Technical Note

The potential impact of VG Energy's lipid oxidation inhibitors on the economics of algal biofuels

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VG Energy has recently announced that it has been able to translate a research discovery related to cancer treatment into a potential breakthrough for biofuels made from algae. Laboratory experiments show that molecules which can disrupt the burning of fats (lipids) in tumor cells can also encourage microscopic plant cells like algae to accumulate and even secrete fats. These fats can be used to produce diesel and jet fuel substitutes for traditional petroleum fuels. This note summarizes a preliminary analysis aimed at understanding the potential for exploiting these findings in commercial technology. The scenarios evaluated include:

- Enhanced production of higher value oils such as omega-3-fatty acids in open pond algae systems
- Enhanced production of fats for oil produced as a feedstock for biofuels in open pond algae systems

The enhanced production scenarios are compared with scenarios based on literature values for currently achievable productivity levels of algal open pond systems. The results show that VG Energy's discovery could transform algae technology from being a negative rate of return proposition to being an attractive and profitable venture. There are many caveats that go with such a statement. The preliminary nature of this analysis, which has a wide margin of error associated with it, and the uncertainty of how these early lab results will translate into practical process schemes are chief among them. Furthermore, while the high price of nutritional markets makes them an attractive near term target for the technology, it is important to bear in mind that any new technologies will face stiff competition from existing commercial producers. As for fuel production, the best we can say is that VG Energy's discovery offers dramatic improvements that move algal biofuels much closer to —but not yet to—the goal of competitiveness with petroleum.

Caveats

Any one considering this analysis should understand that it is preliminary and subject to significant error. The available performance data is simply too thin at this point to give this estimate more than an order-of-magnitude precision. That said, it signals a green light to move forward. Among the things I have not accounted for in this analysis is the value of recycling algae. Because the technology results in secretion of oil, recycle of living algae is possible. This could significantly reduce the cost of algae production. It should be a priority to modify the process model to accommodate this change. That is not a small job in the model as it is now configured. There are other possible cost savings as well. The results presented here include a step for breaking apart the cells to release the oil, which would not be needed if the oil is secreted. This would not be necessary in a system in which the algae secrete the oil.

Evaluating the economics of algal oil

The basics of an open pond algal oil production system are shown in Figure 1. Algae are grown in shallow ponds in which an aqueous suspension of algae circulates in a raceway pattern to maintain mixing and turnover of algae at the surface to improve access to sunlight for photosynthesis. CO_2 from a waste source such as a power plant or ethanol plant is sparged into each pond. Nitrogen, phosphate, potassium and iron are added to support growth. Growth rates are measured in grams of algae per day per square meter, with typical values ranging 10 to 20.

