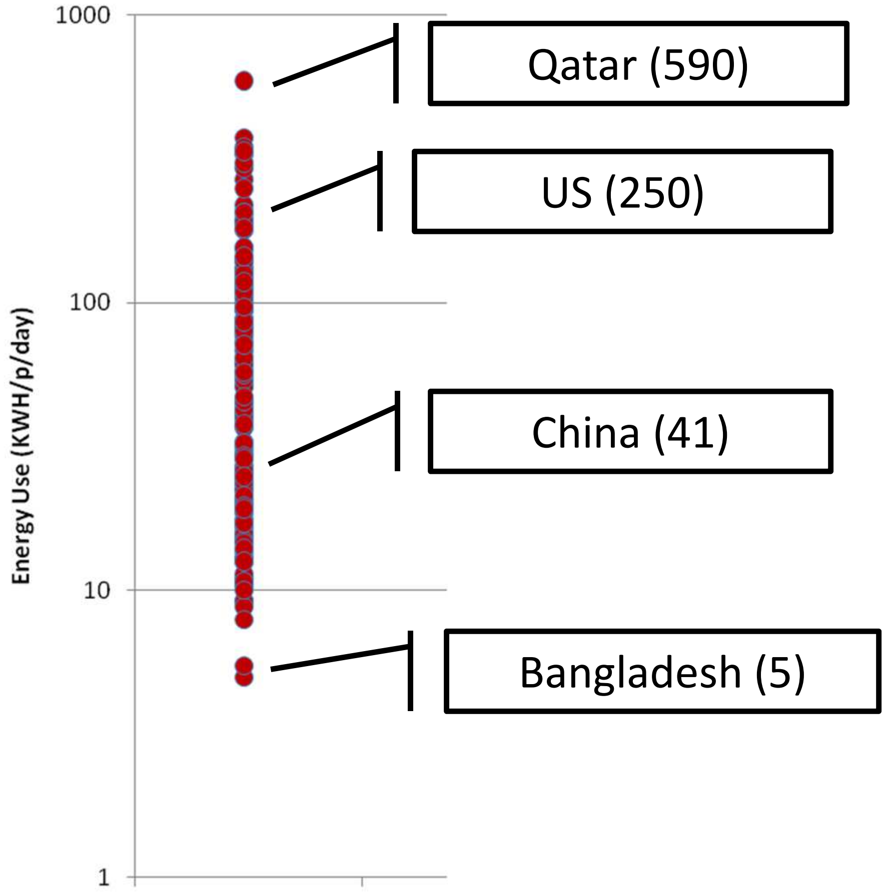
How Green Can Algae Be? Alternative Energy from the Chesapeake Algae Project

Bill Cooke, Karl Kuschner
Dennis Manos, Gene Tracy
Physics Department
College of William and Mary

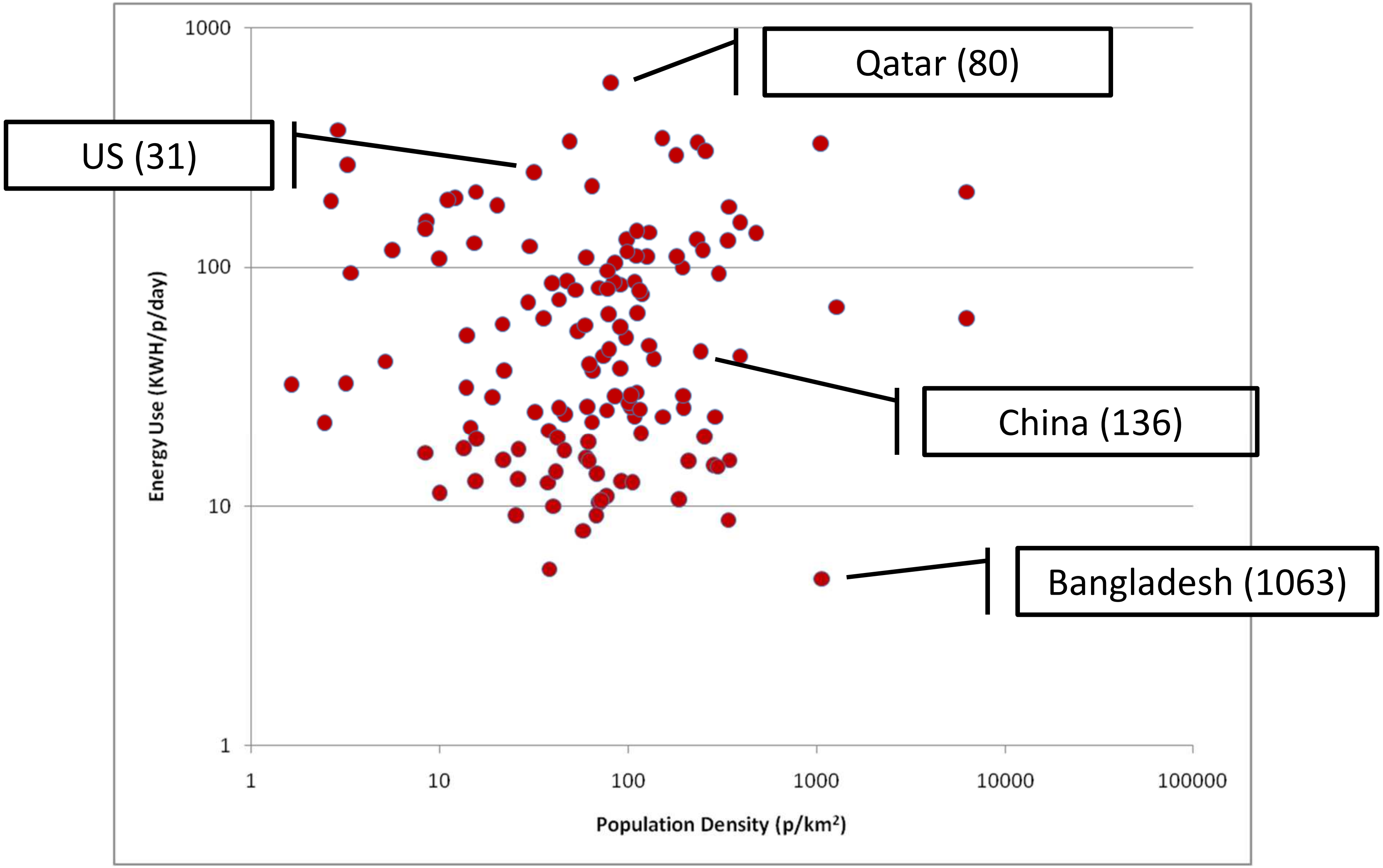
University of Virginia, December 2, 2011

Can Biofuel Supply Our Need?

Ranking countries according to their per capita energy use.

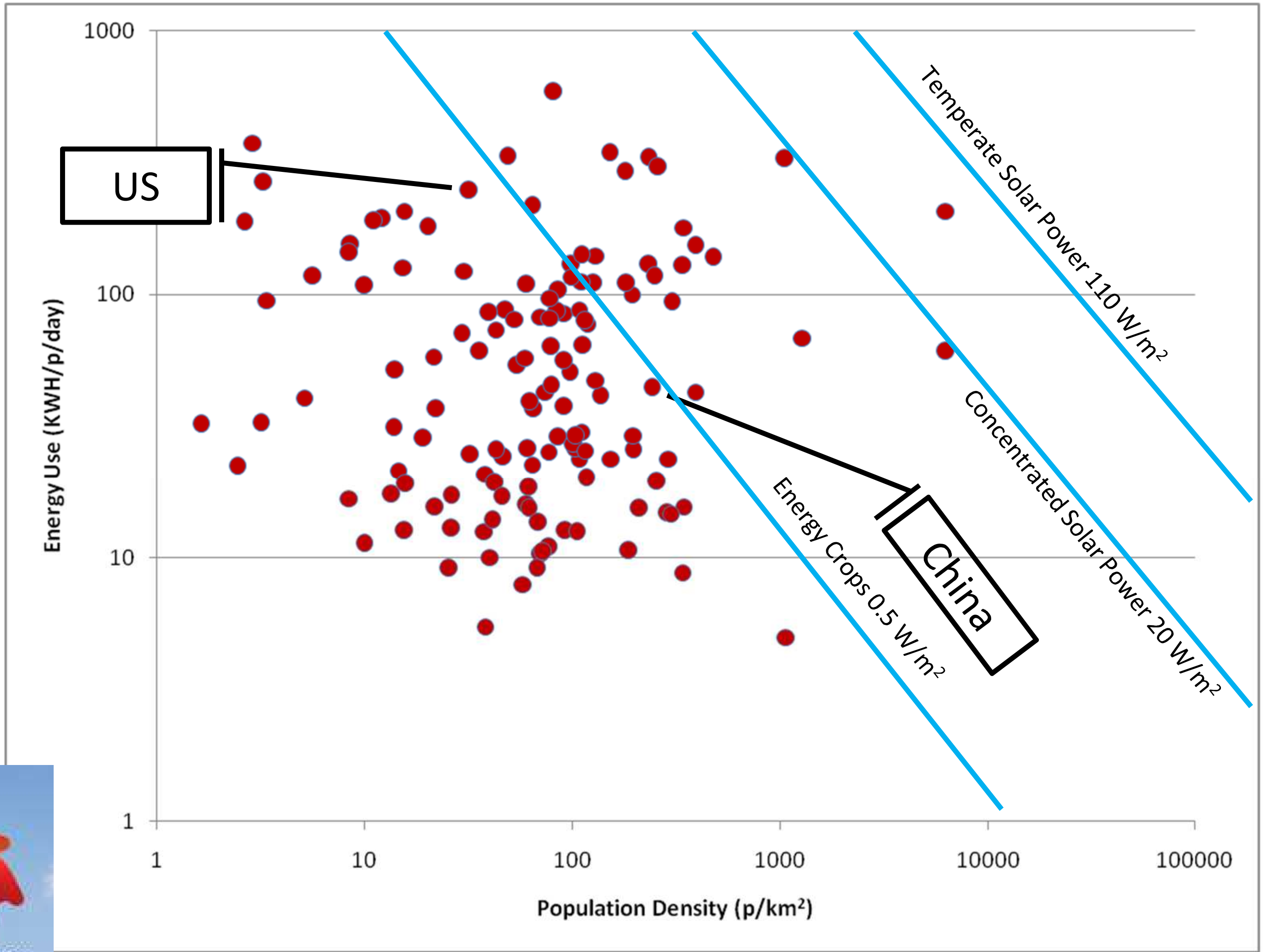


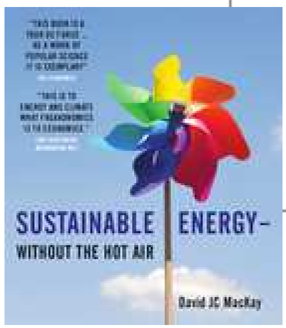
Solar Power Requires Area



Use population density as the horizontal axis

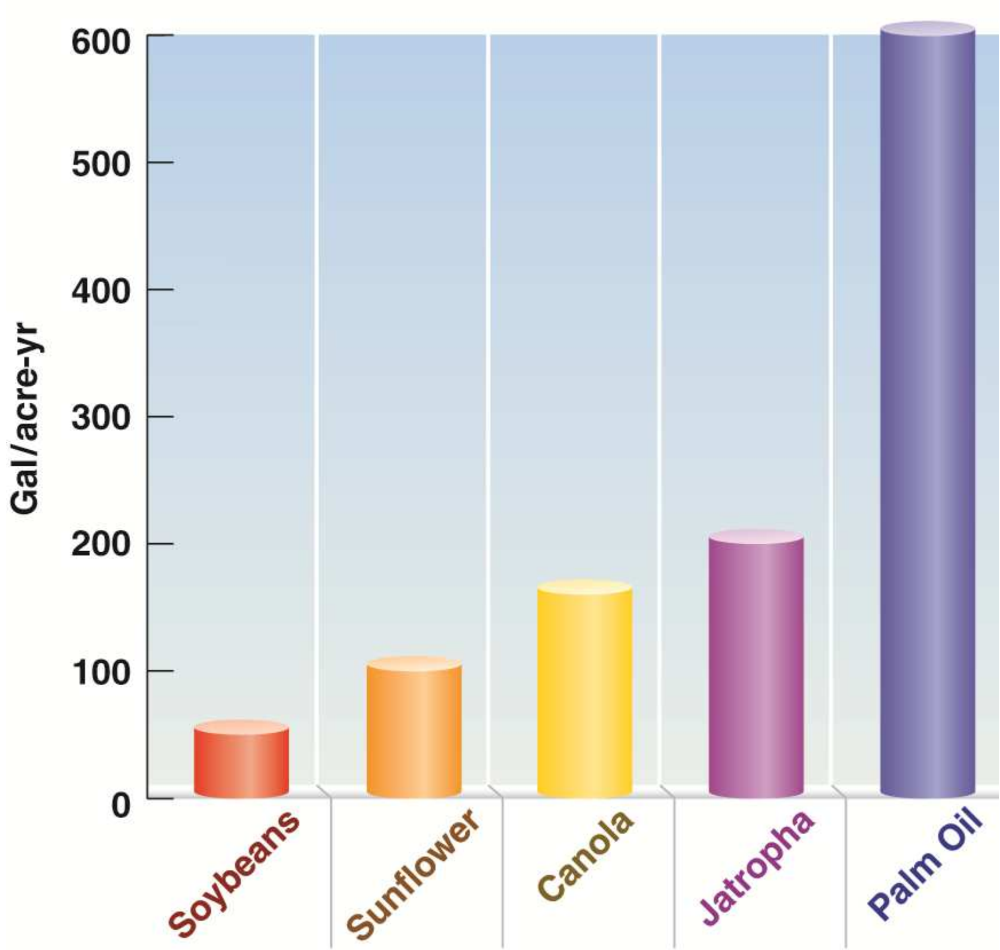
What’s available from the sun?





