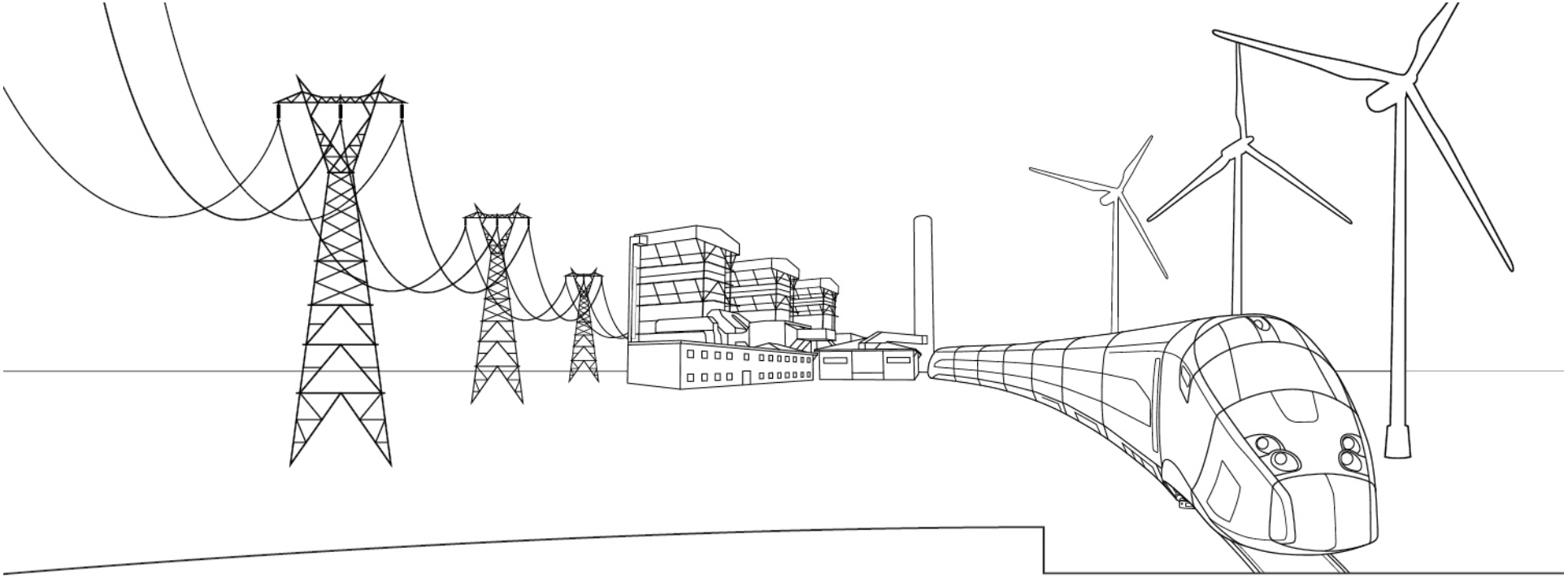

Improvement of Alstom's Chilled Ammonia Process using Membrane Technology

Large Pilot Scale Post Combustion CO_2 Capture
No. FE0026589

National Energy Technology Laboratory \ Department of Energy

October 28, 2015

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Shaping the future

Kick-Off Meeting Agenda

Introductions
Award overview
Alstom

- **Project Background**
  - **Brief overview of Recipient**
  - **Discussion of research leading to this award**
- **Project Objectives**
- **Project Team**
  - **Team member overviews**
- **Project Structure**
  - **Budget Period (length and cost)**
  - **Brief description of Tasks by Budget Period**
- **Project Schedule**
- **Project Management Plan**
  - **Milestones**
  - **Risk Management**
- **Deliverables**
- **Current Project Status**
- **Questions**
- **Closing Comments**

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Discussion Topics

- Project Background (Recipient Overview, Summary of Research)
- Project Objectives
- Project Team
- Project Structure
- Project Management Plan & Schedule
- Project Deliverables
- Current Status & Next Steps

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Project Background

Recipient Overview
Alstom

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Alstom: Three main activities in four sectors

Equipment & services for power generation
Alstom Thermal Power

Equipment & services for power transmission
Alstom Grid

Alstom Renewable Power

Equipment & services for rail transport
Alstom Transport

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Alstom Thermal Power
Turnkey solutions, Products and Services offering

Steam & Gas turnkey power plants

Air Quality Control Systems

Components for Gas, Steam & Nuclear

Services + Operation & Maintenance for Plants & Equipment

… for new power plants and the installed base

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CO2 Capture Technologies developed by Alstom

CO_2 capture technologies pursued by Alstom

Post-combustion

(New + retrofit)

- Advanced Amines Process
- Chilled Ammonia Process

2nd Generation

Regenerative Calcium Cycle (RCC)

Oxy-combustion

(New + retrofit)

- Oxy-combustion with ASU

2nd Generation

Chemical Looping Combustion (CLC)

