Two Phase DFE Project Kickoff

Presentation by

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December 7, 2015

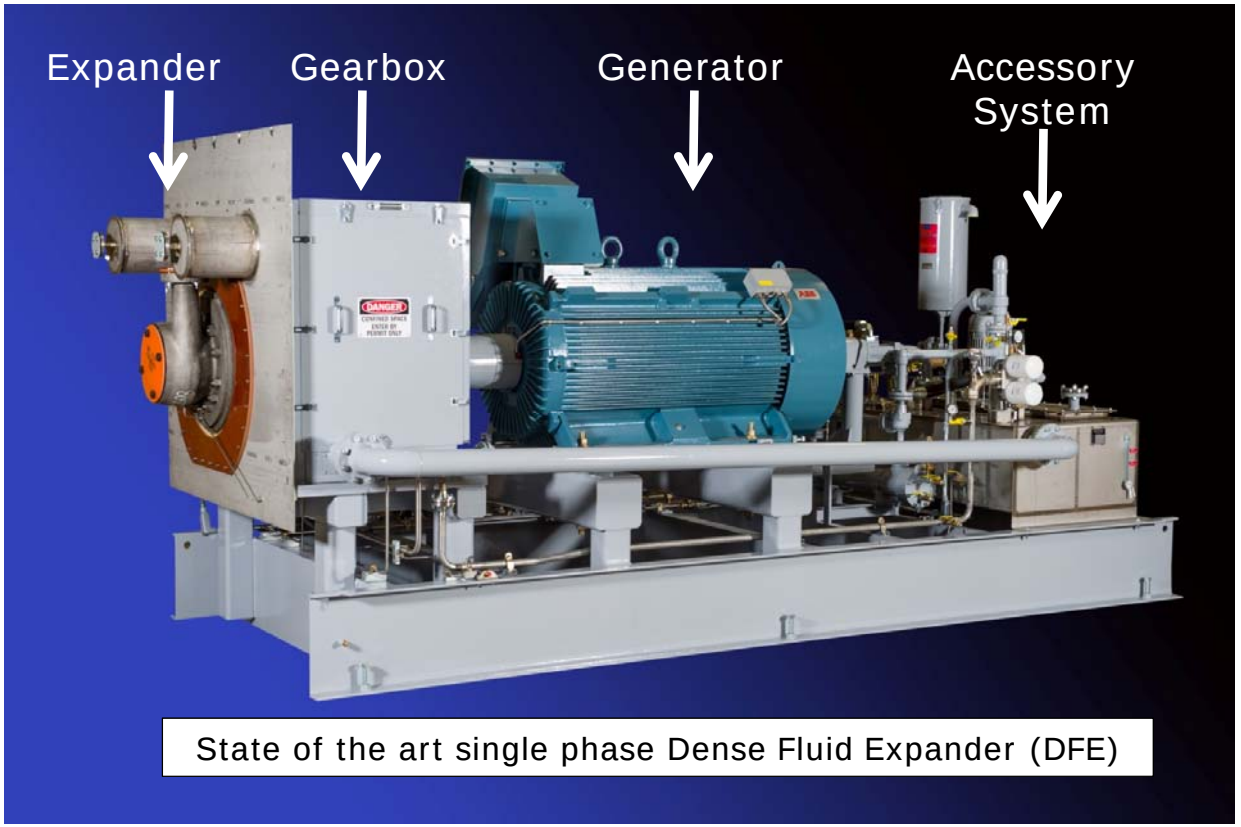
Agenda

Background
Project Objectives
Project Scope
Project Team
Project Schedule
Project Budget
Project Risk Management Plan

Background

- Cryogenic air separation is the state of the art technology used to supply the vast amounts of oxygen required for coal gasification
- Power needed to drive the main air compressor (MAC) in a typical air separation unit (ASU) represents 70-90% of ongoing operating cost for the entire ASU
- Usage of a dense fluid expander within an ASU allows for more efficient plant operation and therefore less power required to produce an equivalent amount of oxygen product

