# Novel Bioreactors for Photosynthetic and Electrofuels-based Systems

Emerging Ideas Workshops

Robert Conrado

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# How can we achieve infrastructure compatible, fossil-fuel competitive energy production?

**Fuel production:** $100/barrel (5.9¢/kwh)

**Electricity production:** 5¢/kwh

- Can we borrow SunShot, $\$1/W_{e-}$ metric for photobioreactors
  - Leads to competitive energy production at 5-6¢/$kwh_{equiv}$
  - Metric breaks down when using concentrated light

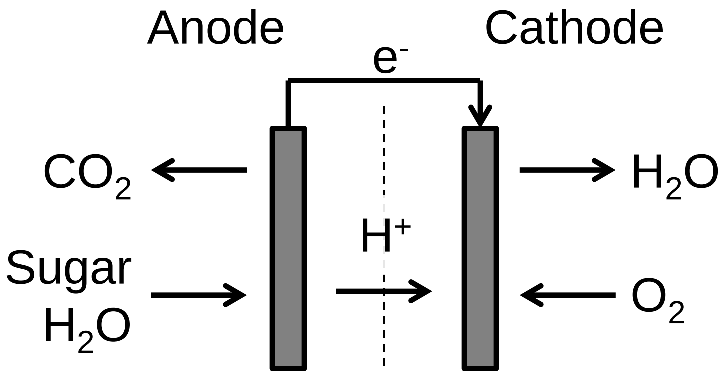
- As a frame of reference, cost of materials only ~30¢/$W_{e-}$ under this target
  - Quick reference to determine if you can afford certain components or materials

# Biological Energy Conversion

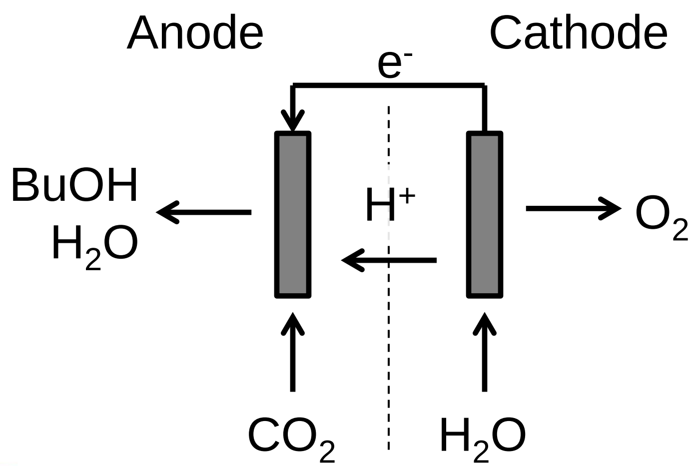
## Solar Fuels

$$CO_2 + H_2O \xrightarrow{\lambda\ (400\text{-}700nm)} BuOH + O_2$$

## Microbial Fuel Cell (MFC)




## Electrofuels



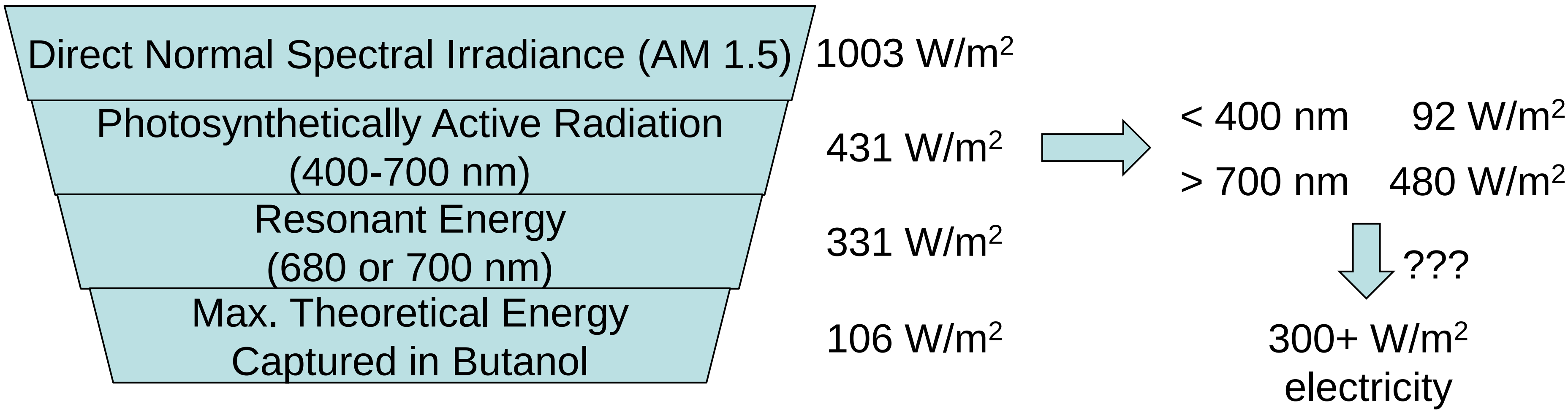
# Cost as function of kinetics and thermodynamics

