Membrane-Sorbent Hybrid System for Post-Combustion CO_2 Capture (Contract No. DE-FE-0031603)

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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 15, 2018**
- **End Date = August 14, 2021**

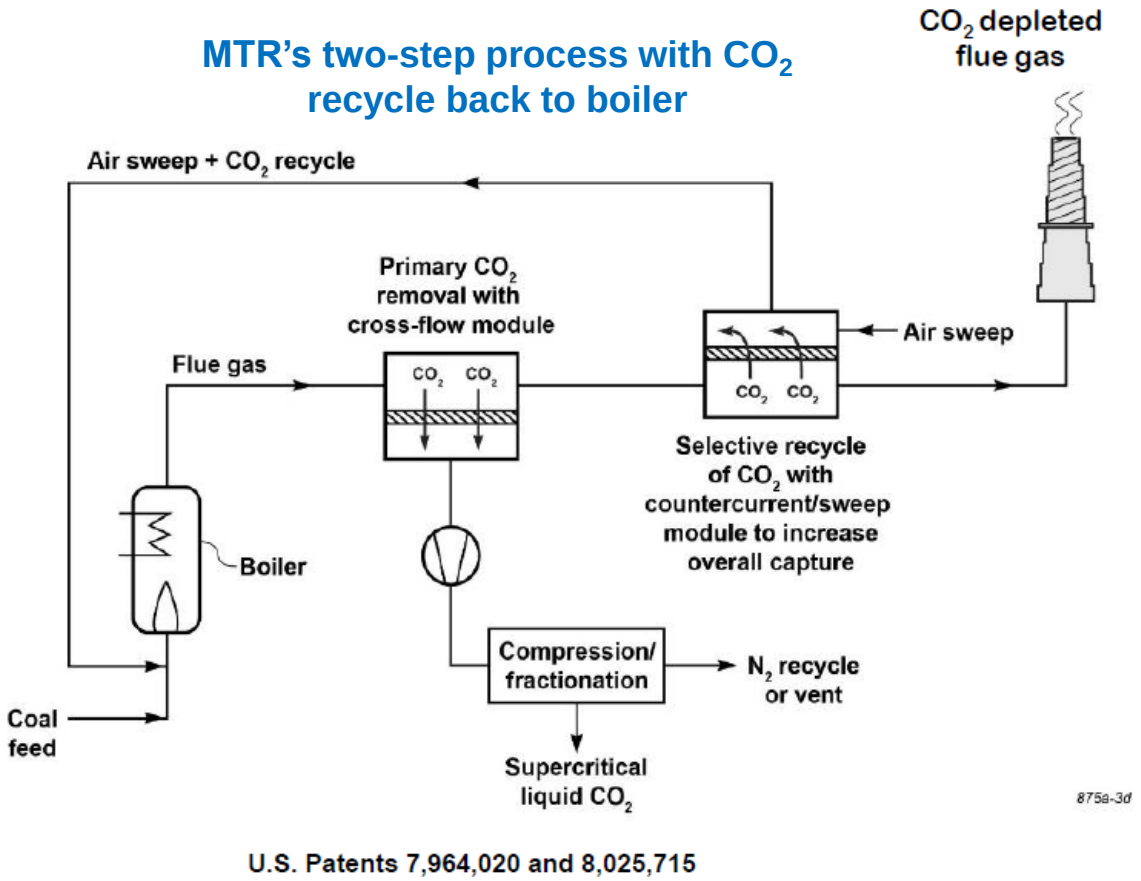
Budget

- **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
  - Allows boiler to generate a high CO_2 flue gas

