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Improving Energy Efficiency of Air Separation via Hollow Fiber Sorbents

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Georgia Tech School of Chemical & Biomolecular Engineering

Meeting Outline

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- Project Overview
- Concept
- Project Objectives
- Project Tasks and Key Milestones
- Project Group Organization Chart
- Budget Summary

Project Overview

- Project Title:
  Improving Energy Efficiency of Air Separation via Hollow Fiber Sorbents

- DE-FE0026163 Award:
  18 month project (Oct. 2015 – Mar. 2017), $1.74MM, 70% Federal cost share

Project Goal

Provide bench-scale data that will allow a complete TEA of process performance of RCPSA when integrated with a cryogenic ASU.

Integrated ASU/RCPSA Module

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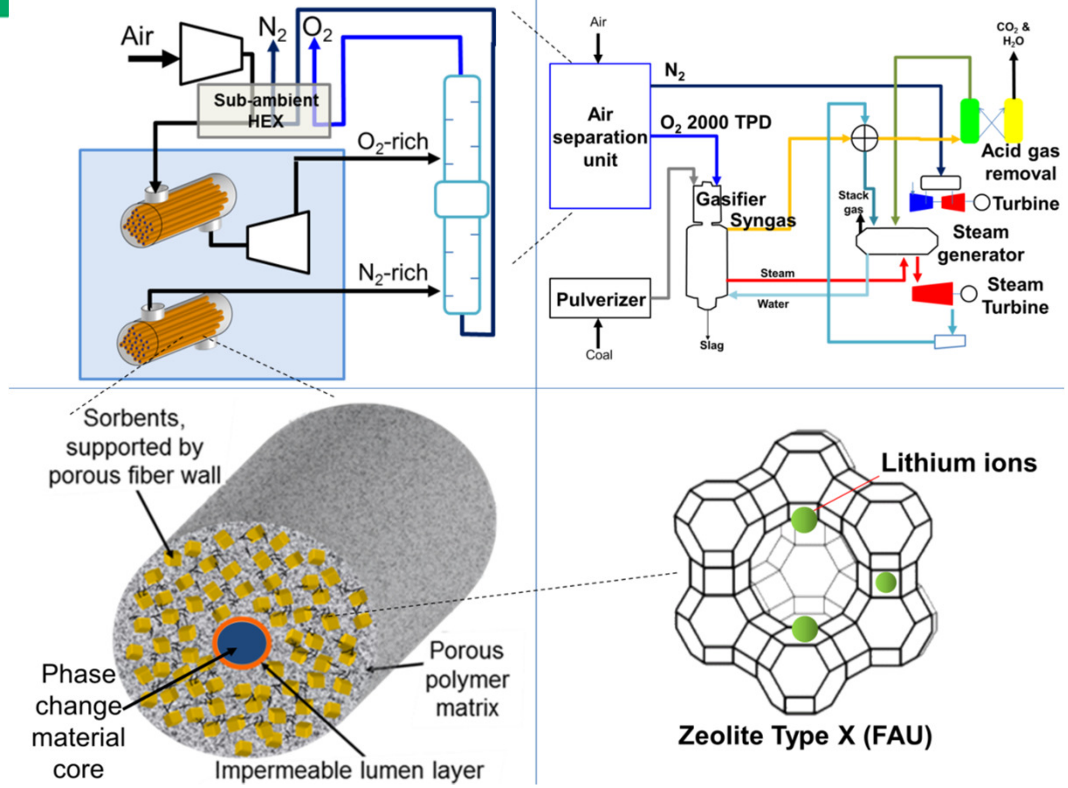
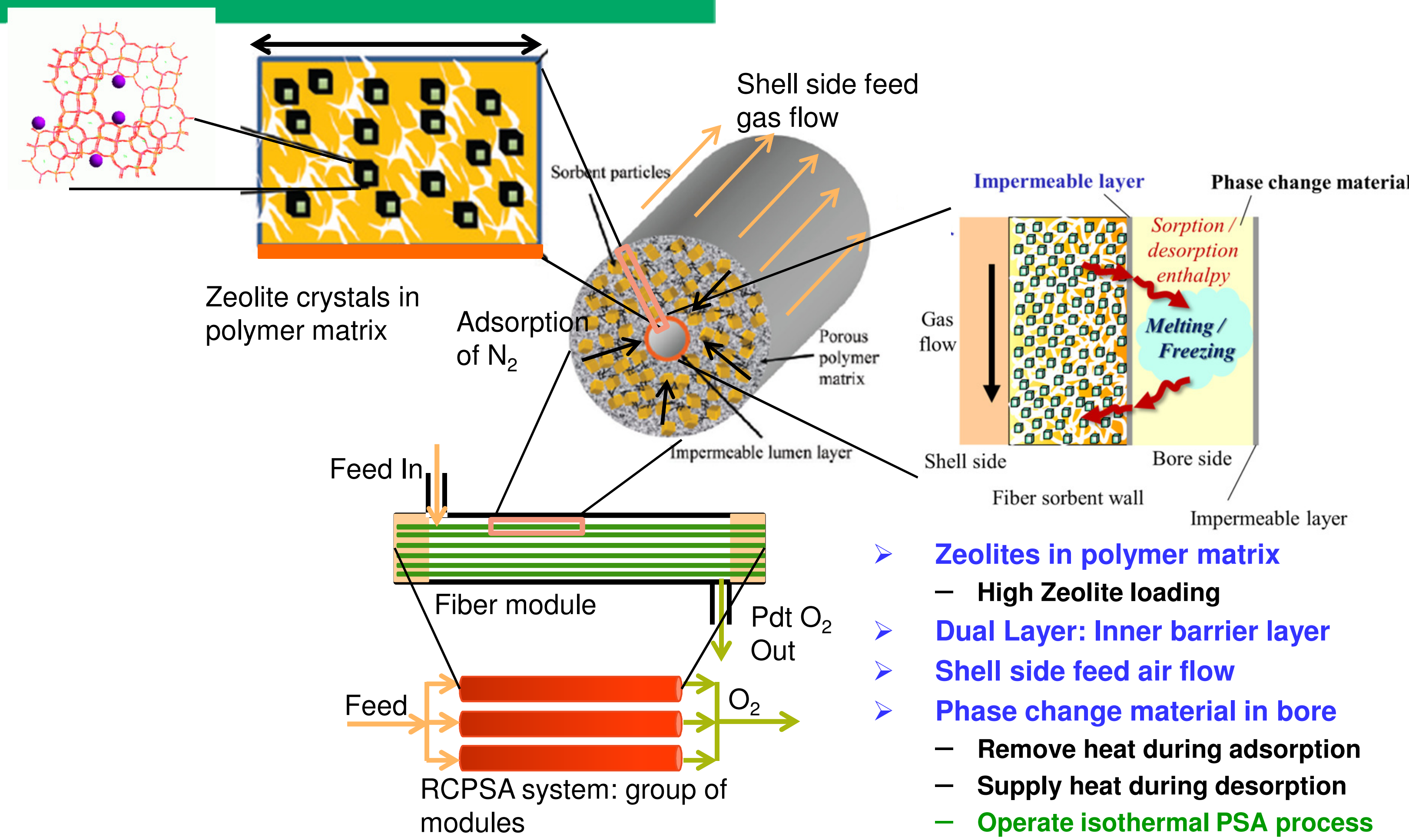


