Engineering-Scale Testing of the Biphasic Solvent Based CO_2 Absorption Capture Technology at a Covanta Waste-to-Energy Facility (DE-FE0032219)

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FECM/NETL Carbon Management Research Project Review Meeting

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Acknowledgements

- ❑ **DOE/NETL Project Manager:** Krista Hill

- ❑ **Project Members**
  - ✓ **Covanta:** Joey Neuhoff; Ken Armellino; Michael Van Brunt; Shanee Halevi; Michael Rathbun; Chetan Chauhan
  - ✓ **University of Illinois:** Kevin O’Brien; Hafiz Salih; Peng Zhang; Scott Prause; Vinod Patel; Hong Lu

1. Project Overview (1)

Overall objectives:

- ☐ Design, build, and test a 2.5 TPD engineering-scale, biphasic solvent-based carbon capture system at a waste-to-energy (WTE) facility
- ☐ Demonstrate and evaluate the techno-economic viability and environmental performance of the technology for deployment at WTE plants

Participants:

- ☐ University of Illinois:

  ISBL design, testing, and evaluations

- ☐ Covanta:

  Host site, OSBL design, permitting, procurement & construction

Project Overview (2)

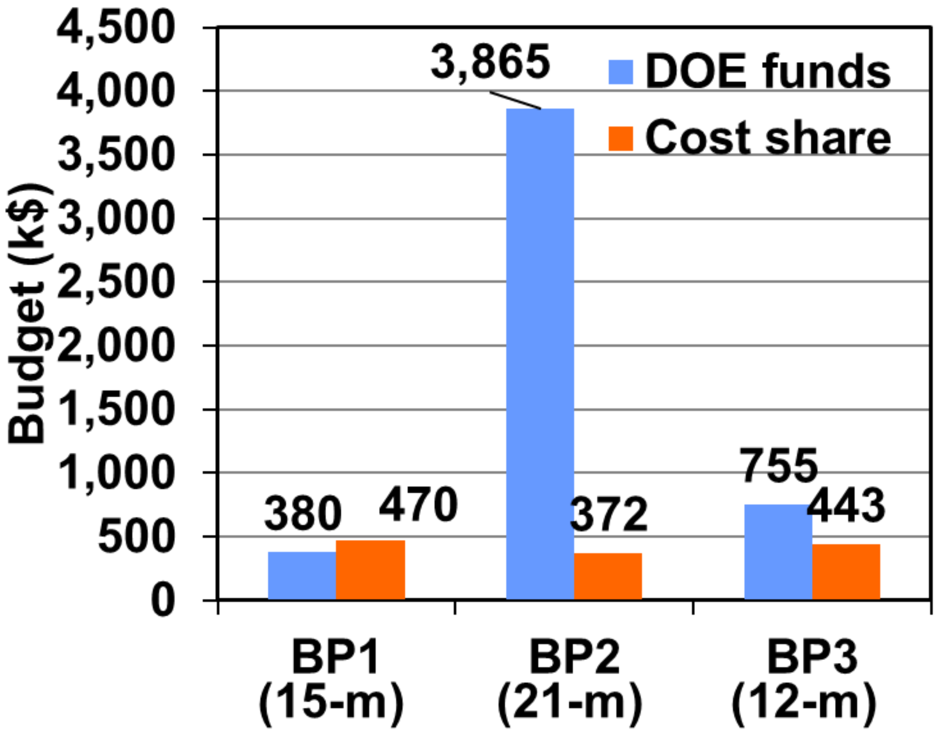
Duration (48 months from Feb 2023 to Jan 2027)

- ☐ BP1: 15 mon (Feb 2023 – Apr 2024) – Design, permitting & quotation
- ☐ BP2: 21 mon (May 2024 – Jan 2026) – Procurement/fab, construction & commissioning
- ☐ BP3: 12 mon (Feb 2026 – Jan 2027) – Testing and evaluation

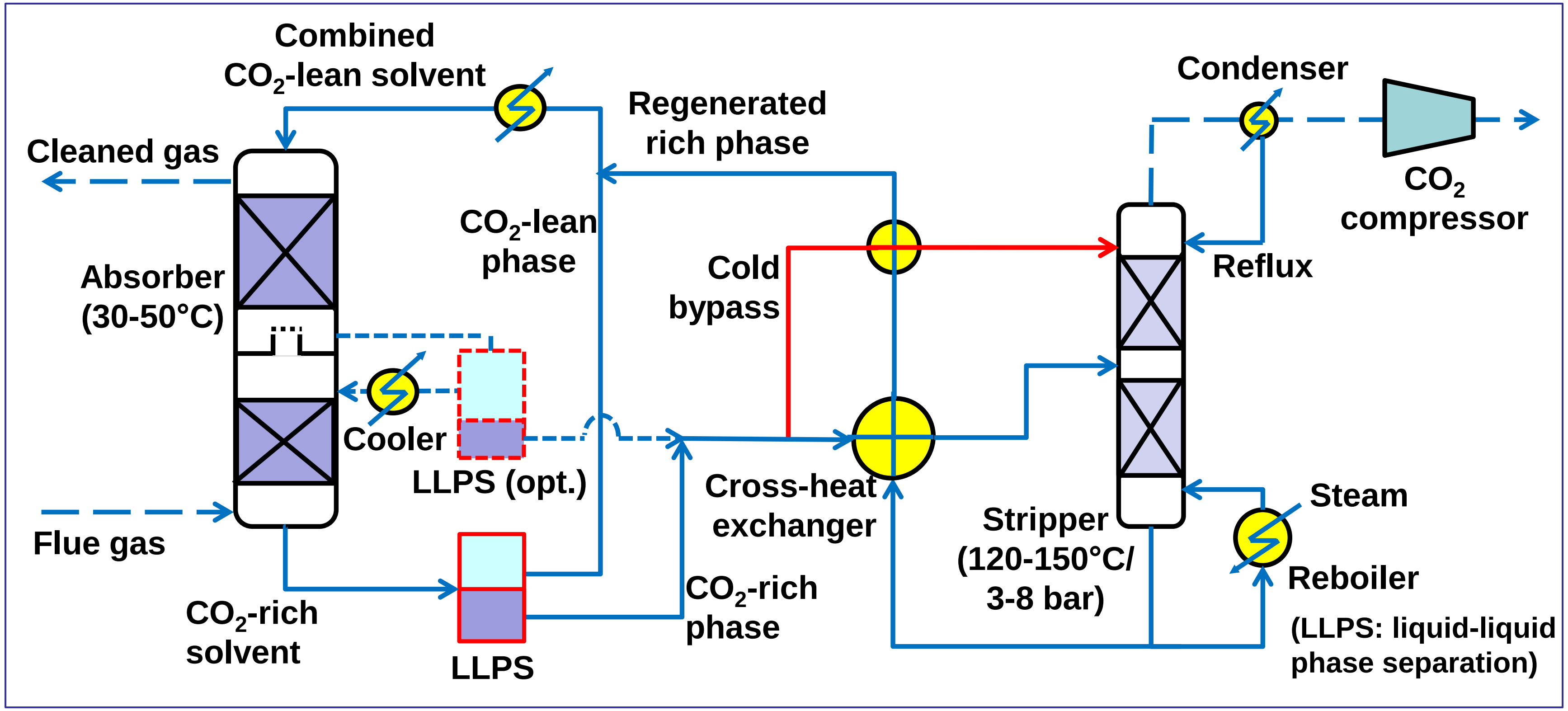
Funding Profile:

- ☐ DOE funding: $4,999,708
- ☐ Cost share: $1,285,668

  (20.5% of total cost)



2. Technology Background: Biphasic CO_2 Absorption Process (BiCAP)



Impact on absorber:

- Higher absorption rate compared with MEA
- Applicable for high-viscosity solvents via multi-stage LLPS to enhance rate

Impact on stripper:

