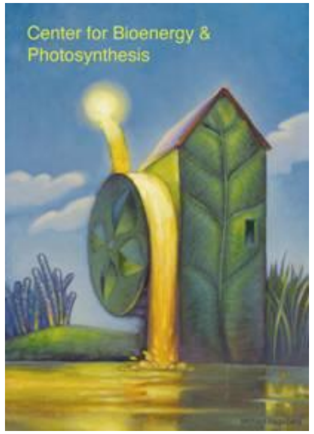
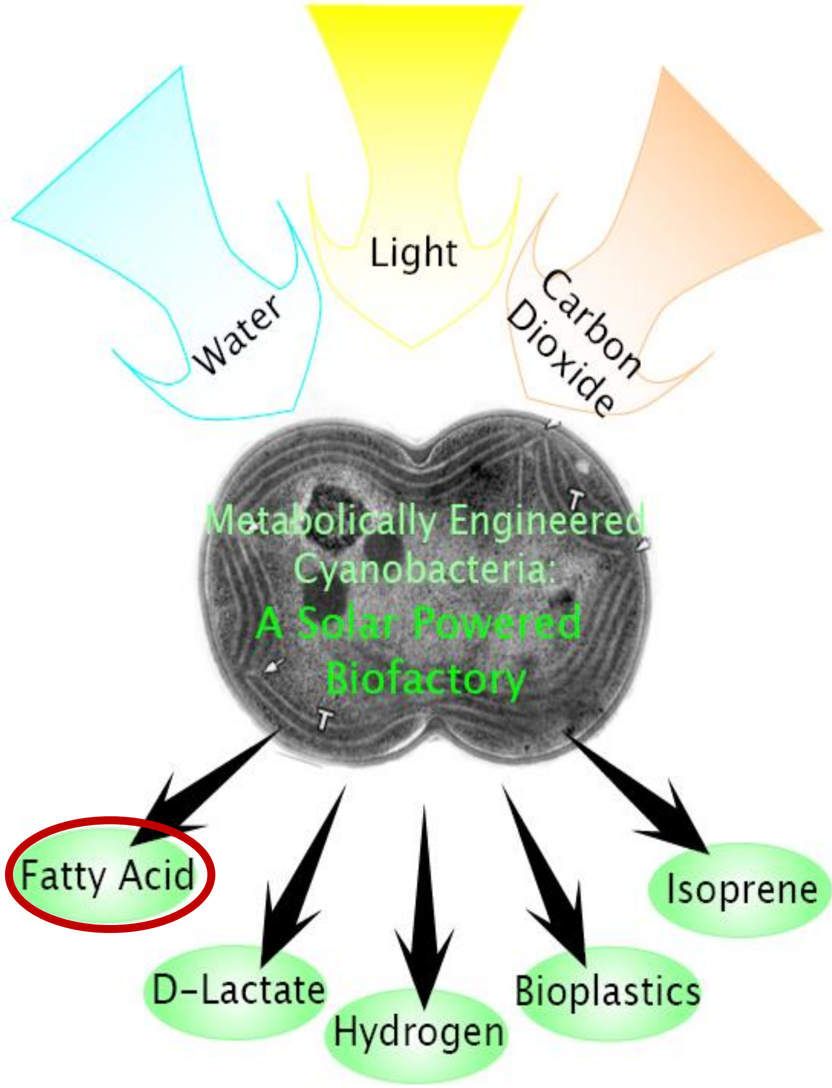
Photosynthetic Energy Conversion Efficiency for Bioproduct Formation

Wim Vermaas
Foundation Professor
School of Life Sciences, and Center for Bioenergy and Photosynthesis
Arizona State University, Tempe, AZ, USA
(480)965-6250; wim@asu.edu





"Gold standard" for photosynthetically generated fatty acids

Carbon fixation:

24 CO_2 + 64 ATP + 40 NADPH -> 8 PGA + 64 ADP + 40 NADP + 64 P_i

8 PGA + 8 ADP + 8 P_i + 8 NAD + 8 CoA -> 8 acetyl-CoA + 8 CO_2 + 8 NADH + 8 ATP

8 Acetyl-CoA + 7 ATP + 16 NADPH -> 8 CoA + C16 fatty acid + 7ADP + 7P_i + 16 NADP

Net: 16 CO_2 + 63 ATP + 48 NADPH -> C16 fatty acid + 63 ADP + 63 P_i + 48 NADP

PGA: 3-phosphoglycerate, the immediate product of the RuBisCO-catalyzed reaction

Good source: David White, The Physiology and Biochemistry of Prokaryotes, Oxford

Light reactions (linear electron flow):

