UCL Université catholique de Louvain

EARTH & LIFE INSTITUTE

ELI-M: Applied Microbiology

Theory and Practice of Scaling up Microalgae Production

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Research review paper

An economic assessment of astaxanthin production by large scale cultivation of *Haematococcus pluvialis*

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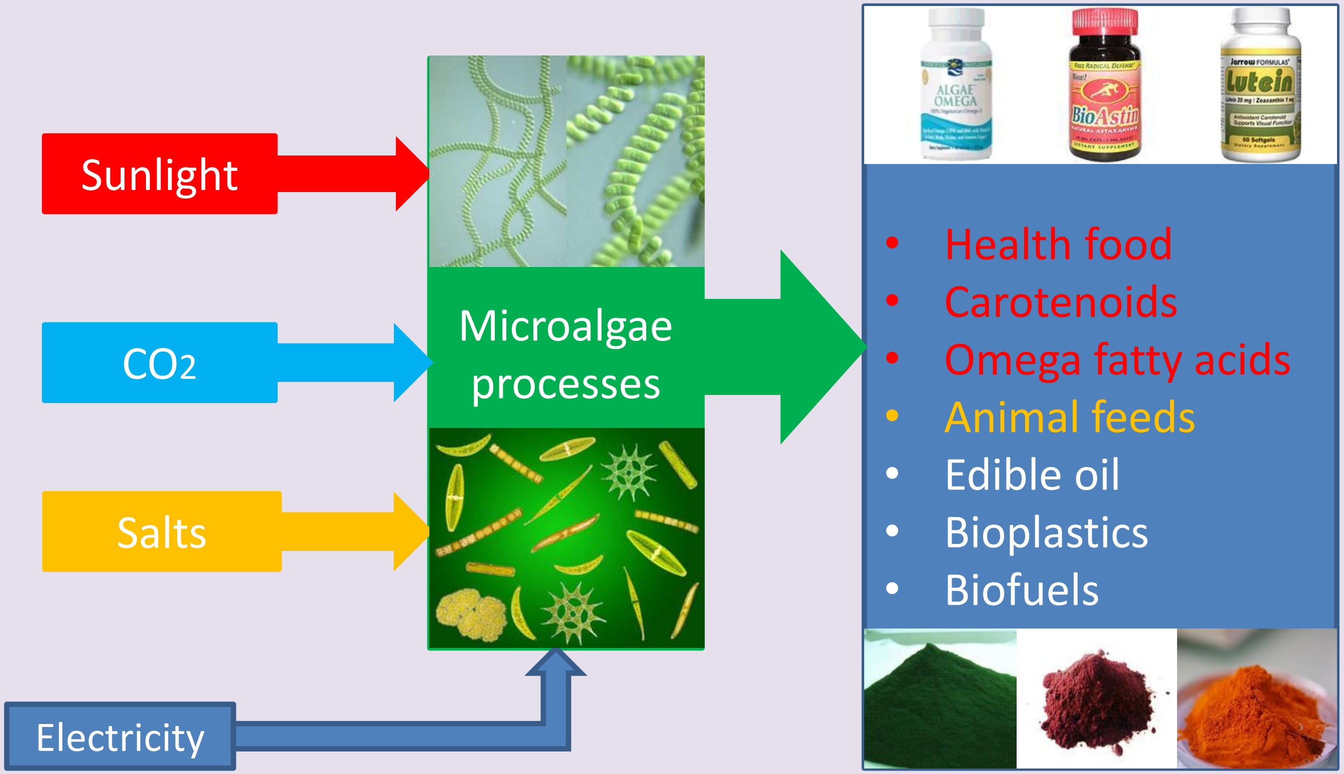
Contents

Introduction- microalgae

- What are microalgae? Simply put it:
    - microorganisms that can do photosynthesis
    - microscopic aquatic plants
- Characteristics
    - have diversified biochemical pathways
    - can be cultivated industrially
    - grow fast

Introduction-microalgal technology



Introduction- the potentials of microalgae

- A green revolution?
- New generation of Agriculture?
- Competing with fermentation?

