Improvement of GE Power's Chilled Ammonia Process using Membrane Technology

Large Pilot Scale Post Combustion CO_2 Capture

No. FE0026589

National Energy Technology Laboratory \ Department of Energy

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Imagination at work

Acknowledgement

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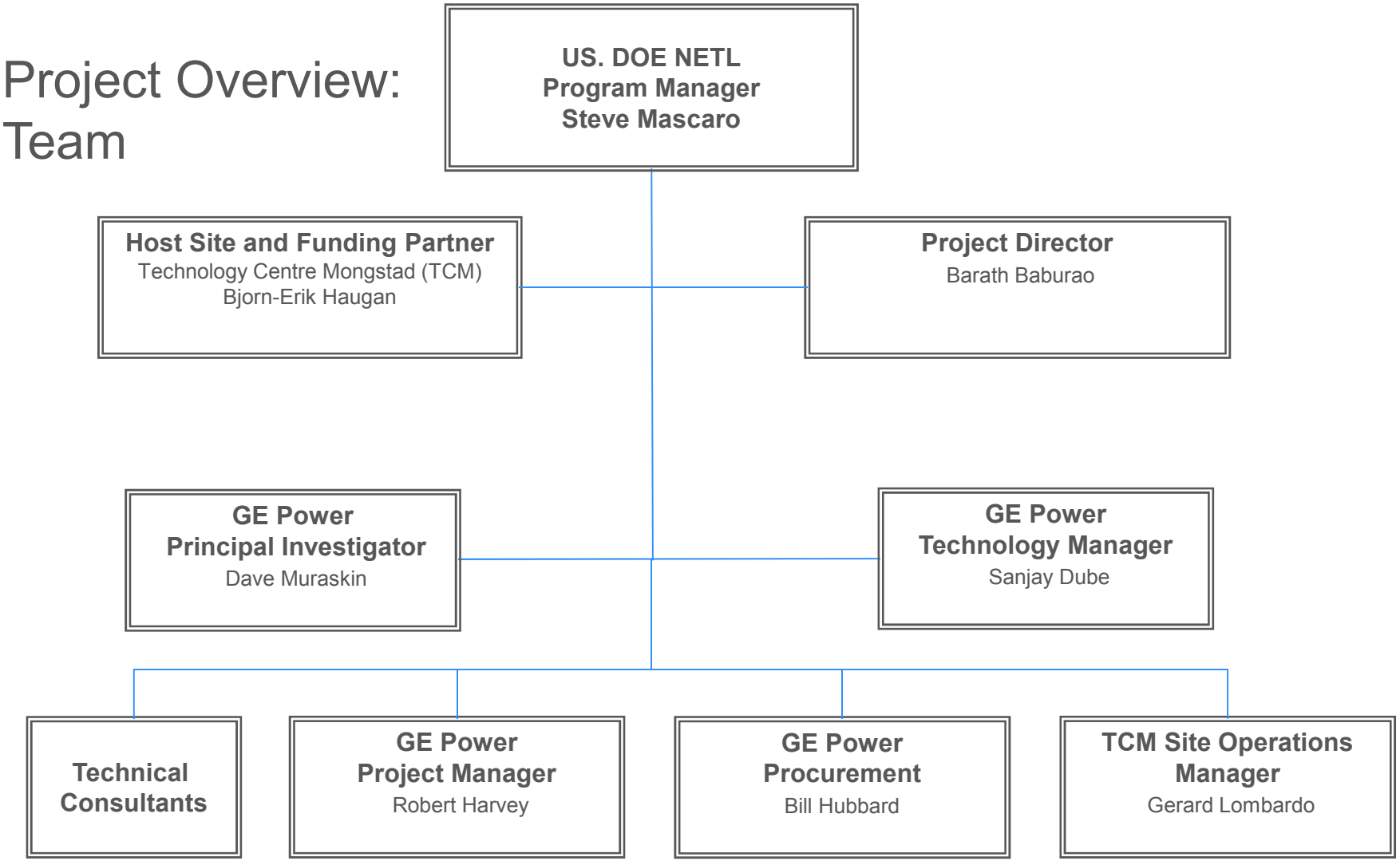
Project Overview: Team



- ElectroSep, Dr. Paul Parisi, Todd Larson
- General Electric Power & Water, Alexander Gorman
- OSMO: Jurgen Muller
- Georgia Inst itute of Technology, Dr. Sankar Nair, Dr. Ryan Lively, Nikita Kevlich

