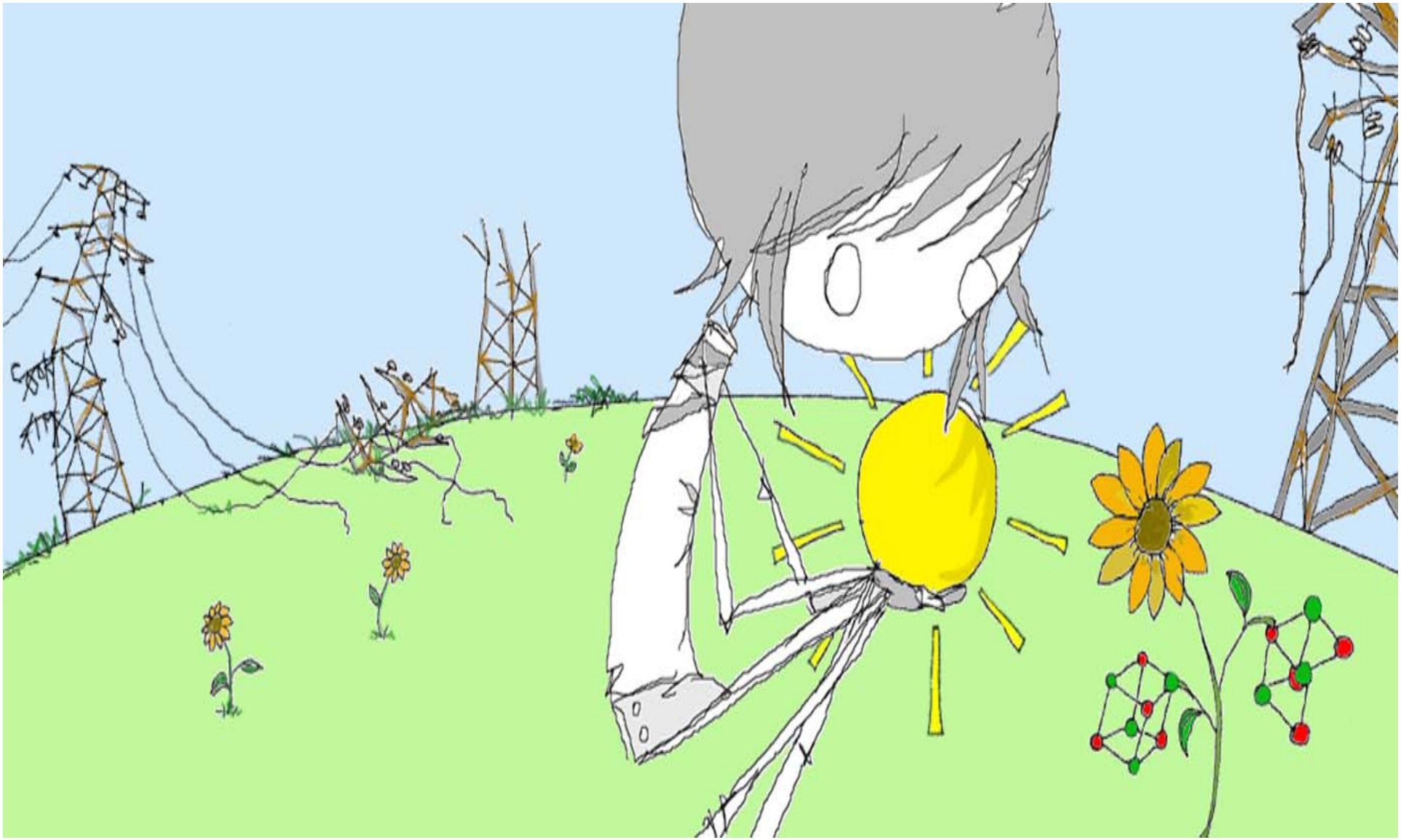
Personalized Energy for 1 (x 6 Billion)



Issues

Currently using 14 TW need 16 TW by 2050

Remember, in the Nocera/Lewis PNAS paper that cites the numbers above, it was assumed that ~14 TW (all the energy we use today) will be conserved…if not then it is 45 TW)

Push for the 16 TW is coming from the 6 billion new energy users (3 billion to be born and 3 billion in the non-legacy world)

Solution to the energy challenge, thus, in my opinion rests in providing the non-legacy world a carbon-neutral, sustainable energy supply

Energy for the non-legacy world: cost is 1st issue, NOT efficiency. In fact, the higher the efficiency, the higher the cost