- Reduced solvent mass to stripper leads to low sensible heat use & small equipment size
- Enriched CO_2 loading increases stripping P & lowers stripping heat
- Cold bypass further reduces stripping heat use

Impact on compressor:

- High stripping pressure (4-6 bar) leads to low CO_2 compression work

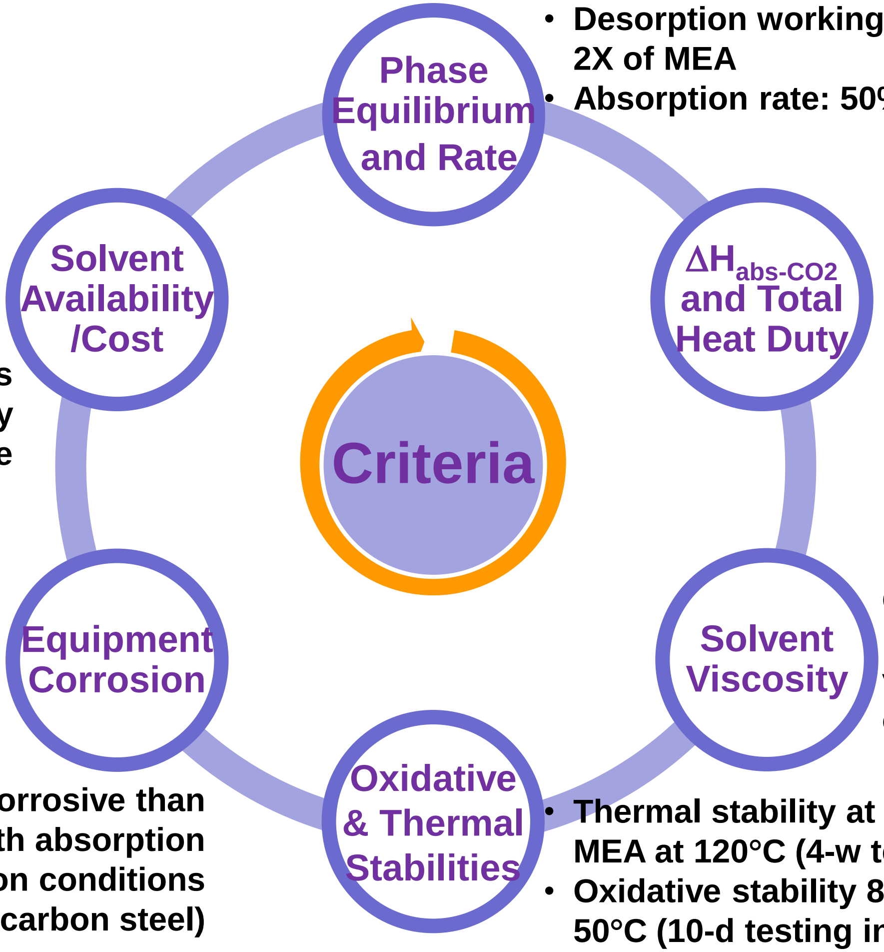
Novel Biphasic Solvents Developed from Previous Work

Biphasic solvents:

- Tunable partitions of volume and species in two liquid phases
- CO_2 loading highly concentrated (>95%) in rich phase
- Water-lean (<30 wt% water)

Two-phase system

Two top-performing solvents identified from the previous lab-scale screening study of ~80 solvents and validated in 40 kWe bench-scale slipstream testing at a power plant



Criteria

Phase Equilibrium and Rate
- **Desorption working capacity: 2X of MEA**
- **Absorption rate: 50% > MEA**

$\Delta H_{abs\text{-}CO2}$ and Total Heat Duty

Reboiler heat duty: 30-50% < MEA in 10 kWe lab tests

Solvent Viscosity

CO_2-saturated heavy phase viscosity: ≤45 cP @ 40°C

Oxidative & Thermal Stabilities
- **Thermal stability at 150°C ≈ MEA at 120°C (4-w testing)**
- **Oxidative stability 8X > MEA at 50°C (10-d testing in 96% O_2)**

Equipment Corrosion

2-3X less corrosive than MEA under both absorption & desorption conditions (<20 μm/yr for carbon steel)

Solvent Availability /Cost

All components commercially available

Progression of BiCAP Technology Development

- Lab proof-of-concept studies of biphasic solvents
- Funding: UI (Graduate dissertation research)

- Solvent screening & characterization (~80)
- 10 kWe lab scale: Separate absorber & stripper column testing
- Funding: DOE / UI

- 40 kWe bench scale: Closed-loop system at Abbott Power Plant
- Solvent handing studies (aerosol emissions, degradation & reclamation, etc.)
- Funding: DOE / UI

New Scaleup Effort – 2.5 TPD at WTE facility

Jan 2013

Jul 2015

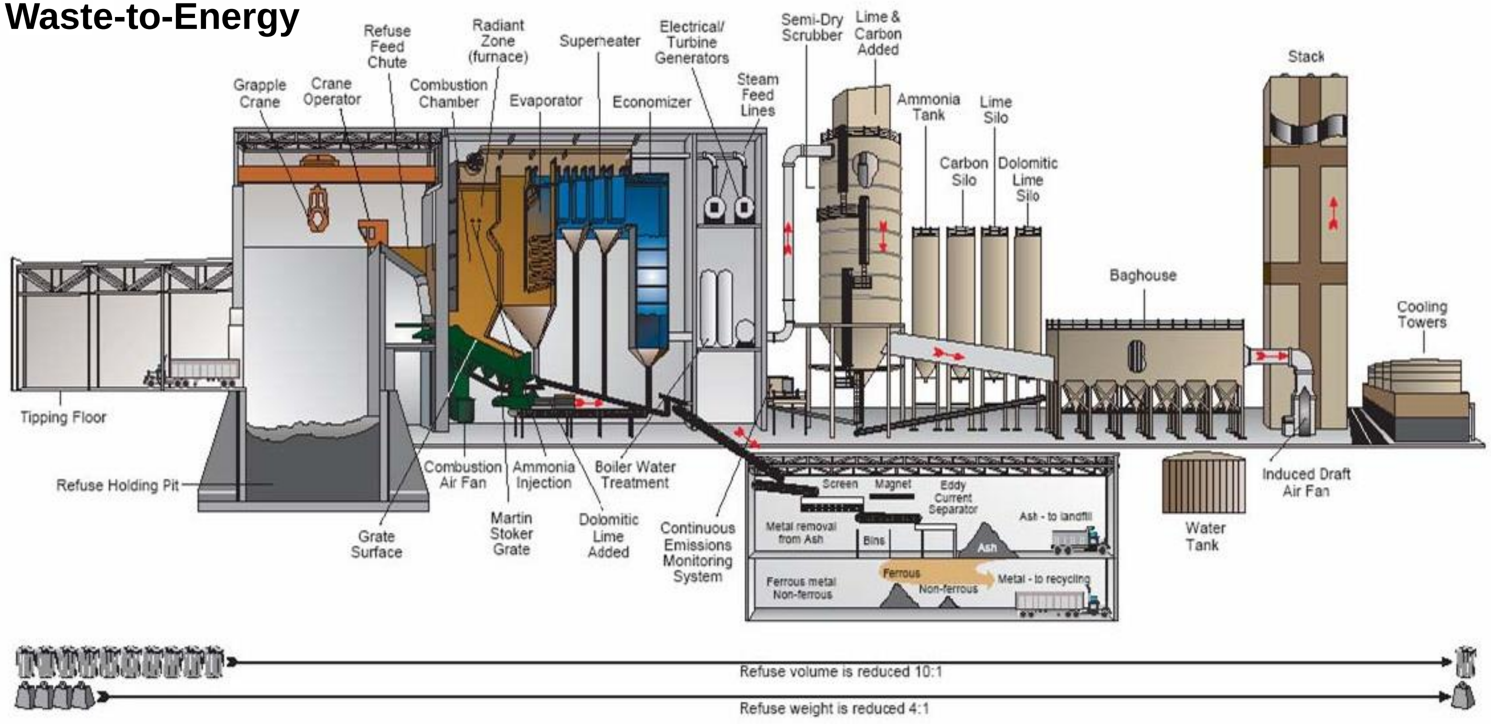
Apr 2018

Mar 2023

Prior Work

Waste-to-Energy (WTE) and CO_2 Capture & Storage

Waste-to-Energy



WTE facilities in the U.S. reduce lifecycle emissions by an average of 1 ton of CO2e per ton of MSW diverted from landfills