Project Review Meeting Agenda

- Project Overview
  - Funding (DOE and Cost Share)
  - Overall Project Performance Dates
  - Project Participants
  - Overall Objectives
- Technology Background
- Technical Approach / Project Scope
- Progress and Current Status
  - Budget Period (length and cost)
  - Accomplishments
  - Performance levels achieved
- Future Testing / Development

Discussion Topics

Project Overview

Technology Background

Technical Approach / Project Scope

Progress / Current Status

Future Development / Testing

Project Background

- Utilize liquid-liquid membrane technology to improve General Electric's Chilled Ammonia Process (CAP) CO_2 capture technology
  - Elimination of CAP liquid ammonium sulfate effluent stream
  - Reduction of CAP energy demand
  - Initial laboratory testing of concepts performed in a development program outside the scope of this work

Project Overview

- Perform Technical Economic Analysis of concepts and compare with DOE Baseline
- Perform Gap Analysis to assess development needs
- Provide Final Report to summarize findings

Project Overview

- Original Project Funding (DOE and Cost Share)

Budget Period No.	Budget Period Start	Government Share $/%	Recipient Share $/%	Total Estimated Cost
1	10/01/2015	$922,709 (74.1%)	$322,933 (25.9%)	$1,245,642
	Total Project	**$922,709 (74.1%)**	**$322,933 (25.9%)**	**$1,245,642**

- Overall Project Performance Dates
  - Technical Economic Analysis 6/30/2016
  - GAP Analysis 9/1/2016
  - Final Report 9/30/2016

