Application of a Heat Integrated Post-Combustion Carbon Dioxide Capture System with Hitachi Advanced Solvent into Existing Coal-Fired Power Plant (FE0007395)

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

NETL CO_2 Capture Technology Meeting, Pittsburgh, PA, August 13-17, 2018

Project Summary

Accomplishments

- Testing completed on four solvents
- Reduced energy penalty through heat integration
- Reduced capital cost via process intensification

Team Members

2 MW_{th} Pilot-Scale CO_2 Capture Project

KU E.W. Brown Generating Station

Sponsored by:

U.S. Department of Energy Office of Fossil Energy
National Energy Technology Laboratory
Kentucky Department of Energy Development and Independence
Carbon Management Research Group
University of Kentucky

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UK Center for Applied Energy Research | LG&E KU PPL companies
MITSUBISHI HITACHI POWER SYSTEMS | DUKE ENERGY
EPRI ELECTRIC POWER RESEARCH INSTITUTE | DEDI
AEP KENTUCKY POWER A unit of American Electric Power

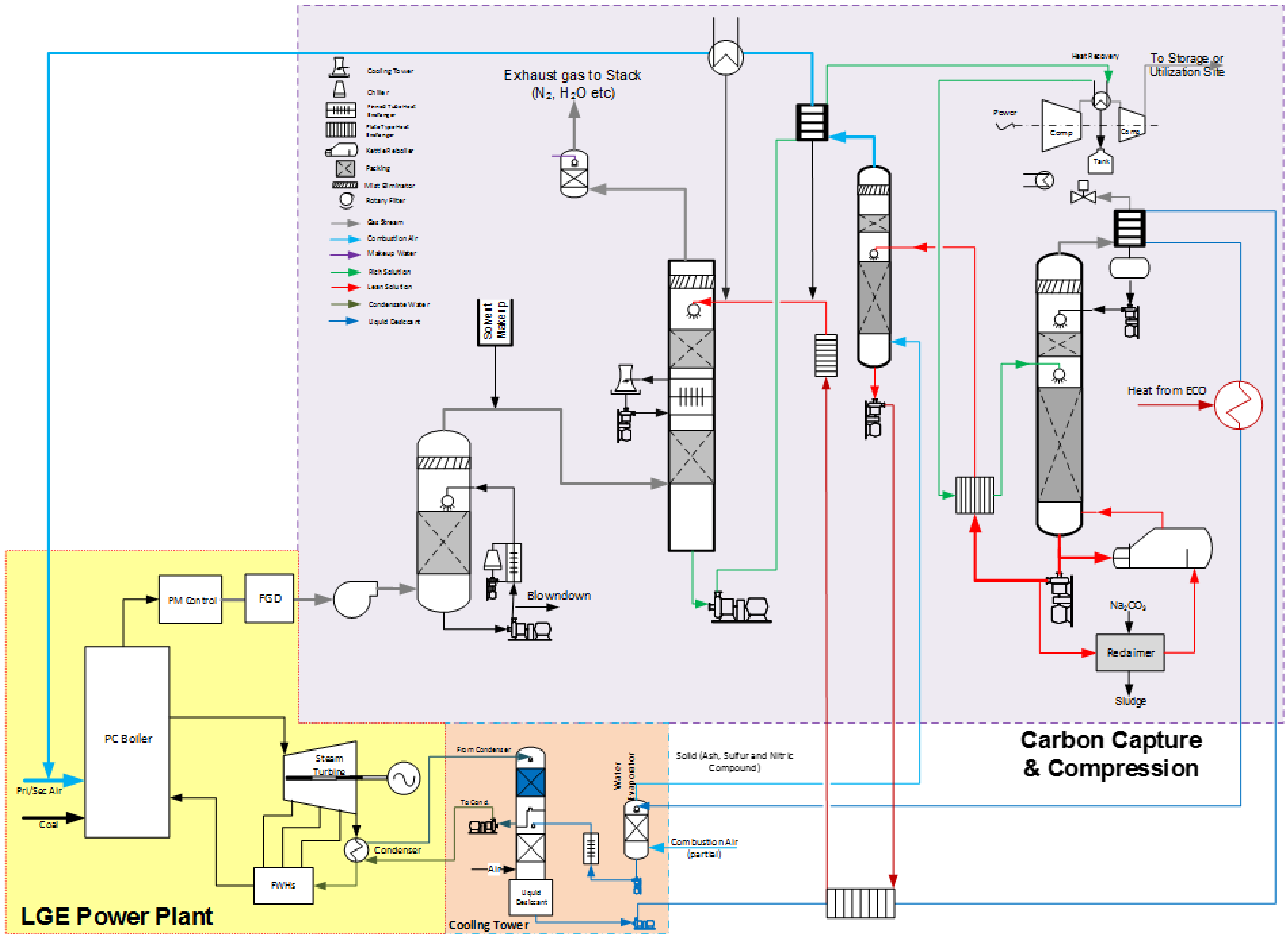
Cooperative Agreement DE-FE0007395

UKy-CAER Advanced Technology

<u>Motivation:</u>

- Reduced energy penalty and costs
  - Utilization of low grade heat via internal heat pump
    - Secondary air stripper
    - Liquid desiccant for cooling tower
  - Near-zero makeup water for amine loop to save operation costs
  - Advanced Solvents

UKy-CAER Advanced Technology



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Small Pilot Project Overview

- 0.7 MWe (2 MWth) Advanced post-combustion CO_2 capture small pilot
- Modular design
- Host Site at Kentucky Utilities E.W. Brown Generating Station in Harrodsburg, KY, approximately 30 miles from UKy-CAER
- Catch and release program
- Includes several UKy-CAER developed technologies
- Four solvent testing campaigns
  - 30% MEA baseline, H3-1 CAER, 40% MEA

Small Pilot Project Performance Dates

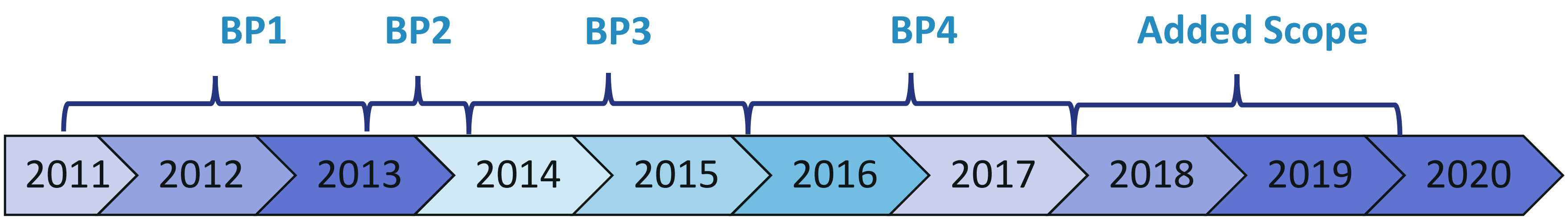
BP1: October 1, 2011 to January 31, 2013 (16 months)

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 March 31, 2017 (24 months)

Added Scope: April 1, 2017 to March 31, 2020 (36 months)



Added Scope: Testing of additional advanced solvents, hybrid system with CO_2 pre-concentrating membrane, and new water wash

BP4 Criteria Met and Project Key Findings

MEA Parametric Campaign

- Process can easily capture 90% of CO_2
- Solvent regeneration energy of 1200–1750 BTU/lb CO_2-captured, ~13% lower than Reference Case 10 (RC 10)