- **Benefits of integrated ASU & RCPSA fiber sorbent module**
  - Potentially smaller cryo ASU (lower # of stages) ➔ Lower equipment costs
  - Obtaining high purity O2 more efficiently
  - Significant reduction in carbon footprint

Low energy oxygen/nitrogen separation driven by sub-ambient adsorption based operation

Monolithic Fiber Sorbent Module



- **Zeolites in polymer matrix**
  - **High Zeolite loading**
- **Dual Layer: Inner barrier layer**
- **Shell side feed air flow**
- **Phase change material in bore**
  - **Remove heat during adsorption**
  - **Supply heat during desorption**
  - **Operate isothermal PSA process**
- **Bore side feed also possible**
- **Other benefits**
  - **Low Δp, low bed void, high MTC**
  - **No field loading, smaller footprint**
  - **Fast cycling PSA processes**

Lively and Koros et al., *Int. J. Hydrogen Energy* **2012**

Techno-Economic Analysis of ASU/RCPSA Fiber Sorbent Module

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- **A technology analysis plan (TAP) will be established for fiber sorbent-RCPSA system module performance (Praxair):**
  - Key parameters assessing the advanced fiber sorbent module performance will be identified
- **Detailed simulation studies of the fiber sorbent module at sub-ambient conditions will be done to establish a performance model in gPROMS (GT)**
  - Modeling will be done according to NETL guidelines on the input parameters
  - Non-linear optimizers will then be coupled to the model to obtain trade-offs of integrated fiber modules vs. ASU
  - Model results will be communicated using appropriate reporting guidelines
- **Detailed comparison between SOA and integrated ASU/fiber sorbent module case studies will be done (Praxair)**
  - Benefits of the fiber sorbent RCPSA system will be quantified
  - Potential performance and cost goals will be quantified
- **Cost of electricity (COE) & net power plant efficiency (HHV & LHV) metrics of the integrated ASU/fiber sorbent module will be calculated and compared with SOA baselines (Praxair)**

Project Objectives

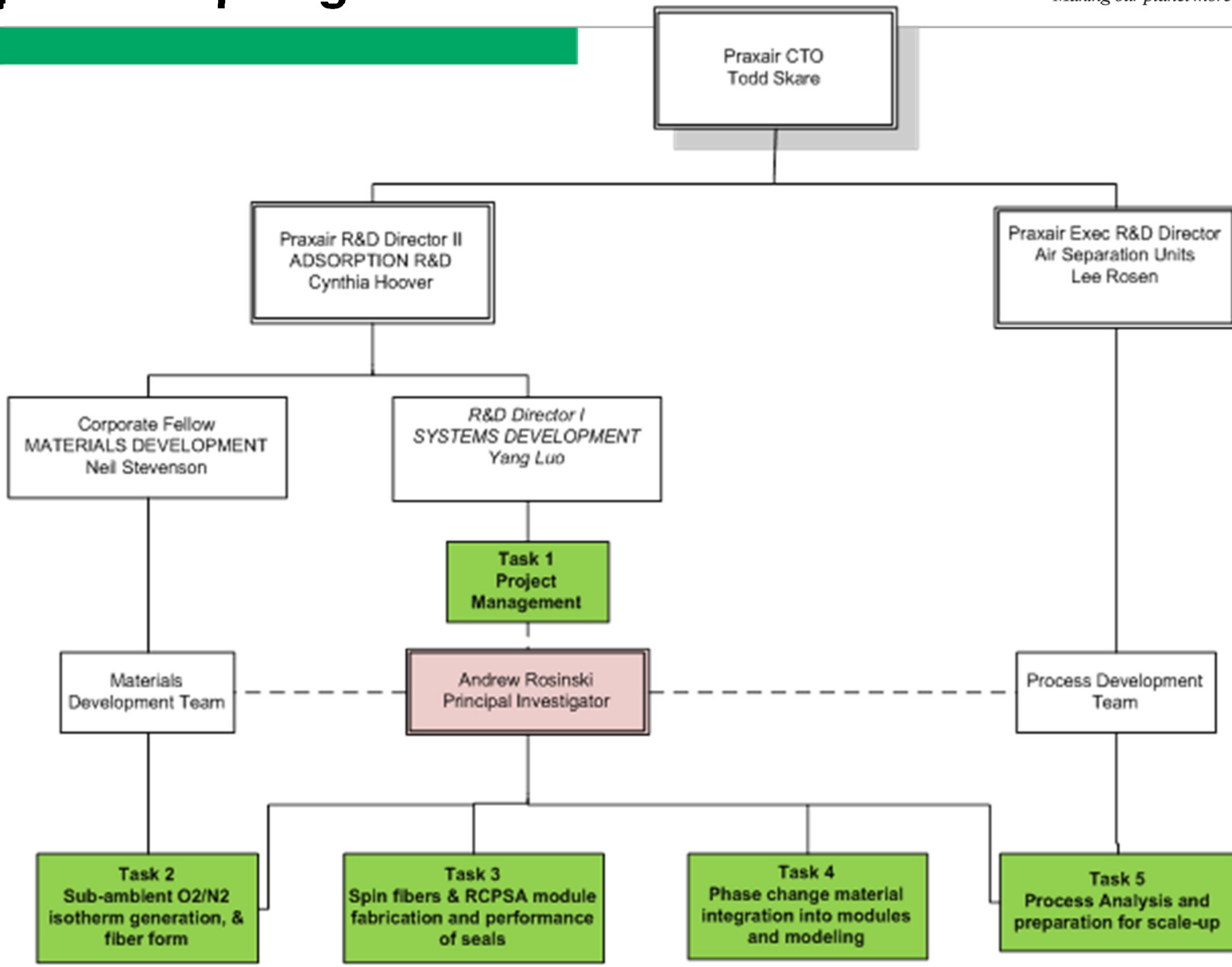
- Measure and evaluate oxygen and nitrogen isotherms on lithium exchanged zeolite powder at sub-ambient temperatures,
- Manufacture prototype hollow fiber lithium exchanged adsorbents with bore side phase change material and successfully activate the prototypes at high temperature,
- Assemble fiber sorbent modules and complete performance testing at various experimental conditions of interest,
- Optimize process design parameters / flowsheet integration and perform a techno-economic assessment to evaluate cost and performance of a full scale system against the current state-of-the-art.

