LA-UR- 10-07954

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Title: LANL's Biofuels Program

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Intended for: Multiple Briefings

Los Alamos
NATIONAL LABORATORY
EST. 1943

National Alliance For Advanced Biofuels and Bio-products

Initiatives in Algal Bio-Fuels

José A. Olivares
NAABB Executive Director
Los Alamos National Laboratory and
The Donald Danforth Plant Science Center

Work Funded By USDOE Office of Biomass Program, DE-EE0003046

Los Alamos National Laboratory

NAABB National Alliance For Advanced Biofuels and Bio-products

Donald Danforth Plant Science Center

Biomass

U.S. Department of Energy

U.S. 2008 Transportation Fuel Stats

U.S. 2008 Transportation Fuel Stats

Gasoline (cars & trucks)

140 bgy

Diesel (on-road, rail)

43 bgy

Aviation (jet fuel)

25 bgy

US Focus

Technoeconomic Analysis
Resource Analysis/ Allocation

Advanced Biofuels R&D

Algal Biofuels R&D

Biomass Intermediates

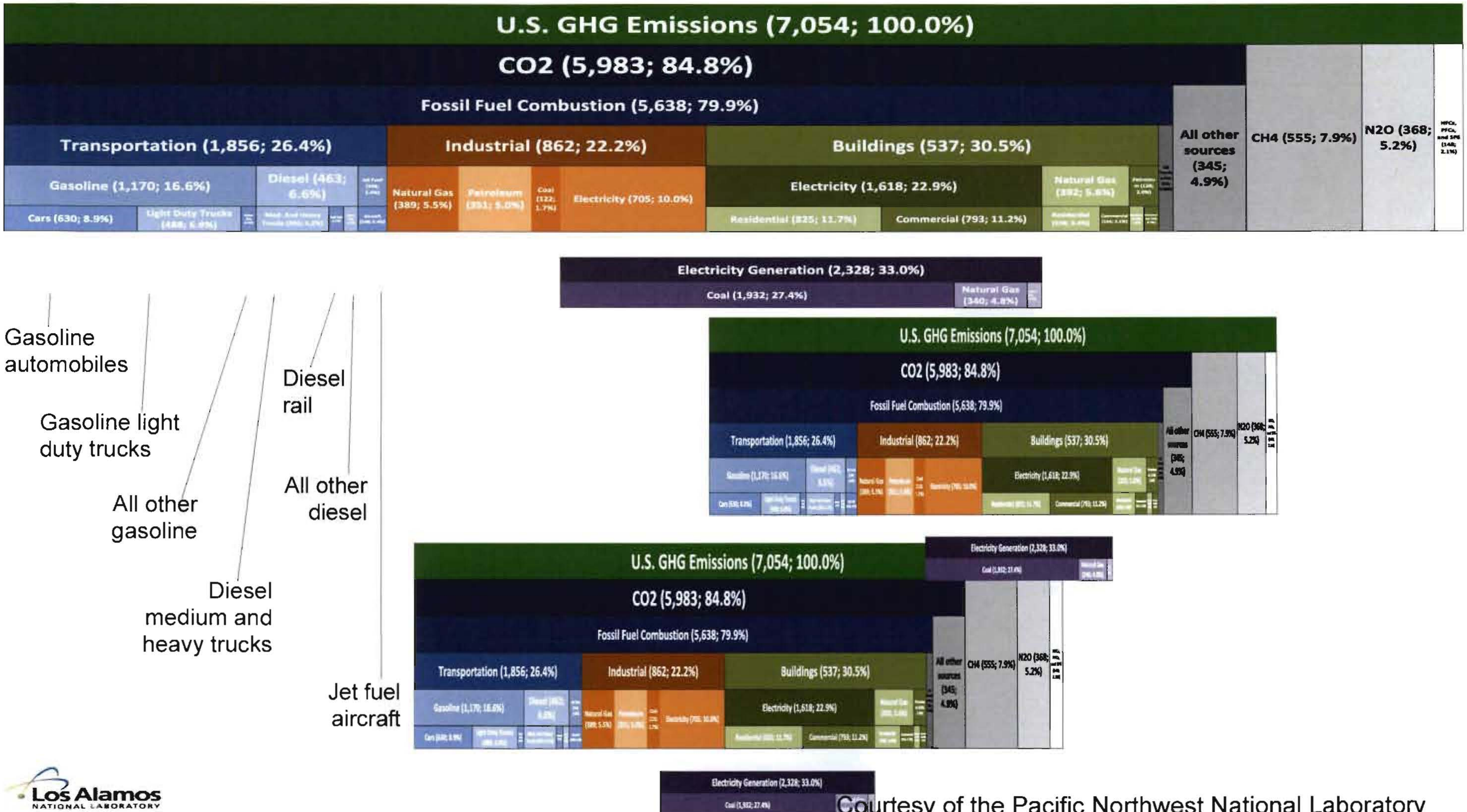
Biopower

Cellulosic Ethanol RD&D

Sustainability Analysis & LCA

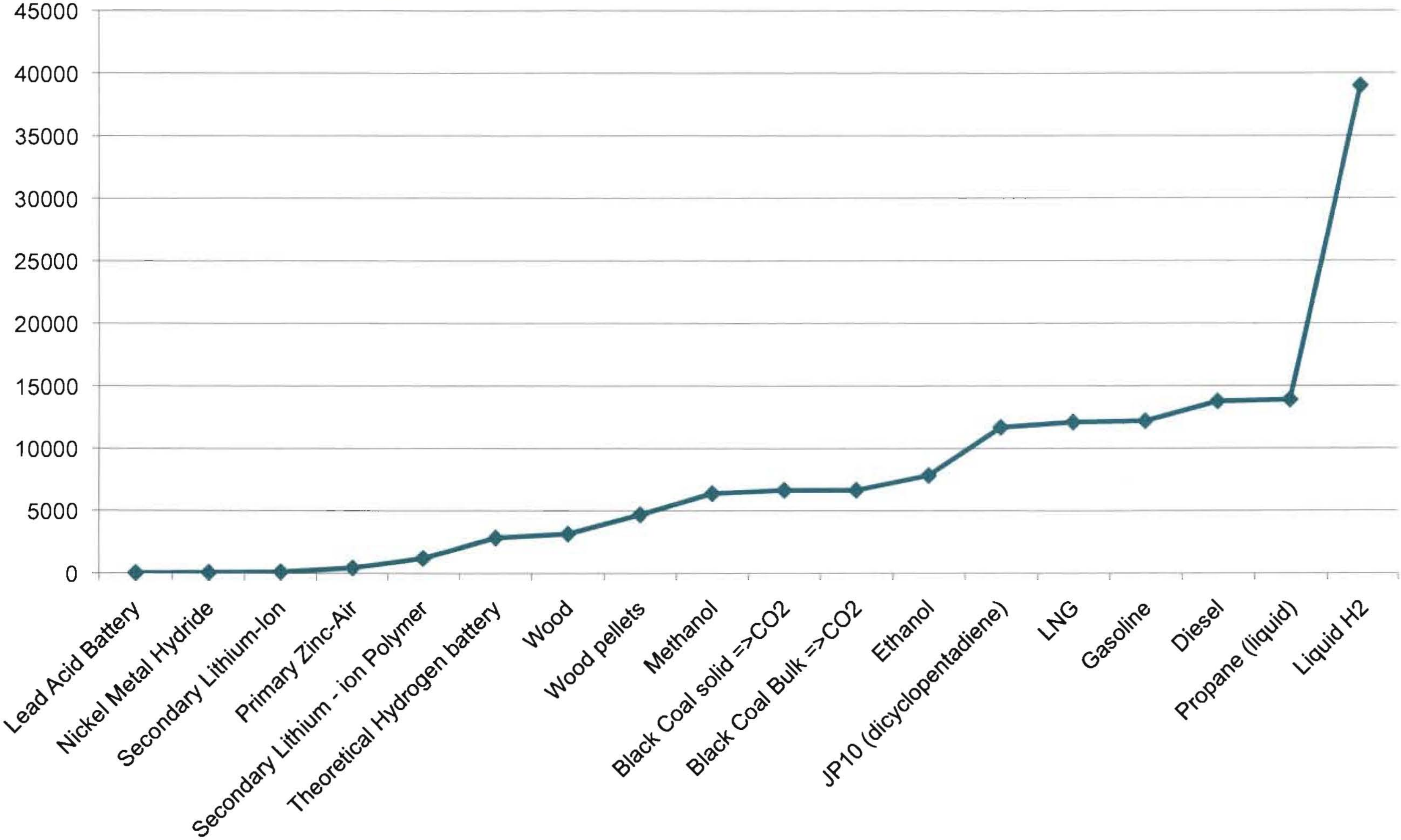
Courtesy of the National Advanced Biofuels Consortium

Annual GHG Emissions – US Only (Tg CO2 equivalent, 2006)



Courtesy of the Pacific Northwest National Laboratory

Fuel and Energy Storage Systems Energy Density (Wh/kg)

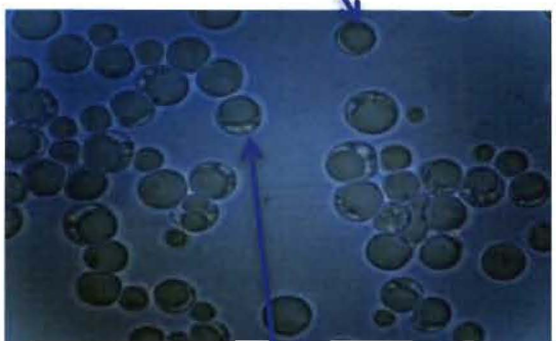


Goal –> *Algae to Jetfuel*

BIOFUELS FOR THE U.S. MILITARY

Biofuels from Algae

4-50%
Lipid biomass



50-90%
Other biomass

Rapid growth rate

Double in 6-12 hours

High oil content

4-50% non-polar lipids

All biomass harvested

100%

Continuous harvesting

24/7, not seasonally

Sustainable

Capture up to 90% of injected CO_2

Utilize waste water

Non-food

Headliner Productivity

The New York Times

Olympic nightmare: A red tide in Yellow Sea

By Jim Yardley
Published: Monday, June 30, 2008

BEIJING — With less than six weeks before it plays host to the Olympic sailing regatta, the city of Qingdao has mobilized thousands of people and an armada of small boats to clean up an algae bloom that is choking large stretches of the coastline and threatening to impede the Olympic competition.

