Microalgae Route to Biodiesel: Prospects, Potential and Process Design

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Biodiesel From Algae

In the beginning, there were algae, but there was no oil

Then, from algae came oil.

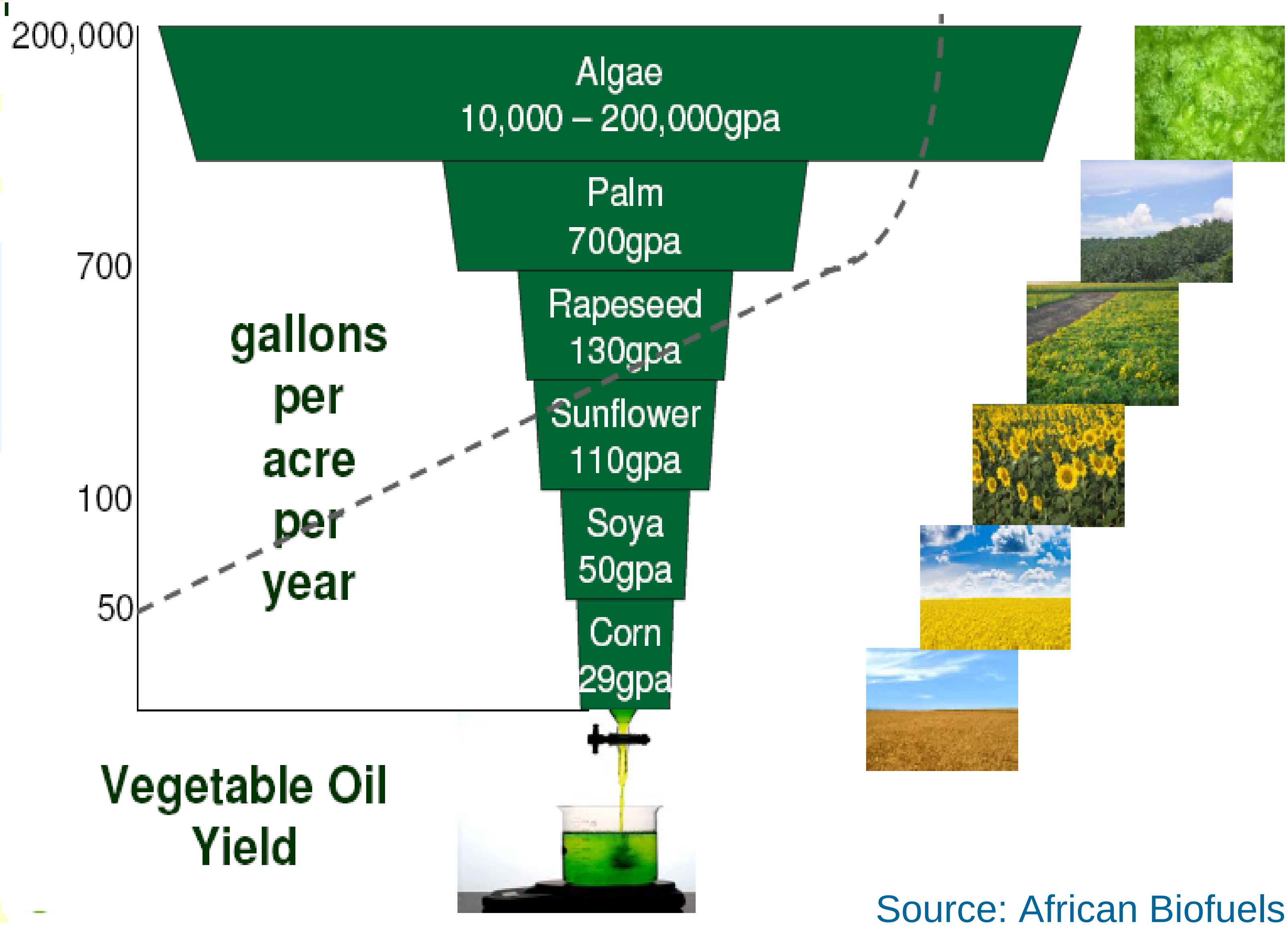
Now, the algae are still there, but oil is fast depleting

In future, there will be no oil, but there will still be algae

So, doesn't it make sense to explore if we can again get oil from algae?

