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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Acknowledgement and Disclaimer

Acknowledgement

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Project Summary

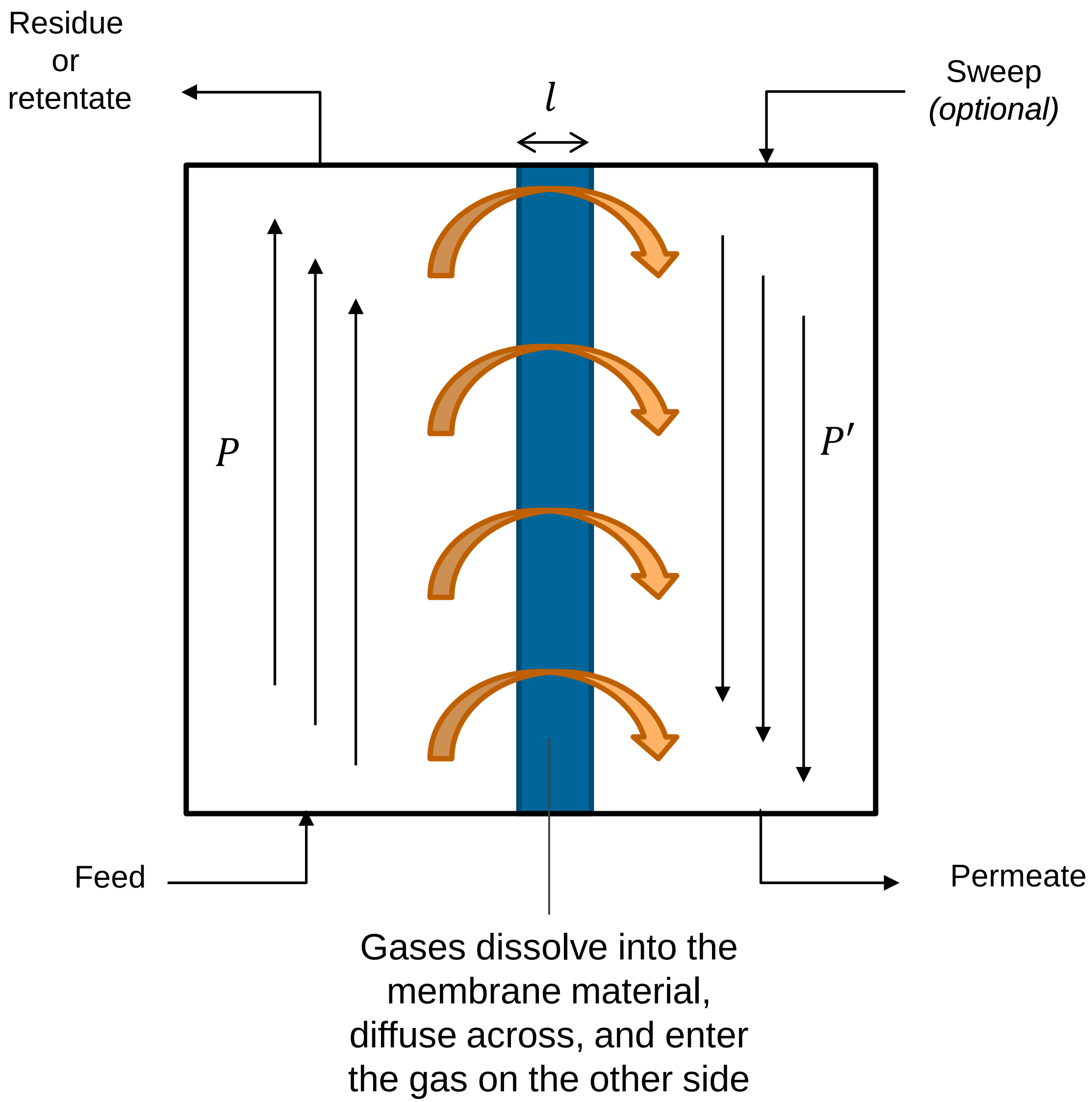
- **Approach**
  - Perform an initial engineering design & cost estimate commercial-scale, membrane-based, post-combustion CO_2 capture system retrofit to Duke Energy's East Bend station 600MWe coal-fired power plant
- **Advantages**
  - Reduces coal plant CO_2 emissions to those of a natural gas-fired plant
  - Utilizes MTR's second-generation Polaris™ membranes with CO_2 permeance 2X that of their first-generation membrane technology
  - No modifications to existing plant steam cycle - avoids New Source Review
  - Simple passive operation; no degradation caused by flue gas SO_X and NO_X
  - Unlike solvent capture – no new contaminants introduced into the flue gas
- **Challenges**
  - Minimizing the cost of each tonne of CO_2 captured while maintaining current net output of the 600 MWe station
  - Efficiently supplying auxiliary power to the capture system at low cost