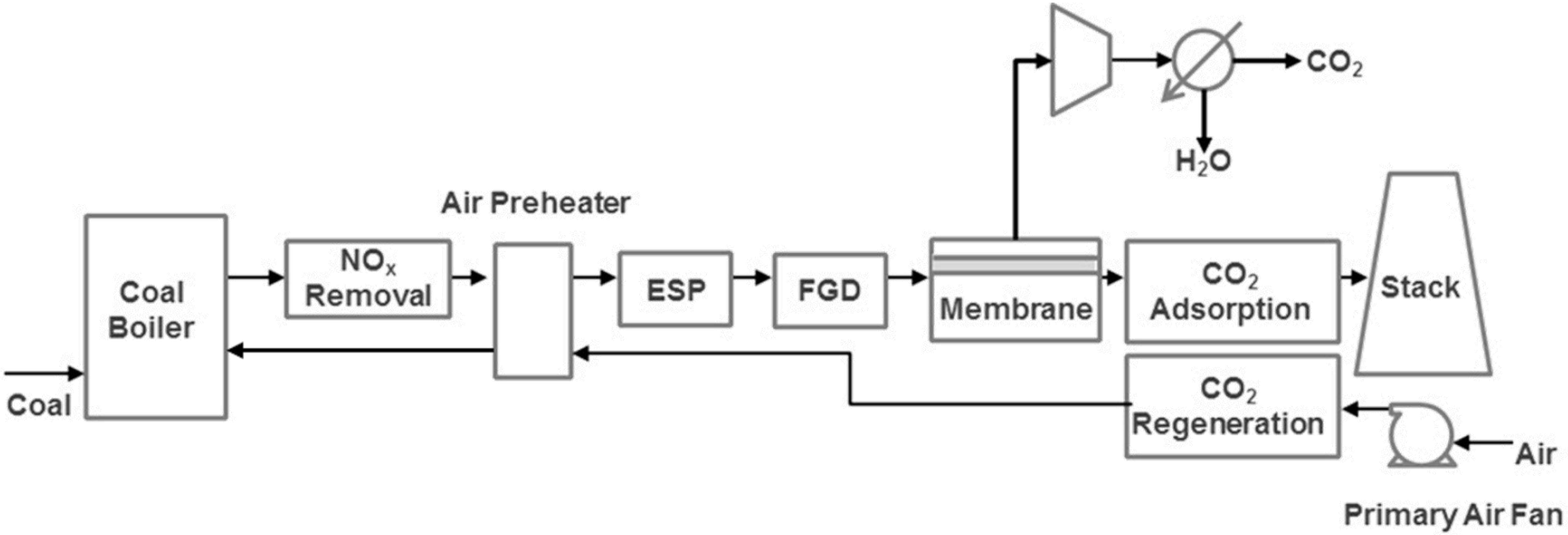


U.S. Patents 7,964,020 and 8,025,715

- **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

TDA RESEARCH

Hybrid Membrane Sorbent Process



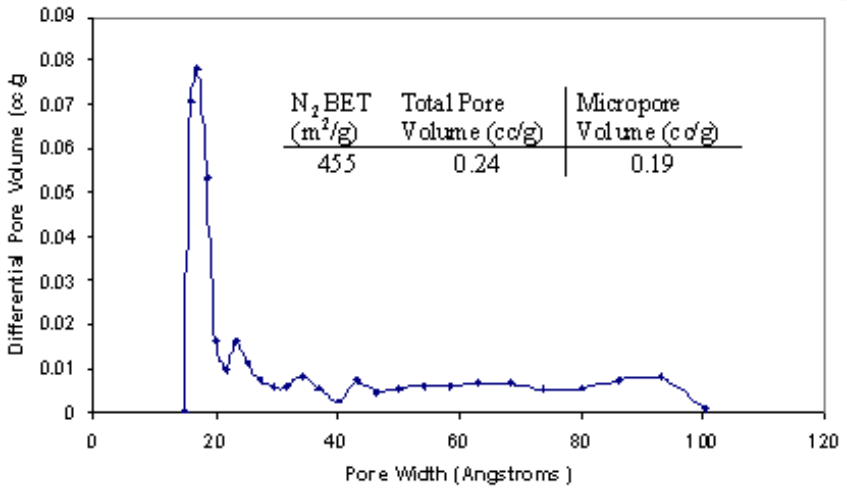
- **Membrane operates at ~50°C under mild vacuum, (≈0.3 atm) removes ≈50% of CO_2 and almost all water**
  - TDA's sorbent removes remaining CO_2 in the membrane effluent (retentate) ensuring 90% carbon capture
  - The boiler feed air is used as a sweep gas to facilitate sorbent regeneration
  - Low 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**

