Sandia National Laboratories

Attached algae cultivation for coupling remediation of runoff with biomass production

Ryan W. Davis

U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

BIOENERGY TECHNOLOGIES OFFICE

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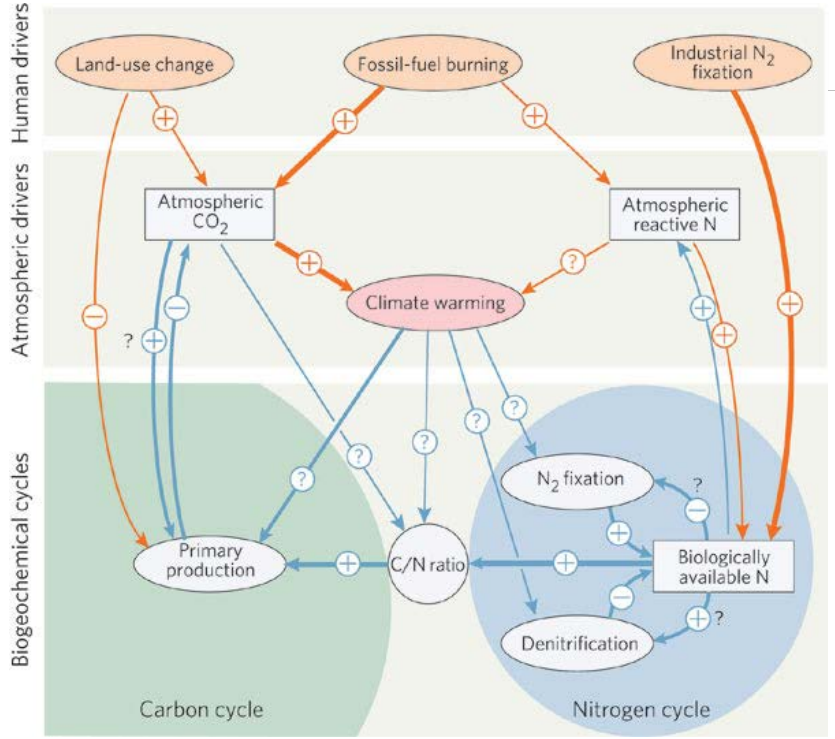
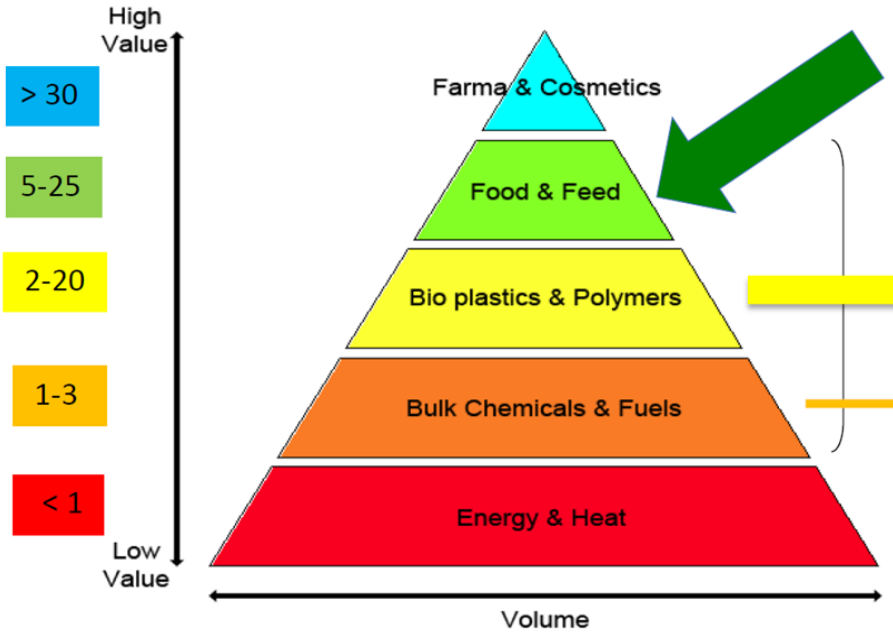
Algae: Global Biogeochemical Cycles & Markets



Gruber & Galloway Nature 2008

Ulva prolifera (Chlorophyta)

