VSB TECHNICAL UNIVERSITY OF OSTRAVA | ENERGY AND ENVIRONMENTAL TECHNOLOGY CENTRE | ENERGY RESEARCH CENTRE

Membrane separation of hydrogen applied on various industrial gases

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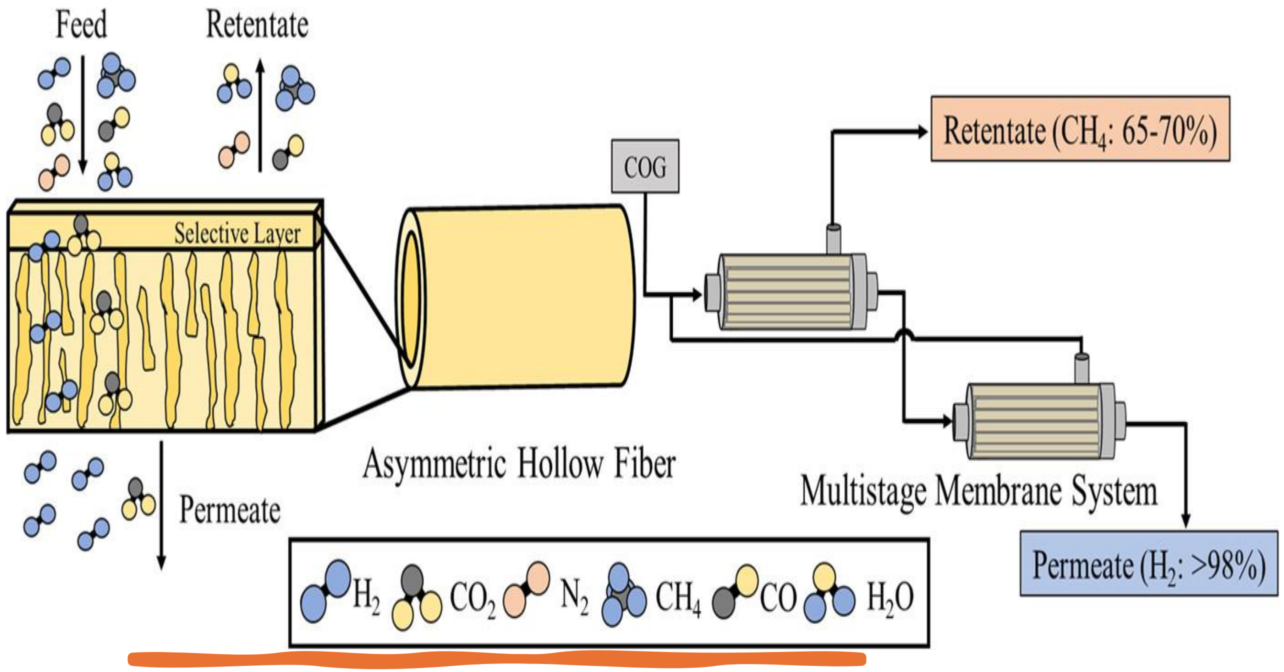
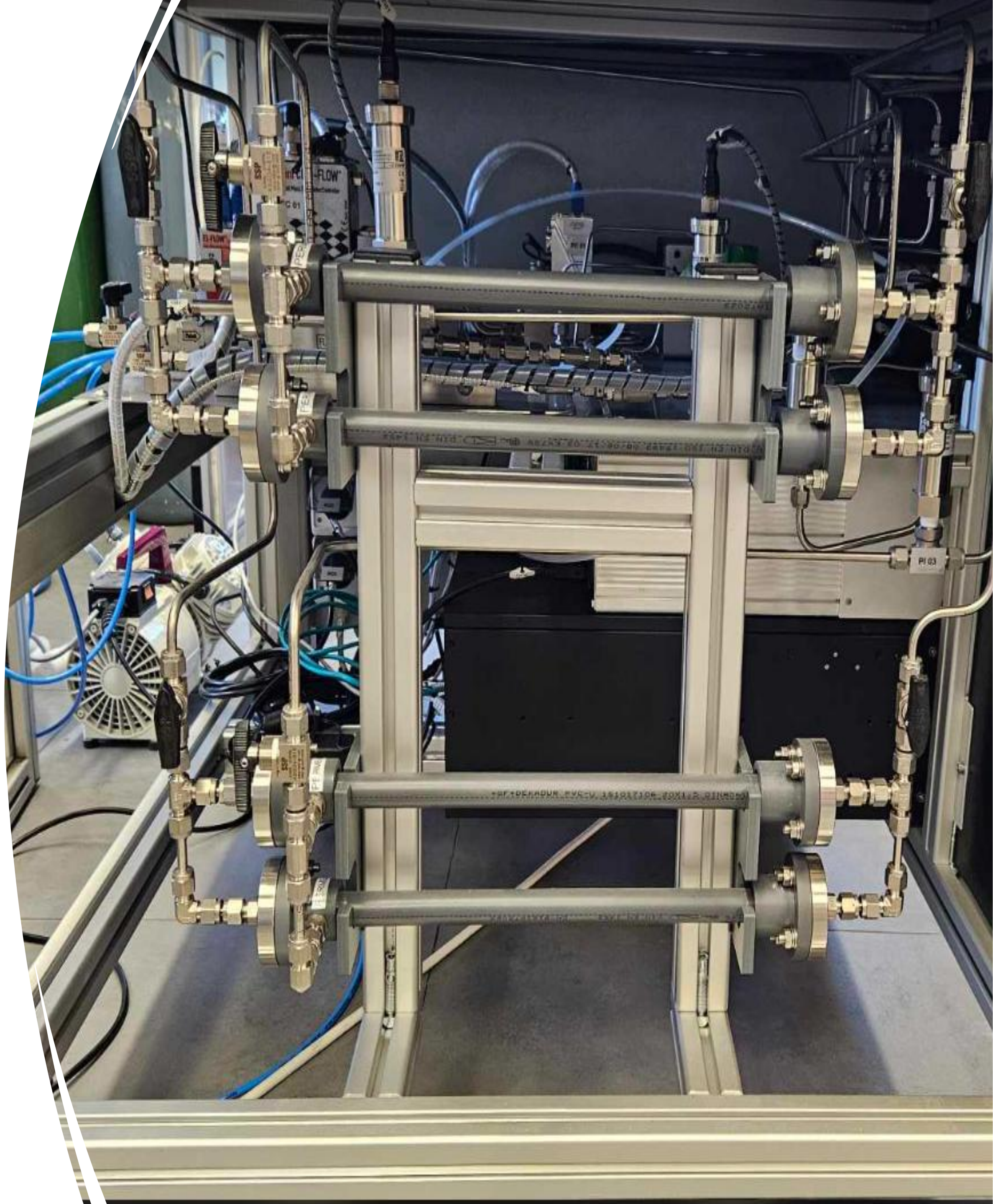
Energy Research Centre

