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ROTA-CAP: An Intensified Carbon Capture System Using Rotating Packed Beds

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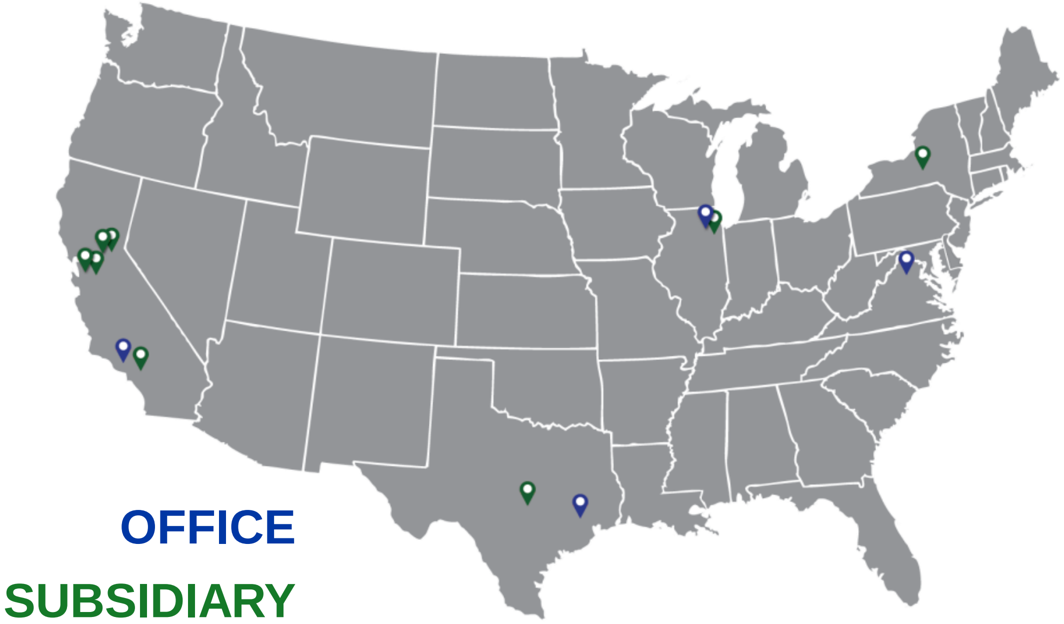
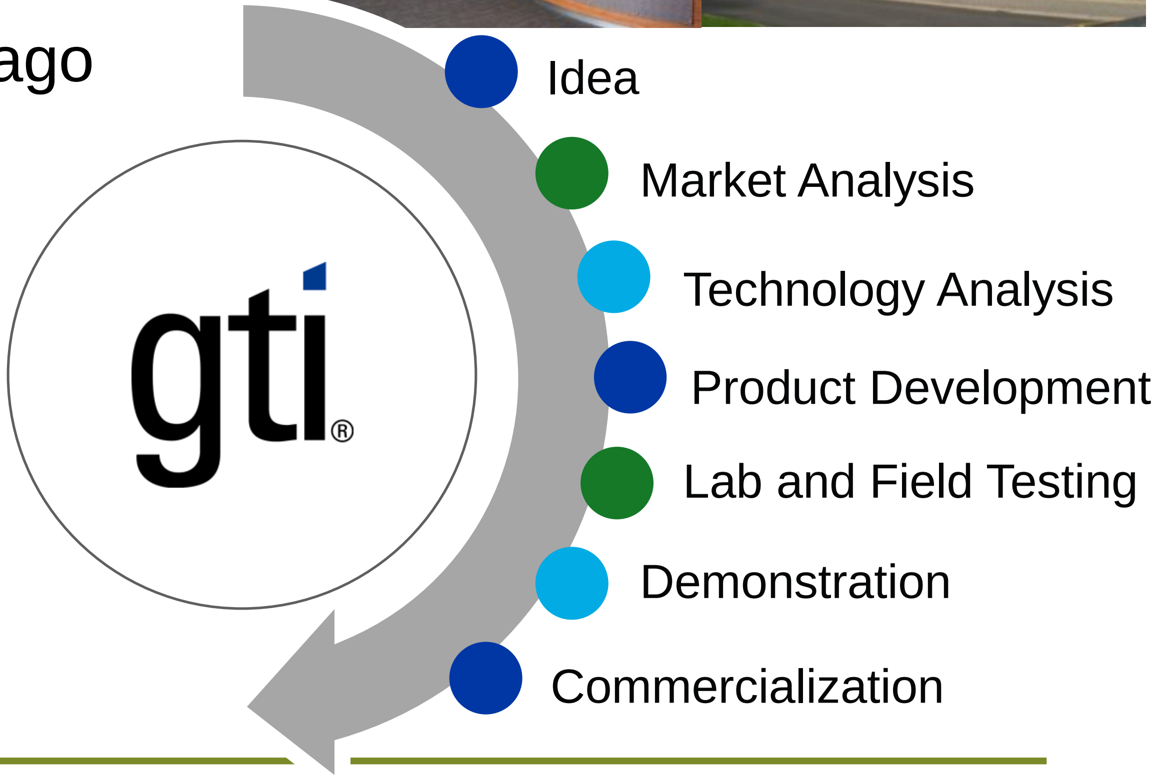
Outline

- **Project Overview**
- **Technology Background**
- **Technical Approach Discussion**
- **Progress and Current Status**
- **Plans for Future**

Introduction to GTI

- Research organization, providing energy and environmental solutions to the government and industry since 1941
- Facilities: 18 acre campus near Chicago





Project Overview

ROTA-CAP: An Intensified Carbon Capture System Using Rotating Packed Beds

- **Sponsor**

DE-FE0031630

- **Funding**: $3,482,222 ($2,784,222 DOE plus $698,000 co-funding)
- **Duration:** 30 months

  BP1: 10/1/2018 – 3/31/2020 BP2: 4/1/2020 – 3/31/2021

- **Objective**: To develop and validate a transformational carbon capture technology—ROTA-CAP to meet DOE's cost target of ≤$30/tonne CO_2, 90% capture rate, and product CO_2 purity target of ≥95 %.