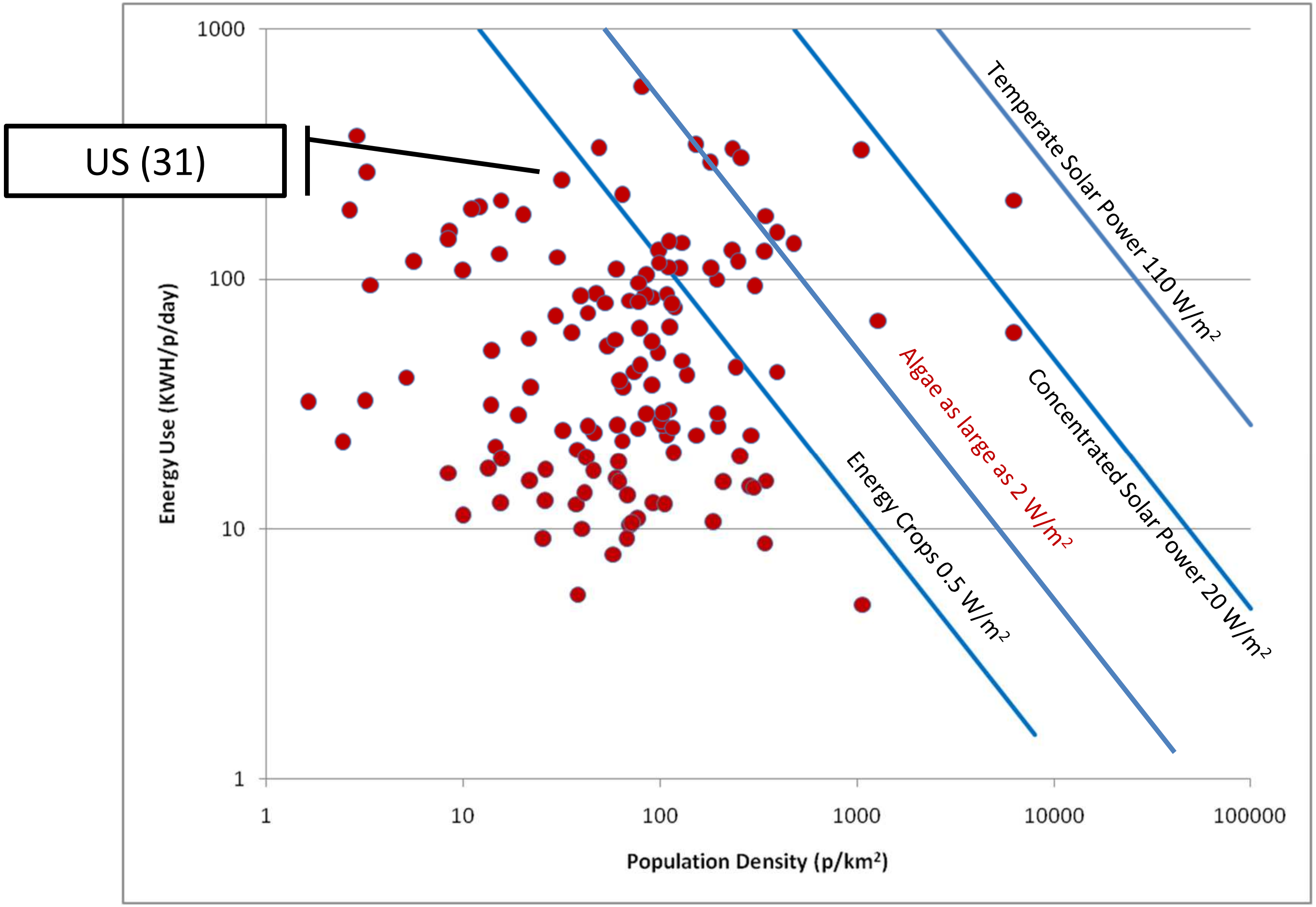
http://www.inference.phy.cam.ac.uk/sustainable/book/data/powerd/PPPersonVsPDen2.png

Why Algae is Exciting



DARPA projects claim algae biodiesel at 2000 gal/acre-yr

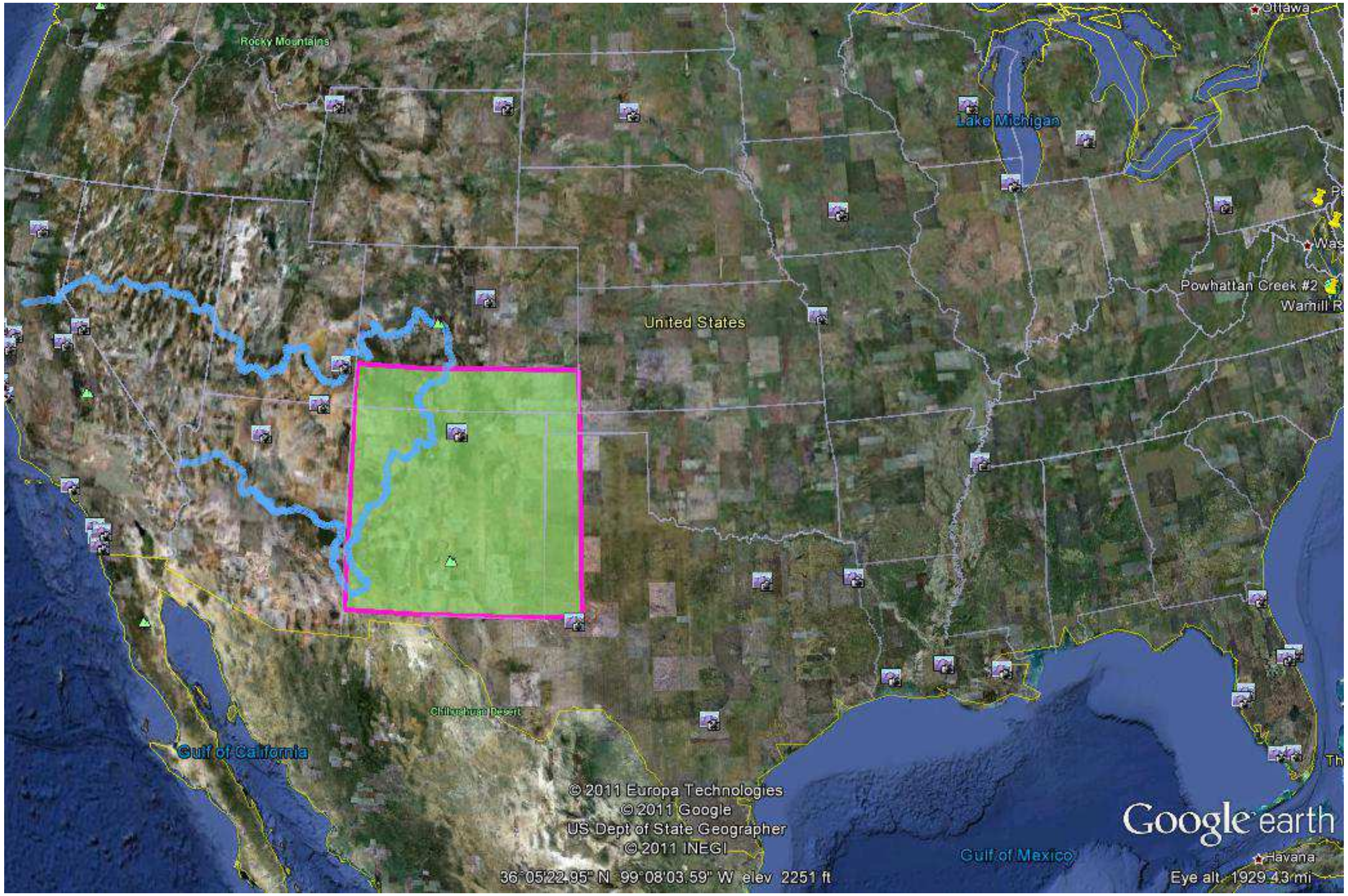
Algae out-produces all other plants



Using algae biofuel farms can be small!

100 million acres of algae could eliminate all US oil imports!

But the farms are planned for non-arable land in the west



With its own set of problems

Sapphire Energy plant in *Las Cruces*, *NM*

- Water
- Nutrients
- Transportation
- CO_2

Algae fuel could be a major Greenhouse Gas Problem

A full life cycle analysis shows that making and using algae biodiesel generates as much GHG as burning fossil fuel.

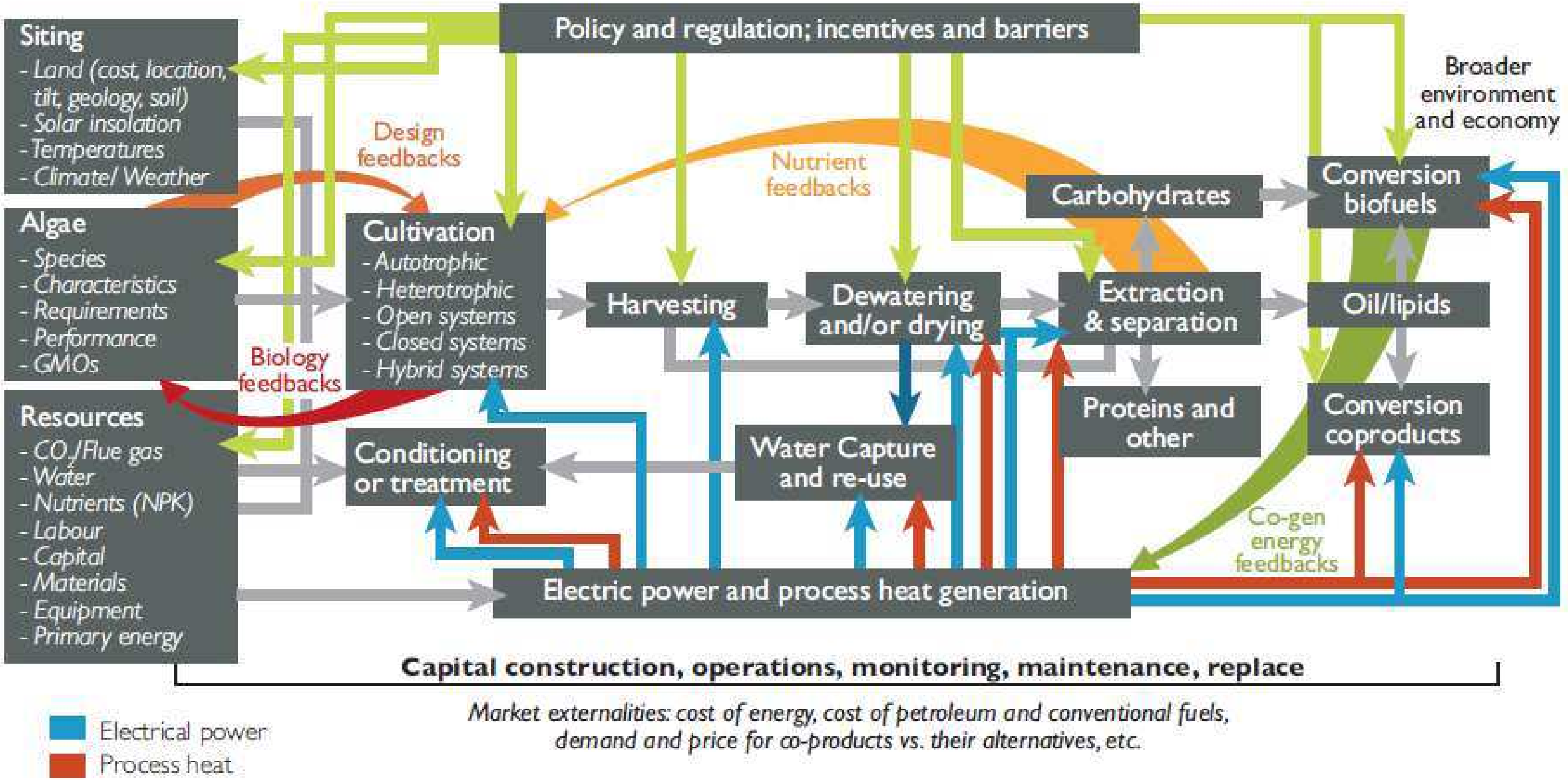
Major Contributors:

- Drying algae
- Fertilizing algae
- Water control

Environmental Life Cycle Comparison of Algae to Other Bioenergy Feedstocks C L A R E N S , *et al.*
McIntire School of Commerce
University of Virginia
Environ. Sci. Technol. ***2010, 44, 1813–181***

Michael Matturro, Exxon-Mobil
Corporate Programs Laboratory,
Algal Biomass Summit
October 25, 2011

High GHG also means high costs and complications



Another View of the Complexities of the Algae-to-Biofuels Value Chain. *Source: U.S. Department of Energy, (2010): National Algal Biofuels Technology Roadmap. U.S. DOE: Office of Energy Efficiency & Renewable Energy, Biomass Program.*

Biofuels at a glance

HOW GREEN ARE BIOFUELS?

Biofuels are getting a bad rap as stories of rising food prices and shortages fill the news. But the environmental, energy and land use impacts of the crops used to make the fuels vary dramatically. Current fuel sources – corn, soybeans and canola – are more harmful than alternatives that are under development.

