Laboratory to commercial scale micro-algae culturing: success, failures and opportunities

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Scope

- Introduction
- Culturing
- Success stories
- Failures
- Conclusions

Introduction

- Context
  - no high value products considered
- Low cost potential uses of micro-algae
  - Sustainable wastewater treatment
  - Biomass production for renewable energy
- Challenges for micro-algal energy
  - Cost of production
  - Nutrients

N & P

- Redfield ratio
  - C:N:P
  - 106:16:1
- 100,000 barrel/year microalgal plant
  - 800 tonne P
  - 5000 tonne N

Anaerobic digestion & CH_4

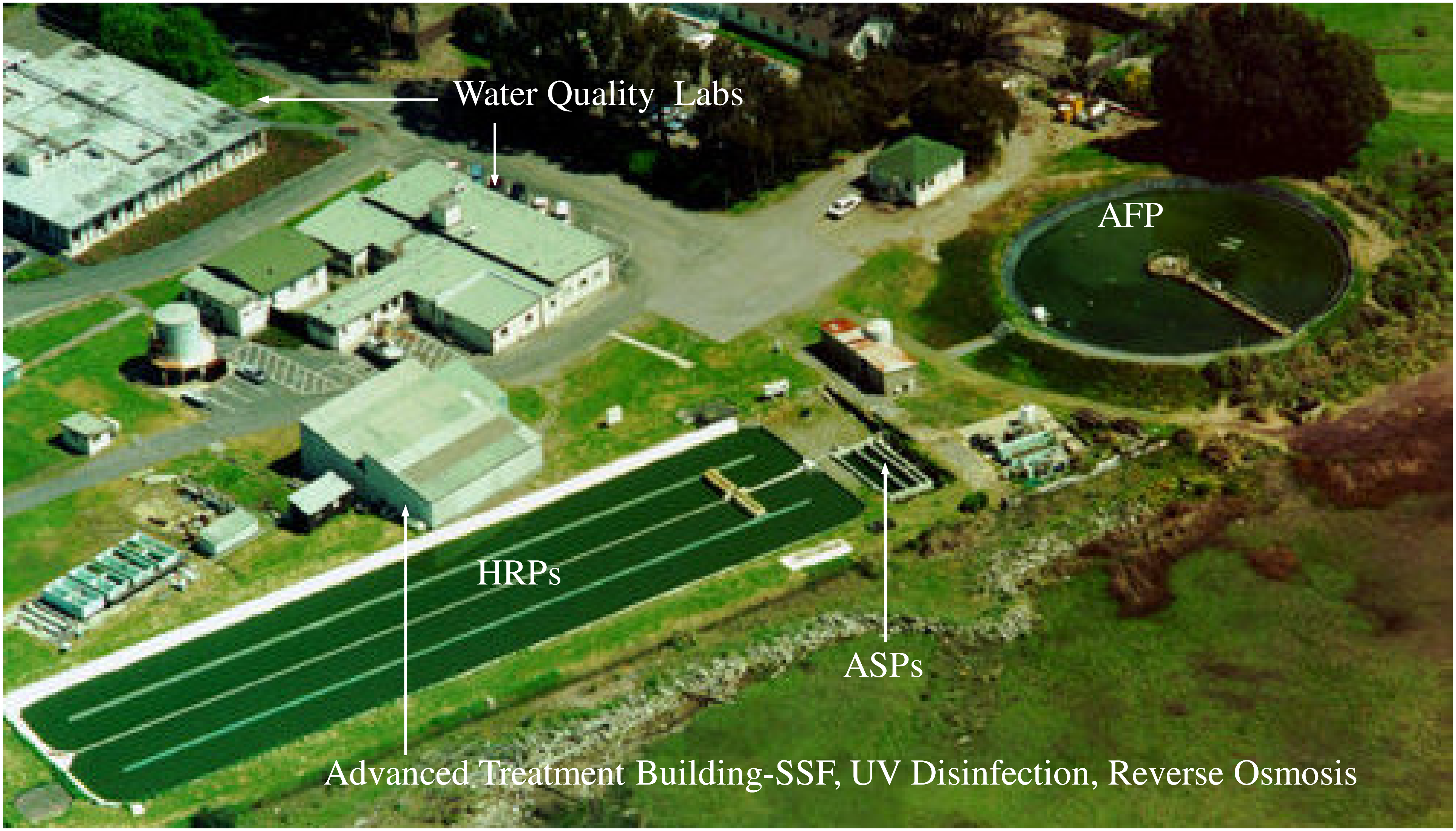
- Advantages
  - AD suitable for high-strength industrial wastes
  - Accepts high loading rates
  - AD can biodegrade xenobiotic compounds
    - Chlorinated aliphatic hydrocarbons, trichloroethylene, recalcitrant compounds including lignin

Anaerobic digestion & CH_4

- Disadvantages
  - Slower process that aerobic digestion
  - Sensitive to toxicants
  - Long start up period
  - Require high concentrations of primary substrates

