Development and Bench-Scale Testing of a Novel Biphasic Solvent-Enabled Absorption Process for Post-Combustion Carbon Capture (DE-FE0031600)

Presenter: Paul Nielsen

Illinois State Geological Survey

Pittsburgh, PA · August 16, 2018

Project Overview

Technology Background

Scope of Work/Technical Approaches

Current Status

Plan for Future Scale-Up /Development

Objectives

- Advance the development of a transformational biphasic CO_2 absorption technology from lab- to bench-scale
- Design, fabricate and test an integrated 40 kWe bench-scale capture unit with simulated and actual coal flue gas
- Demonstrate the technology progressing toward achieving the DOE's Transformational Capture goals

Project Participants

- University of Illinois (Technology Developer)

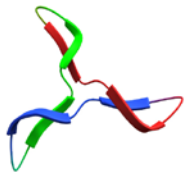
Illinois State Geological Survey

  - David Ruhter (MS, Lab Manager)
  - Hafiz Salih (PhD, Environmental Engineer)
  - Hong Lu (PhD, Chemical Engineer)
  - Qing Ye (Post-Doctoral Research Fellow)
  - Varenya Mehta (MS, Environmental Engineer)
  - Paul Nielsen (PhD, Chemical Engineer)
  - Yonggi Lu (PhD, Chemical/Environmental Engineer)

Illinois Sustainable Technology Center

  - BK Sharma (PhD, Senior Chemical Engineer)
  - Kevin O'Brien (PhD, Director)
  - Wei Zheng (PhD, Senior Chemist)

- **Trimeric Corporation** (Design and Fabrication, TEA)
  - Darshan Sachde (PhD, Senior Chemical Engineer)
  - Katherine Dombrowski (Principal Technical Staff)
  - Kevin Fisher (VP, P.E., Principal Engineer)
  - Ray McKaskle (P.E., Principal Engineer)



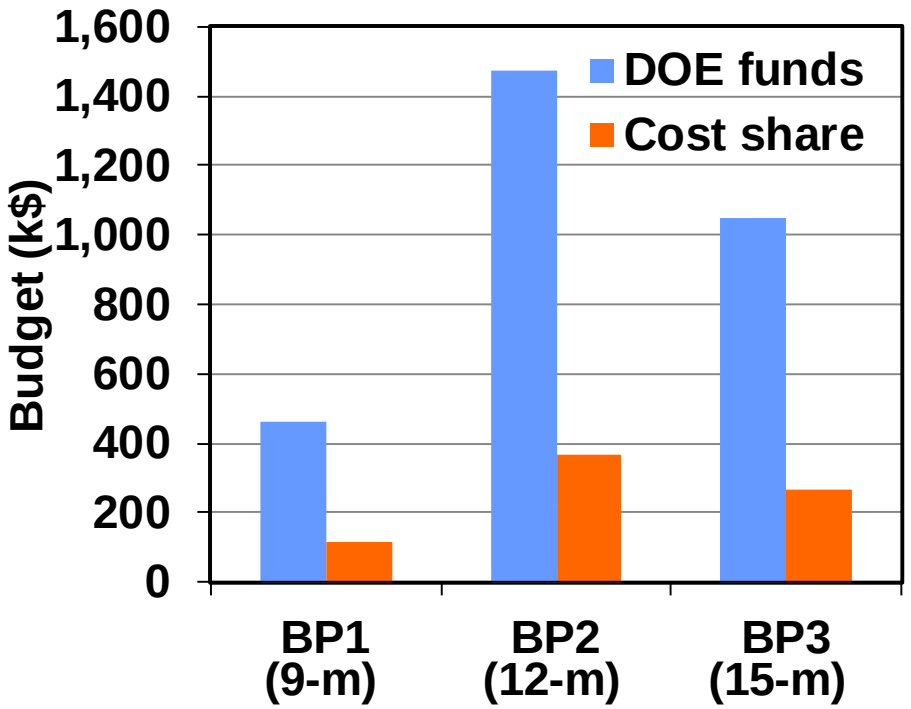
Budget Profile and Duration

Project duration: 36 mon, 3 Budget Periods (4/6/18–4/5/21)

- BP1: 9 mon (4/6/18-1/5/19)
- BP2: 12 mon (1/6/19-1/5/20)
- BP3: 15 mon (1/6/20-4/5/21)

Funding Profile:

- DOE funding of $2,981,779
- Cost share (in-kind) of $750,051 (20.1%)



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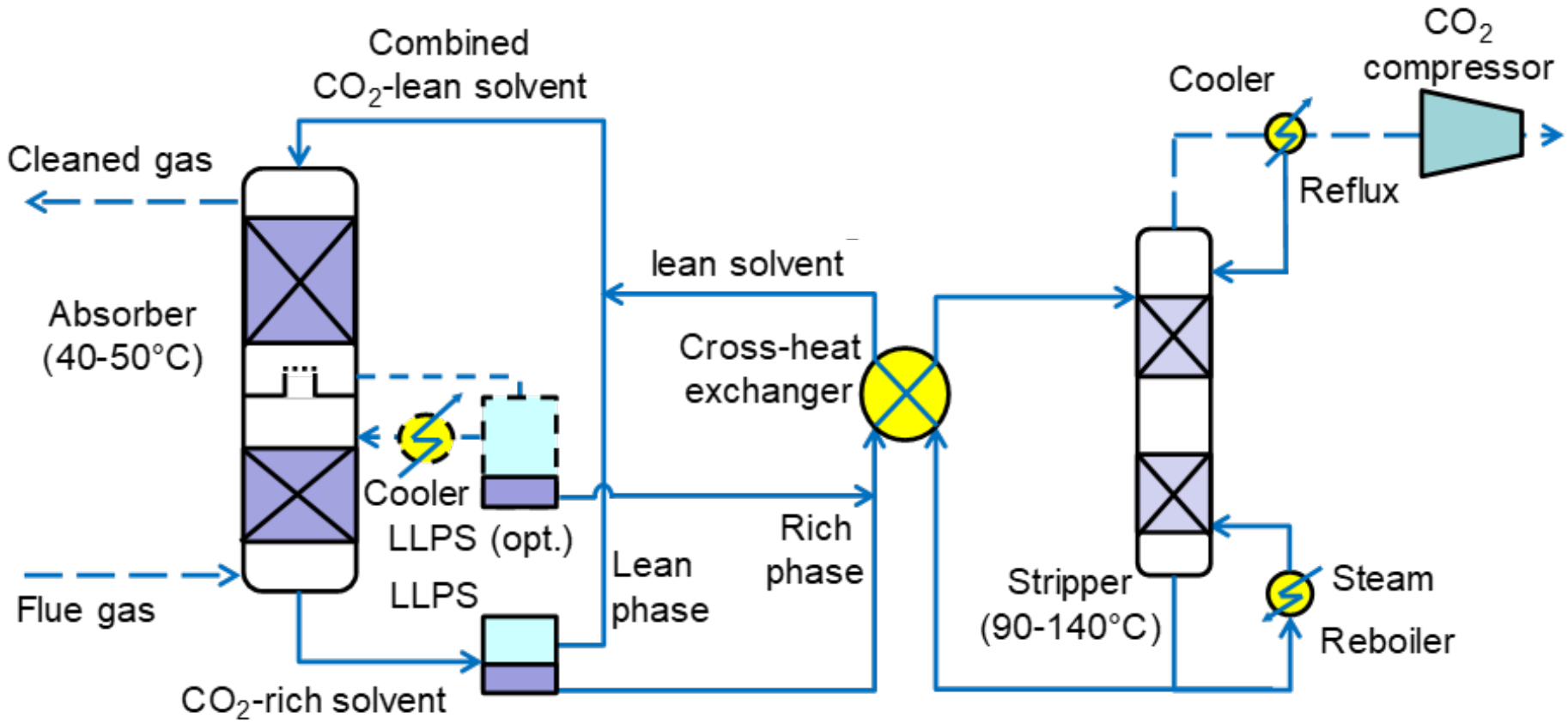
Biphasic Process (BiCAP)



