A review of progress and future plans

USU Algae Energy Systems Initiative

8.25.2008

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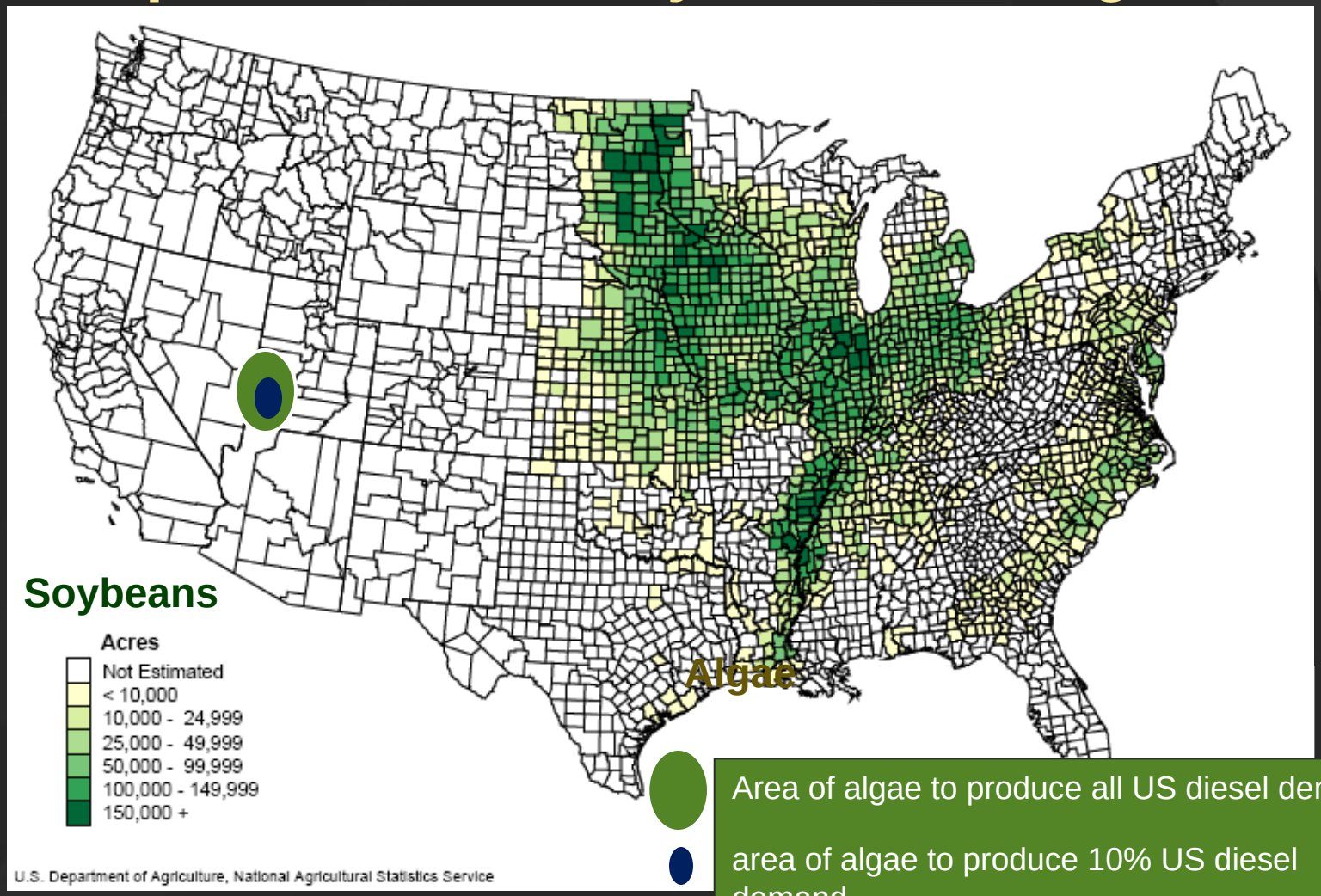
Comparison of biodiesel production potential from soybeans and algae



Area of algae to produce all US diesel demand

area of algae to produce 10% US diesel demand

The total US soybean crop would provide less than 10% of domestic diesel demand.