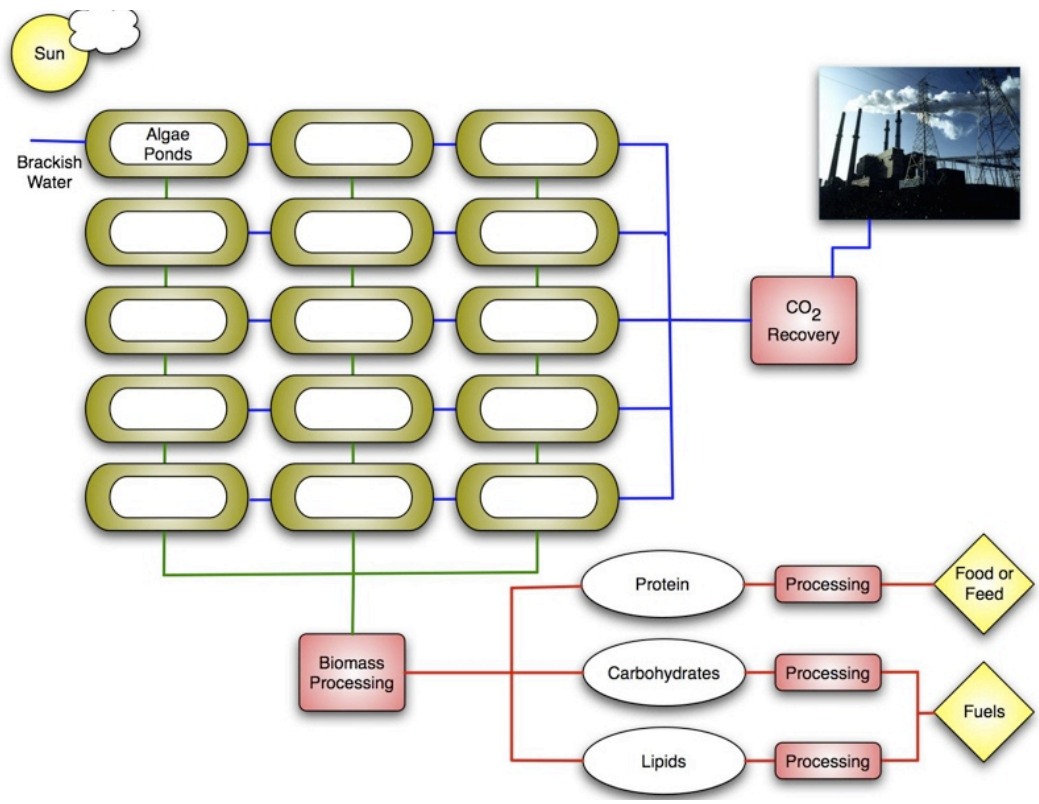


Figure 1: The US Department of Energy's concept of algae for biofuels

The algae can accumulate large amounts of carbohydrates (sugars and starches), lipids (fats) or protein depending on the species and the condition under which they are grown. Of particular interest to energy technologists is the ability to achieve high levels of lipid content in these fast growing simple plants. The combination of rapid growth and oil production makes algae technology potentially more productive than even the fastest growing oil crops in the world such as oil palm.

This analysis only considers open pond systems. They represent the lowest cost and simplest design of an algae production system. Many companies are currently working on new so-called photobioreactor systems. These designs may change the economic landscape for algae given the extent to which they can lead to improved light capture, better control of (and therefore independence from regional) climate conditions, and increased concentration of algal biomass. The obvious trade-off for such systems is cost. Even the simplest step toward enclosing algae production systems (plastic covers or greenhouse type enclosures) dramatically increase the capital cost of the system.

The following table summarizes other key inputs and assumptions in the analysis. The analysis is based on a process engineering model developed in the form of an Excel® spreadsheet several years ago. The model incorporates two downstream process options. In the first option, a conventional hexane extraction is used to recover the oil. This is an energy intensive process that requires two stages of water removal followed by drying of the algal biomass prior to extraction. Dried biomass from extraction is assumed to have value as a fertilizer coproduct. The second option is a much lower cost and lower energy alternative that uses a three phase centrifugal extractor to directly remove the oil from a wet paste of algal biomass. Such an approach has been used in a commercial process for recovering neutraceutical grade beta carotene from open pond algae systems. It's use for high yield recovery of total neutral lipids from algae has not been demonstrated. Thus, this second option represents an unproven but plausible scenario. Liquids and biomass from the extractor in this second option are sent to an anaerobic digester, which produces methane used for heat and power production. It also generates a CO_2 stream and a liquid effluent containing some of the nutrients (nitrogen, phosphate and potassium), both of which can be recycled to the growth ponds and used to reduce total nutrient supply costs. Note that CO_2 is not free. It is assumed to cost $80 per metric ton.

Table 1. Key process assumptions

Item	Assumption	Comment
Financial parameters	• 10% rate of return on investment (after inflation) • 10 year depreciation • 20 year plant life time • 40% tax rate	This model starts with the minimum rate of return on capital that is required and then calculates the associated minimum selling price for oil. All parameters are adjustable by the user.
Pond design	Open pond raceways per Benneman (1996) and Weissman (1987)	The costs of these ponds is roughly $20,000 per hectare. This is an aggressive assumption—costs could be higher.
CO_2 source	CO_2 is recovered CO_2 from a power plant	The cost of CO_2 delivered to the facility is assumed to be $80 per metric ton of CO_2. This is an adjustable user input.
Process options	• Conventional hexane extraction versus a novel three phase centrifugal extraction (per Benemann 1996 report) • Centrifugal extraction uses anaerobic digester. Methane from the digester is used to generate electricity and nutrient rich effluent is recycled to the ponds.	Benemann (1996) introduced a centrifugal extractor based on technology used at a commercial Beta carotene facility for recovery of oil without the need for drying or hexane. In this case, the wet solids and aqueous stream from the centrifugal extractor are sent to a digester producing methane (burned for electricity) and a recycle stream with recovered nutrients.

