Membrane-Sorbent Hybrid System for Post-Combustion CO_2 Capture

(Contract No. DE-FE-0031603)

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Project Kick-off Meeting

October 1, 2018

TDA Research Inc. • Wheat Ridge, CO 80033 • www.tda.com

Project Objective

- **Project objective is to design and construct a 1 MW scale membrane-sorbent hybrid post-combustion carbon capture system and evaluate its operation in a long duration field test using flue gas**
- **Hybrid process consists of a polymeric membrane and a low temperature physical adsorbent to remove CO_2 from the flue gas**
  - **Membrane is being developed by MTR**
  - **Adsorbent has been developed by TDA for post-combustion capture**
  - **Early proof-of-concept demonstrations in an SBIR Phase II/IIB project (DE-SC0011885) proved the feasibility of the hybrid system**

Main Project Tasks

BY1	**- Design of the 1 MW scale test unit**
	- Design review
	- Preliminary Techno-economic analysis
BY2	**- Fabrication of the test unit**
	- Site Preparation, Installation and Shakedown Tests
BY3	**- Field Tests (6-12 months duration)**
	- High Fidelity Techno-economic analysis

TDA RESEARCH

Project Team

NATIONAL ENERGY TECHNOLOGY LABORATORY

TDA RESEARCH

MTR Membrane Technology & Research

UNIVERSITY of CALIFORNIA • IRVINE

gti

TECHNOLOGY CENTRE MONGSTAD

Project Duration

- **Start Date = August 17, 2018**
- **End Date = August 16, 2021**

Budget

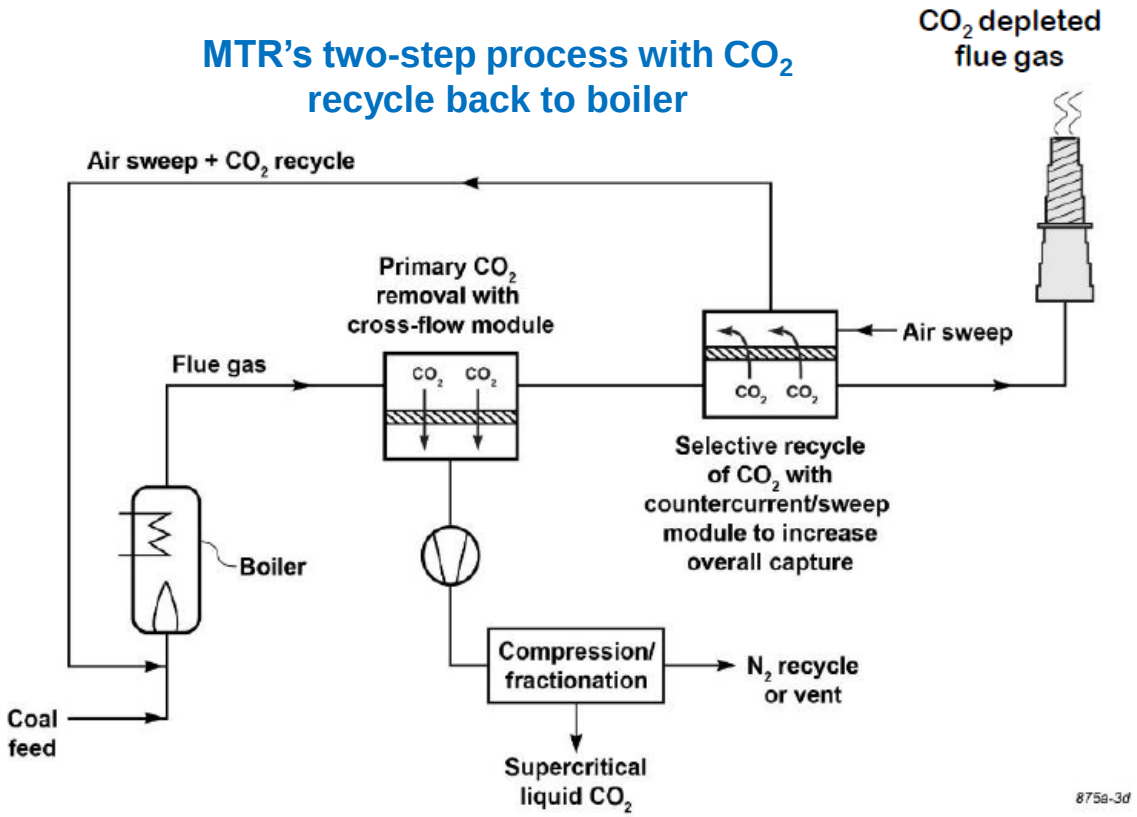
- **Project Cost = $10,000,025**
- **DOE Share = $8,000,000**
- **TDA and its partners = $2,000,025**

TDA RESEARCH

Two-Stage Membrane Approach

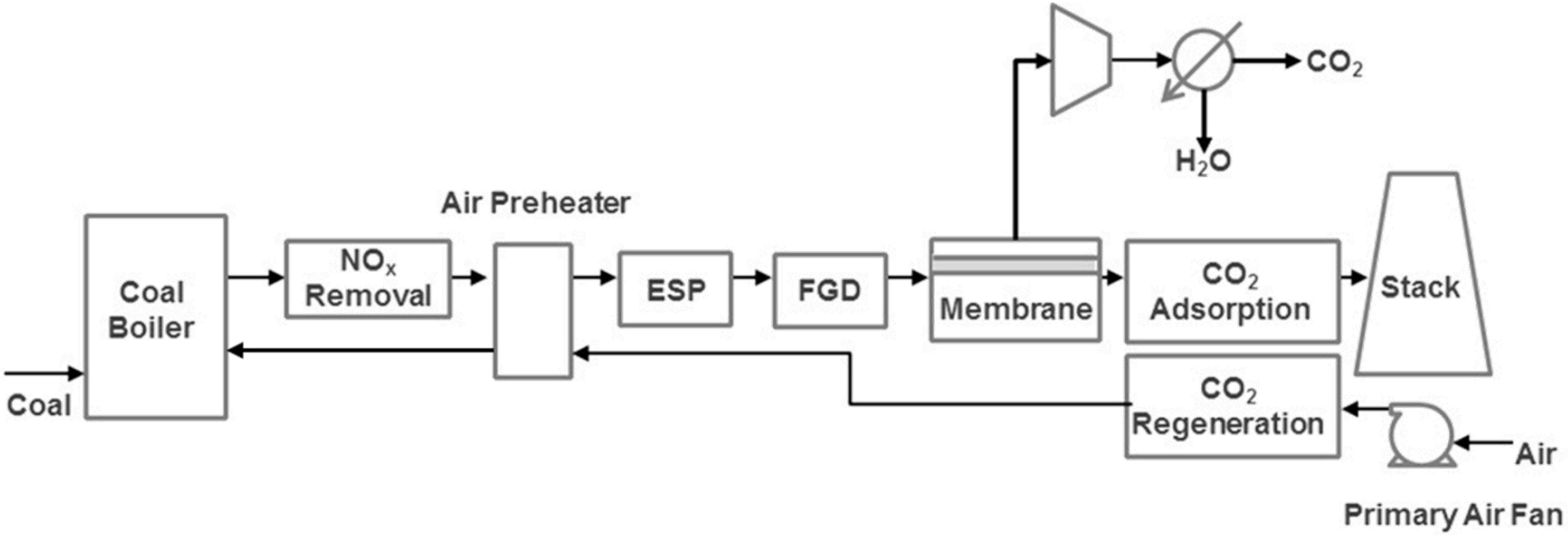
- **Two membranes in series**
  - Primary membrane to remove ~50% of the CO_2 in the flue gas
  - Secondary membrane uses air sweep to reduce the CO_2 released
- **Advantages**
  - Avoids high vacuum needed to achieve high CO_2 removal efficiency
  - Boiler to generate a high CO_2 flue gas
- **Challenges**
  - The need to pressurize the flue gas to ~2-3 atm for reasonable performance in secondary membrane
  - High pressure drop in secondary membrane
  - Oxygen transfer from boiler air intake into the flue gas

MTR's two-step process with CO_2 recycle back to boiler



U.S. Patents 7,964,020 and 8,025,715

Hybrid Membrane Sorbent Process



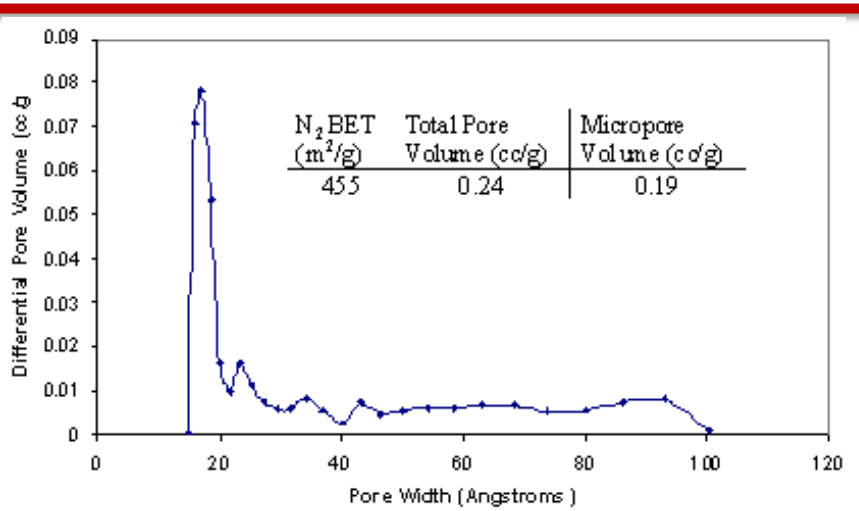
- **Membrane operates at ~50°C under mild vacuum, (~0.3 atm) removes ~50% of CO_2 and almost all water**
  - TDA's sorbent removes remaining CO_2 in the membrane effluent (retentate) ensuring 90% carbon capture
  - The boiler feed air is used as a sweep gas to facilitate sorbent regeneration
  - Low pressure drop
  - TDA's sorbent is less affected by the low P_{CO2} in the second stage
  - Greatly reduced oxygen transfer (from the air side to flue gas side)

TDA Sorbent

- **TDA's uses a mesoporous carbon modified with surface functional groups that remove CO_2 via strong physical adsorption**
  - CO_2-surface interaction is strong enough to allow operation at low partial pressures
  - Because CO_2 is not bonded, the energy input for regeneration is low
- **Heat of CO_2 adsorption is 4-5 kcal/mol**

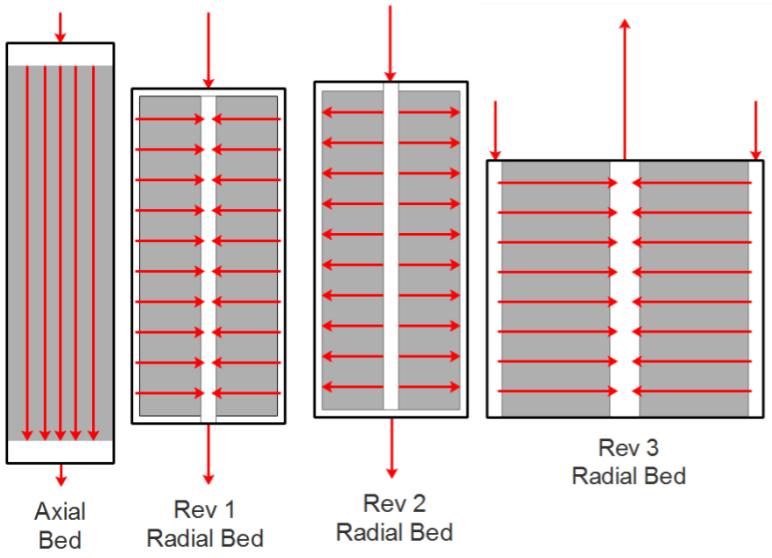
Sorbent optimization and production scale-up was completed in a separate DOE project (DE-0013105)

