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

University of Kentucky Research Foundation

Partnered with

U.S. Department of Energy NETL

Louisville Gas & Electric and Kentucky Utilities

Electric Power Research Institute (with WorleyParsons)

Hitachi Power Systems America

Smith Management Group

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CENTER FOR APPLIED ENERGY RESEARCH

Goals and Objectives

- Objectives
  1) To demonstrate a heat-integrated post-combustion CO_2 capture system with an advanced solvent;
  2) To collect information/data on material corrosion and identify appropriate materials of construction for a 550 MWe commercial-scale carbon capture plant.
     - To gather data on solvent degradation kinetics, water management, system dynamic control as well as other information during the long-term verification runs;
     - To provide scale-up data and design information for commercial-scale projects;
- Goal
  - Develop a pathway to achieve the NETL Post-combustion CCS Target – 90% CO_2 capture with a cost increase (ICOE) of less than 35% ($40/tonne CO_2 captured)

Benefits of Technology to the Program

- Advance post-combustion CCS to be more competitive with Oxyfuel and pre-combustion approach.
- Technologies are being developed in this project that could be applied to any solvent-based post-combustion CCS:
  - An innovative heat integration process with at least 1 percentage point higher efficiency
  - Cost-effective advanced coating
  - Protocols on solvent and water management
  - Control logic to process dynamic behavior
  - Elimination of solvent mist and nitrosamines
- Technologies are being developed in this project that could be applied to any steam-cycle plant:
  - An integrated cooling tower

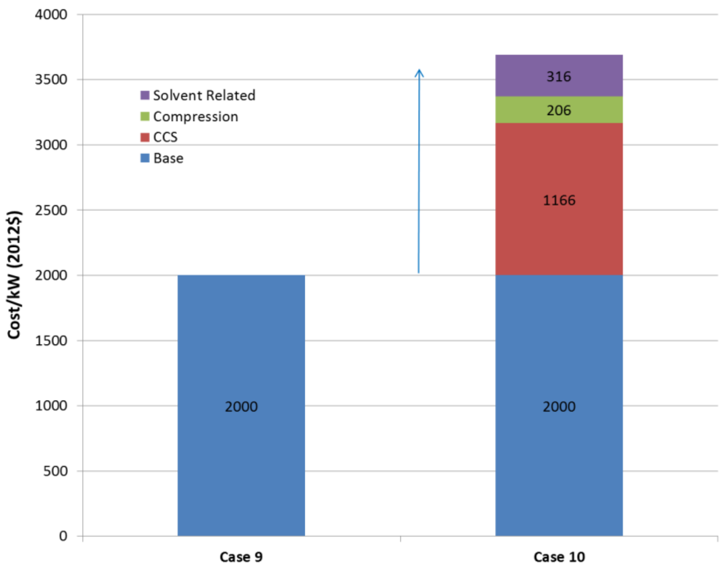
The Background for CO_2 Capture from a Utility Plant

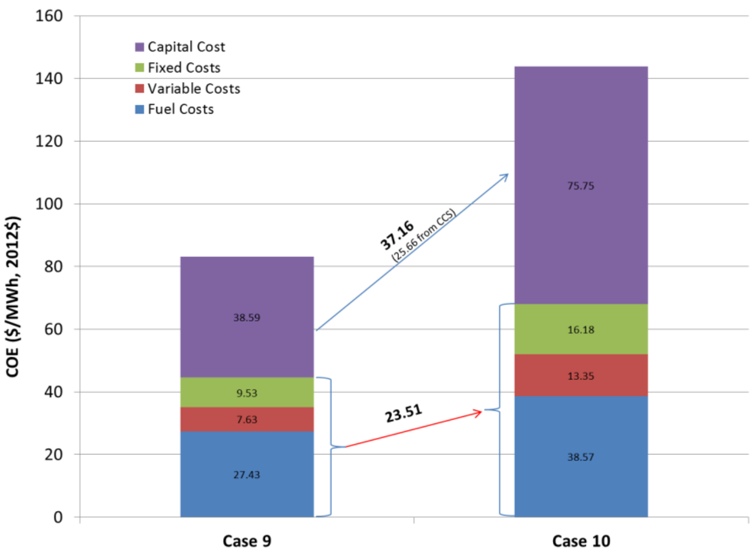
Challenges:

- Low CO_2 partial pressure (~0.14 atm)
- Large volume
- Contamination

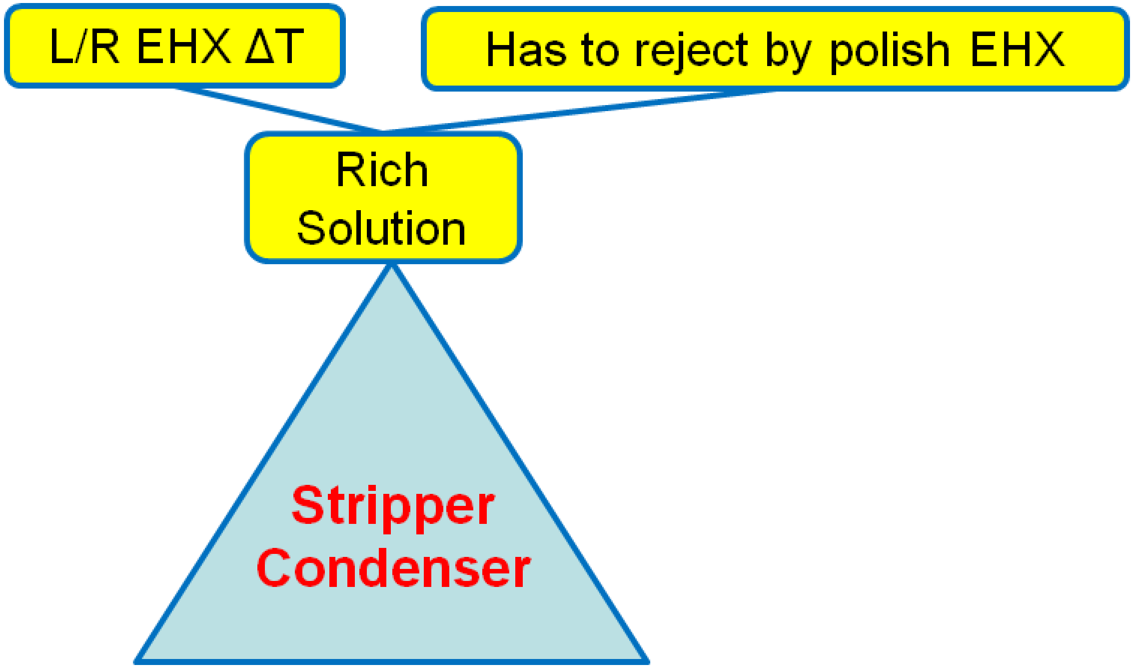
Consequences (using 30% MEA):

