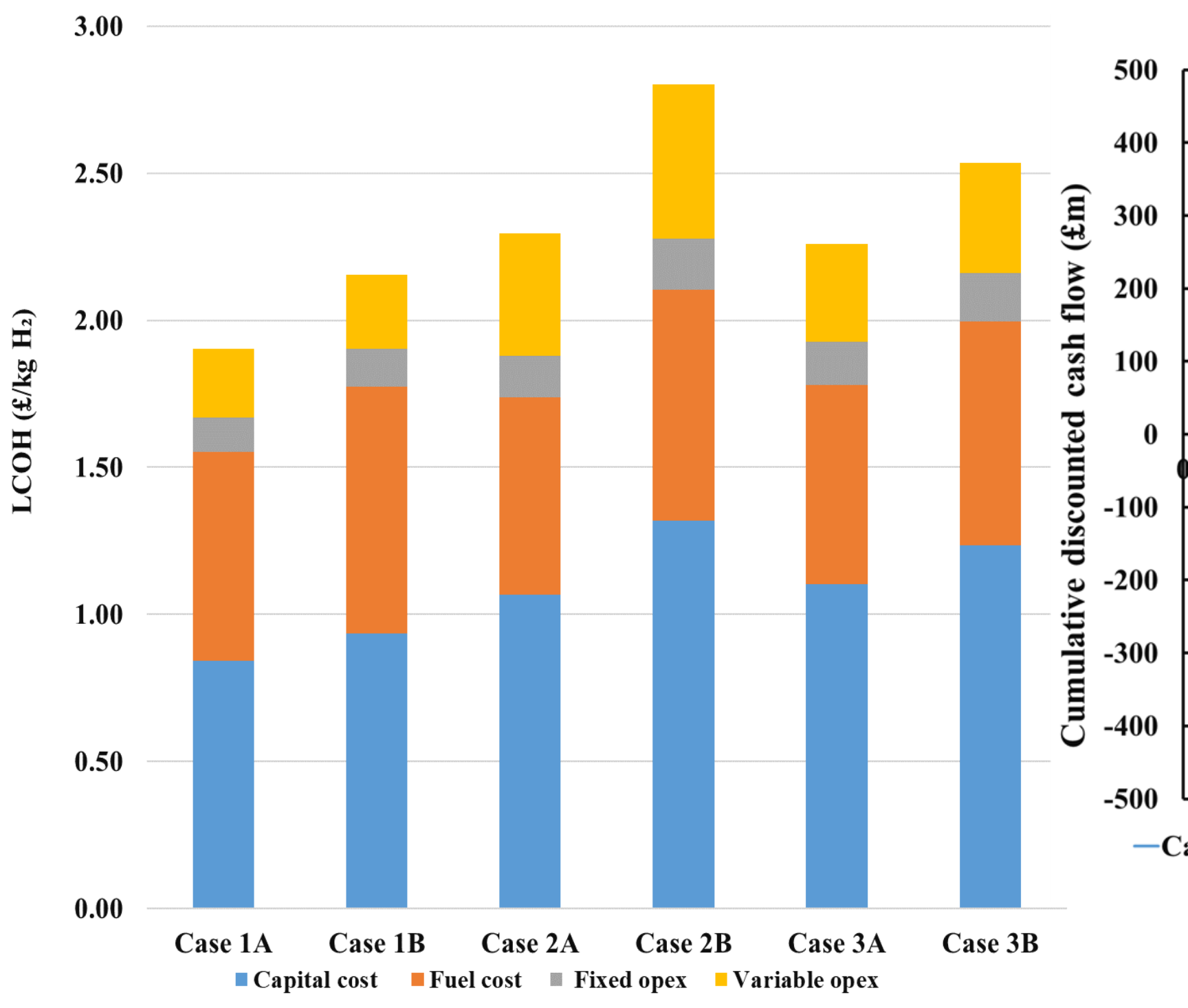


Fig. 1 Distribution of different costs of levelised cost of hydrogen for different SE-SMR processes.