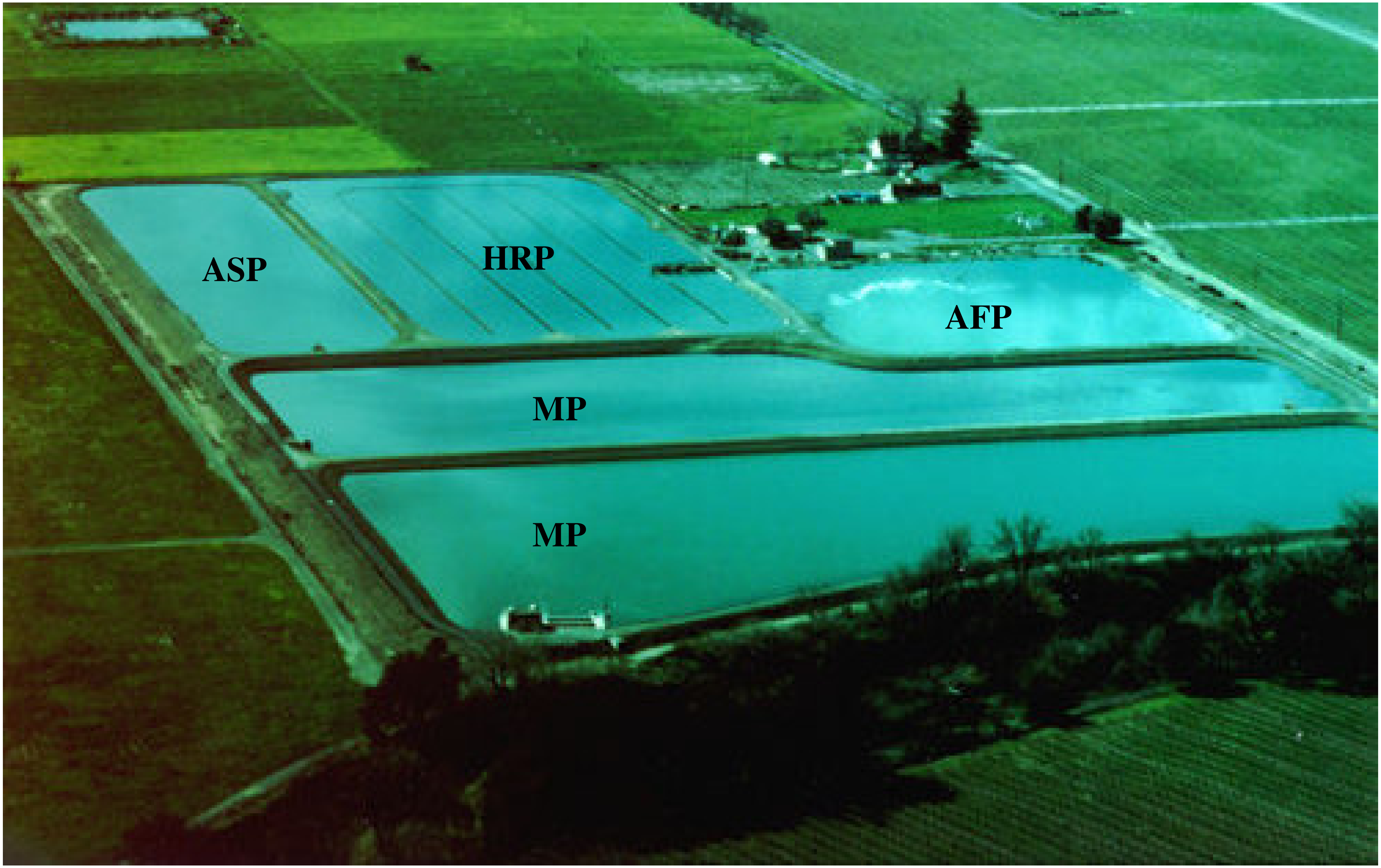
AIWPS® TECHNOLOGY COMPONENTS

- Headworks (screening, grit removal, flow measurement, flow distribution)
- In-Pond Digesters (IPDs)
- Advanced Facultative Ponds (AFPs)
- Algal High Rate Ponds (HRPs)
- Algae Settling Ponds (ASPs)
- Maturation Ponds (MPs)
- Algae Drying Beds (ADBs)
- Downstream Tertiary Processes



