For Airborne Wind Energy Friends

I am writing about Seawater electrolysis very briefly

I. Theoretical Requirements for treating 1 mol of Carbon

I.1 Theoretical Requirements of Energy and Materials for 1 mol of CO_2 or Carbon

-in case of producing NaHCO3

To treat 1mol of CO_2, we need theoretically **58.5m^3 of air** (383/1,000,000|=383ppm|= 22.4L/**58,486L**).

To process 1 mol of CO_2 with NaOH into NaHCO3, we need 1 mol of **Na**Cl.

To get 1 mol of **Na**Cl, we need **2.14Kg of seawater** (1mol Na/0.468 mol Na/Kg seawater= 2.14Kg seawater=2.0878L seawater). [1]

For the **RO**(**R**everse **O**smosis) pretreatment with NaOH alkalization to 2.14Kg seawater, we need **0.07mol NaOH**. (NaOH density=39.9971g/mol). [2]

To treat 2.14Kg seawater with state-of-the-art RO(**R**everse **O**smosis), we need **15.03kJ(e)**. [3]

For the Chlor-Alkali Electrolysis of 1 mol NaCl to obtain 1 mol NaOH, we need 212kJ theoretically and **268.5~421.9 kJ(e)** practically with commercial electrolyzer. [4]

$$NaCl + H_2O \rightarrow NaOH + 0.5Cl_2 + 0.5H_2 \quad +212kJ \qquad (1)$$

$$NaOH + CO_2 \rightarrow NaHCO3 \quad -70kJ \qquad (2)$$

$$0.5Cl_2 + 0.5H_2 \rightarrow HCl \quad -92.3kJ \qquad (3)$$

We may obtain 0.0223 mol $CaCO_3$, 0.1141mol $Mg(OH)_2$, 1 mol $NaHCO_3$ as precipitation and 1mol HCl. To treat $Mg(OH)_2$ we need HCl and energy for electrolysis.

$$0.01141 Mg(OH)_2 + 2HCl \rightarrow MgCl_2 + 2H_2O \text{ and } MgCl_2 + \text{electolysis} \rightarrow Mg + Cl_2 \qquad (4)$$

The required energy for 0.01141mol $MgCl_2$ electrolysis is **94.824kJ**. (=0.01141mol x 831.06kJ/mol Mg). [5]

$$9.5kWh/Kg\ Mg \times 3.6\ MJ/kWh \times Kg/1{,}000g \times 24.3g/mol\ Mg = 831.06\ kJ/mol\ Mg \qquad (5)$$

The required HCl for the process (4) $Mg(OH)_2 + 2HCl \rightarrow MgCl_2 + 2H_2O$, is supplied from the process (3).

So, we need only additive NaOH (0.07 mol), for the RO pretreatment. We need the electrical energy 0.07 x (268.5~421.9kJ(e)) and 0.07 x 2.17Kg= 0.1498Kg seawater to be chlor-alkali electrolyzed.

The theoretical requirement and product in case of producing $NaHCO_3$ with 1 mol of carbon is summarized as following table.

Theretical Requirements of Energy and Materials for treating 1mol Carbon - in case of producing $NaHCO_3$			
		1 mol Carbon	
Input Material	Air	58.5m^3	58.5m^3
	Seawater	2.14Kg	2.29Kg
	NaOH for RO pretreat.	0.07mol	
	HCl for $Mg(OH)_2$	2 x 0.1141 mol	
Required Energy	Reverse Osmosis	15.03kJ(e)	15.03kJ(e)
	NaCl Electrolysis	268.5~421.9kJ	287.3~451.4kJ
	Pumping & Spraying	?	?
	$MgCl_2$ Electrolysis	94.824kJ(e)	94.824kJ(e)
Product and Byproduct	$NaHCO_3$	1 mol	1 mol
	$CaCO_3$	0.0223 mol	0.0223 mol
	Mg	0.1141 mol	0.1141 mol
	HCl	1 mol	0.7718 mol
	1/4 Exothermic HCl proc.	23kJ(e)	23kJ(e)

