Commercial Opportunities of Microalgae

Animal and Aquaculture Feed

BIO-Pacific Rim Summit on Industrial Biotechnology and Bioenergy

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Image DARPA approved for public release

General Atomics Develops, Manufactures, and Fields Advanced Technology Systems for Defense and Energy

GENERAL ATOMICS

Algae for Energy Security Solutions

Algal Biomass

For

Energy

(DARPA, AFRL, DLA)

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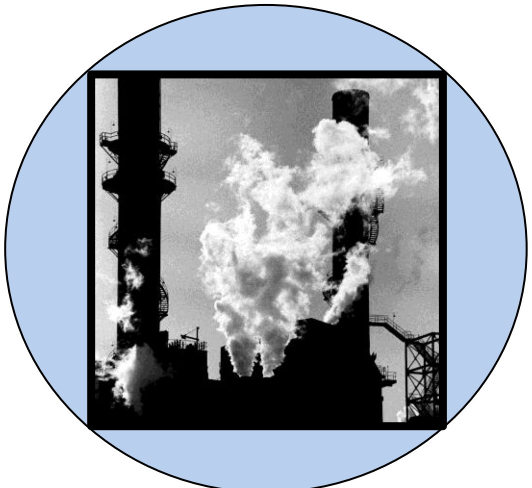
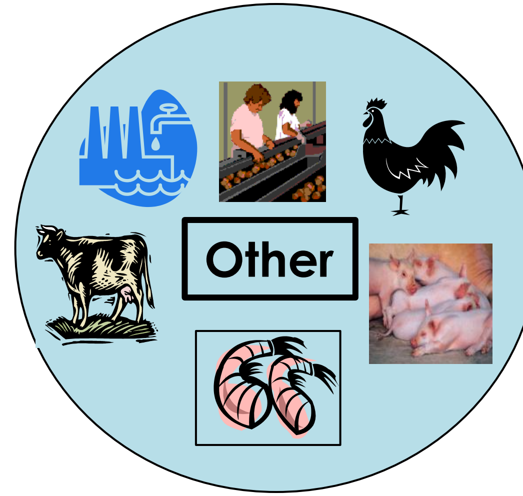
Biodiesel, JP-8, JP-5

Algal Biomass Production: Carbon Feedstocks





Phototrophic Algae

Heterotrophic Algae

Mixotrophic Algae

Carbon

Water

Nutrients

Sunlight

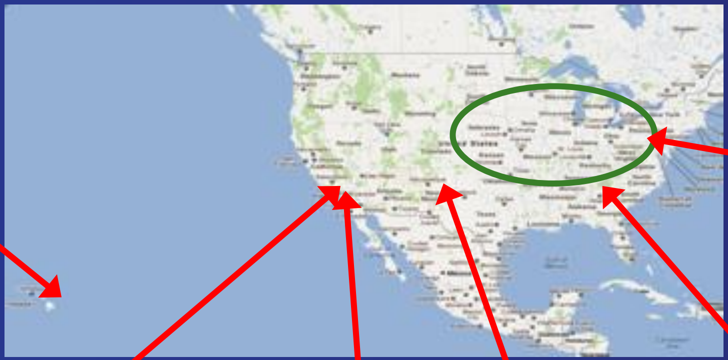
Algae

Oil

Fuel

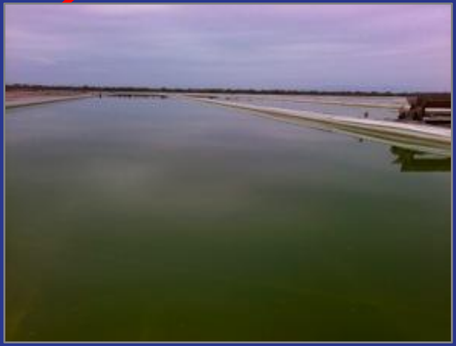
Works in Various Climates

Kauai, HI
Solar input: 5.1 kWH/m2/day
Precipitation: 1050 mm/year
Average temp. range: 18-30 °C



Kentucky: Agriculturally rich, abundant coal, water, land

San Diego, CA
Solar input: 5.4 kWH/m2/day
Precipitation: 262 mm/year
Average temp. range: 9-25 oC