This is what we try to do – explore the potential of getting oil from algae

Biodiesel Feedstock Tree



Source: African Biofuels 2007

Lipid Content of Algal species

- Some algae naturally manufacture hydrocarbons that are suitable as high energy fuels.
- Botrycoccus braunii, a common species, can contain more than 50% oil, mostly in form of hydrocarbons.
- Genetically engineering species of Botrycoccus braunii can be made to grow faster.

Strain or Species	% Lipid (by mass on dry basis)
Scenedesmus sp.	12 - 40
Chlamydomonas sp.	21
Clorella sp.	14 - 22
Spirogyra sp.	11 - 21
Dunaliella sp.	6 - 8
Euglena sp.	14 - 20
Prymnesium sp.	22 - 38
Porphyridium sp.	9 - 14
Synechoccus sp.	11

Microalgal Oil

- Composition of microalgae (dry basis): protein (12–35%); lipid (7.2–23%); carbohydrate (4.6–23%).
- Algal-oil is very high in unsaturated fatty acids, like the canola oil. Some UFA's found in different algal-species include:
- Arachidonic acid(AA)
- Eicospentaenoic acid(EPA)
- Docasahexaenoic acid(DHA)
- Gamma-linolenic acid(GLA)
- Linoleic acid(LA)
- Catalytic hydrogenation of oil prior to tranesterification is a possible solution.

Microalgal Biodiesel

- Not significantly different than the biodiesel produced from vegetable oil.
- Microalgal oil contains high levels of polyunsaturates which can pose stability problem due to possibility of oxidation.
- Due to lower melting point of polyunsaturates (than mono-unsaturates or saturates), algal biodiesel possesses better cold weather properties.
- Growing algae using exhausts of power plants for CO_2 source can help reduce carbon and NO_x emissions.

Mass Production of Microalgae

- Historical milestones of microalge production
  - Production of Chlorella species in Japan: 1960.
  - Spirulina harvesting facility in Mexico and Thailand in 1970 and 1977 respectively.
  - 46 large scale factories in Asia by 1980 producing about 1 ton/month of microalgae.
  - Spirulina production by 2000 stands at remarkable figure of about 3000 tpa (USA, China, Thailand being major producers).

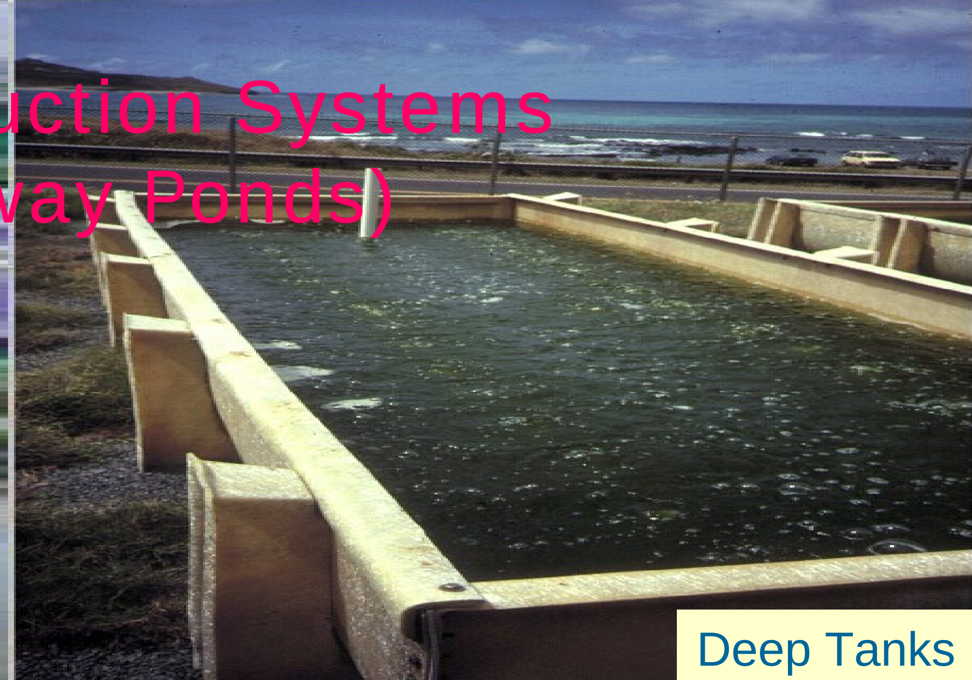
- Proper choice of large scale culture system:
  - Basic biology of algae
  - Cost of land, labor, energy, water and nutrients
  - Prevailing climatic conditions