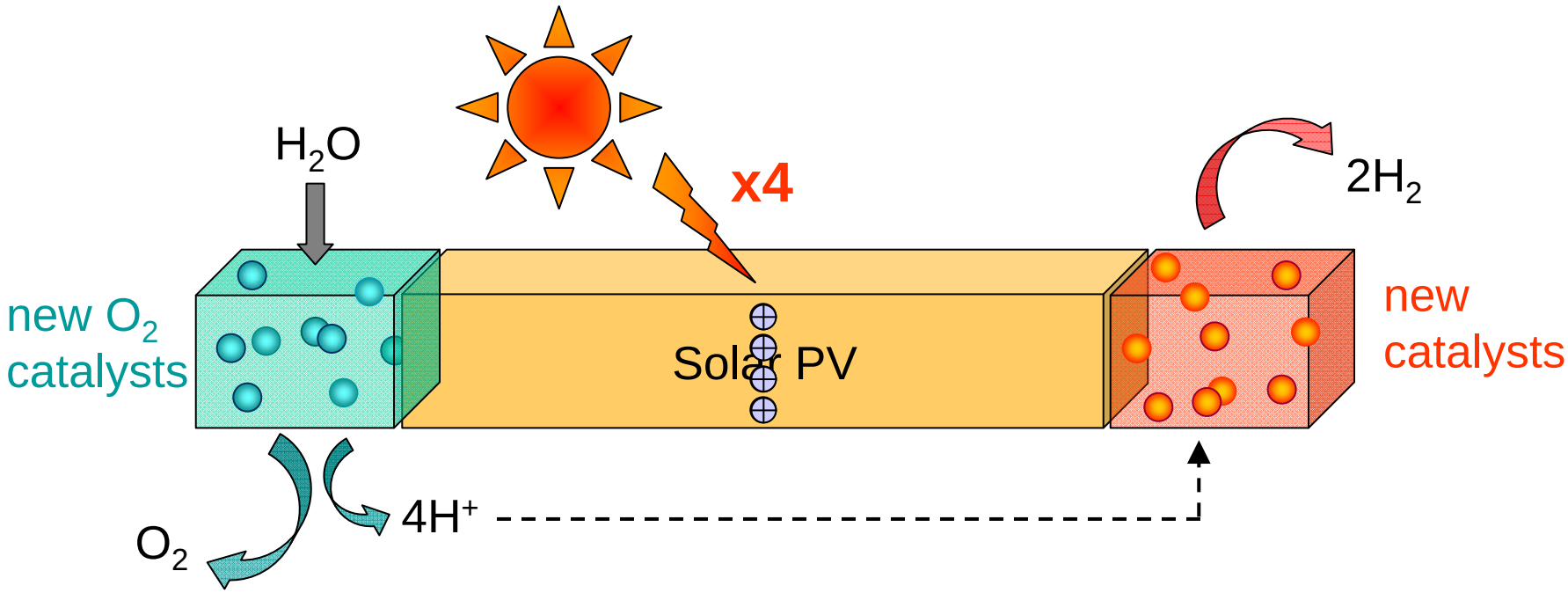
Distribute (personalized) energy is the key for the non-legacy world. Do not downsize current energy systems, owing to Balance of System costs – start with a blank piece of paper and create and invent!

Design to the individual and then scale with manufacturing (this is how the world works)

An Artificial Leaf

a design that captures the three elements of photosynthesis:

Capture (photon) | **Conversion (to wireless current)** | **Storage (fuels and O_2)**



difficult part of water splitting is getting O_2 out

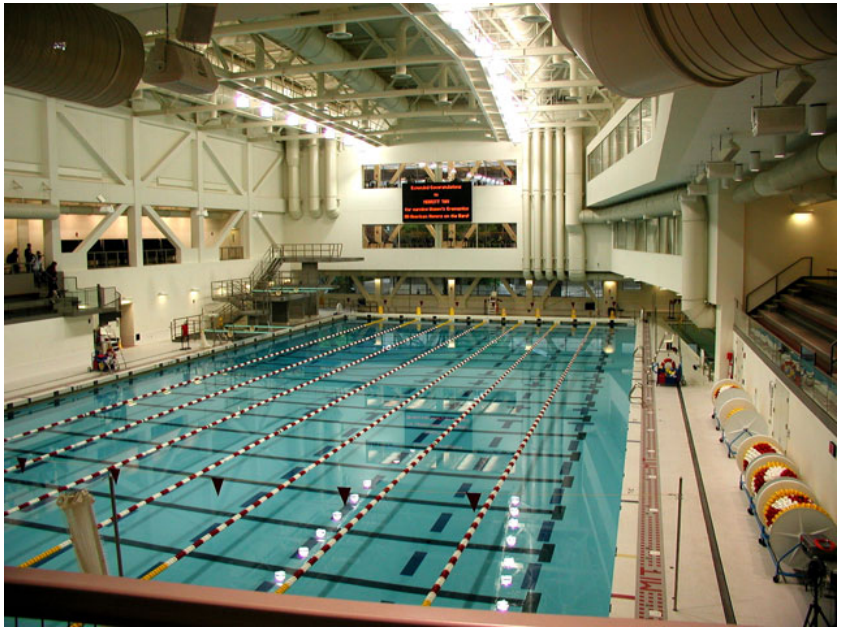
How Much Energy Stored in Water Splitting?

