SAND2019-14312C

Attached Algae Cultivation for Coupling Sustainable Biomass Production and Environment Remediation

PRESENTED BY

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U. S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy

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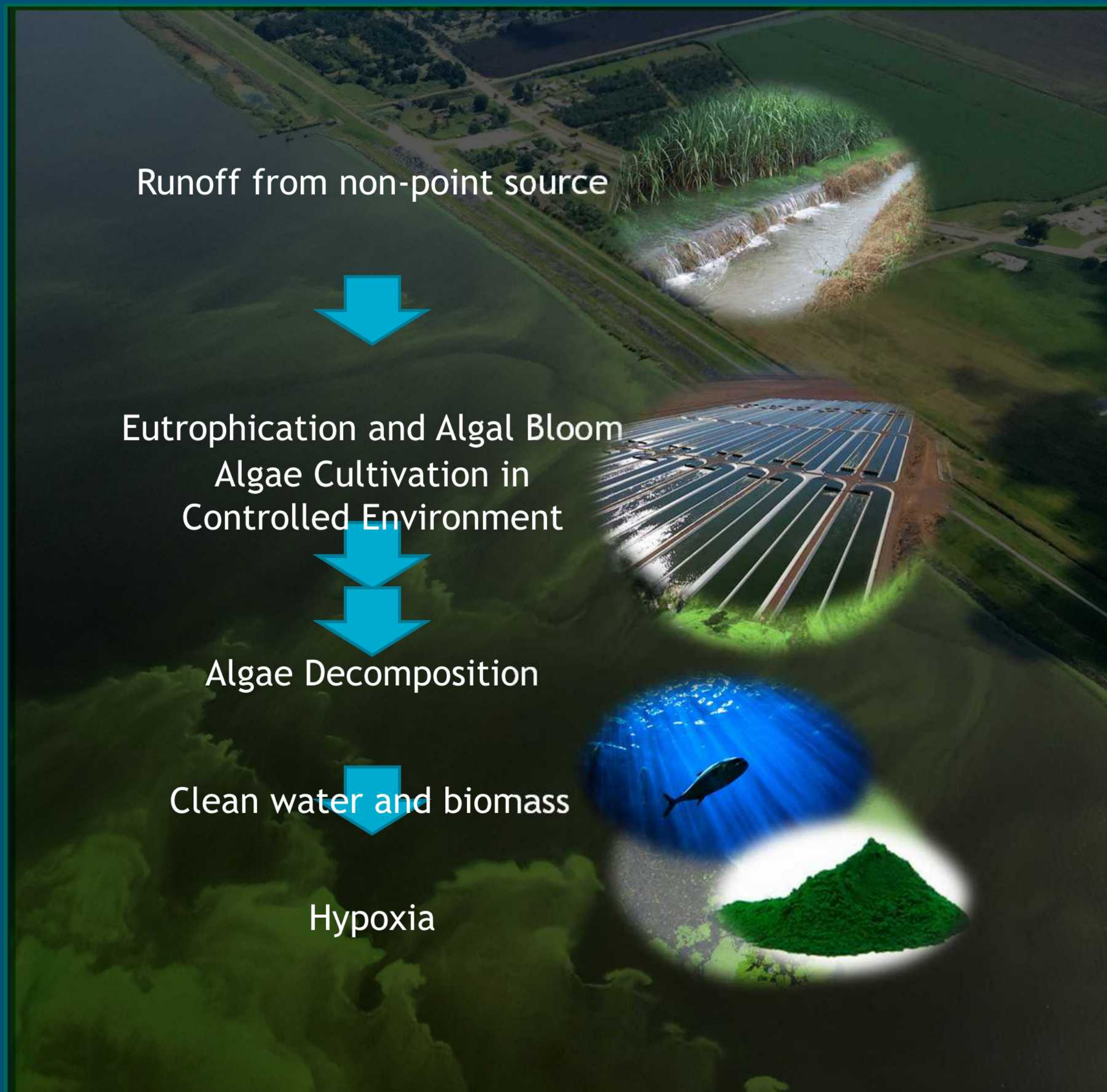
Harmful Algal Bloom (HABs) in the US



An aerial view of Lake Okeechobee in Florida shows an algal bloom. A third of all lakes studied by the USGS contained toxins produced by similar blooms.

Photograph credit: Nicholas Aumen, USGS.

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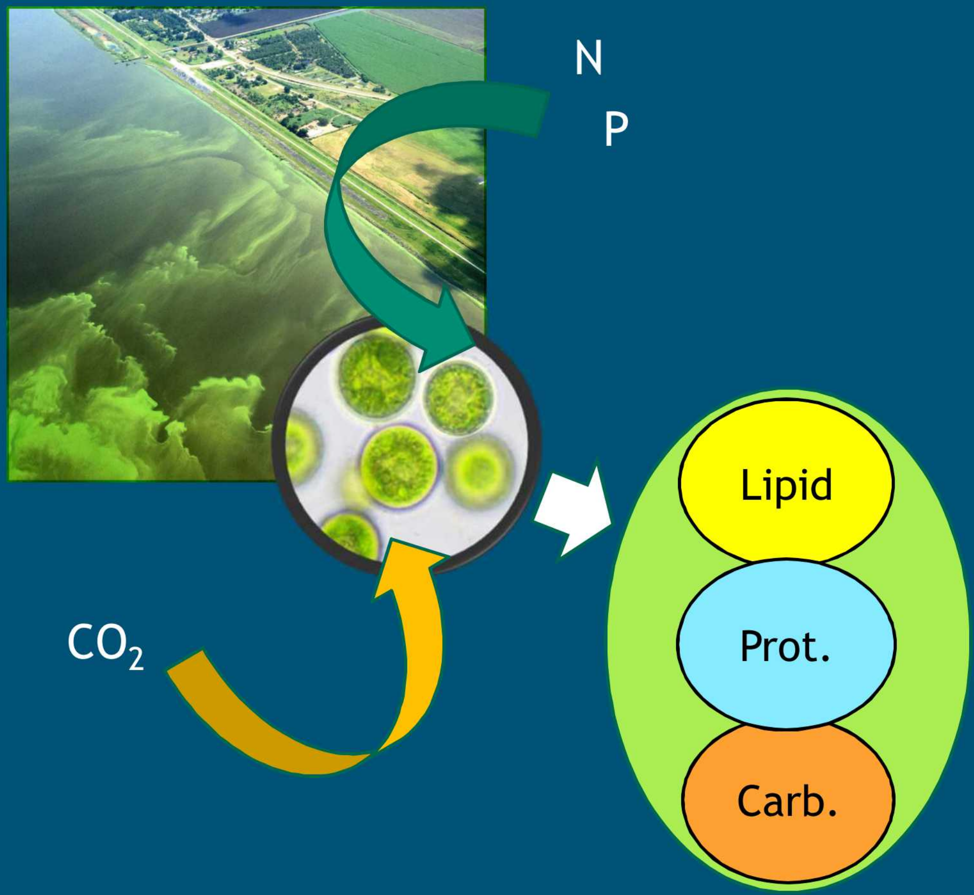