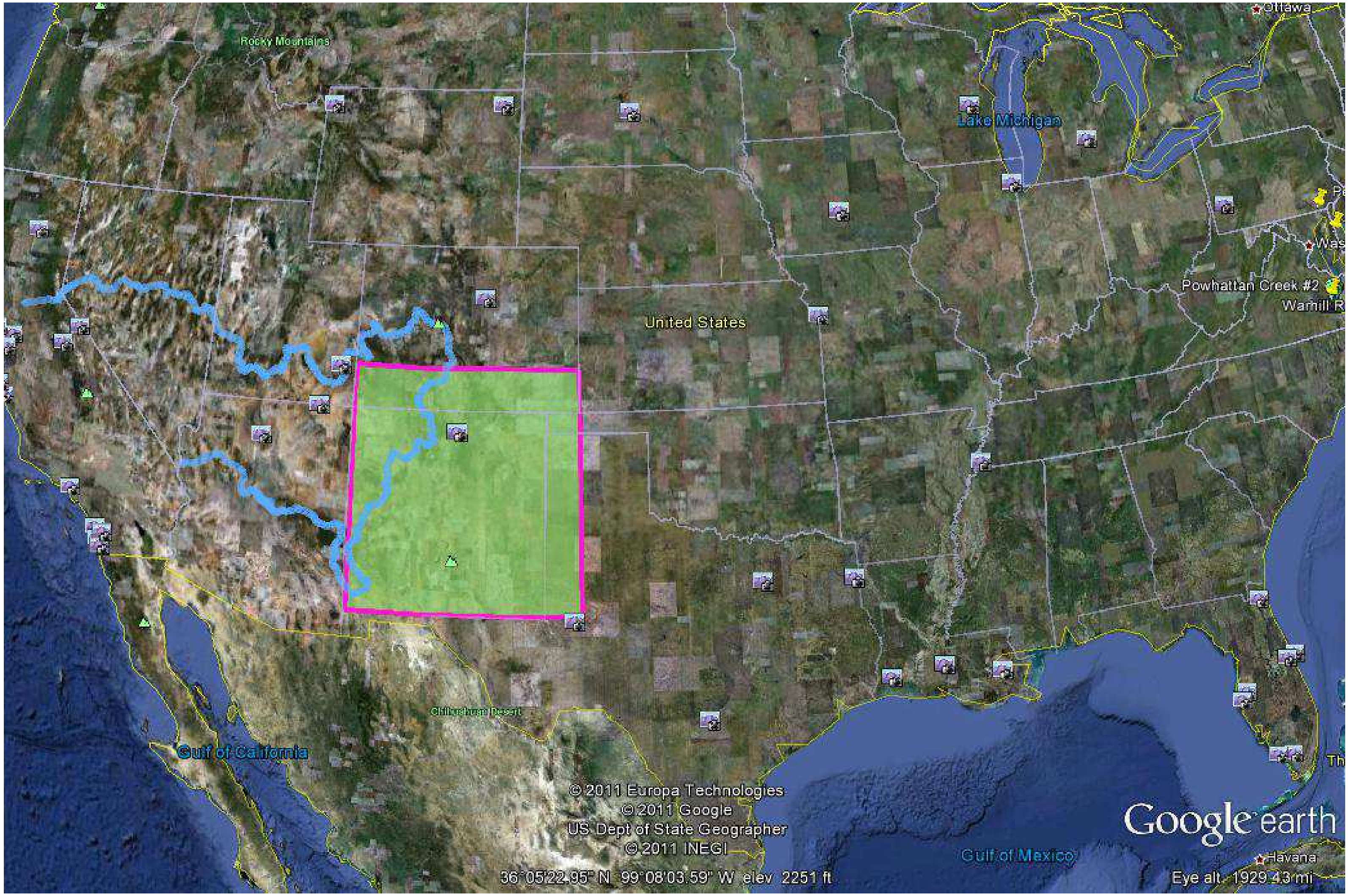
FUEL SOURCES		GREENHOUSE GAS EMISSIONS* Kilograms of carbon dioxide created per mega joule of energy produced	USE OF RESOURCES DURING GROWING, HARVESTING AND REFINING OF FUEL				PERCENT OF EXISTING U.S. CROP LAND NEEDED TO PRODUCE ENOUGH FUEL TO MEET HALF OF U.S. DEMAND	
CROP	**USED TO PRODUCE**		WATER	FERTILIZER	PESTICIDE	ENERGY		**PROS AND CONS**
Corn	Ethanol	81-85	high	high	high	high	**157%-262%**	Technology ready and relatively cheap, reduces food supply
Sugar cane	Ethanol	4-12	high	high	med	med	**46-57**	Technology ready, limited as to where will grow
Switch grass	Ethanol	-24	med-low	low	low	low	**60-108**	Won't compete with food crops, technology not ready
Wood residue	Ethanol, biodiesel	N/A	med	low	low	low	**150-250**	Uses timber waste and other debris, technology not fully ready
Soybeans	Biodiesel	49	high	low-med	med	med-low	**180-240**	Technology ready, reduces food supply
Rapeseed, canola	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	**30**	Technology ready, reduces food supply
Algae	Biodiesel	-183	med	low	low	high	**1-2**	Potentia[illegible] huge production levels, technolog[illegible]ot ready

* Emissions produc[illegible] the growing, harvesting, refining and burning of fuel. Gasoline is 94, di[illegible]

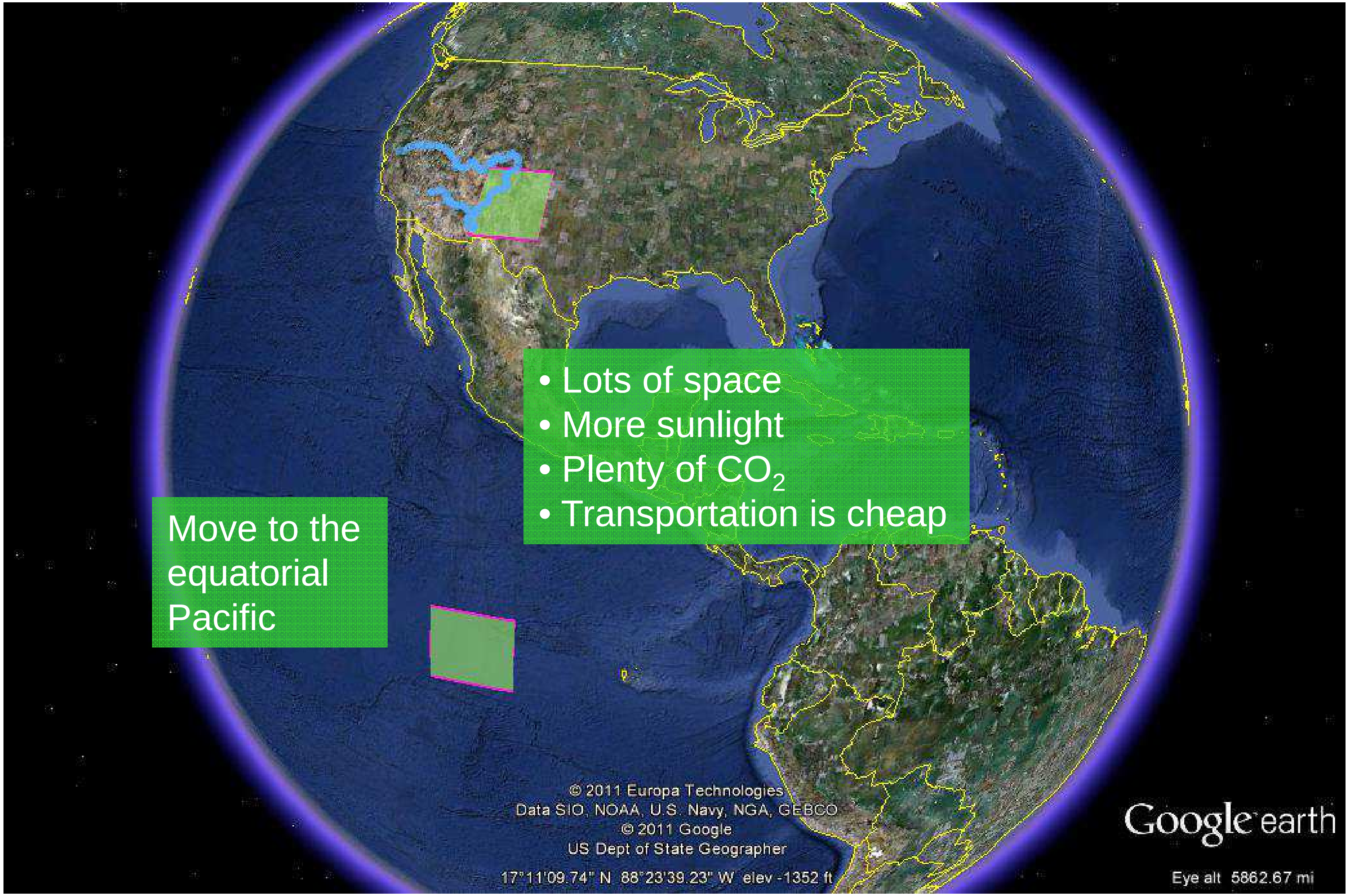
Source: Martha Groom, University of Washington; Elizabeth Gray, The Nature Conservancy; Patricia Townsend, University of Washington; as published in Conservation Biology

SEATTLE P-I

But the high productivity *should* be useful.



The Chesapeake Algae Project Aims for Open Water



- Lots of space
- More sunlight
- Plenty of CO_2
- Transportation is cheap

Move to the equatorial Pacific

The Ocean Food and Energy Farm
Howard A. Wilcox (another physicist) in 1974

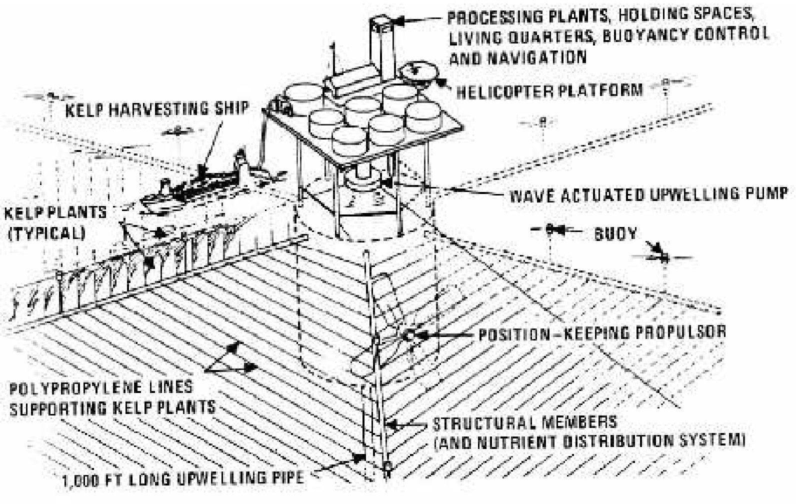


Figure 12. Initial concept for an Ocean Food and Energy Farm (Wilcox, 1975)

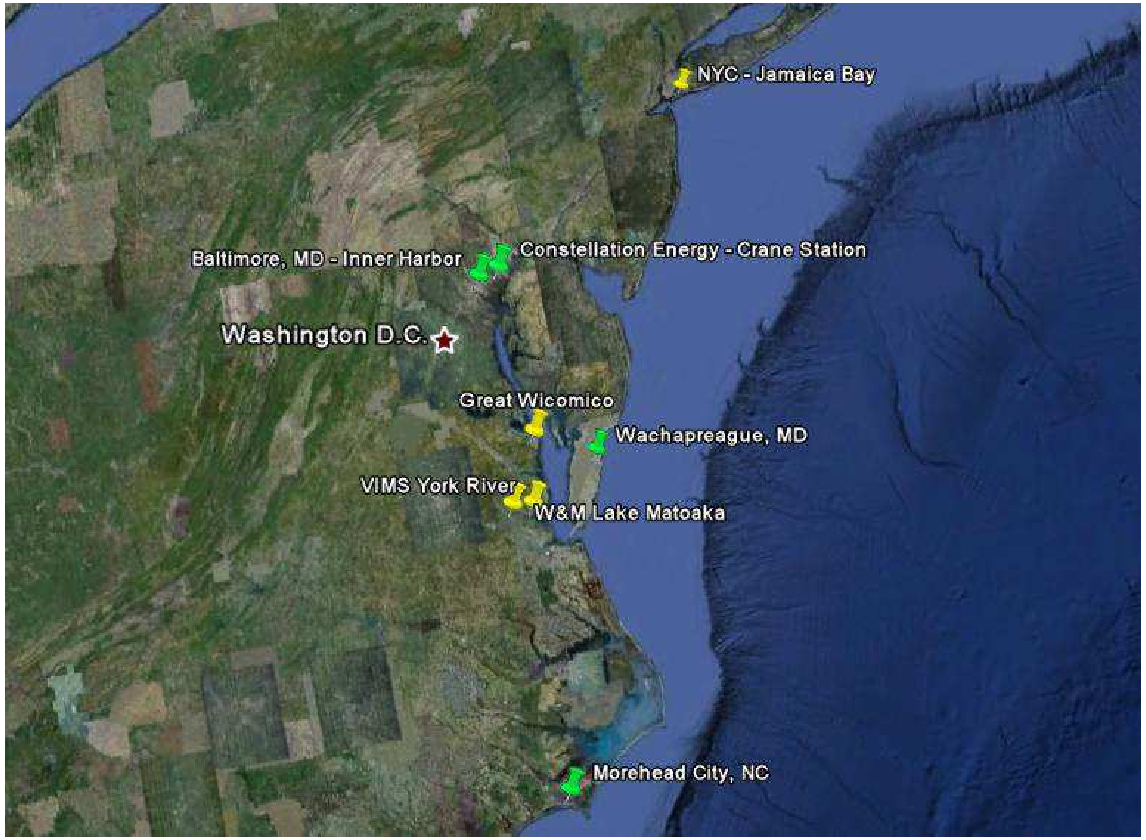
- Target productivity of 26 tons per acre per year (18 g/m^2/day)
- Mesh of ropes to grow seaweed
- Artificial upwelling to deliver nutrients
- Three attempts, the longest lasting for less than a month.

