Microalgae for Energy production

... between dream and reality

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Resource → **A World** → Waste

where our one-way use of resources

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Is there a way to make this dream true?

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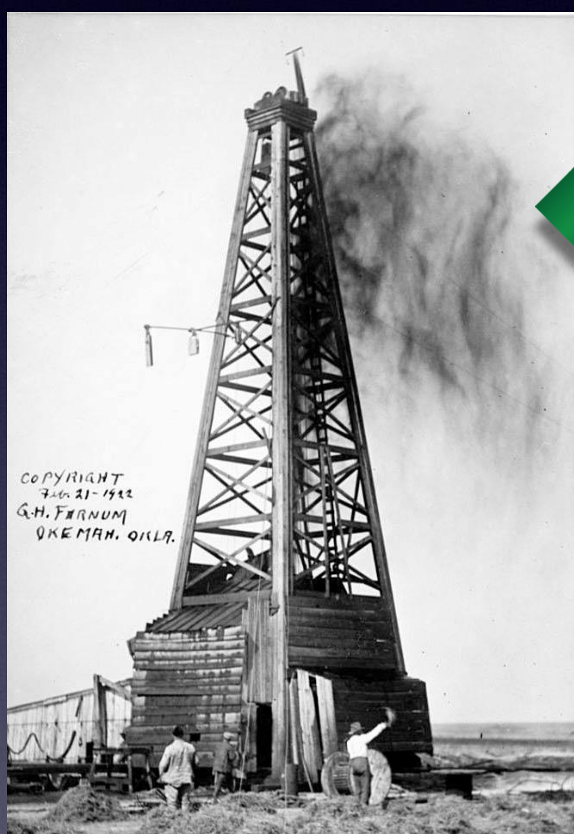
Let's think about the liquid fuels

How does it work now?

refining



drilling

selling

using

CO_2

releasing

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How do we wish it might work?

"refining"

~~drilling~~

selling

using

CO_2

releasing

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Why do we hope to find a solution?

Because we can hardly expect to spend money to capture CO_2 only to hide it under the carpet

Achieving this dream requires…

innovation

… and innovation is

a PROFITABLE EXECUTION of STRATEGIC CREATIVITY

innovation is like surfing

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- identify the good wave before it rises

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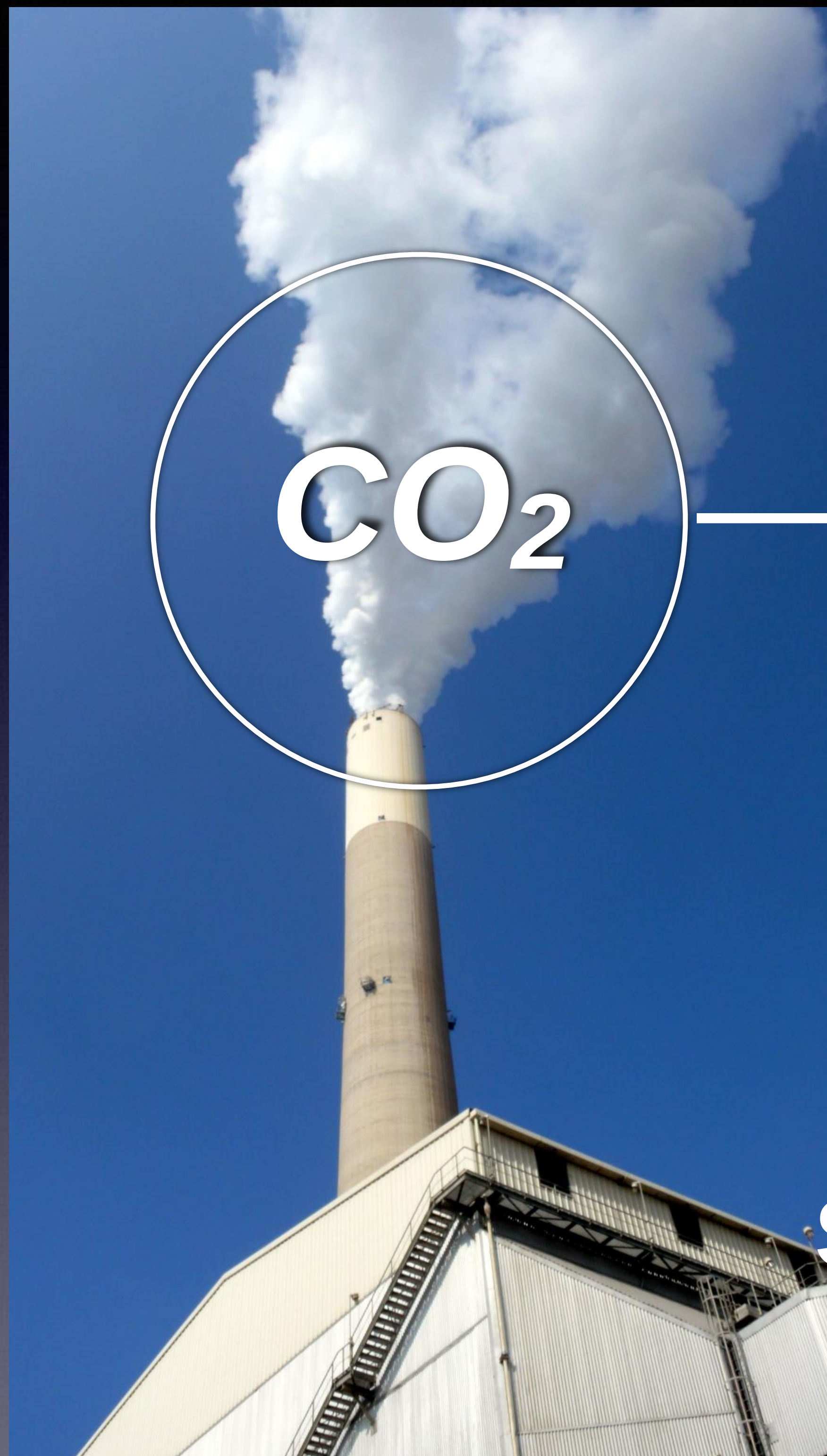
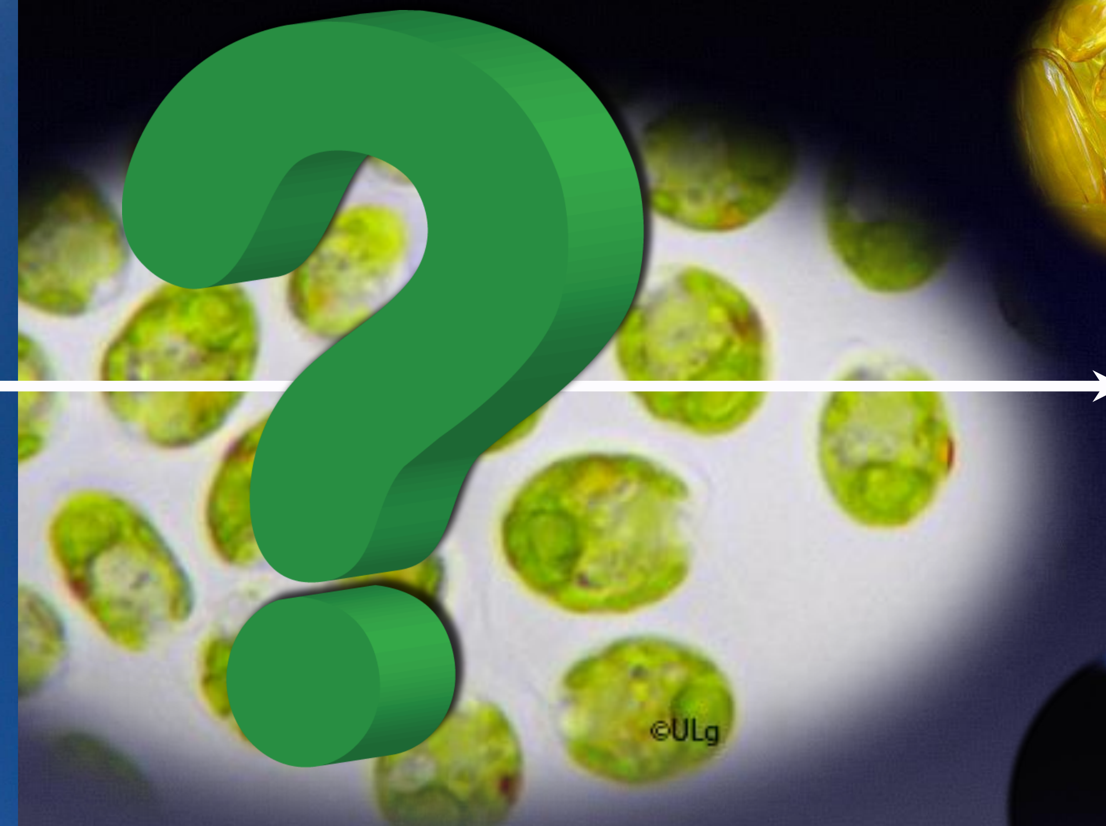
- begin to paddle before it comes