Aim of the study

Evaluate	Study	Assess	Provide
Evaluate membrane separation of H_2 from syngas (H_2–CO–CO_2)	Study effects of pressure, flowrate, and gas composition	Assess key performance metrics: purity, recovery, selectivity, stage cut	Provide insights for industrial hydrogen recovery and purification operations.

Schematics of the membrane separator





Overview of the study

- **Feedstock:** Hydrogen is usually produced in mixtures with CO and CO_2 → requires purification for clean use.
- **Simulation:** A synthetic gas mixture of H_2, CO, and CO_2 with known compositions.
- **Process:** Separation carried out using a **single-stage** gas membrane unit at different pressures and flowrates.
- **Measurements:** Gas composition analyzed in feed and permeate streams using GC.
- **Key Analysis:** Calculated hydrogen purity, recovery, selectivity, and stage cut for each run using Jupyter Notebook (python).
- **Relevance:** This study provides insight into membrane transport mechanisms and offers a practical demonstration of the potential of membrane separation processes for efficient and scalable hydrogen purification and recovery in industry.

Process of Separation

- Controlled flowrate of (50–180 L/h) and Pressure (2–8 bar).

Driving force: pressure difference → H_2 molecules permeate faster due to:

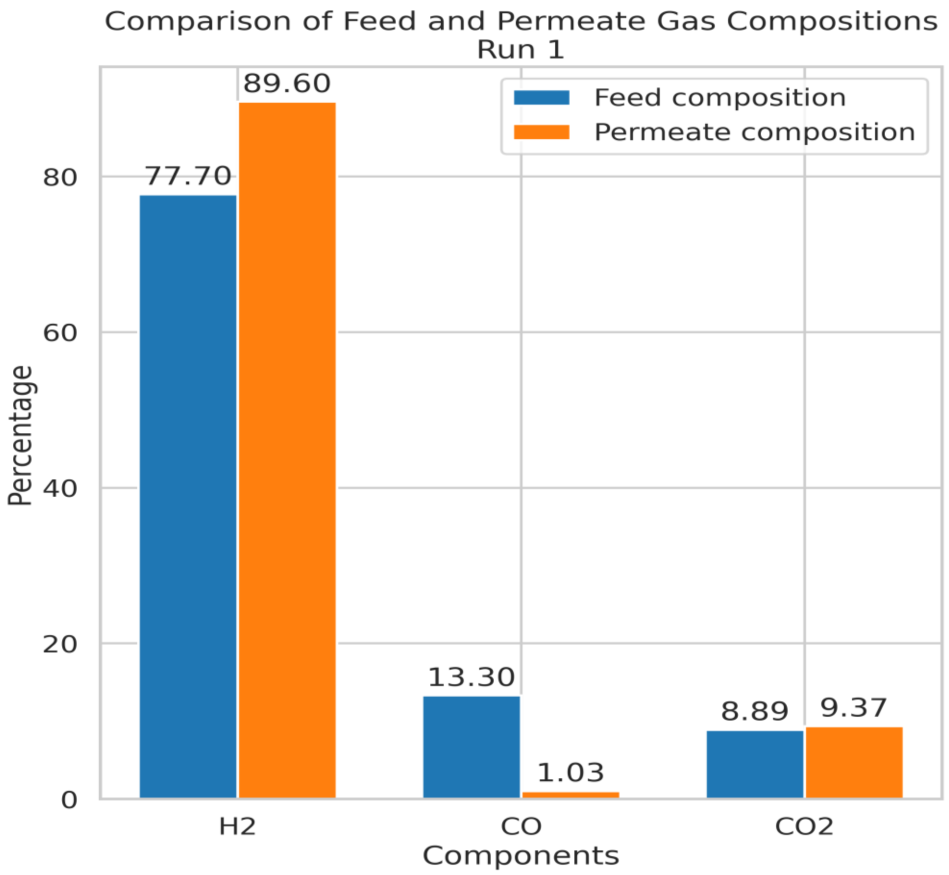
  - Lower molecular weight
  - Smaller kinetic diameter (~0.29 nm)

