Application of a Heat Integrated Post-combustion CO_2 Capture System with Hitachi Advanced Solvent into Existing Coal-Fired Power Plant

Award Number DE-FE0007395

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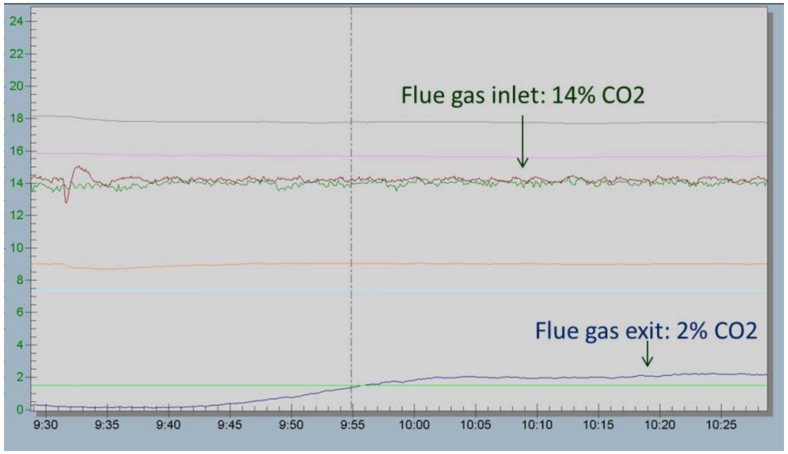
University of Kentucky - Center for Applied Energy Research

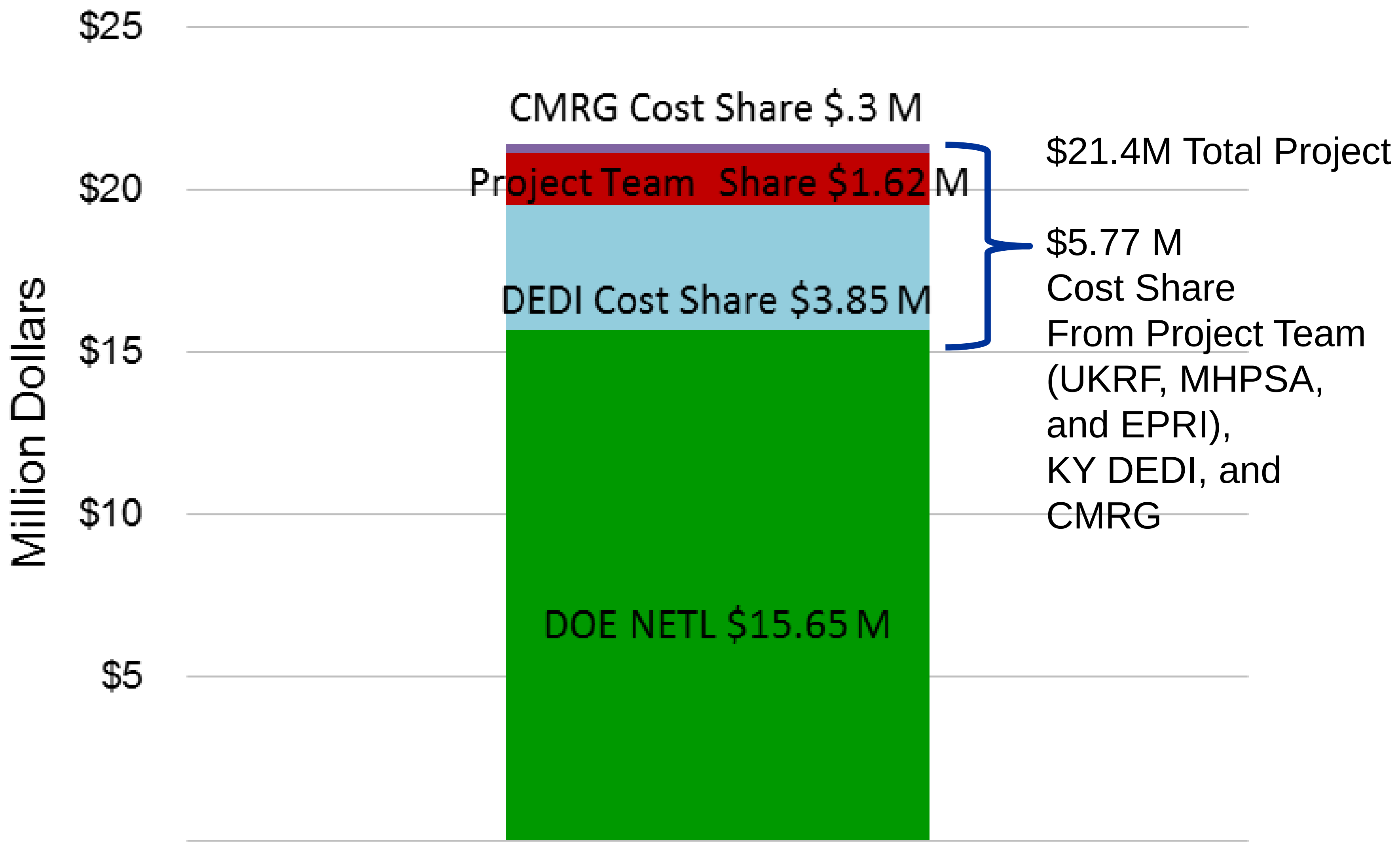
http://www.caer.uky.edu/powergen/home.shtml



Project Overview

- 2 MWth (0.7 MWe) advanced post-combustion CO_2 capture pilot
- Catch and release program
- Designed as a modular configuration
- Testing at Kentucky Utilities E.W. Brown Generating Station, Harrodsburg, KY, approximately 30 miles from UKy-CAER
- Includes several UKy-CAER developed technologies
- Two solvent testing campaigns (MEA baseline and MHPS's advanced H3-1)

Project Funding



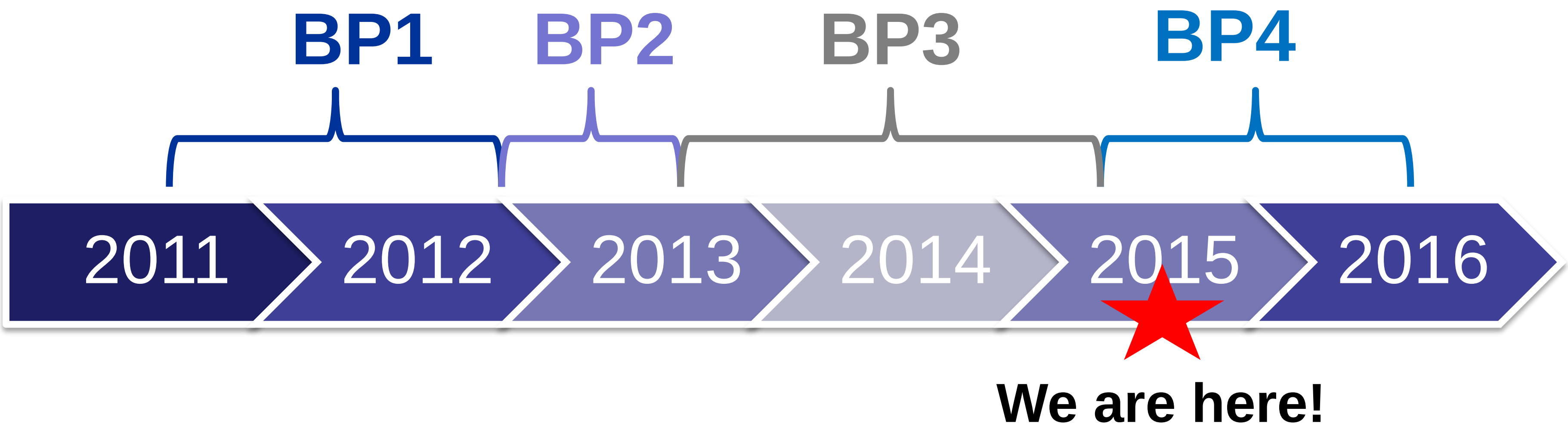
Project Performance Dates

BP1: October 1, 2011 to January 31, 2013 [16 months]

