TEAM M119

Carbon Capture and Recycling Reactor: Converting CO_2 into Synthetic Methane through Thermocatalysis

Anas Al Zaid (CHE), Mohammed Ahmed (CHE), Ahmed Sagheir (CHE),
Feras Albeesh (ME), Saud Alshehri (ISE), Abdulrahman Askndar (ISE)
Coach: Dr. Omar Eldalgamouny

ME ISE 3 CHE

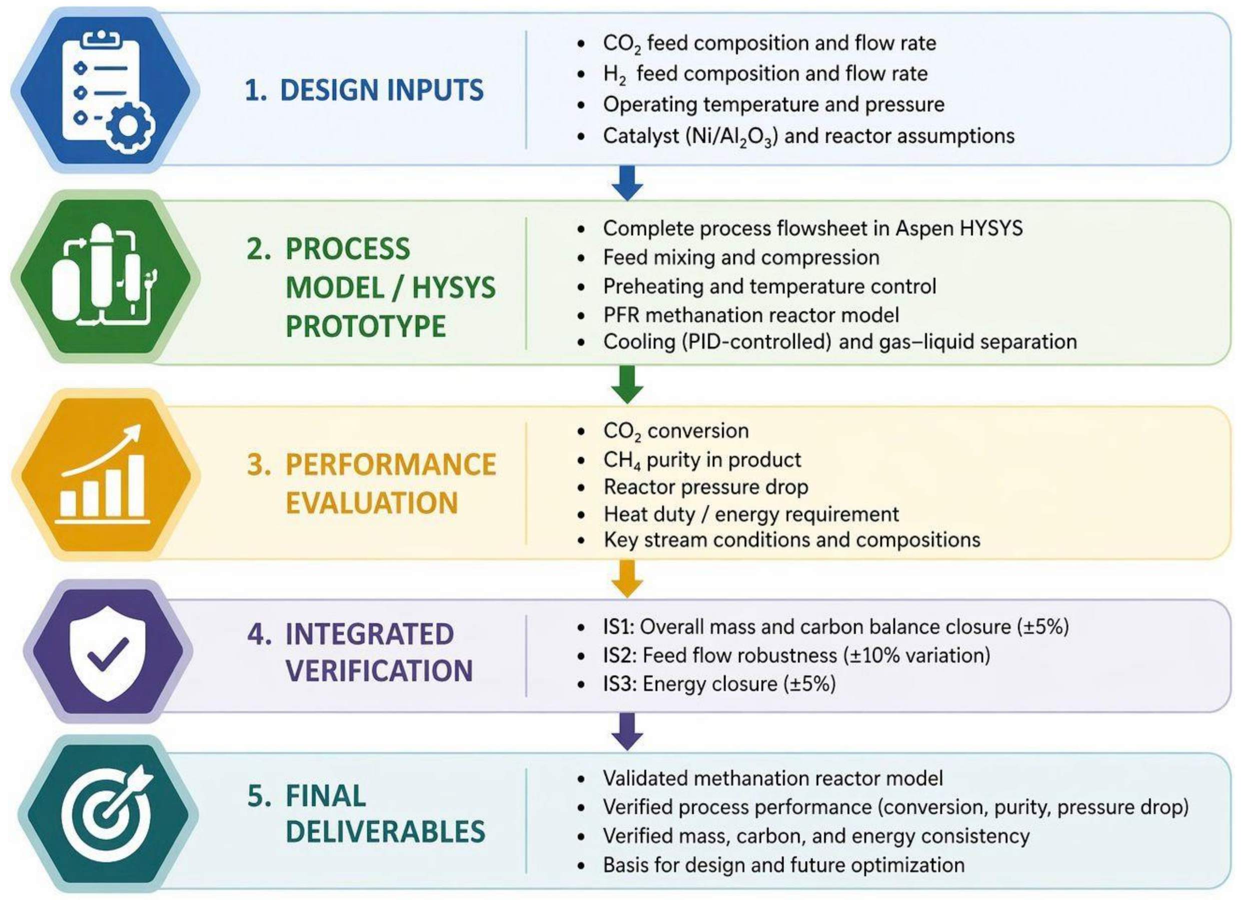
Introduction

Carbon dioxide emissions create a strong need for processes that convert captured CO_2 into valuable products. This project investigates CO_2 methanation through the Sabatier reaction to produce synthetic methane using hydrogen and a *Ni/Al_2O_3* catalyst. A complete reactor prototype was developed in Aspen HYSYS to evaluate process performance in terms of CO_2 conversion, methane purity, pressure drop, and energy consistency under safe and realistic operating conditions.