$H_2O \longrightarrow H_2 + \frac{1}{2} O_2$ energy = 237 kJ/mol

energy = 13 million J/liter

MIT pool

3.2 million liter of H_2O

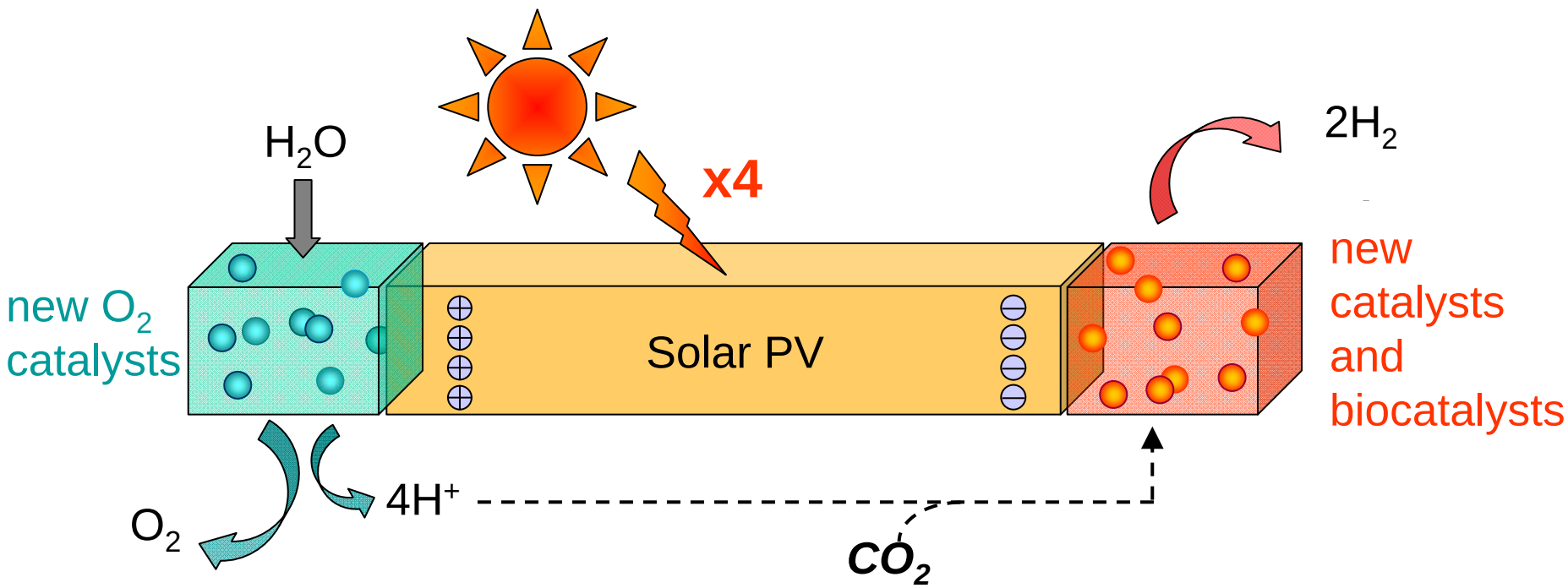


volume of MIT pool to H_2 and O_2 per sec = 43 TW

An Artificial Leaf

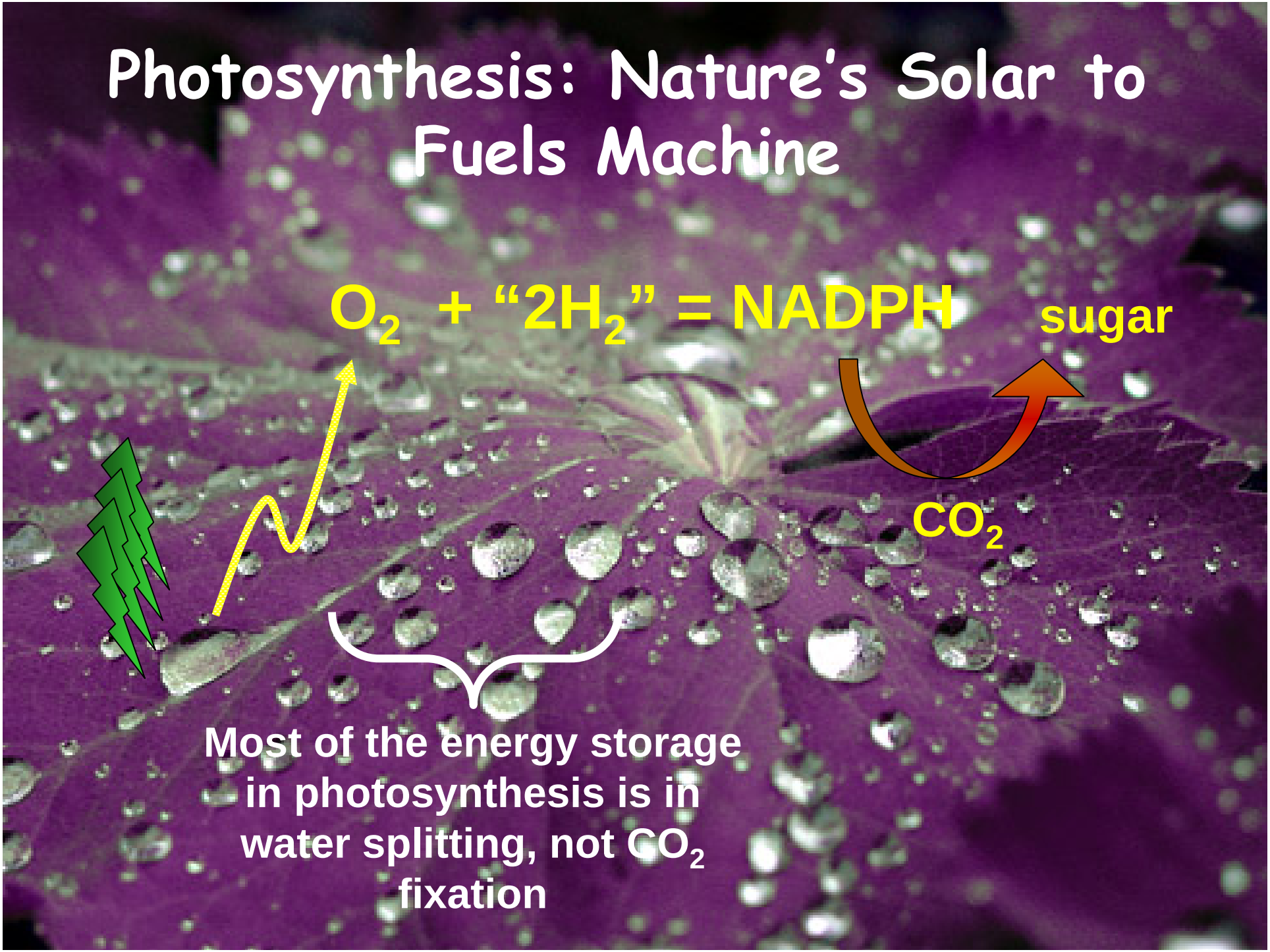
a design that captures the three elements of photosynthesis:

Capture (photon) | **Conversion (to wireless current)** | **Storage (fuels and O_2)**



difficult part of water splitting is getting O_2 out and making C-C bonds

Photosynthesis: Nature's Solar to Fuels Machine



ARPA-E Energy Research

created to foster R&D of transformational (disrupt status quo) energy-related technologies.

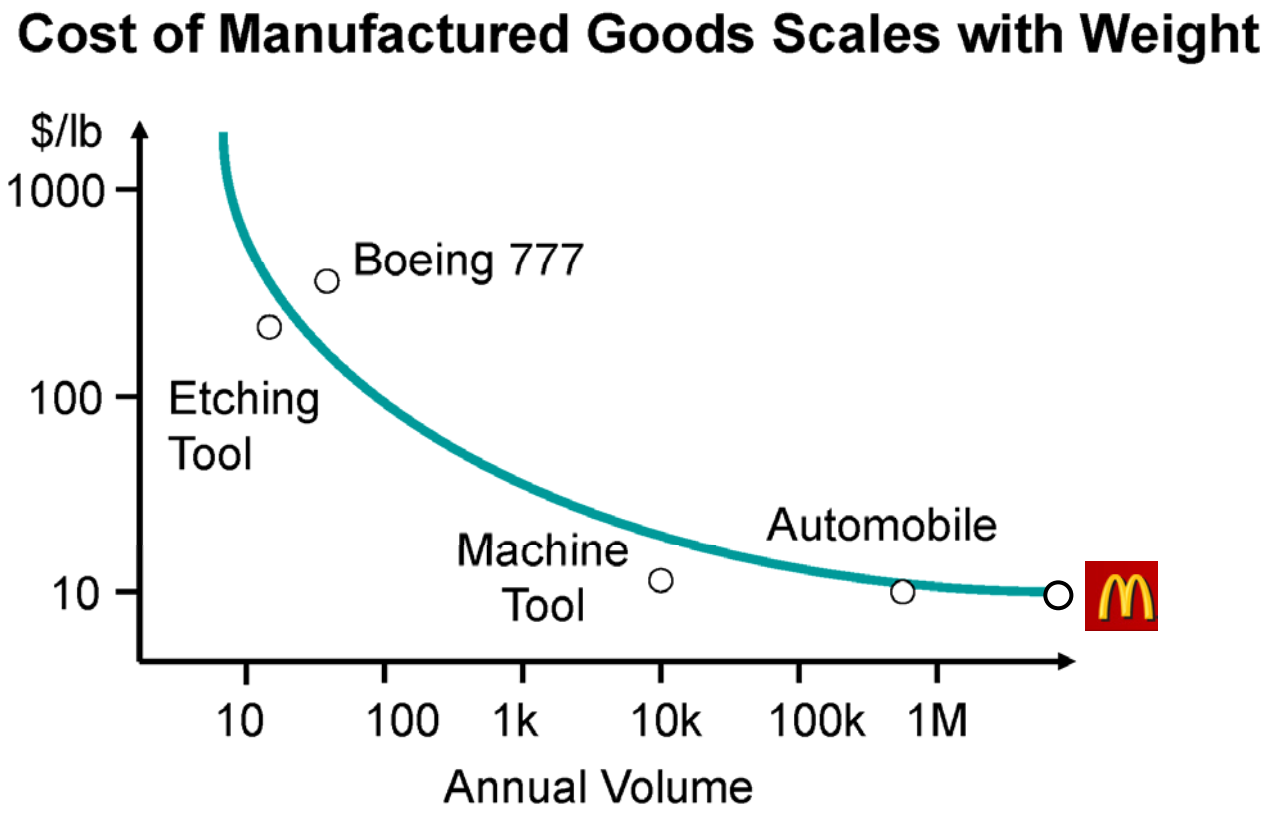
judge ARPA-E judged on whether technologies come to market and are being used widely enough that significantly reduce (1) domestic oil use and (2) energy-related emissions of greenhouse gases.

develop it beyond the “valley of death”

not exclusively a basic research program – **Technology Readiness Levels (TRL)** benchmarks (ARPA-E, TRL2-7)

choose basic research problems with consideration to markets and technology sector

