Algenol Biofuels: Overview and Summary of Carbon Footprint and Water Use Compared to Other Fuel Technologies

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Biofuels: Drivers and Issues

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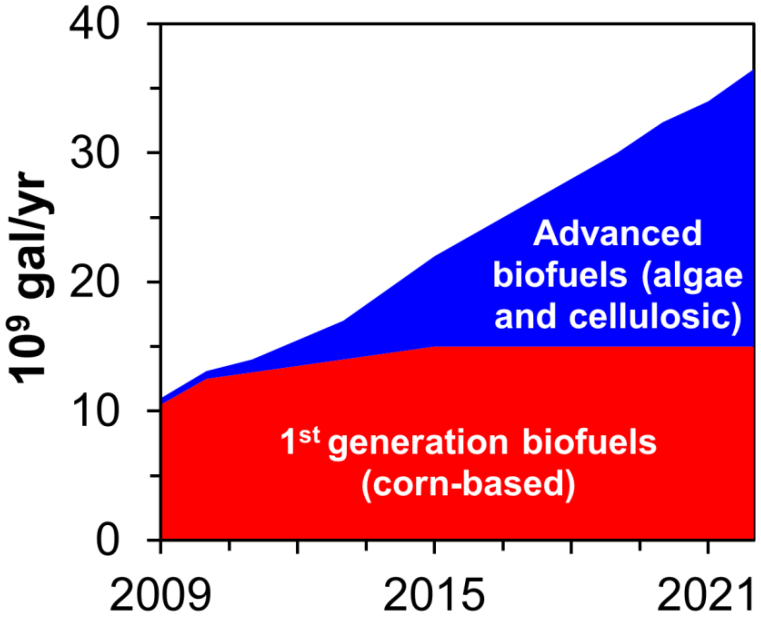
Major Drivers for Biofuels

- Incremental Energy Supply Needs
  - Adds another significant, less cost-volatile, component to energy portfolio
  - Contributes to energy diversity and energy independence
- Climate Change
  - Potential for a low carbon footprint (uses CO_2)
  - Potentially a low risk carbon mitigation strategy
- Environment
  - Potential for lower fresh water use than fossil fuels
  - Potential to be cleaner than fossil fuels
- Value Proposition
  - Potentially large, sustainable financial gain
  - Must compete favorably with fossil fuels



Adapted from USEPA Renewable Fuel Standards - 2009

Major Issues for Biofuels

- Competition with Food Supply
- Land Use – Direct and Indirect
- Fresh Water Use
- Economics Relative to Fossil Fuels
- Carbon Footprint Relative to Fossil Fuels

The Biofuels Family

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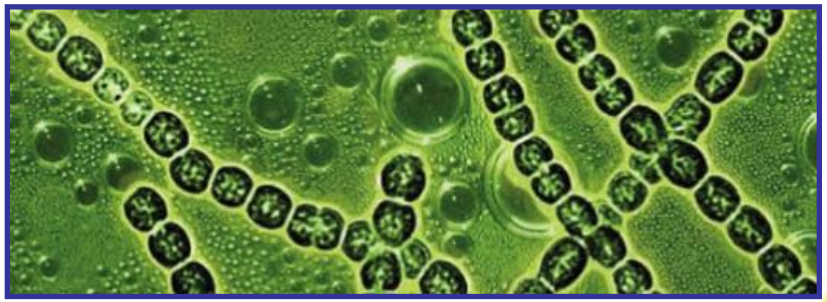
- **1st Generation**
  - Sugarcane or corn to ethanol
  - Competes with food supply
  - Major land use and water use issues
  - Low to moderate impact on greenhouse gas emissions
  - Generally not cost-competitive with fossil fuels


- **2nd Generation**
  - Cellulosic fuels and crop-based biodiesel
  - May be less competitive with food supply
  - Significant land use and water use issues
  - Generally positive impact on greenhouse gas emissions
  - Economics still to be proven


- **3rd Generation (Advanced)**
  - Algae to biodiesel and/or ethanol
  - No competition with food
  - Little or no land use or water use issues (closed system)
  - Positive impact on greenhouse gas emissions
  - Economics still to be proven