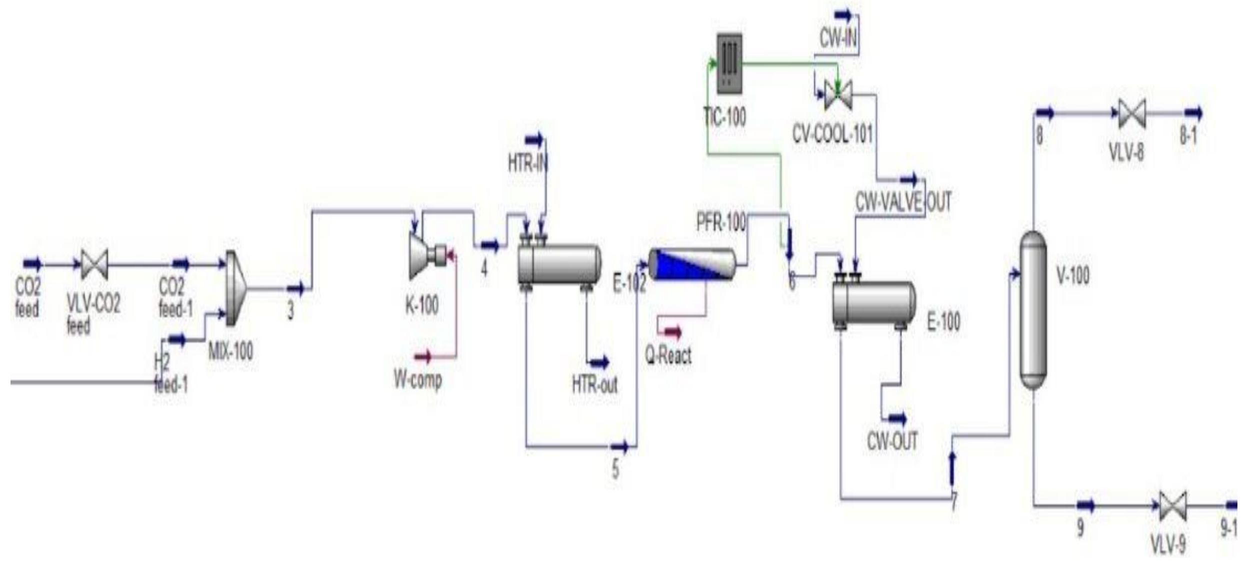
Problem Statement

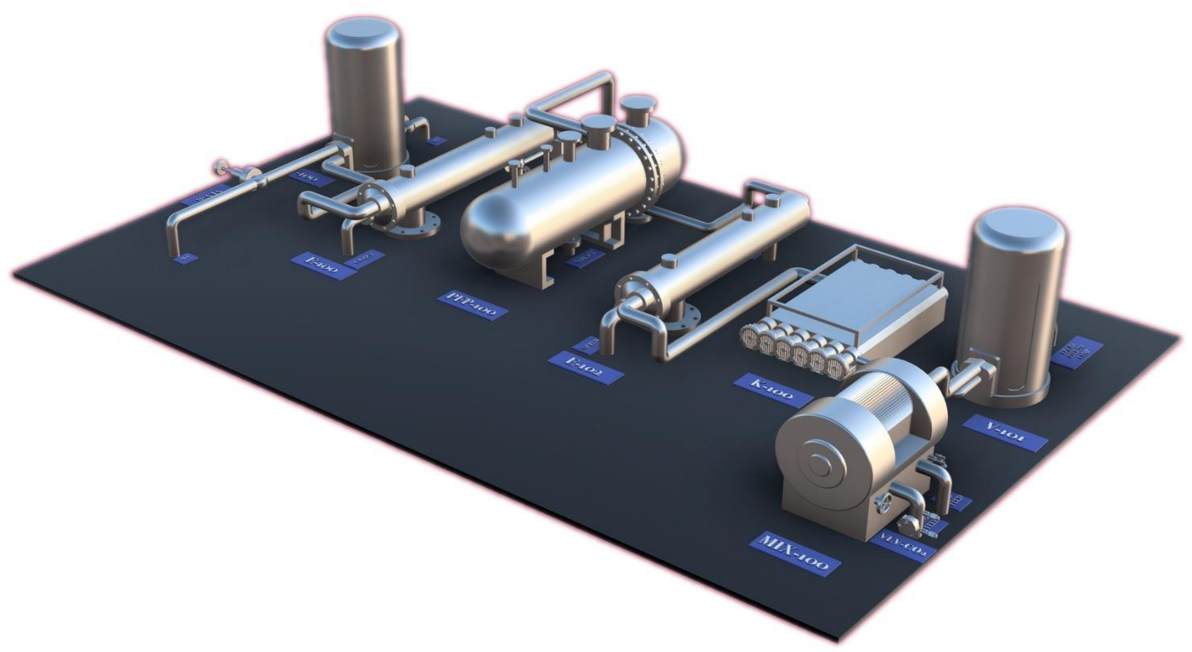
The safe and efficient conversion of captured CO_2 into synthetic methane is limited by the challenges of high-temperature reaction conditions, hydrogen handling, and process-performance verification, creating a need for a validated reactor system that can reliably evaluate conversion, methane purity, pressure drop, and energy consistency.