- Qingdao, China
- Green alga (*Ulva prolifera*)
- late May - early July 2008
- > 200,000 tons biomass
- < 17 km^2 coastal area (~ 4,200 acres)

> 47 tons/acre

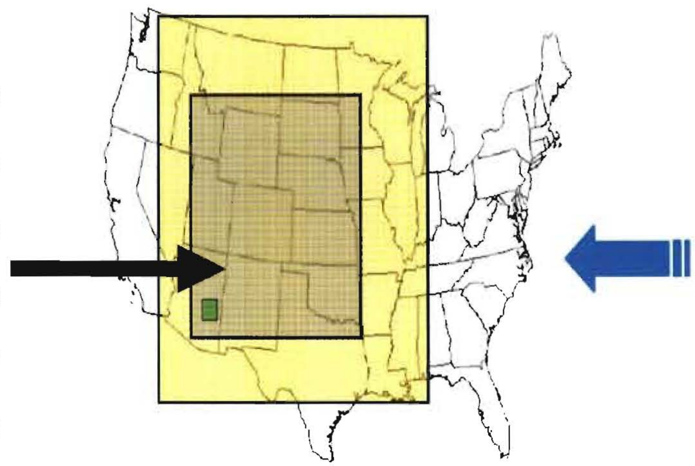
The Promise of Algae-Based Biofuels

Algae has potential advantages over corn, cellulosic materials, and other crops as an alternative to petroleum-based fuels

Gallons of Oil per Acre per Year	
Corn	**18**
Soybeans	**48**
Safflower	**83**
Sunflower	**102**
Rapeseed	**127**
Oil Palm	**635**
Micro Algae	**1000 - 7000**

Figure courtesy of Sandia National Laboratory

Sandia National Laboratories



The amount of land required to replace 50% of the current petroleum diesel usage using corn, soybean, and algae.

- *High biomass productivity potential*
- *Oil feedstock for higher energy-content fuels*
- *Can avoid competition with agricultural lands and water for food & feed production*
- *Can use non-fresh water, resulting in reduced pressure on limited fresh water resources*
- *Captures CO2 and recycles carbon for fuels and co-products*

Land Needed for Biofuel to Replace 50% of Current Petroleum Diesel using oil from:
Corn
Soybean
Algae

Los Alamos National Laboratory

NAABB National Alliance For Advanced Biofuels and Bio-products

Donald Danforth Plant Science Center

Biomass

U.S. DEPARTMENT OF ENERGY

Technical Challenges

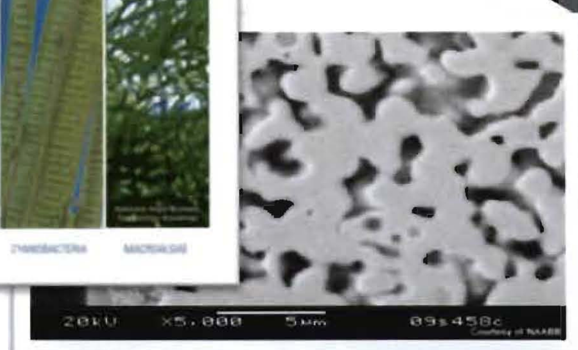
Biology and Cultivation

Example Cultivation Systems

- Cultivation system design
  - Temperature control
  - Invasion and fouling
- Cultures
  - Growth, stability, and resilience
- Input requirements
  - CO_2, H_2O sources, energy
  - Nitrogen and phosphorous
- Siting and resources

Biomass Harvesting and Recovery

- Energy efficient harvesting and dewatering systems
- Biomass extraction and fractionation
- Product purification



A nano-membrane filter being developed by a NAABB partner

Conversion and End-use

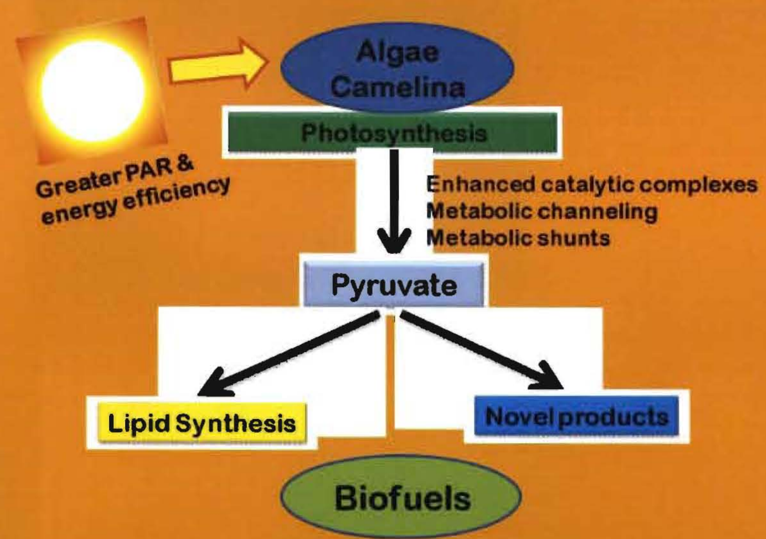
A gasifier being used by a NAABB partner to convert algal biomass to fuels

- Process optimization
  - Thermochemical
  - Biochemical
- Fuels characteristics
- Co-Products

DOE- Office of Science - Energy Frontier Research Centers

CABS
Center for Advanced Biofuel Systems

Center for Advanced Biofuel Systems

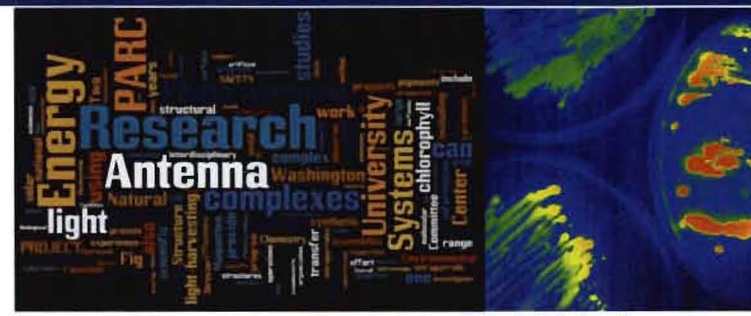


August 1, 2009 - July 31, 2014 - $15M

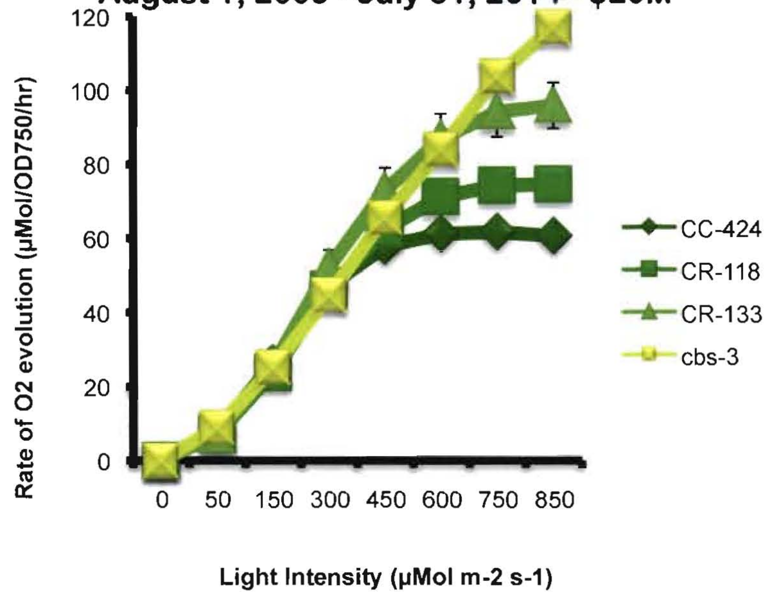
Increasing the thermodynamic and kinetic efficiency of plant and algal biofuel production systems using rational metabolic engineering approaches

