Large Pilot Testing of the MTR Membrane Post-Combustion CO_2 Capture Process

(DE-FE0031587; FOA 1788)

Richard W. Baker, Tim Merkel, Brice C. Freeman

Membrane Technology and Research, Inc.

NETL Project Manager: Sai Gollakota

Project Kickoff Meeting

May 22, 2018

Project Overview

- **Award name:** Large Pilot Testing of the MTR Membrane Post-Combustion CO_2 Capture Process (DE-FE0031587; FOA 1788)
- **Project period:** 4/1/18 to 7/31/19
- **Funding:** $957k DOE + $239k cost share = $1.196M total
- **DOE-NETL Project Manager:** Sai Gollakota
- **Participants:** MTR (prime), Trimeric, WorleyParsons, EPRI, NRG (host)

- **<u>Overall goal:</u>** Design, build, and operate a 200 TPD large pilot capture system using partial capture to achieve the lowest cost-of-capture possible ($/tonne CO_2).
- **<u>Project plan:</u> (Phase I)**
  - selection of the host power plant
  - conduct environmental information volume
  - secure of financial commitments
  - update pilot design and budget, and finalizing team commitments and organization for Phase II / III

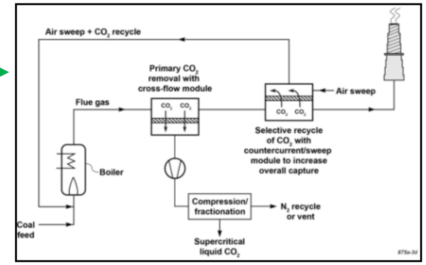
MTR

Topics

- Background
- Technical Approach
- Project Objectives
- Project Structure
- Project Schedule
- Project Budget
- Project Management Plan and Risk Management

MTR CO_2 Capture Development Timeline

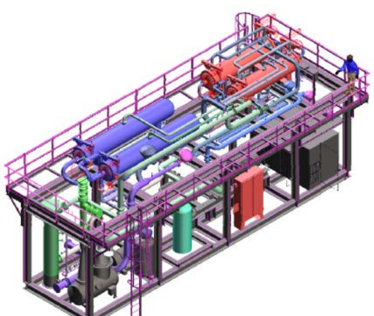
Feasibility study (DE-NT43085)
- Sweep concept proposed
- Polaris membrane conceived



APS Red Hawk NGCC Demo
- First Polaris flue gas test
- 250 lb/d CO_2 used for algae farm

APS Cholla Demo (DE-FE5312)
- First Polaris coal flue gas test
- 1 TPD CO_2 captured (50 kW_e)

NCCC 1 MW_e Demo (DE-FE5795)
- 11,000 hours of 1 TPD system operation
- 1 MW_e (20 TPD) system operation



Low Pressure Mega Module (DE-FE7553)
- Design and build a 500 m^2 optimized module