Pilot-Scale AIWPS® WWTP

UC Berkeley's Engineering Field Station
in Richmond, California

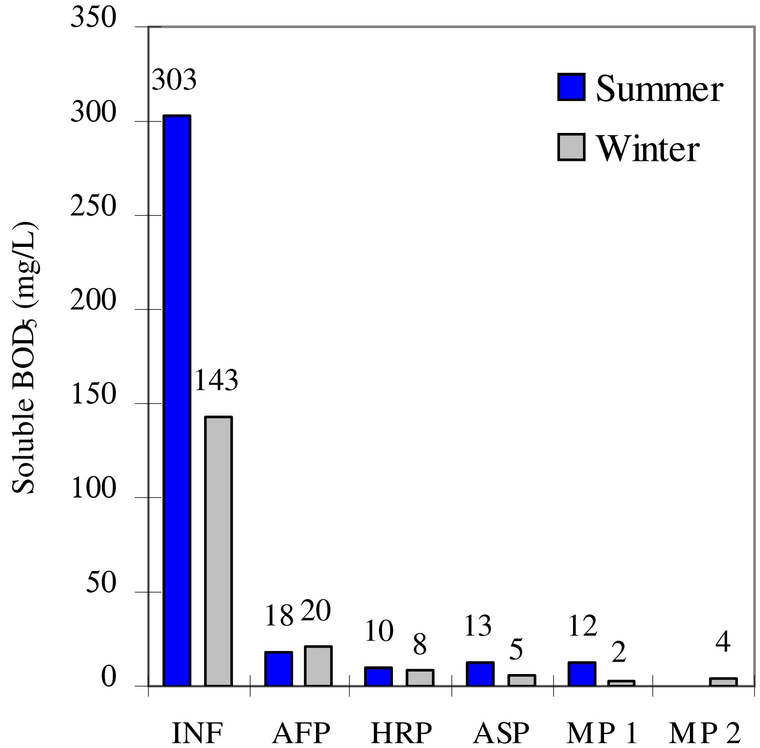


City of St. Helena AIWPS® WWTP c. 1967

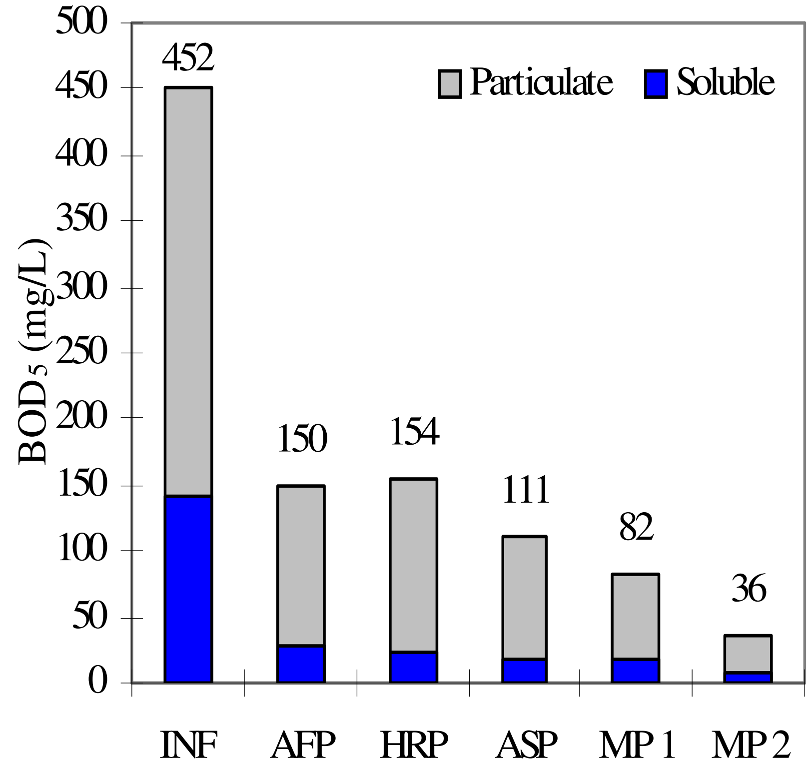
Environmental Quality

- Highest Effluent Quality of all WWT Processes at Least Cost
- No Odors
- No Sludge
- Safe Water Reuse for Agriculture and Aquaculture
- Safe Nutrient Recycle through Algal Biomass used as a Animal or Fish Feed or Fertilizer
- Enhanced Work Place Safety & Aesthetics
- Compatible with Parks & Urban Greenbelts

Mean BOD Removal by AIWPS® Process

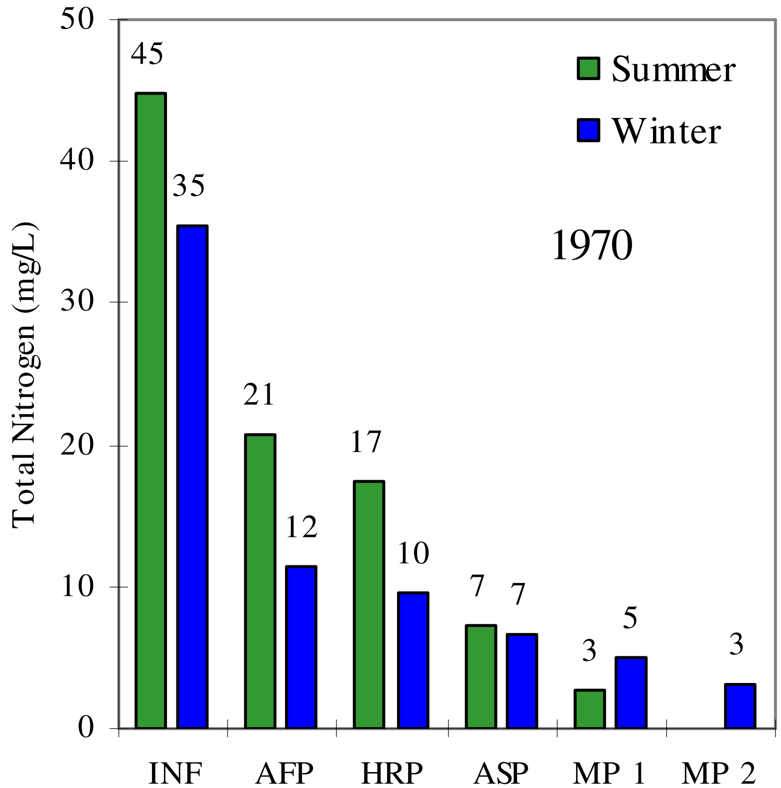


St. Helena AIWPS® Facility
(Meron, 1971)

