The Midwest Nuclear Regional Direct Air Capture Hub (MINDAC)

DE-FE0032386

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2024 FECM/NETL Carbon Management Research Project Review

August 9, 2024

Objective

Explore the feasibility of a nuclear-powered DAC hub in the Midwest and develop an ownership structure and business model.

Evaluate, and develop a model for how we can integrate the efforts of: (1) capture technology solutions providers, including for the frontend (e.g. contacting), concentrated point source CO_2 release, and water/humidity management; (2) access to CO_2 pipelines and to eventual sequestration sites; (3) storage/utilization technology providers; (4) expertise in DAC site assessment and development; (5) expertise in scaling/manufacturing at scale; (6) financing providers (including parties equipped to monetize carbon credits); and (7) partners bringing experience in community, labor, and diversity, equity, and inclusion (DEI) engagement.

Project Budget

Total Project Budget: $3,829,387

	Federal Budget	Cost Share
Budget Period 1: ***May 2024*** *- Jan 2025*	$1,098,165	$309,658
Budget Period 2: *Feb 2025 – April 2026*	$1,871,312	$550,252
Total Project	$2,969,477	$859,910

Northwestern University

- Top 10 US research institution
- $1 billion in annual research expenditures
- MINDAC is housed within the Paula M. Trienens Institute for Sustainability and Energy.
- The project is also supported by the Northwestern-Argonne Institute of Science and Engineering (NAISE)
- Together, Trienens and NAISE have managed over $14 million in large-scale, multi-institutional projects in the past five years

Each partner brings deep and complementary expertise

CCUS Technology Developers:

- Avnos
- RepAir
- LanzaTech

- Constellation: Provision of nuclear power
- Argonne National Laboratory: Process scale up
- 3M: Materials Manufacturing
- TotalEnergies: CCS
- Siemens: CCS Infrastructure
- Energy Capital Ventures: Financing and markets; technology maturation

COMPANY INTRODUCTION

AVNOS, INC.

