# Anthropogenic $CO_2$ as a Feedstock for Cyanobacteria-Based Biofuels

ALGENOL

*Harnessing the sun to fuel the world.®*

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**Bioenergy 2015**
**June 24, 2015**
**Washington, DC**

# Algenol Overview

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## Advanced Industrial Biotechnology Company

- Started up in 2006
- Headquartered in Fort Myers, Florida
- Over 200 employees (~150 in Florida and ~50 in Berlin, Germany)


Fort Myers Research Labs

## Research and Development Facilities

- 90,000 $ft^2$ of Research and Development lab space in Fort Myers and Berlin
- 4 acre Process Development Unit (PDU)
- 36 acre Integrated Bio-Refinery (IBR)

Process Development Unit

## Commercializing Direct To Ethanol® Technology

- $200M equity capital
- $25M Department of Energy Integrated Biorefinery grant
- $10M economic development grant from Lee County, FL

Integrated Biorefinery
[Paul Woods & Ed Legere]

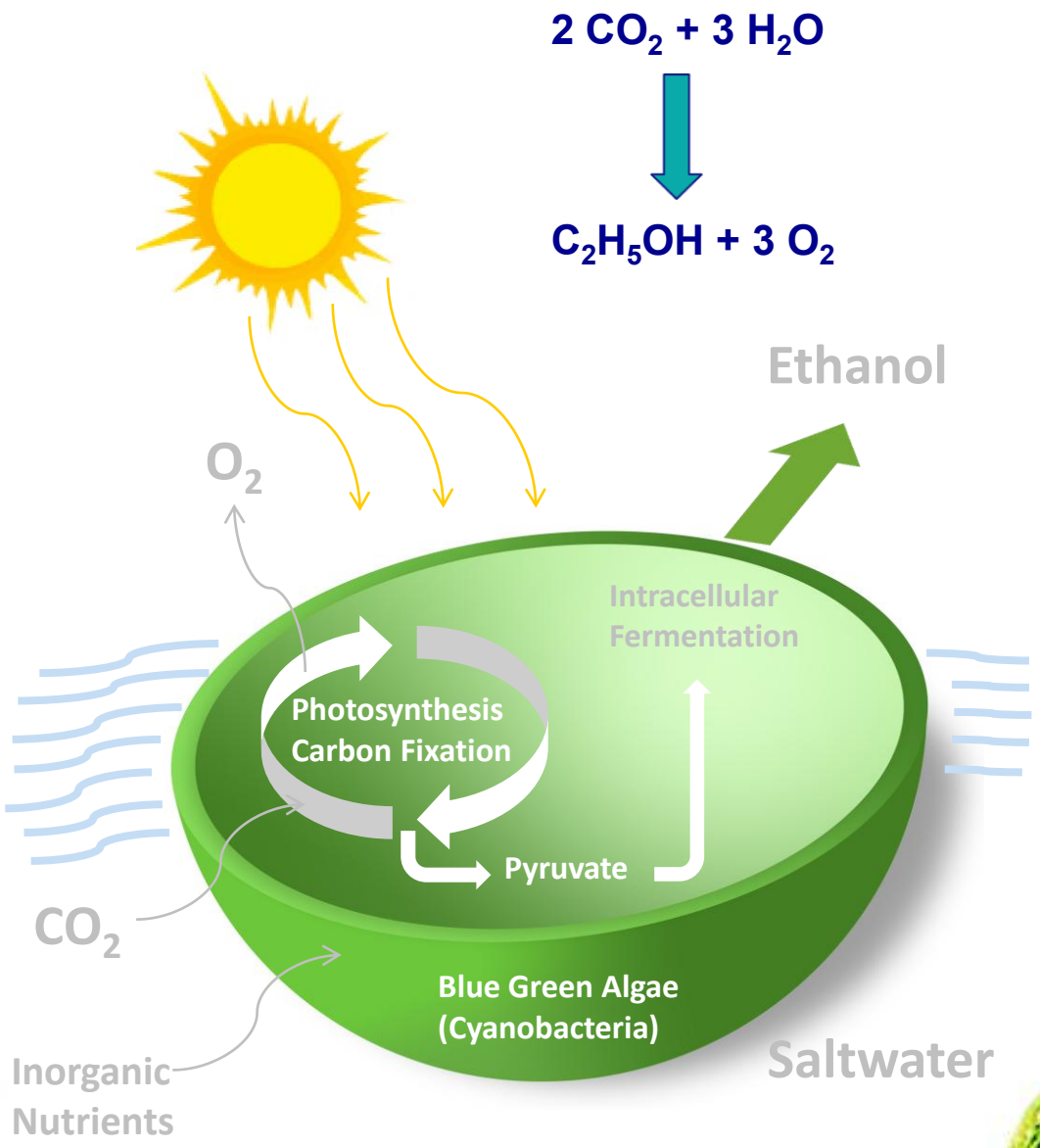

# Headquarters and Commercial Development Campus

Fort Myers, Florida

# Core Technology: Enhanced Cyanobacteria

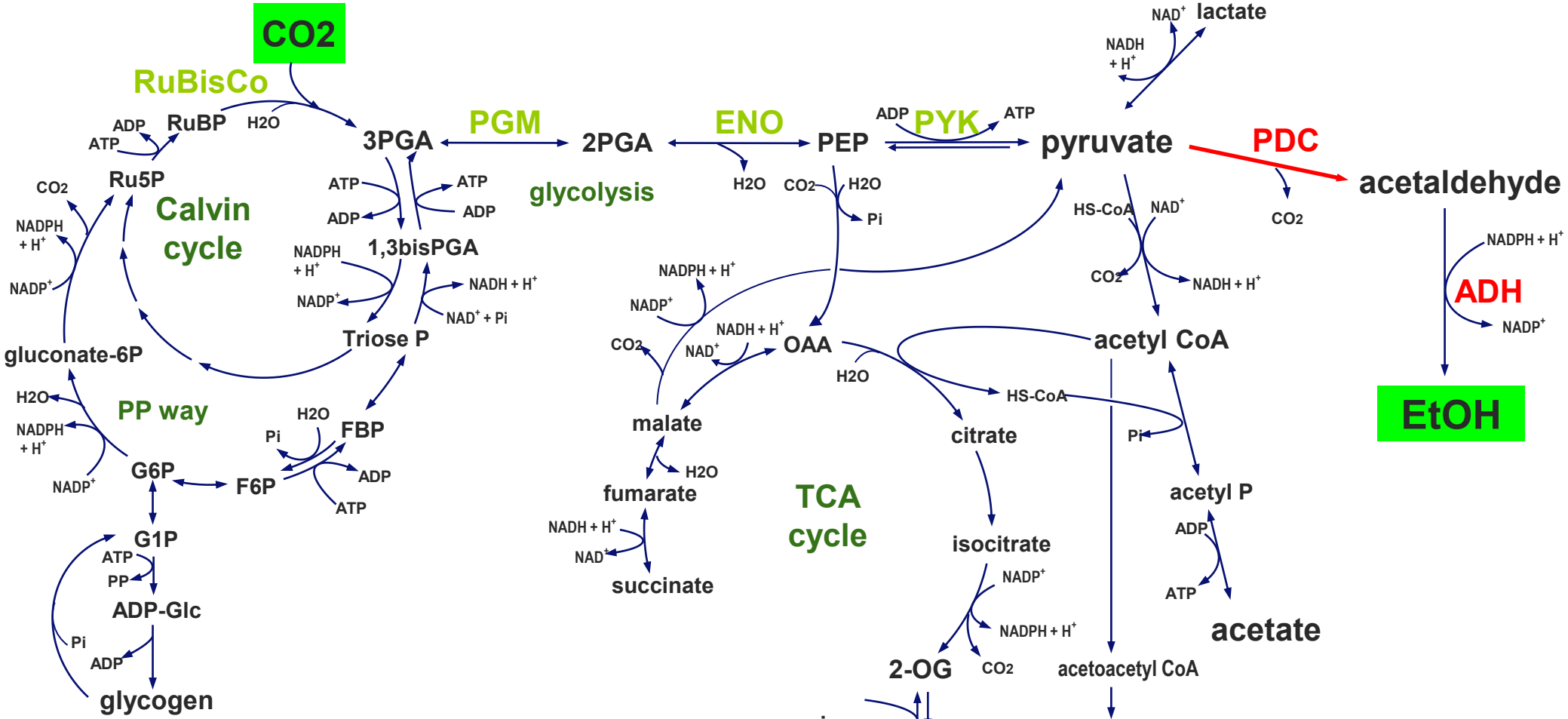
**Algenol's Direct to Ethanol® process uses genetically enhanced cyanobacteria to produce ethanol**

- 2,300 strains collected globally and screened as candidates for development.
- Fermentation pathway enzymes are over-expressed to enhance ethanol production.
- A commercial strain has been selected and is being optimized.
- Main product is ethanol, but also convert biomass to hydrocarbons in the gasoline, diesel, and jet fuel ranges.