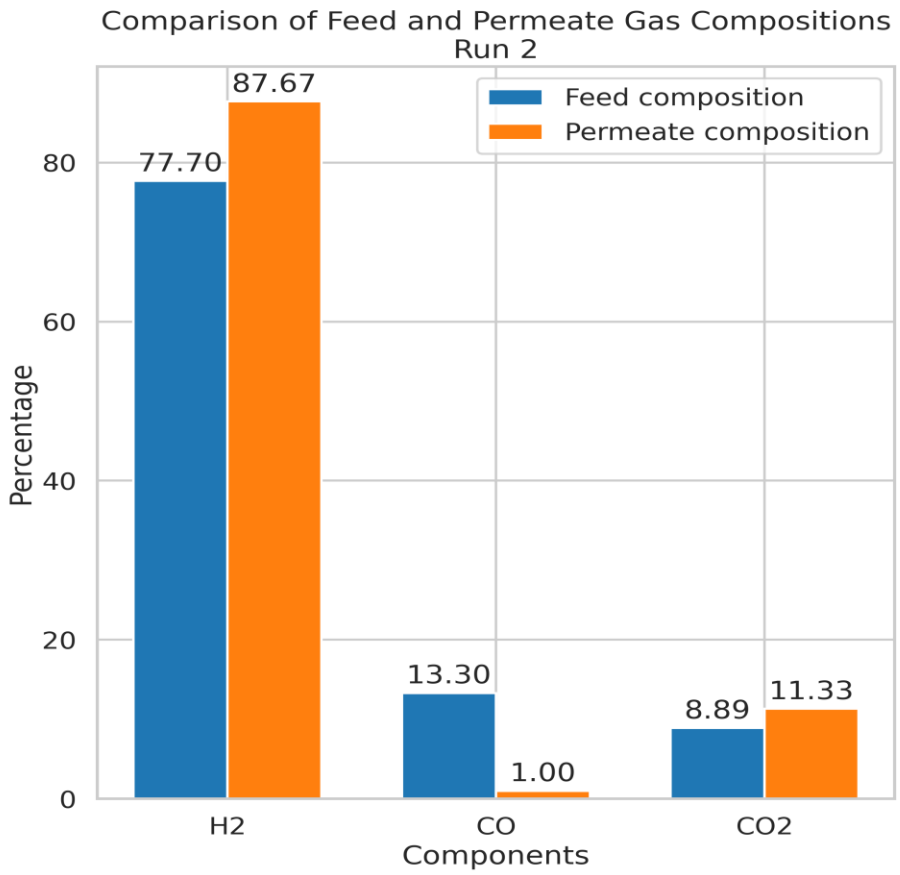
- Permeate gas enriched in H_2, while CO (3.74 nm) and CO_2 (3.33 nm) are retained in the retentate.
- Output streams analyzed using gas chromatography (GC) to determine composition.