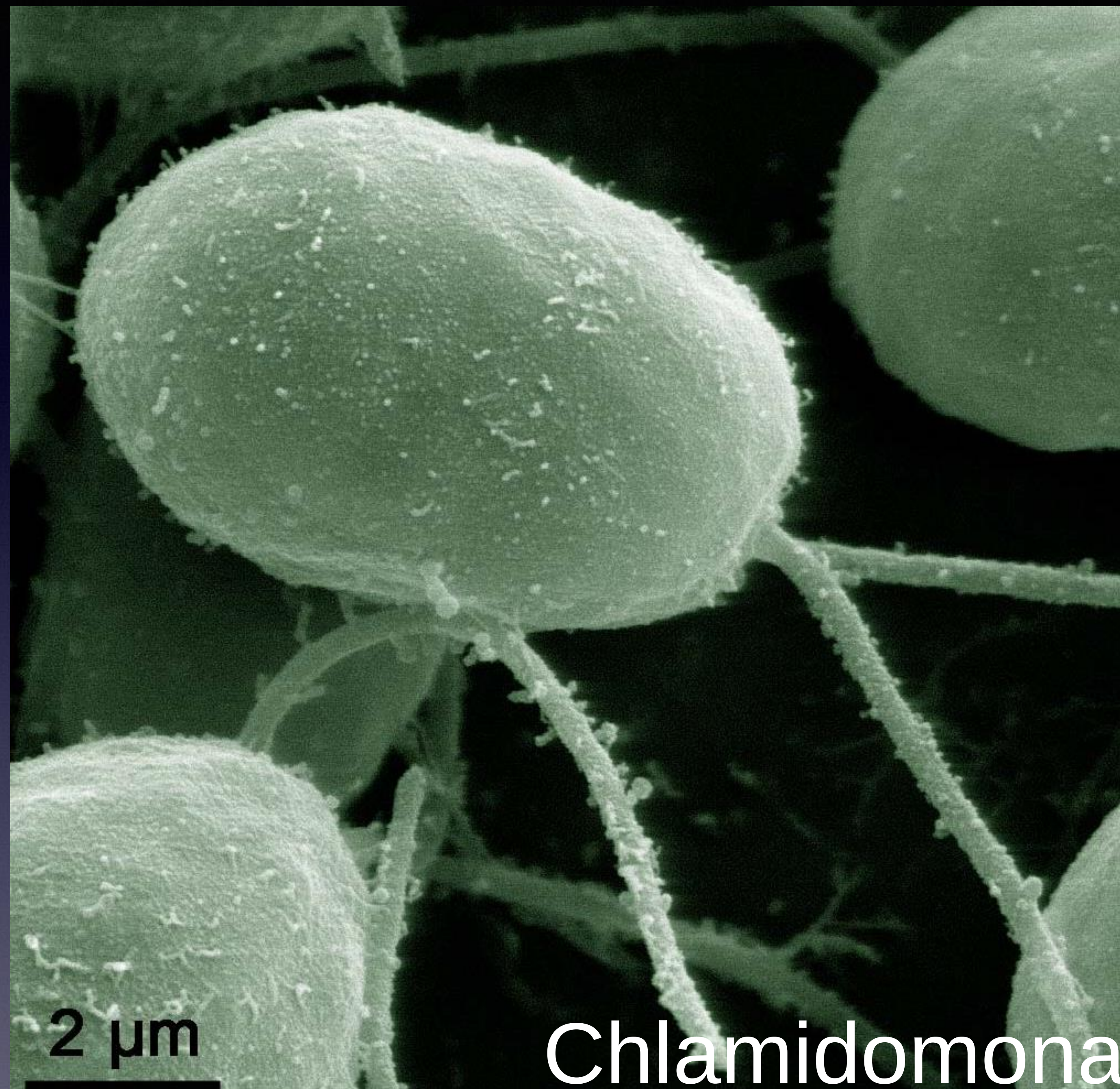
- Don't fall until you reach the beach

So, here is our problem





Could part of the solution come from microalgae?



Chlamidomonas

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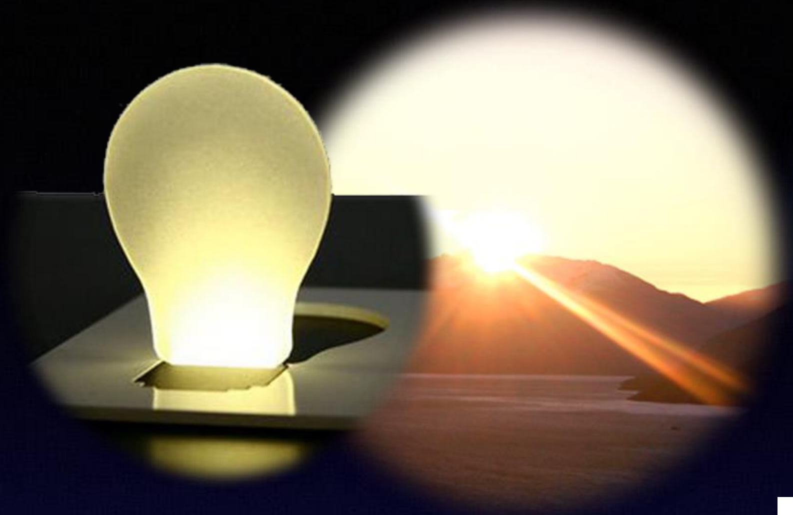
900 nm

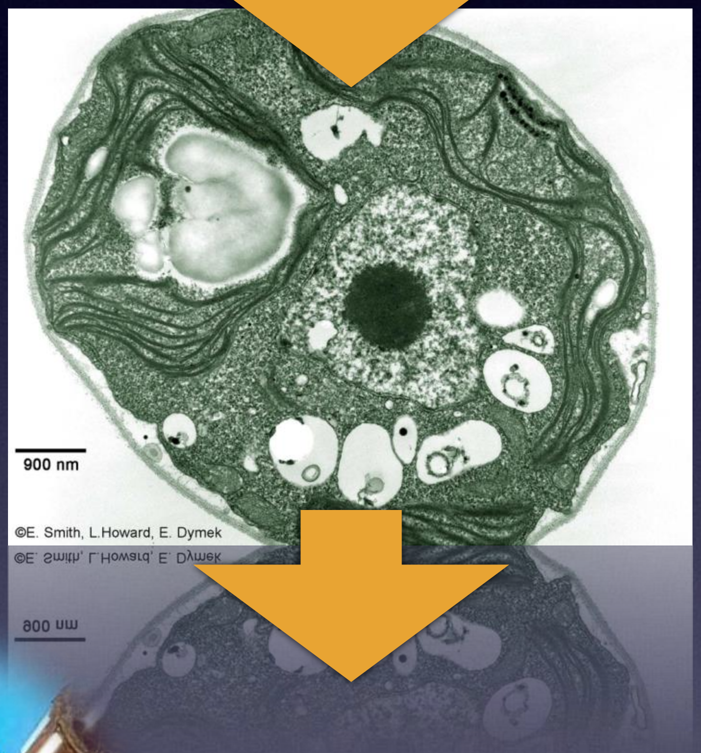
Microalgae = microfactories



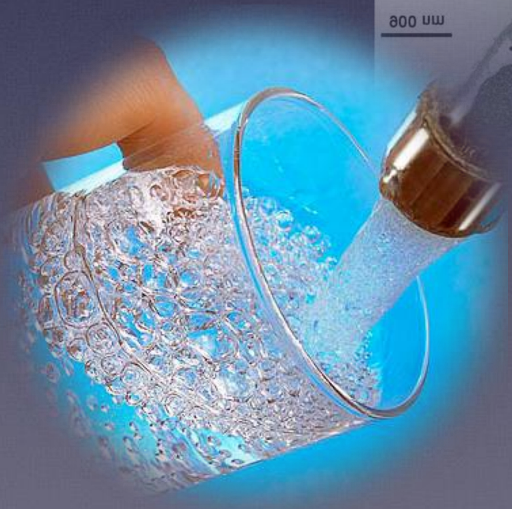
light

CO_2

reclaimed water



energy



water

chemicals

livestock food

fuel

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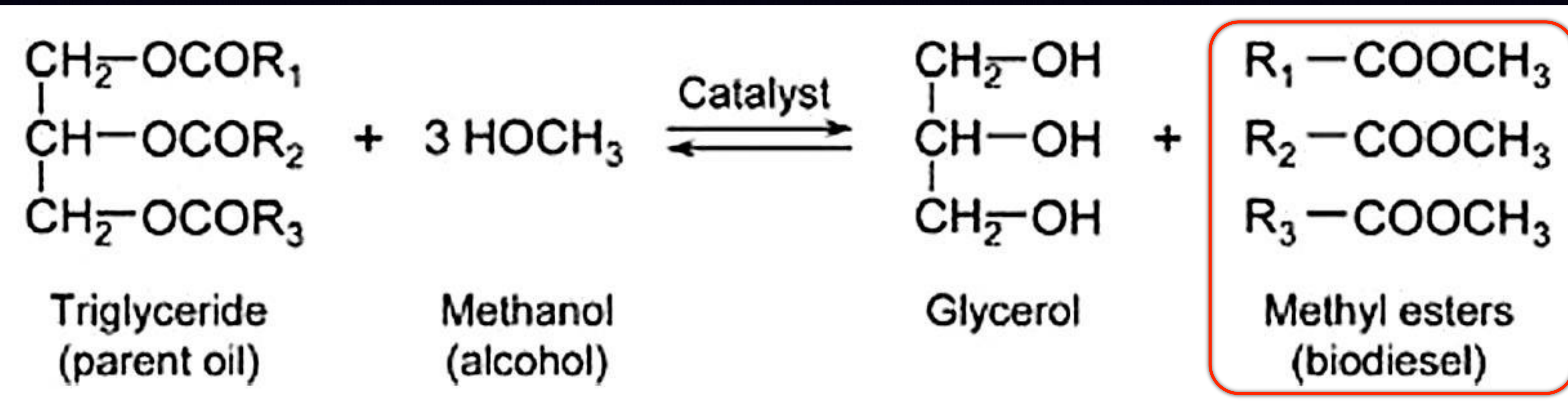
plants synthesize oil that gives fuel



The oil generated by the microalgae is converted into "biodiesel" by a transesterification reaction that generates a large amount of glycerol

