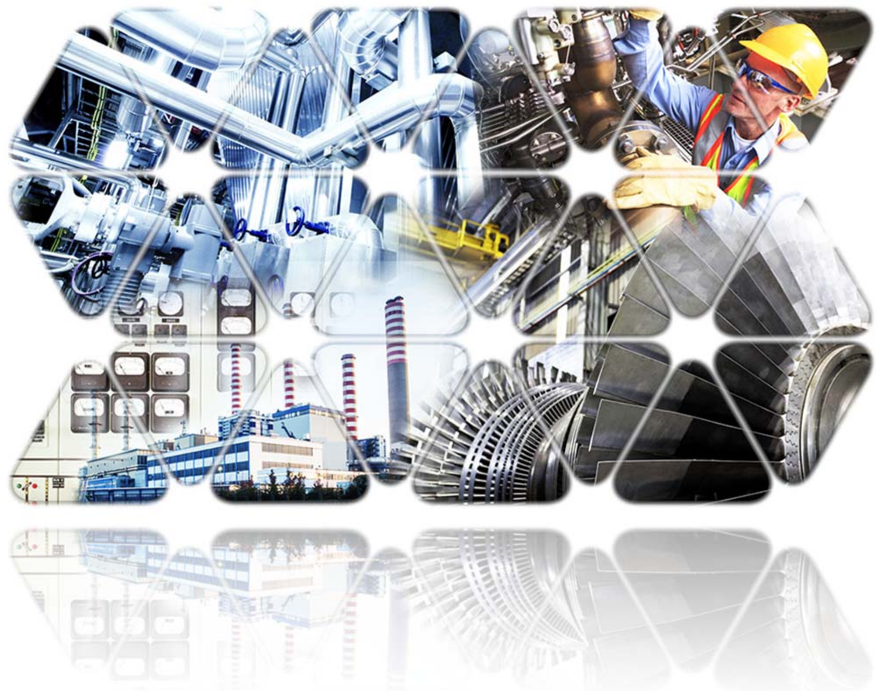
High-Efficiency Thermal Integration of Closed Supercritical CO_2 Brayton Power Cycles with Oxy-Fired Heaters



Andrew Maxson and David Thimsen
Electric Power Research Institute

Advanced Combustion Systems Kickoff Meeting Webcast
October 22, 2015

Agenda

- Background
- Technical Approach
- Project Objectives
- Project Structure
- Project Management Plan, including Risk Management
- Project Schedule
- Project Deliverables