Project Tasks

- Task 1 - Project Management and Planning
- Task 2 - Sub-ambient O2/N2 isotherm generation, and fiber formation
- Task 3 - RCPSA module construction, sub ambient temperature performance testing of seals after activation, and RCPSA system testing
- Task 4 - Phase change material (PCM) integration into hollow fiber sorbent modules and modeling
- Task 5 - Process analysis and preparation for scale-up

A1

Project Group Organization Chart



Experimental Facilities – Georgia Tech

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School of Chemical & Biomolecular Engineering at Georgia Tech. Laboratory facility includes:

Asymmetric hollow fiber spinning and testing

- polymer/particle spin dope preparation
- temperature controlled spin dopes, bore fluid delivery systems, and quench baths.
- Multi-layer fiber spinning
- solvent exchange and drying stations
- gas permeation module testing stations

Sorption and cyclic sorption capabilities

- Particulate Systems HPVA-II with a helium cryostat
- Custom-built sub-ambient rapid PSA systems (L&C Science & Technology, from current DOE support)
- High pressure ambient temperature sorption cells (>10)
- Cryogenic sorption analyzers (3)
- Mercury porosimetry
- Water vapor and organic vapor sorption (3)
- Custom-built rapid temperature swing adsorption systems (2, from previous DOE support)

