Large Scale Production of Microalgae for Biofuels

Dr. Bryan Willson

Co-Founder & Chief Technology Officer

Solix Biofuels

June 28, 2009

3 Points:

- Solix is the leading developer of production systems for algae-based biofuels – with a background in fuels and a focus on low-cost, high productivity production technology
- Solix's cost trajectory shows that fuel production from algae can be cost-competitive with petroleum – but requires full value extraction from the production co-products
- Solix will soon demonstrate the world's largest closed photobioreactor for biofuel production.

Outline

Solix / Algae Intro

- Open Pond Overview
- Closed Photobioreactor Overview
- Solix AGS System
- Harvesting & Extraction
- Scaleup
- Production Costs
- Conclusions

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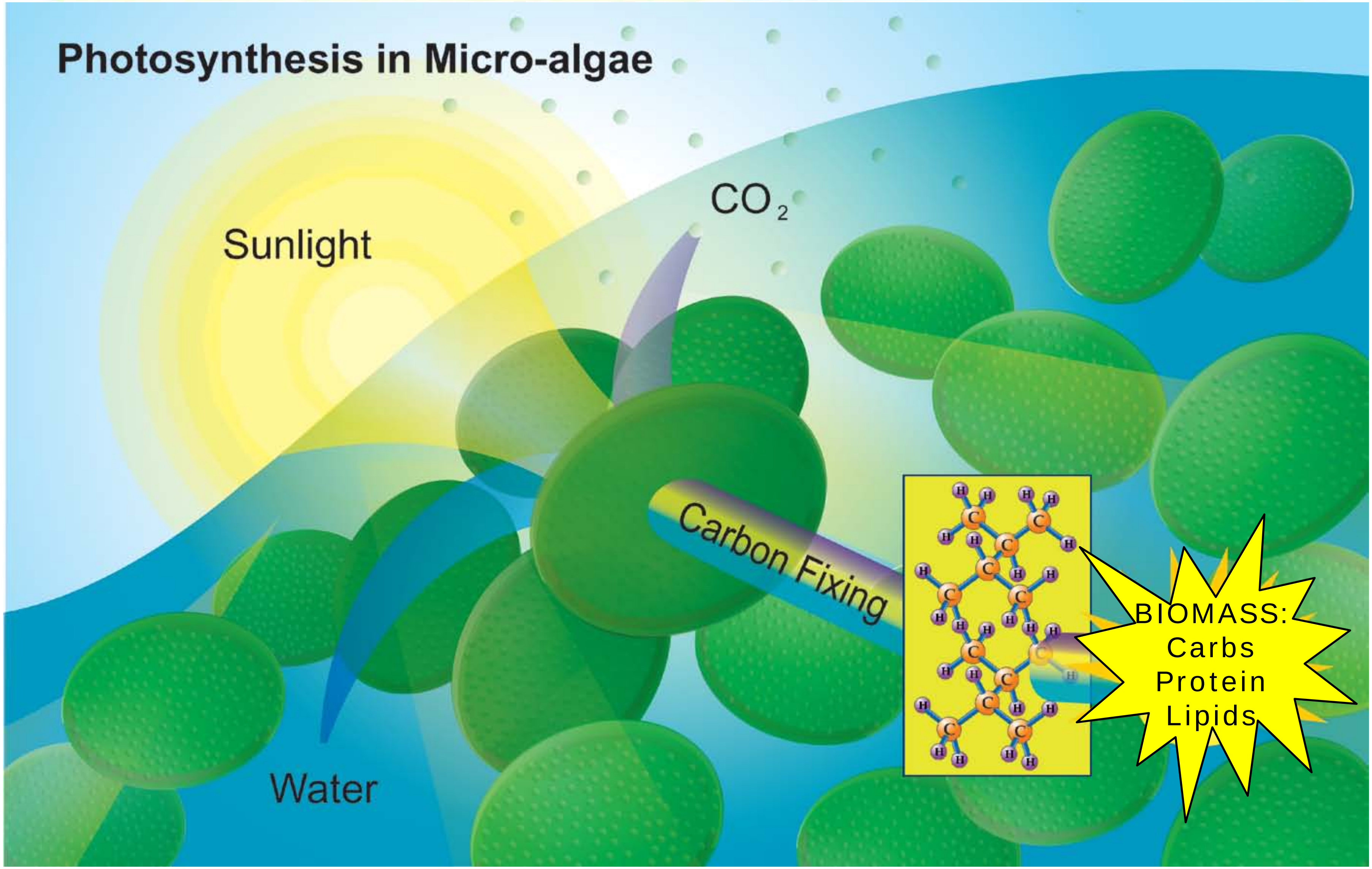
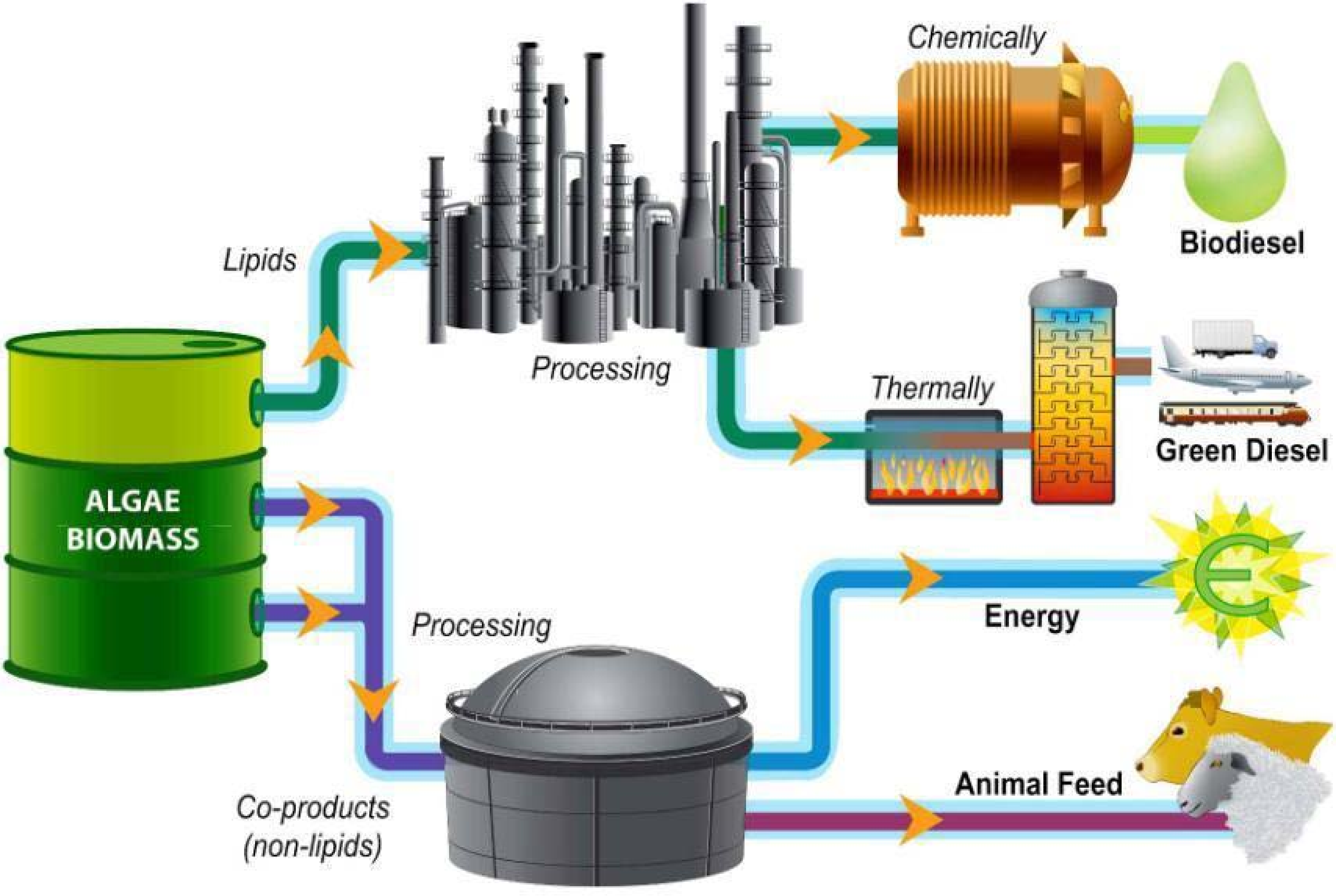
About Solix

- Focused on the development and commercialization of large-scale algae-to-biofuels systems
- Launched in March, 2006
- Located in Fort Collins, Colorado
- Privately funded
- 50+ employees: 40 full-time + 15 FTE from students / faculty
- Headquartered at CSU Engines & Energy Conversion Laboratory
- Solix facilities
  - 6,000 ft^2 office space, 18,000 ft^2 lab / fab space
  - Outdoor R&D facility in Fort Collins
  - Scaleup facility being constructed in SW Colorado
- Significant strategic partners in industry, science and engineering

Basic Photosynthesis



Processing

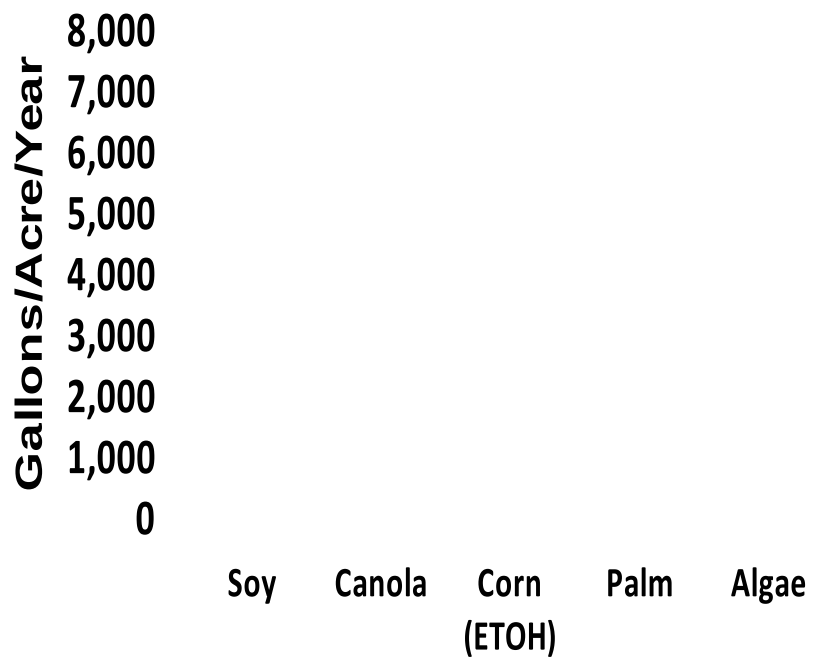


Chemically
Biodiesel
Lipids
Processing
Thermally
Green Diesel
ALGAE
BIOMASS
Energy
Processing
Animal Feed
Co-products
(non-lipids)

Land & Water Efficiency

Annual Production

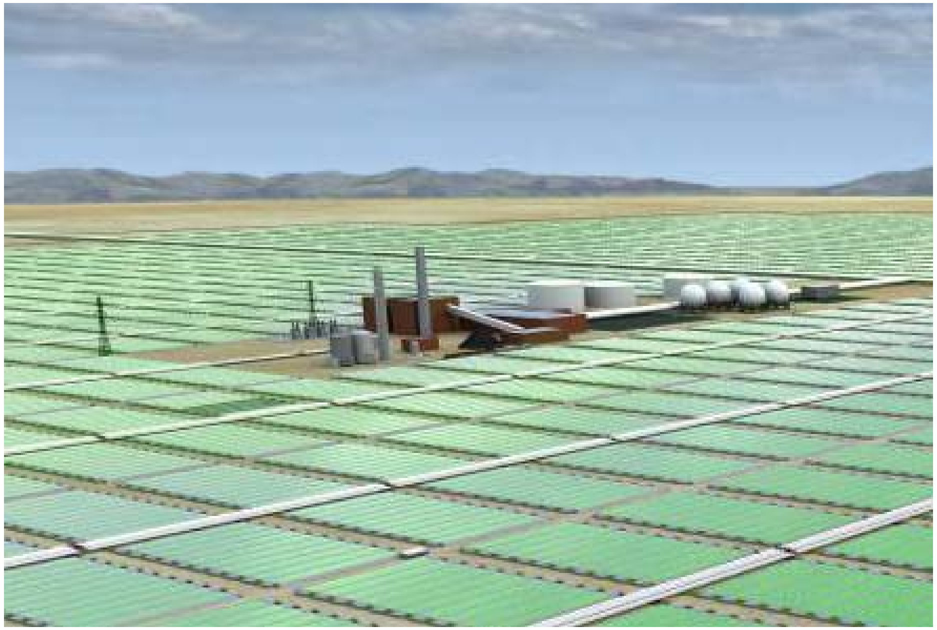
- Soybean: 40 to 50 gal/acre
- Rapeseed: 110-145 gal/acre
- Mustard: 140 gal/acre
- Jatropha: 175 gal/acre
- Palm oil: 650 gal/acre
- Algae est.: 5,000-10,000 gal/acre
  7,000 “nominal”



Realism

Ya gotta dream. . .

But you also gotta obey the laws of physics. . .