Photosynthetic Antennae Research Center

Optimizing light harvesting efficiency



August 1, 2009 - July 31, 2014 - $20M



US DOE – ARPA-E Projects

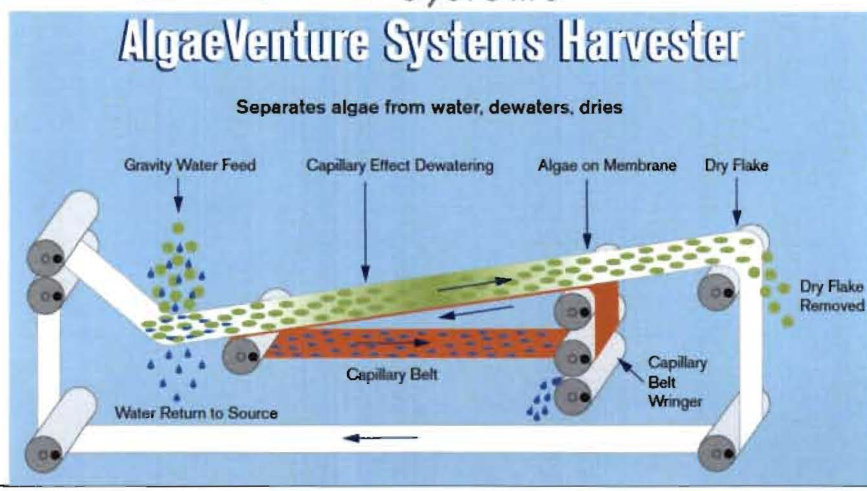
DUPONT

The miracles of science™

Butamax™ Advanced Biofuels LLC

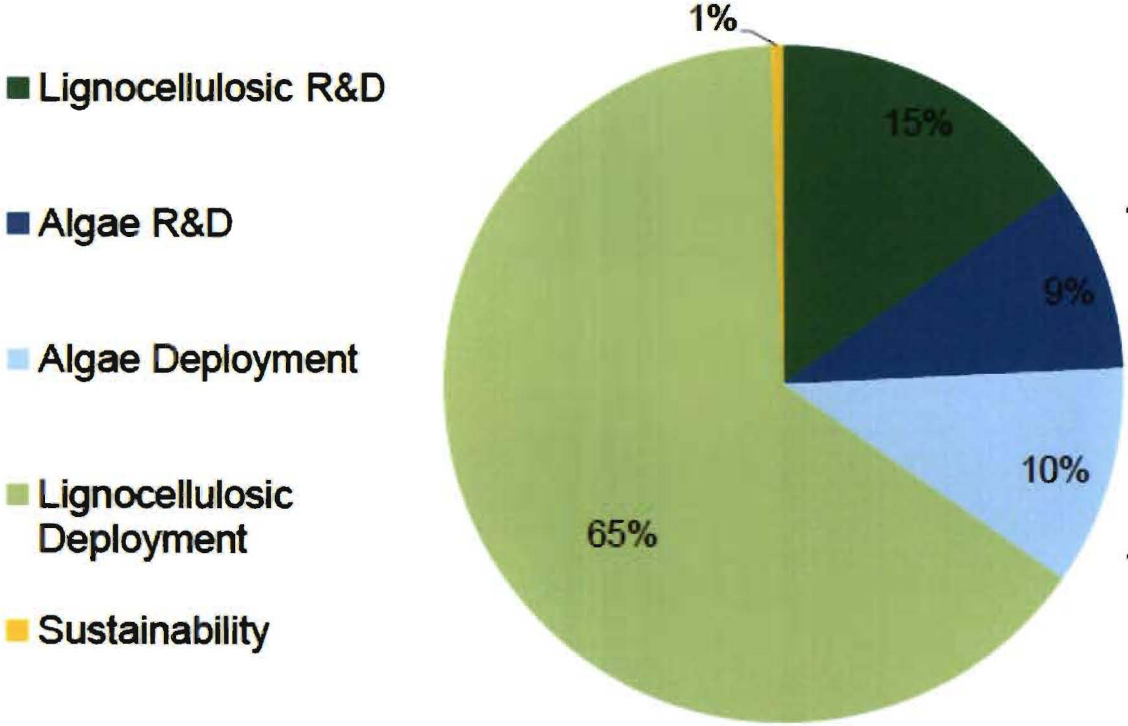
MacroAlgae Butanol -
Isobutanol from Seaweed

Algaeventure systems



Office of Biomass Programs Investments

OBP 2010 Investment* $938M



The 2010 investment in algae totals more than $180M and includes:

- $35M for algae R&D, as directed by Congress
- $49M for the NAABB consortium
- $50M for Sapphire to deploy an open pond algal biofuel system
- $25M for Algenol to pilot a photobioreactor algal biofuel system
- $22M for Solazymes to pilot a heterotrophic algal biofuel system

*Includes regular FY2010 appropriations and 2009 ARRA funds

US DOE Algal Biofuels Consortia

CELLANA
ALGAE TECHNOLOGY. NATURALLY.

- New algal harvesting technologies
- Pilot-scale cultivation test beds
- Animal feed for the aquaculture industry.
- $9 M Federal

SABC
Sustainable Algal Biofuels Consortium
cultivating energy solutions

- Biochemical conversion
- Physical chemistry properties of algal fuels and fuel intermediates
- $6 M Federal

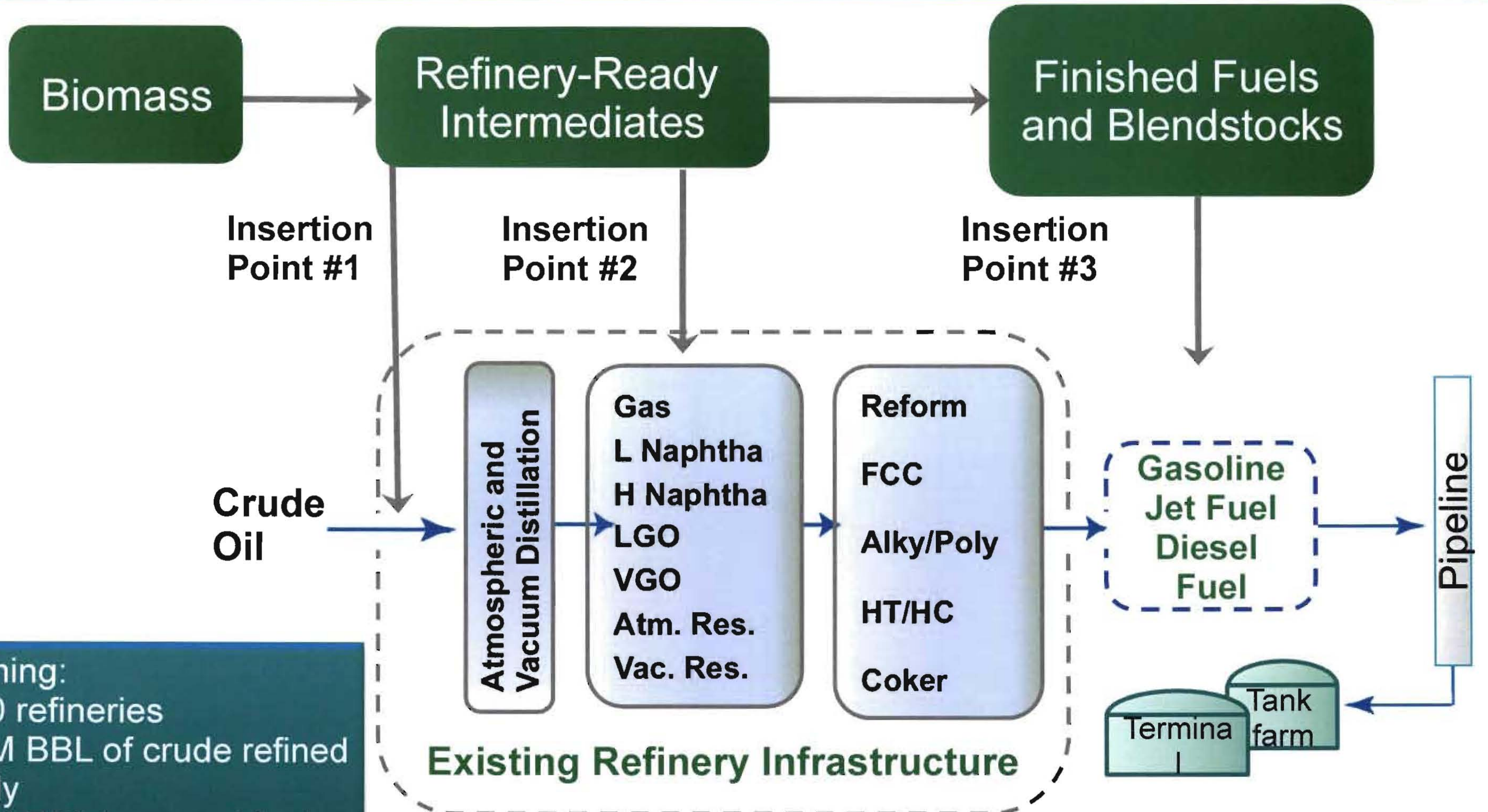
Consortium for Algal Biofuels Commercialization

- Crop protection
- Algal nutrient utilization and recycling
- Genetic tools
- $9 M Federal

NABC
National Advanced Biofuels Consortium

Aim: Use Current infrastructure to Produce and Transport Biofuels

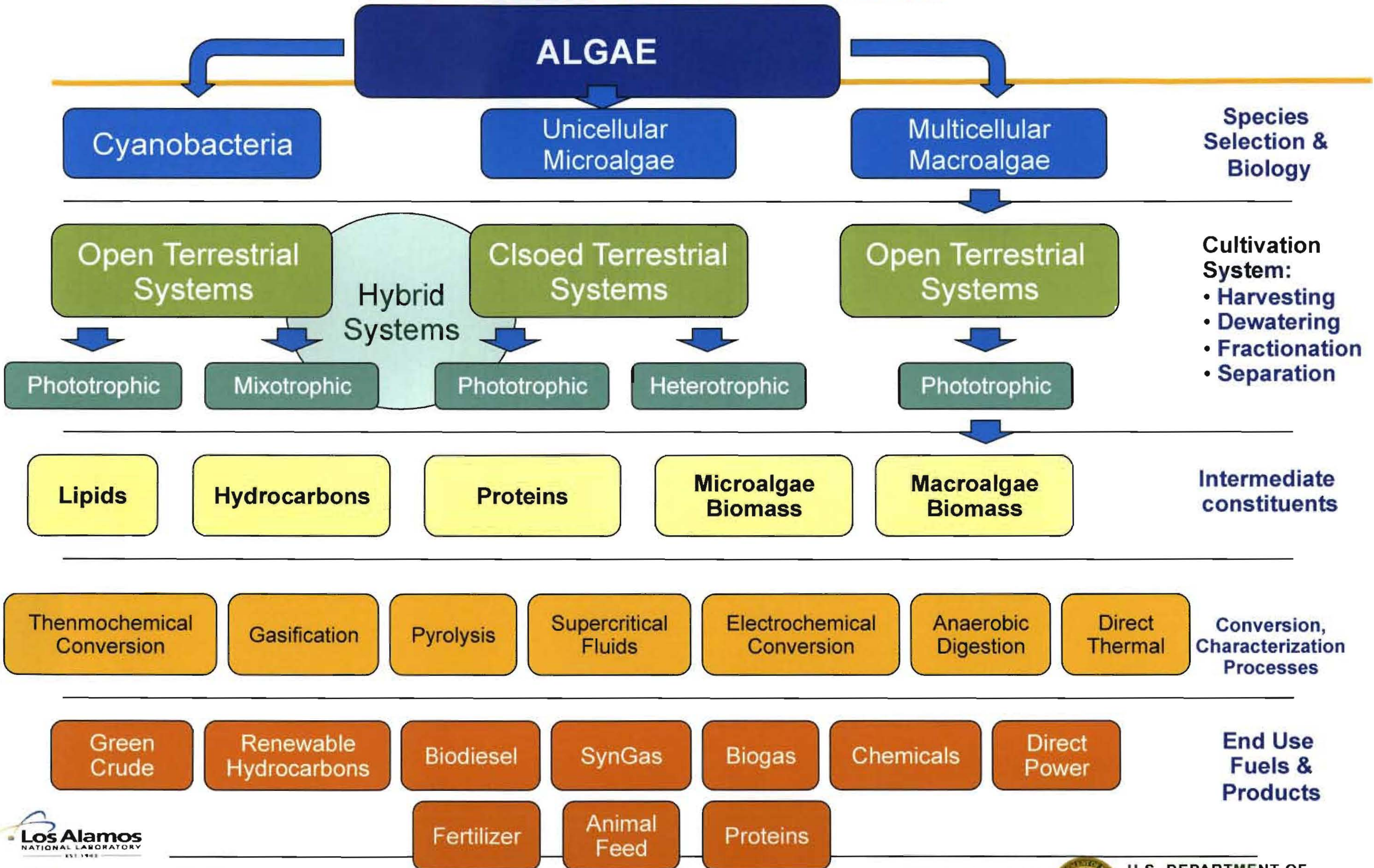
$35M Federal + $11M Cost Share



Refining:
- 750 refineries
- 85M BBL of crude refined daily
- 50M BBL transport fuels


