# Greenhouse Gas Footprint Analysis of the Calera Process March Draft/ Progress Report

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## Executive Summary

The Yallourn brown coal fired power station (1,460MW) in Victoria Australia is used as the baseline scenario to model the Calera carbon capture and storage process. The Yallourn power station emits 1.3 tonnes of $CO_2$ per MWh generated. A theoretical size of 200MW was selected by Calera, and is used as the basis of this analysis. Carbon dioxide extracted from the flue gases is combined with divalent cations ($Ca^{2+}$) and alkalinity ($OH^-$) to form stable carbonates. The alkalinity and divalent cations are extracted from materials near the Yallourn power station. A baseline scenario and two cases are modeled to assess the life cycle greenhouse gas (GHG) balance of the Calera process at the Yallourn demonstration facility.

1. Yallourn baseline (200MW)
2. Yallourn, Calera process (200MW)
3. Yallourn, Calera process with 15% alkalinity from Electrochemistry (200MW)

A consequential life cycle approach is utilized to assess changes in both upstream and downstream GHG emissions that occur when the Calera process is utilized at the Yallourn facility, which includes the displacement of Portland cement at the concrete mixing plant level. The GHGs from electricity transmission are not included in this analysis because they are constant for each scenario. From 2003-2007 the average utilization rate at the Yallourn Power Station was 78%, but this is not factored into this analysis, because full utilization operating conditions are assumed.

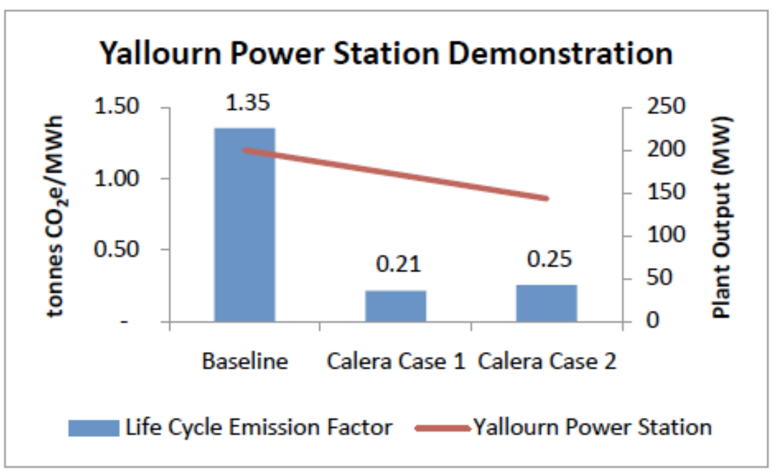


Figure 1: Emission factors and power output for the Yallourn power station baseline and Calera case studies

**Calera Process:** Each hour234 tonnes of $CO_2$ are mineralized into 481.6 tonnes of $Ca_3(CO_3)_2(HCO_3)_2$ that can be used as supplementary cementitious materials (SCMs) in the production of concrete. The Calera process is able to capture 90% of the $CO_2$ from the flue gas.

$$234\ CO_2 + 135.6\ OH^- + 159.8\ Ca^{2+} \rightarrow 481.6\ Ca_3(CO_3)_2(HCO_3)_2 + 47.9\ H_2O \text{ (tonnes per hour)}$$

Carbon dioxide extracted from Yallourn's flue gas is sequestered into the built environment because the SCMs can be used to replace Portland cement in concrete mixes in a 1:1 mass ratio.

**Greenhouse Gases:** GHGs are reported as $CO_2$ and $CO_2$ equivalent. The assessments covers the six GHG emissions covered by the Kyoto Protocol, i.e. $CO_2$, $CH_4$, $N_2O$, HFCs, PFCs, and $SF_6$.

**Constant System Inputs:** Each hour 343.54 tonnes of brown coal and 630 $m^3$ of water is required to generate 200MW of electricity at the Yallourn power station (48.91% of the incoming water requires treatment).

**Life Cycle Emissions:** Both upstream and downstream greenhouse gas emissions that result from producing electricity at the Yallourn power station are accounted for in this analysis. Currently the upstream GHG emissions include coal mining and transportation, and downstream emissions are the GHGs that result from wastewater treatment.

**Unit Processes:** Adjustments are required for the Calera cases because for each MWh output at Yallourn, there are additional GHGs for the upstream and downstream processes. Each unit process represents a portion of the product system for which data is calculated (all scaled to 1MWh).

**Power Output:** Although the emission factors are considerably lower than in the baseline scenario, the power output at the facility is reduced in both cases that utilize the Calera process because of the parasitic load (Figure 1).

**Adjusted Life Cycle Emissions Factors:**

Table 1: Life Cycle Emissions Factors at Yallourn facility

| Process | Baseline (tonne $CO_2$e / MWh) | Case 1 (tonne $CO_2$e / MWh) | Case 2 (tonne $CO_2$e / MWh) |
|---|---|---|---|
| Upstream | | | |
| Coal mining | 0.00668 | 0.0074 | 0.0089 |
| Coal transportation | 0.00135 | 0.00148 | 0.00179 |
| Yallourn power station + Calera | 1.3 | 0.151 | 0.181 |
| Downstream | | | |
| Water treatment | 0.044 | 0.052 | 0.062 |
| Total (no displacement) | 1.35 | 0.21 | 0.25 |
| Transportation Displacement | 0 | 0.271 | 0.325 |
| Cement Displacement | 0 | (2.34) | (2.80) |
| Total (with displacement) | 1.35 | (1.86) | (2.22) |

**Transportation Impacts:** Railways, ocean freighters, and transport trucks are used to move building materials produced in the Calera process from Yallourn Australia to destinations in China. Each tonne of building materials shipped from Yallourn to China travels over 8,500 kilometers and generates 0.12 tonnes $CO_2$ equivalent. To properly account for the use of Calera SCM as a cement substitute, transportation impacts were calculated for Portland cement as well.

**Portland Cement Substitution:** Portland cement production is a carbon intensive process, and replacing a portion of Portland cement with Calera SCM presents an additional carbon reduction opportunity. Cement substitution is modeled as an additional downstream process of the Calera life cycle. The Calera SCM is expected to replace Portland cement at the concrete mixing plant. Calera SCM can replace Portland cement in a 1:1 mass ratio. It expected that 20% of Portland cement will be replaced by Calera SCM at a concrete mixing plant.

**Traditional Carbon Capture and Sequestration Comparisons:** Preliminary comparisons have been made with the CSS technologies covered in the analysis performed by Kolstad and Young. This includes the following CSS technologies:

- Post- Combustion MEA
- Oxy-fuel
- Advanced Amine

**Additional Environmental Impacts:** This analysis only considers the GHGs associated with the Calera process and the Yallourn facility. Because the scale of electricity generation and the Calera process is so large, additional environmental impact indicators need to be considered in future analyses. Simply looking at greenhouse gases can represent a myopic view of the total system.

**Model Development:** This analysis splits the Yallourn power station and the Calera process into smaller unit processes that have inputs and outputs recorded for each MWh generated. Additional upstream or downstream unit processes or emissions ($NO_x$, $SO_x$, etc.) can be added as more data becomes available.

**Data Sources:** Plant data was obtained from TRUenergy's Yallourn social and environmental report summary (2007), the Ecoinvent 2.0 life cycle inventory database, and PE International's life cycle inventory database.