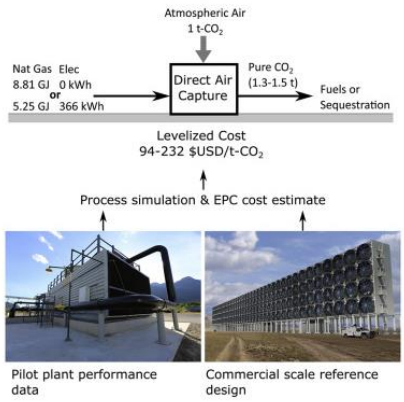
Mass CO_2 collection for refined multipurpose carbon chemicals leveraging Air to Fuels technologies

This project is predicated on firstly, direct air capture technology to produce massive amounts of multipurpose and multifunctional carbon chemicals. Carbon chemicals can used to produce hydrocarbon fuels, Solar fuels which may be produced at high-insolation low-cost locations from direct air captured CO_2 and electrolytic hydrogen using gas-to-liquids technology enabling decarbonization of difficult-to-electrify sectors such as aviation. And secondly, direct air captured CO_2 sequestration allows carbon removal from our global atmosphere.

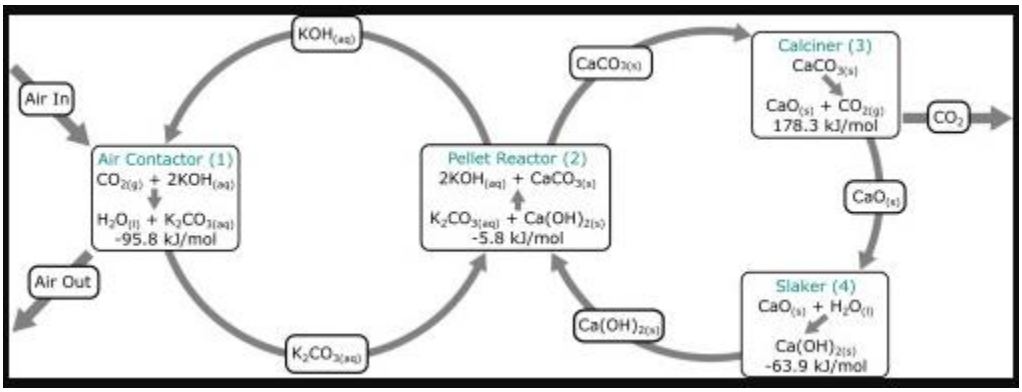
The direct production of liquid fuels from CO_2 hydrogenation has attracted enormous interest for its significant roles in mitigating CO_2 emissions and reducing dependence on petrochemicals. Here we report a highly efficient, stable, and multifunctional Na–Fe_3O_4/HZSM-5 catalyst, which can directly convert CO_2 to gasoline-range (C_5–C_{11}) hydrocarbons with selectivity up to 78% of all hydrocarbons while only 4% methane at a CO_2 conversion of 22% under industrial relevant conditions. It is achieved by a multifunctional catalyst providing three types of active sites (Fe_3O_4, Fe_5C_2 and acid sites), which cooperatively catalyse a tandem reaction. More significantly, the appropriate proximity of three types of active sites plays a crucial role in the successive and synergetic catalytic conversion of CO_2 to gasoline. The multifunctional catalyst, exhibiting a remarkable stability for 1,000 h on stream, has the potential to be a promising industrial catalyst for CO_2 utilization to liquid fuels.

Graphical Abstract



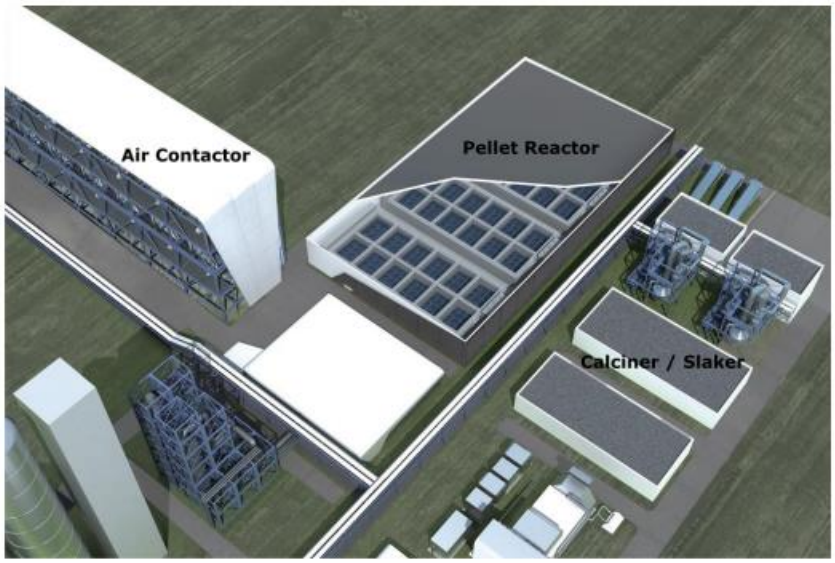
The design captures ~1 Mt-CO_2/year in a continuous process using an aqueous KOH sorbent coupled to a calcium caustic recovery loop. The design rationale, summarize performance of the major unit operations, and provide a capital cost breakdown developed with an independent consulting engineering firm. The report results from a pilot plant that provides data on performance of the major unit operations. To summarize, the energy and material balance computed using an Aspen process simulation, the levelized cost per ton CO_2 captured from the atmosphere rangers from $94 to $232/t-$CO_2$.