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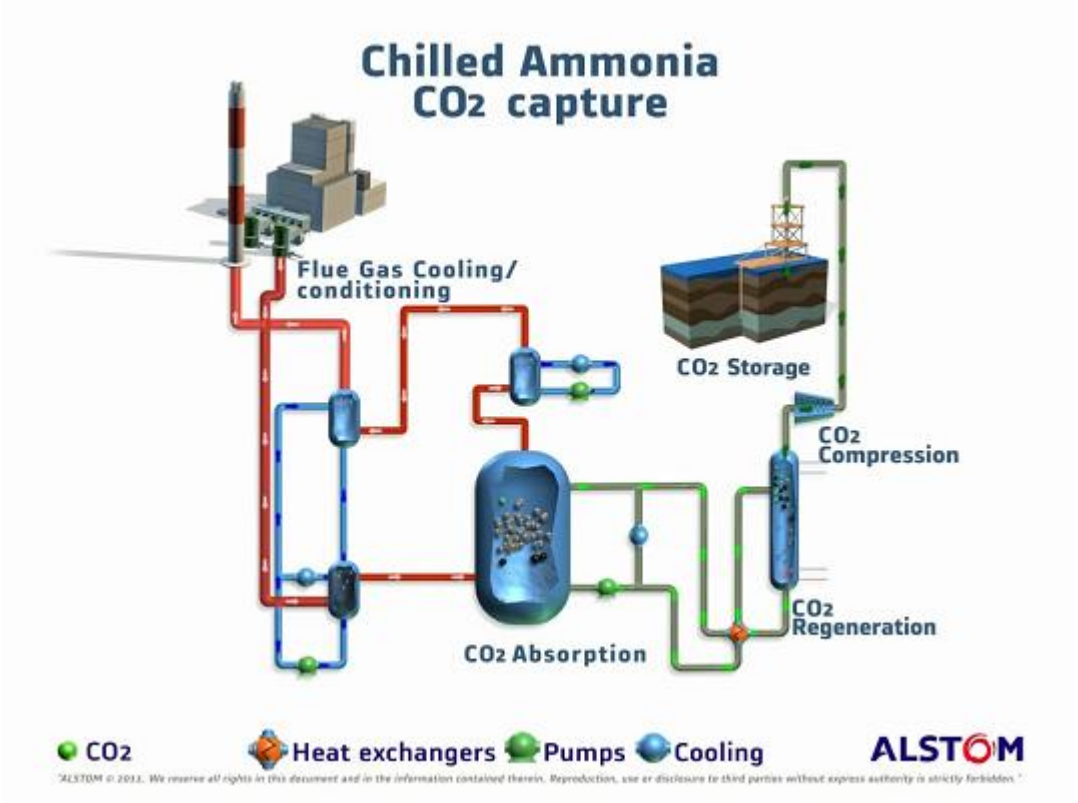
Chilled Ammonia Process (CAP) Features

Principle

- Ammonia based solution reacts with CO_2 of cooled flue gas
- Raising the temperature reverses this reaction, pressurized CO_2 is released, the solution is recycled



Advantages

- High CO_2 purity
- Tolerant to oxygen and flue gas impurities
- Stable reagent, no degradation or emission of trace contaminants
- Low-cost, globally available reagent
- Commercial by-product

Membrane Improvements - Summary

Membrane technology improvements for the CAP Large Pilot include:

- Reduction in CAP energy demand
  - Absorber chiller duty can be minimized significantly.
  - Stripper duty can be reduced significantly or eliminated.
  - These and other membrane concept for CAP can reduce overall specific steam energy by 20-30%.
  - Stripper and associated heat exchanger sizes can be reduced.
- Overall CAP Improvement
  - Projected overall reduction in cost of electricity depend upon membrane initial and lifecycle costs.
  - Phase I study to further define the project incremental change in cost of electricity with CAP membrane concepts.

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Project Background

Recipient Overview
Technology Center Mongstad

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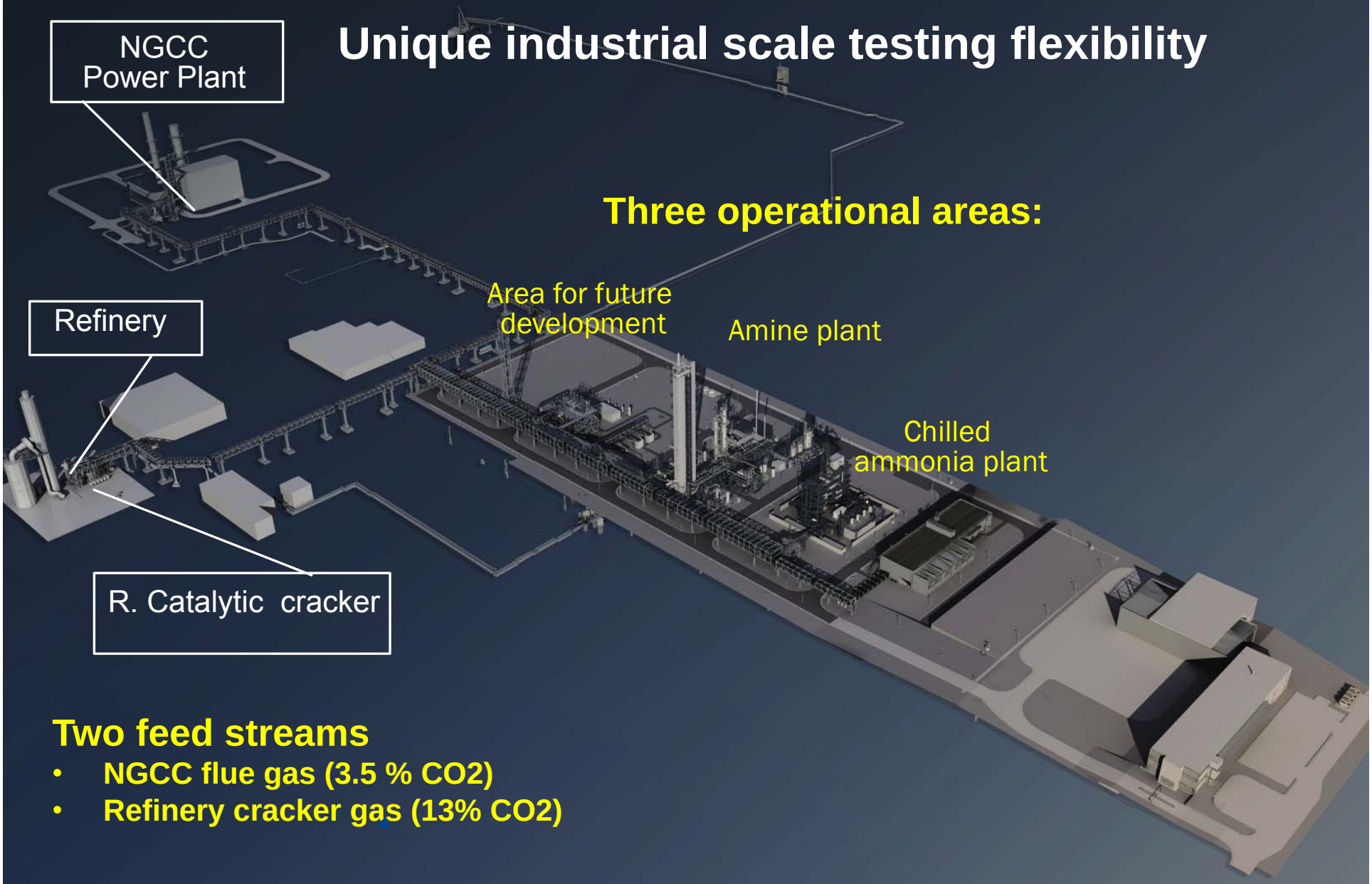
Technology Centre Mongstad (TCM)
Norway
GASSNOVA
75.12%
Statoil
20%
sasol
reaching new frontiers
2.44%
2.44%
TECHNOLOGY
CENTRE
MONGSTAD