AVNOS EXECUTIVE SUMMARY

Hybrid Direct Air Capture (HDAC) Technology Captures Water *and* CO2

HDAC IS A TRANSFORMATIONAL ADVANCE IN THE DAC LANDSCAPE

Produces Water

- Inverts DAC Water Paradigm

Proprietary Technology

- Exclusive Intellectual Property

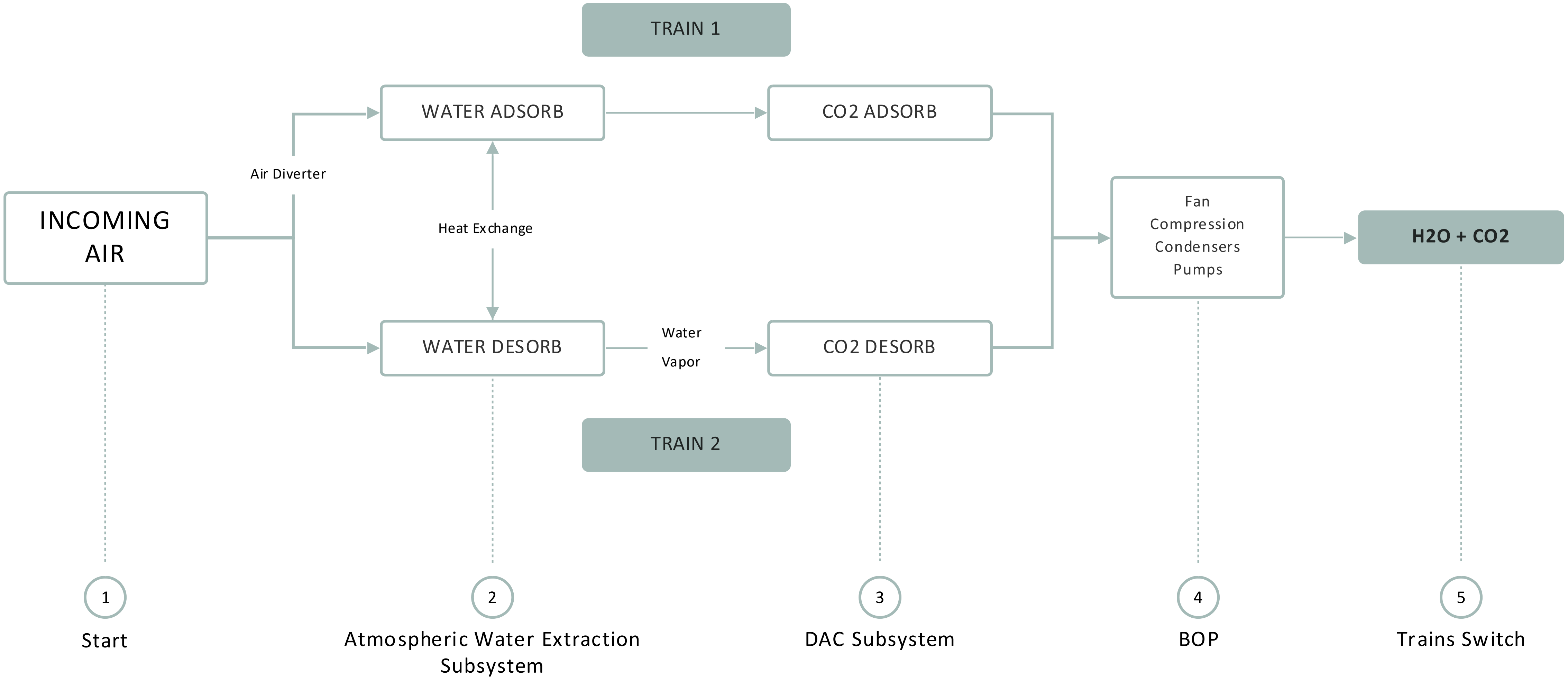
Moisture Swing CO2 Adsorption

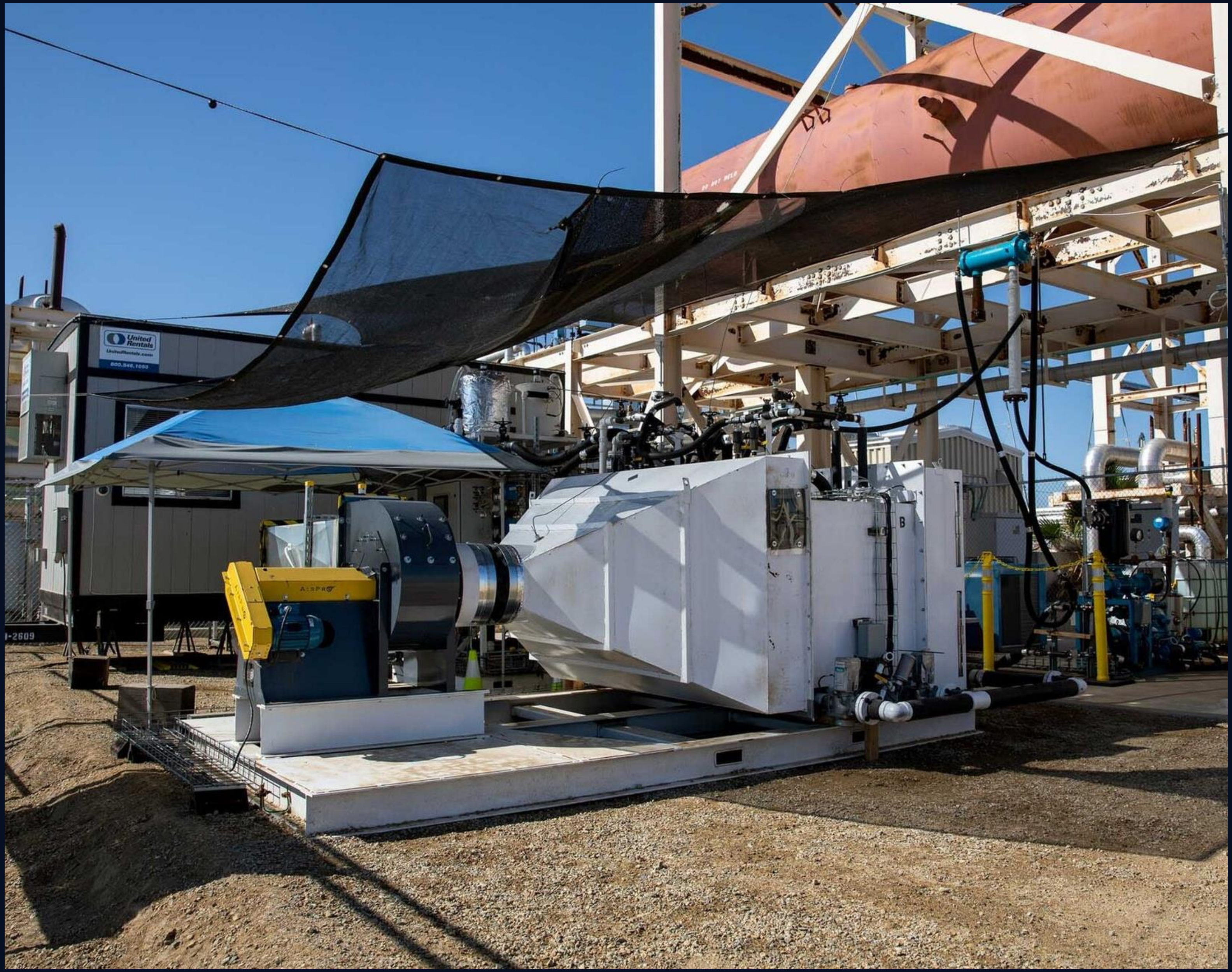
- Eliminates Heat Input

Lowest Cost in DAC

- ~$95/ton *Nth Plant* Levelized Cost of Capture

THE HDAC PROCESS





FIRST FIELD-DEPLOYED PILOT SYSTEM

DOE SPONSORED $3.2M, 30TPA UNIT

Bakersfield, CA

TRL-6

U.S. Department of Energy

30 tons-CO2 per year pilot unit

First field deployment

$3.2M DOE Sponsorship

Operating

Bakersfield, CA

U.S. Office of Naval Research

450 tons-CO2 per year demo unit

Commercial "Module"

$4.8M ONR Sponsorship

Commissioning 1Q25

Bakersfield, CA

Commercial Reference Unit

4,500 tons-CO2 demo system

10 Modules

$20M Commercial Sponsorship

Target Commissioning: 1H26

Bakersfield **OR** Louisiana

Efficient. Scalable. Affordable.

Carbon Capture

Amir Shiner, Co-Founder & CEO
Jean-Philippe Hiegel, Head of Strategy & Growth

RepAir

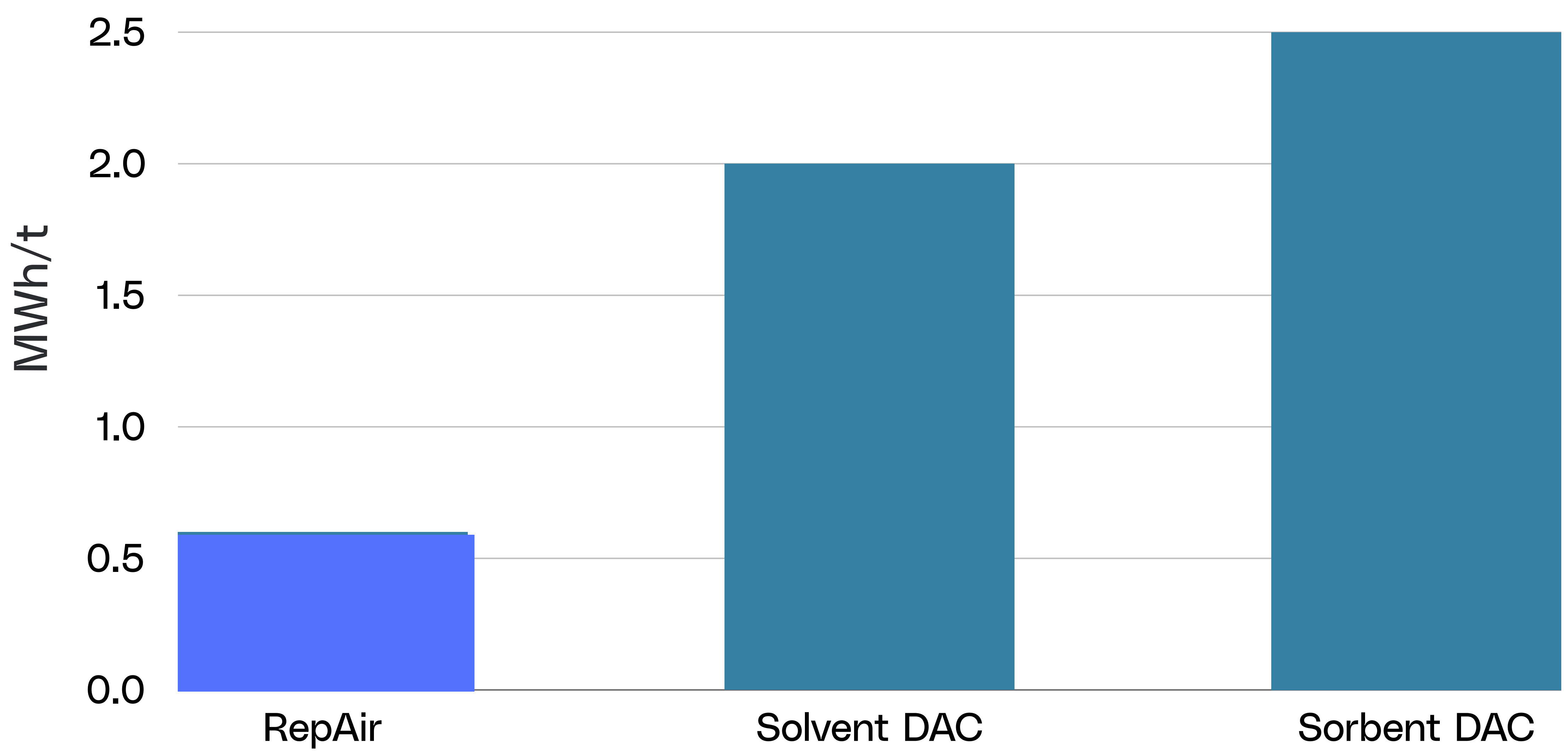
1. LOWEST ENERGY CONSUMPTION REGARDLESS OF ENERGY SOURCE

