PRELIMINARY ESTIMATES OF MATERIALS YIELDS FROM DESALINATION BRINES AT *DOS PALMAS*, SONORA

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August 25 2016

We assume a fresh water production rate of 1,600,000 gallons per day, or 6,056.6589 cubic meters per day, which will round off to 6,000 cubic meters per day, or 6,000 metric tons per day. We assume that each volume of freshwater produced is matched by one volume of waste brine, twice as concentrated as seawater, or around 70 parts of salt per thousand by weight. This is a slight underestimate, because water in the Sea of Cortés is a somewhat saltier than average seawater.

We estimate the amounts of limestone, brucite, salt, hydrogen, oxygen, and chlorine that could be extracted from brine in steady-state operation.

LIMESTONE

The calcium concentration in seawater is 10 mM (milli Molar), 411 ppm (parts per million), and 20 mM in the brine. This assumes that there is no precipitation of limestone scale in the desalination process, some of which is unavoidable. However, any scale is then dissolved by backwashing the membranes with acid; and, after a time delay, the calcium goes into the brine. The brine yields a total of 4.9 tons of calcium per day. But no more than one fifth of this can be precipitated as limestone, because seawater contains only about 2 mM bicarbonate—of which only half is available for precipitation as limestone, the remainder being released as CO_2. So we are talking about one half ton per day of extractable calcium, or 1.25 tons per day of calcium carbonate limestone. To increase the amount of limestone precipitated electrochemically, it would be necessary, as in the *calera* process, to add industrial quantities of CO_2 from a fossil fuel power plant—but at tremendous cost in chemicals and electricity.

Experiments show that we produce about one kilogram of solid material per kilowatt hour of electricity used; therefore, the electricity needed to produce a half ton (of limestone) is about half a megawatt—costing $25 at a rate of $05/KWh. If the *Infiernillo* tidal power plant is able to produce electricity at $.02/KWh, as is expected, then input energy costs would be only 40% of those calculated. Costs for energy inputs at this rate will be shown in brackets, below. Please note that, in this paper, "$" indicates USD.

If the price of limestone is estimated at $40–$80 per ton, the yield will be $50–$100/day. Bulk limestone can be dug cheaply from any surface location; and local prices will vary with transportation costs. Limestone resulting from the

Biorock process cannot really be compared with bulk limestone rock or powder, since the former is produced in precise sizes and shapes that determine its useful value. In other words, even when it may not be worth the (cheaply available) energy required to produce it, Biorock's bulk limestone may in fact become much more valuable when produced as architecturally finished, prefabricated forms such as walls, roofs, or blocks. Here, we estimate the values of the raw materials produced; but their value as end products will be far greater. The local production of such materials will eliminate the transportation costs that greatly increase the price of the shipped product.

The Biorock material--about three times harder than concrete—costs around $50 of energy per ton to produce from brine. The production of wet-slurry (as opposed to dry-bagged) cement costs about $75 per ton; but the price is dependant upon the distance from the factory and limestone sources. While prices in Hermosillo seem to be around $90 per cubic meter ($60 per ton), greater transport distances to locations such as Kino will increase these numbers—which means that, locally, we are able to make limestone structures that are three times harder than concrete, and cheaper than their cement counterparts in many places

Brucite

Containing about 1,290 ppm of magnesium, Seawater will produce around 15.48 tons of magnesium, or 37.14 tons of Brucite, per day, provided all the magnesium can be extracted by electrolysis—which is highly likely. As brucite prices range from around $250–$500 per ton, the value/yield of brucite could be from $9,285–$18,570 per day. Since brucite production requires about .2915 T/MWh (tons per megawatt hour, or 127.41 MWh/day), the cost of the electricity to produce it (assuming $50/MWh, or 5 cents/KWh) will be on the order of $171.52/T, or $6,370.5/day. Brucite is a cement that absorbs atmospheric CO_2, will be converted to magnesium carbonate, and can be several times harder than limestone. Concrete production is a major source of CO_2 emissions. In the event of a carbon tax, not only would brucite be cheaper than concrete, but it should qualify for carbon credits. Since each molecule of brucite can absorb one molecule of carbon, one ton of brucite can absorb .206 tons of carbon or, .755 tons of CO_2. Carbon credits are uncertain at this time, but carbon trading prices from tens to hundreds of dollars per ton of carbon are commonly suggested; so carbon credits for this sink could be up to 7.65 per TC/day, with a value/yield from $70–$700 per day. If the cost of CO_2 emissions were included, the cost of concrete would be significantly higher than that of brucite cements.

