# ROTA-CAP$^{tm}$: An Intensified Carbon Capture System Using Rotating Packed Beds

## DOE Contract No. DE-FE0031630

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*GTI (Gas Technology Institute)*

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U.S. Department of Energy

National Energy Technology Laboratory

Carbon Management and Natural Gas & Oil Research Project Review Meeting

Virtual Meetings August 2 through August 31, 2021

# Outline

- Project Overview
- Technology Background
- Technical Approach Discussion
- Progress and Current Status
- Summary

# 79-year History of Turning Raw Technology into Practical Energy Solutions

**FOR A BETTER ECONOMY AND A BETTER ENVIRONMENT**

SUPPLY ▶ CONVERSION ▶ DELIVERY ▶ UTILIZATION

**World-class piloting facilities headquartered in Chicago area**

RESEARCH & DEVELOPMENT

PROGRAM MANAGEMENT

TECHNICAL/ ANALYTICAL

CONSULTING

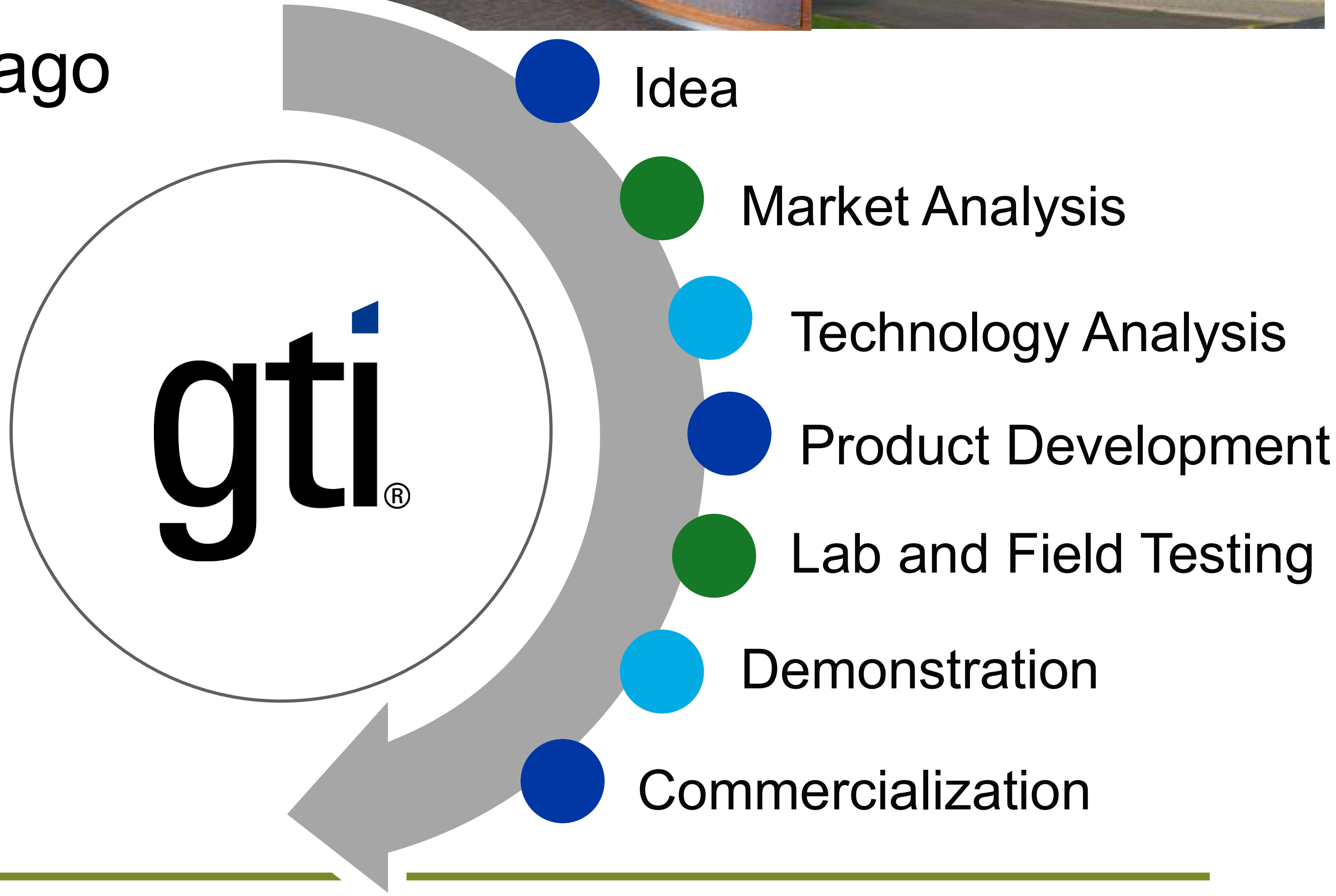
TRAINING

COMMERCIALIZATION

400+ EMPLOYEES

# 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$^{tm}$: An Intensified Carbon Capture System Using Rotating Packed Beds

- **Sponsor**

U.S. DEPARTMENT OF ENERGY    NATIONAL ENERGY TECHNOLOGY LABORATORY

**DE-FE0031630**

- **Funding**: $2,784,222 DOE ($743,000 co-funding), Duration 42 months

- **Objective**: The objective of this project is to develop and validate a transformational carbon capture technology—ROTA-CAP$^{tm}$ to meet DOE's cost target of ≤$30/tonne $CO_2$, 90% capture rate, and product $CO_2$ purity target of ≥95 %.

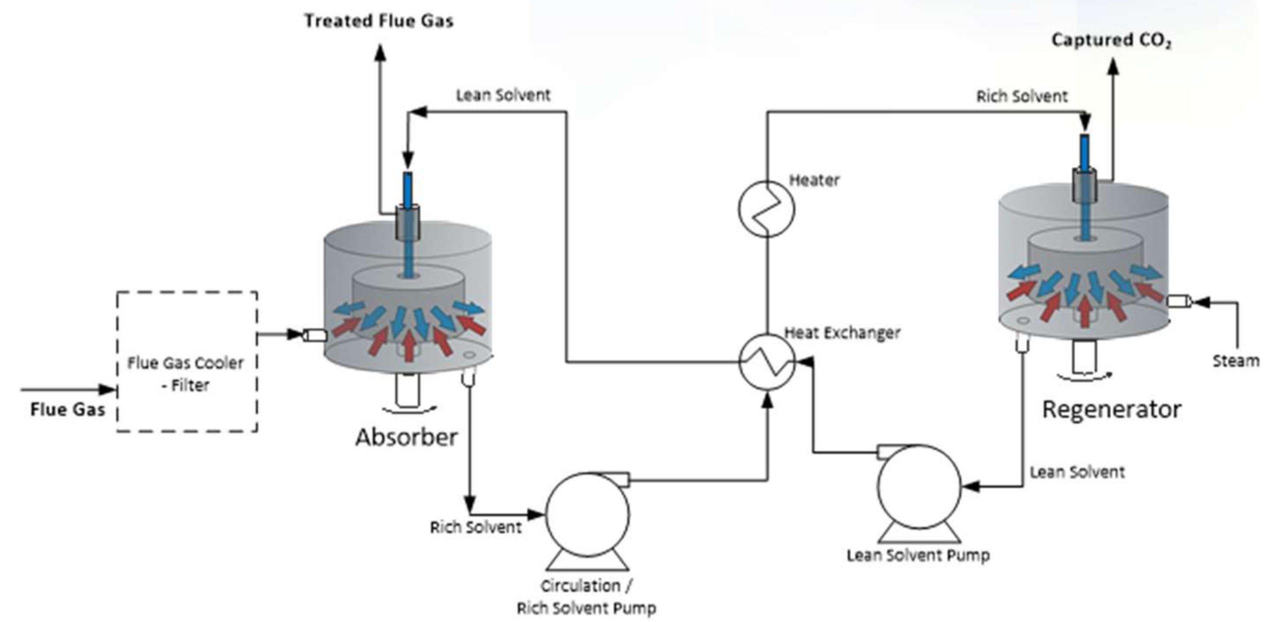
BP1: 10/1/2018 – 3/31/2021    BP2: 4/1/2021 – 3/31/2022

# ROTA-CAP$^{tm}$: DOE/NETL Project Objectives and Members

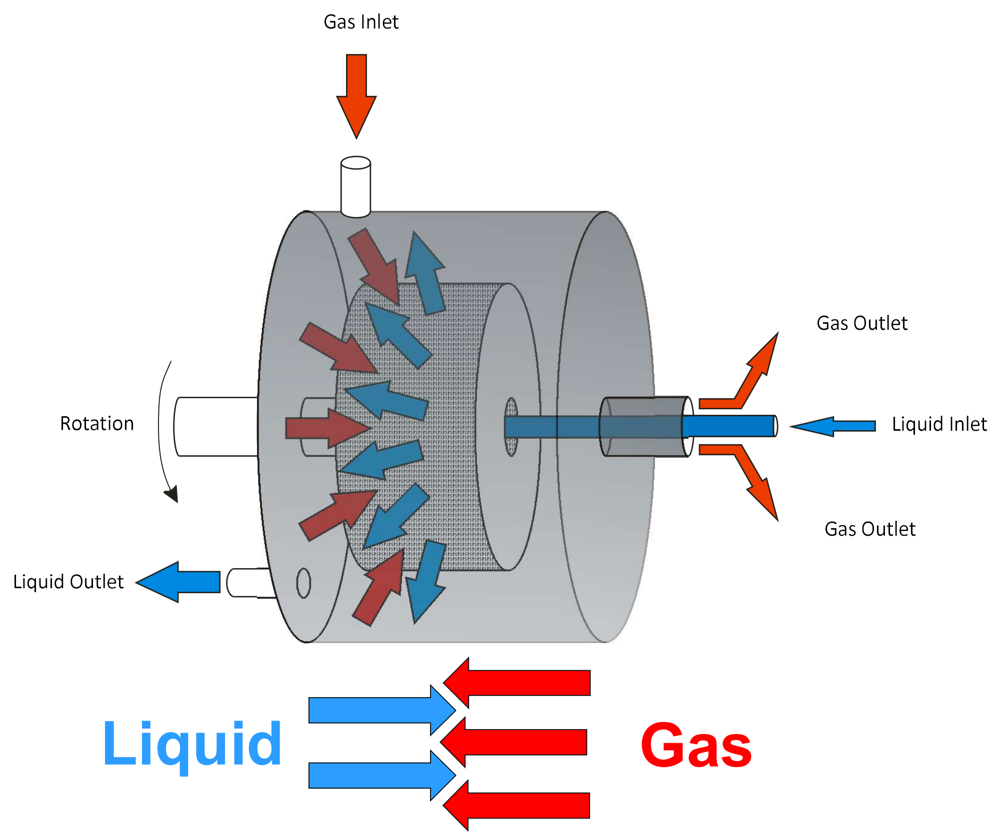
- Design, construct, test and model novel rotating packed bed (RPB) absorbers and regenerators
- Assess the performance of the integrated hardware and solvent under a range of operating conditions
- Test with simulated flue gas at GTI
- Long term test with real flue gas at the National Carbon Capture Center (NCCC)

