Can Algae Really Do CCU?

Status and Potential of Biological Carbon Capture and Use



USEA Technology Series

March 12, 2018

Matt Carr

Executive Director

mcarr@algaebiomass.org

ALGAE BIOMASS ORGANIZATION

Algae Biomass Organization

- Trade association for the algae industry (est. 2008)
- Over 200 corporate, institutional and individual members
- World's leading developers of algae-based technologies and products **+** their customers, suppliers and other industrial partners
- Host of Algae Biomass Summit, world's largest algae event (Oct 14-17, 2018, Houston, Texas)

ALGAE BIOMASS ORGANIZATION

THANK YOU TO OUR MEMBERS

Platinum Members

bioprocessalgae

ACCELERGY CORPORATION

WSGR Wilson Sonsini Goodrich & Rosati PROFESSIONAL CORPORATION

Gold Members

cellana algae-based products for a sustainable future

TRITON ALGAE INNOVATIONS

ALGENOL

subitec

COMMERCIAL ALGAE PROFESSIONALS From Concept to Commercialization

Corbion

CARLSONSV CPAs & ADVISORS

GLOBAL ALGAE INNOVATIONS

LanzaTech

EARTHRISE a member of the DIC group DIC Color & Comfort

QUALITAS HEALTH

KELLER AND HECKMAN LLP SERVING BUSINESS THROUGH LAW AND SCIENCE

SYNTHETIC GENOMICS

Silver Members

DIVERSIFIED TECHNOLOGIES, INC.

TOTAL

μBIO MICROBIO ENGINEERING

APPLIED CHEMICAL TECHNOLOGY The World Leader in Process Equipment Design

OUC The Reliable One

ATP3 Algae Testbed Public-Private Partnership

FedEx Express

valensa

Bigelow National Center for Marine Algae and Microbiota

NESTE OIL

PHITEC SUSTAINING EFFICIENCY

TEXAS A&M AGRILIFE RESEARCH

AstaReal Be you, Just healthier

DSM BRIGHT SCIENCE. BRIGHTER LIVING.

SCHOTT glass made of ideas

The Challenge

- Reduce GHG emissions from fossil power generation and other industrial sources…

Economically

A Carbon Strategy for the 21st Century

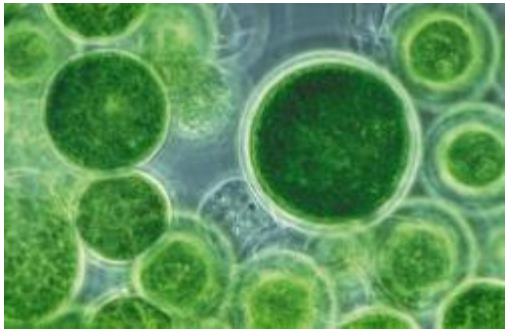
Harness Earth's original CO_2 mitigation technology…

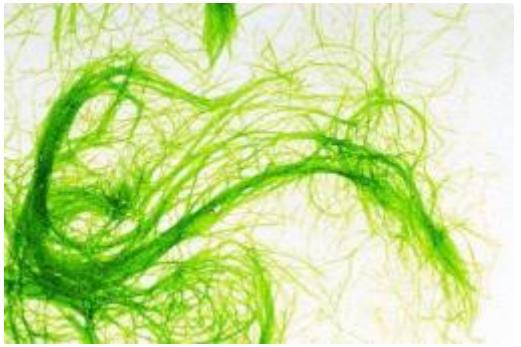
What are Algae?




Algae

- Some of earliest life on Earth
- Highly diverse set of organisms
  - Estimated 50,000+ species
- Size: microscopic (microalgae) to large seaweeds (macroalgae) e.g. giant kelp
- Microalgae include:
  - Cyanobacteria (blue-green)
  - Green, brown and red algae





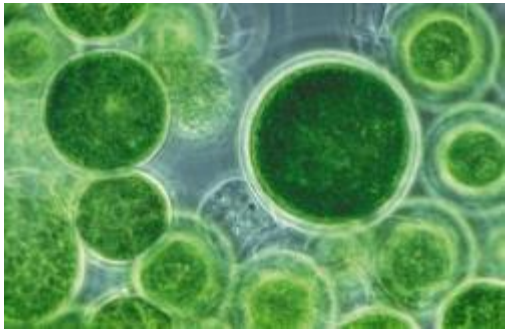
What are Algae?

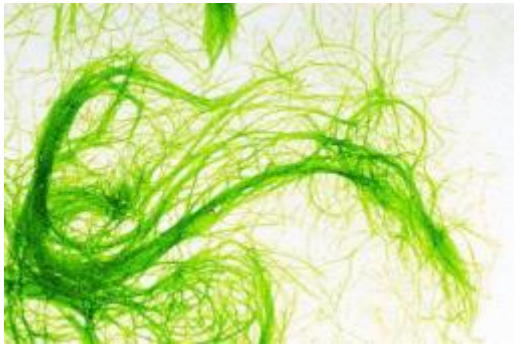
- Transformed Earth's early super-greenhouse atmosphere…

What are Algae?

Algae

- Mostly photosynthetic
  - Sunlight + CO2 (autotrophic)
- Some feed on sugars…
  - Heterotrophic
- …or do both
  - Mixotrophic





What are Algae?

