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Title:	Initiatives in Algal Bio-Fuels
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Intended for:	Multiple Briefings

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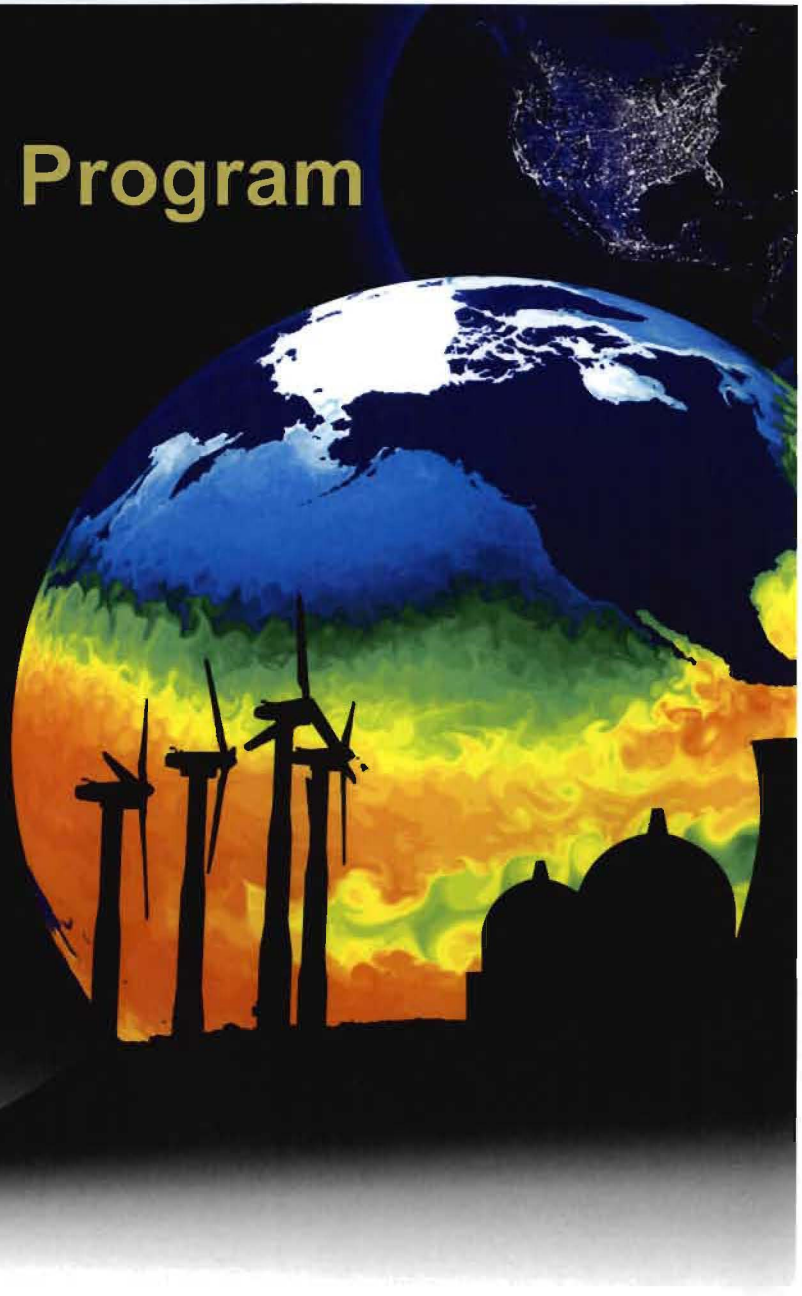
Form 836 (7/06)

LANL's Biofuels Program

José Olivares
Biofuels Program Lead
Los Alamos National Laboratory

Executive Director, NAABB
Donald Danforth Plant Science Center



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US Focus

U.S. 2008 Transportation Fuel Stats

Gasoline (cars & trucks)

140 bgy

Diesel (on-road, rail)

43 bgy

Aviation (jet fuel)

25 bgy

Technoeconomic Analysis Resource Analysis/ Allocation

Advanced Biofuels R&D

Algal Biofuels R&D

Biomass Intermediates

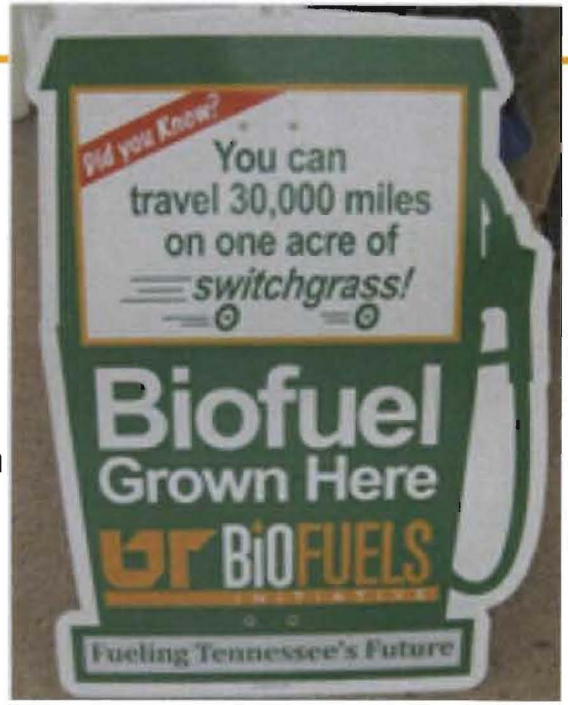
Biopower

Cellulosic Ethanol RD&D

Sustainability Analysis & LCA

Biomass Market Trends

- **Shift from an ethanol only to biomass for energy.**
  - Market for corn-based ethanol will plateau.
  - Renewed interest in Biopower.
  - Biomass requires regional solutions and smart choices on applications.
- **Liquid fuels are most valuable.**
  - Liquid fuels for heavy trucking, rail and aviation remain even with plug-in hybrids.
  - Infrastructure is not set up for boutique fuels—need fungible diesel, jet and gasoline.
- **Algae is Hot!**
  - New science and engineering still needed in genomics, growth, production to overcome economic barriers.
- **Serious questions on sustainability of biofuels and CO_2 mitigation remain.**
  - National Labs offer science-based solutions.



