Oxy-fired Pressurized Fluidized Bed Combustor (Oxy-PFBC)
DE-FE0009448 Kickoff Meeting

Morgantown, WV
October 22, 2012

EAR 99

Agenda

1:00	Introductions by NETL	Fout
1:15	Project Overview	Subbaraman
1:30	Phase I Objectives & Tasks	Mays
1:50	Team Members & Responsibilities	Mays (Lead)
2:10	Risks & Mitigation	Mays
2:25	Phase I Schedule & Deliverables	Follett
2:30	Phase I Budget & Spend Plan	Follett
2:35	Summary	Subbaraman
2:40	Discussions/Action Items	All
3:00	Adjourn	

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Oxy-fired Pressurized Fluidized Bed Combustor (Oxy-PFBC) Overview

Pratt & Whitney
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Description and Impacts

- ***Phase 1 Description***
  - Validate the Oxy-PFBC process with specific process performance and economic models developed by NETL
  - Budget: $1.267M ($1.0M DOE funding)
- ***Impacts***
  - Enable production of electricity from coal with near zero emissions
  - Captured CO_2 may be sequestered at dedicated sites or oilfields for enhanced oil recovery

Goals and Objective

1. **Goals**
   - Capture >90% of CO2 with no more than 35% increase in cost of electricity
2. **Overall Objectives**
   - Enable direct capture of all emissions, including CO2
   - Verify economic feasibility of Oxy-PFBC
   - Mature to TRL 6
3. **Phase I Objectives**
   - Validate performance and plant economics with NETL guidelines
   - Identify technology gaps that need to be closed to reach TRL 6

Commercialization path

- Proof of concept testing / studies (~2 years)
- Pilot plant (~2 years)
- Demo Plant (~4 years)
- Commercial Plant Demo (5-10 years)

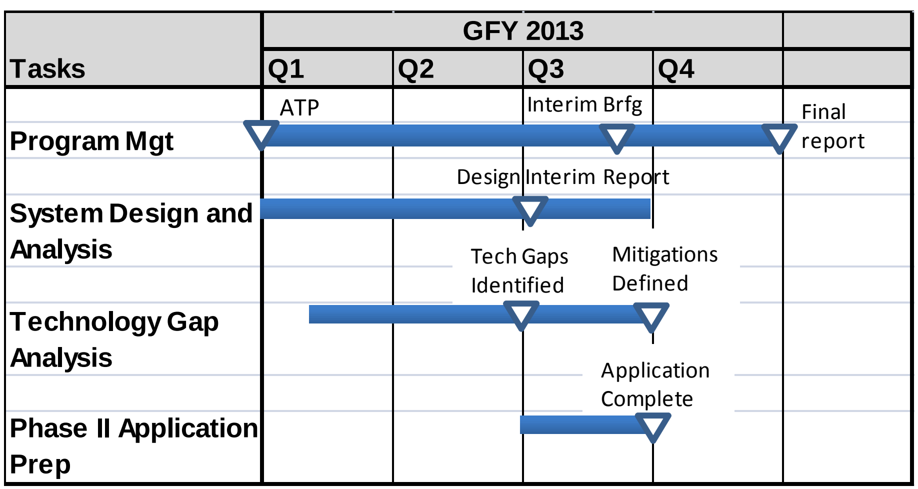
Novel Technologies - Pressurized combustion with O_2 enables:

- High efficiency through staged combustion and reduced O2 use
- Heat recovery from exhaust H_2O vapor for higher efficiency
- Economical carbon capture due to pure pressurized CO2 exhaust stream ready for sequestration

