SOLIX
Fueling a better world

Low Cost Photobioreactors for Algal Biofuel Production & Carbon Capture

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Solix Biofuels / Colorado State University
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Outline

Solix / Algae Intro

Growth Metrics

Light Management in PBRs

Solix AGS System

Extraction

Scaleup

Production Metrics

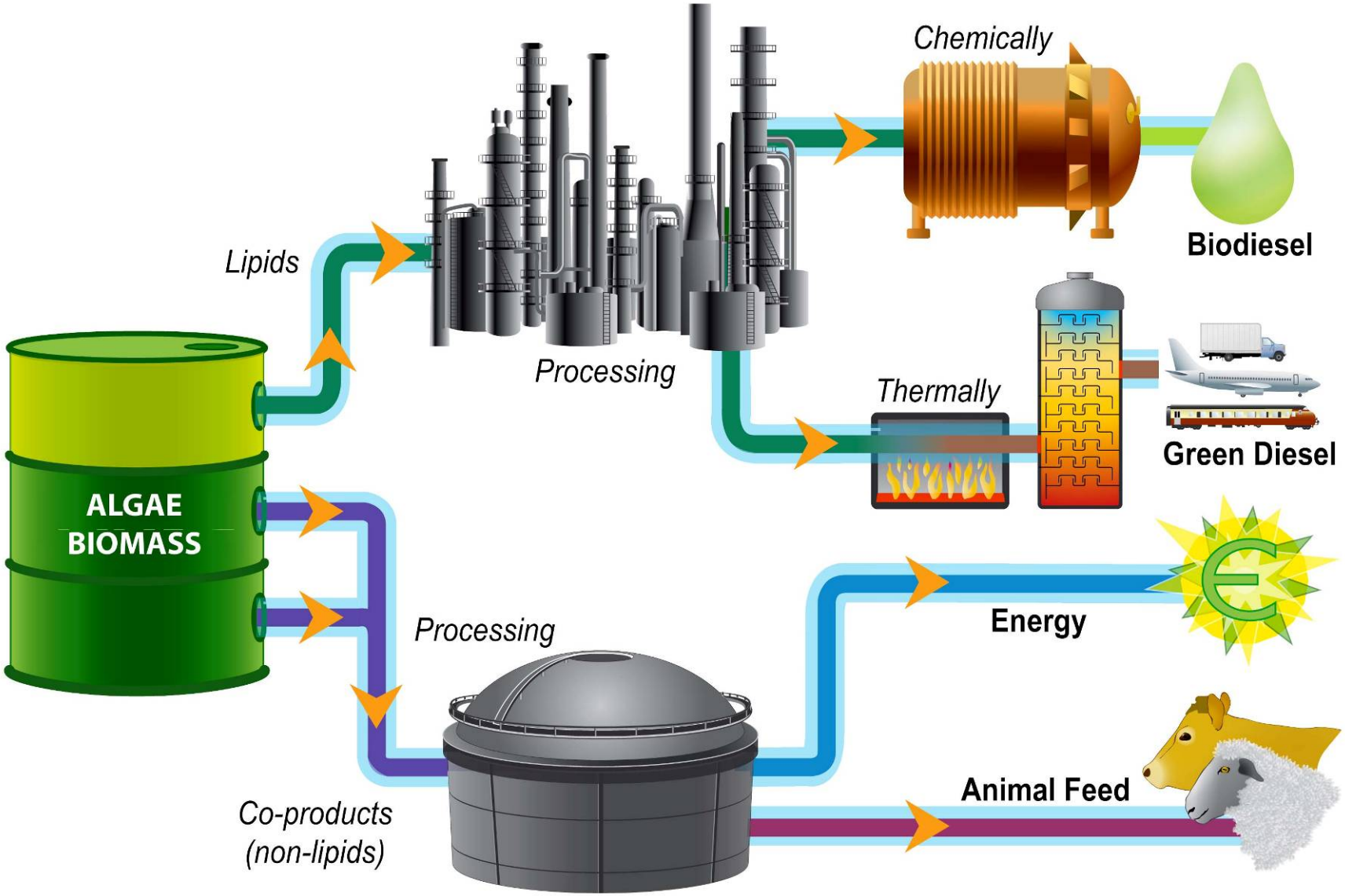
Production Costs

Conclusions

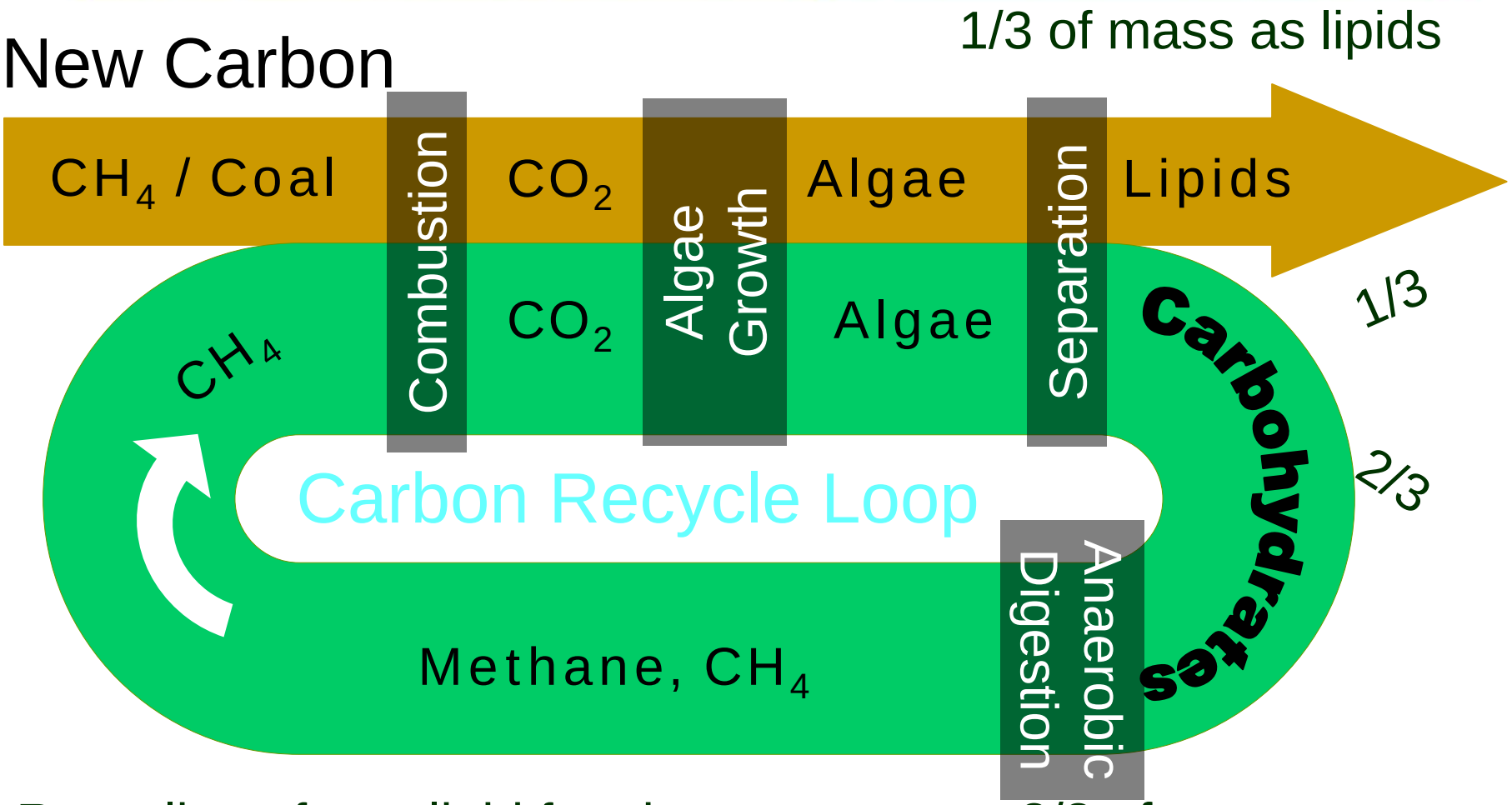
About Solix

- **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: 35 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 / lab space**
  - **Outdoor solar lab facilities**
- **Significant strategic partners in industry, science and engineering**

Processing


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

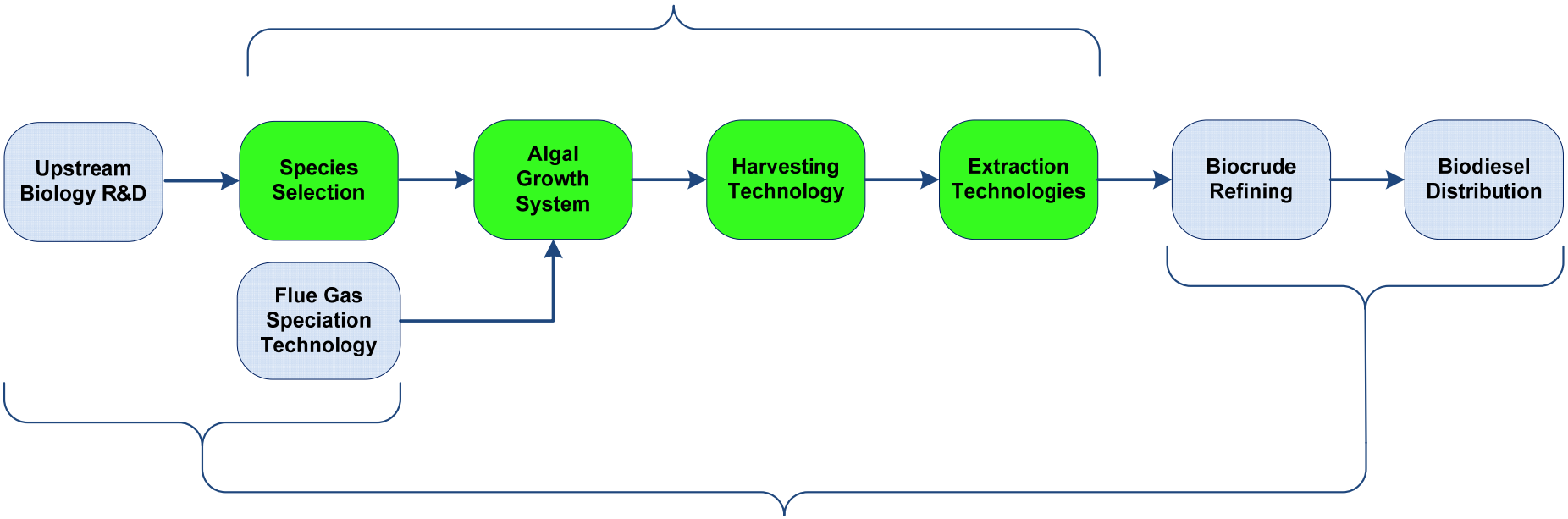
Potential Carbon Cycle



Recycling of non-lipid fraction contributes 2/3 of fuel

≈2/3 of mass as carbohydrates & protein

Solix Focus Area



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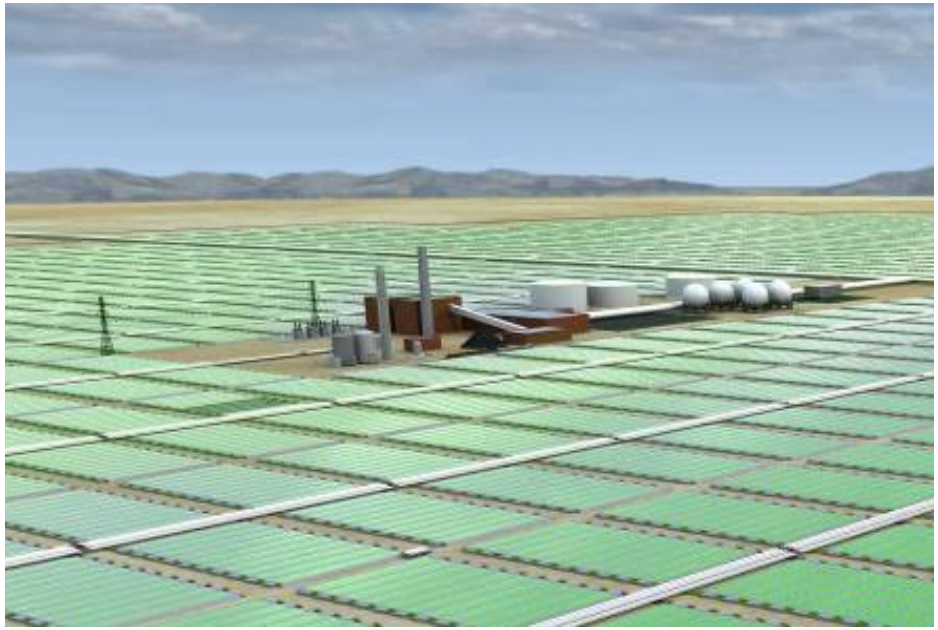
Realism

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…"

