

SUPPLEMENTARY INFORMATION

Marine microalgae commercial production improves sustainability of global fisheries and aquaculture

Colin M. Beal^{1,2}, Léda N. Gerber², Supis Thongrod³, Wutiporn Phromkunthong⁴,
Viswanath Kiron⁵, Joe Granados², Ian Archibald^{2,6}, Charles H. Greene^{2,7}, Mark E.
Huntley*^{2,8}

¹ B&D Engineering and Consulting LLC, 7419 State Hwy 789, Lander, WY 82520,
United States

² University of Hawaii at Hilo, Pacific Aquaculture & Coastal Resources Center, College
of Agriculture, Forestry, and Natural Resource Management, 200 W. Kawili St., HI
95720, United States

³ Thai Union Feedmill Co., Ltd., 89/1 Moo2, Tambon Kalong, Amphoe Muang,
Samutskorn Province, Thailand 74000

⁴ Prince of Songkla University, Department of Aquatic Science, Faculty of Natural
Resources, Hat Yai, Songkhla Province, Thailand 90112

⁵ Nord University, Faculty of Biosciences and Aquaculture, 8049 Bodo, Norway

⁶ Cinglas Ltd, Chester, United Kingdom

⁷ Cornell University, Department of Earth and Atmospheric Sciences, 4120 Snee Hall,
Ithaca, NY 14853, United States

⁸ Cornell University, Department of Animal Sciences, 149 Morrison Hall, Ithaca, NY
14853, United States

* Corresponding author. Tel: +1(808) 640-4239, E-mail address: meh333@cornell.edu

Supplementary Table S1. Capital costs for a 111-ha facility in Thailand.

Item	Cost (\$/ha)
Water Supply Equipment	27,400
Water Supply/Discharge Piping	170
PBR System	1,420
PBR Piping	5,390
Pond System	77,100
Pond Piping	28,800
CO2 Piping	50
Secondary Settlers (earthworks & liner)	315
Ring Dryer	14,300
Filter Press	10,400
Instrumentation + control	6,550
Other Piping	40.0
Electrical	11,500
Buildings	30,800
Land preparation	20,600
Other	26,000
Cultivation Total (\$/ha)	261,000
Cultivation Total (\$)	29,000,000
Processing Total (\$/ha)	2,590
Processing Total (\$)	289,000
Total Cost \$	29,300,000

Supplementary Table S2. Labor costs for facility in Thailand

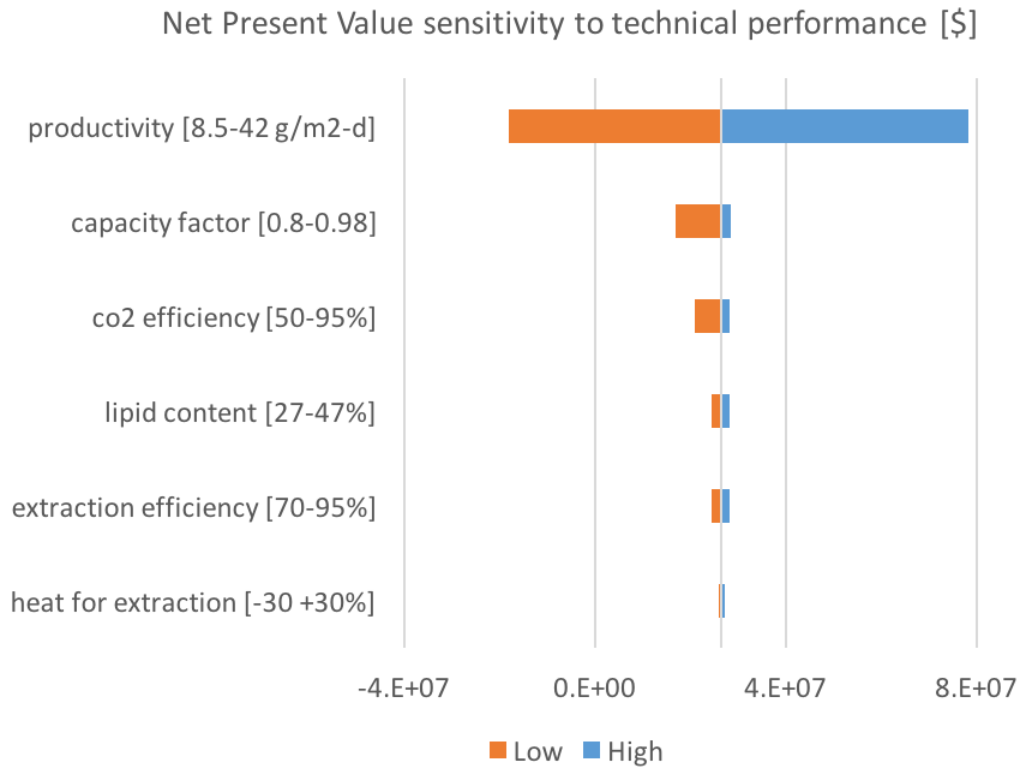
Thailand	Per Employee						
		Base	Fringe	Hourly	Annual	No.	Total
Position	Function	(\$ h-1)	(\$ h-1)	(\$ h-1)	(\$ yr-1)	FTE	(\$000s yr-1)
Operations Staff							
Harvest technician	Harvest/inoculate ponds	\$1.72	\$0.60	\$2.33	\$4,750	17.0	\$80.69
Processing tech	Operate processing eq.	\$2.32	\$0.81	\$3.13	\$6,380	3.0	\$19.15
Plant engineer	Plant maintenance	\$3.60	\$1.26	\$4.86	\$9,910	5.0	\$49.57
Lab technician	Scale-up + QA/QC	\$3.56	\$1.25	\$4.81	\$9,820	10.0	\$98.17
IT engineer	Process control system	\$5.06	\$1.77	\$6.84	\$13,900	2.0	\$27.90
Production manager	Operations	\$6.47	\$2.26	\$8.74	\$17,800	1.0	\$17.82
Total Operations						38.0	\$293
Administrative Staff							
Franchise manager	Overall administration	\$11.76	\$4.12	\$15.88	\$32,400	1.0	\$32.40
Sales manager	Sales & marketing	\$8.91	\$3.12	\$12.03	\$24,500	1.0	\$24.54
Accounting	Fiscal management	\$7.65	\$2.68	\$10.32	\$21,100	0.5	\$10.53
Human resources	Personnel	\$7.65	\$2.68	\$10.32	\$21,100	0.5	\$10.53
Total Admin.						3.0	\$78
Personnel Summary							
Total Operations						38	\$293
Total Administration						3	\$78
Total Personnel						41	\$371