Feed composition Range

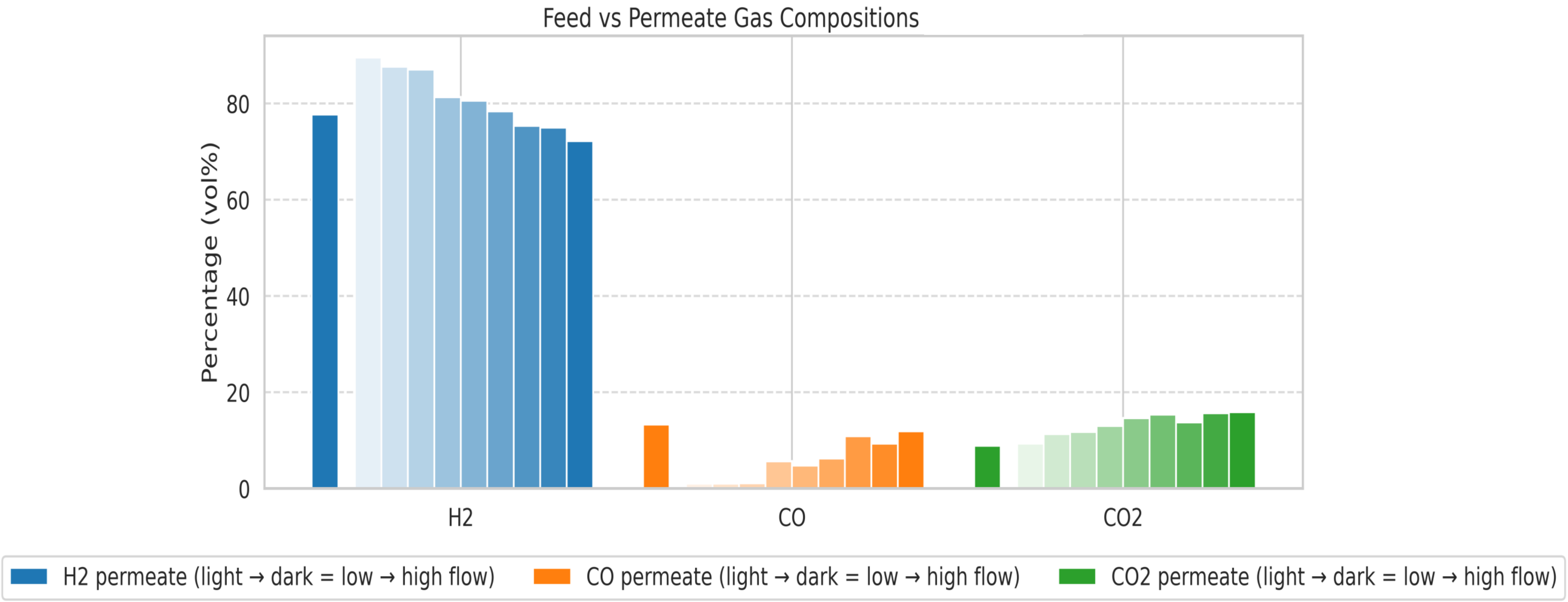
- **H_2: ~55–60%**
- **CO: ~20–25%**
- **CO_2: ~15–20%**

Results

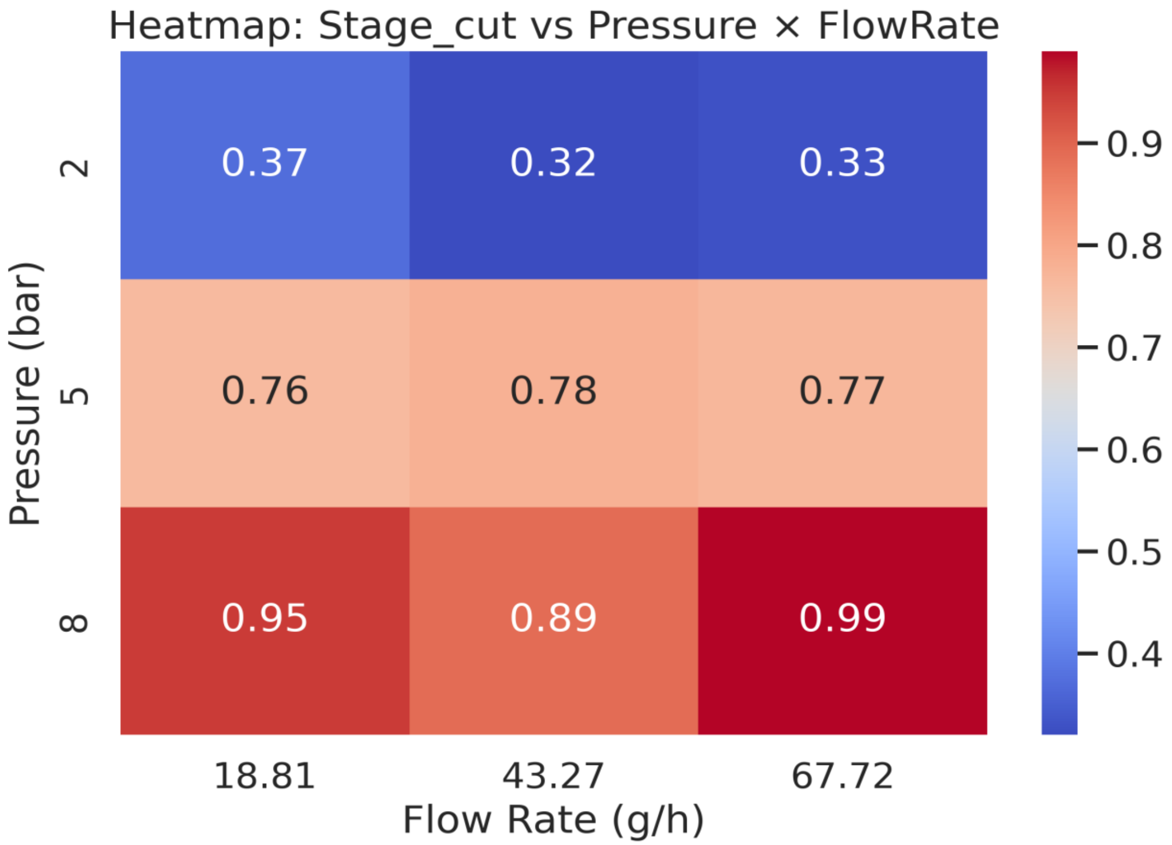

Comparison of Feed and Permeate Gas Compositions
Run 1
Feed composition
Permeate composition
77.70
89.60
13.30
1.03
8.89
9.37
Percentage
0
20
40
60
80
H2
CO
CO2
Components