Background



Air Products Model **ETAGG-3DF**

Background

- State of the art cryogenic dense fluid expanders used in air separation are typically limited to single phase flow (liquid in, liquid out)
- A single phase DFE design with only liquid in the discharge typically experiences very little volume change upon expansion
- A two-phase DFE may experience volume increases of up to 10 times upon expansion
- The large volume difference between vapor and liquid poses challenges to designing equipment as it relates to machine efficiency, durability, erosion, stable operation, and other performance criteria

Background

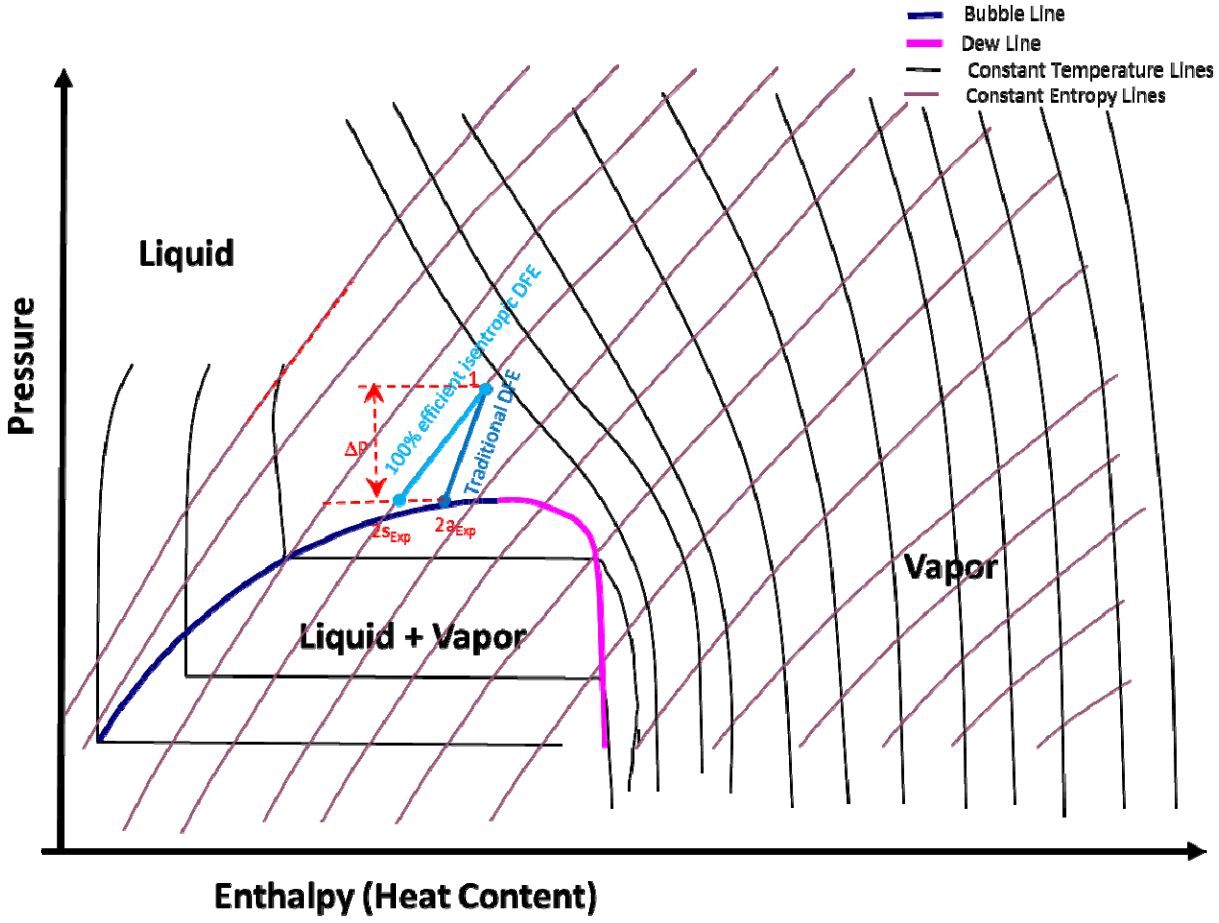
- Developing a successful two phase dense fluid expander for cryogenic air separation will open doors for additional DFE applications and overall ASU plant efficiency improvement:

  1. Run traditional DFE applications two phase leading to more efficient plant operation. Current DFE's are back-pressured to keep discharge flow single phase.

