Initial Engineering Design of a Post-Combustion CO_2 Capture System for Duke Energy's East Bend Station Using Membrane-Based Technology

DE-FE0031589

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Carbon Capture, Utilization, Storage and Oil and Gas Technologies Integrated Review Meeting
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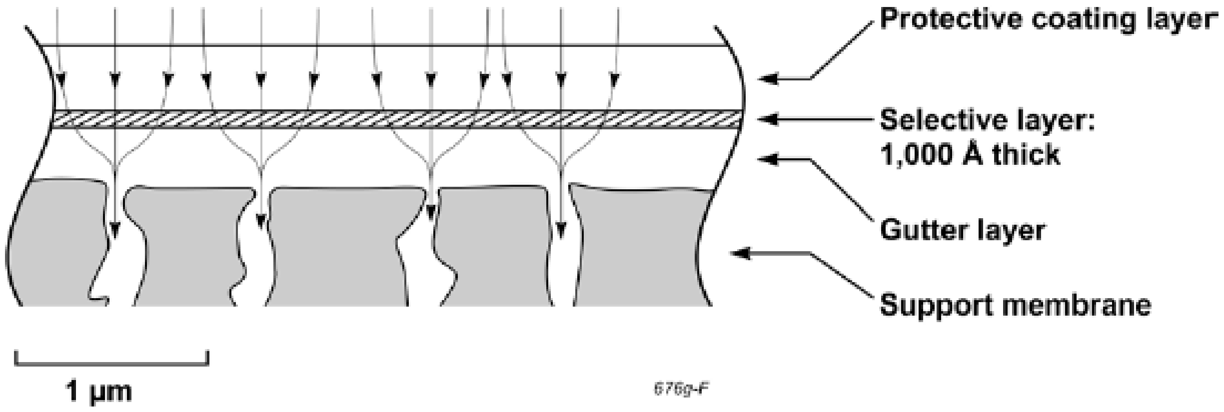
Project Overview

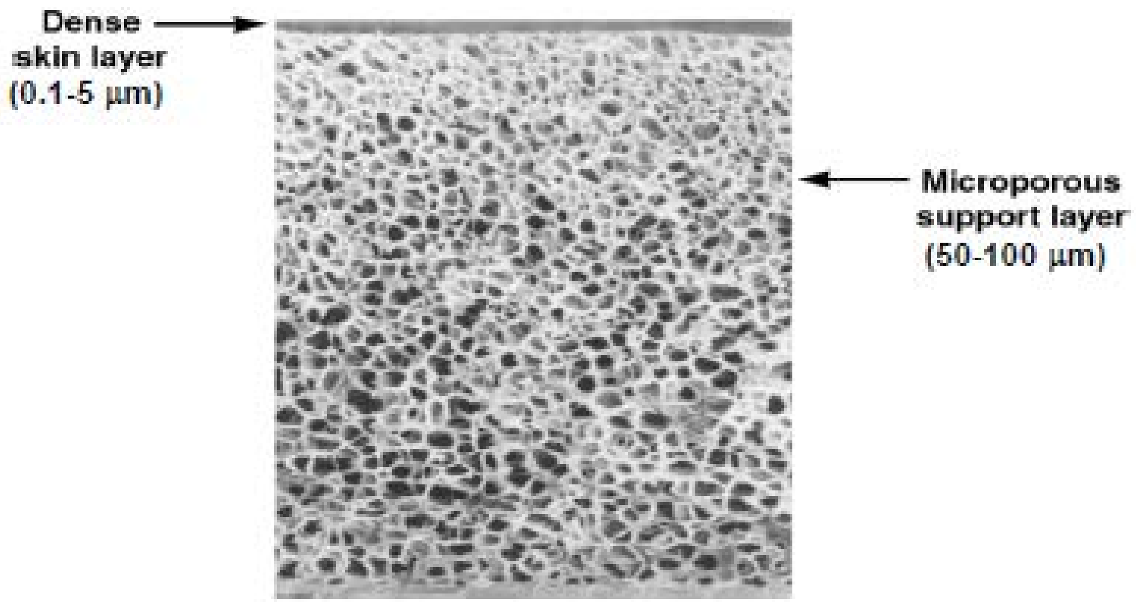
- **Funding**
  - Federal Share: $ 1,625,244
  - Non-Federal Share: $ 406,485
  - TOTAL $ 2,031,729
- **Project Performance Dates**
  - 04/06/2018 to 03/31/2020
- **Project Participants**
  - **Prime:**
    - Electric Power Research Institute
  - **Sub-contractors:**
    - Membrane Technology and Research
      - *Trimeric*
    - Nexant Inc.
      - *Bechtel*
  - **Site Host:**
    - Duke Energy

- **Project Objective**
  - Perform an initial engineering design and cost estimate for a commercial-scale, membrane-based, post-combustion CO_2 capture system retrofit to Duke Energy's 600MWe coal-fired East Bend Unit.

Background - MTR Polaris Membrane

- MTR has developed a CO_2 selective polymeric membrane material and module - the MTR Polaris membrane
- This provides higher CO_2 permeance for post combustion flue gas applications than existing polymeric membranes

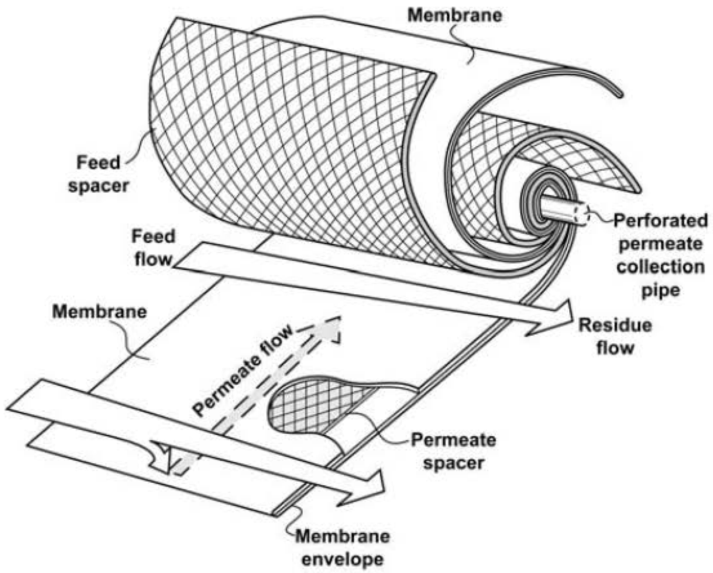


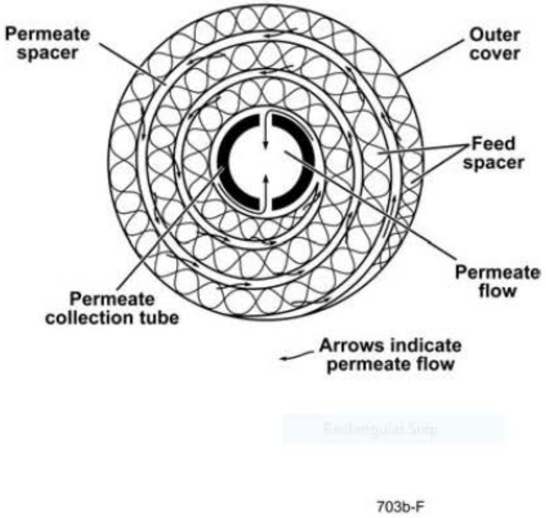


Images Courtesy of MTR

Background – Membrane Module

- Membranes are widely used for desalination and natural gas sweetening
- The largest existing systems are similar in scale to those required for a 550MWe coal fired power plant

