the Energy to Lead

Energy Efficient GO-PEEK Hybrid Membrane Process for Post-combustion CO_2 Capture

DOE Contract No. DE-FE0026383

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Presentation for Kickoff meeting

December 7, 2015

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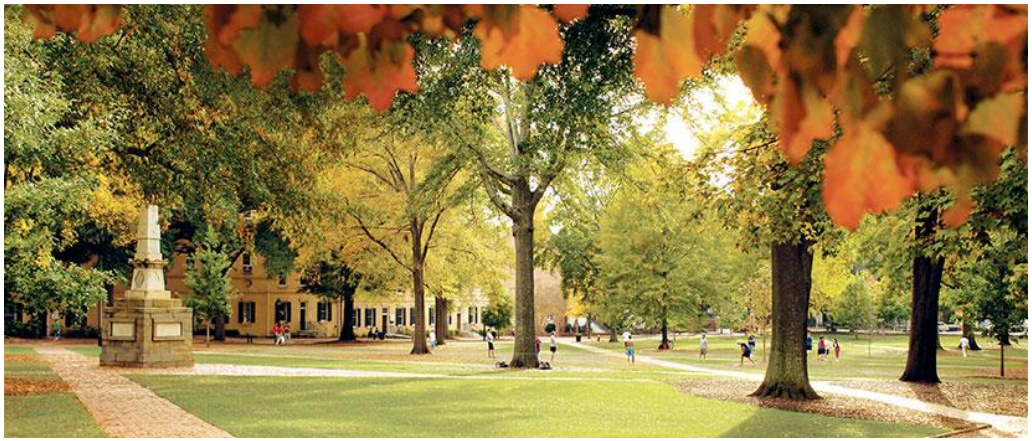
Outline

- Introduction to team members
- Project overview
- Technology fundamentals/background
- Plans for each budget period

Introduction to GTI and USC

- **Not-for-profit** research company, providing energy and natural gas solutions to the industry since 1941
- **Facilities**: 18 acre campus near Chicago, 28 specialized labs

- **Co-educational research university** located in Columbia, South Carolina
- **Prof. Yu Group**: expertise in thin films, coatings, membranes, absorption and transport mechanisms



Introduction to PoroGen and Trimeric

TRIMERIC CORPORATION

- **Materials technology** company commercially manufacturing products from high performance plastic polyether ether ketone (PEEK)
- Products ranging from membrane filters to heat transfer devices

- Chemical process engineering, R&D, and other technical services
- Extensive experience on CO_2 processing facilities
- Several staff members have led carbon capture technoeconomic evaluation projects for the DOE

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Project overview

- **Performance period**: Oct. 1, 2015 – Sep. 30, 2018
- **Funding**: $1,999,995 from DOE; $500,000 cost share
- **Objectives**:
  - Develop a hybrid membrane process combining a conventional gas membrane unit and a hollow fiber membrane contactor (HFMC) unit to capture ≥90% of the CO_2 from flue gases with 95% CO_2 purity at a cost of electricity 30% less than the baseline CO_2 capture approach
- **Project participants:**

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PoroGen INNOVATIVE MEMBRANE PRODUCTS PEEK inside

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TRIMERIC CORPORATION

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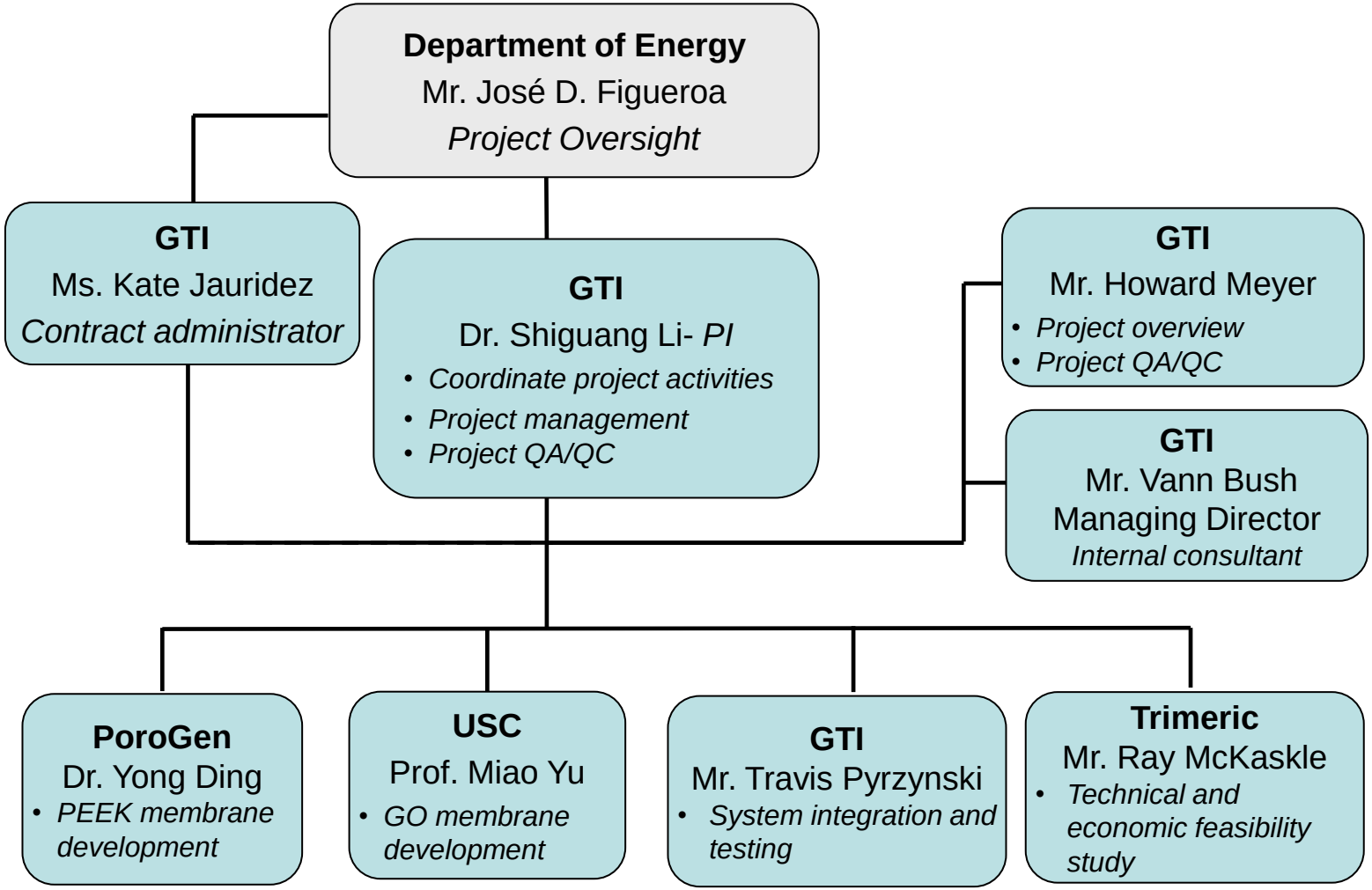
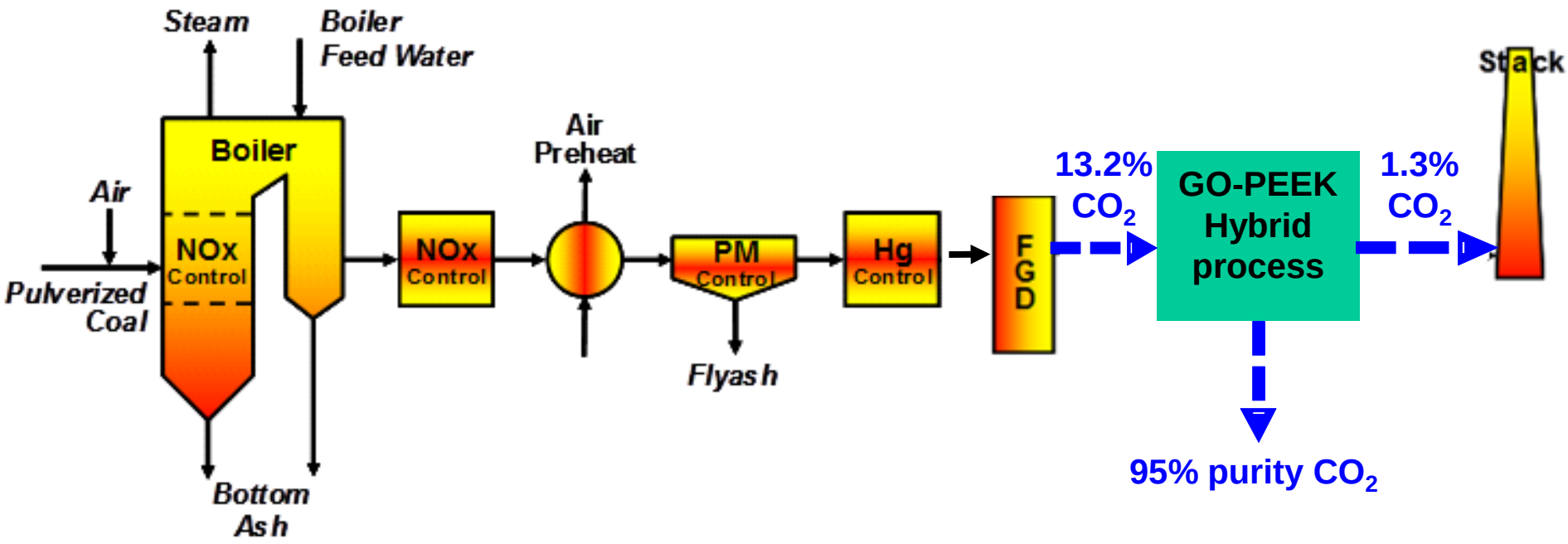
Team member roles