# ROTA-CAP$^{tm}$: Process Intensification (PI) by Using Rotating Packed Bed Reactors to Replace Conventional Absorber and Regenerator

ROTA-CAP$^{tm}$ uses rotating packed bed (RPB) absorbers and regenerators for contacting flue gas with an advanced solvent such as Carbon Clean's CDRMax ® for carbon capture




Simplified ROTA-CAP$^{tm}$ flow diagram

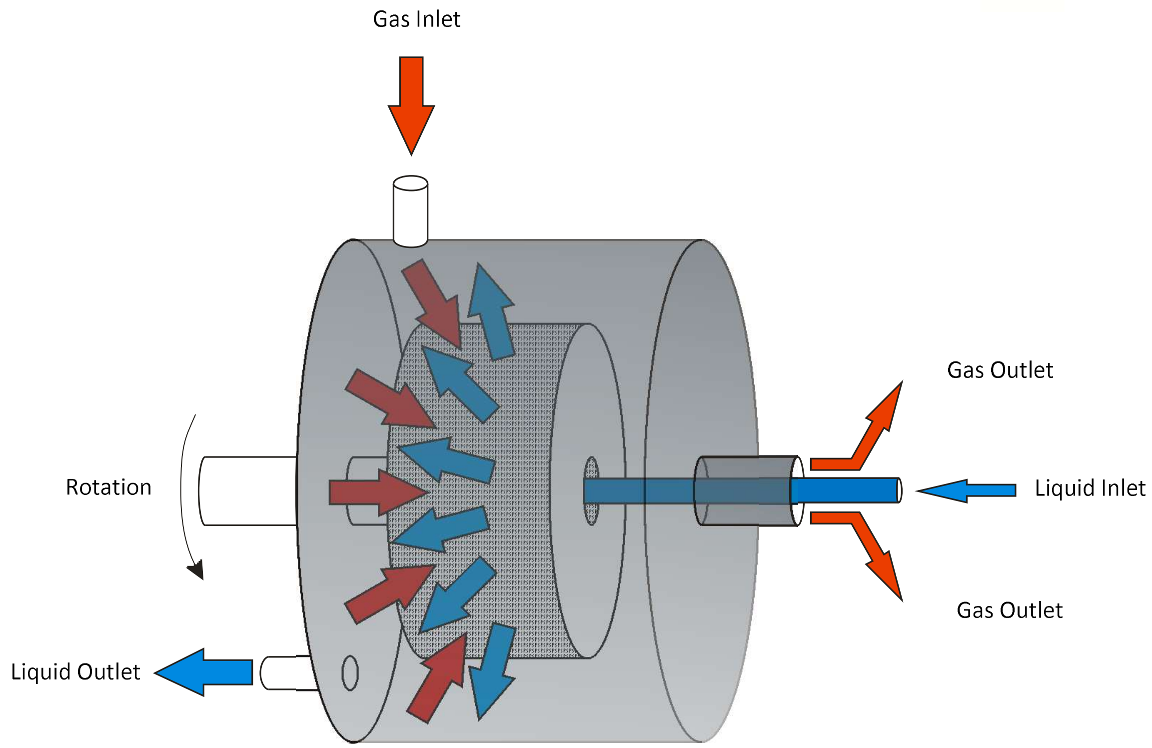


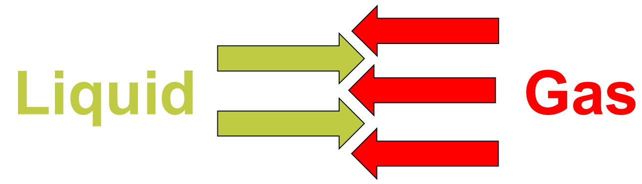

COUNTER CURRENT CONTACT

ROTA-CAP$^{tm}$ Absorber and Regenerator RPBs

# Technology Background

# RPB Absorber Background




COUNTER CURRENT CONTACT

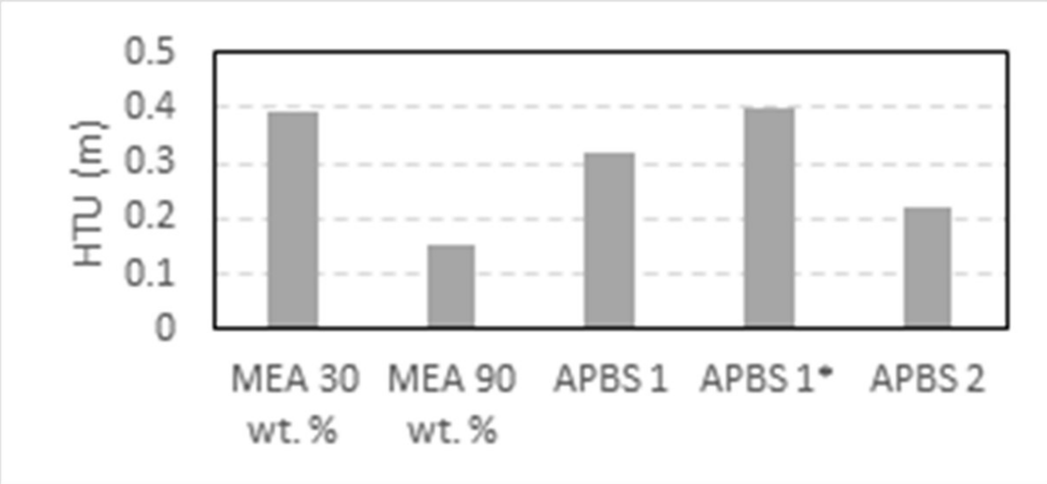
- Initial tests (UK) on laboratory prototype absorber performance measured mass transfer of CO2 (12 vol.%) into 4 solvent systems.
- Counter current contact:
  - Solvent distributed from inner radius to outer radius under centrifugal force generated by rotation of the packed bed.
  - Gas flows from outer radius to inner radius of packed bed.
- Absorber tests measurements:
  - Inlet and outlet gas phase CO2 concentrations
  - Inlet, outlet and sump solvent temperature
  - Gas and liquid flow rates
  - Speed of rotation

# Solvent Background

- 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

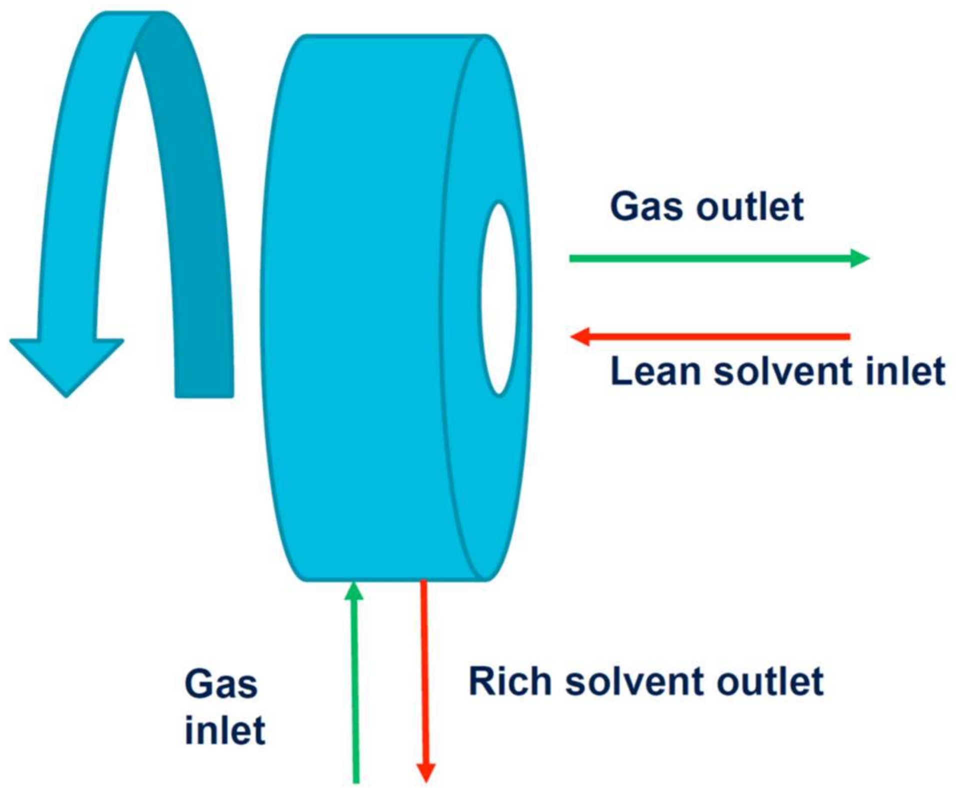



| Solvent | 30 wt.% MEA | APBS 2 |
|---|---|---|
| Absorber Type | Static | RPB |
| $CO_2$ in (mol.%) | 12.0 | 12.0 |
| $CO_2$ out (mol.%) | 7.2 | 7.2 |
| Packing Height (m) | 0.94 | 0.11 |
| Relative Size Reduction | Base | 8.5 |

