Carbon-Negative Soda Ash (CODA)

1. Statuskonferenz KlimPro Industrie

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Soda Ash - Na_2CO_3 Anhydrate

Soda ash (Na_2CO_3) facts

Globaly **56 million metric tons/a** produced (Top10 of inorganic commodity chemicals):

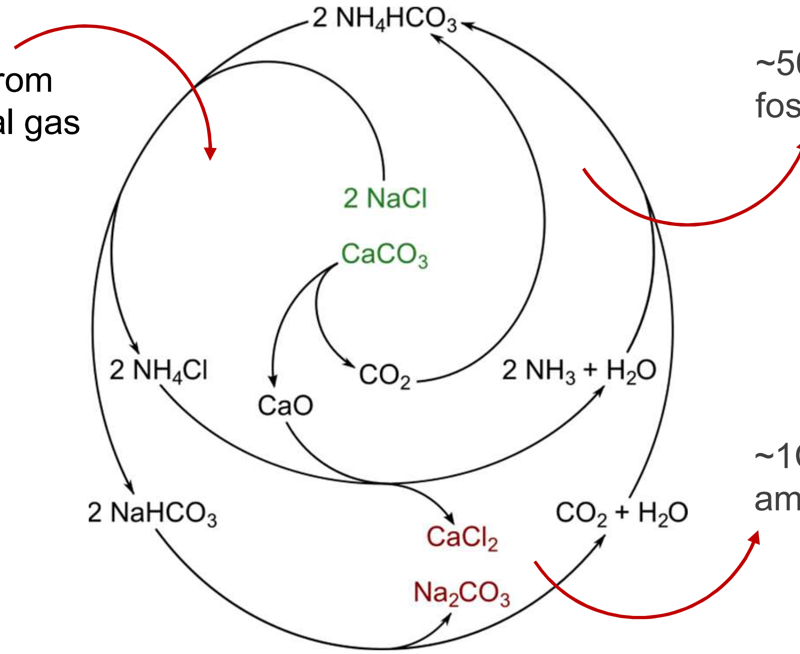
- **48 %** by Ammonia-Soda (Solvay) process (250-300€/t)
- **27 %** from natural sodium carbonate minerals
- **25 %** other methods

Applications

Ammonia-Soda Process

- 1864 by Ernest Solvay, one of first highly integrated process but based on fossil carbon/ energy sources

