ZS2 Technologies Ltd.

Carbon Dioxide Removal Purchase Application
Fall 2022

General Application - Prepurchase

(The General Application applies to everyone; all applicants should complete this)

Company or organization name

ZS2 Technologies Ltd. (ZS2)

Company or organization location (we welcome applicants from anywhere in the world)

Calgary, Canada

Name(s) of primary point(s) of contact for this application

Doug Brown ([redacted]), Danny Wong [redacted]), Robert King [redacted])

Brief company or organization description

ZS2 has created a waste to cement process that produces green building materials through DAC and storage as mineralized CO_2.

1. Project Overview[1]

a. Describe how the proposed technology removes CO_2 from the atmosphere, including as many details as possible. Discuss location(s) and scale. Please include figures and system schematics. Tell us why your system is best-in-class, and how you're differentiated from any other organization working on a similar technology.

ZS2's technology has created a novel process for waste to cement production with a low cost micro modular direct-air-capture (DAC or µ-CC) system that provides a high strength carbon negative cement. This process incorporates waste brine and mine tailings into a breakthrough CO_2 storage technology that shows significant cementing properties based on magnesium.

[1] We use "project" throughout this template, but note that term is not intended to denote a single facility. The "project" being proposed to Frontier could include multiple facilities/locations or potentially all the CDR activities of your company.

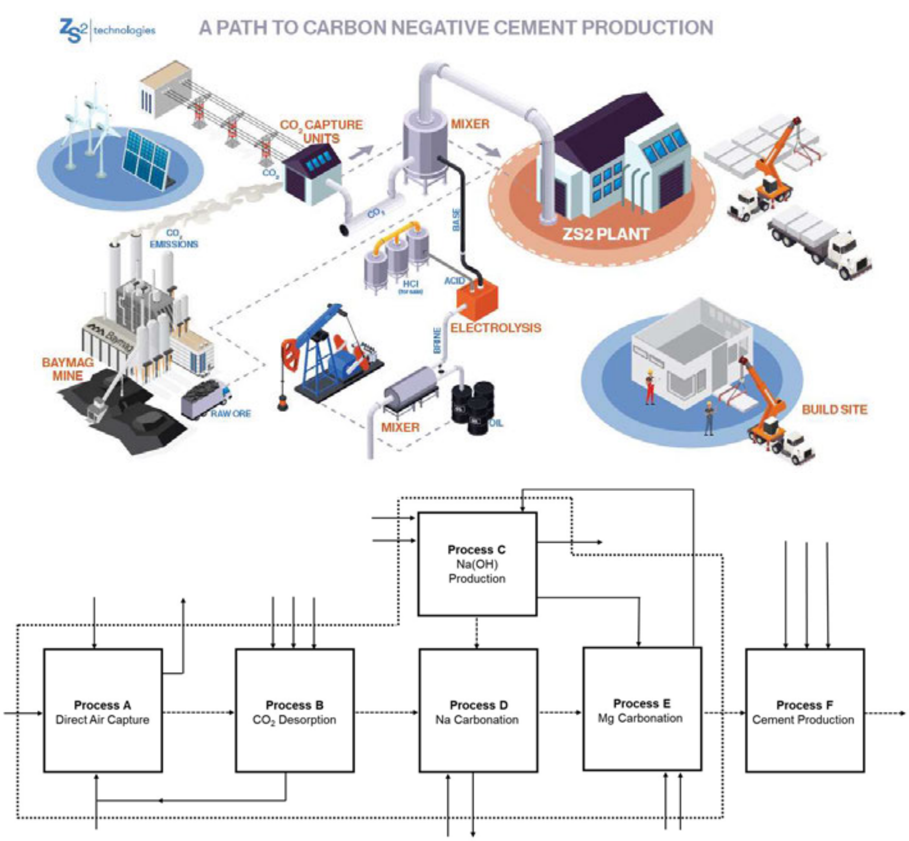


Figure 1: Schematic of waste to mineralization cement process.

The schematic above illustrates ZS2's technology which is described in Processes A through F. ZS2's solution provides a capture to storage solution that is cost competitive at the 3500 tCO_2/yr scale. Its low energy process works by filtering air through a dual chamber process that removes water and carbon dioxide separately that are then independently regenerated via a temperature/pressure swing system. The target output gas is a low-grade (9-25% CO_2) uncompressed CO_2/Air mixture that is fed into a second process for permanent storage via mineralization of waste brines produced from either Oil and Gas, desalination, potash or other rich waters of calcium and magnesium. In some cases, the brine waters are carbonated directly and this results in a process that operates at 3.35 GJ/tCO_2 captured and stored. This would be a greater than 50% decrease in energy costs on technologies currently being deployed (Climeworks, Carbon Engineerings, etc. see below) at a significantly smaller level of capital equipment deployment (~$5M system). Where brines are acidic ZS2 has a electrolysis treatment process for an addition 3.49 GJ/tCO_2 to provide a system that can mineralize CO_2. Currently, the mineralized products are used in the production of magnesium based cements (MBC) and can tolerate impurities such as NaCl, which is a substantial advantage compared to conventional Portland cement. MBC saves substantial cost and energy by minimizing the need for mined products, purification and fresh water. The MBC impurities can be expelled during the cementing process on the surface of the precast concrete and removed by water submersion or sanding.

Over the last year, ZS2 has demonstrated a process at the 360 kg/yr scale of DAC that produced over 2000kg of mineralized waste that was turned into cement (7-17% CO_2 content). Current companies, such as CarbonCure, sequestering CO_2 into Portland cement

(Ca-based) observe that CO_2 content above 0.2 wt.% result in reduced mechanical performance of cement. The cement strength over 28 days compared to the industry baseline of 20 MPa for a Type I cement exceeds 30 MPa. The CO_2 stored in the cement is in the form of $MgCO_3$ and this displaces an equivalent amount of MgO that would otherwise have been required. This provides a dual benefit of removing a portion of the carbon intense MgO that is conventionally manufactured and replacing it with a CO_2 gas that needs to be stored for disposal. The proposed technology produces MBC building materials that represent the majority of the building envelope for ZS2's projects.

Present studies are investigating molecular engineered activated carbons and silicas to overcome challenges with efficiency losses in humid air and removing the need for a desiccant for great geographic deployability outside of Nordic Canada. The CO_2 is desorbed through heat and pressure swings assisted by the addition of air. A rotating packed bed is used to greatly enhance CO2 reaction rates by providing large surface areas to rapidly produce mineralized carbonates from brines. This process is similar to ocean capture. However, our process is able to avoid the need for reverse osmosis in systems used by companies such as Heimdal. Instead, we use higher metal cation concentration waste brines from geothermal, oil and gas and salt cavern wells in Alberta, Canada. The substantial brine requirements have led ZS2 to locate the preliminary pilot plant north of Edmonton, Canada. The waste brines have gone through industrial processes, and serve as the primary Mg^{2+}, Ca^{2+}, Na^{+} and water sources. The ability to use waste as the main feedstocks to our mineralization and cement process is a significant competitive advantage as it lowers cost while being more environmentally friendly.

ZS2 is prototyping a novel electrolysis unit that has the potential to reduce the energy consumption of the production of base over the conventional chlor-alkali process by >66%. It is estimated that the production of sodium hydroxide consumes 3.3 – 5 kWh electricity per kg of NaOH.[i] A novel process based on the closed loop electrolysis and production of hydrogen for a comparable process have suggested 0.928 kWh per kg $Mg(OH)_2$.[ii]

The carbonation of waste brine water creates $CaCO_3$ and $MgCO_3$ that is directly isolated as "cakes" through a filter press. The cakes are incorporated into a cement mix with additional aggregates from waste and recycled products. The resulting cement is pressed into cement with between 8 and 17 wt.% CO_2. The improvement in compressive strength can be seen in Figure 2. The end result is an X-Prize verified net-negative carbon intensity cement and/or precast cement building product with an average of 12 wt.% CO_2 sequestered. The primary storage or sequestration of most commercial carbon capture companies is through compression, purification and transportation to pumped underground cavities or for enhanced oil recovery. Our proposed process avoids the need for compression, purification and transportation of CO_2 by providing a capture to utilization solution at a much lower cost.

b. What is the current technology readiness level (TRL)? Please include performance and stability data that you've already generated (including at what scale) to substantiate the status of your tech.

To date ZS2 has demonstrated its µ-CC process and waste feed stream input to a level of TRL 3/4. The current operational DAC unit uses a proprietary mixture of drying agent and solid sorbent CO_2 selective material that was demonstrated outside at a 1 kg per day CO_2 captured scale under ambient humidity and temperature from September 2021 to March 2022. The captured CO_2 is sequestered into $MgCO_3$/$CaCO_3$ by mineralization of high Mg/Ca content brines. This is precast into MBC tiles and cylinders for composition analysis and compressive strength testing. The µ-CC has had verified input gas streams that have been successfully stripped of CO_2 in -20°C to +20°C & RH 35-85% with CO_2 concentrations from 400 ppm to 100,000 ppm. This technology showed an improved performance in Nordic climates that experience dry and cold conditions, such as Calgary, Canada where the tests were performed. Performance of the DAC unit under average weather conditions (18C 65% Humidity) are >90% CO_2 removal from air stream up to 10 weight percent (10 wt.%) loading on sorbent (max 18%).

The team is presently developing a 9 tCO_2/yr lab-scale unit, as the next iteration, which will operate for 6 months. Equipment including sensors, fan units, ducts, sorbents and desiccant wheels that have been procured and are in transit to begin development of the DAC unit. Simultaneously, partner company Occams Technology is assisting in the external procurement and development of the RPB to promote mineral carbonation. The team is targeting to engineer/build and field demonstrate the unit at a maximum capacity of 3500 tCO_2/yr (followed by upscaling to 35,000 tCO_2/yr) and integrate the system into its cement production lines for ZS2's Phase I pilot plant. This system will involve securing supply agreements for raw inputs (achieved LOI Baymag, Progressive Planet, Veracity Energy), engineering/building equipment (quoted/estimated), customer acquisition (achieved off-take agreement FalkBuilt) and validating operating efficiencies for carbon credit generation (agreement signed with SCS Global (Validator), Brightspot (Quantifier) and Devvstream).

c. What are the key performance parameters that differentiate your technology (e.g. energy intensity, reaction kinetics, cycle time, volume per X, quality of Y output)? What is your current measured value and what value are you assuming in your nth-of-a-kind (NOAK) TEA?