# ROTA-CAP$^{tm}$

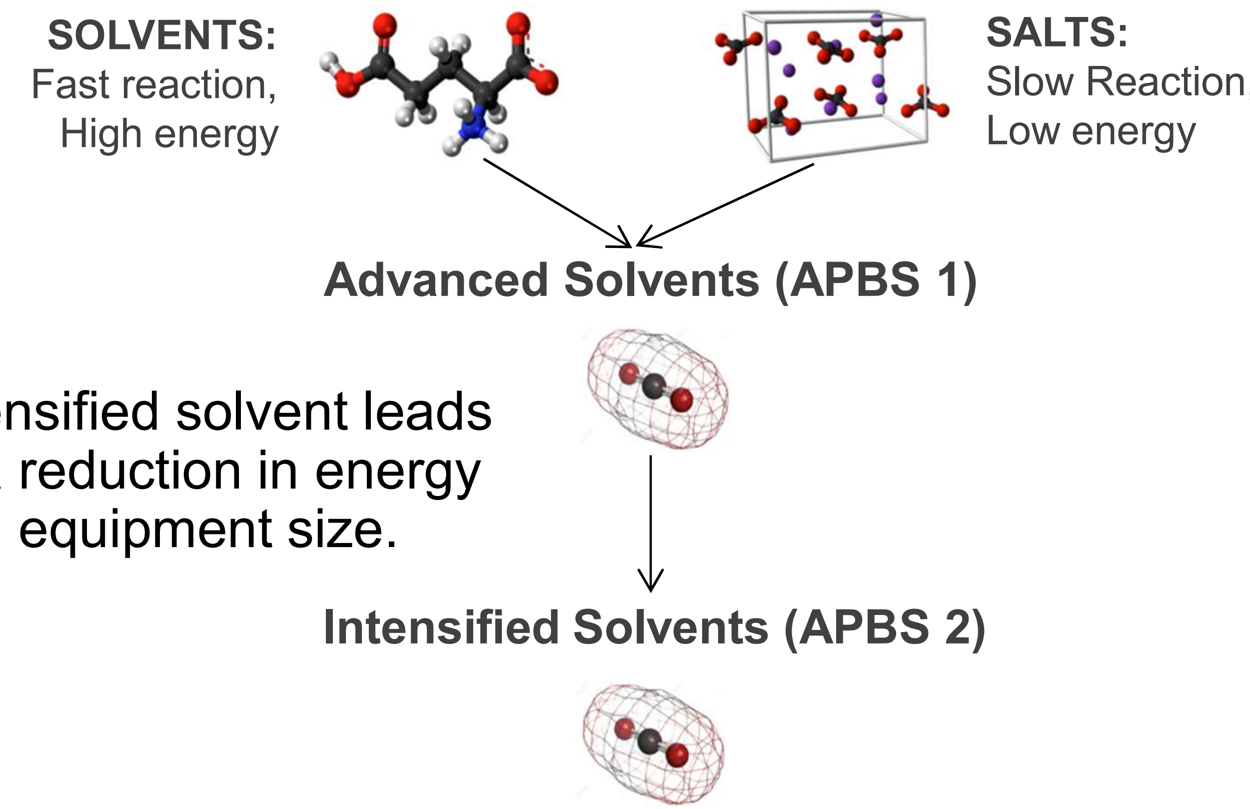
## ROTA-CAP EQUIPMENT

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.

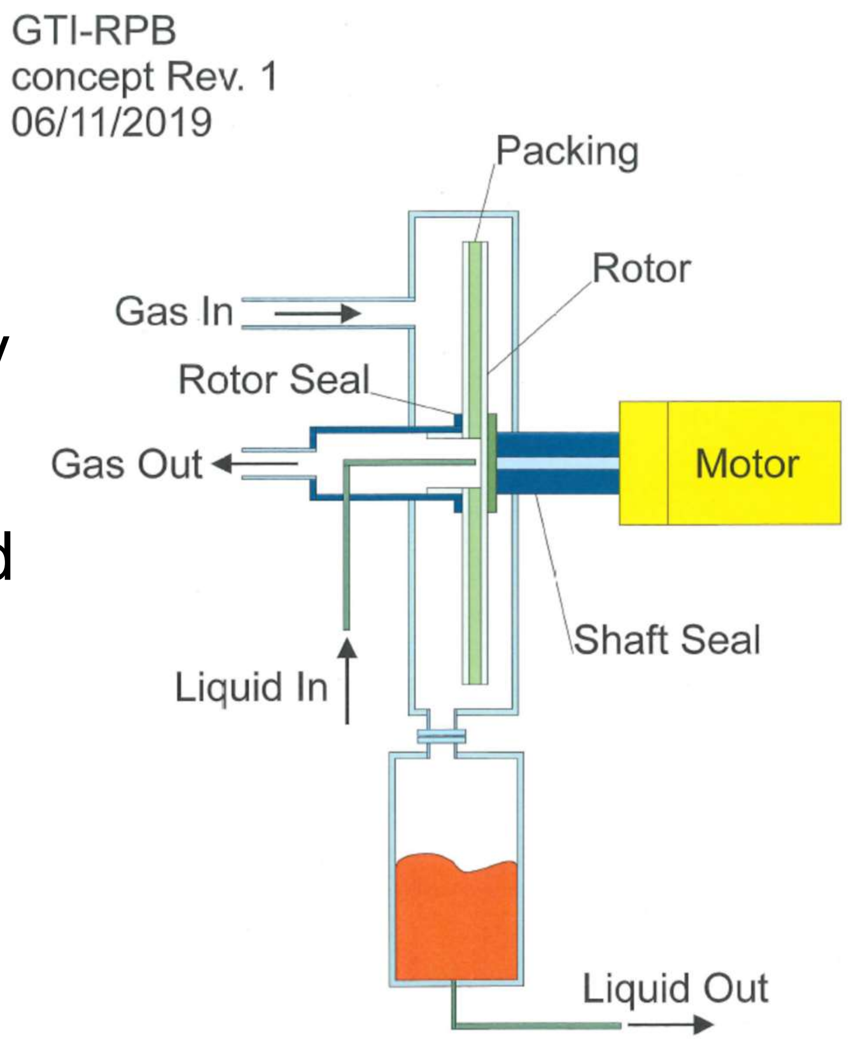



Intensified solvent leads to a reduction in energy and equipment size.

**RPB equipment with intensified solvent will improve typical economics**

# ROTA-CAP$^{tm}$: Rotating Packed Bed Design

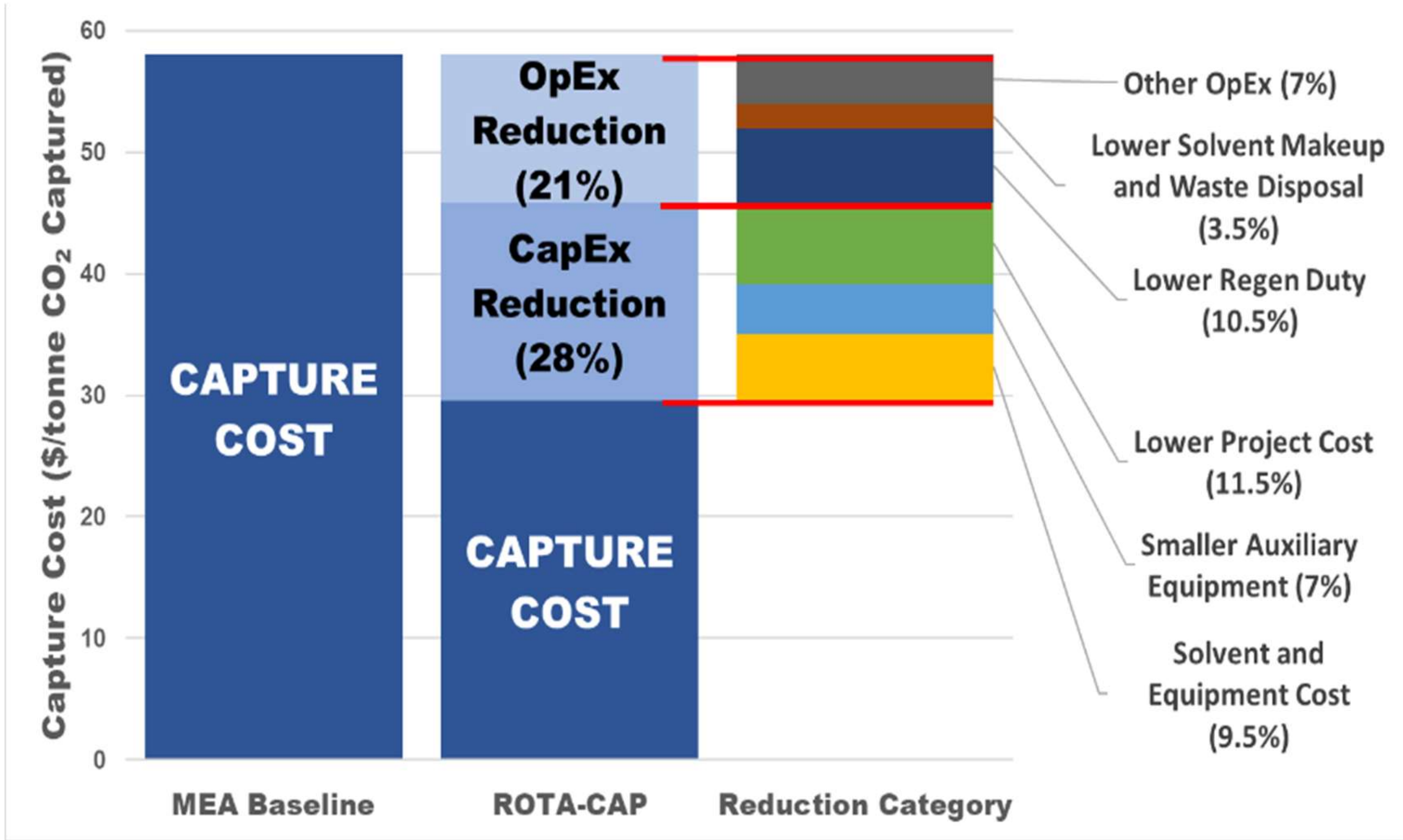
- GTI and its predecessor institutions GRI and IGT has experience on RPB process technology for natural gas dehydration and bulk acid gas removal process design and operation
- GTI Engineering Team reviewed mechanical requirements of the RPB sizing submitted by Carbon Clean.
- GTI prepared initial RPB design concept and mechanical design for rotating packed beds.
- Packing for RPB's are provided by Montz, Germany.




