Algal Biofuels and Bioproducts Production

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What is the potential of algal-based biofuels as an energy source and the impact on water in Texas?

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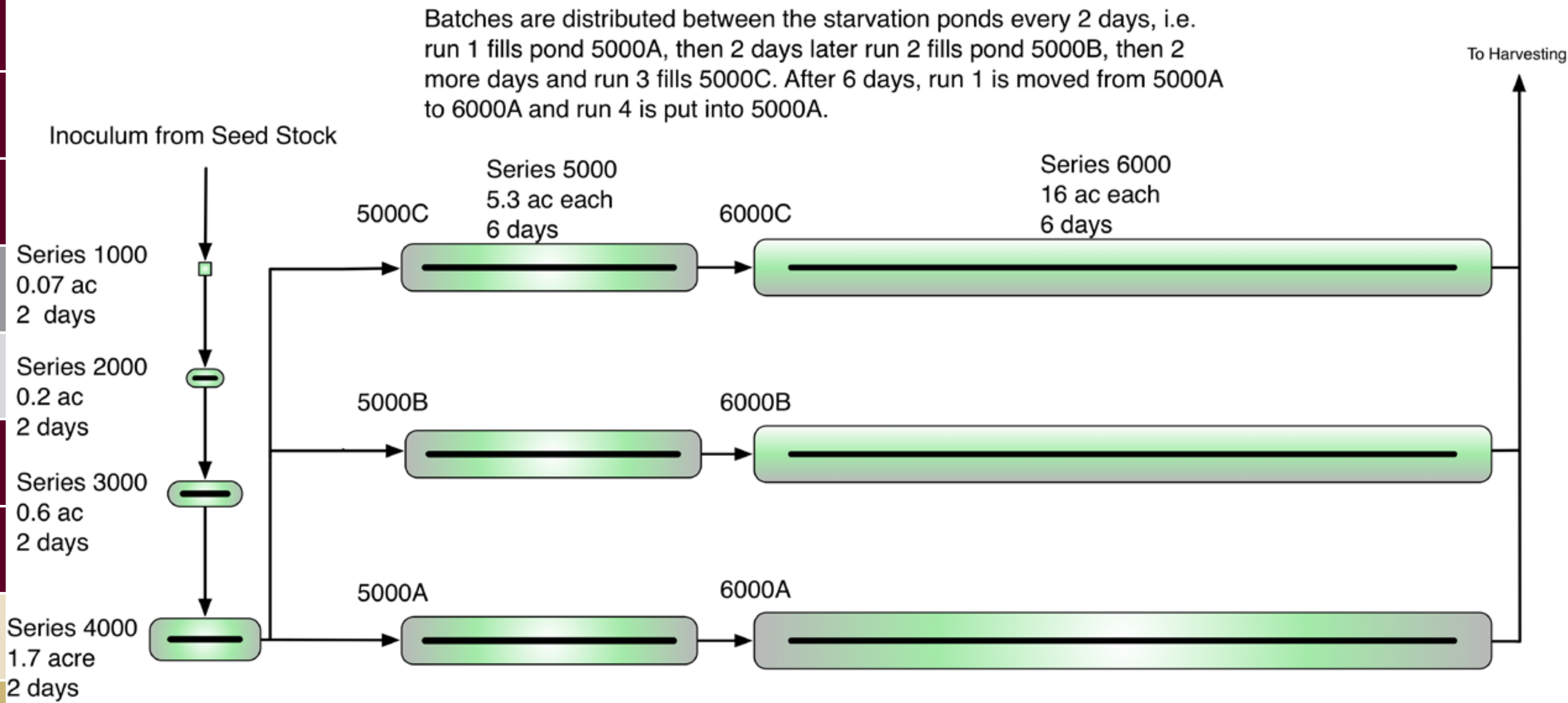
Algae for Biofuels - 101

- Algae are grown in a dilute aqueous solution ~ 0.03% – 0.1% solids
- Growth is limited at the lower end by photo-inhibition and at the upper end by self-shading
- Commercial scale production is accomplished by sequential growth in a series of raceway ponds

Challenges

- How do you determine the performance of a commercial scale system when you haven't built one yet?
- What are the critical operating parameters?
- What are the associated costs?