Unique industrial scale testing flexibility

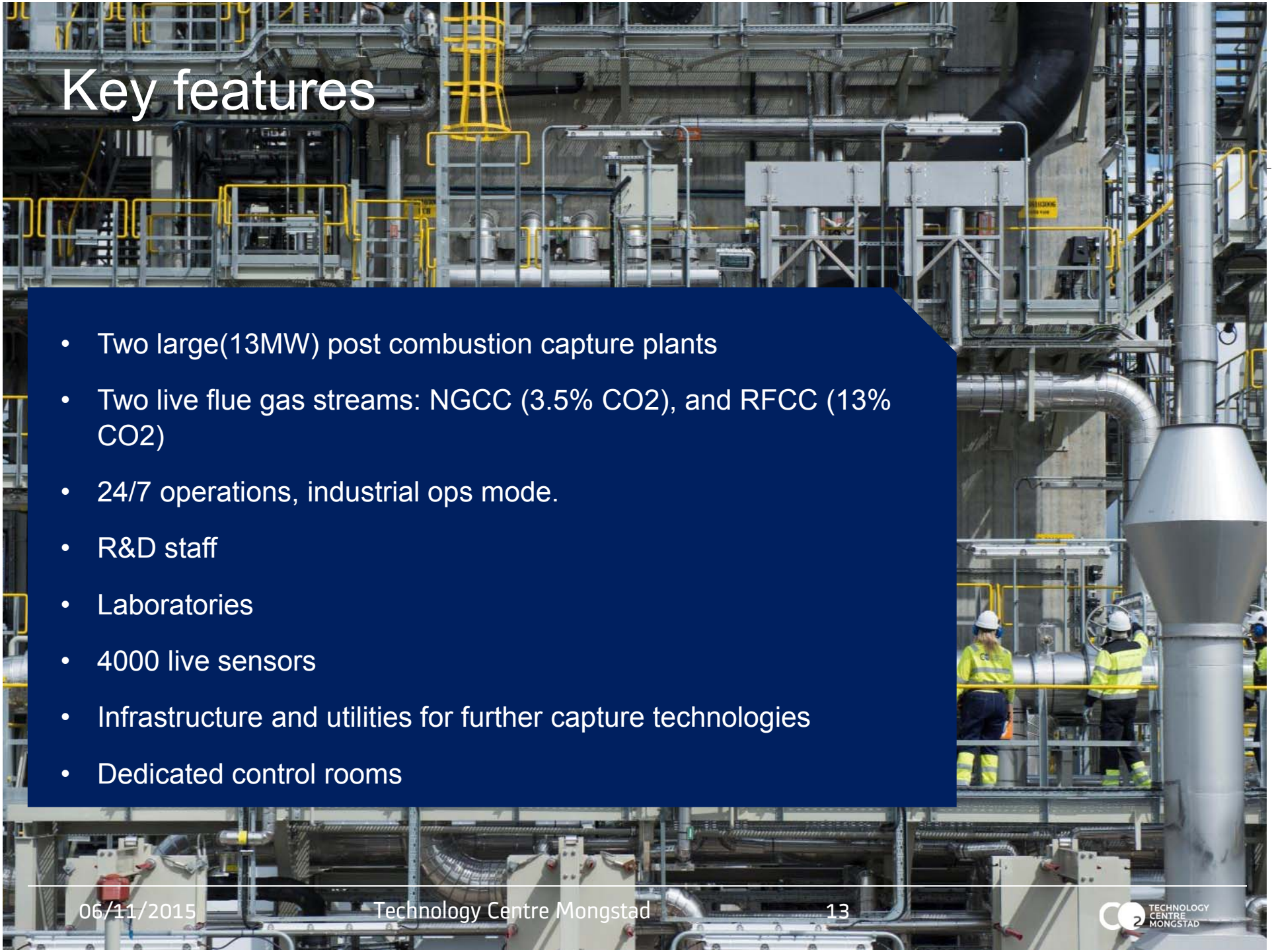


Three operational areas:

Two feed streams

- **NGCC flue gas (3.5 % CO2)**
- **Refinery cracker gas (13% CO2)**

Key features



- Two large(13MW) post combustion capture plants
- Two live flue gas streams: NGCC (3.5% CO2), and RFCC (13% CO2)
- 24/7 operations, industrial ops mode.
- R&D staff
- Laboratories
- 4000 live sensors
- Infrastructure and utilities for further capture technologies
- Dedicated control rooms

Chilled Ammonia Plant

Project Background

Research leading to Award

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Chilled Ammonia Process
Update on Alstom 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

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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

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Membrane Concepts for Development

- Membrane Concept 1: Electrodialysis for DCC-DCH to dissociate ammonium sulfate
- Membrane Concept 2: Reverse osmosis to concentrate stripper feed
- Membrane Concept 3: Reverse osmosis membrane for concentration of CO_2 wash bottoms