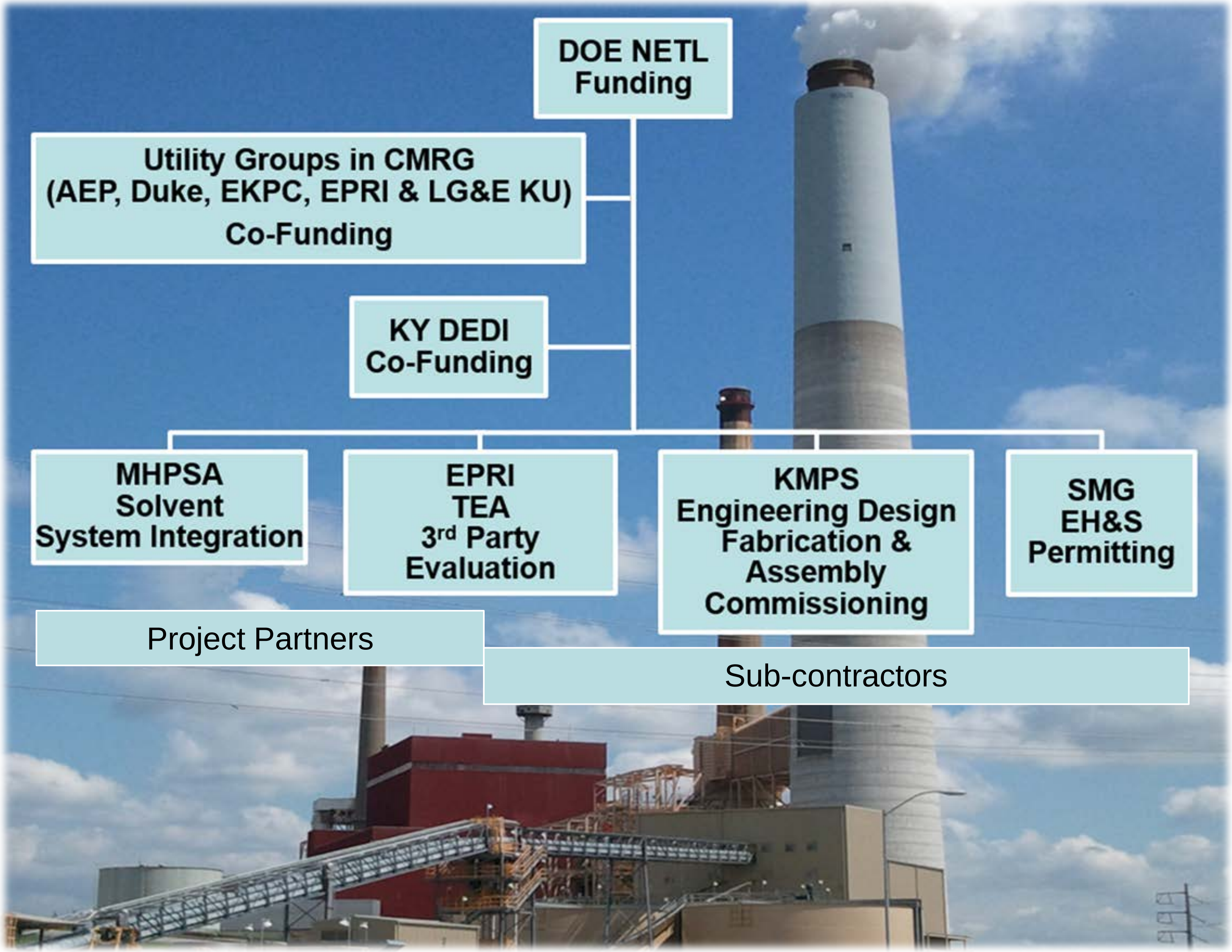
BP2: February 1, 2013 to August 31, 2013 [7 months]

BP3: September 1, 2013 to March 31, 2015 [19 months]

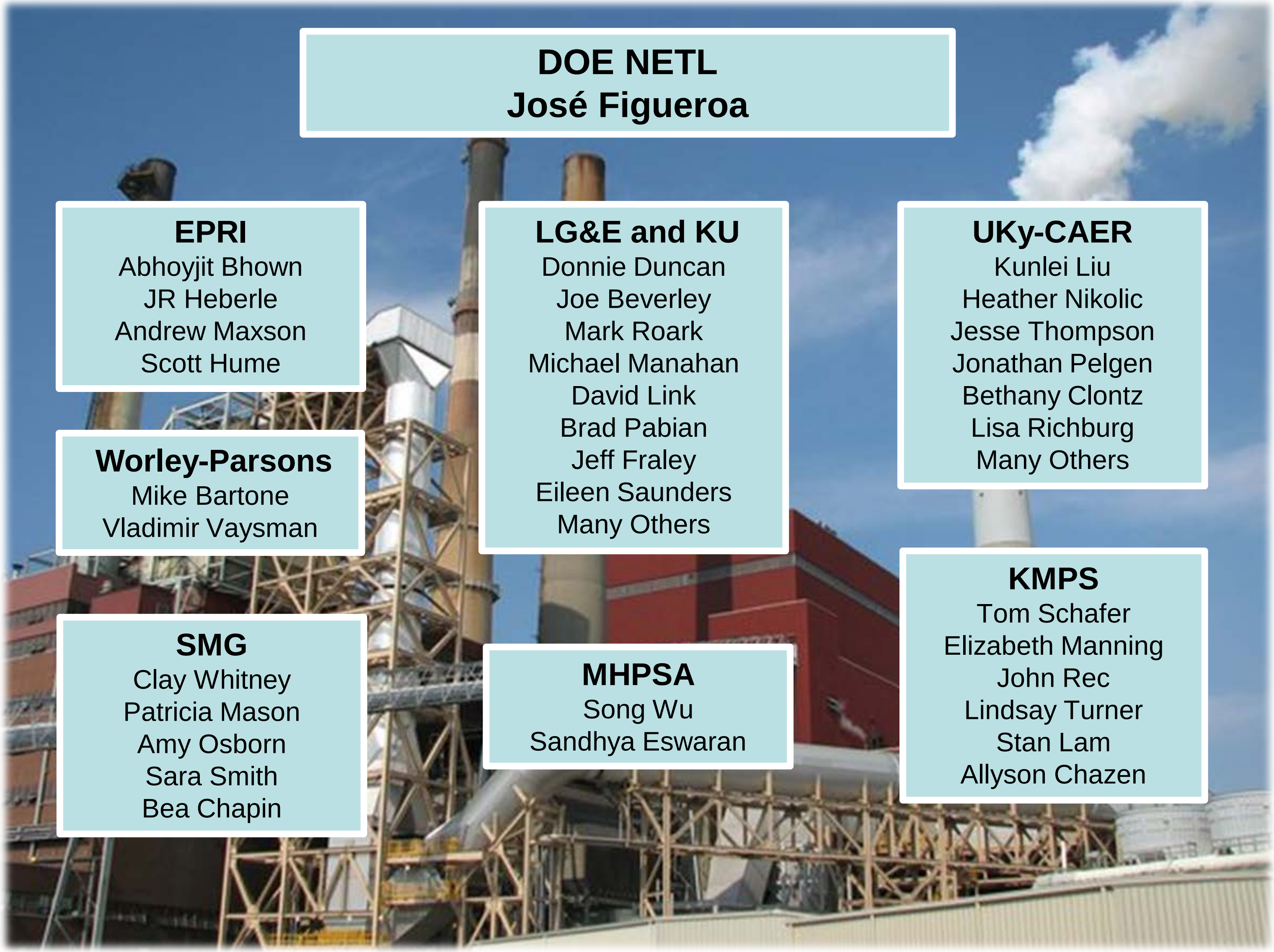
BP4: April 1, 2015 to September 30, 2016 [18 months]



Project Organization



Project Participants



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EPRI
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LG&E and KU
Donnie Duncan
Joe Beverley
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MHPSA
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Project Goal and Objectives

Goal

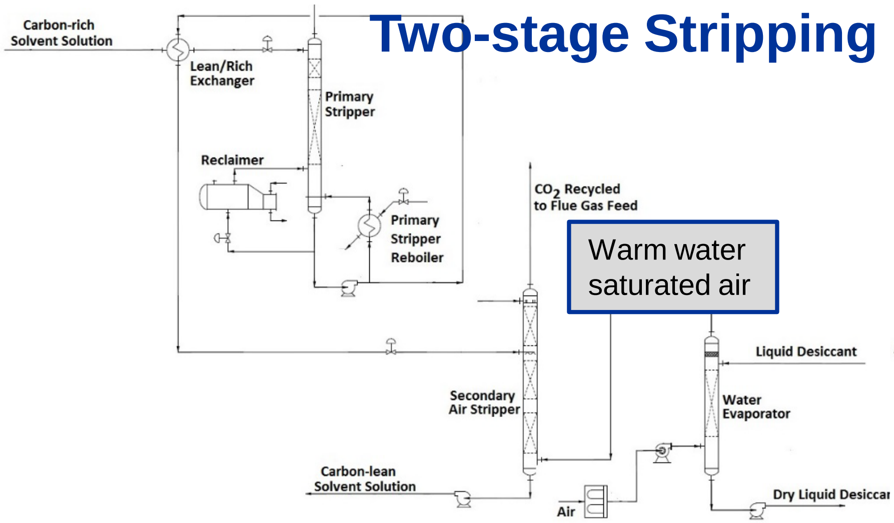
- Develop a pathway to achieve the US DOE NETL post-combustion CCS target of 90% CO_2 capture with a cost increase (LCOE) of less than 35% ($40/tonne CO_2 captured)