"We expect to produce 100,000 gallons (of vegetable oil) per acre per year," which is a much higher yield than soybeans and other plants being used for biofuel…"

Motivation

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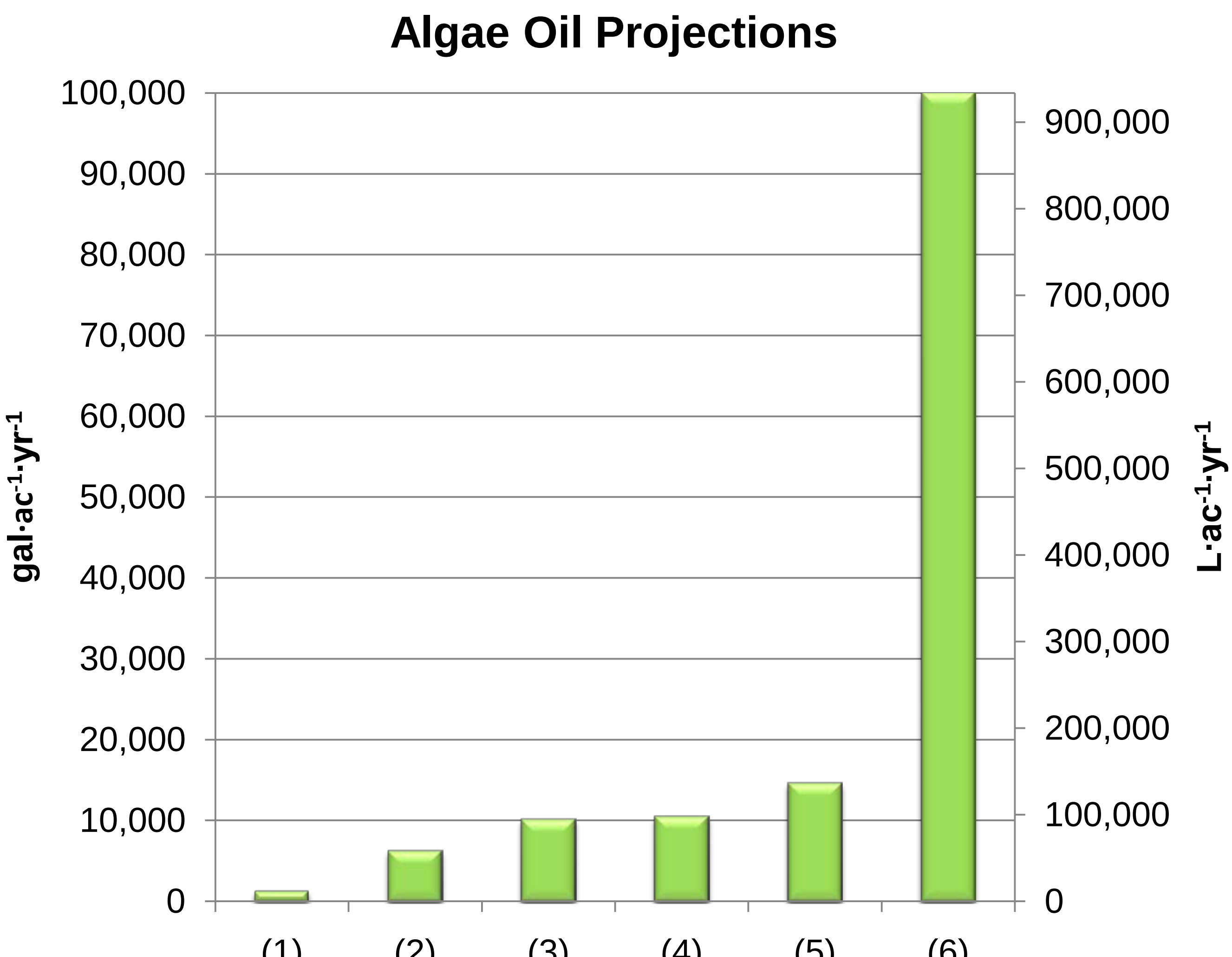
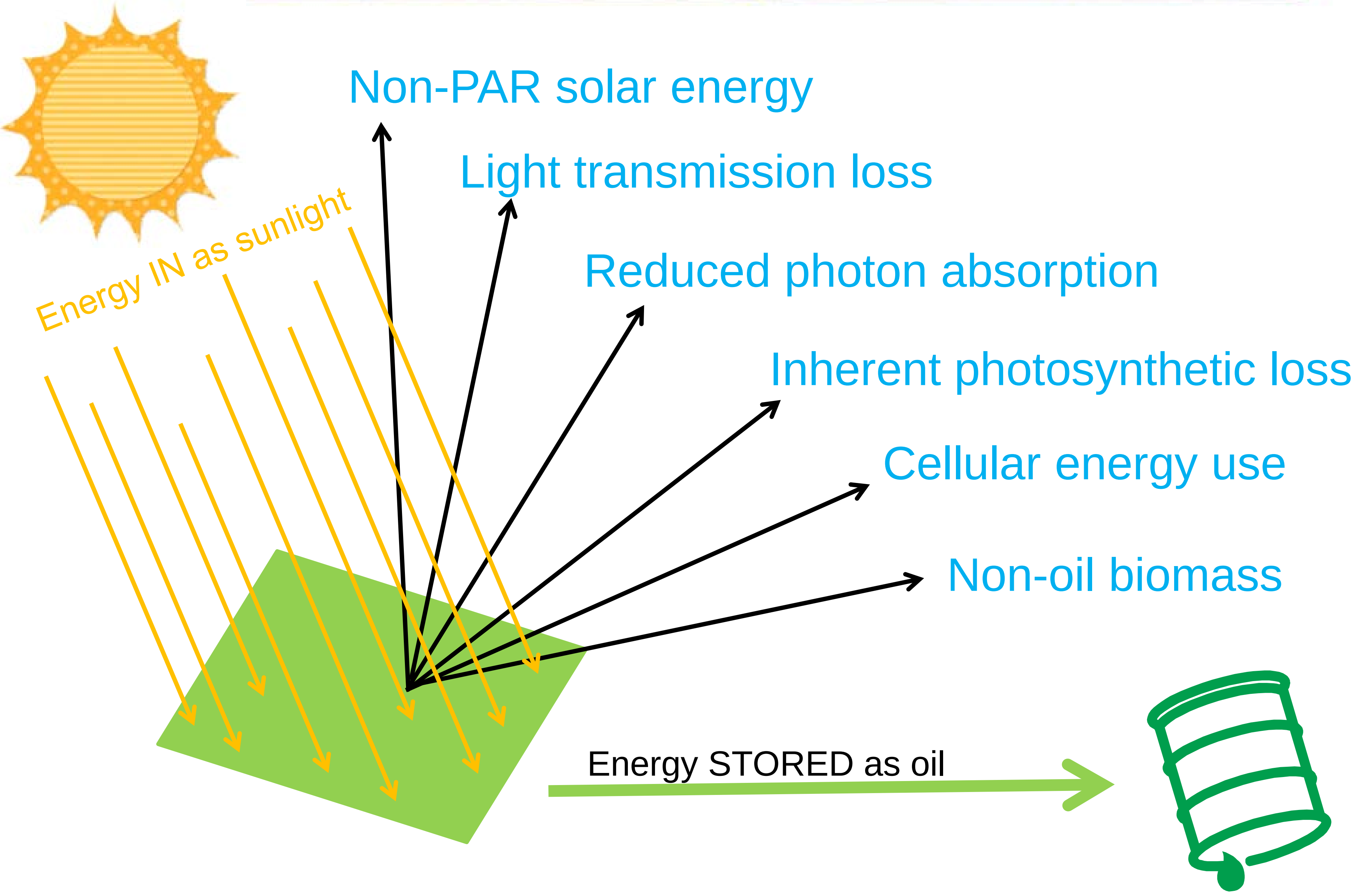


(1) Schenk, 2008
(2) Chisti, 2007
(3) NREL ASP, Sheehan et al., 1998
(4) Schenk, 2008
(5) Chisti, 2007
(6) Report on CNN, Apr 4, 2008

Wide range of projections…

What is the ultimate upper limit?

Method


Non-PAR solar energy
Light transmission loss
Reduced photon absorption
Inherent photosynthetic loss
Cellular energy use
Non-oil biomass
Energy IN as sunlight
Energy STORED as oil

Practical Case: Results

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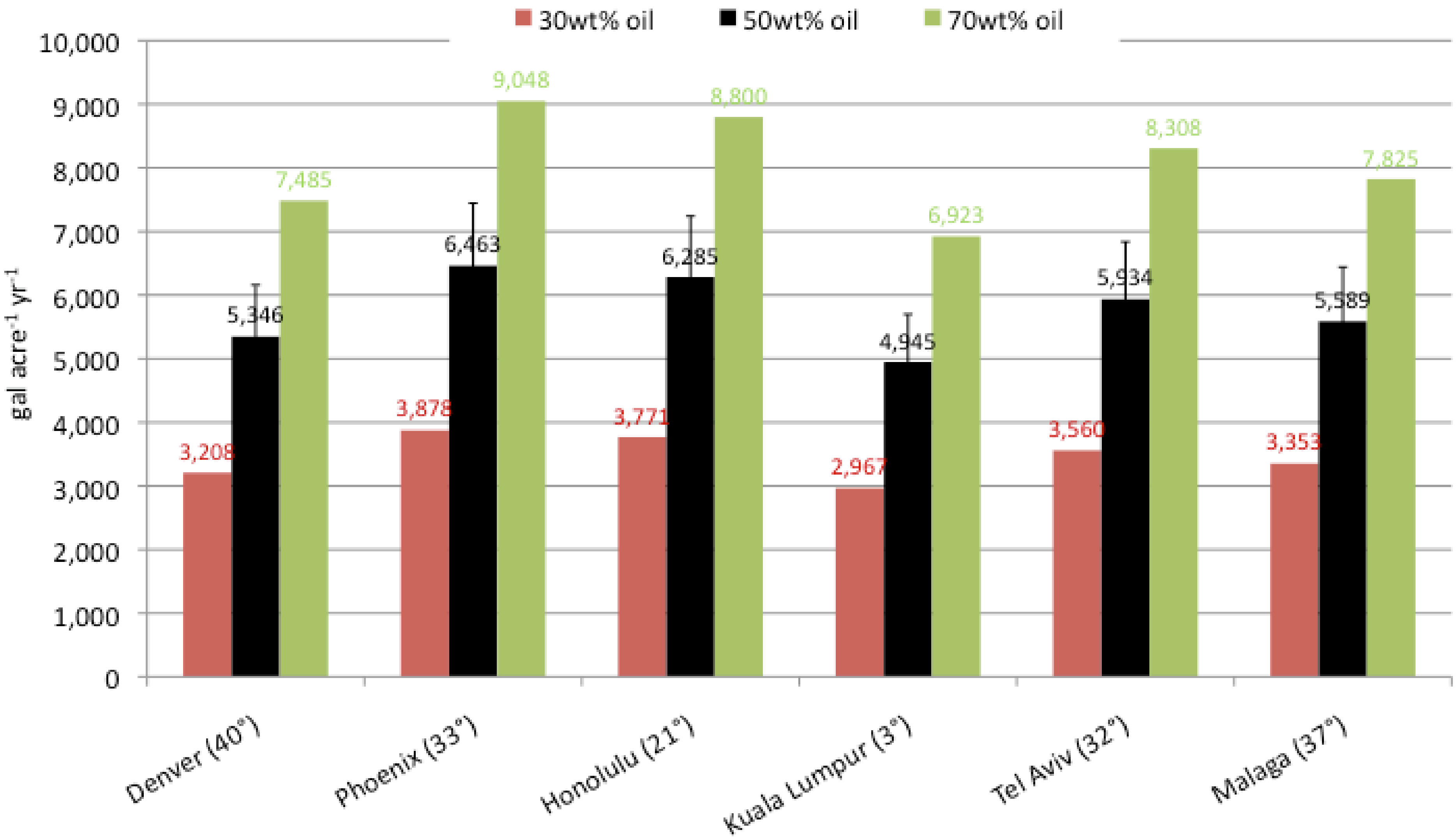
Practical Maximum Range: 4,900 – 6,500 gal·acre^{-1}·yr^{-1}