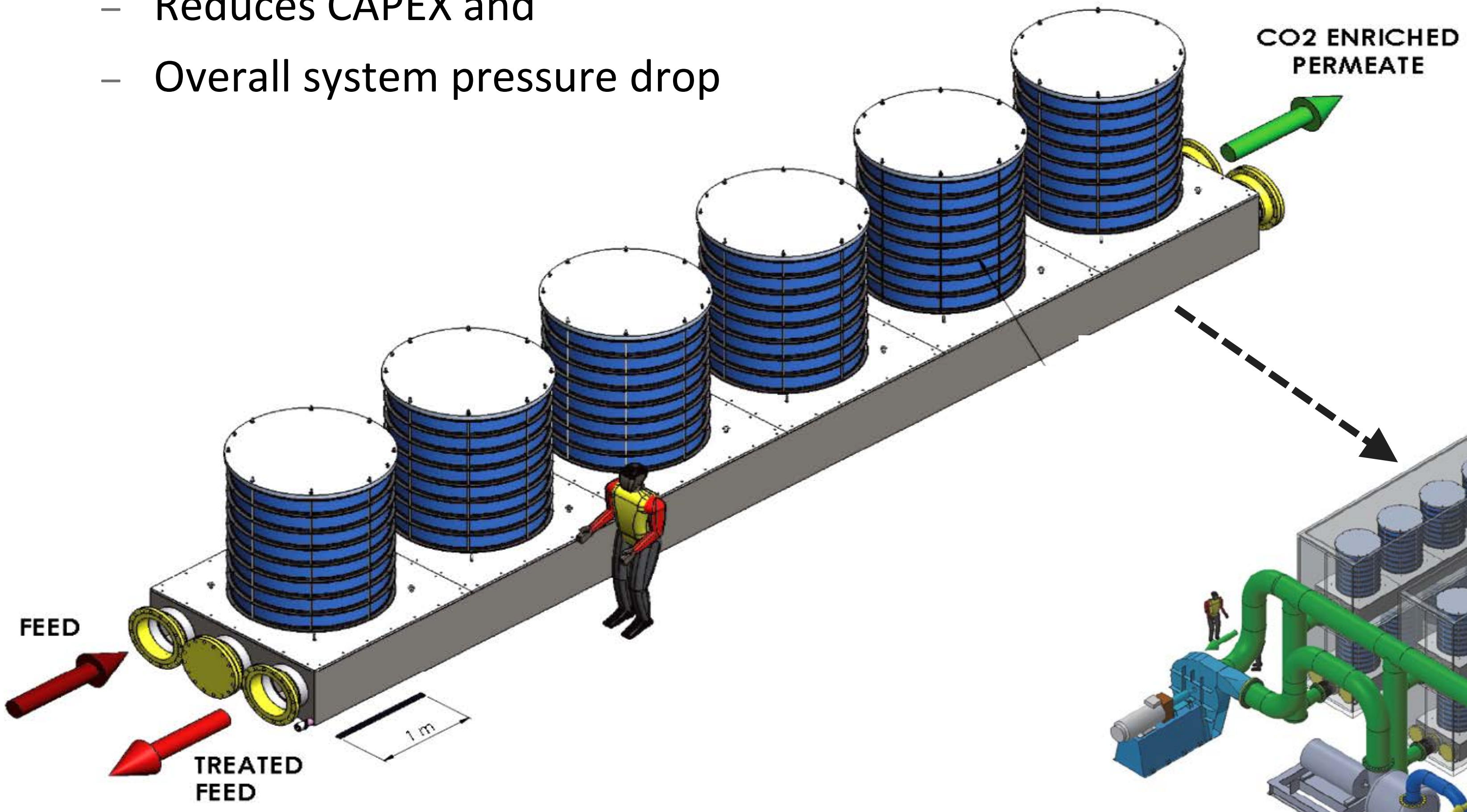


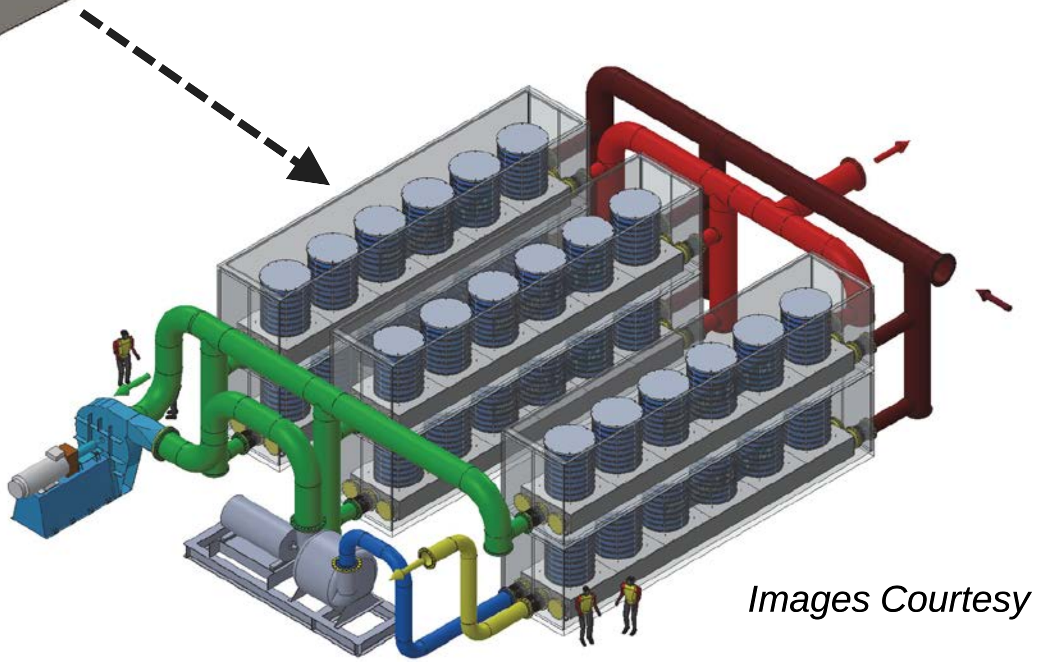


Images Courtesy of MTR

Background - Low Pressure Drop Modules

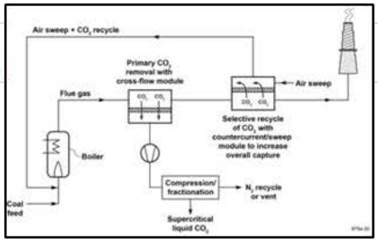
- Compact modular system design using high permeance membranes
  - Reduces CAPEX and
  - Overall system pressure drop