Yield Considerations

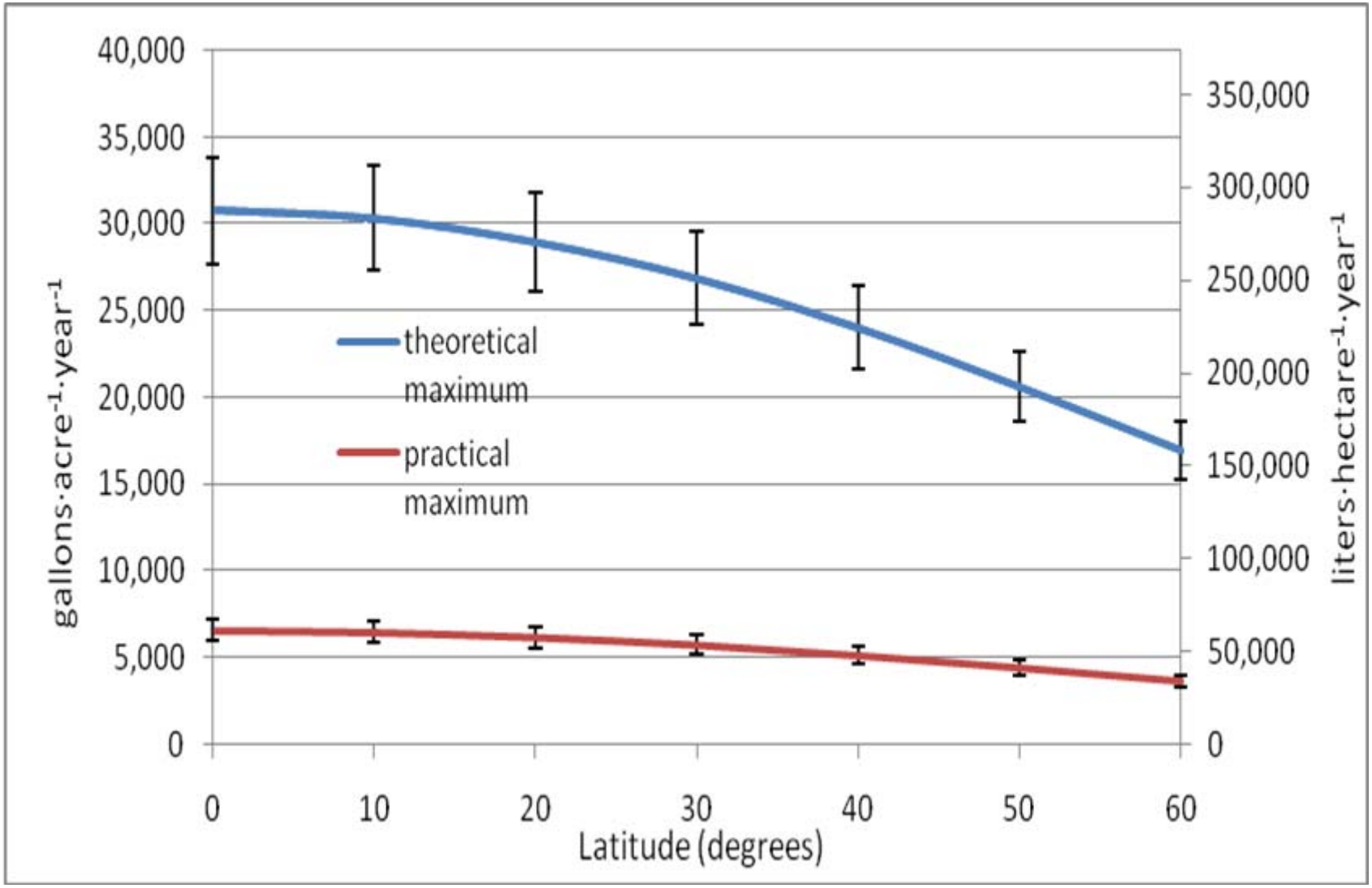
A process of employing basic physical laws, known values, and conservative assumptions has produced robust theoretical and practical maximum of algae oil yields. **For the nominal case of 20° latitude and 50% cell oil content, the theoretical maximum annual oil production from algae was calculated to be 28,950 gallons/acre/year (270,730 liters/hectare/year) with an uncertainty of roughly 10%. The practical maximum was calculated to be 6,180 gallons/acre/year (57,810 liters/hectare/year).** *Both the latitude of the production site and the cell oil content have significant effects on these maxima. A number of other efficiency terms were maintained at 100%, but in real-world production will certainly be less than perfectly efficient. Thus, optimized algae production designs should realistically be expected to achieve some value less than this.*

(2008: Weyer, Darzins, Willson – in review)

Projected Yield

Term	Theoretical Maximum Case	Practical Maximum Case	Units
Daily average biomass growth	136.3	48.5	$\frac{grams\ biomass}{m^2 \cdot day}$
Annual oil production	28,947	6,181	$\frac{gallons\ oil}{acre \cdot year}$
(English units)	270,734	57,808	$\frac{liters\ oil}{hectare \cdot year}$

Latitude Considerations



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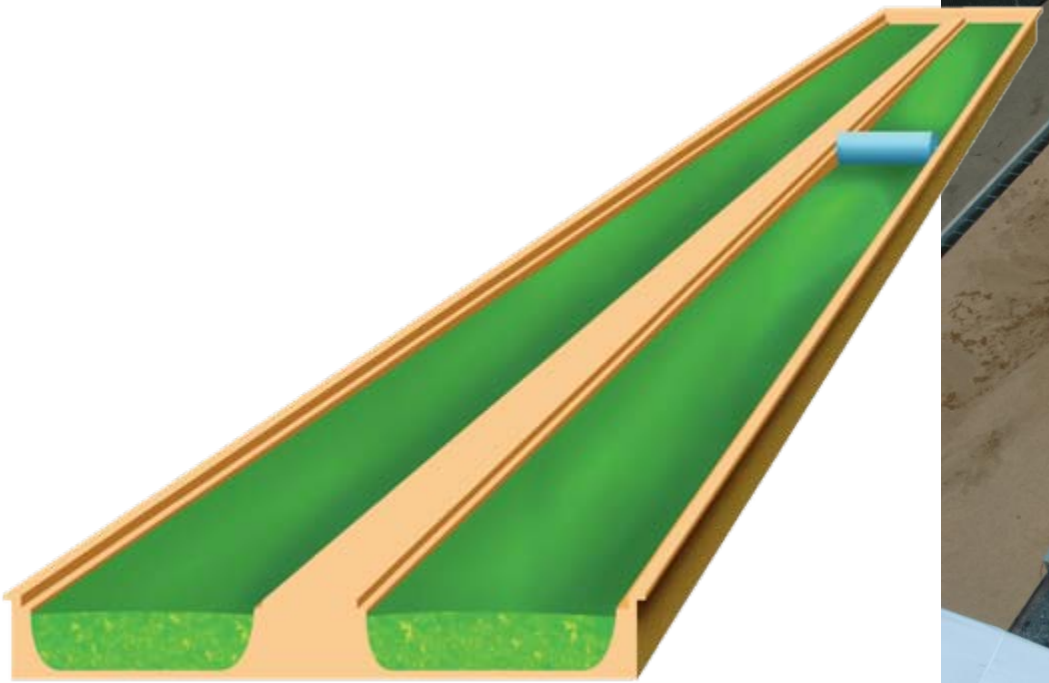
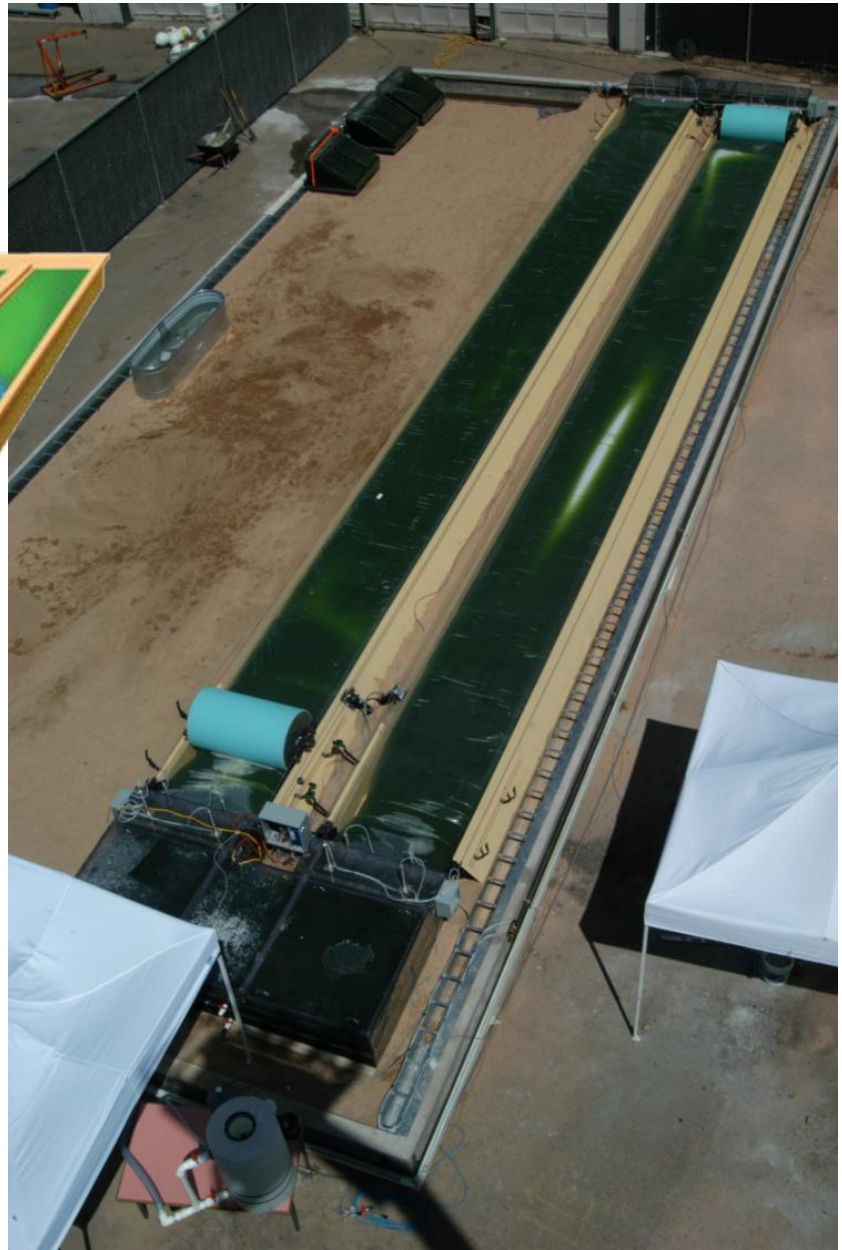
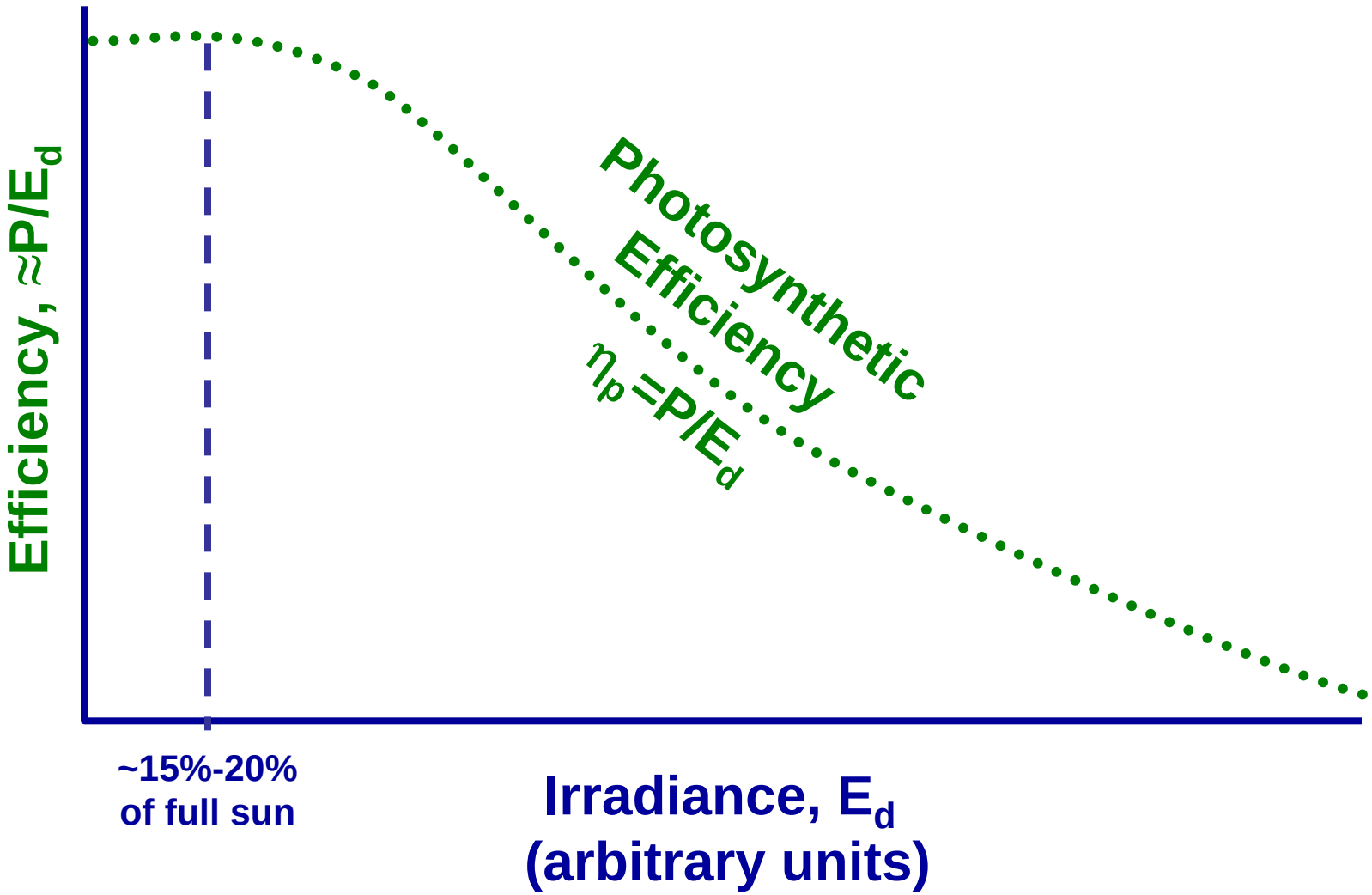
Open Pond Cultivation