NAABB
National Alliance For Advanced Biofuels and Bio-products
Algal Biology
Greater space-time lipid/algae yields
Cultivation
Harvesting and Extraction
Novel techniques to reduce cost and environmental impact
Valuable Coproducts
Livestock feed
Direct energy production
Chemicals for industry use
Fuel Conversion
High energy-density fungible fuels
CO_2
Water
Land
Nutrier

NAABB RESEARCH, DEVELOPMENT AND DEPLOYMENT PROGRAM



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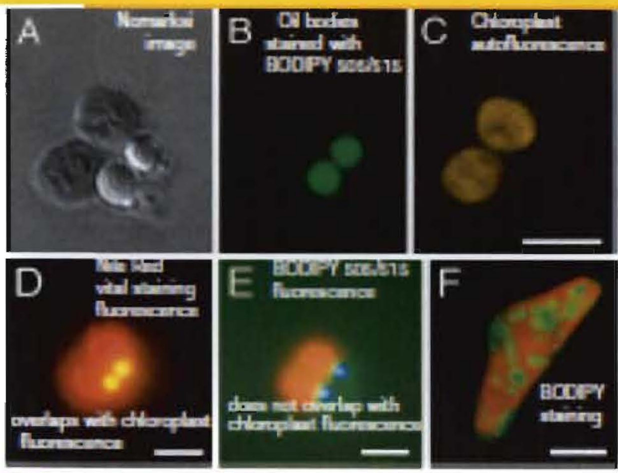
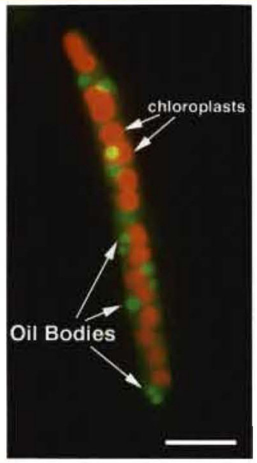
Biomass

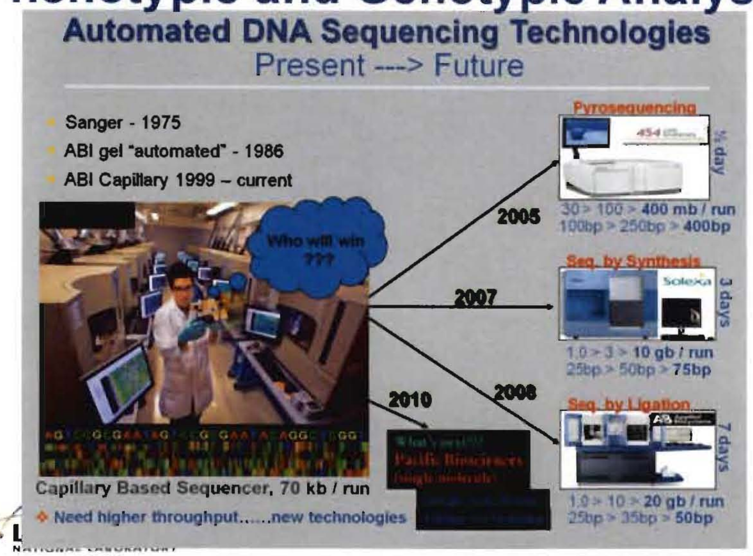
U.S. DEPARTMENT OF ENERGY

ALGAL BIOLOGY





Phenotypic and Genotypic Analysis



GOALS:

- **High rate growth cultures**
- **High lipid/hydrocarbon content**
- **Crop protection**
- **New organisms from diversity of nature**

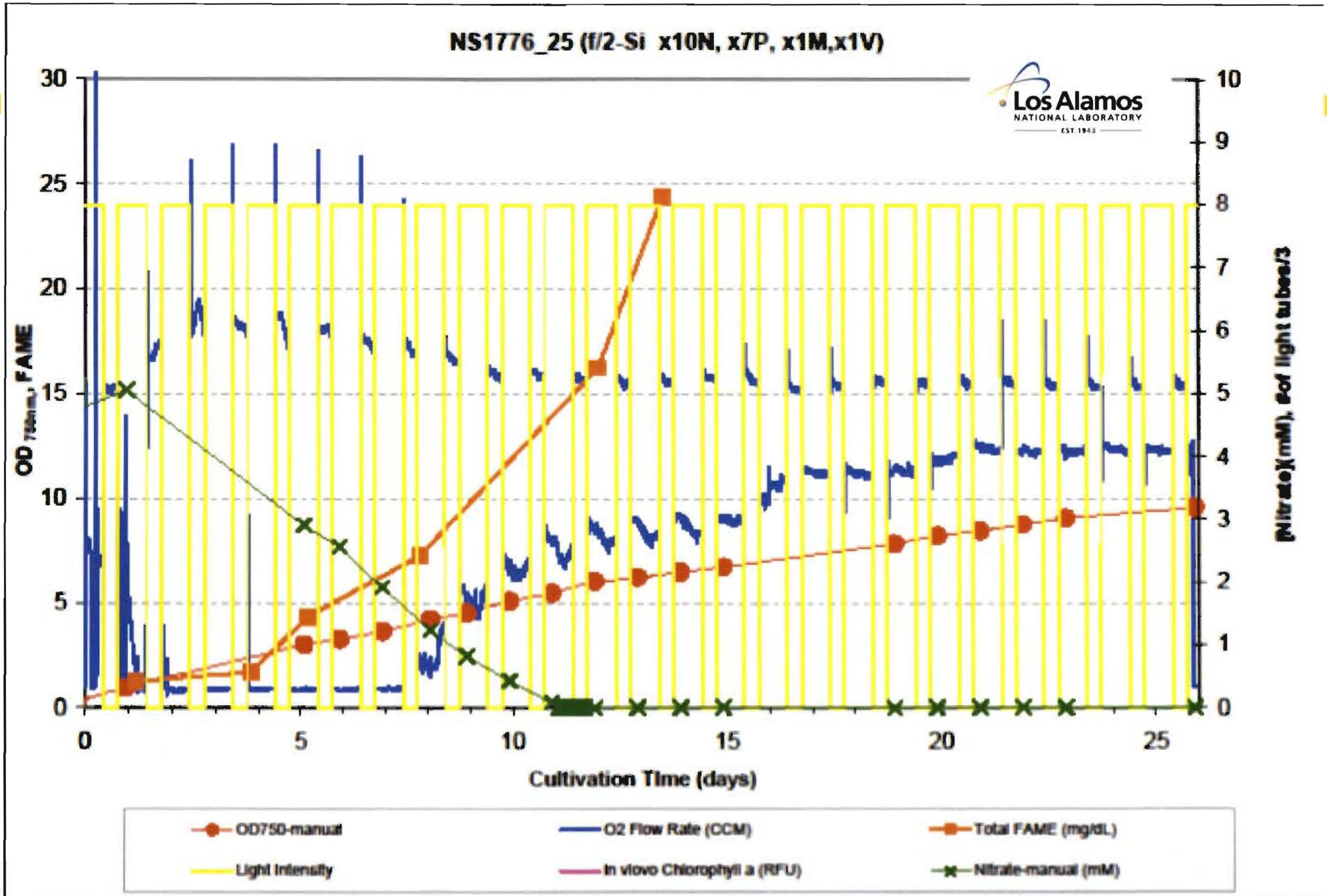
Systems Biology

- Sequencing/Transcriptomics/Proteomics
- Mutagenesis
- Genetic modification

Model & Production Organisms:

- Chlamydomonas reinhardti
- Chlorella protothecoides
- Nannochloropsis salina
- Botryococcus braunii