Algae

- Exceptionally fast-growing
  - Mature in days vs. months/years

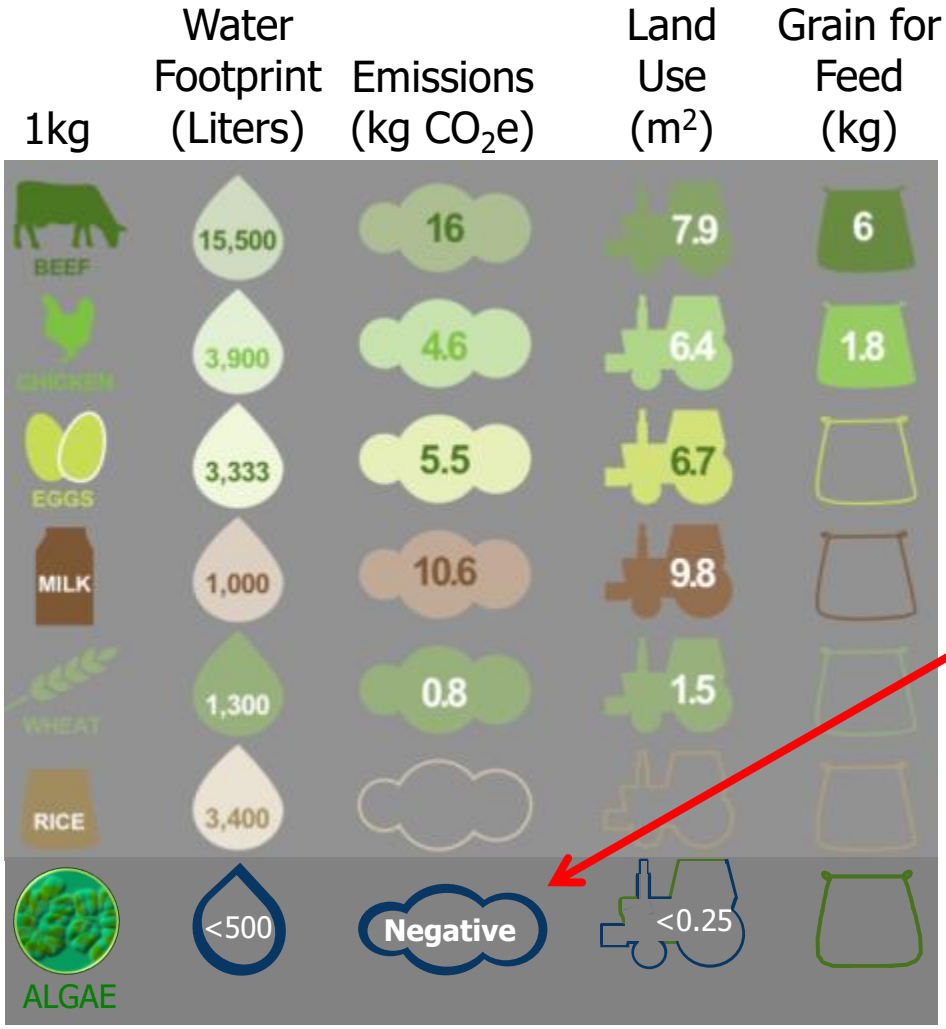
- Exceptionally productive

Why Algae: Yield

Comparison of Feedstock Crops					
Plant	**Average Biomass Yields** (MT / ha / yr)	**Oil Content** (% dry mass)	**Sugar / Starch Content** (% dry mass)	**Energy Content of Oil / Sugar / Starch** (boe / 1000ha / day)	**Protein Content** (% dry mass)
Soy/Soy oil	1 - 2.5	20%	18%	3 - 8	37%
Rapeseed	3	40%	NA	22	23%
Palm/Palm oil	19	20%	NA	63	15%
Jatropha	7.5 - 10	30 - 50%	NA	40 - 100	24 - 28%
Corn	10 - 12	4%	75%	240 - 300	4 - 14%
Sugarcane	60 - 70	NA	12 - 16%	230 - 370	3 - 4%
Microalgae	**100+**	**25 - 50%+**	**15 - 25%**	**330 - 785+**	**25 - 60%+**

Why Algae: Sustainability

Lowest Carbon, Water, & Arable Land Footprints of Any Crop



Sources: Water www.waterfootprint.org/?page=files/productgallery; *emissions and land use UK DEFRA* (2006), http://goo.gl/T12.ho; *grain* National Geographic, http://goo.gl/4CgFB; *Algae*, Cellana estimates

The Biological Capture and Utilization Opportunity

Algae

- CO_2 eating machines…

1,000 acres of algae consume as much CO_2 as 20,000,000 trees

- 1.2 tonnes CO_2 / ac-yr consumed by average US forest vs. 75 tonnes /ac-yr for direct-to-ethanol
- Equivalent to 125,000 acres of average US forest
- Based on EPA Estimates

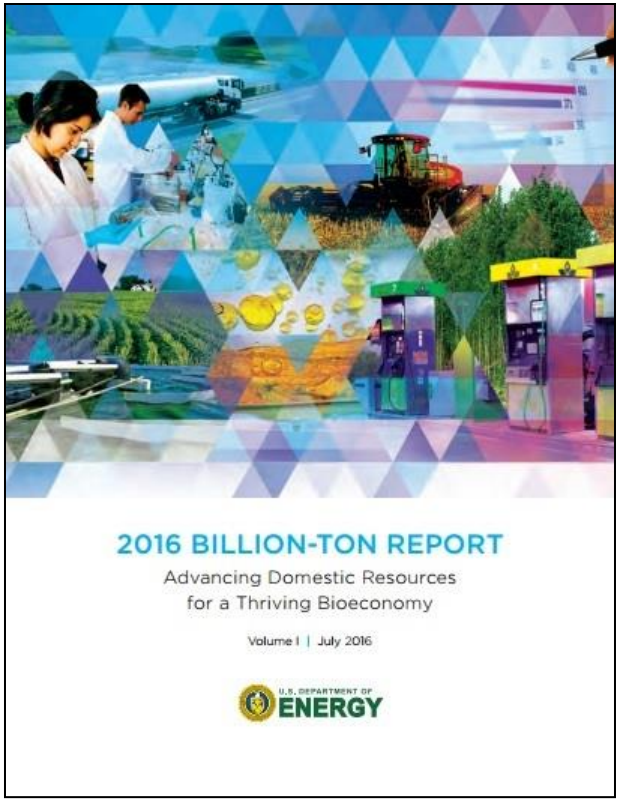
The Biological Capture and Utilization Opportunity




- Can produce …
  50-100 gallons biofuel per ton CO_2
- Product value from algae conversion:
  > $100 / ton CO_2
- Today: Algae developers buy CO_2
  (at $40+ / ton) as a feedstock
- Industrial CO_2 Challenge **+ Algae =**
  Opportunity

Co-Location Potential

- **2016 DOE/ORNL Analysis*:**
  Substantial U.S. Potential for Algae CCU:



*2016 Billion-Ton Report *https://bioenergykdf.net/billionton2016/overview*

Co-Location Potential

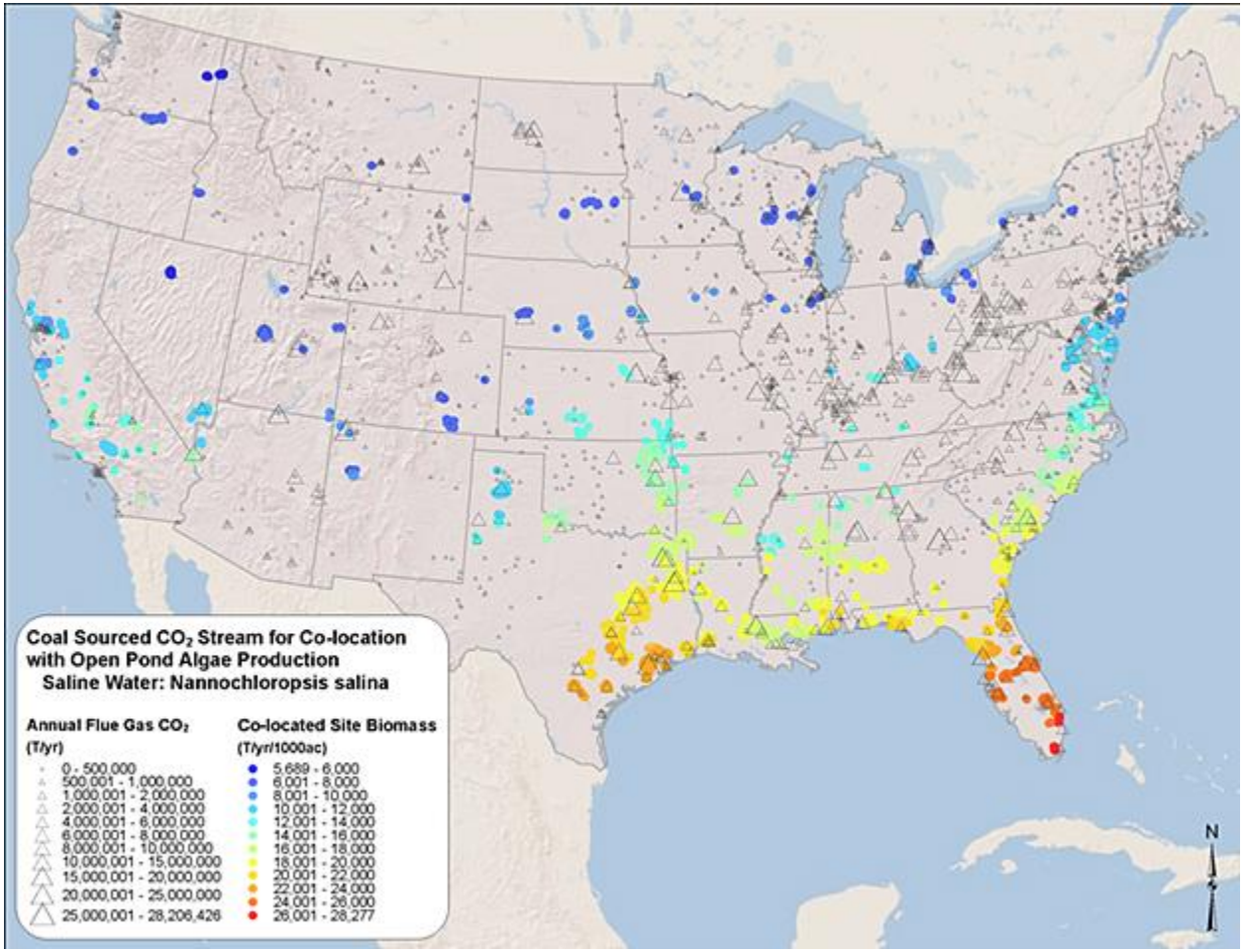
- 140,000 sq. miles suitable for open pond production (≈75,000 farms)
- Even with highly conservative assumptions, using existing technology:
  - **More than 500 viable point sources**
  - **Potential to utilize > 200 million tons CO_2 / year**
- Much larger quantities possible beyond 2030, especially with CO_2 price/regulation