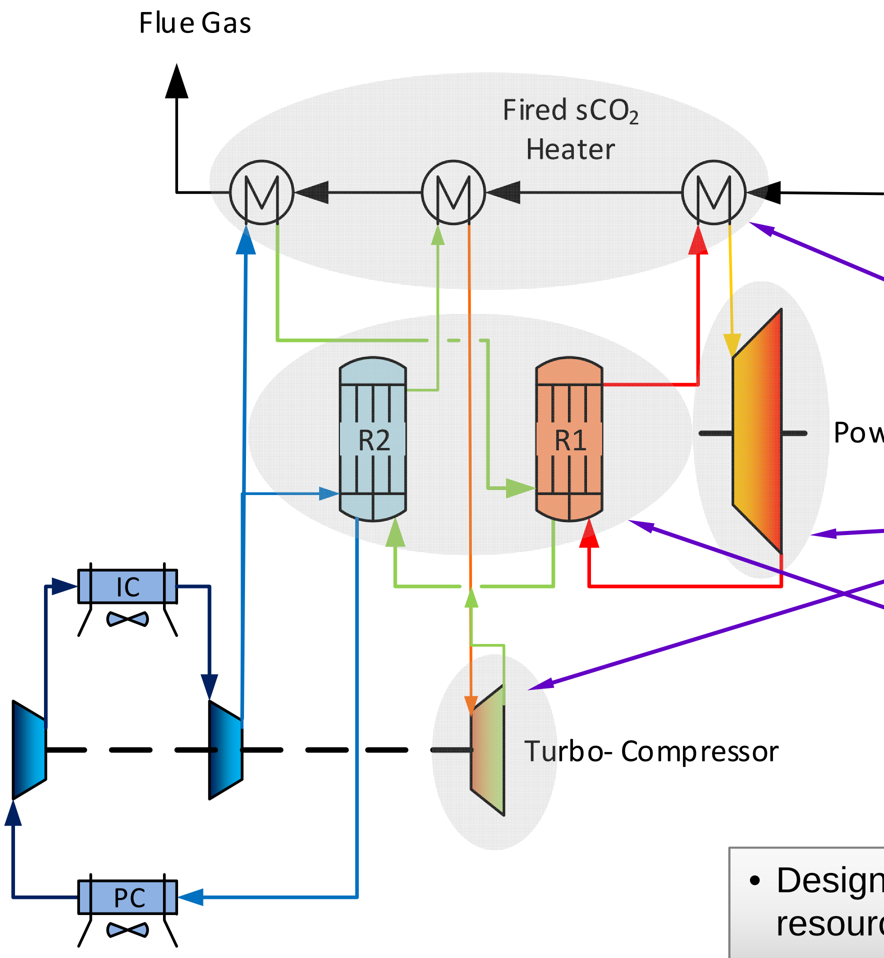
Background

- Increasing efficiency of coal power is critical for reducing costs as well as minimizing associated CO_2 emissions
- Replacing the steam-Rankine cycle in coal-fired power plants with a closed Brayton power cycle using supercritical CO_2 (SCO_2) as the working fluid has the potential to increase efficiency by 3–5% points
- Coupling SCO_2 Brayton cycles with oxy-combustion further has the potential to capture CO_2 economically

Technical Approach

- Cascaded and recompression SCO_2 Brayton cycle structures have been studied. Thermal integration with the coal-fired heater will be different for each structure.
- **Cascaded SCO_2 Brayton Cycles:** Focus is on thermally integrating medium-temperature heat (>380°C) into the power cycle so that conventional (recycle) air heaters (AHs) can be used
- **Recompression SCO_2 Brayton Cycles:** Achieving high plant efficiency will require incorporation of a very high-temperature (>500°C) AH with the fired heater and deployment of very high-temperature air handling/combustion equipment