ROTA-CAP: An Intensified Carbon Capture System Using Rotating Packed Beds

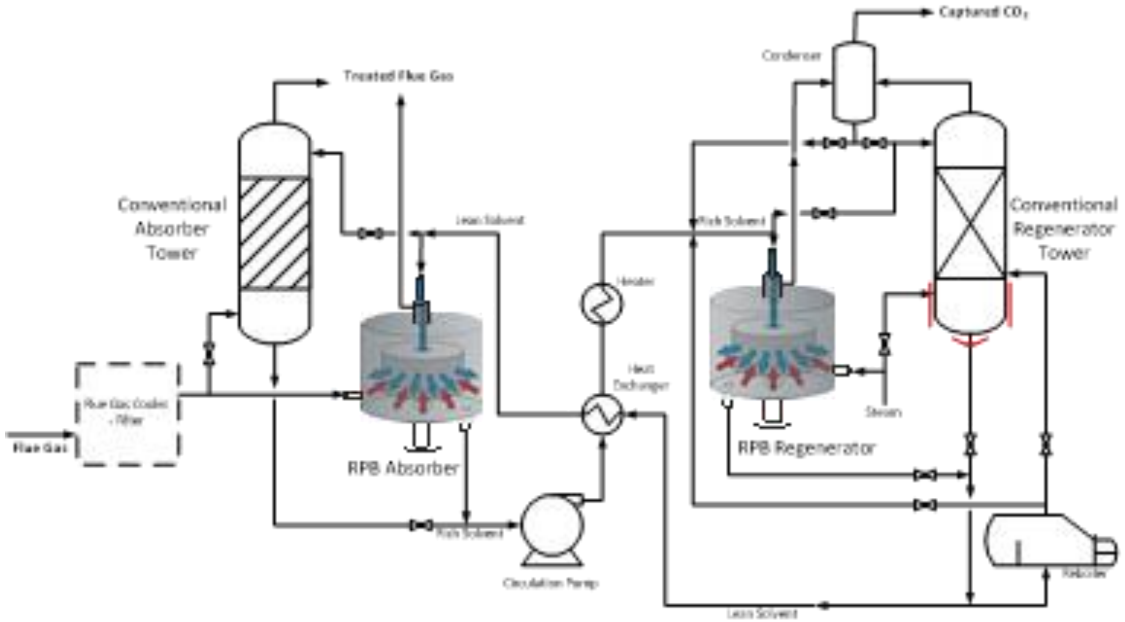
- **Team:**

Member	Expertise
gti	• GTI has expertise is in bench-scale and pilot-scale research and development (R&D) plus scoping economic analysis. We bring over 75 years of performing applied R&D for DOE and other governmental agencies as well as industry and bringing technology to the market to the effort.
CCS Carbon Clean Solutions	• CCSUS, a wholly owned subsidy of CCSL, is an early stage process technology venture with commercially proven products and process licensing with technologies for industrial decarbonization, while reducing the environmental impact of man-made emissions. Their focus is to provide the most cost-effective CO_2 capture and CO_2 treating technology with patented chemistry and engineering know-how.
NC National Carbon Capture Center	• NCCC specializes in evaluation of developing technologies using coal-derived gas with the concomitant impurities, providing critical information on material and process suitability for scale-up to commercial applications.

Project Objectives

The objective of this project is to develop and validate a transformational carbon capture technology, ROTA-CAP

ROTA-CAP uses rotating packed bed (RPB) absorbers and regenerators for contacting flue gas with CCSUS’s solvent for carbon capture



Simplified ROTA-CAP flow diagram

Project Objectives (cont.)

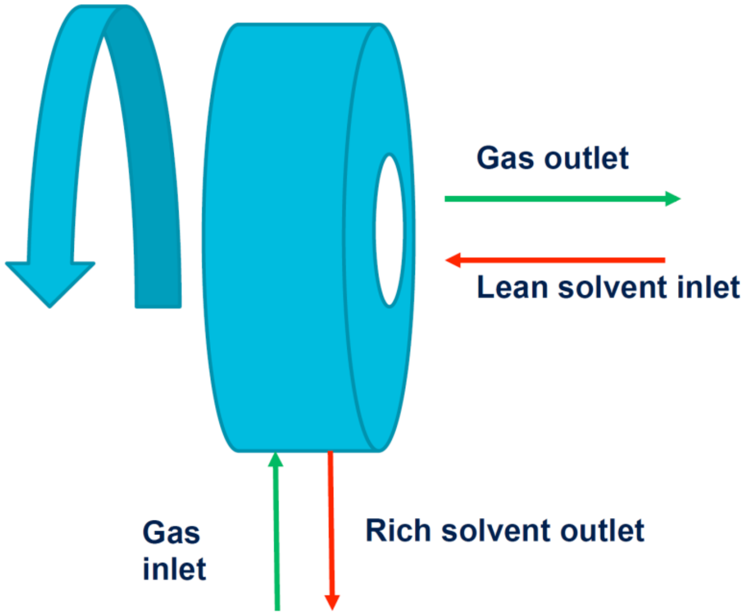
BP	Objectives
1	• Design, construct and commission ROTA-CAP equipment at GTI. • Develop a preliminary process model and perform an initial fabrication feasibility study for commercial process. • Test with simulated flue gases and natural gas burner flue gas at GTI to determine key operating parameters. • Calibrate process model and measure solvent carry over.
2	• Perform long-term reliability and operability testing at NCCC. • Verify process model. • Determine scale-up challenges, solvent degradation, and aerosol formation. • Complete high-level techno-economic analysis.