Supplementary Table S3. Key parameters for the techno-economic analysis.

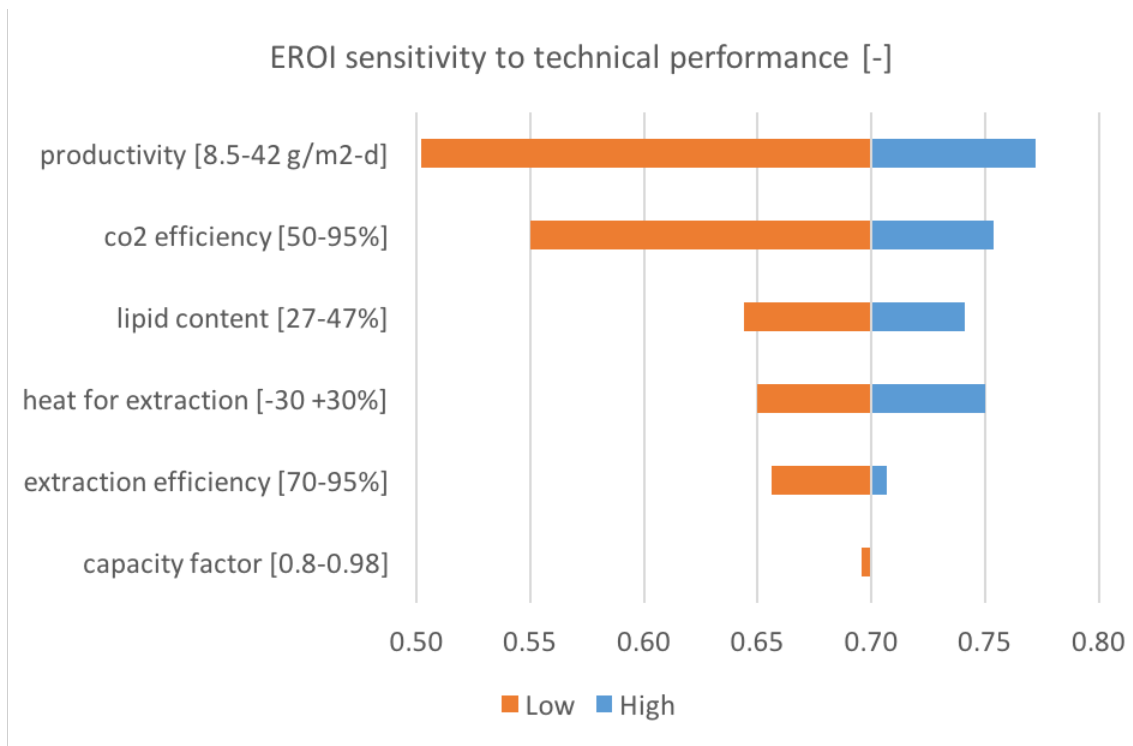
<u>Parameter</u>	<u>Value</u>
Discount rate	10%
Tax rate	20%
Capital	\$29.3M
Equity	40%
Interest rate	8%
Loan term	10 years
Depreciable investment	89% (\$26.0M)
Maintenance rate (of capital)	1% per year
Insurance rate (of capital)	1% per year
Land rent (scaled to Thailand) ¹	\$11.89/ha-yr
MACRS % depreciation ² , years 1-8	14.3, 24.5, 17.5, 12.5, 8.9, 8.9, 8.9, 4.5
Facility life	30 years
Algal biomass meal baseline market value ³	\$1,400/MT
Algal lipids baseline market value ³	\$1,800/MT

