



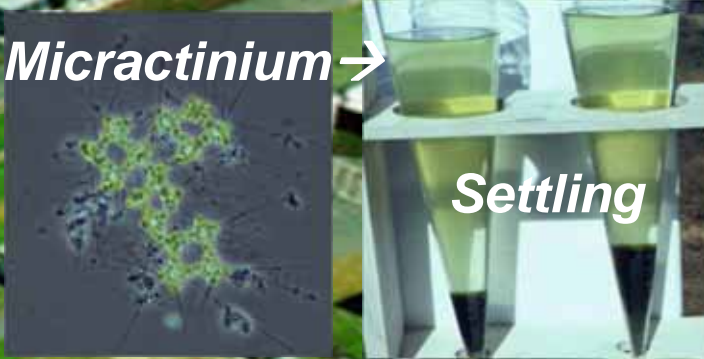
John Benemann: “CO₂ Microalgae Utilization - Historical and Global Overview” Orlando, FL, US DOE BETO Algae Cultivation for Carbon Capture and Utilization Workshop, 05/23/17

- Facilities Designs
- Equipment
- Wastewater Reclamation
- Scientific Consulting
- R&D
- Life Cycle Assessments
- Techno-Economic Analyses



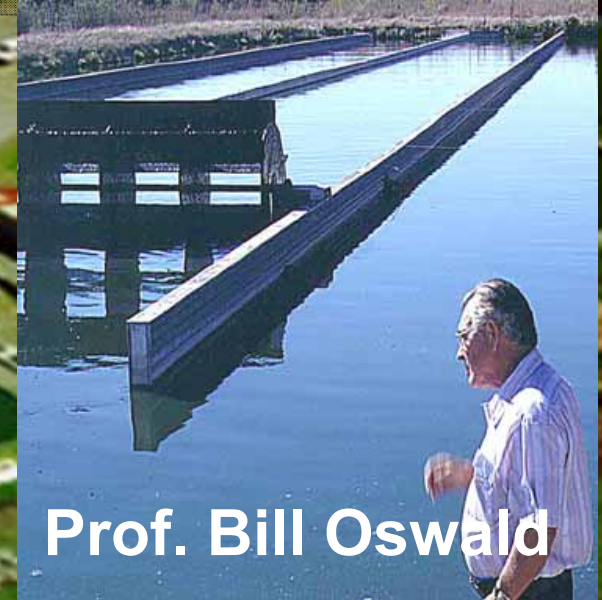
U.C. Berkeley, Sanitary Engineering Research Lab. Ca 1977
US DOE funded algae biofuels and wastewater treatment projects

Micractinium →



two x 0.1 ha ponds

First use of paddle-wheels for
mixing large raceway ponds,
Demonstrated settling algae for harvesting
and CO₂ fertilization (Benemann et al, 1980)




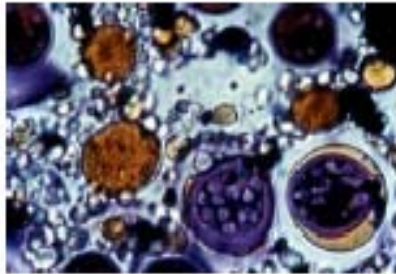
Prof. Bill Oswald

Aquatic Species Program U.S. DOE 1980 -1996

NREL/TP-580-24190

A Look Back at the
U.S. Department of Energy's
Aquatic Species Program:
Biodiesel from Algae

J. Sheehan,
P. Roessler,
T. Dunahay,
J. Weissman
J. Benemann 
(Principal Investigator)



Close-Out Report



**Paul Roessler now
at Algenol (before that
at Synthetic Genomics)**



Joe Weissman

Algae-powered cars: Science fiction or science?

Say algae, and most people think of those unpleasant green organisms found in swarming ponds and fish tanks. But to the scientists and engineers of ExxonMobil, algae conjure something far more appealing: Opportunity. Why? Because algae can create renewable energy while absorbing CO₂.

