Pre-combustion Carbon Capture by a Nanoporous, Superhydrophobic Membrane Contactor Process

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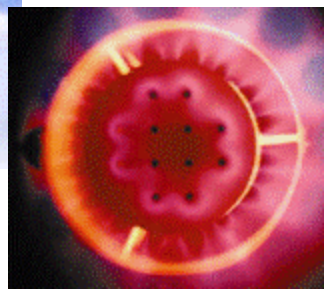
Nov. 13, 2009 DE-FE0000646

Outline

- Introduction of GTI and PoroGen
- Introduction of Membrane Contactor Technology
- Details of the Project
- Summary

Gas Technology Institute



Solving Important Energy Challenges via:

- > Contract Research
- > Program Management
- > Technical Services
- > Education and Training

> Over 1,000 patents
> Nearly 500 products commercialized

Facilities & Staff

> Main Facility:

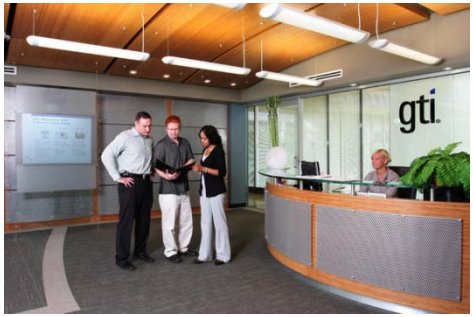
18-Acre Campus

Near Chicago

- Over 200,000 ft^2 of laboratory space
- 28 specialized laboratories and facilities

> Staff of 250

- 70% are scientists and engineers
- 45% with advanced degrees



Offices & Labs

Flex-Fuel Test Facility

Energy & Environmental Technology Center

GTI Alignment with Industry Value Chain

SUPPLY	DELIVERY	END USE
Needs		
Provide a secure, stable, competitive domestic energy supply	Address strategic concerns of domestic energy T&D infrastructure	Maintain industrial competitiveness and improve affordability and applicability of gas
Focus		
> Unconventional Natural Gas Resources > Gasification of Coal and Biomass > Carbon Capture and Sequestration	> Safety > Pipeline Integrity > Cost Reduction > Efficiency	> Efficiency and environmental > Product development and commercialization > Competitive industry

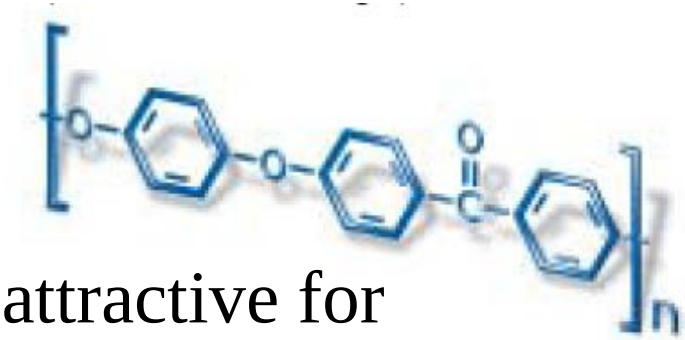
Specific GTI Programs Related to CCS

- R&D on Carbo-Lock™ Technology
- Morphysorb® for pre-combustion CO_2 capture, natural gas CO_2 removal
- U-Gas® fluidized-bed coal or biomass gasification
- Wood gasification (to liquid transportation fuels) and gas cleanup
- Selective removal/recovery of H_2S from syngas (UCSRP)
- CO_2 to Biomethane (Algae)
- Regional Partnership for Carbon Capture (SW and Midwest Partnerships)
- Reservoir monitoring and site selection

PoroGen Corporation

- Material technology company
- Building products manufactured from specialty high performance plastic PEEK
- Core of PoroGen's patented technology is porous PEEK materials
- Diverse line of products ranging from membrane fluid separation filters to heat transfer devices

PoroGen's Competitive Advantage



- The properties that make PEEK attractive for preparation of membranes make it difficult to process PEEK into membranes.

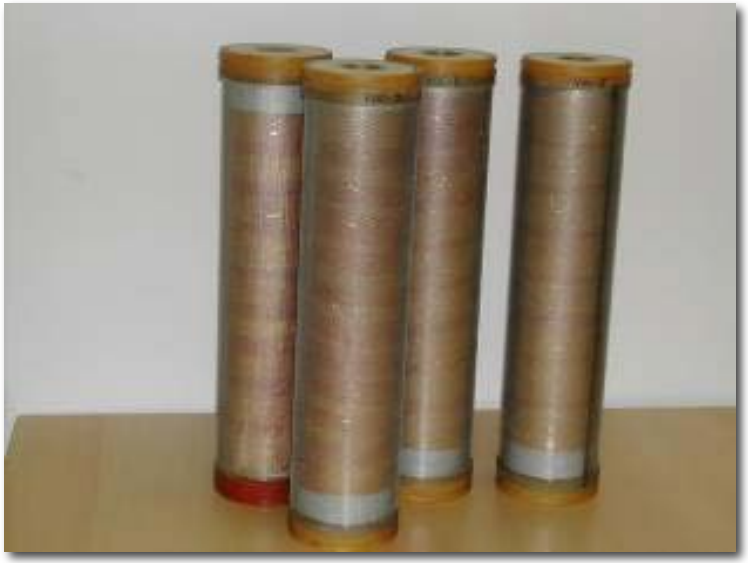
PoroGen's patented technology enables PEEK membrane preparation by conventional melt extrusion

- PoroGen is the only worldwide manufacturer of PEEK membranes

PoroGen Milestones

- Developed new fundamental technology platform based on porous PEEK materials technology
- Built manufacturing plant with 5,000 module annual nameplate capacity
- Commercialized PEEK-SEP™ line of products for aggressive liquid filtration, gas separation and gas/liquid transfer
- Four US Patents issued with several pending

PEEK-SEP™ Products Available Today



VOC abatement filter

Features:

- Module area up to1000 ft^2 in single cartridge
- Withstand high temperature up to 200° C
- Durable
- Robust

