



EXPANDING THE BIOECONOMY

Date: Wednesday, 11 July 2017

Venue: SHERATON PENTAGON CITY, Washington, DC

ELLEN B STECHEL

Arizona State University

ASU-LightWorks*

Bioeconomy 2017: Domestic Resources for a Vibrant Future

**Beyond Biofuels: Leveraging the Bio-economy to Manage Carbon, Open Markets,
and Increase Global Economic Efficiency**

***ASU campus wide initiative on light inspired
research for energy and sustainability,
impact and scale**



REFRAMING THE FUTURE OF CARBON IN SOCIETY:

"Every problem has in it the **seeds** of its own solution. If you don't have any problems, you don't get any seeds."

Norman Vincent Peale (1898 - 1993), American Author

"Each problem has hidden in it an **opportunity** so powerful that it literally dwarfs the problem. The greatest success stories were created by people who recognized a problem and turned it into an opportunity."

Joseph Sugarman, American Author

"We can't solve problems by using the same kind of thinking we used when we created them." - Albert Einstein

"Inventing is seeing the same problem that everyone around the world is seeing, but looking at it differently."

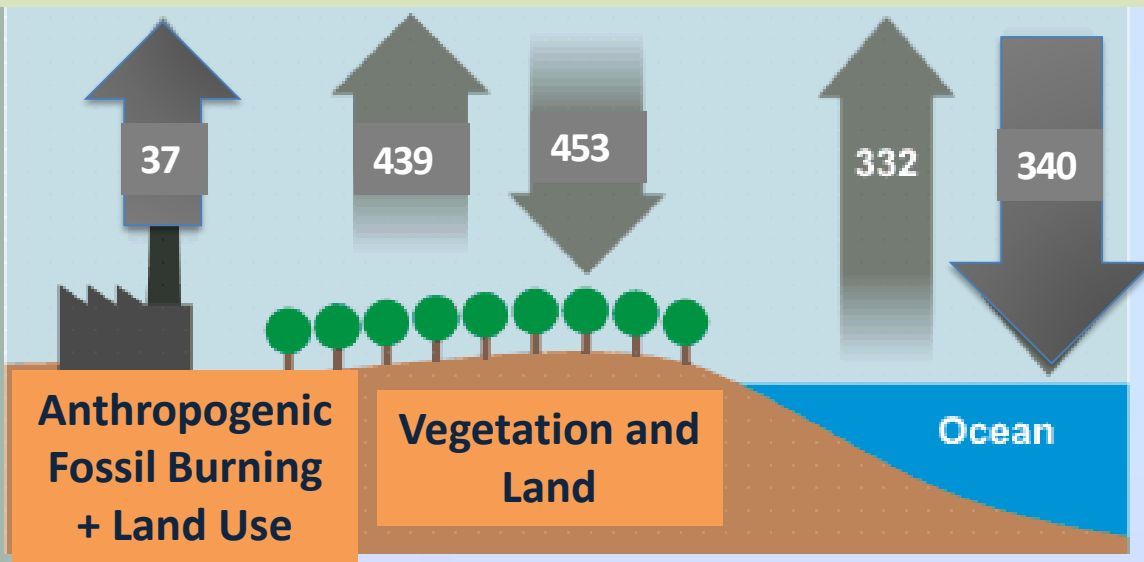
Dean Kamen, Most Known as the Inventor of the Segway



TOO MUCH OF A GOOD THING CAN BE BAD -- SOURCES EXCEED SINKS

2040 ± 310 GtCO₂ 1750-2011 → 880 ± 35 additional GtCO₂

Problem: Increasing content in the atmosphere & surface ocean



Accounts for ~76% of GHG

Uptakes ~35%

Uptakes ~25%

~3100 GtCO₂ total in the atmosphere

Was ~ 2200 Gt pre-industrial

Beyond ~3500 Gt is considered too much >450 ppmv

Proven fossil reserves:

~2800 Gt potential CO₂ emissions

Cumulative budget left < 900 GtCO₂

~4.25% yoy decrease in net

30% in 8 yrs and 50% in 16 yrs

We could actively mine the excess CO₂ in the atmosphere as a resource

1300 Gt-CO₂ at \$10 per tonne profit would be \$13T.



THINKING DIFFERENTLY ABOUT CO₂

Managing as a resource rather than waste to just get rid of or worse a pollutant

**REDUCE, REUSE, DOWN-CYCLE, RECYCLE,
DISPOSE WHAT'S LEFT ONLY AS A LAST RESORT**

Automobiles are the most recycled consumer product in the world today. There are >9,000 vehicle recycling facilities around the US.
\$32B/yr in sales; >140,000 employed.