MEA Long-term Campaign

- Ambient conditions have an impact on CO_2 capture
- Absorber liquid/gas distribution has an impact on performance
- Lean/rich exchanger performance is critical
- Elemental accumulation in the solvent needs to be monitored

H3-1 Parametric Campaign

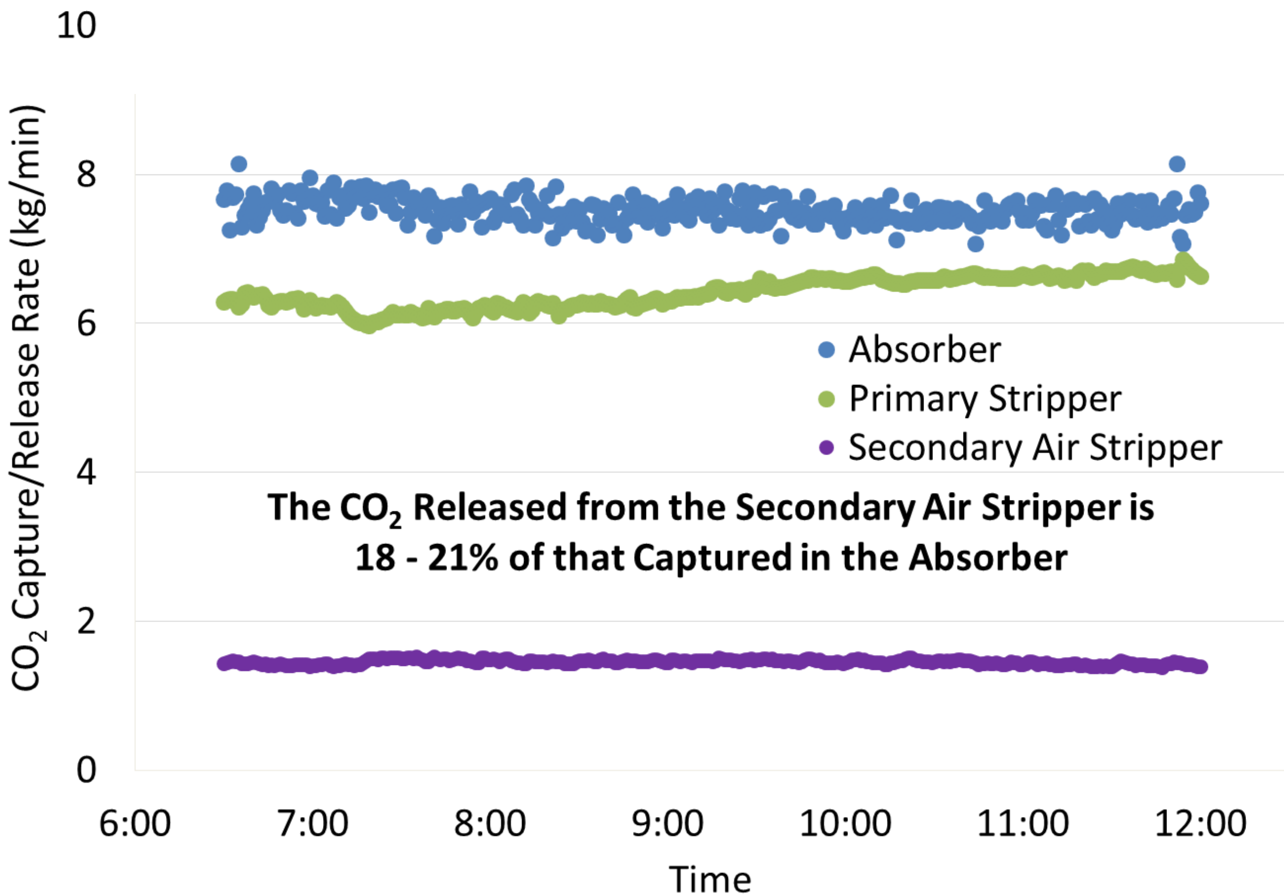
- Solvent regeneration energy of 900–1600 BTU/lb CO_2-captured, ~36% lower than RC10
- Secondary air stripper performs as expected

H3-1 Long-term Campaign

- 90% CO_2 capture and low solvent regeneration energies are possible with a range of solvent concentrations

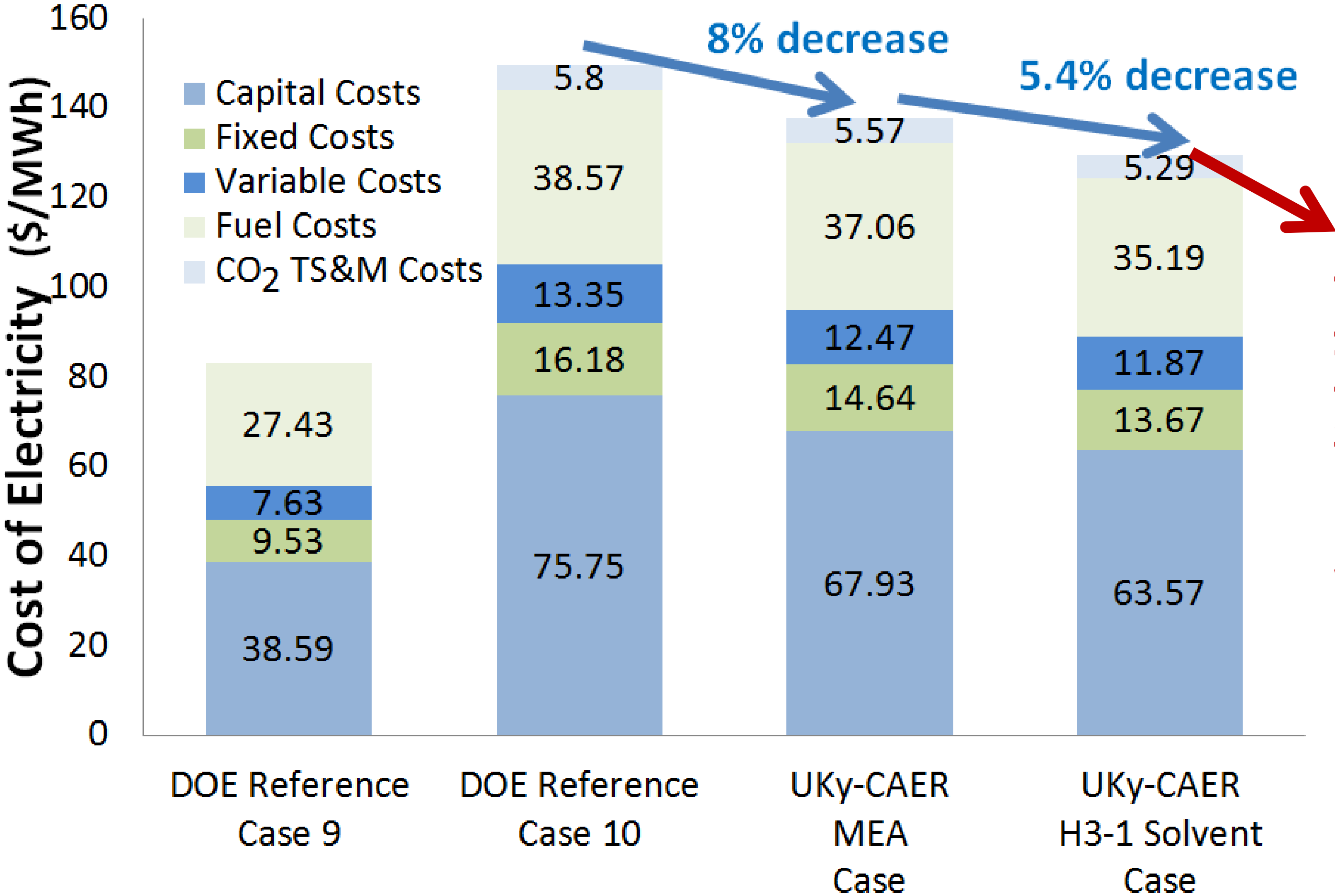
BP4 Success Criteria - Achieved

A heat-integrated post-combustion CO_2 capture system



Partial CO_2 recycle (10-20% of CO_2 captured) to enhance gaseous CO_2 pressure at the absorber inlet.

