SheehanBoyce, LLC

Technical Note

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

Prepared for VG Energy

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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
- Scenarios that take advantage of observed oil secretion in VG-treated algae to permit non-destructive recovery of oil and recycle of algae to ponds.

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. It is in the fuel markets that VG Energy's technology show the promise to compete with crude oil in today's market.

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.

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.

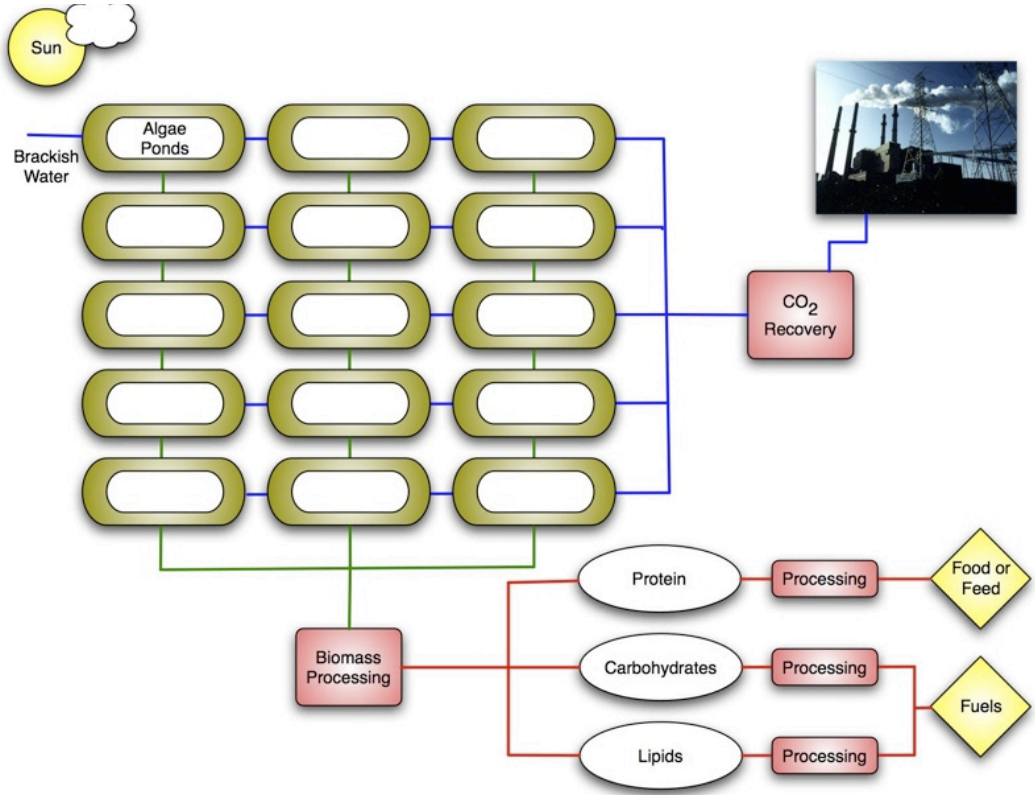


Figure 1: The US Department of Energy's concept of algae for biofuels

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.

Table 1 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 (shown in Figure 2), 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. 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. • Optional recycle of biomass from the centrifugal extractor back 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. VG Energy's early observations are that the cells actually secrete the neutral lipids. This allows for the possibility of recycling live biomass back to the production ponds/bioreactors.

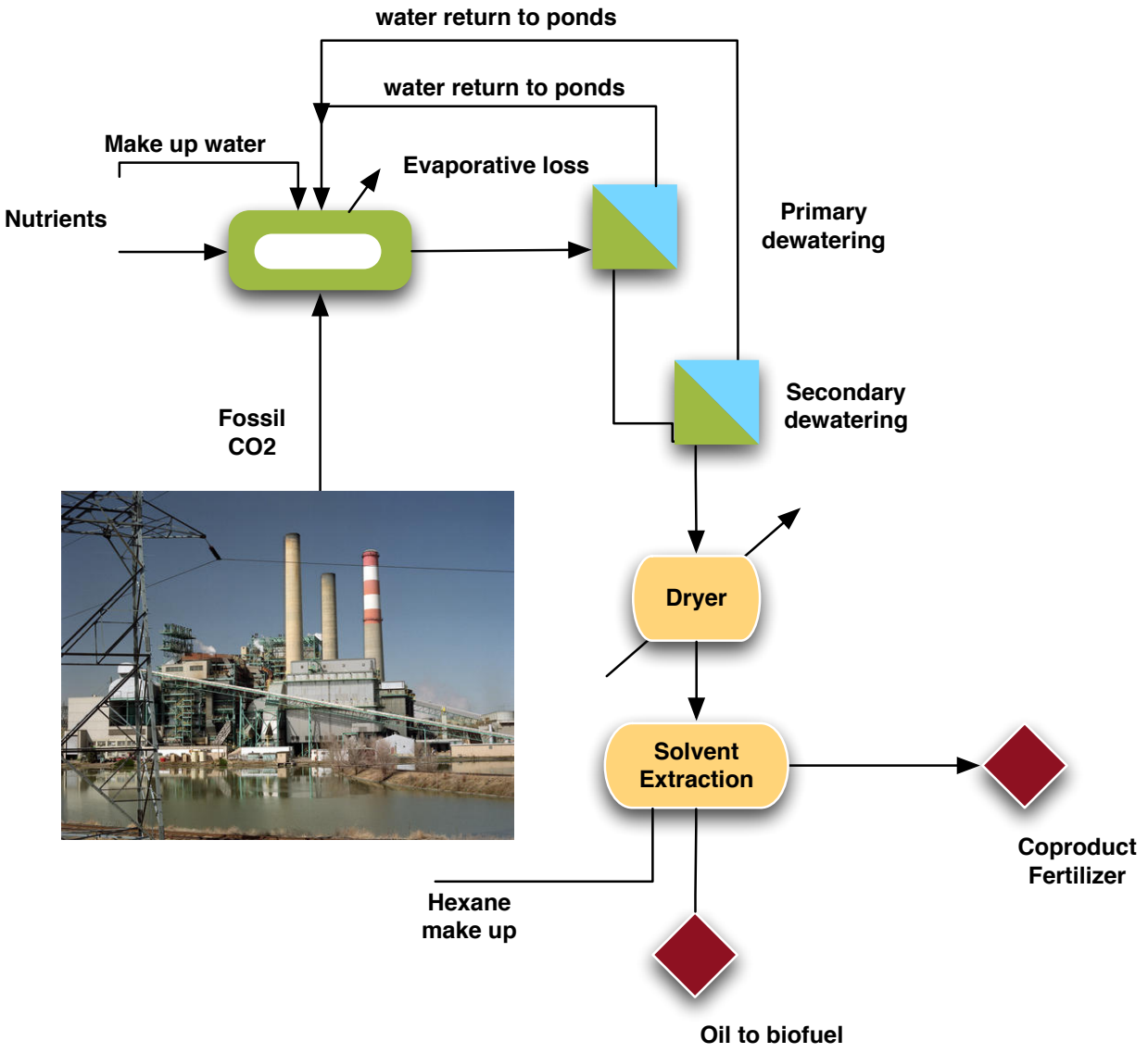


Figure 2. Case 1conventional hexane extraction and drying for oil and fertilizer coproduct recovery

The second option (shown in Figure 3) 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.

