



## Algal Transformation of CO<sub>2</sub> to Bio-fuels

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Biotech and Chemical Technologies*

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## Who We are

- **Consulting**
  - Industrial Gases, Separations, Clean Energy, Carbon Capture, Advanced Technologies, and Business Dev.
- **Technology Development**
  - Biotechnology of Algae to Bio-fuels
  - Advanced gas separations

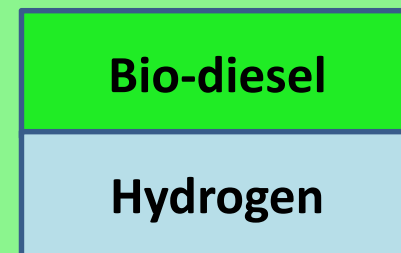
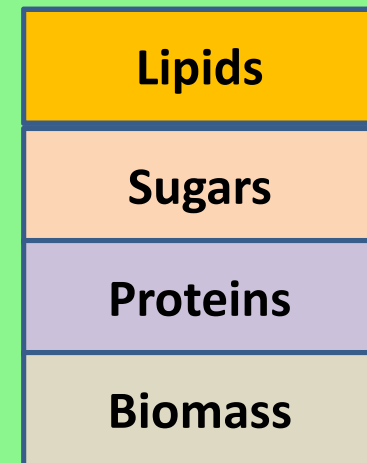
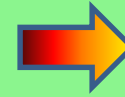
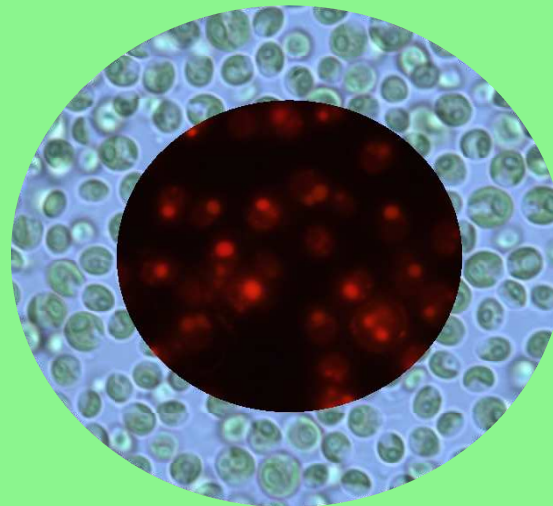
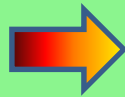
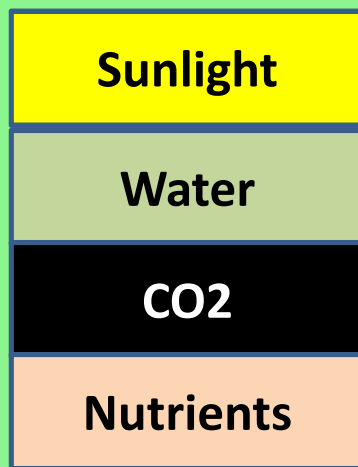


## Overall Objective

- **Develop novel algae technology for efficient capture of CO<sub>2</sub> from flue gas streams and conversion to bio-diesel and hydrogen**
- **Focus is on demonstrating technical viability & establishing foundation for Phase2 effort**



# The Promise of Algae



- Grow
- Induce
- Recover Oil



## Drivers for Development

- **85% of US energy comes from fossil fuels**
  - ~60% of petroleum consumed is imported
- **US energy related CO2 emissions is ~5.8 billion TPY**
  - Most of this is from fossil fuels
- **A technology to efficiently convert CO2 emissions to fuels would**
  - Reduce net CO2 emissions
  - Increase renewable energy
  - Reduce dependency on imported fuels & fossil fuel consumption in large industrial sources



## Features of Helios-NRG Technology

- **Extraordinary growth rates**
  - Can be more than 100%/day
  - Short harvest times
- **Very high oil content**
  - Up to 40-50% by weight
- **Step change productivity/acre**
- **High CO2 capture efficiency**
- **Co-production of biodiesel & H2**
  - Very high conversion of biomass to fuels



Crop	Yield
	(Gal/acre/yr)
Corn	18
Soybean	48
Sunflower	100
Canola	128
Palm	635
Algae	~10,000



## Some Key Achievements

- Preferred species selected
- Photo-bioreactors developed
- High CO<sub>2</sub> capture efficiency demonstrated
- Very high growth rates achieved – especially on high CO<sub>2</sub>
- Lipid induction demonstrated
- >98% H<sub>2</sub> produced in 1-step with wet algae (CO free)
- Sophisticated model developed for culture in PBR