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USU Research Infrastructure

1. State Investment: $6.5 million over 5 yrs.
2. ~25 faculty, research staff, students
3. New research facilities
4. GCMS & IC
5. Covered raceway (5000 gal)
6. 20 different enclosed reactors
7. Custom experimental tools

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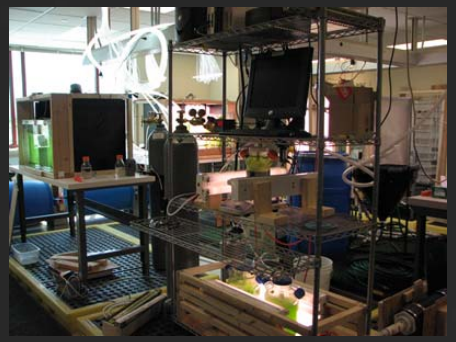
Research Infrastructure



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USU Focus Areas

Business Areas:	Science & Technology
Liquid fuels } current focus	Sunlight utilization } 1st two hires
CO_2 recycling } emerging 2nd focus	Bioreactor design } 1st two hires
Hydrogen	Algae physiology } 3rd hire
Aquaculture	Metabolic pathway eng. } 3rd hire
High-value products	Engineering Systems
Envir. remediation	Advanced Materials

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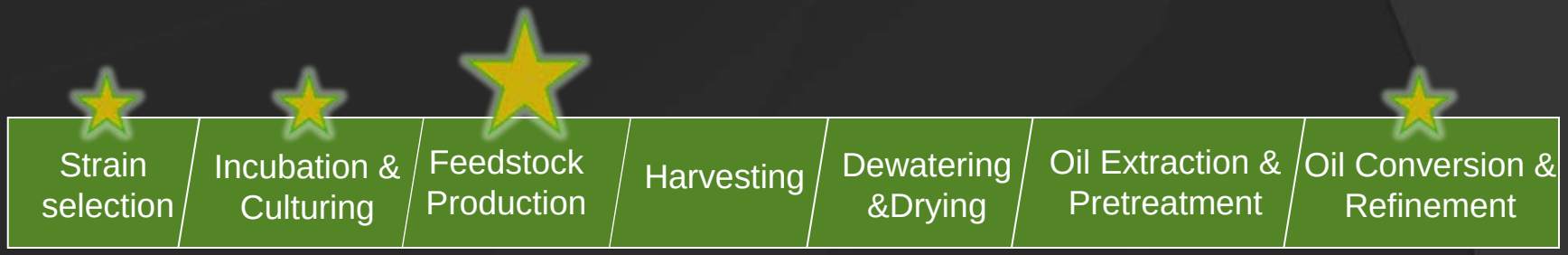
Existing / proposed focus areas

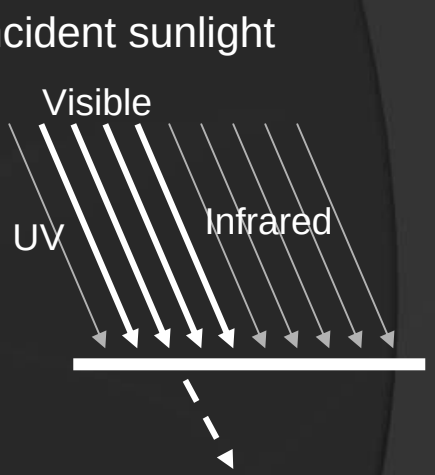
Algae Biofuel Production Steps



USU Focus Areas

Challenges Addressed by USU:

- Eliminating photosynthetic saturation & surface shading
- Converting wasted UV/IR into usable energy streams
- Eliminating biofouling in closed reactors
- Scalable, low-cost reactor designs
- Increasing areal yield & volumetric growth



In passive systems, less than 4% of the incident energy in sunlight is used constructively to grow algae

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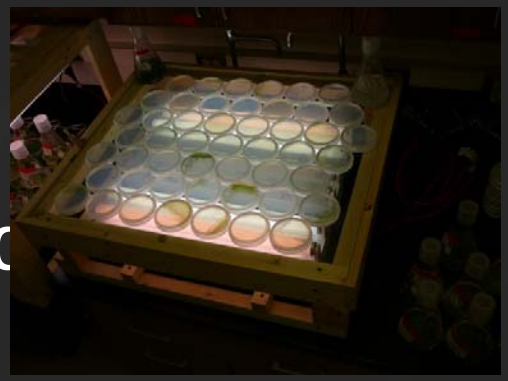
Species / Strain Characterization

- >30 species collected and subcultured
  - Includes species from the aquatic species program
- 15 species grown in larger cultures (5 Liters) for lipid characterization
  - Total yields
  - Absorbance Comparisons
  - Time of growth
- Lipid quantification completed
- Compounds vary

Fatty Acids; TAGs; Sterols; Phytols (branched chain alcohols); Straight Chain Alkanes



Analogy: We are all humans, but look at our differences.