Hybrid Capture (DE-FE13118)
- Membrane-solvent hybrids with UT, Austin

B&W Integrated Test

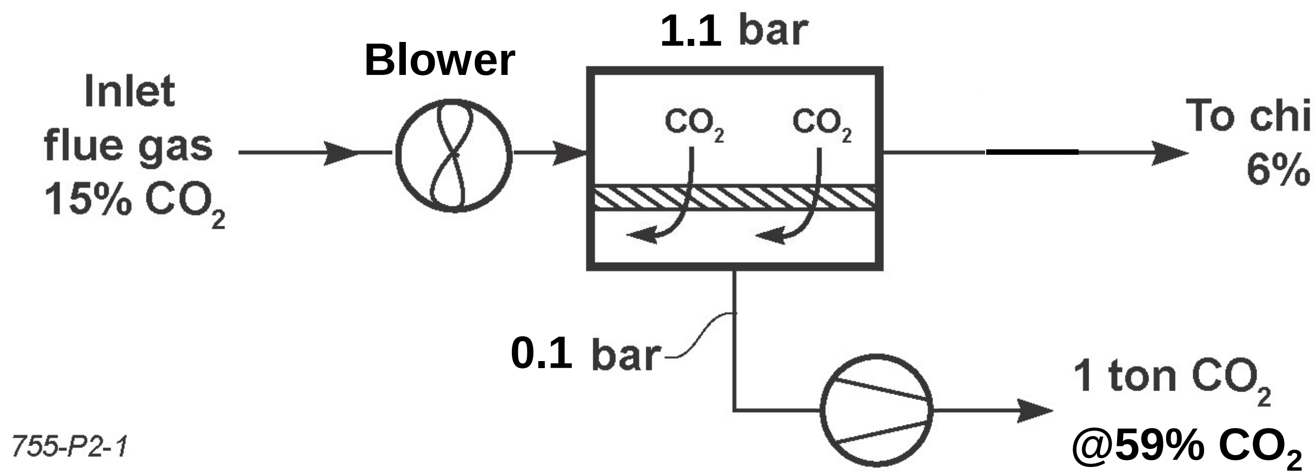
10+ MW_e Large Pilot

TRL3 TRL4 TRL5 TRL6 TRL7 TRL8

2006 2008 2010 2012 2014 2016 2018 2020

Membrane Separation Basics
Power Consumption is Key

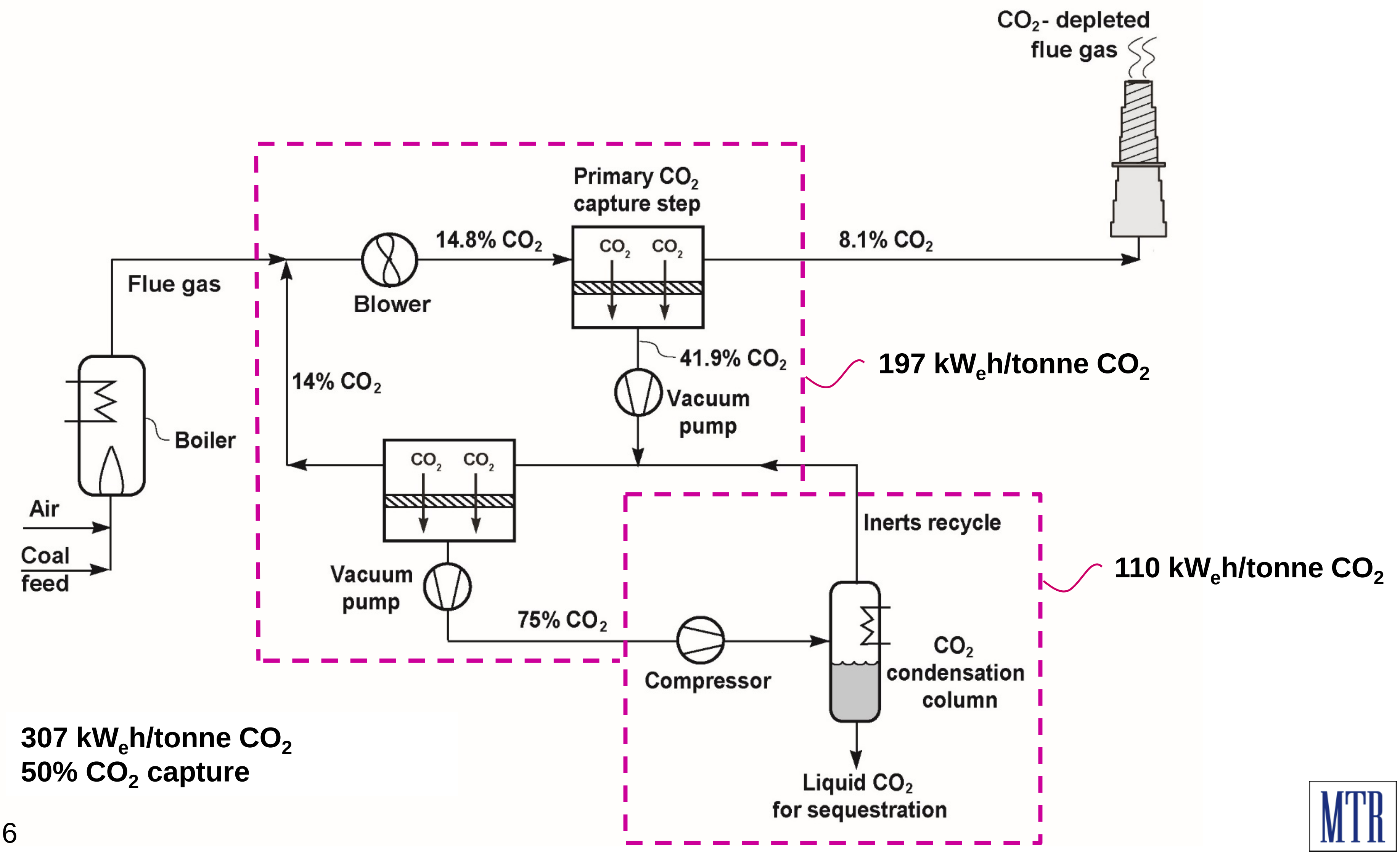
Permeate vacuum to 0.1 bar, 70% CO_2 capture



Feed / Permeate Pressure (bara)	Power	Membrane Area	Permeate Concentration
5.5 / 1.0	330 kW_e/tonne CO_2	X	43.5% CO_2
1.1 / 0.2	91 kW_e/tonne CO_2	5X	43.5% CO_2
1.1 / 0.1	99 kW_e/tonne CO_2	2.5X	59% CO_2