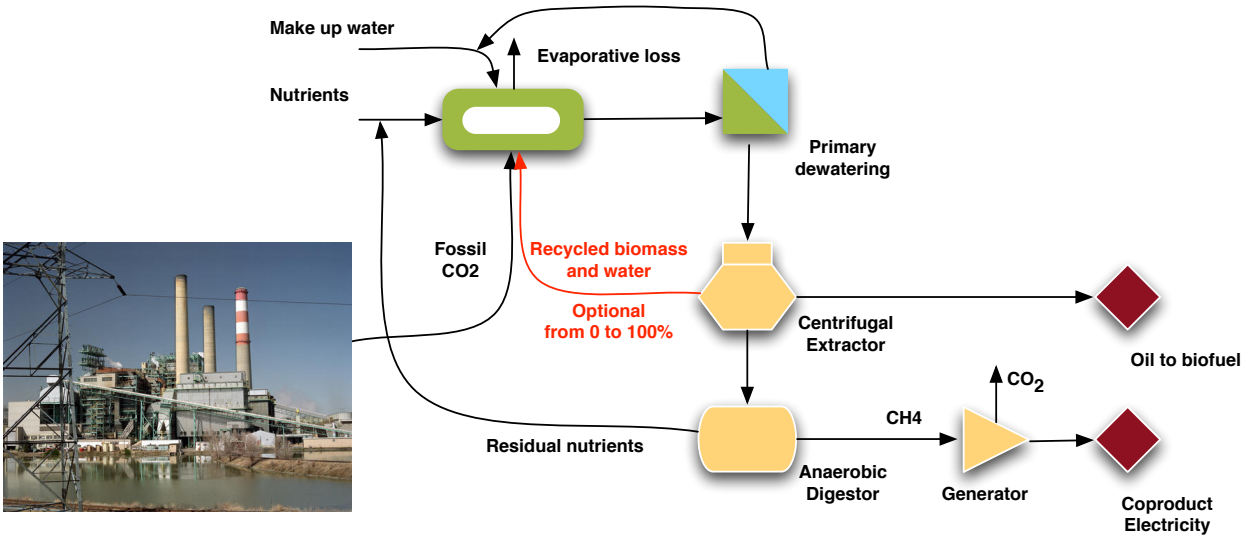


Figure 3. Cases 2 and 3 based on centrifugal extractor for oil/water/biomass separation with and without recycle of algae to growth ponds

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 results 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. Minimum selling price of oils

	Light limited		Not light limited	
	$ per gallon	$ per barrel	$ per gallon	$ per barrel
Hexane extraction base case	$41.72	$1,752	$41.72	$1,752
Centrifugal extraction base case	$32.87	$1,381	$32.87	$1,381
Hexane extraction with VG additive	$6.69	$281	$6.69	$281
Centrifugal extraction with VG additive	$4.14	$174	$4.14	$174
Centrifugal extraction 25% biomass recycle	$3.84	$161	$3.51	$147
Centrifugal extraction 50% biomass recycle	$3.59	$151	$2.87	$121
Centrifugal extraction 75% biomass recycle	$3.32	$139	$2.24	$94
Centrifugal extraction 100% biomass recycle	$2.96	$124	$1.59	$67

NOTES: "Light limited" refers to requirement that the cell concentration be maintained between 0.5 and 0.6 grams per liter to permit sufficient light penetration. All recycle cases assume use of VG additive

The improved performance scenarios with the VG additive all fall well below the low end of the high value oil market benchmark of $10 per gallon. Of greater interest is how the VG additive scenarios, with the addition of recycle made possible by the ability to non-destructively recover oil secreted by the algae, fare against price of crude oil as a feedstock for fuel production.. As Figure 2 shows, oil futures have been highly unstable, reaching a high of around $140 per barrel in mid 2008 and dropping to under $40 per barrel after the economic collapse in late 2008. As the economy as slowly begun to rebound, oil prices have once again climbed. Even before the recent unrest in the Middle East, prices were back in the $70-$84 per barrel range. USDOE's long term estimates for oil price are conservatively low at $135 per barrel in the year 2010.

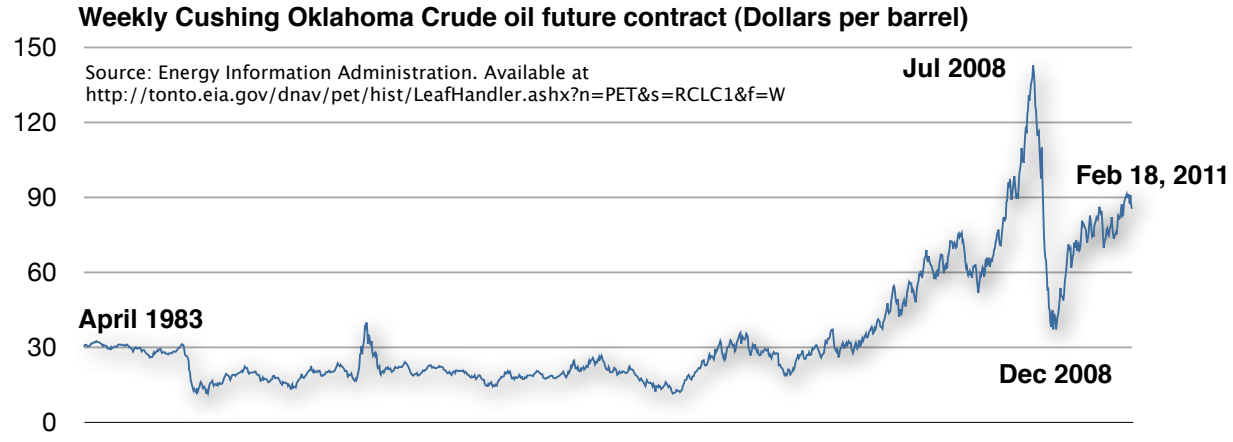


Figure 2. Minimum prices for algal oil

Figure 3 shows compares selected scenarios of improved performance and recycle of biomass with the VG additive, high value oil price ranges and petroleum prices. At 75% recycle levels (cases 3a and 3b), algal oil prices are $94 to $139 per barrel, easily within range of DOE oil price projections for 2035, and almost competitive with current oil futures prices. At the theoretical (but not likely practical) maximum for recycle rate of 100%, the price of algal oil competes favorably at only $67 per barrel.

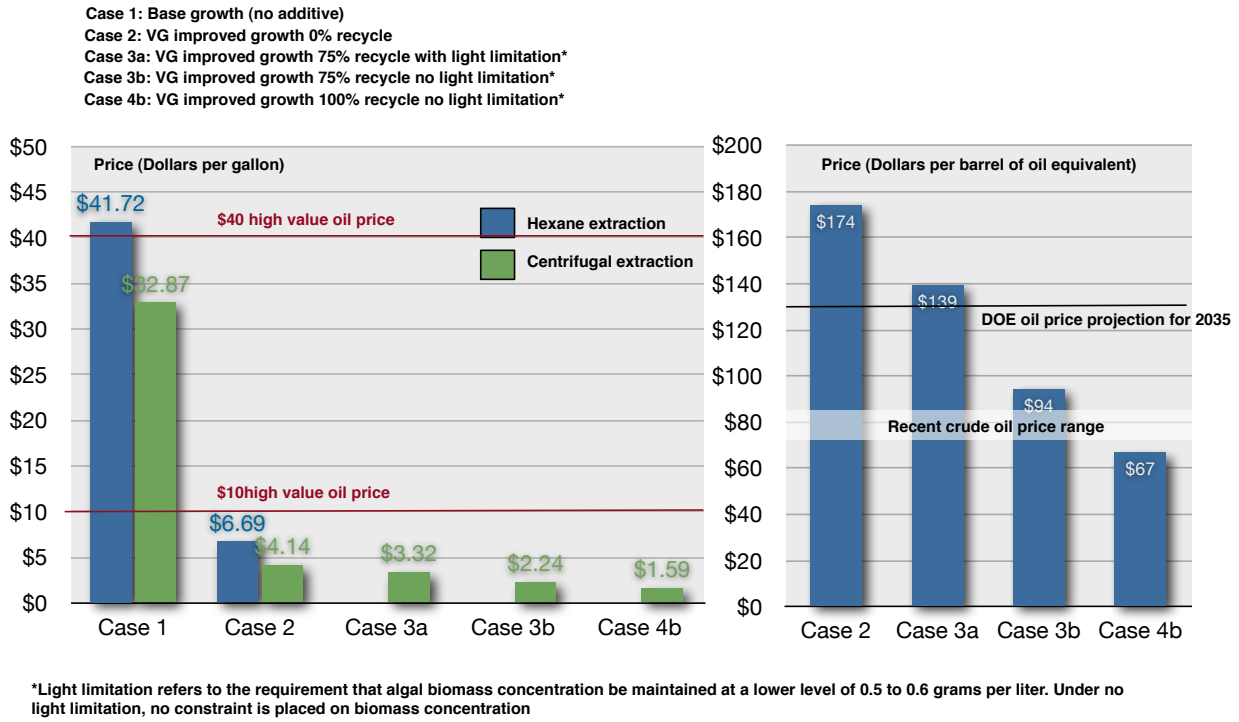


Figure 3. Comparison of selected results for VG additive with market prices for oils.

Conclusions

The introduction of VG Energy's additives offers the ability to knock down the cost of algal oil production by almost a factor of ten as a result of productivity improvements. If oil secretion currently observed in the lab can be fully demonstrated in larger scale growth systems, there is a potential for further decreasing costs by another factor of roughly two. These represent dramatic changes in the economics of algae technology, and are truly game-changing. A lot of work remains to be done to establish the robustness of the VG Energy's lab results, but these preliminary economic analyses show that the promise of the technology warrants further investment and investigation.

