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Opportunities & Challenges For CO_2 Capture & Utilization with Algae

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Illinois Sustainability Technology Center Board Meeting
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30 years
1985-2015

Algae in the National News

"If we could make energy out of algae, we will be doing alright. "

"Algae can replace up to 17% of the oil we import for transportation."

Feb. 23, 2012 University of Miami

Algae has attracted significant investment

- Exxon-Mobil committed up to $600 Million for algal biofuel research
- Algal companies attracting significant venture capital- Sapphire, Algenol, Aurora, Heliae
- Algal biofuel trials by the Navy, United Continental, and Virgin Atlantic Airlines
- AlgaeWheel wastewater system receives the Water Environment Federation's Innovative Technology Award in 2015

Why is Algae Interesting for CO_2 Capture?

Life and the Evolution of Earth's Atmosphere

James F. Kasting[1,*] and Janet L. Siefert[2] (Science, 2002)

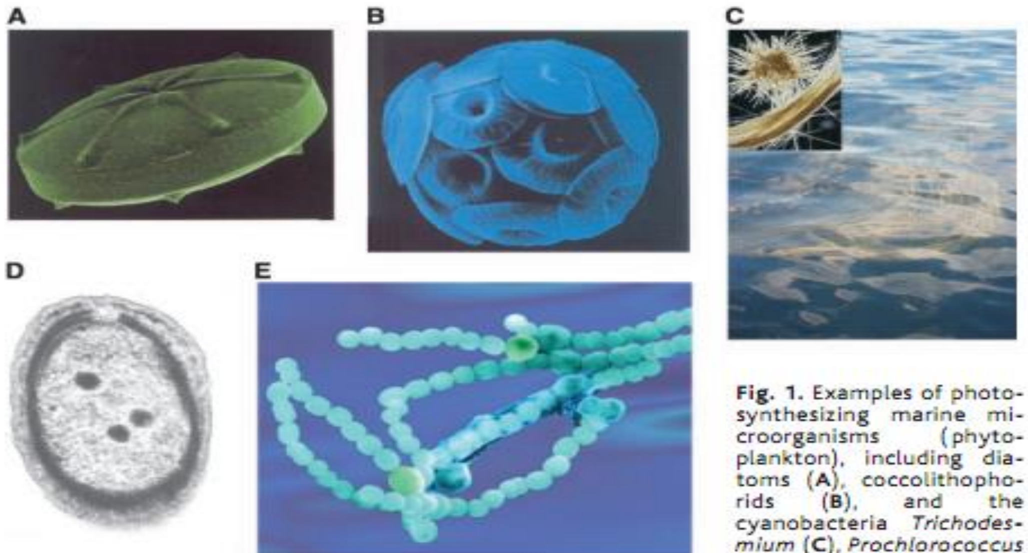


Fig. 1. Examples of photosynthesizing marine microorganisms (phytoplankton), including diatoms (**A**), coccolithophorids (**B**), and the cyanobacteria *Trichodesmium* (**C**), *Prochlorococcus* (**D**) and *Anabaena* (**E**). [(A)

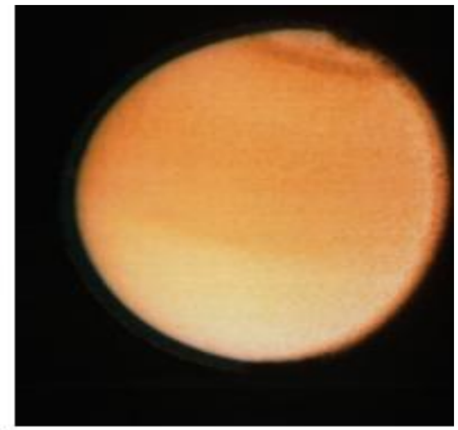


Fig. 2. This photograph of Saturn's m Titan, shows the orange-tinted haze th thought to be formed by photolysis charged-particle bombardment of met in Titan's upper atmosphere. The Cassini sion, now on its way to Saturn, will test model by dropping a probe into Titan'