What Effects Algal Growth?

- Selected Algal strain
- Light conditions
- Temperature
- Water flow rate
- Supply of carbon dioxide (use exhaust of power plants)
- Macronutrients: C, N, P, Mg, Ca, K, Na, Cl
- Micronutrients (Trace elements): Fe, B, Zn, Mn, Mo, Cu, SO4, Co, Cd, Va, Al, Br, Etc..
- Vitamins
- Marine microalgae: Seawater supplemented with commercial fertilizers
- Biodiesel is carbon neutral – no net accumulation of CO_2 in atmosphere.

Mass Production Systems (Raceway Ponds)


Circular Ponds


Deep Tanks


Unstirred pond


Paddlewheel Raceways

PHOTOBIOREACTORS


Stirred Tank Reactor


Bag Culture


Airlift Bioreactor


Tubular Reactor

Features of Raceway Ponds

- Closed loop recirculation channel; mixing achieved with paddle wheel.
- MOC: concrete, compacted earth or lining with white plastic to reduce seepage losses.
- Typical dimensions: Depth – 20-30 cm; Area – 100-250 hectare, production – 0.1 to 0.5 g dry weight per liter.
- Limitations:
  - Significant evaporation losses.
  - Poor thermal or temperature control.
  - Poor utilization of CO_2 due to evaporation or stripping.
  - Contamination from unwanted algae and micro-organisms.
  - Low biomass concentration due to poor mixing and optically dark zones.

Features of Photobioreactors

- Known as closed systems and permit cultivation of single species for longer duration.
- Basic designs: Flat plate reactors and tubular reactors. Principle is to reduce path length of light.
- Tubular array with each tube of 3-4 in. dia.
- Microalgal broth is circulated through a degassing tank with either mechanical pump or airlift pump.
- Either horizontal or vertical array is possible. Illumination could be natural or artificial.
- Temperature control of broth by placing a coil in degassing tank or circulation of water through a jacket around tube.
- Operational difficulties:
  - Growth of algae in tube walls blocking light.
  - High oxygen concentration that can inhibit photosynthesis.
  - Limit on the length of the tube in single run.