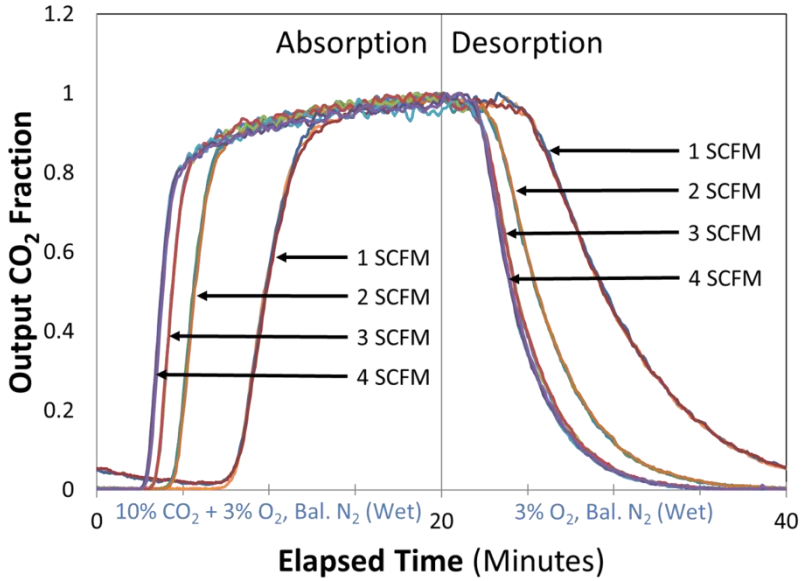
US Patent 9,120,079, Dietz, Alptekin, Jayaraman "High Capacity Carbon Dioxide Sorbent", US 6,297,293; 6,737,445; 7,167,354

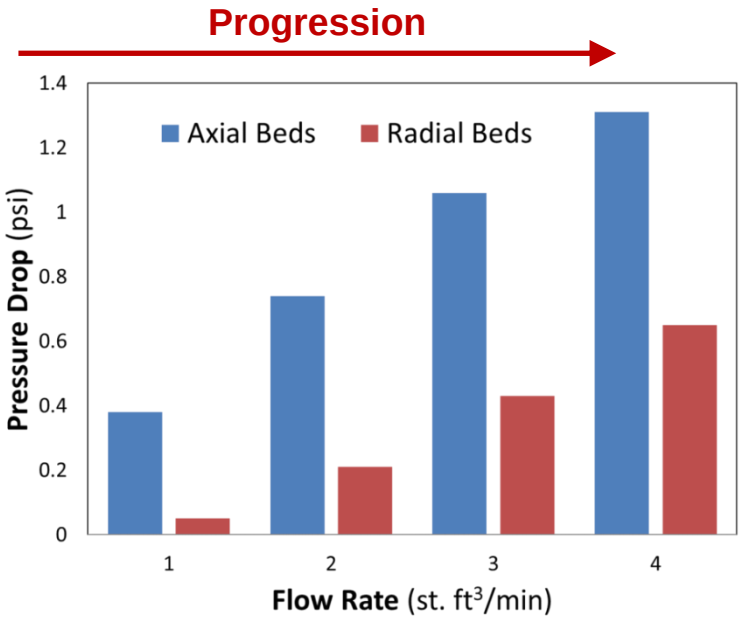


Sorbent operation in a VSA system was successfully demonstrated with actual flue gas (DE-0013105)

Radial Flow Contactors

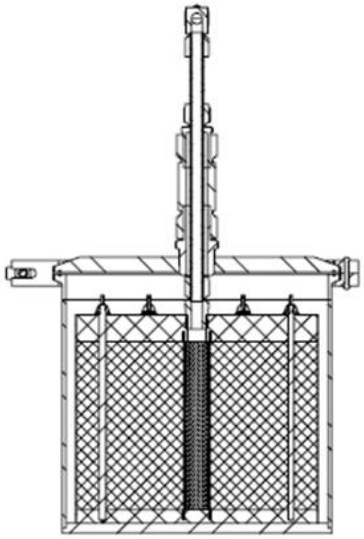


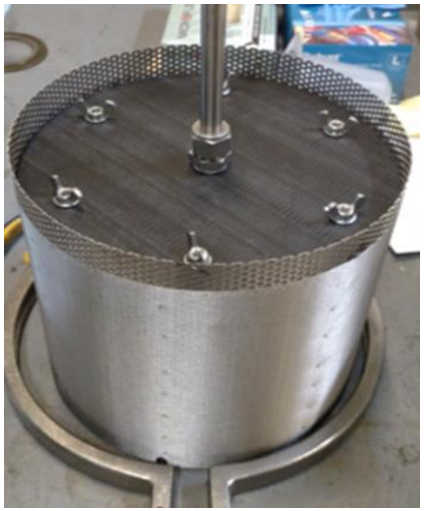




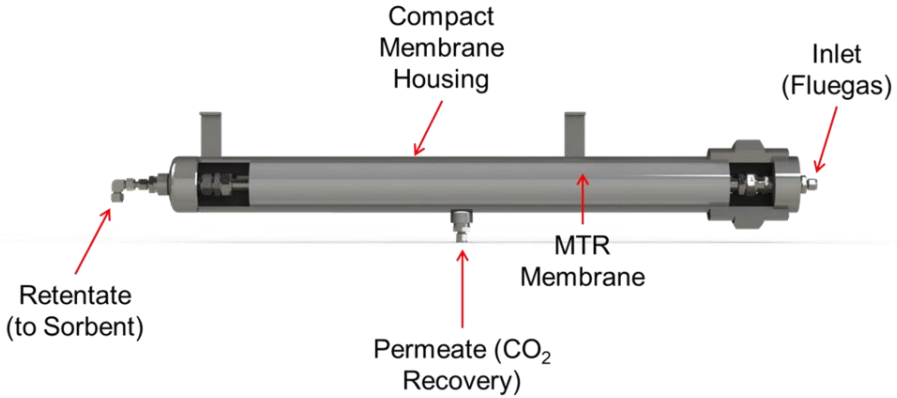
- TDA has developed a radial flow contactor concept to increase viability of using sorbents in fixed-beds for post-combustion capture
  - Reduces the pressure drop through the beds
  - Allows rapid sorbent regeneration

Concept Demonstration Under SBIR Phase II

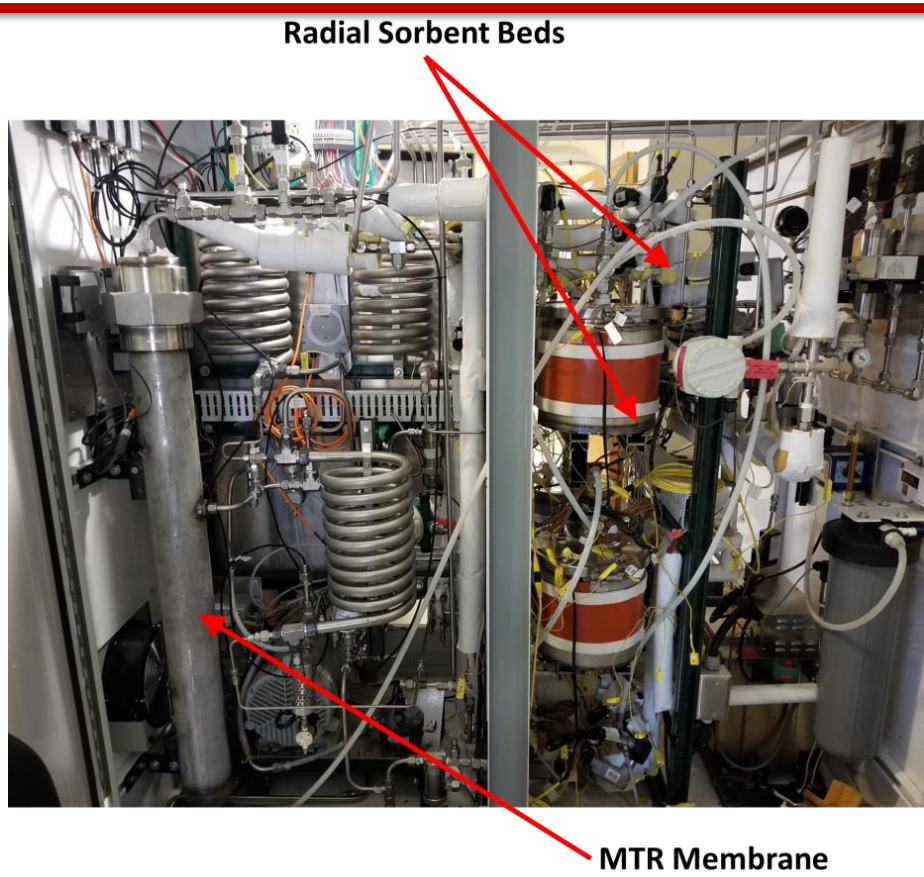




TDA's Rev 3 Radial Flow Sorbent Reactors



MTR's Membrane Module



Lab and field tests at 2-4 scfm (20-40 kg/day CO_2) scale with coal-derived flue gas at Western Research Institute (Laramie, WY)

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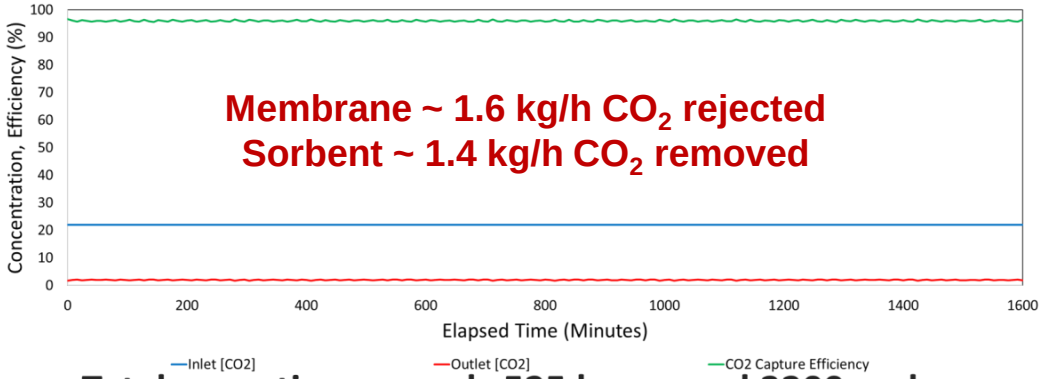
Test Results at WRI

Continuous 4-Bed Cycling Performance (Cycle# 2,000 -2,160)