"Automotive recycling has evolved into a sophisticated market and technology-driven industry that constantly changes to keep abreast of innovations in automotive technology and manufacturing techniques."

Automotive Recyclers Association



RECYCLING CO₂ INTO THE PRODUCT IT CAME FROM: NO SUCH THING AS WASTE ONLY WASTED RESOURCES

MINOR DISTINCTION – WE DO HAVE DECARBONIZE PRIMARY ENERGY

WE DO NOT HAVE TO DECARBONIZE THE ENERGY SYSTEM

**TODAY'S PRIMARY ENERGY IS REALLY STORED ANCIENT
SUNLIGHT AND SEQUESTERED CARBON**

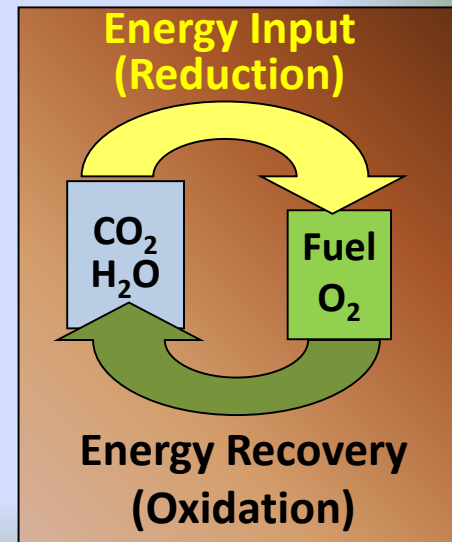
BIOMASS IS STORED MODERN SUNLIGHT AND FIXED CARBON



Fossil dominates today – must move to **carbon free** resources

No reason this part of the energy system has to be carbon free. Biomass is a carrier: **secondary energy** Carriers produced from sun, CO₂, and water

Services Societal value Hydrocarbons (**stored energy**) and other carbon-based products





MOST FUELS ARE ESSENTIALLY STORED SUNSHINE

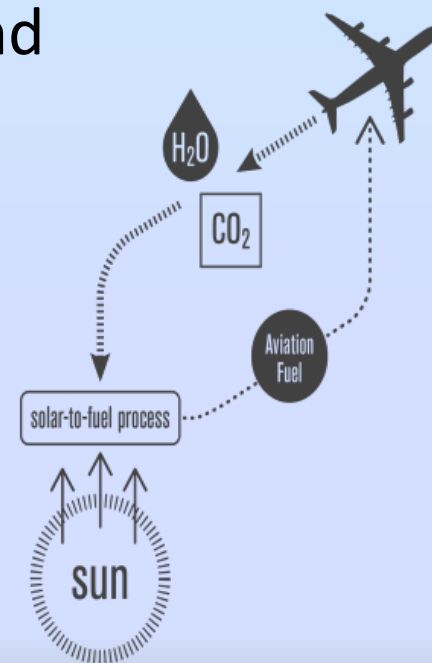
FOSSIL FUELS — STORED BURIED SUNSHINE

- Prehistoric biomass, processed for **millions of years**: ancient stored solar energy
- Accelerate the natural process to make new energy carriers from modern sunlight: i.e., Solar fuels and materials.

LIQUID HYDROCARBONS ARE ENERGY DENSE AND CONVENIENTLY STORED AND TRANSPORTED ECONOMICALLY OVER LONG DISTANCES, TRILLIONS OF \$ OF INFRASTRUCTURE

THE QUESTION WE SHOULD BE ASKING IS WHAT WILL BE THE ENERGY CARRIERS OF THE FUTURE? (H_2 , CO, CH_3OH , NH_3 , DME, OME, CH_4)

