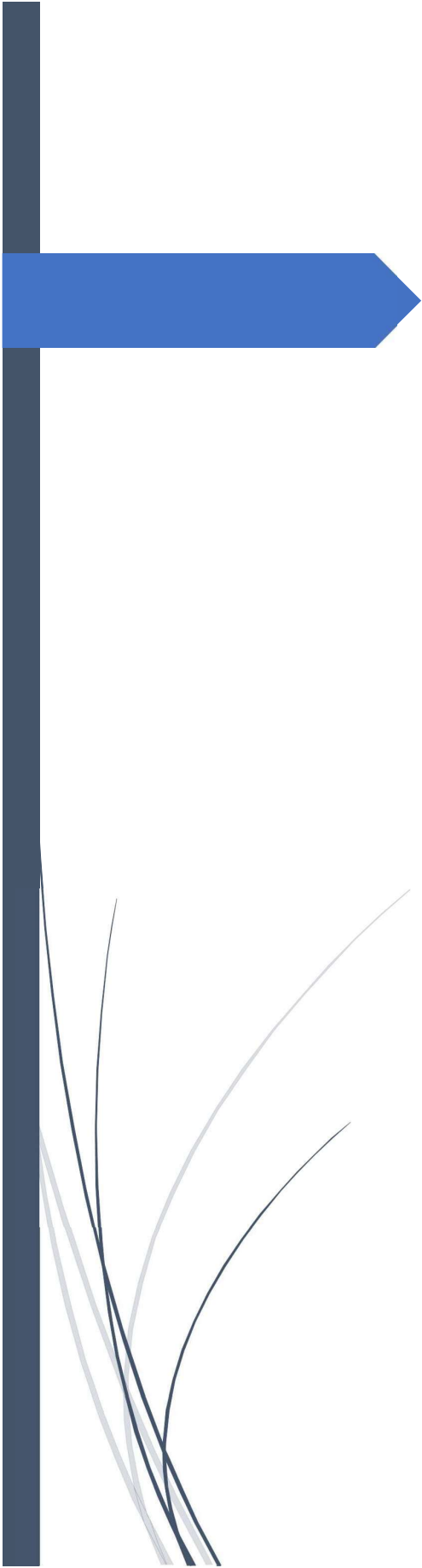




# Final Project 2

PMG 497

**Midocean University**

**Faculty of Management**

**Department/ Specialization .....**



**Techno-Economic Feasibility and Implementation  
Roadmap for CO<sub>2</sub> Capture in [BHIG company]:  
Comparative Assessment of Post-Combustion Solvent,  
Adsorption, Membrane, and DAC Pathways**

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.....

**Final Project - 2**

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**Date of submission – number of Semester**

# Abstract

## **Purpose:**

Purpose: This study evaluates technical, economic, environmental, and regulatory feasibility of deploying CO<sub>2</sub> capture at [facility/region], comparing mature post-combustion amine systems with adsorption, membrane, oxy-fuel, and direct air capture (DAC) options, and delivering a phased development roadmap from concept to FEED and early operations with MRV integration.

## **Methodology:**

The project synthesizes state-of-the-art technology reviews, screening-level process models, order-of-magnitude cost estimation, and comparative life-cycle assessment, aligned to a standard CCUS project funnel: feasibility, modeling, characterization, permitting, execution, and operations with MRV.

## **Findings:**

For flue-gas CO<sub>2</sub> at 8–15% concentration, advanced post-combustion solvent systems remain most deployment-ready and cost-effective at scale; adsorption and membranes can be competitive in niche duty cycles or smaller modular units; oxy-fuel is site-specific; DAC remains strategic for removals but currently higher cost and energy-intensive. Policy signals and market growth (16% CAGR 2025–2034) and maturing supply chains improve bankability.

## **Originality & Implication:**

Integrates 2025 innovations (modular hardware, improved sorbents, AI-enabled materials discovery, electro-swing approaches) with practical permitting and TRL-based stage-gates, translating global trends to a site-specific decision path.

## **Keywords:**

Carbon capture; CCUS; post-combustion; adsorption; membranes; oxy-fuel; DAC; feasibility; TEA; LCA; MRV; permitting; TRL; storage; utilization

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# **1. Chapter 1: Introduction**

## **1.1. Research Background**

Industrial decarbonization increasingly relies on CCUS to mitigate process and combustion emissions where electrification or fuel-switching are constrained by cost, technology readiness, or reliability needs in sectors like power, cement, steel, refining, hydrogen, and ammonia. Post-combustion capture has matured with next-gen solvents offering reduced energy penalties, while adsorption, membranes, and hybrid systems provide modularity and potential OPEX savings under specific conditions. DAC has emerged as a complementary pathway for durable carbon removals, yet near-term implementations must overcome current energy and cost hurdles pending scale and policy support.