Reference

[1] http://www.seafriends.org.nz/oceano/seawater.htm#composition

The main salt ions in seawater

chemical ion	valence	concentration ppm, mg/kg	part of salinity %	molecular weight	mmol/kg
Chloride Cl	-1	19345	55.03	35.453	546
Sodium Na	**1**	**10752**	**30.59**	**22.990**	**468**
Sulfate SO4	-2	2701	7.68	96.062	28.1
Magnesium Mg	**2**	**1295**	**3.68**	**24.305**	**53.3**
Calcium Ca	**2**	**416**	**1.18**	**40.078**	**10.4**
Potassium K	1	390	1.11	39.098	9.97
Bicarbonate HCO_3	**-1**	**145**	**0.41**	**61.016**	**2.34**
Bromide Br	-1	66	0.19	79.904	0.83
Borate BO3	-3	27	0.08	58.808	0.46
Strontium Sr	2	13	0.04	87.620	0.091
Fluoride F	-1	1	0.003	18.998	0.068
Water H_2O					53,600

The main salt ions quantity in 2.14Kg seawater(2.0879liter)

chemical ion	valence	concentration ppm, mg/kg	molecular weight	mol	wt.(gram)
Chloride Cl	-1	19345	35.453	1.16844	41.4247
Sodium Na	1	10752	22.990	**1.0015**	23.0249
Sulfate SO4	-2	2701	96.062	0.06013	5.77659
Magnesium Mg	2	1295	24.305	**0.1141**	2.77228
Calcium Ca	2	416	40.078	**0.0223**	0.89198
Potassium K	1	390	39.098	0.02134	0.83419
Bicarbonate HCO3	-1	145	61.016	**0.005**	0.30554
Bromide Br	-1	66	79.904	0.00178	0.14193
Borate BO3	-3	27	58.808	0.00098	0.05789
Strontium Sr	2	13	87.620	0.00019	0.01706
Fluoride F	-1	1	18.998	0.00015	0.00276
Water H_2O			18.01528	**114.7**	2066.42
Dissoved CO2 gas			44.010	**0.0046**	0.20164

[2] **Desalination**,Volume 153, Issues 1-3, 10 February 2003, Pages 109-120

Study of seawater alkalization as a promising RO pretreatment method, Samir El-Manharawy

linkinghub.elsevier.com/retrieve/pii/S0011916402011104

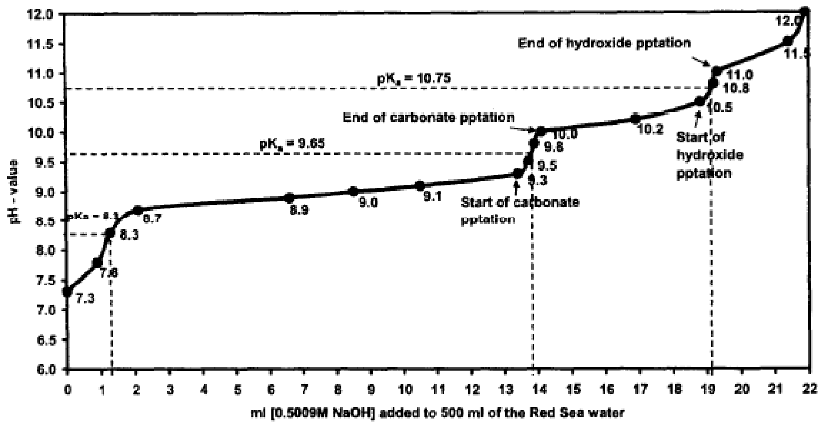


Fig. 1. The relationship between pH value and added 0.5009 M NaOH volume, Red Sea water.

NTP). The consumed amount from 100% NaOH in the 1st pH 10 and 2nd pH 11 stages reactions are given below:

Consumed $NaOH_{1st}$
$= [(13.85+0.25)(0.5009\times39.997/1000)(1000/500)]/1.0299$

$= 548.57$ mg/kg
$= 0.54857$ kg per one ton of the Red Sea water.

Consumed $NaOH_{2nd}$
$= [(19.2 + 0.1)(0.5009*39.997/1000)(1000/500)]/1.0299$
$= 750.88$ mg/kg
$= 0.75088$ kg per one ton of the Red Sea water.

[3]

Required 100% NaOH for NaOH Akalization for RO pretreatment		
1st pH 10 stage	2nd pH 11 stage	
0.5487Kg*	0.75088Kg *	per 1 ton of Red Sea water
1.174218g	1.606883g	per 2.14Kg Seawater
0.0293576mol	**0.040175mol**	NaOH density=39.9971g/mol
0.0293576 mol +	0.040175mol =	0.0695326mol
* from "Study of seawater alkalization…" Samir El-Manharawy		
linkinghub.elsevier.com/retrieve/pii/S0011916402011104		

[4] Int. J. Electrochem. Sci., 3 (2008) 444 - 451

Low Energy Consumption **in Chlor-alkali Cells Using Oxygen Reduction Electrodes,**

Yohannes Kiros and Martin Bursell*

http://www.electrochemsci.org/papers/vol3/3040444.pdf

It is an energy intensive process, where electrical power consumption between 2100 and 3300 kWh t-1 Cl2 is used depending on the operating parameters and the type of the process.