Total operation exceeds 525 hours and 3200 cycles

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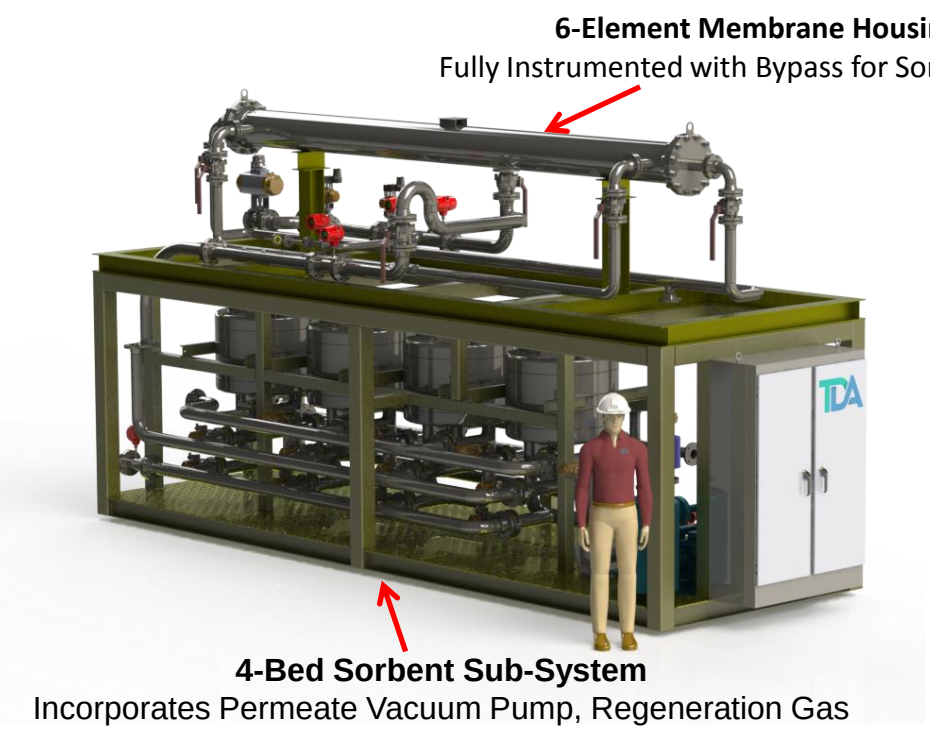
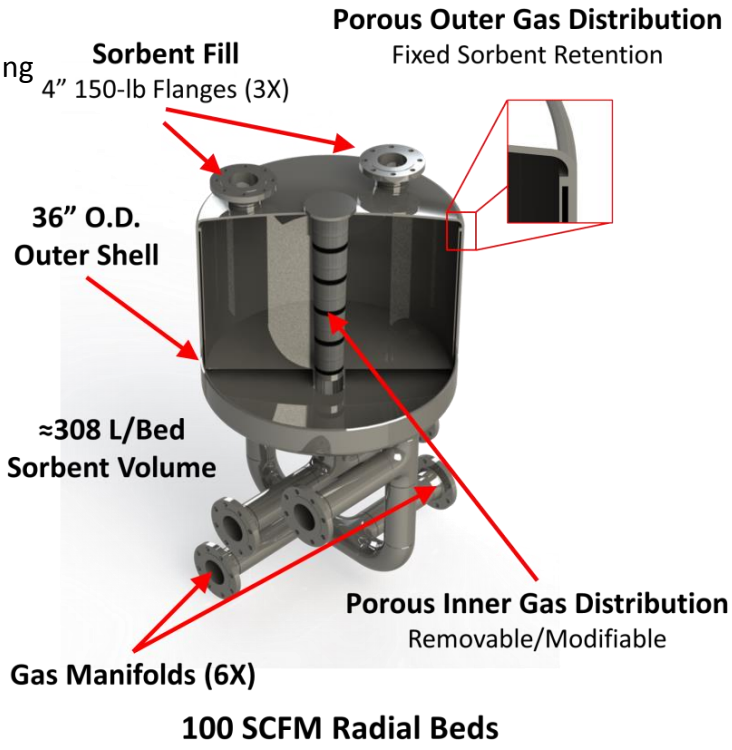
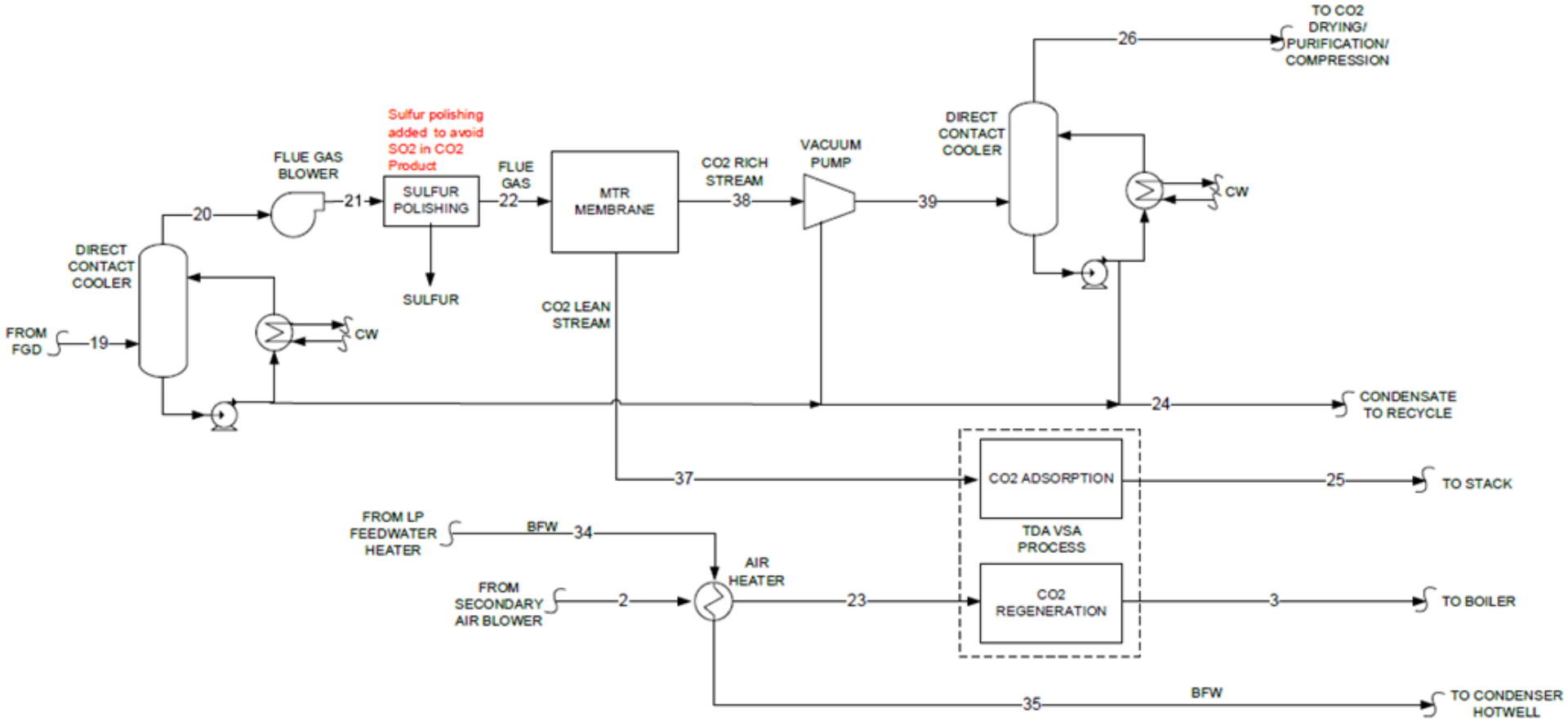
50 kW Module Hybrid System





- **In SBIR Phase IIB project TDA and MTR is developing a ~50 kW hybrid membrane-sorbent system**
- **While the system has 4-beds with a different internals for flow distribution, this unit will run two-bed cycle sequence to gain experience**
- **Field test scheduled in summer of 2019 at the Wyoming Integrated Test Center at Basin Electric Power Cooperative Dry Fork Station near Gillette, WY**

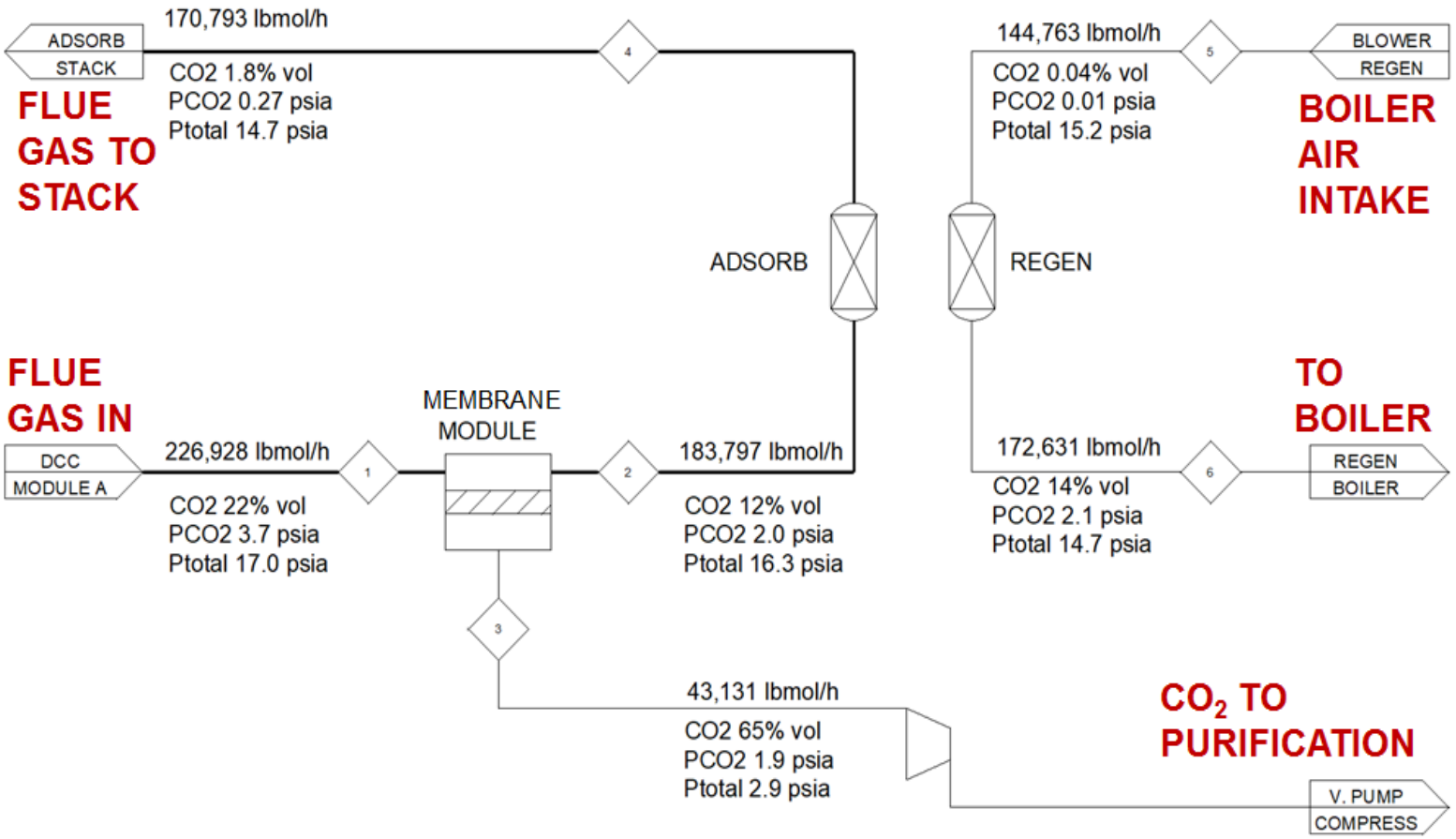
Process Flow Diagram



Key features of the Hybrid CO_2 Capture System

- **Reduced flue gas pressurization**
- **Minimal flue gas treatment**

Stream Data



- **About 50% of the CO_2 removed in the 1st membrane stage**
- **Rest of the CO_2 transferred from flue gas to the boiler feed air**
  - Greater than 90% carbon capture