Summary of TEA

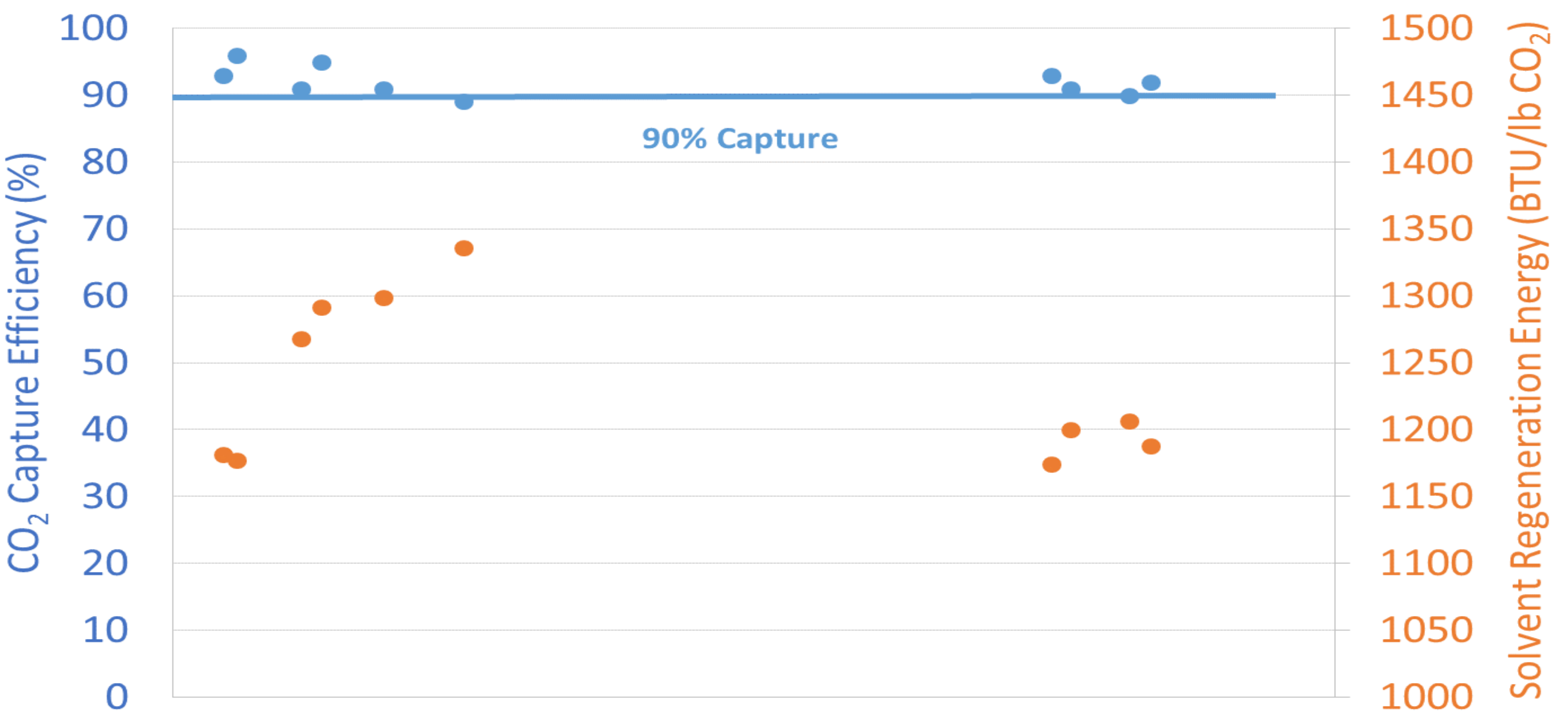


UKy-CAER's Pathway to Target of $35/tonne:

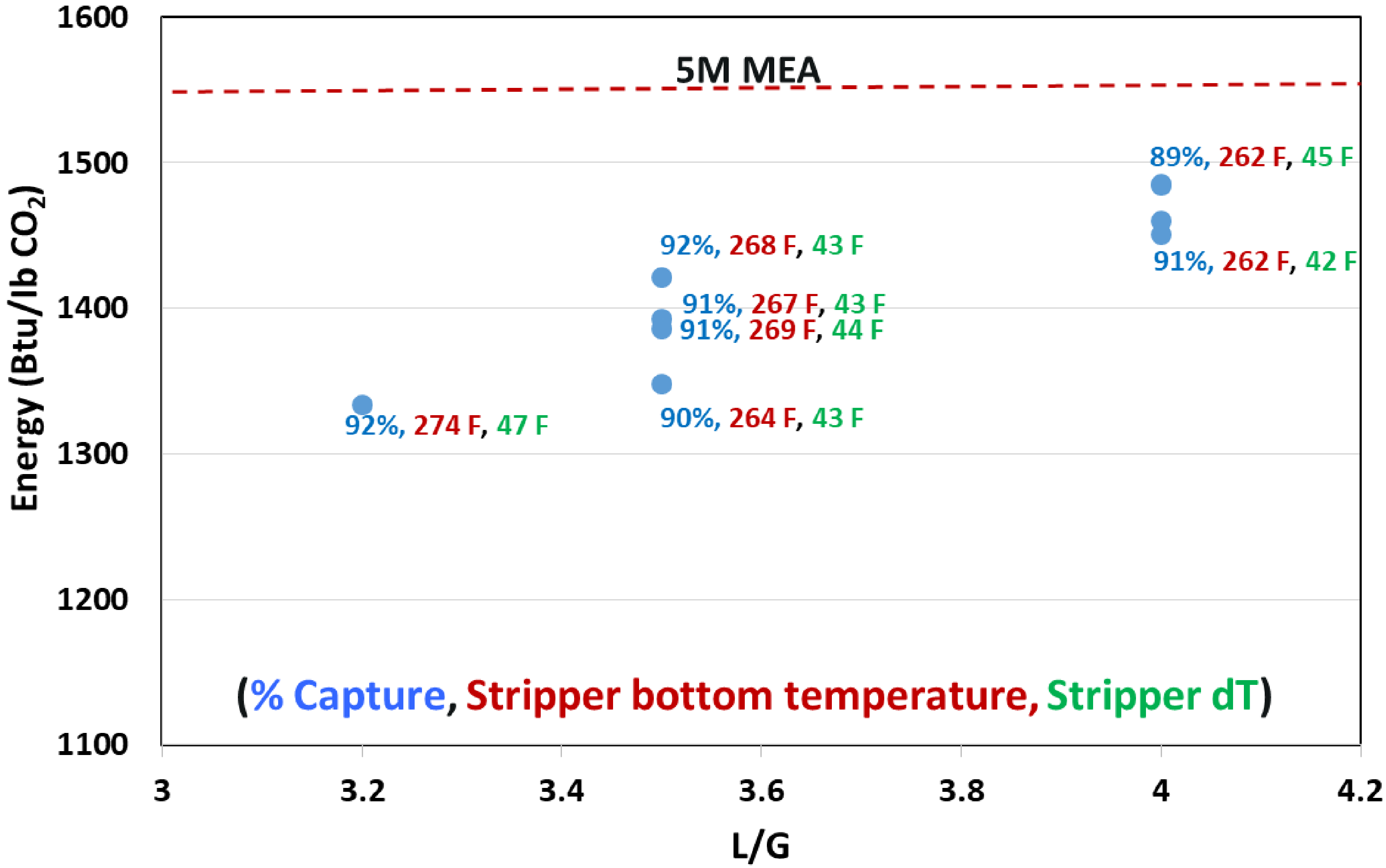
- Hybrid process with pre-concentrating membrane
- Absorber gas inter-conditioner
- 3rd generation solvent

