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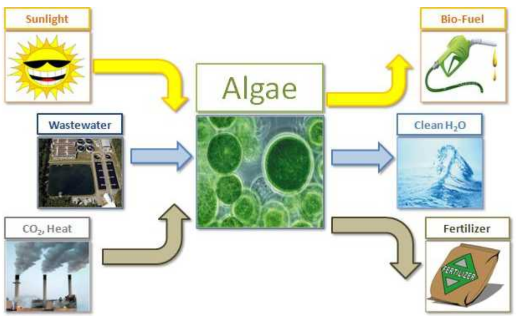

Techno-Economic Analysis (TEA) of "Algal Turf to Fuel"

Using algal turf scrubber® (ATS™) cultivation as a source for Biofuel Feedstock

Cadet Stephen Horvath, United States Coast Guard Academy

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Exceptional service in the national interest

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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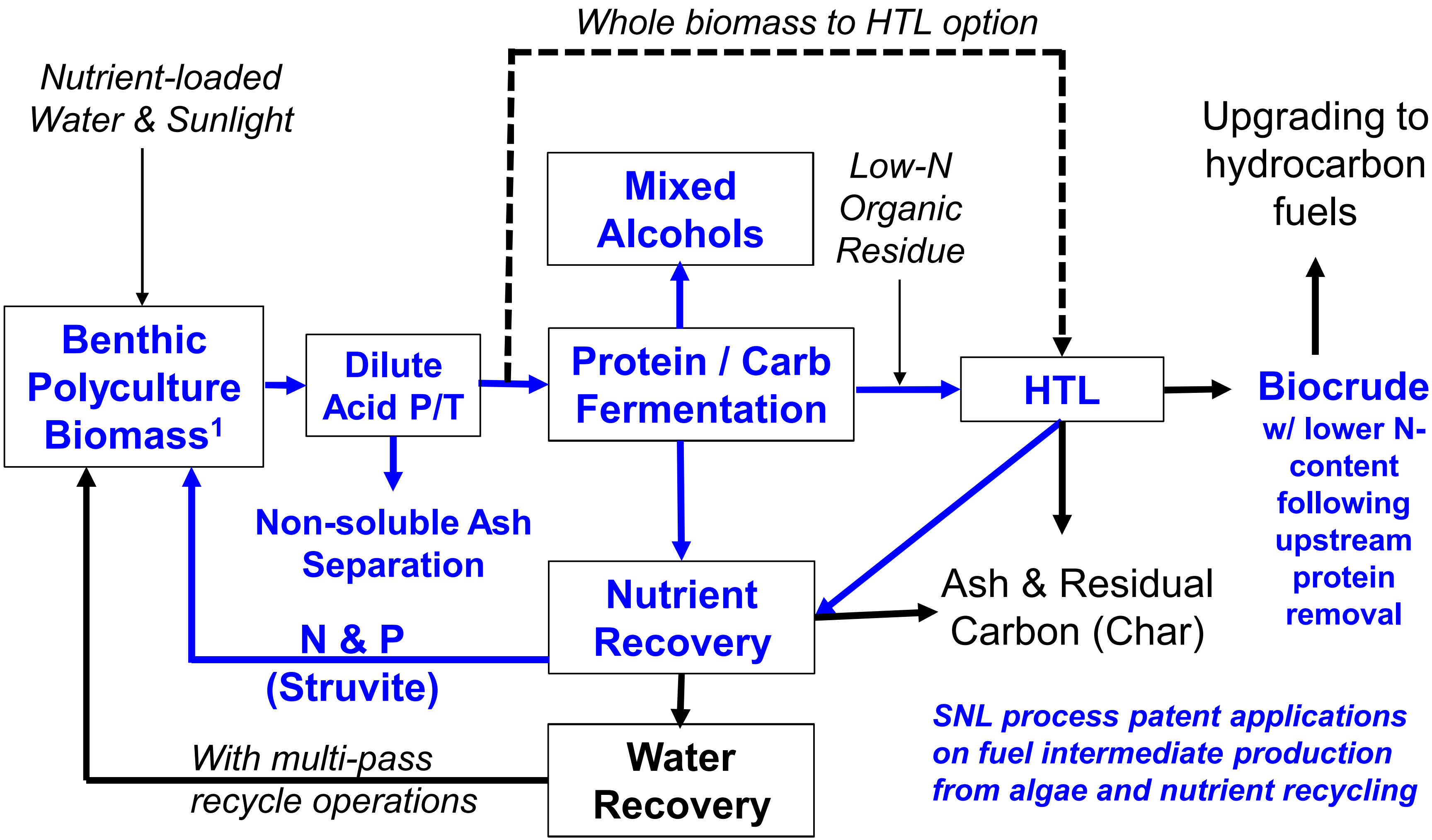
Goal

- To model the processes and costs included in the production of fuel from algal turf