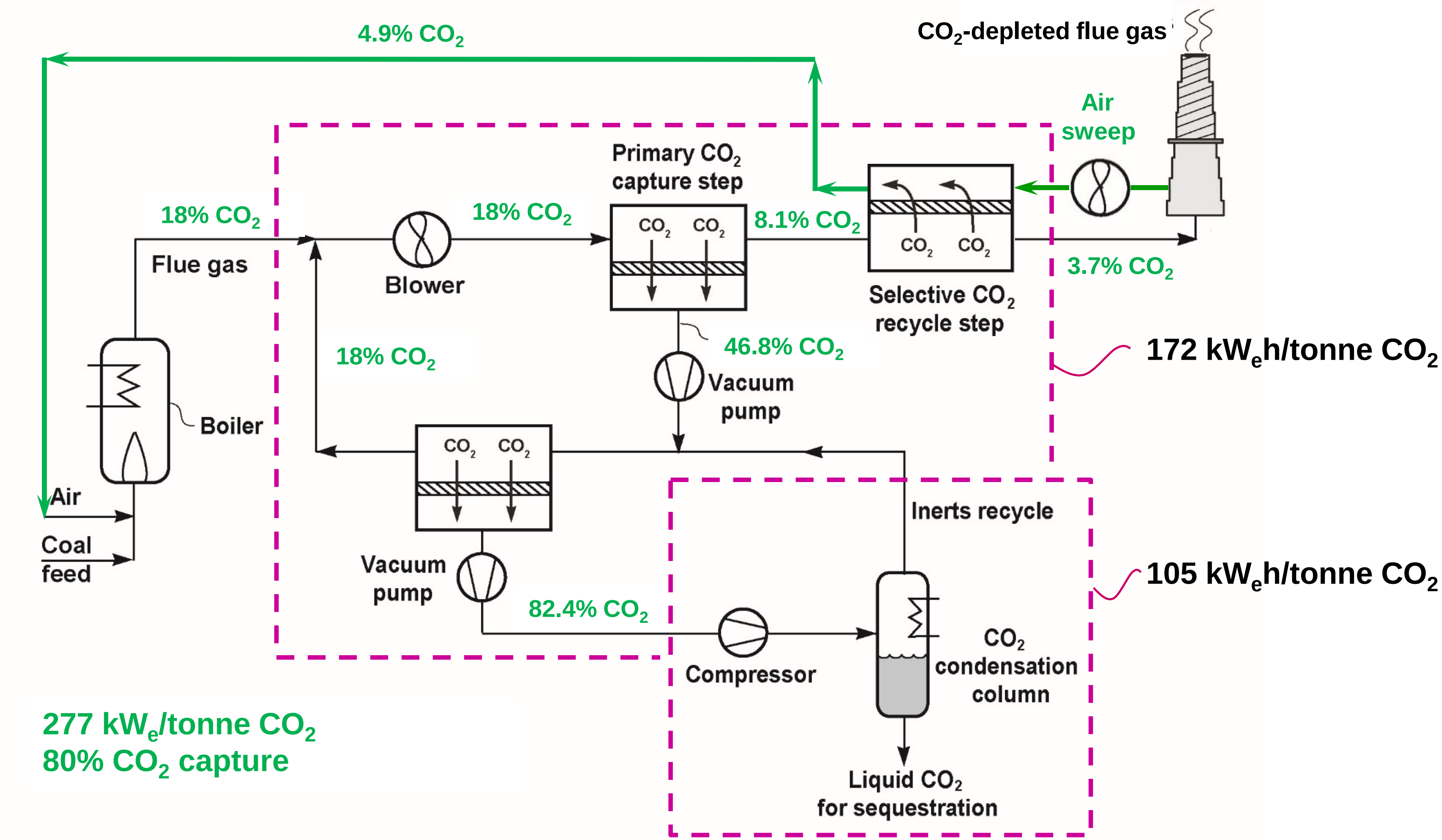
Vacuum at 0.1 to 0.2 bar is the way to go.

Partial CO_2 Capture with a Two-Stage Membrane Process



307 kW_eh/tonne CO_2
50% CO_2 capture

Using a Contactor Helps a Lot



Using a contactor reduces power by 10% and increase CO_2 capture from 50 to 80%.