3rd Generation Solvent is Needed

- CAER solvent blend showed good performance at the bench-scale
- Kinetics faster than 2nd generation solvent
- 15-30% better than MEA while the cost is only ~2X



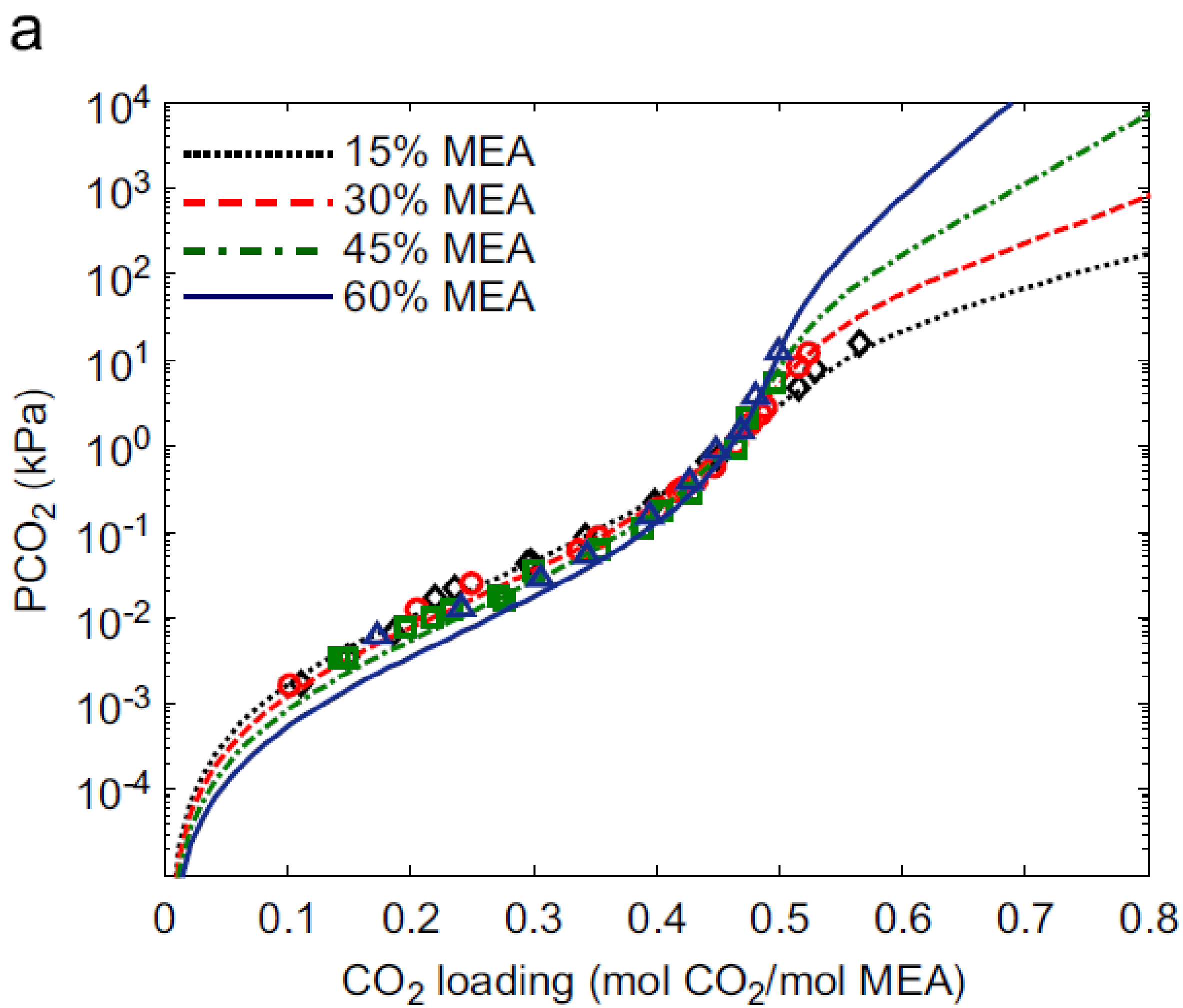
Liquid Circulation Rate (L/G)