Energy Systems and the Cost of Manufactured Goods



Make It Light and Enable High Throughput Manufacturing

cost most important, efficiency secondary concern

Problem Nowhere Better Illustrated than with Energy Storage Especially to Fuels

Commercial Electrolyzers

…under harsh conditions

- concentrated base
- high temperature
- high pressure
- cheap catalyst
- intolerant of impurity ions

…in water

- expensive catalysts
- expensive membranes
- intolerant of impurity ions

Manufactured 1 at a time
High balance of systems costs that don't scale

$10,000 (smallest) - $50,000 (typical)

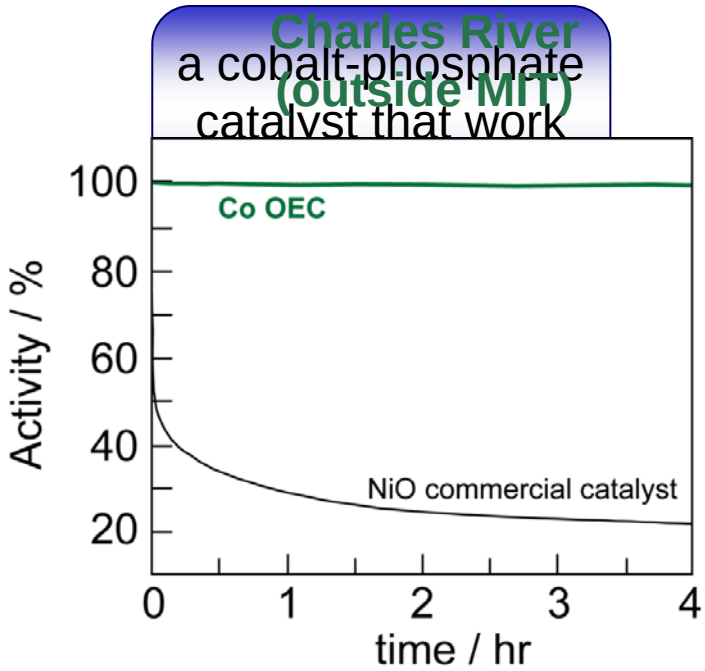
Will Take a Hit in Efficiency if…

cheap

easy to manufacture

able to operate under benign (simple) conditions