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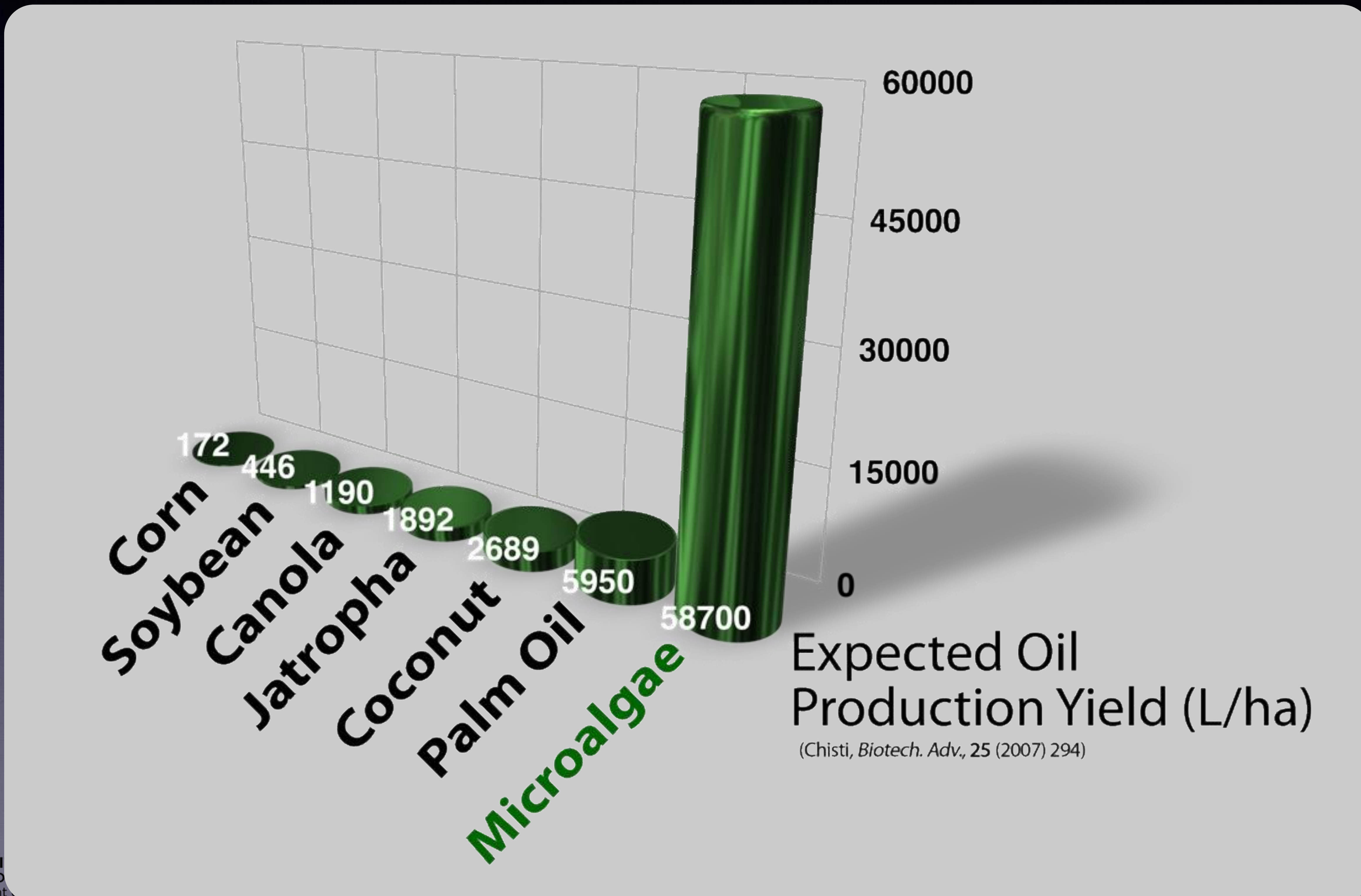
Microalgae offer the highest oil production Yield



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Do we need alternative fuels?

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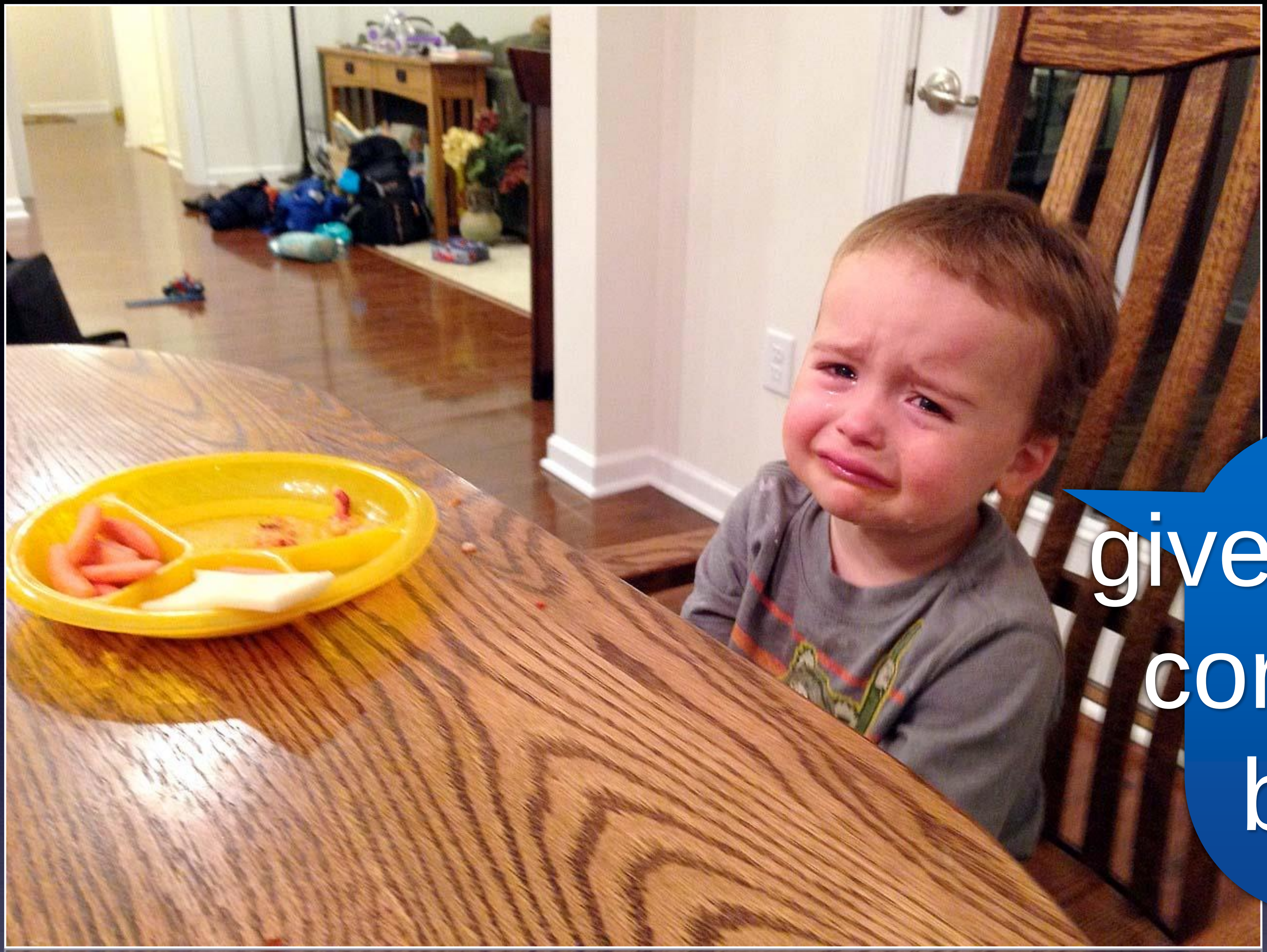
Fossil fuels are still here for long, but…

- Global demand for alternative fuels is expanding due to population growth, increased attention to energy security, and environmental policy mandates.
  - *Environmental Protection Agency set 2011 renewable fuel standards volume requirements at 1.35 billion gallons of advanced biofuels.*
  - *U.S. Navy's goal is to operate at least 50 percent of its fleet on clean renewable fuel sources by 2020.*
  - *All major Aircraft companies are looking for substituting resources to fossil jet-fuels.*

give me my forest back

We could use palm oil, but...

compete with wildlife protection



We could use corn-based ethanol, but…

compete with edible culture

How do we grow microalgae?

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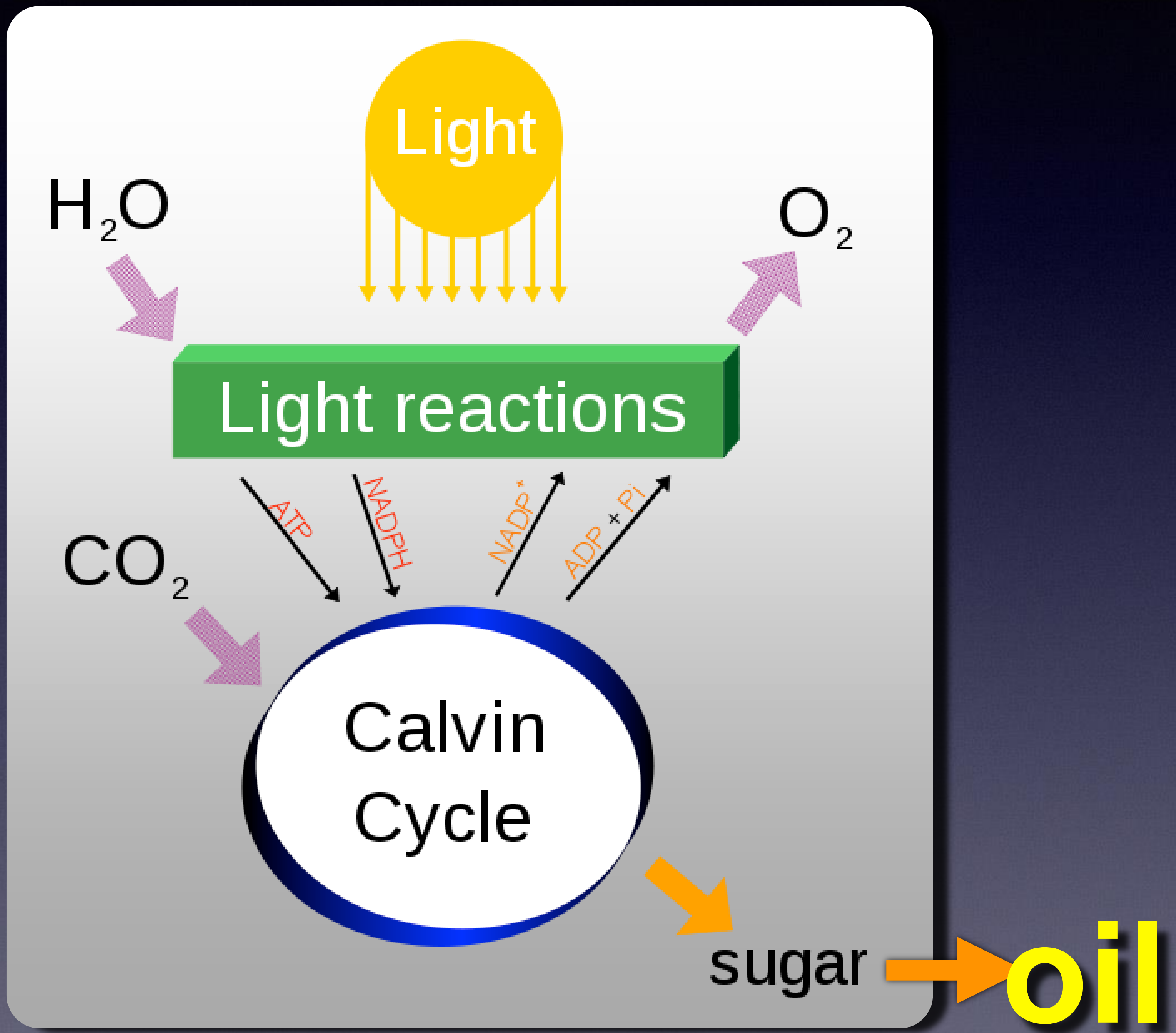
Photosynthesis = the autotrophic pathway