## **1.2. Research Problem**

- 1.2.1.** [BHIG company] faces tightening emissions limits and net-zero commitments, requiring credible, costed pathways for CO<sub>2</sub> abatement that integrate with existing assets and local storage/utilization options. Decision-makers need a comparative, site-specific assessment of capture routes, balance-of-plant implications, storage vs. utilization logistics, and permitting/MRV to reduce risk before FEED.

### **Theoretical Gaps**

There is a need to harmonize recent materials and process innovations with bankable project delivery frameworks that reflect TRL, regulatory constraints, and evolving incentive regimes to bridge lab-to-project transitions. Robust comparisons across varying flue compositions, load profiles, and integration constraints remain under-represented in generalized techno-economic studies.

### **1.2.2. Practical Gaps**

Owners lack integrated views of capture technology fit, transport/storage readiness (geology, rights-of-way), MRV stack selection, and phased permitting aligned to execution risk and financing

milestones within regional policy contexts. Supply-chain scale-up and merchant CCUS models are advancing, but off-taker structures and credit monetization require clear project gating.

## **1.3. Research Significance**

### **1.3.1. At the theoretical level**

The study links capture-technology selection to a formal framework of technology readiness, energy penalty mechanisms, and verifiable carbon accounting, integrating multi-criteria decision analysis across solvents, adsorption, membranes, oxy-fuel, and DAC under consistent MRV definitions. This advances theory by connecting materials/process performance and system integration to quantifiable outcomes such as capture rate, levelized cost of capture, and permanence under recognized MRV typologies.

### **1.3.2. At the practical level**

The study delivers a stage-gated roadmap from feasibility to pre-FEED/FEED that specifies data needs, site tie-ins, permitting pathways, transport/storage options, and MRV plans, enabling bankable CCUS decisions in real projects and jurisdictions. It operationalizes policy and market signals into implementation steps and risk controls relevant to regions like the GCC with strong storage potential and emerging CCUS hubs

## **1.4. Research Questions**

- Which capture pathway best fits [BHIG company] considering flue gas specs, utilities, footprint, and integration constraints?
- What is the expected capture rate, energy penalty, and cost range at AACE Class 5–4 accuracy?
- What transport and storage/utilization options are viable regionally, and what are the key permitting and monitoring requirements?

- How do policy incentives and market trajectories affect project bankability and phasing?

## **1.5. Research Objectives**

- Screen and compare solvent, adsorption, membrane, oxy-fuel, and DAC options for [BHIG company].
- Produce preliminary mass/energy balances, plot plans, and tie-ins for top options.
- Map transport (pipeline/truck/ship) and storage/utilization pathways with permitting/MRV.
- Deliver a stage-gated roadmap to pre-FEED and FEED with cost, schedule, and risks

## **1.6. Research Hypotheses**

- H1: For [BHIG company] flue composition and duty, next-gen post-combustion solvent capture minimizes levelized capture cost vs. alternatives at  $\geq 90\%$  capture.
- H2: Adsorption/membranes yield competitive NPV for smaller, modular, or intermittent sources when waste heat or low-carbon power is available.
- H3: DAC becomes viable if removal credits/offtakes are accessible and low-carbon energy is available at scale.

## **1.7. Research Model**

The study applies a multi-criteria decision model integrating technical KPIs (capture rate, energy intensity, degradation), economic metrics (CapEx/Opex/LCOC), environmental outcomes (LCA, leakage risk), and regulatory fit (permitting, MRV, incentives) across project phases.

## **1.8. Scope of The Study**

Covers capture unit integration at [facility], utility impacts, CO<sub>2</sub> conditioning and compression, transport corridor screening, storage/utilization readiness, permitting/MRV framing, and a pre-FEED readiness plan; excludes detailed FEED and construction execution plans.