Oxygen consumption by bacteria in bioreactor culture of NS 1776



16S RNA Analysis Results of NS1776 Culture

100% Genus Identity

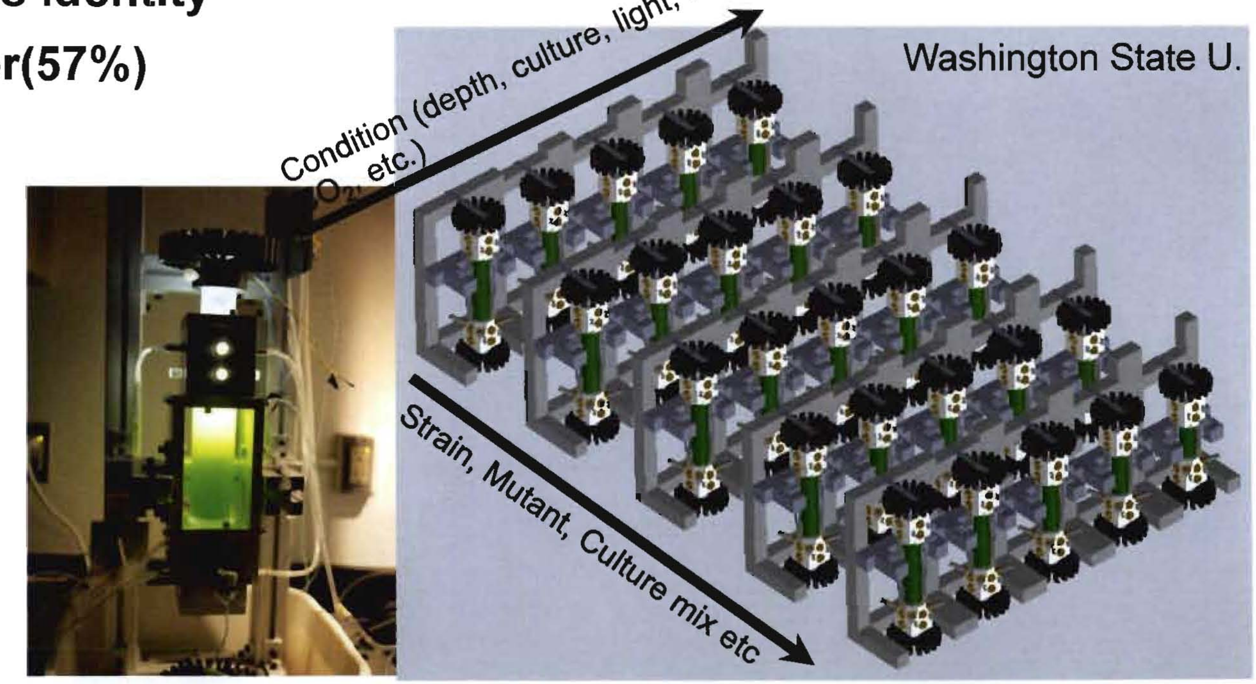
- **Algoriphagus**
- **Marinobacter**
- **Limnobacter**

Less than 100% Genus Identity

- **Haliscomenobacter(57%)**
- **Oceanicola(67%)**
- **Tateyamaria(78%)**
- **Henriciella(88%)**

•Marinobacterhas ability to degrade hydrocarbons
•Limnobactercan oxidize thiosulfate
•Haliscomenobacter has ability to breakdown sludge

New High Throughput Tools for Control of Cultures



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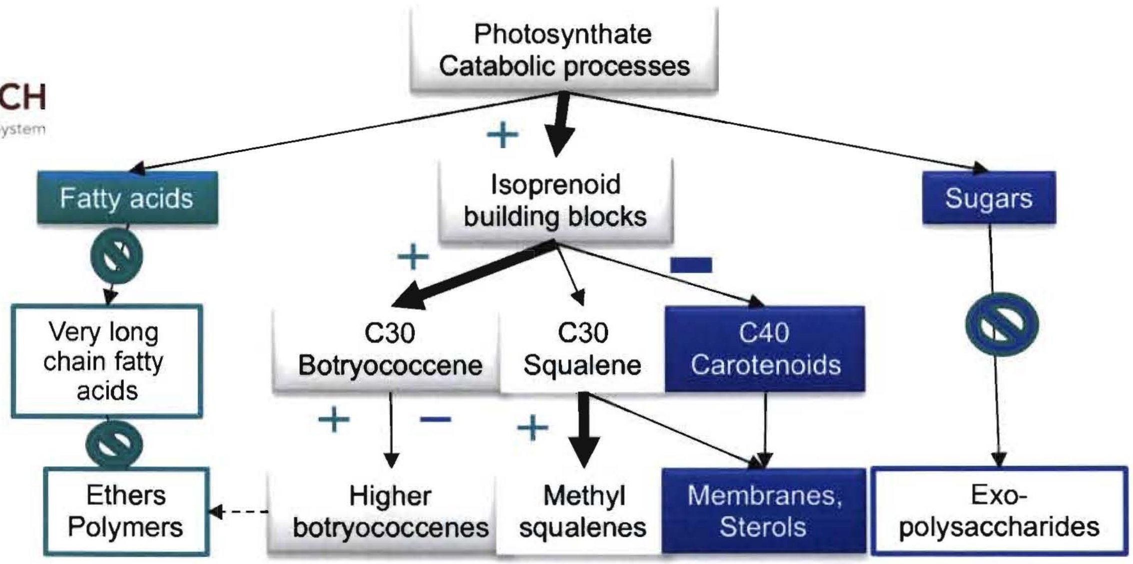
Algal Genetics, Selection, and Manipulation

- **Methods to genetically modify algae**
- **Plasmid vectors to transfer genetic material between species, and sustained in different algal species.**
- **Plasmid vectors to insert cloned algal genes of interest for their over-expression under the control of promoters that function well in algae.**
- **Modulate oil biosynthetic pathway enzymes to optimize hydrocarbon composition and yield for the production of carbon-neutral, renewable biofuel production.**



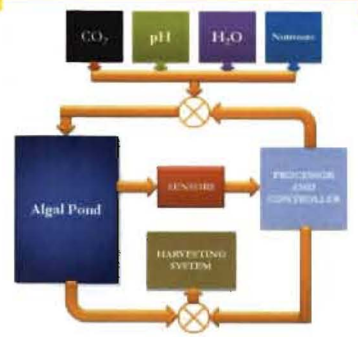
AgriLIFE RESEARCH Texas A&M System

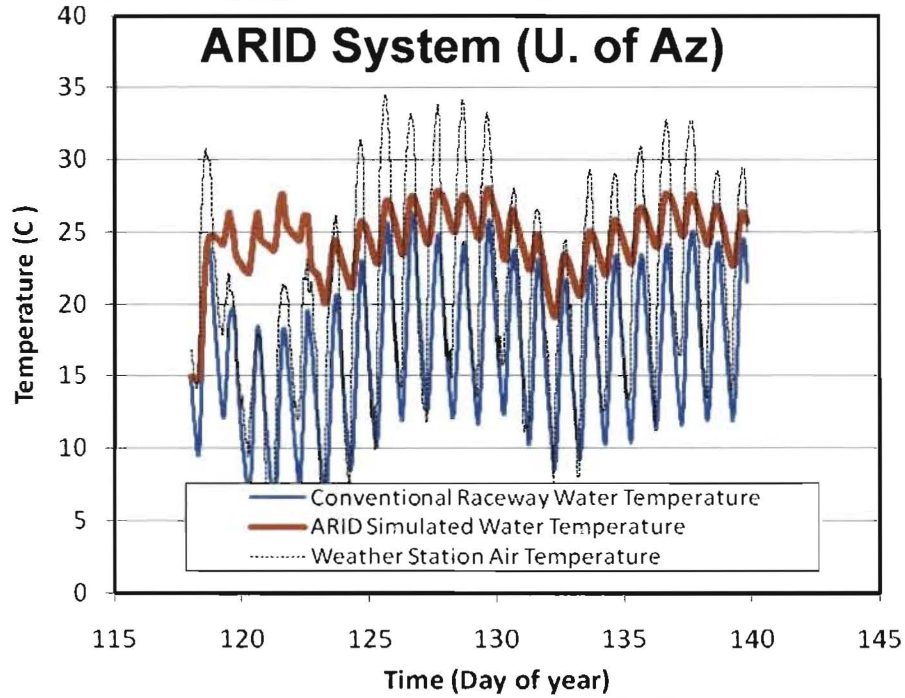
Los Alamos National Laboratory

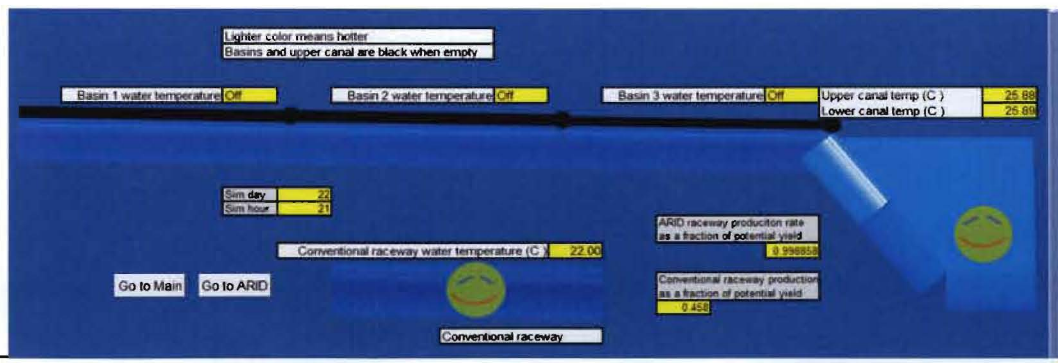
The University of Arizona

Cultivation – Productivity, Environment, Nutrients, Water

Real-time In-situ Monitoring (JA Thomasson, TAMU)