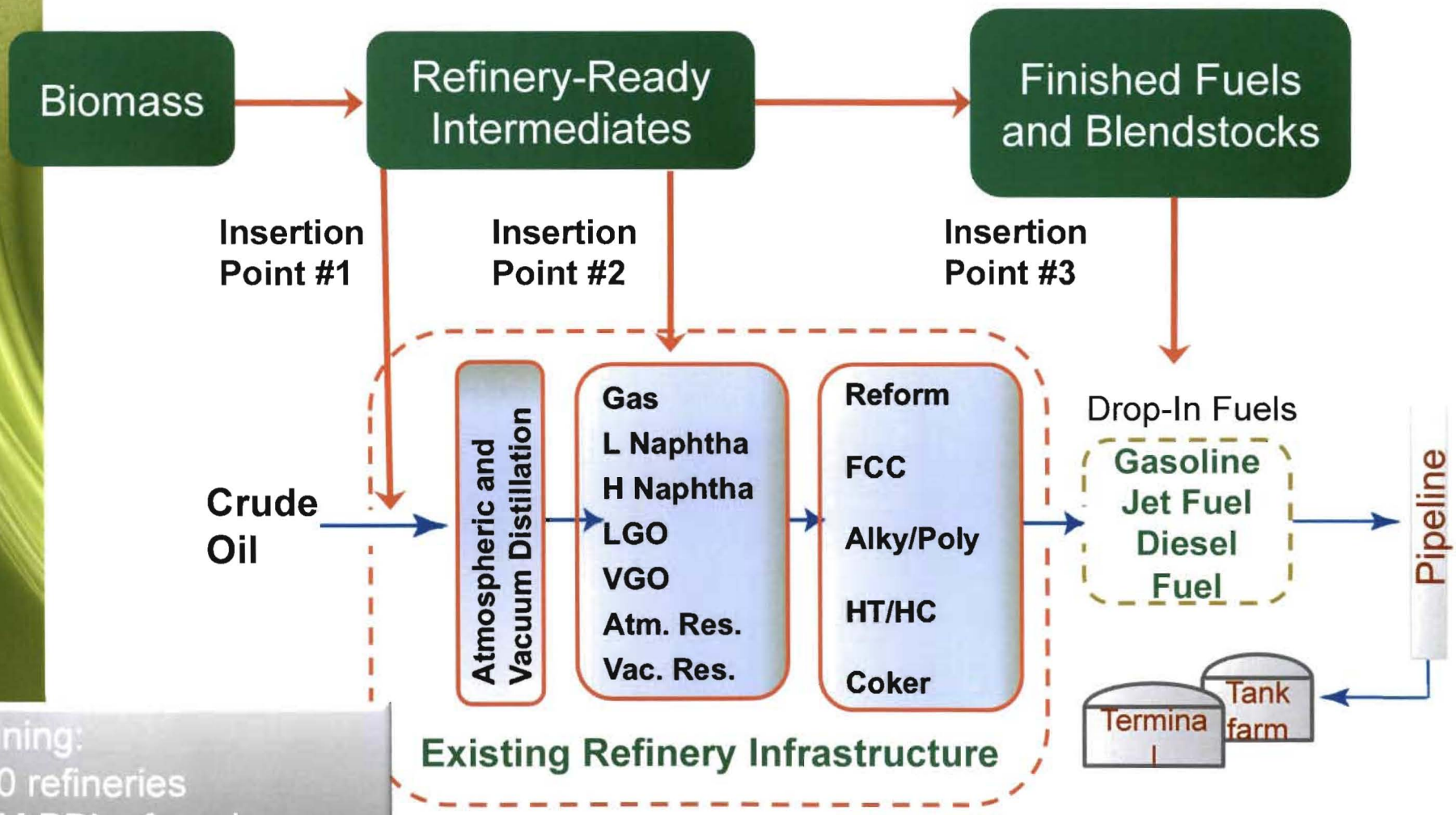
LANL Programs in Biofuels

- **New DOE Consortia**
  - $13.5 M in Research and Development as a Partner in:
    - Photosynthetic Antenna Research Center
    - National Advanced Biofuels Consortium
    - National Alliance for Advanced Biofuels and Bioproducts
- **Collaborative Research and Development Agreements with Industry**
  - ~$2.5 M in Research and Development with Major Industry
    - **Procter and Gamble** – Development of replacement feedstocks for surfactants and other products
    - **DSM** – Development of highly stable enzymes
    - **Solix Biofuels** – Development of Algal Harvesting and Extraction Technologies
- **Laboratory Directed Research and Development (~$10M)**
  - Understanding and Engineering of Enzymes that Degrade Cellulose
  - Catalytic Processes for Breakup of Lignin, Production of High Density Fuels
  - Basic Biology of Algae and Metabolic Regulation

