LCRI LOW-CARBON RESOURCES INITIATIVE

EPRI

GTI ENERGY

EXECUTIVE SUMMARY

Cost and Performance Study of Carbon Capture in Industrial Sectors

INTRODUCTION

EPRI has engaged Wood to conduct the Cost and Performance Study of Carbon Capture in Industrial Sectors aimed at decarbonizing the different industrial complexes located in the U.S.A.

The focus of this study is to evaluate the design performance and economics of the following three cases:

- Retrofit cement manufacturing facility with 90% carbon capture.
- Retrofit pulp and paper manufacturing facility with 90% carbon capture.
- Retrofit petroleum refining facility with 90% carbon capture.

The study has been executed according to the following tasks:

- Definition of the baseline case to fix capacity, technology, and characteristics of the reference facilities. The assessment is performed by Wood with in-house data.
- Technical assessment of the CO_2 capture retrofit for the three reference facilities, with sizing of the new the carbon capture and compression units and the required utility units.
- Economic assessment of the CO_2 capture retrofit for the three reference facilities with definition of the investment (AACE Class 4, with -20%/+40% level accuracy) and operating costs.

PROCESS ALTERNATIVES – BASELINE CASES

The reference cases for each type of facility are defined below.

- The **Cement Plant** is a facility with a nominal capacity of 900,000 tonnes per year of cement clinker. The process stages include raw material extraction, grinding, proportioning, blending, pre-heating, kiln phase, and cooling. The flue gas from cement plant is characterized by low CO_2 concentration, due to air in-leakage from the raw meal during this process. The flue gas NOx levels are too high for

amine-based solvents and would result in solvent degradation, so they shall be reduced to acceptable levels through a selective catalytic reduction (SCR) system. No steam is available in the reference cement plant, therefore dedicated steam generation and relevant utilities shall be installed dedicated to the CO_2 capture requirements. Required power shall be imported from external grid.

- The **Pulp and Paper Plant** is a facility with a nominal capacity of 400,000 air-dried tonnes per year of softwood pulp. The process stages include wood preparation, cooking and delignification, washing, oxygen delignification, bleaching, drying, black liquor treatment, chemical recovery and energy production, recausticizing, lime production, bark combustion. Steam generation is present in the reference plant mainly fed with sub-products and excess steam previously used in a steam turbine can be diverted to the CO_2 capture unit. The plant's boilers are assumed to be relatively new, negating the need for additional flue gas treatments before the carbon capture. Required power shall be imported from external grid.
- The **Refinery Plant** capacity is 400,000 barrels per day. The plant includes the following main process units: CDU/VDU, FCC, SMR, CRF, DCU, VHT, NGCC/Boiler. The flue gases generated from units using refinery flue gas contain SOx levels too high for the amine-based solvent which would lead to solvent degradation, so installation of a flue gas desulfurization unit before CO_2 capture in necessary. The refinery is characterized by presence of multiple CO_2 sources that shall be partially collected to minimize the number of absorbers. It is assumed that the existing steam and power generation in the reference refinery is dedicated to the existing process unit, therefore a dedicated combined heat (steam) and power unit (CHP) shall be installed for the CO_2 capture unit requirements according to philosophy of the most refineries to self-produce the required utilities.

RESULTS OF TECHNICAL ASSESSMENT

The study investigated the three different facilities, and the following new units have been deemed necessary for the CO_2 capture retrofit:

Cement

- CO_2 capture unit: generic amine-based technology. Designed for 90% CO_2 capture.
- CO_2 compression unit.
- New utilities: steam generation system (auxiliary boiler); raw water system; demineralized water system; condensate recovery and boiler feed water system; natural gas supply dedicated to the auxiliary boiler; cooling water system; wastewater treatment.

Pulp and Paper

- CO_2 capture unit: generic amine-based technology. Designed for 90% CO_2 capture.
- CO_2 compression unit.
- New utilities: cooling water system; raw water system; wastewater treatment.

Refinery

- CO_2 capture unit: generic amine-based technology. Five absorber sections for the units FCC, SMR/DCU/VHT, CRF/VDU/CDU/boiler, NGCC, new CHP unit, each designed for 95% CO_2 capture to reach 90% capture overall minimizing the CO_2 sources to be treated. One single regeneration section.
- CO_2 compression unit.
- New utilities: CHP; condensate recovery and boiler feed water system; cooling water system; wastewater treatment.