Key performance parameter	**Current observed value (units)**	**Value assumed in NOAK TEA (units)**	**Why is it feasible to reach the NOAK value?**

Capture Rate	50-95% at lab scale	>90%	Present tests have indicated the ability to go from ~400 ppm air down to ~20 ppm CO_2.
Ability to dilute with air for enhanced desorption	8-12% CO_2, remainder air	>10% CO_2 into RPB	The RPB is designed for feed inputs greater than 8 wt.% CO_2 with adjustable liquid Na(OH)/brine input determined by the CO_2 feed stream concentration
Uptake per kg of Sorbent	14-110g /kg sorbent	60-185 g /kg sorbent	Modelling data achieved
CO_2 Flux	0.05 g/m^2/s	>0.1 g/m^2/s	Literature data confirmed
CO_2 mass percent in cement	8-17 wt.%	>10 wt.%	Present cements with up 16.5 wt.% CO_2 have shown viable compressive strengths beyond the industry standard of 20 MPa
Cement compressive strength	Up to 64 MPa	>20 MPa	The introduction of $MgCO_3$ produced from waste brine and sequestered CO_2 into magnesium
Cost of CCS at scale	$256/ton CO_2	<$100/ton CO_2	The ability to avoid high cost process such as calcining, slaking, purification and compressing CO_2 help to reduce the cost of the proposed process.
Cost of cement tile	$7.00	$5.00 - $6.00	
Energy (GJ/ton CO_2)	<11	<9	Engineering estimates presently predict energy consumption less than 9 GJ/tCO_2 based on the component quotes received.

d. Who are the key people at your company who will be working on this? What experience do they have with relevant technology and project development? What skills do you not yet have on the team today that you are most urgently looking to recruit?

<u>Leadership Team -</u> The senior management team has given direct approval to allocate the relevant human and in-kind resources to the project. Scott Jenkins, CEO, CPA, has several decades experience leading public and private companies. As the former President and

Director of DIRTT Environmental Solutions, he led and grew sales at the company from $6 million in annual revenue to almost $300 million. Other qualifications include former President of MgO Systems, former CFO of Pure Technologies (now Xylem) and leading DIRTT's successful IPO on TSX in November 2013.

Technical team – The research and development team is led by Dr. Doug Brown, the CTO and co-founder of ZS2, Dr. Brown has a Ph.D. in chemistry and was on the founding team of Carbon Engineering. He holds multiple patents relating to green technologies around carbon capture and magnesium-based cements. Other project members include Dr. Matt Henderson – Ph.D. in chemistry, previously a lead chemist at Carbon Engineering, founder of Occams Technologies (https://www.occams-tech.com/), and now works with ZS2 to develop carbon capture and utilization technology; Dr. Roger Mah - Ph.D. in chemistry, VP of R&D for Progressive Planet (https://progressiveplanet.ca/) and previously worked on carbon capture metal-organic-frameworks (MOFs) that are currently licensed by Svante and now works with ZS2 formulating carbon neutral cements; Ben Hilderbrandt is the Principal Investigator for Green Building Technologies R&D at SAIT specializing in product development, commercialization and R&D of industrial equipment. Other ZS2 team members include Dr. Danny Wong (Ph.D. in mechanical engineering, previous experience in carbon capture with 2 patents and 19 peer-reviewed publications), Robert King (BSc Industrial Engineering, helped develop X-Prize system), Pary Roshan (MSc in Chemistry, co-inventor of carbon neutral magnesium-based cement patent), Christian Smed (20 years' experience journeyman machinist). Additional hiring for personnel with experience in electrochemistry for electrolyzer setup and carbon capture for CO2 absorption and desorption is to be conducted before the end of 2022.

e. Are there other organizations you're partnering with on this project (or need to partner with in order to be successful)? If so, list who they are, what their role in the project is, and their level of commitment (e.g., confirmed project partner, discussing potential collaboration, yet to be approached, etc.).

Partner	Role in the Project	Level of Commitment
Progressive Planet	Will be providing mineral processing capacity; CO2 foam and aggregates such as PozGlass and rock powder for the MBC. As well as direct investor in the company.	Confirmed Project Partner

Occam's Technologies	Develop RPB technology and consult with the overall project goals.	Confirmed Project Partner
Baymag Inc.	Provide MgO and off-spec waste ore from location in Alberta. As well as a financial contributor to the project.	Confirmed Project Partner
Veracity Energy	Provider of Brine used in the production of MBC.	Confirmed Project Partner
Lithium Bank	Provider of Brine used in the production of MBC.	Possible Project Partner
Southern Alberta Institute of Technology (SAIT)	Instrumental partner for testing, characterization, and conceptualization. Centre for Innovation and Research in Advanced Manufacturing and Materials to develop an intermediate sized system prior to final deployment.	Research Partner
University of Calgary (UofC)	Collaborate for ANSYS simulations. This helps to model the air flow from the fan to the sorbent, and optimize the fan speed and rotation between adsorption and desorption. ANSYS modelling also helps determine the carbon content of air between various fan modules to determine the spacing required to minimize recycling low CO2 air.	Research Partner
Journey Engineering	Retained for development of the full-scale plant due to their experience in developing full-scale gas purification plants.	Discussing Potential Collaboration
FalkBuilt	Verbal agreement to purchase 2'x2' MBC tiles from ZS2.	Distribution Partner

f. What is the total timeline of your proposal from start of development to end of CDR delivery? If you're building a facility that will be decommissioned, when will that happen?

January 2nd, 2023 - January 2nd, 2026 Scale-up and integration of component μ-CC into MBC products will be completed in 3 years. This plant will have a 30 year timeline, but will be modified for increased capacity.

g. When will CDR occur (start and end dates)? If CDR does not occur uniformly over that time period, describe the distribution of CDR over time. Please include the academic publications, field trial data, or other materials you use to substantiate this distribution.

In 2023, gradual scale up from continuous batch-based operation of the single fan unit with capacity of 9 tCO_2/yr. During 2024, the unit will be decommissioned and full capacity units will be installed with a capacity of 10x. This unit will then be included into an array and array calibrated and run for 6 months, arrays will be replicated to reach capacity. Gradually upscaled and optimized until final capacity of 10x reached in 2029 with an expected life of 30 years. In 2025, a year of continuous batch operation involves capturing 2740 $kgCO_2$/d and permanently sequestering into ~32,040kgMBC/d.

h. Please estimate your gross CDR capacity over the coming years (your total capacity, not just for this proposal).

Year	Estimated gross CDR capacity (tonnes)
2023	9
2024	693
2025	1000
2026	3150
2027	12000
2028	21000
2029	31500
2030	31500

i. List and describe at least three key milestones for this project (including prior to when CDR starts), that are needed to achieve the amount of CDR over the proposed timeline.

	Milestone description	Target completion

		date (eg Q4 2024)
1	Complete cost and engineering analysis - Complete engineering and site-specific work; finalize request for quotes and procurement list; finalize regulatory approvals, permits, feedstock & offtake agreements	April 30th 2023
2	Procure and commission CCS and brine processing units near Fort McMurray, Canada - Procure all necessary components; contract and monitor the construction of the pilot plant components; assemble components on-site	December 31st 2023
3	Integrate processes A through E plus F. Optimize plant production from continuous batch operation and optimize to meet key technical deliverables highlighted in Section 3e. Ensure standard operating procedures; optimize synergy of processes to output final cement tiles; ensure final products meet specifications	January 1st 2025
4	Operate continuous facility to capture minimum 1000 tCO_2/yr stored in ~8000 tMBC/yr. - Ramp up to 3500 tCO_2/yr capacity; continuous operations through seasonal; marketing uptakes and sales of final MBC; test recyclability of end product.	January 1st 2026

j. What is your IP strategy? Please link to relevant patents, pending or granted, that are available publicly (if applicable).

Our current IP strategy has resulted in multiple patent applications in Canada and the United States. We are currently in the process of submitting PCT applications (patent cooperation treaty) to expand our patent coverage. ZS2 works closely with our patent and trademark legal counsel Oyen Wiggs LLP to ensure appropriate intellectual property protection and internal procedures. All ZS2 team members have signed employment agreements which stipulate ZS2 is the sole owner of any created intellectual property and any confidential information provided out of necessity with third parties (investors, certification & testing organizations, post-secondary partners, strategic partners) is subject to non-disclosure agreements (NDA). ZS2 has the resources and business experience to enforce any intellectual property rights it currently has or develops in the future.

In summary, the Company's trade secret protection is for specific aspects of reaction/residence times and specific formulations required to enhance certain properties, as well as to methods for producing monitoring/sensoring and air contactor technology that can be used in CO2 sequestration and storage processing.

Background IP:

ZS2 Technologies – Magnesium Based Carbon Neutral Cements – Filed but unavailable publicly (No. 63/374002.)

Foreground IP:

ZS2 & Occams – Sodium Hydroxide carbonation using a Rotating Packed Bed Reactor – Potential patent

k. How are you going to finance this project?

ZS2 Technologies has engaged Fort Capital (https://www.fortcapital.ca/) to lead in the raising of \$10-\$20MM CAD, with use of proceeds to fund and expand our carbon capture capacity to manufacture MBC across North America. We expect this round of funding to be completed by the end of 2023. ZS2 to date has raised ~\$5.2MM in funding and secured ~\$0.75MM in government funding. ZS2 has also secured a \$1.05M credit facility.

In addition, ZS2 has secured commitments for \$1.4 MM and \$2.6 MM in private funding from strategic partners, Progressive Planet Inc. and Baymag Inc. respectively pending grant approval, to develop the 3,500 tCO_2/yr μ-CC to MBC facility in Alberta, Canada.

In combination with private funding, ZS2 has pursued numerous opportunities for provincial and federal government grant funding. At the start of 2022, ZS2 received a \$250,000 grant award from Next Generation Manufacturing Canada (NGEN) to research our CDR solution. Although unconfirmed at the time of this application, ZS2 is in the review round for government funding from Sustainable Technology Development Canada (STDC) and Emissions Reduction Alberta (ERA) that could result in up to \$7 MM of grant funding for this project.

A pre-purchase agreement from Frontier for this project would accelerate ZS2's CDR goals. The financing would help to drive the development of DAC and electrolysis research to generate the required alkaline sorbents with lower energy consumption.

l. Do you have other CDR buyers for this project? If so, please describe the anticipated purchase volume and level of commitment (e.g., contract signed, in active discussions, to be approached, etc.).

There are no additional CDR buyers for this project at this time. The future commercialization of ZS2's carbon credits are under preliminary investigation through the involvement of third-party industry carbon credit brokers via DevvStream. A agreement for feasibility and potential with DevvStream has been reached. Agreements have been signed with SCS Global to validate the carbon footprints and Brightspot has been engaged for consultation.

m. What other revenue streams are you expecting from this project (if applicable)? Include the source of revenue and anticipated amount. Examples could include tax credits and co-products.