- Capital Costs >$1166/kW (2012$)
  - Large packed absorbers, with 3-4X the diameter of the FGD
  - Strippers and balance of plant
- 25-35% of plant output reduction
- 80% increase of LCOE





Heat Integration is Essential



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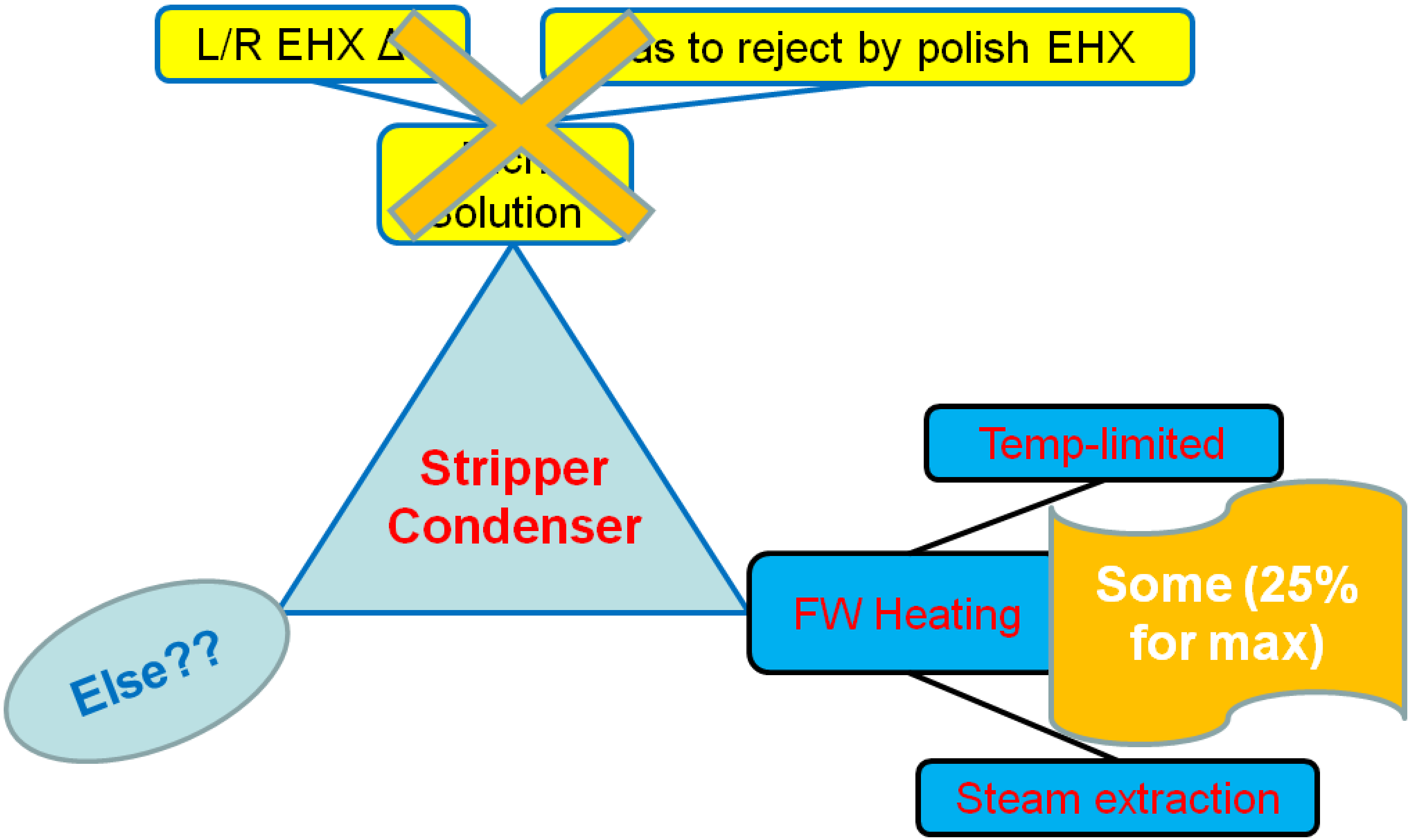
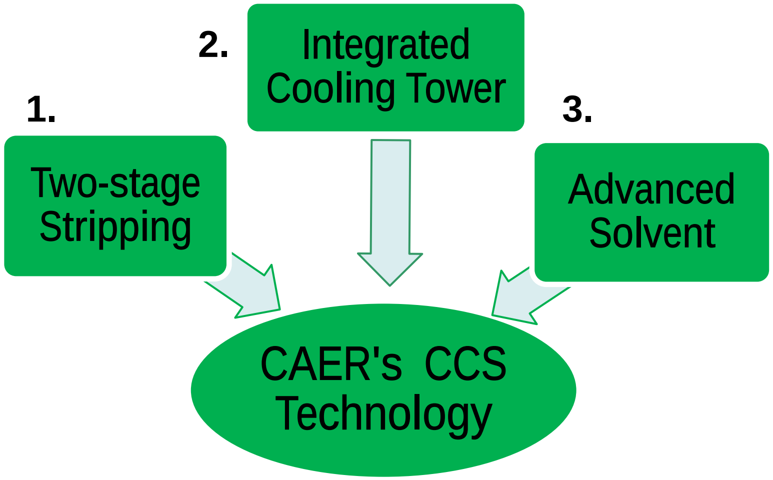


Technology Under Study

Engineering design, build and install an advanced CO_2 capture system into an existing PC power plant at a 0.7 MWe slipstream scale (~15 TPD CO_2)

Three novel concepts will be designed and included: 2-stage solvent stripping, cooling tower desiccant, and Hitachi solvent