Todays Presentation Topics

- Background
- Technical approach
- Project objectives
- Project structure
- Project schedule
- Risk management
- Project deliverables
- Next steps and Q&A

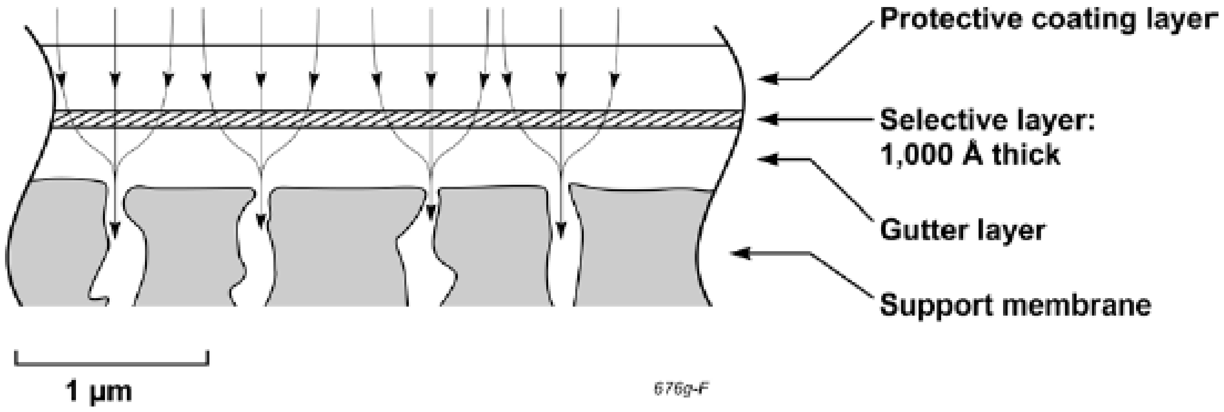
Background - Membrane Basic Principles

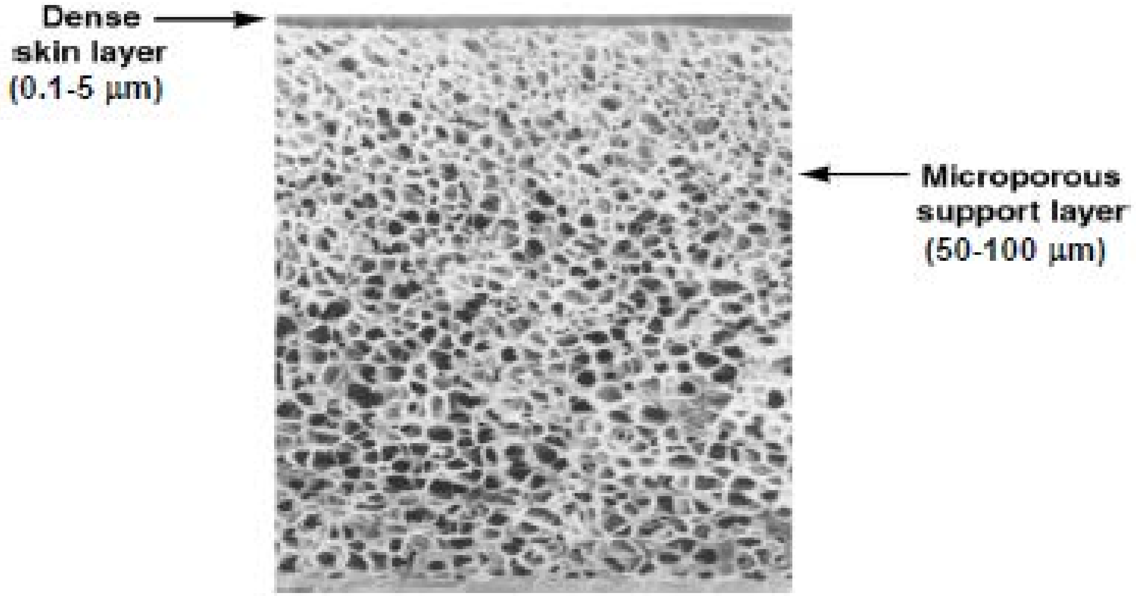
- Polymeric membrane typically operate via the solution-diffusion mechanism
- Gases dissolve into an active layer and diffuse across to the other side
- Permeation is driven by differences in partial pressures