Images Courtesy of MTR

MTRs CO_2 Capture Development to Date



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

2006 | 2008 | 2010 | 2012 | 2014 | 2016 | 2018 | 2020

MTR MEMBRANE TECHNOLOGY & RESEARCH

Images Courtesy of MTR

Advantages of the Membrane Capture Process

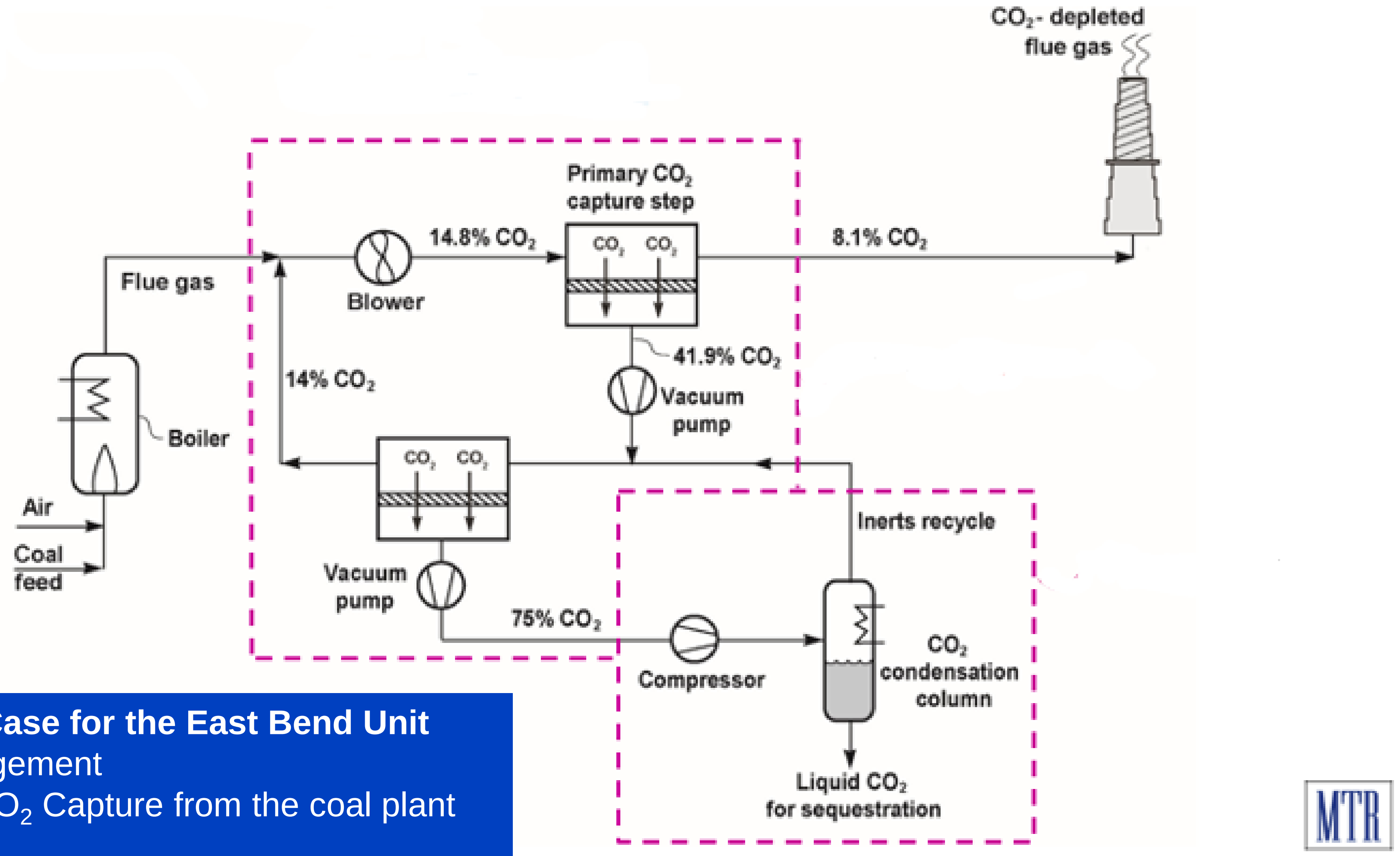
- Simple, passive operation with no chemical handling, emissions, or disposal issues
- Membrane not effected by O_2, SO_x or NO_x; co-capture possible
  - $O_{2,}$ SO_x or NO_x permeate and therefore impact the overall process design
- Modular technology – high volume manufacturing to lower cost, pre-assembled, containerized skids
- No steam use → no modifications to existing boiler/turbines
- Near instantaneous response; high turndown possible
- Very efficient at partial capture (40-60% CO_2 recovery)

Challenges of the Membrane Capture Process

- Develop a design that will **minimize the impact** on the power plant by disrupting as little of the existing facilities as possible.
  - Also shorten the amount of downtime before the plant can resume normal operations
- Develop a design that will **minimize the cost** of each tonne of captured CO_2 while also maintaining the net 600 MW output of the East Bend Station (EBS).
  - This will be done by optimizing the percentage of CO_2 captured (~60%) and by adding a natural-gas-fired combustion turbine (CT) or possibly a combined cycle to offset the new auxiliary loads

Initial Conceptual Flow Diagram

Partial CO_2 Capture with 2 Stage Membrane Process



Preliminary Design Case for the East Bend Unit

- 2 membrane arrangement
- Aiming for ~60% CO_2 Capture from the coal plant
- No boiler recycle

Technical Approach 1/2

- Following a data gathering task that will include several site visit to the EBS, a preliminary process design will be developed for one Post Combustion Capture (PCC) system which captures CO_2 from the entire flue gas stream of the power plant.
- This preliminary design will then be subjected to a series of analyses to examine various options for minimizing the cost of CO_2 capture on a \$/tonne-captured basis.
- The analysis will also examine several options for providing the PCC system's auxiliary power via a CT-based power plant.
- Once an optimized process design has been identified, that design will be detailed and documented in a complete Process Design Package (PDP).

Technical Approach 2/2

- As part of this effort a HAZOP and constructability review of the design will be conducted.
- The PDP data will be used to carry out a techno-economic analysis that will include a +/-30% accuracy capital cost estimate as well as an estimate of the first year cost of electricity and $/tonne cost of CO_2 capture for the retrofitted power plant.
- The marginal operating cost of the retrofitted plant with also be calculated and used in a unit dispatch model to predict how the retrofit will impact how often the coal plant is called on to operate.

Project Schedule

TASK NAME:	DATES:		BUDGET PERIOD 1:												BUDGET PERIOD 2:											
	Start	End	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
TASK 1: Project Management and Planning (EPRI lead)	4/1/2018	3/31/2020																								
1.1 Project and Risk Management (EPRI)			M1	M2							DP															M11
1.2 Financial and Project Reporting (EPRI)						Q1			Q2			Q3			Q4			Q5			Q6			Q7		
1.3 Technology Maturation Plan (MTR)					M3																					
TASK 2: Develop Design Basis document (Nexant Lead)	4/1/2018	9/30/2018						M4																		
TASK 3: Establish Base Case Model (Nexant Lead)	7/1/2018	9/30/2018						M5			M5															
TASK 4: System analysis of Integration options (EPRI Lead)	8/1/2018	04/31/2019																								
4.1 Opitmize CO2 Capture Plant Design (MTR)																										
4.2 Evaluate Options for Aux Power (EPRI, Nexant)																										
4.3 Finalize Design Configuration (EPRI , MTR, Nexant)															M6											
DECISION POINT: Examine and Review Retrofit Options	1/31/2019	4/15/2019													DP											
TASK 5: Finalize Overall Retrofit PC Design (EPRI Lead)	3/1/2019	9/30/2019																								
5.1 Design Package of the Membrane CCS System (MTR)		7/30/2019																M7								
5.2 Design Package for BOP & Aux. Power (EPRI & Nexant)	xxx	9/30/2019																		X						
5.3 Preliminary HAZOP Review (Nexant, Bechtel, MTR & Duke)		10/30/2019																			M8					
5.4 Constructibility Review (Nexant , Bechtel & Duke)		10/30/2019																			M9					
TASK 6: Techno-Economic Analysis (EPRI Lead)	8/1/2019	12/31/2019																								
6.1 Capital Cost Estimation of Integrated PCC Design (Nexant)		10/30/2019																			M10					
6.2 O&M Cost Estimation of Integrated PCC Design (Nexant, EPRI)		10/30/2019																			X					
6.2 TEA and Dispatch Analysis (EPRI & DUKE)		12/31/2019																								
TASK 7: Final Report Preparation (EPRI Lead)	1/1/2020	3/31/2020																								FR