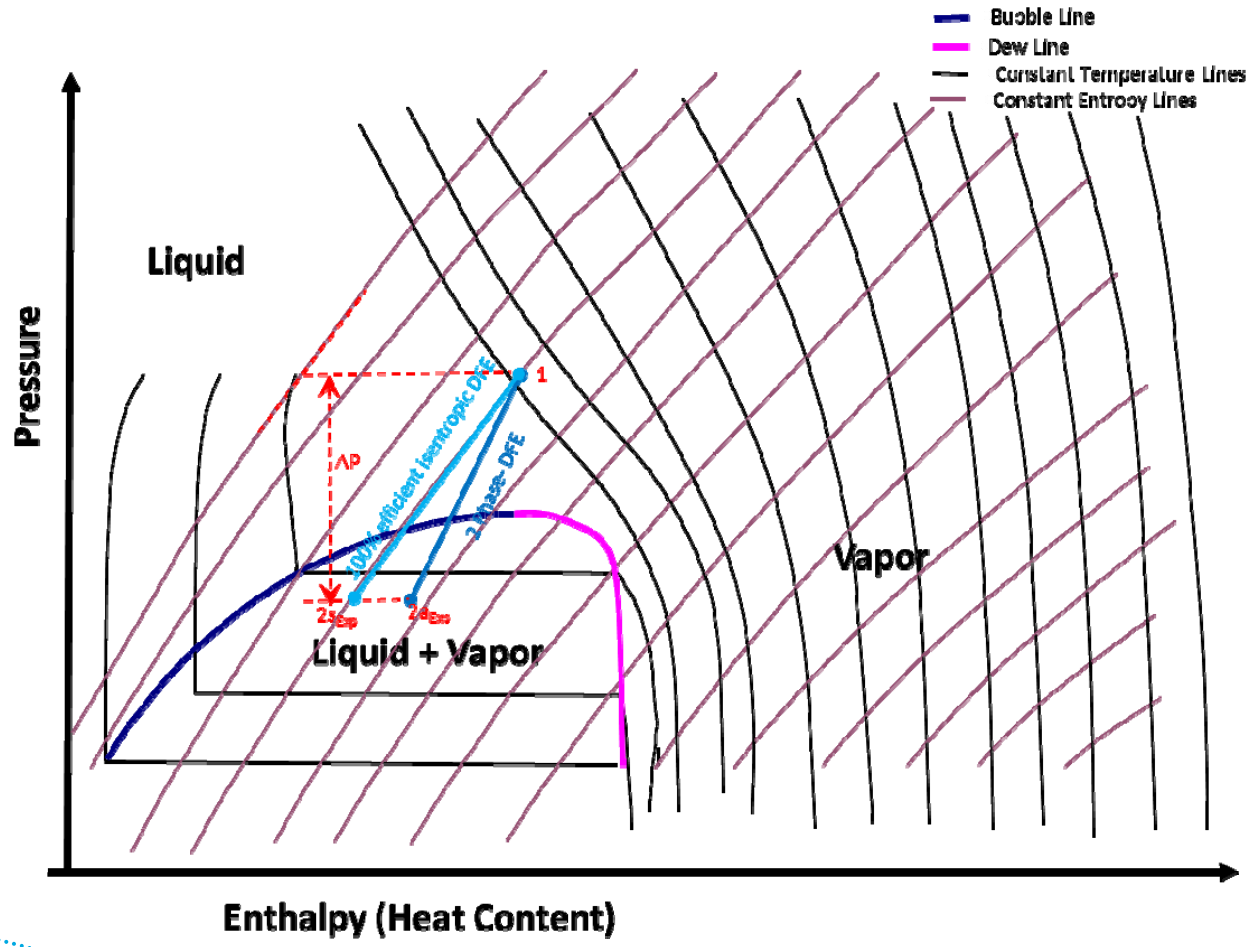
  2. Replacement of letdown valves with DFE's (3-6 valves per typical ASU)