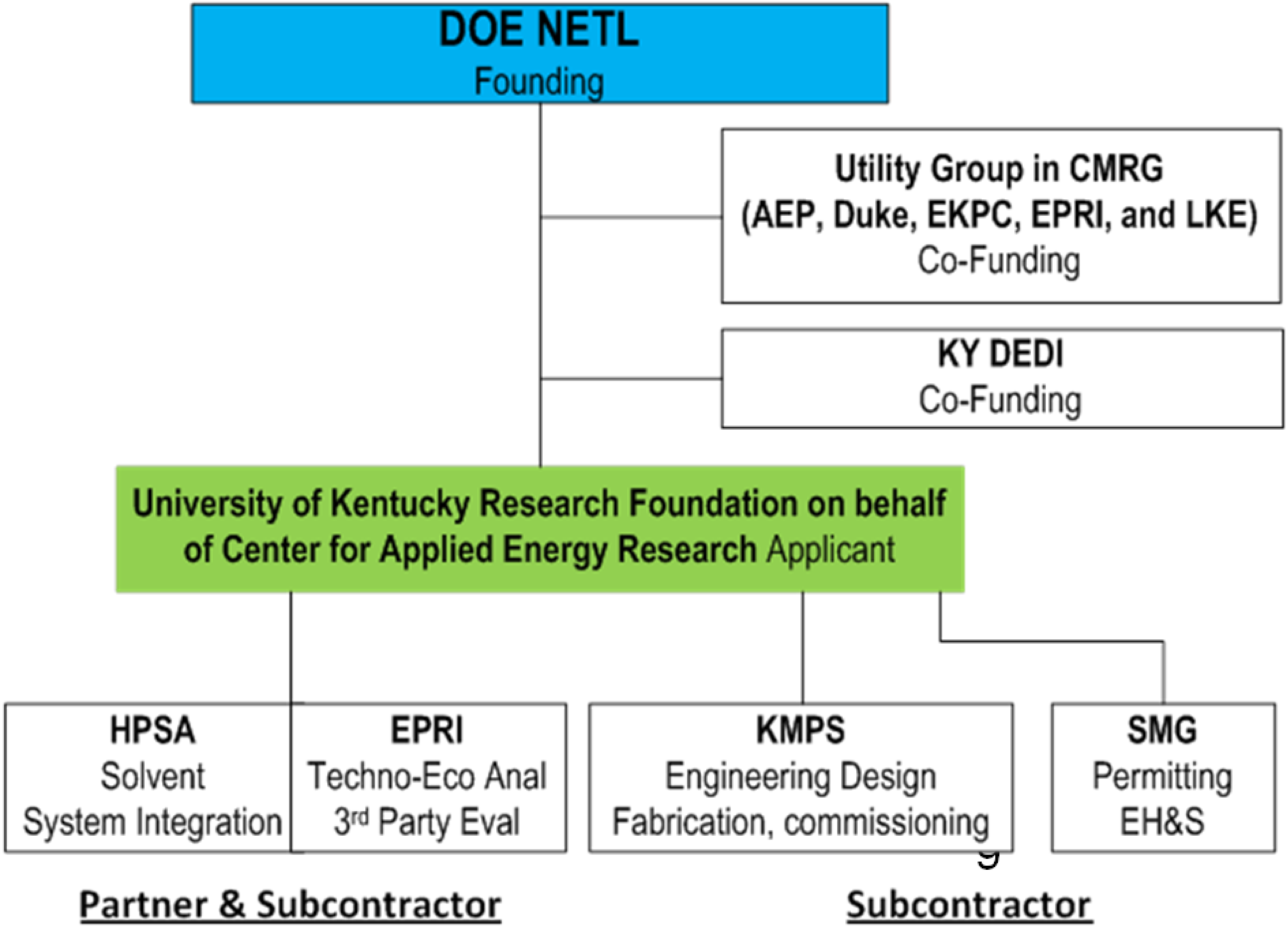
1. **Two-stage Stripping:**
   - Increase solvent working capacity by providing a secondary air-stripping column following the conventional steam stripping column.
   - Air stripping stream sent to the boiler as combustion air to increase the P_{CO_2} in the flue gas exiting the boiler

2. **Integrated Cooling Tower:**
   - Use regenerated CO_2 stream waste heat to dry the liquid desiccant
   - Liquid desiccant is used to dry the cooling tower air, resulting in improved power plant cooling tower and steam turbine efficiency

3. **Advanced Hitachi Solvent (H3-1):**
   - A blend amine-based solution

Organization Chart

Organization Chart

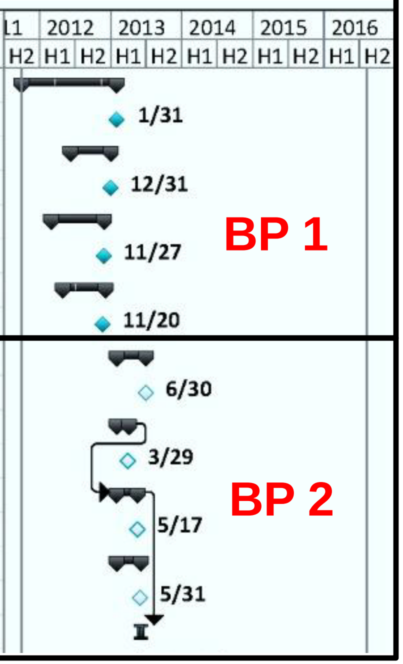


Budget Period Profiles

- Overall Performance Dates:
  - BP-1 October 1, 2011 to January 31, 2013
  - BP-2 February 1, 2013 to June 30, 2013
  - BP-3 July 1, 2013 to May 31, 2014
  - BP-4 June 1, 2014 to May 31, 2016
- Budget Profile
  - Budget Period 1 - $1.1M
  - Budget Period 2 - $1.26M
  - Budget Period 3 - $9.11M
  - Budget Period 4 - $7.81M