- Water lean Aqueous/Organic amine blend
  - CO_2-rich solvent separates into 2 liquid phases
- Reduced solvent flow to regenerator
- Enhanced CO_2 absorption via removal of rich solvent

Progression of Technology Development

Currently

40 kWe Test, Laboratory & Power Plant Slipstream

Future Scale-Up Development

10 kWe Test, Laboratory

Bench Scale Closed-Loop Unit
Funding: *DOE / UI (2018-2021)*

Solvent study, Laboratory

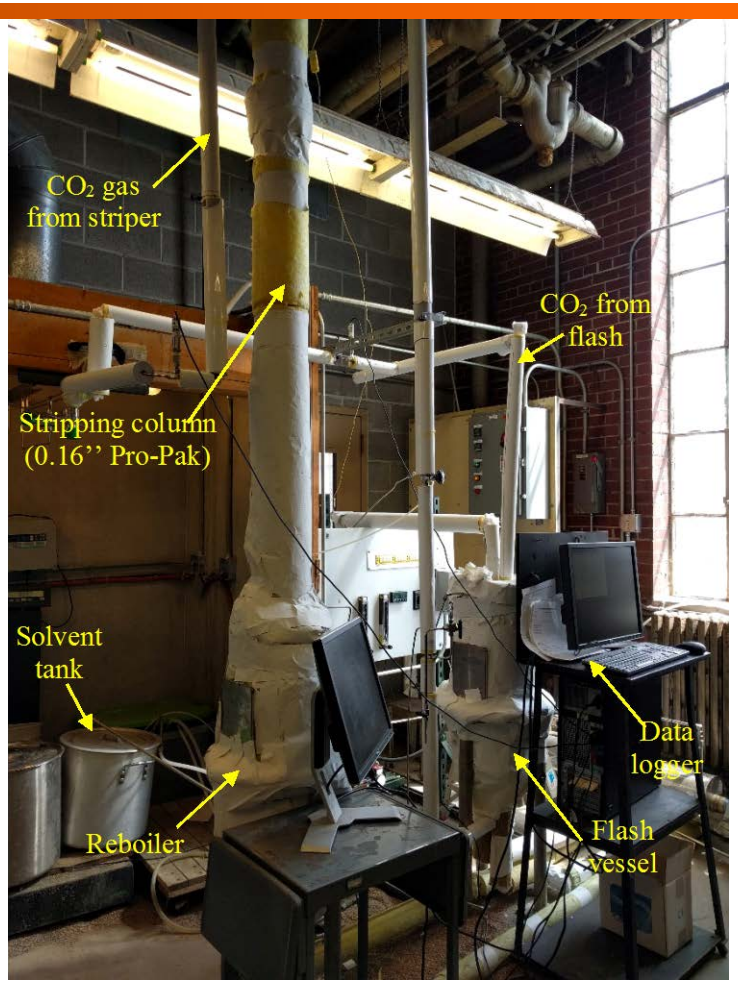
Separate Absorber / Stripper
Funding: *DOE / UI (2015-2018)*

Proof-of-Concept
Funding: *UI (Part of Dissertation Research, 2013-2015)*

Current Status of Solvent and Process R&D

Solvent Development	Results	Status
~80 solvents screened	2 solvents selected	Completed
VLE	Absorption capacity: similar to 5 m MEA	Completed
Absorption kinetics	Comparable to faster than MEA	Completed
Oxidation and thermal stabilities	Thermal stability at 150°C ~ MEA at 120°C; Oxidation stability ~8 times < MEA	Completed
Viscosity	CO_2-saturated rich phase solutions < 50 cP	Completed
Phase Separation	≥98% of CO_2 uptake in <50% of solution	Completed
Heat of desorption	Estimated with VLE data	Completed
Corrosion effect	Less corrosion than MEA on CS or SS	Completed
CO_2 absorption	Lab 10 kWe absorption column; Faster rates than MEA demonstrated in testing	Completed
CO_2 stripping	Lab 10 kWe desorption system; Heat duty 2400 kJ/kg CO_2 for BiCAP-1, 2000 for -2	Near Completion

Lab 10 KW_e Absorption and Desorption Tests Demonstrated Performance of BiCAP



- CO_2 absorption rate 12% faster than 5 m MEA for BiCAP-1
- Demonstrated effectiveness of liquid-liquid phase separation unit

- Tested up to 150 °C, 9 bar
- Minimum Reboiler Heat Duty:
  - BiCAP-1: 2400 kJ/kg CO_2
  - BiCAP-2: 2000 kJ/kg CO_2