Technology Background

ROTA-CAP Background: Introduction

ROTA-CAP EQUIPMENT

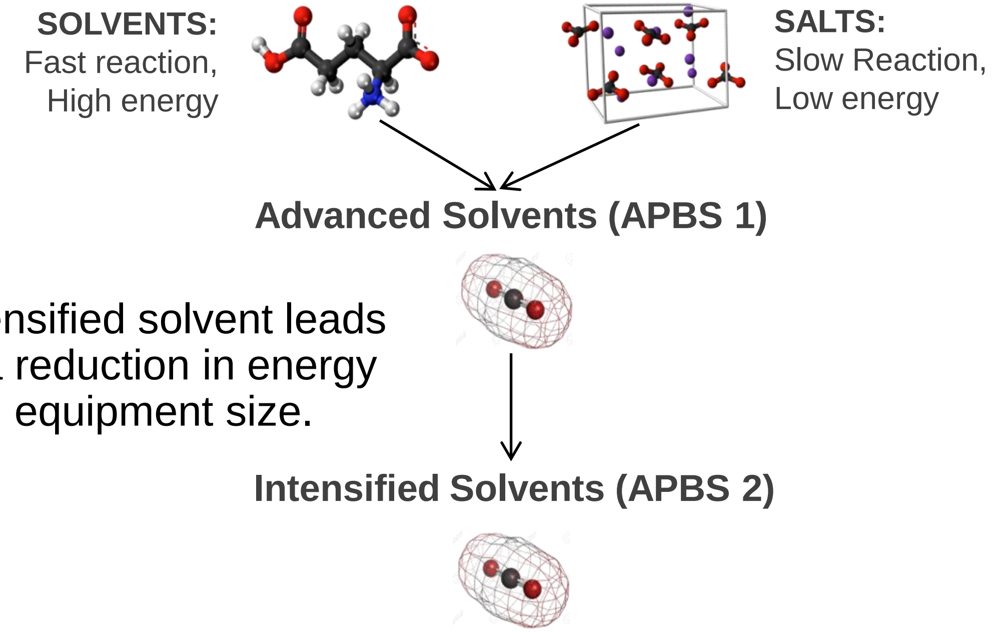
RPB equipment improves mass transfer leading to up to 90% volume reduction from a conventional static column.



INTENSIFIED SOLVENT

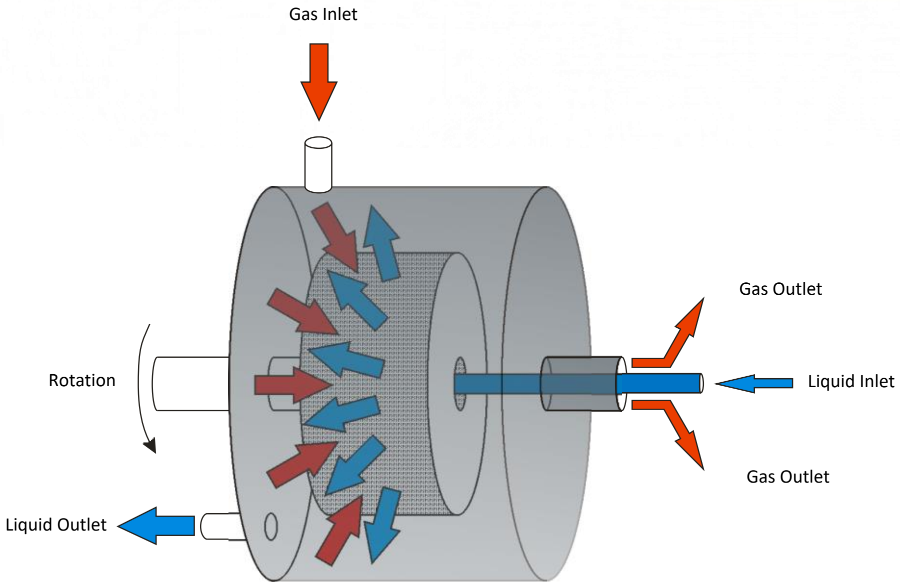
CCS's advanced solvents (Amine Promoted Buffer Solutions or APBS) remove CO_2 from a variety of gas streams – for use in new and existing industrial facilities.

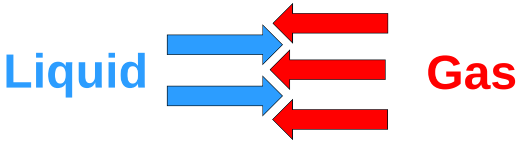
Intensified solvent leads to a reduction in energy and equipment size.



RPB equipment with intensified solvent will improve typical economics

ROTA-CAP Background: Absorber



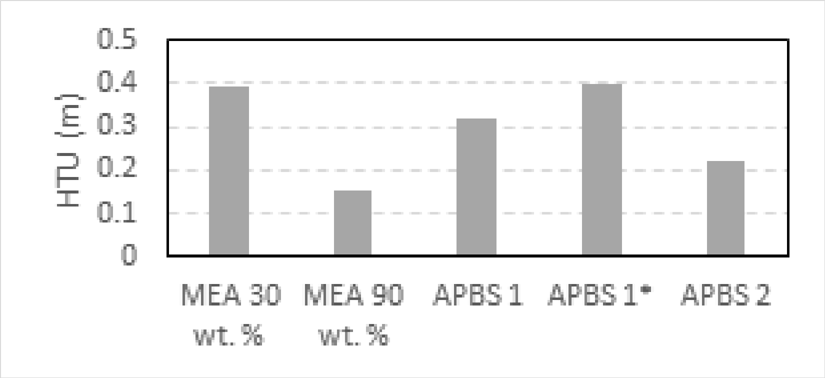


COUNTER CURRENT CONTACT

- Initial tests by Newcastle University UK, on bench-scale prototype absorber performance measured mass transfer of CO_2 (12 vol.%) into 4 solvent systems.
- Counter current contact:
  - Solvent distributed from inner radius to outer radius under centrifugal force generated by rotation of the packed bed.
  - Gas flows from outer radius to inner radius of packed bed.
- Absorber tests measurements:
  - Inlet and outlet gas phase CO_2 concentrations
  - Inlet, outlet and sump solvent temperature
  - Gas and liquid flow rates
  - Speed of rotation

Rota-Cap Background: Solvent

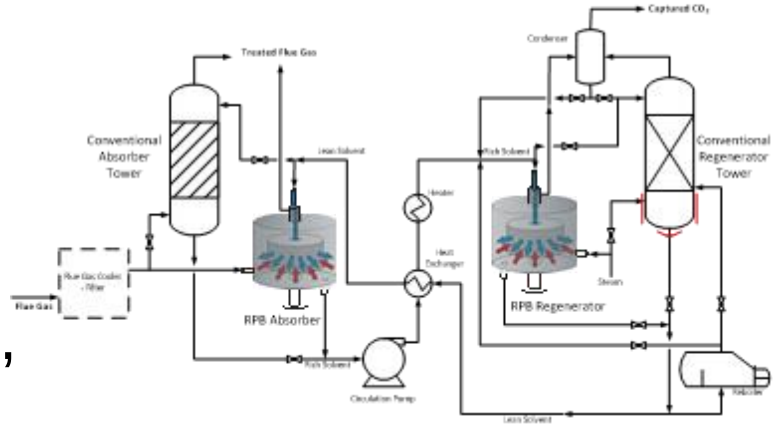
- Intensified solvents have been developed to achieve higher CO_2 loadings than those used in conventional systems – these are more viscous than conventional solvents.
- Intensified solvents (MEA 90 wt.% and APBS 2) exhibited higher mass transfer rates (low HTU) than non-intensified solvents (MEA 30 wt.% and APBS 1).
- Simulation determined a conventional absorption process with 30 wt.% MEA requires packing height of 0.94 m to achieve equivalent mass transfer of CCSL's intensified solvent in RPB with 0.11 packing height – leading to close to 90% size reduction