# Advantages Over Traditional Processes

- RPB technology reduces the size and therefore cost of the absorber. RPB regenerator size reduction is comparable to that of an RPB absorber

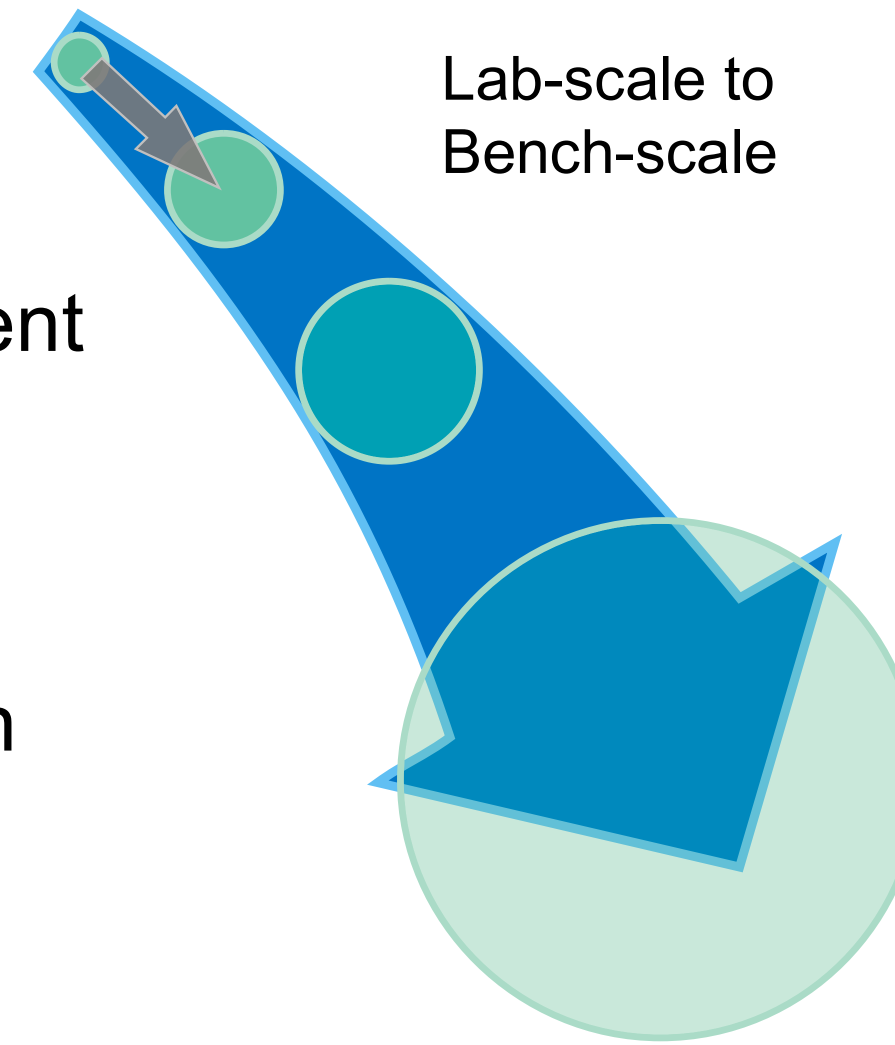
- Lower circulation rate reduces sizing requirements of heat exchangers, pumps, and coolers by up to 50%




- Lower residence time of the solvent in the absorber and lower reboiler duty reduces oxidative and thermal degradation by up to 77%

# 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



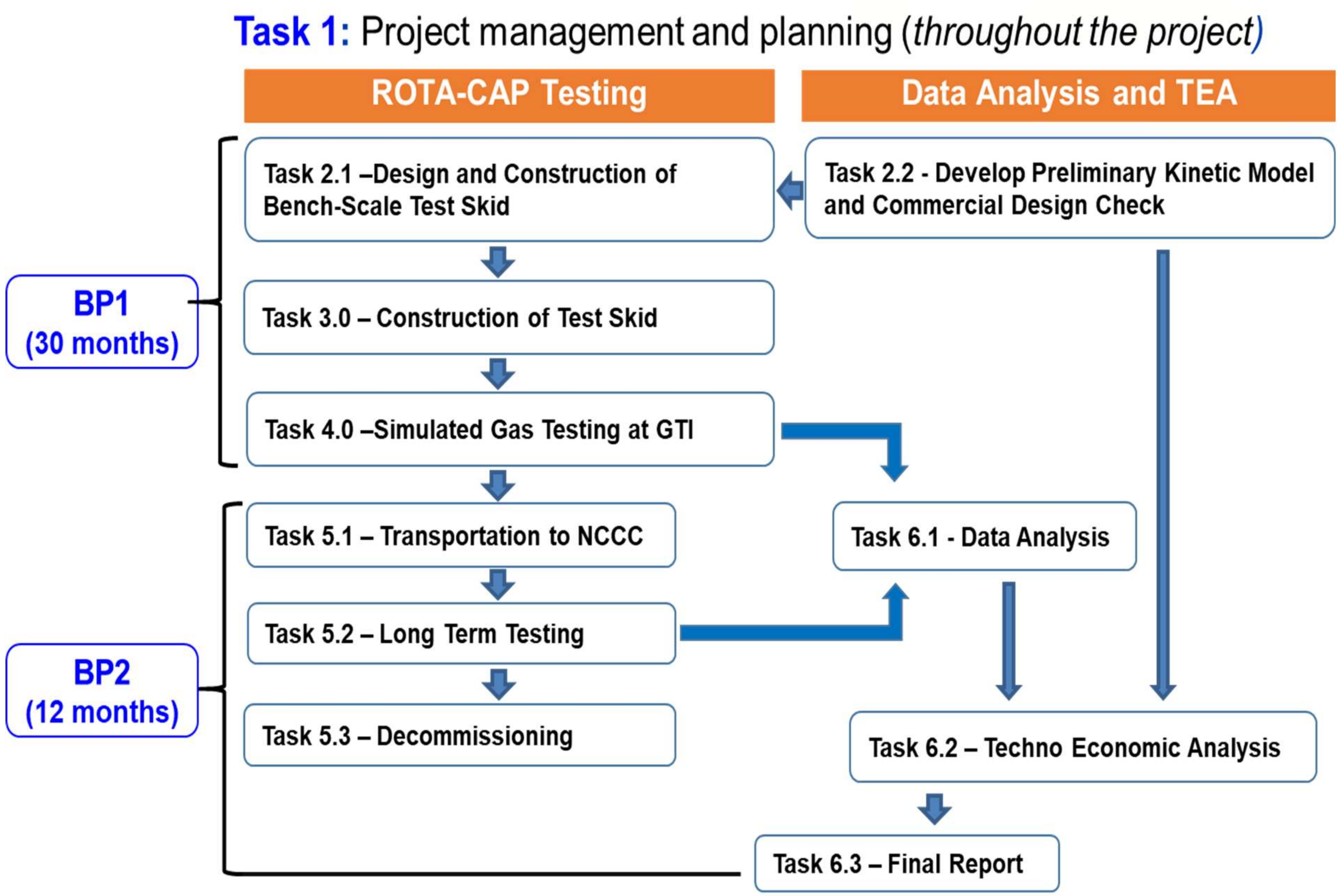
# Technical Approach

# Test Plan and Key Experimental Parameters

| Parameter | Range |
|---|---|
| Rotational Speed | 100–500 RPM |
| Absorber Liquid/Gas ratio | 0.5–5.0 kg/m3 |
| Solvent Circulation Rate | 30–150 kg/h |
| Solvent Concentration & Viscosity | 35–70 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 |

- 50kWe (1000kg/day $CO_2$ removal) scale integrated carbon capture skid
- Design, construct, test and model novel rotating packed bed (RPB) absorbers and regenerators
- Assess the performance of the integrated hardware and solvent under a range of operating conditions
- Test with simulated flue gas at GTI
- Long term test with real flue gas at the National Carbon Capture Center (NCCC)
- Test conventional column performance using NCCC's Slip Stream Test Unit (SSTU)

# Project Schedule and Milestones




| Milestones | Planned | Actual |
|---|---|---|
| Finish Construction of Test Skid | 2/8/21 | 2/12/21 |
| Start Parametric Testing | 2/15/21 | 2/28/21 |
| Develop Preliminary Kinetic Model | 8/1/19 | 6/1/19 |
| Update Kinetic Model Based on Experimental Data | 5/31/21 | 5/31/21 |
| Transport Skid to Host Site | 8/31/21 | |
| Start Long-Term Testing | 10/15/21 | |
| Verify Kinetic Model with Real Flue Gas Data | 3/31/22 | |

## Summary Schedule:

| | |
|---|---|
| 2019 Q1 – Q3 | Design Test Skid |
| 2019 Q4 – 2020 Q3 | Construct RPBs |
| 2020 Q4 – 2021 Q1 | Coplete Test Skid |
| 2021 Q1 – 2021 Q2 | Testing at GTI |
| 2021 Q3 | Transport to NCCC |
| 2021 Q3 – 2022 Q1 | Testing at NCCC |

# Success Criteria

| Decision Point | Date | Success Criteria |
|---|---|---|
| **Go / No-Go** | 3/31/2021 | • Complete design for bench scale ROTA-CAP$^{tm}$ skid utilizing continuous absorption-regeneration operation.<br>• Viable design for a commercial scale unit verified.<br>• Successful testing of the ROTA-CAP$^{tm}$ bench scale skid with RPB absorber and regenerator using simulated gas and natural gas burner flue gas:<br>1. Continuous operation with absorber and regenerator coupled together.<br>2. Quick startup and shutdown duration for the skid. |
| **Completion of the project** | 3/31/2022 | • Successful long duration testing:<br>1. Cumulative 1000 hr testing with real flue gas.<br>2. Minimal solvent carryover and degradation. |