Introduction- Microalgal industry

- Production cost
  - Cultivation cost 50-80%
  - Down stream processing cost 20-50%

The current costs of production

Spirulina
>€4/kg

Chlorella
>€8/kg

Haematococcus
>€40/kg

Dunaliella
>€20/kg




Introduction- Scale up of microalgae production

- What?
- Why?
- When?
- How?
  - Develop production processes at pilot scales
  - Design the conceptual production facility
  - Cost and economic analysis

The safest way to increase production is simply to multiply the production units! This is, however, often too expensive!

Process development at pilot scales

- Can be challenging, time-consuming and expensive
  - Technical difficulties
  - Duration of operation
  - Scale of area
- The objectives
  - Developing the most inexpensive processes for production
  - Obtaining process parameters for scale up and facility design
  - Building the team for scale up and design production facility
  - Show off to your potential investors

"Commit your blunders on a small scale and make your profits on a large scale"

Leo Henricus Arthur Baekeland, the inventor of Bakelite, 1916

Process development at pilot scales

- Cultivation strategies
  - Autotrophic versus Heterotrophic
  - Sunlight versus Artificial light
  - Raceway pond versus Photobioreactors

Process development at pilot scales

Setting up the laboratory

- Seed culture
  - Monoculture
  - Axenic or sterile
- Sample Analysis
  - Quantity
  - Quality

Clean hood
Autoclave
Shakers

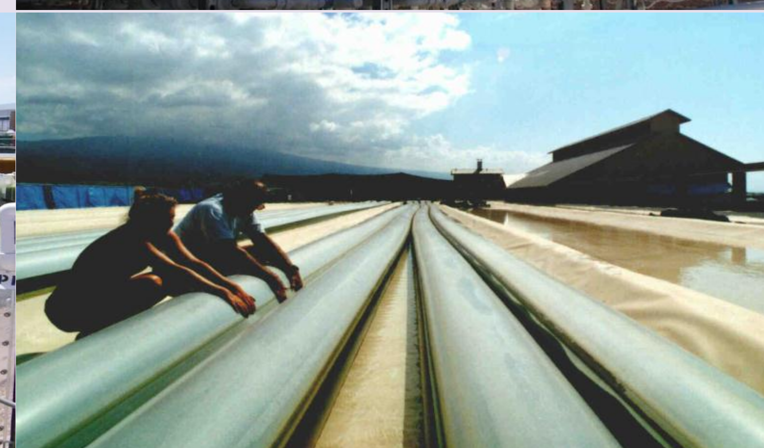
Microscope
Spectrophotometer
Cell counter
Centrifuges

Compressed air supply
CO_2 supply
Water and electricity

Process development at pilot scales

- Photobioreactor cultivation
    - Photobioreactor selection
    - Cultivation process optimization

    - Temperature Light Turbulence
    - pH (CO_2) DO   Nutrients



Process development at pilot scales

- Raceway pond cultivation
  - Design variables
  - Control variables
  - Cultivation process optimization

Process development at pilot scales

- Downstream process development
  - Selection of dewatering instrument
  - Selection of drying instruments
  - Selection of cell breaking machines
  - Selection of extraction instrument




Process development at pilot scales

- Summarization of process parameters

Table 1
Summarization of process parameters.