Benefits of WTE for net GHG avoidance:

- ❑ WTE avoids GHG emissions by diverting waste from landfills (landfill methane avoidance, metals recovery, energy generation)
- ❑ WTE has lower carbon footprint than fossil fuel power generation due to MSW containing biogenic carbon
- ❑ With CCS, particularly the storage of biogenic CO_2 (>60% of WTE stack CO_2 is from organic sources) would further amplify these benefits. **WTE+CCS is BECCS leading to negative GHG emissions**

3. Technical Approach / Project Scope: Task Flow & Success Criteria

BP1 (15 months):

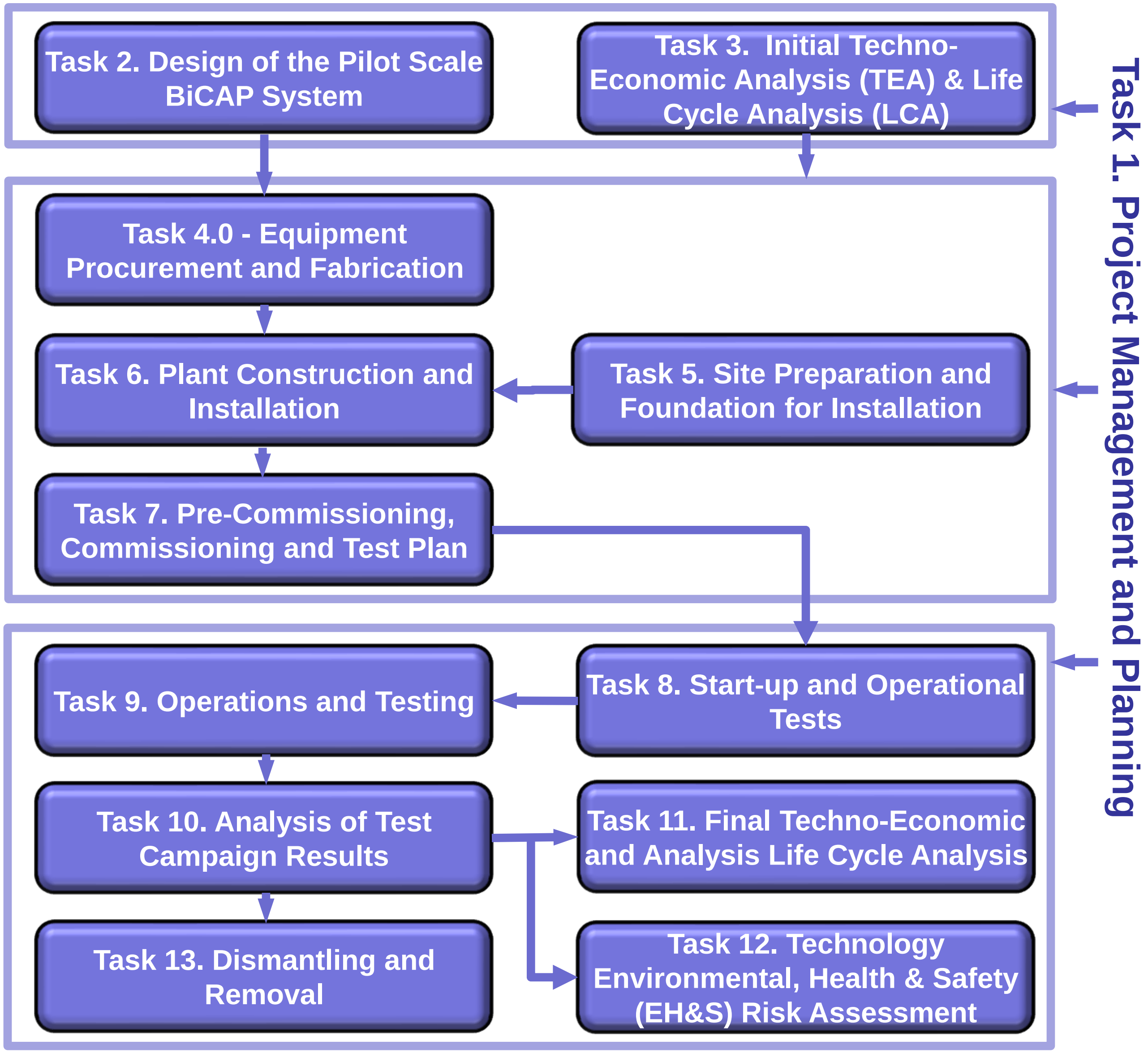
Pilot design,
Initial TEA & LCA,
permitting, and quotation

BP2 (21 months):

Equipment fabrication,
construction, and
commissioning

BP3 (12 months):

Pilot testing,
EH&S studies, and
final TEA & LCA



Task 2. Design of the Pilot Scale BiCAP System

Task 3. Initial Techno-Economic Analysis (TEA) & Life Cycle Analysis (LCA)