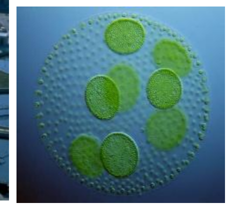
Imperial Valley, CA
Solar input: 5.8 kWH/m2/day
Precipitation: 74 mm/year
Average Temperature range: 4-43 oC

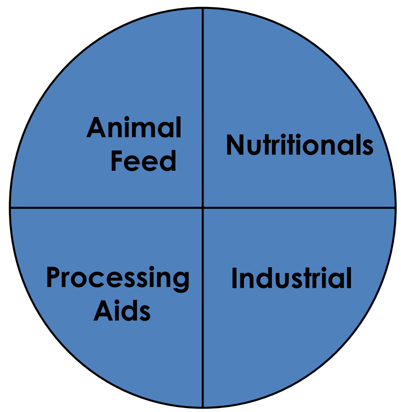
Pecos, TX
Solar input: 5.7 kWH/m2/day
Precipitation: 295 mm/year
Average temp. range: -2-37 °C

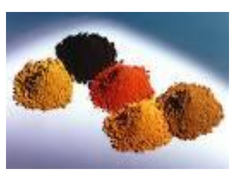
Mississippi: Plenty of water, CO_2, land, forestry, sun

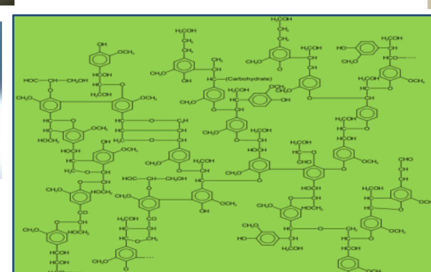
Algal Biomass and Product Opportunities

Opportunities









Technologies

Algae: High Oil and Protein Yields on Waste Carbon

Crop	Oil gal/ac/yr	Supply U.S. oil demand (million acre)
Soybean	48	4167
Camelina	86	2326
Rapeseed	124	1613
Coconut	287	697
Palm Oil	635	315
Algae (DARPA)	2,000	100
Algae-(IR&D)	3700	54
Algae (plausible)	5000	40

Algal Biomass Post-Oil Extraction 'Spent Biomass'