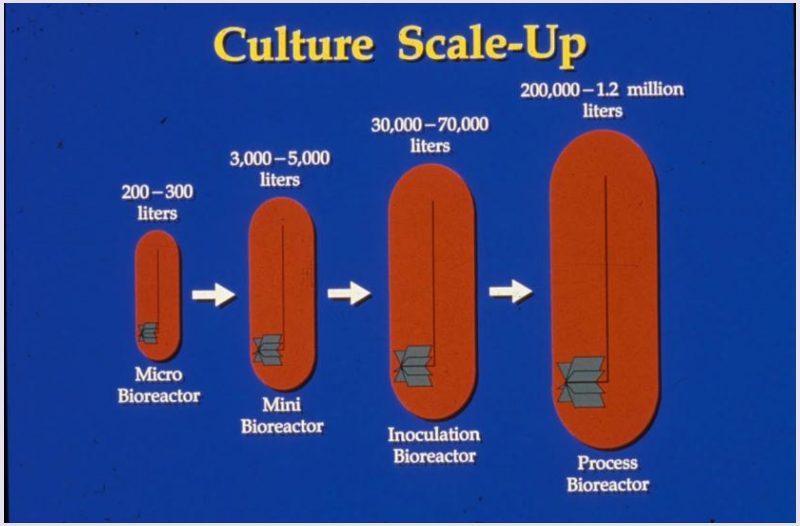
Photobioreactor process control parameters	Values	Ranges
Bioreactor culture temperature	Below 25 C	10–25 C
Bioreactor aeration rate	0.05 v/v/min	
Starting cell concentration of the 1000 L bioreactor	6×10^4 cells/ml	$5–8 \times 10^4$ cells/ml
Final cell concentration for the 1000 L bioreactor	5×10^5 cells/ml	$5–7 \times 10^5$ cells/ml
Starting cell concentration of the 8000 L bioreactor	6×10^4 cells/ml	$5–7 \times 10^4$ cells/ml
Daily renewal rate of the 8000 L bioreactor	0.25 per day	
Photobioreactor process performance parameters	**Estimated values**	**Ranges**
Power consumption for cooling the 1000 L bioreactor	10 kWh per day	0–30 kWh per day
Power consumption for cooling the 8000 L bioreactor	50 kWh per day	0–200 kWh per day
Aeration power input for the 1000 L bioreactor	0.1 kW	
Aeration power input for the 8000 L bioreactor	0.4 kW	
Days for 1000 L bioreactor cell culture to be ready	5 days	4–6 days
Days for 8000 L bioreactor cell culture to be ready	5 days	4–6 days
Working cell concentration for the 8000 L bioreactor	5×10^5 cells/ml	$4.2–6.0 \times 10^5$ cells/ml
Semi-continuous operation of the 8000 L bioreactor	40 days	30–60 days
CO_2 consumption of the 1000 L bioreactor	1.5 kg per day	1.0–2.0 kg per day
CO_2 consumption of the 8000 L bioreactor	4.5 kg per day	3.5–5.0 kg per day
Pond process control Parameters	**Values**	**Ranges**
Pond culture depth	15 cm	
Pond water flow speed	30 cm/s	
Pond inoculation cell concentration	6×10^4 cells/ml	$5–7 \times 10^4$ cells/ml
Pond process performance parameters	**Estimated values**	**Ranges**
Pond reddening days	9 days	8–9 days
Final pond culture concentration in biomass dry weight	0.4 g/L	0.27–0.55 g/L
Pond CO_2 consumption	2 kg per day	1.5–2.5 kg per day
Pond power input	400 W	
Downstream process parameters	**Estimated values**	**Ranges**
Dry biomass in cell slurry	1.4%	1.2%–1.5%
Dry biomass in cell paste	13.5%	10%–15.5%
Astaxanthin content in dry biomass	2.5%	2.1%–3.2%
Power consumption for centrifugation	3.0 kWh/kg biomass	2.5–3.5 kWh/kg
Oil consumption for spray drying	1.5 kg oil/kg biomass	1.2–1.5 kg/kg
Power consumption of cell pulverization	3.5 kWh/kg biomass	3.2–3.6 kWh/kg

Process development at pilot scales

- Strategies for process development at pilot scales
  - Site selection
  - Appropriate size of operation
  - Process modelling
  - Large scale outdoor photobioreactors

Designing a production facility

- Scale up of raceway ponds
    - Constant lamellar flow speed
    - Constant culture depth
    - pH
    - DO