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

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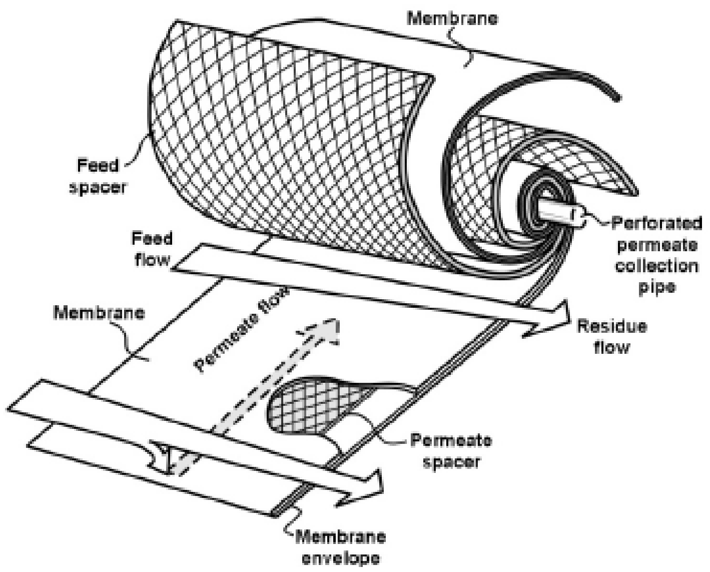
Background - Membrane Module

- Compact modular system design using high permeance membranes reduces CAPEX and overall system pressure drop
- 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



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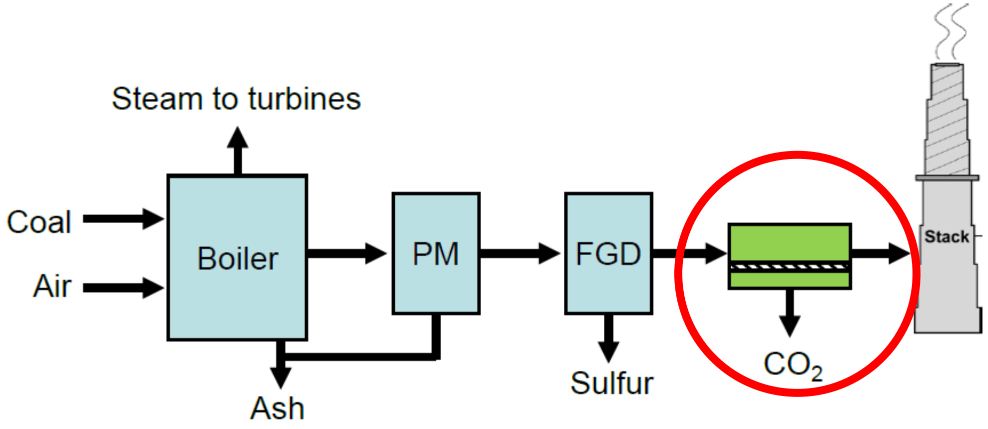
Membrane Retrofit to an Existing Coal Power Plant

- Duke Energy East Bend Station is equipped with:
  - ESP for particulate control
  - SCR system that removes 85% of NO_x
  - FGD system that removes 90% SO_x
  - Viable options for CO_2 storage and EOR
  - Abundance of space for Capture equipment



Images Courtesy of MTR and Google Maps

Membrane Power Requirements

- Unlike solvent PCC systems - No steam requirement, but significant power is required to drive the membrane systems fans, blowers, vacuum compressors pumps and CO_2 compression
- 4 Integration options will be considered:
  – New natural gas-fired simple cycle,
  – New combined cycle
  – New simple cycle with heat recovery steam generator supplying steam to the coal power plant feedwater heaters
  – Auxiliary power supplied from the existing station
- The technical and economic feasibility of adding a pipeline to supply the required amount of natural gas will be examined.
- The impacts of turning off the PCC during periods of high power demand will be evaluated (if the site has sufficient power export capacity).