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Key Accomplishments

1. Host site agreed to EPRI team's proposed capture system's auxiliary power source
2. Identified all electrical loads and initiated refinement of the power demands for the full-scale CO_2 membrane capture system
3. Completed membrane arrangement and CO_2 processing unit flow diagram and developed preliminary equipment list
4. Completed a comprehensive review of process cooling requirements and verified that the preliminary layout of the overall retrofit plant will fit the space available

Key Accomplishment 1

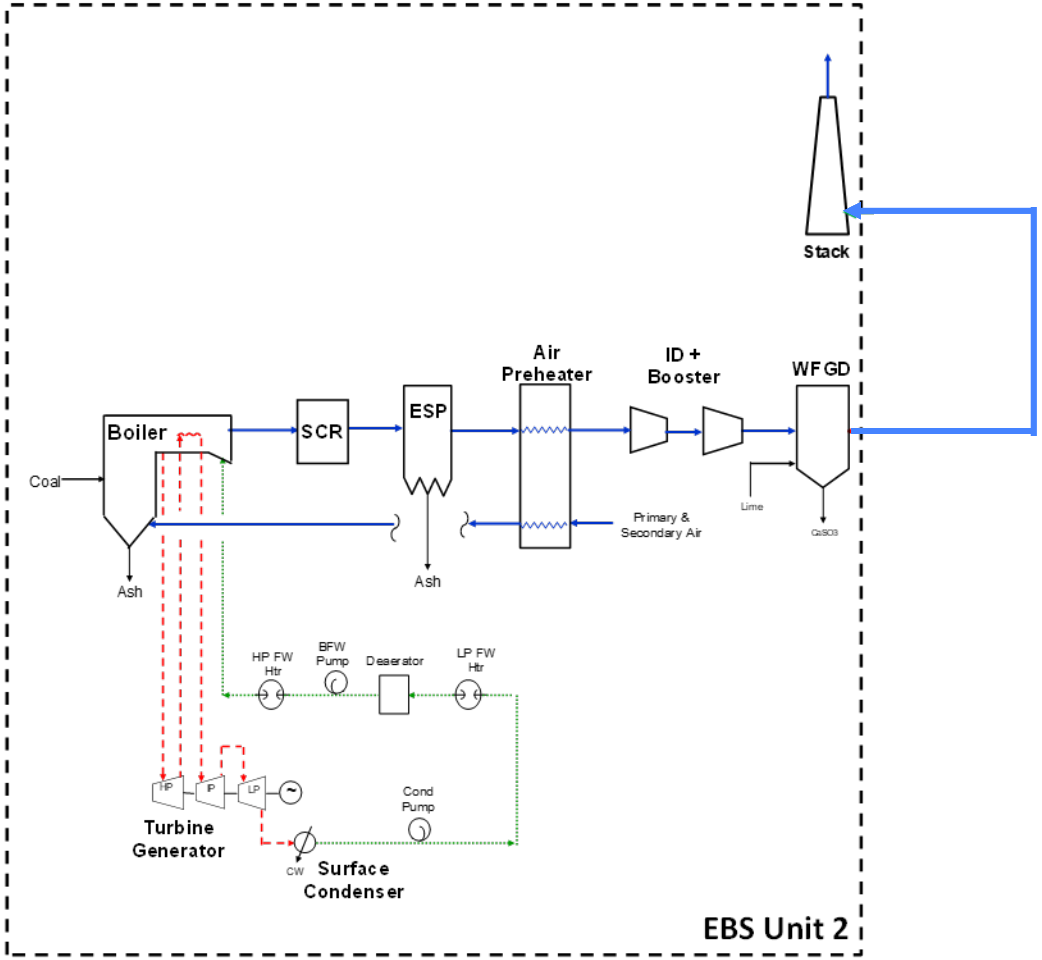
Host site agreed to EPRI team's proposed capture system's auxiliary power source

- The retrofit team prepared and presented to site hosts Duke Energy an assessment of 4 auxiliary power options for the membrane capture system.
- A single Gas Turbine Simple Cycle Power island was recommended as best suited for the East Bend station application
- Duke Energy accepted the project team's recommendation. This represents a significant decision point in the project plan.

Supplying the Membrane System Power Requirements

- Unlike solvent PCC systems - No steam requirement, but power is required to drive the membrane systems fans, blowers, vacuum compressors pumps and CO_2 compression
- 4 ways to supply power have been considered:
  - Option 1: New natural gas-fired simple cycle,
  - Option 2: New natural gas-fired combined cycle
  - Option 3: New simple cycle with HRSG steam to the coal plant FWH
  - Option 4: Auxiliary power supplied from the existing coal station
- Examine which option is **best suited** for MTR PCC integration implementation at EBS

Aux Power Option 1: New natural gas-fired simple cycle



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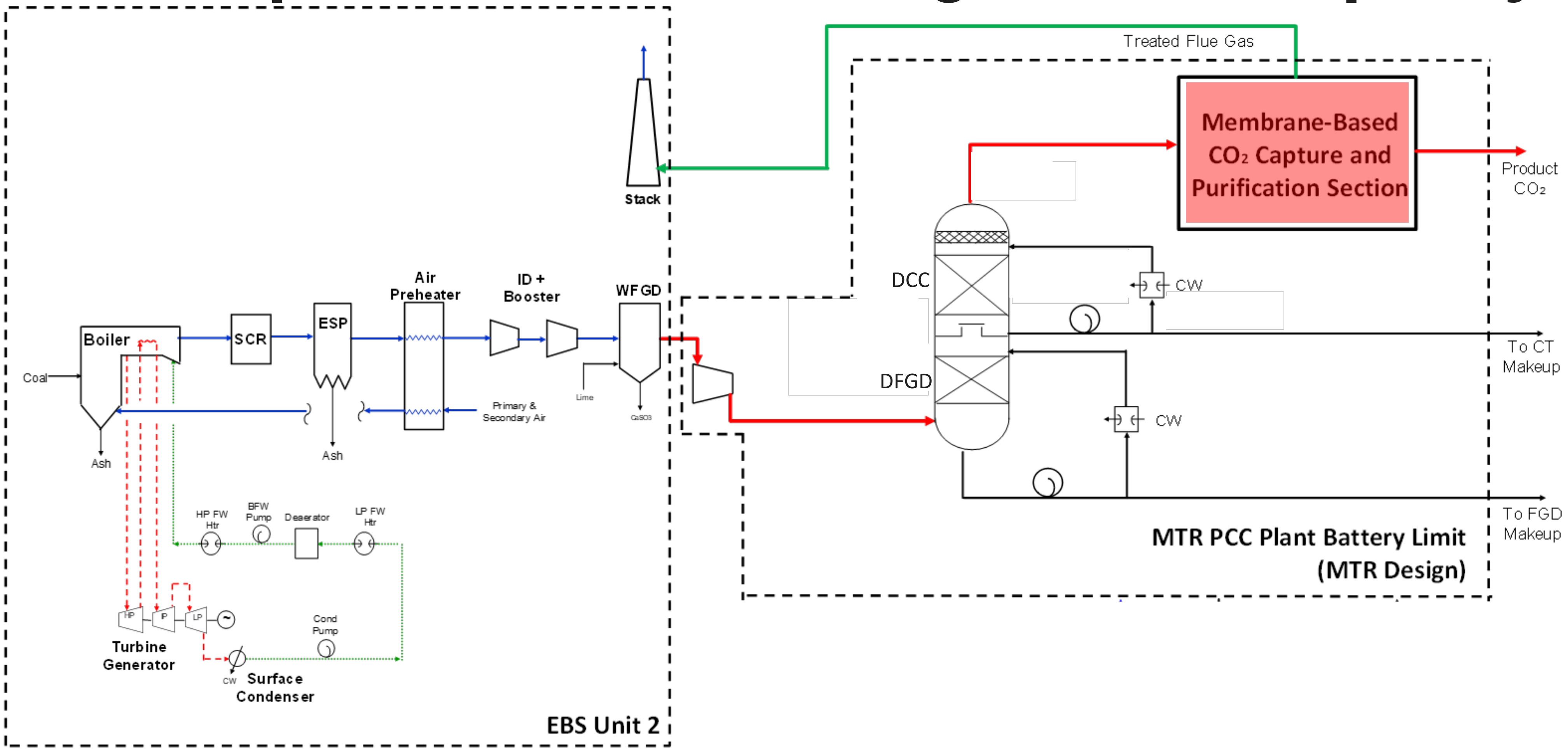