Discussion

There are two major benefits to VG Energy's discovery: 1) the ability to maintain and even increase growth rates of algae while also increasing the relative amount of lipid produced per unit of biomass; and 2) the observation that the algae actually secrete the lipids as they accumulate in the cell. The economic repercussions of higher growth and lipid production are obvious. The ability to get cells to secrete the lipids offer some less obvious advantages. First, it improves the ease with which lipids can be separated from the water and biomass coming out of the growth systems. Second, it opens up the possibility that oil can be separated and recovered from the algae in a non-destructive way. This is important because it means that it is now possible to recycle living cells back to growth system. The system no longer has to completely replace biomass that is lost in conventional destructive processes for recovery of lipids.

This analysis has been done in such a way that we can evaluate these benefits separately. In particular, results are presented for:

- A conservative base case growth rate and oil production with conventional extraction
- A conservative base case growth rate and oil production with centrifugal extractor and recycle options
- Enhanced growth rate and oil production with conventional extraction

- Enhanced growth rate with centrifugal extractor and recycle options

Each of these cases are further split into two scenarios. One in which the ability to get light into the system limits the concentration of biomass to 0.5-0.6 grams per liter, and one in which limit limitations are ignored and the cell concentration is allowed to increase with increasing recycle rate. Maintaining cell concentration at a lower level is achieved by reducing the residence time of the growth reactors as recycle rate is increased.

All of the analysis results are presented in Tables 4 thru 7.

Table 4. Analysis results for base case, with light limitations

	Total cost per gallon	Coproduct credit	Electricity credit	Net cost	Biomass level (g/l)	Residence time (days)	Oil Production (gallons per year)	Oil per acre
Hexane	$52.40	$10.68	$0.00	$41.72	0.5	10	470,706	191
Centrifuge	$38.18	$0.00	$5.31	$32.87	0.5	10	470,615	191
25% recycle	$30.91	$0.00	$3.91	$27.00	0.5	7.7	617,269	250
50% recycle	$23.81	$0.00	$2.50	$21.31	0.5	5.2	896,700	363
75% recycle	$16.49	$0.00	$1.10	$15.39	0.5	2.9	1,638,374	663
100% recycle	$9.29	$0.00	$0.00	$9.29	0.5	0.5	9,476,739	3,837

Table 5. Analysis results for base case, with no light limitations

	Total cost per gallon	Coproduct credit	Electricity credit	Net cost	Biomass level (g/l)	Residence time (days)	Oil Production (gallons per year)	Oil per acre
Hexane	$52.40	$10.68	$0.00	$41.72	0.5	10	470,706	191
Centrifuge	$38.18	$0.00	$5.31	$32.87	0.5	10	470,615	191
25% recycle	$29.57	$0.00	$3.96	$25.61	0.66	10	617,269	250
50% recycle	$20.96	$0.00	$2.61	$18.35	0.95	10	896,700	363
75% recycle	$12.36	$0.00	$1.26	$11.10	1.74	10	1,638,374	663
100% recycle	$3.75	$0.00	$0.00	$3.75	10.07	10	9,476,739	3,837

Table 6. Analysis results for VG improved performance, with light limitations

	Total cost per gallon	Coproduct credit	Electricity credit	Net cost	Biomass level (g/l)	Residence time (days)	Oil Production (gallons per year)	Oil per acre
Hexane	$9.88	$3.19	$0.00	$6.69	0.6	2	8,472,716	3,430
Centrifuge	$6.07	$0.00	$1.93	$4.14	0.6	2	8,471,068	3,430
25% recycle	$5.27	$0.00	$1.43	$3.84	0.6	1.6	10,760,396	4,356
50% recycle	$4.52	$0.00	$0.93	$3.59	0.6	1.15	14,745,370	5,970
75% recycle	$3.75	$0.00	$0.43	$3.32	0.6	0.72	23,417,882	9,481
100% recycle	$2.96	$0.00	$0.00	$2.96	0.6	0.3	56,860,435	23,020

Table 7. Analysis results for VG improved performance, with no light limitations

	Total cost per gallon	Coproduct credit	Electricity credit	Net cost	Biomass level (g/l)	Residence time (days)	Oil Production (gallons per year)	Oil per acre
Hexane	$9.88	$3.19	$0.00	$6.69	0.6	2	8,472,716	3,430
Centrifuge	$6.07	$0.00	$1.93	$4.14	0.6	2	8,471,068	3,430
25% recycle	$4.95	$0.00	$1.44	$3.51	0.76	2	10,760,396	4,356
50% recycle	$3.83	$0.00	$0.96	$2.87	1.04	2	14,745,370	5,970
75% recycle	$2.71	$0.00	$0.47	$2.24	1.66	2	23,417,882	9,481
100% recycle	$1.59	$0.00	$0.00	$1.59	4.03	2	56,860,435	23,020

Figures 4 and 5 show net and total cost results for each of data sets. There are a few points to note.

- First, that, as recycle rate increases, the relative difference between net and total cost declines. That is because recycling reduces the amount of biomass available for coproduct and electricity production.
- Second, the impact of recycling of the algal biomass is much greater for the low base case productivity scenarios. To understand this, just consider that if 80% of the biomass recycled, that means that the reactor volume needed to grow algae drops by a factor of 5. At lower growth rates, the starting cost of the growth reactors (that is, without recycle) is much higher than the starting cost of the enhanced growth system.
- Third (and really the inverse of the second point), the relative cost savings as a function of recycle rate is much lower for the higher growth rate scenarios.
- Fourth, the difference between conventional hexane and centrifugal extraction processes is much greater for the higher growth rate scenarios. This makes sense since, under higher growth rates, the cost of the growth systems is lower and the savings associated with downstream recovery steps represent a larger portion of the total cost of the system.
- Finally, if light limitations require the growth reactors to be operated so as to maintain lower cell concentrations, the benefit of recycling the biomass is reduced by roughly a factor of 2, as can be seen by comparing the cases a) and b) in each of the figures.