Projected Energy Performance for Net 550 MW_e

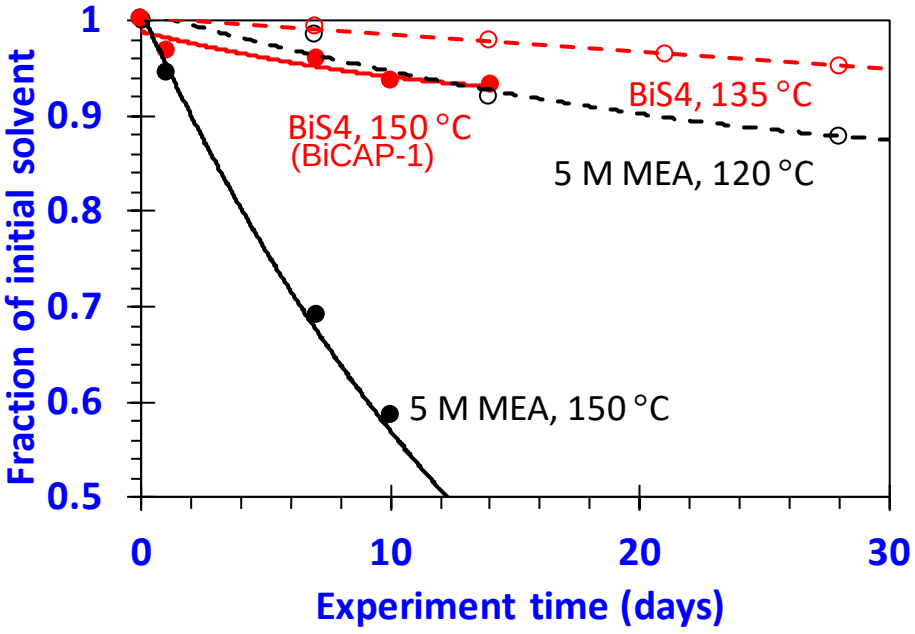
	BiCAP*	DOE Case 12 (MEA)	DOE Case B12B (Cansolv)
Net Generating Capacity, MWe	**550**	**550**	**550**
Gross Generating Capacity, MWe	**700**	**802**	**728**
Amount of CO_2 captured, tonne/hr	**478**	**548**	**480**
Total Steam Derate, MWe	**71.1**	**139**	**86**
Reboiler/Flash Heat Duty, MWth	278	542	331
Thermal to Electric Energy, %	25.6	25.6	25.8
Direct Electrical Derate, MWe	**44.8**	**75.2**	**51.7**
Compression Duty, MWe	31.5	44.9	35.7
Other (Pumps, Fans, etc.), MWe	13.3	30.3	16.0
Total Derate for CO_2 Capture, MWe	**116**	**214**	**137**
Total parasitic use for entire plant, MWe	**150**	**252**	**178**

* Updated BiCAP case (Cold rich feed bypass the heat exchanger)

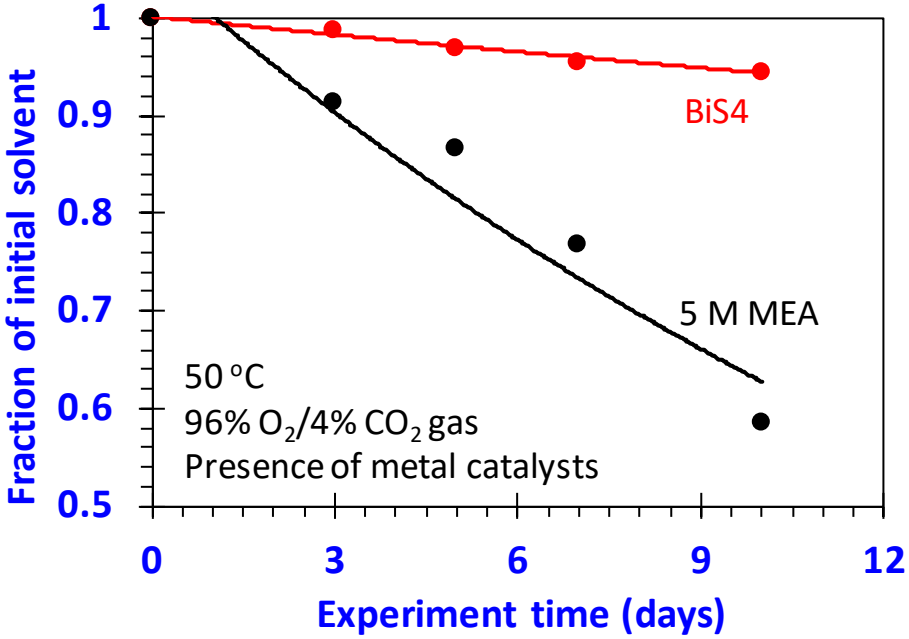
- Total derate 43% less than MEA
- CAPEX 20% less than MEA

Biphasic Solvents are Stable

- Thermal Stability: BiCAP-1 @ 150 °C ~ MEA @ 120 °C



- Oxidative Stability: BiCAP-1 8x < MEA @ 50 °C



- Corrosion rate of 2-3 times < MEA for carbon steel, minimal for stainless
- Viscosity <50 cP for CO2-rich phase, <10 cP mixed @ 40 °C

