

# Opportunities for Low-Cost CO<sub>2</sub> Mitigation in Electricity, Oil, and Cement Production

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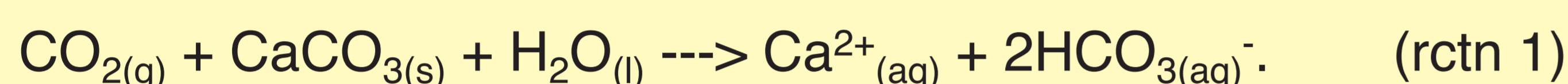
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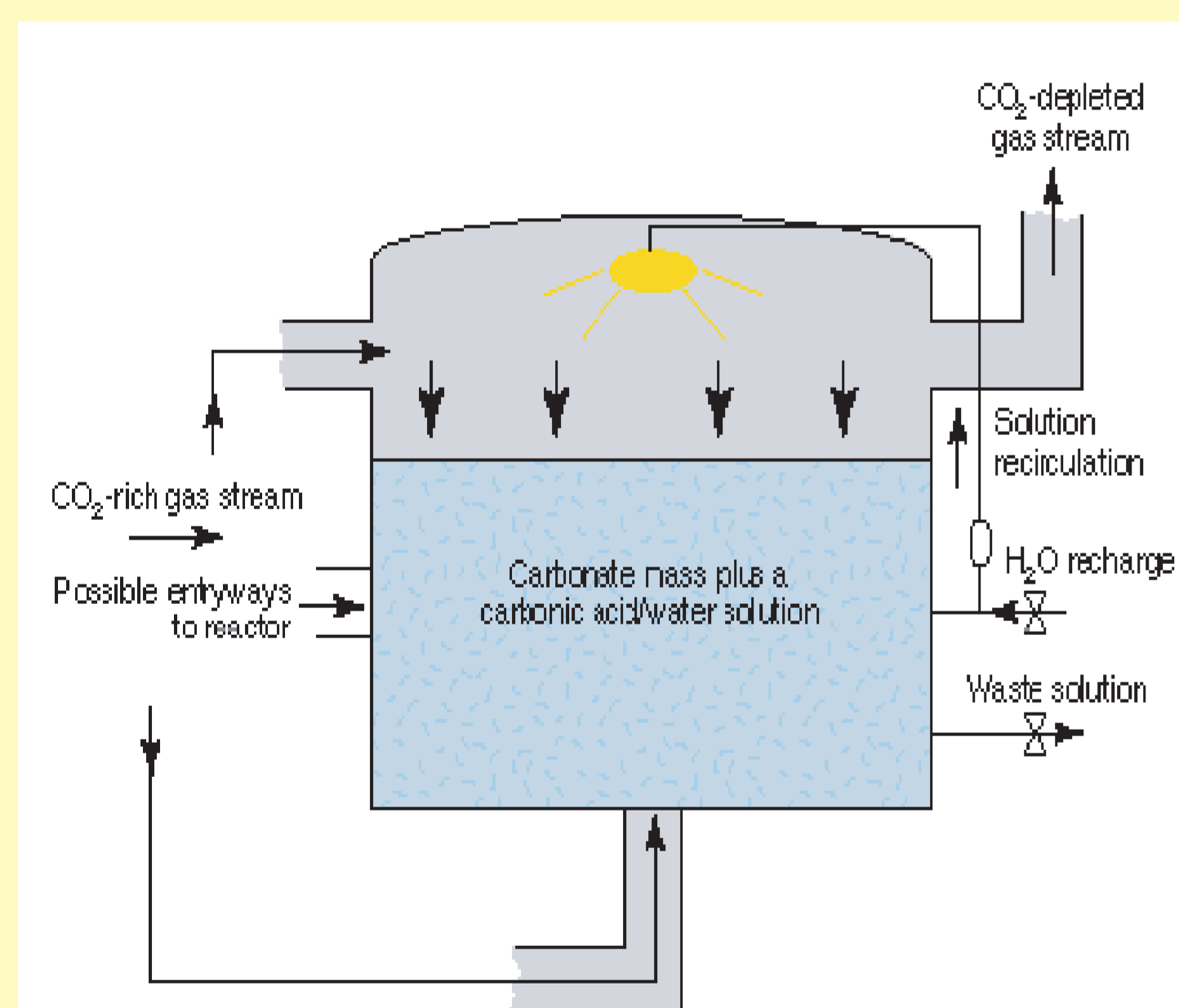
**SUMMARY:** Several low-cost opportunities exist for scrubbing CO<sub>2</sub> from waste gas streams, utilizing spontaneous chemical reactions in the presence of water and inexpensive or waste alkaline compounds. These reactions convert CO<sub>2</sub> to bicarbonate or carbonate in dissolved or solid form, thus providing CO<sub>2</sub> capture and low-risk CO<sub>2</sub> storage underground, in the ocean, or in some cases on land. Useful by-products and co-benefits can also be generated by these processes. In certain settings this approach will be significantly less energy intensive, less costly, and less risky than "conventional" molecular CO<sub>2</sub> capture and geologic storage.