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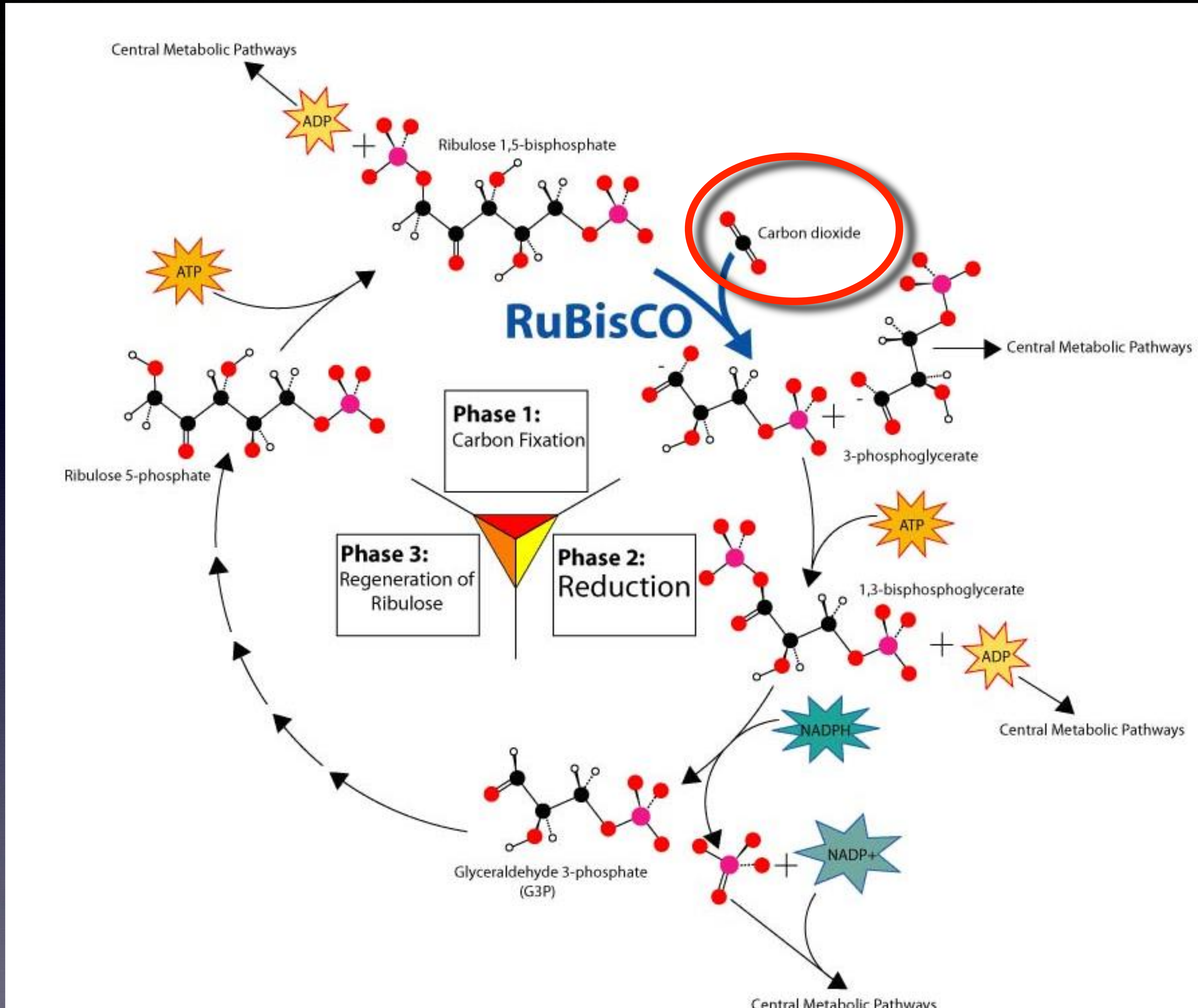
The Calvin Cycle



$6\ CO_2 + 12\ H_2O +$ 48 photons $\rightarrow C6H12O6 + 6\ O_2 + 6\ H_2$

The heterotrophic approach

- Some microalgae strains can grow in dark by feeding on dissolved sugars

solazyme

- Example: Solazyme, Inc. (USA)
  - Solazyme, Inc. is a renewable oil and bioproducts company that transforms a growing range of abundant plant-based sugars into high-value triglyceride oils and other bioproducts. Headquartered in South San Francisco, Solazyme's renewable products can replace or enhance oils derived from the world's three existing sources – petroleum, plants and animal fats. Solazyme is commercializing its primary products as either tailored oils, powdered oils, and closely related products in the chemicals, fuels and food markets or as branded consumer products. **They announced a 450,000 ton oil production with USA and Brazil partners.**

Heterotrophic *vs* Autotrophic

- Heterotrophic growth
  - Does not require light
  - Uses adapted bioreactors
  - Does not consume CO_2
  - Requires specific microalgae strains
- Autotrophic growth
  - Uses a larger range of microalgae (> 40,000)
  - consumes CO_2
  - Needs light
  - Technology (photobioreactors) not as advanced as autotrophic process (bioreactors)

Three types of autotrophic production

- Level 1: Gathering
  - Cheap, but no control, and low efficiency

- Level 2: Agriculture
  - Better control, higher productivity, but still dependent on external parameters (temperature, seasonal & daily light fluctuations)

- Level 3: Industrial
  - More expensive, but independent from external parameters, major improvements required

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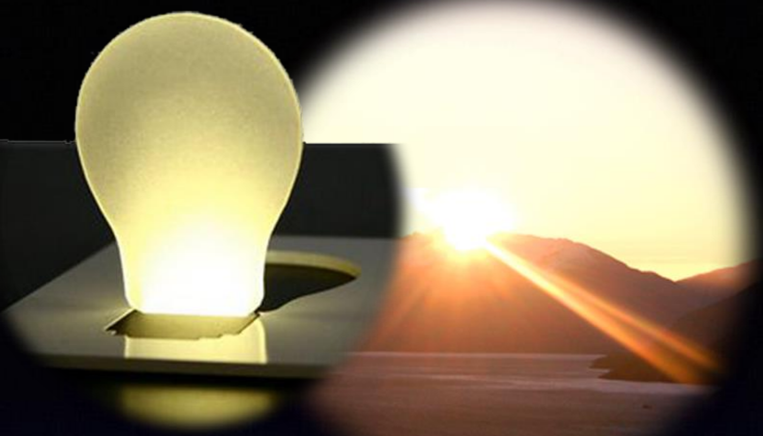
What do we need?



energy

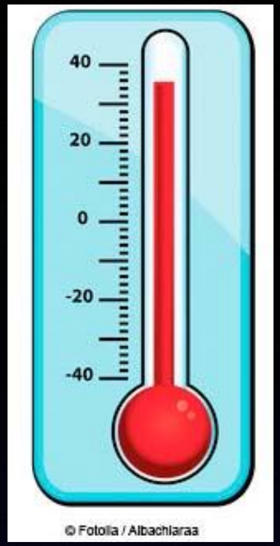
+

CO_2

+

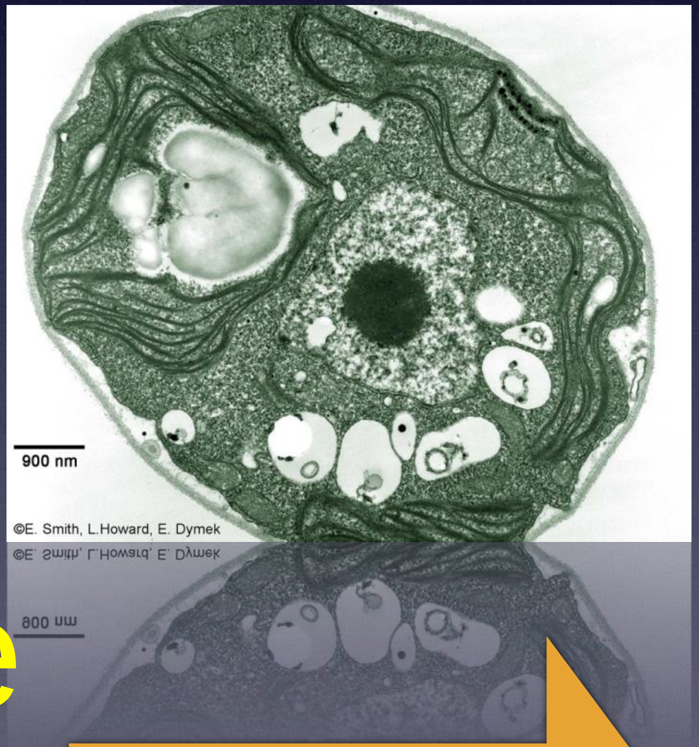
reclaimed water

+



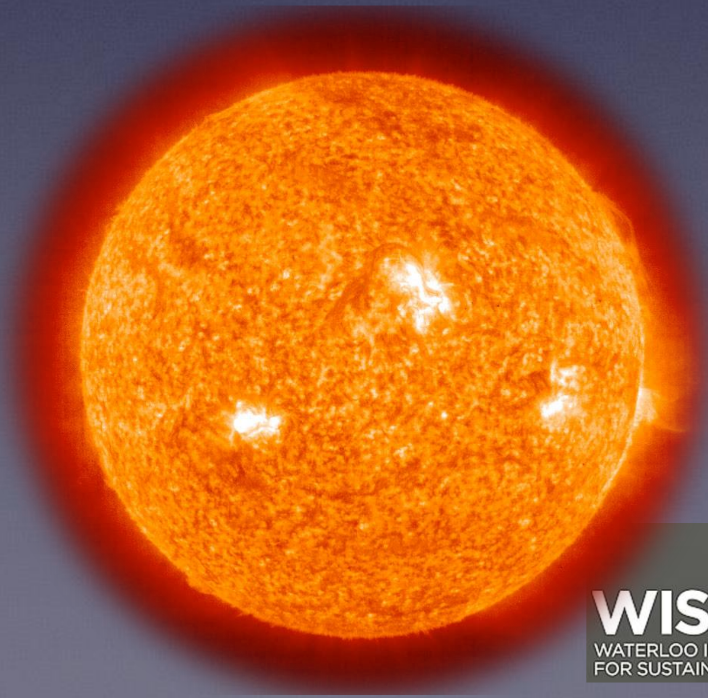
temperature

=



need for a free energy source

sun



So, let's go there…

Not such a good idea

- Sun is here but not water
- How do we bring CO_2 on site?
- Important temperature fluctuations
- Daily light & temperature fluctuations do not favour continuous production
- Deserts are fragile ecosystems
- What about water evaporation?
  - 50 m^3/ha.day => 1,000 ha = 50,000 m^3/day!