  3. Waste heat recovery cycles requiring two phase DFE's

Schematic - Traditional DFE

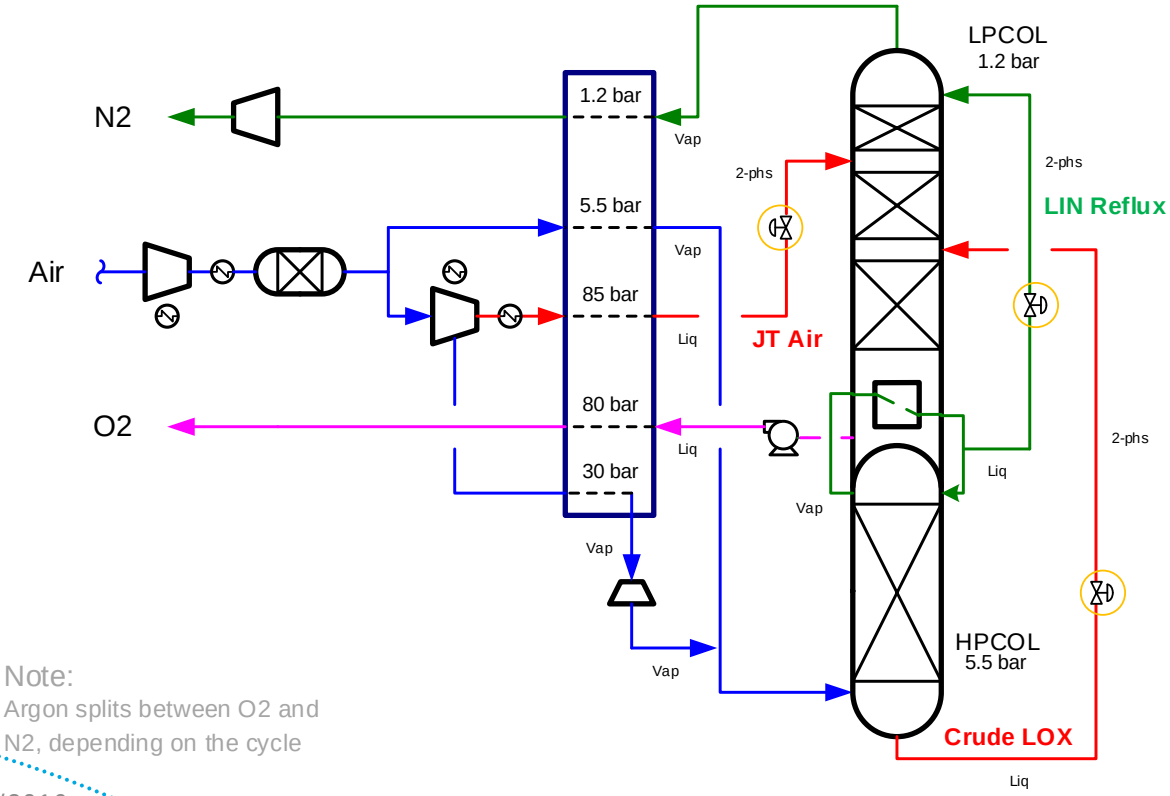


Schematic - Two Phase DFE



Opportunities for Additional DFE's in ASU Applications

Pumped-LOX Cycle



Note:
Argon splits between O2 and N2, depending on the cycle

Project Objectives

- The first objective is to better understand the limitations associated with two-phase dense fluid expansion from aerodynamic, thermodynamic, and mechanical perspectives
- The second objective is to apply this knowledge to construct a prototype device to further explore the basic properties of two-phase dense fluid expansion

Project Scope

- Project will be completed with one budget period in two phases

Phase 1 – Research and technical analysis of two phase DFE applications

Phase 2 – Design, fabricate, and test two phase DFE prototype

Project Scope – Phase 1

- Complete aerodynamic, thermodynamic, and mechanical research and analysis of three potential applications:

1. Waste Heat Recovery From Main Air Compressor (MAC) Intercoolers
   - Savings equal to ~5% of MAC electrical power

2. Crude Liquid Oxygen Let Down
   - Savings equal to ~1% of MAC electrical power

3. Traditional DFE in Two-Phase Operation
   - Savings equal to ~0.3% of MAC electrical power

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Project Scope – Phase 1

- Complete technical evaluation of machinery options:
  - Research field of two phase cryogenic expansion for centrifugal machinery
  - Research field of two phase cryogenic expansion for positive displacement machinery (screw, reciprocating, linear, lobe, other types)
- Identify preferred type of machinery for each identified application and complete technical risk evaluation for each
- Complete Computational Fluid Dynamic (CFD) analysis to quantify performance/efficiency impacts as well as to further identify concerns associated with two phase flow