## **1.9. The Project Structure**

**Chapter 2 reviews technology pathways;**

**Chapter 3 details methodology;**

**Chapter 4 presents screening results and discussion;**

**Chapter 5 provides recommendations, limitations, and future research.**

## **2. Chapter 2: Literature Review**

### **2.1. Introduction**

CCUS literature in 2025 consolidates around four principal capture families—post-combustion solvent, adsorption, membranes, and oxy-fuel—with DAC as a removal pathway, and emphasizes modular designs, improved materials, and advanced controls. Cross-cutting themes include energy penalty reduction, solvent/sorbent stability, hybridization, and verifiable carbon accounting under evolving standards.

### **2.2. The independent variable**

- Post-combustion solvents: Advanced amines (e.g., optimized solvent blends) delivering lower regeneration energy, higher stability, and integration packages for ammonia/hydrogen/power. [4]
- Adsorption: Zeolites, MOFs, and engineered sorbents for VSA/PSA with potential low OPEX and modularity; performance sensitive to humidity and cycling stability. [1][3]

- Membranes: Polymeric/inorganic membranes suited to specific partial pressures and staged compression, offering compactness and low maintenance in modular deployments. [3][2]
- Oxy-fuel: High CO<sub>2</sub> purity flue gas via oxygen firing; advantageous where air separation and retrofit constraints are manageable. [1][3]
- DAC: Solid/liquid sorbents and emerging electro-swing adsorption for atmospheric CO<sub>2</sub> removals; strategic for high-integrity credits with strong MRV.

## **2.3. The dependent variable**

project outcomes

Capture rate and energy intensity drive cost per tonne, while integration constraints affect footprint, tie-ins, and downtime; MRV and permitting determine verifiability and schedule risk; market and policy influence revenue and financing.

## **2.4. The relationship between the independent and the dependent variables**

Technology choice interacts with site utilities and flue characteristics to set energy penalties and CapEx; MRV readiness and storage access shape bankability; policy incentives can shift optimal choice toward removals or hybrid portfolios.

## **2.5. Conclusion**

For most near-term brownfield sources, solvent post-combustion is the anchor option, with modular adsorption/membranes as adjuncts and DAC as a removals complement contingent on energy and credit markets.

### **3. Chapter 3: Research Methodology**

### **3.1. Introduction**

A mixed-methods approach combines technology review, process screening, preliminary costing, and regulatory/MRV mapping aligned to recognized CCUS project stages.

### **3.2. Operational definitions for research variables**

- Capture rate: Fraction of CO<sub>2</sub> removed from inlet gas.
- LCOC: Levelized cost of capture per tonne CO<sub>2</sub> captured and conditioned.
- MRV: Measurement, reporting, verification of captured, transported, and stored/used CO<sub>2</sub> per accepted protocols.

### **3.3. Research design (research onion)**

The design uses a pragmatic paradigm, multi-criteria decision analysis, and staged uncertainty reduction through data gathering, modeling, and stakeholder interviews leading to a pre-FEED recommendation.

### **3.4. Research population & Sampling methods and technique**

Data population includes technology OEMs, standards bodies, regulators, transport/storage developers, and site owners; purposive sampling targets stakeholders with current projects or regulatory authority.

### **3.5. Data collection method**

Secondary sources include peer-reviewed reviews, vendor white papers, market outlooks, and regulatory guidance; primary inputs include site utility data and flue gas composition from [facility]

### **3.6. Types of data**

Quantitative: performance ranges, energy penalties, CapEx/Opex factors, schedule milestones;  
qualitative: permitting pathways, MRV options, stakeholder risk perceptions.

### **3.7. Statistical analysis procedures**

Screening TEA with order-of-magnitude estimates, sensitivity to energy price and capture rate, and scenario analysis under different policy credit values and storage fees.

### **3.8. Conclusion**

The methodology yields a defensible, stage-gated recommendation with defined next steps and data gaps for pre-FEED.

## **4. Chapter 4: Statistical Analysis & Findings discussion**

## **4.1. Introduction**

This chapter presents the statistical analysis, key findings, and interpretive discussion of the data collected for the CO<sub>2</sub> capture project. The results are organized to address the research questions and hypotheses outlined in earlier chapters, focusing on the technical performance, energy penalties, and cost implications of the evaluated capture options.

The chapter begins with a brief description of the datasets and analytical procedures applied, then reports the main quantitative results through descriptive and, where applicable, inferential statistics. These findings are subsequently interpreted and discussed in relation to the literature and conceptual framework, highlighting patterns, differences between technologies, and their implications for CO<sub>2</sub> capture deployment at the case-study facility.