$/Kg



Current market

1. Pigments, carotenoids
2. Omega-3 fatty acids
3. Vegan proteins

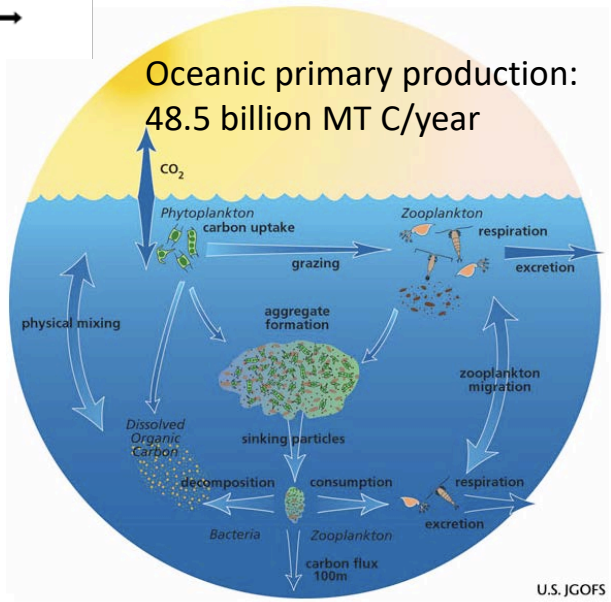
Near term market penetration

Long term R&D focus

Liu & Davis, 2018

Mowry Slough: Newark, CA

Oceanic primary production: 48.5 billion MT C/year



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Resource assessment: availability of waste nutrients in the continental U.S.

- N/P equivalents for algae cultivation:
  - 100 MGGE/year from municipal wastewaters
  - >1 **B**GGE/year from agricultural runoff

    (30% fertilizer runoff, 70% livestock effluent)

- However, once entering river ways, the <u>agricultural runoff N/P concentration is 10-30x more dilute that municipal wastewaters</u>

wastewater for algae growth?

…cultivation strategy will depend heavily on nutrient loading

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Symptoms of a waste nutrient problem

- Algae-induced aquatic Hypoxia: **"Dead Zones"**
  >600 confirmed algal-bloom induced dead zones world-wide, up ~800% since 70's
- **>$4B annual loss in US alone** as a result of harmful algae blooms

Why: Fertilizer Runoff (non-point source ag.)

↓

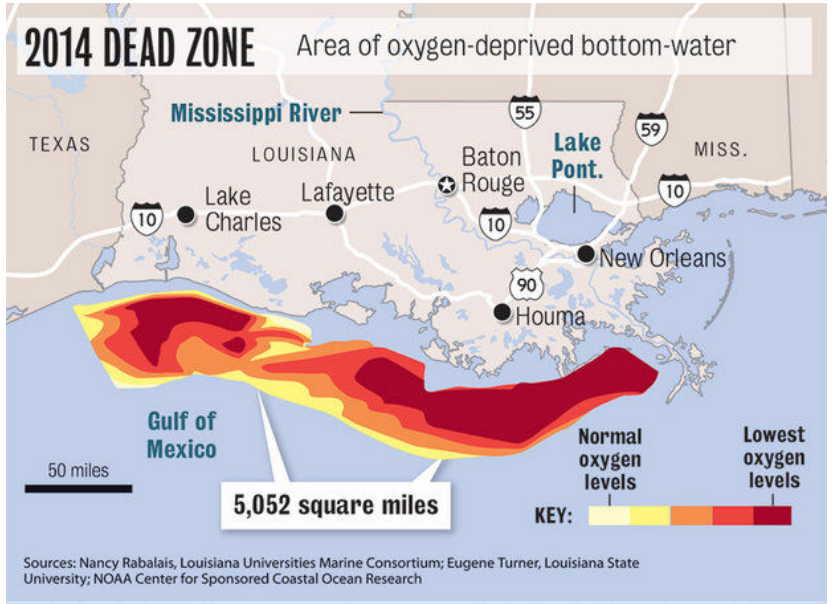
Algae Bloom

↓

Eutrophication
(algae decomposition)

↓

Hypoxia



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Comparing technoeconomic feasibility of algae cultivation systems for distinct [N/P]

Benthic Algae Turf

e.g., Hydromentia – Vero Beach, Florida

- Polyculture – resilient and resistant to crashes
- Growth: 5-20+ g/m^2/day (AFDW)*
- **No N/P nutrients or external CO_2 added**
- Harvest & dewatering simple, but ash reduction needed
- Requires energy for water pumping to maintain flow
- Polyculture biomass focus - low neutral lipids & higher ash
- Similarities with open field agriculture

VS

Algae Raceway Pond

e.g., NBT – Eilat, Israel

- Monoculture – vulnerable to crashes
- Growth: 5-20+ g/m^2/day(AFDW)*
- Needs fertilizer & CO_2
- Harvest & dewatering more difficult & energy-intensive
- Requires energy for water supply and paddle wheel flow/mixing
- Lipid focus (historical)