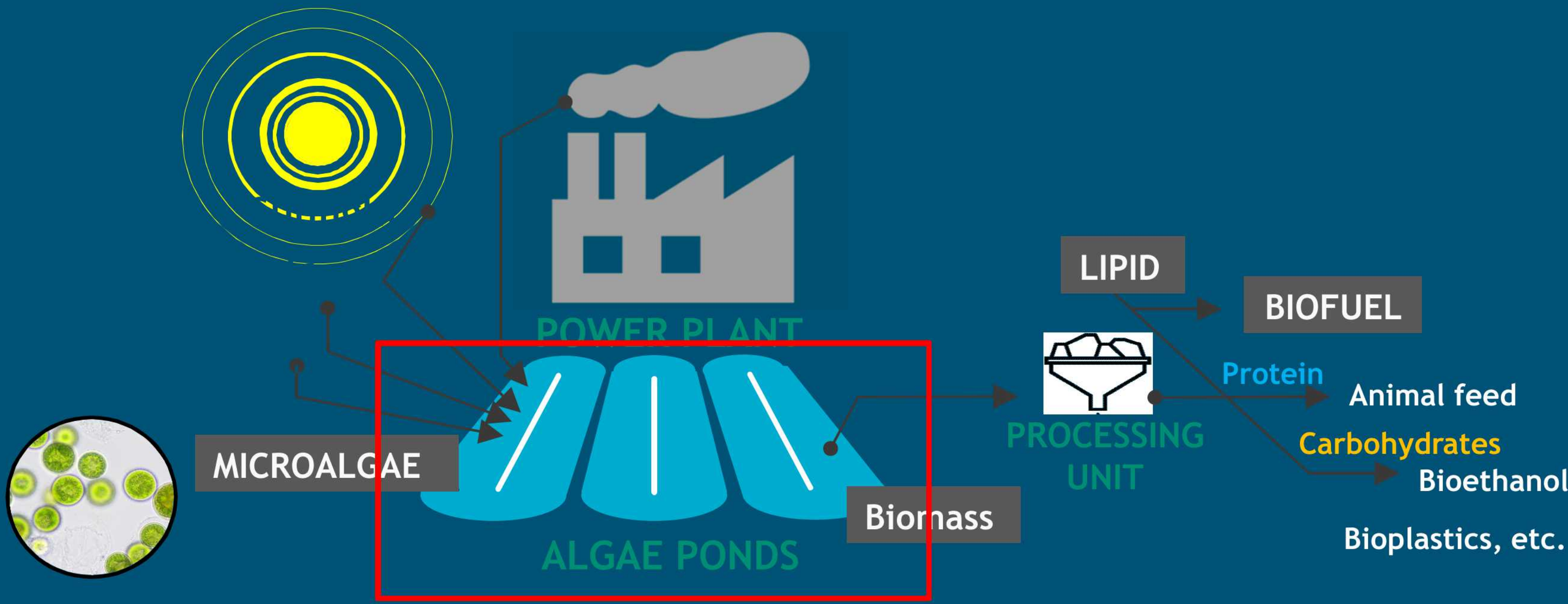
Fuel

Chemicals

Plastics

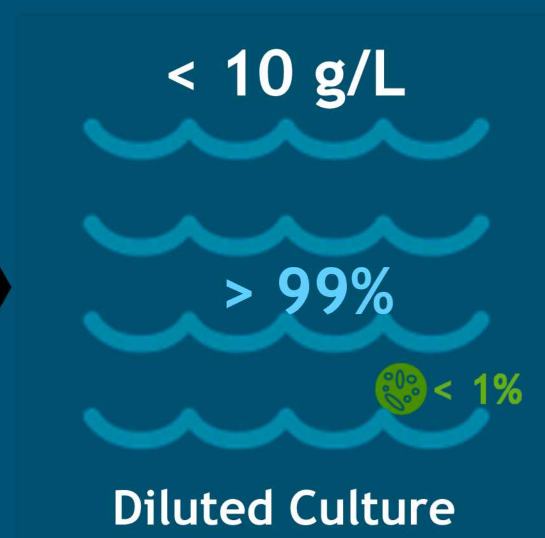
Food/Feed/Supplements

Typical Cultivation Process and Its Drawbacks



Photobioreactors (PBRs)

Open Raceway Ponds (ORPs)



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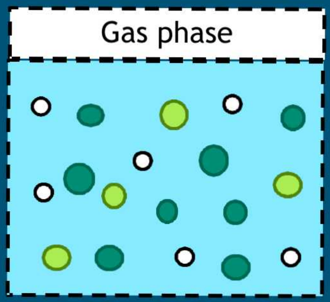
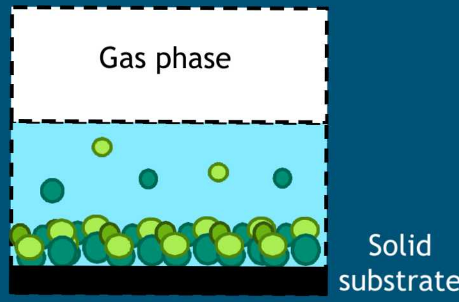
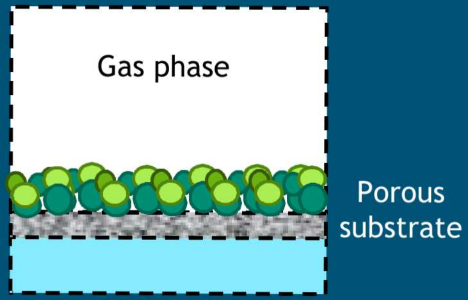
Suspended cultivation



Attached cultivation



Submerged



Porous substrate-based

Attached Periphytic Algal Flow-way

Porous Substrate-Based Attached Algae Cultivation

Strength and Weakness of Each System

	Both	Submerged	Porous substrate-based
Strength	• Resilient and resistant to crashes • Harvest & dewatering cheap and simple	• Scalable at lower cost • Higher water treatment rate and capacity • Higher resistance to weather condition	• Higher footprint biomass productivity **(~30 AFDW g/m^2/day)** • Single strain cultivation is possible • Minimum water usage and working volume • Densest culture achievable
Weakness	• Energy for water pumping • High ash content (can be strength in terms of ash removal from source water)	• Lower footprint biomass productivity **(3-20+ AFDW g/m^2/day)** • Hard to grow specific algal strain -> best for natural periphyton polyculture • Low lipid content	• Not safe from harsh weather condition -> must be semi closed system (greenhouse) • Scalable at higher cost
Suggestion		**Coupling with water remediation**	**High-value product production**

Attached Periphytic Algal Flow-way

Deployment 3:

Savannah, GA

GEORGIA SOUTHERN UNIVERSITY

Deployment 2:

Brawley, CA

Salton Sea, Imperial Valley Irrigation District

IMPERIAL VALLEY CONSERVATION RESEARCH CENTER

IID A century of service.

TEXAS A&M AGRILIFE RESEARCH

Deployment 1:

Corpus Christi, TX, Texas A&M AgriLife

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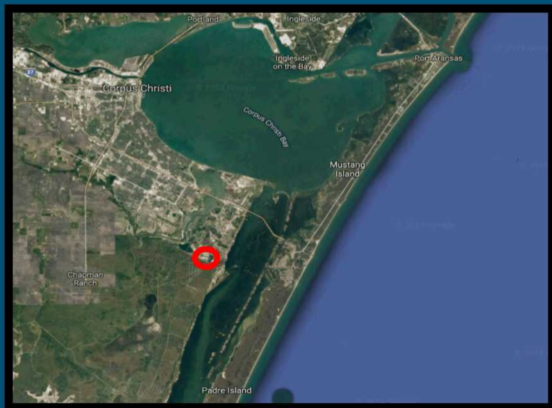

- Marine-estuarine source water
- Power plant site with fresh water reservoir and marine water intake canal
- Pumping station for cooling water & AgriLife research station use
- Side-by-side raceway & floway operation for comparative assessment

Pioneer algal turf (benthic diatoms) → **Established algal turf (*Cheatomorpha*)** → **Weekly harvest (low cost)** → **Biomass!**

- Stably operating since May, 2016
- Initially populated by modest productivity pioneer turf
- Rapid population shift to stable, high productivity by filamentous green alga following pioneer phase

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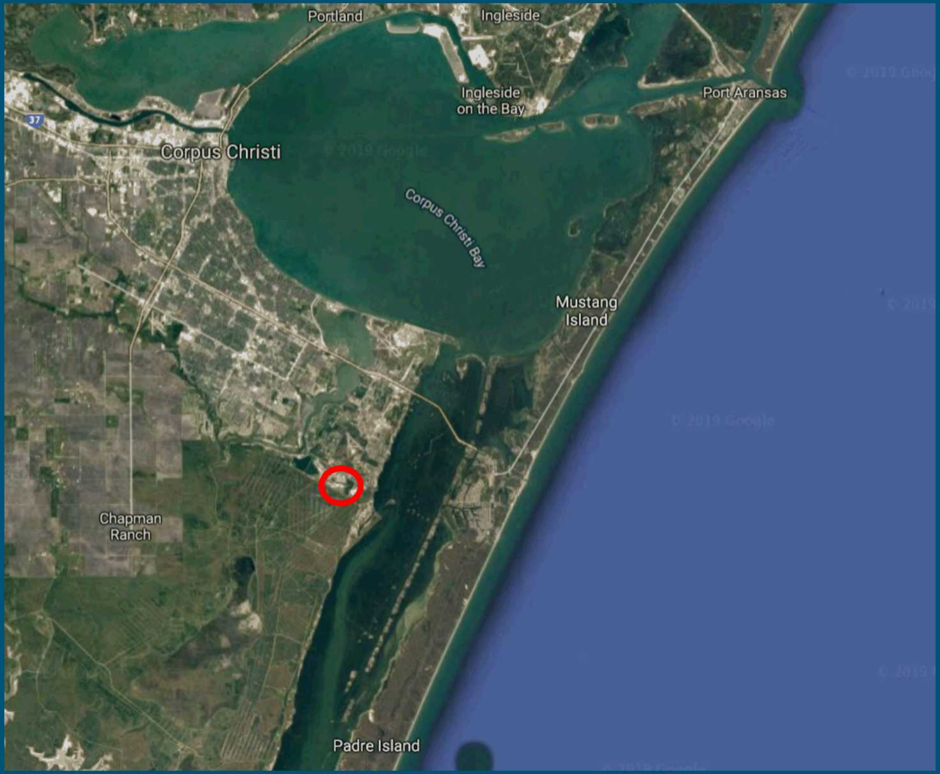