↓

Protein, free amino acids, fatty acids pigments, minerals, carbohydrates

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Poultry, cattle, pigs, fish

Algae for Food Security Solutions

Algal Biomass

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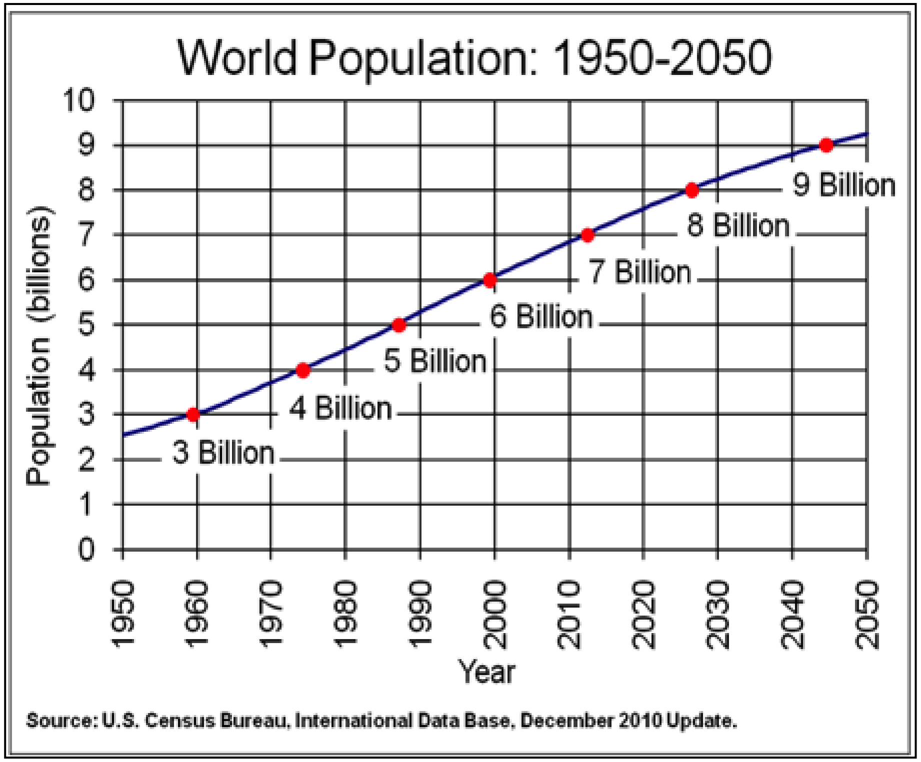
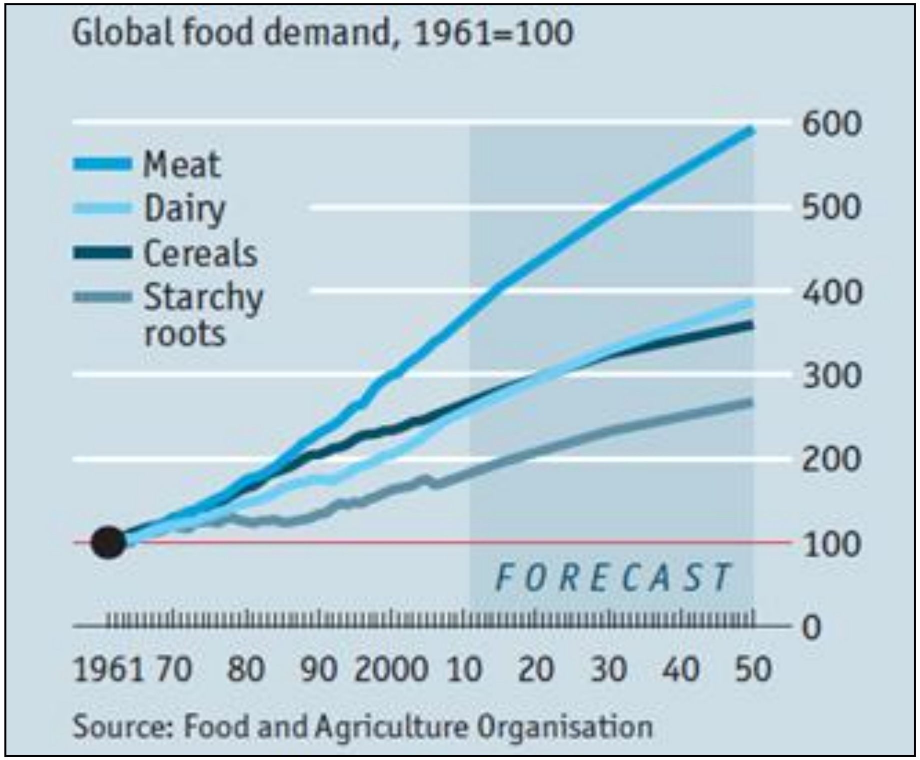
Protein and nutrition for animals and aquaculture

