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Carbon Capture Technologies for Small Scale Biomass Combustion Facilities

"A Sustainable Approach to Negative Carbon"

Workshop IEA Bioenergy Task 32: Current Projects in the Area of Combustion
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Outline

- Why BECCS for Decarbonisation?
- Defining Small-Scale Wood Combustion Systems for BECCS
- IEA Inter Task BECCUS Phase 2 Project
- High level technology overview of potential carbon capture (CC) technology types for small-scale wood combustion systems
- Highlights from CCU Technology Assessment Study for 1.5MWth District Heating Plant in Ottawa, Ontario
- Toundra Greenhouse Case Study – a BECCU innovative showcase in Quebec

CanmetENERGY-Ottawa (CE-O) at Natural Resources Canada

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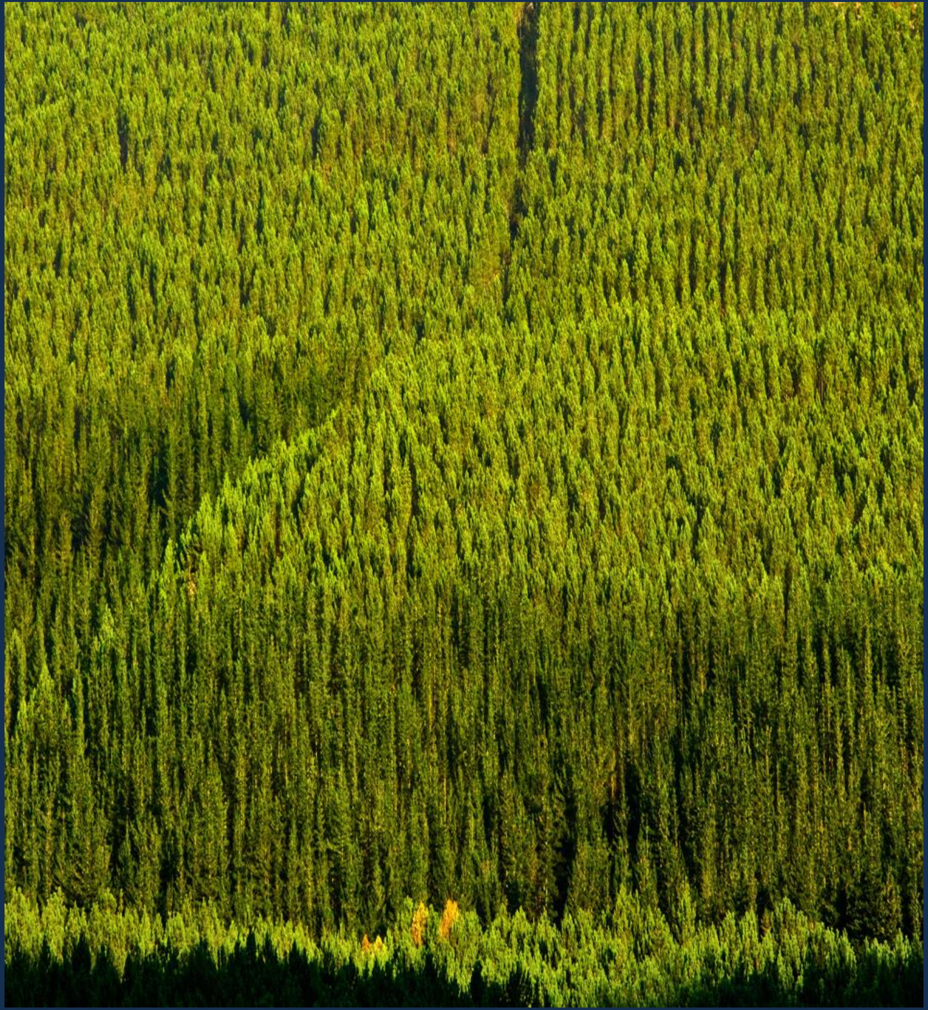
Why BECCS for Decarbonisation?

When combined with sustainable bioenergy, Carbon Capture and Storage (CCS) serves as a crucial pathway for achieving negative emissions by permanently removing CO_2 from the carbon cycle. BECCS is featured in three out of the four model pathways outlined by the Intergovernmental Panel on Climate Change (IPCC) to limit global warming to 1.5 degrees Celsius.



