Global Thermostat

Carbon Negative Power Plants And Their Impact On Environment

Graciela Chichilnisky
CEO & Co-Founder

Earth Dialogues
Puerto Madryn, Argentina
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Global Thermostat

Breakthrough

Carbon Negative Powerplants can Transform US $53 Trillion global power plant infrastructure from emitters to sinks for CO_2

Cleaning the Atmosphere While Producing Electricity

Global Thermostat

Positive Business Impact while Reversing Climate Change

Meeting Requirements of Byrd-Hagel Law 1997

- New Jobs
- Expanding Exports
- Economic Progress

2018: Moving Ahead at Breakthrough Speed

GT's Competitive Advantage vs. Existing Supply

..Huge demand for CO_2 unmet..[1]

Industrial Markets:
Over $1tn, including: Food & Beverages, Enhanced Oil Recovery, Refrigeration & Greenhouses, Carbonates, Concrete/Cement, Polymers, Graphene, Crop Improvement

Oil & Gas:
Enhanced Oil Recovery (EOR), Clean up of Natural Gas Processing

Renewable Fuels:
Algae Biofuels, Synthetic Gasoline

..Due to three critical issues..

Limited, Stranded Supply:
Natural subterranean reserves are limited. Supply is depleting and geo-specific. Other sources are inadequate

High Capture Costs:
Competing carbon capture methods prohibitively expensive

Difficult to Transport:
CO_2 is difficult to transport economically. Trucking and pipelines require significant capital investment for an inefficient process

1. Appendix: **CO_2 – A MARKET FLOODED BY DEMAND**

ENORMOUS UNMET DEMAND FOR CO_2

GT's Competitive Advantage vs. Existing Supply

Huge demand for CO_2 unmet..

Industrial Markets
Food & Beverages, Refrigeration & Greenhouses, Carbonates, Concrete/Cement, Polymers, Crop Improvement

Renewable Fuels
Algae Biofuels, Synthetic Gasoline

Emerging Technologies
Bio-plastics, Graphene, Carbon Fibers

..due to three critical issues..

Limited, Stranded Supply
Natural subterranean reserves are limited. Supply is depleting and geo-specific. Other sources are inadequate

High Capture Costs
Competing carbon capture methods prohibitively expensive

Difficult to Transport
CO_2 is difficult to transport economically. Trucking and pipelines require significant capital investment for an inefficient process

.. GT addresses these issues

.. GT provides an unlimited supply of CO_2

.. GT captures CO_2 at a fraction of the cost of traditional sources from flue gas or ambient air

.. GT offers modular, "plug and play" units that can be located anywhere

For the first time in human history abundant, low cost CO_2 is available anywhere, anytime.

Carbon Negative Power Plants

By Graciela Chichilnisky and Peter Eisenberger,
Global Thermostat LLC

Global Thermostat LLC (GT) (*www.globalthermostat.com*) was formed in 2006 to develop and commercialize a unique technology for the direct capture of carbon dioxide from the atmosphere and other sources. The GT process "co-generates" carbon capture with other industrial processes—such as power production—by using the process heat from those processes to drive its carbon capture technology. By combining CO_2 capture from air along with capture from the flue gas of an electrical power plant, and using the power plant's low cost process heat to provide the energy needed for the air capture process, GT technology has the capability of transforming power plants into net carbon sinks. Global Thermostat technology also can work with renewable power plants, because it captures carbon directly from air using the plant's process heat. For example, heat from a Concentrated Solar Plant (CSP) can be used by Global Thermostat to drive its capture process.

CO_2 capture from air is different from other

CO_2 air capture has gained momentum on the policy front and in the business community as a viable and economic solution for reducing carbon emissions and is now being introduced commercially with pilot demonstration plants. The first GT pilot plant erected at SRI International in Menlo Park, CA, captures 1,000 tpy (tons per year) of CO_2 and was co-developed with Corning and BASF. The CO_2 captured at plants like this is available for use in applications such as enhanced oil recovery, greenhouses, production of industrial grade formic acid, producing bio-fuels from algae, and, when combined with hydrogen, for producing hydrocarbons such as high octane gasoline.

According to the International Energy Agency, over 41 percent of all human based emissions of CO_2 are generated by power plants and 89 percent of electricity production around the world is powered by fossil fuels. This represents an energy infrastructure valued in excess of $55 trillion dollars. As this cannot easily be replaced, CO_2 emissions

by GT's process can be as high as 98–99 percent, and the stream can be further purified and/or liquefied using standard "compression" techniques.

Transportation costs for large volume gaseous CO_2 is significant and can run as high as $1.5 million per mile for a pipeline, plus compression. With the GT process, these costs are drastically reduced or eliminated; a CO_2 air capture plant can be located anywhere, needing only air and heat to operate. A

GT HISTORICAL TIMELINE

2010

Incubation
Key author of the Kyoto protocol establishes Global Thermostat (GT) with leading researchers from Princeton, Harvard, Columbia and Stanford Universities

Capitalization
Through 2015, GT successfully raises an aggregate of **$29.5 million** anchored by Edgar Bronfman, NRG, and Vice Media

Pilot Demo Plant

2013

Technology Validation
GT collaborates with industry leaders Corning, Linde, NRG Haldor Topsoe, and BASF. Achieves **32 patents** to date, **protected in 147 countries**. GT proprietary modules achieve an unprecedented competitive advantage with industry-leading margins

Commercial Demo Plant

2015

Partnerships
GT proliferates the global CO_2 value chain with key partnerships including **NRG, Georgia Tech, Corning, SRI, and Linde** as strategic partners

2016

Commercialization & Scale Up Deployment
GT starts exploring commercial contracts to address market demand

2017

Funding and Commercial Construction
GT successfully closes investment round of **$20 million** bringing the aggregate amount of funding to **$42 million.** GT starts building first commercial plant for **major carbonated beverage producer**