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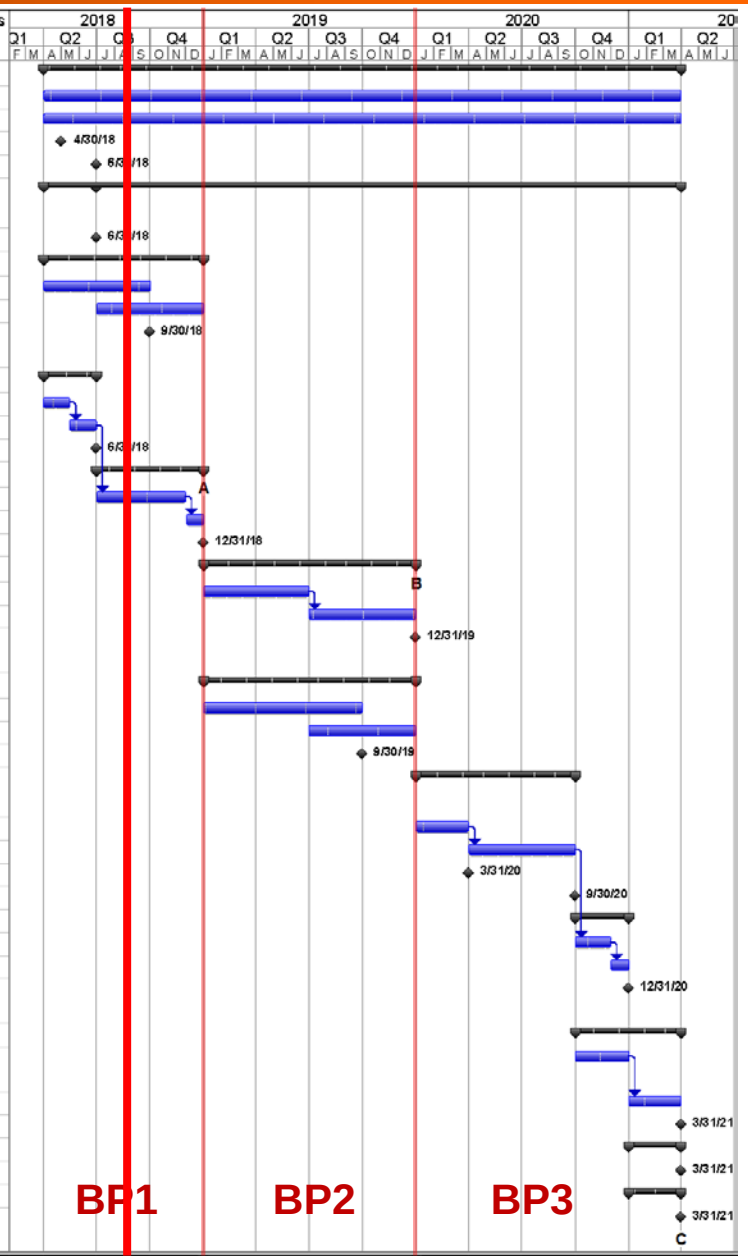
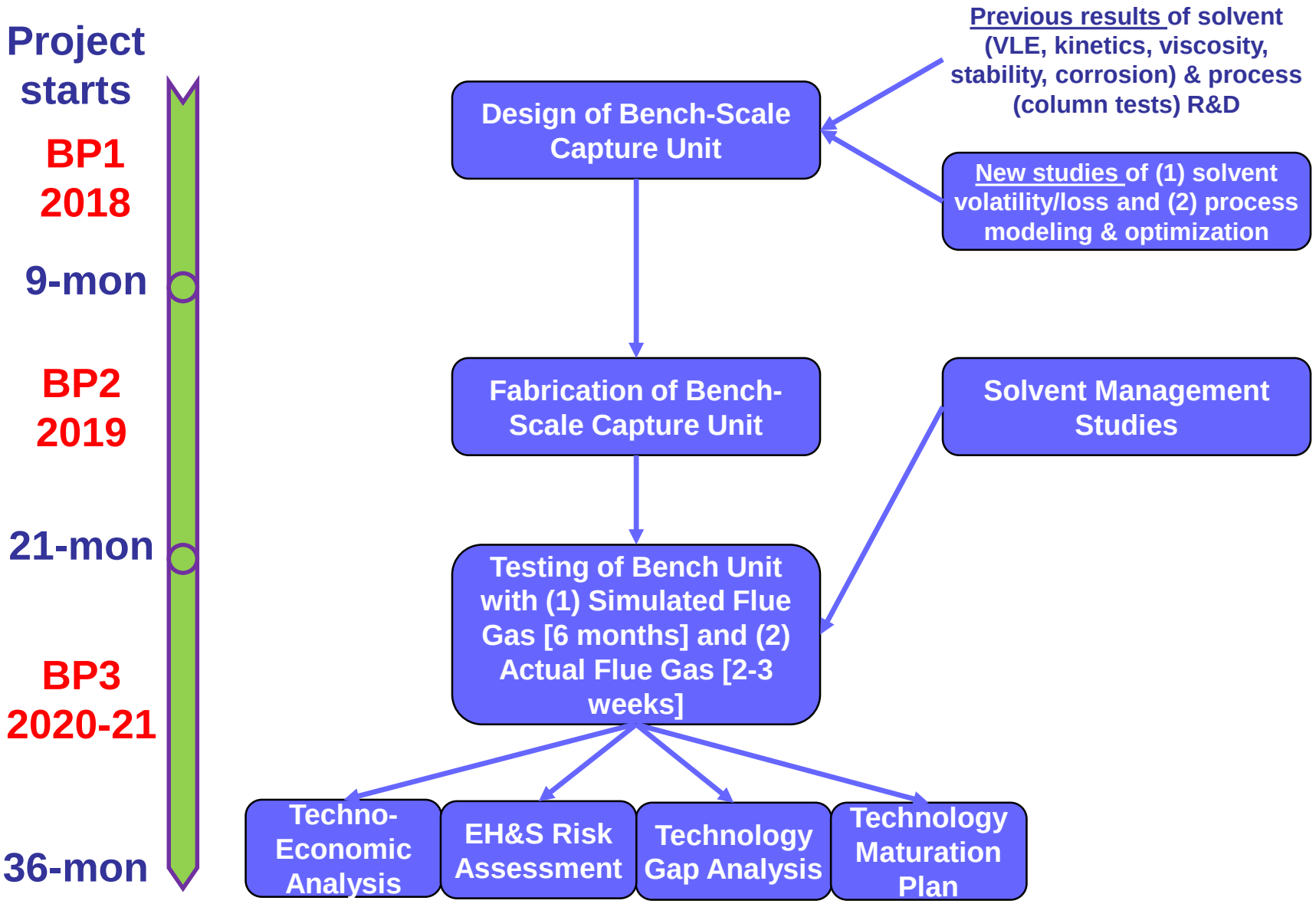
Plan for Future Scale-Up /Development

Schedule and Milestones (36-mon, 4/6/18-4/5/21)