Conventional DACs consume up to 4x the energy.

RepAir:

- Lowest energy consumption <**600 kWh/t** demonstrated by 5,000 hours of continuous data
- We can deploy **today** regardless of the energy source, maintaining carbon net-negativity

Total Energy Target for 1 ton Net CO2 Removed



RepAir

2. OPTIMAL APPROACH TO REACH SCALE

Standardized StackDAC Modules

- Seamlessly stacked interlocking modules

Mass Manufacturability

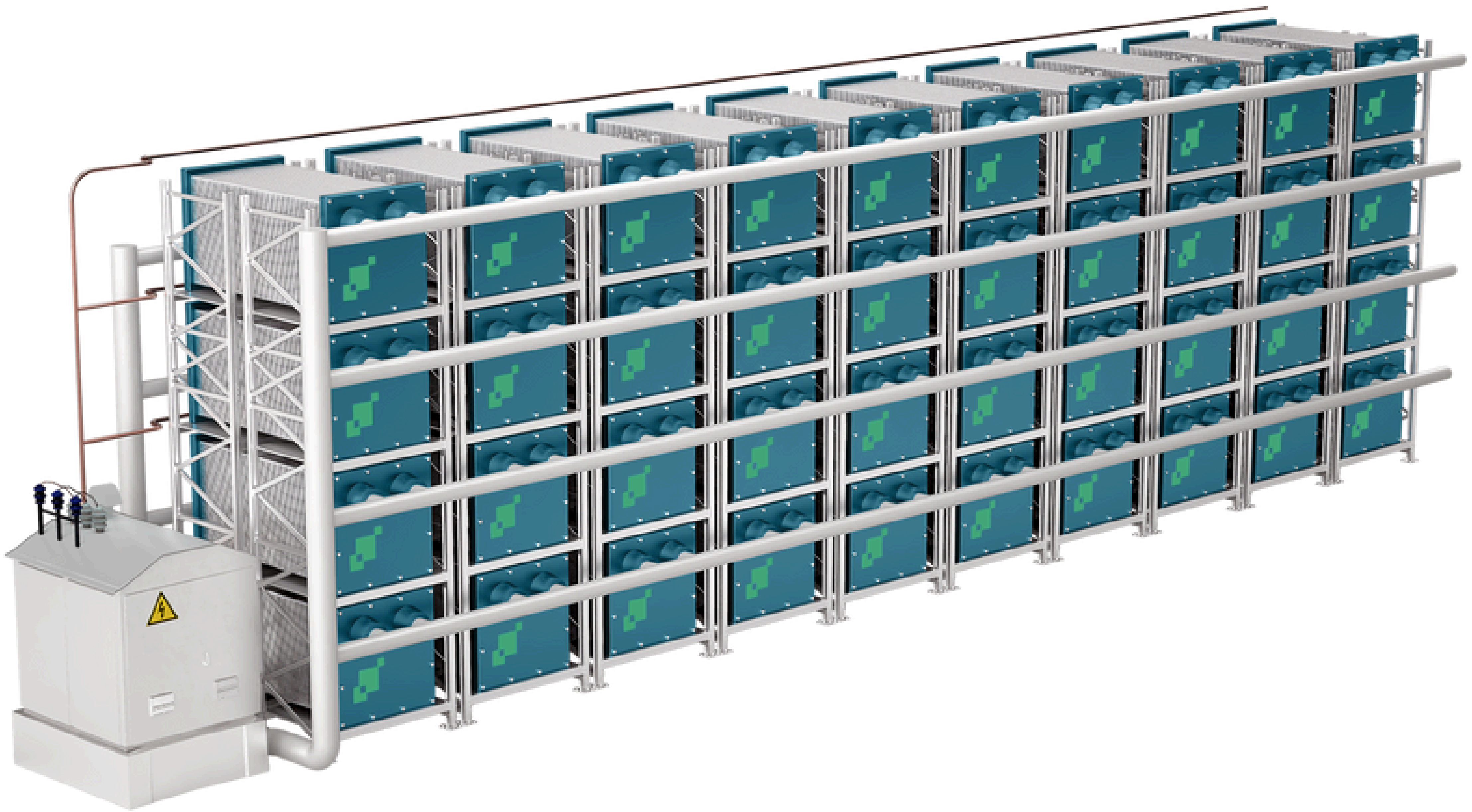
- Simplistic, novel design for mass manufacturing
- Build giga factories inspired by battery technology

Easy Deployment

- StackDAC approach for quickest, most efficient, cost-effective and safe deployment
- No solvents, no liquids, no heat (ambient temp.)