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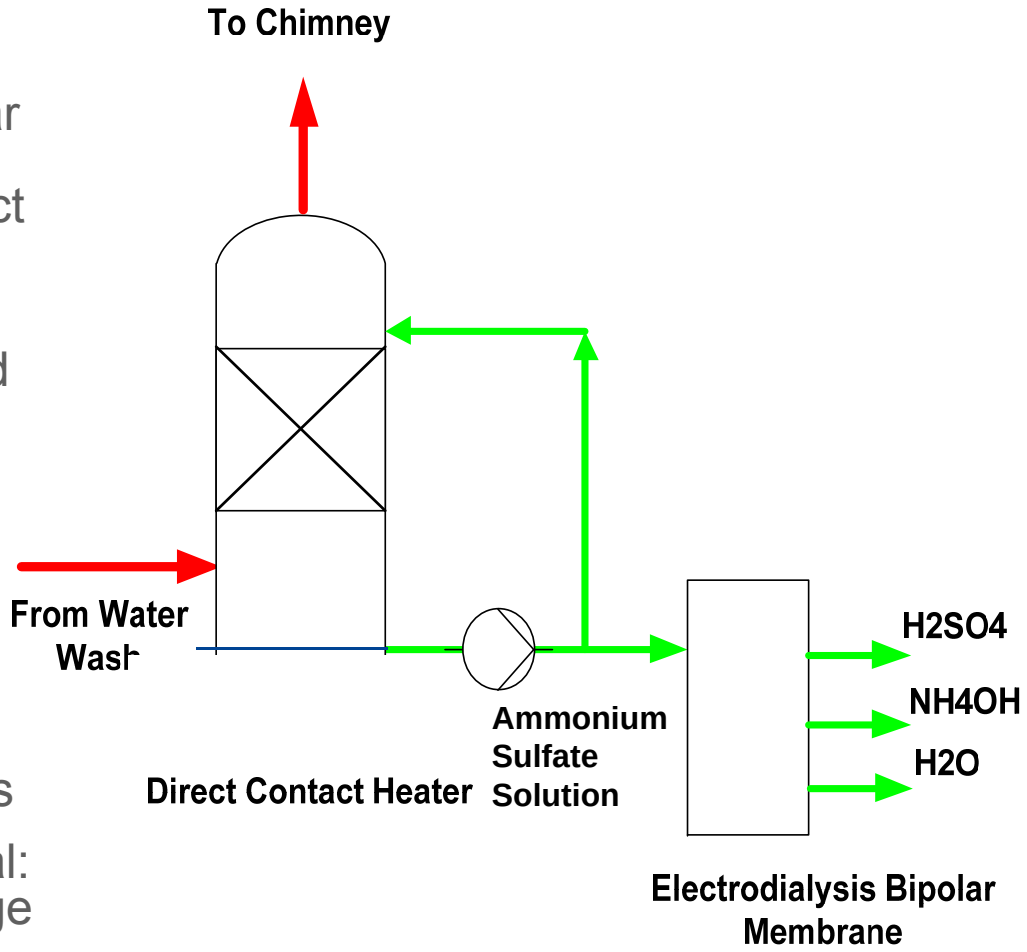
Improvement Concepts - Membrane Technology

Electrodialysis for Ammonium Sulfate Dissociation

- Benefits
  - Use of electrodialysis bipolar membrane to convert ammonium sulfate byproduct to sulfuric acid, aqueous ammonia, and water
    - 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



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CAP Membrane Development – Bench Scale ED Testing

- Bench-scale Testing
  - Bipolar membrane electrodialysis by ElectroSep
  - Membrane systems (Fumatech)
    - Anode exchange membrane
    - Cathode exchange membrane
    - Bipolar membrane
  - Initial Test program completed
    - Parametric test program using synthetic solutions
    - Results indicate initial membrane selection is feasible

Electrodialysis Test Unit
ElectroSep Test Facilities
Saint Lambert, Quebec

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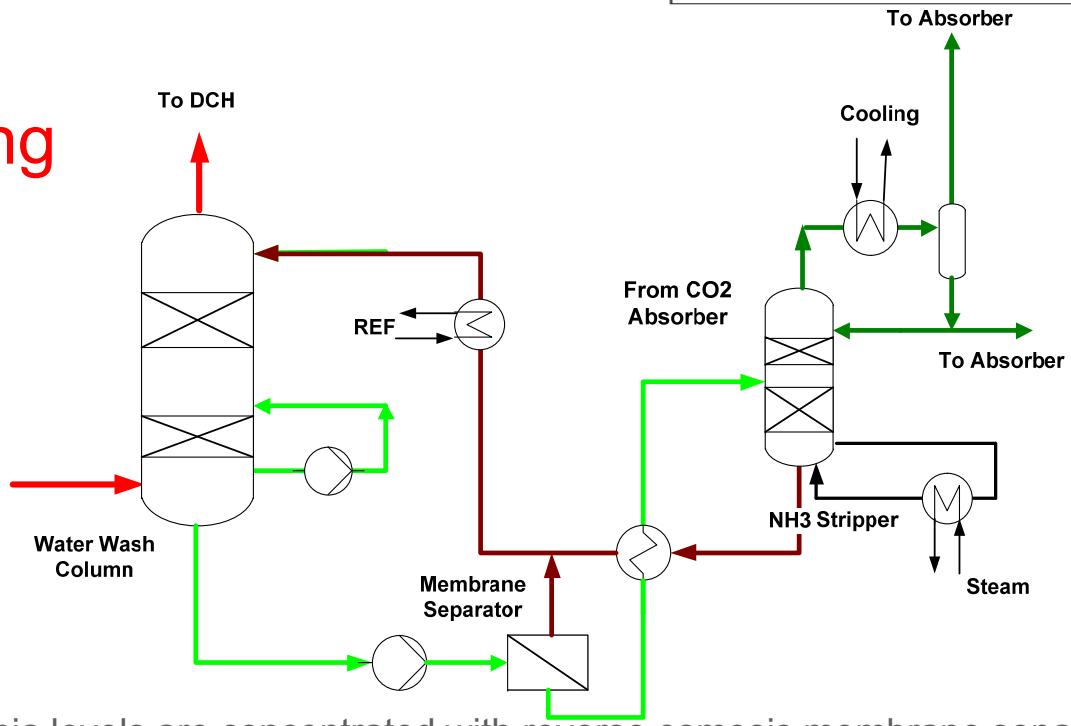
Improvement Concepts - Membrane Technology