*2016 Billion-Ton Report *https://bioenergykdf.net/billionton2016/overview*

Billion Ton Study
Algae Chapter Highlights

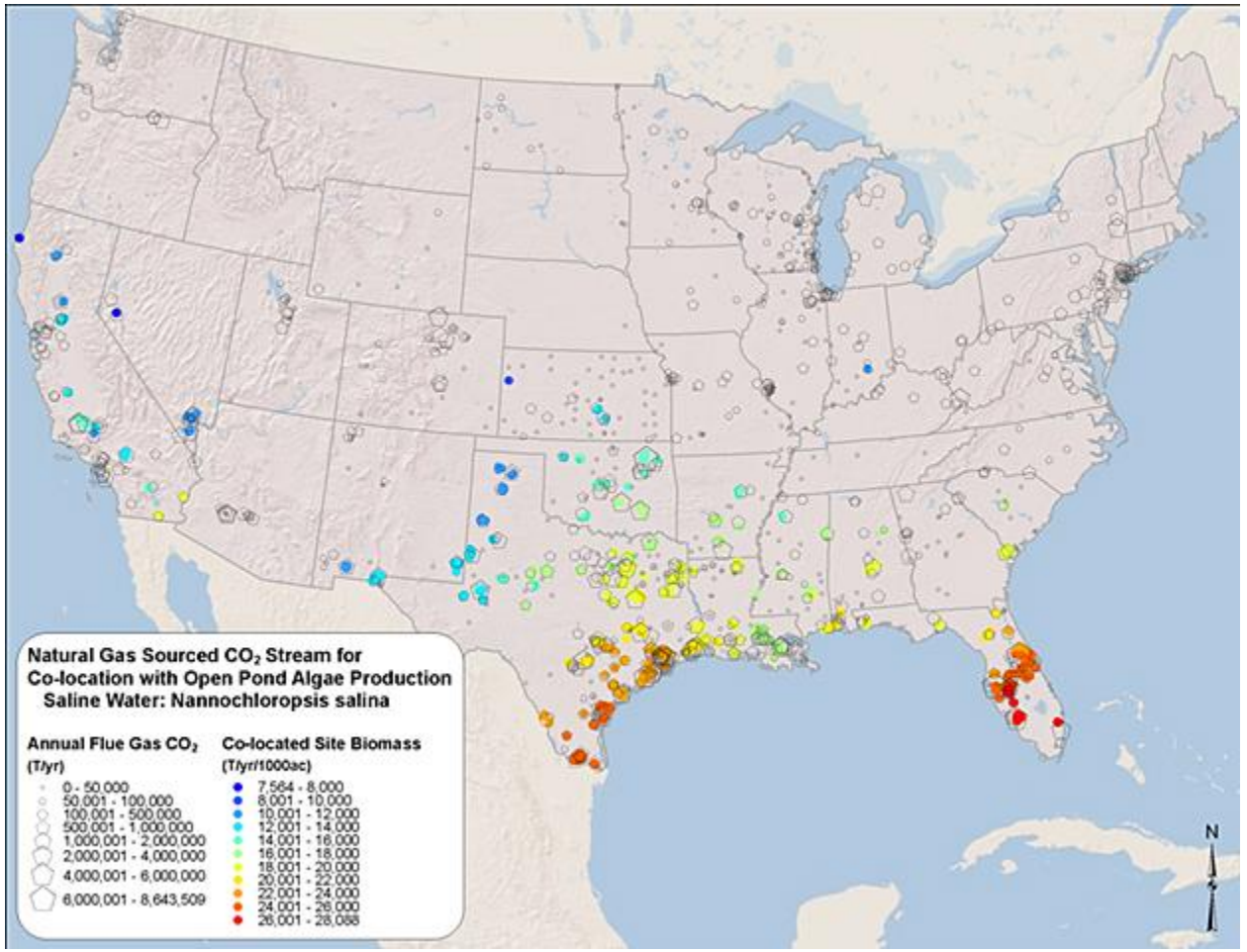



COAL - Saline Strain, Current Productivity



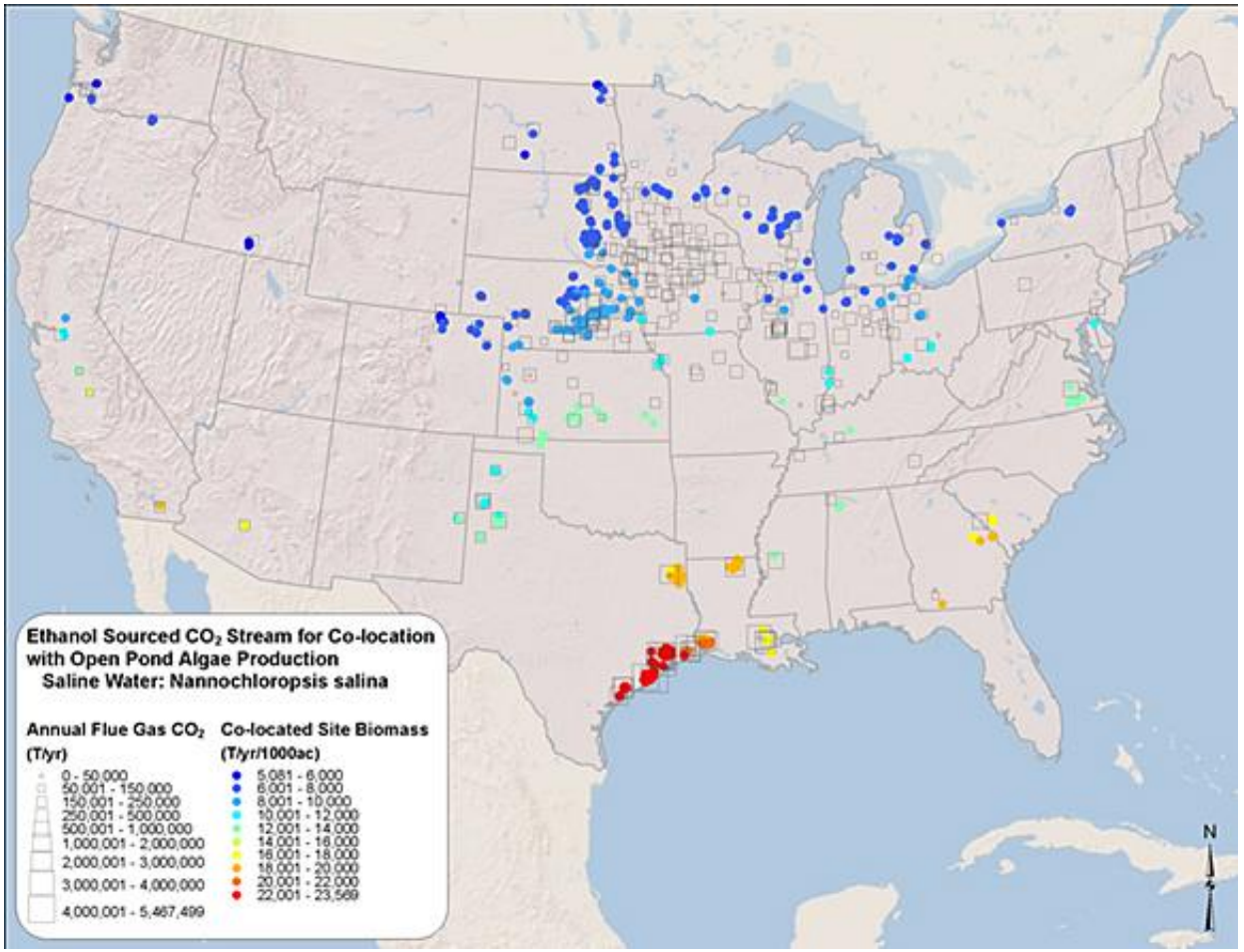
Billion Ton Study
Algae Chapter Highlights