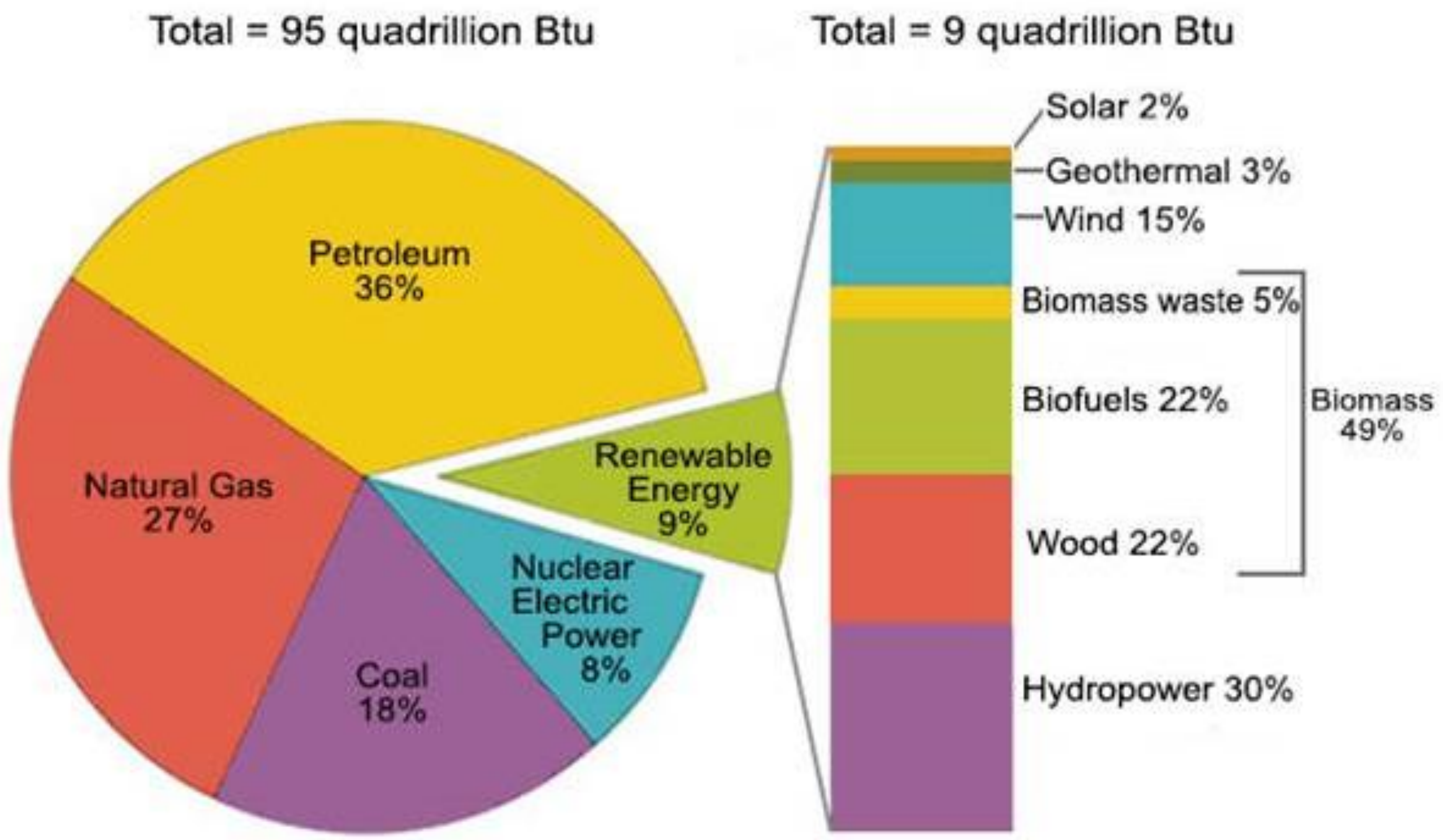
- Algae have already had a transformative effect on the earth's atmosphere!
- Can we tap the power of algae to transform our world again?