NASA's Project OMEGA

Offshore Membrane for Growing *Algae*

- Jonathan Trent (Astrobiologist)
- Uses wastewater for nutrients
- CO_2 added
- Freshwater Algae in plastic bags
- $12M for exploratory research
- No LCA as of yet

What is ChAP?

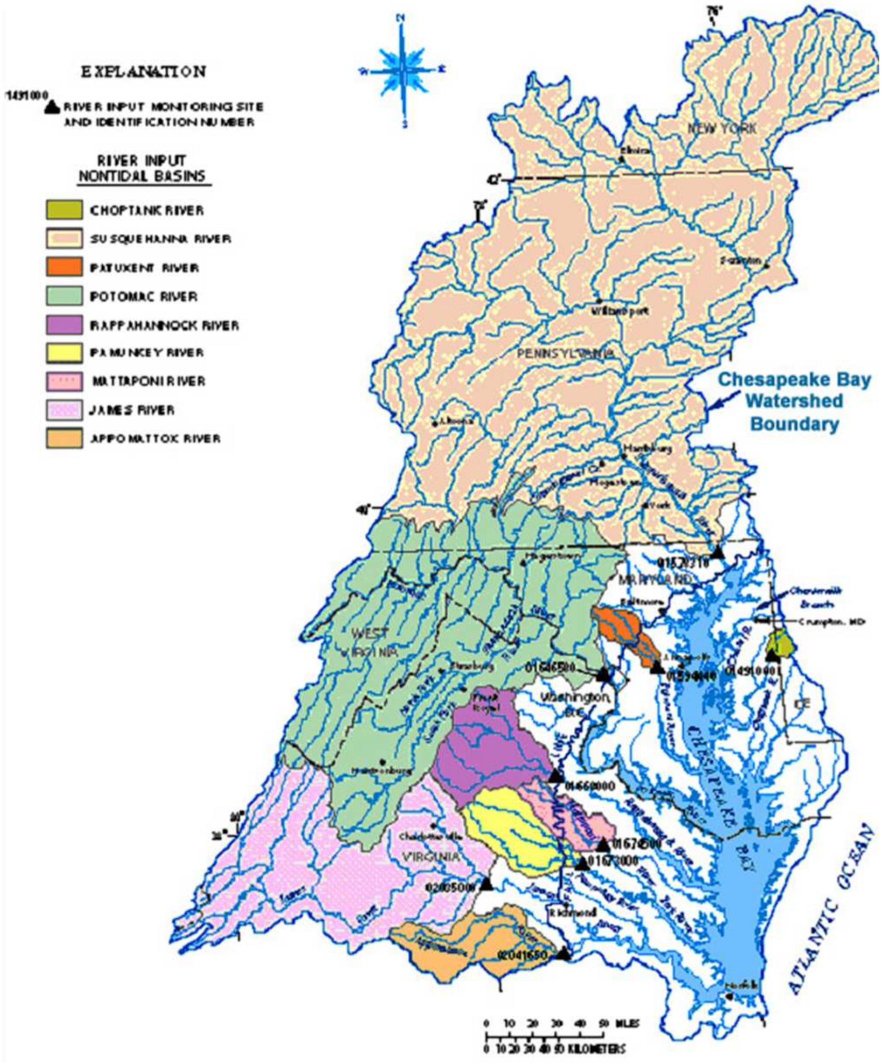


- VIMS
- CWM
- Blackrock Energy
- UMD
- Smithsonian
- U. Arkansas
- U Western Michigan

A novel algal energy scheme initially funded by Statoil (a Norwegian Oil Company)

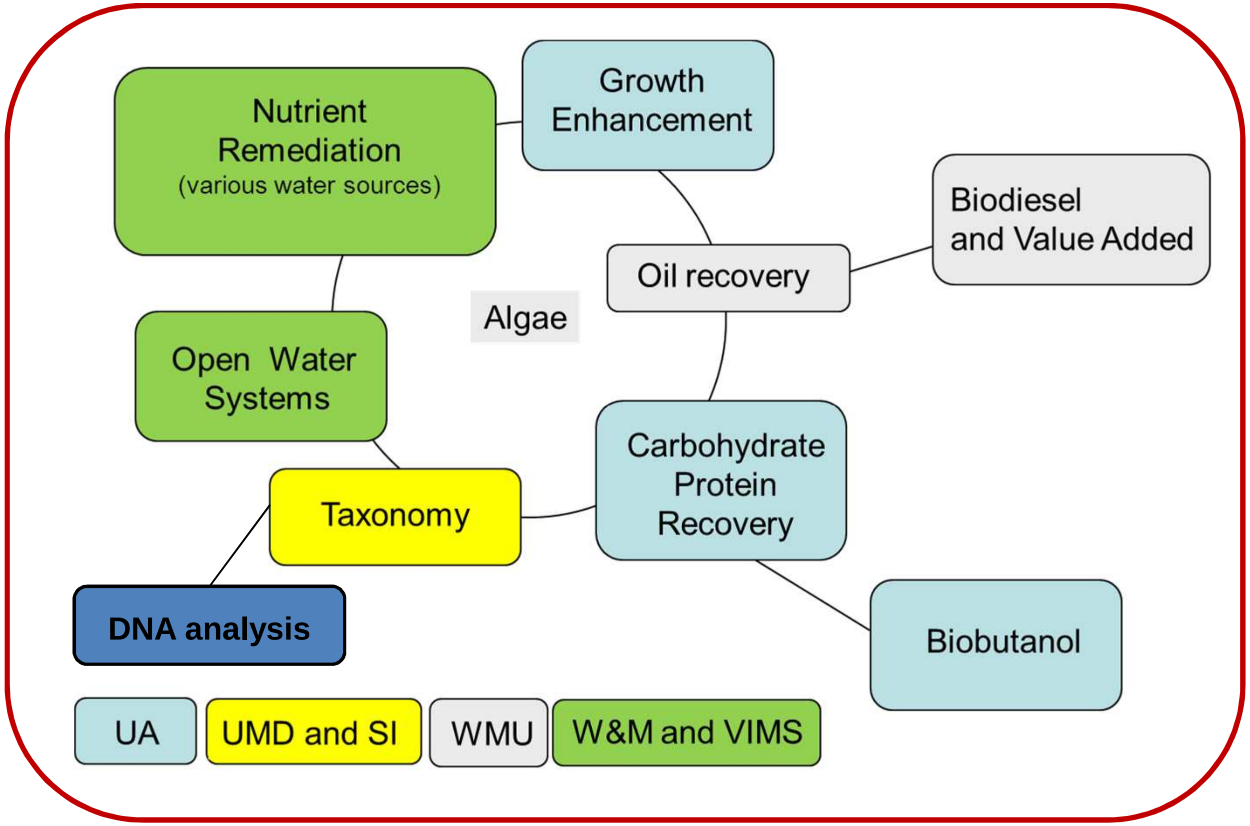
ChAP

- Develop systems to grow, harvest and process wild algae as a fuel feedstock.
- Test the suitability of chemically and biochemically converting the feedstock into fuels.
- Develop algae cultivation systems suitable for offshore locations.



chesapeake.usgs.gov/ featureflowandload.html

A multi-institution effort



Supported by:

How Is ChAP Different?

- Open water focus
- Algal farms *in* rivers and estuaries.
- Natural algae & other aquatic biomass
- Community focus rather than single species
- Site specific – optimized products and services
- Environmental remediation plus energy

Why wild algae in the water?

- Fast growing, naturally selected biofuel feedstock
- Captures and stores solar energy
- Does not compete for arable land or freshwater

A multi-part strategy

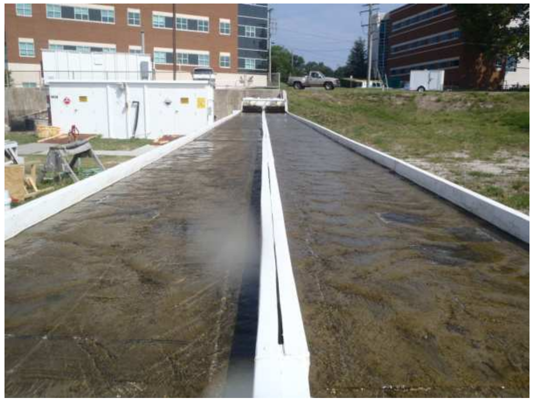
Land-based technology (Algae Turf Scrubber©)

Proven technology

Aquatic systems

Research and Development

Double-Wide ATS©



York River Research Platform

Advantages of Filamentous Wild Algae

- Easily harvested.
- Little (or no) drying necessary.

Advantages of Filamentous Wild Algae

- Easily harvested.
- Little (or no) drying necessary.

Sapphire Algae
<1% solids at
harvest

Our Algae
18-20% solids at
harvest

ChAP Fuel Production
Small Batch Experiments

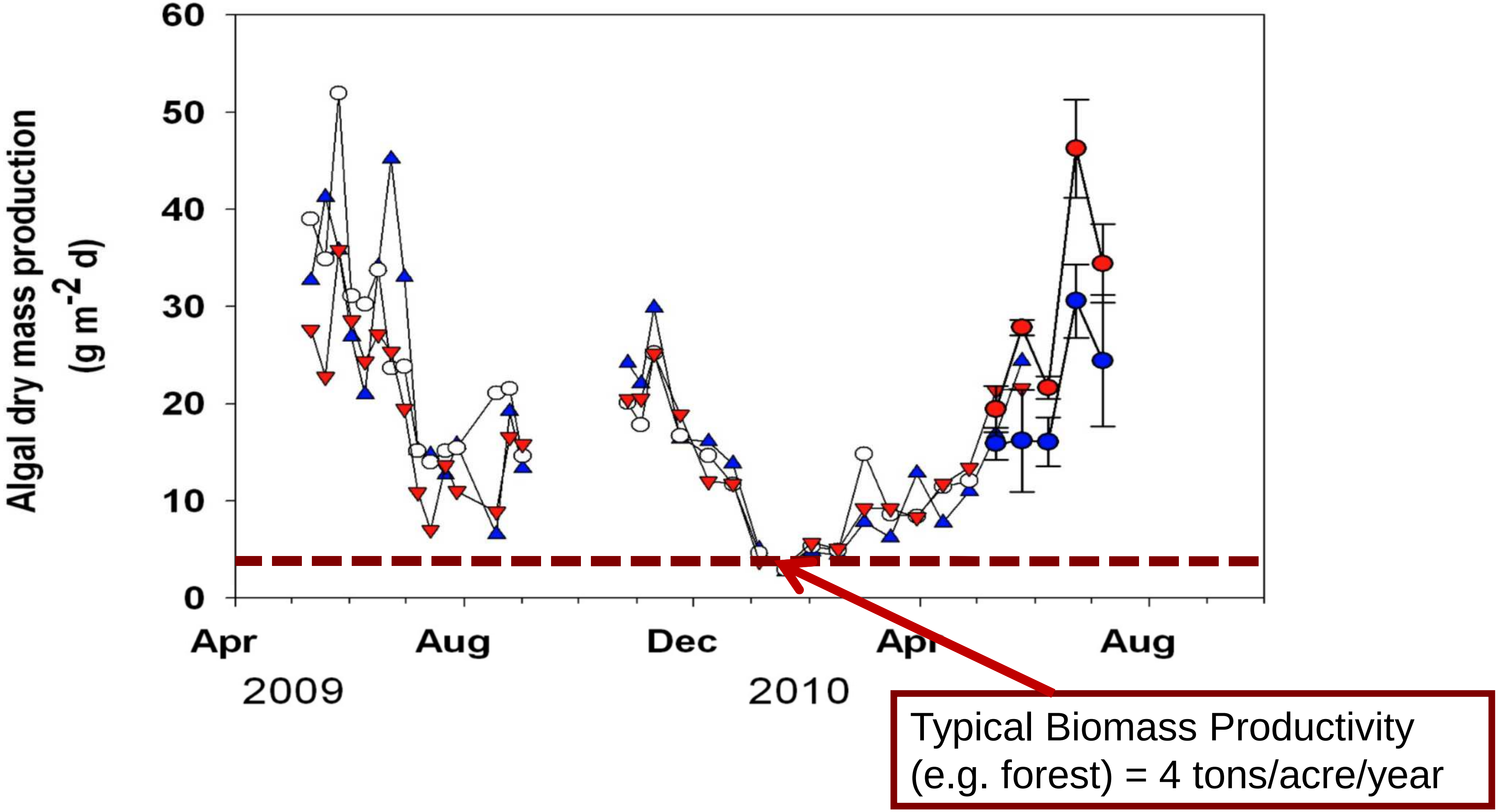
Preprocessing algal sugars to make butanol (a drop-in gasoline replacement)

Algae photosynthesis produces carbohydrates. But the big market is for biodiesel.