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% or eliminated

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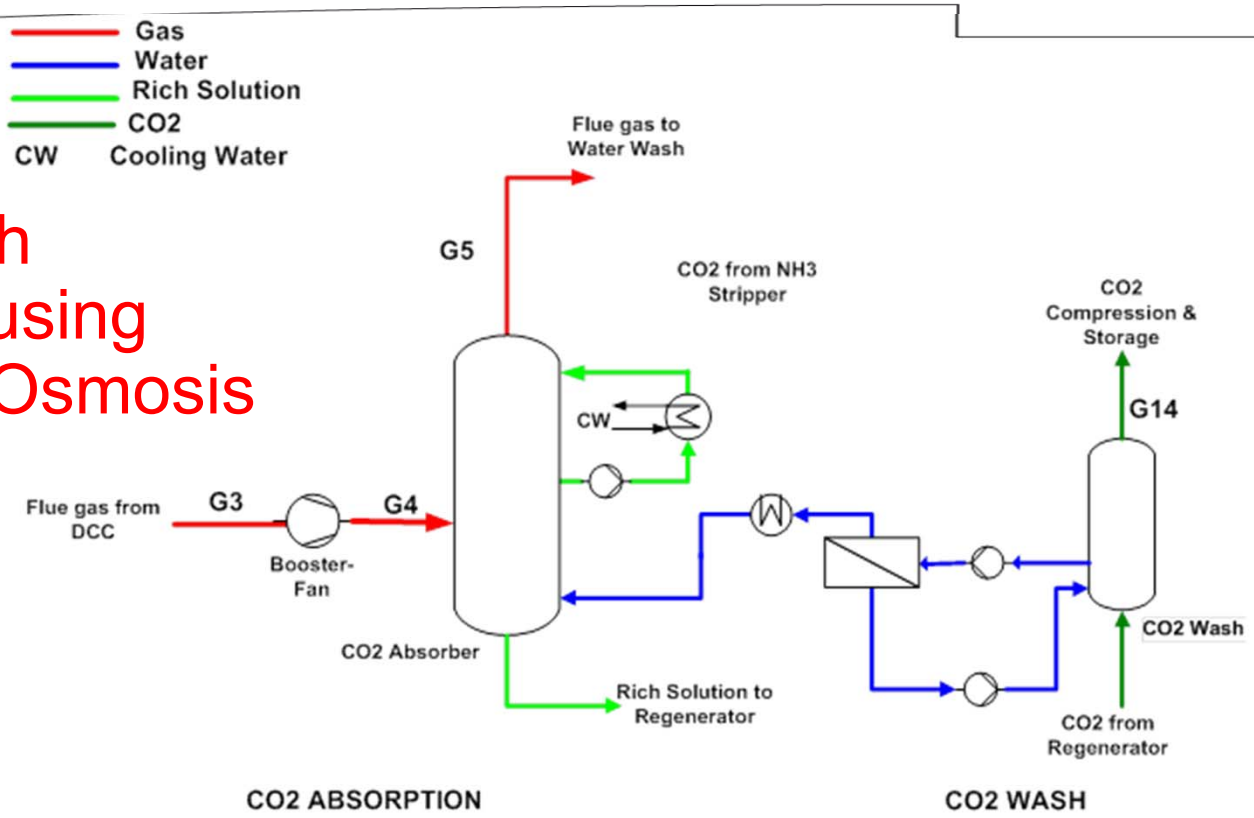
Improvement Concepts - Membrane Technology

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

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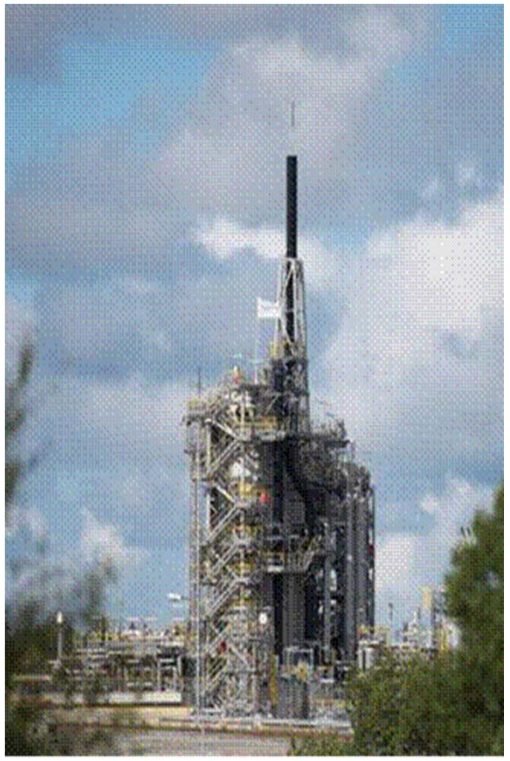
Proposed Next Steps

- Continue techno-economic assessment study based upon original performance projections
  - Elimination of ammonia stripper
  - Membrane ammonia rejection of >80%
  - Electrodialysis concept results suitable for scale-up to large scale pilot
- Development of new reverse osmosis membrane is not planned
- Complete reverse osmosis testing of commercial, spiral wound membrane element in parallel with study
- RO Membrane testing and membrane selection to be completed within the Phase 1 effort (as soon as possible)
- Report findings and status of test results periodically



CAP Validation Pilot on Gas
CO2 Technology Center Mongstad

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Discussion Topics

- Project Background (Recipient Overview, Summary of Research)
- **Project Objectives**
- Project Team
- Project Structure
- Project Management Plan
- Project Deliverables
- Current Status & Next Steps

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Project Objectives

- Implement several improvement concepts utilizing membrane technology at an existing CAP large-scale pilot plant to lower the overall cost of the Chilled Ammonia Process (CAP) CO_2 capture technology.
- Leverge CAP experience in collaboration with Technology Centre Mongstad, the Host Site, which operates an existing CAP large pilot facility (approximately 15 MWe equivalent) in Norway.
- Complete a preliminary techno-economic assessment (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.