Algae's Synergy with Power Production

Point source CO_2 for algae growth

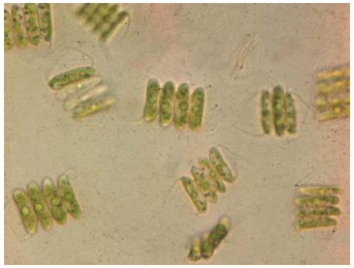
- Total US CO_2 emissions = 6.6 billion tons CO_2 / yr
- US power industry CO_2 = 2.5 billion tons CO_2 / yr
- 100% US diesel via algae ~ 1 - 4 billion tons CO_2/yr
- Algae ponds can utilize 30% - 90% of injected CO_2
- Algae growth and power usage both follow a diurnal pattern

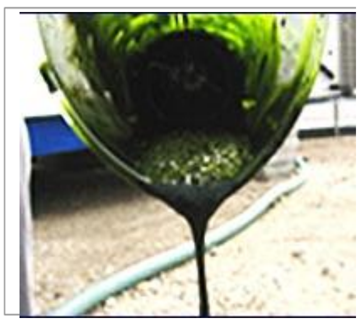
Renewable Alternatives to Petroleum Could Scale with Power Production

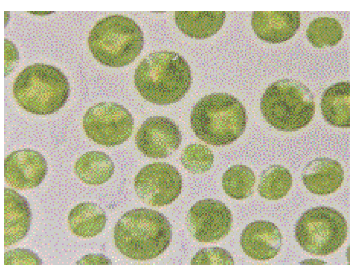


Note: Sum of components may not equal 100% due to independent rounding.
Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 1.3 and 10.1 (April 2013), preliminary 2012 data.

Algae can grow fast and be a feedstock for biofuels







Crop and Fuel	Fuel Yield (gal/acre)
Soy Biodiesel	45 - 60
Canola Biodiesel	100 - 130
Algae Biodiesel (15% oil, 10 $g/m^2/d$) (50% oil, 50 $g/m^2/d$)	600 - 10,000
Corn Ethanol	300 - 600
Miscanthus Eth.	800 - 1,200

Source: Chisti, 2009

- Long-term Field Studies
  - 10 $g/m^2/day$, Wiessman, 1988, 730 days, 1000 m^2, New Mexico
  - 30 $g/m^2/day$, Laws, 1985, 400 days, 48 m^2, Hawaii,
  - 20 $g/m^2/day$, Seambiotic, 650 m^2, Israel
  - 40 $g/m^2/day$, AlgaeLink, Netherlands, (bioreactor)

Algae can be an advantageous animal feed product

- Omega 3/6 PUFA enriched meat & egg products
- Adding algae to the diet of cows resulted in
  - Lower breakdown of unsaturated fatty acids
  - Better weight control, healthier skin and a lustrous coat (Pulz and Gross 2004)
- Improved the color of the skin, shanks and egg yolks of poultry

Algae Can Provide Significant Nutritional Products

- Ancient Chinese and Aztec cultures record algal food uses
- Algae provide ~ 50% of global primary production
- Global algae production > 7000 tons/yr and $1-2 Billion/yr
- Many algae are rich in protein and amino acids (>60%)
  - Peptides extracted from *Chlorella* can prevent cellular damage *(Lordan et al, 2011)*
- Many algae are rich in natural pigments and antioxidants
  - Astaxanthin- red pigment in krill oil and pink color in salmon
  - Phycocyanin- highly desired natural blue pigment
- Many algae are a rich source of Omega 3 poly-unsaturated fatty acids (PUFAs)