- Some species produce lipids naturally.
- Some species convert sugars to lipids (e.g. Solazyme).
- Algal sugars can also be fermented into ethanol.
- Algal carbohydrates can be converted into hydrocarbons using catalysts (*e.g.* supercritical water).
- Algal sugars can be converted into syngas using a Fischer–Tropsch process.

Sugar to hydrocarbon is exothermic!

Floway Results:
Algal Productivity



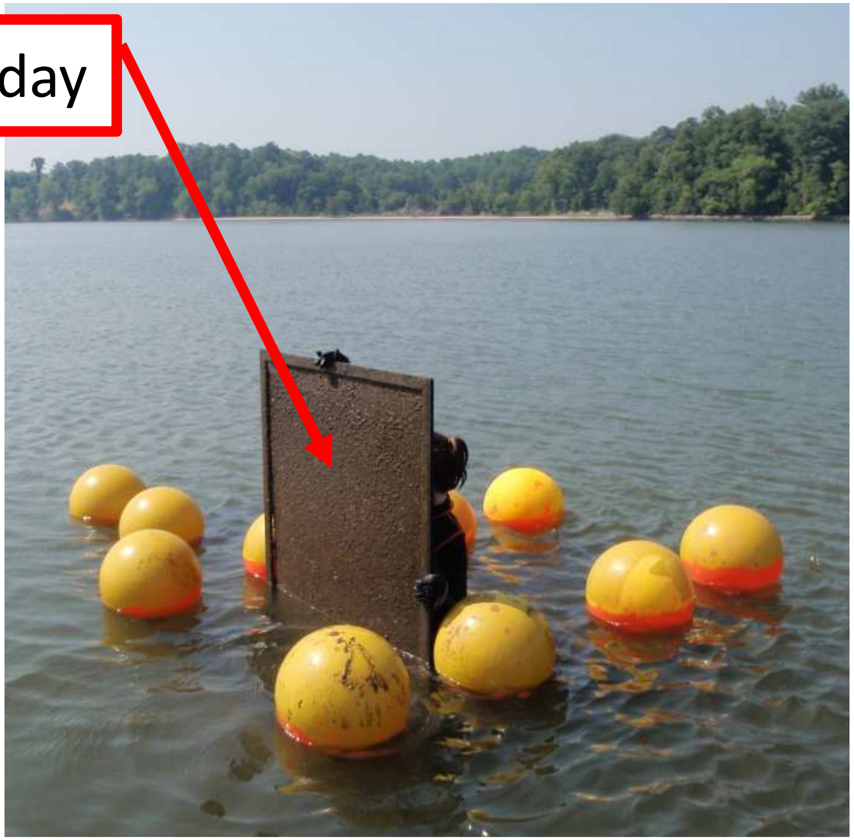
Early Success in the Water

Filamentous strands up to a meter long within a week.

Subscale
November 2009

Early Success in the Water

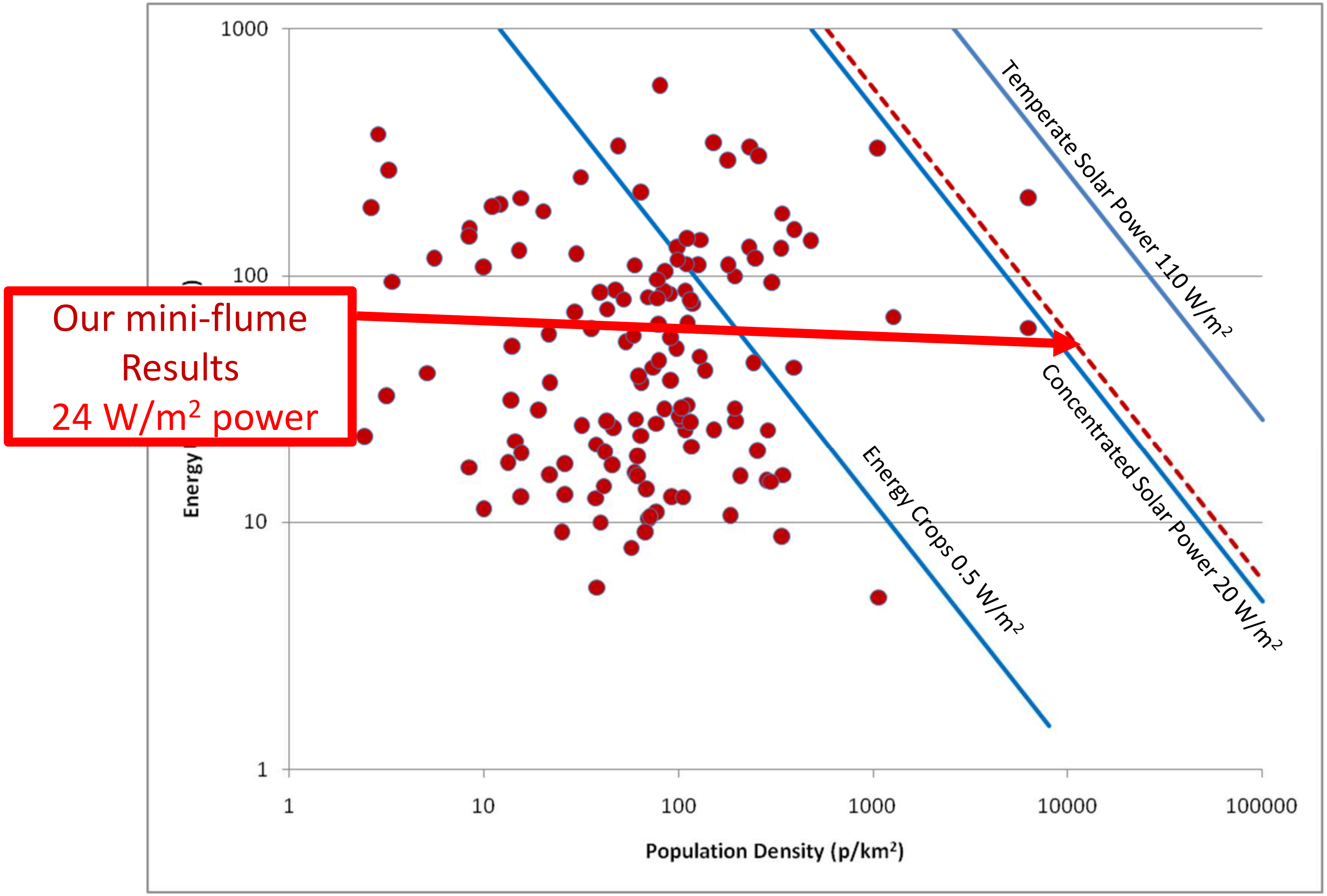
>500 gm/m^2/day



The York River here is 5 meters deep at low tide.

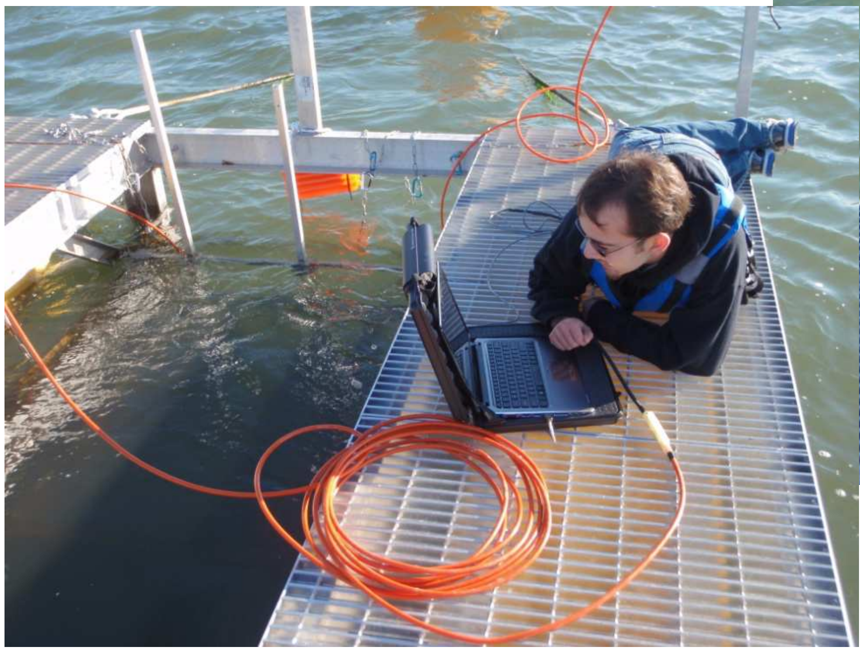
Miniflume
June 2010

An Aquatic Biomass Production System does not even need land!



York River Research Prototype: deployed October 2010

York River Research Prototype: A Floating Laboratory



- Substrates only 1 m deep
- Water confined from bow to stern

York River Research Prototype: Taxonomy

Mostly algae and sediment

- High cell counts
- 85% Ash

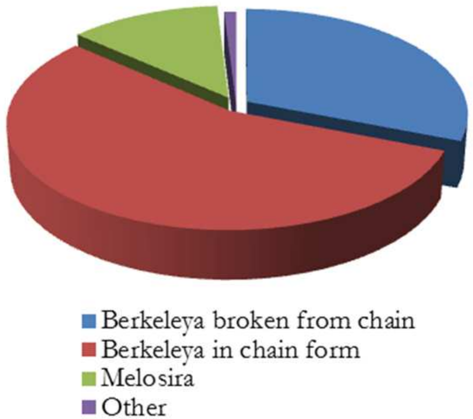


Figure : Primary Species Composition

Carbohydrates

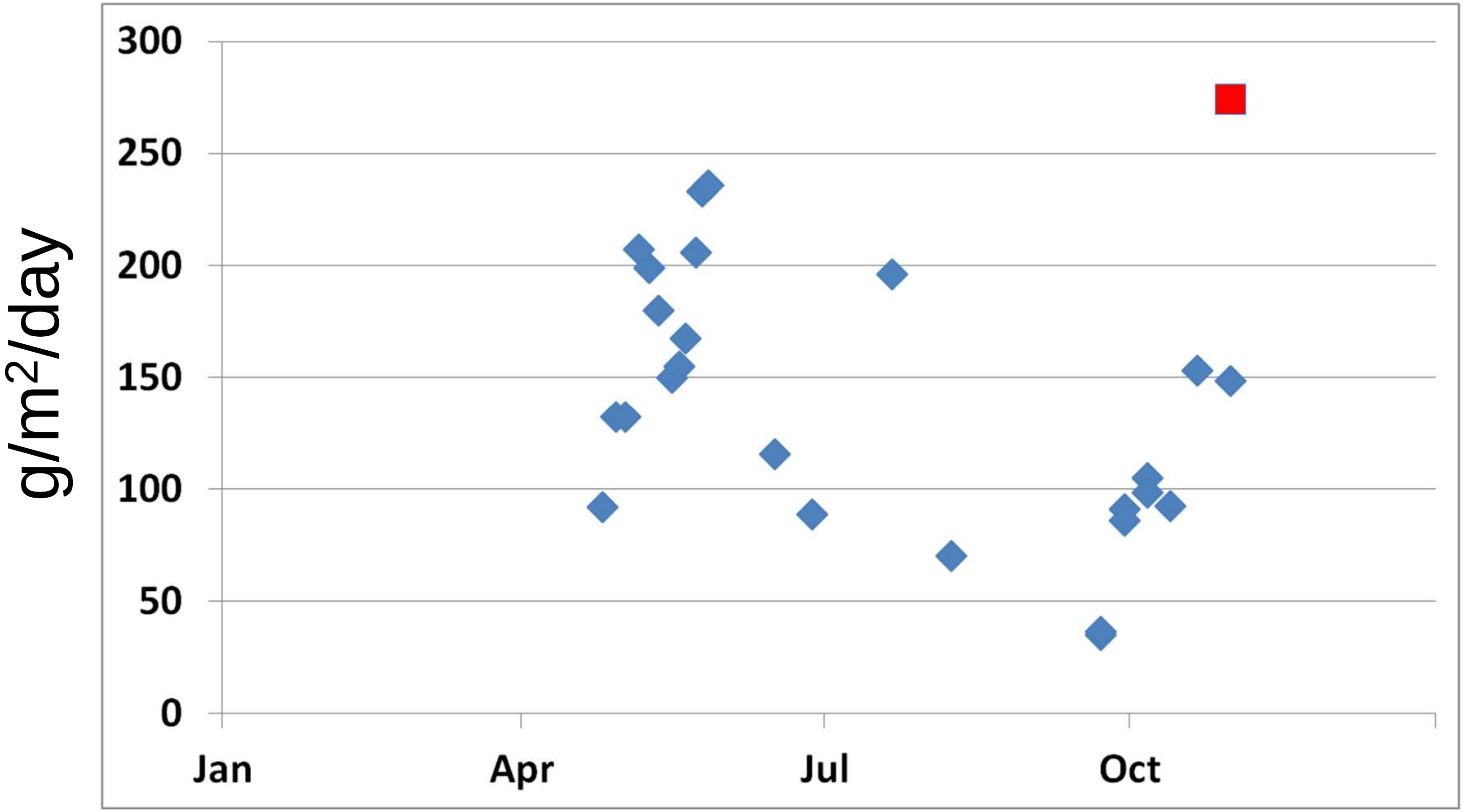
- Algae characteristics
  - Carbohydrate content can be as high at 35 - 40%
  - Very little cellulosic sugars
- Acid hydrolysis of biomass
  - Releases most of the sugars for fermentation
  - Various yields of carbohydrates via simple acid hydrolysis