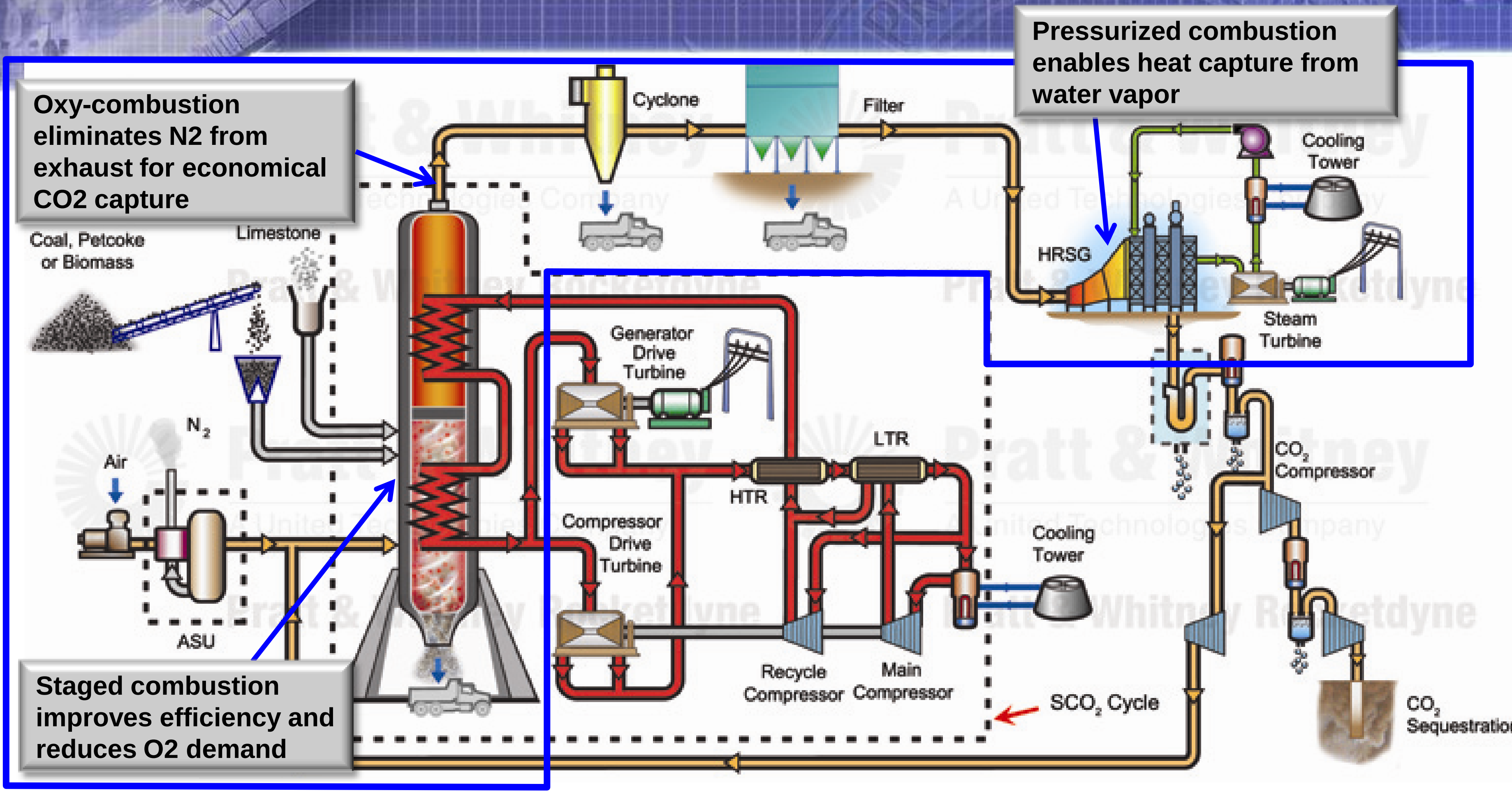
Team members & roles

- Pratt & Whitney Rocketdyne – Lead, PFBC technology
- Linde, LLC – Gas supply, CPU technology, HEX design, EPC
- Pennsylvania State University – Sorbent reaction risk mitigation, fluidized bed design support
- Electric Power Research Institute – End user insight, technology gap assessment, cost modeling
- Jamestown Board of Public Utilities – End user insight, demo site

Schedule



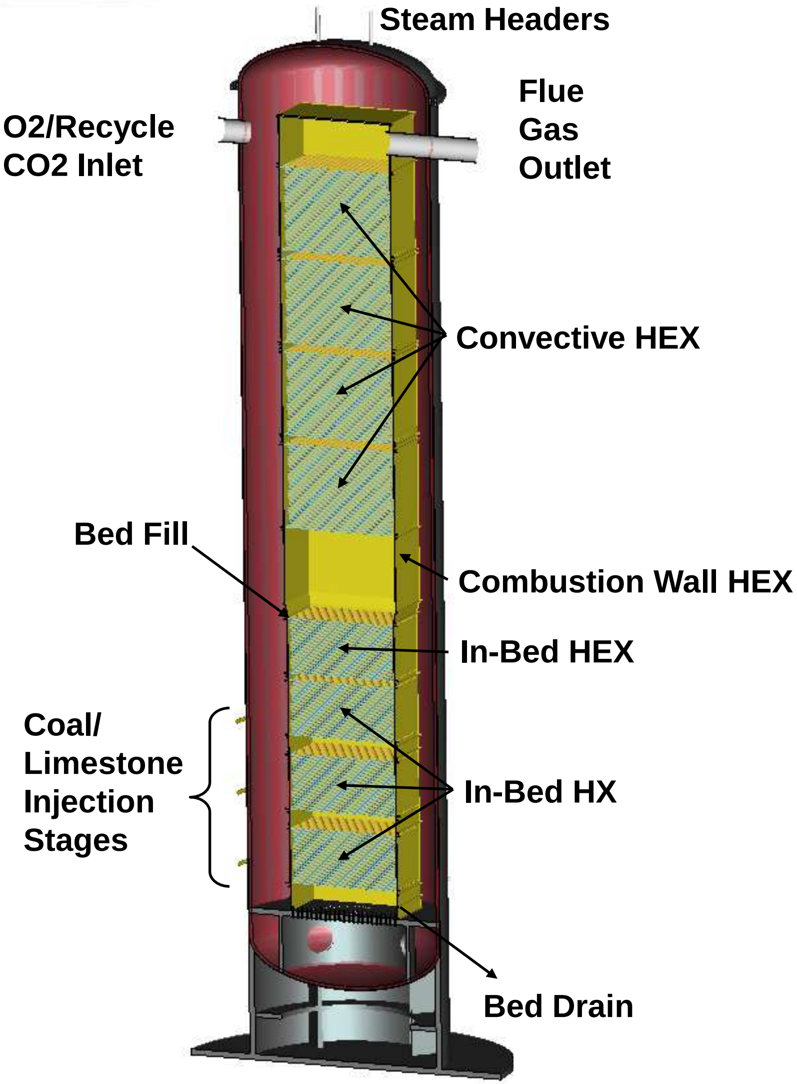
ZEPS™ Powerplant Concept

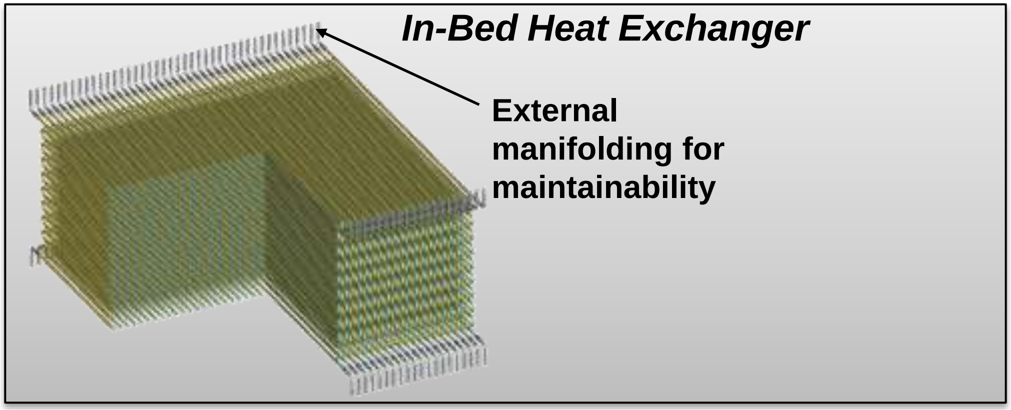


This program's focus

Enhanced efficiency and zero emissions
- **Program focused on Oxy-PFBC with steam-Rankine cycle**
- **Supercritical CO2 Brayton can be utilized for added efficiency**