[5] **Journal of Alloys and Compounds,** Volume 465, Issues 1-2, 6 October 2008, Pages 255-260

Electrolytic magnesium production and its hydrodynamics by using an Mg–Pb alloy cathode

Gökhan Demirci and İshak Karakaya

linkinghub.elsevier.com/retrieve/pii/S0925838807020129

“Energy consumption was nearly constant at about 9.5 kWh for producing 1 kg of magnesium at lower anode tip angles and it increased at higher anode tip angles as can be seen in Fig. 4.”

II. Actual Requirements for treating 1 ton of Carbon

As 1 ton of Carbon is equivalent to 83259.09 mol, (=1,000,000 gram/12.0107 g mol^{-1}), we need to multiply the required materials and energy for 1mol of carbon with 83259.1.

To treat 1 ton of carbon (83259.1 mol), we need theoretically 4,870,657m^3 and practically **13,916,164 m^3** with the assumption of 35% capture. [1]

And the energy for operating fan to blow air with 2m/s in the reference [1] is omitted, because we will use sea wind with average speed of about 10m/s which will be discussed in chapter III.

Assuming that we selected a chlor-alkali electrolysis cell consuming 299.47kJ(e) and we use regenerative energy using the exothermic process of HCl formation, we need **300kJ for NaOH production and CO_2 related process and 94.824kJ(e) for $MgCl_2$ electrolysis.**

The actual requirement and product for processing 1 ton Carbon is summarized as following table.

Actual Requirements of Energy and Material for treating 1 ton Carbon
- in case of producing NaHCO3

		1 mol Carbon			1 ton Carbon	Note(assumption)
Input Material	Air	58.5m^3	58.5m^3		13,916,164m^3	CO2 capture:35%
	Seawater	2.14Kg	2.29Kg		19.1 ton	
	NaOH for RO pretreat.	0.07mol				
	HCl for $Mg(OH)_2$	2 x 0.1141 mol				
Required Energy	Reverse Osmosis	15.03kJ(e)	15.03kJ(e)	323kJ-23kJ =300kJ(e)	24.978GJ(e)	
	NaCl Electrolysis	268.5~421.9kJ	*299.47kJ(e)			*299.47 kJ for NaCl electrolysis
	NaOH solution Pumping	6.7kJ(e)	6.7kJ(e)			
	Nozzle pressure energy	1.8kJ(e)	1.8kJ(e)			
	$MgCl_2$ Electrolysis	94.824kJ(e)	94.824kJ(e)	94.824kJ(e)	7.90GJ(e)	
Product and Byproduct	$NaHCO_3$	1 mol	1 mol		6,994Kg	
	$CaCO_3$	0.0223 mol	0.0223 mol		185.83Kg	
	Mg	0.1141 mol	0.1141 mol		230.9Kg	
	HCl	1 mol	0.7718 mol		5.464Kg	
	1/4 Exothermic HCl proc.	23kJ(e)	23kJ(e)			

III. Cost and Benefit Analysis

IV.1. Cost Estimation

The weight of daily products ($NaHCO_3$, $CaCO_3$, Mg, and HCl) by 1.53 GW electricity is 39,220 ton.(I need to modify for the 0.8GW case)

The longest ship "Knock Nevis" has length 458.4m and loading capability of 564,763 dwt. We assume our system's deadweight coefficient($C_D = dwt / W$ where W is fully loaded displacement) is 0.86 because our products except HCl does not need careful treatment and our system's deadweight is 570,000 dwt which comprises two weeks' products cargo(39,220 ton/day x 14 days = 549,080 ton) and 20,920 ton of crew, provisions, foods, Etc.

With the above assumptions, the fully loaded displacement W will be as following:

$W = dwt / C_D$

$W = 570,000 / 0.86 = 662,791$ metric tons

Light weight displacement=$W - dwt$

Light weight displacement=662,791- 570,000=92,792 metric tons

Our system's light weight displacement which is generally defined as the mass of the ship excluding cargo, fuel, ballast, stores, passengers, crew is 92,792 tons.

We assume the half of 92,792 tons is steel structure and hulls and the rest half consists electrolyser and chemical plant to adsorbs CO_2 to NaOH spraying and its accessories.

The price of such sized super tanker is 105M$, we can count our ship hull cost as 70% of 105M$; 73.5M$.