The energy from algae might someday produce biofuels that are compatible with those made from conventional crude oil. That's why ExxonMobil is committed to a major long-term research and development program aimed at developing algae as a viable fuel source. Unlike other biofuel sources such as corn and sugar cane, algae do not compete with our food supply. And because they consume CO₂, algae could help reduce greenhouse gases.

ExxonMobil is partnering with Synthetic Genomics Inc., pioneers in biotechnology, on this groundbreaking research effort. Our goal is to produce biofuels from algae in the future to supplement the fuels we use in our vehicles today, while reducing greenhouse gas emissions. Algae have never looked so inviting.

www.exxonmobil.com



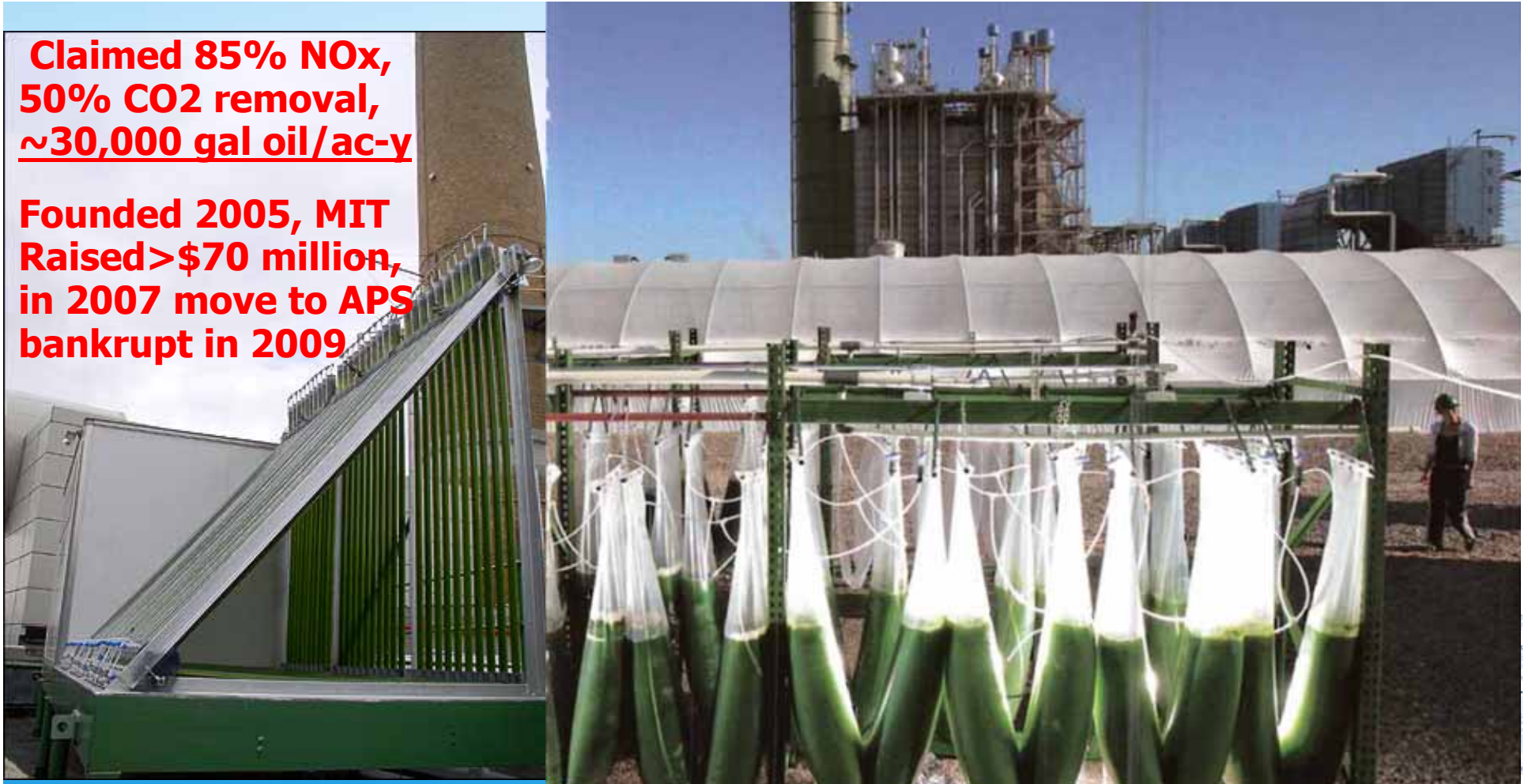
ExxonMobil obil
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ExxonMobil
Taking on the world's toughest energy challenges™