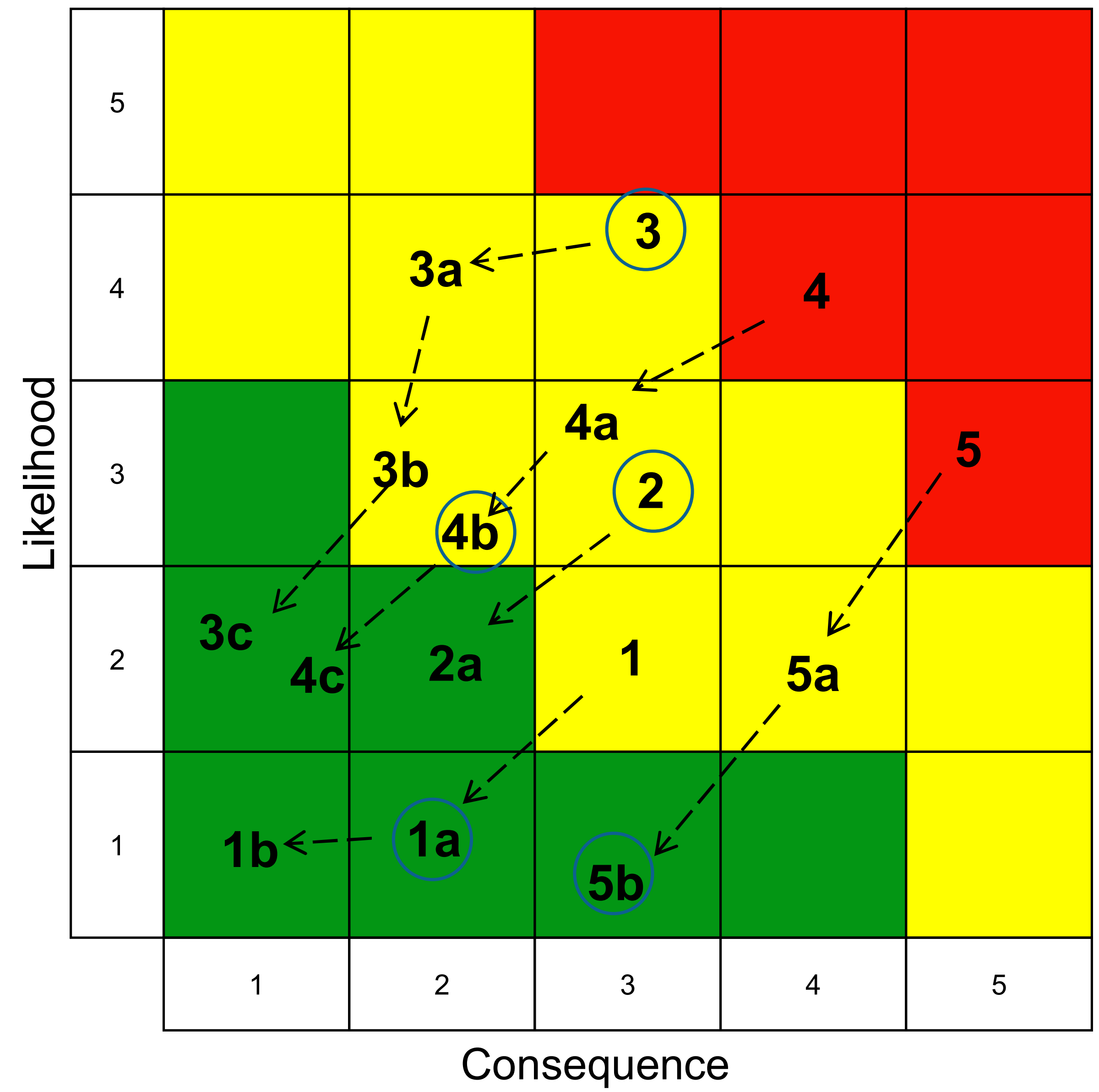
# Project Risks and Mitigation Strategies

## 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 operating conditions to achieve desired capture efficiency
   4c. Modify solvent concentration as necessary

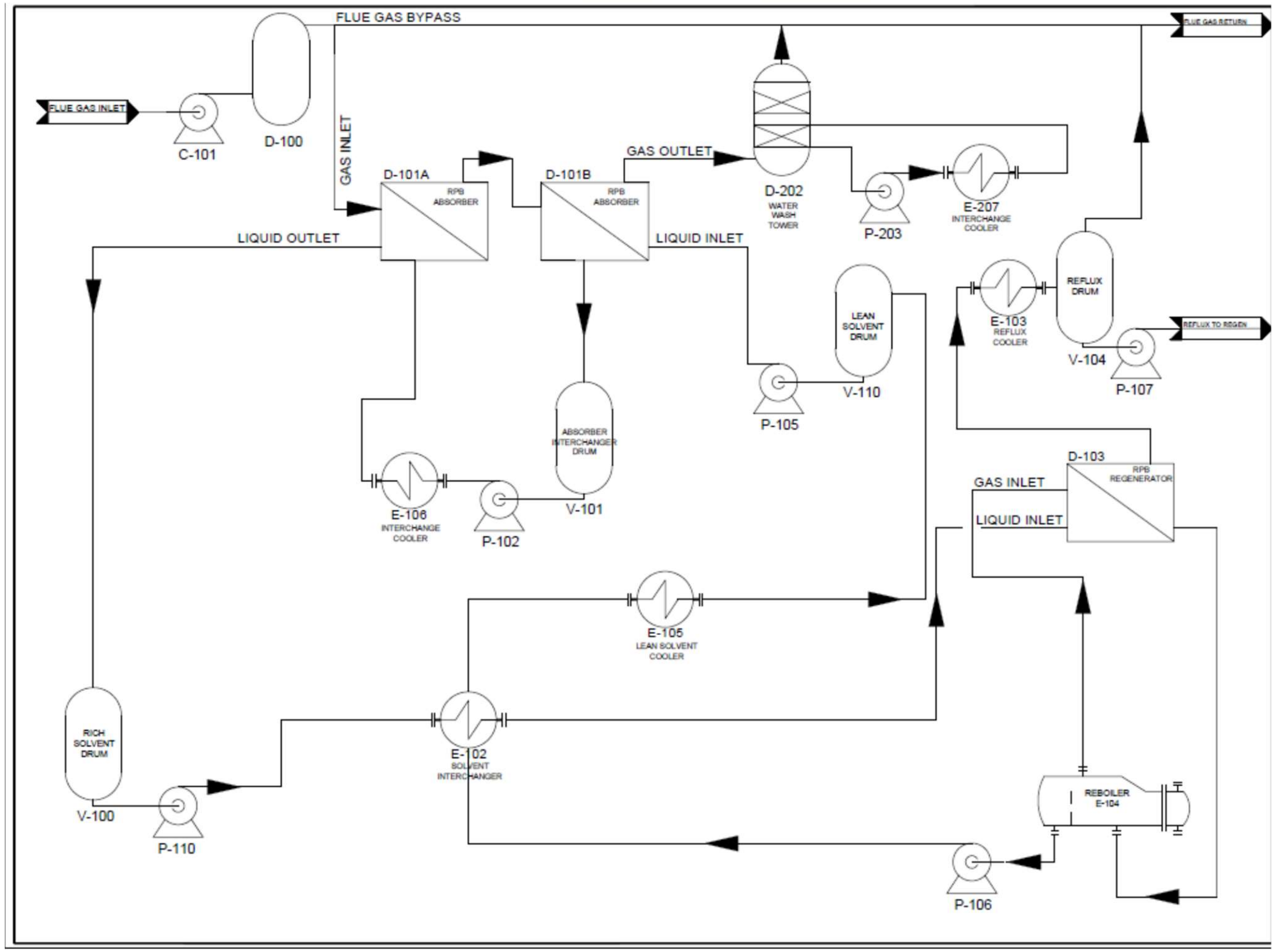
## Safety Risk:

5. **Rotating equipment related safety**
   5a. GTI Engineering Team has the tools and expertise to design and evaluate rotating equipment requirements.
   5b. GTI has access to prototype/one off design engineering facilities for design evaluation. RPB's use GTI's inhouse mechanical design.



# Progress and Current Status

# ROTA-CAP™ Process Flow Diagram (PFD)

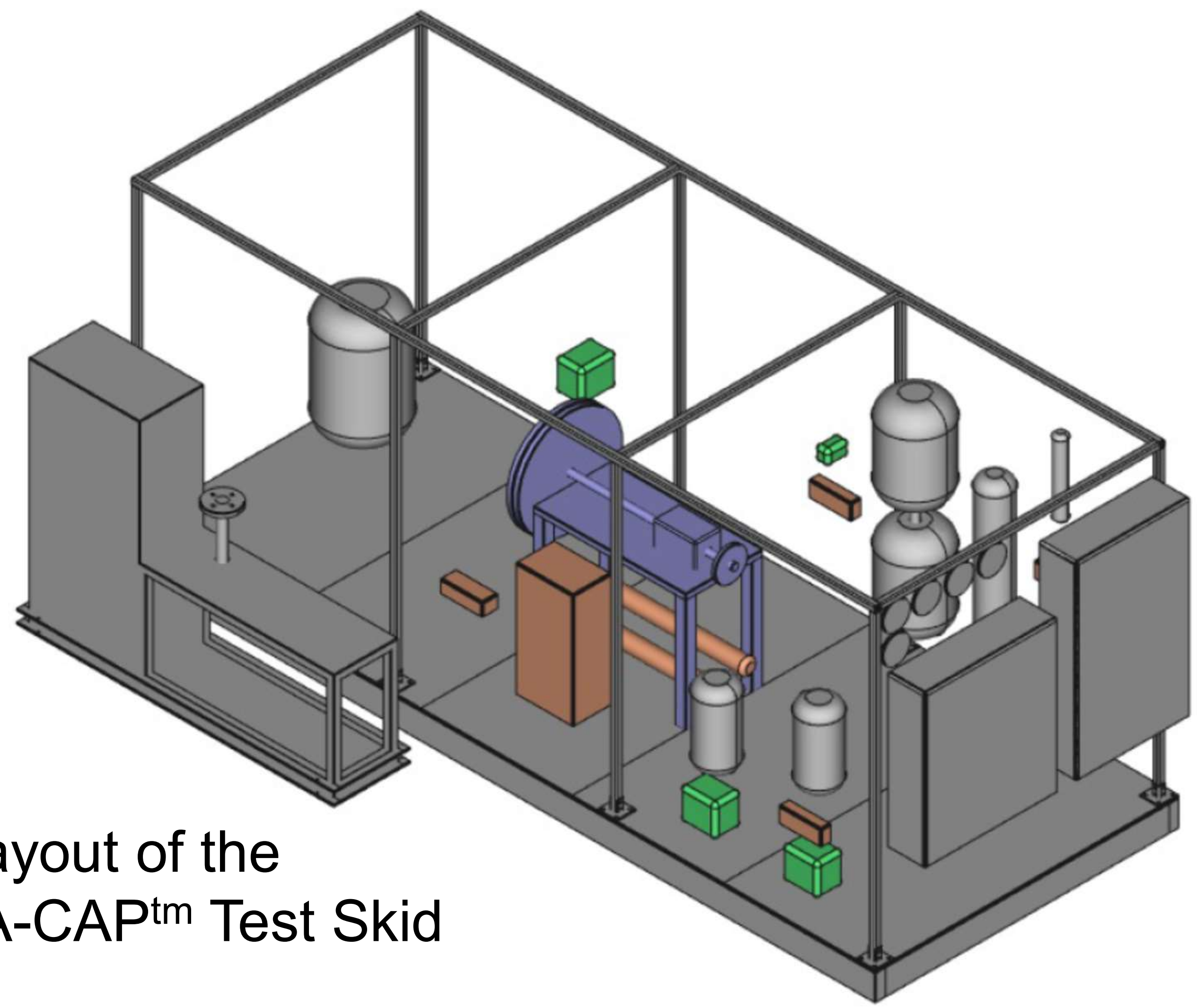



Simplified

ROTA-CAP$^{tm}$ PFD

ROTA-CAP$^{tm}$ has two stages of absorber RPB and one regenerator RPB with a separate reboiler.