Baseline Module 50 ac-ft*



* Assumes 9 inches depth

Approach

- Define "commercial scale" as 1,000 ac-ft of volume in one contiguous location.
  - 1,333 acres at 9 inches depth
    - 539.5 Ha at 22.9 cm
  - Twenty of the 50 ac-ft modules

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What is the real production rate for algae biofuels?

- Factors that reduce production from ideal:
  - Growth rate
    - Constant versus Seasonal
  - Inherent variability at each stage
    - Constant versus ± 25%
  - Loss of batches
    - No loss versus 1% chance of failure at each stage
  - No surge capacity between stages
    - Surge tanks versus no surge tanks

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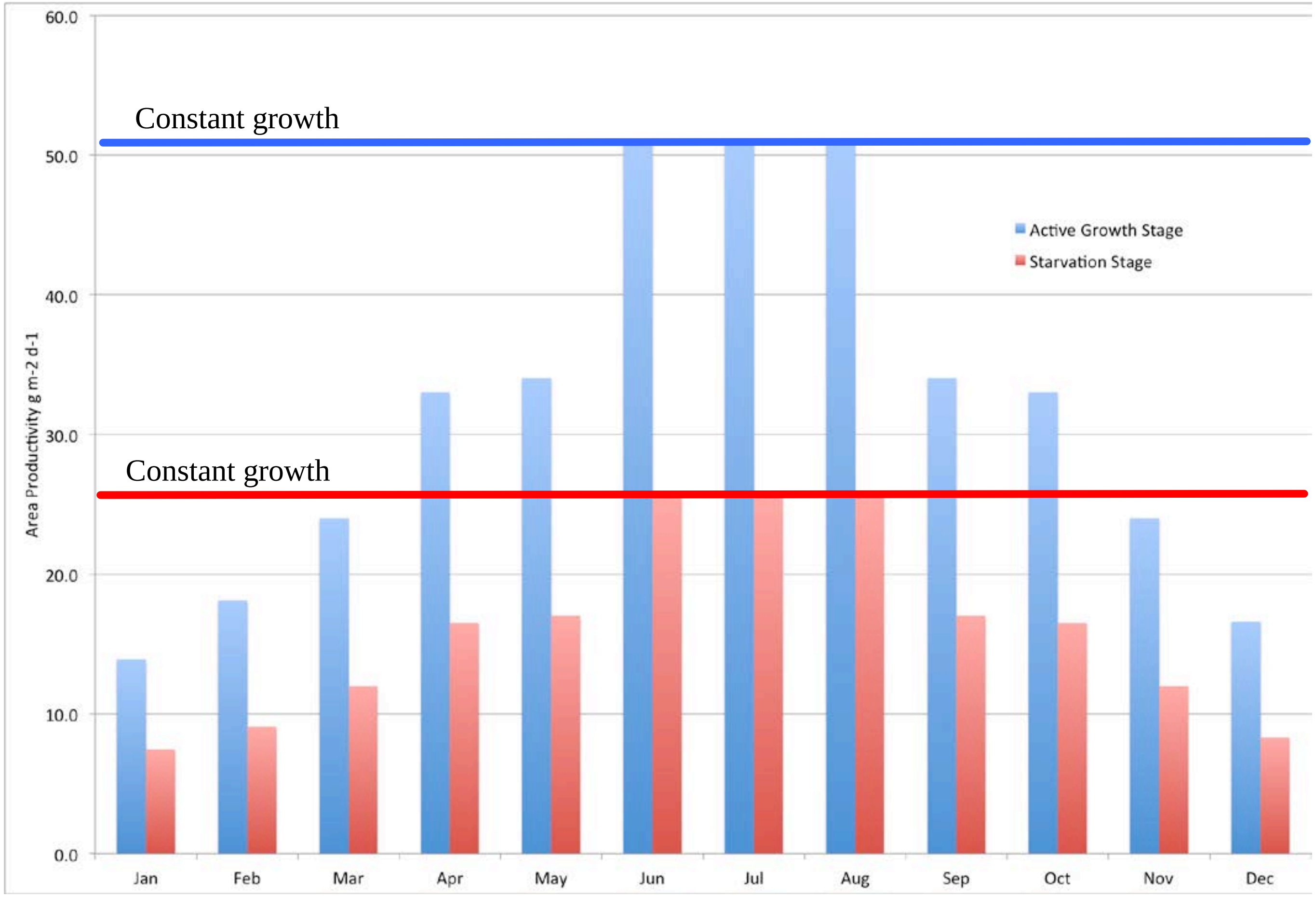
Constant versus Seasonal Growth