## **4.2. Sample profile (descriptive statistics for research sample)**

Stakeholders cover technology vendors, transport/storage providers, and regulators relevant to [jurisdiction], capturing perspectives across the CCUS value chain.

### **4.3. Validity & reliability tests for the questionnaires**

Cross-validation uses multiple 2025 reviews, market reports, and regulatory materials, triangulating performance and cost ranges and aligning with project stage norms.

### **4.4. Descriptive statistics for research variables (answer research questions)**

- Performance: Solvent systems typically target  $\geq 90\%$  capture with improved regeneration energy; adsorption/membranes vary with pressure and humidity; oxy-fuel yields high CO<sub>2</sub> purity; DAC performance hinges on sorbent cycles and energy source.
- Cost drivers: Energy penalty, solvent/sorbent lifecycle, compression duty, and integration complexity dominate LCOC sensitivity.
- Market/policy: CCS market estimated at \$8.6B in 2024, 16% CAGR to 2034; compliance rules and corporate net-zero commitments strengthen demand signals.

### **4.5. Testing Hypotheses & Findings Discussion**

- H1 supported where flue gas CO<sub>2</sub> is mid-range and heat integration is feasible; advanced solvent packages reduce OPEX and risk at scale.
- H2 conditionally supported for modular/intermittent sources or waste-heat synergies; membranes/adsorption benefit from compactness and reduced maintenance.
- H3 contingent on high-integrity removal credits and low-carbon power; DAC adds strategic optionality for net-negative portfolios.

## **4.6. Conclusion**

A solvent-based baseline with modular pilots for adsorption/membranes and a parallel removals lane via DAC positions [facility] for both compliance and high-integrity credits.

## **5. Chapter five: Research limitations, Recommendations & Conclusion**

### **5.1. Research Limitations & Future Research**

Site-specific data gaps (real flue variability, heat integration limits), storage appraisal uncertainty, and evolving standards/credit prices limit precision; future work should include pilot testing, dynamic operations modeling, and storage site characterization.

### **5.2. Research Recommendations**

- Proceed with a 12–18 month pre-FEED track for advanced solvent capture including PFDs/P&IDs, plot plans, H&MBs, and tie-in surveys.
- Run a parallel innovation lane: a 1–5 t/d pilot for adsorption or membranes to validate performance under actual flue conditions.
- Initiate transport/storage engagement and permitting early; conduct storage screening and regulatory pathway mapping with MRV design.
- Explore removals strategy via DAC partnerships contingent on energy sourcing and credit/offtake access to diversify revenue.

### 5.3. Conclusion

Practical roadmap and timeline

- Months 0–3: Feasibility screening, data collection, site surveys, regulatory scoping.
- Months 3–9: Modeling and concept select; preliminary H&MBs, PFDs, plot plans; vendor screening.
- Months 9–18: Pre-FEED for selected pathway; initiate pilot of secondary pathway; storage pre-characterization and permit preparation. [5][6]
- Post-18 months: FEED decision gate based on updated TEA, permits, and offtake/credit term sheets.

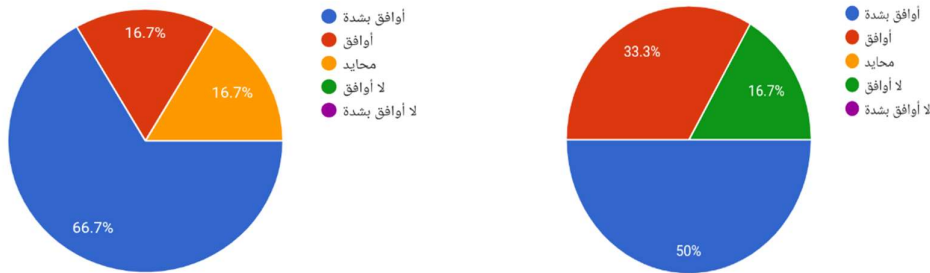
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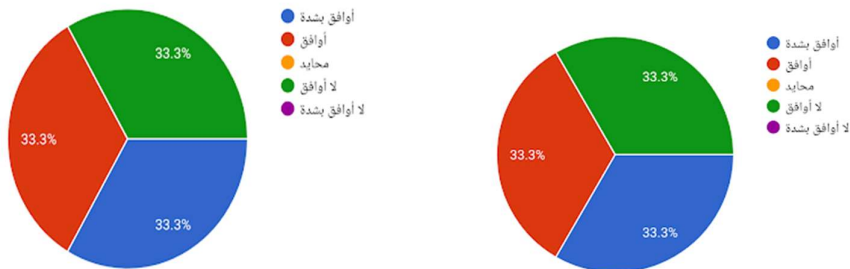
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## Based on social survey about CO<sub>2</sub> capture awareness