Fixed gas flow, inlet CO_2 concentration of 14 vol% at 36 psia stripper pressure

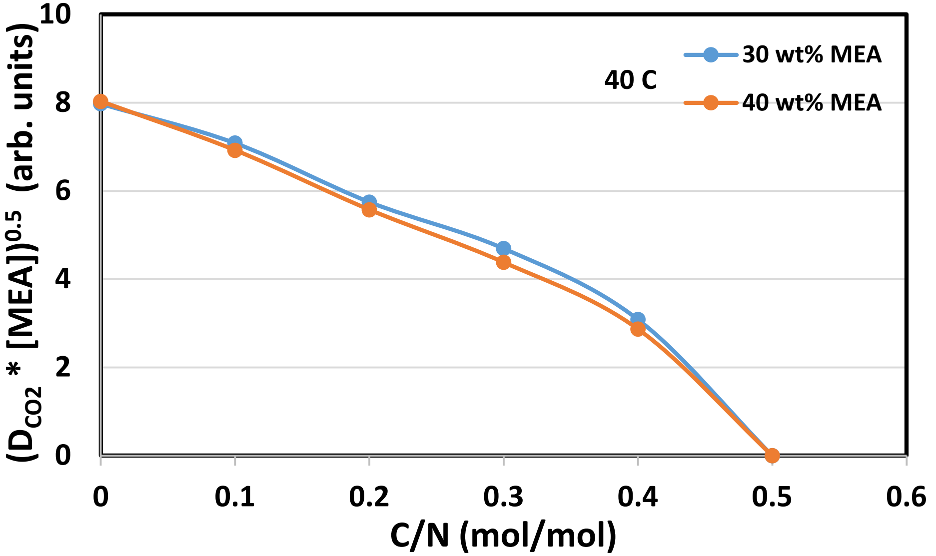
High Concentration Solvents

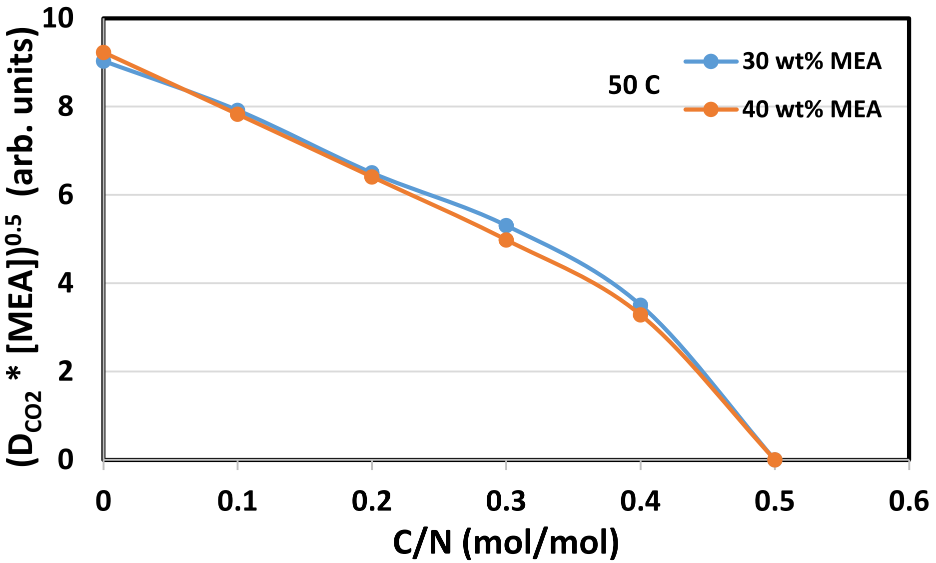
Interest among International Test Center Network (ITCN) members to test open-source amines solvents and solvents at high concentrations: 40% MEA



Aronu, U.E. et al. Chemical Engineering Science, 2011, 66, 6393-6406

Mass Transfer Estimates

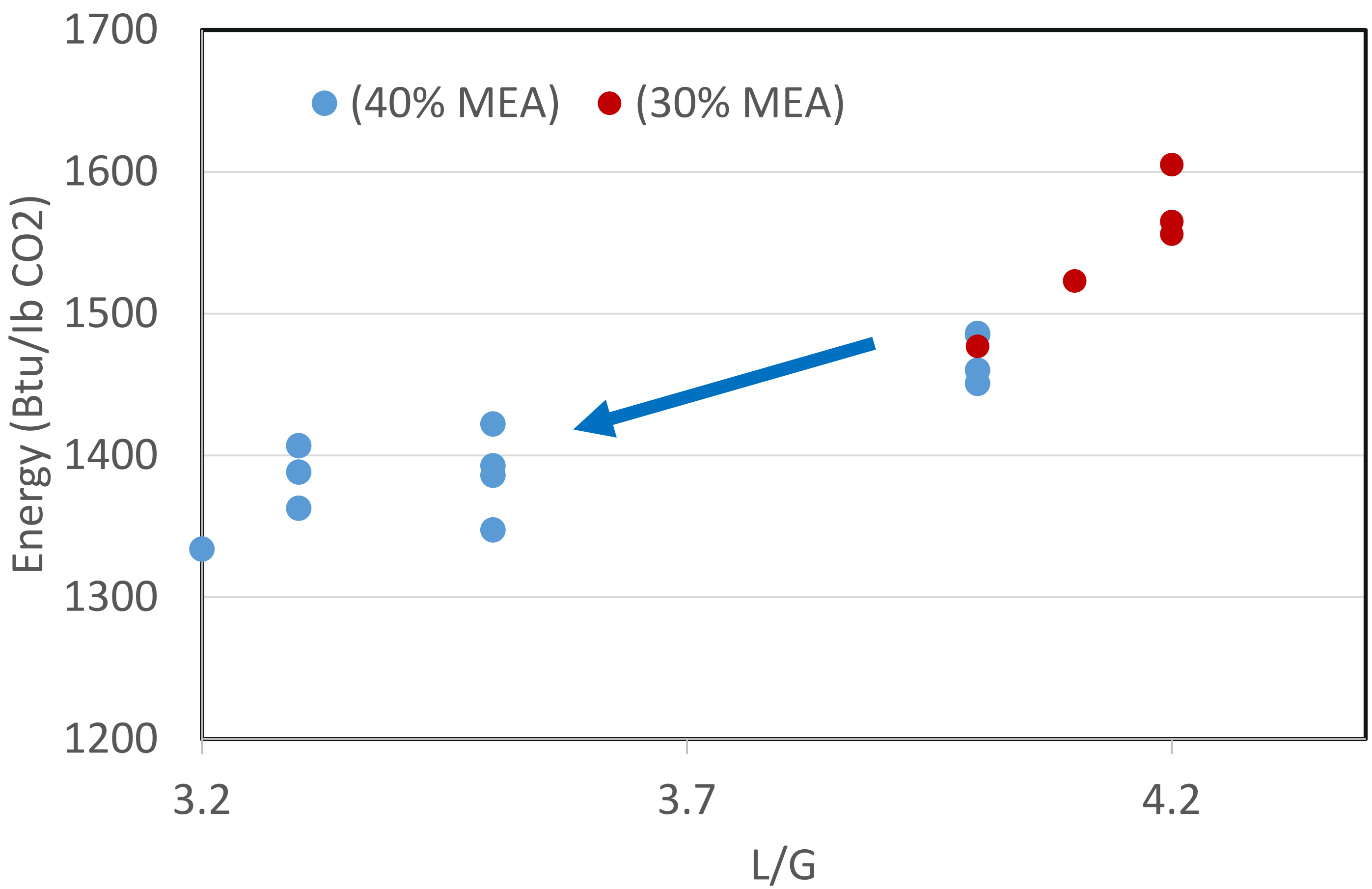




$$k_g{}' = \frac{\sqrt{k D_{co2}[Am]}}{H_{co2}}$$

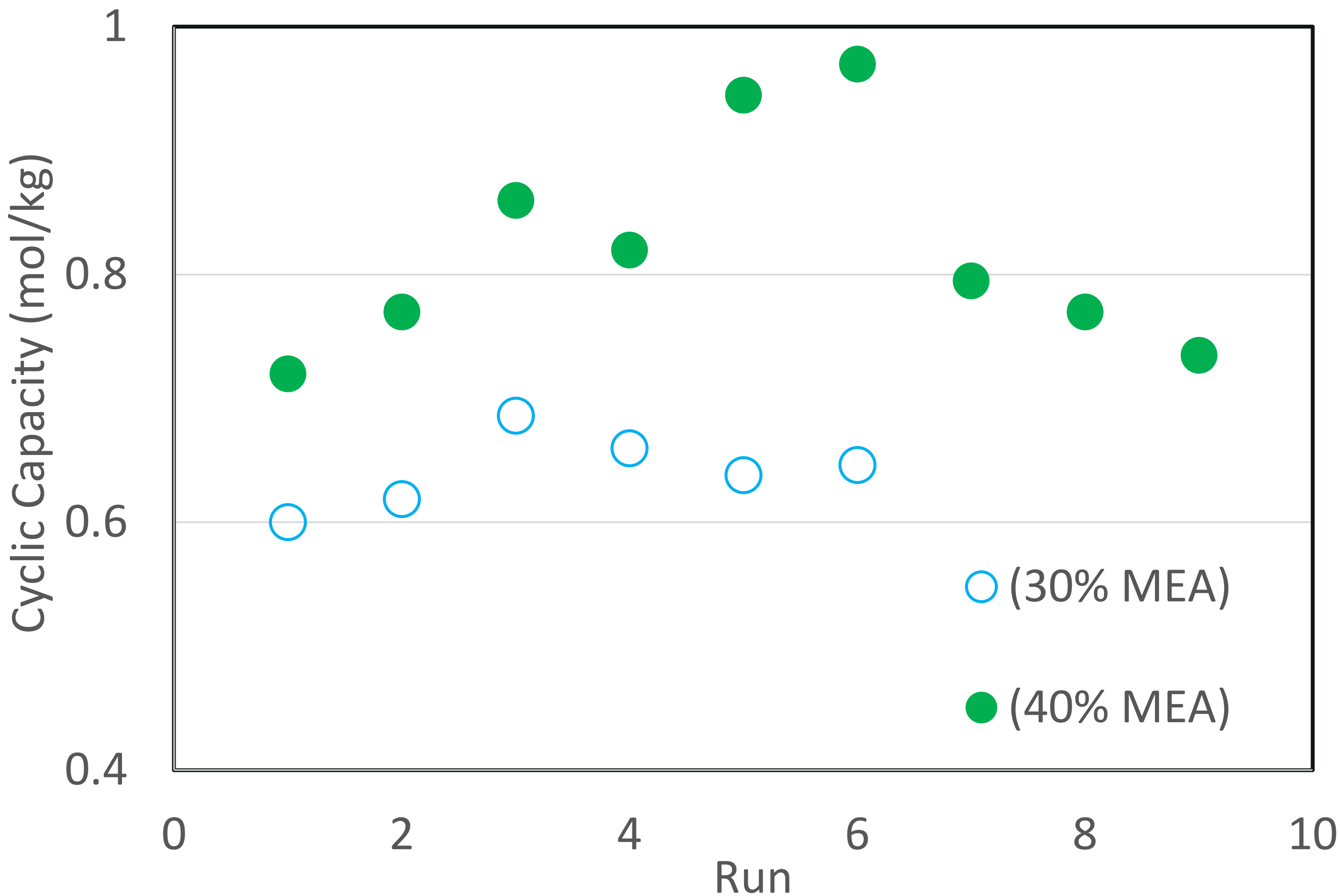
Approximation with constant rate (k) and Henry's constant (H_{CO2})