Preliminary TEA

- **TEA for sub- and super-critical power plants suggest substantial improvement in cycle efficiency for the new hybrid technology**

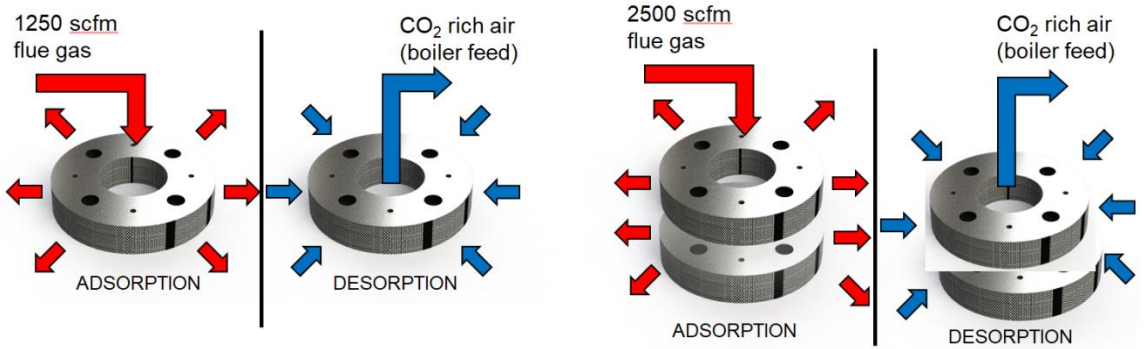
Power Plant Type	Sub-critical Pulverized Coal fired Power Plant			Super-critical Pulverized Coal fired Power		
CO_2 Capture Technology	No Capture Case DOE Case 9	Reference Amine DOE Case 10	MTR-TDA Membrane Hybrid System	No Capture Case DOE Case 11	Reference Amine DOE Case 12	MTR-TDA Membrane Hybrid System
CO_2 Capture, %	0	90	90	0	90	90
Gross Power Generated, kW_e	582,600	672,700	704,312	580,400	662,800	694,044
Auxiliary Load, kW_e	32,580	122,740	154,352	30,410	112,830	144,044
Net Power, kW_e	550,020	549,960	549,960	549,990	549,970	550,000
Net Plant Efficiency, % HHV	36.8	26.2	29.7	39.3	28.4	31.9
Coal Feed Rate, kg/h	198,391	278,956	245,339	185,759	256,652	229,137
Raw Water Usage, m^3/MWh	2.4	4.6	3.5	2.2	4.2	3.3

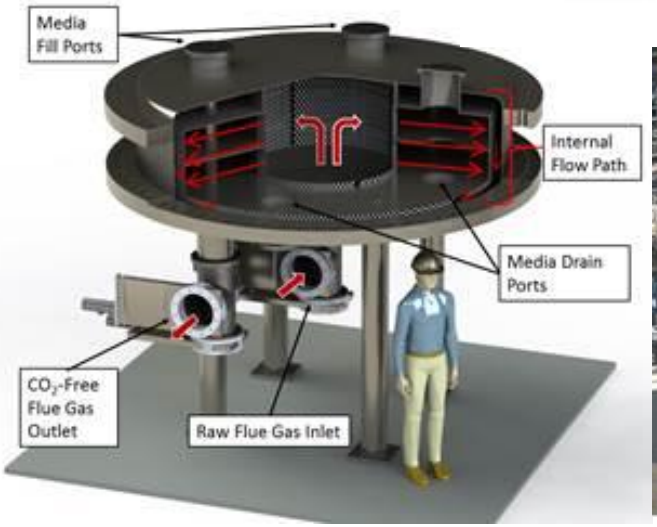
- **1st year cost of electricity (including the TS&M costs) is calculated as $120.1/MWh for MTR-TDA hybrid system; much lower than the $147.4/MWh calculated for the amine scrubbers**
- **CO_2 capture cost for our hybrid system is less than $35.5 per tonne (excluding transportation and storage) on 2011 $ basis**

TDA RESEARCH

Current Project Focus

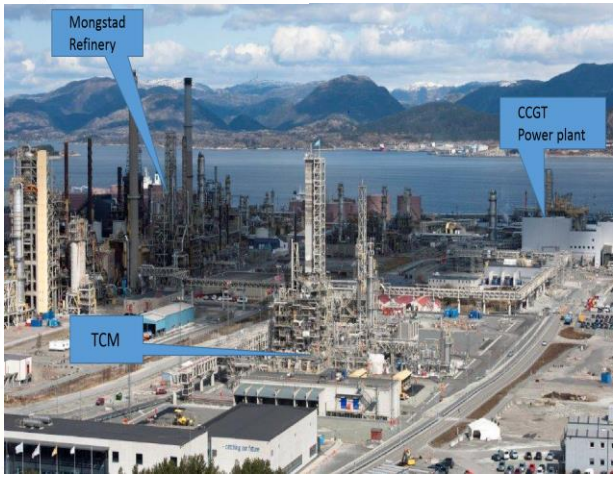
- **To fully evaluate the concept at 1 MW_e scale**
  - TDA will develop its modular sorbent bed concept
  - MTR will modify an existing unit (20 tpd) previously evaluated at the NCCC
  - TCM will host the evaluation of the integrated test unit





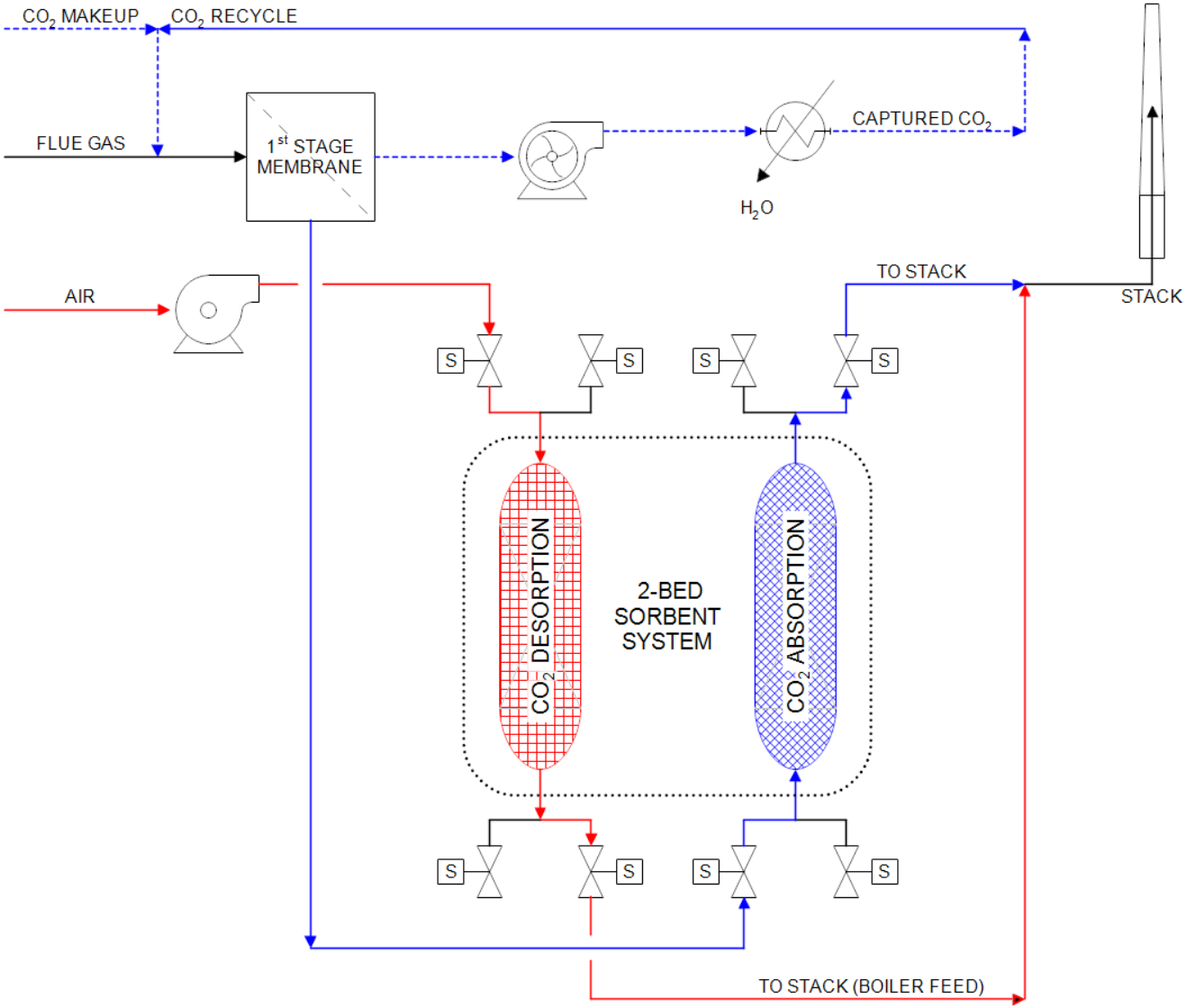
TDA's Sorbent System

Existing MTR Membrane Module (20 TPD evaluated at NCCC)