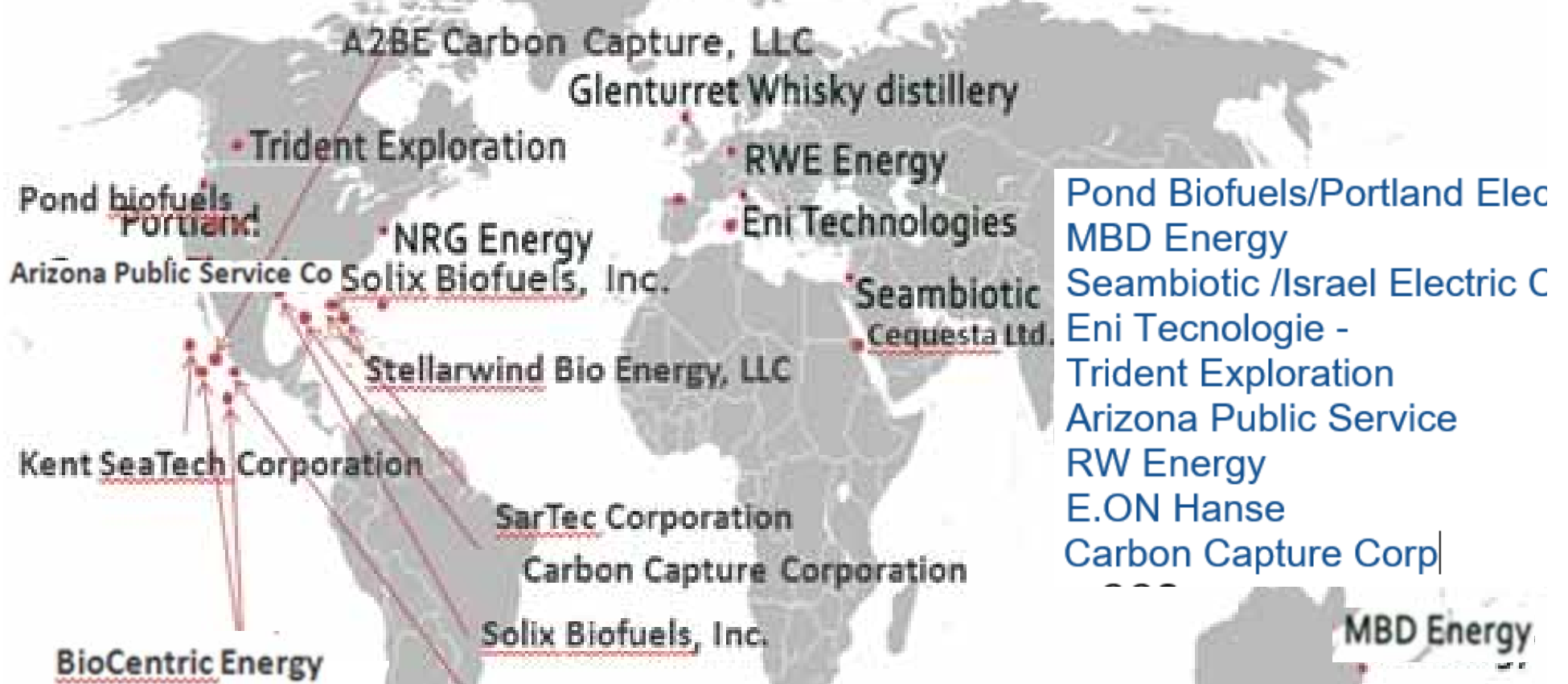
GreenFuel Technologies & Arizona Public Services (APS)