# ROTA-CAP$^{tm}$ Test Skid and Layout

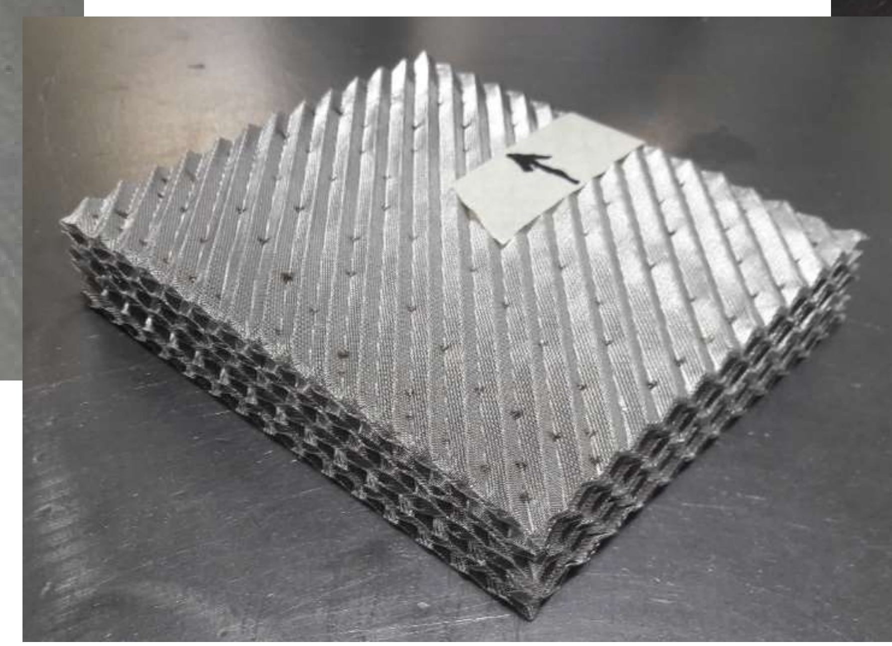


3D Layout of the
ROTA-CAP$^{tm}$ Test Skid

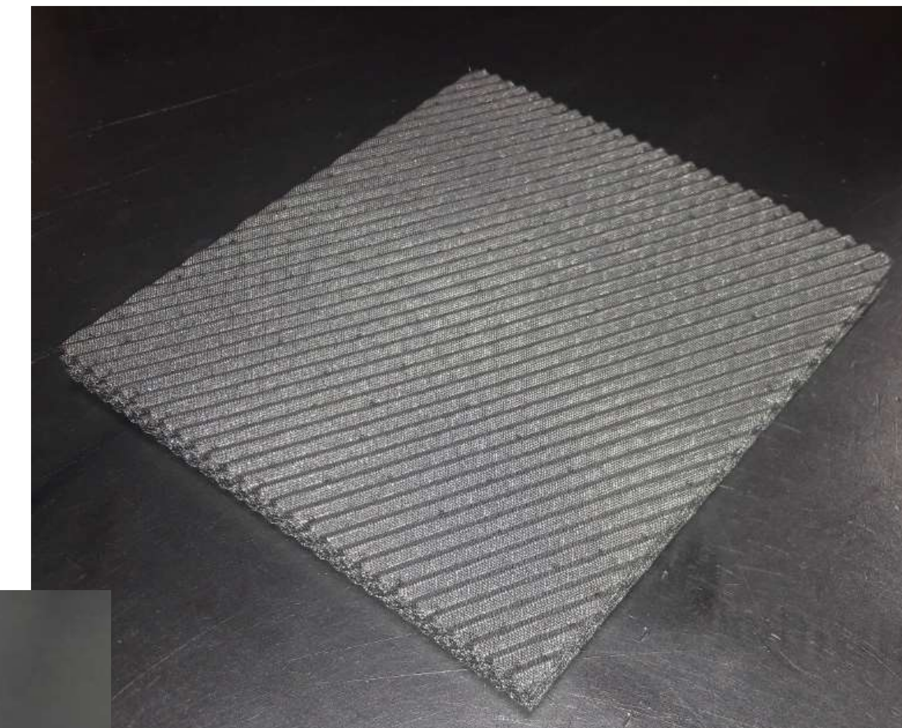
ROTA-CAP$^{tm}$ Power and Control Panels

# RPB Packing Material by Montz

Novel Packing Material for RPB
manufactured by Montz
(Low Density)



Mid Density Packing



High Density Packing

# Project DE-FE0031630 – Technical Updates


RPB Construction Inspection


RPB Delivery to GTI

# Project DE-FE0031630 – Technical Updates


Skid Construction at GTI

# Project DE-FE0031630 – Technical Updates


# Project DE-FE0031630 – Technical Updates

Absorber RPB's and Flue Gas Piping


ROTA-CAP$^{tm}$ Skid Before Shakedown

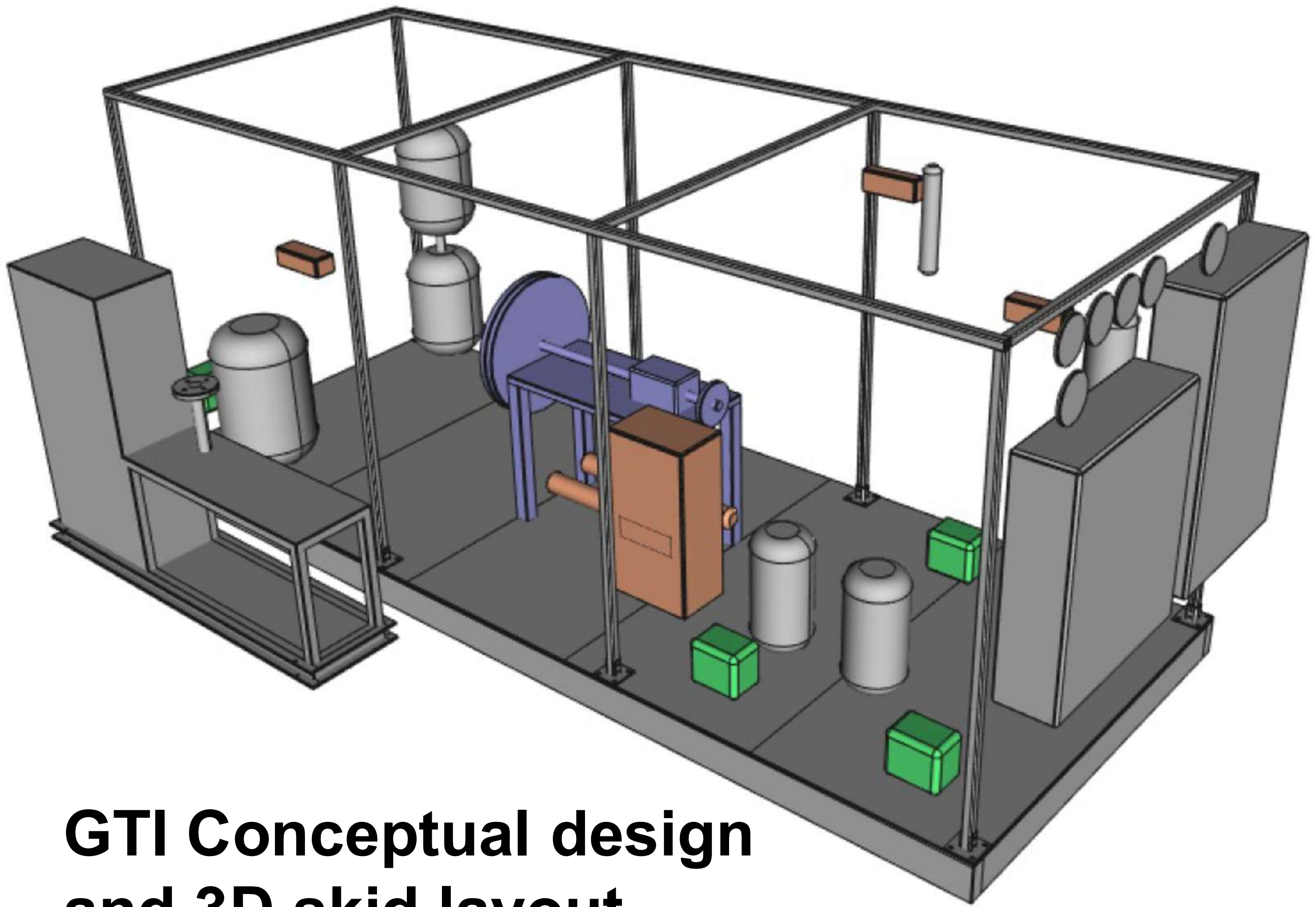
# ROTA-CAP$^{tm}$: Bench Scale Test Unit

**Experimental Development Unit**

- 1 ton $CO_2$ per day removal capacity
- Skid size is 20 feet x 8 feet x 8 feet (NOT OPTIMIZED)
- RPB diameter is about 1 meter

# ROTA-CAP$^{tm}$: Bench Scale Test Skid Design

Integrated (RPB absorber and RPB regenerator), Continuous, Bench-scale, 1 TPD test skid at GTI