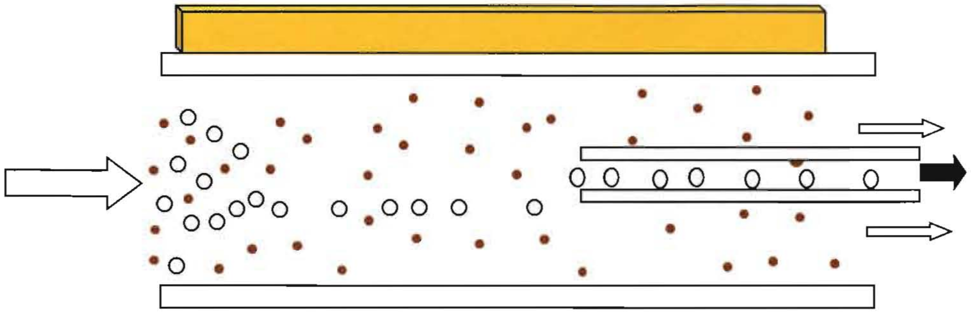


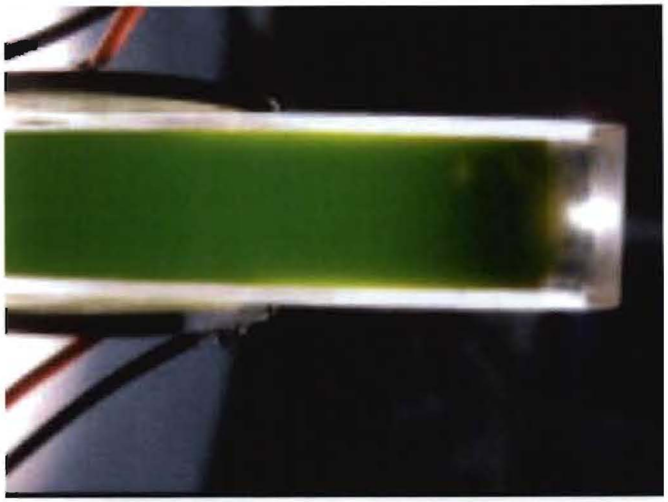


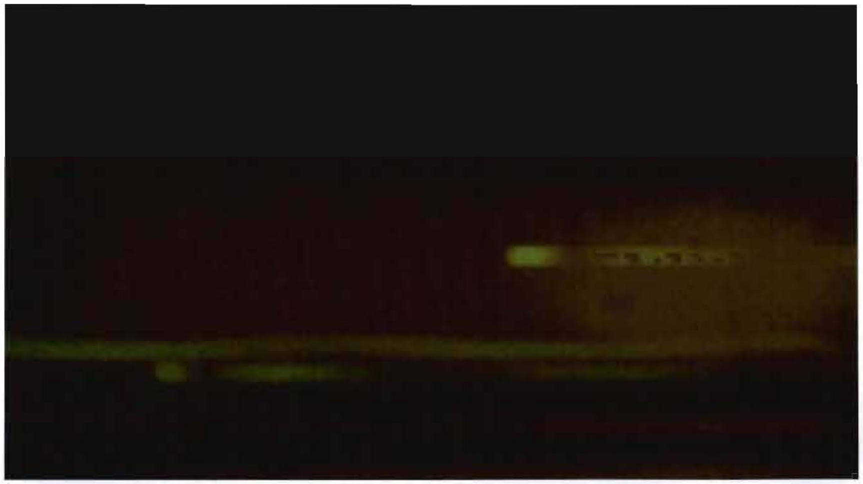


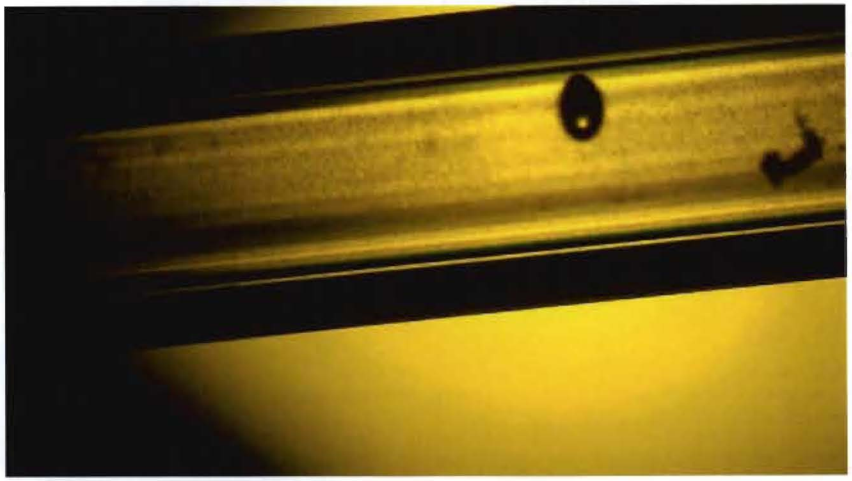
Solix Biofuels Coyote Gulch

Acoustic Concentration of Algae from Culture Medium
Los Alamos National Laboratory (2010 R&D 100 Winner)



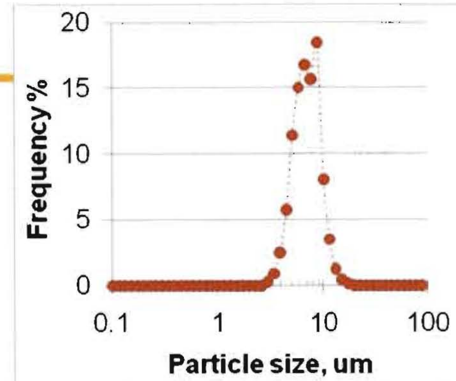




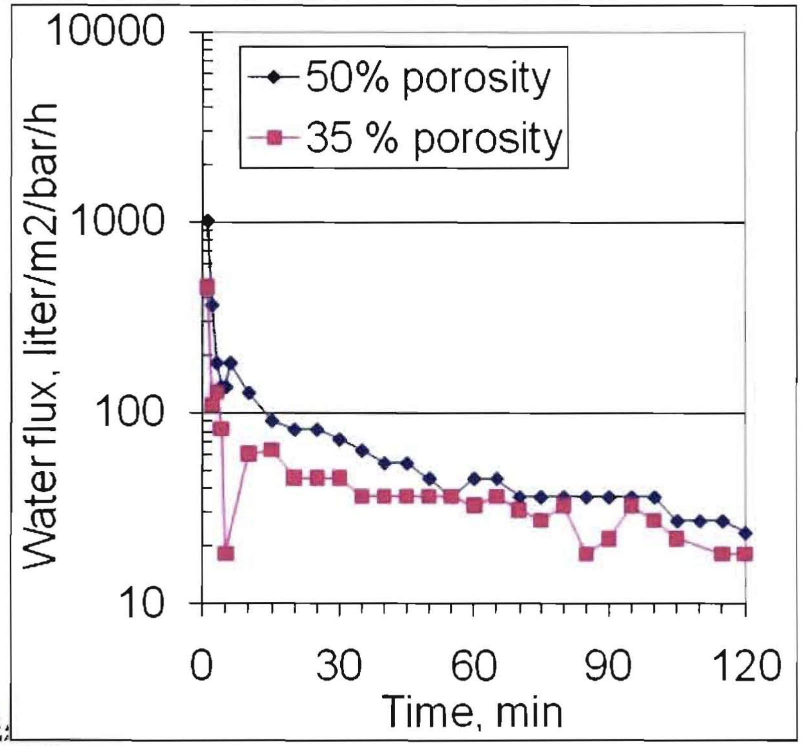


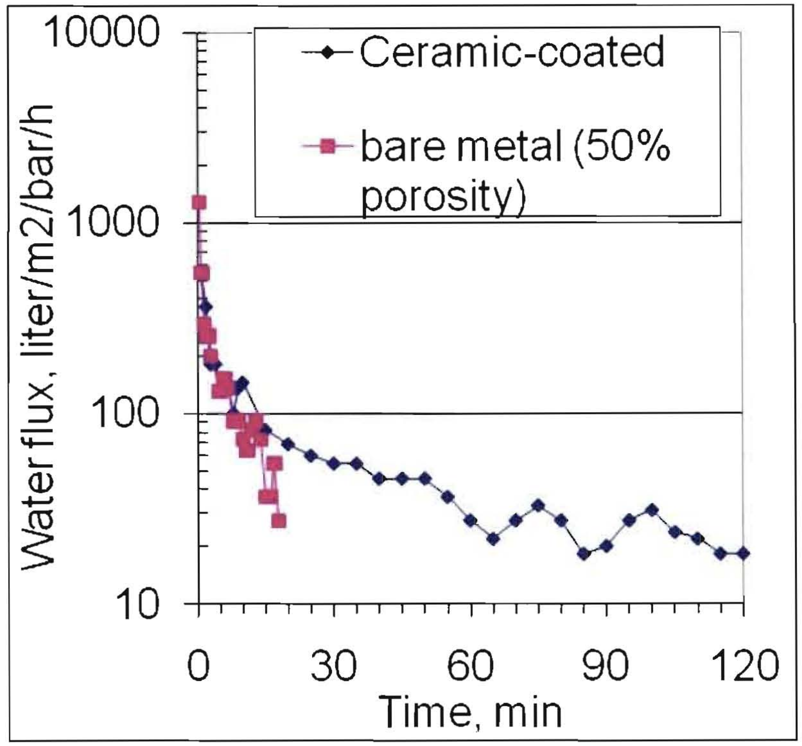
Preliminary testing results of an algae culture solution

Pacific Northwest NATIONAL LABORATORY

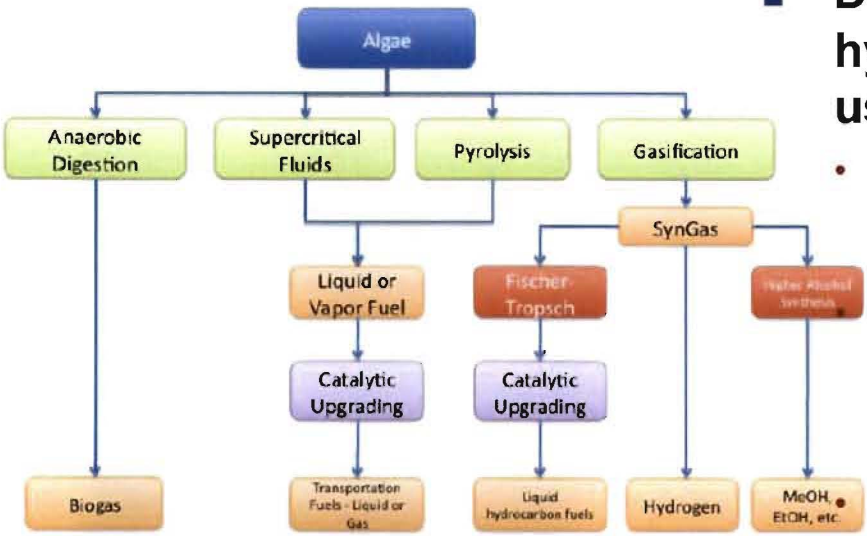


- Filtration under a constant ΔP at very low surface velocity (~0.03cm/s).
- Algae particles (2 to 20um) are easily filtered out.
- Water flux is very high at the beginning but rapidly declines with time on stream.