Why Algae?...Global Food Demand





Growing affluent populations demand more meat protein

GENERAL ATOMICS

DEMAND

ANNUAL FISH REQUIREMENT

1 Million Tonnes

X

Feed Conversion Ratio

2.0

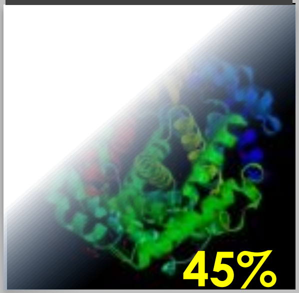
=

TOTAL FEED REQUIRED

2 Million Tonnes

X

% PROTEIN IN MARINE SPECIES DIET



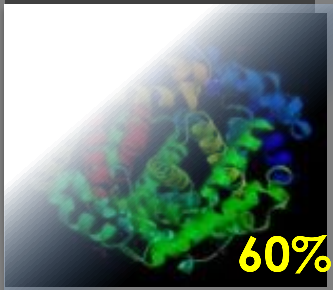
Annual Protein Demand = 900k Tonnes

SUPPLY

Annual Algae Yield Per Acre

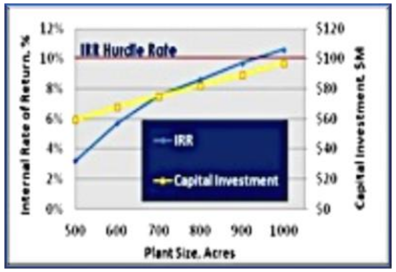
X

% Protein in GA Algae



Annual Protein Yield Per Acre = 24 Tonnes

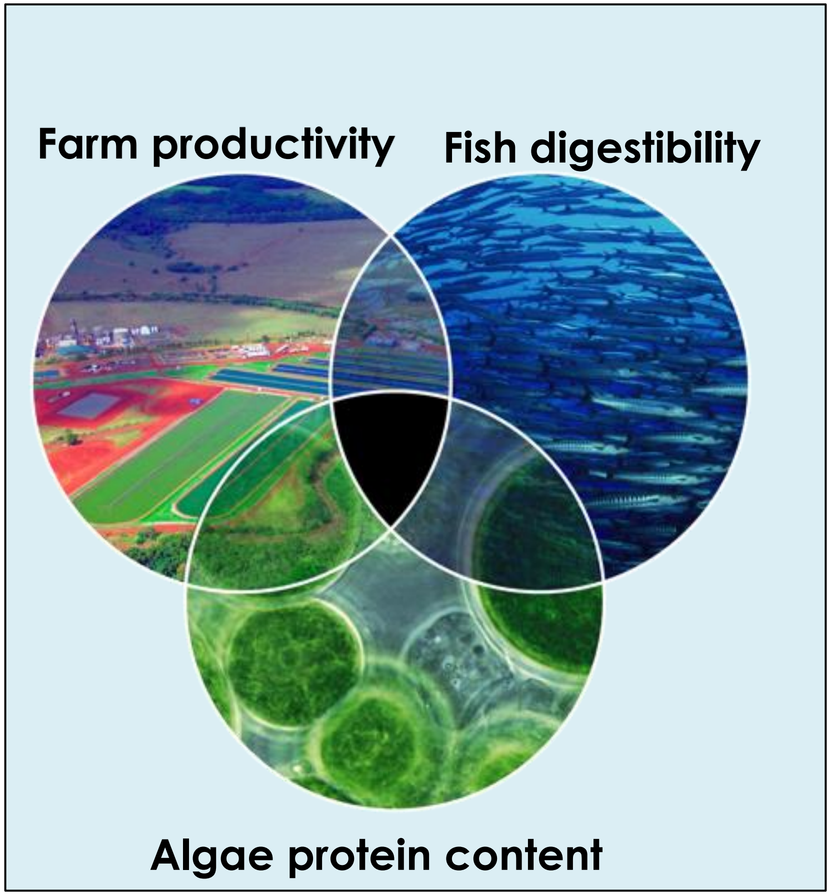
DEMAND / SUPPLY = 37,500 Acres + Profitable Plant Size