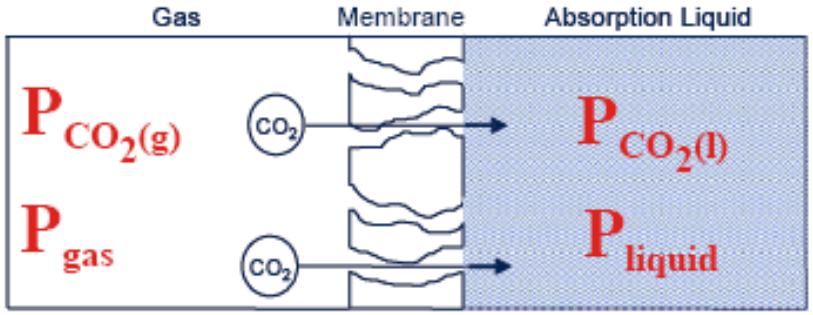
Natural gas purification filter

Introduction of Membrane Contactor Technology

Basic Principles

Membrane mass transfer principle

- Porous, hollow fiber membrane
- Unique membrane material, PEEK
- Membrane matrix filled with gas
- Mass transfer by diffusion reaction
- Driving force: difference in partial pressures of component to be removed/absorbed ($PCO_2(g)>PCO_2(l)$)
- Liquid on one side, gas on the other side of the membrane
- Pressure difference between shell and tube side almost zero
- ($P_l \geq P_g$), i.e. the mass transfer is not pressure driven



Previous Work – Membrane Contactors

- GTI worked closely with Kvaerner (now Aker) on ePTFE based membrane contactor process development
- This project successful verified membrane contactor advantages
  - ✓ High mass transfer rates
  - ✓ Up to 75% reduction in volume and 65% reduction in weight
- GTI performed extensive dehydration and AGR field tests with Kvaerner, Shell, Duke Energy, and Chevron
- Wetting of pores in PTFE membranes observed resulting in solvent loss and loss of productivity
- Process economics for prior option was high due to
  - ✓ Limitation of module design affected cost per attainable performance
  - ✓ High cost of pressure control system

Previous Work – Dehydration Unit

Field scale gas/liquid membrane contactor unit

- **2 MMscfd**
- **1 gpm**
- **1375 psig**

This unit is available and can be modified for syngas carbon capture using PEEK hollow fiber membrane modules.

Previous Work – Natural Gas H_2S and CO_2 Removal

Field scale gas/liquid membrane contactor unit

- **4.5 MMscfd**
- **22 gpm**
- **1290 psig**

While this unit is not available, the design for this unit is available and can be modified for syngas carbon capture using PEEK hollow fiber membrane modules.

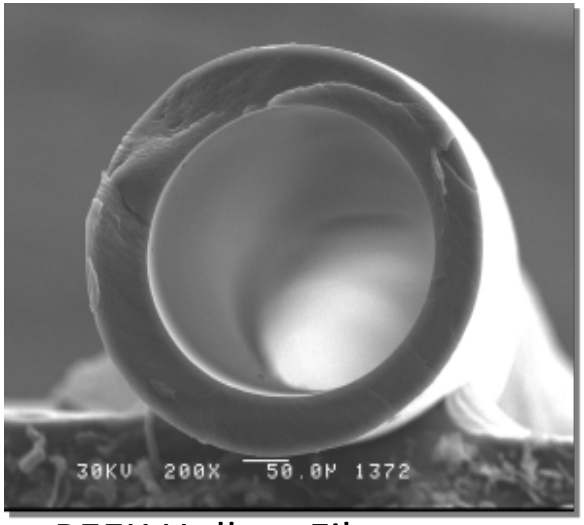
Previous Work – Exhaust Gas Pilot Test Unit

- **1.7 MMscfd flue gas**
- **5 ton/hr solvent flow**
- **4.7 ton/day CO_2 capture capacity**

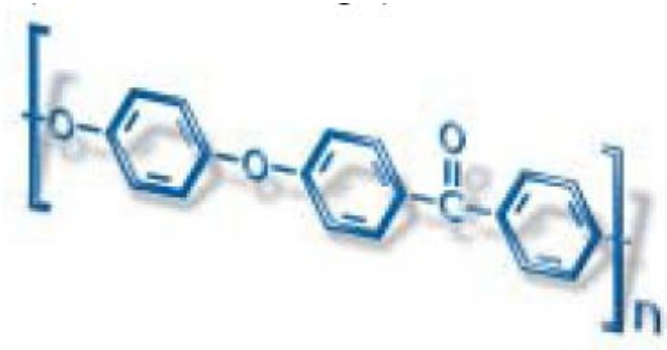
This unit is available and can be moved to sites for testing of PEEK membrane contactor for flue gas carbon capture.

Membrane Material Properties of PEEK

- Very high heat resistance
- High rigidity
- High dimensional stability
- Good strength
- Excellent sliding friction behavior
- Excellent chemical resistance
- Excellent hydrolytic stability
- Average pore size 1 to 50 nm
- Average porosity 40 to 70%
- 800 psi water breakthrough pressure



PEEK Hollow Fiber



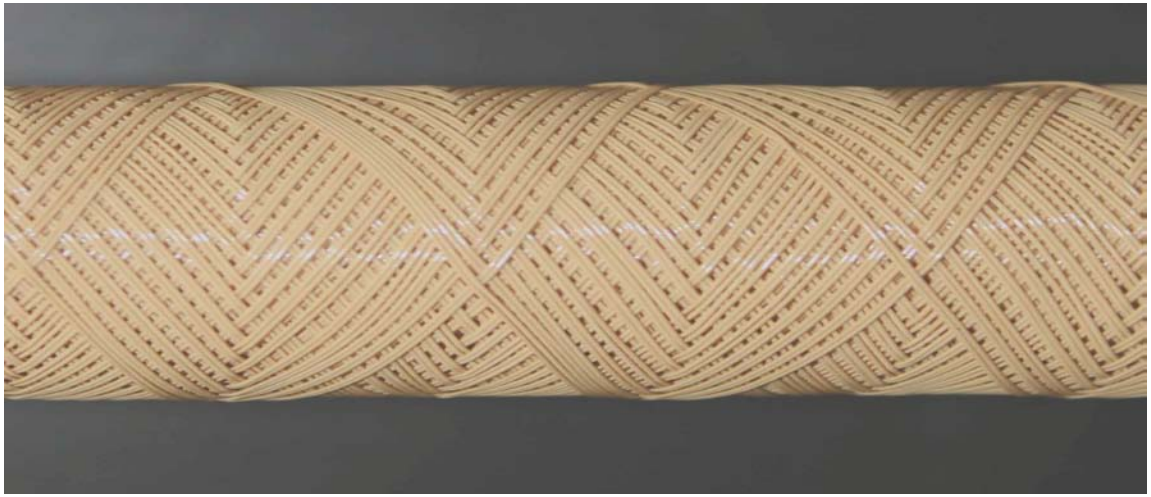
PEEK can operate continuously in contact with aggressive solvents.