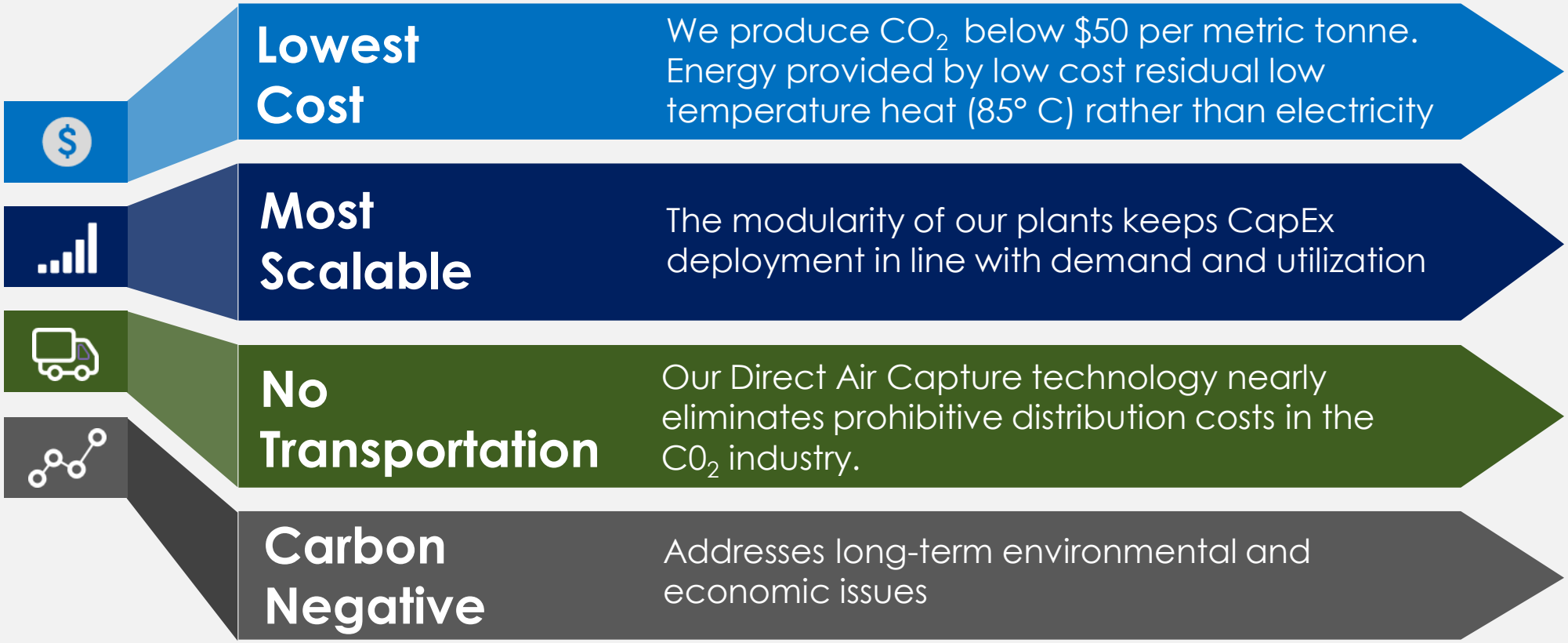
2018

First GT Commercial Plant (4,000/ TPY)
Completed at Huntsville, AL For Global leading provider of carbonated beverages and production of bio-degradable plastics

Commercial Plant

COMMERCIAL VALUE PROPOSITION

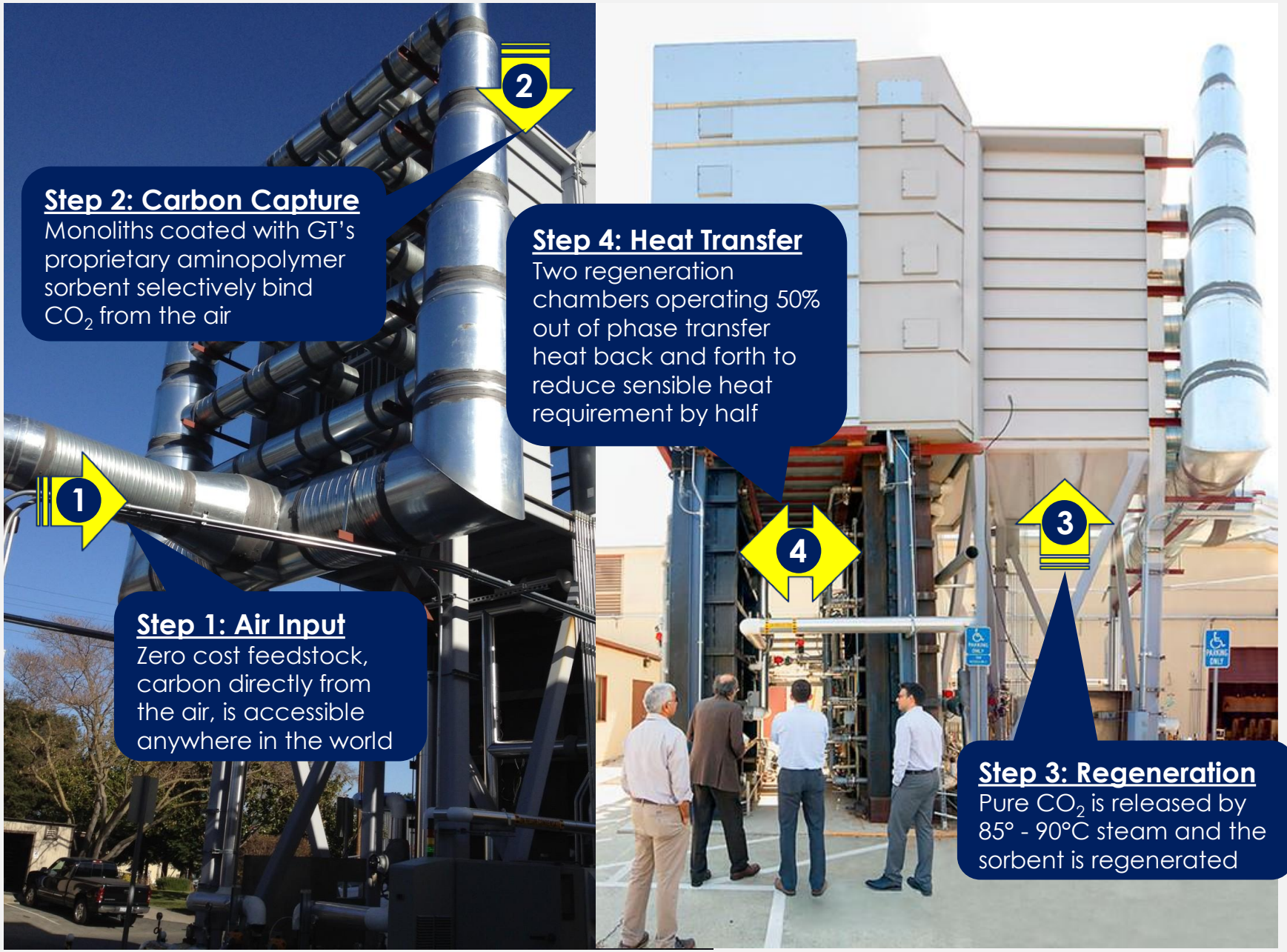
A major and unprecedented CO_2 market disruptor