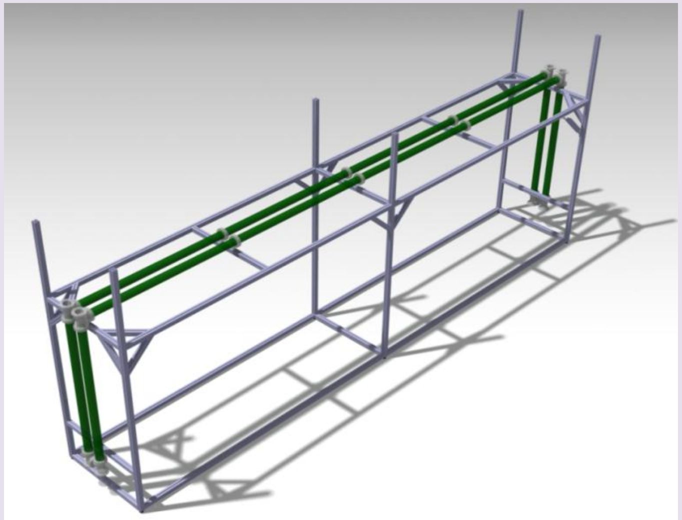
Professor William J. Oswald

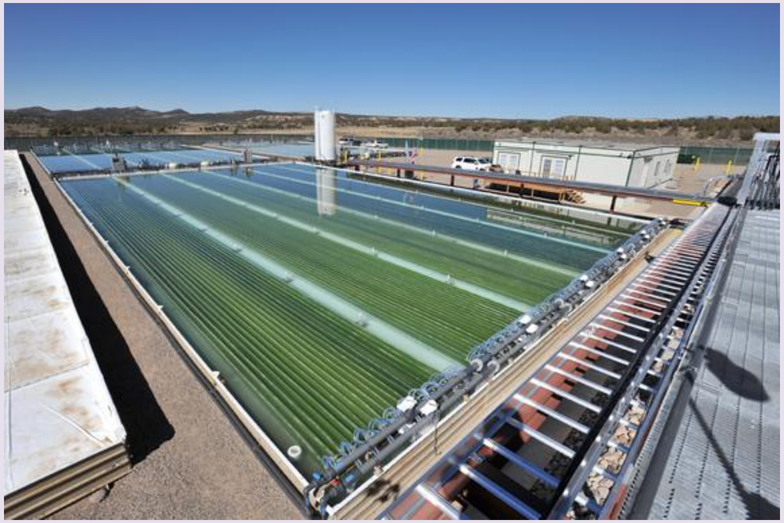
The reason that I could see so far is that I stood on the shoulders of giants.
Isaac Newton

Designing a production facility

Scale up of photobioreactor cultivation

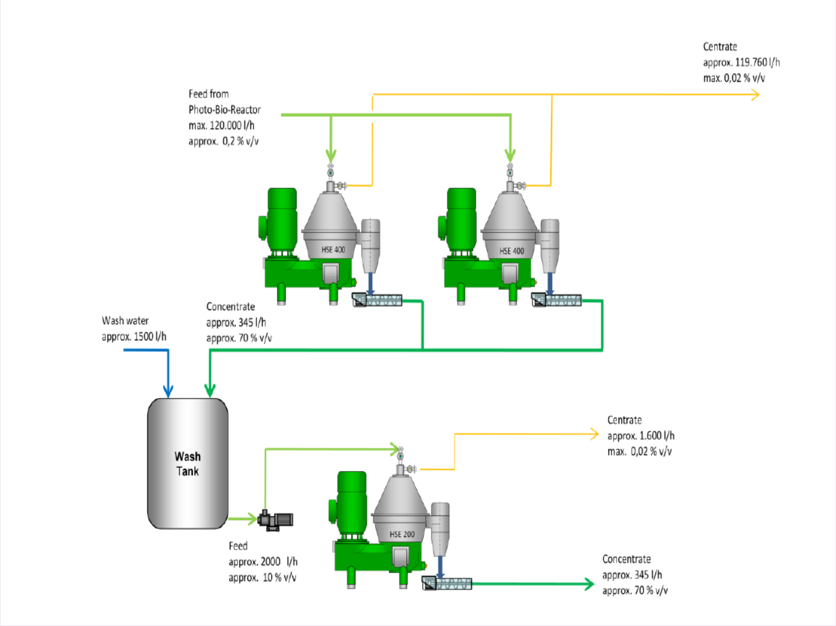
- Photobioreactors still in the forefront of innovation
- Scale up of an individual photobioreactor
- Multiplication of single photobioreactors





Designing a production facility

- Scale up downstream processing
    - Scale up of centrifuges
    - Scale up of dryers
    - Scale up of homogenizers
    - Scale up of pulverizers



Designing a production facility

- Cost analysis
  - Capital cost
  - Operational cost

Table 2
Summarization of fixed capital cost for the conceptually designed facility.