Oxy-PFBC Layout



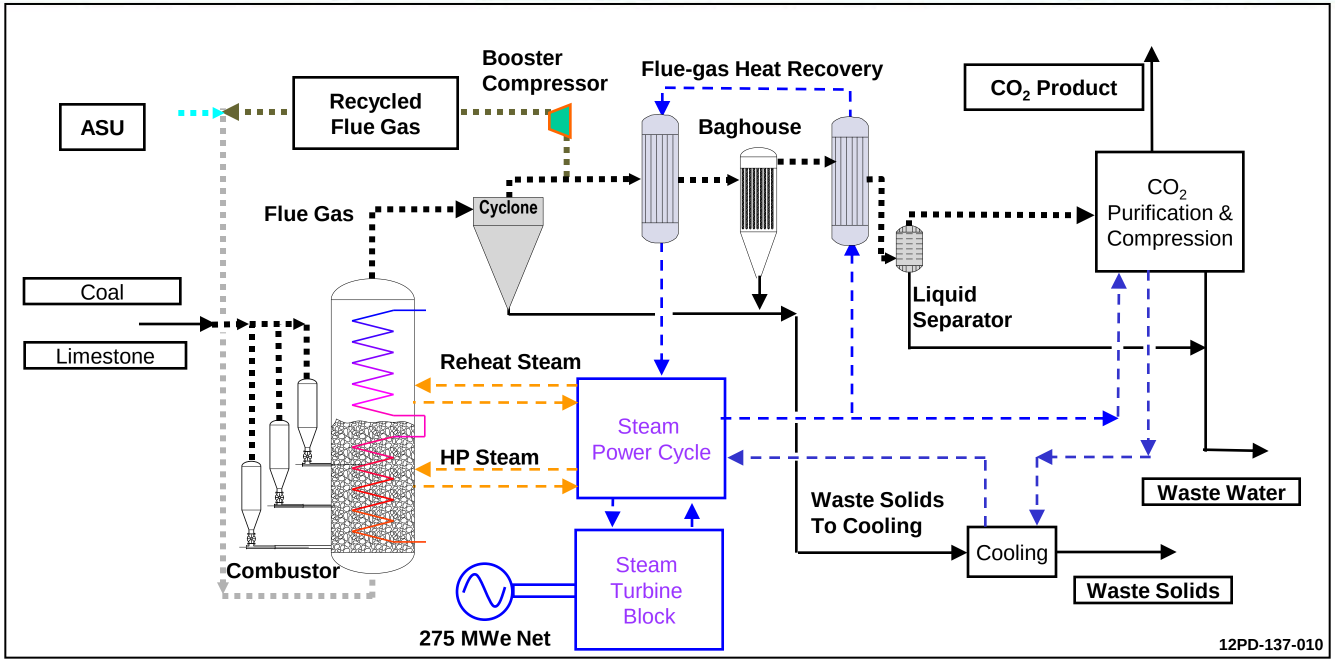


Oxy-PFBC Predicted Performance

	Air-Fired SCPC without CO_2 Capture	Oxy-Fired Atmospheric SCPC	PWR Oxy-PFBC
Heat Input, MWth	1,396	1,878	1,662
Gross Power, Steam Turbine, MW	580	787	739
Total Auxiliary Loads, MWe	30	232	189
Net Power Output, MWe	550	555	550
Net HHV Efficiency, %	39.4	29.5	33.1
Carbon capture (>90% is DOE Objective)	0%	90%	98%
Increase in COE relative to SCPC w/o carbon capture (<35% is DOE Objective)	Baseline	50%	30%
	DOE/NETL-2007/1291 Case 1	DOE/NETL-2007/1291 Case 5a	

- **PWR Oxy-PFBC preliminary performance predicted to exceed DOE objectives**
  - Provides 98% carbon capture (goal of >90%)
  - LCOE increased by less than 30% (goal of <35%)
- **Phase I objective includes validation with NETL guidelines**

Oxy-PFBC Key Features



Efficiency Enhancement

- Staged combustion with elutriation – Reduces O2 consumption, with high sulfur capture
- Oxy combustion – Reduces energy required for CO_2 purification
- Pressurized – Reduces CO2 compression required for sequestration

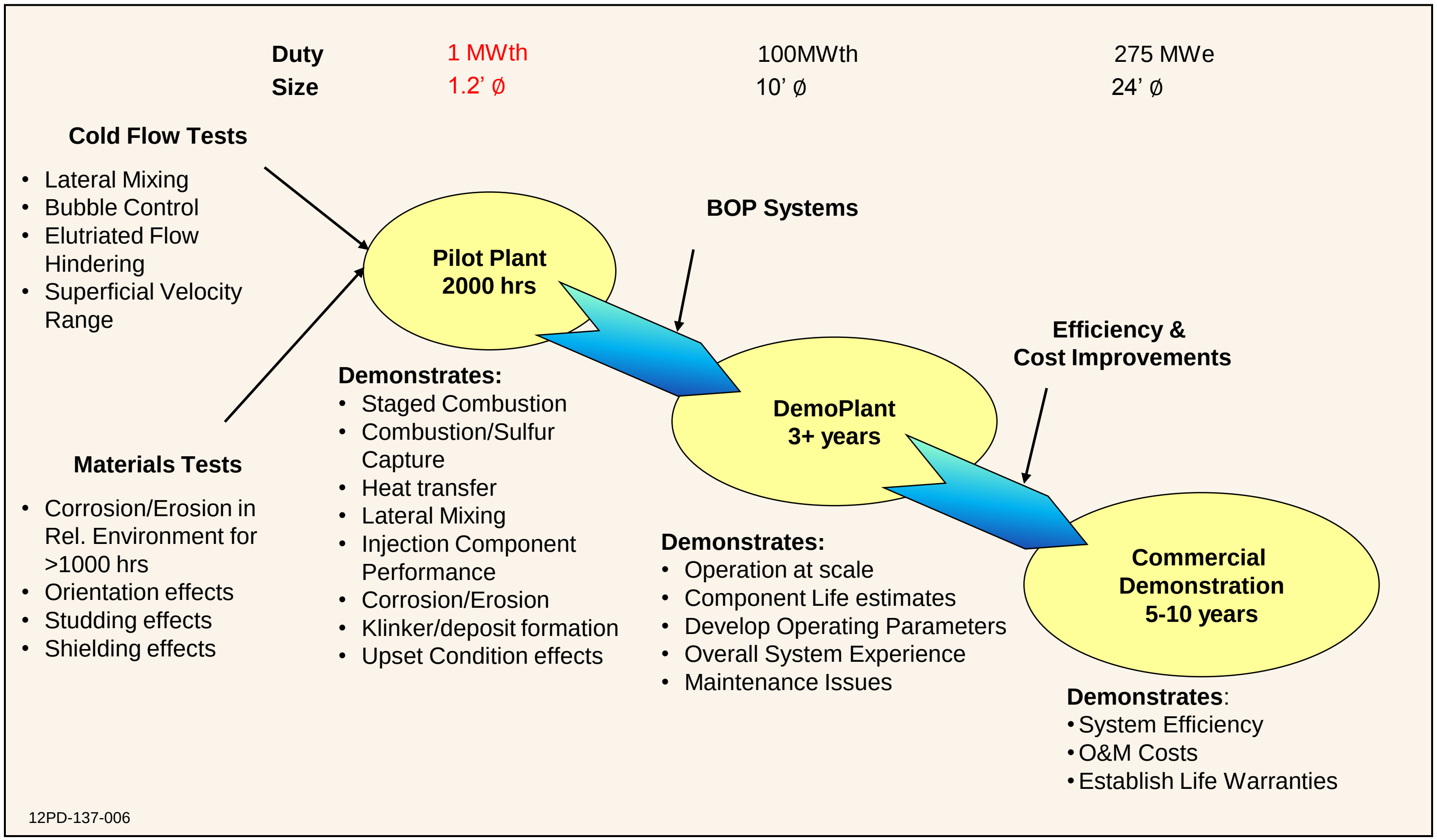
Cost Reductions

- PFBC – More compact combustor with lower Capex
- Simpler, lower-cost CPU
- Elimination of FGD (Potentially)