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Annual Productivity under Different Assumptions

Conditions	Biomass (mt yr^{-1})	Lipid (gal yr^{-1})
Constant Growth No Variability No Failure Surge Capacity	52,885	2,885,676
Seasonal Growth No Variability No Failure Surge Capacity	15,242	831,612
Seasonal Growth Variability No Failure Surge Capacity	14,736	804,406
Seasonal Growth Variability Failure Surge Capacity	14,457	788,492
Seasonal Growth Variability Failure No Surge Capacity	12,724	694,342

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Algae Cultivation

- "Real World" productivity is about 25% of ideal productivity
- Seasonal growth rate has the single greatest impact on productivity
  - Algal strains to balance seasonal biomass productivity vs. lipid content
  - Locate facilities to mitigate seasonal effects
  - Minimize costs, maximize production

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What are the costs?

- Estimate operating costs for a commercial scale algae cultivation and harvesting facility
- Evaluate water “footprint” of the facility
- Implications for Texas based algal biofuels production

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Baseline assumptions

- Growth and evaporation are seasonal, based on a inland location
  - (e.g. Pecos, TX)
- No external limitations on the system
  - (e.g. adequate water, etc.)
- Growth and lipid production follow currently established patterns.
  - 3:1 volume accumulation
  - Fed batch process

Other Assumptions in Model

- Water costs @ \$0.05 m^{-3} (\$63 per acre-ft)
- CO_2 costs @ \$0.0075 kg^{-1}
  - 25% efficient in uptake
- Media costs based on modified f/2 recipe
- Failure probability = 0.01
- Average lipid content = 21%
- Mixing at 1.5 fps during growth periods