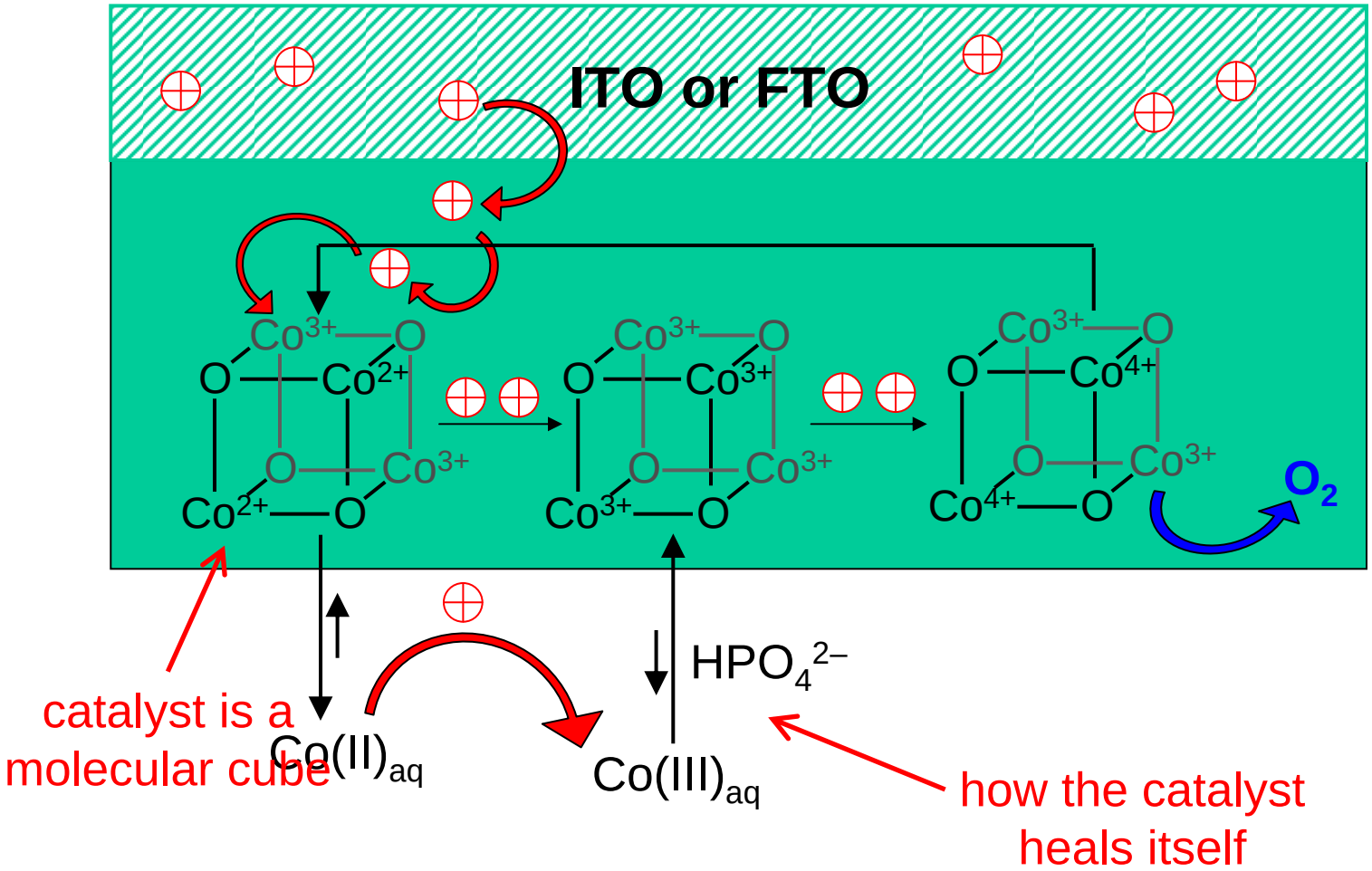
Discovered an Oxygen-Evolving Catalyst



- New water splitting catalyst developed that is unique…
  works under ambient conditions
  inexpensive
  highly manufacturable
  self-healing
- Even has the same structure as the leaf's water splitting machine but with cobalt instead of manganese
- Fully functional in sea and natural waters – when combined with a fuel cell, can produce distributed clean water

Thus distributed energy and distributed clean water for the individual in the non-legacy world

How the Self-Healing Catalyst Works



Solar Fuels Storage is Exemplary of the Cost Problem

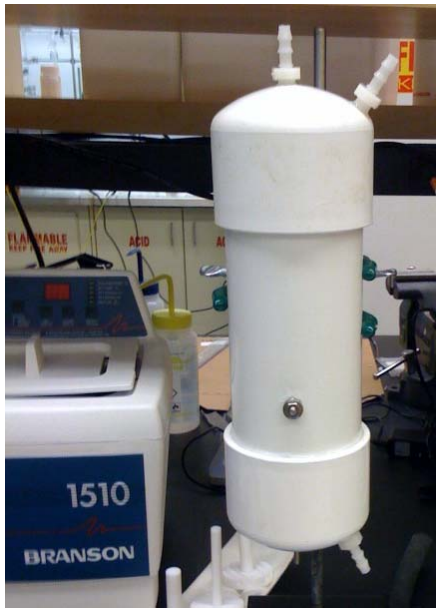
Commercial Electrolyzers

1000 mA/cm²

manufactured 1 at a time

$10,000 (smallest PEM) - $50,000 (typical)