Solix G1

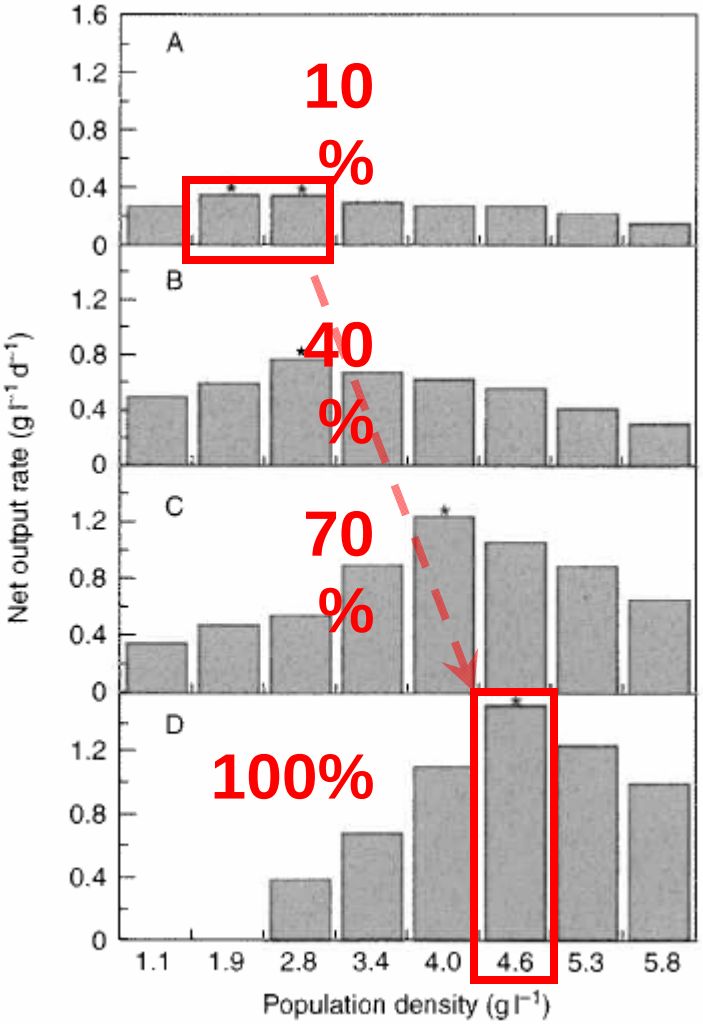




Photosynthetic Efficiency



Impact of Light Intensity



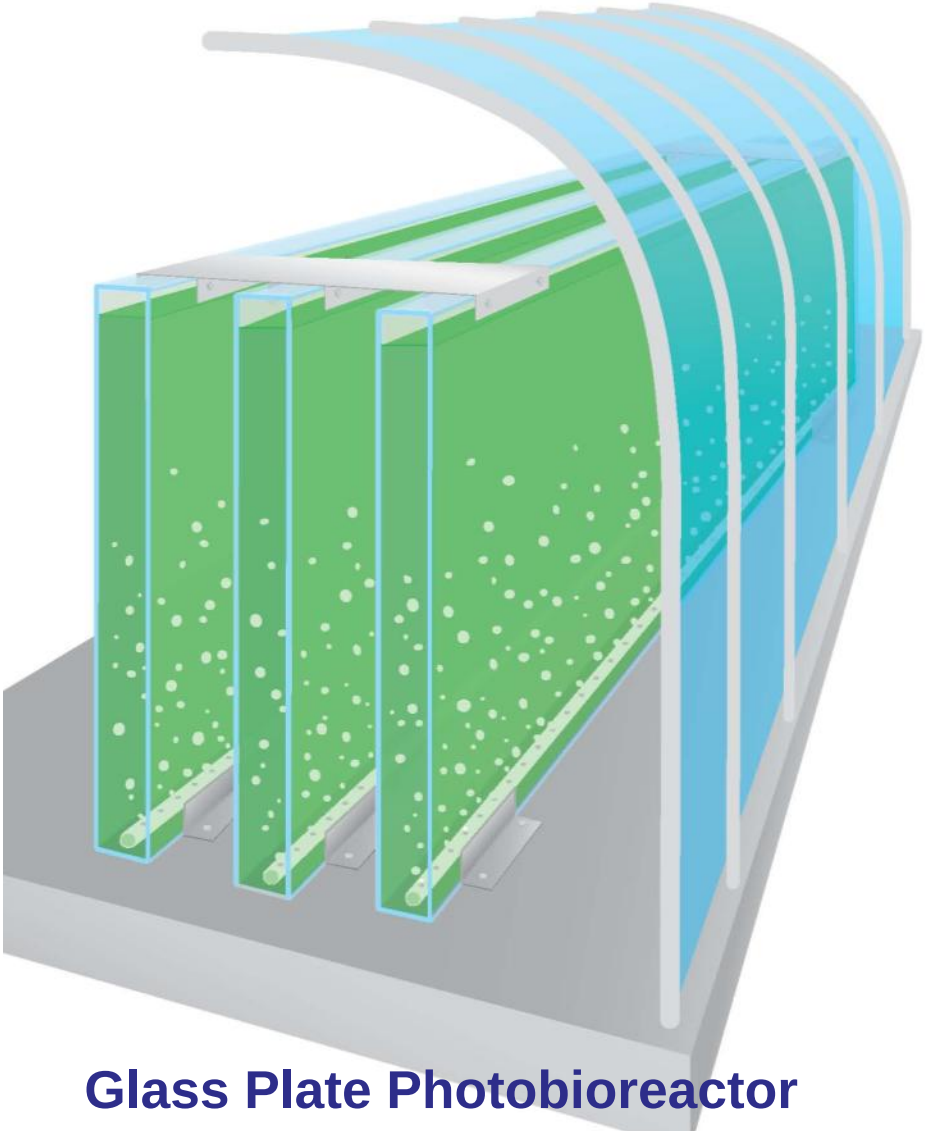
*Optimal population density

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.*).

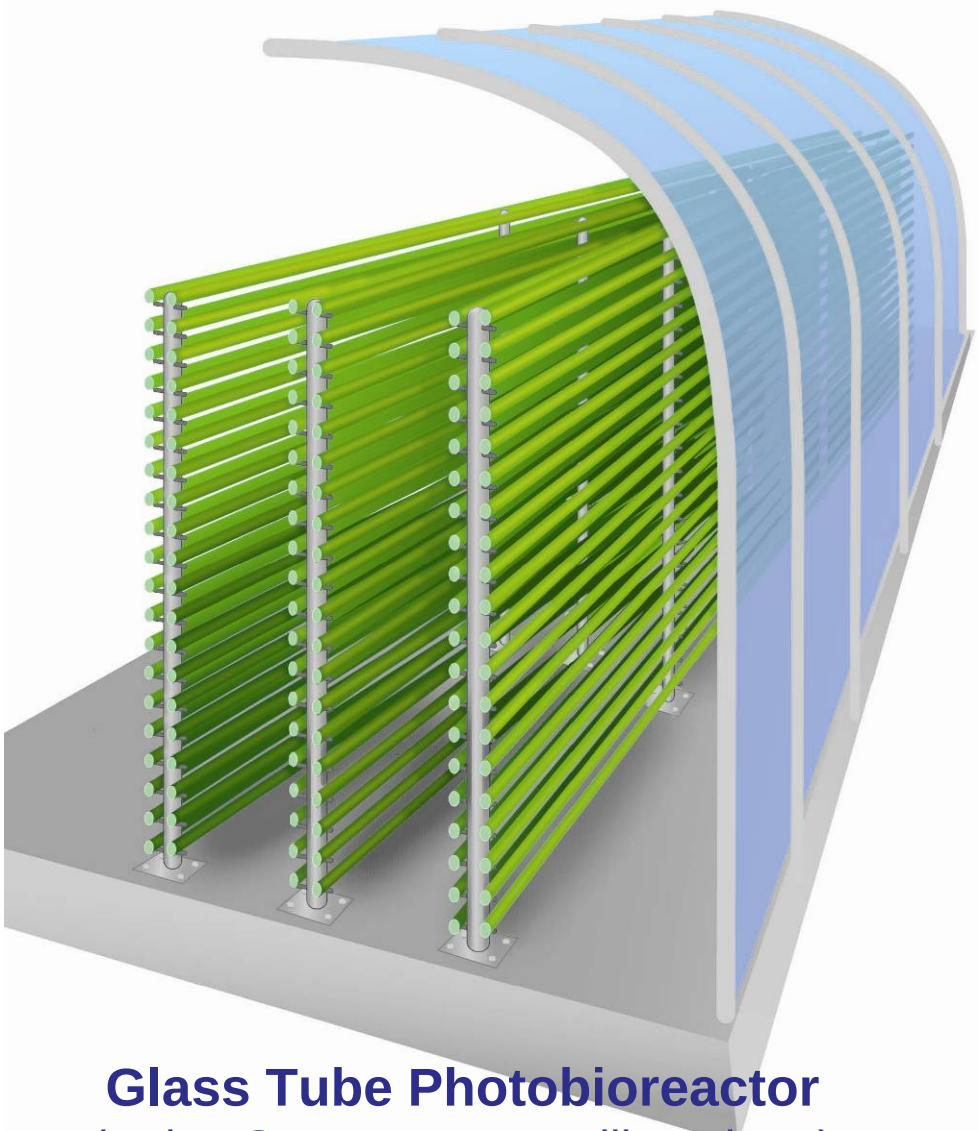
Note: 10X increase in light, but only 3.5X increase in output. Implies a 3X reduction in photosynthetic efficiency.

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

Extended Area PBRs



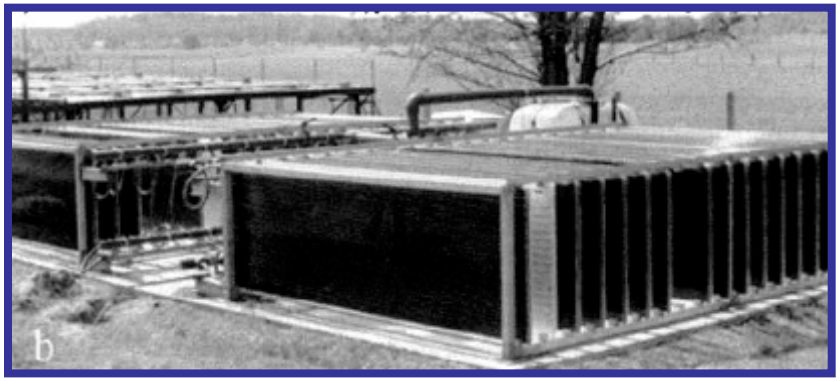
Glass Plate Photobioreactor
(Pulz, Richmond, others)



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

“Full-Sun” vs. Diffuse PBRs

Direct Light PBR:
Low Cost



Diffuse PBR:
High Productivity

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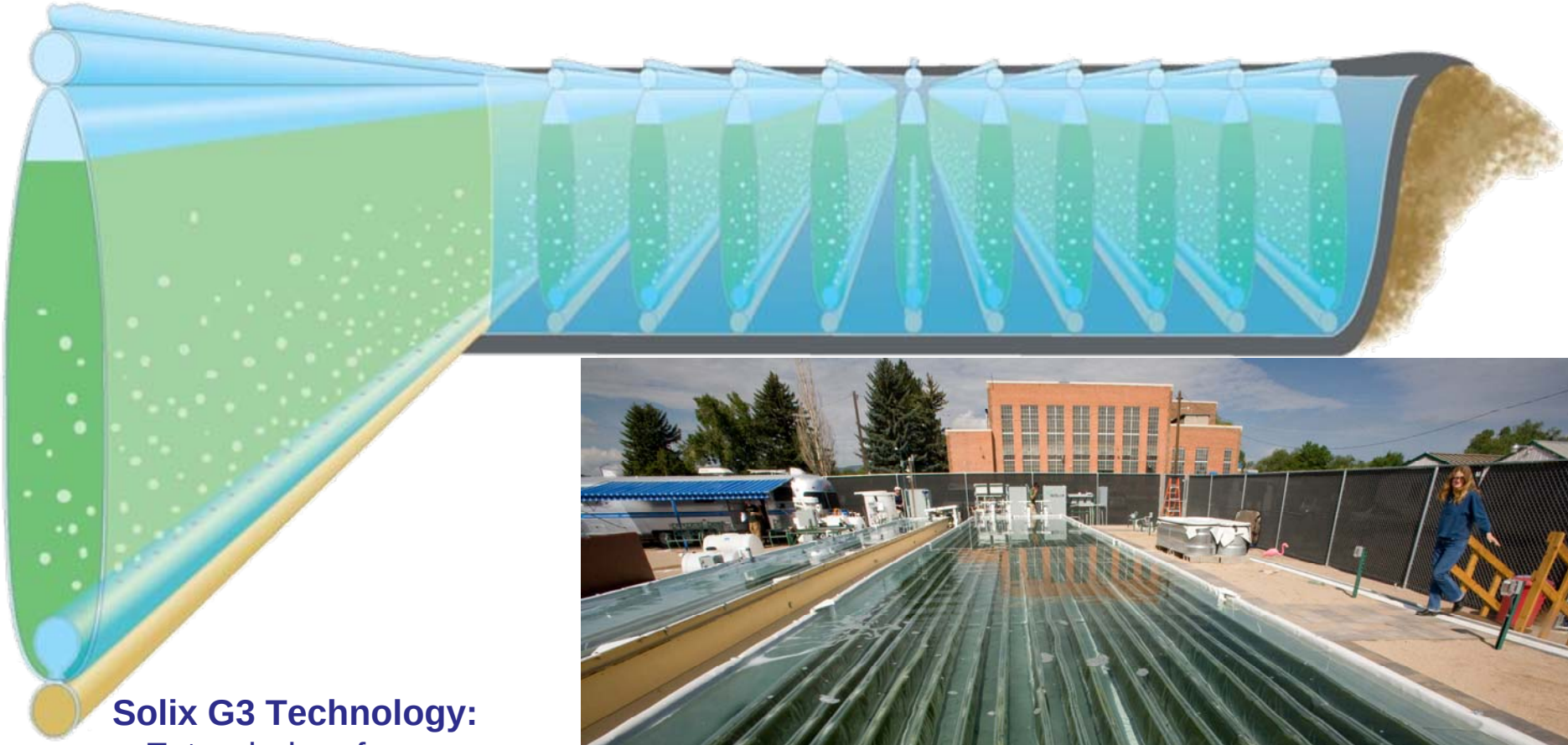
Solix G2 – May ‘07