Changes Since Proposal

- **Pilot Size reduced from 4-6 MWth to 1MWth**
- **Specific testing identified for Penn State**
  - Address new risk item (below) with testing and analysis
- **New Risk Identified**
- **Re-evaluated In-bed Heat Exchanger (IHX) risk**
- **Initiated discussions with additional partners for Phase II**
  - Consol (Pilot Testing)
  - Tata Power (Commercialization)
  - Others

Commercialization Plan



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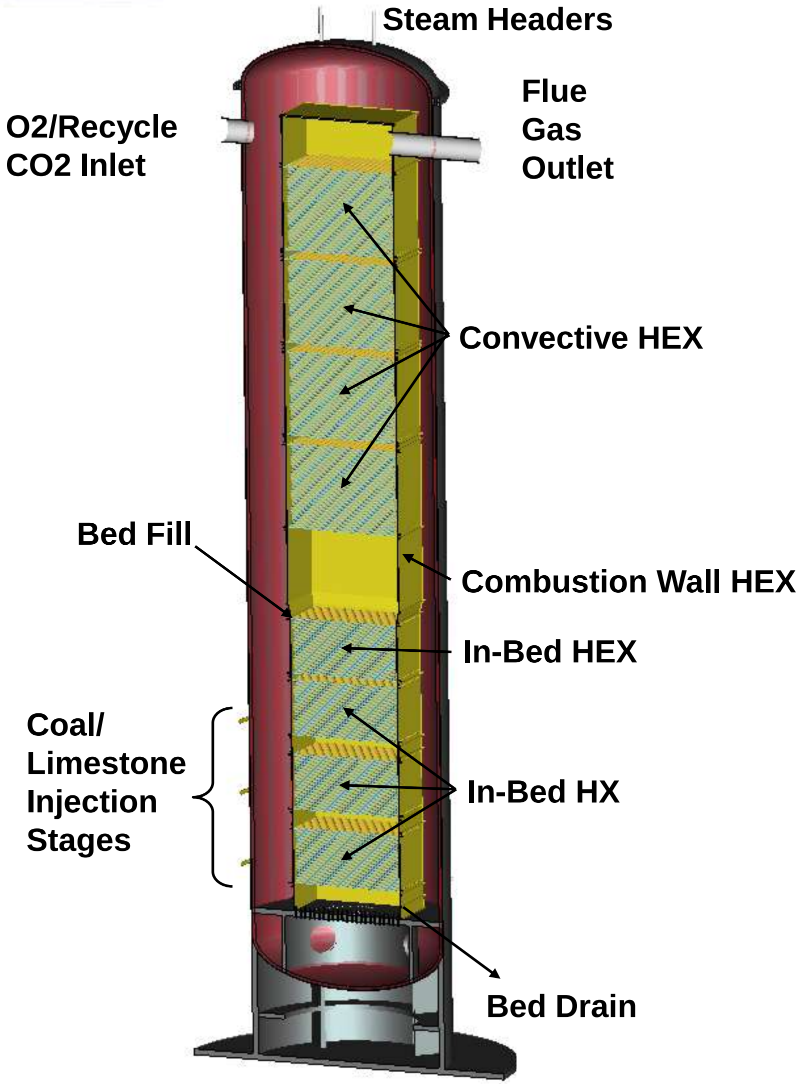

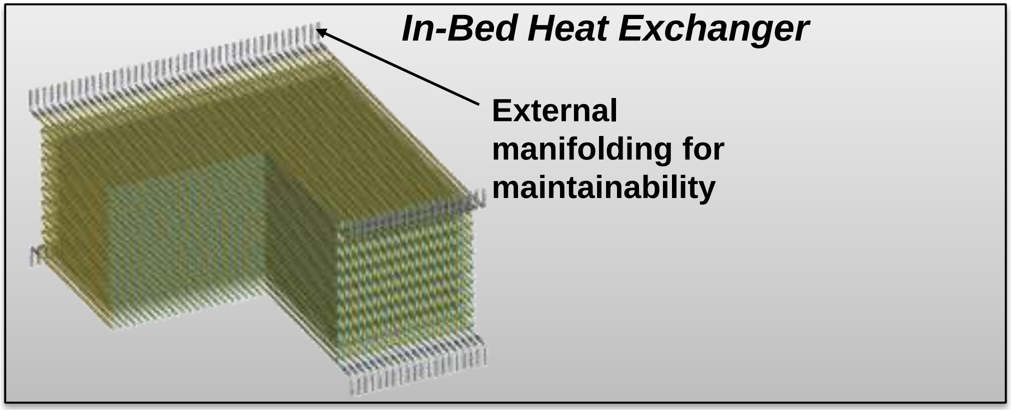

Phase 1 Objectives

- Validate System Performance of Oxy-PFBC with steam-Rankine system using standardized tools (ASPEN) and specified guidelines
  - Baseline Performance – DOE/NETL-2010/1397, Rev 2
  - Process Simulation – DOE/NETL-341/081911
  - Feedstock Baseline – DOE/NETL-341/011812
  - CO2 Impurity Baseline – DOE/NETL-341/011212
- Validate plant economics of Oxy-PFBC system using standardized tools and compare with established baseline
  - Baseline Costs – DOE/NETL-2010/1397, Rev 2 & 341/082312
  - Cost Methodology – DOE/NETL-2011/1455
- Perform Technology Risk Assessment per Attachment E of DE-FE0000636
  - Identify Technology Gaps
  - Plan/execute near term risk mitigation
- Finalize business agreements with team members
- Complete Phase II application

Phase 1 Tasks

WBS #	WBS Level	WBS Title	Phase 1 Deliverables
1.0	Task	Project Management and Planning	Project Management Plan (and updates) Phase 1 Topical Report
1.1	Subtask	Project Monitoring and Control	
1.2	Subtask	NEPA Documentation	
1.3	Subtask	Briefings, Periodic Reports and Conference Attendance	
2.0	Task	System Design and Analysis	Technology Engineering Design Basis Report Technology Engineering Design Interim Report Final Phase 1 Technology Engineering Design and Economic Analysis Report
2.1	Subtask	Design Basis Definition	
2.2	Subtask	System Performance Analysis	
2.3	Subtask	Economic Performance Analysis	
3.0	Task	Technology Gap Analysis	Final Phase 1 Technology Gap Analysis
3.1	Subtask	Technology Gap Identification	
3.2	Subtask	Risk Mitigation and Pilot Plant Planning	
4.0	Task	Phase II Application Preparation	Phase II Application
4.1	Subtask	Technical Narrative	
4.2	Subtask	Budget Justification	
4.3	Subtask	Partner and Subcontractor Support	