40% MEA Comparison vs 30% MEA (Energy)



- **Lower energy at higher 6M MEA concentration at reduced L/G**
- **Decreased circulation results in 10-15% energy savings**

40% MEA Comparison vs 30% MEA (Energy)



Higher cyclic capacity at 40% MEA concentration

Temperature Around L-R Heat Exchanger

	(Lean In) Stripper Bottom F	(Rich Out) Stripper Top F	Hot Side DT	Lean Out F	Rich In F	Cold Side DT
40% MEA	262	229	33	220	189	31
	264	230	34	222	193	29
	268	232	36	224	195	29
	267	232	35	225	195	30
	270	234	36	226	194	32
	250	218	32	215	191	24
30% MEA	254	222	32	208	186	22
	255	222	33	209	187	22
	255	221	34	208	186	22
	256	223	33	208	185	23

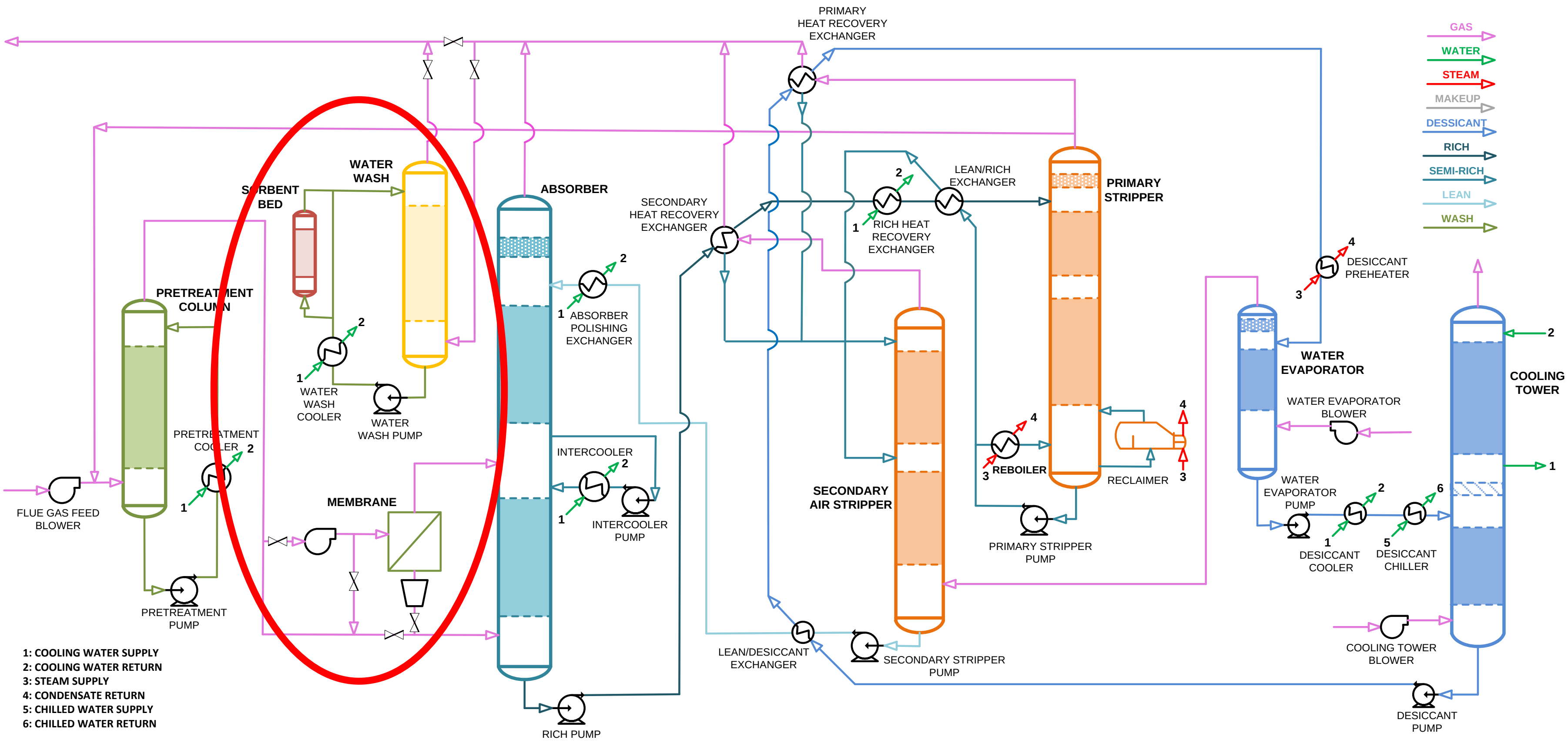
Similar hot side temperature of approach for 30% and 40% MEA

Cold side temperature difference is higher for the 40% runs at the higher (> 250 F) stripper bottom temperatures; but similar for 30% and 40% MEA at equivalent stripper bottom temperatures

Solvent Comparison

Performance Compared to 30 wt% MEA	Hitachi H3-1	CAER	40% MEA
Energy Penalty	27% savings	20-25% savings	~12-15% savings
Solvent Circulation Rate	~35-45% reduction	~30% reduction	~15-20% reduction
Cyclic Capacity	~1.5X	~1.5X	~2X
Viscosity (40 °C)	2.5 – 3X	~1.5X	~2X
Surface Tension	~0.6X	~1.0X	Similar
Degradation	Low	Low	Similar
Solvent Regeneration Energy Measured at Uky-CAER Small Pilot CCS	1022 Btu/lb CO_2 on 0.7 MWe	1070-1600 BTU/lb CO_2 on 0.7 MWe	1350 BTU/lb CO_2 on 0.7 MWe

