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What Green (and other members of the algae family) Can Do For You

Lance Schideman, PhD, PE

Illinois Governor's Sustainability Awards
November 1, 2016

Acknowledgements

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- Microbial Energy Systems Virginia Cobia Farms

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 is an interesting long range possible solution, that over the next 30 to 50 years might be helpful. "

Feb. 24, 2012- Fox News interview

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Not all the algae news is good news

npr WILL AM news arts & life music programs

AROUND THE NATION

Toxic Algae Problem Likely To Get Worse Before It Gets Better

September 15, 2014 · 4:52 AM ET
Heard on Morning Edition

LEWIS WALLACE

Toxic algae struggles leave Toledo's reputation hanging in the balance

Prospect of recurring woes imperils rebranding efforts

By Tom Henry | BLADE STAFF WRITER

Published on Aug. 2, 2015 | Updated 12:07 p.m.

Algae has attracted significant investment

- Exxon-Mobil committed up to $600 Million for algal biofuel research in 2009
- Algal companies attracting significant venture capital- Sapphire, Algenol, Aurora, Heliae
- Algal biofuel trials by the Navy, United Continental, and Virgin Atlantic Airlines
- UAL signed a letter of intent to purchase 20 Mgal/yr of renewable algal bio fuels in 2014
- AlgaeWheel wastewater system receives the Water Environment Federation’s Innovative Technology Award in 2015

Why all the interest in Algae?

Life and the Evolution of Earth's Atmosphere

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

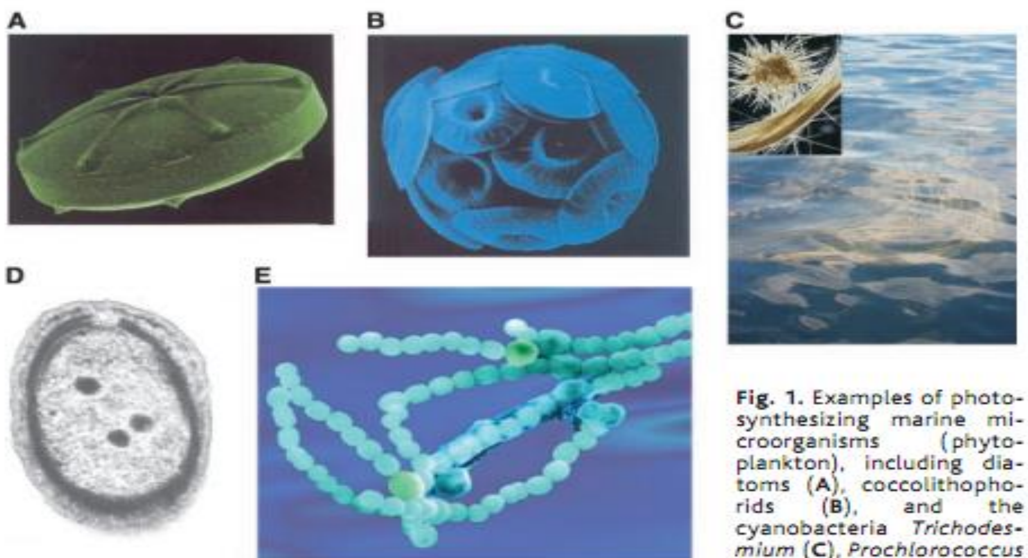


Fig. 1. Examples of photosynthesizing marine microorganisms (phytoplankton), including diatoms (A), coccolithophorids (B), and the cyanobacteria *Trichodesmium* (C), *Prochlorococcus* (D) and *Anabaena* (E) [(A)

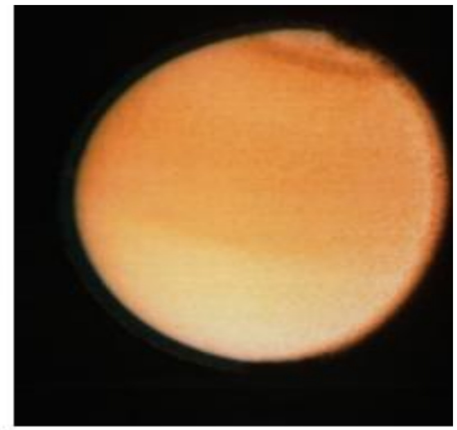


Fig. 2. This photograph of Saturn's m Titan, shows the orange-tinted haze th thought to be formed by photolysis charged-particle bombardment of met in Titan's upper atmosphere. The Cassini sion, now on its way to Saturn, will test model by dropping a probe into Titan'

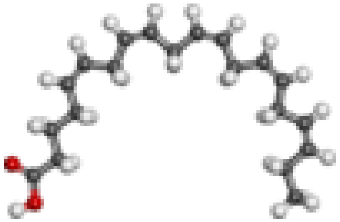
- Algae has had transformative effects on the earth!
- Can we tap the power of algae to transform our world again into a more sustainable paradigm for the environment, energy and economy?

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)

ALGAVIA™
Microalgae Food Ingredients

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

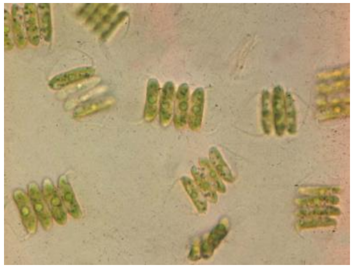
Algae can be an advantageous animal feed product

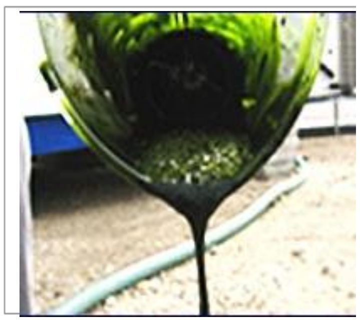
- Omega 3/6 PUFA enriched meat & egg products
- Adding algae to the diet of cows resulted in
  - Lower breakdown of unsaturated fatty acids
  - Better weight control, healthier skin and a lustrous coat (Pulz and Gross 2004)
- Improved the color of the skin, shanks and egg yolks of poultry

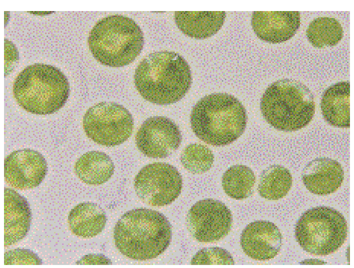
Algae can be used for Cosmetics and other Chemical Products

- 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

Algae can provide significant biofuels:
High productivity & oil content







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

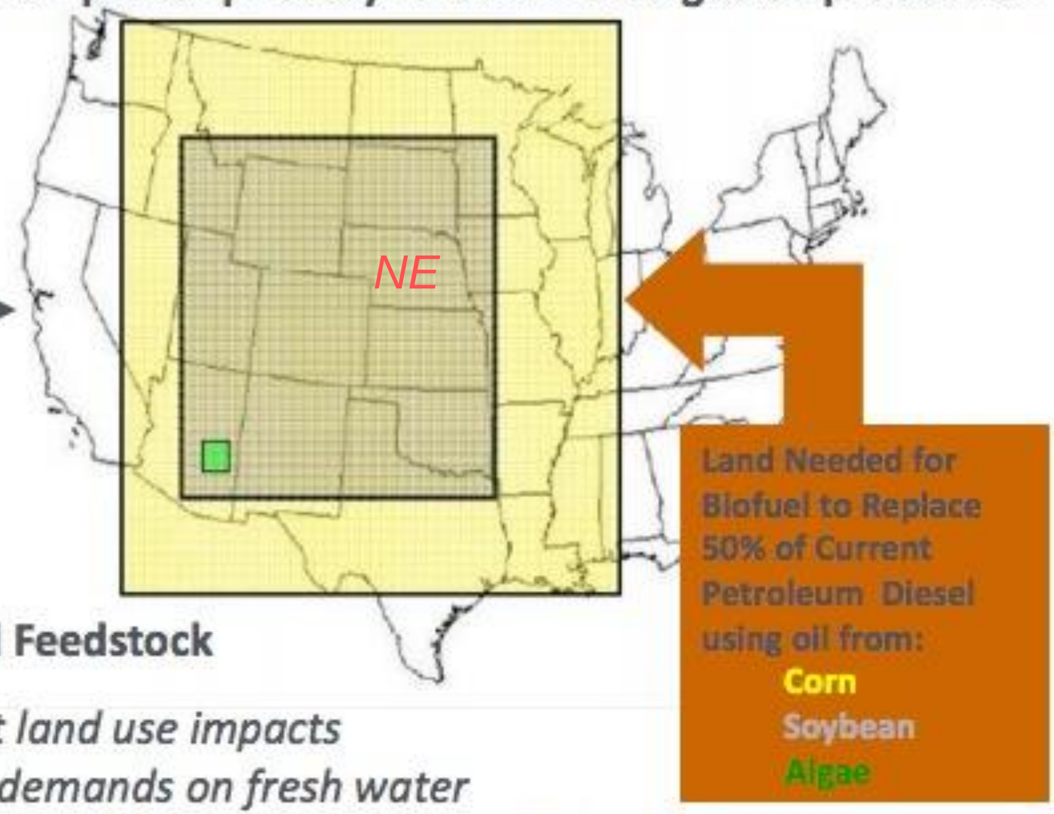
- Long-term Field Studies
  - 10 $g/m^2/day$, Wiessman, 1988, 730 days, 1000 m^2, New Mexico
  - 30 $g/m^2/day$, Laws, 1985, 400 days, 48 m^2, Hawaii,
  - 20 $g/m^2/day$, Seambiotic, 650 m^2, Israel
  - 40 $g/m^2/day$, AlgaeLink, Netherlands, (bioreactor)

The Potential Advantages of Algae

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

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

Algae Can Provide Carbon Capture:

Synergy with power plant CO_2 mitigation

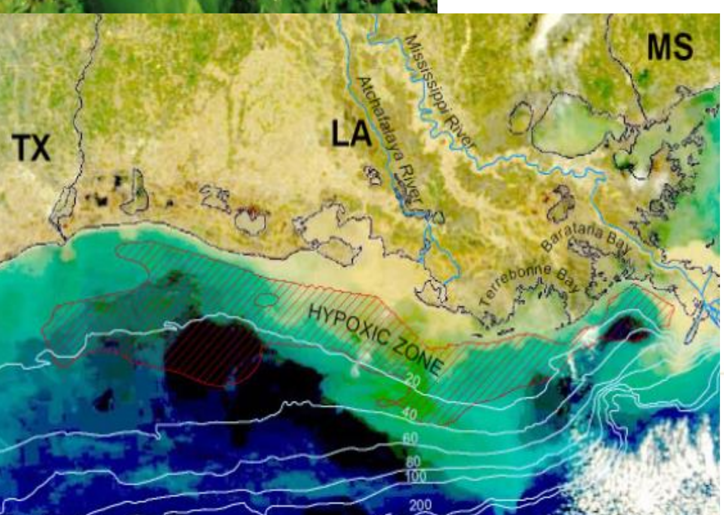
- Total US CO_2 emissions = 6.6 billion tons CO_2 / yr
- US power industry CO_2 = 2.5 billion tons CO_2 / yr
- 100% US diesel via algae ~ 1 - 4 billion tons CO_2/yr
- Algae bioreactors can utilize 30% - 90% of injected CO_2
- Algae growth and power usage both follow a diurnal pattern

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…"*

Impacts of Residual Wastewater Nutrients



- N and P removal at WWTPs is costly: \$8,130 and \$49,500 per ton *(Hey et al., 2006)*
  - Most conventional nutrient removal processes do not beneficially reuse nutrients
  - Opportunity for added value from algae cultiv.
- Environmental algae grow on residual nutrients & cause downstream problems
  - Eutrophication
  - Algal toxins
  - Hypoxia

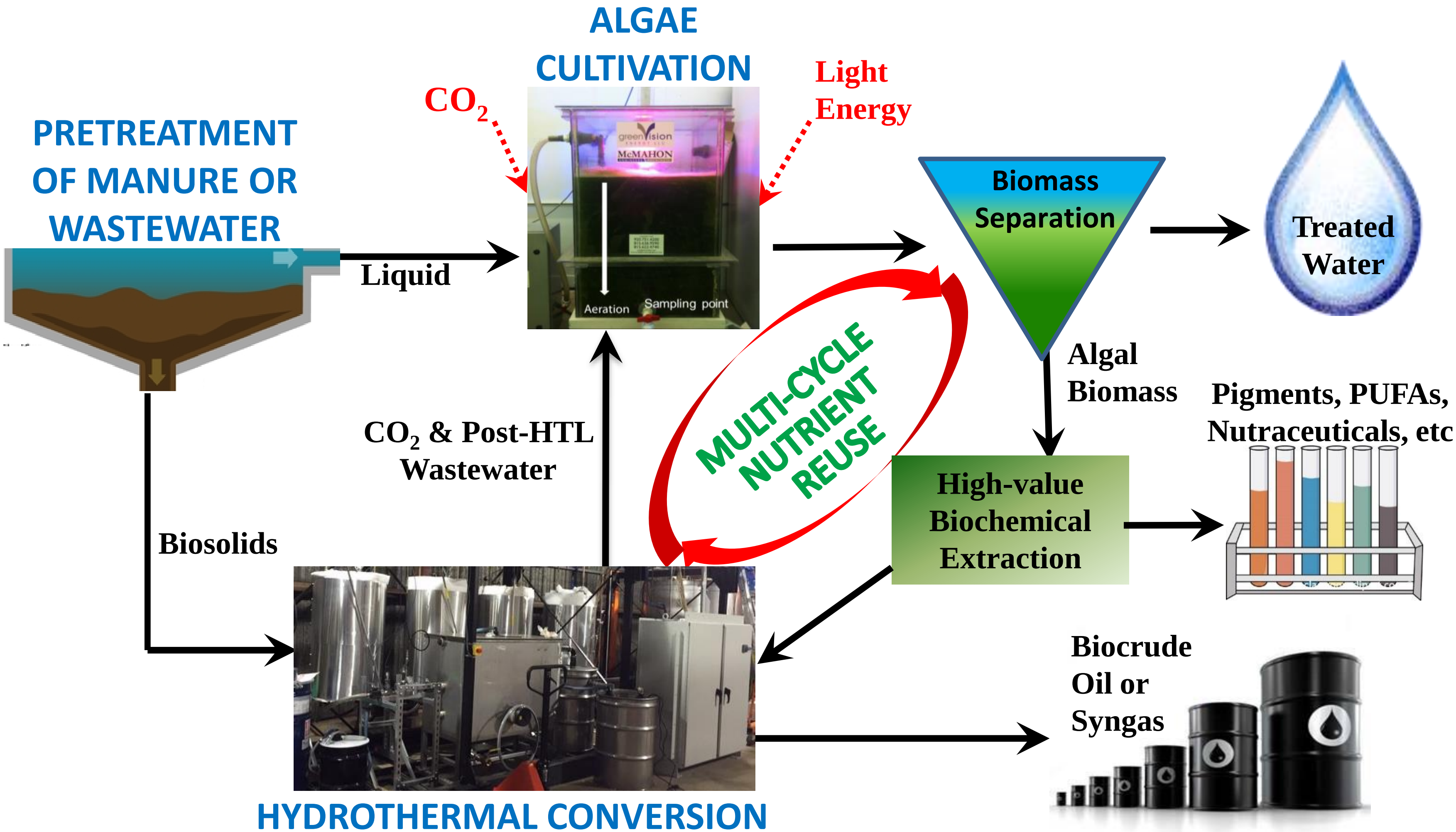
Current Demonstration Project @ UIUC Swine Research Center

How Much do Algal Biofuels Cost?

	2015 SOT	2022 Projection	AOU	AHTL-Algaewheel	Ads-Algaewheel
Feedstock (Cost per gallon oil produced $/gal-oil)	$11.3	$3.2	$7.0	$7.8	$6.8
Conversion	$1.2	$0.5	$4.2	$2.1	$1.9
Upgrade to Finished Fuels	$0.4	$0.3	$0.3	$0.4	$0.4
CHG	$1.5	$0.6		$1.5	
Balance of Plant	$0.3	$0.2			
Total Cost before Byproduct Credit ($/ gal)	**$14.8**	**$4.7**	**$11.4**	**$11.9**	**$9.2**
Byproduct Credit					
WW Treatment Credit (BOD removal) ($/gal oil produced)			$9.0	$43.1	$36.9
Electricity Credit ($/gal oil produced)			$1.5	$0.3	
Minimum Selling Price ($/gallon oil)	$14.8	$4.7	$0.91	-$31.5	-$27.7

- Wastewater Treatment Credits are highly advantageous for economic viability of algal biofuels

Combining Algae Cultivation with Wastewater Treatment Can Amplify Algal Biofuels Production



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Why Hydrothermal Conversion (HTL/G)?

It converts wet, low-lipid biomass into crude oil or gas

Demonstrated HTL Feedstocks

Municipal sludge
Manure
Algae
Crop residues
Woody materials

Reactor

High T:200 – 350 ºC
High Pressure : 80 – 120 atm

Gas Product (CO_2 rich)

Aqueous Product (N, P, & sCOD rich)

Solid Residue (Mineral rich ash)

Oil Product (Energy Rich, C_xH_y)

<u>HTL has a positive net energy balance</u>

Eout : Ein > 3:1 at lab-scale (% solids =20%)
Eout : Ein > 10:1 w/ heat exchangers
Oil characterization: *Vardon et al. 2011, Bioresource Tech.*