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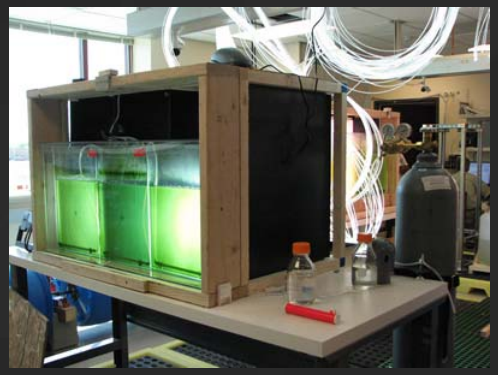
Growth Environment Options

USU Open pond



USU Closed Photobioreactors

USU has constructed an open pond system for benchmarking and acquiring large quantities of algae for post-processing - while developing new reactor designs, materials and processes to address closed-system challenges.

<u>Disadvantages</u>

- Overheating
- Oxygen accumulation
- Biofouling / mixing issues
- Cell damage by shear stress
- Deterioration of materials
- Scale-up/cost

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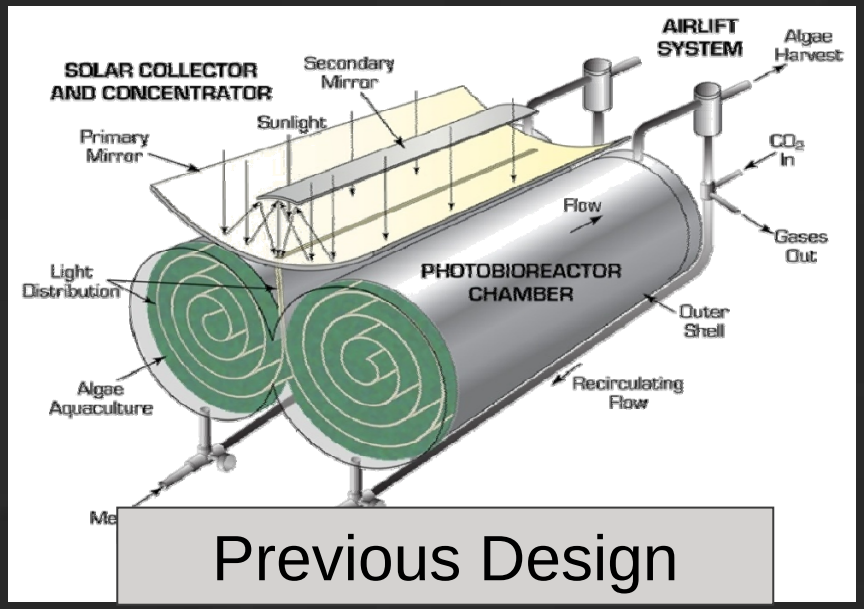
Bridging the gap between reactor types

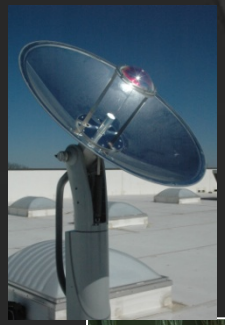
passive

single-axis tracking



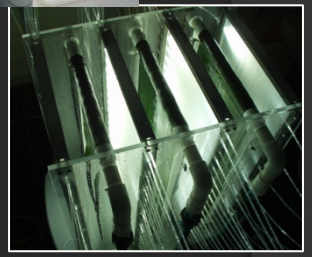
Previous Design

two-axis tracking



ORNL Collector

USU Biofilm Reactor



Leverages:

- solar thermal electric systems
- hybrid solar lighting technology
  - visible light separation from UV/IR
  - uniform visible light redistribution using planar waveguides

Goals: >10X improvement in:

- sunlight utilization per unit area
- volumetric yield over ponds & reactors
- $ for light collection/distribution -vs- 2-axis tracking systems

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We are developing advanced materials & components

Old ideas are being made possible by new "transformational" components & materials.