Reliable, lowest cost CO_2 available anytime, anywhere in the world

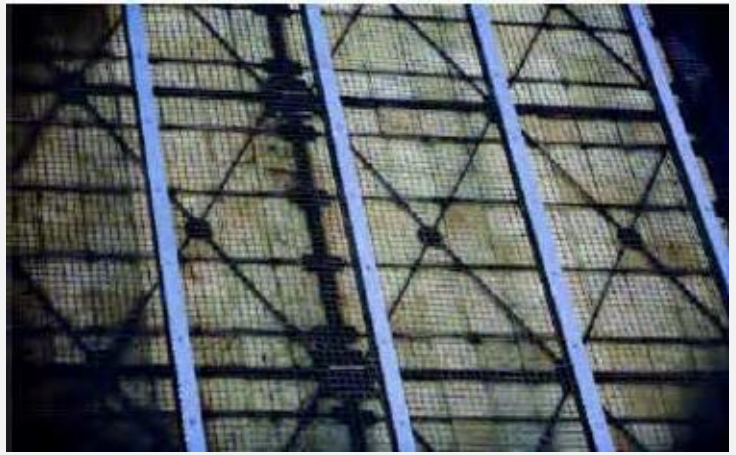
HOW IT WORKS

Our proprietary **Cyclic Adsorptive CO_2 Capture** method selectively captures high-purity CO_2 from free air at any location. The process also conserves energy in an efficient heat cycle



2010: 1st PILOT GT PLANT

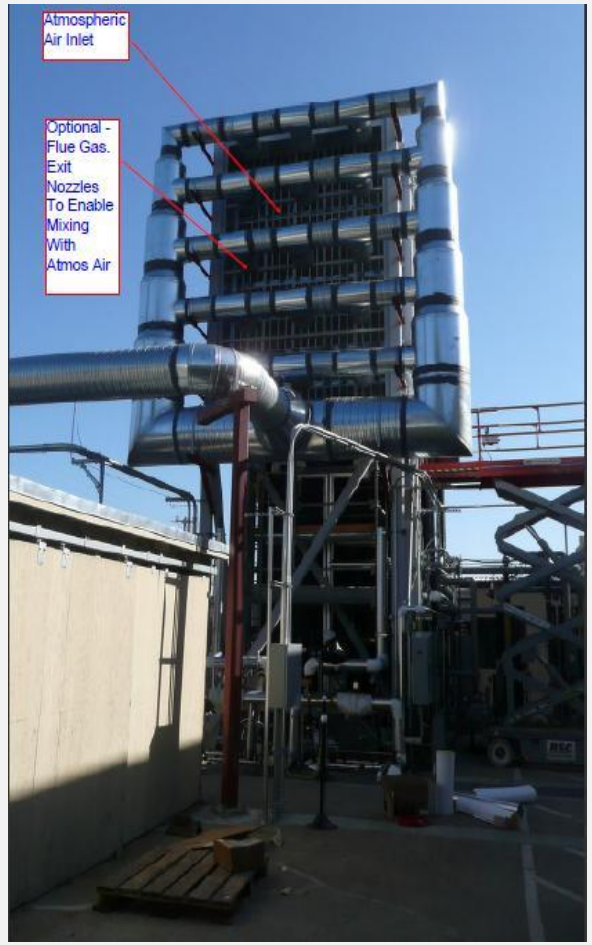
Captures CO_2 directly from air



SRI International (formerly Stanford Research Institute), 333 Ravenswood Avenue, Menlo Park, CA 94025

2013 COMMERCIAL GT DEMO PLANT at SRI

Captures CO_2 from SRI fossil fuel power plant and also directly from air
[GT achieves US DoD/DoE Technology Readiness Level-8 (TR8)]



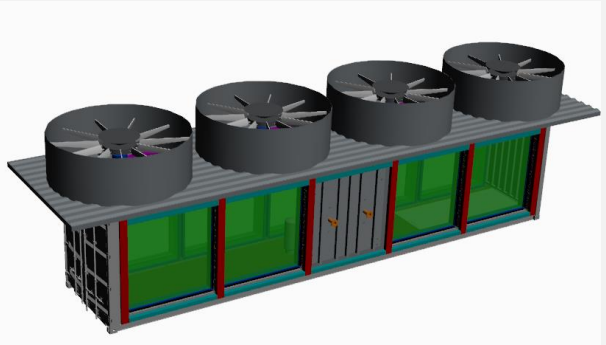
333 Ravenswood Avenue, Menlo Park, CA 94025

2018 GT COMMERCIAL PLANT in Huntsville, Alabama

Global Thermostat

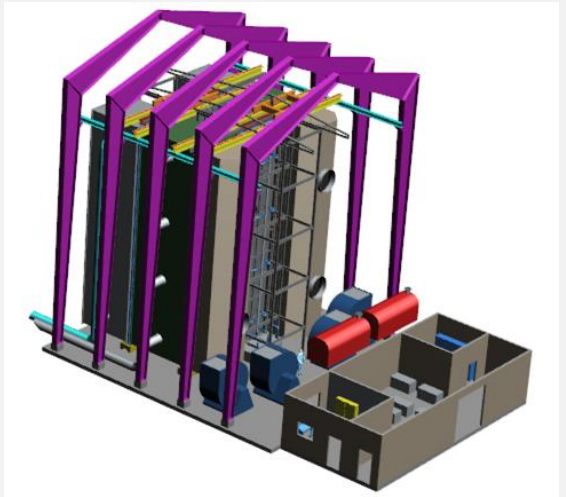
2018 GT COMMERCIAL PLANT in Huntsville, Alabama

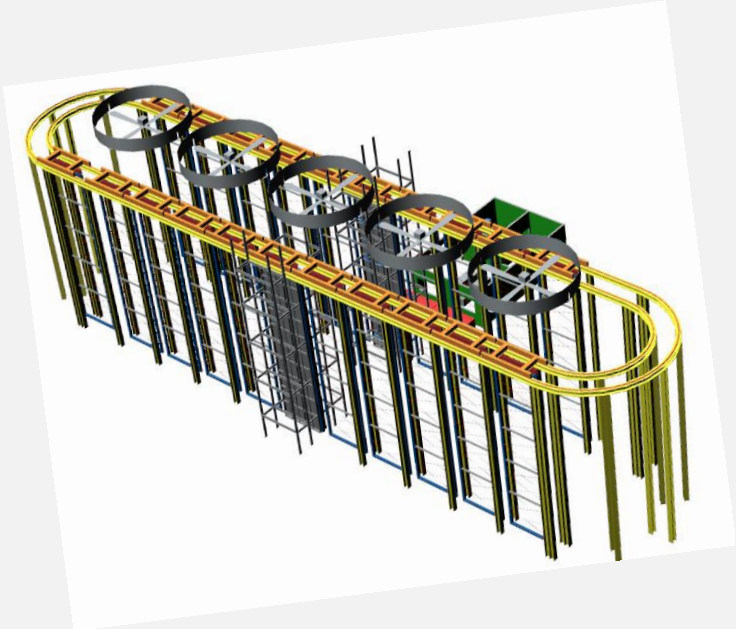
First GT Commercial Plant (4,000/ TPY)



Containerized GT-Carburetor
40’ ISO container
10,000 tonnes CO_2 / year

Conceptual design for Containerized Carburetor is complete. Next step is detailed engineering.