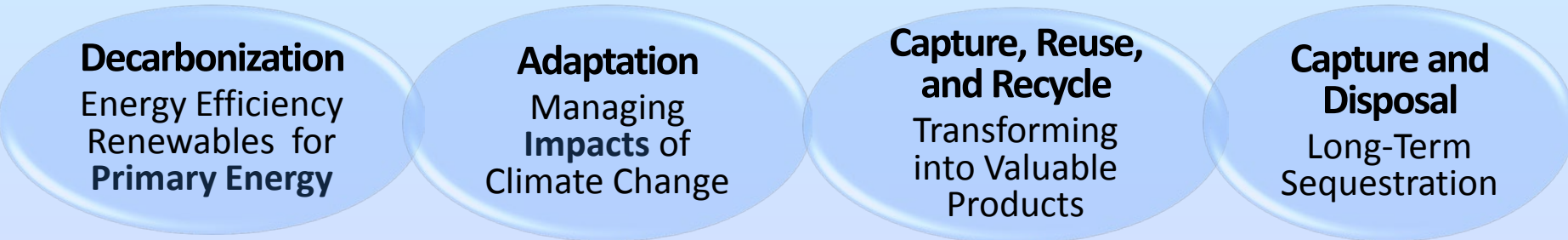
ELECTRICITY IS BEST USED AS IT IS PRODUCED — BUT NOT EASILY STORED ESPECIALLY FOR **SEASONAL SHIFTS**





REFRAMING: CREATING VALUE FROM AND SINKS FOR THE EXCESS CO₂ IN THE ATMOSPHERE

Economically viable **carbon-based** innovation ecosystem in a few decades – in addition to – not instead of, not part of **decarbonizing primary energy**?



Progress but Not Fast Enough, mostly in electricity

Increasingly Necessary but expect suffering

Seeking added value, Impact transportation & Manufacturing
Can also address “overshoot”

Verified, Safe and Secure Disposal

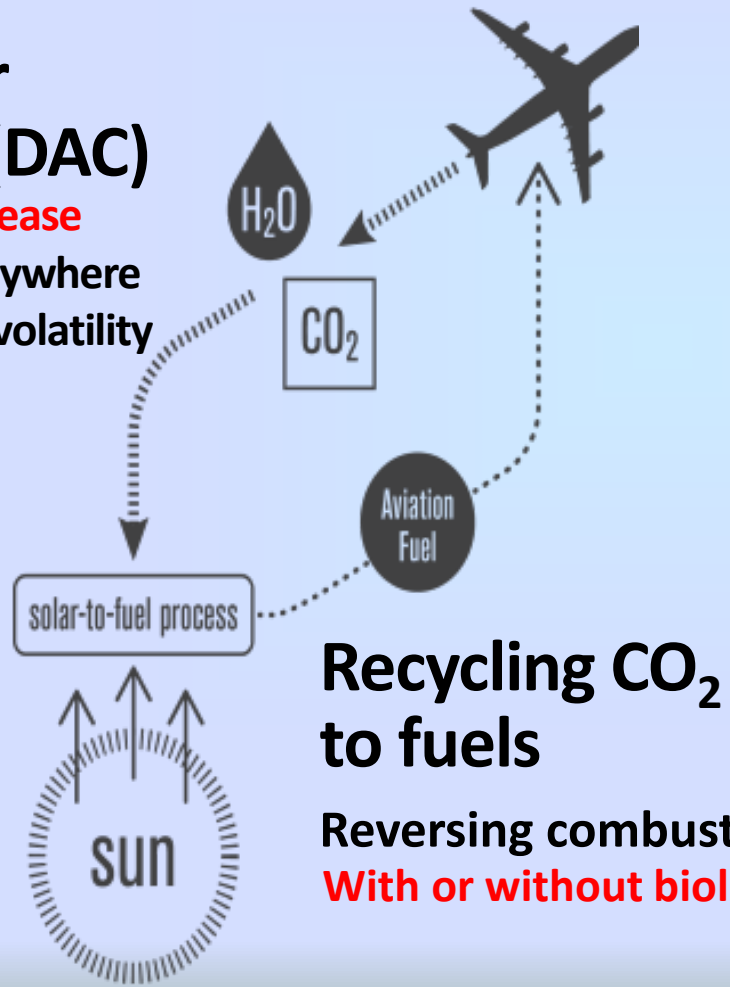
Multi Gt-CO₂/yr scale industry: steel, concrete, agriculture, coal, oil, and gas, and plastic is getting close