Equipment to be purchased

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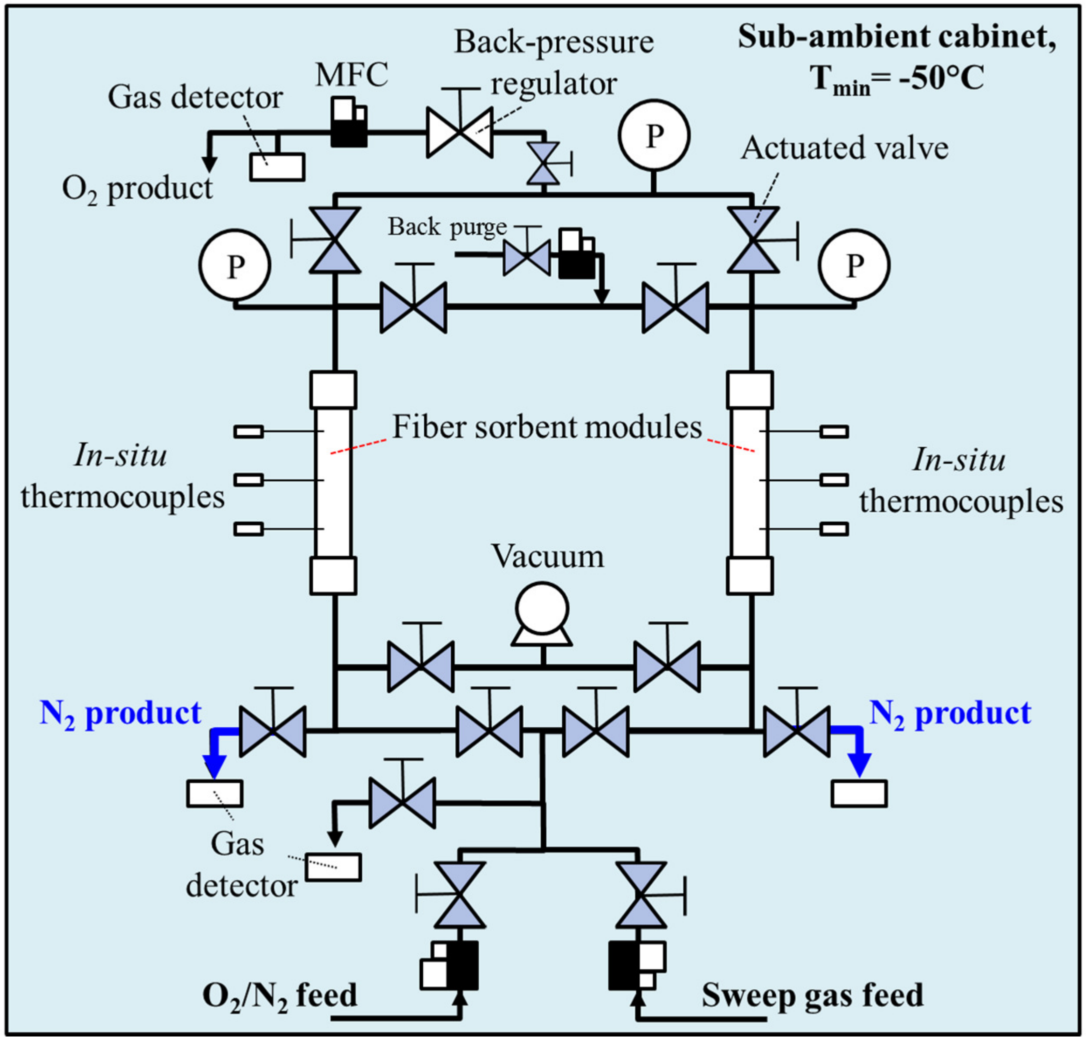
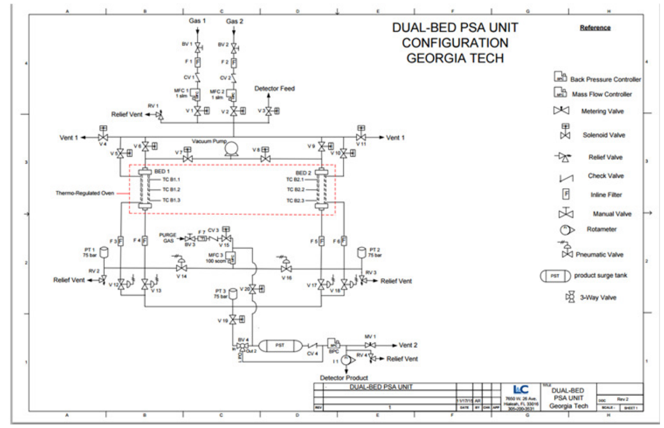
Sub-ambient cyclic PSA unit



Being built by L&C Sci. & Tech.