The proposed pilot CDR has multiple revenue streams. ZS2 is providing an alternative use for waste products that it expects to be paid for to collect (~$0.5/bbl). It will be creating a product that will be sold into the building/construction materials sector ($15MM/yr). The DAC credits are projected to be high-value with anticipated revenue at $200/t$CO_2$ of $1.12MM/yr. In addition, to the intended purpose of the development there are indirect benefits that are generated in the production of caustic soda and mineral extraction via carbonation that could have crossover benefits to other industries. The ability to sell carbonates to partner Progressive Planet or others.

The ability to reduce emissions or repurpose oil wells and create a greener economy is expected to help transition Alberta's oil based economy. There have been negotiations for decontaminating (removing Mg contamination) lithium extraction feed streams for repurposing wells which will further lower costs for ZS2. ZS2's forecasted revenue from the sale of tiles, carbon credits and offset credits is approximately $6.6 billion CAD by 2050. This strong income means that there will be substantial re-investment in Alberta infrastructure and projects that will also drive additional out-of-province investment. This includes the carbon credit, licensing and cement.

n. Identify risks for this project and how you will mitigate them. Include technical, project execution, ecosystem, financial, and any other risks.

Risk	Mitigation Strategy
Processing of Brine water	Due to the relatively low concentrations of magnesium in the brine solutions, there will need to be substantial amount of brine water processed in order to extract the required amount of Magnesium. In order to mitigate this risk, we intended to locate the necessary processes near the selected brine producing well. This will eliminate unnecessary logistic emissions of moving brine water to a new location.
Handling of the corrosive outputs from process C (electrolysis)	The output of process C (electrolysis) is Na(OH) and HCl. In concentrated forms both these products are corrosive, therefore to mitigate this risk, detailed engineering to select proper alloys will need to be conducted for process D (RPB).
Technology scale up of carbon capture from 1 kg/d to min. 2740 kg/d	Intermediate scale is presently under development to enable scale-up. The current setup can capture 360 kgCO_2/yr. Timelines are aggressive, but the team has experience from previous companies developing similar DAC technology (Carbon Engineering).

Ability to secure site for building plant	Letter of support from oil and gas company (Veracity E), but presently pursuing companies with higher Mg content brines such as Lithium Bank.
Recyclability of MBC at end-of-life	ZS2 presently uses waste products as the feedstocks to our cements. The recycling of MBC would undergo rigorous in-house and 3rd party testing to recertify the products produced.
Controls malfunction and don't turn off input fan during desorption	Control system logic in place to turn off booster fan during desorption. Redundant limit switches based on temperature to mitigate. CO2 enriched gas is a toxic gas and system will be designed with numerous redundancy and CO_2 alarms to monitor environment.
Insufficient air flow into the system to reach target goals including excess pressure drop	Instrumentation in place to measure pressure drop with controls in place to verify it is within the range of fan and adsorbent capabilities. Height of adsorbent adjustable to compensate for excess pressure drop
Ability to substantially reduce energy consumption of this projects electrolysis process versus conventional chlor - alkali	The feasibility of the proposed electrolysis process. A professional electrochemist with experience in brine processing will be engaged in order to help mitigate possible issues that may arise for this process. Brine that does not require electrolysis treatment is being pursued. Desalination of ocean water concentrated salt waste stream would be ideal. Pursuing multiple waste brines that do not require electrolysis.
μ-CC via DAC commercial feasibility	The feasibility of μ-CC has been overcome by developing an energy efficient process with a clear end application. In addition, the carbon credits market has also been explored for additional risk mitigation.
Adoption of environmentally friendly, fire-proof and durable MBC by construction industry and individual builder	ZS2 has developed a strong marketing and sales team, along with an international distribution network to help raise awareness of MBC and sell building products. The ability to replace Portland cement with more durable, fire-resistant and more sustainable product can be done universally.
Certification for final cement siding and tile	Third party, independent verifiers including QAI Laboratories.

products to bring to market	

2. Durability

a. Describe how your approach results in permanent CDR (> 1,000 years). Include citations to scientific/technical literature supporting your argument. What are the upper and lower bounds on your durability estimate?

The final chemical form of the sequestered CO_2 is mineralized magnesium and calcium carbonate. CO_2 is extremely stable in this form and will not decompose under ambient conditions for > 1000 years. The CO_2 bonds with metal oxides of calcium and magnesium are thermodynamic syncs. Hence, exposed metal oxides of these metals naturally carbonated over time and we intend to accelerate this natural process by several orders of magnitude. Mineral storage is considered the most permanent form of CO_2 storage and are stable for up to millions of years, as assumed by other companies such as 44.01.[iii]

b. What durability risks does your project face? Are there physical risks (e.g. leakage, decomposition and decay, damage, etc.)? Are there socioeconomic risks (e.g. mismanagement of storage, decision to consume or combust derived products, etc.)? What fundamental uncertainties exist about the underlying technological or biological process?

We have stated that the carbonates of magnesium and calcium will remain 99% stable over the expected lifetimes. If CO_2 is released by the process of heating the carbonated magnesium and calcium to the decarbonization (calcination) temperature of >350C that once cooled the rock should carbonate the exposed metal oxide surfaces. Mineralization is considered one of the most stable ways for long-term storage of CO_2. Risks to re-emission would be limited, but in the presence of excessive heat or strong acid the minerals would decompose into the oxide and CO_2. The newly exposed metal oxide could over time re-carbonate as the most thermodynamically stable product. We have accounted for this potential flux that could happen in the presence of strong acid rain by suggesting the surface may exhibit CO_2 carbonation/decarbonation equilibrium of 1%. Given the largely stable form of this type of storage the re-emission strategy is largely not considered in the use of our product as carbonation of cement generally increases over time. The beneficial nature of Magnesium carbonated cement is its affinity for carbonation and significant carbonation capacity due to the low weight of magnesium relative to other cementing minerals.

3. Gross Removal & Life Cycle Analysis (LCA)

a. How much GROSS CDR will occur over this project's timeline? All tonnage should be described in **metric tonnes** of CO_2 here and throughout the application. Tell us how you calculated this value (i.e., show your work). If you have uncertainties in the amount of gross CDR, tell us where they come from.

Gross tonnes of CDR over project lifetime	961,852 tonnes of CDR
Describe how you calculated that value	Intermediate scale of 9 tCO_2/yr in 2023. Gradual scale up from batch operations 10 tCO_2/month Jan, 2024 to capacity (83.3 tCO_2/month) in Sep, 2024. 1000 tCO_2/yr run and optimized for 1 year in 2025. Upscaled through additional modules to 3500 tCO_2/yr in 2026 and further upscaled until scaled to 35000 tCO_2/yr in 2028. The expected life is 30 years. Multiplied by 90% operating capacity for conservative estimate of downtime and maintenance

b. How many tonnes of CO_2 have you captured and stored to date? If relevant to your technology (e.g., DAC), please list captured and stored tons separately.

~ 0.5 tonnes CO_2. The carbon is captured and sequestered.

c. If applicable, list any avoided emissions that result from your project. For carbon mineralization in concrete production, for example, removal would be the CO_2 utilized in concrete production and avoided emissions would be the emissions reductions associated with traditional concrete production. Do not include this number in your gross or net CDR calculations; it's just to help us understand potential co-benefits of your approach.

The baseline for business-as-usual activities is described in components that best represent our all-in-one solution. Carbon Engineering is chosen as our baseline for direct-air-capture (DAC) as their information on process design is widely accessible. The energy consumption for a commercial DAC unit is estimated in literature as 5.25 GJ of gas and 366 kWh of electricity per tonne of CO_2 (tCO_2) captured.[iv] Carbon Engineering baseline represents process A and B in the proposed technology. Na(OH) and $Mg(OH)_2$ production feedstocks are included in the baseline as part of the alkaline sorbents used in carbon capture by both ZS2 and Carbon Engineering. The Carbon Engineering baseline also consumes two mole (mol) equivalents of

hydroxide per mol_{CO2} in their process, potassium hydroxide (KOH) and $Ca(OH)_2$, for comparison. The initial feedstock production is not accounted for in Carbon Engineering's calculations, and is therefore added to the baseline. They are also vital intermediaries for cement manufacturing. Na(OH) and $Mg(OH)_2$ GHG emissions are based on literature, and correspond to process C.[v,vi] Process D and E are not included in the baseline, as they are intermediaries of the proposed process to reduce reliance on mined magnesite and limestone. The energy consumption calculations for Carbon Engineering also do not account for an end case usage or sequestration. Process F for manufacturing siding tiles is compared to available reports for James Hardie cement siding planks. The water usage for siding production is accounted for separately; cement manufacturers and companies such as James Hardie assume negligible GHG emissions for freshwater consumption during cement manufacturing that does not accurately represent the associated environmental impacts. Overall, the proposed baseline for the suggests avoided emissions equal to 8,188.19 tCO_{2e} and DAC of 1000 tCO_2 to displace 8,009 tonnes of equivalent Portland cement building materials. This matches output for 2025.

d. How many GROSS EMISSIONS will occur over the project lifetime? Divide that value by the gross CDR to get the emissions / removal ratio. Subtract it from the gross CDR to get the net CDR for this project.

Gross project emissions over the project timeline *(should correspond to the boundary conditions described below this table)*	280 tCO_2/yr in 2025
Emissions / removal ratio *(gross project emissions / gross CDR–must be less than one for net-negative CDR systems)*	= 280/1000 = 0.28
Net CDR over the project timeline *(gross CDR - gross project emissions)*	720 tCO_2/yr in 2025

e. Provide a process flow diagram (PFD) for your CDR solution, visualizing the project emissions numbers above. This diagram provides the basis for your life cycle analysis (LCA). Some notes:

- The LCA scope should be cradle-to-grave
- For each step in the PFD, include all Scope 1-3 greenhouse gas emissions on a CO_2 equivalent basis
- Do not include CDR claimed by another entity (no double counting)
- For assistance, please:
  - Review the diagram below from the CDR Primer, Charm's application from 2020 for a simple example, or CarbonCure's for a more complex example
  - See University of Michigan's Global CO_2 Initiative resource guide
- If you've had a third-party LCA performed, please link to it.