<u>Technical Challenges:</u>

- Distribution uniformity
- Optical throughput
- Biofouling
- Co-production of energy streams

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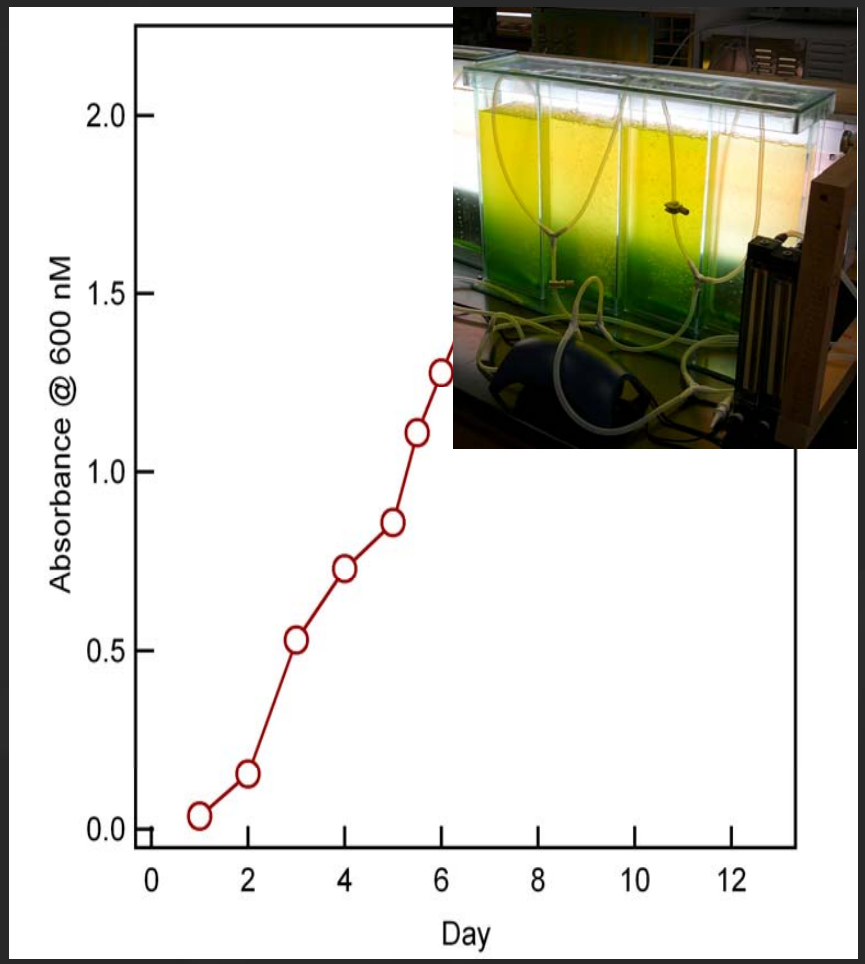
Ultrathin Reactors



- Rationale: minimize volume by growing cultures in ultrathin chambers
- several species/strains growing well (if cultured properly)
- Leading to radical changes in reactor design criteria

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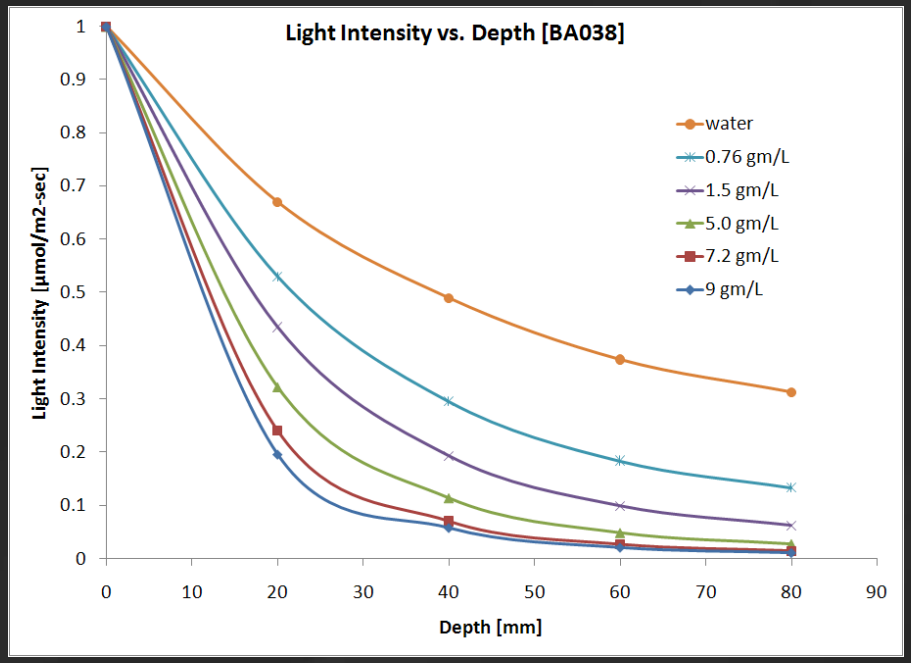
Dr. Brett Barney – 435.797.1613

We are developing tools to aid in reactor design



Combining experimental data w/ analytical tools, USU is developing unique modeling capabilities applicable to all reactor designs.