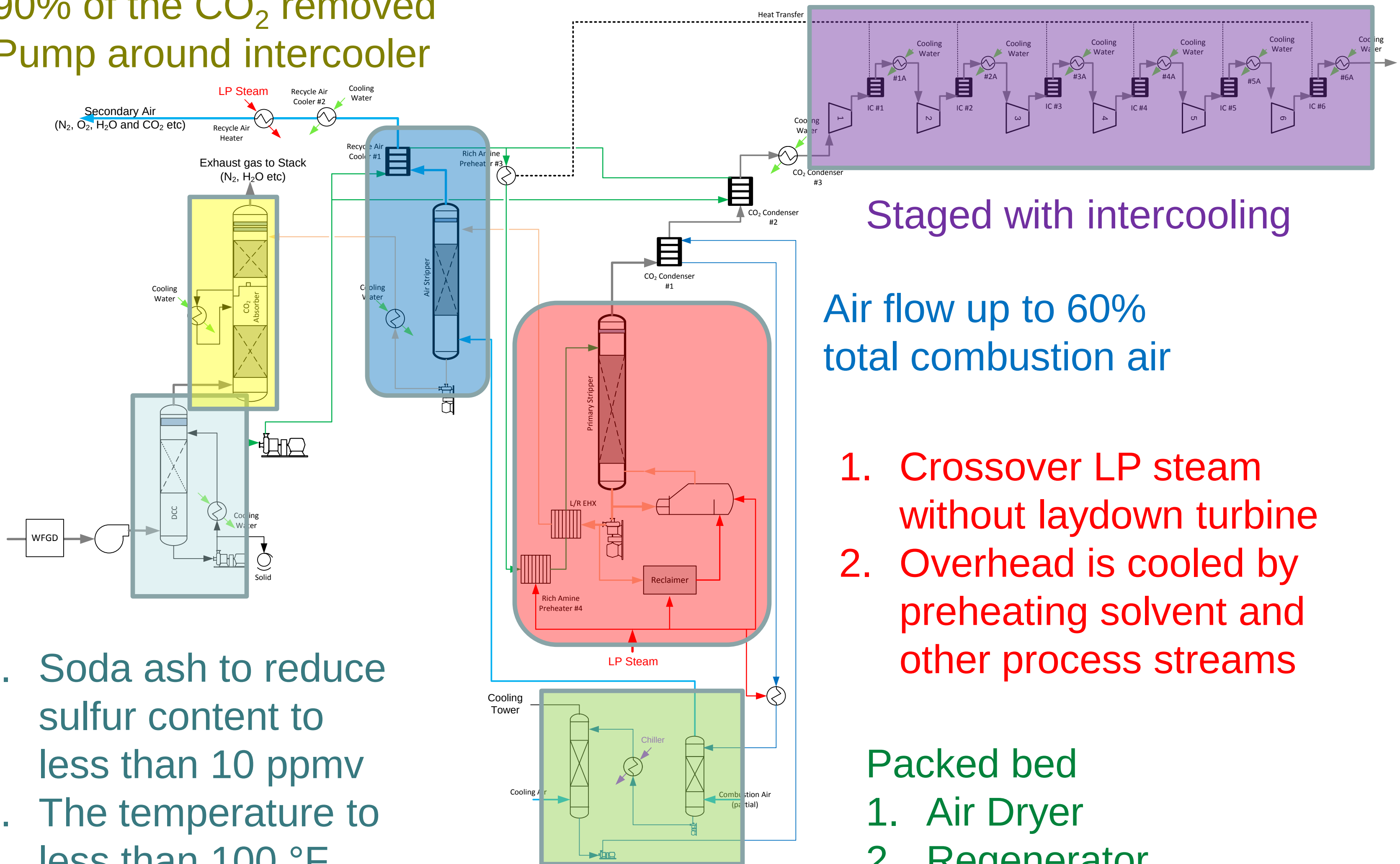
Tasks and Milestones up to date

Task Name	Start	Finish
1 Project Planning and Management	**10/1/11**	**1/31/13**
1.1 Go/ No Go Decision Point	**1/31/13**	**1/31/13**
2 Detailed Update of Techno-Economic Analysis	**6/8/12**	**12/31/12**
2.1 Topical Report	12/31/12	12/31/12
3 Initial EH&S Assessment	**3/1/12**	**11/27/12**
3.1 NEPA Questionnaire Evaluation Completed	11/27/12	11/27/12
4 Basic Process Specification and Design	**5/1/12**	**12/3/12**
4.1 Design Basis Report Submitted	11/20/12	11/20/12
5 Project Planning and Management	**2/1/13**	**6/30/13**
5.1 Go/ No Go Decision Point	6/30/13	6/30/13
6 Slipstream Site Survey	**2/1/13**	**4/4/13**
6.1 Identification of Flue Gas Clean-up Requirements	3/29/13	3/29/13
7 Finalized Engineering Specification and Design	**2/1/13**	**5/17/13**
7.1 Koch to Modify P&ID	5/17/13	5/17/13
8 Test Condition Selection and Test Plan	**2/1/13**	**6/4/13**
8.1 Uky Finalize Test Plan	5/31/13	5/31/13
9 System Engineering Update and Model Refinements	5/20/13	6/19/13