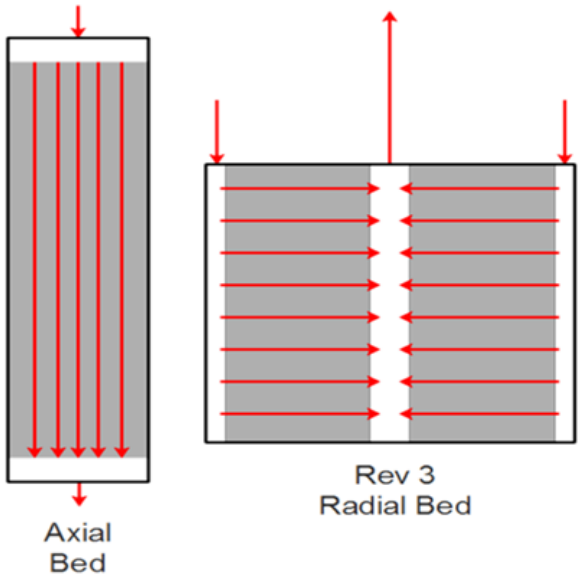
US Patent 9,120,079, Dietz, Alptekin, Jayaraman "High Capacity Carbon Dioxide Sorbent", US 6,297,293; 6,737,445; 7,167,354