# Metabolic Pathway for Ethanol Production

## Direct linkage of EtOH synthesis to carbon fixation via 5 enzymatic steps




**Simplified network of central carbohydrate metabolism in cyanobacteria**

**PDC = Pyruvate decarboxylase**
**ADH = Alcohol dehydrogenase**

# Photosynthetic Efficiency and Productivity Targets

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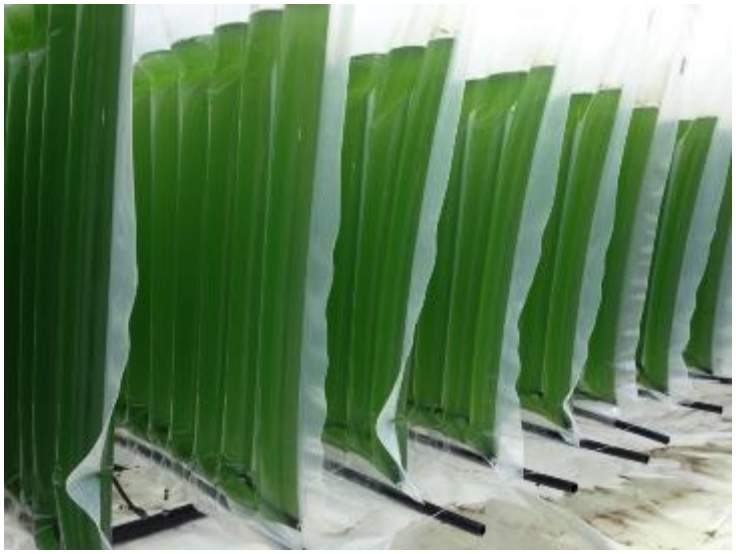
## Ethanol Production Target

- Algenol target is >7000 gal ethanol/acre-yr
- Corn is about 400 gal/acre-yr; sugarcane about 1000
- 2013 actual outdoor production exceeded 7000 gal/acre-yr at Algenol's Florida facility
- Target and recent results corresponds to 2-3% solar energy conversion efficiency (all % referenced to average US solar radiation)
- Efficiency similar to commercial biomass conversion for Chlorella (food supplements) as well as more conventional crops
- Absolute theoretical limit (8 photons per C fixed) is about 30,000 gal/acre-yr of ethanol



Algenol Vertical Photobioreactors

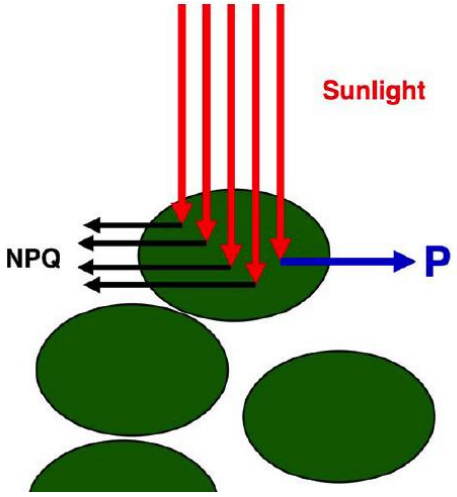
## Potential Yield Limitations

Ethanol branching ratio

Light (photosaturation, photoinhibition)

Contaminants

$CO_2$ and/or Nutrient supply




Photosaturation Illustration
(Melis, Plant Science (2009))

# TECHNOLOGY OVERVIEW

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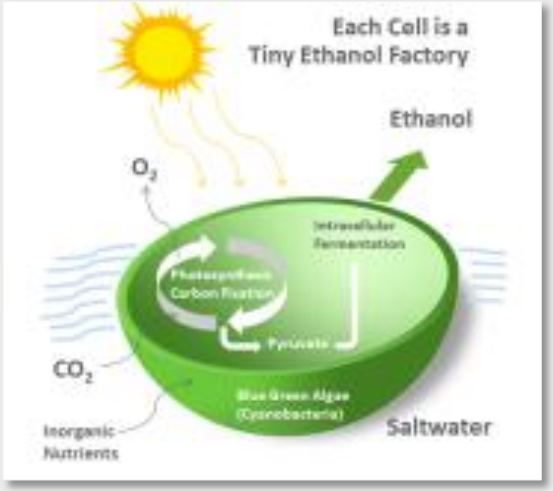
**Algenol's Direct to Ethanol® process has three key components:**