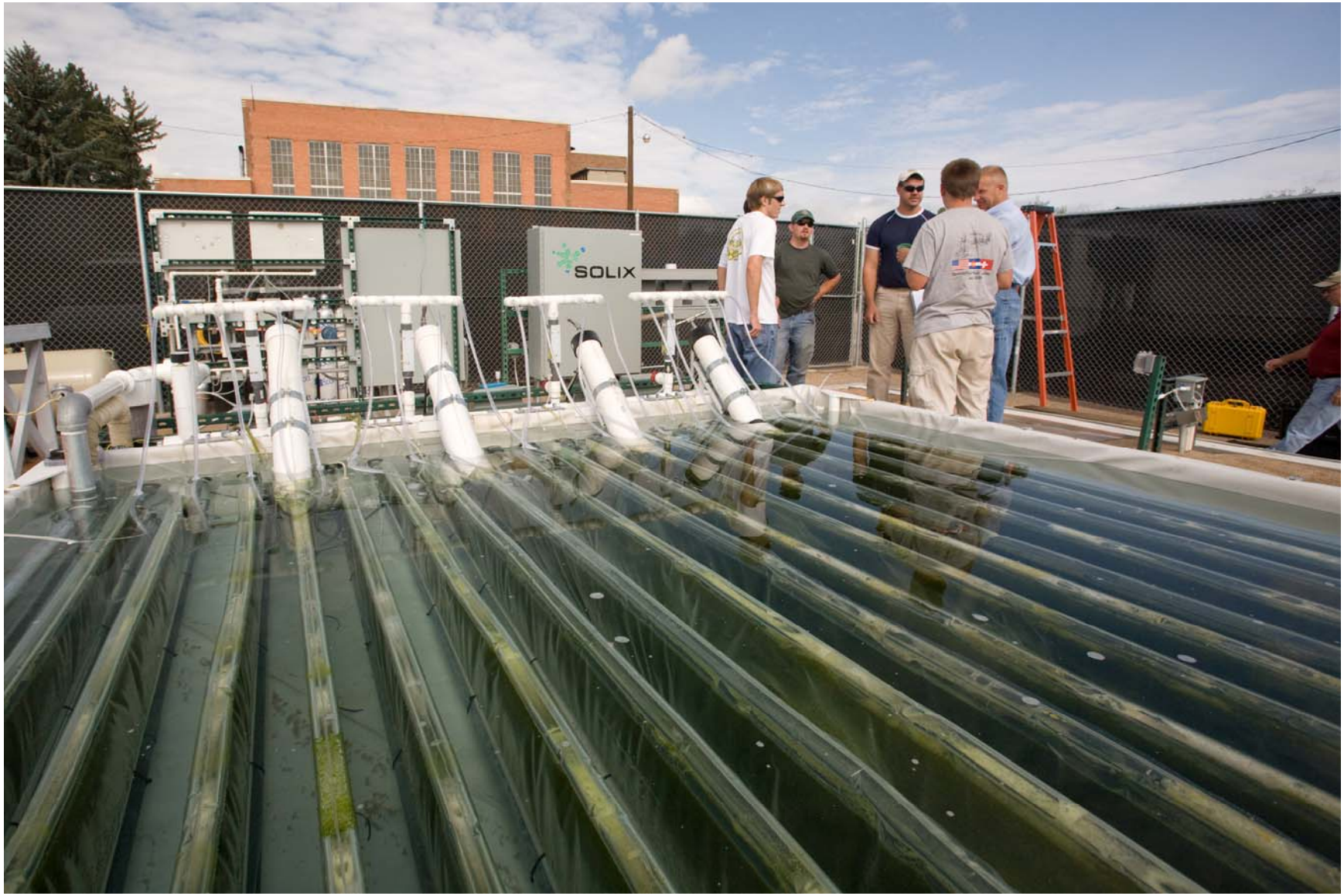
Photo-bioreactor (G3)



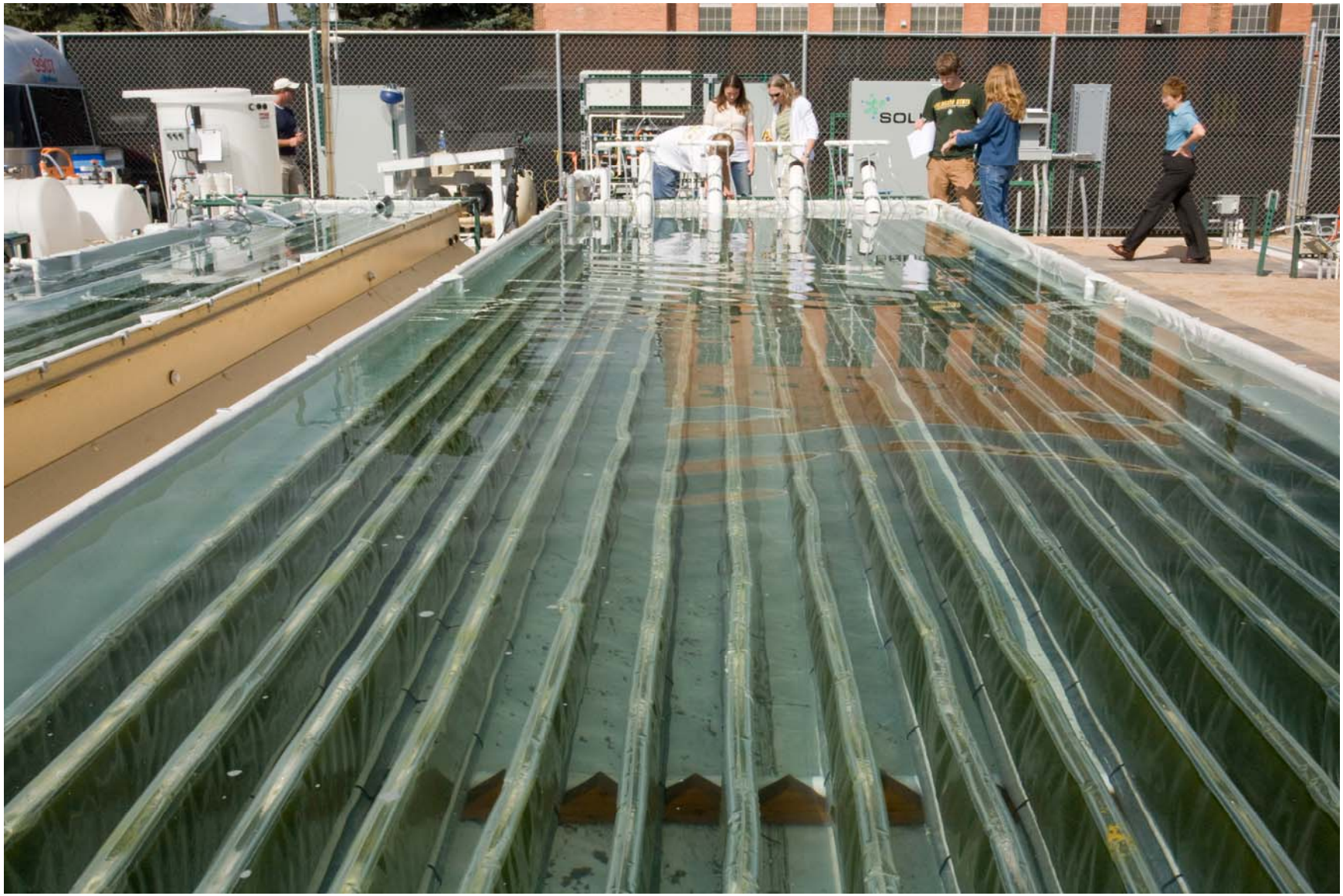
Solix G3 Technology:

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

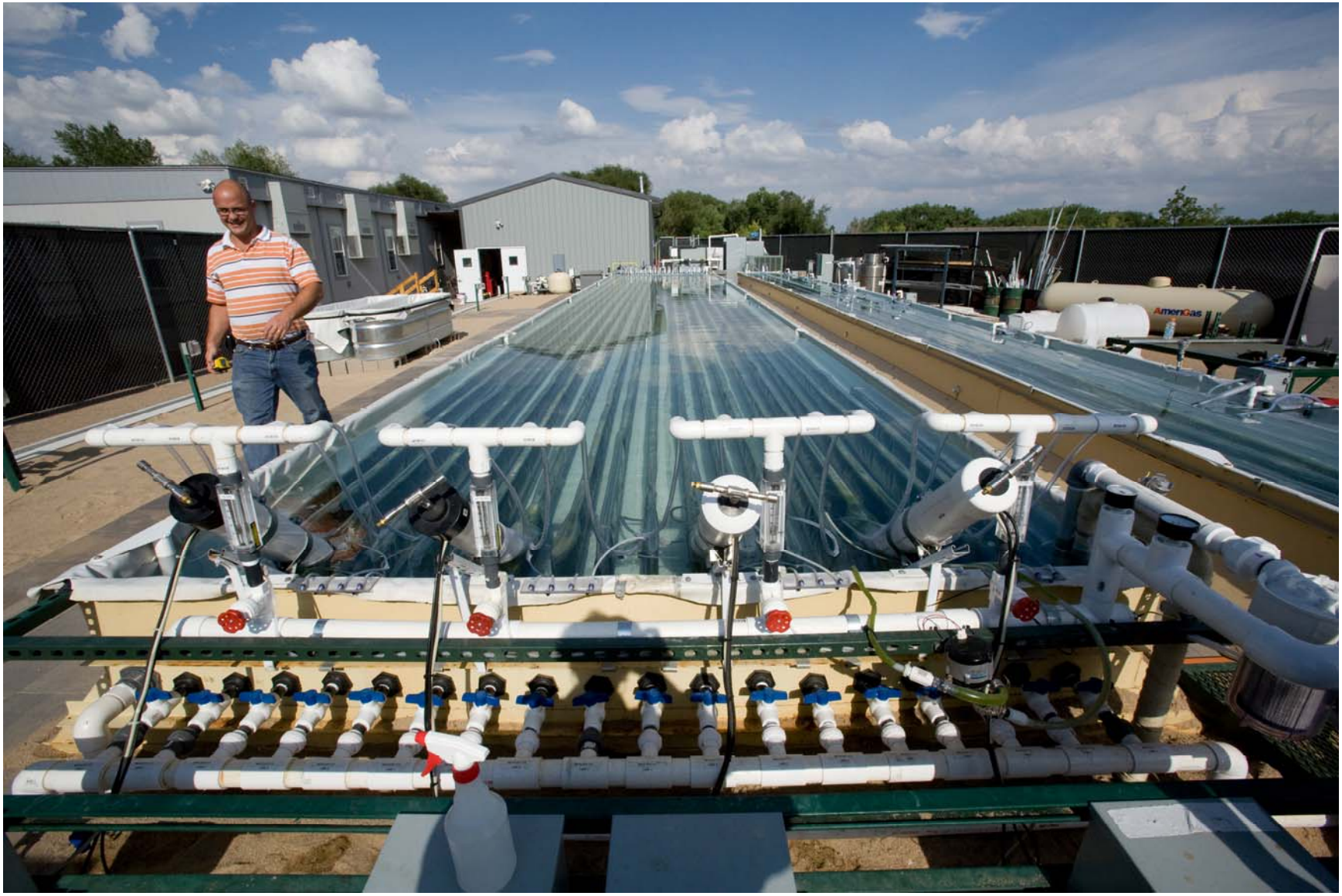
Solix G3 (cont)



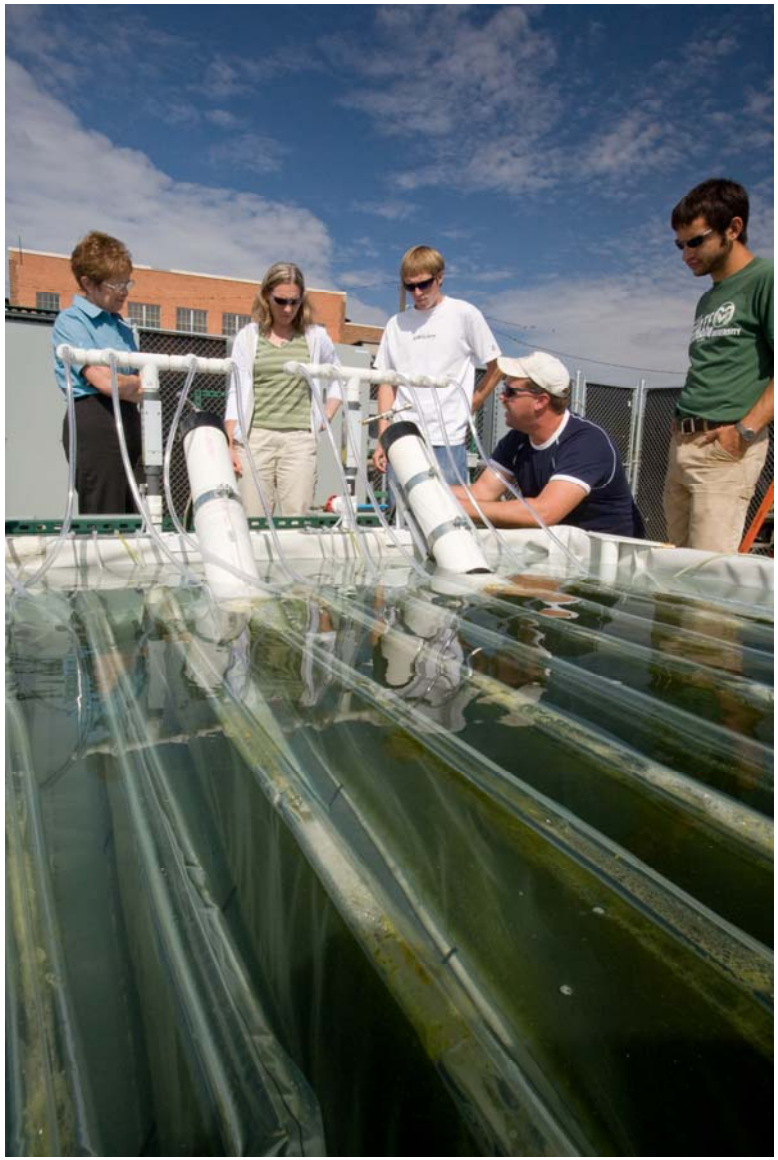
Solix G3 (cont)