Cascaded Closed SCO_2 Brayton Cycle

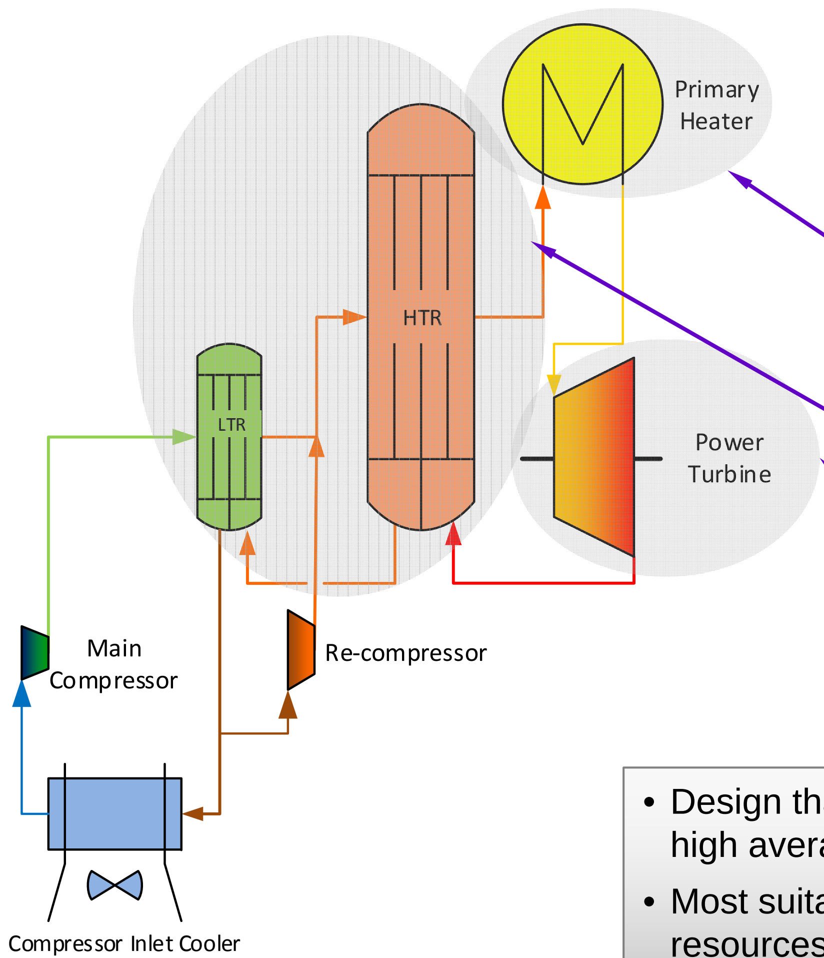


Critical Components Requiring Development

- sCO_2-fired Heater
- sCO_2 Turbine(s)
- Recuperators

- Design that can exploit "waste" heat thermal resources
- Most suitable for fossil-fired thermal resources in the short term

Recompression Closed SCO_2 Brayton Power Cycle



Critical Components Requiring Development

- sCO_2-fired Heater
- Recuperator
- sCO_2 Turbine

- Design that maximizes cycle efficiency; heat is added at a high average temperature
- Most suitable for concentrating solar and nuclear thermal resources
- May be suitable for fossil-fired thermal resources but requires a high-temp AH

Project Objectives

- **Process Designs and Performance:**
  - Develop process designs for test cases that optimally integrate candidate closed Brayton power cycles using SCO_2 as the working fluid with oxy/coal-fired SCO_2 heaters for comparison with relevant DOE/NETL baseline cases employing steam-Rankine power cycles. The primary optimization parameter will be net plant efficiency.
  - Identify technology gaps in the SCO_2 Brayton power cycle plants that can be closed by future R&D
- **Cost Estimates:**
  - Develop Association for the Advancement of Cost Engineering (AACE) Class-5 cost estimates for the SCO_2 Brayton cycle power plants for comparison with relevant DOE/NETL and other baseline case capital costs and associated levelized cost of electricity (LCOE)/first-year power costs
- **Review and Update Designs:**
  - Identify opportunities to optimize (minimize) LCOE/first-year power costs by changes to plant design with associated re-estimates of capital costs
  - Identify high-cost components whose cost might be reduced by focused R&D

Project Task Descriptions

- **Task 1 – Project Management and Planning**

Budget Period 1

- **Task 2 – Develop Power Block Design Basis and Baseline:**
  - Develop the design basis and identify baseline plant designs for 550 MWe net and 55 MWe net pulverized-coal (PC) cases
  - Selection of multiple SCO_2 Brayton cycle test cases, parameters including:
    - Turbine inlet temperature (600ºC, 760ºC)
    - Oxy-combustion technology (atmospheric pressure PC and chemical looping combustion [CLC])
    - SCO_2 Brayton cycle architecture (cascaded vs. recompression with a high-temperature AH)
- **Task 3 – Optimize Thermal Integration between Fired Heater and Power Cycle:**
  - Develop flow sheets for the cases identified in Task 2 that integrate the fired heater and the SCO_2 Brayton cycle to maximize efficiency
  - For each test case, provide a heat and mass balance; oxy-fired heater schematics including temperature profiles and flows; performance specifications for major equipment and estimates of sizing; and overall plant footprint and interconnecting piping diagram

Project Tasks (continued)

Budget Period 2

- **Task 4 – Conduct Cost Estimates:**
  - Conduct AACE Class-5 cost estimates for cases down-selected from Task 3
- **Task 5 – Process Design and Cost Review:**
  - Review the cost estimates for the test cases to identify specific high-cost items employed in the flow sheets. For each item identified, an assessment will be conducted to evaluate the impact on overall plant performance and costs of using a lower-cost item.

Summary of Phase 1 Test Cases to Be Studied

Plant Size	Nominal Turbine Inlet Conditions	Case	Air- or Oxy-Fired	SCO_2 Brayton Cycle	Fired-Heater Technology
55-MWe	600°C/275 bar	1	Air	Cascaded	PC with conventional AH
	700–760°C/275 bar	2	Air	Recompression	PC with high-temp AH
550-MWe	600°C/275 bar	3	Oxy	Cascaded	PC with conventional AH
		4	Oxy	Cascaded	CLC with conventional AH
	700–760°C/275 bar	5	Oxy	Cascaded	PC with conventional AH
		6	Oxy	Cascaded	CLC with conventional AH