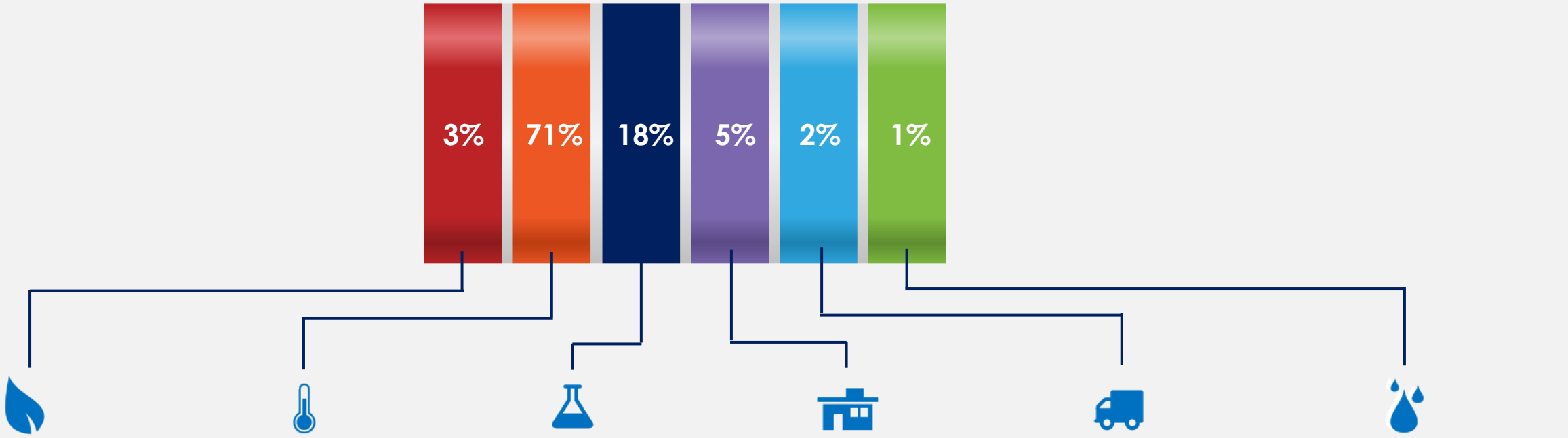
Full-scale GT-DAC
18m tall, 50m long, 6m wide
50,000 tonnes CO_2 / year

Basic design for Full-scale modules completed with NRG and Sargent & Lundy. Next step is detailed engineering.

Huntsville, Alabama

GLOBAL THERMOSTAT: INITIAL MARKET VERTICALS

$6.7 billion annual CO_2 market in initial target segments



Biofertilizers
>$205m/yr
Existing market

Industrial Gases
>$4.8bn/yr
Existing market

Food & Beverage
>$1.3bn/yr
Existing market

Building Materials
>$340m/yr
Existing market

Synthetic Fuels
>$135m/yr
Existing market

Seawater Desalination
>$70m/yr
Existing market

Global Thermostat: Exciting New Developments

GT Direct Air Capture units to supply Coca Cola bottlers with CO_2 for carbonation of beverages – 950 bottlers worldwide as our client

Status: Business Meeting at Huntsville 10/4. Investment & Termsheet

GT Direct Air Capture units for Air Liquide, the second largest supplier of industrial gas worldwide.

Status Business Proposal Received

A joint research program with Exxon Mobile with the purpose of scaling up GT's CO2 capture technology to a gigaton of CO_2/year

Status – Term Sheet Completed

A commercial agreement to incorporate GT technology into CO_2 production plants at ASCO, a leading producer and distributor of CO_2 in developing nations

Status: Negotiating Terms for Clients

GT Direct Air Capture units for Newlight Technologies, a company based in Irvine, California, known for capturing carbon for use in the production of plastics sold to IKEA, Inc.

Status: Signed Agreement (testing)

$2 Million Grant Department of Energy Awarded to Global Thermostat along with Georgia Tech and Alegnol for Bioenergy Research and Development

LEADERSHIP

Dr. Graciela Chichilnisky

CEO & Cofounder

- World leading economist and mathematician
- Two PhD's: Math, MIT; Economics, Berkeley
- Successful Entrepreneur: Founded & sold financial services tech companies FITEL, and Cross Border Exchange
- Authored Kyoto Protocol carbon market
- Tenured Professor at Columbia University, previously at Harvard and Stanford
- 2015 "CEO of the Year" Selected by IAIR, Yale Club NY April 2015

Dr. Peter Eisenberger

CTO & Cofounder

- Leader and technology innovator in global energy industry and CO_2 capture
- 20+ year career including global R&D head at Exxon and lead scientist at Bell Labs
- Tenured professor, former Vice Provost at Columbia University
- Founding Director Columbia University Earth Institute
- Founding Director Princeton University Materials Institute

Edgar Bronfman, Jr.

Executive Chairman

- Chairman, Endeavor Global
- General Partner at Accretive LLC
- Former Chairman and CEO of the Warner Music Group
- Recently successfully sold Warner for US$3.3 billion
- Former President and CEO of the Seagram Company

GT AWARDS

"The 30 Most Innovative Companies to Watch 2018"
– Insights Success Magazine, March 2018

"World's Top-10 Most Innovative Company in Energy"
– Fast Company, April 2015

"2015 CEO of The Year: Graciela Chichilnisky"
– Yale Club of New York City IAIR Award, April 2015

"2016 Top 50 Most Innovative Company in Renewable Energy"
– Company Energy, May 2016

"Finalist and $250k Grant Winner"
– NYSERDA, June 2016

"World's Top 50 Innovators from the Industries of the Future: Graciela Chichilnisky "
– Codex, July 2017

"The Companies with Most Disruptive Innovation"
- Insights Success, 2018

Contact

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New York, NY 10065

LABORATORIES

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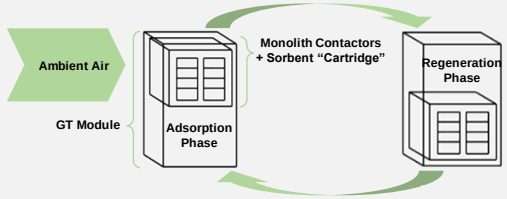
Advanced Technology Development Center
Georgia Institute of Technology
311 Ferst Dr NW
Atlanta, GA 30332

Silicon Valley
SRI (formerly Stanford Research Institute)
333 Ravenswood Ave
Menlo Park, CA 94025