Objectives

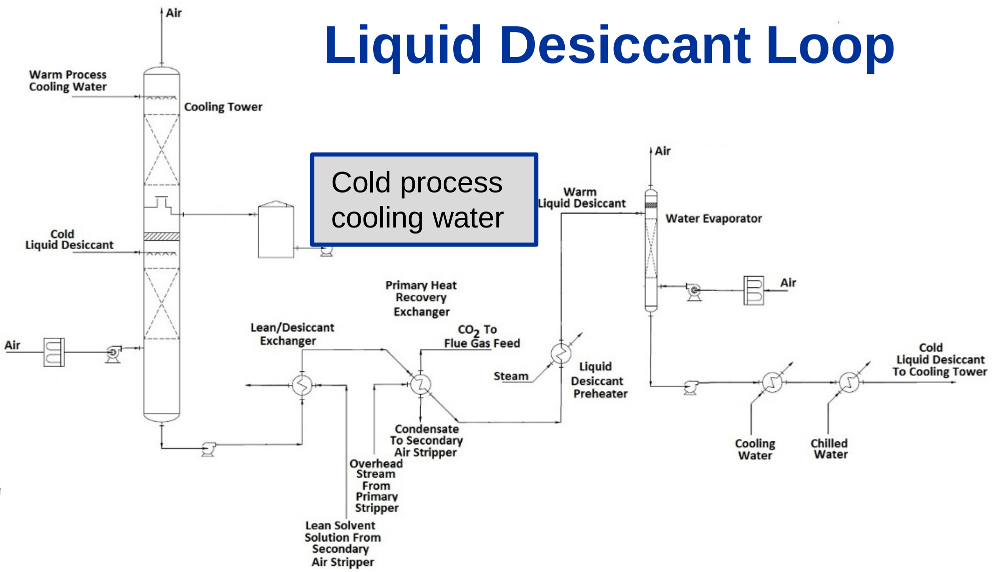
- To demonstrate a heat-integrated post-combustion CO_2 capture system with an advanced solvent
- To collect corrosion data leading to selection of appropriate materials of construction for a 550 MWe commercial-scale carbon capture plant
- To gather data on solvent degradation, water management, system dynamic control and other information during the long-term verification campaigns
- To provide data and design information for larger-scale pilot plant followed by a commercial-scale project

Technology Description

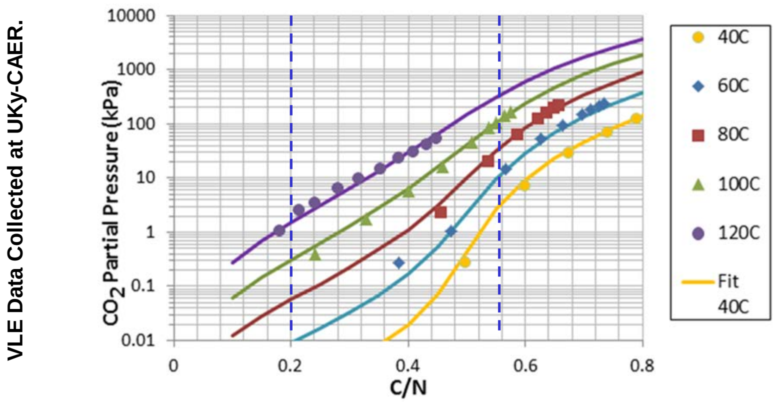
Two-stage Stripping



Liquid Desiccant Loop



■ Non-linear chemical absorption - desorption relationship between carbon loading and CO_2 partial pressure



■ Non-linear relationship between relative humidity for wet air and the wet-bulb temperature

■ Provide warm, water-saturated air to the secondary air stripper and provide cooling water to the system: <u>Heat Recovery</u>

Previous Technology Development

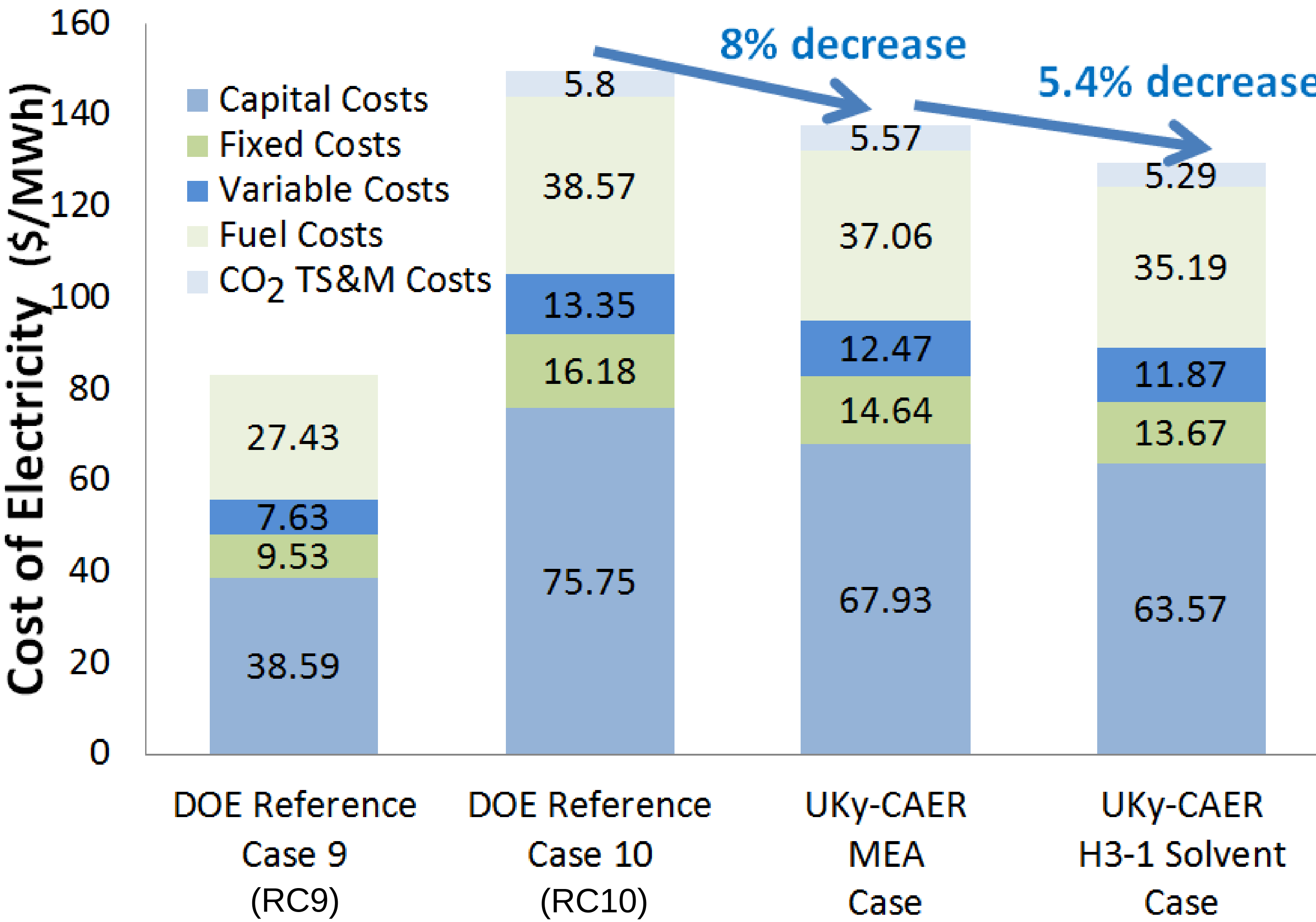
MHPS's H3-1 advanced solvent has a lower regeneration energy (33%), a higher CO_2 absorption capacity (30%), and a lower degradation rate than 30 wt% MEA.

Experimental data for H3-1 was collected at UKy-CAER lab to fill in data gaps and complete an Aspen kinetic model.

Emissions Sampling

Solvent emissions and degradation studies have been conducted using UKy-CAER bench-scale unit and analytical testing lab. Solvent degradation analytical methods have been developed and are in practice.

Technical and Economic Advantages



55.8% increase in Cost of Electricity from RC9

$46.93/tonne CO_2 Captured, lower than RC10 by $14.38/tonne CO_2

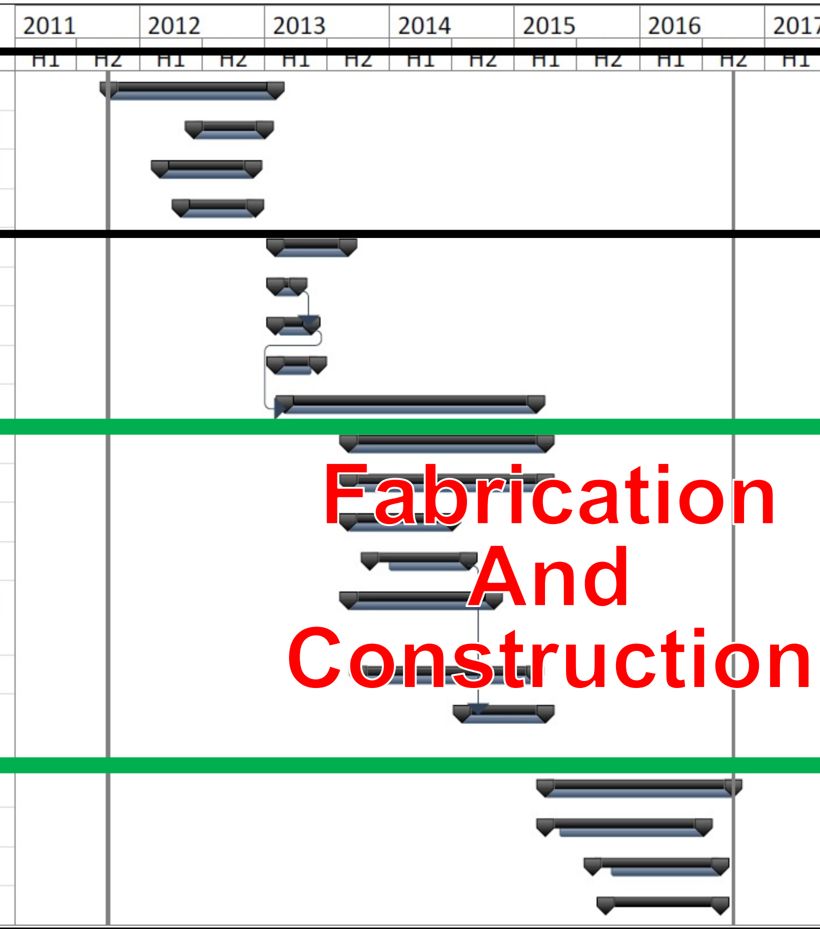
All at 90% capture rate and CO_2 compression to 2200 psia.