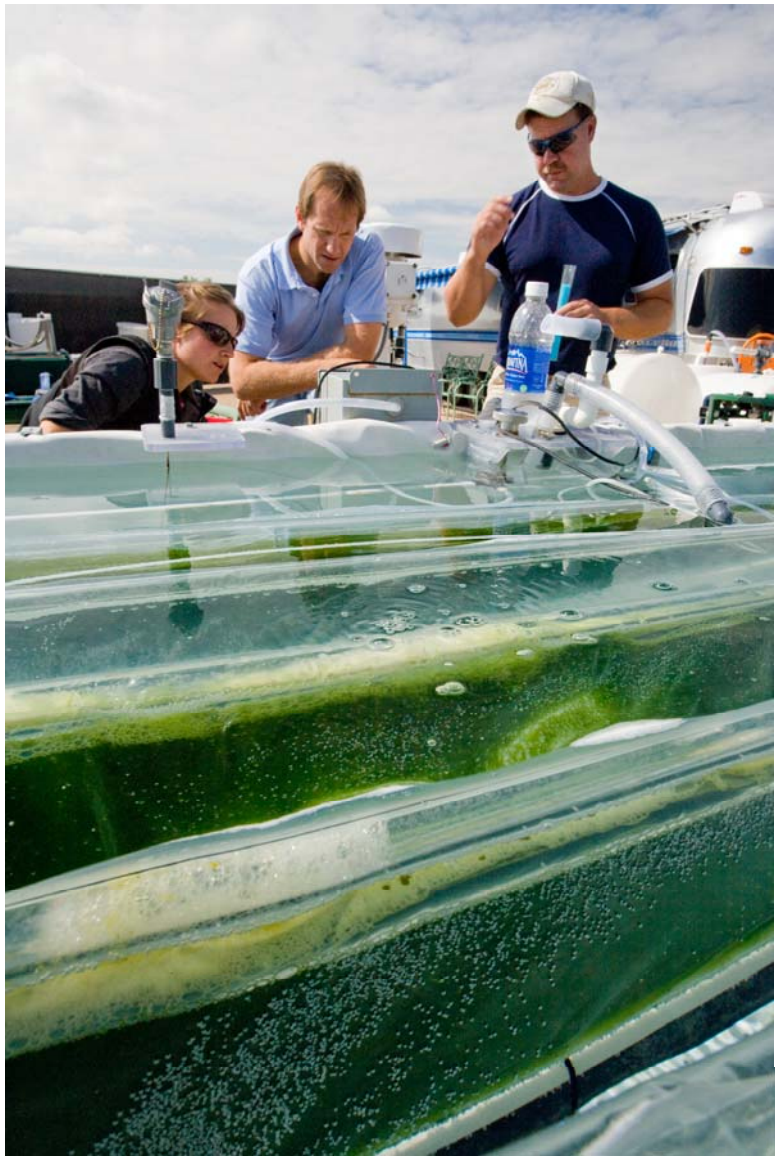
Solix G3 (cont)

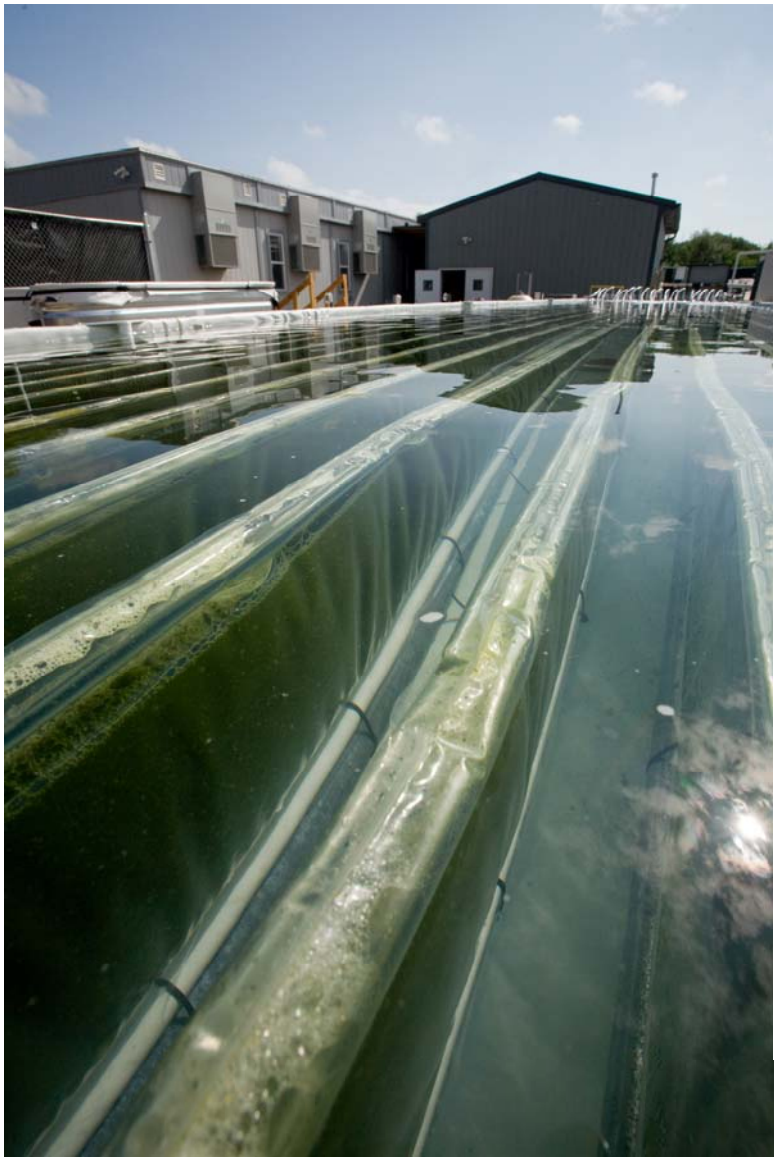


Solix G3 (cont)

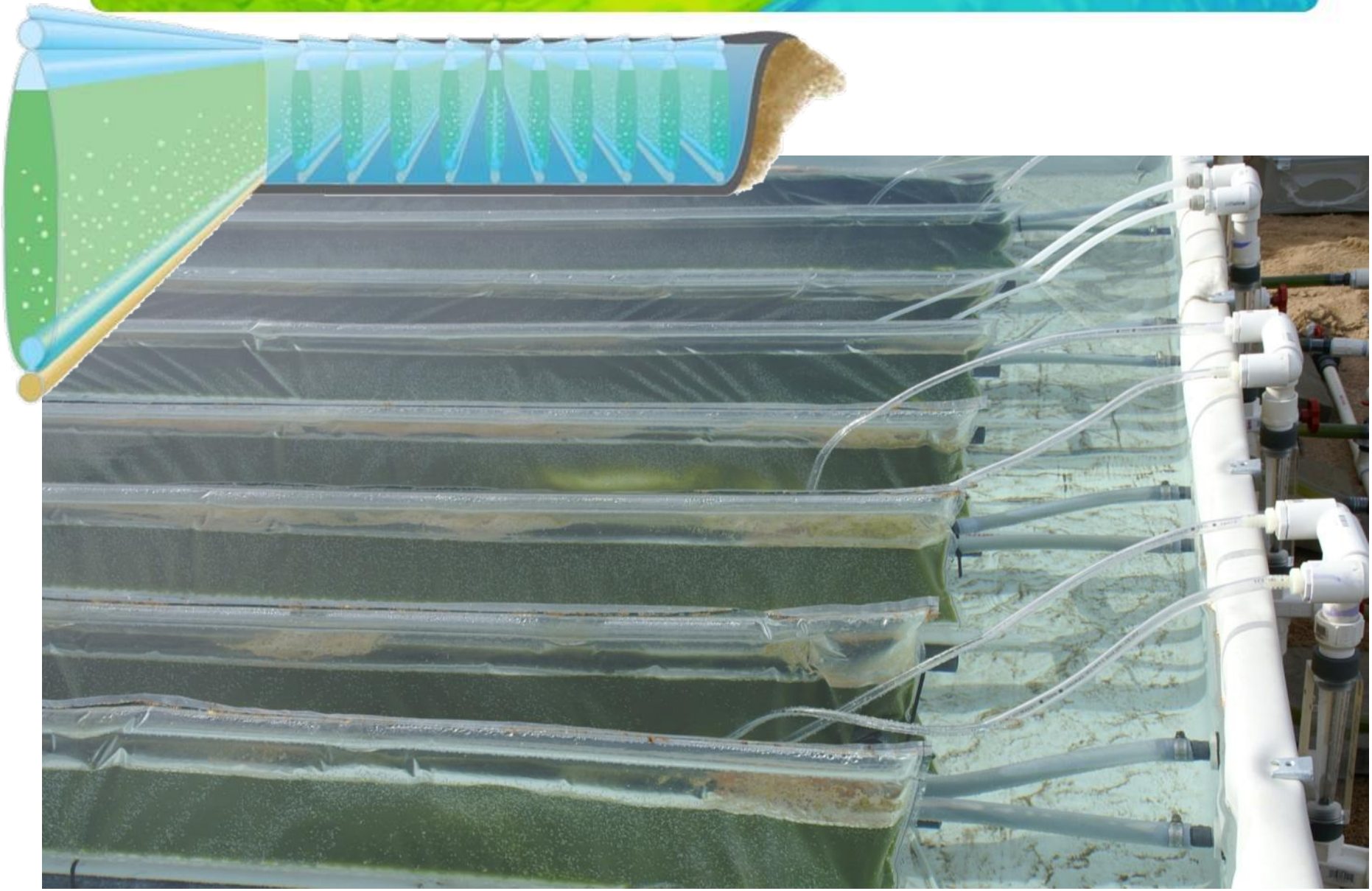


Solix G3 (cont)

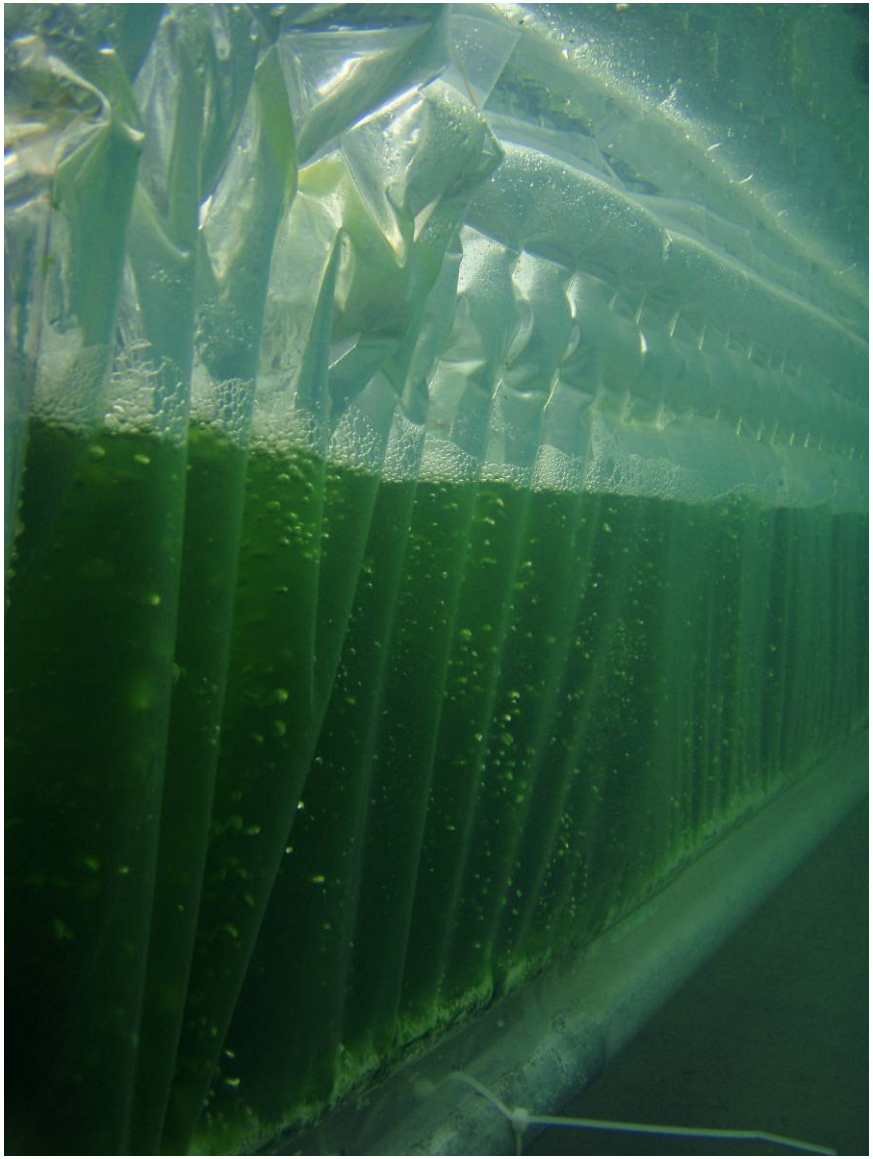




Solix G3 (cont)



Solix G3 (cont)