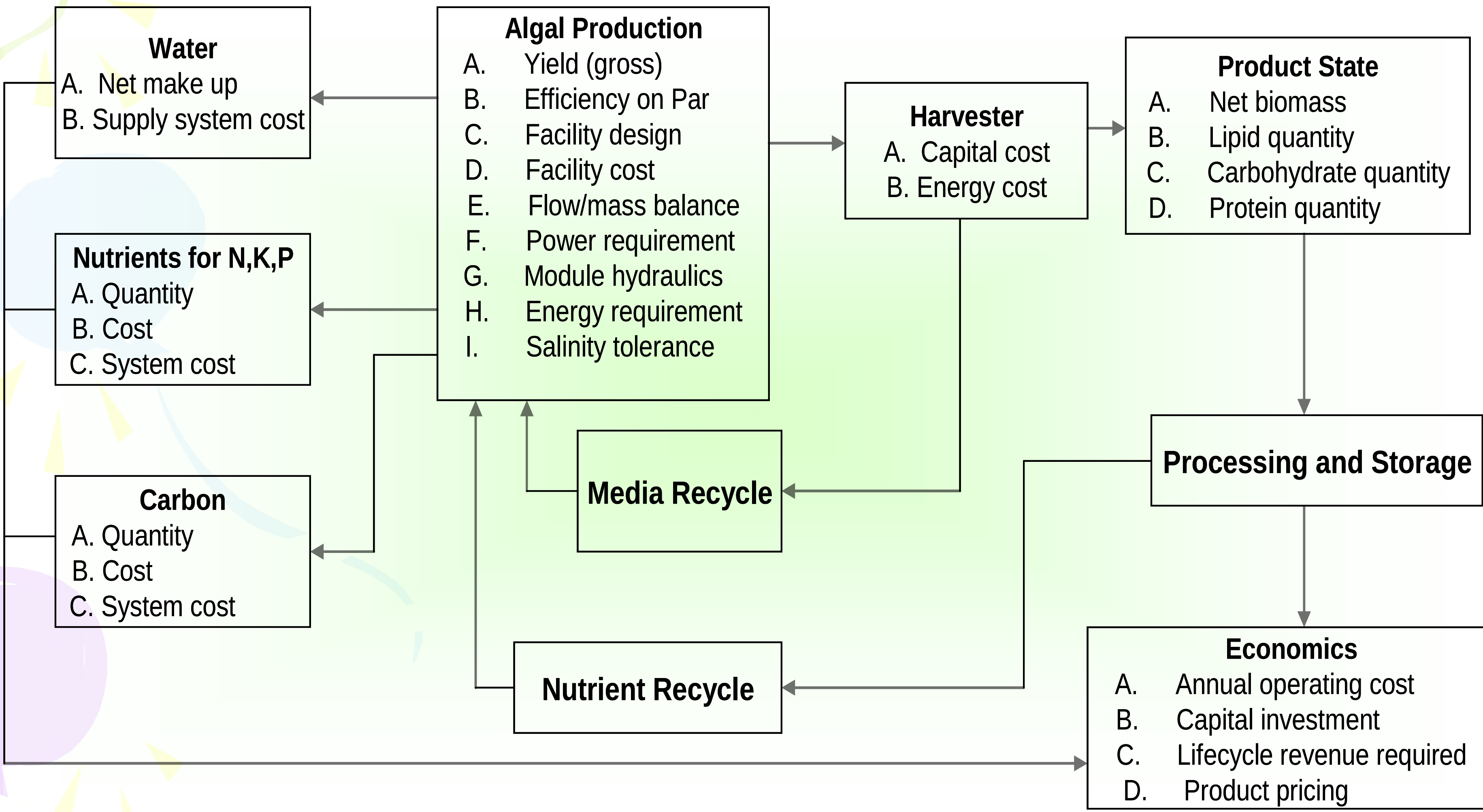
Raceway Ponds vs. Photobioreactors

- 13-fold high biomass productivity and higher oil yield per hectare in photobioreactors.
- Recovery of biomass is also an important issue.
- Recovery cost in photobioreactor is a minor fraction of total processing cost due to high biomass concentration.
- Total area need for photobioreactor is smaller.
- Effective utilization of area can be achieved with BIOCOIL.
- Typical volume of BIOCOIL: 1000 Liter