Quick ramp-up/shutdown

- Operates at a flip of a switch
- Fast response to intermittencies



PATENTED, EFFICIENT ELECTROCHEMICAL TECHNOLOGY

How it works

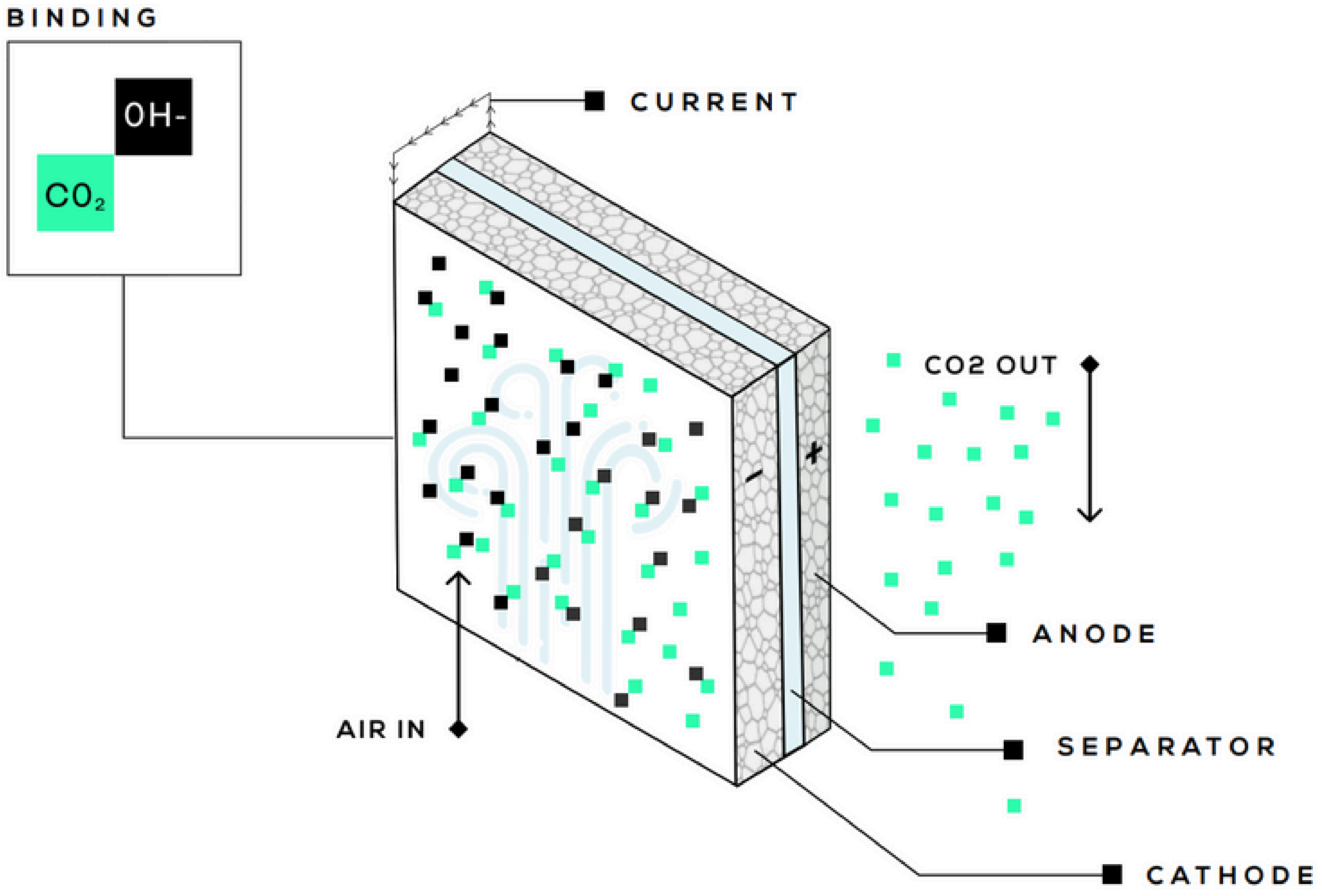
Two identical electrodes & a selective separator

Humidified air flows on the surface of the cathode

Electric current is applied, triggering an electrochemical reaction

CO2 molecules are transferred selectively from one side of the cell to the other

Pure CO2 gas at 98%+ purity is drawn out while depleted air goes back into the atmosphere



RepAir

THE MASS MANUFACTURABLE STACKDAC MODULE

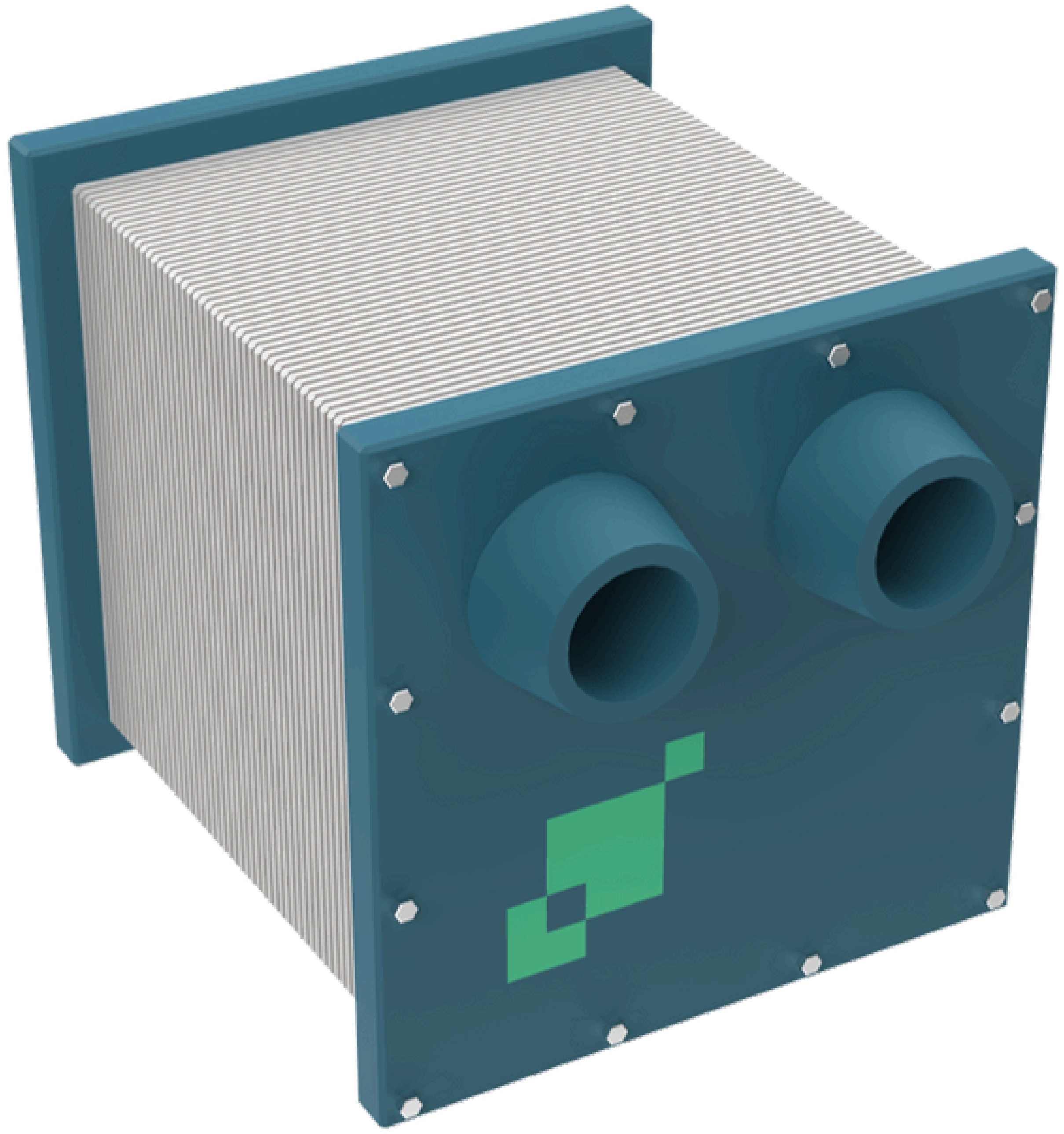
Capture capacity: **50 - 70 tons of CO2 per year**