Technical and Economic Challenges

- Liquid desiccant loop applicability to large-scale power plant
- Verification of low solvent degradation with air stripper exposure through long-term pilot-scale testing (MEA and H3-1)
- Validation of emission control system performance during long-term steady state and dynamic campaigns
  - Periodic gas sampling and analysis will be conducted by UKy-CAER and EPRI, separately. Process modifications will be implemented as needed.
- Solvent losses greater than expected due to operational excursions during test campaign
  - Conduct root-cause analysis and implement modifications as necessary.

Project Schedule

Task Name	Start	Finish
1 Project Management and Planning Budget Period 1	10/3/11	1/31/13
2 Detailed Update of Techno-Economic Analysis	6/8/12	12/31/12
3 Initial EH&S Assessment	3/1/12	11/27/12
4 Basic Process Specification and Design	5/1/12	12/3/12
5 Project Management and Planning Budget Period 2	2/1/13	8/31/13
6 Slipstream Site Survey	2/1/13	4/8/13
7 Finalized Engineering Specification and Design	2/1/13	5/16/13
8 Test Condition Selection and Test Plan	2/1/13	6/4/13
9 System Engineering Update and Model Refinements	3/1/13	3/4/15
10 Project Management and Planning Budget Period 3	9/3/13	3/31/15
11 Update of EH&S Assessment	9/3/13	3/31/15
12 Site Preparation	9/1/13	7/1/14
13 Fabrication of Slip-stream Modules	11/4/13	8/18/14
14 Procurement and Installation of Control Room/Field Lab Section	9/3/13	10/31/14
15 Fabrication of Corrosion Coupons	10/1/13	2/28/15
16 Slipstream Facility Erection, Start-up, Commissioning and Shakedown	7/31/14	3/31/15
17 Project Management and Planning Budget Period 4	4/1/15	9/30/16
18 Slip-stream Test Campaign	4/1/15	7/5/16
19 Final Update of Techno-Economic Analysis	8/17/15	8/23/16
20 Final EH&S Assessment	9/24/15	8/23/16



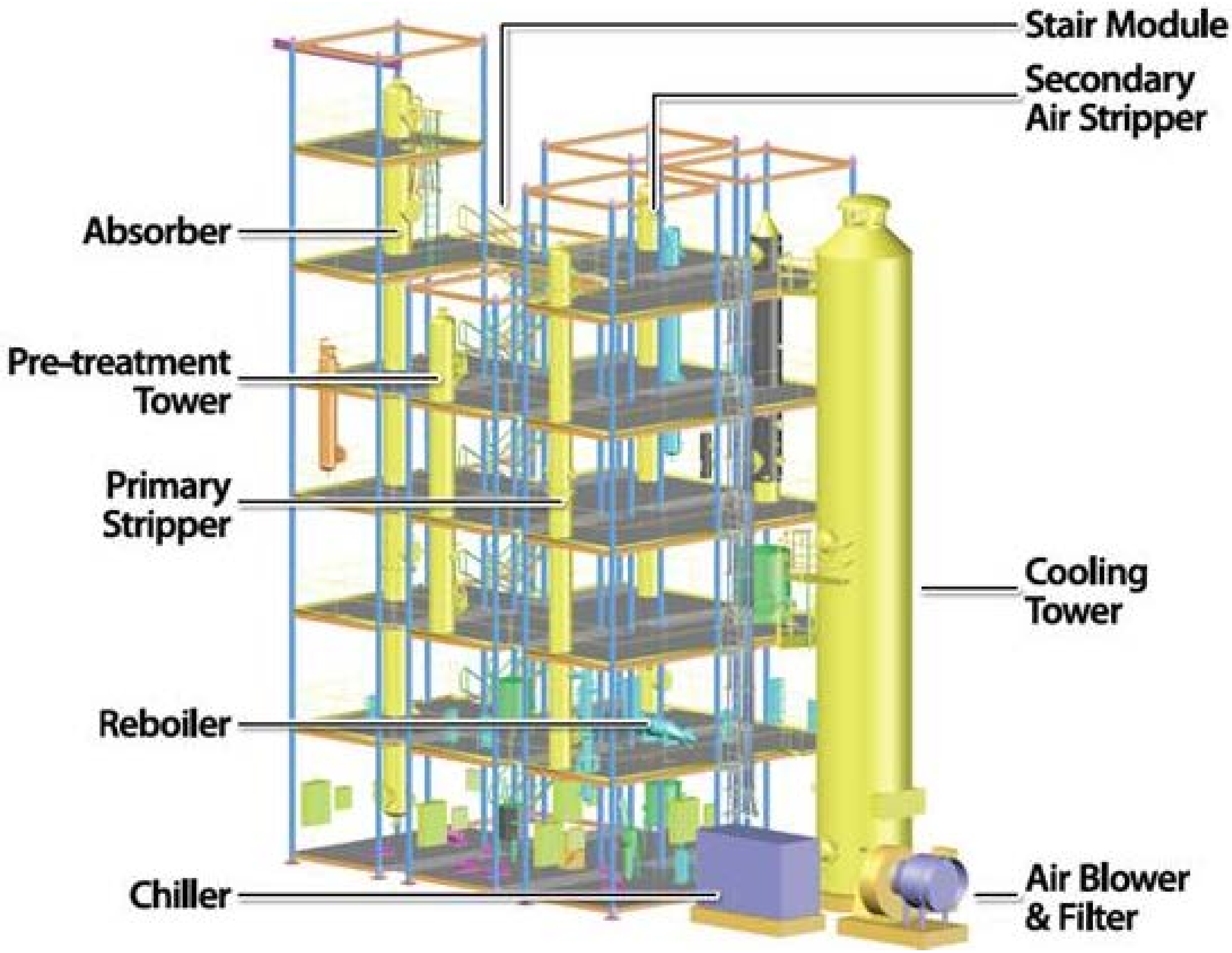
Project Key Milestones

BP	Title	Completion Date
1	Preliminary Technical and Economic Analysis that details the viable technical merit of UKy-CAER CCS process for slipstream scale study	12/18/12
1	Initial EH&S report that details environmental implication of slipstream operation and proposed mitigation for anticipated environmental safety obstacles to operation, if any	11/27/12
2	Finalize P&ID for slipstream modular unit fabrication	5/16/13
2	UKy-CAER Finalize Test Plan for slipstream campaigns with completed P&ID specifications	5/15/2013
3	Pouring of foundations for platform for slipstream modular units setup which meets engineering design load/specifications	9/11/14
3	KMPS fabricates slipstream modular units and delivers to EW Brown Generating Station for installation	8/28/14
3	Control Room/ Field Lab Trailer Assembled, Setup and Permitted	2/20/15
3	Tie-in piping with power plant complete	3/6/15
3	Slipstream pilot unit commissioning	3/31/15
4	MEA long term test campaign, 2000 hours of load-following run with 30 wt% MEA	11/20/15
4	H3-1 long term test campaign, 2500 hours of load-following run	7/5/16
4	Final Technical Economic Analysis and Final EH&S Assessment	8/23/16
4	Project Final Scientific Report	9/30/16

Project Key Success Criteria

BP	Success Criteria	Percent Complete
1	A complete specification list for the proposed 2 MWth pilot slip-stream facility detailing major equipment sizing with mass and energy balances that will serve as a blueprint for the engineering design. The specification list will show that the proposed design is within the approved budget.	100%
2	A finalized detailed engineering process design package meeting the specifications from Task 4. The final package will include a ± 10% accuracy price estimate of the system that is within the project budget stipulated in the agreement.	100%
2	A completed preliminary test matrix plan for the slip-stream test campaign to achieve the program objectives and success criteria of the 2MWth (0.7 MWe) pilot slip-stream modular facility.	100%
3	Inspection of the pilot plant site that has been appropriately graded for temporary parking, driveways, and the platform foundation sufficient for pilot plant erection by subcontractors.	100%
3	Documented delivery of the slip-stream modules and control room/field lab onto the plant site according to the design and construction specifications.	100%
4	A heat-integrated post-combustion CO_2 capture system with (a) 15-25% less energy consumption compared to the DOE reference case using 30 wt% MEA; (b) partial CO_2 recycling to enhance gaseous CO_2 pressure at the absorber inlet; (c) much cooler recirculating cooling water compared to a conventional cooling tower at the same ambient conditions; and (d) an advanced solvent that has less degradation and corrosivity than a 30 wt% MEA.	0%
4	The completed final technical and economic analysis of the proposed process concept for a 550 MW power plant that shows a pathway to achieving carbon capture up to 90% with a LCOE increase less than 35% according to the DOE guidelines.	0%
4	Final technical report issued including analysis of CO_2 capture, energy consumption, solvent make-up, coupon corrosion, water balance, solvent degradation, and gaseous emissions.	0%