TCM Mongstad, Norway

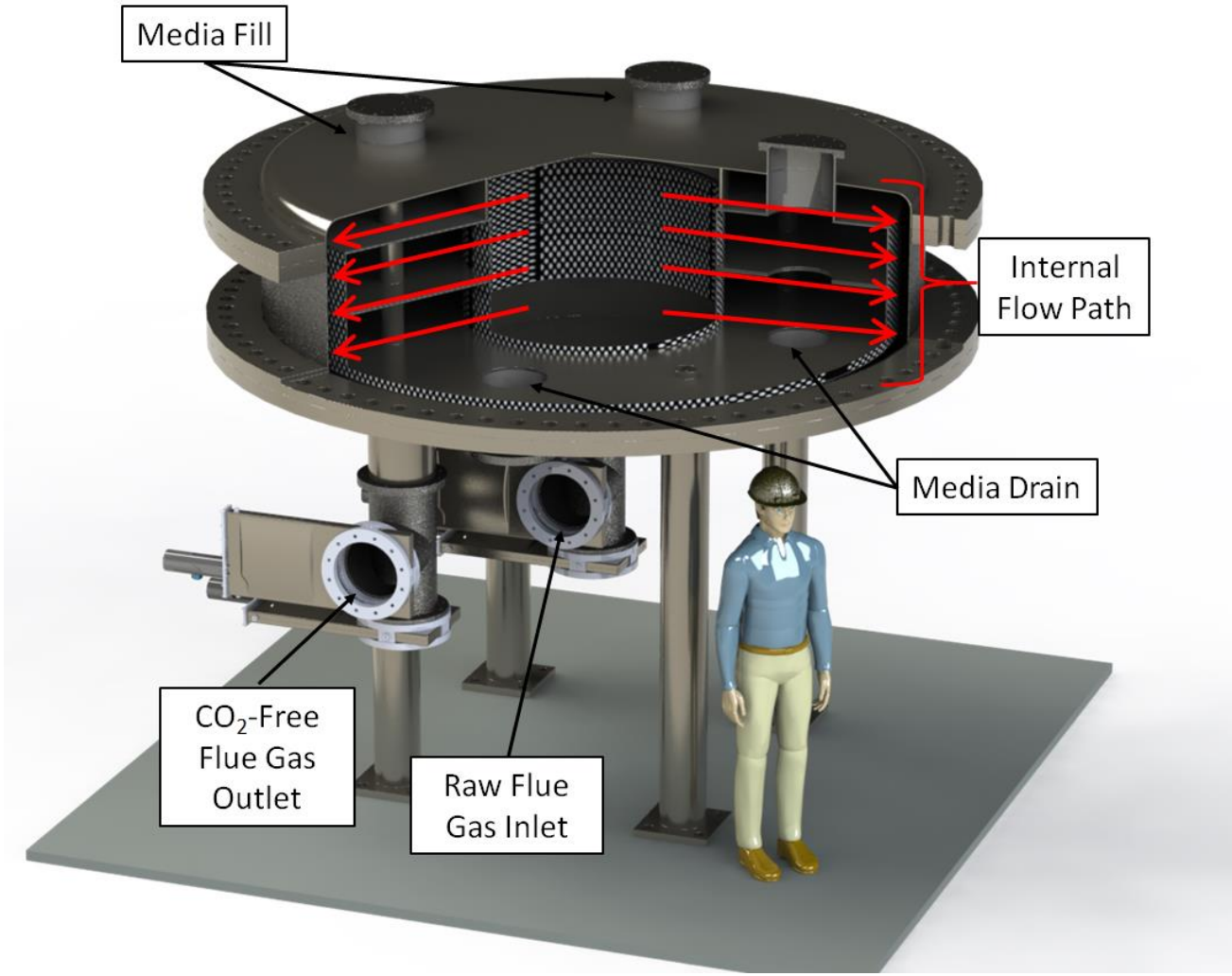
PFD of the Field Test Unit



Modular Radial Outflow Reactor Concept

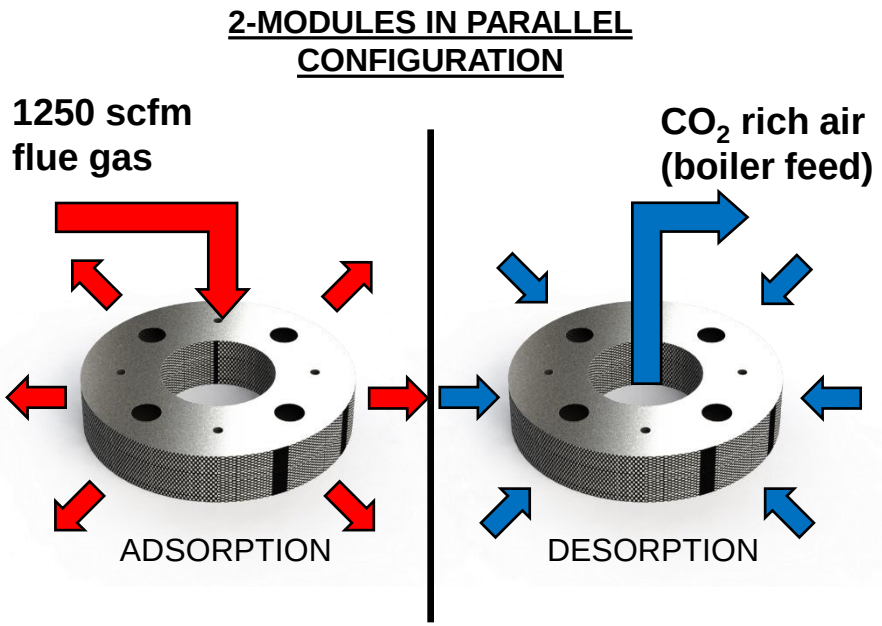
1 MW scale module

(two modules used to provide continuous transfer of CO_2 into boiler air)

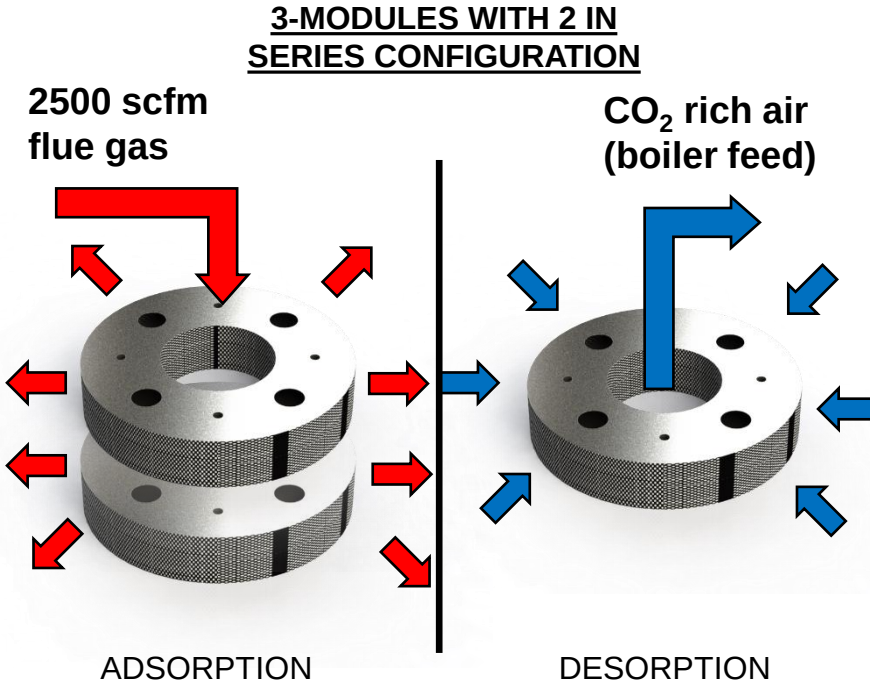


Modular Concept Demonstration Tests

0.5 MW scale tests with two modules (baseline)



1 MW scale tests with two modules in series

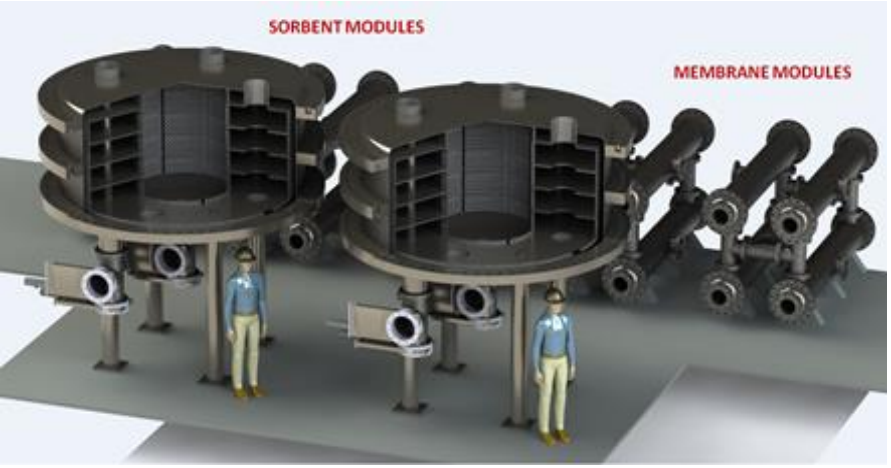


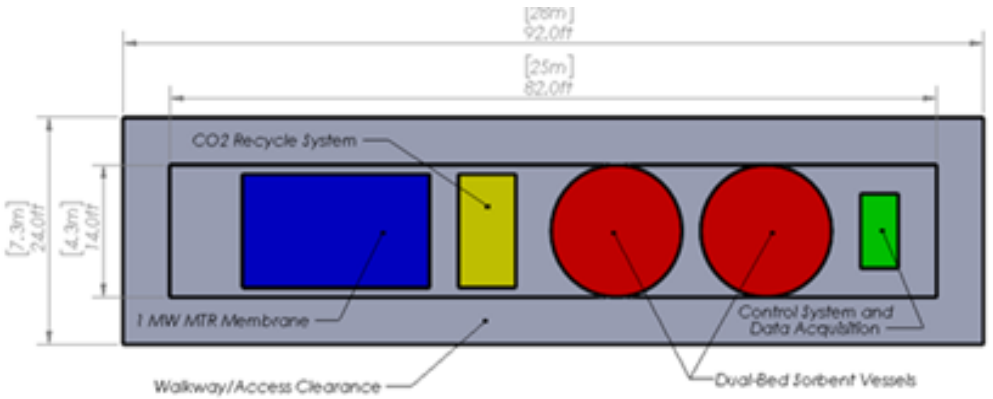
- **TDA will build 3 modules to demonstrate the modular design concept works**
  - Tests to show that data obtained with 1 module is directly applicable when having multiple modules in series

Budget Period 1

Budget Period 1 (BP1: 8/15/2018– 8/14/2019)

- **Design the 1 MW scale modular pilot unit**
  - GTI to assist in computational fluid dynamic (CFD) simulations
  - MTR will design the membrane module
  - TDA will carry out the design of the sorbent module and the BOP
- **Get full approval from TCM**
- **Both MTR membrane module and TDA's sorbent system are modular and the data generated in the field tests will be directly applicable to the design of a full-scale system**

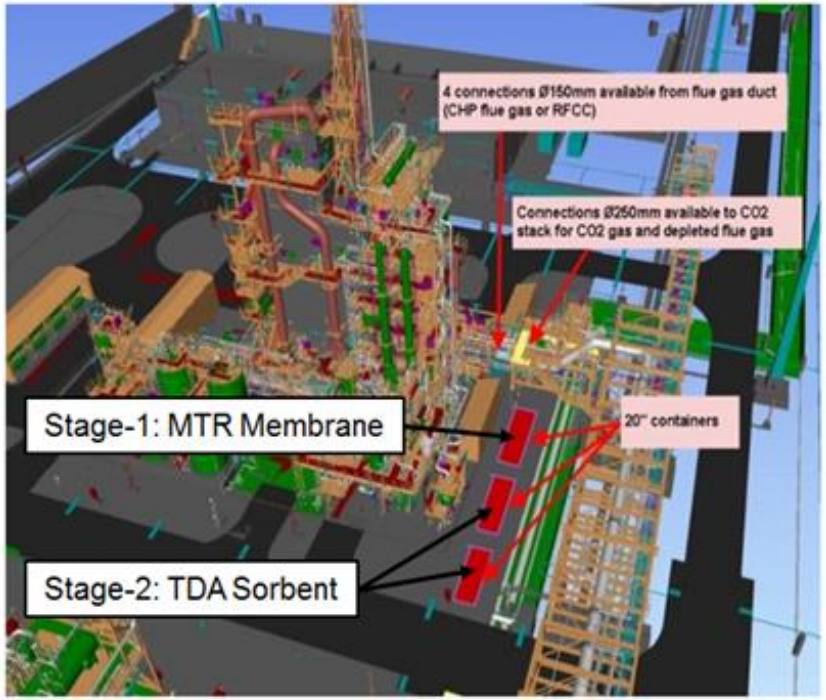




Budget Period 2

Budget Period 2 (BP2: 8/15/2019– 8/14/2020)

- **TDA and MTR complete the fabrication/integration of the 1 MW membrane-sorbent hybrid test unit**
- **TCM to carry out all the site modifications needed to host field tests**
- **Prepare and submit a test plan to DOE**
- **UCI will update the Aspen® process simulation model**
- **Ship and install the 1 MW pilot unit at TCM facilities in Mongstad, Norway**



Budget Period 3

Budget Period 3 (BP3: 8/15/2020– 8/14/2021)