Simplified Flowchart for Process Simulation

1. 90% of the CO_2 removed
2. Pump around intercooler



Staged with intercooling

Air flow up to 60% total combustion air

1. Crossover LP steam without laydown turbine
2. Overhead is cooled by preheating solvent and other process streams

1. Soda ash to reduce sulfur content to less than 10 ppmv
2. The temperature to less than 100 °F

Packed bed

1. Air Dryer
2. Regenerator

Summary Performance of Proposed Process

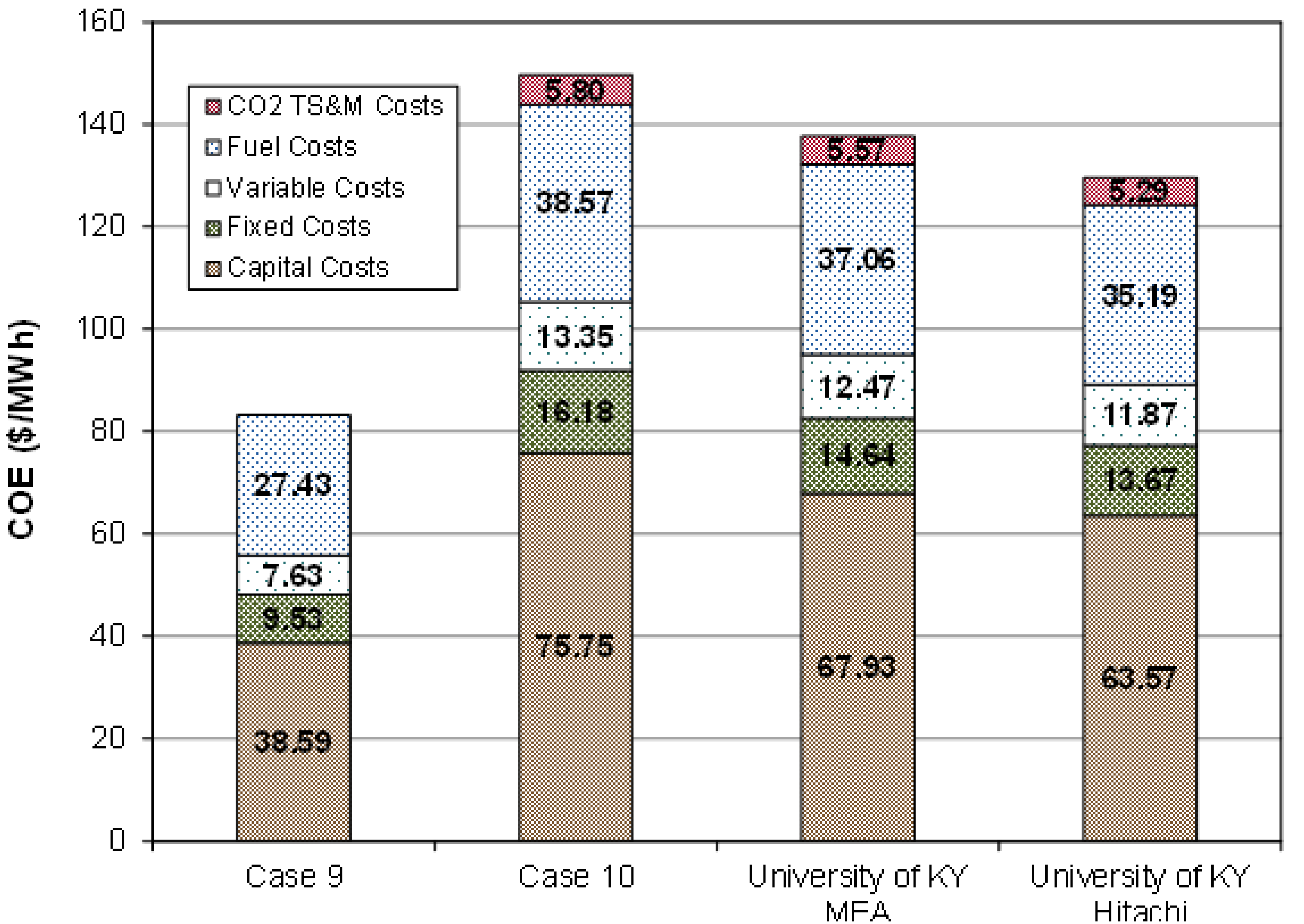
POWER SUMMARY (Gross Power at Generator Terminals, kWe)	Case 10	With MEA	With H3-1
Steam Turbine Power	672,700	691,000	722,300
TOTAL (STEAM TURBINE) POWER, kWe	672,700	691,000	722,300
AUXILIARY LOAD SUMMARY, kWe			
Coal Handling & Conveying	540	540	540
Pulverizers	4,180	4,180	4,180
Sorbent Handling & Reagent Preparation	1,370	1,370	1,370
Ash Handling	800	800	800
Primary Air Fans	1,960	1,980	1,980
Forced Draft Fans	2,500	2,890	2,890
Induced Draft Fans	12,080	11,410	11,410
SCR	70	70	70
Baghouse	100	100	100
Wet FGD	4,470	4,470	4,470
CO_2 Removal System Auxiliaries	22,400	22,122	21,485
CO_2 Compression	48,790	48,930	48,930
Miscellaneous Balance of Plant[2,3]	2,000	2,000	2,000
Steam Turbine Auxiliaries	400	400	400
Condensate Pumps	700	750	870
Circulating Water Pump	11,190	8,830	9,587
Ground Water Pumps	1,020	720	780
Cooling Tower Fans	5,820	4,590	4,980
Transformer Losses	2,350	2,410	2,520
TOTAL AUXILIARIES, kWe	122,740	118,562	119,362
NET POWER, kWe	549,960	572,438	602,938
Net Plant Efficiency (HHV)	26.2%	27.2%	28.7%
Net Plant Heat Rate (Btu/kWhr HHV)	13,046	12,533	11,899
Net Plant Efficiency (LHV)	27.1%	28.2%	29.7%
Net Plant Heat Rate (Btu/kWhr LHV)	12,583	12,088	11,477
COOLING TOWER DUTY (10^6 Btu/hr)	5,326	4,200	4,560
Consumables			
As-Received Coal Feed (lb/hr)	614,994	614,994	614,994
Limestone Sorbent Feed (lb/hr)	62,235	62,235	62,235
Thermal Input (kWth HHV)[1]	2,102,645	2,102,645	2,102,645
Thermal Input (kWth LHV)	2,028,027	2,028,027	2,028,027

An extra 30.5 MW compared to MEA (52.9 MW more than DOE Case 10)

Lower net plant heat rate by 634 Btu/kWh compared to MEA, (1147 Btu/kWh lower than Case 10)

Lower heat rejection by 766 MBtu/hr compared to Case 10

Cost Analysis for Proposed Technology



Cost Analysis for Proposed Technology

	Case 9	Case 10	Univ. KY MEA	Univ. KY Hitachi
COE ($/MWh, 2012$)	83.19	149.65	137.69	129.60
CO_2 TS&M Costs		5.80	5.57	5.29
Fuel Costs	27.43	38.57	37.06	35.19
Variable Costs	7.63	13.35	12.47	11.87
Fixed Costs	9.53	16.18	14.64	13.67
Capital Costs	38.59	75.75	67.93	63.57
LCOE (2012$/MWh)	105.36	189.59	174.59	164.33
Cost of CO_2 Captured ($/tonne CO_2)		61.31	53.05	46.93
Cost of CO_2 Avoided ($/tonne CO_2)		90.35	74.36	62.18
ICOE		80%	66%	56%

$20.05/MWh, an 13.4% ↓

$25.26/MWh, an 13.4% ↓

$14.38/MWh, an 23.5% ↓

$28.17/MWh, an 31.2% ↓

Information Collected

Initial Proposal

- Operation information
- Process flow diagrams

Information from CAER

- Anticipated operating parameters
- Estimated air emissions
- Estimated waste generation and discharged

Solvent information

- Hitachi solvent MSDS
  - No EPA List of Lists chemicals for Hitachi solvent
- Monoethanolamine MSDS

Literature review

- Potential health risks and toxicity, ecotoxicity, biodegradability and environmental impacts of solvent degradation products
- Potential amine emissions and nitrosamine formation