Algenol Overview

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- Algenol is an advanced industrial biotechnology company
  - Headquartered in Bonita Springs, Florida
  - Research labs in Fort Myers, Florida and Berlin, Germany
  - 150 employees including 60 Ph.D.s
- Algenol is commercializing its patented algae technology platform for ethanol production and green chemistry
  - $25MM DOE grant for Integrated Biorefinery
  - Partners: NREL, GaTech, MTR, Univ. Colorado
  - Phase 2 began with ground breaking 3Q11
- New Fort Myers, Florida R&D facility consolidates Algenol's existing U.S. lab and outdoor testing facilities
  - Enabled by $10MM grant from Lee County
  - Lab operations began in early August 2010
  - 50,000 ft^2 of biology and engineering lab space
  - 4 acre outdoor Process Development Unit
  - 36 acre outdoor demonstration facility, including 17 acres for Integrated Biorefinery

Fort Myers Research Labs

Process Development Unit

Metabolic Pathway for Ethanol Production

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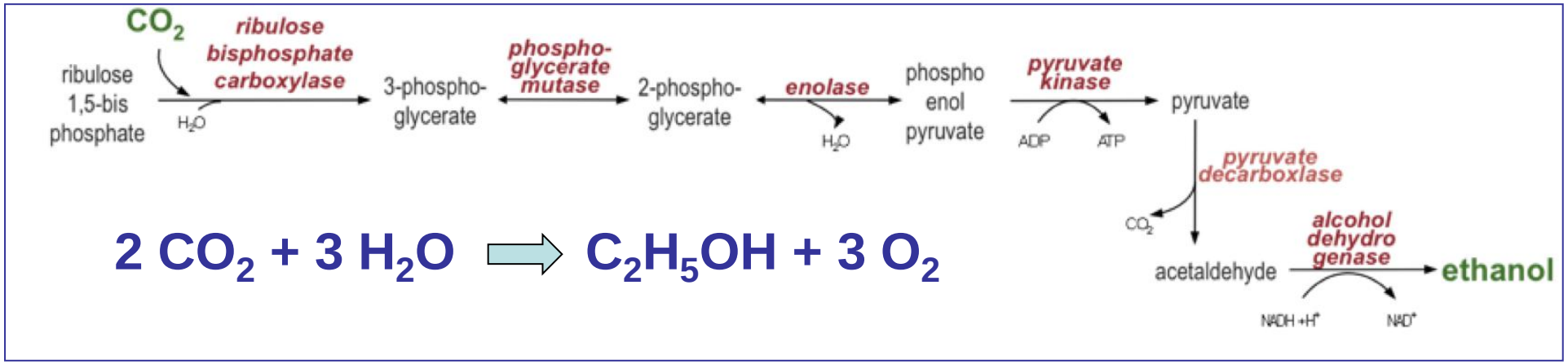
Metabolically enhanced cyanobacteria, photobioreactors, and ethanol separation systems are key, proprietary components of the Algenol technology



Enhanced ethanol production via over-expression of fermentation pathway enzymes

- Pyruvate decarboxylase (PDC) and alcohol dehydrogenase (ADH) are found widely in nature
- PDC catalyzes the non-oxidative decarboxylation of pyruvate to produce acetaldehyde
- ADH converts acetaldehyde to ethanol
- Ethanol diffuses from the cell into the culture medium and is collected for downstream processing

From the Laboratory to the Field

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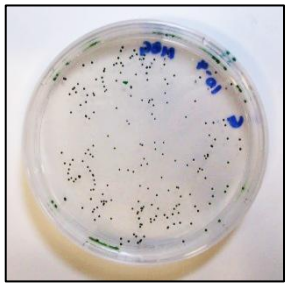
Algenol has the unique capability to move biology and engineering from lab scale to the field at one site

Strain Development → Physiology → Aquaculture → Engineering → Biorefinery



Petri Dishes

Shake Flasks

1-L PBR systems

150-L foil-mixed integrated systems

4500-L foil-mixed integrated systems

Algenol Research Facilities in Fort Myers, Florida

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Environmental Studies

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Environmental Issues of Concern for Florida

- *Algenol is the only algae company who has run extensive environmental studies.*

- ***Plant Pest**, can algae harm crops and other plants?*
- ***Toxic**, does Algenol algae contain toxins?*
- ***Non-Invasive**, can Algenol algae become invasive and harm other plants and animals?*