NET NEUTRAL: CLOSING THE CYCLE; RESTORING THE CARBON BALANCE

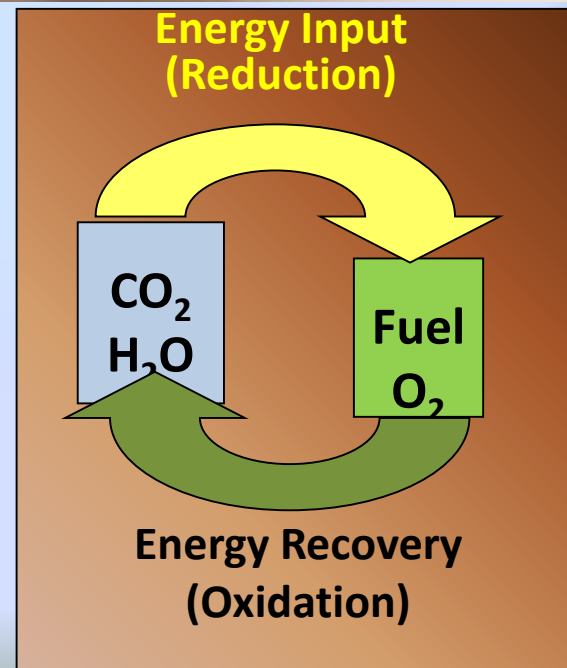
Direct air capture (DAC)

Capture & Release
Available everywhere
No feedstock volatility



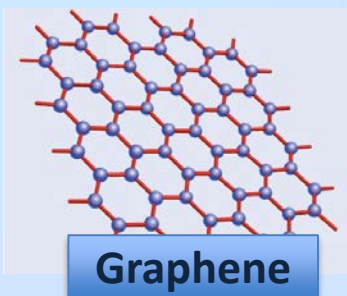
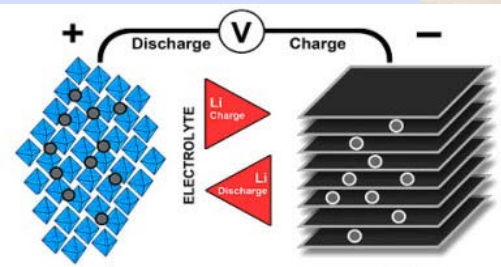
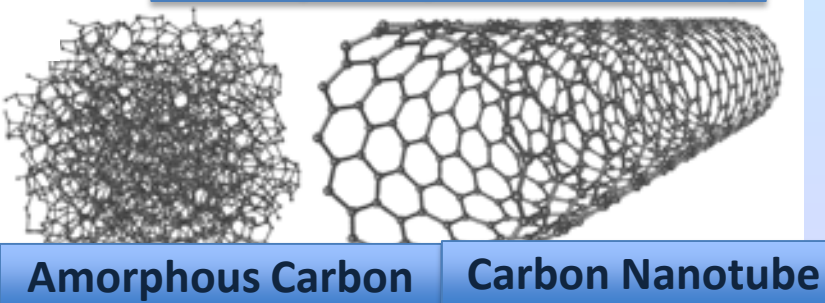
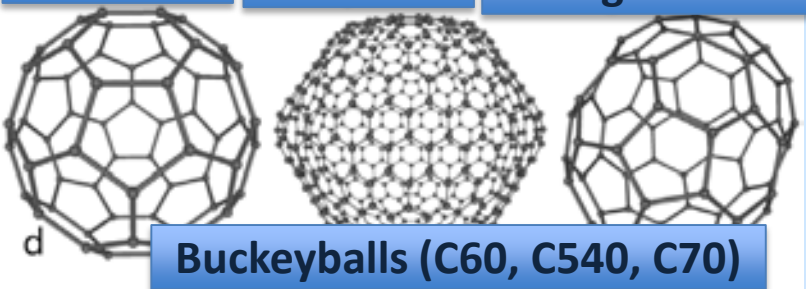
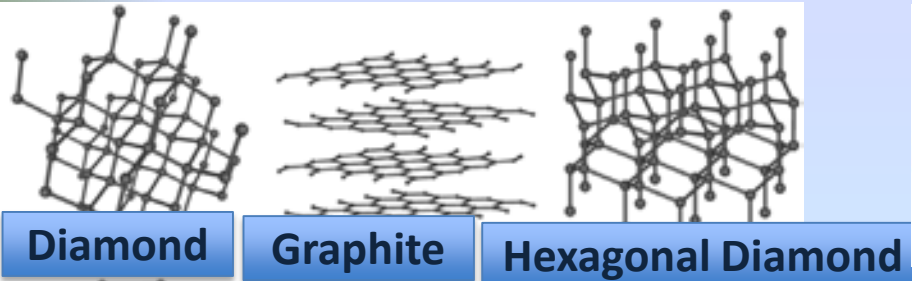
Recycling CO₂ to fuels