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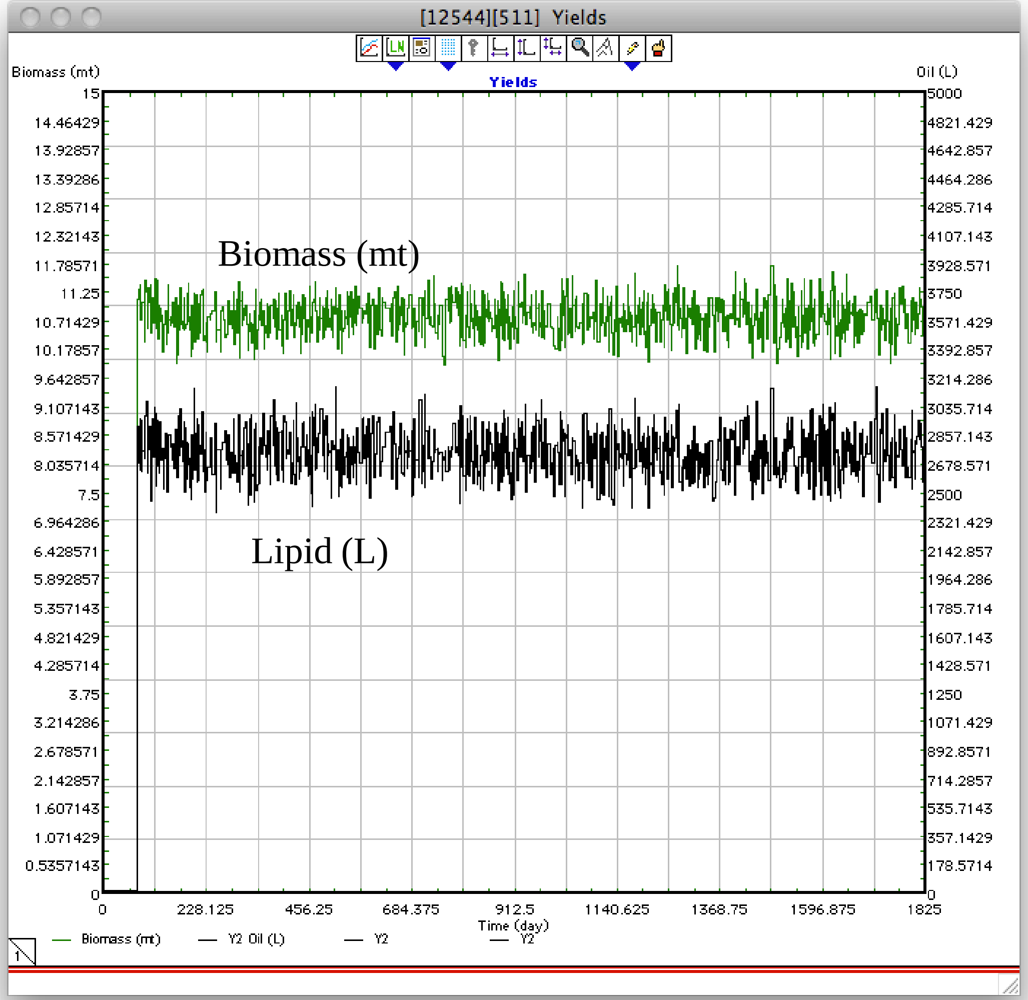