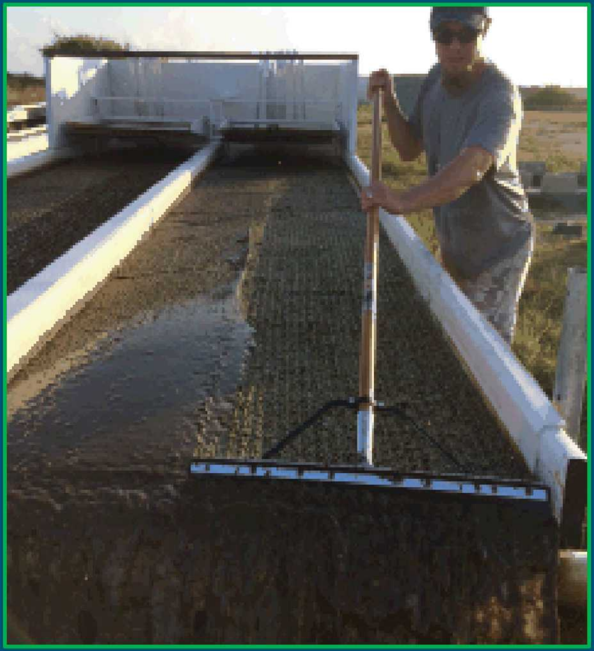

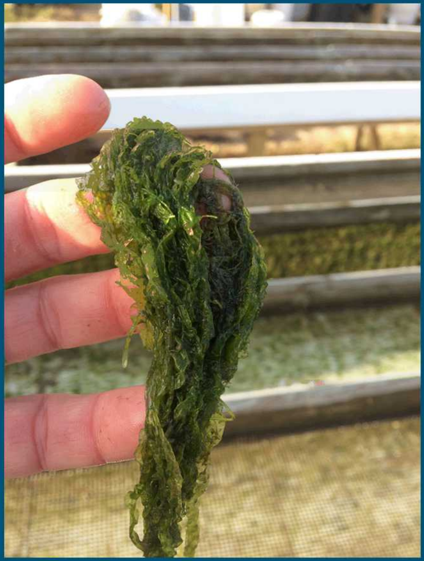

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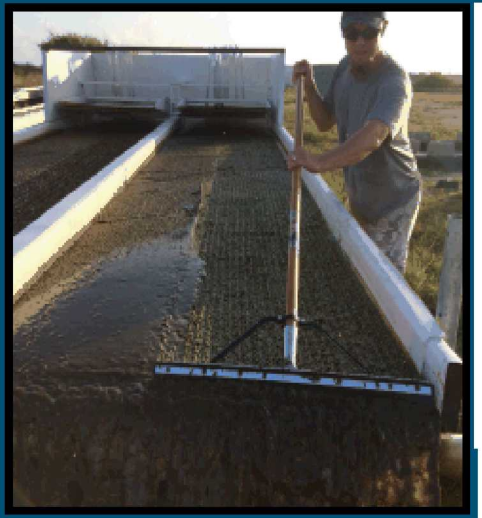
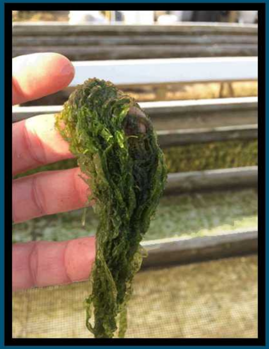
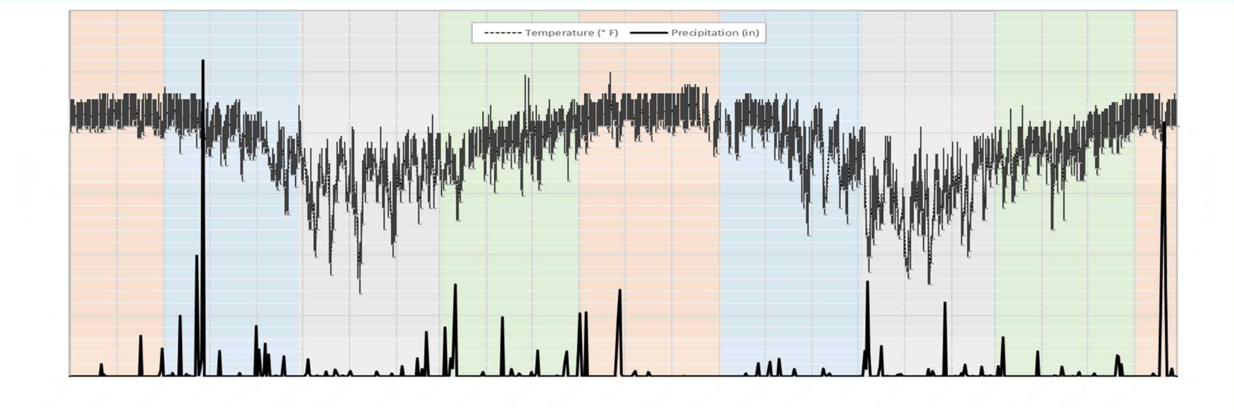
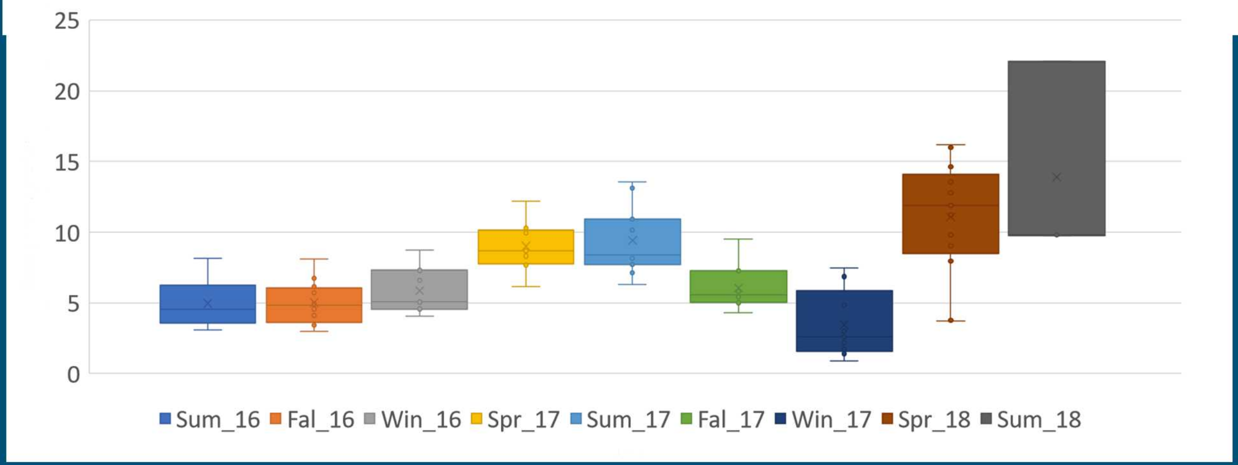




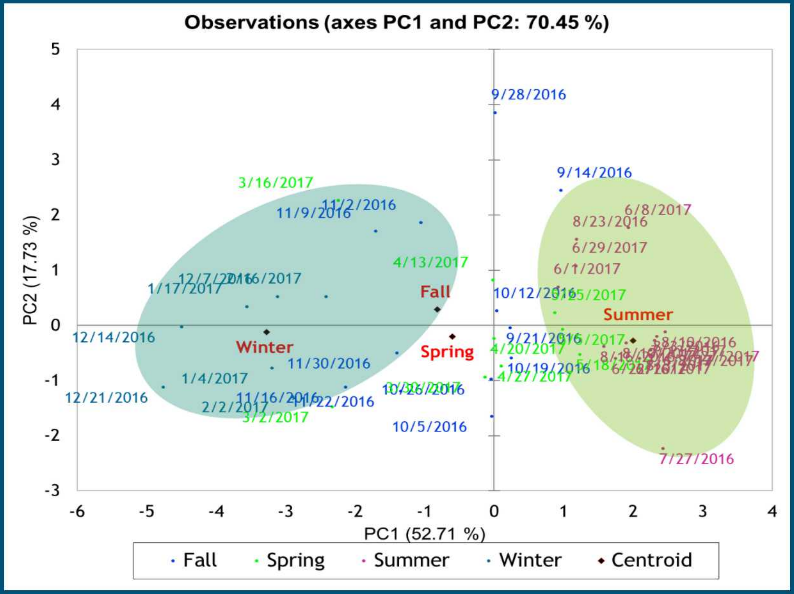


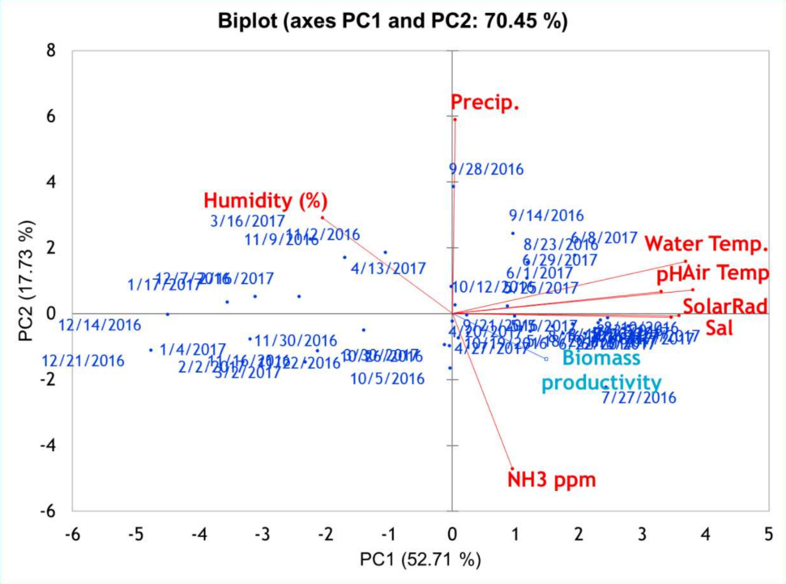
Temperature (° F)
Precipitation (in)