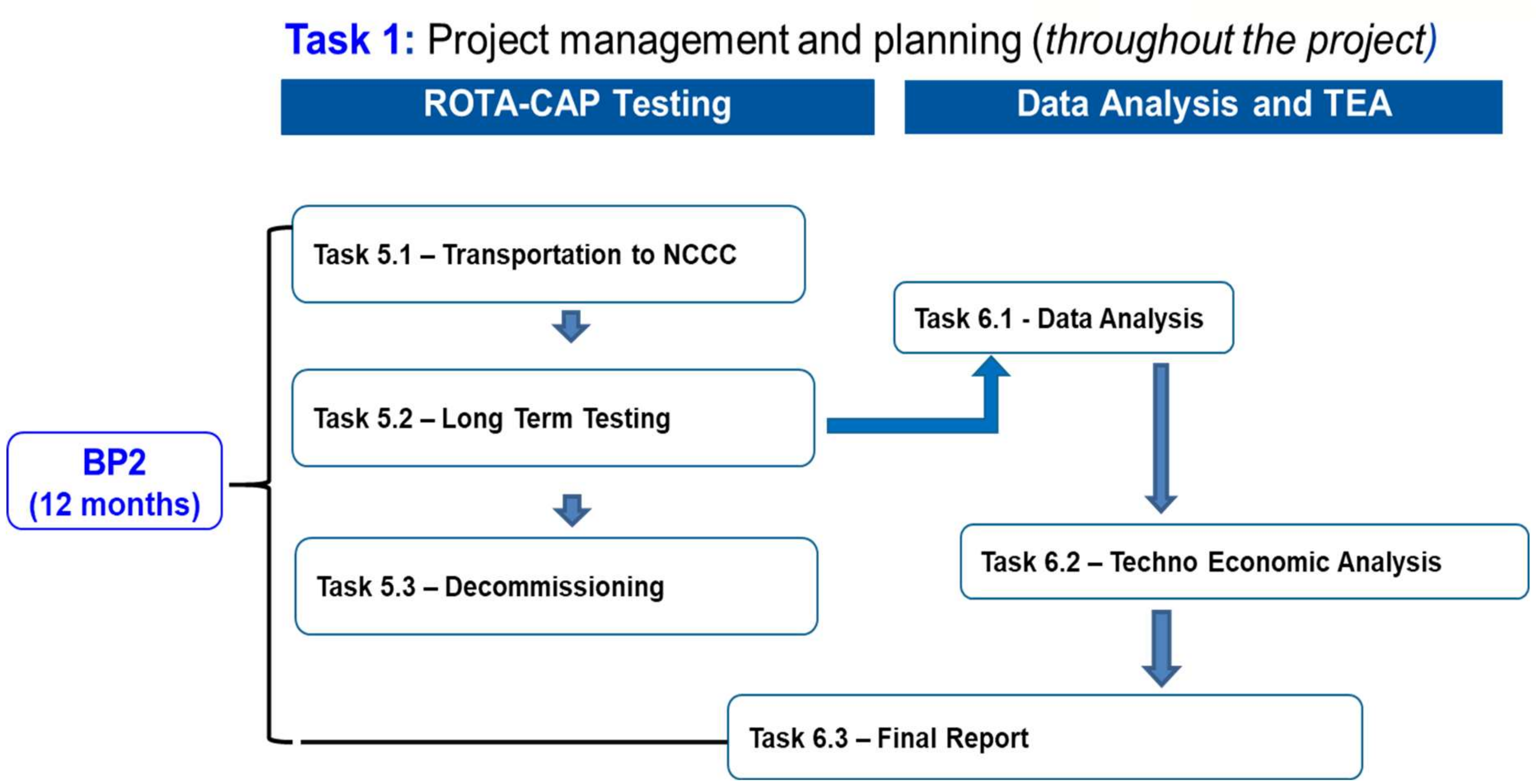


**GTI Conceptual design and 3D skid layout**

**Operational ROTA-CAP$^{tm}$ skid at GTI**

# Plans for Future Testing / Scale-Up

# Current Project BP2 Overview




| Success Criteria | Completion Date |
|---|---|
| Complete design for bench scale ROTA-CAP skid utilizing continuous absorption-regeneration operation. | 12/31/2019 |
| Viable design for a commercial scale unit verified. | 10/1/2020 |
| Successful testing of the ROTA-CAP bench scale skid with RPB absorber and regenerator using simulated gas:<br>• Continuous operation with absorber and regenerator coupled together.<br>• Quick startup and shutdown duration for the skid. | 5/31/2021 |

gti

# ROTA-CAP$^{tm}$: Future Projects and Scale Up Plan

- Evaluating different industrial emission sources for ROTA-CAP$^{tm}$ applications.
    - Steel
    - Concrete
    - Petrochemical

- Engineering scale development unit at 2.5 TPD proposed

- Next Scale-Up unit at 10 TPD is designed

- Modular expansion to 100 TPD commercial unit

# Summary of BP1 Work

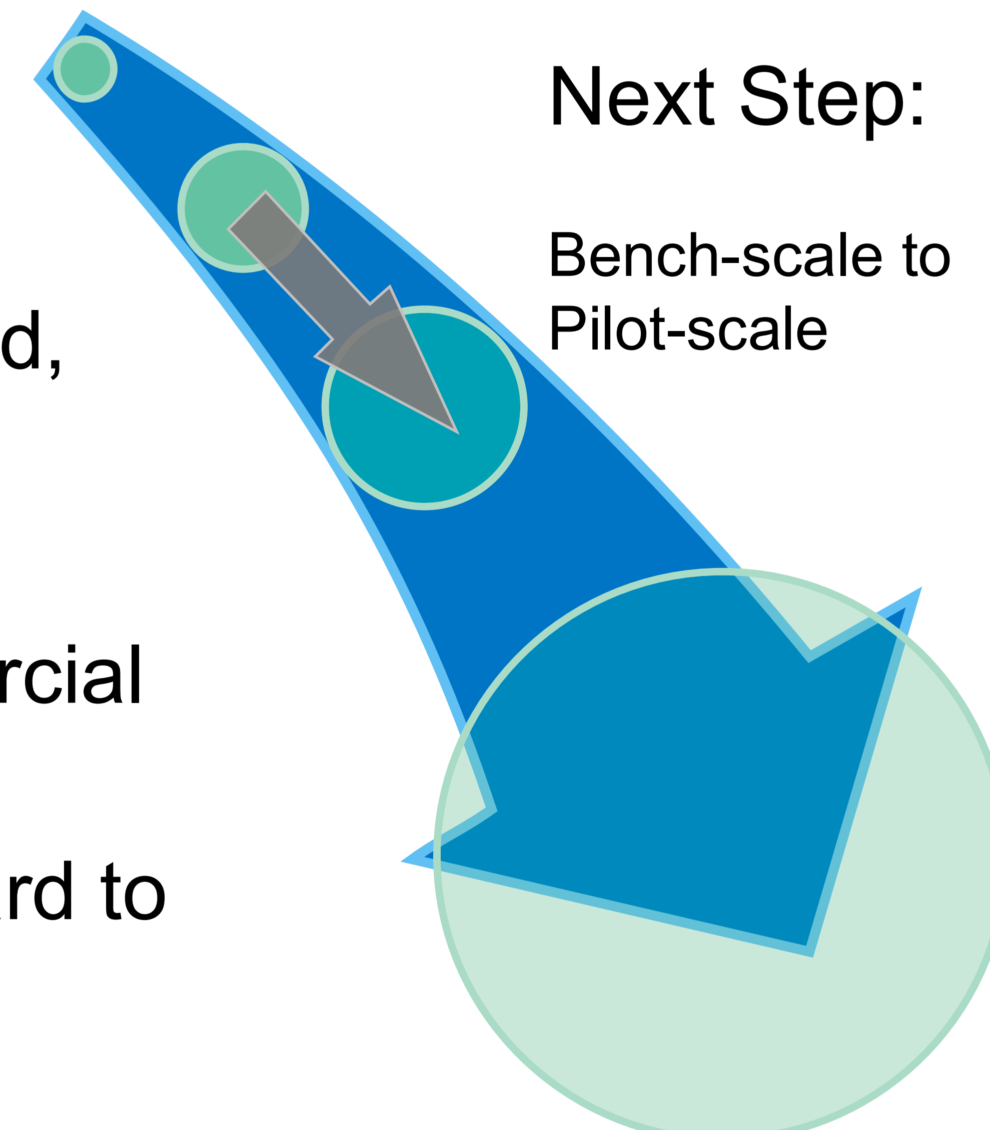
- ROTA-CAP[tm] process design was developed
- Packing material for RPBs fabricated and installed
- 2 stage RPB absorber and 1 stage RPB desorber designed and constructed
- ROTA-CAP[tm] skid constructed, commissioned and operated
- Parametric testing with simulated gas performed at GTI

# Summary:

- ROTA-CAP[tm] : More versatile process compared to other next generation $CO_2$ capture technologies

- RPB reactors are agnostic to the solvent used
- First RPB absorber AND RPB regenerator integrated, continuous, bench-scale $CO_2$ capture skid

- Challenges of scale up from bench-scale to commercial scale; Maybe limited to modular design approach
- Design of seals, wall effects and area affects are hard to determine for commercial scale



Next Step:

Bench-scale to Pilot-scale

# Acknowledgements

- Financial Support

U.S. DEPARTMENT OF ENERGY

NATIONAL ENERGY TECHNOLOGY LABORATORY

carbon clean
TECHNOLOGY TO ACHIEVE 'NET ZERO'

- DOE NETL

  Bruce Lani

  Andrew O'Palko

  Carl P. Laird

  Lynn Brickett

  José Figueroa

  Dan Hancu

- NCCC Team

NATIONAL CARBON CAPTURE CENTER

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# Turning Raw Technology into Practical Solutions