Similar to CarbonCure, ZS2's GHG emissions and LCA impacts have been validated by third-party audits as part of funding programs. BrightSpot Consulting has validated the methodology as part of Emissions Reduction Alberta's (ERA) Circular Economy Challenge. Sustainable Development Technology Canada (SDTC) and the Carbon XPRIZE have also validated. The emissions from cement and tile manufacturing have been neglected, as it is not directly related to the CDR solution. It is part of the end product for ZS2, but the formation of $MgCO_3$ and $CaCO_3$ in (21) already represents sequestration of CO_2 that could be a clear cradle-to-grave solution comparable to ocean capture technologies. Additionally, Process C has been included for worst case scenario of brine processing, but as stated above there are several brine sources that do not require electrolysis treatment.

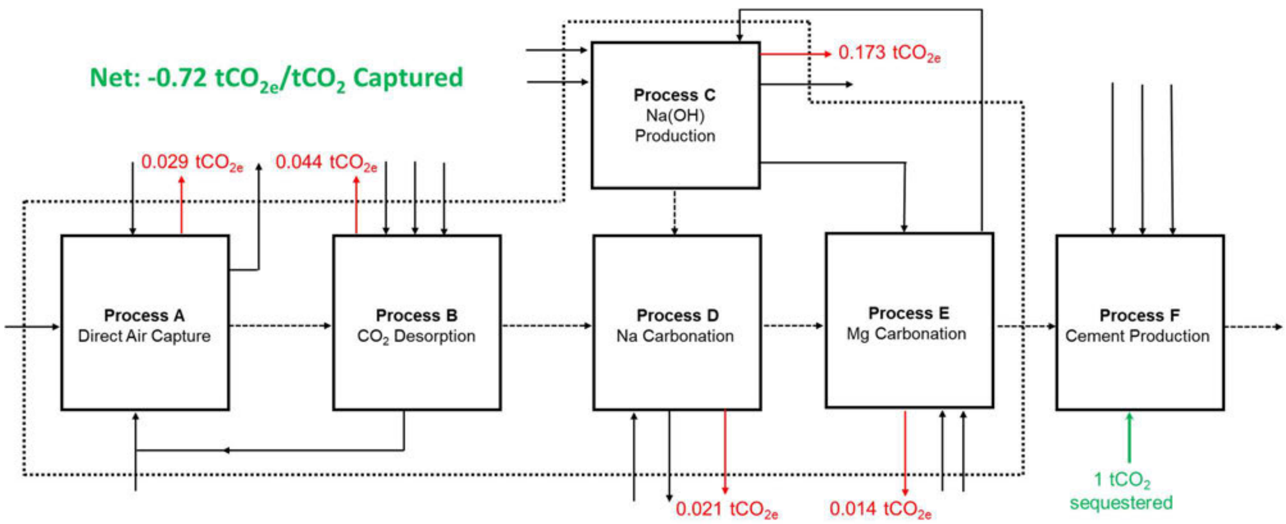


Figure 2. PFD showing the GHG emissions for each process (red). The dotted black box represents the cradle-to-grave system boundary for the CDR solution. The inputs represent full operating capacity capturing 3,500 tCO_2/yr.

f. Please articulate and justify the boundary conditions you assumed above: why do your calculations and diagram include or exclude different components of your system?

The cradle begins with air input into DAC. The end grave is CO_2 sequestration to form $MgCO_3$ and $CaCO_3$ (21 in Figure 3). The emissions from cement and tile manufacturing have been neglected because it's not directly related to the CDR solution. It's part of the end, marketed product for ZS2. $MgCO_3$ and $CaCO_3$ represents clear cradle-to-grave solution comparable to ocean capture.

The plant is located next to the waste brine. Pumps from oil and gas wells input directly into the electrolyzer rather than waste wells. Wastes into the system are not included because they're already at end of life.

g. Please justify all numbers used to assign emissions to each process step depicted in your diagram above. Are they solely modeled or have you measured them directly? Have they been independently measured? Your answers can include references to peer-reviewed publications, e.g. Climeworks' LCA paper.

Process Step	CO_2(eq) emissions over the project lifetime (metric tonnes)	Describe how you calculated that number. Include references where appropriate.
A	3013	Energy consumption 473 MJ/tCO_2. Natural gas emissions 1930 gCO_{2e}/m^3 CO_2, 0.037 g CH_4/m^3, 0.033 g N_2O/m^3 (Table 5, Alberta carbon offset emission factors handbook).[vii] 26.9 m^3 natural gas/GJ energy.[viii] Global warming potential of CH_4 and N_2O are 25 and 298 kgCO_{2e}/kg, respectively, per Technology Innovation and Emissions Reduction (TIER) regulation. Desiccant and sorbent re-used for sufficient cycles to be negligible (<1%) because <0.1 wt.% wear rate (attrition). From the Climeworks LCA model, it is assumed that carbon footprint for DAC plant construction is on the order of 10^{-3} kg CO_{2e}/kg CO_2 captured (<1%), and is therefore neglected. Values have been experimentally determined to feed the pilot modelled values. [X-prize validated]
B	4630	Energy consumption 1268 MJ/tCO_2 Same methodology as process step A. Values have been experimentally determined to feed the pilot modelled values. [X-prize validated]
C	18144	Energy consumption 3,488 MJ/tCO_2 Same methodology as process step A. Brine input assumed to be inputted by third party oil-well site, as direct replacement for pumping to tailings ponds or disposal wells.
D	2194	Energy consumption 395 MJ/tCO_2 Same methodology as process step A. Values have been experimentally determined to feed the pilot modelled values. [X-prize validated]
E	1449	Energy consumption 251 MJ/tCO_2 Same methodology as process step A.

F	5323	Energy consumption 974 MJ/tCO_2 Same methodology as process step A. Values Modelled.
Transportation	1806	Not included in cradle-to-grave, as the transport is from process E to F. It is for the manufacture of ZS2's end-product, but beyond scope of CDR. Rail transport of $MgCO_3$ and $CaCO_3$ from plant in Fort McMurray to Calgary, Alberta. Rail fuel consumption 4.55 mL/ton/km. Diesel emits 2.681, 7.8E-5 and 2.0E-5 tonnes of CO_2, CH_4 and N_2O per kL, respectively.

4. Measurement, Reporting, and Verification (MRV)

Section 3 above captures a project's lifecycle emissions, which is one of a number of MRV considerations. In this section, we are looking for additional details on your MRV approach, with a particular focus on the ongoing quantification of carbon removal outcomes and associated uncertainties.

a. Describe your ongoing approach to quantifying the CDR of your project, including methodology, what data is measured vs modeled, monitoring frequency, and key assumptions. If you plan to use an existing protocol, please link to it. Please see Charm's bio-oil sequestration protocol for reference, though note we do not expect proposals to have a protocol at this depth at the prepurchase stage.

> Approach to quantifying CDR
> The CDR is quantified by inputting a constant mass flow rate of air into the sorbent packed bed. The CO_2 concentration is continuously monitored versus time (input/output). The resulting data is integrated to determine the CDR based on the room temperature and pressure. A sample graph representing adsorption measurements are shown in *Figure 3*3. This data helps to determine the optimal cycle time to reach target of 90% CO_2 in real time versus ambient conditions. The present sampling frequency is 1 Hz with constant data tracking and logging. Similar curves are generated for desorption to verify the amount of CO_2 removed and this data will guide cycle times. This also ensures the beads are ready for the next cycle. The CO_2 stream is also tracked into and out of the RPB unit and finally via quantification in the final cement. This allows the CO_2 efficiency of the process to be calculated. Thus far, we have been able to convert more than 90% of the CO_2 inputted directly into carbonates for the boards.

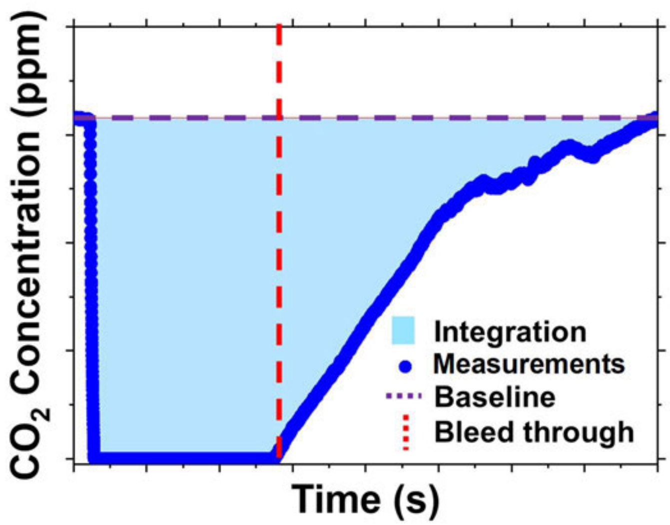


Figure 3: Example of CDR quantification methodology based on CO_2 adsorption.

Measured vs. Modeled data
The data is presently measured, but we are working with collaborators at SAIT and UofC to model the air flow through the packed bed via ANSYS. This will help to determine the flow patterns to alter packing structure and space out modules to avoid recycling exhaust airs. The models will be verified by measured data, and used to reduce experimental requirements once validated.

Key assumptions
The present methodology assumes a constant baseline averaged from the initial and final equilibrium values. The data is integrated analytically via OriginLabs graphing software and numerically through data for each second.

b. How will you quantify the durability of the carbon sequestered by your project discussed in 2(b)? If direct measurement is difficult or impossible, how will you rely on models or assumptions, and how will you validate those assumptions? *(E.g. monitoring of injection sites, tracking biomass state and location, estimating decay rates, etc.)*

The lifetime of the cement is tracked via consumer products sold by ZS2. The sequestered CO_2 in carbonates gives the cement the reported compressive strength. Changes in the compressive strength may result in deformations to the building envelope that would be directly reported by clients. ZS2 will continue to monitor products sold in order to quantify the carbon sequestration. The products would use fiber glass as opposed to steel for tensile strength reinforcement. This reduces concerns around corrosion and rusting in construction and buildings.

Magnesium and calcium carbonates have been known to be stable for millennia, except potentially under acidic conditions. No notable CO_2 release can be observed when leaching the carbonates in solutions of pH 2 or higher.[ix] Furthermore, the solid residues from acid treatment showed higher CO_2 content than before treatment. This suggests that the carbon

sequestering via carbonates is highly feasible.