Number of cells: **200 - 300**

Cell active area: **0.8 - 1.2 m2**

Cell hardware material: **recycled polymers**

Dimensions: **2.8m x 1.4m x 1.4m for a 300 cell stack**



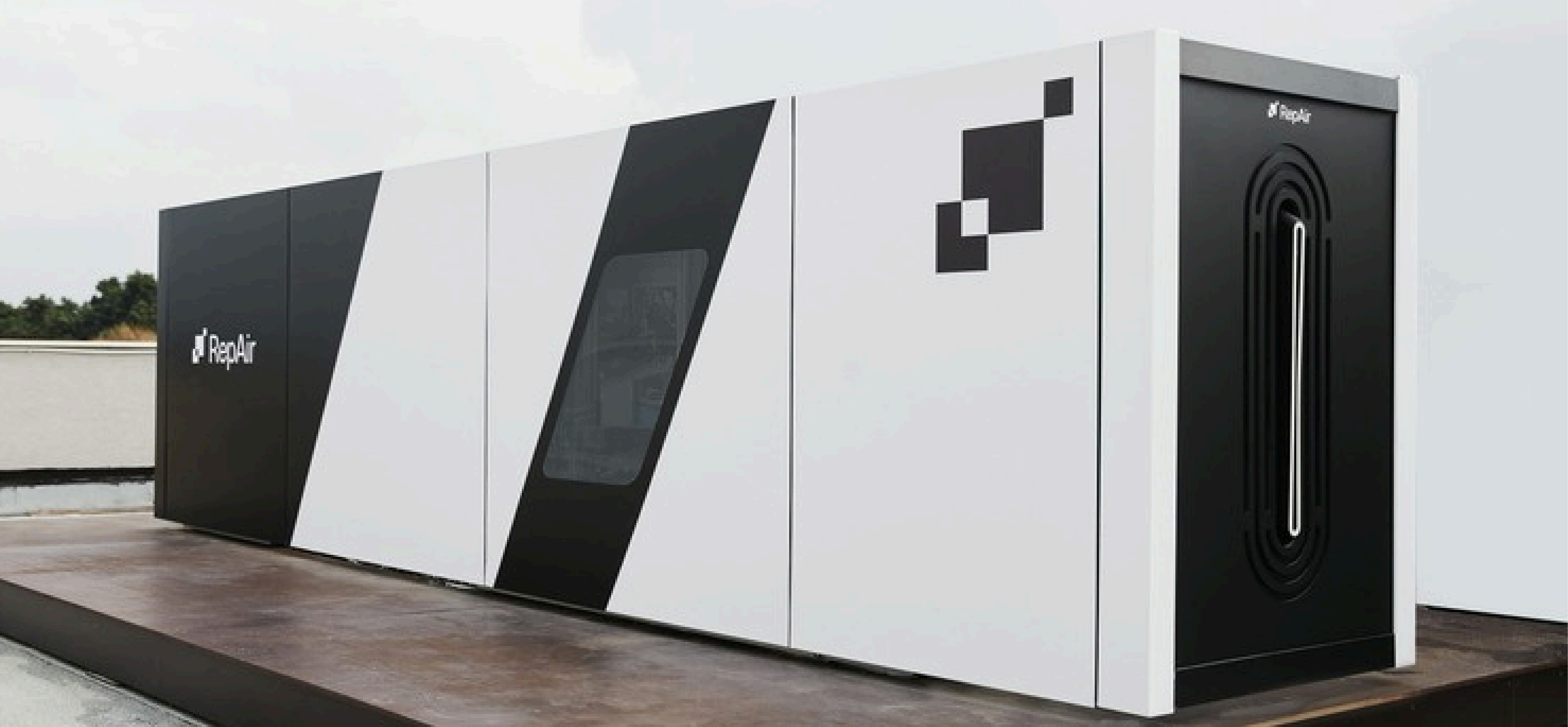
ESTABLISHING MASS PRODUCTION CAPABILITIES WHILE LEVERAGING EXISTING, SCALED TECHNOLOGIES

Cell architecture inspired by alkaline exchange membrane fuel cells

Nickel electrodes already commercialized at the giga scale (battery industry)

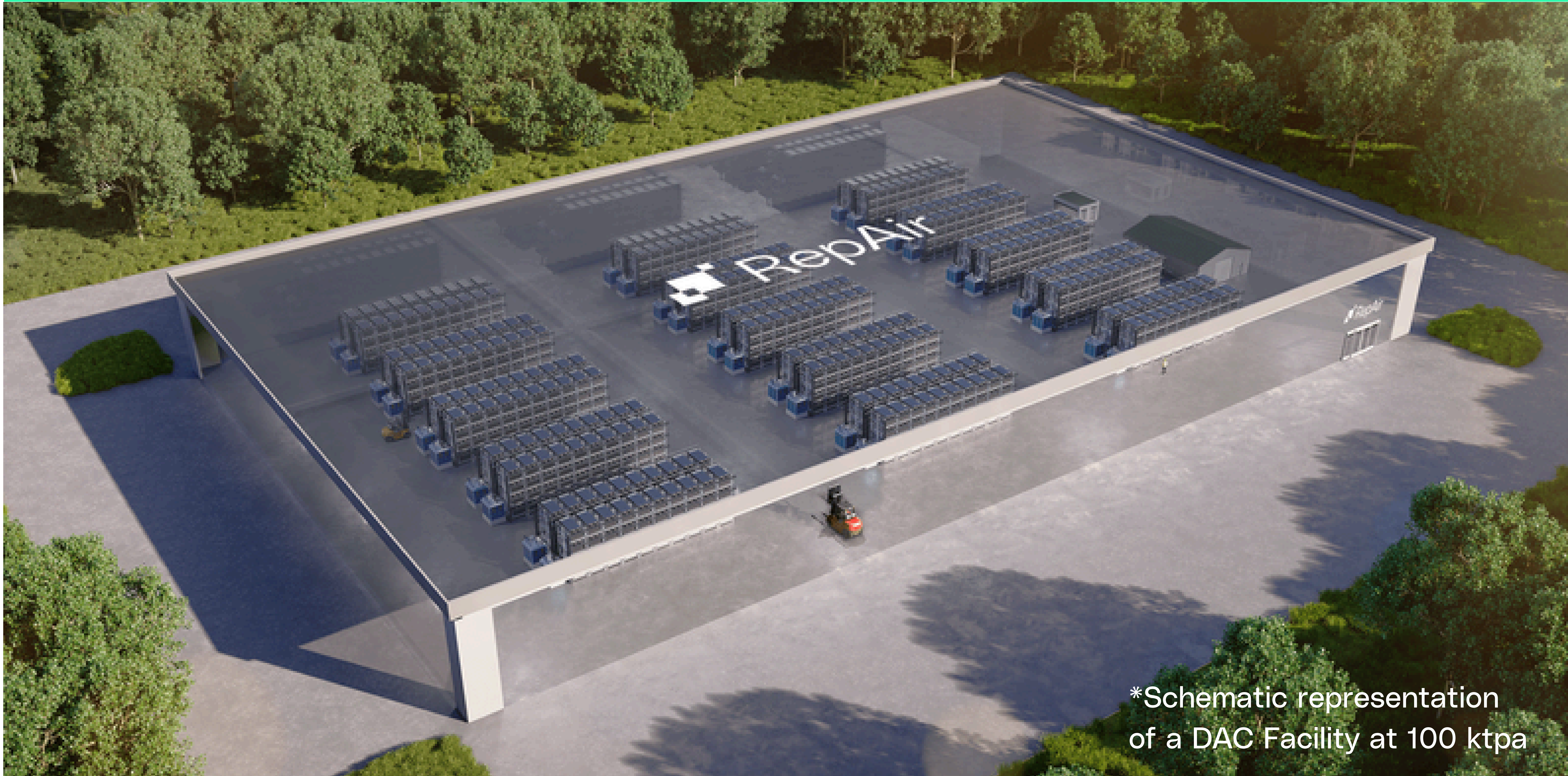
Widely used plastic injection molding for cell hardware