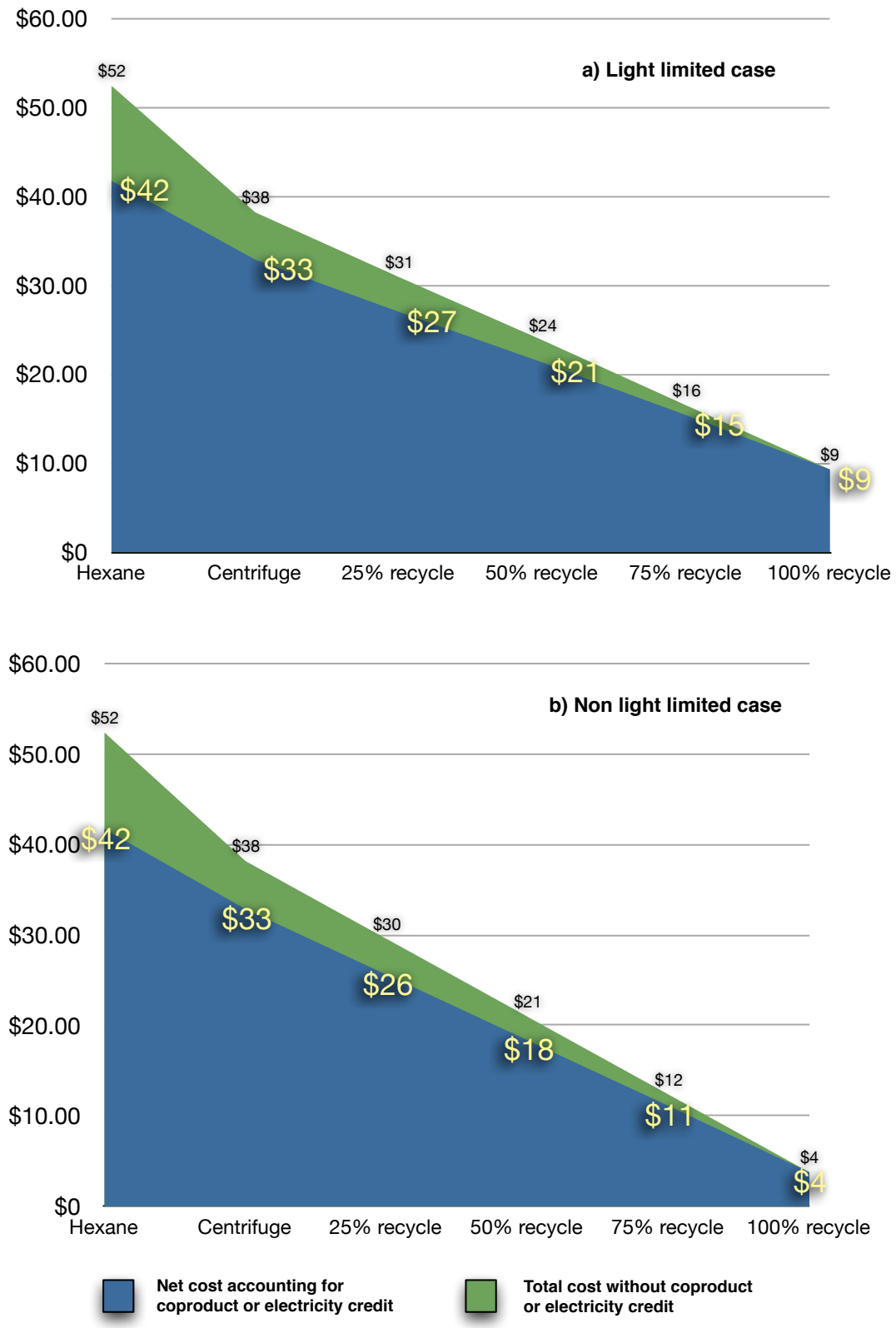


Figure 4. Base growth rate and oil production scenarios

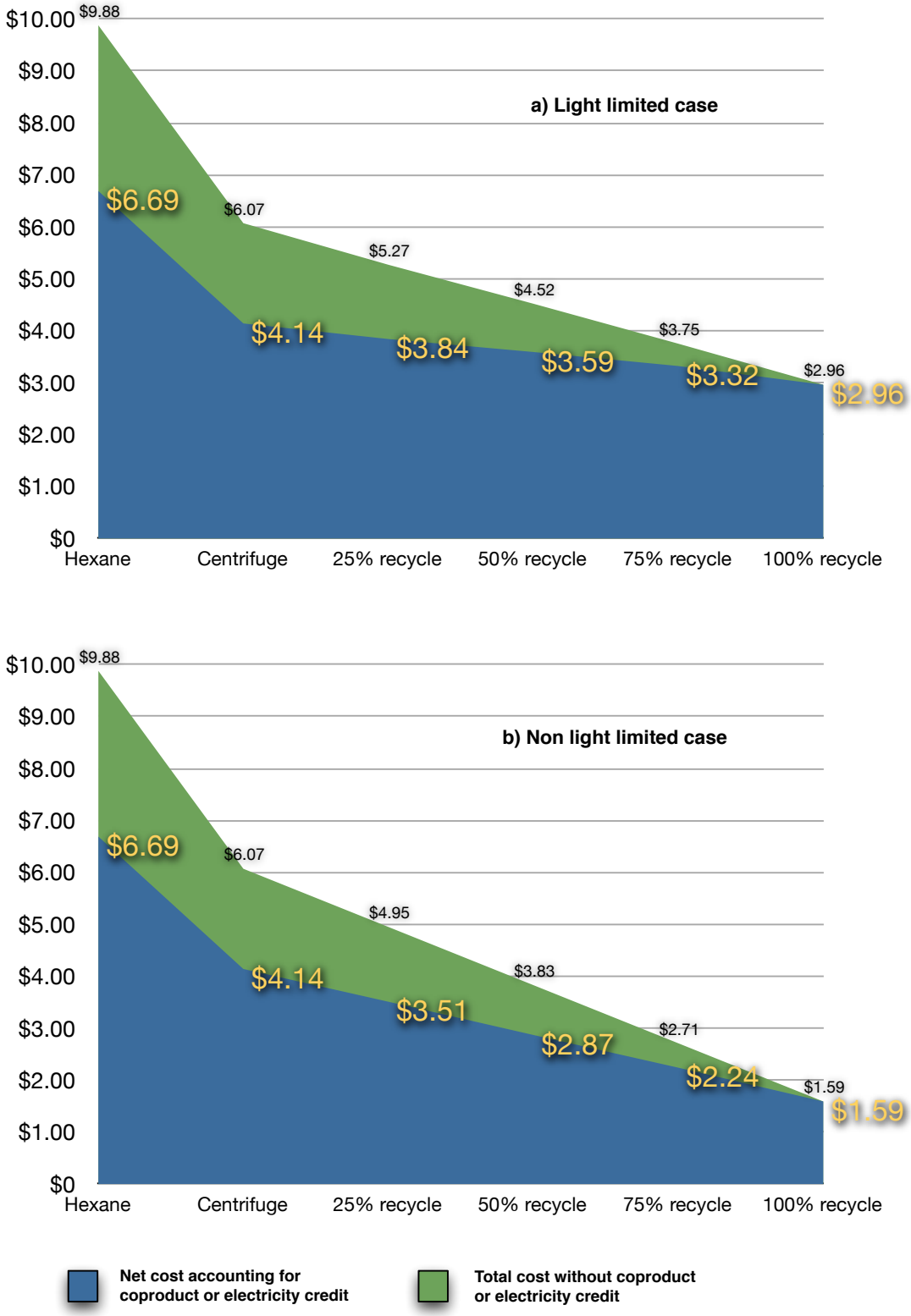


Figure 5. VG enhanced growth rate and oil production scenarios

Appendix

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.

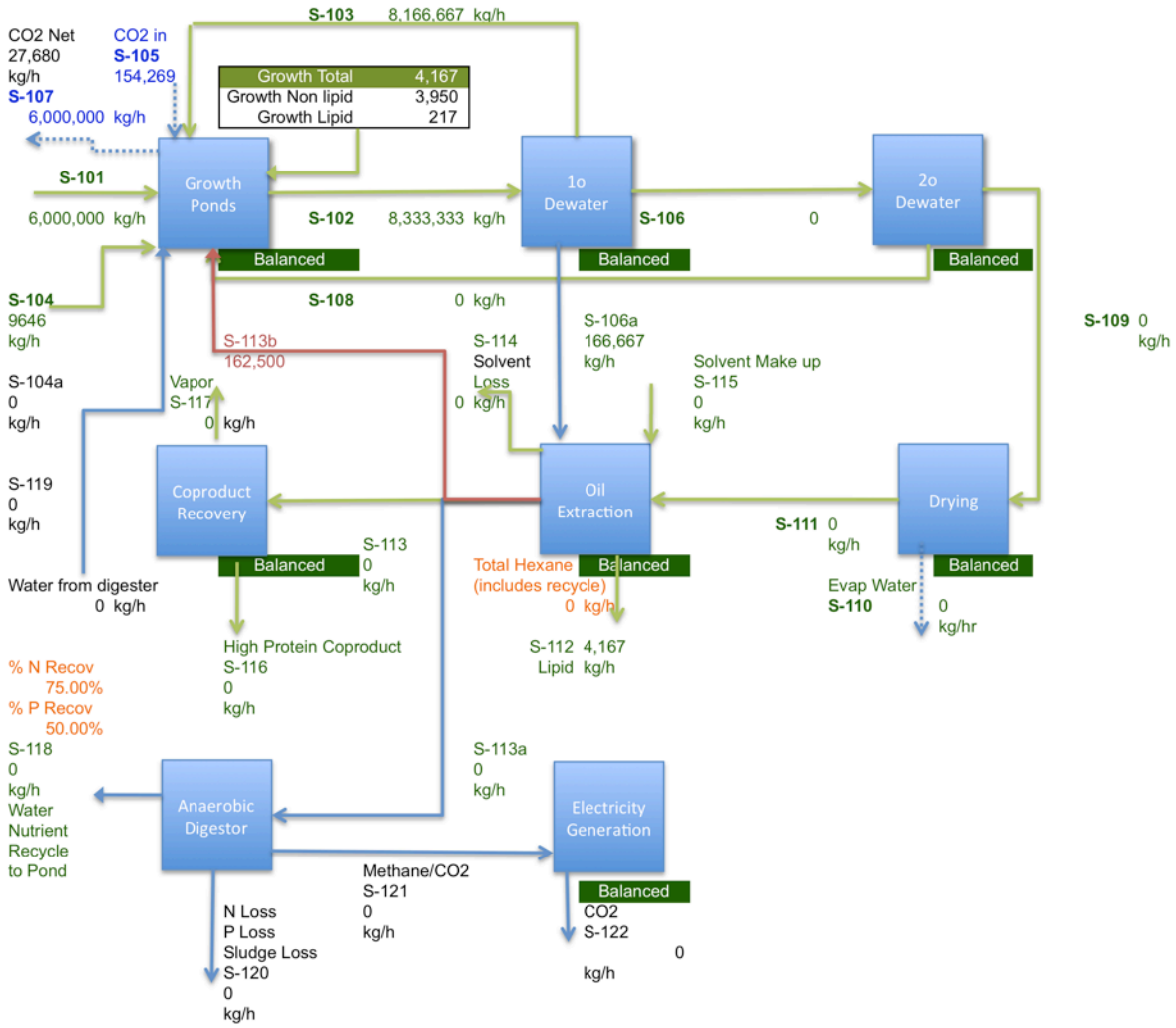


Figure A1. Mass balance summary sheet example output

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%
Additive cost ($ per gallon oil)	$0.00
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	20
Evaporation Rate cm/day	0.6
Area Productivity g/sq m-d	10
% Lipid Content	5%
Total Pond Area (incr 10 ha)	1000
Percent biomass recycle	100%
Retention Time days	10
Pond Algae Concentration g/l	0.50
Single Pond Flow lpd	4,000,000
Total Pond Flow lpd	200,000,000
Pond volume liters	40,000,000