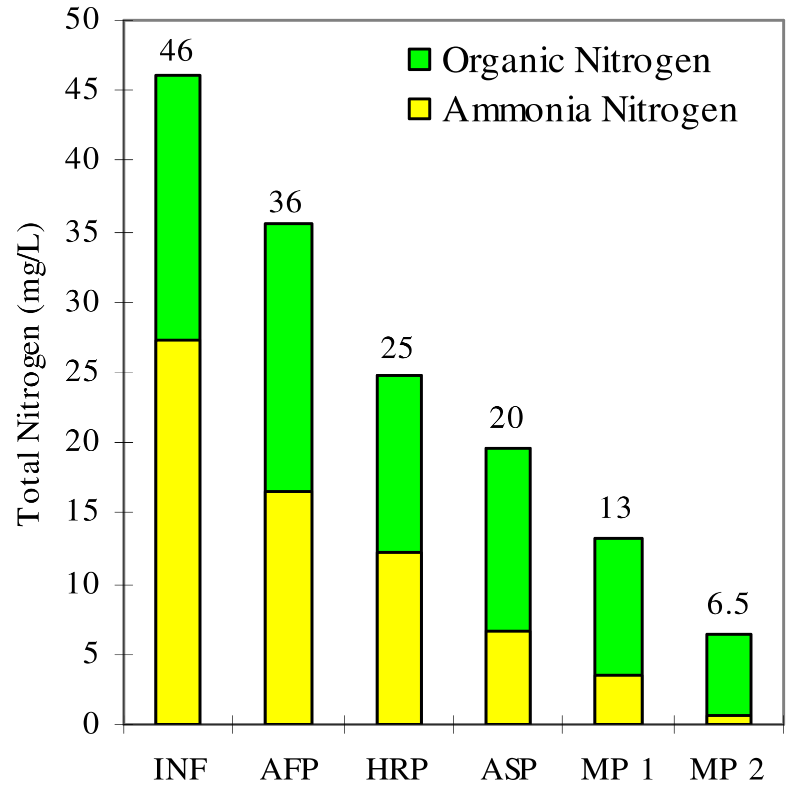


St. Helena AIWPS® Facility
(U.S. EPA, 1996)

Mean Total Nitrogen Removal

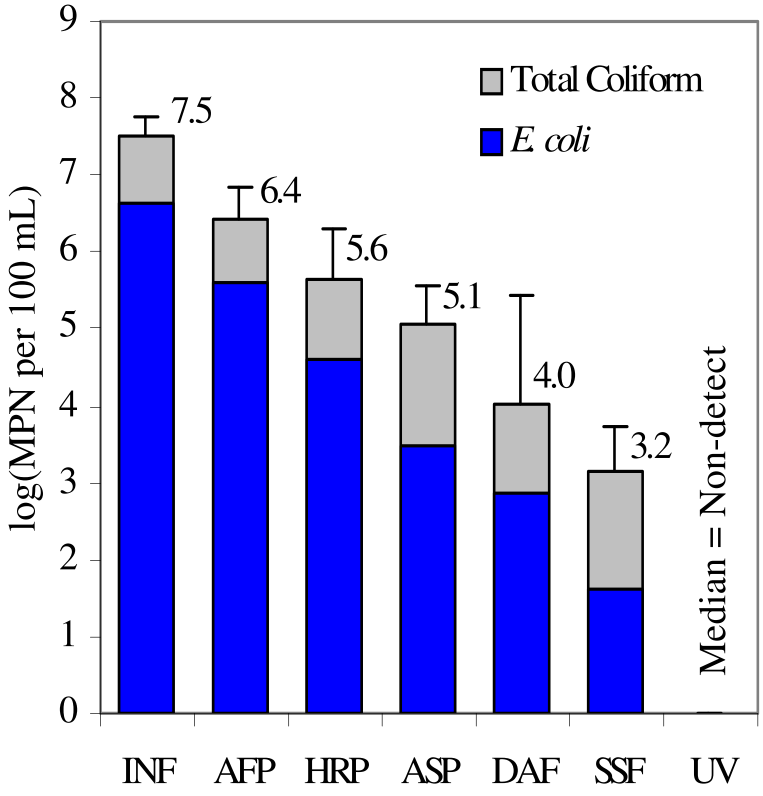


St. Helena 1970
(Meron Dissertation)