FIELD PILOT - TRL 6 VALIDATED TECHNOLOGY



GLOBAL COMMERCIAL GROWTH

UNIQUELY POSITIONED TO REACH THE MEGATON SCALE



*Schematic representation
of a DAC Facility at 100 ktpa

LANZATECH CAPTURES & TRANSFORMS CARBON

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Background and Summary

LanzaTech's role in MINDAC

- In MINDAC LanzaTech is a utilizer of CO_2
- The LanzaFlex™ biomanufacturing process converts CO_2 into ethanol using a proprietary organism and reactor system.
- CarbonSmart™ ethanol is a building block for high value sustainable materials and fuels.
- Recycling CO_2 displaces the need for fossil carbon allowing it to stay in the ground.

LanzaTech

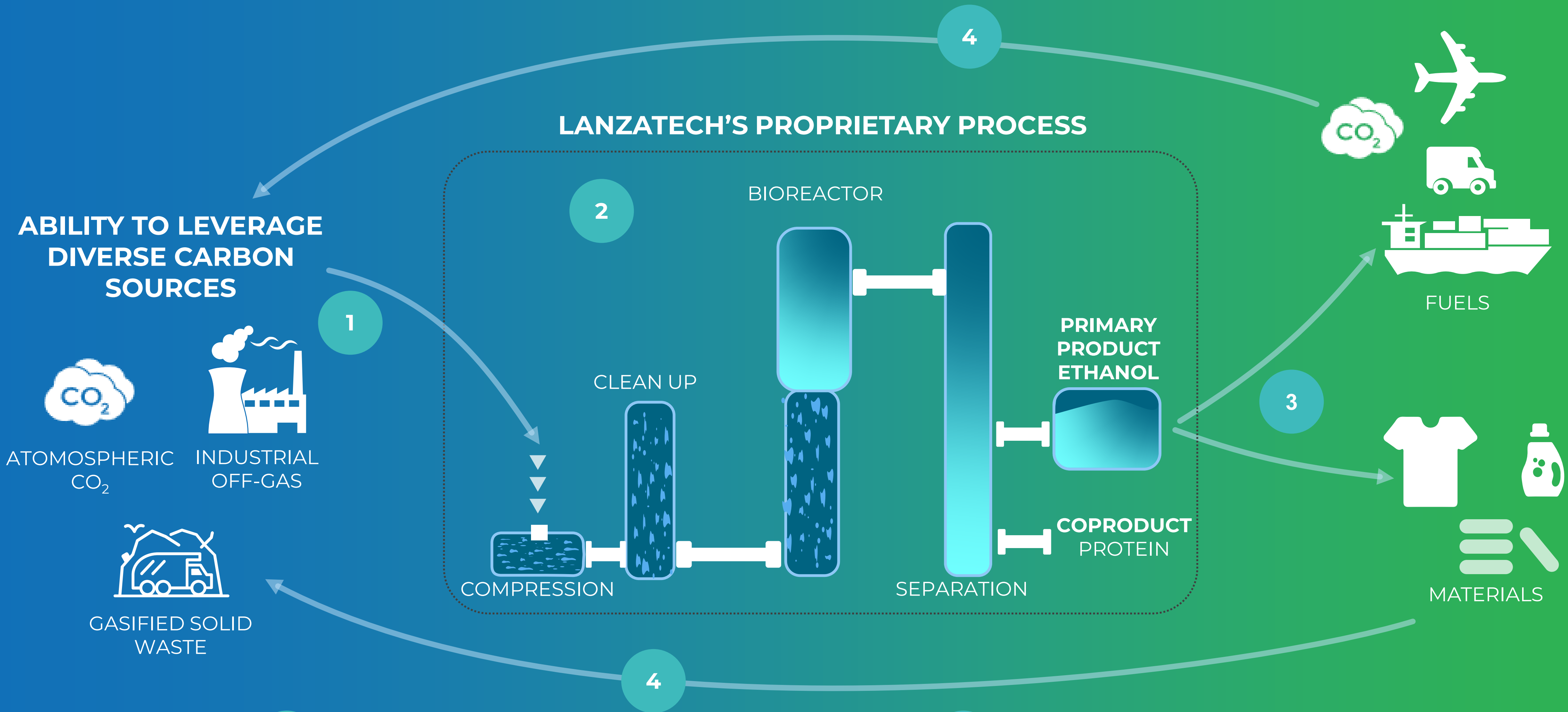
The Science Behind LanzaTech

How the LanzaFlex™ process works

- The LanzaFlex™ biomanufacturing process converts CO_2 into ethanol using a proprietary organism and reactor system (next slide).
- Since CO_2 doesn't contain energy, low carbon intensity hydrogen—such as green H_2—is used to provide energy to the organism.
- The process operates under mild conditions.
- The process is continuous and robust.