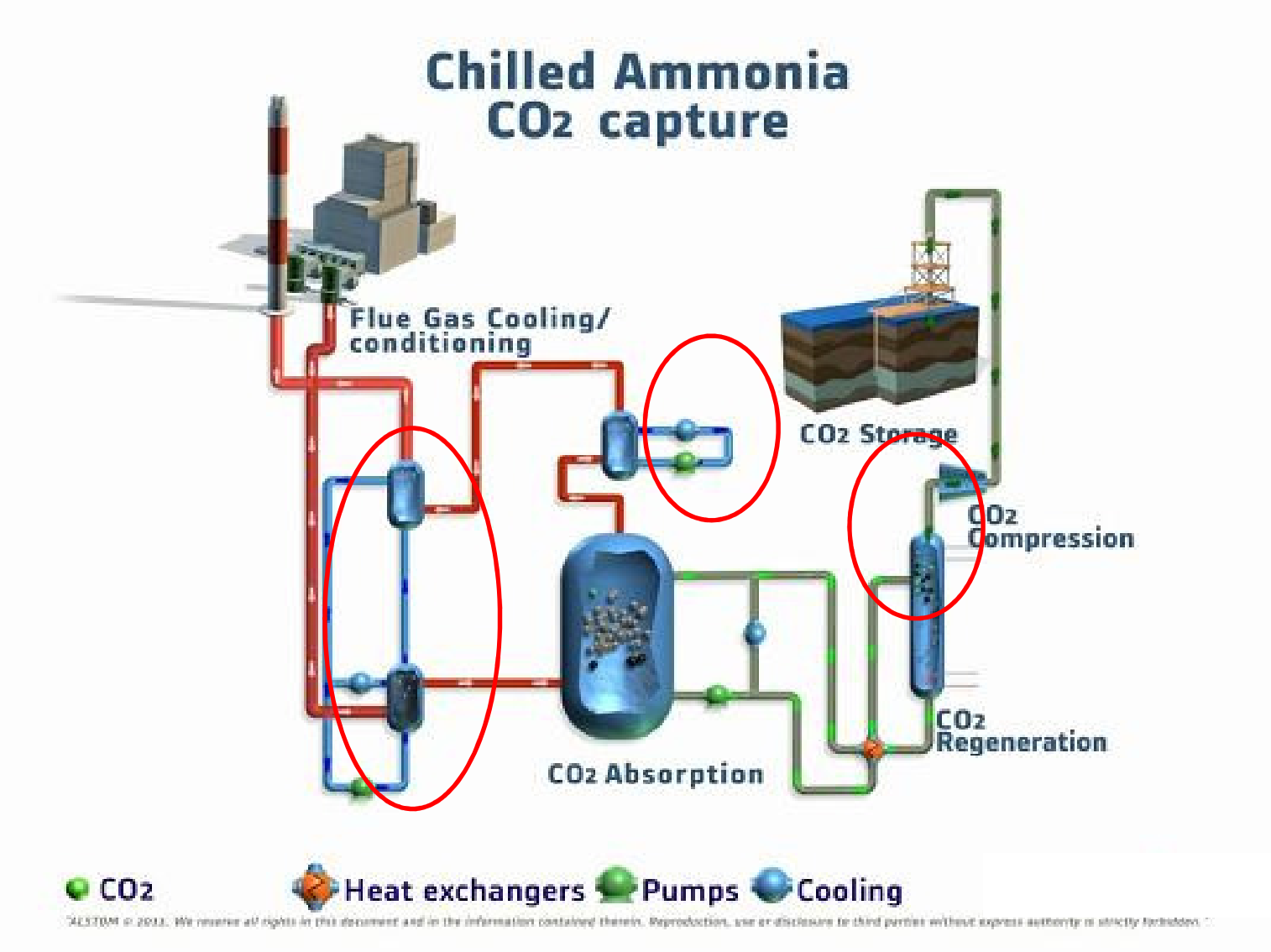
Project Overview

- Phase I Overall Objectives (original)
  - Complete a preliminary techno-economic analysis (TEA) and technology gap analysis of membrane concepts for the Chilled Ammonia Process at a full scale 550 MW power generation facility to show the concepts have the potential to meet DOE's desired cost and performance goals.
  - Complete a firm estimate of the costs and schedule needed to modify the existing large pilot facility at the host site.
  - Develop key project success criteria values and risks.
- Modification of membrane development program due to laboratory test results
  - Decision not to proceed with the Large Pilot Modifications and application for Phase II funding
- Phase I Overall Objectives (revised)
  - Complete a final Techno-Economic Analysis (TEA) and Technology Gap Analysis (TGA) of membrane concepts for the Chilled Ammonia Process at a full scale 550 MW power generation facility to show the concepts have the potential to meet DOE's desired cost and performance goals.
  - Develop key project risks.

Discussion Topics

- Project Overview
- **Technology Background**
- Technical Approach / Project Scope
- Progress / Current Status
- Future Development / Testing

CAP Technology Background



Technology Background

- Membrane Concepts for Development in the Chilled Ammonia Process
  - Concept 1: Elimination of CAP Ammonium Sulfate Byproduct and Reduction of Reagent Consumption
  - Concept 2: Reduction of CAP Ammonia Stripper Energy Using Membrane Technology
  - Utilize commercially available membrane systems

Technology Background
Concept Advantages

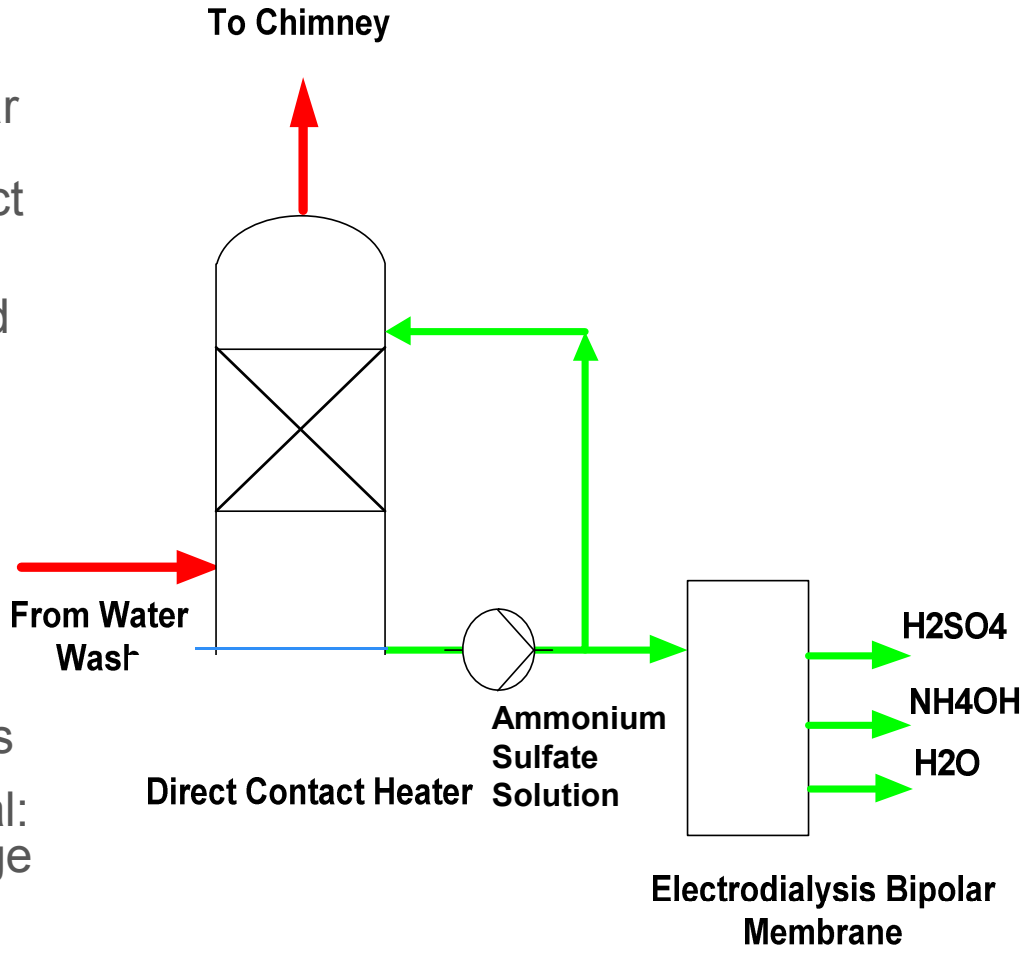
Membrane technology improvements include:

- Concept 1 Bipolar membrane electrodialysis
  - Elimination of CAP ammonium sulfate byproduct stream, costs for disposal or crystallization, concentration
- Concept 2 Membrane technology to reduce stripper energy using reverse osmosis
  - Reduction in CAP energy demand
  - Stripper duty can be reduced significantly.
  - Stripper and associated heat exchanger sizes can be reduced
- Overall reduction in cost of electricity as compared to DOE Baseline

Technology Background
Membrane Improvement Concept 1

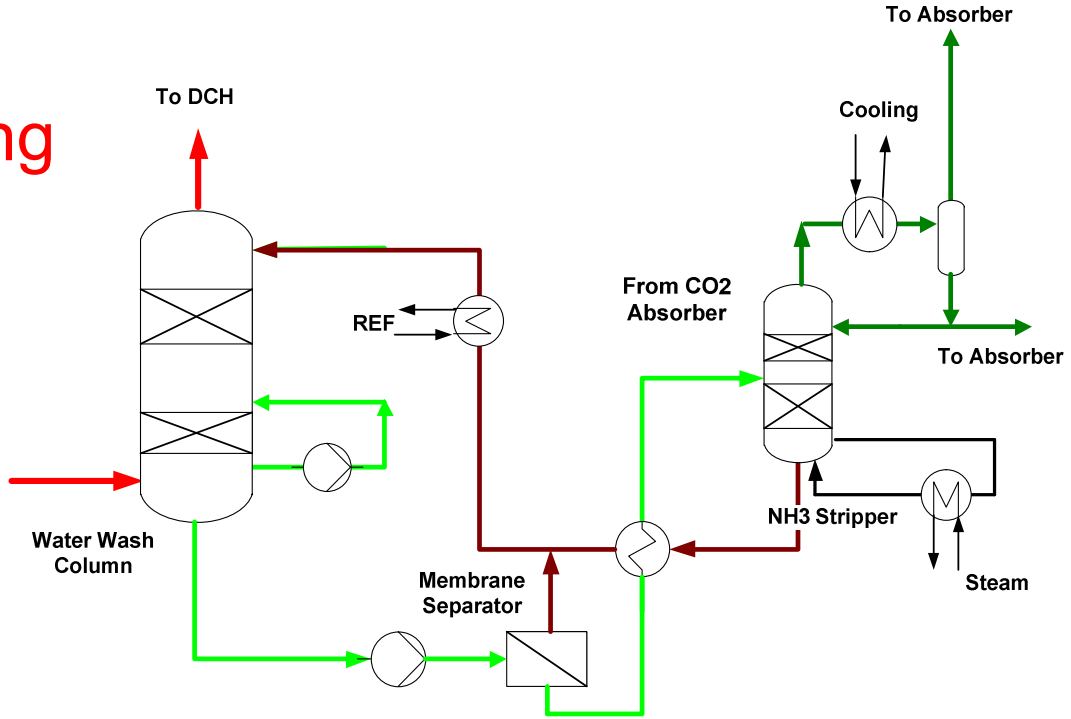
Electrodialysis for Ammonium Sulfate Dissociation