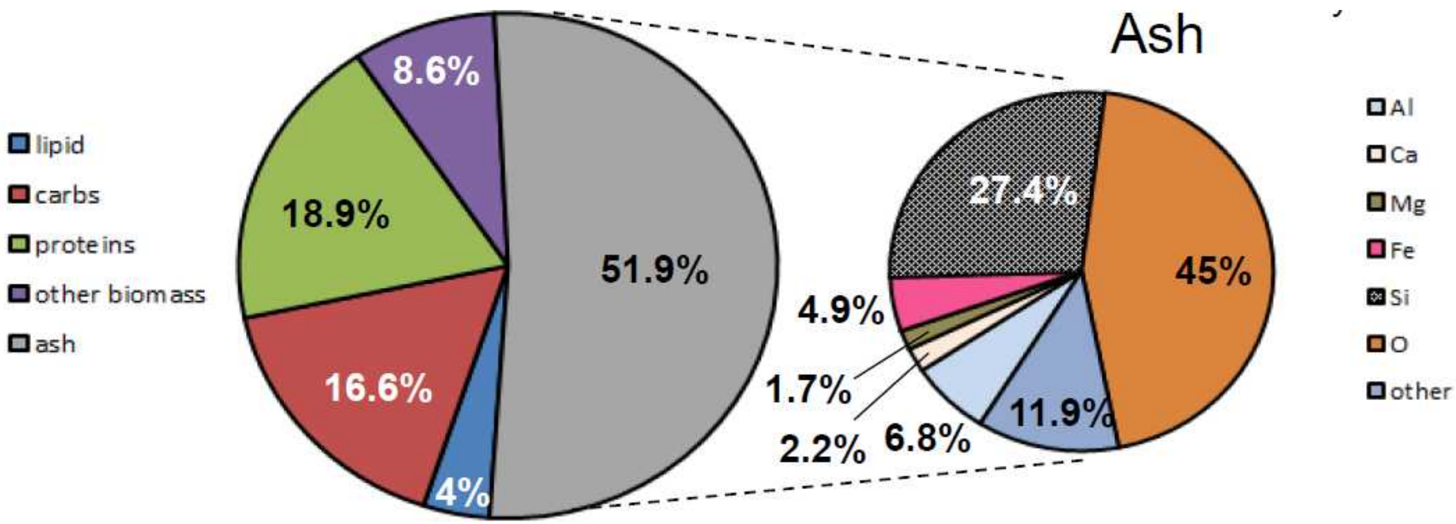
Key Processing/Recycling Pathways



[1] Benthic algal polyculture turf will also include entrained planktonic species

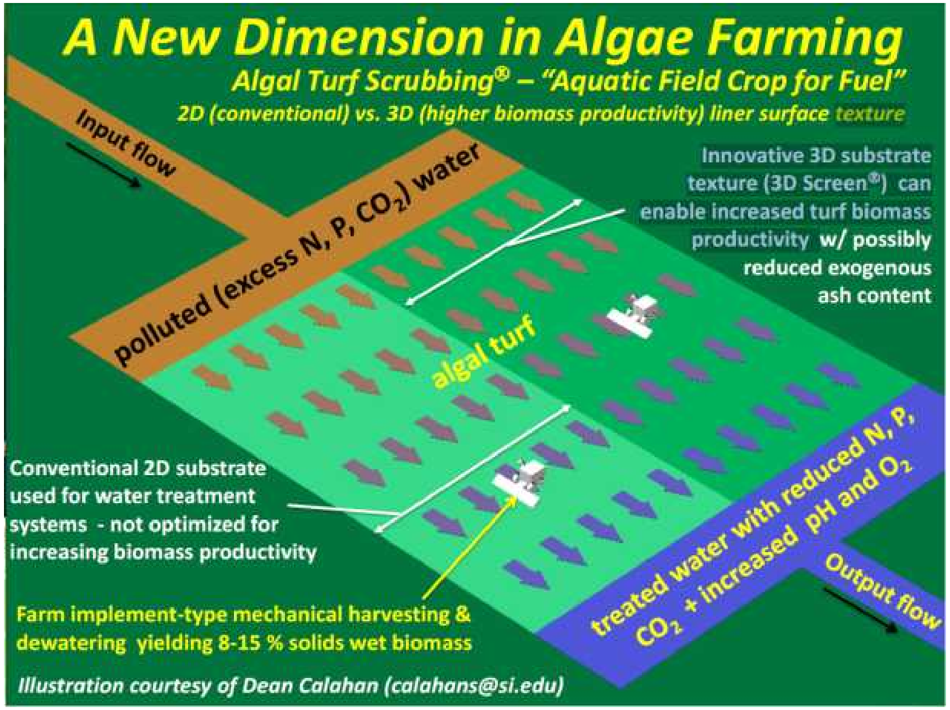
Assumptions/Givens

- Scale to the DOE's 2012 Harmonization Study for algal biofuels
  - Average Production of 1340 Short Tons (AFDW) of Algae per day being delivered to the Fuel Production Plants
  - Approximate Composition of Biomass Being Processed