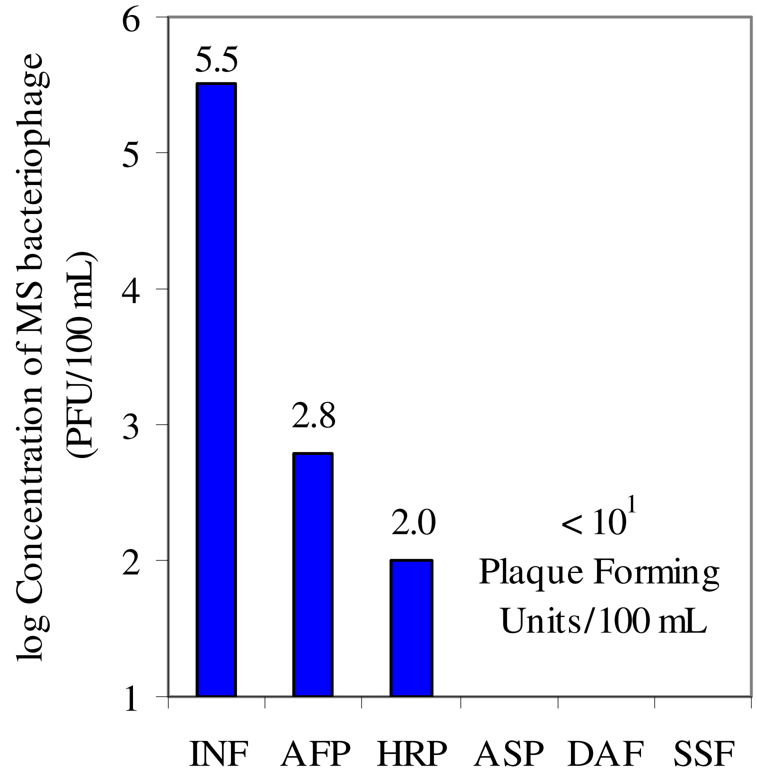


St. Helena 1996
(U.S. EPA)