**Claimed 85% NO_x,
50% CO₂ removal,
~30,000 gal oil/ac-y**

**Founded 2005, MIT
Raised >\$70 million,
in 2007 move to APS
bankrupt in 2009**



http://www.powerplantccs.com/ccs/cap/fut/alg/alg_ccs_liveprojects.html



Major algae-based CO₂ capture /utilization projects in 2010
Reality Check: None still active in this field

Some more recent examples of algae CO2 Utilization Projects:

Reality Check: CO2 flue gas utilization not yet commercial

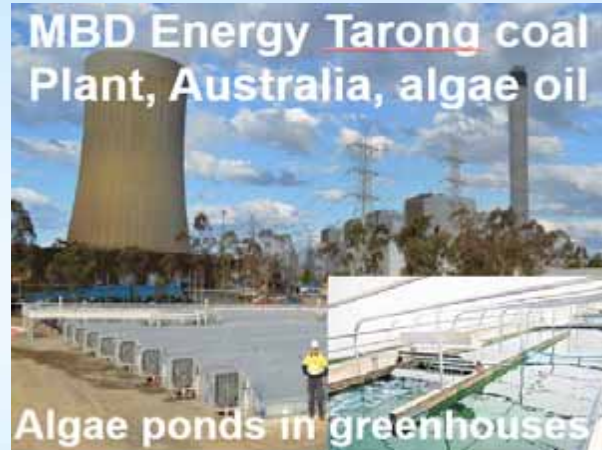
Algae.Tec \$138M algal oil plant
Algae-in-a-box



Macquarie's coal-fired power plant, CO2 utilization, Australia Jul 2013

This block features a collage of images related to the Algae.Tec project. It includes a photograph of a worker in a blue hard hat and safety vest, a 3D schematic of a green algal cultivation system, and a photograph of the Macquarie coal-fired power plant with its distinctive cooling towers.

MBD Energy Tarong coal Plant, Australia, algae oil



Algae ponds in greenhouses

This block shows the MBD Energy Tarong coal plant in Australia. The top image is a wide shot of the industrial facility with a large cooling tower. The bottom image shows several long, narrow algae ponds housed within a large greenhouse structure.

Proviron, Belgium PBRs vertical, in water filled bags



landfill gas power plant

This block displays vertical photobioreactors (PBRs) from Proviron, Belgium, which are described as being in water-filled bags. The top image shows a close-up of these green vertical structures. The bottom image shows a large industrial building, identified as a landfill gas power plant.

Hearol Plant (Yantai, China) 10 ha (US\$ 10M), 0.1 ha raceway ponds; algal oils (nutrition/ aquaculture)



This block shows the Hearol Plant in Yantai, China. The image depicts several long, narrow raceway ponds used for algal cultivation, situated in an industrial area.

Pond Biofuels, Canada



St Mary's Cement, Ontario
6" flue gas pipe

PBR with LED lights

This block features a vertical photobioreactor (PBR) from Pond Biofuels in Canada. The PBR is a large, dark, cylindrical structure with colorful circular lights. A person is standing next to it for scale. A 6-inch flue gas pipe is visible nearby, and the facility is identified as St Mary's Cement in Ontario.