SALT

The remaining minerals cannot be removed easily by electrolysis, and must be evaporated in salt flats. Six thousand tons of brine, containing 70 parts of salt per thousand, will yield a total of 420 tons of salt per day. Salt prices range from around \$40–\$150/T, depending on the degree of refinement. So the yield could vary between \$16,800 and \$63,000 per day.

The area needed to dehydrate 6,000 cubic meters per day can be estimated from the evaporation rates. I have plotted the monthly evaporation rates for Guaymas and Hermosillo (below), and will use an annual average evaporation rate of around 200 mm/month, or 2.4 meters per year. The complete dehydration of the salt in one year will therefore require an area of 2,500 square meters, or 100 meters by 25 meters. Assuming 3.23 hectares are available for evaporation ponds, the height of brine added daily would be 0.1858 meters over the area. At an evaporation rate of about .2 meters per day (see graph at bottom), the area is large enough for total brine evaporation. In practice, a series of smaller ponds of increasing concentration is used rather than a single large one.

HYDROGEN, OXYGEN, CHLORINE

For each atom of magnesium precipitated by electrolysis, one molecule of hydrogen and a half molecule of oxygen are produced. Therefore, we will produce about 1.274 tons of hydrogen and 5.096 tons of oxygen per day, with smaller amounts of chlorine that can be used to make bleach, whose amounts (according to the Nernst Equation) depend upon the precise electrical cell operating voltage. Oxygen costs about \$35–\$80/T, hydrogen around \$60/ton, and chlorine about \$60–\$150/T; so potential gas production yields are around \$76.44/day for hydrogen, \$178.36-407.68/day for oxygen, with chlorine uncertain—lower in amount, but higher in value when sold as bleach.

