Carbon Reimagined
Our Direct Air Capture Solution

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Co-Founder and Chief Technology Officer
Sustaera

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Pittsburgh, PA 15222
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Susteon Inc. (Parent Company of Sustaera)

MISSION
To develop and deploy decarbonization technologies by enabling disruptive innovations in CO₂ capture and utilization and carbon-free H₂ production

APPROACH
De-risk technologies through extensive prototype development and testing while securing a strong IP position

PROCESS

Connect
- Academic / National Labs
- Dept of Energy (+ other Govt. agencies)
- Industry
- Private Sector / VC

Create
Carbon Dioxide
- CO₂ Capture
- CO₂ Utilization

Hydrogen
- Blue/Green Production
- Methane Pyrolysis

Commercialize
- Discovery & Commercial Value Decision
- Leverage Industry and Labs to Fail Fast
- Understand and Develop Go-To-Market Plan

RESEARCH & DEVELOPMENT TEAM

Raghbir Gupta
President & Co-Founder

S. James Zhou
Senior Director

Cory Sanderson
Process Technologist

Vasudev Haribal
Research Engineer

Aravind Rayer
Research Engineer

Jonathan Peters
Research Engineer

S. James Zhou
Senior Director

Cory Sanderson
Process Technologist

Vasudev Haribal
Research Engineer

Aravind Rayer
Research Engineer

Jonathan Peters
Research Engineer

Business & Operations Team

Shantanu Agarwal
President / Co-Founder

Rich McGivney
Chief Financial Officer

Sudarshan Gupta
Commercial Lead

Brian Alexander
Director, Contracts & Legal Affairs

Arleane McKiver
Executive Assistant

Arnold Toppo
Research Engineer

Tyson Lanigan-Atkins
Materials Scientist

Jian Zheng
Sr. Research Engineer

Andrew Tong
Sr. Research Engineer

J.P. Shen
Sr. Chemist

Gary Howe
Lab Director
## CO₂ Capture / Removal Experience of Susteon Team

<table>
<thead>
<tr>
<th>Project</th>
<th>TRL Advance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development of Na-based sorbents for coal combustion flue gas</td>
<td>TRL2 → TRL6</td>
</tr>
<tr>
<td>Development of non-aqueous solvents with low regeneration energy</td>
<td>TRL2 → TRL7</td>
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<tr>
<td>Composite membranes for flue gas CO₂ capture</td>
<td>TRL2 → TRL4</td>
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<tr>
<td>Hybrid membrane/solvent contactor for CO₂ capture from natural gas and syngas</td>
<td>TRL3 → TRL7</td>
</tr>
<tr>
<td>Hybrid membrane/solvent contactor for CO₂ capture from flue gas</td>
<td>TRL3 → TRL5</td>
</tr>
<tr>
<td>Design, construction, and operation of a 1,000 ton/day CO₂ capture plant at Tampa Electric</td>
<td>TRL5 → TRL8</td>
</tr>
<tr>
<td>Development, design, construction, and operation of a 1M TPA CO₂ capture VSA from SMR syngas at Port Arthur, TX</td>
<td>TRL5 → TRL8</td>
</tr>
<tr>
<td>Development of CO₂-organic binding liquids for CO₂ from syngas in H₂/NH₃ plants</td>
<td>TRL2 → TRL4</td>
</tr>
<tr>
<td>Development of high-temperature polymeric membranes for CO₂ separation from syngas</td>
<td>TRL3 → TRL6</td>
</tr>
<tr>
<td>Development of structured sorbents for flue gas CO₂ capture</td>
<td>TRL3 → TRL5</td>
</tr>
<tr>
<td>Development of dual function materials for direct reactive capture of CO₂ from air</td>
<td>TRL2 → TRL4</td>
</tr>
<tr>
<td>Development of catalytic additives for lowering regeneration energy for amines</td>
<td>TRL2 → TRL4</td>
</tr>
<tr>
<td>Flexible CO₂ capture with integration of renewable energy on the grid</td>
<td>TRL3 → TRL5</td>
</tr>
<tr>
<td>CO₂ capture from automobile exhaust</td>
<td>TRL3 → TRL5</td>
</tr>
</tbody>
</table>

1000 ton/day of CO₂ capture plant at Tampa Electric Company, Mulberry, FL
How We Started

- Dr. Robert Farrauto at Columbia University spent over **30+ years working on optimizing monoliths** during his time at BASF
- Dr. Raghubir Gupta spent the last **10+ years working on sodium carbonate** for a variety of sorbent applications

- Dr. Farrauto at Columbia University developed Dual Functional Materials (DFMs) to capture CO\textsubscript{2} and regenerate them to produce renewable natural gas (RNG)
- Susteon partnered with Columbia University to further develop the DFM materials for reactive CO\textsubscript{2} capture

- Susteon developed a new process design for a scalable DAC process.
- Screened numerous sorbent compositions and identified sodium carbonate-based materials.