NABC National Advanced Biofuels Consortium

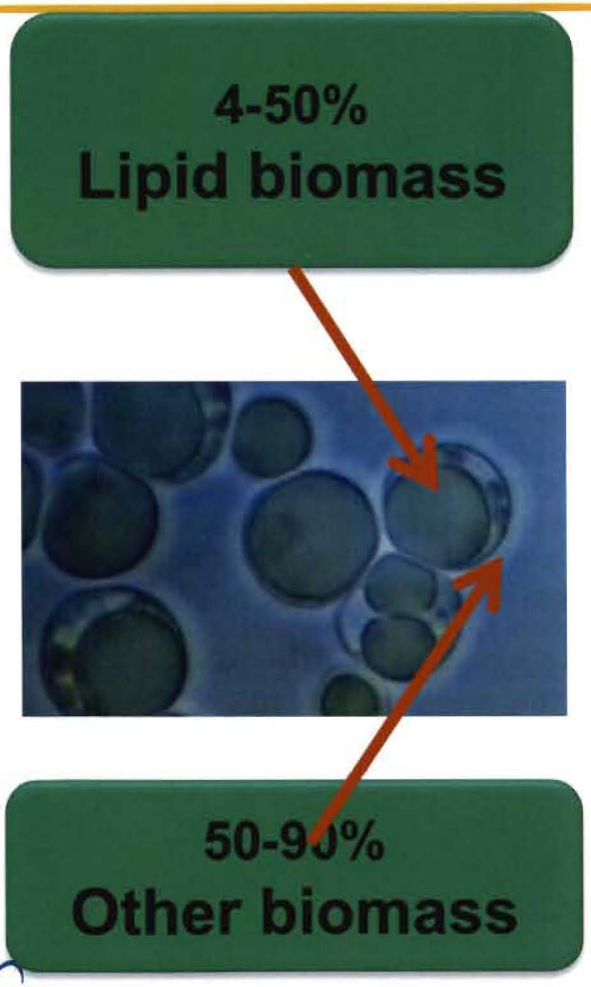
Biofuels for Advancing America

Aim: Use Current infrastructure to Produce and Transport Biofuels



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

Biofuels from Algae



Rapid growth rate

Double in 6-12 hours

High oil content

4-50% non-polar lipids

All biomass harvested

100%

Continuous harvesting

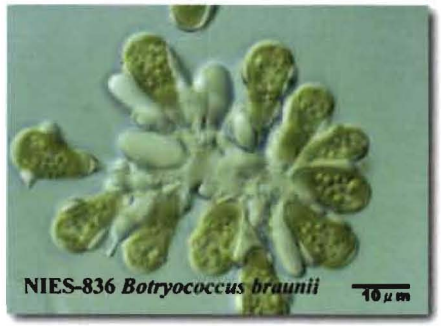
24/7, not seasonally

Sustainable

Capture up to 90% of injected CO_2

Can utilize waste water

Does not need arable land

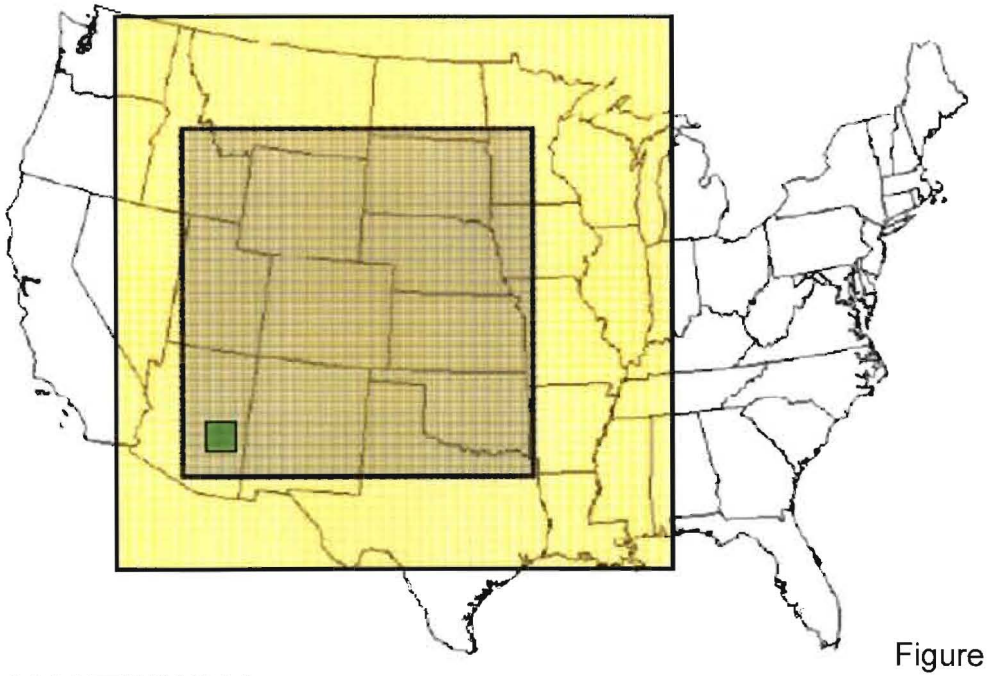


National Alliance For Advanced Biofuels and Bio-products

Donald Danforth Plant Science Center

National Alliance for Advanced Biofuels and Bioproducts

- **Institutional Lead:** The Danforth Plant Science Center (St. Louis, Mo)
- **Leader:** Jose A. Olivares (LANL/DDPSC)
- **Funds:** Federal - $49 M Industry Cost Share - $20M
- ***Goals: significantly increase production; efficient harvest and extraction; and enhance conversion to fuels and co-products.***



Land needed to replace 50% of U.S. diesel with:

Corn

Soybean

Algae

Figure courtesy of Sandia National Laboratory

Algal Biology

Greater space-time lipid/algae yields

Cultivation

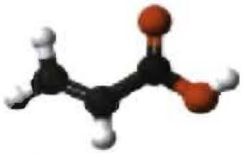
Harvesting and Extraction

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

Nutrients

Other NAABB Partner: Pratt & Whitney

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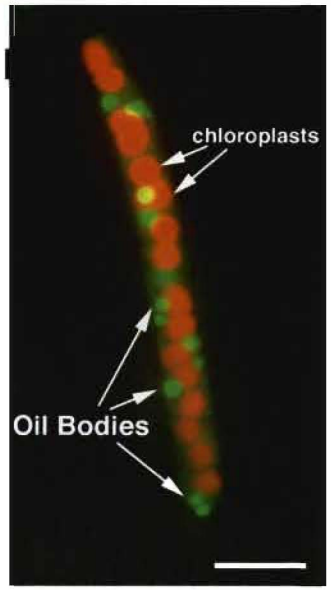
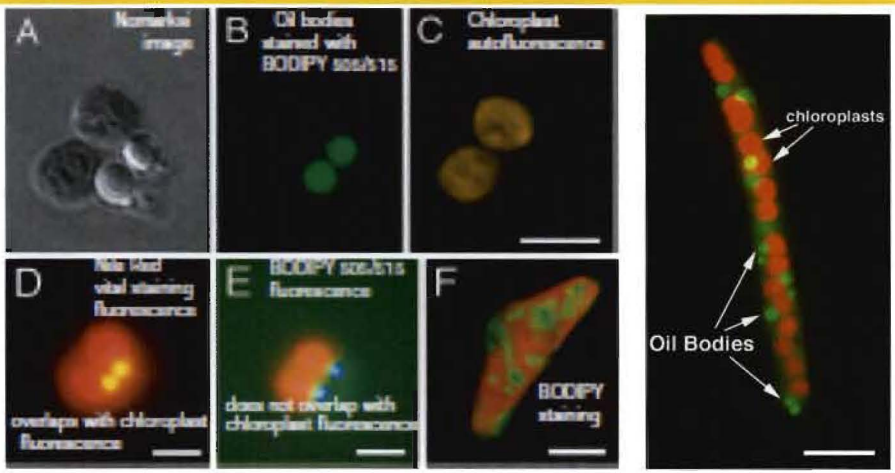
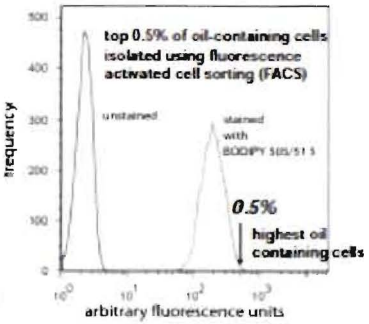
NAABB Algal Biology Objectives

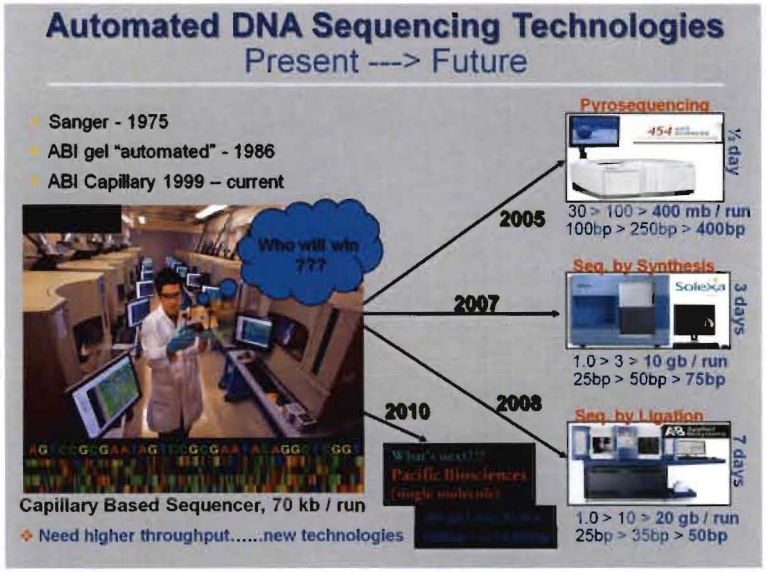
- **Increase overall productivity of algal biomass accumulation and hydrocarbon content**
  - **Mining natural diversity** (Brooklyn, UW)
  - **Mutagenesis for increased lipid production** (WUSL)
  - **Systems biology for lipid production**
    - Genomics, proteomics, transcriptomics (LANL/PNNL, UCLA)
  - **Crop protection**
    - Adaptive evolution (U of Az)
    - Genetic modification for environmental traits (Danforth)
  - **Maximizing yield**
    - Screening tools (WSU), Metabolic regulation (LANL), Nutrient and ionomics (ARS/Danforth)
  - **Maximizing lipid production**
    - Gene ID (WUSL, Danforth), Transcriptomics (UCLA, TG), Lipid secretory system and lipid packaging (Danforth, UW, AXI)
  - **Maximizing production of hydrocarbons**
    - Isoprenoids (LANL, TAMU, UAz)