Project Scope – Phase 1

- Select machinery type most suitable for two phase flow and applications
- Determine prototype device and complete conceptual design and testing plan
- Complete a cost analysis for Phase 2 completion
- Review findings with DOE via interim report and make a decision on whether to proceed with Phase 2

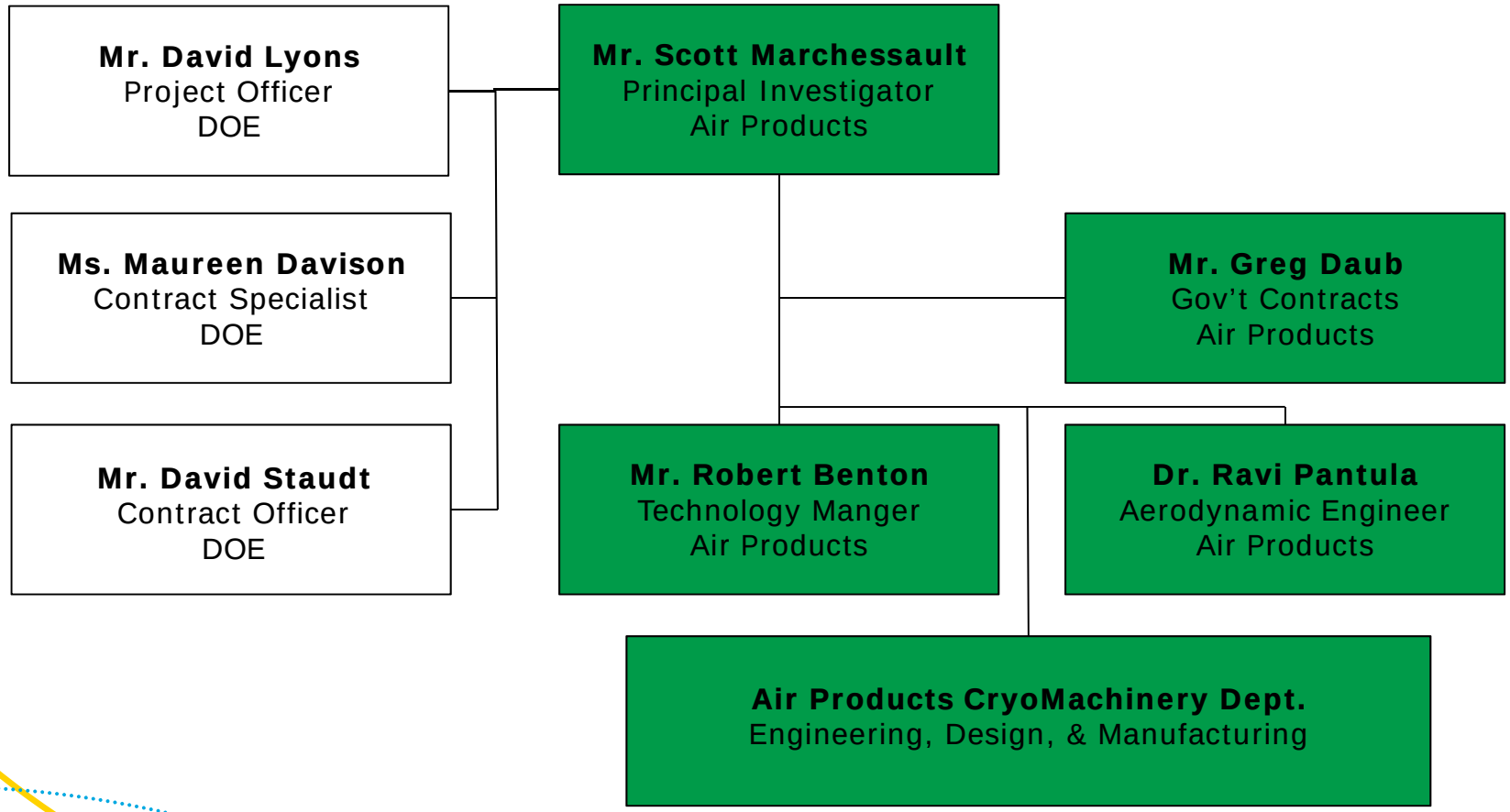
Project Management Plan Decision Point

- **DECISION POINT 1** – Go/No-Go for Phase 2 (Design, fabricate and test prototype)
- The Recipient is NOT authorized to proceed to the subsequent task without the prior written authorization from the DOE Contracting Officer. The Recipient shall meet the following success criteria:
- Based on interim report documenting cumulative project findings through the conclusion of Task 7, and supporting analysis, a conclusion by DOE program officials that (1) project risks are reasonably well mitigated and (2) the budgeted cost to execute the design, fabrication and testing of the two-phase DFE prototype activities are within the remaining authorized project budget.

Project Scope – Phase 2

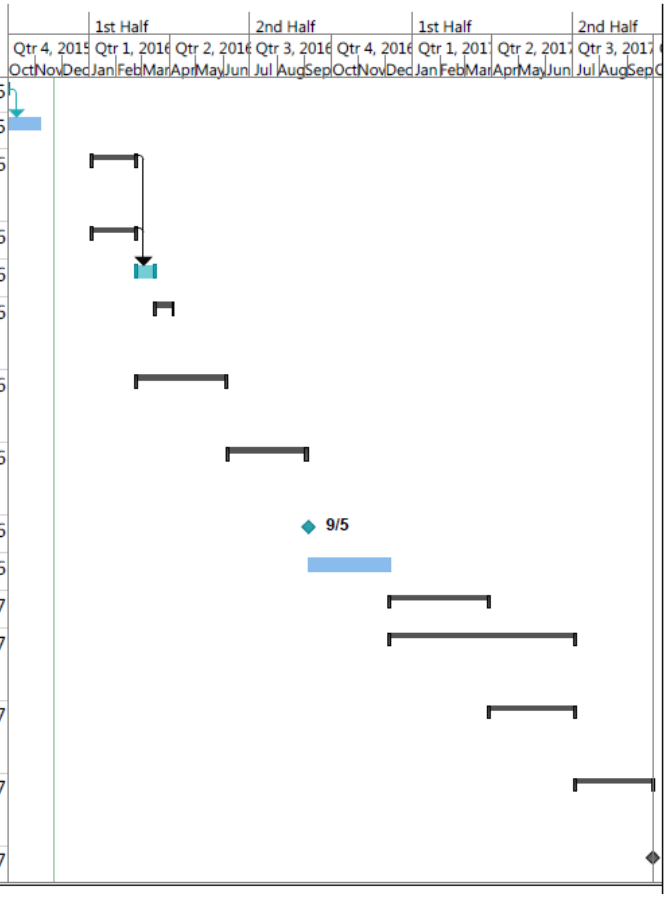
- Design, fabricate, and test prototype device