Plant Pest Concerns

- *Algae is not a plant pest and cannot harm crops*

Toxin Concerns

- *Algenol algae are screened for toxins*
- *Toxicology tests verify lack of toxins*
- *Commercial strains of algae have whole genome analysis to verify no toxin production*

Environmental Studies

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Non-Invasiveness Studies

- *8 studies designed for our enhanced algae with input from Florida Division of Aquaculture have been conducted*
  - *Water samples taken Gulf of Mexico, Estero Bay, rivers, canals and ditches. Our algae is added and measured against control samples*
  - *No evidence of invasiveness – Our algae do not overtake native waters*
  - *Soil samples also analyzed with similar results*
- *Algenol is continuing additional environmental studies*

DIRECT TO ETHANOL® *Commercial Vision*

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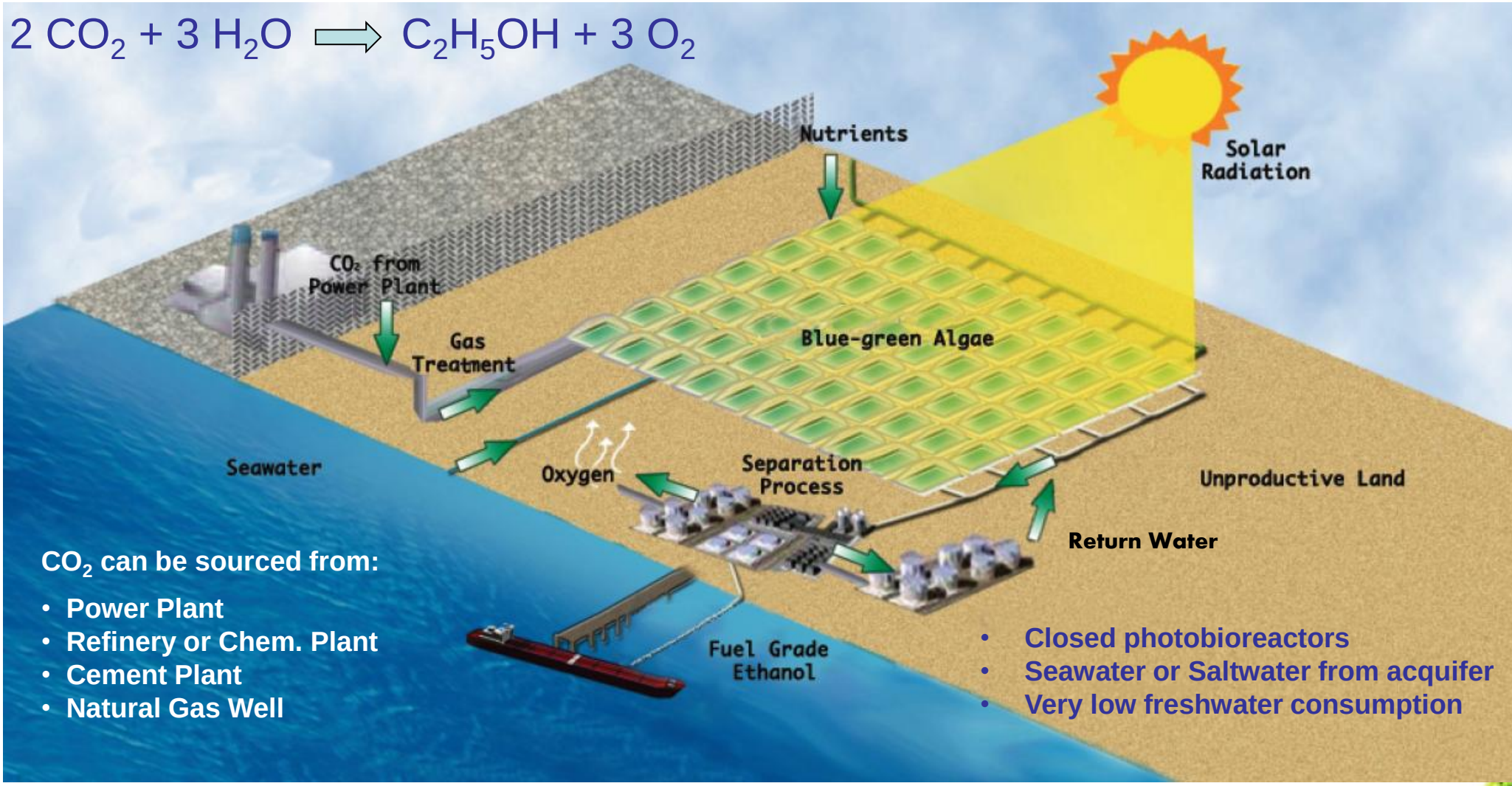
Metabolically enhanced cyanobacteria, CO_2 and solar energy to produce ethanol; Production targets: 6,000 gal/acre-yr (57,000 L/hectare-yr), $1 per gallon