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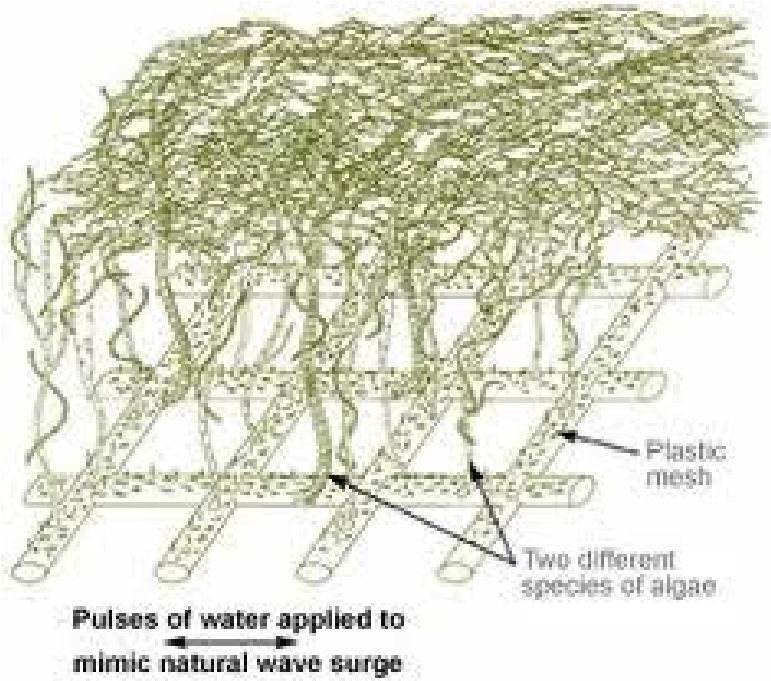
Attached periphytic algae cultivation concept

- Provide habitat for natural filamentous algae assemblages to proliferate
- Attached growth allows utilization of dilute nutrients, ie. flow rate can be adjusted based on nutrient concentration variability
- Potential symbiotic mixotrophy benefits from carbon sources in agricultural runoff
- Potential for dramatic decrease in hydrodynamic residence time for water treatment: 35x improvement in L/m^2 versus conventional raceways
- Regular harvesting to maintain log-phase growth



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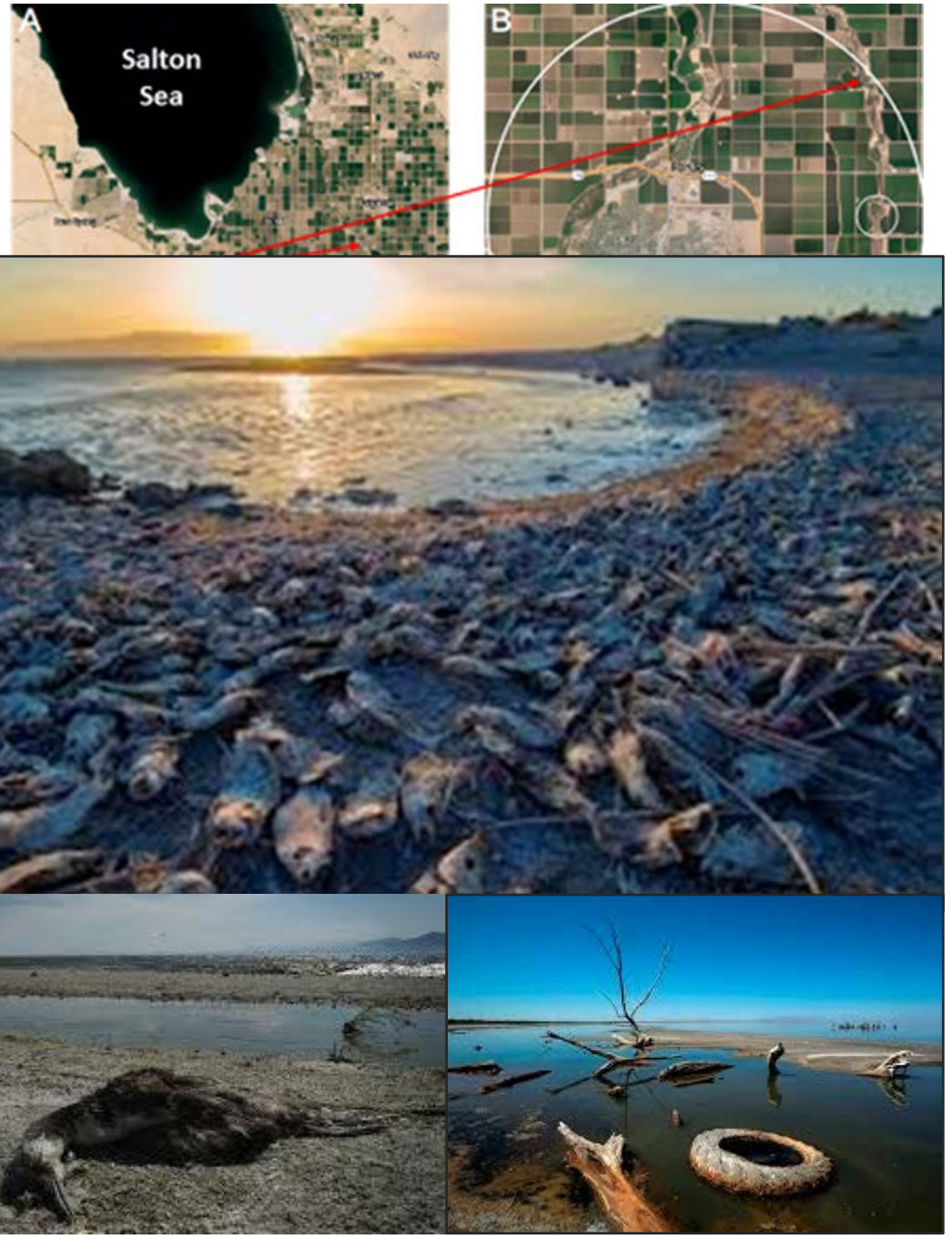
Deployment 2: Brawley, CA Salton Sea, Imperial Valley Irrigation District