Conclusions

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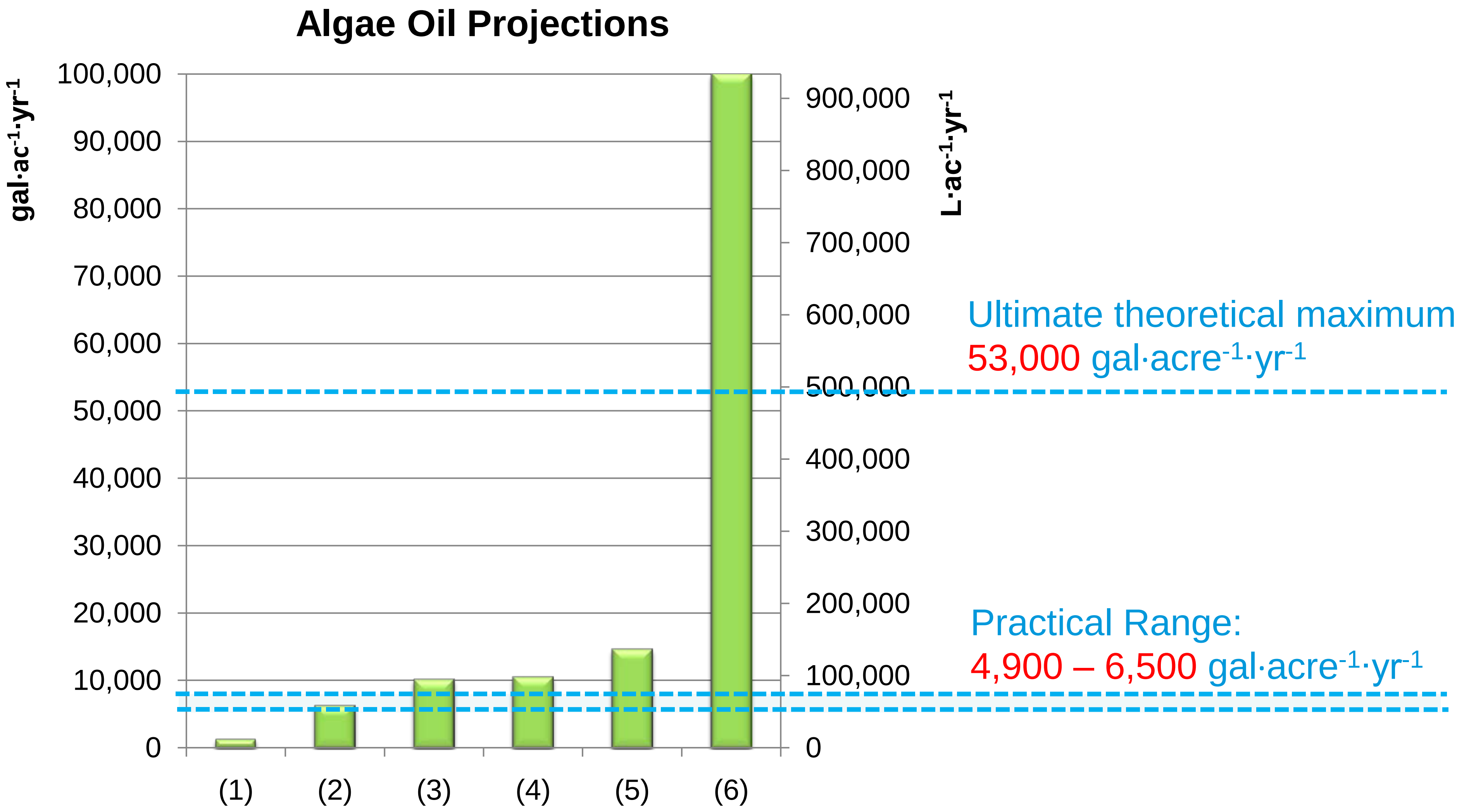
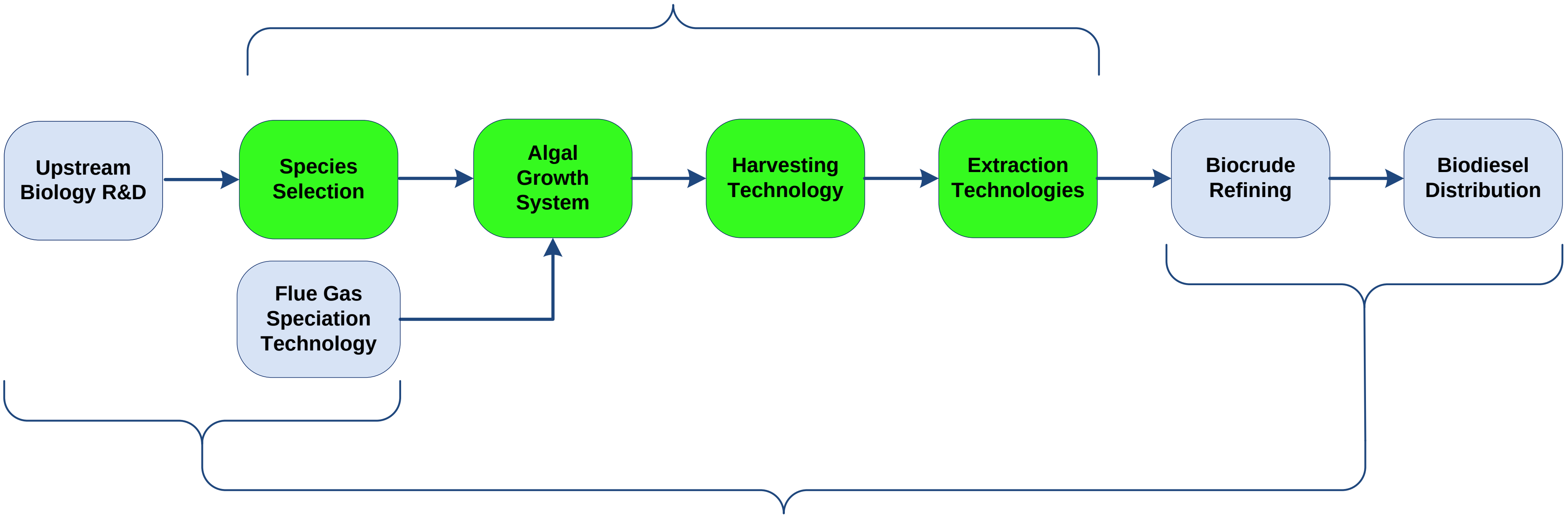


Solix Focus Area



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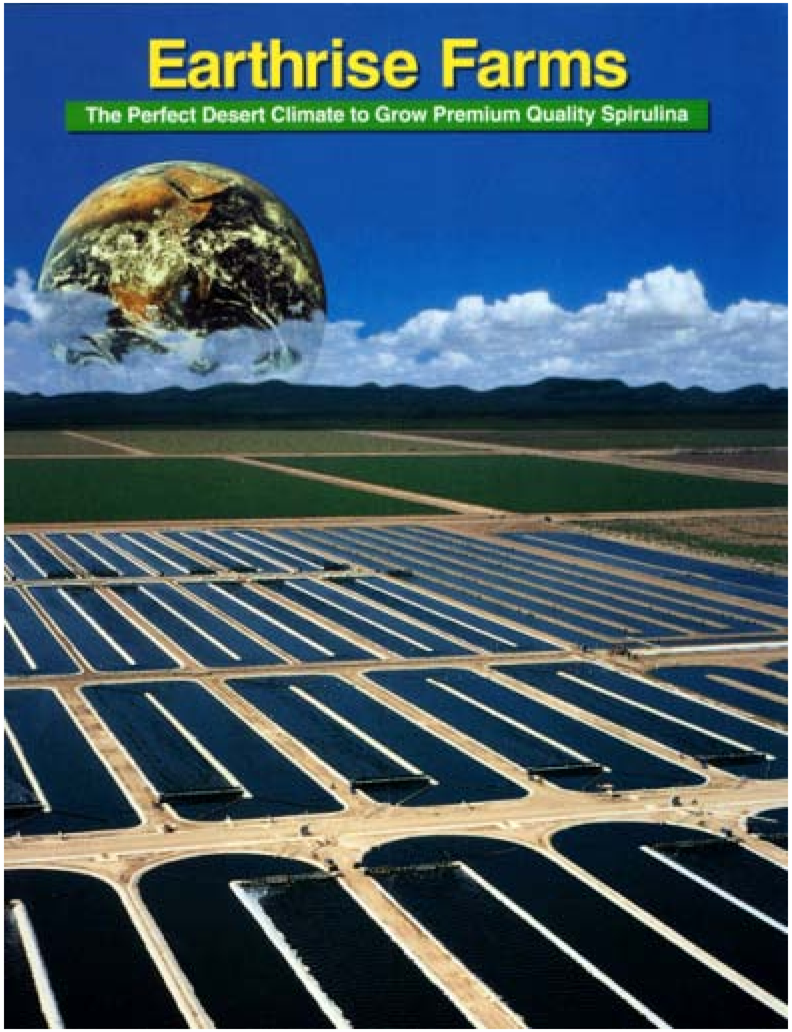
Open Pond Cultivation: Dunaliella, Eilat, Israel

Open Pond Production: Earthrise *Spirulina*. California



Open Pond Production: Seambiotic *Nanno*. Ashkelon, Israel

Open Pond Attributes

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Advantages

- Lowest capital cost
- Only technology demonstrated at large scale – to date
- Can maintain specific cultures of extremophiles

Disadvantages

- Allows contamination of specific culture with local species / strains
- Potential for loss / migration of GMO
- Susceptible to weather
- Water loss from evaporation / percolation

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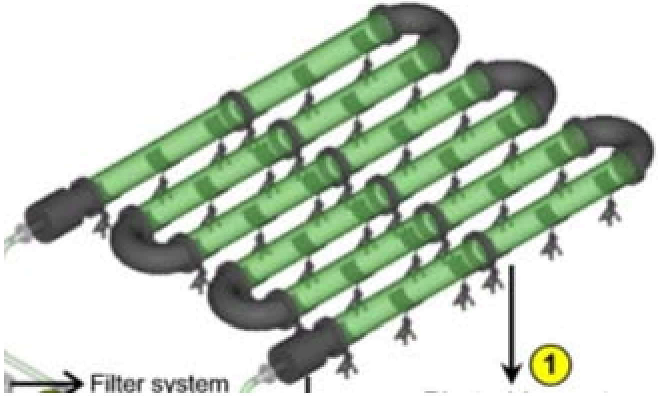
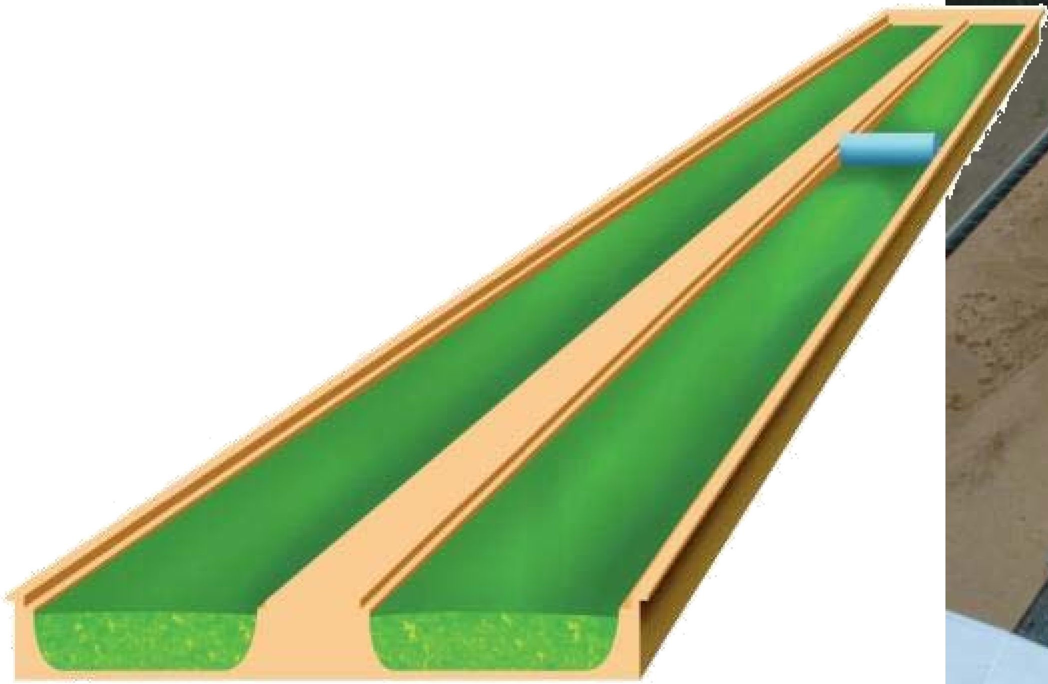
Direct Light PBRs: GreenFuels, 1st Gen

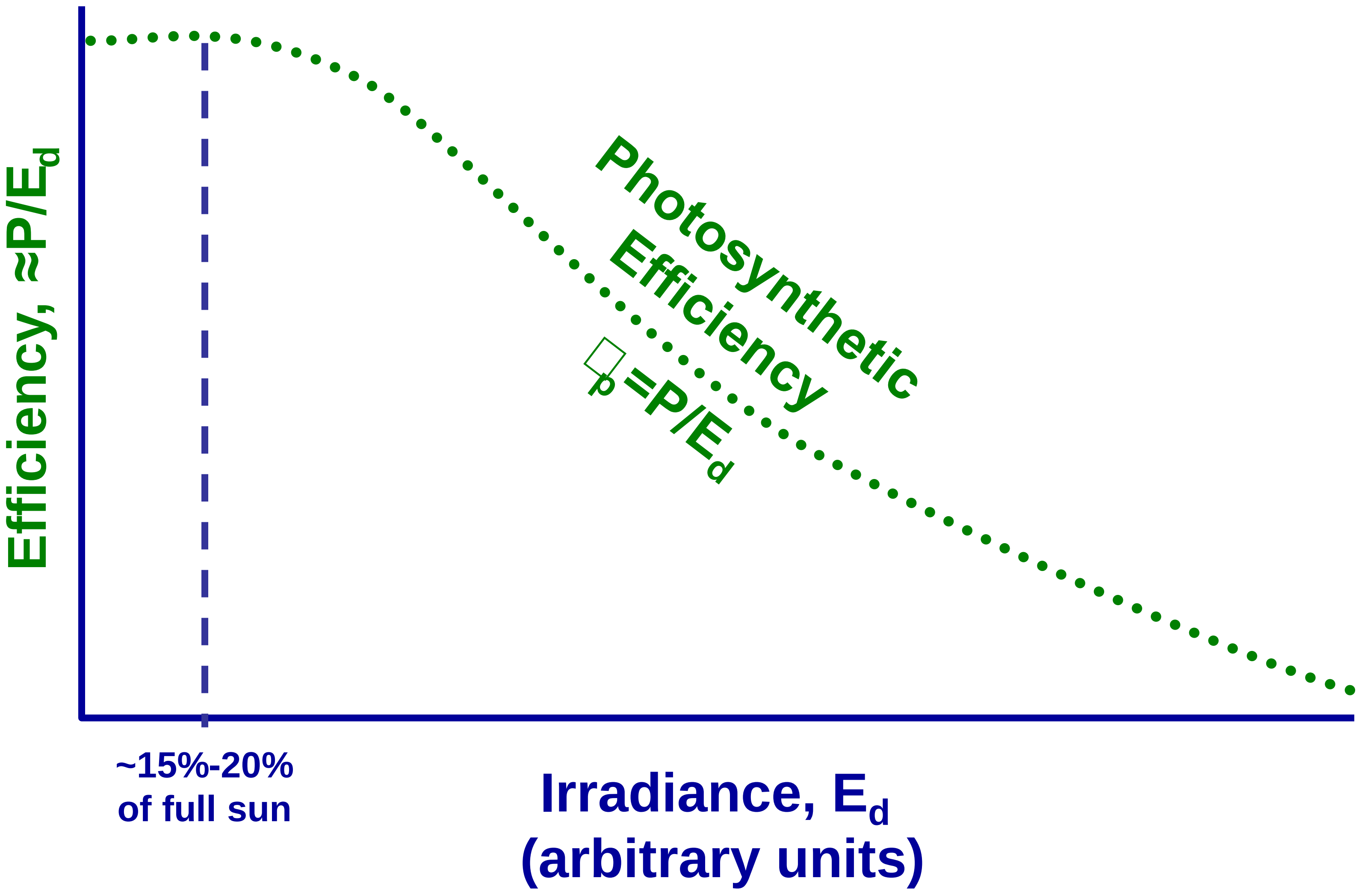
Direct Light PBRs:
AlgaeLink / Bioking



Direct Light PBRs:
Solix, Gen1 (1st Generation)