As 50hp electric motor/generator is 4,500$, we can count 1.53GW generator as

$$\frac{1,530,000\text{Kw}}{37.3\text{Kw}} \text{ x } 4,500\$=184 \text{ Million}\$.$$

For the electrolyzer, we apply the price of ITM-POWER PLC. with 50$/Kw.
1,530,000Kw x 50$/KW=7.65Million$

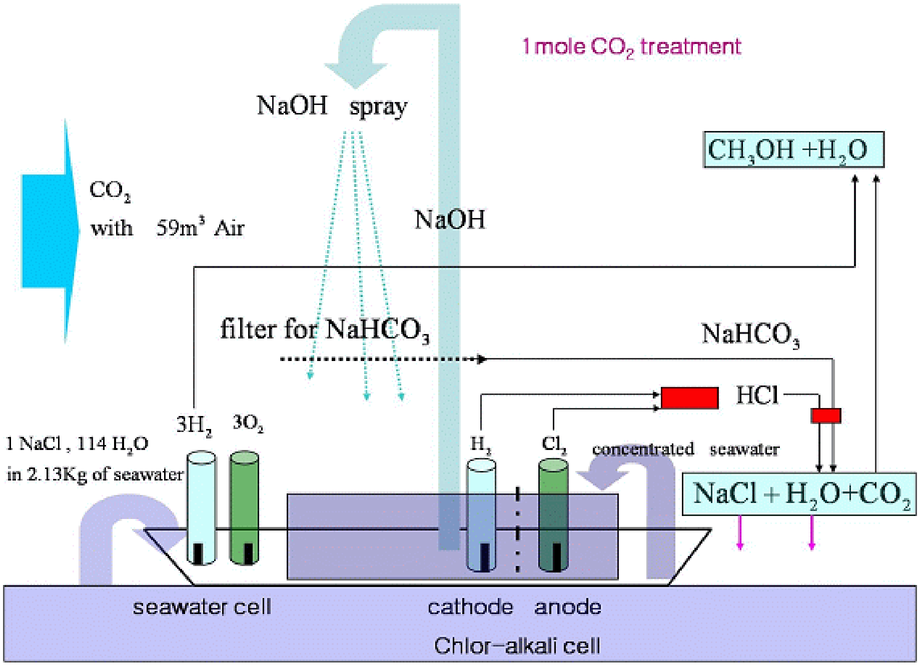
-Annual Productivity for Fighting Weather Change

Products	Molar Mass	Productivity with 395kJ	Productivity with 0.8GW(2,025mol/sec) /second	/second	/ (365.25days)	Price($/t)	$/yr	
$NaHCO_3$	84.01 g	1 mol	2025.0 mol	170.1 Kg	5,368,587 ton	285.0	1,530,047,238	
$CaCO_3$	100.09 g	0.0223 mol	45.2 mol	4.5 Kg	142,634 ton	106.3	15,162,046	
Mg	24.305 g	0.1141 mol	231.1 mol	5.6 Kg	177,219 ton	4,400.0	779,763,569	
HCl	36.46 g	0.7718 mol	1562.9 mol	57.0 Kg	1,798,252 ton	190.0	341,667,787	
Carbon equivalent to NaHCO3	12.0107 g	1 mol	2025.0 mol	24.3 Kg	767,533 ton		2,666,640,640	Sum($)
CO_2 Equivalent to total	44.01 g	1.0223 mol	2070.2 mol	91.1 Kg	2,875,138 ton			
							12,041,631	Expense
							221.5	CostBenefitRatio

-Operation Cost

	Unit Price	Factor, Vol., Mass	Invest.($)	Life Cycle (year)	Yearly Expense($)
Hull Structure	105M$	70%	**73.5M**	**20**	**3,675,000**
Generator	4,500$/37.3kW	800,000kW	**97M**	**20**	**4,825,737**
Electrolyzer	50$/kW	800,000kW	**40M**	**20**	**2,000,000**
Kite	$100/Kg	0.4Kg/m2x10,000m2	**0.4M**	**7**	**57,143**
Tether rope	$150/kg	0.056m2x 1821mx970Kg/m3	**14.84M**	**10**	**1,483,751**
SUM			**225.25M**		**12,041,631**

-Schematic Diagram for Methanol Synthesis



-------However I did not finished Cost Benefit Analysis for Methanol Synthesis

I want finish as early as possible, but I need still to try to find research fund from Korean Government. And I am busy and loses lots of my time for that non-technical reasons. So, I am very sorry.