Reversing combustion
With or without biology





NET NEGATIVE: CARBON IS THE MOST VERSATILE OF ALL THE ELEMENTS



plastics are used in an enormous and expanding range of products



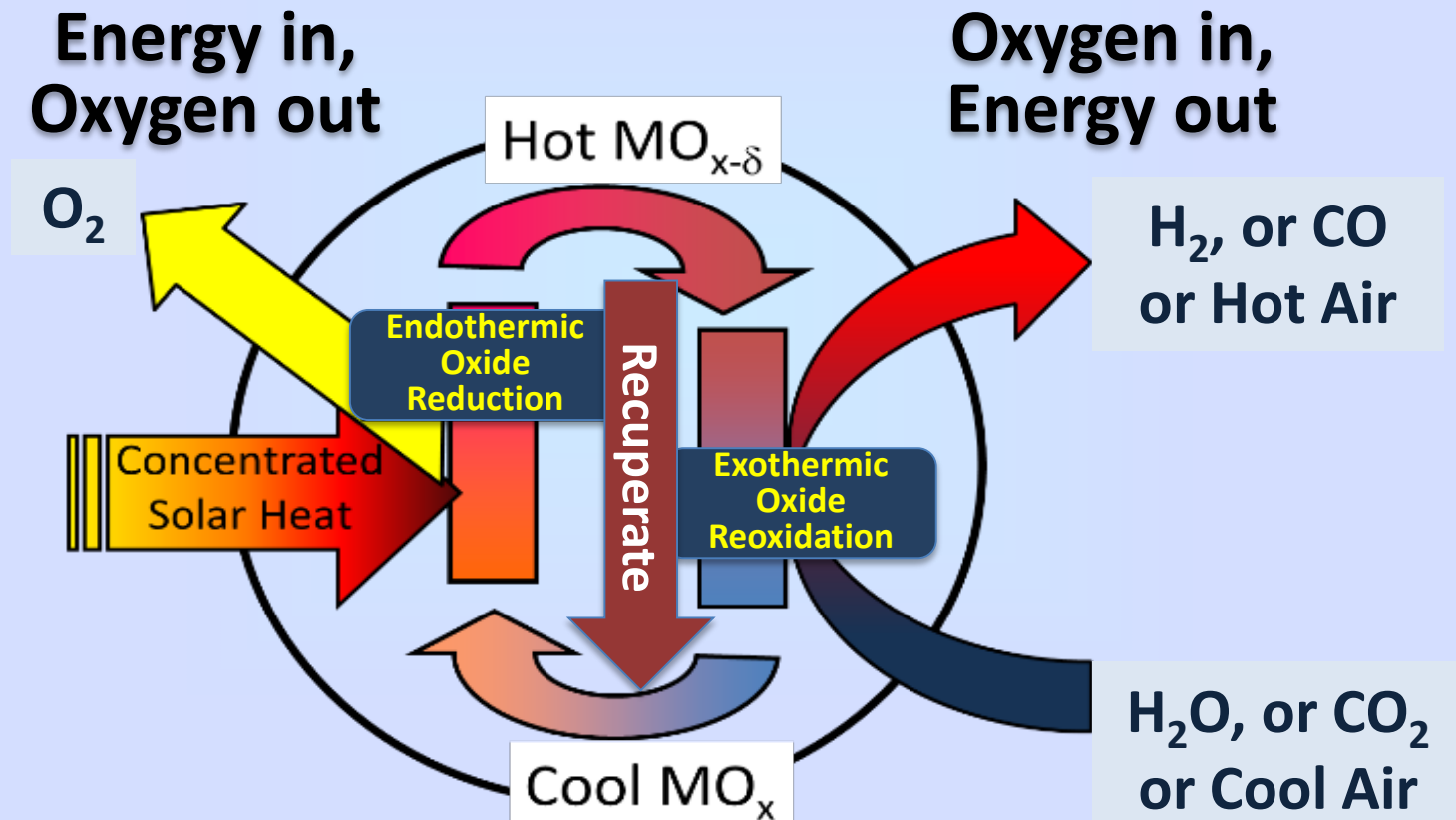
Carbon fiber reinforced polymer



Essential for life, ensures a livable climate via the GH effect of CO₂, stored energy that we have been exploiting, **greatest number of compounds** more than any other element except hydrogen, superior properties. Expect cost breakthroughs on carbon composites from **3D printing**.