Ash is 80-85%

Location and Time		Yield (g sugar/g dry algae)
Boat Basin Floway at [illegible]	04/13/10	0.146
Twin Floway at VIMS	[illegible]4/14/10	0.105
Boat Basin Floway at VIMS	[illegible]/10	0.152
Boat Basin Floway at VIMS	06[illegible]	0.133
York River	06/28/[illegible]	0.11
Boat Basin Floway at VIMS	07/07/10	0.139

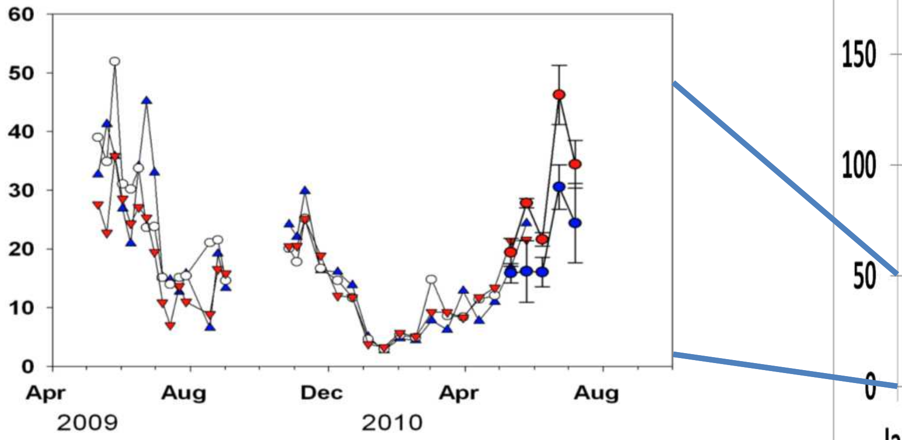
Table I. Sugar Yield from various venues via acid hydrolysis

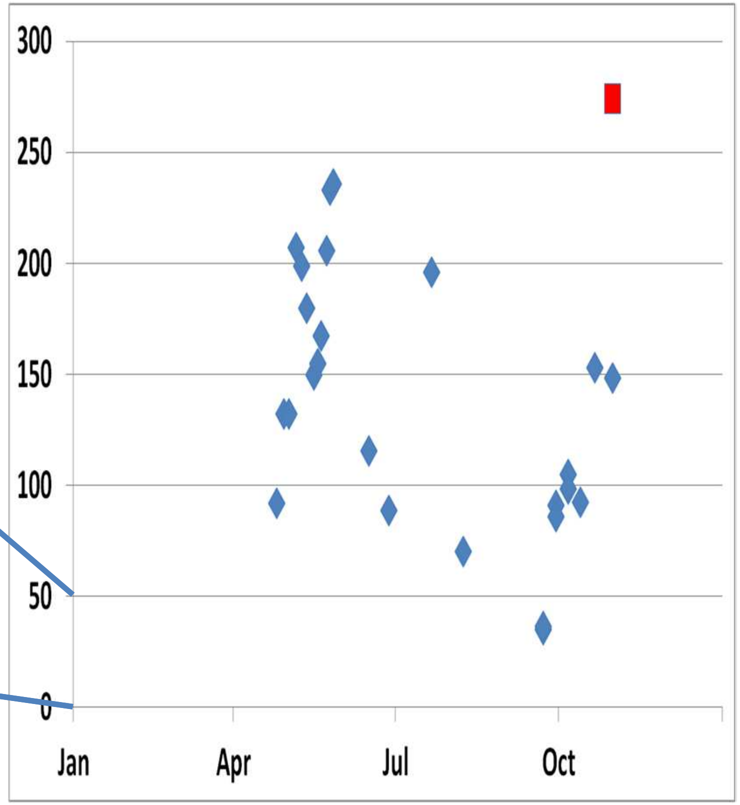
YRRP Results:
Algal Productivity



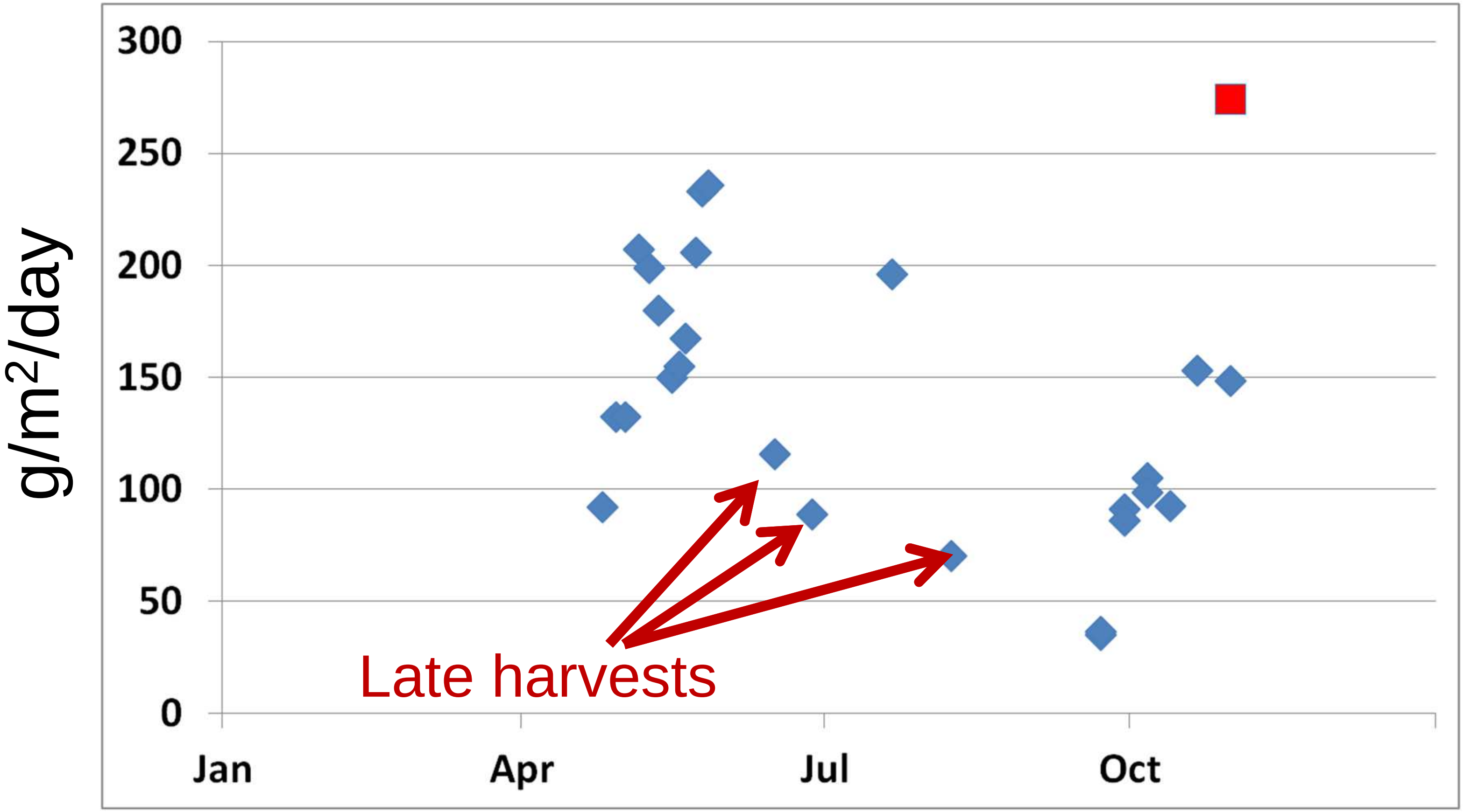
YRRP Results:
Algal Productivity

The minimum YRRP productivity is greater than the maximum flow way productivity!





YRRP Results:
Harvest Before Grazers Arrive



York River Research Prototype: Taxonomy

Diatoms

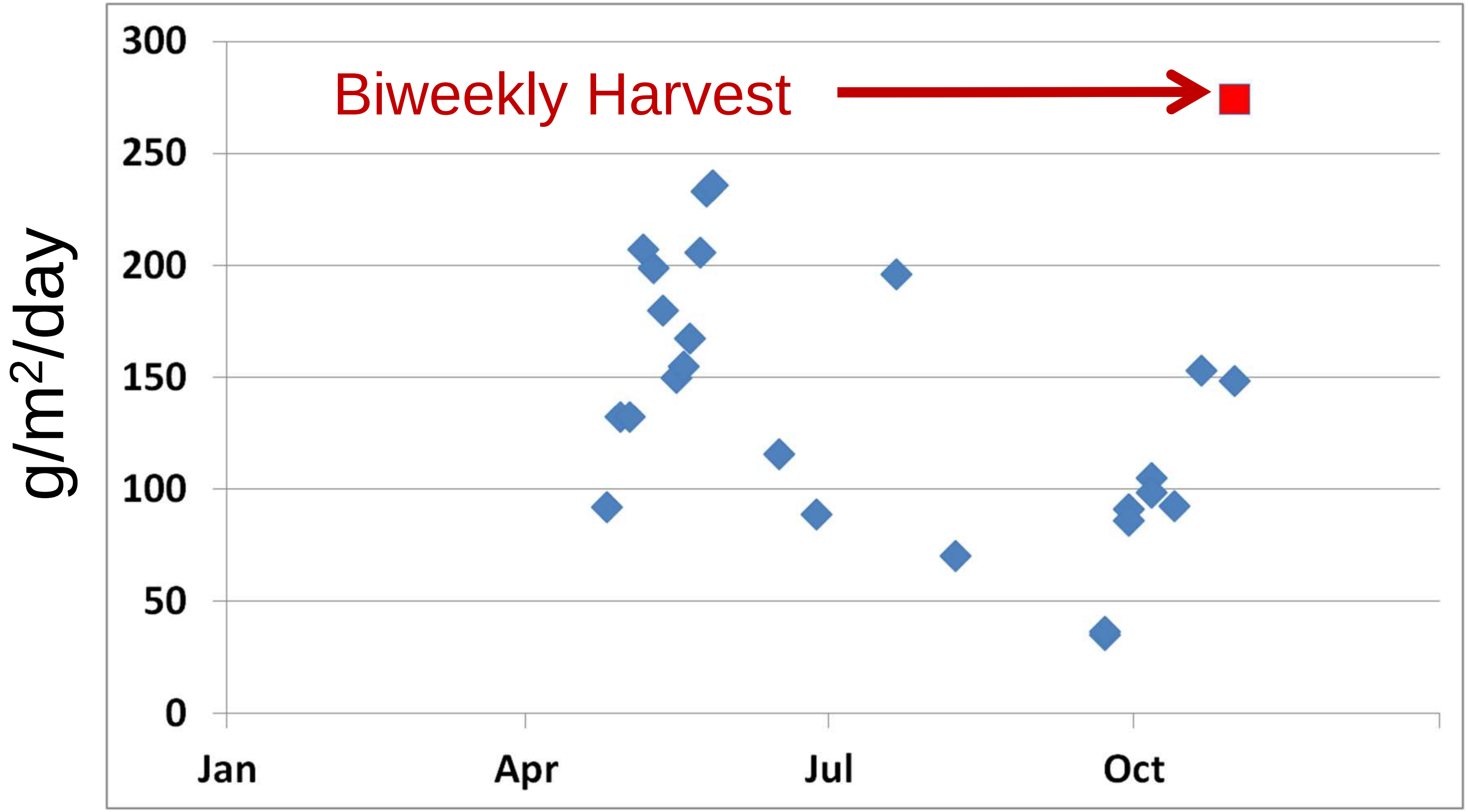
Diatoms and Tunicates

21 days

31 days

40 days

YRRP Results:
But Not Too Often



YRRP Results:
Questions

- How can the productivity be so high?
- Why does algae grow where the sunlight does not penetrate?
- How do you determine the optimum harvest schedule?
- How can you scale this up?
- How can you efficiently harvest the algae?

We are not ready for 100 million acres
Can we do anything with a smaller footprint?

ATS are used to clean water

Water is pumped from rivers or streams, flows over the ATS, and returns.

- 2.5 acre facility
- Treating 5 MGPD
- 2.3 kg/day PO_4 removed

WHY?

To Prevent Algal Blooms

Toxic algae outbreak on the Caloosahatchee River in June 2011.