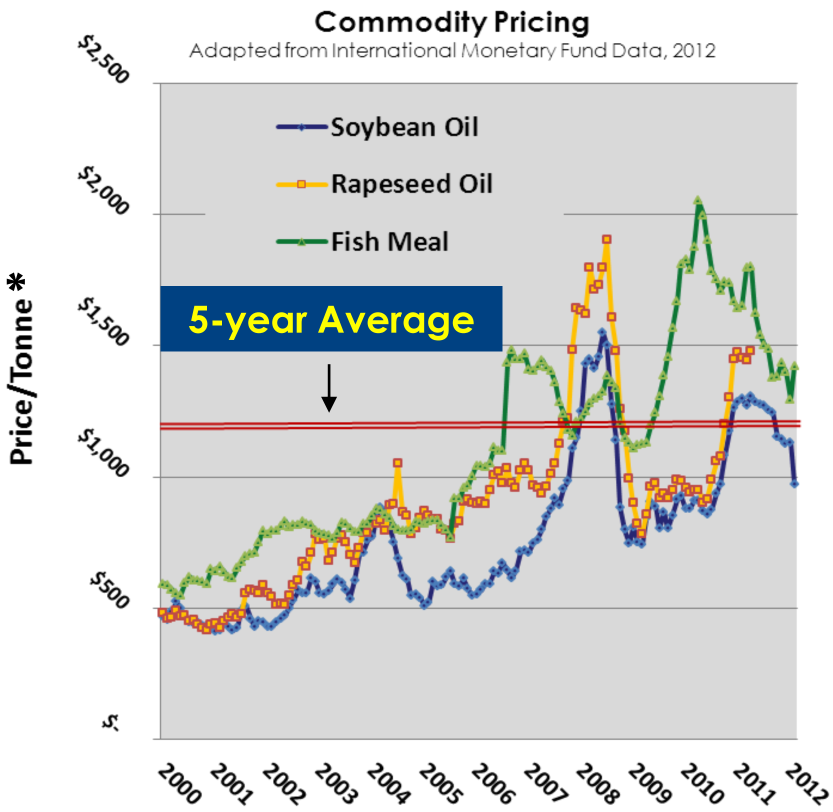


\+ Siting Analysis → # of Plants

GENERAL ATOMICS

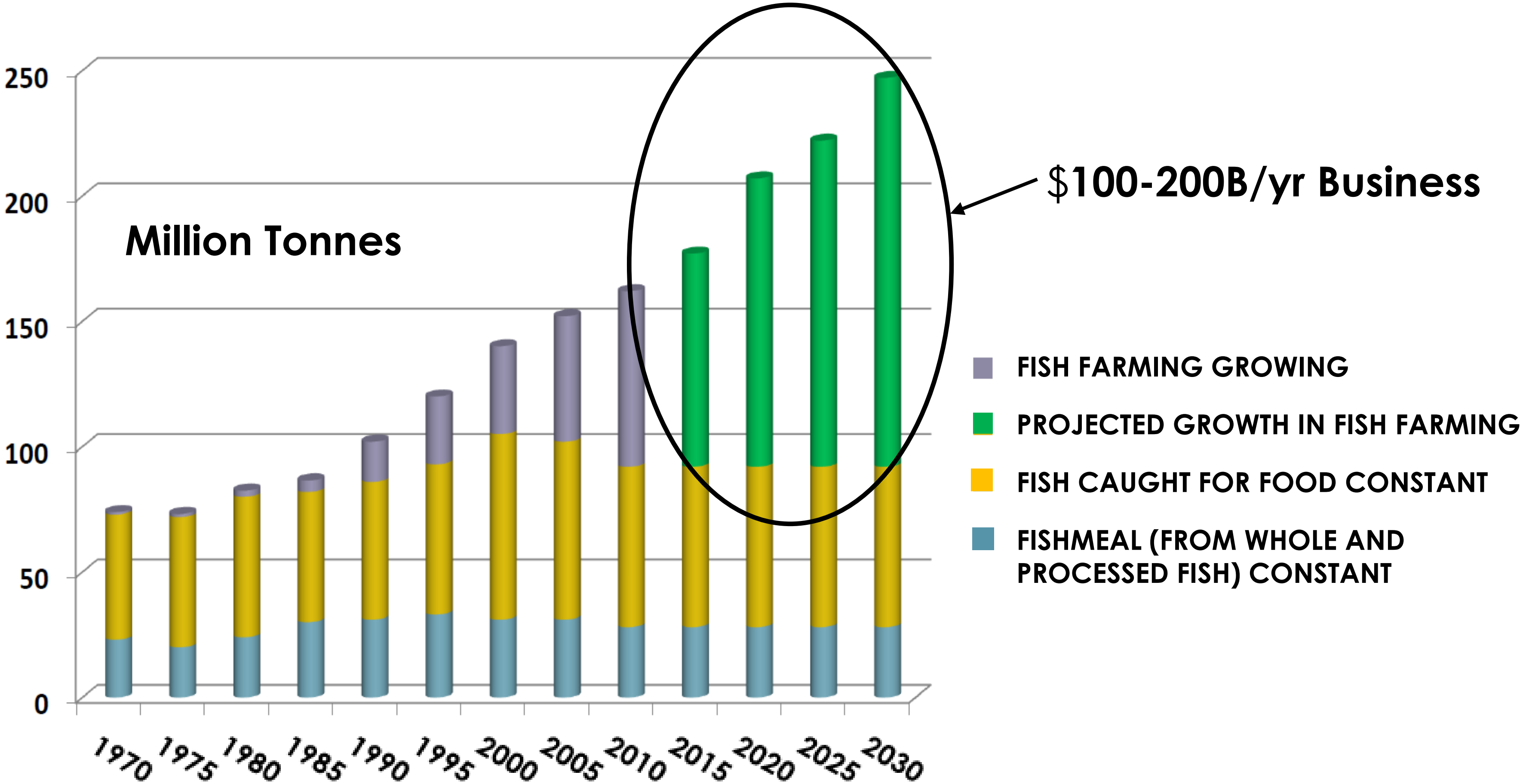
Protein Supply, Demand and Trend