Project Task Timeline

Task Name	Start Date	End Date
Task 1: Project Management and Planning	**12/1/2015**	**11/30/2017**
1.1 Project and Risk Management	12/1/2015	11/30/2017
1.2 Financial Reporting	12/1/2015	11/30/2017
1.3 Project Reporting	12/1/2015	11/30/2017
Task 2: Develop Power Block Design Basis and Baseline	**12/1/2015**	**5/31/2016**
2.1 Identify 550-MWe Baseline Cases and Design Basis for Performance/Economic Evaluations	12/1/2015	1/31/2016
2.2 Develop 55-MWe Plant Design Basis and Cost Calculation Basis	2/1/2016	3/31/2016
2.3 Develop Test Case Specifications with Preliminary Flow Schematics	4/1/2016	5/31/2016
Task 3: Optimize Thermal Integration between the Fired Heater and Power Cycle	**6/1/2016**	**2/28/2017**
3.1 Preliminary Thermal Integration Design	6/1/2016	8/31/2016
3.2 Optimization of the Fired Heater/Power Cycle Flow Sheets	9/1/2016	11/30/2016
3.3 Specification of Optimized Fired Heater/Power Cycle Flow Sheets	12/1/2016	2/28/2017
Task 4: Conduct Cost Estimates	**3/1/2017**	**8/31/2017**
4.1 Individual Fired Heater/Power Cycle Component/System Capital Cost	3/1/2017	4/30/2017
4.2 Total Project Cost Estimates	5/1/2017	6/30/2017
4.3 Levelized Cost of Electricity/First-Year Power Costs	7/1/2017	8/31/2017
Task 5: Process Design and Cost Review	**9/1/2017**	**11/30/2017**

Project Team

Prime

- Electric Power Research Institute, Inc. (EPRI)
  - Andrew Maxson (PI), Scott Hume, Jeff Phillips, and David Thimsen