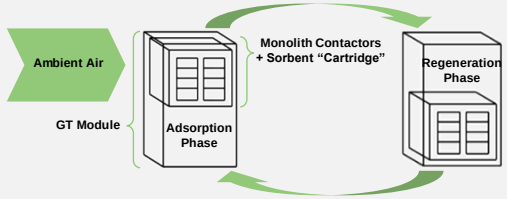
TECHNOLOGY

Technology Operation



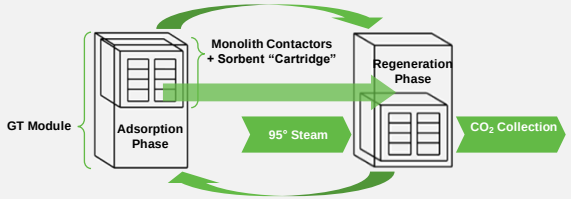
Step 1: Air Input

- GT uses monolith contactors like those in a tailpipe catalytic converter
- Contactors provide high surface contact areas at low pressure drop
- Enables movement of large air volumes with effective contact of CO_2 at low cost



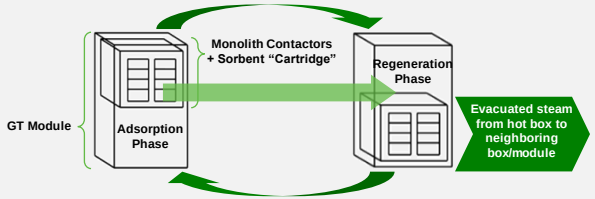
Step 2: Carbon Capture

- GT sorbents proven highly effective by Georgia Tech - confirmed by SRI, BASF, Corning, and DN Veritas
- Process to deposit immobilized amines in pores of the contactor walls at high loading by Corning, Haldor Topsoe, Applied Catalysts



Step 3: Regeneration

- CO_2-rich sorbent is heated with low-temperature process heat steam (95°C)
- CO_2 is collected and sorbent is regenerated (thermal and sweep gas cycle)
- CO_2 can be stored or used in multiple commercial applications
- 16 minute cycle per panel for ambient air



Step 4: Heat Transfer

- Neighboring module has completed Step 2, and enters its regeneration box
- That box is evacuated, and connected to the hot box from which CO_2 was just removed
- Water evaporates from hot monoliths (cooling them) and condenses on cool monoliths, warming them
- This sharing provides 50% of the heat for the cool monoliths

GT Technology Breakthroughs

Contactor Efficiency

- GT modeled different types of contactors, finding honeycomb monoliths significantly outperform all others on a {Surface Area} / {Pressure Drop} / {$} basis
- Channels parallel to the direction of flow minimize pressure drop while maximizing contact area
- Impingement of CO_2 onto active material orthogonal to flow

Regeneration Efficiency & Heat Recovery

- Using steam as sweep gas in addition to heat transfer fluid reduces regeneration temperature to as low as 75C
- Evolved CO_2 is rapidly swept away from the surface, depressing the effective P_{CO2} experienced by the desorbing media
- Sensible heat is recycled by coupling two regeneration boxes in opposite phase
- 50% reduction in sensible heat requirement by preheating a full canister by evaporatively cooling an empty canister

Generational Improvement of Adsorption Media

- Fixed dimension of individual monoliths within a canister allow for direct replacement with new materials with improved performance
- No change in plant components necessary

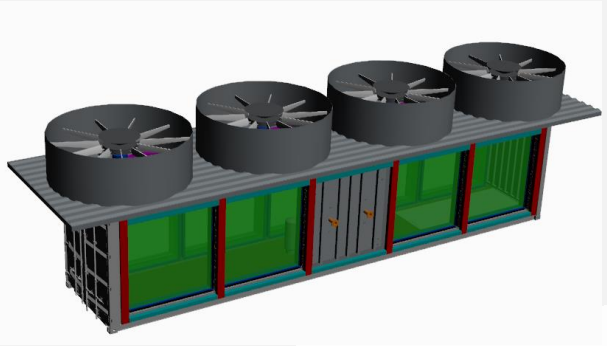
Global Thermostat Module Embodiments & Capacities

1. **Diluted Flue Gas Capture (GT-Carb)**
   - CO_2 captured from flue gas of fossil fuel power plant
   - Electricity, flue gas, and heat integration with power plant
   - Capable of high levels of flue stream decarbonization
2. **Direct Air Capture (GT-DAC)**
   - CO_2 captured directly from the atmosphere at 400 ppm
   - Heat integration capability with nearby manufacturing or downstream processes
   - No power plant proximity requirement or flue gas retrofit
   - Remote CO_2 capture possible if integrated with available on-site energy
3. **Standalone Integrated CO_2 Capture (GT Self-Carb)**
   - On-site nat. gas CoGen plant provides total heat and power needs for CO_2 capture and delivery,
   - CO_2 emissions from CoGen flue gas captured by GT-Carb modules, remaining heat and electricity used to power GT-DAC modules
   - Ideal for larger applications in remote locations without co-located heat

Commercial Module Capacities to Scale with Demand:

	Containerized Module	Full-scale Module
GT-DAC	1,000 – 4,000 MT/y	50,000 MT/y
GT-Carb	10,000 MT/y	100,000 MT/y

Status of Other GT Embodiment Designs
Self Carburetor- Local Power Source CO_2 + DAC



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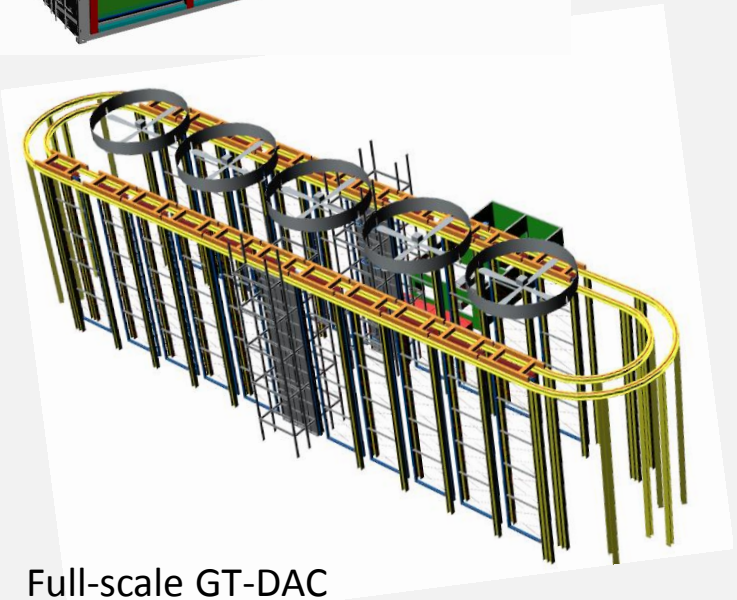

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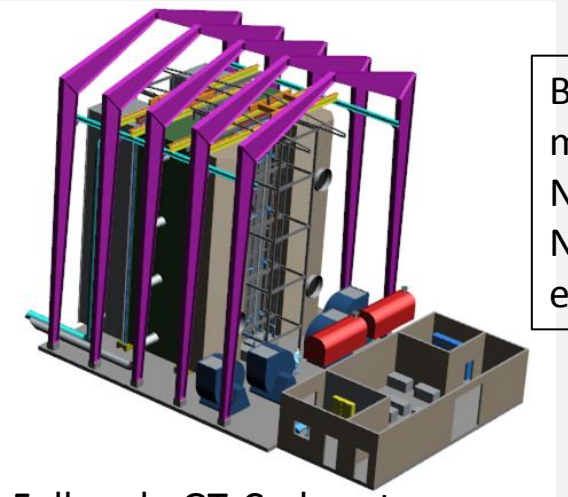
50,000 tonnes CO_2 / year



Full-scale GT-Carburetor
18m tall, 17m long, 20m wide
100,000 tonnes CO_2 / year

Basic design for Full-scale modules completed with NRG and Sargent & Lundy. Next step is detailed engineering.