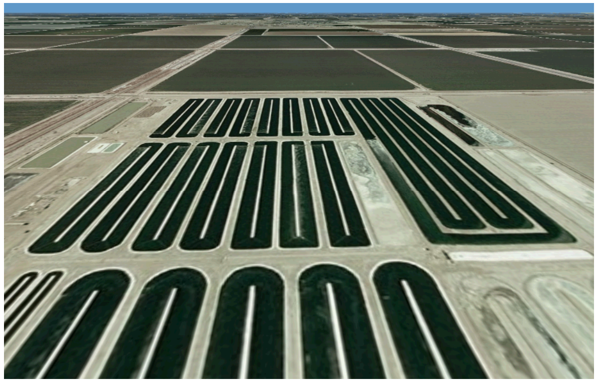
Components of Fuel Production

- Feedstock Growth
  - Algal Turf Scrubber® (ATS™)
- Harvesting
  - Option 1: Scraper
  - Option 2: Vacuum Truck
- Processing into Biofuels
  - Hydrothermal Liquefaction of whole algal biomass
  - Fermentation of algal biomass protein and carbohydrate fractions followed by Hydrothermal Liquefaction



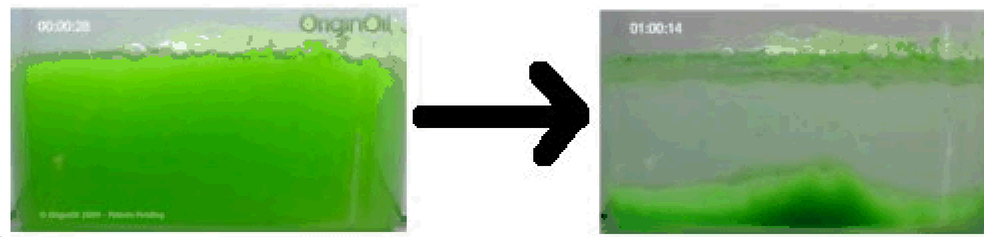
Available Types of Algae Production

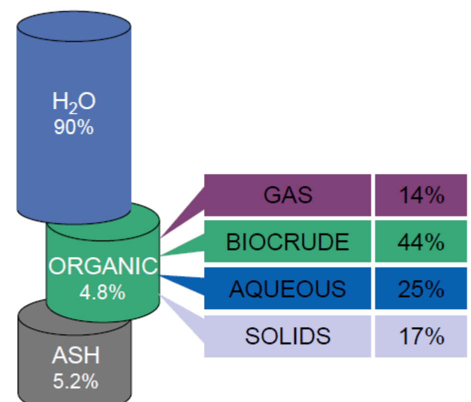
- Open Ponds: Microalgae
- Photo-bioreactors: Microalgae
- Algae Turf Scrubber®: Microalgal Polyculture (many species mixed together in an aquatic ecosystem)



ATS™

- ATS™ generates 10-20 g/m^2/day AFDW, or more using systems not yet optimized for biomass production
- Originally developed and used to clean water as it flows across the surface to which the algae is attached.
- Harvested biomass contains a high percentage of ash from current systems – have not been optimized for reduced ash





Harvesting and Dewatering

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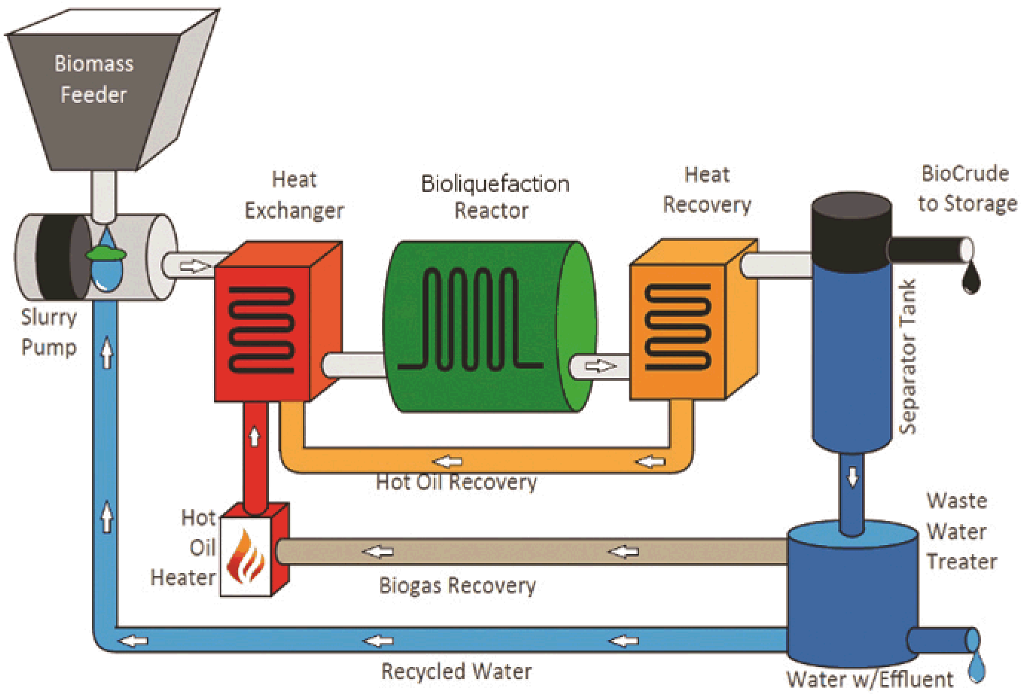
- ATS™ Harvesting: One potential harvester uses a combination, squeegee/vacuum system – low energy intensity !
- Photo-bioreactors/Open Pond Harvesting: requires the use of costly chemicals for flocculation and high-energy-intensity techniques such as centrifuge to separate the algae from the water