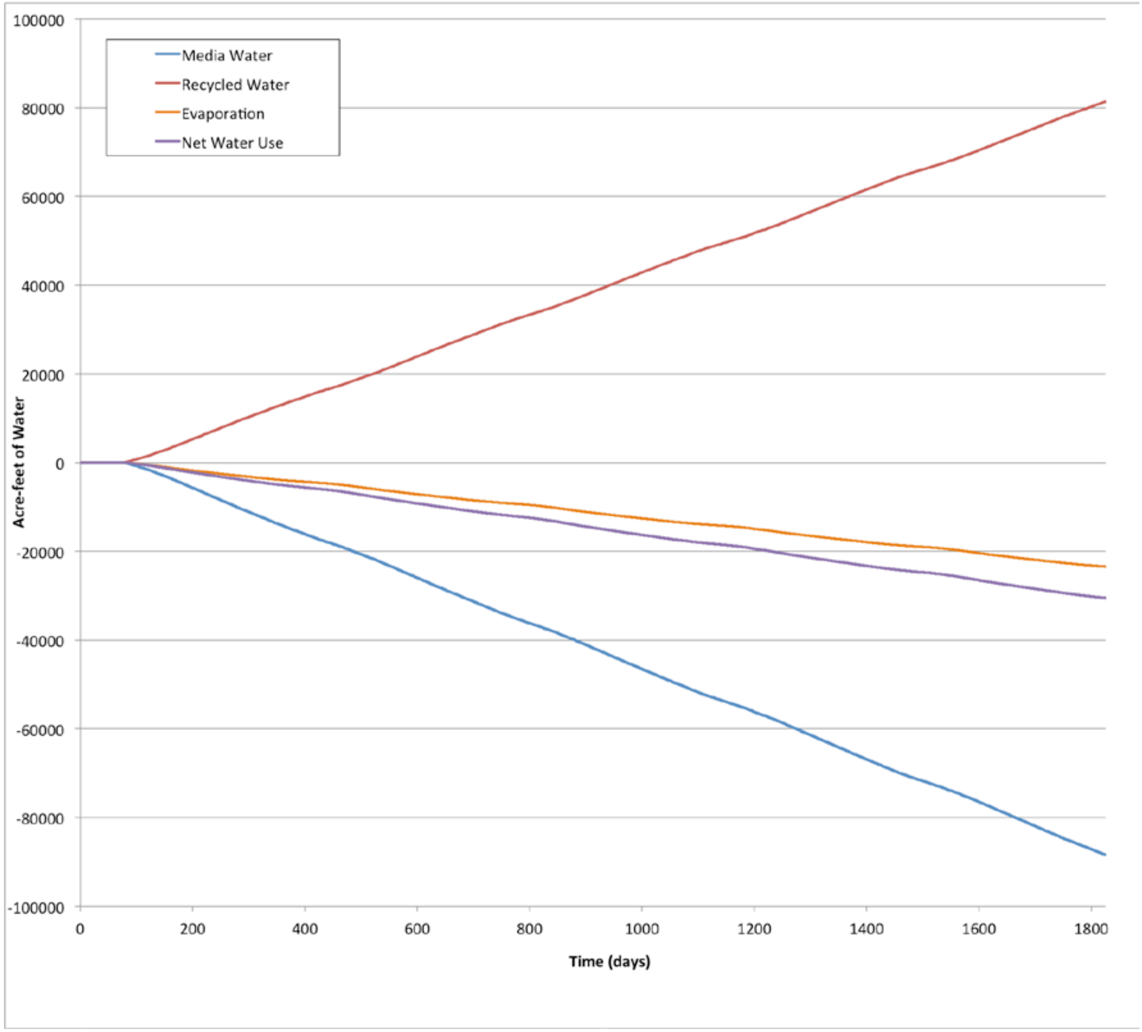
Biomass & Lipid Production