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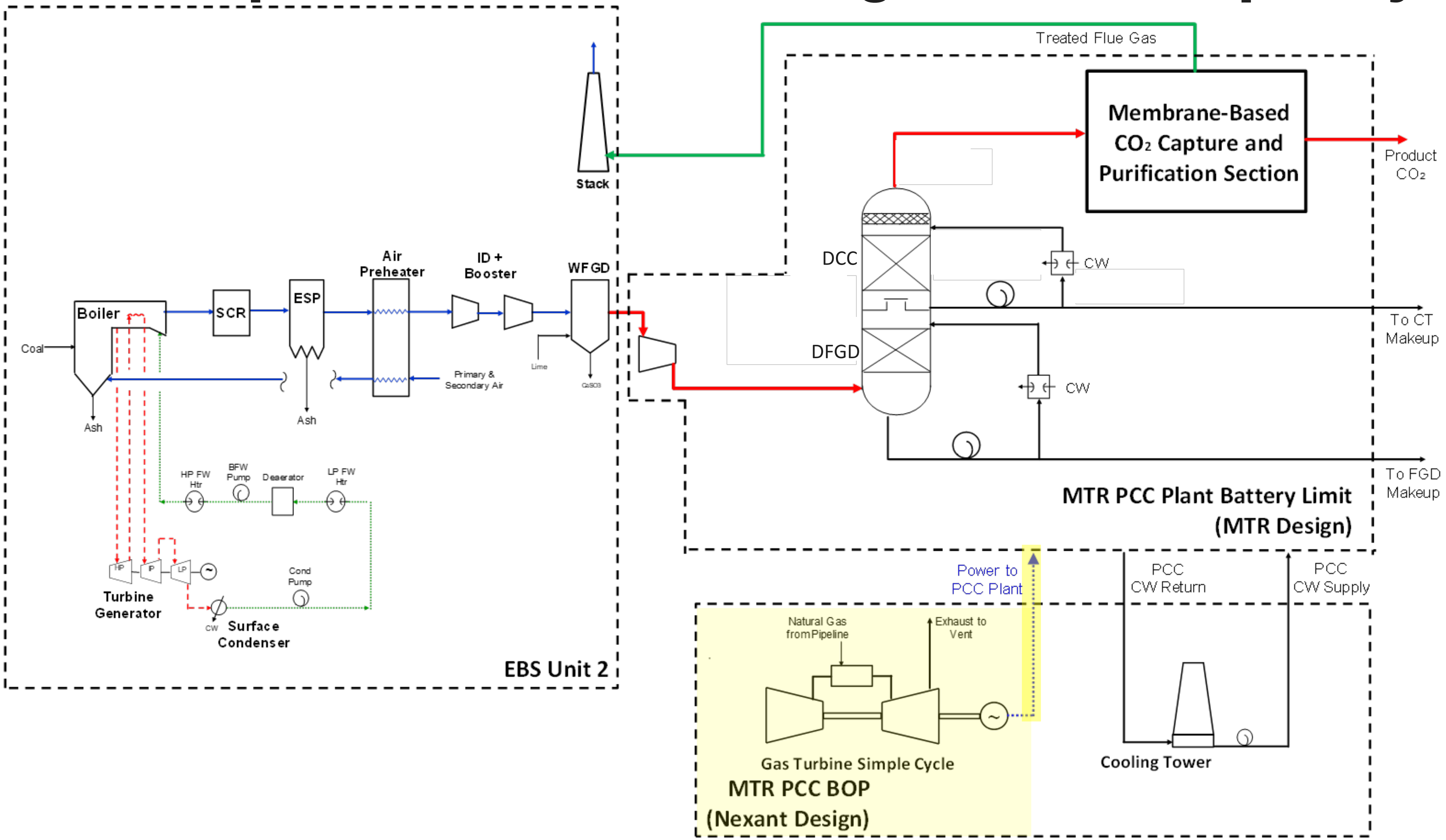
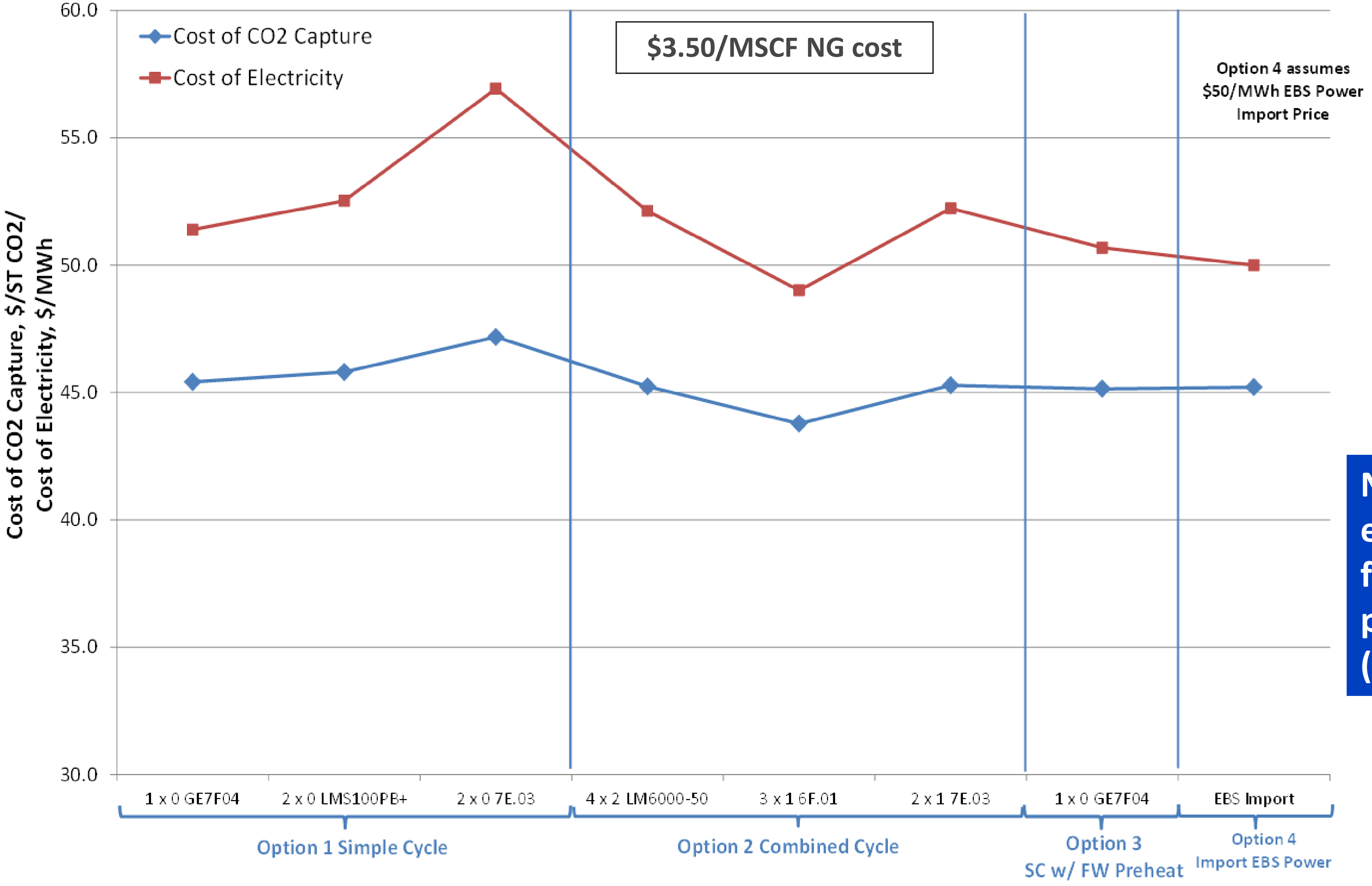