Other Inputs

Electricity Cost	$0.10
lant Recov CO2 Cost oper mt	$50.00
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

Natural Gas Price per MJ	0.00663472
Natural Gas Price per Btu	0.000007

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
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

Other

Yellow indicates input
Blue indicates calculation

RESULTS

	$2006
Total Biomass Production	33,000,000
Total Oil Production	470,706
Total Capital	$67,767,620
Total Operating Cost	$14,640,305
Capital per Annual Gallon	$143.97

	Oil (gal)	Algae (mt)	Pond (ha)
Annualized Capital	$21.26	$303	$10,006
Operating Cost	$31.10	$444	$14,640
Total Cost	$52.36	$747	$24,646
Credit Algae Coprod	$10.68	$152	$5,028
Credit Elec	$0.00	$0	$0
Net Cost	$41.68	$594.49	$19,618
Cost per barrel of oil	$1,750.48		

Base case with Hexane Extraction
10 day residence
0.5 g/l biomass
0% recycle

INPUTS

Economic Parameters	
Desired rate of return	10.00%
Depreciation years	10
Analysis Period (years)	20
Tax Rate	40.00%
Additive cost ($ per gallon oil)	$0.00
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	20
Evaporation Rate cm/day	0.6
Area Productivity g/sq m-d	10
% Lipid Content	5%
Total Pond Area (incr 10 ha)	1000
Percent biomass recycle	100%
Retention Time days	10
Pond Algae Concentration g/l	10.07
Single Pond Flow lpd	198,640
Total Pond Flow lpd	9,932,000
Pond volume liters	40,000,000

Other Inputs	
Electricity Cost	$0.10
Plant Recov CO2 Cost oper mt	$50.00
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

Natural Gas Price per MJ	0.00663472
Natural Gas Price per Btu	0.000007

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
- 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

Other

Yellow indicates input
Blue indicates calculation

RESULTS

	$2006
Total Biomass Production	0
Total Oil Production	9,476,739
Total Capital	$66,464,365
Total Operating Cost	$25,407,255
Capital per Annual Gallon	$7.01

	Oil (gal)	Algae (mt)	Pond (ha)
Annualized Capital	$1.04	$15	$9,813
Operating Cost	$2.68	$38	$25,407
Total Cost	$3.72	$53	$35,221
Credit Algae Coprod	$0.00	$0	$0
Credit Elec	$0.00	$0	$0
Net Cost	$3.72	$53.00	$35,221
Cost per barrel of oil	$156.09		

Base case with Centrifugal Extractor
10 day residence
0.5 g/l biomass
0% recycle

INPUTS

Economic Parameters

Desired rate of return	10.00%
Depreciation years	10
Analysis Period (years)	20
Tax Rate	40.00%
Additive cost ($ per gallon oil)	$0.04
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	20
Evaporation Rate cm/day	0.6
Area Productivity g/sq m-d	10
% Lipid Content	5%
Total Pond Area (incr 10 ha)	1000
Percent biomass recycle	25%
Retention Time days	7.7
Pond Algae Concentration g/l	0.50
Single Pond Flow lpd	3,960,597
Total Pond Flow lpd	198,029,870
Pond volume liters	40,000,000

Other Inputs

Electricity Cost	$0.10
lant Recov CO2 Cost oper mt	$50.00
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

Natural Gas Price per MJ	0.00663472
Natural Gas Price per Btu	0.000007

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
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

Other

Yellow indicates input
Blue indicates calculation

RESULTS

	$2006
Total Biomass Production	0
Total Oil Production	617,269
Total Capital	$78,585,087
Total Operating Cost	$7,474,571
Capital per Annual Gallon	$127.31

	Oil (gal)	Algae (mt)	Pond (ha)
Annualized Capital	$18.80	$268	$11,603
Operating Cost	$12.11	$173	$7,475
Total Cost	$30.91	$441	$19,078
Credit Algae Coprod	$0.00	$0	$0
Credit Elec	$3.91	$56	$2,413
Net Cost	$27.00	$385.00	$16,664
Cost per barrel of oil	$1,133.86		

Base case with Centrifugal Extractor
7.7 day residence
0.50 g/l biomass
25% recycle

INPUTS

Economic Parameters	
Desired rate of return	10.00%
Depreciation years	10
Analysis Period (years)	20
Tax Rate	40.00%
Additive cost ($ per gallon oil)	$0.04
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	20
Evaporation Rate cm/day	0.6
Area Productivity g/sq m-d	10
% Lipid Content	5%
Total Pond Area (incr 10 ha)	1000
Percent biomass recycle	50%
Retention Time days	5.2
Pond Algae Concentration g/l	0.50
Single Pond Flow lpd	4,037,154
Total Pond Flow lpd	201,857,692
Pond volume liters	40,000,000

Other Inputs	
Electricity Cost	$0.10
Plant Recov CO2 Cost oper mt	$50.00
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

Natural Gas Price per MJ	0.00663472
Natural Gas Price per Btu	0.000007

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
- 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

Other

Yellow indicates input
Blue indicates calculation

RESULTS

	$2006
Total Biomass Production	0
Total Oil Production	896,700
Total Capital	$87,884,319
Total Operating Cost	$8,371,842
Capital per Annual Gallon	$98.01

	Oil (gal)	Algae (mt)	Pond (ha)
Annualized Capital	$14.47	$206	$12,976
Operating Cost	$9.34	$133	$8,372
Total Cost	$23.81	$340	$21,348
Credit Algae Coprod	$0.00	$0	$0
Credit Elec	$2.50	$36	$2,244
Net Cost	$21.30	$303.82	$19,104
Cost per barrel of oil	$894.79		

Base case with Centrifugal Extractor
5.2 day residence
0.50 g/l biomass
50% recycle

INPUTS

Economic Parameters

Desired rate of return	10.00%
Depreciation years	10
Analysis Period (years)	20
Tax Rate	40.00%
Additive cost ($ per gallon oil)	$0.04
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	20
Evaporation Rate cm/day	0.6
Area Productivity g/sq m-d	10
% Lipid Content	5%
Total Pond Area (incr 10 ha)	1000
Percent biomass recycle	75%
Retention Time days	2.9
Pond Algae Concentration g/l	0.50
Single Pond Flow lpd	3,962,000
Total Pond Flow lpd	198,100,000
Pond volume liters	40,000,000

Other Inputs

Electricity Cost	$0.10
lant Recov CO2 Cost oper mt	$50.00
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

Natural Gas Price per MJ	0.00663472
Natural Gas Price per Btu	0.000007

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
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

Other

Yellow indicates input
Blue indicates calculation

RESULTS

	$2006
Total Biomass Production	0
Total Oil Production	1,638,374
Total Capital	$110,549,686
Total Operating Cost	$10,686,614
Capital per Annual Gallon	$67.48

	Oil (gal)	Algae (mt)	Pond (ha)
Annualized Capital	$9.96	$142	$16,323
Operating Cost	$6.52	$93	$10,687
Total Cost	$16.49	$235	$27,009
Credit Algae Coprod	$0.00	$0	$0
Credit Elec	$1.10	$16	$1,809
Net Cost	$15.38	$219.35	$25,200
Cost per barrel of oil	$646.00		

Base case with Centrifugal Extractor
2.9 day residence
0.50 g/l biomass
75% recycle

INPUTS

Economic Parameters

Desired rate of return	10.00%
Depreciation years	10
Analysis Period (years)	20
Tax Rate	40.00%
Additive cost ($ per gallon oil)	$0.04
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	20
Evaporation Rate cm/day	0.6
Area Productivity g/sq m-d	10
% Lipid Content	5%
Total Pond Area (incr 10 ha)	1000
Percent biomass recycle	100%
Retention Time days	0.5
Pond Algae Concentration g/l	0.50
Single Pond Flow lpd	3,972,800
Total Pond Flow lpd	198,640,000
Pond volume liters	40,000,000