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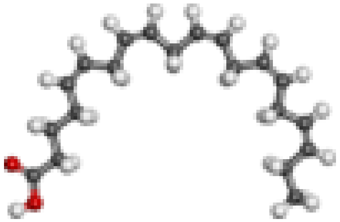
Algae for Ω–3/6 poly-unsaturated fatty acids (PUFA)



- Docosahexaenoic Acid (DHA, 22:6n3)
- Eicosapentaenoic Acid (EPA, 20:5n3)
- Arachidonic Acid (AA, 20:4n6)
- Reduces cardiovascular diseases & obesity (Breslow, 2006)
- Key roles in cellular and tissue metabolism (Cardozo 2007, Guaratini et al. 2007)
  - Regulation of membrane fluidity
  - Thermal adaptation
  - Electron and oxygen transport

Algae PUFA Content and Market Value

	EPA	DHA
Cod Liver Oil	12.5% TFA	9.9% TFA
Isochrysis galbana	22.6%	8.4%
Phaeodactylum tricornutum	29.9%	0.2%
Pavlova sp.	18.0%	13.2%
Market Value	$200,000/ton	$18,000,000/ton

Algae can be used for Cosmetics and other Chemical Products

- Spolaore et al. (2006) noted that algae can
  - Repair signs of early skin aging,
  - Exert skin-tightening effect
  - Prevent stria formation
  - Stimulate collagen synthesis in skin

- Algae has applications for
  - anti-aging cream
  - emollient
  - anti-irritant in peelers
  - sun protection

- Algae has been used in a variety of chemical products
  - plastics, fertilizers, soil conditioners, etc

New Market Target :
High-value algal biomass

Spirulina sp.	3000 tons	China, India, US, Myanmar, Japan	Human/animal nutrition cosmetics, phycobilin pigments
Chlorella sp.	2000 tons	Taiwan, Germany, Japan	Human nutrition, aquaculture, cosmetics
Dunaliella salina	1200 tons	Australia, Israel, US, China	Human nutrition, cosmetics, b-carotene
Haematococcus pluvialis	300 tons	US, India, Israel	Aquaculture, astaxanthin
Crypthecod-inium cohnii	240 tons	US	DHA oil

Total = ~7000 t DW/yr, Value = $1-2 billion /yr

Algae Can Treat Wastewater:
Shared facilities & reuse of water/nutrients

(Photos courtesy of Hydromentia, Inc.)

- 100% US diesel demand via algae would use 0.3 - 40 Billion gpd
  - US fresh water withdrawal = 346 Bgpd
  - US municipal wastewater = 40 Bgpd
- Algal wastewater treatment provides superior nutrient removal to avoid downstream water quality problems
- National Algal Biofuels Technology Roadmap (DOE, 2010)
  - *"Inevitably, wastewater treatment and recycling must be incorporated with algae biofuel production…"*

Issues- How much does it cost?

Synergy of Algal Cultivation & WW Treatment

Algae Treatment Case (100 ha)	Operation expenses	Capital Costs	Electricity Credit	Biofuel prod-uced (bbl/yr)	Cost of fuel (w/o wastewater treatment credit)	Cost of fuel (w/ wastewater treatment credit)
Wastewater Treatment	$2,960,000	$3,170,000	$831,000	12,700	$417/bbl	$28/bbl
Biofuel Production	$2,810,000	$2,720,000	$554,000	12,300	$405/bbl	$332/bbl

A Realistic Technology and Engineering Assessment of Algae Biofuel Production. (Lundquist et al., 2010)

Integrating algae cultivation with wastewater treatment can achieve economically sustainable algal biofuel production.