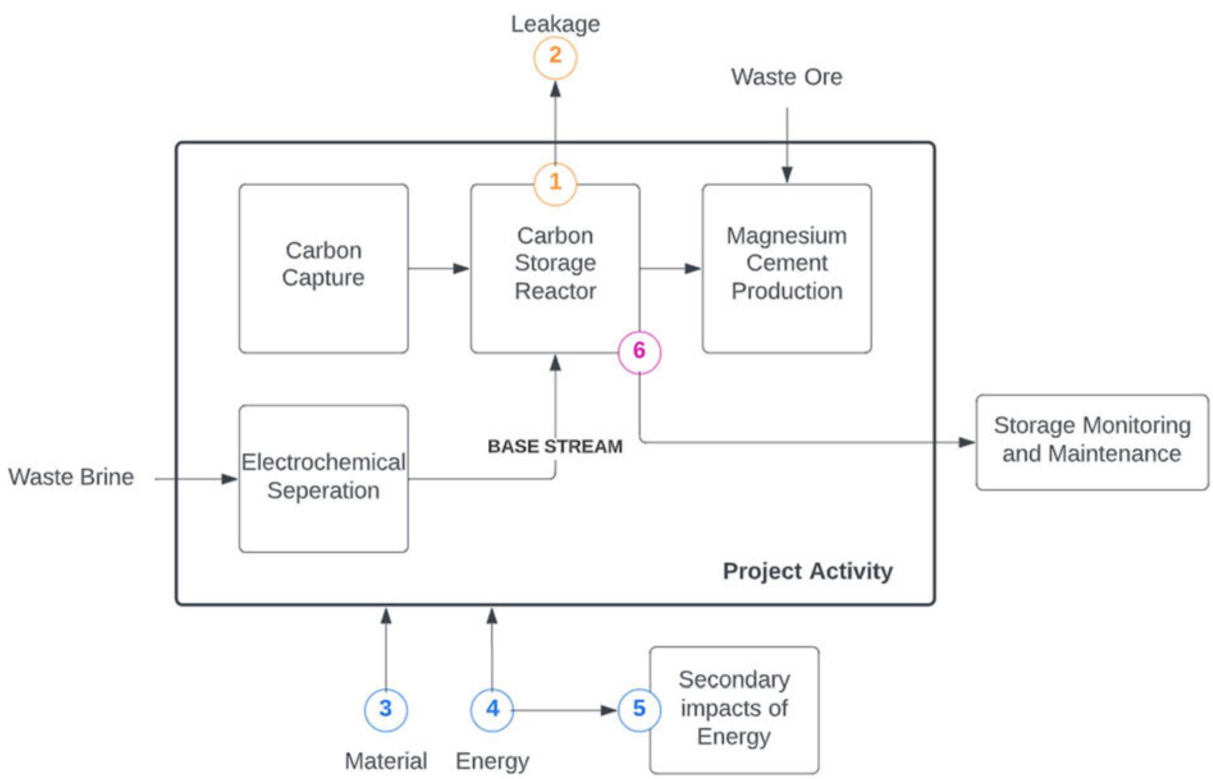
c. This tool diagrams components that we anticipate should be measured or modeled to quantify CDR and durability outcomes, along with high-level characterizations of the uncertainty type and magnitude for each element. We are asking the net CDR volume to be discounted in order to account for uncertainty and reflect the actual net CDR as accurately as possible. Please complete the table below. Some notes:

- In the first column, list the quantification components from the Quantification Tool relevant to your project (e.g., risk of secondary mineral formation for enhanced weathering, uncertainty in the mass of kelp grown, variability in air-sea gas exchange efficiency for ocean alkalinity enhancement, etc.).
- In the second column, please discuss the magnitude of this uncertainty related to your project and what percentage of the net CDR should be discounted to appropriately reflect these uncertainties. Your estimates should be based on field measurements, modeling, or scientific literature. The magnitude for some of these factors relies on your operational choices (i.e., methodology, deployment site), while others stem from broader field questions, and in some cases, may not be well constrained. We are not looking for precise figures at this stage, but rather to understand how your project is thinking about these questions.
- See this post for details on Frontier's MRV approach and a sample uncertainty discount calculation and this Supplier Measurement & Verification Q&A document for additional guidance.

Quantification component Include each component from the Quantification Tool relevant to your project	**Discuss the uncertainty impact related to your project** Estimate the impact of this component as a percentage of net CDR. Include assumptions and scientific references if possible.
1. Storage	This is dependent on optimizing the partial pressure of CO_2, temperature, mixing, reaction time, and pH. ZS2 has optimized the conditions to where we can almost completely consume brines with >30,000 mg/L of Ca and Mg. The regenerated brine has <5 mg/L of Ca and Mg, which is the limit of detection for the ICP tests, after adding the stoichiometric ratios of carbonated Na_2CO_3. The CO_2 concentration and volumetric flow into the carbonation is monitored, and the resulting production mass of carbonates is also monitored to ensure storage. Overall, the MBC can sequester from 0-22 wt.% CO_2 while still meeting the industry standard 20 MPa

	compressive strength. We have assumed 11-12 wt.% CO_2 as an average sequestration value for typical MBC tiles. The amount of CO_2 varies greatly depending on the waste ore (MgO purity), brine input and tile press conditions. The tile press is not the limiting process in this technology, so this has negligible effects on CDR.
2. CO2 Leakage	The CO_2 leakage is assumed to be 10% of the overall CDR. This is consistent with Carbon Engineering estimates where 0.9 tons are sequestered per 1 tCO_2 captured.[x] This can also help to account for inefficiencies in converting to carbonates.
3. System Material Input	The primary input into the system is air and saltwater, which are two of the most abundant materials in the world. Materials uncertainties may lead to changes in the operating conditions, but should not change the CDR. As an example, using ocean water input instead of waste oil and gas brine results in lower salt contents that would increase energy consumption for electrolysis (processing more water) and carbonation of Mg and Ca (mixing and separating more water). Variations in sorbent input and processing may have an effect on the overall CO_2 captured. We have observed variations in adsorption capacity ranging from 0.042 to 0.185 g CO_2/g sorbent depending on the operating conditions. This changes the cycle time for adsorption/desorption and the quantity of sorbent needed, but does not change the net CDR.
4. System Energy Input	Changes in the operating conditions after continuous optimization result in changes to the energy inputs. A plant location in Alberta, Canada leads to high electricity grid emissions (~0.55 tCO_{2e}/MWh) versus neighboring areas such as British Columbia, Canada (~0.12 tCO_{2e}/MWh). This may influence the decision to use natural gas-powered boilers and generators versus direct grid connection. The plant will be deployed to minimize these impacts.
5. Secondary impacts of Energy	Presently, the system is not assumed to be connected to the grid. Discussions are underway with renewable energy providers such as Bullfrog Energy in Canada to provide access to a renewable energy grid at a markup of < \$25/MWh. This means ZS2 would not be displacing demand for renewables.
6. Storage Monitoring and Maintenance	Sequestration of CO_2 in cement via mineralization is a common practice with established durability. It has

	been estimated that cement further sequesters 25% of the theoretical maximum CO_2 over a 100-year life with a target of 0.28 tCO_2/tonne cement. ZS2 is committed to environmentally sustainable practices and monitoring the sequestration. We presently have administrative staff to monitor an array of factors including product recycling, facility energy consumption and waste offtake as part of the companies commitment to achieve B-Corp status.



d. Based on your responses to 4(c), what percentage of the net CDR do you think should be discounted for each of these factors above and in aggregate to appropriately reflect these uncertainties?

10% of the net CDR should be discounted to appropriately account for uncertainties.

e. Will this project help advance quantification approaches or reduce uncertainty for this CDR pathway? If yes, describe what new tools, models or approaches you are developing, what new data will be generated, etc.?

> The quantification is advanced through detailed life cycle analysis and may result in a new carbon counting protocol that will provide access to others looking to deploy this or similar technologies. New models will be developed in conjunction with partners at the University of Calgary to model air flow, pressure drop, air recycling and velocity profile. This will help to better understand the adsorption through the packed bed. We can monitor preferred flow channels and control packing thickness/density through the use of these new models. Another of the uncertainties for DAC is the recycling of low CO_2 air from the output back to the input. The models are to be developed in Fluent. New data around the adsorption properties of the sorbent, and CO_2 uptake of the alkaline materials will also be generated. This will help to further scientific understanding through academic publications. Technical economic assessment around the μ-CC and its feasibility to fill a gap in the market will also be developed. The gap being technologies that are low cost and could provide on site CO_2 at smaller scales for other utilization technologies. This would alleviate the need for large transportation infrastructures.

f. Describe your intended plan and partners for verifying delivery and registering credits, if known. If a protocol doesn't yet exist for your technology, who will develop it? Will there be a third party auditor to verify delivery against that protocol or the protocol discussed in 4(a)?

> ZS2 is presently pursuing trials for two different companies to verify and register credits. SCS Global and DevvStream are both in the process of preparing proposals to validate and verify delivery of the carbon credits. Brightspot Consulting has also been contacted for quantification and consultation around the process emissions and life cycle analysis.

5. Cost

We are open to purchasing high-cost CDR today with the expectation the cost per tonne will rapidly decline over time. The questions below are meant to capture some of the key numbers and assumptions that you are entering into the separate techno-economic analysis (TEA) spreadsheet (see step 4 in Applicant Instructions). There are no right or wrong answers, but we would prefer high and conservative estimates to low and optimistic. If we select you for purchase, we'll work with you to understand your milestones and their verification in more depth.

a. What is the levelized price per net metric tonne of CO_2 removed for the project you're proposing Frontier purchase from? This does not need to exactly match the cost calculated for "This Project" in the TEA spreadsheet (e.g., it's expected to include a margin), but we will be using the data in that spreadsheet to consider your offer. Please specify whether the price per tonne below includes the uncertainty discount in the net removal volume proposed in response to question 4(d).

$572/tonne CO_2 The price includes discount for the potential leakage and uncertainty impacts equivalent to mark-up (10%).

b. Please break out the components of this levelized price per metric tonne.

Component	**Levelized price of net CDR for this project ($/tonne)**
Capex	$205/t$CO_2$
Opex (excluding measurement)	$314/t$CO_2$
Quantification of net removal (field measurements, modeling, etc.)[2]	$0/t$CO_2$
Third-party validation, verification and registry fees (if applicable)	$143/t$CO_2$
Total	$572/t$CO_2$

c. Describe the parameters that have the greatest sensitivity to cost (e.g., manufacturing efficiencies, material cost, material lifetime, etc.). For each parameter you identify, tell us what the current value is, and what value you are assuming for your NOAK commercial-scale TEA. If this includes parameters you already identified in 1(c), please repeat them here (if applicable). Broadly, what would need to be true for your approach to achieve a cost of $100/tonne?

Note: A more detailed breakdown of the NOAK can be submitted using the Frontier TEA as needed.