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Dan Dye

We are isolating variables to find:

- Optimum light levels
- Nutrients necessary to achieve maximum cell densities
- Preferred CO_2 concentration
- Minimum feasible reactor dimensions
- Strategies to reduce biofouling
- Mixing / sparging techniques

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Properties of USU Downstream Processing Technique

	USU Biodiesel (butyl-soyate ester)	Commercial Biodiesel (Methyl-soyate ester)	Petrodiesel
Heating Value (cal/g)	8925.0 **(87%)**	8895.2 **(86%)**	10264.7
Pour Point (˚C)	-13	0	- 24
Cetane index	69	~ 50	40 – 46
Viscosity	4.5	1.9 – 6.0	1.9 – 4.1

- Utilizes a cheap non-food feedstock.
- Uses a common inexpensive catalyst (H_2SO_4).
- Biobutanol commercial by 2010 from Dupont and BP.
- Method produces biodiesel with a high cetane value and a low temperature pour point.

DUPONT The miracles of science

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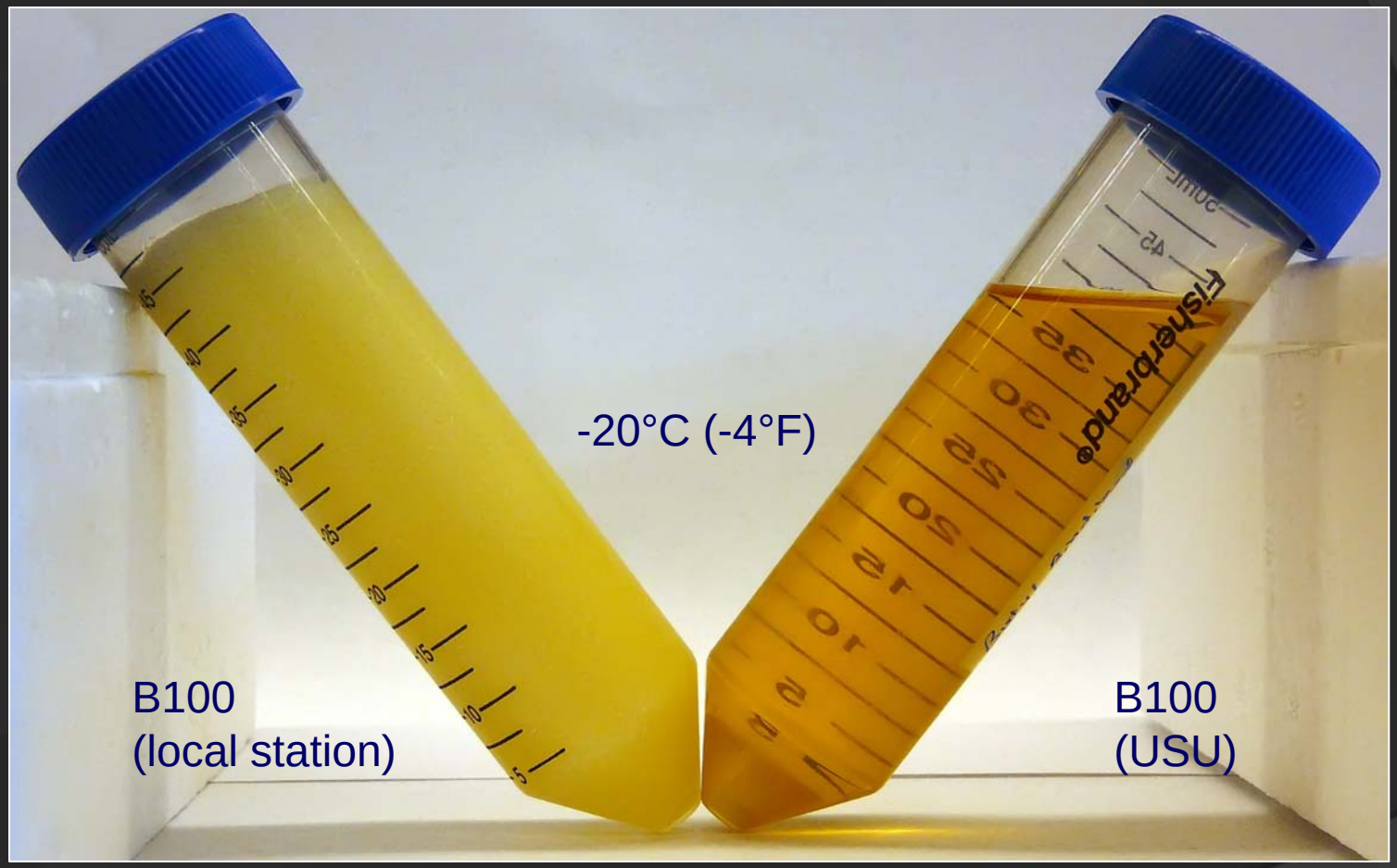
Dr. Lance Seefeldt