PEEK Hollow Fiber Membrane

- Nanoporous hollow fiber manufactured by patented process
- Surface modification to achieve super-hydrophobicity
- Fiber OD can range from 200 μm to 1mm
- Fibers can be made with very thin wall (<25μ) due to strength of PEEK
- Membrane pore size can be controlled from 1 to 50 nm
- Asymmetric membrane structures utilized for high performance
- Hollow fiber has high burst pressure > 500 psig
- Hollow fiber has high collapse pressure > 1000 psig

Advanced Hollow Fiber Module Design

- Hollow fiber modules constructed by computer controlled helical winding
- Modules exhibit best in class flow dynamics – minimal pressure drop, high uniform packing density, thermodynamically most efficient counter-current flow configuration



PEEK-SEP™ Technology Elements

- ✓ Membrane attributes
  - ✓ stable in all solvent systems
    - ✓ Current commercial physical and chemical solvents systems
    - ✓ At higher solvent concentrations
    - ✓ With new advanced more efficient solvents
    - ✓ High temperature stability for the desorption step
  - ✓ High liquid breakthrough pressure (no liquid wet out), high membrane integrity
  - ✓ High membrane productivity
- ✓ Module attributes
  - ✓ exhibit superior mass transfer coefficients
  - ✓ Counter-current flow is thermodynamically most efficient mass transfer
  - ✓ Structured packing of hollow fibers critical for efficient mass transfer. Computer controlled winding provides structured packing to enable enhanced turbulence flow at fiber surface.

Carbo-Lock™ is a Trademark Process Incorporating PEEK-SEP Technology

- ✓ **Lower capital costs**
  - Smaller equipment volume and weight, up to 70% reduction in volume and 65% reduction in weight.
  - Lower materials of construction costs
- ✓ **Lower operating costs**
  - Lower solvent regeneration cost
  - Lower solvent inventory
  - High solvent loading
  - Reduced pump power consumption

Project Details – Project Management Plan

- Section 1.0: Introduction
- Section 2.0: Project Management Approach
- Section 3.0: Management Scope/Work Scope
- Section 4.0: Budget
- Section 5.0: Project Schedule
- Section 6.0: Discussion of Milestones
- Section 7.0: Key Staff
- Section 8.0: Discussion of Project Risk
- Section 9.0: Constraints and Assumptions
- Section 10.0: Communication Procedures

1.0 Project Introduction

- **Technology Goal:**
  - To separate and capture 90% of CO_2 from Integrated Gasification Combined Cycle (IGCC) power plants with less than 10% increase in the cost of energy services

- **Key Objectives:**
  - Tailor highly chemically inert and temperature stable, superhydrophobic, hollow fiber PEEK membrane for precombustion CO_2 capture
  - Manufacturer low cost integrated membrane module
  - Design energy efficient CO_2 recovery process minimizing hydrogen loss

2.0 Project Management Approach

- **PMP Objective:**
  - To clearly communicate GTI's project management practices
  - Leverage GTI's *project management practices* to control the project
  - Accurately track project progress and proactively manage status
- **Advantage:**
  - Standard practices (consistency)
  - Integrates best practices
  - Clear work practices
  - Measures project status with control points

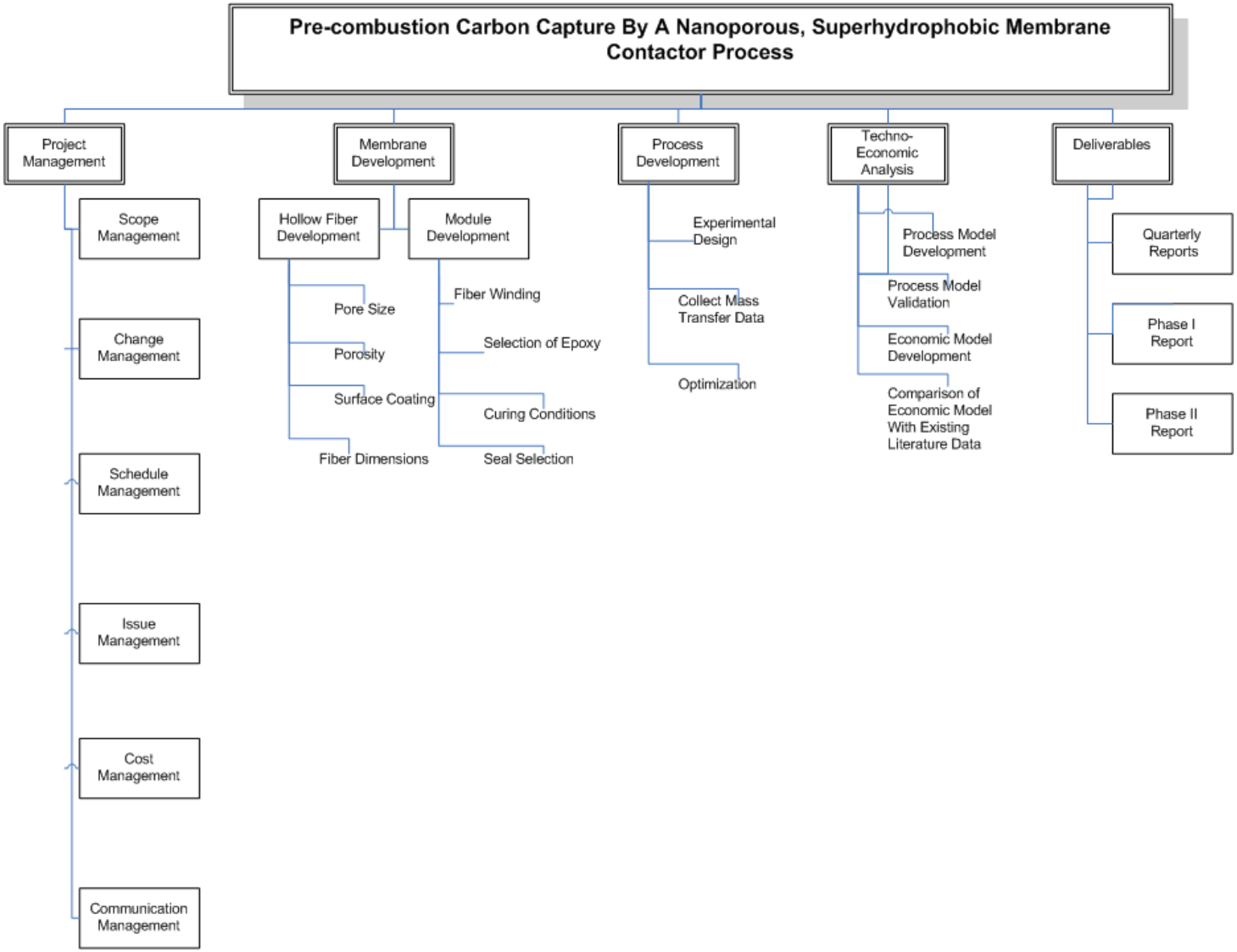
3.0 Management Scope

- **Key Objective**
  - Develop cost effective separation technology for CO_2 capture from syngas based on a hollow fiber membrane contactor
    - Tailor highly chemically inert and temperature stable, superhydrophobic, hollow fiber PEEK membrane for precombustion CO_2 capture
    - Manufacturer low cost integrated membrane module
    - Design energy efficient CO_2 recovery process minimizing hydrogen loss