- Conducted extensive lab and bench scale studies to optimize process conditions and invented the chemical pathway to minimize the regeneration energy.
- Developed a design of a modular DAC system
- Spun out Sustaera in June 2021

**2019**

- DOE / FECM SBIR Phase I and II grants (DE-SC20795) = **$1.85M**

**2020**

- DOE FE00032118 grant = **$1.725M**

**2021**

- Closed Series A with leading Climate Tech VCs = **$10M**
Launch of Sustaera – DAC 2.0

Our Solution

Direct Air Capture using:
- Non-amine sorbent for CO₂ capture
- An integrated selective heating mechanism
- A low-pressure drop support

Resulting in:
- A pathway to < 2,000 kWh/ton of CO₂
- CapEx target <~$600/ton-yr

Key Differentiators

1. Energy provided exclusively by renewable sources (solar, wind)
2. Abundantly available, low-cost capture agent (alkali metal based)
3. Low energy of desorption by controlling the chemistry (~-65 kJ/mol)
4. Fast kinetics of adsorption and desorption
5. Beneficial effect of moisture in ambient air
6. Innovative, highly efficient heating to minimize heat losses
7. Scalability using existing supply chain
8. Strong IP portfolio

Conceptualization
Green Climate Adaptation

Gates-Backed Fund Invests in Carbon Capture Startup Sustaera

The company, which completed a $10 million funding round, has secured Stripe as its first customer.

- Raised ~$4.575M in Grant Funding from:
  - U.S. Department of Energy
  - Breakthrough Energy
  - XPRIZE

- Raised $10M in Series A funding from:
  - Grantham Foundation for the Protection of the Environment

- Sold 5,700+ tons of CO₂ Removal to:
  - stripe
  - shopify
Experienced team with over 20+ R&D projects in CO₂ capture space; 100+ combined years experience in technology development and research; 30+ years of combined experience in start-ups, managing companies; Expertise in designing and starting up gas separation facilities and commercializing new technology.
Sustaera DAC System Architecture

**Goal:** Develop a DAC system to maximize net CO₂ removal efficiency while minimizing the overall cost of capture and meeting the scaling challenge

1. **Minimize Capital Cost**
   - Low-cost materials and manufacturing
   - High performance (high selectivity to CO₂, capture rate, capacity, stability)

2. **Minimize Energy**
   - Low driving force required for regeneration (~80˚C)
   - Low heat of regeneration

3. **Leverage Scalability**
   - Extensive past experience with sorbents and process design
   - Abundant availability of raw materials
   - Mass production infrastructure already exists

Alkali Sorbent for DAC vs Point Source Capture

Perform a thorough IP landscape review of papers, journals, and patents on alkali metal sorbents for CO₂ capture

- Identified potential thermodynamic and chemical pathways
- Alkali metal sorbents have mostly been studied at high temperatures, high concentration of CO₂, and low H₂O to CO₂ ratio due to focus on carbon capture from point sources.

However, direct air capture (DAC) is different than point sources

- Lower CO₂ concentration (415 ppmv vs. 4 to 15 vol%)
- Lower temperature (ambient vs. >40°C)
- H₂O to CO₂ molar ratio (>10 in air vs. <2)
Where We Are Today

Screening Reactor 1 – Test Sorbent Compositions

Screening Reactor 2 – Test Electric Heating

Bench Scale Reactor

*Photos taken May 2022
Sorbent Performance

**CO₂ Removal (ambient conditions)**

![Graph showing CO₂ removal over time]

**Sorbent Regeneration**

![Graph showing sorbent regeneration over time]
**Bench-Scale Unit**

- Designed for 1-2 kg/day of CO₂ from ambient air
- Highly instrumented to obtain high-fidelity mass/energy balances
- All major process components representative of a scaled-up system included
- Full-scale four monolith bricks (150 mm cubes) can be tested
- System fully commissioned in Spring 22
- Fully operational and providing engineering data for 1 ton/day pilot plant
• Each monolith is 6” x 6” x 6”, ~400 are arranged in parallel to create a ‘module’.

• 16 ‘modules’ are arranged together in an air contactor structure to create a ‘unit’.

• Each ‘unit’ with a footprint of 100 m² can capture ~8 t/d of CO₂

• Standard ‘unit’ design with direct integration with renewable electricity
Supply Chain for Scale up

Leverage existing supply chain and manufacturing infrastructure to set up assembly lines of material components of a scaled-up DAC unit.

One Gigaton Scale

<table>
<thead>
<tr>
<th>Material</th>
<th>Alumina Catalyst</th>
<th>Alkali Carbonate</th>
<th>Monolith</th>
<th>Fans &amp; Assemblies</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5 million ton</td>
<td>1 million ton</td>
<td>1500 million ft³</td>
<td>~2000 fan assemblies</td>
<td></td>
</tr>
<tr>
<td>~3% current capacity</td>
<td>~2% current capacity</td>
<td>~15x current capacity</td>
<td>&lt;1% current capacity</td>
<td></td>
</tr>
<tr>
<td>174 million tons / year</td>
<td>55 million tons / year</td>
<td>~100 million ft³ / year</td>
<td>&gt;100 million new fan assemblies per year</td>
<td></td>
</tr>
</tbody>
</table>

- **Automobile production is a good model** for setting up supply chains for building our DAC modules.
- All the **key materials envisioned in this process are widely available**—no new manufacturing processes or infrastructure needs to be developed (unlike amines/MOFs).
- Overall **scalability risk is quite low**, once a 1 TPD prototype is demonstrated.
- 100 TPD modules can be used as **mass manufactured units** to reduce the CapEx.
Cost Projections at Scale

50,000 tons/year

~$175

1 million tons/year

~$78
Due Diligence Process

1. Key experimental results to validate the technical concept (seed funding from DOE)
2. Engineering Analysis
3. Detailed TEA model
4. Working LCA model
5. Filing of background IP
6. Project Team
   1. Technology Personnel
   2. Business Personnel
   3. Key Partnerships
1. Identification of key risks and mitigation plans
2. Scale-up plans
3. Business model
Roadmap for CO₂ Removal

**GOAL:** 500M (0.5Gt) tons of permanent CO₂ removal by 2040
Thank you

On a mission to restore the carbon balance

sustáera.com