Task 1.0 – Project Mgt and Planning

- Ensure coordination and planning of the project with DOE/NETL and other project participants, including the monitoring and controlling of project scope, cost, schedule, and risk, and the submission and approval of required NEPA documentation.
- Maintain and revise the Project Management Plan, and provide periodic reports on activities in accordance with the Federal Assistance reporting Checklist attached to the plan.
- Prepare detailed briefings for presentation to the Project Officer at the Project Officer's facility located in Pittsburgh, PA or Morgantown, WV
  - ✓ Project kick-off meeting held within 45 days of project start date
  - Project status briefing held no more than 30 days before submittal of the final report
- Provide Interim Report 6 months after award
- Complete one presentation at a National Conference - TBD

Task 2.0 – System Design and Analysis

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Due End of October

- Develop a Design Basis Document that describes the approach to be taken to perform the system study, including definition of the cases to be studied and the assumptions to be made for the process and economic performance analyses. Two cases are included in the proposal baseline - 275MWe New Supercritical Steam plant, and a >275MWe steam plant retrofit.

Due 6/29/13

- Complete Configuration Definition and System Performance analysis for the cases identified in the Design Basis Document using AspenPlus per NETL report, “QGESS: Process Modeling Design Parameters”, and complete Economic performance analysis per NETL report, “QGESS: Cost Estimation Methodology for NETL Assessments of Power Plant Performance”. Document results in an Interim and a Final Design and Economic report per FOA DE-FE0000636 Attachment A requirements. Deliver all process simulations and economic models with brief descriptions of modeling approaches to DOE.

Task 3.0 – Technology Gap Analysis

Due 6/29/13

- Complete an analysis of the current state of development of all the major/critical process components for the proposed technology, identify the research needs required to fully develop the technology to commercialization, and show how the proposed Phase II efforts along with any research and development efforts required (or ongoing) outside of the Phase II proposal will aid in the development of the proposed technology.

Task 4.0 – Phase II Application Preparation

- Deliver a Phase II project application per the requirements of DE-FE0000636 Attachment F that proposes efforts focused on the development and testing of:
- Novel process components at the laboratory/bench/pilot scale prior to scale up to a fully integrated system
- Bench/pilot scale integrated systems

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Team Members & Responsibilities

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A United Technologies Company

Organization	Role/Responsibility
Pratt & Whitney A United Technologies Company Pratt & Whitney Rocketdyne, Inc.	• Project lead & PFBC technology • Process & system engineering • Risk mitigation & pilot test planning
Linde	• Gas supply and clean-up systems • PFBC Heat exchanger design support
PENNSTATE	• Fluidized bed design support • Sorbent reaction risk mitigation
JAMESTOWN bpu	• Field demonstration unit site • Engineering support & review
EPRI ELECTRIC POWER RESEARCH INSTITUTE	• Voice of the end-user • Review of process and cost modeling

WBS #	WBS Title	Scope Summary	PWR	Linde	JRPU	PSU	EPRI
1.0	Project Management and Planning						
1.1	Project Monitoring and Control	Ensure project coordination and planning with DOE/NETL and participants (project scope, cost, schedule, and risk).	X				
1.2	NEPA Documentation	Submission and approval of any NEPA documentation required for Phase II testing	X			X	
1.3	Briefings, Periodic Reports and Conference Attendance	Provide periodic reports, detailed briefings, a project status briefing, and submittal of the final report on activities. Complete one conference presentation.	X	X	X	X	X
2.0	System Design and Analysis						
2.1	Design Basis Definition (DBD)	Define the cases to be studied and the assumptions to be made for process and economic performance analyses. Two cases for the proposal baseline are - 550MWe New Supercritical Steam plant, >275MWe plant retrofit.	X	X			X
2.2	System Performance Analysis	Complete system performance analyses for the cases identified in the DBD using AspenPlus per NETL report, "QGESS: Process Modeling Design Parameters",	X	X			X
2.3	Economic Performance Analysis	Complete economic performance analysis per NETL report, "QGESS: Cost Estimation Methodology for NETL Assessments of Power Plant Performance".	X	X			X
3.0	Technology Gap Analysis						
3.1	Technology Gap Identification	Complete an analysis of the current state of development of all the major/critical process components.	X	X		X	X
3.2	Risk Mitigation and Pilot Plant Planning	Identify the research needs required to fully develop the technology to commercialization.	X	X	X	X	X
4.0	Phase II Application Preparation						
4.1	Technical Narrative	Deliver a Phase II project application per the requirements of DE-FE0000636 Attachment F that is focused on the development and testing of: • Novel process components at the laboratory/bench/ pilot scale prior to scale up to a fully integrated system • Bench/pilot scale integrated systems	X				
4.2	Budget Justification		X				
4.3	Partner and Subcontractor Support			X	X	X	X

Lead - X

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PWR

- **Roles and Responsibilities**
  - Overall project lead
  - PFBC technology provider
  - Lead for System Design and Analysis, Phase II Application
- **Previous Experience**
  - Operational H_2 generator field demonstration unit (Current)
    - Fluidized bed and chemical looping operating above atmospheric pressure, and experience with oxy-fired systems
  - PWR’s Compact Gasifier System, and the Dry Solids Pump programs supported by PWR, federal and state/provincial governments and private sectors (Current)
  - Fluidized bed design, analyses, and qualifying components (e.g., In-bed Heat Exchangers) for commercial operation through a DOE-sponsored test program (1980 -1989)
- **Strategic Fit**
  - The Oxy-PFBC fits within PWR’s 50 year legacy of advanced energy production systems and supports PWR’s continued thrust in the clean fossil energy sector
- **Unique qualifications**
  - 50 years experience in advanced technology development for energy and propulsion
  - Relevant core capabilities: Advanced combustion with oxygen, fluidized beds, coal combustion, heat exchangers, sophisticated analysis and design, advanced technology development

The Linde Group

- **Roles and Responsibilities**
  - Jointly define design basis of the proposed oxyfuel system
  - Lead economic analysis and support the integrated system performance, with a focus on:
    - Flue gas processing (with Linde's LiCONOx® technology)
    - Heat exchanger (HEX) design support (i.e. condensing HEX based on Linde's Coil Wound technology)
    - Oxygen supply and optimization/integration of air separation unit (ASU)
  - Critically review technical gaps based on EPC experiences
  - Jointly prepare for Phase II pilot project application
- **Previous Experience**
  - Commercial scale aMDEA based CO2 capture from natural gas, Hammerfest, Norway
  - Pilot scale CO2 processing and DeNOx system for Oxyfuel, Schwarze Pumpe, DE
  - Pilot scale advanced solvent based PCC demo, Niederaussem, DE
  - Ongoing DOE sponsored pilot scale PCC demo, Wilsonville, AL
  - Development of novel integrated oxygen supply technology for oxyfuel (DOE funded project)
- **Strategic Fit**
  - Leading industrial gas supplier and engineering firm with global footprint
  - Strong corporate commitment to Clean Energy technology development and commercialization
- **Unique qualifications**
  - Over 130 years of experiences in engineering and technology innovation
  - Unique combination of industrial gas supply business and engineering capability