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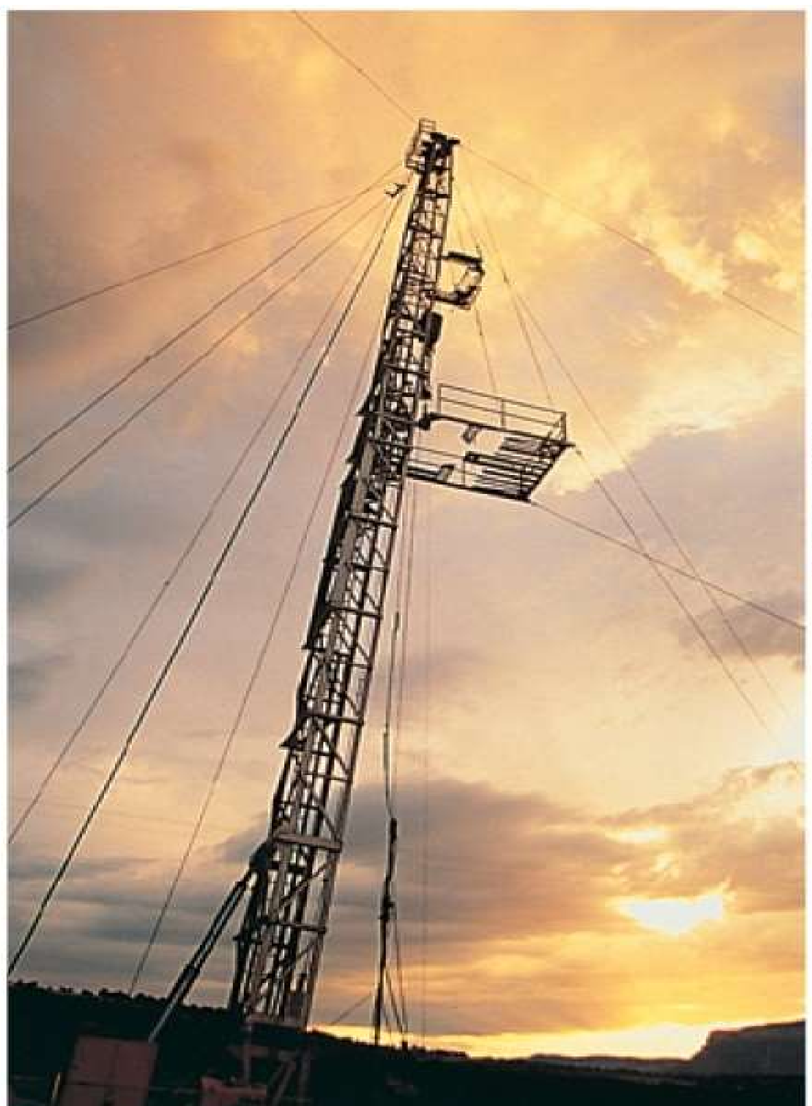


# Appendix



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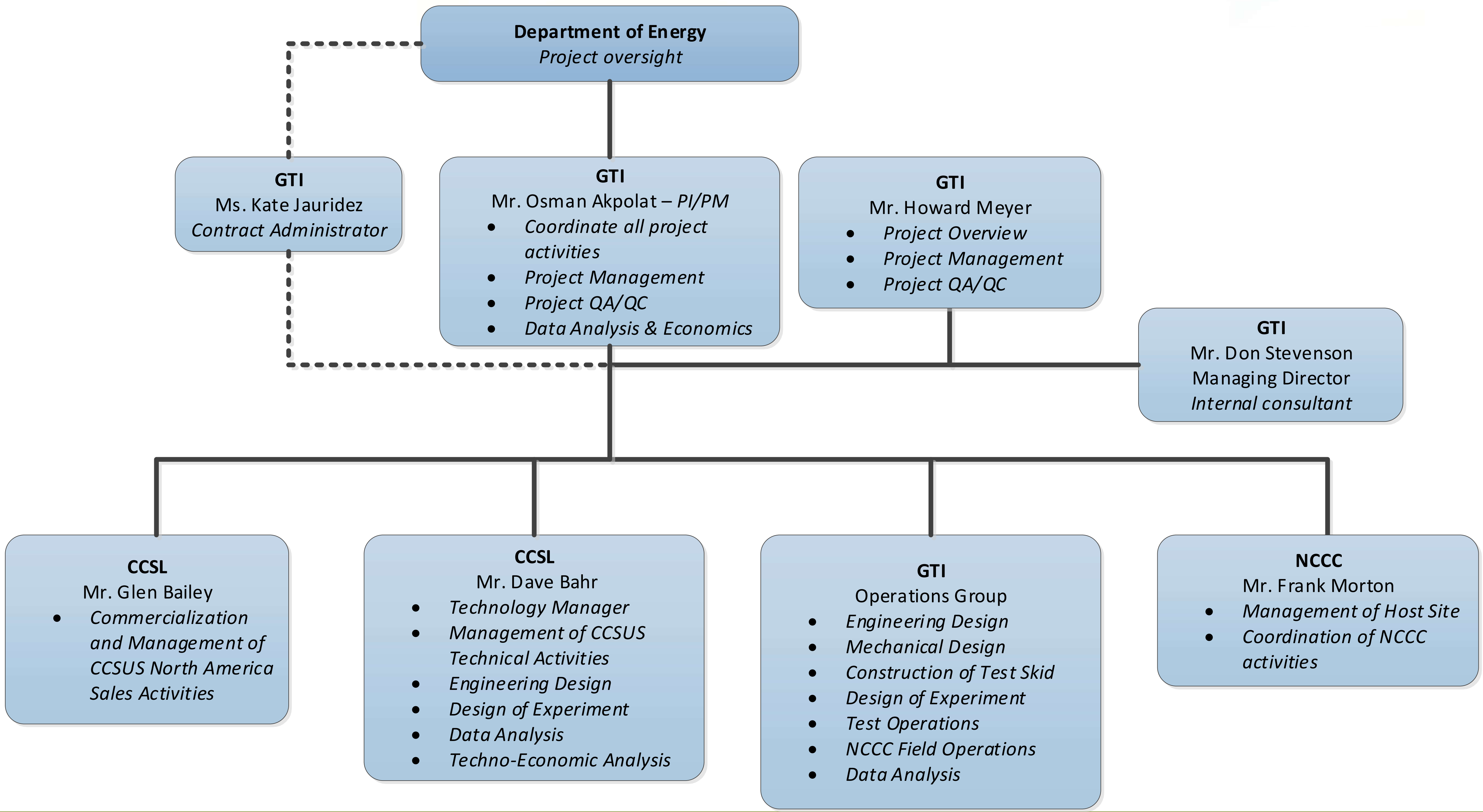
# Planned Project Team



# Project Schedule - Project DE-FE0031630

| ID | Task Name | Start | Finish |
|---|---|---|---|
| 1 | **Project Total** | **10/1/18** | **3/31/22** |
| 2 | **Budget Period 1** | **10/1/18** | **3/31/21** |
| 3 | Project Management and Planning (BP1) | 10/1/18 | 3/31/21 |
| 4 | Preliminary Commercial Design Check | 10/1/18 | 3/31/21 |
| 5 | **Design and Costing of the Bench-scale Test Skid** | **10/1/18** | **12/31/18** |
| 6 | Prepare PFD | 1/7/19 | 1/25/19 |
| 7 | Prepare P& IDs | 2/4/19 | 5/6/19 |
| 8 | Perform HAZOP at GTI | 6/3/19 | 6/7/19 |
| 9 | Perform HAZOP with NCCC | 7/22/19 | 7/26/19 |
| 10 | Finalize equipment and instrument lists | 6/17/19 | 6/28/19 |
| 11 | Prepare DRAFT RPB design | 6/3/19 | 8/9/19 |
| 12 | RPB Mechanical Design | 6/17/19 | 10/4/19 |
| 13 | Data Acquisition and Control system design | 8/5/19 | 9/13/19 |
| 14 | **Construction of Test Skid** | **6/1/19** | **1/31/21** |
| 15 | Construction of liquid ring blower | 6/10/19 | 9/2/19 |
| 16 | Procurement of Skid Equipment | 6/10/19 | 8/30/19 |
| 17 | Design and construction of reboiler | 7/8/19 | 9/13/19 |
| 18 | Skid frame construction | 7/8/19 | 8/16/19 |
| 19 | **BenchScale Unit Construction** | **10/7/19** | **10/2/20** |
| 20 | Control System and HMI Programming (GTI) | 2/15/20 | 5/31/20 |
| 21 | **PLC and Control System** | **1/1/20** | **7/31/20** |
| 22 | Control System Component Purchase | 1/1/20 | 3/31/20 |
| 23 | Control System Panel Fabrication (GTI) | 6/1/20 | 7/31/20 |
| 24 | **RPB Construction (Ability)** | **2/1/20** | **11/23/20** |
| 25 | RPB Packing Design (Montz-GTI) | 2/1/20 | 4/1/20 |
| 26 | RPB Packing Construction (Montz) | 4/1/20 | 7/15/20 |
| 27 | RPB Packing Shipment (Montz) | 7/27/20 | 7/31/20 |
| 28 | RPB Final Assembly (Ability) | 8/3/20 | 10/28/20 |
| 29 | RPB Delivery (Ability) | 11/23/20 | 11/23/20 |
| 30 | High Voltage Control Enclosure Fabrication (Wesa) | 5/15/20 | 6/30/20 |
| 31 | Electrical Wiring Installation (Wesa) | 1/11/21 | 2/1/21 |
| 32 | Test skid Assembly (GTI) | 11/23/20 | 2/15/21 |
| 33 | Skid Shakedown (GTI) | 2/16/21 | 3/1/21 |
| 34 | **Parametric Testing with Simulated Gas** | **11/11/19** | **3/31/21** |
| 35 | Test Matrix Development | 9/1/19 | 9/30/19 |
| 36 | Test Matrix Review | 4/1/20 | 9/30/20 |
| 37 | Simulated Gas Test Campaign | 3/2/21 | 3/31/21 |
| 38 | Data Analysis and Long-term Testing Planning | 1/15/21 | 3/31/21 |
| 39 | GO / NO-GO Decision Point | 3/31/21 | 3/31/21 |
| 40 | **Budget Period 2** | **4/1/21** | **3/31/22** |
| 41 | Start BP2 | 4/1/21 | 4/1/21 |
| 42 | Project Management and Planning (BP2) | 4/1/21 | 3/31/22 |
| 43 | Transportation and Commissioning | 4/1/21 | 7/1/21 |
| 44 | Reliability and Operability Testing | 7/2/21 | 12/29/21 |
| 45 | Decommissioning | 12/30/21 | 3/31/22 |
| 46 | Data Analysis, TEA, and Final Report | 7/2/21 | 3/31/22 |