Technical Approach 1/2

- Following a data gathering task that will include a site visit to the EBS, a preliminary process design will be developed for a 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 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 (TEA) 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.
- The results of each task will be documented in a series of written reports.

Key Project Objectives

- Produce an initial engineering design and cost estimate (+/-30% accuracy) of a membrane-based post-combustion CO_2 capture (PCC) system for retrofitting onto an existing U.S. coal power plant, Duke Energy's East Bend Station (EBS)

Key Project Objectives

- 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.
  - This will be done by optimizing the percentage of CO_2 captured (~45 to 60%) and by adding a natural-gas-fired combustion turbine (CT) or possibly a combined cycle to offset the new auxiliary loads

Project Structure - Tasks (1/2)

- **Task 1 - Project Management and Planning**
  – Conducting the kickoff meeting and attending and presenting at NETL's annual CO_2 Capture Project Review Conference. Reporting activities include submittal of quarterly technical reports.
- **Task 2 - Develop Design Basis Document**
  – The data required to conduct the engineering design study will be gathered. A data questionnaire will be issued to the site host and the project team will visit the East Bend Station to familiarize themselves with the plant layout and to collect additional information.
- **Task 3 - Develop Base Power Plant Benchmark**
  – A process model will be created which replicates the performance of the existing coal power plant. The model will then be used to evaluate the impact of adding the CO_2 capture system
- **Task 4 - System Analysis of Integration and Retrofitting Options**
  – Analysis and optimization studies will be carried out to determine the best option for configuration of the CO_2 capture system as well as the CT-based power plant that will supply the auxiliary power to run the capture system. A decision point regarding whether to include the CT-based power plant in the project design, and if so what type of plant, will occur at the end of this task.

Project Structure – Tasks (2/2)

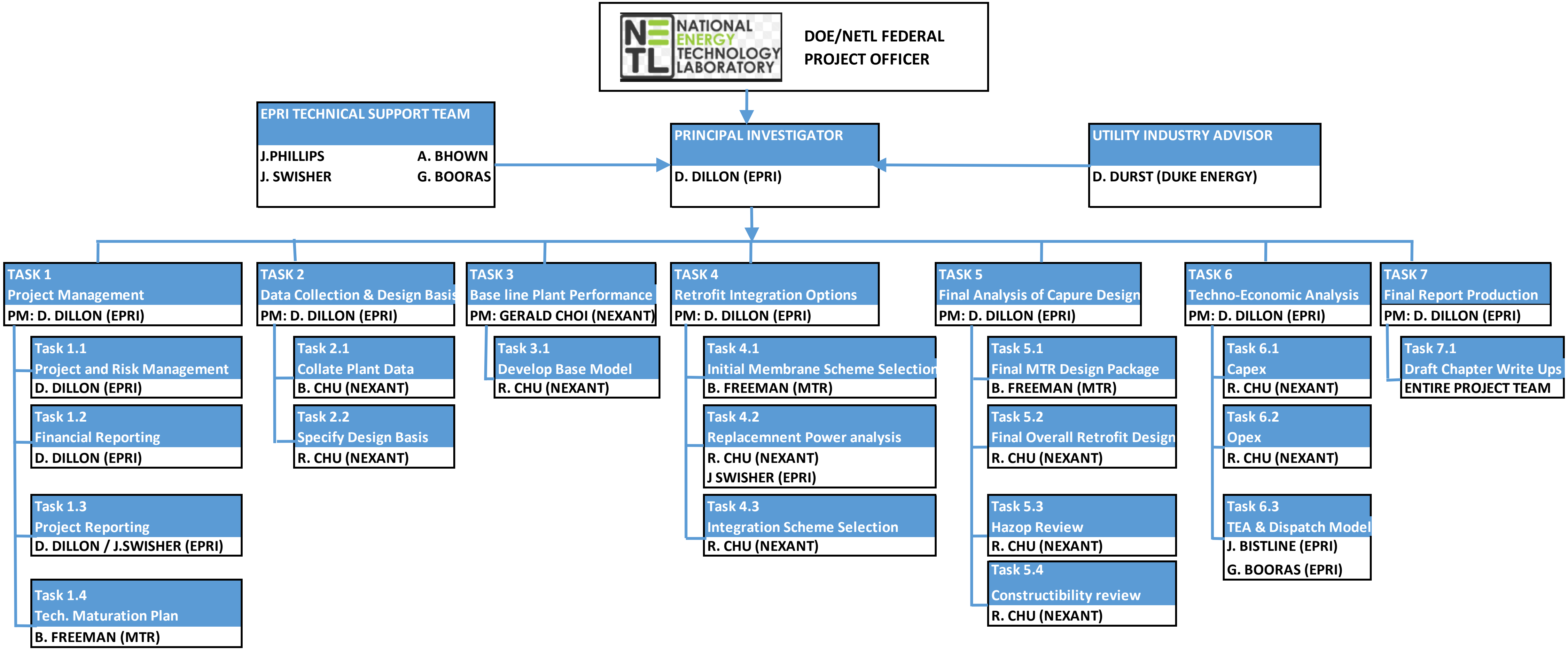
- **Task 5 - Develop Process Design Package for Full Retrofit Project**
  - A complete Process Design Package for the CO_2 capture retrofit system including all balance of plant equipment (and the CT-based power plant if chosen at the end of Task 4) will be developed.