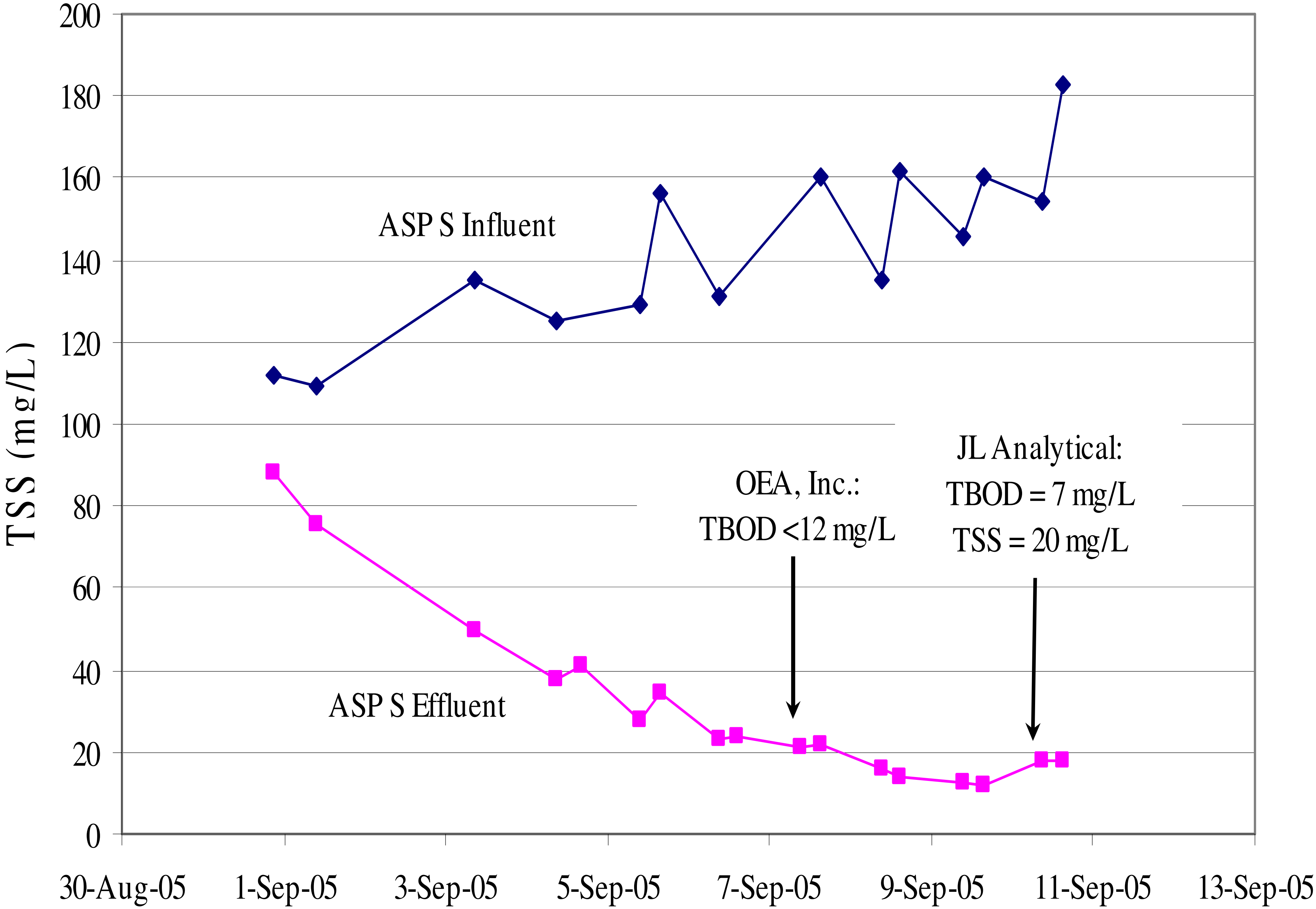
Pathogen Removal



Total coliform
Richmond 1998-1999

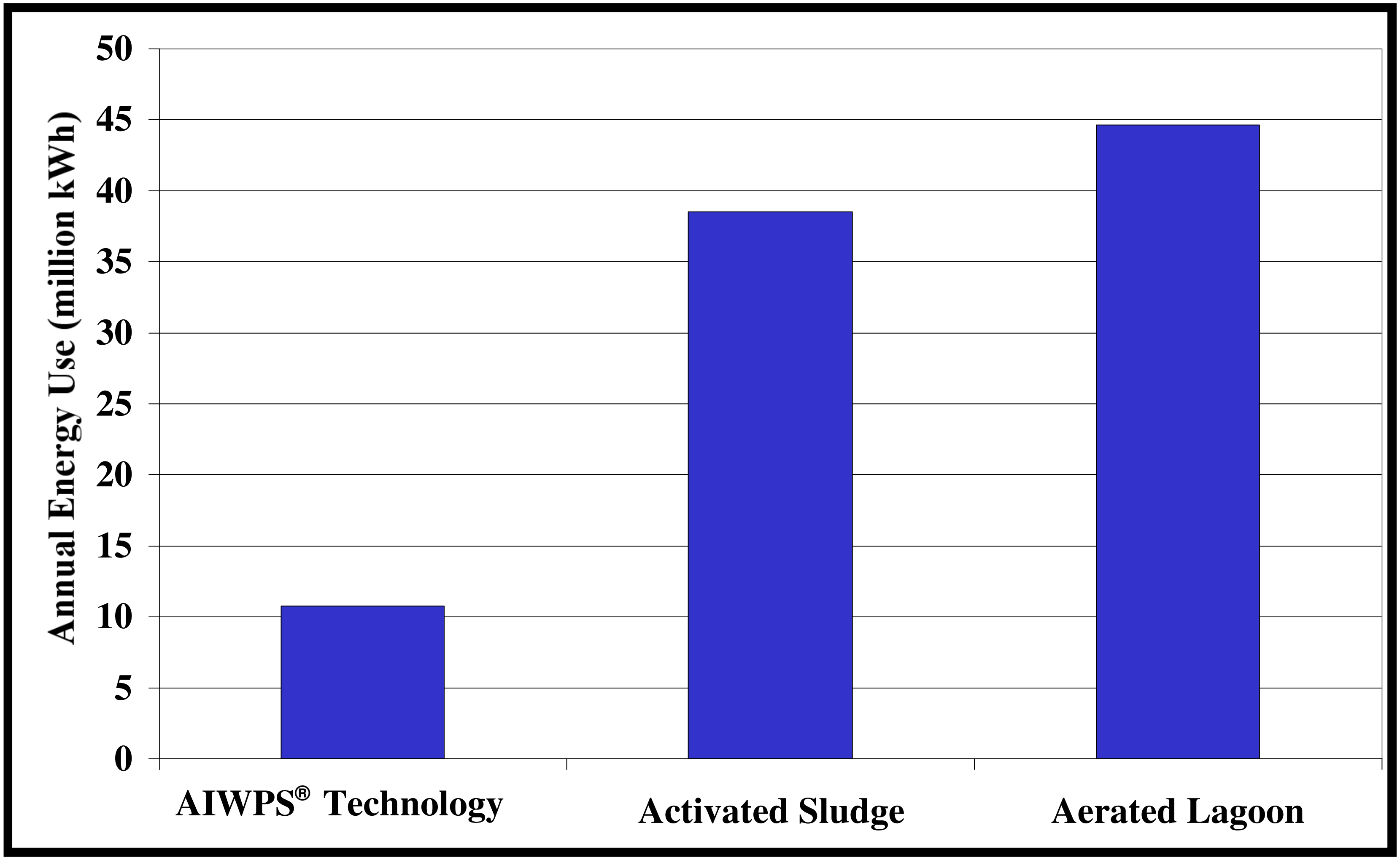


Indicator Virus
Richmond June 1999



200
180
160
140
120
100
80
60
40
20
0
TSS (mg/L)
ASP S Influent
ASP S Effluent
OEA, Inc.:
TBOD <12 mg/L
JL Analytical:
TBOD = 7 mg/L
TSS = 20 mg/L
30-Aug-05
1-Sep-05
3-Sep-05
5-Sep-05
7-Sep-05
9-Sep-05
11-Sep-05
13-Sep-05