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A system must be implemented near the most expensive resource:

CO_2 *vs* light

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Main CO_2 emitters

- Fossil fuelled power plants
- Cement factories
- Biodigesters

All are in industrial/urban locations where lands surfaces are limited & expensive

From Dream to reality

Challenges for an industrial production

- Efficient conversion of CO_2 emissions into valuable biomass.
- Providing a 24/7 production to fulfill industrial requirements.
- Be independent from fluctuating parameters (temperature, light) to allow for a worldwide implementation.
- Provide for a full control and prevent any contamination to allow for the future use of Genetically Modified microalgae.
- Allow for limited footprint biofactory

From Dream to reality

Challenges for a successful technology

- Creating a photobioreactor (PBR) able to work continuously and independently from daily, seasonal or geographical variations
- Dissolving 100% CO_2 being injected as a gas into water
- Keeping constant the optimum conditions for microalgae growth (light, temperature, concentration)
- Providing a design compatible with cost-effective scaling up.
- Using artificial light with a positive energy balance

Dissolve 100% CO_2

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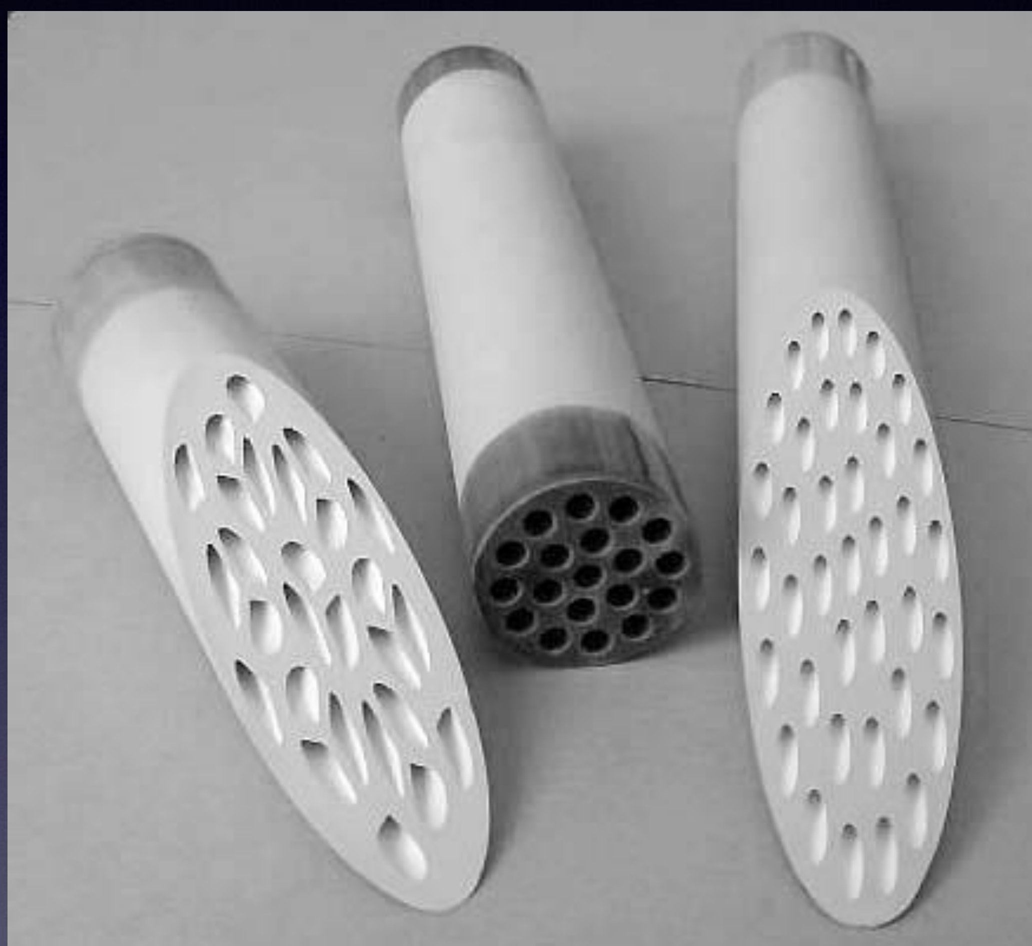
Dissolve 100% CO_2

Bubble-less gas injector



Optimized commercial ceramic support modified by hydrophobic treatment

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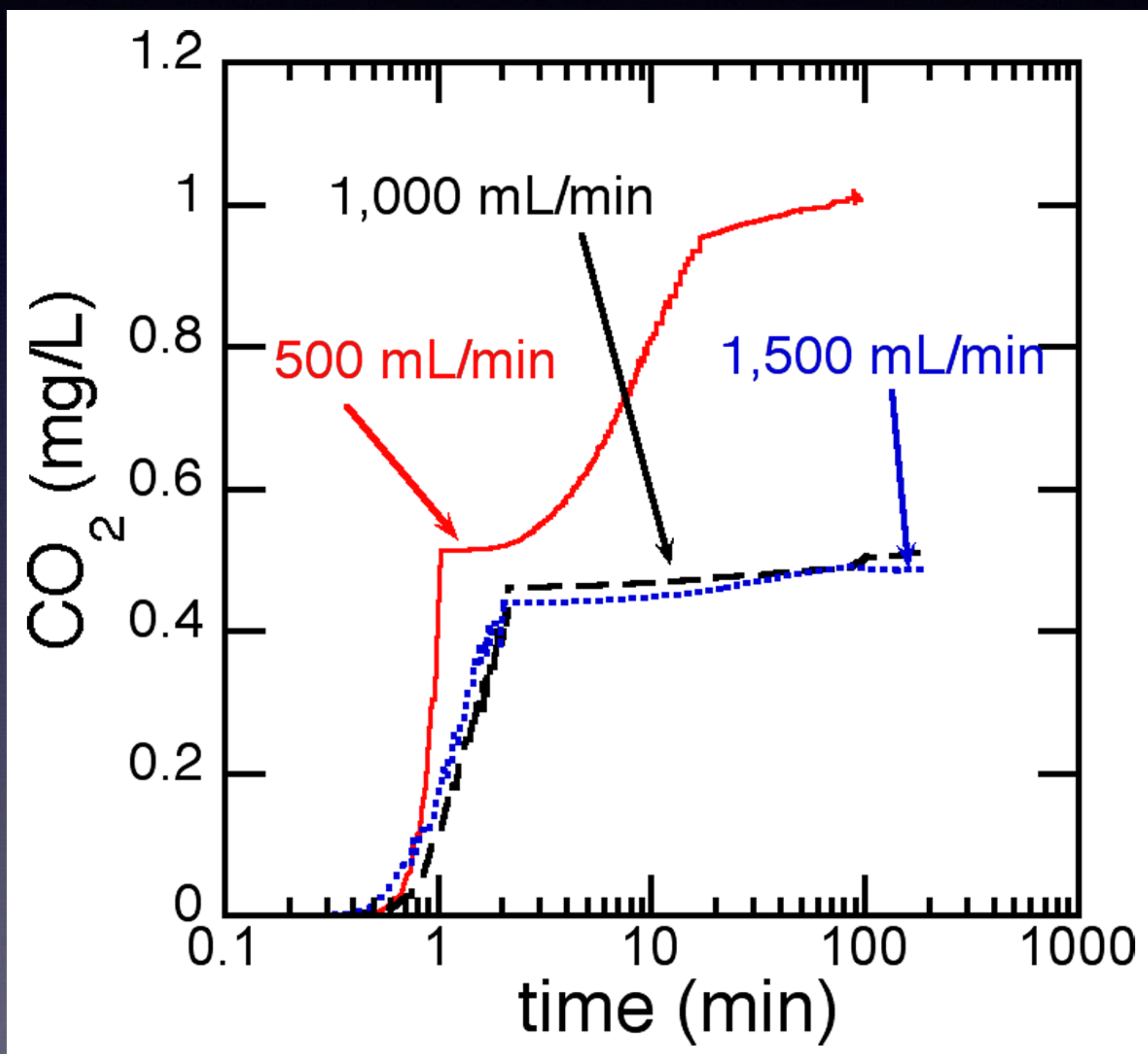
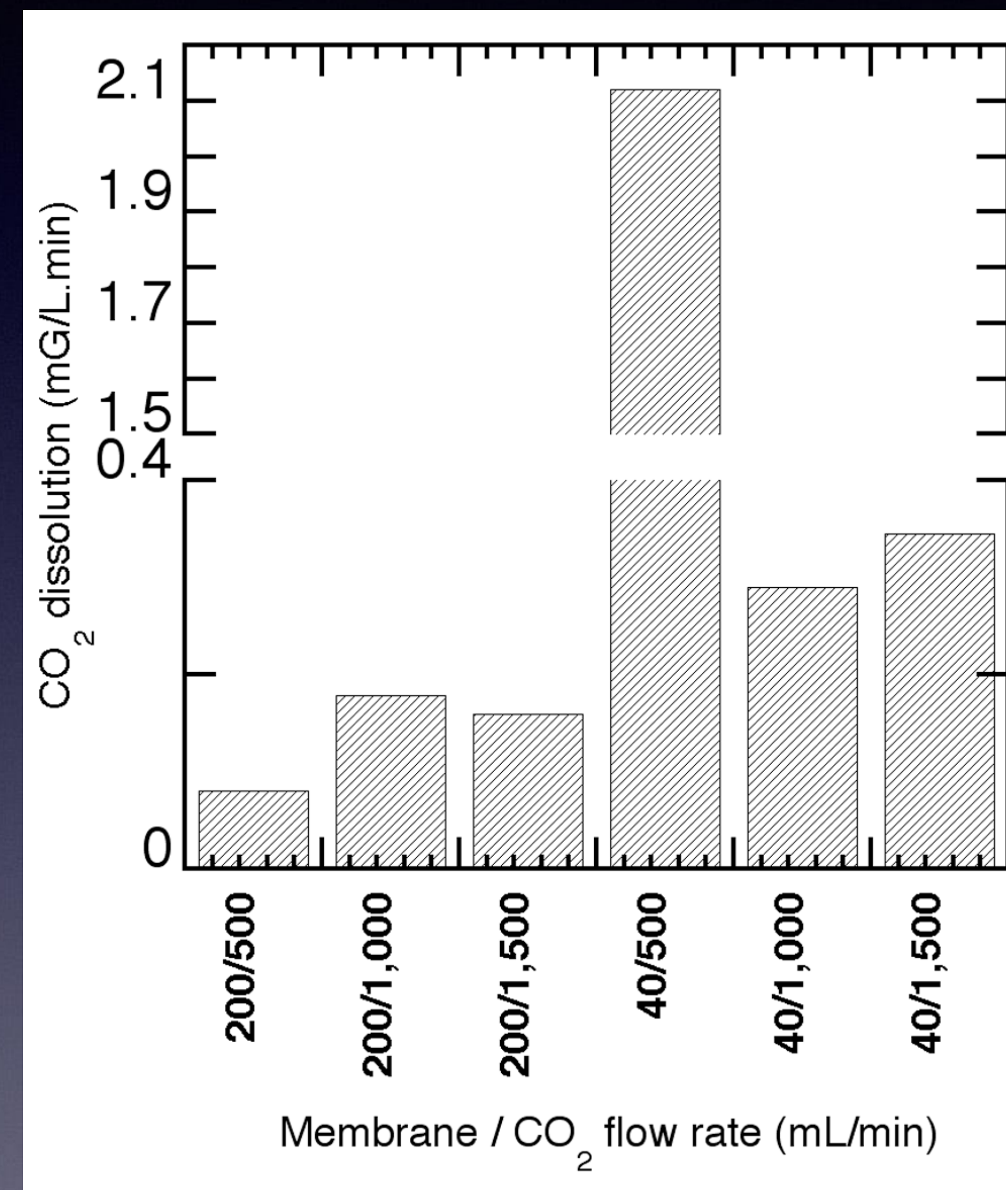
Dissolve 100% CO_2