SOLAR THERMOCHEMICAL STORAGE AND SPLITTING OF WATER OR CO₂

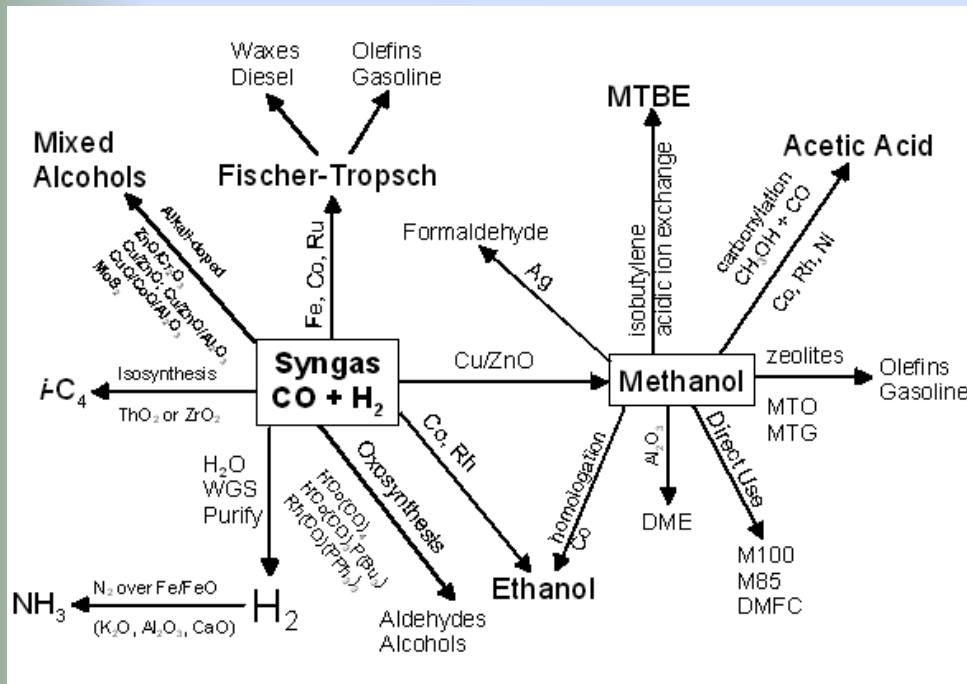


MO_x is the enabling material.
It is a suitable metal oxide

Technology for the arid deserts of the world – no arable land, low water



THE ADVANTAGE OF PRODUCING SYNGAS (CO & H₂)



Source: P.L. Spath and D.C. Dayton, Preliminary screening—technical and economic assessment of synthesis gas to fuels and chemicals with emphasis on the potential for biomass-derived syngas, National Renewable Energy Laboratory, NREL/TP-510-34929, December, 2003.

- Can serve as a universal intermediate
 - Can unite fossil and biomass with direct solar technologies
 - Bridge old energy to new energy
 - Make more product for the same feedstock – no process CO₂ e.g. Solar reforming of CO₂ and natural gas (or biogas)
- Solar gasification of biomass
- Directly splitting water and CO₂, thermochemical, electrolysis, photo-electro-chemical, thermo-electro-chemical

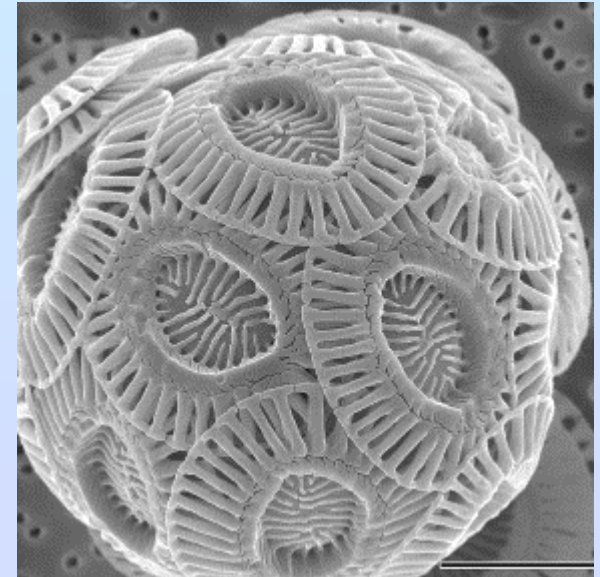
Aim for high carbon atom efficiency and a smoothed transition



WHAT ABOUT INHERENTLY SAFE DISPOSAL CO₂?