CONCLUSION AND RECOMMENDATIONS

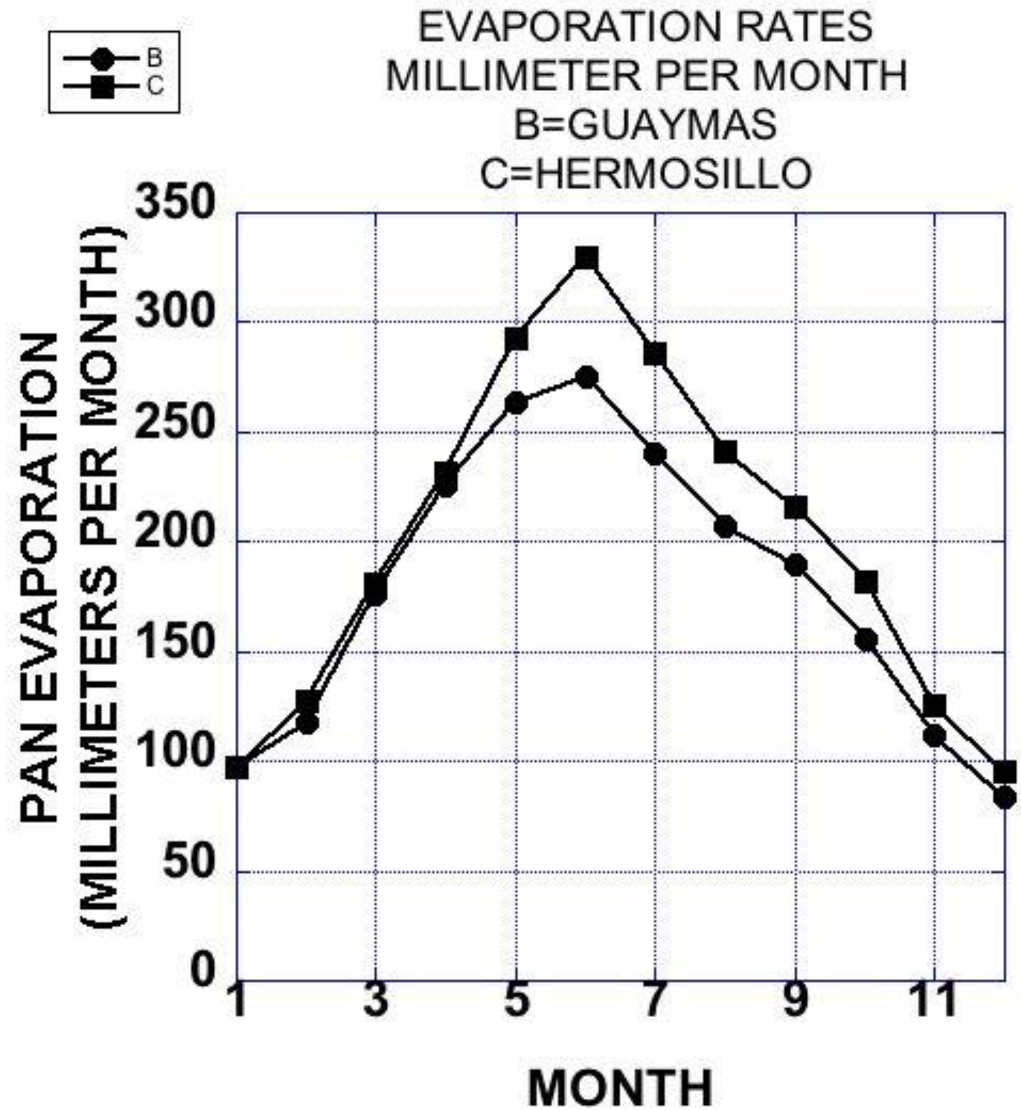
In terms of total value/yield, salt provides the best return, followed by brucite. The total economic benefit of the brine products is around \$100,000 per day, and will require around \$6,300 per day in electricity to produce—assuming a cost of 5 cents per kilowatt hour. The materials plant will require about 7.1 times more electricity than the desalination plant. The value of the products can be compared to the value of the water produced: at a California water price of .019 cents per gallon, 1.6 million gallons per day are worth \$30,400/day, which makes the water's value 10 times greater locally than in California. At California prices, the value of the goods may exceed 3 times the economic value of the water; but water is more valuable at Hermosillo prices.

Using the values/costs/yields assumed here, for a plant producing 6,000 cubic meters of water per day, the water would yield between \$30,000 to \$300,000 per day, and the minerals around $100,000. Daily energy costs are estimated at around $900 for desalination, and $6,390 for minerals production. The profits for water would be from $29,100 per day (California prices) to $299,100 (Hermosillo), and $93,610 for the minerals. Note, especially, that these calculations are only based on steady-state input and output values/yields and do not include capital investment (energy, water, minerals, etc.) in preexisting infrastructure.

One may generally conclude that the mineral product values/yields are economically significant and may exceed those of the water (depending on local water pricing policies); that they will greatly improve the cost/benefit analysis of the plant operation as an integrated whole, prevent salt pollution, and be far more profitable than a desalination plant that pumps its waste brine into the sea, throwing away the potential economic value. These considerations do not include the added economic benefit from the creation of new mineral processing jobs.

The actual amounts, the chemical quality, and the amount of energy used, for each material, need to be determined experimentally in order to obtain real world production, production efficiency, and economic values, in terms of both cost and energy. The *Dos Palmas* pilot materials extraction plant laboratory will precisely measure and record these data (including the chemical composition of the various solid, liquid and gaseous products, and the respective energy requirements) for the purpose of determining and optimizing their economic, energy, and environmental benefits.

The methods and conclusions of this analysis are entirely general, and can be adapted for much larger plants, in proportion to the amount of water produced and applicable local costs and prices.



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