## WET LIMESTONE SCRUBBING OF FLUE GAS:

CO<sub>2</sub> in flue gas can be reacted with water and solid mineral carbonates (e.g., limestone) to spontaneously form bicarbonates in solution:



Possible designs of the required gas-liquid-solids reactor have been previously described (e.g., Rau and Caldeira, US Patent 6,890,497), the approach being analogous to flue gas desulfurization (FGD) using wet limestone. While any water source could be used, seawater would be especially attractive due to its inherent alkalinity and global abundance. Coastal power plants, which already pump vast quantities of seawater for cooling, could simply recycle the water for CO<sub>2</sub> scrubbing prior to water release back in to the ocean.



Possible schematic for gas/water/limestone contactor for CO<sub>2</sub> capture and conversion to HCO<sub>3</sub><sup>-</sup>.



A coastal NG-fired power plant Moss Landing, CA - candidate for wet limestone scrubbing.

### The advantages of this approach are:

- Limestone and seawater are global very abundant; there is a very large CO<sub>2</sub> sequestration capacity using this method.
- CO<sub>2</sub> is spontaneously converted to dissolved bicarbonate, avoiding costly and risky capture, purification, transport and storage of molecular CO<sub>2</sub>.
- Existing power plants can be retrofitted with this technology
- The simplicity of the approach makes is highly applicable to developing countries, as is seawater FGD.
- The carbonate alkalinity added to the ocean by this method will help to offset the present loss of seawater carbonate and biological calcification that is occurring via air-->sea invasion of anthropogenic CO<sub>2</sub>

Further work is needed to better evaluate the cost/benefit and potential market of this CO<sub>2</sub> mitigation approach and those discussed on right.

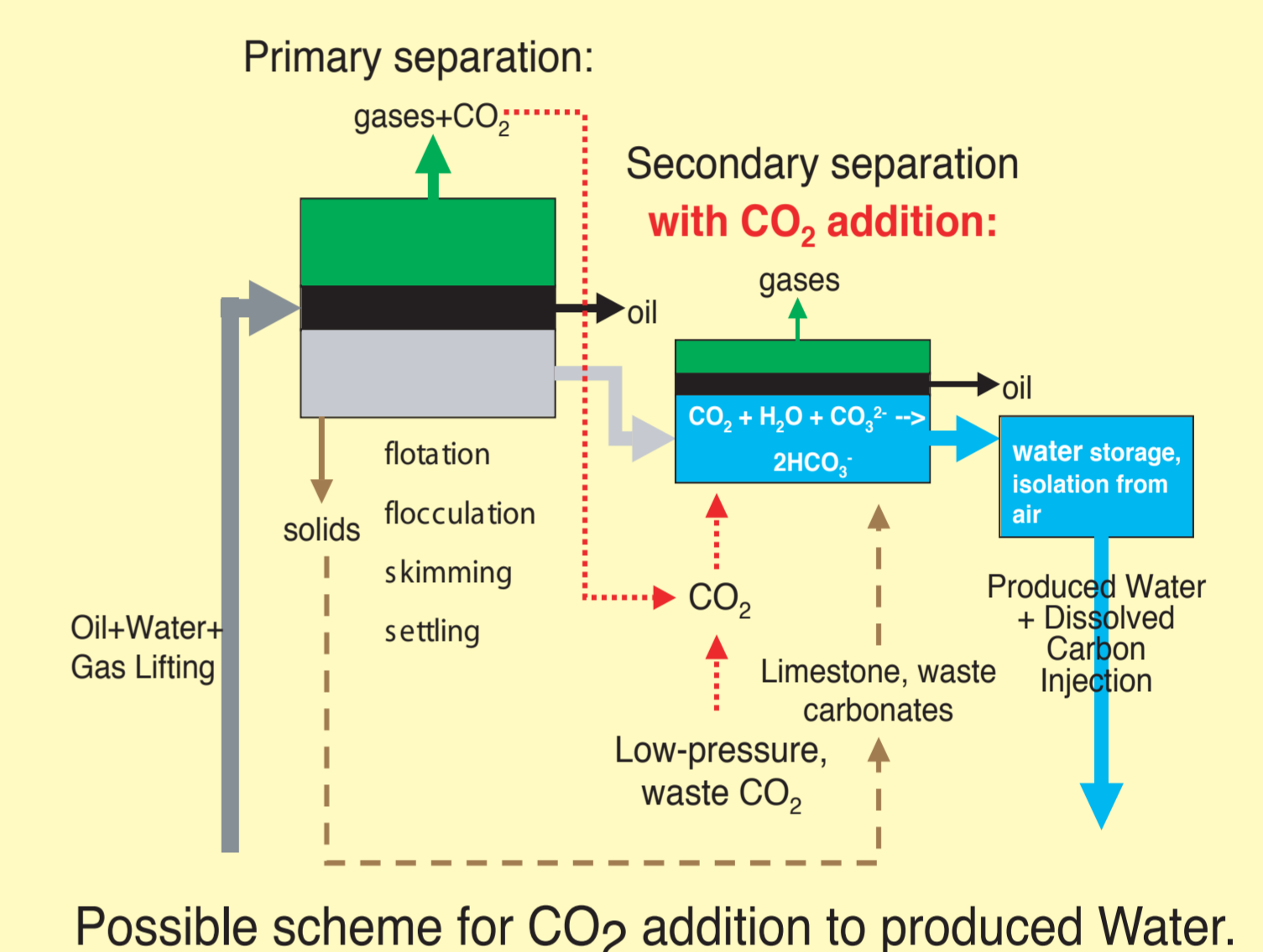
## CO<sub>2</sub> MITIGATION USING PRODUCED WATER:

On average 10 barrels of water are brought to the surface with each barrel of oil produced, and the majority of this water is simply pumped back into the reservoir. Preliminary analysis suggests that most of these waters are significantly undersaturated in CO<sub>2</sub> relative to industrial waste gas streams, and also contain significant alkalinity, meaning they have an enhanced capacity to chemically absorb and transorm CO<sub>2</sub> (e.g. reaction 1).

The average dissolved inorganic carbon content of Texas produced water can be increased by some 170% through simple equilibration with a 15% CO<sub>2</sub> waste gas stream (Table below). Further uptake of waste CO<sub>2</sub> is possible via reaction 1 if additional carbonate (e.g., waste precipitate or limestone, Fig. below) were added. The water is thus significantly carbon-enriched prior to its routine re-injection underground. The overall approach allows simple, low-cost CO<sub>2</sub> capture combined with safe geologic storage of waste carbon in mostly dissolved, ionic forms.

|  | pH    | T, deg. C | pCO <sub>2</sub> , atm | Total Dissolved Inorganic Carbon, mM | waste CO <sub>2</sub> consumed, mM |
|--|-------|-----------|------------------------|--------------------------------------|------------------------------------|
| mean of 500 W. Texas produced waters (USGS data):                      | 6.93  | 25**      | 0.0193*                | 6.6                                  | 0                                  |
| as above and equilibrated with waste gas @ pCO <sub>2</sub> = 0.15 atm | 6.41* | 25**      | 0.150**                | 17.8*                                | 11.2*                              |
| as above and equilibrated with excess limestone                        | 6.64* | 25**      | 0.150**                | 22.8*                                | 13.7*                              |

\*calculated  
\*\*assumed or specified



Possible scheme for CO<sub>2</sub> addition to produced Water.