Member	Specific Project Roles
gti	> Project management and planning > Quality control and performance testing for graphene oxide (GO) and PEEK membranes > Construct an integrated GO-PEEK testing system > CO_2 capture testing of the integrated GO-PEEK process
University of South Carolina	> GO membrane development: CO_2 permeance ≥1,000 GPU; CO_2/N_2 selectivity ≥90
PoroGen Innovative Membrane Products; Air Liquide Advanced Business & Technologies	> PEEK membrane development: intrinsic CO_2 permeance >3,000 GPU
Trimeric Corporation	> High-level technical and economic feasibility study

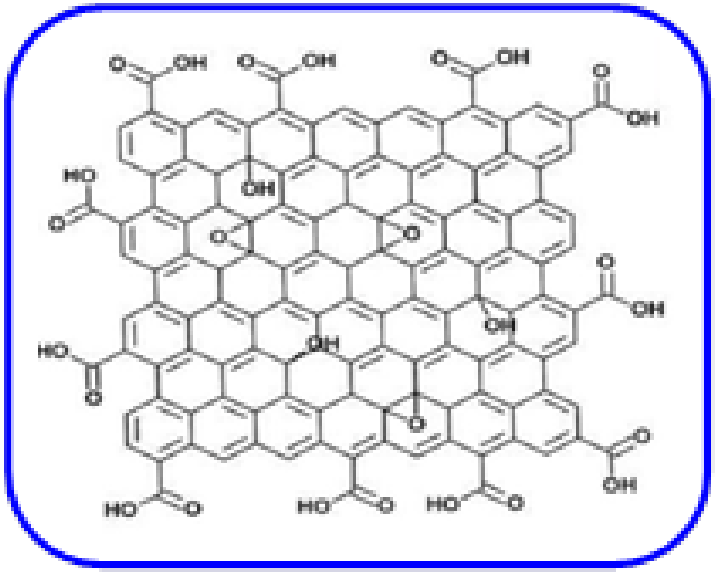
The project organization and structure



Integration with coal-fired power plants: installed downstream of FGD



GO conventional gas membrane process

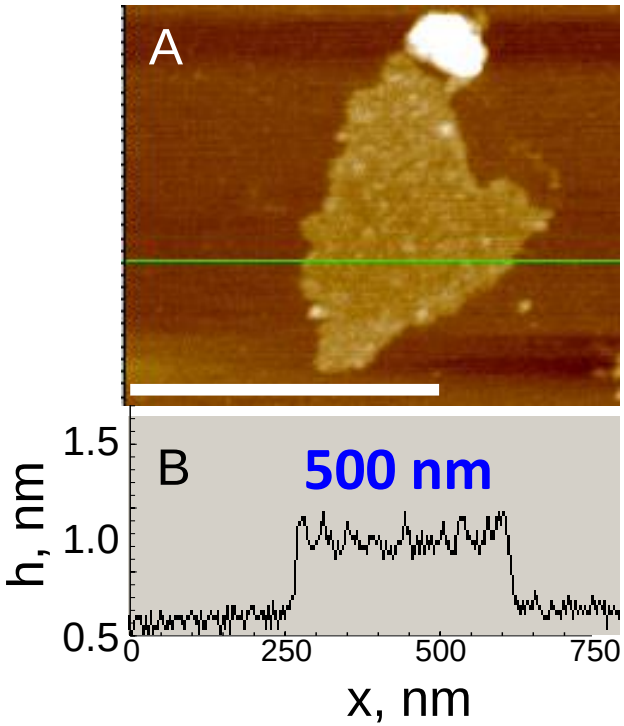


GO: single-atomic layered, oxidized graphene

GO membrane technology based on our pioneering work published in *Science (2013, 342 (6154) 95)*

Science
AAAS

Ultrathin, Molecular-Sieving Graphene Oxide Membranes for Selective Hydrogen Separation
Hang Li *et al.*
Science **342**, 95 (2013);
DOI: 10.1126/science.1236686