Aux Power impact on cost of CO_2 Capture & COE



Note: Preliminary evaluation to help facilitate auxiliary power selection (NOT FINAL RESULTS))

Results From Auxiliary Power Assessment

- Similar cost of CO_2 capture for all integration options (within margin of error)
- Selection of best option may be based on overall ease of integration instead of cost
- Recommend simple cycle (Option 1) using single GE7F04 turbine
  - Lowest upfront cost of all the external power options considered
  - Allow phased implementation of feedwater preheat (Option 3)
  - Enough temperature & heat available for future EBS HP feedwater preheating if desired
  - Potential for future addition of a full size HRSG, should the owner at a later date, consider additional power export of value
  - GE 7F.04 was the old GE 7FA GT and its operation is well established commercially

Key Accomplishment 2

Identified all electrical loads and initiated refinement of the power demands for the full-scale CO_2 membrane capture system

- After selecting the power island, the retrofit team continued to optimize and refine the power load of the capture process to ensure they stay within the capabilities of the power island while maximizing CO_2 captured.
- The largest loads are blowers, membrane permeate compressors, refrigerant compressors and CO_2 pumps.
- In addition, the specific impacts of the East Bend site ambient conditions, flue gas water content, and air in-leakage from the power plant on the final capture system design have been examined.

Summary of Aux Power and Cooling Water Requirements by Subsystem

Item	Normal Motor Power, MW	Cooling Water, gpm	Cooling Duty, MMBtu/hr
Flue Gas Blower	18.6		
DCC w/ DFGD	3.3	31,946	319.6
MTR – Total Power Consumption	130.0		
MTR – CW Load for Power Input		39,914	399.3
MTR – H_2O Condensing CW Load		32,996	330.1
MTR – Misc. Utilities			
Dedicated CT System for PCC	1.6		
Dedicated CW System for PCC	5.6		
BOP	1.3		
Total	**160.3**	**104,856**	**1,049.0**

Note: Preliminary Numbers to Help facilitate the Aux Power selection (NOT FINAL RESULTS)

Direct Contact Cooler

- 2 trains to handle 100% of EBS flue gas (FG) from WFGD
- Each train consists of a FG blower; a DCC contactor with circulation pumps and plate-and-frame heat exchangers; and the associated FG ducting
- Each contactor has two packed bed sections
  - Deep Flue Gas Desulfurization (DFGD) bottom bed to reduce the FG sulfur content down below 5 ppm with caustic scrubbing to meet CO_2 purity specifications (per QGES)
  - Direct Contact Cooler (DCC) top bed to cool the FG, minimizing its moisture content before feeding the MTR membranes

Key Accomplishment 3

Completed membrane arrangement and CO_2 processing unit flow diagram definition and preliminary equipment list

- MTR and Trimeric prepared detailed CO_2 and refrigeration process flow diagrams (PFD).
- Expanding on the original concept outline PFD, this detailed diagram shows the entire process including heat integration between flue gas, cold CO_2 process streams, and refrigerant streams as well as individual equipment items selected to facilitate capture.
- The PFD is being used used to engage with vendors for specific equipment items, performance and cost.