Project Testing Facility



Components and their Locations

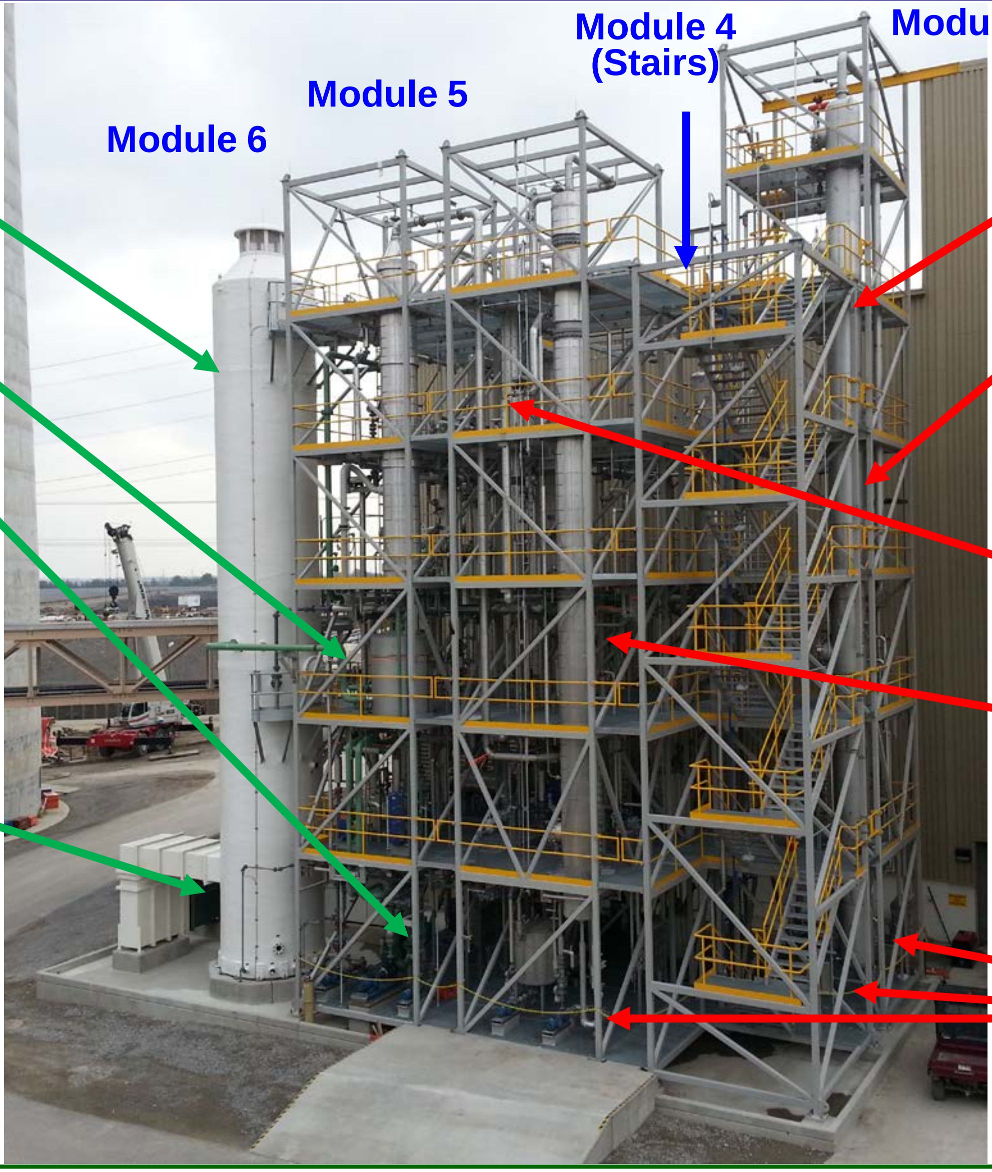
Cooling Water Loop

Two-stage Cooling Tower

Cooling Water Holding Tank

Cooling Water Circulation pump

Cooling Tower Blower



Amine Loop

Absorber

Activated Carbon Filter

Primary Stripper

Secondary Air Stripper

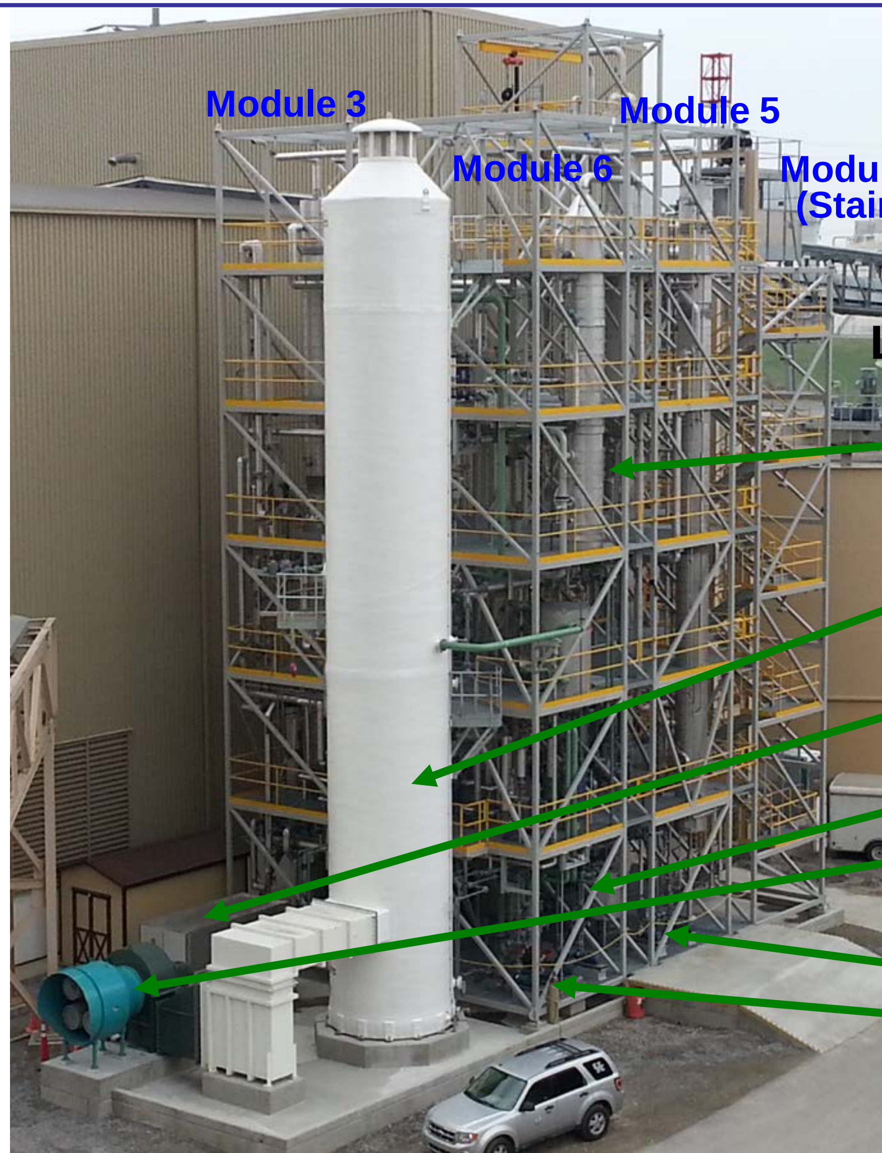
Several Pumps

Components and their Locations (Cont'd)

Conditions at top of primary stripper
T ~ 200-230 °F
P ~ 22-50 psia

Conditions at top of secondary air stripper
T ~ 180 °F
P ~ 15 psia

Conditions at top of absorber
T ~ 100 °F
P ~ 15 psia



Liquid Desiccant Loop

Water Evaporator

Air Pre-drier

Chiller

Desiccant Makeup Tank

Cooling Tower Blower

Pumps
P-106 (Evaporator)
P-110 (Main Loop)

Key BP3 Accomplishments

BP3 Task 12 – Update EH&S Assessment

STANDARD OPERATING PROCEDURE
AMINE SOLVENT USE AND MANAGEMENT

PURPOSE

This SOP addresses potential chemical hazards, proper PPE and spill cleanup procedures for handling Monoethanolamine (MEA) and Hitachi H3-1, an amine based solvent.

PICTOGRAMS/LABELS

MEA

Exclamation Mark

Irritant (skin and eye)
Skin Sensitizer
Acute Toxicity
Narcotic Effects
Respiratory Tract Irritant

Corrosion

Skin Corrosion/Burns
Eye Damage
Corrosive to Metals

Hitachi H3-1

Corrosion

Skin Corrosion/Burns
Eye Damage
Corrosive to Metals

UK CAER Pilot CO_2 Capture System
LGE-KU EW Brown Power Generation Plant
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January 22, 2015

STANDARD OPERATING PROCEDURE
WASTE MANAGEMENT

PURPOSE

The purpose of this SOP is to identify waste streams that may be generated at the pilot scale carbon dioxide (CO_2) capture system (CCS) operated at the E. W. Brown (EWB) Power Station and provide general guidance for characterizing and managing these wastes, consistent with federal and state requirements and LG&E-KU and the University of Kentucky Environmental Management Department (UK EMD) requirements.