48 H_2O + 48 NADP + 192 hν + 64 ADP/P_i -> 48 NADPH + 24 O_2 + 64 ATP

A mole of quanta of 680 nm light: 177 kJ

A mole of C_{16} fatty acid: 9800 kJ

Maximum energy efficiency (680 nm illumination): 9800x100%/(177x192) = **28%**

"Direct" conversion of fixed CO_2 into fatty acids: no need for making carbohydrates

28% energy conservation sounds pretty spectacular...

But:

1. Sunlight covers a wide spectrum, and only half the energy is photosynthetically active radiation (PAR). 28% -> 14%
2. Blue photons have almost twice more energy than red ones, but still count as one photon. 14% -> 10%
3. There is often loss due to non-photochemical quenching, and even if cells do not grow they still need maintenance energy. 10% -> 7%. **Still quite respectable!**

Current efficiency:

- Make 150 μM laurate per day with 150 μmol photons m^{-2} s^{-1} white light (30 cm^2, 200 mL)
- This is equivalent to 30 μmoles laurate produced by 39 mmol photons, so 1,300 photons per laurate
- The maximum 28% efficiency corresponds to 144 photons per laurate
- So, we are at about 1/9th of the maximum efficiency; not a bad start but room for improvement

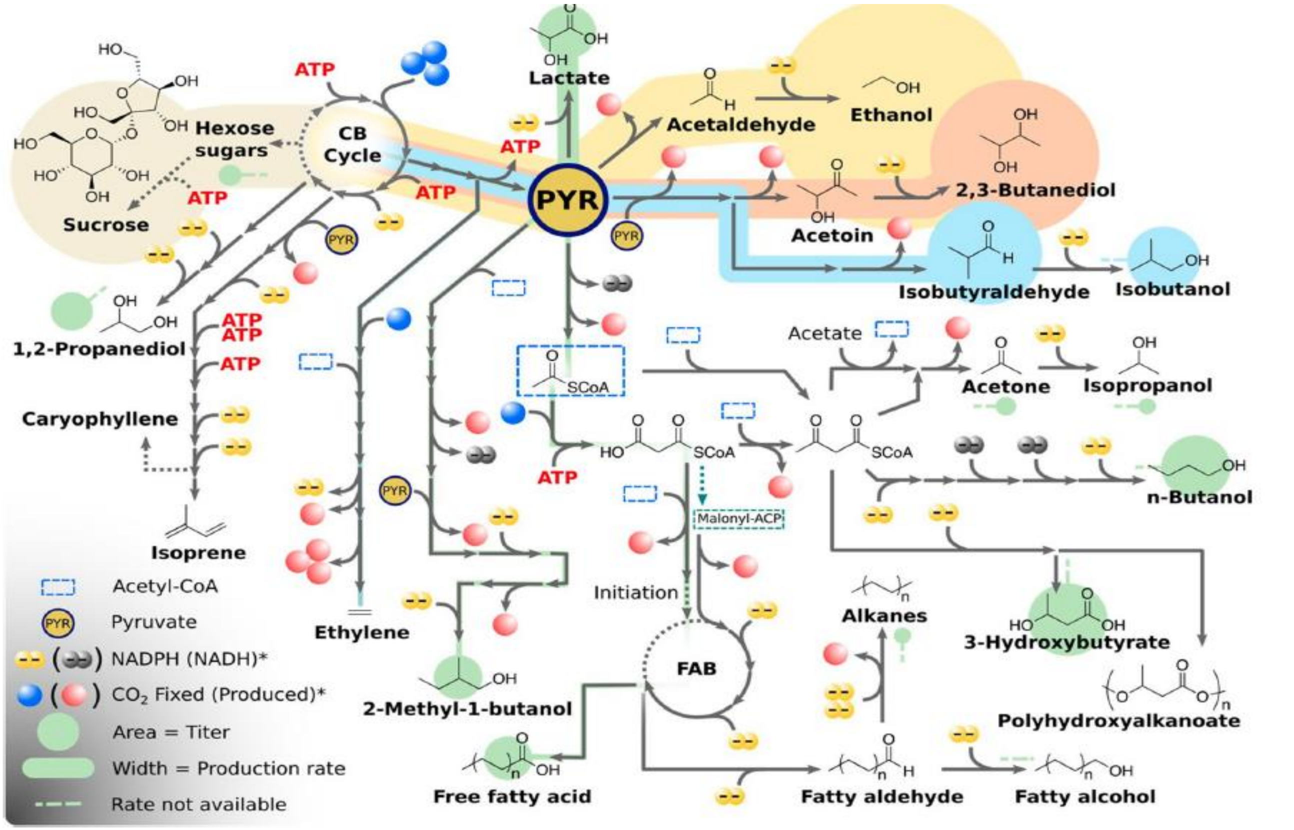
Rapid carbon flux (<30 s) to many compounds including:

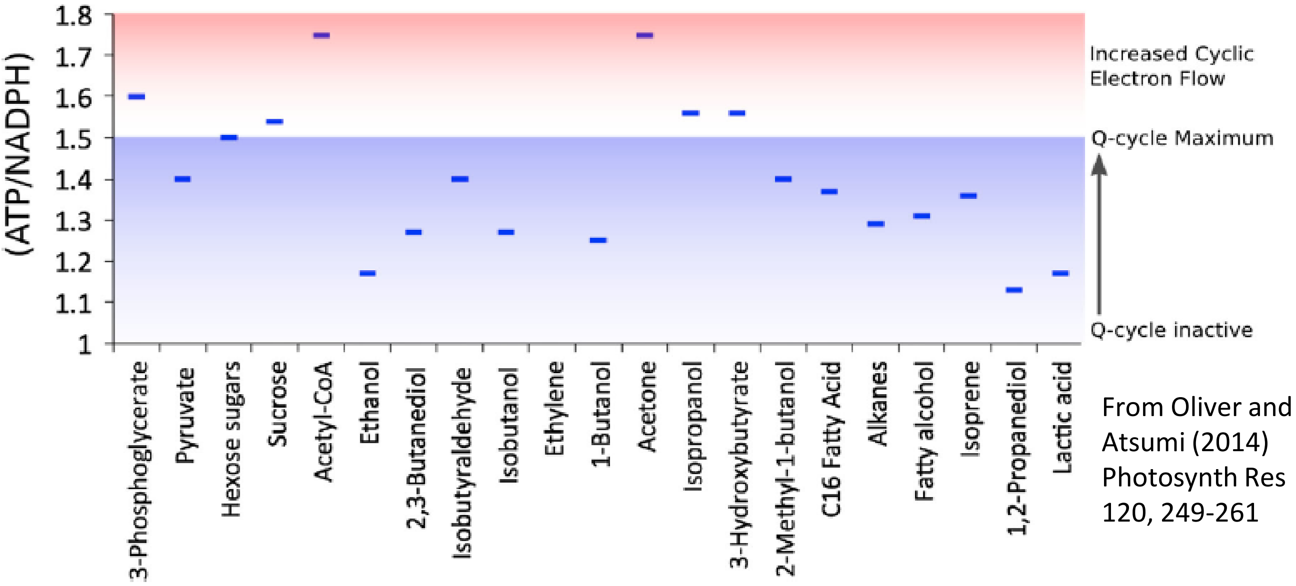
- CBB Cycle sugars
- Phosphoenolpyruvate
- Acetyl-CoA
- Malonyl-CoA

Complication:

Production of different compounds requires different ratios of ATP and NADPH, both of which are produced by photosynthesis

Fortunately, we can modulate the amount of NADPH vs. ATP made by cyanobacteria, for example by modulating the amount of cyclic electron flow around photosystem I





From Oliver and Atsumi (2014) Photosynth Res 120, 249-261

Summary:

- Cyanobacterial light-to-product efficiencies in some cases already are quite acceptable and can be further improved by metabolic engineering
- Supply of ATP/NADPH ratios required for product formation can be adjusted by modulating the amount of cyclic electron flow around photosystem I
- Direct conversion of fixed CO_2 to desired products is more energy-efficient than have plants make sugars and have *E. coli* or yeast use these sugars for production of green chemicals

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