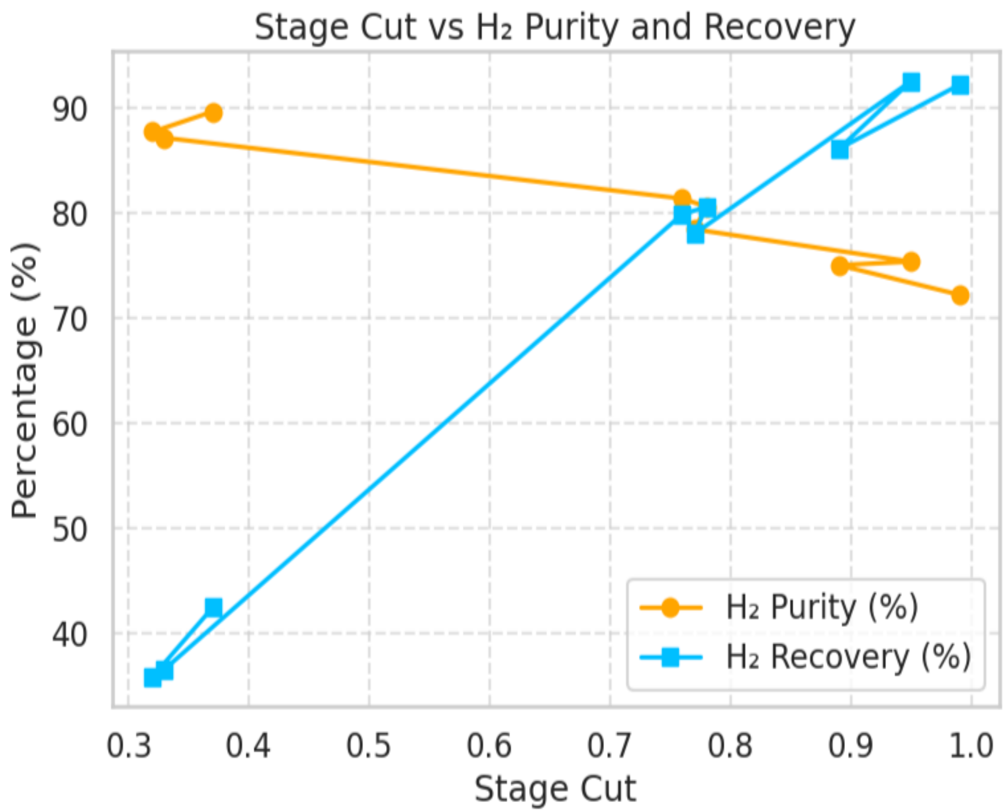

Comparison of Feed and Permeate Gas Compositions
Run 2
Feed composition
Permeate composition
77.70
87.67
13.30
1.00
8.89
11.33
Percentage
0
20
40
60
80
H2
CO
CO2
Components