WASTE CHARACTERISTICS

Wastes generated at the pilot plant will be subject to federal and state waste management and transportation regulations, primarily derived from the federal Resource Conservation and Recovery Act (RCRA, implemented by the U.S. Environmental Protection Agency (EPA) and the Kentucky Division of Waste Management) and the federal Hazardous Materials Transportation Act (HMTA, implemented by the U.S. Department of Transportation (DOT)). Wastes will be generated during initial start-up, normal operations, any process upsets, solvent change and process shutdown. Wastes will either be solid or liquid and may be classified as hazardous or not regulated as hazardous waste. In all cases, the waste will need to be adequately characterized (testing and generator knowledge) for appropriate disposal and contained in suitable DOT approved containers (likely steel or plastic drums) with appropriate labels and markings.

Currently known or suspected wastes, associated constituents and likely testing required to characterize them for appropriate disposal are summarized in the enclosed **Table 1**. Waste characteristics and likely testing requirements are identified from available process information. Additional testing may be required by UK's selected waste vendor. The initial priority for each waste will be to determine whether it is regulated as a hazardous waste or not. Hazardous wastes have stricter management requirements, including registration with the state, personnel training, site accumulation time limits, container management, shipping and disposal.

Hazardous Wastes

If the results of laboratory analysis (listed in Column 5 of **Table 1**) exceed any of the Regulated Limits identified in **Table 2**, the waste will need to be managed as a hazardous waste. If more than 100 kilograms of hazardous waste (combined for all hazardous wastes) is generated in any month, the facility will need to register its activities with the state (referencing the waste codes identified in **Table 2**) and comply with management requirements identified in federal regulations contained in Title 40 of the Code of Federal Regulations (40 CFR) Parts 260 – 262 and 265 and state regulations contained in Title 401 of the Kentucky Administrative Regulations (401 KAR), Chapters 30 – 32, 35 and 39.

UK CAER Pilot CO_2 Capture System
LGE-KU EW Brown Power Generation Plant
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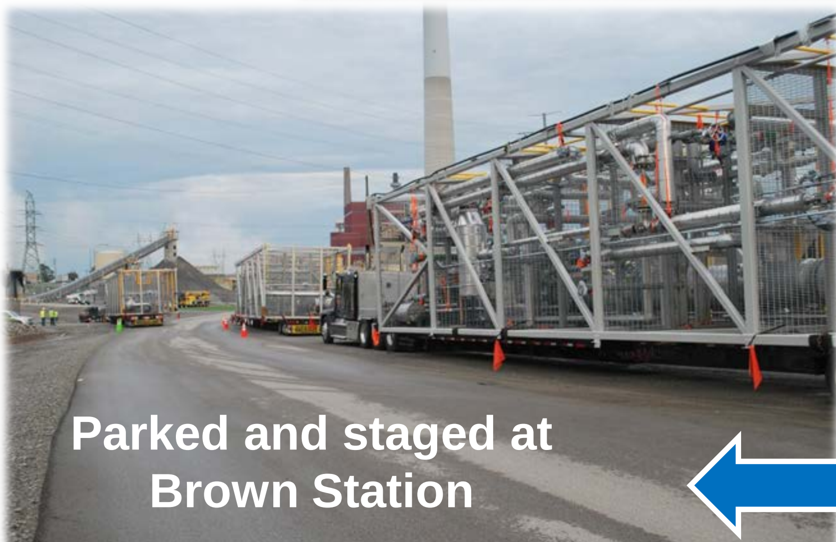
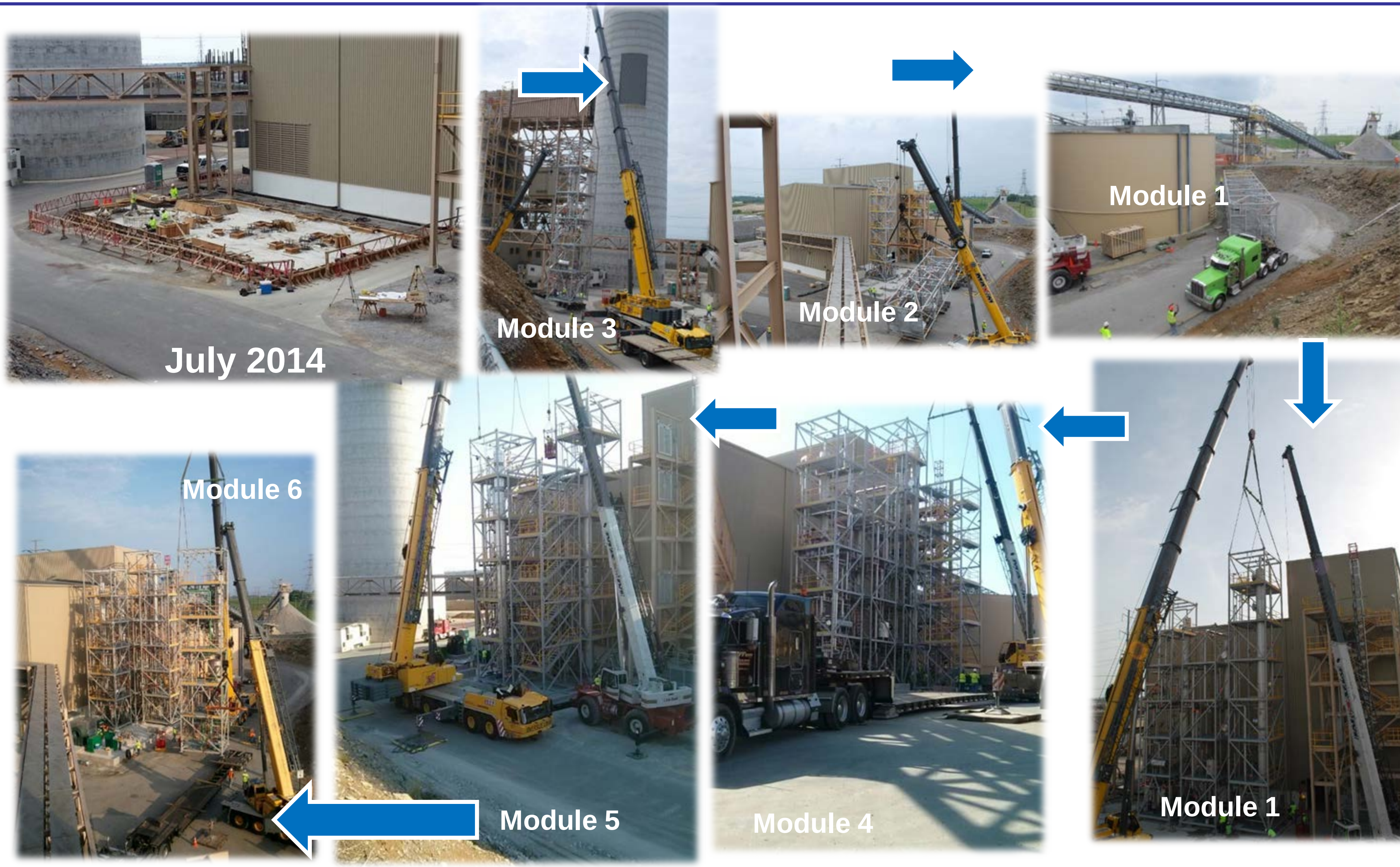
Key BP3 Accomplishments