Defining Small-Scale Wood Combustion Systems for BECCS

- Typically have a heat output ranging from 1 MW to around 8 MW.
- Modular in design with key components assembled into a single unit.
- Plug-and-Play: easily transported as a single unit and installed on site.
- Can be offered as a containerized solution
- Simplified maintenance and scalable.
- Suitable applications such as district heating, industrial processes (drying and space heating), greenhouses, community buildings, small-scale CHP design for residential areas in rural and remote regions (offers a sustainable option for off-grid communities) and be integrated with other renewable energy systems as a hybrid solution to enhance reliability and efficiency.

Assessment of Carbon Capture & Utilization Options for Small Scale Biomass Combustion Systems

- This is part of a larger IEA Inter Task Project: Management of Biogenic CO2 BECCUS Phase 2 (2022-2024)
  - Shed light on (bio)energy system integration of bio-CCUS; and address CO2 mitigation potential of bio-CCUS, allowing for a more systemic consideration of how to take different BECCUS applications to deployment.
  - Task 32 Biomass Combustion is one of the project contributors

- Assessment of CCU technology options was based on 2019 study conducted by CanmetENERGY Ottawa for 1.5 MW thermal wood chip-fired demonstration facility at a Central Heating and Cooling plant in Ottawa, Ontario

High Level Technology Overview Of Potential Carbon Capture (CC) Technology Types for Small-Scale Wood Combustion Systems

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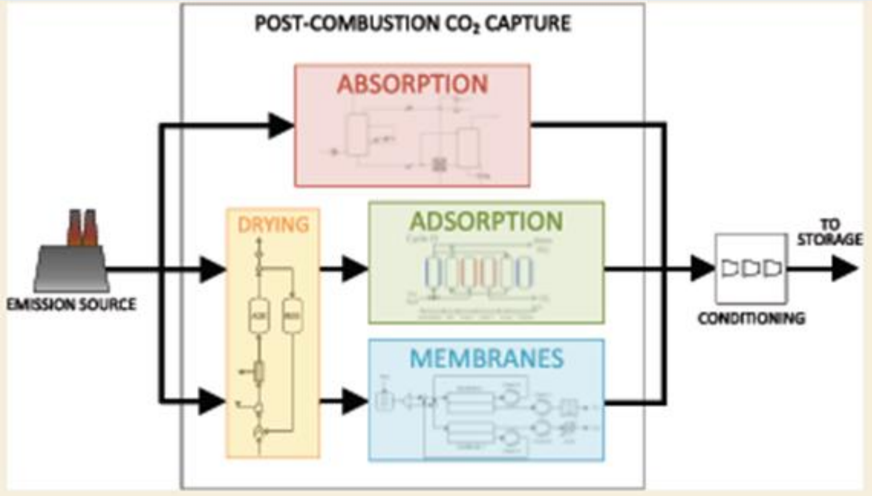
Overview of Post Combustion CC Technologies with TRL ≥7

Post combustion capture technology types are the most mature and are easiest to add to an existing facility (ie, brownfield):

- Adsorption
  - Temperature Swing Adsorption (TSA)
- Absorption
  - Amine Absorption
  - Enzyme-Enhanced Carbonate-Based Absorption
- Membrane
- Cryogenic Carbon Capture



Taken from Zarco et.al. 2021 ….. Postcombustion CO2 Capture: A Comparative Techno-Economic Assessment of Three Technologies Using a Solvent, an Adsorbent, and a Membrane | ACS Engineering Au

Overview of Post Combustion CC Technologies – cont'd

Key Characteristics

Technology Specific: technology readiness level (TRL), CO_2 % recovery rate and purity level, process & utilities required, and generation of by-products

Environmental Related: generation of harmful or toxic liquids or gas

Operational Flexibility: sensitivity to flue gas composition (PM, ash, water, trace metals, etc.)