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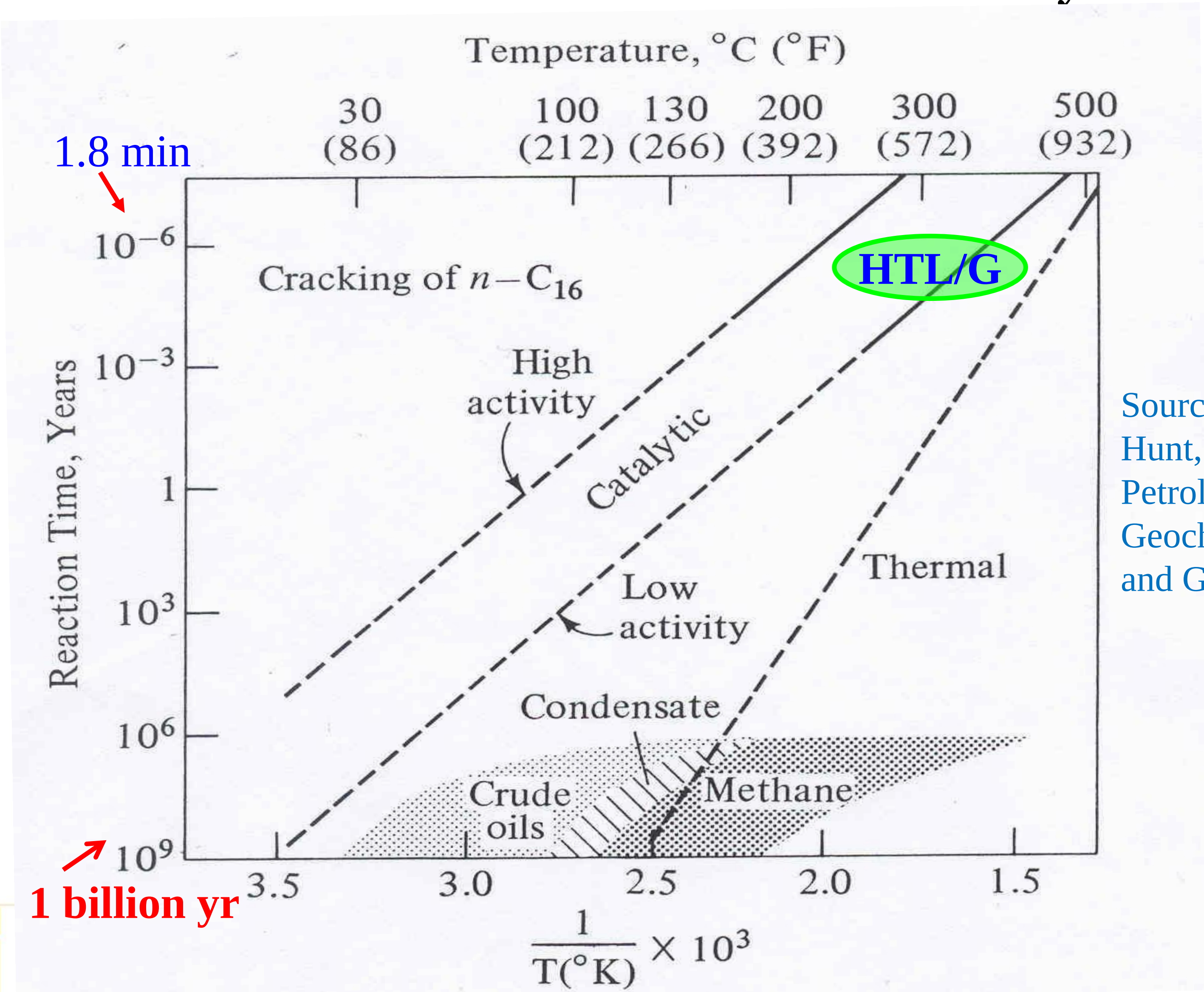
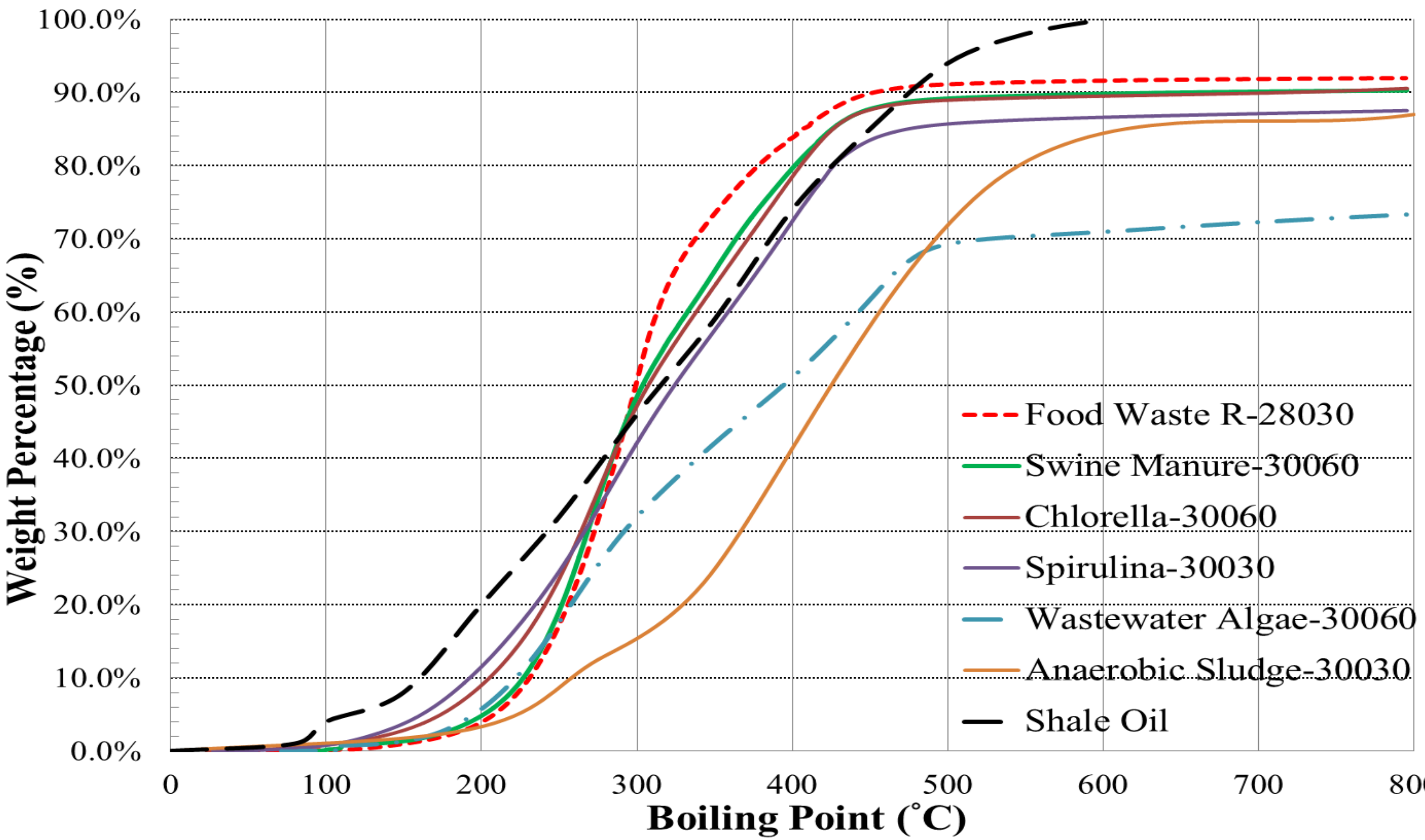
Hydrothermal processes mimic natural fossil fuel production … but accelerate it tremendously

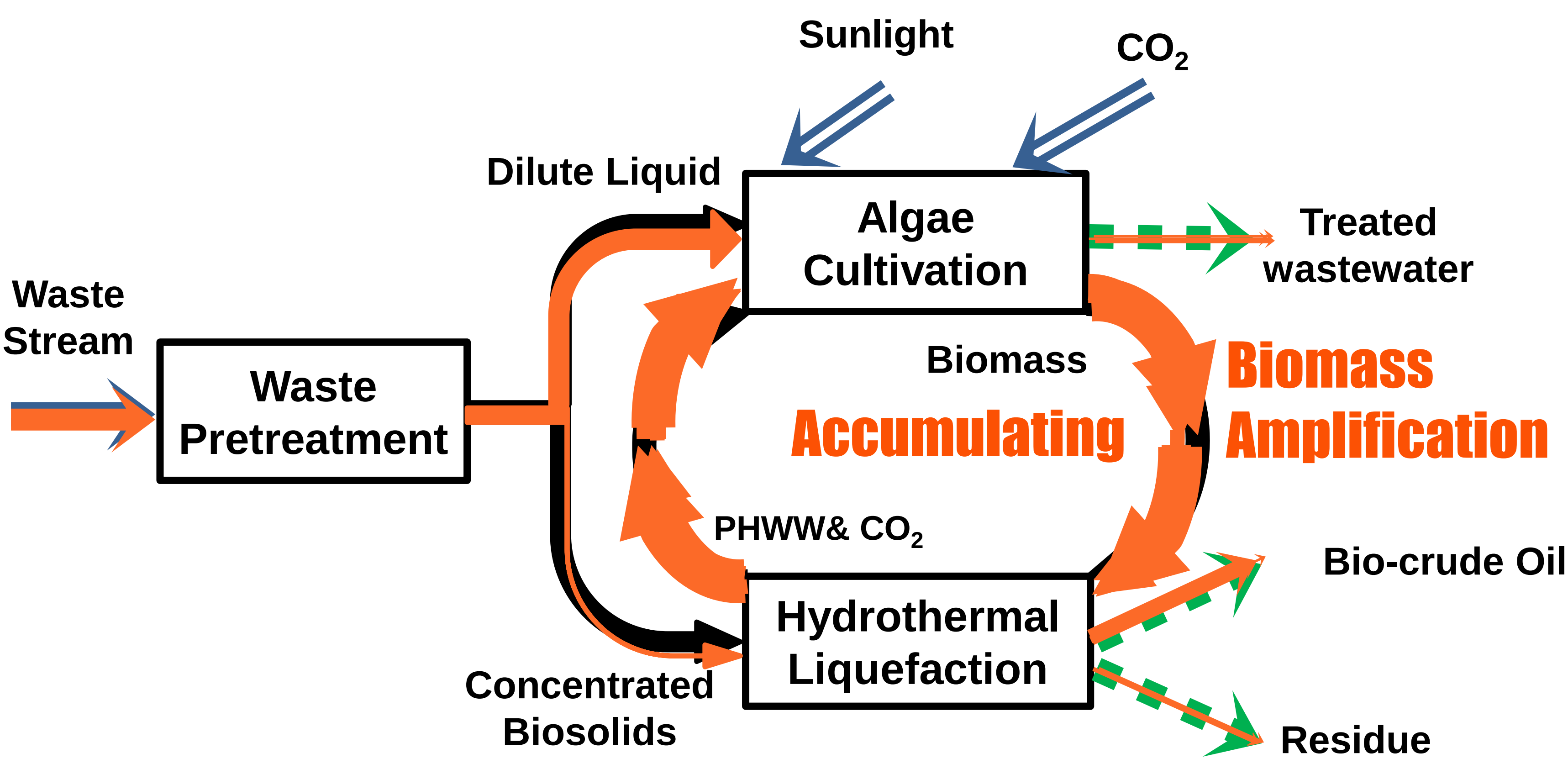


Source:
Hunt, J. (1996) Petroleum Geochemistry and Geology

HTL Bio-oil Distillation is Similar to Shale Oil



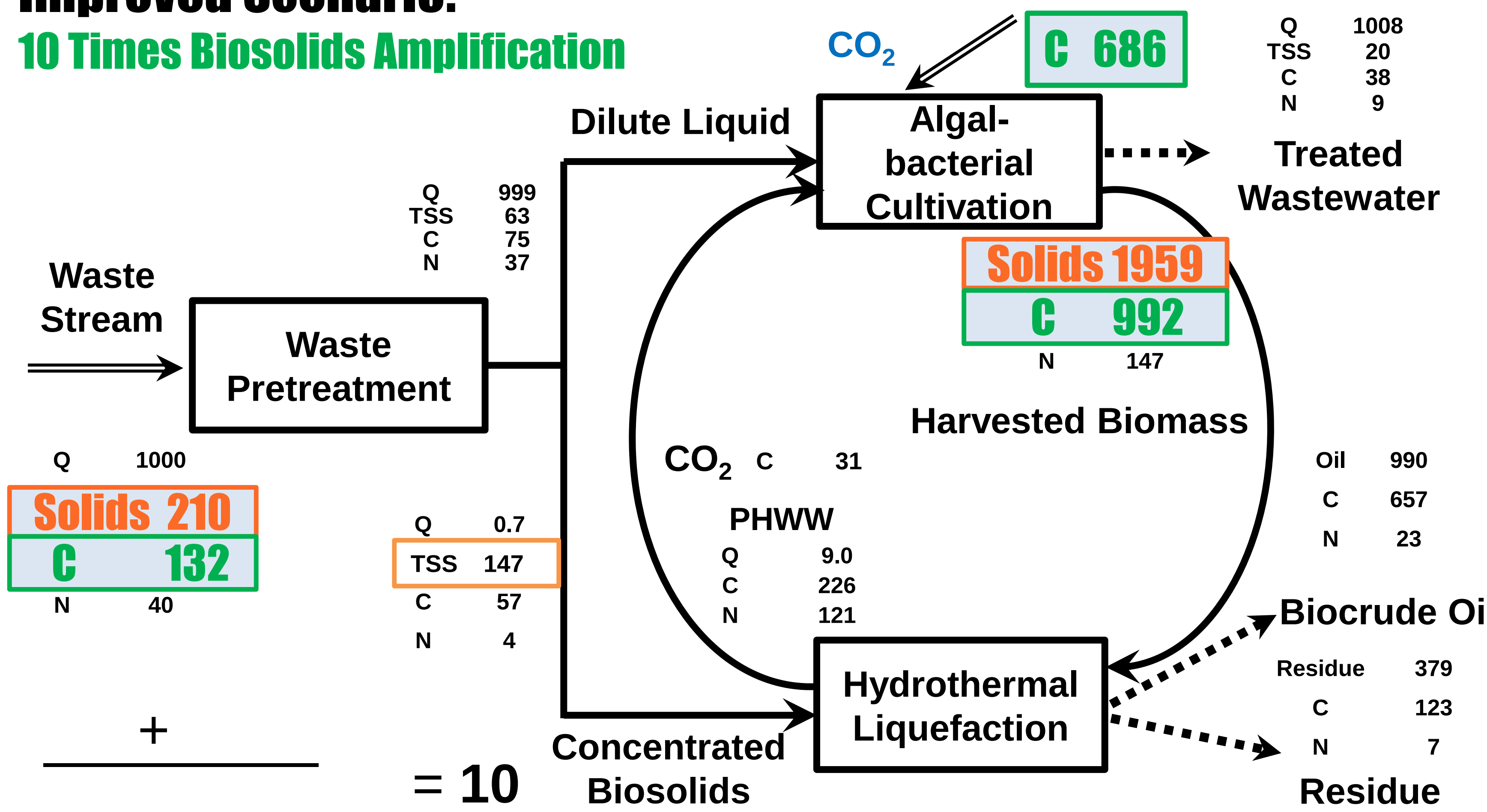
STELLA Modelling of Nutrient Cycling Impacts in the Environment-Enhancing Energy (E2-Energy) System *(Zhou et. al, EES, 2013)*



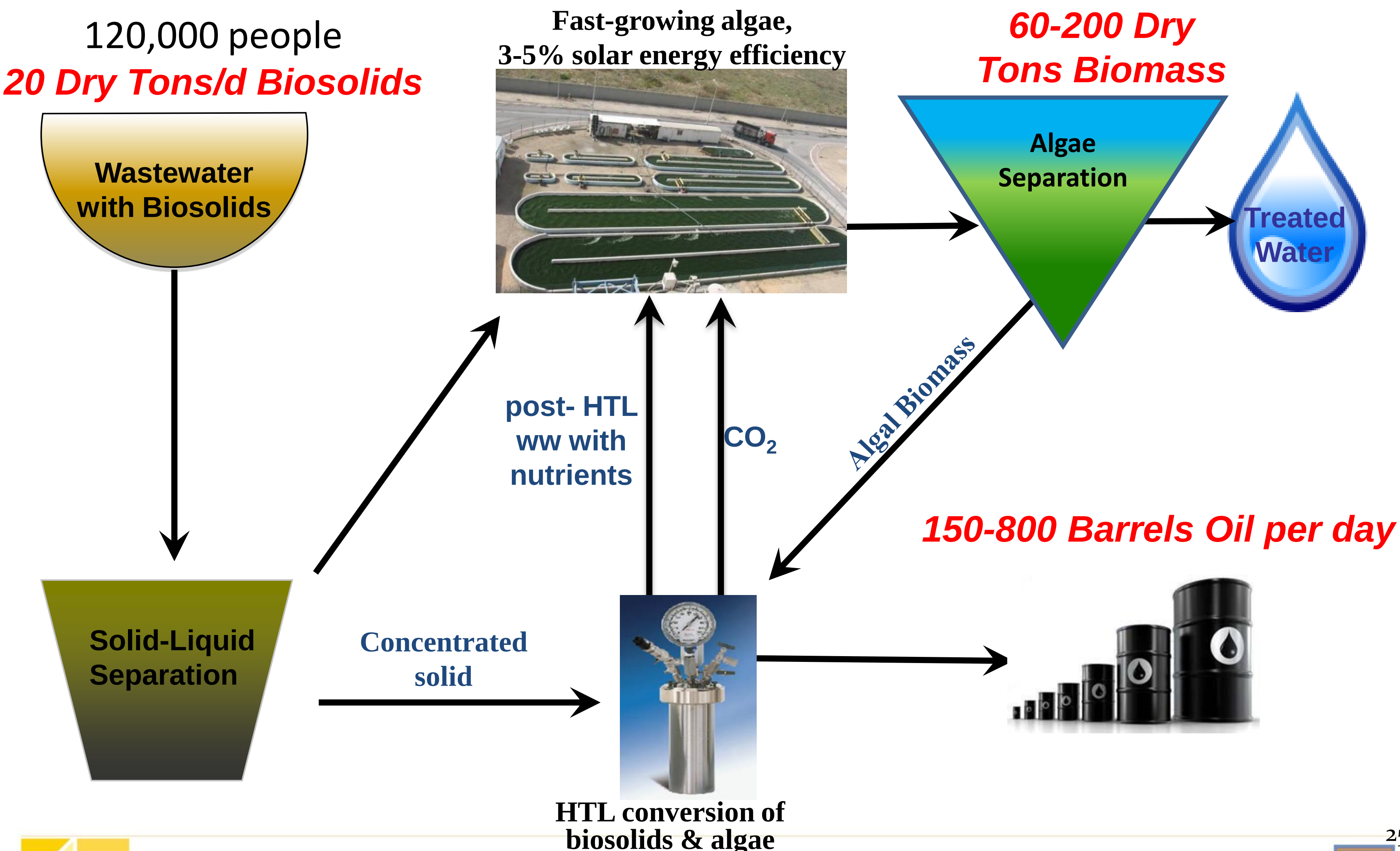
Modelling Results and Discussion

Improved Scenario:

10 Times Biosolids Amplification



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

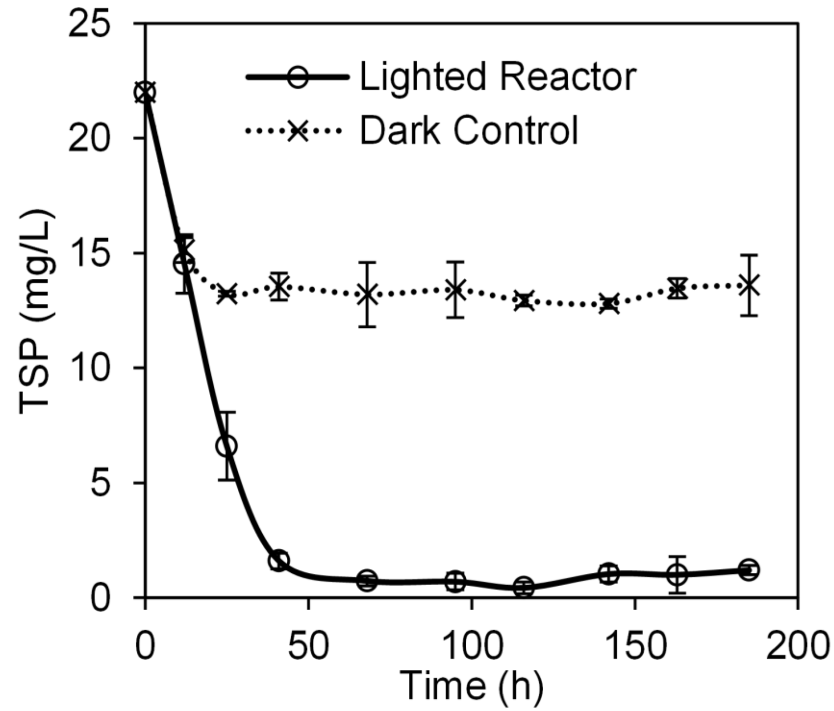
We can CONVERT WW algae into 0.3-1.2 billion tons of bio-crude oil