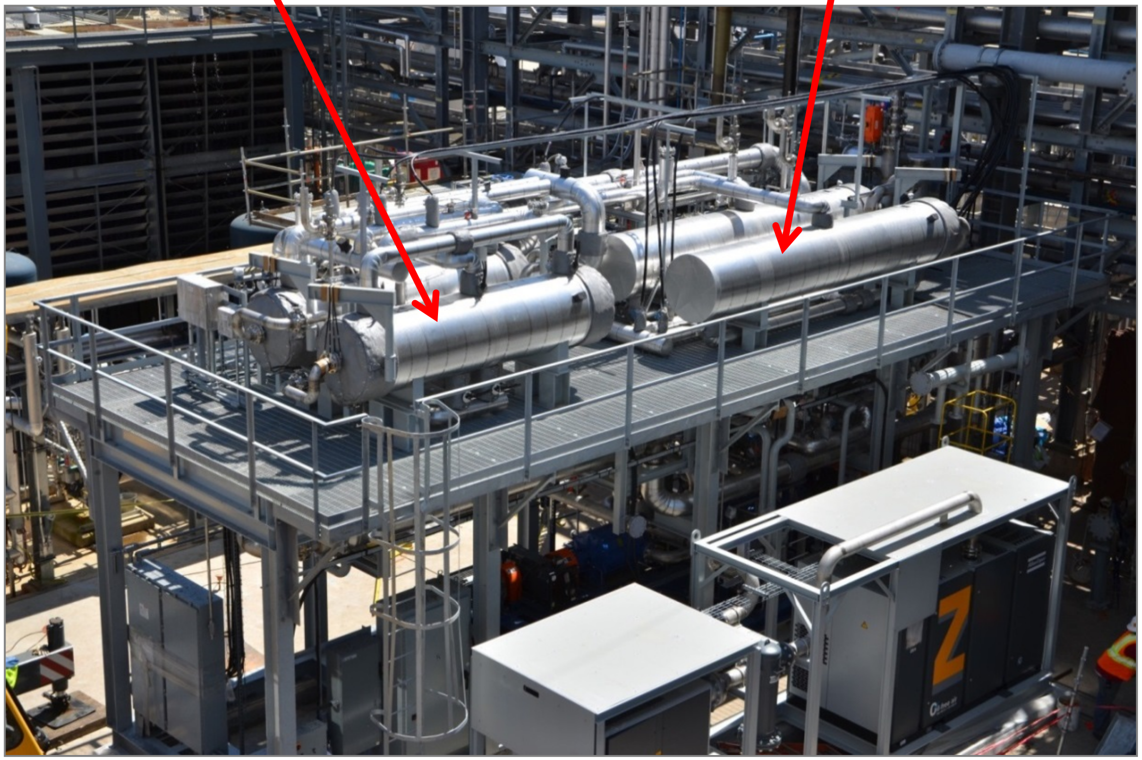
20 TPD System at NCCC

- Membranes are simple and compact compared to competing technologies, such as amines (see columns in photo).

- MTR pilot system completed successful six months of operation.

.

The NCCC 1 MW_e System Used Nested Module Tubes in a Single Large Vessel



We Also Tested Large Area Plate-and-Frame Modules at NCCC

MTR

Topics

- Background
- Technical Approach
- Project Objectives
- Project Structure
- Project Schedule
- Project Budget
- Project Management Plan and Risk Management

The Current State of Development
The “2017 Base Case”

- Membrane
  - ***P*/*ℓ***, 1,500 gpu, **α** 25, 3-year lifetime
- Module
  - Plate-and-frame
  - 0.1 bar feed-side pressure-drop
  - 0.05 bar permeate-side pressure-drop
  - Module and skid: $100/m^2 each
- Rotating equipment
  - 0.2 bar, efficiency 80%, $1,000/kW
- Installation factor: 100% of equipment cost
- Capital expenditure depreciation/amortization change: 12%/annual

MTR

How do we Estimate Cost and Performance

- A CHEMCAD computer simulation package with MTR Membrane Unit Ops calculate system performance.
- A linked Excel program uses cost assumptions to calculate $/tonne CO_2 captured.
- The membrane simulation package is reliable.
- The Excel costing program depends on harder-to-know assumptions.

Ongoing Programs will Change the "2020 Base Case"

- Mongstad test program – ongoing.
- Advanced Polaris^{TM} research program – ongoing.
- The 200 tonne CO_2/day pilot system will be 10x bigger than the NCCC system – economies of scale.

Base Case Changes 2017 – 2020
The Membrane

2017	2020
• ***P*/ℓ** 1,500	• ***P*/ℓ** 2,000
• **α** 25	• **α** 30
• Lifetime tested for 11,000 hrs	• No change
• 3-year lifetime assumed	

MTR

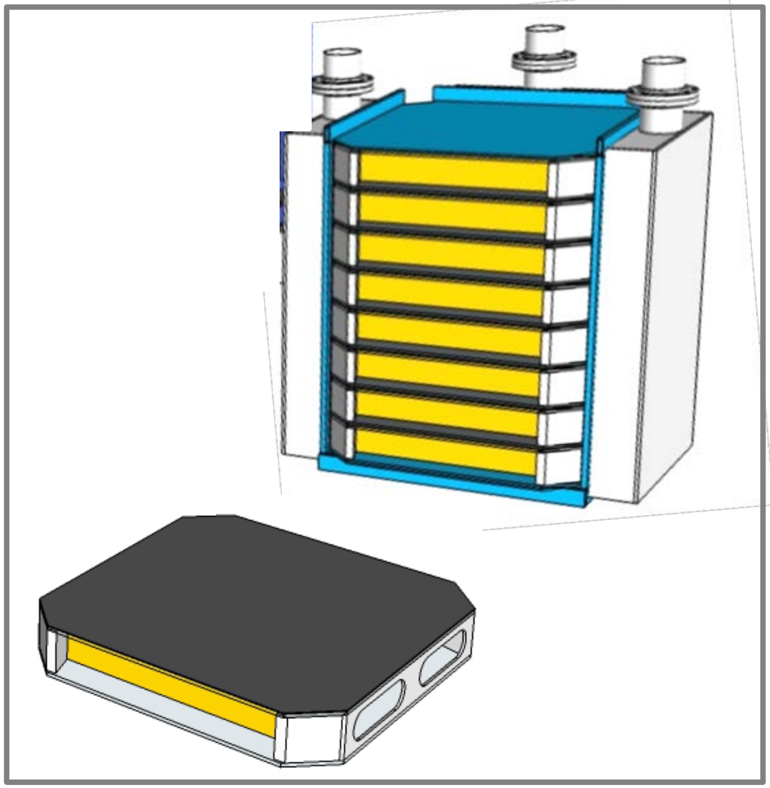
Base Case Changes 2017 – 2020
Plate-and-Frame Skid Costs