LanzaTech

A NOVEL CIRCULAR SOLUTION, RECYCLING WASTE CARBON INTO VALUABLE PRODUCTS



1 Carbon rich waste gases enter compressor. Solids must first be gasified.

2 LanzaTech process occurs within proprietary bioreactor; microbe consumes carbon in gas and produces ethanol and protein coproduct.

3 Ethanol is an intermediate product that can be further upgraded and converted into high value sustainable materials and fuels.

4 Circularity-enabled with solid waste carbon gasified and emitted carbon captured and returned to the process.

Advantages

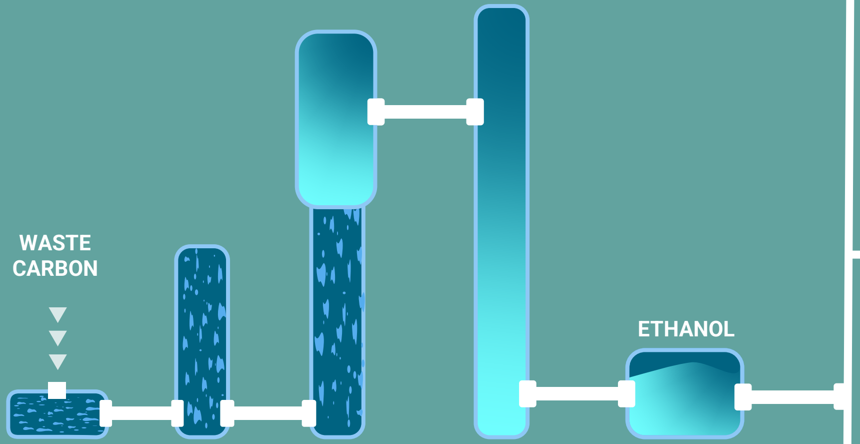
LanzaTech biomanufacturing creates value from CO_2

- Using gas fermentation to recycle CO_2 adds value in two ways.
- CarbonSmart™ products create a revenue stream.
  - Meeting a growing demand for sustainable products.
- Fossil carbon stays in the ground.
  - Production of fossil ethylene is GHG intensive.

LanzaTech

DEMAND FOR SUSTAINABLE PRODUCTS CREATES DEMAND PULL FOR ADDITIONAL LICENSED PLANTS

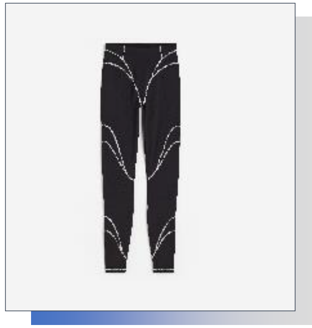
LanzaTech



LanzaTech's **commercial technology** created the chemical building block (ethanol) for this CarbonSmart™ product portfolio

PRODUCTS MADE FROM CARBON EMISSIONS

TEXTILES



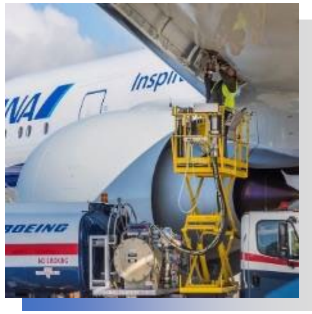
SHOE SOLES

PACKAGING

CLEANING PRODUCTS

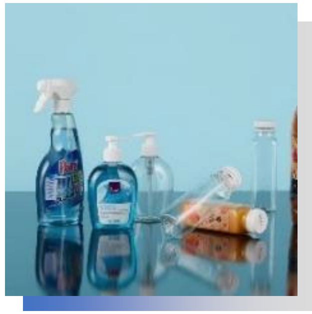
FRAGRANCES

SAF



DETERGENTS

CONTAINERS



SURFACTANTS

COTY SINCE 1904 · ZARA · MIGROS · mibelle GROUP · CRAGHOPPERS · Unilever · L'ORÉAL · On · virgin atlantic · H&M MOVE

LanzaTech

Being CarbonSmart™

In a CarbonSmart™ world, carbon waste is transformed to nearly everything we use in our daily lives

LanzaTech generates profitable ROIs for partners, accelerating adoption of CarbonSmart™

Products with CarbonSmart™

$1T Addressable Market[2]

Potential for **>1 billion** tons/year of product from waste feedstocks

[1] LanzaTech management; [2] Per Grand View Research (2019), Allied Market Research (2018), The Business Research Company (2019), Technavio (2019), Fortune Business Insights (2019) and Knowledge Sourcing Intelligence (2020).

LanzaTech

https://ir.lanzatech.com/static-files/21eb4d1f-3e47-4224-9957-03bfb658aeab

Challenges

- Green hydrogen is an emerging field.
- CarbonSmart™ products have a green premium.
- Policy for products is not developed in the way it is for fuels.

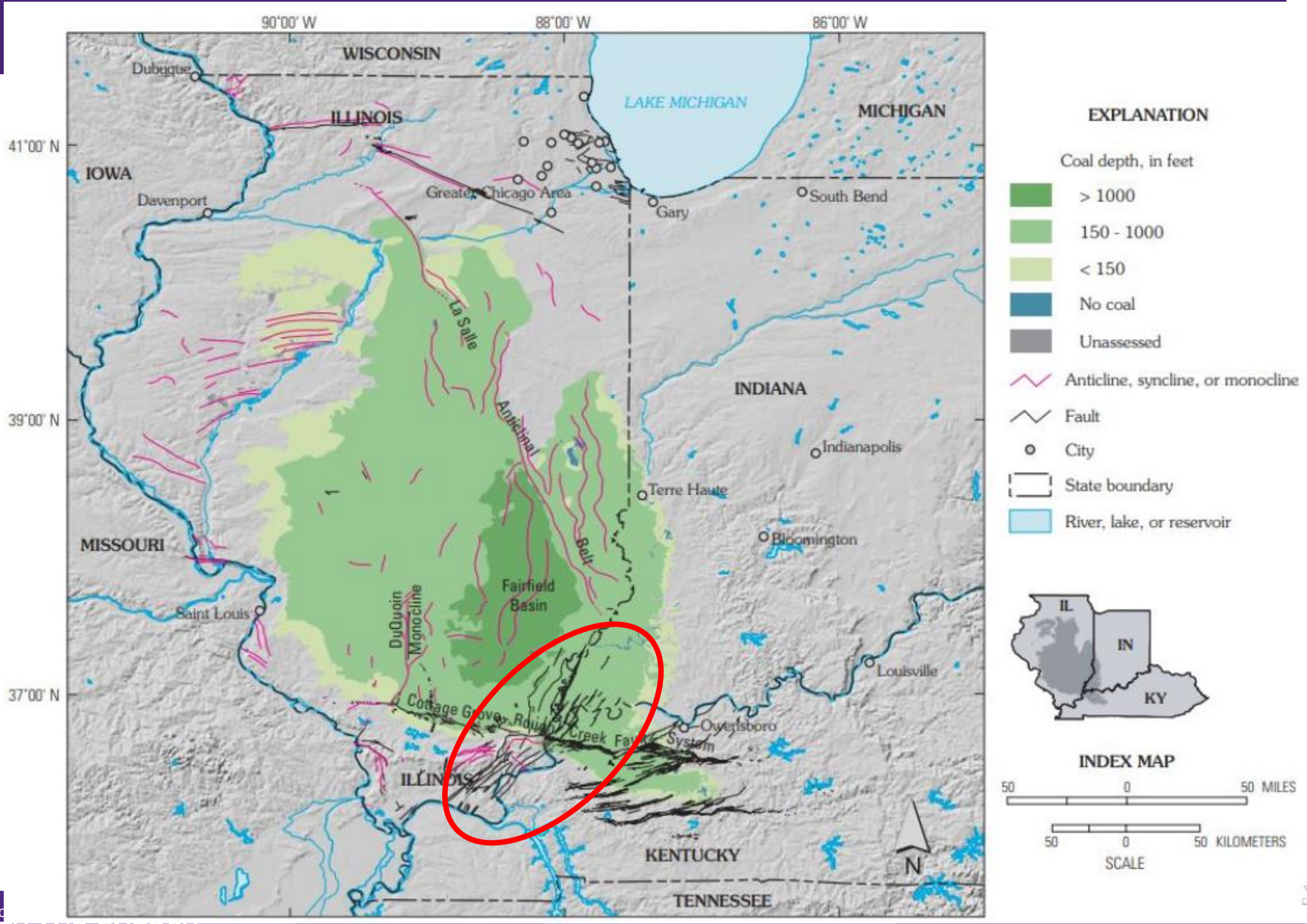
Phase 0 feasibility studies will address key challenges