GENERAL ATOMICS

Fishmeal Cannot Meet Aquaculture Demand



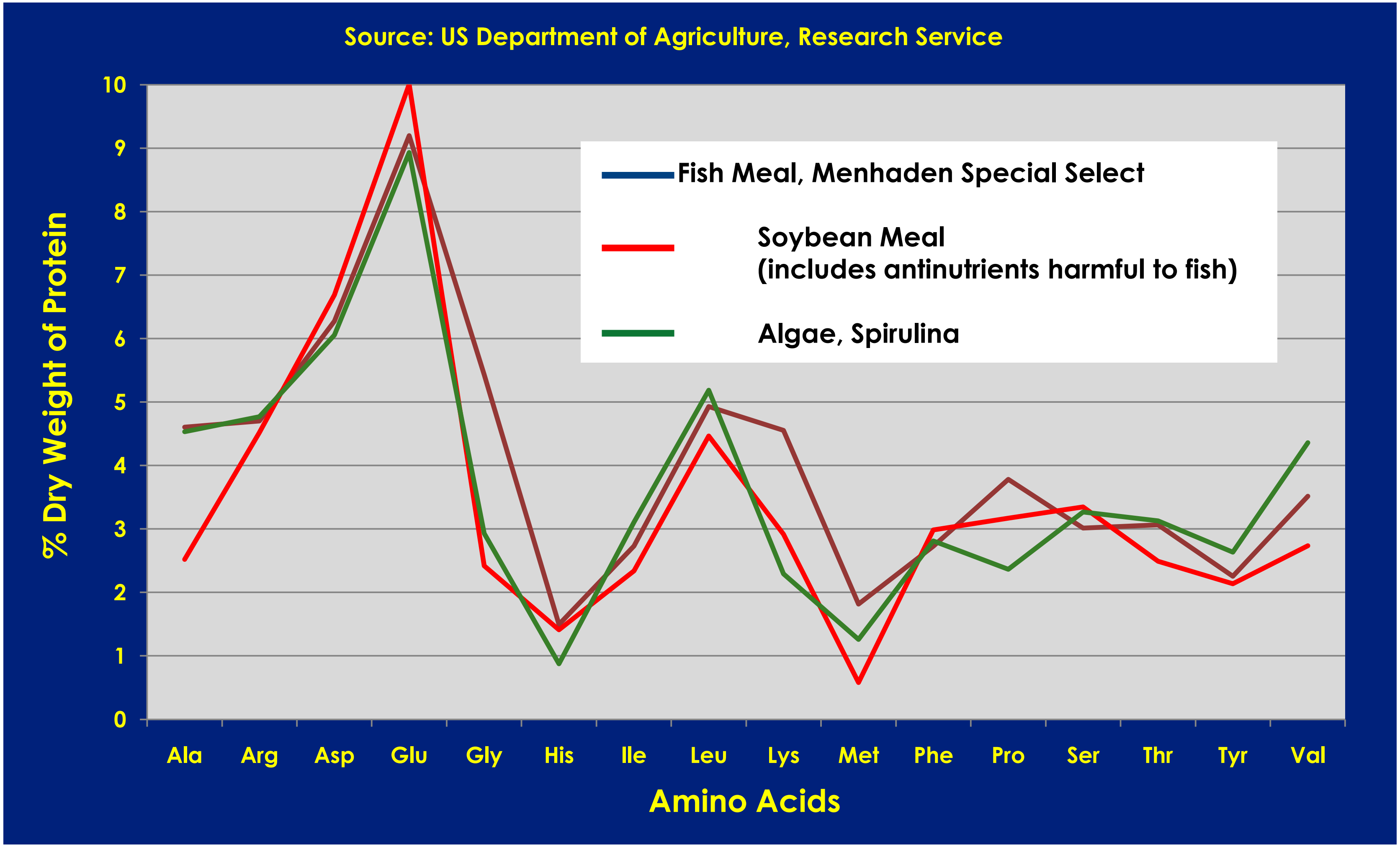
Source: University of Idaho, Aquaculture Research Institute