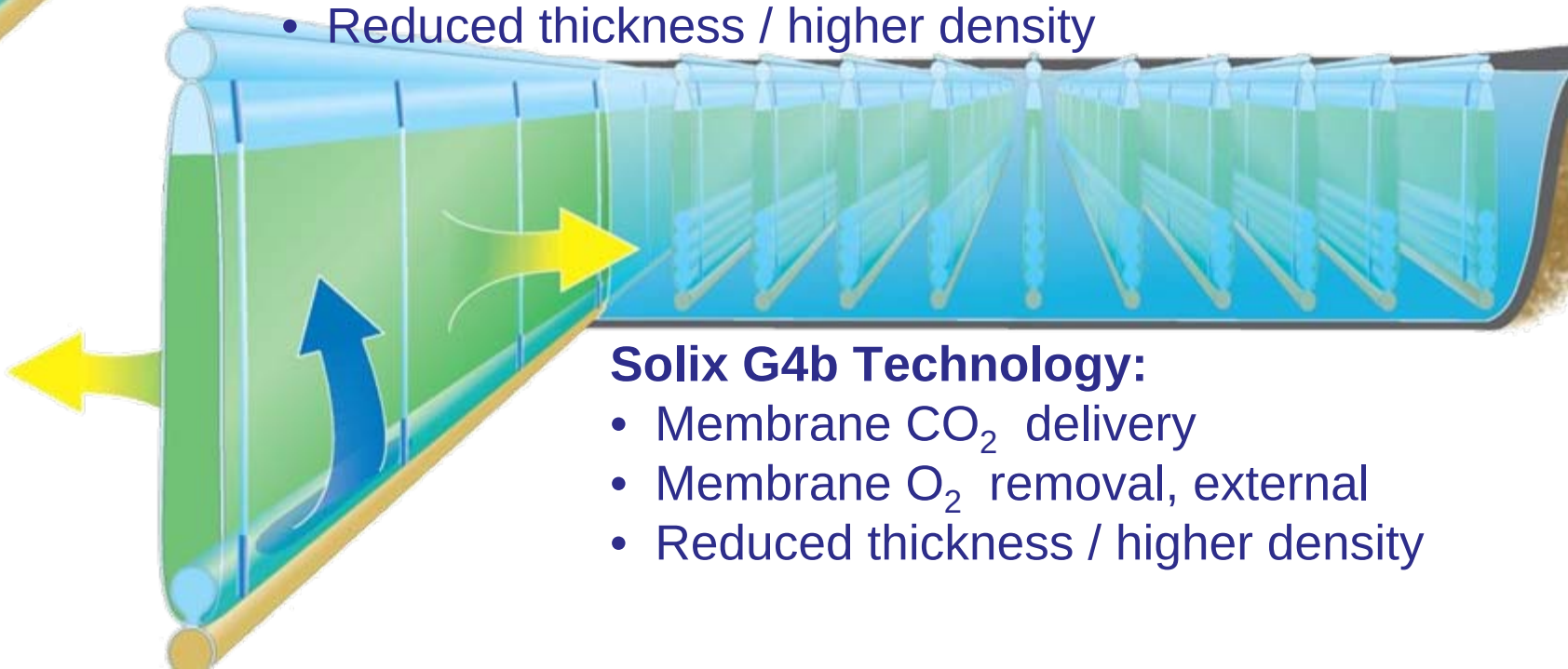
Solix G3 (cont)

Colorado – Algae Paradise?

Solix G4

Solix G4a Technology:

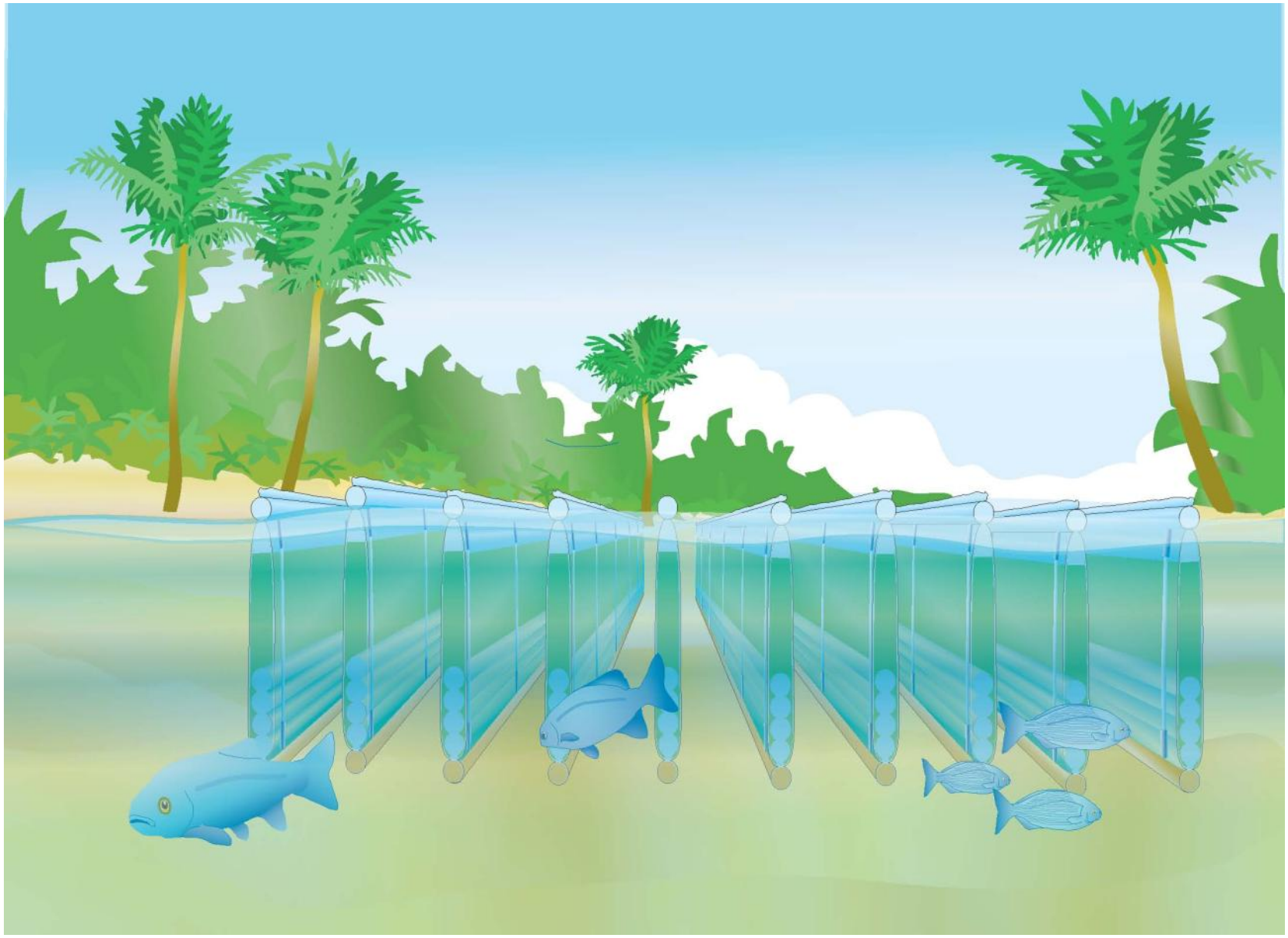
- Membrane CO_2 delivery
- Membrane O_2 removal, internal
- Reduced thickness / higher density



Solix G4b Technology:

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

Potential Open-Water Application



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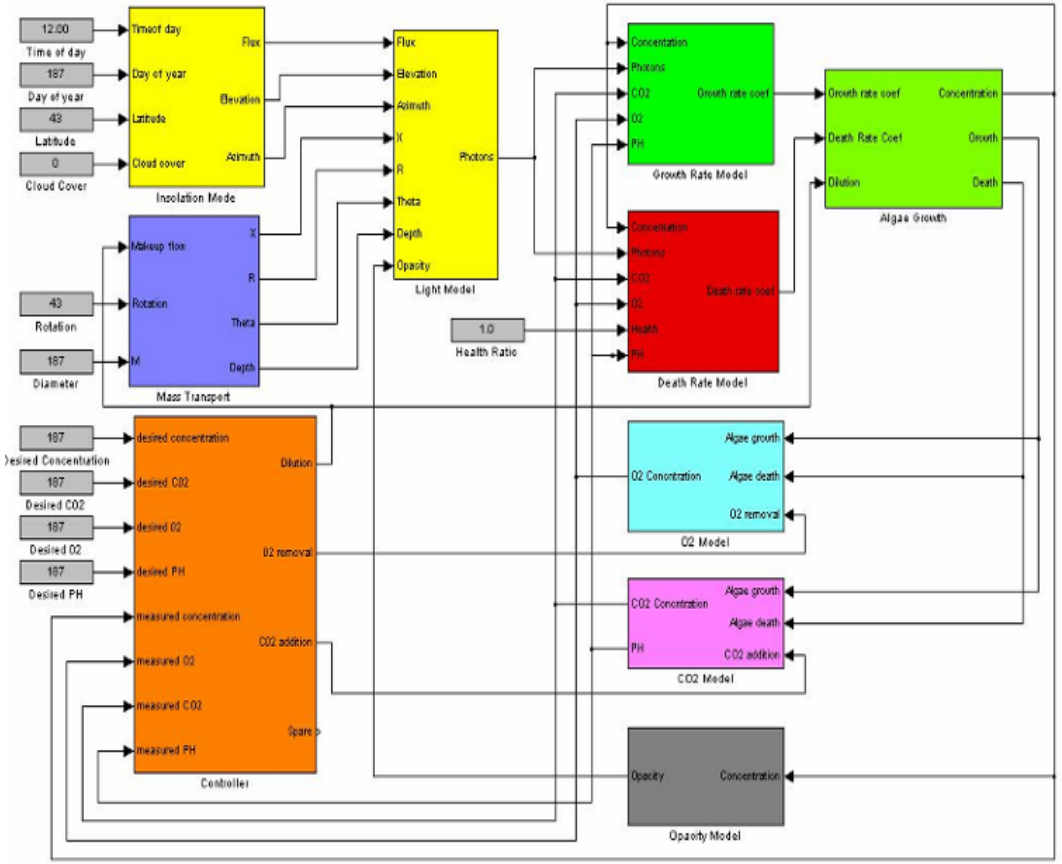
Model-Based Control

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



Biology

SOLIX

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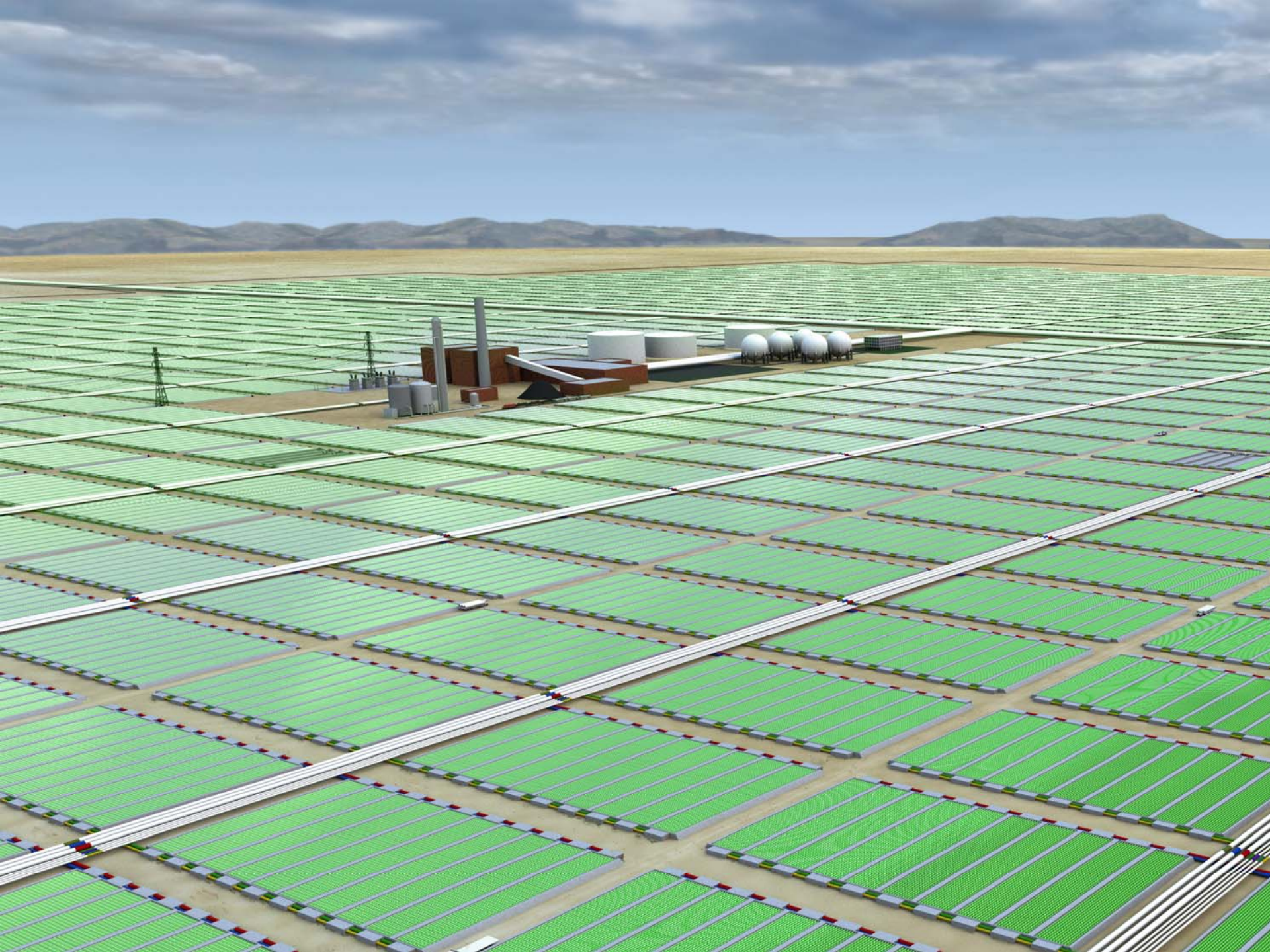
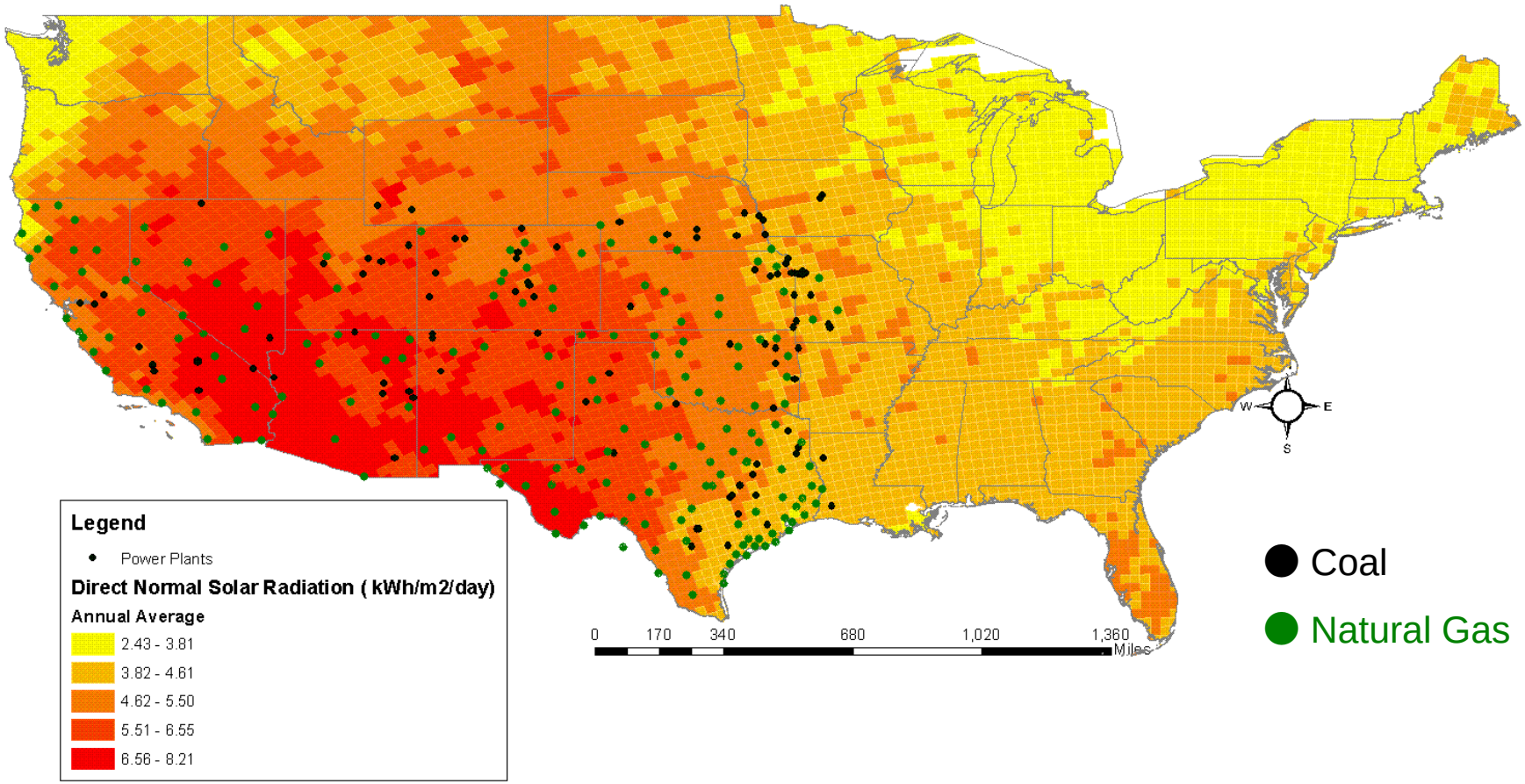