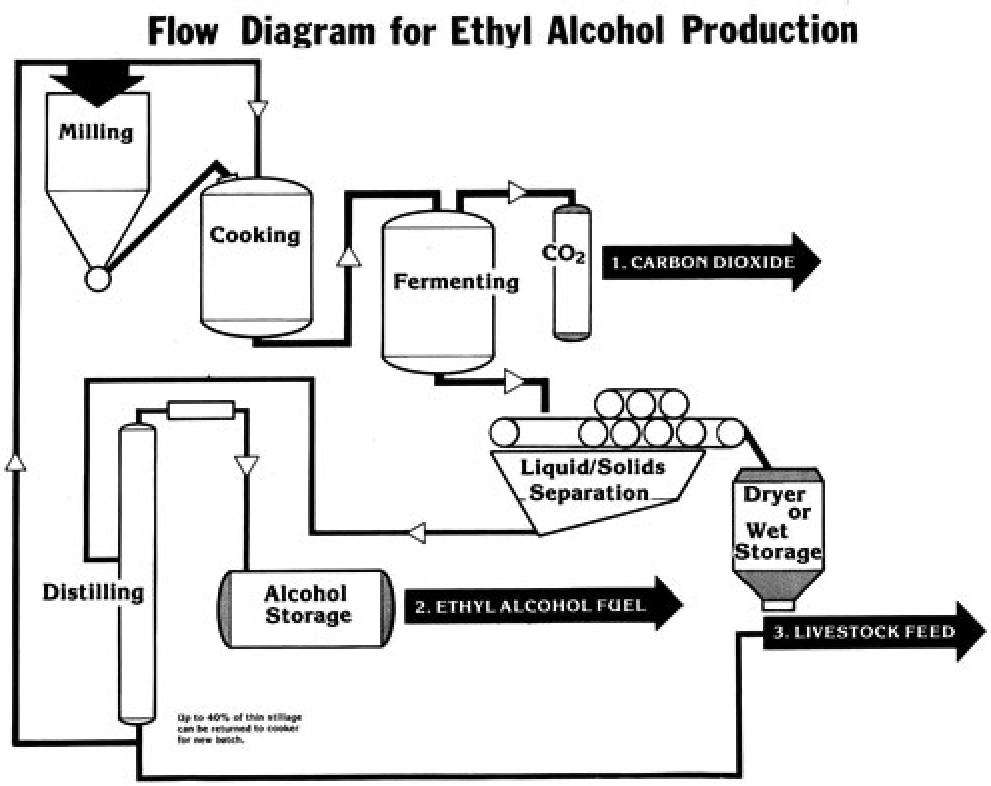
HTL (Thermochemical) Conversion

- Primary production concerns: High pressure, high temperature, time
- Almost any biomass can be processed in HTL
- Typically a 40% to 50% conversion efficiency (by mass)
- Produces "biocrude" product that must be further upgraded to renewable hydrocarbon fuels