Supplementary Table S4: Probability distribution functions

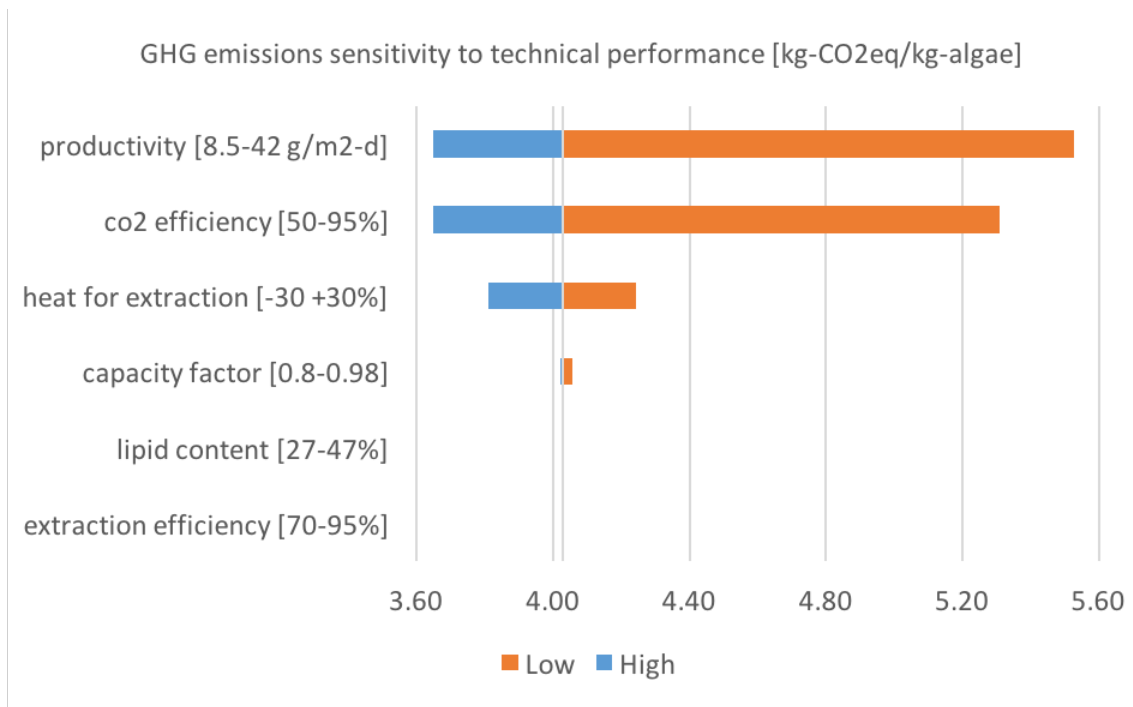
Parameter	Distribution law	mode	min	max	mu	sigma
Productivity [g/m ² -day]	Normal				23.4	4.48
Lipid fraction [-]	Normal				0.37	0.07
Stoichiometric CO ₂ [g-CO ₂ /g-algae]	Triangular	1.78	1.23	1.88		
Efficiency of CO ₂ absorption [-]	Uniform		0.5	0.95		
Capacity factor [-]	Triangular	0.90	0.80	0.98		
Electricity dewatering [kWh/m ³]	Triangular	0.30	0.18	0.43		
Oil extraction efficiency [-]	Uniform		0.70	0.95		
Ammonia price [\$/tonne]	Normal				455	76.0
DAP price [\$/tonne]	Normal				410	60.0
Electricity price [\$/kWh]	Lognormal				-2.65	0.25
Error on investment costs [%]	Uniform		-30%	30%		
Algal oil price [\$/tonne]	Normal				1.80	0.15
Lipid-extracted algae price [\$/tonne]	Normal				1.40	0.05
Geographic cost modifier [-]	Triangular	0.58	0.25	1.00		
CO ₂ price [\$/kg]	Triangular	0.075	0.040	0.160		
PBR plastic cost [%]	Uniform		-30%	+30%		
Heat required for extraction [%]	Uniform		-30%	+30%		
Error on labor costs [%]	Uniform		-30%	+30%		



Supplementary Figure S1: Results of the sensitivity analysis for the Net Present Value (NPV) indicator.



Supplementary Figure S2: Results of the sensitivity analysis for the energy return on investment (EROI) indicator.



Supplementary Figure S3: Results of the sensitivity analysis for the greenhouse gases (GHG) emissions indicator.

Supplementary Information References

1. USDA. Land Values, 2016 Summary, National Agricultural Statistics Service, ISSN: 1949-1867, 2016
2. IRS. *Publication 946 (2013), How to Depreciate Property*, 2013
3. FAO. The State of World Fisheries and Aquaculture 2016. pp. 200, Rome, 2016