Single-layered GO flake prepared as thin as 0.7 nm

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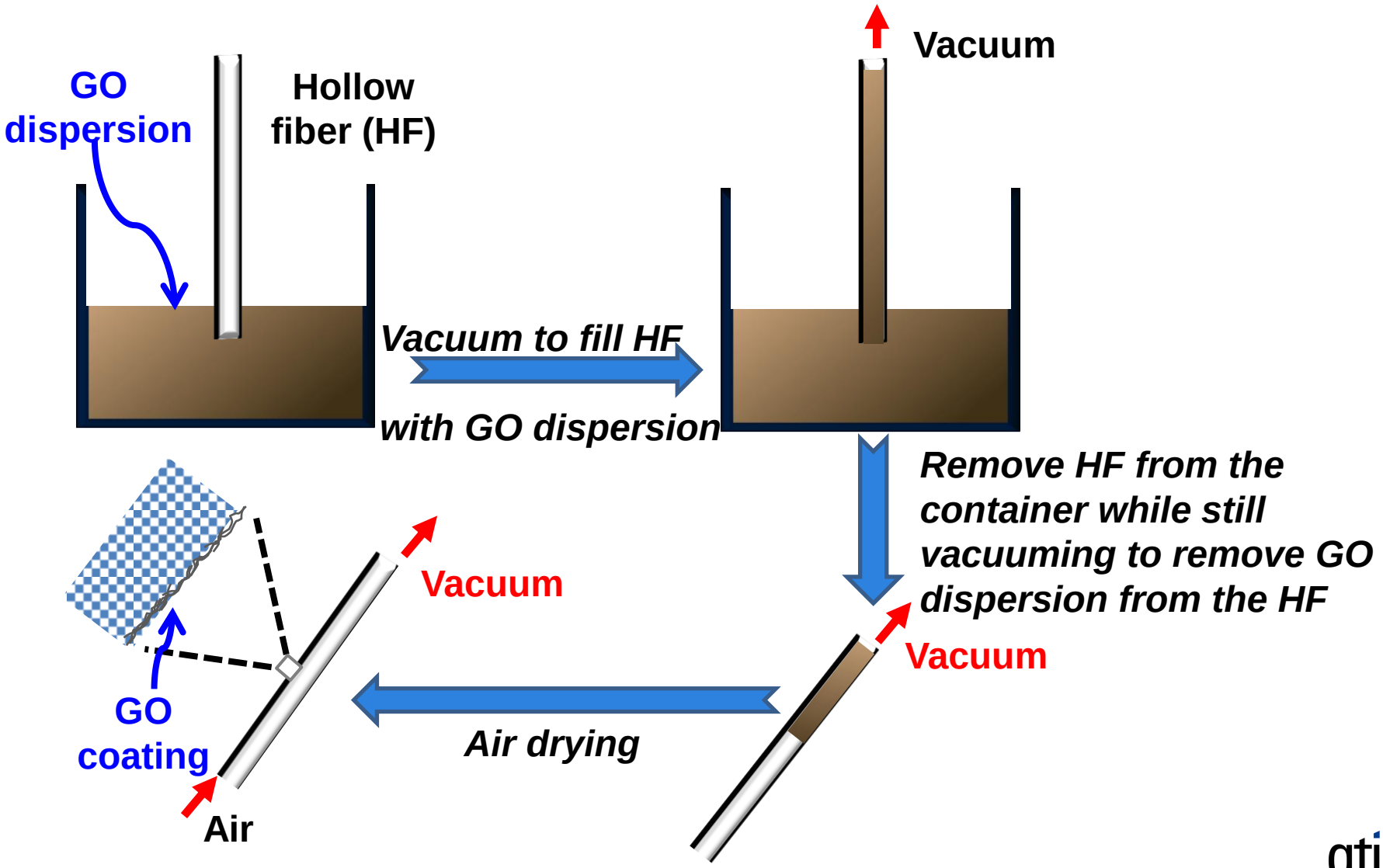
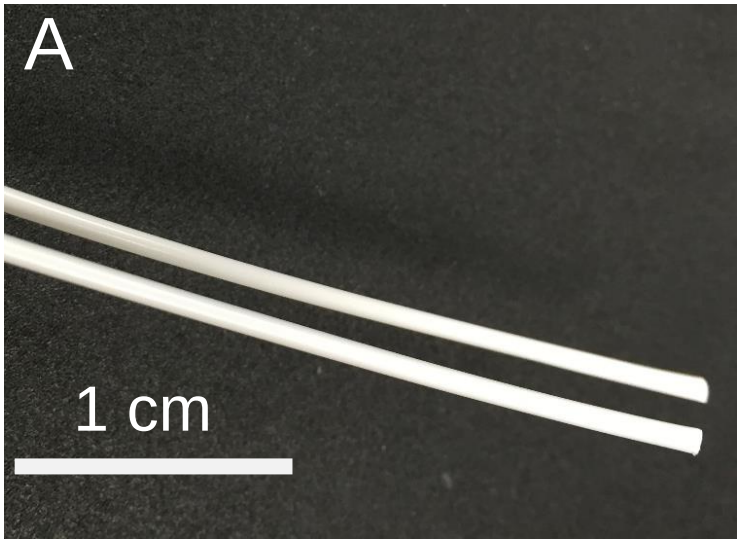
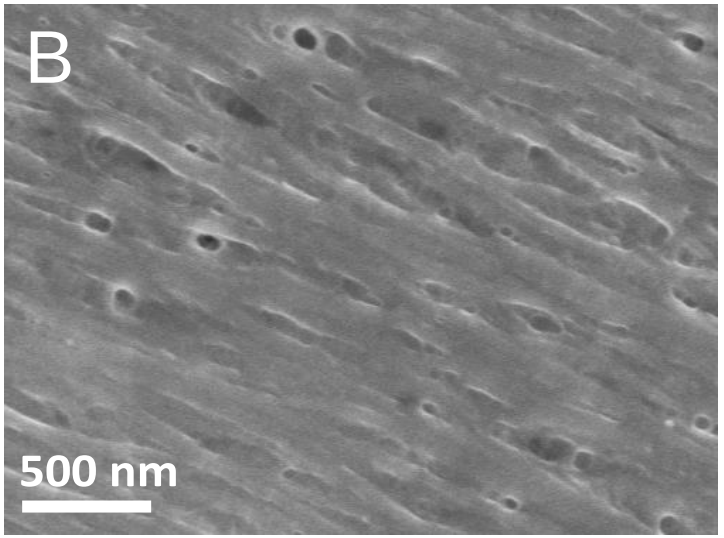
Procedure developed for coating GO on hollow fiber support towards CO_2/N_2 separation



GO membrane supported on polyethersulfone (PES) hollow fiber as thin as 40 nm

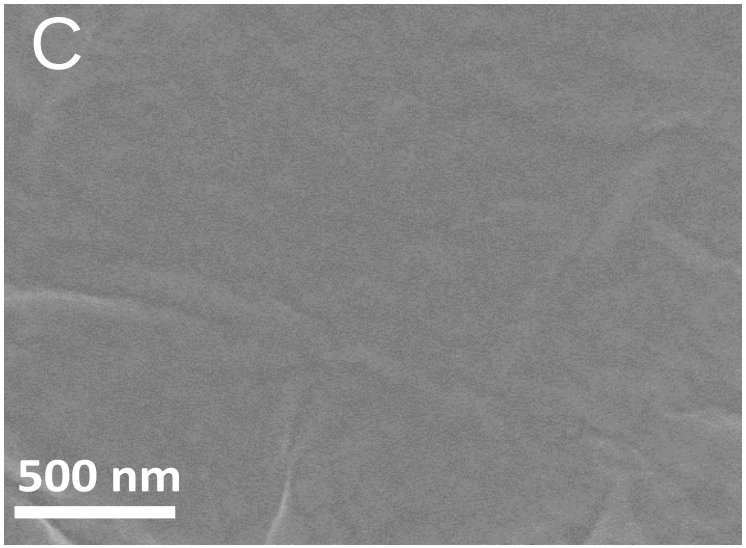
PES fiber

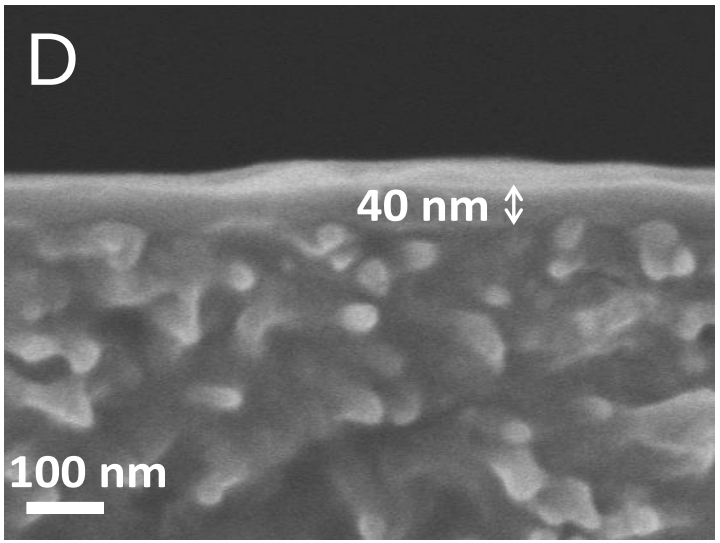




Uncoated fiber surface

Coated fiber surface





Coated fiber cross section

CO_2 permeance of 100 GPU and $\alpha_{CO2/N2}$ of 49 obtained at 40°C for a humidified CO_2/N_2 mixture