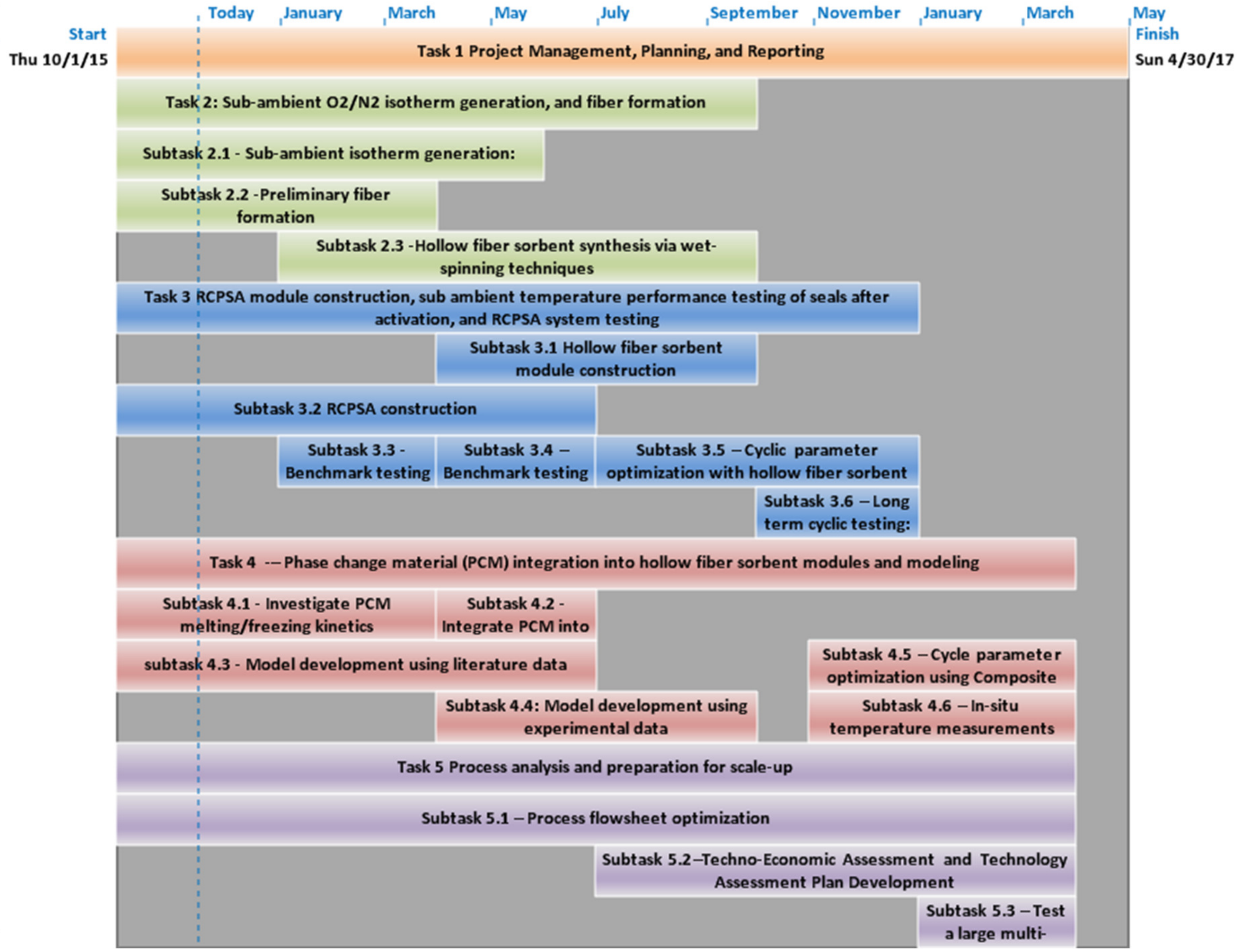


Mass spectrometer (Pfieffer Omnistar) will be purchased for online gas analysis

Project Milestones

Budget Period	Milestone Number	Task/ Subtask Number	Milestone Title/Description	Planned Start Date	Planned Completion Date	Verification Method
1	M-1	1	Updated Project Management Plan	9/1/2015	10/30/2015	DOE Project Manager, PMP plan submitted and filed
1	M-2	1	Kickoff Meeting	12/7/2015	12/7/2015	DOE Project Manager, Clean version of Presentation FIle
1	M-3	2.1	Generate sub-ambient isotherms for O2/N2 in LiX at 10 different temperatures from 100K to 300K	10/1/2015	05/31/2016	Data output - review isotherm graphs
1	M-4	3.1	LiX successfully activated and module seals/barrier layer/polymer support integrity maintained	4/1/2016	6/30/2016	Review of performance measurements after activation
1	M-5	3.5	Cyclic RCPSA experiments using hollow fiber modules	7/1/2016	9/30/2016	Review of performance measurements
1	M-6	4.5	Cyclic RCPSA experiments using phase change material in bore	10/31/2016	1/1/2017	Review of performance measurements
1	M-7	5.1	Optimized process flowsheet	10/1/2015	10/1/2016	Process modeling
1	M-8	5.2	Complete Technoeconomic assessment	7/1/2016	3/31/2017	Process modeling
1	M-9	5.3	Test large (3/8”-1/2” ID, ~20” long, ~100 fiber) modules in RCPSA continuously for 2 weeks	1/1/2017	3/31/2017	Review of performance measurements