Bubble-less gas injector





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J. CO_2 Utilization, 6 (**2014**) 12

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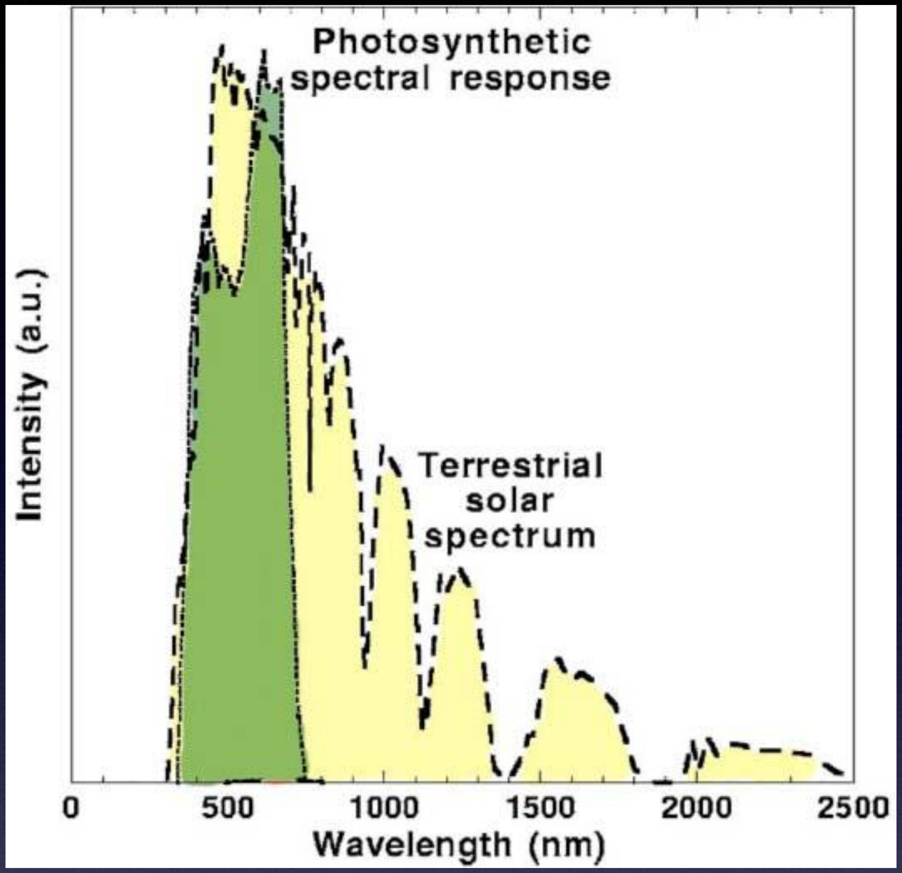
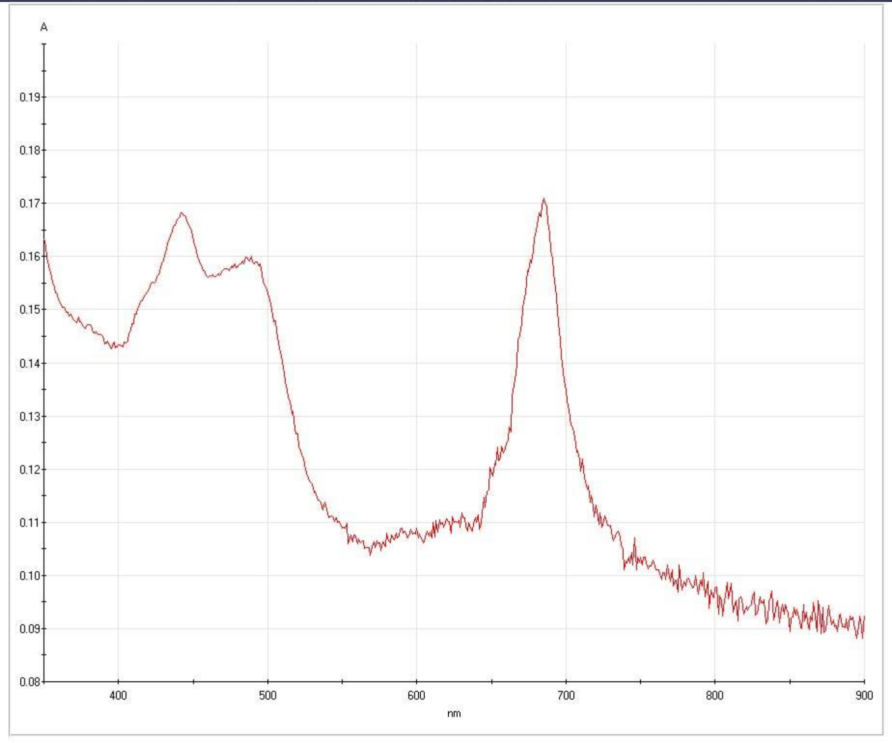
cost-effective lighting





Green microalgae absorb only in blue and red

We use only blue/red LEDs

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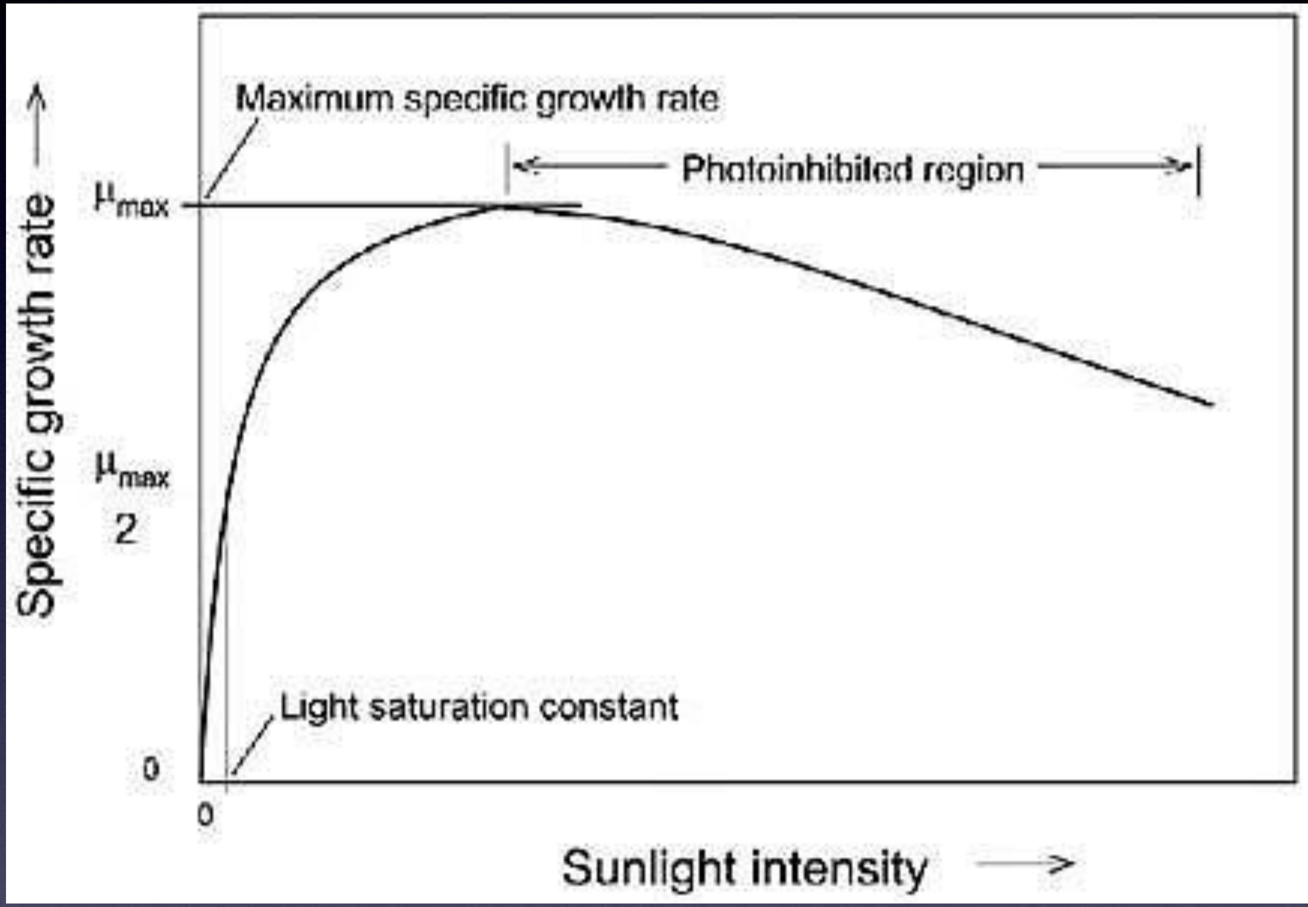
cost-effective lighting

Algae cannot absorb high intensity light



above a given light intensity, the photosynthesis is inhibited

photons are only required for a very small part of time of the photosynthesis mechanism

We switch on light only for 1/100 of the total time

as a result, the energy balance overall is at least a 5:1 operation

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Industry-ready process

Cost effective industrial platform

State-of-the-art in open pond production...