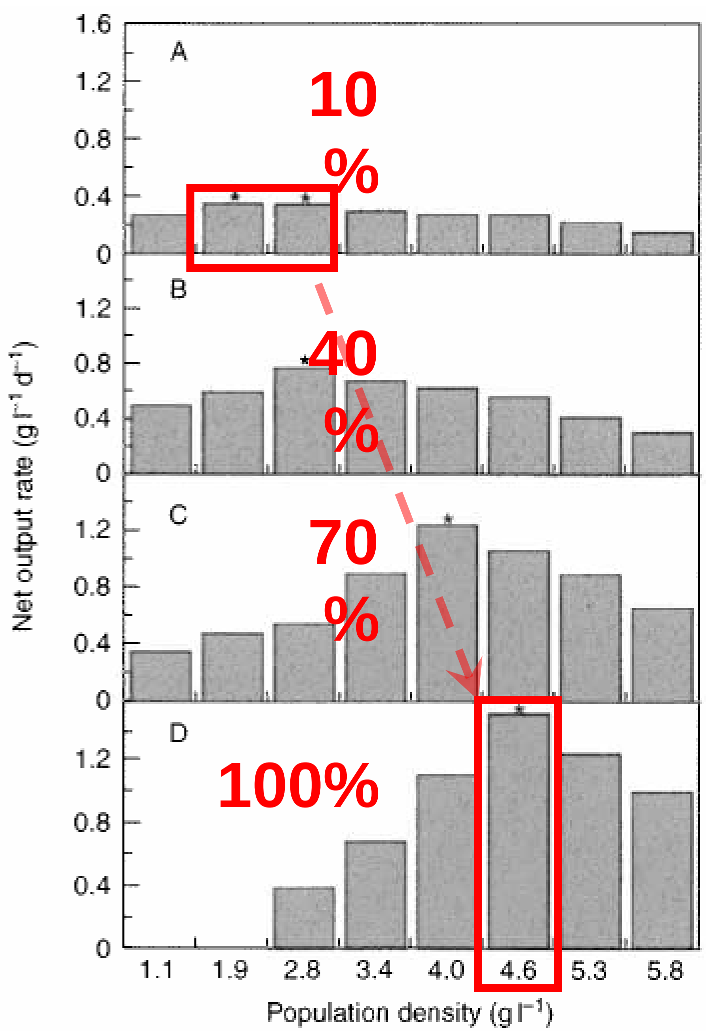


Photosynthetic Efficiency



Impact of Light Intensity

SOLIX



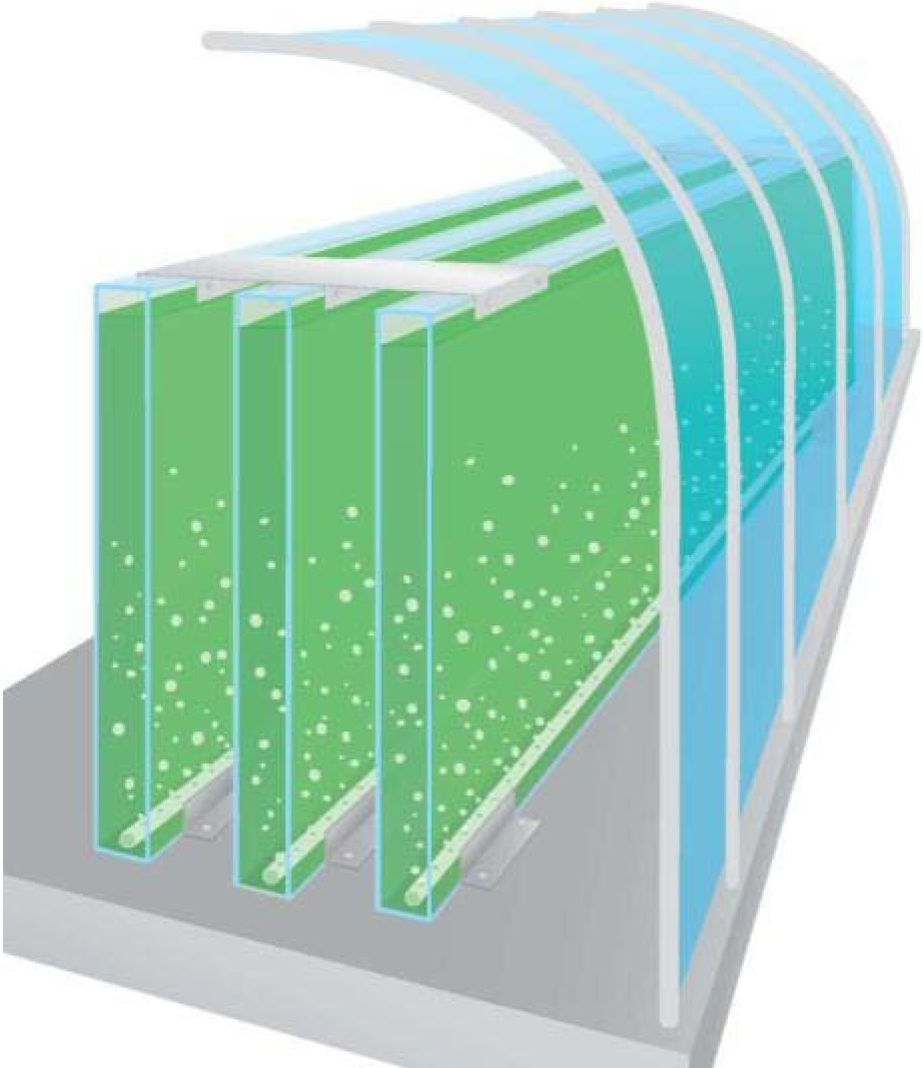
*Optimal population density

Fig. 8.3. Interrelationships between incident PFD, optimal population density and net output rate. A = 90% shade; B = 60% shade; C = 30% shade; D = no shade, full sunlight (from Hu & Richmond, 1994). Reprinted with permission from Kluwer Academic Publishers (*J. Appl. Phycol.*).

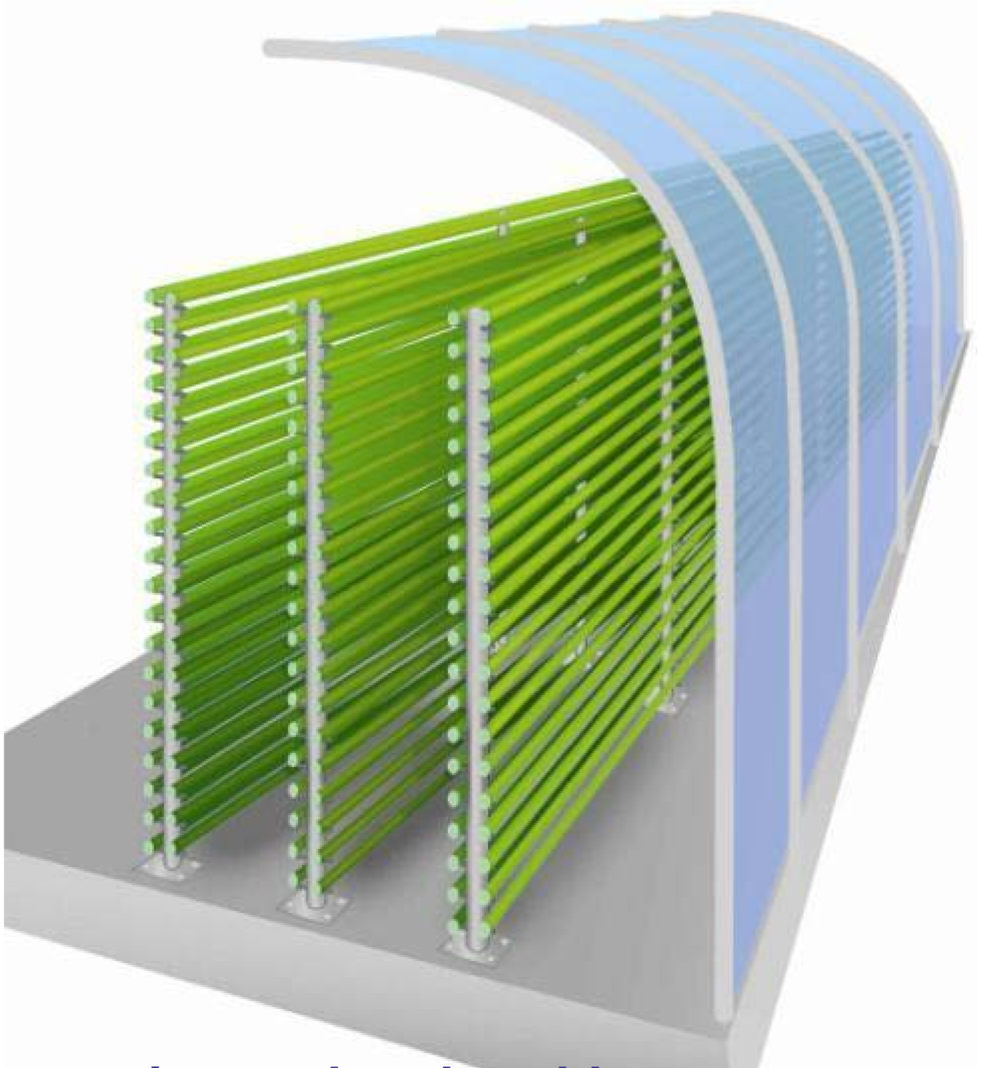
Note: 10X increase in light, but only 3.5X increase in output. Implies a 3X reduction in photosynthetic efficiency.

Conversely, if diffuse light can be used over extended surface area, 3X increase in output possible.

Extended Area PBRs

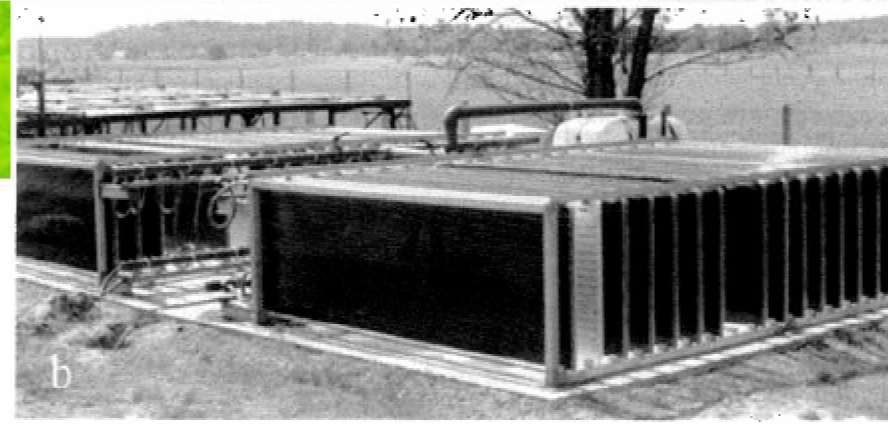


Glass Plate Photobioreactor
(Pulz, Richmond, others)

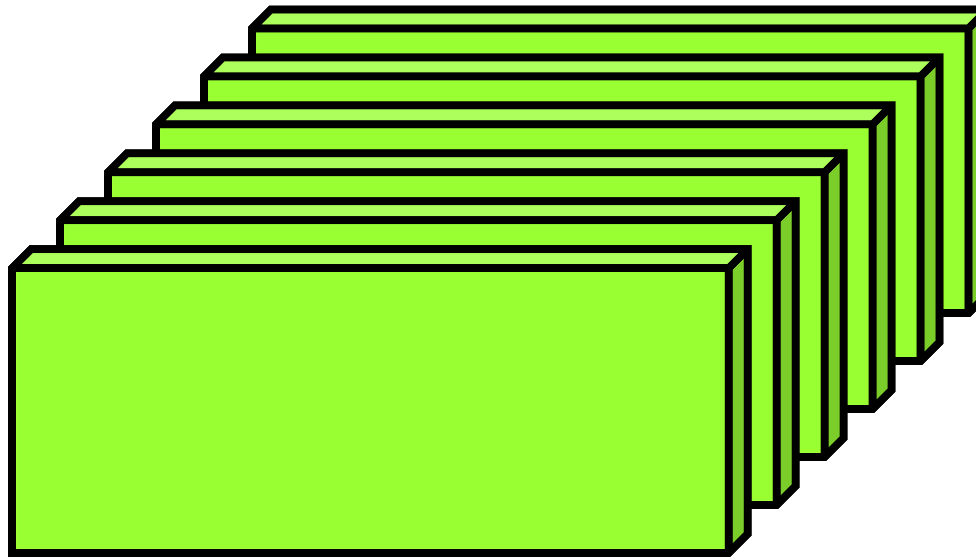


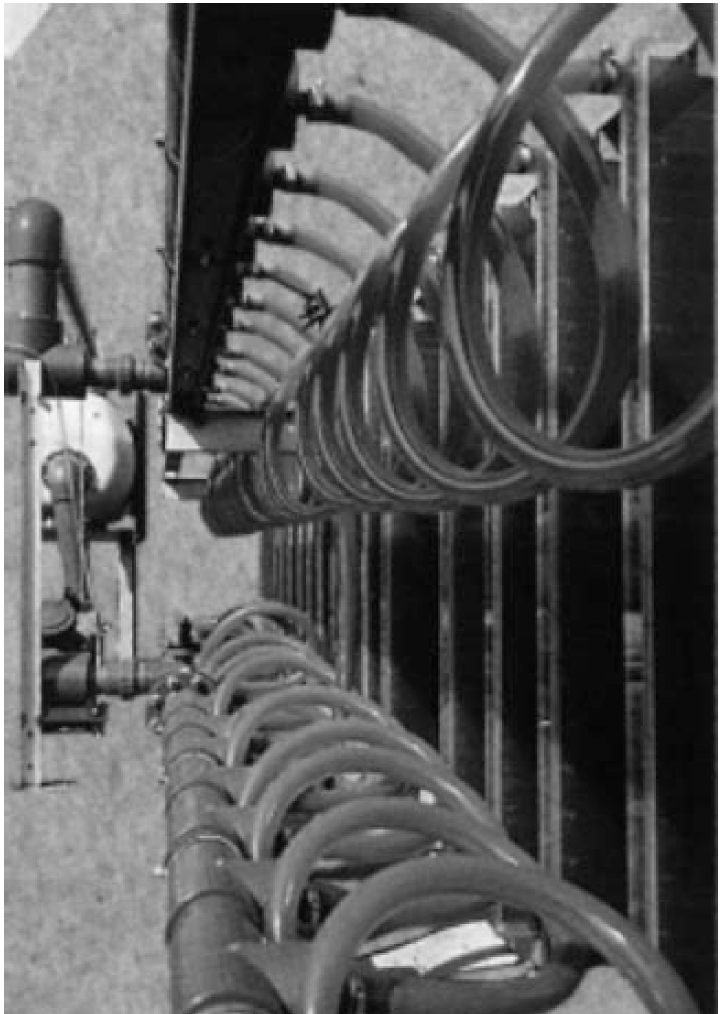
Glass Tube Photobioreactor
(Pulz, IGV, Ketura, Torzillo, others)

IGV Diffuse PBR



≈5 m² illuminated area for 1 m² of ground area





Utilizes diffuse light, short photic distances (approaches ideal cycle time of 20 ms) for high photosynthetic efficiency

Figure 8. Meandering plate cultivator 100 to 6000 L. IGV Institut für Getreideverarbreitung.