Co-OEC Electrolyzer



100 mA/cm²

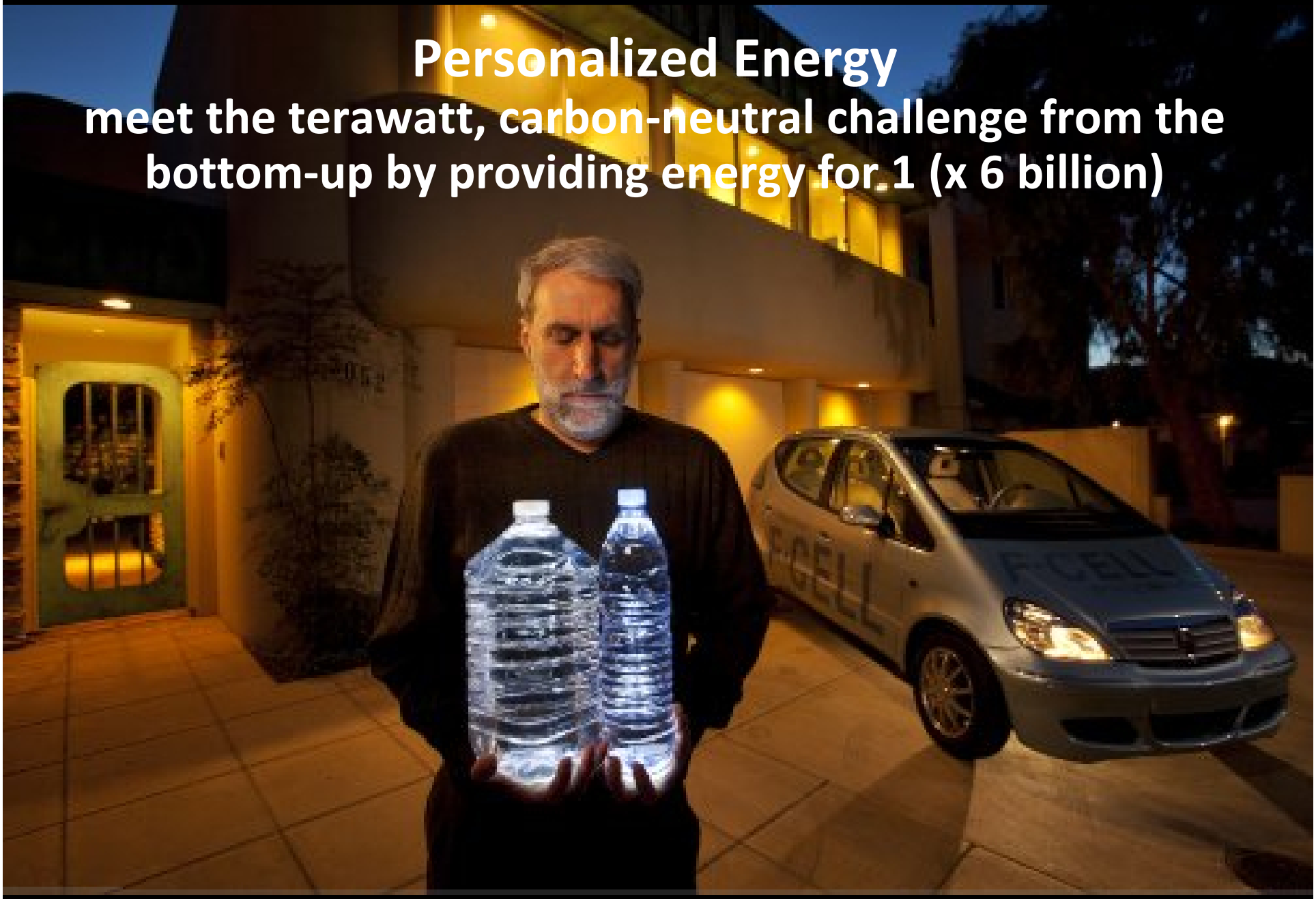
mass produced

$~100

…and the new electrolyzer can use any water source

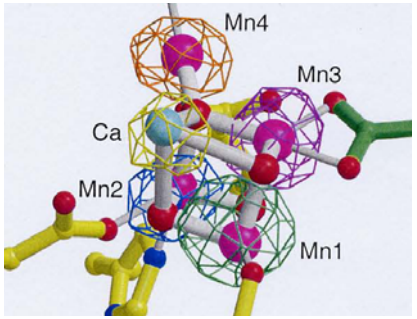
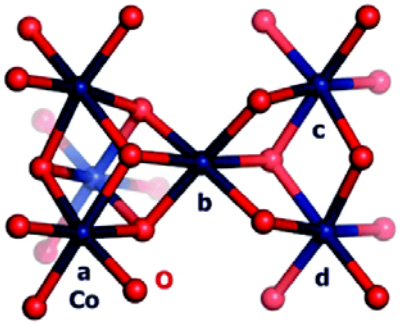
Personalized Energy

meet the terawatt, carbon-neutral challenge from the bottom-up by providing energy for 1 (x 6 billion)



National Geographic, Sept. 09

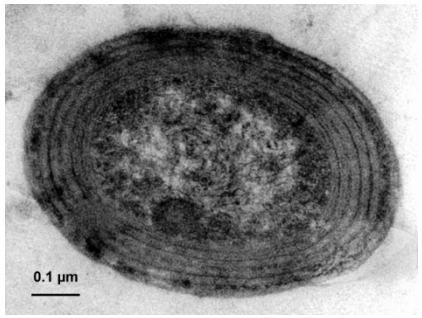
An Artificial Photosynthesis

	Photosystem II OEC	*Co-OEC*
Self-Assembly	earth-abundant metal (Mn) all oxo core self-assembled from water by oxidation of Mn^{2+} to Mn^{3+}	earth-abundant metal (Co) all oxo framework self-assembled from water by oxidation of Co^{2+} to Co^{3+}
Repair	D1 protein	HPO_4^{2-}/Co^{3+} equilibrium
O_2 Generation	from neutral water at 1 atm and RT at low overpotential proton carrier (amino acids)	from neutral water at 1 atm and RT at low overpotential proton carrier (HPO_4^{2-})
Structure	***a Mn-oxo cube*** 	***a Co-oxo cube*** 

both cubes are of precisely the same dimension!

How the Planet Breathes?

Prochlorococcus



smallest known photosynthetic organism
most abundant (populates deep ocean)
singularly produces 20% of the planet's oxygen