$$2\ CO_2 + 3\ H_2O \Rightarrow C_2H_5OH + 3\ O_2$$



CO_2 can be sourced from:

- **Power Plant**
- **Refinery or Chem. Plant**
- **Cement Plant**
- **Natural Gas Well**

- **Closed photobioreactors**
- **Seawater or Saltwater from acquifer**
- **Very low freshwater consumption**

Commercial Facility Water for a Florida Site

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- Site regulation
  - Federal Regulatory Agencies
    - Environmental Regulatory Agency
    - Department of Agriculture
  - State Regulatory Agencies
    - Florida Department of Agriculture Division of Aquaculture (Aquaculture permit)
      - Best Management Practices – Zero discharge facility
    - Florida Department of Environmental Protection
      - Saltwater well permit
        - Supply and injection well
    - South Florida Water Management District
      - Site water management
  - County permitting
    - Construction permitting

Commercial Facility Water for a Florida Site

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- Salt water
  - Primary water demand is salt water from a deep well with same salinity as ocean water
    - Salt water supply well is primary source of all water for commercial plant
    - Algae culture requires salt water that has been filtered and treated
      - Micro filtration of incoming water to 0.2 micron
      - Ultrafiltration of incoming water to 0.01 micron
      - Water sterilization using ozone
    - Post production
      - Water and algae are separated
      - Water is filtered to 0.2 micron and organics are removed
      - Water is injected into deep well for storage
    - Fresh water supply
      - Reverse osmosis production from salt water supply well
    - Brown/black water from offices/labs
      - County waste treatment facility
      - On-site treatment if county facilities are not accessible