Gel Point of Biodiesels



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USU raceway benchmarking

Dr. Sridhar Viamajala

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USU techno-economic models will aid in commercial-scale evaluation

$$Q = \left(\frac{V_L f_L}{\rho_L} + (1 - f_L) V_a + S - M \right) P_a - A$$

Q	=	Revenue from photobioreactor
V_L	=	Value of lipids produced
f_L	=	Lipid content of microalgae
ρ_L	=	Density of microalgae lipids
V_a	=	Value of non-lipid microalgae mass
S	=	Value of services provided
M	=	Per-kg cost of production
P_a	=	Production rate of microalgae
A	=	Annual operation costs

S	=	Heavy metals removal
		Carbon sequestration
		Wastewater Treatment
M	=	Upstream processing
		Supplemental nutrients
		Downstream processing
		Packaging and shipping
		Waste disposal
A	=	Labor
		Electricity
		Heating
		Maintenance

V_a, S, M, and A are currently not well known, thus accurate revenue predictions are difficult to make.

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Dr. Byard Wood

Targeted High Value Products

- Essential Fatty Acids
  - important to human health
  - found in fish oils, baby formula.
  - displace fish derived oils (DHA & EPA)
- Alkanes
  - directly used as fuels and precursors to a vast array of polymers and specialty chemicals
  - displace petroleum feedstock for such chemicals
- Wax Esters
  - high value lubricants and cosmetic ingredients
  - displace Jojoba oil and sperm whale oils
- Carotenoids
  - antioxidants vital to human health
  - high value nutritional market
  - displace plant sources

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Collaborations

Lumitex

SUU SOUTHERN UTAH UNIVERSITY

DARPA

MONTANA STATE UNIVERSITY

DSC DIXIE STATE COLLEGE OF UTAH

OAK RIDGE National Laboratory

Utah Transportation Center Utah State University

UVU UTAH VALLEY UNIVERSITY

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A few relevant grants / contracts

- Oak Ridge National Laboratory
  - DARPA Seedling Project
  - Advanced reactor concepts
- DOE Biomass - teamed with MSU (selected for award negotiation 9/11/2008)
  - Lipid characterization of species in extreme environments
- DARPA (Prime: General Atomics)
  - USU role aligned with presentation above
  - pending