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Industry-ready process

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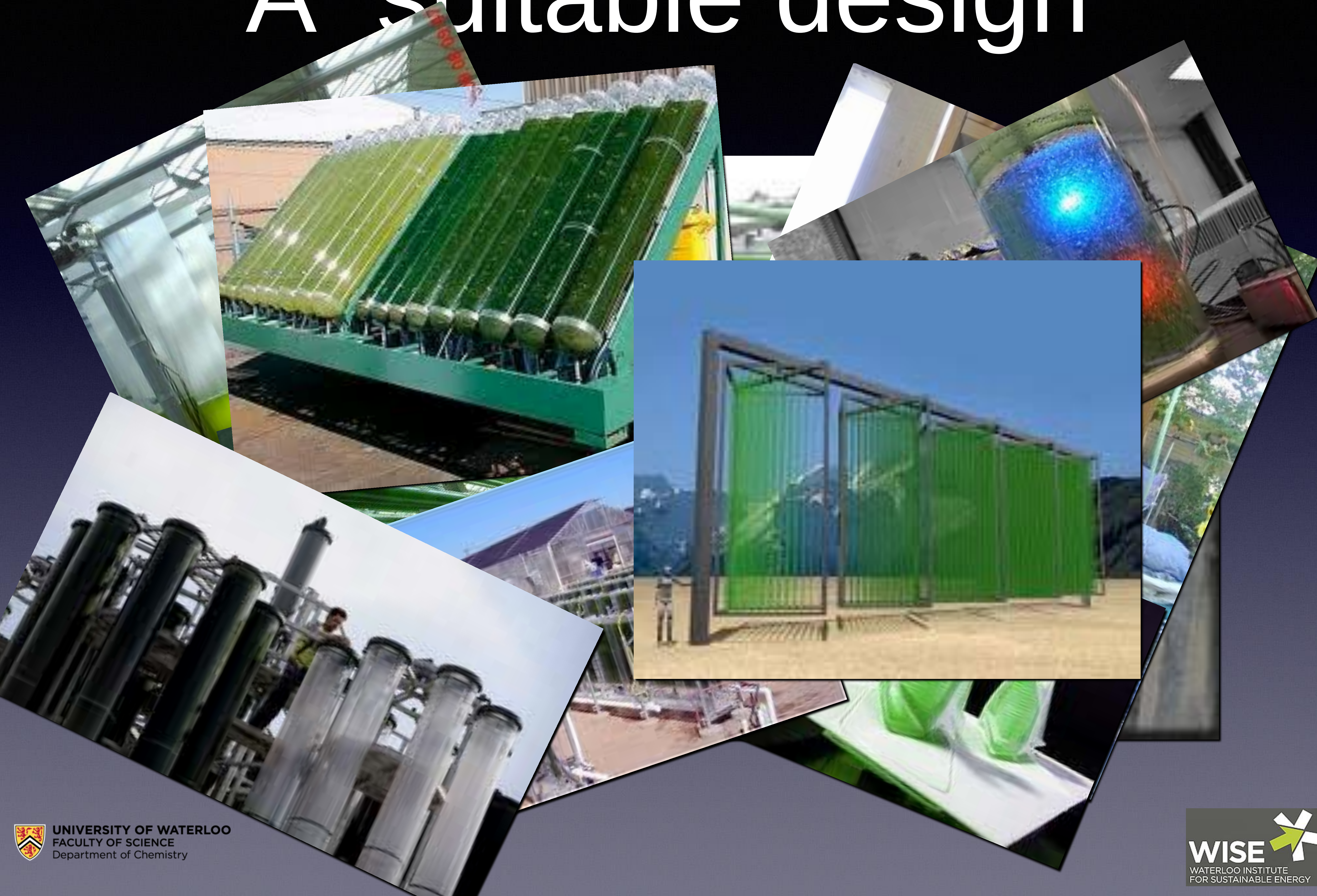
A suitable design



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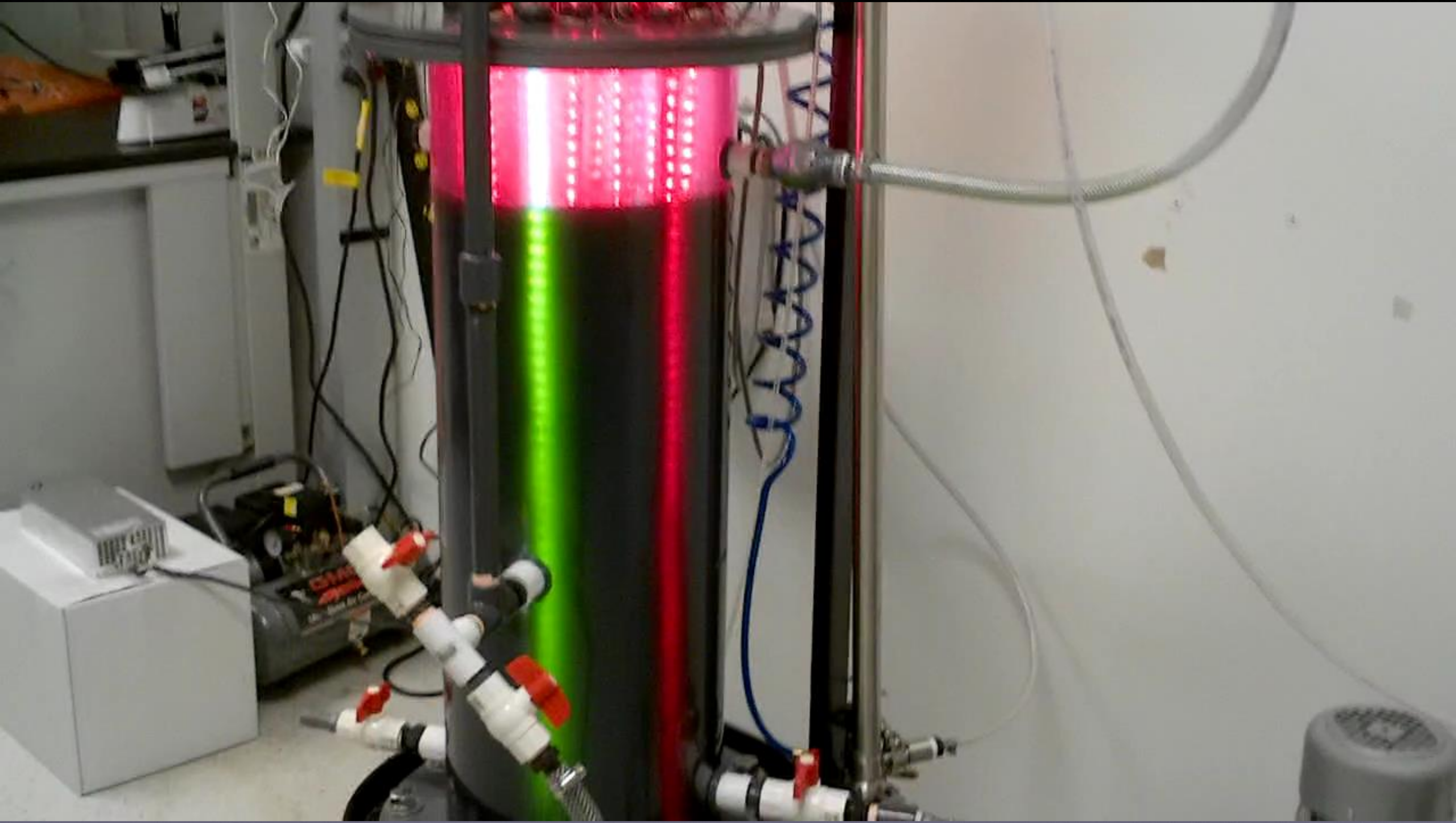
Scaling up

- One tube: ø = 10 cm
  - to obtain a total volume of 100 m^3
  - tube length = 12,700 m

Our solution

- closed photobioreactor for complete control and industrial production
- a tank for easy and cheap scale up
- a lighting system adapted to the correct wavelength
- a lighting frequency adapted to minimize the energy cost