- Complete the shakedown tests of the Hybrid Field test unit
- Carry out a 9 to 12 month long field test campaign at TCM
- Based on the field test results
  - Update the state point data table for the membrane performance
  - Complete an updated TEA

- Provide DOE with
  - Environmental Health & Safety (EH&S) risk assessment
  - Technology GAP Analysis (TGA)
  - Technology Maturation Plan (TMP)

Project Work Plan

Task 1. BP1 Project Management and Planning

Budget Period 1 (BP1: 8/15/2018 – 8/14/2019)

- Task 2. Field Test Unit Design
- Task 3. Critical Design Review
- Task 4. Initial Techno-economic Analysis

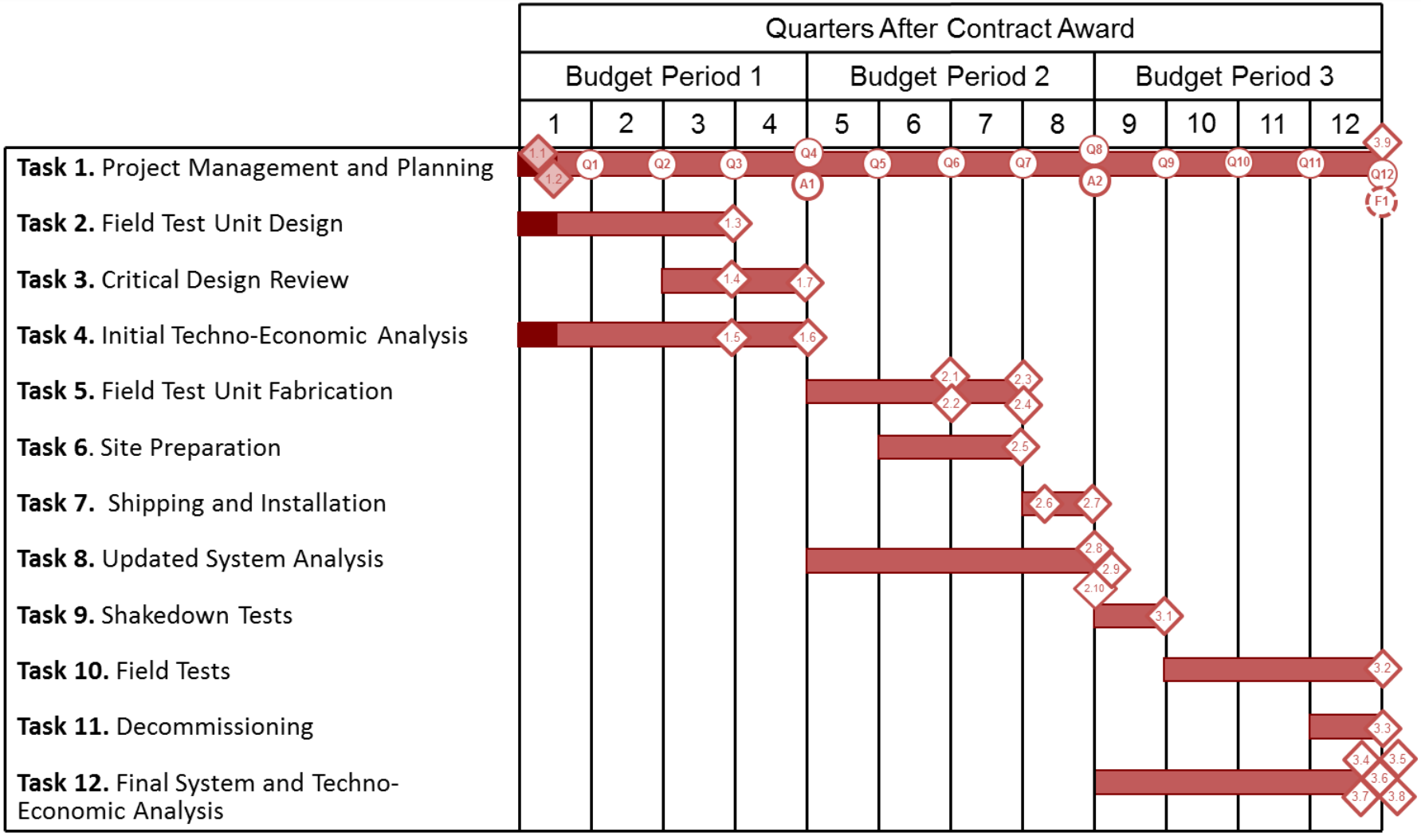
Budget Period 2 (BP2: 8/15/2019 – 8/14/2020)

- Task 5. Field Test Unit Fabrication
- Task 6. Site Preparation
- Task 7. Shipping and Installation
- Task 8. Updated System Analysis

Budget Period 3 (BP3: 8/15/2020 – 8/14/2021)

- Task 9. Shakedown Tests
- Task 10. Field Tests
- Task 11. Decommissioning
- Task 12. Updated System and Techno-economic Analysis

Project Schedule



TDA Research

Progress to Date on Key Technical Issues

- **Project kick-off meeting is held via web conference on October 1, 2018**
- **Started the Initial Techno-Economic Analysis (TEA)**
  - Information exchange w/ DOE Carbon Capture Simulation for Industry Impact ($CCSI^2$) Group
- **TDA initiated the work on Adsorption Modeling**
- **GTI has informed on the plan for the CFD Model Development for the 2-bed radial flow pilot unit**
  - Current focus is in the reactor design that will be used for the pilot evaluation (to provide a basis for model validation)
- **The project team has started the discussions on the design of the 1 MW scale hybrid Pilot unit**
- **TDA initiated subcontract negotiations with MTR and GTI**
- **TDA initiated preliminary discussions with TCM to identify site requirements**

Task 1. Project Management and Planning

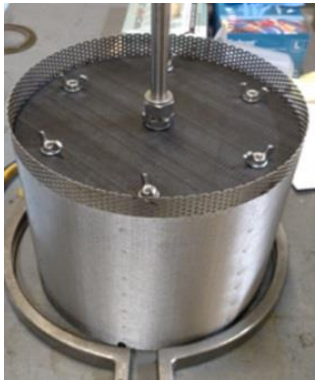
- **TDA will assure that the project team successfully completes the research program within budget and schedule**
- **We will also ensure the submission and approval of NEPA documentation**

Budget Period 1
8/15/2018 – 8/14/2019

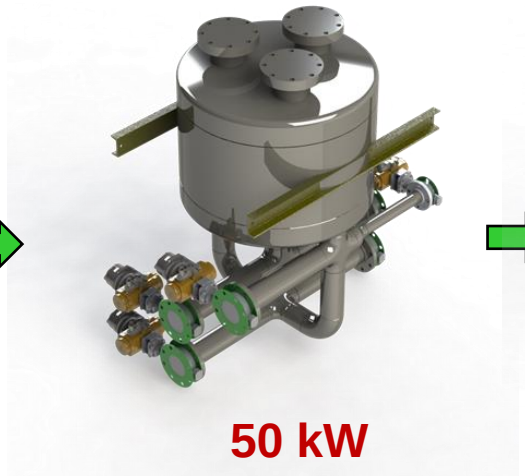
Task 2. Field Test Unit Design

Task 2.1 CFD Modeling

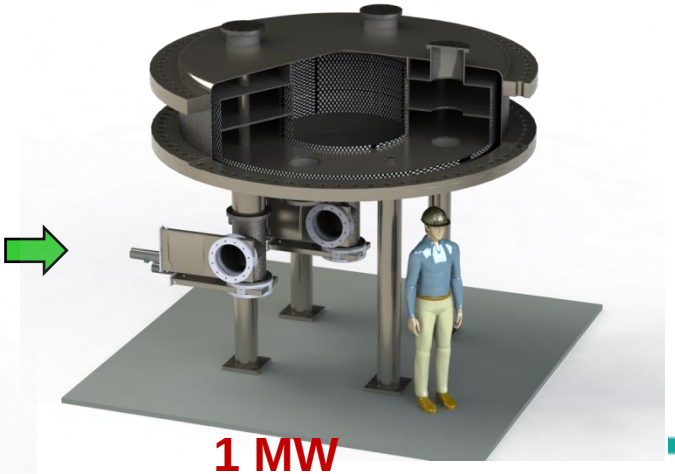
- **CFD analysis will provide information on intra-modular flow, concentration and temperature distributions in sorbent beds**
- **The model results will be used to optimize the configurations to ensure uniform flow distribution, lower the pressure drop, while meeting performance requirements for the test unit and the full scale system**
  - Using code such as FLUENT, local heat and mass transfer processes will be explored to develop axial and radial temperature and concentration profiles
- **Data from our earlier tests in the SBIR project with smaller modules will be used to validate and develop the CFD models for the 1 MW scale module**



2 kW



50 kW

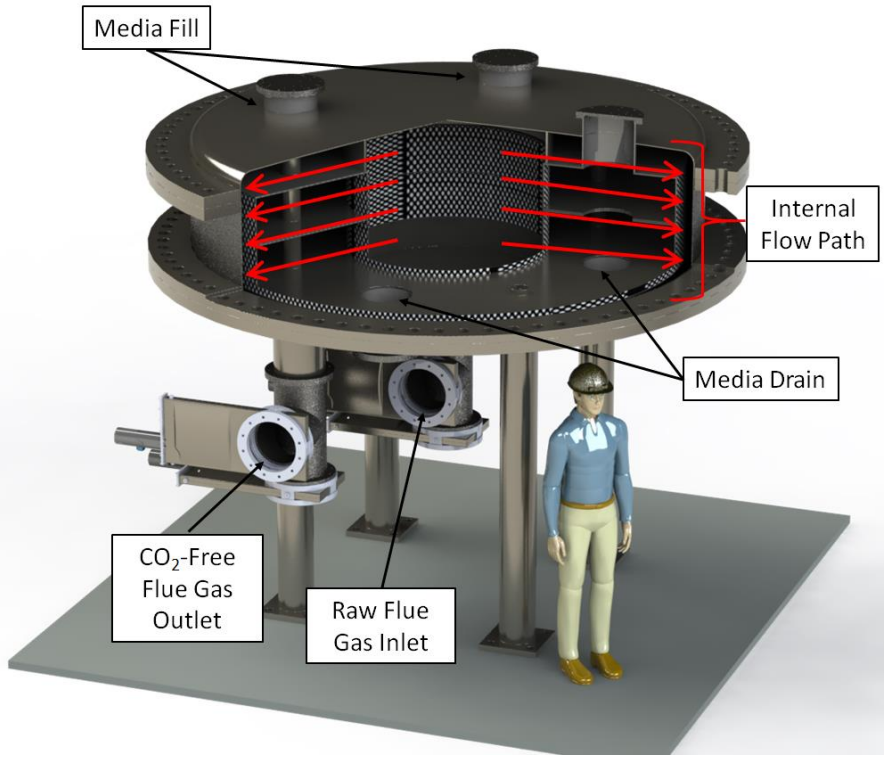


1 MW

1 MW Module Reactor Design

50 kW Module

1 MW Module

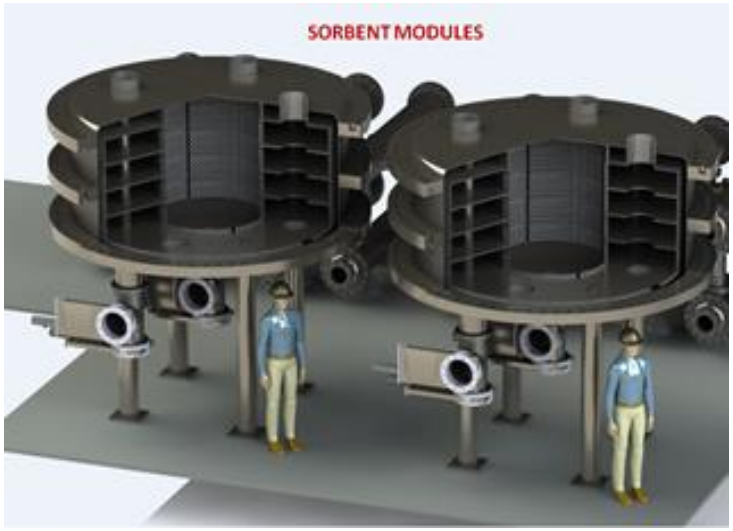


- **Field test data from the reactor designs evaluated in the SBIR project at the 50 kW module size will be used in CFD model validation and to finalize the design of 1 MW modules**
- **Modular design, each module at a size that it can be shipped via road**