- **Benefits**
  - Use of electrodialysis bipolar membrane to convert ammonium sulfate byproduct to process reagents
    - Reduction in sulfuric acid and ammonia reagent consumption
  - Elimination of ammonium sulfate byproduct stream (beneficial for locations where off-taker is not available).
  - Reduction in operating costs
  - Reduction in reagent (typical: anhydrous ammonia) storage on site



Technology Background
Membrane Improvement Concept 2

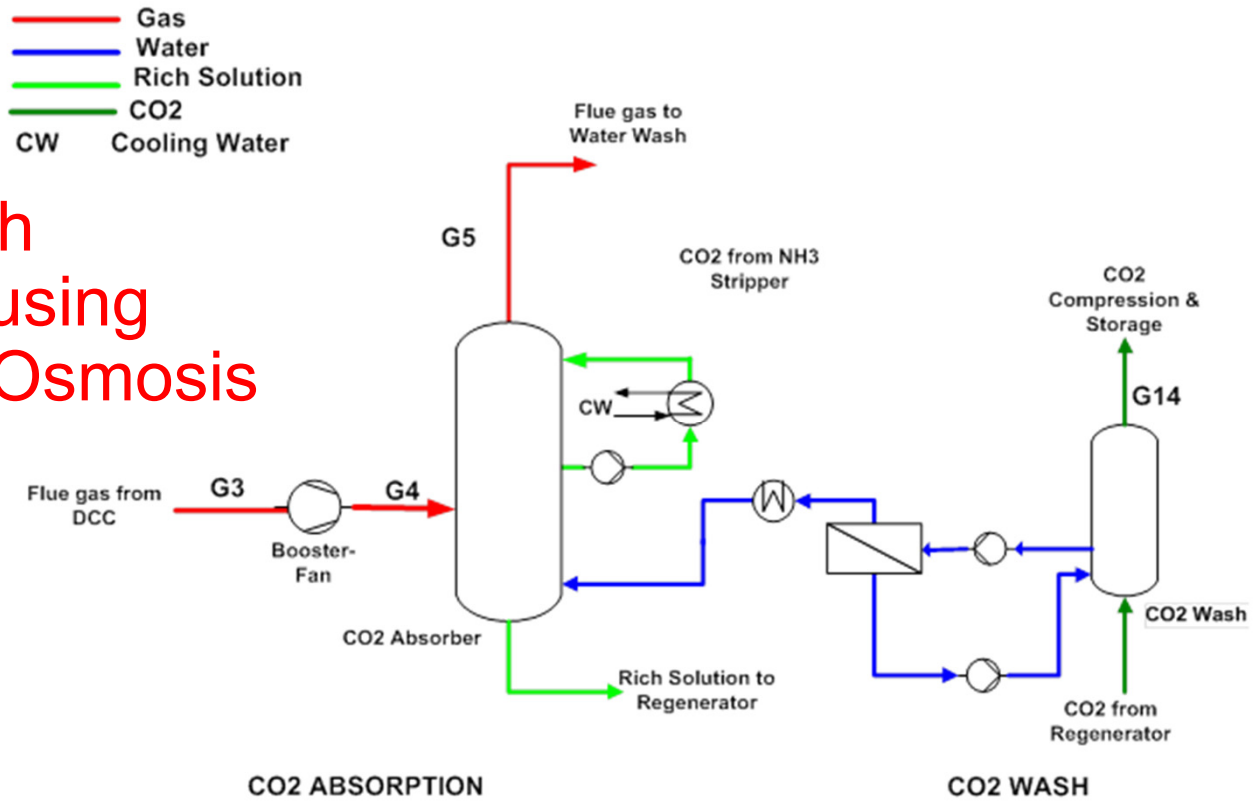
Stripper Feed Concentration using Reverse Osmosis



- **Benefits**:
  - Stripper feed ammonia levels are concentrated with reverse osmosis membrane separator resulting in reduced feed flow rate
  - Higher ammonia slip from the absorber is allowable.
  - Absorber chiller duty can be minimized significantly.
  - Stripper duty can be minimized significantly or eliminated resulting in specific steam energy Stripper and associated heat exchanger sizes can be reduced by ~50%