Other Inputs

Electricity Cost	$0.10
lant Recov CO2 Cost oper mt	$50.00
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

Natural Gas Price per MJ	0.00663472
Natural Gas Price per Btu	0.000007

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
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

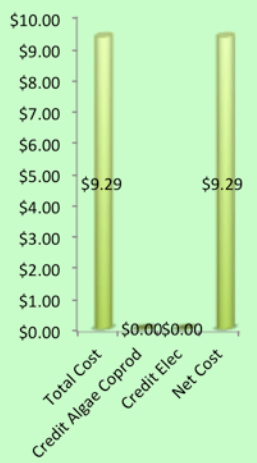
Other

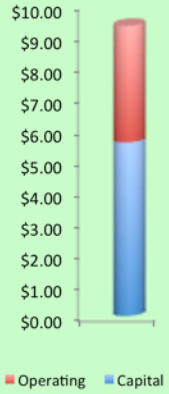
Yellow indicates input
Blue indicates calculation

RESULTS

	$2006
Total Biomass Production	0
Total Oil Production	9,476,739
Total Capital	$356,697,704
Total Operating Cost	$35,369,095
Capital per Annual Gallon	$37.64

	Oil (gal)	Algae (mt)	Pond (ha)
Annualized Capital	$5.56	$79	$52,666
Operating Cost	$3.73	$53	$35,369
Total Cost	$9.29	$132	$88,035
Credit Algae Coprod	$0.00	$0	$0
Credit Elec	$0.00	$0	$0
Net Cost	$9.29	$132.48	$88,035
Cost per barrel of oil	$390.16		





Base case with Centrifugal Extractor
0.5 day residence
0.50 g/l biomass
100% recycle

INPUTS

Economic Parameters

Desired rate of return	10.00%
Depreciation years	10
Analysis Period (years)	20
Tax Rate	40.00%
Additive cost ($ per gallon oil)	$0.04
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	20
Evaporation Rate cm/day	0.6
Area Productivity g/sq m-d	10
% Lipid Content	5%
Total Pond Area (incr 10 ha)	1000
Percent biomass recycle	25%
Retention Time days	10
Pond Algae Concentration g/l	0.66
Single Pond Flow lpd	3,049,660
Total Pond Flow lpd	152,483,000
Pond volume liters	40,000,000

Other Inputs

Electricity Cost	$0.10
lant Recov CO2 Cost oper mt	$50.00
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

Natural Gas Price per MJ	0.00663472
Natural Gas Price per Btu	0.000007

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
- 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

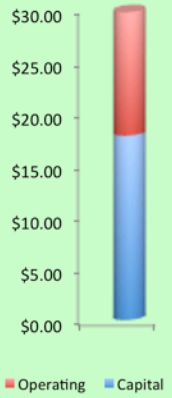
Other

Yellow indicates input
Blue indicates calculation

RESULTS

	$2006
Total Biomass Production	0
Total Oil Production	617,269
Total Capital	$74,022,294
Total Operating Cost	$7,323,472
Capital per Annual Gallon	$119.92

	Oil (gal)	Algae (mt)	Pond (ha)
Annualized Capital	$17.71	$253	$10,929
Operating Cost	$11.86	$169	$7,323
Total Cost	$29.57	$422	$18,253
Credit Algae Coprod	$0.00	$0	$0
Credit Elec	$3.96	$56	$2,445
Net Cost	$25.61	$365.20	$15,807
Cost per barrel of oil	$1,075.55		



Base case with Centrifugal Extractor
10 day residence
0.66 g/l biomass
25% recycle

INPUTS

Economic Parameters

Desired rate of return	10.00%
Depreciation years	10
Analysis Period (years)	20
Tax Rate	40.00%
Additive cost ($ per gallon oil)	$0.04
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	20
Evaporation Rate cm/day	0.6
Area Productivity g/sq m-d	10
% Lipid Content	5%
Total Pond Area (incr 10 ha)	1000
Percent biomass recycle	50%
Retention Time days	10
Pond Algae Concentration g/l	0.95
Single Pond Flow lpd	2,099,320
Total Pond Flow lpd	104,966,000
Pond volume liters	40,000,000

Other Inputs

Electricity Cost	$0.10
Plant Recov CO2 Cost oper mt	$50.00
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

Natural Gas Price per MJ	0.00663472
Natural Gas Price per Btu	0.000007

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
- 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

Other

Yellow indicates input
Blue indicates calculation

RESULTS

	$2006
Total Biomass Production	0
Total Oil Production	896,700
Total Capital	$73,783,914
Total Operating Cost	$7,904,901
Capital per Annual Gallon	$82.28

	Oil (gal)	Algae (mt)	Pond (ha)
Annualized Capital	$12.15	$173	$10,894
Operating Cost	$8.82	$126	$7,905
Total Cost	$20.96	$299	$18,799
Credit Algae Coprod	$0.00	$0	$0
Credit Elec	$2.61	$37	$2,343
Net Cost	$18.35	$261.71	$16,456
Cost per barrel of oil	$770.76		

Base case with Centrifugal Extractor
10 day residence
0.95 g/l biomass
50% recycle

INPUTS

Economic Parameters

Desired rate of return	10.00%
Depreciation years	10
Analysis Period (years)	20
Tax Rate	40.00%
Additive cost ($ per gallon oil)	$0.04
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	20
Evaporation Rate cm/day	0.6
Area Productivity g/sq m-d	10
% Lipid Content	5%
Total Pond Area (incr 10 ha)	1000
Percent biomass recycle	75%
Retention Time days	10
Pond Algae Concentration g/l	1.74
Single Pond Flow lpd	1,148,980
Total Pond Flow lpd	57,449,000
Pond volume liters	40,000,000

Other Inputs

Electricity Cost	$0.10
Plant Recov CO2 Cost oper mt	$50.00
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

Natural Gas Price per MJ	0.00663472
Natural Gas Price per Btu	0.000007

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
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

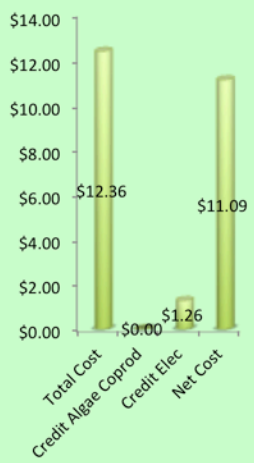
Other

Yellow indicates input
Blue indicates calculation

RESULTS

	$2006
Total Biomass Production	0
Total Oil Production	1,638,374
Total Capital	$73,151,198
Total Operating Cost	$9,448,147
Capital per Annual Gallon	$44.65

	Oil (gal)	Algae (mt)	Pond (ha)
Annualized Capital	$6.59	$94	$10,801
Operating Cost	$5.77	$82	$9,448
Total Cost	$12.36	$176	$20,249
Credit Algae Coprod	$0.00	$0	$0
Credit Elec	$1.26	$18	$2,072
Net Cost	$11.09	$158.22	$18,177
Cost per barrel of oil	$465.96		



Base case with Centrifugal Extractor
10 day residence
1.74 g/l biomass
75% recycle

INPUTS

Economic Parameters

Desired rate of return	10.00%
Depreciation years	10
Analysis Period (years)	20
Tax Rate	40.00%
Additive cost ($ per gallon oil)	$0.04
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	20
Evaporation Rate cm/day	0.6
Area Productivity g/sq m-d	10
% Lipid Content	5%
Total Pond Area (incr 10 ha)	1000
Percent biomass recycle	100%
Retention Time days	10
Pond Algae Concentration g/l	10.07
Single Pond Flow lpd	198,640
Total Pond Flow lpd	9,932,000
Pond volume liters	40,000,000

Other Inputs

Electricity Cost	$0.10
lant Recov CO2 Cost oper mt	$50.00
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

Natural Gas Price per MJ	0.00663472
Natural Gas Price per Btu	0.000007

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
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

Other

Yellow indicates input
Blue indicates calculation

RESULTS

	$2006
Total Biomass Production	0
Total Oil Production	9,476,739
Total Capital	$66,464,365
Total Operating Cost	$25,757,894
Capital per Annual Gallon	$7.01

	Oil (gal)	Algae (mt)	Pond (ha)
Annualized Capital	$1.04	$15	$9,813
Operating Cost	$2.72	$39	$25,758
Total Cost	$3.75	$54	$35,571
Credit Algae Coprod	$0.00	$0	$0
Credit Elec	$0.00	$0	$0
Net Cost	$3.75	$53.53	$35,571
Cost per barrel of oil	$157.65		