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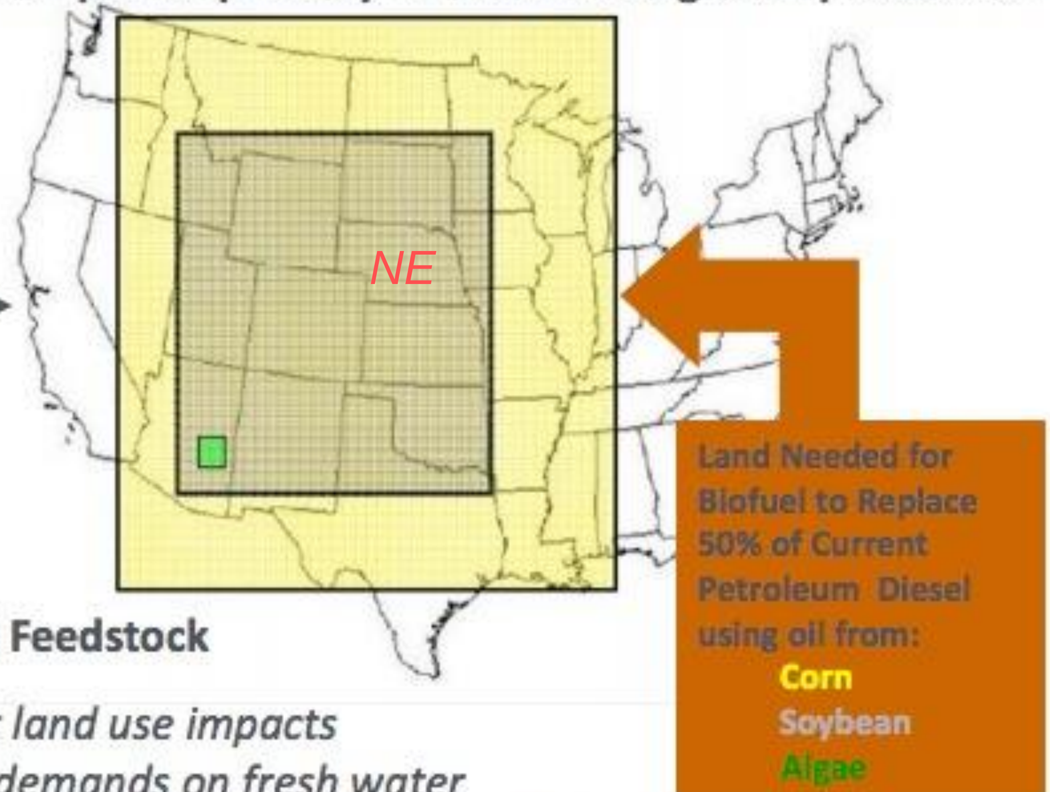
Issues: Algae land requirements
Is there enough land?

Gallons of Oil per Acre per Year (approximate)	
Corn	18
Soybeans	48
Safflower	83
Sunflower	102
Rapeseed	127
Oil Palm	635
Micro Algae	700 - 7000