Solvent	30 wt.% MEA	APBS 2
Absorber Type	Static	RPB
CO_2 in (mol.%)	12.0	12.0
CO_2 out (mol.%)	7.2	7.2
Packing Height (m)	0.94	0.11
Relative Size Reduction	Base	8.5

Advantages Over Traditional Processes

- RPB regenerator size reduction is comparable to that of an RPB absorber
- RPB technology reduces the size and therefore cost of the absorber
- Reduced sizing requirements of heat exchangers, pumps, and coolers by up to 50%
- Lower residence time of the solvent in the absorber
- Reduced oxidative and thermal degradation

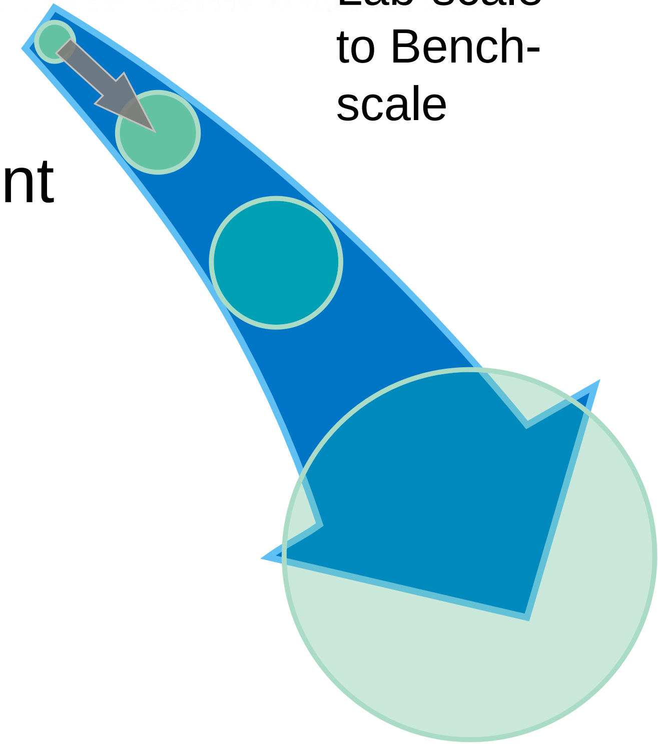


Simplified ROTA-CAP flow diagram

Technical and Economic Challenges

- The integrated use of RPBs as both absorber and regenerator in a single system
- The mechanical design parameters of rotating equipment
- Solvent stability performance during operation
- Integrating and achieving required solvent regeneration using an RPB regenerator

Lab-scale to Bench-scale

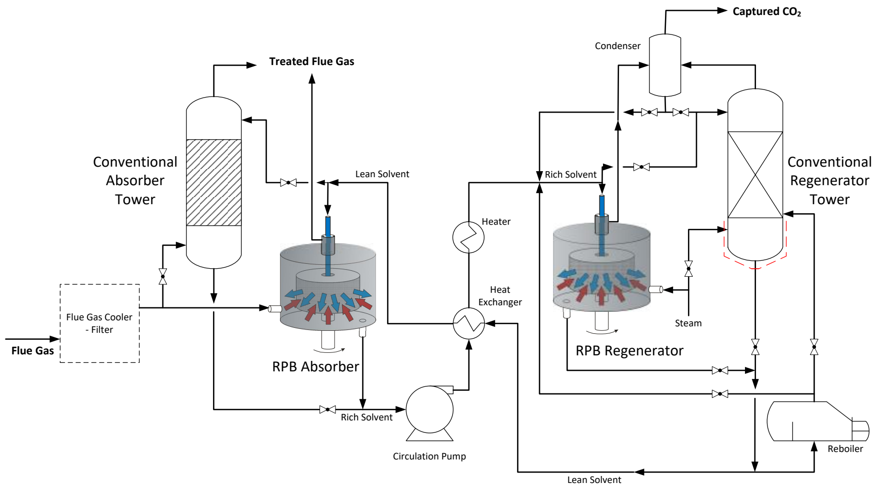


Technical Approach

Test Equipment

- 50kWe (1000kg/day CO_2 removal) scale integrated carbon capture skid
- Test with simulated flue gas at GTI
- Long term test with coal-fired flue gas testing at the National Carbon Capture Center (NCCC)
- Test conventional column performance using NCCC's Slip Stream Test Unit (SSTU)

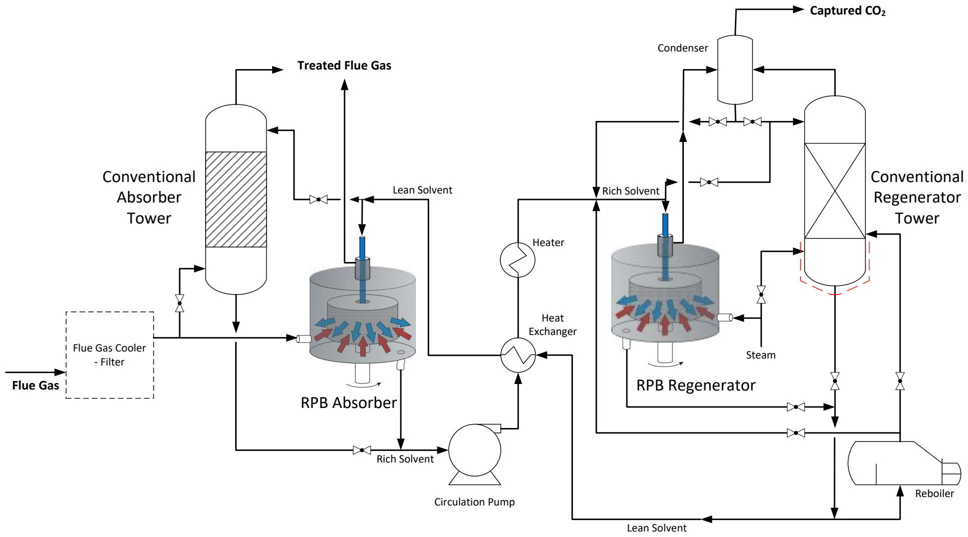
Test Campaign	Duration
Simulated gas parametric testing	2 months
Natural gas burner flue gas	1 month
Long-term testing at NCCC	Cumulative 1000 hr