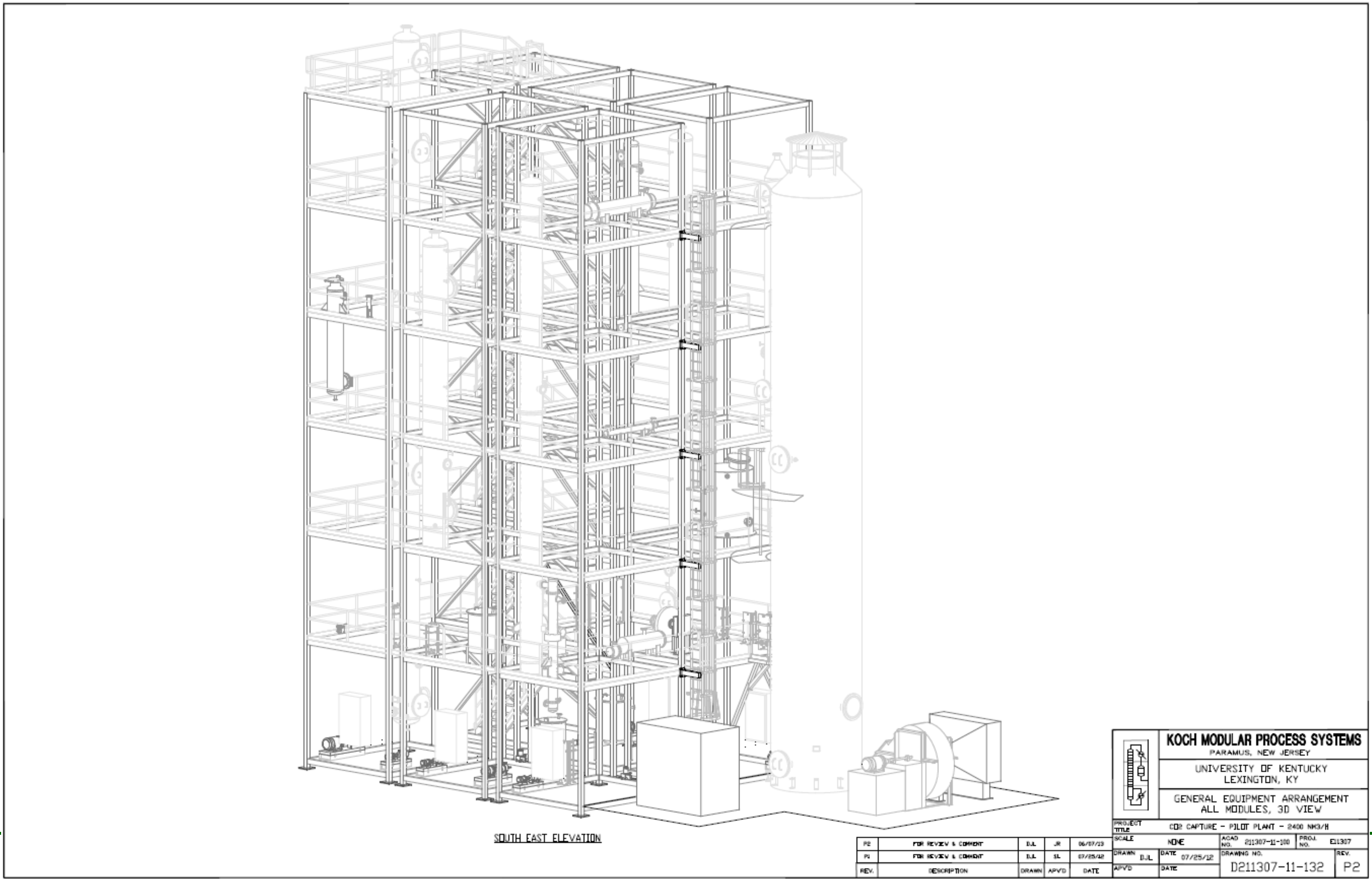
Air Emissions from Initial EH&S

Pollutant	Emissions Estimates and Permitting Evaluation
VOC	Below Kentucky permitting threshold
HAP	Below Kentucky permitting threshold
MEA, Hitachi solvent	Below NIOSH Recommended Exposure Limits (RELs) and OSHA Permissible Exposure Limits (PELs)
NH_3	Below NIOSH Recommended Exposure Limits (RELs) and OSHA Permissible Exposure Limits (PELs)
Total emissions	Do not represent an unacceptable environmental risk

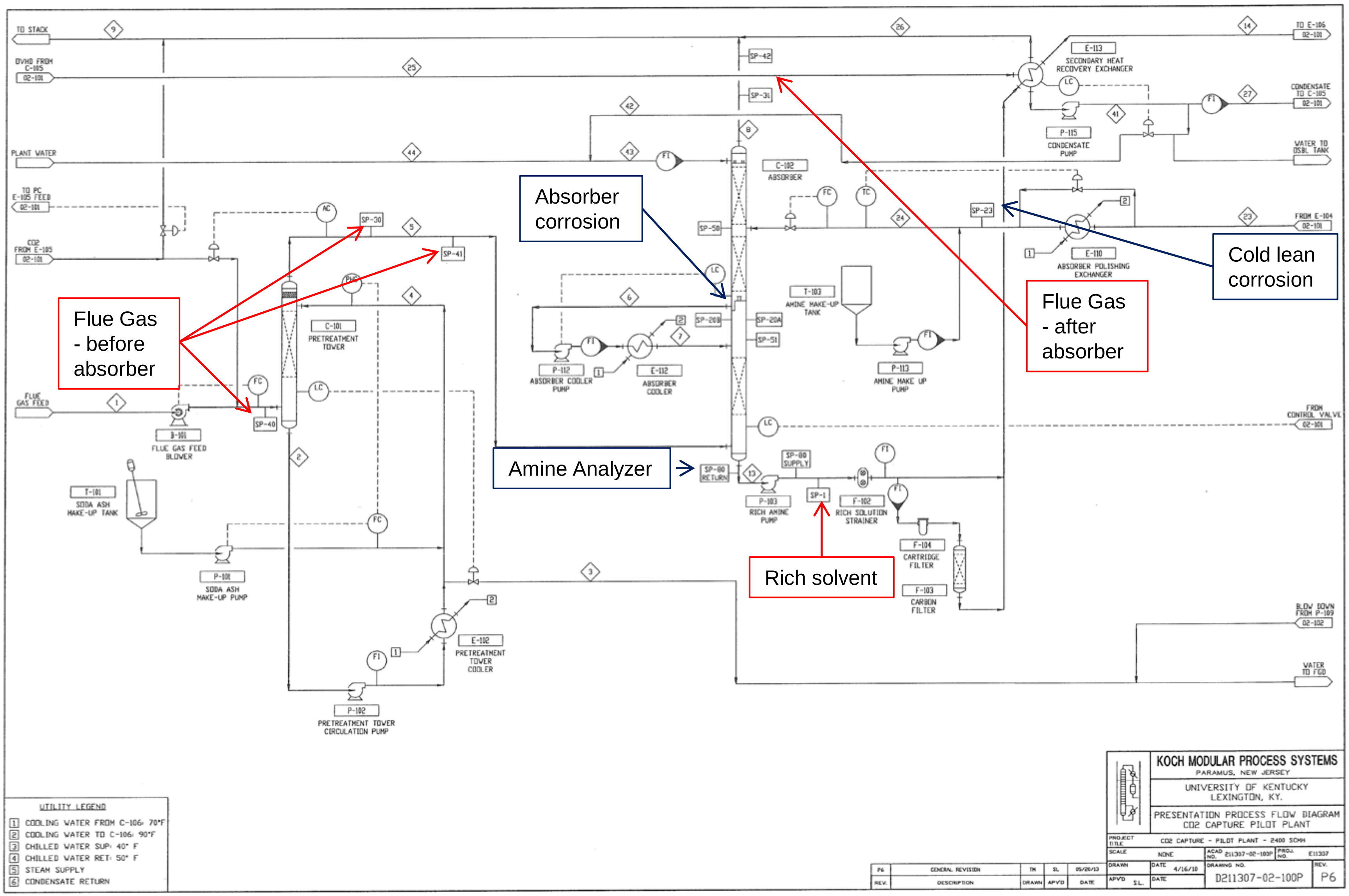
The Guideline for Design and Fabrication