Results

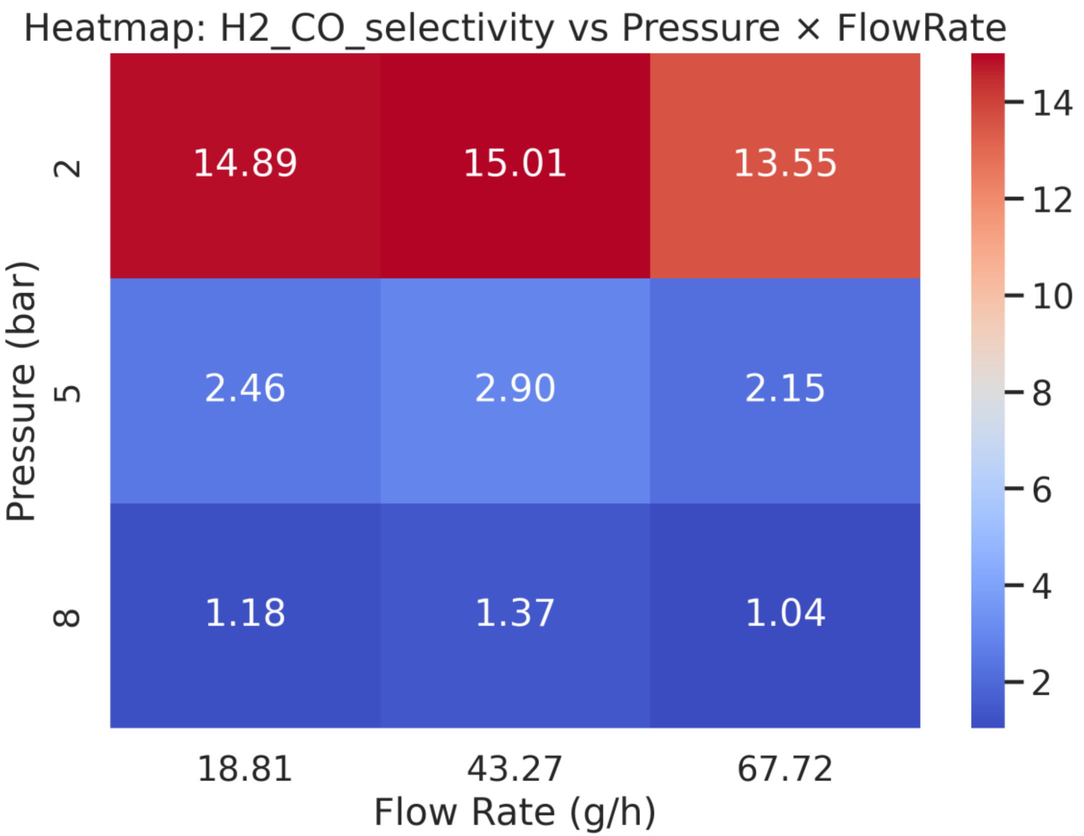

Feed vs Permeate Gas Compositions
Percentage (vol%)
0
20
40
60
80
H2
CO
CO2
H2 permeate (light → dark = low → high flow)
CO permeate (light → dark = low → high flow)
CO2 permeate (light → dark = low → high flow)

Results

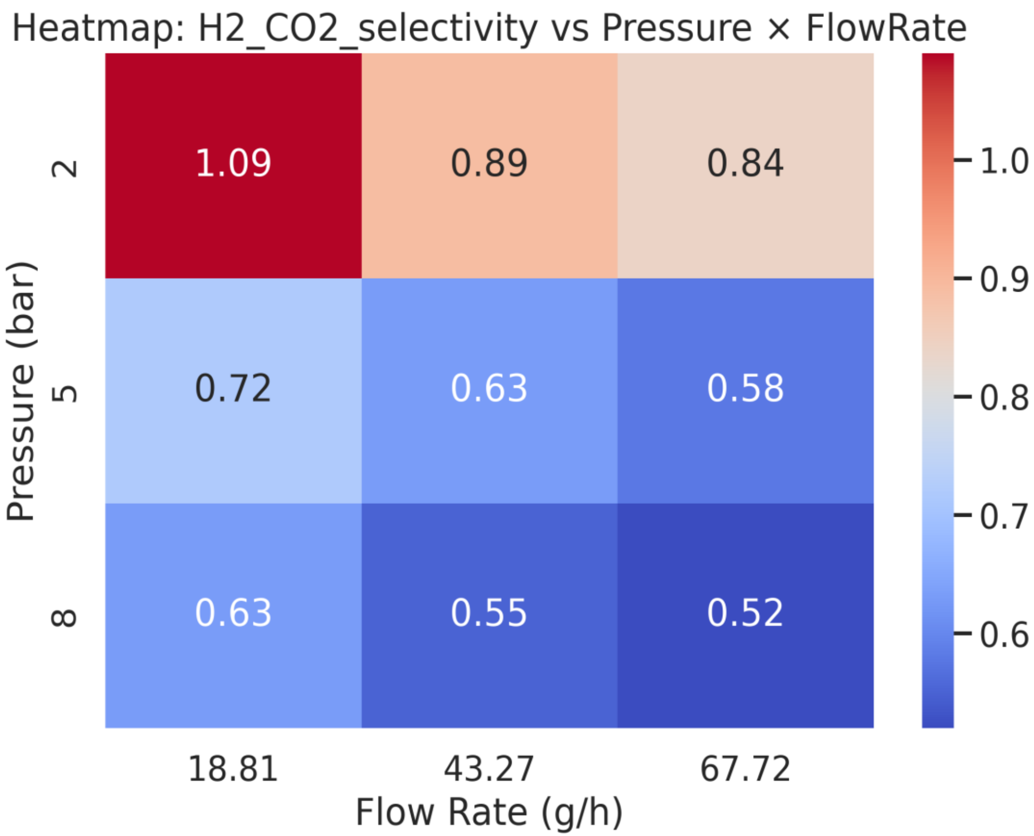

Heatmap: Stage_cut vs Pressure × FlowRate
Pressure (bar)
2
5
8
0.37
0.32
0.33
0.76
0.78
0.77
0.95
0.89
0.99
18.81
43.27
67.72
Flow Rate (g/h)
0.9
0.8
0.7
0.6
0.5
0.4


Stage Cut vs H₂ Purity and Recovery
Percentage (%)
90
80
70
60
50
40
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Stage Cut
H₂ Purity (%)
H₂ Recovery (%)