25
20
15
10
5
0
Sum_16 Fal_16 Win_16 Spr_17 Sum_17 Fal_17 Win_17 Spr_18 Sum_18

a





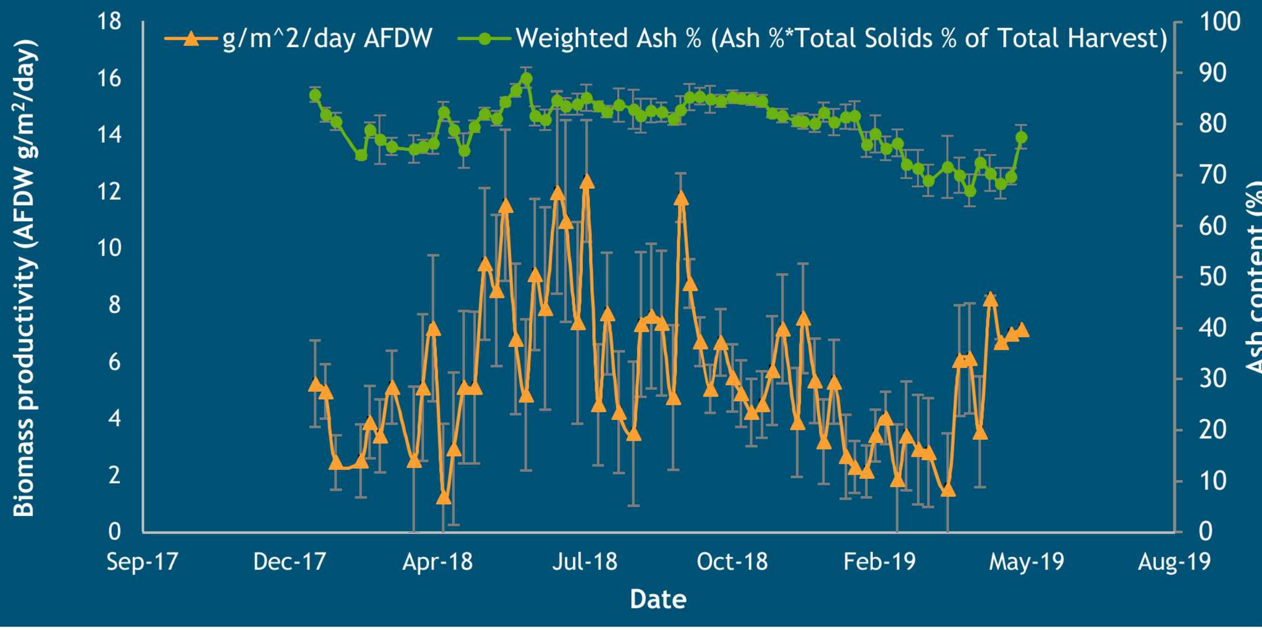
	PC1	PC2
Eigenvalue	4.252	1.439
Variability (%)	53.144	17.983
Cumulative %	53.144	71.128

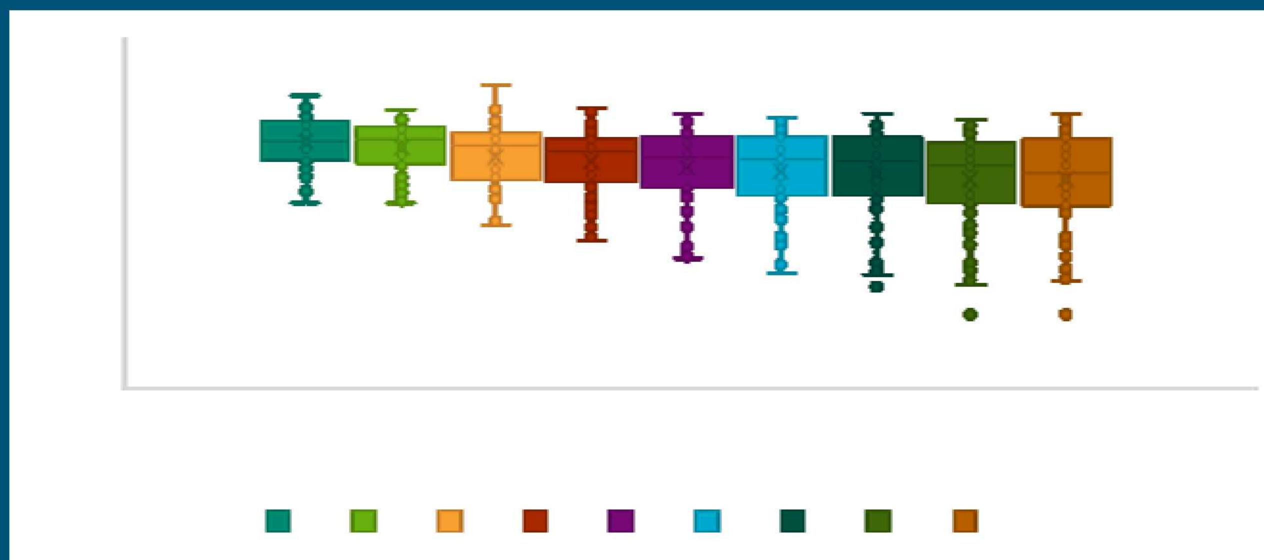
	PC1	PC2
Air Temp	**20.961**	0.507
SolarRad	**18.526**	0.011
Precip.	0.014	**49.737**
Water Temp.	**19.772**	3.111
Sal	**16.941**	0.024
pH	**15.940**	2.153
NH3 ppm	1.854	**30.320**
Humidity (%)	5.992	**14.137**

- Group of points that have high biomass productivity are located where shows positive correlation with water temperature, air temperature, pH, solar radiation, and salinity. This group consist mostly samples from summer season and some from spring and fall. Non of samples from winter is included in this group, instead they show the opposite correlation.

- Fresh/agricultural runoff source water
- Waters heavily laden with N/P + metals
- Austere site: no power or facilities

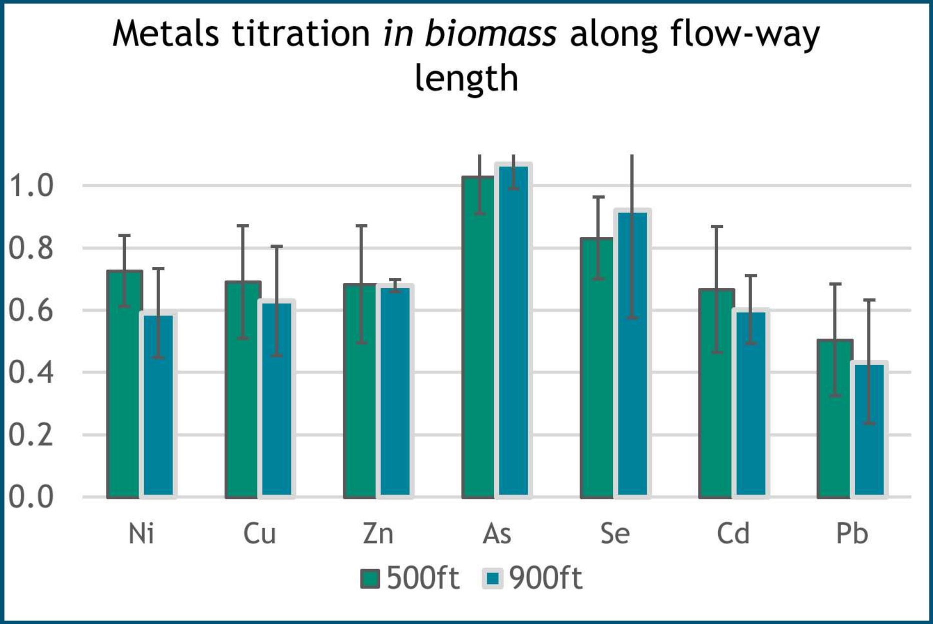
- ~900ft long flow-way deployed with around 20 gpm water loading rate near Brawley, CA on Alamo River tributary to Salton Sea
- State of California interested in bioremediation potential of ATS to prevent heavy metals (esp. Se)accumulation in wetlands fauna
- Austere site: no physical security or facilities, pumping provided by renewable power pumping station
- Source water: 95% agriculture runoff

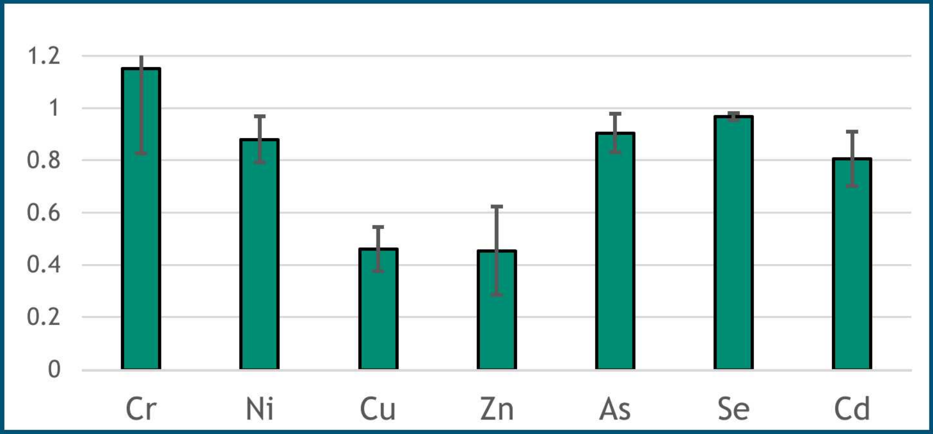

g/m^2/day AFDW
Weighted Ash % (Ash %*Total Solids % of Total Harvest)
Biomass productivity (AFDW g/m²/day)
Ash content (%)
18
16
14
12
10
8
6
4
2
0
100
90
80
70
60
50
40
30
20
10
0
Sep-17
Dec-17
Apr-18
Jul-18
Oct-18
Feb-19
May-19
Aug-19
Date



Remediation of nutrient + metals contaminants

- Algae turf systems previously show to be effective for **<u>dilute N/P</u>** remediation, including recalcitrant N (e.g. alkyl amines)
- For Salton Sea (& western arid lands in general), there is significant interest in trace metals and metalloids remediation: **<u>As, Se, Hg, Pb</u>**
- Conducted 9-month study with ICP-MS analysis of metals in inlet/outlet waters, sediment, and biomass with comparison to non-compromised local riverine site: Santa Ana River, Riverside CA