The process comprises two connected chemical loops (Figure 1). The first loop captures CO_2 from the atmosphere using an aqueous solution with ionic concentrations of roughly 1.0 M OH^-, 0.5 M CO_3^{2-}, and 2.0 M K^+. In the second loop, CO_3^{2-} is precipitated by reaction with Ca^{2+} to form $CaCO_3$ while the Ca^{2+} is replenished by dissolution of $Ca(OH)_2$. The $CaCO_3$ is calcined to liberate CO_2 producing CaO, which is hydrated or "slaked" to produce $Ca(OH)_2$.



Ref. Figure 1 above

CE has developed a process to implement this cycle at industrial scale. Figure 2 provides a simplified energy and material balance of the complete process (and Figure s1 shows a rendering of one possible configuration of plant equipment to perform this process). At full capacity, this plant captures 0.98 Mt-CO_2/year from the atmosphere and delivers a 1.46 Mt-CO_2/year stream of dry CO_2 at 15 MPa. The additional 0.48 Mt-CO_2/year is produced by on-site combustion of natural gas to meet all plant thermal and electrical requirements. Alternate configurations with electricity and gas input are described in the section on Heat and Mass Balance and Alternative Configurations and life cycle carbon balance in the section on Avoided Emissions and Life Cycle Accounting.



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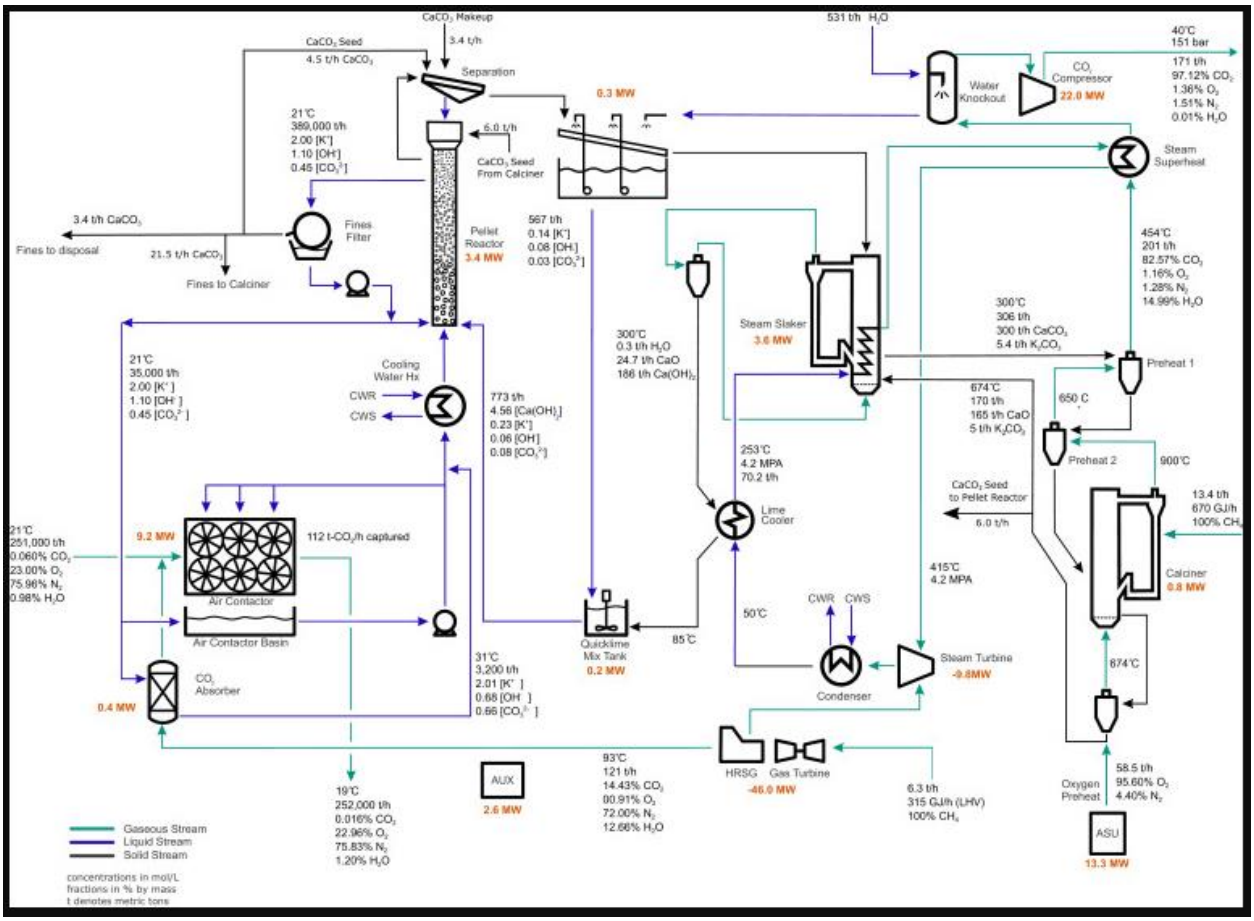