Membrane	Permeance, GPU CO_2	N_2	Ideal selectivity
PES support	240	280	0.86
Dry GO on PES	20	15	1.3
Wet GO on PES*	97	2	49

* Pure gas with 75% saturated water

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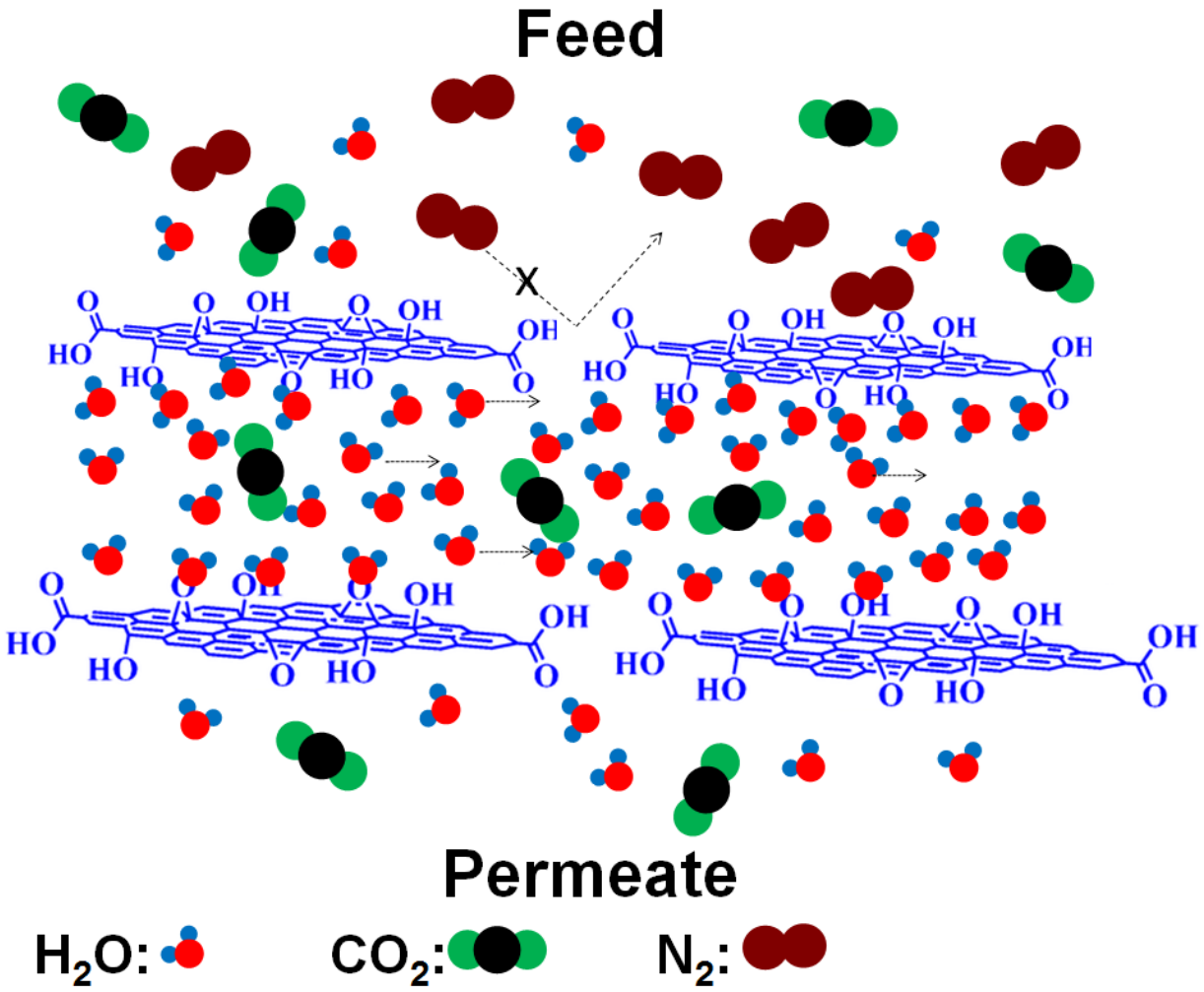
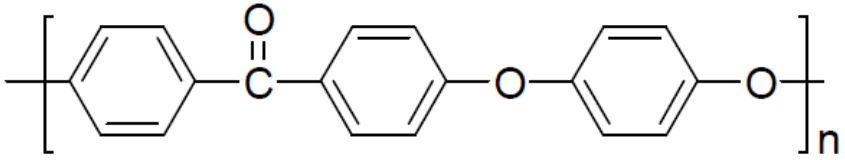
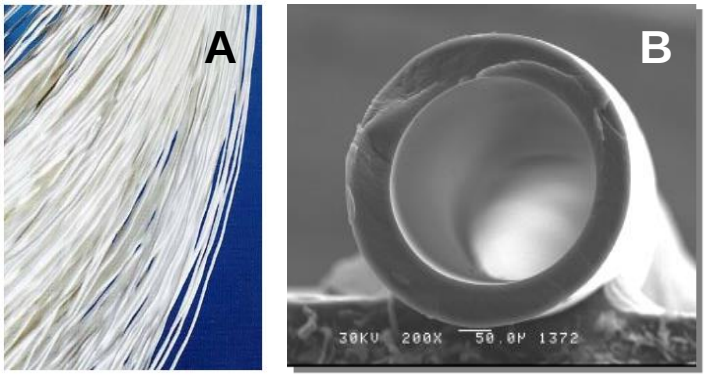
Transport mechanism: hybrid surface/ solution diffusion