grows very slowly

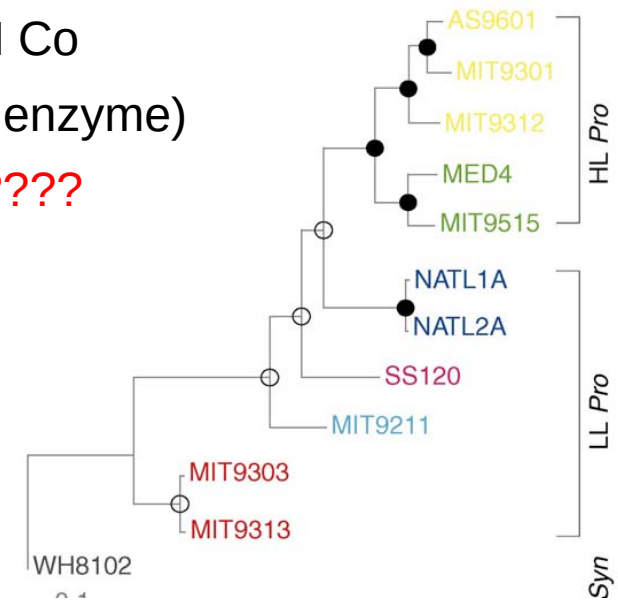
~100 nM Mn : 1-5 nM Co

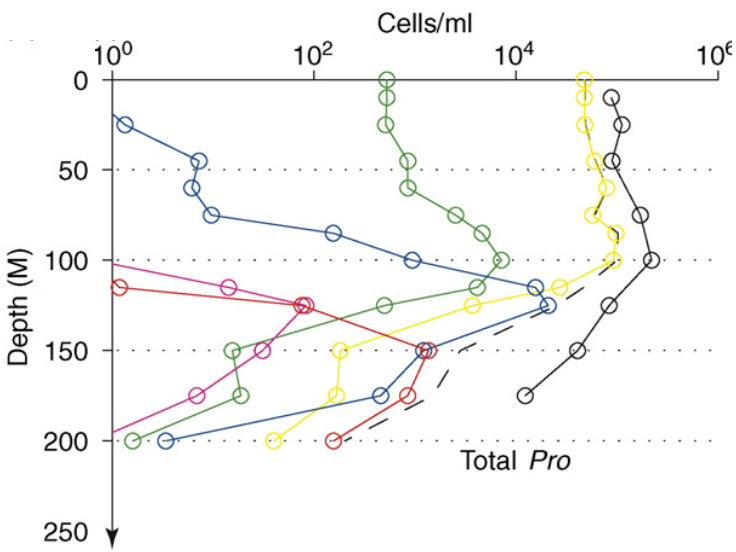
dies with no Co (B12 enzyme)

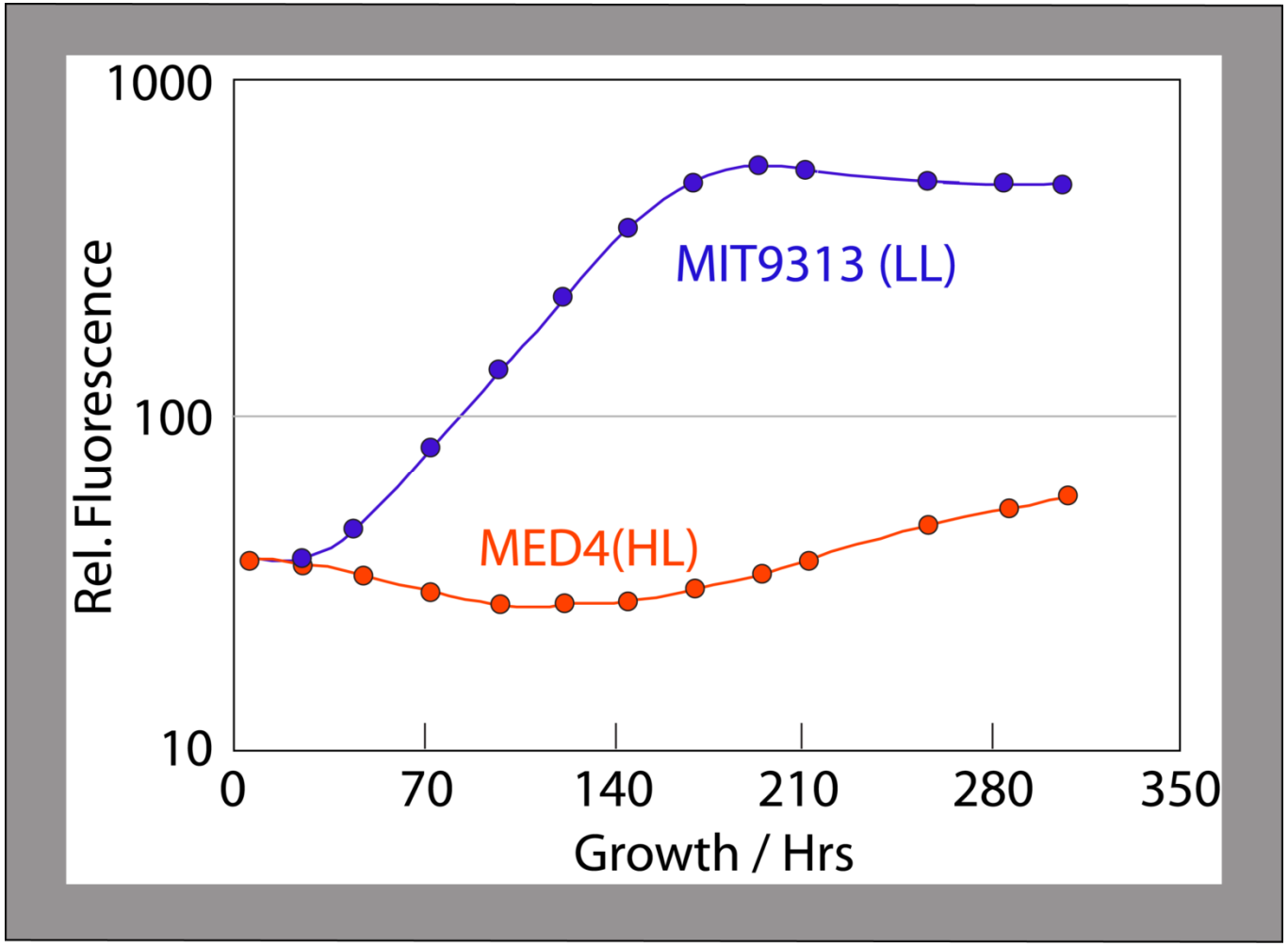
4% Co in B12, 96% ????

grows "happily":
0 Mn, 100 nm Co

A Co_4O_4 OEC???






1000
100
10
Rel. Fluorescence
MIT9313 (LL)
MED4(HL)
0
70
140
210
280
350
Growth / Hrs