- Kinetics has big impact on:
  - Reactor sizing
  - Difficultly of separations
  - Contamination, stability

- Thermodynamics has big impact on:
  - Efficiency
  - Difficulty of down-stream processing

# Thermodynamics of Energy Fuels

## Solar Fuels




## Electrofuels & Microbial Fuel Cells

- Thermodynamics driven by over-potential required for kinetics
- Limit for Electrofuels can approach 100 Coulombic efficiency
  - But at what rates?

# Required Kinetics of Solar Fuels and Electrofuels

$$\text{Power}_{in} \times (\text{SA::V}) \times \text{Conv}_{eff} = \text{Power}_{out}$$

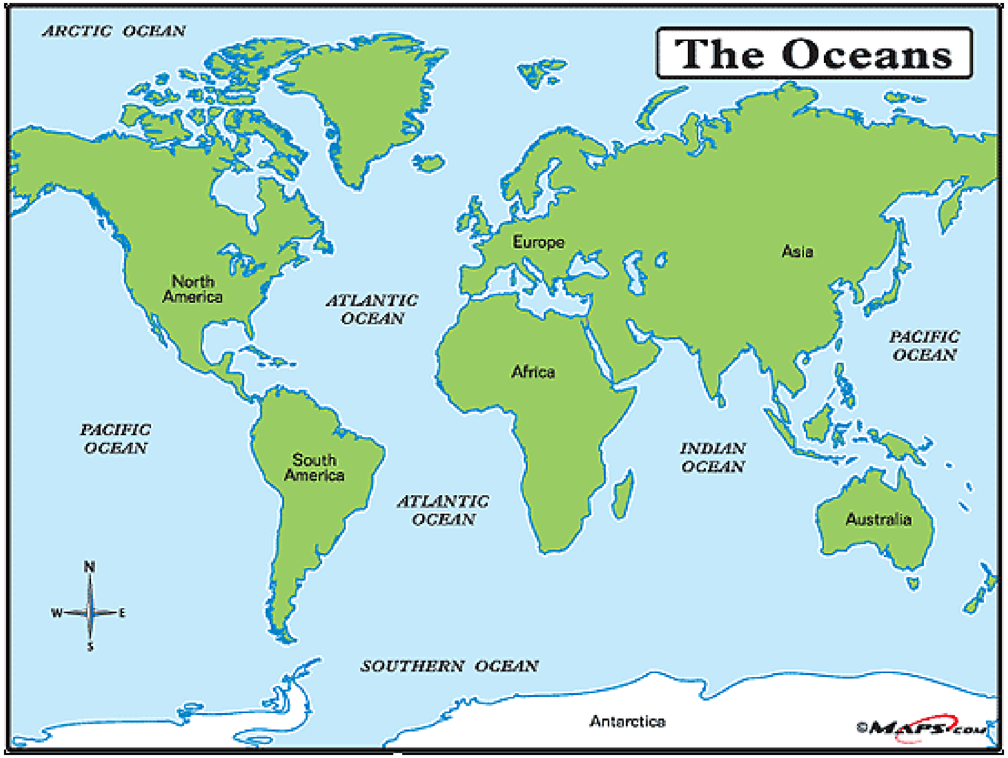
$$[\text{W/m}^2] \times [\text{m}^2/\text{m}^3] \times [\%] = [\text{W/m}^3]$$

$$[\text{g/L/hr}]$$

To achieve 2 g/L/hr butanol production

- **Solar Fuels** - Minimum SA::V = 200 $m^2/m^3$
- **Electrofuels** - Minimum SA::V = 10,000 $m^2/m^3$
  - Assuming 2A/$m^2$