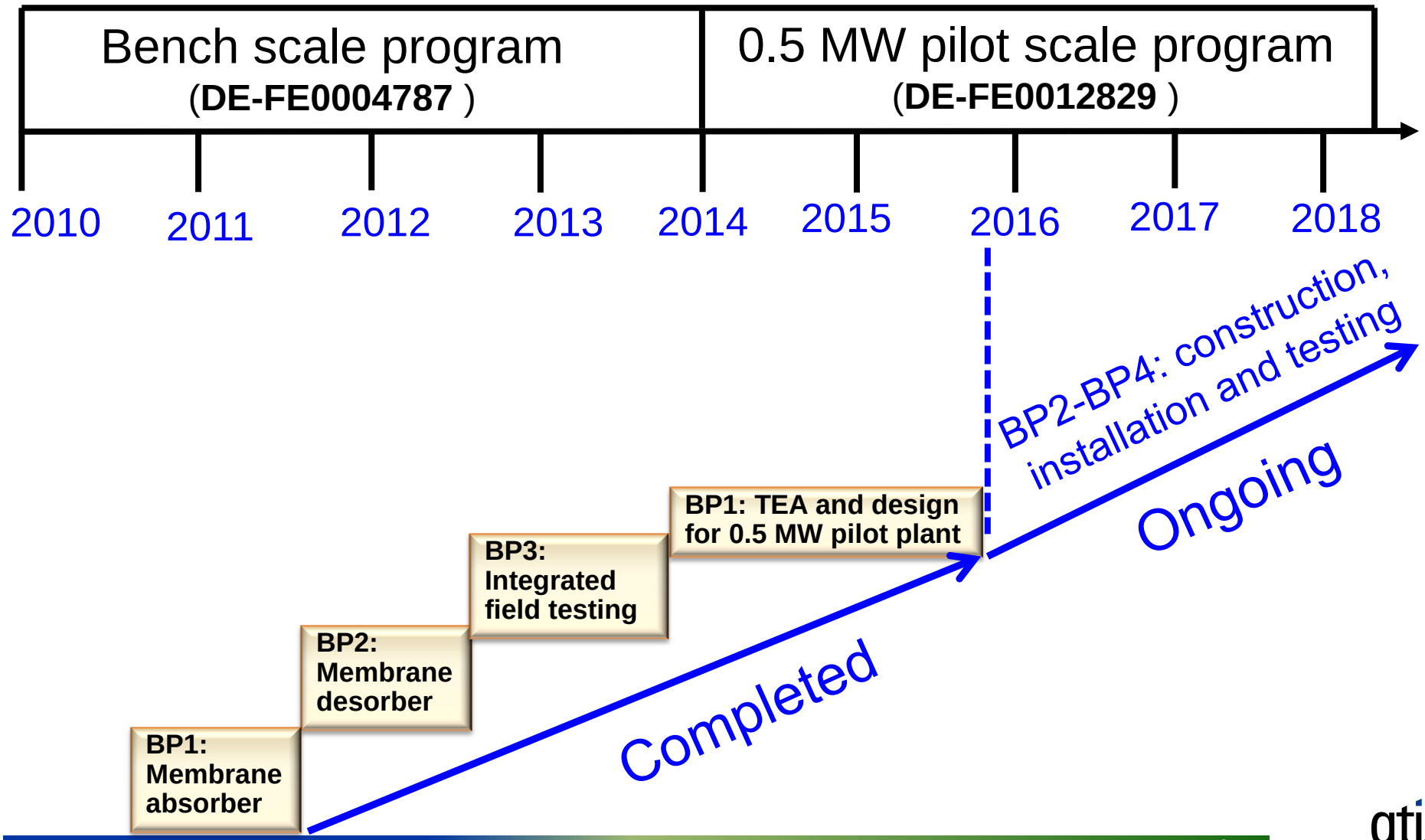


PEEK HFMC process



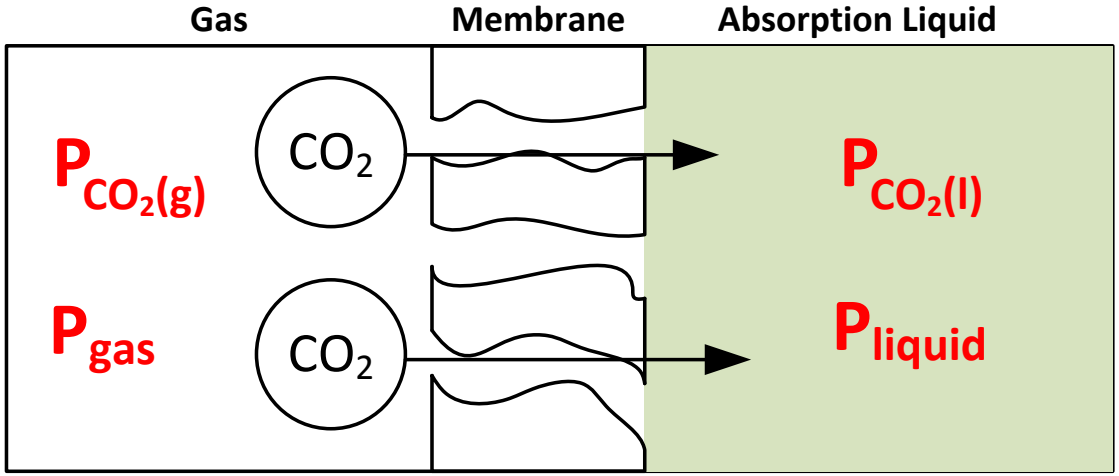


Background: GTI, PoroGen have been developing singular PEEK HFMC technology since 2010



What is a membrane contactor?

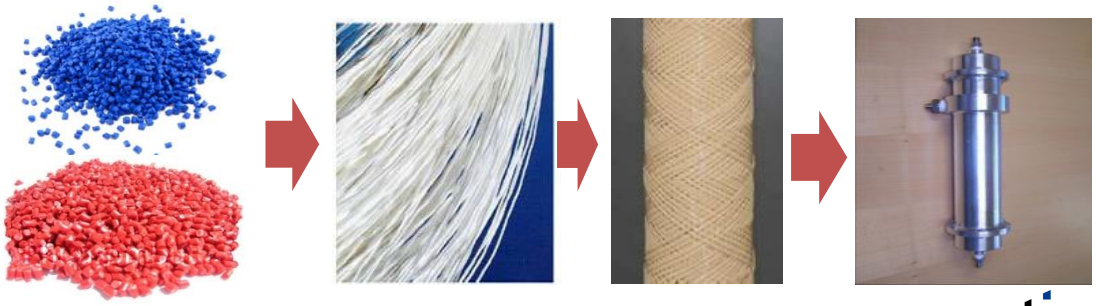
> High surface area membrane device that facilitates mass transfer



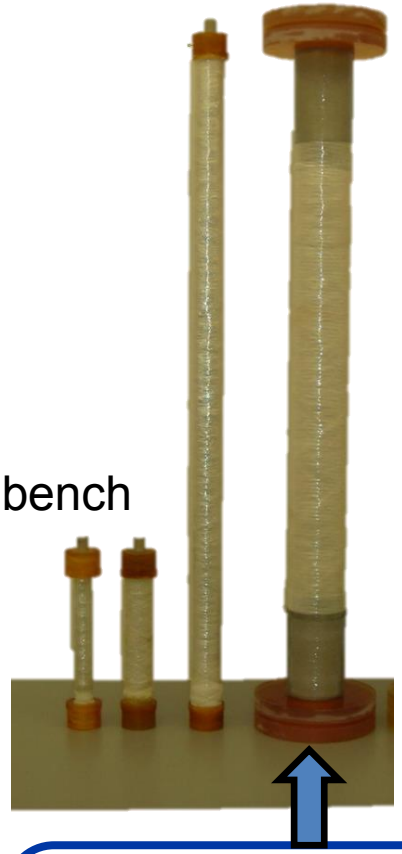
> **Separation mechanism**: CO_2 permeates through membrane and reacts with the solvent; N_2 does not react and has low solubility in solvent

> Why **PEEK HFMC**?