Table 2 summarizes performance assumptions for the base case (literature value) scenario and the VG Energy improved performance assumptions. These values come from an earlier analysis by Professor James Richardson at Texas A&M, who derived them from discussions with Dr. Karen Newell at VG Energy.

Table 2. Algae performance assumptions

Parameter	Base case	VG improved case
Total lipid content (% dry weight of algae)	40%	40%
Lipid product expression	13% of total lipid	39% of total lipid
Algal biomass productivity (g/ sq m/day)	10	60
Cost of VG Energy process chemical additive	$0.037 per gallon of oil	$0.037 per gallon of oil
Market targets for lipid products	High value oils at $10 to 40 per gallon. Neutral lipids competing with crude oil at $90 per barrel.	

Lipid products recovered from the algae fall into two market categories: High value oil products such as omega-3-fatty acids for use in food products and generic triglycerides (neutral lipids) that can be used as a feedstock for biofuels production. The high value oils could range in value from $10 to $40 per gallon. Neutral lipids for biofuels production must be competitive with current crude oil prices, which would be around $2.14 per gallon ($90 per barrel).

Findings

Tables 3 summarizes the findings of this analysis. The reuslts are expressed as a minimum selling price of the algal lipid product required to meet a 10% real rate of return on capital.

Table 3. Per gallon minimum prices for four productivity and extraction scenarios

	Case 1: Base case		Case 2: VG Energy improved case	
	$ per gallon	**$ per barrel**	**$ per gallon**	**$ per barrel**
Conventional extraction	$55.49	$2,330.45	$7.27	$305.21
Centrifugal extractor	$47.96	$2,014.19	$3.06	$128.39

The case has a minimum price that is above the maximum market value of $40 per oil, indicating that (for a 10% rate of return on investment), the algal oil process is not competitive even under the highest market price assumption. Under the improved performance case, the minimum price of oil comes in below the the low range for the high value oil market price of $10 per gallon indicating that it is competitive.

Figure 2 compares minimum algal oil product prices with market prices. The chart on the right compares the minimum price of algal oil for the improved case expressed in dollars per barrel with a range of crude oil prices. This is a much more challenging comparisons. Even with improved biomass and oil productivity, neither the conventional nor the centrifugal extraction cases can beat the current price of oil (roughly $90 per barrel). But the centrifugal extractor case is within shooting range of potential future prices for crude oil. This is a very encouraging result.