  Conduct a HAZOP and a constructability review of retrofitted capture facility
- **Task 6 – Techno Economic analysis**
  - A series of economic analyses will be carried out following the format and containing information and data as defined by NETL/ DOE.
  - First a capital cost estimate will be developed. Then operating and maintenance will be defined.
  - That information will be used to determine the first year cost of electricity of the retrofitted plant.
  - A unit dispatch analysis will be conducted using EPRI's regional dispatch modeling tools. This will examine the impact of adding CO_2 on the capacity factor of the East Bend Station.
- **Task 7 - Final Report**
  - The final reporting for the project will be completed.

Project Structure - Team

TEAM MEMBER	FUNDER	ROLE
US DOE NETL	√	Funder
EPRI	√	Lead Organization, Project management Economic Evaluation, Dispatch Modelling
Duke Energy	√	East Bend Station Owners, Site Hosts, Operators, Data Gathering
Nexant		Engineering Designer, System integration and Costing
Bechtel		Auxiliary Power Source Specification, Engineering and Costing
Membrane Technology and Research (MTR)	√	Membrane System technology provider, Design costing and optimization.
Trimeric		Design and costing of CO_2 compression / condensation / fractionation Unit in the PCC

Organization Chart



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	6/30/2018			M4																					
TASK 3: Establish Base Case Model (Nexant Lead)	7/1/2018	9/30/2018						M5																		
TASK 4: System analysis of Integration options (EPRI Lead)	8/1/2018	12/31/2018																								
4.1 Opimize 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	1/1/2019	15/1/2019										DP														
TASK 5: Finalize Overall Retrofit PC Design (EPRI Lead)	1/16/2019	6/30/2019																								
5.1 Design Package of the Membrane CCS System (MTR)															M7											
5.2 Design Package for BOP & Aux. Power (EPRI & Nexant)																										
5.3 Preliminary HAZOP Review (Nexant, Bechtel, MTR & Duke)																	M8									
5.4 Constructibility Review (Nexant , Bechtel & Duke)																	M9									
TASK 6: Techno-Economic Analysis (EPRI Lead)	7/1/2019	12/31/2019																								
6.1 Capital Cost Estimation of Integrated PCC Design (Nexant)																			M10							
6.2 O&M Cost Estimation of Integrated PCC Design (Nexant, EPRI)																										
6.2 TEA and Dispatch Analysis (EPRI & DUKE)																										
TASK 7: Final Report Preparation (EPRI Lead)	1/1/2020	3/31/2020																								FR

Project Budget

Baseline Reporting Quarter	FY2018		FY2019				FY2020	
	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2
Baseline Cost Plan								
Federal Share	$126,206	$189,309	$189,309	$189,309	$232,778	$232,778	$232,778	$232,778
Non-Federal Share	$31,552	$47,327	$47,327	$47,327	$58,238	$58,238	$58,238	$58,238
Total Planned	$157,758	$236,637	$236,637	$236,637	$291,015	$291,015	$291,015	$291,015
Cumulative Cost Plan								
Federal Share	$126,206	$315,515	$504,825	$694,134	$926,912	$1,159,689	$1,392,467	$1,625,244
Non-Federal Share	$31,552	$78,879	$126,207	$173,534	$231,772	$290,010	$348,247	$406,485
Total Planned	$157,758	$394,395	$631,031	$867,668	$1,158,683	$1,449,699	$1,740,714	$2,031,729