Polymer	Max service temperature (°C)
Teflon™	250
PVDF	150
Polysulfone	160
PEEK	**271**



Membrane module scaled to 4-inch diameter, successful field testing completed at Midwest



> 4” diameter
> 60” long
> 2,000 GPU CO_2 permeance

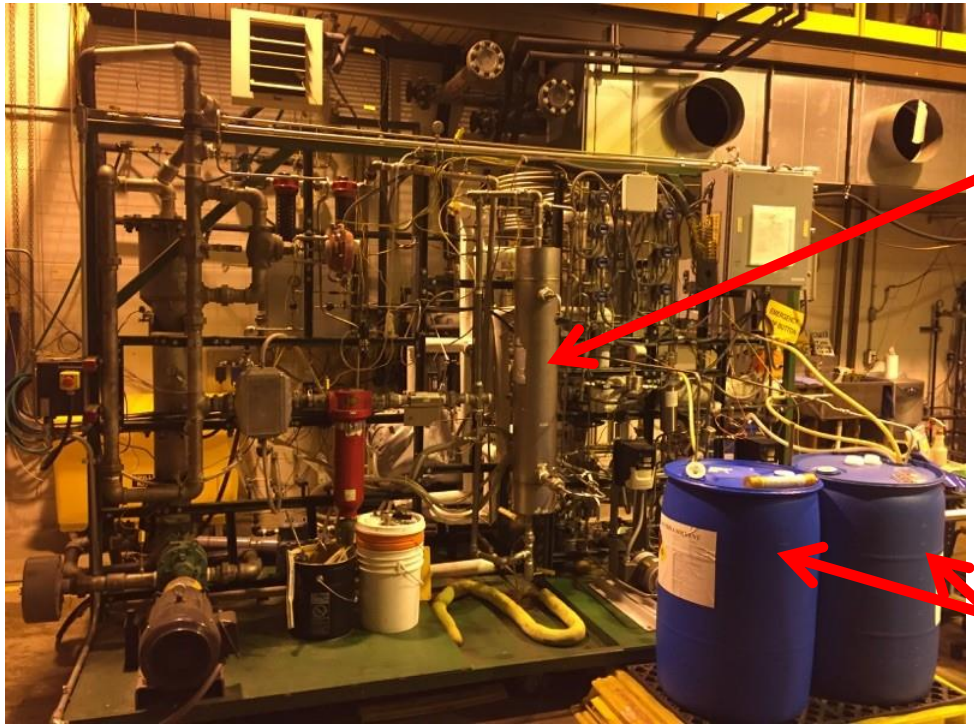
- High mass transfer coefficient achieved with aMDEA solvent

CO_2 removal rate	Mass transfer coefficient,
93.2%	1.2 $(sec)^{-1}$

Conventional contactors: 0.0004-0.075 $(sec)^{-1}$

Recently module further scaled to 8-inch, and showed contactor mass transfer coefficient of 2.0 $(sec)^{-1}$

- 8” diameter
- 60” long
- 2,600 GPU CO_2 permeance



CO_2 removal rate	Mass transfer coefficient
90.3%	2.0 $(sec)^{-1}$

Preliminary TEA for GO-PEEK Hybrid Membrane Process

Preliminary TEA: COE of GO-PEEK process can be 31.4 % lower than that of DOE Case 12

- To achieve DOE's **cost target** (COE 30% < Case 12) requires
  - Lower capital and operating costs: the projected capital costs for GO-PEEK are 14% lower than Case 12
  - Higher net plant efficiency: 31.6% for GO-PEEK vs. 28.4% for Case 12

45%/45% capture case preliminary TEA results

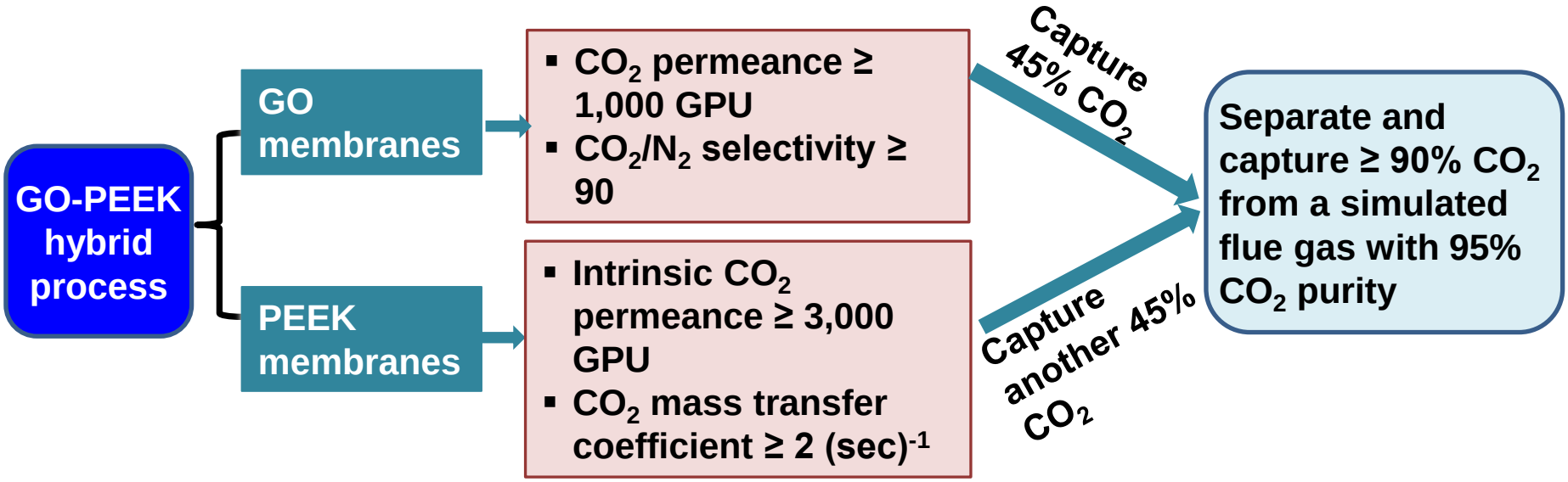
550 MW net power plant	mills/kWh (2012$)
Total capital costs	48.58
Total fixed operating costs	6.57
Total variable operating costs	8.56
Fuel	33.81
CO_2 TS&M	9.99
Total LCOE for GO-PEEK process	107.51
Total COE for GO-PEEK process	**84.81**
Total COE for Case 12	**123.61**
% of COE less than DOE Case 12	**31.4%**

Plans for Each Budget Period (BP)

Two BPs, each 18 months

Technical goals and success criteria

> Technical goals:

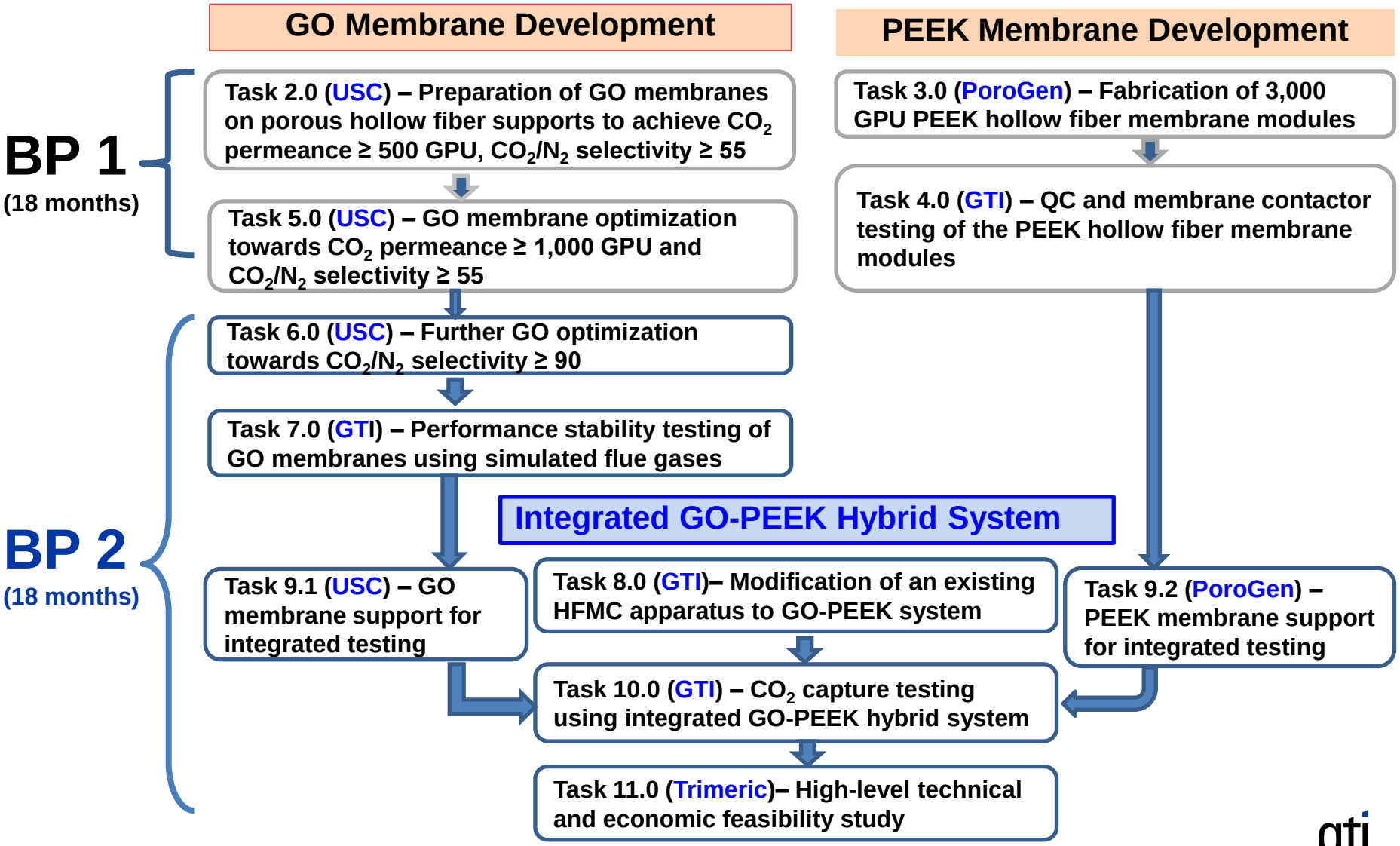


> Success criteria

- Integrated GO-PEEK process testing complete, 90% CO_2 removal rate and 95% CO_2 purity achieved
- Technical and economic feasibility study report issued. DOE cost goal (COE 30% less than baseline CO_2 capture approach) validated
- Final technical report submitted to DOE

Overview/roadmap

Task 1: Project management and planning (*throughout the project*)



BP1 overview

- **Performance period**: Oct. 1, 2015 – March 31, 2017
- **Funding**: $814,748 from DOE; $255,624 cost share (24%)
- **Objectives**:
  - **GO membrane unit**: CO_2/N_2 selectivity ≥55 and CO_2 permeance ≥1,000 GPU
  - **PEEK HFMC unit**: membrane intrinsic CO_2 permeance ≥3,000 GPU; Selectivity will be achieved through the use of aMDEA solvent
- **Project participants:**

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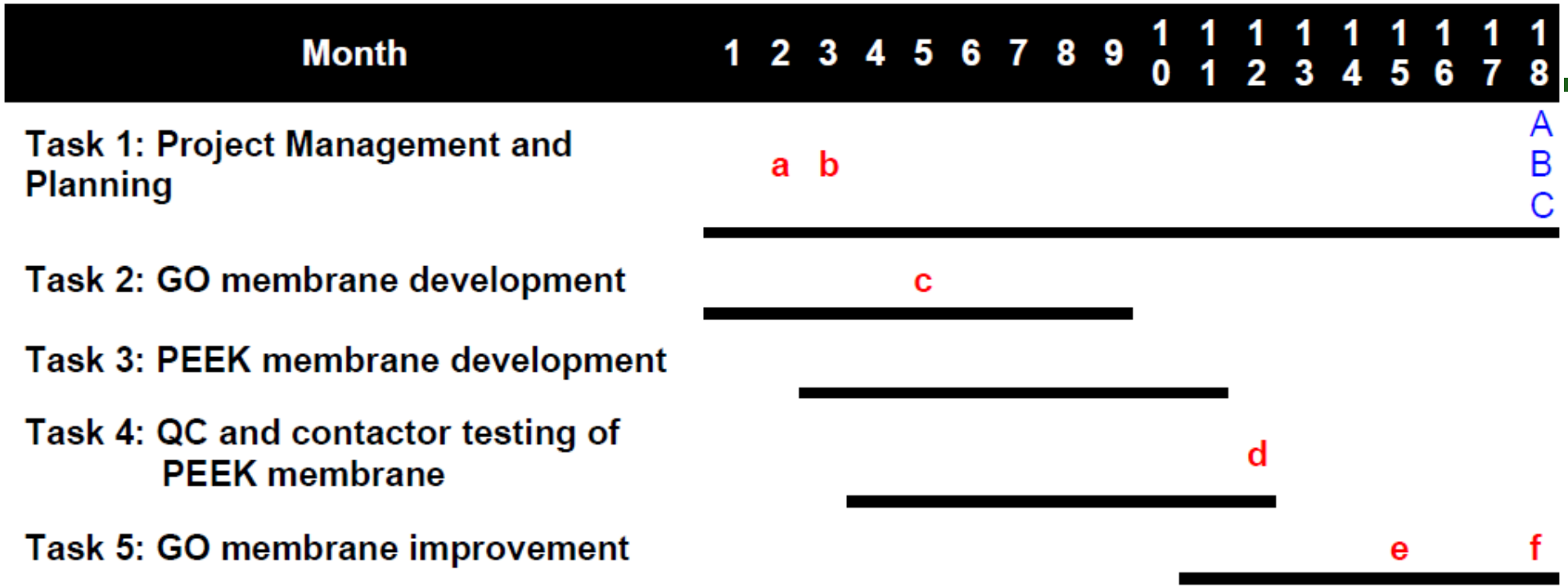
BP1 timeline, tasks, milestones and decision points



Milestones		Decision Points
a	PMP updated	A: Successful completion of all work proposed in BP1
b	Kickoff Meeting complete	B: Achievement of BP1 milestones
c	GO membranes with thickness <30 nm prepared	C: Submission and approval of the Continuation Application
d	PEEK CO_2 permeances of 3,000 GPU achieved	
e	GO membranes with thickness <15 nm prepared	
f	GO membranes exhibit CO_2/N_2 selectivity ≥55 and CO_2 permeance ≥1,000 GPU	

Status/progress of BP1 tasks as of Dec. 7, 2015

- **Task 1**: Project management and planning
  - Agreement with USC signed
  - Agreement with PoroGen (acquired by Air Liquide) is under review
  - Weekly teleconferencing meetings with USC and PoroGen
- **Task 2**: Preparation of GO membranes (USC)
  - Fabrication of GO membrane commenced
- **Task 3**: Development of PEEK membrane (PoroGen)
  - A 2-inch module with new fibers shipped to GTI for testing
- **Task 4**: QC and membrane contactor testing (GTI)
  - The new received 2-inch module is under testing
- **Task 5**: GO membrane improvement (USC)
  - Won't start until July 1, 2016

BP2 overview

- **Performance period**: April 1, 2017 – Sep. 30, 2018
- **Funding**: $1,185,247 from DOE; $244,376 cost share (17%)
- **Objectives**:
  - **GO membrane unit**: GO membrane further improved to achieve CO_2/N_2 selectivity ≥90 and CO_2 permeance ≥1,000 GPU
  - **Integrated GO-PEEK membrane process laboratory-scale testing** to achieve 90% CO_2 removal rate, 95% CO_2 purity
- **Project participants:**