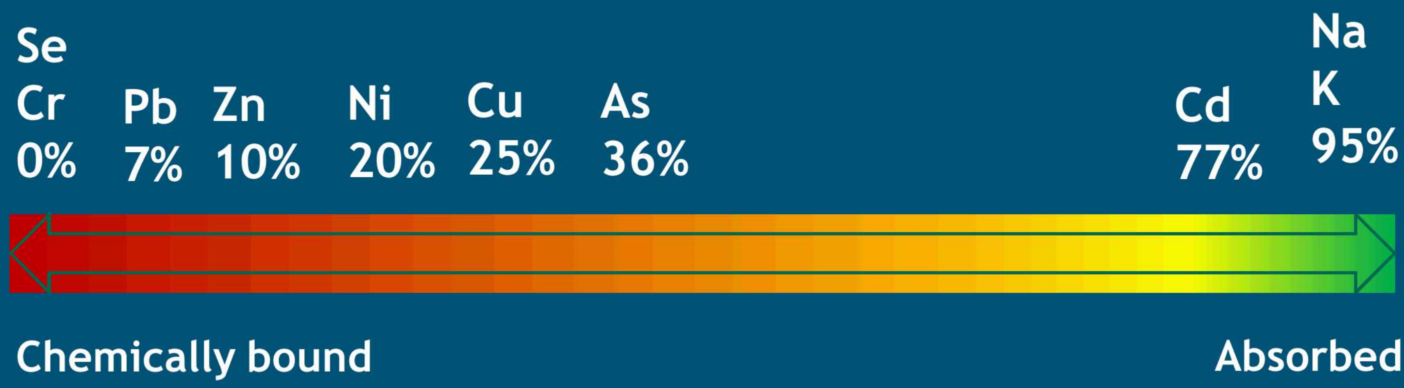




Inlet vs outlet metals concentrations

*Courtesy of Louis Hennequin, Imperial College London

Biomass utilization options with toxic metals contaminants?



- Chemical titration of biomass using EDTA to evaluate whether metals were chemically or physically bound, i.e. can we 'clean' the biomass?
- Preliminary data on bio- and thermochemical conversion for fuels applications, utilization as a blendstock in thermopolymers (e.g. BLOOMFoam™), aquaculture feeds, and biostimulants, but **RCRA may limit these**
- 'Off-the-shelf' means for coupling metals concentration & disposal possible via **anaerobic digestion (AD)**, if scales can be matched. Bench-scale yields up to 46% C, 1 week retention time.

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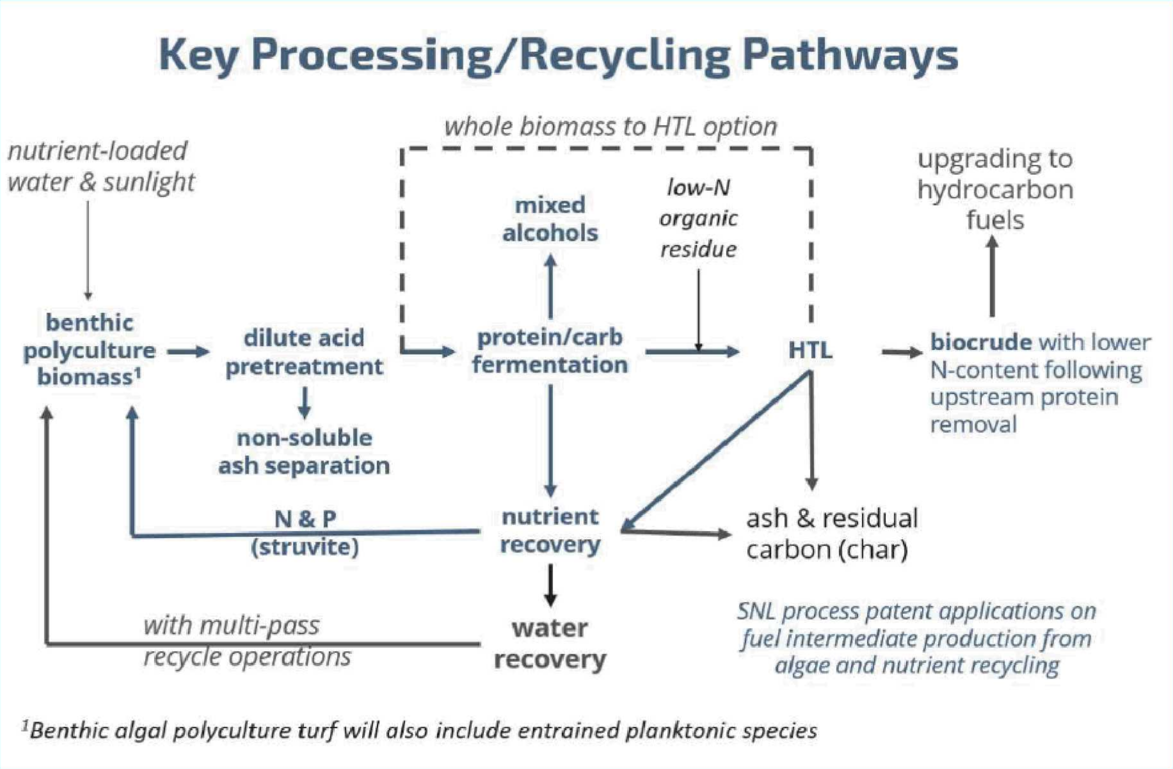

Sandia researchers are investigating key processing and recycling pathways to increase the conversion of all biomass components while containing and recycling nutrients and water. The resulting biocrude is lower in nitrogen making it easier to upgrade to biofuels. Project currently funded by DOE/EERE BioEnergy Technology Office

Current research is focused on developing and accessing processes to convert the whole turf biomass (proteins, carbohydrates, total lipids) into fuel intermediates using biochemical (hydrolysis and fermentation) and thermochemical (hydrothermal liquefaction – HTL) operations. By leveraging both techniques the entire algae turf can be converted to biomass while removing and recycling nitrogen, phosphorous and water. Further technology research will address ash content by enhancing the cultivation and harvesting system design and operations.

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CHALLENGES

Sandia researchers focus on on these challenges:

- Maximizing value from entire biomass (proteins, carbohydrates, and lipids)
- Reducing the ash content of the produced, harvested biomass
- Increasing the overall biomass productivity for higher yields

NUTRIENT RECYCLING

The nutrient recycling process developed at Sandia enables:

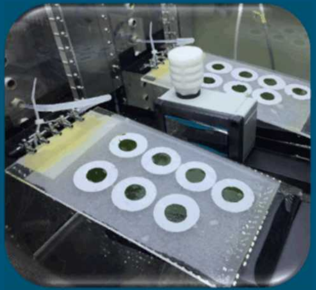
- Recycling of nitrogen and phosphate which keeps phosphate out of the environment.
- Lower nitrogen biocrude for upgrading to biofuels.