3.0 Work Scope

- **Optimization of nanoporous super-hydrophobic PEEK hollow fiber membrane**
  - Optimal pore size
  - Surface chemistry
- **Optimization of hollow fiber membrane module**
  - Mass transfer rates
  - Pressure drop
  - Material compatibility
  - Life time
- **Development of separation process**
  - Process conditions
  - Scaling factors
- **Process economic evaluation**

3.0 Work Breakdown Structure



3.0 Year I: Objectives and Tasks

- **Objectives**
  - Hollow fiber membranes suitable for the membrane contactor application with improved mass transfer
  - Feasibility of the membrane contactor technology for syngas CO_2 separation (absorption and desorption)
  - Process design
  - Economic analysis

Task #	Task Title	Responsible Individual/Organization
1	Tailor membrane performance towards syngas separation	Research Scientist PGC
2	CO_2 capture testing by membrane contactor	Research Scientists GTI and PGC
3	Membrane process design and economic evaluation	Research Scientists GTI and PGC

3.0 Year II: Objectives and Tasks

- **Scale up the process from lab to bench scale**
- **Membrane module fabrication process**
- **Bench scale testing for process stability and sensitivity**
- **Refinement of the process economics**

Task #	Task Title	Responsible Individual/Organization
5	Membrane contactor manufacturing process scale up	Research Scientist PGC
6	Membrane contactor stability and life testing	Research Scientists GTI and PGC
7	Bench scale testing of membrane contactor	Research Scientists GTI
8	Bench scale testing with slipstream from GTI's FFTF	GTI Engineers
9	Refine economic evaluation	GTI Engineers

3.0 Deliverables

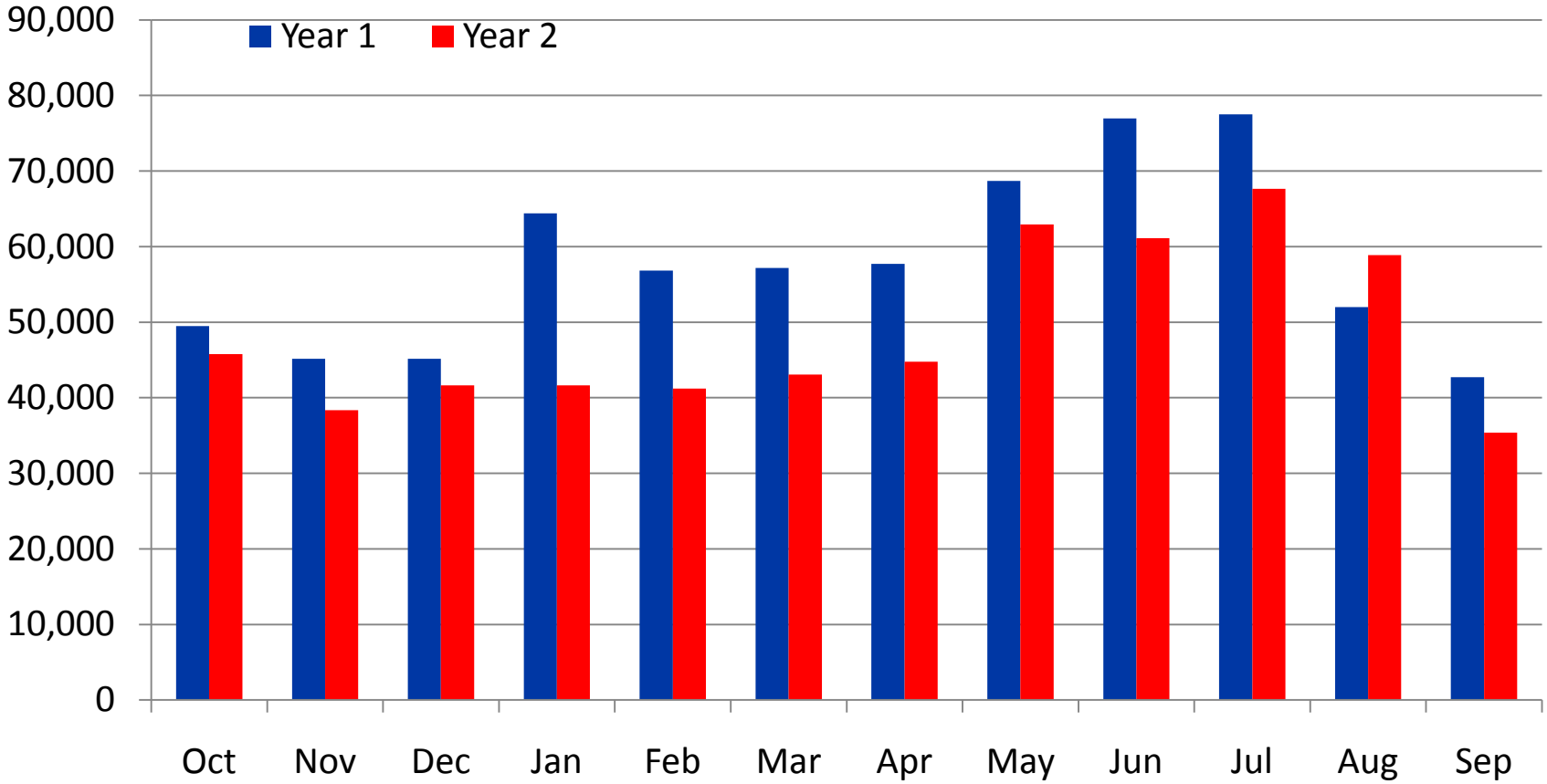
- Quarterly reports
  - Progress, milestones status, recent results, proposed changes in schedule, earned value financials
- Year I report
  - Summary of all Year I work
- Final report