Task 4.0 - Equipment Procurement and Fabrication

Task 5. Site Preparation and Foundation for Installation

Task 6. Plant Construction and Installation

Task 7. Pre-Commissioning, Commissioning and Test Plan

Task 8. Start-up and Operational Tests

Task 9. Operations and Testing

Task 10. Analysis of Test Campaign Results

Task 11. Final Techno-Economic and Analysis Life Cycle Analysis

Task 12. Technology Environmental, Health & Safety (EH&S) Risk Assessment

Task 13. Dismantling and Removal

Task 1. Project Management and Planning

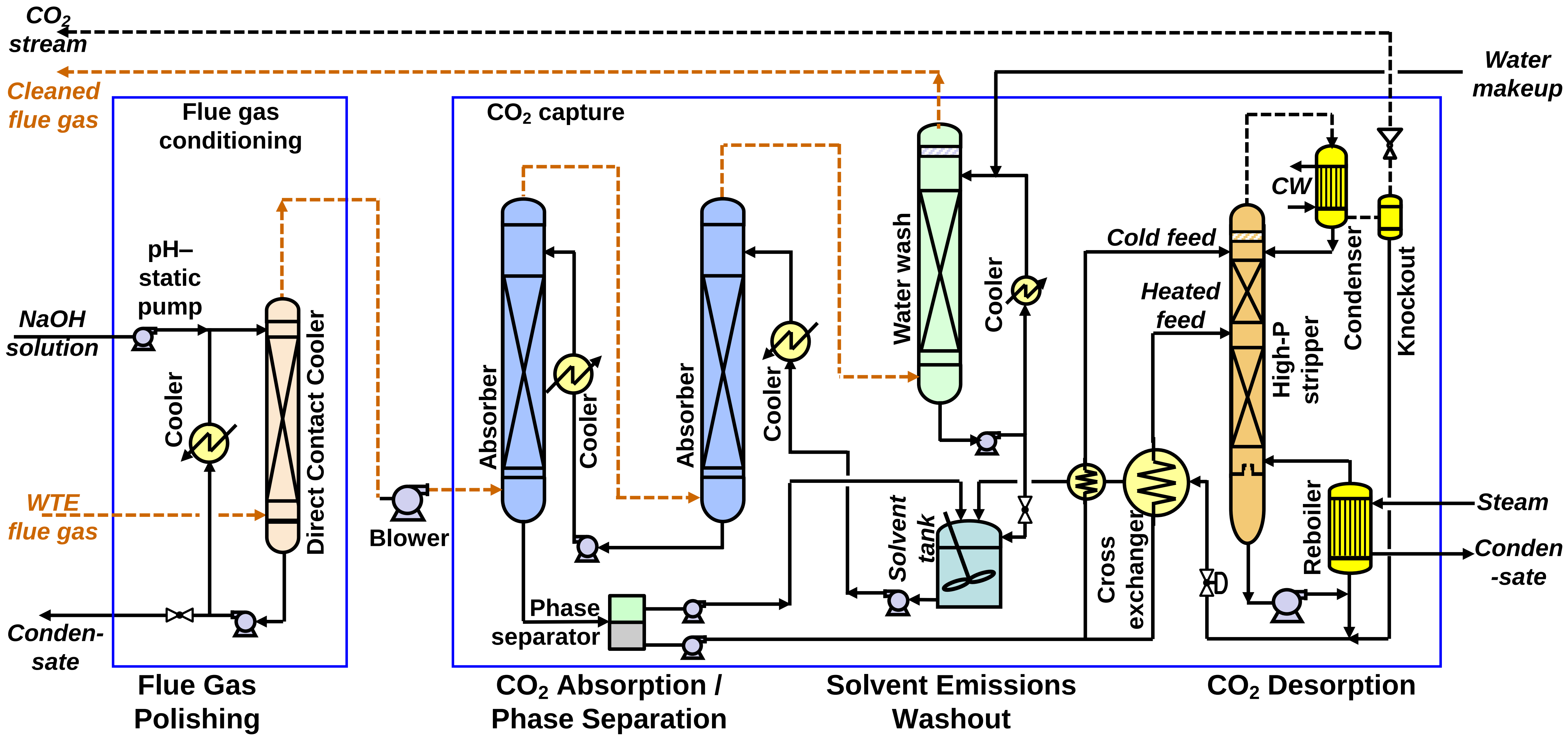
Success metrices:

- ☐ 95% CO_2 removal
- ☐ 95% CO_2 purity
- ☐ Heat duty <2,300 kJ/kg CO_2 captured
- ☐ Stripping pressure of >4 bar
- ☐ 2-month continuous operation of the system integrated into the WTE plant

Project Risks and Mitigation Strategies

Description of Risk	Key Mitigation Strategies
Cost overrun (equipment and construction)	• **Complete and accurate engineering specs** for key equipment and parts. • Select **equipment suppliers/vendors with good reputation** in cost & schedule control. • **Fixed pricing strategy** during equipment ordering. • **A detailed constructability review** to assess construction access, lay-down areas, lift plans, and sequencing of construction work to minimize costs. • Bids preferably from **local construction contractors** or those familiar with the host site. • **Multiple bidders** invited for each scope of work for review and selection.
Schedule overrun (equipment and construction)	• Chose **equipment vendors and suppliers reputable for cost/schedule control**. • **Firm schedule commitments** made during equipment ordering. • Use many of equipment **fabricators and suppliers used with previous experience**. • **Close communication and oversight during fabrication** to ensure schedule. • **A detailed constructability review** to assess and identify sequencing of construction work. • Use **established engineering practices to estimate hours** for each scope of work.
Host site agreement	• **Close communication** through project planning stage • Develop a **strategy for changes in** site status, schedule, and availability
Environmental permits	• Review permitting needs, timelines and other factors; **Develop permitting strategies** early. • Closely communicate with **local and state regulatory compliance agencies**.
Aerosols & contaminants in WTE flue gas and impacts on solvent emissions	• Collect and analyze **available WTE flue gas data**. • **Leverage learnings** from previous lab/bench-scale studies. • **Measure/monitor solvent emissions during pilot testing** to guide operations as necessary.
Integration with operations at WTE facility	• **Work closely with the host site** to understand utilities supply and locate the best tie-in points. • **Incorporate site conditions** (e.g., steam) into design, control logics, and operations. • **Keep close interaction between OSBL and ISBL design teams**.
Wastewater and waste management	• **Review permitting and treatment needs** of wastewater and waste discharge (e.g., flue gas condensate). • **Evaluate possible technical options** for wastewater management that allows recycling or reuse.

4. Progress and Current Status of Project: Pilot Process Design



Schematic of 2.5 TPD Pilot-Scale BiCAP Unit

Design of Key Equipment: Learnings from Previous Work

Except for the phase separator, all equipment is not specialized for CO_2 absorption processes

- **Liquid-liquid phase separator**
  - Remains a static settling design via a density difference between two liquid phases
  - Design method reviewed and optimized based upon previous bench-scale test data and new measurements

- **Reboiler**
  - Remains a forced flow design with forced solvent flow on tube-side and steam flow on shell-side (vs. plate-&-frame and thermosiphon designs)
  - Flow control upgraded to avoid any steam/solvent disruption during dynamic operations with T/P fluctuations

- **Cross-over heat exchanger**
  - Uses a plate-&-frame cross exchanger
  - Design modified including the addition of pressure regulation to minimize vaporization (e.g., <15%)

- **Solvent emissions control**
  - Design modified to enhance water wash as well as allow measurement of solvent emissions
  - Controls updated to allow better temperature and flow controls and recycling of blowdown discharge to the process

Design of Key Equipment (Example): Translating Bench- to Pilot-Scale Phase Separator

- ❑ Phase separation performance demonstrated during previous bench-scale power plant slipstream operations
  - ➢ Efficient phase separation based on static settling
  - ➢ Level of liquid-liquid interface automatically stabilizes based on a static pressure balance
- ❑ Design modifications/upgrading learned from previous work
  - ➢ Critical geometric parameters (e.g., h_1/h_2 and h_3) optimized for solvent/process conditions
  - ➢ Structures (e.g., coalescence baffles) considered to minimize emulsion layer

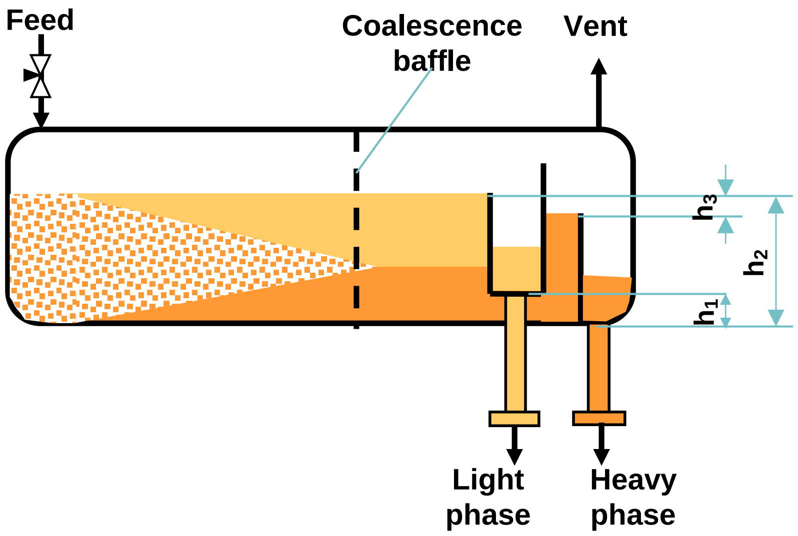
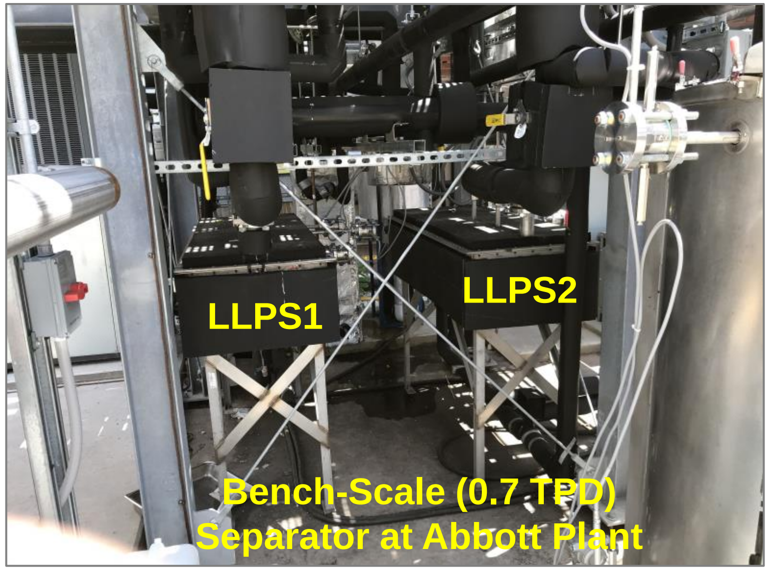