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

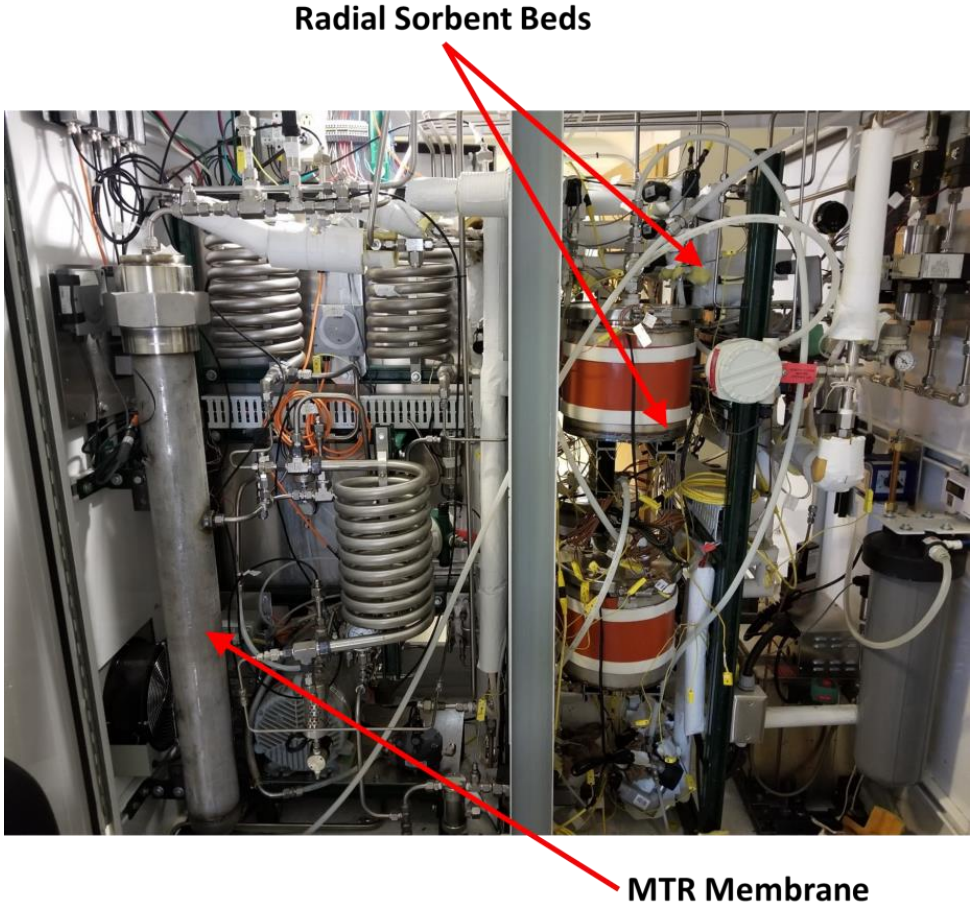


Sorbent operation in a VSA system was successfully demonstrated with actual flue gas (DE-0013105)

Development Under the SBIR Project



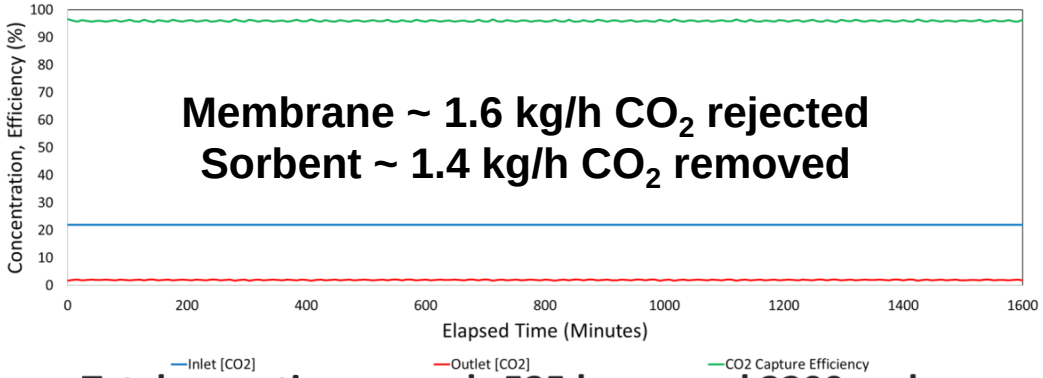
TDA's Radial Flow Sorbent Reactors



- Lab and field tests were carried out at 2-4 scfm (20-40 kg/day CO_2) scale hybrid-membrane sorbent using coal-derived flue gas at Western Research Institute (Laramie, WY)