Life Cycle Analysis for Direct to Ethanol® Process

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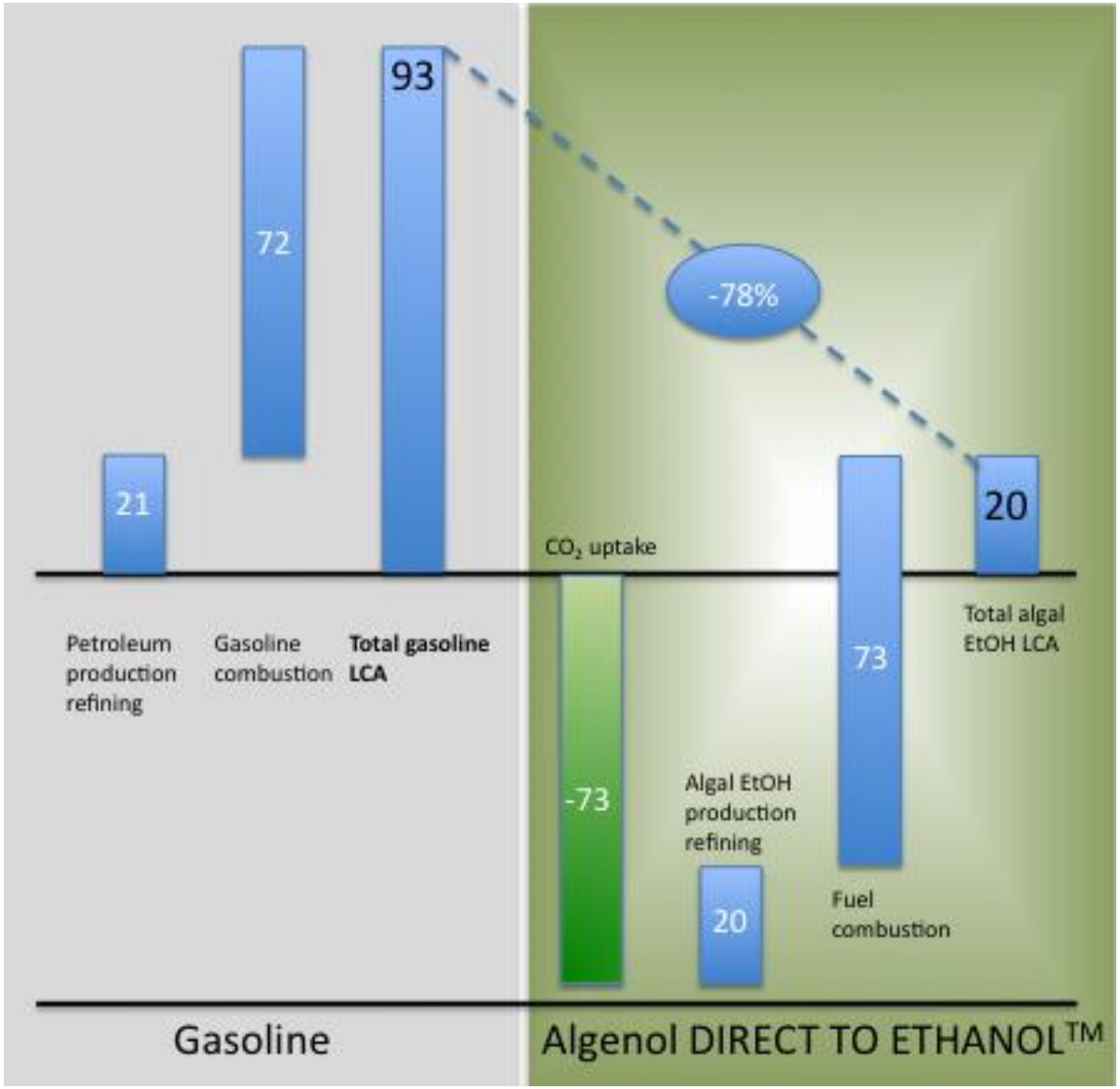

- Scenario-based study of energy demand and CO_2 footprint carried out at Georgia Tech
- Bottom line is a 78% reduction in carbon footprint compared to gasoline on an energy equivalent basis.
- Main contributor to CO_2 emission is ethanol-water separation.
- Sequestration of waste biomass results in carbon footprint of about 12 gCO_2/MJ (87% reduction).
- Peer-reviewed publication: 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.*, 2010, **44** pp 8670–8677.

Energy Cost and Carbon Footprint Comparison

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Transportation Fuel	Fuel energy (MJ/gal)	Production cost ($/gal)	Fuel to vehicle efficiency (MJ/MJ)	Energy to vehicle (MJ/gal)	Cents/MJ (vehicle)	GHGs Emissions (g-CO2/MJ (vehicle))
Gasoline	122.5	3.05 [a]	26%[d]	31.9	9.6	351 [h]
Diesel	134.8	2.94 [a]	35%[d]	47.2	6.2	266 [h]
Corn Ethanol	80.5	3.01 [b]	26%[d]	20.9	14.4	275 [h]
Algenol Ethanol	80.5	1.52 [c]	26%[d]	20.9	7.3	71[i]
		$/grid-MJ	Grid to vehicle efficiency (MJ/MJ)	Energy to vehicle (MJ/grid-MJ)	Cents/MJ (vehicle)	GHGs Emissions (g-CO2/MJ (vehicle))
Grid Electricity (Residential Sector)	US Average	0.019 [e]	65% [f,g]	0.65	3	308 [h]

a *U.S. Energy Information Administration, "Gasoline and Diesel Fuel Update". http://www.eia.gov/oog/info/gdu/gasdiesel.asp (accessed Aug. 2012)*

b *Tao, L., Aden, A., National Renewable Energy Laboratory, "The economics of current and future biofuels" , In Vitro Cell. Dev. Biol. – Plant (2009) 45: 199-217 (Ethanol production prices adjusted for Corn and Natural Gas Market Prices as of Aug. 2012)*

c *Algenol's Economic Model – Average production cost estimate with 6000 gal/acre-yr target (includes capital cost discounted over 15 years, and operating cost)*