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

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

Next Steps: 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

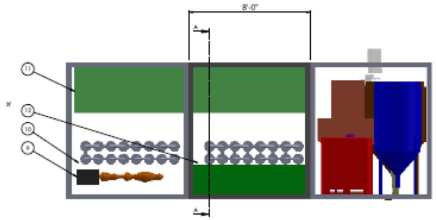


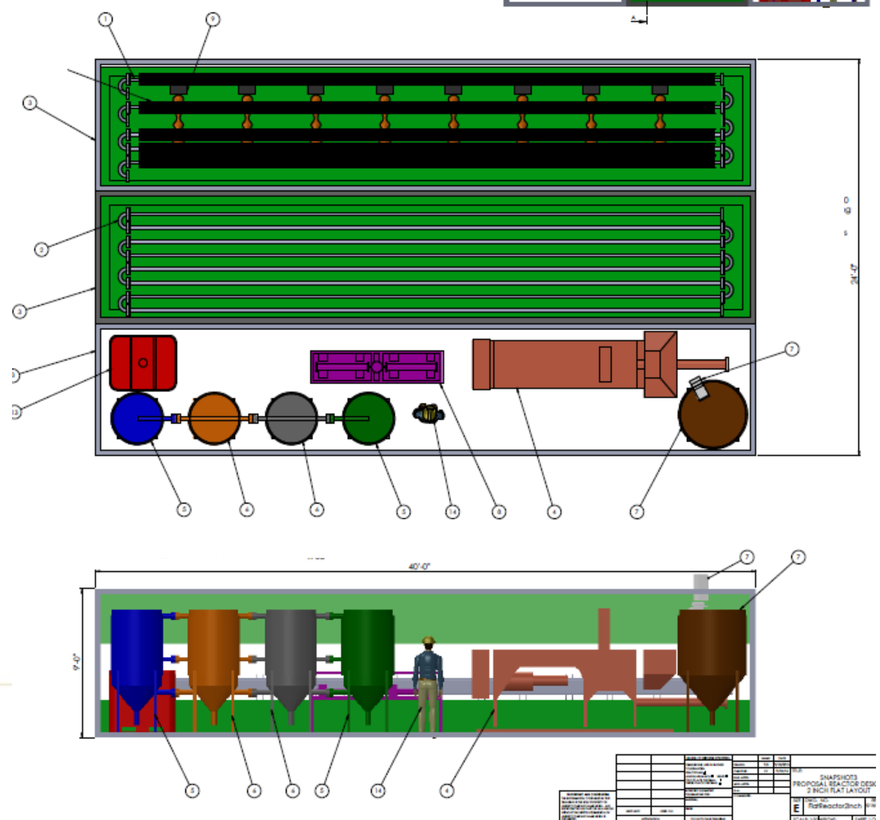
Next steps: POWIR-UhP DOE Proposal ($40-$50 Mil)
Design/Build of Large HTL System for Wastewater Biosolids

10 wet ton/day Demonstration HTL System on UIUC South Farms

Small Commercial HTL System

Large Commercial HTL System Design





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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30 years 1985-2015

HTL recovers most of the energy in wet wastes

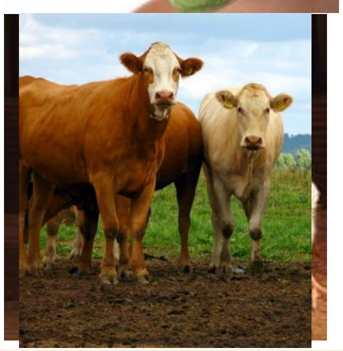
	Food-processing	Slaughter-house	Swine manure	MWW Algae
Feedstook Properties:				
Ash Content (dry based)	1.5	8.38	16.3	47.5
Lipid content	52.3	23.8	20.3	1.7
C	60.7	59.5	41.1	27.9
H	8.49	8.77	5.42	3.01
N	3.33	5.44	3.36	3.9
O	27.5	26.3	50.1	65.2
Biocrude oil yield (% dw TS)	**62.4**	72.1	**39**	**26**
High Heating Value (MJ/kg)	**40.6**	**36.5**	**38.8**	**25.8**
C	75.4	69.7	76.6	59.4
H	12	11.1	10.3	7.79
N	1.79	2.32	3.76	2.5
O	10.8	16.8	9.4	30.3
Energy Recovery (%)*	**91.2**	**96.7**	**83.8**	**47.6**

* ER not include HTL process energy, which takes 5-10% of the biocrude energy

Synergy with Food & Biochemicals
High Value Algae Co-Products Can Improve Economics and Provide Bridge Markets

- Animal Feed Supplements
  - Omega-3 Fatty Acids (FA)
- Dietary Supplements
  - Amino Acids
  - Poly Unsaturated FA- EPA, DHA
- Fertilizers
- Ethanol
  - Direct starch processing
  - Algae residues

Why Algae?



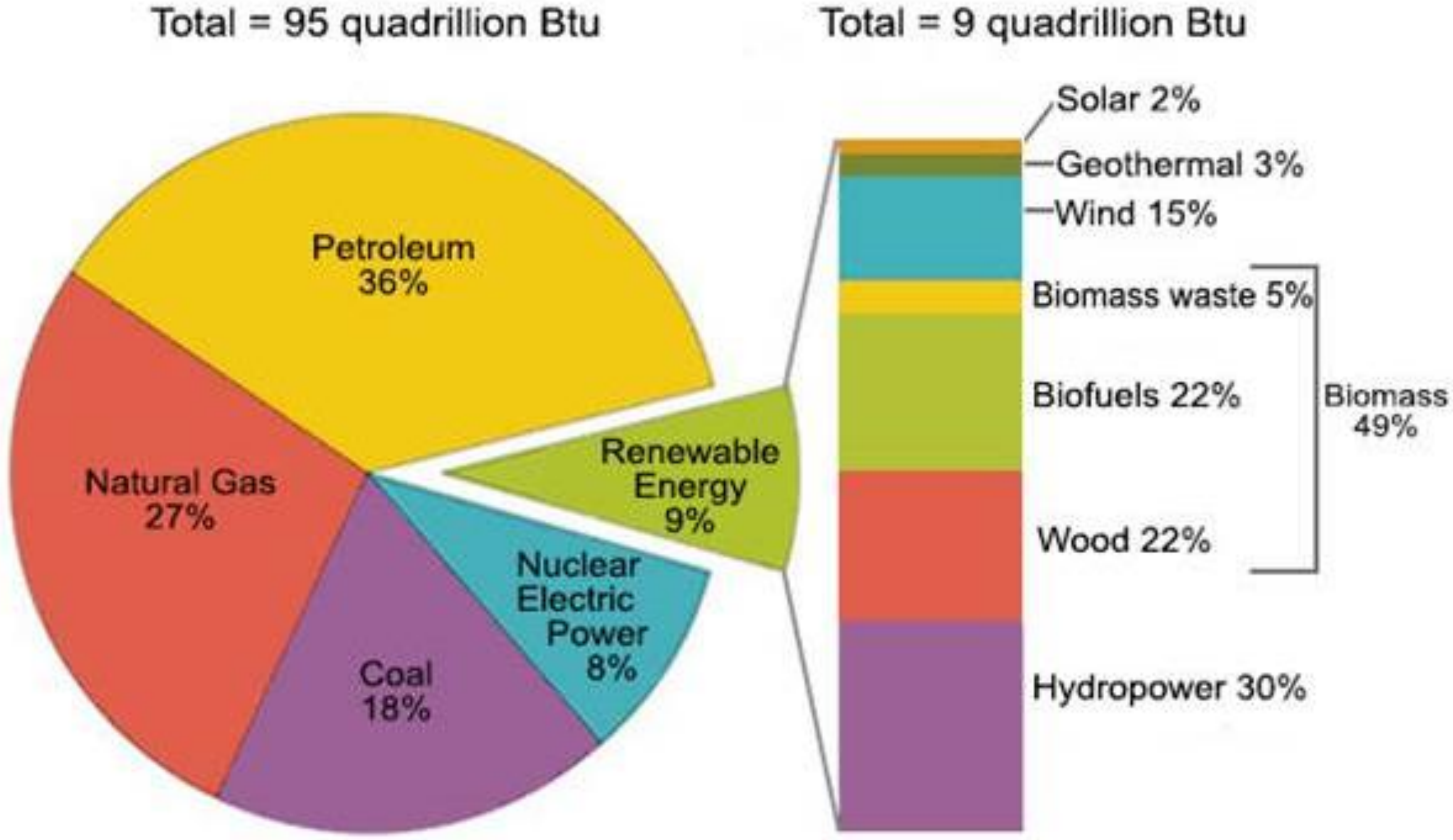
- Algae improves wastewater nutrient removal
- Changes wastewater from CO_2 producing to CO_2 consuming
- High value extracted algal biochemical products
- Highly nutritious animal feed products
  - Better weight control, healthier skin and a lustrous coat (Pulz and Gross 2004)
  - Algae can increase Omega 3/6 PUFA in meat and egg products
  - Improved the color of the skin, shanks and egg yolks of poultry

How would you define waste? …

Provide examples for your definition

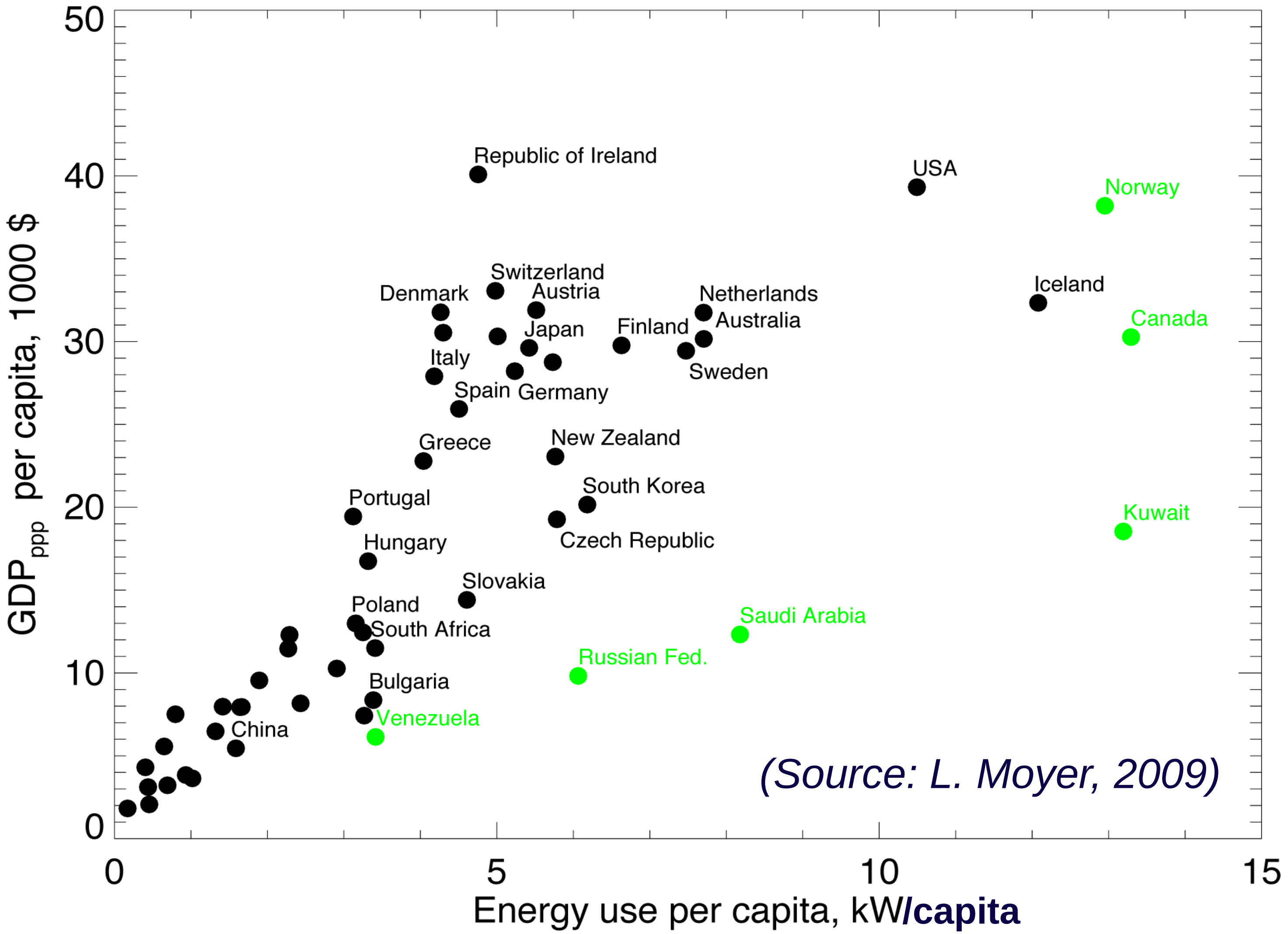
- Material that is not wanted; the unusable remains or byproducts of something
- Something we have too much of to use effectively in a given area
- A resource that we have not yet figured out how to use- Buckminster Fuller

CONTEXT: Breakdown of Current Energy Use Including Renewables



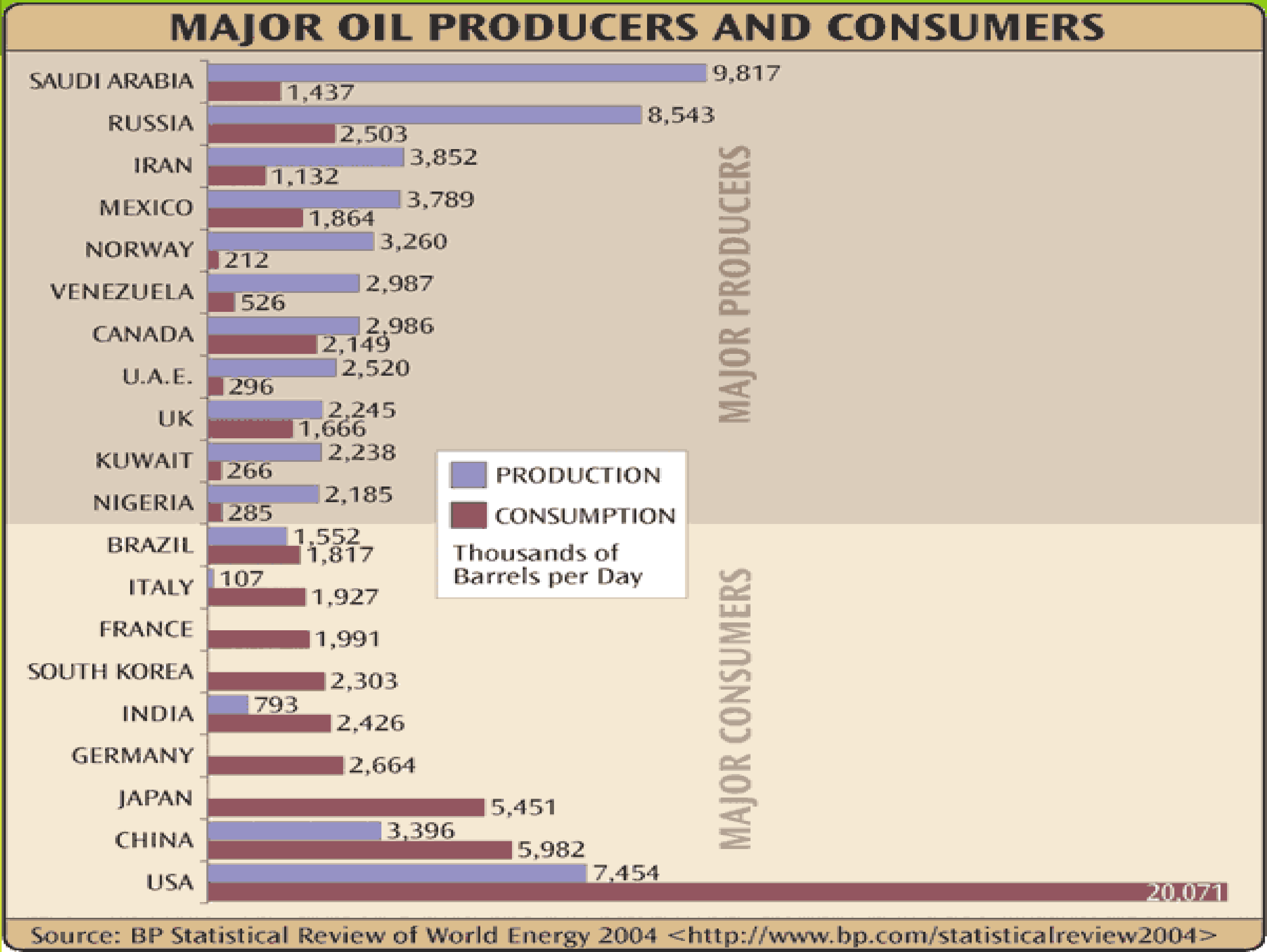
Note: Sum of components may not equal 100% due to independent rounding.
Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 1.3 and 10.1 (April 2013), preliminary 2012 data.

Why is energy policy so important?
Energy use is correlated with prosperity

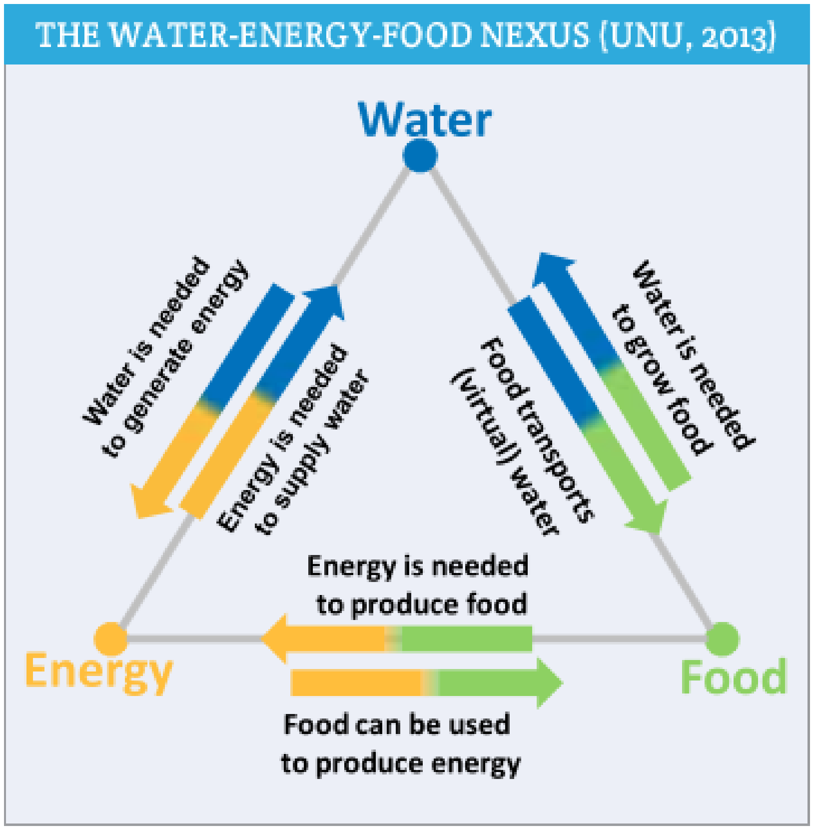


Why is energy policy so important?