Simplified ROTA-CAP flow diagram

Key Experimental Parameters

Parameter	Range
Rotational Speed	200–1000 RPM
Absorber Liquid/Gas ratio	0.5–5.0 kg/m3
Solvent Circulation Rate	30–150 kg/h
Solvent Concentration & Viscosity	40–70 wt.% & 5–80 cP
Regenerator Operating Pressure & Temperature	0.0–1.0 bar(g) & 100–130°C
Flue gas composition	Synthetic - Natural gas-fired - Coal-fired



Simplified ROTA-CAP flow diagram

Milestone Schedule

Budget Period	Milestone	Description	Planned	Actual
1	1.1	Update Project Management Plan	11/1/18	10/29/18
	1.2	Kickoff Meeting	1/1/19	12/14/18
	2.1	Develop Preliminary Kinetic Model	8/1/19	6/1/2019
	3.1	Finish Construction of Test Skid	*9/1/19*	
	3.2	Start Parametric Testing	*9/1/19*	
	4.1	Update Kinetic Model Based on Experimental Data	3/31/20	
2	5.1	Transport Skid to Host Site	6/1/20	
	5.2	Complete Commissioning	8/1/20	
	5.3	Start Long-Term Testing	9/1/20	
	5.4	Removal of Skid and Chemicals from Host Site	3/31/21	
	6.1	Verify Kinetic Model with Real Flue Gas Data	3/31/21	
	6.2	Complete Economic Analysis	3/31/21	

gti

Success Criteria

Decision Point	Date	Success Criteria
Go / No-Go	3/31/2020	• Viable design for a commercial scale unit verified. • Successful testing of the ROTA-CAP bench scale skid: 1. 24 hr continuous operation with absorber and regenerator coupled together. 2. Startup and shutdown sequences are 1 hr each.
Completion of the project	3/31/2021	• Successful long duration testing: 1. Cumulative 1000 hr testing with SCPC flue gas. 2. Achieve 90% CO_2 capture under steady state conditions. 3. RPB uses less than 20% of the packing height required by conventional column. 4. Solvent circulation rate is less than 70% of a conventional column. 5. Solvent water content is less than 25% of a conventional column.

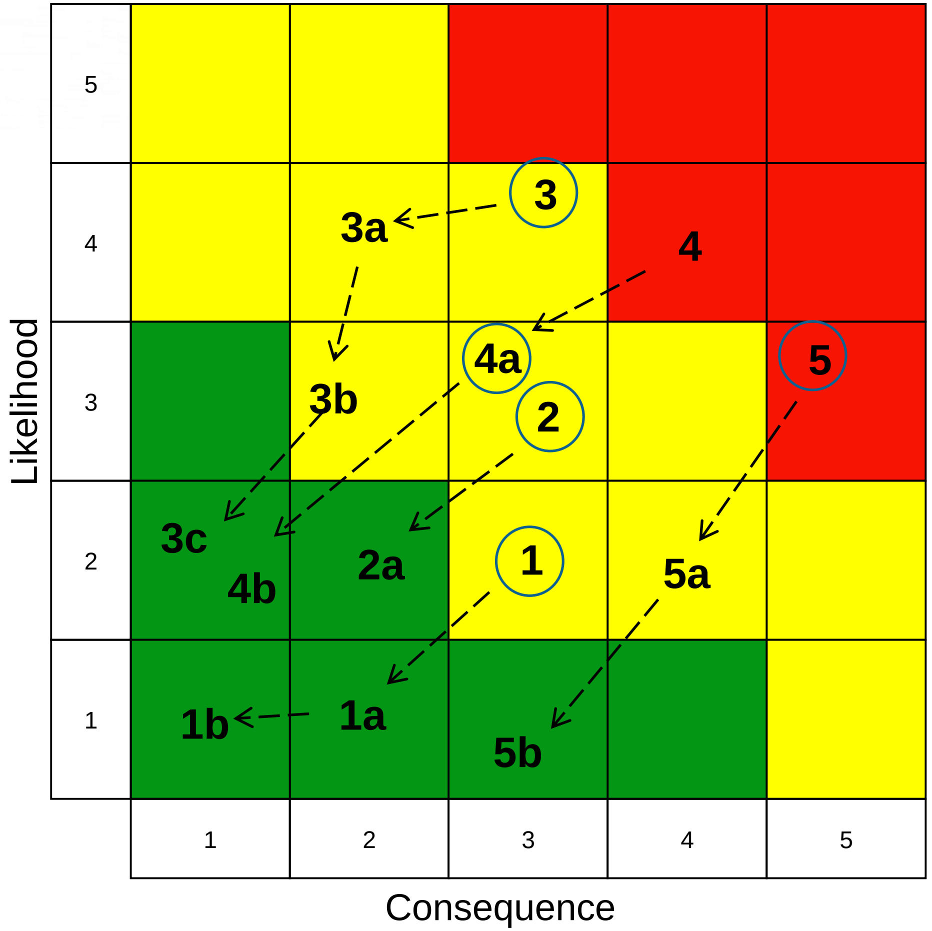
Project Risks and Mitigation Strategies

Technical Risks:

1. **Scale up of rotating packed bed reactor is too problematic**
   1a. GTI's experience on evaluation of high-efficiency gas-liquid contactors for natural gas processing including RPB reactors
   1b. CCSL's previous and current projects involving RPB reactors and other process equipment
2. **Energy use by RPB reactors is too high**
   2a. Reactor design will balance the size of reactor and energy use to achieve economic scale up
3. **Flue gas contaminants degrade solvent or solvent aerosols form on RPB reactor exit**
   3a. Solvent analysis to monitor degradation
   3b. Liquid carryover measurement
   3c. Include a water wash
4. **Not high enough capture efficiency**
   4a. CCSL solvent matched MEA performance using RPB
   4b. Modify solvent concentration as necessary