Water Balance



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Baseline Results: Annual Costs based on five 5-year runs

Annual Costs	
Total Labor	$4,249,393
CO2	$1,421,434
Nutrients	$6,162,665
Harvest Elect.	$68,729
Mixing Elect.	$4,123,032
Transfer Elec.	$175,497
Water Cost	$353,741

Annual Labor	
Lab	$2,275,445
Semi-Skilled	$1,101,923
Unskilled	$872,025

Annual Productivity	
Biomass (mt)	12,724
LEA (mt)	10,306
Lipids (L)	2,628,085

Water Footprint	
(gal H20/gal lipid)	2,540
(m^3/GJ)	66

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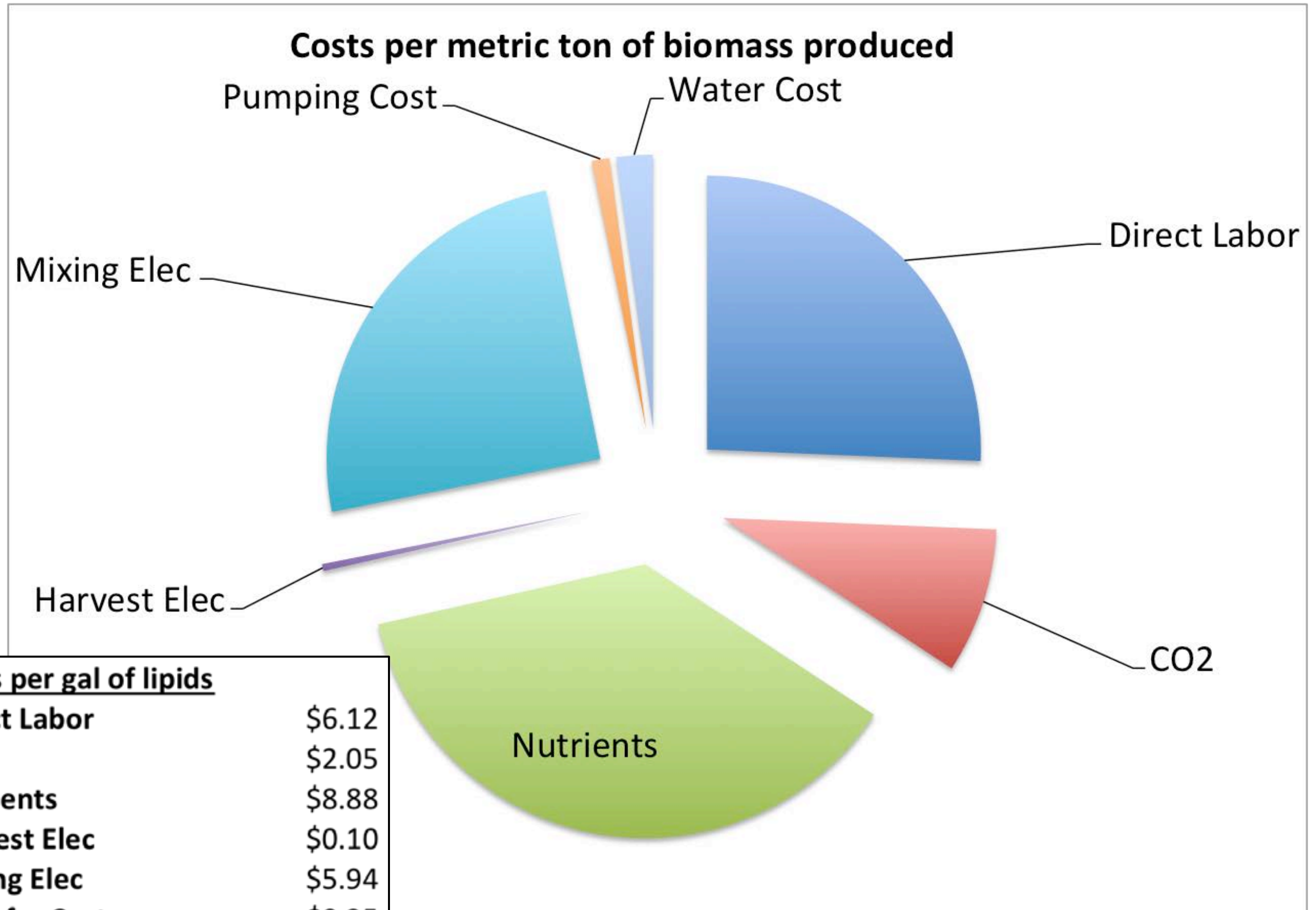
Baseline Operating Costs



Costs per gal of lipids	
Direct Labor	$6.12
CO2	$2.05
Nutrients	$8.88
Harvest Elec	$0.10
Mixing Elec	$5.94
Transfer Cost	$0.25
Water Cost	$0.51
TOTAL	$23.84

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What are the water issues with algae-based biofuel?

- Algae can utilize brackish or saline water for growth
  - Not competing with food crops for water
- Media water can be recycled
- Significant quantity of water is lost to evaporation
  - Coastal location does not reduce this by much
  - Water quantity may be the limiting factor on inland algae cultivation sites