- Technology and Markets
  - Core unit life time
  - Electrode manufacture and stack assembly in the short term
  - Long-term scale up and global supply chain
  - Cost of key inputs (green H_2)
  - Green premium effect
  - Costs of key materials
- Site Feasibility
- Scale up and financial viability

Illinois Basin

Paleozoic structural basin

Favorable location for CO_2 storage due to regional structure, presence of suitable reservoirs at sufficient depth, presence of seal rocks, lack of significant faulting in the basin center, etc.



Hatch and Affolter, 2002

Milestones

M1. [12/17/2024]: Submit Continuation Application that includes the following elements:

- Description of the selected DAC Hub owner and team, site location, CO_2 transport routes, CO_2 storage sites, and CO_2 conversion technologies (if applicable) for the pre-FEED study to be completed in Phase 0b.
- Discuss the current status of the CO_2 storage site(s), including development, characterization, and permitting activities conducted to date.
- Discuss the current status of, and plans for submitting, the UIC Class VI permit to construct application. Recipients must provide an initial design for the DAC Hub BOP.
- Selection of the anchoring DAC technology(ies) (i.e., minimum capacity of at least 50,000 tonnes CO_2 captured from the atmosphere (50 KTA)) for the pre-FEED study to be completed in Phase 0b**.**
- Conceptual design for the initial DAC Hub capacity (minimum 50 KTA CO_2) integrated with required CO_2 storage and/or CO_2 conversion (if applicable).
- If applicable, selection of the CO_2 conversion technology(ies) for the pre-FEED study to be completed in Phase 0b.
- Data tables with preliminary estimates for the DAC Hub, and the selected DAC and CO_2 conversion (if applicable) technologies.
- Description of safety culture, discussion of security considerations, a permitting workflow overview.
- DAC and CO_2 conversion (if applicable) Technology Maturation Plan(s)
- Preliminary Life Cycle Analysis
- CBP Development Proposal (CBPDP). → *Under development, no CBP results to report at this meeting*
- Budget and supporting justification for Phase 0b
- Description of plans for Phase 0b

M2. [4/30/2026]: Submit final data table for each technology in the hub along with the overall hub.

Project success

Established concept of hub formation and pathway and to an economically viable carbon capture hub that achieves sizeable greenhouse gas emissions reductions that will bring community benefits especially in the form of new jobs.

Progress and current status

Project is in early stages

Kickoff meetings and initial setup of TEA/LCA are the primary accomplishments to date

Lessons Learned

- This project is in very early stages
- Main lesson learned is around building relationships and establishing connections as a newly-formed team arising from multiple interactions among subgroups of partners

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Organizational Chart and Project Partners

Lead PI
Northwestern University (NU)
Prof. Jennifer Dunn

Project Manager
Ke Xie (NU)

EMP / Management Consultant
In progress

Sub Group 1
Capture Technology Integration
Farha (NU)
Urgun-Demirtas (ANL)

Sub Group 2
Post-Capture
Sageman (NU)
Urgun-Demirtas (ANL)
Zhou (Siemens)

Sub Group 3
Cross-Cutting Areas
Sargent (NU)
Reguant (NU)
Urgun-Demirtas (ANL)
Zhou (Siemens)

Partner Steering Committee: Siemens, Constellation, TotalEnergies, 3M, Energy Capital Ventures, LanzaTech, RepAir, Avnos

Tasks and Timing

			Phase 0a								Phase 0b															
			2024								2025												2026			
			Q1			Q2			Q3			Q4			Q5			Q6			Q7			Q8		
Phase	Task	Task Name	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4
0	1	Project Management and Planning			X																					
0	1.1	Project Management Plan	X																							
0	1.2	Business Plan																					X			
0	1.3	Financial Plan																					X			
0	1.4	Technology Maturation Plan								X													X			
0	1.5	Community Benefits Plan								X													X			
0a	2	DAC Hub Concept Formation								C																
0a	3	Geographic Region Definition								C																
0a	4	CO2 Storage Site Assessment and Selection								C																
0a	5	Initial Design for DAC Hub Balance of Plant								C																
0a	6	Anchoring DAC Technologies Selection Based on TEA								C																
0a	7	Evaluate CO2 Conversion Technology and Storage								C																
0a	8	Conceptual Design of DAC Hub								C																
0a	9	Safety, Security, and Regulatory Requirements								C																
0a	10	Preliminary LCA								X																
0a		Continuation Report (includes data tables)								X																
0b	11	MINDAC Hub Concept																								
0b	12	Description of Anchoring DAC Technologies and Conversion Technology																								
0b	13	MINDAC Hub Balance of Plant Conceptual Design																					X			
0b	14	Pre-FEED study for Integrated DAC system																					X			
0b	15	Preliminary LCA for DAC Hub																					X			
0b	16	EHS Risk Analysis																					X			
0b	17	Storage Field Development Plan																					X			
0b	18	Integrated Project Schedule																					X			
0b		Finalize Data Tables																								X

C Part of continuation report