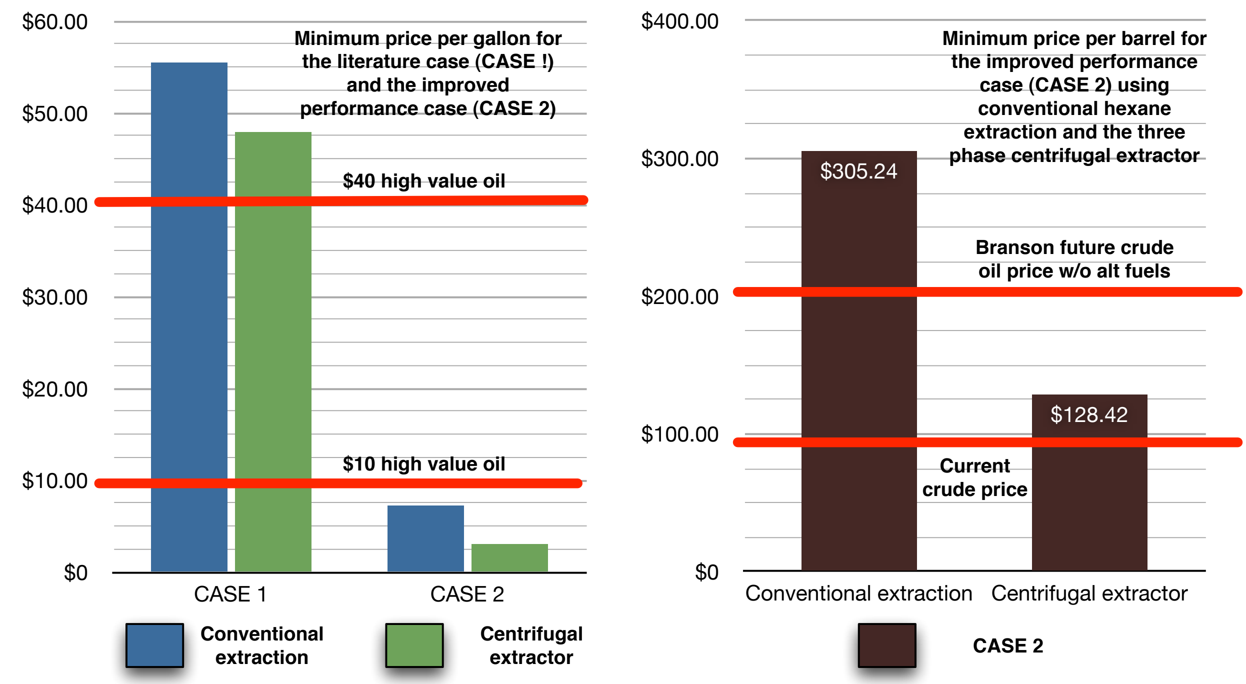


Figure 2. Minimum prices for algal oil

Appendix. Additional details

Table A1 summarizes the model assumptions used by Dr. James Richardson at Texas A&M (shaded in yellow) as well as calculations based on those assumptions. Numbers in red are explicit model inputs for this analysis. The percent of triglyceride available for extraction as a fuel feedstock or as a high value product is calculated as:

%Oil = %High Value Oil x %Lipid

For the literature case shown in Table 1, the percent of extractable oil is

13% x 40% = 5.2%

For the improved performance cases in Table 1, the percent of extractable oil is

39% x 40% = 16%

Table A1. Assumptions for algae oil production system.

	Lit case	HVO $40 Chem 1	HVO $40 Chem 2	HVO$10 Chem 1	HVO $10 Chem 2
Facility size acre ft	500	500	500	500	500
Depth ft	0.667	0.667	0.667	0.667	0.667
Depth m	0.203	0.203	0.203	0.203	0.203
Pond acres	750	750	750	750	750
Pond hectares	304	304	304	304	304
High value oil %	13%	39%	39%	39%	39%
Compound cost $ per gal oil produced		$0.375	$0.0375	$0.375	$0.0375
Biomass volumetric productivity (g/liter/day)	0.049	0.29	0.29	0.29	0.29
Biomass areal productivity (g/sq m/day)	9.959	58.943	58.943	58.943	58.943
Total annual production (gal/AF/year)	1,325	3,972	3,972	3,972	3,972
Lipid %	40%	40%	40%	40%	40%
Extractable Oil (HVO) as % of biomass	5.2%	15.6%	15.6%	15.6%	15.6%
No harvests per year	60	91.25	91.25	91.25	91.25
Volume ponds harvested per cycle (%)	50%	25%	25%	25%	25%
Price HVO	$40.00	$40.00	$40.00	$10.00	$10.00

The spreadsheet model used in this analysis calculates a complete material and energy balance for all flows in the production system up to and including recovery of products and coproducts. A sample material balance summary sheet is shown on the next page.