Energy security affects national security



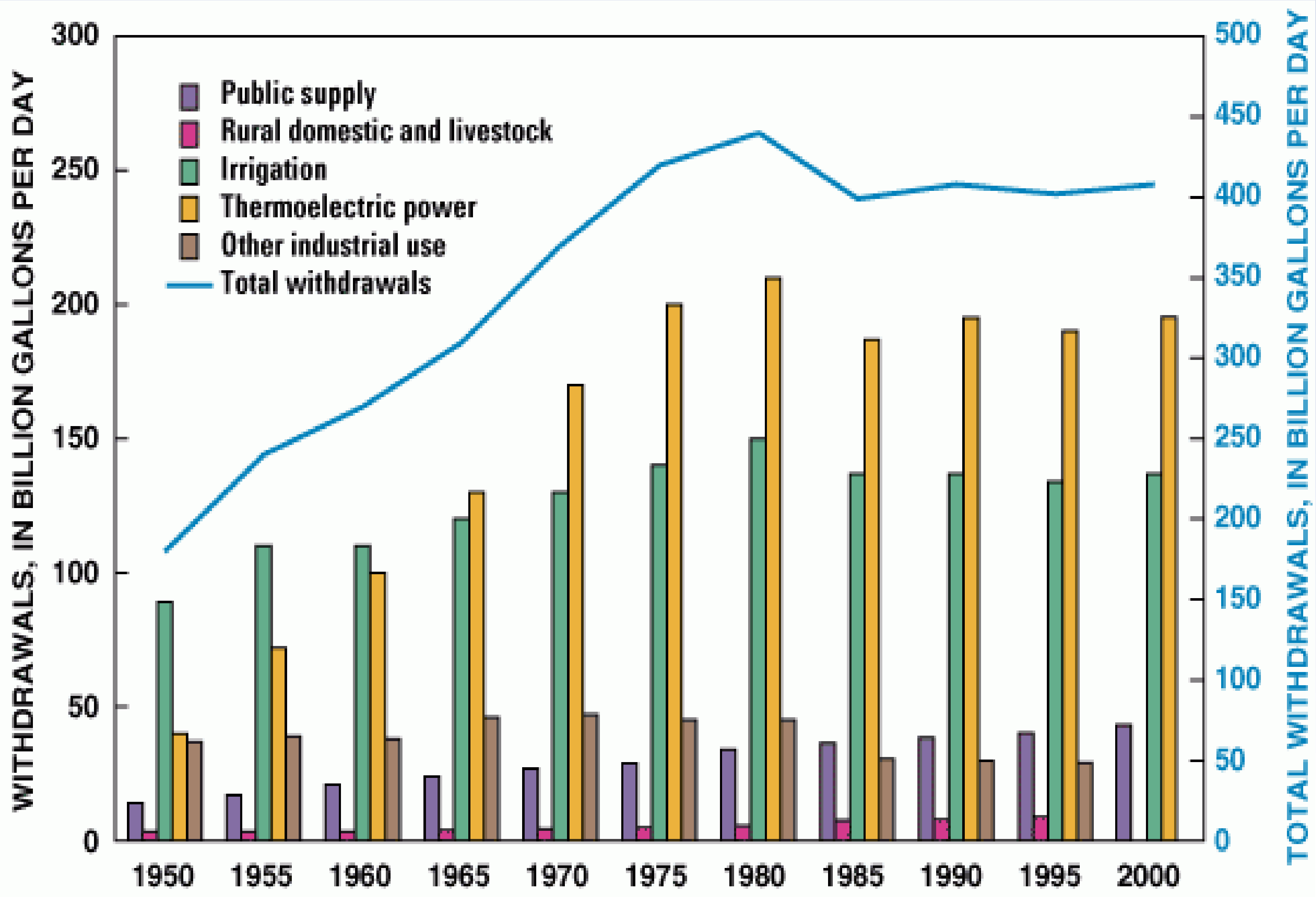
Energy is coupled with… Water–Energy–Food



As population & prosperity increases, need more food, water, and energy

- More food → more water & energy
  - Water & energy for new arable land is higher
- More energy → more water & agricultural products (biofuels)
  - Water needs for remaining fossil fuels is higher
- More water (or higherquality) → more energy
  - Energy for advanced treatment is higher

Largest Water Uses for Energy & Agric.



Source: USGS Circular 1268, Hutson et al. (2004).

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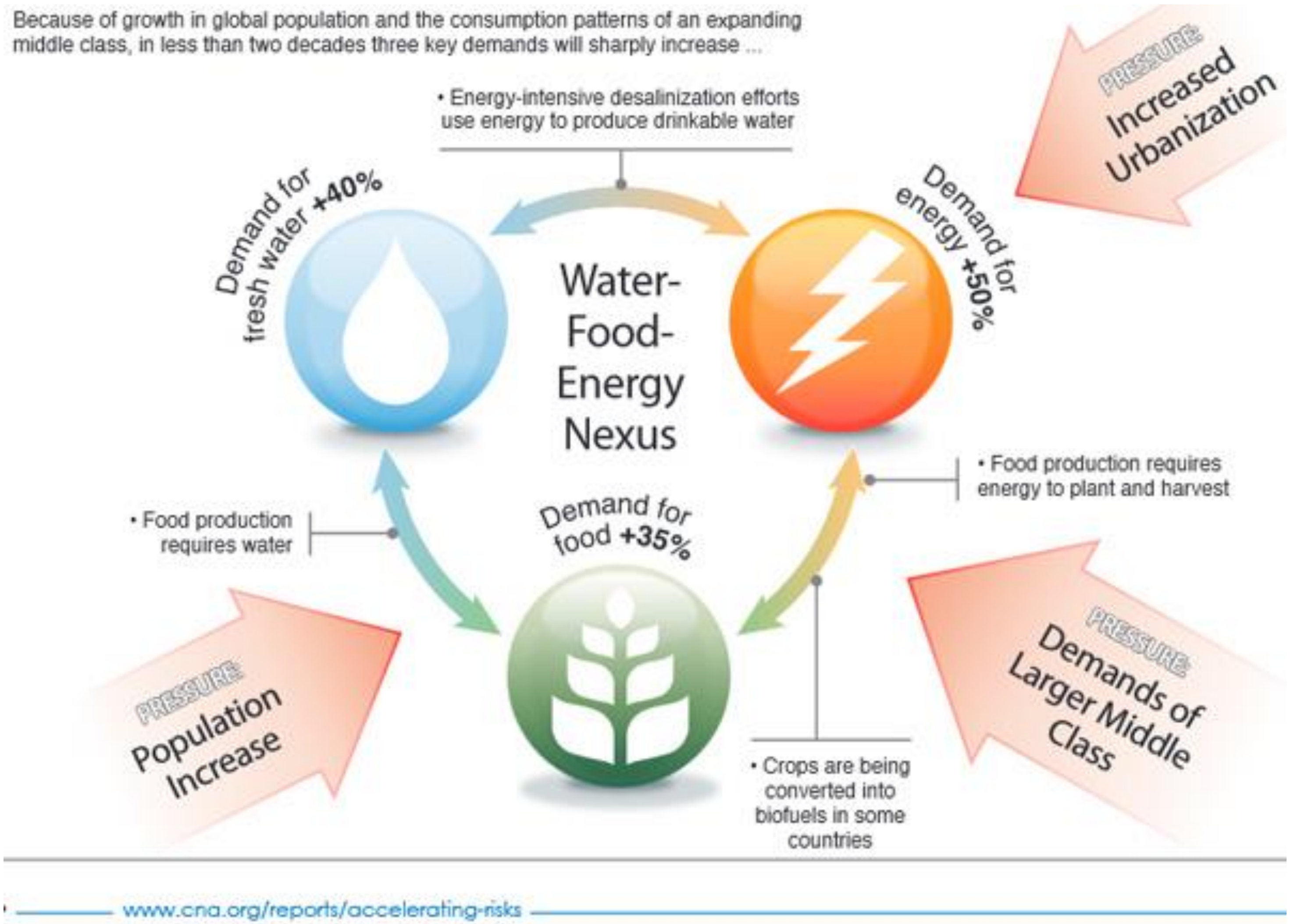
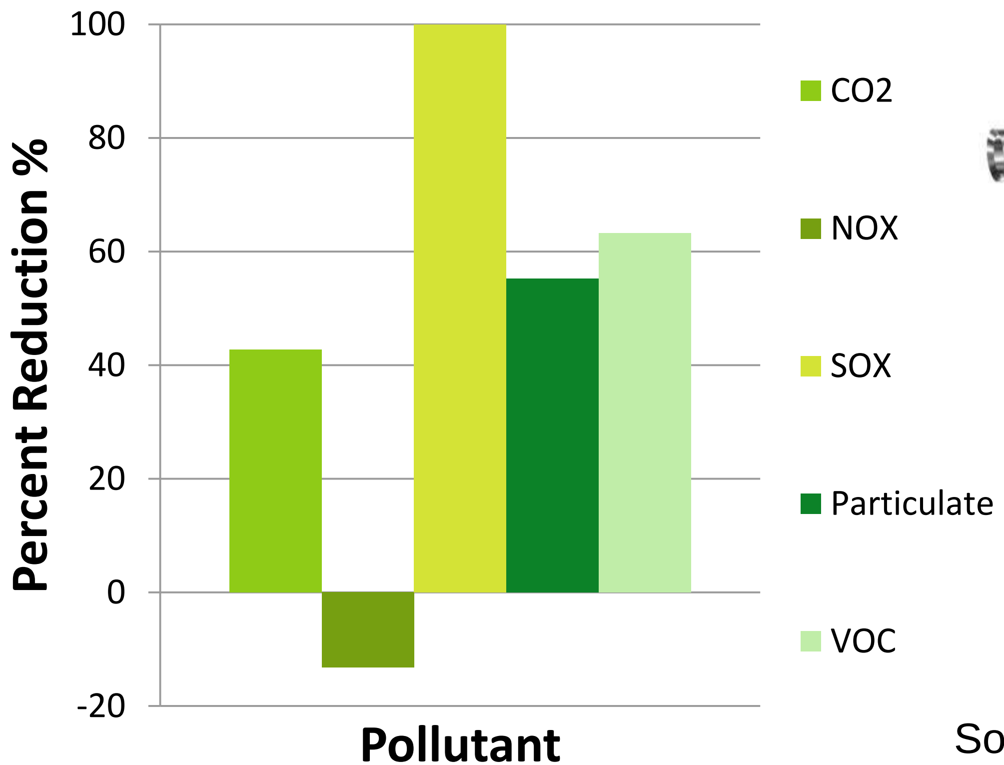
20 yr Projected Increases Food, Energy & Water Demands

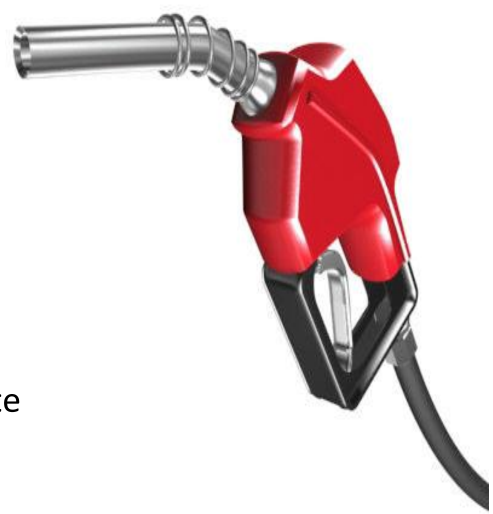


Improved technologies & coordinated management needed to avoid severe resource limitations & price increases

Why Pursue Biofuels?
Reduce undesirable emissions

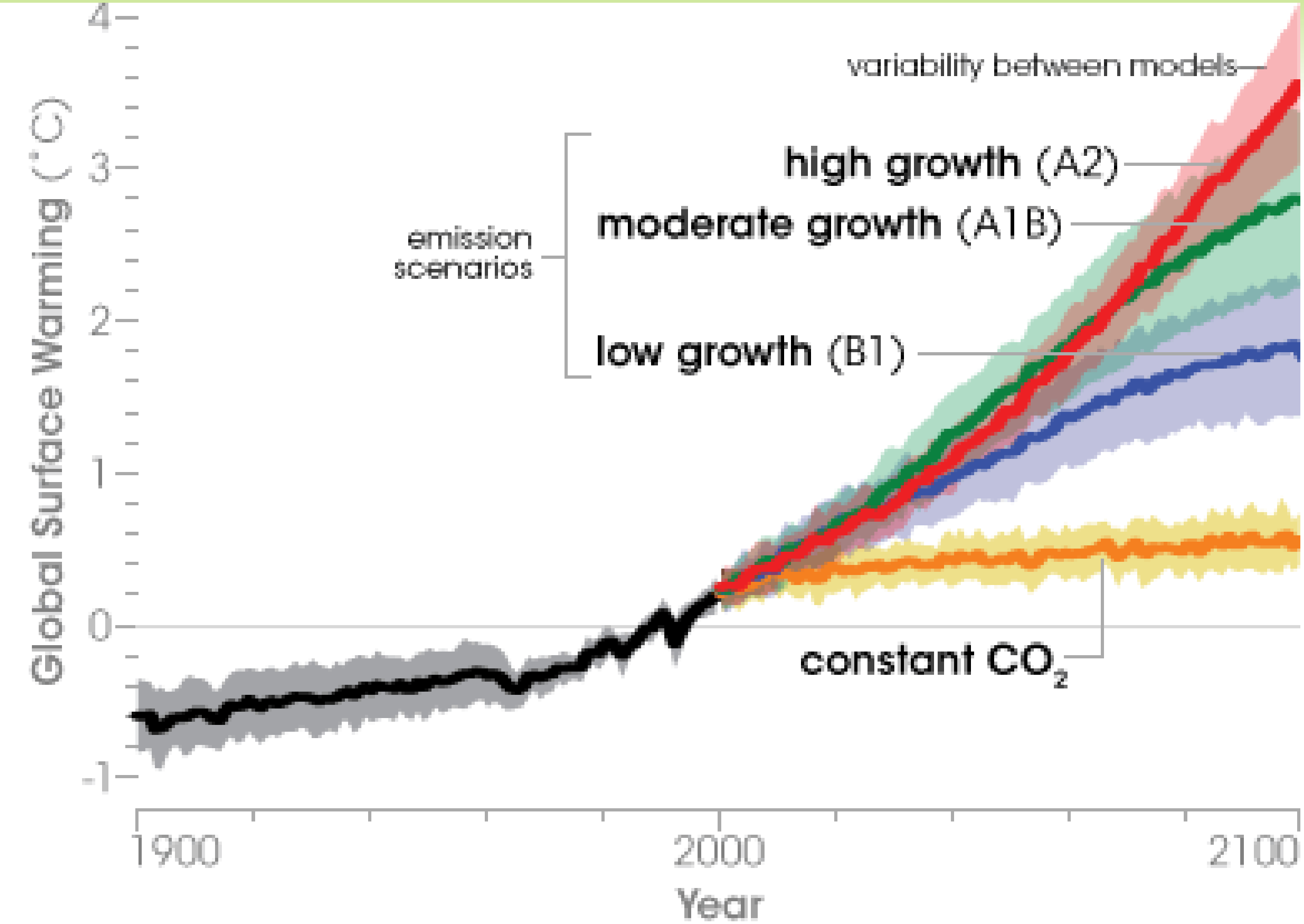
- GHGs reduced & potential to be carbon neutral/negative
- Reduced exhaust emissions using biodiesel





Source: Demirbas, 2009

Current energy use with fossil fuels increases atmospheric CO_2 & projected temperatures



Pop quiz on current US biofuels…

- What are the major types of US biofuels?
- Feedstock sufficiency and competition for land
  - What percentage of current grain goes to ethanol?
  - What percentage is required for sustainable and secure energy security?
- Fossil Fuel Inputs
  - What is the net energy yield of grain ethanol (E_{out}:E_{in})?

Biofuels Evolution & Issues

- **First Generation Biofuels (corn ethanol, soy biodiesel, etc.)**
  - **Food vs. fuel: 25-40% of corn diverted ethanol production**
  - **Insufficient feedstock: Currently, 2%-4% of petroleum demands**
  - **Greenhouse gas benefits reduced: Agrichemicals & land use changes**
  - **Significant water inputs for production and processing**
  - **Commercially viable without subsidy**

Second Generation Biofuels (cellulosic ethanol)

- **Improved feedstock sufficiency:**
  >1 billion tons of US agric. biomass vs. 1.2 billion tons of US oil demand annually
- **Reduced food vs. fuel concerns for ag. residuals but not for energy crops**
- **Water inputs will likely increase**
- **Harvesting biomass could degrade soil**
- **Some commercial plants being built with government support and subsidies**

Food vs Fuel Discussion

- **Is it a good for biofuel feedstocks to also be useful for food?**
  - **"Food vs. Fuel" was a noted concern for corn ethanol with 40% of corn used**
  - **What is the underlying problem?**
  - **What was different when we started building corn ethanol plants?**
  - **Do energy crops resolve this problem?**
  - **Does algae have the same problem?**

Current Algae Markets:
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

Algal BioChemicals for Cosmetics & BioMedical Applications

- For anti-aging cream, regenerating care products, emollient, anti-irritant in peelers, sun protection and hair care products
- Spolaore et al. (2006) showed that algae can
  - Repairs signs of early skin aging,
  - Exerts skin-tightening effect
  - Prevents stria formation
  - Stimulates collagen synthesis in skin

Larger Markets-Animal Feed http://www.allaboutfeed.net/

Table 1 – Global feed tonnage by species and region.

- (Millions of tons)

Country	Poultry	Ruminant	Pig	Aqua	Other[3]	Total
Asia	116.00	80.12	81.00	24.50	4.03	305
Europe[1]	67.96	55.76	61.90	1.72	7.80	200
N. America[2]	91.07	45.50	31.23	0.28	17.09	185
Middle East/Africa	27.71	17.04	0.87	0.60	0.72	125
Latin America	71.26	22.34	24.80	1.88	4.46	47
Others	4.60	3.49	2.00	0.20	0.86	11
Total	378.60	224.25	201.80	29.18	34.96	873

- Feed values range from $100/ton (DDGS) to $2,000/ton (Fishmeal)
- Total Market Value ~$300 Billion

Advantages of algae as an animal feed

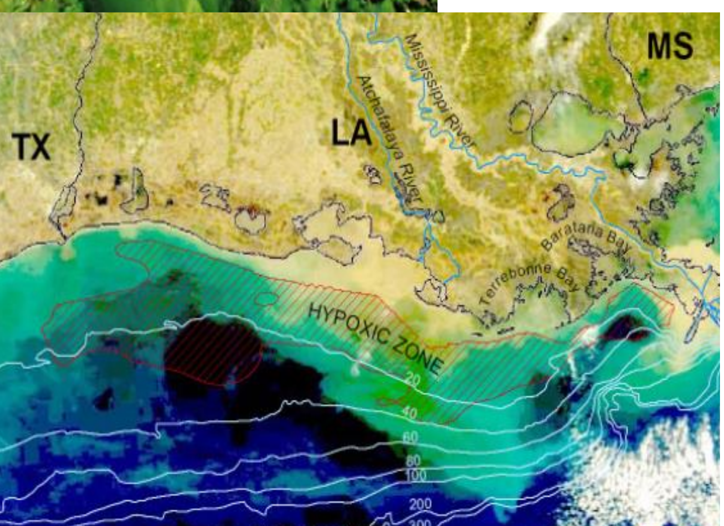
- Increasing market demand for Omega 3/6 PUFA enriched meat & egg products
- Many other benefits (e.g, Pulz & Gross, 2004)
  - Better weight control
  - Healthier skin and lustrous coat
  - Lower breakdown of unsaturated fatty acids
  - Improved color of shanks and eggs

Algal biofuels can synergize with wastewater treatment

(Pictures courtesy of Hydromentia, Inc., Ocala, FL)

- 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…"

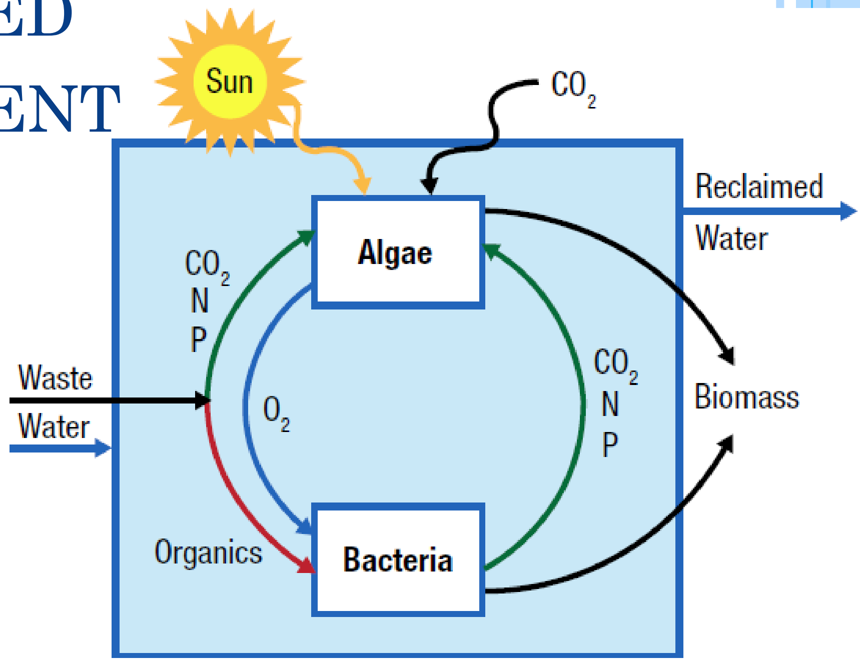
Impacts of Residual Nutrients



- N and P removal at WWTPs is costly: \$8,130 and \$49,500 per ton *(Hey et al., 2006)*
- Environmental algae grow on residual nutrients and cause problems
  - Algal toxins
  - Hypoxia
- Could harvest environmental algae for biofuels
  - Need new harvesting equipment and precision agricultural techniques