Test Results at WRI

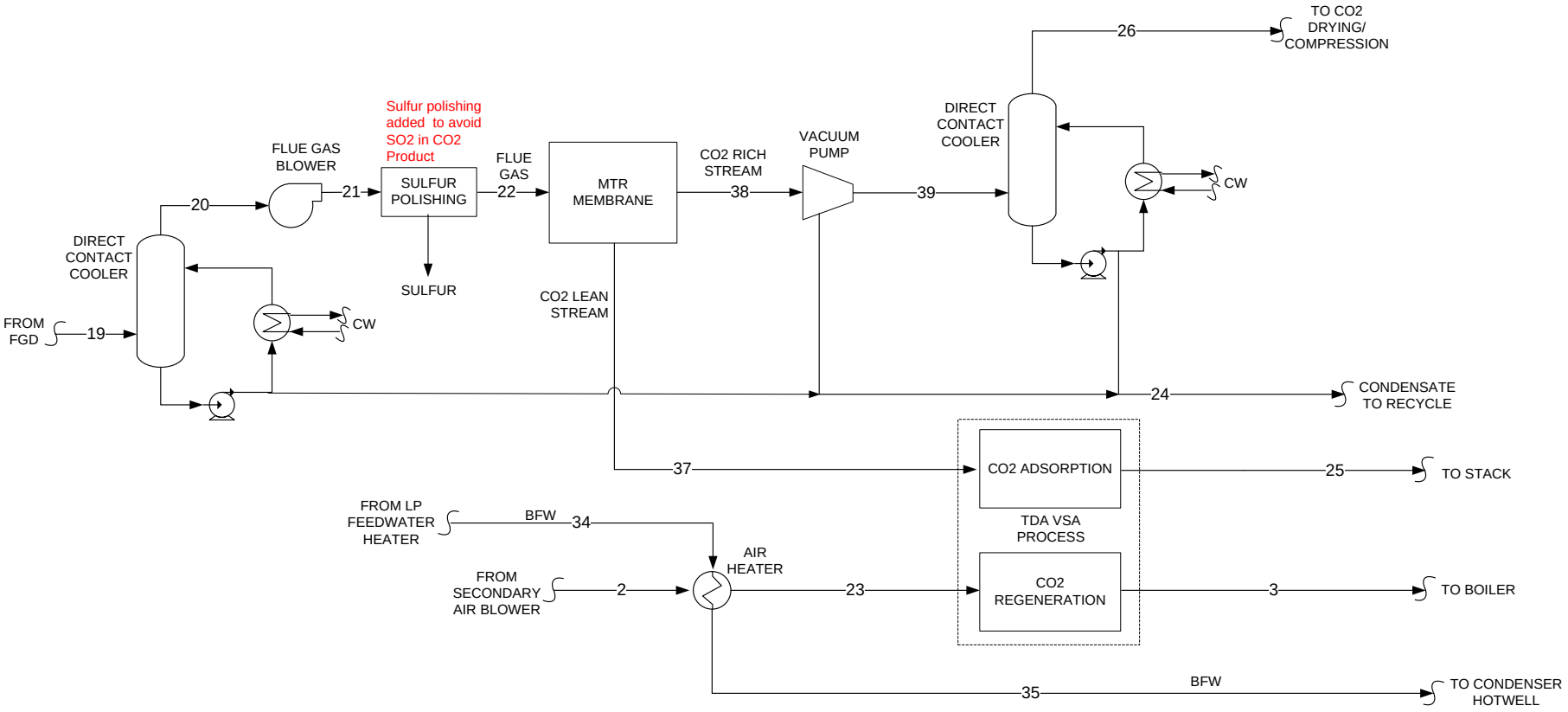
Continuous 4-Bed Cycling Performance (Cycle# 2,000 -2,160)



Membrane ~ 1.6 kg/h CO_2 rejected
Sorbent ~ 1.4 kg/h CO_2 removed

Total operation exceeds 525 hours and 3200 cycles

Aspen Process Modeling (UCI)



Hybrid CO_2 Capture System (PFD)

Advanced Power and Energy Program (APEP)	SBIR Phase 2 Study - Case 2
UCIrvine University of California, Irvine	MTR-TDA PROCESS BLOCK FLOW DIAGRAM SUPERRITICAL PC POWER PLANT MEMBRANE + VSA CO2 CAPTURE

IDA RESEARCH

Preliminary TEA

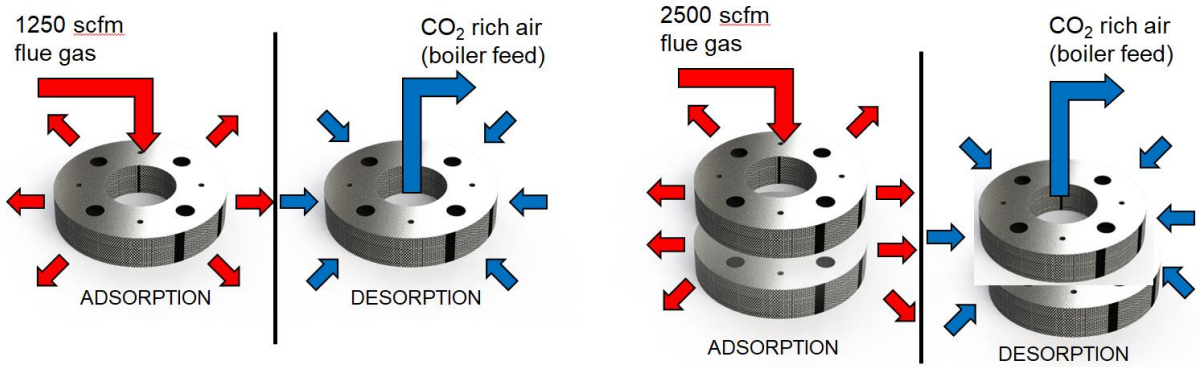
- **TEA for sub- and super-critical power plants suggest substantial improvement in cycle efficiency for the new hybrid technology**