Illustration of Phase Separation

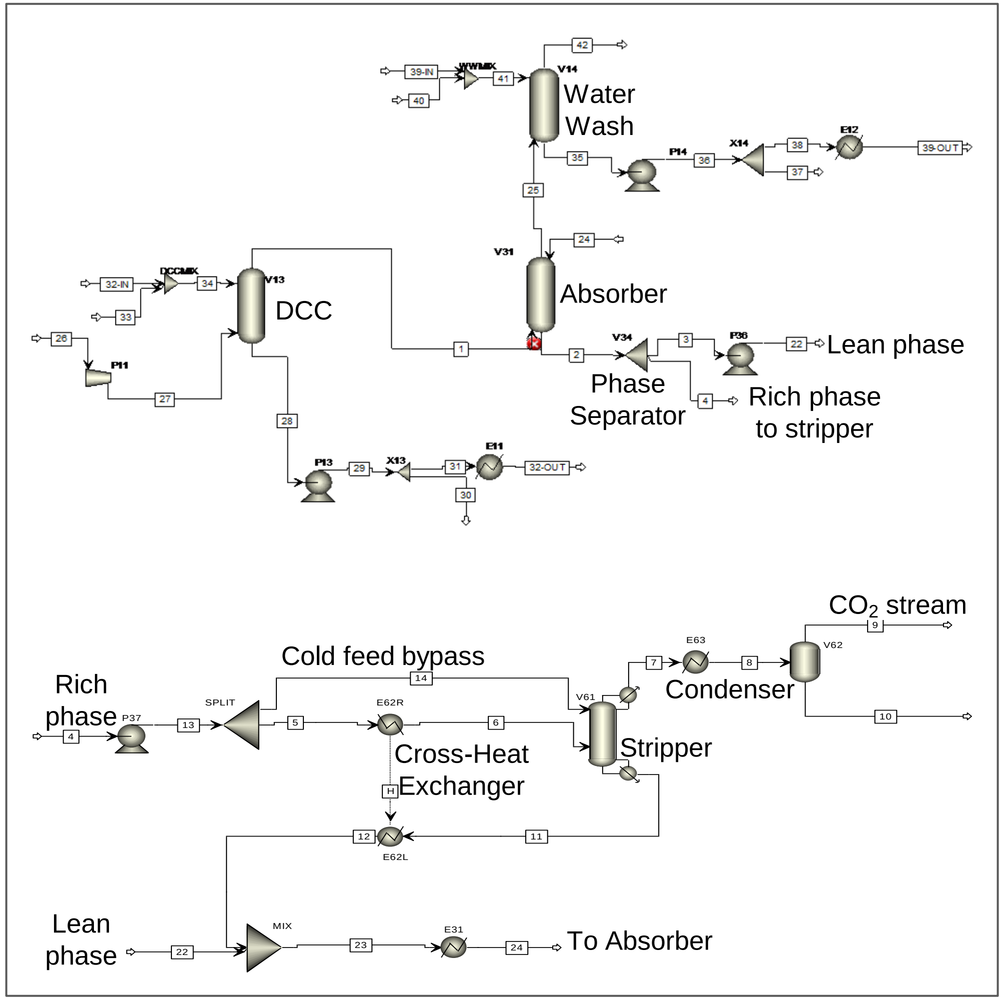
Lab-Scale Phase Separator

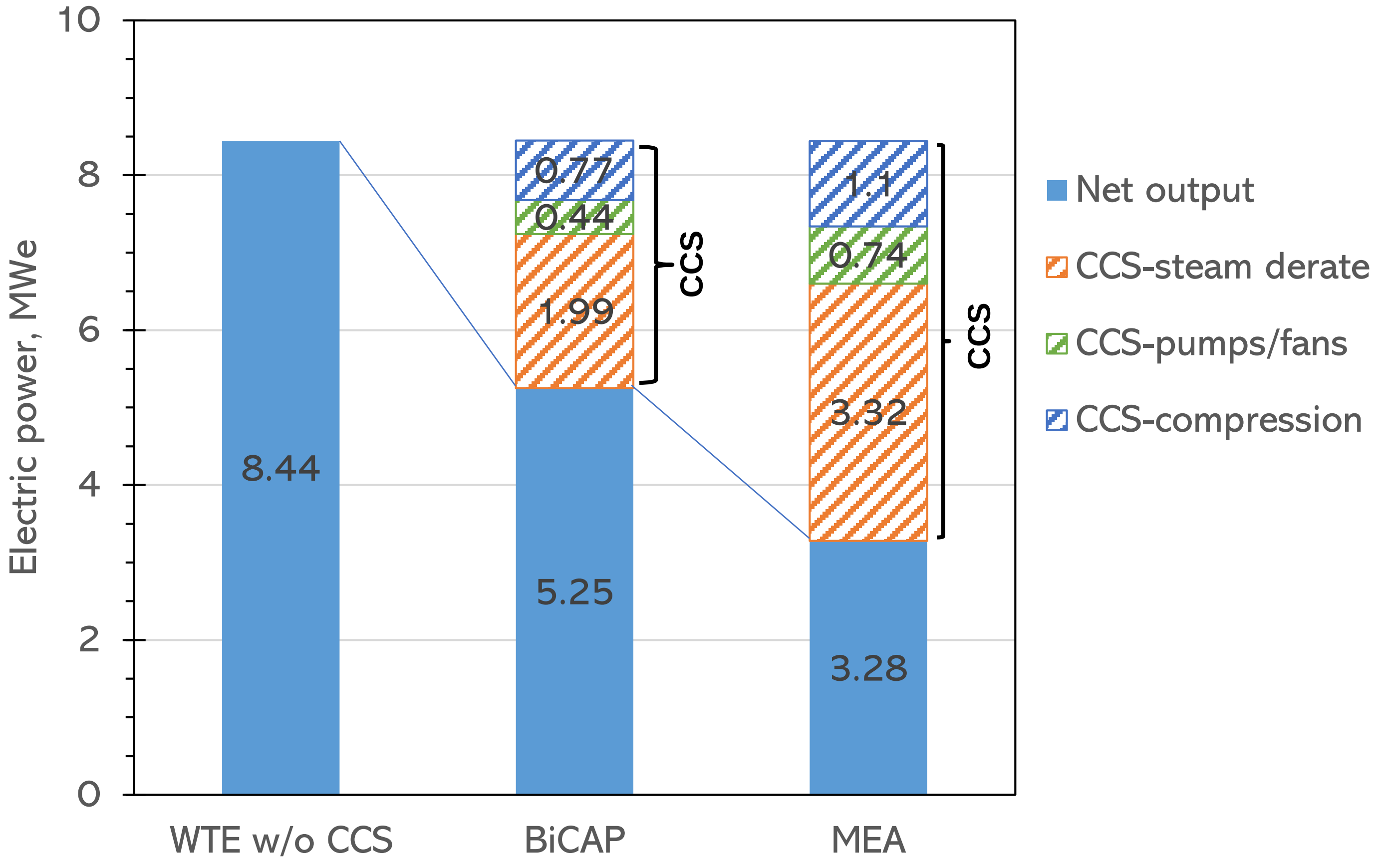


Pilot-Scale (2.5 TPD) Separator in this Project

Initial Techno-Economic Analysis: Process Energy Performance

Rigorous rate-based Aspen Plus modeling for BiCAP process for 100,000 TPY of CO_2 capture from a generic WTE plant at 95% removal