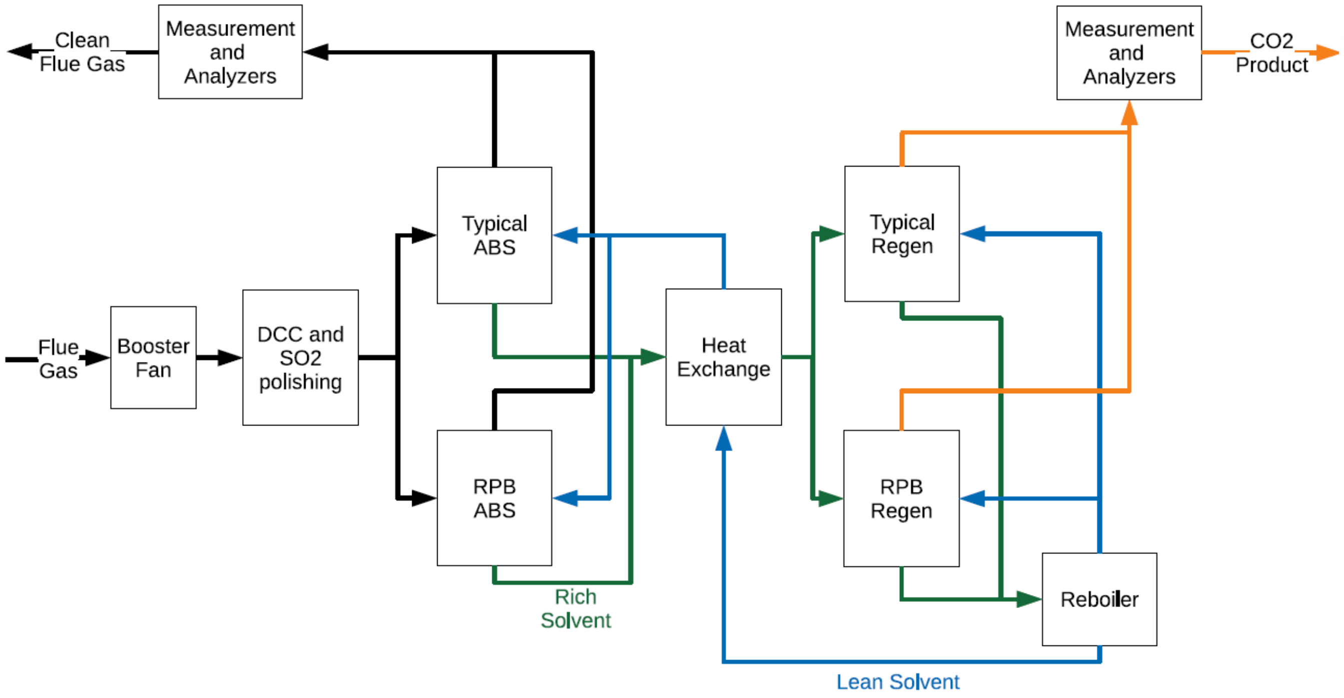
Safety Risk:

5. **Rotating equipment related safety**
   5a. GTI Engineering Team has the tools and expertise to evaluate rotating equipment requirement..
   5b. GTI has access to prototype/one off design engineering facilities for design evaluation if necessary.