Global Thermostat Containerized DAC Module
For Global leading provider of carbonated beverages

Under Construction Now in Huntsville, AL USA — Expecting: Fall 2018 Mechanical Completion

Containerized GT-DAC — Fall 2018 Continuous Operation

2 standard 40-ft. ISO containers + 1 auxiliary container

Nominal 1st module capacity of 3,000 MT CO_2 / year

Ultimate nominal capacity of 4,000 MT / year

Includes NG Cogen unit for heat + power generation

Brief Summary of Huntsville DAC Plant

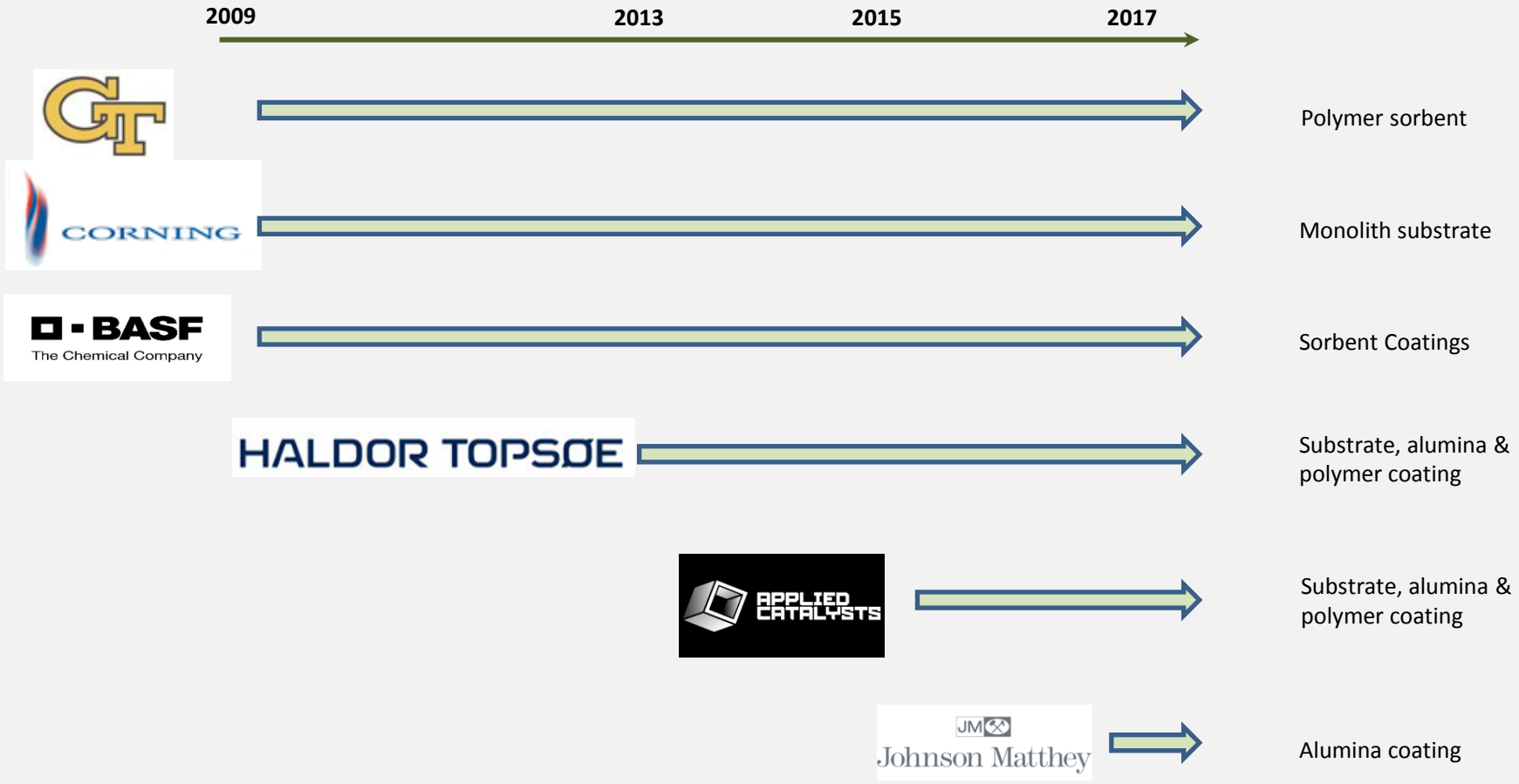
- Commissioning Completed
- Prioritized subsystem testing for extensive preventative assessment to reduce cost and mitigate fully assembled operational risks
  - Regeneration chamber / seals vacuum testing
  - Panel movement system accelerated testing
  - Production Sorbent Apparatus performance
  - PLC / HMI : automated operation and automated safe shutdown


Tecogen
InVerde e+


EXIT
GAS USE
NITROGEN


InVerde e+

Sorbent Apparatus –Monolith/Coating/Sorbent Supply Chain & Co-Development Partners