Hybrid 0.7 MWe CCS Flow Diagram



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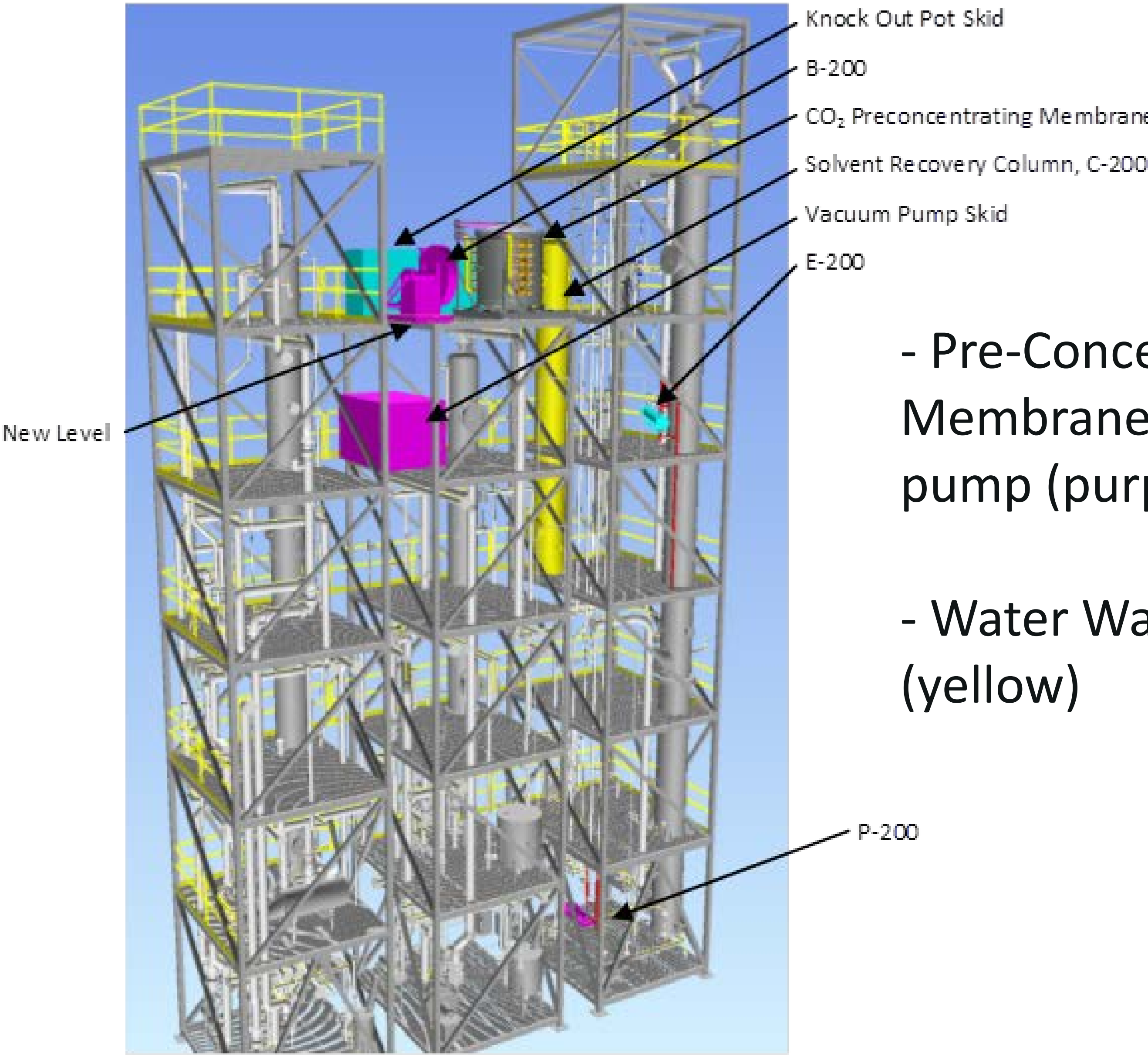
Additional Modifications



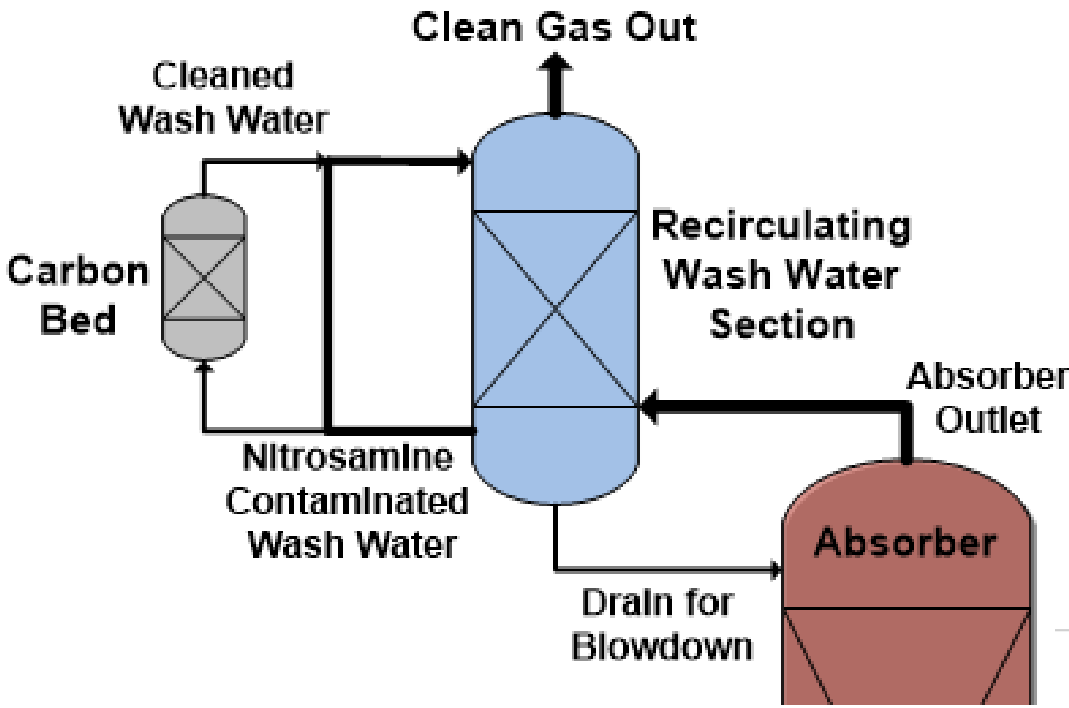
- Pre-Concentrating Membrane w/ vacuum pump (purple)

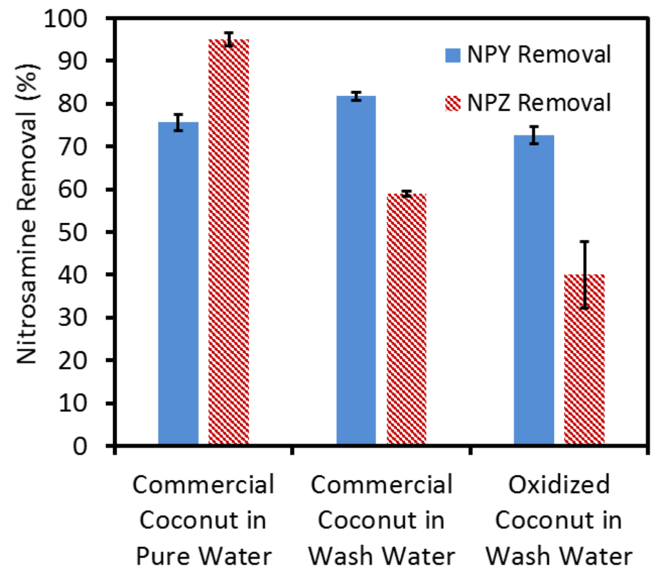
- Water Wash column (yellow)

