Carbon Recycling with Algal Biofuels

Carbon Recycling Conference

Scottsdale, AZ

September 18, 2008

PHYCAL LLC

Introduction to Phycal

Founded in September, 2006

Focus exclusively on commodity bio-energy products

“Open innovation” – License/acquire superior technologies

(Partially) Own and operate project-financed algal facilities

Near-term:

- Begin integrated biorefinery production by 2012
- Improve performance continuously
- Achieve near-term target cost of $2/gal of algal oil

Longer-term, develop technologies (*e.g.,* transgenic algae):

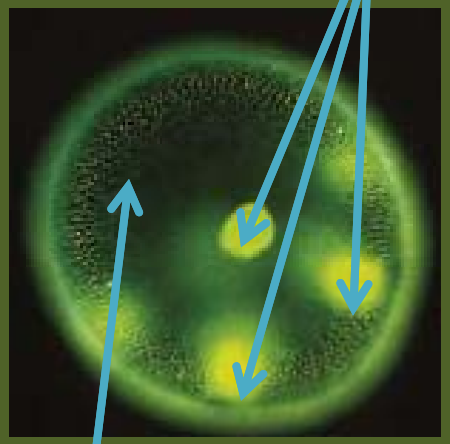
- Relax biological constraints
- Increase geographic range for economic production
- Achieve longer-term target cost of $1/gal of algal oil

Achieving Aggressive Cost Targets

1. Harvesting innovation
   - Increases lipid productivity (gallons/acre/year) by 40%
   - Increases CO_2 productivity (gallons/MT CO_2) by ~40%
   - Reduces capex and opex by eliminating process steps
2. Commodity bio-energy focus
3. Integrated production system design
4. Transgenic or classically selected algae
5. Great team

Biofuel from Algae

5-55%
Non-polar Lipids

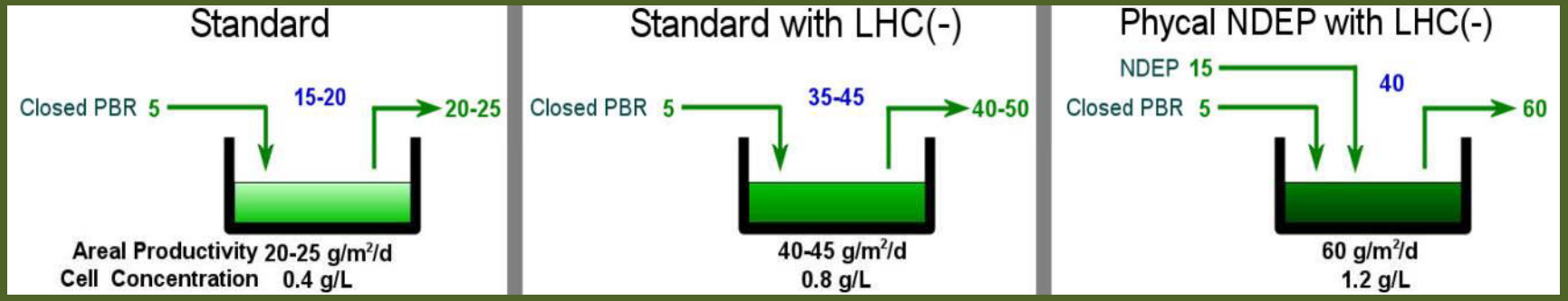


45-95%
Residual Biomass

- Algae are a superior biofuel feedstock
  - ✓ Enormous areal productivity
  - ✓ Not competitive with food supply
- CO_2 fixed in algal biomass
  - ✓ 5-55% in non-polar lipids
  - ✓ 45-95% in residual biomass
- Residual biomass must be harvested and processed into joint bioenergy products to make economics work

The only question is: Can it compete on cost?

System Benefits of NDEP



Higher productivity

- Increased biomass growth rate and lipid accumulation
- Extracts ~100% of non-polar lipids
- Continuous recycling of cells sustains integrity of culture
- Grazers & bacteria reduced or eliminated

Lower cost

- Very high density reduces pond capex, dewatering burden
- Eliminates need for several process steps

Increased Lipid Productivity

Increased biomass growth (measured in gdw/m^2/d)

- 25% increase, depending on species
- Hypothesis: removal of growth inhibitors

Increased lipid accumulation (measured in % lipid)

- 12% increase, depending on species
- Hypothesis: previously milked algae are conditioned to shunt carbon to lipid

Empirically, ~40% more lipid (gallons/acre/year)

- Caution – results from 4x12 gallon reactors
- Building sub-pilot scale facility to test

Increased CO_2 Productivity

Significant percentage of biomass recycled

- Recycled biomass does not need to be re-grown
- 45-95% residual biomass, depending on species and processing steps

Increased CO_2 productivity (gallons/MT CO_2)

- Coincidentally, also ~40% increase, depending on species, system design
- Most sensitive to percentage recycled in production system implementation

Crucially important when a production location is CO_2-constrained

Reduced Capex and Opex

Process Step	Standard Process	NDEP
Primary Dewater (*e.g.,* flocculation)	• Remove 95% water • Finish 90+% water • Low capex, high opex	• Remove 80% water • Finish 95+% water • Mid capex, low opex
Secondary Dewater (*e.g.*, centrifugation)	• Remove 90% water • Finish 80% water • High capex, high opex	• Not needed
Drying (*e.g.*, drum dryer)	• Remove 75% water • Finish 10% water	• Not needed
Extraction (*e.g.*, solvent press)	• Tolerates ~10% water	• Tolerates 99% water • Remove TAGs only
Degumming	• Due to phospholipids	• Not needed

Production System Design

1. Integrated lean production system
2. System engineering to make tradeoffs
3. Sub-pilot scale plant under construction
4. Ready for pilot by Dec 2009
5. Production as early
   as 2012

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Engineering New Capacity to Overcome Biological Barriers

- Increase light use efficiency
  - ✓ Eliminate the LHC complex (*e.g.,* inhibit LHC-II proteins, inhibit Chl a oxygenase, or over-express Chl b reductase)
- Increase efficiency of CO_2 recycling
  - ✓ Reduce photorespiration (*e.g*, eliminate glycolate shunt)
- Engineering lipid yield
  - ✓ Hyper-accumulate lipids: storage and stabilization (*e.g.,* engineering lipid metabolism enzymes)

World Class Team

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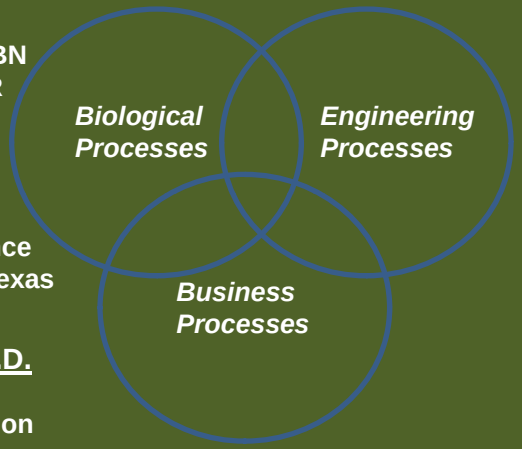

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