- Review performance evaluation of prototype device and report findings to DOE via final report

Project Management Plan
Project Team



Project Management Plan
Project Schedule

ID	Task Name	Start	Finish
1	**Project Kickoff**	Thu 10/1/15	Thu 10/1/15
2	1.0 Update Project Management Plan	Fri 10/2/15	Fri 11/6/15
3	2.0 Aerodynamic and Thermodynamic Analysis	Mon 1/4/16	Mon 2/22/16
7	3.0 Technical Evalution of Machinery Options	Mon 1/4/16	Mon 2/22/16
11	4.0 Equipment and Application Selection	Tue 2/23/16	Mon 3/14/16
12	5.0 Identify Potential Technical Risk Issues of Selected Device/Application Combinations	Tue 3/15/16	Mon 4/4/16
15	6.0 Aerodynamic Analysis of Two Phase Applications	Tue 2/23/16	Fri 6/3/16
17	7.0 Final Machinery Selection and Conceptual Device Design	Mon 6/6/16	Fri 9/2/16
22	**Interim Report**	Mon 9/5/16	Mon 9/5/16
23	**Decision Point**	Mon 9/5/16	Mon 12/5/16
24	8.0 Demonstration Device Design	Tue 12/6/16	Mon 3/27/17
27	9.0 Prototype Device Manufacturing and Assembly	Tue 12/6/16	Mon 7/3/17
30	10.0 Design and Construction of Testing System	Tue 3/28/17	Mon 7/3/17
33	11.0 Prototype Device Testing and Performance Evaluation	Tue 7/4/17	Fri 9/29/17
36	**Final Report**	Fri 9/29/17	Fri 9/29/17