d *Crabtree, G., Argonne National Laboratory, "Where is Transportation Going?" http://ceet.mccormick.northwestern.edu/events/domain_dinner07/crabtree_domain_12-3-07.pdf (accessed Aug 2012)*

e *U.S. Energy Information Administration, "Table 5.6.B. Average Retail Price of Electricity to Ultimate Customers by End-Use Sector". http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_6_b (accessed Aug. 2012)*

f *Elgowainy et. al., Argonne National Laboratory, "Well-to-Wheels Analysis of Energy Use and GHG Emissions of Plug-In-Hybrid Electric Vehicles". www.transportation.anl.gov/pdfs/TA/559.pdf (accessed Aug. 2012)*

g *U.S. Department of Energy," Fuel Economy". www.fueleconomy.gov (accessed Aug. 2012)*

h *Argonne National Laboratory, "Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model". http://greet.es.anl.gov/ (accessed Aug. 2012) [U.S. Mix Fuel assumed: Residual Oil (1.04%), Natural Gas (19.11%), Coal (47.24%), Nuclear Power (20.92%), Biomass (0.44%), Others (11.25%)]*

i *Modified 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., 2010, **44** pp 8670–8677*

Fresh Water Requirements

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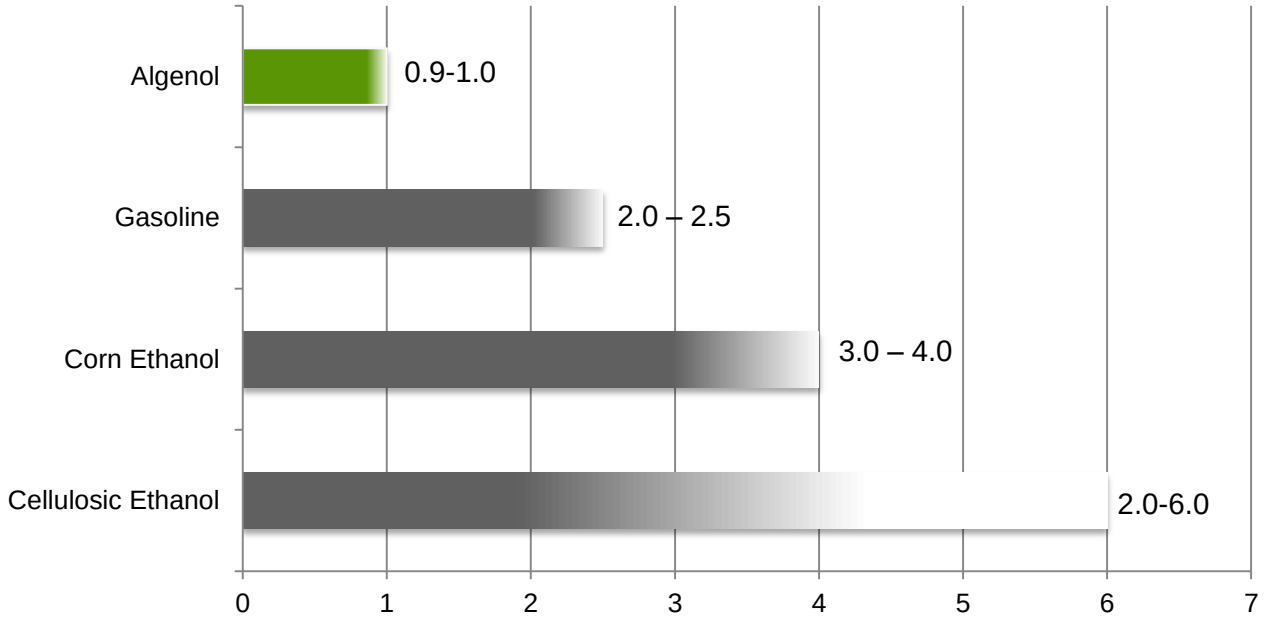

gal. fresh water consumed/ gal. fuel produced

- Substantially less fresh water usage than fossil fuels or competing technologies.
- Fresh water that is consumed in Algenol process comes from sea water via ultra-filtration, and also potentially from reverse osmosis which can produce excess fresh water.
- Source (excepting Algenol): National Renewable Energy Laboratory.

Algenol Employees

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Florida Staff Members

Berlin Staff Members

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ALGENOL

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