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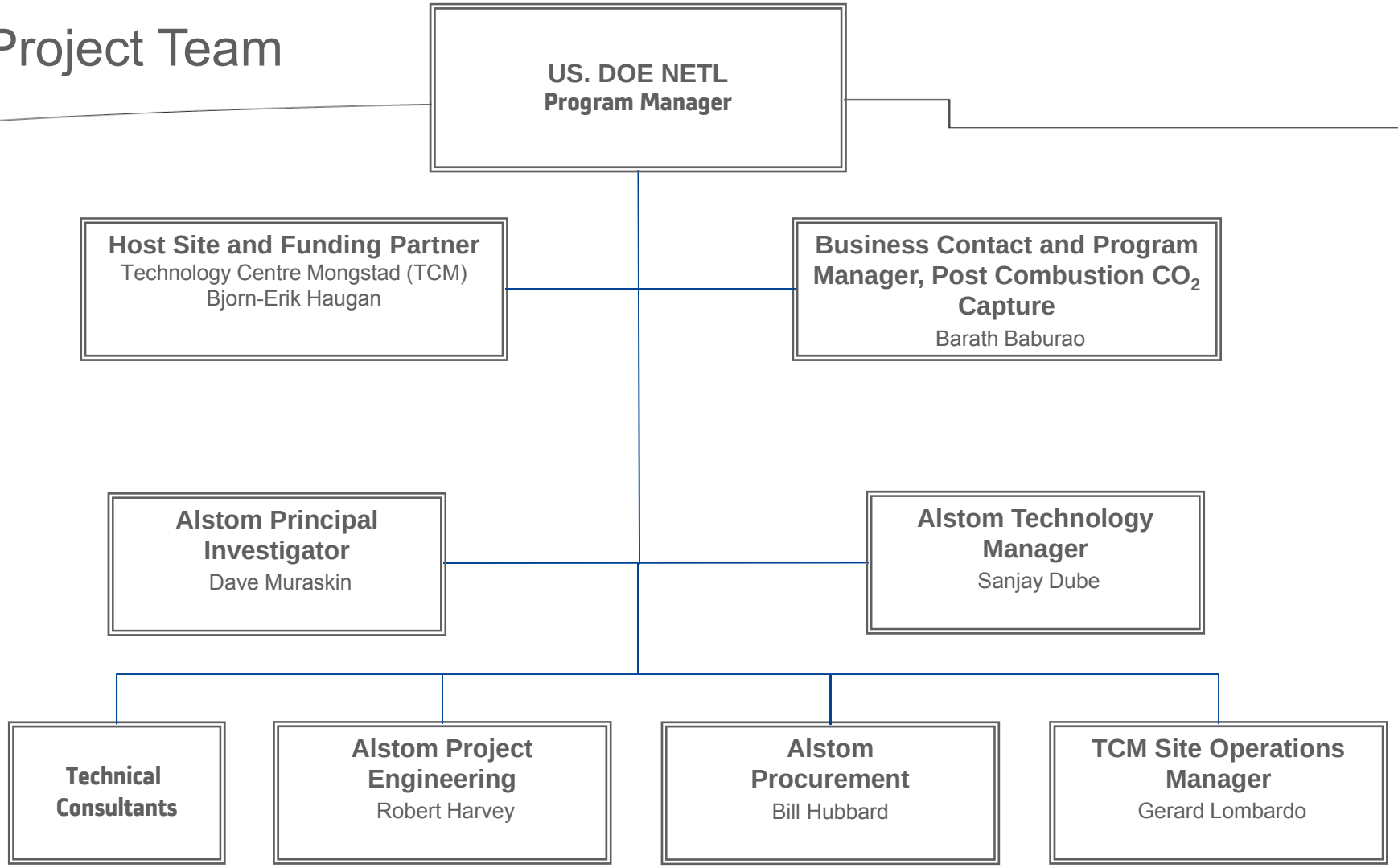
Project Team



- ElectroSep
- General Electric Power & Water/Purecowater
- Georgia Tech

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Project Structure-Budget Period (Length and Cost)

Phase 1 Funding Profile

PHASE 1	1-Oct-15	1-Nov-15	1-Dec-15	1-Jan-16	1-Feb-16	1-Mar-16	1-Apr-16	1-May-16	1-Jun-16
DOE NETL Funding Profile	$0	$123,173	$246,347	$369,520	$492,694	$615,867	$739,041	$831,421	$923,801
Project Forecast	$0	$166,231	$332,462	$498,694	$664,925	$831,156	$997,387	$1,122,061	$1,246,734

Majority of work completed by March 31, 2016 with submission of reports.

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Project Structure-Task by Budget Period

- **Task 1.0 Project Management and Planning**

  - Schedule Issue for Phase 1
  - Monthly Schedule Update
  - Monthly Budget Update
  - Schedule issue for Phase 2
  - Monthly Update Reports
  - Papers and Conference

- **Task 2.1 Phase 1 Design**

  - PFD for 550 MW TEA
  - PFD for 15 MW Pilot
  - Mass Balance for 550 MW TEA
  - Mass Balance for 15 MW Pilot
  - Data sheet for 15 MW Pilot
  - Equipment Summary Sheet for 550 MW TEA

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Project Structure- Task by Budget Period

- **Task 2.2 Cost and Schedule for Phase** 2
- Cost of fabricating skids and shipping to TCM
- Cost of Installation and Commissioning Skids
- Cost of Operating Skids for Testing period
- Cost to decommission Skids
- **Task 2.3 Issue Reports and Analysis**
- Issue TEA addressing 3 Concepts
  - Elimination of CAP Ammonia Sulfate Byproduct by ED
  - Reduction of CAP Ammonia Stripper Energy by Membrane
  - Reduction of CAP CO2 regeneration Energy
- Issue Gap Analysis identifying missing data
- Issue a Topical Report and Firm Cost for testing 3 Concepts at TCM