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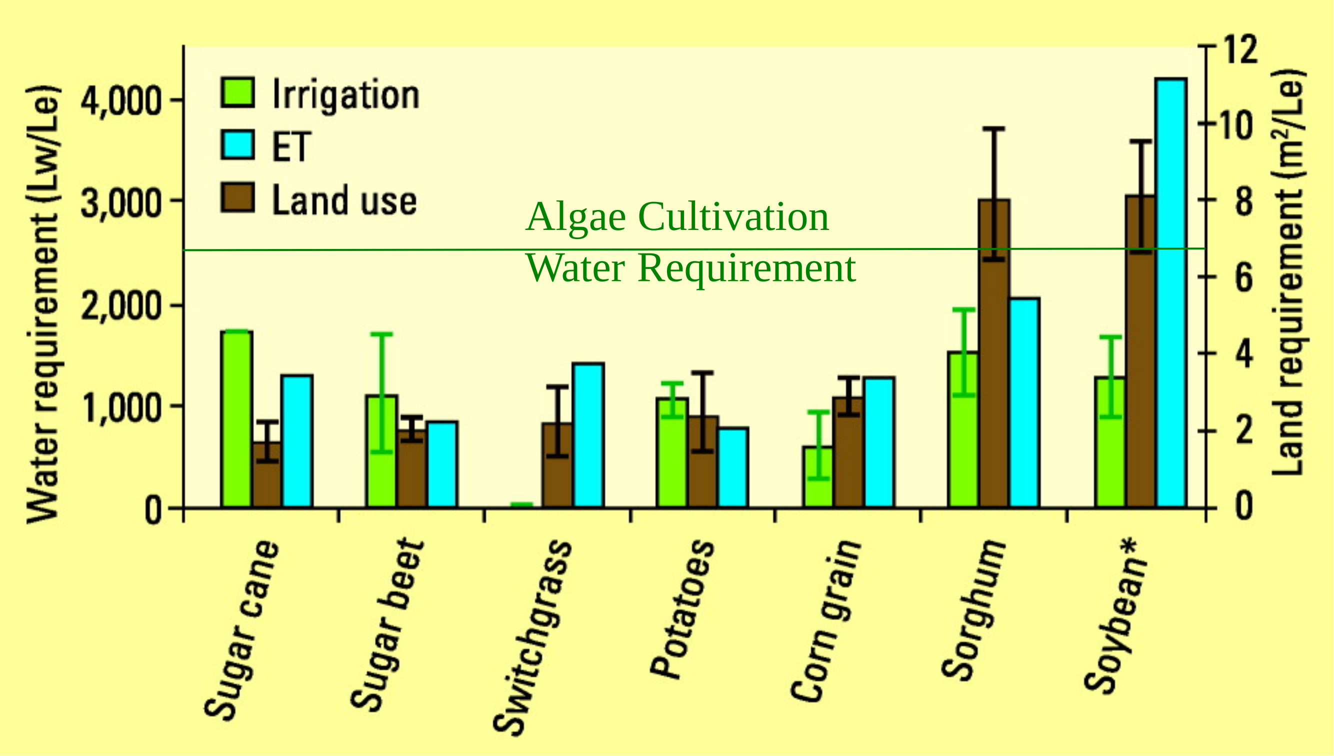
How do algae compare to other energy crops?



Dominguez-Faus, R, S.E. Powers, J.G. Burken, and P.J. Alvarez. 2009. The Water Footprint of Biofuels: A Drink or Drive Issue. *Environ. Sci. Technol.*, 2009, ***43*** (9), pp 3005–3010

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How does algae water consumption compare to other energy sources?

Process	L/MWh
Petroleum extraction	10−40
Oil refining	80−150
Oil shale surface retort	170−681
NGCC[a] power plant, closed loop cooling	230−30,300
Coal IGCC[b]	900
Nuclear power plant, closed loop cooling	950
Geothermal power plant, closed loop tower	1900−4200
EOR[c]	7600
NGCC, open loop cooling	28,400−75,700
Nuclear power plant, open loop cooling	94,600−227,100
Algae cultivation and harvesting	**237,410**
Corn ethanol irrigation	2,270,000−8,670,000
Soybean biodiesel irrigation	13,900,000−27,900,000

a Natural gas combined cycle.
b Integrated gasification combined-cycle.
c Enhanced oil recovery.

Table 1 in Dominguez-Faus, R, S.E. Powers, J.G. Burken, and P.J. Alvarez. 2009. The Water Footprint of Biofuels: A Drink or Drive Issue. *Environ. Sci. Technol.*, 2009, ***43*** (9), pp 3005–3010