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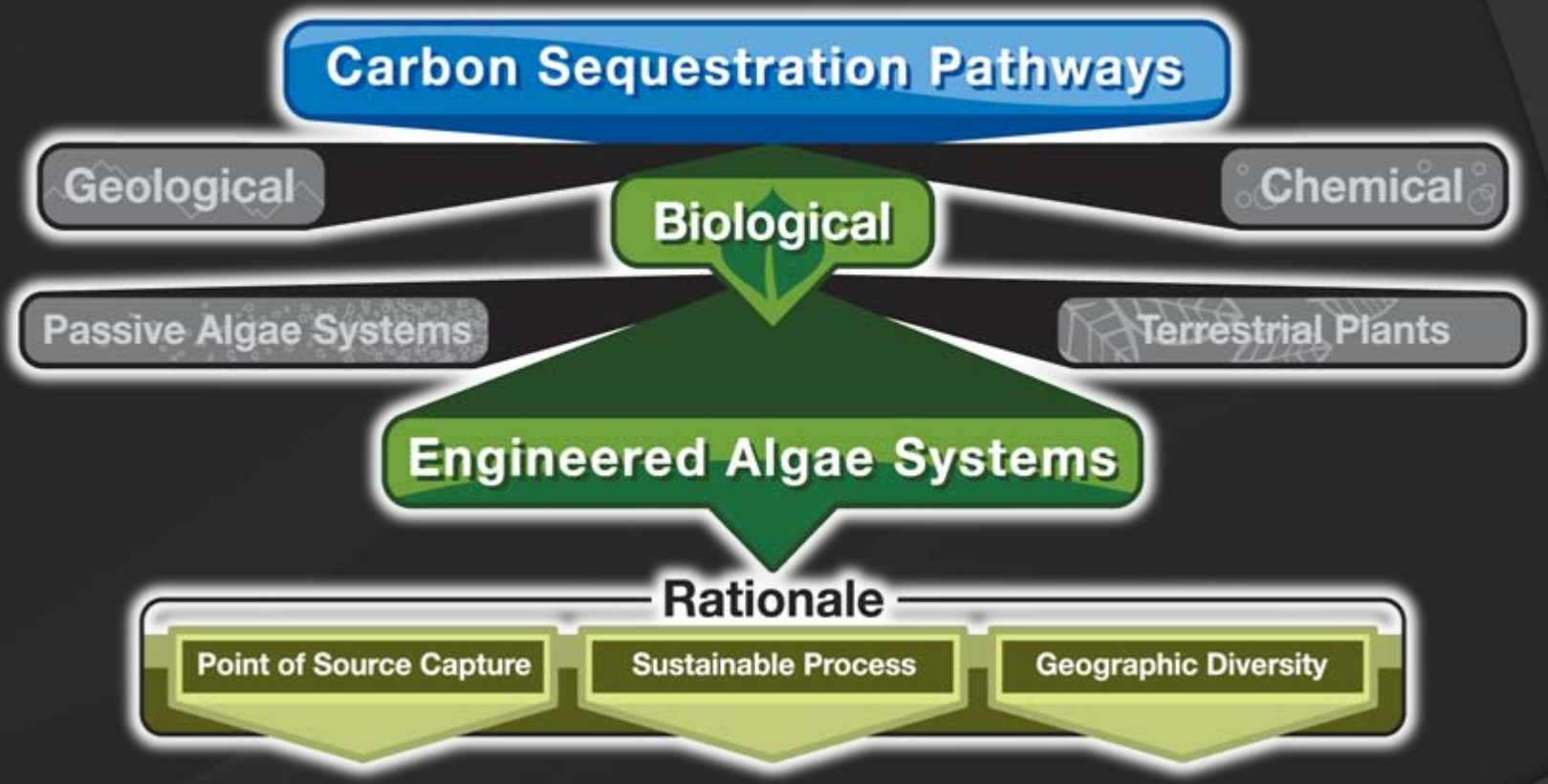
Tech. Roadmap Scope and Boundaries



Value-added co-products

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Outline of Goals, Challenges, and Pathways

Carbon Capture Goals

- 90% Carbon Removal
- No net increase in cost of energy services
- 70% Carbon Recycle

Technical Challenges

- Land/water usage
- Carbon transport/delivery
- Algal growth efficiency
- Co-product generation
- Systems Integration
- System Stability
- Permitting, siting and metering
- Policy and acceptance

R & D Pathways

Process design & optimization	Systems Integration	Synthetic Biology	Co-product generation
Sunlight utilization	Carbon Transport and Delivery	Carbon utilization	Downstream processing
Reactor design & optimization	Heat/Water integration	Product synthesis	Separation of multiple products