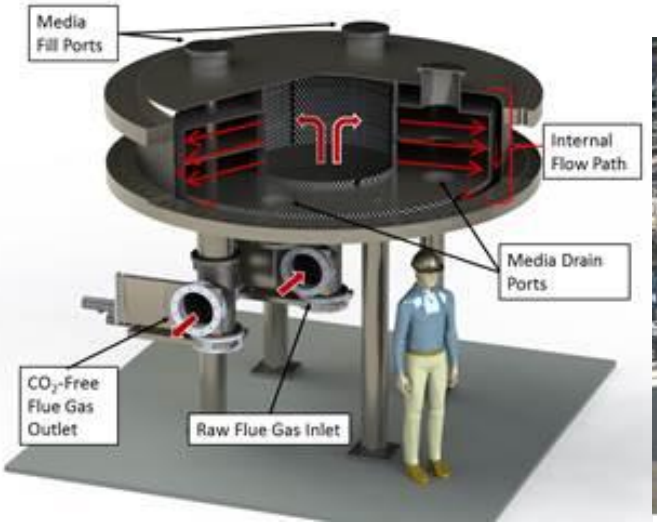
Power Plant Type	Sub-critical Pulverized Coal fired Power Plant			Super-critical Pulverized Coal fired Power		
CO_2 Capture Technology	No Capture Case DOE Case 9	Reference Amine DOE Case 10	MTR-TDA Membrane Hybrid System	No Capture Case DOE Case 11	Reference Amine DOE Case 12	MTR-TDA Membrane Hybrid 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

TDA RESEARCH

Project Focus

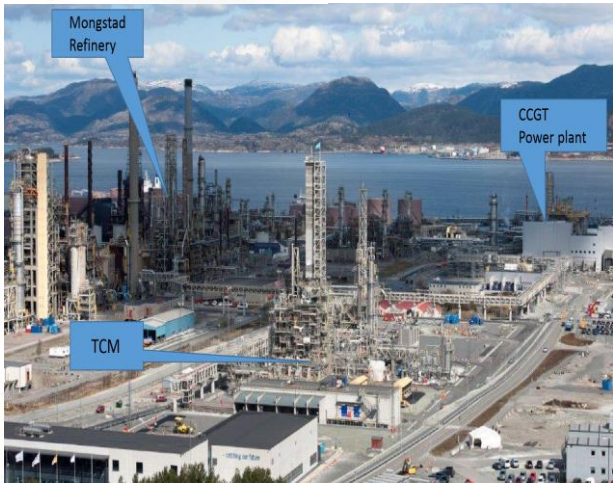
- TDA will develop its modular sorbent bed concept
- MTR will modify an existing unit (20 tpd) previously evaluated at the NCCC
- TCM will host the evaluation of the integrated test unit