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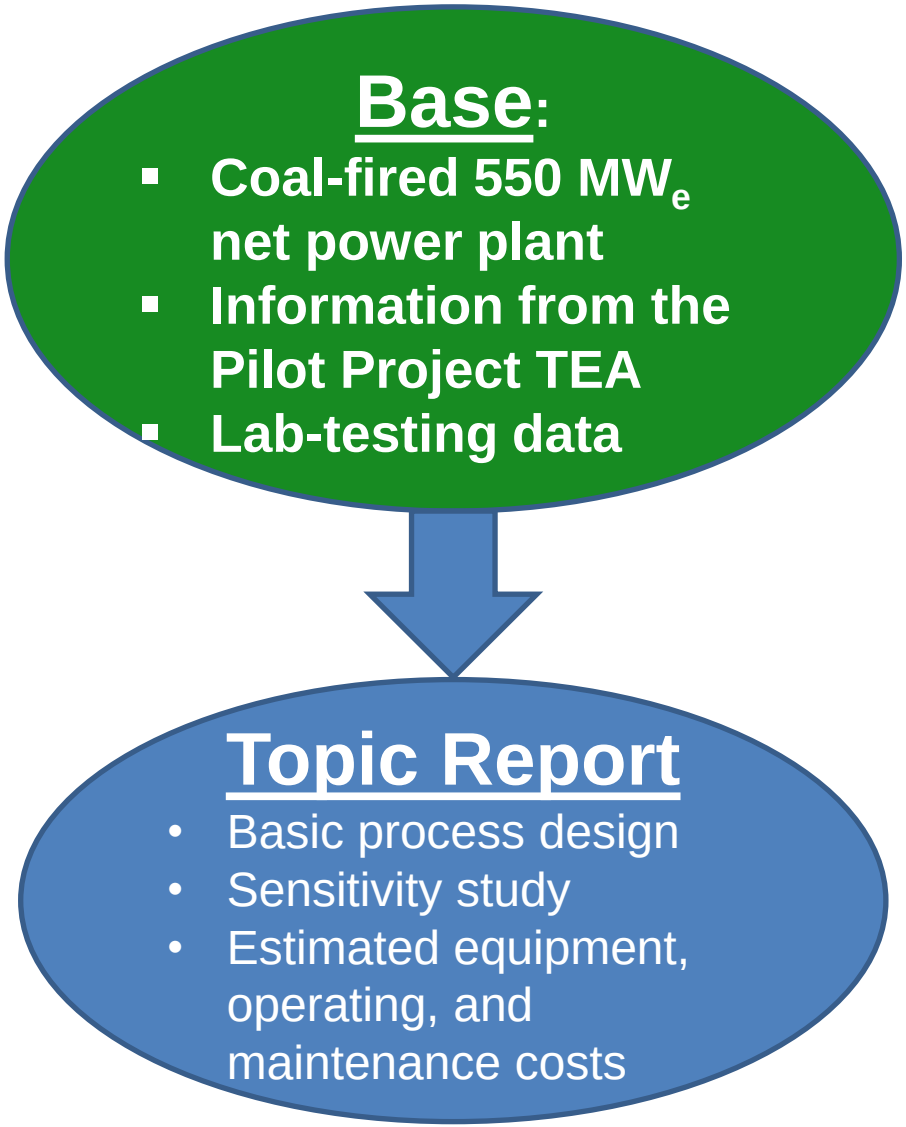
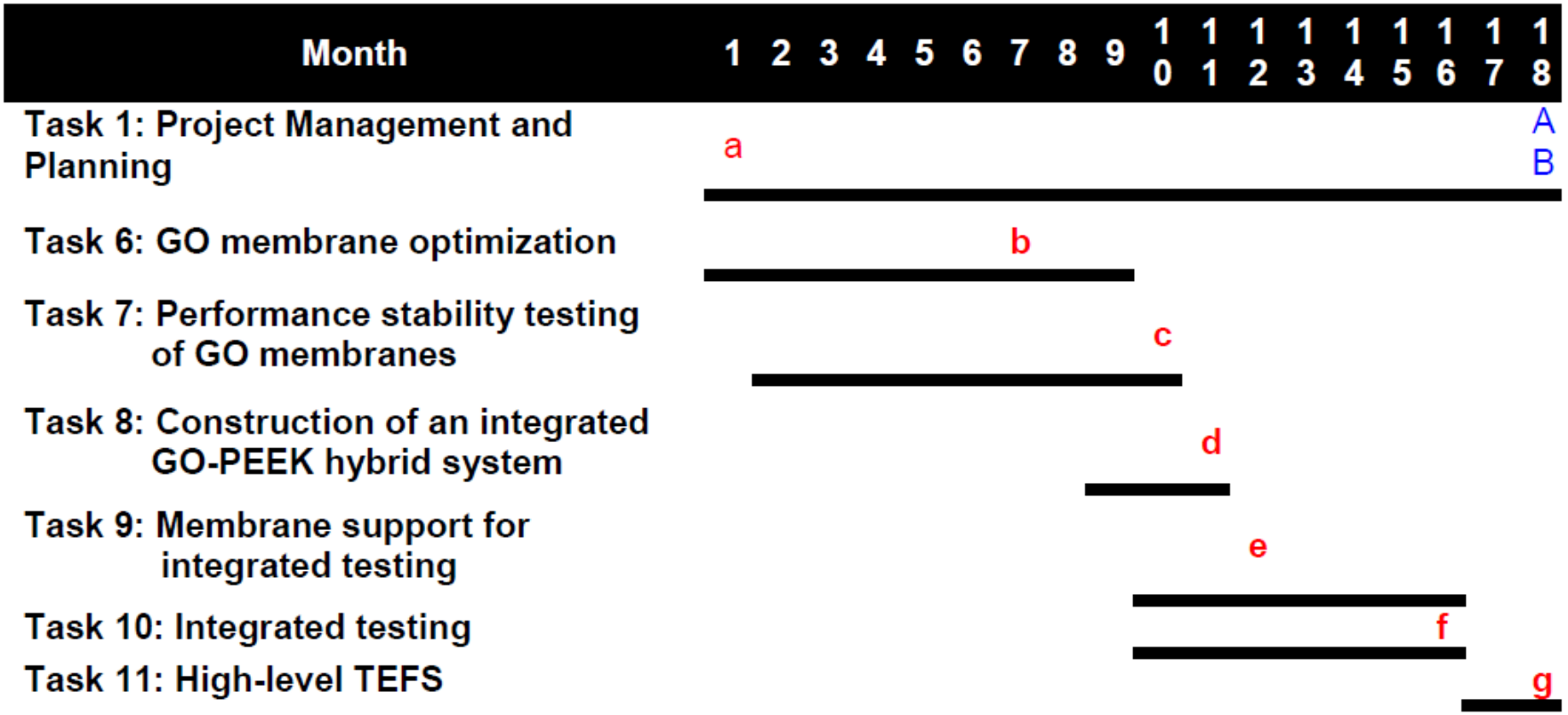
Trimeric: responsible for high-level technical and economic feasibility study (TEFS)



BP2 timeline, tasks, milestones and completion of the project



Milestones		Completion of the project
a	BP1 Technical Report submitted	A: Achievement of technical and cost goals
b	GO membranes shipped to GTI for testing	B: Submission of Final Technical Report
c	GO membranes showed CO_2/N_2 selectivity ≥90 and CO_2 permeance ≥1,000 GPU	
d	Integrated GO-PEEK hybrid system ready for testing	
e	Both GO and PEEK shipped to GTI for integrated testing	
f	Integrated testing complete	
g	Issue high-level TEFS Report	

Summary

- We are developing a novel CO_2 capture process combining a conventional gas membrane unit and a hollow fiber membrane contactor unit
- Preliminary estimate suggests the projected cost can be 31% lower than DOE benchmark technology for a 45%/45% capture case
- SOPO and PMP updated
- BP1 research activities commenced

Acknowledgements

- **Financial support**

- **DOE NETL José Figueroa**