Notional example for photosynthetic microalgae oil production

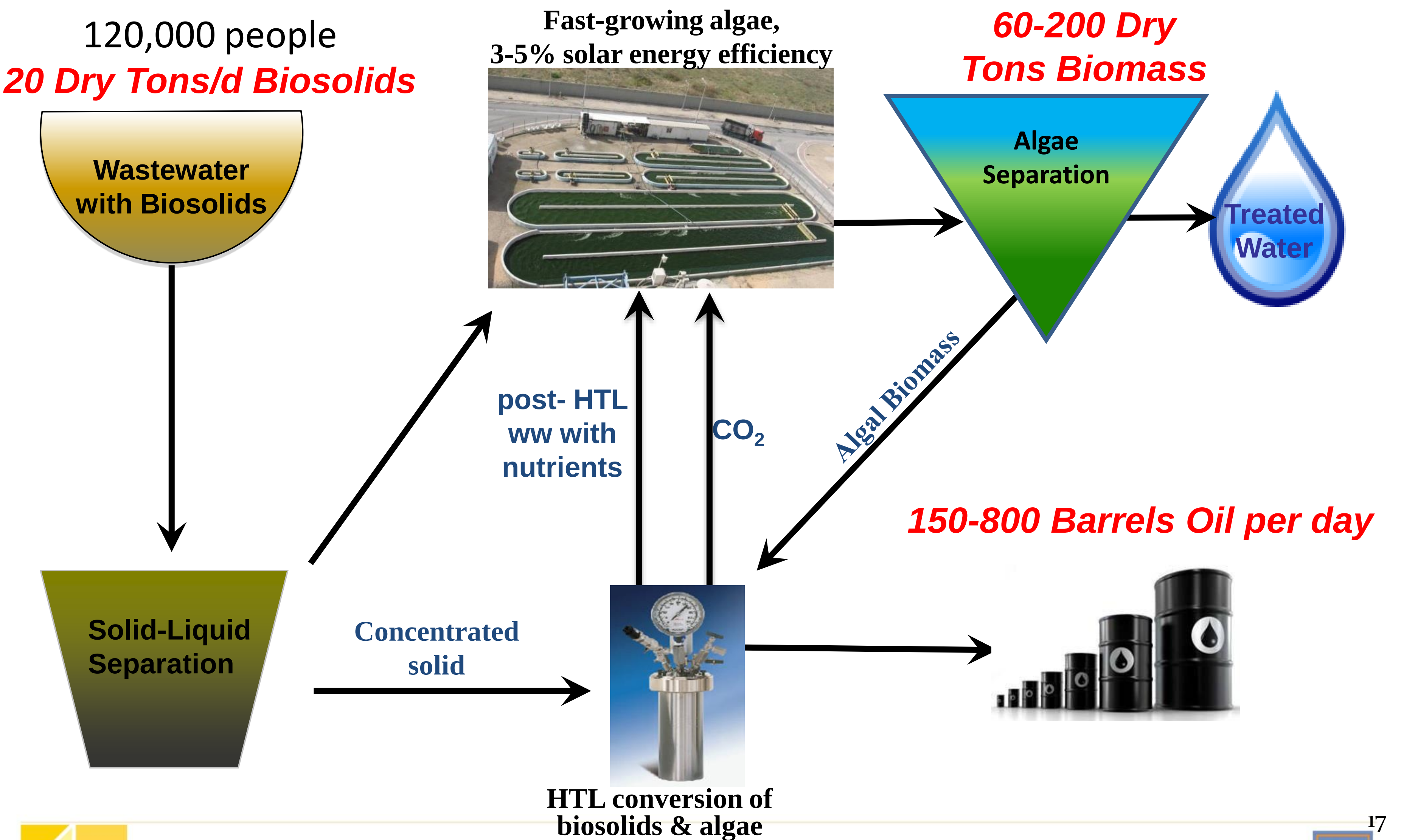


Key Attributes of MicroAlgae as Biofuel Feedstock

- *Reduced land footprint and indirect land use impacts*
- *Can use non-fresh water to reduce demands on fresh water*
- *High production potential for both whole biomass and neutral lipids*
- *Potential source of high quality feedstock for advanced biofuels production*
- *Need not compete with agricultural lands and water for food/feed production*
- *Can potentially recycle CO_2, organic carbon, & nutrients from waste streams*

However, affordable and productive commercial scale operations not yet demonstrated

E^2-Energy Example for Champaign-Urbana



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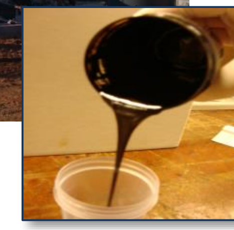
Let's Think Big … The E^2-Energy Potential

US Wastewaters CONTAIN:
- 54 Billion m^3 of water
- 0.2 Billion dry tons of nutrient-rich biosolids