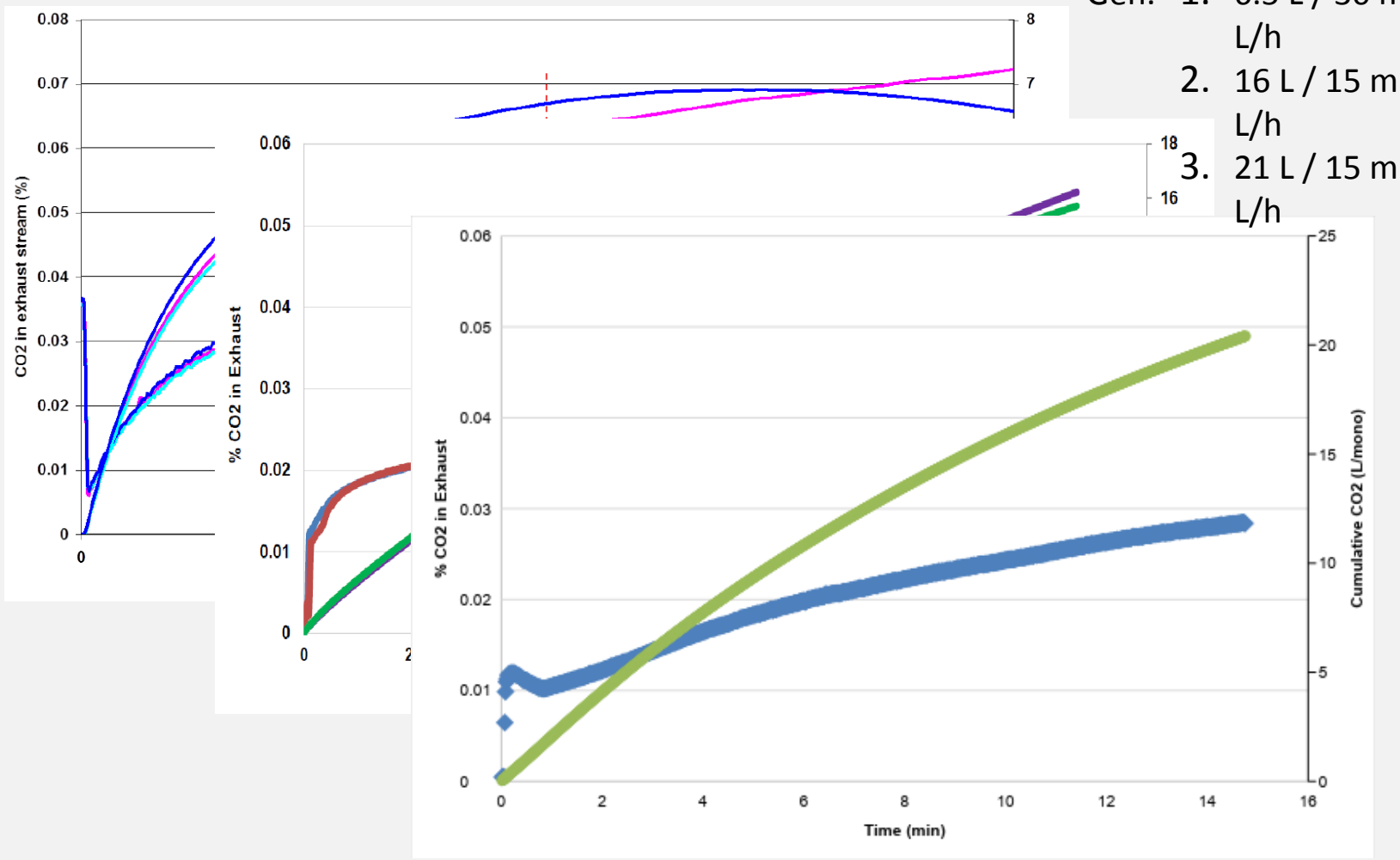
R&D - Material Performance Improvements

Substrate	Alumina Coating	Sorbent

• Cell Density & Open Face Area
  • Pressure drop
  • External mass transfer coefficient
  • Maximum capture efficiency
  • Thermal mass
• Material
  • Thermal mass
  • Cost
	• Thickness
	  • Loading capacity
	  • Pressure drop
	• Mesoporosity and Macroporosity
	  • Sorbent capacity
	  • Sorbent accessibility
	  • Sorbent kinetics
		• Polymer type & molecular weight
		  • Activity, selectivity
		  • Oxidative, hydrothermal, and cyclic stability
		  • Workability
		  • Regenerability
		  • Cost
		• Loading
		  • Uptake kinetics & efficiency
		  • Thermal mass
		  • Cost

Monolith Performance Evolution

Gen.
1. 6.5 L / 30 min; 13 L/h
2. 16 L / 15 min; 64 L/h
3. 21 L / 15 min; 84 L/h



Potential Next Generation

Global Thermostat CO_2 Product Specifications

- Product CO_2 from GT DAC process is >98.5 vol% CO_2 purity (dry basis)
  - Balance (<1.5%) composition = feed composition

- For onsite delivery of beverage grade CO_2, downstream purification and liquefaction by turnkey skid-mounted unit
  - Purification/liquefaction solutions to liquid ISBT standard CO_2 (CGA Grade I) from (e.g.) TOMCO2, Pentair, ASCO, & others.

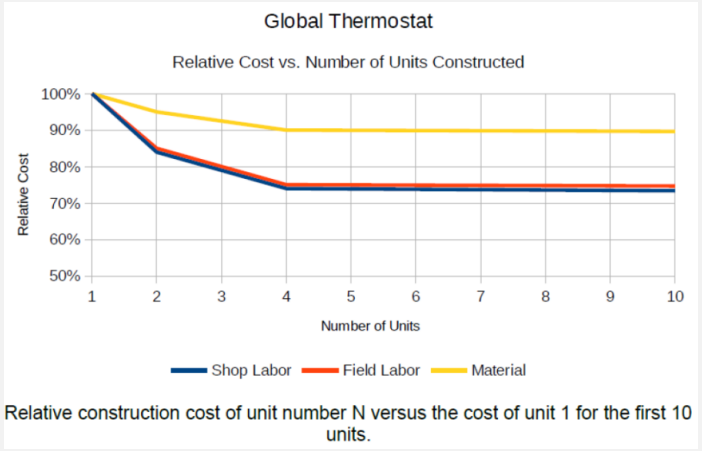
- Alternative GT patent-pending process for the production of high purity CO_2 (99.9%+) directly via the GT process
  - Avoids the need for cryogenic polishing processes
  - To be demonstrated with GT DAC plant in Huntsville

- In general, high purity CO_2 can be provided if needed by:
  - GT producing beverage grade directly
  - Standardized system from turnkey manufacturer
  - Integration with existing capability from an industrial gas partner

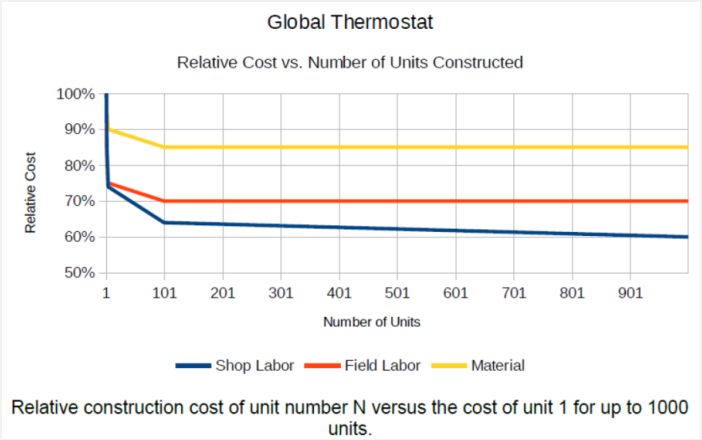
Sample DAC Product CO_2 Composition	
CO2	98.71%
O2	0.27%
N2	1.01%
Ar	116 ppm
Ne	230 ppb
He	65 ppb
SO2	12 ppb
NOx	7 ppb
VOC	n/a

Plant Capex & Cost Reduction Pathways

- 1st Plant Capex (without Cogen units): ~2MM USD
  - Significant one-time costs of detailed engineering, manufacturing equipment setup (seal molds, monolith extrusion dies, regeneration box templates, etc.)
- 2nd Plant and Beyond cost reductions from vendor volume discounts, assembly learning, streamlined instrumentation, etc.
  - See below charts from joint report from GT's fabricator and EPC regarding cost reductions with # of units



Relative construction cost of unit number N versus the cost of unit 1 for the first 10 units.