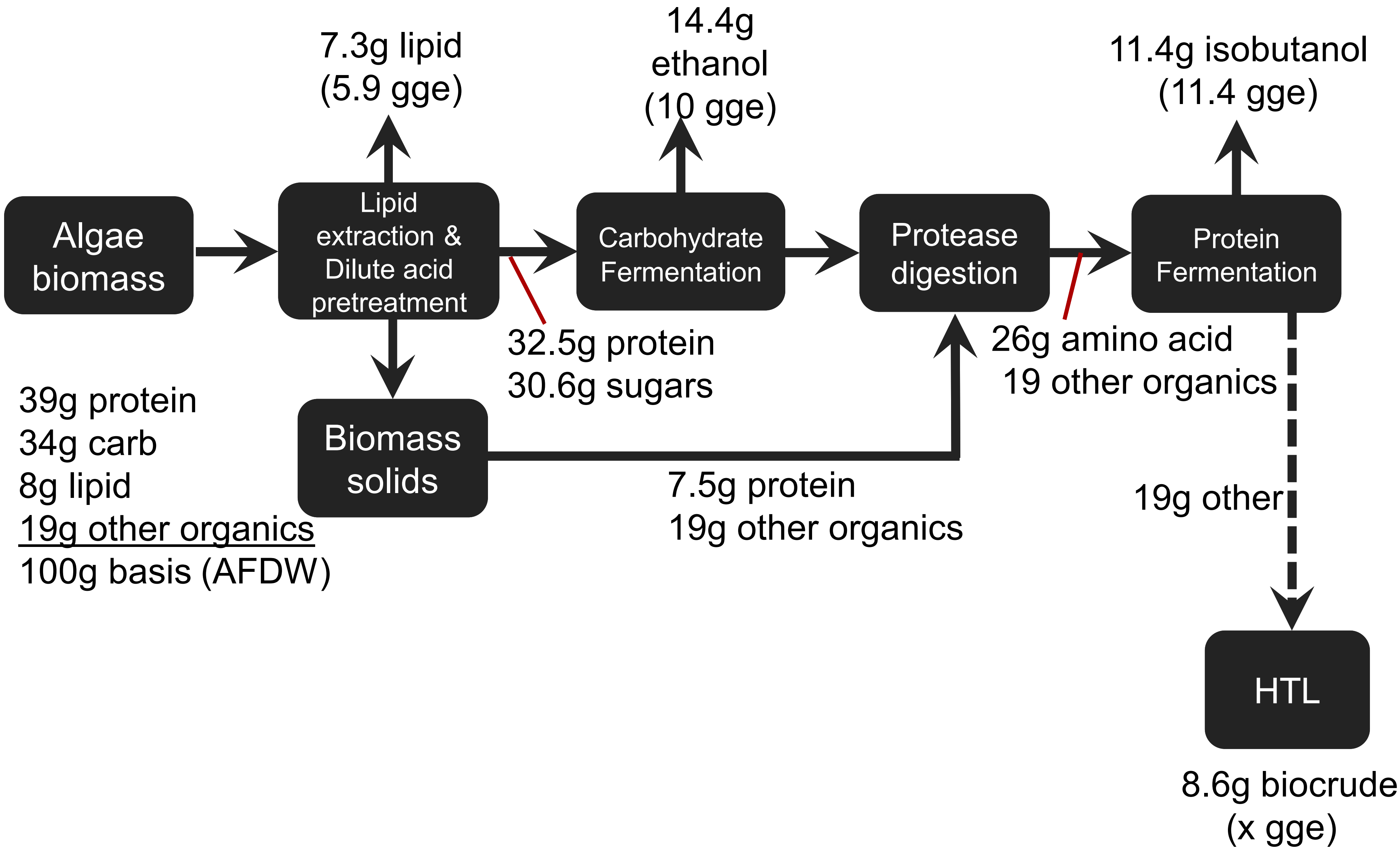


Fermentation (Biochemical)

- Primary production concerns: Living organisms, time, regulated temperatures
- Efficiency ranges based on organisms used and component of biomass being processed
- Can convert protein and carbohydrate fractions of the biomass into a mix of alcohols



Fermentation with HTL Conversion



Main Products

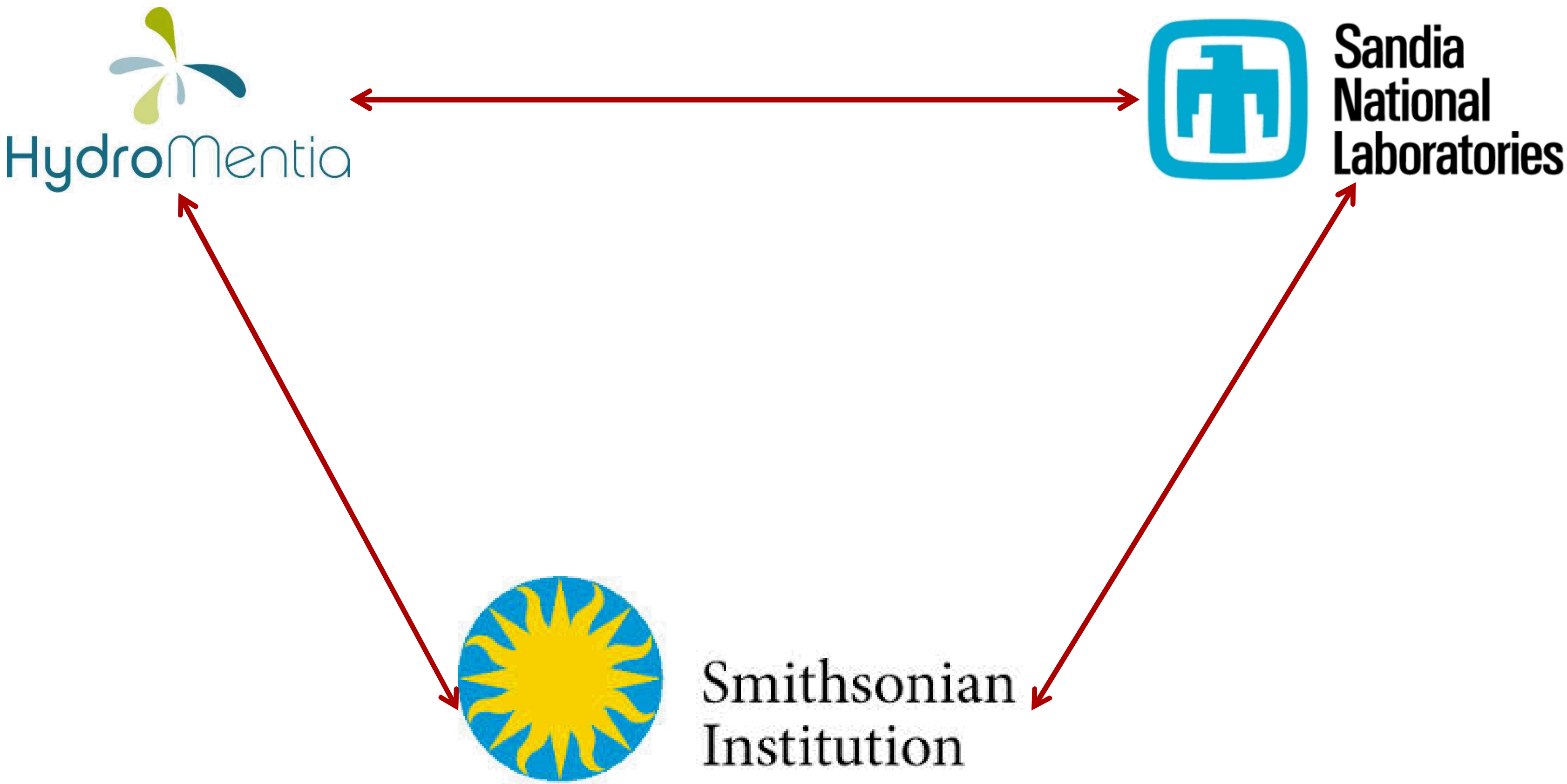
HTL only (after fuel upgrading)