We can GROW 0.6-2.0 billion dry tons of mixed algal biomass



We can CONVERT WW algae into 0.3-1.2 billion tons of bio-crude oil

*** The US currently consumes ~1.1 billion tons of crude oil.**

*** Corn ethanol production is 0.06 billion tons of biofuel.**

Next Steps: E2-Energy Demonstrations at UIUC

- Upscaling of HTL equipment
  - 10 wet ton/day pilot on south farms
  - Raising funds for next pilot @ WWTP
- Develop refining & product markets
  - Biofuels and asphalt bio-binders
  - Algae animal feed products
- Lower cost algae cultivation
  - Co-cultivation of rice and algae
  - Grow algae in road drainage infrastr.
- Demo CO_2 capture for power plant
  - New $1.25 M DOE project

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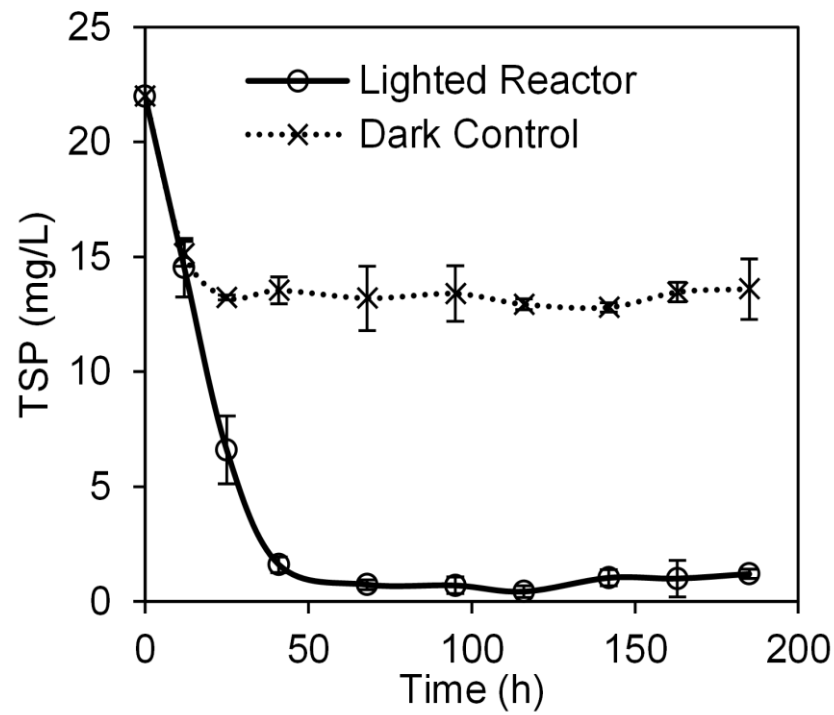
Next Steps: SUNRAES- New Algal Wastewater Project with Metropolitan Water Reclamation District (MWRD)

- **S**calable **U**rban **N**utrient **R**emoval via **A**lgae **E**xtraction from **S**ewage
- Rapid nutrient removal is the key goal
  - Reduce retention time from 48 hr to 8 hr
  - Illinois proposing effluent P < 1.0 mg/L
- Algae (lighted reactor) can provide improved removal of phosphorus (TSP) and nitrogen (TSN) in comparison to activated sludge process (dark control)
- Algae can also provide enhanced removal of emerging contaminants
  - Endocrine Disruptors, Pharmaceuticals



Summary and Conclusions

- Algae can be advantageous for a wide variety of uses and services
  - Nutritional products for humans or animals
  - Biofuels and other biochemicals
  - Wastewater treatment and carbon capture
- Lower value commodity products like biofuels made from algal biomass need a co-product or subsidy for economic viability
- Integration of wastewater treatment with algae cultivation and hydrothermal liquefaction provides synergistic benefits and lower costs
  - Enhanced removal of nutrients and bioactive compounds
  - Dual-use infrastructure facilitates cost effective algal biomass production
  - Potential to amplify the biomass/biofuel produced
  - Improves the net energy recovery from wet wastes
  - Destruction of bio-active compounds
- Next steps
  - Upscaling hydrothermal liquefaction systems
  - Reducing the retention time of algal wastewater treatment systems

THANK YOU

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