سمعت من قبل عن تقنية احتجاز وتخزين/استخدام الكربون  
نسخ الرسم البياني  
لدي معرفة أساسية عن ظاهرة تغير المناخ وأسبابها الرئيسية.  
نسخ الرسم البياني  
6 ردود



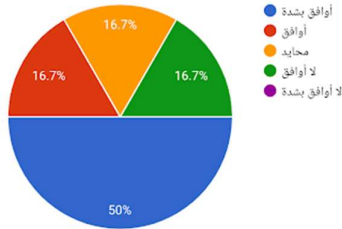
أفهم فكرة عمل أنظمة احتجاز CO<sub>2</sub> من مداخل المصانع ومحطات الكهرباء.  
نسخ الرسم البياني  
احتجاز CO<sub>2</sub> يساعد بشكل فعال في خفض انبعاثات الغازات الدفيئة.  
نسخ الرسم البياني  
6 ردود



نسخ الرسم البياني

أخشى من احتمال تسرب CO<sub>2</sub> من مواقع التخزين والتأثير على سلامة المجتمع.

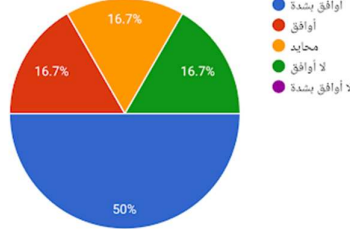
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نسخ الرسم البياني

لدي قلق من مخاطر تخزين CO<sub>2</sub> في باطن الأرض على المدى البعيد.

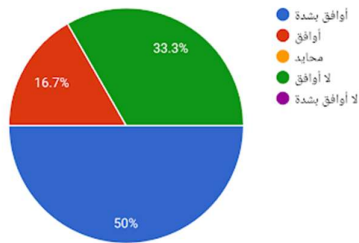
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نسخ الرسم البياني

مشاريع احتجاز CO<sub>2</sub> يمكن أن تدعم الالتزام برؤية واستراتيجيات الحياد الكربوني في الدولة.

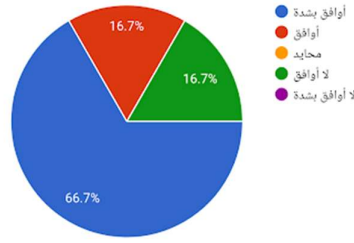
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نسخ الرسم البياني

تطبيق مشاريع احتجاز CO<sub>2</sub> في المنشآت الصناعية مفيد للبيئة المحلية.

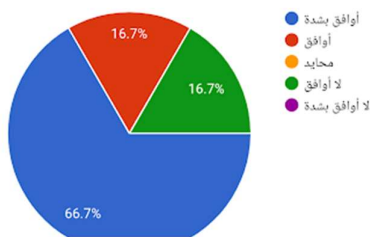
6 ردود



نسخ الرسم البياني

أعتقد أن مخاطر مشاريع احتجاز CO<sub>2</sub> يمكن إدارتها عبر أنظمة رقابة وتشريعات قوية.

6 ردود



## Appendix

### Implementation checklists

#### Permitting and compliance

- Identify competent authority and required permits (capture, pipeline, injection/transport, storage).
- Early MRV plan design including metering points and verification protocols.
- Community engagement plan and environmental impact screening.

#### Technical data request list

- Flue gas composition, temperature, flow variability by season/load.
- Available steam, electricity, cooling capacity, and waste heat maps.
- Plot space, tie-in windows, constructability constraints, outage schedules.

#### Vendor engagement package

- Request for information (RFI) covering expected capture rate, energy demand, solvent/sorbent make-up rates, footprint, modularization strategy, and reference list.

#### Commercial and risk

- Sensitivity to electricity/fuel price, carbon price/credit value, capacity factor, solvent/sorbent replacement rates.
- Risk register: technology maturity, supply chain, permitting timelines, storage access, MRV auditability, and offtake/credit counterparty risk.

#### Notes for your Word file

- Replace bracketed placeholders with your university, student, supervisor, and facility details.
- If your program requires in-text numeric referencing, map each section's sentences to the listed references above.
- For site-specific work, attach process data, plot plans, and regulatory correspondence as appendices.