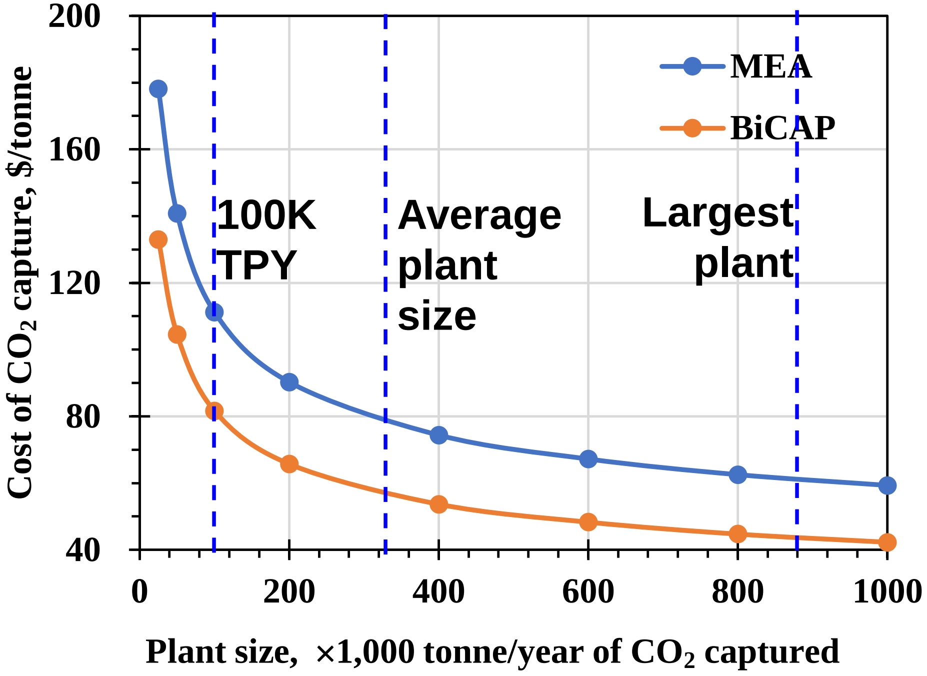
- Base plant w/o CCS: Thermal input (LHV) of 33.76 MWth and CO_2 emissions of 14.14 tonne/hr
- Total parasitic power derate for CO_2 capture reduced by ~38% with BiCAP vs. MEA

(Higher power derate for CCS because of relatively lower generation efficiency and higher CO_2 emission intensity (/kWh) of WTE plants vs. fossil fuel power plants)

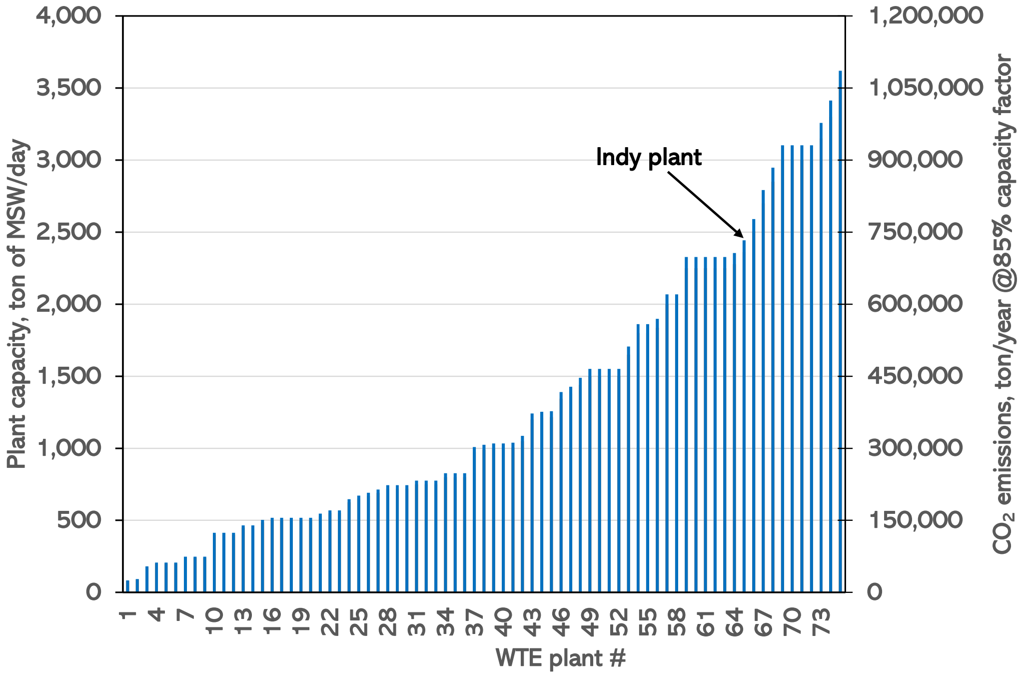
Initial Techno-Economic Analysis: Cost Analysis

CO_2 capture cost with BiCAP:

- ❑ At scale of 100,000 TPY: \$82/tonne (~27% lower than MEA)
- ❑ At average WTE plant size in the US (~330,000 TPY): \$57.8/tonne; at 1,000,000 TPY scale: \$42.26/tonne



Capture cost vs. plant size
(All costs in December 2018 dollars)

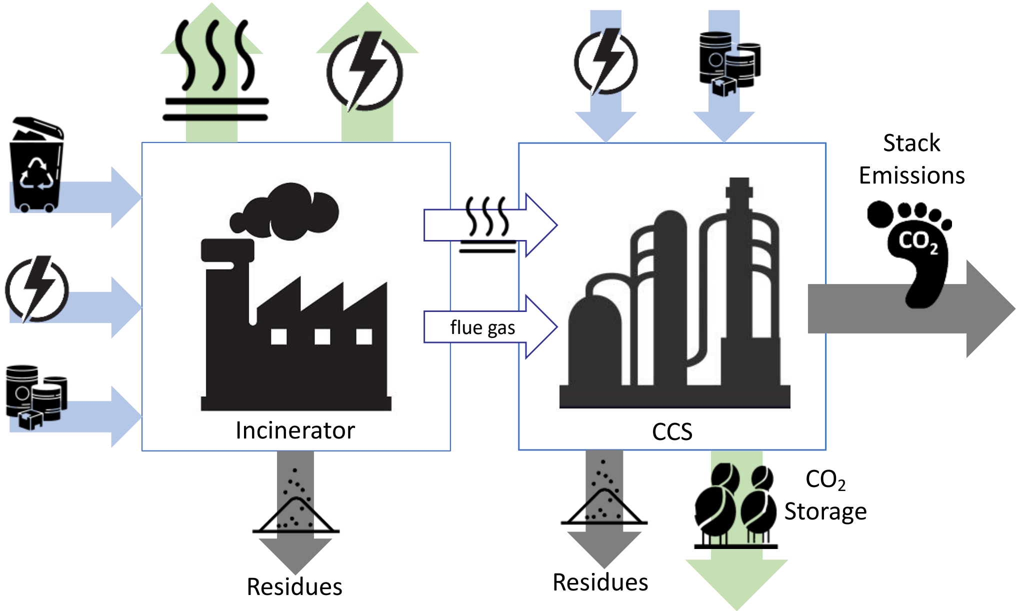


WTE plants in the US

(Data source: Michaels & Krishnan. 2018 Directory of Waste-to-Energy Facilities. Energy Recovery Council.)

