Valorising CO₂ with the Photosynthetic Factory

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Today’s theme
Good Circle or Bad Circle
A Good Circle

circular economy

Design/manufacture

Retailer

Consumer/householder/LAs

Re-use/repair/recycling

Recycling sector
A Bad Circle
Global CO$_2$ Balance – The Hard Way
Global CO$_2$ Balance – The Hard Way
Global CO$_2$ Balance – The Better Way
Global CO$_2$ Balance – The Better Way
To achieve the better way

• We need to replace most fossil fuels with renewable substitutes.
• Substitution allows us to retain the valuable energy services while....
• Slowing and eventually reversing the atmospheric build up of CO$_2$ with realistic CO$_2$ capture
## Scale! Scale! Scale! Scale! Scale!

- Human activities now use ~16 TerraWatts (TW = a trillion watts = 10-billion 100-watt light bulbs) of energy.
  - ~84% is from fossil fuels (13 - 14 TW): 34% oil, 32% coal, 14% natural gas
- Current rates of energy use project a 60% increase by 2030.
- Thus, bioenergy sources must work on a **very large scale** to be of significant value towards the goal of replacing fossil fuels.
• Human Energy Use Rate: ~16 TW total, 13-14 TW fossil

• Sunlight hitting the Earth’s surface: 173,000 TW
  – More than 10,000 times what we use
  – Here is the upside potential

• Sunlight energy captured as all biomass: ~140 TW
  – Only 11 times more than we use in fossil fuels today
  – Here lies the heart of the scale problem today: Human society demands more energy than is routinely and safely provided by natural photosynthesis.
The Principle For Renewable Bioenergy

1. Solar energy is captured by photosynthesis into biomass and takes up CO$_2$. The electrons come from H$_2$O.

2. Some biomass can be used directly as a bio-fuel, such as wood. Most biomass is converted into other useful forms that are......

3. Converted to useful energy for electricity, heating.

The generation steps return CO$_2$ to the biosphere $\Rightarrow$ C neutral!
Areal productivity is 10- to 100-fold higher with photosynthetic microorganisms!

or

Plant photosynthesis is (much) less than 1% efficient

And, photosynthetic microorganisms do not compete for arable land, since they grow in a water slurry, not in soil!

Photosynthetic microorganisms do better ~ 4%
A “classic” approach is to grow massive amounts of biomass, preferably with high lipid content.

Inputs are sunlight and CO₂, the true resources.

The left side could be, instead of an MFC for electricity, an MEC for H₂, anaerobic digestion for CH₄, or some combination.
What’s the “rub” today?

1. The cost of the output product is way too big! -- Gasoline for $20/gallon!?! 
2. The productivity is too low to offset the capital costs. 
   1. Good today: 20 g DW/m$^2$-day
   2. Realistic today: 5 – 10 g DW/m$^2$-day
   3. The potential: up to 100 g DW/m$^2$-day

3. What is stopping us?
A “classic” approach is to grow massive amounts of biomass, preferably with high lipid content

Roadblock 1: CO₂ Delivery and pH Control
ACED – Atmospheric CO$_2$ Enrichment and Delivery

- A new DoE-funded project
- PIs: Bruce Rittmann and Klaus Lackner
- Make it possible to have high-rate CO$_2$ delivery and pH control in any sunny place
ACED Concept
Atmospheric CO₂ Capture and Membrane Delivery

1. CO₂ Capture
2. CO₂ Release
3. CO₂ Storage (bicarbonate)
4. CO₂ Delivery (membrane)

Open Pond
Photobioreactor
Bench-scale Experimentation

Can achieve:
- High transfer fluxes
- 100% CO$_2$ transfer
- Precise pH control
Based on our past work with commercially available gas-transfer membranes, we project being able to supply enough CO\textsubscript{2} to support a productivity of 50 g DW/m\textsuperscript{2}-day with a specific surface area of only 10 m\textsuperscript{2}/m\textsuperscript{3} in moderately bright light and with only 5% CO\textsubscript{2}.

We now anticipate 80% CO\textsubscript{2} or higher.

Essentially infinite delivery capacity with a few fibers.
A “classic” approach is to grow massive amounts of biomass, preferably with high lipid content.

Roadblock 2: Harvesting the biomass when it is growing fast.
Maximizing the Biomass Production Rate

The integrated PBR+MFS system. The system features a coupling between a PBR and a membrane filtration system (MFS).

The goal is to make biomass harvesting independent from the water flow rate. Done properly, we can have a very high biomass production rate and a very small water flow through.

In the terminology of environmental biotechnology: SRT << HRT!!
The best predicted performance is for ~1,000 mg/L DW and is stable with LI from ≥~ 150 W/m$^2$ PAR (690 µE/m$^2$-sec). The top production rate is ~ 600 mgDW/L-day, which translates roughly to 90 gDW/m$^2$-day for a 6-inch water depth: i.e. 4.5-fold faster than our “good today” value.
Actual PBR-MFS System in the Lab

- PBR
- Harvest tank
- Feed tank
- Feed pump
- Harvest pump
- Pellicon II
- Pellicon II pump
- Permeate tank
- BT-PBR
- Synechocystis
- Modified BG-11
- Biomass
- MFS
- Permeate tank
So far, in semi-continuous operation, production rates as high as 550 mg-DW/L-day were attained at the highest possible incident PAR light setting ($L_{I_0} \sim 160 \text{ W/m}^2$ (725 $\mu$E/m$^2$/s)). This translates to as much as 82 g DW/m$^2$-day.
Overall Summary

• Photosynthetic microorganisms hold high promise for producing enough renewable, biomass-based energy to have a chance to replace fossil fuels without causing severe environmental and social problems.

• The weak link so far is low productivity.
Overall Summary

• ACED and the integrated PBR+MFS hold the keys to increasing productivity up to 10 fold.
  – Overcoming cost barriers
  – Making it possible to have a “photosynthetic factory” in any sunny place.
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The optimal pH is 8.5, and $C_i \leq \sim 0.2$ mM ($= 2.4$ mgC/L) seriously slows photosynthesis. No need to have very high $C_i$, but pH control is of true value. $C_i \sim 1$ mM = 12 mgC/L and pH of 8 – 9 are good.