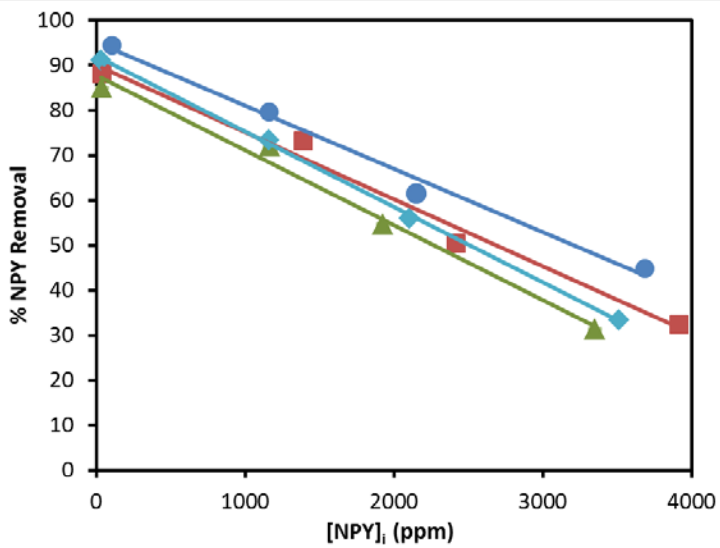
CO_2 Pre-Concentrating Membrane

MTR membrane skid arrived onsite, has been pressured tested and is ready for installation

Water Wash – Nitrosamine Removal







Commercial coconut charcoal activated carbon showed a high capacity towards nitrosamine in amine water wash solutions

Widger, et.al., Environ. Sci. Technol. 2017, 51, 10913-10922

Remaining Tasks

1) Water wash testing

2) Pre-concentrating membrane performance evaluation

<u>Construction schedule:</u>

Membrane module delivered: June

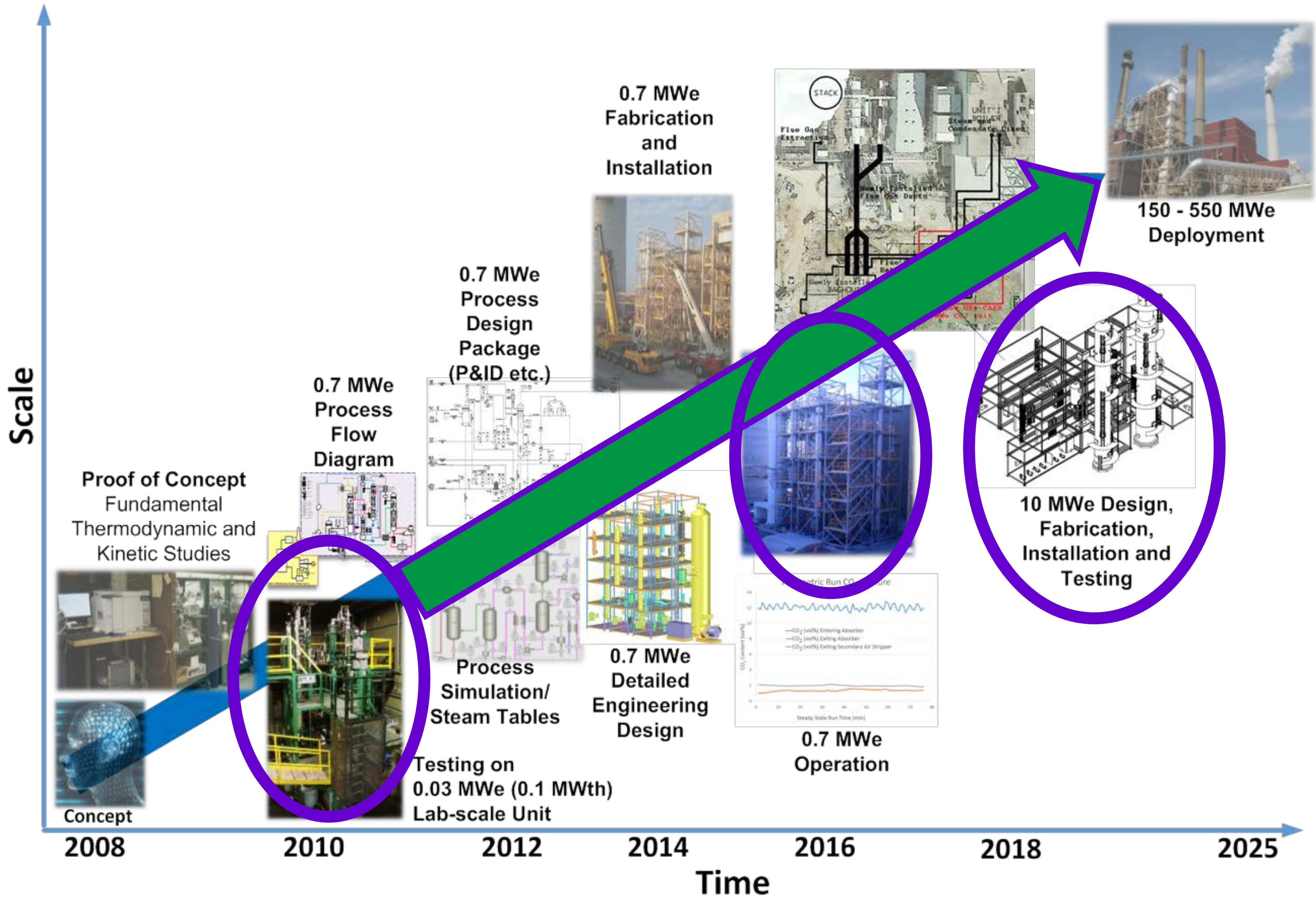
Column/piping fabrication and installation: September

Electrical and auxiliary installation: November

Key Knowledge Gained

- Liquid/gas distribution can significantly reduce the absorber efficiency.
- It is important to consider the L/R exchanger performance when reporting and comparing solvent regeneration values.
- Thermal reclaiming may be needed for RCRA element management.

Technology Development Pathway



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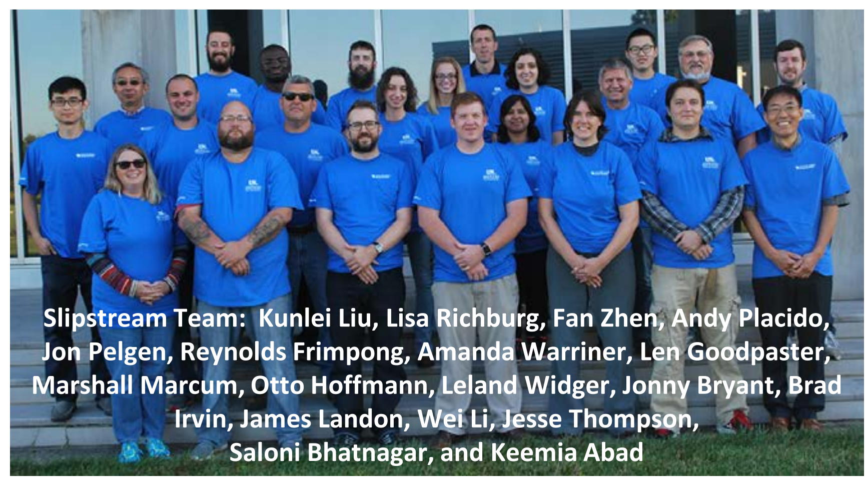

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