Items	Unit costs	Quantities	Units	Total cost ($)
1. Land acquisition and improvements	$12	25,000	m^2	$300,000
2. Building area	$300	500	m^2	$150,000
3. Laboratory instruments	$35,000	1	Set	$35,000
4. 8000 L bioreactor systems	$12,000	26	Set	$312,000
5. 1000 L bioreactor systems	$8,000	6	Set	$48,000
6. Medium supply station for bioreactors	$12,000	1	Set	$12,000
7. Low pressure air supply	$3,000	2	Set	$6,000
8. Raceway ponds	$12	20,000	m^2	$240,000
9. Harvest cell broth storage tank	$4,000	4	Units	$16,000
10. CO_2 storage tank	$40,000	1	Unit	$40,000
11. Centrifuge	$8,000	4	Units	$32,000
12. Dryer	$30,000	1	Unit	$30,000
13. Pulverizer	$60,000	1	Unit	$60,000
14. Air compressor and tubing	$2,500	1	Set	$2,500
15. Pumps, valves, piping and control	$10,000	1	Set	$10,000
16. Electrical	$25,000	1	Set	$25,000
17. Engineering and supervision	$50,000	1		$50,000
18. Construction expenses	$100,000	1		$100,000
Total fixed cost				US$1,468,500

Table 3
Summarization of operational costs for the conceptually designed facility.

Items	Unit costs	Quantities	Units	Total costs
1. Potassium nitrate	$500	15	Tons	$7,500
2. Disodium hydrogen phosphate	$800	3	Tons	$2,400
3. Sodium bicarbonate	$250	150	Tons	$37,500
4. Carbon dioxide	$200	170	Tons	$34,000
5. Other nutrients	$2,000	3	Tons	$6,000
6. Water and waste water treatment	$0.3	90,000	Tons	$27,000
7. Medium filters	$100	170	Pieces	$17,000
8. Air filters	$60	130	Pieces	$7,800
9. Other consumables	$8,000	1		$8,000
10. Power for bioreactor cooling	$0.15	270,000	kWh	$40,500
11. Power for low pressure air	$0.15	72,000	kWh	$10,800
12. Power for compressed air	$0.15	7500	kWh	$1,125
13. Power for pond paddling	$0.15	288,000	kWh	$43,200
14. Power for cell pulverization	$0.15	36,000	kWh	$5,400
15. Power for pumping	$0.15	43,200	kWh	$6,480
16. Oil consumption for the dryer	$1,000	48	Tons	$48,000
17. Labor	$5,000	19	People	$95,000
18. Supervision	$8,000	4	People	$32,000
19. Maintenance	$20,000			$20,000
20. General plant overheads	$50,000			$50,000
Total direct cost of production				US$499,705
Direct production cost of biomass				US$14
Direct production cost of astaxanthin				US$555
Depreciation of fixed capital cost (10 years)				US$146,850
Unit production cost of biomass				US$18
Unit production cost of astaxanthin				US$718
Depreciation of fixed capital cost (5 years)				US$293,700
Unit production cost of biomass				US$22
Unit production cost of astaxanthin				US$882

Production facility design – multidisciplinary team

- Bioprocess engineers
- Mechanical engineers
- Control engineers
- Electrical engineers
- Civil engineers
- Agricultural engineers

Conclusions

- Scale up is a serious of R&D activities to bring the laboratory results into large scale production.
- The first step of scale up is to build a pilot plant and develop production process at pilot scales.
- A conceptual production facility can be designed based on pilot process parameters and process scale up principles.
- Large scale production cost can be analysed based on the conceptual plant, and decision can be made whether to build the real plant or not.

Thank you for your attention!

And questions or comments?