NATURAL GAS - Saline Strain, Current Productivity



Billion Ton Study
Algae Chapter Highlights

ETHANOL - Saline Strain, Current Productivity



U.S. Algae Industry Progress

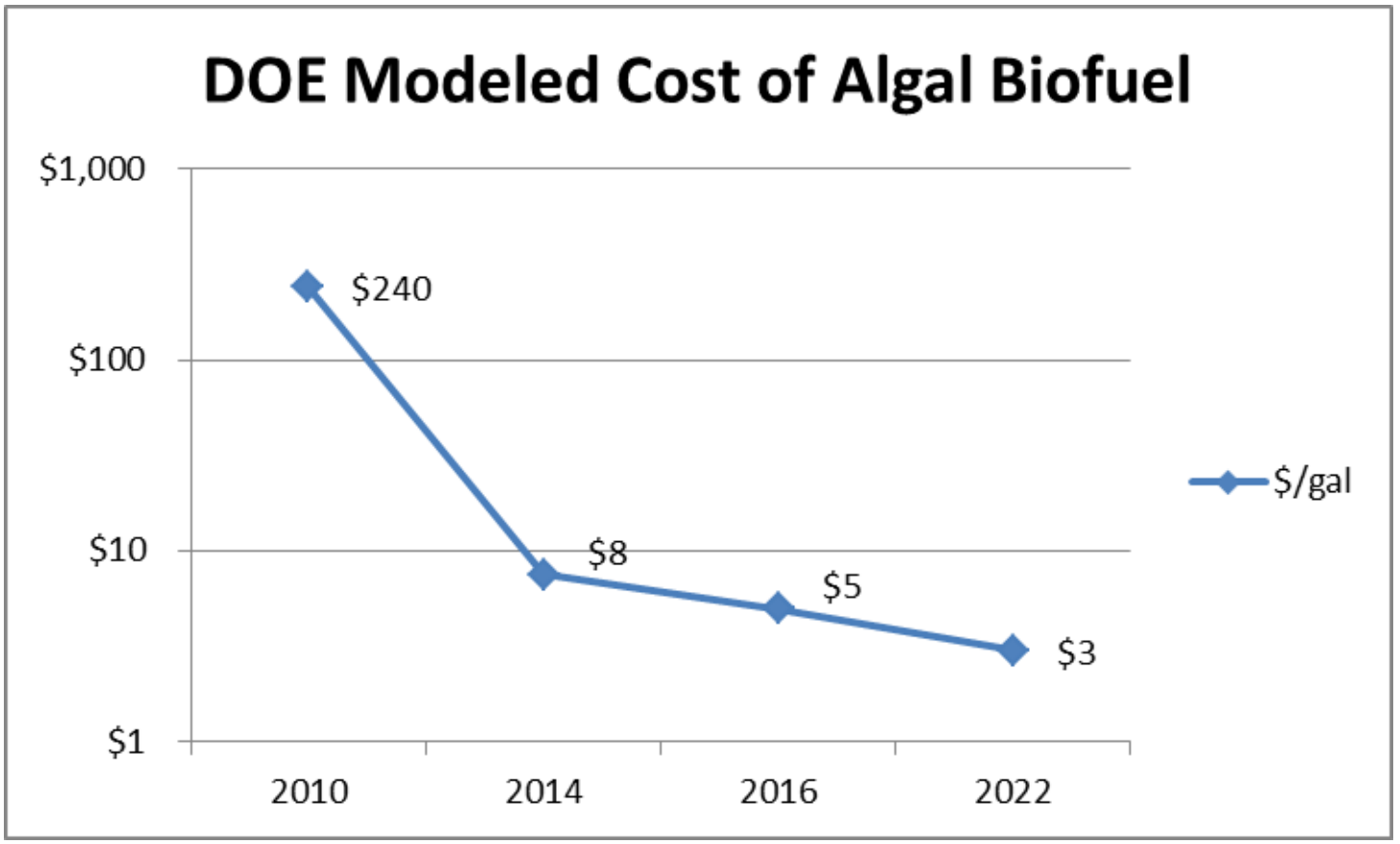



- **Technology Gains**
  - Productivity, System Design
- **New Markets**
  - Food & Feed, Fuel, Fertilizer, High-Value Components
- **Global Partnerships**
  - Investments from India, China
- **New Federal Policy Support**
  - 45Q

Technology Progress




➢ Cost of Production Cut 98% in 7 years



Technology Progress

- **ExxonMobil, Synthetic Genomics last year announced doubling of algae productivity…**

SYNTHETIC GENOMICS®

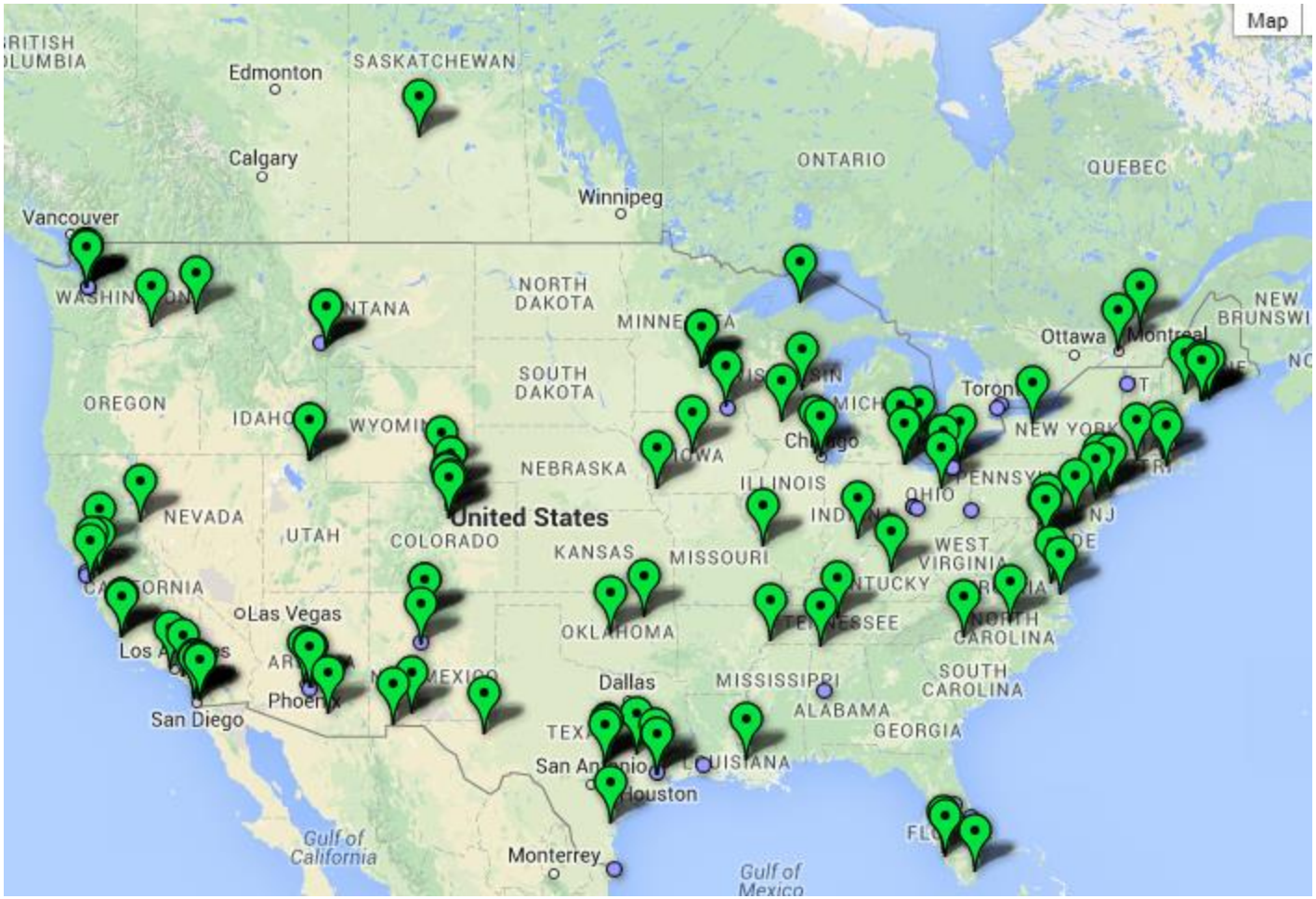
About Us | Core Technology | Bio-Based Production

ExxonMobil and Synthetic Genomics Report Breakthrough in Algae Biofuel Research

- Algae strain developed and modified by Synthetic Genomics more than doubled oil production
- Additional research and testing required before commercial application
- Results published in peer-reviewed journal *Nature Biotechnology*

IRVING, Texas and LA JOLLA, Calif. – ExxonMobil and Synthetic Genomics Inc. today announced a breakthrough in joint research into advanced biofuels involving the modification of an algae strain that more than doubled its oil content without significantly inhibiting the strain's growth.