3.0 Briefings/Technical Presentations

- Attend project kickoff meeting
- Attend DOE annual program review meetings
- Present the project results at appropriate technical conferences or meetings, as directed by the DOE Project Officer

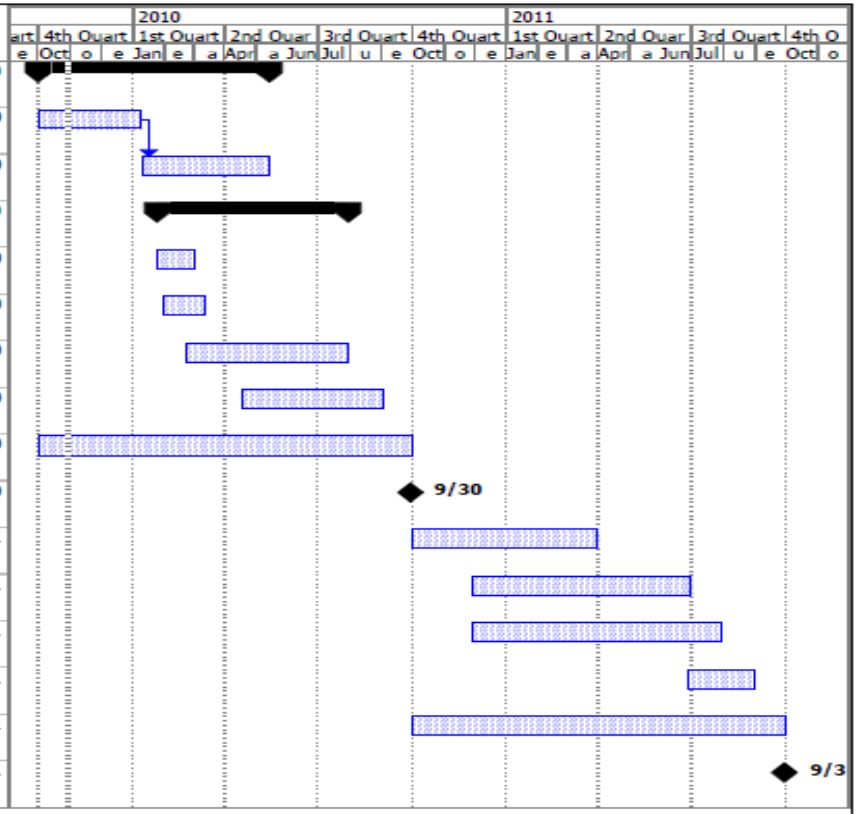
4.0 Budget

- Total Budget: $1.27MM
  - Federal $1.0MM
  - Cost Share $276K



5.0 Project Schedule

ID	Task Name	Start	Finish
1	**Hollow fiber membrane modification**	**Thu 10/1/09**	**Fri 5/14/10**
2	Nano-porous PEEK hollow fiber substrate preparation	Thu 10/1/09	Fri 1/8/10
3	Surface modification	Mon 1/11/10	Fri 5/14/10
4	**CO2 capture demonstration membrane contactor**	**Mon 1/25/10**	**Fri 7/30/10**
5	Membrane test unit construction	Mon 1/25/10	Mon 3/1/10
6	Membrane module construction	Mon 2/1/10	Fri 3/12/10
7	CO2 capture performance demonstration	Mon 2/22/10	Fri 7/30/10
8	**Membrane process design/economic evaluation**	Mon 4/19/10	Fri 9/3/10
9	**Phase I project management**	Thu 10/1/09	Thu 9/30/10
10	**Phase I final report**	Thu 9/30/10	Thu 9/30/10
11	**Membrane contactor scale up**	Fri 10/1/10	Thu 3/31/11
12	**Contactor stability and life testing**	Mon 11/29/10	Thu 6/30/11
13	**Bench scale testing of membrane contactors**	Mon 11/29/10	Fri 7/29/11
14	**Refined economic evaluation**	Tue 6/28/11	Wed 8/31/11
15	**Phase II project management**	Fri 10/1/10	Fri 9/30/11
16	**Phase II final report**	Fri 9/30/11	Fri 9/30/11



Project: Timeline
Date: Thu 10/29/09

Task		Rolled Up Task		External Tasks	
Progress		Rolled Up Milestone		Project Summary	
Milestone		Rolled Up Progress		Group By Summary	
Summary		Split		Deadline	

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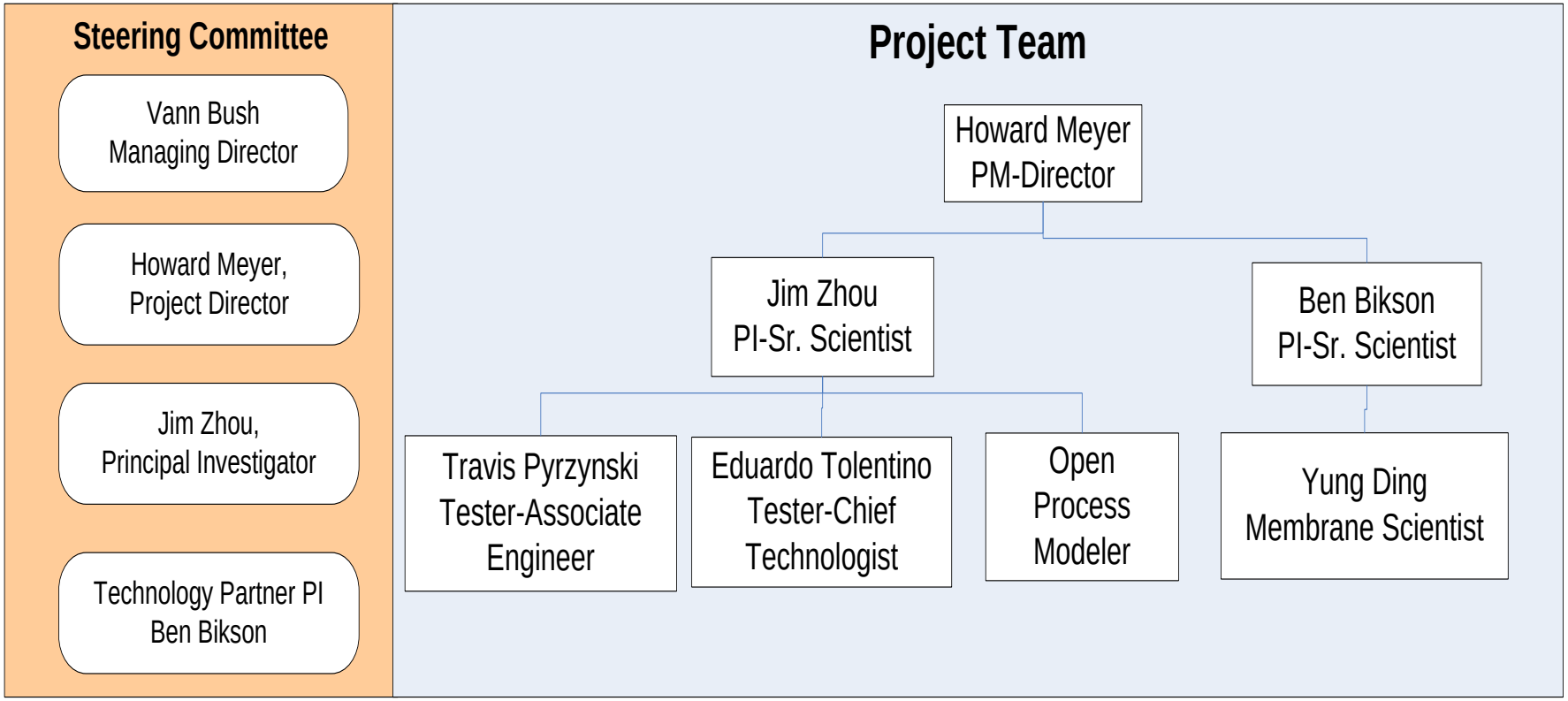
6.0 Discussion of Milestones