Pumped Tubewall PBR: IGV
Haematococcus Pluvialis

Figure 4: The cultivation in the PBR 4000 from 21.04.2006 to 21.05.2006 with sunlight and no artificial light

Pumped Tubewall PBR: AlgaTech *Haematococcus Pluvialis*

High-Growth Phase

Stress Phase

Closed PBR Attributes

Advantages

- Allow growth of specific cultures
- Allows environmental control
- Potential for much higher growth rates (with extended surface area and/or high turbulence)

Disadvantages

- Potential for high capital cost
- Potential for high energy costs
- Low-cost production has not been demonstrated

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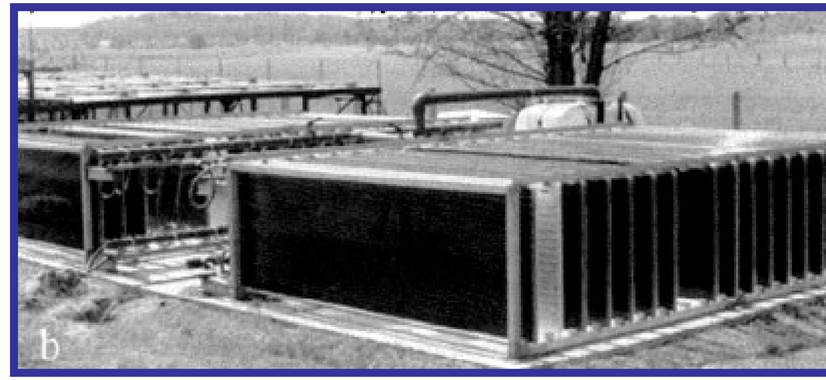
Cost vs. Productivity

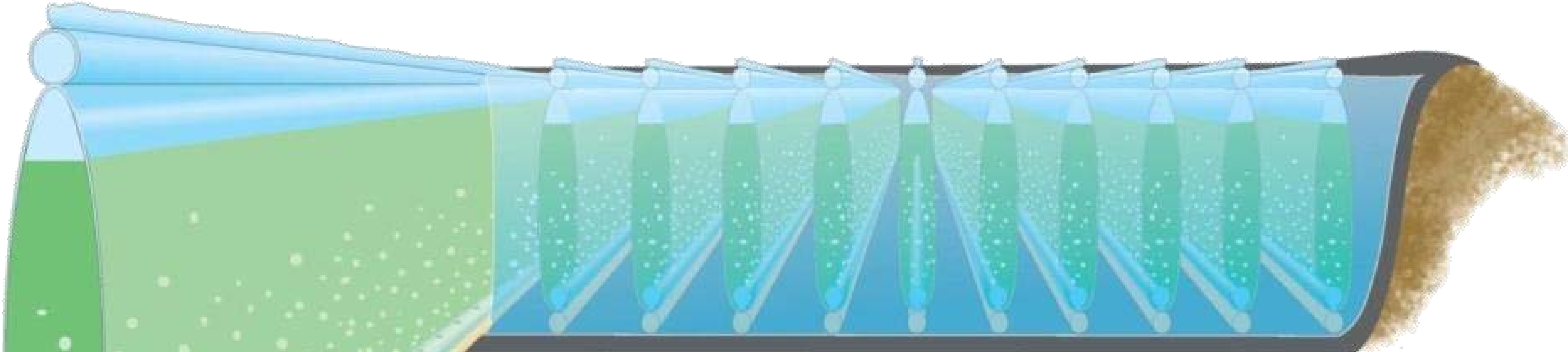
Direct Light PBR:
Low Cost & Productivity



Diffuse PBR:
High Cost & Productivity

Solix G2 – May '07

Photo-bioreactor (G3)



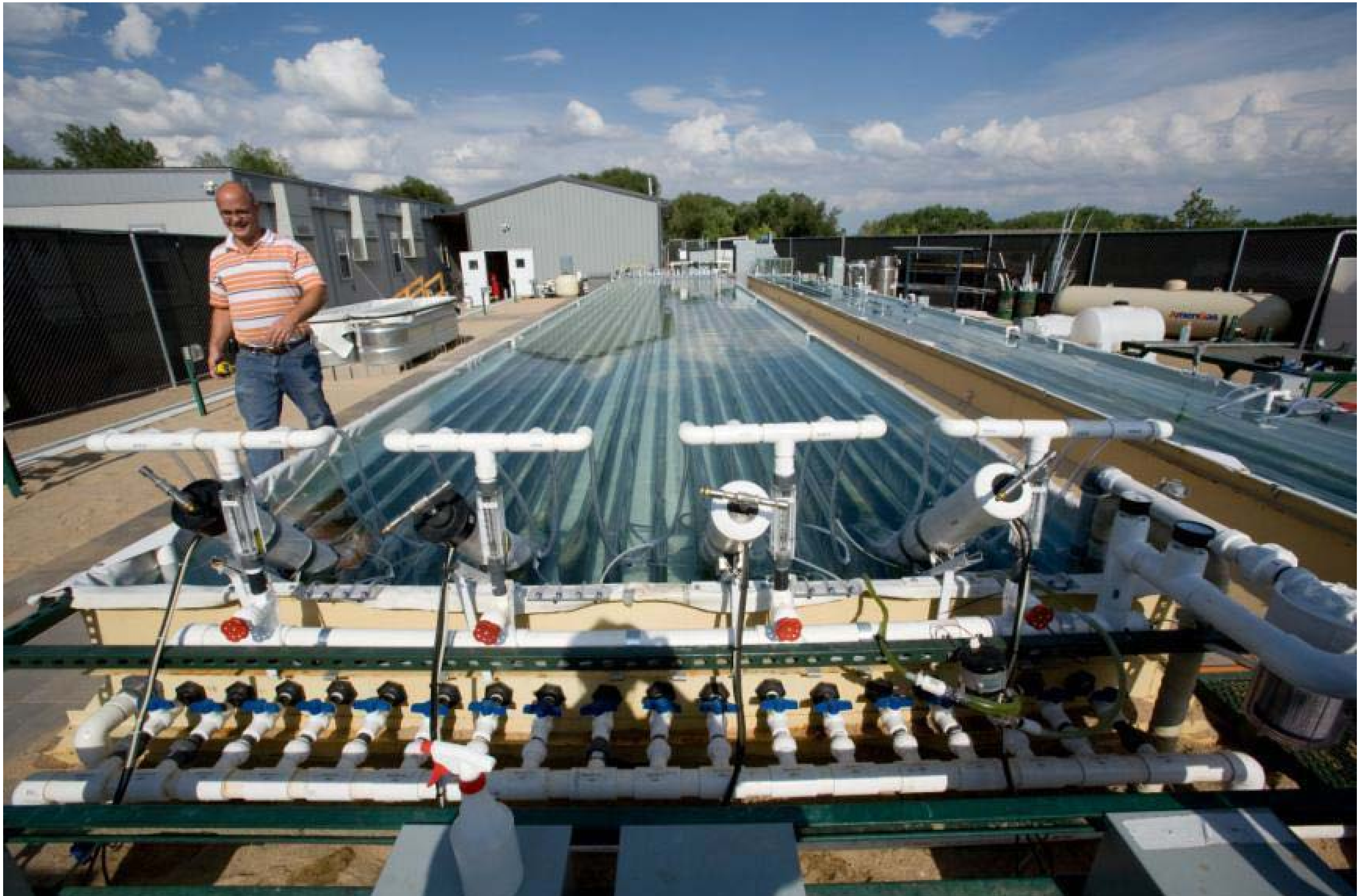
Solix G3 Technology:

- Extended surface area
- Water supported
- Integrated CO_2 / air sparging
- G4 – membrane exchange in development

Solix G3 (cont)

Solix G3 (cont)

Solix G3 (cont)



Solix G3 (cont)

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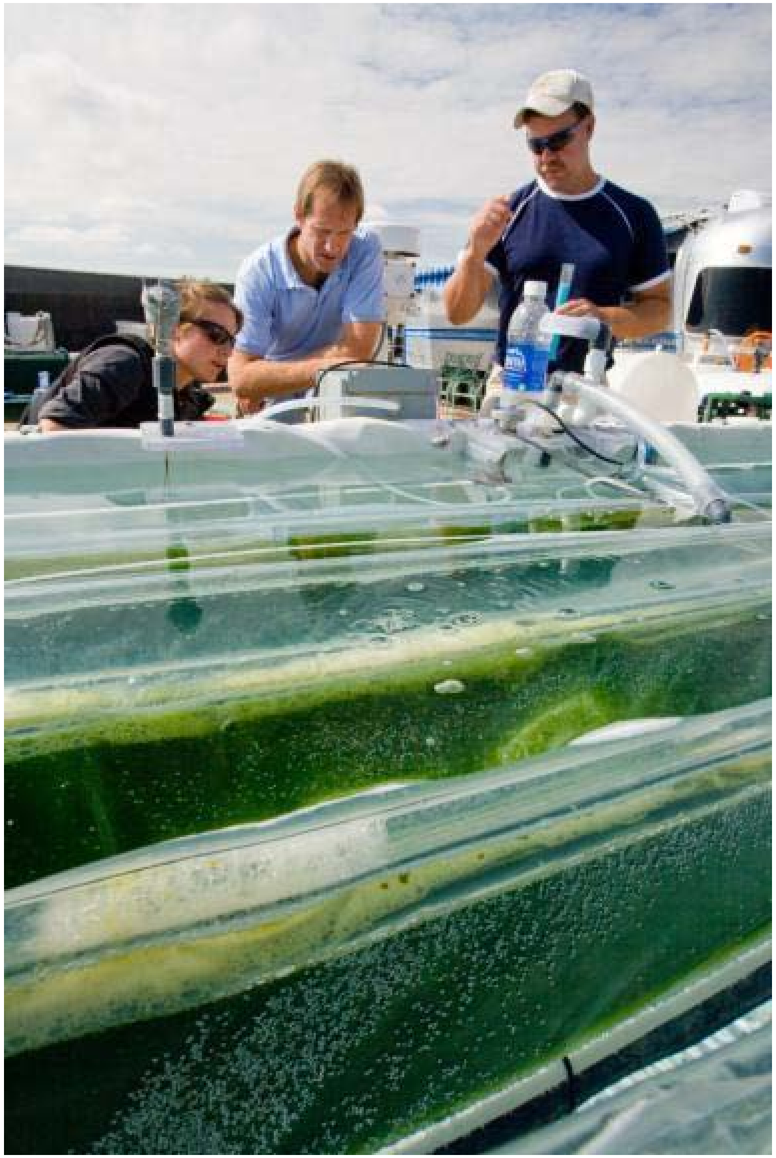
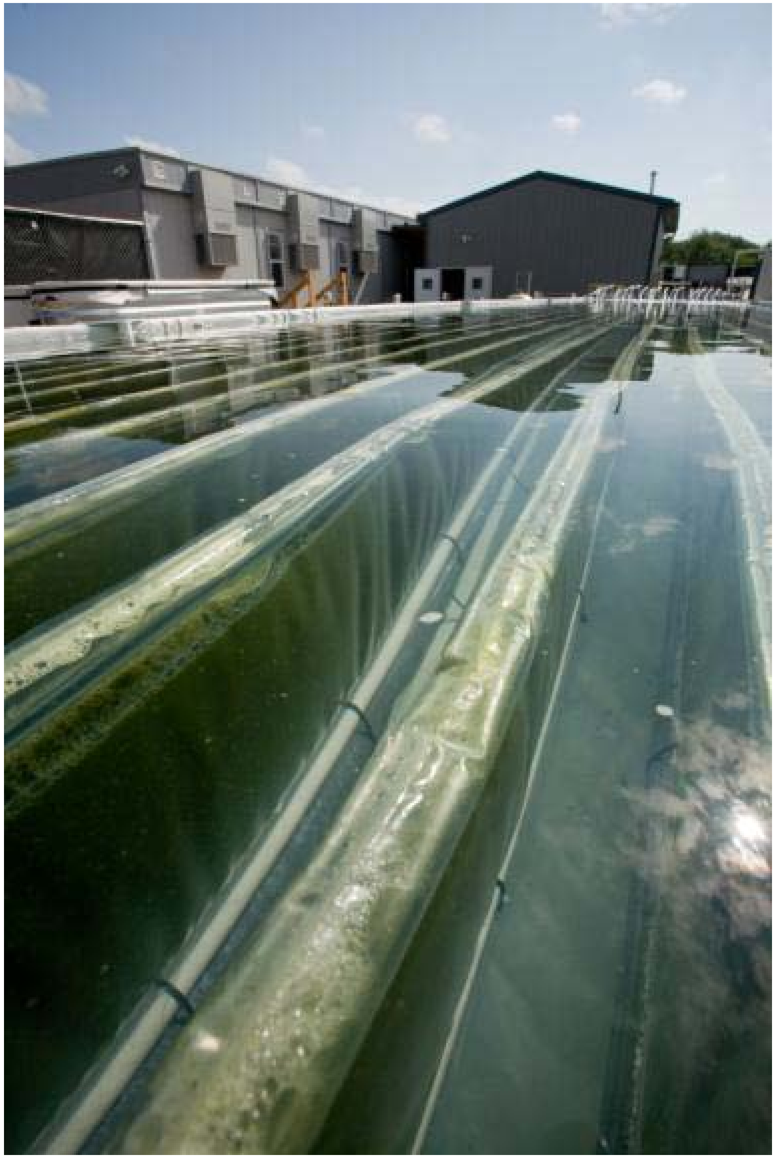
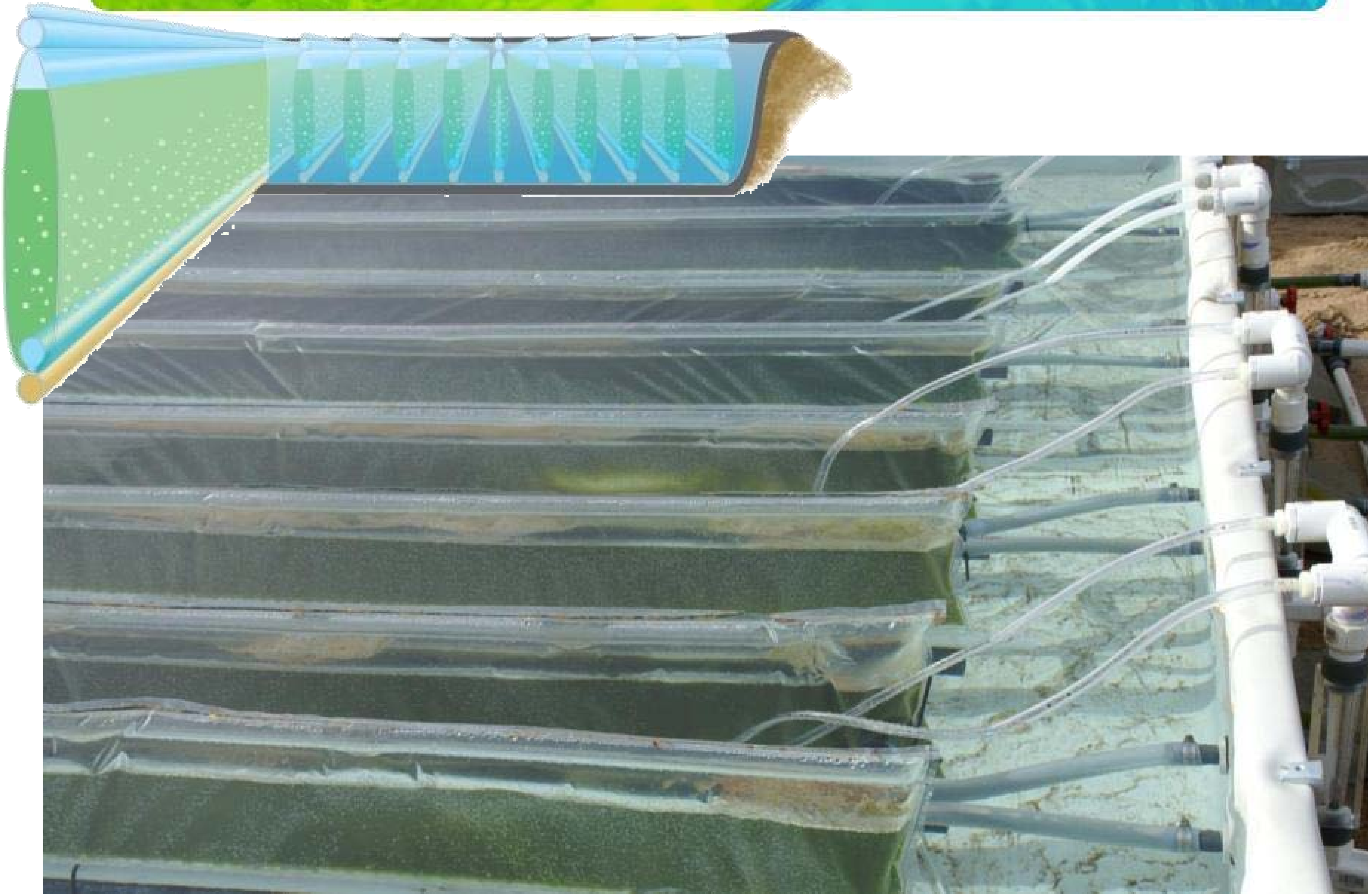