- Fresh/agricultural runoff source water
- Waters heavily laden with N/P + metals (Hg, Pb) & metalloids (Se, As)
- Austere site: no power or facilities
- Side-by-side raceway & floway operation for comparative assessment



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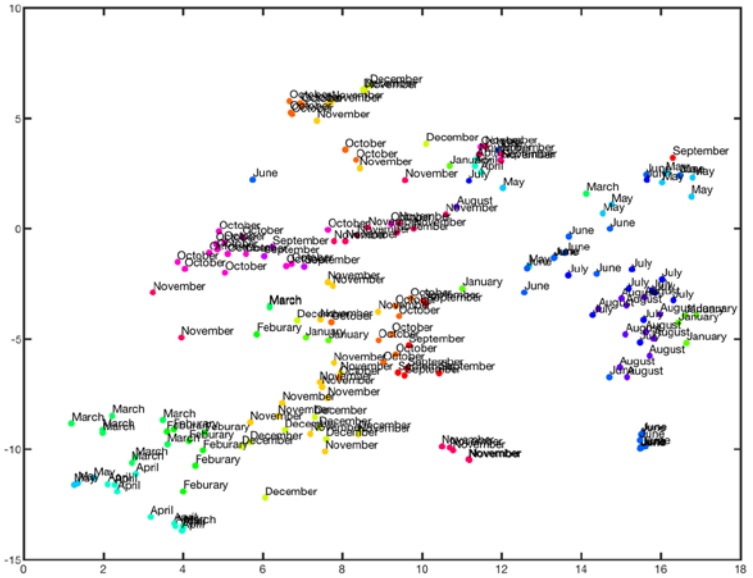
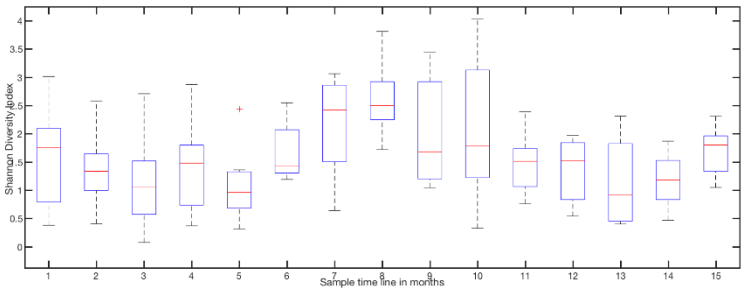
Salton Sea Algae Floway Deployment & Biomass Production

- 900-ft floway (80m^2) in Brawley, CA on Alamo River tributary to Salton Sea
- State of California interested in bioremediation potential of system to prevent heavy metals (esp. As & Se) accumulation in wetlands fauna
- Austere site: no physical security or facilities, pumping provided by renewable power pumping station
- Source water: 95% agriculture runoff

Metagenomics analysis for characterizing variation in microbial ecology

- 300,000 OTUs, 8 – 10x more than raceway algae polycultures
- Diversity in samples show repeatable seasonal variation
- Data being used to identify strains that are associated with high productivity for development of seed cultures for rapid onset of high yield biomass production.
- No indication of system harboring toxigenic algae species