EARTHJUSTICE
Because the earth needs a good lawyer

Algae has a complicated relationship with the environment

SCIENTIFIC AMERICAN™

The Origin of Oxygen in Earth's Atmosphere

The breathable air we enjoy today originated from tiny organisms, although the details remain lost in geologic time

By David Biello | August 19, 2009 |

CYANOBACTERIA BLOOM: Thanks to algal blooms like this one, the Earth's atmosphere is 21 percent oxygen. Image: Courtesy of J.L. Graham / USG

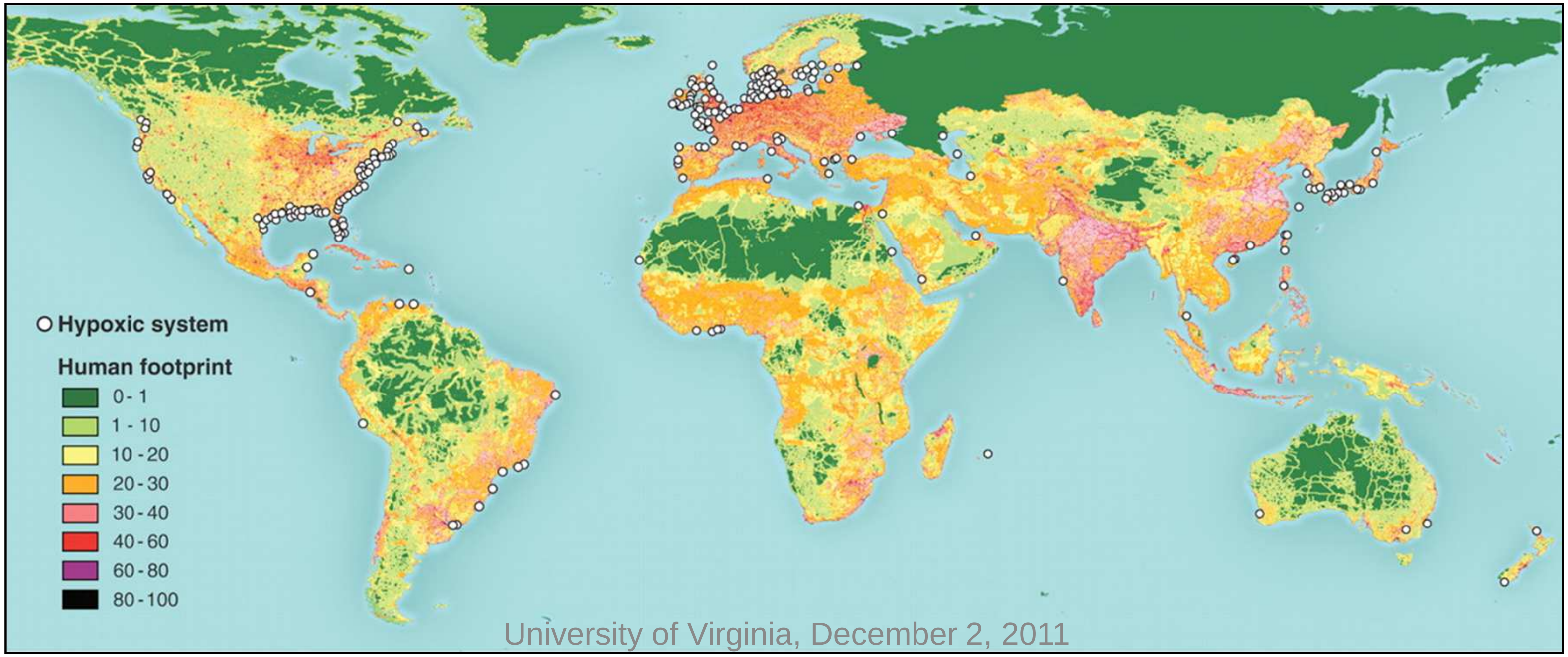
But now it is depleting oxygen

15 AUGUST 2008 VOL 321 **SCIENCE** www.sciencemag.org

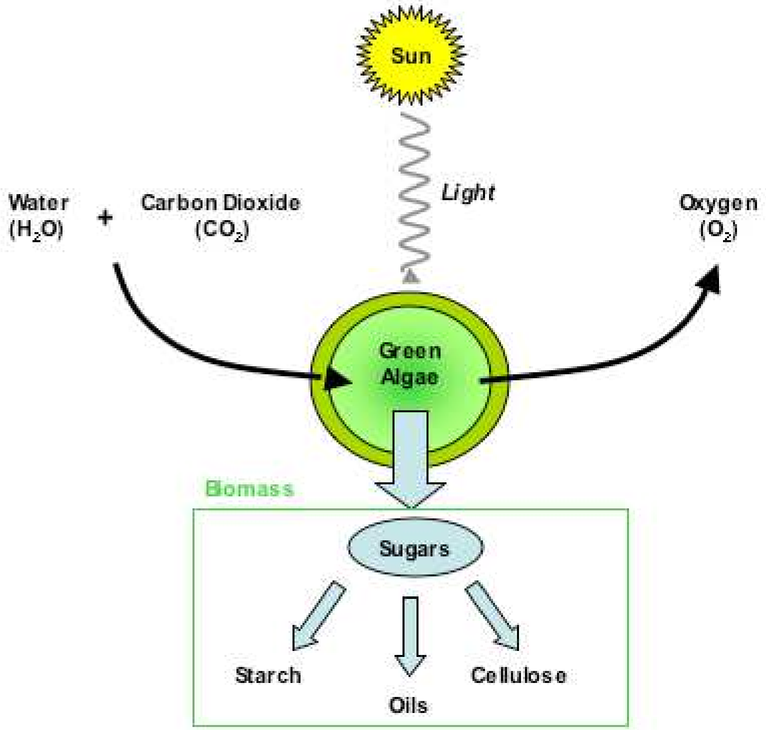
Spreading Dead Zones and Consequences for Marine Ecosystems

Robert J. Diaz[1]* and Rutger Rosenberg[2]

Dead zones in the coastal oceans have spread exponentially since the 1960s and have serious consequences for ecosystem functioning. The formation of dead zones has been exacerbated by the increase in primary production and consequent worldwide coastal eutrophication fueled by riverine runoff of fertilizers and the burning of fossil fuels. Enhanced primary production results in an accumulation of particulate organic matter, which encourages microbial activity and the consumption of dissolved oxygen in bottom waters. Dead zones have now been reported from more than 400 systems, affecting a total area of more than 245,000 square kilometers, and are probably a key stressor on marine ecosystems.



These algae are phototrophic



Graphic©SustainableGreenTechnologies-2008

Problems start when the algae die.

As they decay, the nutrients return to the water to cause another algal bloom.

The bacteria that cause the decay remove oxygen from the water, and release CO_2.

The Only Good Alga is a Live Alga

- Living algae creates oxygen, stores solar energy, and uses excess nutrients.
- Dead algae undoes all this – at the bottom of the water body.
- So harvest the algae before it dies, and let it clean the water.

Flow way Results:
Nutrient reduction efficiency

Typical Nitrogen reductions (80' floway):

- 20% Decrease in TDN
- 50% Decrease in NH_3
- 64% Decrease in NO_x

- More algal production drives greater decreases
- Higher ambient nutrients produce greater decreases

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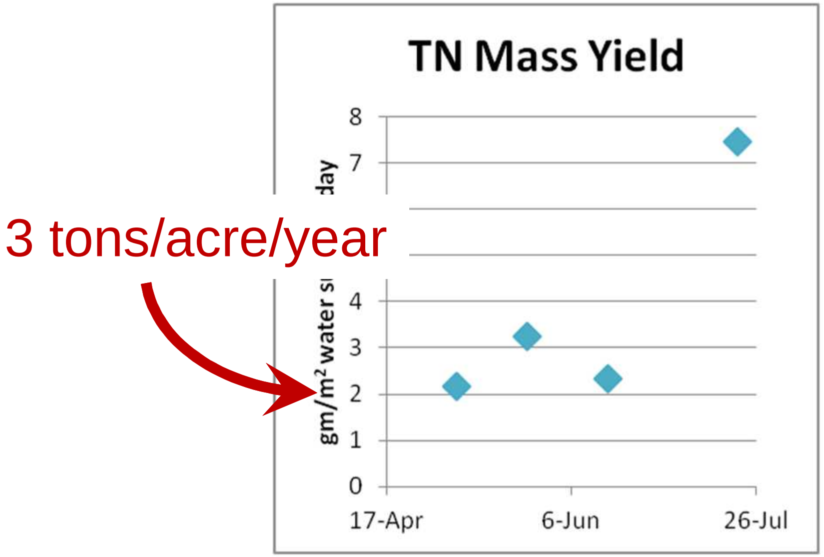
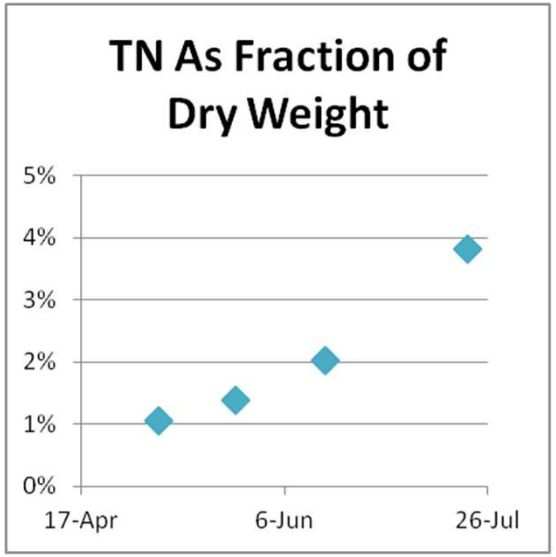
YRRP Results:
Nitrogen Removal





Nitrogen is always at least 1% of the total weight. Phosphorus is usually between 0.3-1%. We believe the variation shows the evolution of the community.

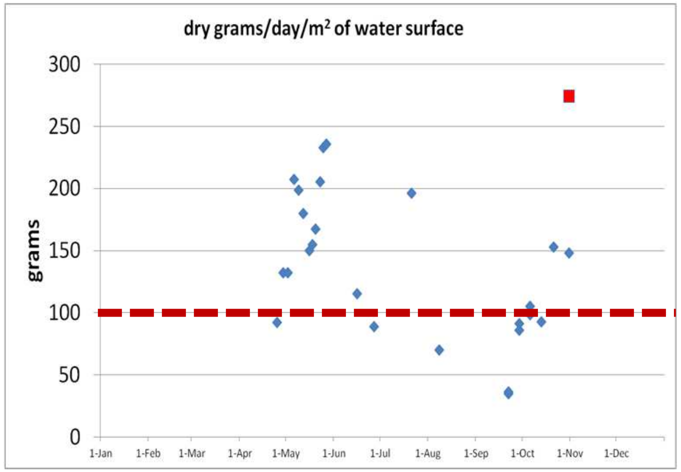
Scaling the York River Research Prototype

Scaling the York River Prototype:

Each year a 1 acre facility would :

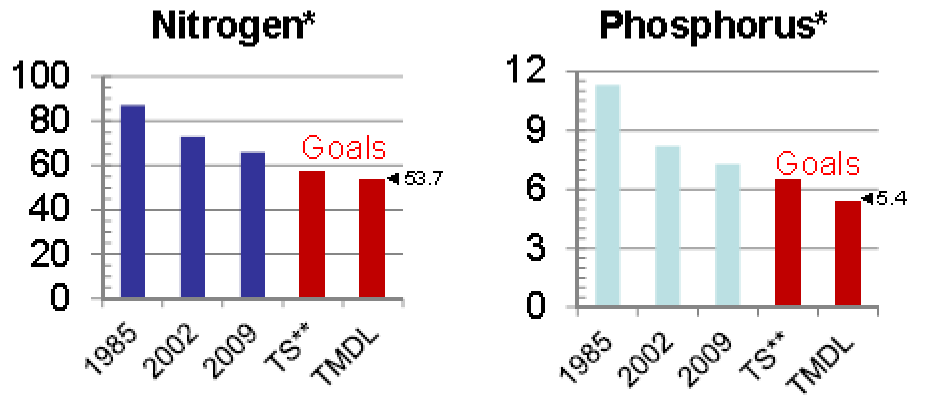
- Produce >150 tons of dry algae
- Sequester 1.5 tons of TN (17 acres of Wetlands)
- Sequester 450 pounds TP (45 acres of Wetlands)
- Sequester 70 tons of sediment
- Sequester 5.5 tons of CO_2

Sequestered amounts can be easily verified by an analysis of the algal product!



- Biogrowth removes N,P, and sediment
- Biogrowth removes CO_2

Can we afford environmental cleanup?



* Virginia's Nitrogen and Phosphorus loads into the Chesapeake Bay in million pounds per year.
**TS refers to the Tributary Strategy goals adopted by Virginia in 2005.

VA has agreed to reduce:

5500 tons N
1300 tons P

Chesapeake Bay TMDL Watershed Implementation Plan: What Will it Cost to Meet Virginia's Goals
Senate Finance Committee, November 18, 2011

We are already committed!