Technology Background
Membrane Improvement Concept 2

CO_2 Wash Bottoms using Reverse Osmosis



- **Benefits:**
  - Utilize reverse osmosis membrane technology to concentrate CO2 wash bottoms stream
  - Allows operation of the regenerator at lower pressure and higher ammonia emissions
  - Allows lower pressure steam to regenerator

Technology Background

Research Leading to Award

Chilled Ammonia Process
Update on GE Power roadmap





Membrane improvement concepts developed

2006 2010 2020 & beyond

CCS

Test Rigs → Industrial Pilots → Validation Pilots → Large-scale demonstration → Commercial

Validation Pilots → CCU commercially available

GE Power

Vaxjö Sweden
0.25 MWth

We Energies Pleasant Prairie
USA - 5 MWth, Coal

EoN Karlshamn
Sweden - 5 MWth, Oil

AEP Mountaineer
USA - 58 MWth, Coal

TCM Mongstad
Norway - 40 MWth, Gas

Roadmap to commercialization, 90% CO_2 capture demonstrated

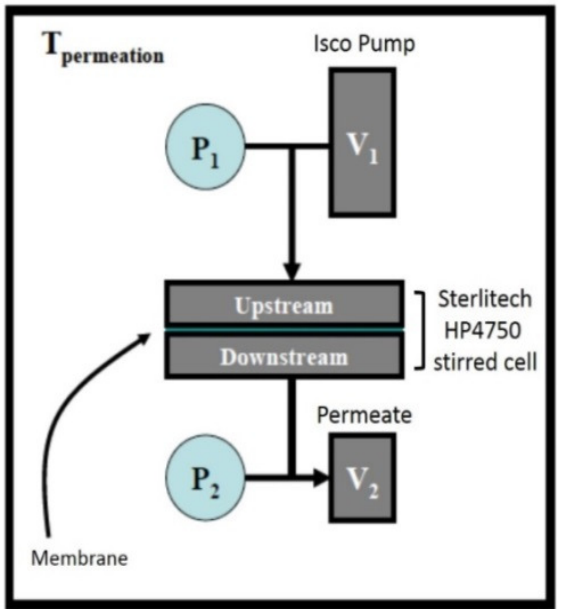
Technology Background
Bench Scale Electrodialysis Testing

- Bench-scale Testing
  - Bipolar membrane electrodialysis by ElectroSep
  - Membrane systems
    - Anode exchange membrane
    - Cathode exchange membrane
    - Bipolar membrane
  - Test program completed
    - Parametric test program using synthetic solutions
    - Results indicate initial membrane selection is feasible
  - Additional experience provided by GE Power & Water

Electrodialysis Test Unit
ElectroSep Test Facilities
Saint Lambert, Quebec

Technology Background
Preliminary Results Reverse Osmosis Testing

- Bench-scale testing at Georgia Institute of Technology
- High rejection, seawater membrane samples tested from multiple suppliers
- Cellulose acetate, polyamide membranes
- Synthetic feed solution (stripper feed)
  - Ammonia-CO_2 solution: 1.5 M NH_3 using ammonium bicarbonate.
- Higher osmotic pressure needed to achieve desired ammonia rejection performance, flux
- Further testing with high pressure membranes is required



Reverse Osmosis Membrane Test Unit
Georgia Institute of Technology
Membrane Test Facilities
Alanta, Ga.

Technology Background
Membrane Development Challenges

Concept 2

- Higher pressure Reverse Osmosis membranes required
  - Increase in power consumption, operating costs
  - Increased capital cost
  - Increased membrane replacement costs
  - Decreased economic attractiveness
- New Reverse Osmosis concept considered to utilize lower pressure membranes
  - Laboratory testing of concept is needed
  - Economic assessment of concept needed
  - Development program to be revised

Discussion Topics

- Project Overview
- Technology Background
- **Technical Approach / Project Scope**
- Progress / Current Status
- Future Development / Testing

Technical Approach / Scope
Project Deliverables

	Date	Status
Phase 1 550 MW Technology Engineering Design and Economic Analysis	June 30, 2016	Submitted June 30, 2016
Phase 1 Technology Gap Analysis	September 1, 2016	September 1, 2016
Phase 1 Final Report	September 30, 2016	September 30, 2016

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Progress of Project
Project Schedule & Key Milestones