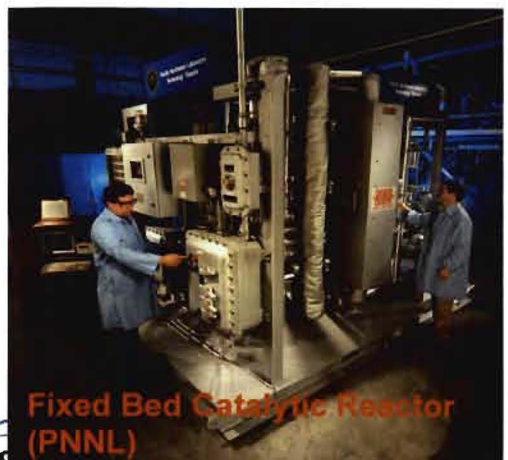




Conversion Strategies



- **Development of technologies to convert lipids/ hydrocarbons and biomass residues into useful fuels**
  - **Lipid conversion to fuels** • *Catalytic decarboxylation and deoxygenation* • *Catalytic and supercritical transesterification*
  - **Biomass conversion to fuels** • *Catalytic gasification* • *Thermochemical gasification and power* • *Fast pyrolysis and hydroprocessing* • *Anaerobic fermentation to EtOH and gasoline*
  - **Fuel characterization** • *Physical and chemical properties of algal esters and biofuels* • *Thermophysical and transport properties of biofuels*



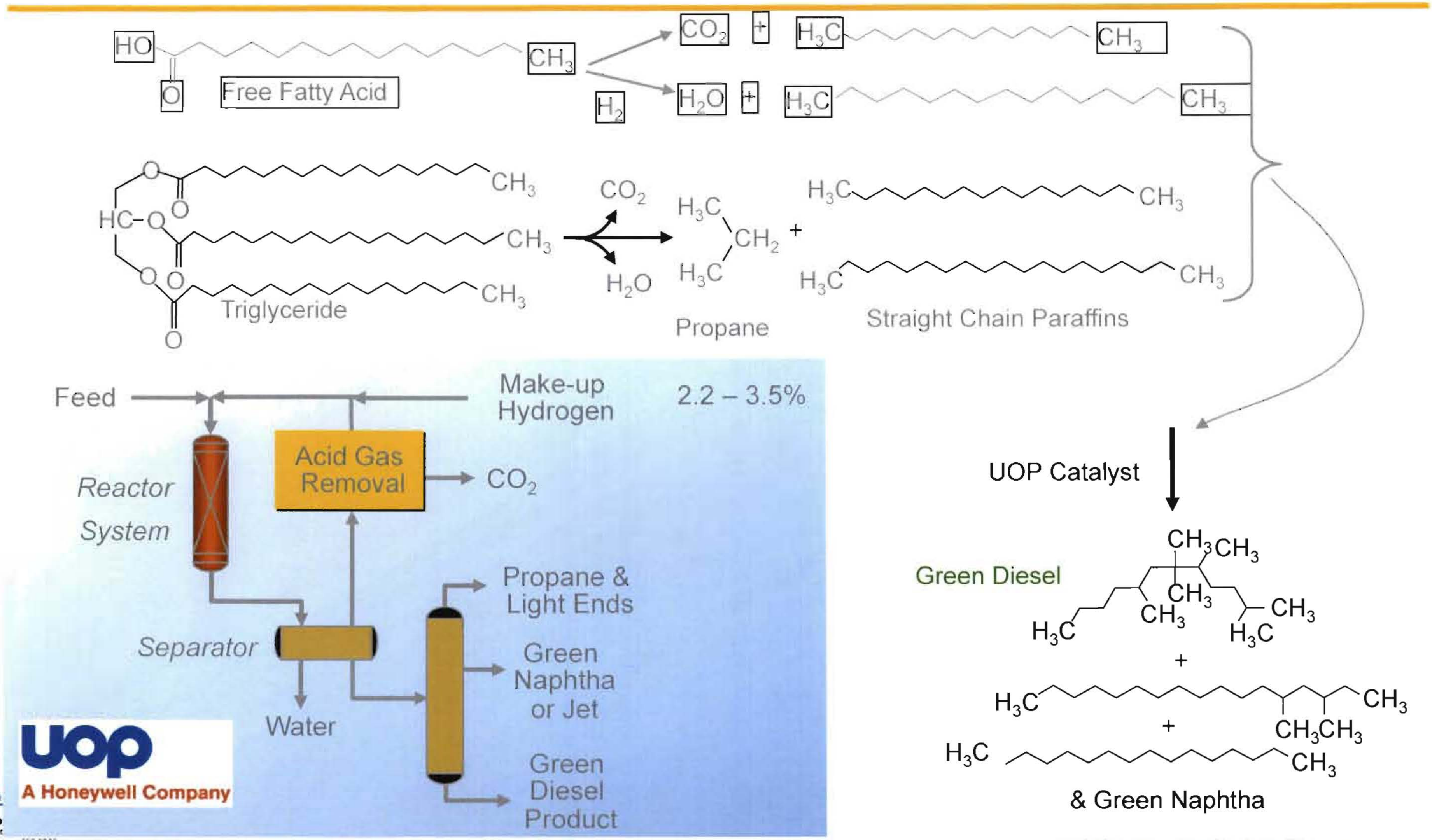
Fixed Bed Catalytic Reactor (PNNL)

T300 Heterogeneous Catalyst (Catilin)

Fuel properties characterization CSU Engine Lab; UOP

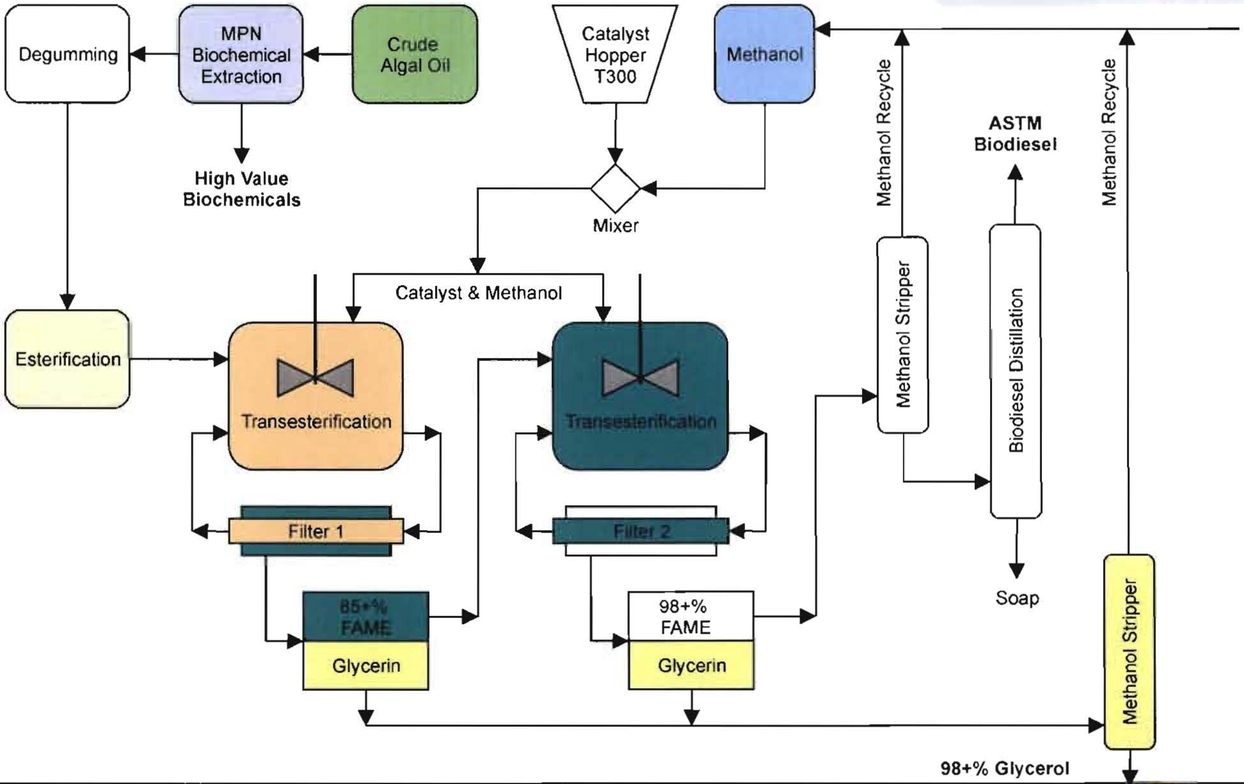
Ecofining Chemistry & Simplified Process Diagram

Product is a High Quality Pure Hydrocarbon known as Green Diesel



T300 Heterogeneous Catalyst

- Granular solid with an APS of 12-20 µm.
- Surface area of 15 m^2/gr and density of 2.6 gr/ml.
- High attrition resistance.
- Non-hazardous for low cost disposal