- Considering two solvents under investigation
  - 30% MEA as design solvent
  - H3-1 as performance solvent
- Flexible
  - The impact of physical properties for both MEA and H3-1 such as viscosity on heat and mass transfer flux
  - The impact of solvent performance such as ΔH_{abs}, cyclic capacity, and stability
- Reliable
  - Robust, simple loop control
  - Spare rotary devices
- Accessibility
  - Safe
  - Easy

General Arrangement



Sampling Locations



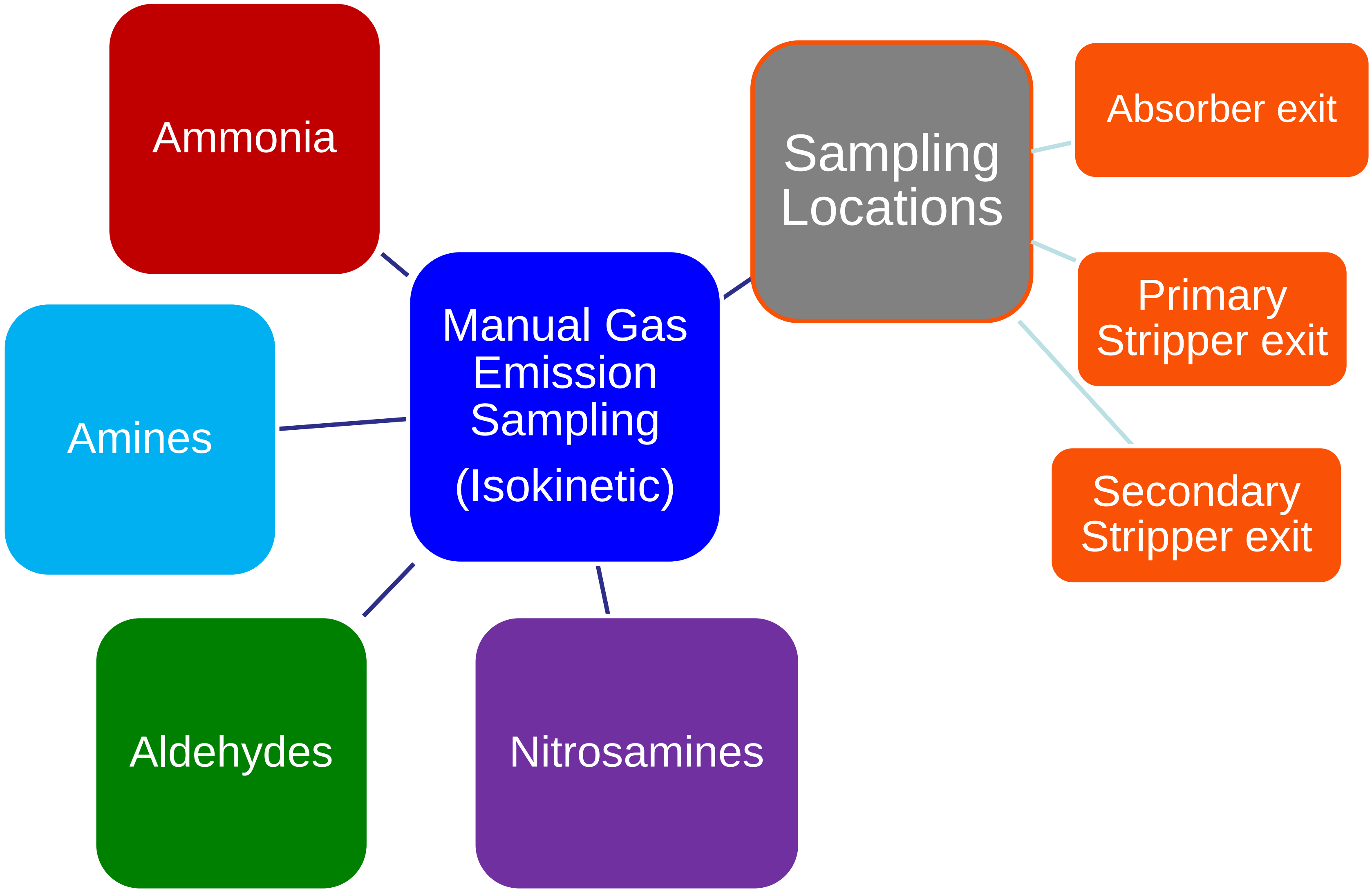
Test Plan – Parametric Testing

- Baseline MEA with a performance comparison to the Hitachi advanced solvent
- Four independent variables will be investigated at three levels using a one-third fractional design (3^{4-1} design) approach with one block of 27 experiments