Power Plants in Southwest

Direct Normal Solar Radiation and Powerplant Locations



Initial Gemini Site: 1 acre

Potential CO2 Capture

Solix G3 (cont)

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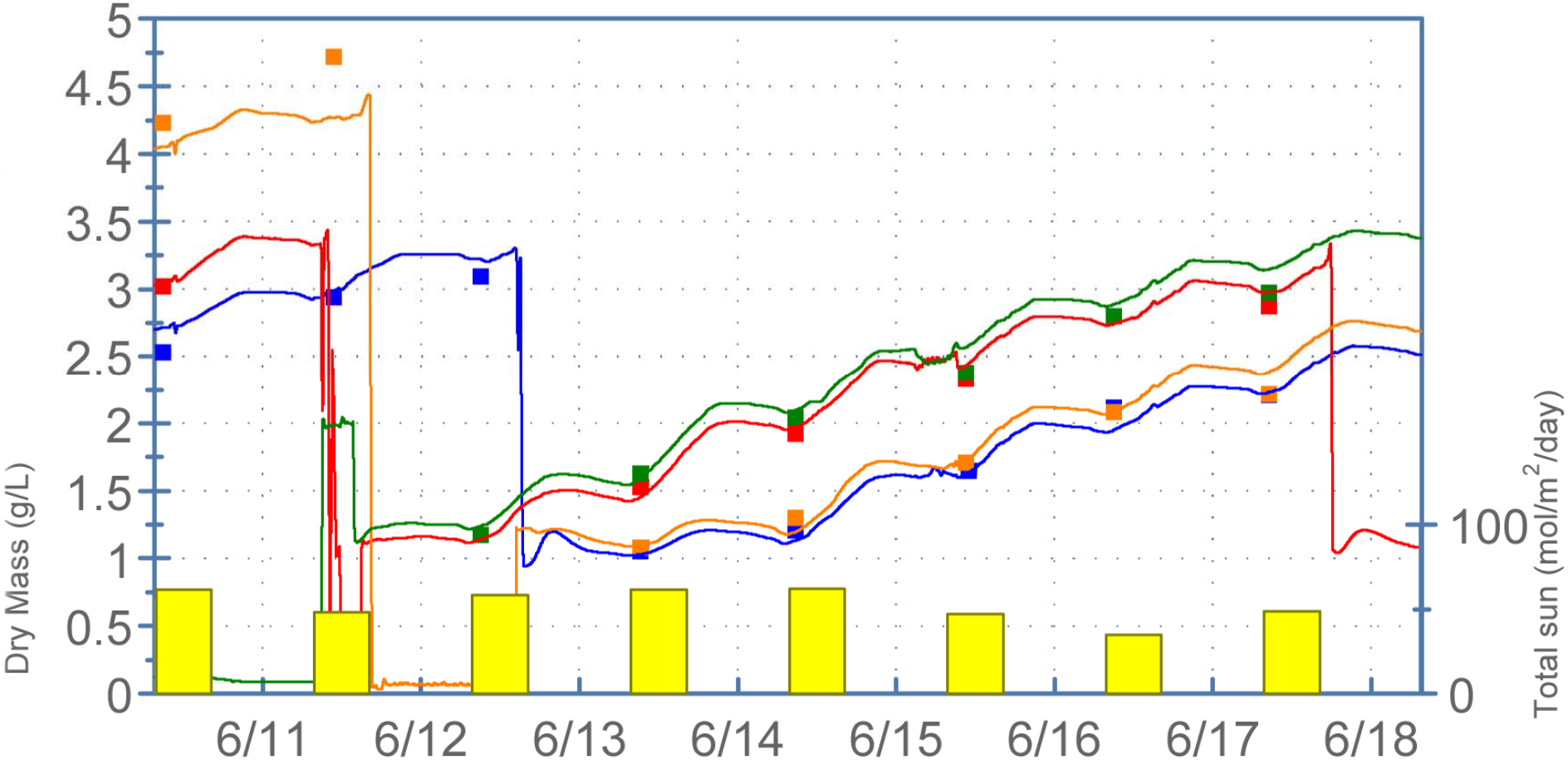
Automated Production Report



Production Metrics
(current & near-term)

Integrated PAR	10-65 mol/m^2/d
Culture Density	1-10 g/l
Volumetric Production	≈0-0.7 g/l/d (≈0.45 “typical” before depletion, ≈0.25 after)
Lipids (as FAMEs)	16% - 47%
Areal Production	0 – 24.5 g/m^2/d
Production	0 – 1800 gal/ac/yr
Expected productivity by ‘09 Q2:	30-40 g/m^2/d 2500 gal/ac/yr
Gen 2 Operation	May ’07 – Oct ‘07
Gen 3 Operation	Oct ’07 - present

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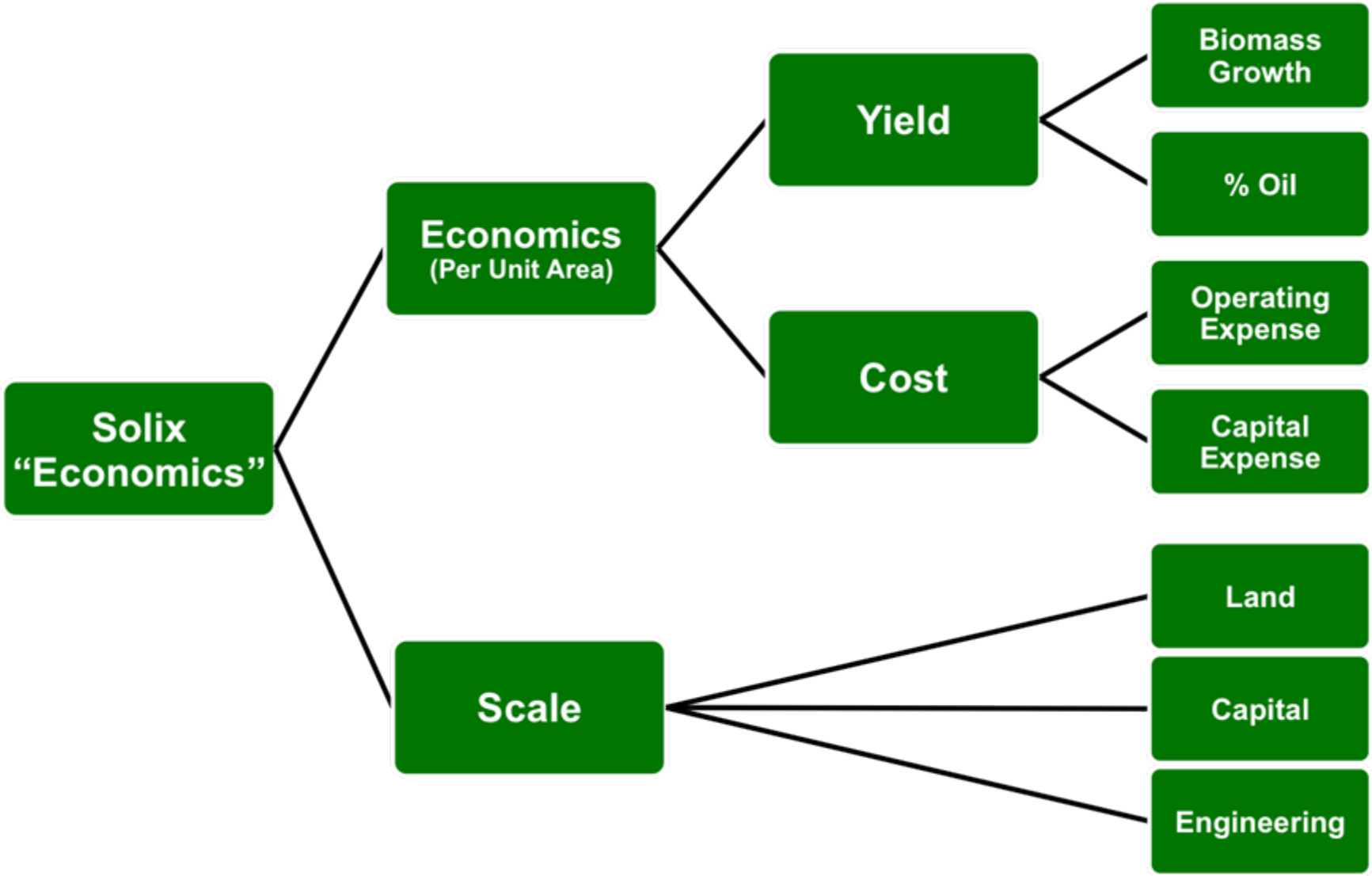
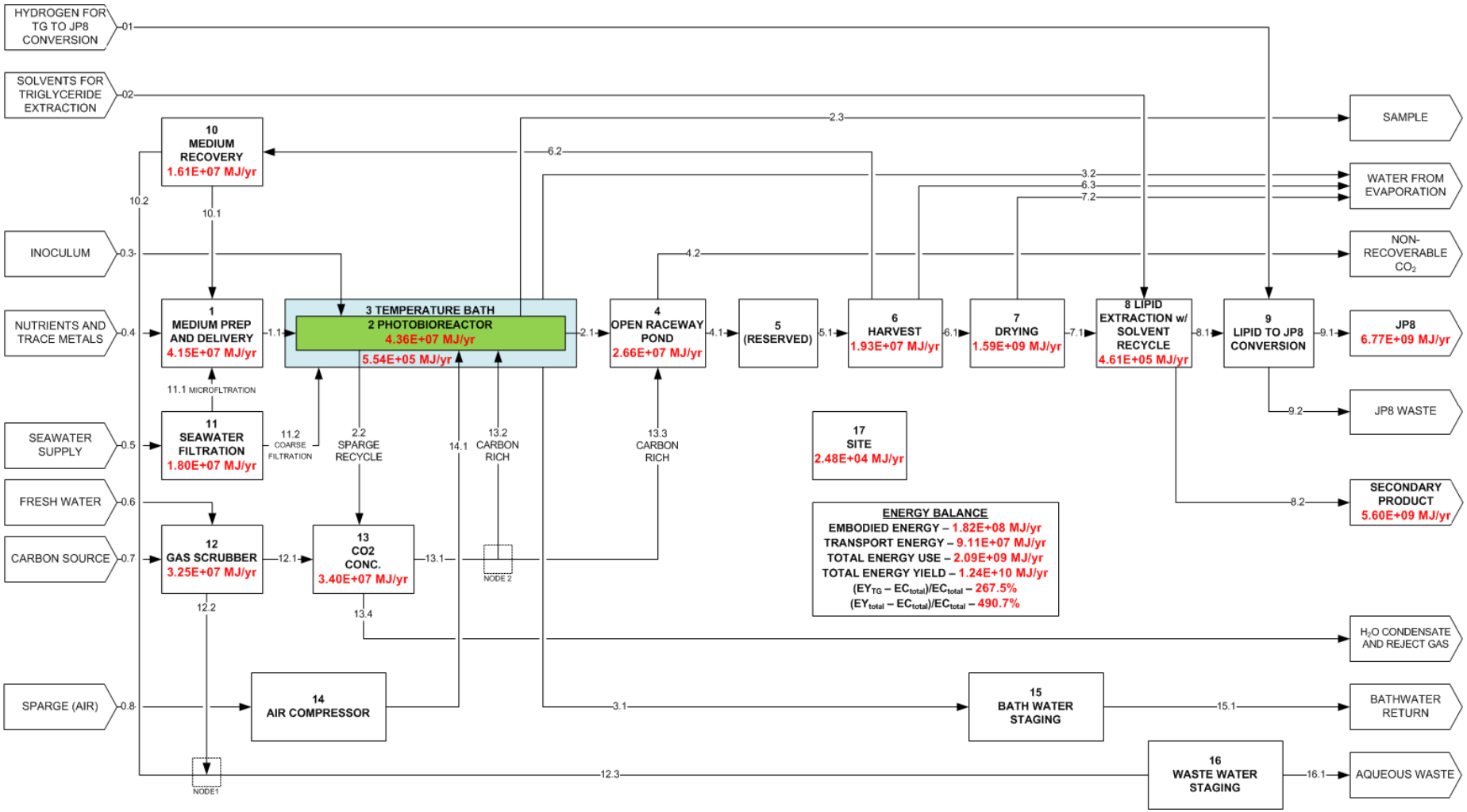
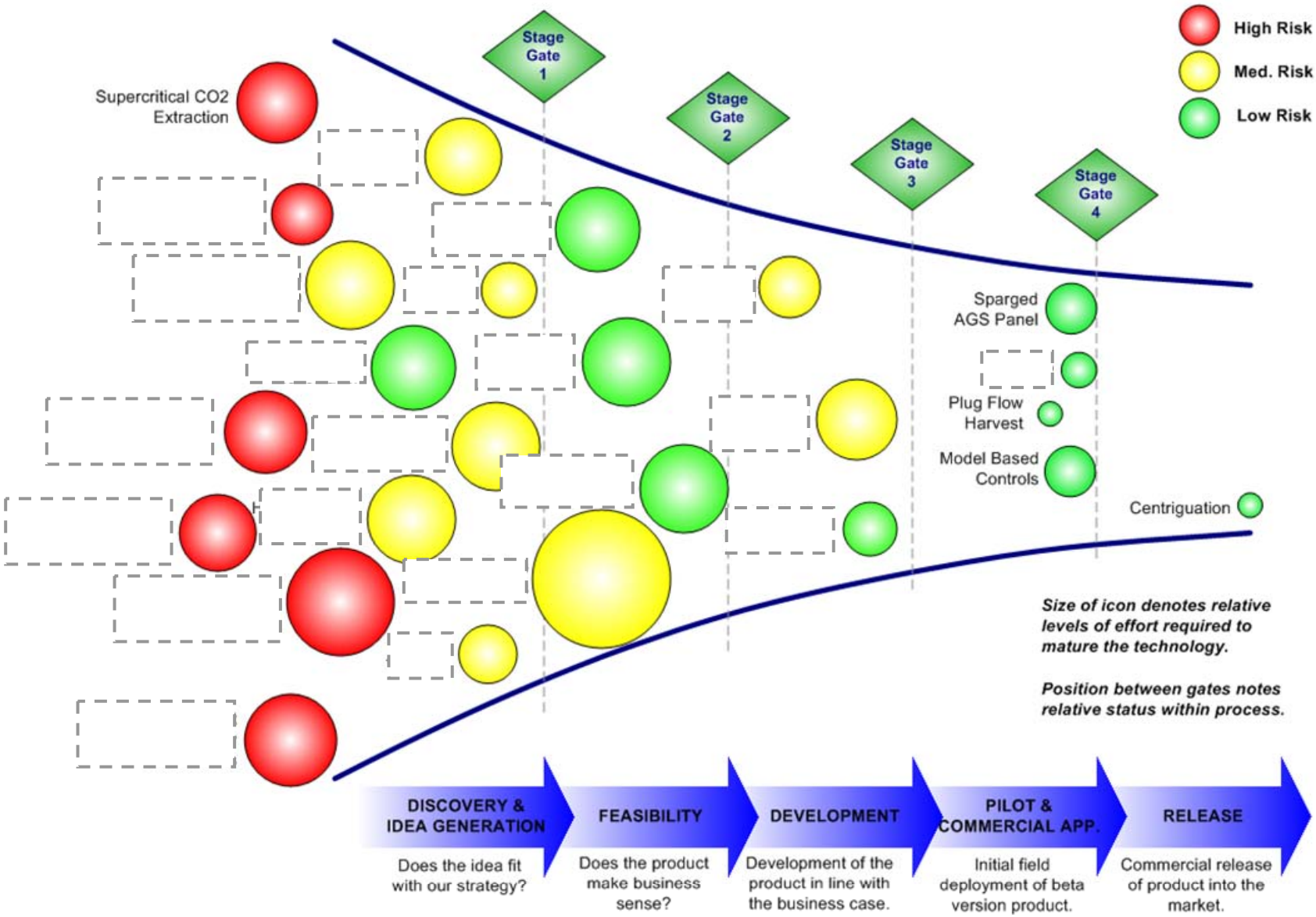
Economic Overview