Cladophorales

MAGPie

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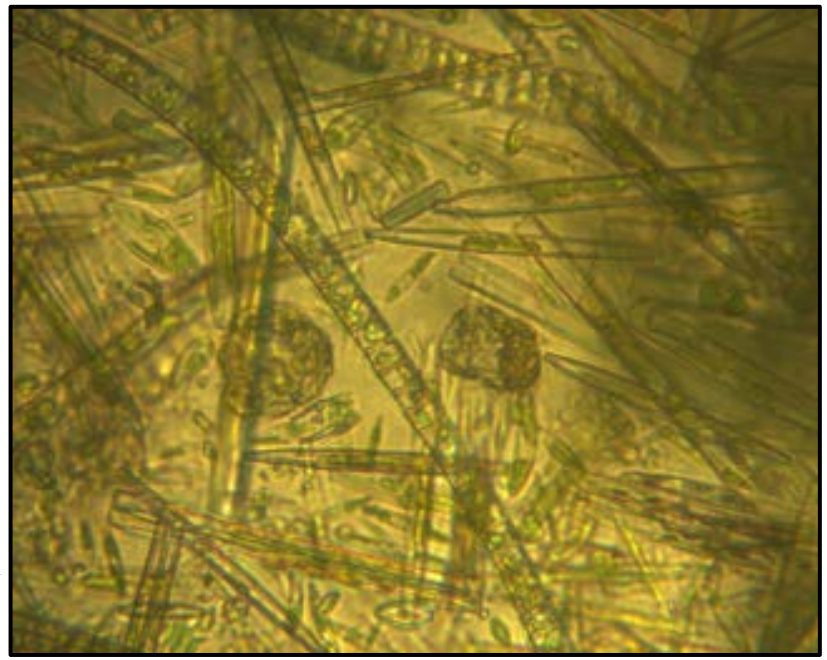
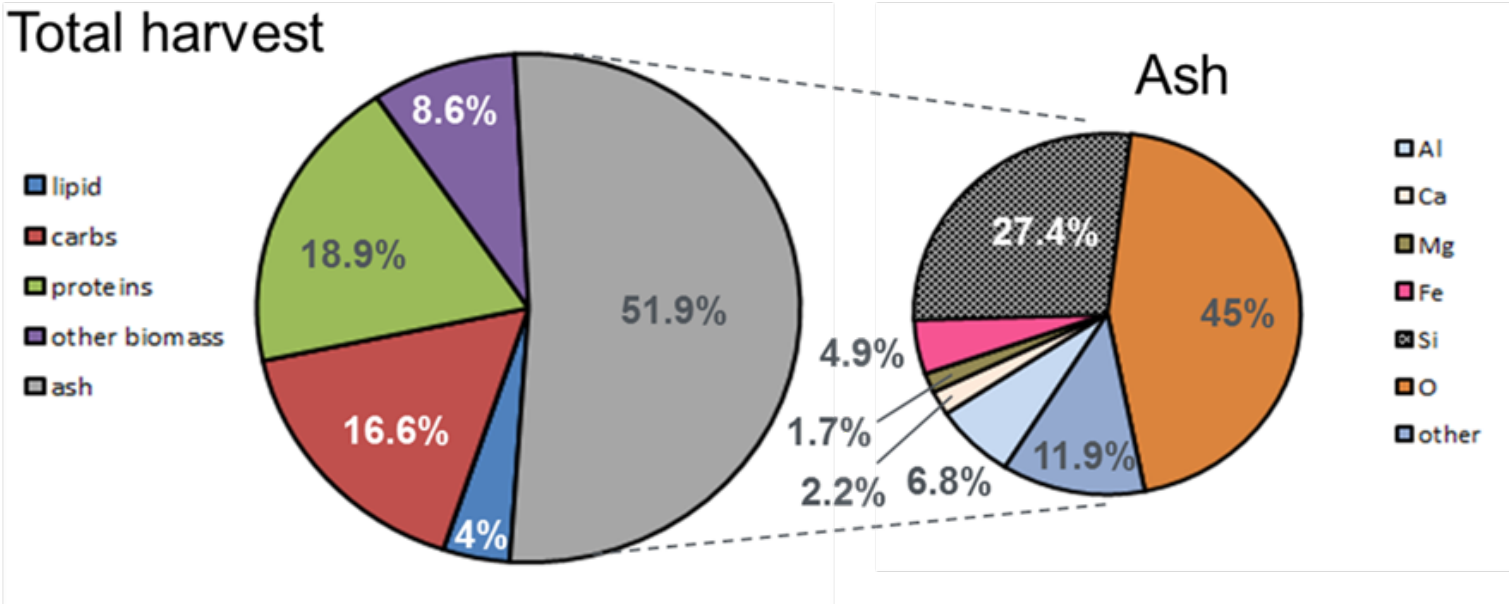
Biochemical characteristics of periphytic biomass

- Variable composition: expected dependence on water source, climate, and season
- Composed of multiple phylogenetic groups: dominant clades include chlorophyta, diatoms, green alga, and cyanobacteria
- Low lipid content
- Biogenic and non-biogenic ash content
- Cultivation & harvest system not optimized for lower ash