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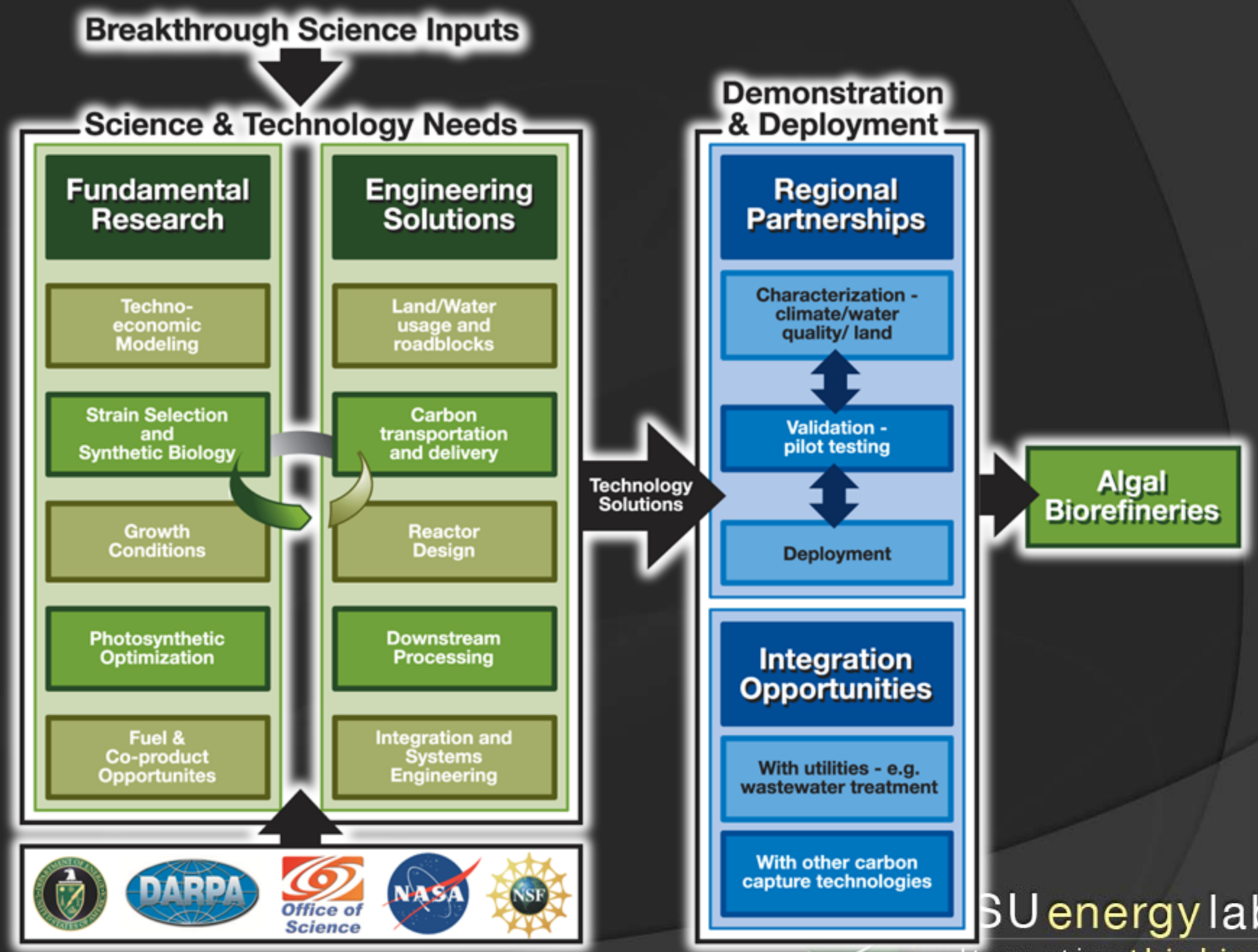
Breakthrough Science Inputs
Science & Technology Needs
Fundamental Research
Techno-economic Modeling
Strain Selection and Synthetic Biology
Growth Conditions
Photosynthetic Optimization
Fuel & Co-product Opportunites
Engineering Solutions
Land/Water usage and roadblocks
Carbon transportation and delivery
Reactor Design
Downstream Processing
Integration and Systems Engineering
DARPA
Office of Science
NASA
NSF
Technology Solutions
Demonstration & Deployment
Regional Partnerships
Characterization - climate/water quality/ land
Validation - pilot testing
Deployment
Integration Opportunities
With utilities - e.g. wastewater treatment
With other carbon capture technologies
Algal Biorefineries
SU energy lab
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Request for Participation

Requirements

- Sign-up and actively participate in weekly teleconferences beginning soon
- Help refine goals, system requirements, challenges, pathways, metrics, timeline, resource needs, etc.
- Draft paragraphs / sections as needed
- Attend follow-up mtg. at Algae Biomass Summit (optional)
- Attend workshop in SLC to finalize roadmap (preferred)

Benefits

- accelerate pathways to commercialization
- guide future carbon recycling R&D program
- visibility / Involvement
- Engage / Network / Collaborate

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Thank you.

Visit us at: http://energylab.usu.edu

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