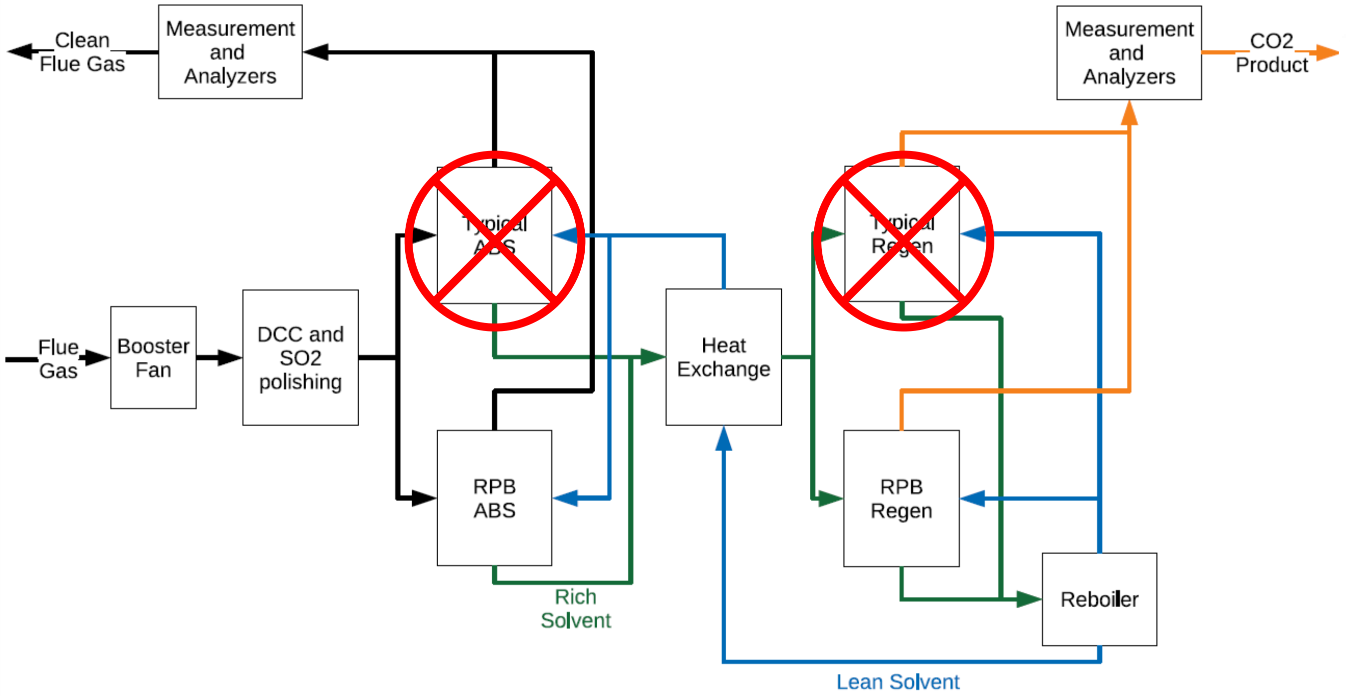
Progress and Current Status of Project

ROTA-CAP Block Diagram



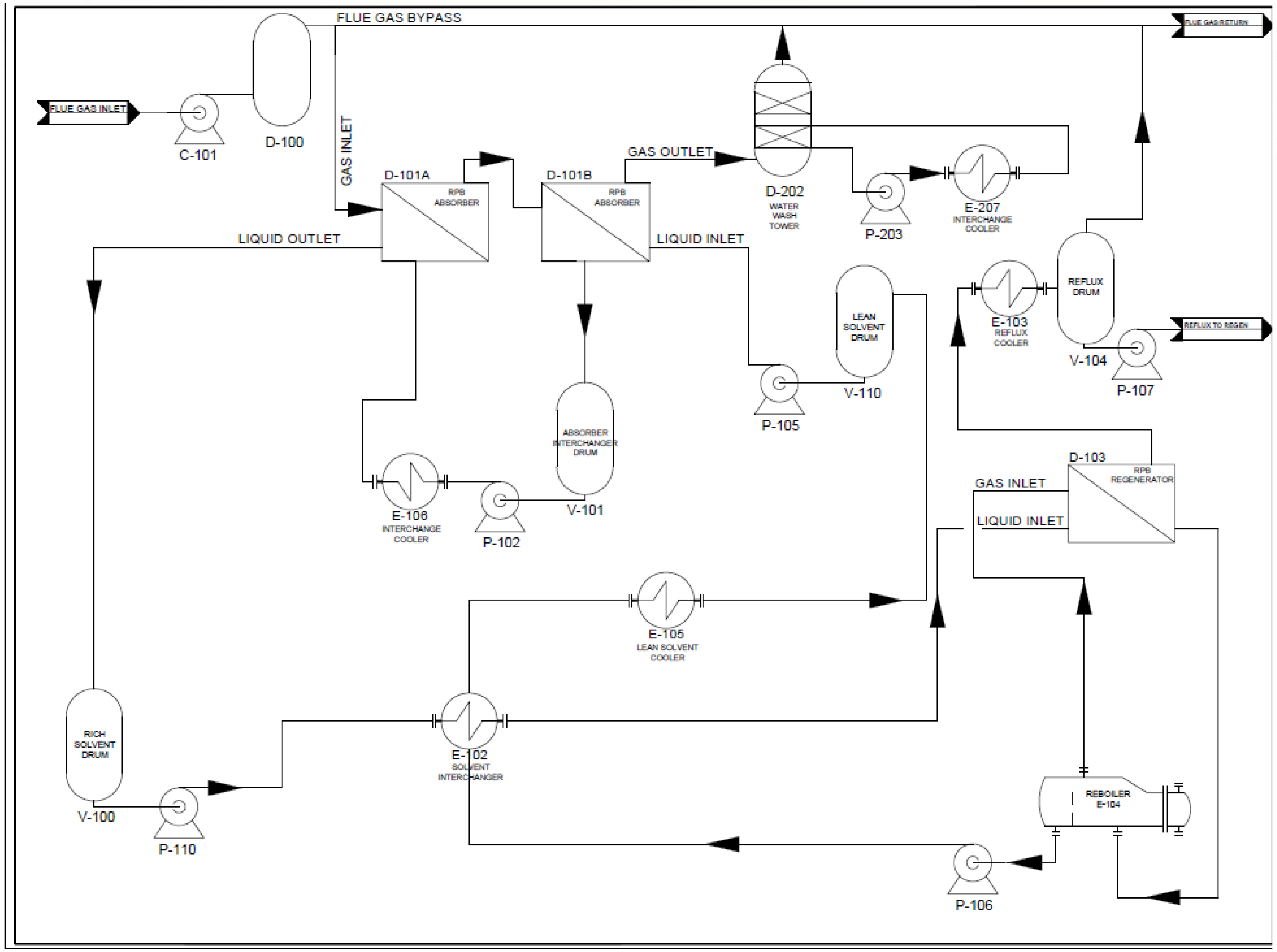
- Initial ROTA-CAP block diagram

ROTA-CAP Block Diagram



- Initial ROTA-CAP block diagram
- Modified after decision to utilize NCCC's Slipstream Test Unit (SSTU).

ROTA-CAP Process Flow Diagram (PFD)



Simplified

ROTA-CAP PFD

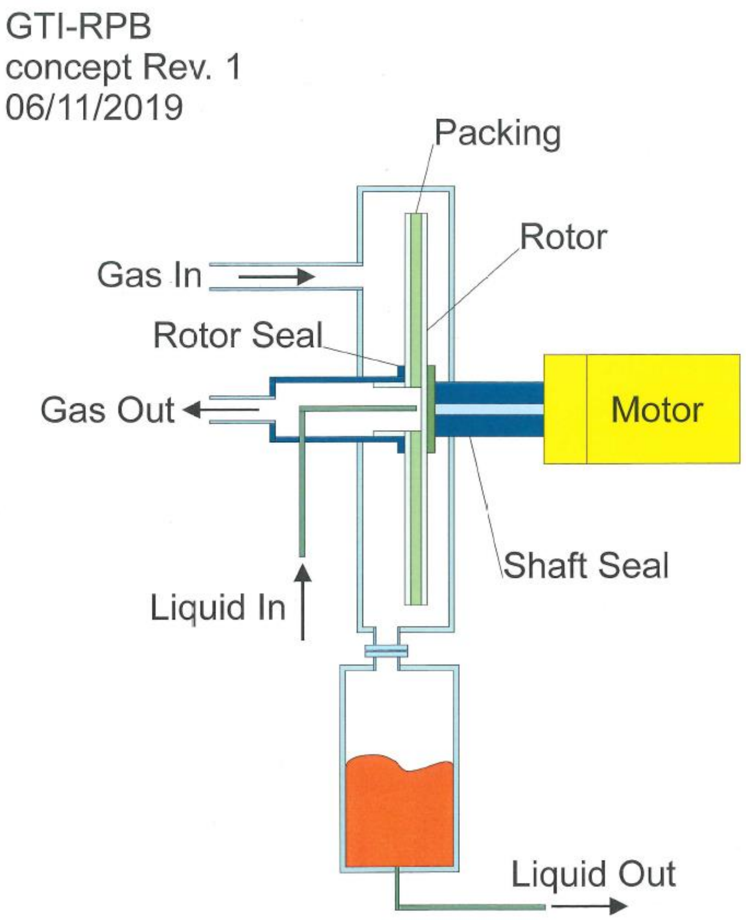
ROTA-CAP has two stages of absorber RPB and one regenerator RPB with a separate reboiler.