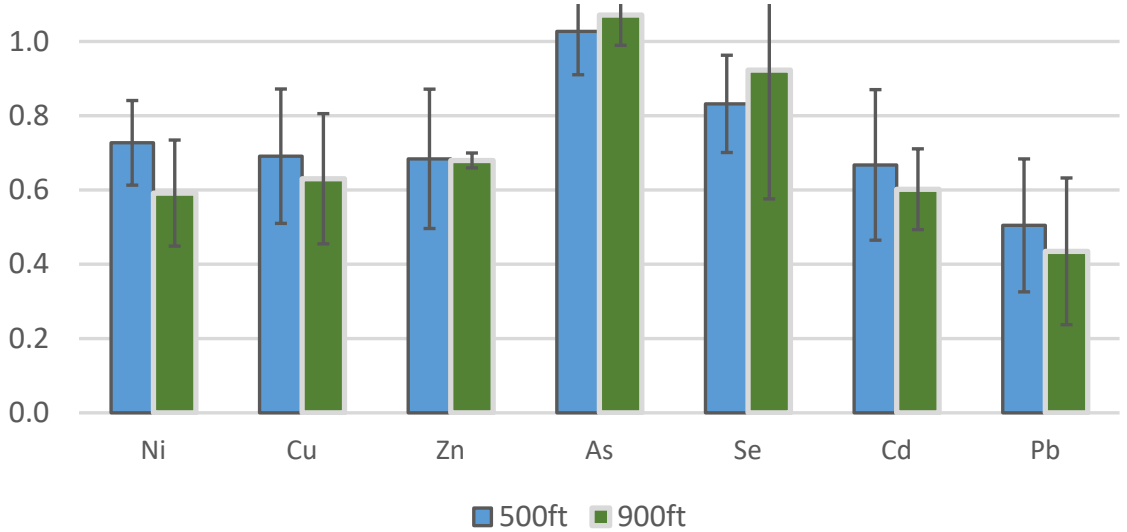
40x established culture micrograph: Agricultural/storm runoff attached microalgae consortium

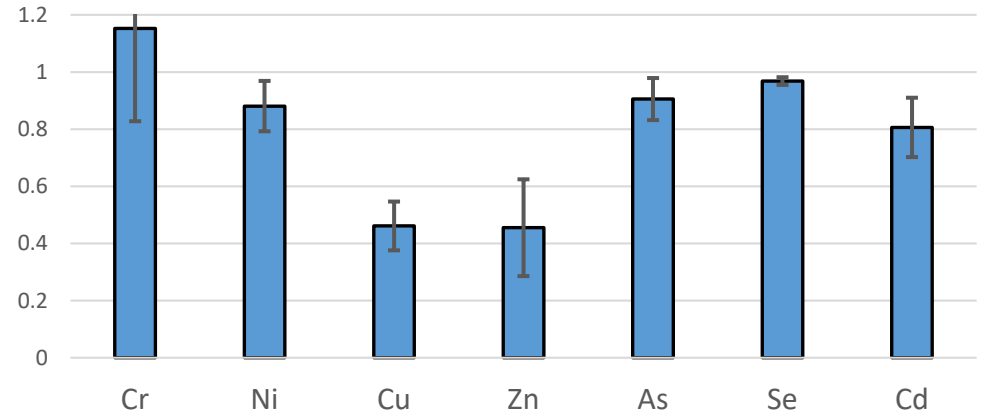


Remediation of nutrient + metals contaminants

- Algae turf systems previously show to be effective for **dilute N/P** 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: **As, Se, Hg, Pb**
- 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