Economic Related: total annualized cost ($/t$CO_2$)

Overview of CC Technologies

Key Metric/ Technology Type	Adsorption (TSA)	Absorption (Amine solvent)	Absorption (Enzyme-Enhanced Carbonate-Based)	Membrane	Cryogenic Carbon Capture
TRL (as of 2024)	8	7 -9	8	8	7
CO_2 Recovery rate (%)	90	80-95	83-90	70-90	90-98
Maximum achievable CO_2(g) purity	95%	99.9%	99.95%	95%[a]	99.99% CO_2(l)
Process inputs and utilities needed	Air, natural gas (for steam), cooling water, power	Cooling water, steam, power, amine solvent, process water	Hot water, power, cooling water, solvent and enzyme	Cooling water, power	Power (electricity), cooling water
Electricity needed (kWh/tonne CO_2)	189	160	169	374	410
Heating requirements	Steam for regenerating adsorbent	Steam for regenerating solvent	Hot water for regenerating solvent	No, operates at ambient temp	No, operates at ambient temp
Water usage	• Direct contact cooling • Steam generation	• Direct contact cooling • Solvent dilution • Steam generation	• Direct contact cooling • Hot water for solvent regeneration • Stripper column	• Direct contact cooling	• Process cooling
Type of products / by-products	CO_2, flue gas condensate	CO_2, Flue gas condensate	CO_2, flue gas condensate	CO_2, Flue gas condensate	CO_2(l)

[a] *Xu, 2019*

Overview of CC Technologies – cont'd

Key Metric/Technology Type	Adsorption (TSA)	Absorption (Amine)	Absorption (Enzyme-Enhanced Carbonate-Based)	Membrane	Cryogenic Carbon Capture
ENVIRONMENTAL RELATED					
Liquid and Gas Disposal (toxic materials)	No toxic materials	Yes Many solvents are toxic	Yes Less toxic than amine solvents	Yes pH too low to discharge to municipal water	No toxic materials
OPERATIONAL FLEXIBILITY					
Sensitivity to Flue Gas Composition	Yes Ash deposition risk on sorbent	Yes Remove NO_x and SO_x before absorption column	Yes Remove NO_x and SO_x before absorption column	Yes Remove ash and NO_x and SO_x	No Can handle impurities from gas stream, including NO_x
ECONOMIC RELATED					
Total Annualized cost ($CAD/tonne CO2)*	146[a]	60[a]	39[b]	131[a]	46[c]

[a] *Zanco, 2021*
[b] *Fradette, 2017*
[c] *Rodrigues, 2021*

Summary for Post Combustion Capture Technologies Overview

All the considered technology types show promise to be suitable for small scale biomass heating /CHP plants:

- CO_2 capture in the range of 80 – 90 % with resulting CO_2 purity > 95%
- Energy (electricity and heating/cooling) requirements vary widely depending on technology type
- Adsorption (TSA), absorption and membrane technologies are sensitive to PM and NO_x, SO_x in the flue gas
- Solvent can be toxic, and liquid effluents may need to be processed before discharging (pH too low)
- Total annualized cost to capture one tonne of CO_2 varies widely.

Highlights from CCU Technology Assessment Study for 1.5MW$_{th}$ District Heating Plant in Ottawa, Ontario

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Study Background and Design Basis

- Confederation Heights Central Heating and Cooling Plant in Ottawa, ON, supplies hot water to a district heating network comprised of 9 buildings
- Public Services and Procurement Canada (PSPC) initiated a study for potential implementation of a carbon capture and utilization (CCU) technology to meet Greening Government Strategy target of min. of 50% net reductions in GHG emissions
- 1.5 MW thermal wood chip-fired boiler with particulate removal via multi-cyclone and baghouse
- Biomass boiler emits roughly ~16 tonnes/day (tpd) CO_2
- Design basis:
  - Capture rate of 10 tpd CO2 (~62%) to provide a buffer for indirect emissions
  - Desired on-stream factor is 220 days per year

Selection of CCU Technology Options

Level 1 Screening

- Identified technologies sufficiently developed to meet the needs of the facility:
  - TRL 7+ for capture
  - TRL 6+ for utilization
- Began with nearly 50 technologies
  - 20 capture
  - 21 utilization
  - 7 combined
- Passed Level 1
  - 7 capture, 12 utilization and 4 combined

Level 2 Screening

- Technology demonstrated at the scale required at the facility
- Technology provider has a commercial presence in North America
- Application is logistically feasible at the heating plant
- Sufficient information available to complete the next stage of analysis

Detailed Analysis

On 4 capture, 4 utilization, 3 combined capture/ utilization technologies

Evaluation Criteria Matrix:

- Technology description
- Description of reference plant(s)
- SWOT* analysis
- Feedstocks/product streams
- Lifecycle considerations
- Space requirements
- CO_2-derived products
- Permanence of CO_2 utilization

*SWOT: Strengths, weaknesses, opportunities and threats

General Cost Assessment

Each technology evaluated has its own cost implications, and ongoing research aims to optimize their efficiency and economic viability.