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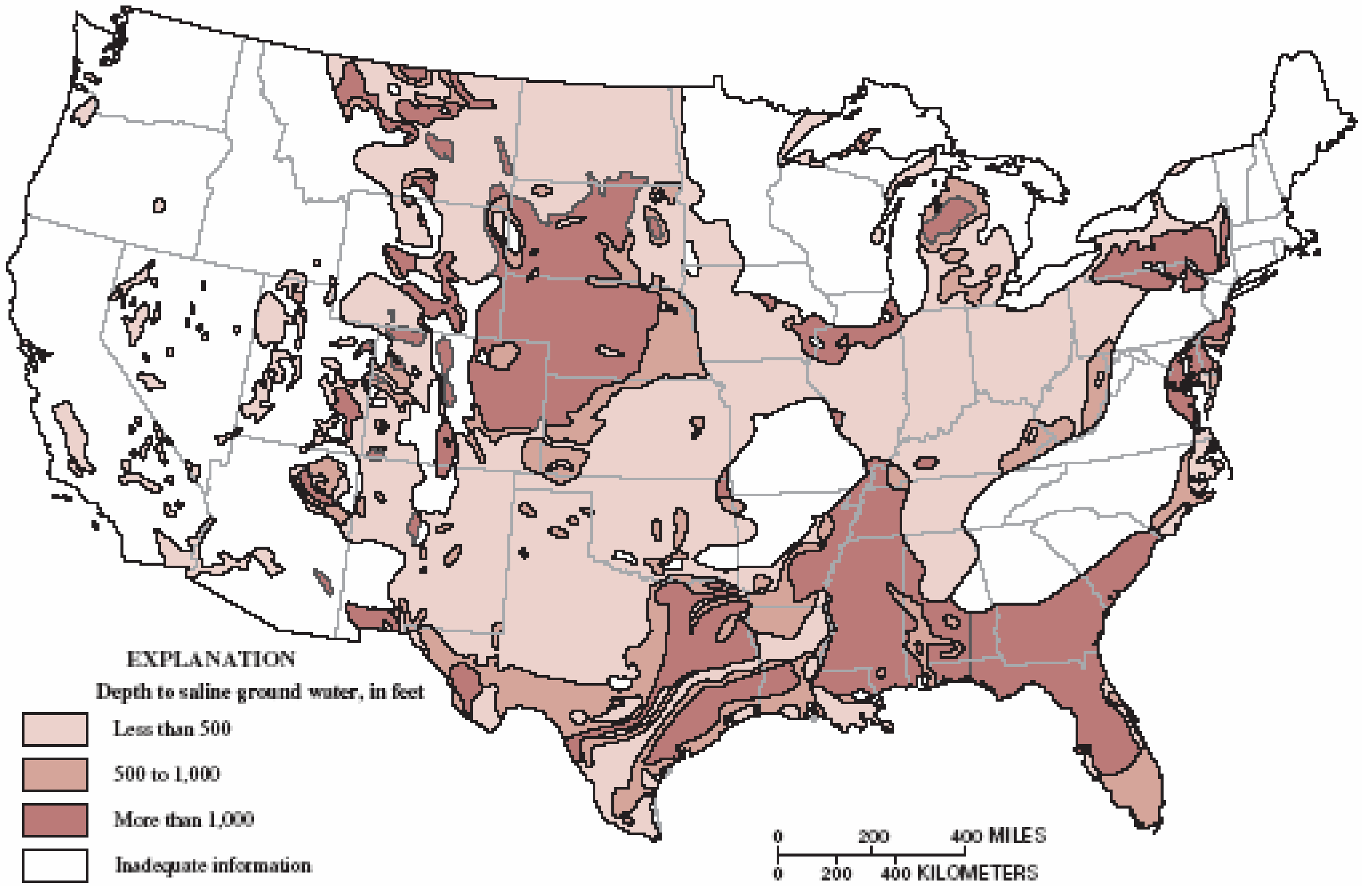
Where are the degraded water sources?



USGS, U.S. Geological Survey (2003a). Desalination of Ground Water: Earth Science Perspectives, USGS Fact Sheet 075-03.

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Summary

- Algae costs can be reduced if:
  - Use free nutrients
  - Reduce mixing rates
  - Automate and reduce labor
- Algae cultivation impacts water resources
  - Use greater than other energy sectors but less than other bioenergy crops
  - Can utilize non-potable, brackish, or saline water

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Thanks for your attention

Sources of free nutrients

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