Parameter with high impact on cost	**Current value (units)**	**Value assumed in NOAK TEA (units)**	**Why is it feasible to reach the NOAK value?**
Capital Expenses (especially electrolyzer)	$205/t$CO_2$ (~22% of cost)	$26/t$CO_2$ (~20% of capital cost)	Broadly, we have seen that scaling reduces the cost by up to 75% based on economies of scale. This is based on our present scaling

[2] This and the following line item is not included in the TEA spreadsheet because we want to consider MRV and registry costs separately from traditional capex and opex.

			from 0.365 tCO_2/yr to 9 tCO_2/yr. There is less uncertainty in the NOAK. This would lead to a capex of as low as \$23/tCO_2 The electrolyzer contains the most uncertainty of the capex. The alternative is to supplement with Na(OH) purchased from conventional chlor-alkali process.
Fixed operating expenses (operating labor and improved energy efficiency)	\$314/tCO_2	\$65/tCO_2	As the system is scaled up, the required personnel is not expected to change substantially as the operations remain consistent. 1 additional employee per shift (4 total) is required to safeguard against challenges. This would result in overall operating expenses of as low as \$44/tCO_2.
Variable operating expenditures (maintenance and contingency)	\$53/tCO_2	\$41/tCO_2	The maintenance costs remain fairly consistent on a per tCO_2 basis. Efficiencies in the energy consumption are considered based on the scaled-up system and advancements in technology.

d. What aspects of your cost analysis are you least confident in?

> The capital expenses of the electrolyzer unit and its requirement hold the most uncertainty. The cost of the scaled-up commercial system may vary from the offtake quotes and small-scale setups currently used. The remainder of the capital expenses are expected to be fairly accurate.

e. How do the CDR costs calculated in the TEA spreadsheet compare with your own models? If there are large differences, please describe why that might be (e.g., you're assuming different learning rates, different multipliers to get from Bare Erected Cost to Total Overnight Cost, favorable contract terms, etc.).

> The CDR cost estimate from TEA is higher than ZS2 models due to the higher contingency values placed based on the TRL level. Our model accounts for the process being supplemented by waste Na(OH) from partner Progressive Planet's processing facility. However, this is not included in the Frontier application to avoid overlaps in the carbon

credit accounting.

f. What is one thing that doesn't exist today that would make it easier for you to commercialize your technology? (e.g., improved sensing technologies, increased access to X, etc.)

Electrolysis alone makes up almost 50% of energy for the entire CDR solution. Scalable alternatives to attain waste alkaline Na(OH), including Progressive Planet's processor, would help to commercialize. This would also remove the primary uncertainty around the electrolysis cost and GHG emissions.

6. Public Engagement

In alignment with Frontier's Safety & Legality criteria, Frontier requires projects to consider and address potential social, political, and ecosystem risks associated with their deployments. Projects with effective public engagement tend to:

- Identify key stakeholders in the area they'll be deploying
- Have mechanisms in place to engage and gather opinions from those stakeholders, take those opinions seriously, and develop active partnerships, iterating the project as necessary

The following questions help us gain an understanding of your public engagement strategy and how your project is working to follow best practices for responsible CDR project development. We recognize that, for early projects, this work may be quite nascent, but we are looking to understand your early approach.

a. Who have you identified as relevant external stakeholders, where are they located, and what process did you use to identify them? Please include discussion of the communities potentially engaging in or impacted by your project's deployment.

Our stakeholders are identified as inputs into our technology where we can be an in-line process to handle non-virgin, undesirable waste products. Our stakeholders also use the DAC technology and/or the MBC products containing up to 22 wt.% sequestered CO2.
Progressive Planet (Kamloops, British Columbia) has been identified as the primary external stakeholder. They produce waste Na(OH) that can be used in our carbonation process. They also purchase Na_2CO_3 as a part of their other business ventures that can be generated from the sequestered CO_2. We have identified Veracity Energy and Lithium Bank as potential sources of brine to provide waste inputs into the electrolysis and carbonation systems. They have waste brines located in Alberta and Saskatchewan, respectively, that require the removal of salts (Mg, Ca).
Other stakeholders include government entities (Emissions Reductions Alberta, Sustainable Development Technology Canada, Environment and Climate Change Canada, National Research Council Canada) and local communities in Fort McMurray. We have discussed the

potential positive impacts to local communities by reducing salt content in soil and underground wells.

ZS2 is focused on equitably distributing benefits from this project. We are at a pivotal moment to ensure a just transition to the green economy. We use our business to advocate for equity, environmental justice and circular economy solutions, which is why our business is currently undergoing BCORP certification, EPD and Life Cycle Analysis. As a company we are focused on job creation, training, community engagement and advocating for policy reform. ZS2 has achieved numerous certifications to demonstrate our commitment to environmental justice. One example is the Solar Impulse Foundation label which is given to the top 1000 viable technologies that are decarbonizing systems, cutting energy use, cleaning up air and water. We met the United Nationals sustainable development goals around water, clean energy, cities and responsible consumption.

b. If applicable, how have you engaged with these stakeholders and communities? Has this work been performed in-house, with external consultants, or with independent advisors? If you do have any reports on public engagement that your team has prepared, please provide. *See Project Vesta's community engagement and governance approach as an example and Arnestein's Ladder of Citizen Participation for a framework on community input.*

ZS2's CDR project is still in early development. We have identified key external stakeholders, Veracity Energy and Lithium Bank as potential sources of waste brine inputs for the electrolysis and carbonation systems, as well as Progressive Planet - a direct investor in ZS2 and a confirmed supplier of aggregate material for the final MBC products. Engagement with these key stakeholders is continuous and ongoing and it is critical for the success of this project. For example, Progressive Planet and ZS2 share working space in Calgary, Canada to collaborate on the development and optimization of MBC. Additionally, constant ICP analysis are conducted on waste brine samples provided by Veracity and Lithium Bank in order to further optimize Magnesium and Calcium extraction yields.

The project also aims to engage and improve construction in indigenous communities. Presently, ZS2 has engaged and provided MBC building materials to indigenous communities in Cambridge Bay, Nunavut, Canada and Kanaka Bar, British Columbia, Canada. Kanaka Bar is a community located near Lytton, British Columbia that was devastated by forest fires in June 2021, where most of the community buildings were destroyed and hundreds of people were displaced. Through local and provincial leaders, an innovation challenge (https://foresightcac.com/learn/kanaka-bar-resilient-housing-solutions-challenge-results/) was proposed to building technology companies to help re-build the community in a sustainable way. ZS2's MBC solution was named as a finalist in this challenge after completing a rigorous evaluation.

Multiple homebuilders across western Canada and western United States have engaged with ZS2 to develop new industrial, commercial and residential building, utilizing ZS2's MBC building products. Two of the primary users are Trico and Melcom Homes in Alberta, Canada.

c. If applicable, what have you learned from these engagements? What modifications have you already made to your project based on this feedback, if any?

> Through partnerships with quantifiers and validators, we have learned that there is a substantial opportunity to generate carbon offset credits based on the embodied and operational GHG emission reductions. Embodied reductions look at the enhanced lifetime, reduced maintenance, installation and transportation emissions of the end building product (MBC) versus conventional Portland cement-based products. Operational reductions look at the use of recycled waste materials in our process versus high emission virgin feedstocks for Portland cement. The value of these two groups has pushed ZS2 to accelerate the pursuit of the technology.

d. Going forward, do you have changes to your processes for (a) and (b) planned that you have not yet implemented? How do you envision your public engagement strategy at the megaton or gigaton scale?

> We have a growing queue of potential end-users for both the carbon-sequestered cement and the μ-CC carbon capture technology. This includes alternative brine sources that we need to explore, flue gas emitters for point source carbon capture, sodium hydroxide producers, and other builders that have been quoted for Made-in-Canada MBC. Additional plants across the world are required to reach the megaton or gigaton scale. This involves additional public engagement with governments, local communities, potential partners and end-users. We are in early discussions with other users of CO2 that do not require high grade compressed CO_2 as an input.

7. Environmental Justice[3]

As a part of Frontier's Safety & Legality criteria, Frontier seeks projects that proactively integrate environmental and social justice considerations into their deployment strategy and decision-making on an ongoing basis.

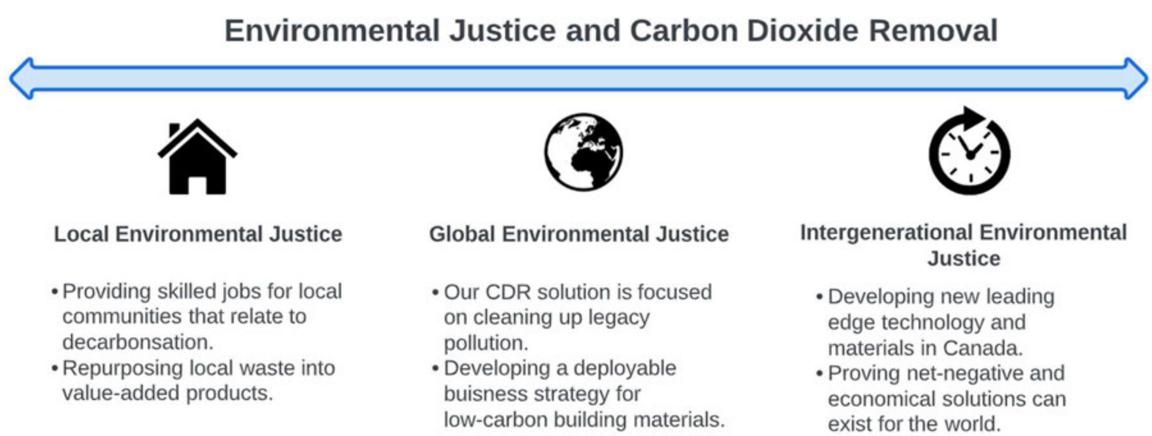
a. What are the potential environmental justice considerations, if any, that you have identified associated with your project? Who are the key stakeholders? Consider supply chain impacts, worker compensation and safety, plant siting, distribution of impacts, restorative justice/activities, job creation in marginalized communities, etc.

> This process helps underserved communities by providing carbon capture credits, desalinated water and prefabricated CO_2 sequestered building materials. The development of carbon capture units and transport of materials represents the potential for additional involvement from workers in marginalized communities. The desalinated water has less harm to surrounding land, and may potentially be processable in municipal water processing

[3] For helpful content regarding environmental justice and CDR, please see these resources: C180 and XPRIZE's Environmental Justice Reading Materials, AirMiners Environmental and Social Justice Resource Repository, and the Foundation for Climate Restoration's Resource Database

facilities for potable water. Underserved communities often do not have the resources or personnel to undergo construction projects. The design and manufacture of materials to their specifications represents an opportunity to build modern, energy efficient structures where they are needed most. These CO_2 utilization projects can help to restore outdated structures.