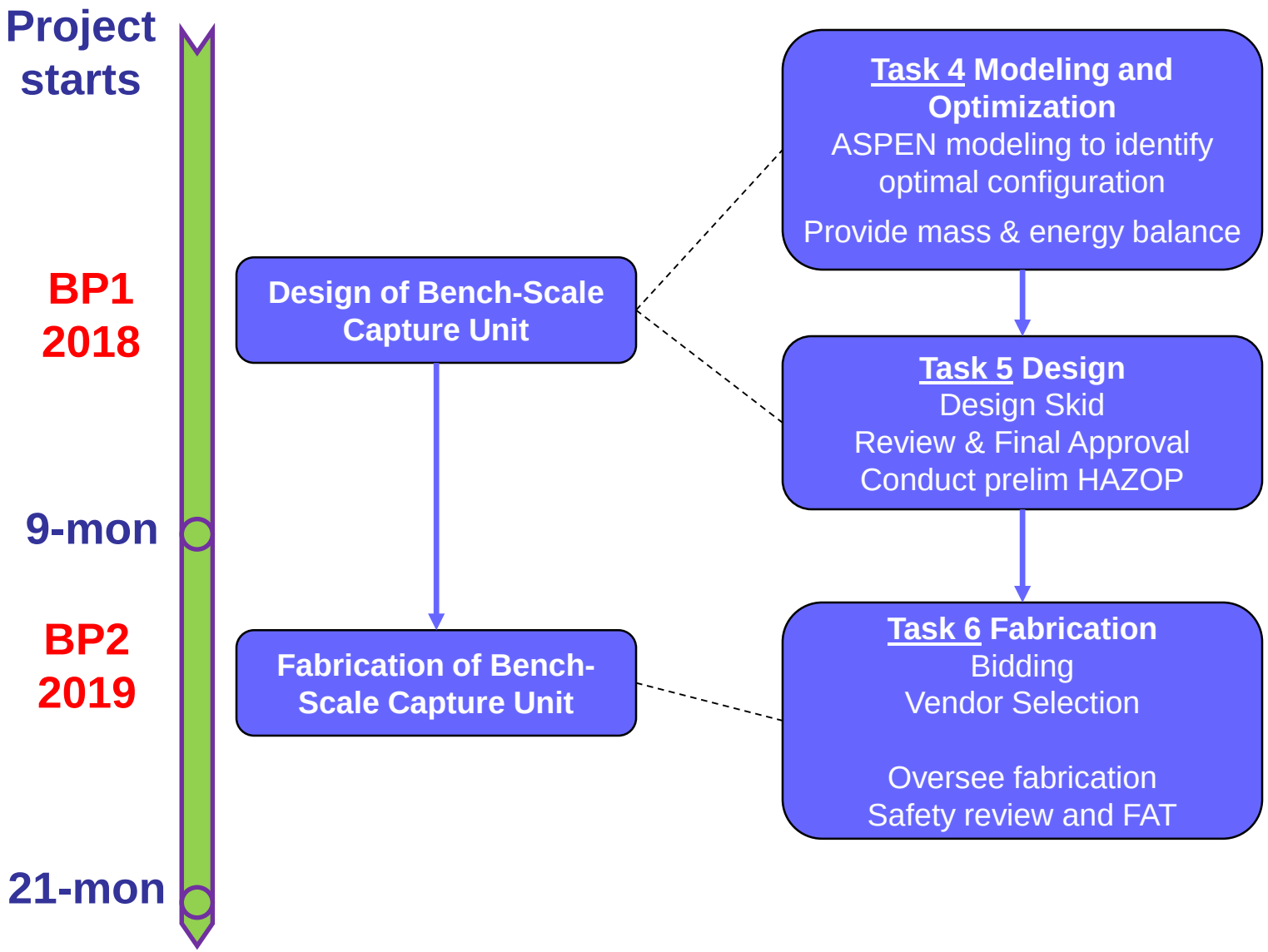
ID	Task Name	Start	Finish	Resource Names
1	**Task 1.0 - Project Management and Planning**	**4/1/18**	**3/31/21**	**UIUC**
2	1.1 - Project Monitoring and Control	4/1/18	3/31/21	UIUC
3	1.2 - Briefings and Reports	4/1/18	3/31/21	UIUC,Trimeric
4	a - Updated Project Management and Planning	4/30/18	4/30/18	
5	b - Project kickoff meeting	6/30/18	6/30/18	
6	**Task 2.0 - Developing & Implementing a Technology Maturation Plan**	**4/1/18**	**3/31/21**	**UIUC**
7	c - Technology Maturation Plan prepared	6/30/18	6/30/18	
8	**Task 3.0 - Studies of Solvent Volatility and Losses**	**4/1/18**	**12/31/18**	**UIUC**
9	3.1 - Solvent Volatility Measurement	4/1/18	9/30/18	UIUC
10	3.2 - Testing of Solvent Losses in a Laboratory Absorption Column	7/1/18	12/31/18	UIUC
11	d - Volatility measurement and preliminary results of water wash performance obtained	9/30/18	9/30/18	
12	**Task 4.0 - Modeling & Optimization of Biphasic CO2 Absorption Process**	**4/1/18**	**6/30/18**	**UIUC**
13	4.1 - Process Modeling and Optimization	4/1/18	5/15/18	UIUC
14	4.2 - Bench-Scale Unit Process Simulations	5/16/18	6/30/18	UIUC
15	e - Optimal process configuration identified	6/30/18	6/30/18	
16	**Task 5.0 - Design of Bench-Scale Capture Unit**	**7/1/18**	**12/31/18**	**Trimeric**
17	5.1 - Design of Bench-Scale Capture Unit	7/1/18	11/30/18	Trimeric
18	5.2 - Design Review and Approval	12/3/18	12/31/18	Trimeric
19	f - Bench-scale equipment design completed	12/31/18	12/31/18	
20	**Task 6.0 - Fabrication of Bench-Scale Capture Unit**	**1/1/19**	**12/31/19**	**UIUC,Trimeric**
21	6.1 - Bidding Solicitation and Selection of a Manufacturing Vendor	1/1/19	6/30/19	Trimeric,UIUC
22	6.2 - Fabrication of Bench-Scale Capture Unit	7/1/19	12/31/19	UIUC,Trimeric
23	g - Bench-scale unit fabricated and factory acceptable test completed	12/31/19	12/31/19	
24	**Task 7.0 -Solvent Management Studies**	**1/1/19**	**12/31/19**	**UIUC**
25	7.1 - Solvent degradation and reclamation study	1/1/19	9/30/19	UIUC
26	7.2 - CO2 loading correlation and in-situ measurement	7/1/19	12/31/19	UIUC
27	h - Solvent reclamation option identified	9/30/19	9/30/19	
28	**Task 8.0 - Parametric Testing of Bench-Scale Unit with a Simulated Flue Gas Stream**	**1/1/20**	**9/30/20**	**UIUC,Trimeric**
29	8.1 - Installation and Commissioning	1/1/20	3/31/20	Trimeric,UIUC
30	8.2 - Parametric Testing of Bench-Scale Unit	4/1/20	9/30/20	UIUC
31	i - Bench-scale unit installed on skid	3/31/20	3/31/20	
32	j - Parametric testing of bench-scale unit completed	9/30/20	9/30/20	
33	**Task 9.0 - Testing of Bench-Scale Capture Unit at a Power Plant**	**10/1/20**	**12/31/20**	**UIUC,Trimeric**
34	9.1 - Field Test Preparation	10/1/20	11/30/20	UIUC,Trimeric
35	9.2 - Bench-scale Testing with Actual Flue Gas	12/1/20	12/31/20	UIUC
36	k- Field testing with a slipstream of coal combustion flue gas completed	12/31/20	12/31/20	
37	**Task 10.0 - Techno-Economic Analysis**	**10/1/20**	**3/31/21**	**Trimeric**
38	10.1 - Process Analysis and Updating Mass & Energy Balance Calculations	10/1/20	12/31/20	Trimeric
39	10.2 - Techno-Economic Analysis	1/1/21	3/31/21	Trimeric
40	l - Techno-Economic Analysis topical report completed	3/31/21	3/31/21	
41	**Task 11.0 - Technology Gap Analysis**	**1/1/21**	**3/31/21**	**UIUC**
42	m - Technology Gap Analysis topical report completed	3/31/21	3/31/21	
43	**Task 12.0 - Environmental Health and Safety Risk Assessment**	**1/1/21**	**3/31/21**	**UIUC**
44	n - Environmental Health & Safety Risk Assessment topical report completed	3/31/21	3/31/21	