Evaluation of algae-based wastewater (WW) treatment

- Algal-bacterial symbiosis
  - "Photosynthetic Aeration" reduces energy input
  - High nutrient and organic removal is possible
  - New biomass "resources"



(National Algal Biofuels Technology Roadmap, 2010)

- Why don't we use more algal WW systems?
  - Currently no use for extra biomass
  - Removal is dependent on light, temperature, etc.
  - Clean Water Act funded activated sludge
  - Energy was considered plentiful and cheap

Synergy of Algal Biofuels and Wastewater Treatment

National Algal Biofuels Technology Roadmap:
(DOE, 2010, pg. 83)

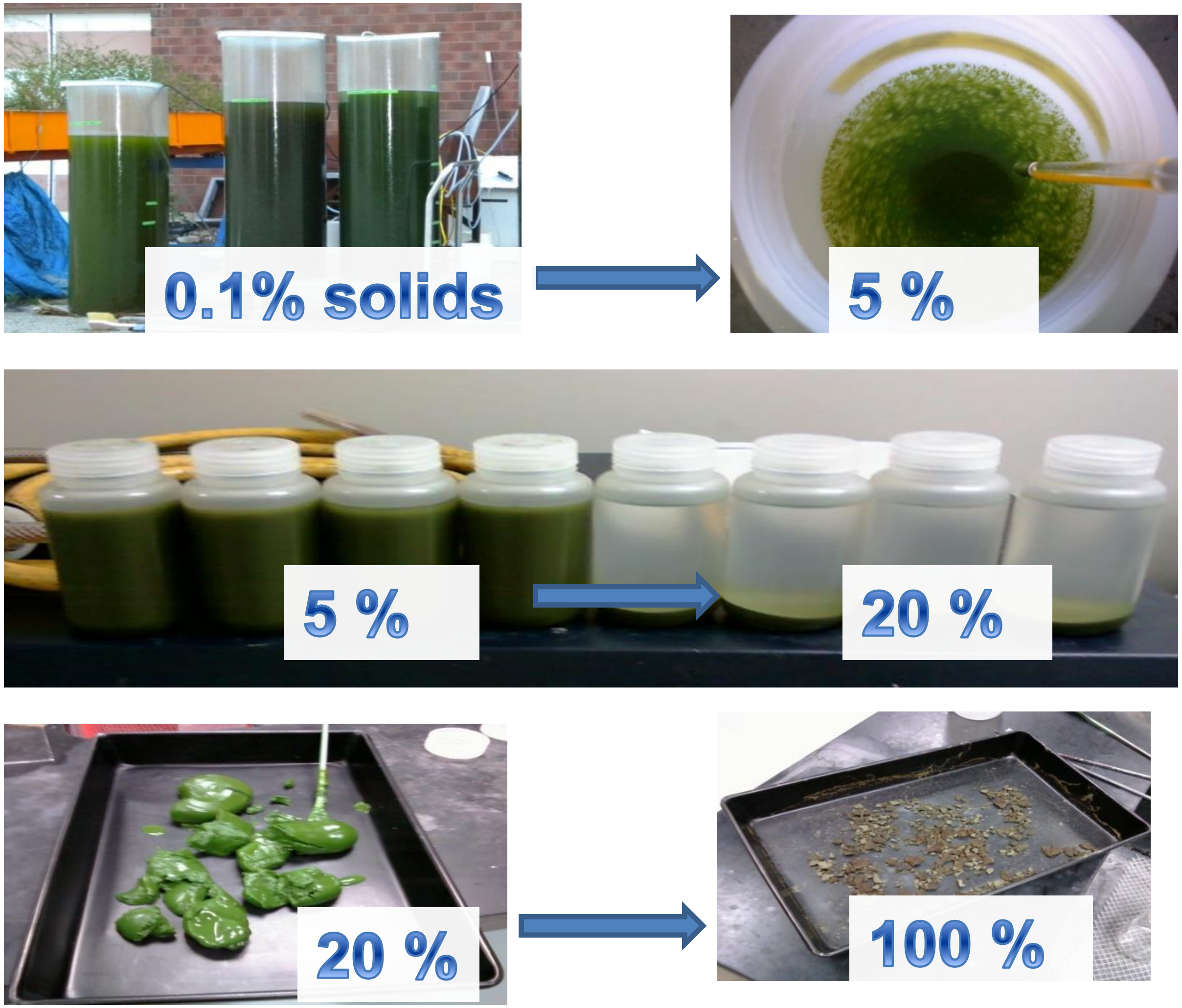
"Inevitably, wastewater treatment and recycling must be incorporated with algae biofuel production."

However…

"Nutrient recycling would be needed since wastewater flows in the United States are insufficient to support large-scale algae production on the basis of a single use of nutrients."

How can we accomplish this vision?...

Understanding water needs for algal cultivation



- Lesson- Using wastewater reduces input costs and environmental impacts, but favors low-oil biomass. (Also, not enough waste nutrients if used only once.)

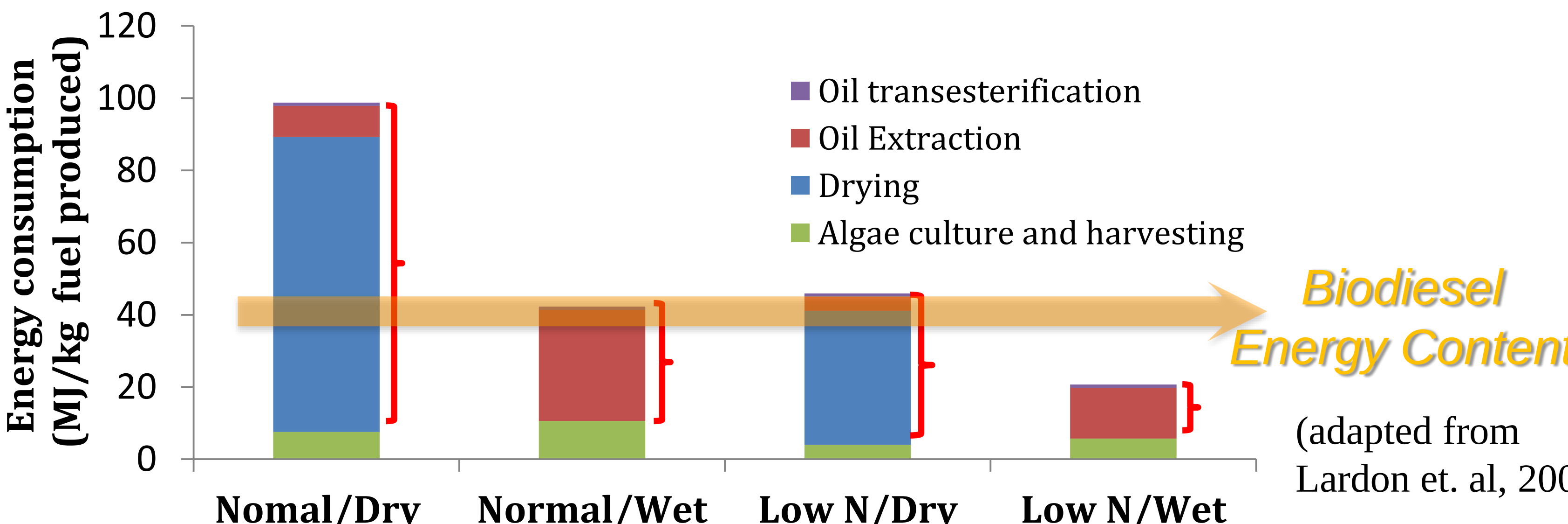
Problems with early algal biofuel paradigms

- Most current algal biofuels approaches focus on high-oil algae

- Problems
  - Energy balance
  - Contamination at large-scale with low-oil species
  - Cost and/or environmental impact of inputs
    - Water, Nutrients, CO_2

Problem: Energy Balance

- Most energy spent on drying, extraction & harvesting

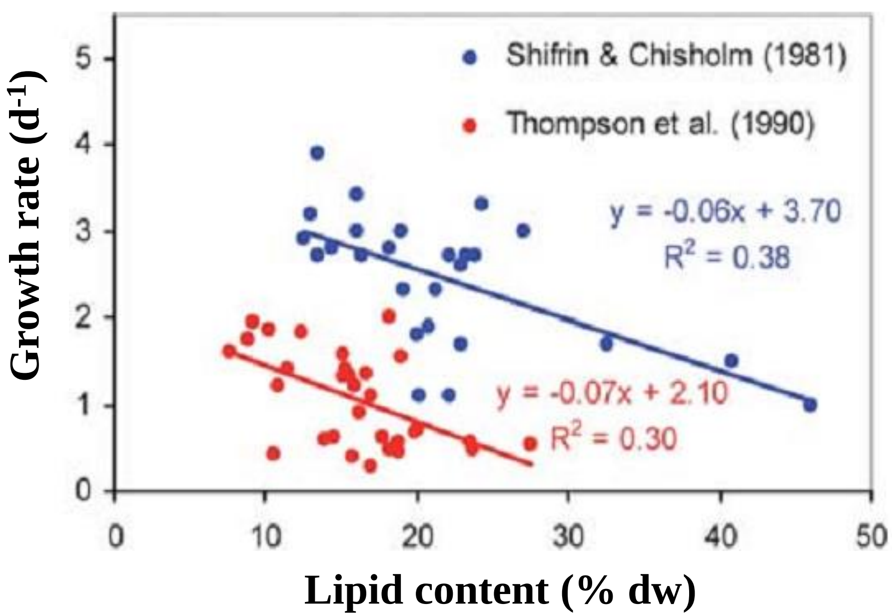


(adapted from Lardon et. al, 2009)

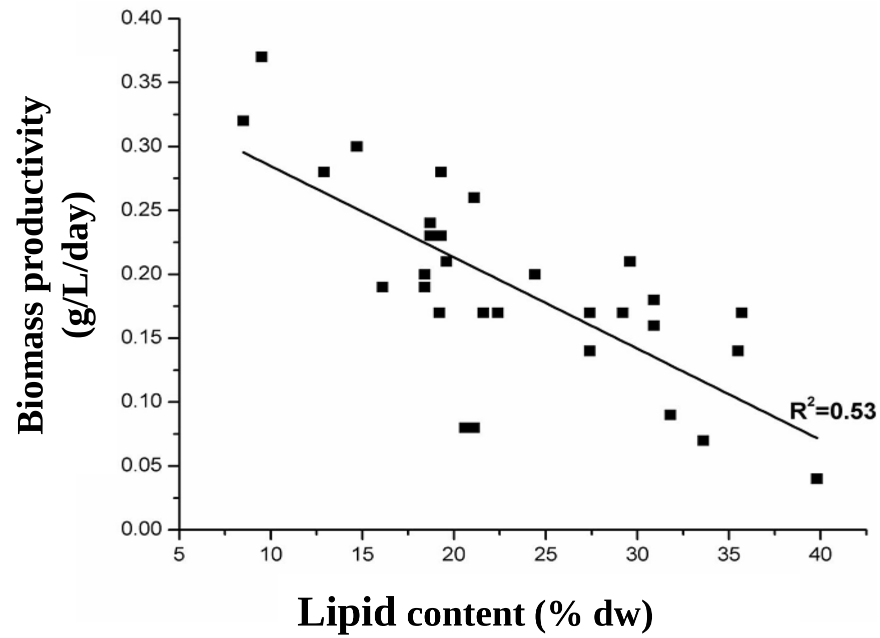
- Lesson: Must process wet (dewatered) biomass

Problem: Contamination of Target Species (High-Oil Algae)

- Fat Algae vs. Fast Algae



(Williams & Laurens, 2010)



(adapted from Rodolfi et al., 2009)

- Lesson: Biofuel processes that utilize low-oil biomass are highly advantageous
  - Natural selection becomes an ally

Past Algal Biofuels Economic Analysis

Source	Productivity (mt/ha/yr)	Lipids %	Capital cost ($/ha)	Operation cost ($/ha)	Algae oil ($/bbl)	Algal oil ($/gal)
Benemann et al., (1982)	67.5	40	$88,519	$41,085	$225	$6.09
Weismann and Goebel (1987)	112	30	$139,784	$58,744	$241	$5.75
Benemann and Oswald (1996)	109.5	40	$108,889	$38,577	$101	$2.41
Average values	96.3	36.7	$112,397	$46,135	$199	$4.75

(Gallagher , 2011)

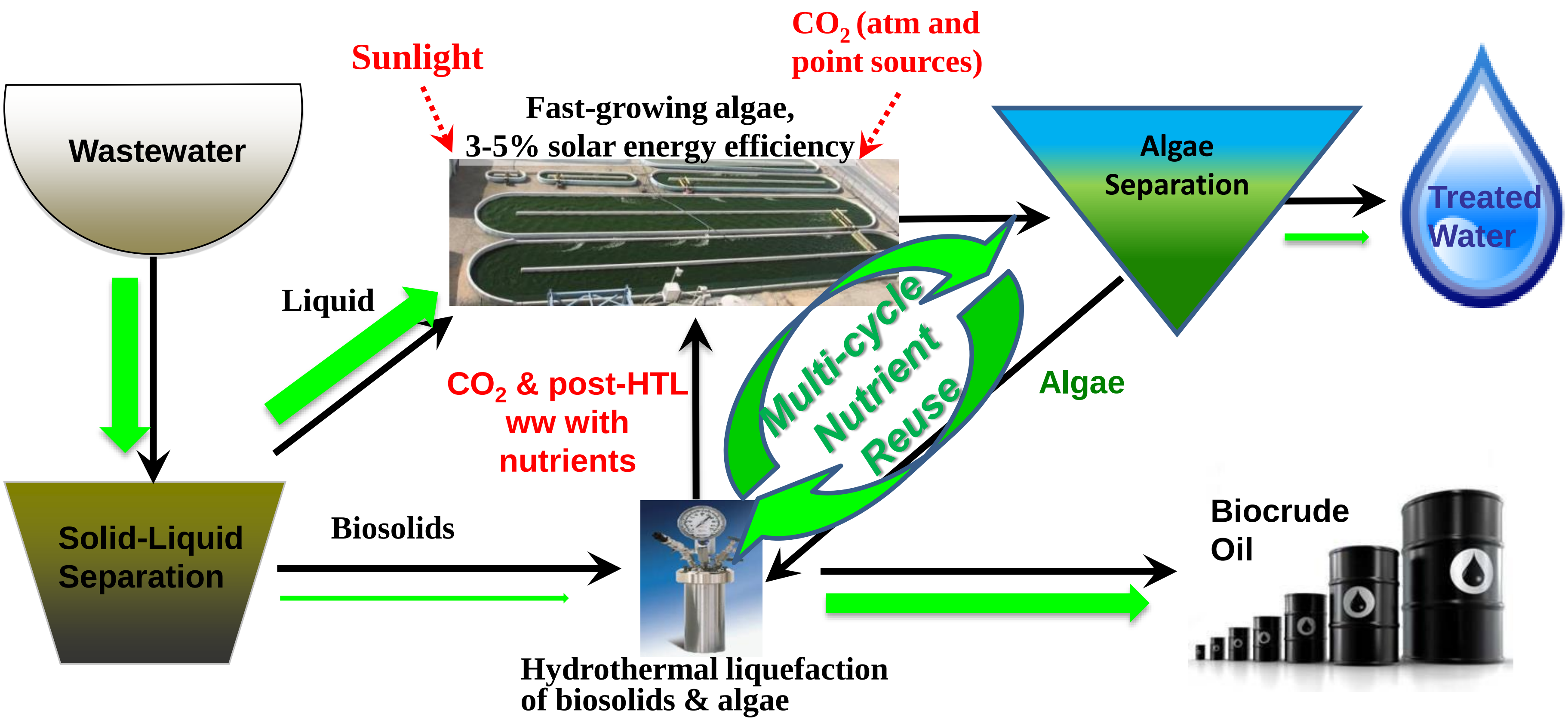
Algal biofuels can be cost-effective when combined with waste treatment

Algae Treatment Case (100 ha)	Operation expenses	Capital charge	Electricity produc-tion credit	Biofuel produc-tion (bbl/yr)	Cost of fuel (w/o wastewater treatment credit)	Cost of fuel (w/ wastewater treatment credit)
Wastewater Treatment with Biofuel Production	$2,960,000	$3,170,000	$831,000	12,700	$417/bbl	$28/bbl
Biofuel Production Only	$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)

Environment-Enhancing Energy-

A new approach that synergistically combines algal wastewater treatment with hydrothermal liquefaction to resolve all 3 major problems with current algal biofuel paradigms, and introduces…



Multi-cycle Nutrient Reuse, **which leverages waste nutrients to maximize biofuel production**

Component A- Algal wastewater treatment systems have been scaled-up…

Algal Turf Scrubber (Mulbry et al., 2008; Hydromentia)

algaewheel
CLEAN WATER • CLEAN AIR • CLEAN ENERGY

(Biotown- Reynolds, IN, 2010)

These systems produce low-oil, mixed algal biomass

Component B- Hydrothermal liquefaction (HTL) converts wet, low-lipid biomass into crude oil

Demonstrated HTL Feedstocks

Municipal sludge
Manure
Algae
Crop residues
Woody materials

Reactor

High T:200 – 350 ºC
High Pressure : 8 – 12 atm

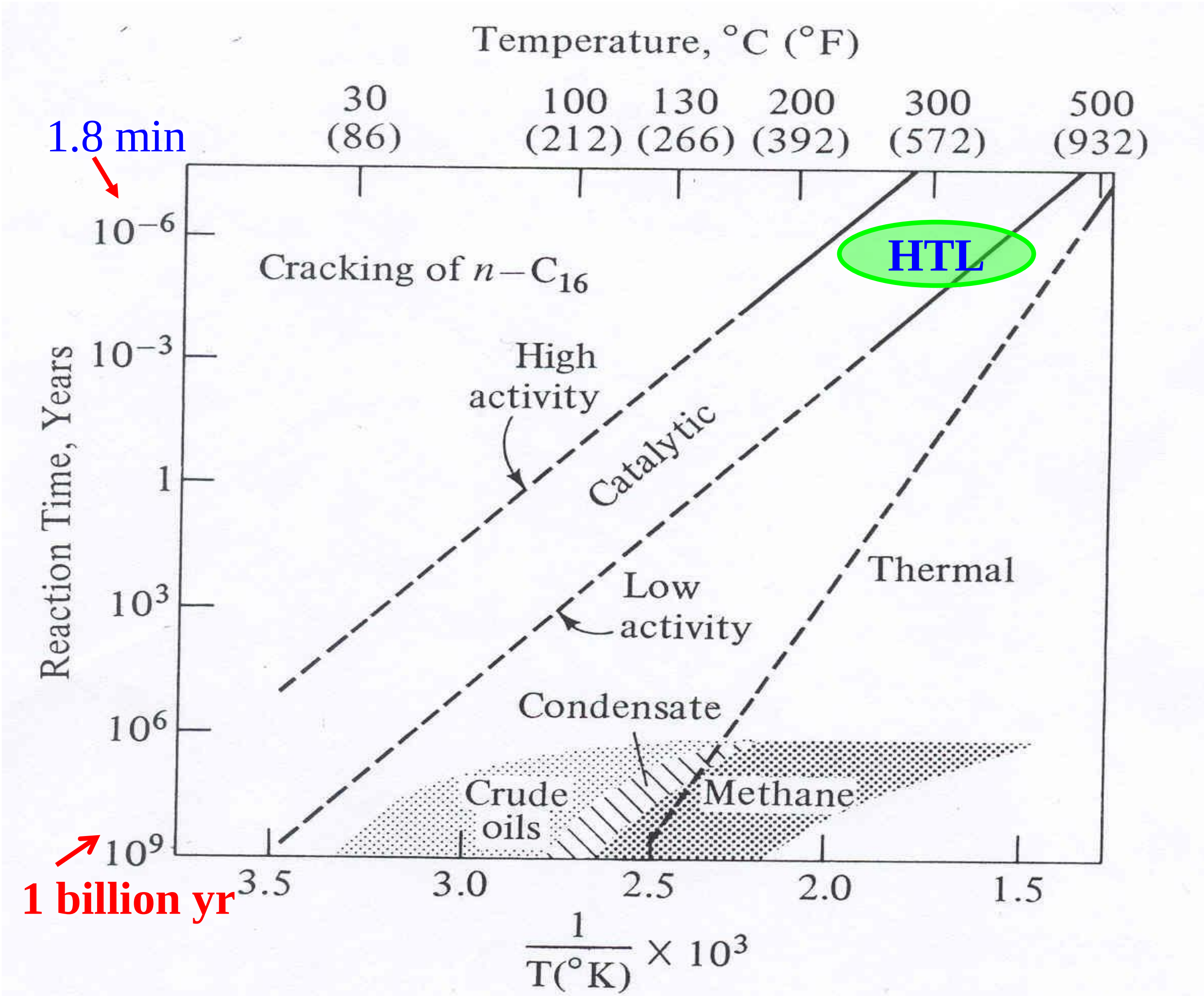
Gas Product

Post-HTL WW

Solid Residue

Oil Product

Eout : Ein > 3:1 at lab-scale (% solids =20%)
Eout : Ein > 10:1 w/ heat exchangers as projected by commercial partners