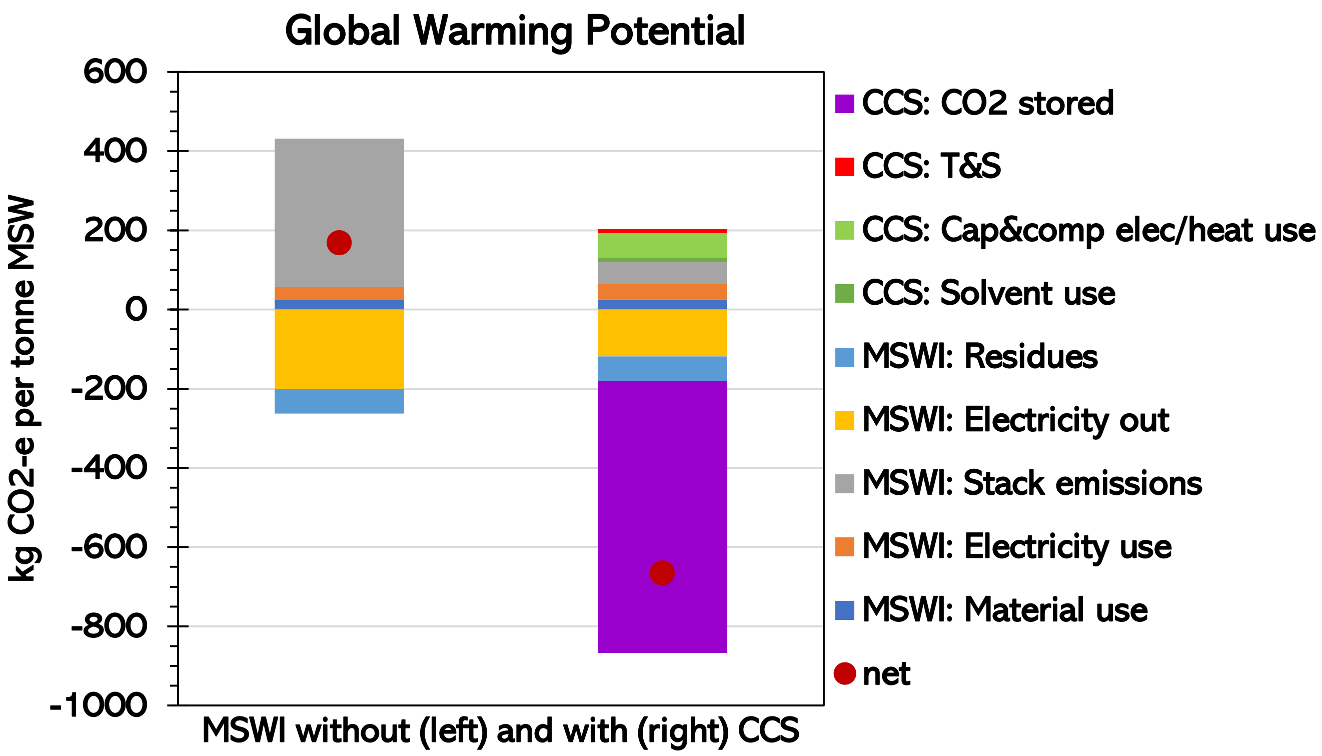
Initial Life Cycle Analysis (LCA)

openLCA software and NETL CO2U Database (v2.1) were used for the LCA study



System boundary for a cradle-to-gate LCA for WTE with CCS in the base case with electricity generation only

(Note: Plant construction was not considered in this Initial LCA as the construction phase and raw materials don't dominate in LCA. However, they will be included in the Final LCA)



(MSWI: municipal solid waste incineration; CCS: CO_2 capture & storage)

- WTE without CCS has low carbon footprint of **+168 kg CO_2-e /tonne of MSW** because of high biogenetic carbon (i.e., ~61%) in MSW
- WTE with BiCAP-CCS is BECCS, with net negative emissions of **-665 kg CO_2-e /tonne of MSW**

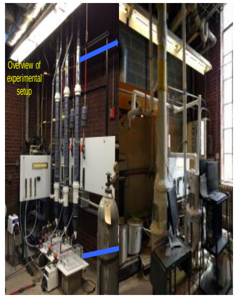
5. Plans for Future Work: in This Project

Remaining of BP1 (by 4/30/24)	Secure the Host Site
	Obtain environmental permits
	Complete 2.5 TPD detailed engineering design
	Obtain quotes/bids for all ISBL and OSBL equipment; Obtain quotes/bids for construction/install and a construction contractor is selected
BP2 (5/1/24-1/31/26)	Purchase all equipment
	Complete the pilot system installation
	Conduct pre-commissioning and commissioning of the pilot system
BP3 (2/1/26-1/31/27)	Parametric testing (~3-month); 2-month continuous testing
	Complete evaluations (TEA, LCA, EH&S, etc.)

Plans for Future Work: Next Stage Development after This Project

Solvent study,
Laboratory
(TRL 2/3)

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



10 kWe Testing,
Laboratory
(TRL 3→4)

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

40 kWe Testing,
Coal-Fired Power Plant Slipstream
(***TRL 4→5***)

Bench Scale
Close-Loop
Unit **Funding**: *DOE / UI (2018-2023)*

2.5 TPD CO_2 testing,
WTE plant slipstream
(*TRL 5→6*)

Engineering scale
Funding: DOE /UI/ Covanta (2023-2027)

This project

Large pilot,
(TRL6→7)

Industrial sources (WTE, cement, steel, chemicals, etc.)

NGCC Plants

Coal-Fired Power Plants

Future projects

Summary

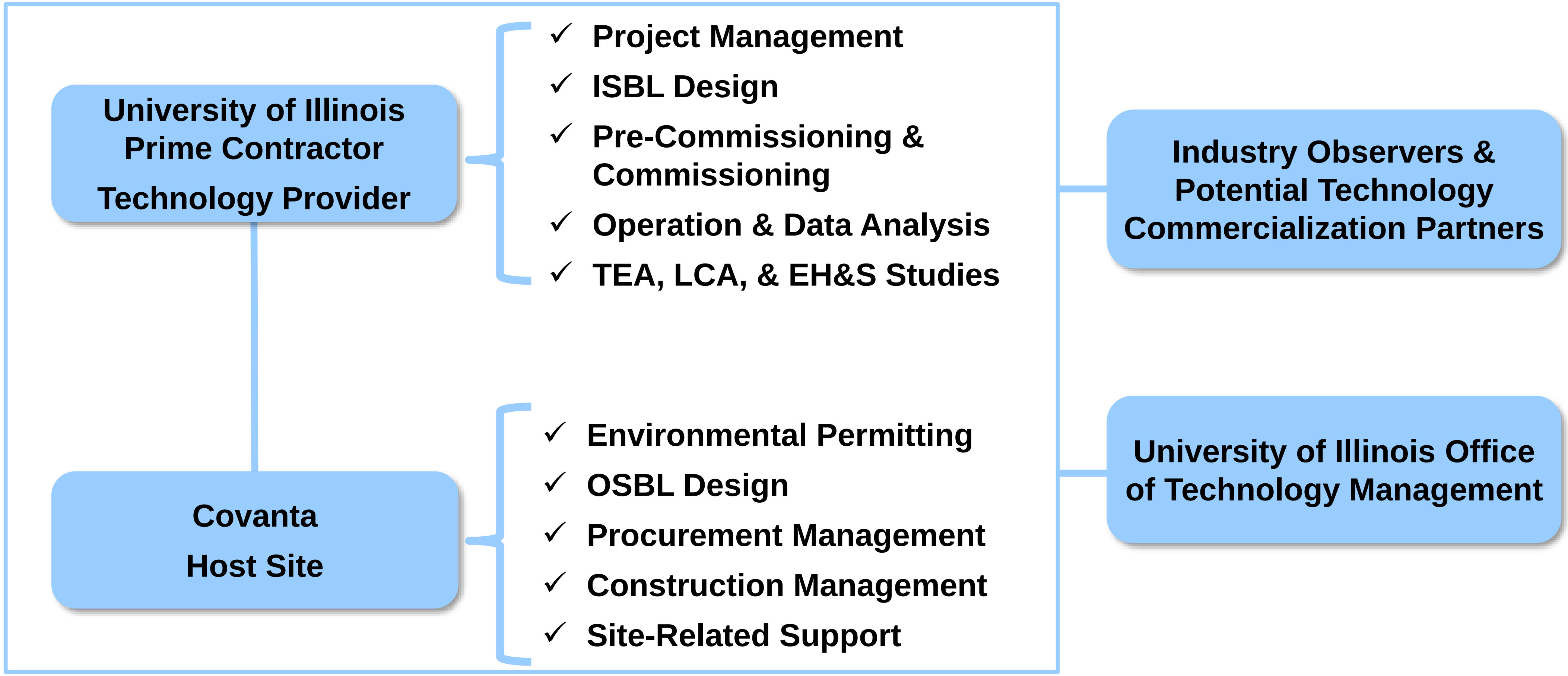
- WTE combustion process and flue gas conditions (e.g., 6-12 vol% CO_2 concentration) are comparable to those of coal-fired power plants, making them viable sources for CCS applications