## Species Selection

- **Several algae species screened**
- **2 promising candidates identified**
  - Max oil & biomass rates
  - Operate in high CO<sub>2</sub>
  - CO<sub>2</sub> capture efficiency
  - Culture robustness
- **Optimization of culture technology is important**
  - Temperature, pH
  - Flow rates, Mass transfer
  - Nutrients, seeding
  - Feed CO<sub>2</sub>

Algae Species	Algae Type	Measured Growth Rate	CO <sub>2</sub> Capture Tests	H <sub>2</sub> Production	Lipids Induction
C-0322	high starch	moderate	yes	yes	not tested
H-1415	high lipid	high	yes	yes	yes
H-1903	high lipid	high	yes	yes	yes





# Photo-bioreactor Technology

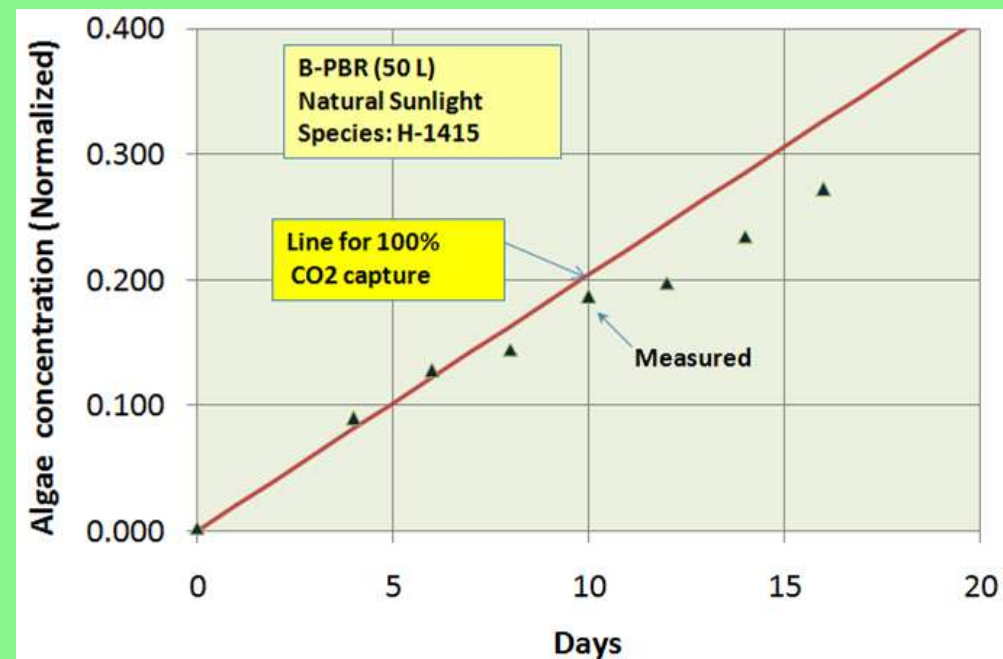
- **A key technology element**
  - Enable high growth rate
  - Avoid contamination
  - Enable high CO2 capture
  - High light utilization
- **Three PBR designs built & operated**
- **Harvesting technology demonstrated**
- **Advanced continuous process developed**

PBR Type	Volume (l)	# of PBR's	Gas	Stages in series	Species grown
L	0.5	16	Air or Air + CO2	Up to 3	H-1415
					H-1903
					C-0322
B	50	4	Air	Single	H-1415
					H-1903
A	16	2	Air or Air + CO2	Single	H-1415
					H-1903