Solix G3 (cont)



Solix G3 (cont)

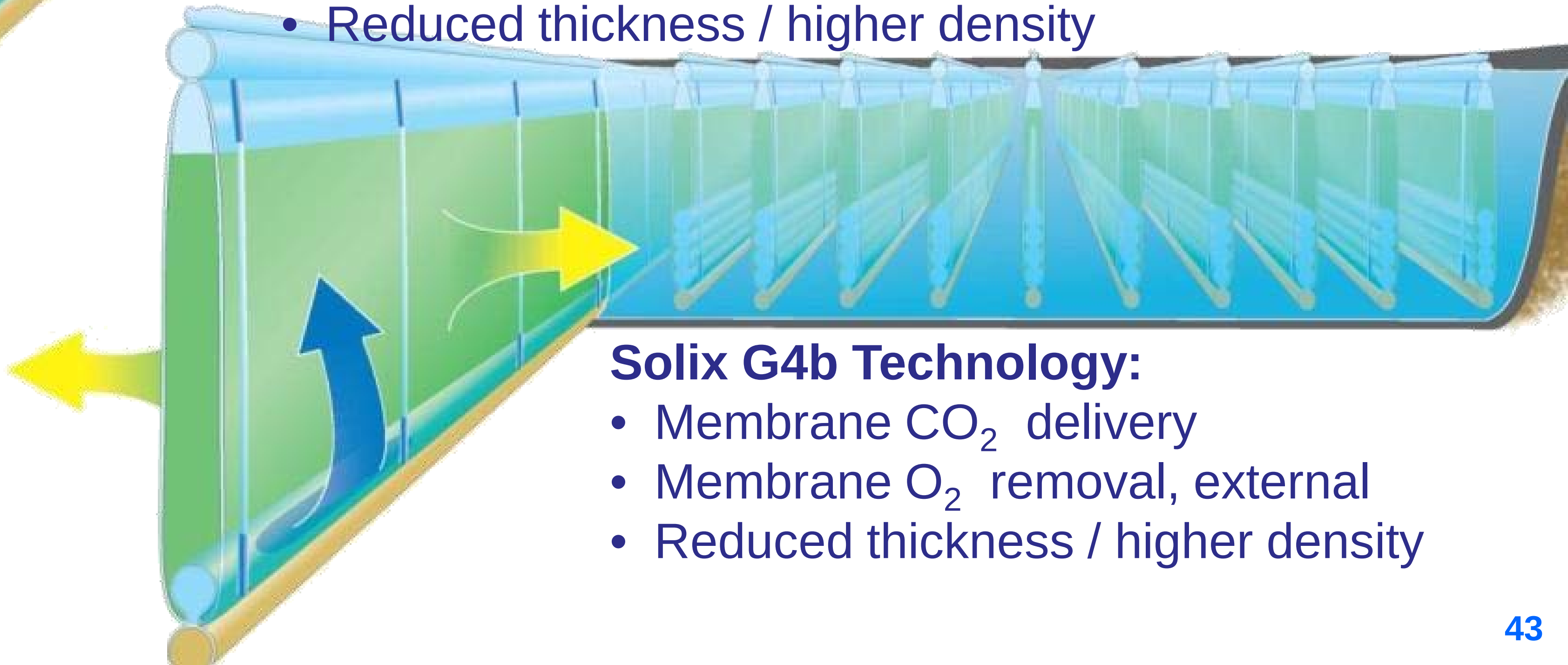
Solix G3 (cont)

Colorado – Algae Paradise?

Solix G4

Solix G4a Technology:

- Membrane CO_2 delivery
- Membrane O_2 removal, internal
- Reduced thickness / higher density

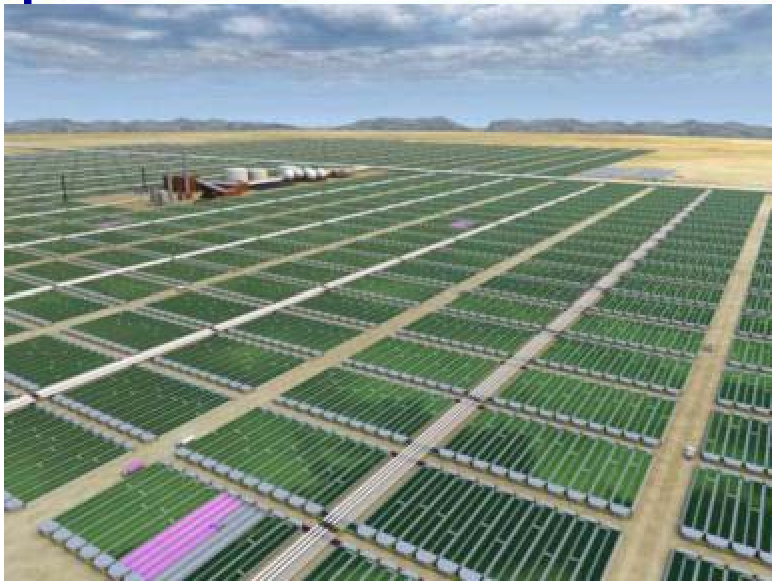
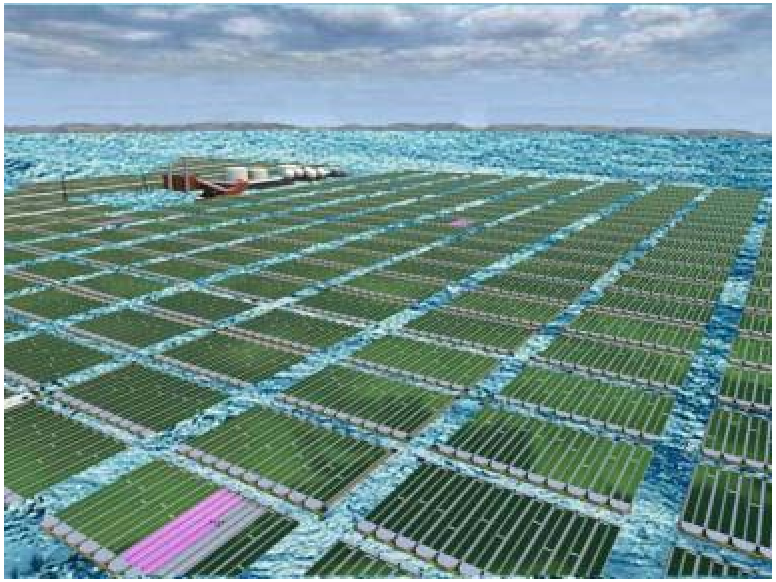
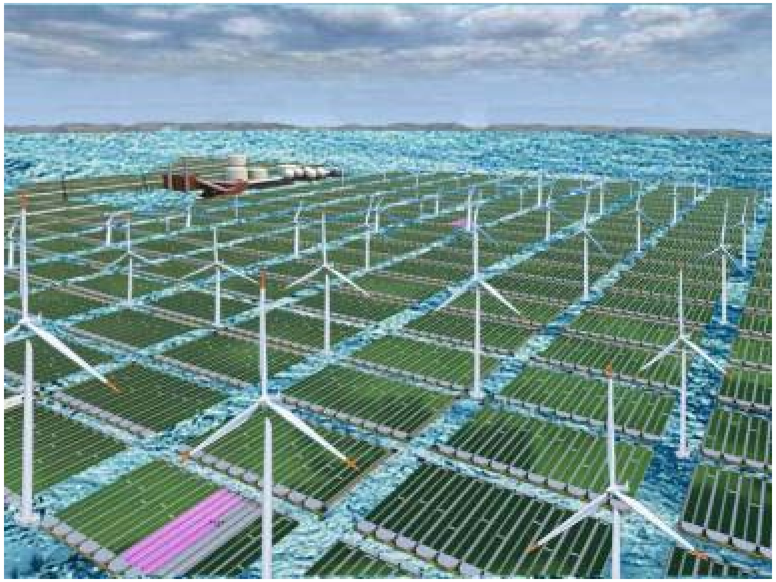


Solix G4b Technology:

- Membrane CO_2 delivery
- Membrane O_2 removal, external
- Reduced thickness / higher density

Potential Open-Water Application

Offshore Production?
Denmark Workshop, Apr 20-22

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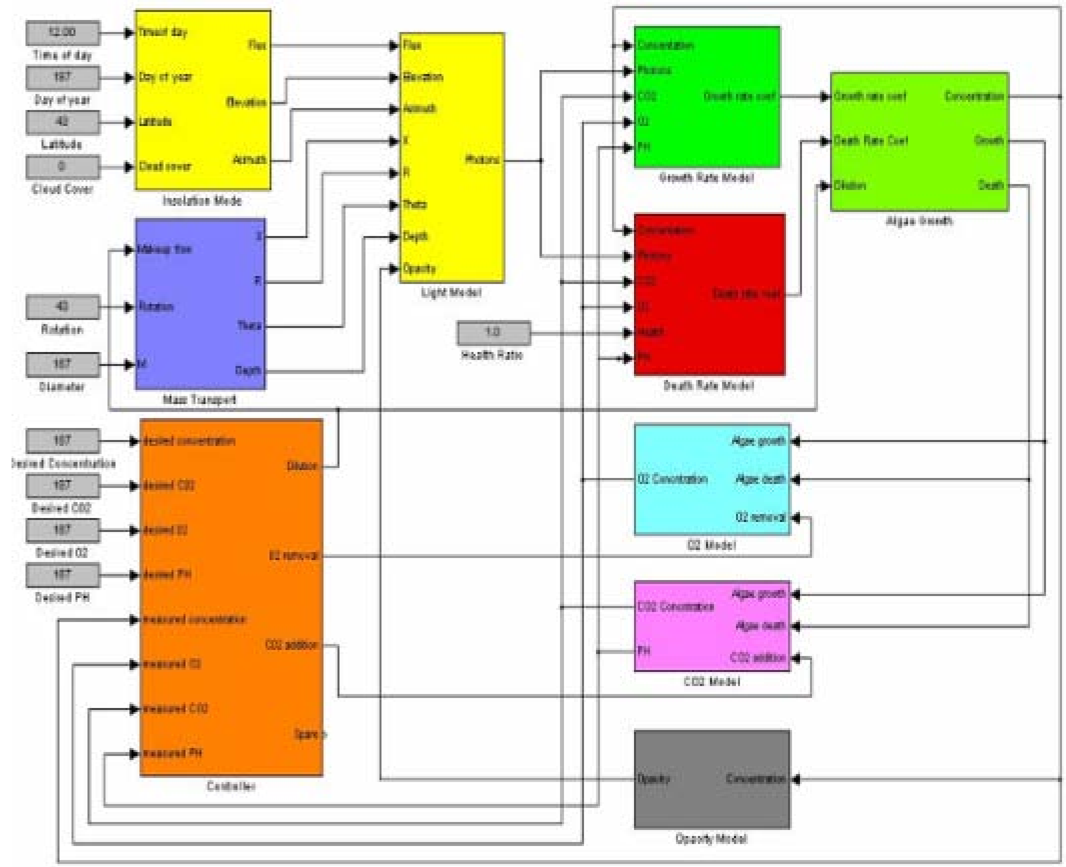
Extraction