Task 2.2 Field Test Unit Design

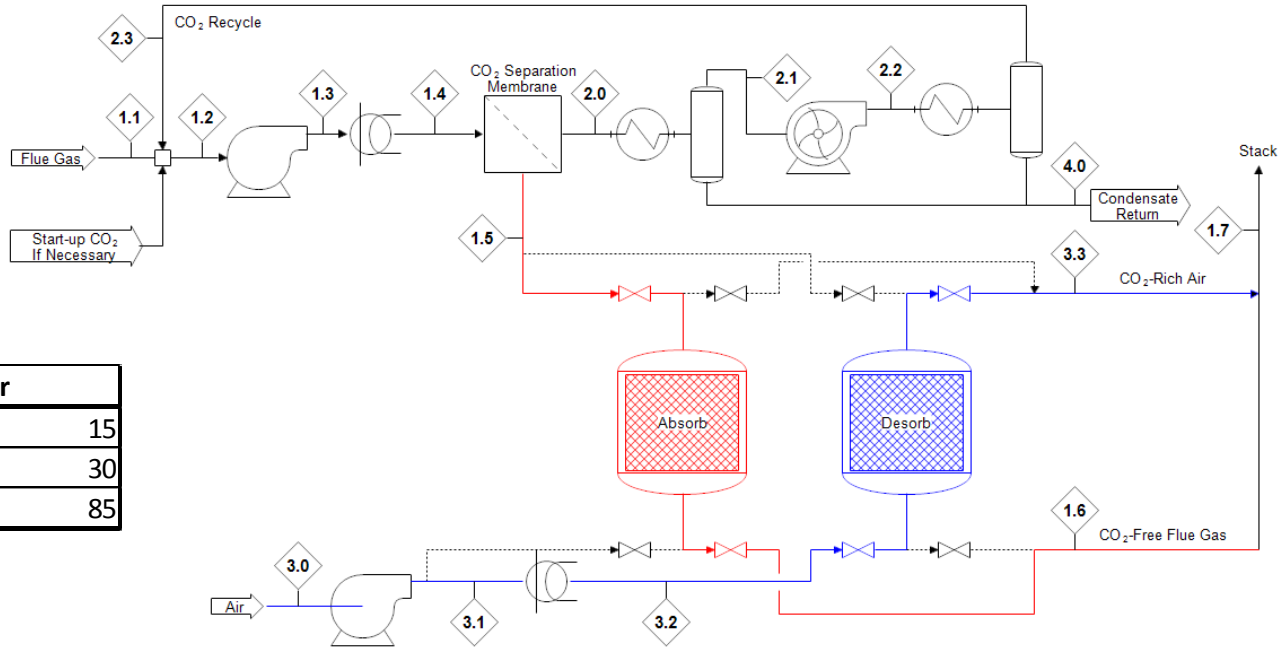
- **We will conduct detailed design of the 1 MW test unit**
- **We will carry out the design of the major system components, including the membrane module, sorbent beds, major equipment such as the vacuum pump, flow switch valves as well as the CO_2 purification system**
- **We will generate:**
  - engineering drawings and 3-dimensional layouts for all critical equipment
  - complete process flow diagram and process and instrumentation diagrams
- **MTR will identify modifications needed to their 20 TPD CO_2 membrane skid**

Existing MTR Membrane Module (20 TPD evaluated at NCCC)



TDA's Sorbent Module (20 TPD to be built)

PFD and Stream Data - TCM 1MW

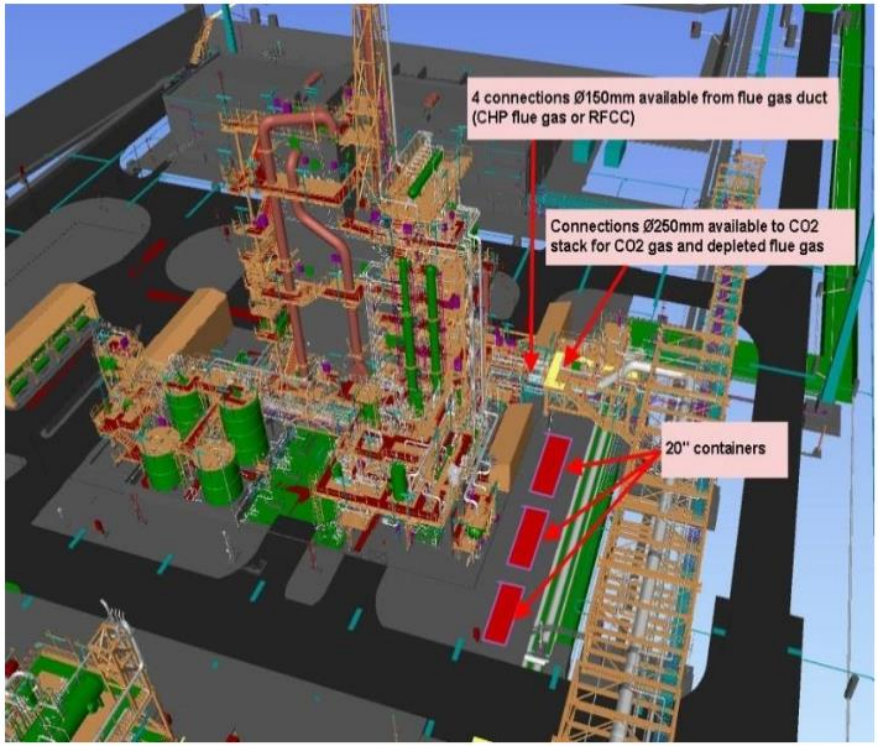


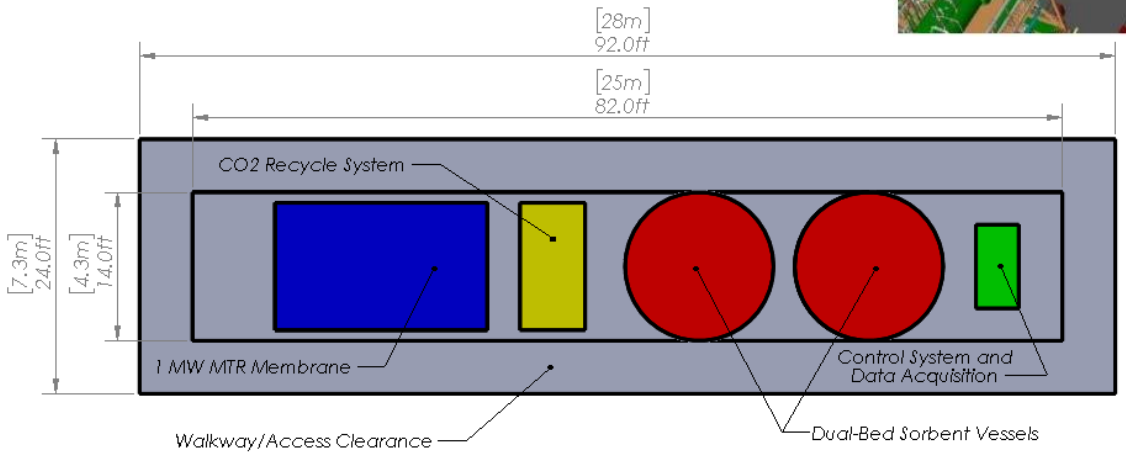
Cooling Water	
Supply Temp C	15
Return Temp C	30
Total Flow kg/min	85

Stream Number	1.1	1.2	1.3	1.4	1.5	1.6	1.7	2.0	2.1	2.2	2.3	3.0	3.1	3.2	3.3	4.0
Temperature, C	40.0	40.8	61.4	61.4	61.4	61.4	60.6	61.4	40.0	172.8	45.0	20.0	37.0	60.0	60.0	45.0
Pressure, mbar	1042.4	906.7	1150.0	1150.0	1150.0	1150.0	1060.0	200.0	200.0	1042.4	1042.4	1012.2	1060.0	1060.0	1060.0	906.7
Mass Flow, kg/min	97.6	118.0	118.0	118.0	97.0	76.1	170.9	21.0	21.0	21.0	20.4	73.9	73.9	73.9	94.8	0.6
Molar Flow, kmol/h	194.0	227.8	227.8	227.8	192.0	163.5	345.6	35.8	35.8	35.8	33.8	153.6	153.6	153.6	182.1	2.0
Volumetric Flow , m3/hr	4845.4	6558.6	5509.2	5509.2	4643.5	3953.8	9048.0	4977.9	4660.0	1463.8	986.2	4306.0	3736.9	4013.8	4758.9	0.03
Volumetric Flow , Sm3/hr	4348.3	5106.0	5106.0	5106.0	4303.6	3664.4	7746.6	802.4	802.4	802.4	757.7	3442.9	3442.9	3442.9	4082.1	-
Density, kg/m3	1.2	1.1	1.3	1.3	1.3	1.2	1.1	0.3	0.3	0.9	1.2	1.0	1.2	1.1	1.2	1046.9
Molecular Weight, g/mol	30.2	31.1	31.1	31.1	30.3	27.9	29.7	35.2	35.2	35.2	36.2	28.9	28.9	28.9	31.2	18.0
Dynamic Viscosity, cP	0.018	0.018	0.019	0.019	0.019	0.020	0.020	0.017	0.016	0.022	0.017	0.018	0.019	0.020	0.020	-
Vapor Fraction	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
Mole Fractions																
H_2O	0.04	0.05	0.05	0.05	0.03	0.04	0.02	0.16	0.16	0.16	0.11	0.00	0.00	0.00	0.00	1.00
CO_2	0.15	0.21	0.21	0.21	0.15	0.00	0.08	0.52	0.52	0.52	0.56	0.00	0.00	0.00	0.16	0.00
O_2	0.03	0.03	0.03	0.03	0.03	0.04	0.11	0.02	0.02	0.02	0.03	0.21	0.21	0.21	0.18	0.00
Ar	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.00	0.00	0.00	0.00	0.00
N_2	0.77	0.70	0.70	0.70	0.78	0.91	0.78	0.27	0.27	0.27	0.29	0.79	0.79	0.79	0.66	0.00

Task 2.3 Utility and Site Requirements

- **Work with TCM to finalize the utility and site requirements for the field test unit**
  - Overall Space Estimated:
    92’ x 24’ (28.0 m x 7.3 m)
  - Usable Space Estimate:
    82’ x 14’ (25.0 m x 4.3 m)
  - 1 MW MTR System:
    20’ x 12’ (6.0 m x 3.7 m)
  - TDA Sorbent System: 30’ x 14’ (9.0 m x 3.7 m)