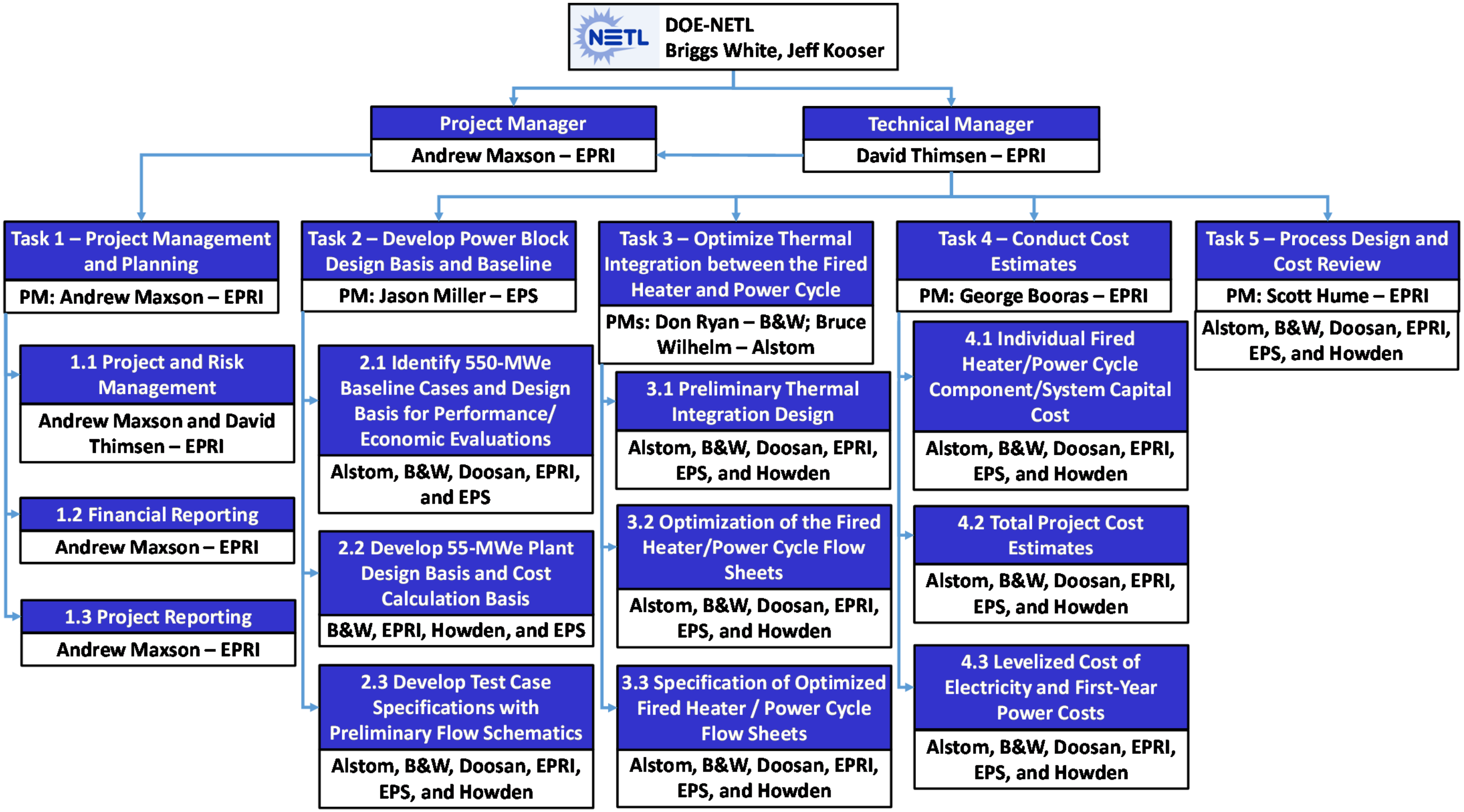
Sub-Contractors

- Alstom Power, Inc. (Alstom)
  - Ray Chamberland, Glenn Jukkola, and Bruce Wilhelm
- Babcock and Wilcox Company (B&W)
  - Don Ryan and Paul Weitzel
- Doosan ATS America, LLC (Doosan)
  - Hyoungju Lee and Gyu Nam
- Echogen Power Systems, LLC (EPS)
  - Tim Held and Jason Miller
- Howden Group Ltd. (Howden)
  - Jim Cooper, Dougal Hogg, and Richard Smith

Project Team Roles

- **EPRI:** Focused on project management, supporting the design efforts, and leading the cost calculations
- **Alstom:** Focused on the design, performance, and cost of a 550-MWe CLC system integrated to a SCO_2 Brayton cycle
- **B&W:** Focused on the design, performance, and cost of a 55-MWe air-fired and 550-MWe atmospheric oxy-combustion systems integrated to a SCO_2 Brayton cycle
- **Doosan:** Focused on the design and cost of the CO_2 turbines for the 550-MWe cases
- **EPS:** Focused on the design, performance, and cost of the SCO_2 Brayton cycles for all cases and turbomachinery for the 55-MWe cases
- **Howden:** Focused on the design and cost of the high-temperature AHs for the 55-MWe air-fired case

Project Structure



Project Risk Management

Description of Risk	Probability	Impact	Mitigation and Response Strategies
Technical Risks:			
Project team has difficulty reaching consensus on technical direction and process and technology choices	Low	High	Significant upfront discussion has been held to understand the design philosophies of each organization, which have been accounted for in the scope. EPRI will serve as arbiter of any technical disagreements based on its position as prime along with its understanding of the needs of the power industry. Also, several decision points have been proposed to reduce excessive spending if a consensus cannot be reached.
Nature and maturity of some technologies make it difficult to produce a Class-5 cost estimate	Low	Moderate	Standardized engineering procedures and appropriate modeling and costing software will be used to produce cost estimates. Even for relatively immature technology, this combination has been demonstrated to enable relatively accurate estimates when done by experienced staff. All of the organizations involved have significant expertise in performing and assessing cost estimates.

Project Risk Management (cont.)