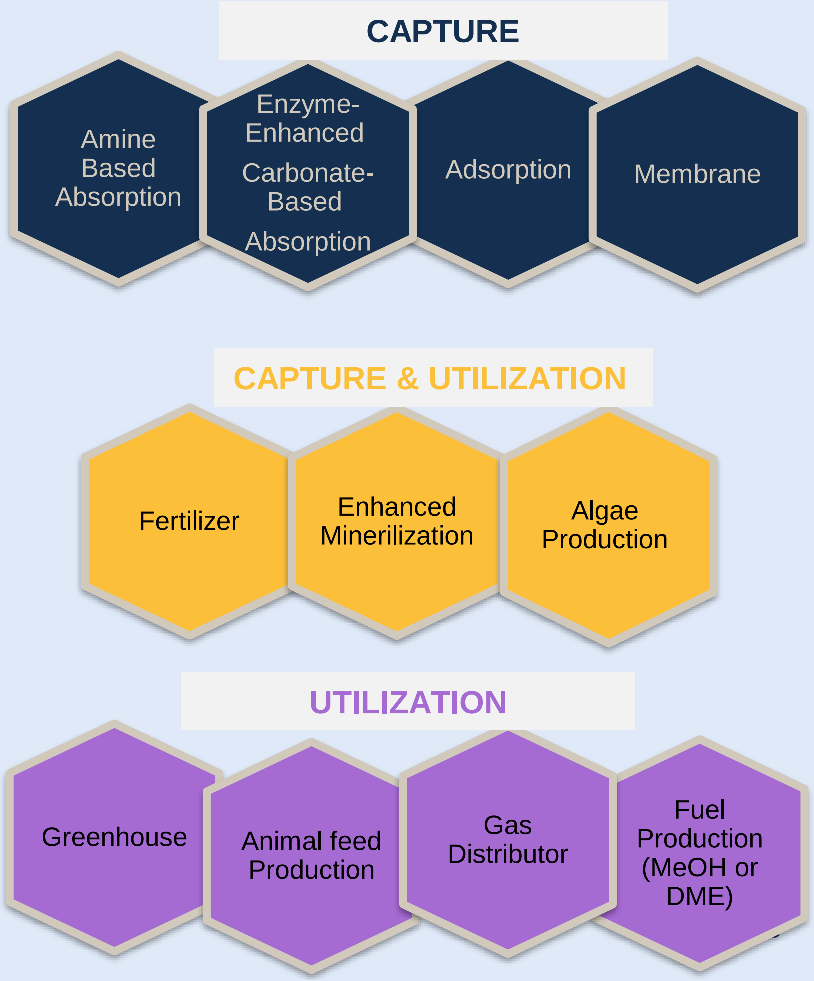
<u>Capex range</u>: from $9M for absorption (enzyme) to over $63M for algae

<u>Operating range</u>: from $2M for absorption (enzyme) to $12M for algae

<u>Revenue range</u>: from $0.5M for fuel production to $10M for fertilizer

<u>First year cost range</u>: $1 to $4.5M, except for algae around $11M (based on 20-year plant life)

Cost estimates are continuously refined as technology advances and more data becomes available.



Summary of Assessment of CCU Options for 1.5 MWth Central Heating Demonstration Plant

- Existing capture technology options can achieve 10 tpd CO2 capture rate
- Capture technologies are generally at higher TRL than utilization and combined capture/utilization
- CO_2 capture facilities are not expected to add considerable complexities to the operation of the heating plant; while CO_2 utilization facilities can bring complexities to the operation
- Wide range in capital investment costs among the capture, combined capture & utilization technologies
- The capture technologies are expected to add to existing O&M costs
  - Additional power consumption
  - Heat integration of new facilities with current plant is important to reduce additional power and natural gas consumption
  - Some additional costs could be offset through the sale of CO_2-derived products

Toundra Greenhouse – Turning Waste Heat and Emissions into Food!

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Toundra Greenhouse – Turning Waste Heat and Emissions into Food!

A successful example of leveraging BECCS technology in the shift towards sustainable practices.