Results

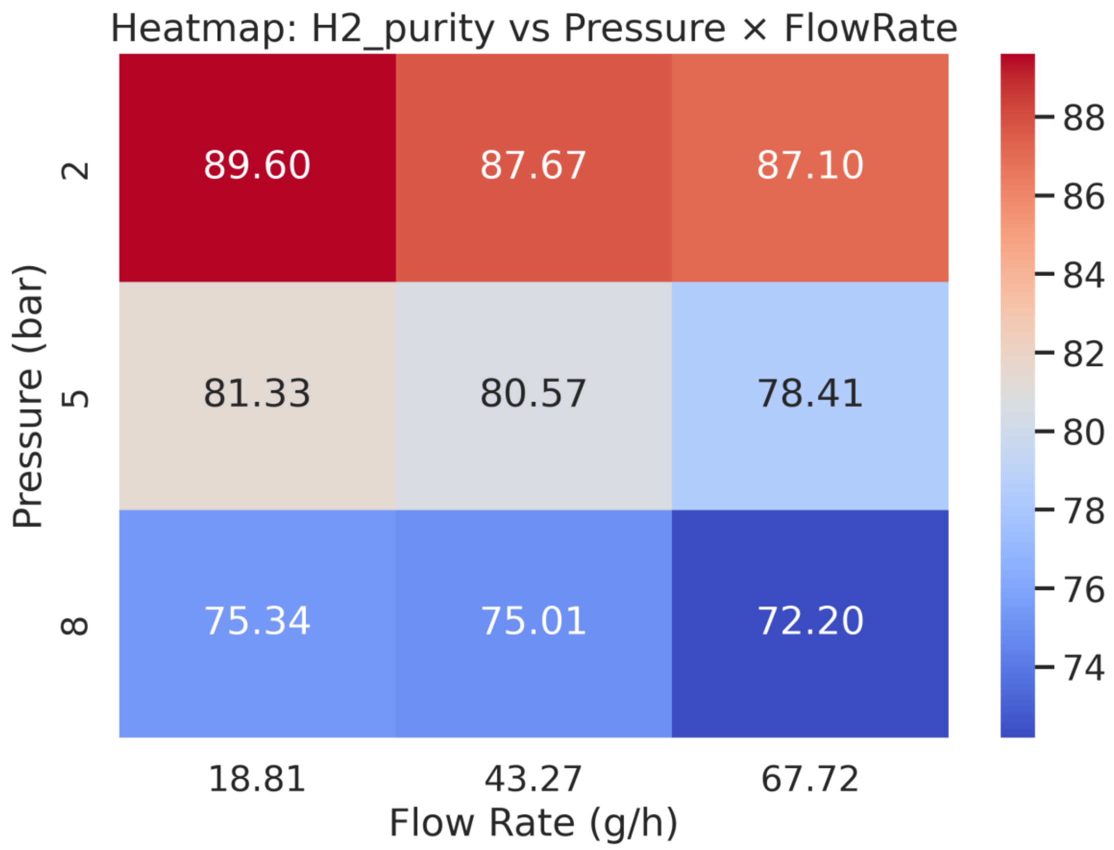


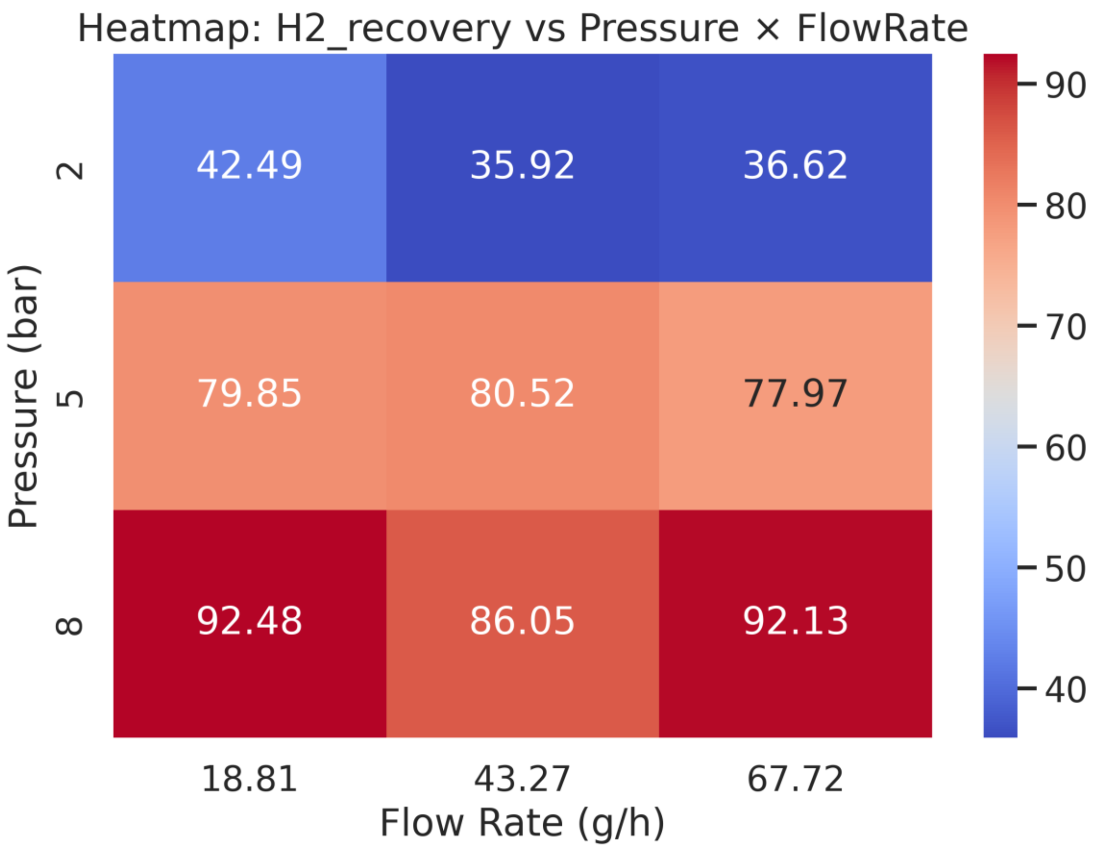
Heatmap: H2_CO_selectivity vs Pressure × FlowRate
Pressure (bar)
2
5
8
14.89
15.01
13.55
2.46
2.90
2.15
1.18
1.37
1.04
14
12
10
8
6
4
2
18.81
43.27
67.72
Flow Rate (g/h)