Skid 2017

$40,000/400 m^2

$100/m^2

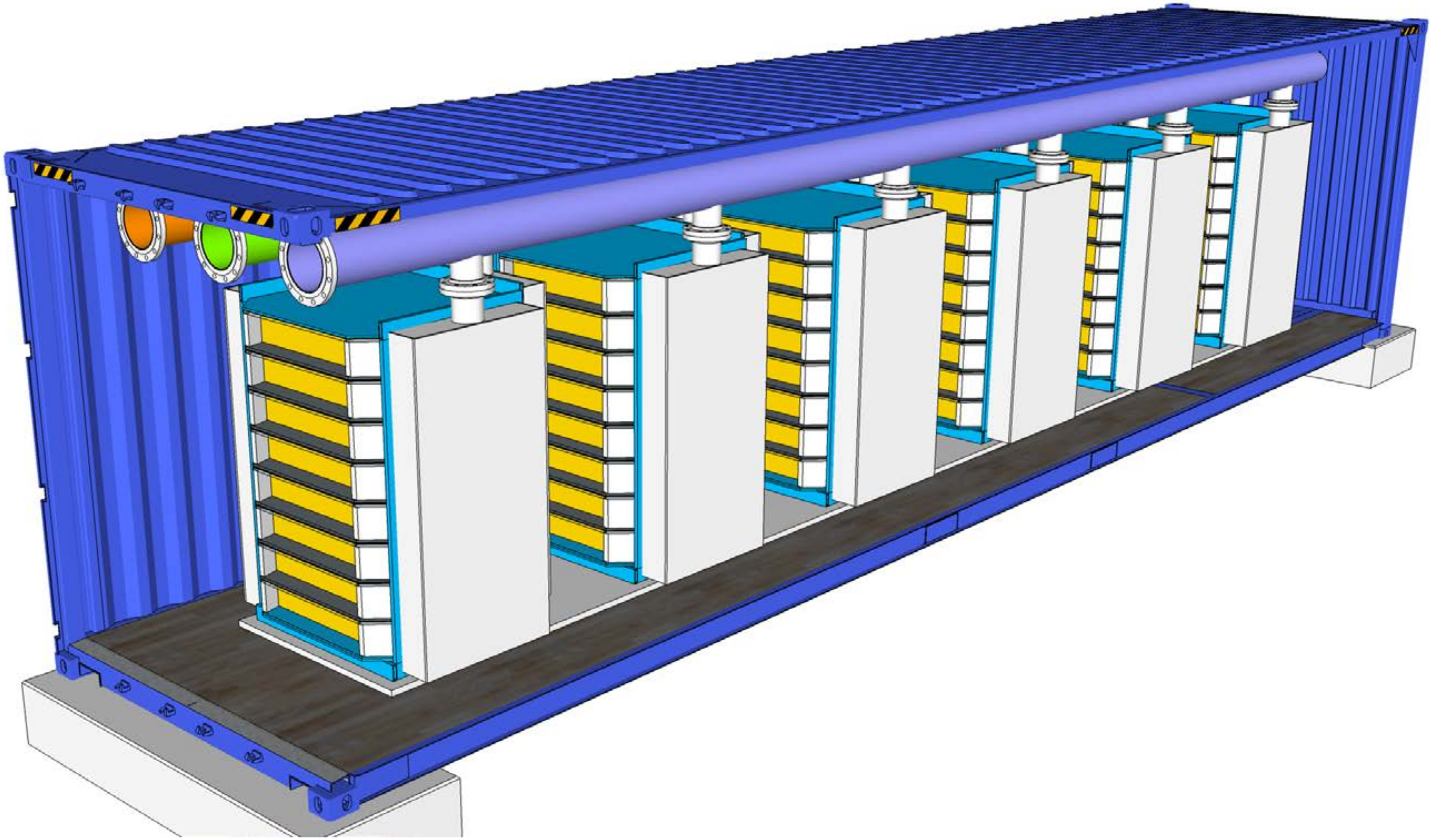
Skid 2020



~ $15,000/600 m^2

$25/m^2

The Future: Low-Pressure Containerized Plate-and-Frame Modules



The Current State of Development
The 2017 Base Case

- Membrane
  - ***P***/$\boldsymbol{\ell}$, 1,500 gpu, $\boldsymbol{\alpha}$ 25, 3-year lifetime
- Module
  - Plate-and-frame
  - 0.1 bar feed-side pressure-drop
  - 0.05 bar permeate-side pressure-drop
  - Module and skid: $100/m^2 each
- Rotating equipment
  - 0.2 bar, efficiency 80%, $1,000/kW
- Installation factor: 100% of equipment cost
- Capital expenditure depreciation/amortization change: 12% per annual