Fossil energy from coal and natural gas

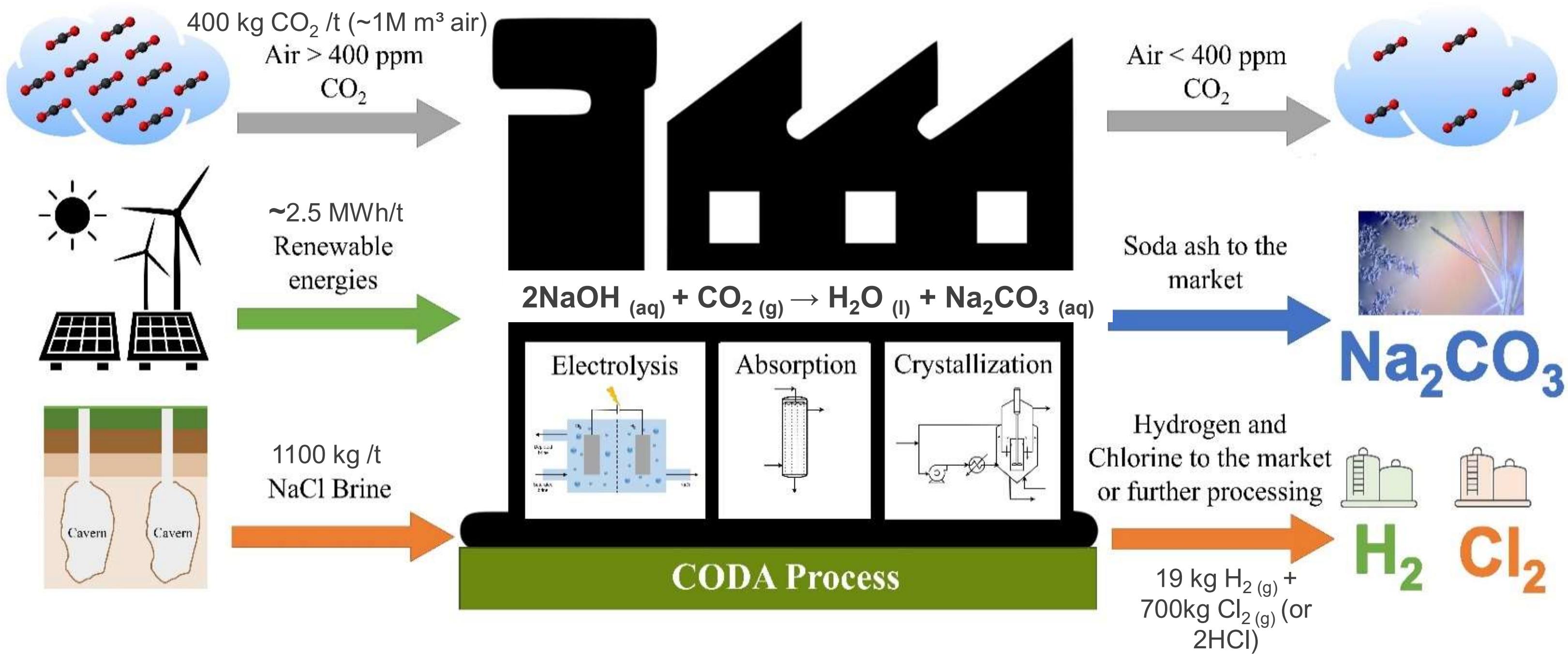


~500kg/t soda ash fossil CO_2 emissons

~1$CaCl_2$ /t soda + ammonia emission

Czaplicka N, Konopacka-Łyskawa D. SN Applied Sciences. 2019 May;1(5):1-8
https://en.wikipedia.org/wiki/Solvay_process#/media/File:Solvay_process_reaction_scheme.svg

CODA Concept



Major Challenges

Economic:

- Max. productivity (kg/m³/h)
- Min. energy consumption (kWh/kg)

→ Min. CAPEX + OPEX

Technical:

- Air T and RH changes (day/night, summer/winter)
- Renewable energy fluctuations