Metals titration *in biomass* along flow-way length





*Courtesy of Louis Hennequin, Imperial College London

Inlet vs outlet metals concentrations

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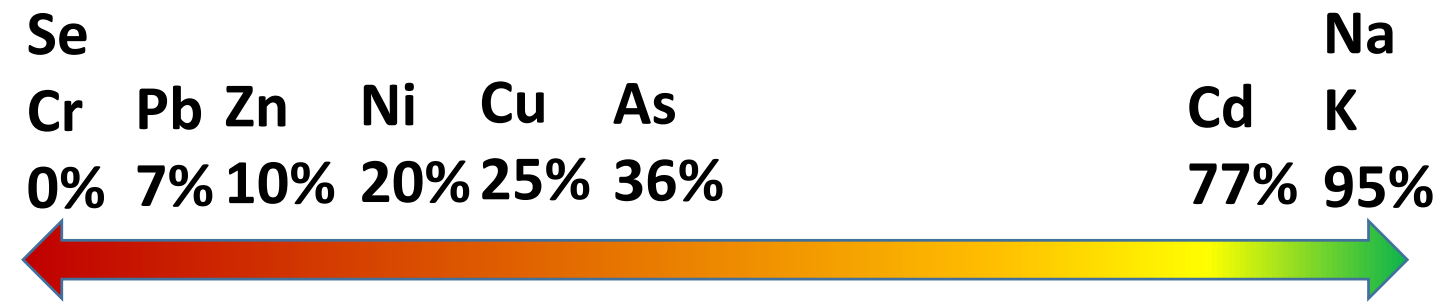
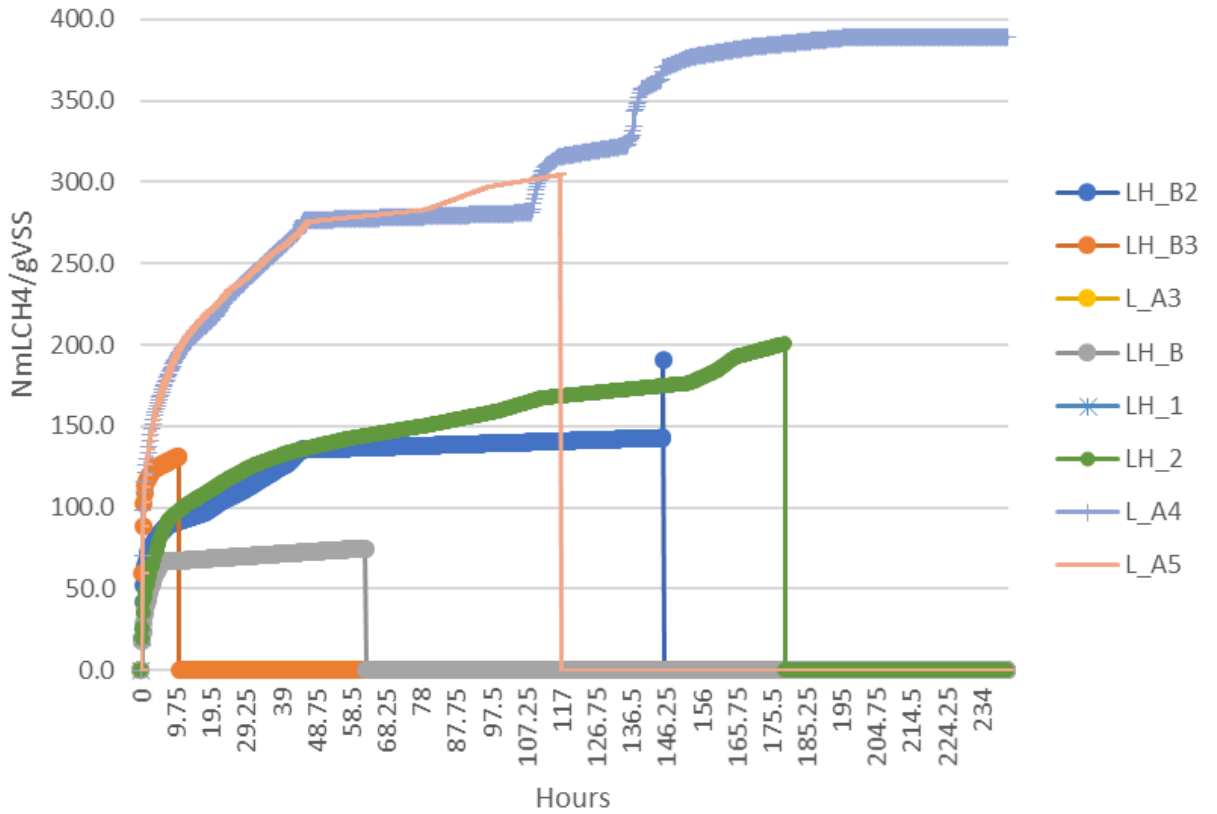
Biomass utilization options with toxic metals contaminants?

- 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.



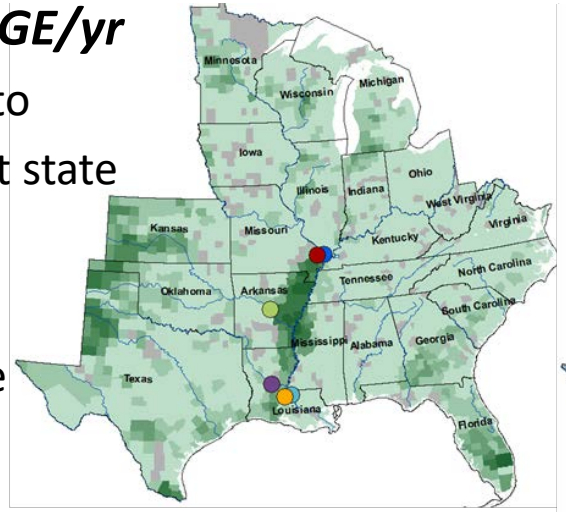


Irrigated, Commercially Fertilized, and Manure Treated Acreage in the Lower MS River Watershed

Scale-up potential ***> 1 billion GGE/yr***

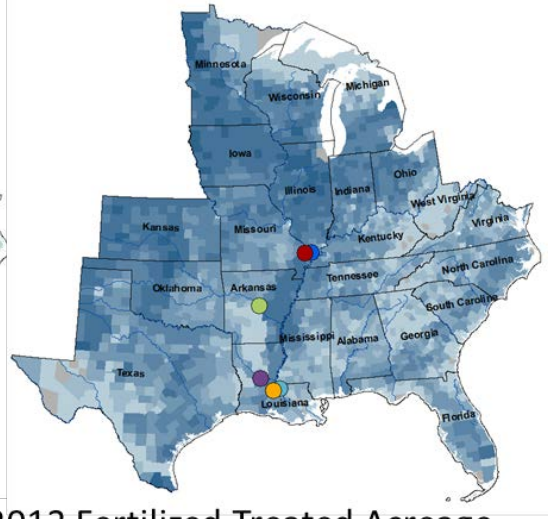
suitable land area closely adjacent to impaired surface waters in the eight state Southeastern region with minimum monthly temperatures > 30˚ F