Comparison of Large Scale Systems

Reactor Type	Mixing	Light utilization Efficiency	Temperature control	Gas transfer	Hydrodynamic stress on algae	Species control	Sterility	Scale up
Unstirred shallow ponds	V.poor	Poor	None	Poor	V. low	Difficult	None	V.difficult
Tanks	Poor	V. poor	None	Poor	V. Poor	Difficult	None	V.difficult
Circular stirred pond	Fair	Fair-Good	None	Poor	Low	Difficult	None	V.difficult
Paddle wheel Raceway	Fair-good	Fair-Good	None	Poor	Low	Difficult	None	Very difficult
Stirred tank reactor	Largely uniform	Fair-Good	Excellent	Low-high	High	Easy	Easily achievable	Difficult
Airlift reactor	Generally uniform	Good	Excellent	High	Low	Easy	Easily achievable	Difficult
Bag culture	Variable	Fair-Good	Good (indoors)	Low-high	Low	Easy	Easily achievable	Difficult
Flat plate reactor	Uniform	Excellent	Excellent	High	Low-high	Easy	Achievable	Difficult
Tubular reactor (serpentine)	Uniform	Excellent	Excellent	Low-high	Low-high	Easy	Achievable	Reasonable
Tubular reactor (Biocoil)	Uniform	Excellent	Excellent	Low-high	Low-high	Easy	Achievable	Easy