Algae Research and Commercial Facilities in U.S. and Canada



Technology Progress

- **DOE-funded integrated algae biorefinery commercial demonstration projects in:**
  - Florida (Algenol)
  - New Mexico (Sapphire)
  - Iowa (BioProcess Algae)

- **Pilot / demonstrations with flue gas from variety of industrial sources:**
  - Coal, other power plants
  - Cement, steel
  - Ethanol

Beneficial Re-use of Carbon Using Microalgae
University of Kentucky / Duke Energy

- **Pilot project at Duke's East Bend Coal-powered Generating Station**
- **Recently awarded 2nd $1 million DOE Fossil Energy Grant**

CAER Center for Applied Energy Research

UK UNIVERSITY OF KENTUCKY

DUKE ENERGY

GLOBAL ALGAE INNOVATIONS

33-Acre Kauai Algae Facility

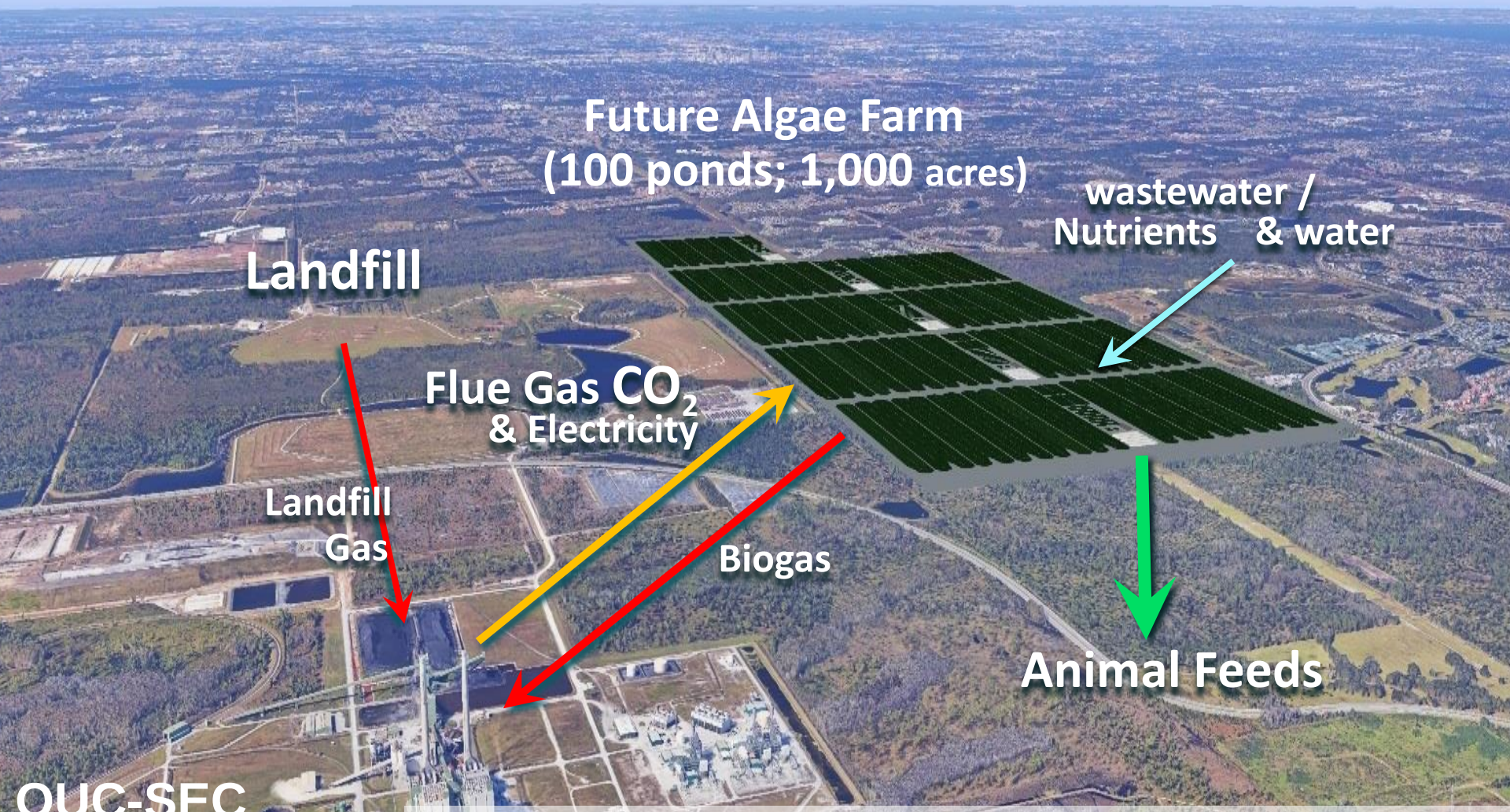
- DARPA-funded project with General Atomics
- Co-located with fuel oil-powered steam-injected combustion turbine power plant

DOE NETL Funded PROJECT
MicroBio Engineering Inc.
"Microalgae Commodities from Coal Plant Flue Gas CO2"

Rob Teegarden
OUC-SEC

Orlando Utilities Commission Stanton Energy Center

Microalgae CO2 Utilization → biogas, waste treatment, feeds



OUC-SEC two ~450 MW Coal-fired Power Plants

Orlando Utilities Commission Stanton Energy Center

"Microalgae Commodities from Coal Plant Flue Gas CO2"

DOE NETL Funded Project MicroBio Engineering Inc

State of Algae Carbon Utilization Technology

➢ BioProcess Algae

- 5-acre commercial demonstration in Shenandoah, IA, co-located with Green Plains **corn ethanol plant**
- Continuous operation since 2009 utilizing waste CO2, waste heat, waste nutrients
- Markets: Fuel, fish/animal feed

bioprocessalgae
Valuing Carbon

State of Algae Carbon Utilization Technology

➢ Algenol Biofuels

- 2-acre commercial demonstration in Lee County, FL
- Pilot demo at Reliance **petroleum refinery** in India
- Received EPA approval as advanced biofuel with 69% GHG reduction vs. gasoline

ALGENOL BIOFUELS

Harnessing the sun to fuel the world®

Large-Scale Commercial Algae Farms in Production Today

- **Earthrise Nutritionals (est. 1982)**
  - Spirulina production on 100+ acres of ponds in Imperial Valley, California
  - Exports to 20+ countries