Ref. Figure 2 above

The energy and material balances come from an Aspen Plus simulation. That simulation depends on performance models of individual unit operations; and these models depend, in turn, on a combination of vendor data and data from the pilot plant described later. The mass expansion of the project is also dependent on commercial cooling-tower technology, while the geometry and fluid chemistry differ from conventional cooling towers. Most of the Air to fuel technology relies on many of the same components, including fans, structured packings, demisters, fluid distribution systems, and fiber-reinforced plastic structural components. It is the unit that diverges farthest from industrial precedent in that crossflow cooling-tower components are used for a chemical gas-exchange process, rather than the counterflow vertically oriented tower philosophy typically used for chemical processes. This design choice is a crucial enabler of cost-effective DAC, as designs using vertical packed towers are far more expensive. In these papers, it is possible to have an efficient air to fuel and air to multipurpose carbon and I wanted to include the cost efficiency in comparison to an air-liquid contactor for large scale capture of CO2 from air, which have been marketed elsewhere.

For each major unit, described on the tables below sourced from Joule, provided are some important process parameters internal to the unit, as well as the most important unit performance parameters. Energy consumption values are given for each ton of CO_2 processed by the unit where for calciner, slaker and compressor, the amount processed is larger than the amount captured from air because of the CO_2 from the power cycle.

Parameter	Value	Justification
Contactor		
Process parameters		
Mass transport coefficient	1.3 mm/s	pilot data and laboratory work[28]
Air velocity	1.4 m/s	economic optimization of capital and operating costs[23]
Packing specific surface	210 m^2/m^{-3}	packing parameters are based on Brentwood XF12560 with pressure drop reduced by 30% (see section on the Contactor)
Packing pressure drop	9.7 Pa/m at 1.4 m/s	
Packing air travel depth	7 m	economic optimization of capital and operating costs[23]
Max liquid flow	4.1 L/m^2s	required for full wetting—manufacturer's specification
Average liquid flow	0.6 L/m^2s	pilot data on flow rate cycling
Performance metrics		
Fan energy	61 kWh/t-CO_2	ΔP from pilot data and 70% fan efficiency from SPX
Fluid pumping energy	21 kWh/t-CO_2	pump efficiency 82% from GPSA data book
Fraction of CO_2 captured	74.5%	performance model validated by pilot data
Capture rate unit inlet area	22 t-CO_2 m^{-2}/year	determined from velocity and fraction captured assuming 400 ppm CO_2

Pellet Reactor		
Process parameters		
Fluidization velocity	1.65 cm/s	pilot and benchtop show good performance at 1.65 cm/s for our target pellet size, performance degrades for significantly lower velocities
Bed height	4.5 m	rough optimization of cost of managing fines versus cost of increasing retention; optimization uses empirical performance model driven by pilot data
Calcium loading	20 kg-Ca/m^2hr	
Pellet size	>0.85 mm	pellets removed from bed by passing over a 20 mesh (0.85 mm opening) shaking screen
Performance metrics		
Calcium retention	90%	performance model driven by pilot data
Fluid pumping energy	27 kWh/t-CO_2	determined from loading rate, fluidization velocity, and pumping efficiency of 82% based on GPSA data

Calciner		
Process parameters		
Bed bulk density	710 kg/m^3	pilot data
Fluidization velocity	0.25–2.5 m/s	minimum and operating fluidization velocity from pilot data
Operating temperature	900°C	reaction thermodynamics and pilot data
Performance metrics		
$CaCO_3$ → CaO conversion efficiency	98%	pilot data
Energy consumption	4.05 GJ/t-CO_2	determined by Aspen Plus simulation in consultation with Technip

Slaker		
Process parameters		
Pellet water carryover	11% by mass	pilot data
Operating temperature	300°C	estimate based on preliminary tests
Performance metrics		
Power produced from slaking heat	77 kWh/t-CO_2	estimate from simulation, note that the slaker also consumes 32 kWh/t-CO_2
Conversion to CaO	85%	estimate based on tests conducted by Ben Anthony at CanmetENERGY

Auxiliary Equipment Specifications		
ASU power usage	238 kWh/t-O_2	quote from major ASU vendor for 95% purity delivered at 120 kPa
CO_2 absorber—capture frac	90%	Aspen simulation
CO_2 absorber—pressure drop	1 kPa	
Compressor power usage	132 kWh/t-CO_2	Aspen simulation, with validation from independent calculations