- Methane
- Naphtha
- Renewable Diesel

Fermentation and HTL (after fuel upgrading)

- Isobutyl Alcohol
- Methane
- Ethanol
- Naphtha
- Renewable Diesel

Team Contributors



My Role

- To compile the information into a spreadsheet for a cost analysis vs. production output

Spreadsheet Breakdown

- Diagram
- Inputs
- ATS™
- Harvesting
- Processing
  - Entire Biomass HTL
  - Fermentation with HTL Extraction
- Total Production of Fuel
- Capital Costs
- Summary
- Subsidies
- Charts
- Production Cost Reviews

Spreadsheet - Summary

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	A	B	C	D	E	F	G	H	I	J
1										
2										
3	**Capital Costs (Total Installed Cost)**									
4	ATS (Low Production) A		2789.418766	million $						
5	ATS (High Production) B		1394.709383	million $						
6	Harvesting (Vacuum) (Low Production) 1		37.53254529	million $						
7	Harvesting (Vacuum) (High Production) 2		18.76627265	million $						
8	Harvesting (Scraper)			million $						
9	All HTL processing .1		252.6	million $						
10	Fermentation Process/HTL .2		440.358966	million $						
11										
12										
13					Option A1.1	Option A1.2	Option B2.1	Option B2.2		
14	Total Capital Costs				3079.551311	3267.310277	1666.075656	1853.834622		
15										
16	**Operational Costs / Year**									
17	ATS (Low Production) A		85.48887228	million $/year						
18	ATS (High Production) B		42.74443614	million $/year						
19	Harvesting (Vacuum) (Low Production) 1		28.78900232	million $/year						
20	Harvesting (Vacuum) (High Production) 2		14.39450116	million $/year						
21	Harvesting (Scraper) 2			million $/year						
22	All HTL processing .1		34.79947687	million $/year						
23	Fermentation Process .2		78.83835581	million $/year						
24										
25					Option A1.1	Option A1.2	Option B2.1	Option B2.2		
26					149.0773515	193.1162304	91.93841417	135.9772931		
27	Maintenance Cost	1%	(original capital cost)		30.79551311	32.67310277	16.66075656	18.53834622		
28	Total Operational Costs				179.8728646	225.7893332	108.5991707	154.5156393		
29										
30										

Spreadsheet - Inputs

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	A	B	C	D	E
1					
2			**Algae**		
3	Biomass Composition (ash free dry weight)				
4		lipids		8%	
5		carbs		34.60%	
6		proteins		39.40%	
7		other biomass		18.00%	
8					
9	Desired Loading Rate of Production Factory			1340	Tons AFDW algae/day
10	Biomass Productivity (Low Production)			10	g/m2/d
11	Biomass Productivity (High Production)			20	g/m2/d
12					
13					
14	Algae Chemical Composition				
15		Carbon		38%	wt%
16		Hydrogen		8%	wt%
17		Oxygen		48%	wt%
18		Nitrogen		5%	wt%
19		Phosphorous		1%	wt%
20					
21			**ATS™ Design**		
22	Desired Length of ATS™			500.00	feet
23	Desired Water Flow over ATS™			10.00	gal/min/linear foot
24	ATS™ module tilt (α)			0.50	%
25	D = days of pumping operation per year			365	D
26	T = hours of pumping operation per day			24	h
27	η_{π} = total pumping efficiency			0.67	%
28	H_{τ} = Total pumping head			4	m
29					
30	Size of Production Unit			1000.00	acre/unit
31	Total Cultivation Area Required (Low Production)			30026.04	acre
32	Total Cultivation Area Required (High Production)			15013.02	acre
33	Number of Required Units (low Production)			30.03	units
34	Number of Required Units (high Production)			15.01	units
35	Actual land needed for production			1200.00	acre
36					
37	Cost of Electricity			10.10	cents/KWh
38				0.10	$/KWh
39					
40	Production Goal				
41			**tons of biomass AFDW (delivered to plant)**	1340	ton AFDW algae/day
42			Composition of Lipids	100897115.7	g/day
43			Composition of Carbs	420607253.4	g/day
44			Composition of Proteins	478957392.6	g/day
45			Composition of other Biomass	218813022	g/day