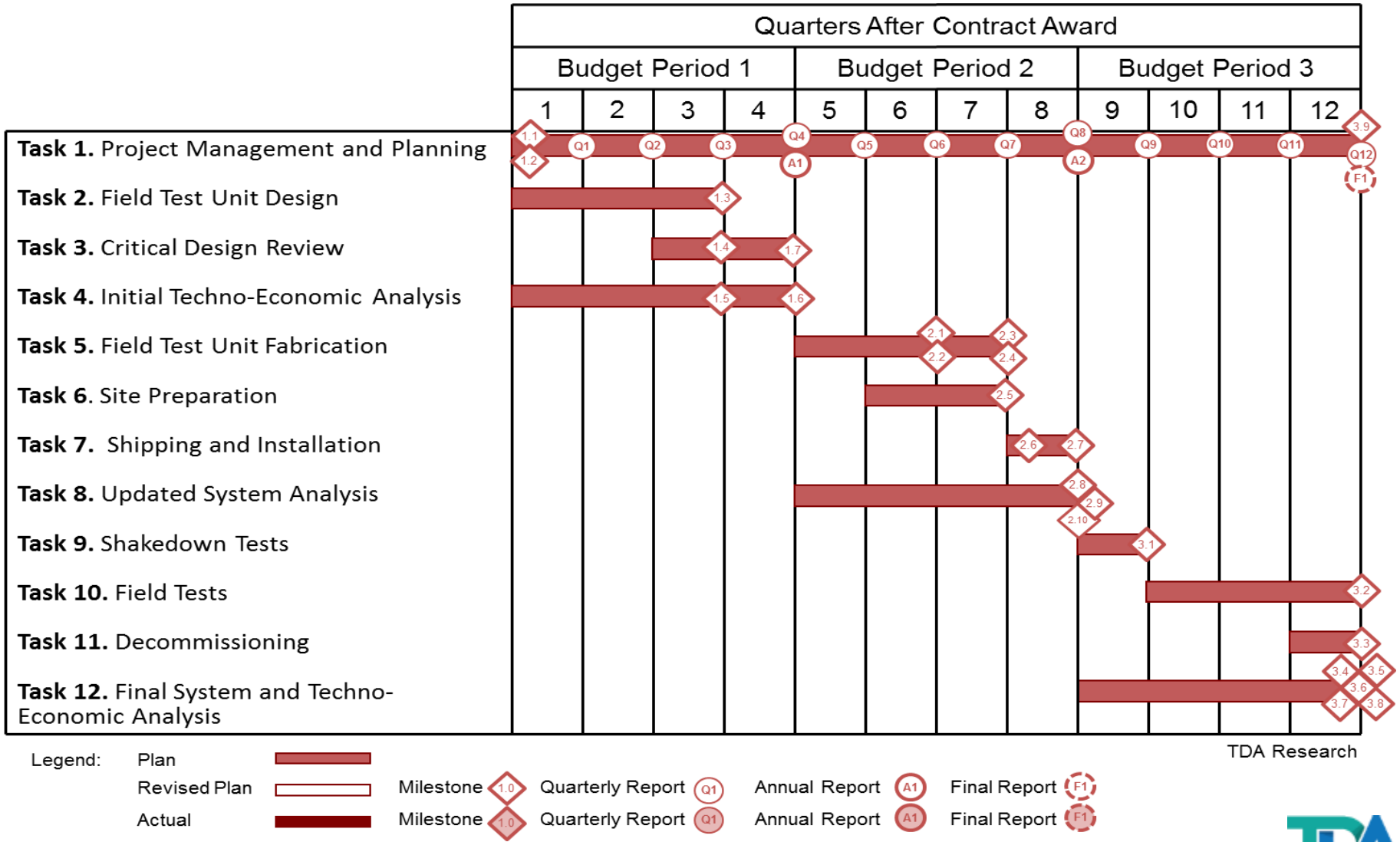
TDA's Sorbent System

Existing MTR Membrane Module
(20 TPD evaluated at NCCC)