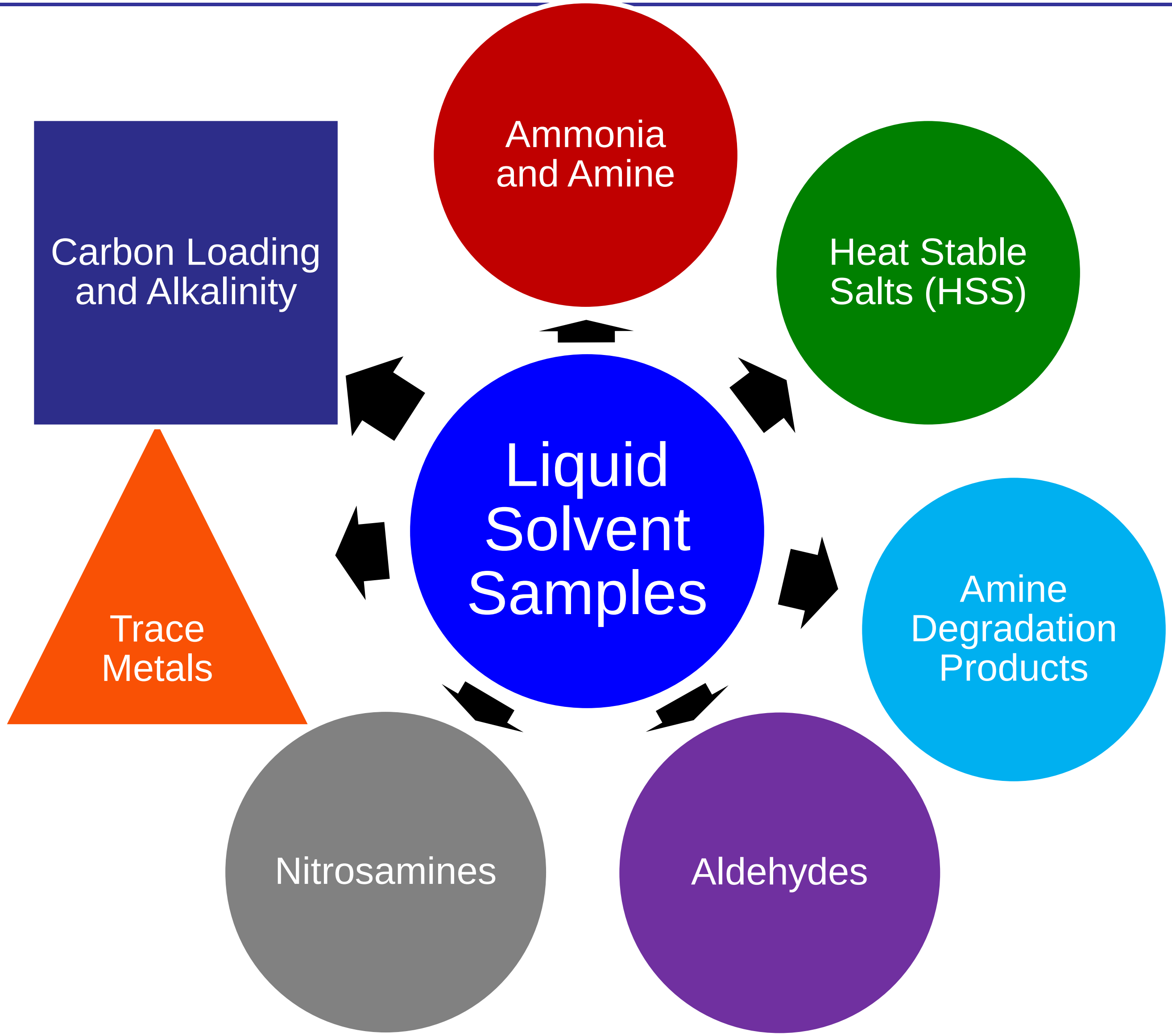
Factors	Description	Level 1, (-1)	Level 2, (0)	Level 3, (1)
A	L/G Ratio (wt/wt)	1	2.5	4
B	Stripper Pressure (bar)	1.3	3	4.5
C	Inlet CO_2 Concentration (vol %)	12	14	16
D	Contaminant Level (%)	0.5	1	2

- Continuous long-term verification with MEA (2000 hrs) and Hitachi advanced solvent (2500 hrs)
  - Best conditions from parametric tests will be used
  - Assess CO_2 removal fluctuation and energy consumption
  - Study materials corrosion
  - Establish solvent management protocol

Degradation - Gas Emissions



Degradation - Solvent



EPRI – 3rd Party Verification

Gas[a] (and accompanying liquid[b]) sampling and analysis requirements

Stream	H_2O	O_2	SO_2	NO_x	CO_2	NH_3	HC	Hg	Aldehydes	SO_3	HAP[d]	PM
Flue gas supply	X	X	X	X	X	X	X	X	X	X	X	X
Treated flue gas	X	X	X	X	X	X	X	X	X	X	X	X
Product CO_2	X	c	X	X	X	X	X					

Analyte	H_2O	O_2	SO_2	NOx	CO_2	NH_3	VOC	Hg	Aldehydes	SO_3	HAP[d]	PM
U.S.EPA sampling/analysis method	4	3A	6C	7E	3A	027	25A	29			29	5
NCASI sampling/analysis method										8A		
SW Method									846-0011			

[a] Daily gas sampling campaigns will consist of three individual test runs.

[b] During each gas sampling test run, a single liquid sample will be collected and analyzed for each stream and reported on the same basis as the gas sampling runs.

[c] O_2 analysis in the CO_2 to compression stream will have a detection limit of 10 parts per million by volume.

[d] Sampling train using acidic hydrogen peroxide and acidic potassium permanganate. Analytes include: arsenic, beryllium, cadmium, chromium, cobalt, lead, manganese, nickel, selenium.

Project Team

DOE Project Manager: José D. Figueroa

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  - Andrew Maxson
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- KMPS
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  - Allyson Chazen
- LG&E and KU
  - John Moffett
  - Michael Manahan
  - David Link
- LG&E and KU (cont'd)
  - Jeff Fraley
  - Donald Duncan
- SMG
  - Sara Smith
  - Clay Whitney
- UKRF
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  - Jim Neathery
  - Joe Remias
  - Lisa Richburg
  - Heather Nikolic
  - Jesse Thompson
  - Others
- Worley-Parsons
  - Jacqueline Bird
  - Mike Bartone
  - Jay Whiting