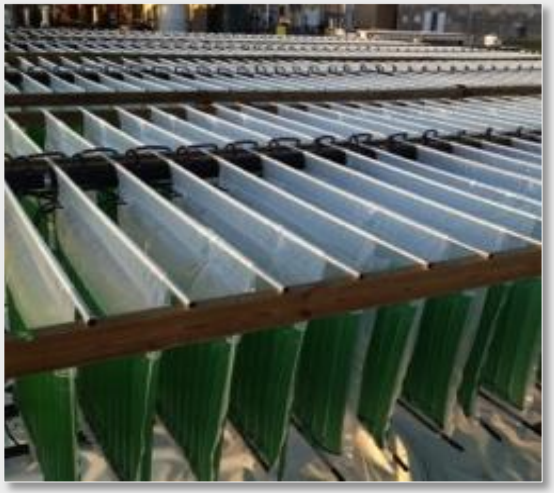
## A Very Productive Algal Platform




Proprietary cyanobacteria make ethanol and biomass directly from $CO_2$, water, and sunlight.

- Ethanol productivity in Florida ranges from 4000-8000 gal/acre-yr (gepay) dependent on season
- Target is >7,000 gepay "annualized"

## Specialized VIPER™ Photobioreactors



Cyanobacteria are grown in saltwater contained in proprietary PBRs that are exposed to the sun and are fed $CO_2$ and nutrients.

- A production cycle runs 3-6 weeks
- Spent algae are separated from the water-ethanol mixture
- PBRs are manufactured at an Algenol facility in Florida

## Energy Efficient Downstream Processing

Energy efficiency is critical for economics and for low carbon footprint

- Water-ethanol mixture is sent to patented downstream processing equipment that provides a 10-fold increase in concentration, then on to fuel grade
- Spent algae are processed into a green crude that can be refined into diesel, gasoline, and jet fuel

# Process Scale-up in 2013 at the IBR

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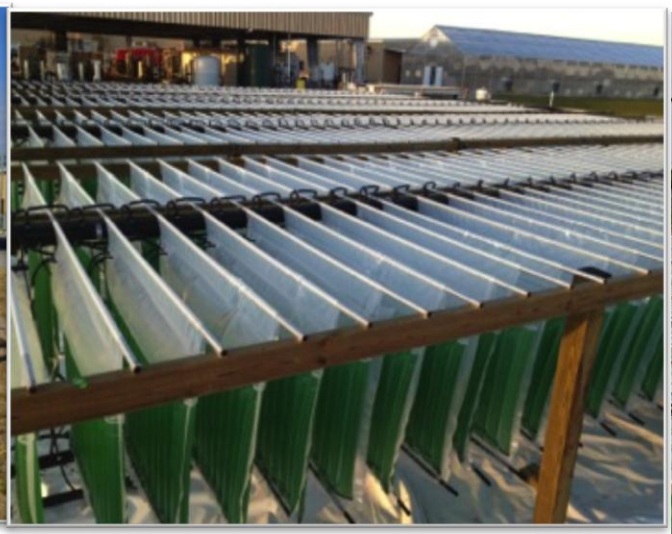
**10 x Scale Up**

**4000 Module**

| 40 Block | 400 Block | 4000 Block |
|---|---|---|
|  |  |  |
| First Inoculation February 6 | First Inoculation March 15 | First Inoculation July 19, 2013<br>Taken down June 2015 |

**2 acre demonstration unit – about 6500 10-ft wide photobioreactors. First inoculation in January 2015. Shakedown runs will be complete in June.**