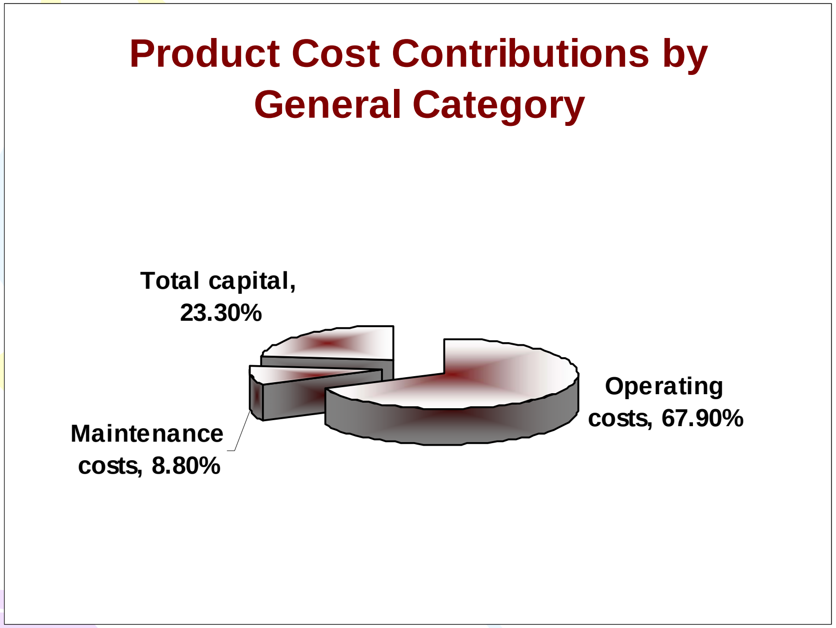
Algal Production and Economics Model



Parameters Affecting Microalgal Production Economy

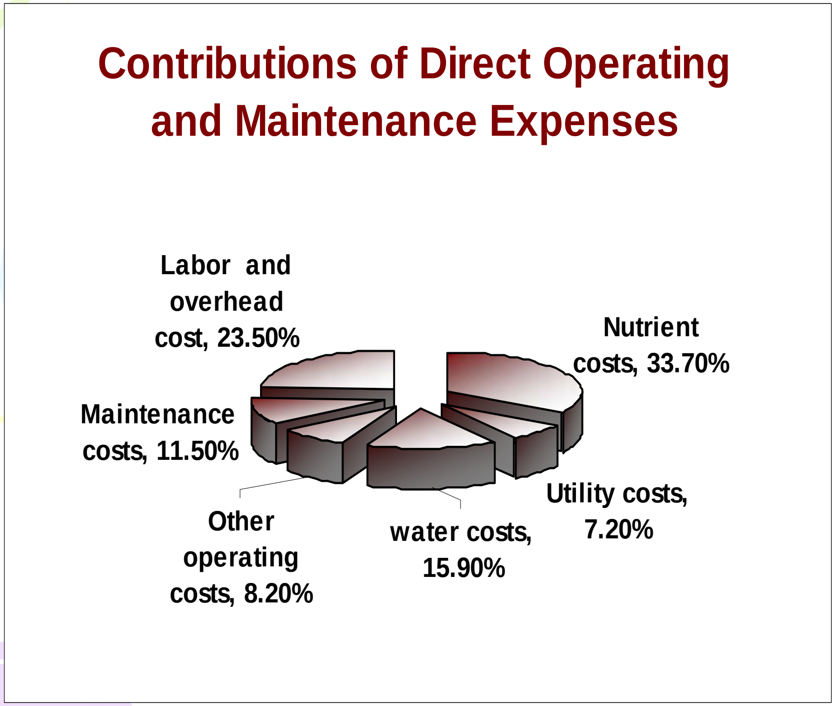
Resource Parameters	Facility Design	Biology Parameter	Financial Parameter
▪ Evaporation ▪ Salinity of source water ▪ N_2 in source water ▪ P in source water ▪ C in source water ▪ Land cost ▪ Energy cost ▪ Water cost ▪ Ammonia cost ▪ Super phosphate cost ▪ Potassium cost ▪ Distance from CO_2 source ▪ CO_2 cost	▪ Effective culture area ▪ Effective culture downtime ▪ Module size pond ▪ Channel width ▪ Depth of culture ▪ C, N, P, K in the medium ▪ C,N losses ▪ Mixing velocity ▪ Mixing system efficiency ▪ Harvester solids removal ▪ Harvester type (microstrainer/centrifuge etc.)	▪ Ash, lipid, carbohydrates and protein content ▪ Salinity tolerance ▪ Phosphorous cell content ▪ Growing season and photosynthetic efficiency ▪ Depth ▪ Detention time ▪ Density	▪ Return on dept ▪ Return on common stock ▪ Return on preformed stock ▪ Cost escalation(inflation) ▪ Cover and liner cost

Economic Analysis of Microalgae Production



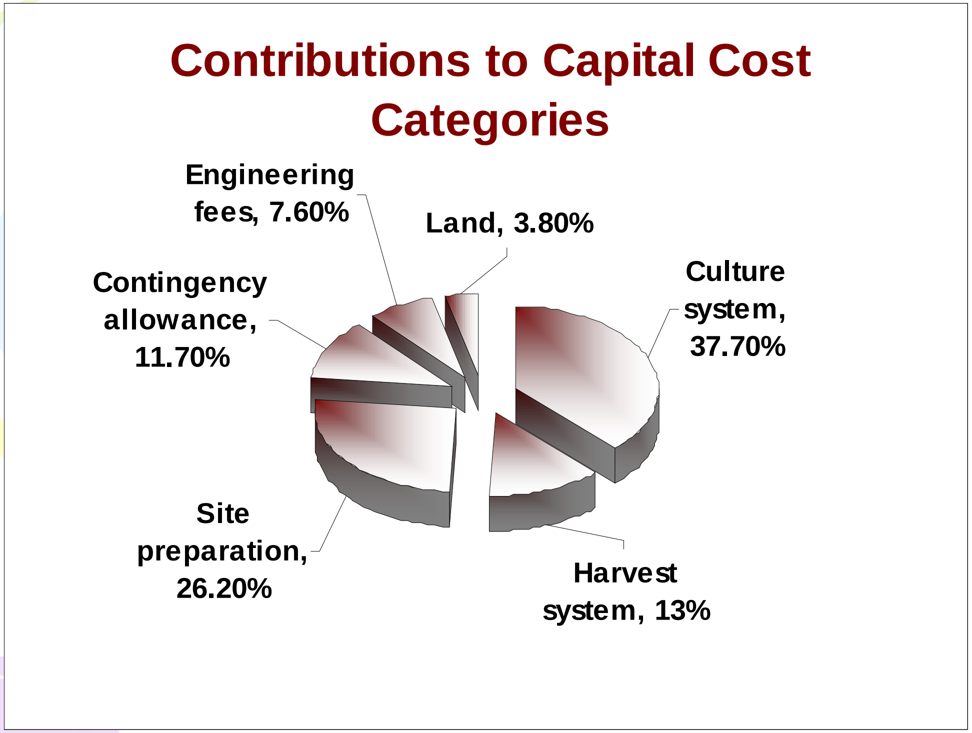
- Economic potential can be judged by assessing individual cost centers.
- General cost distribution for total product cost:
  - Operating costs: 68%
  - Capital costs (depreciable and non-depreciable): 23%
  - Maintenance costs: 9%