Base case with Centrifugal Extractor
10 day residence
10.07 g/l biomass
100% recycle

INPUTS

Economic Parameters	
Desired rate of return	10.00%
Depreciation years	10
Analysis Period (years)	20
Tax Rate	40.00%
Additive cost ($ per gallon oil)	$0.04
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	20
Evaporation Rate cm/day	0.6
Area Productivity g/sq m-d	60
% Lipid Content	16%
Total Pond Area (incr 10 ha)	1000
Percent biomass recycle	0%
Lipid secretion	2
Retention Time days	1.7
Pond Algae Concentration g/l	0.51
Single Pond Flow lpd	23,529,412
Total Pond Flow lpd	1,176,470,588
Pond volume liters	40,000,000

Other Inputs	
Electricity Cost	$0.10
lant Recov CO2 Cost oper mt	$50.00
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
Natural Gas Price per MJ	0.00663472

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
- 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

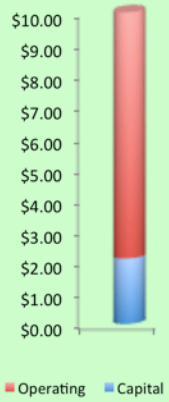
Oil Recovery
- Hexane
- Hexane
- W/O/S Centrifuge
- Other

Yellow indicates input
Blue indicates calculation

RESULTS

	$2006
Total Biomass Production	198,000,000
Total Oil Production	8,472,716
Total Capital	$120,017,611
Total Operating Cost	$66,822,685
Capital per Annual Gallon	$14.17

	Oil (gal)	Algae (mt)	Pond (ha)
Annualized Capital	$2.09	$89	$17,720
Operating Cost	$7.89	$337	$66,823
Total Cost	$9.98	$427	$84,543
Credit Algae Coprod	$3.19	$136	$27,012
Credit Elec	$0.00	$0	$0
Net Cost	$6.79	$290.56	$57,531
Cost per barrel of oil	$285.19		



VG Improved Hexane Solvent Extraction
2 day residence
0.6 g/l biomass
0% recycle

INPUTS

Economic Parameters	
Desired rate of return	10.00%
Depreciation years	10
Analysis Period (years)	20
Tax Rate	40.00%
Additive cost ($ per gallon oil)	$0.04
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	20
Evaporation Rate cm/day	0.6
Area Productivity g/sq m-d	60
% Lipid Content	16%
Total Pond Area (incr 10 ha)	1000
Percent biomass recycle	0%
Lipid secretion	Yes
Retention Time days	2
Pond Algae Concentration g/l	0.60
Single Pond Flow lpd	20,000,000
Total Pond Flow lpd	1,000,000,000
Pond volume liters	40,000,000

Other Inputs	
Electricity Cost	$0.10
lant Recov CO2 Cost oper mt	$50.00
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
Natural Gas Price per MJ	0.00663472

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
- 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

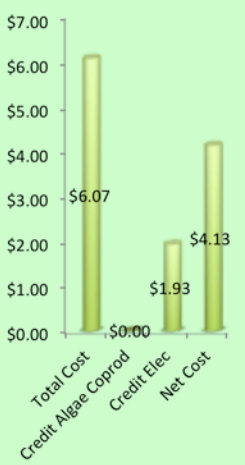
Oil Recovery
- W/O/S Centrifuge
- Hexane
- W/O/S Centrifuge
- Other

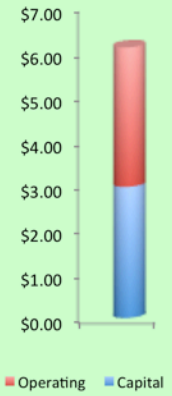
Yellow indicates input
Blue indicates calculation

RESULTS

	$2006
Total Biomass Production	0
Total Oil Production	8,471,068
Total Capital	$168,607,155
Total Operating Cost	$26,487,864
Capital per Annual Gallon	$19.90

	Oil (gal)	Algae (mt)	Pond (ha)
Annualized Capital	$2.94	$126	$24,895
Operating Cost	$3.13	$134	$26,488
Total Cost	$6.07	$260	$51,383
Credit Algae Coprod	$0.00	$0	$0
Credit Elec	$1.93	$83	$16,367
Net Cost	$4.13	$176.84	$35,015
Cost per barrel of oil	$173.61		





VG Improved Centrifugal Extraction
2 day residence
0.6 g/l biomass
0% recycle

INPUTS

Economic Parameters	
Desired rate of return	10.00%
Depreciation years	10
Analysis Period (years)	20
Tax Rate	40.00%
Additive cost ($ per gallon oil)	$0.04
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	20
Evaporation Rate cm/day	0.6
Area Productivity g/sq m-d	60
% Lipid Content	16%
Total Pond Area (incr 10 ha)	1000
Percent biomass recycle	25%
Retention Time days	1.6
Pond Algae Concentration g/l	0.61
Single Pond Flow lpd	19,681,125
Total Pond Flow lpd	984,056,250
Pond volume liters	40,000,000

Other Inputs	
Electricity Cost	$0.10
lant Recov CO2 Cost oper mt	$50.00
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

Natural Gas Price per MJ	0.00663472
Natural Gas Price per Btu	0.000007

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
- 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

Other

Yellow indicates input
Blue indicates calculation

RESULTS

	$2006
Total Biomass Production	0
Total Oil Production	10,760,396
Total Capital	$185,759,780
Total Operating Cost	$29,243,820
Capital per Annual Gallon	$17.26

	Oil (gal)	Algae (mt)	Pond (ha)
Annualized Capital	$2.55	$109	$27,427
Operating Cost	$2.72	$116	$29,244
Total Cost	$5.27	$225	$56,671
Credit Algae Coprod	$0.00	$0	$0
Credit Elec	$1.43	$61	$15,401
Net Cost	$3.84	$164.09	$41,270
Cost per barrel of oil	$161.09		

VG Improved Centrifugal Extraction
1.6 day residence
0.61 g/l biomass
25% recycle

INPUTS

Economic Parameters

Desired rate of return	10.00%
Depreciation years	10
Analysis Period (years)	20
Tax Rate	40.00%
Additive cost ($ per gallon oil)	$0.04
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	20
Evaporation Rate cm/day	0.6
Area Productivity g/sq m-d	60
% Lipid Content	16%
Total Pond Area (incr 10 ha)	1000
Percent biomass recycle	50%
Retention Time days	1.15
Pond Algae Concentration g/l	0.60
Single Pond Flow lpd	19,982,261
Total Pond Flow lpd	999,113,043
Pond volume liters	40,000,000

Other Inputs

Electricity Cost	$0.10
Plant Recov CO2 Cost oper mt	$50.00
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

Natural Gas Price per MJ	0.00663472
Natural Gas Price per Btu	0.000007

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
- 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

Other

Yellow indicates input
Blue indicates calculation

RESULTS

	$2006
Total Biomass Production	0
Total Oil Production	14,745,370
Total Capital	$219,738,367
Total Operating Cost	$34,177,526
Capital per Annual Gallon	$14.90

	Oil (gal)	Algae (mt)	Pond (ha)
Annualized Capital	$2.20	$94	$32,444
Operating Cost	$2.32	$99	$34,178
Total Cost	$4.52	$193	$66,622
Credit Algae Coprod	$0.00	$0	$0
Credit Elec	$0.93	$40	$13,690
Net Cost	$3.59	$153.58	$52,932
Cost per barrel of oil	$150.77		

VG Improved Centrifugal Extraction
1.15 day residence
0.60 g/l biomass
50% recycle

INPUTS

Economic Parameters

Desired rate of return	10.00%
Depreciation years	10
Analysis Period (years)	20
Tax Rate	40.00%
Additive cost ($ per gallon oil)	$0.04
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	20
Evaporation Rate cm/day	0.6
Area Productivity g/sq m-d	60
% Lipid Content	16%
Total Pond Area (incr 10 ha)	1000
Percent biomass recycle	75%
Retention Time days	0.72
Pond Algae Concentration g/l	0.60
Single Pond Flow lpd	20,096,389
Total Pond Flow lpd	1,004,819,444
Pond volume liters	40,000,000

Other Inputs

Electricity Cost	$0.10
lant Recov CO2 Cost oper mt	$50.00
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

Natural Gas Price per MJ	0.00663472
Natural Gas Price per Btu	0.000007

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
- 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

Other

Yellow indicates input
Blue indicates calculation

RESULTS

	$2006
Total Biomass Production	0
Total Oil Production	23,417,882
Total Capital	$291,711,819
Total Operating Cost	$44,849,387
Capital per Annual Gallon	$12.46