Location:	Saint-Felicien, Quebec, Canada.
Key Technology:	Bioenergy Carbon Capture & Utilization (BECCU) using innovative enzyme-enabled carbon capture technology designed with no toxic emissions or waste.
Key Stakeholders:	Toundra Greenhouses and Resolute Forest Products.
Project:	Designed as a JV deal, Toundra uses waste heat and captures 30 TPD CO_2 emissions from the neighbouring pulp mill to enhance growth of cucumbers. Reduced 75% of fossil usage by using sustainable biomass fuel.

Acknowledgement

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- NRCan-PERD and PSPC for funding support.

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Questions ?

Additional Slides related to CCU Technology Assessment Study for 1.5 MW_{th} Wood Chip Central Heating Plant

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Analysis of Capture Technologies

Key Metric	Adsorption	Enzyme-Enhanced Carbonate-Based Absorption	Amine Absorption	Membrane
TRL (in 2019)	7	7	7	7
Resulting CO_2 product	95% CO_2(g)	99.95 % CO_2(g)	CO_2(l)	CO_2(g)/N_2(g) mixture
CO_2 emission reduction [%]	29.8	52.2	42.6	61.1
Energy req. [kWh/tCO_2]	350	351	244	382
Space req.	80-100 m2	400 m2	260 m2	60 m2
Building/tower/stack height	No higher than existing buildings	Tower: 20-30 m; RPB: fits within existing building	15 m	3 m

Analysis of Utilization Technologies

Key Metric	Fuel Production	Greenhouse	Gas Distributor	Animal Feed Production
TRL (in 2019)	7	9	9	7
Resulting CO_2 product	Methanol and/or DME	Food	N/A	Biomass for use as animal feed
CO_2 emission reduction [%]	-2.8 (SMR*), 40.0 (electrolysis, ON)	Unknown	N/A	Potential up to 90%
CO_2 retention time	Short	Short	Short (most applications)	Short
Energy req. [kWh/tCO_2]	Unknown	N/A	N/A	Unknown
Space req.	120 m2	20-40 ha	N/A	Unknown
Building/tower/stack height	No higher than existing buildings	N/A	N/A	No higher than existing buildings

*SMR Steam Methane Reforming

Analysis of Capture & Utilization Technologies

Key Metric	Precipitation Process	Enhanced Mineralization	Algae Production
TRL (in 2019)	7	7	7
Resulting CO2 product	PCC and PCM	Fertilizer	Algae for use as animal feed
CO2 emission reduction [%]	58.3	-902.6	48.7
CO2 retention time	Long	Long	Short
Energy req. [kWh/tCO2]	70	55-210	3000-5500
Space req.	100 m2	450 m2	1250 m2
Building/tower/stack height	8 m	7.7 m	Unknown

LCA considers GWP as Part of a Holistic Approach to Assessing Environmental Impact

- The **Global Warming Potential (GWP)** is a measure of how much a greenhouse gas contributes to global warming over a specific time frame, relative to carbon dioxide (CO_2), **which has a GWP of 1.**
- GWP values provide a standardized way to compare the warming potential of different carbon capture and utilization technologies and greenhouse gases, allowing policymakers and scientists to assess their impact on climate change

A maximum GWP of 0.20 will meet Greening Government's net emissions reduction target of 50%

LCA Results – Carbon Capture Technologies

Capture Technology	GWP (COteq/CO2tcap)	Key Contributors to GHG Emissions	Meet PSPC Net Emissions Reduction Target of 50%
Membrane	0.03	Major: Auxiliary Power Minor: Product Liquefaction	**YES**
Enzyme-Enhanced Absorption	0.16	Major: Required boiler for Solvent Regeneration Minor: Auxiliary Power	**YES**
Amine Absorption	0.32	Major: Sorbent/Solvent Regeneration NG Combustion and Production	NO
Adsorption	0.54	Major: Sorbent/Solvent Regeneration NG Combustion Minor: Auxiliary Power and NG Production	NO

LCA Results: Utilization & Combined Technologies

Technology	GWP (COteq/CO2tcap)	Key Contributors to GHG Emissions	Meet PSPC Net Emissions Reduction Target of 50%
CAPTURE & UTILIZATION			
Precipitation Process	0.07	Other Chemicals Production	**YES**
Enhanced Mineralization	0.60	Other Chemicals Production	NO
Algae Production	0.24	Auxiliary Power	**YES**
UTILIZATION			
Fuel Production (Ontario Electrolysis	0.52	Auxiliary Power and Capture Process	**NO**
Fuel Production (Quebec Electrolysis)	0.18	Capture Process	**YES**