TCM Site: Physical Space

Utility Requirements

Type	Specifications	Connection
Electrical	3-Phase 400VΔ, ≈ 240 kW Continuous	Wire Gauge TBD, Hard Wired in Metal Conduit
Flue gas feed	2,500 SCFM (4250 m^3/hr) 25°C < T > 50°C P > 1 psig (≈ 7 kPa) Total SO_2 ≤ 500 ppmv Total SO_x ≤ 100 ppmv Free of Liquids, Aerosols, and Particulates	12-inch 150-lb Flange Connection
Compressed Air (Pneumatics)	≤ 10 SCFM (18 m^3/hr) T = Ambient ; P = 70 psig	1” Compression-Style (Swagelok) Tube Fitting
CO_2 Supply (startup)	≈ 20,000 ft^3 (570 m^3) CO_2 (g)	4-inch 150-lb Flange
CO_2 Supply (Cont.)	≈ 15.8 ft^3/min (26.8 m^3/hr) CO_2 (g)	4-inch 150-lb Flange
Cooling Water Supply	150 kg/min (20°C ΔT) T < 20°C ; P > 35 psig	4-inch 150-lb Flange
Overall Footprint	≈ 92’ x 24’ (28.0 m x 7.3 m) (Complete System)	Rough, Maximum Size Requirement

Task 3. Critical Design Review

- **We will bring MTR (partner) and TCM (host site) together for a comprehensive Design Review**
- **We will incorporate the feedback from the partners to update the design as needed and generate an approved design to complete the modifications to the MTR skid and fabricate the sorbent modules and the balance of the 1 MW unit**

Task 3.1 Preliminary Design Review (PDR)

- **We will complete PDR and update the design this will include:**
  - Process Hazard Analysis (PHA)
  - Preliminary Hazard and Operability (HAZOP) study
  - Preliminary Failure Mode Effects Analysis (FMEA)

Task 3.2 Final Design Review (FDR)

- We will complete the FDR with the partners which will include the final PHA, HAZOP and FMEA and seek DOE approval for the final fabrication

Task 4. Initial Techno-economic Analysis

- **We will complete initial Techno-economic Analysis (TEA) and Technology Maturation Plan (TMP)**
- **TEA for sub- and super-critical power plants suggest substantial improvement in cycle efficiency for the new hybrid technology**

Power Plant Type	Sub-critical Pulverized Coal fired Power Plant			Super-critical Pulverized Coal fired Power		
CO_2 Capture Technology	No Capture Case DOE Case 9	Reference Amine DOE Case 10	MTR-TDA Membrane Hybrid System	No Capture Case DOE Case 11	Reference Amine DOE Case 12	MTR-TDA Membrane Hybrid System
CO_2 Capture, %	0	90	90	0	90	90
Gross Power Generated, kW_e	582,600	672,700	704,312	580,400	662,800	694,044
Auxiliary Load, kW_e	32,580	122,740	154,352	30,410	112,830	144,044
Net Power, kW_e	550,020	549,960	549,960	549,990	549,970	550,000
Net Plant Efficiency, % HHV	36.8	26.2	29.7	39.3	28.4	31.9
Coal Feed Rate, kg/h	198,391	278,956	245,339	185,759	256,652	229,137
Raw Water Usage, m^3/MWh	2.4	4.6	3.5	2.2	4.2	3.3

- 1st year cost of electricity (including the TS&M costs) is calculated as $120.1/MWh for MTR-TDA hybrid system; much lower than the $147.4/MWh calculated for the amine scrubbers
- CO_2 capture cost for our hybrid system is less than $35.5 per tonne (excluding transportation and storage) on 2011 $ basis

RESEARCH

BP1 – Milestone Log

Budget Period	ID	Task Number	Title	Planned Completion Date	Verification Method
			Actual Project Start Date	8/15/18	
1	1.1	1	Update (PMP)	09/14/18	PMP file
1	1.2	1	Kickoff Meeting	09/14/18	Presentation
1	1.3	2	Complete Field Test Unit Design Package	05/14/19	Design Package
1	1.4	3.1	Complete Preliminary Design Review	05/14/19	HAZOP document
1	1.5	4	Complete Initial Techno-Economic Assessment (TEA)	05/14/19	Topical Report #1
1	1.6	4	Complete Initial Technology Maturation Plan (TMP)	08/14/19	TMP file
1	1.7	3.2	Complete Final Design Review	08/14/19	HAZOP document
			Annual Briefing #1	08/14/19	Presentation
			Annual Report #1	08/14/19	Annual Report #1
			Go/No-Go Decision Point #1	08/14/19	

Decision Point	Date	Success Criteria
Decision Point: End of Budget Period 1	08/14/2019	Complete detailed design and critical design review for the 1 MW modular hybrid membrane-sorbent post combustion CO_2 capture unit and provide DOE with a Design Package.
		Complete an initial TEA demonstrating that hybrid membrane sorbent post combustion CO_2 capture system can capture CO_2 at a cost 15% lower than the DOE target of $40 per tonne

Budget Period 2
8/15/2019 – 8/14/2020

Task 5. Field Test Unit Fabrication

Task 5.1 Modification of the 1 MW Membrane Skid

- MTR will modify their existing 1 MW two-stage membrane skid previously tested at NCCC and B&W
- Modifications include replacement of flue gas compressor with a blower to reduce power consumption, and installation of high performance membrane elements
- Recycle module to recycle the CO_2 from the permeate back to the feed to simulate the CO_2 enrichment of the flue gas when using boiler air sweep to regenerate the sorbent beds

Task 5.2 Fabrication of the 1 MW Sorbent Skid

- We will construct the modular sorbent skid that can be used in hazardous environment (Class I Division II)
- We will use LabView Hardware for automated operation to allow stand-alone operation, with remote monitoring and controls that enables system operation without TDA and MTR personnel being on-site

Task 5.3 Sorbent Production

- We will prepare ~3 m^3 sorbent (sufficient for 1 MW field unit including extra material for another full load) and benchmark their performance

Task 6. Site Preparation

- **TCM will carry out any necessary site modifications needed to their CO_2-capture facility**

Task 7. Shipping and Installation

- **We will package, transport and install the 1 MW field test unit (both the membrane and sorbent skids) at TCM**

Task 8. Updated System Analysis

- **We will complete system analysis for the full scale system**
- **We will update the TEA**
- **We will complete initial Environmental Health & Safety (EH&S) risk assessment**
- **We will complete an initial Technology GAP Analysis (TGA) for the technology**

BP2 – Milestone Log

Budget Period	ID	Task Number	Title	Planned Completion Date	Verification Method
2	2.1	5.2	Complete Fabrication of Sorbent Reactors	02/14/20	Results update
2	2.2	5.3	Complete Sorbent Production	02/14/20	Results update
2	2.3	5.1	Complete Modifications to Membrane Skid	05/14/20	Results update
2	2.4	5.2	Complete Fabrication of Sorbent Skid	05/14/20	Results update
2	2.5	6	Complete Site Preparation and Field Test Plan	05/14/20	Topical Report #2
2	2.6	7	Ship the 1 MW skids to Technology Centre Mongstad (TCM)	06/14/20	Results update
2	2.7	7	Complete Installation of the Field Unit at the Test Site	08/14/20	Results update
2	2.8	8	Complete System Analysis	08/14/20	Topical Report #3
2	2.9	8	Complete Initial Environmental Health & Safety (EH&S) Risk Assessment	08/14/20	EH&S Report #1
2	2.10	8	Complete Initial Technology GAP Analysis (TGA)	08/14/20	TMP file
			Annual Briefing #2	08/14/20	Presentation
			Annual Report #2	08/14/20	Annual Report #2
			Go/No-Go Decision Point #2	08/14/20	

Decision Point	Date	Success Criteria
Decision Point: End of Budget Period 2	08/14/2019	Complete the fabrication and installation of the 1 MW hybrid membrane sorbent system onsite at TCM
		Complete the detailed design of the full scale system based on the modular design concept and update the TEA and show that the COE is at least 30% lower than a supercritical pulverized coal-fired power plant with amine-based CO_2 capture

Budget Period 3
8/15/2020 – 8/14/2021

Task 9. Shakedown Tests

- **We will integrate the membrane and the sorbent modules with the control system**
- **We will tune all PID loops and other control systems to ensure that all critical system parameters can be controlled at the given range**
- **We will carry out shakedown and troubleshooting of the integrated system at TCM facilities with flue gas**
- **We will evaluate the operation of the valves, blower and all supporting equipment to ensure successful operation**

Task 10. Field Tests

- **The unit will be evaluated in a planned 9-12 month test campaign using flue gas generated from RFCC which is very similar in composition to the coal derived flue gas**
- **A series of tests will be performed to evaluate the system's performance at different operating conditions**
- **We will work closely with CCSI^2 team to develop a Design of Experiments (DOE) and parametric evaluation**
- **A minimum of 6,000 hours testing is scheduled with continuous operation**

Task 11. Decommissioning

- **The field test unit will be decommissioned and transported back to TDA and MTR**

Task 12. Updated System and Techno-economic Analysis

- **We will incorporate the results from the field tests into the Aspen Plus® model and complete the cost analysis of the supporting sub-systems and update the costs for the hybrid membrane CO_2 capture system based on the new results**
- **These results will feed into the detailed techno-economic analysis, which will be carried out by UCI based on DOE guidelines in the Attachment 3 of the FOA for a supercritical coal fired power plant**
- **We will also provide DOE with the final TEA, EH&S, TMP and TGA**

BP3 – Milestone Log

Budget Period	ID	Task Number	Title	Planned Completion Date	Verification Method
3	3.1	9	Complete Shakedown Tests	11/14/20	Results update
3	3.2	10	Complete Field Tests	08/14/21	Topical Report #4
3	3.3	11	Complete Decommissioning	08/14/21	Results update
3	3.4	12	Complete Updated State Point Table	08/14/21	Data Table
3	3.5	12	Complete Updated Techno-Economic Assessment (TEA)	08/14/21	Topical Report #5
3	3.6	12	Complete Environmental Health & Safety (EH&S) Risk Assessment	08/14/21	EH&S Report #2
3	3.7	12	Complete Technology Maturation Plan (TMP)	08/14/21	TMP file
3	3.8	12	Complete Technology GAP Analysis (TGA)	08/14/21	TGA file
3	3.9	1	Final Review Meeting	08/14/21	Presentation file
			Final Report	08/14/21	Final Report

Decision Point	Date	Success Criteria
Project Completion: End of Budget Period 3	08/14/2021	Complete the testing of the 1 MW scale modular pilot unit for at least 6,000 hours, demonstrating 90+% CO_2 capture with 95+% CO_2 purity, and stable hybrid system performance, less than 2% degradation over 6,000 hours of operation
		Complete detailed TEA based on field test data and show that hybrid membrane sorbent post combustion CO_2 capture system can capture CO_2 at a cost of $30 per tonne of CO_2 captured much lower than DOE target of $40 per tonne

Deliverables

1) Task 1.0 Updated PMP
2) Task 2.0 Design Package
3) Task 6.0 Topical Field Test Plan
4) Task 8.0 Topical report summarizing Field tests
5) Task 8.0 Updated State Point Table
6) Task 10.0 Techno-Economic Analysis (TEA)
7) Task 10.0 Technology GAP Analysis
8) Task 10.0 EH&S Risk Assessment
9) Task 10.0 Technology Maturation Plan