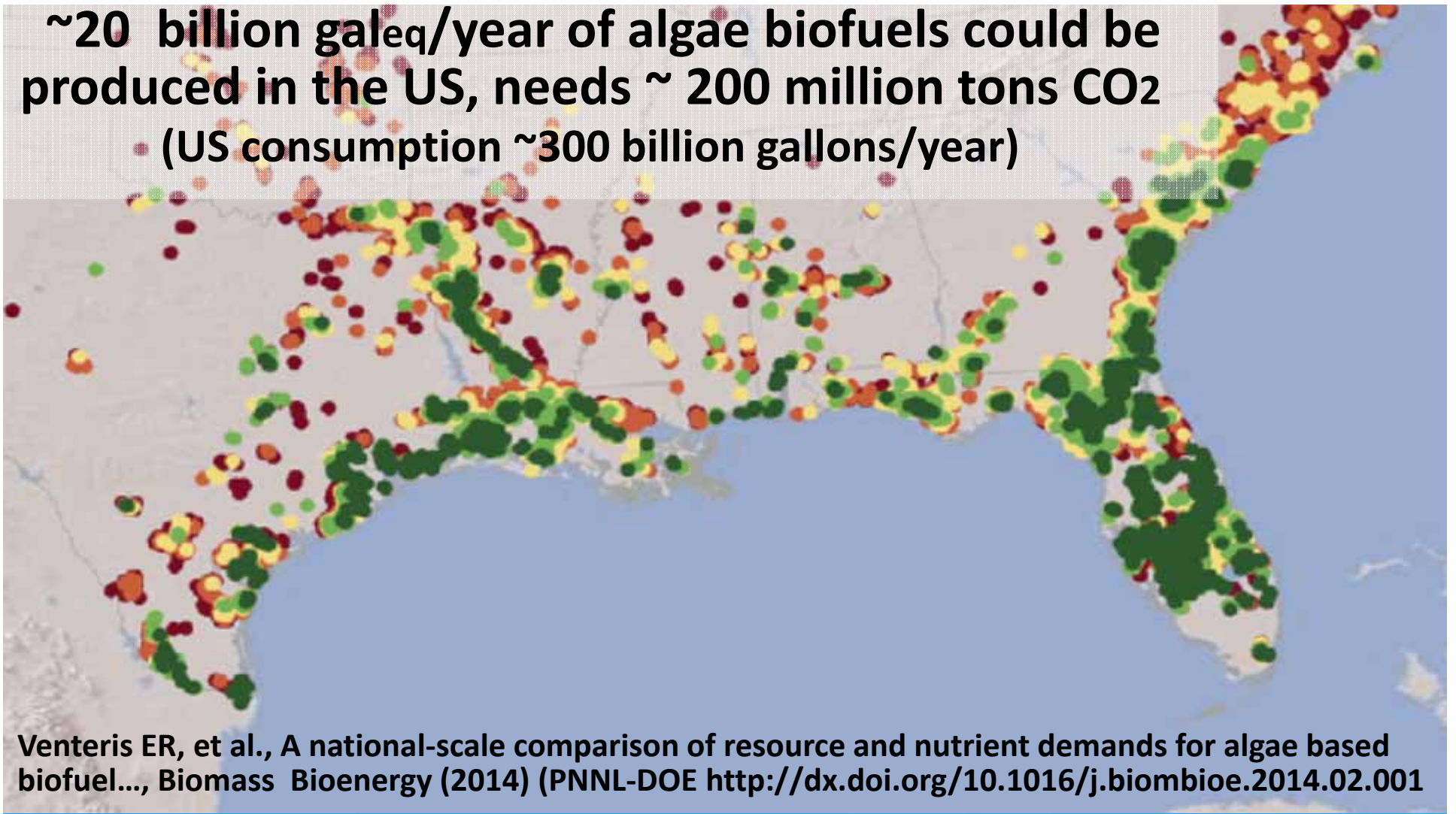
Buggypower, Porto Santo, Portugal, ~three thousand PBRs, 8 m tall ~40 cm diam



CO2 from oil-fired power plant

This block shows the Buggypower facility in Porto Santo, Portugal. The image displays a large array of vertical photobioreactors (PBRs) arranged in rows. The facility is powered by CO2 from an oil-fired power plant.