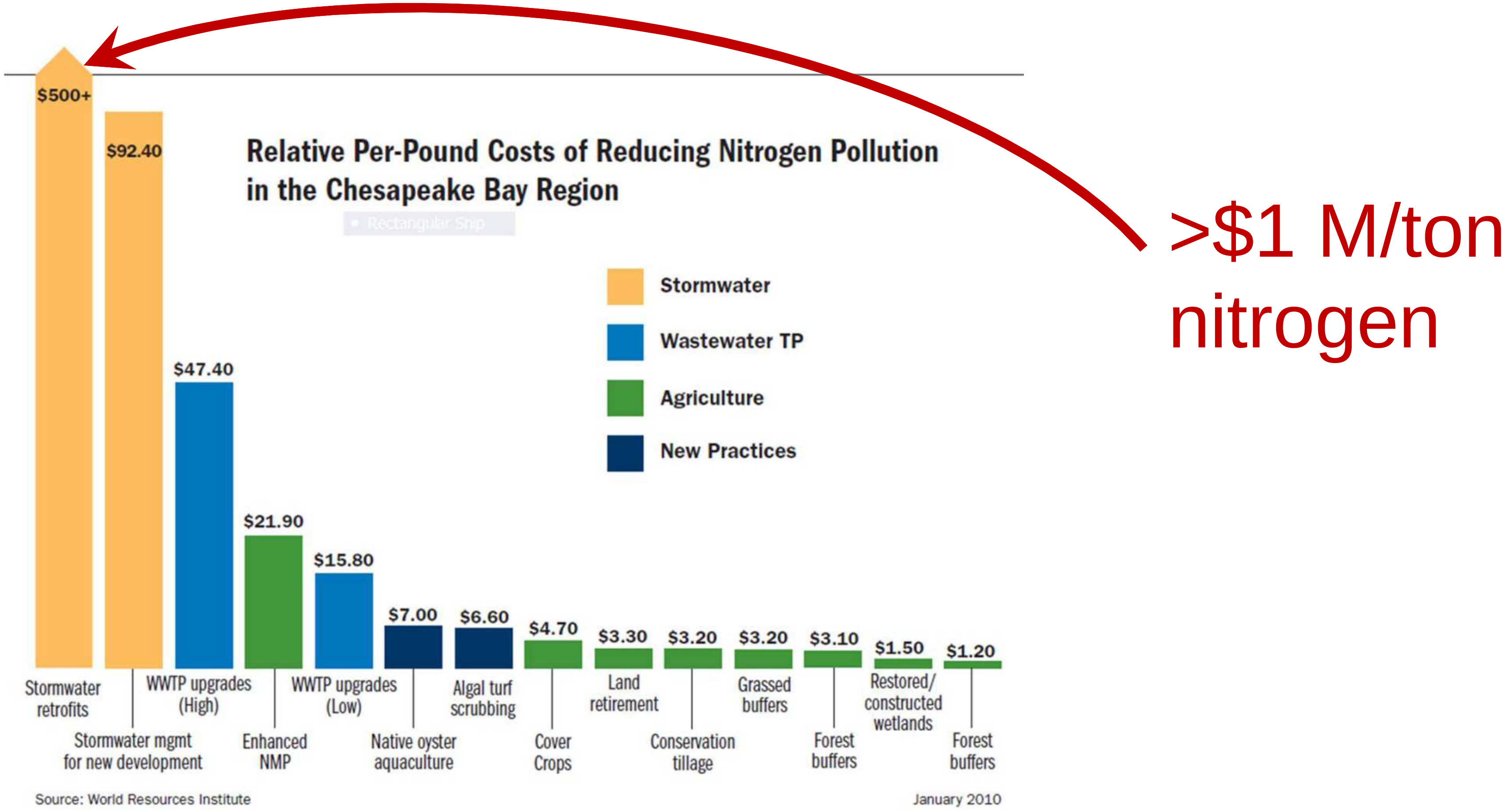
	Projected Total Cost ($ in billions)	Who Pays	Potential State Costs ($ in billions)	Potential Sources of Funding
Wastewater (including CSOs)	$1.4	State Govt./Local Govt./Rate-payers	$0.3 (plus $78 million for CSOs?)	WQIF, State GF, Bonds/Local GF, Bonds/Tax Assessments, Sewer Rates
Agriculture	$1.2+	State Govt./ Farmers	$0.8+	WQIF, State GF/ Agribusinesses
Stormwater	$9.4 to $11.5 (including VDOT)	Local Govt./ Property Owners/ VDOT	$2.1 (VDOT Share)	Local GF, Bonds/Utility Fees, Assessments/ Transportation Trust Fund
Onsite/ Septic Systems	$1.6	Property Owners	Unknown What Role State May Play	"Betterment loans", Potential for Tax Credits or Grants
Bay TMDL Total	**$13.6 to $15.7**	**Potential State Total**	**$3.2+**	

$580,000 per ton of nitrogen removed!

(State share only)

Chesapeake Bay TMDL Watershed Implementation Plan: What Will it Cost to Meet Virginia's Goals
Senate Finance Committee, November 18, 2011

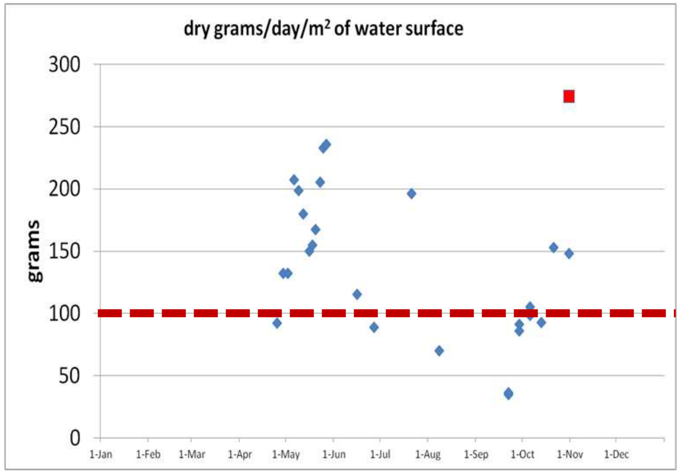
And that is NOT the low hanging fruit!



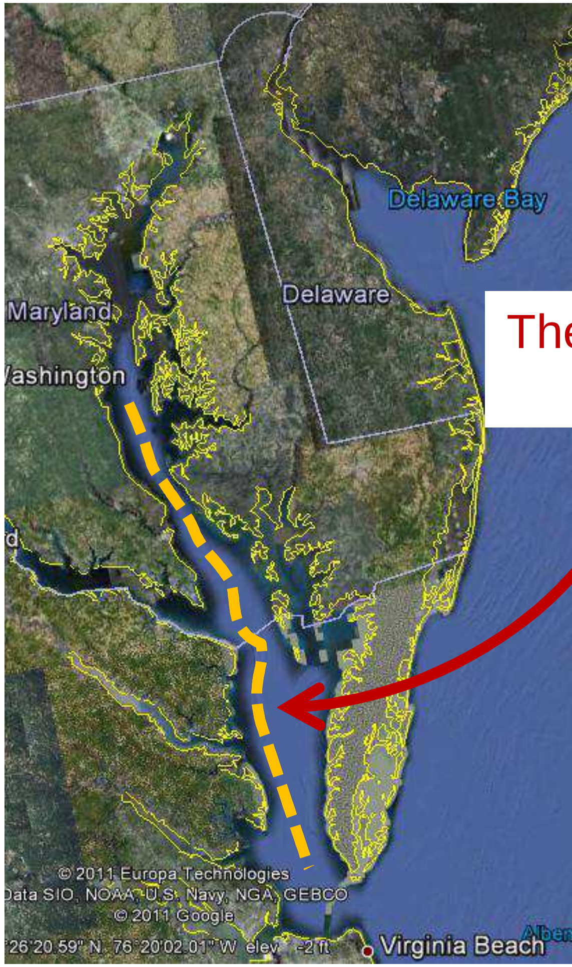
Chesapeake Bay TMDL Watershed Implementation Plan: What Will it Cost to Meet Virginia's Goals
Senate Finance Committee, November 18, 2011

Meeting Virginia's TMDL for the Chesapeake Bay

An in-water system, 70 meters wide, and 200 miles long would remove at least 5500 tons of nitrogen per year.



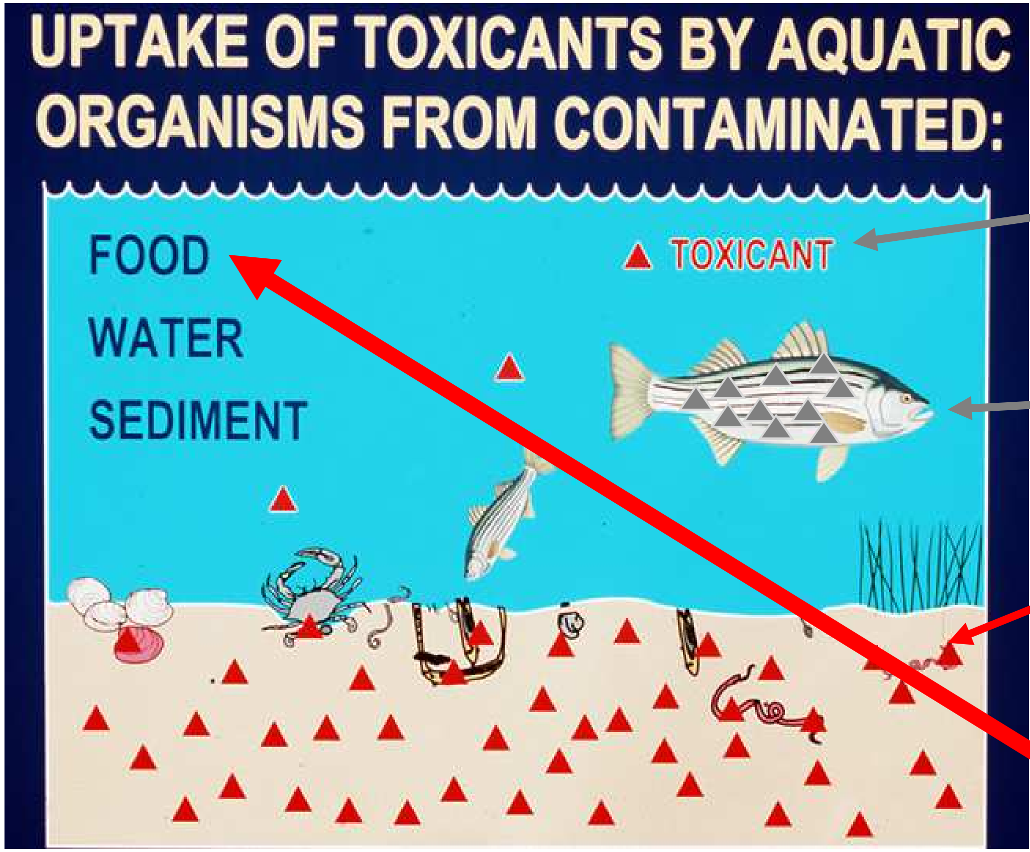
1.5 tons of nitrogen per year per acre!



The width of I-64

Can this help with toxic chemicals?

Hydrophobic contaminant fate is governed by partitioning



Limited water solubility "hydrophobic"

High affinity for lipid material "lipophilic" organic carbon

Algae contains lipids too

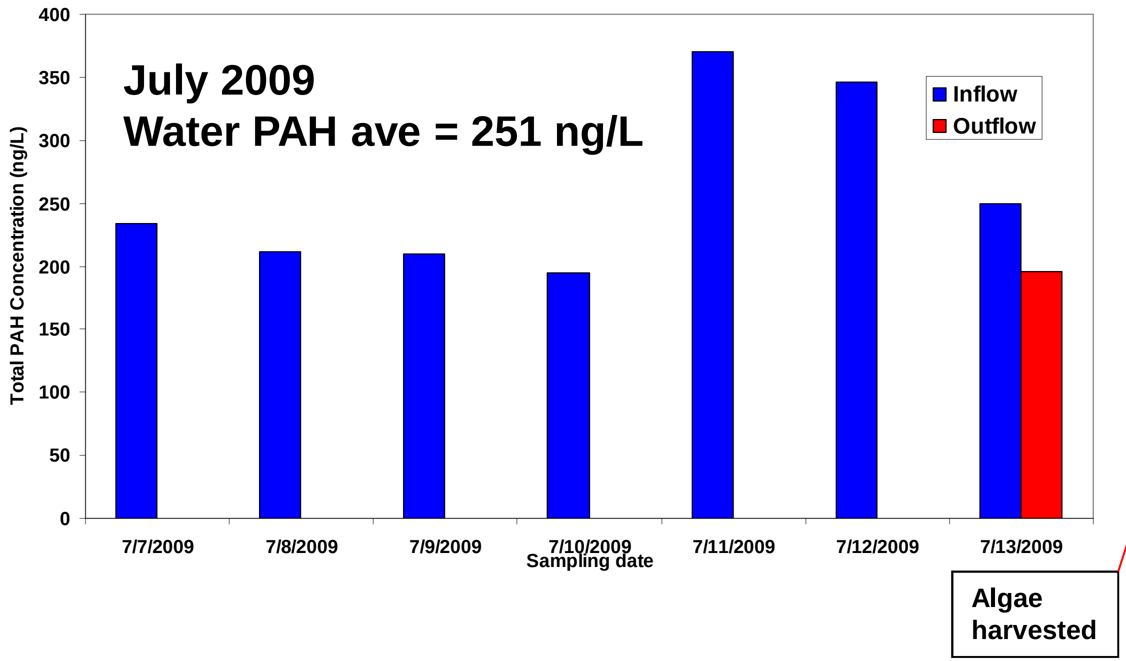
Algae is a main pathway for introducing higher organisms to hydrophobic contaminants

"Like Dissolves Like"

Other Toxic Chemicals

York River Floway, Virginia

Polycyclic aromatic hydrocarbons (PAH)
Combustion products and toxic, water soluble components in oil pollution



Algae	ng/g PAH
Rep 1	2687
Rep 2	2848
Rep 3	2857
Rep 4	2552
Ave	2736 ng/g

PAH in algae similar to Susquehanna

PAH are lower in effluent

PAH Apparent Partitioning Coefficient

$$K_{app} = \frac{2736 \text{ ng/g}}{251 \text{ ng/kg}} = 10{,}900$$

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Algae Biofuel Summary

Sustainable in-water algae farming can generate fuel.

Sustainable in-water algae farming can improve water quality throughout the Commonwealth.

Sustainable in-water algae farming can be a new aquaculture industry.

The Chesapeake Algae Project

We aim to turn pollution into fuel

Algae link two of society's most pressing challenges:

"the source problem"—dwindling fossil fuel supplies
"the sink problem"—fouling of the global environment

The ChAP Teams

CWM Growth Systems
Randy Chambers
Charlotte Clark
Bill Cooke
Karl Kuschner
Dennis Manos
Gene Tracy

Fuel Processing
Robert Beitel (UA)
Mark Forsythe
Jaime Hestegen (UA)
Robert Hinkle
John Miller (UWM)
Kurt Williamson

VIMS Flow way
Walter Adey (Smithsonian)
Emmet Duffy
Paul Richardson

Other flow ways
Walter Adey (Smithsonian)
Patrick Kangas (UMD)
Dail Laughinghouse (UMD)

Industrial Coordination
Jay Diezick (Blackrock Energy)

VIMS Biochemistry
Elizabeth Canuel
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