# World-scale Phototrophic Reactors




# World-scale Electrochemical Reactors

| | Chlor-Alkali | Aluminum Smelting |
|---|---|---|
| Company | Dow Mitsui | Dubai Aluminum |
| Location | Westport, TX | Al Taweelah, Abu Dhabi |
| Production Rate (M tons/yr) | 0.9 $Cl_2$ | 1.5 Al |
| Production Rate (BOE/d) | 1100 | 7200 |
| Required Current | $7x10^7$ Amps | $5x10^8$ Amps |
| Required Power | | 2.35 GW |
| Project Cost | $0.411 B | $5.7 B |
| CapEx ($/BPD) | $400,000 | $800,000 |
| Co-products | 0.98 M tons/yr (NaOH) | 50 M tons/yr (fresh water) |

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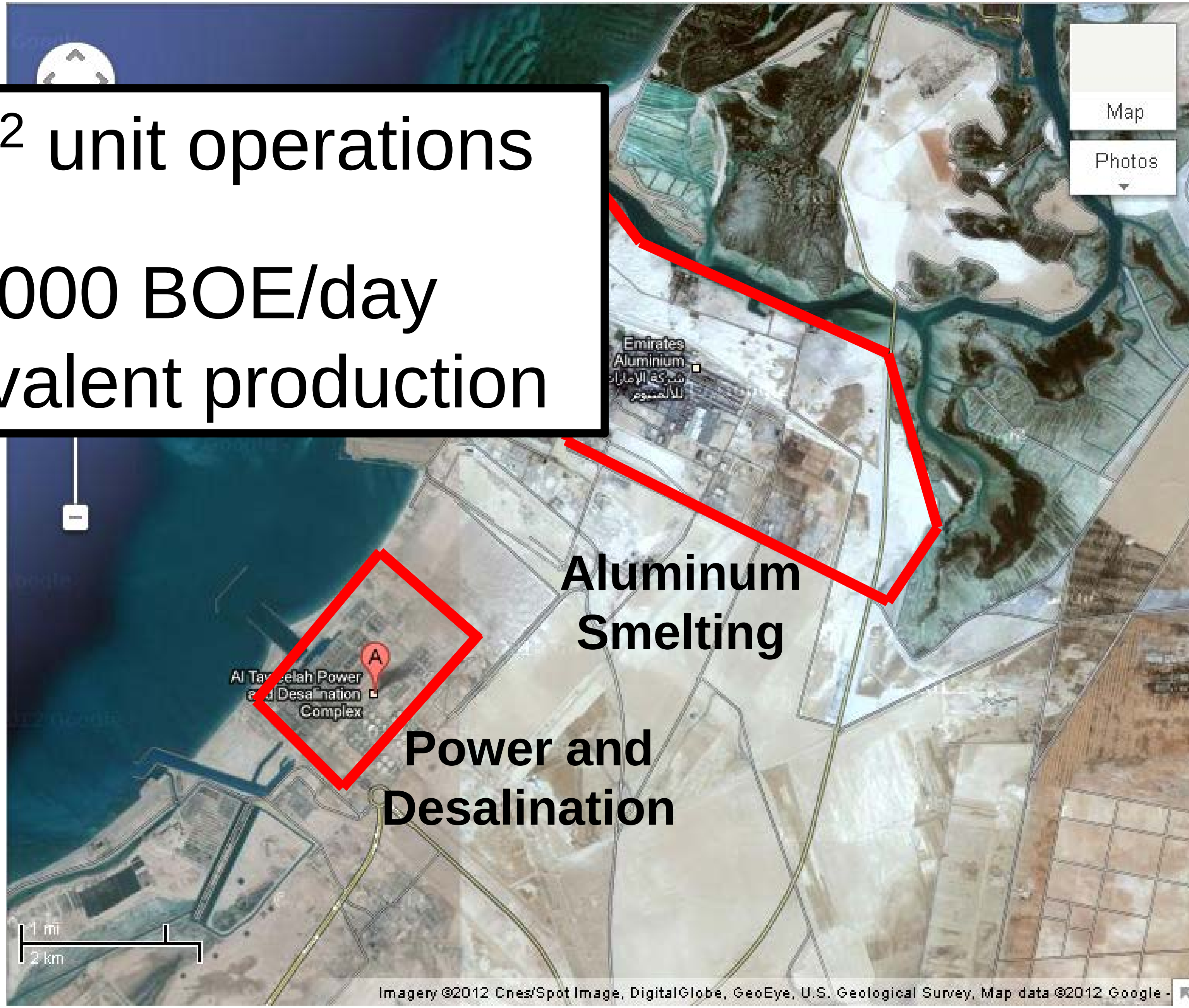
# Dubai Aluminum, Abu Dhabi