PFD Development: Flue Gas Conditioning

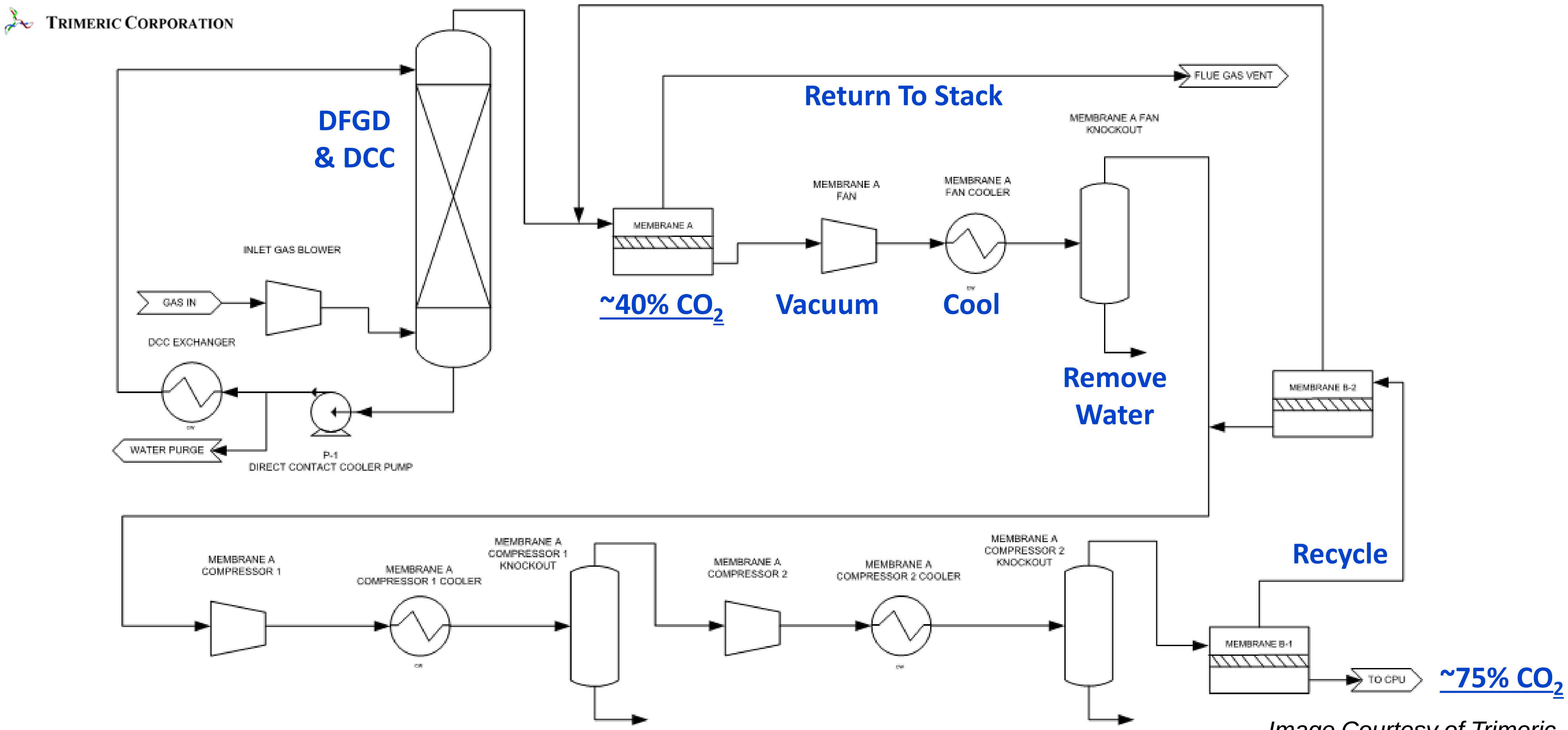
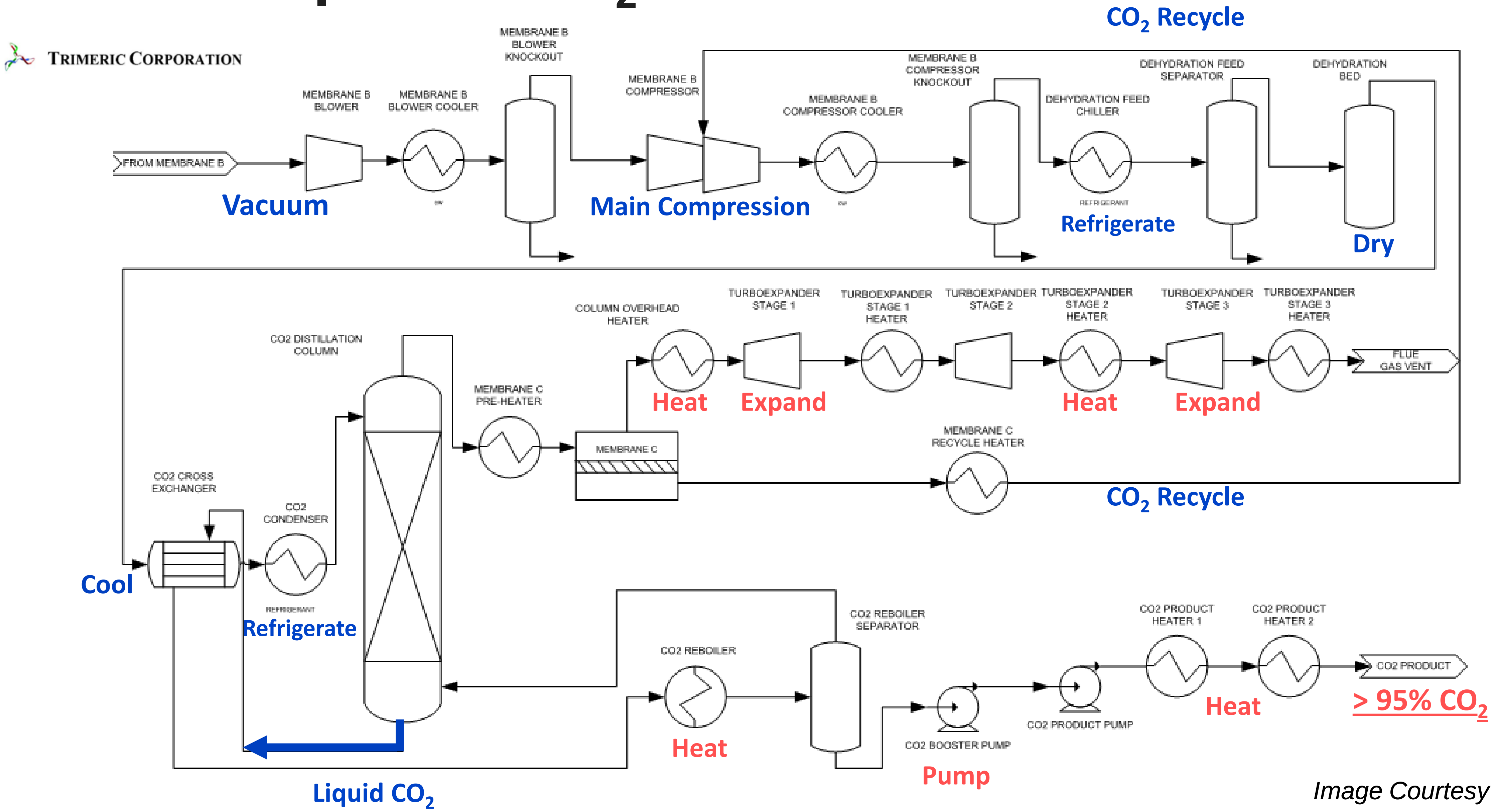


Image Courtesy of Trimeric

PFD Development: CO_2 Purification Unit



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PFD Development: Refrigeration System