Description of Risk	Probability	Impact	Mitigation and Response Strategies
Technical Risks:			
Performance calculations for optimization cases yield efficiency improvements less than 3–5 % points	Low	Moderate	The teams involved have significant experience and expertise in SCO_2 Brayton cycles and oxy-combustion, and have already performed similar design and modeling work that shows efficiency improvements of this order of magnitude. The decision to look at multiple cases will drive towards an optimal integration and increase the likelihood that this goal will be met.
Project team has difficulty obtaining information from technology vendors	Low	Low	Components included in the design of the test cases for this project are not available as commercial offerings. The team members possess internal expertise to develop performance and cost data for the components adequate for the work proposed and have done so for similar efforts. In addition, the team can exploit previous experience working with outside vendors to develop costs and specifications for similar components that will inform the capital costing effort. Little reliance on outside technology vendors is anticipated for this project.

Project Risk Management (cont.)

Description of Risk	Probability	Impact	Mitigation and Response Strategies
Resource Risks:			
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.
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 from key staff members and appropriate managers 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. All companies have significant bench strength to minimize this risk.

Project Risk Management (cont.)

Description of Risk	Probability	Impact	Mitigation and Response Strategies
Management Risks:			
Negotiations associated with contracting and acceptance of project startup documents requires excessive time to complete, subsequently delaying start of the program	Moderate	Moderate	EPRI and several team members have conducted work for DOE/NETL and with each other under various teaming arrangements. To minimize time associated with contracting, negotiations will begin as soon as DOE/NETL releases contract language to EPRI. After contracts are in place, EPRI will work with its sub-contractors to plan an approach to enable prompt completion of all startup requirements, including updating the PMP if necessary.
Project expenditures exceed the plan, resulting in a budget overrun	Low	Moderate	EPRI will employ project controls, including financial tracking and recurring meetings on schedule and budget, to monitor the project financial performance and prevent cost overruns.

Project Milestones and Decision Points

Budget Period	Task No.	Milestone Description	Planned Completion	Verification Method
1 and 2	1.1	1. Updated Project Management Plan	12/15/2015	PMP file
1 and 2	1.1	2. Kickoff Meeting	12/31/2015	Presentation file
1	End of Task 2	3. Decision Point; Review of Design Bases and Flow Schematics; Decision Point	05/31/2016	Review meeting with DOE/NETL
1	3.1	4. Preliminary Thermal Integration Design	08/31/2016	Progress update in quarterly report
1	End of Task 3	5. Review of Test Case Performance Results; Decision Point	02/28/2017	Review meeting with DOE/NETL
2	4	6. Review of Capital Cost Estimates	06/30/2017	Progress update in quarterly report
2	5	7. Review of LCOE and First-Year Power Cost Estimates	08/31/ 2017	Progress update in quarterly report

Project Schedule

Task Name	Start Date	End Date	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
			Budget Period 1															**Budget Period 2**								
Task 1: Project Management and Planning	**12/1/2015**	**11/30/2017**																								
Task 1.1	12/1/2015	11/30/2017	M1, M2																							
Task 1.2	12/1/2015	11/30/2017		Q			Q			Q			Q			Q	F		Q			Q			Q	F
Task 1.3	12/1/2015	11/30/2017		Q			Q			Q			Q			Q	F		Q			Q			Q	F
Task 2: Develop Power Block Design Basis and Baseline	**12/1/2015**	**5/31/2016**																								
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Task 2.2	2/1/2016	3/31/2016																								
Task 2.3	4/1/2016	5/31/2016						M3																		
Task 3: Optimize Thermal Integration between the Fired Heater and Power Cycle	**6/1/2016**	**2/28/2017**																								
Task 3.1	6/1/2016	8/31/2016									M4															
Task 3.2	9/1/2016	11/30/2016																								
Task 3.3	12/1/2016	2/28/2017															M5									
Task 4: Conduct Cost Estimates	**3/1/2017**	**8/31/2017**																								
Task 4.1	3/1/2017	4/30/2017																								
Task 4.2	5/1/2017	6/30/2017																			M6					
Task 4.3	7/1/2017	8/31/2017																					M7			
Task 5: Process Design and Cost Review	**9/1/2017**	**11/30/2017**																								F

Project Deliverables

Task	Deliverable	Due Date
2	Task 2 Report and Listing and Review of Recommended Test Cases	05/31/2016
3	Task 3 Report	02/28/2017
4	Task 4 Report	08/31/2017
5	Final Report	11/30/2017

Next Steps

- Get all five sub-contractors under contract by December 1, 2015; contracts are being drafted
- Initiate technical work with kickoff meeting by December 15, 2015

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