1 mi
2 km

# Dubai Aluminum, Abu Dhabi

6 mi$^2$ unit operations

7000 BOE/day equivalent production

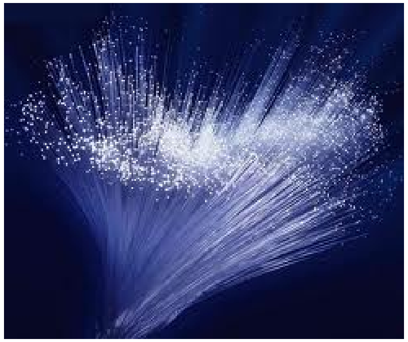



1 mi
2 km

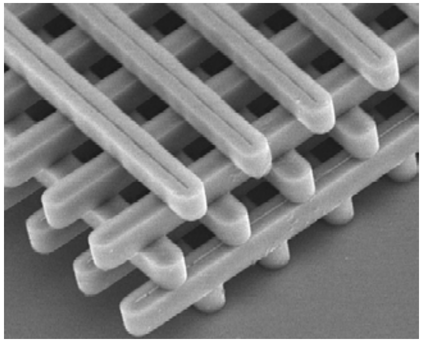
# Aluminum Smelting Scaled Out

# Focus on bioreactors with high SA::V ratios

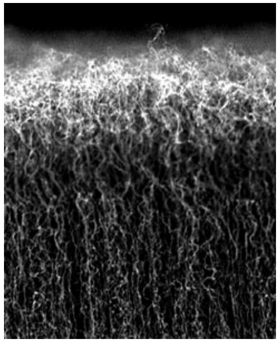
- High productivity requires high ratio
- High thermodynamic efficiency keeps this ratio achievable



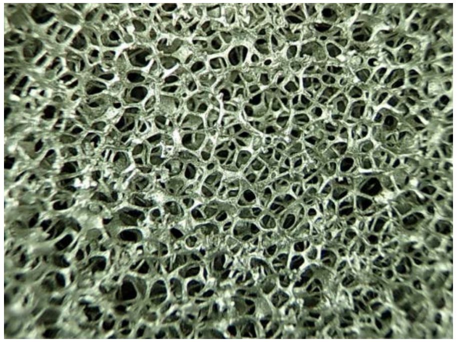
**Optical Fibers**
**$10^3$-$10^4$ $m^2/m^3$**



**Photonic Crystal**
**$10^5$-$10^6$ $m^2/m^3$**



**Battery Electrode**
**$10^3$-$10^4$ $m^2/m^3$**



**Nickel Foam**
**$10^3$-$10^4$ $m^2/m^3$**

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# Other requirements – heat and mass transfer

Mass transfer requirements @ 2 g/L/hr

- $k_L a$ ~ 10 is required with pure $CO_2$
- **Observation:** May require microbubbles to avoid pressure drop in high surface area reactors
  - Bubble diameter must be less than the feature size

Heat transfer requirements @ 2 g/L/hr

- 18 $kW/m^3$ is power output
- **Observation:** May need to remove > 50 $kW/m^3$ heat for photobioreactors
  - Can this be accomplished without evaporating water?