The main performance data of the analyzed cases are summarized in Table 1 below.

Table 1. *Performance Summary Table*

Facility	CO_2 captured	LP steam cons. per CO_2 captured	Electric power cons. per CO_2 captured	Specific CO_2 Emissions – without CO_2 Capture	Direct Specific CO_2 Emissions – with CO_2 Capture (1)	Indirect Specific CO_2 Emissions – with CO_2 Capture (2)
	t/h	t Steam/ t CO_2	kWh / t CO_2	kg CO_2 / kg	kg CO_2 / kg	kg CO_2 / kg
Cement	83.5 (90%)	1.40	135	0.73 kg CO_2 / kg Cement	0.09 kg CO_2 / kg Cement	0.15 kg CO_2 / kg Cement
Pulp and paper	110.8 (90%)	1.40	134	2.70 kg CO_2 / kg Pulp	0.27 CO_2 / kg Pulp	0.43 CO_2 / kg Pulp
Refinery	596.3 (90%)	1.54	136	0.21 CO_2 / kg Oil	0.03 CO_2 / kg Oil	0.02 CO_2 / kg Oil

Notes:
1. Direct CO_2 emissions consider CO_2 emissions from the existing facility with the additional CO_2 emissions from the new units.
2. Indirect CO_2 emissions consider Direct CO_2 emissions with the additional CO_2 emission from external sources (i.e. imported power).

- The specific steam required per ton of CO_2 captured is higher in the refinery since the absorber are designed for 95% of capture, instead of 90%, increasing the specific steam required for amine regeneration.
- Indirect specific emissions for cement increase with respect direct emissions due to import of electric power.
- Indirect specific emissions for pulp & paper increase with respect to direct emissions due to reduction of electric power export since available steam is not used anymore to produce power in the existing steam turbine but diverted to the CO_2 capture unit for amine regeneration.
- Since in the pulp and paper facility the origin of the CO_2 is approximately 95% biogenic, the CO_2 emission could be considered negative.

ECONOMIC EVALUATION SUMMARY

For each case of the study, the Total Plant Cost (TPC) and Total Capital Requirement (TCR) relevant only to the new retrofit units (CO_2 capture, CO_2 compression, utilities) are determined through use of a Wood in-house database and the development of conceptual estimating models, based on the specific characteristics, materials, and design conditions of each equipment.

In addition, fixed and variable operating costs at 90% of capacity factor are determined for each case.

The economical results are summarized in the following Table 2.

Table 2. *Economic Summary Table*

	Total Plant Costs (TPC)	Specific TPC	Total Capital Requirement (TCR)	Fixed Operating Costs	Variable Operating Costs	Total O&M
	MM$	MM$ / t/h CO_2	MM$	MM$/y	MM$/y	MM$/y
Cement	470.7	5.6	618.3	21.5	17.8	39.3
Pulp and paper	398.3	3.6	522.5	16.9	18.8	35.7
Refinery	2393.0	4.0	3137.5	85.2	98.4	183.6

- Specific Total Plant Cost for cement facility is higher compared to other plants due to the lower CO_2 concentration in the flue gases and necessity to install all the necessary utilities in a relatively small facility (low scale factor).
- Specific Total Plant Cost for pulp and paper takes advantage of the presence of existing steam boilers and other relevant utilities in the reference facility.
- Specific Total Plant Cost for the refinery includes high costs for installation of steam boilers and steam turbines; however, the greater size of this plant allows to take advantage from the economical scale factor for the CO_2 capture unit (average bigger size of the absorbers and one single high-capacity regeneration section) and compression unit.

THE LOW-CARBON RESOURCES INITIATIVE

This report was published under the Low-Carbon Resources Initiative (LCRI), a joint effort of EPRI and GTI Energy addressing the need to accelerate development and deployment of low- and zero-carbon energy technologies. The LCRI is targeting advances in the production, distribution, and application of low-carbon energy carriers and the cross-cutting technologies that enable their integration at scale. These energy carriers, which include hydrogen, ammonia, synthetic fuels, and biofuels, are needed to enable affordable pathways to economy-wide decarbonization by mid-century. For more information, visit www.LowCarbonLCRI.com.

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