Project Management Plan

- Initial evaluation and technical feasibility first
- Refine concept and present options
- Select optimum arrangement
- Detail design and costing (+/- 30% accuracy) on one option
- Unit dispatch and economic analyses to build final business case for retrofit
- The milestone status and any anticipated deviation from the planned milestone schedule will be routinely reported to DOE/NETL as part of the required quarterly progress reports

Risk Management – Technical Risk 1/5

Description of Risk	Probability	Impact	Mitigation and response strategies
Project team has difficulty reaching consensus on technical direction and technology choices	Low	High	The key personnel from EPRI, Duke Energy, Membrane Technology and Research (MTR) and Nexant have worked well together during previous projects related to CO_2 capture. They have shown they can reach consensus using fact-based analysis. Should consensus not be reached, EPRI will serve as the final decision maker based on its position as prime along with its understanding of the needs of the power industry
Nature and maturity of some technologies make it difficult to produce a +/-30% cost estimate	Low	Moderate	The only element of the project which has not been built at commercial scale is MTR's membrane CO_2 capture system. However, the recent TEA of MTR's membrane CO_2 capture system completed as part of their DOE-funded project which tested a 1 MW pilot has strengthened the knowledge of that technology's cost. This justifies the ranking as a low probability.

Risk Management – Technical Risk 2/5

Description of Risk	Probability	Impact	Mitigation and response strategies
Analysis reveals insurmountable or highly costly barriers to adding full-scale CO_2 capture at East Bend Station	Low	High	East Bend Station currently has only one 600 MW unit on a site with 1600 acres of land. Originally intended to host multiple units - there is abundant space to accommodate a PCC plant. Nexant will be able to draw on the experience of Bechtel Power’s plant design engineering staff. That team has design multiple retrofits of emission control equipment onto existing coal power plants. In addition, Nexant and Bechtel have conducted CO_2 capture retrofit evaluations of six coal power plants as part of a previous EPRI study and, in every case, found feasible solutions to the flue gas ducting without overly burdening the project cost.

Risk Management – Technical Risk 3/5

Description of Risk	Probability	Impact	Mitigation and response strategies
Unit Dispatch Modeling reveals major negative impact on plant capacity factor	High	Low	The current electricity markets are very close to parity between natural gas combined cycles and coal power plants. Consequently, even a modest increase in coal power plant heat rate could result in significant decreases (>5%) in capacity factor. However, this is important information for public policy makers to know if they do want to encourage deployment of CO_2 capture on existing US coal plants. Consequently, the dispatch analysis will look at a range of CO_2 prices which could be paid for enhanced oil recovery. This information will provide guidance to policy makers on the level of price (or tax) subsidy which may be required to induce such projects.

Risk Management – Technical Risk 4/5

Description of Risk	Probability	Impact	Mitigation and response strategies
The existing coal power plant requires costly upgrades to its emission controls equipment to provide flue gas acceptable to the CO_2 capture system	Moderate	Moderate	EPRI's previous evaluations of post-combustion CO_2 capture on six existing coal power plants has shown that the $/tonne captured cost can be significantly impacted by the need to add emission control equipment to meet the flue gas purity requirements of the CO_2 capture technology. However, all of EPRI's previous studies used solvent-based capture technology that was negatively impacted by the presence of NOx and SOx in the flue gas. The membrane technology proposed for this study is more tolerable to NOx and SOx. In addition, the East Bend Station has highly effective SCR and FGD systems already installed, so only a water wash to remove trace amount of particulates is anticipated to be required between the FGD and the CO_2 membrane modules.

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Risk Management – Technical Risk 5/5

Description of Risk	Probability	Impact	Mitigation and response strategies
Cost of delivering natural gas to the site makes use of a combustion turbine (CT) to provide the power for the CO_2 capture system unattractive.	Moderate	Moderate	East Bend Station currently does not have natural gas to provide power to operate the capture system. The team will conduct a feasibility study for adding a natural gas pipeline from the nearest trunk line. This pipeline cost estimate will be used when the options for providing auxiliary power are evaluated. If the cost is prohibitive, a recommendation to exclude the CT power plant will be made and auxiliary power to operate the capture facility will come from the existing coal plant. This will decrease the net power output from the site, but will still provide valuable information on the cost and performance of the CO_2 capture retrofit.