TCM Mongstad, Norway

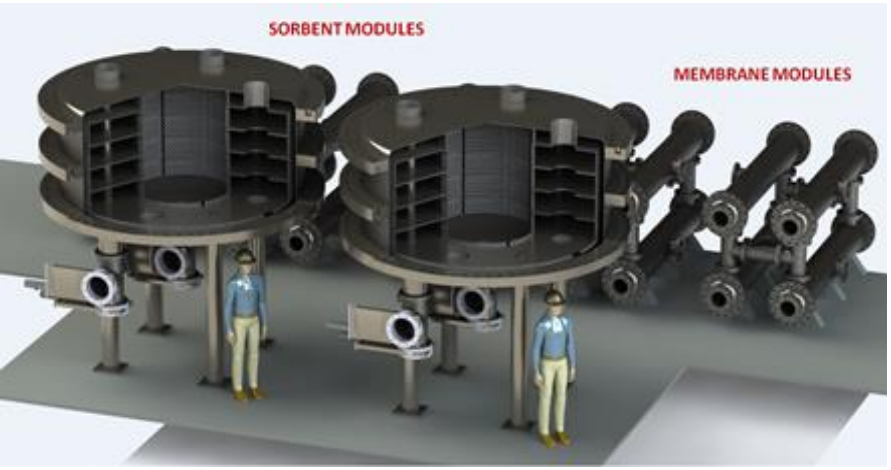
Project Schedule

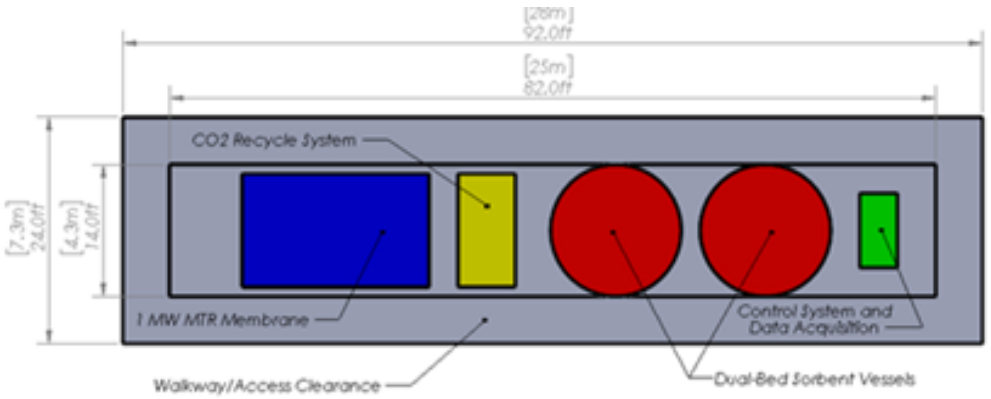


Budget Period 1

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
- **Seek 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**

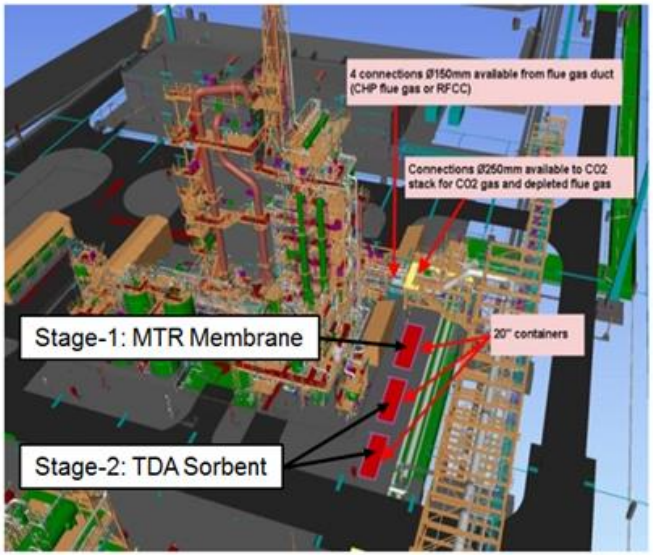




Budget Period 2

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)