Large-Scale Commercial Algae Farms in Production Today

- **Algae Life Sciences (China)**
  - 80 acres = > 1000 km of glass tube photobioreactors
  - Astaxanthin for human nutrition, animal feed

LanzaTech

AEMETIS
8MGPY
Biomass
Syngas

ArcelorMittal
21MGPY
Steel Off
Gas

首钢朗泽
Shougang LanzaTech
16MGPY
Steel Off
Gas

SWAYANA
TBC
Ferro Alloy
Off Gas

इंडियनऑयल
IndianOil
13MGPY
Refinery
Off Gas

Commercial Projects Around the World

Big Market Opportunities

- **Aquaculture Feed**
  - 130 million tons, $9B / yr

TerraVia DSM BRIGHT SCIENCE. BRIGHTER LIVING. cellana algae-based products for a sustainable future ADM

- **Livestock Feed**
  - 1B tons, $370B / yr

- **Fertilizer**
  - 180 million tons, $90B /yr

ACCELERGY CORPORATION heliae

Source: Bloomberg New Energy Finance Research Note 5 June 2015

Feed

➢ Omega-3 oils for Feed

DSM
BRIGHT SCIENCE. BRIGHTER LIVING.

EVONIK
POWER TO CREATE

SKRETTING
a Nutreco company

Corbion

BUNGE

BioMar

SYNTHETIC GENOMICS

ADM

Feed

➢ Fish & Animal Feeds

Diverse & Successful Feed Trials

- Successful large-scale feed trial for Salmon, Carp, & Shrimp
  - *Marine microalgae from biorefinery as a potential feed protein source for Atlantic salmon, common carp and whiteleg shrimp*, V. Kiron (Bodo Univ.) *et al.*, Aquaculture Nutrition, Vol. 18, Issue 5, pp. 521-531, Oct. 2012
    - Cellana's ReNew Feed was acceptable for the three animals at the maximum levels tested (Salmon 10%, Carp 40%, Shrimp 40%)
- Successful large-scale feed trial for Broiler Chicks
  - *Potential and Limitation of a New Defatted Diatom Microalgal Biomass in Replacing Soybean Meal and Corn in Diets for Broiler Chickens*, Xin Gen Lei (Cornell) *et al.*, J. of Agricultural & Food Chemistry, 61(30), pp. 7341-8, July 2013
    - Cellana's ReNew™ Feed could substitute for 7.5% of soybean meal alone, or in combination with corn, in diets for broiler chicks when appropriate amino acids are added
- Successful large-scale feed trial for Broiler Chicks and Weanling Pigs
  - *Nutritional and Metabolic Impacts of a Defatted Green Marine Microalgal (Desmodesmus sp.) Biomass in Diets for Weanling Pigs and Broiler Chickens, Xin Gen Lei (Cornell) et al.*, J. of Agricultural & Food Chemistry, *62* (40), pp. 9783–91, Sept. 2014
    - Broilers fed 15% Cellana's ReNew™ Feed had 16% greater gain/feed efficiency than the control diet over the 42-day period.

Food-Energy-Water Nexus

RESEARCH | OPEN ACCESS

New feed sources key to ambitious climate targets

Brian J. Walsh, Felicjan Rydzak, Amanda Palazzo, Florian Kraxner, Mario Herrero, Peer M. Schenk, Philippe Ciais, Ivan A. Janssens, Josep Peñuelas, Anneliese Niederl-Schmidinger and Michael Obersteiner

Carbon Balance and Management 2015 **10**:26 | **DOI:** 10.1186/s13021-015-0040-7 | © Walsh et al. 2015
Received: 23 October 2015 | **Accepted:** 27 November 2015 | **Published:** 1 December 2015