	Oil (gal)	Algae (mt)	Pond (ha)
Annualized Capital	$1.84	$79	$43,071
Operating Cost	$1.92	$82	$44,849
Total Cost	$3.75	$161	$87,921
Credit Algae Coprod	$0.00	$0	$0
Credit Elec	$0.43	$18	$9,979
Net Cost	$3.33	$142.39	$77,941
Cost per barrel of oil	$139.79		

VG Improved Centrifugal Extraction
0.72 day residence
0.60 g/l biomass
75% recycle

INPUTS

Economic Parameters	
Desired rate of return	10.00%
Depreciation years	10
Analysis Period (years)	20
Tax Rate	40.00%
Additive cost ($ per gallon oil)	$0.04
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	20
Evaporation Rate cm/day	0.6
Area Productivity g/sq m-d	60
% Lipid Content	16%
Total Pond Area (incr 10 ha)	1000
Percent biomass recycle	100%
Retention Time days	0.3
Pond Algae Concentration g/l	0.60
Single Pond Flow lpd	19,864,000
Total Pond Flow lpd	993,200,000
Pond volume liters	40,000,000

Other Inputs	
Electricity Cost	$0.10
lant Recov CO2 Cost oper mt	$50.00
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

Natural Gas Price per MJ	0.00663472
Natural Gas Price per Btu	0.000007

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
- 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

Other

Yellow indicates input
Blue indicates calculation

RESULTS

	$2006
Total Biomass Production	0
Total Oil Production	56,860,435
Total Capital	$560,370,222
Total Operating Cost	$85,707,595
Capital per Annual Gallon	$9.86

	Oil (gal)	Algae (mt)	Pond (ha)
Annualized Capital	$1.46	$62	$82,739
Operating Cost	$1.51	$64	$85,708
Total Cost	$2.96	$127	$168,446
Credit Algae Coprod	$0.00	$0	$0
Credit Elec	$0.00	$0	$0
Net Cost	$2.96	$126.74	$168,446
Cost per barrel of oil	$124.42		

VG Improved Centrifugal Extraction
0.30 day residence
0.60 g/l biomass
100% recycle

INPUTS

Economic Parameters	
Desired rate of return	10.00%
Depreciation years	10
Analysis Period (years)	20
Tax Rate	40.00%
Additive cost ($ per gallon oil)	$0.04
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	20
Evaporation Rate cm/day	0.6
Area Productivity g/sq m-d	60
% Lipid Content	16%
Total Pond Area (incr 10 ha)	1000
Percent biomass recycle	25%
Retention Time days	2
Pond Algae Concentration g/l	0.76
Single Pond Flow lpd	15,744,900
Total Pond Flow lpd	787,245,000
Pond volume liters	40,000,000

Other Inputs	
Electricity Cost	$0.10
lant Recov CO2 Cost oper mt	$50.00
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

Natural Gas Price per MJ	0.00663472
Natural Gas Price per Btu	0.000007

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
- 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

Other

Yellow indicates input
Blue indicates calculation

RESULTS

	$2006
Total Biomass Production	0
Total Oil Production	10,760,396
Total Capital	$166,665,481
Total Operating Cost	$28,611,504
Capital per Annual Gallon	$15.49

	Oil (gal)	Algae (mt)	Pond (ha)
Annualized Capital	$2.29	$98	$24,608
Operating Cost	$2.66	$114	$28,612
Total Cost	$4.95	$212	$53,220
Credit Algae Coprod	$0.00	$0	$0
Credit Elec	$1.44	$62	$15,535
Net Cost	$3.50	$149.83	$37,684
Cost per barrel of oil	$147.09		

VG Improved Centrifugal Extraction
2 day residence
0.76 g/l biomass
25% recycle

INPUTS

Economic Parameters

Desired rate of return	10.00%
Depreciation years	10
Analysis Period (years)	20
Tax Rate	40.00%
Additive cost ($ per gallon oil)	$0.04
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	20
Evaporation Rate cm/day	0.6
Area Productivity g/sq m-d	60
% Lipid Content	16%
Total Pond Area (incr 10 ha)	1000
Percent biomass recycle	50%
Retention Time days	2
Pond Algae Concentration g/l	1.04
Single Pond Flow lpd	11,489,800
Total Pond Flow lpd	574,490,000
Pond volume liters	40,000,000

Other Inputs

Electricity Cost	$0.10
lant Recov CO2 Cost oper mt	$50.00
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

Natural Gas Price per MJ	0.00663472
Natural Gas Price per Btu	0.000007

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
- 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

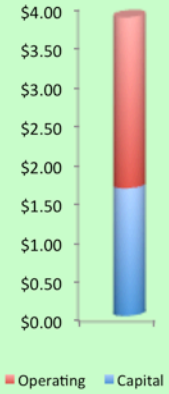
Other

Yellow indicates input
Blue indicates calculation

RESULTS

	$2006
Total Biomass Production	0
Total Oil Production	14,745,370
Total Capital	$163,285,659
Total Operating Cost	$32,308,070
Capital per Annual Gallon	$11.07

	Oil (gal)	Algae (mt)	Pond (ha)
Annualized Capital	$1.64	$70	$24,109
Operating Cost	$2.19	$94	$32,308
Total Cost	$3.83	$164	$56,417
Credit Algae Coprod	$0.00	$0	$0
Credit Elec	$0.96	$41	$14,086
Net Cost	$2.87	$122.82	$42,331
Cost per barrel of oil	$120.57		



VG Improved Centrifugal Extraction
2 day residence
1.04 g/l biomass
50% recycle

INPUTS

Economic Parameters

Desired rate of return	10.00%
Depreciation years	10
Analysis Period (years)	20
Tax Rate	40.00%
Additive cost ($ per gallon oil)	$0.04
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	20
Evaporation Rate cm/day	0.6
Area Productivity g/sq m-d	60
% Lipid Content	16%
Total Pond Area (incr 10 ha)	1000
Percent biomass recycle	75%
Retention Time days	2
Pond Algae Concentration g/l	1.66
Single Pond Flow lpd	7,234,700
Total Pond Flow lpd	361,735,000
Pond volume liters	40,000,000

Other Inputs

Electricity Cost	$0.10
Plant Recov CO2 Cost oper mt	$50.00
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

Natural Gas Price per MJ	0.00663472
Natural Gas Price per Btu	0.000007

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
- 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

Other

Yellow indicates input
Blue indicates calculation

RESULTS

	$2006
Total Biomass Production	0
Total Oil Production	23,417,882
Total Capital	$155,930,140
Total Operating Cost	$40,352,919
Capital per Annual Gallon	$6.66

	Oil (gal)	Algae (mt)	Pond (ha)
Annualized Capital	$0.98	$42	$23,023
Operating Cost	$1.72	$74	$40,353
Total Cost	$2.71	$116	$63,376
Credit Algae Coprod	$0.00	$0	$0
Credit Elec	$0.47	$20	$10,934
Net Cost	$2.24	$95.81	$52,442
Cost per barrel of oil	$94.05		

VG Improved Centrifugal Extraction
2 day residence
1.66 g/l biomass
75% recycle

INPUTS

Economic Parameters

Desired rate of return	10.00%
Depreciation years	10
Analysis Period (years)	20
Tax Rate	40.00%
Additive cost ($ per gallon oil)	$0.04
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	20
Evaporation Rate cm/day	0.6
Area Productivity g/sq m-d	60
% Lipid Content	16%
Total Pond Area (incr 10 ha)	1000
Percent biomass recycle	100%
Retention Time days	2
Pond Algae Concentration g/l	4.03
Single Pond Flow lpd	2,979,600
Total Pond Flow lpd	148,980,000
Pond volume liters	40,000,000

Other Inputs

Electricity Cost	$0.10
lant Recov CO2 Cost oper mt	$50.00
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

Natural Gas Price per MJ	0.00663472
Natural Gas Price per Btu	0.000007

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
- 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

Other

Yellow indicates input
Blue indicates calculation

RESULTS

	$2006
Total Biomass Production	0
Total Oil Production	56,860,435
Total Capital	$127,566,121
Total Operating Cost	$71,375,102
Capital per Annual Gallon	$2.24

	Oil (gal)	Algae (mt)	Pond (ha)
Annualized Capital	$0.33	$14	$18,835
Operating Cost	$1.26	$54	$71,375
Total Cost	$1.59	$68	$90,210
Credit Algae Coprod	$0.00	$0	$0
Credit Elec	$0.00	$0	$0
Net Cost	$1.59	$67.88	$90,210
Cost per barrel of oil	$66.63		

VG Improved Centrifugal Extraction
2 day residence
4.03 g/l biomass
100% recycle