Heatmap: H2_CO2_selectivity vs Pressure × FlowRate
Pressure (bar)
2
5
8
1.09
0.89
0.84
0.72
0.63
0.58
0.63
0.55
0.52
1.0
0.9
0.8
0.7
0.6
18.81
43.27
67.72
Flow Rate (g/h)

Results


Heatmap: H2_purity vs Pressure × FlowRate
Pressure (bar)
2
5
8
89.60
87.67
87.10
81.33
80.57
78.41
75.34
75.01
72.20
88
86
84
82
80
78
76
74
18.81
43.27
67.72
Flow Rate (g/h)


Heatmap: H2_recovery vs Pressure × FlowRate
Pressure (bar)
2
5
8
42.49
35.92
36.62
79.85
80.52
77.97
92.48
86.05
92.13
90
80
70
60
50
40
18.81
43.27
67.72
Flow Rate (g/h)

Results

Feedstock	Pressure (bar(a))	Flow Rate Regime (l/h)	H_2 recovery %	H_2_CO_ selectivity	H_2_CO_2_ selectivity	Stage-cut	Hydrogen purity
Natural Gas	2	50	42.48	14.89	1.094	0.36	89.60
Natural Gas	2	115	35.92	15.00	0.88	0.31	87.67
Natural Gas	2	180	36.61	13.55	0.84	0.32	87.10
Natural Gas	5	50	79.85	2.45	0.71	0.76	81.33
Natural Gas	5	115	80.51	2.89	0.62	0.77	80.57
Natural Gas	5	180	77.96	2.15	0.58	0.77	78.41
Natural Gas	8	50	92.47	1.18	0.62	0.95	75.34
Natural Gas	8	115	86.05	1.37	0.54	0.89	75.01
Natural Gas	8	180	92.12	1.03	0.51	0.99	72.20

Key Findings on Gas Separation Performance

H_2 separation performance:

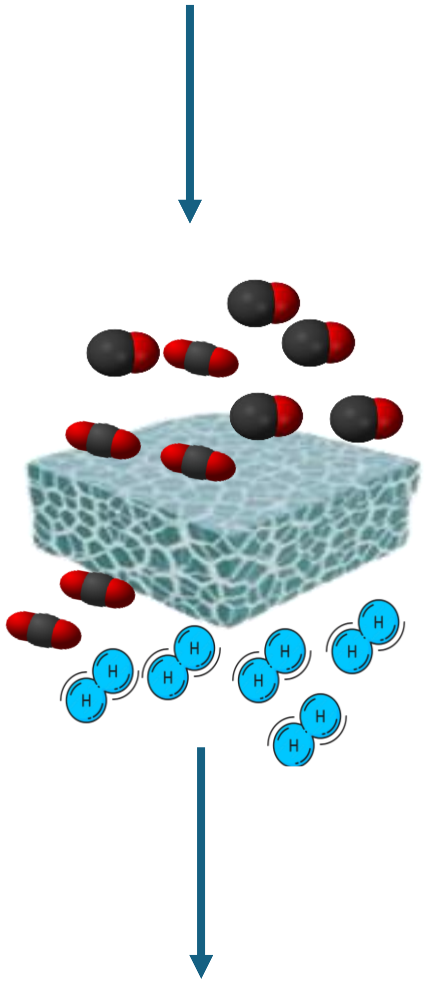
- High purity (up to ~90%) at low pressures and flow rates.
- Purity decreases at higher pressures and stage cuts.

Competition from CO and CO_2 against H_2:

- Partial pressure increase at high pressure drives CO and CO_2 permeation.
- CO_2 shows higher solubility in the membrane → stronger competition.
- At high stage cuts, separation factor decreases → permeate resembles feed.

Overall trade-off:

- Low stage cut → high purity, low recovery.
- High stage cut → high recovery, lower purity.



Implications and Conclusion

H_2 › CO_2 › CO permeation

- Lower pressure and flowrates enhance hydrogen selectivity, while higher operating conditions increase overall throughput and reduce hydrogen purity.
- Operating conditions must be optimized depending on the application: if purity of hydrogen is highly required **(fuel cells)**, we operate at low stage cut: if high recovery **(industrial processes)** is priority, we push towards higher stage cuts at the expense of purity.

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Thank You for Listening

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