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Discussion Topics

- Project Background (Recipient Overview, Summary of Research)
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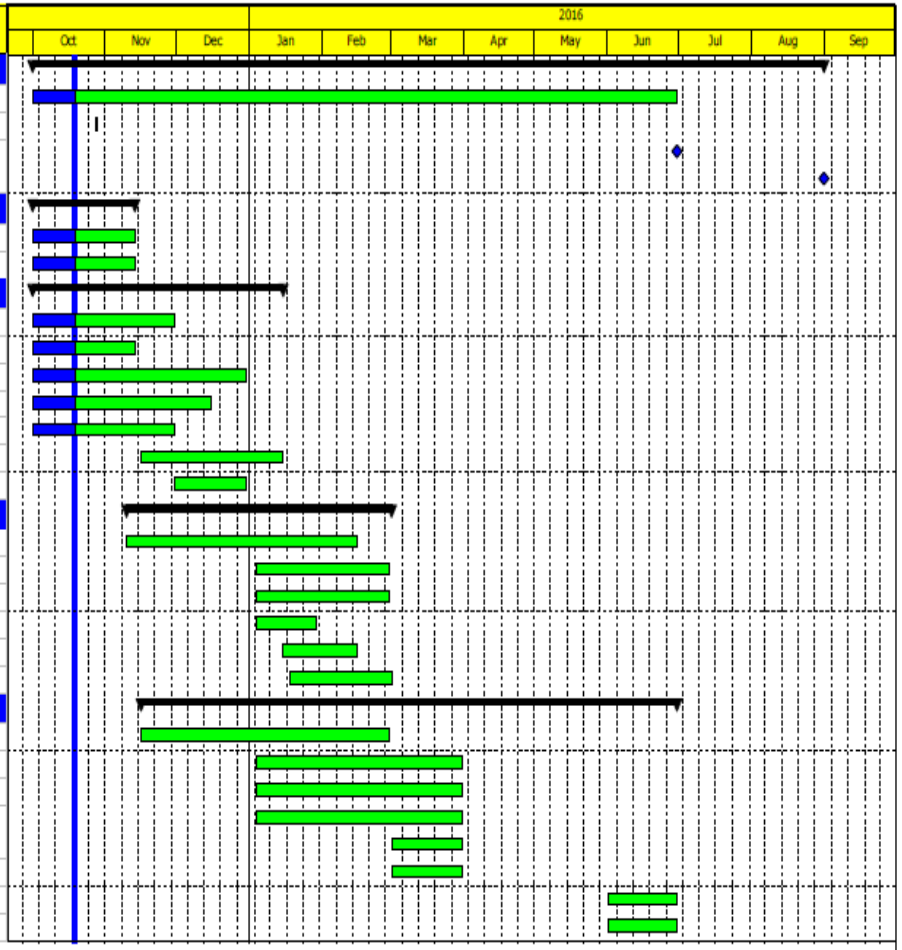
PMP- PROJECT SCHEDULE

Activity ID	Activity Name	Original Duration	Start	Finish
Task 1.1 - Project Management		**219**	**01-Oct-15 A**	**31-Aug-16**
A1100	Phase 1 Monthly Reports (P/E & Planning)	189	01-Oct-15 A	30-Jun-16
A1980	Kick-off Meeting	1	28-Oct-15*	28-Oct-15
A2010	Issue GO/NO GO for Phase 2	0		30-Jun-16*
A1970	Issue Notification of Phase 2 Award	0		31-Aug-16*
Task 1.2 - Briefings, Reports, & Conferences		**22**	**01-Oct-15 A**	**13-Nov-15**
A1080	Phase 1 Schedule (Initial Setup)	22	01-Oct-15 A	13-Nov-15
A1090	Project Management Plan for Phase 1 - Revise	22	01-Oct-15 A	13-Nov-15
Task 2.1 - Phase 1 Design		**90**	**01-Oct-15 A**	**15-Jan-16**
A1120	Process Flow Diagrams 550 MW (1 PFD w/all 3 concepts)	20	01-Oct-15 A	30-Nov-15
A1130	Mass Balances 550MW (1 MB w/3 concepts)	20	01-Oct-15 A	13-Nov-15
A1160	Steam Cycle Simulation (Windsor/Weisbaden) (500 MW)	41	01-Oct-15 A	30-Dec-15
A1410	Process Flow Diagrams 15 MW Pilot	20	01-Oct-15 A	15-Dec-15
A1420	Mass Balances 15MW (w/3 concepts)	20	01-Oct-15 A	30-Nov-15
A1200	Equipment Sizing & Summary Sheet (500 MW)	39	16-Nov-15	15-Jan-16
A2000	Data Sheets for 15 MW Skids (1 ea. concept)	21	30-Nov-15	30-Dec-15
TAsk 2.2 - Phase 2 Cost Estimate & Schedule Development		**75**	**10-Nov-15**	**01-Mar-16**
A1340	Operating Cost Summary Spreadsheet-TEA-550 MW	64	10-Nov-15	15-Feb-16
A1390	Phase 2 Schedule	41	04-Jan-16*	29-Feb-16
A1540	Skid Design/Engineering (Assume Vendor) 15 MW (1 ea. ur	41	04-Jan-16	29-Feb-16
A1580	RFQ and Bids for Skids 15 MW (1 ea. concept)	20	04-Jan-16	29-Jan-16
A1230	Cost for 550 MW Membrane Systems Plant	22	15-Jan-16*	15-Feb-16
A1320	Cost Estimate for TEA (Development of Cost of Elec. COE)	32	18-Jan-16	01-Mar-16
Task 2.3 - Preliminary Techno-economic Analysis (TEA)		**157**	**16-Nov-15**	**30-Jun-16**
A1300	Phase 1 EHS - Preliminary	70	16-Nov-15	29-Feb-16
A1240	Techno-Economic Analysis Report-550 MW Baseline + 3 cor	64	04-Jan-16*	31-Mar-16
A1260	Technology Gap Analysis (500 MW)	64	04-Jan-16	31-Mar-16
A1400	Project Management Plan for Phase 2	64	04-Jan-16*	31-Mar-16
A1310	Renewal Application Summary	23	01-Mar-16	31-Mar-16
A1380	Topical Report on Pilot Plant	23	01-Mar-16*	31-Mar-16
A1280	Executed Financial Arrangements	22	01-Jun-16	30-Jun-16
A1290	Executed Site Host Agreements	22	01-Jun-16	30-Jun-16



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PMP- MILESTONES LOG for WORK