MTR

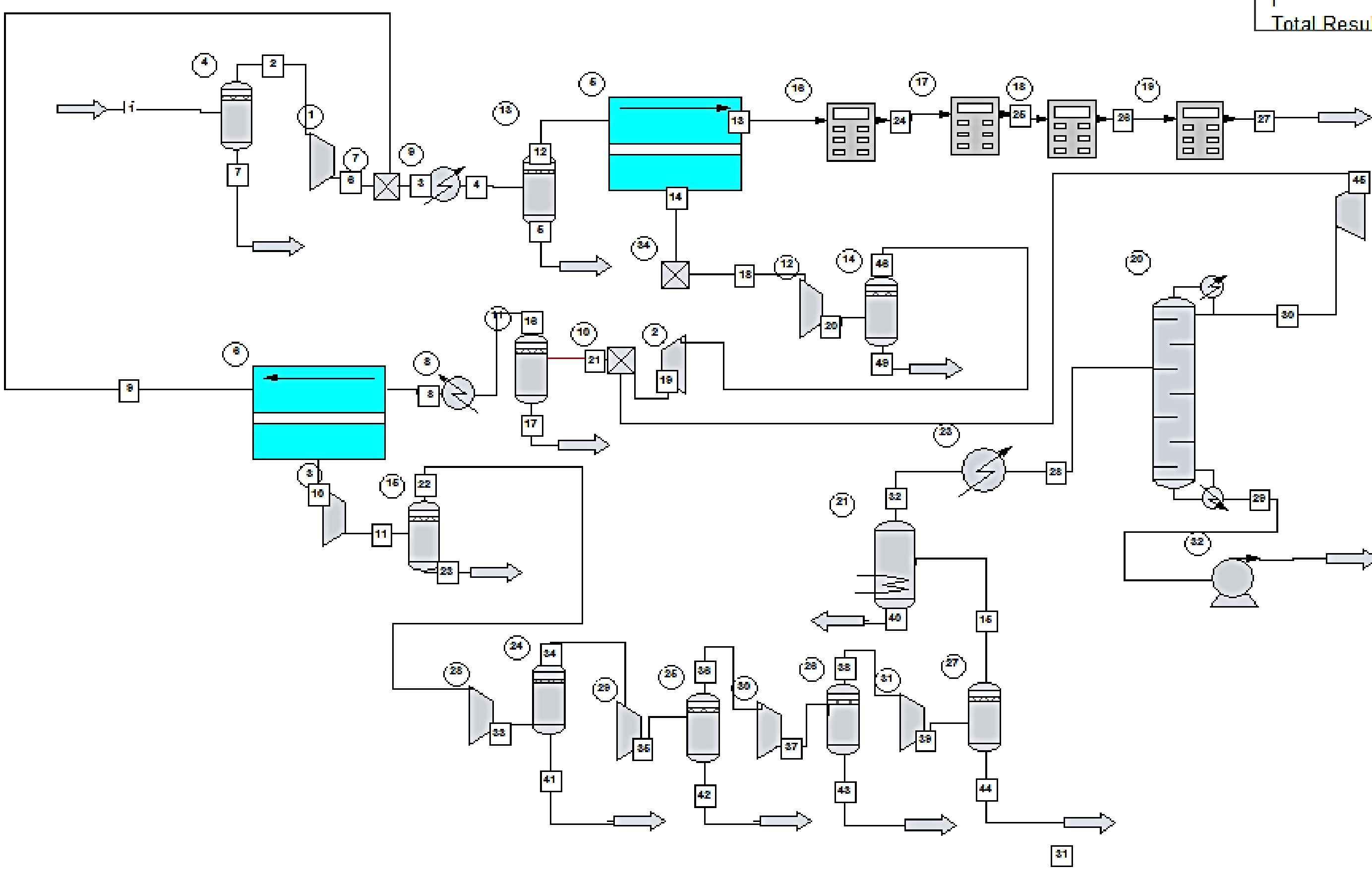
The System We Propose to Build

Equip. No.	17
Name	Kw/ton CO2
A	2520.8635
B	21241.4609
Total Result	280.2556

Equip. No.	18
Name	tons CO2/day
A	18194.1758
Total Result	198.0691

Equip. No.	19
Name	capture %
A	198.0691
B	36589.0117
Total Result	49.7261

Equip. No.	16
Name	total power
A	714070.5625
B	378974.0938
C	1.5520e+006
D	3.1072e+006
E	791896.4375
F	559717.6250
G	745430.5625
H	530889.3750
I	-226417.0625
Total Result	2520.8635



Equip. No.	5
Name	
Calculation type	4
Membrane area m2	33562.8711
Stagecut %	19.2485
Key Comp. No.	1
Key Comp. Conc.	8.3000
Feed Pressure Drop (bar)	0.0500
Permeate Pressure Drop (bar)	0.0250
Permeate Pressure bar	0.2000
P/I comp. 1	2000.0000
P/I comp. 2	66.7000

Equip. No.	6
Name	
Calculation type	4
Membrane area m2	4830.6025
Stagecut %	50.4650
Key Comp. No.	1
Key Comp. Conc.	14.0000
Feed Pressure Drop (bar)	0.0500
Permeate Pressure Drop (bar)	0.0250
Permeate Pressure bar	0.2000
P/I comp. 1	2000.0000
P/I comp. 2	66.7000

Site #1 NRG's WA Parish (Houston)

Connect to Unit #7 or Unit #8 (Petra Nova)

Site #2 NRG's Limestone Generating Station

Topics

- Background
- Technical Approach
- Project Objectives
- Project Structure
- Project Schedule
- Project Budget
- Project Management Plan and Risk Management