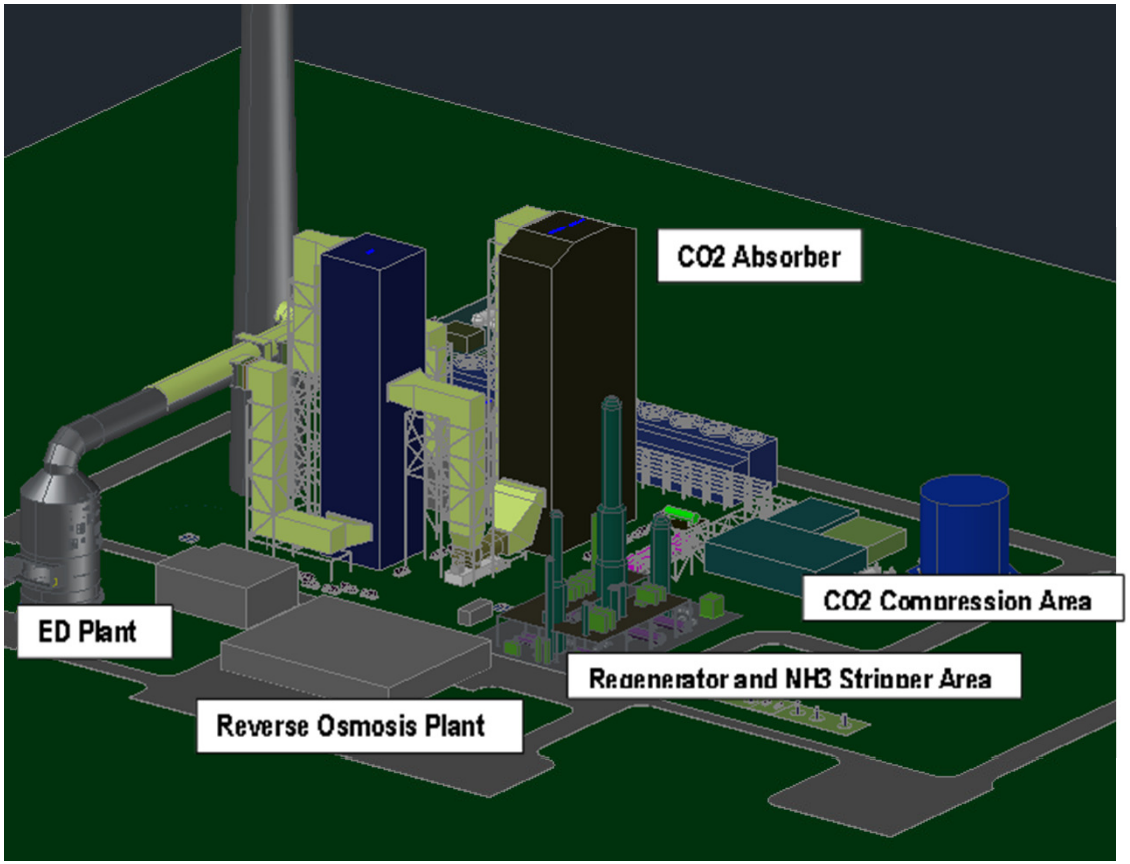
Table 1 Milestone Log for Q3 ENDING 6/31/2015