# Bio-refinery Flow Chart and Unit Operations

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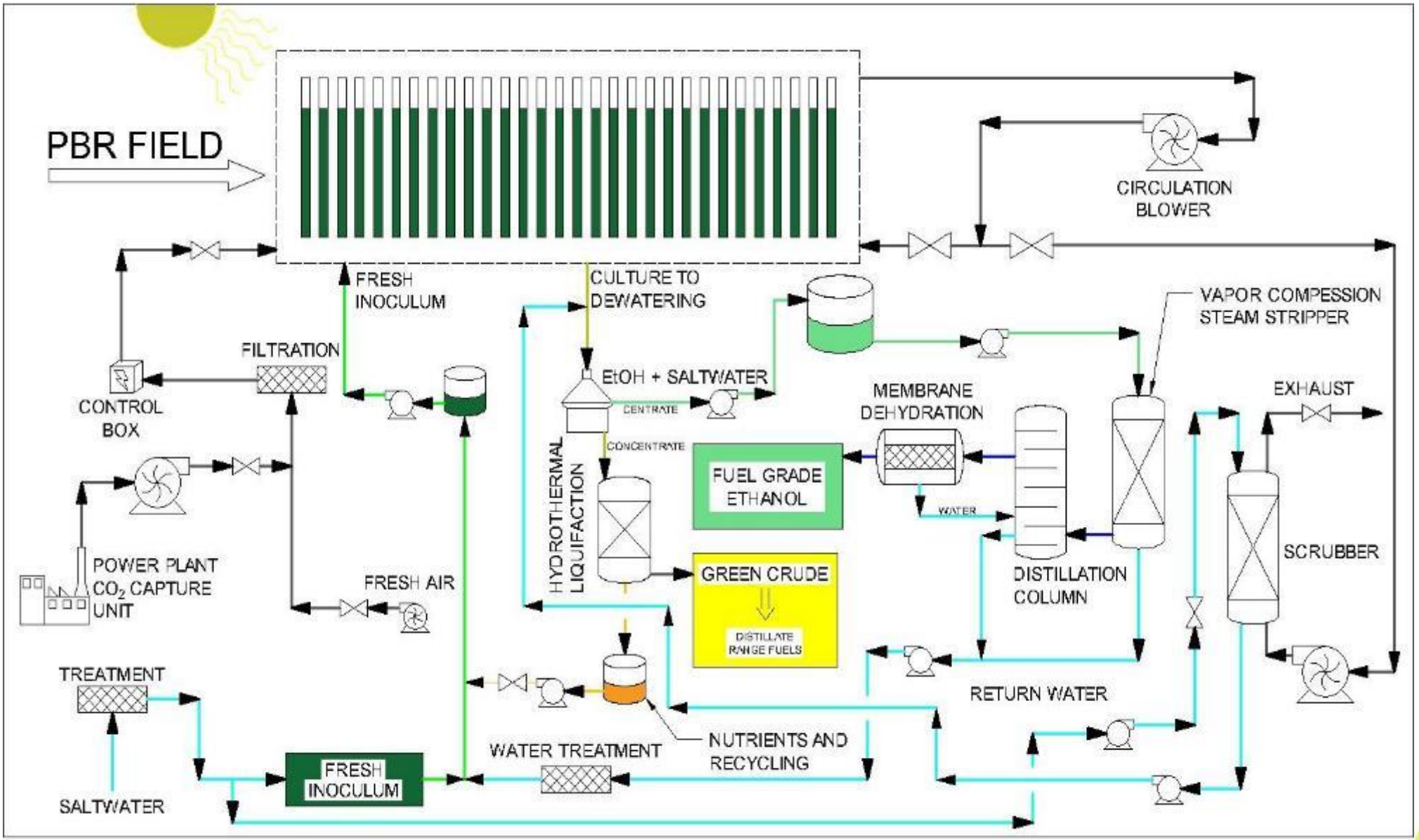
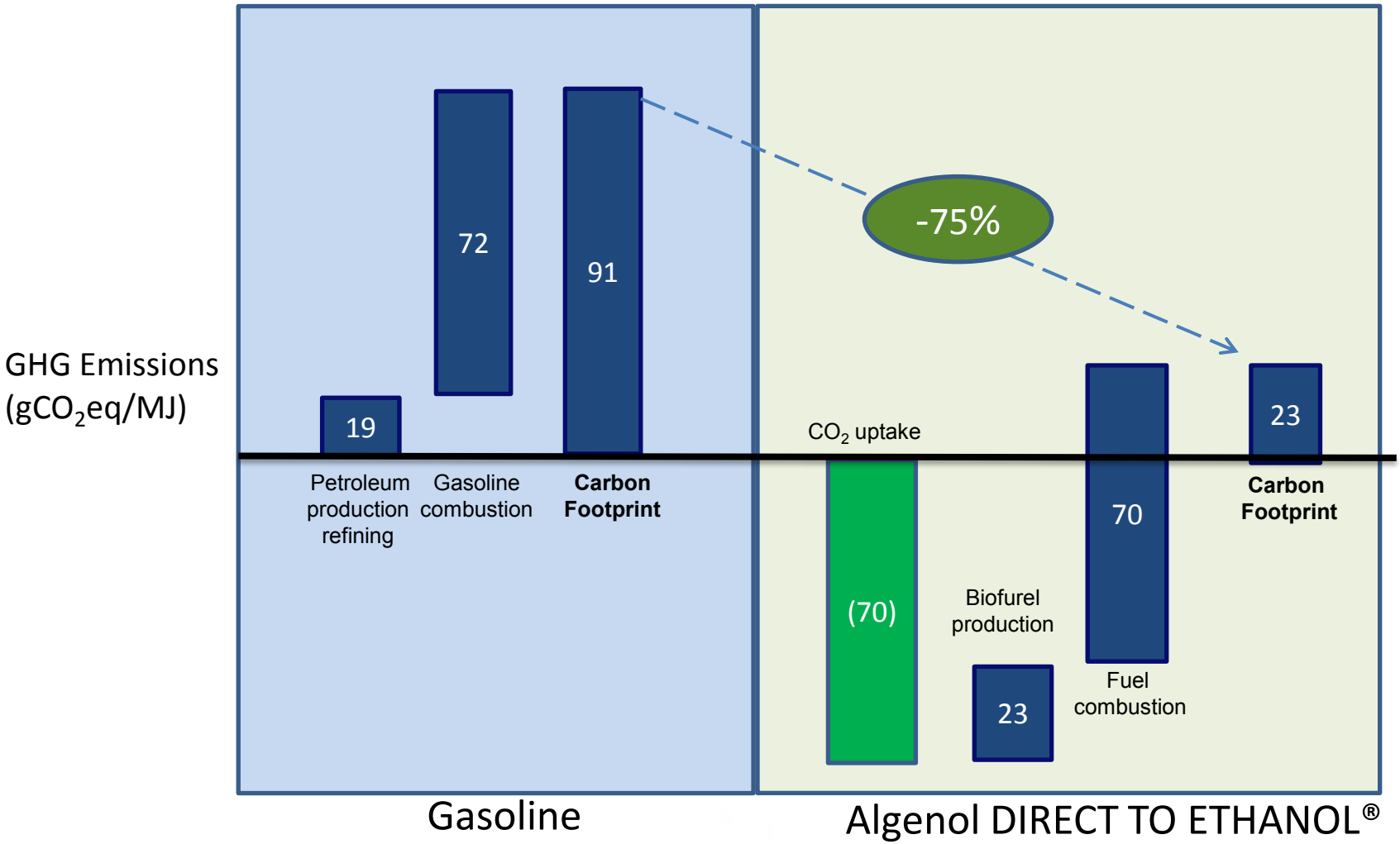