Spreadsheet – Cost Analysis

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	A	B	C	D	E / F
1	**Corn Stover Design Report Case: 2012 model DW1102A**			1.00	
2					
3	**Assumptions**	**Value**		Land Requirement	
4	Fixed Capital Investment	$5,789,556,465		36163	Acres (acreage for the entire facility,including at
5	General Plant and ATS Construction	$5,789,556,465		$3,000	/acre
6	Steam Plant	$0			
7					
8	Equity	40%			
9	Loan Interest	8.0%			
10	Loan Term, years	10			
11	Annual Loan Payment	$517,688,784			
12	Periodic expenses		No. Bags	0	
13	Baghouse Bags (5 yr life, Ryton MOC)	$0	Bag Cost	$ -	
14			Quote year	1998	
15					
16	Working Capital (% of FCI)	5.00%			
17	Salvage Value				
18	General Plant	0	Not permitted since 2002		
19	Steam Plant	0	Not permitted since 2002		
20	Depreciation Period (Years)				
21	General Plant	7	IRS Pub 946		
22	Steam/Electricity System	20	IRS Pub 946		
23	Construction Period (Years)	3			
24	% Spent in Year -2	8%			
25	% Spent in Year -1	60%			
26	% Spent in Year 0	32%			
27	Start-up Time (Years)	0.25			
28	EtOH production/Feedstock use (% of Normal)	50%			
29	Variable Costs (% of Normal)	75%			
30	Fixed Cost (% of Normal)	100%		Solve Product Cost	
31	Discount Rate (Internal Rate of Return [IRR])	10.00%	Short et. al		
32	Income Tax Rate	35.00%			
33	Diesel Production Rate (MMgal/yr)	46			
34	Methane Production Rate (MmBtu/year)	4,564,036			
35	Ethanol Production Rate (Mmgal/year)	0			
36	Biocrude Production Rate (Mmgal/year)	0			
37	Naphtha Production Rate (Mmgal/year)	9			
38	Isobutanol Production Rate (Mmgal/year)	0			
39					
40	Cost Year for Analysis				
41	**Minimum Diesel Selling Price ($/gal)**	**$3.50**	**Manipulated Value**		
42	**Methane Selling Price ($/Btu)**	**$0.00**	http://www.bloomberg.com/energy/		
43	**Ethanol Selling Price ($/gal)**				
44	**Biocrude Selling Price ($/gal)**				
45	**Naphtha Selling Price ($/gal)**	$0.37	http://af.reuters.com/	http://www.eia.gov/cfapps/ipdbproject/docs/unitswithpetro.cfm	
46	**Isobutanol Selling Price ($/gal)**				
47					
48	**Net Present Value**	($233,426,535)	**Targeted Value**		
49					

Total Capital Investment

Process Area		**Purchased Cost**	**Installed Cost**
ATS Installation			$ 2,789,418,766
Harvesting Units			$ 37,532,545
Installation of HTL system			$ 252,600,000
Area 300: Enzymatic Hydrolysis & Fermentation			
Area 400: Enzyme Production			
Area 500: Recovery			
Area 600: Wastewater			
Area 700: Storage			
Area 800: Boiler			
Area 900: Utilities			
Totals (Excl. Area 100)			**$ 3,079,551,311**
Warehouse	4.0% of ISBL		$ 123,182,052
Site Development	9.0% of ISBL		$ 277,159,618
Additional Piping	4.5% of ISBL		$ 138,579,809
Total Direct Costs (TDC)			**$ 3,618,472,791**
Prorateable Expenses	10.0% of TDC		$ 361,847,279
Field Expenses	10.0% of TDC		$ 361,847,279
Home Office & Construction Fee	20.0% of TDC		$ 723,694,558
Project Contingency	10.0% of TDC		$ 361,847,279
Other Costs (Start-Up, Permits, etc.)	10.0% of TDC		$ 361,847,279
Total Indirect Costs			**$ 2,171,083,674**
Fixed Capital Investment (FCI)			**$ 5,789,556,465**
Land			$ 108,489,730
Working Capital	5.0% of FCI		$ 289,477,823
Total Capital Investment (TCI)			**$ 6,187,524,019**
TCI per annual gallon			133.12 $/gal
Dollars			
*Feedstock Handling not included in this calculation			DW1102A

Delta-T factor #DIV/0!