Protein Content of Algal Biomass

- **Available land, water, sunlight, CO_2 and nutrients**
  - Land can be arable and non-arable
  - Quality and type of water is flexible
  - Sunlight is limited to 14 $MJ/m^2/day$ annual average
  - CO_2 can be generated through a variety of sources
  - Nutrients can be costly
- **Protein yield per weight is significant**
  - Comparable to fishmeal

Ingredient	Protein (g) per 100 grams
Dried whey	13
Non-fat milk powder	36
Low-fat soy flour	47
Low-fat sunflower seed flour	48
De-fatted peanut flour	52
Spirulina	58
GA 254	62
Vital wheat gluten	75
Soy protein isolate	81
Egg white powder	82
Unsweetened dry gelatin	86

Fishmeal and Algae Have Comparable Protein and Other Nutrient Profiles



GENERAL ATOMICS

Amino Acid Profile of Algae and Soybean

	Algae 1	Algae 2	Algae 3
	% Sample Basis	% Sample Basis	% Sample Basis
Dry Weight	91.09	91.03	83.61
Ash	9.93	18.75	29.43
Moisture	8.91	8.97	16.390
Ash-free Dry Weight	81.16	72.28	54.18
Protein (Crude)	41.15	55.06	58.69
Fiber (Crude)	0.67	10.60	1.59
	Amino Acid	Amino Acid	Amino Acid
Methionine	0.69	1.09	1.13
Cystine	0.51	0.73	0.52
Lysine	4.42	3.83	3.10
Phenylalanine	1.63	1.88	2.57
Leucine	2.83	3.50	4.69
Isoleucine	1.22	1.45	1.85
Threonine	1.64	2.68	2.51
Valine	1.84	1.96	2.86
Histidine	0.83	1.13	0.94
Arginine	2.09	3.36	4.78
Glycine	1.84	2.70	3.41
Aspartic Acid	3.09	6.56	5.59
Serine	1.43	2.81	2.69
Glutamic Acid	3.99	8.34	8.49
Proline	2.14	5.27	5.57
Hydroxyproline	0.01	0.14	0.39
Alanine	2.61	3.54	5.57
Tyrosine	1.12	1.19	1.86
Taurine	0.07	N/A	N/A
Total	34.09	52.19	58.53

Soybean, mature seeds, raw	
Protein	36.49 g
- Tryptophan	0.591 g
- Threonine	1.766 g
- Isoleucine	1.971 g
- Leucine	3.309 g
- Lysine	2.706 g
- Methionine	0.547 g
- Cystine	0.655 g
- Phenylalanine	2.122 g
- Tyrosine	1.539 g
- Valine	2.029 g
- Arginine	3.153 g
- Histidine	1.097 g
- Alanine	1.915 g
- Aspartic acid	5.112 g
- Glutamic acid	7.874 g
- Glycine	1.880 g
- Proline	2.379 g
- Serine	2.357 g

GENERAL ATOMICS

Substitution in Chicken Feed

- Carbohydrates
- Fats ★
- Proteins ★
- Vitamins ★
- Minerals ★
- Water
- Antioxidants ★
- Pigments ★
- Enzymes
- Antimicrobials