The Pennsylvania State University

- **Roles and Responsibilities**
  - Sorbent reaction risk mitigation
    - *Review literature and identify technology gaps*
    - *Develop a technology maturation roadmap to close identified gaps.*
    - *Conduct necessary early analyses and/or tests, if feasible during Phase I that may be further refined during Phase 2.*
    - Support in Fluidized bed Design
- **Previous Experience**
    - PSU conducted the largest and most extensive study in a laboratory and at a full scale operating CFB boiler in identifying factors that control sulfur capture characteristics of limestones and dolostones in1990s and worked with several industries in this area.
    - Produced more than half a dozen theses (PH.D. and M.S.) in the area of sulfur capture and attrition mechanisms of limestones in CFB boilers including a study on sulfur capture by limestones at high pressures.
- **Strategic Fit**
    - Sorbent performance is a key component in the demonstration and development of *Pratt & Whitney Rocketdyne's (PWR's) Pressurized Fluidized bed Combustor (PFBC) concept.*
- **Unique qualifications**
    - With PSU's proven record with several scientific papers in this area and current activity understanding of the mechanisms and models, it is uniquely positioned in this partnership

Electric Power Research Institute

- **Roles and Responsibilities**
  - Voice of the end-user
  - Review of process and cost modeling
  - Technology gap analysis
- **Previous Experience**
  - Extensive utility-scale fluidized bed boiler field monitoring experience – bubbling and circulating beds.
  - Monitoring and operations of a pressurized coal combustor/gasifier at the US Department of Energy-funded Pressurized Systems Development Facility (PSDF) in Wilsonville, Alabama.
  - Numerous engineering and economic evaluations of utility power plant efficiency improvement technologies.
  - EPRI and PWR have ongoing projects since 2010 on ZEPS related R&D
- **Strategic Fit**
  - EPRI has routine dealings with electric utilities who are candidates for deploying pressurized oxy-coal technology and can bring the technology to these utilities.
  - EPRI personnel bring unique field experience with utility-scale fluidized bed combustion at both atmospheric pressure and elevated pressure.
- **Unique qualifications**
  - Significant direct experience in coal-fired power plant operations and maintenance.
  - On-going access to domestic US and worldwide coal-burning electric utilities and those contemplating coal-fired power plants.
  - Operations and monitoring at the AEP Tidd PFBC project in the 1990s; experience directly relevant to PWR's pressurized oxy-FBC technology.

Jamestown BPU

- **Roles and Responsibilities**
  - Planned host site for the Pratt & Whitney Rocketdyne PFBC technology
  - Predict the economic feasibility of the project as it relates to a power producer

- **Previous Experience**
  - Have operated coal-fired power plants for nearly 100 years
  - Have operated natural gas combined cycle power plant for nearly 15 years
  - Participated in CCP I-3 in pursuing a 50MWe Oxy-Coal CFB Project

- **Strategic Fit**
  - The Oxy-Fired PFBC fits within Jamestown Board of Public Utilities needs as an alternative 15-25 MW power producing facility
  - Plan for initiating 15-25 MWe retrofit by 2015 with operation beginning no later than 2019

- **Unique qualifications**
  - Local Business Foundation, Political, and Customer support for advanced clean coal technology project to be implemented within its community

  - Municipal Utility with electric generation experience; coal and natural gas power plant currently in operation

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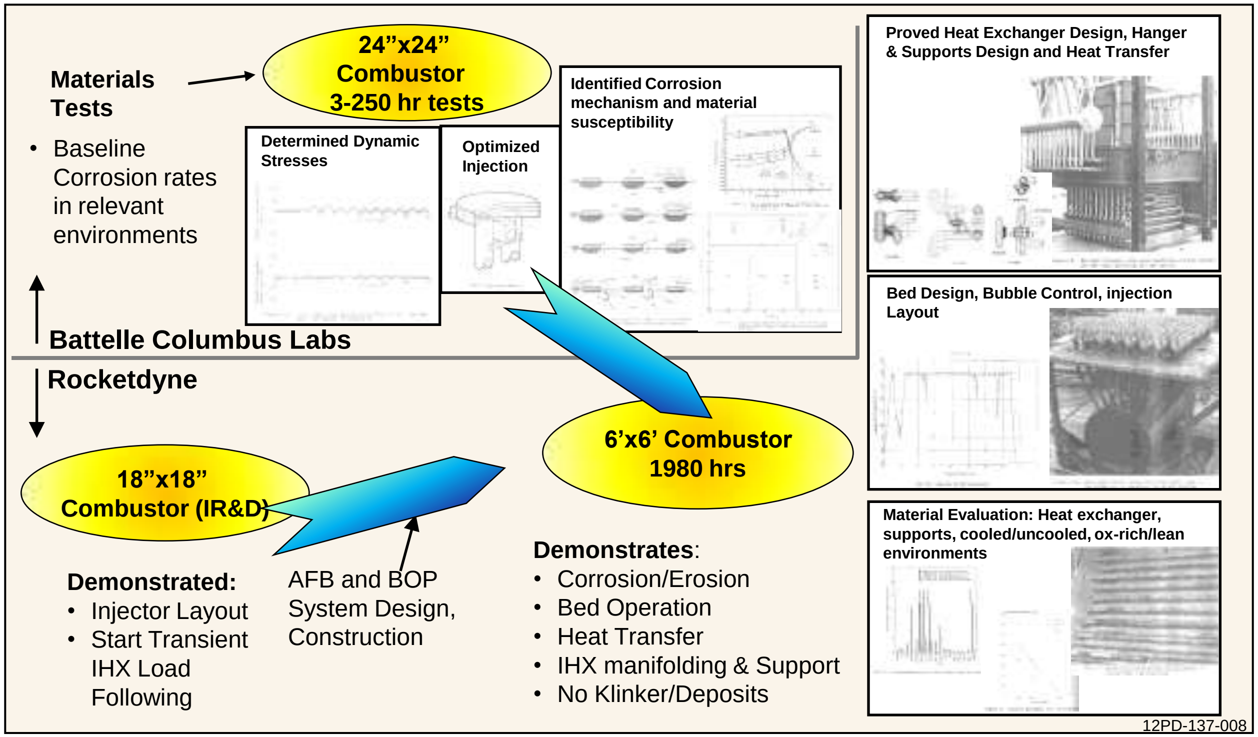
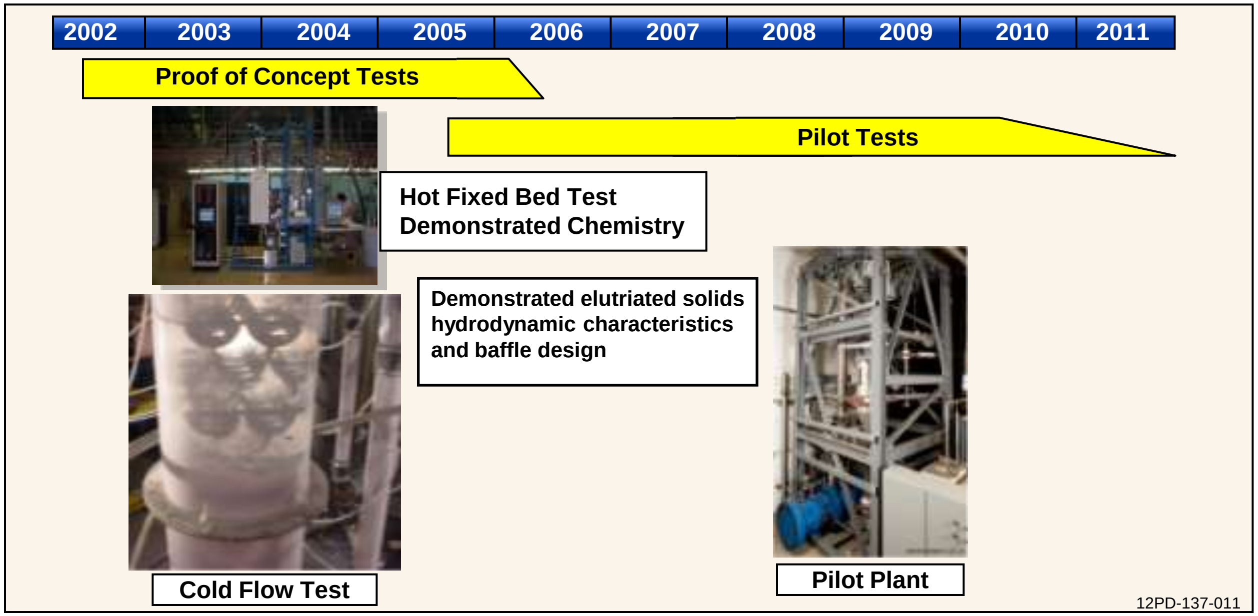
Risk Mitigation- Relevant Experience