Milestone	Budget Period	Task	Milestone Description	Planned Completion	Verification Method
1	1	1.1	Kick-Off Meeting	10/28/2015	Meeting
2	1	1.1	Updated Project Schedule	10/28/2015	Presentation
3	1	1.1	Updated Project Management Plan	11/15/2015	Report File
4	1	2.1	Mass Balance 550 MW (C, S, and Water) for TEA	11/15/2015	Report File
5	1	2.1	Mass Balance 15 MW (C, S, and Water) for Pilot plant	11/30/2015	Report File
6	1	2.1	Steam Cycle Simulations for TEA	11/30/2016	Report File
7	1	2.1	PFD & Block Flow diagram 550 MW TEA	11/30/2015	Report File
8	1	2.1	PFD & Block Flow diagram 15 MW Pilot	12/15/2015	Report File
9	1	2.1	Data Sheet for 15 Mw skids (1 each concept)	12/30/2015	Report File
10	1	2.1	Equipment Summary Sheet 550 MW	1/15/2016	Report File
11	1	2.2	RFQ Skids 15 MW	1/4/2016	Report File
12	1	2.2	Vendor Engineering Skids complete 15 MW	2/28/2016	Report File
13	1	2.2	Capital Cost Estimate for TEA-550 MW	2/15/2016	Report File
14	1	2.2	Operating Cost Estimates for TEA-550 MW	2/15/2016	Report File
15	1	2.2	Cost of Electricity for TEA-550 MW	3/1/2016	Report File
16	1	2.2	Itemizerized Cost Summary-550 MW	3/15/2016	Report File
17	1	2.2	Phase 2 Schedule	2/29/2016	Report File
18	1	2.3	Phase 1 EHS preliminary assessment	2/29/2016	Report File
19	1	2.3	Topical Report with Itemized Cost Summary for Phase 2	3/31/2016	Presentation
20	1	2.3	Updated PMP for Phase 2	3/31/2016	Report File
21	1	2.3	TEA Report 550 MW	3/31/2016	Presentation
22	1	2.3	GAP Analysis	3/31/2016	Presentation
23	1	2.3	Application for Renewal (write-up)-Phase 2	3/31/2016	Presentation
24	1	2.3	Executed Financial Arrangments	6/30/2015	Report File
25	1	2.3	Executed Site Host Agreements	6/30/2015	Report File
na	na	na	GO/NO GO for Phase 2	6/30/2015	Notification
na	na	na	Notification of Phase 2 Award	8/31/2016	Notification

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Agenda

- Project Background (Recipient Overview, Summary of Research)
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- **Project Deliverables**
- Current Status & Next Steps

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Project Deliverables

Updated PMP and Schedule	Nov 13, 2015
Phase 1 Technology Engineering Design and Economic Analysis	March 31, 2016
Phase 1 Technology Gap Analysis	March 31, 2016
Phase 1 EH&S	March 31, 2016
Phase 1 Topical Report and Cost for Phase 2	March 31, 2016
PMP for Phase 2	March 31, 2016
Completed Contract Agreements (Site Host, Financial, Representations and Certifications)	June 30, 2016

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Agenda

- Project Background (Recipient Overview, Summary of Research)
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- **Current Status**

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Current Project Status

Tasks	Status
Agreements with sub-recipients	In-progess
Project Schedule (Level 1)	Developed
Project Schedule (Level 3)	In-progress
PMP	In-progress
Process Design Basis	In-progress
PFD	In-progress
Mass Balances and Simulations	In-progress

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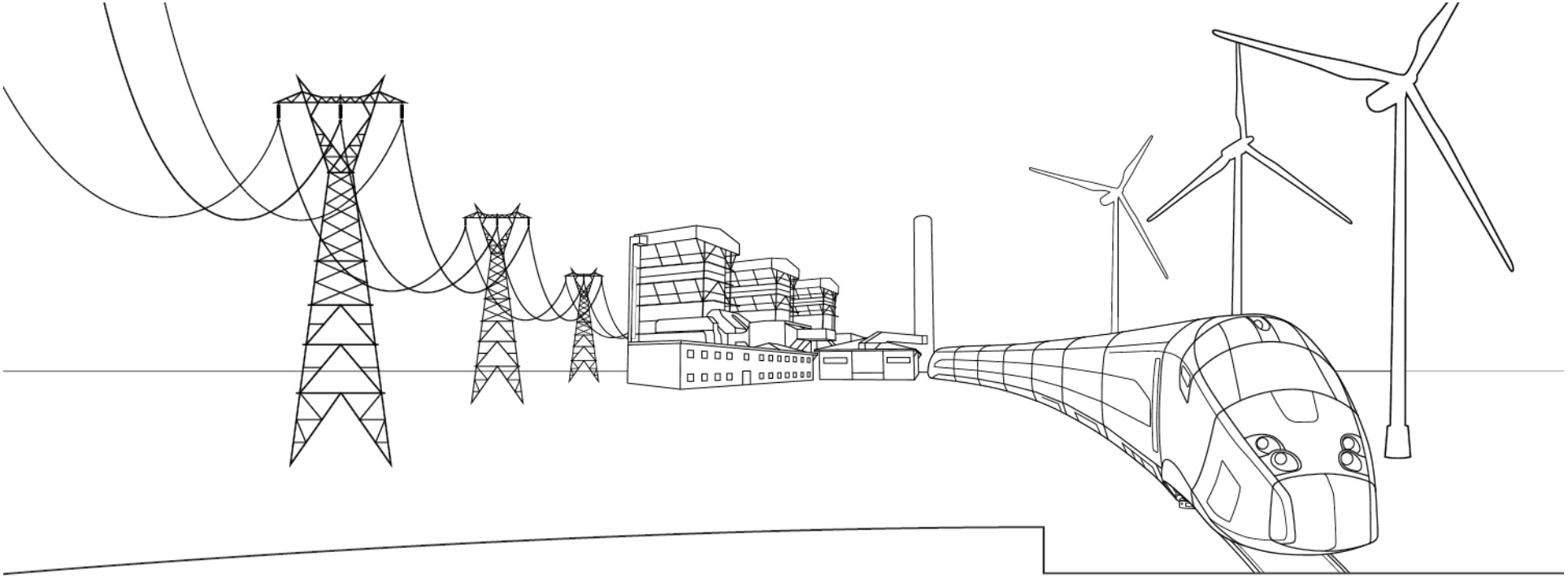

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