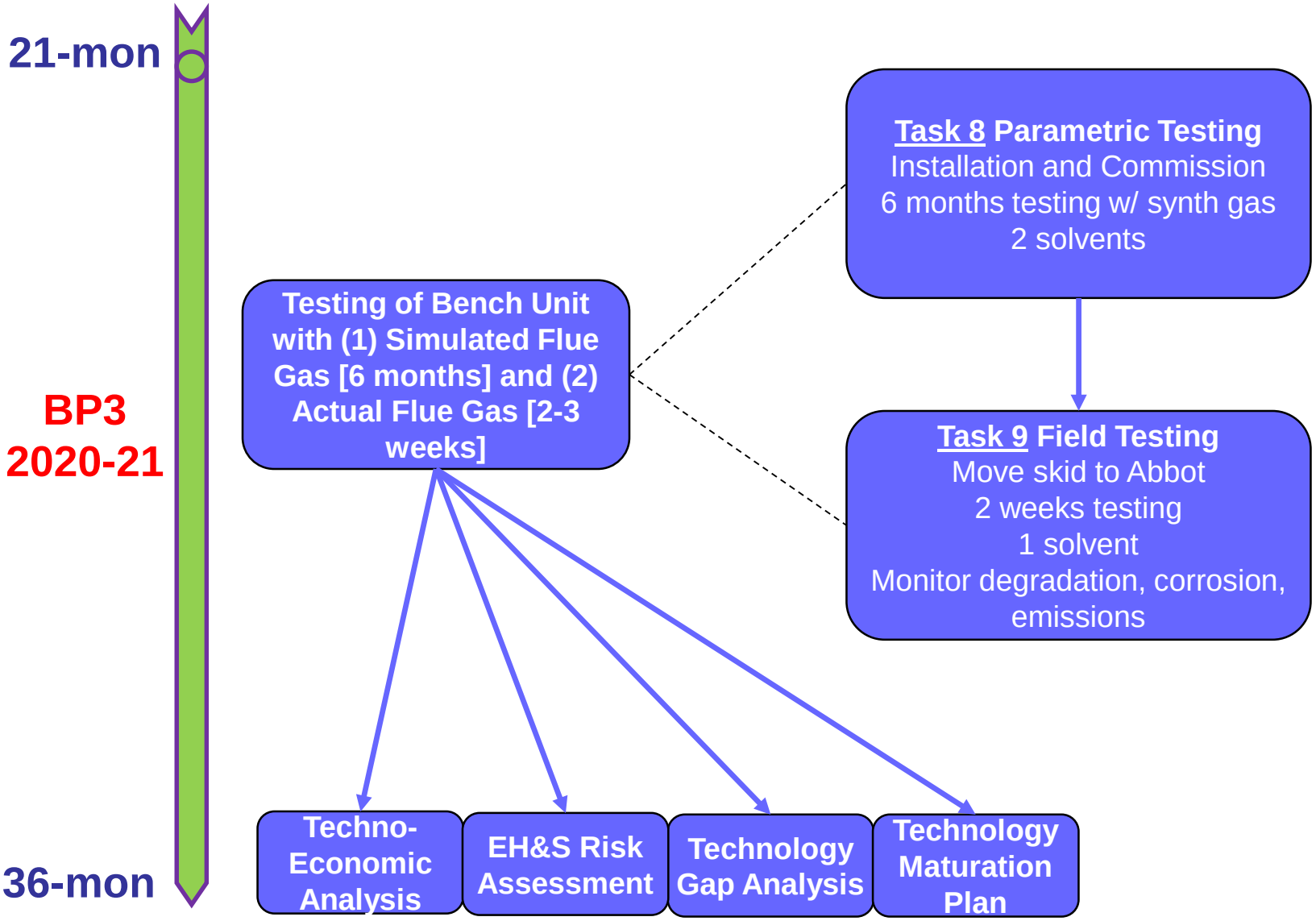
Project Task Flow



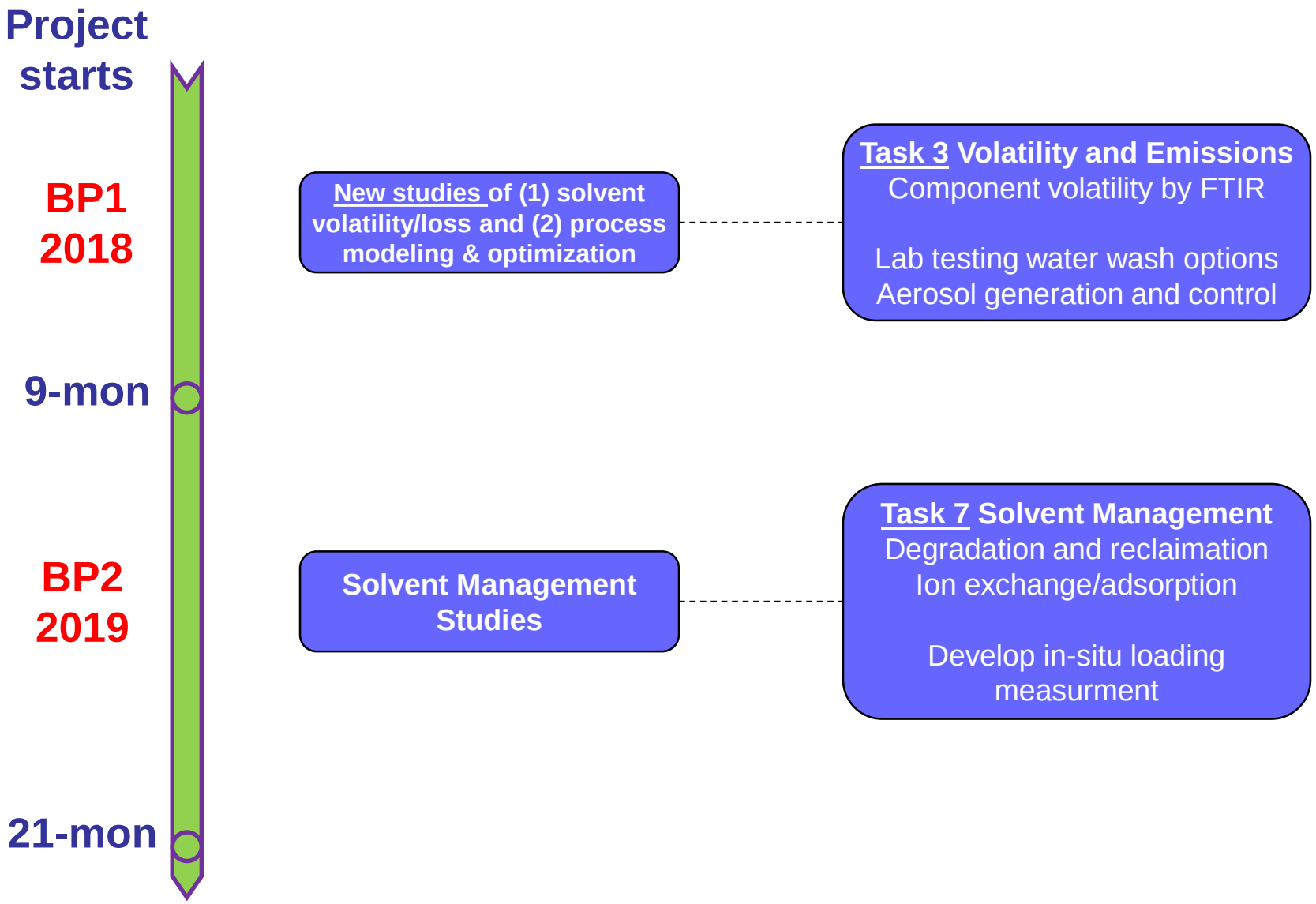
Design and Fabrication (BP1 and BP2)