Spreadsheet – Cost Analysis pt. 2

			-2	-1	0	1	2	3	4	5
50	**DCFROR Worksheet**									
51	Year		-2	-1	0	1	2	3	4	5
52	Fixed Capital Investment		$185,265,807	$1,389,493,552	$741,063,228					
53	Land		$108,489,730							
54	Working Capital				$289,477,823					
55	Loan Payment					$517,688,784	$517,688,784	$517,688,784	$517,688,784	$517,688,784
56	Loan Interest Payment		$22,231,897	$188,971,123	$277,898,710	$277,898,710	$258,715,504	$237,997,642	$215,622,351	$191,457,036
57	Loan Principal		$277,898,710	$2,362,139,038	$3,473,733,879	$3,233,943,806	$2,974,970,526	$2,695,279,384	$2,393,212,951	$2,066,981,204
58	Diesel Sales					$137,831,016	$183,774,657	$183,774,657	$183,774,657	$183,774,657
59	Subsidies Credit					$672,356,042	$768,406,905	$768,406,905	$768,406,905	$768,406,905
60	Total Annual Sales					$810,187,058	$952,181,562	$952,181,562	$952,181,562	$952,181,562
61	Annual Manufacturing Cost									
62						$157,388,757	$179,872,865	$179,872,865	$179,872,865	$179,872,865
63	Total Product Cost					$157,388,757	$179,872,865	$179,872,865	$179,872,865	$179,872,865
64	Annual Depreciation									
65	General Plant Writedown					14%	24.49%	17.49%	12.49%	8.93%
66	Depreciation Charge					$827,327,619	$1,417,862,378	$1,012,593,426	$723,115,603	$517,007,392
67	Remaining Value					$4,962,228,846	$3,544,366,468	$2,531,773,042	$1,808,657,440	$1,291,650,047
68	Steam Plant Writedown					3.75%	7.22%	6.68%	6.18%	5.71%
69	Depreciation Charge					$0	$0	$0	$0	$0
70	Remaining Value					$0	$0	$0	$0	$0
71	Net Revenue					($452,428,028)	($904,269,185)	($478,282,370)	($166,429,256)	$63,844,269
72	Losses Forward						($452,428,028)	($1,356,697,213)	($1,834,979,583)	($2,001,408,839)
73	Taxable Income					($452,428,028)	($1,356,697,213)	($1,834,979,583)	($2,001,408,839)	($1,937,564,570)
74	Income Tax					$0	$0	$0	$0	$0
75	Annual Cash Income					$135,109,517	$254,619,914	$254,619,914	$254,619,914	$254,619,914
76	Discount Factor		1.2100	1.1000	1.0000	0.9091	0.8264	0.7513	0.6830	0.6209
77	Annual Present Value	$3,134,513,823				$122,826,834	$210,429,681	$191,299,710	$173,908,827	$158,098,934
78	Total Capital Investment + Interest		$382,344,795	$1,736,311,142	$1,308,439,761					
79	Net Present Worth				-$233,426,535					
80										
81										
82						If taxable income < 0, tax = $0				
83						Loan Interest subtracted from taxable income.				
84						Loan payment subtracted from annual cash income				
85						Interest on construction loan added to investment				
86										
87	NPV of Income Tax	$926,893,797				$0	$0	$0	$0	$0
88	NPV of Diesel Income	$1,707,446,100				$125,300,924	$151,879,882	$138,072,620	$125,520,564	$114,109,603
89										
90										
91								0.32	0.19	0.12
92								0.16	0.10	0.06
93										

Spreadsheet - Subsidies

Subsidies

	A	B	C	D	E
5	Algae Harvested	4.43704E+11		g/year	
6	Nitrate Removal rate	5%		g Nitrogen/g algae	
7	Phosphate Removal rate	1%		g Phosphate/g algae	
8	Carbon Removal Rate	38%		g Carbon/g algae	
10	Mass of Nitrogen Removed per year	22185209175		g/year	These numbers may need to be changed based on the amount of nutrients actually recovered
11	Mass of Phosphorous Removed per Year	3993337652		g/year	These numbers may need to be changed based on the amount of nutrients actually recovered
13	Subsidy for Nitrogen Removal	0.0085		$/gram	Algal Turf Scrubber (ATS) Algae to Energy Project: Cleaning Rivers while Producing Biofuels and Agricultural and Health Products
14	Subsidy for Phosphorous Removal	0.1452		$/gram	Algal Turf Scrubber (ATS) Algae to Energy Project: Cleaning Rivers while Producing Biofuels and Agricultural and Health Products
16	Total Nitrogen Subsidy	188574278		$/year	
17	Total Phosphorous Subsidy	579832627		$/year	
19	Total Subsidies	768.406905		million$/year	

Preliminary Conclusions

- More cost effective than traditional biofuel creation processes despite lower lipid production yields and potential higher processing costs
  - Credits for Purifying water
  - No cost for water use
  - Not as energy intensive for harvesting
- "HTL only" processing creates approximately 94 million GGE per year
- "Fermentation and HTL Combination" produces approximately 75 million GGE per year

		Entire Biomass HTL				Fermentaion Alternative Conversion			
		Low					Low		
Methane		252,442,608	g/day				16,502,588	g/day	
Ethanol			gal/day				59,644	gal/day	
Biocrude			gal/day					gal/day	
Diesel		127,349	gal/day				99,867	gal/day	
Naptha		25,941	gal/day				20,980	gal/day	
isobutanol			gal/day				46,116	gal/day	

Where to go from here?

- Research into the conversion processes, specifically from ATS algae biomass into fuel
- Research into specific locations, and resource availability for implementation of this system
- Research into the “real-world” costs of construction for the system (many assumptions were made in order to be consistent with other published papers)
- Research into more realistic prices for nutrient removal rates from water

Big Thanks To…

- Staci Dorsey (MAC Coordinator)
- Ron Pate (Project lead)
- Vanessa Vargas (SNL NM)
- Mark Zivojnovich (Hydromentia)
- Ryan Davis (SNL CA)
- All the other team members
- All of the OAA's in the building
- Don Shirah (Organizer of the Wednesday Lunch Bunch)
- All the other interns

Sources for Pictures

- http://www.hydromentia.com/Products-Services/Algal-Turf-Scrubber/Product-Documentation/Assets/ATS-Technical-Brochure.pdf
- http://algae.illinois.edu/Projects/Hydrothermal.html
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- Renewable Diesel from Algal Lipids: An integrated Baseline for Cost, Emissions, and Resource Potential from a harmonized Model