MTR

Project Objectives

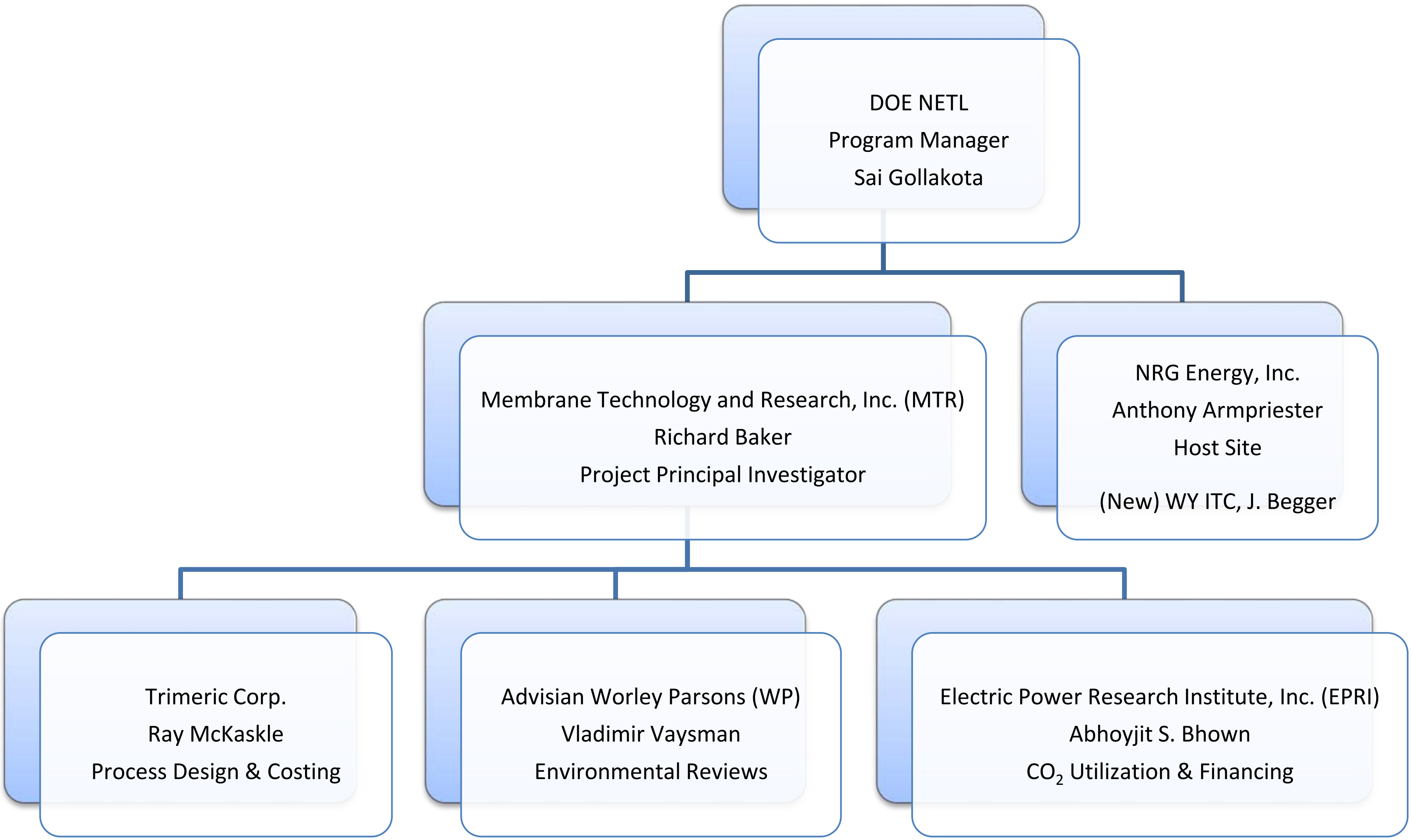
- Bring MTR's membrane-based, post-combustion CO_2 capture process to the final pre-commercial/ demonstration stage of development.
- Design, build, and operate a 200 TPD large pilot capture system using partial capture to achieve the lowest cost-of-capture possible ($/tonne CO_2).
- Phase I:
  - selection of the host power plant
  - conduct environmental information volume
  - secure of financial commitments
  - update pilot design and budget, and finalizing team commitments and organization for Phase II / III

MTR

Topics

- Background
- Technical Approach
- Project Objectives
- Project Structure
- Project Schedule
- Project Budget
- Project Management Plan and Risk Management

Project Team



Roles and Responsibilities

Large Pilot Testing of the MTR Membrane Post-Combustion CO_2 Capture Process (DE-FE0031587)

- Phase I award: $1,000,000 / April 1, 2018 to July 31, 2019.
  - **MTR** (prime): Design process design for partial capture system sized at 200 tonnes/day using partial capture.
  - **Trimeric**: Update design for carbon purification unit.
  - **EPRI**: Evaluate opportunities for CO_2 utilization and Phases II and III cost-sharing.
  - **WorleyParsons**: Perform Environmental Information Volume.
  - **NRG**: Provide site information for candidate host site.

MTR

Topics

- Background
- Technical Approach
- Project Objectives
- Project Structure
- Project Schedule
- Project Budget
- Project Management Plan and Risk Management

Project Schedule

Project Tasks	Start Date	End Date	2018									2019					
			Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Task 1. Project Management and Planning	4/1/2018	6/30/2019															
Task 2. Select Project Host Site																	
Task 2.1. Visit Host Site for Evaluation	4/1/2018	9/31/2018															
Task 2.2. Obtain Host Site Commitment	4/1/2018	9/31/2018															
Task 3. Prepare an Environmental Information Volume (EIV)	10/1/2018	12/31/2018															
Task 4. Update System Design, Budget and Schedule	7/1/2018	3/31/2019															
Task 4.1 Update Process Design	7/1/2018	12/31/2018															
Task 4.2. Update Budget and Schedule	7/1/2018	3/31/2019															
Task 5. Obtain Commitments for the Phase II/ Phase III Program	10/1/2018	3/31/2019															

NOTES:

See Milestone Log for description of milestone sets for each budget period.