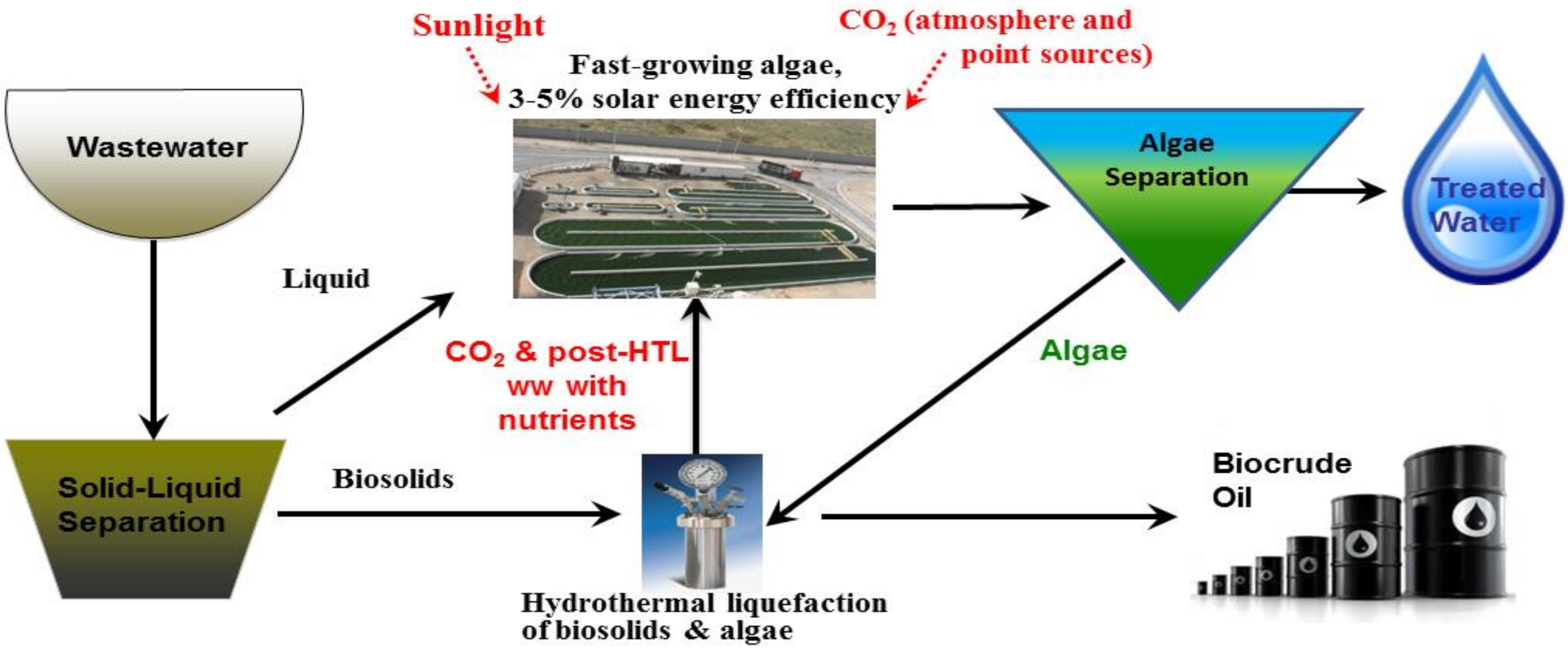
Source: Hunt, John. 1979.
Petroleum Geochemistry and Geology

Upscaling E2-Energy System- HTL Equipment

10-20 ton/day Demonstration HTL System on South Farms

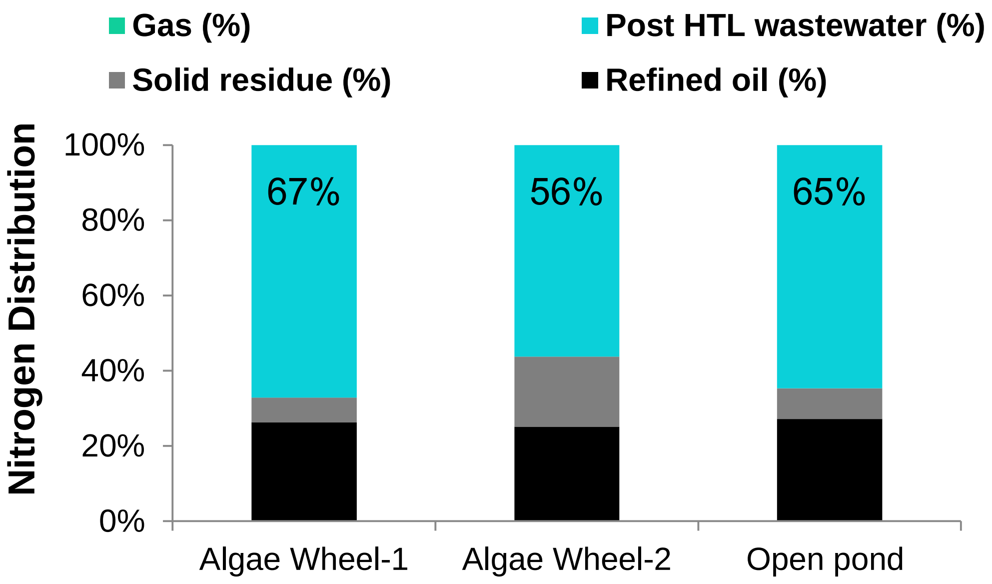
4 steps of E^2-Energy confirmed at bench scale

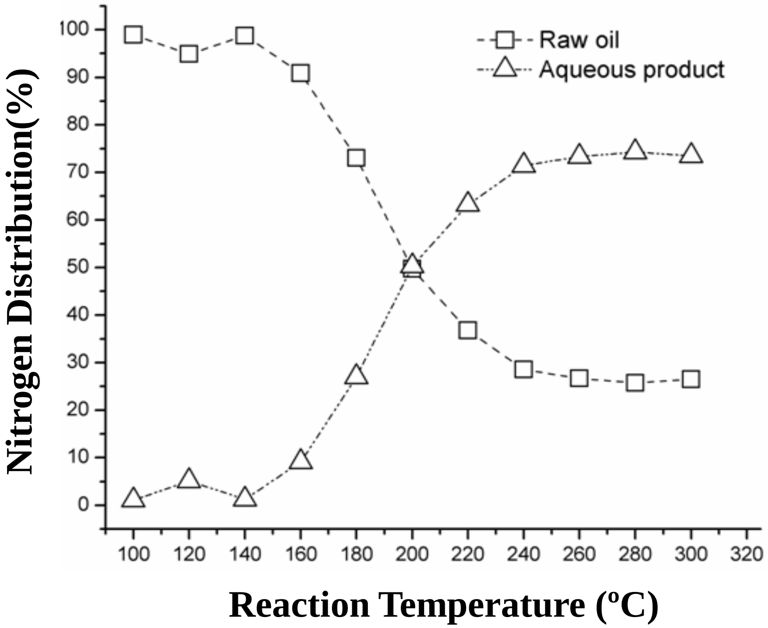
1. Algae can be *grown* in raw ww and post-liquefaction ww.
2. Organics and nutrients can be removed from ww and recovered during algal biomass production.
3. Algal biomass in ww can be converted into biocrude oil via hydrothermal liquefaction.
4. Nutrients can be recycled within this system to maximize the biomass and bioenergy production from wastes.



Step 4. Can HTL re-release nutrients captured in algal biomass for multiple cycles of algal growth?

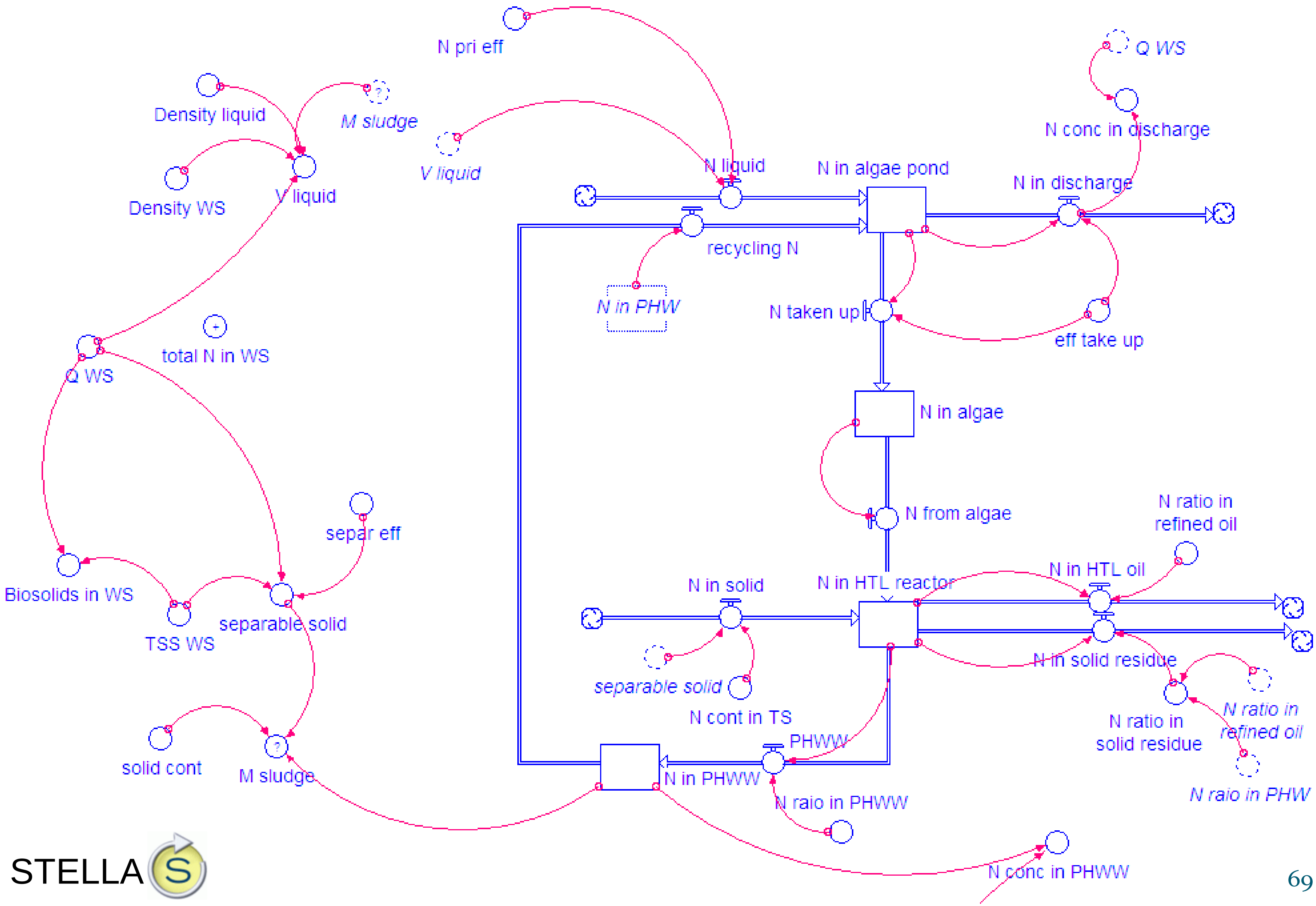
- N distribution
  - ✓ 45-75% N in post-HTL ww
  - ✓ N distribution can be manipulated with HTL conditions





(Yu et. al, 2011)

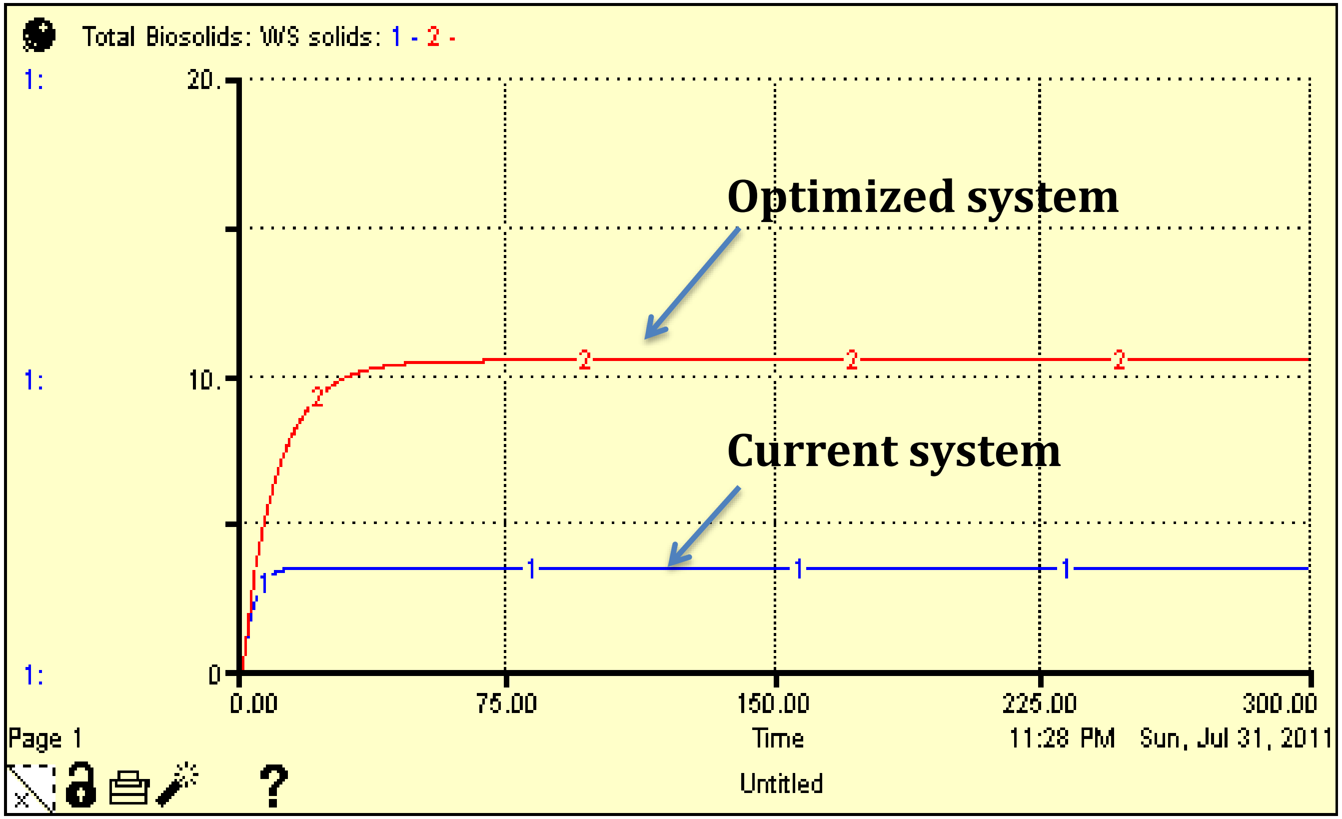
E²- Energy System Modeling with Stella Software



STELLA

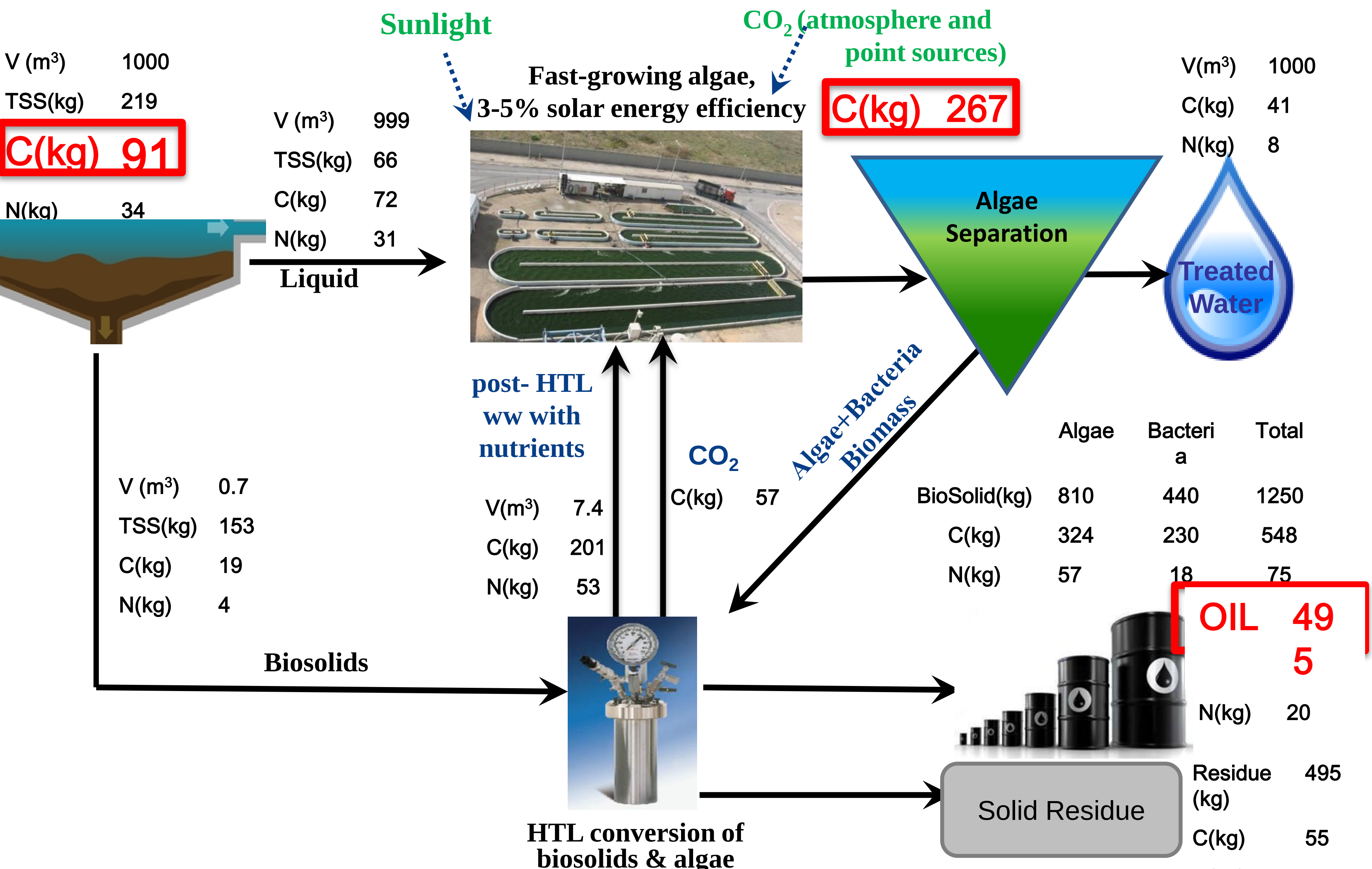
System Modeling of Biomass Multiplication Ratio