Task 16 – Facility Erection, Startup Commissioning and Shakedown



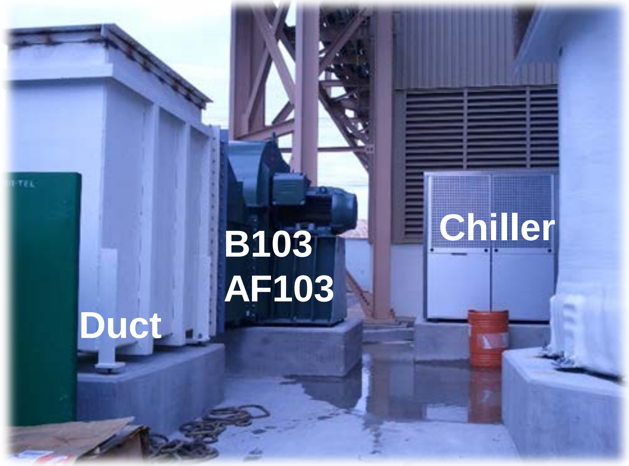
Task 16 Details

Module Erection



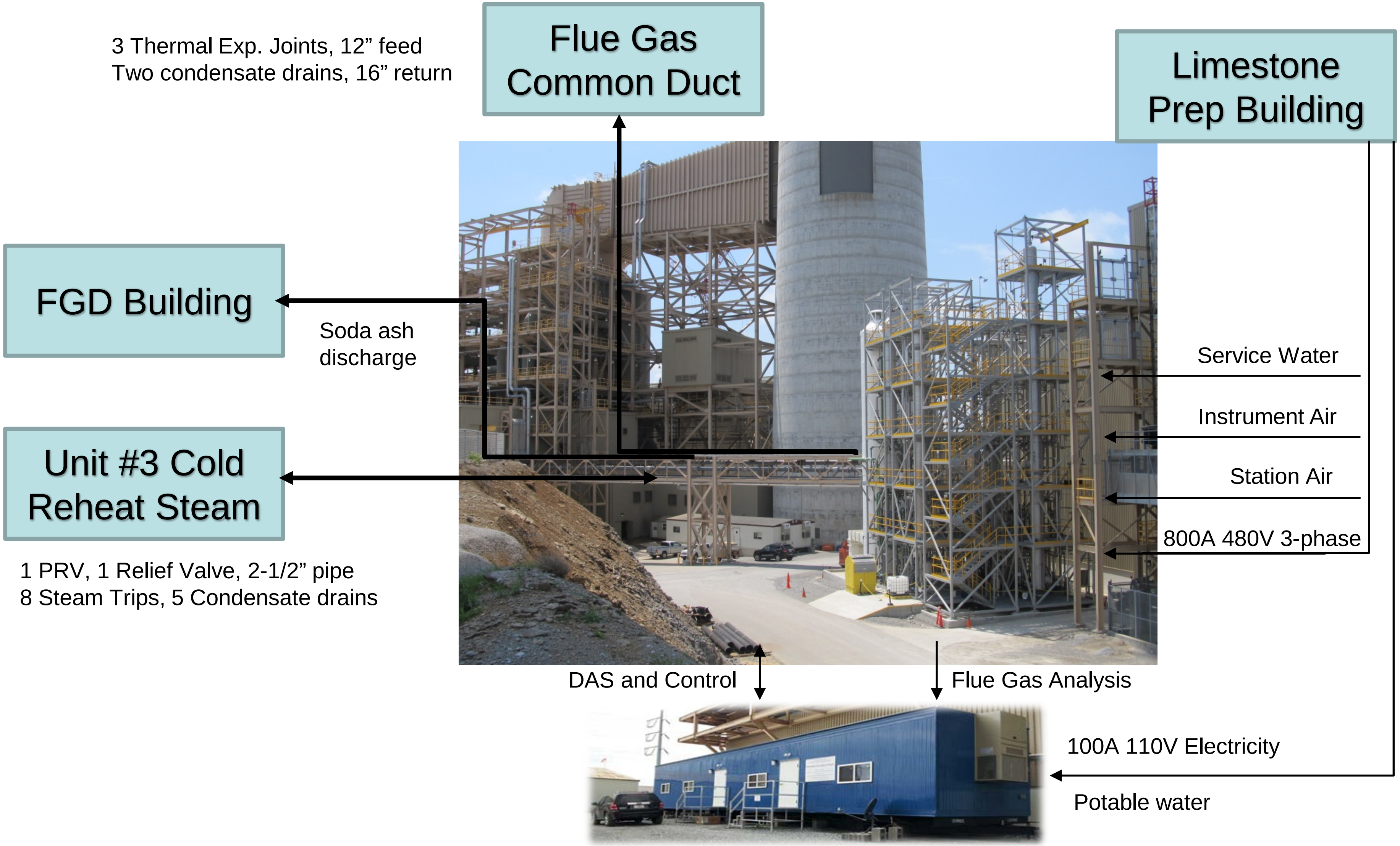
Task 16 Details

Erection and Installation of Other Equipment



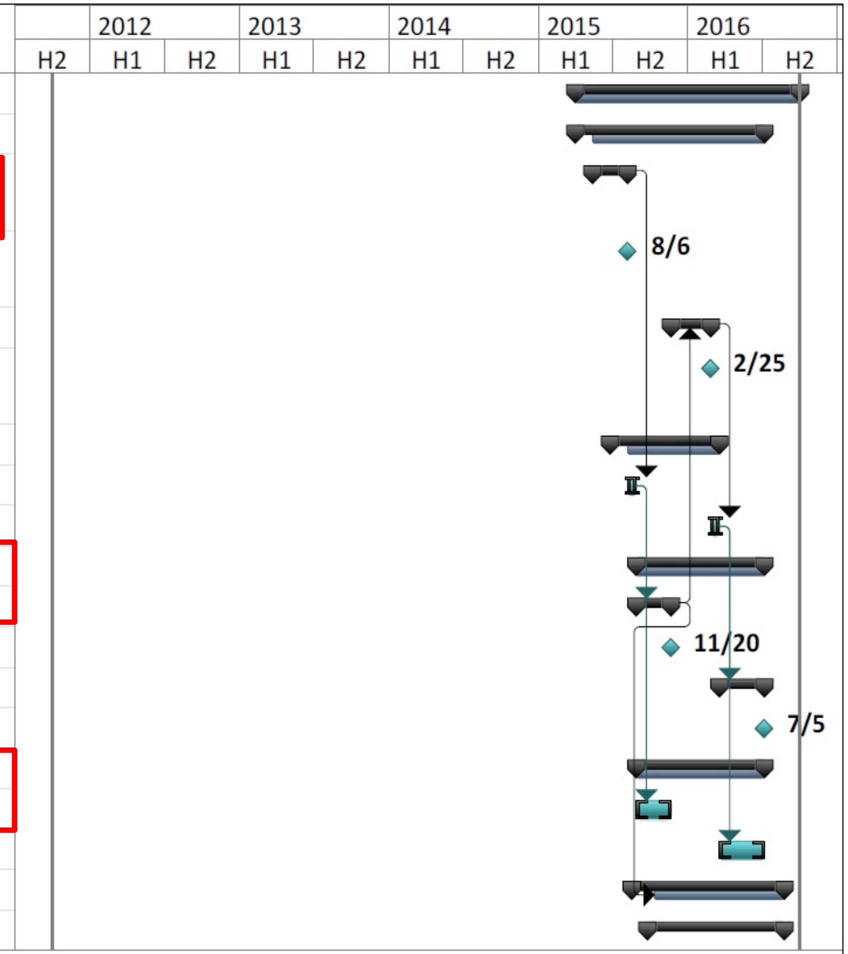
There were ~260 pieces and boxes of loose shipped equipment from KMPS.

Power Plant Connections



BP4 Schedule

Task Name	Start	Finish
17 Project Management and Planning Budget Period 4	**4/1/15**	**9/30/16**
18 Slip-stream Test Campaign	**4/1/15**	**7/5/16**
18.1 Parametric study using 30% wt MEA (2 conditions per day)	**5/13/15**	**8/6/15**
18.1.1 Completion of Parametric study using 30% wt MEA (27 conditions X3)	8/6/15	8/6/15
18.2 Parametric study using H3-1 (2 conditions per day)	**11/21/15**	**2/25/16**
18.2.1 Completion of Parametric study using H3-1 (27 conditions X3)	2/25/16	2/25/16
18.3 System dynamics evaluation (2 conditions per day)	**6/25/15**	**3/17/16**
18.3.1 Dynamics for MEA	8/7/15	8/27/15
18.3.2 Dynamics for H3-1	2/26/16	3/17/16
18.4 Long-term verification test/materials study (24/7)	**8/28/15**	**7/5/16**
18.4.1 Long-term for MEA	8/28/15	11/20/15
18.4.1.1 Complete MEA Study	11/20/15	11/20/15
18.4.2 Long-term for H3-1	3/18/16	7/5/16
18.4.2.1 Complete H3-1 Study	7/5/16	7/5/16
18.5 Solvent degradation study	**8/28/15**	**7/5/16**
18.5.1 MEA	8/28/15	11/20/15
18.5.2 H3-1	3/18/16	7/5/16
19 Final Update of Techno-Economic Analysis	**8/17/15**	**8/23/16**
20 Final EH&S Assessment	**9/24/15**	**8/23/16**



Experimental Design and Work Plan

30 wt% MEA Campaign

- Parametric Campaign
- Transient, Load-following Campaign
- 2000-hour Long Term Continuous Campaign

H3-1 Campaign

- Parametric Campaign
- Transient, Load-following Campaign
- 2500-hour Long Term Continuous Campaign

Evaluation Parameters

- Energy Requirements
- Solvent and Water Loss
- CO_2 Absorption Capacity
- Solvent Degradation
- Gaseous Emissions
- Material Corrosion

Activities Planned in BP4

BP4 Testing and Evaluations	
MEA Testing Campaigns	Parametric and long term verification studies, including dynamic studies
H3-1 Testing Campaigns	Parametric and long term verification studies, including dynamic studies
Corrosion Studies	Corrosion coupons will be placed at four processes locations and removed periodically during both solvent long term verification runs to monitor the performance of two UKy-CAER developed corrosion resistant coatings.
Solvent Degradation Studies	Levels of solvent degradation products will monitored during the MEA campaign.
Solvent Emissions Monitoring	Gas sampling at the exit of each column will occur during the solvent campaign to evaluate the effectiveness of the UKy-CAER solvent recovery systems.
Effectiveness of the Liquid Desiccant Air Drying System	The amount of additional cooling provided by the liquid desiccant air drying system will be evaluated at various ambient conditions to determine usefulness at a commercial scale.
Reclaimer vs. Activated Carbon Filter	The UKy-CAER process includes both a reclaimer and an activated carbon filer for the removal of heat stable salts. We will monitor the HSS accumulation and operate both the reclaimer and the ACF to determine which is more effective for commercial scale use.
Accurate Modeling of All Column Profiles	Each column includes liquid/gas sampling ports to experimentally determine carbon contents along the profiles. The experimental data will be used to improve UKy-CAER developed models.
RCRA Metals Monitoring	Levels of the RCRA metals in the solvents will be monitored