▲ = Milestone

Topics

- Background
- Technical Approach
- Project Objectives
- Project Structure
- Project Schedule
- Project Budget
- Project Management Plan and Risk Management

MTR

Project Budget

Phase I - Budget Period I

	02/01/2018-4/30/2018	05/01/2018-07/31/2018	8/1/2018-10/31/2018	11/1/2018-3/31/2019	4/1/2019-6/30/19	Total BPI
	Q1 Total	Q2 Total	Q3 Total	Q4 Total	Q5 Total	
Federal Share	$182,187	$246,746	$301,864	$226,314	$0	$957,111
Non-Fed Share	45,547	61,686	75,466	56,579	$0	239,277
Total Planned	$227,734	$308.432	$377,330	$282,892	$0	$1,196,388

MTR

Topics

- Background
- Technical Approach
- Project Objectives
- Project Structure
- Project Schedule
- Project Budget
- Project Management Plan and Risk Management

Phase I – Project Tasks

- Task 1. Project Management and Planning
- Task 2. Select Project Host Site
  - *Subtask 2.1. Visit Host Sites for Evaluation*
  - *Subtask 2.2. Obtain Host Site Commitment*
- Task 3. Prepare an Environmental Information Volume (EIV)
- Task 4. Updated System Design, Budget and Schedule
  - *Subtask 4.1. Update Process Design*
  - *Subtask 4.2. Update Budget and Schedule*
- Task 5. Obtain Commitments for the Phase II/Phase III Project

Project Milestones

Milestone Number	Task/ Subtask No.	Milestone Description	Planned Completion Date (*)	Verification Method
Phase I Milestones				
1	2.2	Host site selected and commitment received.	9/31/18	Letter of intent written
2	3	Completion of EIV.	12/31/18	EIV report
3	4.1	Updated system design based on host site completed	12/31/18	Quarterly report
4	4.2	Revised Phase II/III budget and schedule completed.	3/31/19	Final report
5	5	Team commitments with cost share contributions signed.	3/31/19	Agreement signed

Phase I – Success Criteria

- Signed host-site agreement for Phase II/III activities.
- Completion of Environmental Information Volume and NEPA review.
- Completion of updated budgetary estimate (±30%) and schedule for Phases II/III.
- Letters of commitment from project team with necessary capabilities to execute Phases II and III.
- Signed cost-sharing agreement for Phase II/III effort.

MTR

Risk Management

Description of Risks	Probability (Low, moderate, high)	Impact (Low, moderate, high)	Risk Management Mitigation and Response Strategies
Management/Resource Risks			
Difficulty finding a host site	Low	High	We have 3 candidate host sites that meet all of MTR's criteria. A key Phase I task will be to evaluate the pros and cons of these sites, select the preferred location, and finalize commitments to proceed with the large pilot project.
Timing uncertainty related to NEPA documentation and any other required environmental permits	Low	High	NRG completed environmental reviews at the possible host sites. WP has experienced environmental impact assessment personnel who will conduct an EIV study in Phase I.
Long-lead time procurement creates project delays	Low	Moderate	Long lead time items and equipment will be identified in Phase I Task 4. These items can be prioritized for procurement after the Phase II FEED is completed.
MTR's financial, manufacturing and engineering capability to bring this technology to the large pilot scale	Low	High	MTR is a commercial producer of gas separations systems for the petrochemical, refinery and natural gas processing industries. The largest commercial systems we have installed are ~$20 million projects to treat >100 MMscfd of gas. These systems are bigger than the large pilot to be built in this project. MTR has the engineering, membrane manufacturing, and management capability to execute the proposed project. We are collaborating with a large end user (NRG), engineering companies (WP and Trimeric), as well as an energy industry non-profit (EPRI) to help insure the success of this project. We have cost share commitments for Phase I secured and are actively working on Phase II/III funding.

Risk Management, Cont.

Description of Risks	Probability (Low, moderate, high)	Impact (Low, moderate, high)	Risk Management Mitigation and Response Strategies
Technical Risks			
Membrane stability is less than expected	Low	Moderate	Prior projects at NCCC have demonstrated a Polaris membrane lifetime of greater than one year treating coal flue gas, so we are confident the large pilot will perform well. However, each system is different, so careful performance monitoring will be conducted during operation in Phase III.
Uncertainty in vacuum pumps and compression equipment	Low	Moderate	In previous test systems, robust but inefficient vacuum pumps and compressors were used to ensure the system would operate consistently. This experience gives us a low risk option for the large pilot. However, we also plan to work with Trimeric and major OEM suppliers in Phase I on selection of more efficient equipment that will be more appropriate for larger scales.
Market Risks			
CO_2 emissions are not regulated.	High	Low	Regulations on CO_2 emissions are in flux in the U.S. and worldwide. Changes in the regulations during the term of the project are likely, but their effect on the project's execution is expected to be low. Ultimately, efficient, low-carbon technologies will find use in power and industrial settings.

Questions?

MTR