Extraction

Extraction

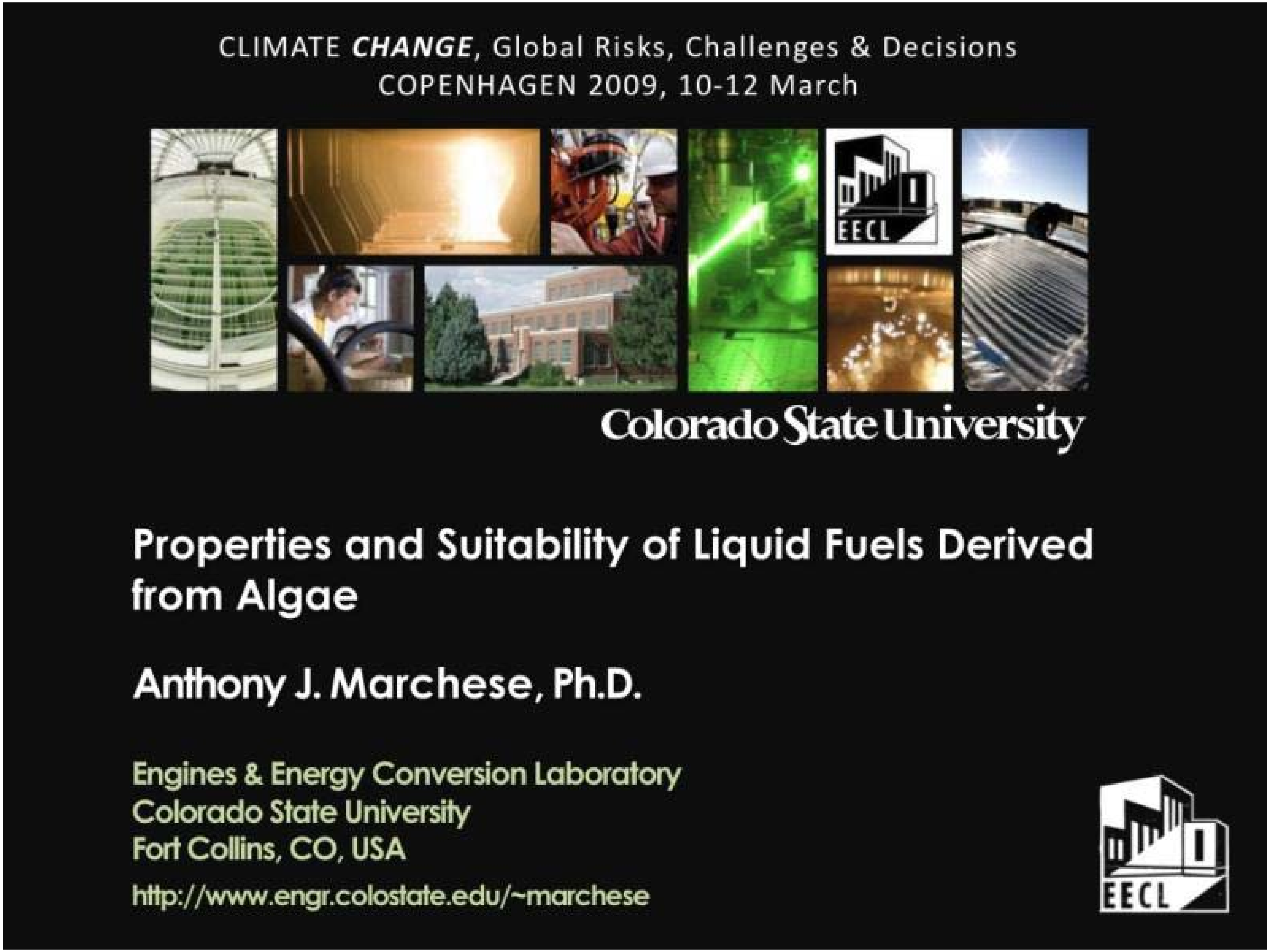
Model-Based Control

- ***Automates conditions for optimal productivity of different organisms in different climates***
- ***Gives predictive and diagnostic capabilities***

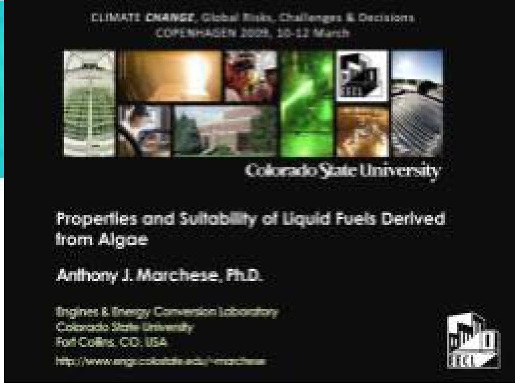


Biology

Fuel Properties - General

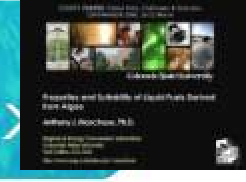


Fuel Properties - General



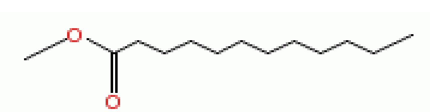
- Algal oil is unique in that it tends to contain a significant quantity (~5-20% by volume) of long highly unsaturated oils, which are rarely observed in more traditional biodiesel feedstocks, such as soy and rapeseed (canola) oil.
- The two most common types of long and highly unsaturated oils found in algae oil tested to date are eicosapentaeonic acid (EPA) and docosahexaenoic acid (DHA).

Feedstock Composition

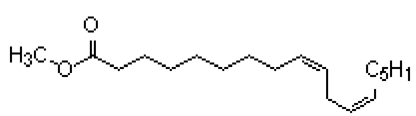


Fatty acid content varies widely depending on the feedstock. The chemical composition has implications in terms of combustion characteristics.

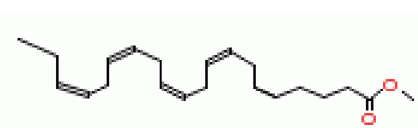
	Saturated Acids						Mono Unsaturated Acids			Total Poly Unsaturated Acids		
	10:0	*12:0*	*14:0*	*16:0*	*18:0*	*>18:0*	*16:1*	*18:1*	*22:1*	*n:2*	*n:3*	*n:4-6*
Coconut	7	**47**	15	8	2			6		2		
Palm			3	40	3			46				
Rapeseed			3	2	1	1		12	**55**	15	8	
Soybean				9	4	8	1	26		**55**	6	
Nannochloropsis Oculata			2	15	2	2	16	10	1	6	4	**31**
Nannochloropsis sp.			3	14	11	3	19	6		7	3	**20**



methyl dodecanoate (coconut)



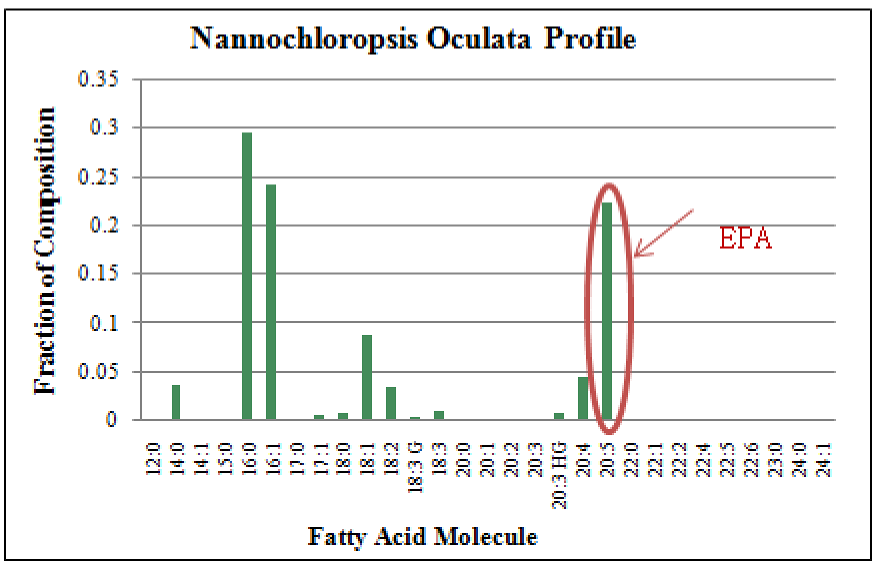
methyl linoleate (soy)

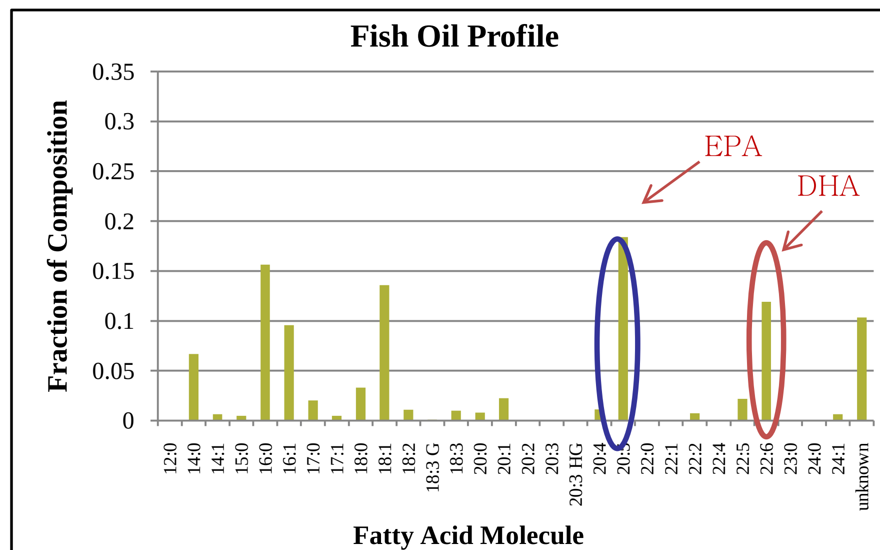


eicosapentaeonic acid methyl ester (algae)

Composite Algal Oil

- **Algal oil differs from soy and rapeseed in that many algae species under consideration produce up 20% of Omega-3 fatty acids.**
- **For engine tests, “synthetic” algae oil is created by mixing a variety of vegetable oils with pharmaceutical grade fish oil.**
- **Pharmaceutical grade fish oil is used as a source of Omega-3 fatty acids found in algal oil (e.g EPA and DHA)**





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Scaling Up. . .