- Learnings from previous testing/operations applied to the pilot system design:
  - Design of pilot process/equipment and selection of materials/parts updated/improved
  - Operational reliability, system flexibility, and weather conditions taken into consideration
  - Environmental controls incorporated

- Initial TEA shows that BiCAP for WTE is advantages to the conventional technology (MEA):
  - Parasitic power loss reduced by ~38%;
  - CO_2 capture cost reduced by ~27%

- WTE has low carbon footprint and is a promising source for BECCS. Initial LCA shows that BiCAP for WTE results in significantly negative carbon emissions

Appendix 1. Organization Chart



University of Illinois Prime Contractor

Technology Provider

- ✓ Project Management
- ✓ ISBL Design
- ✓ Pre-Commissioning & Commissioning
- ✓ Operation & Data Analysis
- ✓ TEA, LCA, & EH&S Studies

Covanta

Host Site

- ✓ Environmental Permitting
- ✓ OSBL Design
- ✓ Procurement Management
- ✓ Construction Management
- ✓ Site-Related Support

Industry Observers & Potential Technology Commercialization Partners

University of Illinois Office of Technology Management

Appendix 2. Gantt Chart

ID	Task Name	Start	Finish
1	**Task 1.0 – Project Management and Planning.**	**2/1/23**	**1/31/27**
2	Subtask 1.1 – Project Management Plan.	2/1/23	1/31/27
3	Milestone a: Updated Project Management Plan Submitted.	2/28/23	2/28/23
4	Subtask 1.2 – Technology Maturation Plan.	2/1/23	1/31/27
5	Milestone b: Initial Technology Manturation Plan Submitted.	4/30/23	4/30/23
6	Milestone c: Host Site Agreement.	10/27/23	10/27/23
7	Milestone n: Final Technology Manturation Plan Submitted.	10/30/26	10/30/26
8	**Task 2.0 – Design of the Pilot Scale BiCAP System.**	**2/1/23**	**4/30/24**
9	Subtask 2.1 – Site Design Basis and Initial Test Plan.	2/1/23	4/30/23
10	Subtask 2.2 –Basic Engineering Design ISBL.	3/1/23	6/15/23
11	Subtask 2.3 –Basic Engineering Design OSBL.	3/1/23	6/15/23
12	Subtask 2.4 – Detailed Design ISBL.	6/16/23	11/30/23
13	Subtask 2.5 – Detailed Engineering OSBL.	6/16/23	11/30/23
14	Subtask 2.6 – HAZOP Review.	12/1/23	12/15/23
15	Subtask 2.7 – Constructability Review.	12/16/23	1/31/24
16	Subtask 2.8 – Solvent Procurement and Logistics Plan.	12/16/23	1/31/24
17	Subtask 2.9 – Environmental permitting and compliance.	2/1/23	1/31/24
18	Subtask 2.10 – Host Site Agreement.	2/1/23	7/31/23
19	Subtask 2.11 – Equipment Bid/Quote Solicitation.	12/1/23	4/30/24
20	Milestone d: Equipment specs and detailed ISBL/OSBL design completed and reviewed	1/31/24	1/31/24
21	**Task 3.0 – Initial Techno-Economic Analysis (TEA) and Life Cycle Analysis (LCA).**	**3/1/23**	**9/30/23**
22	Subtask 3.1 – Initial Techno-Economic Analysis (TEA).	3/1/23	9/30/23
23	Subtask 3.2 – Initial Life Cycle Analysis (LCA).	3/1/23	9/30/23
24	Milestone e: Initial TEA submitted	9/30/23	9/30/23
25	Milestone f: Initial LCA submitted	9/30/23	9/30/23
26	**Decision Point A: Initial TEA results meet Success Criteria & equipment quotation obtained**	4/30/24	4/30/24
27	**Task 4.0 – Equipment Procurement and Fabrication.**	**5/1/24**	**1/31/25**
28	Subtask 4.1 – ISBL Procurement.	5/1/24	1/31/25
29	Subtask 4.2 – OSBL Procurement.	5/1/24	1/31/25
30	Subtask 4.3 – Other ISBL Procurement and Fabrication.	5/1/24	1/31/25
31	Subtask 4.4 – Other OSBL Procurement and Fabrication.	5/1/24	1/31/25
32	Milestone g: All equipment procurement and fabrication completed	1/31/25	1/31/25
33	**Task 5.0 – Site Preparation and Foundation for Installation.**	**10/1/24**	**1/31/25**
34	**Task 6.0 – Plant Construction and Installation.**	**2/1/25**	**11/30/25**
35	Subtask 6.1 – Module and Equipment Installation.	2/1/25	6/30/25
36	Subtask 6.2 – Onsite Construction and System Integration.	7/1/25	8/31/25
37	Subtask 6.3 – OSBL Onsite Construction and Tie-ins.	7/1/25	11/30/25
38	Milestone h: Engineering-scale capture unit construction & install completed	11/30/25	11/30/25
39	**Task 7.0 – Pre-commissioning, Commissioning and Test Plan.**	**12/1/25**	**1/31/26**
40	Subtask 7.1 – Pre-Commissioning.	12/1/25	12/31/25
41	Subtask 7.2 – Commissioning.	1/1/26	1/31/26
42	Subtask 7.3 – Finalize Test Plan.	1/1/26	1/31/26
43	Milestone i: Shakedown and commissioning of the engineering-scale capture system comple	1/31/26	1/31/26
44	**Decision Point B: Pilot system meets design specs and ready for testing**	1/31/26	1/31/26
45	**Task 8.0 – Start-up and Operational Tests.**	**2/1/26**	**2/28/26**
46	**Task 9.0 – Operations and Testing.**	**3/1/26**	**7/31/26**
47	Milestone j: Continuous testing of the engineering-scale capture system for 2 months	7/31/26	7/31/26
48	**Task 10.0 – Analysis of Test Campaign Results**	**6/1/26**	**8/31/26**
49	**Task 11.0 – Technology Environmental Health and Safety (EH&S) Risk Assessment.**	**5/1/26**	**10/31/26**
50	Milestone k: Technology EH&S submiitted	10/31/26	10/31/26
51	**Task 12.0 – Final Techno-Economic Analysis (TEA) and Life Cycle Analysis (LCA).**	**2/1/26**	**10/31/26**
52	**Subtask 12.1 – Final Techno-Economic Analysis (TEA).**	**2/1/26**	**10/31/26**
53	Milestone l: Final TEA submitted.	10/31/26	10/31/26
54	**Subtask 12.2 – Final Life Cycle Analysis (LCA).**	**5/1/26**	**10/31/26**
55	Milestone m: Final LCA submitted.	10/31/26	10/31/26
56	**Task 13.0 – Dismantling and Removal.**	11/1/26	1/31/27