1.	Issue Initial PMP	11/1/09
2.	Kickoff Meeting	11/13/09
3.	Complete Tailor Membrane Performance towards Syngas Separation	4/30/10
4.	Complete CO_2 Capture Testing Membrane Contractor	6/30/10
5.	Complete Membrane Process Design and Economic Evaluation	7/30/10
6.	Issue Year 1 Project Report	9/30/10
7.	Complete Membrane Contractor Manufacturing Process Scale Up	5/30/11
8.	Complete Membrane Contractor Stability and Life Testing	3/31/11
9.	Complete Bench Scale Testing of Membrane Contractor	8/31/11
10.	Complete Slipstream Testing of Membrane Contractor	8/31/11
11.	Complete Refine Economic Evaluation	8/31/11
12.	Issue Project Final Report	9/30/11

7.0 Key Staff

Role	Organization	Resource Name	Role Definition/Skills	Reports to
Project Manager	GTI	Howard Meyer	Manages the project outcomes to a defined scope, cost, scheduled time. Manages the project using the project disciplines. Manages the project customer and provides project reports. Assigns, tracks project work. Provides direction on project issues	Vann Bush
Principle Investigator	GTI	Jim Zhou	Manages the day to day project activities. Assigns, tracks project work. Provides direction on project issues. Designs the experiment. Communication of the experiment design	Howard Meyer
Process Modeler	GTI	Open		Jim Zhou
Tester	GTI	Travis Pyrzynski	Sets up the project experiment. Performs testing, collects results, writes up results and communicates progress to the PI and PM.	Jim Zhou
Tester	GTI	Eduardo Tolentino	Sets up the project experiment. Performs testing, collects results, writes up results and communicates progress to the PI and PM.	Jim Zhou
Subcontractor	PoroGen	Ben Bikson	Membrane Scientist	Howard Meyer
Subcontractor	PoroGen	Yong Ding	Membrane Scientist	Ben Bikson

7.0 Key Staff - Organizational Chart



8.0 Discussion of Risk

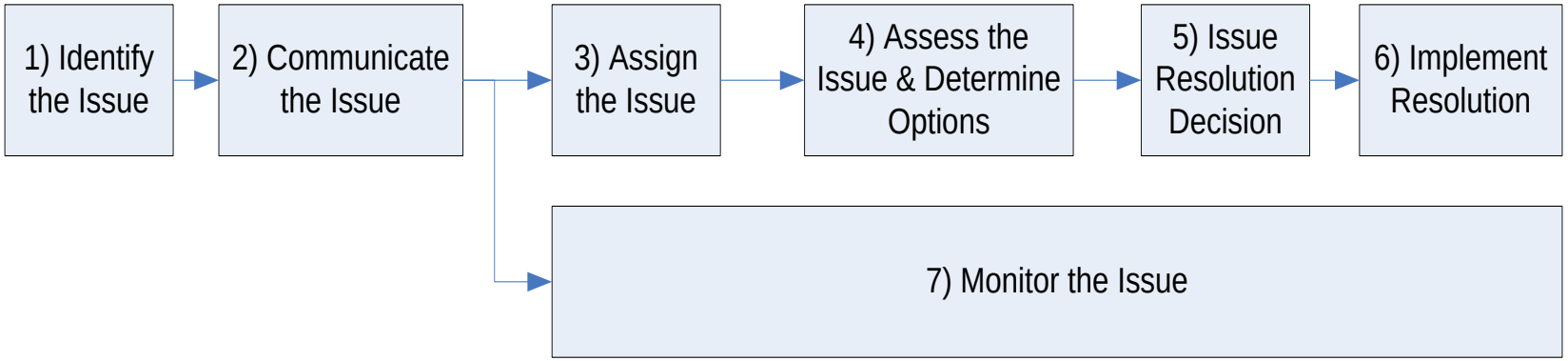
- **Objective:** Minimize Technical, Resource and Management (Cost, Schedule) Risk
- **Risk Management Approach:** (Monitor, Assess, Act)
  - **Technical Monitoring:** Monitor Work Progress
  - **Management (Cost) Monitoring:** Deltek Account System Cost Reports, Actual/Planned Cost Tracking
  - **Management (Schedule) Monitoring:** Status Updates, Baseline schedule comparisons, Earned Value Tracking
  - **Management Monitoring:** Project Director and Contract Analyst monitor GTI projects
- **Baseline Variances:**
  - Overall project and task earned value reports will be provided monthly and quarterly
  - Variances exceeding established thresholds will be resolved with DOE project monitors