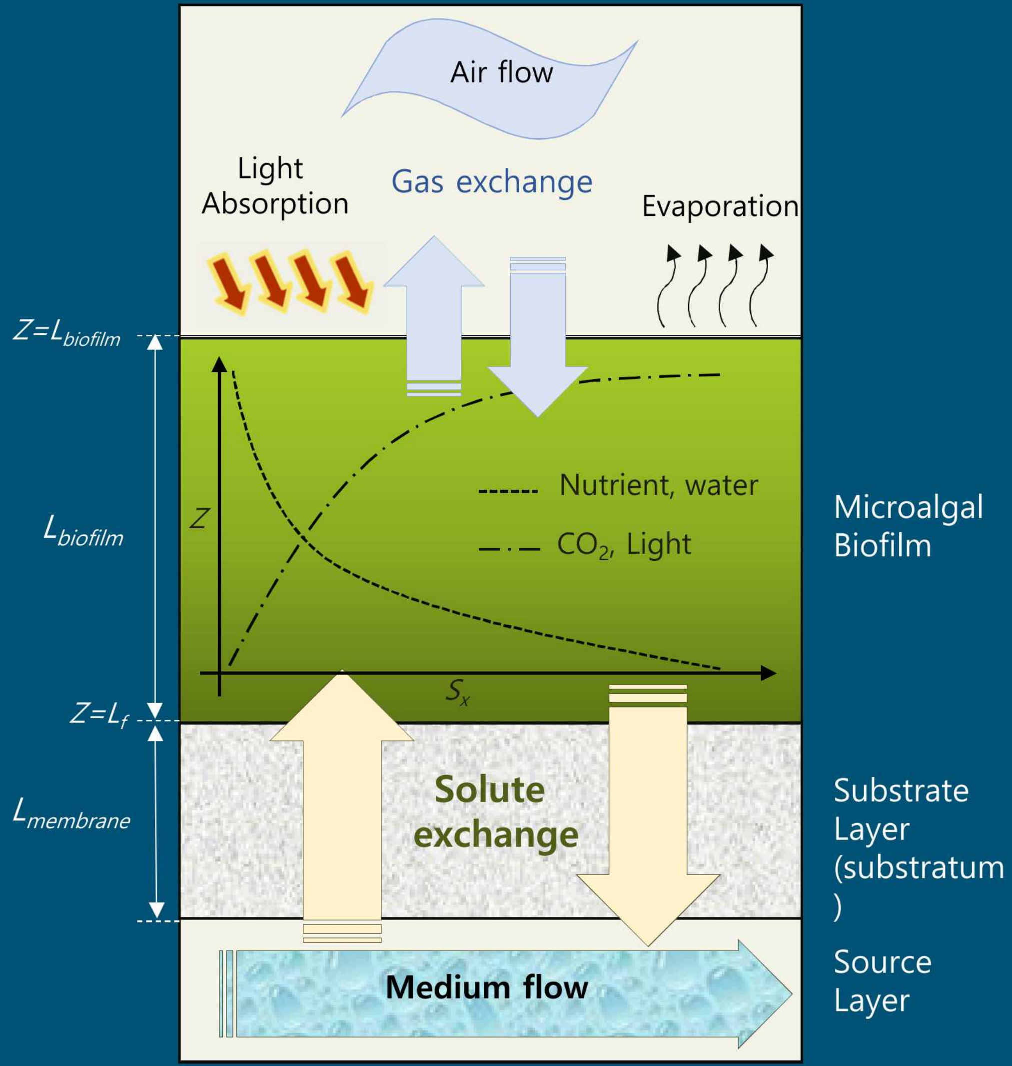
PROTEIN FERMENTATION

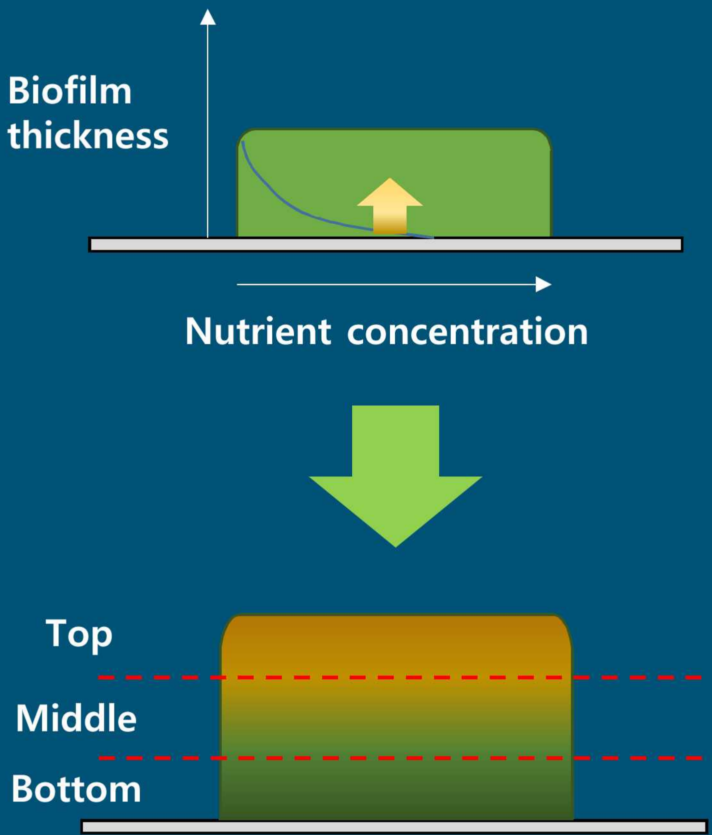
Fermenting proteins and carbohydrates from algae enables the creation of high-value chemicals including:

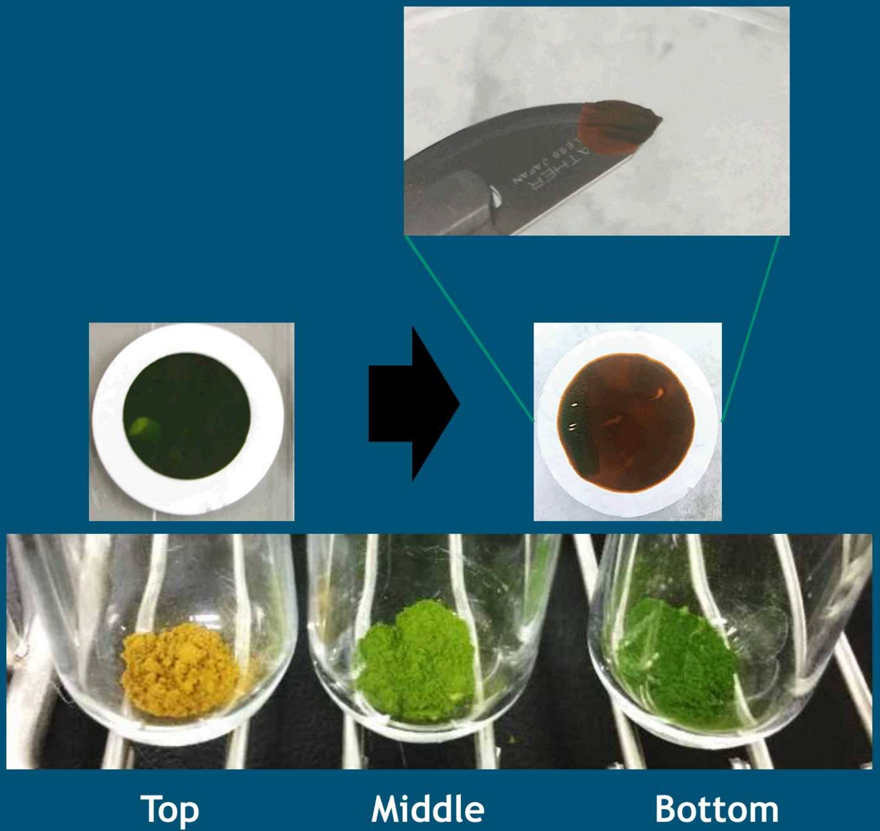
- Industrial solvents
- Polymers
- Fragrances and flavoring agents
- Biocides and insect repellants
- Pharmaceutical lead compounds
- Fertilizers

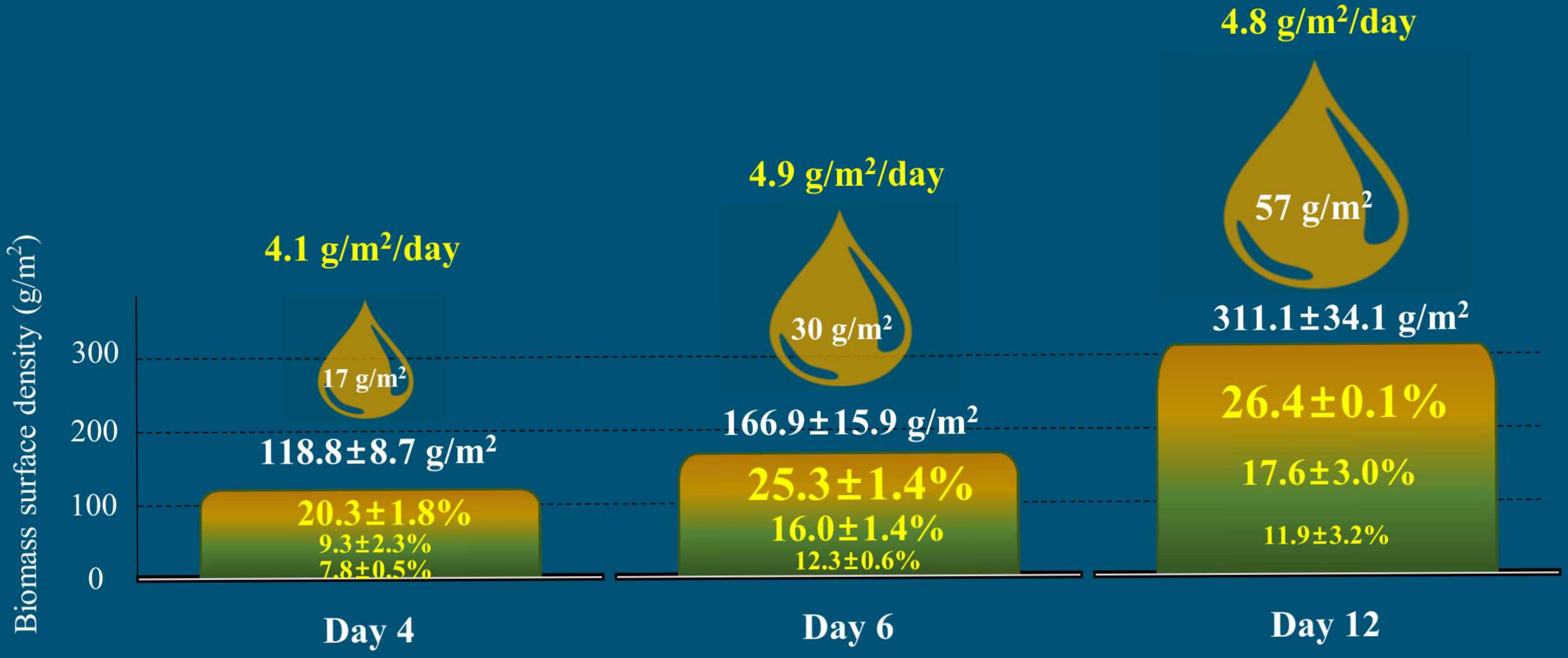

LED Light
Source Layer
Medium & Gas Out
Gas In
Medium In
Biofilm on a Porous Membrane