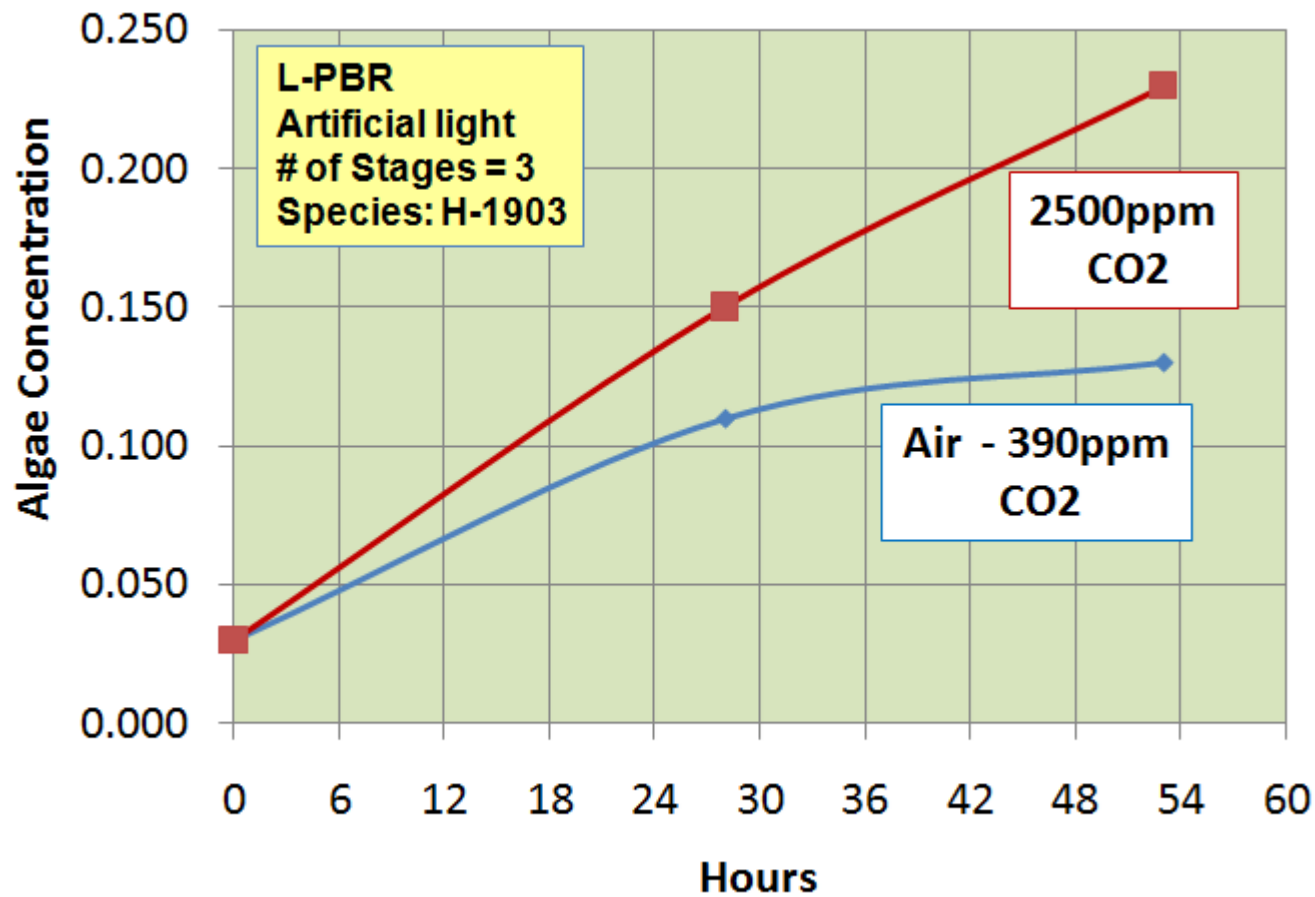
## CO2 Capture Efficiency

- High CO2 capture efficiency achieved
- >90% with multi-stage
- Must tailor algae culture to feed CO2 conc.
- Gas flow dynamics is important