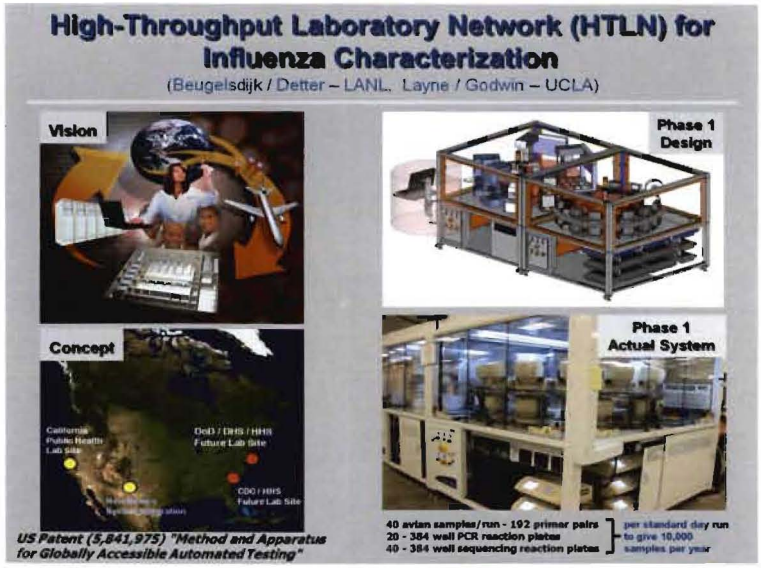


Phenotypic and Genotypic Analysis









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Genomics and Transcriptomics Sequencing

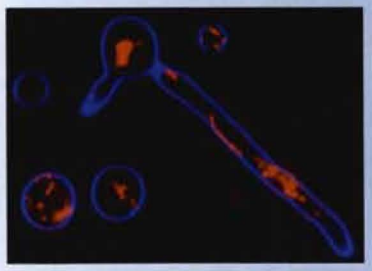
Chris Detter and Shannon Johnson (B-6)

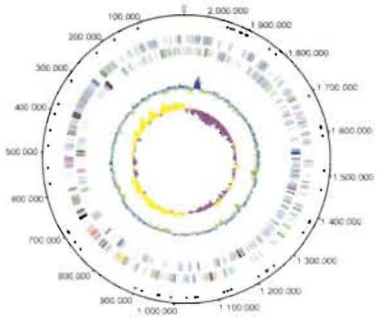
The Joint Genome Institute (JGI)-LANL finishes and analyzes microbial genome sequences that are critical to DOE missions such as bioremediation, alternative energy production, carbon sequestration, and biotechnology development.

- **Focus on High Quality Draft Sequencing of Algal Organisms**
- ***Nanochloropsis salina* CCMP1776**
- ***Chlamydomonas reinhardtii***
- ***Chlorella protothecoides* (UTEX 25)**
- ***B. braunii Race A* (UTEX 2441)**

JGI DOE JOINT GENOME INSTITUTE US DEPARTMENT OF ENERGY OFFICE OF SCIENCE

Comprehensive understanding of microbes for biofuels





Readily accessible sequence information

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Systems Biology-based Metabolic Engineering

Min Park, C. Kuske, S. Twary, C. Unkefer, P. Unkefer (B-8)

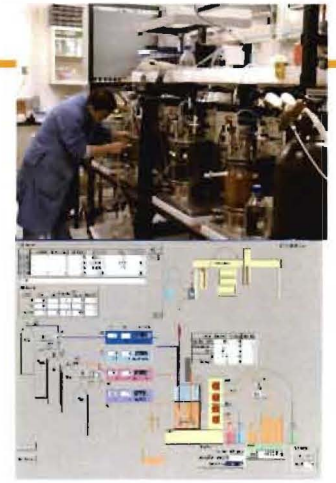
1. Develop "on demand lipid accumulation"
2. Optimize lipid biosynthesis pathways

Require a Fundamental Characterization of gene regulation and metabolic flux

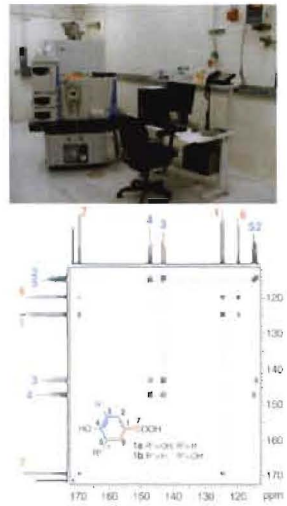
Approach:

Systems biology analysis of nutrient stress-induced lipid production in algae

- **Integrated systems (-omics knowledge, comparative pathway and metabolic flux analysis, carbon-fate map, retro-synthesis, enzyme engineering, synthetic biology)-based reconstruction of isoprenoid synthesis pathway**



Controlled growth analysis



Metabolic pathway analysis

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Maximizing Hydrocarbon Production via Isoprenoid Pathways

Andy Koppisch (B-8)