Project Timeline



Budget by Quarter

Quarterly Project Cost Profile:
41% Labor
1% Materials, travel
58% Contractual -GT

Baseline Reporting Quarter	Budget Period 1 (10/1/2015 - 03/31/2017)						
	10/1/15 - 12/31/15	01/1/16 - 03/31/16	04/01/16 - 06/30/16	07/01/16 - 09/30/16	10/01/16- 12/31/16	01/01/17 - 3/31/17	Total Budget Period 1
	Q1	Q2	Q3	Q4	Q5	Q6	
Baseline Cost Plan							
Federal Share	$ 182,670	$ 190,411	$ 200,712	$ 232,176	$ 210,553	$ 183,437	$ 1,199,959
Non-Federal Share Praxair Inc.	$ 78,288	$ 81,605	$ 86,019	$ 99,504	$ 90,237	$ 78,616	$ 514,268
Total Planned (Praxair SF424A)	$ 260,958	$ 272,016	$ 286,731	$ 331,680	$ 300,789	$ 262,053	$ 1,714,228
Non-Federal Share, Georgia Tech	$ 3,083	$ 3,083	$ 3,083	$ 3,083	$ 3,083	$ 3,083	$ 18,498
Total Planned w/ GT	$ 264,041	$ 275,099	$ 289,814	$ 334,763	$ 303,872	$ 265,136	$ 1,732,726

Project Spend Continued – Georgia Tech

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58% Contractual – Georgia Tech

Category	Spend	
Labor	$ 398,981	53%
Material (Travel, Supplies + Cost Share)	$ 135,423	18%
Equipment*	$ 220,000	29%
Total Georgia Tech Spend	$ 754,404	

* Mass Spectrometer (80K), L&C automated pressure swing adsorption system (100K). Sub-ambient Cabinet (40K)

Risk Management

Risk Monitoring is continuous. Monthly reviews will address the following

- Risk Identification
  - Identify new risks

- Risks Quantification
  - Validate previous risk assessment (likelihood and impact)
  - Quantify any new risk identified

- Risk Response
  - Avoid the risk.
  - Transfer the risk.
  - Mitigate the risk.
  - Accept the risk.

- Risk Monitoring and Control
  - Identify status of actions to be taken
  - Track Risk Response
  - Evaluate effectiveness of actions taken

Risk Response Plan and Register

Category	Risk Event	Probability	Impact	Overall Risk	Risk Response	Risk Owner	Status
Technical	Barrier layer integrity compromised during zeolite activation	Low	Mod	Moderate	Polyacrylonitrile (PAN) forms a dense "ladder" polymer under high heating, and the barrier properties are improved.	GT	Monitoring
Technical	Support polymer (Torlon®) morphology is lost during zeolite activation	Moderate	High	Moderate	If the Torlon® support loses its morphology during high temperature activation, we will utilize more thermally resistant polyimide supports.	GT	Monitoring
Technical	Failure of sealing for fiber modules	Moderate	Moderate	Low	Specialty epoxies resistant to broad temperature changes will be used to seal modules.	GT	Monitoring
Technical	Phase change material with melting temperature equivalent to optimum operating temperature cannot be found	Low	Low-Moderate	Low	There are several response strategies to this risk: • Change the operating temperature to match the closest melting point of a readily available material. • Investigate liquid (solid) mixtures. • to simply leave out the phase change material—	GT	Monitoring
Resource	Delays in production of LiX by Praxair	Low	High		LiX will be purchased commercially; if there are issues with suppliers, Praxair can synthesize the required quantities of LiX	Praxair	Monitoring
Management	Difficulty in recruiting postdocs at GT	Low	Moderate	Low-moderate	Shift existing GT personnel between tasks to manage temporary vacancies ; all GT PIs have a large backlog of post-doc applications	GT	Monitoring
Management	Lack of synergy among project partners	Low	Moderate		Project partners already have a proven record of collaboration; regular project meetings are scheduled with all partners	Praxair	Monitoring

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Backup Material

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