Our hiring practices use an intersectional lens to remove systemic barriers to entry to ensure our workforce is as diverse as our society. We ensure all jobs are paid above living wages and are actively recruiting individuals from the fossil fuel industry to ensure no one gets left behind in the transition. We collaborate with post-secondary institutions to create economic opportunities for future green leaders. Finally, as a green business we are not only aware of government policies, but we frequently advocate for reform of the construction industry to ensure environmental justice.



b. How do you intend to address any identified environmental justice concerns and / or take advantage of opportunities for positive impact?

We anticipate developing mutually beneficial partnerships with high emitting industries and potential users to take advantage of the positive impacts including public relations. We re-purpose difficult to dispose waste, such as alkaline/acidic brines to generate useful end products. This reduces the cost of the end product and minimizes potential GHG emissions as a result of feedstocks.

In the process of hiring, we may require skilled labor that perpetuates injustices in underserved communities. At ZS2, we are committed to equal opportunity hiring, and have a strong track record as illustrated in our pursuit of BCORP. Operating labor for the cement and tile manufacturing aims to hire diverse backgrounds to ensure environmental justice.

8. Legal and Regulatory Compliance

a. What legal opinions, if any, have you received regarding deployment of your solution?

> ZS2 has received legal guidance from Oyen Wiggs for the patenting of the solution. In addition, this solution will comply with the federal and provincial health & Safety, environmental and social regulations set forward in Canada.

b. What permits or other forms of formal permission do you require, if any, to engage in the research or deployment of your project? What else might be required in the future as you scale? Please clearly differentiate between what you have already obtained, what you are currently in the process of obtaining, and what you know you'll need to obtain in the future but have not yet begun the process to do so.

> ZS2's solution does not require special permits to operate this solution, instead we anticipate relying on the environmental permitting associated to the organization we partner with that supplies waste brine for our solution. The brine is neutralized prior to disposal to ensure that no additional permits are required.

c. Is your solution potentially subject to regulation under any international legal regimes? If yes, please specify. Have you engaged with these regimes to date?

> Our solution has no issue with international legal regimes. Currently, the Canadian government is incentivizing the transition of the country's economy, by supporting companies with circular economy capabilities, and emission reduction technology.

d. In what areas are you uncertain about the legal or regulatory frameworks you'll need to comply with? This could include anything from local governance to international treaties. For some types of projects, we recognize that clear regulatory guidance may not yet exist.

> Regulatory frameworks for CDR in Canada have not yet defined protocols for DAC operations. ZS2 will closely monitor for any updates that may impact this project in the future. In addition, all strategic partners and suppliers for this CDR solution comply within relevant regulatory frameworks.
>
> Extensive third-party testing and validation will be required to confirm that the new MBC products with sequestered CO_2 meets the minimum required structural and physical characteristics for the National Building Code of Canada, International Building Code, Alberta Building Code and many more codes, in order to be accepted in North American markets.

e. Do you intend to receive any tax credits during the proposed delivery window for Frontier's purchase? If so, please explain how you will avoid double counting.

No sale of carbon tax credits are expected during the proposed delivery window for Frontier's purchase. DevvStream has been engaged to asses the potential, perform accounting and marketing credits after the delivery window.

9. Offer to Frontier

This table constitutes your **offer to Frontier**, and will form the basis of contract discussions if you are selected for purchase.

Proposed CDR over the project lifetime (tonnes) *(should be net volume after taking into account the uncertainty discount proposed in 4(c))*	1000
Delivery window *(at what point should Frontier consider your contract complete? Should match 1(f))*	Q4 2025
Levelized Price ($/metric tonne CO_2) *(This is the price per tonne of your offer to us for the tonnage described above)*	$572 USD / ton

Application Supplement: DAC

(Only fill out this supplement if it applies to you)

Note: these questions are with regards only to air capture: e.g. your air contactors, sorbents or solvents, etc. Separately, there exist Geologic Injection and CO_2 Utilization supplements. We anticipate that most companies filling out this DAC supplement should ALSO fill out one of those supplements to describe their use of the CO_2 stream that's an output of the capture system detailed here.

Physical Footprint

1. What is the physical land footprint of this project, and how do you anticipate this will change over the next few years? This should include your entire physical footprint, i.e., how much land is not available for other use because your project exists. Also, what is the estimated footprint if this approach was removing 100 million tons of CO_2 per year?

Land footprint of this project (km^2)	< 1 (0.0008)
Land footprint of this tech if scaled to 100 million tons of CO_2 removed per year (km^2)	8

Capture Materials and Processes

1. What material(s) is/are you using to remove CO_2?

The process uses a proprietary combination of alkaline materials (Na(OH), $Ca(OH)_2$, $Mg(OH)_2$) and commercially available functionalized materials (Zeolite 13X, activated carbon, silica gel).

2. How do you source your material(s)? Discuss how this sourcing strategy might change as your solution scales. Note any externalities associated with the sourcing or manufacture of it (e.g., hazardous wastes, mining, etc.). You should have already included the associated carbon intensities in your LCA in Section 3.

The waste brine is presently sourced from oil and gas producers. This brine is the source of minerals used to form alkaline materials for carbon capture in carbonates. Some wells produce more than 20 m^3 (125.8 barrels) per day.[xi] It has been estimated that oil wells produce approximately 18 barrels of brine per barrel of oil.[xii] This means that one well can produce approximately 360,000 L/day that can be supplied to our process. By comparison, our process requires approximately 270,000 L/day of brine based on the mineral concentrations observed from ICP testing. As the plant scales from the pilot (3500 tCO_2/yr to 30000 tCO_2/yr), we need to work with multiple oil wells to supply the 2.3 ML/day required. This source is scalable to other locations, as there exists salty water sources throughout the world (ie. Oceanwater, Salar de Uyuni). The different salt contents require the electrolyzer to scale to different water inputs. These are waste sources that do not have associated carbon intensities except pumping to the proposed electrolysis process.

The other raw materials (Zeolite, silica, activated carbon) are sourced from commercial sources presently. We partner with external manufacturers of these materials. As the solution scales, we may acquire materials from multiple sources. The durability of the materials suggests that we do not need regular supply, such that the current sourcing strategy may be sufficient. The chemical alterations of the material required may be performed by ZS2 independently.

Waste inputs for the cement are sourced from partnership agreements with partners Progressive Planet and Baymag.

3. How much energy is required for your process to remove 1 net tonne of CO_2 right now (in GJ/tonne)? Break that down into thermal and electrical energy, if applicable. What energy intensity are you assuming for your NOAK TEA?

The process requires 6.85 GJ/tCO_2. This assumed to be powered by natural gas powered boiler to minimize reliance on Alberta's high carbon emission grid (~0.55 tCO_2/MWh). While efficiency factors have been built into this value, we understand that the final project may require more energy. We are assuming under 8 GJ/tCO_2 to remain competitive with Carbon Engineering (8.81 GJ/tCO_2). As noted previously, with certain brines tested and waste inputs we are able to remove the electrolysis step, which results in a >50% energy decrease to 3.35 GJ/tCO_2.

4. What is your proposed source of energy for this project? What is its assumed carbon intensity? How will this change over the duration of your project? (You should have already included the associated carbon intensities in your LCA in Section 3).

Natural gas is the proposed source of energy. Burning emits 1930 gCO_{2e}/m^3 CO_2, 0.037 g CH_4/m^3, 0.033 g N_2O/m^3 (Table 5, Alberta carbon offset emission factors handbook).[xiii]

26.9 m^3 natural gas is required per GJ energy.[xiv] Global warming potential of CH_4 and N_2O are 25 and 298 kgCO_{2e}/kg, respectively, per Technology Innovation and Emissions Reduction (TIER) regulation.

Desiccant and sorbent re-used for sufficient cycles to be negligible (<1%) because <0.1 wt.% wear rate (attrition). As stated for the reasons above, the project will switch to grid when the carbon intensity of the grid becomes more amenable.

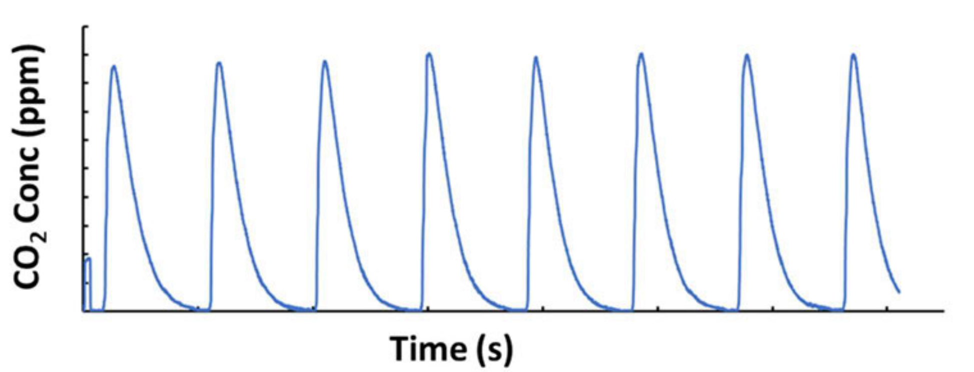
5. Besides energy, what other resources do you require (if any, such as water)? Where and how are you sourcing these resources, and what happens to them after they pass through your system? (You should have already included the associated carbon intensities in your LCA in Section 3).

Waste brine is sourced from oil and gas producers. A majority of the brine is used in the process, and excess with most minerals stripped is returned to the oil and gas producer to be disposed of (pumped underground) for a fee. If oil and gas brines become less available a focus on Lithium extraction, geothermal wells, etc. will occur. ZS2's in stream process essentially removes Mg/Ca and leaves the brines little changed.

6. Do you have experimental data describing how your system's CDR performance changes over time? If so, please include that data here and specify whether it's based on the number of cycles or calendar life.

Overall, the adsorption efficiency goes from an average > 95% carbon capture in colder winter months (November to April) to < 80% (May to October) carbon capture in warmer summer months. The temperature and relative humidity of the air input does have impacts on the CDR performance.

The number of cycles had a negligible effect on the CDR performance, as shown below. Over a year of experiments did not show substantial degradation. The sorbents and desiccants in the commercial operation are expected to be topped-up monthly and replacement may be considered every 5 years.



7. What happens to your capture medium at end-of-life? Please note if it is hazardous or requires some special disposal, and how you ensure end-of-life safety.

The choice of materials are chosen to avoid hazardous end-of-life products. Independent studies are required to be conducted for verification. The alkaline materials are consumed and regenerated, which does not pose any hazardous disposal. Acidic outputs (HCl) from the electrolyzer are used to neutralize the mineral extracted base stream and excess is sold at a discount versus conventionally used H_2SO_4 to incentivize users to purchase. 231*10^6 t H_2SO_4/yr and 20*10^6 tHCl/yr are produced and used worldwide.[xv,xvi]

8. Several direct air technologies are currently being deployed around the world. Why does your DAC technology have a better chance to scale and reach low cost than the state of the art?