Project Management Plan
Project Budget

	DOE Funds	Air Products	Total
Budget	$876,294	$219,073	$1,095,367
% Share	80%	20%	

Project Management Plan
Project Budget

Phase 1:

Month	OCT 2015	NOV 2015	DEC 2015	JAN 2016	FEB 2016	MAR 2016	APR 2016	MAY 2016	JUN 2016	JUL 2016	AUG 2016	SEP 2016*
Recipient $	0	778	778	9941	12664	17022	6809	6809	9191	19972	13585	0
Federal $	0	3112	3112	39762	50656	68088	27235	27235	36766	79890	54338	0
Total $	0	3890	3890	49703	63320	85110	34044	34044	45957	99862	67923	0

Phase 2:

Month	OCT 2016*	NOV 2016*	DEC 2016	JAN 2017	FEB 2017	MAR 2017	APR 2017	MAY 2017	JUN 2017	JUL 2017	AUG 2017	SEP 2017
Recipient $	0	0	14015	14015	14015	14015	12976	18174	16509	8931	5480	3394
Federal $	0	0	56058	56058	56058	56058	51904	72699	66037	35730	21923	13574
Total $	0	0	70073	70073	70073	70073	64880	90873	82546	44661	27403	16968

*Note: DOE Hold Point Sep 2016 – Nov 2016

Project Management Plan
Risk Management Plan

Risk	Description	Mitigation Plan
Isothermal efficiency of the centrifugal machine is poor.	CFD analysis reveals poor efficiency of the centrifugal machine design option.	• Evaluate options with different types of non-radial equipment and inform DOE of the equipment selected for further analysis.
Inability to accurately predict results using CFD analysis.	Results of CFD analysis are inconclusive.	• Investigate alternative modeling methods available in academia or commercially. • Evaluate if alternative testing can be done to validate CFD analysis and advise DOE of the proposed testing.
Rotor/bearing system issues due to two-phase flow.	Rotordynamic and vibration problems arise which could result in premature bearing failure.	• Complete rotordynamic analysis including review of cross-couple stiffness excitation. • Test initial machine with additional instrumentation to assess rotordynamic and bearing performance. Additional instrumentation could include X&Y vibration probes on two planes and bearing temperature monitoring.
Nozzle mechanism issues due to two phase flow.	Performance issues or failed components due to new nozzle mechanism. Potential for operability problems due to not being able to move the nozzles.	• CFD analysis will be performed on the nozzles for accuracy. • Radial Omni-seals will be used on the zero-clearance plate to eliminate some uncertainty in seal spring force on clamping calculations. • Drill multiple bleed holes at different radii in the zero-clearance plate so modifications can be made to adjust the nozzle clamping force.

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Project Management Plan
Risk Management Plan

Risk	Description	Mitigation Plan
Erosion of the rotating component.	Mechanical degradation of the rotating component resulting from two phase flow.	• Perform a detailed analyses to determine if material selected for rotating component is suitable for service. • Identify alternative materials of construction if issues arise from initial material selection; advise DOE of the proposed change and timing if impacted.
Prototype process testing fluid availability.	Unforeseen air permitting issues.	• Air Products will leverage its extensive process knowledge to investigate additional streams and inform DOE of the proposed changes.
Failure to meet milestones during prototype manufacturing.	A long delay in manufacturing the required DFE components.	• Air Products will evaluate and modify the test plan and present alternate timing to DOE.
Failure to meet milestones within allotted time.	Milestones missed for reasons not specifically identified, e.g., operational difficulties during prototype testing, convergence issues during modeling.	• Identify events that led to the milestone being missed and provide this information to DOE with an action plan for addressing the milestone.

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