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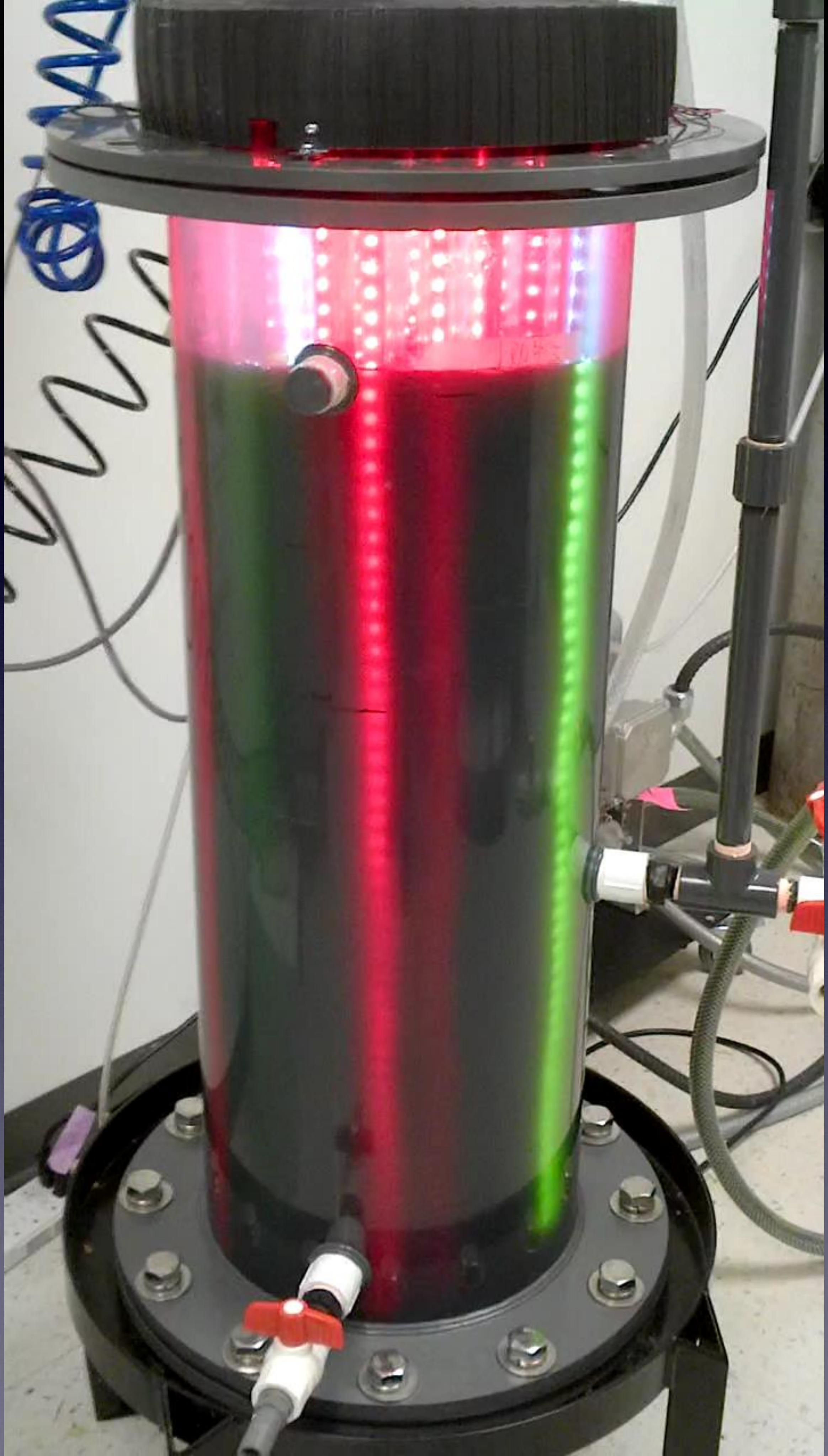

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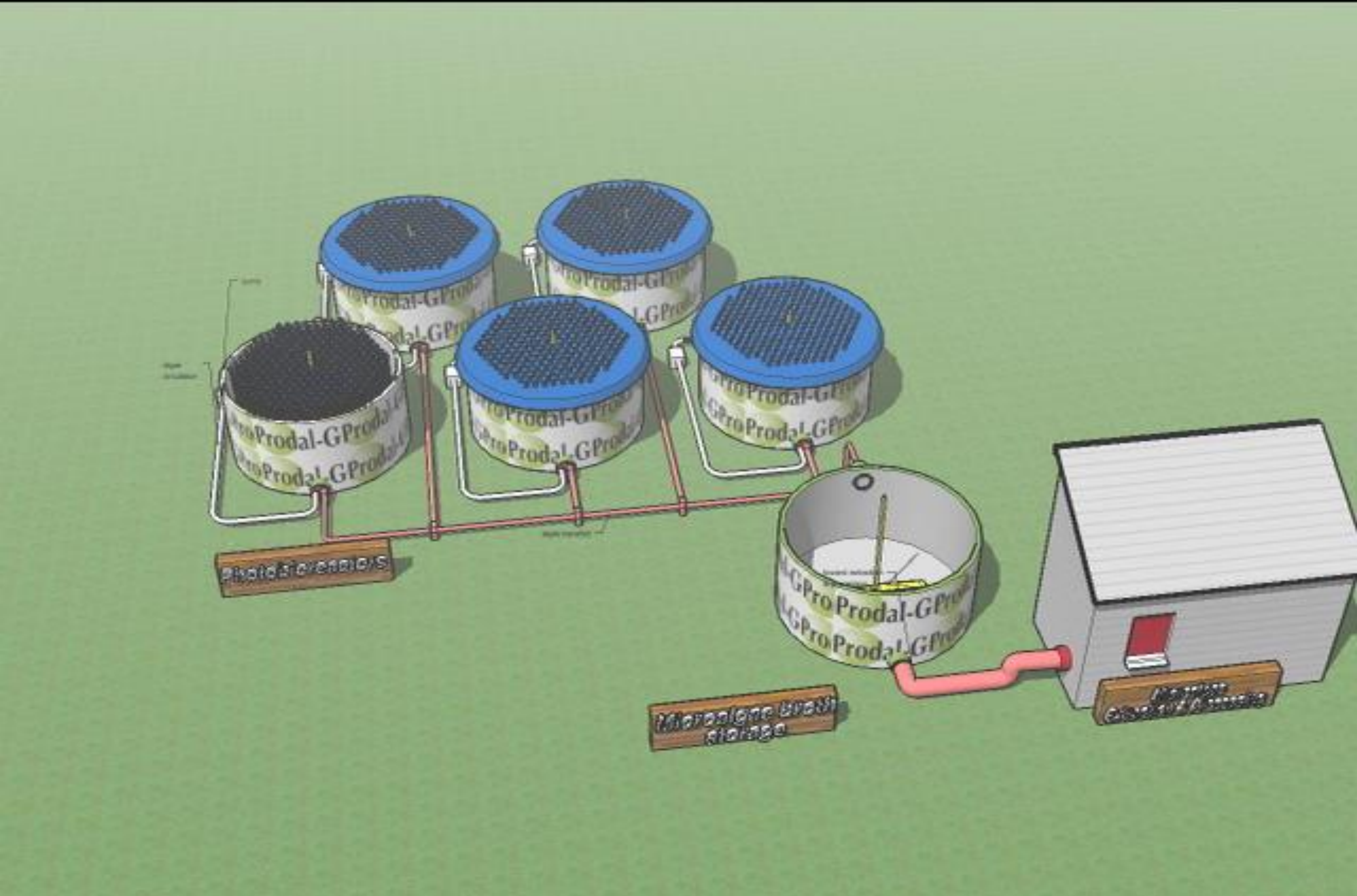
how a production platform could look like



One more thing…

biomass high concentration production is required

- open pound = 0.3 g/L
- tubular photobioreactor = 3 g/L
- biomass extraction:
  - up to 40% overall cost
- <u>higher concentration (40-100 g/L) required for harvesting</u>

Yes, we can…

…achieve these high concentrations

So... Can we dream?

1890

"Eole" of Clément Ader

one "passenger"

Only 117 years

2007*

850 passengers

Airbus "A380"

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* commercial flight

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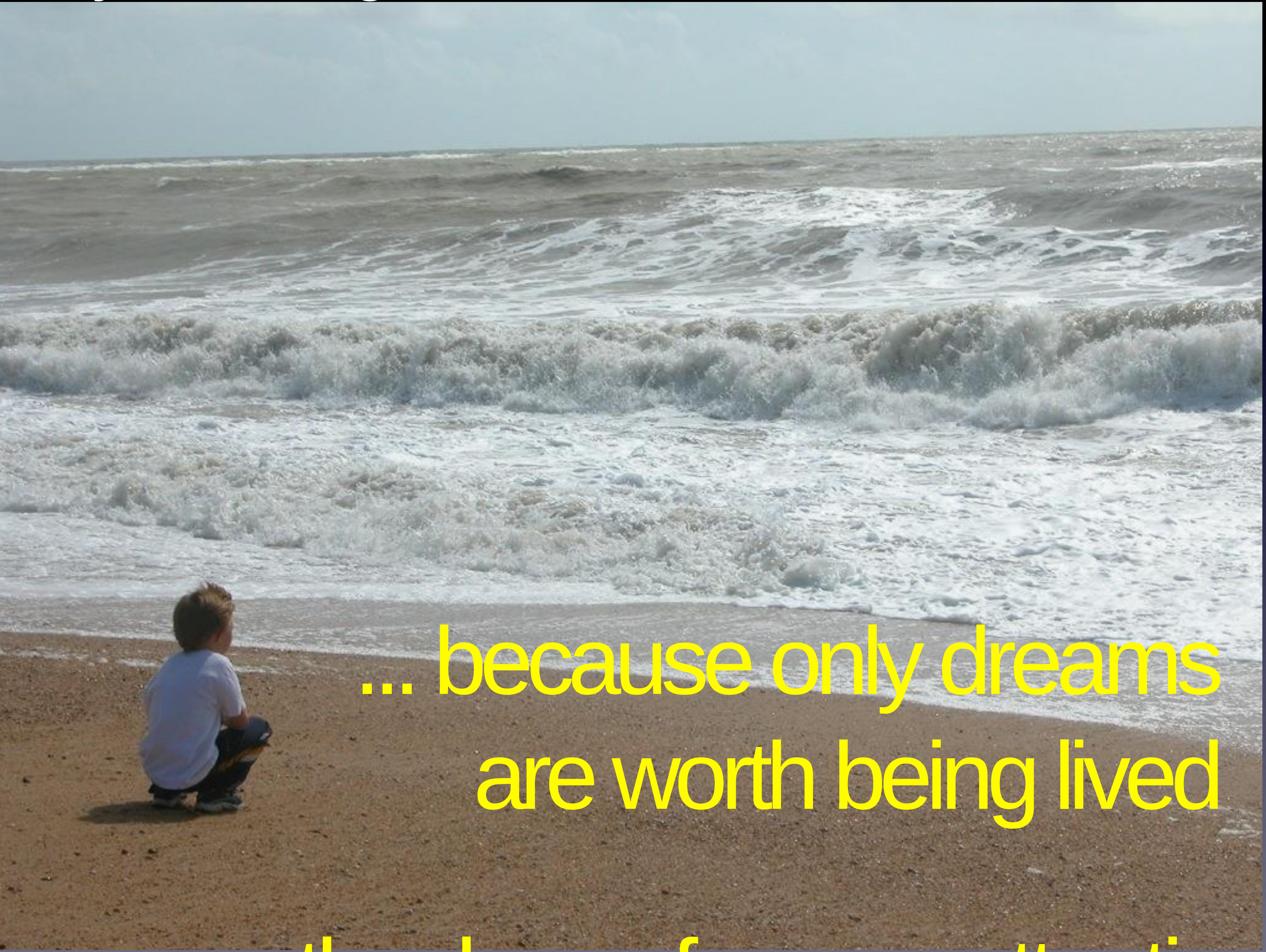
Why dreaming about new solutions?...



... because only dreams are worth being lived

thank you for your attention

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