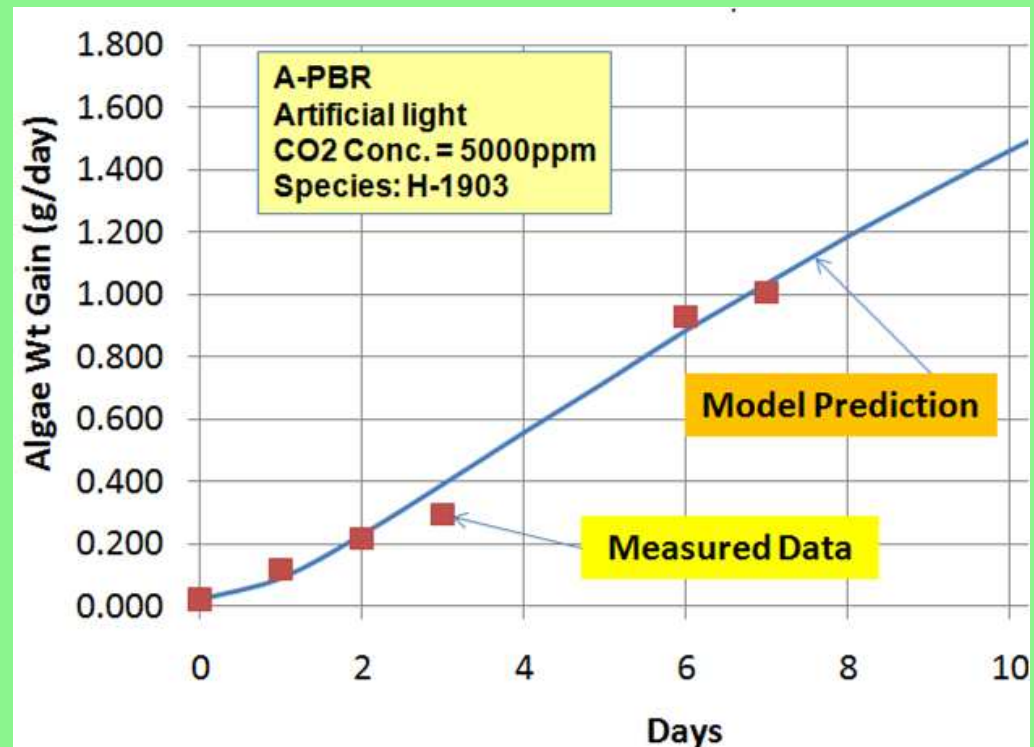
## Algae Growth Accelerated using CO<sub>2</sub>





## Photo-bioreactor Model

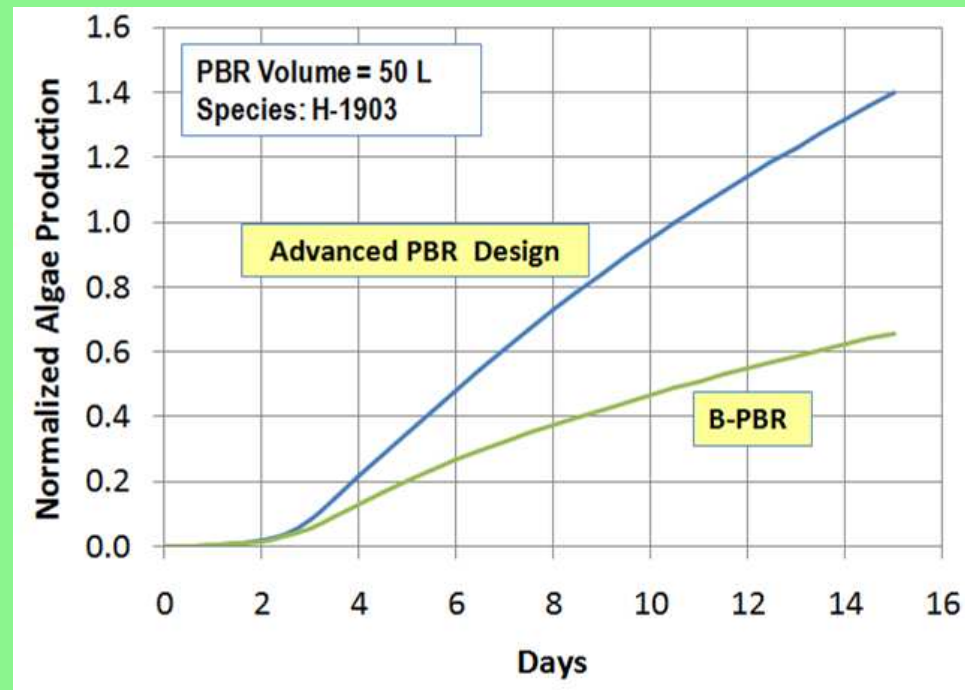
- Predicts algae growth rate based on many factors
  - PBR geometry
  - Gas flow
  - CO<sub>2</sub> concentration
  - Light availability
  - Seed concentration...
- Calibrated for preferred species
- Predicts observed complex phenomena





## Advanced Continuous Process

- Based on model prediction
- Step change increase in productivity
- High light utilization
- Efficient CO<sub>2</sub> capture
- Reduced operating cost





## Commercial Potential

- **Potential to reduce fossil fuel consumption/CO2 emission in large industries by ~50%**
- **Lab results suggest that oil yield > 10,000 gal/acre possible**
- **Bio-diesel can be competitive with current price of diesel**
  - CO2 credits will improve eco
- **Issues:**
  - Scale up
  - Waste Streams
  - Develop Process
  - Multiple Products