One of the largest criticisms of DAC is the high cost. The primary advantage of ZS2's DAC technology is the ability to have a defined, high value end-product where CO_2 improves the final performance of the product (MBC). Our technology can capture/store up to 12% which is substantially higher than state-of-the-art technologies on the market such as CarbonCure that stores 0.2 wt.% in conventional cement. The production of $MgCO_3$ and $CaCO_3$ also enables easier transport and storage of the end captured CO_2 compared to compression and geological injection used. The end products (cement & concrete) are ranked as the most-used man-made materials on the planet behind only fresh water, so there is an abundance of opportunity and demand for scale-up.

Compared to Climeworks or Carbon Engineering, the energy consumption is lower because we are able to avoid slaker, purification, transport and calcination steps. We are also more efficient than ocean capture technologies because we use higher salt content brines, and a more energy efficient electrolysis process based on hydrogen. The low operating energy consumption reduces operating costs, which are dominant compared to the amortized capital costs.

Application Supplement: Surface Mineralization and/or Enhanced Weathering

(Only fill out this supplement if it applies to you)

Source Material and Physical Footprint

1. What source material are you using, and how do you procure it?

> Brine from oil and gas wells containing high concentrations of Na^{+}, Ca^{2+}, Mg^{2+} is attained after end of life from enhanced oil recovery. Partnerships with Veracity Energy and pending partnerships with ATCO and Lithium Bank are in place to provide the brine as operators pursue net-zero operations.

2. Describe the ecological impacts of obtaining your source material. Is there an existing industry that co-produces the minerals required?

> The oil and gas sector in Alberta creates brines with high concentrations of Na, Ca and Mg required. It is a waste off-stream at the end of life. We are diverting it from tailings ponds and waste wells which has a positive ecological impact. As Oil and Gas is phased out the technology can also use brines connected to desalination or lithium extraction.

3. Do you process that source mineral in any way (e.g., grinding to increase surface area)? What inputs does this processing require (e.g. water, energy)? You should have already included their associated carbon intensities in your LCA in Section 3.

> No processing of the brine or minerals within the brine is required at this stage. In some instances of samples received we have been able to avoid electrolysis as the natural brine is sufficiently basic to carbonate.

4. Please fill out the table below regarding your project's physical footprint. If you don't know (e.g. you procure your source material from a mining company who doesn't communicate their physical footprint), indicate that in the table below.

	Land area (km^2) in 2021	**Competing/existing project area use (if applicable)**
Source material mining	N/A	
Source material processing	N/A	

Deployment	Physical footprint not communicated	

5. How much CDR is feasible globally per year using this approach? Please include a reference to support this potential capacity.

Alberta is estimated to have 459,000 total oil wells with 156,000 active wells that produce substantial brine.[xvii] Some wells produce more than 20 m^3/d (125.8 barrels).[xviii] It has been estimated that oil wells produce approximately 18 barrels of brine per barrel of oil.[xix] The initial commercialization targets the ~364 larger wells that produce greater than 125.8 barrels per day.[xx] These estimates yield a conservative CDR capacity of 1,512,905 tCO_2/yr based on average measured mineral concentration of 31,430 mg/L. Aside from brine, the proposed technology can also be applied to ocean and seawater desalination at larger scales.

6. If you weren't proceeding with this project, what's the alternative use(s) of your source material? What factors would determine this outcome?

The waste brine would be disposed of in tailings ponds and waste wells. ZS2 is also in discussion with companies isolating lithium from brine. Removal of magnesium and calcium makes it less time and energy intensive to remove lithium from our output streams. The salty brine would be returned.

Human and Ecosystem Impacts, Toxicity Risk

7. What are the estimated environmental release rates of heavy metals (e.g. Cr, Ni, Pb, Hg)? Dust aerosol hazards? P loading to streams? How will this be monitored?

Environmental sensors will be used to monitor the toxicity and impacts of the release. GrayWolf Sensing Solutions has been contacted to help monitor outputs. Oil and gas partners may also be asked to assist in monitoring as part of the commercial agreement. Element Laboratories helps to conduct inductively coupled plasma (ICP) to quantify the heavy minerals in brines after the process. Heavy metals release (Cr, Ni) is negligible (<0.01 mg/L). The process removes ~0.2 mg/L of Pb from the waste brine.

8. If minerals are deployed on croplands, what are the estimated effects on crop yields? Include citations to support this claim. How will actual effects be monitored?

The minerals are not deployed in croplands. We are removing salts from waters and improving water ecosystems.

9. How will you monitor potential impacts on organisms in your deployment environment? (e.g. health of humans working in agricultural contexts, health of intertidal species, etc.)

The minerals are captured and used for cement production. The environmental impact on organisms are monitored through off gas testing and independent studies through verified third parties such as QAI Laboratories. Oil and gas partners are presently monitoring waste sites for their excess brine disposal. ZS2 may partner with these companies to monitor environmental impacts together. Temporal stability studies and accelerated aging experiments will be conducted on final cements to ensure no leaching of minerals.

Application Supplement: CO_2 Utilization

(Only fill out this supplement if it applies to you)

CO_2 Feedstock

1. How do you source your CO_2, and from whom? If your approach includes CO_2 capture and it's described above (e.g., general application and one of the supplements), simply respond N/A here.

N/A

2. What are alternate uses for this CO_2 stream?

The CO_2 stream produced from the proposed DAC process could be used in enhanced oil recovery, food and beverage, greenhouses, cooling & metal fabrication. ZS2 and partners use it to create CO_2 foam for cement density control. Progressive Planet, a partner in this project, has filed a patent for the methodology to create CO_2 based foam for magnesium based cement. Other alternate uses for the created CO_2 stream include geological injection in underground formation suitable for CO_2 sequestration, sequestering of CO_2 during the mixing and curing of Portland cement (similar to Carbon Cures process) or standard tank storage.

Utilization Methods

3. How does your solution use and permanently store CO_2? What is the gross CO_2 utilization rate? *(E.g. CO_2 is mineralized in Material at a rate of X tCO_2 (gross) / t storage material).*

This solution permanently stores CO_2 by way of mineralization. The final chemical form of the sequestered CO_2 is mineralized Magnesium and Calcium carbonate (~0.5 tCO_2/t-carbonates). CO_2 is extremely stable in this form as described above.

CO_2 utilization rates will be 2740 $kgCO_2$/d and permanently sequestering into ~32,040 kgMBC/d. This results in a 0.1-0.15 tCO_2/tMBC.

4. What happens to the storage material (e.g. concrete) at the end of its service life, and how does that impact its embodied carbon storage over time? How do you know?

The carbonates remain 99% stable over the expected lifetimes. The carbonates are stable at temperatures <300 °C which represents the initial off-gassing temperature of $MgCO_3$.[xxi] The complete loss of CO_2 typically requires temperatures of 500°C. Once cooled the cement is expected to re-carbonate over time.

At the end of life, MBC can be repurposed by grinding and reintroducing a portion of the MBC into the new product batch. The recycled MBC content is limited to maintain quality standards. Excess recycled MBC could be used as fertiliser in the agriculture industry, since magnesium is an essential nutrient for plants.

5. How do you ensure that the carbon benefits you are claiming through a CO_2 utilization process are not double counted? *(E.g. If sourcing CO_2 from a DAC system, or selling your product to a user interested in reducing their carbon footprint, who claims the CDR benefits and how could an independent auditor validate no double counting?)*

ZS2 proposes an all-in-one technology solution to go from DAC to CO_2 sequestered in MBC. The carbon benefits are only claimed once based on the captured CO_2 content that is used to carbonate Ca and Mg to make $CaCO_3$ and $MgCO_3$ respectively. ZS2 claims the CDR benefits of the end product. The builders and construction industry using the products would not claim the CDR benefits, but may be offered a portion of the credit as a rebate through ZS2 as an incentive to work with a new product. The incentive for customers of the product is to market the more sustainable products, and the enhanced mechanical properties (primarily compressive strength) that result in increased durability. They may advertise the usage of CO_2-sequestered products, but not monetize it. These will be strictly described in our terms and conditions of our projects.

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[i] https://chem.libretexts.org/Bookshelves/Introductory_Chemistry/Introductory_Chemistry_(CK-12)/23%3A_Electrochemistry/23.10%3A_Electrolysis_of_Molten_Salts_and_Electrolysis_of_Brine

[ii] https://doi.org/10.1073/pnas.2114680119

[iii] https://raw.githubusercontent.com/stripe/carbon-removal-source-materials/master/Project%20Applications/Fall2021/%5B44.01%5D%20Stripe%20Carbon%20Removal%20Purchase%20Application.pdf

[iv] https://www.sciencedirect.com/science/article/pii/S2542435118302253

[v] https://www.researchgate.net/publication/236900871_Life_Cycle_Assessment_of_Sodium_Hydroxide

[vi] https://www.sciencedirect.com/science/article/abs/pii/S0959652618325745

[vii] https://open.alberta.ca/publications/carbon-offset-emission-factors-handbook-version-3

[viii] https://energyrates.ca/natural-gas-conversion-gigajoule-m3/

[ix] https://www.sciencedirect.com/science/article/abs/pii/S0196890406000987

[x] https://doi.org/10.1016/j.joule.2018.05.006

[xi] https://open.alberta.ca/dataset/de4e3106-d682-4e10-a898-14ea5fdfbe8f/resource/2e0df7e0-7604-4a32-b0ee-621799a4d1dc/download/24-not-every-oil-well-is-a-gusher-formatted.pdf

[xii] https://www.ag.ndsu.edu/publications/environment-natural-resources/environmental-impacts-of-brine-produced-water

[xiii] https://open.alberta.ca/publications/carbon-offset-emission-factors-handbook-version-3

[xiv] https://energyrates.ca/natural-gas-conversion-gigajoule-m3/

[xv] https://www.essentialchemicalindustry.org/chemicals/sulfuric-acid.html

[xvi] https://en.wikipedia.org/wiki/Hydrochloric_acid
[xvii] https://www.alberta.ca/oil-and-gas-liabilities-management.aspx
[xviii] https://open.alberta.ca/dataset/de4e3106-d682-4e10-a898-14ea5fdfbe8f/resource/2e0df7e0-7604-4a32-b0ee-621799a4d1dc/download/24-not-every-oil-well-is-a-gusher-formatted.pdf
[xix] https://www.ag.ndsu.edu/publications/environment-natural-resources/environmental-impacts-of-brine-produced-water
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