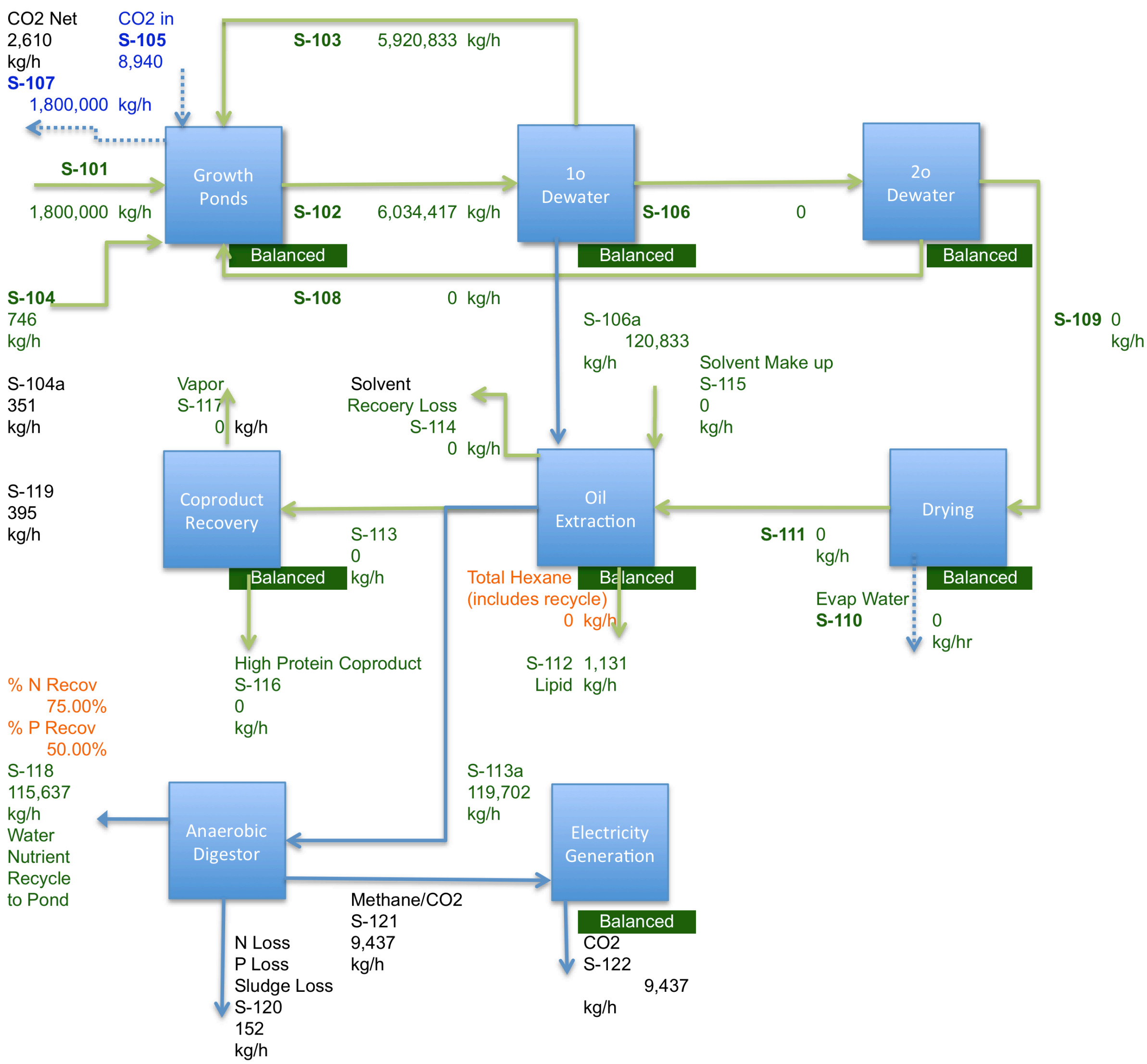
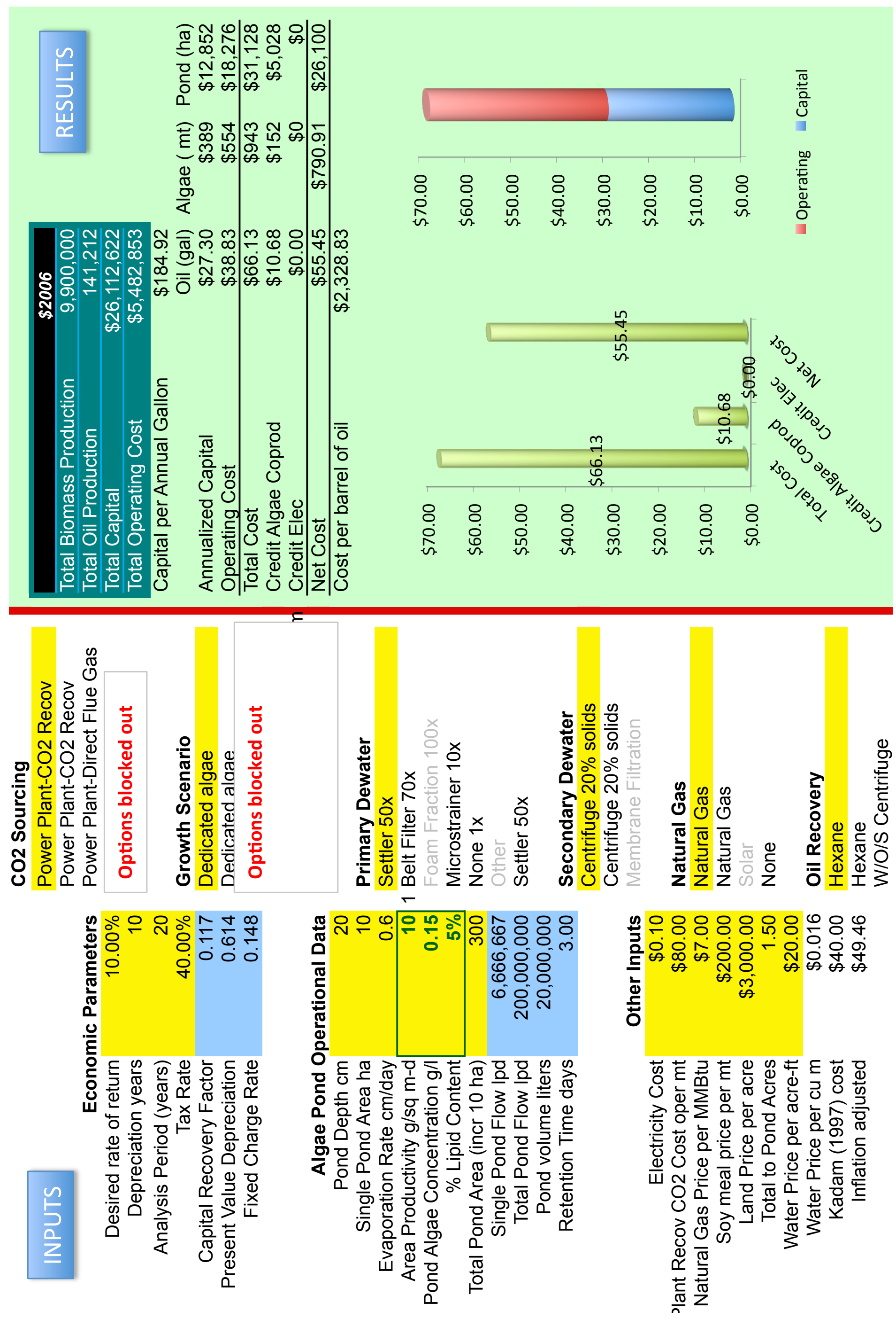