Design and Procurement

- ROTA-CAP P&IDs are prepared and reviewed.
- Process equipment, vessels, transmitters, pumps, heat exchangers, control hardware etc. has been received.
- CCSUS submitted rotating bed reactor sizing.
- HAZOP review ranking and recommendation document is prepared.
- NCCC proposed using their currently available conventional column skid (Slip Stream Test Unit, SSTU) instead of building a parallel system.
- GTI proposed and NETL approved utilizing NCCC's SSTU.

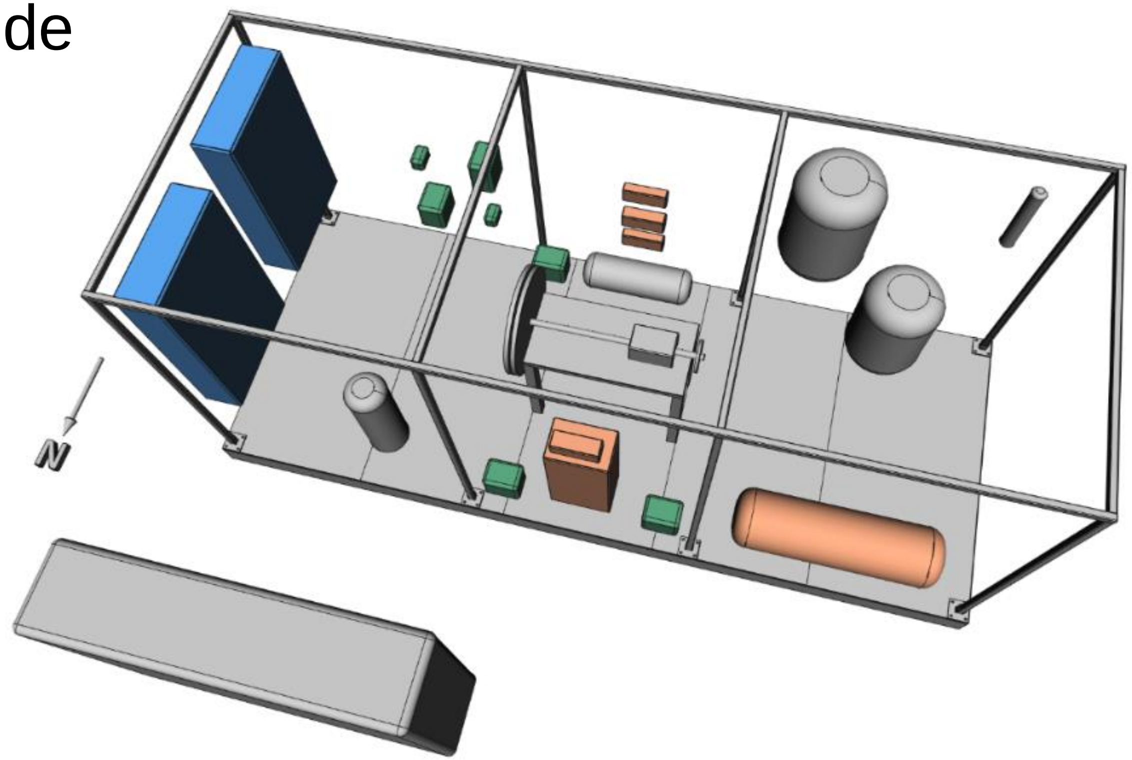
Rotating Packed Bed Design

- GTI prepared initial RPB design concept.
- Mechanical design for rotating packed beds is done by GTI. GTI Engineering Team reviewed mechanical requirements of the RPB sizing submitted by CCS-US.
- GTI reviewed previous project reports on HIGEE and mass transfer and fluid dynamics studies for dehydration and bulk acid gas removal projects performed by GTI's predecessor institutions: GRI and IGT.
- CCS-US contacted Sulzer and Koch-Glitsch for packing selection for the RPBs. Glitsch was the packing provider for the GRI HIGEE research program. Communications are underway to use Koch-Glitsch for structured packing for the RPBs.



Test Skid Design and Layout

- Designed, ordered and received the test skid frame.
- Prepared initial 3D skid layout to guide construction and installation.



Plans for Future Testing

Potential Project Benefits and Outcomes

- More versatile process compared to other next generation CO_2 capture technologies

  RPB reactors are non-selective to the solvent used

- Process simulation model for ROTA-CAP

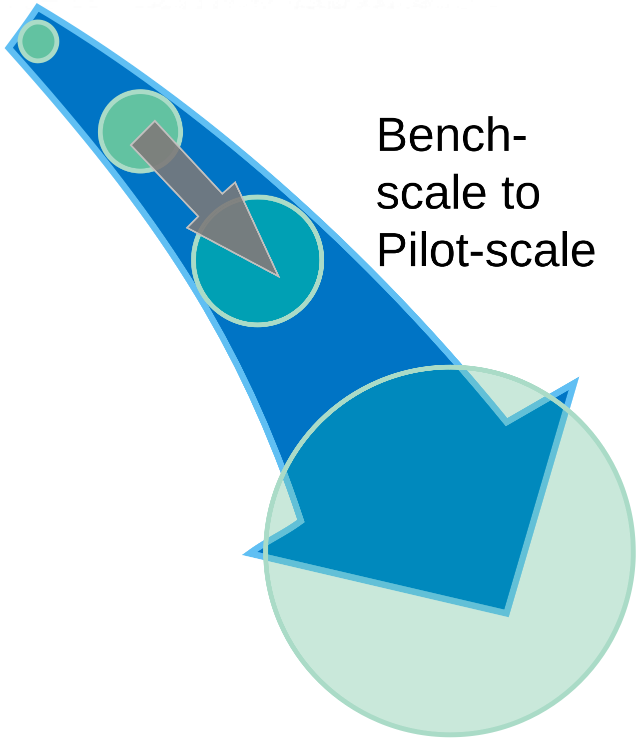
  Used for larger-scale ROTA-CAP technology deployment

- High-level techno-economic analysis (TEA)

  Used for proving the value of the ROTA-CAP technology in the carbon capture market

Limitations of Experimental Approach

- Challenges of scale up from bench-scale to commercial scale
- Next expected step up is 10x
- Design of seals, wall effects and area affects are hard to determine for commercial scale
- Investigate modular design approach



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