8.0 Discussion of Risk

- **Technical Risks:**
  - Membrane hydrophobic properties change with solvent contact causing leakage
    - Mitigated by surface chemistry optimization
  - Mass transfer coefficient not sufficiently high for gas absorption in the membrane contactor
    - Mitigated by optimization of structured packing and fiber pore size
- **Management Risks:**
  - The schedule for Subtask 2.3, CO_2 capture performance demonstration, assumes that the Flex-Fuel Testing Facility will be performing a coal gasification test during 3QFY2011
    - Mitigated by GTI monitoring the plans for FFTF to communicate with DOE on the most appropriate time for those tests

9.0 Constraints and Assumptions

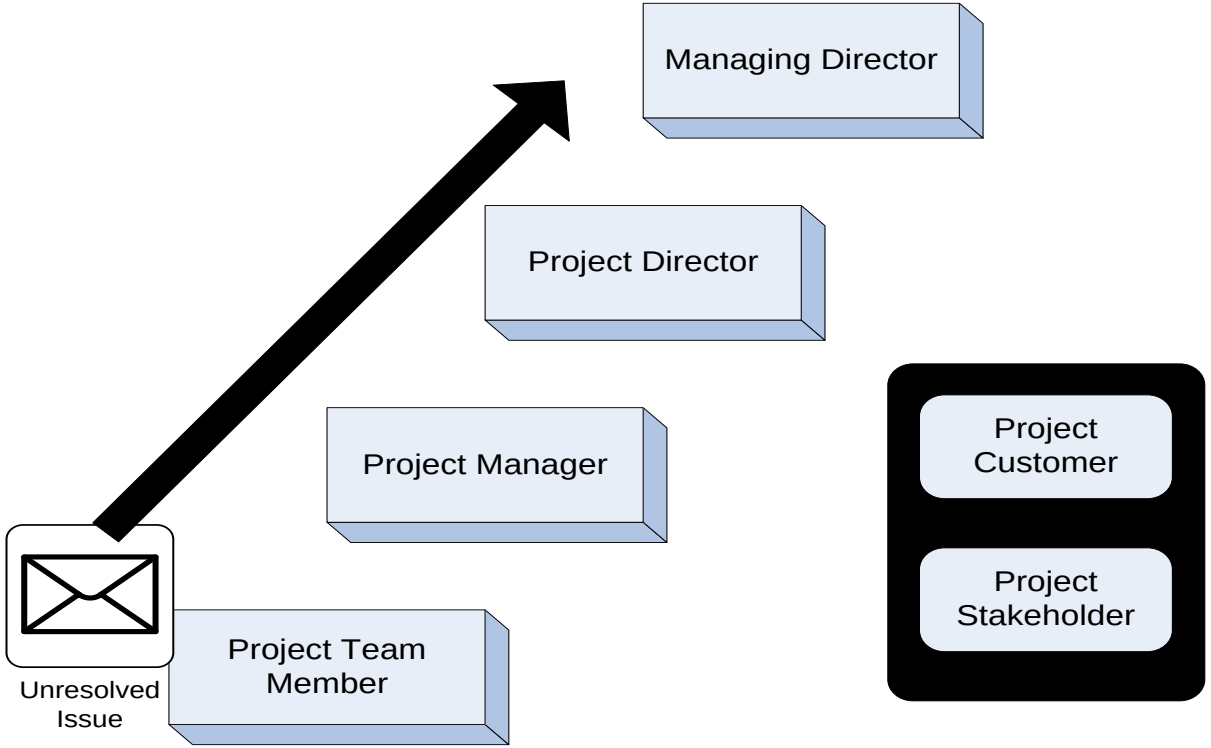
- **Summary of Constraints:**
  - Do not have any project constraints
- **Issue Management Process:**
  1. Issue Identification
  2. Communicate to the project manager
  3. Assign issue with action
  4. Assess issue and develop options to resolve
  5. Decision to resolve issue and provide direction
  6. Implement
  7. Monitored to ensure progress



9.0 Constraints and Assumptions

- **Escalation Process:** Intended to resolve issues that require immediate attention.

Escalation moves the issue to the next management level for resolution



10.0 Communication Procedures

- **Key Objective:**
  - Establish a reliable communication model
  - Create a common understanding throughout the project
  - Efficient communication process
  - Communicate project status, highlight accomplishments, and reinforce project expectations

10.0 Communication Procedures - Reports

#	Item	Involved Parties	Method/Media	Frequency
Reports				
1	Project Progress Report	**Sponsor**; U.S. DOE Sr. Manager **GTI;** Project Manager, Principle Investigator **Partner Companies**;	Status Report, Earned Value Report	Quarterly
2	U.S. DOE Review	**Sponsor**; U.S. DOE Sr. Manager **GTI;** Project Manager, Principle Investigator **Partner Companies**;	Report Presentation Packet	Determined by Schedule
3	Cross Team Status Report	Representatives for the contractor and sub-contractors. Project details, task status, issues, across multiple teams.	Project Schedule Status, Issues, Technical Spec's	As Needed
-	Special Status Report	**Sponsor**; U.S. DOE Sr. Manager **GTI;** Project Manager, Principle Investigator **Partner Companies**;	Email	Quarterly
-	U.S. DOE to Stakeholders	U.S. DOE, Project Communications Manager	Report, Newsletter, Webpage, Presentation	As Needed
-	Final Scientific/ Technical Report	**Sponsor**; U.S. DOE Sr. Manager **GTI;** Project Manager, Principle Investigator **Partner Companies**;	Electronic Submission http://www.osti.gov/elink-2413.	Determined by Schedule
-	Conference Papers/ Proceedings	**Sponsor**; U.S. DOE Sr. Manager **GTI;** Project Manager, Principle Investigator **Partner Companies**;	Electronic Submission http://www.osti.gov/elink-2413.	Determined by Schedule