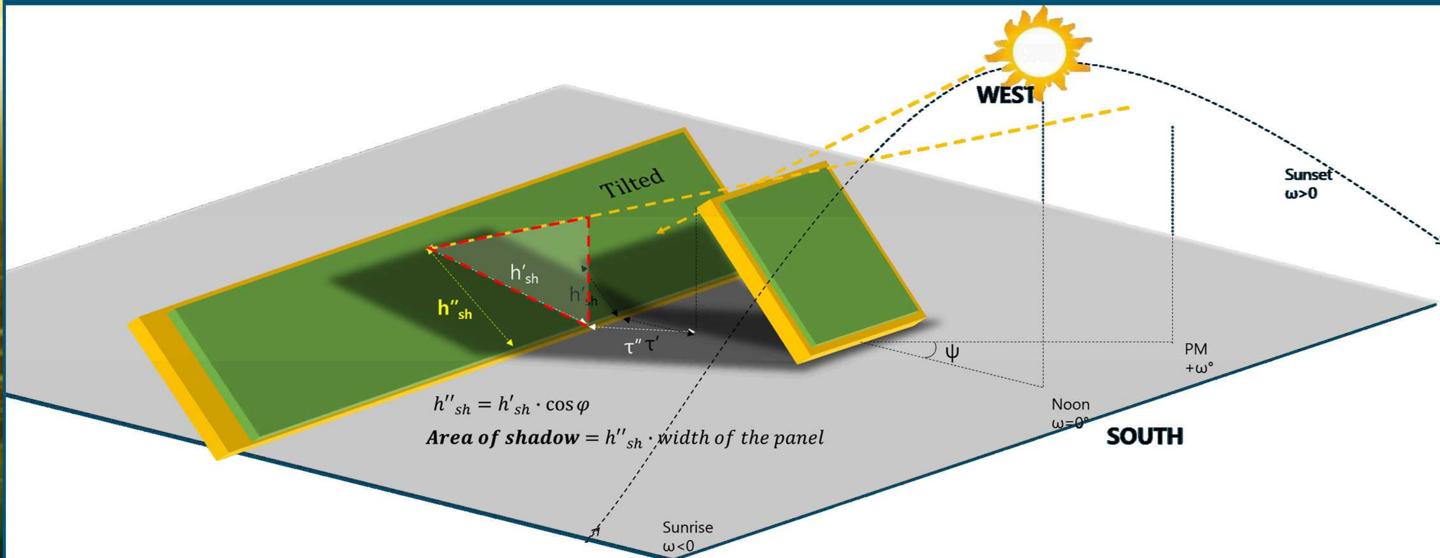

Air flow
Light Absorption
Gas exchange
Evaporation
Z=L_biofilm
L_biofilm
Z=L_f
L_membrane
Z
S_x
Nutrient, water
CO2, Light
Solute exchange
Medium flow
Microalgal Biofilm
Substrate Layer (substratum)
Source Layer

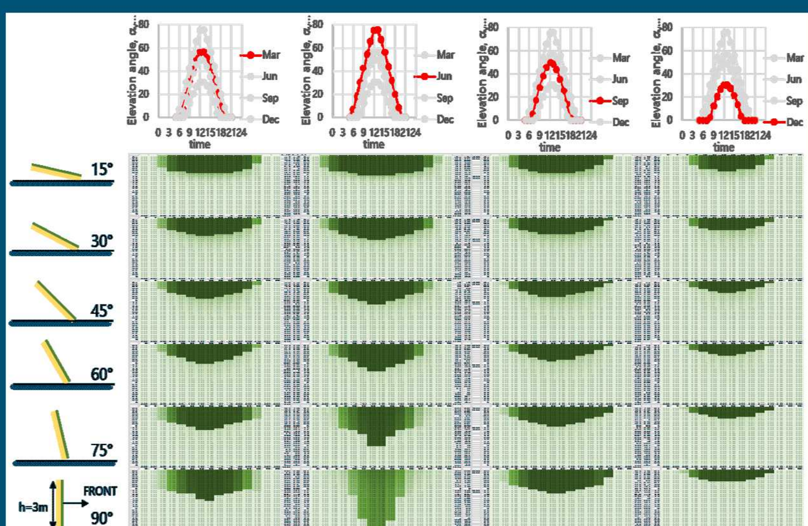

Biofilm thickness
Nutrient concentration
Top
Middle
Bottom


Top
Middle
Bottom



Biomass surface density (g/m2)
300
200
100
0
4.1 g/m2/day
17 g/m2
118.8±8.7 g/m2
20.3±1.8%
9.3±2.3%
7.8±0.5%
Day 4
4.9 g/m2/day
30 g/m2
166.9±15.9 g/m2
25.3±1.4%
16.0±1.4%
12.3±0.6%
Day 6
4.8 g/m2/day
57 g/m2
311.1±34.1 g/m2
26.4±0.1%
17.6±3.0%
11.9±3.2%
Day 12





H=0.9m	Spring	Summer	Fall	Winter	Yearly avg.
β (˚), τ(m)	90, 0.4	75, 0.4	90, 0.4	90, 0.4	
Avg PFD (umol/m2/s)	123.4	115	137	77.5	
FBP ($g/m^2/day$)	**13.9**	**13.6**	**12.7**	**6.5**	**11.7**
SBP ($g/m^2/day$)	6.2	6.0	8.5	4.0	**6.2**

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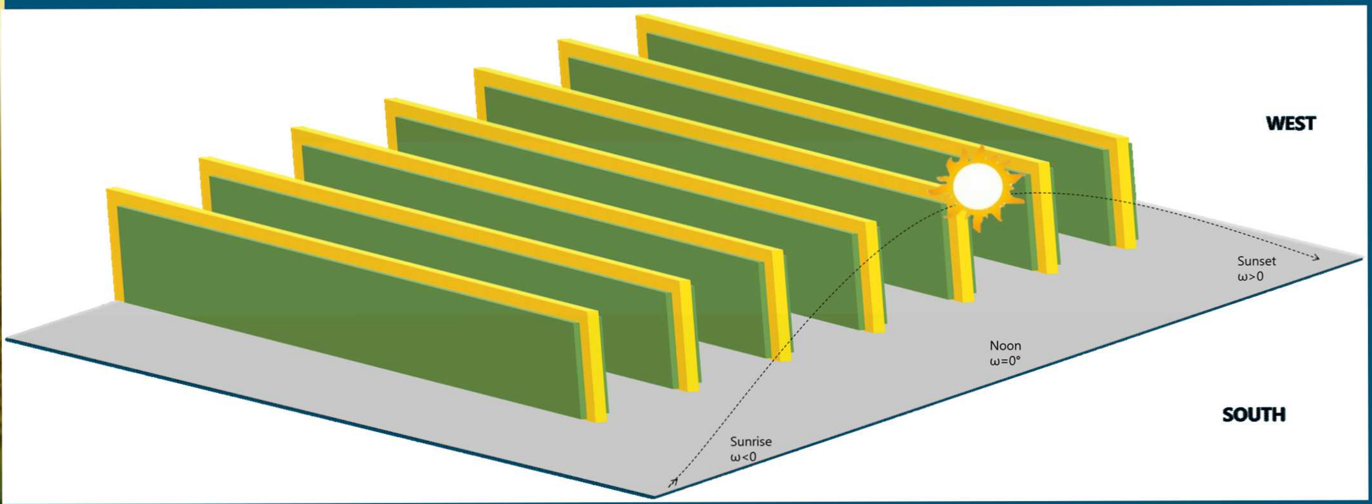
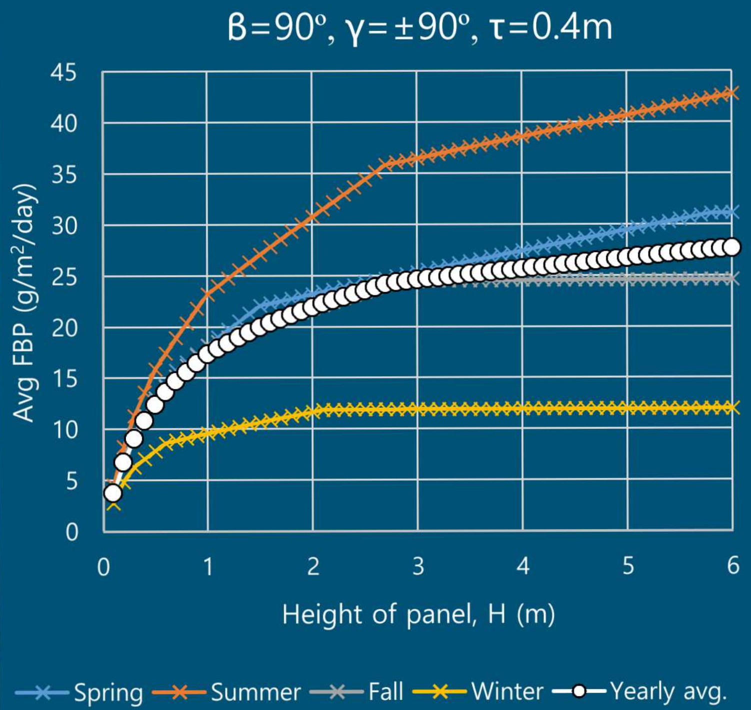
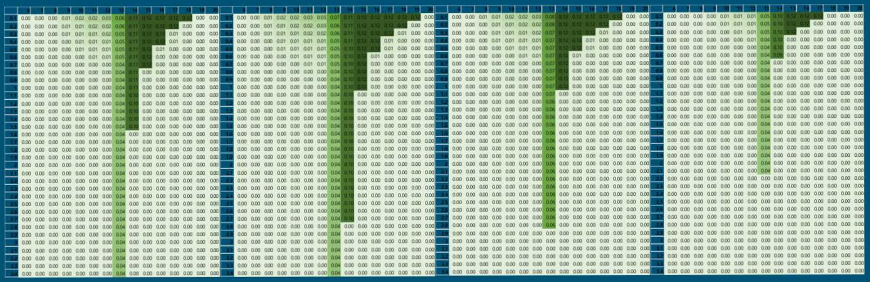




In order to meet FBP: <u>25 g/m²/day</u>



H=3.4m	Spring	Summer	Fall	Winter	Yearly avg.
Avg PFD (umol/m2/s)	63	87	75	25	
FBP ($g/m^2/day$)	**26**	**37**	**25**	**12**	**<u>25</u>**
SBP ($g/m^2/day$)	3.1	4.4	2.9	1.4	**3.0**

Summary

Supplementary

Co-Optima Project

The Co-Optima Initiative
Better Fuels | Better Engines | Sooner

9 National Laboratories
13 University Partners

Project Goal: 30% per vehicle petroleum reduction through efficiency gain and displacement