New Site:
Southwest Colorado, Coyote Gulch

Coyote Gulch

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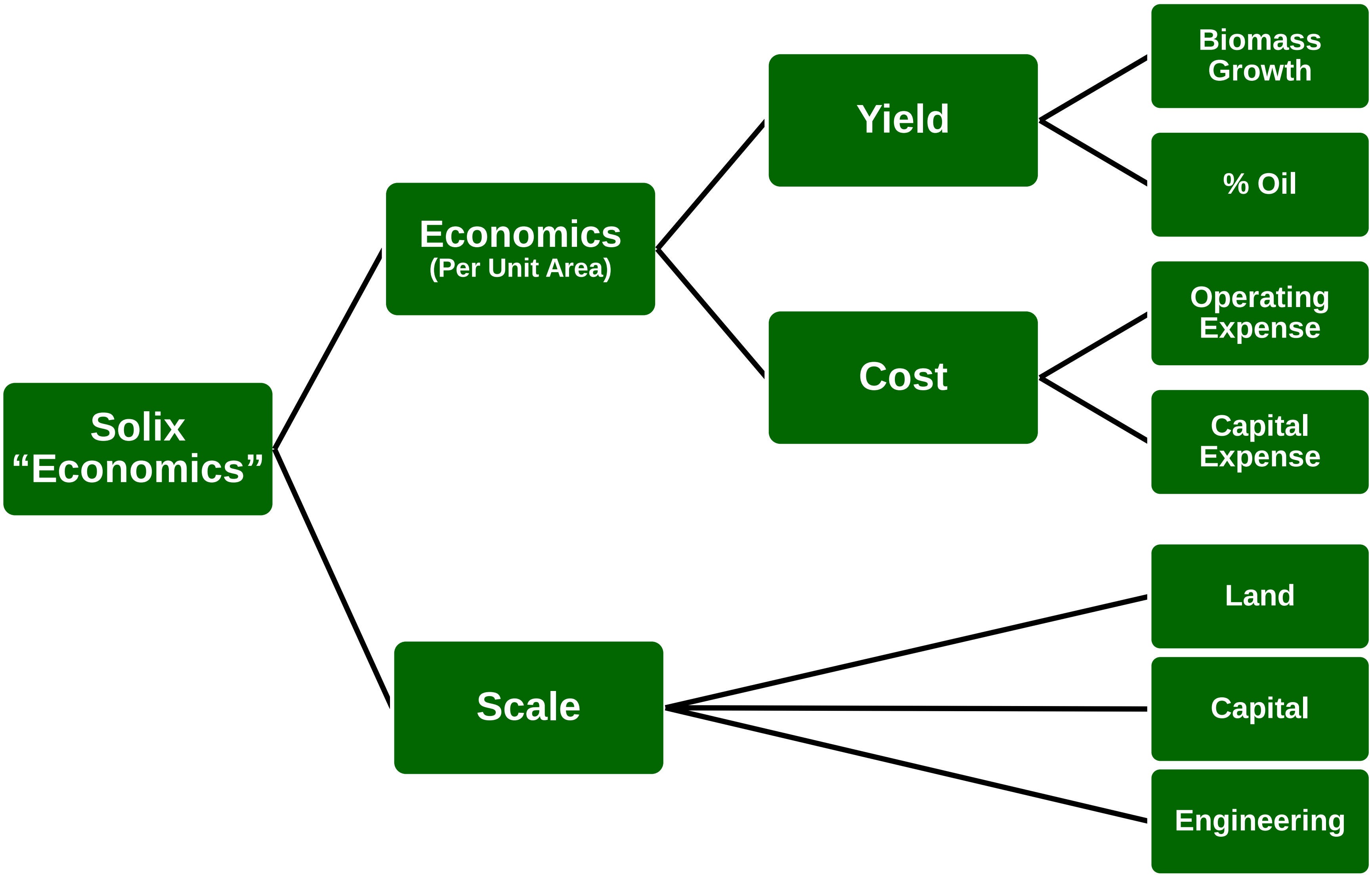
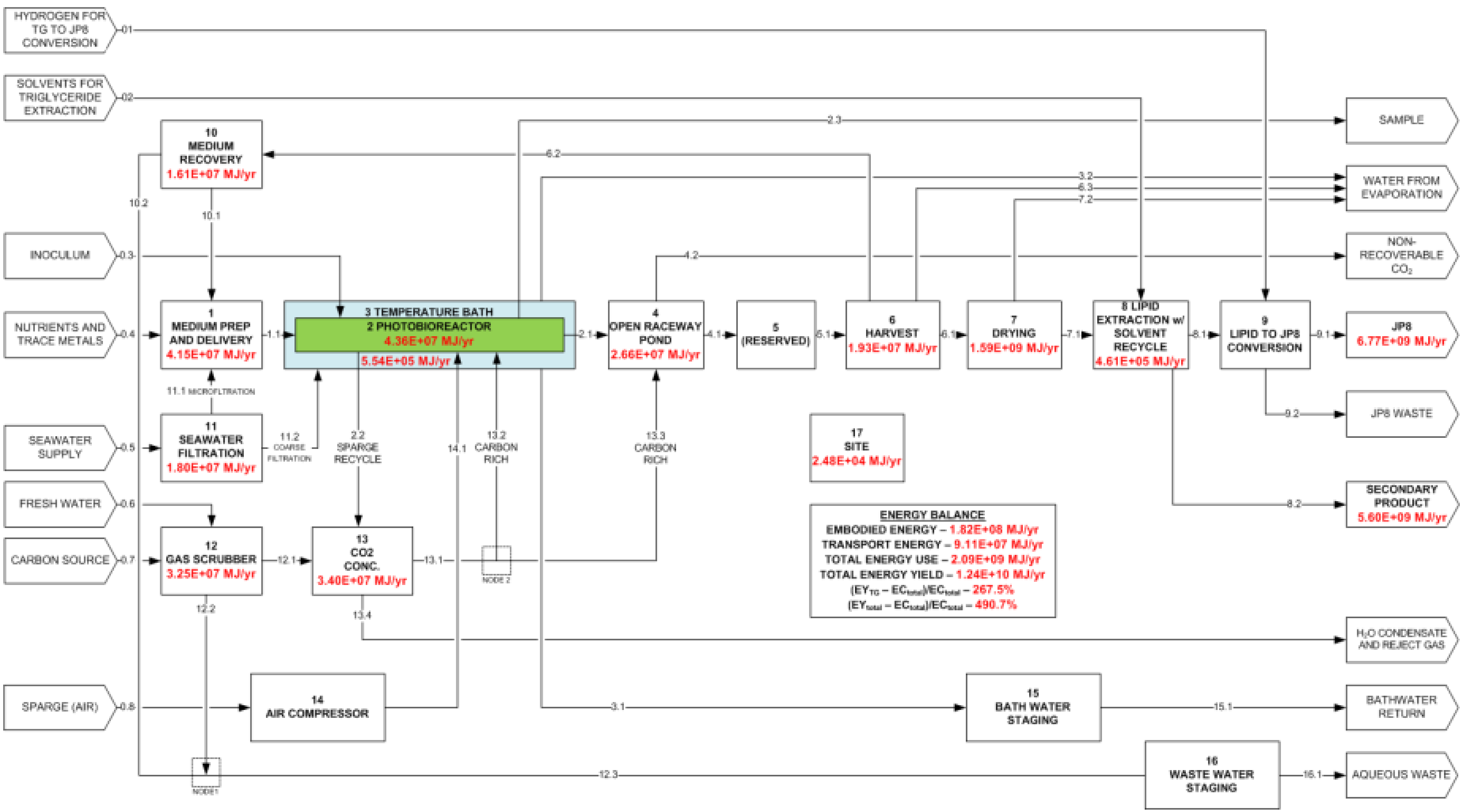
Economic Overview

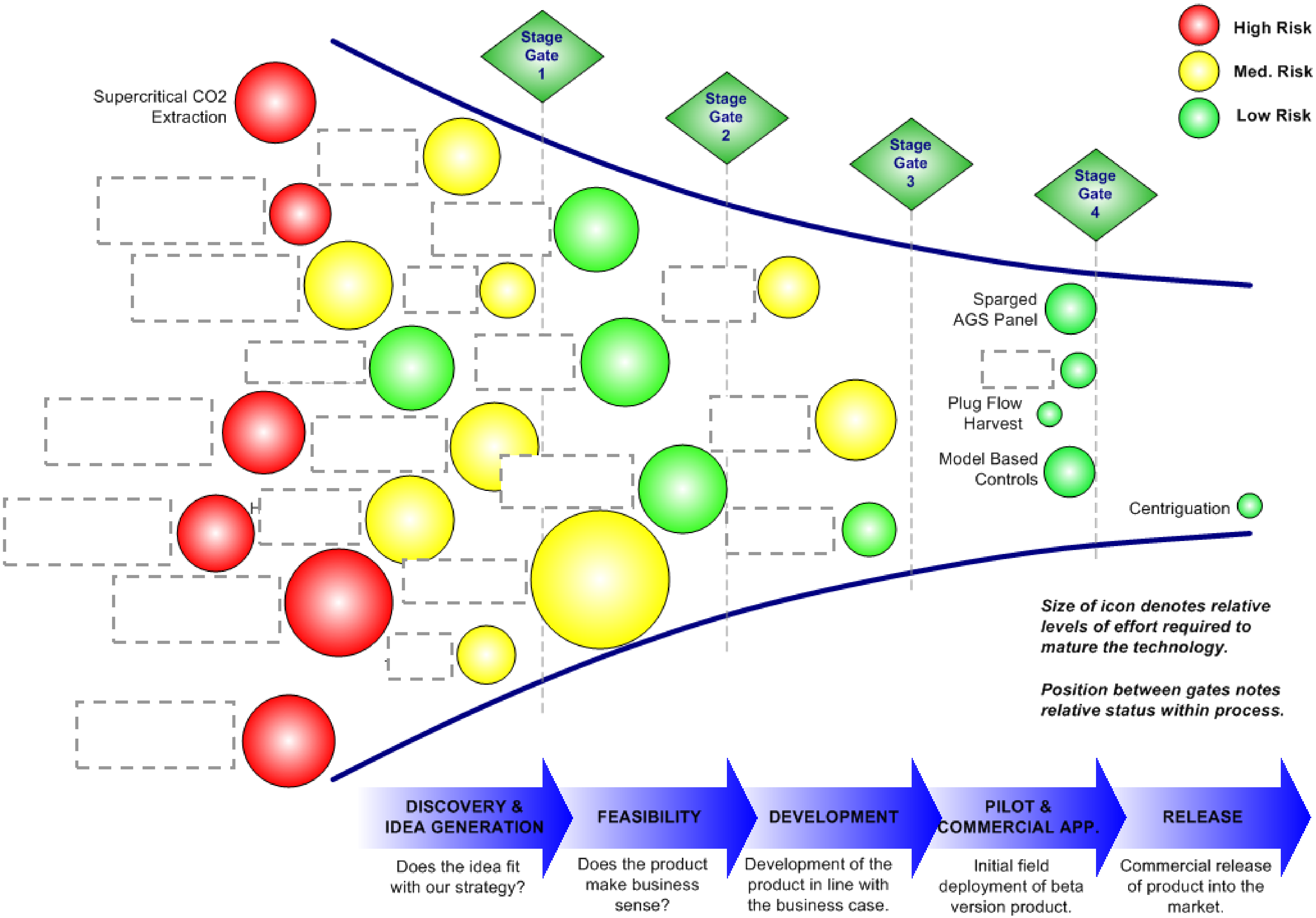


System Analysis / Modeling

SOLIX

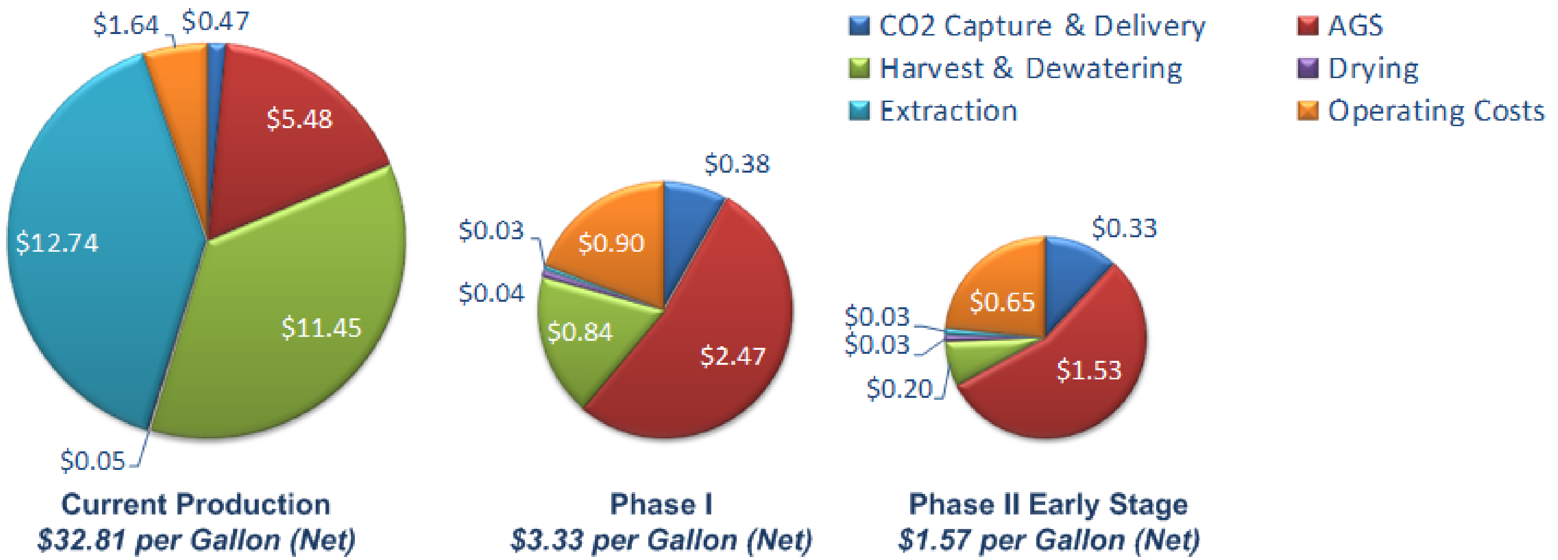


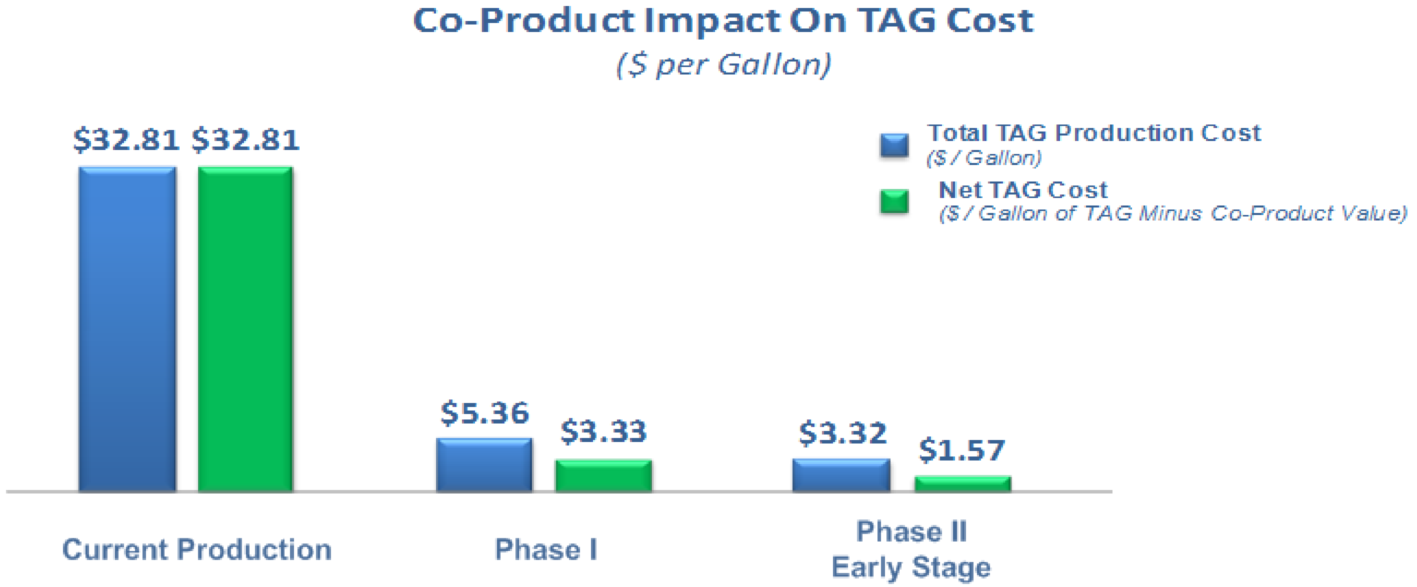
Technology Development Process



COST OF TAG PRODUCTION

(Production @ $0.06/kW-Hr)





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- Economical biofuel production appears feasible, using low-cost high productivity photobioreactors
- Requires tight coupling of biology and engineering
- Value of co-products must be captured; may approach or exceed value of oil
- Systems modeling/integration required to achieve cost targets

Contact Information

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