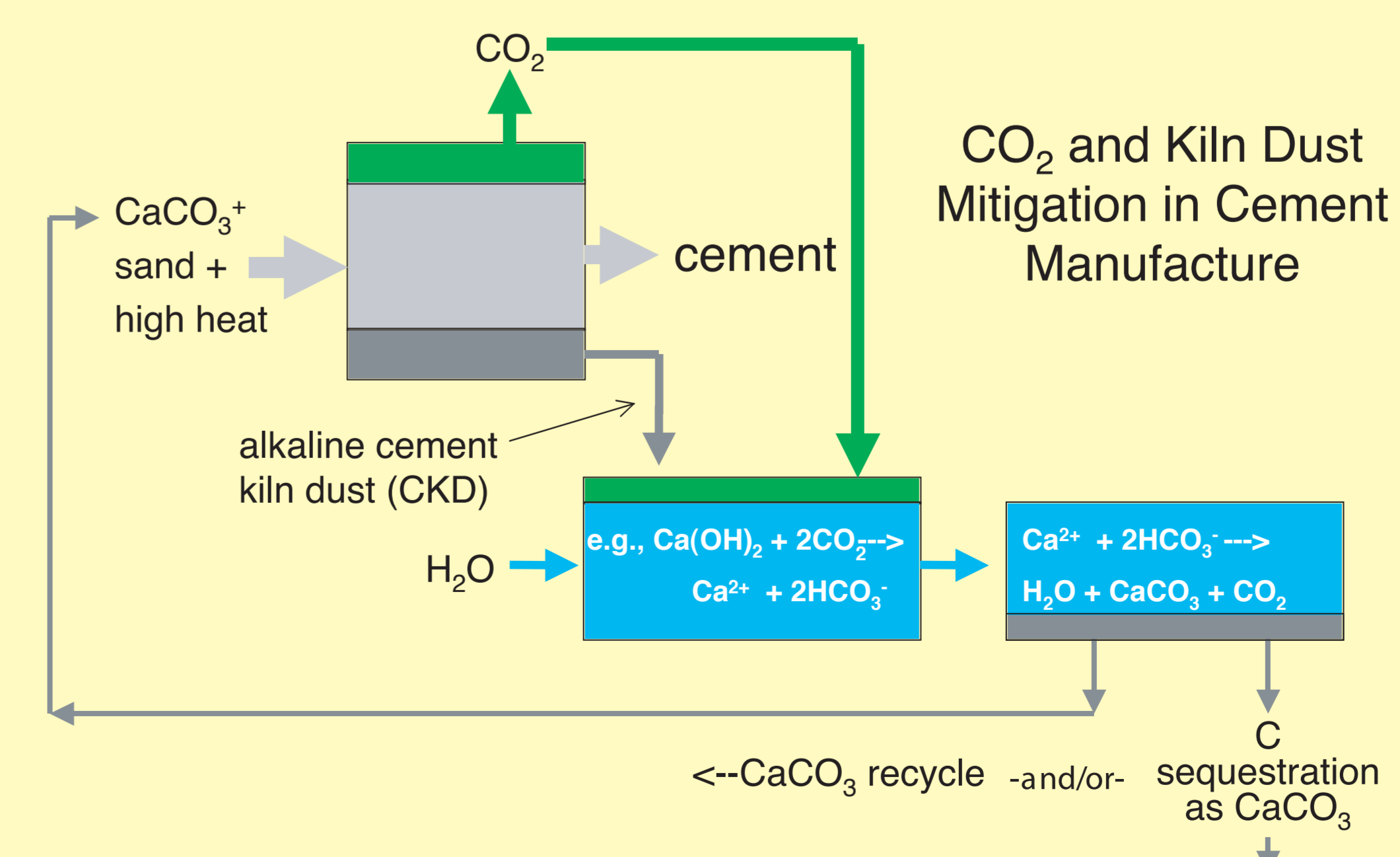
### The advantages of this approach are:

- Low-tech chemical CO<sub>2</sub> capture with geologic sequestration.
- Low energy consumption - piggybacks on existing groundwater injection.
- Low cost - probably <\$1/tonne CO<sub>2</sub> avoided.
- May enhance oil-water separation, and eliminate scaling and microbial growth.

## MITIGATING CO<sub>2</sub> AND CEMENT KILN DUST:

The manufacture of cement globally generates some 1.5 Gt CO<sub>2</sub>/year. The waste gas stream can contain >30% CO<sub>2</sub>. In addition, waste solids (cement kiln dust, CKD) are generated, composed of a complex, highly alkaline mixture of Ca, Na, Mg, and K salts, silicates, oxides, and hydroxides. This poses a significant kiln dust management and storage problem.

We suggest mitigating both the CO<sub>2</sub> and CKD by dissolving in water the soluble components of the CKD, in particular the metal oxides (e.g., CaO), forming hydroxides such as Ca(OH)<sub>2</sub>. Equilibration of this with CO<sub>2</sub> waste would form dissolved metal carbonates and bicarbonates and would significantly lower solution pH, e.g.: 2CO<sub>2</sub> + Ca(OH)<sub>2</sub> ---> Ca<sup>2+</sup> + 2HCO<sub>3</sub><sup>-</sup>. Subsequent exposure to air would precipitate the captured carbon as CaCO<sub>3</sub>, which could be recycled for cement production, or stored as a CO<sub>2</sub> sequestrant. E.g.:



### The advantages of this approach are:

- Simple re-routing and wetting of CO<sub>2</sub> and CKD waste streams results in mitigation of both streams
- Low-tech, low-energy, and low-cost approach that that has co-benefits, and is widely applicable to the cement industry.