Botryococcus braunii

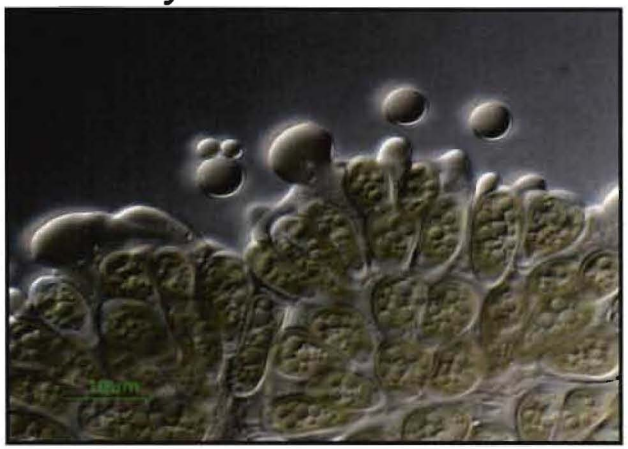
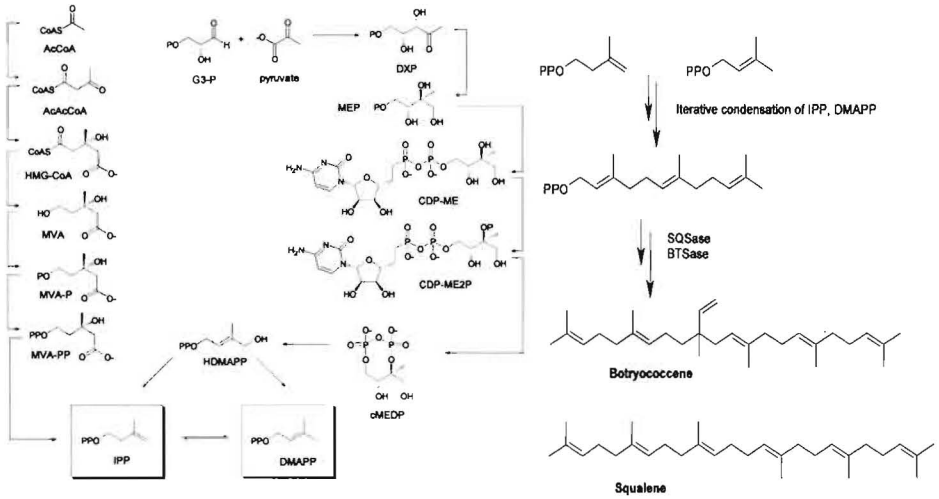


Image courtesy of T. Devarenne, Texas A&M University



Isoprenoid precursors amd Botryoccene Synthesis

- **Vigorous producer of isoprenoid hydrocarbons**
- **Botryococcenes transformed to fuel via caustic hydrolysis**
- **Understand biosynthesis of these systems**
- **Transform them into more productive strains**

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NAABB Algal Harvesting and Extraction Strategies

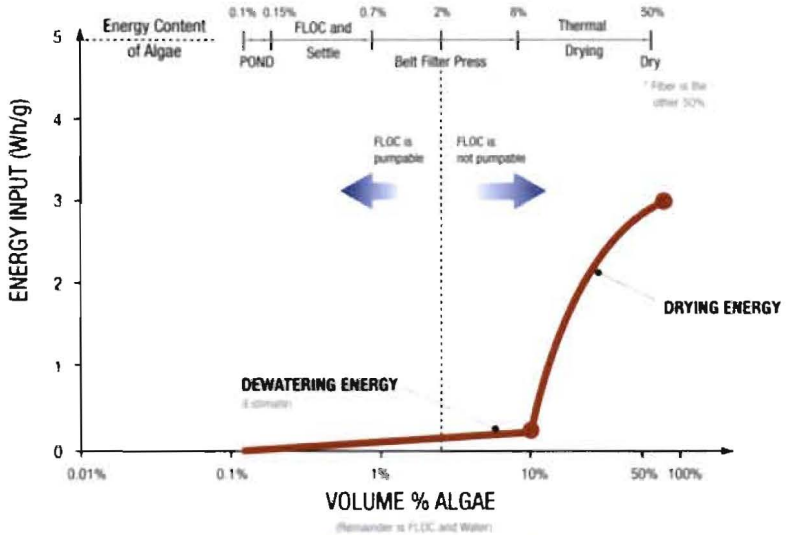
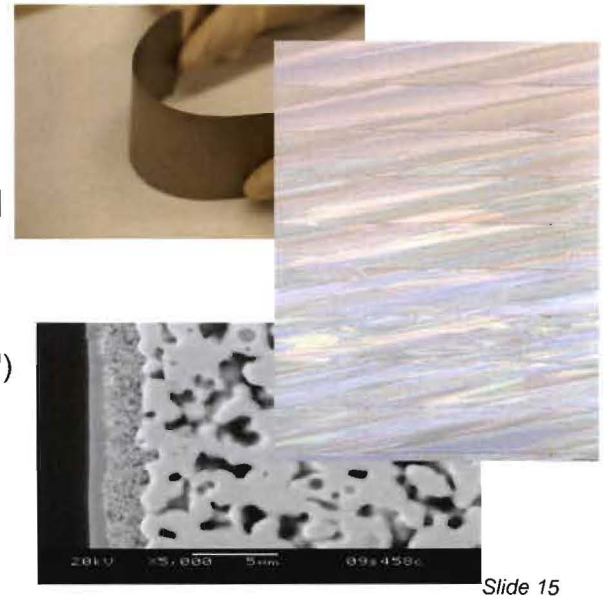


Figure 4: Approximate energy curve for harvesting, dewatering, and drying considering a process of flocculation, sedimentation, belt filter pressing, and drum oven heating.

- Sedimentation, filtration, dried air flocculation
- Centrifugation alone 15% solids
- Centrifugation and drying >90%
- Belt filter press - 30%
- Attached growth systems - surfaces
- Bioharvesting



NAABB will develop cost-effective and energy efficient harvesting and lipid extraction technologies