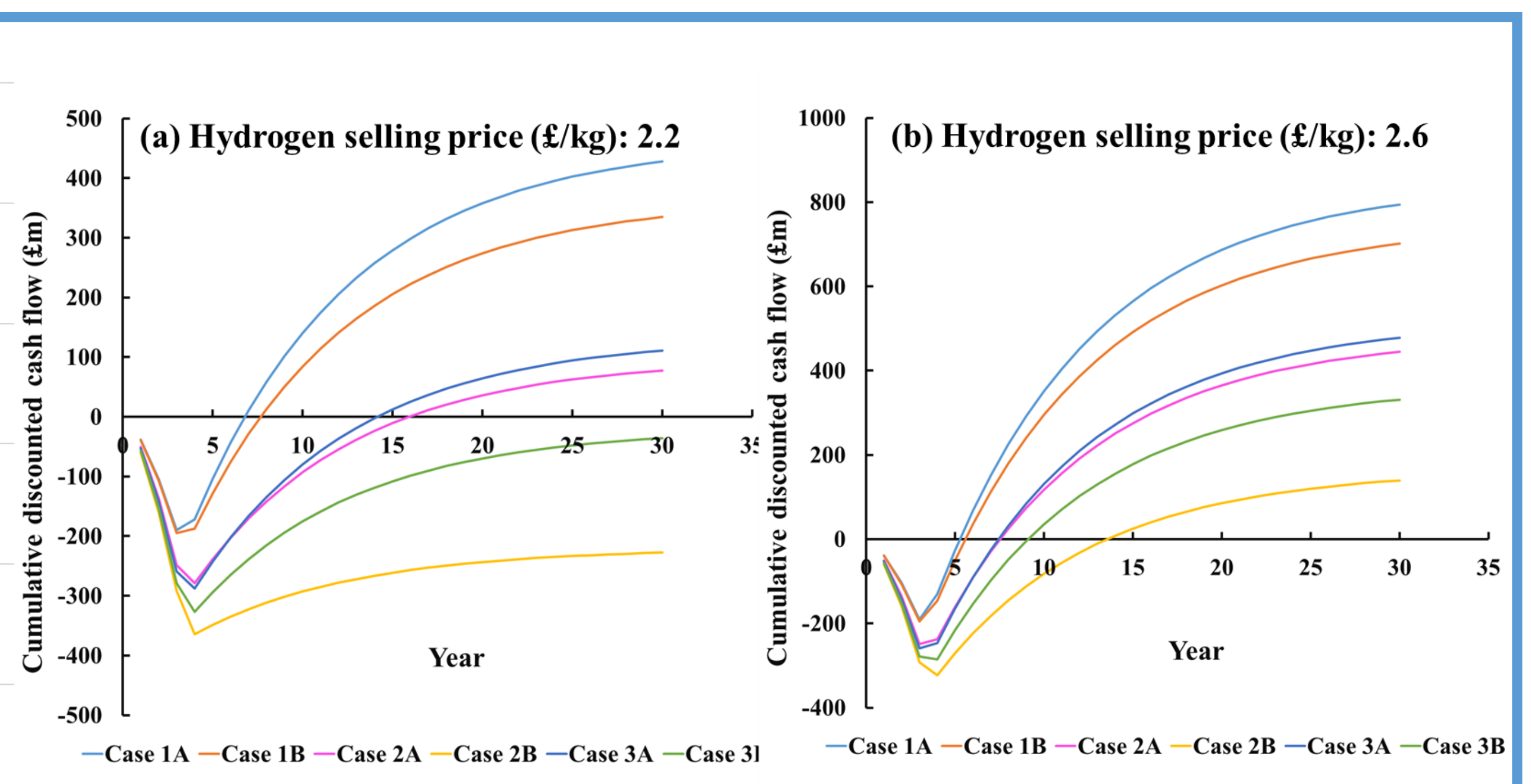


Fig. 2 Cumulative discounted cash flow of SE-SMR plants under different hydrogen selling price

Conclusions

- ❑ The results revealed that the proposed systems were comparable with conventional steam methane reforming (SMR) with carbon capture and storage (CCS).
- ❑ The LCOH of the proposed SE-SMR plants ranged from £1.90-2.80/kg, and the costs of CO_2 avoided ranged from £33-69/tonne.
- ❑ By applying a carbon price (£16/tonne CO_2), the costs of CO_2 avoided for the proposed SE-SMR processes could be significantly reduced.
- ❑ The results provide flexible options for blue and carbon-negative H_2 production.

References: [1] R. K. Sinnott, J. M. Coulson JFR. Coulson and Richardson's Chemical Engineering Volume 6 - Chemical Engineering Design (4th Edition). 2005. doi:10.1016/b978-0-08-041865-0.50014-3. [2] Y. Yan, D. Thanganadar, P.T. Clough, S. Mukherjee, K. Patchigolla, V. Manovic, E.J. Anthony, Process simulation of blue hydrogen production by upgraded sorption enhanced steam methane reforming (SE-SMR) processes, Energy Convers. Manag. 2 (2020) 1–36. [3] Y. Yan, P.T. Clough, V. Manovic, E.J. Anthony, Techno-economic analysis of low-carbon hydrogen production by sorption enhanced steam methane reforming (SE-SMR) processes