10.0 Communication Procedures - Reports

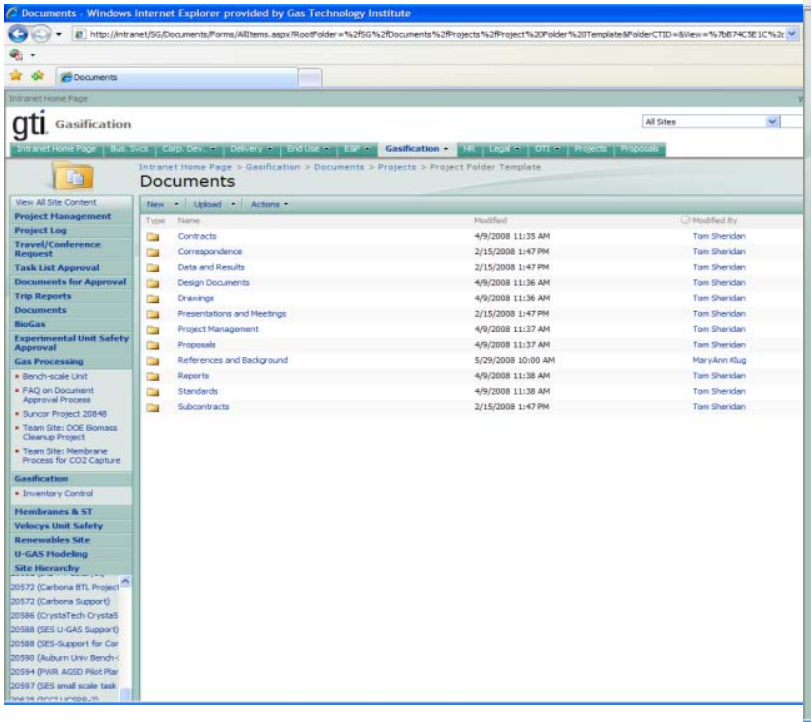
#	Item	Involved Parties	Method/Media	Frequency
Reports				
-	**Financial** Reporting	**Sponsor**; U.S. DOE Sr. Manager **GTI;** Project Manager, Principle Investigator **Partner Companies**;	Electronic Submission http://www.whitehouse.gov/omb/grants/grants_forms.aspx	Determined by Schedule
-	**Closeout Reports** (Patent/ Property Certification)	**Sponsor**; U.S. DOE Sr. Manager **GTI;** Project Manager, Principle Investigator **Partner Companies**;	Electronic Submission http://www.directives.doe.gov/pdfs/forms/2050-11.pdf and http://grants.pr.doe.gov.	Determined by Schedule
-	**Other Reports:** Indirect Cost Proposal,	**Sponsor**; U.S. DOE Sr. Manager **GTI;** Project Manager, Principle Investigator **Partner Companies**;	Electronic Submission	Annually
-	**Other Reports:** Inventory of Federally Owned Property	**Sponsor**; U.S. DOE Sr. Manager **GTI;** Project Manager, Principle Investigator **Partner Companies**;	Electronic Submission	Annually
-	**American Recovery and Investments**	**Sponsor**; U.S. DOE Sr. Manager **GTI;** Project Manager, Principle Investigator **Partner Companies**;	Electronic Submission http://www.federalreporting.gov	As Needed

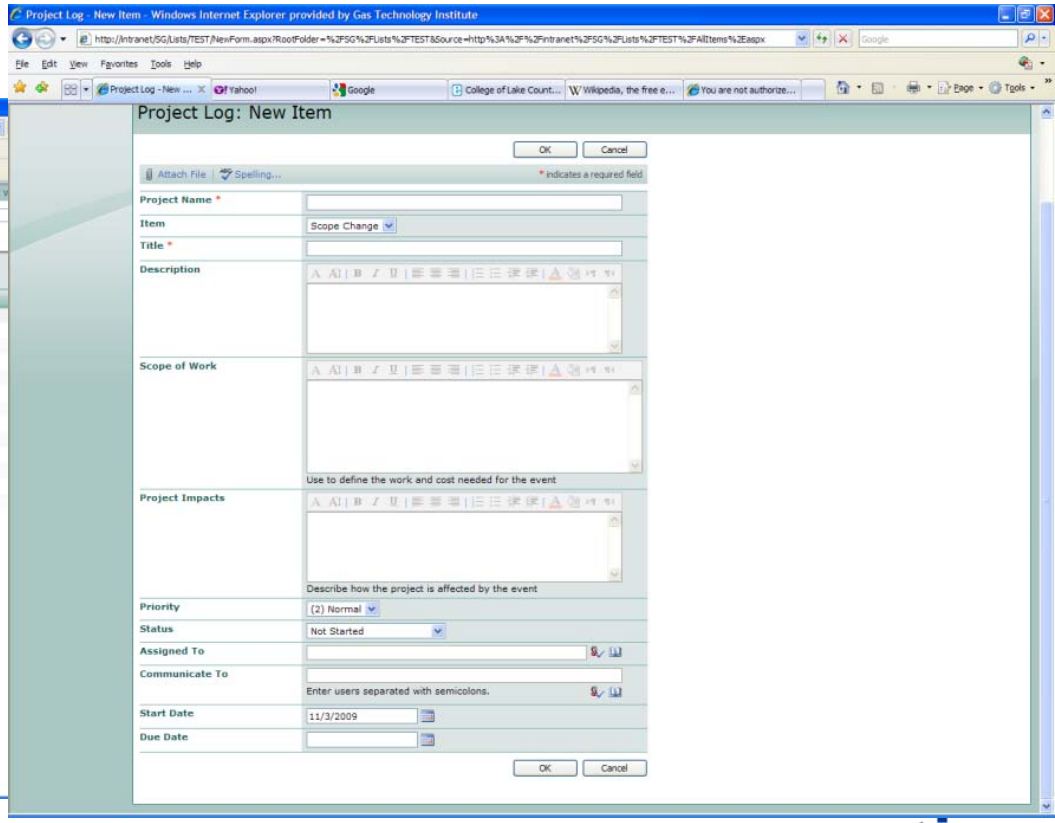
10.0 Communication Procedures - Meetings

Meetings				
#	Item	Involved Parties	Method/Media	Frequency
1	**Project Kickoff** Meeting	**Sponsor**; U.S. DOE Sr. Manager **GTI;** Project Manager, Principle Investigator **Partner Companies**; Project Manager	Meeting	November 13, 2009
2	**U.S. DOE Review**	**Sponsor**; U.S. DOE Sr. Manager **GTI;** Project Manager, Principle Investigator **Partner Companies**; Project Manager	Conference Call Meeting	Determined by Schedule
3	**Cross Team** Meeting: Project status, issues, across teams.	**GTI;** Project Manager, Principle Investigator, Testers, Process Modeler **Partner Companies**; Project Managers for the contractor and sub-contractors.	Conference Call Meeting	Weekly or As Needed
4	**Technical Working Sessions**	Technical engineers for requirements, design, build and problem solving work	Conference Call Meeting	As Needed

10.0 Communication Procedures

- **SharePoint for: (Centralized Location)**
  - Document Management
  - Issues Management





Summary

- High technology readiness increases the probability of bringing this technology to commercialization within DOE timetable
- GTI and PoroGen are committed to the success of this technology development because it is aligned with our core business strategies
- Membrane contactor technology combines advantages of membrane and absorption processes and enables economic utilization of next generation absorbents