- **Biomass multiplication = 3.4 to 10.4 times original ww VS**

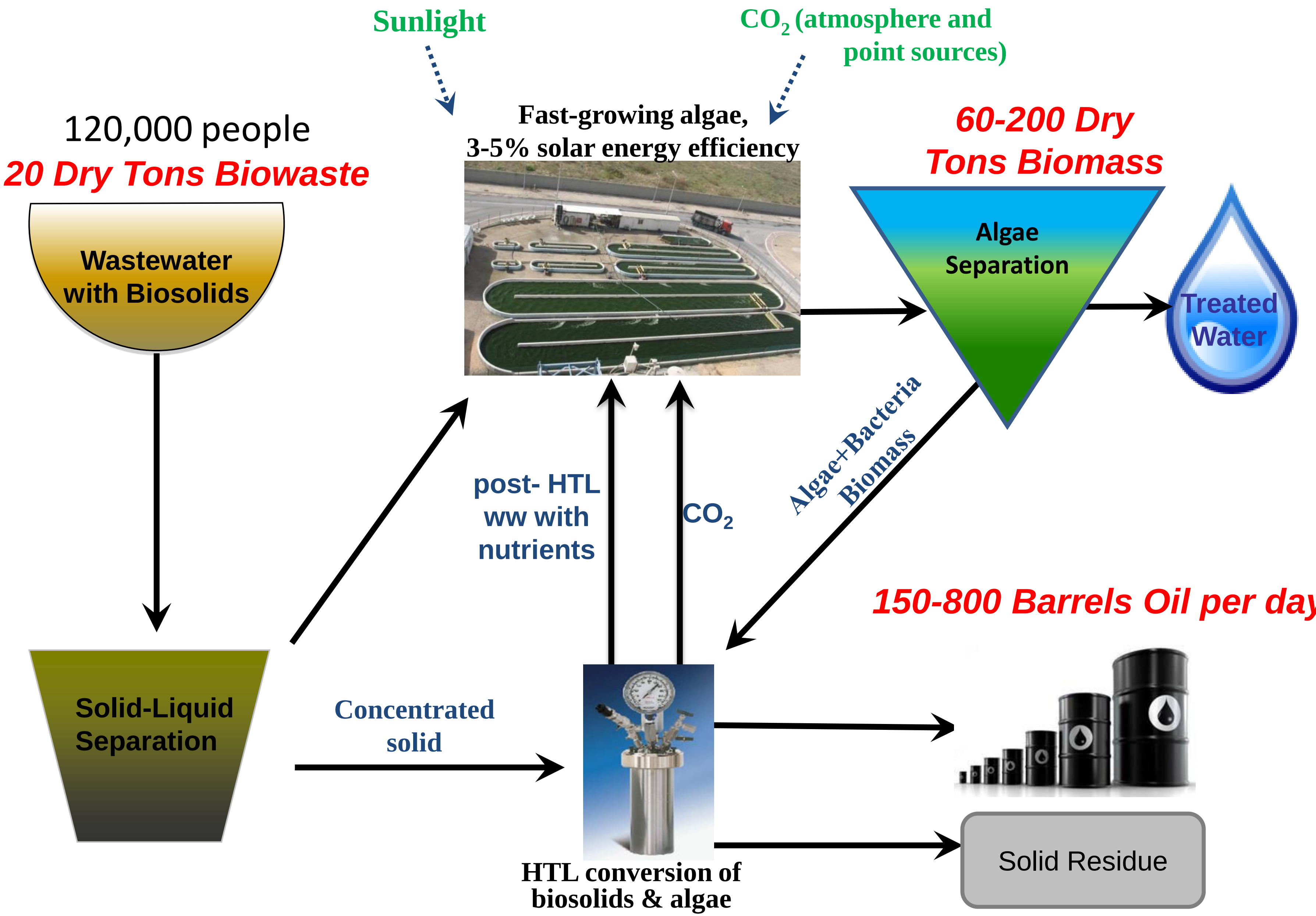


STELLA

Example Model Output: C, N and Mass (Water) Flows



E^2-Energy Example for Champaign-Urbana



Now Let's Think Big…

US collects and processes 200 million dry tons of biosolids per year…

200 million tons of organic biowastes → 0.6 to 2 billion tons of algae biomass → 0.3 to 1.2 billion tons of biocrude oil

US oil consumption is ~1.1 billion tons/yr !!!

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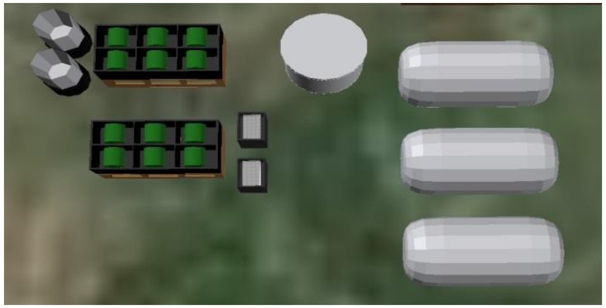
Next Steps: E^2-Energy Demonstration Facility

- **Many partners supporting development of an E^2-Energy research and education facility at the UIUC swine farms,**
  - Phase 1- gal/day, Phase 2- bbl/day (current), Ph 3- Deploy
- **Need additional partners- Waste producers, Capital Supply, Refined product users, Continued R&D**



ANY QUESTIONS?

- Lance Schideman schidema@illinois.edu
- Illini Algae Club http://algae.illinois.edu

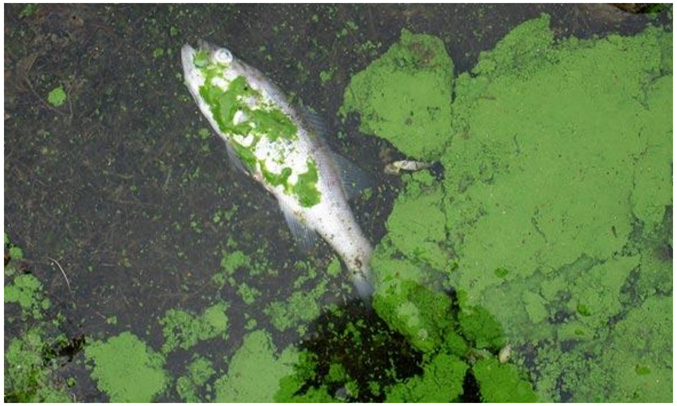
How would you define waste? …

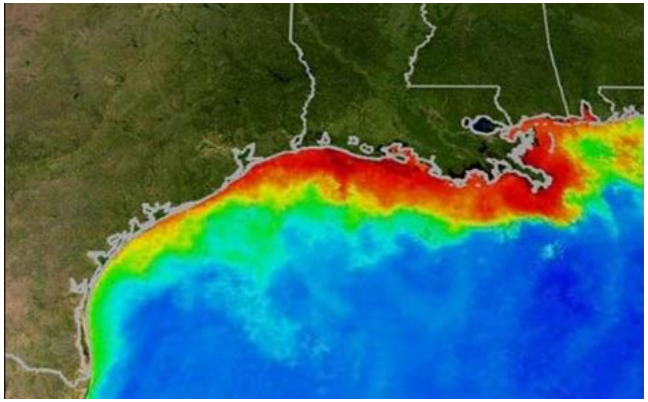
Provide examples for your definition

- Material that is not wanted; the unusable remains or byproducts of something
- Something we have too much of to use effectively in a given area
- A resource that we have not yet figured out how to use- Buckminster Fuller

Another algal biofuels opportunity…

Harvesting Algae from hypoxic zones





CASE STUDY: GULF OF MEXICO HYPOXIA

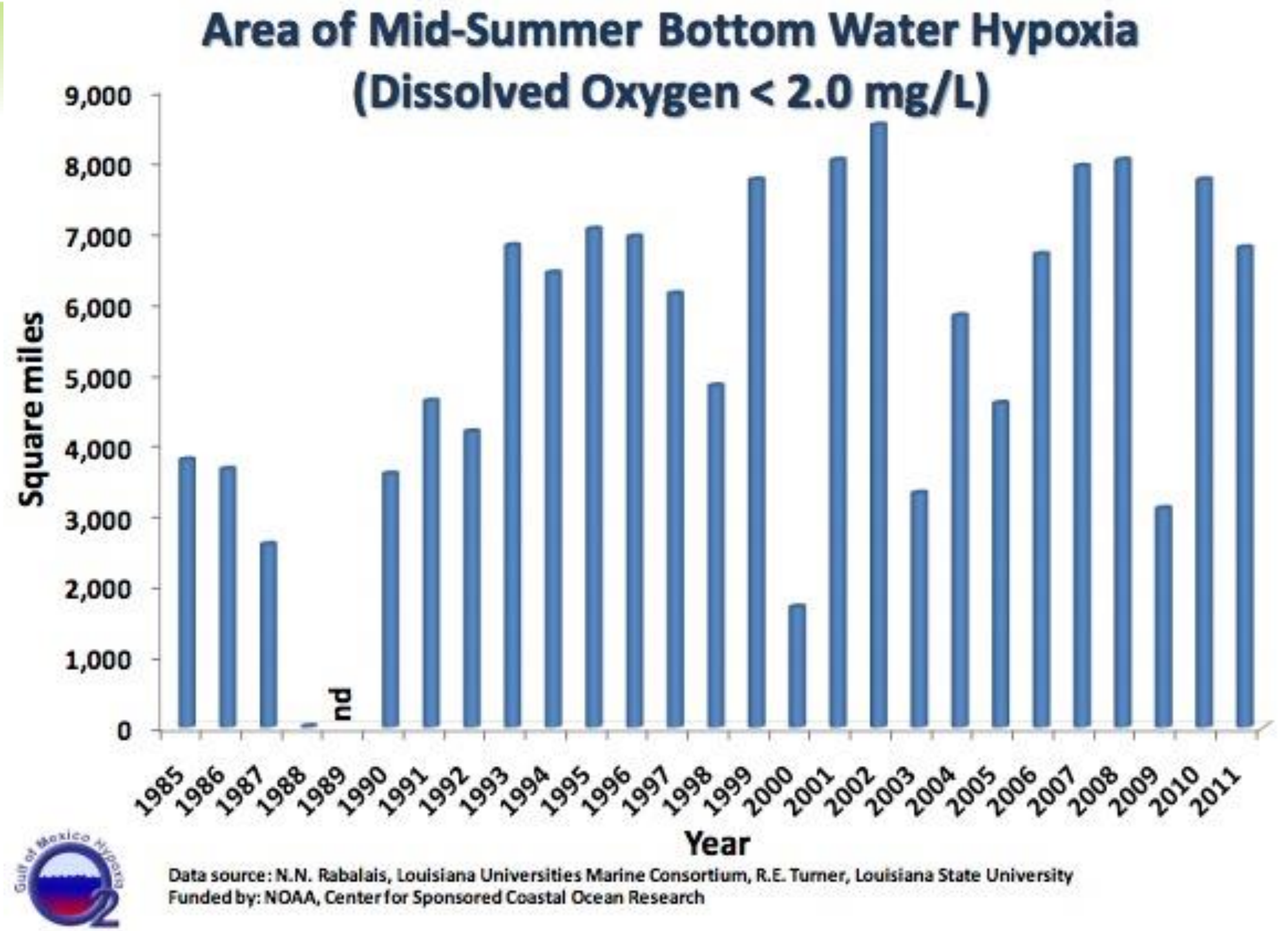
- Synergy with environmental clean-up

Hypoxia = Dissolved O_2 < 2ppm

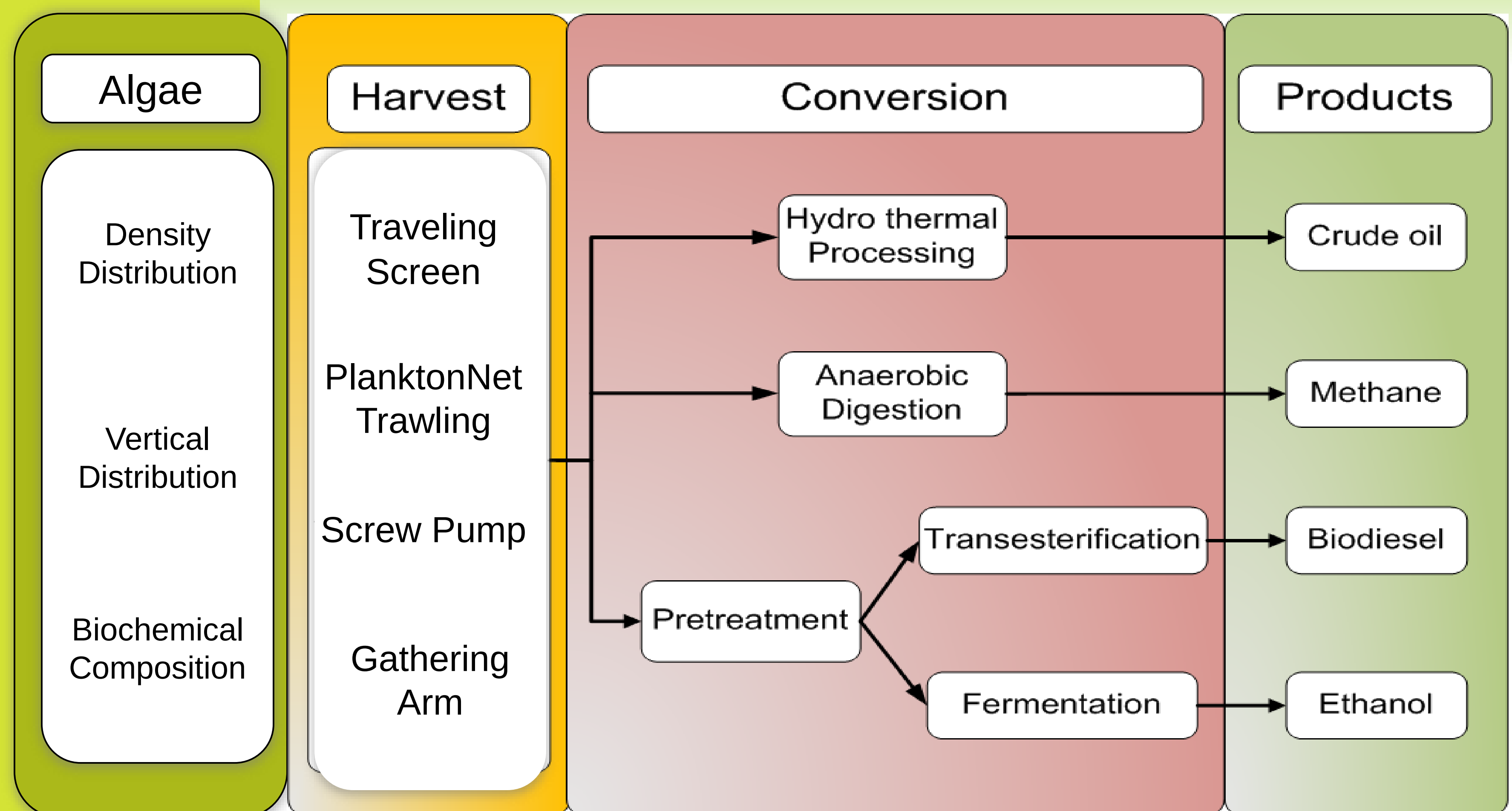
Hypoxia occurs after algal blooms

Hypoxic zone size is 2000 - 8000 mi^2

EPA goal is 2000 mi^2 by 2015 (5000 km^2)



Harvest Algal Biomass for Energy Recovery Model (HABER)



HARVESTING TECHNOLOGIES

Plankton Net Trawling

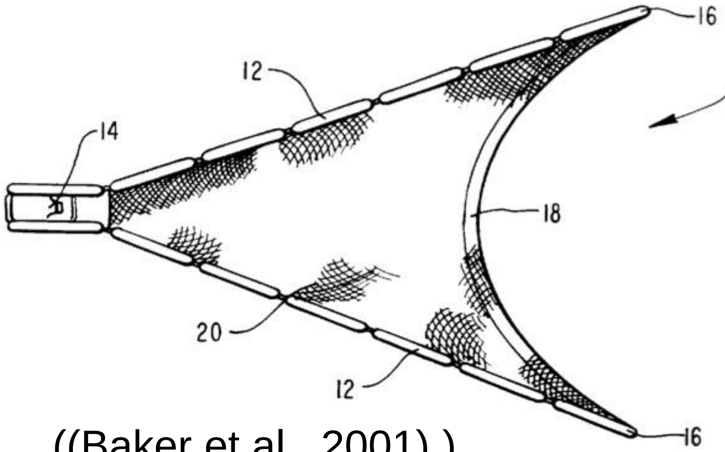
Traveling Screen

(Simplexity Creative)

Screw Pump/Filter

Focusing Arm (Floating Boom)

((Omsett, 2010))



((Baker et al., 2001))

BIOFUEL CONVERSION TECHNOLOGIES

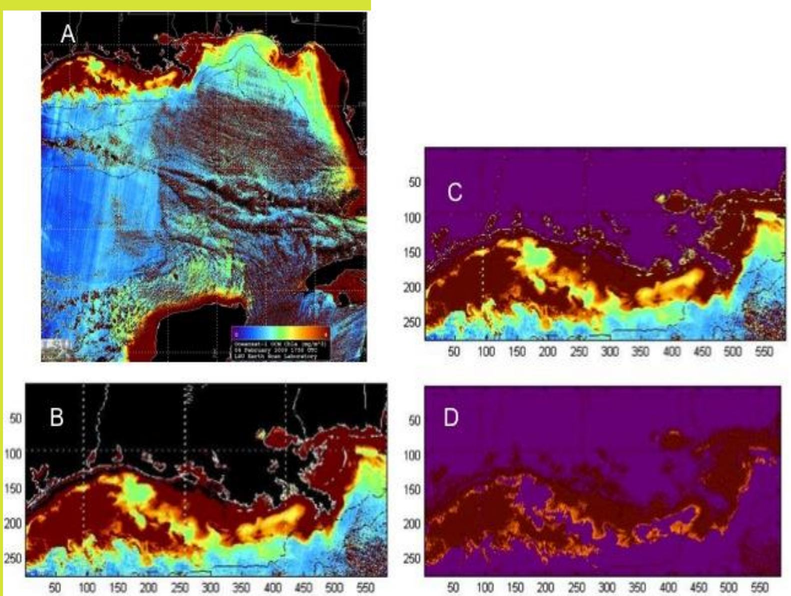
Fermentation
Ethanol

Transesterification
Biodiesel

Anaerobic Digestion
Methane

Hydrothermal Liquefaction
Crude Oil

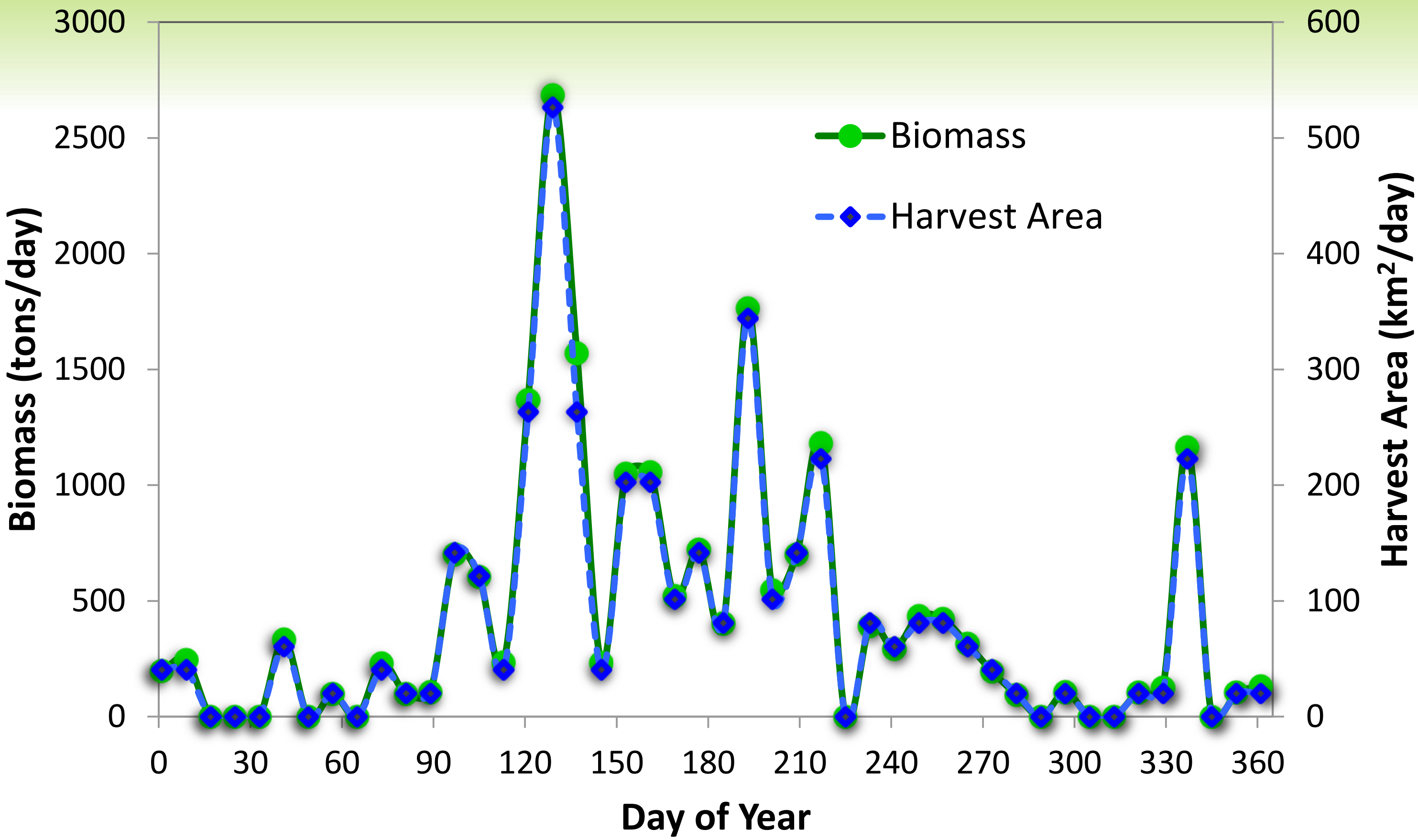
GULF OF MEXICO *SATELLITE CHLOROPHYLL IMAGERY*