Atmospheric Fluidized Bed (AFB) Project Provided Evaluation of IHX materials & Fluidized Bed Combustor Design

Risk Mitigation- Relevant Experience



Hydrogen Generator Broke Ground on Elutriated Bubbling Bed Operation and Identified Design Parameters

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Phase 1 Schedule

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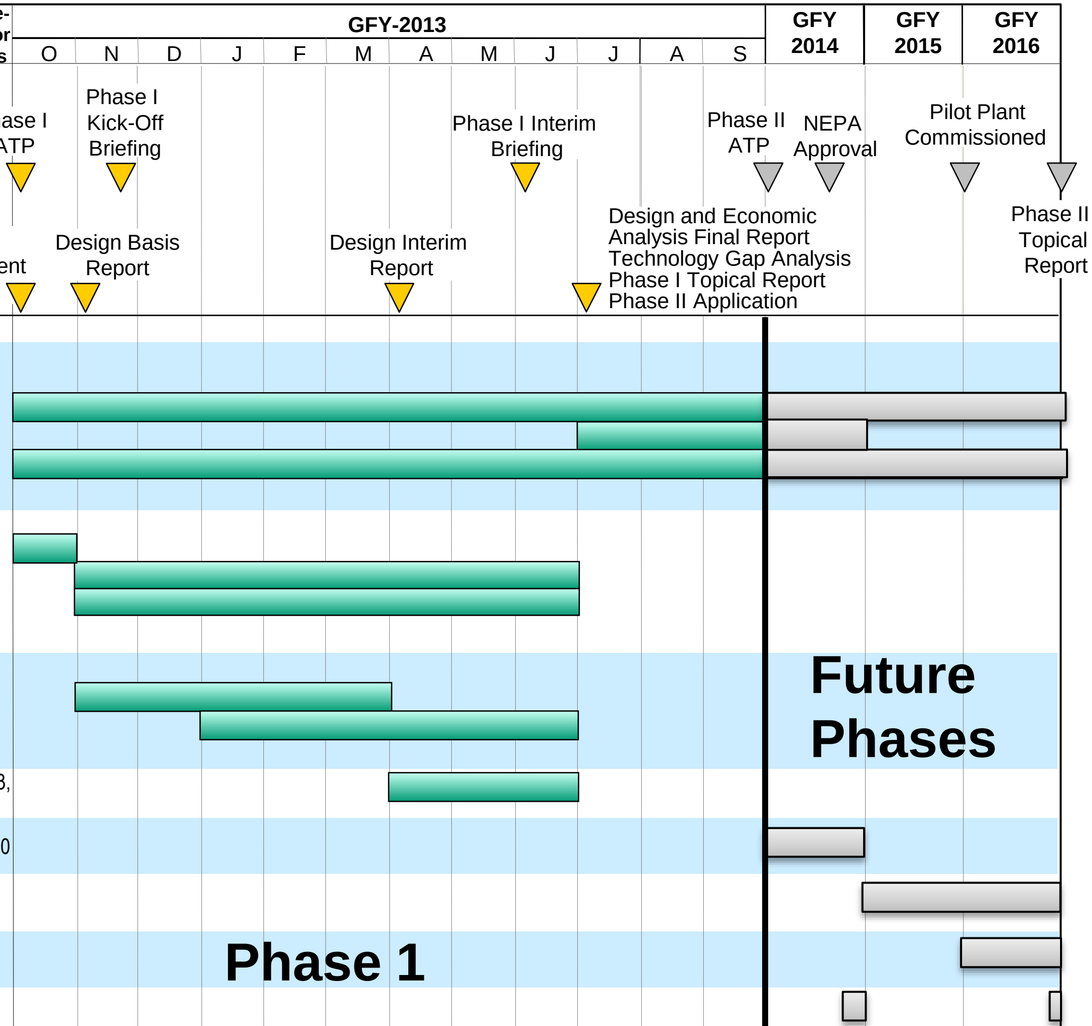
Phase 1 Deliverables	Start Date	End Date	Total Cost	Predecessor Tasks
1.0 Project Management and Planning				
1.1 Project Monitoring and Control	10/1/12	9/30/16	$114K	
1.2 NEPA Documentation	7/1/13	3/31/14	$9K	3.2
1.3 Briefings, Reports & Conferences	10/1/12	9/30/16	$65K	
2.0 System Design and Analysis				
2.1 Design Basis Definition	10/1/12	10/31/12	$467K	
2.2 System Performance Analysis	11/1/12	6/30/13	$133K	2.1
2.3 Economic Performance Analysis	11/1/12	6/30/13	$36K	2.1
3.0 Technology Gap Analysis				
3.1 Technology Gap Identification	11/1/12	3/31/13	$156K	2.1
3.2 Risk Mitigation &Pilot Plant Planning	1/1/13	6/30/13	$97K	3.1
4.0 Phase II Application Preparation	4/1/13	6/30/13	$97K	2.2,2.3, 3.2
5.0 Component Risk Mitigation	10/1/13	9/30/14	tbd	3.2, 4.0
6.0 Pilot Plant	7/1/14	9/30/16	tbd	5.0
7.0 Field Demonstration Planning	4/1/15	9/30/16	tbd	5.0
8.0 Commercialization Plan	4/1/14	9/30/16	tbd	3.2

