ORANGE = manipulated parameters
RED = selected energy/emissions outputs
GREEN = energy generated

Constants		
Faraday's constant	96485	C/mol
Molar mass CaCO3	100.087	g/mol
Molar mass Ca(OH)2	74.093	g/mol
Molar mass CaO	56.077	g/mol
Wt % CaO in clinker	0.65	% decimal
Thermal to electric efficiency	0.5	% decimal

Operating cost difference (Echem-Thermal)		
Electrochemical cement	70.3	$ / t cement
Thermal cement	71.0	$ / t cement
Difference (echem - thermal)	**-0.8**	**$ / t cement**

TARGET RATES & PLANT SPECIFICATIONS		
Parameter	**Value**	**Units**
Cement production rate	40	ton / day
Clinker content in cement	0.95	% decimal
Ca(OH)2 production	32.64	ton / day
CaCO3 consumption	44.08	ton / day
Hourly CaCO3 consumption	18352.7	mol / h
Electricity price	0.030	CAD $ / kWh
Grid emissions intensity	0.150	kg CO2 / kWh
Grid emissions intensity	41.67	kg CO2 / GJ
Regional carbon tax	85.00	$ / t CO2

THERMAL CEMENT PRODUCTION		
CaCO3-fed dry rotary kiln + preheater + precalciner		
Kiln + precalciner energy consumption	**2.90**	**GJ / t cement**
Equivalent electrical energy	*5.80*	*GJ / t cement*
% coke in fuel blend	0.00	% decimal
% coal in fuel blend	0.00	% decimal
% oil in fuel blend	0.00	% decimal
% CH4 in fuel blend	1.00	% decimal
% H2 in fuel blend	0.00	% decimal
Fuel mix emission intensity	56.10	kg CO2 / GJ
Fuel cost	4.20	$ / GJ
Emissions intensity of kiln	**162.69**	**kg CO2 / t cement**
Electricity demand for aux. equipment	90.00	kWh / t cement
Electricity demand for aux. equipment	0.32	GJ / t cement

ENERGY		
Thermal energy consumption	2.9	GJ / t cement
Electric energy consumption	0.3	GJ / t cement
Total energy consumption (thermal)	**3.1**	**GJ / t cement**
Total energy consumption (electric)	**6.1**	**GJ / t cement**

EMISSIONS		
Electricity generation for electrolyser	0	kg CO2 / t cement
CO2 released from CaCO3	484.6	kg CO2 / t cement
Kiln fuel use	162.7	kg CO2 / t cement
Electricity for aux. equipment	13.5	kg CO2 / t cement
Total emissions	**660.81**	**kg CO2 / t cement**

OPERATING COST		
Electricity cost	2.7	$ / t cement
Thermal energy cost	12.2	$ / t cement
Carbon cost	56.2	$ / t cement
Thermal energy cost	**71.0**	**$ / t cement**

ELECTROCHEMICAL CEMENT		
Step 1: CaCO3 --> Ca(OH)2 (cement electrolyser) CURRENT METRICS		
Cell voltage	2.5	V
Current density	0.3	A / cm2
Current efficiency	1	% decimal
Ca2+ formation rate	0.3	A / cm2
Ca2+ formation rate	5.60E+00	mmol / cm2 h
Ca2+ formation rate	5.60E+01	mol / m2 h
H2 formation rate (cathode)	5.60E+00	mmol / cm2 h
CO2 formation rate (chemical)	5.60E+00	mmol / cm2 h
O2 formation rate (anode)	2.80E+00	mmol / cm2 h
Electrochemical unit specifications (calculated)		
Electrode area	328	m2
Total current	0.984	MA
Power	2.459	MW
Electricity consumption	6.51	GJ / t Ca(OH)2
Electric energy demand	**5.59**	**GJ / t cement**
Emissions from electricity generation	271.29	kg CO2 / t Ca(OH)2
Emissions from electricity generatio	**233.0**	**kg CO2 / t cement**
Utilization of O2, H2, CO2		
H2 Heat of combustion (const.)	0.286	MJ / mol
H2/O2 combustion efficiency	0.8831	% decimal
Energy from combustion of H2/O2	3.41	GJ / t Ca(OH)2
Energy from combustion of H2/O2	**2.78**	**GJ / t cement**
Utilization of CO2 from electrolyser	1	% decimal
Step 2: Ca(OH)2 --> CaO (dry rotary kiln)		
Thermal energy (ΔG)	139.0	KJ / mol (@900K)
Thermal energy required (ΔG)	1.61	GJ / t cement
Kiln energy consumption - CaO feed	2.60	GJ / t cement
Thermal energy required for sintering	1.17	GJ / t cement
Kiln operation		
Energy consumption - Ca(OH)2 feed	**2.78**	**GJ / t cement**
Equivalent electrical energy	*5.56*	*GJ / t cement*
% coke in fuel blend	0.00	% decimal
% coal in fuel blend	0.00	% decimal
% oil in fuel blend	0.00	% decimal
% CH4 in fuel blend	1.00	% decimal
% H2 in fuel blend	0.00	% decimal
Fuel mix emission intensity	56.10	kg CO2 / GJ
Fuel cost	4.20	$ / GJ
Emissions intensity of kiln	**156.02**	**kg CO2 / t cement**
Electricity demand for aux. equipment	90.00	kWh / t cement
Electricity demand for aux. equipment	0.32	GJ / t cement

ENERGY DEMAND		
Thermal energy consumption	0.0	GJ / t cement
Electric energy consumption	5.9	GJ / t cement
Total energy consumption (thermal)	**3.0**	**GJ / t cement**
Total energy consumption (electric)	**5.9**	**GJ / t cement**

CO2 EMISSIONS		
Electricity generation for electrolyser	233.00	kg CO2 / t cement
CO2 released from CaCO3	0.00	kg CO2 / t cement
Kiln fuel use	0.00	kg CO2 / t cement
Electricity for aux. equipment	13.5	kg CO2 / t cement
Total emissions	**246.50**	**kg CO2 / t cement**

OPERATING COSTS		
Electricity cost	49.3	$ / t cement
Thermal energy cost	0.0	$ / t cement
Carbon cost	21.0	$ / t cement
Total energy cost	**70.3**	**$ / t cement**

Fuel specifications				
Fuel	**Emissions (kg**	**Net calorific value (MJ**	**Cost (CAD**	**Kiln fuel use in Canada**
Coke (petroleum)	92.8	31.44	2	0.25 % decimal
Hard coal	96	26.62	2.05	0.52 % decimal
Oil	74	41	21.74	0.05 % decimal
Natural gas	56.1	47.1	4.2	0.18 % decimal
H2	0.005	120	14	1.00 Total