# Life Cycle Analysis

## Green House Gas (GHG) emissions reduced by 75% compared to gasoline

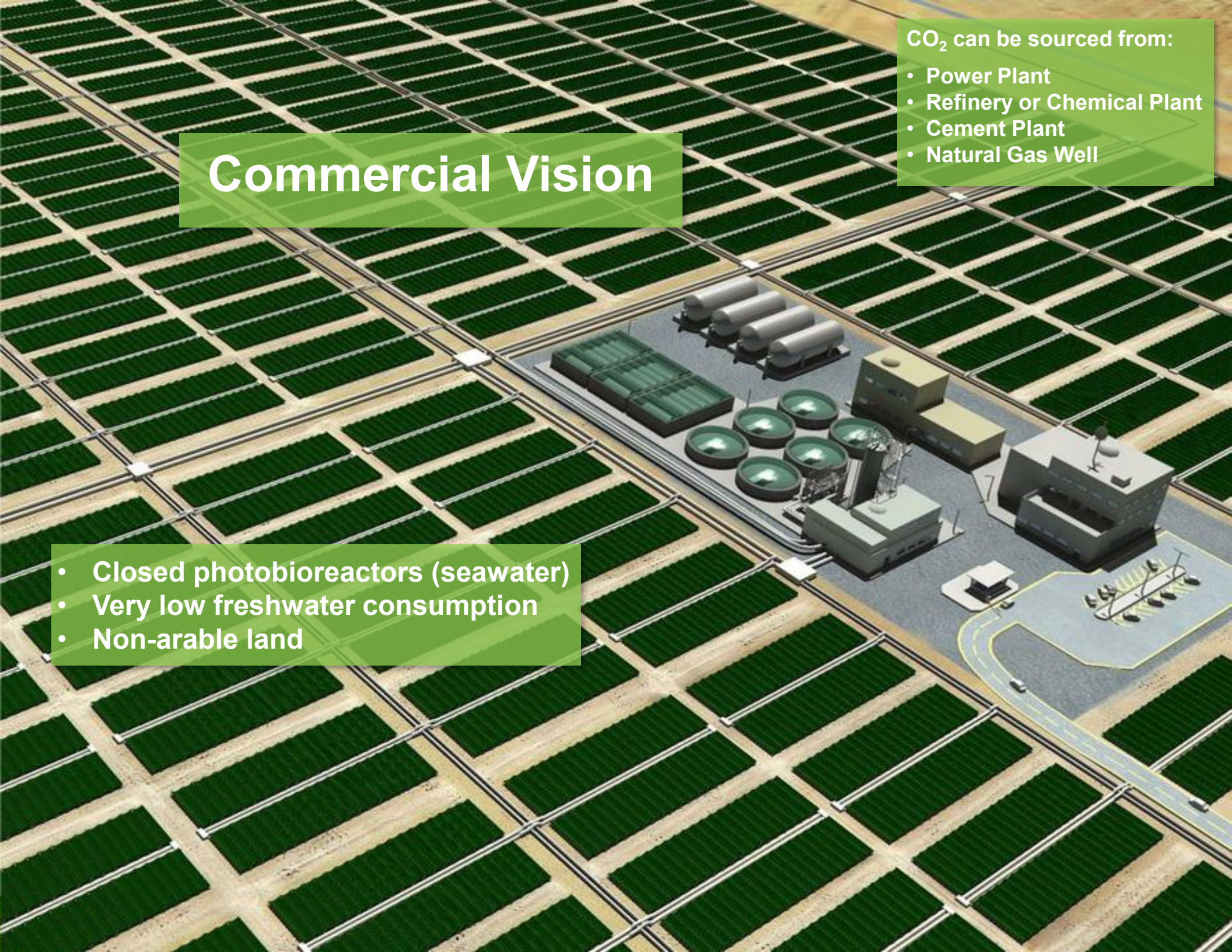



Updated (T. Fishbeck et al) from: D. Luo, Z. Hu, D. Choi, V. Thomas, M. Realff, and R. Chance, "Life Cycle Energy and Greenhouse Gas Emissions for an Ethanol Production Process Based on Blue-Green Algae", *Env. Sci. & Tech*. 44, 8670 (2010); see also, R. Lively, P. Sharma, D. Luo, B. McCool, J. Beaudry-Losique, V. Thomas, M. Realff, and R. Chance, "Anthropogenic $CO_2$ as a feedstock for the production of algal-based biofuels", *Biofuels, Bioproducts & Biorefining* **9**, 72-81 (2015).

# Commercial Vision

$CO_2$ can be sourced from:

- Power Plant
- Refinery or Chemical Plant
- Cement Plant
- Natural Gas Well



- Closed photobioreactors (seawater)
- Very low freshwater consumption
- Non-arable land

# Acknowledgements


# Acknowledgements – External Organizations


## Georgia Tech

Matthew Realff (ChBE)
Valerie Thomas (ISyE)
Bill Koros (ChBE)
Ryan Lively (ChBE)

## Pacific Northwest National Lab

Rich Hallen
Andy Schmidt
Doug Elliot
Dan Anderson
John Holladay

## Membrane Tech & Res

Richard Baker
Ivy Huang
Doug Gottlisch

## Humboldt University

Thomas Börner
Wolfgang Lockau
Ralf Steuer

## Giessen University

Annegret Wilde

## University of Freiburg

Wolfgang Hess

## University of Amsterdam

Lucas Stal

**This material is based upon work supported in part by the Department of Energy under Award Number DE-FOA-0000096.**



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**Part of this material is based upon work supported by the German Federal Ministry of Education and Research – FORSYS – Systems Biology of Cyanobacterial Biofuel Production**