System Analysis / Modeling

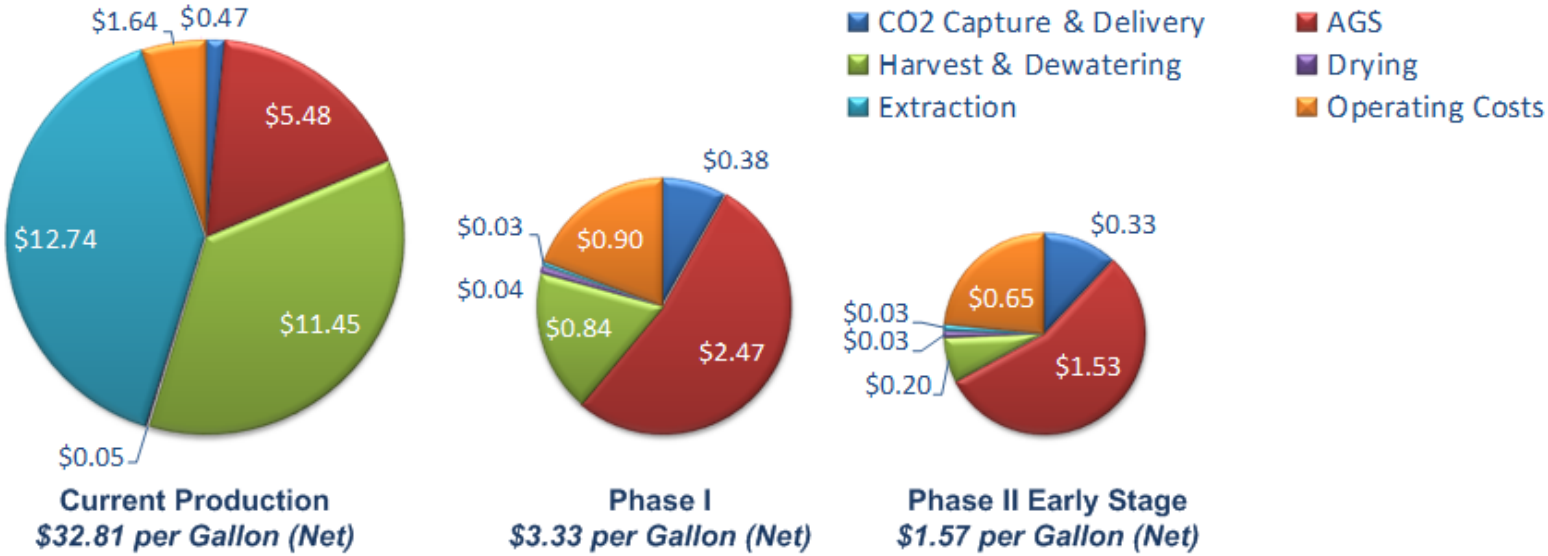


Technology Development Process



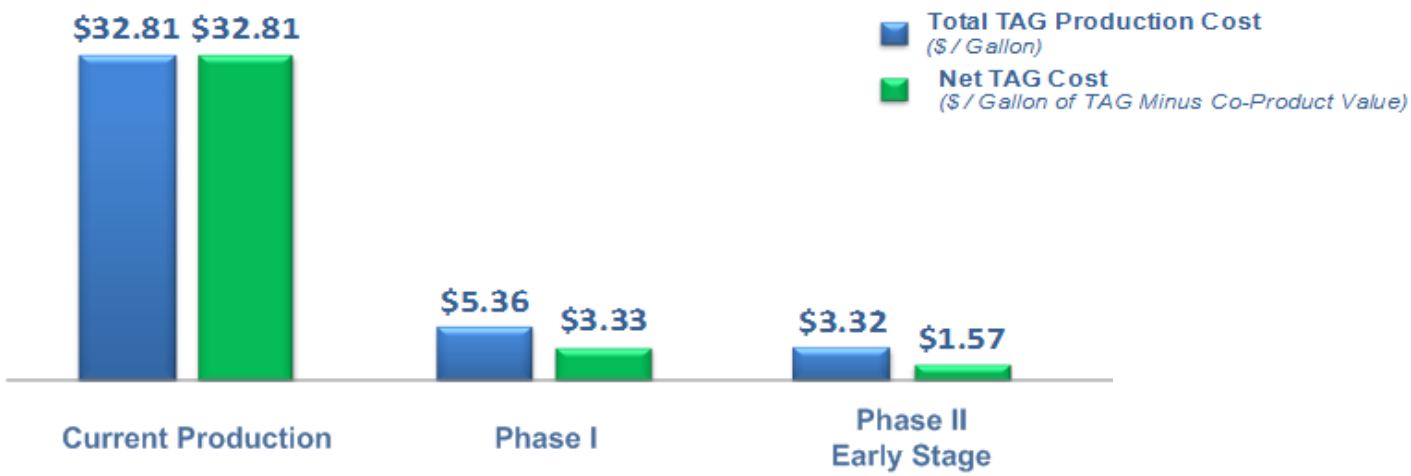
COST OF TAG PRODUCTION

(Production @ $0.06/kW-Hr)



Co-Product Impact On TAG Cost

($ per Gallon)



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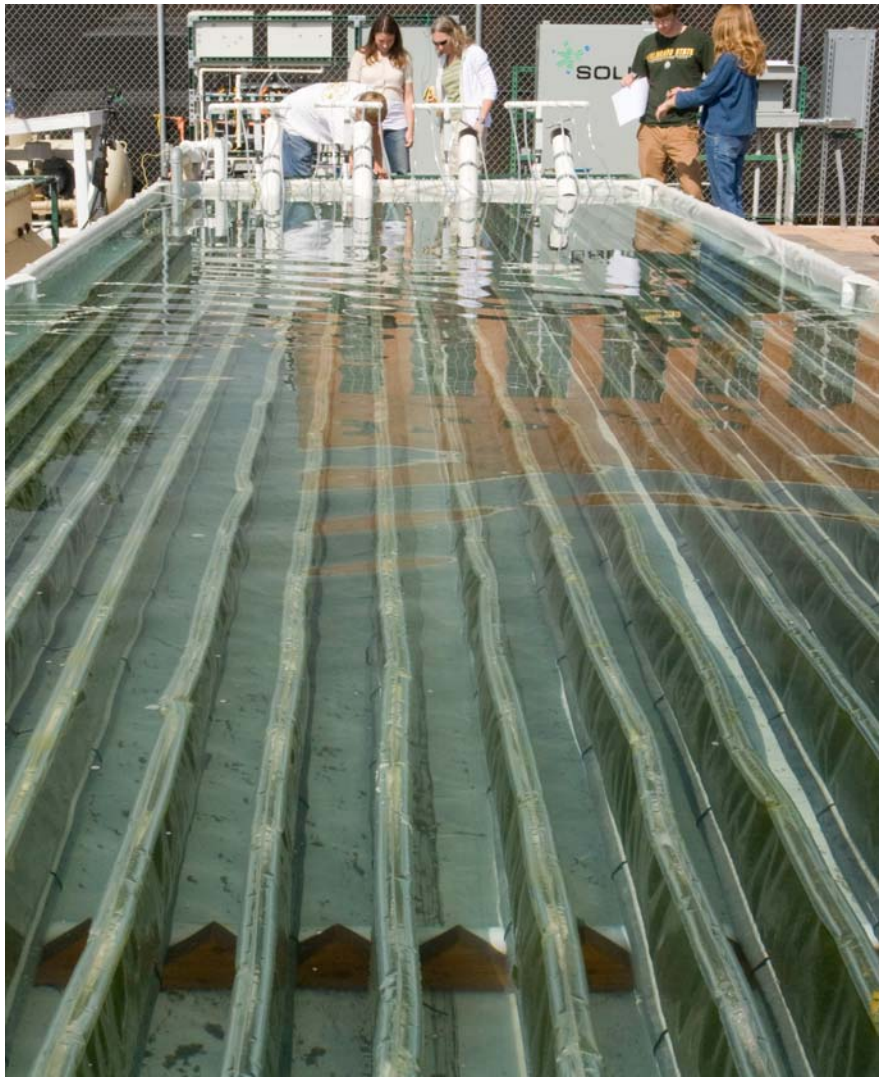
- Economical biofuel production appears feasible, using low-cost high productivity photobioreactors
- Requires tight coupling of biology and engineering
- Value of co-products must be captured; may approach or exceed value of oil
- Systems modeling/integration required to achieve cost targets

Contact Info

www.solixbiofuels.com

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