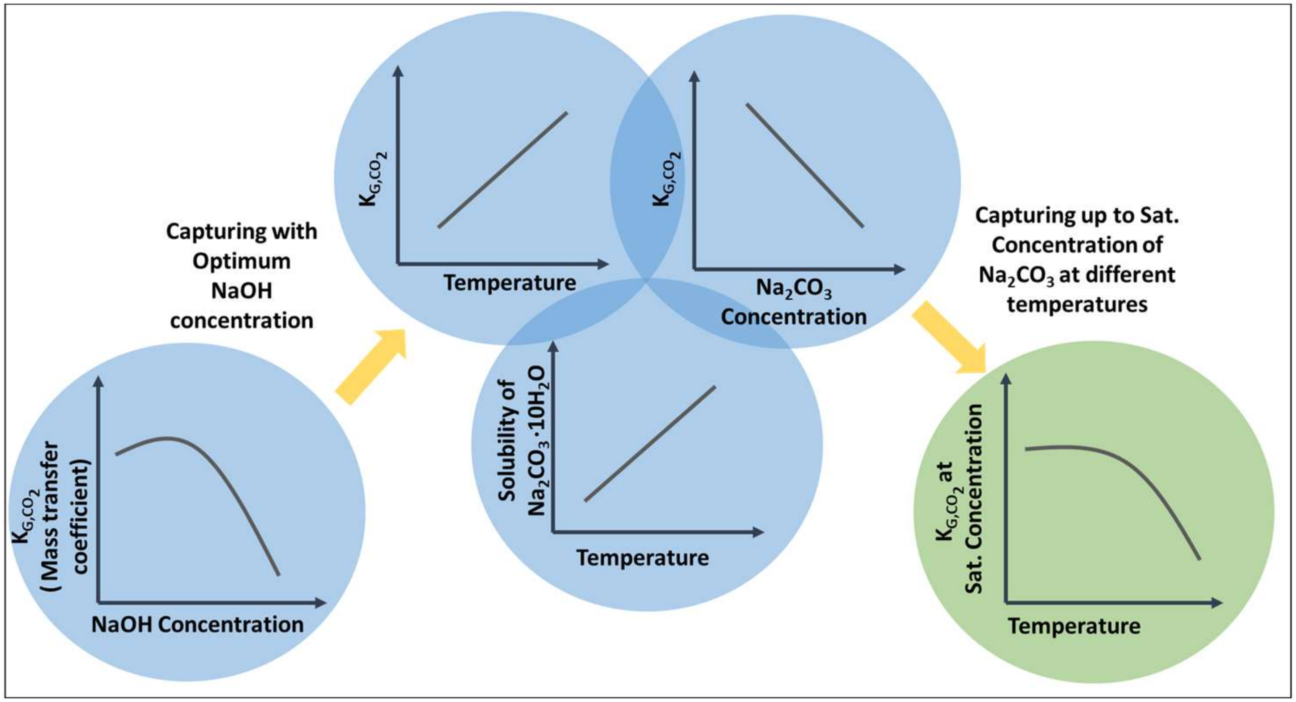
→weather dependence

- CO_2 Direct Air Capture (DAC) towards Climate Change mitigation* (Climate Positive)
- Based on green energy (high electrification level)
- Carbon Negative (500CDA+400CCU kg CO_2/t soda ash)
- Additional valuable products Hydrogen and Chlorine (or HCl by bipolar electrodialysis)
- No (much less) Chloride and ammonia effluents, no land fills

According to the IPCC (Intergovernmental Panel on Climate Change), CO2 emissions must be reduced by about 30-80% by 2050

Fundamentals of CO_2 Absorption

- ✓ Experimental investigation of CO2 absorption in carbonated sodium hydroxide solutions
- ✓ Dynamic model of the absorption process based on lit. and exp. Data
  - ➢ Predict mass transfer coefficient at different conditions (T, C) for absorber design



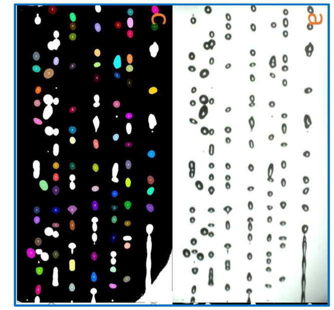
Somayyeh Ghaffari, Maria F. Gutierrez, Andreas Seidel-Morgenstern, Heike Lorenz, and Peter Schulze. Sodium Hydroxide-Based CO2 Direct Air Capture for Soda Ash Production–Fundamentals for Process Engineering. Industrial & Engineering Chemistry Research, 2023. DOI: 10.1021/acs.iecr.3c00357

CO_2 DAC Process Development

Specific DAC challenges:

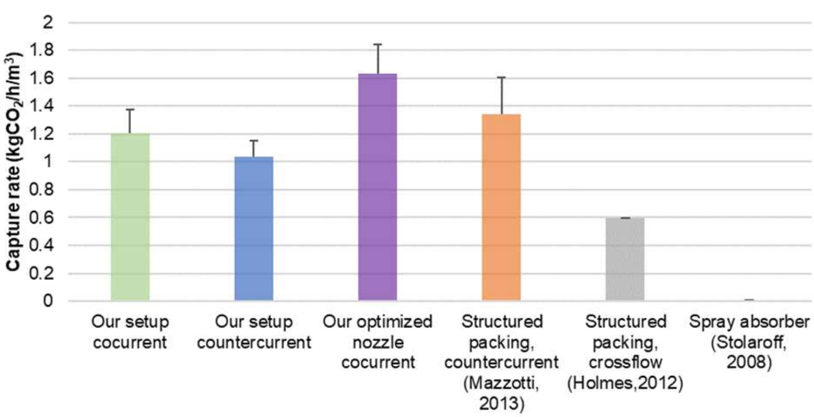
- Operation up to saturation concentrations of **CO_3^{2-} →** crystallization of **$Na_2CO_3 \cdot 10H_2O$ possible (e.g. air T and RH changes)**

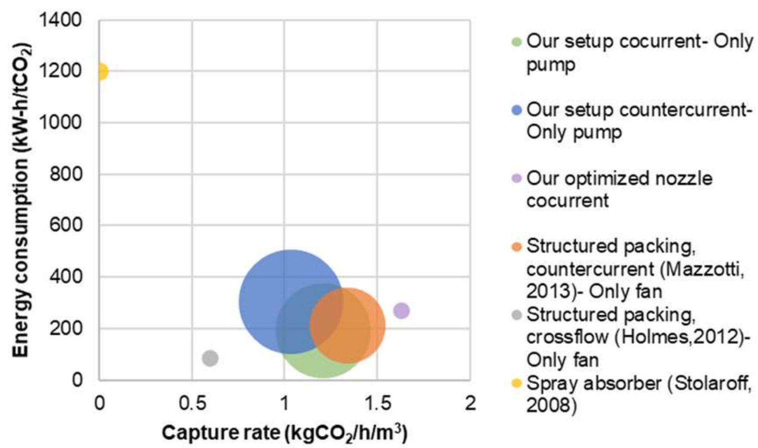
→ no packed absorption column



MonoDisperse Droplet Absorber MDDA:

- Simple design: Nozzle head and pipe, no packing
- Low pressure drops (liquid and gas)

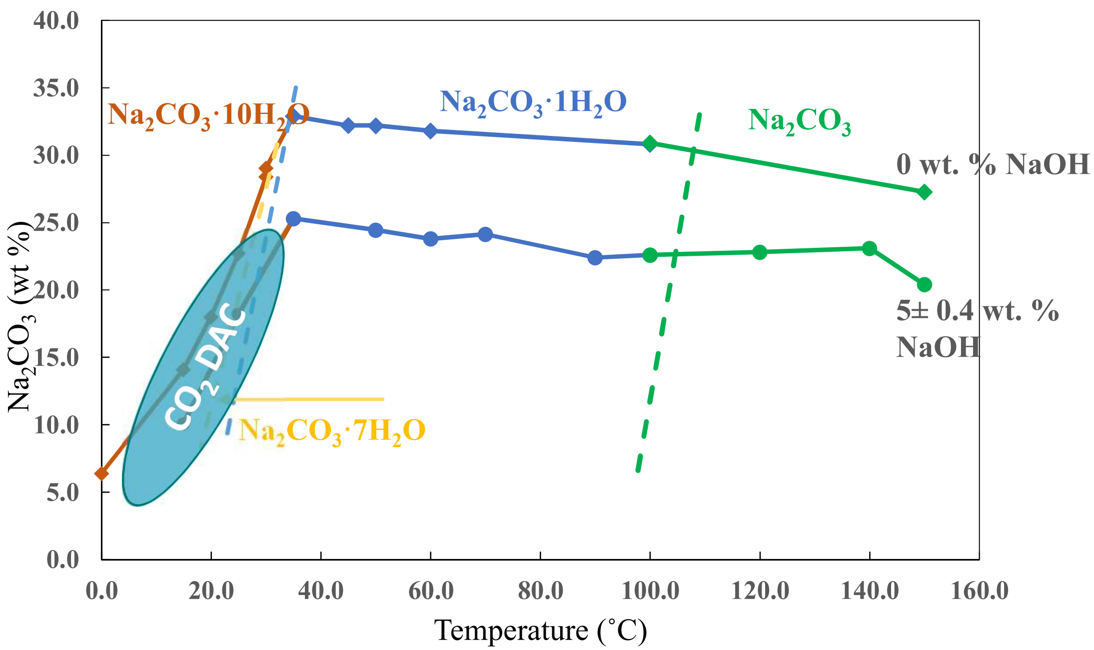




Crystallization Process Development

Specific crystallization challenges

- Changing feeds from DAC
- Quality (size, bulk density and purity)
- Energy demand (water evaporation)



Decahydrate crystalls from cooling cryst.

Two general process routes:

a) Crystallization of Decahydrate in DAC → slower DAC, less energy consumption

b) No crystallization of Decahydrate in DAC → faster DAC, more energy

Process design

→Solubility and metastable zone widths data of NaOH/Na_2CO_3/H_2O (literature+own exp.)

→Crystallization kinetics (each hydrate) (own exp.)

Engineering of Pilot Plant

Ongoing and upcoming:

- Engineering for TRL5 pilot plant at CIECH industrial site (10 t/d)
- Minimize investment and operational costs for (stay in budget)
- Find proper plant manufacturer

Summary and Outlook

Challenges

- Solvay process to be replaced by an environmental friendly and sustainable process
- CO_2 DAC is necessary to reach climate goals
- CODA economy heavily depends on energy price → green power plant at site
- Strong dependence of DAC on weather conditions (T and RH)

Solutions

- Special MDDA absorber for DAC (tolerates crystallization)
- Options for robust crystallization process design with optimal heat integration and target product quality
- Process design and optimization by combination of modelling and experiments

Outlook

- Finish crystallization process development
- Overall integrated process optimization (min. CAPEX and OPEX)
- Industrial pilot plant (10t/d) engineering, construction and testing until 2025 (lead my CIECH)

Acknowledgements

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Thank you

Crystals of soda ash on a sodium hydroxide droplet in contact with air