Comparative Energy Use



Scale – oil from algae

- Dilute cultures (0.5 – 1.0 g_{AFDW}/L)
- Large surface areas required (100's hectares)
- Extremely low cost product (~$1/kg lipid)
- Massive-scale production
- Technically feasible for decades[2]
- No commercial fully integrated plant in operation[3]

[2] Burlew, J. S. (1953). Algal Culture: From Laboratory to Pilot Plant, (Publication No. 600) DC Carnegie Institution of Washington
[3] Hu, Q., Sommerfeld, M., Jarvis, E., Ghirardi, M., Posewitz, M., Seibert, M. and Darzins, A. (2008). Microalgaltriacylglycerols as feedstocks for biofuel production: perspectives and advances. Plant Journal, 54(4), 621-639

Laboratory scale

- Suitable for initial screening
- Biological systems very difficult to scale up (or down)
- Don’t assume productivities etc are reproducible at scale
- Know you product and species before choosing the right system*

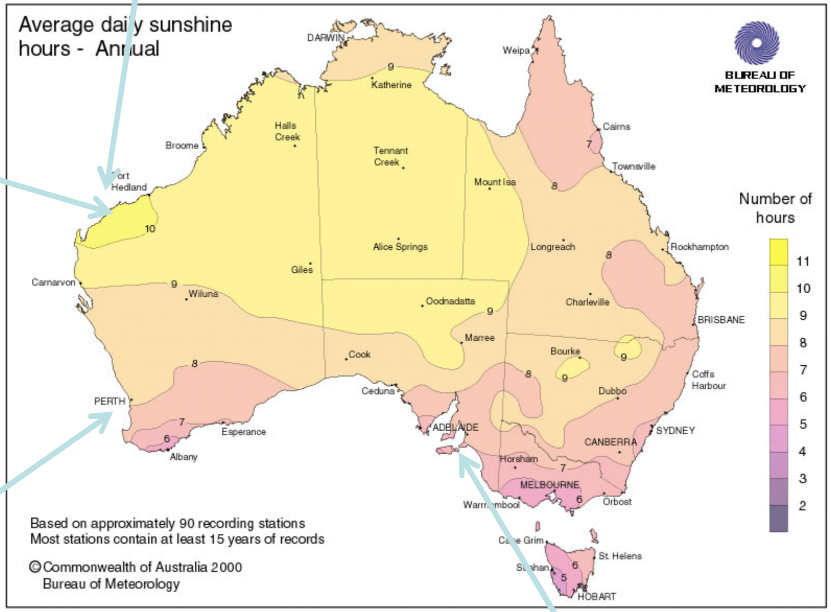
*M.A. Borowitzka(1999) Commercial production of microalgae: ponds, tanks, tubes and fermenters. Journal of Biotechnology

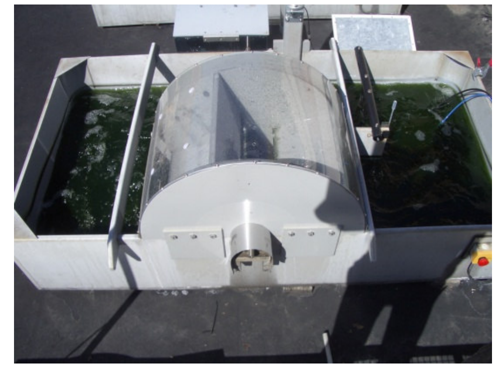
Commercial processes

Species	**Used for**	**Where grown**	**Main culture system(s)**	**Estimated cost of production ($AUS.kg^{-1})**
Chlorella spp	Health food, health food extracts	Japan, Indonesia, Germany	Open circular pivot ponds, raceway ponds. Tubular photobioreactors (Germany only)	15+
Spirulina spp	Health food, health food extracts	Japan, Taiwan, Thailand, USA,China, India	Raceway ponds	8-12
Dunaliella salina	β-carotene	Australia, India	Extensive open ponds, raceway ponds (in India)	8+
Haematococcus pluvialis	astaxanthin	USA, Israel	Raceway ponds (USA), closed photobioreactor (Israel)	40+ (photobioreactor)
Crypthecodinium cohnii	DHA	USA	Heterotrophic cultivation on glucose	~2
Chaetoceros spp. *Nannochloropsis* spp. *Navicula* spp. *Tetraselmis* spp. *Pavlova* sp. etc.	Feed for aquaculture species	Throughout the world	Raceway ponds, tanks, large bag reactors	80-2000

Similar latitude and geography as Walvis Bay!!