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Risk Management - Resource Risk

Description of Risk	Probability	Impact	Mitigation and response strategies
Available DOE/NETL funding to support this work is reduced	Low	High	EPRI will work with DOE/NETL to determine if appropriate funding exists to conduct some fraction of the originally-proposed program. If so, the project team will negotiate an appropriate project scope to fit the available budget. EPRI will also seek additional cost share contributions from the project team and EPRI's utility members to allow the work to continue.
Planned project staff are not available to support project at time of award due to staff attrition or deployment on other projects	Moderate	Low	All teams have obtained commitments to ensure that proposed staffing levels can be met. For instances where staff attrition occurs, appropriate (experienced) replacements will be identified from existing staff or hired, and provided with proper training to enable them to effectively assume the vacated project responsibility. EPRI, MTR and Nexant all have significant bench strength to minimize this risk.

Risk Management – Management Risks 1/2

Description of Risk	Probability	Impact	Mitigation and response strategies
Negotiations associated with contracting and acceptance of project startup documents requires excessive time to complete, subsequently delaying start of the program	Low	Low	EPRI, MTR and Nexant have all conducted work for DOE/NETL. MTR and Nexant have worked with EPRI in various projects. Both organizations are familiar with EPRI's contracting requirements as well as DOE/NETL's. Negotiations with the sub-contractors will begin as soon as DOE/NETL releases the award to EPRI. After contracts are in place, EPRI will work with its sub-contractors to enable prompt startup, including updating the PMP.
Project expenditures exceed the plan, resulting in a budget overrun	Low	Moderate	Because this project only involves engineering calculations and not procurement of equipment, the risk of cost overruns is low. EPRI has a good track record in conducting similar projects for DOE. EPRI will employ project controls, including financial tracking and recurring meetings on schedule and budget, to monitor financial performance and prevent cost overruns

Risk Management – Management Risks 2/2

Description of Risk	Probability	Impact	Mitigation and response strategies
East Bend Station Outages delay access to plant design and performance data	Moderate	Low	The East Bend Station has a planned outage which was scheduled to be completed before the end of May. Assuming they do not run into any major issues that prolong the outage, Duke staff will be available to support our initial data request and host the site visit before the end of June.

Final Report Content

- A final report will be written that shall include:
  - A description of the existing plant and the retrofit changes required to add CO_2 capture.
  - Process descriptions with process flow diagrams, and heat and material balances for the PCC plant including CO_2 compression.
  - A plot plan to establish the space required for the PCC plant.
  - Equipment lists with sizing of major items for the PCC plant.
  - Breakdown of costs by system for the PCC plant.
  - Power, cooling water, and consumables used by the PCC plant.
  - Description on preliminary PCC startup, shutdown, and bypass operating procedures with flow diagrams, and equipment requirements for integration with the existing power plant.
  - All environmental emissions from the retrofitted PCC plant, including all disposal requirements.

Other Project Deliverables

Budget Period	Task No.	Milestone Description	Planned Completion	Verification Method
1	1	1. Updated Project Management Plan	4/30/2018	PMP file
1	1	2. Project Kickoff Meeting with NETL PM	6/01/2018	Presentation file
1	1	3. Preliminary Technology Maturation Plan	6/30/2018	Topical Report
1	2	4. East Bend Station Site Visit for Data Collection	6/30/2018	Progress update in quarterly report
1	3	5. Creation of Process Model that Accurately Replicates Existing Plant Performance	9/30/2018	Progress update in quarterly report
1	4	6. Completion of Evaluation of CT- based Plant for Auxiliary Power. Decision Point	12/31/2018	Presentation file
2	5.1	7. Completion of Process Design Package for CO_2 Capture Module	4/30/2019	Progress update in quarterly report
2	5.3	8. Completion of HAZOP Review	06/30/2019	Topical Report
2	5.4	9. Completion of Constructability Review	06/30/2019	Topical Report
2	6.1	10. Completion of Capital Cost Estimate	9/30/2019	Progress update in quarterly report
3	1 & 7	11. Completion of Final Report and Project Close-out Meeting	3/31/2020	Final report & presentation file

Next Steps

- Finalize contracts with Nexant and MTR
  - Finalize their subcontracts with Bechtel and Trimeric
- Gather base plant data
  - Finalize design specification
- East Bend Site visit
  - Meet and discuss with plant operators, establish current performance model
- Prepare Technology Maturation Plan
  - Due end of July

QUESTIONS?

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