TABLE 10-1 Formulas for Reference Diets for Chicks

Ingredient	Practical Diet[a]	Soy Isolate Diet[b]	Chemically Casein Diet[c]	Chemically Defined Diet I[d]	Defined Diet II[e]
Ground yellow corn (8.8% protein)(g/kg)	580	—	—	—	—
Soybean meal (48.5% protein)(g/kg)	350	—	—	—	—
Isolated soybean protein (g/kg)	—	250	—	—	—
Casein (g/kg)	—	—	200	—	—
DL-Methionine (g/kg)	2.5	6	5	—	—
L-Arginine (g/kg)	—	—	10	—	—
Glycine (g/kg)	—	4	20	—	—
Crystalline amino acids (g/kg)	—	—	—	204.8[f]	286[g]
Corn oil (g/kg)	30	40	30	50–150	150
Starch (g/kg)	6.5–1 kg	—	—	558–1 kg	205
Dextrose (g/kg)	—	6.08–1 kg	678–1 kg	—	—
Sucrose (g/kg)	—	—	—	154	
Cellulose (g/kg)	—	30	—	30	30
Sawdust (g/kg)	—	—	—	—	100
Choline chloride (100%) (g/kg)	0.75	2	2	2	1.625
Thiamin HCl (mg/kg)	1.8	15	20	20	1.6
Riboflavin (mg/kg)	3.6	15	10	10	5
Calcium pantothenate (mg/kg)	10	20	30	30	15
Niacin (mg/kg)	25	50	50	50	35
Pyridoxine HCl (mg/kg)	3	7.8	6	6	6
Folacin (mg/kg)	0.55	6	4	4	1.5
Biotin (mg/kg)	0.15	0.6	0.6	0.6	0.1
Vitamin B_{12} (mg/kg)	0.0	0.02	0.04	0.04	0.03
Inositol (mg/kg)	—	—	100	100	100
Para-aminobenzoic acid (mg/kg)	—	—	2	2	2
Ascorbic acid (mg/kg)	—	—	250	250	—
Vitamin A (IU/kg)	1,500	4,500	5,200	5,200	1,880
Vitamin D_3 (ICU/kg)	400	450	600	600	375
Vitamin E (IU/kg)	10	50	20	20	31.3
Vitamin K (mg/kg)	0.55	1.5	2	2	1.3
Antioxidant (mg/kg)[h]	125	100	—	12-5	—
Iodized salt (g/kg)	5	—	—	—	—
NaCl (g/kg)	—	6	8.8	8.8	2.75
$CaCO_3$ (g/kg)	10	14.8	3	3	15
$CaHPO_4 \cdot 2H_2O$ (g/kg)	20	20.7	—	—	30
$Ca_3(PO_4)_2$ (g/kg)	—	—	28	28	—
$MgSO_4 \cdot 7H_2O$ (g/kg)	—	6	3.5	3.5	—
$MgCO_3$ (g/kg)	—	—	—	—	2.38
KH_2PO_4 (g/kg)	—	10	9	9	—
K_2CO_3 (g/kg)	—	—	—	—	5.25
$NaHCO_3$ (g/kg)	—	—	—	—	5
$Al(OH)_3$ (g/kg)	—	—	—	—	5
KCl (g/kg)	—	1	—	—	—
$MnSO_4 \cdot H_2O$ (mg/kg)	170	350	650	650	—
$MnCO_3$ (mg/kg)	—	—	—	—	91.5
$ZnSO_4 \cdot H_2O$ (mg/kg)	110	—	—	—	—
$ZnCO_3$ (mg/kg)	—	150	100	100	—
ZnO (mg/kg)	—	—	—	—	25
$Fe_2(SO_4)_3 \cdot 7H_2O$	—	500	—	—	250
Ferric citrate (mg/kg)	500	—	500	500	—
$CuSO_4 \cdot 5H_2O$ (mg/kg)	16	30	20	20	15.5
Na_2SeO_3 (mg/kg)	0.2	0.2	0.2	0.2	0.23
KI (mg/kg)	—	—	40	40	—
KIO_3 (mg/kg)	—	2	—	—	0.6
$CoCl_2$ (mg/kg)	—	1.7	—	—	—
$CoSO_4 \cdot 7H_2O$ (mg/kg)	—	—	1	1	1
H_3BO_3 (mg/kg)	—	—	9	9	9
$Na_2MoO_4 \cdot 2H_2O$ (mg/kg)	—	8.3	9	9	2.5

NOTE: Dash indicates a zero value for the ingredient.
[a] National Research Council (1977).

Summary

- **Algae can be grown on a variety of feedstocks to generate biomass**
- **Protein and fatty acids are valuable ingredients for animal feed**
- **Aquaculture and poultry farming can greatly benefit from algal primary/by-products**
- **Agriculture biomass and CO_2 to algal biomass to animal biomass process represents a valuable commercial option for a growing nutrition demand worldwide**