Deliverables



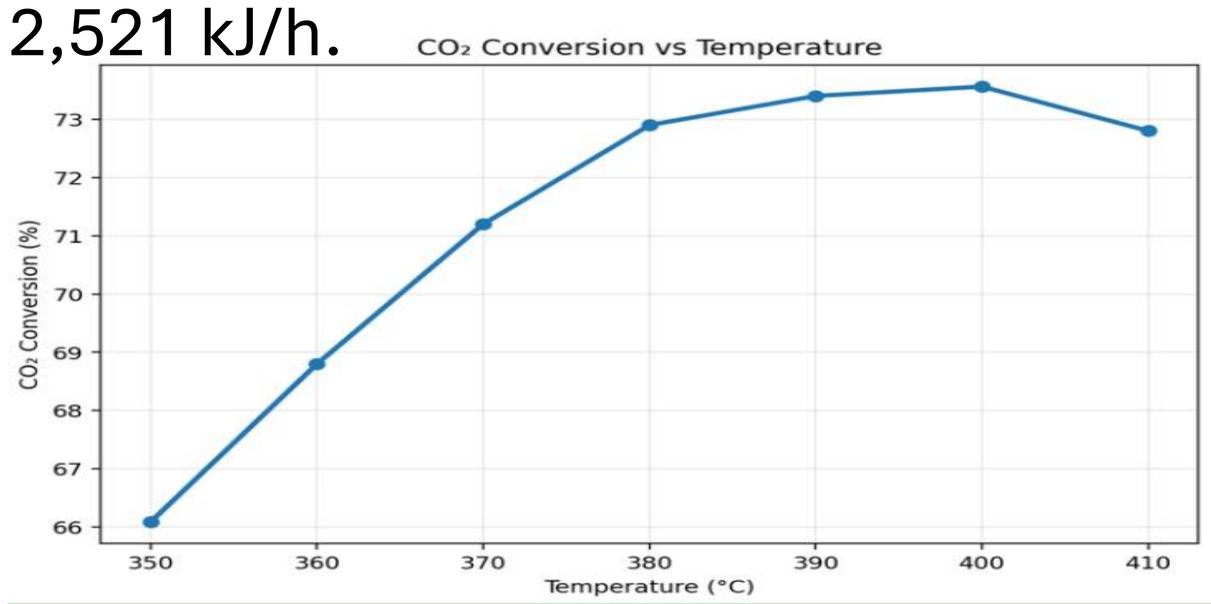
Prototype





Results

Under the selected operating conditions of 400 °C and 4.95 bar, the developed methanation prototype achieved a CO_2 conversion of 73.56% and a CH_4 carbon-basis purity of 73.58%, with an energy closure error of 0.0125%, a reactor pressure drop of 5.0 kPa, and a reactor heat flow of 2,521 kJ/h.



Testing / Validation

- Aspen HYSYS prototype convergence verified
- CO_2 conversion and CH_4 purity validated
- Pressure-drop and heat-flow checks completed
- Mass and carbon balance closure verified
- Energy-closure analysis completed
- ±10% feed-flow sensitivity evaluated

Constraints and Specifications

CHE — Chemical Engineering	
C1	**Reaction:** Sabatier — $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$
C2	**Catalyst:** Ni/Al_2O_3 pellets, 50–250 g, d_p = 2 mm
C3	**Operating:** T = 250–450 °C | P = 1–10 bar | ΔP = 4–6 kPa
S1	**CO_2 Conversion:** 60–80%
S2	**CH_4 Purity:** 65–85% (carbon basis, dry)
ME — Mechanical Engineering	
C4	**Insulator Surface:** Outer ceramic T < 60 °C
S3	**Energy Efficiency:** ≥65% of input energy as CH_4 heat value
S4	**Heat Duty:** 400–800 KJ/h
ISE — Industrial & Systems Engineering	
C5	**AHP Consistency:** CR ≤ 0.1
S5	**Demand Forecast:** Gas consumption via time-series (zero stockout)
S6	**Scenario Selection:** Max weighted score — CO_2 conv. (0.70), utility cost (0.15), env. impact (0.15)
Integrated Specifications	
IS1	**Balance Closure:** Mass ≤ 0.5% & carbon ≤ 0.5% (Aspen HYSYS + Excel verified)
IS2	**Energy Closure:** Error ≤ 5% — $(\dot{Q}_{heater} + \dot{W}_{comp} - \dot{Q}_{cooler}) = \Delta H_{process}$

Constraint Specification (darker = constraint, lighter = specification)

Conclusion

A compact carbon capture and recycling reactor was designed to convert CO_2 into synthetic methane under controlled conditions. The system provides a strong basis for future optimization and prototype development.