Project Milestones



Phase 1 Deliverables

- Technology Engineering Design Basis Report (due October 31, 2012)
- Technology Engineering Design Interim Report (due March 31, 2013)
- Final Phase I Technology Engineering Design and Economic Analysis Report (due with Phase II application by June 29, 2013)
- Final Phase I Technology Gap Analysis (due with Phase II application by June 29, 2013)
- Quarterly Progress reports (December 31, 2012; March 31, 2013;June 30, 2013)
- Final report (9/30/2013)

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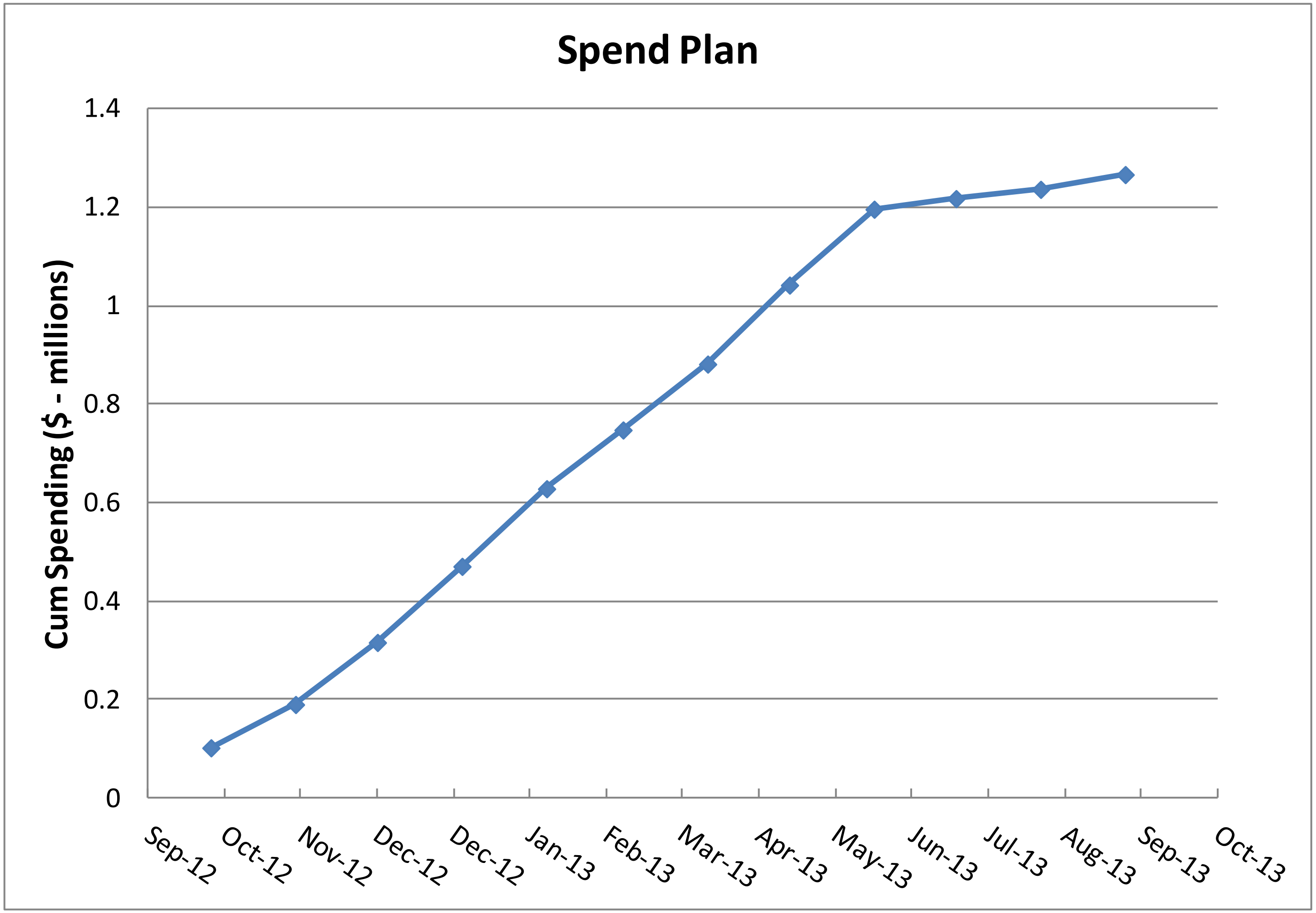
Budget


Spend Plan
Cum Spending ($ - millions)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Sep-12
Oct-12
Nov-12
Dec-12
Dec-12
Jan-13
Feb-13
Mar-13
Apr-13
May-13
Jun-13
Jul-13
Aug-13
Sep-13
Oct-13

Cost Share Plan

Quarter	Government Funding ($)	Cost share funding					
		Total	PWR	Linde	EPRI	JBPU	Penn State
Total	1,000,000	267,070	171,891	62,654	12,500	7,500	12,525
1	249,456	66,622	42,834	15,663	3,125	1,875	3,125
2	340,485	90,933	57,629	21,929	4,375	2,625	4,375
3	354,189	94,593	61,289	21,929	4,375	2,625	4,375
4	55,870	14,921	10,138	3,133	625	375	650

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Summary

- Power generation based on Oxy-PFBC technology shows significant potential to meet DOE goals for CO2 capture and LCOE
  - CO2 Capture: 98% (vs. 90% DOE goal)
  - LCOE increase: <30% (vs. <35% DOE goal)

- PWR Team has the breadth of capabilities to assess and mature technology during Phase 1 and beyond
  - Multiple commercialization opportunities being defined

- Team has initiated Phase 1 work with updates to technology and gaps based on insights from operating air-fired PFBC plants
  - Discussions initiated with Consol towards Phase 2 efforts

- Team looks forward to continued partnership with DOE upon validating Oxy-PFBC performance and economics

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3:00	Adjourn	