Adopting a more fuel-centric approach to biofuel production

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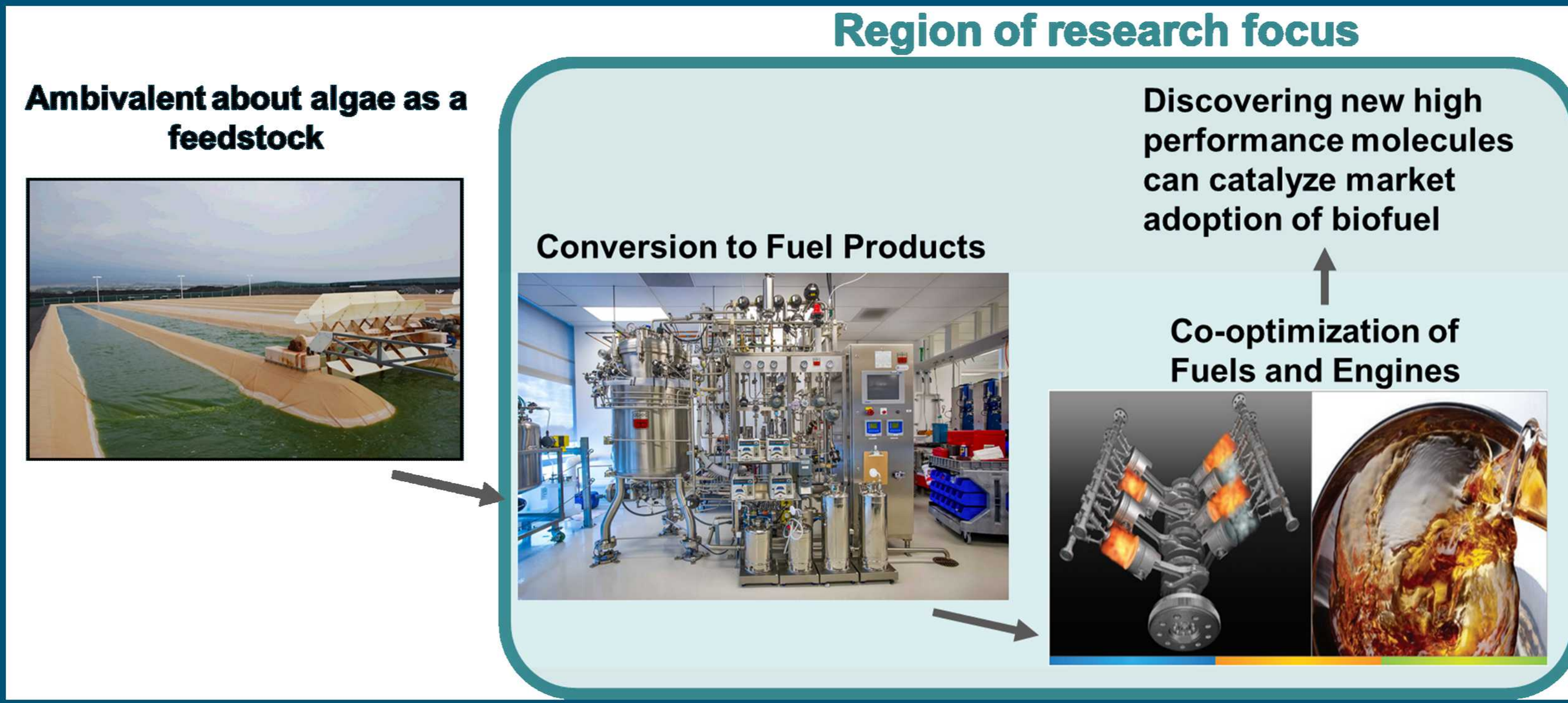
Supplementary



The Co-Optima Initiative: rethinking the approach to biofuel production

Biomass Production

What is the best biomass to use?

Conversion

Can we make it from biomass?

High performance fuel products can strengthen the value proposition of biofuels

Co-optimization of Fuels and Engines

What is the best biofuel molecule?

3

Supplementary

Central Engine Hypothesis

There are engine architectures and strategies that provide higher thermodynamic efficiencies than are available from modern internal combustion engines; new fuels are required to maximize efficiency and operability across a wide speed / load range

Central Fuel Hypothesis

If we identify target values for the critical fuel properties that maximize efficiency and emissions performance for a given engine architecture, then fuels that have properties with those values (regardless of chemical composition) will provide comparable performance

Supplementary

Supplementary

Attached Algae Flow-way

Porous substrate-based attached algae cultivation

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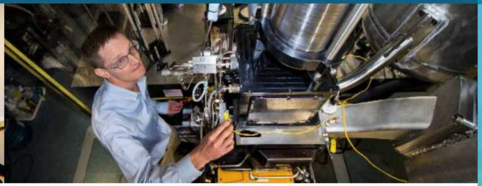
Section Break Slide



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Section Break Slide

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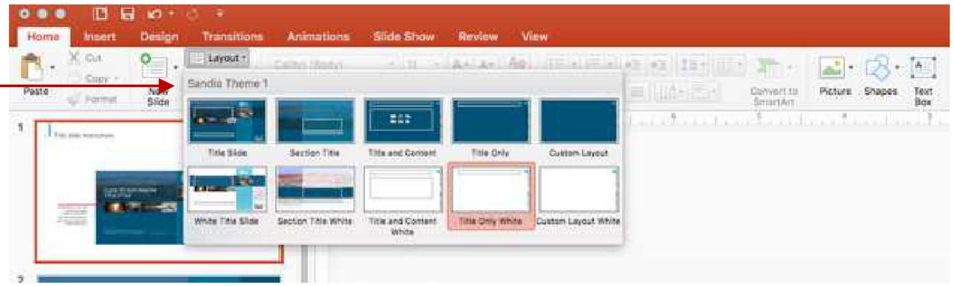

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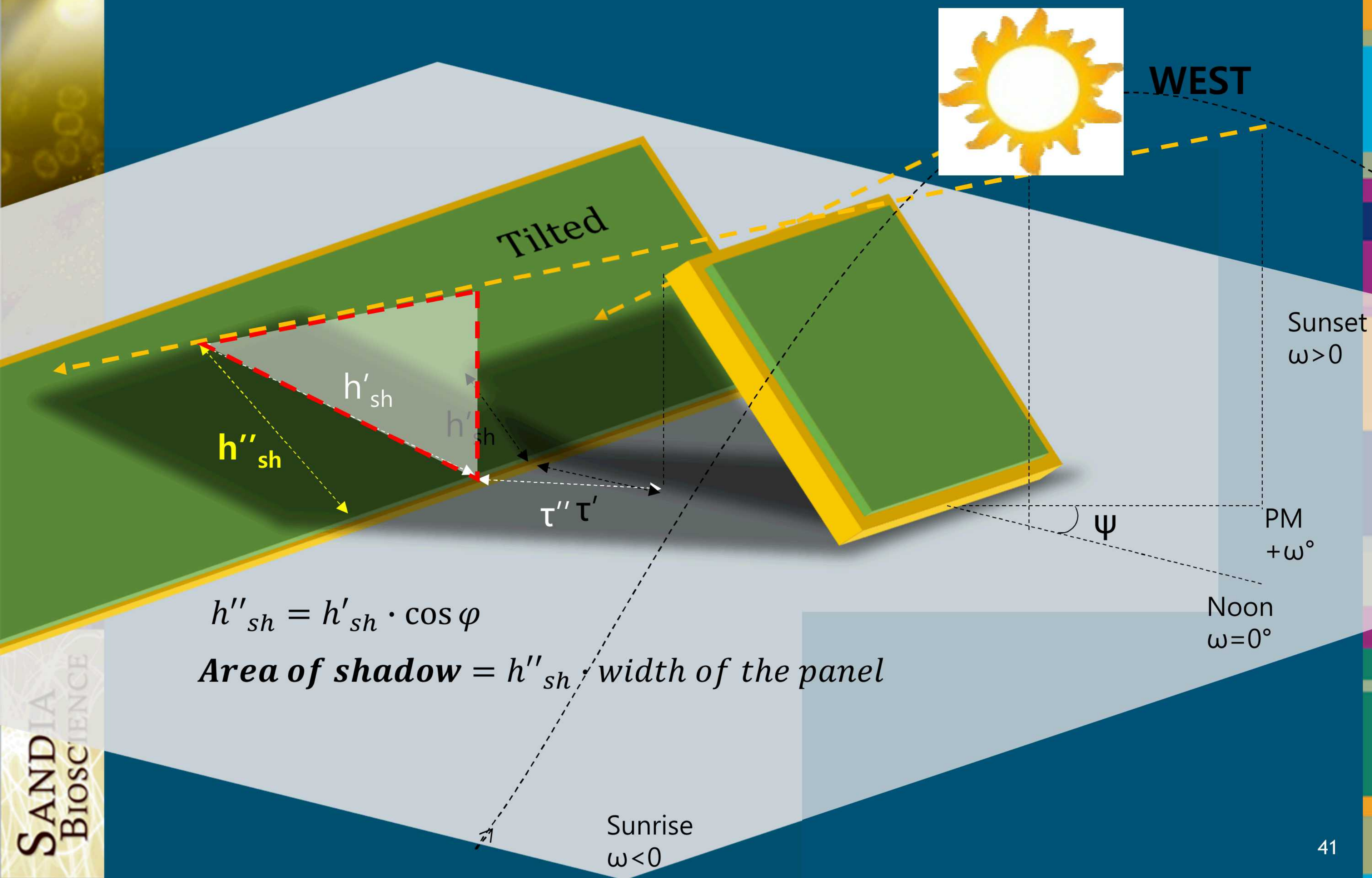
Add Sand Number to the funding statement within the Master Title slide



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$$\boldsymbol{Area\ of\ shadow} = h''_{sh} \cdot width\ of\ the\ panel$$