Figure A1. Mass balance summary sheet for case 2 (Improved performance with centrifugal extraction)

Summary reports for each case analyzed are presented in the subsequent pages.



INPUTS

Economic Parameters	
Desired rate of return	10.00%
Depreciation years	10
Analysis Period (years)	20
Tax Rate	40.00%
Capital Recovery Factor	0.117
Present Value Depreciation	0.614
Fixed Charge Rate	0.148

Algae Pond Operational Data	
Pond Depth cm	20
Single Pond Area ha	10
Evaporation Rate cm/day	0.6
Area Productivity g/sq m-d	10
Pond Algae Concentration g/l	0.15
% Lipid Content	5%
Total Pond Area (incr 10 ha)	300
Single Pond Flow lpd	6,666,667
Total Pond Flow lpd	200,000,000
Pond volume liters	20,000,000
Retention Time days	3.00

Other Inputs	
Electricity Cost	$0.10
Plant Recov CO2 Cost oper mt	$80.00
Natural Gas Price per MMBtu	$7.00
Soy meal price per mt	$200.00
Land Price per acre	$3,000.00
Total to Pond Acres	1.50
Water Price per acre-ft	$20.00
Water Price per cu m	$0.016
Kadam (1997) cost	$40.00
Inflation adjusted	$49.46

CO2 Sourcing
Power Plant-CO2 Recov
Power Plant-CO2 Recov
Power Plant-Direct Flue Gas
Options blocked out

Growth Scenario
Dedicated algae
Dedicated algae
Options blocked out

Primary Dewater
Settler 50x
1 Belt Filter 70x
Foam Fraction 100x
Microstrainer 10x
None 1x
Other
Settler 50x

Secondary Dewater
Centrifuge 20% solids
Centrifuge 20% solids
Membrane Filtration

Natural Gas
Natural Gas
Natural Gas
Solar
None

Oil Recovery
Hexane
Hexane
W/O/S Centrifuge

RESULTS

	$2006		
Total Biomass Production	9,900,000		
Total Oil Production	141,212		
Total Capital	$26,112,622		
Total Operating Cost	$5,482,853		
Capital per Annual Gallon	$184.92		
	Oil (gal)	Algae (mt)	Pond (ha)
Annualized Capital	$27.30	$389	$12,852
Operating Cost	$38.83	$554	$18,276
Total Cost	$66.13	$943	$31,128
Credit Algae Coprod	$10.68	$152	$5,028
Credit Elec	$0.00	$0	$0
Net Cost	$55.45	$790.91	$26,100
Cost per barrel of oil	$2,328.83		

Case 1: Literature values with conventional hexane extraction.