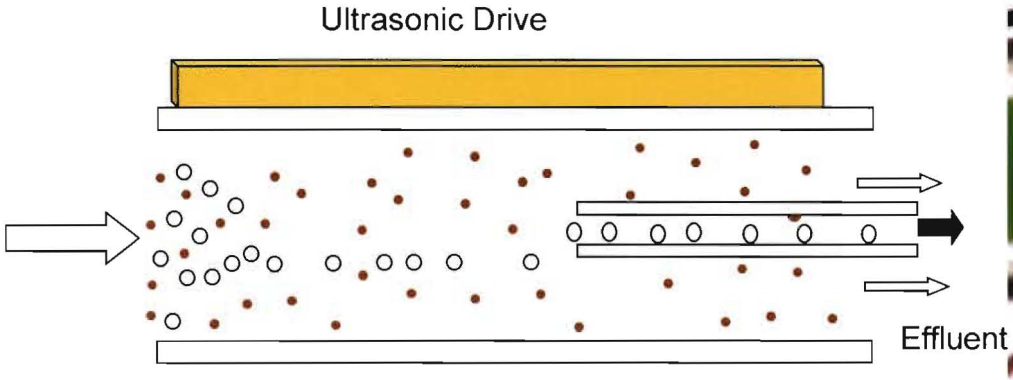
Harvesting technologies

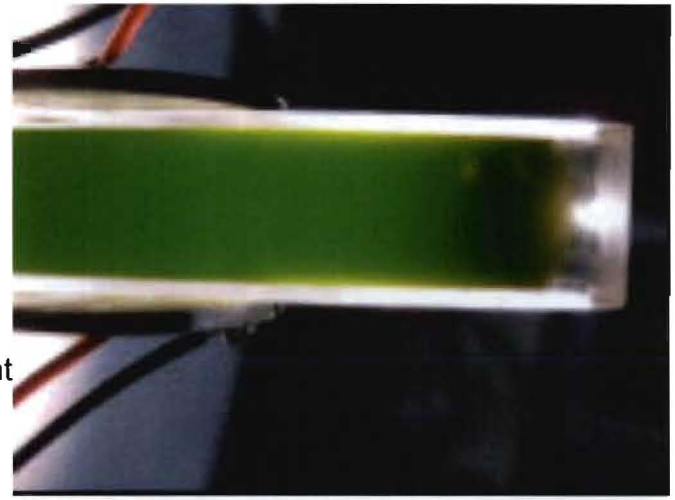
- **Acoustic focusing** (LANL)
- **Hybrid capacitive deionization/electro deionization** (CDI/EDI) (TAMU)
- **Membranes and flocculants** (PNNL)

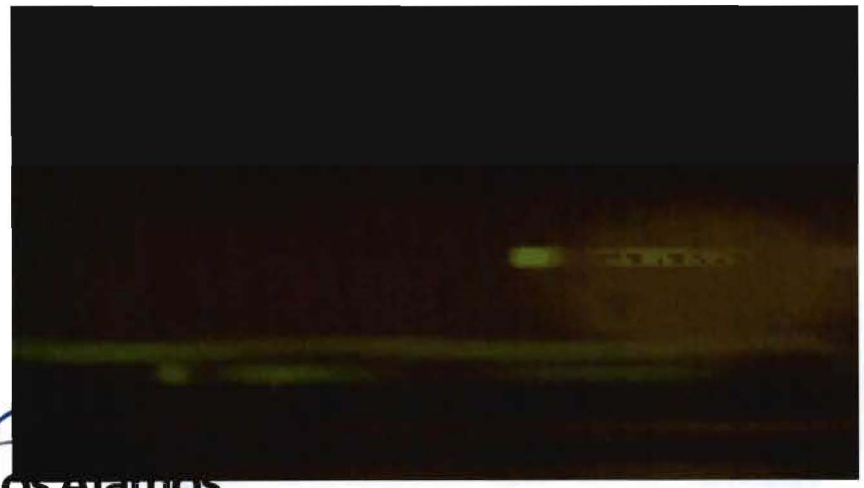
Extraction Technologies

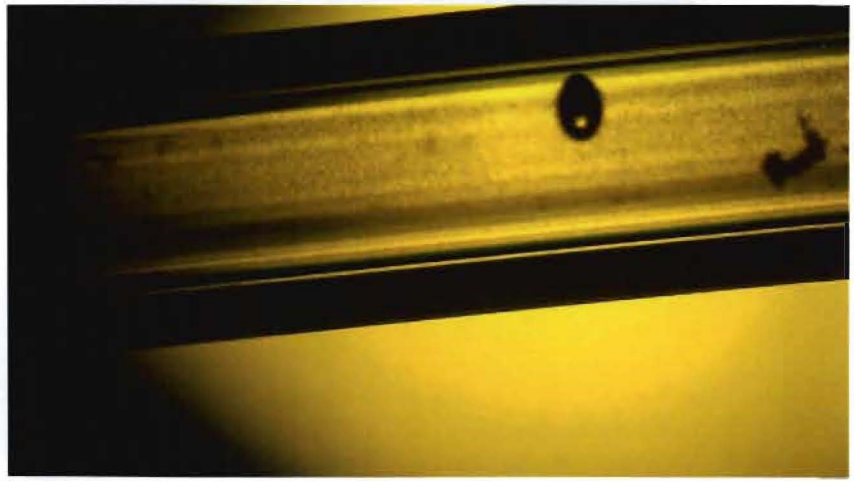
- **Acoustic technologies** (LANL)
- **Mesoporous nanomaterials (MNM)** (Catilin)
- **Amphiphilic solvents** (TAMU)