Operation (BP3)



Solvent Management (BP1 and BP2)



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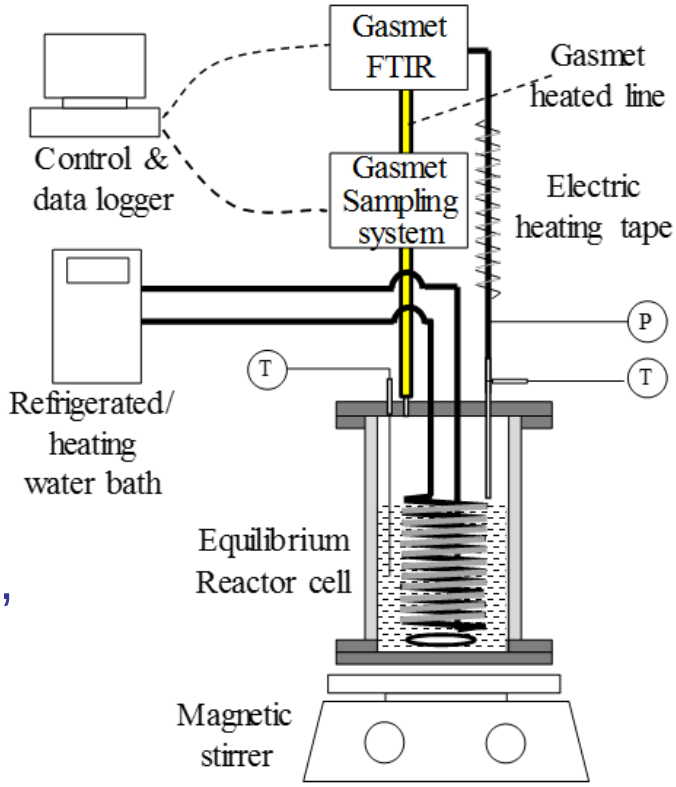
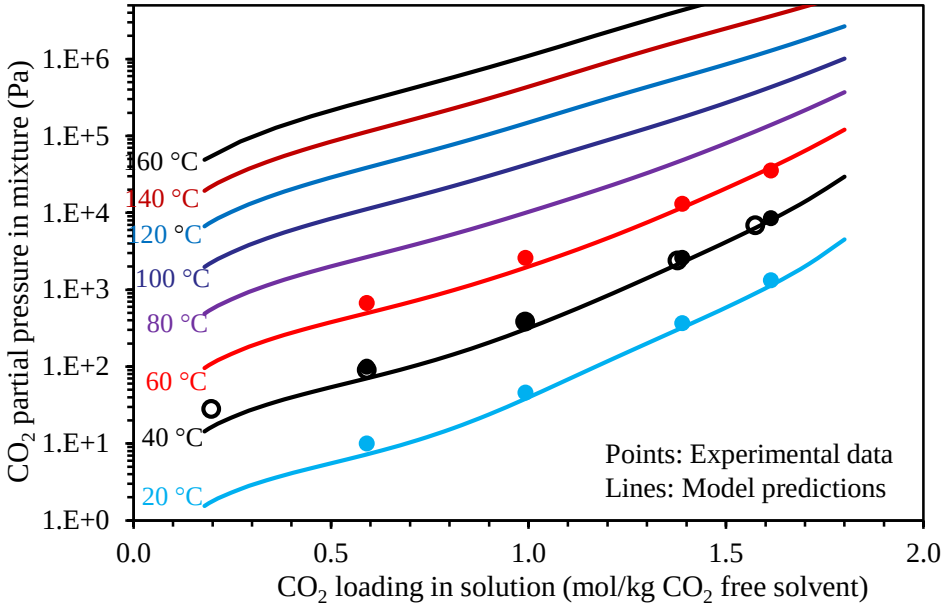
Solvent Volatility & Losses

- DX-4000 FTIR purchased from GASMET
  - Volatility measurements in existing VLE cell in August/September
- Volatile losses and aerosol control to be tested in existing 10 kW lab absorber column
  - Water wash section to be added
  - 2-3 trays/packings to be tested
  - Total emissions to be measured by FTIR, aerosols collected by membrane filters and analyzed by TOC
  - Purchasing SO_3 aerosol generator