Relative construction cost of unit number N versus the cost of unit 1 for up to 1000 units.

- Further cost reductions from automated manufacturing, learning by doing, etc.

Cost Reduction Pathways (continued)

- Monolith cost reductions estimated by Corning, Haldor Topsoe to be up to a factor of 2 with large scale manufacturing
  - E.g. Corning's fully robotic facility for Celcor substrates reduced manufacturing costs by a factor of 3 for automotive and stationary ceramic monoliths
  - China has costs 4x or more lower

- With generational Monolith performance improvements, per-tonne Capex will decrease as well as Opex
  - Same CAPEX that delivers 4,000 tonnes/year can have 5,000 tonne/year capacity with 25% increase in per-monolith CO_2 capture performance - 6000 tonne/year possible
  - Scheduled monolith exchange can provide step-change in plant productivity and economics with drop-in generational replacements
- Overall, the CAPEX of a GT plant is likely to decrease by 50% over 1st plant CAPEX
- CAPEX per tonne can decrease even further with increased productivity
- OPEX per tonne will also decrease as monolith performance increases

Technology Partners

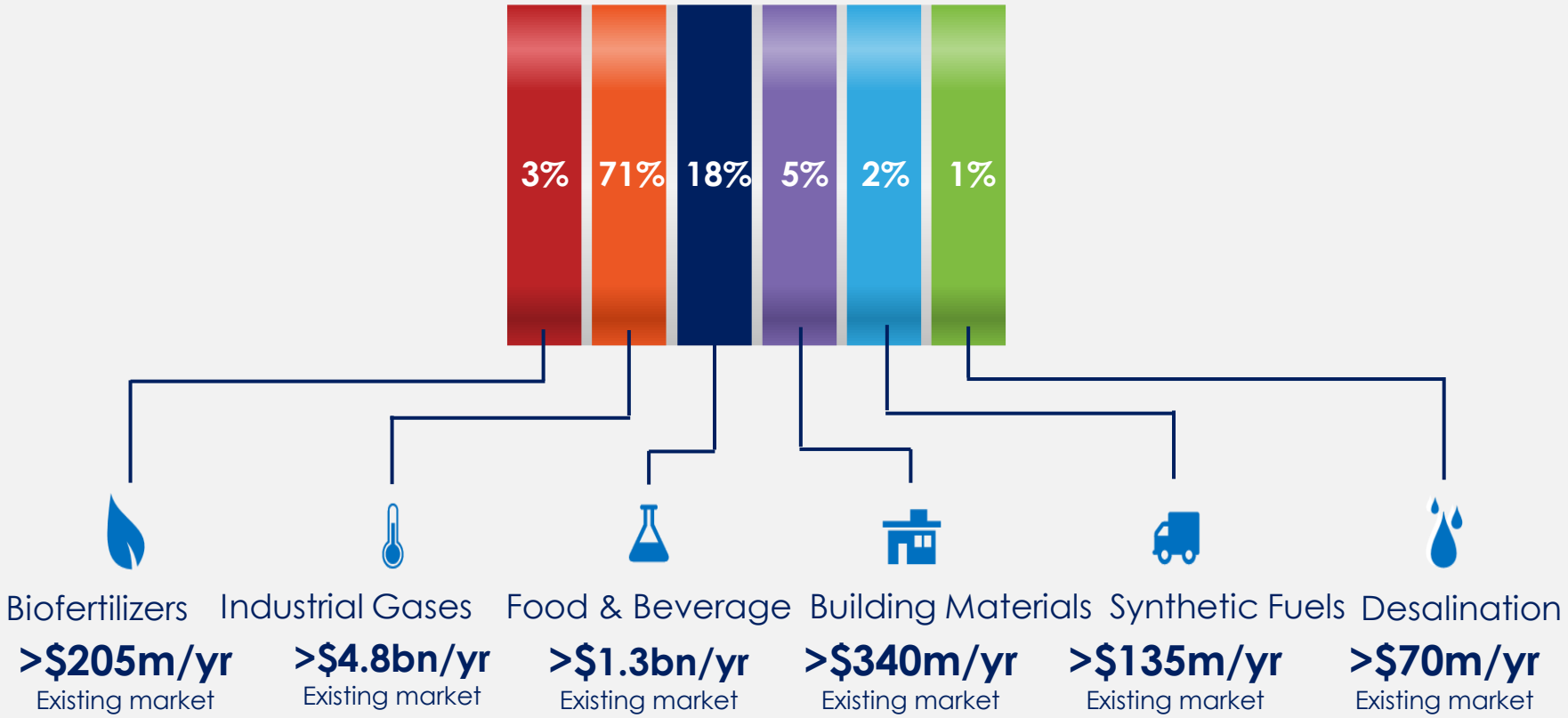
Partner	Activity	Relationship Terms
SRI International	▪ Pilot plant operation and R&D; lab testing	▪ Contract R&D
BASF	▪ Sorbent development/supply; lab testing	▪ Strategic Supplier
Haldor Topsoe, Corning	▪ Monolith development/supply	▪ Joint development, Strategic Supplier
Linde	▪ Carburetor Pilot/EPC Contractor	▪ EPC Contractor
Georgia Tech	▪ Sorbent R&D; contactor testing	▪ Contract R&D
Streamline Automation	▪ System design, engineering, fabrication	▪ Contract EPC
Carmagen Engineering	▪ System design, engineering, optimization	▪ Contract consulting
G.A. West	▪ Mass fabrication, EPC contractor	▪ Manufacturing
Applied Catalysts	▪ Contactor, sorbent development/supply	▪ Joint development, Strategic Supplier

Future Development Plans

- Further expansion of R&D personnel and capabilities
- New R&D facilities to enable larger scale testing and synthesis
- Developing Joint Development Agreements with Suppliers
- Exploring development of in-house Sorbent Apparatus monolith manufacturing

INITIAL MARKET VERTICALS

$6.7 billion annual CO_2 market in initial target segments



RENEWABLE ENERGY
AND
MATERIALS ECONOMY

Industrial Version of Photosynthetic Process

- Inputs
  Renewable Energy, Carbon from the air, Hydrogen from Water
- Outputs

  Carbon Neutral Synthetic Fuels

  Carbon Negative Materials (eg carbon fiber)