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

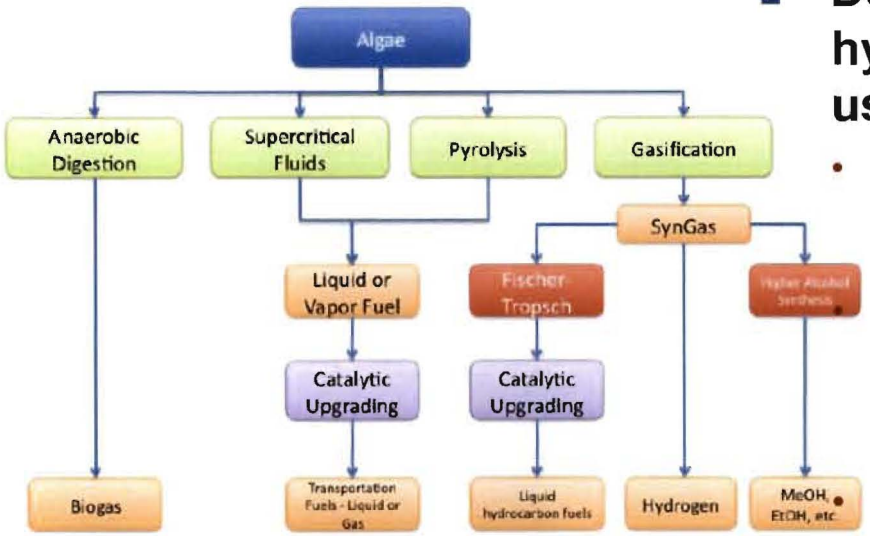








Conversion Strategies



- **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, UCR

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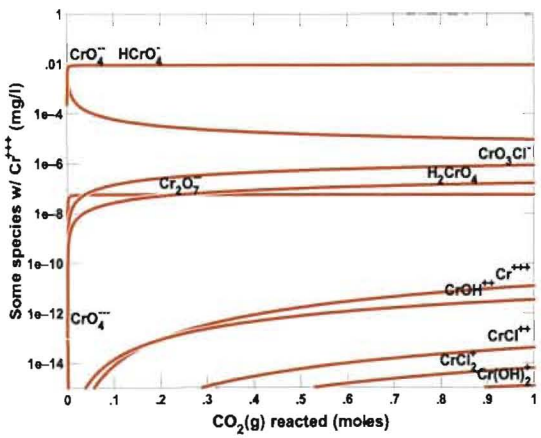
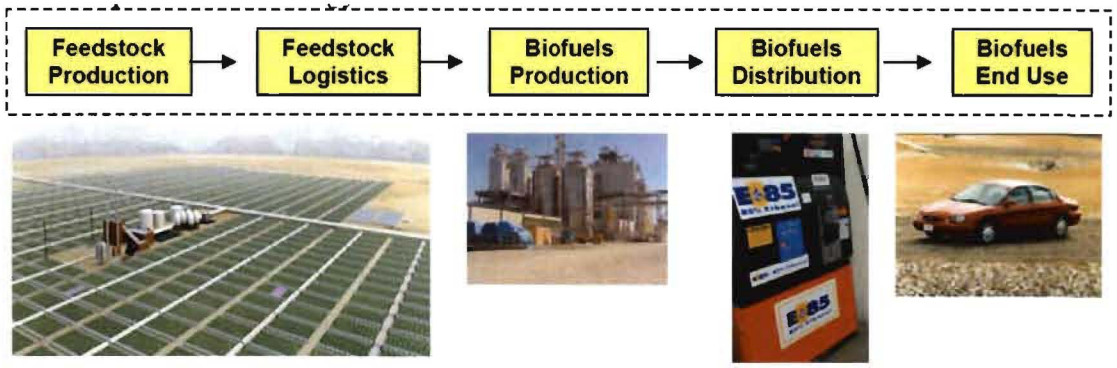
NAABB Sustainability

- **Quantitatively assess the energy, environment, economic viability and sustainability of the NAABB approaches to guide our strategy**
  - **Economic analysis** • Economic models • Global analysis • LCA an Process Analysis (TAMU, PNNL NMSU, UOP, UA)
  - **Resource Management** • CO2 management • Hydrology/water management (LANL, NMSU, PNNL, HRBP)





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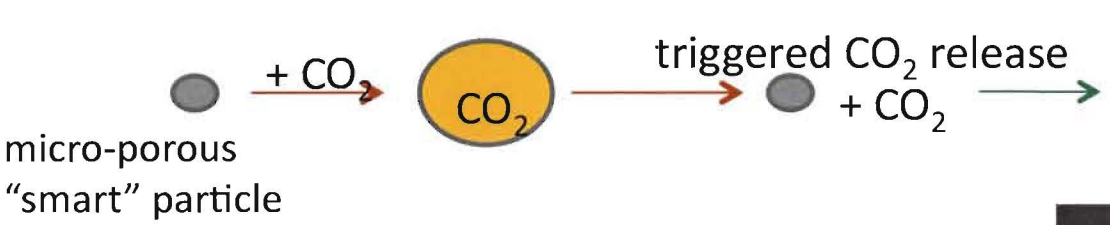
CO_2 Management Technologies

Robert Currier (C-CSE)Amr Abdel-Fattah and Dennis Newell (EES-14)

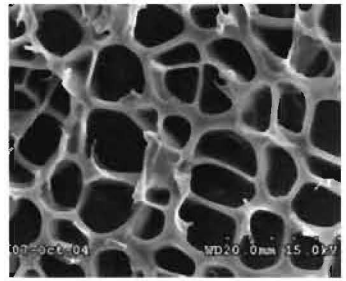


- **Micro-porous particles designed to capture CO_2**
  - power plant emissions, atmosphere
- **Release CO_2 in algal ponds**
  - environmental or induced triggers (e.g., pH, acoustic field)

Hydrogel designed to sorb H_2O

Electric Field Swing Adsorption (EFSW)

Industrial-scale adsorption beds



SEM image of porous structure

CO_2 Separation via traditional Temperature and Pressure Swing Adsorption uses significant amounts of energy.

Opportunities and challenges

- Mandate for renewable fuels will require research and commercialization through 2022
- Office of Biomass Programs goal to convert ARRA to sustainable funding
- Los Alamos has demonstrated that smart partnering is key to program success
- Sustainability will require execution + innovation