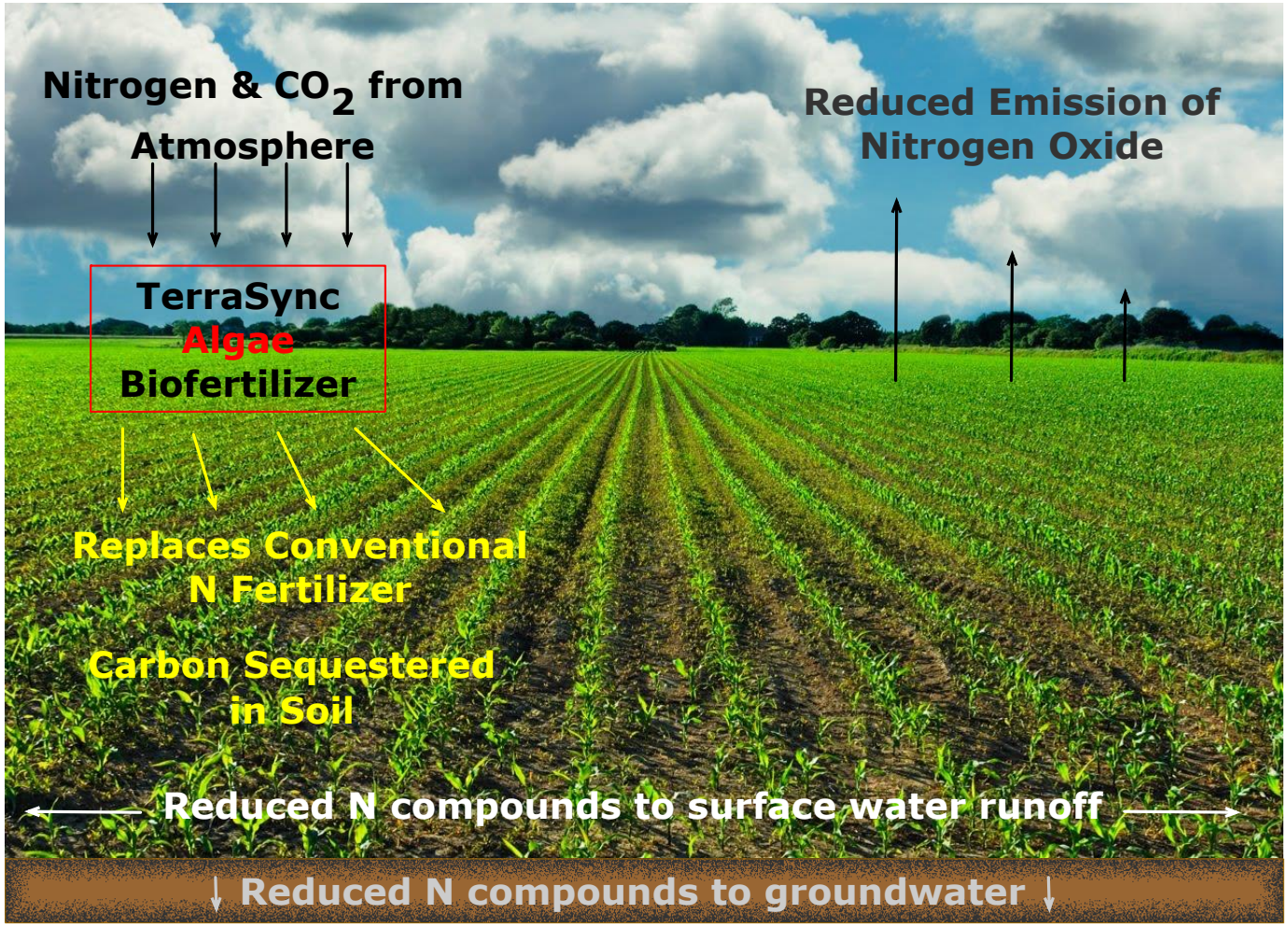
Abstract

Net carbon sinks capable c
acidification have been ide
2010). Land scarcity alread
is likely to intensify as popu
next-generation energy sou
overlooked. Here we use th
to free up to 2 billion hectar
these areas can conceivab
energy and LULUC sectors
and sequestration (CCS) te
levels by the end of the present century. Though previously thought unattainable, carbon sinks and climate change mitigation of this magnitude are well within the bounds of technological feasibility.

"Used as feed, microalgal biomass can free up to 40 % of pastures, meadows, and feedcrop land. In this way, highly-productive algacultural technologies can be harnessed to offset the resource and environmental costs of rising demand for animal proteins… [T]his strategy is expected to reduce global temperature change 0.7C"

Soil Health

➢ Soil Amendments and Biofertilizers



Soil Health

➢ Soil Amendments and Biofertilizers

200 Acre Algae Biofertilizer Demonstration – Arizona Farm

ACCELERGY

- Algae cultivated in simple PBR's adjacent to the melon field
- Algae distributed through drip irrigation system

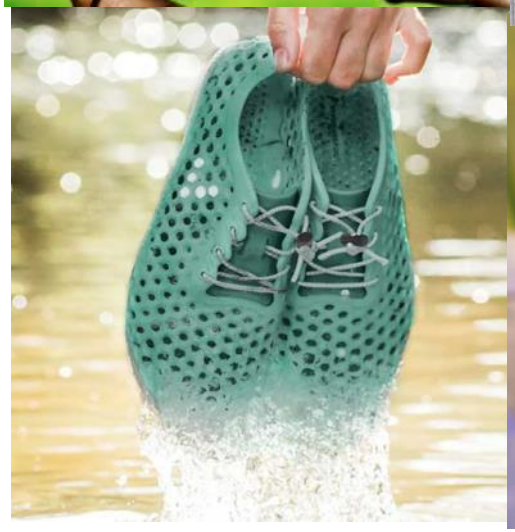
Del Monte Quality

Yosemite Melons	
Germination	2X
Early Growth	2.5X
Plant Size & Density	3X
Early Melon Maturity	2X
Mature Melon Size	1.4X
Mature Melon Weight	1.5X
Taste (blind panel test)	14:1

Biobased Materials




➢ Biomaterials, Inks and Dyes

Food

- **Plant-based proteins, oils and nutritional ingredients**

High Value Components

Astaxanthin – Powerful antioxidant

heliae

Phycocyanin – First natural blue food color

EARTHRISE

MATRIX GENETICS

Animal Health

- **Therapeutic proteins and animal health**
  - **Replacement for antibiotics agri-/aquaculture**

TRITON HEALTH & NUTRITION

ALGAL SCIENTIFIC

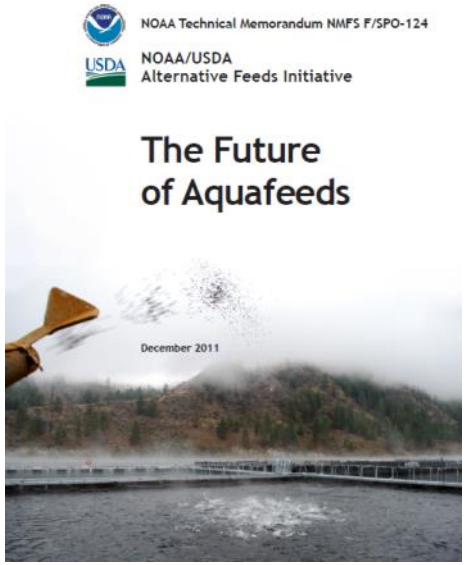
Nutrient Management

➢ Algae-based systems for N, P recycling

Macroalgae

Macroalgae

- Harvested/grown for food/feed in Asia for centuries
- Trending as sustainable food / feed ingredient
- Ecosystem services + jobs in coastal communities



Global Partnerships

ALGENOL

Reliance Industries Limited

LanzaTech

ArcelorMittal

JOULE

HEIDELBERGCEMENT

TerraVia

BioMar

Federal Policy Support




➢ Carbon Utilization R&D

- ❖ $2 million in FY2015
  - Funded 2 pilot projects
- ❖ $10 million in FY2016, FY2017
  - 2 additional algae awards
- ❖ Still 1/10 funding level vs. capture, storage

Federal Policy Support




➢ 45Q CCU Tax Credit

- Bipartisan Budget Act of 2018 extends existing section 45Q carbon capture tax credit and expands in several ways:
  - ✓ Adds up to $35 / ton credit for non-geologic utilization, including: "*fixation… through photosynthesis or chemosynthesis, such as through the growing of algae or bacteria.*"
  - ✓ Industrial and air capture facilities now eligible
  - ✓ Reduces minimum capture threshold to 25,000 tons/year for non-geologic use at small-to-mid-size facilities (vs. 500,000 tons/year CCS/EOR)

Federal Policy Support




➢ 45Q CCU Tax Credit

Credit for non-geologic utilization based on LCA:

"shall be equal to the metric tons of qualified carbon oxide which the taxpayer demonstrates, based upon an analysis of lifecycle greenhouse gas emissions… were—

"(I) captured and permanently isolated from the atmosphere, or

"(II) displaced from being emitted into the Atmosphere."

Policy Outlook

- **Algae Well Aligned with Administration Priorities:**
  - **Manufacturing**
  - **Infrastructure**
  - **Rural Revitalization**

JOBS!

2018 Algae Biomass Summit

Oct 14-17, 2018, Houston TX

Matt Carr

mcarr@algaebiomass.org

ALGAE BIOMASS SUMMIT 2018

THE WOODLANDS • HOUSTON • OCT 14-17