- Seastar Satellite launched with a Sea Viewing Wide Field-of-View Sensor (sea-WiFS)
- Detect the reflection of sun light during an algae bloom
  - Chlorophyll absorbs red and blue light and reflects green light (500-600nm).
- Convert radiance values to in-situ measurements of chlorophyll density

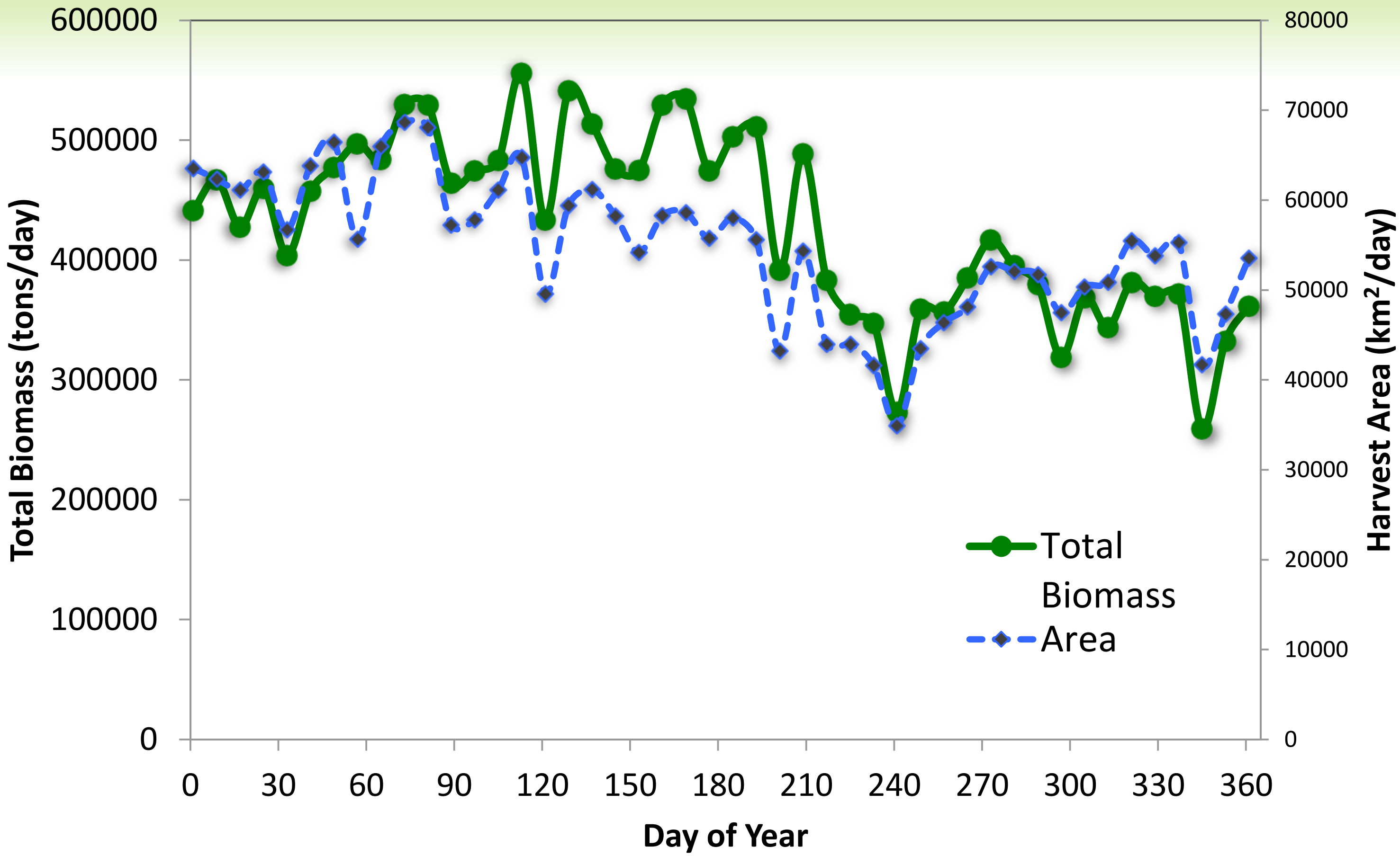
(NASA,2010)

HIGHLY EUTROPHIC SURFACE AREA BIOMASS ESTIMATED USING SATELITE IMAGARY



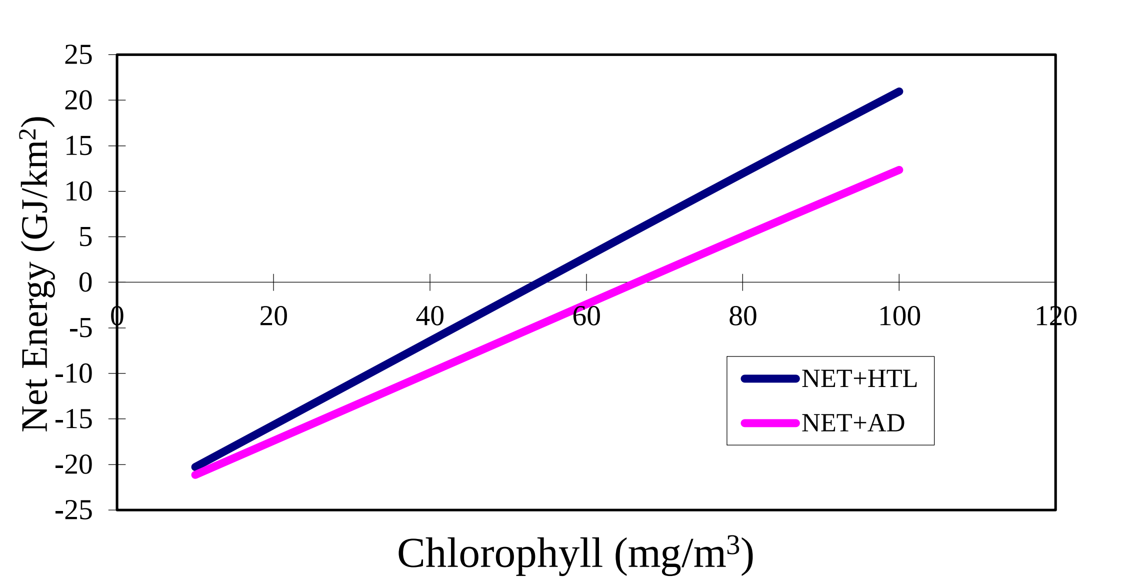
Highly eutrophic area: (chlorophyll a > 67 mg/m^3)
Surface = 0 - 0.5 m depth

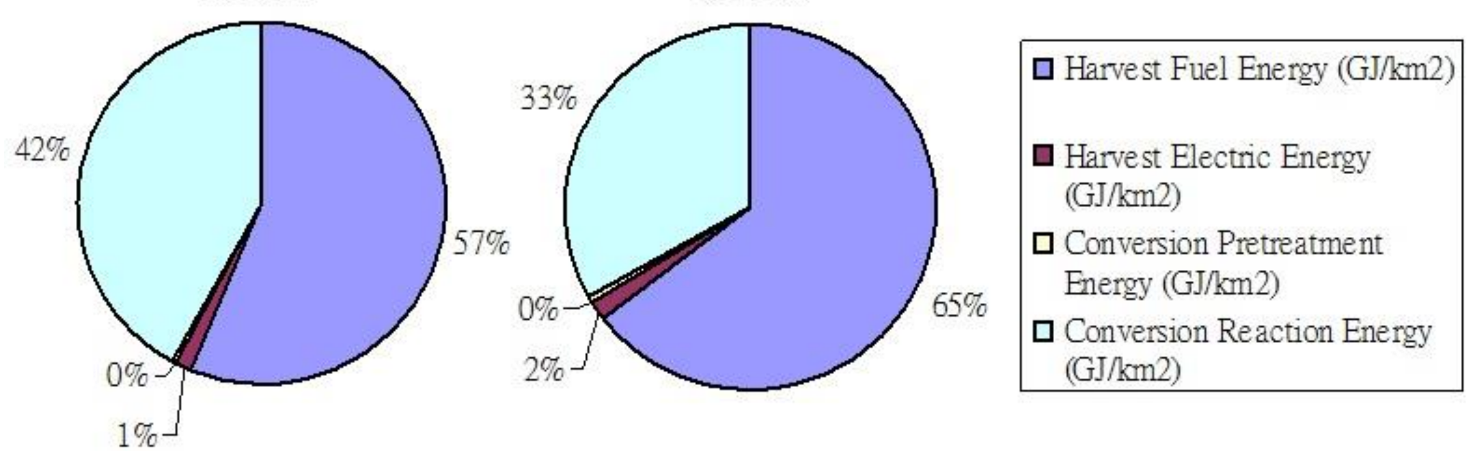
CASE STUDY: GULF OF MEXICO
HIGHLY EUTROPHIC AREA TOTAL ALGAL BIOMASS



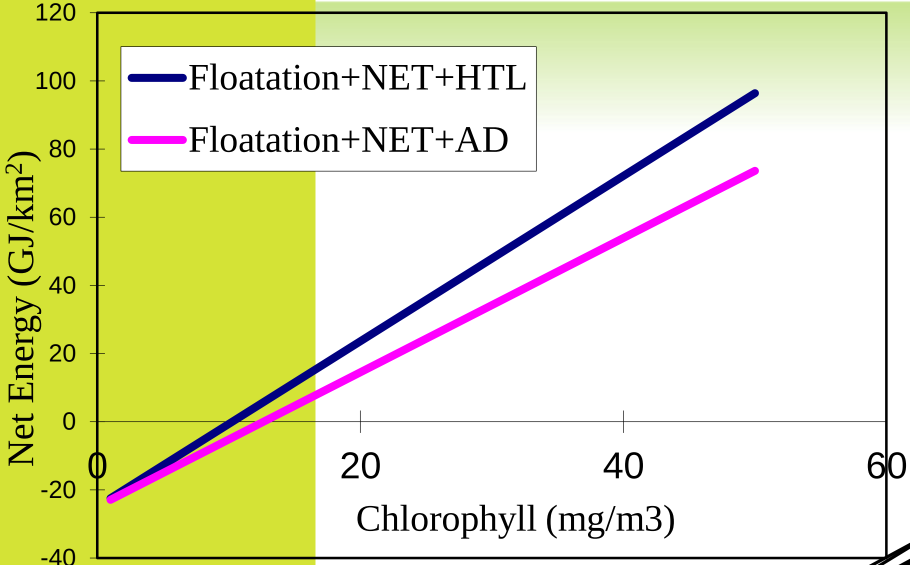
Highly eutrophic area: (chlorophyll a > 67 mg/m^3)

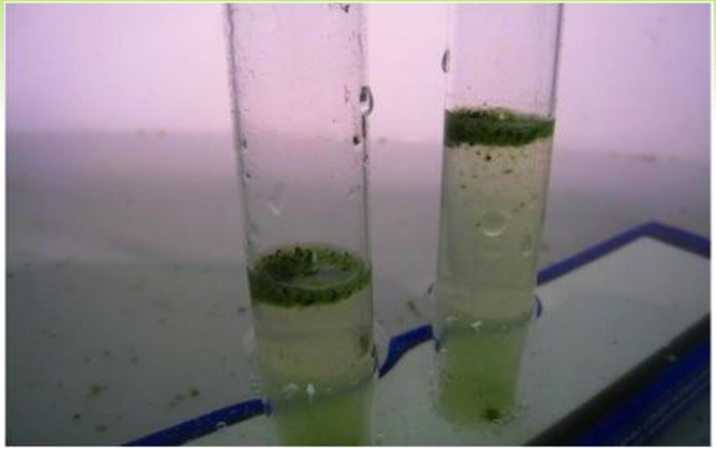
ENERGY "BREAK-EVEN" POINT AND ENERGY CONSUMPTION RATIO



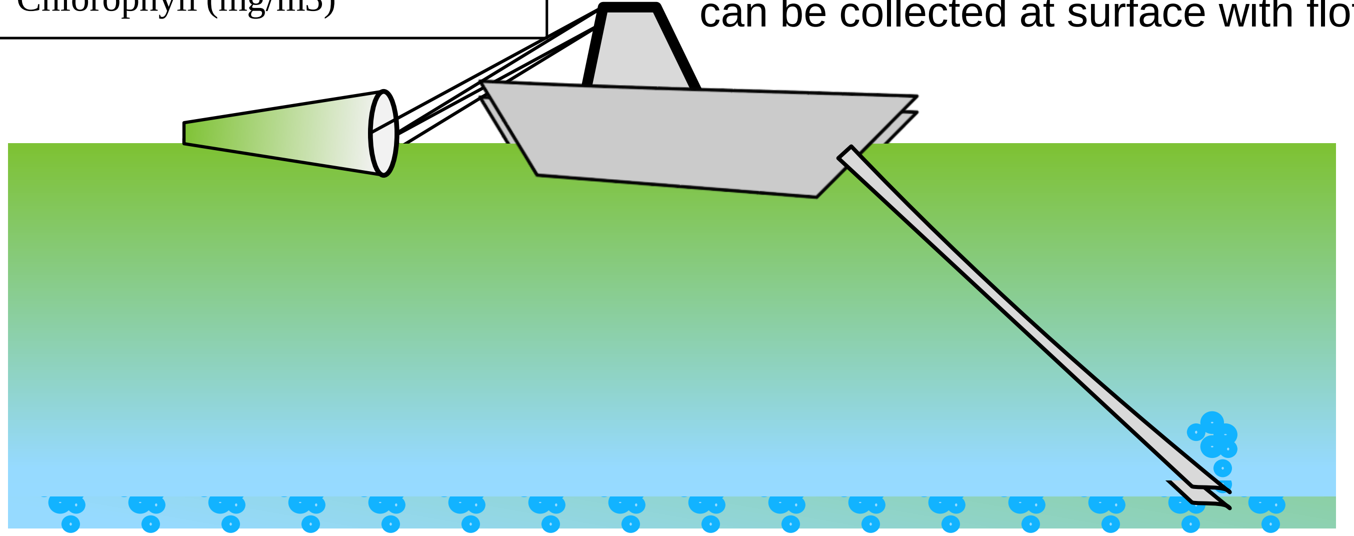


VERTICAL FLOTATION INTEGRATED HARVESTING





Lab tests showed 72% of total biomass can be collected at surface with flotation



ECONOMIC ANALYSIS

	Remove Algal Bloom Chl_{sat}>50	Energy Production Chl_{sat}>67	Harvest with Vertical Focusing Technology Chl_{total}>67
Number of Vessel Required	32	9	2278
Annual Bloom Area (km^2)	6,669	3,382	2,517,835
Annual Biomass (ton)	27,781	17,666	19,780,685
Annual Net Biofuel Production (barrel)	4,597	6,430	12,377,143
Annual Biofuel Income ($)	413,730	578,700	1,113,942,870
Annual Labor Cost ($)	1,333,800	676,400	503,567,000
Equipment Cost ($)	7,360,000	2,070,000	523,900,000
Total Cost ($)	8,693,800	2,746,400	1,027,467,000
Annual Net Income ($)	(8,280,070)	(2,167,700)	86,475,870

Conclusions

WILL ALGAE BE A FUEL OF THE FUTURE?

- Algal biofuels have significant promise
  - Higher productivity, non arable lands, etc.
- Current limitations
  - Contamination, high harvesting energy, nutrient costs
- Natural algal bloom harvesting has potential
  - Plankton nets with hydrothermal liquefaction was best
  - Harvesting Gulf algae and converting it to biofuels can produce **12 million barrels** and a **net profit of $86 M**
  - Resolves a significant environmental problem
- E2-Energy maximizes biofuel production from wastewater via multi-cycle nutrient reuse
  - Can potentially provide up to 1.2 billion tons /yr of oil

NEXT STEPS
Harvesting Natural Algal Blooms

- Develop new algal bloom harvesting equipment
  - Ship mounted add-on
  - Dissoved air flotation
- Foreign applications with more severe algal bloom problems
- Intelligent (precision) harvesting system
  - Integrate meteorological data and satellite imagery to plan optimum harvesting route

Illini Algae Club- Education, Outreach & Tours

- Tours and demos for students
- Online interactive website at **Algae.Illinois.edu**

Campus Sustainability Project Algal Biofuels for Carbon Capture

- Abbott Power Plant - coal and natural gas
- Located on campus next to Memorial Stadium

Abbott FY08 Co2 Emissions

- Campus CO_2 emissions - **505,272 tons**
- Abbott gas emissions (40%) - **203,464 tons**
- Abbott coal emissions (33%) – **167,293 tons**
  - *Average power plant produces 1.2 million tons CO_2 annually*
- Assuming 2kg of CO_2 per 1kg of algae & 20% oil
- Potential for **245 million gallons** of oil annually

Emission data obtained from www.energymanagement.uiuc.edu

THANK YOU FOR YOUR TIME….

ANY QUESTIONS?

- Lance Schideman schidema@illinois.edu
- Illini Algae Club http://algae.illinois.edu

Why Algal Biofuels?
Less competition for arable land use

vs.

- Algae require less land and can use marginal lands and waterbodies not suitable for agriculture
  - Reduced "Food vs. Fuel" concerns
- Creation of new arable land incurs a debt for greenhouse gases (GHGs) (Fargione et al., 2008)
  - Soy biodiesel: 37 – 319 years
  - Corn ethanol: 48 – 93 years
  - "biofuels made from waste biomass … incur little or no carbon debt and can offer immediate and sustained GHG advantages."