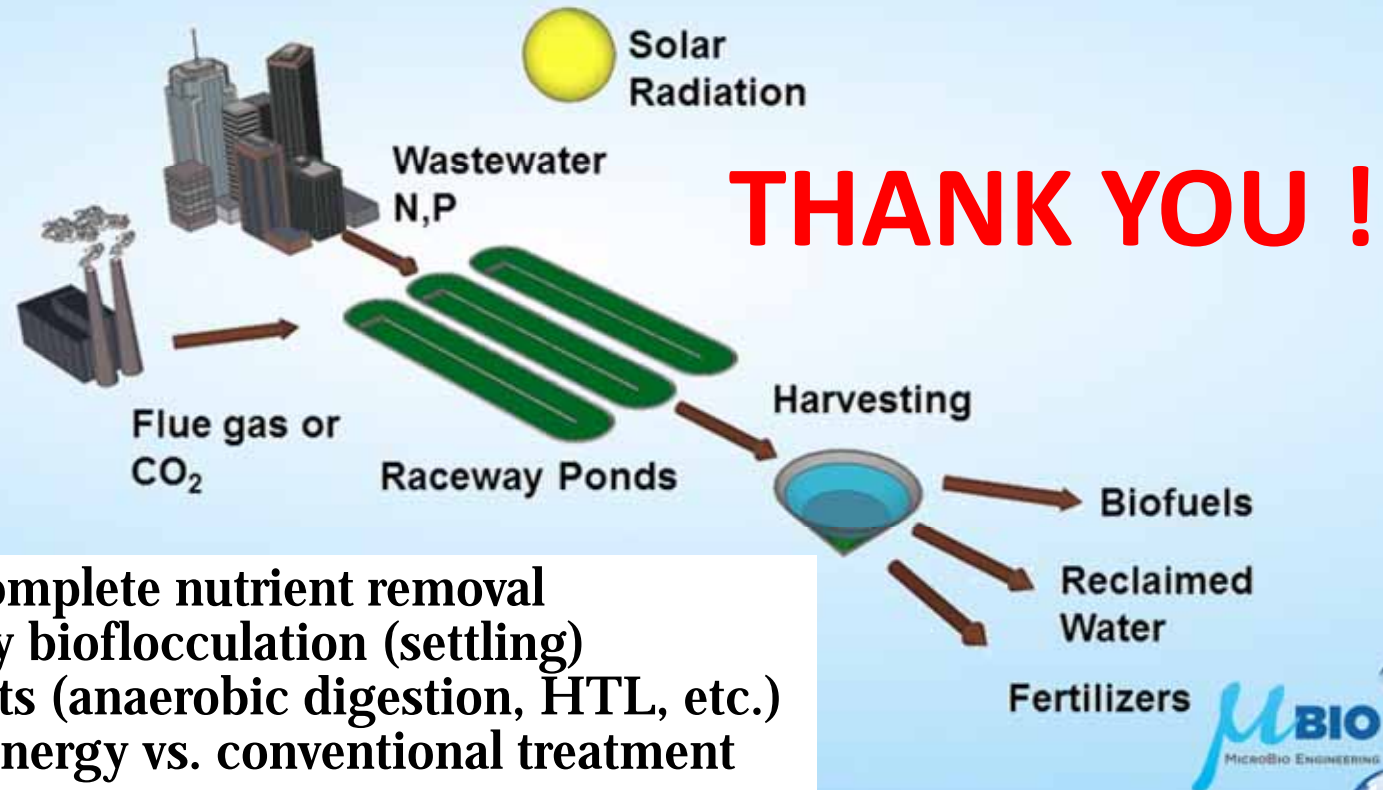
~20 billion galeq/year of algae biofuels could be produced in the US, needs ~ 200 million tons CO₂ (US consumption ~300 billion gallons/year)



Venteris ER, et al., A national-scale comparison of resource and nutrient demands for algae based biofuel..., Biomass Bioenergy (2014) (PNNL-DOE <http://dx.doi.org/10.1016/j.biombioe.2014.02.001>)

MicroBio Engineering Inc. RNEW[®] Process for wastewater treatment, biofuels and CO₂ utilization

Recycle
Nutrients
Energy
Water



- CO₂ addition for complete nutrient removal
- Algae harvesting by bioflocculation (settling)
- Biofuels co-products (anaerobic digestion, HTL, etc.)
- Low cost and low energy vs. conventional treatment