Coccolithophores produce an exoskeleton made of CaCO₃ plates (i.e., 'coccoliths').

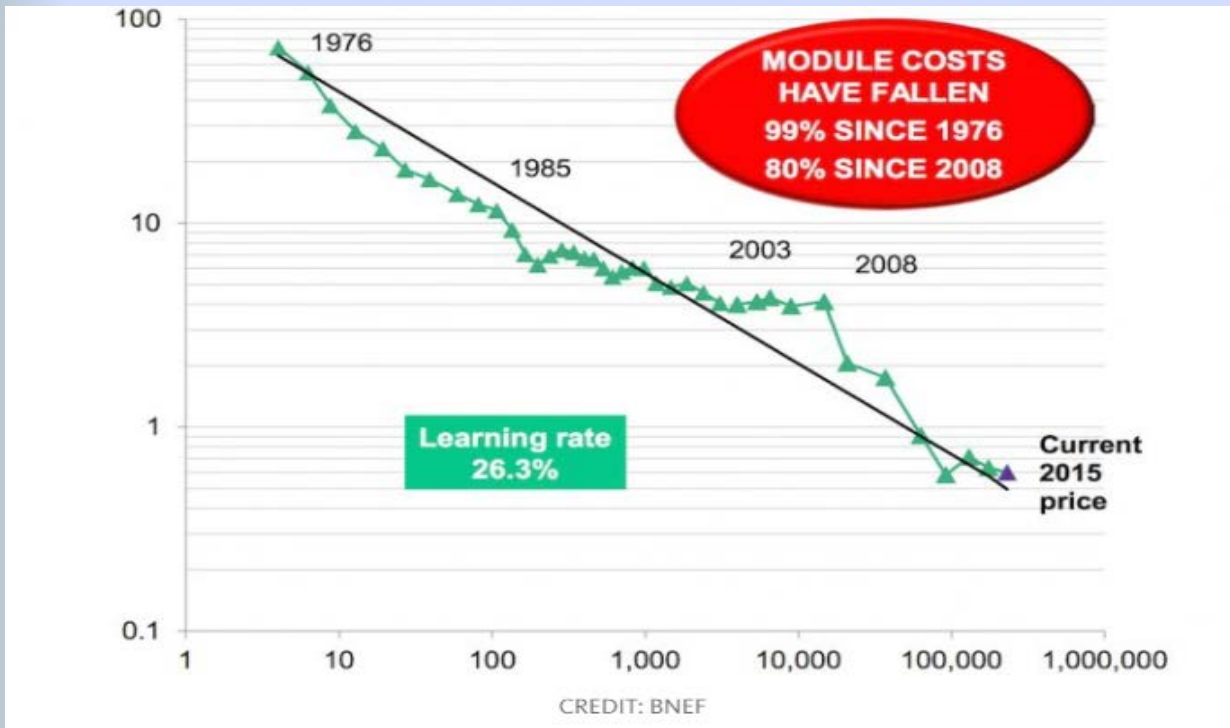
- *One celled marine plants*
 - Very widely distributed globally
 - Leading calcite producers in the ocean
 - Ideal system for **secure biomineralization** of CaCO₃



Kevin Redding and Bruce Rittmann



WE CAN COUNT ON THE MIRACULOUS LEARNING CURVE



If start at 0.1 Mt/yr
If grow at 25%/yr
Then 41 years to hit 1 Gt/yr
Or ~13 doublings
If 16% learning
Fall 90%

Not long ago people were still saying solar is niche and always will be. Direct air capture and direct conversion should be able to get on similar learning curves.



LET'S TOGETHER CREATE A SUSTAINABLE CARBON-BASED FUTURE WITH AND WITHOUT BIOLOGY

The best way to predict the future is to create it.

Peter Ducker

quoteagency



I skate to where the puck is going to be and not where it has been.

Wayne Gretzky



Thank you the audience for your attention and
Dave Babson for the kind invitation
Grateful acknowledgments to colleagues
Gary Dirks, Klaus Lackner, James Miller, Bruce
Rittmann, and Elisa Graffy, and many more