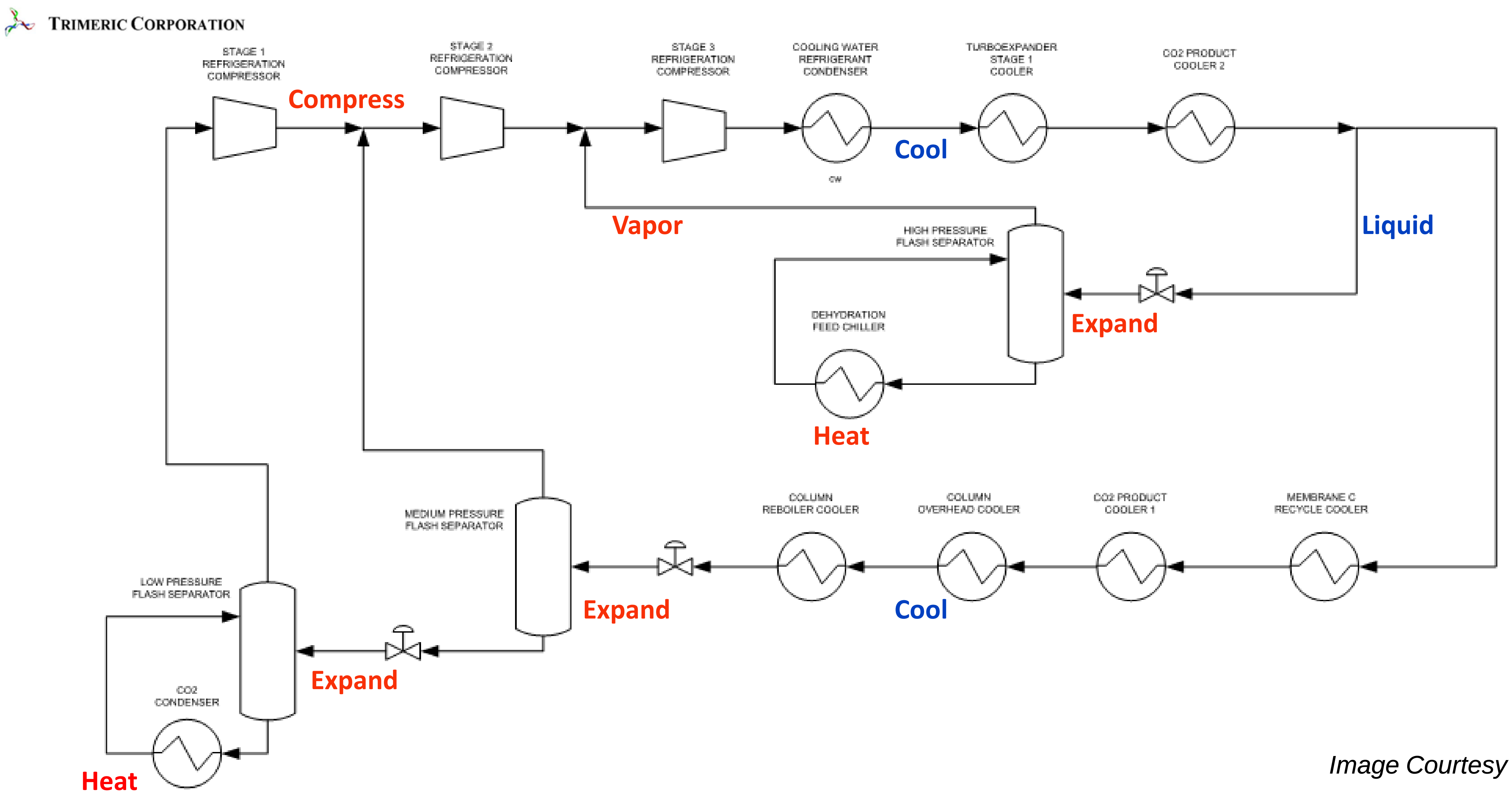


Image Courtesy of Trimeric

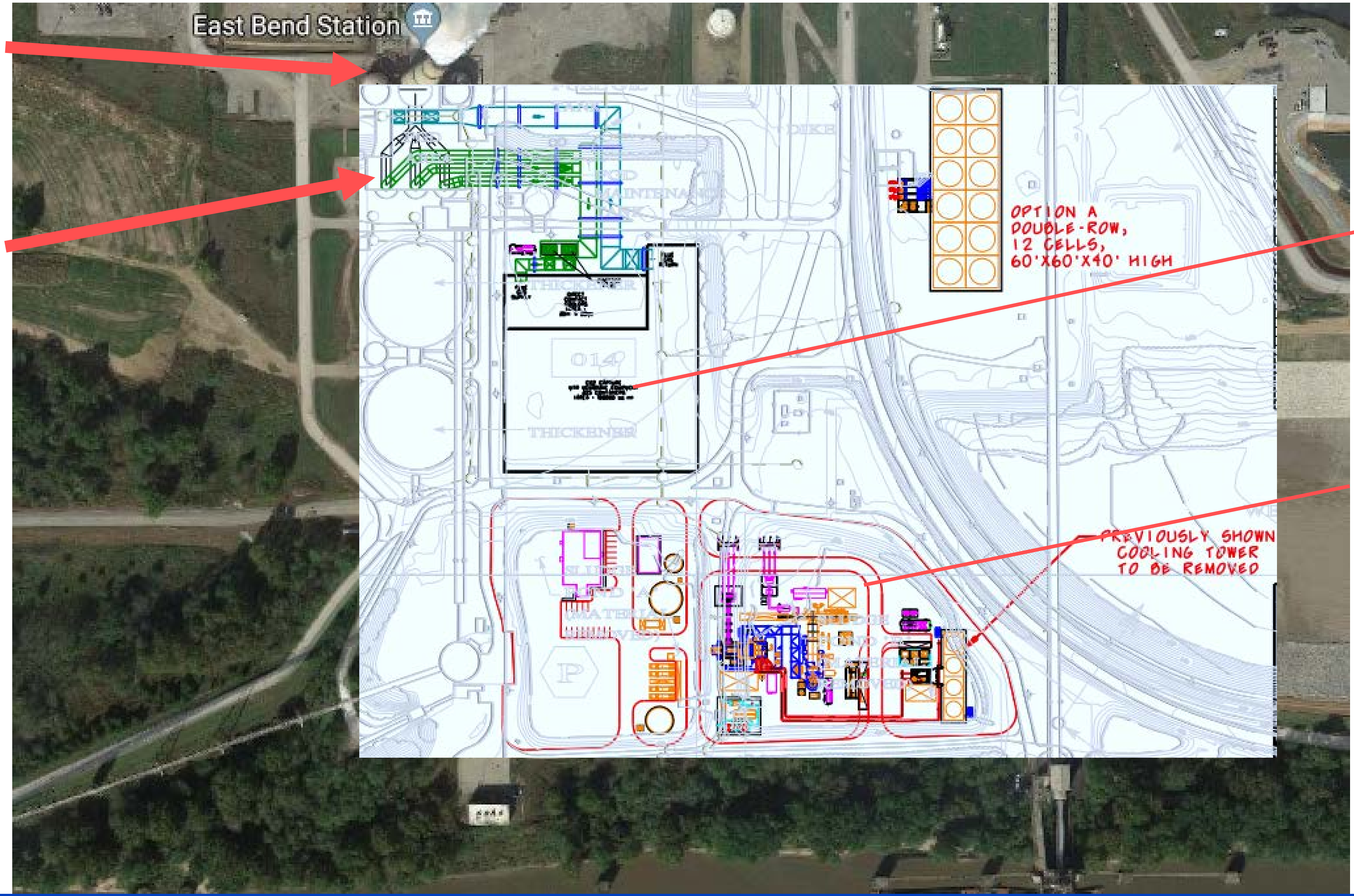
Key Accomplishment 4

Completed a comprehensive review of process cooling requirements and verified that the preliminary layout of the overall retrofit plant will fit the space available

- The membrane capture system preliminary cooling water duty and the cooling water flow rate requirements have been defined as well as the design of the direct contact cooler.
- These allow the capture island's additional cooling towers to be sized and positioned.
- An initial layout of the cooling towers and the capture system (including its tie-ins to the existing station flue gas) has been drafted.
- This illustrates that the membrane retrofit can fit within the space available on the existing East Bend site.

East Bend Station Plot Plan

East Bend Station w/ MTR PCC Plant Plot Plan



Stack

Wet FGDs

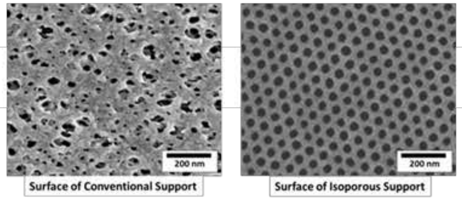
CO_2 Capture island

New Power Island

Note: Preliminary Layout (NOT FINAL RESULTS)

MTRs CO_2 Capture Development – Current Projects

Self-Assembly Isoporous Supports, CA (DE-FE31596)
- Improve gas transport through support layer
- Enables a reduction in membrane area
- Build and test new membrane at NCCC



Surface of Conventional Support
Surface of Isoporous Support

Pilot Testing at TCM, Norway (DE-FE31587)
- 1 MWe - advanced Polaris™ membrane
- Partial capture for low cost-of-capture
- New modular construction

Pilot Testing at TCM, Norway (DE-FE31603)
- 1 MWe - Hybrid testing with TDA
- Membrane + solid sorbent for 90% capture
- Selective CO_2 recycle using sorbents

Full-Scale Pre-FEED at Duke Energy's East Bend Station, KY (DE-FE31589)
- 460 MWe – using Advanced Polaris™
- Partial capture and modular membrane
- Rapid retrofit deployment

Large-Pilot Testing at WY ITC, WY (DE-FE31587)
- Phase I – Design ~16 MWe pilot; secure host site
- Phase II – FEED and permitting
- Phase III – Fabricate, install and operate

2018 2019 2020 2021 2022 2023 2024 2025

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Together…Shaping the Future of Electricity

Acknowledgement and Disclaimer

Acknowledgement

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