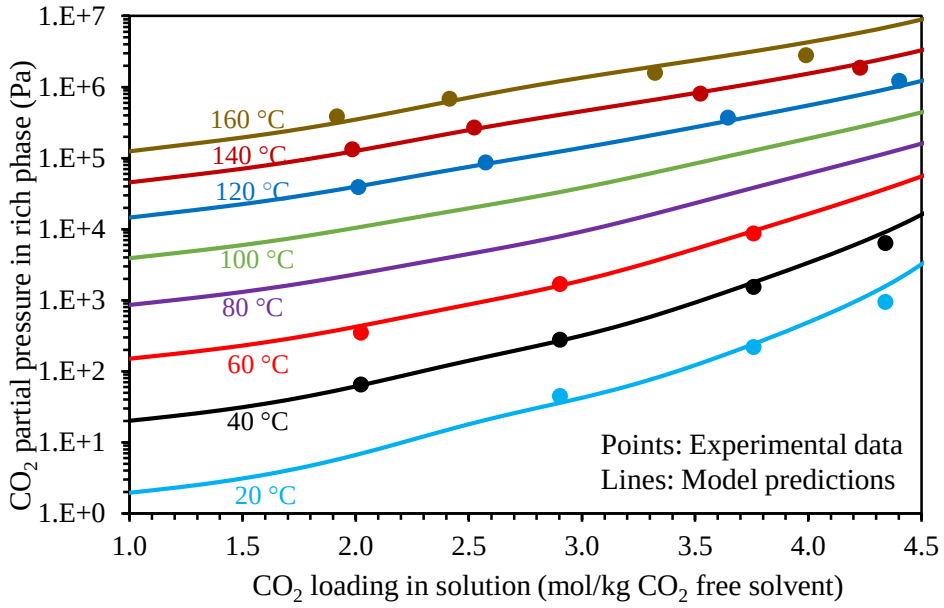


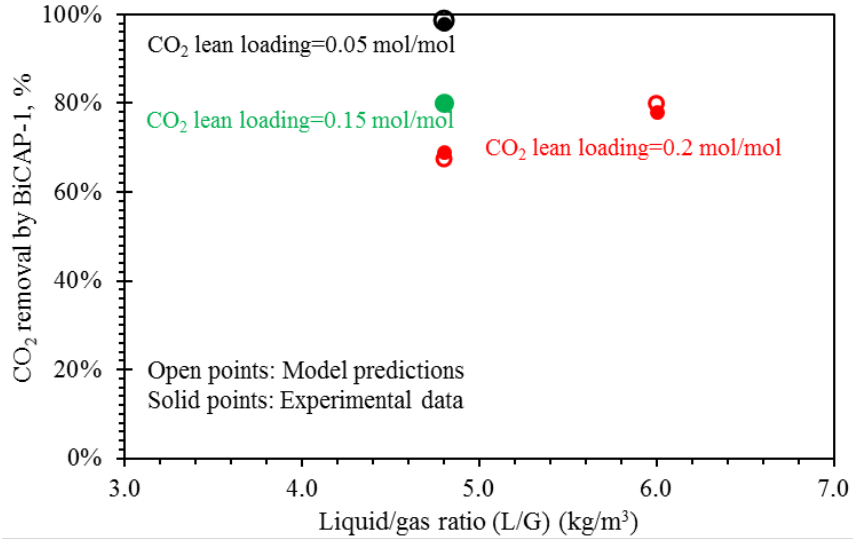
ASPEN Process Modeling

Mixed Solvent (Absorber)



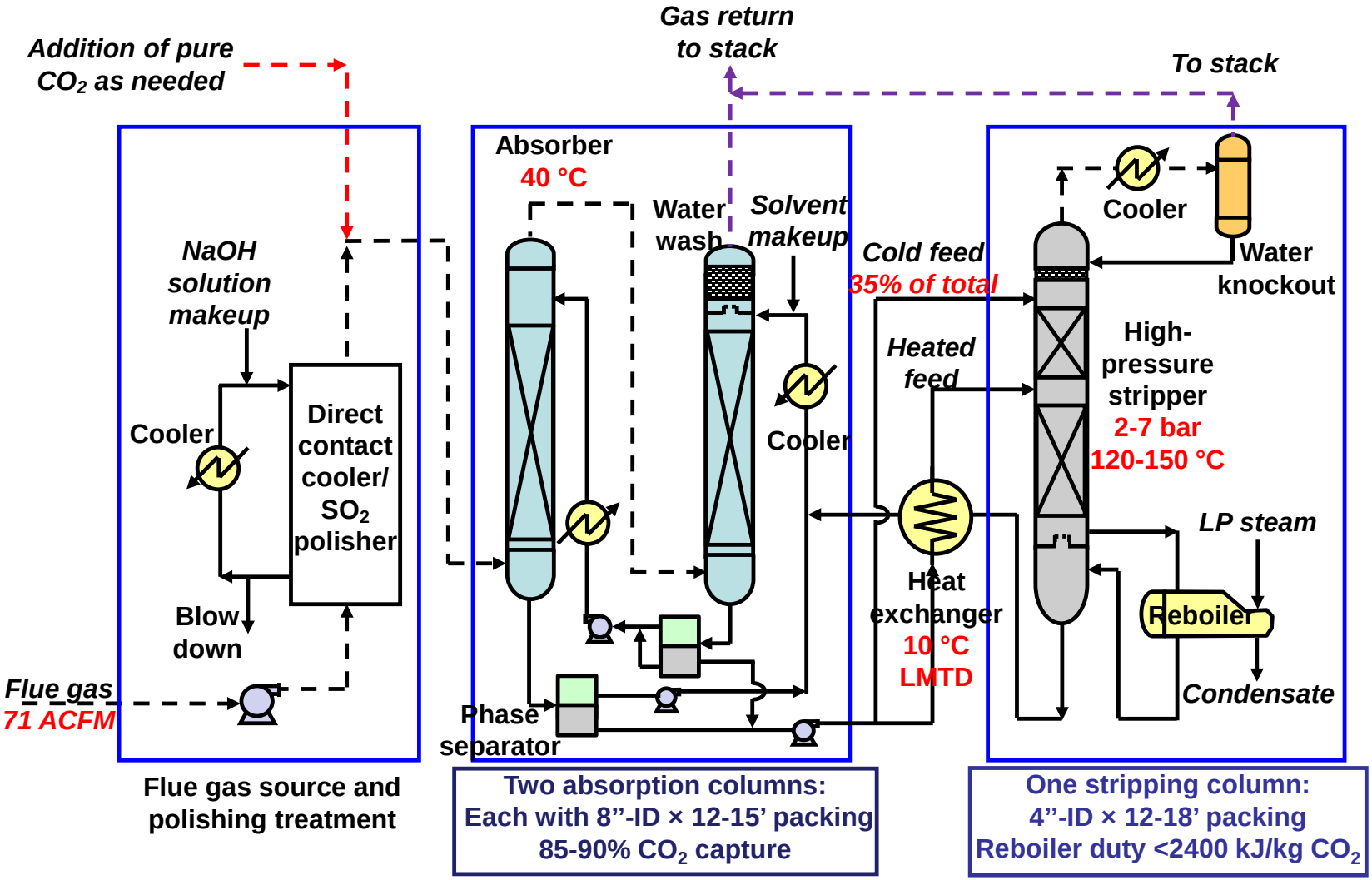
CO2-Rich Phase (Stripper)





- Process model regressed for BiCAP-1, in progress for -2
- BiCAP-2 expected to have better performance

Proposed Skid Flow Diagram



- Finish modeling ASAP (optimization and range for parametric testing)
- Finalize design by end of year

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10 kWe Test, Laboratory

Solvent study, Laboratory

Separate Absorber / Stripper
Funding: *DOE / UI (2015-2018)*

40 kWe Test, Laboratory & Power Plant Slipstream

Bench Scale Close-Loop Unit
Funding: *DOE / UI (2018-2021)*

0.2-1 MWe, Power Plant /Test Center

Small Pilot
Funding: *DOE / UI / Corporate partners/ State*

10 MWe, Power Plant

Large Pilot
Funding: *DOE / Corporate Partners /State / UI*

Proof-of-Concept
Funding: *UI (Part of Dissertation Research, 2013-2015)*

Acknowledgments

- Funding Support by USDOE/NETL through Cooperative Agreement No. DE-FE0031600

- DOE/NETL Project Manager: Andrew Jones

- DOE/NETL Contract Specialist: Bethan Young

Thank you!

Contact Information:

Yongqi Lu (Project PI)

Illinois State Geological Survey

Tel: 217-244-4985

Email: yongqilu@Illinois.edu