INPUTS

Economic Parameters

Desired rate of return	10.00%
Depreciation years	10
Analysis Period (years)	20
Tax Rate	40.00%
Capital Recovery Factor	0.117
Present Value Depreciation	0.614
Fixed Charge Rate	0.148

Algae Pond Operational Data

Pond Depth cm	20
Single Pond Area ha	10
Evaporation Rate cm/day	0.6
Area Productivity g/sq m-d	10
Pond Algae Concentration g/l	0.15
% Lipid Content	5%
Total Pond Area (incr 10 ha)	300
Single Pond Flow lpd	6,666,667
Total Pond Flow lpd	200,000,000
Pond volume liters	20,000,000
Retention Time days	3.00

Other Inputs

Electricity Cost	$0.10
Plant Recov CO2 Cost oper mt	$80.00
Natural Gas Price per MMBtu	$7.00
Soy meal price per mt	$200.00
Land Price per acre	$3,000.00
Total to Pond Acres	1.50
Water Price per acre-ft	$20.00
Water Price per cu m	$0.016
Kadam (1997) cost	$40.00
Inflation adjusted	$49.46

CO2 Sourcing
Power Plant-CO2 Recov
Power Plant-CO2 Recov
Power Plant-Direct Flue Gas
Options blocked out

Growth Scenario
Dedicated algae
Dedicated algae
Options blocked out

Primary Dewater
Settler 50x
1 Belt Filter 70x
Foam Fraction 100x
Microstrainer 10x
None 1x
Other
Settler 50x

Secondary Dewater
Centrifuge 20% solids
Centrifuge 20% solids
Membrane Filtration

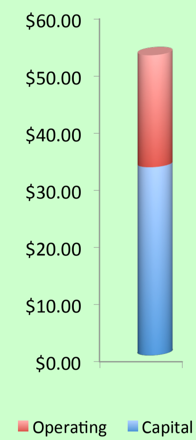
Natural Gas
None
Natural Gas
Solar
None

Oil Recovery
W/O/S Centrifuge
Hexane
W/O/S Centrifuge

RESULTS

	$2006
Total Biomass Production	0
Total Oil Production	147,837
Total Capital	$32,937,028
Total Operating Cost	$2,895,946
Capital per Annual Gallon	$222.79

	Oil (gal)	Algae (mt)	Pond (ha)
Annualized Capital	$32.90	$491	$16,210
Operating Cost	$19.59	$293	$9,653
Total Cost	$52.48	$784	$25,864
Credit Algae Coprod	$0.00	$0	$0
Credit Elec	$4.56	$68	$2,249
Net Cost	$47.92	$715.61	$23,615
Cost per barrel of oil	$2,012.68		



Case 1a: Improved performance with centrifugal extractor

INPUTS

Economic Parameters

Desired rate of return	10.00%
Depreciation years	10
Analysis Period (years)	20
Tax Rate	40.00%
Capital Recovery Factor	0.117
Present Value Depreciation	0.614
Fixed Charge Rate	0.148

Algae Pond Operational Data

Pond Depth cm	20
Single Pond Area ha	10
Evaporation Rate cm/day	0.6
Area Productivity g/sq m-d	58
Pond Algae Concentration g/l	1.2
% Lipid Content	16%
Total Pond Area (incr 10 ha)	300
Single Pond Flow lpd	4,833,333
Total Pond Flow lpd	145,000,000
Pond volume liters	20,000,000
Retention Time days	4.14

Other Inputs

Electricity Cost	$0.10
Plant Recov CO2 Cost oper mt	$80.00
Natural Gas Price per MMBtu	$7.00
Soy meal price per mt	$200.00
Land Price per acre	$3,000.00
Total to Pond Acres	1.50
Water Price per acre-ft	$20.00
Water Price per cu m	$0.016
Kadam (1997) cost	$40.00
Inflation adjusted	$49.46