Karratha - Site for fully integrated pilot plant: 3 x200m^{2}raceway ponds commission date July 2010



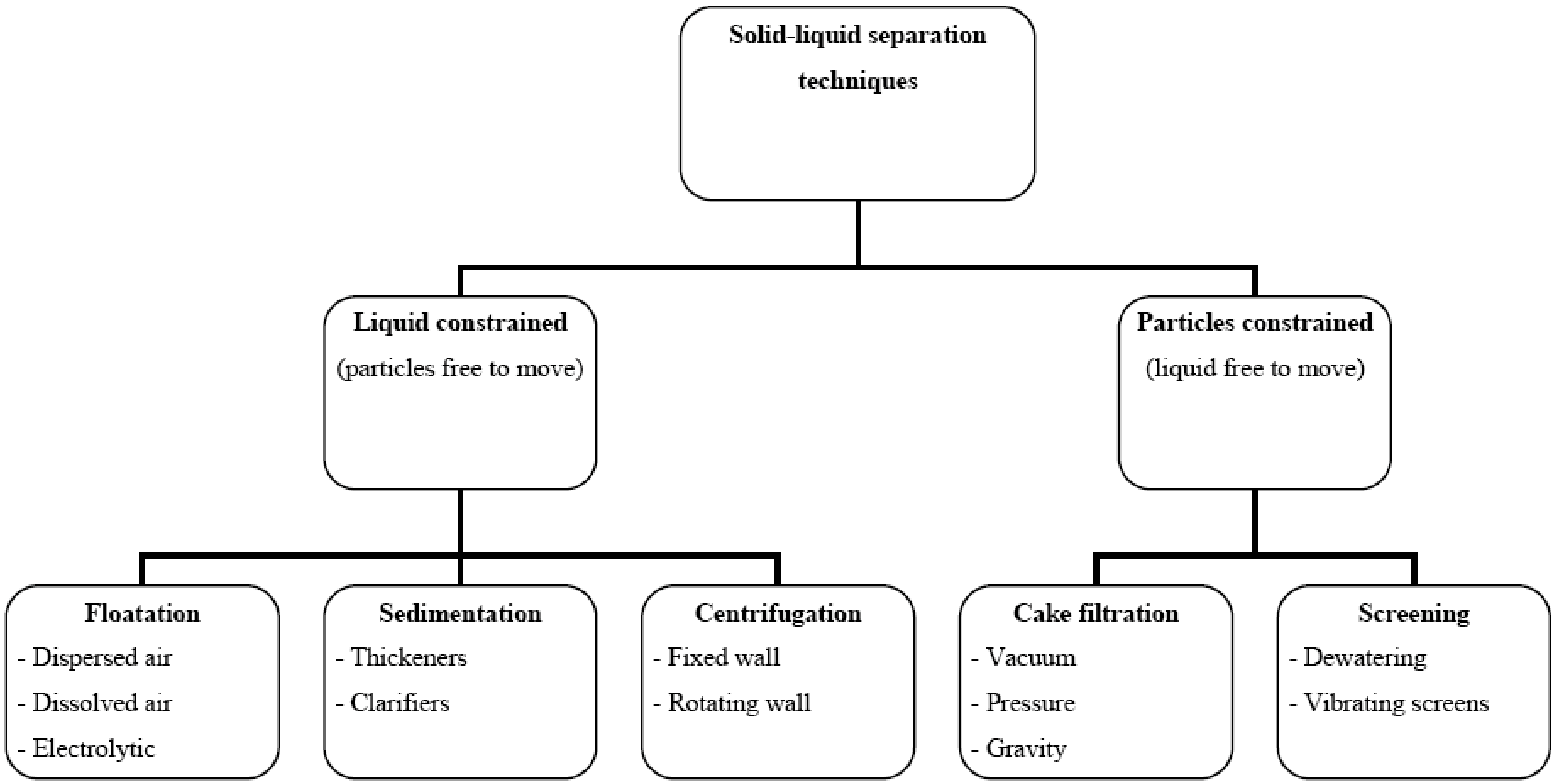


Murdoch University Algae R&D Centre

OUR PROJECT

University of Adelaide Microalgal Engineering Research Group

Harvesting options
no silver bullet!



Harvesting – system under development

- Liquid constrained
  - 0.050 kWh.m^{-3} ($0.01/L lipid [7c/kWh]) 0.05-1 to 1-2% solids
  - t_d ~30 minutes
- Developing combined harvesting + extraction unit operation

Failures

- Greenfuels – primary reason is they used closed photo-bioreactors reactors for a low value product - fuel!
  - Mass transfer – excessive O_2 limits growth!
  - Excessive capital and operational costs
  - Contamination issues – closed reactors are inherently difficult to maintain axenic conditions
  - Heat – PBRs get very hot in direct sunlight

Conclusions

- AIWPS sustainable wastewater treatment
- Can produce methane and recycle N & P from harvested biomass
- Oil rich algae can be grown in open saline water ponds
- Large scale algal farming will create jobs and renewable energy
- Sustainable - reduce CO_2 footprints
- Scalable (once you are out of the lab!)
- “Horses for courses” what process is suitable for one algal species might be unsuitable for another

Thankyou

- Larry
- ACP
- Pat & Jeff
- Sorry for not being present!


Adelaide AUSTRALIA Welcomes
8th Asia Pacific Conference
on Algal Biotechnology
July 2012
‘Challenges and opportunities for microalgae
and seaweed in the Asia Pacific region’