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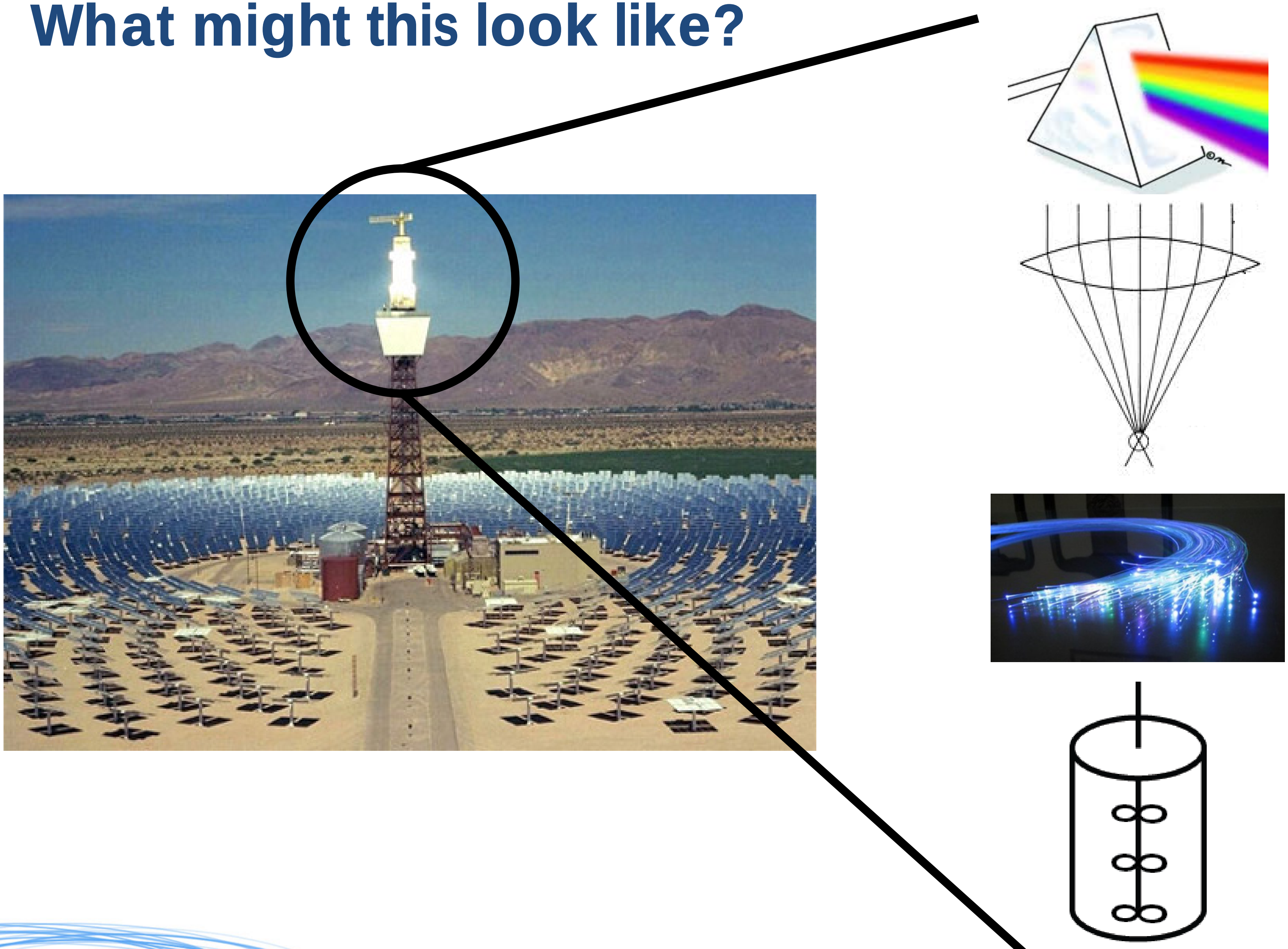
# What might this look like?



# Agenda – Bioreactor Workshop

| | |
|---|---|
| 8:45 AM – 10:00 AM | Introductions, 1-Slide Each |
| 10:00 AM – 10:15 AM | BREAK |
| 10:15 AM – 12:00 PM | Morning Breakout Sessions |
| 12:00 PM – 12:45 PM | Lunch and Breakout Reports |
| 12:45 PM – 1:00 PM | BREAK |
| 1:00 PM – 2:45 PM | Afternoon Breakout Session |
| 2:45 PM – 3:00 PM | Coffee Break |
| 3:00 PM – 3:30 PM | Breakout Summary and Wrap Up |