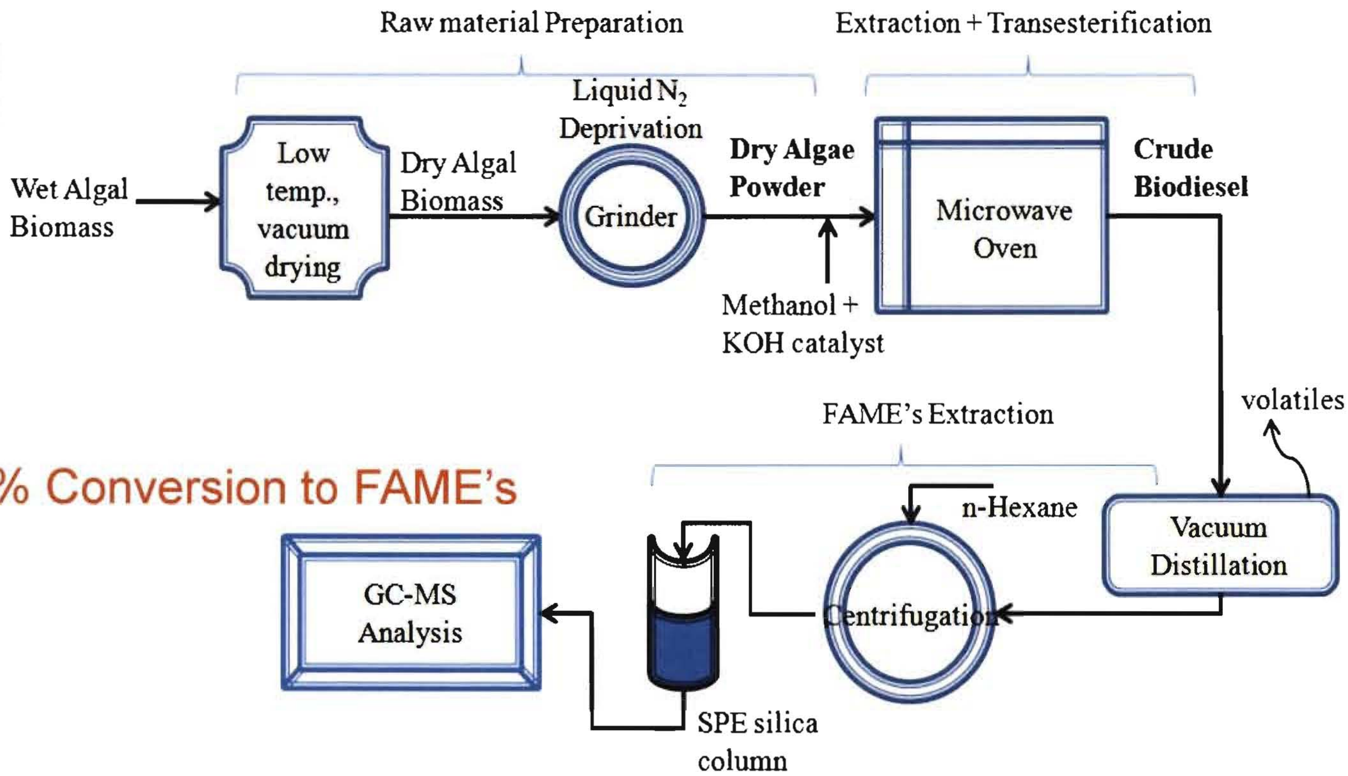


FAME Purification Comparison

BIODIESEL PROCESS COMPARISION CHART				
	Units	Catilin Pilot Plant	Commercial Test Run	ASTM Specs
Feedstock		Soy	Mix Corn, Tallow, Soy	
FFA	%	<0.05	>0.60	
Post Treat		Dry Wash	WFE	
Conversion	%	99.2	99.9	
Free Glycerin	%wt	0.004	0.004	<0.02
M bound Glycerin	%wt	0.15	0.07	N/A
D bound Glycerin	%wt	0.03	0	N/A
T bound Glycerin	%wt	0.003	0	N/A
Total Glycerin	%wt	0.187	0.074	<0.24
Monoglyceride	%wt	0.58	0.27	N/A
Diglyceride	%wt	0.20	0.00	N/A
Triglyceride	%wt	0.03	0.00	N/A
Acid Number	mg KOH/gr	0.43	0.23	<0.5
Moisture	%vol	ND	ND	<0.05
Calcium	ppm	<1	1.2	<5
FLASH POINT	C	100	>150	>130
Methanol	%wt	0.18	<0.01	<0.2
Cold Soak Test	sec	100	60-90	360

Microwave Transesterification of Dry Algae

NM STATE UNIVERSITY



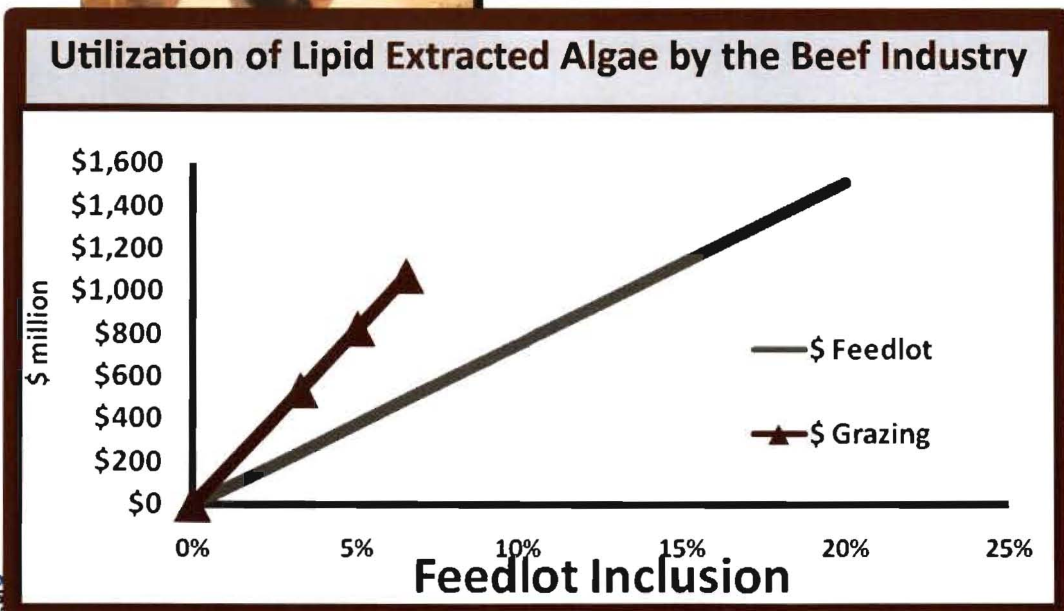
37-82% Conversion to FAME's

FAME: Fatty acid methyl ester ; SPE: Solid phase extraction

Patil, P.D., et al. "Optimization of microwave transesterification of dry algal biomass using RSM." *Bioresour. Technol.* accepted (2010)

Animal and Mari-culture Industry

Amino acid content
Digestibility coefficient
Biological value
Net protein utilization
Protein efficiency ratio
peptides, carbohydrates, lipids, vitamins,
pigments, minerals and other valuable trace elements

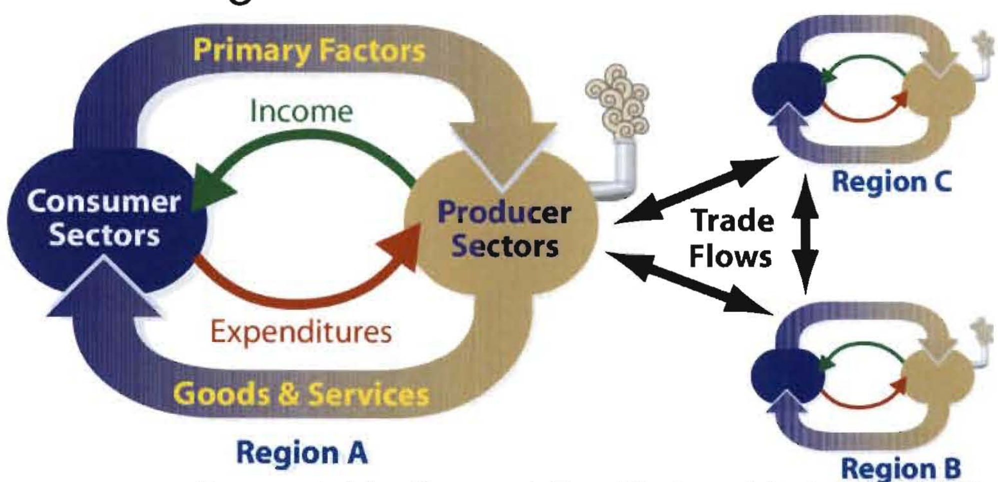


Sustainability

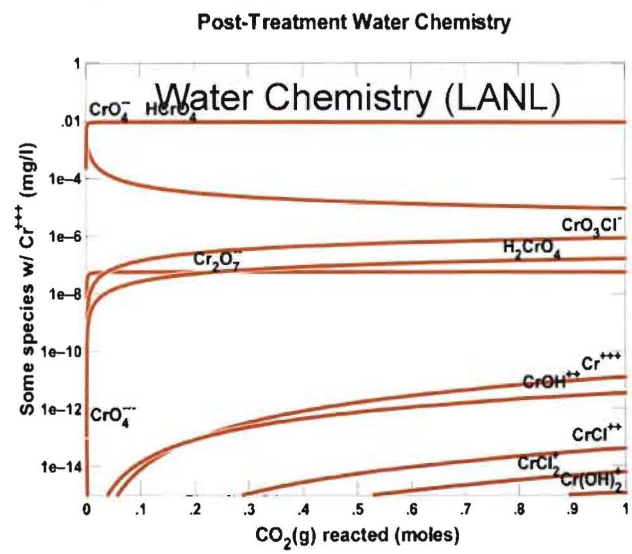
Quantitatively assess the energy, environment, economic viability and sustainability of approaches to guide our strategy

Economic analysis • Economic models • Global analysis • LCA an Process Analysis

Resource Management • CO2 management • Hydrology/water management



Computable General Equilibrium Model (TAMU)



Sustainability Targets

1. GHG Reduction of a minimum of 60% relative to Petroleum Standard
2. Water Use/Loss in Process and Finished Product less than Petroleum baseline and Corn Based Ethanol Standards
3. Energy Return on Investment > 1
4. Potential for Economic Viability for Firm/ Industry (at the Nth level)

NAABB Deliverables
>50% lipid content at harvest
>20g/m2/day biomass yield (open system)
5g dw/l/day biomass yield (closed system)
5,000 gal/day processing capability for a harvesting unit
15 gal/day lipid extraction capacity per unit
Certified Animal Feed
LEA $250-1000/ton
Glycerol $80/ton
$2.10/gal/lipid
$0.40/gal processing cost

$$C(Y_t) = Pelec * Elec + PNutr * QNutr + PWater * QWater + PLabor * Labor + PCarbon * QCarbon$$