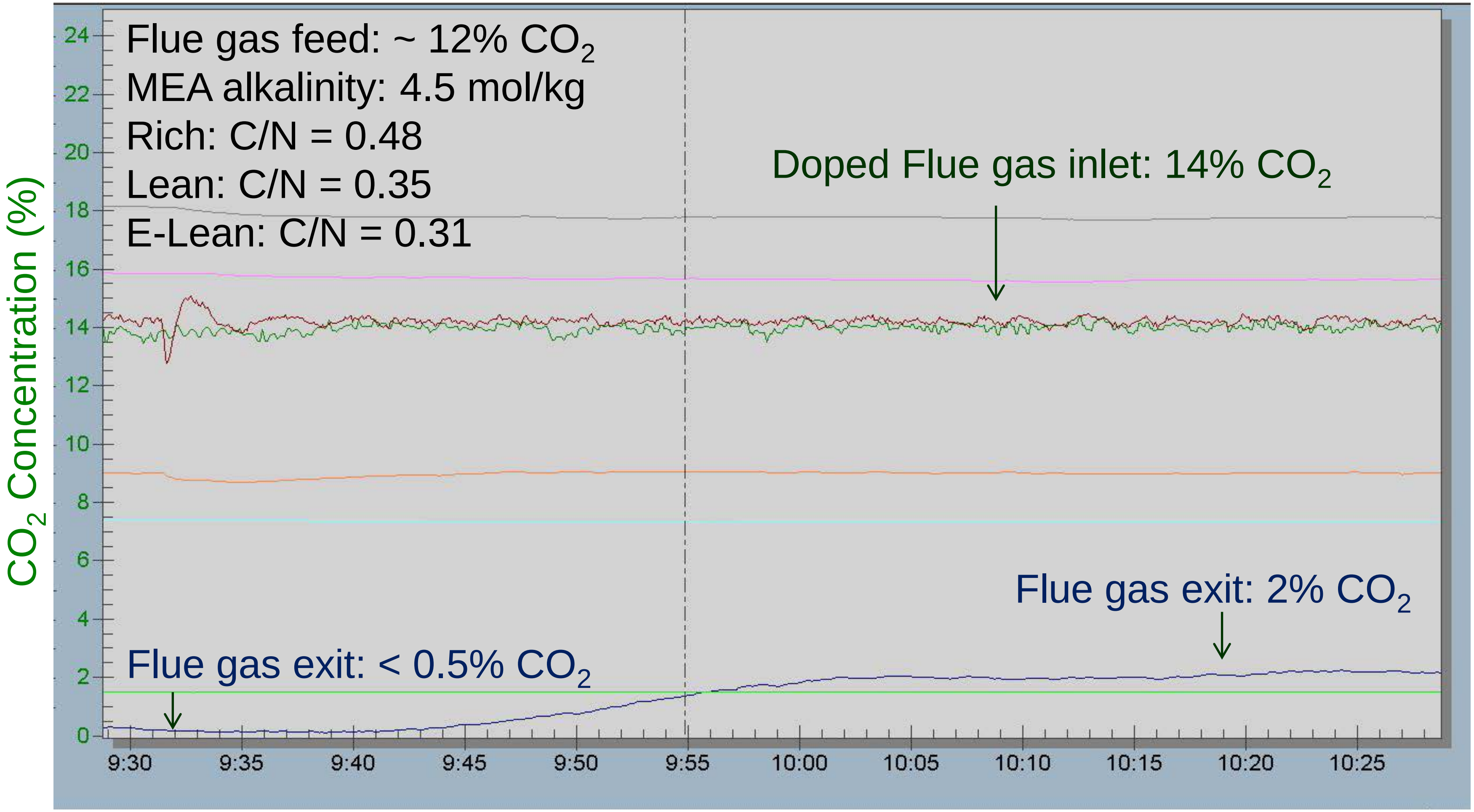
Process Operational Independent Variables and Levels

Independent Variable	Level 1 (-1)	Level 2 (0)	Level 3 (1)
L/G Ratio (wt/wt)	3.5	4.0	5
Stripper Pressure (bar)	1.3	2.5	3.5
Inlet CO_2 Concentration (vol %)	12	14	16
Solvent Blow-down (%)	0.5	1	2

Preliminary System Operating Conditions

Solvent	Absorption Temperature (°C)	Absorber L/G (L/m^3)	Stripper Pressure (bar)	Stripper Temperature (°C)
30 wt% MEA	40	4.0	1.3	108-110
H3-1	45	3.0	1.6	113

Early BP4 Highlights



- CO_2 doping system is working
- Secondary Air Stripper giving leaner solvent

Lessons Learned

1) There is a difference in standards between a University and a commercial facility. Maintaining a **good working relationship**, that benefits both organizations, is crucial to working through a project of this nature.

2) OSHA standards are not **black** and white.

3) For any future project of this nature, a host site safety review of all areas of the project where safety standards may apply would be helpful for good communication and to address potential issues earlier rather than later.

Specific examples include: definition of *construction work*, cross-over grating requirements, human access to the modules, yellow reflective paint, etc.

4) Finding unknown things buried in the ground is common during excavation. Budget and schedule allowances should be made.

Potential Future Research

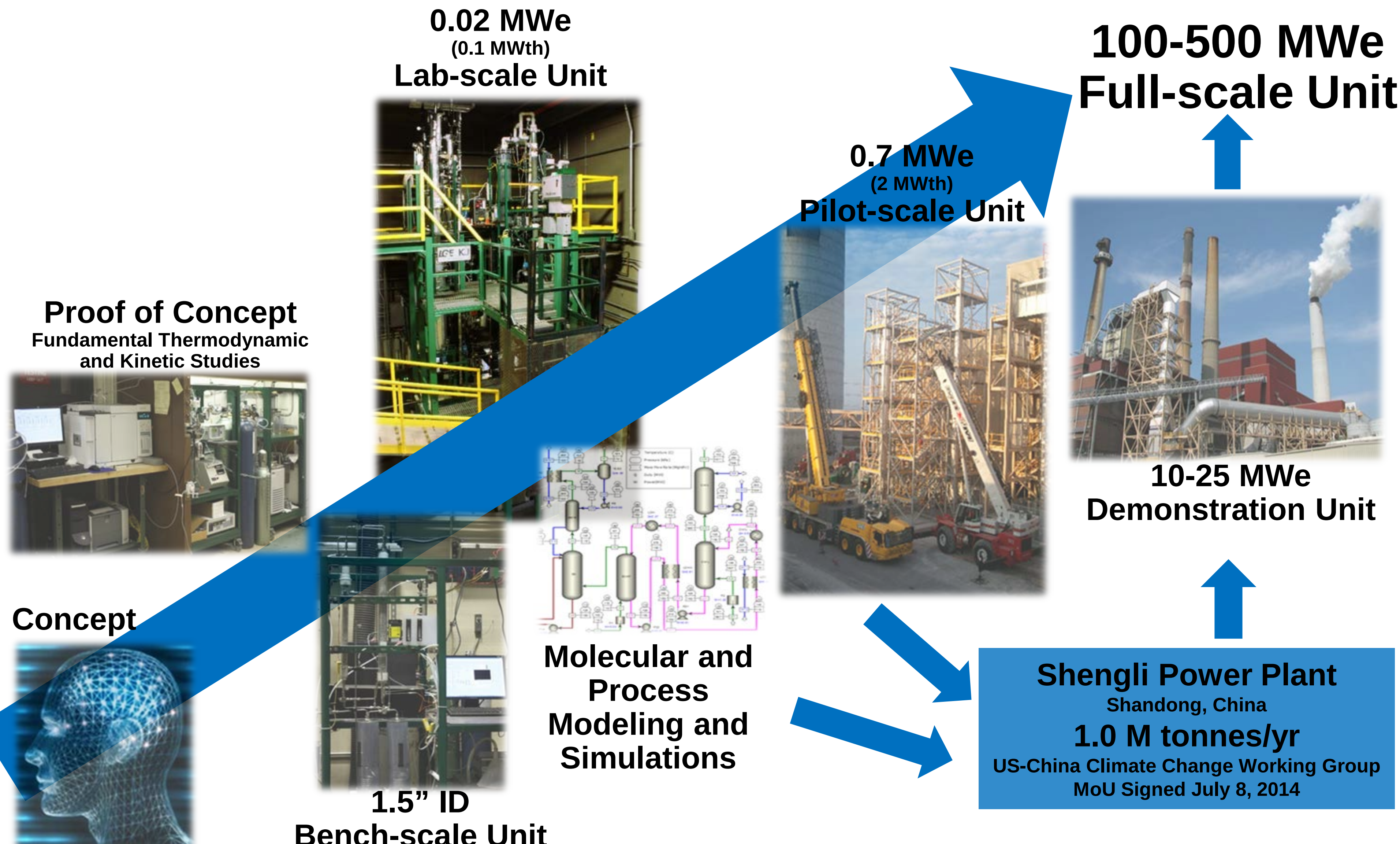
Open, modular design

- Allows for ease of advanced process modification (such as addition of membrane or flash stripper, column design changes, etc.)

Advanced technologies can be more closely studied

- Absorber intercooler protocols (cooling temperature and location variation)
- Hybrid systems
- Application of sorbent to improve solvent stability or control heavy metals accumulation
- Control logic to accommodate solvent specific dynamic behavior

Technology Development Pathway



Acknowledgements

José Figueroa, DOE NETL

CMRG Members

Donnie Duncan, LG&E and KU

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Jeff Fraley, LG&E and KU

Eileen Saunders, LG&E and KU

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KENTUCKY POWER
A unit of American Electric Power

PPL companies