Direct Costs



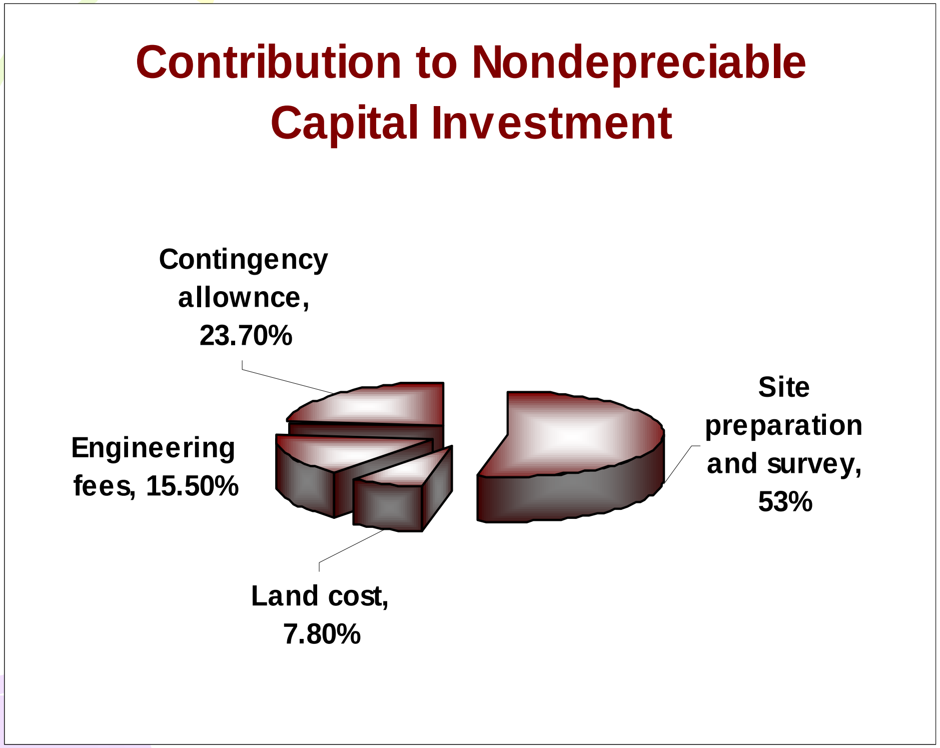
- Direct production costs (combined annual maintenance and operating costs) contribute highest: 68%
  - Nutrient expenses: 33.7%
  - Labor and overheads: 24%
  - Water: 16%
  - Electricity: 7%
- Some uncertainty is involved as some cost components are location specific.

Capital Costs
(Depreciable and Nondepreciable)