CO2 Sourcing

Power Plant-CO2 Recov
Power Plant-CO2 Recov
Power Plant-Direct Flue Gas

Options blocked out

Growth Scenario

Dedicated algae
Dedicated algae

Options blocked out

Primary Dewater

Settler 50x
1 Belt Filter 70x
Foam Fraction 100x
Microstrainer 10x
None 1x
Other
Settler 50x

Secondary Dewater

Centrifuge 20% solids
Centrifuge 20% solids
Membrane Filtration

Natural Gas

Natural Gas
Natural Gas
Solar
None

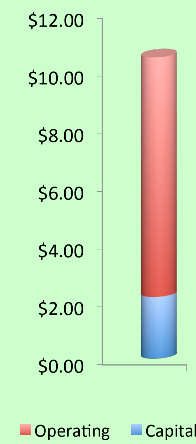
Oil Recovery

Hexane
Hexane
W/O/S Centrifuge

RESULTS

	$2006
Total Biomass Production	57,420,000
Total Oil Production	2,457,088
Total Capital	$35,423,791
Total Operating Cost	$20,370,788
Capital per Annual Gallon	$14.42

	Oil (gal)	Algae (mt)	Pond (ha)
Annualized Capital	$2.13	$91	$17,434
Operating Cost	$8.29	$355	$67,903
Total Cost	$10.42	$446	$85,337
Credit Algae Coprod	$3.19	$136	$26,112
Credit Elec	$0.00	$0	$0
Net Cost	$7.23	$309.43	$59,225
Cost per barrel of oil	$303.71		



Case 2. Improved performance with conventional hexane extraction

INPUTS

Economic Parameters

Desired rate of return	10.00%
Depreciation years	10
Analysis Period (years)	20
Tax Rate	40.00%
Capital Recovery Factor	0.117
Present Value Depreciation	0.614
Fixed Charge Rate	0.148

Algae Pond Operational Data

Pond Depth cm	20
Single Pond Area ha	10
Evaporation Rate cm/day	0.6
Area Productivity g/sq m-d	58
Pond Algae Concentration g/l	1.2
% Lipid Content	16%
Total Pond Area (incr 10 ha)	300
Single Pond Flow lpd	4,833,333
Total Pond Flow lpd	145,000,000
Pond volume liters	20,000,000
Retention Time days	4.14

Other Inputs

Electricity Cost	$0.10
Plant Recov CO2 Cost oper mt	$80.00
Natural Gas Price per MMBtu	$7.00
Soy meal price per mt	$200.00
Land Price per acre	$3,000.00
Total to Pond Acres	1.50
Water Price per acre-ft	$20.00
Water Price per cu m	$0.016
Kadam (1997) cost	$40.00
Inflation adjusted	$49.46

CO2 Sourcing

Power Plant-CO2 Recov
Power Plant-CO2 Recov
Power Plant-Direct Flue Gas

Options blocked out

Growth Scenario

Dedicated algae
Dedicated algae

Options blocked out

Primary Dewater

Settler 50x
1 Belt Filter 70x
Foam Fraction 100x
Microstrainer 10x
None 1x
Other
Settler 50x

Secondary Dewater

Centrifuge 20% solids
Centrifuge 20% solids
Membrane Filtration

Natural Gas

Natural Gas
Natural Gas
Solar
None

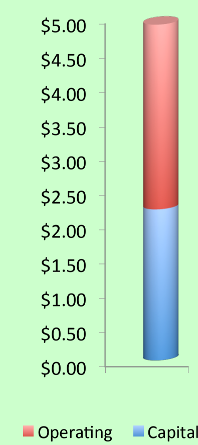
Oil Recovery

W/O/S Centrifuge
Hexane
W/O/S Centrifuge

RESULTS

	$2006
Total Biomass Production	0
Total Oil Production	2,572,366
Total Capital	$38,333,271
Total Operating Cost	$6,925,126
Capital per Annual Gallon	$14.90

	Oil (gal)	Algae (mt)	Pond (ha)
Annualized Capital	$2.20	$99	$18,866
Operating Cost	$2.69	$121	$23,084
Total Cost	$4.89	$219	$41,950
Credit Algae Coprod	$0.00	$0	$0
Credit Elec	$1.87	$84	$16,058
Net Cost	$3.02	$135.27	$25,892
Cost per barrel of oil	$126.82		



Case 2a: Improved performance with centrifugal extractor