Based on fuel yield ≥2500 GGE/acre



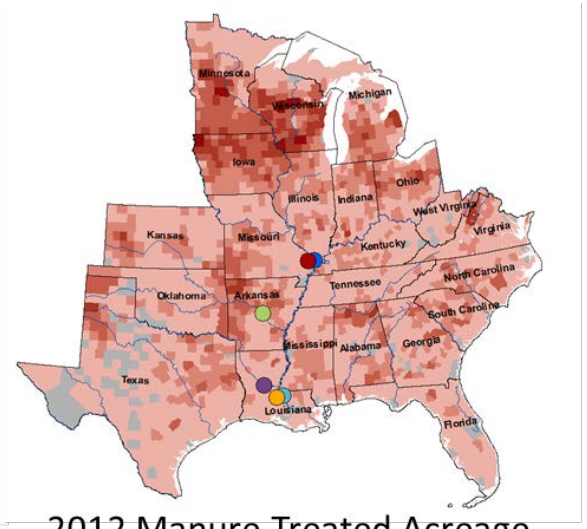
2012 Irrigated Acreage by County

*thousand acres



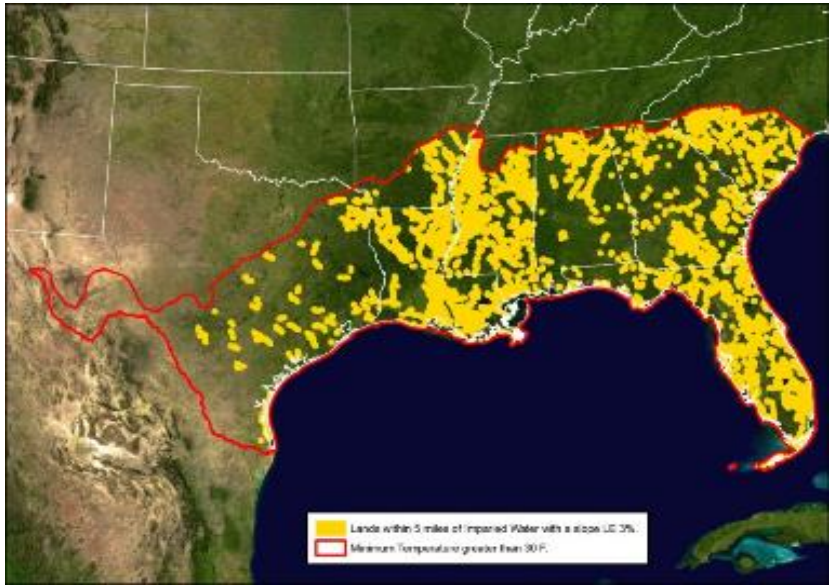
2012 Fertilized Treated Acreage by County

*thousand acres

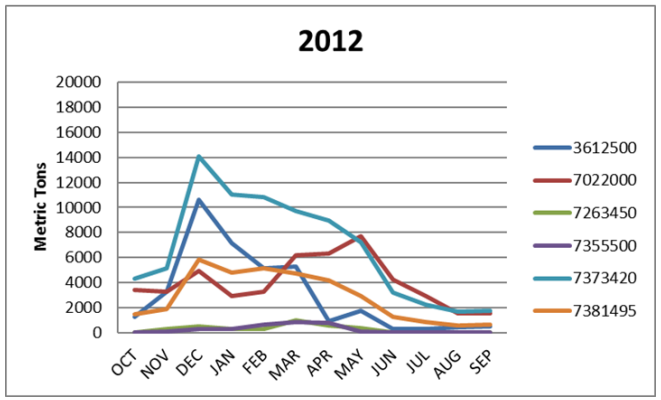


2012 Manure Treated Acreage by County

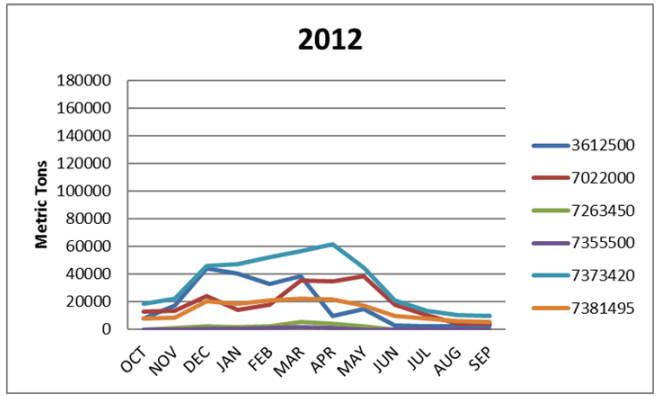
*thousand acres



USGS Station Data for Phosphorous



USGS Station Data for Nitrite and Nitrate



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