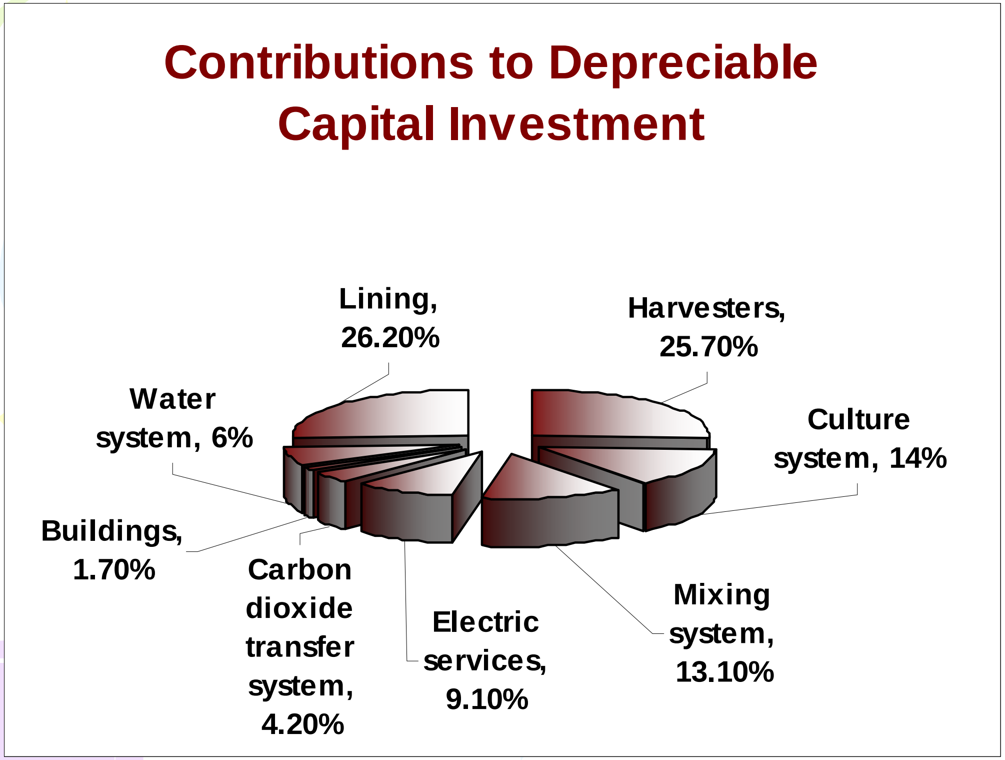
- Fixed costs: 23.3% with depreciable equipment costs: 51% of present value of capital.
- Culture system (37.7%) includes module construction, internal distribution systems, pond lining, mixing system etc.
- Other major factors include site preparation and surveying (26.2%), harvester system (13%) and contingency (12%).

Nondepreciable Capital



- These are non-equipment expenditures not subject to depreciation.
- 49% of total present value of capital investment.
- Use of novel technology warrants higher contingency allowance.
- Low contribution of land cost is due to use of marginal land for algae cultivation.

Depreciable Investment



- Specific life time for each equipment differs but average life is ~ 15 years.
- Highest contribution by the harvesting system.
- Lining of pond bottoms, construction of piping system, mixing system are other components contributing to depreciation.

Summarization

- Hill's analysis gives an idea of economic potential of microalgal biodiesel:
  - Production of 33,171 tpa of microalgae incurs total annualized production cost of $13 million.
  - This gives cost of algal biomass as $393 per ton or $0.35 per kg with approx lipid content of 30%.
  - Thus, annual lipid yield is 71072 bbl with production cost of $1.2 per liter.
  - Compare to this, the cheapest vegetable oil costs $465 per ton or $0.52 per liter.
  - Petrodiesel costs approx $0.75/liter (inclusive of taxes at 20%, crude oil cost 52%, refinery expenses 19% and distribution and marketing 9%).
  - Target price for microalgal oil should be $0.5 per liter assuming it is tax free!

Improvement of Microalgal Biodiesel Economics

- Biorefinery based strategy to utilize every component of biomass raw material.
  - Residual biomass can be animal feed.
  - Anaerobic digestion of biomass for methane production which can be used for producing electricity.
- Revenue earned out of side products can improve economics of production.
- Other strategies would be genetic and metabolic engineering. Possible methodologies are:
  - Increase photosynthetic efficiency.
  - Enhance biomass growth rate.
  - Increase lipid or oil content of biomass.
  - Elimination of light saturation phenomena, photo-inhibition effect, susceptibility to bio-oxidation.

Conclusion

- Microalgal route to biodiesel is a potential alternative to vegetable oil.
- Overall economics of the process needs improvement to be competitive substitute to petrodiesel.
- Roots of improvement in economy lie in both science and technology of microalgae.
- Enhancement in lipid content through genetic modification is one route.
- Much simpler and effective way to achieve the same goal would through photobioreactor engineering. Extensive research on diverse aspects of photobioreactor is needed.
- Biorefinery approach can also improve the economics significantly.

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