Milestone Description	Planned Completion date	Actual Completion Date	Verification Method	Comments (progress toward achieving milestone, explanation for deviation from plan, etc.)
Kick-Off Meeting	10/28/2015	10/28/2015	Meeting	Done
Updated Project Schedule	10/28/2015	10/28/2015	Presentation	Done
Updated Project Management Plan	11/15/2015	NA	Report File	Effort discontinued. No phase 2 application will be submitted
Mass Balance 550 MW (C, S, and Water) for TEA	11/15/2015	11/6/2016	Report File	Done
Mass Balance 15 MW (C, S, and Water) for Pilot plant	11/30/2015	12/3/2015	Report File	Done
Steam Cycle Simulations for TEA	11/30/2016	12/15/2015	Report File	Done
PFD & Block Flow diagram 550 MW TEA	11/30/2015	11/20/2015	Report File	Done
PFD & Block Flow diagram 15 MW Pilot	12/15/2015	12/7/2015	Report File	Done
Data Sheet for 15 Mw skids (1 each concept)	12/30/2015	12/17/2015	Report File	Effort discontinued. No phase 2 application will be submitted
Equipment Summary Sheet 550 MW	1/15/2016	6/30/2016	Report File	Done
RFQ Skids 15 MW	1/4/2016	NA	Report File	Effort discontinued. No phase 2 application will be submitted
Vendor Engineering Skids complete 15 MW	2/28/2016	NA	Report File	Done
Capital Cost Estimate for TEA-550 MW	2/15/2016	6/30/2016	Report File	Done
Operating Cost Estimates for TEA-550 MW	2/15/2016	6/30/2016	Report File	Done
Cost of Electricity for TEA-550 MW	3/1/2016	6/30/2016	Report File	Done
Itemizerized Cost Summary-550 MW	3/15/2016	6/30/2016	Report File	Done
Phase 2 Schedule	2/29/2016	NA	Report File	Effort discontinued. No phase 2 application will be submitted
Phase 1 EHS preliminary assessment	2/29/2016	NA	Report File	Effort discontinued. No phase 2 application will be submitted
Topical Report with Itemized Cost Summary for Phase 2	3/31/2016	NA	Presentation	Effort discontinued. No phase 2 application will be submitted
Updated PMP for Phase 2	3/31/2016	NA	Report File	Effort discontinued. No phase 2 application will be submitted
TEA Report 550 MW	3/31/2016	6/30/2016	Presentation	Done
GAP Analysis	3/31/2016	8/30/2016	Presentation	Will be released with final report Aug 30, 2016
Application for Renewal (write-up)-Phase 2	3/31/2016	NA	Presentation	Effort discontinued. No phase 2 application will be submitted
Executed Financial Arrangments	6/30/2015	NA	Report File	Effort discontinued. No phase 2 application will be submitted
Executed Site Host Agreements	6/30/2015	NA	Report File	Effort discontinued. No phase 2 application will be submitted
GO/NO GO for Phase 2	6/30/2015	NA	Notification	Effort discontinued. No phase 2 application will be submitted
Notification of Phase 2 Award	8/31/2016	NA	Notification	Effort discontinued. No phase 2 application will be submitted

- Large Pilot Accomplishments
  - Heat and Material Balances
  - Membrane estimates
  - Initial plant layout developed
  - Project discontinued
- Technical economic analysis
  - Submitted for review
  - Cost of electricity improvement from Baseline
  - Improvement not sufficient to proceed with existing design at large pilot

Progress of Project
Techno-Economic Analysis

- Plant layout
- Capital cost estimate
- Construction costs
- Power generation facility costs
- Steam cycle and steam / water integration
- TEA submitted for review



Techno-Economic Analysis Results

- Comparison to DOE Baseline (Case 12)
  - Improvement in power plant steam cycle efficiency
  - Decrease in total overnight costs
  - Reduction in cost of electricity (CoE) from the DOE baseline
  - **Performance: degree of CoE improvement not sufficient to justify further development of the original Concept 2 Reverse Osmosis**
  - New Reverse Osmosis membrane concept developed using low pressure membranes: expected to improve capital and operating costs, CoE

Technology Gap Analysis

Technology areas considered in this project and the respective gaps are listed below

Technology area	Current R&D status	Technology Gap and R&D plan
Chilled Ammonia Process without membranes	Tested at different pilot scales and ready for large scale testing	• Ammonium sulphate removal where no market takers • Stripper energy consumption optimization • NH_3 volatility reduction in absorber
Electro-dialysis unit	Tested at pilot scale in batch mode and ready for large pilot scale testing	• Potential for impurity interferences: test using power plant solutions • Scale-up to full scale sizes
Reverse osmosis membrane separation	Tested at bench scale and ready for pilot scale testing	• Low pressure membranes can only be used with modified process flow scheme • New process flow scheme with low pressure membranes has to be validated at bench and pilot scale • High pressure membranes are not cost effective and are currently with low lifetime

- Technology Gap Analysis Report is due September 1st, 2016
- Initial Gap Analysis draft completed: internal review

Progress Summary

- Techno-Economic Analysis Submitted on June 30, 2016
- Gap Analysis to be submitted September 1, 2016
- Final Report (summary of TEA & Gap Analysis) to be submitted September 30, 2016

Discussion Topics

- Project Overview
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- Progress / Current Status
- **Future Development / Testing**

Future Development & Testing

- New membrane improvement concept development
  - Lower pressure membrane design
  - Conduct laboratory testing at supplier facilities
  - Conduct laboratory testing at GE test facilities
  - Economic assessment to be performed to determine feasibility
  - Research and development budget to be determined in January, 2017